7th International Conference on Fog, Fog Collection and Dew
Wrocław, Poland • 24 – 29 July 2016

Proceedings book

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www.fog-conf.meteo.uni.wroc.pl
Word of Welcome

The community of people, representing both science and practice, in a field of fog and dew related issues, shows an interesting behaviour to gather every three years. That is why we had excellent meetings, which started from Vancouver in 1998, through Saint John’s, Cape Town, La Serena, Muenster to Yokohama in 2013, where we had opportunities to contact each other presenting the results of our work, confronting different ideas, and planning future cooperations.

This time we meet in Wrocław, the capital of Lower Silesia region, at the 7th International Conference on Fog, Fog Collection and Dew. Here in Poland, the tiny droplets of fog and dew impact in different ways the human life as well as the existing ecosystems, just like they do all over the world. I wish you to make a step forward, following steps made so far, in understanding these relations during the present conference.

I hope that, in addition to the professional benefits from the conference, you will enjoy your stay in Lower Silesia, having also time for a moment of reflection on the turbulent past of this land.

Mieczysław Sobik
Chair of the Organizing Committee

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III

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Organizing committee

- Mieczysław Sobik, Conference Chair
- Marek Błaś, Conference Secretary
- Krzysztof Migała
- Żaneta Polkowska
- Elwira Żmudzka
- Otto Klemm, Scientific Committee Chair
Foreword

Welcome to Wroclaw, Poland! Welcome to the 7th International Conference on Fog, Fog Collection and Dew (FFCD) from 24 to 30 July, 2016. A big “thank you” to the conference organizers for their intense and dedicated work over the past months and weeks. This conference series now covers a period of almost 20 years, it is very energetic, it attracts both experienced and emerging scientists and engineers, and will go on. Thematic topics include fog climatology, fog physics and chemistry, the interaction between a foggy atmosphere and the vegetation, remote sensing and forecasting, all the way to applied topics such as fog in traffic systems and the collection of fog water as a freshwater resource. Dew is another important topic of the conference. Dew formation, chemistry, predictability and its potential to serve as a resource of freshwater production are ongoing and developing issues. The scientific field of the conference is rather broad, which attracts contributors from various fields and from many countries representing six continents. I wish us a week of intense discussion of results and arguments.

A special section in the journal *Aerosols and Air Quality Research (AAQR)* will be produced from the contributions to this conference. Participants are invited to submit their results to this journal. Manuscripts will undergo the journal’s review process while the scientific chairman of the conference will be a guest editor for this special section. Details will be announced during the conference. Please stop by with any question.

Last not least, I want to ask for your support during the foundation of an international association for the support of this conference series. With a more formal organisational background, activities such as decision-making and fund-raising will be easier to conduct in the future. The association shall be as lean as possible in order to minimize the bureaucratic workload for all of us. A proposal is presented during the conference, and the founding procedure shall happen on Friday. Please discuss the proposal and please consider to run as a candidate for the board.

Again, I wish a fruitful conference to all of us.

Best regards,

*Otto Klemm*

*Scientific Committee Chair*
**The conference Scientific Committee**

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The quality of the language is the author’s responsibility.
Fog interaction with vegetation
The coastal Namib Desert of southwestern Africa supports a rich, diverse fauna and flora dependent on fog water for growth and reproduction leading, inter alia, to inscription of the Namib Sand Sea as a World Heritage Site.

The 2000 km north-south extent of the Namib Desert reaches up to 120 km inland over a 1% gradient. Current research (FogNet, FogLife, SEALS-sA) is attempting to establish the distribution of fog along its N-S and E-W extent.

In the central Namib, fog precipitation peaks at about 30–60 km from the coast while current research is investigating details of this pattern and its associated biota.

On the plains, lichens and phytoliths are the most obvious component of the fog-influenced flora while several dwarf shrubs are restricted to the western ‘fog zone’. Despite reports to the contrary, none of the plains invertebrate fauna has been observed to take up fog water directly although their population dynamics are influenced by the presence of fog. Fog water contributes to the diet of some of the desert reptiles and is currently under investigation.

The Namib Sand Sea makes available a mobile, well aerated subsurface habitat that supports endemic fauna and flora dependent on fog water where uptake has been demonstrated, inter alia, using labeled water.

The diverse tenebrionid fauna as well as numerous other invertebrates and a few reptiles and small mammals have been found to uptake fog water in various ways. Simple ‘fog webs’ may involve up to six levels after initial uptake of atmospheric fog and are currently under investigation.
FOGLIFE: INVESTIGATING FOG AS THE FOUNDATION OF THE NAMIB DESERT ECOSYSTEM

The coastal Namib Desert of southwestern Africa supports a rich, diverse fauna and flora dependent on fog water for growth and reproduction leading, inter alia, to inscription of the Namib Sand Sea as a World Heritage Site.

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The diverse tenebrionid fauna as well as numerous other invertebrates and a few reptiles and small mammals have been found to uptake fog water in various ways. Simple 'fog webs' may involve up to six levels after initial uptake of atmospheric fog and are currently under investigation.
Background
Montane cloud forest is one of the most endangered ecosystems. However, there are few comprehensive studies on the distribution of subtropical montane cloud forest (SMCF).

Aim
The aim of this study is to understand which vegetation types of Chamaecyparis forest occur in Taiwan and what their relationship to important environmental factors is.

Method
Plots used for this study were selected from the National Vegetation Database of Taiwan. Formalized vegetation classification was applied and the Cocktail Determination Key of each vegetation types were constructed.

Results
Two alliances were defined and topography and altitude explain the contrasting habitat requirements of these two alliances, whereas seasonality of moisture, soil properties and altitude explain differences in floristic composition at the association level. The alliance of Chamaecyparidion formosanae on slopes and ridges includes coniferous or mixed coniferous and evergreen broad-leaved forests; it is found at higher altitudes and is more influenced by the summer monsoon than the other alliance. Five associations are defined within this alliance. The alliance of Pasania kawakamii - Machilion japonicae growing on slopes and in valleys contains evergreen broad-leaved forests or forests with a mixture of coniferous and evergreen broad-leaved species. Six associations can be determined under the alliance of Pasania kawakamii-Machilion japonicae.

Conclusion
The density of fog and fog seasonality are the key factors influencing the species composition in subtropical montane cloud forest in Taiwan.
WHAT PLANTS CAN TEACH US ABOUT FOG COLLECTION

Background
Fog collection offers an alternative water source in the driest regions on Earth.

Aim
The goal of our research is to design new fog collectors inspired by the plant species that have adapted to the extreme fog ecosystem of the Chilean Atacama Desert.

Method
Our research is based on a biomimetic approach, whereby biophysical analyses of living organisms and their adaptations form the basis for designing new technologies.

Results
We have analyzed the performance of two Chilean air plants (Tillandsia landbeckii and Tillandsia mucronae) adapted to the extreme fog environment of the Atacama Desert. Our analysis focused on three different aspects of fog collection: the interception of water droplets, their conduction along the leaves, and their absorption. Droplet interception is a well-understood process, known to depend on the Stokes number. We have found that the surface trichomes of T. landbeckii allow the plant to reach the high Stokes numbers necessary to maximize interception while current fog collector meshes reach only intermediate Stokes numbers. Moreover, the complex 3D structure of the plant is much more efficient at capturing water droplets than the 2D configuration of fog collectors. We have also analyzed water conduction on the surface of these plants. The results are described in a poster by Pepin et al. Finally, Tillandsia plants show outstanding performance for the absorption of water through their trichomes. Leaf can absorb surface water at a rate of 50ml/hr/m2 while the rate of water loss under dry conditions is at least 1000 times less. Therefore, the Tillandsia trichome functions as a highly selective water valve which as yet no technological equivalent.

Conclusion
A biomimetic analysis of fog collecting plants offers a wealth of useful information about the optimal design of fog collectors.
QUANTIFYING CLOUD WATER HYDROLOGY IN TROPICAL MOUNTAIN FORESTS USING TIME-LAPSE PHOTOGRAPHY

Background
Cloud water associated with orographic processes on forested mountain slopes contributes to soil moisture and streamflow, suppresses transpiration, and moderates drought. Cloud water is difficult to quantify in the water budget, yet may be vulnerable to changes in amount and frequency due to warming climate. Frequency, duration, elevation range and liquid water content data are essential to improve estimates of cloud water deposition in mountain forests.

Aim
We are developing a methodology to quantify cloud water in remote forests using time-lapse photography, dewpoint, ceilometer, and cloud water deposition rate measurements.

Method
At 5 sites from 600-1000 m in the Luquillo Mountains in Puerto Rico, cloud immersion conditions were monitored using time-lapse photography and temperature/relative humidity sensors. An active-strand collector provided estimates of cloud water deposition rates and liquid water content. Images were classified using four cloud-sensitive image characteristics (SCICs) computed for image subregions: contrast, coefficient of variation and entropy of pixel luminance, and image colorfulness.

Results
Classification applied to 9-12 months of data showed spatial and temporal patterns of cloud immersion in the study area. Euclidian distances between SCICs vectors of cloudy and clear images showed potential to quantify cloud density in addition to immersion. T/RH sensors recorded temperature < dewpoint, but the data cannot indicate “hydrologically significant” fog and are used to supplement image results. Deposition measurements showed that cloud events without rainfall provided enough water to sustain headwater streamflow. These complementary data sets quantified cloud immersion and will contribute to an improved water budget for the region.

Conclusion
The presented approach offers promising applications for observation and measurement of cloud immersion and cloud water deposition at remote mountain sites, where standard instruments to measure visibility and cloud base may not be practical.
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THE CONTRIBUTION OF FOG TO THE BIOGEOGRAPHY AND BIOLOGY OF ARTHRAERUA LEUBNITZIAE IN THE CENTRAL NAMIB DESERT

Fog is a key service provider to the diverse coastal Namib Desert biota delivering five times more moisture than rain. Apart from the importance of fog as a source of water for plants, fog is also associated with particulates and therefore may contain substantial essential nutrients for plants. Furthermore, dry deposition can be an important input of nutrients to many ecosystems, but without water dust deposited on leaves or on soil is inaccessible for plant uptake. In other studies of coastal ecosystems (Strandveld) it has been found that this combined deposition of nutrients represents a major source of nutrients to terrestrial ecosystems. In this case, the plants decreased inland, with the range of the species being limited to those areas where fog occurs.

Meteorological data from the SASSCAL-funded FogNet array of stations based at Gobabeb were used. The stations are located in perpendicular transects, seven from near the coast to 100 km inland at 1000 m elevation and four from Gobabeb northward at 400-500 m elevation. This study investigated the plant morphological and physiological attributes of A. leubnitziae (Amarenthaceae) to determine whether these contribute to fog interception and the uptake of water and nutrients. Some of the other attributes of the plants investigated include canopy properties (leaf area per stem area), leaf foliar properties, the ability to take up foliar applied deuterium-labeled water, tissue elemental concentrations and tissue water, C and N isotopes. Elemental and isotopic composition of the soils along the transect were also measured.

Arthraerua leubnitziae was found to use fog water and nutrients therein. Further research aims at quantifying fog water use.
STRUCTURAL AND FUNCTIONAL ADAPTATIONS OF TAIWAN YELLOW CYPRESS (CHAMAECYPARIS OBTUSA VAR. FORMOSANA) TO PERSISTENT LEAF WETNESS FROM FOG

Background
With more than 4,000 mm/y precipitation, more than 340 days/y of fog, and up to 4 – 16 hours of fog per day, Taiwanese yellow cypress lives in an extremely humid climate in the Northeast of Taiwan. Problems may arise from continuous coverage of the stomata by water, which hinders CO2 uptake.

Aim
The aim was to describe structural adaptations of the leaves to this unique environment and to evaluate possible threats from air pollution.

Method
Leaf morphology, leaf wetness, gas exchange and minimum epidermal conductivity (gmin) of Taiwan yellow cypress were investigated at the Chi-Lan Mountain site. Environmental scanning electron microscopy (ESEM) was used to study condensation processes on the leaves.

Results
Field measurements showed about the double amount of foliar leaf water amounts on upper compared to lower leaf surfaces. Ionic concentrations of leaf water were comparable to previous values from bulk precipitation at this site, with higher concentrations on sun leaves compared to shade leaves.

Chamaecyparis leaves are xeromorphic, although they seem to be specifically adapted to the humid environment. They have hidden, clustered stomata in clefts between the leaf sections, and clearly elevated Florin rings. High density of stomatal covering (> 90%) inside the clefts are in contrast to the almost stomata free areas on the visible abaxial and adaxial surfaces. This stomatal distribution presumably prevents the coverage of stomata by the water due to surface tension, whereas CO2 can still diffuse to the stomata. As shown by ESEM videos, the Florin rings also prevent stomatal openings to be covered.

Gas exchange measurements indicated high efficiency of light and CO2 use. VPD curves indicated differences between older and younger leaves, with lower water use efficiency for older leaves. This might come from salt accumulation on leaves with time, as was also supported by elevated gmin values after spraying with different types of salt solutions.

Conclusion
Yellow cypress is well adapted to the humid environment. Polluted fog water might create a threat.
Background
In various mountain areas in Central Europe, especially in the Bohemian Massif, developing coniferous forest degradation was observed since the 1950s. The Sudetes – mid-size mountains on the border between Poland and the Czech Republic – constitute one of the most affected areas. The observed ecological disaster was the initial reason for radical reduction of emissions in this area, which took place since the beginning of the 1990s. It was followed by a significant decrease of pollutant deposition, evidenced by numerous hydro-chemical studies.

Aim
There are a number of theories explaining the causes of undergone ecological disaster. However, they do not explain why, even on a limited area, some parts of the previous stands declined completely, but others remained almost unchanged.

Method
During the project approx. 2000 Norway spruce trees were dendrochronologically sampled, using the increment borers. Sampling sites were located in different altitudinal zones in the Central European mid-mountains. All the cores have been subjected to the standard dendrochronological procedures, using COFECHA, ARSTAN and WINDENDRO tools. Finally, the obtained data were used for GIS modeling the relationship between morphological relief, climatic conditions and the trees growth reaction.

Results
The research results made it possible to quantify the spatial relationships between the basic parameters of the terrain relief and trees growth reaction to pollutant deposition. The most intense forest destruction was observed at the sites with extremely effective fog deposition: mountain summits and upper parts of western to north-western slopes (windward to prevailing airflow), where the ratio of annual growth in 1980s to 1950s reached 0.2-0.3. In these locations the weakest correlation with the climatic conditions were also detected. According to GIS analysis the W-NW macroscale aspect (50 km) in relation to long-range emission sources was the primary controlling factor of tree rings growth. In the subalpine spruce forests at leeward (eastern slopes) the growth reduction was significantly smaller, reaching 0.5-0.6 of the 1950s value. Only slight growth reductions were visible at foothill reference sites with high rate of pollutant wet deposition and fog deposition being negligible. In such places, annual increments respond rather to other climatic factors.

Conclusion
The spatial pattern of spruce forest destruction stays in close connection with spatial distribution of fog deposition, which is the most important factor contributing to observed changes in the stands conditions. The results indicate also the need to specify methodology of dendrochronological sampling sites selection for the climatological studies to minimize influence of non-climatic factors (e.g. fog deposition) on the climatic models.
SEA-FOG AND COASTAL FOREST IN EASTERN HOKKAIDO, JAPAN

Background
Synoptic-scaled convection fog from sea is located at several regions in the ocean rim. Warm vapor become fog when its temperature is below the vapor saturation point through passing over the cold ocean. In the northwest of Pacific, fog makes changes in coastal climate during spring to autumn: i.e. low irradiance and temperature, high humidity, but not so much precipitation. Those factors are keys in shaping terrestrial ecosystem, and then several unique features in coastal land comparing to inland are expected.

Aim
Quantitative evaluation about alternation of terrestrial ecosystem along coast by seafog in eastern Hokkaido, Japan, through 1) emergence of unique vegetation, 2) alternation of decomposition rate of organic matter, and 3) transportation of marine-derived material.

Method
Study area was set from the coast to subalpine of inland at Konsen Uplands and Akan Mountainous, eastern Hokkaido, Japan. Fog covered coast during almost 100 days a year in this area. 1) Geographical distribution of three birch species, which are typical trees in early ecological succession, was investigated. 2) Decomposition rate of fallen leaves was quantified by litter-bag experiment for 90 days (TBI-method; Keuscamp et al. 2013) along a transect line. 3) δ^{34}S value, which is one of the major markers for detecting marine-originated materials, was measured for lichen and plants (Giesemann et al. 1994).

Results
1) Two dominant birch species distributed almost exclusively, and a mountainous species found also along coastal area. 2) Decomposition was slower in coastal comparing to higher-elevation or inland sites. 3) Higher δ^{34}S values were observed at coastal sites, comparing to inland or higher-elevation sites.

Conclusion
Emergence of mountainous species, slower decomposition, and higher signals of marine-originated materials in coastal area suggest the alternation of biodiversity and material circulation by sea-fog in eastern Hokkaido, Japan.
Background
Fog may play a major role in the physiology of subtropical evergreen forests. Fog decreases the photosynthesis through the reduction of available shortwave radiation and through covering the stomata of plants. However, fog may also decrease the amount of transpiration through the same mechanisms, and even lead to deposition of liquid water, thus favoring the water balance of the vegetation during dry periods. Some species are specialized to perform particularly well during foggy conditions while the role of fog in species competition is rather unknown for primary forests in the subtropical climate.

Aim
The aim of this study is to study the influence of fog on the hydrological regime of a primary subtropical mountain evergreen forest during the dry monsoon season. How much reduction of evapotranspiration is caused during foggy conditions? Is the input of liquid water through fog droplet deposition an important water resource?

Method
We employed the eddy covariance method at a 30 m meteorological mast at the Ailaoshan ecological research at 24.54062 N 101.02811 E, 2476 m above sea level, to quantify the turbulent evaporation of fog droplets and the synchronous evapotranspiration. Radiation and sensible heat flux are measured as well to study the role of fog particularly during early morning evapotranspiration. Our measurement period is from December 2015 to March 2016.

Results
Preliminary results indicate that the liquid water content of the foggy air masses is rather low. The deposition rates are low as well, although the evapotranspiration fluxes were reduced during foggy conditions as compared to non-foggy conditions. Data analysis is underway.

Conclusion
This is one of the first applications of the eddy covariance method to quantify fog water deposition at a subtropical primary mountain forest. The potential effect of changing fog regimes resulting from global and regional warming on the evergreen forest will be estimated from the results of this study.
CHARACTERISTICS OF THE EVAPOTRANSPIRATION OF A JAPANESE CEDAR MONTANE CLOUD FOREST IN XITOU, TAIWAN

Background
As climate change has an increasing influence on the water cycle, the water dynamics of environments as montane cloud forests, which highly rely on the occurrence of fog and clouds, may undergo greater negative impacts. Evapotranspiration plays an important role in terrestrial water cycles, and further related researches may help to better understand the characteristics of cloud forests hydrology.

Aim
We aimed to discuss the characteristics of the evapotranspiration of a Japanese cedar montane cloud forest in central Taiwan, via the estimation of this forest’s Transpiration/Evapotranspiration ratio.

Method
We separately estimated the annual evapotranspiration $ET$ and transpiration $T$ via eddy covariance and sap flow measurements method, respectively. For the eddy covariance measurements we used a forty-meter-high eddy flux tower equipped with an open-path CO$_2$/H$_2$O gas analyzer (LI 7500, LI-COR, Lincoln, NE) and a 3D sonic anemometer (CSAT3, Campbell Scientific, Logan, UT). On the other hand, we used Granier’s thermal dissipation probe to measure the sap flow velocity of 15 Japanese cedars, from which we deduced the stand-scale $T$.

Results
The results showed that the annual $T/ET$ ratio of the Xitou site was about 18% (varying from 2 to 41% according to different range of vapor pressure deficit), which is almost three times inferior to other environments one, including temperate coniferous forests or tropical rainforests.

Conclusion
Our research demonstrated the specificity of the evapotranspiration characteristics of the forest studied. However, as studies related to $T/ET$ ratio in cloud forests are still missing, further researches are still needed, such as the contribution of soil evaporation and understory transpiration to evapotranspiration, or the annual variation of $T/ET$ ratio.
DISTRIBUTION OF FLOWERING IN A FOG OASIS OF THE ATACAMA DESERT AFTER THE UNPRECEDENTED EL NIÑO YEAR AND ITS RELATION WITH FOG DENSITY

Background
The extreme event "El Niño" occurred in August 2015 in the Atacama Desert recorded rainfall of 50 mm in Alto Patache Fog Oasis (annual average of 1 mm), activating the germination of many species of the place. However, distribution, diversity and density of species, might be directly related to the constant fog density.

Aim
To characterize the flowering event after the unprecedented "El Niño" event on August 2015, and their relation with the altitudinal distribution of the fog density on the coastal cliff of Alto Patache, in the coastal Atacama Desert.

Method
On the south-west slope of Alto Patache, horizontal transects were demarcated at 100 meters elevation intervals, from the 350 m ASL to 850 m ASL. In each transect we identified plant species presence and dominance, taking field notes, photos, reference specimens and from previous flora checklists. Floristic data was compared with the altitudinal distribution of fog density using the data measured with the Standard Fog Collector between 2001 and 2002 and microclimate measurements for the post-rain period (August 2015-January 2016) at the same transects.

Results
We identified 42 species, near the total number of species (54) surveyed for this area in a six-year prospection between the years 1999-2005, observing a higher diversity in the zone with more presence and density of fog, between 600 m asl and 800 m asl.
FOG WATER CONTRIBUTION TO THE LAUREL FORESTS IN TENERIFE (CANARY ISLANDS, SPAIN): A MULTIDISCIPLINARY APPROACH

Background
Fog (upslope fog) is a frequent phenomenon at mid altitudes in the north side of the Canary Islands (Spain), linked with the trade winds, trade winds’ inversion and the topography of the islands. Laurel forests (laurisilva) are relict vegetation of the Macaronesia region associated with cloud immersion, but the role of fog is still questioned despite the various studies carried out to quantify its contribution.

Aim
We selected a plot at 1015 m a.s.l. in the Anaga cliff (Tenerife), frequently affected by wind-driven fogs, and that was heavily instrumented in order to clarify the influence of fog (water) in the laurisilva forests.

Method
In addition to standard micrometeorological measurements, fog water was quantified using cylindrical artificial collectors and sampled from the atmosphere for isotopic and chemical analysis using an active fog sampler. Throughfall and rainfall were also sampled for analysis using a range of pluviometers below and above the canopy. In addition soil water content was recorded continuously along a soil profile 1 m deep with TDR probes and samples of the soil solution were collected on a (by-) weekly basis. Groundwater samples from nearby underground reservoirs (galleries and wells) were collected every three months. Sap flow was continuously monitored in different tree species of the laurel forests using heat ratio gauges, which permit measurements of bidirectional (from leaves to roots and reversely) sap flow. Finally, an eddy covariance system permitted continuous evaluation of the gas exchange between the vegetation and the atmosphere.

Results
We present the first results of this multidisciplinary study, which intend to understand the subtle contribution of fog to the laurisilva ecosystem. Cloud immersion is shown to reduce the vegetation transpiration water losses and contribute to a lower extent to soil water content. Isotopic analysis permitted to follow the water from the atmosphere until it reached the aquifer.

Conclusion
The elusive role of fog in the laurel forest environment requires the combination of many techniques to be able to understand its contribution.
FOG, NAMIB DESERT ANIMALS, AND CLIMATE CHANGE

Though still unpredictable in space and time, advective fog is a more-reliable source of water in the hyperarid Namib Desert than is rainfall. By its irrigation and wetting of detritus and sparse vegetation, fog contributes to that fuel that will be combusted to form metabolic water and to pre-formed water in and on plant material, water sources on which many desert animal species can survive. Some species do consume free fog water. Iconic amongst these are the tenebrionid beetle species that collect fog droplets on their carapaces by fog-basking on dune crests, and those that bulldoze trenches on dune slipfaces to act as fog traps. Many other species use free fog water opportunistically, drinking droplets from the substrate or from vegetation, or off their bodies, or extracting water from films on the substrate. Some species are able to employ water derived from the vapour phase; even in dense fog the bulk of atmospheric water is in the vapour phase rather than the liquid phase. Whether the consumption of free fog water is elective, or is obligate to balance an animal’s water budget, requires quantitative analysis of its water balance, accomplished most-accurate by the doubly-labelled water technique, so far applied to very few species. Incorporating the dilute fog water into body tissues without fatally disrupting osmotic balance, when a single drink may amount to 40% of an animal’s mass, requires unusual osmoregulatory processes, and some Namib animal species have unique solutions to the problem. How Namib animal species which rely currently on advective fog will respond to changes in the fog regime under climate change remains an unanswered research question.
Regional frequency of fog and frost events have experienced sharp variations under the global climate change scenarios and are being further aggravated on account of moisture in the air and pollution that limits sunshine during the day, prolonging the misery of the low temperatures/frost and foggy conditions. Fog plays an important role in the earth’s ecosystem being a medium for the exchange of water and pollutants between the atmosphere and the biosphere. Fog which often occurs in the winter time during stable weather situations plays an important role in tropics and sub-tropics affairs and air quality all over the globe. Satellite remote sensing based fog climatology using time series data is important because long term knowledge of regional changes in fog frequency, fog properties and frost are of significance for climate resilient. The total foggy days in whole winter season ranged between 18 to 52 during the entire growing period in the region. Maximum foggy events (25) in a month were recorded in January, 2003. Average maximum foggy events (12) too were recorded in the month of January. In a particular winter season, the highest foggy events (52) were recorded during 2007-08 and the minimum (18) during 1997-98. About 39 per cent of variability in foggy events can be explained over the time due to climatic fluctuations. During the whole winter season the lower temperature deviation (<4.0°C) ranged 6 to 34 days (T_{min}) and 2 to 51 days (T_{max}). The highest numbers of days (34) with below -4.0°C deviation in minimum temperature were observed during growing season of 199899 and such days were 51 in maximum temperature during winter of 1997-98. Mustard, an oilseed crop experienced low productivity (<15.0 q/h) in Haryana during most of the growing seasons except 2003-04 (15.5 q/h), 2008-09 (17.4 q/h), 2009-10 (16.6 q/h) and 2010-11 (18.7 q/h) under reference. The fluctuations in productivity of Mustard may be attributed to sensitivity of crucial phenophase particularly flowering and reproductive stage of crop to the abnormal and untimely weather events viz., foggy and frosty events in the region. Frequency and duration of foggy events have increased in winter season of 1995 through 2015 as compared to long term normal. Such type of continued and varied climatic situations in the region affecting the agricultural productivity adversely and symbolized the shift in local climate. Continued foggy conditions for days together especially more than a week along with frost occurrence caused considerable damage to rainfed field crops like Mustard. The growth and development of Mustard was adversely affected due to reduced or little PAR available for photosynthesis, cold stress and congenial conditions for diseases and insect-pest development in the region. Various resilient strategies viz., altered sowing dates, frequent light irrigations and other frost evading measures with use of resistant mustard varieties have to be adopted for sustainable productivity.
EVAPOTRANSPIRATION FROM A PRIMARY SUBTROPICAL EVERGREEN CLOUDY FOREST IN SW CHINA

Background
Subtropical evergreen cloudy forests represent the transition between temperate and tropical forests. They are sensitive with respect to the impact of climate change such as precipitation frequency and intensity variability.

Aim
Evapotranspiration (ET) was observed over a 5-year period at a primary subtropical evergreen cloudy forest in southwest China. The objectives of this study are (1) to quantify the magnitude and seasonal dynamics of evapotranspiration, and to evaluate the potential groundwater supply from these forests, (2) to evaluate the contributions of Es, Ei, and Et to total ET during the various seasons of this pronounced monsoon climate, and (3) to estimate the potential consequences of future global change and land-use change on these ecosystems.

Method
The eddy covariance method was employed.

Results
The annual ET ranged between 785 mm and 901 mm. Solar radiation was a driver for ET while the occurrence of drought limited the tree transpiration and thus ET. The humidity at the deep soil level played an important role during the dry season. During the wet season, the VPD became one of the main drivers. Various physiological strategies of tree taxa lead to a strong influence of evergreen trees on Et and ET during the warm and moist summer season, while deciduous trees play a more important role during the months of March through May and September through November.

Conclusion
Although the hydrological system is evaluated to be stable at the present state, it is anticipated that the groundwater recharge from the ecosystem may be largely reduced in the future either through climate change and a positive temperature–ET feedback associated with it, or through land use change through afforestation with tree species that transpire more effectively than the natural subtropical evergreen forest.
STAND-SCALE ANALYSES OF SPATIAL VEGETATION PATTERNS OF FOG-ECOSYSTEMS IN THE ATACAMA USING UAV-BASED REMOTE SENSING

Background
Fog oases dominated by plants of the genus Tillandsia populate the coastal Atacama in northern Chile. These plants deserve special attention due to their role as bioindicator of the coastal fog climate and climate change.

Aim
This work aims at analyzing the spatial patterns and geo-ecological factors of fog dependent vegetation in hyperarid environments at stand-scale.

Method
Aerial images covering three study areas (approx. 1 x 1 km² each) of fog oases along the coastal fog belt of the Tarapacá region, Chile, at 20°S - 21°S, have been obtained during several flight campaigns with the parachute-UAV "SUSI-62". The image data was processed to 3 cm orthomosaics and 6 cm digital surface models using Structure-from Motion software. On this data basis, an object-oriented image analysis routine was developed and applied for the automated detection of vegetation cover presence and characterization of vegetation patterns through spatial metrics, namely vegetation cover fraction, predominant pattern formations (banded vs. irregular patterns), inter-band spacing and patch shape.

Results
The resulting presence maps show high accuracy when compared to manual photo interpretation as a benchmark, with Kappa coefficients (κ) of >0.985. The derived spatial metrics are presented and statistical relationships with geo-ecological factors (fog water income measured in the field with Standard Fog Collectors; topographic variables derived from the UAV-based surface model) are discussed.

Conclusion
The work demonstrates how UAV remote sensing is applied for analyzing stand-scale spatial vegetation patterns of fog-dependent ecosystems in the Atacama, thereby providing valuable information in the context of studies on the fog climate, climate change, biosphere-atmosphere interactions and the use of fog as a fresh water resource.
Dew
Global Dew Yield Estimate From Simple Meteo Data

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Abstract

A simple analytical formulation of dew yield on planar dew collectors is proposed. It is based on laboratory experiments showing that cooling power and heat losses with surrounding air are the dominant factors that limit dew condensation. The formulation is adapted to radiative cooling with a model sky emissivity. A simple analytical formulation is then derived, which only needs the values of cloud coverage, wind speed, and air and dew point temperatures. Agreement within typically 30% is found with dew measurements in 10 places in the world with different climates. Such an analytical relationship can thus provide a useful tool to obtain a worldwide estimation of the dew potential.

1. Introduction

There is a common need to determine dew yield in any place of the world. However, its determination requires systematic measurements and/or sophisticated instrumentation that are not available everywhere and depends on the particularities of the dew collector (for a review, see Tomaciewicz et al., 2015).

Dew models are generally based on energy balance such as the Penman-Monteith equation (Monteith, 1957, Garratt and Segal, 1988). Cooling by radiation deficit between the surface and the atmosphere is balanced with heating by conduction (solid surface contact), convection (with surrounding air) and condensation (water latent heat of condensation). Difficulties appear in the evaluation of the radiation deficit and the convection losses estimated from mass and thermal coupling coefficient. The use of Computational Fluid Dynamics (CFD) (Clus et al., 2009) can help, especially for concave structures such as cones. Artificial networks (statistical approach) have also been proposed and tested by Lekouch et al. (2012).

Dew yield is strongly correlated with only a few statistically independent meteorological parameters (Lekouch et al., 2012): air temperature $T_a$, dew point temperature $T_d$ or relative humidity $RH$, and wind speed $V$ (measured or extrapolated at 10 m elevation). These data are collected on a regular basis in many meteorological stations in the world (e.g. in airports) and can be easily obtained. The goal of this study is then to provide a physical model with explicit analytical dependence of dew yield on $T_a$, $T_d$, $N$, and $V$, keeping in mind that differences of 40% between different condenser shapes are regularly found although the meteorological parameters are rigorously the same (Clus et al., 2009). This difference gives the range of the possible approximations that can be made for modeling dew formation. (For details, see Beysens, 2016).

2. Theory

Dew yield calculation requires solving a thermal problem based on an equilibrium equation

$$\frac{dT_c}{dt} + R_{he} + R_{cond} = \frac{1}{MC_c} \left( \frac{dM}{dt} c_w \right)$$

(1)

Here $T_c$ is the condenser surface temperature, $M$ and $m$ are the masses of the condenser and of the condensate, respectively, $c_c$ and $c_w$ are the specific heats of the condenser materials and water, respectively, and $t(s)$ is time. The variables in the right part of the equation represent the various thermal processes of heat transfer at the condenser surface, $R_i$ is for cooling energy (practically less than 100 Wm$^{-2}$), $R_{he}$ for heat exchange with ambient air and $R_{cond}$ for the energy gain due to the latent heat of condensation per unit of mass, $L_c$ (J.Kg$^{-1}$). The conductive term of the condenser support has been omitted: one assumes that the condensing surface is set on an adiabatic material. Condensation and heat exchange terms can be written as

$$R_{cond} = L_c \left( \frac{dm}{dt} \right)$$

and

$$R_{he} = aS_c (T_a - T_c),$$

where $a$ is the coefficient of convective heat...
Global Dew Yield Estimate From Simple Meteo Data

D. A. Beysens\textsuperscript{1,2}

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Abstract

A simple analytical formulation of dew yield on planar dew collectors is proposed. It is based on laboratory experiments showing that cooling power and heat losses with surrounding air are the dominant factors that limit dew condensation. The formulation is adapted to radiative cooling with a model sky emissivity. A simple analytical formulation is then derived, which only needs the values of cloud coverage, wind speed and air and dew point temperatures. Agreement within typically 30\% is found with dew measurements in 10 places in the world with different climates. Such an analytical relationship can thus provide a useful tool to obtain a worldwide estimation of the dew potential.

1. INTRODUCTION

There is a common need to determine dew yield in any place of the world. However, its determination requires systematic measurements and/or sophisticated instrumentation that are not available everywhere and depends on the particularities of the dew collector (for a review, see Tomaciewicz et al., 2015). Dew models are generally based on energy balance such as the Penman–Monteith equation (Monteith, 1957, Garratt and Segal, 1988). Cooling by radiation deficit between the surface and the atmosphere is balanced with heating by conduction (solid surface contact), convection (with surrounding air) and condensation (water latent heat of condensation). Difficulties appear in the evaluation of the radiation deficit and the convection losses estimated from mass and thermal coupling coefficient. The use of Computational Fluid Dynamics (CFD) (Clus et al., 2009) can help, especially for concave structures such as cones. Artificial networks (statistical approach) have also been proposed and tested by Lekouch et al. (2012).

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2. THEORY

Dew yield calculation requires solving a thermal problem based on an equilibrium equation between sensitive and latent heat fluxes,

$$\frac{dT_c}{dt} (M \gamma_c + mc_w) = R_i + R_{he} + R_{cond}. \quad (1)$$

Here $T_c$ is the condenser surface temperature, $M$ and $m$ are the masses of the condenser and of the condensate, resp., $\gamma_c$ and $c_w$ are the specific heats of the condenser materials and water, resp., and $t$ (s) is time. The variables in the right part of the equation represent the various thermal processes of heat transfer at the condenser surface, $R_i$ is for cooling energy (practically less than 100 Wm$^{-2}$), $R_{he}$ for heat exchange with ambient air and $R_{cond}$ for the energy gain due to the latent heat of condensation per unit of mass, $L_c$ (J.Kg$^{-1}$). The conductive term of the condenser support has been omitted: one assumes that the condensing surface is set on an adiabatic material.

Condensation and heat exchange terms can be written as $R_{cond} = L_c (dn/dt)$ and $R_{he} = a S (T_a - T_c)$, where $a$ is the coefficient of convective heat
transferred and $S_c$ is the condenser surface. The parameter $a$ is correlated with the thickness of the thermal boundary layer and depends on the air speed $V$ (m/s) far from the plate, i.e. wind speed if this latter is larger than natural convection velocity ($\approx 0.6$ m/s, according to Baysens et al., 2005). The equation representing the condensed mass is described by the rate of condensation,

$$\frac{dm}{dt} = \begin{cases} wS_c(p_a(T_a) - p_w(T_c)) & \text{if positive} \\ 0 & \text{if negative} \end{cases}$$

where $p_{sat}(T_c)$ is the saturation water vapor pressure at condenser temperature $T_c$ (K) and $p_a(T_a)$ is the water pressure in the humid air above the condenser. The water vapor transfer coefficient, $w$, is proportional to $a$ in Eq. 4 as it depends on the same hydrodynamic boundary layer, the values of the thermal diffusivity coefficient and the diffusion coefficient of water molecules in air being nearly equal. Determining $dm/dt$ requires solving Eqs. 1 and 2, which can be done by iteration (Pedro and Gillespie, 1982) and/or $T_d$ measurements (Nikolayev, 1996).

A simplification in $R_{he}$ formulation above is assuming that dew starts to form at the dew point temperature (true only for hydrophilic substrates or on geometrical or chemical surface defects; measurements indeed indicate that $T_p$ rarely exceeds 1K). Then heat losses can be reformulated as $R_{he} \approx aS_c(T_a - T_d)$, which now depends only on meteorological measurements.

3. LABORATORY STUDY

Experiment are carried out with a vertical square stainless steel plate of side $L=0.2$ m and thickness $e = 2$ mm (Fig. 1), thermally coupled with a cooling Peltier element. Temperatures of the Peltier element, $T_p$, and surface temperature, $T_s$, of the steel plate are recorded. The experiment is performed in a small laboratory room whose window is left half open to make air temperature and humidity vary between day and night and reproduce outdoor conditions. The parameters of the ambient air ($T_a$, $T_d$) are recorded. Condensed water is weighted on an electronic balance and its mass $m$ is recorded.

The useful heat flow per unit surface, $q$, for cooling and condensing is evaluated by measuring the difference in temperature $T_a - T_p$. The latter is correlated with the Peltier input electric power. Values are in the range 1-100 W/m$^2$, similar to radiative cooling powers found in natural dew condensation.

Figure 1 represents a typical evolution of the condensation rate per surface area, $dm/dt$, with respect to ($T_p$-$T_a$). A simple linear fit describes the data:

$$\frac{1}{S_c} \left( \frac{dm}{dt} \right) = \frac{d\mu}{dt} = \begin{cases} \beta q + a(T_d - T_a) & \text{if positive} \\ 0 & \text{if negative} \end{cases}$$

The parameters $\alpha$ and $\beta$ are not a function of the cooling power and are constant ($\alpha = 6.1\times10^{-3}$ kg/h/m$^2$K$^{-1}$, $\beta = 1.3\times10^{-2}$ kg/h/W$^{-1}$). The linear variation of $d\mu/dt$ with $T_d - T_a$ means that the condensation process is mainly limited by the heat losses with the neighboring air. In Eq. (1), making $R_l = -qS_c$, and in the stationary regime where $dT_l/dt = 0$, it comes the same Eq. (3) where $\beta = 1/L_c$ and $\alpha = a/L_c$. The value $1/L_c$ compares well with the experimental value (1.25×10$^{-2}$ kgf$^{-1}$ when in the same units). Concerning the temperature dependence, the experimental value corresponds to a current heat transfer coefficient $a \approx 2.5$ W.m$^{-2}$.K$^{-1}$.

Fig. 1. Rate of surface condensation $d\mu/dt$ with respect to $T_p$-$T_a$. The line is a linear fit (Eq. 10).

4. RADIATIVE COOLING

Natural dew yield of a radiative condenser can be evaluated by applying Eq. 3, with cooling heat flux ensured by the radiation deficit $R_l$. The surface emissivity is assumed to be unity (condensed water emissivity is anyway nearly unity). The shape and size of the condenser and the particular air flow around it determine the heat transfer coefficient, $a$. Heat exchange of condenser thermally insulated from below is only due to a mix of natural and forced convection, a difficult problem that can only be approached with CFD simulations (see e.g. Clus et al. 2009). For any wind direction and wind speed lower than 4 – 5 m s$^{-1}$, the yield of these condensers
vary only in a range of ~ 30%. Within this wind speed range, dew yield can thus be expressed within about 30% for any condenser shape with a unique heat transfer coefficient, to be determined experimentally.

The $T_d - T_e$ dependence of dew yield leads to a typical dependence where nearly all data lie below an envelope line (Fig. 2). This line, with mean slope of order 0.06 mm/d K$^{-1}$, corresponds to Eq. (3) above with a slope close to the experimental value found in the laboratory experiments. The maximum natural dew yield is on average about 0.37 mm/d$^{-1}$, corresponding to a mean maximum cooling temperature difference to obtain dew of about -6°C. The mean line that envelops the data (Fig. 2) can thus be considered as the dependence of dew yield on $(T_d - T_e)$ in the laboratory experiment (Fig. 3b) and corresponds to the maximum cooling power available at a given site. The yields below this line correspond to lower available powers due to weather conditions: strong winds occurrence (enhances convective heat transfer) and/or presence of clouds (reduce radiative cooling power).

\[ dh/dt = 0.0238893 \times V^{0.86} \times \exp \left[ -0.1 \times (T_d - T_e + 2.5) \right] \]

where $T_d$ is the condenser temperature, $T_e$ the ambient temperature. The parameters $a$ and $b$ are evaluated by applying Eq. 3, with cooling heat transfer and are constant ($a = 6.1 \times 10^6$ kg J$^{-1}$ and $b = 0.0238893$ mm/d K$^{-1}$). The linear dependence, the experimental value is closer to zero.

Here $\sigma = 5.67 \times 10^8$ W.m$^{-2}$K$^{-4}$ is the Stefan-Boltzmann constant.

\[ \frac{dh}{dt} = \begin{cases} \beta^* R_e \times (T_d - T_e) \times (V/V_0) & \text{if positive and } V < V_0 \\ 0 & \text{if negative or } V > V_0 \end{cases} \]

with $\beta^*$ and $\alpha$ being adjustable parameters on order the values $\beta$ and $\alpha$ determined in the above laboratory experiments, section 3. They are taken from the mean experimental values from natural dew condensation of the studied sites in Table 1:

<table>
<thead>
<tr>
<th>Site</th>
<th>$Y$ (explical)</th>
<th>Characteristics (Köppen-Geiger climate)</th>
<th>Elevation (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ajaccio</td>
<td>1.02</td>
<td>Mediterranean island (Csa)</td>
<td>70</td>
</tr>
<tr>
<td>Bahar-Dar</td>
<td>0.57</td>
<td>tropical elevation (Cwb)</td>
<td>1840</td>
</tr>
<tr>
<td>Balou</td>
<td>0.86</td>
<td>semi-arid (Bsh)</td>
<td>-24</td>
</tr>
<tr>
<td>Bordeaux</td>
<td>0.53</td>
<td>oceanic coastal humid (Cfb)</td>
<td>17</td>
</tr>
<tr>
<td>Cres</td>
<td>1.02</td>
<td>Mediterranean coast (Cib)</td>
<td>5</td>
</tr>
<tr>
<td>Grenoble</td>
<td>0.48</td>
<td>urban alpine valley (Cib)</td>
<td>215</td>
</tr>
<tr>
<td>Kothara</td>
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<td>oceanic coastal arid (BWh)</td>
<td>21</td>
</tr>
<tr>
<td>Mierlof</td>
<td>0.98</td>
<td>oceanic coastal arid (BWh)</td>
<td>43</td>
</tr>
<tr>
<td>Tahiti</td>
<td>0.94</td>
<td>tropical monsoonal island (Am)</td>
<td>97</td>
</tr>
<tr>
<td>Zadar</td>
<td>1.02</td>
<td>Mediterranean coast (Cfa)</td>
<td>5</td>
</tr>
</tbody>
</table>

Table 1. Characteristics of the investigated sites (adapted from Beyens, 2016).

The sky emissivity is a function of the water vapor content of air, a quantity which can be estimated from $T_d$ and elevation $H$ of the considered site. One considers for the sky emissivity the formulation by Berger et al. (1992). With $T_d$ in °C and $H$ in km, $1 - \epsilon_d = 0.2422[1 + 0.204323H - 0.0238933H^2 - (18.0132 - 1.04963H + 0.21891H^2) \times 10^{-7}T_d]$. The effect of wind couples with natural thermal convection to enhance the convective heat transfer. Practically speaking, it is quite difficult to obtain dew for windspeed $V$ (measured at 10 m elevation) larger than $V_0 = 4.4$ m/s. One will thus simply consider a cut-off function where the heat exchange increases much above $V_0$, as e.g. $C(V/V_0) = 1 + 100(1 - \exp[-(V/V_0)^{20}])$; $C=1$ if $V < V_0$ and 101 if $V > V_0$. Daily dew yield (on mean night duration 12 h.) can eventually be expressed as

\[ \frac{dh}{dt} = \begin{cases} \beta^* R_e \times (T_d - T_e) \times (V/V_0) & \text{if positive and } V < V_0 \\ 0 & \text{if negative or } V > V_0 \end{cases} \]
Measurements are often performed on a periodical basis with interval $\Delta t$ (e.g. $\Delta t = 1/4$ h). A correction has thus to be given; with $\Delta t$ in h, one gets $(dh/dt)_{exp} = (\Delta t/12)(dh/dt)_{calc}$. Dew yields calculated from Eqs. 5-6 are compared with measurements performed in 10 different sites, using either 1 m$^2$, 30° tilted condensers or 0.16 m$^2$ horizontal planar condensers. The comparison between experimental and calculated values is performed by the quality of the correction between the cumulated sum of experimental and calculated dew yields from day $d_1$ to day $d_2$ (Fig. 3). A linear fit is then performed, from which the proportionality factor $Y = \frac{\sum (dh/dt)_{exp}}{\sum (dh/dt)_{calc}}$, expected unity, is deduced. The $Y$ values for the 10 investigated sites are reported in Table 1, with the mean value 0.95 ± 0.05 (one SD). The experimental values are lower or equal than the calculated values because local air circulation can only increase heat losses and thus lower cooling. (In addition, dew water collection is sometimes measured without scraping).

Fig. 3. Example of correlation between the cumulated experimental and calculated yields [Zadar (Croatia), (Muselli et al., 2009)].

5. CONCLUSION

An analytical formulation for dew yields is generated, which derives from simplified energy equations. It uses only a limited number of regular and commonly available meteorological data. Limitations are concerned with intrinsic approximations and the fact that sometimes meteo data are not always available at the place of interest. Good agreement between calculated and measured values is nevertheless found in many places in the world representing various climates. It is thus anticipated that such analytical expression can be valuable to model dew formation in numerous places in the world, leading to global dew maps. Evolution due to global climate change can be further evaluated by using proper climate evolution models.

ACKNOWLEDGEMENTS

This work has been partially funded by the Sorbonne-Paris-Cité Program.

REFERENCES


PROJECTED CLIMATE CHANGE IMPACTS UPON DEW YIELD IN THE MEDITERRANEAN BASIN

Background
Dew harvesting studies are relatively limited causing difficulty in feasibility assessments. Closing the gap can be achieved through estimating yields using mathematical models and interpolating the results into a dew map.

Aim
A dew atlas for the Mediterranean region is presented with forecast trends in yield based on projected climate change impacts.

Method
Nightly passive dew yield was estimated using an analytical approach with meteorological data from 142 locations throughout the Mediterranean region. Results were then interpolated using geostatistical analysis to develop a baseline dew atlas for the region. Forecasted trends in temperature and relative humidity were then examined under low and high emissions scenarios and applied to the baseline dew map to predict future changes in dew yield.

Results
Cumulative monthly dew yield can exceed 2.8 mm during the dry season (April-October) in the Mediterranean region. During the driest months, monthly yield can exceed 1.5 mm (June, July, and August), compared to <1 mm of rainfall during the same period in some areas. The analysis of future emission scenarios through 2080 reveal up to 30% increase in dew yield in Spain and up to 27% decrease along the eastern Mediterranean. The decline in dew yield is often less than projected decrease in rainfall (up to 40%) in the region.

Conclusion
Expansion of dew harvesting has been hindered because of limited experimental studies. Mapping of estimated dew yields allows the identification and assessment of the best suited areas for dew harvesting.

Reference
CONSENSATION WATER HYDROLOGICAL PROCESS IN THE ALPINE MEADOW REGION OF HULU WATERSHED IN THE QILIAN MOUNTAIN

Background
Alpine mountain condensate mainly mitigates periodic physiological water induced by hypothermia, the reason of which is soil moisture cannot be absorbed at low temperature, rather than no water is supplied. So, reason of frequent occurrence and enrichment process of condensate is a potential exploration in the study of invisible water in alpine mountains.

Aim
Contribution to the Alpine mountain hydrological cycle water condensation on the annual scale.

Method
The author set up mini-lysimeter observation in the alpine region of Qilian Mountains. A cylinder mini-lysimeter, 31.5 cm in diameter, 40.5 cm in height. Two mini-lysimeters, named A and B, were set up at observation field located at Hulu watershed in the Qilian Mountain, 3009 m in altitude. Every morning and evening each weighing observation time (8:00), weighing accuracy of 1 g.

Results
In the process of observing evapotranspiration, it was found the condensation water quantity was abundant. From Jan. 1, 2013 to Oct. 31, 2015, the condensate collected in A and B is 94.45 mm and 92.69 mm, respectively. Since no precipitation and snow were observed in precipitation gauges during that period, the condensate was not counted in precipitation estimation process. Percentages of condensate in annual precipitation from 2013 to 2015 monitored using A and B are 6.14%, 5.73%, 6.19% and 6.18%, 5.62%, 5.91%, respectively.

Conclusion
Therefore, in the Alpine mountain region, condensation water cannot be ignored in estimating water quantity. It not only can offset the solar radiation, reduce evaporation, and reduce vegetation physiological water, but also has certain contribution to water storage capacity of hydrological processes during freezing period.
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STABLE ISOTOPE ANALYSES OF RAINFALL AND NON-RAINFALL INPUTS IN THE NAMIB DESERT

Background
Water is a key limiting factor to dryland productivity therefore any additional source would have a positive impact on the ecosystems. Fog and dew are often overlooked water sources in arid and semi-arid ecosystems but they can exceed annual rainfall in some systems. The Central Namib Desert is characterized by erratic rainfall, advective and radiation fog and dew likely provides more stable water resources to the biomes here.

Aim
In this study, we aim to better understand the contributions and sources from each of these three vectors to ecosystem functions using a stable isotope approach.

Method
We collected and analyzed the isotopic distributions of both rainfall and non-rainfall vectors within the Namib Desert.

Results
Fog has been found to be isotopically enriched compared to rain but our preliminary results showed that it is not always the case. Furthermore, our dew sample is the most depleted among all the components.

Conclusion
The distinctness of the isotope signatures indicates that these can potentially be used to calculate the contribution of each of these water sources to the overall water balance of plants in this area.
A comparative study on fog and dew water chemistry at New Delhi, India

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ABSTRACT

Fog and dew water, formed via different formation mechanisms are suitable to study the liquid-gas-solid phase chemical interactions taking place in the ambient atmosphere. This study was conducted in an urban environment of New Delhi to understand the pollution sources and chemical interactions. 24 fog water and 19 dew water samples were collected using Caltech Active Strand Cloud water Collector 2 and dew condensers, respectively, at Jawaharlal Nehru University, a receptor site, in New Delhi during the winter months of 2014-15. All samples were characterised for pH and soluble inorganic ions using IC.

The dew samples were alkaline (pH=6.26±0.37) in comparison to fog (pH=5.38±1.3). The volume weighted mean cations concentrations followed the order NH₄⁺> Ca²⁺> Mg²⁺~ K⁺> Na⁺ and anions as SO₄²⁻> NO₃⁻~ Cl⁻> HCO₃⁻> F⁻> NO₂⁻ in fog water where as the order for cations in dew water was Ca²⁺> NH₄⁺> Na⁺> K⁺> Mg²⁺ and SO₄²⁻~ HCO₃⁻> Cl⁻> NO₂⁻> NO₃⁻> F⁻ for anions. Ca²⁺ was higher than NH₄⁺ in dew samples while NH₄⁺ was higher than Ca²⁺ in fog. Nitrite was higher in comparison to nitrate in dew water while this was reverse in fog water. Alkaline pH of dew water might have played a role in the gas phase transfer and the base catalyzed transformation of NOx to HONO and subsequent dissolution of HONO in dew water in comparison to fog water. Acidity was caused more by sulphate during the winter months of 2014-15. All samples were characterised for pH and soluble inorganic ions using IC.

The differences in the fog and dew composition are primarily linked to their formation processes. The agricultural fields and fossil fuel combustion were sources for ammonium sulphates, nitrate and nitrite whereas locally resuspended crustal materials added calcium and magnesium carbonates.

1. Introduction

Fog and dew water droplets can serve as micro reactors converting primary pollutants into secondary pollutants and play significant role in different ecological and environmental processes. The chemical composition of fog and dew are determined by meteorological parameters, number and composition of aerosol particles, atmospheric gases and multiphase chemical reaction. Fog and dew can serve as proxy for pollutants, their sources and chemical interaction in ambient atmosphere.

Fog and dew chemistry are being studied extensively by different group of scientists across the world in France, Japan, USA, Chile, Poland, Germany, India (Collett et al., 2008, Beyens et al., 2016, Herckes et al., 2015). In India, in spite of the fact that fog is an important wintertime phenomenon which bring life at halt due to visibility reduction to as low as 5 meter, a few studies have been carried out. The present work on fog and dew chemistry at New Delhi, one of the most polluted city, include chemical characterization, comparison and understanding the sources and process involved in determining their chemistry.

2. Methodology

Fog samples were collected using using Caltech Active Strand Cloud water Collector (CASCC2; Collett et al., 2008). Dew samples were collected using CRSQ- 0.25 OPUR Dew Condenser (Beyens et al., 2006). All collected samples were subjected to the measurement of pH, electrical conductivity (EC), and total dissolved solids (TDS) immediately. All the fog and dew water samples were filtered through 0.22 µm Millipore membrane filters and was divided into three aliquots and stored in separate bottles. First part was preserved with chloroform for organic acid analysis, second part was stored as such and third was stored after filterate is stabilized with HNO₃ for cation analysis. All samples were stored at about 4°C for chemical analysis.

Major cations (Ca²⁺, Mg²⁺, Na⁺, K⁺, and NH₄⁺), anions (F⁻, Cl⁻, NO₃⁻, NO₂⁻ and SO₄²⁻) were analyzed using Metrohm Ion Chromatograph (IC) model 882 Compact IC pro equipped with conductivity channel.
3. Ionic Composition of Fog Water and Dew Water

The NH$_4^+$ and Ca$_{2+}$ ions are dominant cations present in dew and fog water samples analysed during the study period (Fig. 1). The general order of abundance of cation in dew water sample is Ca$_{2+}$>NH$_4^+$>Na$^+$>K$^+$>Mg$^{2+}$ (Fig. 2a) while in fog water samples collected at the rooftop of SES, the order is NH$_4^+$>Ca$_{2+}$>Mg$^{2+}$>K$^+$>Na$^+$ (Fig. 3a). However, the cations collected at the ground surface near Shipra has cations in the order of NH$_4^+$>Ca$_{2+}$>Mg$^{2+}$>K$^+$>Na$^+$ (Fig. 4a). NH$_4^+$ and Ca$_{2+}$ are almost equal, NH$_4^+$ being slightly greater than Ca$_{2+}$ in the fog water samples collected at the ground surface near Shipra hostel. Large NH$_3$ emission in the northern India has been reported from fertilizer applications, biomass burning and animal breeding, human and animal excretion in Delhi. Source of Ca$_{2+}$ and Mg$^{2+}$ may be the construction activities, re-suspension of surface dust, roadside dust and secondary calcium carbonates in aerosols. Increased burning of wood and dry leaves during winter and dense forests in the vicinity areas are the possible source of K. Na$^+$ could have been contributed by sea spray via western disturbance.

In dew water samples anions follow the order of SO$_4^{2-}$>HCO$_3^-$>Cl$^-$>NO$_2^-$>NO$_3^-$>F$^-$ (Fig. 2b) while in fog water samples collected at the rooftop of SES and ground level of Shipra, the order is SO$_4^{2-}$>Cl$^-$>NO$_3^-$>F$^-$ (Fig. 3b and 4b). Among the anions, it is observed from figure 3(b) and 4(b) that SO$_4^{2-}$ and Cl$^-$ are the dominant anions present in the fog water samples analysed during the study period while SO$_4^{2-}$ and HCO$_3^-$ are dominant anions in dew water samples (Fig. 2b). Among the anions, SO$_4^{2-}$ ion dominates as there is a large emission of SO$_2$ from combustion of fossil fuel in two thermal power plants located around the sampling site. Natural source of Cl$^-$ is salt spray. High concentration of F in fog samples may be attributed to a large number of brick kilns around Delhi. NO$_2^-$ in all samples shows that enough NO is released from vehicular emissions in Delhi. This suggests that the light-mediated oxidation pathway starting from NO to NO$_2$ and NO$_3^-$ is the major contributor of the nitrate detected.

NH$_4^+$ followed by SO$_4^{2-}$-Cl and Ca$_{2+}$ are dominant ions that contribute nearly 84% of the analysed soluble ionic content in case of fog water samples of rooftop and 80% in case of fog water samples collected at ground level near Shipra hostel. The small (9% in the rooftop and 11% in Shipra) contribution of nitrate may be due to cleaner fuel used in vehicles, CNG introduction and more stringent pollution control rules in vehicles in Delhi. Nitrate contributed only 5% in dew water samples and nitrite contributed a significant amount of 8% which signifies the presence of nitrite in dew showing heterogeneous chemical reactions.

4. Comparison of fog water with dew water

The concentration of soluble cations and anions is more in fog water compared to dew water as fog represents suspension of water droplets near surface and dew droplets represent condensed water on a surface. However, the percentage contribution of each ion to the bulk fog water and dew water samples does not change significantly as both gets the imprints of pollutants from the ambient environment.

Fog samples collected at the rooftop of SES has a greater volume weighted mean concentration of major ions NH$_4^+$, SO$_4^{2-}$, Cl$^-$, F$^-$ in comparison to the fog samples collected near the ground surface of Shipra. However, the fog samples collected near the ground surface of Shipra showed greater volume weighted mean concentration of Ca$_{2+}$, Na$^+$, K$^+$, Mg$^{2+}$, NO$_3^-$ and HCO$_3^-$.

5. SO$_4^{2-}$/NO$_3^-$ Ratio

SO$_4^{2-}$/NO$_3^-$ ratio in both types of samples were calculated to assess the contribution of anthropogenic sources to the atmospheric precipitation. The higher values of this ratio (2.46 for fog water and 4.52 for dew water samples) indicated that the SO$_4^{2-}$ emissions dominate over NO$_3^-$ in the study area and there is role of SO$_4^{2-}$ in determining the acidity of the fog samples. Coal burnings in thermal power plants located in and around Delhi and vehicular emissions are the possible reasons for such high ratios. Relative contribution of SO$_4^{2-}$ and NO$_3^-$ towards the acidification was computed using the ratio (SO$_4^{2-}$/[SO$_4^{2-}$+NO$_3^-$]) and (NO$_3^-$/[SO$_4^{2-}$+ NO$_3^-$]) respectively. The contribution of H$_2$SO$_4$ in dew water samples was found as 80% and that of HNO$_3$ is 20% whereas in case of fog water it is 70% and 30% respectively.

6. Neutralization factor (NF)

The role of NH$_4^+$, Ca$_{2+}$ and Mg$^{2+}$ ions in neutralizing the acidity has been validated by calculating neutralization factors using empirical formula, NF$_X$ = [X/SO$_4^{2-}$+NO$_3^-$], where X is the cation for which NF is to be
calculated. The strength of neutralization decreases in the order \( \text{NH}_4^+ > \text{Ca}^{2+} \) and \( \text{Mg}^{2+} \) for all studied fog water while dew water samples showed the different trend of \( \text{Ca}^{2+} > \text{NH}_4^+ \) and \( \text{Mg}^{2+} \). By virtue of its higher solubility and residence time its subsequent conversion to \( \text{NH}_4^+ \) suppresses the acidity effect of \( \text{SO}_4^{2-} \) and \( \text{NO}_3^- \) ions in fog and dew samples. The trend in the strength of neutralization factors in fog water samples remains similar (\( \text{NH}_4^+ > \text{Ca}^{2+} \) and \( \text{Mg}^{2+} \)) to that reported Ali et al., (2004). But the NF value of individual cationic species is significantly higher in the present samples compared to the previous studies. This could be related to higher emissions of \( \text{Ca}^{2+} \) and \( \text{Mg}^{2+} \) or lowering of \( \text{SO}_4^{2-} \) and \( \text{NO}_3^- \). In case of dew water samples, previous studies indicate high neutralization by \( \text{NH}_4^+ \) whereas we report it by \( \text{Ca}^{2+} \).

7. Correlation analysis

A correlation was observed between \( \text{Ca}^{2+} \) and \( \text{Mg}^{2+} \) (\( r=0.879 \) for dew and \( r=0.898 \) for fog) suggesting that they have common crustal origin. Similarly, the acid forming anions \( \text{SO}_4^{2-} \) and \( \text{NO}_3^- \) are closely correlated (\( r=0.868 \) for fog and \( r=0.883 \) for dew) indicating that they are simultaneously released from anthropogenic sources in Delhi. Correlation coefficient values of \( \text{NH}_4^+ \) vs \( \text{NO}_3^- =0.812 \) and \( \text{NH}_4^+ \) vs \( \text{SO}_4^{2-} =0.844 \), for fog, shows that neutralization reaction forms (\( \text{NH}_4 \text{H}_2\text{SO}_4 \) and \( \text{NH}_4\text{HNO}_3 \) while for dew correlation coefficient values of \( \text{NH}_4^+ \) vs \( \text{NO}_3^- =0.710 \) and \( \text{NH}_4^+ \) vs \( \text{SO}_4^{2-} =0.676 \) shows that neutralization reaction forms \( \text{NH}_4\text{HNO}_3 \) and (\( \text{NH}_4 \text{H}_2\text{SO}_4 \) but the dominant product of neutralization in dew is \( \text{NH}_4\text{HNO}_3 \) (\( \text{NH}_4^+ \) vs \( \text{NO}_3^- =0.939 \)). Calcium sulphate and calcium nitrate are also important neutralization product in fog and dew as indicated by the correlation matrix (\( \text{Ca}^{2+} \) vs \( \text{SO}_4^{2-} =0.831 \) and \( \text{Ca}^{2+} \) vs \( \text{NO}_3^- =0.83 \) for fog; \( \text{Ca}^{2+} \) vs \( \text{SO}_4^{2-} =0.858 \) and \( \text{Ca}^{2+} \) vs \( \text{NO}_3^- =0.868 \) for dew). It thus, signifies that various neutralization reactions take place in atmosphere while interacting with atmospheric water like fog and dew as well as particulate matter.

Figure 1. Volume weighted mean ionic concentration of major ions (in meq L\(^{-1}\)) in fog and dew water samples collected in Delhi.

Figure 2. Percentage contribution of individual ions to the a) total cationic, b) total anionic, and c) total ionic composition of dew water samples collected at rooftop of SES, JNU in Delhi.
8. Conclusion

Dew water samples were alkaline in nature (average pH = 6.26) as opposed to the natural rainwater pH of 5.6. The collected fog water and dew water show noticeable variations in ionic compositions within the samples collected during the same year. The observed order of abundance of species in dew water samples was Ca\(^{2+}\) > NH\(_4\)\(^+\) > Na\(^+\) > K\(^+\) > Mg\(^{2+}\) for cations and SO\(_4\)\(^{2-}\) > HCO\(_3\) > Cl\(^-\) > NO\(_2\) > NO\(_3\) > F\(^-\) for anions. NH\(_4\)\(^+\) followed by SO\(_4\)\(^{2-}\) > Cl\(^-\) and Ca\(^{2+}\) are dominant ions that contribute nearly 84% of the analysed soluble ionic content in case of fog water samples of rooftop and 80% in case of fog water samples collected at ground level. The strength of neutralization decreases in the order NH\(_4\)\(^+\) > Ca\(^{2+}\) and Mg\(^{2+}\) for all studied fog water while dew water samples showed the different trend of Ca\(^{2+}\) > NH\(_4\)\(^+\) and Mg\(^{2+}\). The nitrite concentration was found to be higher in dew in comparison to fog water.

9. References


**DEW AS A NIGHTTIME RESERVOIR FOR ATMOSPHERIC AMMONIA**

**Background**
Ammonia (NH₃) is a highly water soluble gas-phase pollutant yet its interaction with dew is poorly understood. Dew evaporation is one hypothesis used to rationalize a frequently observed but currently unexplained morning increase in NH₃ occurring between ~7:00-10:00 local time.

**Aim**
Simultaneous quantification of dew composition, dew amount and NH₃ gas-phase concentrations to address the following: 1) if dew is a significant reservoir for NH₃, 2) how much NH₄⁺ in dew is released as NH₃ during evaporation, 3) whether or not dew evaporation can explain the NH₃ morning increase.

**Method**
Measurements were carried out over a 90-day period in a remote high elevation grassland site in Colorado, USA. Dew was collected off a Teflon sheet covering a horizontal styrofoam block. Dew amount was continuously monitored using a “dew meter” consisting of a tray with artificial turf resting atop an analytical balance. Atmospheric NH₃ was measured via cavity ringdown spectroscopy at a resolution of 1 min.

**Results**
Roughly two-thirds of boundary layer NH₃ was sequestered in dew overnight suggesting it is a significant reservoir. Dew composition and pH were used to estimate that, on average, 94% of dew NH₄⁺ is released to the atmosphere as NH₃ during evaporation. Coincident timing of dew evaporation and NH₃ increase, as well as calculated fluxes and approximate mass balance closure of NH₄⁺ and NH₃ provide strong evidence that, at least at this site, dew evaporation is responsible for the morning increase in NH₃. Implications for other water soluble gases (e.g. HONO, acetic acid, formic acid) are also discussed.

**Conclusion.**
To our knowledge this is the first study to simultaneously quantify dew composition, dew amount and the concentration of gas phase ammonia. Results strongly suggest that dew plays a critical role in modulating NH₃ concentrations.
Measurements were carried out over a \( \text{Ammonia (NH}_3 \) method\) using an analytical balance. Atmospheric \( \text{NH}_3 \) was continuously monitored with artificial turf resting atop an grassland site in Colorado, USA. Dew amount was collected off a Teflon sheet covering with a “dew meter” consisting of a tray\). Dew composition, dew amount and \( \text{NH}_3 \) were sequestered in dew overnight with the help of an “acetic acid, formic acid) are also included\). Leaf surface wetness in a spruce forest was detected by the high correlation between electrical conductance and ambient relative humidity and could be attributed to the presence of leaf surface particles. Leaf surface wetness on potato leaves was already detected below 40% r.h. of ambient air. The comparison between leaf wetness sensors and commercial dew sensors (artificial leaves) showed that transpiration contributed to the formation of leaf surface wetness. In the ESEM, condensation on leaf surfaces started at the deliquescence point of salts, e.g., at 75 r.h. for NaCl. Despite the hydrophobicity of cuticles, salt solutions expanded and salts migrated during repeated humidity cycles. The effectiveness of salt expansion was related to the Hofmeister series. Kosmotropic salts like NaCl remained mostly immobile, but eventually showed dendritic growth after several deliquescence/efflorescence cycles. The surface tension was reduced at high concentrations of chaotropic salts like KSCN and KI, and migration into stomatal openings could clearly be observed.

Conclusion

Condensation to hygroscopic nuclei on leaf surfaces starts earlier than predicted by dew theory and is additionally fostered by leaf transpiration. Minute, invisible amounts of water can be permanently present on leaves even in hot, dry environments. They are not relevant in hydrological terms, but they make the leaf surface chemically active for the exchange of trace gases with the atmosphere. Deliquescent particles can establish a liquid connection along the stomatal pathway, where liquid water, dissolved and dispersed substances, and hydraulic signals are transported between leaf surface and apoplast.
DEW DEPOSITION EFFECTS ON LEAF WATER ISOTOPIC ENRICHMENT FROM AN ENERGY BALANCE PERSPECTIVE

Background
Dew deposition occurs widely and regularly in almost all ecosystems. However, dew frequency varies geographically and seasonally and is not always well captured by sensors. This makes it difficult to properly quantify the impacts of dew on vegetation. Because they are a unique signature of the chemical and physical processes undergone by water, stable isotopes of oxygen and hydrogen are widely used to understand the interaction of plants with their environment. In particular, water fluxes coming into—or out of—a leaf from different pools can be distinguished by their isotopic composition.

Aim
The aim of this study is to determine a simple relationship between dew deposition frequency and leaf water isotopic composition.

Method
Dew deposition can influence leaf water through direct entry of dew water into the leaf and also through a modification of the leaf albedo and boundary layer. Moreover, dew evaporation provides additional cooling to the leaf surface. In this study, we model the leaf transpiration rate by combining a dew deposition and evaporation model, driven by common meteorological data, and a leaf energy balance model. The latter includes the effects of dew. The output of this model is used to solve the isotopic mass balance equation and calculate the isotopic composition of the leaf.

To verify the model, leaf samples are collected at two sites in California where long term meteorological and leaf wetness data are available. Leaf water is extracted using cryogenic vacuum distillation and analyzed for oxygen and hydrogen isotopic composition on an isotope ratio infrared spectrometer.

Results
This analysis provides a simple yet powerful tool to estimate dew frequency from standard meteorological data and leaf water isotopes.
Dew deposition can influence leaf water. The aim of this study is to determine the impact of dew on a leaf's isotopic composition.

**Background**

Dew deposition occurs widely and is a unique signature of water fluxes coming into a leaf. The isotopic composition of dew makes it difficult to properly quantify the impacts of dew on vegetation.

**Method**

To verify the model, leaf samples are collected at two sites in California where dew frequency varies geographically and seasonally. Leaf water isotopes are extracted using cryogenic vacuum distillation and analyzed for oxygen and hydrogen isotopic composition on an isotope ratio infrared spectrometer.

**Results**

Seasonal and diurnal changes in SFV suggested that water from tap root was the main source of decumbent stems without adventitious roots. Under dry condition in surface soil layer, decumbent stems with adventitious roots were supplied sufficient water from top root in both day and night. However, abrupt cessation of night time water supply from tap root was observed immediately after subsoil became wet by rainfall and dew drop. It suggested the presence of hydraulic redistribution (especially hydraulic lift) between tap root and adventitious roots. Changes in leaf water potential and SFV suggested direct absorption of dew by leaf in nighttime.

**Conclusion**

*Juniperus sabina* can absorb dew drop through stomata, but does not transport in deeper soil layer. Multilayer root system of deep tap root and dense adventitious roots on decumbent stem can transport soil water as hydraulic redistribution. Under dry condition, hydraulic lift is dominated which suggests an altruistic response. Just after a rain in a long dry period, hydraulic descent is detected.
Temporal variability, magnitude and physiological importance of dewfall in a Mediterranean savanna ecosystem

Background
Dewfall has been reported as an important water source in arid ecosystems. Dewfall takes place under certain atmospheric conditions (e.g. radiative cooling). It is usually associated to stable, low turbulence surface-layer conditions and, therefore, can be poorly characterised by the eddy covariance technique. Among alternatives, lysimeters offer an effective way to quantify dewfall. However, the lack of long-term studies hamper the quantification of the relative importance of dewfall in the annual water balance and to evaluate phenological factors influencing dewfall formation such as vegetation development and structure.

Aim
Here we aim to (i) assess dewfall formation and its contribution to the annual balance and its beneficial effects on plants (ii) to evaluate the underestimation of eddy covariance technique for measuring negative latent heat flux which can be interpreted as dewfall.

Method
We will address the aims by simultaneous, combined measurements via classical eddy-covariance (EC) and replicated lysimeters in a Mediterranean-savanna ecosystem. We use one year of data from six weighting-lysimeters and meteorological measurements (i.e. radiation, humidity, soil-moisture). The phenological stages will be determined in terms of CO2-uptake as measured by EC.

Results
EC missed most dewfall events detected by the lysimeters due to stable surfacelayer conditions. Preliminary results showed a high seasonal variability in dewfall pattern; high in the growing season and during the fall but low during senescence period. On the annual scale, dewfall did not contribute significantly to the water balance. However, it had important physiological and ecological implications. For example, dew fall mitigated plant water stress during the transition from the growing to senescence period.

Conclusion
Dewfall cannot be characterized at EC sites without active dewfall measurements. This is particularly relevant to arid environments, where dewfall influences important physiological processes.
DEW WATER HARVESTING IN CHILE

The availability of fresh water has become a serious problem in arid and semi-arid areas of the world. Dew water collection can be a partial solution for water scarcity in arid and semi-arid areas. Passive dew condensers do not require external energy and its environmental impact is very low.

In this work, the results of the first year of the research project entitled “Experimental assessment and predictive modelling of rooftop dew collection for water supply in Chile” (Fonddecyt 11140863, CONICYT, Chile) are presented. The overall objective of this project is to assess the dew water collection by passive radiative cooling at eight locations in the north and central area of Chile (Quillagua, Antofagasta, Caldera, Copiapó, Coquimbo, Combarbalá, Paihuen and Valparaíso). At each place are set 1 m² dew condensers based on galvanized steel sheets coated with paint containing infrared emitting minerals (TiO₂ and BaSO₄), and a non-soluble surfactant (manufactured by OPUR, France). Each condenser was provided with instrumentation for recording dew yields and surface temperature (every 15 min.). Each location has a meteorological station as well as a standard fog collector to record fog events. Dew, fog and rain water samples are collected and analysed to determine their physical-chemical properties. The collectors started to operate at different times between October 2015 and January 2016. The implementation works and the first results from Valparaíso, Paihuen and Combarbalá are presented and discussed. Daily average dew yields of 142.5 mL/m² (Valparaíso), 65.3 mL/m² (Paihuen) and 11.1 mL/m² (Combarbalá) were obtained in the first months. The first dew water samples from Valparaíso showed that the physical-chemical parameters comply with the OMS standards for drinking water.

This work was supported by FONDECYT N° 11140863 project from CONICYT (Chile)
A 10-YEAR ANALYSIS OF DAILY DEW MEASUREMENTS ON AN URBAN ROOF

Background
Daily dew measurements have been made on an urban roof in Jerusalem starting in 2003.

Aim
The measurements were made to assess the long-term quantity and variability of daily dew, seasonality, and annual deposition in comparison to annual precipitation.

Method
Five passive planar dew collectors were installed side-by-side on a university rooftop in Jerusalem, Israel. Land area is 125 km², population size is about 890,000, climate is Mediterranean and the annual average rainfall is about 540 mm but summer-dry. The rooftop is at an elevation of 780 m on a 3-story building. The collectors were all 1 m² in size, set at a 30° angle from horizontal, insulated with 3 cm styrofoam, and covered with different substrates to compare efficiency. The substrates consisted of a 0.4 mm OPUR polyethylene foil with embedded TiO₂ and BaSO₄ microspheres, 4 mm clear PVC (Polyvinyl Chloride) sheet, 1 mm corrugated white PVC sheet, 3 mm Polycarbonate sheet, and a 3 mm Acrylic sheet.

Results
Annual dew collection ranged between 30-40 mm equivalent of precipitation and about 7% of annual precipitation. Dew occurred on about 50% of nights per year. The majority of overnight dew events had between 0.1 to 0.3 mm on the collectors. The highest overnight dew yields were consistently during the summer months, even though this period has the shortest night length. The highest overnight dew amount recorded was equivalent to 0.63 mm. Under 10% of daily observations were missing or were totals of back-to-back dew nights. A model was developed to estimate overnight dew for such cases using meteorological data obtained from the roof weather station.

Conclusion
The data shows that dew is a regular occurrence and was highest in the dry summer months. Urban roofs may be used to collect dew to contribute to water requirements of green roofs, which is becoming a popular way to ameliorate urban heat island effects. Moss biocrusts are desiccation tolerant and their thin substrate makes it ideal as a roof cover that can be supported by dew.
DEW AS AN ADAPTATION MEASURE TO MEET REFORESTATION DEMAND

Aim
We conduct a feasibility assessment to evaluate the potential for utilizing harvested dew for reforestation.

Method
Dew harvesting is conducted during the 2013 Mediterranean dry season (April-October) in Beiteddine, Lebanon. In conjunction, soil moisture sensors placed both below the dew condenser and 3 m away measure and compare volumetric water content (VWC) for with dew (WD) and without dew (WOD) conditions. Measured dew volumes are also compared to irrigation demand of selected tree seedlings estimated using evapotranspiration-based modelling to assess the feasibility of irrigation from dew harvesting.

Results
Data collected from passive dew condensers in the study area showed a nightly average dew yield of 0.13 L m⁻² with a maximum yield of 0.46 L m⁻² d⁻¹. Dew events occur more frequently than rainfall events, with an estimated 43% of nights producing dew condensate. Moreover, dew yields >0.2 L m⁻² d⁻¹ can result in a notable increase (> 3%) in VWC at shallow depths for WD conditions when compared to WOD conditions on a diurnal basis. When evaluating the cumulative effect of dew in the absence of other irrigation methods, VWC at shallow depths is maintained above the permanent wilting point (PWP) for WD conditions during the dry season, whereas VWC at shallow depths is below the PWP for WOD conditions and thus any soil moisture present is unavailable for plant transpiration.

Conclusion
Harvesting and storing condensed dew (2 m⁻² condenser) is sufficient to irrigate tree seedlings (4.5 L seedling⁻¹ every 30-40 days), mitigating tree mortality.
EFFECT OF SOIL TYPE AND SURFACE LAYER ON NON-RAINFALL WATER INPUTS

Background
Non-rainfall water inputs (NRWIs), which include fog deposition, dew formation, and direct water vapor adsorption by the soil, play a vital role in arid and semiarid regions. Environmental conditions, namely radiation, air temperature, air humidity, and wind speed, largely effect on the water cycle driven by NRWIs. The substrate type (soil type and the existence/absence of a crust layer) may as well play a major role.

Aim
Our objective was to quantify the effects of soil type (loess vs. sand) and surface layer (bare vs. crusted) on the gain and posterior evaporation of NRWIs in the Negev Highlands throughout the dry summer season.

Methods
Four undisturbed soil samples (20 cm diameter and 50 cm depth) were excavated into a PVC tube (Microlysimeter, ML), two from a loess and two from a sand sites in the Negev. From each site, one sample was crusted and in the other the crust was removed. The samples were brought to the Jacob Blaustein Institutes for Desert Research (BIDR), Ben-Gurion University of the Negev, Israel (31°08’ N, 34°53’ E, 400 meter above the sea level) where they were exposed to the same environmental conditions. The four MLs were placed on top of scales and the samples mass was continuously monitored. Soil temperatures were monitored at depths of 1,2,3,5 and10 cm in each ML using Copper-Constantan thermocouples.

Results
The magnitudes of the changes of the samples mass differed from each other. The results indicate that the crusted samples absorbed more water vapor than their corresponding crustless samples. The loess samples absorbed more water than the sandy samples. The measured temperature profiles were as well affected by both soil structure and presence of crust.

Conclusions
These findings are in agreement with the research hypothesis that clay content and crust play a major role in determining the amount of water vapor adsorption.
Background
In arid regions, where rain is not a reliable source of water, non-rainfall water inputs (NRWIs) are of great importance, despite their small size. While their quantification is important, it is a challenging effort.

Aim
We aimed to test the applicability of turbulent-based micrometeorological methods for measuring latent heat flux (LE) involved in NRWIs formation and evaporation in the Negev desert.

Methods
A micrometeorological station was setup near the Blaustein Institutes for Desert Research of the Ben-Gurion University of the Negev, Israel (31°08’ N, 34°53’ E) during September-October 2014. Net-radiation was measured with a 4-way net radiometer; soil heat flux (G) was computed by the calorimetric method and by the combination method; sensible heat flux (H) was measured with eddy covariance (EC) and with surface layer scintillometer (SLS); and LE was assessed by direct EC measurement; as a residual of the energy balance with H measured by SLS; and through application of the flux variance method. LE fluxes were compared to measurements of a microlysimeter (ML; an undisturbed soil sample, 20 cm diameter and 50 cm deep). Evaluation performance of the LE estimates was based on the closure test.

Results
Best closure (90%) was obtained using the calorimetric method to compute G, H obtain from EC and LE from the ML. While all LE measurements were within a reasonable magnitude compared with the ML, inconsistency was observed. Noteworthy is that the LE derived from the energy balance method did not perform well, likely due to measurement errors of the soil heat flux.

Conclusions
The results show some promise in using turbulent-based micrometeorological methods to monitor latent heat flux involved in the formation and evaporation of NRWIs. More research is needed to improve the estimates of soil heat flux over hot and dry soils.
Dew Plant to Produce Bottling Water

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ABSTRACT

A plant has been constructed in Kothara village (Gujarat, India), in a hot semi-arid environment, to demonstrate that atmospheric moisture can be harvested and processed into safe drinking water comparable in quality and price to reverse osmosis (RO). It consists of a condenser field of 540 m² surface area, a conveyance and storage unit to collect and hold the water and a protective boundary fence. Computational Fluid Dynamics study is carried out and dew water output can be estimated from meteorological parameters. It results that water passively harvested from atmospheric moisture can be cheaper than RO water and does not pollute the environment, supporting the importance of dew and rain resources to provide supplementary supply of potable water.

1. INTRODUCTION

The increasing need of fresh water in the world leads to consider rain and dew precipitations as new source of water. It is particularly the case in north-western India (Kutch area), in a hot semi-arid zone where shortage of potable water is chronic and widespread. It is especially of concern in villages near the coast like the Kothara village (7000 inhabitants), which has piped supply pumped out from 135 m depth. Water is not potable, it is used for wash and given to cattle. Average rainfall in Kutch area in a year is 200-300 mm and is very erratic. During some years, rain does not happen at all. Pan evaporation is as filtration. RO causes groundwater level going down year on year; pumping out this ever depleting groundwater has become increasingly costlier. In addition, fresh water obtained from RO is only about 20 – 50% of the total processed water. The rest is disposed off in the surrounding, leading to accelerated degradation of soil and groundwater quality. RO process is not a sustainable solution in the long run. Greater use of atmospheric moisture (dew and rain water) can reduce dependence on RO process. In addition to rain (~ 300 mm during the monsoon season, June to September) dew occurs from October to May with 100 to 115 dew-nights and 15-20 mm of dew water. While the condensers are specifically engineered to condense dew, rain can be routinely harvested using the same surface. Chemical and biological tests of dew water (Sharan, 2011; Sharan et al., 2011) around the Kothara dew plant site: Suthari (13 km), Sayara (111 km), Panandhro (82 km) and Satapar (420 km) show that dew is potable according to Indian regulation. The project to construct a plant to produce bottling water from dew and rain started in August 2013 in Kothara (23°07’36.08”N, 68°55’50”E) and the construction works a few months later.

2. DEW PLANT CONSTRUCTION

The dew harvesting plant is rated to process on an average 500 L/day. It has 4 main components: (i) catchment, (ii) sand filter, (iii) raw water cistern for storage and (iv) purifier and packaging unit. The catchment is erected on level wall compacted ground over a rectangular, 40×16 m² plot. In appearance it is similar to an...
array of panels of solar power installations (Fig. 1). Seen from longitudinal end each row has an “M” profile with gutter in the middle. Mounts have side slope of 30° from horizontal, the “best” angle to enhance dew droplet recovery by gravity while not much lowering radiative cooling (Beyens et al., 2003). This form was selected to make the facility compact and to provide more condensing area per unit land area. There are 15 modules or rows of the mounts. A 50 cm wide access walkway is set between two adjacent rows for cleaning and repairs. Each of the 15 rows of panels, made of two inclined planes facing each other, are separated by 0.225 m. The distance between the top of each “V” is 0.5m. Each plane of the “V” is 1m wide, 18m long and 0.025m thick; it is a sandwich with 25mm styrene foam board in the middle and plastic film wrapped around. The total surface area of all these 15 “V”-shaped rows of mounts is 540 m² and represents the catchment area.

Fig. 1. Fully finished dew plant.

All 15 primary gutters (2% slope) drain into a common secondary gutter. This gutter runs to the nodal cabin (Fig. 1) that moves raw water to the cistern via a sand filter. Dew condenses during clear and humid nights. Rainwater is simply intercepted by the panels during the rainy season. Processing and packaging unit is located inside a cabin right above the cistern (Fig. 1). The purification unit is made up several stages: (1) Micro filtration to remove the μ–particles by disposable candles. (2) Carbon filtration for removal of physical impurity from 50 to 30 µm, removal of chemical impurity (color and odor), removal of biological impurity, removal of chlorine and other organic impurities. (3) Granular activated carbon filtration to remove bad odor of chemicals and other smells. (4) Ultra-filtration membrane to desalt raw water for reducing sand bacteria. (5) UV filtration to disinfect water from biological impurities up to 95%. (6) Post carbon filtration by silver carbon to add taste in the drinking water.

3. METEOROLOGICAL DATA AND DEW POTENTIAL

Climate in NW India is characterized by (i) summer, from February to May, with W or SW nocturnal wind; (ii) monsoon season, from June to September; (iii) winter, from October to January, with N or NE nocturnal wind. Day temperature in winter is about 31°C and rises to over 45°C in summer. In general, night time humidity is high, especially from March to July. Although the rainy season is normally 4 months long, the average number of rainy days is only about five. The sky remains cloudy preventing dew from forming.

Figure 2 reports typical data obtained during the dry season (October 2004 - May 2005; Sharan et al., 2007a): air temperature $T_a$, relative humidity RH or dew point temperature $T_d$, windspeed $V$, wind direction and cloud cover N. Wind speed is extrapolated to 10 m above the ground. Dew yield was measured on an un-insulated, corrugated galvanized iron roof not thermally isolated, with low emissivity 0.23. A multiplicative coefficient (1.4, see Sharan et al., 2007a) is applied to compare the data with thermally isolated condenser with emissivity unity. In Fig. 2 are also reported the night time cloud cover; it shows that the sky is generally clear. Air and dew point temperature evolution indicates that the low dew yield during December and January is due to a significant deficit in RH (and somewhat greater windspeed).

It corresponds to a different atmospheric circulation regime, air from the North being less humid according to the season. Dew forms mainly for wind directions 240°-360° and 0°-100° (from SW to NE).

Fig. 2. Typical data in Kothara. (Adapted from Sharan et al., 2007a).

Nightly dew yield can be evaluated at any location globally according to an analytical
model (Beysens, 2016), which needs only a few data: site elevation, $T_a$, RH or $T_d$, $V$ at 10m elevation and $N$. Results for Kothara are shown in Fig. 3 for the dew season 2004-2005 (from October to May); it corresponds to 15 mm. The uninsulated galvanized iron unit yielded 7.2 mm.

Fig. 3. Dew yield estimation from Beysens (2016) analytical expression.

4. NUMERICAL SIMULATIONS

The aim of the CFD numerical simulation is to estimate the dew water output with respect to meteorological parameters. As the actual yield depends on cooling power and heat exchange, the determination of the maximum temperature drop $(T_c - T_a)$ ($T_c$ is the condenser surface temperature) is a good indicator of the dew yield (Clus et al., 2009). Simulation can thus be only concerned with the thermal exchanges with atmosphere where wind velocity and wind direction are the main parameters.

Fig. 4. Temperature map on the condenser surface for $V_{10} = 2.5$ m.s$^{-1}$ at 3 wind directions: (a) 90°, (b) 45° and (c) 0°.

Commercial software, COMSOL Multiphysics, was used to analyze the heat transfer by conduction, convection and radiation, and fluid flow around the plant. Typical night conditions are considered: $N=0$, $T_a = 288.15$ K (15°C), RH = 80% i.e. $T_d = 11.8$°C. Standard numerical values are used for the air properties (density, thermal conductivity, specific heat, etc).

For sake of simplicity, only 7 rows have been considered (Fig. 4) and 3 main wind directions: 90° (perpendicular to rows), 45° and 0° (parallel to rows). Simulations are performed with typical wind speeds (10 m elevation) $V_{10}$ from 0.5 to 4 m.s$^{-1}$. In Fig. 4 is shown the temperature map on the condenser surface. For 90° and 45° the first rows efficiently lower heat exchange for the other rows, and the following rows present a similar temperature field.

A relevant parameter is the space average of temperature cooling $<\Delta T> = T_c - <T> = 15^\circ C - T$ (Fig. 5). Angles 45° and 90° are seen to cool more efficiently, in a manner similar to a plane inclined at 30°. Wind along the rows (0°) give the lowest cooling, due to enhanced heat exchange with air. Dew forms when $<\Delta T> > 3$°C. Highest yields correspond to orientations between 45° and 90°.

Fig. 5. Wind speed dependence of the difference $<\Delta T> = T_c - <T>$ between ambient air temperature and mean surface temperature. Different wind orientations are shown. For comparison are given the results for a 1m$^2$ plane at 30° from horizontal with 0° wind orientation directed towards the hollow part.

5. ECONOMICS

Most of residents (75%) buy untreated water from vendors. These good water sources are depleting, prices increasing and quality deteriorating. The remaining 25% of the residents has installed RO machines at home. There was 440 RO plant in operation in 2014. The RO appliances cost between USD 50 to 230, with low running costs of about USD 1.5 per month. Typically permeate to condensate ratio of
home RO units is 1:5. All RO owners together thus dispose off nearly 53,000 L of reject water daily with solids estimated close to a ton per week. One entrepreneur has set up a commercial RO plant (2000 L/h.) and is selling water USD 0.0075/L at the plant. The convenience and cost-effectiveness is making RO process the main means to meet the needs. But unregulated disposal of reject water from household and commercial vendors is however leading to degradation of surroundings, top soil and ground water, making RO not sustainable in such regions where aquifers are already strained and soils widely salt-affected.

One square meter condenser can harvest 300 mm of rain water and up to 20 mm of dew water in their respective normal seasons. Making allowance for collection and inevitable conveyance losses of 15%, the potable water output will be 270 L/m². Harvesting rain and dew water from the same catchment improves the economic viability of rain harvest systems. Total cost of the 540 m² harvest surface plant was USD 22,500 or USD 41.7 /m². It includes the civil works USD 20/m² (ground preparation, cistern, gutters, installation of mount array, purifier cabin), mounting frames USD 5.3 per m², condenser panels materials and fabrication and installation USD 6.6 per m², the rest was site supervision. Instrumentation (a data logger for meteorology parameters, water testing apparatus) is excluded as it was for research and will not be needed for working installations at users. The functioning is expected to last 10-15 years, corresponding to 0.0015-0.001 USD/L, to be compared to RO (0.0075 USD/L at the plant). It thus comes out that water passively harvested from atmospheric moisture can be cheaper than that from RO while not polluting the environment.

### 6. CONCLUDING REMARKS

While rain water is limited, dew water is not. The amount of water that can be obtained is potentially very large and is limited only by the technology used. Several research groups in the world are working to develop more efficient and affordable dew condensing technology. Thus, as technology improves, more can be harvested. Active means are also interesting but they are not yet affordable. Simulations over each of the twelve months showed that water production will vary from a minimum of 1500 L/day in January to a maximum of 3200 L/day in July. This can be tapped to meet human needs and possibly that of greenhouse crops. Cost of product water was computed as 0.55 kWh/L, which is not high, however, the upfront investment for such active means is limiting, which in this case was upwards of $200,000. Further R&D is needed to bring down the initial costs to make this very large and sustainable dew resource commercially viable.

### ACKNOWLEDGEMENTs

GS and AR acknowledge support from the Indian Institute of Management, Ahmedabad (India). Sponsor is Department of Science and Technology, Government of India, Delhi. DB, AM and LR acknowledge support from Sorbonne-Paris-Cité Program, France.

### 2. REFERENCES


Improve Dew Harvest with Edges and Microgrooves

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ABSTRACT

During natural dew condensation on an inclined plane substrate, small drops remain pinned by surface defects and evaporate at sunrise. This effect considerably lowers the yield of dew condensers. Two methods are proposed here to enhance shedding. (1) Edge effects: Drops on edges harvest more moisture, hence grow faster than those in the middle of a plane. Since they grow faster they detach sooner and act as natural wipers. Origami-shaped dew condensers can thus collect up to 400% more water than a simple plane with the same projected surface. (2) Favouring drop coalescence on the surface thanks to microgrooves. Multiple tiny drops merge into a few large drops, which can then slide by gravity. Additional grafting of hydrophilic polymers even increases the efficiency of such condensation devices.

1. INTRODUCTION

In a context of pure water decrease and global warming, dew water resources, mostly ignored until now, could serve as an additional water source, supplementing rain and fog water. This could be particularly useful where precipitation is low or lacking. Dew yield potential cannot exceed about 1 L/m² due to the available cooling power which does not exceed 60Wm⁻² (Bliss, 1961). Neglecting the energy for cooling and considering only the latent heat of condensation, \( L = 2.5 \times 10^3 \text{J/kg} \), one indeed gets for a 12h night a condensed volume of \( 60 \times 12 \times 3.6 \times 10^6 / 2.5 \times 10^6 \approx 1 \text{ L/m}^2 \). Practically, the maximum observed yields are rather 0.6 L/m²/night, and more often <0.3 L/m²/night in the best conditions.

In addition, small dew events are generally lost because tiny drops remain pinned at the condenser surface and evaporate in the morning. Dew harvesting thus fundamentally differs from the current studies (see e.g. Lee et al., 2012) devoted to increase steady state condensation yield. Here, the goal is to collect dew water as soon as condensation starts.

In order to approach the maximum yield and collect small dew droplets, the use of geometric or thermal discontinuities at the top of inclined condensers was recently proposed by Medici et al. (2014). The droplets near discontinuities get more vapour than those in the middle of the surface, which compete with each other to get moisture, resulting in a faster growth. Discontinuities indeed locally increase the vapour gradients. Drops thus grow more rapidly and reach faster the critical shedding radius (~mm, see Fig. 1) at which gravity overcomes pinning forces (see e.g. Bomme et al., 2014). This phenomenon is particularly interesting for droplet collection because drops which detach from edges act as natural wipers to scrape off the other droplets on the surface.

Fig. 1. Balance of pinning and gravity forces acting on a drop lying on an inclined surface.

Another approach inspired from biomimetic material can be envisaged to increase the drop radii: transform a myriad of tiny droplets into a few large drops that eventually detach by gravity. Several studies have recently shown that bio-inspired surface can harvest dew water. Certain cacti (Malik et al., 2014a; 2014b) or some beetles
(Guadarrama-Cetina et al., 2014) and lizards (Gans et al., 1982) which live in arid environment can harvest dew water thanks to their textured surface. In this aspect, micro-grooved surface that induce coalescence of droplets (Narhe and Beysens, 2004) can substantially increase dew water harvesting. In addition, grooves are expected to be less subject to aging and contamination than chemical treatments, like alternated wetting and non wetting stripes, proposed for steam condensation (Chaudhury et al., 2014).

2. EXPERIMENTAL INFORMATION

Condensation experiments are carried out in a temperature (T) and relative humidity (RH) – controlled environmental chamber. The substrate holder is a 2 mm thick stainless square steel plate of 173.2 × 173.2 mm size, screwed and pressed with thermal grease onto an electrolytic copper plate of same size in contact with a Peltier element thermostat, whose temperature (T) is recorded. Different tilt angles (α=15°, 30°, 40°, 60°, 75°, 90°) are considered. The substrate temperature (T) is measured with a thermocouple taped on the substrate. The drop growth process is observed from above with a high-resolution CCD camera connected to a computer. The images of the droplets are then analysed with an image analysis software (ImageJ) to obtain the size of the droplets in a given image area and then the condensed mass.

Fig. 1. Groove dimensions.

Usual micro-fabrication techniques are employed to produce grooved substrates on silicon wafer, a strip pattern structure of width w (30-500 µm), separation s (30-500 µm) and height h (50–150 µm) (Fig. 2). Water is collected at the bottom of the condensing substrate by a strip of fabric, positioned at about 100 µm from the bottom of the substrate. This fabric is connected to a recording balance.

3. EDGE EFFECTS

A sessile drop grows by incorporation of the diffusing water vapor molecules (monomers) around it. At time t and distance r from the drop center, the concentration of monomers, c(r, t), proportional to water vapor pressure p(r, t), obeys, in the quasi-static approximation, a Laplace equation \(\Delta c=0\). Its resolution with proper boundary conditions gives the concentration profile. As can be seen on Fig. 3a, edge drops collect more monomers than drops in a surface pattern and hence grow faster. Growth is proportional to the diffusing flux of monomers at the drop surface. It means that isolated drops (at one edge or a corner) collect more monomers and grow faster than drops in a pattern. From the study by Medici et al. (2014), the gain is a factor 2 on a linear edge and 4 on a corner (Fig. 3). Drops at corners and edges thus reach sooner the critical radius where they slide down, wiping the drops on the substrate. On the fresh bare area a new generation of drops nucleates and grows.

Fig. 3. (a) 2D calculation of the water vapor concentration (colors, arb units) near an edge and diffusion flux (arrows). (b) Condensation on a smooth substrate inclined at \(\alpha=30^\circ\) (silicon wafer with water contact angle \(\approx 90^\circ\); \(T_s=26^\circ\), RH = 60%, \(T_a=1.2^\circ\); 156 min condensation). On the fresh bare area a new generation of drops nucleates and grows. (From Medici et al., 2014).

The above study gives a theoretical framework to understand the performance of new kinds of condensers of origami shape (Beysens et al. 2013). This configuration benefits from symmetrical hollow structure, such as cones or inverted pyramids (see e.g. Clus et al. 2009), to lower wind heating effect and improve edge effects. Figure 4 compares the ratio of dew yields of an origami structure, an egg-box –like
structure with nearly the same hollow structure effect but without edges, and an inclined plane structure \((\alpha=30°)\), taken as a reference. The ratio is expressed with respect to the dew yield on the planar structure. The gain is negligible for large dew yield (> 0.12 mm/day) but can reach 150% for the egg-box (hollow effect) and 400% for the origami (hollow + edge effects).

![Image](image1.png)

**Fig. 4.** Dew yield of different structures scaled to a reference planar substrate yield. (Adapted from Beysens et al., 2013).

### 4. GROOVE EFFECTS

The effect of grooves is to promote droplet coalescence (Figs. 5 and 6). The formation of a few large drops instead of many small droplets naturally improves early shedding (Fig. 5).

![Image](image2.png)

**Fig. 5.** Condensation on vertical plates \((\text{RH} = 40\%, T_e = 33^\circ C, T_p = 4^\circ C); \text{condensation time: 1h. Left: vertically grooved surface (s=w=100 \mu m, h=65 \mu m). Right: Smooth surface of the same material. (Bar: 1cm).}\)**

Narhe and Beysens (2004) have detailed the effect of grooves: the droplets which form on the plateaus \(w\) between the grooves move by the haphazard of coalescences towards the channel \((s, h)\) filled with water droplets, with which they merge by capillarity. Water in grooves overflows in some places, forming large droplets. The latter are fed by the grooves, themselves fed by the tiny droplets from the plateaus. Grooves thus lead to the formation of large drops instead of many tiny droplets.

![Image](image3.png)

**Fig. 6.** A large drop drains water from grooves, which themselves drain water from the tiny droplets continuously forming on the plateaus. (From Narhe and Beysens, 2004).

In addition, the length of triple line is decreased (and then the pinning force) when compared to a smooth surface (in the ratio \(w/(w+s)\)). This facilitates drop sliding of the drops when the substrate is not horizontal.

The groove parameters \(h, s, w\) have been varied to see their influence on the run-off time. No dependance on depth \(h\) was observed, in the range 45-150µm. When the groove channel width \(s\) is decreased from 300µm, the run-off start time decreases rapidly until 150µm and then remains constant. Reducing the groove plateau width \(w\) from 500 to 10µm corresponds to a weak linear run-off start time decrease.

Figure 7 shows a typical evolution of collected water mass for two different grooved structures \((s=w=100\mu m\text{ and }300\mu m, \text{resp., same depth } h = 65 \mu m)\) and condensation conditions of Fig. 5. For both grooved surfaces, the collected mass exhibits a linear evolution after the first drop has shed at the onset time \(t_1\). This time depends on the geometrical aspects of the texture. The dashed line in Fig. 7 indicates the evolution of the actually condensed mass of water (mass attached on an identical but smooth surface where drops do not slide for at least 5h). It is thus possible to deduce the mass of water that remains attached on the grooved surfaces during time \(t_1\) and not collected. On the grooved and smooth substrates with 20cm\(^2\) surface area, the condensation rate is 0.14 Lm\(^{-2}\)h\(^{-1}\) (interrupted line in Fig. 7). During at least 5h, no water is collected from the smooth surface. Extrapolation to a 10h night duration assuming that water starts to flow after 5h on the smooth surface would give a value lower than 0.14×(10-5)= 0.7 Lm\(^{-2}\)d\(^{-1}\) (smooth) and 0.14×(10-1)= 1.26 Lm\(^{-2}\)d\(^{-1}\) (groove). This would represent a gain factor larger than 2 for the grooved surface. The extrapolation to a typical natural dew event...
(condensation rate 0.03 \text{ Lm}^{-2}\text{h}^{-1} for a 10h night duration) would correspond to a start time increase of 0.03/0.14=4.7. This time would be about 4.7×1h=4.7h for grooves and more than 5×4.7=23h for the smooth substrate: No water drops would have been collected from the smooth substrate.

\[ t = 40\% \]

Fig. 5. Structure with nearly the same hollow structure origami (hollow + edge effects).

The effect of grooves is to promote droplet coalescence (Figs. 5 and 6). The formation of a large drop drains water from grooves, whereas water in grooves overflows and does not collect. On the grooved and smooth substrates, no water is collected after 5h. Extrapolation to a typical natural dew event gives a value lower than 0.14 ×(10−1) = 0.7 \text{ Lm}^{-2}\text{d}^{-1}

\[ \text{condensation rate} \]

For which dew water is not collected. In order to see their influence on the run-off time, no drops do not slide for at least 5h. It is thus possible to deduce the mass of water that remains for which dew water is not collected. The actually condensed mass of water (mass of surface droplets to obtain a few large drops, instead of a multitude of tiny droplets.)

Fig. 7. Collected water mass evolution for different grooved surfaces (see text) under Fig. 5 condensation conditions. The first drop is collected at time \( t_1 \). Interrupted line: Actually condensed water mass.

5. CONCLUSION

Dropwise condensation can be significantly enhanced by geometric discontinuities. Growth enhancement can reach nearly 400% on edges or corners. With inclined substrates, drop shedding occurs earlier on edges and can wipe out the smallest drops of the substrate that are still pinned. Comparison of natural dew condensing on origami shape collectors and plane shows an increase of up to 400% of the yield compared to a typical smooth substrate.

Micro-grooved substrates favor the coalescence of surface droplets to obtain a few large drops, which shed early, instead of a multitude of tiny droplets that remain pinned for a long time. In addition, grooves reduce pinning forces and thus favor shedding. The most suitable parameters are found in a range slightly lower than 150\( \mu \text{m} \), for which substrates are easy to manufacture.

Harvesting natural dew can then be much improved by using edges and grooves. It is expected at least a factor 2 increase for high condensation rates and long condensation times (present experiment), and much more for low condensation rates and short condensation times, for which dew water is not collected. In order to go further and try to improve condensers yield, tuning the wetting properties by grafting polymers is presently underway.

ACKNOWLEDGEMENTS

This work has been partially funded by the Sorbonne-Paris-Cité Program.

REFERENCES


Relative Contributions of Rain, Drizzle, Fog and Dew at Baku (Azerbaijan)

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ABSTRACT

Contribution and validity of unconventional sources of water in the semi-arid region of Baku (Azerbaijan) is evaluated. Measurements were taken over a year (1/4/2010-31/3/2011) on a dew condenser on a terrace of the botanical garden of Baku and compared to the rain measurements at the Baku airport located within 23 km. Significant relative contributions are found from rain (84 mm), dew (15 mm), drizzle (13 mm), fog (6 mm). Harvested atmospheric water can thus be increased by factors as large as 20-60\% when compared to rain by using surfaces that can condense dew water and collect weak precipitations like fog and drizzle.

1. INTRODUCTION

Diminution of clean fresh water in many areas of the world and global warming can make more attractive alternative source of water like rain, drizzle, fog and dew. Located in a semi-arid region, the Baku region (Azerbaijan) is on the southern shore of the Absheron Peninsula, which projects into the Caspian Sea. The territory suffers from scarceness of water, especially during the dry season that lasts from June to October. Two rivers (Kura and Araz) constitute 80\% of water reserves in Azerbaijan, however contaminated with hazardous materials. In the capital, tap water is not potable. The average annual rainfall is low, 200 mm or less. Mean relative humidity is, however, high (over 70\%), which makes drizzle a frequent phenomenon. Dew, although not referenced, also should be abundant, although strong winds, known to hamper dew formation, are frequent (Baku is known as the “city of winds”).

In order to determine in Baku the potentiality of other sources of water than rain, and in particular the contributions of dew, fog and drizzle, measurements were performed over one year (1/4/2010-31/3/2011). Although carried out for one year only, the results are expected to give a significant vision of the different water contributions. (More information can be found in Meunier and Beysens, 2016).

2. MEASUREMENTS

The measurement location (40°21′20″N, 49°48′43″E) is located on a terrace of the botanical garden, at 3.40 m off the ground, in an open area. The condenser is the same as currently used in many other studies (Berkowicz et al., 2004, Jacobs at al., 2008; for a review see Tomaszkiewicz et al., 2015). It is constituted (Fig. 1) by a 1×1 m\(^2\) plane tilted at 30° with horizontal as indicated to be the “best” angle (Beysens et al., 2003). The condenser is thermally isolated from below by 30 mm thick Styrofoam and equipped with an hydrophilic radiative foil of 0.35 mm thickness manufactured by OPUR (2016). The foil is made of low density polyethylene enclosing a few % of TiO\(_2\) and BaSO\(_4\) particles with water insoluble food proof surfactant at its surface (Nilsson, 1996). The interest of such foil lies in its enhanced dew collection ability and its chemical inert properties.

In addition to collect dew, the condenser also collects rain, drizzle and fog. Corrections related to the tilt angle with horizontal (rain) or vertical (fog) are made. Concerning fog, a vertical mesh is generally used to collect water (Cereceda and Schemenauer, 1996). The difference in yield between an inclined plate and a vertical mesh has been reported by Lekouch et al. (2012) where both devices (mesh and inclined plates) gave the same yield by units of projected vertical area.
Water is collected by gravity in a gutter and the corresponding volume is measured by a pluviometer. The resolution of water collection is 0.014 Lm⁻². An automatic weather station is placed nearby. Air temperature, \( T_a \), dew point temperature, \( T_d \), relative humidity RH and wind speed \( V \) are recorded every hour. The anemometer has a stalling speed of 0.5m/s and resolution 0.1 m/s; it is placed at 1.5m above the terrace (4.9m above the ground). Wind speed is extrapolated at 10 m height \( (V_{10}) \) by using classical logarithmic variations.

Cloud cover data \( (N, \text{ in oktas}) \) are obtained visually at 5:00 hour from the Baku Heydar Aliyev Airport located within 23 km from the measurement site. Rain data are also taken there, with 0.3m minimum daily collected data. Distinction between dew, fog, drizzle and rain can be delicate to perform. Dew occurs at night on long period of time with yields lower than \( \approx 0.08 \text{ Lm}^{-2}\text{hour}^{-1} \). As cooling by radiative deficit is no more than a few K below \( T_a \), dew typically forms when RH \( \approx 80\% \).

![Graph](image)

**Fig. 1.** Evolution of collected water: dew followed by radiative fog. The arrow separates both contributions. Left ordinate: water summation (dots); right ordinate: relative humidity (squares).

Fog exhibits higher hourly yields and can occur day and night. The distinction between dew and fog can be subtle as fog can be radiative and occurs at the end of the night. It can extend during the morning till typically noon (Fig. 1). Nightly fog is deduced from an hourly rate larger than \( 0.08 \text{ Lm}^{-2}\text{hour}^{-1} \) and/or by considering visual observation at 5:00 observation. Drizzle is a light precipitation that can be distinguished from rain when dew and fog contributions are determined. One can indeed separate drizzle from rain by comparing the precipitation data at station and airport. The airport rain gauge sensitivity for precipitation is 0.3 mm.day⁻¹, however the geometry and surface properties of the station collector authorizes more efficient water collection.

![Histogram](image)

**Fig. 2.** Histogram of (a) dew (b) fog (c) rain events.

Uncertainty on the relative contributions of rain, dew, fog, drizzle mainly comes from the different locations of rain data (airport). Although statistically the rain yield should be the same in both locations due to their vicinity, some rain events (storms) can be localized and bias the
that is, nearly 1/3 rd of the year. Mean and median yields are 0.28 and 0.18 mm, respectively, with a maximum at nearly 0.87 mm.d⁻¹. Foggy days are less frequent than dewy days (5.5% of the year). Rain events (11% of the year) are more erratic, however with the same evolution tendencies as for dew. The mean rain yield is 2 mm.d⁻¹, with median close to 1 mm.d⁻¹. The maximum yield is more than 12 mm.d⁻¹. As discussed above in section 2, drizzle contribution is delicate to estimate since it is indirectly obtained from data taken at two different locations. It is thus not impossible to sometimes obtain negative contributions.

3. DISCUSSIONS

Statistics concerning dew, fog, drizzle, rain and all contributions are reported in Fig. 2 and Table 1. In Fig. 3 are also shown the monthly evolution of dew, fog and all contributions from condenser data, plus the rain measurements at the airport.

Table 1. Dew, fog, drizzle and rain characteristics at Baku (01/04/2010-31/03/2011). Correction is made for inclined collected surface by multiplying the collected volume by (1) 1/sin30° and (2) 1/cos30°. The yearly total sums are not exactly conserved due to differences in rain amount between station and airport, leading to uncertainty within about 15 mm (see text). (From Meunier and Beysens, 2016).

One notices that dew forms during all year, with a large maximum in fall (September-November) and two secondary maxima in spring (March and May-June). One observes dew during 118 days, that is, nearly 1/3 rd of the year. Mean and median yields are large, 0.13 and 0.09 mm.d⁻¹, respectively. A dew peak has been observed at 0.52 mm.d⁻¹. Concerning fog, the same kind of evolution as for dew is observed, which looks reasonable as fog is mostly radiative. Mean and median yields are 0.28 and 0.18 mm, respectively, with a maximum at nearly 0.87 mm.d⁻¹. Foggy days are less frequent than dewy days (5.5% of the year). Rain events (11% of the year) are more erratic, however with the same evolution tendencies as for dew. The mean rain yield is 2 mm.d⁻¹, with median close to 1 mm.d⁻¹. The maximum yield is more than 12 mm.d⁻¹. As discussed above in section 2, drizzle contribution is delicate to estimate since it is indirectly obtained from data taken at two different locations. It is thus not impossible to sometimes obtain negative contributions.
that is, nearly 1/3rd of the year. Mean and median 1. In Fig. 3 are also shown the monthly evolution Statistics concerning dew, fog, drizzle, rain and rain might be again more important than contribution of dew, fog drizzle with respect to airport, which could mean that the relative give rain contribution less at station than at evaluating rain from airport data. All three events 9.7 mm airport, 0.66 mm station. The overall year) are more erratic, however with the same contribution. In Fig. 9 is plotted the monthly statistics. The statistics of such events can be analyzed from the rain histogram (Fig. 2). Three events of high intensity are clearly off the main body of the histogram and can be attributed to events of high intensity are clearly off the main body of the histogram and can be attributed to

<table>
<thead>
<tr>
<th>Year</th>
<th>Mean (mm/day)</th>
<th>h max (mm/day)</th>
<th>Nb. daily events</th>
<th>Sensitivity (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dew</td>
<td>0.0087</td>
<td>0.521</td>
<td>118</td>
<td>15.32</td>
</tr>
<tr>
<td>Rain</td>
<td>0.014</td>
<td>8.486</td>
<td>279/268</td>
<td>0.0087</td>
</tr>
<tr>
<td>All</td>
<td>0.014</td>
<td>8.486</td>
<td>245</td>
<td>0.0087</td>
</tr>
</tbody>
</table>

Dew station, (b) fog station, (c) rain airport, (d) the particular water collecting properties of dew condensers, which permit small water volumes to be harvested. It then appears feasible to significantly increase atmospheric water resources at Baku by collecting, in addition to rain, dew, fog and drizzle. This resource can be made potable after evaluating its chemical quality. Low cost plants that collect dew, rain, drizzle and fog, in a way similar to those constructed in India (Sharan et al., 2016), could then be envisaged.

**ACKNOWLEDGMENTS**

DB acknowledges support from Sorbonne-Paris-Cité Program, France.

**REFERENCES**


Observing cars to obtain quantitative dew measurements

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ABSTRACT

Measuring dew amount needs significant amount of knowledge and experimental means, which is not always possible to gather everywhere. A simple method is described to obtain absolute dew determination, based on observing dew formed at the sunrise on cars. Dew indeed forms differently on three main parts that nearly all car exhibits: roof top, windshield and window side. The presence or absence of dew at the sunrise at these positions provides an observation scale index n with 4 levels, which can then be used to quantify dew yield following \( h = Kn \). The validation of this scale and the determination of \( K \) is performed with experiments where dew was observed on several cars for several years. The value obtained is \( K = 0.067 \text{ mm} \), with a 20-30% uncertainty to account for the various local environments that can be encountered around the condenser.

1. INTRODUCTION

Standard planar condensers of 1m×1m collection area, inclined 30° from horizontal and thermally insulated from below are currently used as a standard for dew measurements (for a review, see Tomaszkiewicz et al., 2015). The yield can vary up to 20-30% at the same location depending on their orientation as regards to wind direction and nearby obstacles (Clus et al., 2009). It looks therefore unnecessary to measure dew with a better accuracy than 20-30%. We thus propose a simplified method that uses cars as condensers and which has the merit to be based on visual observation only. This method gives 30 % accuracy and can be easily used to obtain dew potential in all part of the world where cars are present.

The method is based on the recognition that cars display specific features also found in standard dew collectors: (i) horizontal flat roof top, painted and thermally isolated, (ii) 20°–40° inclined non isolated glass windshield and (iii) near vertical, about 70° inclined non isolated glass side windows. The rear window often presents the same inclination than the windshield. Glass emissivity is high (0.92–0.95), as paints’ (0.92–0.96). On these three different substrates, dew forms with different yields because of distinct angles with horizontal and different thermal insulation. Rear window is not considered as its angle with horizontal varies considerably according to the models. Consequently, the visual observation of dew occurrence or absence on these different locations can provide information on the amount of dew yield. We thereby propose a 4 level scale \( (n = 0, 1, 2, 3) \) depending whether dew does not form \( (n=0) \), forms on roof top \( (n=1) \), windshield \( (n=2) \) or side windows \( (n=3) \). We show that the nocturnal dew yield \( h \) (mm/day) is proportional to \( n \), and determine from experiments the proportionality constant. It results that the simple observation of dew formation on different parts of a car can give an estimation of the local dew potential, with an accuracy that can be estimated within 20-30%. The measurements uncertainty is not dependent on the environment but on the approximation made with the 4-level scale and will remain the same in any environment, as it is the case for any dew condenser.

Measurements on car roof top are not dependent on wind direction. Concerning side windows, the effect is averaged on two wind directions and corresponds to using two symmetric standard planar condensers. It is also the case when the windshield and rear windows have the same inclination.

The use of simple means (cars) and simple evaluation (one observation per day) by non-experts in arid and semi-arid countries is thus particularly appealing as these areas, in addition to suffer from water scarcity, quite often lack of
financial and intellectual resources, making dew water evaluation a challenging process.

2. DEW YIELD & OBSERVATION SCALE

A car can be schematized as being made up of 3 (or 4 when rear window and windshield have the same inclination) planar condensers of size on order 1 m²: (i) roof (R), horizontal and thermally insulated from below, (ii) windshield (W), not insulated and making an angle with horizontal of \( \alpha_1 = 30° \pm 10° \), depending on the models) and (iii) side windows (S), not insulated and making an angle \( \alpha_2 \) close to 70° with horizontal.

\[
\Delta = \frac{h}{h_0} \quad \text{(ratio of dew yield)}
\]

Fig. 1. Variation with tilt angle of reduced dew yield \( h' \) for cloth on wood (adapted from Kidron, 2005; see text) and for isolated and non-isolated planar condensers (adapted from Beyens et al., 2003). The bold circles correspond to car roof top (R), windshield (W) and side windows (S) angles.

Beyens et al. (2003) studied the influence on condenser radiative cooling of angle \( \alpha \) with horizontal, using radiative foil either thermally isolated or not. Surface temperature was measured and the \( \alpha \)-dependence of a performance ratio \( \Delta \) was obtained, \( \Delta = \frac{T_\text{r}(\alpha)-T_\text{a}}{T_\text{r}} \). Here \( T_\text{r} \) is the surface temperature of the condenser and \( T_\text{r} \) is the surface temperature of an identical, thermally insulated, horizontal condenser placed aside the condenser under study. Cooling efficiency \( T_\text{r} \) and dew water yield are well correlated. As shown in Clus et al., 2009, dew yield \( \sim \Delta \). Kidron (2005) also studied dew yield \( h \) as a function of tilt angle by weighing cloths attached on wooden boxes. A reduced yield \( h' = h(\alpha)/h(0°) \) can be deduced. The thermal experimental conditions can be considered as intermediate between the non-isolated and isolated cases above as wood thermal conductivity is significantly larger than Styrofoam.

\[
\text{In Fig. 1 are reported the } \alpha \text{-variations of } \Delta \text{ and } 0.8h' \text{ (mean between isolated and non-isolated cases); good agreement is seen between both experimental determinations. The three corresponding observation location on the car (R, W, S; isolated – non-isolated) are also shown in Fig. 1. By taking as reference the maximum yield } h_0 (\alpha =30°; \text{isolated}; \Delta = 1.18 \pm 0.05), \text{ one finds the correspondence between the three levels } n=0 \text{ (no dew on R, W, S), } n=1 \text{ (dew on R, no dew on W, S), } n=2 \text{ (dew on R and W), } n=3 \text{ (dew on R, W, S). The corresponding values in units of } h_0 \text{ are listed in Table 1. They correspond to Fig. 2a where } n=0 \text{ corresponds to a reduced dew yield between a very small value } \varepsilon =0 \text{ and } AB=A'B'=0.15, \text{ that is } h/h_0 =0.075 \pm 0.075; \text{ } n=1 \text{ corresponds to a reduced dew yield between } AB=0.15 \text{ and } CD=C'B'=0.40, \text{ that is } h/h_0 =0.275 \pm 0.125. \text{ } n=2 \text{ corresponds to a value between CD and EF=E'B' } (h/h_0=0.64 \pm 0.24) \text{ and } n=3, \text{ to a value between EF and GB' } (h/h_0=0.94 \pm 0.06). \text{ These values (Table 1) are used in Fig. 2b where a near linear relationship is revealed between the mean } h/h_0 \text{ and } n: h/h_0 = a +
bn, with \( a = 0.05 \pm 0.1 \) and \( b = 0.30 \pm 0.05 \) (error: one standard deviation). Due to the very small value one can impose \( a = 0 \) in the relationship. In that case \( h/h_0 \) and \( n \) become proportional, \( h/h_0 = bN \), with \( b = 0.32 \pm 0.03 \) (error: one standard deviation). Note that the relative uncertainty on \( h/h_0 \) decreases when \( n \) increases, from 100% for \( n = 0 \) to 6% for \( n = 3 \).

![Table 1: Data used to determine the relation between \( h/h_0 \) and \( n \), with \( h_0 \) the maximum dew yield in Fig. 1 (thermally isolated planar condenser at 30° from horizontal).

<table>
<thead>
<tr>
<th>Reduced dew yield ( h/h_0 )</th>
<th>Angle isolation</th>
<th>Case</th>
<th>( N ) level</th>
<th>Reduced dew yield ( h/h_0 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( 1 \times 10^{-3} )</td>
<td>30</td>
<td>Y</td>
<td>Reference (Ref.)</td>
<td>( 0.27 \pm 0.125 )</td>
</tr>
<tr>
<td>( 0.85 \pm 0.04 )</td>
<td>0</td>
<td>Y</td>
<td>Roof top (R)</td>
<td>dew/R</td>
</tr>
<tr>
<td>( 0.69 \pm 0.01 )</td>
<td>30</td>
<td>N</td>
<td>Windshield, near window (W)</td>
<td>dew/T+W</td>
</tr>
<tr>
<td>( 0.12 \pm 0.00 )</td>
<td>60</td>
<td>N</td>
<td>Side window (S)</td>
<td>dew/T+V+R</td>
</tr>
</tbody>
</table>

3. EXPERIMENTS

Two kinds of experiments on 3 different sites have been performed. In experiment type 1, which lasted 3 months, dew collected on rooftops of cars and weighted was correlated with \( n \) as deduced from the observations. In experiment type 2, only the observation of the car was carried out, on a long period, near 4 years basis. Dew yield calculation based on a theoretical model (Beysens, 2016) which uses meteo data was then exploited to provide the correlation \( h - n \). Meteo data come from internet meteo sites (weather underground and accuweather) at the nearest meteo station from the studied sites. A conversion table (NOAA/NWS, 1998) relates the sky observation with cloud coverage in oktas.

3.1. Experiment-type 1

Experiments of dew collection on cars have been performed between Feb. 15, 2015 and May 13, 2015. The observation sites are open parking lots with large sky view at Auchel (latitude 50° 30’ 59.5584” N, longitude 2° 27’ 9.1476” E) and Villeneuve d’Ascq (latitude 50° 37’ 43.65” N, longitude 3° 08’ 3.10” E) (France). Two cars (Peugeot 206 hdi 2006 at Auchel and Opel Corsa C 2006 at Villeneuve d’Ascq) were used for observation. The window angles are listed in Table 2 jointly with the sites used and the measurement time. Observation of dew formation is performed just before sunrise. Dew is collected on the roof top by using a tissue of 0.25m², which is then weighted with an electronic balance of 0.1g accuracy, corresponding to a measurement uncertainty of 10⁻² mm. Meteo data are from (Auchel) a station located within 2 km (FERFAY2) and (Lille) Lesquin airport, within 6km from Villeneuve d’Ascq.

3.2. Experiment-type 2

Other measurements are concerned with long term visual observation. They are performed at Le Mesnil-en-Thelle (latitude 49° 10’ 41” N, longitude 02° 17’ 10” E). From Jan.1st, 2011 to Dec. 31st, 2013, observation has been made on a Volkswagen Golf GTI 1991, then, until Sept. 30, 2014, on a Ford Focus break 2009. Another car has been observed during all the course of the experiment, a Renault Scenic 2009. Window angles are listed in Table 2 together with the site characteristics. Meteo data are collected from a station located in Creil (LFPC (07057)), 15 km away from Le Mesnil en Thelle from which dew yields have been computed according to the analytical formula developed by Beysens (2016).

<table>
<thead>
<tr>
<th>Site (latitude, longitude, elevation)</th>
<th>measure- ments time</th>
<th>Car type and color</th>
<th>Angle with horizontal (deg.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Auchel (50° 30’ 59.5584” N, 2° 27’ 9.1476” E, 157m)</td>
<td>2/15/2015 5/13/2015</td>
<td>Peugeot 206 hdi 2006 red</td>
<td>Windshield Side window</td>
</tr>
<tr>
<td>Le Mesnil-en-Thelle (49° 10’ 41” N, 02° 17’ 10” E, 30m)</td>
<td>9/30/2014 6/30/2015</td>
<td>Ford Focus break 2009 gray</td>
<td>Side window</td>
</tr>
<tr>
<td>Villeneuve d’Ascq (50° 37’ 43.65” N, 3° 08’ 3.10” E, 30m)</td>
<td>1/1/2011 12/31/2013</td>
<td>Volkswagen Golf GTI 1991 white</td>
<td>Side window</td>
</tr>
<tr>
<td>Le Mesnil en Thelle (49° 10’ 41” N, 02° 17’ 10” E, 30m)</td>
<td>1/4/2014 6/1/2015</td>
<td>Renault Scenic 2009 black</td>
<td>Side window</td>
</tr>
</tbody>
</table>

Table 3. Characteristics of the studied sites, measurement dates and observed cars.

4. DATA ANALYSIS

In experiment-type 1 dew mass \( m \) collected at the sunrise is converted into daily yew yield \( h \) (mm/day) and correlated with scale index \( n \) coming from cars observation. In Fig. 3a one sees a good proportionality between the summation of events in \( h \) (mm) and \( n \). A fit to sum \( h = k \times n \) gives \( k = (5.66 \pm 0.03) \times 10^{-2} \) mm
(uncertainty: one standard deviation). This factor corresponds to dew forming on a thermally isolated flat plane. When compared to dew forming on a standard collector (isolated plane at 30° from horizontal) a factor 1.2 has to be accounted for. In that case the connection $h - n$ can be written as $h = K \cdot n$, with $K = (6.80 \pm 0.04) \times 10^{-2}$ mm.

The same kind of correlation (Fig. 3b) can be obtained from experiment-2 data by estimating dew yield on a standard collector (thermally isolated, 30° from horizontal) from Eq. 1 and meteo data. Fig. 4 shows this correlation. A fit to Eqs. 6-7 gives $K = (6.664 \pm 0.003) \times 10^{-2}$ mm (uncertainty: one standard deviation). This value compares well with the value obtained from mass measurements, $K = (6.80 \pm 0.04) \times 10^{-2}$ mm. Because of the number of approximations made, the uncertainty can be estimated to about 20-30% with $K = (6.7 \pm 2) \times 10^{-2}$ mm.

5. CONCLUDING REMARKS

Simple observation of dew formed at sunrise on cars can give an easy quantitative evaluation of natural dew condensation. Despite 20-30% tangible accuracy of measurement, based on a 4-level scale, the relevance of this method lays in the fact that the observation can be performed in nearly all parts of the world with few material needed, and still provide a valuable estimation of the dew potential, even in remote areas. Another asset of this process is that it can be effortlessly implemented since few time and materials are required and that no special skills are needed to collect the data, apart from regular observation. It is eventually anticipated that this method could be of great help in many places in the world where water is lacking and dew can help to answer the demand. The plainness of the mode of operation is also a powerful tool in all programs or projects related to raising awareness concerning water issues.

ACKNOWLEDGMENTS

We thank Josué Bulot and Adil Erchouk for measurements at Auchel and Villeneuve d’Asq France). DB acknowledges support from Sorbonne-Paris-Cité Program, France.

REFERENCES

Ten Years of Dew Investigation in Croatia by OPUR

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ABSTRACT

Following studies initiated in the 30’s by Wolf Klaphake an evaluation of the dew resources as compared to rain has been initiated by the OPUR organization in Croatia. Systematic and long-term investigations of the quantity and the quality (chemical properties) of dew water as compared to rain have been performed in several locations of the Dalmatian coast (Zadar) and Adriatic sea islands (Biševo, Vis, Čres, Zadar), thanks to the facilities offered by the Hydro-Meteorological Institute of Zagreb. The data have provided a detailed estimation of dew and rain water quantity and quality and initiated various publications.

In various locations and arid regions, where fresh water is lacking, dew can serve as an alternative source of water, supplement to rain and fog. Dew can indeed condense atmospheric humidity on a surface without any external energy sources thanks to radiative deficit cooling. The Croatian coastline is composed of thousands of islands, most of them being composed of limestone with poor water retention. This area currently lacks water, especially during the dry summer season: due to tourism, the population increases by nearly a factor 10.

The potentiality of harvesting dew water in Croatian islands has already been noticed in the 30’s by a German scientist, Wolf Klaphake, who set up several dew condensers in the small island of Vis, off the Croatian Dalmatian coast. Klaphake left Germany in 1935, and the documents concerning his activity before the 2nd world war remain incomplete, unknown or untraceable (Klaphake, 1936). In order to determine what kind of technology was used and solve the “mystery” of these Vis dew condensers, OPUR and his members started in 2002, in collaboration with the Australian historian Klaus Neumann and with the support of Australian government, a first investigation of the Klaphake constructions (Fig.1) (Neumann, 2003, 2008).

Then systematic and long-term investigations have been performed, thanks to the facilities offered to OPUR by the Hydro-Meteorological Institute of Zagreb. These studies have been concerned with the quantity and the quality (chemical properties) of dew water as compared to rain in several locations of the Dalmatian coast: Zadar, and islands: Biševo, Vis, Čres (Figs. 2 and 3). The data gathered so far has enabled a thorough evaluation of the interest of using in the Croatian coast and islands dew water as an alternative source of water. The results of these studies have been reported in various publications: see e.g. Beysens et al. (2007), Muselli et al. (2009) and Lekouch et al. (2010). Others are in progress concerning e.g. dew water in Čres.

Fig. 1. Apparent remnants (Nov. 2002) of the Klaphake dew condenser on the Vis island.
ABST RACT
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REFERENCES
Background
Many research studies have indicated relatively high concentration levels of pollutants in dew compared with atmospheric precipitation or dry deposition. The significance of the problem is confirmed by the fact that frequency of dew appearance is relatively high. Pollutants present in dew can be particularly harmful due to their concentration during morning evaporation.

Aim
The main aim of this research study is to determine whether dew can be a substantial source of contamination in the urban area in comparison with rural sites. To achieve this goal, water volume as well as the level of concentration of major ions in dew collected at urban and rural sites is compared.

Method
Investigations, described in this work, concerning dew efficiency and chemistry were conducted from February 2008 to February 2010. The deposited dew/hoarfrost was collected by means of insulated plain radiative condensers. A measurement campaign was carried out at various sites in Poland including both urban and nearby rural sites in three different regions. Samples collection was made in pairs of urban/rural stations: Wroclaw in a lowland SW Poland, Krakow in a montane forefield (S Poland) and Gdansk coastal area in the north of the country. Urban sites represent city centers while rural stations were set in a distance of 10-30 km from the relevant downtown area.

Results
The achieved results show that the dew volume at the rural stations is about two times higher than in the nearby city centres. This regularity is consistent with higher temperatures and less frequent saturation conditions observed in urban environment, which were reported in other studies documenting the occurrence of the Urban Heat Island in large Polish cities. Dew contamination differs substantially between urban and nearby rural sites. Electric conductivity and Total Inorganic Ionic Content (TIC) of dew from city centres is on average about twice as high as at rural sites. On the other hand, urban dew is less acidic, what results from positive character of the pH versus dew volume dependency. Higher electric conductivity determined in dew samples collected from urban areas result mainly from higher concentration levels of \( \text{NO}_3^- \), \( \text{Ca}^{2+} \) and \( \text{SO}_4^{2-} \). Correlation coefficients of these ions indicate their anthropogenic origin. According to Lekouch formula, more than 95% of \( \text{Ca}^{2+} \), 85% of \( \text{SO}_4^{2-} \) and almost 100% of \( \text{NO}_3^- \) ions have non marigenic origin at urban sites. The hypothesis concerning regional character of pollution, confirms location of Krakow and Gdańsk, within highly industrialized regions, where emission of \( \text{Na}^+ \) and \( \text{NH}_4^+ \) respectively, is abundant.

Conclusion
The results indicate, that the pollution have mostly regional character affecting dew composition at both rural and urban sites situated in a distance of several tens or even a few hundred kilometers away from pollution sources. However, the highest pollutant concentrations in dew occurred when there was a lack of precipitation in advecting air mass and weak synoptic- or local-scale airflow was observed supplying the area of dew formation with pollutants emitted from local sources.
Aim
The aim of the paper is to present a method that permits precise, with a short time step (even 1 hour), determination of the intensity of water infiltration from the atmosphere to the soil during non-rainfall periods.

Method
The estimation of water infiltration from the atmosphere was performed with the use of a method in which the only input parameters, easy to measure, are the moisture content of the surface layer of soil and its temperature. The measurement of volumetric soil moisture and soil temperature were made with the use of TDR sensors (manufactured at the Institute of Agrophysics PAS in Lublin). To determine the intensity of the infiltration, aluminium barriers impermeable to water were installed in the surface horizon of soil. Thanks to that, the changes in the volumetric moisture of the soil were caused solely by water influx from the atmosphere and the infiltration of water was the only unknown in the equation of water balance within the space under analysis.

Results
The application of the TDR technique for the determination of the diurnal dynamics of the intensity of effective non rainfall water flux requires the application of a temperature correction during the determination of volumetric moisture. The lack of such a correction may cause that the value of the intensity of effective non rainfall water flux will be estimated with an error of up to 26%. The agreement between the values of the intensity of effective non rainfall water flux calculated with the method proposed and the values obtained from the collector is better for periods with dew than for periods with hoarfrost. The relevant root mean square values equal 0.044 and 0.054 mm day\(^{-1}\), respectively.

Conclusion
The study demonstrated the applicability of the method which employs TDR sensors and aluminium barriers, impermeable to water, installed below soil surface, for the determination of the intensity of water infiltration from atmospheric precipitates.
Apparent Non-Stomatal Fluxes of Ozone and Water: A role for Particle-Induced Surface Wetness?

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ABSTRACT

A reevaluation of the CODE91 micrometeorology study of extensive vineyards in California’s San Joaquin Valley suggests that particle deposition on leaf surfaces may have a previously unrecognized but important role. Down-scaled eddy covariance flux data for ozone and water vapor, and up-scaled direct measurements of stomatal conductance, originally suggested that a combination of heterogeneous surface reactions and titration of ozone by soil-derived nitrogen oxides may have explained a persistent residual conductance, including fluxes in darkness, that could not be reconciled with stomatal conductance. Recent results show that 1) soil-derived NOx emissions are not inhibited at temperatures found in this study, 2) that residual canopy conductance behavior in this study under wet and dry conditions was not consistent with background surface reactions, and 3) that particle deposition may form thin aqueous films under conditions of low light and high relative humidity. As fog and ambient particle concentrations were high early in the growing season, and humidity was sufficient to form dew 35% of the time in mornings and evenings, we suggest that surface reactions and NOx titration may be inadequate to explain the observations, and that particle-induced surface wetness may have a role that unifies these and other puzzling aspects of canopy behavior.

1. INTRODUCTION

Grape (Vitis vinifera) occupies 40,000 ha in the San Joaquin Valley of California. Exchanges of ozone (O₃) and water vapor (WV) with this vegetated surface are important drivers of regional air pollution and hydrology. A large micrometeorology study (CODE91; Massman and Grantz, 1995; Massman et al., 1994; Grantz et al., 1995) combined direct porometric measurement of single leaf stomatal conductance (gₑᵥₑᵥₑ) scaled to the canopy level (gₑᵥₑ) with aircraft- and tower- based eddy covariance (EC) measurements of fluxes and conductances for ozone (O₃; gₒₒ) and WV (gₒᵥₑ). During the period of this study fog was common early in the growing season when ambient particle pollution was high (PM₁₀ > 800 µg m⁻³; mostly NH₄NO₃). Fog and PM declined during the growing season, while O₃ increased, but even in the warm summer (maximum T_air > 40 °C) dew formed on leaves during 35% of morning and evening hours, defined as 0 < PPFD < 1000 µmol m⁻² s⁻¹. In recent years drought in western North America has reduced the frequency of fog occurrence, while regulatory activity has reduced winter PM concentrations. Even in the absence of dew, hygroscopic particles deposited on the leaf surface may hydrate and thereby participate in fluxes of O₃ and WV. Heterogeneous surface reactions with O₃ increase total O₃ deposition by a non-stomatal pathway. Thin aqueous films may establish connectivity between the leaf surface, where evaporation occurs, and the interior of the leaf with its relatively large water volume. This may contribute to transpiration that is not well predicted by stomatal aperture.

In addition to surface reactions, non-stomatal deposition of O₃ may also represent titration of O₃ below the height of the eddy covariance sensors, at the expense of NOx emitted from heavily fertilized agricultural soils. Recent measurements (Oikawa et al., 2015) indicate that emissions of NOx from these soils are strongly temperature dependent and do not show inhibition at the high temperatures of this environment. Grape is hypostomatous (stomatal pores only on the abaxial, under side of leaves). During the CODE91 study, grape exhibited surface conductance to O₃ and WV that exceeded values predicted from scaled single leaf measurements of gₒᵥₑ. Three modeling approaches combining up-scaled leaf measurements and down-scaled eddy covariance measurements indicated a large non-stomatal pathway for fluxes of O₃ and WV. This was originally (Massman and Grantz, 1995; Massman et al., 1994; Grantz et al., 1995) attributed to heterogeneous surface reactions and titration of O₃ by NOx from fertilized soil. Recent studies, however, do not support these suggestions and suggest an alternative mechanism involving hygroscopic particles deposited on leaf surfaces.
2. RESULTS AND DISCUSSION

2.1 All Data

Measurements from all daylight hours (0 < PPFD < 2000 µmol m⁻² s⁻¹) were filtered to exclude data in which leaf wetness sensors indicated the presence of dew on the canopy (dry conditions; Massmann and Grantz, 1995). Values of $g_{cx}$ derived from different methods (all converted to WV using the ratio of $O_3$ and WV diffusivities, 1.56) were modeled as a linear function of PPFD to establish compatible coefficients that could be directly compared. At low levels of PPFD, $g_e$ derived from both $O_3$ deposition and from transpiration, exceeded values predicted by $g_{leaf}$. The exceedance by the $O_3$ derived value was 3-fold larger than for the WV derived value. All measures of surface conductance increased up to full sun, but the slopes and intercepts differed such that the differences between the different approaches declined. For $O_3$, a residual conductance remained even at full sunlight. For WV, however, the difference declined to zero at full sunlight.

2.2. Morning and Evening Data

Measurements were restricted to morning and evening hours, with PPFD restricted to half-full sunlight. Over this period, approximately 35% of measurements exhibited dew. Data were analyzed for wet and dry conditions separately (Grantz et al., 1995). Under dew-wetted conditions, $g_{WV,O3}$ derived from $O_3$ deposition was much larger than $g_{leaf}$ at low PPFD. This difference persisted, as $g_{WV,O3}$ increased in parallel with $g_{leaf}$ over the full range of PPFD, up to half-full sunlight. The resulting $g_{residual}$ under wet conditions remained high. Under dry conditions, $g_{WV,O3}$ was larger than $g_{leaf}$ at low PPFD but converged at half-full sun. The resulting $g_{residual}$ under dry conditions declined to zero.

2.3 Single Leaf Data

Direct measurements of single leaf $g_{WV}$, and scaled values of $g_{leaf}$ indicated zero WV flux in darkness.

2.4 A role for particle-induced leaf surface wetness?

Data obtained since the CODE91 (Oikawa et al., 2015) study suggest that soil emissions of NOx may not respond to PPFD (and covarying temperature) to explain the observed diel patterns of $g_{residual}$. Direct measurements of soil emissions of NOx from another fertilized field in California (Oikawa et al., 2015) demonstrated that these fluxes increased strongly with soil temperature, over the range observed in grape, and that previous assumptions of inhibition of NOx fluxes at the high end of this temperature range are not supported by data. The continued increase of NOx emissions with increasing insolation suggests that NOx titration and $g_{residual}$ would increase with PPFD, contrary to the observed values of $g_{residual}$ calculated from $O_3$ fluxes ($g_{WV,O3}$), which declined with PPFD. In both model treatments, a reduced but significant $g_{residual}$ was observed at high PPFD for $O_3$ derived $g_{WV,O3}$. This may reflect the upper bound of the contribution of NOx titration to $O_3$ deposition. At low PPFD (and high relative humidity) conductance derived from both $O_3$ and WV fluxes exhibited substantial $g_{residual}$. However, unlike $g_{residual}$ from the $O_3$ derived $g_{WV,O3}$, the $g_{residual}$ from the WV derived $g_{WV}$ declined to zero at high PPFD. As high PPFD covaried with high $T_{air}$, $T_{soil}$, and $g_{WV}$, and thus with low relative humidity, a role for surface reactions is suggested. The high and constant $g_{residual}$ obtained from $O_3$ fluxes under dew-wetted conditions, suggests that in the presence of an aqueous leaf surface film, $O_3$ deposition to the surface was substantial. However, even under conditions in which dew was not detected by the leaf wetness sensors, the presence of hygroscopic particles on the leaf surfaces could have resulted in a thin film that formed on the surface and that may penetrate the stomatal pores (Burkhardt et al., 2001). Additional data obtained since the CODE91 study suggest that this could establish a continuous aqueous link between the leaf interior and the drier air in the boundary layer (Burkhardt et al., 2001). For example, the presence of 500 ng mm⁻² of aerosol particles (NaNO₃; with $0.5 < d < 1$ µm) increased water vapor flux and $g_{WV}$ at all levels of directly observed stomatal pore size. These studies with Sambucus nigra have since been reproduced with numerous other species. The presence of hygroscopic particles could contribute to the large $g_{residual}$ for $O_3$ deposition at low PPFD (and correspondingly high RH), and for its decline with increasing PPFD under dry but not dew-wetted conditions. Similarly, the $g_{residual}$ derived from WV fluxes, which was greater at low PPFD and declined to zero at high PPFD, could be a response to changes in relative humidity and the hydration of particles previously deposited to the leaf surface. By establishing a liquid phase pathway for water flux from the interior of leaves, this component of transpiration might be poorly controlled by stomatal closure. The apparent decline of single leaf conductance to zero at very low PPFD is not consistent with this hypothesis. However, the cuvette-based measurements are made with elevated levels of turbulence which may dry or otherwise disrupt the leaf surface moisture. Similarly, the correspondence between dew formation on clean leaf wetness
sensors and actual dew formation on particle-impacted leaves is unknown in this system. These and other aspects of this potential mechanism for g\textsubscript{\text{residual}} will require more detailed error analysis in future studies.

3. CONCLUSIONS

Heterogeneous reactions of O\textsubscript{3} would remain constant over the full range of g\textsubscript{\text{leaf}} and PPFD, as observed for O\textsubscript{3} deposition under dew-wetted conditions. Under dry conditions, g\textsubscript{\text{residual}} declined with increasing PPFD and declining RH. This is not consistent with a constant background level of surface deposition.

NO\textsubscript{x} emissions increased with temperature in a similar agricultural environment. This suggests that g\textsubscript{\text{residual}} would increase with PPFD if non-stomatal O\textsubscript{3} deposition were driven by NO\textsubscript{x} titration. In contrast, g\textsubscript{\text{residual}} was constant under wet conditions and declined with increasing PPFD under dry conditions.

Hygroscopic particles may increase V\textsubscript{d} for O\textsubscript{3}, and also increase a component of transpiration (WV flux) that is not detected porometrically due to chamber turbulence, under dew-wetted conditions and as RH increases with declining PPFD. This mechanism remains speculative and subject to rigorous error analysis in future studies. It has the potential to unify several disparate observations regarding non-stomatal O\textsubscript{3} deposition, and elevated diurnal minimum stomatal conductance.

4. REFERENCES


Fog physics
Background

Fog can be very dynamic and the small-scale variability of visibility and droplet size distributions can change within seconds. To obtain a realistic average that allows assessing potential effects of changes in fog characteristics to climate is one challenge. Another challenge is to relate the average conditions to aerosol transports over long distances. African dust is a prominent source of aerosols that can distributed over large areas of the globe, including the Caribbean.

Aim

Our aim was to measure the cloud droplet size distribution in the size range 2–49 µm in the presence and absence of African dust. This was done to assess the effect of African dust on the droplet size distribution, which could have an important effect on surface reflectivity of fog that forms a cloud deck blocked by the Puerto Rican mountains.

Method

We used an FM-100 fog monitor that resolved the droplet spectrum in 40 size bins at high temporal resolution (around 12.5 Hz). In parallel, the turbulent motion was measured using an ultrasonic anemometer (also 12.5 Hz).

Results

At Pico del Este (PE), Puerto Rico, a fog event typically starts with droplets of a single size at the low end of the resolvable size spectrum, which quickly— that is, within minutes to less than an hour— evolves into a bimodal distribution with a large number of small droplets (sizes <6 µm). These, however, are almost negligible for the total liquid water content (LWC) of the fog, and a second peak in the range 10–20 µm is containing the relevant share of LWC. Using hierarchical clustering we found three dominant clusters of characteristic droplet size distributions, of which cluster 1, with a dominance of the smallest droplet sizes, coincided with conditions when aerosol concentrations exceeded that of background sea salt spray. It was, however, not possible to unanimously relate these enhanced aerosol concentrations to African dust, but evidence from the coloring of collected fog water and back-trajectories calculated with the HYSPLIT model suggest a link between the droplet size distributions and African dust transport events at PE.

Conclusion

If such a link between African dust transport events and droplet sizes in fog exists, then this would feed back to climate via the aerosol indirect effect: more but smaller droplets means an increase of surface reflectivity and hence albedo.
THE VARIABILITY OF CLOUD DROPLET SIZES DURING CLOUD EVENTS AND THEIR LINK TO LONG-RANGE DUST TRANSPORT – A CASE STUDY FROM PUERTO RICO

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A major challenge of weather forecasting in cold climates is accurate predictions of low visibilities (Vis) resulting from ice fog conditions. Ice fog composed of only ice crystals can usually form over mountainous terrain and Arctic continental regions where ice nuclei (IN) exist at cold temperatures (T). Its occurrence poses serious limits to military, aviation, and marine operations. Unmanned Aerial Vehicles (UAVs) are particularly vulnerable, given the sensitivity of hardware to moisture and frost. Virtually no detailed studies exist on ice fog formation over complex terrain, and there are a few studies of ice fog over the Arctic regions. A comprehensive wintertime experiment (2014-2015), to understand the life cycle of ice fog events, was conducted in Utah as a part of the Mountain Terrain Atmospheric Modeling and Observations (MATERHORN) Program. An Arctic ice fog project, Fog Remote Sensing and Modeling (FRAM)-Ice Fog (IF) project, was also conducted during 2010-2011 winter near the Yellowknife International Airport, NWT, Canada, to better document ice fog microphysical properties. A suite of instruments was deployed during both projects, which included tethered balloons, radiosondes, several flux towers, sodars and lidars, various particle counters as well as visibility, ice fog spectra, and precipitation measurement instrumentation.

Assuming that ice fog usually occurs when relative humidity with respect to water (RH_w) is less than 100%, a relationship between RH_i (RH with respect to ice) and Vis is obtained, and Vis can be related to microphysical parameters such as ice water content (IWC) and ice crystal number concentration (N). Based on ice microphysical spectral observations, the influence of both IWC and N on extinction (also on Vis) is investigated using both US Weather Regional Forecasting (WRF) and Canadian High Resolution Regional Deterministic Prediction Model (HRDPS) models, and new parameterizations for ice fog are proposed. The results suggest that the forecasting performances of numerical weather models routinely used to predict ice fog episodes is strictly related to their ability to properly estimate IN number concentration and moisture availability in the boundary layer. If either IWC or N is ignored and only RH_i is used for ice fog Vis prediction, the uncertainty in prediction of ice fog Vis can be larger. This result has significant repercussions for aviation and marine applications. In this presentation, challenges of ice fog measurements and issues related to its prediction based on high resolution models will be discussed and ice fog characteristics related to Vis for both mountainous and Arctic regions will be summarized.
EXPLORING MICROPHYSICAL, RADIATIVE, DYNAMIC AND THERMODYNAMIC PROCESSES DRIVING FOG AND LOW STRATUS CLOUDS USING GROUND-BASED LIDAR AND RADAR MEASUREMENTS

Background
Radiation fog formation is largely influenced by the chemical composition, size and number concentration of cloud condensation nuclei and by heating/cooling and drying/moistening processes in a shallow mixing layer near the surface. Once a fog water layer is formed, its development and dissipation becomes predominantly controlled by radiative cooling/heating, turbulent mixing, sedimentation and deposition. Key processes occur in the atmospheric surface layer, directly in contact with the soil and vegetation, and throughout the atmospheric boundary layer. Very high-resolution models and proper representation of microphysical processes can be used to provide detailed descriptions of these processes for idealized cases.

Aim
To study key physical processes in real fog situations we explore the added value of active remote sensing profilers to monitor the temporal evolution of key parameters at several heights (surface, inside the fog, fog top, free troposphere).

Method
We use a comprehensive dataset of backscatter Lidar, Doppler Lidar, Doppler cloud radar, and microwave radiometer provided by the SIRTA atmospheric observatory. This dataset gathers over 100 continental fog events (radiation fog and stratus-lowering fog) collected over 5 years. The method used here consists in studying the temporal evolution of microphysical, radiative and dynamical processes based on measured and retrieved parameters derived from remote sensing profilers.

Results
The presentation will describe how Backscatter Lidar measurements can be used to study the height and kinetics of aerosol activation into fog droplets. Next we will show the potential of Cloud Doppler Radar measurements to characterize the temporal evolution of droplet size, liquid water content, sedimentation and deposition. Contributions from Doppler Lidars to study vertical profiles of turbulent mixing and Microwave Radiometers to study vertical profiles of temperature and humidity will be discussed. This presentation will conclude on the potential to use Backscatter Lidar and Cloud Doppler Radar remote sensing measurements to support operational fog nowcasting. Examples from a recent field experiment carried out at the Paris Charles-de-Gaulle airport will be shown.

Conclusion
Atmospheric profiling of key parameters based on remote sensing measurements provides quantitative information of actual processes driving fog evolution. Analyses of the temporal evolution of these parameters can be used to support fog nowcasting.
AEROSOL PROCESSING BY CLOUDS DURING THE HCCT-2010 HILL CAP CLOUD EXPERIMENT

Background
To study physical and chemical interactions of aerosol and clouds under natural conditions, the Lagrange-type cloud experiment “Hill Cap Cloud Thuringia 2010” (HCCT-2010) was performed in 2010 at Mount Schmücke, Germany, where a hill cap cloud served as a natural flow-through reactor.

Aim
The aim of the campaign was to study aerosol-cloud interactions in ambient air. In this contribution, the influence of clouds on the chemical composition of particles was evaluated.

Method
Three measurement sites were set up (Fig. 1): An upwind site to comprehensively characterize incoming air masses, an in-cloud site on the Schmücke summit to sample the different phases of a cloud, and a downwind site to study possible modifications of the aerosol after the cloud passage.

Fig. 1: Scheme of the campaign area and the 3 sites
An extended pool of various offline- and online-instruments was installed at the sites, including two 5-stage Berner impactors at the valley sites and four aerosol mass spectrometers (AMS) at both the valley and the summit sites to study in-depth possible chemical modifications of aerosol particles due to cloud processing.

Results
An analysis of meteorological parameters and inert tracers (Tilgner et al. 2014) allowed for the identification of several cloud events where the air flow along the measurement sites was fully connected and representative air masses were sampled before, during, and after their passage through the hill-cap cloud ("full cloud events"). Similarly, "non-cloud events" with favorable flow connectivity between the sites but no cloud occurrence at the summit site were identified as reference cases. Generally, during "non-cloud events" the chemical composition of aerosol particles was found to agree well when comparing upwind and downwind sites. During “full cloud events”, downwind concentrations were consistently lower than upwind concentrations for both particle number concentration and chemical particle constituents. This concentration gradient can likely be attributed to physical loss processes such as droplet deposition along the forested area of the air flow path and/or entrainment of cleaner air masses.

When accounting for such loss processes by a conserved tracer approach, indications of increased sulfate and organics concentrations were obtained. Estimated downwind mass additions were in the order of several tenths of µg m⁻³ and were likely related to aqueous phase reactions occurring in the cloud.

Acknowledgments
This work was supported by German Research Foundation (DFG) under contract HE 3086/15-1.

References

Conclusion
In-field observations of aerosol modifications after a cloud passage were obtained and quantitative estimates of sulfate and organics mass increase were deduced.

Acknowledgments
This work was supported by German Research Foundation (DFG) under contract HE 3086/15-1.

References

Ground-based cloud radars are able to observe cloud layers with high vertical and temporal resolution. This detailed information represents a potential for improving short-term forecasts of the development and eventual dissipation of fog. For this application, the radar observations must be linked to physical quantities describing the processes that affect the vertical profile of fog liquid water (radiative budget, droplet sedimentation, turbulent mixing).

**Aim**
The aim of this study is to define quantitative parameters for describing the radiative and microphysical properties of continental fogs that can be derived using cloud radar observations, and to study the range of values these parameters take during the different phases of fog.

**Method**
This study is based on observations taken at the SIRTA atmospheric observatory in Palaiseau (Paris) in the period 2010-1016. The microphysical properties of observed fog layers are quantified by applying various inversion approaches to the reflectivity and Doppler velocity from the BASTA 95GHz FMCW cloud radar. To calculate the radiative budget, a single-column radiative transfer model is applied, using the retrieved microphysics as well as surface meteorology and radiosondes as input. Synergetic algorithms using more instruments (ceilometer, microwave radiometer) are also studied. For validation, in-situ measurements from ground-based radiometers, sensitive precipitation measurements, and optical droplet counters during tether balloon campaigns are applied.

**Results**
I will present the range of variability of the radiative budget, liquid water path and microphysical properties observed during the different phases (formation, development and dissipation) of continental fogs at SIRTA. I will also present uncertainty ranges of the estimates of these physical quantities, based on the validation from collocated in-situ measurements. A comparison of the precision obtained by the different retrieval approaches (which demand a varying amount of instrumentation) will also be presented.

**Conclusion**
The presentation will conclude on the range of values observed for the radiative and microphysical properties during each phase of continental fog.
Characteristics of Fog Water in Mt. Oyama, Japan

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ABSTRACT

Acid fog is frequently observed in Mt. Oyama, and about 30% of a year is covered with fog at the summit. Air pollution has been improved in Japan, and the number of acid fog events has been decreasing, but the average pH has been approximately constant. Characteristics of fog water observed for 25 years in Mt. Oyama are investigated, and the dominating factors are summarized.

1. INTRODUCTION

We have been investigating acid fog at Mt. Oyama (35°28′N, 139°46′E, 1252 m asl.) in the Tanzawa Mountains, Japan (Igawa et al., 1991; 1998). Mt. Oyama is located at about 50 km west-southwest of Tokyo and abuts on the southwest of the Kanto Plain, which is the largest source of air pollutants in Japan. At the mountain, the acid fog events frequently occur, and large amount of fog water containing much air pollutants deposits on the forest in the mountain, where fir forest has declined. However, air pollution has been improved significantly for recent years in Japan, and acid fog events has been decreasing.

In this paper, we will report the results of the long-term observation of fog frequency and fog water components. We also report the effect of acid fog on the canopies of cedar trees. The annual change of the fog characteristics during the term will be summarized.

2. EXPERIMENTAL

We have collected fog samples using an active collector of CALTECH type with a refrigerator to store the fog samples and a time recorder at 680 m altitude on Mt. Oyama (Jacob et al., 1985). The fog water was also collected by passive collectors and passively collected fog, rain, throughfall under cedar trees, and gases in some points of different altitudes were collected and analyzed for the fog-water components. The pH, conductivity, and the concentrations of the major ions in the samples were measured in a usual way.

The air pollution and the meteorological phenomena were measured at a meteorological station, the city hall of Isehara situated at the base of Mt. Oyama, by the Air Preservation Section of Kanagawa Prefecture. Weather phenomena were observed for wind direction and velocity, temperature, and humidity in the mountain.

For the observation of the fog frequency and the fog base altitude, Mt. Oyama was observed using a night view video camera (Litton Systems, Inc., Intellivu IV-2400) from the base, the roof of the Isehara City Hall, and the images were recorded every hour on a digital still recorder (Sony Co., DKR-700). Since 2008, we have also observed fog frequency at the top of the mountain by using a backward scattering type visibility meter (Lazer Fog Sensor of Sten Lofving Optical Sensors).

3. RESULTS AND DISCUSSION

Frequency of fog events is about 30% of a year and high in summer and low in winter. The volume of fog water collected in passive collector is large in the months when the frequency of fog event is high. In August, however, the sample volume is small, although the frequency is high. In the month, dense fog is frequently formed, the wind speed is very low in the dense fog, and...
limited fog sample volume can be collected when the wind speed is low. In a day, the liquid water content is the highest at a.m. 10 and p.m. 9, and low in the midnight and the afternoon.

The fog frequency depends on the altitude, and the fog base can be estimated by using Henning’s equation and the temperature and humidity at the base of the mountain. We observed the fog event from the base using a night view video camera and detected the fog base altitude. The difference between the estimated and observed fog base altitudes depends on SPM, and the altitude becomes lower than the estimated value when the concentration of the particulate matters, the condensation nuclei of fog droplets, is high as shown in Figure 1. These data were calculated from the every hour data and mist may be considered as fog for the far observing point of video camera to the mountain (9 km between the summit and the observing point). These phenomena have been already reported (Igawa et al., 2002), but the SPM concentration decreased significantly in recent years. Therefore, the air pollutants loading via fog may decrease especially in the low altitude. When the observed altitude is much higher than the estimated one, fog may be formed in the conditions other than upslope fog.

Figure 2 shows the annual change of air pollution at the Isehara City Hall, the base of Mt. Oyama. SO$_2$ has decreased significantly since 1970’s and the other air pollutant has also decreased for recent years. The decreasing of NOx started later than that of SPM. Ozone concentration is slightly increasing exclusively, which is an important air pollution problem in Japan (Hatakeyama et al., 2004). This tendency of the overall improvement of air pollution is confirmed not only at the base of Mt. Oyama but also for most of the cities in Japan. The improvement of air pollution may decrease the air pollutant loading via fog water.

We have measured the fog characteristics from 1988 to 2014 at the midslope of Mt. Oyama (Igawa et al., 2014). At the first several years, we measured only a fog season but after that we have observed continuously all year round. Figure 3 shows the annual change of fog water, where the annual average concentrations have varied. In 2000, an eruption occurs in the vicinity and in 2004, typhoon often came to the Kanto district. In these years, the average concentrations were higher than other years. The concentration data were fluctuated but pH has been increasing slightly and the number of the acid fog events with very low pH decreased significantly.

![Figure 1. Difference of fog base altitude vs. SPM concentration: difference is the estimated altitude minus observed altitude.](image1)

![Figure 2. Annual change of air pollution at the base of Mt. Oyama.](image2)

![Figure 3. Annual change of fog water at the midslope of Mt. Oyama.](image3)
Figure 4 shows the annual change of fog water collected passively at the summit of Mt. Oyama. pH has increased and sulfate, nitrate, and ammonium ions have decreased. Ammonium ion concentration becomes high to neutralize the acidy when the fog is acidified. Sulfate and nitrate in this site are formed from the air pollutants. This tendency shown in this figure is in consistent with those shown in Figures 2 and 3.

Figure 5 shows the annual change of throughfall under cedar trees at the summit of Mt. Oyama. The data are the average values of throughfall components under three cedars. Fir trees are declining but there were no fir trees at the summit, while cedar trees are not declining there. Throughfall components are caused from rain, aerosol, gas, fog, and leaching from needles, and the total concentration is about the same as that of fog. The components of the throughfall resembles with that of fog except for proton, ammonium ion and calcium ion. Calcium and potassium ions are leached from the needles and calcium ions are exchanged with proton and ammonium ions, which are absorbed to the needles (Shigihara et al., 2008). Calcium ion leaching has been decreasing in recent years.

Figure 6 shows the relationship between total ion concentration and the fog water amount collected by a passive fog water collector at the summit. There is a high correlation between the concentration and the collected volume of fog water except for the data at 680 m, and the slope of the relation between the concentration and the volume is about minus one in the double logarithm graph. At 680 m, the sample volume is very small, and some irregular data was obtained. This result mean that the fluctuation of the deposition of air pollutants is small and the concentration of fog water is dominated mainly by the collected fog volume. There is also a tendency of the slight decrease of the deposition with the altitude because the fog is mainly formed as the upslope fog and the dominant source of the air pollutants is the Kanto plains. The 1062 m point is the exception because the point is well ventilated for the topographical effect, that is, a saddle-back point.

The dominant factors of fog characteristics are air pollution and water content. The fog water content is affected by many meteorological conditions, that is, humidity, wind speed, wind direction, and rain intensity. Transpiration from the plants in the mountains also affects the humidity and fog water content, and it may be an important remaining subject.

4. CONCLUSIONS

Fog characteristics in Mt. Oyama has been changing during 25 years along with the
improvement of the air pollution. The dominating factors of its characteristics are air pollution and fog water content dominated by many meteorological factors.

5. REFERENCES


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AEROSOL IMPACT ON FOG MICROPHYSICS

Background
Comprehensive field campaigns dedicated to fog life cycle observation were conducted during winters of 2010-2013 at the SIRTA observatory in the Paris suburb area.

Aim
In situ microphysical measurements collected during 23 fog events are examined to document their properties with the objective to evaluate the impact of the aerosol on the fog microphysics.

Method
To derive accurate estimation of the actual activated fog droplet number concentration (Nact) we determine the hygroscopicity parameter (K), the dry and the wet critical diameters and the critical supersaturation for each case by using an iterative procedure based on the kappa-Kohler theory that combines cloud condensation nuclei (CCN), dry particle and droplet size distribution measurements.

Results
Resulting values of $K = 0.17 \pm 0.05$ were found typical of continental aerosols. Our study reveal low values of the derived critical supersaturation with median of 0.043% and large values of both the wet and the dry activation diameters. Consequently the corresponding Nact values are low with a median concentration of 53.5 cm$^{-3}$ and 111 cm$^{-3}$ within the 75th percentile. No detectable trend between available aerosols with diameter > 200 nm and activated particle concentration was observed. Radiative fogs are associated to higher aerosol loading compared to stratus lowering events, but the Nact values are similar for both fog type.

Conclusion
The actual supersaturation reached in these fogs are too low to observe a simultaneous increase of both aerosols > 200 nm and droplet concentrations. High aerosol loading limits the supersaturation values.
A STUDY OF AEROSOL HYGROSCOPICITY DURING FOG EVENTS IN KINMEN, TAIWAN

Aim
To investigate the interaction of aerosols and fog.

Method
The hygroscopicity of ambient aerosols was investigated using a cloud condensation nuclei counter (CCNc), a condensation particle counter (CPC) and a scanning mobility particle sizer system (SMPS) in the period of Mar 31st to May 1st 2015 at Kinmen, Taiwan (24.4077°-N, 118.2889°-E). The single hygroscopicity parameter (Kappa) of aerosols was derived by the measured activation ratios (N_{CCN}/N_{CN}) and aerosol size distribution. Aerosols were sampled using a micro-orifice uniform deposit impactor (MOUDI) and analyzed by an Attenuated Total Reflectance - infrared spectroscopy (ATR-IR) for the functional groups as a function of size.

Results
Two fog events during this campaign were observed (fog_I and fog_II) and the air parcels mainly came from South China Sea according to NOAA back trajectory analysis. The average Kappa is in the range of 0.26-0.64 for fog_I case and 0.15-0.29 for fog_II case. The lower hygroscopicity at fog_II is likely due to the difference of aerosol chemical component distribution and the possible surface tension variation due to the presence of organic carbon. As the fog formed, the chemical composition at size distribution was varied, such as the black carbon distribution was shifted slightly to larger size during fog events as compared to non-fog days based on the functional group analysis. The interaction between the chemical and physical properties of aerosols and fog formation will be further investigated and discussed.

Conclusion
The fog event in Kinmen is mainly controlled by the meteorological conditions. However, the hygroscopicity of aerosols can affect the intensity of fog and the presence of fog might affect the chemical reactions in the atmosphere which will modify the aerosol composition. The interaction between aerosols and fog is complicate and will require further investigation.
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FOG RESEARCH IN THE SOUTHERN ATACAMA: MEASUREMENT SETUP AND FIRST RESULTS OF THE NEW CRUSTWEATHERING PROJECT

Background
Coastal fog in northern Chile provides the most important water source for a sparse vegetation dominated by biological soil crusts. These crusts are considered key-stone organisms regarding the local phosphorus cycle and depend largely on the currently unknown and spatially and temporally variable fog water input.

Aim
We quantify the fog water input and classify fog events according to their vertical liquid water content profiles into the dominant fog types (advective, orographic, radiation) in the research area.

Method
Measurements will be conducted in march and april 2016 at two locations: the first location is in the southern part of the Atacama desert in the Pan de Azúcar national park. The second one is in the semi-arid part approx. 400 km to the south of the first location near La Serena. At each location three automatic weather stations equipped with fog collectors will be installed (below, within and above main fog levels). In parallel, a drone with an optical particle counter will be used to collect vertical profiles of liquid water contents of the coastal fog. The optical particle counter measures the number of particles with respect to 30 particle size classes from 2 µm to 50 µm.

Results
We will show the measuring setup of the project and present the results of the first field campaign. These encompass for the first time vertical particle size distributions of fog in the southern part of the Atacama desert. The vertical profiles will be classified into the dominant fog types (advective, orographic, radiation).

Conclusion
The results will serve as input for the spatial delineation of fog, fog type and associated liquid water profiles using satellite data.
The analysis covers period 2004-2006. It is based on a series of meteorological observations from two meteorological stations: one located in coastal tundra (Polish Polar Station Hornsund, WMO 01003, 15m asl), second one located in the ablation zone of Hans glacier (200m asl). To estimate share of evaporation and condensation we’ve used equations of energy and mass balance proposed for ablation zone of Morteratsgletscher in Alps by Oerlemans (2000). Latent heat flux \( H_w \) approximation was based on thermodynamic equations and meteorological observations from both stations.

Preliminary calculations for ablation seasons: 2004, 2005 and 2006 show that the share of evaporation in ablation at Hans glacier accounted for 0.38 cm, 0.34 cm and 0.72 cm of water equivalent respectively, which is 0.2% to 0.8% of total ablation in given periods. At the same time income of water from condensation in successive seasons was 1.6 cm, 1.05 cm and 0.86 cm in water equivalent. Additionally energy flux released in condensation process contributed to the ablation of snow cover at Hans glacier by 12 cm of w.e. in the 2004, 7.8 cm w.e. next year, and 6.4 cm w.e. in 2006.
Background
Generally, most typical fog type at inland areas is radiation fog. However, in areas with a large water body, other types such steam or advection fog may occur. Steam fog differs from other types by the formation mechanism, time scale, and spatial distribution. Moreover, the size of water body may play an important role in the formation and characteristics of steam fog. In our knowledge, there is still lack of research conducted to steam fogs formation at medium size River.

Aim
In this study we analyzed micro-meteorological characteristics before steam fog onset and the influence of evaporation from the Nakdong River on fog formation.

Method
To observe fogs around the Nakdong River, two flux towers (EC-150) with Automatic Weather Stations (AWS) and visibility sensors (SWS-200) were installed on the west and east sides of the river. Data interval was one minute for AWS and visibility, where 10 Hz for flux measurement. The observation data cover 3-year period from January 2013 to October 2015. The fogs were classified into four types (radiation, advection, steam, and frontal fog) using Park et al.’s (2015) method. To analyze the influence of evaporation from open water surface on fog formation, energy flux data during the six hours before the fog onset were considered. Using the Eddy-Pro software (LI-COR Co.) 30 minutes average fluxes, QC, and footprint from the 10Hz flux data were computed.

Results
Using the classification algorithm, a total of 74 steam fogs were identified during the study period at the observation sites. The fogs formed typically between 3:00 and 7:00 AM LST. A significant land breeze effect was observed at both sites before the fog formations. The land breeze flow seems to be supported by a down slope winds from the hills of the Nakdong River catchment area. The maximal wind velocity measured by ultrasonic anemometer at 1 hour before fog formation was 4.12 m s⁻¹, suggesting that steam fog may form even under stronger wind condition than generally expected. At the west site the sensible heat flux varied between -143.76 ~ 39.03 W m⁻² and latent heat flux between -332.01 ~ 183.85 W m⁻². At the east site, the sensible heat and latent heat flux varied between -100.3 ~ 34.55 W m⁻² and -123.27 ~ 136.09 W m⁻², respectively. The footprint analysis revealed that the most of these fluxes originated from land rather than from the water surface. Therefore, to estimate the evaporation from a river, another approach such as Penman method is needed.

Acknowledgements
This work is supported by the "Advanced Research on Applied Meteorology" of National Institute of Meteorological Sciences (NIMS) funded by the Korea Meteorological Administration (KMA).

References
THE CHARACTERISTICS OF FOG SIZE SPECTRUM AT XITOU MOUNTAIN VALLEY AND KINMEN ISLAND

Background
Two sites’ campaigns at Taiwan were conducted to measure the size distribution of fog droplets.

Aim
The characteristics of fog droplet at mountain valley and island are revised for further field programs.

Method
DMT FM120 fog monitor was arranged to take one-month continuous measurements.

Results
This experiment took place at Xitou (mountain sampling site) for one month. Xitou is a north-south valley at the north of Alishan Range in Taiwan, where has significant mountain-valley breeze weather pattern. During the daytime, valley breeze lifts the aerosol and moist air from the downslope-side urban region. As air parcel lifts along the slope, the temperature decreases. Water vapor then condenses on aerosol and develops for at the mountain slope. After sunset, wind field turns to mountain breeze and fog dissipates rapidly. Sometimes the northeast monsoon is strong enough to maintain the upslope wind. A typical diurnal variation of fog event was observed at Xitou with a maximum number concentration and mixing ratio of water about 6 and 20 µm, respectively (Figure 1). There is a permanently haze mode at 3 to 8µm, which might be caused by transportation of urban pollution. On the other hand, Kinmen is an island situated at the southeast continental boundary of mainland China. The monsoons have transition period between cold northeast monsoon airflow to southwest warmer monsoon airflow happens in April of Taiwan. A typical fog event at Kinmen occurs frequently during southwest prevailing wind. The advection of warm moist air over cold ocean surface causes sea fog formation. During nighttime, sea fog moves onshore into Kinmen Island. The cool and stable weather condition during nighttime retains the fog event until the morning. Then the sun activates turbulence in the boundary layer and mix the fog with dry air into the base of low cloud. The sea fog has bimodal pattern, one peak appears at 7 µm and the other one at 28 µm. The smaller diameter mode has a higher number concentration, but the larger diameter mode contributes more to the mass of fog water (Figure 2). Rarely, there is also fog occurring during northeast prevailing wind with turbid urban pollutants of China. However, these for events are dries and one mode at small diameter only.

Conclusion
There is a permanently haze mode (urban pollution) at 3 to 8µm at mountain valley Xitou, but sea fog at Kinmen Island has bimodal pattern, at 7 µm and 28 µm.
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Conclusion

There is a permanently haze mode (urban pollution) at 3 to 8 µm at mountain valley Xitou, but sea fog at Kinmen island has bimodal pattern, at 7 µm and 28 µm.

Figure 1. The example of fog event at Xitou (Oct.11, 2015) upper panel is the number concentration and mixing ratio of water in the lower panel.
ESTIMATING FOG-TOP HEIGHT THROUGH NEAR-SURFACE MICROMETEOROLOGICAL MEASUREMENTS

Background
Fog-top height (fog thickness) is very useful information for aircraft maneuvers, data assimilation/validation of Numerical Weather Prediction models or nowcasting of fog dissipation. This variable is usually difficult to determine, since the fog layer top cannot be observed from the surface. In some cases, satellite data, ground remote sensing instruments or atmospheric soundings are used to provide approximations of fog-top height. These instruments are expensive and their data not always available.

Aim
In this work two different methods for the estimation of fog-top height from field measurements are evaluated from the statistical analysis of several radiation-fog events at two research facilities.

Method
Field observations of radiation fog at the CIBA observatory in Spain and the CESAR observatory in the Netherlands.

Results
Firstly, surface friction velocity and buoyancy flux are here presented as potential indicators of fog thickness, since a linear correlation between fog thickness and surface turbulence is found at both sites. An operational application of this method can provide a continuous estimation of fog-top height with the deployment of a unique sonic anemometer at surface. Secondly, the fog-top height estimation based on the turbulent homogenisation within well-mixed fog (an adiabatic temperature profile) is evaluated. The latter method provides a high percentage of correctly-estimated fog-top heights for well-mixed radiation fog, considering the temperature difference between different levels of the fog. However, it is not valid for shallow fog (~ less than 50 m depth), since in this case, the weaker turbulence within the fog is not able to erode the surface-based temperature inversion and to homogenise the fog layer.

Conclusion
The proposed method can provide a continuous estimation of fog-top height with the deployment of a sonic anemometer and screen level fog observations by a visibilimeter or human observations.

Figure 2. The example of fog event at Kinmen Island (Apr. 6, 2016) upper panel is the number concentration and mixing ratio of water in the lower panel.
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Conclusion
The proposed method can provide a continuous estimation of fog-top height with the deployment of a sonic anemometer and screen level fog observations by a visibilimeter or human observations.
Background
Despite extensive research on fog in the last centuries, we still do not understand the processes governing fog, and it is difficult to forecast fog accurately. This is mainly due to the discontinuous nature of fog, which is the result of a complex interaction of multiple meteorological and microphysical processes. Furthermore, we have little knowledge about the vertical-temporal evolution of fog, mainly because we lack continuous data on its vertical structure.

Aim
The current study aimed at analysing the vertical-temporal fog dynamics with the aid of ground-based and atmospheric measurement techniques for fog events measured between September and December 2012.

Method
To provide a dataset suitable to study the processes during radiation fog, a new 94 GHz frequency-modulated continuous-wave cloud radar and other active and passive remote sensing instruments together with in situ sensors were deployed at the Marburg Ground Truth and Profiling Station in Germany.

Results
Fog events with conspicuous characteristics could be identified. The fog events could be differentiated based on the time of the year and their vertical extent. Between September and December 2012, a total of 17 fog events, with an average duration of 12 h, were identified. On most of these occasions, fog formed after sunset and dissipated several hours after sunrise. On two occasions, the fog had dissipated before sunrise. In general, November and December fogs had a greater vertical extent. Cloud radar reflectivity values were higher for fogs with a greater vertical extent. Differences were also seen in net radiation, which was more negative during the formation phase of fogs November and December. A strong relationship between the horizontal visibility and the wind speed and direction could be identified.

Conclusion
The results indicate that atmospheric profiling instruments available at the Marburg Ground Truth and Profiling Station deliver useful information for studying vertical temporal fog dynamics.
POROUS CORUNDUM PLATE SENSOR FOR ATMOSPHERIC WATER DEPOSITS TDR MEASUREMENTS

Aim
In some regions the amount of water supplied to the soil due to the existence of fog, dew, hoarfrost and direct water adorption from the atmosphere can exceed that of rainfall. For this reason, the atmospheric water deposits can be the main source of liquid water for living organisms. On this account, the measurements of the amount of water thus added to the soil are of crucial importance from the ecological perspective.

Method
For measuring the atmospheric water deposits intensity the TDR (Time Domain Reflectometry) sensor was designed and produced. The sensor was equipped with a water collector in the form of a corundum ceramics plate. The plate was placed between a flat surface made of laminate covered with copper, which was impermeable to water, and a copper wire. The metallic layer and the wire formed a transmission line. The properties of the porous material used for manufacturing the plates do not change in time, which ensures high measurement repeatability. The results are obtained immediately. Moreover, the TDR technique allows to achieve the desirable resolution and accuracy of the atmospheric water deposits measurements.

Results
The aim of the research was to test the sensor for the atmospheric water deposits intensity measurements and to define its measuring range and detection level. In order to achieve this goal six sensors with ceramic plates were tested in the laboratory. The performance of the produced sensors was also examined during field measurements. The outdoor readings taken simultaneously with a set of six sensors with different porous plates thicknesses allowed obtaining a wide measuring range while maintaining a high level of detection. Additionally, the conducted field measurements revealed that the designed sensor is also capable of measuring the rainfall of very low intensity.
Fog climatology
AN OVERVIEW OF SEA FOG STUDY IN QINGDAO (TSINGTAO) CHINA

This talk may provide useful information for those who want to know the latest trends of sea fog study in China. Qingdao (also spelt Tsingtao, or Tsingtau) is located in the southern coast of the Shandong Peninsula (German: Schantung-Halbinsel), and is a beautiful coastal city. In Chinese, Qīng (青) means "green" or "lush", while dǎo (岛) means "island". It stretches in latitude from 35°35'N to 37°09'N and in longitude from 119°30'E to 121°00'E, and occupies about 10,654 square kilometres. Qingdao is also a major seaport and industrial center. The world's longest sea bridge, the Jiaozhou Bay Bridge, links the main urban area of Qingdao with Huangdao district, straddling the Jiaozhou Bay sea areas. It is also the brewery site of Tsingtao Beer, one of the most famous beers in the world.

Qingdao has a temperate, four-season, monsoon-influenced climate that lies in the transition between the humid subtropical and humid continental regimes. The period from April to July along the southern coast of Shandong Peninsula is a typical fog season. Sea fog may be frequently observed over the Yellow Sea, especially if the sea surface temperature is lower than the surface air temperature.

The meteorological observation of Qingdao started from 13 March 1898. At that time, Qingdao was occupied by Germany. The early observational data included air temperature, air pressure, wind direction, wind speed, relative humidity, cloudiness and precipitation etc. It suggests that study of sea fog in Qingdao has long-time historical data.

In this talk, we will try to give an overview of sea fog study in Qingdao during the past decades. Especially, the stories of three generation of sea fog researcher in Ocean University of China (previously named as Shandong College of Oceanography from 1959 to 1988, and Ocean University of Qingdao from 1988 to 2002, respectively).

The first generation, Professor WANG Binhua from the Department of Marine Meteorology in Ocean University of China was regarded to be one of the greatest pioneers of sea fog research in the world. He started the collection of sea fog data from the beginning of 1940s. At that time, China was in a very difficult period of the World War II. Later, during his scientific researching and teaching of few decades, he tried his best to put "sea fog" into the undergraduate course of "marine meteorology" as one part of his teaching content. In 1966, after many efforts, he wrote the manuscript named as "Sea Fog" by hand, and was ready to open a course to the senior students. Unfortunately, the subsequent "Cultural Revolution" in China made this manuscript be burn away by Red Guard, as the bourgeois reactionary academic materials. When the "Cultural Revolution" was ended in 1976, ten years have gone. With his horrendous perseverance, he recovered the frame of this manuscript according to his memory after many hard efforts. With the help of left fragments and the recent references of sea fog study he could find at that time, in 1983, he published the first book in Chinese on sea fog research in the world named as "Sea Fog". In this book, he systematically introduced the formation and the classification of sea fog, the distribution of sea fog over the global oceans, the oceanic and meteorological conditions for sea fog formation, Also, the physical properties of sea fog and the forecasting method of sea fog were discussed. Later, with the help of Professor WANG Mingxing from Institute of Atmospheric Physics, Chinese Academy of Sciences, Professors ZHANG Huai, XU Jingqiu, HU Jifu, XIE Liusen from...
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Shandong College of Oceanography, this Chinese version book was translated into English. Ms ZENG Zuo was the typewriter of English manuscript. After adding some references provided by Professor ZHOU Faxiu, the English book SEA FOG was published jointly by China Ocean Press and Springer Verlag company in 1985. The first systematic observational study of sea fog in Qingdao China can be traced back to the period from 1960 to 1970. During two particular sub-periods from 1965 to 1966, and from 1971 to 1973, a great number of teachers and students in Shandong College of Oceanography took part in special survey of sea fog over the Yellow Sea, and obtained first-hand observational data related to sea fog. From 1991 to 1995, Ocean University of Qingdao and Institute of Oceanology, Chinese Academy of Sciences jointly completed a national project “Research on Numerical Prediction Method of Sea Fog over the Yellow Sea”. The project was regarded to be one of the most systematic and comprehensive sea fog studies in China after the publishing of book SEA FOG. As the second generation of the sea fog researchers, Professor ZHOU Faxiu, made significant contributions to the development of sea fog research in China.

In order to continue the sea fog researching cause inherited from the older-generation of Chinese meteorologists, a sea fog research group in Ocean University of China, formed with Prof. FU Gang Fu, Prof. ZHANG Suping, Prof. GAO Shanhong, and Dr. LI Pengyuan made significant attempts to promote the development of sea fog research. For more than ten years, they guided 5 Ph. D students and 27 master students to investigate the sea fogs over the China Seas from different angles: observational analyses, numerical modelling, microphysics of sea fog, climatology of sea fog. Since February 2009, Prof. GAO Shanhong also opened a web (http://222.195.136.24/) to give forecasting information of atmospheric visibility based upon WRFV3-3DAVR. In January 2012, they published another English book UNDERSTANDING OF SEA FOG OVER THE CHINA SEAS in China Meteorological Press. This book consists of 215 pages with two parts. The first part is on case study, and the second part is on comprehensive study. This book was funded by China Meteorological Administration under the grant number of GYHY (QX) 200706031 and National Natural Science Foundation of China under the grant numbers of 40675006, 40706004, 40975003 and 41175006. This book can be used as a reference book for researchers and graduate students who are interested sea fog study in China.
A GROUND OBSERVATION BASED CLIMATOLOGY OF WINTER FOG: STUDY OVER INDO-GANGETIC PLAINS, INDIA

Background
The impact of fog is recognized as the challenging threat to societies and economies across Indo-Gangetic plains (IGP). Fog events are probably the fastest in formation, largest in areas, durations and severe in intensity, compared to other fog areas of the world.

Aim
The aim of the study is to analyse the spatial and temporal variability of winter fog over Indo-Gangetic plains.

Method
Long term ground observations of visibility (1971-2010) have been analysed to understand the formation of fog phenomena and its relevance during winter months. In order to examine temporal variability, time series and trend analysis were carried out using MannKendell Statistical test. The magnitude of the trend was estimated using Theil and Sen’s median slope estimator. Diurnal variability and average daily persistence were computed using descriptive statistical techniques. Geostatistical analysis of fog was carried out to understand the spatial variability of fog.

Results
Trend analysis performed using Mann Kendall test accepts the alternate hypothesis with 95% confidence level that there exists a trend. Kendall tau’s statistics showed that there exists a positive correlation between time series and fog frequency. Further, Theil and Sen’s median slope estimate showed that the magnitude of trend is positive. Magnitude is high during January compare to December for entire IGP except in December when it is high over western IGP. Decade wise time series analysis revealed that there has been continuous increase in fog days. The net overall increase of 99 % was observed in last four decade. Geostatistical analysis of fog revealed that the Indo-Gangetic plains are a high fog prone zone with fog occurrence frequency of more than 66 % days during the study period. Diurnal variability indicates the peak occurrence of fog is between 0600-1000hrs local time and average daily fog persistence extends to 5 to 7 hours during peak winter season.

Conclusion
The results would offer new perspective to take proactive measures in reducing the irreparable damage that could be caused due to changing trends of fog.
**Variability of fog as a fresh water resource and its relation with regional and local oceanic-atmospheric-geographic indicators. Atacama Desert Alto Patache Fog Oasis, Chile**

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**ABSTRACT**

Since 1997 fog behavior had been studied and recorded in Alto Patache and Cerro Guatalaya, Atacama Desert in Chile. That year was a strong Niño only similar in his indicators with the event occurred during 2015 – 2016. This research shows the interannual variability relation between these phenomena with the local variation on the coastal stratocumulus and the water obtained from the fog. This research wants to establish if the water resource that can be obtained from fog is related with ENSO conditions in order to determine his reliability.

We used two Standard fog collectors (Schemenauer & Cereceda, 1994). Regional and local oceanic-atmospheric indices were worked with Satellite images to get the spatiotemporal variability. Local observations and intense field work had been done to get and validate observations. Main results show a consistent production of fog water in the last 15 years, around 8 L/m$^{-2}$/day$^{-1}$, with a clear seasonal variation, and a very low decreasing trend in the coast, few kilometers inland there are no variation. Correlations between fog water yields and local indices shows significant results (coastal oktas $r = 0.63$; coastal SST $r = -0.40$), but in the macro scale (El Niño Southern Oscillation (ENSO) interannual variability (Garreaud et al., 2008). We focus our study in coastal Tarapacá region of Chile (19°-21°30’S). We provide fog water data (1998–2015) explained in table 1. For seasonal analysis, based in Alto Patache fog site: at the summit of the coastal cliff at site 1.1 and at the top of Cerro Guatalaya (1050 m a.s.l.; ~3.5 km lineal distance from the coastline ), and at the top of Cerro Guatalaya (1050 m a.s.l.; ~3.5 km lineal distance from the coastline ).

The extreme complex relation oceanic-atmospheric in the South East Pacific is reflected in the interannual variability of fog water collected. Nevertheless, the ENSO anomalies in the SEP not always manifest expected variations in fog water yields, supporting the idea that local conditions play a key role in the circumstances that explain the amount of water collected.

1. **INTRODUCTION**

In this work, we contrast fog-water data record, with local and regional atmospheric and oceanographic variables to assess the main controllers affecting the interannual fluctuations of fog in northern Chile. In this manner, we aim to determine the role of offshore climate and surface ocean conditions in the fog cloud extension, its water content and how these vary through time. We apply a multi-scale geographic analysis, including the use of remote sensing and local observations to provide a complete perspective. We analyze fog spatial and temporal variability under different ENSO scenarios, an aspect that help us to assess the potential of fog water availability in the future for the coastal Atacama Desert. Our main goal is to assess the role of regional-wide forcing on local water availability in the coast of Atacama, including El Niño Southern Oscillation (ENSO) interannual variability (Garreaud et al., 2008). We focus our study in coastal Tarapacá region of Chile (19°-21°30’S). We provide fog-water collection data obtained from the Atacama UC Research Station (AUCRS) (20°49’ S - 70°09’ W). The main scientific questions guiding this research are as follows: to identify some of the physical factors affecting the interannual fog water yields variability? In this regard does ENSO variability affects Tarapaca fog-water yields? What is the fate of fog-cloud and associated fog-water resource in the near future under the future modeled climate conditions for the Atacama?
1. INTRODUCTION

Our work focuses on the freshwater-limited Tarapacá region of northern Chile, where the effect of present climate change has been recently consider (Larrain et al. 2002; Cereceda et al. 2008a; Schulz et al., 2010, 2011; Garreaud et al., 2008; Falvey and Garreaud, 2009; Vuille et al., 2015).

We present fog water data (1998 – 2015) obtained by Standard fog collectors (SFC) (Schemenauer and Cereceda 1994) located at two sites: at the summit of the coastal cliff at site (AUCRS), (850 m a.s.l.; ~3.5 km lineal distance from the coastline), and at the top of Cerro Guatalaya (1050 m a.s.l.; ~12 km lineal distance from the coastline) see figure 1.

1.1 Methodology

For seasonal analysis, based in Alto Patache fog water yields data we divide in trimester according to 3 months with higher (July, August, September –JAS-) and lower (January, February, March – JFM-) period, coinciding with year trimester calendar, completing with April, May, June (APJ) and October, November, December (OND).

In order to assess the relation between fog and ocean-atmosphere components, we select multi-scale indices. These indicators are mapped in figure 2 and their respective characteristics are explained in table 1.

Figure 1. Schematic topographic profile at the coastal Atacama Desert of coastal fog dynamic and SFC location.

Figure 2. South Pacific basin including Inter Tropical Convection Zone (ITCZ), High pressure (H), Low pressure (L) and the location of regional and local indices.
1.2 Results

Our measurements of water collected by the SFC at Alto Patache show mean maximum values over 14 L/m²/day during August and September, which is in contrast with the less than 1 L/m²/day collected during February and March. Even more, the water yields from June to October concentrate over 75% of the yearly amount of water collected with an average of mean maximum values of 11.4 L/m²/day.

The fog water yields of Alto Patache and Cerro Guatalaya present for August and September a fog water concentration over 78%, but presents much lower yields, the mean maximum values for the same period (June-October) is a little bit higher than 1.5 L/m²/day and during summer is practically 0 L/m²/day (See figure 3).

The fog water yields of Alto Patache and Cerro Guatalaya presents a strong and positive correlation with the oktas ($r = +0.60$ and $r = +0.68$ respectively), confirming that the Sc clouds is the main source of moist in the coastal cliff, here typified as advective marine fog.

The SST at 1+2 present a strong and negative correlation for the complete study period with the fog stations ($r=-0.66$ at Alto Patache and $r=-0.57$ at Cerro Guatalaya; both at 99% confidence level). For instance, SST at 1+2 seems to be a “key” variable in the Sc/fog ocean-atmospheric interactions, due to SST 1+2 also correlate with the rest of variables analyzed ($r=+0.66$ with SST Iquique; $r=+0.88$ with SST Tarapacá; $r=-0.66$ and during summer is practically 0 L/m²/day).

<table>
<thead>
<tr>
<th>Variable</th>
<th>Indicator</th>
<th>Scale</th>
<th>Coordinates (point or area)</th>
<th>Source</th>
<th>Time data available</th>
<th>Analyzed time data</th>
<th>Temporal scale data</th>
<th>Temporality used</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fog water</td>
<td>L/m-2/day-1</td>
<td>Local</td>
<td>20°46'S - 70°10'W (Alto Patache)</td>
<td>Centro del Desierto de Atacama UC</td>
<td>1998 - Present</td>
<td>1998 - 2014</td>
<td>Monthly</td>
<td>Monthly</td>
</tr>
<tr>
<td>Fog water</td>
<td>L/m-2/day-1</td>
<td>Local</td>
<td>20°46'S - 70°10'W (Cerro Guatalaya)</td>
<td>Centro del Desierto de Atacama UC</td>
<td>1996 - 2013</td>
<td>1998 - 2014</td>
<td>Monthly</td>
<td>Monthly</td>
</tr>
<tr>
<td>Cloud cover</td>
<td>Okta</td>
<td>Local</td>
<td>20°32°S - 70°10°W</td>
<td>Dirección Meteorológica de Chile (DMC)</td>
<td>1996 - Present</td>
<td>1998 - 2014</td>
<td>Daily</td>
<td>Monthly</td>
</tr>
<tr>
<td>SST Iquique</td>
<td>Local</td>
<td>20°12'16°S - 70°08'52°W</td>
<td>Servicio Hidrológico y Oceanográfico de la Armada, Chile (SHOA)</td>
<td>1994 - Present</td>
<td>1998 - 2014</td>
<td>Daily</td>
<td>Monthly</td>
<td></td>
</tr>
<tr>
<td>SST Tarapacá</td>
<td>Local</td>
<td>20°32°S - 70°10°W</td>
<td>Servicio Hidrológico y Oceanográfico de la Armada, Chile (SHOA)</td>
<td>1994 - Present</td>
<td>1998 - 2014</td>
<td>Daily</td>
<td>Monthly</td>
<td></td>
</tr>
</tbody>
</table>

Table 1. Multi-scale oceanic-atmospheric indicators analyzed.

Figure 3. Interannual variability of fog water yields at Alto Patache (black line) and Cerro Guatalaya (grey line) for the period 1998-2014. Dotted lines indicate the trend for the period.
with LCA Tarapacá; r=-0.48 with oktas; all at 99% of confidence level).

1.3 Conclusion and recommendations

We found some expected and significant positive correlations between fog water interannual variability and presence of cloud cover at different scales, and significant negative correlations between SST and fog water yields. Probably the most interesting and strong correlation is the one between 1+2 and the rest of the oceanic-atmospheric indices for all the study period, for instance, SST at 1+2 seems to be a “key” variable in the Sc/fog ocean-atmospheric interactions. Exist a positive correlation between SST 3.4 or ONI and fog water at Alto Patache during summer (JFM), but not during the rest of the seasons (AMJ, JAS, OND).

The use of fog as a water resource seems to be feasible on time, despite ENSO specific conditions or PDO phase, due to its low interannual variability, specifically during the season when most of the water is collected. Both SFC present similar monthly, seasonal and interannual trends, with differences in the amount of water collected and maximum month peaks in water yields that response to local geographical conditions, like coast distance, altitude and topography. Confirming the results obtained by Larraín et al. (2002) and Cereceda et al. (2008a), now under a longer period of analysis, and maintains the interest in extending this valuable time series

1.4 Acknowledgements

Special acknowledgements for the institutions that make this research possible: Dirección General de Aeronautica Civil DGAC; Servicio Hidrográfico y Oceanográfico de la Armada de Chile SHOA; considerations for Horacio Larrain, Pilar Cereceda and Felipe Lobos to always help and contribute to create this valuable Fog database

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VARIABILITY OF CLOUD LIQUID WATER ON COASTAL FOG FORESTS OF NORTHERN CHILE

Cloud liquid water is a fundamental quantity for several climate reasons. Cloud composition and size distribution determines the amount of radiation that is reflected back to space and the amount of radiation that reaches the surface of the planet. Also, cloud liquid water controls the rate of the processes that control precipitation formation. Cloud liquid water content and size particle distribution are also a major input to understand the persistence of relict forests in the slopes of coastal ranges in the semi-arid region of Chile around 30°S, where precipitation amounts to less than 200 mm per year, and species typical of much wetter climates exists. The geometry between the coastal topography and cloud that allows the persistence of such forests also provides a unique opportunity for the in-situ observation of cloud properties using state of the art meteorological equipment. We describe our initial efforts to establish a state of the art meteorological station in the Talinay forest in the southernmost part of the Fray Jorge natural reserve, that could potentially evolve into a full cloud observatory in the near future. The projected site is currently under the administration of the National Forest Corporation (CONAF). We plan to perform continuous measurements of cloud liquid water and cloud droplet distribution using a Fog Monitor (fog spectrometer) to establish the relationship between near ocean temperatures, height and top of the cloud and vertical liquid water content distribution and to estimate the degree of adiabaticity of low clouds that intercept the topography. Vertical structure of the cloud can also be probed by the construction and deployment of simple water collector devices that can measure the water flux intercepted by a mesh or the extinction of simple light sources and measured by light detectors.
Background
Occurrence of dense haze and wintertime fog in National Capital Region (NCR) Delhi deteriorates visibility which causes severe disruption to the aviation, ground transport, and train services. During the winter season the whole part of the Northern India (Indo-Gangetic plains) experiences western, which leads to intense fog and haze in the region.

Aim
For the first time we have conducted mega filed campaign to understand the dynamical, physical/chemical mechanism of fog formation and dispersion (fog cycle) at Delhi, IGP region. The aim of this field campaign was to coordinating simultaneous measurements of surface conditions, radiation, turbulence, vertical thermo-dynamical structure of the surface layer, droplet and aerosols microphysics, aerosol and fog water chemistry to describe the complete environment in which fog develops.

Method
To document simultaneously all key processes involved in the life cycle of fog, a suite 32 remote sensing and in situ sensors were deployed at Indira Gandhi International Airport, new Delhi. The experimental setup was designed to monitor on a routine basis surface conditions, large- and small scale dynamics, radiation, turbulence, precipitation, droplet and aerosol microphysics, and aerosol chemistry, combining in situ and remote sensing instruments to describe the complete environment in which fog develops.

Results
This paper describes first results of fog formation in polluted air masses, and evolution of different fog types in Delhi. The results shed some light on fog number and size concentration, aerosols size distribution, fog water chemistry, liquid water contain and other important process during fog field Campaign 2015-16 at Delhi. The paper also describes the noteworthy meteorological and physical conditions encountered and illustrates key processes involved in various fog types.
Southern California Fog’s Disappearing Act: Climate Change, ENSO or PDO?

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ABSTRACT

Recent warming in the Eastern Pacific has led to a decrease in coastal fog along southern California coast. A possible shift in the Pacific Decadal Oscillation (PDO) back to the warm phase is coupled to this decrease. Earlier studies of the regional fog pattern have implicated coastal urban heat islands, decreases in particulate air pollution, coastal sea surface temperature (SST) rise, and coastal upwelling changes. Looking at fog frequencies, defined as visibility <1000 m, seasonally for the last 15 years (2000-2015) for Los Angeles Airport (LAX) and San Diego Airport (SAN), show that the PDO does influence fog variability. Recent increases in fog at both stations since 2000 corresponded to the shift to the cool phase of the PDO. Since 2014, unusually warm water off the west coast of North America has led to soaring air temperatures and much fewer fog events. This study looked at climate change, ENSO and PDO trends to explain fog variability and the recent decreases. While climate change may be reducing fog events generally, it does not explain fog variability as well as ENSO and PDO. With the 2015 strong El Nino and the possible shift to warm phase of PDO, it is likely that fog frequencies will continue to decrease in the coming years.

1. INTRODUCTION

Fog is an important part of the coastal California climate. It moderates temperatures along the coast and is an important variable in maintaining coastal ecosystems (O’Brien et al. 2013). In previous studies, numerous controls of coastal southern California fog have been identified. Leipper (1994) discusses low-level atmospheric inversions and Santa Ana winds contributing to fog formation, while decreasing condensation nuclei has led to a reduction of 90% of dense fog (visibility < 400m) from the 1950s until today (Witiw and LaDochy 2008). Increased urbanization along with warming ocean temperatures were associated with reduced fog in Sao Paulo from 1933 to 2005 (Goncalves et al. 2008). Williams et al. (2015) reported urbanization to be the cause of decreased fog in coastal southern California. They saw an increase in night time minimum temperatures, an increase in dew point depression, and a decrease in fog related to urbanization. The Pacific Decadal Oscillation (PDO) as well as ENSO events have also impacted the occurrence of Southern California fog.

Johnstone and Dawson (2010) show that fog frequencies in northern California correlate strongly with the PDO, with higher summer fogs during the PDO cool phase, when surface wind conditions favor coastal upwelling. Computer simulations also show the interannual variability in northern California fog associated with the PDO (O’Brien et al. 2013). Declining low stratus clouds along the west coast from the 1950s to 2012 from Alaska to southern California were also related to the PDO and sea surface temperatures along the eastern North Pacific (Schwartz et al. 2014).

Most recently, Torregrosa (2014) addressed the 33 per cent decrease in coastal California fog during the 20th century and the possible reasons for this including long term cycling of ocean temperatures including that represented by the PDO. She emphasized the important role coastal fog had both for ecology and society. She also discussed the wide range of aerosols that serve as condensation nuclei during fog formation and their fluctuations. These current studies explaining decreasing coastal fog counter earlier beliefs that global warming with increased temperature contrasts between land and water
temperatures were associated with reduced fog in urbanization along with warming ocean Southern California fog. Events have also impacted the occurrence of Decadal Oscillation (PDO) as well as ENSO in fog related to urbanization. The Pacific increase in night time minimum temperatures, an coastal southern California. They saw an increase in condensation nuclei has led to a reduction of 90% of dense fog inversions and Santa Ana winds contributing to Leipper (1994) discusses low-level atmospheric southern California fog have been identified. In previous studies, numerous controls of coastal ecosystems, (Schwartz et al. 2014). Increased temperatures along the eastern North Pacific also related to the PDO and sea surface 2022 from Alaska to southern California were clouds along the west coast from the 1950s to recent warming in the Eastern Pacific has led to a decrease in coastal fog along the southern California coast. would strengthen onshore airflow and lead to increases in fog (Sydeman et al. 2014).

2. PACIFIC DECADAL OSCILLATION

Historically, the Pacific Decadal Oscillation (PDO) tends to remain basically in one phase for 20 to 30 years. During a warm phase, water temperatures anomalies are positive near the coast (above normal) and negative over the central and western Pacific. The opposite is true during the cool phase. The change from warm to cool phase is about one degree Celsius near the coast of North America. From about 1922 to 1945, the PDO index was mainly positive; from 1946 to 1976, negative, then from 1977 to 1998 positive again. However, since 1998, the changes in polarity have occurred more frequently – every four to five years. From 1998 to 2002, PDO remained in the cool phase. With the warm phase from 2002 through 2007, Johnstone and Dawson (2010) saw a decrease in coastal fog. Witiw and LaDochy (2015) described a rebound in coastal fog with the cool phase of the PDO that lasted through 2013. But that was short lived as a rapid warming of coastal sea surface temperatures (SSTs) along the west coast since 2014, mark a return of positive PDO values and a drop in southern California fog frequencies. In this study PDO monthly values were provided by the University of Washington, Joint Institute for the Study of the Atmosphere and Ocean (PDO 2016).

3. UPWELLING AND SEA SURFACE TEMPERATURES (SST)

Sea surface temperatures track closely with PDO values as can be seen in the chart below (Figure 1). We can clearly see the increase in SST as the PDO index shifts from negative to positive. Upwelling indices also track well with the phase of the PDO. Looking at Figure 2, it can be seen how positive upwelling generally correlates with the cool phase of the PDO and negative upwelling indices with the warm phase of the PDO.

4. RESULTS

Although no significant relation was shown between number of fog hours at LAX with either the SOI or PDO during the cool season, San Diego showed a significant relationship with both independent variables; for the SOI, p<0.01; for the PDO, p<0.05 (Figures 3-8). Interestingly, when we looked just at the warm season (April – September), there was no significant relation found between hours of fog at SAN with either the SOI or PDO index. LAX, however showed a strong relation with the SOI (p<0.05) and a somewhat weaker relationship with the PDO index (p=0.09). Summer fog at SAN is fairly rare and so the annual summer values are quite small with high variability. However summer
conditions near LAX find frequent low clouds and fog conditions, especially in spring, early summer when the Pacific High strengthens the California Current System producing eddy circulations and stronger upwelling (Schwing and Mendelssohn 1997). Of particular note was the recent shift from cool to warm phase in the PDO. Fog frequencies decreased along with warming coastal SSTs and weakening upwelling indices in the southern California region since 2014.

5. CONCLUSIONS

Recent change to the positive phase of the PDO, since 2014, has led to substantial decreases in fog occurrences in southern California. As PDO phases tend to last two to three decades, warmer coastal water, less upwelling and unfavorable atmospheric conditions may continue to reduce fog formation not only in southern California, but possibly along much of the U.S. west coast. The present study joins several other investigations linking oceanic climatic indices to coastal fog characteristics. In explaining coastal California fog variability, PDO cannot be ignored.
6. Acknowledgements

The authors would like to thank students Brandi Gamelin and Freddy Hsu, and Professor Pedro Ramirez, CSULA for helping with some of the statistical analyses and graphics.

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IMPACT OF AIR POLLUTION ON CENTRAL VALLEY FOG FREQUENCY

Background
In California, the frequency of Central Valley (CV) radiation fog increased steadily from 1930-1970 (~83% increase in Fresno). However, in the last 30 years, fog days declined ~50% (Baldocchi and Waller, 2014, Herkes et al., 2014). The dominant hypotheses suggest fog decline can be explained by rising temperatures associated with climate change or urban heat islands. These explanations cannot account for the significant increase in CV fog midcentury.

Aim
We hypothesize that changes in air pollution better explain this upward then downward temporal trend.

Method
Using over 75 years of meteorological measurements, we developed fog climatology over 15 locations. Additionally, we developed historical records of nitrogen oxide (NOx) air pollution trends throughout these sites. We then analyzed the spatial and temporal correlation between fog frequency, air pollution, and climatic drivers.

Results
Growth in vehicle use greatly increased emissions of NOx midcentury, followed by a significant decrease due to statewide regulations from 1980-Present. In the CV, ammonium nitrate (NH4NO3), the dominant wintertime aerosol, is limited by NOx concentration. NH4NO3’s size range and hygroscopicity make it an important source of cloud condensation nuclei (CCN). Thus, air pollution growth from 1930-1970 increased the availability of CCN necessary for fog formation, followed by air pollution mitigation after 1980 that reduced NOx, and thus CCN and fog frequency. CV fog exhibits a pronounced north-south gradient, with fog consistently more frequent and persistent in southern latitudes than northern. Surface measurements confirm a steep overall decrease in fog frequency from 1980-Present. Additionally, NOx concentration also shows a similar north-south gradient, with concentration consistently highest in the south and a steady ~50% decline in all sites since 1990.

Conclusion
We conclude that fog trends in the CV are more closely correlated with changes in air pollution, than with climate change.
Background
A network of passive fog collectors has been established at a dozen sites that span a range of about 400 km along the California Coast. Given that the state of California is suffering from a long-term water deficit, a heightened interest exists in the role of fog to provide moisture during the drier seasons.

Aim
The intention of this study is to better understand and quantify the flux of fog water to terrestrial coastal ecosystems along the California Coastal region. In particular, we hope to gain further insight concerning how a region’s potential fog water deposition varies with latitude, distance from the coast, and elevation. We are also interested in examining longer term trends and changes in fog water deposition.

Method
Passive samplers were deployed along central and northern CA during the summer fog season from 2009–2015 with the largest number of deployments occurring during the 2014 and 2015 fog seasons. The southernmost site, deployed in 2015, is at 36° 4’ N and the northernmost site, deployed in 2014, is at 41° 4’ N. Data were recorded at 15 minutes intervals. Accompanying meteorological data were available near most of the sites.

Results
The network revealed significant water deposition variability across the state in terms of latitude as well as distance from the coast. Evidence also exists of a heightened inversion layer across a good portion of the state during the 2014-2015 fog seasons compared to earlier years, resulting in extremely low fog water deposition, particularly during the month of August, at lower elevations.

Conclusion
This work points to the value and utility of long-term, broad-scale fog water deposition monitoring and emphasizes the multi-scale variability inherent fog water deposition phenomena.
CLIMATOLOGY OF ARCTIC COASTAL FOG IN EAST GREENLAND FROM GROUND AND RADIOSONDE OBSERVATIONS

Background
Many Arctic glaciers terminate in coastal regions where sea fog is a common cloud type during summer. Fog may significantly affect glacier melt if it advects over the ablation zone. However, Arctic fog advection over land is poorly quantified. Especially with sustained Arctic warming increasing atmospheric moisture, more information is needed about its local and regional climatological characteristics and temporal trends.

Aim
The purpose of this study is to establish a climatology of melt season fog in East Greenland, and to provide validation for satellite-derived fog height and thickness.

Methods
We expand on Gueye (2014: MSc thesis) by comparing Danish Meteorological Institute weather station measurements (humidity, temperature, wind) with direct observations of visibility and fog type. Additionally, upwind sea ice concentrations were determined from NSIDC-0051, and fog height, inversions, and upper air parameters from IGRA data. General climatological characteristics of fog were statistically and graphically analysed over periods of 30-50 years, and spatial and temporal patterns explained.

Results.
Arctic coastal fog is mostly of the advection-type, and is associated with stable synoptic conditions, characterised by deep and strong low-level temperature inversions. Fog is most frequent in mid-summer, and requires sea ice breakup and sea breezes with wind speeds between 1-4 m/s. Dense fog events with skies invisible occur often, during which fog thickness can be several hundred metres and reaching the top of the boundary layer. Fog horizontal visibilities are higher at higher latitudes, where daily fog duration is also longer. Longterm temporal trends are quite insignificant, and of uneven sign in northern and southern locations.

Conclusion
This research contributes to understanding Arctic coastal fog occurrence and characteristics. Our results will be included in glacier melt models and may serve as a basis for fog forecasting.
NEW METHODOLOGY TO MONITOR FOG AND DEW EMPLOYING COMMERCIAL CELLULAR DATA BACKGROUND

The propagation of electromagnetic radiation in the lower atmosphere, at centimeter wavelengths, employed by commercial cellular networks, is impaired by atmospheric conditions, mainly moisture in its different forms (Messer et al., 2006). Absorption and scattering of the radiation, at frequencies of tens of GHz, are directly related to the atmospheric phenomena, primarily precipitation, oxygen, mist, fog, dew and water vapor.

As was recently shown, wireless communication networks supply high resolution precipitation measurements at ground level and as we have also shown can provide fog and dew monitoring which is crucial (David et al. 2015, Harel et al. 2015). On the other hand, at present, there are no satisfactory real time fog warning and dew monitoring facilities found to cope well with this phenomenon. I will exemplify the fog warning & dew monitoring potential of the commercial wireless communication system in Israel with comparison to other measurements like RVR, human visibilities and satellite fog algorithms. Fog monitoring maps and moisture maps (David et al. 2009) generated by our proposed method, will be presented and compare to classical observations. It should be noticed that we have recently demonstrated the great importance of dew for plants in semi-arid regions; see Ben-Asher et al. (2010).

References
CHARACTERISTICS OF FOGS IN THE AIRPORT OF TBILISI CITY

Background
Monitoring of fogs is important for the needs of aviation. In this work the analysis of data of the new automatic meteorological station installed in the airport of Tbilisi city is represented.

Aim
The aim of the work is the study of fogs in the airport of Tbilisi city and their influence on the horizontal visibility.

Method
The data of the meteorological station (472 m a.s.l., 41.67° N, 44.95 E) on the number of fog days, fogs duration and horizontal visibility with standard statistical methods were analysed.

Results
48 days with the fog in 2013-2015 are fixed. Most frequently of fogs during January (33,3% of cases) was observed. The fogs were not observed from May through October. The average duration of fogs during the day was 4.1 hour (min -0,5; max - 16,5 hour). Fogs appears most frequently with 0 to 3 hour (33,9% of cases), least frequently - from 15 to 18 hour (1,7 % of cases). Horizontal visibility in the fogs on the average was 0,5 km (min - 0,1; max - 1,0 km). Most frequently fogs with the horizontal visibility 0,4 -0,5 km (of 25% cases) were observed. Fogs with the visibility 0,1-0,2 km in 8,3% of cases was observed. In the center of Tbilisi (17 km from the airport) in three years only 4 days with the fog were observed. The possible reasons for this discordance are analysed.

Conclusion
Data of new meteorological station will make it possible to refine the characteristics of fogs in the Tbilisi airport.
NUMBER OF DAYS WITH FOG AND DURATION OF FOGS IN SOME REGIONS OF GEORGIA

Background
A detailed analysis of the variability of the number of fog days per year in Georgia are given in our previous studies. This work is a continuation of the mentioned investigations.

Aim
The aim of the study of the climatology of the number of days with the fog and their duration in 25 localities of Georgia.

Method
The data of Hydrometeorological department of Georgia for 25 meteorological stations (elevations: 1 - 1926 m a.s.l.; latitude: 41.33° - 42.27° N; longitude: 41.63 - 46.30 E. Observation period: 1966-1992) on the number of fog days and fogs duration with standard statistical methods were analysed.

Results
The average to the meteorological station number of days with the fog per annum (N) is equal to 23 (min - 2, max - 92), the average duration of fogs (T) - 187 hours (min - 6, max -1109). The map of the distribution of values N and T is made. The repetition of the number of days with the fog and their duration for the ranges of the duration of fogs 1-3, ..., 22-24 hour is studied. The correlation coefficient between the values of T and N changes from 0.60 to 0.99. The corresponding equations of linear regression are obtained. The analysis of seasonal variations in the repetition of the number of days of fogs and their duration in particular showed that into the cold half-year this repetition it is inversely proportional to height (for the warm season - vice versa).

Conclusion
The additional data about the climatology of fogs for 25 locations of Georgia are acquired.
DISTRIBUTION AND LONG-TERM TRENDS IN VARIOUS FOG TYPES OVER SOUTH KOREA

Background
Analysis of long-term trends based on annual climatological reports from the Korea Meteorological Administration showed a decrease in the fog frequency of about three fog events per decade over the last 30-year period. For a more detailed understanding of the temporal trends in the fog frequency, analyses of fog typology and details on the spatial and temporal variability are needed. Fogs can be divided into several types. Each fog type involves different formation mechanisms, thus different factors might be related to long-term trends in the fog frequencies.

Aim
The objective of this study is to investigate the spatial and temporal distributions and long-term trends in various fog types in South Korea. Furthermore, plausible mechanisms related to fog formation and the relationships to temporal trend at several locations were considered.

Method
The meteorological variables available for this study were visibility, near-surface temperature, ceiling height, cloud cover, precipitation, wind speed, and specific humidity. The dataset covers 25 years (1989 to 2013) for 24 stations. Fog events were identified by a sequence of consecutive visibility observations that were equal or less than 1 km. Fog events were classified using the existing algorithm developed by Tardif and Rasmussen (2007). The algorithm was modified for applicability with available meteorological observations and extended by including a category for advection-radiation fog. Meteorological conditions during the 9 hours prior to fog onset and during fog formation were taken into account to classify each fog event. To identify the potential factors related to the decrease in radiation fog events, the temporal trends in annual mean nocturnal maximal cooling rates and annual mean nocturnal specific humidity during nights with clear sky and clam winds were examined.

Results
According to our results, the most common fog type in Korea is radiation fog, corresponding to 38.5 % of all fog events. Except for Seoul observatory, radiation fog was the dominant type at all inland stations. Maximum annual frequency (34.5 events year⁻¹) was found at Andong and accounted for 65 % of all fog types. At large cities Daegu and Seoul the frequencies in radiation fogs were only 1.6 events year⁻¹ and 1.4 events year⁻¹, respectively, indicating the negative influence of strong heat island effect on radiation fog. Regardless of the fog type, a significant decrease in fog occurrence was found at most of the inland stations. Fogs at Chuncheon, Wonju, and Andong were found to be decreasing rapidly by 10.9, 10.7, and 8.9 events/decade, respectively. Results of long-term trends for each fog type reveal that the dramatic reduction of fogs at inland stations is mainly due to the decline in radiation fogs. Six of seven stations with a significantly negative trend are located in fast growing urban areas and have experienced population growth in the past two decades. The most rapid decrease in radiative cooling was at station Wonju (-0.16 °C h⁻¹ decade⁻¹ and specific humidity -0.16 g kg⁻¹ decade⁻¹). This corresponds to the largest negative trend for radiation fog. Regardless of the fog type, a significant decrease in fog occurrence was found at most of the inland stations. Fogs at Chuncheon, Wonju, and Andong were found to be decreasing rapidly by 10.9, 10.7, and 8.9 events/decade, respectively. Results of long-term trends for each fog type reveal that the dramatic reduction of fogs at inland stations is mainly due to the decline in radiation fogs. Six of seven stations with a significantly negative trend are located in fast growing urban areas and have experienced population growth in the past two decades. The most rapid decrease in radiative cooling was at station Wonju (-0.16 °C h⁻¹ decade⁻¹ and specific humidity -0.16 g kg⁻¹ decade⁻¹). This corresponds to the largest negative trend for radiation fog. A similar result was found at Cheongju, where the maximal cooling rate decreases by 0.12 °C h⁻¹ decade⁻¹ and specific humidity decreases by 0.16 g kg⁻¹ decade⁻¹.

Conclusion
The results support following conclusions: In Korea, fogs are more frequent at inland-type regions with prevailing radiation fog type. Most of the inland stations showed a significant decline trends due to decrease in radiation fog frequencies. Overall, our results suggest that the general decrease in fog frequency is related to patterns in urbanization.
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Acknowledgements
This work is supported by the "Advanced Research on Applied Meteorology" of National Institute of Meteorological Sciences (NIMS) funded by the Korea Meteorological Administration (KMA).

References
ROLE OF FOG ON URBAN HEAT ISLAND MODIFICATION IN KRAKOW, POLAND

Background
Rural areas surrounding Krakow experience katabatic flows and cold air reservoir formation which favors fog formation, while urban areas' impact is the opposite. Therefore, it can be expected that the UHI magnitudes for the clear nights might be significantly modified by the fog occurrence.

Aim
The aim of the study is to verify the hypothesis that fog occurrence in Krakow modifies UHI magnitude significantly, but the impact is different for the two vertical urban zones distinguished: larger for the valley bottom than for the areas located 50 m above.

Method
Krakow is a city in southern Poland, on the river Vistula, with an area of 326.8 km² and about 760,000 permanent registered inhabitants. The urbanized areas can be found in the river valley with its terraces and in convex landforms to the south and north. Height differences are about 100 m, and the built-up areas do not reach those hilltops.

The analysis is divided into a long-term tendency study (1966-2015) and detailed analysis (2010-2015). Data on fog occurrence, air temperature, wind speed and direction and cloudiness come from two stations: Botanical Garden (city centre, valley floor) and Krakow-Balice Airport (rural area, valley floor). UHI magnitude for 1966-2015 is estimated using minimum temperature from Balice and Botanical Garden, while for 2010-2015 it is calculated with air temperature data from selected points in the automatic network with 5-minute resolution. Synoptic situations’ calendar for Southern Poland by Prof. Tadeusz Niedźwiedź was used to define situations favourable for fogs. Case study method was applied to periods of a few consecutive days with fog. All the analyses were performed for standard seasons separately.

Results
Expected results: verification of the initial assumption based on the results of statistical analyses.
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NAMIB FOG LIFE CYCLE ANALYSIS

This contribution presents planned research into the temporal and spatial patterns of fog development in the coastal Namib Desert. The hyperarid Namib desert is one of the driest places on Earth; water input via fog has been shown to be an important factor for various natural systems in the region. The importance of fog as a source of water for ecological processes has been the subject of numerous studies in recent years, highlighting the diverse mechanisms employed for harvesting and using fog water. Despite its ecological importance, spatially and temporally complete observations of Namib-region fog are still missing. Life cycle stages and the impact of aerosol have not been considered systematically, nor have other meteorological determinants.

The planned project consists of three components, each of which is intended to analyze fog processes from a different perspective. Field observations provide basic insights into processes and patterns of fog and water distribution at the ground. Satellite-based remote sensing contributes a spatial perspective to the analysis of seasonal and regional patterns of fog distribution and microphysics, and links to Atlantic stratocumulus clouds. A numerical modelling approach is employed to test and improve the understanding of the factors guiding fog development from formation to dissipation. On this basis, an identification of life cycle stages and their characteristics will be performed. Collaboration with others conducting and planning research in the region is invited.
Mesoscale modelling of radiation fog in the Netherlands: exploring contrasts between cities and countryside

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ABSTRACT

A case of radiation fog over Holland (the Netherlands) is simulated by the WRF model with a new high-resolution (100 m) land use map for the area. The main objective is to illustrate the contrast between urban and rural sites regarding radiation fog development, as these are exposed by WRF. The analysis of the model outputs reveals a realistic representation of the specific fog development, as well as an improved representation of the urban sites. Fog duration was two hours longer over the rural site compared to the urban areas. The increase of anthropogenic heat release in urban areas reduced the fog duration by ~6 hours and the amount of liquid water content by ~0.04 g/kg. Finally, the impact of double CO₂ concentration in the atmosphere, on fog development showcased a half hour delay for Rotterdam.

1. INTRODUCTION

Radiation fog has a significant impact on daily life. Poor visibility conditions on an airport during a fog event are a major reason for flight delays and are translated into substantial economic losses (NOAA, 2008). Additionally, fog can lead to accidents and even casualties due to reduced visibility (Pagowski et al, 2004) or affect human health and nature through atmospheric deposition of pollutants (Lange et al, 2003). Despite its importance, it is exceptionally difficult to model fog due to the complex physical processes and conditions that are necessary for fog formation. Moreover weather forecast models usually encounter difficulties in fog simulation due to their coarse representation of horizontal resolution (Gultepe et al, 2007). The Weather, Research Forecasting (WRF) model is able to provide reliable simulations for fog development (e.g. Ronda et al, 2013). Nevertheless there are cases where it has difficulties as well (e.g. Van der Velde et al, 2010). For this study the Advanced Research WRF model (WRF-ARW) version 3.5.1 (Skamarock et al, 2008) with a new detailed land use map of the Netherlands (Attema et al) is utilized for the examination of differences in fog evolution between urban and rural areas of the Netherlands. Moreover this study examines the impacts of the anthropogenic heat flux (AHF) and CO₂ concentration in atmosphere as these are simulated by WRF-ARW.

2. METHODOLOGY

2.1 Model Set Up

The WRF-ARW model was utilized for the simulation of an observed radiation fog over Holland on 6 October, 2005 from midnight to noon. Steeneveld et al (2015) used WRF-ARW model to simulate the specific fog event over Cabauw. The comparison of the model outputs with observations indicated a realistic representation of the fog event. In contrast to the study of Steeneveld et al (2015), a new land use map for the area of Holland is used for this study with a higher horizontal resolution. Figure 1a illustrates the new land use map that was used for the simulations along with the default one (Figure 1b) for WRF-ARW for the third domain of the simulations. It appears that the new land use map illustrates urban areas more accurately compared to the default. This provided us the opportunity for a fine horizontal resolution. Therefore three nested domains with horizontal resolution of 12.5 km (120x120 grid points), 2.5 km (121x121 grid points) and 0.5 km (121x121 grid points) were utilized. This is the first time that horizontal resolution of 500 m is applied to WRF-ARW model for a case of radiation fog. For the numerical experiments, the simulated period was from 5 October, 2005 00:00 UTC to 7 October, 2005 00:00 UTC. The first day of the simulation was used as spin up by the model in order to
obtain proper values for the parameters which are critical for reliable simulations, such as downward shortwave radiation and surface temperature (Angevine et al., 2014). The vertical resolution consisted of 50 eta levels with finer grid mesh near the surface. For the implementation of the urban surface characteristics and the associated energy exchange processes into the simulations, the WRF model was coupled with the single-layer urban-canopy model (SLUCM) (Kusaka et al., 2001, Chen et al., 2001).

The model outputs from Rotterdam airport occurred from third domain, whereas for Cabauw station from the second, since it is located in the border of the third domain. The plots showed a good correlation between observations and the model for both stations. The major differences were detected in the onset and dissipation of fog, as well as in its duration which seems limited for the model. This issue has been addressed by researchers in the past, stating the difficulties of numerical weather prediction models in forecasting the onset and fog development (e.g. Roman-Cascon et al., 2012). At noon, on 6 October the model underestimated the downward shortwave radiation and the dewpoint depression for both stations. The reason was the misinterpretation of the fog height by the model which simulated a low cloud instead of fog.

3. RESULTS

3.1 Urban vs Rural

The urban areas are represented by model outputs from one point in The Hague and one in Rotterdam and rural areas by the point easterly of Rotterdam (Figure 1b). Figure 3 displays the time series of the modelled liquid water content (LWC) for the first model level (approx. 45 m from the surface), representing the radiation fog, for the three points under study. The anthropogenic heat flux was set to zero for this simulation.

Regarding the onset of fog it was similar for the rural point and Rotterdam, where for The Hague it was delayed by an hour compared to these sites. The dissipation of fog over the rural point was delayed by 2 hours compared to Rotterdam and by

Fig. 1: New land use map (a) and default (b) of the third domain of the simulations (Holland). Rural areas (green), urban areas (red), water bodies (blue).

Fig. 2: Comparison between WRF results and observations for the period 5 October 2005, 00:00 UTC – 7 October 2005, 00:00 UTC.

Fig. 3: Time series of LWC for the period 6 October, 00:00 UTC – 6 October, 12:00 UTC.

The Hague
Rotterdam
Rural

Fig. 2: Comparison between WRF results and observations for the period 5 October 2005, 00:00 UTC – 7 October 2005, 00:00 UTC.
1 hour compared to The Hague. The overall duration of fog over the rural point was 9 hours, whereas for the urban points it was 7 hours.

3.2 Impact of AHF on fog development

Figure 4 illustrates the impact of AHF on fog development. Different simulations with characteristic values were performed. The AHF values were 25 W/m² (typical city), 50 W/m² (city with heavy industry), 75 W/m² (commercial city with heavy industry) and 100 W/m² (tropical city with high anthropogenic emissions) (Quah and Roth, 2012). The displayed parameters are the duration of LWC at the first level of the model and the average total LWC throughout the fog depth (the amount of LWC for each height was multiplied with the level depth, all these values were summarized and the sum was divided by the total depth of the fog) for The Hague and Rotterdam points. The illustrated values for both parameters were the average of the period 6 October, 02:00 UTC to 6 October, 08:00 UTC (maintenance phase of fog). The AHF increase reduced LWC by 0.04 g/kg and the duration of the LWC by 6 hours. This result agrees with results of Williams et al (2015) that observed a decrease in fog formation due to urbanization for the southern coastal part of California. However it is noteworthy that there is a threshold at 50 W/m² for the decrease in the duration of LWC. Further increase of AHF even to extreme values possibly would not affect the duration of LWC at the first level of the model.

3.3 Impact of CO₂ increase on fog development

Figure 5 shows the impact of increased CO₂ in the atmosphere regarding fog development, as represented by WRF. More particularly the time series of the downward longwave radiation and the LWC for the period 6 October 2005, 00:00 UTC – 6 October 2005, 12:00 UTC were compared for a simulation with current day CO₂ concentration (355 ppm) and a simulation with double CO₂ concentration (710 ppm).

The downward longwave radiation denoted a slight increase of approximately 1-2 W/m² at 00:00 UTC for the double CO₂ concentration for the three points under study. According to the study of Trenberth et al (2009) this could be a realistic outcome since the impact of the greenhouse effect can lead to an increase of 0.9 W/m² for the downward longwave radiation. Regarding the LWC, WRF simulated the onset of fog for the Rotterdam point with a half hour delay for the double CO₂ concentration compared to the current one. This is a substantial difference, especially for a city with airport planning operations. The rural point also showcased some variation of the LWC for the double CO₂ concentration. The fog has been uplifted to a low cloud for half hour at 9:00 UTC. At 9:30 UTC fog was observed again and dissipated after 12:00 UTC.
4. CONCLUSIONS

A real case of radiation fog over the Netherlands was simulated by WRF model using a new detailed land use map for the Netherlands. The new map provided a more realistic representation of the urban areas and therefore a fine horizontal resolution was selected for the simulations. The comparison with respect to simulated fog development between one rural point east of Rotterdam, one in Rotterdam and one in The Hague reveal a longer duration of the fog event over the rural point compared to the urban ones. The fog dissipation was delayed over the rural point by two hours compared to Rotterdam and by one compared to The Hague. The increase of anthropogenic heat flux in the model reduced the duration of fog by approximately 6 hours and the amount of LWC by 0.04 g/kg for The Hague and Rotterdam. Finally, the increase of the CO$_2$ concentration to double than the current one in the atmosphere led to a delay of half hour for the simulated fog development over Rotterdam.

Acknowledgements

Observations for Rotterdam airport and Cabauw were provided by KNMI.

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INFLUENCE OF TROPICAL CYCLONES IN THE NORTHERN HEMISPHERE ON LOW VISIBILITY IN THE SOUTHERN HEMISPHERE

Background
Low visibility in the Northeast of Brazil (NEB) has not been studied enough for its forecasting. Some influence of meteorological processes in the Northern Hemisphere on phenomena in the tropical region of the Southern Hemisphere was detected in our studies.

Aim
The study of circulation between the Northern and Southern Hemispheres, which can affect low visibility formation, was the first aim. Use of the PAFOG (Parameterised FOG) forecasting model for these atypical events was the second aim.

Method
Synoptic scale systems and tropospheric vertical structure were analysed using the BRAMS, CFSR and NCEP-DOE models. Streamlines, pressure, vertical velocity and potential equivalent temperature were analysed at ten pattern levels.

Results
Low visibility events in the NEB were registered on 11-13/06/2010 and 2021/08/2015. Each of two events was associated with circulation from the tropical cyclones, Alex and Danny-15, respectively. These tropical cyclones form an intense confluence at the low levels, then air mass lifting occurs in the cyclone center and creates a diffluent current at the 200 hPa level. This current at the high level crosses the equator to the south and reaches the NEB center at the high levels. Unification of this current with a frontal zone or trough from the Southern Hemisphere creates sinking in the NEB. Fog, mist, drizzle and stratus clouds in different points of the NEB were the result of this sinking. Fog was forecasted using the PAFOG model with 12h antecedence. Few differences in fog duration and intensity were registered between observational and forecasted visibility in these events.

Conclusion
The main conclusion is to emphasize the role of circulation between the two hemispheres on low visibility formation in the NEB and the possibility of fog forecasting using the PAFOG model for these atypical situations.
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CHARACTERISTICS OF LOW ATMOSPHERIC VISIBILITY ASSOCIATED WITH SEA FOG OCCURRENCE OVER THE NORTHERN ATLANTIC

In this study, the recent 100-year ICOADS (International Comprehensive Ocean and Atmosphere Data Set) data from 1909 to 2008 is utilized to investigate the horizontal distribution of sea fog occurrence frequency over the Northern Atlantic as well as the meteorological and oceanic conditions for sea fog formation. The occurrence of sea fog is judged by atmospheric visibility and weather conditions in ICOADS data. In this study, the atmospheric visibility less than 1 km (the code of VV is 90-94 in ICOADS) is defined as sea fog occurrence in this paper. In order to describe the temporal and spatial distribution of sea fog over the Northern Atlantic, the occurrence frequency of sea fog is analyzed. Firstly, the research area is divided into small grids with the resolution of 2°×2°. Based on the level of atmospheric visibility and the definition of sea fog, the total number of observation reports and occurrences of sea fog are counted in each small grids. The sea fog relative frequency is defined as the total number of occurrences of sea fog divided by the total number observations. The research results indicate that sea fog over the Northern Atlantic mainly occurs over middle and high latitudes. Sea fog occurrence frequency over the western region of the Northern Atlantic is higher than that over the eastern region. The maximum sea fog occurrence frequency is distributed along a belt region from Long Island to east of Newfoundland. In terms of seasonal variation, sea fog occurrence frequency gradually increases from April to July and then rapidly decreases from August with the maximum sea fog occurrence frequency down to slightly over 10% during this period, as oppose to over 24% in July during the peak month. It suggests that the fog season in the Northern Atlantic is from April to August. Sea fog occurrence frequency is When sea fogs occur, the prevailing wind direction in the study area is from southerly to southwesterly wind and the favorable wind speed is around 8m/s. Without distinguishing the wind direction, the favorable wind speed is between 4.4m/s to 12.3m/s. The wind speed at 6.7m/s is the most favorable. Under the driving of wind from south to southwest, the warm wet air from low latitude move northward to the study area, the air becomes near saturated or supersaturated on the cold sea surface. This is favorable for the formation and maintenance of sea fogs. It is most favorable for the formation of sea fogs when sea surface temperature is 5°C to 15°C. When sea surface temperature is higher than 25°C, it is difficult for the air to get saturated, and there is almost no report of sea fog. When sea fogs form, the difference between sea surface temperature and air temperature is mainly -1 to 3°C, and 0°C to 2°C is the most favorable conditions for fog formation. There are two types of sea fogs: advection cooling fog and advection evaporating fog. The study suggests that the advection cooling fog occurs much more frequently than advection evaporating fog in the study region.

Acknowledgements
This study was financially supported by the National Natural Science Foundation of China (Grant No. 41305086, and 41275049). Dr. Lu Chungu is supported by U.S. National Science Foundation’s Independent Research and Development fund.
The number of fog events at São Paulo City presents a high variability yearly, from around 40 up to 120 per year. Fog events have been notified by the IAG Meteorological Station since thirties of last century and it is located in a park, Agua Funda Park, which has huge green surroundings, the largest of the city. São Paulo climate presents the higher number of fog events from April to September, late autumn to earlier springtime. The fog event decade variability since then has been declined, from around 160 per year, during the 30’s decade to 67 at 90s, and to 70 per year, from 2000 to 2015. However, the amount of events still maintains a high inter-annual variability. On the other hand, the years with less than 50 events were rare during last century, which has been reported only the year of 1995 where only 41 fog events had occurred. The year of 1995 had 2nd warmest winter during the whole timeseries. Nevertheless, during the XXI century, two years, 2014 and 2015 present lower number of events as well, 42 and 49, respectively, the unique situation with two years in a row. Both winters were very warm, and these two years are among the warmest on record, with 3rd and 2nd place of mean annual temperatures from whole period and quite warm winter. The hottest year of the record is the year of 2002, with the warmest winter ever; however, during the months of July and September of this year, temperatures were close of the climatology which explains the higher amount of fog during this year, 71. Besides, the year of 2015 is associated to El Niño phenomenon, but that did not happen at year of 2014. The preliminary conclusion is the smaller amount of fog events can be supported by climate change where the warmest years are concentrated recently where the intensity of the decreasing are becoming higher during last 2 years particularly.
THE VARIABILITY OF FOG EVENTS FROM 1930 TO 2015 IN SÃO PAULO CITY

The number of fog events at São Paulo City presents a high variability yearly, from around 40 up to 120 per year. Fog events have been notified by the IAG Meteorological Station since thirties of last century and it is located in a park, Agua Funda Park, which has huge green surroundings, the largest of the city. São Paulo climate presents the higher number of fog events from April to September, late autumn to earlier springtime. The fog event decade variability since then has been declined, from around 160 per year, during the 30’s decade to 67 at 90s, and to 70 per year, from 2000 to 2015. However, the amount of events still maintains a high inter-annual variability. On the other hand, the years with less than 50 events were rare during last century, which has been reported only the year of 1995 where only 41 fog events had occurred. The year of 1995 had 2nd warmest winter during the whole timeseries. Nevertheless, during the XXI century, two years, 2014 and 2015 present lower number of events as well, 42 and 49, respectively, the unique situation with two years in a row. Both winters were very warm, and these two years are among the warmest on record, with 3rd and 2nd place of mean annual temperatures from whole period and quite warm winter. The hottest year of the record is the year of 2002, with the warmest winter ever; however, during the months of July and September of this year, temperatures were close of the climatology which explains the higher amount of fog during this year, 71. Besides, the year of 2015 is associated to El Niño phenomenon, but that did not happen at year of 2014. The preliminary conclusion is the smaller amount of fog events can be supported by climate change where the warmest years are concentrated recently where the intensity of the decreasing are becoming higher during last 2 years particularly.

FOG MODELLING IN THE MEXICO BASIN

Background
Mexico City, located in the Mexico Basin, has the highest nation’s population density and the largest share of the gross domestic product. Thus, fog has important economic impacts mainly because it interferes with both land and air transportation. The Basin stands at an average altitude of 2,240 m a.s.l. and is mostly surrounded by mountains. These conditions pose a challenge for the modelling and forecasting of fog.

Aim
The purpose is to investigate the ability of the Weather Research and Forecasting Model (WRF) to simulate the formation and development of fog events in the Mexico Basin.

Method
First, a characterization of fog episodes according to their formation mechanisms (radiative, advection and frontal) was realized using ten years (2003-2012) of climatological data. Second, numerical simulations of individual events in the region were performed using the WRF with diverse microphysical and planetary boundary layer parameterizations. Weather stations, atmospheric soundings and reanalysis data were used to evaluate these results. Third, past events were simulated to evaluate the sensitivity of the model to different spatial and time resolutions.

Results
In general, the WRF correctly reproduced the time periods for the formation and dissipation of fog and the height of the mixed layer, and predicted reasonable amounts of cloud water concentrations. However, in some cases the surface wind speed was underestimated. The sensitivity study indicates that the modelling results strongly depend on the configuration used, which in turn depends on the fog formation mechanism.

Conclusion
It is concluded that the WRF adequately simulates the formation and development of fog events in the Mexico Basin with the configurations and settings used. It is expected that the proposed model configurations will result in a scheme to successfully forecast fog in the region.
A NUMERICAL STUDY OF THE EFFECTS OF LAND-USE CHANGES ON FOG OVER RECLAIMED ISLAND OFF THE WEST COAST OF THE KOREAN PENINSULA USING THE WEATHER RESEARCH AND FORECASTING MODEL

Background
Topography and land-use changes influence on the turbulence characteristics that directly contribute to the formation and dissipation of fog at Incheon International Airport off the west coast of the Korean Peninsula. During the investigation period from January, 2010 to June, 2014, local meteorological characteristics of coastal ground fog are similar to those of radiation fog typically seen over the land surface since the reclaimed island was constructed. After sun rises, relative humidity over the land surface decreases rapidly within a couple of hours due to the surface heating that is controlled directly by shortwave radiation. Over the sea surface, however, the sea fog still remains with the relative humidity higher than 95% even during daytime.

Aim
This study aims at seeing if the geographical datasets including topography and landuse are appropriate for the reclaimed island on which Incheon International Airport is built. Then this study investigates the effects of modifying topography with land-use on the surface heat flux and further fog physics at Incheon International Airport.

Method
Weather Research and Forecasting model ver. 3.5.1 is employed for sensitivity tests for coastal ground fog and sea fog.

Results
The simulation with original topography and land-use does not produce the diurnal variations in relative humidity and air temperature at the lowest level, and consequently fails to predict the onset and dissipation time of fog at Incheon International Airport. That is because the model prescribes that Incheon International Airport is located over the sea surface. On the other hand, the simulation with modified topography with land-use yields the improved results: the local meteorological characteristics are consistent with the observation. In particular, the modeling performance to forecast the dissipation time of fog gets quite better. That makes sense because the model is able to simulate the surface heating over the land surface after sunrise. When Incheon International Airport is assumed to be over the sea surface in the simulation with original topography and land-use, moisture supply plays a significant role in increasing liquid water path at Incheon International Airport.

Conclusion
The modification contributes to better forecasting the turbulent heat flux by changing the sensible and latent flux over the reclaimed island. Finally it is improved to forecast the onset and dissipation time of fog.
OBSERVATIONS ON FOG/LOW CLOUD PATTERN UNDER CLIMATE CHANGE IN CENTRAL TAIWAN

Background
Xitou region, as the epitome of mid-elevation cloud forest ecosystem in Taiwan, possesses a rich diversity of flora and fauna and is a famous forest recreation area. Long-term fog/low cloud pattern under climate change is highly concerned.

Aim
The purpose of this study is observing/understanding the characteristics of fog/low cloud pattern and planetary boundary layer.

Method
The atmospheric profile observations from unmanned aerial vehicle (UAV) carrying self developed measurements were compared from October 2014 to December 2015.

Results
Long-term microclimate has been monitored more than 80 years by the Experimental Forest, National Taiwan University. Preliminary study indicated the mean temperature was 17.05 °C in Xitou region from June 2005 to May 2013 which was 0.7 °C warmer than the 1980s. The warming rate was about 0.29 °C/Decade for the above-mentioned period while from the 1940s to the 1980s it was about 0.1 °C/Decade. It was nearly three times the warming accelerates. Moreover, the frequency of foggy days in valley area was 87.7% in 2005, 75.6% in 2011 (Liang et al., 2009; Wey et al., 2011) and decreased to 58.1% in 2015 whereas the foggy days near the top of surrounding ridge was still as high as 95.7%. The totally UAV fly missions were over 240 times. This UAV can observe up to 2000m height above ground level and it was more economical than traditional radiosonde instruments. The atmospheric profiles indicated the diurnal/seasonal variations of planetary boundary layer were dramatic and positively correlated with air temperature. The fog/cloud top height were always under the based height of the inversion layer and the maximum fog/cloud thickness was around 800m which was higher than the surrounding ridges of Xitou valley.

Conclusion
The study suggested the foggy events decreasing may be accompanied with the local microclimate warming and one of the major reasons may be a very rapid development of local tourist industry in Xitou region driven by tourists’ number increased from 1 million/year in 1999 to 1.8 million/year in 2014. A total solution of integrating multi-direction ceilometer, UAV and remote sensing technology for monitoring/understanding the characteristics of Xitou microclimate change are on-going.
TEMPORAL VARIATION OF FOG EVENTS IN THE CONTINENTAL PART OF CROATIA

Background
Fog is one of the most dangerous meteorological phenomena affecting all types of traffic, air quality, etc. which is characterised by a significant spatial and temporal inhomogeneity in its occurrence.

Aim
The aim of this paper is to analyse fog climatology, the trends of long-term changes of fog events and their relationship with air humidity in the continental part of Croatia during 54-year period (1961-2014). For this purpose meteorological data from 3 main meteorological stations (Sisak, Varaždin and Zagreb-Maksimir) have been used.

Method
Trends in series of monthly and annual number of days with fog were examined using the Mann-Kendall non-parametric trend test and the Sen’s non-parametric method on monthly and annual basis.

Results
The number of days with fog primarily saw two-stage variations, with an increasing trend before 1980’s and a decreasing trend after 1990’s. The previously mentioned decreasing trend at all stations considered, especially after 1990’s, is in accordance with the decreasing trend of the surface relative humidity. The reduction of horizontal visibility (< 1 km) due to a fog occurrence is related to winter season as well as late autumn.

Conclusion
The number of days with fog in winter is almost six times greater than in the summer. During the analysed 54-year period the total number of fog events ranged from 2618 (Zagreb-Maksimir) to 3530 (Sisak). The highest number of days with fog for Sisak, Zagreb-Maksimir and Varaždin was 26 (October 1969), 23 (December 1971) and 22 (January 1989), respectively. The relationship between monthly occurrences of mist and fog for the previously mentioned period was also analysed and briefly discussed. The relationship between fog and mist is strong, linear, and positive.
AN SPATIO-TEMPORAL ANALYSIS OF SUMMER FOG IN TENERIFE, CANARY ISLANDS

The geographical location of the Canary Islands, at 28° N in the Atlantic Ocean, means that stratiform clouds from the Azores anticyclone are the most prominent feature of its climate. When these clouds come into contact with the relief of the islands they become advection fog depositing large amounts of water and their frequency is greater during the summer. Therefore, the objectives of this article are:

- to study the spatial frequency of this phenomenon during the summer.
- to quantify the volume of fog water collected.
- to build an hourly model of the frequency and quantity of the fog water.

The study period is from June to September of the 17 years between 1999 and 2015. The data analysis is performed on an hourly time scale. The instruments used are the two Quarter fog collectors connected to automatic weather stations, located in the NE and NW of the island of Tenerife, at 842 m and 900 m a.s.l., respectively (1). This information is supplemented with data provided by forest warden from two fire towers with a good view, located in the northwest and the centre of the island, at 1,400 m and 1,717 m a.s.l. (2).

The results indicate that the island's topography, mainly the altitude and orientation of the relief, plays an important role in the spatial distribution of the fog. Thus, the fog is more frequent in the NE sector than in the NW of the island (80% versus 50% respectively); it is more frequent on the northern slopes than on the southern slopes; it is more frequent between 7 pm and 8 am than during the day (80% vs. 20%); it is more common between 600 and 900 m a.s.l. than at higher altitudes. Finally, five times more fog water is collected during the summer than the winter.
The SE Pacific subtropical anticyclone hosts a large stratocumulus (Sc) cloud deck extending off the coasts of southern Peru and northern Chile. The vertical extent of this Sc cloud layer is limited by the subsidence temperature inversion, featuring diurnal, weekly, intraseasonal and seasonal oscillations. When the subsidence inversion descends below the cloud base (mixing condensation level) clear skies are observed. In particular a tendency to coastal clearing in the afternoon is related to coastal subsidence enhancement fostered by the daytime circulation along the arid western Andes slope. Over the Fray Jorge and Talinay fog forests, laying at both sides of the low-Limari valley, the orographic component of the inshore air flow seems to partially compensate for the afternoon increase in coastal subsidence.

This study is aimed at assessing the role of the daytime Limari up-valley pumping, supposedly forcing the coastal marine boundary layer flow to converge against the coastal escarpment. Surface meteorological data at Fray Jorge (700 m amsl), Caleta Toro (sea level) and Ovalle (inland station) have been used and complemented with upper air data (Santo Domingo radiosoundings), GOES satellite imagery and CFSR reanalysis. A set of completely overcast and clear days were selected to highlight differences in the local atmospheric flow.

Results show that maximum valley pumping appears in the afternoon during overcast days in which inland up-valley flow exceeds the coastal one by 3 m s⁻¹. The previous clear day, following a typical sequence of coastal low propagation, features a maximum coast-inland atmospheric pressure difference, preconditioning the inland advection of marine air. In spite of a low resolution version of the CFSR wind data, a case study reveals a clear difference between prevailing coastal divergence/convergence in clear/overcast days at 975 hPa level in the afternoon (14:00 LT). To improve on these qualitative results, numerical simulations with the WRF model will be presented.

It can be concluded that coastal topography and coastal shape set the stage for the valley pumping that favors cloud persistence after the Sc wedge, following the culmination of the coastal low, drifts southward.
This study is aimed at assessing the role of the SE Pacific subtropical anticyclone of the daytime Limarí up-valley pumping, the afternoon increase in coastal flow seems to partially compensate for the orographic component of the inshore air both sides of the low-Limari valley, the Jorge and Talinay fog forests, laying at the western Andes slope. Over the Fray Ovalle daytime circulation along the arid subsidence enhancement fostered by the afternoon is related to coastal tendency to coastal clearing in the clear skies are observed. In particular a cloud base (mixing condensation level) subsidence inversion descends below the and seasonal oscillations. When the sea level temperature inversion, the extent of this cloud layer is limited by Peru and northern Chile. The vertical deck extending off the coasts of southern hosts a large stratocumulus (Sc) cloud.

First calculate probabilities of fog for the type of atmospheric circulation. Typically the highest probabilities were achieved for the southern and south-western influx of air masses during anticyclonic circulation. Exceptions were 2 coastal stations where the maximum values were obtained for the southern cyclonic circulation and at the Gdansk station for which the highest probability corresponded to south-eastern cyclonic circulation. Usually, the minimum value of the probability of the fog was observed during cyclonic circulation with the inflow of air masses from the north, north-east or east.

To perform the calculations were used data for 8 Polish synoptic stations located at the largest airports in the country from the period 2005-2014 contained in dispatches METARs on the website OGIMET.com. In most studies of fogs authors underline the local nature of the phenomenon. The aim of this work, was an attempt to answer the question: is there a type of atmospheric circulation or group, where the fog form more often? Basing on the probability and frequency of days with fog for a given type of atmospheric circulation.

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In addition, the frequency fogs depending on the type of atmospheric circulation was investigated. For all analyzed stations clearly the most days with fog was reported during anticyclonic circulation and inflow of air masses from the south, south-west or west. Least fogs formed during days with the southern cyclonic circulation. The exception is the station at Gdansk Airport with cyclonic circulation in the period the event occurred a little less misty than in other cases.

Conclusion
On overall, the results show that fog most often occurs during advections from the south-west and anticyclonic circulation. Because of different frequencies of circulation types maximum frequency of days with fog at given atmospheric circulation not always coincides with the largest probability values (see coastal and Katowice airport stations).
THE STUDIES ON THE RELATIONSHIP BETWEEN MOUNTAIN VALLEY BREEZE AND UPSLOPE FOG AT XITOU REGION IN CENTRAL TAIWAN

Background
Xitou region is characterized by a quite regular daily wind regime. A valley wind from N occurs predominantly during daytime and a mountain wind from S during the nights. The climatological regime driven by significant periodic wind were highly concerned.

Aim
The purpose of this study is observing/understanding the characteristics of fog occurred driven by valley breeze and dissipated by mountain breeze.

Method
The fog frequency was measured/determined by Mini-OFS (Mini Optical Fog Sensor) and automatic time lapse camera.

Results
Long-term microclimate has been monitored more than 80 years by the Experimental Forest, National Taiwan University. Preliminary study indicated the mean temperature was 17.05 °C in Xitou region from June 2005 to May 2013 which was 0.7 °C warmer than the 1980s. The warming rate was about 0.29 °C/Decade for the above-mentioned period while from the 1940s to the 1980s it was about 0.1 °C/Decade. It was nearly three times the warming accelerates. Moreover, the frequency of foggy days in valley area was 87.7% in 2005, 75.6% in 2011 (Liang et al., 2009; Wey et al., 2011) and decreased to 58.1% in 2015 whereas the foggy days near the top of surrounding ridge was still as high as 95.7%.

The totally UAV fly missions were over 240 times. This UAV can observe up to 2000m height above ground level and it was more economical than traditional radiosonde instruments. The atmospheric profiles indicated the diurnal/seasonal variations of planetary boundary layer were dramatic and positively correlated with air temperature. The fog/cloud top height were always under the based height of the inversion layer and the maximum fog/cloud thickness was around 800m which was higher than the surrounding ridges of Xitou valley.

Conclusion.
The study suggested the foggy events decreasing may be accompanied with the local microclimate warming and one of the major reasons may be a very rapid development of local tourist industry in Xitou region driven by tourists’ number increased from 1 million/year in 1999 to 1.8 million/year in 2014. A total solution of integrating multi-direction ceilometer, UAV and remote sensing technology for monitoring/understanding the characteristics of Xitou microclimate change are on-going.
THE URBAN HEAVY FOG CLIMATIC FEATURE AND TEMPERATURE CHANGE IN THE CHONGQING OF CHINA

Background
The urban expansion may contribute the change of the urban heavy fog over 60 years in Chongqing. So, the climatic features of the fog is examined in this study.

Aim
The aim of the study should be provided the city weather service.

Method
The Climatic statistics method is used in the paper. The data used in this study is the situ data, including fog, temperature and air pollution index, that the observation stations are located in Chongqing, China over 60 years.

Results
We present evidence for a significant decreasing trend in urban fog for the 31 year period of 1980 - 2010 (mean daily minimum visibility is 3109 meter ) in Chongqing . Low visibility cases mainly occurs in 1951 to 1979 (mean daily minimum visibility is 515 meter). The urban heavy fog also shows a significant decreasing trend from 1951 to 2010 in the city. However, the temperature shows a raising trend from 1924 to 2004. When the fog weather is happened, the air pollution is also existed in the fog. The all API (FirstWrApi, Pm10Api, NoxApi ,So2Api) are decreasing in the period of 2000 to 2012. The FirstWrApi, Pm10Api and SO2Api have the larger decreasing trend than NOXApi ' s in Chongqing urban.

Conclusion
The increasing trend of air temperature and the decreasing trend of heavy fog and API may relate to the urban expansion.
Spatio-temporal variability of fog water and its meteorological conditions in the coastal Atacama Desert, Chile.

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ABSTRACT

The coastal area of the Atacama Desert in northern Chile is punctuated by fog ecosystems. One of these ecosystems includes the fog dependent Tillandsia Landbeckii species, which shows altitudinal variability in terms of density and vitality. We hypothesize this could be a response of the amount of fog water received, becoming an indicator of the presence and variability of the fog in this area. The main objective of this study is then to analyze the altitudinal variation of the fog water income in Cerro Oyarbide (20°29’S) and its spatial relation with the distribution of Tillandsia Landbeckii through the installation of five Standard Fog Collectors in an altitudinal profile. The year 2015 data suggests that the fog water show strong altitudinal gradients, with major water volumes obtained between 1.180 and 1.219 m ASL at Oyarbides Site. From this altitudinal range, fog-water decrease towards lower and higher areas. For instance, during the wettest season (winter-Spring) the SFC at 1219 m collected 70 % more than any of the other four SFC installed in Cerro Oyarbide. In this regard, the fog-water yields decrease upward and downward with 3.2 l/m²/day in September (early spring) and 3.6 l/m²/day in October, which is consistent with the known cycle of fog-water in Cerro Oyarbide. Thus, we have found between ENSO and fog-water at this latitude (~1200 m ASL in our site). An unusual large amount of fog water was detected by our data. An unusual large amount of fog events occur along with fog events, so we can also assess the meteorological conditions that yield using an altitudinal transect approach to assess how fog changes along this variable. We yields using an altitudinal transect approach to assess how fog changes along this variable. We

1. INTRODUCTION

The Sc deck offshore Atacama Desert coast is produced by the thermal inversion originated by Anticyclonic air-subsidence, intensified by the Humboldt cold waters (Rutllant et al., 2003; Cereceda et al., 2008). This determines the existence of a dynamic marine advection fog, providing moisture to a hyper-arid environment and allowing the development of ecosystems and biodiversity along the Atacama coast. [Pinto et al., 2001; Cereceda et al., 2008]. High biodiversity along the Atacama coast.
high biodiversity along the Atacama coast. [Pinto et al., 2001; Cereceda et al., 2008b; Garreaud et al., 2008]. Humidity used this way by plants, has proved to be an abundant water resource with great potential for human use. BUT, we still lack basic knowledge of the spatiotemporal distribution /variability of fog-water in the desert. In this work, we analyze the fog-water yields using an altitudinal transect approach to assess how fog changes along this variable. We also assess the meteorological conditions that occur along with fog events, so we can constrained atmospheric variables in a climate change scenario.

2. DATA SOURCES

The coastal topography of the Atacama Desert present optimal conditions to the fog generation because of the existence of the imposing coastal cliff (Cordillera de la Costa) that intercepts the Sc cloud at this latitude (20ºS) between ~ 400 and ~ 1.200 m ASL (Cereceda et al., 2004). The study area is located at Cerro Oyarbide (20º29'S) (Fig. 1), which includes an extensive Tillandsia Landbecki field in a 300 m elevation range. We used the ecologic conditions and elevation of Oyarbide oasis as a base criterion for installing five Standard Fog Collectors (SFC) (Schmeinuver and Cereceda, 1994) (Fig. 2) to be representative of local variability. Each SFC includes an automatic 10-minute record (rain gauge and logger) of fog water along an altitudinal gradient from 1.069 m ASL to 1.350 m ASL. The SFC 1.219 m ASL includes a temperature and relative humidity sensor. All data was processed to generate hourly averages to the Spatio-temporal and meteorological analysis.

3. RESULTS

3.1 FOG WATER YIELDS AND ALTITUDE

The fog water derived from the Sc in the coastal Atacama has an altitudinal variability, which was recorded by our SFCs in the altitudinal profile in Cerro Oyarbide (Fig. 1). In this regard, the SFC 1.219 m ASL has the highest fog water yields compared with the other SFCs throughout the year (Fig. 3) with the highest amount of water with 3.2 l/m²/day in September (early spring) and 3.6 l/m²/day in October, which is consistent with the known cycle of fog-water in Atacama Desert (Farias et al., 2005; Cereceda et al., 2008b; Garreaud et al., 2008). On the other hand, The SFC 1.350 m ASL, at the top of the Cerro Oyarbide, produced the lowest fog-water yields (close to 0 l/m²/day) suggesting the top of the fog cloud at this elevation. Similarly, at the base of the Oyardibe Site, where Tillandsia Landbecki find it lowermost distribution, the SFC 1.069 m ASL (Fig. 1) yielded the second lowest fog-water collection of all five SFCs installed in the area. The data then suggests that fog-water yields decrease upward and downward ~1200 m ASL in our site.

Fig. 3 Altitudinal Variability of Fog Water Income during 2015 in Coastal Atacama.
3.2 THE METEOROLOGY OF FOG EVENTS

Here we define “fog event” as a continues record of fog water during one hour or more, no matter the amount of fog-water collected. A total of 70 fog events were this way identified between January and December 2015 at the SFC 1.219 m ASL. We analyze their meteorological characteristics to assess the optimal air conditions linked to the presence of wet-fog. Table 1 and Fig. 4 summarize the meteorological structure of local conditions during the fog events in Cerro Oyarbide during 2015.

Table 1
Local meteorological conditions of fog events at Cerro Oyarbide between January and December of 2015*.

* February and November without register

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Number of Events</th>
</tr>
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<tbody>
<tr>
<td>Temperature (°C)</td>
<td></td>
</tr>
<tr>
<td>&lt; 7</td>
<td>8</td>
</tr>
<tr>
<td>7 - 10</td>
<td>26</td>
</tr>
<tr>
<td>10 - 13</td>
<td>22</td>
</tr>
<tr>
<td>13 - 16</td>
<td>8</td>
</tr>
<tr>
<td>&gt; 16</td>
<td>6</td>
</tr>
<tr>
<td>Relative Humidity (%)</td>
<td></td>
</tr>
<tr>
<td>&lt; 60</td>
<td>3</td>
</tr>
<tr>
<td>60 - 80</td>
<td>6</td>
</tr>
<tr>
<td>80 - 90</td>
<td>9</td>
</tr>
<tr>
<td>90 - 95</td>
<td>19</td>
</tr>
<tr>
<td>&gt; 95</td>
<td>33</td>
</tr>
<tr>
<td>Fog event duration (Hrs.)</td>
<td></td>
</tr>
<tr>
<td>1 - 2</td>
<td>8</td>
</tr>
<tr>
<td>3 - 5</td>
<td>25</td>
</tr>
<tr>
<td>6 - 10</td>
<td>18</td>
</tr>
<tr>
<td>11 - 15</td>
<td>17</td>
</tr>
<tr>
<td>&gt; 15</td>
<td>2</td>
</tr>
</tbody>
</table>

As expected, the air temperatures measured during fog events are linked to the season, with the highest values in summer (late December, January, February and early March) and the minimum in winter (late June, July, August and early September) (Fig. 4).

It is noted that the main fog events occur with temperatures between 7°C and 13°C, concentrating 48 of the 70 events considered (69%).

Moreover, the relative humidity in fog events has a homogeneous behavior throughout the year (Fig. 4), exceeding 90% in the 74% of the events, except in January, which has the lowest percentage of moisture (near to 60%) in fog events (Fig. 4).

Finally, the duration of these fog events varies between 1 hour and 15 hours, with the longest ones occurring during springtime. However, most event durations are between three and five hours. There is a strong correlation between the duration of events and fog water obtained (r = 0.9, p < 0.001).

4. CONCLUSIONS

Fog water collected shows clear spatial gradients, correlated with the elevation, with the highest volumes obtained at about 1200 m ASL and lowest ones at the top and base of the Tillandsia Landbecki field, exposing the direct link between fog and coastal plants. Despite the fact that the fog events occurs every month, at 1.350 m ASL, the fog water here is close to zero, which indicate that is the top of the stratocumulus cloud. Respect to the meteorological conditions of fog events, most events occur with temperatures between 7°C and 13°C and with relative humidity above 90%.

Interesting is what happens in the summer months, where fog events occur in environments with relative humidity close to 60%. There is a strong correlation between the duration of events and fog water obtained (r = 0.9, p < 0.001).
5. ACKNOWLEDGEMENTS

This work would not have been possible without the support of the Instituto de Geografía and the Centro del Desierto de Atacama of the Pontificia Universidad Católica de Chile, Dep. für Geographie. Research Group for Earth Observation (rgeo), Heidelberg University of Education and Heidelberg University. We also want to thank to Pilar Cereceda, Horacio Larrain and Felipe Lobos, who were fundamental in the beginning of this project.

5. REFERENCES


Meiyu is a rainy season lasting about 20-30 days in June - July in the southeast coast of China and the East China Sea. Sea fog often occurs in the East China Sea in Meiyu period. Due to its low visibility fog produce heavy losses of human life and property. Rainfall, sea fog and low stratus appear intermittently associated with the quasi-stationary Meiyu front. Most studies have focused on precipitation so far. It is still hard to forecast fog occurrence because the observations over the sea is rare and our knowledge falls short about the mechanisms of sea fog formation, maintenance and dissipation under Meiyu conditions.

On 24-25 June 2013, China’s southeast coastal area and the western East China Sea experienced Meiyu rain. During this period, a sea fog event occurred in the Hangzhou Bay off the coast; the visibility was less than 100m in about 6 hours. This study investigates the physical mechanism involved in the fog process by using in-situ observations (shipboard auto-weather station, ceilometer, GPS soundings, etc.) and models (HYPLIT and WRF).

It is found that a coastal front existed during the foggy episode. A sinking air branch existed on the cooler sea flank and a rising air flow on the warmer land flank of the front, thus forming a secondary circulation in the atmospheric boundary layer (ABL). With this secondary circulation, the coastal front both strengthened the stability in the ABL over the sea and adjusted the surface wind direction from northeasterlies to southeasterlies. The southeasterlies winds was cool and humid favorable to the formation of fog. The Meiyu front produced a heavy humid surroundings and a warmer southwesterly air advection above the ABL, which was conducive to the maintenance of fog. The sea fog maintained until the weakening of the coastal front, when the sinking air flow over the sea was replaced by a rising one controlled by the approaching of the low pressure systems. These results are helpful for sea fog forecast in Meiyu period and for our understanding of mechanisms involved in sea fog processes.
EVENT-BASED FOG CLIMATOLOGY AT ZAGREB INTERNATIONAL AIRPORT

Background
Long-lasting fog events at airports can cause significant flight. Therefore, study of fog is important for aviation meteorology, as improved forecasts can lead to considerable savings.

Aim
The aim is to create an analysis of fog at Zagreb Airport. The analyzed data should provide operational forecasters with useful climatological knowledge which can be helpful in fog forecasting.

Method
The data used consists of METAR reports from 1994 to 2014. The data was analyzed in the MATLAB computing package, by using a procedure similar to the one outlined by Tardif and Rasmussen (2007). Fog was classified into 5 different types according to physical mechanism of formation, and every fog event was classified accordingly.

Results
There has been a decrease in the annual number of fog events in the last 21 years at Zagreb Airport. Fog most often occurs in the period between September and February, which can be described as ‘fog season’ in Zagreb. During spring and summer fog is a relatively rare phenomenon, and events last very short. An exception is May, during which longer lasting events can be encountered. Fog events with minimal visibilities larger than 550m are a rare occurrence. Radiation fog is the dominant type, constituting over 70% of events. Yearly distribution of radiation fog is very similar to the yearly distribution of fog in general. Advective fog is very rare during summer, while precipitation fog and cloud base lowering fog occur only during fall and winter. Evaporation fog can occur throughout the entire year. Southwesterly wind directions are prevailing during onset and dissipation of radiation fog. Persistence of radiation fog is most probable in October, and least likely during spring and summer (March-August).

Conclusion
The study provides detailed and useful data on fog climatology at Zagreb Airport.
Fog in transportation & Miscellanea
ABSTRACT
Mist Collector is a collaborative work between art and science and focuses on the creation of an aesthetic experience that will also intend to propose an innovative solution to the world's water shortage by means of harvesting fog. In our research we discovered that a change of paradigm was necessary to obtain large efficiencies; thus, we have been focusing on a forest of flexible threads replacing the standard meshed net and exploring new shapes and structures. Our investigation has concentrated on understanding the principles of water droplet collection on parallel fibres and on the development of aerodynamic structures that could improve water collection. Currently the project is at the proof of concept development stage. Simultaneously, tests are being performed on a small-scale lab model, as well as on large-scale prototypes as part of artistic development. This presentation's focal point is artistic research.

1. INTRODUCTION
Fog harvesting is "an extremely promising and low-cost water harvesting system for drinking water, crop irrigation, livestock beverage and forest restoration in dry land mountains" (FAO report). In general fog collection systems consist of woven meshes that have been deployed successfully in several countries (Klemm et al., 2012). The main limitations in the efficiency of such meshes are the clogging of the mesh by coalesced drops and re-entrainment of droplets in the wind. Therefore, it is necessary to find a balance between adhesion of the drops (low contact angle) and fast drainage (low contact angle hysteresis), which requires a specific treatment of the fibers surface (Park et al., 2013). In our research we propose a new paradigm by creating a novel 'textile'. While keeping the raw material of nylon fishing thread (easily obtained and cheap) we employ a different structure, namely a forest of flexible nearly parallel fibers and unconventional architecture.

Working with scientists and artists, and advocating for a hybrid model where one becomes the other, LadHyX has been exploring a path between art and science that mixes both scientific and artistic imaginations since 1992. Formulating questions in science is pure imagination and intuition that does not involve only the rational side of the brain but the sensitive side, which is able to be non-incremental, to understand faster and anticipate. Instead of showing scientific proof or technique, it is possible with Art -Science to directly attempt to share this aesthetic and emotional experience. These art works are then like writing poems using fluid mechanics and by doing so re-interrogating the scientific practice and the societal role of science. They are public sharing beyond outreach, a form of Public 'inreach'.

Figure 1: Time series' photographs showing the progressive collection of mist on parallel flexible fibers.

2. Through the Looking Mist …
We have thus experimented with a specific surface composed of parallel fibers (Fig. 1). The mist droplets impact the fibers and coalesce,
Mist collector: Art and Science project

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2. Through the Looking Mist …

We have thus experimented with a specific surface composed of parallel fibers (Fig. 1). The mist droplets impact the fibers and coalesce,
forming capillary bridges that quickly lead to the collapse of adjacent fibers (Duprat and Protière, 2015). This results in the formation of long liquid columns that prevent clogging and drop re-entrainment due to the immediate coalescence of incoming droplets. Based on these findings and using a fast camera we have created the Through the looking mist ... artwork that involves a large projection of a video, capturing water droplet nucleation on the parallel fibers (Fig. 2). Through a change of spatio-temporal scale, visitors are able to see drops slowly appearing, growing and then falling. This change of scale invites the spectator to question her/his point of view and to feel the phenomenon at the scale of a constitutive fog droplet, similarly to the heroine of Alice in Wonderland, whose body proportions vary depending on different notions of space. One might interpret this phenomenon with a new point of view that allows us to see, explore and discover the world in a different scale, where importance does not depend on size, but on the balance of forces. The phenomenon obeys so-called scaling laws; changes in size inducing a self-similar transformation in time, as if the clock in wonderland rushes Alice into the white rabbit’s den.

In the video, the drops ‘tremble’ in the wind and seem to struggle to stay attached. A growing tension, the anthropocentric feeling of resignation facing the ineluctable, give rise to different formations and various rhythms, creating an ‘ode’ to the cycle of formation and fall.

Figure 2: Through the Looking Mist..., ISEA 2014 (Dubai).

3. Misty Way

Misty Way, the second artwork developed based on our research, incorporates three main elements involved in fog collection: humidity, wind and a harvesting system. In this installation, light droplets of various sizes (captured with a fast camera with a high magnification) are projected onto multiple textile screens made from parallel threads, especially designed and produced for this piece. The light drops passing along and through the fibers moving in a wind generated by ventilators, are captured by the ‘textile’ and cast a second projection on the floor (Fig. 3). They literally splash on the spectator and on the floor. This installation creates an immersive environment where viewers are submerged in a virtual mist of widely spattered drops of light, shadows and sound.

Figure 3: Misty Way, presented at Les Recollets, Paris (October 2015).

1 photo credit: Ana Rewakowicz.
4. Mist Collector

Currently, we are in the process of developing a multi-sensory installation entitled Mist Collector, in which visitors will be immersed in an environment of water collection from humidity. For this purpose we intend to use the model of laboratory experiments that involve the construction of a human sized environmental wind tunnel developed from the original design proposed by J.-M. Chomaz and A. Garcia for the project Smocking while waiting with Analia Garcia Ramirez in 2007.

Multiple, independent stackable units, connected in different formations, will create an adjustable wall of fog guided by the wind (Fig. 4). In this controlled fog environment, several fog-harvesting structures will emerge. In our research, these structures have drawn inspiration from the study of various-shaped porous sails, keeping the constraints of parallel threads that can guide the fog while optimizing the collection. Thus we arrived at the eerie sail (Fig. 5).

Placed in the fog, this sculpture comes to life as it gather droplets that run along the threads to be collected.

The significance of this installation will be manifold; the sails represent an immobile voyage through the water in the air. The slow dripping of water preciously collected from the materiality of fog will offer visitors reflection on the importance of water in our lives, alerting us to fussy futures (or lack of them) and the laborious journey awaiting humanity in the pursuit of water supplies.

5. CONCLUSION

Our method of art and science collaboration concurs with the design-science concept coined by Buckminster Fuller, in which design is not a fragmented notion applied to specialized disciplines but a creative process that lies at the heart of any human activity. In the “Architecting the Future” lecture, Michael Ben Eli (2010) describes design as a process of realizing intentions that starts from comprehensive goals (that come from experience) taken on the path of action towards realization, accompanied by the step-by-step (systematic) process of constant evaluation. In the design process there is no such thing as failure because every failure becomes a departure point for new adjustments and resembles a spiral of evolution. He also asserts that design suffers when its intentions are narrow, when we separate (banish) ourselves from the larger orders of life in the Universe. Over centuries the tendency of narrowing focus has created specialized fields of production and has “ensured that we could not simultaneously concentrate on both the big and the small, the real and the symbolic, the human and non-human, the scientific and the vécu.” (Latour, 2005)
Science, when it is not confused with its practice of the proof, is a creative design in the sense of Buckminster Fuller (1965). Its method is based on design with errors and trials leading the shaping of a form of progress. But to “architect a Future” progress should be thought. In that scheme the art & science practice represents a protocol to a broader design, in order to not rely, as in the present system, on the notion of experts with a fragmented view. It allows to re-engage with critical thinking which has been the primordial destruction of the Anthropocene as asserted by Timothy Morton (2007, 2010). Instead to delegate perception to knowledgeable entities, the public is emotionally engaged with the space emanating from the artwork and the ethic reflection on the preciousness of water and life.

Mist Collector project, by bringing humanity at the scale of a single drop by embarking the visitor aboard an Earth size vessel sailing in the fog states the necessity for all human kind (and not human), artists, scientists, shepherds or gardeners to start building a share narrative, an uncertain shadow of an ever failing Future that shall still be shaped and imagined together. It also corresponds to, in the words of Michael Ben Eli, “the purpose of design-science … to make world resources work for 100% of humanity in the shortest possible time through spontaneous cooperation and without ecological offense or disadvantage of anyone.” Only then may we not have to mutter “Oh dear! Oh dear! I shall be too late!”

Acknowledgements

We acknowledge Ecole Polytechnique, La Diagonale Paris Saclay, the Department LaSIPS of the University Paris Saclay and Fondation Carasso for their continuous support. Ana Rewakowicz wishes to thank the Conseil des arts et des lettres du Québec and Canada Council for the arts for its financial support.

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3 Caroll L., Alice’s Adventures in Wonderland
Background
Aviation safety and economic efficiency of airports and airlines are strongly affected by weather and natural hazards. One of these weather events is low visibility determined by fog and low ceiling. To predict low visibility is challenging due to the complex underlying physical processes.

Aim
A nowcasting tool is suggested providing probabilistic visibility forecasts. This supports airport decision makers in their work assuring aviation safety and reducing economic losses.

Method
At Vienna Airport, visibility conditions are divided into four classes based on reduction of visibility and ceiling. The four classes are closely related to the airport capacity. To predict occurrence probabilities of these classes, we propose an ordered logistic regression model based on time series of standard meteorological point measurements.

Results
One large challenge in this study is the rare occurrence of the classes with low visibility. The most important model inputs are lagged values of visibility, temperature and humidity. Lead times up to 3 hours were tested, which are needed for tactical planning at the airport. The forecasts of the ordered logistic regression outperform persistence forecasts. Model skill decreases with increasing lead time but the benefit over persistence increases. The logistic model is competitive even compared to human forecasts.

Conclusion
The presented low visibility nowcasting tool leads to promising results despite using only few simple input variables. An extension of the model inputs could further increase the model skill.
Background
The crash of the Polish presidential plane took place on 10th April 2010 in Smolensk, Russia, in the conditions of low visibility caused by fog. There are many hypotheses and speculations, including conspiracies, about the origin of that fog.

Aim
Our intention is to examine the atmospheric and topographic conditions related to fog formation and to explain untypical intensification of fog several hours after sunrise.

Method
The available weather data were analyzed from both synoptic and local perspective. The exchange of information between the crew and flight control as well as the plane black box recordings were also taken into account.

Results
There was weak south-eastern anticyclonic circulation with the advection of relatively cool and humid air in the lower part of the atmospheric boundary layer. On the night before the crash a large formation of low-base stratus clouds was observed travelling slowly to the north-west. Prior to the arrival of the stratus clouds, the air within the Dnieper River valley was subjected to radiative cooling, which reduced the water vapor deficit to less than 0.5 hPa. Just before the time of the crash at the Smolensk airport, which is situated at an local upland about 80 meters above the valley bottom, the air reached the saturation point, air temperature was around 1 degree C, south-eastern wind was blowing with the speed of 2 m/s and the visibility deteriorated below 500 m.

Conclusion
Fog, that was observed when the plane crashed, was complex in origin. A large air parcel with low-base stratus travelling north-west, was lifted by the local topography with the inclusion of cool air formed in the valley. This resulted in further adiabatic cooling with the intensification of mist/fog and the decrease of both ceiling and horizontal visibility.
A High Resolution NWP Modelling Study of Fog at Perth Airport

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ABSTRACT

Fog has a major impact on airline operations in terms of safety and economics yet reliable forecasting of fog remains a significant challenge. This is a particular issue at Perth Airport in the southwest of Australia as the airport is remote and when required to divert during heavy fog conditions the nearest airport suitable for large aircraft is located more than two hours flying time away. In this study we examine the utility of the Australian Bureau of Meteorology’s modelling suite, the Australian Community Climate and Earth-System Simulator (ACCESS), to provide an understanding of the physical processes associated with fog at Perth Airport. Case studies have been conducted of three cool season fog events at Perth Airport in 2013 and 2014. Analysis of the NWP model output concentrates on how well the model represents the mesoscale dynamics, which have an impact on the airflow, temperature and moisture and hence the development of fog. The model output is sensitive to the representation of land-surface characteristics and topography. The results presented here suggest that the escarpment east of Perth Airport has a significant impact on the occurrence of fog at the Airport. Variations in the topography contribute to complex local circulations which may affect the location and timing of fog. The model has provided a good representation of the mesoscale circulations associated with the fog events that have been examined. A number of issues have been identified that need to be addressed to ensure the ACCESS model will provide better forecasts of fog in the future.

1. INTRODUCTION

Perth Airport is located on a coastal plain on the southwest coast of Australia. It is around 20 km from the coast and the elevation is approximately 20 m. About 10 km east of the Airport and extending well to the north and south is an escarpment, the Darling Scarp, which rises sharply to an elevation of 250-300 m (Figure 1). Although the airport only has an average of 12 fog events per year, the impact of fog on the aviation industry is large due to the vast distances to alternate international airports for diversions. An unforecast fog event when an aircraft has limited fuel reserves presents a significant safety risk. At the same time a high false alarm ratio when forecasting fog at an airport has an economic cost due to the additional carriage of unnecessary fuel and a possible reduction in load capacity.

In the cool season, which we define as the period 1 April – 31 October, Perth comes under the influence of frontal systems moving eastward across the south of Australia. The prevailing winds are moist westerlies although a light east to northeast katabatic wind often occurs overnight at Perth Airport. Most fog events occur at this time of the year with 10-11 events in this period. These can be associated with a variety of synoptic situations including cut-off lows, post-frontal situations and developing high pressure ridges.

Figure 1: Topography map of the Perth area and airport location (YPPH). Contours are at 30, 100, 200 and 300 m.
There is often precipitation in the hours prior to the fog event and the fog can develop over the airport or in areas nearby and then advect over the airport.

Huang, et al. (1990) suggested that there are four types of fog in Perth; radiation, post-frontal, advection and rain fog, with the predominant type in Perth being rain fog. They illustrated the potential use of a NWP model in fog forecasting by initializing their model with observations from Perth Airport. In a high (4 km) resolution NWP study of fog by Golding (1993), the significance of the terrain in Western Australia in the formation of fog has been noted. Golding found that fog can form near the stagnation point between the cold drainage flow off the escarpment to the east and the moist onshore flow from the west. He also remarked that the drainage flow is perturbed by the irregularities in the orography, which in turn lead to variations in the area of fog development. To date the work of Golding (1993) has been the main contributor towards our understanding of the local fog processes at Perth Airport. Now, more than 20 years later, new case studies are conducted using the Bureau of Meteorology’s high resolution ACCESS model to test this theory and discern the ability of the model to provide guidance on the physical processes associated with fog at Perth Airport. There have been substantial improvements in numerical weather prediction (NWP) models in recent years, with improved horizontal and vertical resolution as well as updated physical parameterisations. These improvements enable a more detailed analysis and understanding of the processes associated with fog events and offer the potential for further improvements in forecast performance, although the intricacies of the local influences and interactions of variables are still not well observed or understood.

2. CASE STUDIES

Three cool season fog events at Perth Airport, with synoptic conditions favourable for fog formation in 2013 and 2014 are presented. For each of the cases we examine the output from the model run with a base time of 0000 UTC (0800 LST) in the morning prior to the fog event and concentrate on how well the model represents the mesoscale dynamics. In the first case (9 Jun 2013) there was a low pressure system centred over the southwest of Western Australia which moved east overnight and a ridge developed south of the state. The gradient level flow backed from westerly in the evening to southeast by morning. For the second case (1 Jun 2014) Perth was in a col area following the passage of a weak trough along the south coast and the gradient level flow was relatively light west to southwesterly for the night. For the third case (19 Jun 2014) there was a high pressure ridge lying east-west across the coast north of Perth with the high pressure centre moving inland overnight. The gradient flow was initially a moderate west to southwesterly and this veered to the northwest overnight. For all of these events drizzle or showers were observed in the period before the fog developed.

2.1 Model Setup

ACCESS is a coupled climate and earth system simulator which has been developed as a joint initiative of the Bureau of Meteorology and the Commonwealth Scientific and Industrial Research Organisation (CSIRO) in cooperation with the university community in Australia. The system is based on the UK Met Office NWP Unified Model (Davies, et al., 2005) and four-dimensional variational data assimilation scheme (4DVAR) (Bureau of Meteorology, 2010; Puri, et al., 2013). In ACCESS the NWP model is fully coupled to the Joint UK Land Environment Simulator (JULES) land surface model in order to simulate the atmosphere–land coupling and the fluxes of heat, moisture and gases between them (Best, et al., 2011; Clark, et al., 2011). ACCESS is configured to run across a range of domains extending from the global, regional, and city scale models covering the major population areas. For the case studies an experimental version of the soon to be operational upgraded city scale model (ACCESS-C) is used. It is a forecast only model, nested in the 12 km resolution regional model and has a horizontal resolution of 1.5 km with 70 vertical levels up to a height of about 40 km.

2.2 Results

ACCESS-C did not forecast fog at Perth Airport for any of the cases presented although it did forecast reduced visibility in the range 3000 – 5000 m. However, the model forecasts agreed well with the observed mesoscale circulations and the overnight temperature and dew point in the area around Perth Airport.
moved east overnight and a ridge developed 2013) there was a low pressure system centred LST) in the morning prior to the fog event and model run with a base time of 0000 UTC (0800 each of the cases we examine the output from the with synoptic conditions favourable for fog Three cool season fog events at Perth Airport, 2. CASE STUDIES

improvements in forecast performance, although with fog events and offer the potential for further and understanding of the processes associated improvements enable a more detailed analysis of the orography, which in turn lead to variations in flow from the west. He also remarked that the

found that fog can form near the stagnation point of fog has been noted. Golding 1993) has been the main contributor to the airport. In a high (4 km) resolution from Perth Airport. In a high (4 km) resolution the orography, which in turn lead to variations in

type in Perth being rain fog. They illustrated the types of fog in Perth; radiation, post-frontal, Huang, et al. (1990) suggested that there are four the airport.

There is often precipitation in the hours prior to

Figure 2: Time series of modelled and observed surface variables at Perth Airport for 20130609

Figure 2 shows the time series of the observed and modelled temperature, wind and visibility at the airport for 9 June 2013. For all the cases there was a westerly gradient flow in the afternoon prior to the fog event and the surface wind reflected this in areas closer to the coast and areas east of the Darling Scarp. However the wind field near the base of the Scarp was more complex. Figure 3 shows a plot of the surface temperature and winds (top) and a vertical profile through the latitude of the airport (bottom) for a fog hour on 19 June 2014. For two of the cases the model cross section showed a blocked flow at the base of the Scarp in the afternoon with a cooler more stable airmass and northerly winds below the height of the Scarp. The presence of precipitation and low cloud and can enhance the blocking in these situations due to reduced radiative heating during the day and the effect of evaporative cooling. Moreover, ascent of the westerly flow as it overrides the blocked flow and the Scarp can further enhance precipitation on the coastal plain, increasing the humidity and hence the likelihood of fog. As temperatures decrease during the night the cross sections show development of a nocturnal inversion which is most evident at the base of the Scarp. An east to northeast katabatic wind develops with convergence and ascent at the boundary with the westerly environmental flow.

3. CONCLUSIONS

The model has provided a good representation of the mesoscale circulations associated with the fog events that have been examined.

The results presented here suggest the Darling Scarp may have a significant impact on the occurrence of fog at Perth Airport. The observations of the mesoscale flow are consistent with the finding of Golding (1993) that the stagnation zone at the boundary between the environmental westerly and the drainage flow
due to the Darling Scarp is favourable for the development of fog. Local variations in the topography along the Darling Scarp may impact on the location and timing of fog formation and clearance due to local enhancement of the drainage flow. Such an enhanced drainage flow would be associated with increased turbulence and some drying but the impact on development or clearance of fog over Perth Airport is unclear. The turbulence and drying associated with the enhanced drainage flow may prevent the development of fog over Perth Airport or lead to early clearance of existing fog. However if there is a saturated air mass over the airport the development of a relatively cold drainage flow down the valley and mixing with the saturated air mass may lead to development of fog or the enhancement of pre-existing fog.

3.1 Issues and future work

A number of issues have been identified that need to be addressed to improve the capability of the ACCESS model to forecast fog. The parameterisation for visibility and fog probability in ACCESS is dependent on temperature, total moisture and the aerosol mass mixing ratio (currently set to a 'climatological' value in the ACCESS model). The sensitivity of this parameterisation to the input variables needs to be investigated and calibrated for the Perth area and more generally for Australia. After sunrise the forecast screen level temperature and soil temperature at 10 cm increases significantly slower than the observed temperatures. Such a difference in the heating rate could have a significant impact on the expected clearance of fog. Early experiments for this study showed the model output is sensitive to the model topography and the representation of the tree heights in the land-surface model. The land surface characteristics will influence the fluxes across the land-atmosphere interface with a direct impact on the mesoscale dynamics, including the temperature, moisture and air flow in the lower boundary layer. This will also have an impact on the diagnosed visibility and fog probability. There is a need to investigate the current land surface types in the land surface model more fully, including the urban characteristics and soil type, to ensure they are the most appropriate for the model domain and resolution.

Further investigation of the cases presented here and other cases is necessary to refine our understanding of the model's performance and quantifying improvements with future upgrades. This should include analysis of cases when fog was expected but did not develop. Of particular interest is the contribution that the blocked flow and the development of the drainage flow might have on the development and clearance of fog.

4. REFERENCES


COSMO-PAFOG: THREE-DIMENSIONAL FOG FORECASTING WITH THE HIGH-RESOLUTION COSMO-MODEL

Background
The presence of fog can have critical impact on shipping, aviation and road traffic increasing the risk of serious accidents. Thus the improvement of fog forecasts including localization, duration of fog as well as variations in visibility holds immense operational value.

Aim
The aim of the study is the development of an efficient three-dimensional numerical fog forecast tool based on a mesoscale weather prediction model.

Method
The microphysical parameterization of the one-dimensional fog forecast model PAFOG is implemented in the three-dimensional mesoscale weather prediction model COSMO of the German Weather Service. For this cloud water droplets are introduced in COSMO as prognostic quantities, thus allowing a detailed description of droplet sedimentation. Furthermore, a visibility parameterization depending on the liquid water content and the droplet number concentration is implemented. The resulting fog forecast model COSMO-PAFOG is run with high horizontal and vertical resolution. Model results are compared with satellite observations and routine observations of the German Weather Service for a domain in Western Germany.

Results
Various fog events will be presented revealing that COSMO-PAFOG is able to represent quite well the horizontal structure of fog patches. Especially small fog patches typical of radiation fog can be simulated with sufficient accuracy. Ground observations of fog related parameters such as temperature and relative humidity are also well reproduced. The consideration of droplet sedimentation is essential since simulations without droplet sedimentation yield unrealistically high liquid water contents. This in turn reduces the radiative cooling of the ground. The calculated visibility agrees well with observations. However, the reduction of visibility by fog tends to be delayed and fog dissolves too early.

Conclusion
As a first result of the investigated fog events it is concluded that the three-dimensional fog forecast model COSMO-PAFOG is able to simulate fog events reasonably well without considerable additional computational expense.
During the main fog season of 2015, we investigated the relevance of marine fog to microbial communities in the Atacama Desert. The fog zone ranges in altitude from 500 to 800 m elevation, and is maintained in place by a thermal inversion. Oceanic fog represents the main source of humidity in the core of the Atacama Desert, where rainfall is practically absent. Microbial communities are the dominant biological component in Atacama Desert soils, driving essential ecosystem functions such as nitrogen fixation and carbon capture. Because hyperarid conditions in the Atacama Desert, we postulate that microbes transported by fog from over the Pacific Ocean could be the main component of microbial communities found in the Atacama Desert soils.

We investigated the relevance of marine fog as a source of microbial diversity transported from the Pacific Ocean to the Atacama Desert.

During the main fog season of 2015, we recorded oceanic fog inputs to three sites along a 1,000 km latitudinal gradient on the coastal Atacama Desert (20°48 S, 69°45 W - 31°06 S, 71°25 W). In each site, we collected replicated fog samples for assessing microbial activity and community structure. Fog samples were collected at different elevations within the fog zone to assess the effect of air temperature and fog density on microbial presence and activity.

Fog inputs peaked in different months along the latitudinal gradient. In the northernmost site (Patache), maximum fog inputs occurred in late summer and autumn (March-June). In contrast, at the southern margin of the Atacama (Fray Jorge), fog inputs peaked in late spring and summer (September-February) providing moisture to vegetation and soils during the rainless season. Fog-transported microbial community composition and cyanobacterial activity varied greatly among samples from different study sites, in response to changes in fog density, air temperature and elevation.

Fog-transported microbial communities were present and active in all samples along the latitudinal gradient studied, which suggests that oceanic fog contributes significant microbial inputs to enrich Atacama Desert soils.
Inter-mesh Comparisons of Passive Fog Collectors

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ABSTRACT

Abstract: This paper documents a comparison between a POSS-PEMA-coated 14 square per centimeter metallic mesh mounted on a passive standard fog collector and a Raschel mesh also mounted on a standard fog collector. Results from approximately a year of sampling indicate a variety of regimes over which the performance of the different mesh types may be studied. Of particular interest are cases when both the POSS-PEMA mesh and the Raschel mesh recorded nonzero fog water volumes, cases where the Raschel mesh recorded nonzero volumes and the POSS-PEMA mesh recorded none, and cases where the POSS-PEMA mesh recorded nonzero values and the Raschel mesh recorded none. Results illustrate wind dependence on the sampling efficiency, particularly when both types of mesh collected nonzero samples. During most of these periods, the Raschel mesh typically collected more water than did the POSS-PEMA mesh (about 840 samples). However, during this experiment, there were a significant number of intervals during which the POSS-PEMA mesh collected water from fog when the Raschel mesh did not (about 430 samples) and many fewer when the Raschel mesh collected water from fog and the POSS-PEMA one did not (165 samples). In addition to the relationship with wind speed, the variations in the water volumes collected between mesh types may indicate a droplet size dependence.

1. INTRODUCTION

This study is a part of a large, statewide deployment of standard fog collectors at multiple locations along the California coastal region (Weiss et al. 2016). All told, there are over a dozen sites spread out over a distance of several hundred kilometers. A number of fog collectors are deployed at several of these sites, each with a different type of mesh. Coupled with in situ weather instrumentation, which includes wind speed and direction, temperature and relative humidity, this provides an excellent test bed for examining the fog collection efficiencies of different mesh types under a variety of meteorological conditions.

This report examines the first of such comparisons from this network, although there are many other locations where such setups were deployed with several different types of mesh.

2. METHODS

Standard fog collectors (Schemenauer and Cereceda, 1994) were deployed as shown in Figure 1. One consisted of mesh made from Chilean 35% shade coefficient Raschel fabric and the other from a 14 square per cm metallic mesh coated with a POSS-PEMA hydrophobic substance (Park et al., 2013). Fog water from each collector was sampled with calibrated tipping bucket rain gauges every 15 minutes. In conjunction, meteorological instruments at this site collected (at 10 minute intervals) wind speed...
and direction, temperature, relative humidity, long- and short-wave solar irradiance, barometric pressure, and rainfall.

**Figure 1:** These are the standard 1.0 m² fog collectors located at one of the sites in Marina, CA. The collector on the left consists of the POSS-PEMA mesh. The collector on the right uses the Raschel mesh.

The first deployment of a Raschel mesh at this site in Marina, CA took place in July, 2014. However, the POSS-PEMA mesh was not deployed until October, 2014. Since fog events become less common (and the weather can be more severe) during winter months, these sites are taken down typically by December and re-deployed in late spring. This study represents data that were collected primarily between October 2014 and October 2015 with a hiatus from January 2015 through July 2015.

This paper presents measurements that were made only when both fog collectors were operating in conjunction and when any rain events were removed from the record. Of particular note are several data regimes. One is when both of the fog collectors recorded nonzero water. Another is when the one of the collectors recorded an event and the other did not (but was still operating). During the measurement period, there were around 840 samples (each 15 minutes long) when both collectors recorded a value simultaneously. There were about 430 samples when the POSS-PEMA collector recorded a nonzero value while the Raschel mesh recorded nothing and about 165 when the Raschel mesh recorded a nonzero value and the POSS-PEMA mesh recorded nothing.

**3. RESULTS**

Figure 2 shows the results of the difference between fog water collected from both meshes as a function of the wind speed. It can be seen that, for these 840 samples, the Raschel mesh tends to collect more than the POSS-PEMA mesh and that that difference seems to have some wind speed dependence, although there is significant scatter.

**Figure 2:** This graph represents the difference between fog water collection volumes over 15-minute intervals between the Raschel mesh and the MIT-14 POSS-PEMA coated mesh as a function of wind speed. This represents cases from Marina, CA when both collectors recorded a value and from which data with rain in them were removed. As the wind speed increased during fog events, the Raschel mesh in this study tended to collect more water than did the mesh with the POSS-PEMA coating.

Figure 3 illustrates the cases where the POSS-PEMA mesh recorded no volume but the Raschel mesh did. Interestingly, these 165 samples seem to show a “quantization” which is simply due to the fact that the Raschel mesh never collected a significant volume when the POSS-PEMA mesh did not collect. In other words, the tipping bucket connected to the Raschel mesh tipped only one, two or three times (or, in one case, five times) as depicted by the rather small associated volume indicated by each of the horizontal regions on the graph in this figure.

**Figure 3:**
Figure 3: This graph illustrates the volume of water collected from the MIT-14 mesh as a function of wind speed during times when the Raschel mesh collected none (428 samples). There does not appear to be a strong dependence on wind speed.

A very different case is seen in Figure 4. This graph illustrates the volume of water collected from the POSS-PEMA mesh when the Raschel mesh did not collect any. These 430 samples show a weak negative dependence on wind speed and they exhibit the rather large volumes of water collected by the POSS-PEMA mesh (in many cases, a significant fraction of a liter and in some cases as much as a liter) over each 15-minute interval when the Raschel mesh collected none.

Figure 4: This graph illustrates the volume of water collected from the POSS-PEMA mesh as a function of wind speed during times when the Raschel mesh collected none (428 samples).

4. DISCUSSION

The data indicate a variety of circumstances that may occur when comparing different mesh types. Specifically, in addition to periods of time when both meshes collect, there are a large number of time periods when one mesh collects and the other does not. In particular, in this study, the number of 15-minute intervals when the POSS-PEMA mesh collected water from fog and the Raschel mesh did not (427 samples) equated to roughly 50% of the number of times of when both mesh collected samples simultaneously (836 samples). These numbers significantly exceeded the number of intervals when the Raschel mesh collected fog water that the POSS-PEMA mesh did not (165 samples). While the Raschel mesh tended to collect more water than did the POSS-PEMA mesh during those times when they both collected water (115 liters versus 82 liters), the amount of water collected from fog during those periods of time when the POSS-PEMA mesh alone recorded nonzero values by far exceeded the amount of water collected by the Raschel mesh when it alone collected (20 liters versus 2 liters).

Park et al. (2013) describe the different features of the mesh that result in a decreased amount of fog water and how these factors manifest in different mesh types. Specifically, the characteristics of the mesh that lead to blocking and re-entrainment of tiny and coalesced fog droplets tend to reduce the amount of fog water collected. Blocking is a result of the accumulated droplets that tend to limit the airflow through the mesh. Re-entrainment is the characteristic of droplets to be blown off the mesh and evade collection. According to Park et al., the “optimal” fog water collector for a given droplet size and wind speed will be one that minimizes entrainment as well as blocking. This will promote water to run down the mesh and enter the trough rather than remain on the mesh and either block the air flow or re-entrain into the air stream. This study points to the potential efficacy of a hydrophobic coating on a mesh size of about 0.45 mm being optimal for fog water collection for a wind speed of 2.0 m/s.

The study also points to the significant advantage that the coated metallic mesh has over the Rachel mesh, which is not fully played out in the data collected. However, the large number of events when the Raschel mesh collected nothing and the POSS-PEMA mesh collected significant amounts of fog water is consistent with the end results of the study.

While very comprehensive, the limitations to the Park et al. (2013) study include the fact that the wind velocity (as seen in Figures 2-4) is often greater than 2.0 m/s. This points to other wind parametrizations that need to be considered in the model. Additionally, within the Park et al. (2013) study, entrainment is considered a limiting factor. However, some degree of entrainment does not result in significant loss for the standard fog collector, which incorporates a tray that extends about 15.0 cm in the leeward direction of the standard fog collector and is designed to capture the heavier water droplets that will become partly entrained by the wind and fall into (or, in some cases, past) the
collection tray. An enhanced model that addresses this degree of entrainment may add an important dimension to the theoretical studies of passive fog water collection efficiencies.

These results indicate the challenge of doing direct comparisons of passive mesh efficiency. In other words, there are a variety of conditions that result in one mesh producing significantly more fog water than the other. Wind speed appears to be one such factor. However, as Park et al. (2013) indicate, droplet size is also likely an important factor and one that this experiment does not yet report the results of. The results of this study indicate that there may be significant variation in the fog droplet sizes over the course of the different measurement periods.

5. CONCLUSIONS AND RECOMMENDATIONS

One of the observations of this study is that the Raschel-based standard fog collectors are not consistent fog collectors across the broad spectrum of fog events. That is, there were a sizeable number of events when the metal mesh coated with the POSS-PEMA compound collected significant amounts of fog water while the Raschel mesh collected none. While the converse was also true to some extent, the events when the POSS-PEMA mesh collected no fog water and the Raschel mesh collected some were rather limited in number and in volume of fog water collected.

Interestingly, during those periods when both the Raschel mesh and POSS-PEMA mesh drew in fog water, the Raschel mesh collected, on average, about 40% more fog water.

These disparities between fog water efficiencies between the various mesh are associated both with wind speed and, also, most likely, with variations in droplet sizes. This phenomenon has also been observed when comparing data from passive and active collectors in the field. That is, our group has observed periods when the fine Teflon strings on a CASCC-based active collector (Weiss et al., 2016) generate fog water samples that the Raschel passive collector does not record.

Additionally, the POSS-PEMA coated metal mesh exhibits a “broader” spectrum of events over which it records water collected, though in this study the total amounts of liquid fog water collected are slightly less than that of the Raschel mesh.

Furthermore, this study illustrates that a direct comparison of the efficiency of different fog collection devices becomes more precise when qualified by accompanying meteorological conditions, including wind speed and, most probably, fog droplet size.

6. Acknowledgements

The authors wish to acknowledge Mr. Dick Lind for his assistance and for providing the meteorological data.

7. REFERENCES


Background
The Lublin Airport became operative on 17 December 2012. From the very first there have been difficulties in forecasting of some hazardous weather phenomena e.g. thunderstorms, snow showers and fog. There is no climatological background for the area hence comprehensive research of weather conditions may be helpful in forecasts.

Aim
The study compares weather conditions at three weather stations (synoptic, airport and climatological one) to understand factors that aid fog creation.

Method
Weather stations are situated in the distance of 21km in different directions in relation to the center of Lublin city. Data come from personal visual observations and observations made by Automatic Weather Observation Systems. Descriptions of synoptic situations are taken from the Internet archive weather websites. Some statistical software is used to compare data.

Results
Due to the fact of the importance of fog for security of the airline industry the study considers all cases of fog appearance at Lublin airport during its operational activity. The paper takes a stab of analyzing all factors that may support fog creation. A flat pressure gradient area, wind direction, high level of relative moisture, stability in the surface layer play a crucial role in fog creation. Research underscores the consequence of visual observations for correct diagnosis of current weather conditions and consequently for nowcasting. Unknown factors like condensation nuclei, local transportation of moisture, type of soil and topography are mentioned to try to understand dynamics and structure fog in the vicinity and in the airport area.

Conclusion
All weather stations are affected by local microclimate and should be investigated in further research.
AN ECONOMICAL LIQUID WATER FLUX INSTRUMENT

Background
One of the key parameters in the study of fog is the amount of liquid water content (LWC) that is present in it. However, it can be difficult and expensive to measure it. The product of the velocity and the LWC is the liquid water flux (LWF).

Aim
The purpose of this study was to develop a robust, economical, low power, hot-wire-based instrument to measure the liquid water content (LWC) and liquid water flux (LWF).

Method
The method involved designing, building and testing the electronics, probe and housing along with a wind tunnel. Calibration and measurement procedures were written and the probe was tested in the wind tunnel.

Results
A prototype of the system, which includes the probe, electronics, and housing was developed (see figure). The system includes on-board measurement of temperature, pressure and humidity and connections for a cup anemometer and wind vane. In addition, it includes data logging to a micro SD card and wireless transmission of the data via an XBee antenna for use in a wireless sensor network. The measurements of wind speed, temperature and hot-wire power are combined to derive the liquid water content. The electronics accommodates multiple hot-wire probes, for measurement of velocity and LWC without a cup anemometer. A wind tunnel was built for instrument calibration. Preliminary tests of the system in the wind tunnel have shown that the system power is a function of both wind speed and LWC.

Conclusion
The preliminary results of this study indicate that a properly calibrated instrument will enable economical measurements of LWC, LWF and other environmental conditions. Further, the relatively low cost and wireless connectivity will enable spatially distributed measurements in the field.
Background
The fog at the airports is undesirable phenomenon. Determination of circulation conditions is crucial for fog forecasting.

Aim
The aim of the study is to analyse the circulation condition favorable to fog occurrence at the airport of Wrocław, SW Poland, 1976 to 2005.

Method
We have used detailed information on fog occurrence from the airport of Wrocław Strachowice, including: fog intensity, time of occurrence and decay, type of fog after synoptic code from the years 2001-2005 and monthly number of foggy days from the years 1976 to 2000. Occurrence of fog is classified according to circulation types appointed with an automatic classification which is based on high resolution data from the WRF model.

Results
The analysis reveals seasonal differences between the number of circulation types favorable to fog occurrence and its durability. Autumn and spring are similar in terms of the determined circulation types favorable to fog occurrence. For summer and winter fog occurred in the lower number of circulation types but in the cold months it was more often observed during the types with advection from sector N. The longest fog duration at Wrocław Airport appeared in winter, however the most frequent fog and the lowest visibility were both noted in autumn. Multiannual correlation (1976-2005) confirmed the role of selected, especially low and upper anticyclonic circulation types in seasonal fog occurrence.

Conclusion
Results show that identification of circulation type during weather forecasting could improve the information about occurrence and intensity of fog.
BACKGROUND
The main focus of Eigenbrodt GmbH & Co KG is to be found in development in close cooperation with Universities, Scientific Institutions, Weather Services and Environmental Departments, followed by production itself and the marketing of meteorological instruments and environmental measurement products.

AIM
An automatic fog water collector ANES 220 was developed and now revised after field campaigns last year in order to optimize the efficiency of fog water sampling as well as to check different materials and its surfaces for the reconstruction of fog water impaction inlets.

METHOD
All construction elements of the ANES220 like fog water jet collector and its impaction units, the path of the water flow from the impaction of fog droplets to the cooling unit of the water sample as well as the air flow were revised and optimized. Chemical and mechanical properties of different materials for the fog water impaction units in combination with some special treatments of the impaction surface were analysed at the central chemical laboratory of the BTU Cottbus Senftenberg by ion chromatography, REM-EDX and contact angle measurements.

RESULTS
The sampling efficiency of the ANES220 was tested by a fog droplet generator as well as in field experiments during fog events. Signals of a PVM 100 (Particle Volume Monitor) and a visibility analyser were used to operate the sampling activity of the fog water collector ANES220. The sampling efficiency of the ANES 220 was calculated using the measured Liquid Water Content (LWC) to be between 60% and 70% in the field as well as in laboratory.

CONCLUSION
The revising of the fog water collector was successful and the ANES220 is ready to collect fog water in clean and polluted environments.
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Fog chemistry & deposition
The role of orographic cloud in the deposition of sulphur and nitrogen at upland sites: monitoring and modelling studies in Poland and the UK

Background
Orographic clouds are formed by the forced ascent over terrain and cooling of air. Particulates in the air act as cloud condensation nuclei and can result in high pollutant concentrations in cloud droplets. These cloud droplets can be washed out by rain falling from above in a process known as the ‘seeder-feeder effect’.

Aim
The aim of the study is to demonstrate through a variety of measurement techniques as well as local process modelling and national scale atmospheric transport modelling that the presence of orographic cloud leads to high levels of acid deposition in the hill areas of Poland and the UK.

Method
Methods include monitoring studies of the concentration of pollutants in cloud and rain water at hill sites as well as a process model of the seeder-feeder effect and the national scale FRAME atmospheric chemical transport model.

Results
Monitoring studies of precipitation chemistry at hill sites in the UK showed that the concentration of sulphate, nitrate and ammonium in precipitation was typically 50% higher than in lowland areas. Combined with a two-fold increase in precipitation, the seeder-feeder effect caused acid deposition to increase by a factor of up to three at elevated sites.

Incorporation of this effect into the FRAME national atmospheric transport model led to high levels of wet deposition in the hills of Snowdonia (Wales) and the Lake District (England) as well as the Sudete mountains (Poland).

Conclusion
The seeder-feeder effect leads to significant increases in both the concentration of pollutants and the amount of rainfall at upland sites frequently causing the exceedance of critical loads.
THE ROLE OF OROGRAPHIC CLOUD IN THE DEPOSITION OF SULPHUR AND NITROGEN AT UPLAND SITES: MONITORING AND MODELLING STUDIES IN POLAND AND THE UK

Background
Orographic clouds are formed by the forced ascent over terrain and cooling of air. Particulates in the air act as cloud condensation nuclei and can result in high pollutant concentrations in cloud droplets. These cloud droplets can be washed out by rain falling from above in a process known as the ‘seeder-feeder effect’.

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The seeder-feeder effect leads to significant increases in both the concentration of pollutants and the amount of rainfall at upland sites frequently causing the exceedance of critical loads.
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CLOUD DEPOSITION OF RADIONUCLIDES AT THE PUY DE DOME (PDD) MOUNTAIN, FRANCE

Background
Soils are relevant traps for airborne radionuclides after their deposition. Mountain areas, when located at cloud altitudes, receive considerable occult precipitation due to horizontal cloud interception.

Aim
The aim of the study is to assess radionuclide concentration in cloud water and cloud deposition of radionuclides that could explain an excess of soil radionuclide content.

Method
Soil cores have been taken using a drill every 80 m along the slopes of the Puy de Dôme volcano mountain (1465 m) over a total elevation of about 800 m to evaluate the radionuclide inventory. PDD is located in the central part of France and represents the first high-altitude relief facing the Atlantic Ocean, with frequent humid air masses and windy conditions. We conducted a field study on cloudwater deposition using precision balance. Weighing was performed every 20-30 minutes and required to maintain the balances under plastic hoods to avoid wind disturbances.

Results
Based on LWC monitoring, the average cloud immersion time is around 45% at the summit. Cloud water deposition flux ranged 0.3 to 10 g/min/m². Contrary to what can be observed in fogs at lowland rural areas, cloud features at high-altitude site vary rapidly and exhibit alternately cloud and no-cloud conditions especially when the cloud base altitude is close to the altitude site. This leads to fast deposition stage followed by fast evaporation stage. Multiplying the ¹³⁷Cs concentration by the cloudwater amount leads to ¹³⁷Cs deposition ranging between 0.05 to 0.215 mBq/m² per cloud event and 0.6 mBq/m² over the five-day campaign.

Conclusion
Preliminary results from a field campaign in June 2015 at the Puy de Dôme mountain indicates that cloud deposition can significantly enhance the radionuclide soil content. This is of primary importance to better assess the cloud deposition capability after a nuclear accident release to the atmosphere.
TWENTY-YEAR MEASUREMENTS OF CLOUD WATER CHEMISTRY AT MT. BAMBOO IN EAST ASIA: OVERVIEW AND CASE STUDIES

Background
Northern Taiwan frequently receives significant acid deposition during winter seasons when northeast monsoon flows originating from Asian continent prevail. In order to investigate the relative contribution of acid deposition through long-range transport, particularly from Asian continent, we have conducted a long-term experiment of cloud water chemistry at a mountain peak in very northern Taiwan. Under such a sampling condition, contamination of cloud water by local activities should be avoided. Therefore, cloud water chemistry obtained at the mountain peak can be used as a registered parameter for quantifying the contribution of regional pollutions to precipitation chemistry collected at urbans.

Aim
The aim of the study is to characterize the wintertime cloud water chemistry collected at Mt. Bamboo (~1,100 m MSL), Taiwan, for 20 years and further to investigate the impact of regional pollutions (for instance, Asian dust, biomass burning and regional haze) on cloud water chemistry.

Method
A long-term study of wintertime cloud water collection on an hourly basis for each event has been conducted at the peak of Mt. Bamboo in northern Taiwan since 1996. Passive cloud water collectors were deployed. The pH, conductivity, anions and cations of cloud water samples were analyzed. In addition to overall statistical analysis, the parameters of Acidifying Potential (AP), Neutralizing Potential (NP) and Seasalt Potential (SP) were used to characterize the cloud water chemistry. HYSPLIT backward trajectories for all samples were performed for investigating the source/receptor relationship.

Results
Our cloud water collection has been conducted for 20 years. In total, more than 150 events and 5,000 samples were obtained. Cloud water chemistry is comprehensively characterized. In general, the cloud events can be further categorized into two cloud types, which are associated with northeast monsoon flows and frontal passages. The average pH for all events ranged in 3.2-5.8. On average, the dominant ions in collected cloud water were Na\(^{+}\), Cl\(^{-}\), SO\(_4^{2-}\), NO\(_3^{-}\), and NH\(_4^{+}\). The first two sea salt ions generally can account for more than 50% of total ion concentration. Parameters AP, NP and SP were used to characterize the cloud water chemistry with respect to cloud types. The source/receptor relationship between source regions and cloud water chemistry was further studied. Results indicated that regional air pollutants can be possibly carried through clouds to northern Taiwan via the long-range transport. Two case studies of how regional pollutions (Asian dust, biomass burning and regional haze) impacted on cloud water chemistry were investigated.

Conclusion
Wintertime cloud water chemistry collected at Mt. Bamboo in northern Taiwan for 20 years indicated regional air pollutants (for instance, Asian dust, biomass burning and regional haze) can be possibly carried through clouds to downwind receptors via the longrange transport.
The study area was Japanese cedar forest over Mt. Rokko in Japan. Field observations of throughfall and stemflow were made using typical tipping bucket rain gauges under tree canopies at more than ten locations (mainly forest edge). The observation started from September 2015 and still continues. Leaf area index (LAI) and canopy height of cedar trees were also measured at each location on September 2015.

Results and discussions
In September 2015, a very high amount of fogwater deposition as 30 mm for only 6 hours was recorded from measured throughfall data, which was higher than that collected in our past field campaign at the same forest. The amount of fogwater deposition accumulated from 1 September to 31 October 2015 was 70% of rainfall amount of outside the forest. During the same period, the ratio of fogwater deposition to rainfall averaged for all locations was 40 %, which may be a typical contribution of fogwater deposition in this area. The throughfall amount correlated with some topographical parameters of elevation, curvature, and slope.

Conclusion
A large amount of fogwater deposition was observed at the edge of Japanese mountain needle-leaf forest. Further study based on long-term throughfall observation with LiDAR data is required to model the relationship between fogwater deposition and forest structure.
Cloud Chemistry Monitoring at Mt. Brocken, Germany, 1992-2009

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ABSTRACT

From October 1992 until October 2009 were carried out at the highest elevation in the northern part of Central Europe, Mt. Brocken/Harz (1142 m a.s.l.) a measurement programme which included cloud water sampling, cloud and meteorological observations and gas measurements (SO₂, O₃, NO, NO₂). From April 1993, we collected and analysed 23,842 1-hour cloud water samples using an automatic string collector. Liquid water content, cloud base and backward trajectories are available for each sample. Additional, 1676 daily rain water samples from a foot-hill site Schierke (612 a.s.l.) we collected (1992-1995 and 1999-2006).

1. INTRODUCTION

We started the mountain cloud chemistry programme on Mt. Brocken, partly together with other groups. Some key results we found, have been published earlier, such as ozone destruction within clouds (Acker et al. 1995), the changing acidity (Möller et al. 1996a, Acker et al. 1998b), the relationship between ionic content and liquid water content (Möller et al. 1996b), formation of nitro phenols in clouds (Lütke et al. 1997, 1999), occurrence of trace elements in cloud water (Plessow et al. 2001), formation and occurrence of nitrous acid in clouds (Acker et al. 2001, 2008), sulphite in clouds (Tian et al. 1999), macromolecular substances (HULIS) in clouds (Feng and Möller 2004), and the relationship between liquid water content and visibility (Chaloupecky et al. 2007, Acker et al. 2010). Here we present a brief overview of the results from the complete programme 1992-2009 concerns air pollution change, cloud physics, and cloud chemical composition.

1. EXPERIMENTAL

Several studies have shown that Mt. Brocken represents a large-scale area for air quality and cloud processing; the summit lies almost above the boundary layer. The station was equipped with an automatic weather station. Continues measurements of O₃, SO₂, NO, and NO₂ were made using commercial automatic analysers. Cloud water was collected using a passive string collector (Mohnen and Kadlec 1989) in combination with an automatic sampling unit and analysed by ion chromatography. Since June 1993 we collected cloud water with 1-h time resolution to be in coincidence with the time scale of synoptic observations (cloud type, cloud frequency, cloud base) and the typical time scale of weather changes. Liquid water content (LWC) of clouds was measured continuously by a laser diffraction technique using a Gerber Particulate Volume Monitor. Cloud base was detected by a ceilometer from the foot-hill site.
3. RESULTS

3.1 Air pollution

The specific emission (i.e. area related) before German reunification of SO₂ and dust in East Germany was by a factor of about 14 larger; almost due to coal-based power plants. In contrast, specific NOₓ and NH₃ emission were similar in East and West. However, NOₓ was emitted to about 70% through high stacks (together with SO₂ and dust) from power plants, resulting in larger NOₓ burden in higher altitudes and preferential long-range transportation. On the other side, in West Germany about 70% of NOₓ was emitted by traffic near ground in urban areas. However, it is worth to mention that the potential acidity due to acid gas emission from power plants in East Germany was largely neutralised by alkaline flue ash emissions. The more vigorous decline of dust emission comparing to SO₂ between 1989 and 1994 in East Germany led to temporarily acidity increase in rain and clouds (Möller et al. 1996a).

3.2 Cloud physics

Based on visual observation by the Weather Service, the Brocken summit is on average 50% within clouds. The preferential wind directions are between SW and NW; this sector has a much larger probability having clouds then cloud-free conditions; the situation is conversely in all other directions. Hence, cloudy air masses from south to east are unusual. There is no trend between 1992 and 2010 concerns the signal “station-in-cloud” as well as for the yearly hours of sun shine (1423±166 h). As one would expect, between both quantities exist a high correlation \( r^2 = 0.8 \). Despite large variations between the years, the cloud base increased by about 100 m (yearly mean) from 1992 until 2010. The yearly mean LWC frequency distributions are very similar and do not vary large. The LWC of 80% of all clouds (“in-station”) is within the range 10 to 400 mg m⁻³; maxima are between 1100 and 1400 mg m⁻³. The monthly means also not vary large (in mg m⁻³): May: 309±86; June: 328±58; July: 290±68; August: 292±44; September: 317±43; October: 294±46. However, LWC can vary extreme during cloud events. With increasing altitude above the cloud base, LWC increases approximately linear (from 0 to 800 mg m⁻³ from the cloud base up to 500 m in clouds) and the droplet spectrum shifts to larger droplets. Based on our ceilometer measurements, we sampled cloud water almost (about 40%) between 50 and 150 m above the cloud base; the cloud layers between 0-50 m and 150-200 m contribute each to around 15%. However, deep clouds can go down to the foot-hill site (500 m down). On the relationships between LWC and TIC (total ionic content) as well as specific ions we reported elsewhere (Möller et al. 1996b), best correlated by power functions. With decreasing LWC, in other terms, near the cloud base, TIC varies extreme due to droplet evaporation and condensation processes. Because of the dependency between LWC and ionic content, it is essential to measure LWC in cloud chemistry programmes and to construct weighted aqueous-phase concentration means.

3.3 Cloud chemical composition

Table 1 shows the annual means of cloud water chemical composition. The means are LWC weighted according to

\[ \frac{\sum_i (LWC \cdot c_i)}{\sum_i LWC} \]

LWC – liquid water content during sampling period of individual samples \( i \) (1-n), c - concentration of specific ion \( j \) in individual sample \( i \), n – total number of samples within the averaging period. In contrast to arithmetic means, weighted means are less sensible against extreme values (large c due to low LWC or polluted air). Despite large year-to-year variations, there is a significant decrease of cloud water concentration for nitrate, sulphate, ammonium and calcium, typically air pollutants. No trend is seen for sea-salt (Na, Cl, Mg) and terrestrial (K) components. However, the decrease reflects more the West German then the East German emissions trend, a more or less continues decrease for sulphate and ammonium between 1992 and 2009. When looking into more detail, the picture is similar to that of gaseous SO₂; three characteristics can be seen, a) the number and quantity of events with high sulphate concentration (> 800 µeq L⁻¹) was significant larger before the year 2000, b) a “typical background < 200 µeq L⁻¹ represents the large-scale west European sulphate in cloud water and c) extreme values (> 1800 µeq L⁻¹) are either pollution events (eastern air masses) or (very few only) events with specific microphysical characteristics. The product from LWC and
cloud-water concentration represents the residual, namely the aerosol concentration. The mean 1992-2009 amounts 2.9±3.0 µg m⁻³, which is identical with the large scale German background sulphate in particulate matter. Cloud-water sulphate at Mt. Brocken is not very different from that from the five White Mountains (1986-1989), ranging from 176 to 489 (290±124) µeq L⁻¹ and Whiteface Mt. (1994-1999), varying between 202 and 379 (298±86) µeq L⁻¹. Very low sulphate has been found in Northern Europe in clouds from northern directions (around 30 µeq L⁻¹) whereas air masses from south contained 700 µeq L⁻¹ (Ogren and Rodhe 1986). In the early 1990s, cloud-water sulphate estimated from other mountains in Europe ranges between 300 and 500 µeq L⁻¹ (Möller 2014). Not clear is the reason why nitrate not significant decreased in the 1990s (Table 1). It is not unlikely that HNO₃ replaced sulphate by nitrate in CCN in interaction with ammonia. The strong decrease of calcium, which we believed to be associated with SO₂ emissions from coal-fired power plants and finally detected as CaSO₄, can support the idea of sulphate replacement by nitrate in particulate matter.

4. CONCLUSIONS

Long-term cloud water sampling and analysing is very laborious and costly. In spite of meanwhile existing longer time-series in the world, the Brocken programme is unique for Europe, covering the significant air quality change in the early 1990s. Our monitoring programme likely also comprised the world-wide largest time-resolution of cloud water samples and availability of accompanying chemical and physical data. At the end, however, we miss information on aerosol particles (CCN, PM) and droplet size distribution (automatic sensors are available only since a few years), important parameters for climate change. Many more data can be measured during field campaigns getting deeper insights into cloud chemistry and physics despite limited time and often unwanted weather situations. Changing air quality, in our opinion, can be monitored simpler on appropriate elevated sites by total sampling (e.g. using scrubbers) of soluble species in place of droplet sampling; unalterable would be sampling of particulate matter and additional gaseous species.

5. ACKNOWLEDGEMENT

Without generous funding by the Ministry of Education and Research (former BMBF) until 1995, the station would have been remained an idea only. As anybody knows, long-term monitoring is not funded for universities; to continue the measurements after 1996, DM misused other third-funding projects and thanks the university administration to turn a blind eye. We also thank our former co-workers Renate Auel, Gisela Hager and Günther Mauersberger for her contributions to the programme. Last of all DM thanks the history (very special East German circumstances) that he decided end of 1974 to become an atmospheric chemist.

6. REFERENCES


Table 1: Annual means of LWC (in mg m⁻³) and ions (LWC weighted means in µeq L⁻¹) and pH; n number of samples (total 22.841 with LWC); 1992 event based – from 1992 1-h-samples

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mean 338 82 221 172 285 84 4 45 21 64 4.19
Major inorganic ions and pH index in fog water were determined for fog water and aerosol in the remote marine atmosphere. Some fractions of ions are derived from anthropogenic sources transported from the land and ocean surface. However, it is not well known their uptakes of aerosol to fog droplet under fog formation process. The goal of this study is to understand the fog formation from marine aerosol as cloud condensation nuclei using chemical reaction of major inorganic ions. Marine aerosol was collected with a wind sector controller avoiding contamination of exhaust from the vessel at an interval of 12 hours in order to segregate aerosol into two modes (fine: \(d < 2.5 \, \mu m\); coarse: \(d > 2.5 \, \mu m\)) during the R/V Hakuho Maru cruise, KH-04-3 (7 July – 25 August 2004). Samples of sea fog water were also collected. The pH and ion concentrations in fog water and aerosol were obtained. Non sea salt (nss-) \(SO_4^{2-}\) and \(NH_4^+\) in coarse particle could be taken into fog droplet, since their behaviors in fog water were almost the same as those in aerosol. The particulate Na+ concentrations were compared with outside and inside of the fog canopy. Sodium ion in fog droplet was derived from the sea surface in the fog canopy during the fog event. Chlorine loss reaction was caused mainly by sulfate because chemical composition in sea fog was almost the same as that in coarse particle and low nitrate concentration had less capacity for the reaction. The chlorine loss was caused mainly outside of the fog canopy, because the reaction could undergo faster in the aerosol phase than in the liquid phase (fog droplet). Coarse aerosol acts as a fog nuclide. Chlorine loss reaction suggests that nss-\(SO_4^{2-}\) of fog droplet was derived as marine aerosol from the outside of the fog canopy.
Background
Fogs/clouds can play both a physical and chemical role in the fate of atmospheric species. Fogs/clouds act as processors of atmospheric aerosol particles and trace gases by aqueous oxidation of gas phase precursors and the interaction of aerosol with atmospheric water and also cleansing of the atmosphere by scavenging and removal of atmospheric particles. In addition to playing a central role in the hydrologic cycle and influencing atmospheric radiative transfer, clouds interact with a variety of chemical species. Together with gases and particles, clouds and fogs comprise a complex multiphase system.

Aim
To understand the interaction of aerosol with fogs/clouds and fog chemical composition better, we conducted a fog sampling campaign and physical and chemical measurements of aerosol at the Baengyeong Island (Intensive Air Quality Monitoring Station), South Korea, during June – July, 2014 and 2015.

Method
Fog samples were collected using a compact version of the Caltech Active Strand Cloudwater Collector (CASCC2) and a two-stage fog/cloud water collector (sf-CASCC) that collects “small” and “large” drops. The chemical composition and physical properties of aerosol particles before, after and during fog were characterized by a high resolution time of flight aerosol mass spectrometer (HR-ToF-AMS, Aerodyne) and a Scanning Mobility Particle Sizer (SMPS, TSI).

Results
The pH of the collected fog/cloud samples was measured on-site while sample aliquots were preserved for later analyses of organic acids, total organic carbon (TOC), and major ions (Cl−, NO3−, SO4²−, Na+, NH4+, K+, Ca²⁺, and Mg²⁺) in the laboratory.

Conclusion
The presentation will provide an overview of the chemical composition of fog/cloud samples and aerosols and examine changes in particle chemical composition and microphysics by fog/cloud processing in the boundary layer.
FOG CHEMISTRY IN TWO SUBTROPICAL RAINFORESTS IN TAIWAN

Background
Fog could be an important sources of nutrient input to forest ecosystems especially in cloud forests. Although cloud forests are widespread in Taiwan, subtropical/tropical island in Southeast Asia studies on fog chemistry are limited.

Aim
To 1) examine the role of orographic effects and mountain agriculture on fog frequency, duration, and chemistry, and 2) compare and contrast fog and rain chemistry and explore the possible causes.

Method
Active fog collectors were used to automatically collect fog water and record time and duration of fog occurrence on two forests. The Fushan Experimental Forest, at approximately 700 m above sea level (asl) is located in northern Taiwan without any industry or agriculture but close to the largest city in Taiwan and on the windward side relative to northeast monsoon which may bring pollutants via long-range transport. The Chitou Experimental Forest, at approximately 1200 m asl, located in central Taiwan has substantial plantation forests at and is surrounded by mountain agriculture in central.

Results
Concrete results should be stated and discussed here. It is suggested that they constitute around 50% of the abstract volume.

Conclusion
There were approximately 200 foggy day at Fushan and more than 300 days at Chitou possibly due to differences in orographic effects. Fog was highly enriched in all measured ions (10-90 times in Fushan) compared to rainwater in both forests. Moreover, the maximum concentration of nitrate and sulfate in fog reached more than 3000 meq L\(^{-1}\) in both forests and the minimum pH was 2.76 in Fushan and 3.05 in Chitou suggesting that both forests may be under the threat of acid fog. Fushan Experimental forest had much higher concentration of all analyzed ions both in rain and fog than Chitou except ammonium likely due to it is close to the largest city in Taiwan and is more affected by long-range transport. However, the Chitou Experimental Forest had higher concentration of ammonium in both rain and fog compared to Fushan most likely reflect the influence of mountain agriculture.
Northern parts of India often experiences fog which is a visible aggregate of minute water droplets suspended in the atmosphere during the winters period (Dec, Jan. and Feb). In the foggy period, the horizontal visibility reduced up to few meter and affects the daily normal life, harming human health and completely clamping air and road transport services. In such conditions, the loading of atmospheric aerosols increased tremendously and affect visibility impairment. In view of the above, in situ and columnar measurements of aerosol optical properties (AOPs) [Aerosol optical depth (AOD), Angstrom Exponent (AE), Aerosol scattering (σscat) and absorption (σabs) coefficients and single scattering albedo (SSA)] along with soot particles (Black carbon: BC) and fine particles (PM2.5: d≤ 2.5 μm) and visibility data were continuously recorded at an urban site in Delhi, India during foggy period (Winter: December, 2011 to March, 2012). Average values of AOD, AE, σscat, σabs, and SSA for the observation period were found to be 0.79±0.26, 0.94±.19, 1027.36±797.1Mm⁻¹, 85.95±73.2Mm⁻¹ and 0.93±0.03, respectively. Higher values of σscat and σabs were occurred in December (1857 and 148Mm⁻¹), however, relatively low values of σscat (585Mm⁻¹) and σabs (44 Mm⁻¹) were occurred in March and February respectively. SSA, however, was higher in January (0.94) and lower in March (0.89). Bimodal distributions were observed with higher σscat and σabs coefficients during 0800 and 0900 hrs LT (traffic rush hours) and at 2200 and 2300 hrs LT (low boundary layer height due to nocturnal inversion conditions) and lower values during the daytime between 1500 to 1700 hrs LT, respectively. The σscat peak in the morning may be attributed to large emissions of aerosol in the traffic rush hours and production of secondary aerosols with increasing solar radiation and temperature. During the study period, σscat (mean) was 13% lower during daytime as compared to nighttime. An interesting feature was seen in monthly day and night averaged values of σscat which was 18% and 22% higher during December and January, but only ~ 4% lower during February and March; it is due to the effect of meteorology. The impact of meteorological parameters such as wind speed (WS), wind direction (WD), visibility (VIS) and mixed layer depths (MLDs) on AOPs along with fine and soot particles were studied. A clear negative correlation between atmospheric visibility with σscat (r = 0.64); σabs (-0.57) and PM2.5 (-0.56) were observed. During foggy days (VIS ≤ 1000m), the AOPs, fine and soot particles were substantially (~1.8 times) higher as compared to clear days however it was ~2.3 times higher during dense foggy days (VIS ≤ 500m). Similarly, higher (~ 2 times) AOPs and aerosol concentrations were also seen below 200m MLDs. In addition to this, ~ 4 times higher AOPs and aerosol mass concentrations were observed when WS was below 1 m/s. In view of the above results and analysis, we can say that meteorological parameters play a crucial role in the enhancement of aerosols at ground level during winter over the study area.
CLOUD AND FOG PROCESSING OF ATMOSPHERIC ORGANIC MATTER

Background
Clouds and fogs play an important role in processing chemical species in the atmosphere. Scavenging and deposition of fine particles helps cleanse the atmosphere. The uptake of soluble gases followed by aqueous reaction can increase atmospheric particulate matter concentrations.

Aim
We provide an overview of research examining processing of atmospheric organic matter by clouds/fogs. This includes measurements of fogs and clouds across the Pacific, including North America, South America, and Asia.

Method
Cloud/fog samples were collected using Caltech Active Strand Cloud Collectors and the CSU/NCAR airborne cloud collector. Total organic carbon content was measured. Sample organic composition was measured by aerosol mass spectrometer (AMS) and LC/MS. Samples were photochemically aged in the lab with hydroxyl radical.

Results
Field observations reveal efficient, but differential scavenging and deposition of carbonaceous fine particles from different source types. Observed cloud and fog TOC concentrations ranged from < 2 to > 200 ppmC. Photochemical aging of organic matter in clouds leads to increased oxidation of that material. Impacts on the amount of secondary organic aerosol (SOA) released when the cloud evaporates shift with aging extent. At earlier stages, organic matter functionalization increases SOA formation; later, aging leads to fragmentation that produces smaller, higher volatility molecules that release back to the gas phase. Oxidant competition in high TOC fog/cloud water can slow the aging process.

Conclusion
Clouds and fogs interact strongly with atmospheric organic matter, influencing its atmospheric lifetime, chemical form, and gas-particle partitioning.
From Foe to Friend: Fog Changing Nature
A Case Study of an Amazigh Community in Southwest Morocco

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Abstract: Organization Dar Si Hmad for Development, Education and Culture (DSH) is currently running one of the largest fog collection projects in Africa; 5 villages having access to drinking fog-water in the Anti-Atlas mountains of Southwest Morocco. The project launched its experimental phase in 2005 and was officially inaugurated in 2015. While today the beneficiaries consider themselves privileged at being the sole example in the country and region to benefit from this project, a very complex, volatile and unpredictable relationship to fog has characterized the decade-long construction of the project. Engaging into an anthropological interpretative reading (close-text analysis of interviews, observant-participation), of the traditional lore of the Berber Amazigh communities-beneficiaries towards fog, this paper thinks through how such a phenomenon as fog is conceived, experienced, and lived as an example of the community’s engagement with the natural world. The paper examines first the beliefs surrounding fog and how these beliefs inform norms of behavior, and then looks very closely at the very act of transformation that occurred as the project delivered on its premise. The main body of the paper addresses how the beneficiary-communities transited from a state of apprehension, dismissal of and fear from fog as a liminal, dangerous “in-between” to accepting fog and recognizing it as a valued, even prized, source of potable water. The understanding gleaned from the detailed presentation of this case, notably the analysis of the traditional lore of fog among a specific group, and then locating the nexus of transformation and how this transformation occurred, allows for a deep appreciation of how applied fog projects enable change. The conclusion being two-pronged, one proposing a pedagogical blueprint for similar applied projects in other parts of the world. And the second, is partaking in the larger conversation concerning patterns of adaptation to climate change.

I. Current Conception of Fog
As we duly celebrate the achievements of the hard sciences and their various positive effects on Humanity, we are also letting go of a world of beliefs, interpretations and connections to our natural world. One that is inhabited by feelings, by myth, by spirits and by the ineffable; one that is only read through the cultural lenses. For when science approaches a phenomenon, it offers cause-effect, hard-factual evidence of how such a phenomenon occurs, the methodology of science is to isolate the ‘event’ and determine the discreet units that make each component and each sequence, look into the causality, the elements all leading to a ‘plausible’ and scientific explanation (Latour, 1993). This way of knowing and proving has had the consequence of explaining all natural phenomena, the human Logos at work, and demystifying it all, from thunder, rain, fire or lightning. While, as a scientist myself, I believe in the power of reason and the hard sciences, I equally decry the killing of magic, the reduction of all this amazing enchantment (Bachelard, 2002 ed) to a simple superstition closing, or at best demeaning, a wealth of knowledge and a way of approaching the world that touches such essential core of how we, as humans, approach and comprehend our world.

The following paper re-constructs an experiment, one in which the world of hard science and the world of beliefs have come together through the fog-collection project in Morocco.
The conception of the natural world through local cultural determinants constructs fog as a largely negative entity. So at the level of cognition, fog is a problem; at the level of living conditions and material culture, fog causes rust to agricultural material and to one’s health; and culturally, it is conceived as a negative phenomenon. As for the physical aspect of fog, fog is humid, and it is a humidity believed to cross the boundaries of the flesh to seat itself in the marrow of the bones. It is a humidity that hurts and dis-enables one’s body. A dampness close to ailing, a state of impossible-liquidity and yet impossible-dryness, but an in-between-ness that blurs clear boundaries and contained, clear-cut states. Fog is considered more so as a nuisance, a harbinger of lack of rain and a heaviness too hard to bear, it is not held in high esteem. Because of its elusive nature, it has come to stand figuratively for another negative image as when one says “your words are worth fog,” it is as though one is saying that one’s words are void, null, and bearing no consequences. Generally, fog denotes figuratively a state of mental blur, things of equivocal nature, and of uncertainty.

When inside fog, fog is never there... but always seems to be displaced ahead of one, like a mirage deferred to some other space/time. Fog is there and not there, it is felt, seen but never grasped and always differed to some other moment and place. Fog, located and representing a sort of unending liminality is largely negative. When fog comes into its densest form, the landscape disappears behind a veil of white cloudy air that parts as one walks through it. There is only a fluff of wet-whiteness enveloping one, landmarks disappearing and time becoming all uniform, an eeriness and a sense of unreality that displaces all the references that constantly locate us temporally and spatially. It is this characteristic of eeriness when walking into a landscape of fog that endows fog with its ‘un-trust-ability’ and the creation of suspicion and a sense of loss. It has the virtue of erasing, like some magic eraser, everything surrounding one... there is only a consciousness of one being there.
and of a potential, tangible real world that has disappeared behind the veil of fog. And because of this sense of eeriness, it is believed to be an entity that is alive, populated by unknown beings, spirits of sorts, ones whose intentions and motivation remain a mystery to humans. The expression of “fog lifted” is seen as a ‘liberation,’ as a return to a state of normalcy and clarity, one in which the suspicion of some unnamed being may be lurking and perhaps polluting the water.

The Amazigh women of the region report playing a game, when fog would hang over their heads for too long, in which each village would be separated in two moiety, one called Fog, one called Heat. Both go into the mountain with a leather satchel, this open satchel being the object of the fight, and the two teams would physically feign fighting and the moment the Heat team snatches the satchel, it closes it and thus imprisons fog which, by the power of evocation, disappears the next day. For the communities, fog, is indeterminate, a sort of negation, neither rain nor dry condition. Fog is an “enemy” that needs to be defeated, held captive and when the project was launched, a skepticism and then a resistance to drinking water from a “defeated” source became for DSH a reality to reckon with.

II. Transformations, Parallels and Horizons

While the temporalities of villagers toward the water project passed through refusal, resistance, sabotage, doubt, curiosity, ambivalence, slow acceptance, and finally pride, what fog is continues being a concern for them. On the onset, the project was framed by two larger issues: developing alternative access to water in a world where water sources are increasingly compromised (so this is an experimental scientific aspect of the project); and delivering water inside households, women’s hard labor and time investment in the chore of water fetching will diminish, creating, thus, new opportunities for them to improve their living conditions (and this is more about the social science aspect of it). But this water is culturally tainted, seen as a coming out of an unpleasant, unwanted source, and also the critique of the villagers targeted both the negligible quantities, that is the yield being too insignificant to have any impact whatsoever, and the second whether this water is at all safe to drink if it has no “salts” at all.

Working in separate workshops with women and men, DSH solicited a special dowser to create a nuanced understanding of fog as a potential water-source, and also to find a way of engaging with the communities in finding a solution to what is identified as “dead water,” that is water with no mineral salts in it. For the necessity of thinking through transformations, we invited Moulay, widely known and respected in the region, who possesses a special gift for knowing, feeling and relating to water. For Moulay, just like the remaining members of the community, the water gathered out of fog is “dead and this is why you need water that is alive.” While images of “clean” and “polluted” water abound, we rarely speak of life-death of water in and of itself, but evoke them mostly for situations of either abundance or lack of water. But for Moulay, water is not only for what it services, for what it does, but it is as is an entity in itself. Dead water stands for water without minerals, that hasn’t been married (that is coupled) with the earth, with rocks, the purveyors of minerals and salt. Underground water is alive and like in the theory of the sacred, once another type of water, ‘dead’ water in this case, mixes with it, it, in its turn, becomes alive and purveyor of life. This is reminiscent of the archetypal representation of that by which the spirit of life touches even of a carrion to make it alive anew.

This understanding of the sacredness of the well-water, living water coupled with the fog water was unanimously accepted by the community as a means for relating to the fog-water differently, that is not simply as a nuisance or an unwanted resource. This reality of giving “life” to dead water, was an acceptable and extremely favorable option to everyone involved. It is as though the traditional world view gave
us fixed categories with attributions, but at the same time, there are alternatives in this construction to view the world differently, they simply need to be found.

But the reality of fog itself causing long stretches of dampness, leading to sluggishness, to rust, to mold which destroy belongings of poor communities or causing health concerns (Asthma and skin disease as clothes remain damp), and although each villager knows fully the sequencing of nature, that the fog comes and then slowly dissipates under the rays of the sun, the reality of the 142 days of fog everyday in this state of in-betweeness that has upsets the categories of wet-dry and hot-cold, continues being of concern to everyone. The impact of the project has been widely positive for all involved, women, children with the Water School, men, the community as a whole, and the immediate environment as there is community stability and better stewardship of the environment. Developing an esthetic or appreciation for fog is, however, a far-flung horizon for them. It is a source for water, a vital at that. But no beauty can be ascribed to it.

To conclude here, I’d like to write about a different approach to fog, one that sees and considers fog as a most moving and motivating experience. Let me start with the tempo of fog. It is majestic, standing on top of the mountain, it is a sea of white cotton, rolling extremely slowly, filling the space with grace and elegance. This pace of nonchalant and real slow are to be interpreted in a positive way in a world where fast-pace is de rigueur. This tempo is reminiscent of gentleness, unlike a heavy-pouring rain or a tornado, there is a caressing and care to the oncoming of fog that wraps, fills, and sits so delicately, that its touch can only be soothing.

Then the fog is temperamental, it comes when it desires to do so; at times it chooses dawn, at times at dusk, and then at others it is the setting sun. When it comes, it does so during these moments that link endings and beginnings, it comes to affirm and sustain the spirit of life. And then once inside it, enshrouded by its thickness, penetrated by its wetness, and enlivened by its presence, fog becomes a mirror for one’s naked self because it is the only reality that is visible. When in fog, there is nothing but fog as all outside references are weak or absent. Our natural connection to this natural world becomes then so evident, so potent.

What is the smell of fog? If its touch is cool, then fog smells of the sea that its tiny droplets carry, then it smells of all the natural elements it has encountered in its voyage, from shore to inland, it smells of freshness and of promise, it smells of the endless cycles it has traversed through the millennia. And then fog dissipates, both in real and a figurative speech for saying that all is clear, and surely the landscape looks clean, as though unsoiled after the careful hand of fog touches it... and fog dissipates so slowly, so majestically like when it came. Withdrawing with grace a scene it had just so nurtured with care and beauty.

Unlike heavy rain or devastating heat, fog doesn't have violent manifestation. Its motto is calm and steady, slow and peaceful, gentle and nourishing. Let us make of this an ode to fog, an ode to an element that sings the praise of care and let the magic be alive, transport us through this new phase of human-earth relation.

Consulted Works
COALE K.1, HEIM W.1, OLSON A.1, CHISWELL H.1, BYINGTON A.1, NEWMAN A.1, BONNEMA A.1, JOHNSON M.2, FERNANDEZ D.3*, WEISS-PENZIAS P.4 & PARKER C.4

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4 University of California, Santa Cruz.

DIMETHYL MERCURY IN SEA WATER: A POTENTIAL SOURCE OF MONOMETHYL MERCURY IN FOG

Background
We have observed twenty times the monomethyl mercury (MMHg) concentrations of in fog, compared to rain. Because MMHg is bioaccumulated, biota from foggy watersheds contain up to 1000 times more mercury than biota from non-foggy watersheds. Fog originates over the ocean, implicating a marine source, but fog is the vector.

Aim
The intention of this study is to determine what processes/mechanism may act to account for this pathway of monomethyl mercury from the ocean, via fog, to the terrestrial ecosystem.

Method
We carried out several cruises to quantify mercury species in several different reservoirs including plankton, marine snow, sediments, and the water column itself, from nearshore to 200 miles offshore and in cyclonic and anticyclonic mesoscale eddies.

Results
We found that cyclonic mesoscale eddies are major features of the California Current and major regions of dimethyl mercury (DMHg) evasion. This regional flux, derived by DMHg gradients and vertical eddy diffusion, far exceeds previous estimates based on physical gas evasion calculations. Although DMHg seems to be stable at high pH (8), it can demethylate to MMHg rapidly under acidic conditions found in fog and on marine aerosols. Only about 10% of the daily DMHg flux and it’s subsequent demethylation is necessary to explain the MMHg found in fog and its subsequent deposition to land.

Conclusion
We propose that DMHg evades from the surface waters, especially in regions of cyclonic eddies. Demethylation to MMHg occurs in acidic fog water, or within the acidic hydrous coating of aerosol particles. As fog drifts ashore, fog water rich in MMHg collects in the watershed on leaves and stems (wet deposition). As fog evaporates, MMHg is re-aerosolized and falls out as “dry” deposition. Fog is enriched in MMHg (relative to rain) because it forms at the surface of the ocean, in direct proximity to the source of DMHg, and to the production of marine aerosols.

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Aim

We have observed twenty times the...

Background

Current and major regions of dimethyl...

are major features of the California...

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We propose that DMHg evades from the...

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Aim

This study aims to confirm those...

Method

A total of 153 fog water samples were...

Results

The mean concentration of MMHg across all terrestrial sites for both years was 1.7 ± 2.3 ng L⁻¹, which corresponds to 6.1% MMHg as a fraction of total Hg (HgT) in fog. Five rain water samples collected with the CASCC at 3 terrestrial sites contained 0.20 ± 0.12 ng L⁻¹ of MMHg corresponding to 1.4% MMHg. Fog water samples collected at sea had a mean MMHg concentration comparable to that of rain (0.11 ± 0.16 ng L⁻¹, N = 10). MMHg concentrations at terrestrial sites varied spatially and temporally with significantly higher MMHg concentrations nearer to the coast and significantly higher concentrations in June over September. The six -site mean fluxes of MMHg and HgT were found to be 30 ± 26 ng m⁻² y⁻¹ and 546 ± 326 ng m⁻² y⁻¹, respectively.

Conclusion

The measured mercury fog flux values are 29% and 15% of the rain water flux estimated from an earlier study for MMHg and HgT, respectively. While these were lower than those published in 2012, they still represent a significant source of mercury to the terrestrial ecosystem at a time when some plants in this region depend upon summertime fog water.
Fog Water Chemical Composition in Villa María Lomas (Lima – Peru)

Franz N. García Huazo (1), (2), Wilfredo Baldeón Quispe (1)

(1) National Agrarian University – La Molina (UNALM), Lima, Peru
(2) Peruvian Center for the Resilience of Urban Socioecosystems – Urbes Center

ABSTRACT

Fog water harvesting is an alternative to get freshwater in zones where drinking water access is limited or non-existent. Nonetheless, atmospheric pollution can contaminate fog water. Fog is the principal water supply in some ecosystems in Lima called “Lomas”. In Villa María Lomas, there are contamination by a cement factory, pig farms, garbage burning and the general air pollution in Lima. Therefore, with the aim to evaluate the fog water quality in Villa María Lomas, seven Standard Fog Collectors were used to collect fog water in the study area. Fog water samples were taken once per month, from August to October 2015. Cations, anions and trace elements in water fog samples were analyzed by ICP-OES, Ion Chromatography and ICP-MS respectively. High levels of lead are found in almost all samples of water fog, exceeding the human consumption water standard values. The samples taken near the cement factory contain high levels of aluminium, arsenic, chloride, nitrate, nitrite, sulfate, iron and lead. Values of pH show that fog water is suitable for agricultural and animal drinking use, only northwest of Villa María Lomas.

1. INTRODUCTION

In some coastal hills and mountains of Peru and north of Chile, there are especial ecosystems called “Lomas”, where endemic vegetation and animals life, using fog water like the most important water supply in this kind of ecosystem. Fog quality is important for ecosystem and inhabitants who live around it. Considering the possible pollution sources in this ecosystem, the aim of this investigation is evaluate the fog water quality and determinate their suitable uses.

2. SITE DESCRIPTION

Villa María Lomas is located in the district of “Villa María del Triunfo”, in Lima, Peru. This ecosystem is one of the wettest places in Lima. Fog water is used for vegetation, animals and some inhabitants that live around this ecosystem. However, there are possible fog pollution sources in the study area. So, inhabitants that live around to Villa María Lomas burn their garbage and the fumes are mixed with fog. There are also pig farms around this Lomas that emit foul odors. Furthermore, cement factory south of Villa María Lomas could be a great source of particulate matter in fog. Finally, Lima is one of the most contaminated cities in Peru, so, air pollution could influence in fog water quality.

3. MATERIALS AND DESCRIPTION

For the study, seven fog collectors were installed in different sites in Villa María Lomas. In Figure 1 are showed the fog water sampling sites.

![Sampling sites locations](image)

Each site had a 1m² fog collector. The collector design is similar to Standard Fog Collector (SFC), proposed to Schemenuer and Cereceda (1994). Sampling sites was selected according to the conditions indicated by Furey (1998).
4. RESULTS

During the three months that fog water quality was evaluated, chemical concentration were changing during the winter of 2015. About water standard Category 1, A1, August is the month with higher concentrations in 2015. Aluminum and iron have HQ values higher than one in P1, P3 and P5, CE and nitrate in P7, arsenic in P1 and P7, nitrite in P4 and P6, sulfate in P4 and P7, lead in all samples except P1, and low pH in P5 and P6 (6.34 in both sites). In September, there were HQ values higher than one for iron from P3 and P5, and high pH in P1 and P7 (8.79 and 8.70 respectively). Finally, in October, HQ values higher than one for CE, TDS, arsenic, chlorine, nitrate and sulfate from P7 and aluminum, iron and lead from P5 (figure 2).

Fog water samples were taken from August to October in 2015; one sample per month. Cations (Na, Mg, K, Ca), anions (HCO₃⁻, F, Cl, NO₃⁻, SO₄²⁻, NO₂⁻) and trace elements (Sr, Li, SiO₂, Al, As, B, Ba, Co, Cr, Cu, Fe, Mn, Mo, Ni, Pb, S, Sb, Sn, Ti, V, Zn) were analyzed in water fog samples by ICP-OES, Ion Chromatography and ICP-MS respectively. In-situ parameters taken were electric conductivity (CE), total dissolve solids (TDS), pH and temperature.

For fog water quality evaluation, Hazard Quotient (Seal et al, 2010) was used. This quotient is the measured trace-element concentration to the chronic toxicity standard for that element. It is used to evaluate water toxicity. However, Peruvian water quality standards do not have a chronic toxicity values; so, for this research, HQ was modified, so that, this quotient is the ratio of measured elements and components of fog water to the Peruvian Water Quality Standard. So, when HQ is higher than one, indicate fog water is not suitable for the water use that the standard indicate. But this quotient is not applicable for pH, because pH has upper and lower limits.

Peruvian Water Quality Standards (D.S. 015-2015-MINAM), consider different water uses. Due to the conditions of the communities, only are considered human use (drinking water), (Category 1, A1), agricultural use (Category 3, D1) and animal drinking use (Category 3, D2). For this reason, three types of HQ index were used, one for every king of standard.

The selected sites have different contexts. “P1” is located near “12 de junio” community and the city of “Villa María del Triunfo”. “P2” is located east of “Edén del Manantial” community, but there are a separation of 200 m. of the community. “P3” is located near “Virgen de Chapi” community, and west of sampling site, there is a pig farm that emits foul odors. “P4” is the farthest sampling site from any pollution source, except for a way for which cars eventually pass, but this way is not consider like an important pollution source. “P5” is located near a second pig farm around this ecosystem. “P6” is located near “Villa Lourdes” community, east of Villa María Lomas, and this site is near the city of “Villa María del Triunfo”. Finally, “P7” is located near “Asociación Agroindustrial Llanavilla” community, the city of “Villa María del Triunfo” and it is near a cement factory that could incorporate particulate matter in fog.
For agricultural use (Figure 3), there were just problems with fluorine and pH. So, in August, HQ from fluorine was higher than one for P7, and pH was 6.34 in P3 and P5. In September, pH was higher in P1 and P7 (8.79 and 8.70 respectively). Finally, in October, HQ from fluorine was higher than one for P7, again.

![Figure 3 HQ graphics for fog water quality, consider Water Quality Standard for agricultural use (Cat. 3, D1)](image)

Figure 3 HQ graphics for fog water quality, consider Water Quality Standard for agricultural use (Cat. 3, D1)

For animal drinking use (Figure 4), HQ of all parameters were under one, but pH are lower than Water Quality Standard in August, in P3 and P5 (6.34 in both sites), and higher than this standard in September, in P1 and P7 (8.79 and 8.70 respectively). In October, there were no problems with water quality.

![Figure 4 HQ graphics for fog water quality, consider Water Quality Standard for animal drinking use (Cat. 3, D2)](image)

Figure 4 HQ graphics for fog water quality, consider Water Quality Standard for animal drinking use (Cat. 3, D2)

5. DISCUSSIONS

There are different components in fog water quality. So, along the month when fog water was evaluated, water quality had changes. August had the highest concentrations of all winter of 2015, and September had the lowest concentrations. In October, concentrations increase respect to September, but they do not reach levels of August.

In P1, P3 and P5, presence of aluminum and iron in high concentrations were common. These three sampling sites are near Villa María city or a pig farm, and the soils around these sites have lack of vegetation, so, the source of these metals could be the soil, whose particles were carried by
the wind. Lowest pH values were in P5 and P6; they could be explained by the natural atmospheric water acidity, due to CO₂ dissolution.

Otherwise, many components are higher that one in their HQ values in P7. The principal possible pollution sources are the general air pollution in Lima and the cement factory. So, arsenic, chloride, nitrate, CE, fluorine, lead, TDS and sulfate are pollutants in this site. Moreover, in September, high values of pH are registered. The sources from nitrate and sulfate could be fossil fuel combustion from traffic fumes (Yue et al., 2012) and cement factory ovens. High pH values can explain by alkaline dust particles, with presence of CaCO₃, which may come from limestone quarries of cement factory. The presence of pollutants like As, F, Cl⁻, elevated CE and TDS just in P7, mean that cement factory could influence in fog water quality. Moreover, P1 also registered high values of As and pH. It could be influence by cement factory, because P1, P7 and cement factory are south of Villa Maria Lomas.

Finally, lead was present with high values in almost all sampling places in August, except P1, and it was present in P5 in October. In this case, the source of Pb could be the general air pollution in Lima.

6. CONCLUSION

Fog water quality in Villa Maria Lomas changes in time and space in 2015. Higher concentrations of components were registered in August, then, decreased in September and finally, increase in October, but the concentrations in this month do not reach the levels in August. Furthermore, fog water quality is different in each sampling point in this ecosystem.

According to the results, any site in Villa Maria Lomas is appropriate for human consumption, according to Peruvian Water Quality Standards, category 1, A1 (D.S. 015-2015-MINAM), because in almost all site are high concentrations of lead, except southwest of Villa María Lomas (near “12 de junio” community), but this site have elevated concentrations of aluminum, arsenic and iron. This condition was present just in August, but, due to the changing atmospheric conditions in this ecosystem, is convenient prevent contaminated fog water events.

According to the same standard, category 3, D1 and D2, fog water collected northwest of Villa María Lomas (“San Gabriel – Paraíso”) is suitable for agricultural and animal drinking use. East Villa María Lomas (“Nueva Esperanza” and “Manchay”), in some evaluations, registered pH values under 6.5, values under lower limit of standard. South of Villa María Lomas (around “Cercado de Villa María” and “Asociación Agroindustrial Llanavilla” community), registered pH values over 8.5, values over upper limit of standard.

Otherwise, the most contaminated site in the study area is around “Asociación Agroindustrial Llanavilla” community, due to general air pollution of Lima and the emissions of cement factory, located south of this site. In some evaluations, high concentrations of arsenic, fluorine, chlorine, lead, nitrate, sulfate, elevated electric conductivity and pH were found.

7. ACKNOWLEDGEMENTS

This work was funded by National Agrarian University – La Molina (UNALM), in Lima, Peru. Special thanks are due to Peruvian Center for the Resilience of Urban Socioecosystems – Urbes Center, for their collaboration during develop of field work.

8. REFERENCES


THE CONTRIBUTION OF FOG TO NITROGEN DEPOSITION: ESTIMATION OF SPATIAL PATTERN BASED ON DATA-DRIVEN GEOSTATISTICAL MODEL

Background
Nitrogen has an important role in the biogeochemistry of forests. The contribution of fog to deposition is often neglected due to the lack of measured data on fog chemistry, though it might be important, particularly in mountain areas.

Aim
The aim of the study was to estimate the contribution of fog to nitrogen deposition over the Czech forests.

Method
The fog contribution was estimated using the data-driven geostatistical model. We used the difference in inorganic nitrogen (NH₄⁺ and NO₃⁻) measured routinely in throughfall and wet only samples at 26 sites across the Czech Republic.

Results
Our results indicated that fog contribution to nitrogen deposition was 0.25–1.0 g N m⁻² yr⁻¹ over 85% of forested area. The independent data for model validation were scarce: measurements only from four mountain sites at the borderline area were available and these were used for comparison with model results. Model results were systematically lower than measured data.

Conclusion
Not accounting for fog deposition resulted in underestimation of atmospheric deposition of nitrogen. In spite of numerous uncertainties, the presented model can be used as a surrogate of fog contribution to nitrogen deposition making the spatial pattern over one country more complete.
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INTER-ANNUAL VARIATION OF HUMIC-LIKE SUBSTANCES CONCENTRATION IN CLOUD WATERS AND AEROSOLS AT THE SUMMIT OF MT. FUJI

Background
Humic-like substances (HULIS) are the major components of the water soluble organic carbon (WSOC) in the atmosphere, which have impacts on climate change and contaminants transport. However, their behavior and source remain largely unknown. Moreover, quantitative data in Japan are limited.

Aim
To elucidate the background concentration level in Japan, we measured HULIS concentration at the top of Mt. Fuji at free troposphere.

Method
Observations were conducted in July and August in 2006 and 2014 during the summer observation campaign period at the Mt. Fuji Research Station located at the summit (3776 m a.s.l.). Cloud water and PM2.5/SPM were collected by a passive water sampler and high volume air sampler, respectively. Concentration of soluble HULIS in cloud water and PM2.5/SPM were determined using DEAE-UV method (Yamanokoshi et al. 2014).

Results
The average concentration of HULIS in aerosols was 0.204 μg/m$^3$ (Fulvic acids, 0.172 μg/m$^3$; Humic acids, 0.0134 μg/m$^3$), which was on the same level as Mt. Sonnblick located on the free troposphere in Europe (Feczko et al., 2007). The average concentration of HULIS in cloud water is 0.176 mg/L (Fulvic acids, 0.131 mg/L; Humic acids, 0.045 mg/L). In diurnal variation, the HULIS concentration increased when the air mass came from the Continent, along with the air pollutants. This is the first report on the long-term observation of HULIS concentration in the free troposphere over Japan.
FOGWATER CHEMICAL COMPOSITION AT AILAOSHAN MOUNTAIN, YUNNAN PROVINCE, SW CHINA

Background
The Ailaoshan Natural Reserve in the Yunnan Province, SW China, is a mountainous region with major valleys and ridges in NW-SE orientation and numerous side valleys oriented in SW-NE direction. The Ailaoshan ecological research site is located at 24.54062° N 101.02811° E, 2476 m above sea level. There are two major monsoon seasons with winds from the SW during the wet season from May to October, and a drier and cooler season with winds from the SE from November to April. The wind direction at the site is from SW throughout the year due to channeling of the flow within the valley. Fog occurs frequently during the year with a higher fog frequency during the summer than during the winter season.

Aim
The aim of this study is to provide first data on fog chemistry at this rather remote site in mountainous SW China. It is a preliminary study that may lay the basis for further studies on fog chemistry throughout the year.

Method
We employed an active fog collector of the CASCC style that was activated whenever the horizontal visibility was below 1000 m. We collect fog samples from December 2015 to March 2016 with a time resolution between 1 and 5 hours. The samples are analyzed for pH, electric conductivity and major inorganic cations and anions.

Result
Preliminary results indicate that the air masses arriving the site had travelled over SW China, Vietnam, and Thailand before arriving at the site. The fog water was rather acidic (pH’s as low as 3.6) for most samples, although high pH’s (up to over 5.0) also occurred. Further analysis of the composition of the fog will be conducted together with an analysis of air mass back trajectories.

Conclusion
Acidic fog was found at the Ailaoshan research site (Yunnan Province) during the dry winter monsoon season. It is suggested that a perennial fog collection project should be started that covers all seasons and includes systematic rain collection for chemical analysis as well.
THE INFLUENCE OF MAINLAND CHINA EMISSIONS ON CLOUD WATER CHEMISTRY IN NORTHERN TAIWAN

Background
Mainland China as a country is characterized by high economic growth rates since 2000. High emissions of air pollutants not just lead to a very intense period of haze in the Jing-Jin-Ji (JJJ) area especially in winter and spring since 2007, but also carried through clouds to downwind receptors via long-range transport by northeast monsoon. Thus, northern Taiwan frequently receives significant acid deposition during the winter to spring season. To investigate the influence of Mainland China emissions on cloud water chemistry in northern Taiwan, we collect cloud water in the northern-most tip of Taiwan at a mountain site.

Aim
The aim of the study is to investigate the influence of long-range pollutants transport from Mainland China to cloud water chemistry as collected at Mt. Bamboo in winter, and to understand the composition of cloud water when the arriving air mass had passed over different source regions in SE Asia including the industrialized areas of mainland China.

Method
During the months of January and February of the years 2011-2013, cloud water was collected at Mt. Bamboo, Taiwan. The site (25.183 N, 121.530 E) is located at the northernmost tip of Taiwan at 1103 m above mean sea level. A passive string-collector was employed to collect cloud water on an hourly basis whenever cloud occurred. The collected cloud water was analyzed for major ion concentrations, pH and conductivity. A total of 573, 521, and 263 samples were collected during 2011, 2012, and 2013, respectively. Also, the HYSPLIT backward trajectories are used to identify the source regions of pollutants.

Results
In the winter time, although the air masses associated with fog were advected from the North throughout, the chemical composition varied largely. The frequency count of the pH's of cloud water samples collected in 2011 shows a bimodal distribution with a maximum at pH ≈ 3.6 and another maximum at pH ≈ 4.9. While the latter represents pristine air masses with very low levels of ionic concentrations, the former air masses were in contact with surface air over Mainland China and apparently picked up pollutants during their travel over land. Air mass backward trajectories are used to identify the source regions of pollutants. Most analyzed ions showed increased concentrations whenever the pH was low. This includes not only the anions of acids such as non-sea-salt sulfate and nitrate, but also ammonium, which is otherwise known as a neutralizer. The concentration levels of all ions covary. Meanwhile, when heavy haze occurs in northern China, extremely low pH's (as low as 2.87) may occur.

Conclusion
Air mass had travelled over the industrialized and densely populated regions of northern and eastern China before arrival at the site was associated with low pH values and high level of ion concentrations. Another group of air masses, which travelled much more time over the East China Sea before arriving Taiwan and makes up over 80 % of our data set, leads to extremely clean fog water with high pH and very low concentrations of ions. This indicates the cloud water in northern Taiwan in winter is, at times, significantly affected by the Mainland China Emissions.
OBSERVATION OF CLOUD WATER CHEMISTRY IN THE FREE TROPOSPHERE USING MT. FUJI

Background
Mt. Fuji is an isolated peak and its top is located at the free troposphere, so we could observe background concentration of various chemicals in the ambient air and in cloud water over Japan, background pollution due to the long-range transportation from Asian Continent to Japan, and aerosol-gas-cloud interaction.

Aim
To make clear cloud water chemistry in the free troposphere, we studied acidic substances and trace metals at the top of Mt. Fuji.

Method
Observations were conducted in July and August from 2013 to 2015 at the Mt. Fuji Research Station located at the summit (3776 m a.s.l.). Cloud water samples were manually collected by a passive water sampler. Concentrations of major inorganic ions, soluble and insoluble trace metals in cloud water were determined by ion chromatography and ICP-MS, respectively.

Results
Volume weighted mean (VWM) pH of cloud water at the top was 4.10 (n=22), 4.55 (n=59), and 5.05 (n=33) from 2013 to 2015, respectively. The average of NO$_3^-$/nss SO$_4^{2-}$ equivalent ratio (N/S ratio) of cloud water at the top was 0.924 in 2013, 0.860 in 2014, and 0.868 in 2015, respectively. Backward trajectory analysis showed that cloud water at the top of Mt. Fuji was acidified with the decrease of NO$_3^-$/nss SO$_4^{2-}$ and the increase of soluble As and Se when air mass comes from the Continent.
FEATURES OF FE-CONTAINING PARTICLES IN THE ATMOSPHERE AND IN CLOUD WATER AT THE TOP OF MT. FUJI

Background
Iron (Fe) in the aerosols have very important role for the ocean biogeochemistry and climate. They could change their solubility by cloud processing during long-range transport.

Aim
To investigate the Fe solubility of aerosols through cloud processing, we compared the features of particulate matters in the ambient air and in cloud water.

Method
We conducted summer observational campaign at the top of Mt. Fuji, which is located in the free troposphere. We collected aerosol particles and cloud water. Aerosol particles and particulate matter in cloud water were analyzed individually by SEM-EDX or TEM-EDX. Chemicals in cloud water were also analyzed by ion chromatography and ICP-MS.

Results
The geometric mean diameters of Fe-containing aerosol particles in 2011 (2.2 μm) and 2012 (2.7 μm) were larger than that of the total analyzed particles (2.0 and 2.3 μm), respectively. The peak size range of Fe-containing aerosol particles, which collected in August 2013, was 2-3 μm in the Maritime air samples and were 2-3 and 6-7 μm in the Continental air samples. This indicates that the Fe-containing coarse particles were contained in the continental air.
Particulate matters in cloud water mainly contained Al, Si, and Fe. In this presentation, we will also discuss the comparison between individual Fe-containing particles in the ambient air and in cloud water with the change of cloud water chemistry.
OBSERVATION OF VOLATILE ORGANIC COMPOUNDS IN THE AMBIENT AIR AND IN CLOUD WATER IN THE FREE TROPOSPHERE OVER JAPAN

Background
Volatile organic compounds (VOCs) are well known to be responsible for the formation of ozone and secondary particles in the troposphere and it is very important to understand the atmospheric behavior of VOCs. However, limited information on the behavior of VOCs in the free troposphere is available although there are many reports on measurement of VOCs in the ambient air at the ground level.

Aim
To elucidate the concentration, sources, and in-cloud scavenging of VOCs in the free troposphere, we measured the concentration of VOCs in the ambient air and in cloud water at the top of Mt. Fuji.

Method
Simultaneous sampling of VOCs in the air as well as cloud water was performed at the foot of Mt. Fuji (1284 m a.s.l.) and at the top of Mt. Fuji (3776 m a.s.l.) in summer from 2012 to 2014. VOCs in the air and in cloud water were analyzed by a thermal desorption-GC/MS and HS-SPME-GCMS, respectively.

Results
Seventeen chlorinated hydrocarbons (CHs), five monocyclic aromatic hydrocarbons (MAHs), three dicyclic hydrocarbons (DAHs), and six biogenic volatile organic compounds (BVOCs) in the ambient air and in cloud water were measured. Among the measured VOCs, MAHs were abundant, especially toluene contributed to 35% among VOCs in cloud water. The concentration of toluene in cloud water was higher than the Henry’s law prediction, and increased with the decrease of total inorganic ion concentration and the increase of humic-like substances (HULIS). We will discuss the long-range transport from Asian Continent and the subsequent in-cloud scavenging of VOCs in the free troposphere over Japan.

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IN-CLOUD SCAVENGING OF AIRBORNE POLYCYCLIC AROMATIC HYDROCARBONS AT THE TOP OF MT. FUJI IN SUMMER 2015

BACKGROUND
In the last decade, the concentrations of polycyclic aromatic hydrocarbons in the ambient air, especially in the particulate matter have been studied deeply for several reasons such as tracking the sources, understanding their dynamics, and assessing their toxicity to human health. The top of Mt. Fuji gives access to the free troposphere and allows to observe the background concentrations and the long-range transport of PAHs.

AIM
The aim of this study is to give a contribution to the study of the dynamics of PAHs by showing data about their deposition in cloud droplets.

METHOD
Between the 19th of July 2015 and the 20th of August 2015, a passive type cloud water collector, which was made by tefron®, was installed at Mt. Fuji research station at an altitude of 3776 m. Samples were collected every two hours on an event basis and stored in a 20 ml amber glass vial at low temperature (4°C). PAHs in cloud water and in the particulate phase were analyzed by PAHs-fld.

RESULTS
A total number of 33 events were analyzed. The backward trajectory, with a time resolution of 72 hours, revealed that in 40% of the cases the air mass was coming from the Pacific Ocean, in the other 30% from the south Asian continent and in the remaining 30% of the events it was not possible to classify the air mass origin. Before analysis particulate phase in cloud water was separated from dissolved phase by filtration with paper filter (cut off 0.45 μm). Acenaphthene and fluorene were detected in all the samples both in the particulate and dissolved phase except for four events where no PAHs were detected in the dissolved phase. On average the total concentration of PAHs in the particulate phase appeared to be higher compared to the dissolved phase (respectively 2.96 nmol/l and 2.17 nmol/l; n=29, n=33). Other than that, no clear correlation was found between the dissolved phase and particulate phase.

CONCLUSION
PAHs were successfully detected inside cloud water and in-cloud scavenging of PAHs was important even in the free troposphere.
DEPRESS OF OZONE BUILDUP BY DEW FORMATION

Background
Dew formation affects ozone concentration. Dew absorbs gaseous nitrous acid which is a precursor of OH radicals and depresses ozone buildup. This study shows experimental observation of ozone depression by dew.

Aim
To clarify the important role of dew on the atmospheric chemistry.

Method
The ambient air was divided in two lines. In one line, absorption tube of nitrous acid or formaldehyde was connected and in another line no absorption line was connected. Then, the two sample air were passed through the chambers including water droplets. After sunrise, two chambers were exposed by natural sunlight. Before sunrise and after several hours after sunrise, ozone concentrations were measured.

Results
Dew absorbs gaseous nitrous acid in the atmosphere and nitrite is forms in the droplets. Gaseous ammonia is also absorbed in dew efficiently. Concentrations of nitrite and ammonium are usually very high in Sakai, Japan. When dew dies after sunrise, these concentrations become very high and nitrite and ammonium react to form nitrogen and water. Gaseous nitrous acid plays a very important role and is a main source of OH radicals by photo-irradiation. OH is a key compound for ozone buildup. Therefore, when nitrous acid in the atmosphere decreases, ozone formation is depressed. In the last fog conference, we showed the depression of ozone by forming dew using monitoring data and experimental results. This time, we will present an ozone depression by passing through sodium carbonate denuder to remove HONO in the ambient air. The ozone concentration was depressed very much by removal of HONO.

Conclusion
Dew absorbs HONO very efficiently at night and depresses ozone increase. Dew plays a very important role in the atmospheric chemistry.
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Dew absorbs HONO very efficiently at night and depresses ozone increase. Dew plays a very important role in the atmospheric chemistry.
Background
There is a shortage of hydroperoxide data in the high-altitude atmosphere over East Asian countries including Japan.

Aim
The aim of this study is to measure hydroperoxide in the high-altitude atmosphere by a HPLC system a helicopter and the potential capacity for oxidation of SO₂ over a rural site in Japan is discussed.

Method
Measurements of the concentrations of hydroperoxides, O₃, SO₂ and NOₓ* over Imizu City, Toyama, Japan were performed using a helicopter. The concentrations of hydroperoxides were analyzed by a HPLC system within 5-10 minutes after the sampling.

Results
The H₂O₂ concentration was lowest at the surface and highest concentration was detected in the upper boundary layer. The MHP was also higher in the high-altitude atmosphere. Significantly high concentrations of hydroperoxides were observed when air pollutants might have been transported from China in summer. In summer and early autumn the concentration of H₂O₂ was higher than that of SO₂ above 4,000 ft. (about 1,200 m) where potential capacity of SO₂ oxidation in the aqueous phase is large. High concentrations of hydroperoxides (> 50-100 μM) in fog water have been observed frequently in summer or early autumn at Mt. Tateyama located about 50 km east from Imizu City.

Conclusion
A helicopter is useful for measurements of hydroperoxides in the high-altitude atmosphere by a HPLC system equipped in a laboratory.
Soluble inorganic ions in fog water collected over New Delhi, India and their buffering capacities.

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ABSTRACT

Fog is an inconsistent atmospheric phenomenon with spatio-temporal variability and has significant effect on economy, environment and human health. To understand the chemical processes, pollution sources through characterisation of fog water in an urban environment of New Delhi, twenty fog events were collected using Caltech Active Strand Cloudwater Collector2 during winters of 2011-13 at a receptor site in New Delhi and analyzed for pH and major soluble inorganic ions using IC. Fog water was alkaline (pH=6.25±0.23) in comparison to the natural rainwater pH of 5.6. On average basis, ammonium was the abundant ionic species followed by sulfate, calcium, and nitrate. Acidity, caused by sulphate and nitrate, was neutralized by ammonium and calcium ions. The agricultural practices and vehicular emissions contributed ammonia and nitrogen oxides, coal burning added sulphate whereas the locally re-suspended dust was major source of calcium and magnesium. The marine contributions via western disturbances and the plastic burnings contributed chloride. The sum of sulfate, nitrate and ammonium measured herein were higher compared to the majority of radiation and precipitation fogs studied worldwide although the relative percentage contributions of individual ion to total sum of ions are similar to those observed by others. Theoretically calculated and experimentally measured buffering capacities were different. Unexplained buffering, a measure of the extra H+ concentration which must be added to the sample to protonate the unknown buffering agents in fog water while lowering the pH to 5, ranged from 846-191 μM in the analyzed samples. Both, gaseous species and aerosols influence fog chemistry in the region. It is suggested that either different compounds with different pKa values or one compound containing a different functional groups with varying pKa's are responsible for internal buffering.

1. INTRODUCTION

Fog water plays an important role in visibility impairment, cycling of chemical species, scavenging of particles and soluble gases or inorganic and organic compounds (Collett et al., 2008). Fog reduces the number of hours of sunshine and daytime temperature and reduces transpiration and causes plant water deficit. Fog persistence does have serious negative health effects, especially on children, old people, and patients with respiratory diseases.

Fog chemistry is a cumulative outcome of multiphase chemical interactions. Fog droplets have generally more concentration of pollutants than rain as fog is a near surfaced phenomenon within the planetary boundary layer. The relevance of studies on fog is specific to the area under study, its geographical location and temporal variables like meteorological parameters, level of pollutants, duration of study. Delhi experiences dense fog due to high amount of aerosol, which acts as condensation nuclei, and near zero temperature conditions during peak winters. The excessive burning of coal, wood and fossil fuel by people for heating purposes further worsen the situation. The visibility reduces significantly and brings life and transportation to a halt. Fog contains anions and cations derived from strong and weak acids and bases and has tendency to resist the pH changes (Collett et al, 1999). In addition to normal base neutralization of acidity, fog water has internal buffering capacity. Scientific investigations made on chemical characterization and internal buffering capacity of fog over Delhi and other parts of country from time to time remain limited.

2. METHODOLOGY

A total of 20 fog samples were collected between 6 PM and 8 AM on different days in winter seasons of 2011–2013 at a height of nearly 15 m from ground at the roof top of SES, JNU, New Delhi using the CASC2 in 50 ml plastic bottle. Rainwater samples of the intermittent rain event during the winter time fog sampling were also collected for comparison purpose. pH, EC, and total dissolved solid were measured immediately after sample collection. After filtration through 0.45 μm filters, the bulk samples were divided into two aliquots. One part was acidified with nitric acid
acidity by Ca\(^{2+}\), NH\(_4\) in Delhi indicate the effective neutralization of 2011) and (average pH= 6.25; range: 5.87 – 6.53, Year 2013). pH of fog water samples decreases in sequential samples collected on the same night. The alkaline nature of fog water irrespective large contribution of acid precursor gases SO\(_x\) and NO\(_x\) from thermal power plants and vehicular emissions in Delhi indicate the effective neutralization of acidity by Ca\(^{2+}\), NH\(_4\)\(^+\) and Mg\(^{2+}\) ions.

### 3. pH VARIATIONS

With reference to the natural rain pH being 5.6, most of the fog water samples were alkaline in nature (average pH= 6.25; range: 6.0–6.46, Year 2011) and (average pH= 6.25; range: 5.87 – 6.53, Year 2013). pH of fog water samples decreases in sequential samples collected on the same night. The alkaline nature of fog water irrespective large contribution of acid precursor gases SO\(_x\) and NO\(_x\) from thermal power plants and vehicular emissions in Delhi indicate the effective neutralization of acidity by Ca\(^{2+}\), NH\(_4\)\(^+\) and Mg\(^{2+}\) ions.

### 4. IONIC COMPOSITION OF FOG WATER

The general order of abundance of cation in fog water sample is NH\(_4\)\(^+\)>Ca\(^{2+}\)>Na\(^+\)-Mg\(^{2+}\)>K\(^+\). The average percentage contributions of these cations are shown graphically in pie chart in figure 1(a). Large NH\(_4\)\(^+\) emission in the northern India, from fertilizer applications, biomass burning and animal breeding human and animal excretion could be possible source of high NH\(_4\)\(^+\). The Ca\(^{2+}\) and Mg\(^{2+}\) are crustal derivatives and burning of wood and dry leaves may contribute to potassium. Na\(^+\) could have marine source via western disturbance.

Among the anions, SO\(_4\)\(^{2-}\) ion dominates in fog on account of large emission of its precursor gas, i.e., SO\(_2\) from two thermal power plants located around the sampling site. The oxidation could have been enhanced due to presence of soluble Fe (III) and Mn (II) in fog water in alkaline pH range as has also been recorded by Collett et al., (1999). Natural source of chloride is sea salt transported via western disturbance. Source of fluoride ions in fog samples may be attributed to the large number of brick kilns around Delhi. Nitrate in all samples shows that enough NO is released from vehicular emissions in Delhi. The light mediated oxidation of NO to NO\(_2\) and NO\(_3\) is the major contributor of nitrate.

Although concentrations of NO\(_2\) were lower than NH\(_4\)\(^+\) and NO\(_3\) but it is dominant precursor of photochemically produced hydroxyl radical in radiation fog waters. The overall average composition of bulk fog water of all three years of sampling is depicted in figure1(c). NH\(_4\) followed by SO\(_4\)\(^{2-}\)Cl and Ca\(^{2+}\) contribute nearly 84% of the analysed soluble ionic content. Nitrate contributed only 8%. It could be linked to cleaner CNG fuel used in vehicles and more stringent pollution control rules in vehicles in Delhi.

### 5. YEAR WISE VARIATIONS

The yearly averaged ionic concentration of fog samples with standard deviation is shown graphically in figure 2. The contributions of individual ion to the bulk ionic composition of fog water collected during each year is depicted in figure 3 a, b and c for 2011, 2012, 2013 respectively. The NH\(_4\)\(^+\) and SO\(_4\)\(^{2-}\) ions were dominant cation and anion, respectively, in all three year’s fog samples. The ionic concentrations show a decreasing trend in the samples collected in 2011 to 2013, more so for the samples collected in 2013 compared to other two years, the percentage contributions also show similar trend. The larger standard deviations indicate that ionic composition of fog water varies with in a particular year of sampling, however, the variations are limited in 2013 just as the concentrations.

Most dominant is reduction in contribution of Cl\(^-\) from 20 and 24 % in 2011 to 12% in 2013 and increment in nitrate from 7% to 13% in 2013.

Among cations, Ca\(^{2+}\) shows an increase whereas NH\(_4\)\(^+\) shows a decrease from 2011-2013. SO\(_4\)\(^{2-}\) contributions remain same. It can be understood that the chemical species contributed by point and stable source has shown no changes through years whereas the intermittent sources, meteorological parameters and other day to day variations resulted in changes of chemical species. Cl\(^-\) dominantly come from marine sources (western disturbances), NH\(_4\)\(^+\) come from live stock and agriculture fields and Ca\(^{2+}\) through wind assisted aerosols; all these phenomenon are highly variable on seasonal, and yearly basis and have resulted in yearly variations in ionic composition of bulk fog water.

### 6. SO\(_4\)\(^{2-}\)/NO\(_3\)\(^-\) RATIO

The higher values of SO\(_4\)\(^{2-}\)/NO\(_3\)\(^-\) (2.54 for fog water and 2.11 for rain water samples) indicated that the SO\(_4\)\(^{2-}\) emissions dominate over NO\(_3\) in the study area. Coal burnings in thermal power plants located in and around Delhi and vehicular emissions are the possible reasons for such high ratios. Relative contribution of SO\(_4\)\(^{2-}\) and NO\(_3\) towards the acidification was computed using the ratio (SO\(_4\)\(^{2-}\)/[SO\(_4\)\(^{2-}\)+NO\(_3\)\(^-\)]) and (NO\(_3\)/[SO\(_4\)\(^{2-}\)+ NO\(_3\)\(^-\)]),
respectively. The contribution of H₂SO₄ in rain water samples was found as 65% and that of HNO₃ is 35% whereas in case of fog water it is 83% and 27%, respectively.

7. NEUTRALIZATION FACTOR (NF)

The NF is calculated using an empirical formula, NFₓ = [X/SO₄²⁻+NO₃⁻] where X is the cation for which NF is to be calculated. The strength of neutralization decreases in the order NH₄⁺ > Ca²⁺ and Mg²⁺ for all fog water and rain water samples but the NF values of three ions are high in fog samples compared to rain water. The trend remains similar to Ali et al., (2004) but the NF value of individual cation is significantly higher compared to previous studies. This could be related to higher emissions of cations or lowering of SO₄²⁻ and NO₃⁻. We suggest both the possibilities could be true as SO₄²⁻ and NO₃⁻ emissions have decreased since 2001-2002 due to change in the fuel nature from Diesel to CNG and implication of stringent emission norms in the capital city. Simultaneously, Delhi has seen phenomenal growth during 2011-2013 in the infrastructural related construction activities which are potential source of Ca²⁺ and Mg²⁺ rich particles in the atmosphere. Based on the above, it is revealed that the emissions of cation rich dust from construction activities and NH₃ emissions from agricultural practices have increased substantially during the current decade in Delhi.

8. INTERNAL ACID BUFFERING CAPACITY DETERMINATION

The buffering intensity, β, given by the equation:

\[ \beta = \frac{dB}{d\text{pH}} = -\frac{dA}{d\text{pH}} \]

for an acid titration of a basic sample was computed for selected fog samples (Collett et al., 1999). The theoretical buffering curves was computed and compared with measured buffering curves constructed from acid titration data. Buffering from bicarbonate is dominant with a peak at 6.4. The theoretical and measured buffering curves are quite close to one another, so that a difference curve (measured minus theoretical buffering) is close to zero implying that buffering is nearly accounted for by species normally considered as important buffers in the fog, including bicarbonate and ammonia. But in case of other samples, the measured buffering curves exhibit much more buffering than the theoretical calculated using HCO₃⁻ and NH₄⁺. The difference between the observed and theoretical curves is large and occurs over a pH range from 4 to 7. The difference curves exhibit multiple peaks indicating the presence of additional buffering species in fog water.

The amount of buffering present in the four fog samples, we integrated the area under the unexplained buffering curve from the start of the titration down to pH 5. The integrated area (in µM units) is a measure of the extra H⁺ concentration which must be added to the sample to protonate the unknown buffering agents while lowering the fog sample pH to 5. The amount of unexplained buffering ranges from a high of 846 µM in to a low of 191 µM in fog sample. The organic species such as acetate, formate and formaldehyde and humic material and dicarboxylic could contribute to the unexplained buffering in urban fog.

**Figure 1.** Average Percent contributions of individual ions to the (A) total cationic, (B) total anionic and (C) total ionic composition of fog water collected over three consecutive years.
9. CONCLUSION

All the fog water samples of three years were alkaline in nature indicating role of Ca\(^{2+}\) and ammonium ion in effective neutralization of acidity irrespective of high emissions of acid forming nitrogen and sulphur oxides. The fog water show noticeable intra and inter year variations in ionic compositions. NH\(_4^+\) followed by SO\(_4^{2-}\)~Cl\(^-\) and Ca\(^{2+}\) are dominant ions that contribute nearly 84\% of the analysed soluble ionic content in fog water. The SO\(_4^{2-}\) emissions dominates over NO\(_3^-\) in the study area and the role of SO\(_4^{2-}\) in determining the acidity of the fog samples. The strength of neutralization decreases in the order NH\(_4^+ > \text{Ca}^{2+} > \text{Mg}^{2+}\) for all studied fog water and rain water samples. Fog water has sufficient amount of internal buffering in addition to external buffering. The compounds with different pKa's, or one compound containing a variety of functional groups possessing a variety of pKa's, are likely responsible for additional internal buffering.

10. ACKNOWLEDGEMENTS:

SY acknowledge the grants received from JNU-DST-PURSE and utilized in this work. The authors are grateful to Prof Jeffrey Colett Jr for helping us, landing the fog collector, allow us to fabricate it at JNU and providing the algorithm for calculations of internal buffering capacities.

11. REFERENCES


Figure 2. Plot of average concentration of individual ion in the bulk fog water samples collected over Delhi during three years.

Figure 3. Percent contribution of individual ions to the total ionic composition of fog water of (a) 2011, (b) 2012 and (c) 2013.

CONCLUSION

All the fog water samples of three years were alkaline in nature indicating role of Ca$^{2+}$ and ammonium ion in effective neutralization of acidity irrespective of high emissions of acid forming nitrogen and sulphur oxides. The fog water shows noticeable intra and inter-year variations in ionic compositions. NH$_4^+$ followed by SO$_4^{2-} \sim$Cl$^-$ and Ca$^{2+}$ are dominant ions that contribute nearly 84% of the analysed soluble ionic content in fog water. The SO$_4^{2-}$ emissions dominates over NO$_3^-$ in the study area and the role of SO$_4^{2-}$ in determining the acidity of the fog samples. The strength of neutralization decreases in the order NH$_4^+$ > Ca$^{2+}$ and Mg$^{2+}$ for all studied fog water and rain water samples. Fog water has sufficient amount of internal buffering in addition to external buffering. The compounds with different pKa's, or one compound containing a variety of functional groups possessing a variety of pKa's, are likely responsible for additional internal buffering.

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REFERENCES


Na$^+$ 2%
NH$_4^+$ 32%
K$^+$ 2%
Ca$^{2+}$ 15%
Mg$^{2+}$ 1%
F$^-$ 1%
Cl$^-$ 20%
NO$_3^-$ 7%
SO$_4^{2-}$ 20%

Na$^+$ 3%
NH$_4^+$ 22%
K$^+$ 2%
Ca$^{2+}$ 19%
Mg$^{2+}$ 2%
F$^-$ 2%
Cl$^-$ 24%
NO$_3^-$ 7%
SO$_4^{2-}$ 19%

Na$^+$ 1%
NH$_4^+$ 23%
K$^+$ 2%
Ca$^{2+}$ 21%
Mg$^{2+}$ 2%
F$^-$ 2%
Cl$^-$ 12%
NO$_3^-$ 13%
SO$_4^{2-}$ 23%
NO$_2^-$ 1%

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ABSTRACT

Fog collection was introduced to Nepal in 1997 through the efforts of individuals from Canada and Chile, many of whom went on to form the Canadian charity FogQuest in 2000. The initial work included the construction of the first Standard Fog Collectors (SFCs) (Schemenauer, R.S. and P. Cereceda, 1994) (Fig. 1) and Large Fog Collectors (LFCs) (e.g. Schemenauer et al. 1988; Schemenauer and Joe, 1989; Klemm et al., 2012) in Nepal as well as providing training for a local NGO and a Canadian NGO working there. Since 2000, FogQuest has been working with the Namsaling Community Development Centre (NCDC) as well as Nepal Water for Health (NeWaH) to jointly develop projects and conduct studies on potential locations for LFCs using SFCs with remote data logging capabilities. This paper provides a brief overview of the achievements to date and a perspective on what might be accomplished in Nepal in the future.

1. INTRODUCTION

The Nepal Water from Fog Project (NWFP) was started in the spring of 1997 on the initiative of Kevin Kowalchuk, who had previously worked in Nepal on a film project. Kevin made contact with fellow Canadian Robert Schemenauer and they discussed how a water project using fog collectors might be initiated to help the people in the mountain villages of Nepal (MacQuarrie et al. 2001).

As a result of previous cooperative work between FogQuest and the Canadian Centre for International Studies and Cooperation (CECI) in Ecuador, CECI was approached to be involved in a project in Nepal and subsequently provided volunteers for the project and other valuable assistance. In May 1997, the first 1 m² Standard Fog Collectors were set up in Nepal in two locations: Khumjung, in the Everest region and Gotvangan near Kathmandu.

Pablo Osses, who was the first Field Operations Manager of FogQuest, went to Nepal to transfer the technology related to site selection and the construction of large fog collectors. FogQuest has maintained contact with all of the small fog collection projects in Nepal since the beginning and provides assistance and guidance as needed. The main Nepalese NGO involved in the construction of fog collectors in recent years has been Nepal Water for Health (NEWAH). The Dutch NGO SIMAVI has provided some funding. Namsaling Community Development Center (NCDC) now manages new projects.

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2. FOG COLLECTION SITES

Since the inception of the work in 1997, eight sites have been evaluated and LFCs erected in six locations. Initial data from the evaluations using SFCs (Fig. 1) was presented by MacQuarrie et al. (2001).

The longest continuously running operational site has been operating since 2010 at Phativara, Kolbung. (Fig. 2). Several projects have stopped, not as a result of the technology or the inability to provide water; rather, initial investigations indicated that indeterminate ownership and maintenance issues had led to neglect, and in some cases, the collapse of the collectors. The importance of having the involvement of the people in the community and ensuring that they are motivated to sustain the project is of fundamental importance and has been repeated frequently; a ‘bottom – up’ model of community mobilization and involvement as opposed to the imposition of new technologies and activity from the top down (Gurung, 2006; Rosato et al. 2010).

Phativara, Kolbung, LFCs, operational but in need of maintenance. (Fig. 2)

Taplejung, LFC, NEWAH project.

Megma, LFC, out of service due to maintenance and security issues.

Kalplhokari, LFC, dismantled due to dispute over land, scheduled to be reconstructed nearby.

Silauti, SFC, ongoing test location for data logger.

Tinjure, LFC, NEWAH project.

Tumbling, SFC, NEWAH project.

3. OPERATION AND MAINTENANCE (O&M) ISSUES

In addition to ownership issues, collector maintenance is a perennial problem. The maintenance of collectors is complicated by extremely difficult geography (Fig. 3), logistics and a general lack of resources. While some people have been trained to clean and maintain the collectors, the work is seldom done on a regular enough basis, as is seen at the collector at Kolbung, where the system is slowly falling into disrepair. The main issue around maintenance is
the question of who is paying for the maintenance. The collector arrays at Danda Bazaar and Megma, highly successful sites, were damaged as a result of poor maintenance. Solving the maintenance issue(s) is of primary concern for insuring the success of future projects in the region. Unfortunately, the problem is complicated by a background of grinding rural poverty and dependency on NGO programs for income. New local partnerships with NCDC will be focused on addressing the maintenance issues by engaging with the communities as stakeholders and partners.

4. OBJECTIVES FOR THE NEAR FUTURE

New working partnerships with NCDC have been developed in order to ensure regular periodic visits are made to operating sites and to potential new sites. This new partnership includes an ongoing effort to introduce new technology that will collect and send measured fog-water production rates through the cell phone network using small solar-powered data loggers. Developed by Byron Bignell and FogQuest, using Arduino micro-controllers, these data-loggers have been field tested in Silauti, a small temple four hours northwest of Ilam, for the past three years. The devices have been through several iterations and with each generation improvements to the programming, ruggedness and reliability have been made.

4.1 Data-Logging

The current version of the data logger (Figs. 4, 5) has been in service at the Silauti test site for a year and has been logging data with few interruptions. The Silauti test site is located at about 2800 m and the initial data from the test logger shows that the site yields an average of 1.8 to 5 L/m²/day (liters of fog water per square meter per day), depending on the season. Seasonal variability of fog (and rain) in the region is a major factor in data collection. Early indications show that peak collection spans the period May through September and is a combination of fog and rain, this collection volume largely corresponds with the monsoon. The colder winter weather from October through March brings little rain and scant fog, resulting in low collection rates leading to a lower overall seasonal collection rate and per day average. Additionally, the conditions at higher elevations during the colder, drier weather may be resulting in water freezing to the mesh and either melting, resulting in delayed data, or sublimating and being lost altogether. The site will be revisited in October 2016 and new data collected for analysis. The 2016 data will allow us to better understand seasonal fog deposition patterns in the region.

Figure 4. SFC data logger, view of Micro-Controller

Previous iterations of the case and solar panel suffered from a number of physical issues including heat buildup, power shortages and water penetrating the casing. The resulting failures helped improve the physical systems, the result being a new version (Figs. 4, 5) that uses a rugged, insulated, commercially available case and waterproof wire-glands, solving the heat and water issues while also insulating the device from a range of environmental conditions. The addition of higher efficiency (3.5 watt) solar panels to power the data logger allows for the continuous recording of data without relying on batteries.

The long-term goal is for the data-loggers to send data in near real-time to a cloud-based data repository over a mobile network for easier access and analysis.

Figure 5. SFC data logger on the edge of the frame of an SFC
4.2 Increased SFC site testing
Several new sites in and around the Taplejung area have been identified. Working with NCDC and training a small team to set up SFCs and the new data-logger, an on-going program of prospecting and testing new sites for suitability was begun in 2013 and are being developed.

4.3 New Partnerships
Recognizing that maintenance has been an issue and acknowledging the lack of responsiveness of some of the in-country partners, a new partnership with NCDC was initiated in 2010. The goal of the new partnership is to provide constant contact and oversight with communities living at project sites and to provide the much needed mentorship and maintenance.

5. SUMMARY AND CONCLUSIONS
The need for clean water in rural villages of Nepal is apparent. The fog collection technology is effective and long-term projects have been initiated. Evaluations of the potential for new projects in Nepal are ongoing and need to strongly emphasize community involvement and support, with a resolution of maintenance issues and new, stronger local partnerships being keys to the success of future endeavours.

ACKNOWLEDGEMENTS
The projects in Nepal would not have been possible without a lot of help. We at FogQuest are especially grateful to our longstanding partners: The Namsaling Community Development Committee (NCDC), Nepal Water for Health (NEWAH), The Nepal Community Development Foundation (NCDF) and the tireless efforts of our volunteers and supporters.

REFERENCES


MODELING AND ANALYSIS OF THE FOG WATER COLLECTION IN THE ASIR REGION OF THE KINGDOM OF SAUDI ARABIA – A CASE STUDY

Background
Scarcity of fresh water is one of the greatest obstacles to achievement of sustainable development of the Kingdom of Saudi Arabia. About thirty desalination plants are built to satisfy the Kingdom needs.

Aim
The Kingdom is in need of new unconventional water resources such as fog water harvesting system which is important to complement the existing water resources in fog prone areas such as the Asir region.

Method
Passive mesh type fog collector is considered in the present study and an attempt is made to predict the rate of fog water collection by combining a physically based impaction and aerodynamic models.

Results
The results indicate that the greater volumes of water can be collected from the fog associated with higher wind speeds, bigger sizes of fog droplet and higher liquid water content in the fog-laden winds with the threshold mesh shade coefficient of about 0.56. It is found that the aerodynamic efficiency has a significant impact on the overall fog collection efficiency compared to the impaction and deposition efficiencies. The model shows that for the fog droplet size of 30 m with the wind speed of 4 m/s, it is possible to collect the fog water at the rate of 0.65 to 9.7 l/m² per hour when the liquid water content in the fog varies from 0.2 to 3 g/m³, respectively.

Conclusion
The aerodynamic efficiency is the major contributor in determining the overall fog water collection efficiency and it varies narrowly between 22.9 to 23.1% for the variation of shade coefficient from 0.5 to 0.6, respectively, with the peak value of 23.23% at the shade coefficient of 0.56.
DEVELOPMENT OF COST-EFFICIENT DEW AND FOG COLLECTORS FOR WATER MANAGEMENT IN SEMIARID AND ARID REGIONS OF DEVELOPING COUNTRIES

Background
Availability of water is one of the most severe developmental challenges of the World. Many semi-arid and arid regions of developing countries having scarce rainfall still have large amounts of water in the air. It has been claimed that in those areas, harvesting of water from air using dew and fog collectors is a viable option for acquisition of good quality water for households and for irrigation of plantations and reforestation sites.

Aim
The overall goal is to provide practical solutions to water shortages in developing countries. The hypothesis is that utilizing cost-effective and environmentally safe modern materials as a surrogate to collect dew and fog will initiate development and production of dew and fog collectors not only among Finnish industry but also among local industry in the developing countries.

Method
New dew and fog collectors have been tested not only in laboratory but especially in those field conditions where they have been developed for, in semiarid and arid regions. Laboratory measurements have been performed in climatic chamber. The surface material was cooled by Peltier element. Relative humidity, temperature and air velocity were measured at different locations. Field measurements were performed both in Finland and in Kenya. The same parameters were measured as in laboratory with specific emphasis in measuring relative humidity at various heights from the dew-collecting surface in order to make detailed comparison with model calculations.

Results
The results from various new coating materials are presented both from laboratory and field measurements in Finland and in Kenya.

Conclusion
Several simultaneous measurements both in laboratory and in field need to be performed in order to reduce statistical uncertainty. The amount of measured dew collection is in good agreement with theoretical calculations.
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A SYSTEMS ENGINEERING APPROACH TO LARGE FOG COLLECTOR DESIGN

Background
Although fog collection is a proven source of fresh water in many arid and semi-arid regions of the world, its large-scale use has been limited, in part, due to a lack of economic competitiveness relative to other sources.

Aim
The purpose of this study was to design a robust and cost-effective large fog collector (LFC) composed of readily available materials using a systems engineering approach.

Method
A Matlab program was developed to analyze candidate LFC designs while estimating their total initial costs, including all material, assembly, transportation and installation costs. The technically feasible designs were then ranked, in terms of the initial cost per area of collection surface, to identify the most economical design. In the process, gaps in knowledge that are hindering progress in LFC design were identified.

Results
Several thousand LFC designs made up of readily available materials were analyzed. Technically feasible options were then compared on the basis of cost per m² of mesh. The optimum collector was found to have a total initial cost of about 8 USD/m² for 100 to 200 LFCs. This is about 10 times less than current LFC designs, accounting for all costs. The collector, which has a 36 m² mesh, would tolerate high wind loads and is lightweight for rapid installation. The average installation rate is estimated to be approximately 100 m² of mesh per hour, which would be significantly faster than typical installation rates. The design is projected to reduce the cost of fog water to roughly 1 USD per m³, which would be economical relative to alternative rural sources in northern Chile.

Conclusion
It is possible to supply fresh water from fog economically and in sufficient quantities to compete with the current water supplied by trucks to rural areas of northern Chile and probably other areas of the world.
BIOINSPIRED WETTABILITY SURFACES TO CONTROL FOG-WATER COLLECTING ABILITIES

Biological wettability surfaces create the enigmatical reality to display water collecting ability, e.g., wetted spider silk, beetle back, and spines of cactus, etc. They run cooperate between of endlessly arranged various-style gradient micro- and nanostructures (MN) that greatly provide with excellent functions via natural evolvement. Such biological surfaces with multi-gradient micro- and nanostructures display unique wetting functions in nature for water collection, which have inspired researchers to design originality of materials for promising future. In nature, a combination of multiple gradients in a periodic spindle-knot structure take on surface of spider silk after wet-rebuilding process in mist. This structure drives tiny water droplets directionally toward the spindle-knots for highly efficient water collection. Inspired by the roles of gradient MNs in the water collecting ability of spider silk, a series of functional fibers with unique wettability has been designed by various improved techniques such as dip-coating, fluid-coating, tilt-angle coating, electrospun and self-assembly, to combine the Rayleigh instability theory. The geometrically-engineered thin fibers display a strong water capturing ability than previously thought. The bead-on-string heterostructured fibers are capable of intelligently responding to environmental changes in humidity. Also a long-range gradient-step spindle-knotted fiber can be driven droplet directionally in a long range. An electrospun fiber at microlevel can be fabricated by the self-assembly wet-rebuilt process, thus the fiber displays strong hanging-droplet ability. The temperature or photo or roughness-responsive fibers can achieve a controlling on droplet driving in directions, which contribute to water collection in efficiency. In sum, these investigations are helpful greatly to design the materials to be applied for fog-water engineering and system.

References:
In the Namib Desert, one of the driest areas on earth, fog is a prominent feature of the climate and as a source of water for ecological processes more important than precipitation. The fog is of marine origin and advected either as fog from around south-west up to 30 km inland or as stratus from northern directions intercepting with the ascending terrain from 30 up to 120 km inland. There is a general understanding of the climatology of fog in the Namib, but the intermittent observations in the past, both in space and time, leave a number of questions open when it comes to spatiotemporal patterns of fog occurrence and the quantification fog water deposition.

FogNet aims at contributing to these knowledge gaps by observing fog precipitation (FP) within a network of 10 meteorological stations arranged in a west-east and a north-south transect in the Central Namib. So-called Juvik cylinders are used as fog collectors mounted above rain gauges to measure FP. Further measurements include wind speed and wind direction, net and global radiation, air temperature and relative humidity, precipitation, soil moisture and soil temperature, and a leaf wetness sensor. A data logger measures and transmits the data via GPRS to the SASSCAL data base where they are displayed online (www.sasscalweather.net).

In this contribution an analysis of the FP measurements are presented starting from July 2014. FP is displayed depending on wind direction and diurnal courses of FP are analyzed. The spatiotemporal patterns of FP are visualized together with the wind, temperature and humidity field in animated sequences and are compared with the current understanding of fog climatology in the Namib.
FOGHARVESTING AND COMMUNITY RESILIENCE: EXAMINING AN INTEGRATED FOG PROJECT

Background
In 2005 when Association Dar Si Hmad launched its observation period for fog-collecting on Mt. Boutmezguida, southwest Morocco, it did not foresee that the experiment would grow into one of the largest functioning fog projects in the world. While the early concern was ensuring that sufficient fogwater could be collected from the Anti-Atlas Mountains for water-deprived communities, research and community-based programs would strengthen the project and contribute to an integrated model of sustainable development whose central axis remains fog.

Aim
Drawing on 11 years of data and applied research, this paper presents research on the implementation of a holistic water project, and discusses how fogwater harvesting underpins numerous environmental, community and technology programs that advance the project and empower local residents.

Method
The paper analyzes the relationships that tether engineering to society and investigates how infrastructure, technology, community and culture connect. It investigates how these components contribute to a model of integrated, environmentally sustainable development. Methods include Ethnographic Action Research, user-centered design and quantitative and qualitative tools including community census, data-tracking and impact evaluation.

Result
The fog project provides potable water, environmental education, sanitation and hygiene training, literacy support and enhanced livelihoods. These programs support resilient communities: data reveal a decrease in water stress and an increase in community stability. Furthermore, studies show the effectiveness of incorporating Information and Communication Technology (ICT) to monitor fogwater infrastructure and mobile water management tools for marginalized women that help valorize their role as water-guardians. We also discuss the development of a fogwater-fed reforestation project.

Conclusion
The Dar Si Hmad fog project is a dynamic, sustainable water project that serves rural and scientific communities. It is a project where research, participatory development and humanitarian engineering converge. By analyzing the project, this paper contributes to a broader understanding of the complexities of a holistic, integrated model of development.
MEASUREMENT OF THE WATER SPILL OFF THE MESH OF A LARGE FOG COLLECTOR

Background
A potentially important factor of collection efficiency of Large Fog Collectors (LFC) is the water spilt off the mesh, which normally is not considered. Additionally, there are arguments concerning the best orientation of anisotropic meshes (like Raschel mesh) in terms of whether to install the warp threads horizontally or vertically, in order to facilitate drainage and minimize this loss.

Aim
To measure the water spilt off the mesh of a LFC for both horizontally and vertically installed Raschel meshes.

Method
Thirty-six rain gauges were installed on the ground close to a LFC to measure the water falling from the mesh. Additionally, a flowmeter measured simultaneously the water collected at the trough. These measurements allow calculating the fraction of the water collected by the mesh that is lost by spillage (draining loss, DL). This DL can be correlated to wind velocity, event duration (T), collected water (CW) and other weather conditions.

Results
Preliminary results indicate that for a vertically oriented mesh we measured DL in only 2.6% of the studied events, while for the horizontal mesh we measured DL in all the events. On average, 44% of DL with horizontal mesh occurred in the central part of the LFC, between 0.5 m and 3.5 m leeward from the line between the 2 poles. No relationship could be seen between DL and CW and between DL and T. Relations between DL and other weather parameters are being studied.

Conclusion
The preliminary analysis of draining loss with both orientations of the mesh let us conclude that vertical orientation is more efficient.
SIMPLE SOLUTION ON RAIN-CLOUD-FOG WATER COLLECTION
- A HARVESTING UMBRELLA TEST IN THE FIELD

Background
Taiwan as a subtropical island features very humid air. Big parts of the country are covered by mid- and highland cloud forests which frequently experience more than 250 days of fog per year (Liang et al., 2009). The climate is characterized by the two subtropical East Asian Monsoons, typhoons and tropical cyclones, while heavy rainfall disasters are very common. In contrast there is a continuous threat of drought all over Taiwan, especially in the winter dry season. Thus fog becomes interesting as a water source for national parks and farmers. Particularly mountain hikers are interested in an easy solution to collect rain-cloud-fog water in the wild.

Aim
In this study, we propose a simple, decentralized, personal, free standing water collection system based on a water harvesting umbrella. The umbrella was tested in the field, to detect possible problems, quantify the amounts of collectable water and compare it with a rain gauge as well as a standard fog collector (SFC).

Method
The instruments were set up at Shan-liu-jo refuge hut on Xueshan Mountain (3188m AMSL) at nighttime on 18 August 2015 and 21 June 2016 (Figure 1), and at Shuangxi (420 m AMSL, Figure 2) for a period of four weeks from May to June 2016. Shuangxi is located in one of the stream valleys in northern Taiwan where it has wet climate during the whole year. Foggy weather conditions accompanied by rain are very frequent. Xueshan Mountain has wet tropical-like mountain summer weather and dry cold winter weather. The refuge hut is located on a grass slope facing to the east and misty air is lifted up often to the hut during nighttime. This hut can accommodate more than 100 people, but water sources are limited to rainwater and cloud-fog water collection.

The umbrella was originally designed by Taiwan Industrial Technology Research Institute (ITRI) for rain water collection during disaster recovery action in developing countries. We modified the umbrella and chose a mesh which was tested by Tseng et al. (2016) with better harvest performance and added eight pieces of triangle shaped mesh (0.11m²) to construct a pyramid (total area is 0.866 m²) for catching cloud-fog water (Figure 3). During field operation, the umbrella hangs opened, upside-down with pyramid mesh collecting rain-cloud-fog water. Several holes in the main skeleton of the umbrella make water convergence at its surface and flow downwards into a collection bottle. We used a tipping bucket rain gauge with digital counter to record the collected water volume. The rain gauge for water counting was covered to protect it from precipitation.

In addition a Standard Fog Collector (SFC) with a 1 × 1 m² surface and a base 2 m above ground (Schemenauer and Cereceda, 1994) and a standard rain gauge (15.4 cm diameter with 0.2 mm resolution) were installed nearby the umbrella was installed for weather information.

Results
Our study provides the first data for the harvesting umbrella and gives an idea about the quantities of water that can be collected in rainy conditions (16 May 2016) up to 27.4 mm/24 hours at Shuangxi, the umbrella harvested ~15.6 liters rainwater which is nine times more than the water collected by fog net (Figure 4). During two foggy nights at...
In this study, we propose a simple, non-roof based rainwater harvesting concept. The collected water can ideally be used by hikers for drinking or cooking purpose at rural places like Xueshan Mountain. During this study also a few problems occurred, making adjustments and improvements in the product design and material necessary. So far there is a delay in the drainage of the water from the umbrella. That might be due to the fact that the holes in the skeleton are a bit above the bottom so the water can’t drain off completely. Besides the holes might easily get blocked by dust, littles stones or leaves. Also the tube from the umbrella to the collection bottle is quite long and narrow, so that a lot of water gets attached to it walls. Further studies will show if improvements enhance the quantity of collectable water and reduce the vulnerability of this instrument. Later the design could be revised towards a smaller and lighter version to make it even easier to transport the umbrella in the field. In the end the objective is to perform a case study with hikers using the harvesting umbrella to finally find out how good it really fits their needs.

Conclusion
Our study provides the first data for the harvesting umbrella and gives an idea about the quantities of water that can be collected in rainy or foggy conditions. The harvesting umbrella is able to collect reasonable amounts of fog-cloud water and big amounts of rain water with a very simple, non-roof based rainwater harvesting concept. The collected water can ideally be used by hikers for drinking or cooking purpose at rural places like Xueshan Mountain. During this study also a few problems occurred, making adjustments and improvements in the product design and material necessary. So far there is a delay in the drainage of the water from the umbrella. That might be due to the fact that the holes in the skeleton are a bit above the bottom so the water can’t drain off completely. Besides the holes might easily get blocked by dust, littles stones or leaves. Also the tube from the umbrella to the collection bottle is quite long and narrow, so that a lot of water gets attached to it walls. Further studies will show if improvements enhance the quantity of collectable water and reduce the vulnerability of this instrument. Later the design could be revised towards a smaller and lighter version to make it even easier to transport the umbrella in the field. In the end the objective is to perform a case study with hikers using the harvesting umbrella to finally find out how good it really fits their needs.

Figure 1. Shan-liu-jo refuge hut at Xueshan Mountain (3188m AMSL). Location: 24°23’5.47”N 121°16’3.22”E.
Figure 2. Shuangxi base (420m AMSL). Location: 24°58′43.04″N 121°50′28.56″E.

Figure 3. The umbrella used in this study (made by Taiwan Industrial Technology Research Institute). 8 pieces of triangle mesh (0.11m²) is attached to construct a pyramid of 0.866 m² area.
Figure 4. Amounts of harvested water per hour in ml during the day of May 16 to 17, 2016 at Shuangxi site.

Figure 5. The foggy night (June 21, 2016) at Shan-liu-jo refuge hut at Xueshan the water bottle below the umbrella.
THE PERFORMANCE TEST ON DIFFERENT FOG HARVEST MESHES IN TAIWAN

Background
In order to rise up the scientific issue on water source collection of cloud-fog water in Taiwan, we need to find the easy and better solution of mesh types which could be found in Taiwan.

Aim
To identify the higher harvest rate on fog water collection, several popular polytene mesh collected in Taiwan.

Method
The collected meshes were tested on their performance in modified CASCC fog collector. An Ultrasonic oscillator for fog water generator provides constant fog water in front of the meshes 22 cm away in CASCC tunnel, and its mass concentration of this fog generator was measured by DMT FM-120 Fog monitor. A numerical model is also designed and tested to compare the in situ measurement.

Results
During fog water sucking into CASCC under different flow speeds (1~5 m/s) by vehicle motor fan, the harvest water was collected in 10 minutes to estimate the harvest rate in different wind speeds’ scenario. All the water amounts harvested 11 polytene meshes are compared with CASCC strand (named Mesh #12 in this study). In general, the water collected at low wind speed (1 m/s) is less and varies slightly among meshes. Collection rate for Mesh #3, #9, #10 and #11 (Group #1) are all poor at medium wind speed (2~3 m/s), but increases with wind speed without upper bounds. Mesh #1, #2, #7, #8 and #12 (Group #2) have better collection rate at medium speed (2~3 m/s) and folds back at high speed (more than 4 m/s). Collection rate for Mesh #4, #5 and #6 (Group #3) are as efficient as Group #2 at medium wind speed, but become saturated at higher wind speed.

A numerical simulation of collection efficiency for mesh is used to analysis the mesh characteristics. This model is modified from previous studies (Juan de Dios Rivera, 2011; Park et al., 2013). Both the drag effect of mesh and droplet trajectory are taken into consideration in this model. The microscopic measurements on grid width and line width for each mesh is used to calculate the collection efficiency from 3~50 μm diameter of water drop size for each mesh. We found 10 μm of water droplet is the cut off threshold for collecting efficiency estimation. The model simulation shows the variances among all meshes increases as wind speed increases. The decline of fog water collection rate in 3 m/s is less than the one in 2 m/s. Mesh #2, #6 and #10 show satisfying results with the simulation. Mesh #3 and #7 have the worst results.

Conclusion
These 11 types of polytene mesh collected in Taiwan were grouped into 3 categories of collection efficiency. The simulation from numerical model contradict with the in situ CASCC measurement. It is probably due to lack of water droplet run-off along the mesh line.
Evaluation of the Mesh Collection Efficiency of Fog Water based on Meteorological data and measurements of Liquid Water Content

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ABSTRACT

In places where precipitations are scarce and fog events are persistent, fog represents an important alternative water source. The usual method to collect fog water is placing a rectangular mesh perpendicular to the wind which traps fog droplets. The quantity of fog droplets incident over the mesh, only a fraction is collected. This fraction depends on the Mesh Collection Efficiency (MCE). The goal of this paper is to evaluate the MCE of a Raschel Mesh of a Standard Fog Collector, based on meteorological data and measurements of Liquid Water content (LWC) evaluated from data recorded by a fog droplet spectrometer. The MCE was evaluated dividing the water collected by the SFC by the Liquid Water Flow (LWF) incident over the mesh in full fog events. We found that the maximum MCE was 67\% and happened during a night fog event, after an event of dew deposition. In other cases, it ranges between 0\%, also foggy events without water collection, and 40\%. The behavior of the MCE is different according to the size of the droplets: for Mean Volume Diameter (MVD) > 9 \( \mu \)m, MCE decreases with MVD. Furthermore, for Temperature (T) > 12°C, a sharp decrease of MCE was observed.

1. INTRODUCTION

In arid and semi-arid regions fog is an important alternative water resource (Klemm et al., 2012). The quantity of water that can be collected from fog depends on meteorological variables such as wind speed, relative humidity (RH) and Dew Point Depression (Hiat et al. 2012; Schmemauer et al. 1988; Cereceda and Schmemauer, 1993). Usually, fog water is collected by a rectangular mesh or Large Fog Collector (LFC). To catch as many drops, the mesh is placed perpendicular to the wind flow. The quantity of water that are effectively collected to be used for human needs depends on the MCE.

There is not much information about MCE in the literature. Schmemauer and Joe (1989) analyzed the collection efficiency by measuring the LWC at the front and behind a LFC equipped with a Raschel mesh. However, not all the water trapped by the mesh can be effectively collected to be used for human needs. Some of them are lost because they evaporate or fall outside the collection system. The authors found that the effective collection was about 2.9 times smaller than the one found by this method.

The goal of this paper is to evaluate the MCE of a Raschel mesh installed in a SFC, by comparing the LWF incident over the mesh, which depends on the LWC, wind speed and direction, with the collected water. Because there exist a lag between the arrival of fog and the water collection both parameters were evaluated in entire fog events.

2. MATERIALS AND METHOD

2.1 Study site

The study site is located at the Coastal Range of the Norte Chico of Chile (29.51°S, 71.27° W), 7 km from the coast, at the North limit of the Coquimbo Region. The area is characterized by a strong topography gradient with altitudes that vary from sea level to nearly 1000 m in about 10 km horizontal distance. The experimental site is located in a hill called El Sarco (Figure 1), at
700 m altitude, on a saddle point between two hills of about 1000 m altitude.

Figure 1. Study site and its location in Chile

2.2 Experimental design

The experimental design consisted of a Campbell meteorological station equipped with sensors for wind speed, wind direction, T and RH at 2.5 m above ground level (agl), and a rain gauge. Near the meteorological station, a SFC oriented in the SW direction (230°) was installed. The water collected by the SFC was measured by a second rain gauge. The data were registered every 3 seconds and stored every 10 minutes.

In parallel, the fog characteristics were monitored with a Droplet Spectrometer (FM-120) located at 2 m agl during 3 days field campaigns performed in January, February and July, 2015.

2.2 Methodology

The water collected by the SFC (W) in the time interval Δt depends on the MCE η according to the following relation:

\[ W = \eta \rho v \cos\beta A \Delta t \tag{1} \]

The expression \( \rho v \cos\beta \) is the LWF incident over the mesh, with \( \rho \) the LWC (g m\(^{-3}\)), \( v \) (m s\(^{-1}\)) the wind speed, and \( \beta \) the angle between the wind flow and the normal to the mesh; \( A (=1 \text{ m}^2) \) is the area of the mesh.

The wind speed was taken from the meteorological records, \( \beta \) was inferred from the wind direction and the orientation of the mesh, and the LWC was inferred from the droplet size distribution registered by the FM-120.

Because of the lag between the arrival of the fog and the beginning of the collection, entire fog events were considered. A fog event begins when the LWC is larger than 0.01 g m\(^{-3}\) (Gultepe et al. 2007). The MCE was calculated solving (1) for \( \eta \). In our analysis, only wind speeds larger than 1 m s\(^{-1}\), the starting threshold of the anemometer, were considered.

3. RESULTS

Twelve fog events were analyzed, with a duration that ranged between 1 h 20’ and 11 h 50’. The LWC achieved values up to 1.45 g m\(^{-3}\) and the wind speed varies between 1.3 m s\(^{-1}\) and 10 m s\(^{-1}\). We found that there exist a lag between the arrival of fog and the water collection ranging between 0 and 2 hours, higher in the day than at night.

3.1 Analysis of fog events

Figure 2 shows the incident LWF incident over the mesh in 10 minutes intervals and the collected water in the same period in January 21, 2015. As reference the LWC is as well shown. In the figure it is possible to observe three fog events:

- Event 1: 1310 LT to 1530 LT
- Event 2: 1640 LT to 1900 LT
- Event 3: 1910 LT to 2300 LT.

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- Event 1: 1310 LT to 1530 LT
- Event 2: 1640 LT to 1900 LT
- Event 3: 1910 LT to 2300 LT.
In Event 1, there was no fog collection; in Events 2 and 3, fog collection was registered. In both cases a lag of about 1 hour between the arrival of fog and the beginning of the collection was observed. Event 3 has the characteristic that, although the fog event extended until 2300 hour, with relative high values of LWC, at 2150 LT the wind speed descended to values < 1 m s\(^{-1}\) (not shown), and therefore the LWF cannot be calculated.

We found that there were fog events in which the water collection was larger than the LWF incident over the mesh. One of these cases happened on July 30, 2015 and is represented in Figure 3. Such events occurred during the night and/or early morning, and could be related to collection of water caused by dew deposition.

![Figure 3](image)

**Figure 3.** The same as Figure 1 at July 30, 2015

### 3.2 Mesh collection efficiency (MCE)

From the fog events registered we let out those night events when the collected water was larger than the LWF incident over the mesh, as the one shown in Figure 3. We assume that in these cases MCE would be overestimated.

From the 12 fog events analyzed, in 2 cases the MCE was 0%, i.e. fog events without water collection. Both events occurs in January, 2015 and had a duration of 100 minutes and 120 minutes, respectively. One of these events is shown in Figure 2.

The maximum MCE was 67% and happened during a fog event that occurred at night, after a period of dew deposition. In other cases, it achieved values up to 40%.

![Figure 4](image)

**Figure 4.** Mesh collection efficiency and Mean Volume Diameter.

Figure 4 shows the relation between MCE and the Mean Volume Diameter (MVD). Leaving out the highest value of MCE (67%), we found that for MVD > 9 µm, MCE decreases with MVD.

Furthermore, we found that for T > 12°C MCE decreases abruptly with T (not shown).

### 4. SUMMARY AND RECOMMENDATIONS

In this article the fog water collection efficiency of a Raschel mesh installed in a SFC was analyzed. The MCE was defined as the ratio between the collected water and the LWF incident over the mesh in entire fog events.

From the 12 events analyzed, in one case, a night event that occurred after a dew deposition, the MCE was 67%. In other cases, it ranged between 0% and 40%.

We found that MCE decreases with MVD (MVD > 9 µm) and with T (T>12°C). This last result can be explained because low values of T promotes condensation.

The MCE is an important parameter in the fog collection. Nowadays there exists in the market different types of mesh whose MCE needs to be investigated. As we show in this article, MCE depends on atmospheric parameters and fog characteristics. To know the efficiency of alternative mesh types helps to choose the appropriate one for a particular site.
ACKNOWLEDGES

This research was funded by Project Dominga of Andes Iron, SpA. It is attached to the Plan de Mejoramiento Institucional en Eficiencia Energética y Sustentabilidad Ambiental ULS-1401. We thank Darrel Baumgardner for useful conversations.

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WIND FORCE MEASUREMENT AND ANALYSIS OF A LARGE FOG COLLECTOR

Background
To significantly increase the use of fog as an alternative source of fresh water, it is critical to understand the structural behavior of Large Fog Collectors (LFCs). The lack of information about the forces that are applied to an LFC implies an over-dimension and unnecessarily higher cost, or a collector that is too weak and subject to damage from wind loads.

Aim
The aim of this study was to get the load reduction factor that is needed to optimize the design of LFCs.

Method
The LFC cable tensions, wind speed and wind direction were simultaneous measured using load cells, an anemometer and a wind vane, respectively. The load cells were sampled every three seconds and every ten minutes the maximum, minimum and average were recorded. In addition, the LFC was modeled in a structural analysis program (SAP). Using this model, the theoretical forces in the cables were computed, assuming a non-porous mesh for various wind speeds. The load reduction factor, which is the quotient of the real measurements and the measurements given by the model, were calculated.

Results
Nearly 500 data, including tension from ten load cells and wind speed, were measured over the course of 6 months. Comparing the data given by the load cells, with the results of the model, a load reduction factor for each cable and for each wind speed was determined. For example, one of the preliminary results was that in the top cables, the reduction factor for wind speeds of 2 to 10 m/s ranges from 11% to 14% (see figure).

Conclusion
In conclusion, an LFC design based on a worst-case non-porous mesh would result in a significantly oversized structure and reduced competitiveness of fog as an alternative source of fresh water.
IMPROVEMENTS IN FOG COLLECTION EFFICIENCY WITH NEW BIO-INSPIRED THREADS THAT PROMOTE WATER FILM STABILITY

Background
The scarcity of fresh water around the world is a prominent global issue faced by humanity. In many countries such as Chile, the collection of water from fog offers an inexpensive alternative to more costly water acquisition strategies such as desalinization.

Aim
Our research focuses on the design of bio-inspired meshes to maximize fog collection efficiency. The aim of this study is to characterize the dynamics of water droplets flowing along a vertical thread in order to identify design features promoting the stable flow of captured fog droplets. Water film stability on these threads is critical because the formation of large drops leads to re-entrainment and loss of collection efficiency.

Method
Water droplets were injected at fixed time intervals at the top of vertical threads or deposited over the length of the threads using a fog generator. The outflow at the bottom of the threads was measured with high temporal resolution in order to characterize the input-output function for various thread designs.

Results
Our analysis of the input-output functions reveals that threads trapping large water drops rather than forming a film are prone to avalanches of drops whose frequency and size resemble those of other self-organized critical phenomena. Interestingly, the critical behaviour of the input-output function can be eliminated by maintaining a thin water film on the threads. This solution emerges from an analysis of water conduction in the Chilean fog-collecting plant Tillandsia landbeckii; which used hydrophilic scales to force fog droplets to spread and form a stable film.

Conclusion
Re-entrainment of water droplets from fog collecting threads can be eliminated by the presence of hydrophilic scales which help maintain a thin water film onto which incident droplets can coalesce and flow stably downwards.
A COMPARISON OF THREE FOG WATER COLLECTORS USING MODELING AND FIELD DATA

Background
Framed mesh-like open fabrics and wire harp-like fog collectors have been extensively put into practice in the field, either for research or fog water harvesting purposes. However, the optimization of such fog water harvesting devices has not been investigated in depth, apart from very few exceptions.

Aim
We investigate the collection efficiency of different fog water catchers assemblies (mainly flat and cylindrical structures equipped with several screens of staggered filaments).

Method
We introduce different models that vary in complexity and range of applicability, and may be used to analyze the effect that geometry, number of screens, spacing and inclination of the filament strands have on the fog water yield of the collector.

Results
Increasing the number of impacting screens, \( n_R \), is shown to improve the collection efficiency up to an optimum for \( n_R = 3-5 \); beyond \( n_R > 5 \) impermeability to the airflow makes the fog catcher less efficient. Geometry of the collector is shown to be relatively important: unless wind direction varies widely, the rectangular flat design is preferred over the cylindrical one, because of its larger drag, i.e. increased aerodynamic efficiency, \( \eta_a \). In fact \( \eta_a \) is shown to be limiting, such that values over \( \eta_a > 50\% \) are difficult to attain. By contrast the impaction efficiency, \( \eta_{imp} \), of fog water droplets onto multiple \( n_R \) parallel screens of filaments may reach theoretical values of \( \eta_{imp} > 80\% \). Inclination of the impacting screens over the vertical may slightly reduce \( \eta_{imp} \), but this may be compensated by a reduction in flow resistance, i.e. increased aerodynamic efficiency.

Conclusion
The aerodynamic efficiency is limiting during the fog collection process. Our analysis may also help to interpret field data on fog collection with a wide variety of artificial catchers assemblies.
The Tojquia, Guatemala Fog Collection Project 2006 to 2016

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ABSTRACT

FogQuest began working in the Western Highlands of Guatemala in 2005 with the construction of 4 Large Fog Collectors (LFCs) in La Ventosa. In October 2006, 4 LFCs were constructed in Tojquia. Six more LFCs were added to those in Tojquia in 2007 and the project rapidly grew to 35 LFCs. This is about 1400 m² of collecting surface providing about 7000 L of fog water per day in the six-month long dry season. Tojquia is at an elevation of about 3300 m a.s.l. and suffers from serious water shortages, especially in the winter. These 35 LFCs remain operational and productive after 10 years of providing clean water to homes in the village. The continued involvement of the people of the village of Tojquia has been vital to the success of this project. The FogQuest approach is to have several FogQuest members teach, organize, and guide the villagers in the initial construction process and then to have the community members as active participants throughout the evolution of the fog collection project. FogQuest does not take in large numbers of volunteers to build the fog collectors for the community. This approach has given the project vitality and the people of the community have organized a water committee to not only maintain the fog collectors but to initiate construction of new fog collectors. It is not changes in the technology of collecting fog water that are required for the adoption of this water resource but rather a careful choice of location and patient and considerate guidance leading to strong partnership building with the peoples of the communities.

1. INTRODUCTION

In a growing number of countries around the world, efforts have been made to develop fog collection projects in order to supply clean water to vulnerable communities without access to a traditional and clean water source. However, these efforts do not always end with a successful project, which might be defined in part as the provision of a sustainable water supply and at the same time the evolution of an active and empowered local community. Fog collection projects do not have to last forever to be considered successful. They may be urgently required for a number of years until such time as a conventional water supply may become available and, as such, very successfully provide clean water in often very challenging conditions.

This paper will present the experience of one of the most successful fog water collection projects of the planet, Tojquia, Guatemala, based on some of the actual social conditions (motivation, future interest and commitment) and will also look at possible future activities in the community.

![Two Large Fog Collectors (LFCs) in Tojquia](Figure%201%20Two%20Large%20Fog%20Collectors%20(LFCs)%20in%20Tojquia.png)

2. FOG WATER PRODUCTION AND USE

Tojquia is located in the western highlands of the department of Huehuetenango, Guatemala, at an elevation of 3300 m near the top of Chuchumatanes Mountain. During the dry season (November to April), fog is the unique source of fresh water that the community, who are descendants of the Mayan culture, can use for their vital daily activities. In contrast, during the wet period (the rest of the months) many of the
families have traditionally used buckets and containers below the roofs of their homes (virtually every day), this allows them to gather large amounts of water to use not only for drinking and cooking but for cleaning and to supply water to their animals. This traditional use of runoff water from the roof during heavy rains in the wet season continues, even though a cleaner source of rainwater from the large fog collectors is also available.

It is important to mention that before the large fog collectors were built in Tojquia many women, in the dry season, had to walk to old wells located far from the village at the valley bottom in order to obtain water just for the family’s needs. Before 2006, women and their daughters had to walk to these faraway locations and they could only carry containers of 16 liters, so this meant that women had to do this trip 3 or 4 times a day to supply their families with water.

The long-term commitment by FogQuest to working in the village of Tojquia began after FogQuest had done investigations in a number of parts of Guatemala using Standard Fog Collectors (SFCs) (Schemenauer, R.S. and P. Cereceda, 1994). It is important to keep in mind that installing the one-square-meter SFCs not only evaluates the amount of fog water that might be collected at a location it also evaluates the commitment and involvement of the people of the community to the water project. If they are unable to contribute to the measurement program with the SFCs and ensure the security of the SFCs, then it is unlikely they will be able to adequately support a fog collection project using Large Fog Collectors (LFCs) (Fig. 2) (e.g. Schemenauer et al. 1988; Schemenauer and Joe, 1989; Klemm et al., 2012). Moreover, the villagers became true collaborators in a highly participatory process. With a foundation based on trust, the so-called beneficiaries came to make suggestions and lead decisions – rendering them co-creators of this water supply (Rojas et al. 2014). The men and women of Tojquia exhibited a commitment to the project and a work ethic that was vital to the ultimate success of the project.

3. COMMUNITY ORGANIZATION AND EXTERNAL INVOLVEMENT

The Tojquia project has a diversity of participants: the people and family units in the community; the leadership of the community; the Mam Ma Qosquix village association; the Canadian NGO/Charity FogQuest; different funding entities supporting the community through FogQuest (clubs of Rotary International, schools, churches, individuals, etc.).

After ten years of continuous work by all of the participants linked to the project, the community of Tojquia has made significant progress in several aspects that have resulted in this becoming a successful sustainable water project.

3.1. Water Committee

A new water committee was formed in 2015, which was accepted by all the people after a collective vote. Within their responsibilities were: (1) keep a record of any problems with each LFC installed in the community; (2) keep an inventory of the materials and tools delivered by FogQuest on each visit to the community; (3) keep in contact with FogQuest volunteers and leaders and; (4) inform the community about upcoming visits of FogQuest volunteers to Tojquia. The leaders of this committee in 2016 are:

Table 1: Water Committee in Tojquia

<table>
<thead>
<tr>
<th>Position</th>
<th>Person</th>
</tr>
</thead>
<tbody>
<tr>
<td>President</td>
<td>Bernardo Lucas</td>
</tr>
<tr>
<td>Vice President</td>
<td>Lázaro Hernandez</td>
</tr>
<tr>
<td>Treasurer</td>
<td>Tereso Gregorio</td>
</tr>
<tr>
<td>Secretary</td>
<td>Gerónimo Jacinto</td>
</tr>
<tr>
<td>Spokesperson</td>
<td>Demesio Gregorio</td>
</tr>
</tbody>
</table>

3.2. Collecting funds for maintenance

One of the most important ideas that came up in 2015, during a visit to the community, was the creation of a village fund that allows the people to correct maintenance issues with the fog.
collectors that occur over time, like clamps, cable and hosepipe replacement. The people of Tojquia will also pay for a part or the entire cost of new meshes when they are required for repairs or the construction of new fog collectors that the village may initiate. It is true that raising enough money to pay for the entire cost of several new LFCs would be a difficult task for the community right now, but over time the input they could offer would become larger.

After discussing the village fund within the community and looking for each family’s acceptance, the saving format consisted in a bi-monthly fee of 10 to 20 quetzales (local money), delivered at the meeting held every 2 months. This will not only allow the community to save for the maintenance of the LFCs but it empowers the people, making this project their own. The operation of the village fund continues to work well.

3.3. Searching for funding sources

In order to maximize the involvement of the community in the project, the people of Tojquia think that it would be a good idea if FogQuest, in the future, train or teach the community how to ask for local and national funds (in Guatemala), all this is to support the maintenance of the projects and, in the long term, the community itself could create the development of new initiatives within Tojquia and in neighbouring villages.

Fig. 3. Tojquian woman during a fog event

4. SUCCESS FACTORS

As we have seen in the development of this discussion, the success of a fog collection project depends on a number of factors, which may vary depending on the location, culture, religion and availability of financial resources. We can, however, identify four elements that are key to the success of this particular project: (1) the flexibility of FogQuest to adapt to the local needs and idiosyncrasies; (2) co-creation, technology transfer and subsequent management; (3) the strong dedication and empowerment of the community collaborating in the project; and (4) the presence and active participation of a local organization and village leaders.

5. OBJECTIVES FOR THE NEAR FUTURE

In remote villages progress is not measured by speed or the undertaking of huge projects but rather by steady advancement. On the next visit to Tojquia later in 2016, the volunteer team of FogQuest will work to further strengthen the progress achieved to date.

The objectives will include:

- Listening to the people of the village to hear their experiences in the last few months.
- Assisting them as they initiate maintenance to the LFCs or changes to the water storage system.
- Facilitating training in obtaining local and national funds.
- Linking the local elementary school into the project in order to promote environmental education and the efficient use of fog as a water resource.
- Discussing a long-term goal of establishing a greenhouse that utilizes the fog water for growing winter vegetables.

6. DISCUSSION

Years of joint work in Tojquia and a gradual and responsible transfer of knowledge have achieved one of the most successful fog water collection projects in the world. Clean water has been provided for 10 years and the strength of the support for the project within the community is stronger than it has ever been. The success or failure of a project of this nature is determined in large part by the effective transfer of knowledge from the facilitating organization to the community and the empowerment of the community in the development and sustainability of their own projects.
In recent years there have been a number of efforts to develop materials or fog collector structures that are purported to have better fog water yields than the double layer of inexpensive Raschel mesh described by Schemenauer and Joe (1989). Rarely are any costs reported for these proposed materials or structures. If one is speaking about a fog collection project in the developing world, improving the yield of the already highly efficient Raschel mesh is not an important factor. Far more important is cost, which is a real factor and, as well, since these projects are typically in complex mountainous terrain, knowledge and experience in choosing an appropriate site for the fog collectors, something that can make a very large difference in the water yield obtained. In addition, as has been discussed in this paper, it is ultimately the involvement of the people in the village that will determine whether a project succeeds or fails. It is their work on a continuing basis that will determine whether the fog collectors continue to function well and whether the water is moved and stored in an effective way and in a way that ensures that it is clean and safe to consume.

7. ACKNOWLEDGEMENTS

For an all volunteer charity with limited resources to develop and maintain a project over a period of 10 years in a remote area of the mountains of Western Guatemala is not a simple or easy task. A lot of people have been involved since the beginning. The authors would like to acknowledge the dedicated work of several FogQuest volunteers especially Rick and Tia Taylor, Tony Makepeace, Daniel Jiatz, Darrell Piekarz, Philip Jaekl, Fernanda Rojas, Juan Luis Garcia, Bernadita Silva, Adem Miller, Margarito Jerónimo, and the support of Rotary International in the implementation of the projects discussed here, in particular the Grimsby Rotary Club in southern Ontario, Canada, the Kamloops Rotary Aurora Centennial club in British Columbia, Canada, and other clubs and individuals who made contributions to the projects. The funding and volunteers from Round Square International Schools has also been instrumental. Liz Gray, the 2008 and 2009 field trip participants, and the class from Rotchesay Netherwood School merit special mentions. The on-going support from the Denis Morris Catholic High School and St. Francis Secondary School, in St. Catharines, Ontario have been very important contributions. Finally, the invaluable technical and operational support of Marco Antonio Ortiz and his team, (especially Carol and Cesar), and Jorge Aufanc, both from Rotary International in Guatemala City, have been very important.

8. REFERENCES


The CloudFisher is the first standard fog collector that can withstand high wind speeds. It is quick and easy to install, and requires no energy and only minimal maintenance. All the materials are food-safe. The CloudFisher can supply people with high-quality drinking water that meets WHO standards, and can also provide water for agriculture and forestry. It is mainly deployed in mountainous and coastal regions where rainfall is scarce but clouds and fog are plentiful.

Industrial designer Peter Trautwein has developed the CloudFisher Pro and CloudFisher mini for the WaterFoundation. Aqualonis GmbH, based in Munich, was founded to implement this technology worldwide. As a licensee of the WaterFoundation, the company markets and sells the CloudFisher products. Aqualonis develops, plans, builds and maintains fog water collection systems. It is distinct from the WaterFoundation, a strictly non-profit organization that cannot engage in or accept liability for activities involving a commercial aspect.

1. INTRODUCTION CloudFisher Pro™

1.1 Use case
CloudFisher Pro™ can be used for villages, schools, industry, agriculture and forestry.

1.2 Water amount
The amounts yielded per fog-day differ according to region and season. They vary between 6 and 22 litres per square metre of net surface.
The CloudFisher is the first standard fog collector that can withstand high wind speeds. It is quick and easy to install, and requires no energy and only minimal maintenance. All the materials are food-safe. The CloudFisher can supply people with high-quality drinking water that meets WHO standards, and can also provide water for agriculture and forestry. It is mainly deployed in mountainous and coastal regions where rainfall is scarce but clouds and fog are plentiful.

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2. CONSTRUCTION AND PROS
2.1 Dimensions

![Diagram of CloudFisher](image)

2.2 Flexible collecting trough (1)
- Firmly attached to the lower end of the fog net
- The trough follows the movement of the net in the wind
- Flexible polyethylene
- UV-resistant, stormproof and food-safe

2.3 Dynamic net fixture (2)
- Nets and brackets held in place with rubber expanders
- UV-resistant, low risk of fraying and weather damage
- Rubber expanders reduce the impact of wind forces

2.4 Fog net with support grid

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![Diagram of fog net with support grid](image)
3. PROJECT MOROCCO 2016

The project is located in the Aït Baamrane area in the Anti-Atlas mountains near the coastal town of Sidi Ifni. The population is largely made up of berber communities, especially women, children and old people: the men are often absent for months at a time, looking for work in the towns. In recent years, the region has been increasingly menaced by drought; the desert has spread, and the water table is steadily sinking. However, there is still a plentiful supply of atmospheric water vapour from the clouds and fog around Mount Boutmezguida.

Thirtyone Cloudfisher fog collectors, with a total net surface of around 1700 square metres, will be installed here, to provide 14 villages and a school with clean water that can be used for human consumption or to water crops and animals.

The aim is to connect every house to the collector system. Five cisterns in the mountainside ensure that the water remains available during most of the dry season. As a result, the girls in the villages no longer have to spend three hours a day fetching water from the wells in the valley, and the people can grow modest amounts of fruit and vegetables – initially for their own consumption, but also to sell at the market or to hotels.

3.1 Project mission

In 2017 and 2018, 14 villages in the valleys around Boutmezguida are being provided with drinking water from frog. Around 800 inhabitants will have a water supply of up to 18 litres per day, as opposed to 8 litres in the past.

3.2 Acknowledgement

The Morocco project is facilitated by the Federal Ministry for Economic Cooperation and Development (BMZ) with the generous support of the Munich Re Foundation and the German Technical and Scientific Association for Gas and Water (DVGW). In cooperation with our local project partner Dar Si Hmad.
4. CloudFisher mini™

Each fog project starts with the collection of meteorological data on wind speeds and directions, relative humidity and temperature, precipitation and amounts of water collected. These findings are used to decide whether the location is appropriate for a fog water production system and how best to align the collectors. What, though, if the technical knowhow and the financial means for measuring equipment are lacking? What can be done so that people can help themselves and become independent?

4.1 Functionality

During the fog season, the CloudFisher mini can be used to determine the yields of the three net surfaces arranged at different angles. The net that collects the most water is the one positioned at the most favourable angle to the wind. No special instruments are needed: the measurement is done by simply reading off a scale on each water canister.

Text and illustrations © 2016 by WaterFoundation, Aqualonis
WATER YIELD AND QUALITY OF A NOVEL FOG COLLECTOR FOR HIGH WIND SPEEDS

Background
Fog harvesting techniques for water collection have been implemented successfully worldwide for several decades. However, at locations with high wind speeds, traditional installations require high maintenance efforts endangering sustainability of projects. Wasserstiftung has therefore designed a much more durable fog collector.

Aim
We aim to evaluate this novel fog collector, as well as different net materials, in terms of water yield and quality, dependence on meteorological conditions and durability.

Method
The fog collector (cf. submission by Trautwein et al.) has been installed at mount Boutmezguida in Morocco and fitted with equipment for measuring the yield of each net, along with standard meteorological parameters. In addition, water samples were analyzed. Laboratory experiments were performed in an artificial fog chamber and a wind tunnel. A large number of different net materials were evaluated.

Results
Based on onsite measurements and laboratory experiments, rankings of the efficiency of different fog nets could be set up. Monofilaments and three-dimensional structures tended to show higher yields than woven fabrics such as the traditional ‘Raschel’ net. However, the rankings differed from laboratory to field experiment and among fog events in the field. The nets showed less of a wind abating effect than expected and the whole collector resisted the onsite conditions very well. Inorganic water quality was better than that of local wells and met WHO standards, except for the ‘first flush’ just after the start of fog events.

Conclusion
The novel fog collector is well suited to the high onsite wind conditions. Yield can be improved by choosing an optimal net, depending on the specific conditions probably linked to fog parameters (liquid water content, droplet sizes etc.) which should be investigated further. Inorganic water quality at this site was very satisfactory.
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FOG DISTRIBUTION AND FREQUENCY IN EUROPE BASED ON ACTIVE SATELLITE REMOTE SENSING

Background

Information on the distribution and frequency of fog based on passive-sensor satellite data is often incomplete due to cloud overlap.

Aim

The aim of the study is to derive information on fog distribution based on an evaluation of lidar data of the Cloud-Aerosol Lidar and Pathfinder Satellite Observations (CALIPSO) system.

Method

CALIPSO products include information on the vertical distribution of clouds and other atmospheric features below the sensor. This information is filtered by altitude to determine the presence of low-level clouds and fog, and aggregated, to determine their spatial distribution and patterns therein over time.

Results

Maps of fog and low cloud presence and distribution are derived for Europe. This region is chosen as a starting point, since data from other sensors and ground-based measurements are readily available for comparison. In addition to providing an overview of regional patterns, a comparison of conditions at night with the daytime situation is performed.

Conclusion

A comparison with fog distribution maps derived using passive-sensor satellite data yields insights into the frequency of situations with clouds above fog.
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Long-term spatiotemporal variability of stratocumulus (Sc) cloud cover and its relation with fog water yields in the coastal Atacama Desert, Chile

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ABSTRACT

Large-scale Sc variability in the South East Pacific is well understood. However, at local scale the interannual variability and spatial distribution of Sc cloud cover as well as its relation to fog water yields is not properly comprehended. The aim is to analyze and characterize the spatiotemporal variability of fog and its relation with fog water yields in the last 20 years. Two daily GOES satellite images were automatically processed during nighttime of September and February from 1995 to 2015. The variability of Sc was related to fog water yields collected by a SFC since 1997 located in the summit of the coastal range of Atacama desert, northern Chile (20°49´S – 70°09´W). We explore the spatiotemporal long-term Sc/fog variability and its relation with collected fog water. The presence of Sc at the coastal Atacama, as well as the collected fog water during September is quantitative higher than February. Analysis of Sc cloud cover presence shows positive linear tendencies in analyzed areas that coincide with cloud cover observations from coastal airports (Muñoz et al., 2016), a decline is only observed at 1200m asl. ENSO is presented as an indicator of higher variability of Sc and fog water yields during February, but no clear relations were found during September, when most of fog water is collected. El Niño conditions, during February, shows mainly an increase in cloud cover, opposite during La Niña years. The high frequency of Sc cloud cover and lower spatial variability distribution during September within the concentration of the water resource in this season reveal the potential of fog water as a dependable source in an extreme arid environment.

1. INTRODUCTION

The extensive Sc deck at the SouthEast Pacific (SEP) is produced by the thermal inversion created by the large-scale air-subsidence in the subtropical Pacific Anticyclone, intensified by the Humboldt cold Current and the upwelling of even colder waters to the surface of the eastern Pacific (Rutllant et al., 2003; Cereceda et al., 2008). In the coastal Atacama Desert, the SEP stratocumulus (Sc) cloud meets the coastal cliffs to produce a highly dynamic advective marine fog (see figure 1), which embraces a major feature of the local climate, providing humidity to a hyper-arid environment and forming fragile and unique ecosystems (Latorre et al., 2011). In this regard, the Sc cloud annual cycle in coastal Atacama is well-known (Cereceda et al., 2008; Farías et al., 2005), but our knowledge of the detailed spatiotemporal variability of fog and how this changes in concert with the SEP oceanographic and atmospheric realm, remains mostly unknown. The SEP climate variability is mainly controlled by the El Niño Southern Oscillation (ENSO), which seems to exert a direct influence on fog variability (Garreau et al., 2008; Park and Leovy, 2004; Schulz et al. 2011). Nonetheless, this important matter still needs to be assessed with more detail along the Atacama coastline, where for the most part we lack of extended field-recovered-data as those recovered in Estación Atacama UC –Universidad Católica- Oasis de Niebla Alto Patache (UC Atacama Station, Fog Oasis Alto Patache – FOAP-)(see figure 1).

2. DATA and METHODOLOGY

GOES satellites images were processed to comprehend the Sc/fog variability at coastal Atacama during diverse ENSO years. We analyzed the seasonal spatiotemporal percentage
of Sc presence and frequency during September (1995 to 2015) and February (1997 to 2015), months that present the maximum and minimum values of fog data collected (L/m²/month) by a Standard Fog Collector (SFC) (Schemenauer and Cereceda 1994) since 1997 to present at FOAP. Here we process two daily hours (03:39 and 07:39 UTC), that correspond to the maximum time fog presence (Farias et al., 2005; Cereceda et al., 2008a). The identification of low clouds is based in the short (3.8 µm) and long (10.9 µm) thermal infrared wavelengths, widely used (Ellrod, 1995; Underwood et al. 2004).

Figure 1. The stratocumulus deck at the coastal Atacama Desert. This cloud results in the existence of a well defined fog belt within a vertical stretch between about 900 – 1200 m asl at the coastal Cordillera; the rectangle corresponds to the study area analyzed with GOES satellite (base image: Sensor Aqua-MODIS, august 1st 2014, 18:43 UTC; source: Aqua/Modis L1 product).

The long-term spatiotemporal identification of Sc and fog, allows to analyze its variability in different zones (see figure 2), offshore and inland, its behavior during diverse ENSO scenarios and its relation with the fog water yields collected at FOAP.

Figure 2. Study area in coastal Atacama. Points correspond to analyzed areas, where from west to east are located at 65 km offshore, 23 km offshore, 5 km offshore, over coast line, over 1000m asl and over 1200m asl. The latitudinal distance between points (letters) is approximately 21 km.

3. RESULTS

The presence and frequency of Sc or fog at coastal Atacama has a strong temporality, the presence average over the ocean is 90% higher in September than February, in the area between coast line and the terrain altitude of 1000m asl. is 88% and in the rest of the area over 1000m asl. is 82% higher respectively. In terms of fog water collected at FOAP, the amount has similar temporal variations, where September is 93% higher.

Longitudinally, Figure 3 (a and b) shows that during September Sc presence decrease from west to east at all latitudes, with the biggest variability in the coast and inland zone, mainly at 1000m (s=0.16). During February the variability increase, mostly in the norther part (see figure 4a), where even coastal Sc or fog presence could be higher than offshore areas, associated to the formation of orographic fog in detriment of advective marine fog. Surprisingly in the
southern part, the west-east tendency returns (see figure 4b).

Figure 3. Longitudinal profile of September averages for period 1995-2015. Letters correspond to analyzed latitude.

Figure 4. Longitudinal profile of February averages for period 1997-2015. Letters correspond to analyzed latitude.

Latitudinally, during September there is a decrease from south to north, specially in the offshore areas. Inland zones, varies according to coast distance, areas in D, F and G, altitudes of 1000m or 1200m asl are closer to the coast, revealing the relevance of the local component (see figure 5a). During February, the decrease (S to N) is significant just in the most offshore zone (65 km) (see figure 5b).

Figure 5. Latitudinal variations of Sc/fog presence, a) correspond to September, and b) February

The variability of Sc/fog presence present a relation with ENSO only observed during February (see figure 6), same situation occurs with fog collected fog water. The Oceanic Niño Index (ONI) correlate positive and significant (98%) with the 3 zones averages (r=0.67 with Ocean; r=0.66 with coast-1000m; r=0.65 with above 1000m).

Figure 6. Variability of ONI and zonal Sc/fog presence averages along analyzed period (1997-2015) during February.

El Niño years (ONI ≥ +0.5) present a positive percentage difference of 96%, 92% and 91%
over La Niña year (ONI ≤ -0.5) in amount of Sc/fog presence average Sc in the ocean, coast-1000m and above 1000m areas respectively. Finally, the amount of Sc/fog presence in the different areas shows positive lineal tendencies, only negative trends were found at 1200m asl areas, consistence with the decrease in the inversion layer altitude (Quintana & Berrios, 2007).

4. CONCLUSION

The Sc cloud at coastal Atacama has a strong temporality, its presence at different zones (offshore and inland), as well as the fog water collected at FOAP is around 90% higher during September than February.

In a longitudinal profile, the Sc presence decrease from west to east. Only during February, in the northern part of the study area, greater Sc presence were found at the coast and inland areas. Latitudinally, there is a decrease from south to north, mainly during September in offshore areas. February shows a bigger variability, the norther negative trend is only observe in the western offshore area. Local geographical and atmospheric variables seems to be the relevant in coastal and inland variability.

ENSO shows a relation with Sc/fog presence variability during February, when ONI shows positive and significant correlations with the cloud cover in ocean and inland areas. El Niño years presents over 90% bigger amount of Sc/fog than La Niña years in all areas.

The amount of Sc/fog presence present a positive tendency in all areas, also described by Muñoz et al. (2016), the only exceptions are the areas at 1200m asl, which could be related to the decrease in the inversion layer altitude.

5. REFERENCES


Nowcasting of the fog formation by radiative cooling, based on ground-based and satellite observations

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ABSTRACT

A decision assistance tool prototype for fog nowcasting was developed by the HYGEOS Company in collaboration with the CNRS French research institute (Centre National de Recherche Scientifique) in the framework of the PreViBOSS project, financed by the DGA French military agency (Direction Générale de l'Armement).

We analysed data acquired at the SIRTA platform, 20 km South-West of Paris, during the 2011-2012 and 2012-2013 fog seasons, and by the SEVIRI instrument onboard the METEOSAT Second Generation satellite, processed by the EUMETSAT/NWCSAF program to derive a cloud cover classification. Six predictors of the formation of developed and thin fogs by radiative cooling were identified, inferred from the atmospheric visibility, the air temperature change from the surface level up to 30 m height, and the cloud cover above the SIRTA and in a larger region. Tests are made as soon as visibility is included between 5 and 10 km, which defines the moderate visibility event, for an anticipation time varying in average between 2 and 4 h.

Developed fog forms in only one scenario: visibility between 5 and 10 km, negligible temperature change over the first 30 m height, and cloud-free sky over the SIRTA, but with low clouds replacing clear-sky in the 9x9-pixel zone around the SIRTA. The formation probability is 26% and increases up to 40% if visibility decreases below 5 km after this scenario, but reducing the anticipation time to around 1.5 h in average. Other predictors can rapidly be tested and integrated in the tool prototype if they allow to identify undoubtedly further no-fog events. The tool needs to be applied to independent data sets to understand its application limits.

1. INTRODUCTION

The fog specific features as the sudden visibility decrease, its potential long duration and large spatial extent, its spatial heterogeneity, all impair severely transport activities, with possible human injuries. Forecasting is necessary to diminish the hazards caused by low visibility events. Numerical weather prediction models are usually not able to forecast the fog life cycle at satisfying spatial and time resolution [e.g. Clark et al., 2008]. Real time observation allows to improve the forecasting results by not only defining initial conditions of the fog formation, but also as a basis of nowcasting [e.g. Vislocky and Fritsch, 1997; Golding, 1998].

We show how several predictors and adapted criteria allow to distinguish no-fog and pre-fog events a few hours in advance. As predictors witness processes in action, they are dependent on the fog type, and we choose to focus on fogs formed by radiative cooling. Predictors of the fog formation and associated criteria are defined from observations run in November 2011 at the SIRTA platform and jointly by the SEVIRI instrument onboard the METOSAT Second generation (MSG) satellite platform. The cloud cover classification provided by the EUMETSAT/SAFNWC program is used. Fog formation probabilities are computed for 5 months of data in November 2011-March 2013. SIRTA deploys an impressive instrumental payload to survey atmosphere since early 2000s [Haefelín et al., 2005], where around 45% of the fogs are formed by radiative cooling [Dupont et al., 2015]. The PreViBOSS project (http://www.hygeos.com/pages/projects/previboss.php) allowed to bring a focus on the fog phenomenon [Elías et al., 2012], and a second ParisFog field campaign extended over three fog seasons in 2010-2013, after the first 2006-2007 campaign [Haefelín et al., 2010].

2. DATA

The ground-based data set was generated by the SIRTA Observatory (Site Instrumental de Recherche en télédétection Atmosphérique) (Haefelín et al., 2005), located in the suburbs of Paris. Measurements were made during the two fog seasons of October 2011 – March 2012 and
October 2012 – March 2013. Five months with a significant amount of low visibility events were selected: November 2011 and 2012, October 2012, and March 2012 and 2013. Details about the observations are given by Dupont et al. [2015]. Visibility was measured by a Degreane DP20+ diffusometer set up at 3 m above ground level (agl). The vertical thermal gradient as well as relative humidity were measured by thermometers set up along a 30-m meteorological mast. The cloud cover below 6 km agl was sounded by a Vaisala CL31 ceilometer providing a 1-min data set. We also use the cloud type index derived from measurements by the SEVIRI instrument onboard the METEOSAT Second Generation (MSG) satellite, to complement the CL31 ceilometer. The EUMETSAT/SAFNWC algorithm processes MSG/SEVIRI data to classify the cloud cover scene into 20 categories which are aggregated into 6 classes pertinent for our study. The SEVIRI spatial resolution is 4.5x4.5 km² at nadir. All ground-based data are averaged over 15 minutes to keep best details and to be consistent with MSG/SEVIRI time resolution.

3. PREDICTORS

Six predictors were identified from the November 2011 observation data set, as well as criteria which define scenarios of contrasting probability of radiative cooling formation of developed and thin fogs. All events respecting the different scenarios are counted, as well as the number of no-fog and pre-fog events in each scenario. The ratio of pre-fog over added pre-fog and no-fog event numbers provides the probability of fog formation, similarly to Veljovic et al. [2015].

3.1. The visibility predictors

Two predictors concern the visibility: the visibility level and its time evolution. The first criteria are 5 < visibility < 10 km, defining the moderate visibility (mv) event. The second criteria is on the visibility level before or after the mv event. Horizontal atmospheric visibility at surface level is the most pertinent parameter to observe when dealing with the fog phenomena, because 1) visibility describes the adverse impact of fog on human activities and 2) visibility informs about the progress in the clear air-fog life cycle, caused by hydrated aerosols and droplets. As the further condition of clear-sky is set (Section 3.2), only aerosols were responsible for such low visibility in mv events, and no drops. Visibility decreasing because of aerosols growing up by uptake water is a predictor as Elias et al. [2015] showed that such aerosol presence always preceded fogs in November 2011, generating mist. The mist is defined by visibility smaller than 5 km, with absence of fog droplets and drizzle and rain drops [Elias et al., 2015], and the fog is defined by the droplet formation, usually occurring at visibility between 1 and 3 km.

The mv events are chosen for testing the predictors, because significant anticipation time is provided before the fog formation. The mean anticipation time is included between the pre-fog mist duration and the duration of added pre-fog mv and mist events. It was included between 2 and 3.5 h in 2011-2013, being larger for thin fog (2.1-3.8 h) than for developed fog (1.1-3.0 h), with large standard deviation of 70 to 120% per month. Consequently, we consider that the time horizon of our nowcasting scheme is ~2.5 h, even if it is not predicted here and is not a product of our decision assistance tool.

The second test concerns the visibility evolution, as the mv event is not always followed by the fog formation. Three main types of mv events are defined according to the visibility evolution before, during and after the event. Clear-air is defined by visibility > 10 km. The mv event types are:
- the pre-fog mv event: the mv event is followed by mist and eventually by fog. The sequences are mist-mv-mist-fog or clear-mv-mist-fog.
- the no-fog mv event: the mv event is followed by mist where visibility increases back to reach 5 km, and is then followed by another mv event. The two sequences are mist-mv-mist-mv and clear-mv-mist-mv.
- the no-mist mv event: the mv event is followed by clear-air. The two sequences are mv-clear-mv and clear-mv-clear.

542 mv events were observed during the five months. 46 pre-fog mv events were counted, giving a 8.5% probability that fog formed after any of the 542 events. 184 mv events followed the sequence clear-mv-clear, which are disregarded in the following, assuming they can be distinguished soon enough from the other sequences. The other criteria are applied on the 358 other events.

3.2. The cloud cover predictors

Three predictors concern the cloud cover:
1) The cloud fraction (CF) is defined as the
proportion of hits (detected clouds by the CL31) during 15 minutes, and CF is averaged for the duration of the mv event. <CF> is not only a predictor but also defines the fog formation type. Three cloud cover categories are defined:
- clear-sky, as <CF> < 30% and standard deviation < 30%;
- overcast condition, as <CF> > 70% and standard deviation < 30%;
- scattered cloud cover, as 30 < <CF> < 70% or standard deviation > 30%

Clear-sky is observed during 101 mv events, overcast conditions during 240 mv events and scattered cloud cover during 11 mv events. The situation is undefined for 6 cases, which represents around 1% of all situations. Clear-sky is the condition for radiative cooling, and next criteria are applied exclusively on these situations. 23 of these are pre-fog events and the fog formation probability is 23%.

2) The cloud cover above the SIRTA is also provided by the cloud type product delivered by EUMETSAT/NWCSAF, in case clear-sky conditions are identified by the ceilometer. The proportion of both EUMETSAT/NWCSAF clear-sky and cirrus detections in the SIRTA pixel during the mv events is computed as N\text{clear-sky/cirrus} / N\text{mv}, where N\text{clear-sky/cirrus} is the number of times the specific scene is detected in the same pixel during the mv event, and N\text{mv} is proportional to the mv event duration. Three categories are defined:
- cloud-free from bottom to top (CFr): N\text{cirrus} / N\text{mv} < 50%, and N\text{clear-sky} / N\text{mv} >= 50%;
- only cirrus presence (CIR): N\text{cirrus} / N\text{mv} >= 50%, and N\text{clear-sky} / N\text{mv} < 50%;
- other thick clouds in the pixel but not observed over the SIRTA by the ceilometer (MH): N\text{cirrus} / N\text{mv} < 50% and N\text{clear-sky} / N\text{mv} < 50%.

In the 5 months, fog did not form after a mv event when thick clouds are found in the pixel: this is an unfavourable scenario that occurred 7 times. The fog formation probability then increased for the remaining 94 mv events to 24%. Cloud-free from bottom to top is observed during 85 mv events: 66 no-fog and 19 pre-fog events. Cirrus was observed during 4 pre-fog and 5 no-fog mv events, generating a thin fog formation probability of 44% under cirrus.

3) The regional cloud cover change is computed as a change of N\text{clear-sky/middle-high thick} in a 9x9 pixel zone around the SIRTA between 2 time steps. N\text{clear-sky/middle-high thick} is the number of pixels the specific cloud cover is detected in a 9x9-pixel zone during one time step. We consider here the regional increase of low cloud cover (LCI), which occurred for 53 of the 85 CFr events, with a probability of 26% for 14 for formation events.

### 3.3. The vertical thermal gradient predictor

The sixth predictor is the vertical thermal gradient $\Delta T_v$, computed as $(T(30m) - T(2m))/28$, which is also used to define the fog type:
- Not stratified (NS) and developed fog: $\Delta T_v < 0.035^\circ C/m$;
- Strongly stratified (Str) and thin fog: $\Delta T_v > 0.060^\circ C/m$;
- Moderately stratified (MS) and intermediate fog: $0.035 <= \Delta T_v < 0.060^\circ C/m$.

![Figure 1. Visibility (top) and vertical thermal gradient (bottom) for 4 days of November 2011 between 00:00 and 15:00 at SIRTA. Non stratified cases are plotted in red and strongly stratified in blue. Thick lines with circles show the pre-fog cases while the dashed lines with the crosses show the no-fog cases.](image1.png)

**Figure 1.** Visibility (top) and vertical thermal gradient (bottom) for 4 days of November 2011 between 00:00 and 15:00 at SIRTA. Non stratified cases are plotted in red and strongly stratified in blue. Thick lines with circles show the pre-fog cases while the dashed lines with the crosses show the no-fog cases.

### 4. SEVERAL SCENARIOS

Developed fog formed after only one scenario: regional increase of low clouds with cloud-free sky above the SIRTA, and with a non stratified atmosphere in the first 30 m (CFr-LCI-NS). The formation probability is 26% for 6 developed fogs. 8 of the no-fog events respecting this scenario are not followed by mist, and consequently the probability of the developed fog formation increases up to 40% with the further criterion of visibility < 5 km after the mv event. Visibility and the vertical thermal gradient observed during this scenario on 15
November 2011 are plotted in Figure 1. Visibility is between 5 and 10 km between 01:00 and 02:00, when $\Delta T_V$ is below 0.035°C/m, and fog forms slightly before 03:00. However, during same scenario on 13 November 2011, fog does not form even if visibility is observed between 5 and 10 km before 06:00 with $\Delta T_V$ slightly smaller than 0.035°C/m. Same scenario but with strong stratification generates thin fog in 6 cases and no-fog in 12 cases, with 33% probability, and 38% if mist is observed after the mv event. Figure 1 shows clearly the different values in $\Delta T_V$ with the non-stratified cases. During a similar scenario except cirrus are observed, the probability reaches 66% for two thin fogs.

**5. CONCLUSION**

We analysed measurements taken during five months of low visibility levels, to improve nowcasting of fog formation by radiative cooling. The measurements described physical processes occurring at surface level but also along the whole atmospheric. The physical processes were observed from November 2011 to March 2013 at the SIRTA platform by a diffusometer, a ceilometer, and thermometers set up along a 30-m meteorological mast. We also used data acquired by the SEVIRI instrument onboard the METOSAT Second Generation satellite, and processed by the EUMETSAT/NWCSAF program to derive the cloud classification.

Six predictors were identified which allow to define favourable and unfavourable scenarios of thin and developed fog formation. The first predictor is the atmospheric visibility level included between 5 and 10 km, defining the moderate visibility (mv) event. Comparisons are made between parameters observed during the pre-fog and the no-fog mv events to identify the fog formation predictors and the corresponding criteria to apply. The other predictors are the visibility change in time, the air temperature change from surface level up to 30 m height, and the cloud cover above the SIRTA and in the region around the SIRTA. During 5 months, 542 mv events were counted, with 8% fog formation probability. Events with visibility decreasing from 10 km and increasing back to 10 km without entering in a mist event were disregarded, as well as events with clouds detected by the ceilometer, in order to suit the radiative cooling conditions. It remained 101 mv events, with 23 pre-fog and 78 no-fog events.

The fog formation probability is 26% for 6 developed fogs for only one scenario: regional increase of low clouds with cloud-free sky above the SIRTA, and with a non stratified atmosphere in the first 30 m. The probability increases up to 40% if the mv event is followed by mist. The probability is larger under cirrus, from 44 to 66% for thin fogs. Tests during the mist events were made to further increase the fog probability, but not presented here.

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OPTICAL THICKNESS AND EFFECTIVE RADIUS RETRIEVALS OF LOW STRATUS AND FOG FROM MTSAT DAYTIME DATA AS A PREREQUISITE FOR YELLOW SEA FOG DETECTION

Operational nowcasting techniques for sea fog over the Yellow Sea rely on data from weather satellites because ground-based observations are hardly available. While there are several algorithms for detecting low stratus (LST) that are applicable to geostationary weather satellite data, sea fog retrieval is more complicated. These schemes mostly need ancillary data such as Cloud Optical Thickness (COT) and Droplet Effective Radius (DER). To retrieve the necessary parameters for sea fog detection over the Yellow Sea, the Comprehensive Analysis Program for Cloud Optical Measurement (CAPCOM) scheme developed by Kawamoto et al. (2001) was adapted to the Japanese Multifunctional Transport Satellites (MTSAT) system-Japanese Advanced Meteorological Imager (JAMI). COT and DER values were then retrieved for 64 cases over the Yellow Sea (= 85,000 LST pixels) and compared with the COT and DER products from the MYD06/MOD06, CAPCOM-MODIS (Moderate Resolution Imaging Spectroradiometer) and CloudSat (cloud radar). Results showed that the COT and DER values retrieved from JAMI were satisfactory. The MTSAT-2 JAMI data delivered better COT values than the MTSAT-1R JAMI data, due to the re-calibration of MTSAT-2 JAMI’s visible (VIS) band in 2011. Similarly, improvements were seen in DER retrieval, even though the VIS re-calibration primarily affects COT retrieval. By comparing the difference in stratus thickness calculated by MTSAT-1R and MTSAT-2, the COT and DER retrieved from MTSAT-2 JAMI can be used in ground fog retrieval schemes. These values exhibit less bias, especially in cases involving high cloud top and thin cloud thickness. Both the COT and DER retrievals from MTSAT-2 JAMI offer potential as reliable parameters for Yellow Sea fog detection.
DELINEATING THE MOUNTAIN CLOUD FOREST OF TAIWAN USING SATELLITE DERIVED GROUND FOG FREQUENCY MAPS

Background
Mountain cloud forest in Taiwan has been subject to several studies. Its spatial distribution is, however, only vaguely known as it has been mapped based on distinct plots only. Those plots are – due to the inaccessibility of Taiwan's mountainous terrain – mostly located near to roads.

Aim
The aim of the study is the creation of a spatially explicit map about the distribution of mountain cloud forest in Taiwan.

Method
Using a statistical ground fog detection approach, maps of the ground fog frequency for each month of the year have been created from MODIS daytime data. A random forest classifier was trained using point data from a country wide vegetation survey in order to map the cloud forest based on the frequency maps in combination with other input as landsat channels and a digital elevation model.

Results
The quality of the resulting map has been compared to the training data set using an out of bag approach. It is of generally high quality (MCC = 0.8856, POD = 0.9405, POFD = 0.0481, FAR = 0.0899). The map shows a strong height dependence of the cloud forest occurrence but also a decreasing trend in the height of the lower cloud forest limit between the south western and the north eastern part of the island.

Conclusion
It has been shown that ground fog frequency data is well suited for the mapping of mountain cloud forest.
Based on the Weather Research and Forecasting (WRF) model, the performance and sensitivity to different vertical resolutions for simulating the Yellow Sea fog is studied. Numerical experiments with combinations of 3 vertical resolutions (35\(\eta\), 44\(\eta\) and 63\(\eta\)) and 2 planetary boundary layer schemes (YSU, MYNN) are designed and conducted for 10 sea fog cases. The sensitivity of fog-area and fog-top height to vertical resolution is statistically analyzed, and a typical case is investigated in detail to reveal the effects of fog-top long-wave radiation cooling and turbulence inside fog.

The statistical results show that: (1) Fog-area simulation is significantly improved with the increasing of vertical resolution, and the cases, which have larger fog height differences between the experiments with different vertical resolutions, also perform better for fog-area; (2) The YSU scheme is more sensitive than the MYNN scheme, and relative to 35\(\eta\)-experiments, 44\(\eta\)-experiments have 13.29% and 10.22% improvements for averaged probability of detection (POD) and equitable threat score (ETS), respectively. Insight of the typical case indicates that a reliable modeling of fog-top long-wave radiation cooling and turbulence inside fog strongly depends on vertical resolution. It can be outlined as: (1) Coarse vertical resolution with weaker turbulence intensity leads to a failure of simulation; (2) A positive feedback —— ‘increased cloud liquid water → enhancing long-wave radiation → strengthening cooling → cloud liquid water increased’ —— forms near the fog top, and fine vertical resolution is helpful to maintain and strengthen this feedback loop more easily than the coarse; (3) Only the simulations with fine vertical resolution can capture downward developing buoyancy turbulence that is produced by fog-top long-wave radiation cooling. The buoyancy turbulence has a comparable strength with shear turbulence near sea surface, and it results in a phenomenon often observed that sea surface temperature is higher than air temperature during sea fog.
LIQUID WATER CLOSURE EXPERIMENT AT SIRTA OBSERVATORY DURING FOG AND LOW LEVEL STRATUS CLOUD

Background
Liquid water contents and droplet size distributions are important parameters of fog and low-level stratus clouds because they control radiation exchange (both solar and infrared) throughout the cloud layer and vertical redistribution of water in the cloud layer. These parameters can be derived from in-situ sensor measurements or retrieved from remote sensing measurements. Even if instruments are properly calibrated, uncertainties in retrieved parameters remain. Better understanding of these uncertainties can be obtained by comparing parameters derived from in-situ and remote sensing measurements.

Aim
The aim of this study is to validate remote-sensing based retrievals of cloud droplet microphysical properties using in-situ measurement profiles.

Method
Intensive observation periods (IOP) have been conducted at the SIRTA Observatory (Palaiseau, France) where a tethered balloon (between ground level and 500m above ground level) carrying a portable Optical Particle Counter named LOAC was deployed. Droplet microphysical properties derived from the BASTA 95GHz FMCW cloud radar were compared to in-situ measurements of liquid water content and droplet size distributions. Instrument cross-correlation and evaluation between in-situ sensors, active and passive remote sensing have been done.

Results
The data sets of interest include: microwave radiometer liquid water path (LWP), BASTA cloud radar reflectivity [Delanoë et al., 2015], and LOAC droplet size distribution [DSD, Renard et al., 2015]. The LWP can be derived from HATPRO MWR with an accuracy better than 10 g/m². The cloud radar can be calibrated to provide a reflectivity with an accuracy approaching 1 dBZ. Droplet size distribution measurements along the vertical in fog or low-level stratus cloud layers were used to calculate associated reflectivity [Mie, 1906] and next compared to the reflectivity measured with BASTA cloud radar. The reflectivity comparison yields satisfactory results with a slope coefficient better than 0.9 and limited scatter. A fitted Z-LWC relationship was derived from BASTA and LOAC profiles. A liquid water closure is done to compare the liquid water path derived from HATPRO microwave radiometer measurements and calculated from the LWC profile derived from BASTA reflectivity measurements. Good agreements are found for single layer non-drizzling clouds. Significant discrepancies are found when precipitations are present or in case of multi-layer clouds. We are currently investigating the impact of the spatial and temporal variability of the droplet size distribution shape (mono-modal, bi-modal) on the Z-LWC law.

Conclusion
A complete methodology has been developed to derive the liquid water content in fog layers using from the BASTA cloud radar and the LOAC optical particle counter. Vertically integrated values of LWC (LWP), are compared successfully with direct measurement from HATPRO microwave radiometer.

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THE IMPACT OF VERTICAL RESOLUTION ON FOG FORECASTING WITH THE MESO-SCALE MODEL AROME: A CASE STUDY AND STATISTICS

Background
Operational short-term fog forecasting is a real challenge and has security and economic impact, especially for airports.

Aim
In this study, the meso-scale operational limited-area model AROME-France (Application of Research to Operations at Mesoscale, Seity et al 2011) is used to highlight the impact of the vertical resolution on onset, evolution and dissipation of fog through isolated fog case and statistical study at Roissy Charles De Gaulle (CDG) airport.

Method
Simulations were performed with a specific AROME configuration based on the operational AROME-France model. Three different vertical resolutions were used, 60 levels (LR), 90 levels (MR) and 156 levels (HR). Long period simulations using LR and HR configurations were performed over the winter 2011-2012 in order to validate the interest of a fine vertical resolution on fog forecasting.

Results
The vertical resolution has a strong impact on the onset time (two hours between LR and HR) and has also a strong impact on the processes leading to the fog. The fog episode has been simulated as radiation fog by LR and advection-radiation fog by HR. This different model behaviour is due to more pronounced nocturnal jet and turbulence, induced by using finer vertical resolution. Processes involved in the mature and dissipation phases were the same for all configurations but with different intensities and accuracies. The behaviour of HR over a long period confirms the results obtained in the study case, with a more heterogeneous fog and with an earlier onset time compared to LR. Some events are predicted only by HR resolution. However, the number of false alarms is increased by HR.

Conclusion
Using a finer vertical resolution allows to simulate small scale processes occurring close to the ground. The vertical resolution impacts strongly advection and turbulence terms which play essential role on fog onset.

Reference
Simulations were performed with a specific AROME configuration based on vertical resolution to validate the interest of a fine resolution on fog forecasting. Three different vertical resolutions were used, 60 levels (LR), 90 levels (MR), and 120 levels (HR). The impact of the vertical resolution on fog forecasting is essential, especially for airports, as fog has a strong impact on the processes leading to its dissipation. The fog episode has been simulated as radiation fog by LR and to the fog. The fog episode has been described in the following stages: formation, dissipation, and transitions between stratus and fog. The development and principles of the PARAFOG algorithm, a decision support system for radiation fog forecasting based on analysis of ALC measurements, were used to show the efficiency of PARAFOG to detect radiation fog events and quasi-fog events observed at SIRTA and Uccle. The validation series from 2006 to 2014. The validation of PARAFOG was made on ALC data (CL51) measured at Uccle (Belgium).

**Results**

The PARAFOG development is based on the attenuated backscatter signal influenced by the atmospheric relative humidity. This relationship is due to the significant increase of atmospheric hygroscopic aerosols in near-saturation condition, inducing an increase of the backscatter signal. In the framework of the TOPROF COST Action, a methodology was developed to select appropriate fog predictor parameters based on the physical laws that have been established empirically on the ALC datasets between relative humidity and aerosol optical parameters. A selection of several radiation fog events and quasi-fog events were used to show the efficiency of PARAFOG to detect radiation fog events up to 60 min before their occurrence.

**Conclusion**

PARAFOG, combined with ALC measurements, found at most airports, could provide useful warning to airport forecasters about when radiation fog is likely or not likely to impact air traffic.
A SATELLITE VIEW ON FOG DEVELOPMENT IN THE NAMIB DESERT

This contribution presents plans for satellite-based analysis of the temporal and spatial patterns of fog development and the underlying processes in the coastal Namib desert.

In the virtual absence of other types of precipitation, fog in the Namib region is an important source of water and thus of great ecological relevance. Despite its ecological importance, spatially and temporally complete observations of Namib-region fog are still missing. Microphysical characteristics and their temporal development in fog life cycle stages are not yet understood. Links to Atlantic Stratocumulus clouds and interactions with aerosols have not been considered systematically, nor have other meteorological determinants.

In this component of the planned joint research project NaFoLiCa (Namib Fog Life Cycle Analysis), a combination of geostationary and polar-orbiting systems will be applied to detect spatial and temporal patterns of fog, as well as its microphysical properties. Based on retrieved microphysical properties and temporal developments, fog life cycle stages will be identified. Using auxiliary information on meteorological conditions and aerosol, a statistical model will be built to explain the processes determining the development and properties of fog situations. Insights from the other component projects (numerical modelling, field observations) will help to more fully understand fog processes on different tempo-spatial scales.
Background
Constructing an artificial lake may lead to change in local fog frequencies. Lee (1981) investigated the influence of artificial lakes on fog occurrence in Chuncheon and he found a two-fold increase in fog events following the reservoir construction. The increase in the local fog frequencies after lake construction might be explained by contribution of steam fogs that forms over warm water surface during cold nights. However, the influence on radiation fog forming over land in the neighbourhood of the lake is not well investigated yet. An obvious factor is water vapor supply from lake that may enhance the fog formation. On the contrary, as the lake water remains warm even during cold night, produces warming of the near surface air, and may slow down the condensation process. To better understand the relation between these processes and fog formation a more detailed study is required.

Aim
The main goal of this study is to investigate how the artificial lake may affect the fog formation and life cycle of the radiation fog using numerical model.

Method
In this study we used the WRF mesoscale model to simulate typical radiation fog event observed in Chuncheon Basin. The fog first formed over rural areas near the Uiam Lake and later developed into continuous fog layer covering whole Chuncheon Basin including the lake. The model was evaluated against observational data and optimized to produce the most realistic results. The performance of several schemes including nested WRF-LES mode was analysed to select the optimal model configuration. The best results were used as a reference case for current lake state scenario. A scenario without lake was then produced by replacing the lake grid points with forest and agriculture land-use types. The two scenarios (with and without lake) were then compared and analysed.

Results
Simulation of radiation fog using WRF model showed reasonable results. The life cycle and distribution of fog as well as other relevant variables were in acceptable agreement with our field studies. The most realistic results were produced by WRF with LES mode if sufficient spin-up time was provided. According to the model results, fog formed well in both scenarios. In scenario with lake, similarly to our observation, the fog formed first at lake shores and in later stage connected over lake forming continues fog layer. The highest Liquid Water Content (LWC) was produced over surrounding land rather than over water surface. Significantly denser fog developed in scenario without lake, suggesting that the fog density is more sensitive to radiative cooling rather than evaporation from the water surface, which is generally weaker during calm wind condition.

Conclusion
The result demonstrates the importance of heating from warm water surface as well as influence of water vapor supply for formation and development of radiation fogs. The results show that the constructing of artificial lake may affect the local radiation fog in terms of its density, and spatial and temporal distribution of LWC. According to the model, radiation fogs may form over land and develop into wide fog layer. However, the density of the fog is
reduced due to warming from open water surface. On the contrary, the fog would develop into very stable dense fog at the same meteorological conditions in the absence of the artificial lake. In our future studies we plan to perform long period simulations that might reveal how the lake affects the radiation fog frequencies.

Acknowledgements
This work is supported by the "Advanced Research on Applied Meteorology" of National Institute of Meteorological Sciences (NIMS) funded by the Korea Meteorological Administration (KMA).

References
A 10 YEAR FOG AND LOW STRATUS CLIMATOLOGY FOR CENTRAL EUROPE BASED ON METEOSAT SECOND GENERATION DATA

Background
Due to a significant impact of fog and low stratus (FLS) on economy, ecology and traffic systems, there is a growing demand of high resolution information on FLS occurrence and trends in its distribution. Currently, no suitable information is available. A long term FLS climatology based on a homogenously derived dataset is needed to provide the requested information, derive FLS risk maps and discover spatial and temporal trends in the FLS distribution.

Aim
In this study a high resolution FLS dataset based on Meteosat SEVIRI data from 2006 to 2015 is computed for Central Europe. Subsequently spatial and temporal trends in FLS distribution are analyzed.

Method
The SOFOS-scheme for FLS detection developed by Cermak & Bendix (2008) has been adapted to be operationally usable on the full disk while also significantly lowering processing times for each scene. Meteosat SEVIRI data from 2006 till 2015 was processed and a 10 year FLS climatology was derived. To investigate temporal and spatial changes in FLS distribution, risk and trend maps were produced.

Results
Preliminary validation results based on METAR observations show the same quality for the investigated period as presented in Cermak & Bendix (2008). Derived FLS risk maps generally depict a decreasing trend from north to south. Local maxima in FLS occurrence can be found in regions of the baltic sea, north-central Spain, the swiss plateau and parts of the Rhine, Danube and Po valleys. A clear temporal decrease in FLS occurrence for all parts of the investigated domain confirm recent measurements.

Conclusion
As work is still in progress, final conclusions cannot yet be stated.

References
Remote sensing of fog with a scanning K_a-band cloud radar at Munich airport

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ABSTRACT

During the fog season 2015/2016, a scanning K_a-band cloud radar and other remote sensing instruments were set up at Munich airport to observe fog. Different scan procedures were operated. A straightforward and easily interpretable visualization of the measurements has been developed. It is shown that the visualization may help aeronautical meteorological forecasters to improve the nowcasting of the local fog development. Several processes are well observable: the temporal development of the fog layer thickness, the formation/dissipation of fog by stratus base lowering/lifting, the advection of fog as well as the approach of higher clouds and its influence on fog dissipation.

1. INTRODUCTION

Air traffic is strongly influenced by low visibility conditions. Low visibility procedures (LVPs) are typically triggered by a RVR (Runway Visual Range) below 550 m or a ceiling below 200 ft agl. Under such conditions the time interval between take-offs and landings is increased, thus leading to a reduced capacity and economic losses. More precise nowcasts of fog formation and dissipation could help to optimize the management of air traffic control. To improve the nowcasting (up to 30-60 min) of the local fog development, a scanning K_a-band cloud radar (Figure 1) and other remote sensing instruments as sodar, ceilometer and Doppler lidar are used to monitor fog.

The three-dimensional structure of fog and its advection was first measured with a scanning K_a-band cloud radar in Japan (Hamazu et al., 2003). At Munich airport, a scanning K_a-band cloud radar was already operated during the fog season in winter 2011/2012 (Bauer-Pfundstein et al., 2013). In this preliminary campaign, the general applicability of the instrument for observing fog was tested. In addition, the campaign intended to derive an empirical relation between the radar reflectivity factor Z and visibility.

2. MEASURING PROCEDURE

The scanning version of a K_a-band cloud radar (MIRA-36, METEK GmbH; Görsdorf et al., 2015) was set up close to the automatic weather station at Munich airport from October 2015 to January 2016. Two different scanning procedures (PPI and RHI) were operated. One full PPI scan (PPI1 + PPI2) at an elevation of 3.2° and two RHI scans (down to 1.2°) were obtained every 10 min (Figure 2). Both RHI scans were aligned with the wind direction measured by the sodar every 10 min at 80 m agl. The alignment was suppressed for wind speeds below 1 m/s. The intention of both scans is to observe the advection of fog banks across the airport.
Figure 1: Scanning Ka-band cloud radar in Japan (Hamazu et al., 2003).

During the fog season 2015/2016, a scanning Ka-band cloud radar in Japan (Hamazu et al., 2003) was tested. In addition, the campaign intended to derive an empirical relation between the radar reflectivity factor and visibility. Low visibility procedures (LVPs) are typically triggered by a RVR (Runway Visual Range) below 550 m or a ceiling below 200 ft agl. Under such conditions the time interval between take-offs and landings is increased, thus leading to a reduced capacity and economic losses. More precise nowcasts of fog formation and dissipation could help to optimize the management of air traffic control. To improve the nowcasting (up to 30-60 min) of the local fog and easily interpretable visualization of the measurements has been developed. It is shown that the three-dimensional structure of fog and its advection of fog banks across the airport, intention of both scans is to observe the evolution of higher clouds. Furthermore, RVR and MOR (Meteorological Optical Range) are measured by 8 Vaisala FS11 visibility sensors along both runways. Cloud Base Heights (CBH) are obtained by 4 Vaisala LD-40 ceilometer, one at each end of the runways.

3. VISUALIZATION

A visualization which includes all relevant information to quickly get a reliable overview of the current spatial extension and structure of fog at the airport has been developed (see Figures 3, 5 and 6). The visualization consists of three different views (e.g. Figure 3 a, from bottom to top) of the current equivalent cloud radar reflectivity factor Zr (dBZ) of hydrometeors supplemented by additional information:

1. full PPI scan, 5 × 5 km
   - concentric circles (ft) indicating fog layer thickness
   - line of alignment of the RHI scans
   - coarse structure of the two runways for orientation (grey)
   - measured values: MOR (green) and RVR (black) at 8 locations (A-H) and CBH (red) at 4 locations
   - METAR (METeorological Aerodrom Report) visibility (observation at about 50 m agl)

2. RHI2 scan, 0 - 16 hft, (fog layer thickness)
   - wind barbs of the sodar at the time of alignment of both RHI scans
   - elevation line of the PPI scan (3.2°)
   - alignment angles of the RHI plane

3. RHI2 scan, 0 - 400 hft, (higher clouds)
   - wind barbs of the Doppler lidar (only every 10th value is depicted if any)

Experienced aeronautical meteorological forecasters can use this visualization in order to improve the nowcasting of the local fog development.

4. RESULTS

Three days of the campaign (2015-10-24, 2015-12-21, 2015-12-29) are chosen to demonstrate the benefit of the cloud radar, supplemented by additional meteorological parameters (see Section 3), to capture the spatial distribution of fog and its temporal evolution.

Figure 2: Scan procedure of the cloud radar.

Figure 3: Fog development on 2015-12-21. The visualization (description: see Section 3) is shown for three points of time: (a) 00:20 UTC, (b) 02:30 UTC and (c) 03:20 UTC.
The decrease of the fog layer thickness from about 350 - 500 ft at 00:20 UTC to about 75 - 150 ft at 03:20 UTC is well observable on 2015-12-21 (Figures 3 a-c). The temporal trend of this process is useful for predicting dissipation times. Approaching higher clouds from westerly directions (visible at 02:30 UTC) influence the final fog dissipation (at about 04:20 UTC, not shown). Remarkable is the wind shift from easterly directions within the fog towards westerly directions above the fog layer (see wind barbs in Figures 3 a-c). METAR visibility at 03:20 UTC is already 4000 m, while MOR values are still below 650 m, confirming the presence of ground fog.

Fog dissipation by stratus base lifting as well as fog formation by stratus base lowering is observed on 2015-12-29. Both processes are indicated by black arrows in the time-height cross section of Ze in Figure 4. The PPI scan within the visualization illustrates the process of lifting or lowering by an increase or decrease of the “round hole” (area with no reflectivity) in the middle of the plot (see Figure 5 b). The rate of change of this feature is usable for predictive purposes. Moreover, the advection of the stratus from northwesterly directions before lowering can be seen on 2015-12-29 at 17:40 UTC (Figure 5 a). At 19:00 UTC the stratus base reached the ground and mature fog is present (Figure 5 c) with MOR between 150 and 175 m and RVR between 500 and 650 m.

A further hint for a rather soon dissipation of fog can also be the presence of drizzle within the fog layer. Drizzle ($-20 \leq Ze \leq +10$ dBZ) is characterized by higher $Ze$ values than fog ($\approx -60 \leq Ze \leq -10$ dBZ). Furthermore, the formation of streaks is very characteristic for the presence of drizzle, noticeable in both PPI and RHI scans on 2015-10-24 (Figure 6). In this example, the fog is already lifted from the ground (MOR $> 1000$ m) but METAR visibility is still low (800 m). The high fog finally dissipated on that day at about 09:00 UTC (not shown).

**Figure 4:** Time-height cross section of Ze (dBZ) on 2015-12-29. The black arrows indicate stratus base lifting and lowering.

**Figure 5:** Fog development on 2015-12-29. The visualization (description: see Section 3) is shown for three points of time: (a) 17:40 UTC, (b) 18:00 UTC and (c) 19:00 UTC.
Figure 6: Drizzle streaks on 2015-10-24.

To sum up, the applied remote sensing instruments have an advantage over the previous instrumentation at the airport in observing fog in the following situations:

- decrease/increase of fog layer thickness, e.g. 2015-12-21
- fog dissipation due to the influence of higher clouds, e.g. 2015-12-21
- advection of fog or stratus, e.g. 2015-12-29
- stratus-fog formation (stratus base lowering), e.g. 2015-12-29
- stratus-fog dissipation (stratus base lifting), e.g. 2015-12-29; remark: the initial lifting is first observed by near-ground visibility sensors
- fog dissipation in combination with the presence of drizzle, e.g. 2015-10-24

5. CONCLUSIONS AND OUTLOOK

Combined remote sensing measurements appear to be a promising tool for aeronautical meteorological forecasters to improve the nowcasting and situational awareness of fog development at airports. In particular, the scanning K<sub>γ</sub>-band cloud radar seems to be very suitable to capture the spatial and temporal development of fog at airports. The forecasters benefit from a straightforward and easily interpretable visualization which comprises all important measurements at a glance.

A validation campaign will be carried out during the next fog season from October 2016 to January 2017 at Munich airport. Aeronautical meteorological forecasters will use the cloud radar measurements supplemented by additional meteorological parameters to nowcast fog. For that reason, a web interface including the presented visualization will be provided for the forecasters. A first version can be viewed here:

http://guest.metek.de/tefis/combined.html?from=2015.10.26+00:00&to=2015.10.26+23:00

More valuable data and/or images, e.g. surface temperatures or time-height cross section of Ze, can be integrated.

6. REFERENCES


7. ACKNOWLEDGEMENTS

The presented work is embedded into the project LuFo V-1 TeFiS funded by the German government (BMWi).
Background
PARAFOG is a new decision support system for radiation fog forecasting based on analysis of Automatic lidars and ceilometers (ALC) measurements and developed in the framework of the TOPROF COST Action. PARAFOG monitors the backscatter signal behavior of ALC in the boundary layer and helps the forecaster to predict fog formation or lack of fog formation.

Aim
This presentation will show a statistical analysis of the temporal evolution of parameters computed by PARAFOG during the early stage of “elevated” radiation fog formation by comparing these evolutions between fog events that occurred and didn’t occur on two observation sites.

Method
The study was made on ALC dataset (CL31) measured at SIRTA in Palaiseau (France) between 2011 and 2014 and also on the ALC dataset (CL51) measured at Uccle (Belgium) between 2011 and 2014.

Results
Fog alert levels were computed by PARAFOG on a severity scale based on the temporal behavior of attenuated backscatter signal. In the case of “elevated” fogs, the altitudes where an alert threshold is exceeded, are structured in layers. Their heights decrease generally with time before reaching the ground. Two computed parameters deduced from these layered structures can be used to separate fog and quasi-fog situations. The temporal evolution of the layer height of each alert level generally increases during fog events while it remains constant during quasi-fog events.

Conclusion
The knowledge of the temporal evolution of the height and of the thickness of the layer of each alert level may improve the effectiveness of the forecasters using PARAFOG to distinguish between fog and quasi-fog events.
THE PAFOG MODEL APPLIED IN DIFFERENT REGIONS OF BRAZIL

Background
So far, the PAFOG (PArameterised FOG) model has been used in Brazil for fog forecasting only in the Northeast of Brazil (NEB).

Aim
The first aim of the study was to apply this model in three different regions of Brazil. Analysis of synoptic processes in fog formation was the second aim.

Method
Information about fog and surface meteorological parameters was obtained from METAR. The synoptic situation during fog and previous days was analyzed by NCEP reanalysis data and Climate Forecast System Reanalysis (CFSR). Stream lines, pressure, temperature advection, thickness, vertical velocity, potential equivalent temperature and satellite data in the infrared channel were studied for synoptic systems identification. The vertical tropospheric structure was studied by radiosonde data from University of Wyoming and CFSR. This vertical structure was used as input data for the PAFOG model.

Results
Five cities were selected because of their location and radiosonde data availability. A study period of two years (2008-2009) was used for the central (Confins) and southern (Porto Alegre) regions. In the NEB (Recife, Petrolina and Salvador cities), due to the small number of fog events, this period was longer: seven years (2008-2014). Fog was observed more frequently in Porto Alegre and Confins, 82 and 74 events per two years, respectively. In Porto Alegre, fog was observed more frequently during autumn and winter but, in Confins, in spring and summer. One event was detected in Recife and Salvador. In Petrolina, no event was registered. Fog in Porto Alegre was associated with 1) a High, 2) a frontal extremity and barotropic cyclone and 3) cyclogenesis.

Conclusion
Radiation fog in Porto Alegre was forecasted by the PAFOG model with 18h antecedence using CFSR input data. In Recife, fog was forecasted by the PAFOG model with 15h antecedence.
EVALUATION OF PBL AND MICROPHYSICS PARAMETERIZATION FOR A FOG EVENT IN THE INDO GANGETIC BASIN BY USING WRF/WRF_CHEM MODEL

Background
Formation and dissipation of fog depends on micro scale to synoptic scale processes and thermos-dynamical processes and their nonlinear interactions, which are challenging factors for a forecaster. Present Numerical Weather Prediction (NWP) models are able to represent some of the micro physical and meteorological processes which plays crucial role in fog formation, but still there are uncertainties in models representing these processes during fog events. To reduce these uncertainties in model we need to choose proper combination of Planetary Boundty Layer(PBL) and Microphysics which plays crucial role to represent fog in NWP models for better forecast skill.

Aim
The main aim of this study is to find out how different combination of micro physics with different PBL schemes in Weather Research and Forecasting (WRF/WRF_Chem) model representing surface meteorology during fog onset, duration, withdrawal time and thickness in a reasonable way by comparing observational data from Cloud Aerosol Interaction and Precipitation Enhancement Experiment (CAIPEEX) Integrated Ground Observational campaign (IGOC) site located at Varanasi in Indo Gangitic Plain (IGP) region (25.06N & 82.59E).

Method
A 20 m tall micrometeorological tower was setup with complete instrumentation for all Sensible and latent heat flux, temperature, winds and dew point measurements are carried out with all in one weather sensor. Air temperature, relative humidity, wind speed and wind direction, pressure are measured at different heights. Soil Moisture, Soil Temp are measured from 2cm to 100cm. Soil Heat Flux sensors are used at 5 cm depth for measurements of soil heat flux. Two net radiometers are used at 2.3 m height for four components of radiation. We have also used the SFAS sodar (Scintec Inc.) and have a maximum range of 500 m for wind measurements. We have chosen permutation and combination of PBL schemes which works better during stable/unstable boundary layer regimes focusing on one turbulent kinetic energy PBL parameterization QNSE, and two first order closer schemes YSU, ACM2 and MYNN2.5, microphysics Lin et al, WSM3, WSM6, WDM6, Morrison 2 momentum schemes have been chosen for simulating the fog event.

Results
Here we have conducted permutation combination of WRF simulations with 5 different micro physics and 4 PBL schemes and tested which combination of microphysics with PBL producing observed fog phenomenon (either LWC or meteorological parameters) during fog event over Varanasi and we also compared model wind speed and wind direction up to 250m with SFAS sodar data during and after fog event.

Conclusions
During fog event micro physics combined with MYNN2.5 PBL simulations represented 2-m Temperature (T2) well, but during non foggy day all combination of schemes represented more or less same features. Before onset of fog model has under estimated wind speed and comparing with all schemes microphysics combination with ACM2 PBL has given some reasonable results.
Comparing with remaining combinations micro-physics with MYNN2.5 simulations has produced reasonable 2-m relative humidity (RH2). Except WSM6-MYNN2.5 PBL simulation has shown reasonable representation of short wave radiation during fog event. Except WSM6-MYNN2.5 scheme none of the combination of micro-physics and PBL produced Liquid Water Content (LWC).

Only WSM6-MYNN2.5 PBL combination has captured two fog events but dissipation has occurred very early in both days. During non foggy day’s model under estimates Sensible Heat Flux (SHF) and during foggy days model over estimated SHF. Simulation with WRF_Chem model run also shown impact of aerosols during fog event. Primary results will be presented in this conference.
The determination of fog occurrence and disappearance is of significant economic and social interest especially for aviation, marine and road traffic. Although the prediction of fog based on numerical model output is still subject to various error sources today, the forecasts and official meteorological warnings of the DWD mainly have to rely on this data. The high spatially and temporally resolved images of Meteosat facilitate a new way for improved fog detection implemented in the operational monitoring systems at DWD. Thereby the focal point lies on a reliable discrimination of fog and low stratus clouds, as the latter has no effect on visibility at the ground. Furthermore, entities dependently detected as fog are planned to form the basis for an up to 2-hour nowcasting.

The detection scheme SOFOS (Satellite-based Operational Fog Observation Scheme; Cermak, J., 2006) identifies fog via a multispectral analysis of low stratus clouds using Meteosat images in the first step. Secondly the derivation of microphysical cloud parameters allows gaining geometrical cloud information. Both steps in addition provide conclusions regarding visibility conditions at the ground.

The SOFOS package is being interfaced with the operational products of the Satellite Application Facility to Support Nowcasting and Very Short Range Forecasting (NWCSAF) as well as the satellite derivations of Cloud Physical Properties (CPP). As NWCSAF supplies cloud products such as typification and cloud top information, CPP mainly concentrates on cloud microphysics. Both provide constantly renewed products according to latest scientific knowledge. To figure out the benefit of the complements for low clouds and to identify the most eligible combination, a thorough validation with real-time in-situ visibility measurements is accomplished. The presentation will comprise an introduction to the features of SOFOS, the tested combinations with NWCSAF and CPP products and the chosen complements. In conclusion first results from the operational validation are presented to point out the reliability of the newly established fog detection product.
FORECASTING RADIATION FOG AT CLIMATOLOGICALLY CONTRASTING SITES: EVALUATION OF STATISTICAL METHODS AND WRF

Background
Fog forecasting is a challenging task for numerical models. The forecast of radiation fog events has been evaluated through two different approaches. Here we present a combination of rule-based forecasting using numerical and statistical approaches.

Aim
First a climatology of radiation fog is developed for the relatively dry site CIBA (Spain) and the humid site CESAR (Netherlands). A rule-based forecasting method is evaluated and optimised for both sites, and compared with WRF model results.

Method
A 6-year climatology of radiation fog has been compiled at two sites: the Research Centre for the Lower Atmosphere (CIBA, Spain) and the Cabauw Experimental Site for Atmospheric Research (CESAR, The Netherlands). These sites are contrasting in terms of geographical situation, climate zone, altitude, humidity and soil water availability. Also, we extend the statistical method presented by Menut et al. (2014) (M14). This method uses statistics to define threshold values on key variables for fog formation (pre-fog) and verifies its predictability using observations and numerical model output.

Results
Several climatological differences in fog abundance, onset, dissipation and duration have been quantified between both sites. The more humid site (CESAR) is characterised by relatively short radiation-fog events distributed throughout the year. However, radiation fog at the drier site (CIBA) is more persistent and appears during late-autumn/winter months. In general, its formation requires more time after sunset (~2 h more), since further cooling is required to reach saturation. We present some of the most appropriate threshold values for the forecasting of pre-fog periods at both sites, which differ from those presented in M14 and depend on the optimisation of the hit-rate or the false-alarm rate. Additionally, we also extend M14 suggesting other variables as potential predictors for fog formation (friction velocity and visibility tendency). Finally, we focus on the fog simulation by the Weather Research and Forecasting (WRF) model in terms of liquid water content. The WRF model was able to simulate radiation fog when configured with sophisticated physical options and high resolution. However it failed simulating the onset, dissipation and vertical extension of fog (overestimated). The model results were extremely sensitive to the spin-up time.

Conclusion
The fog climatology between the two sites is rather different. The rule-based forecasting could be successfully calibrated for those sites. Roughly speaking WRF with high resolution performs well in simulating the fog events but misses essential details, and WRF performance critically depends on spin-up and initialisation.
Background
Fog forecasting is a challenging task for numerical models, since many physical processes are involved, i.e. radiation, turbulence, microphysics and coupling to the land surface. This means that multiple parameterization schemes are involved. We address the question which parameterization scheme is most critical to the model skill in different parts of the fog life cycle.

Aim
The 1D WRF model is evaluated for a radiation fog event at the Cabauw tower (the Netherlands) for multiple combination of physics parameterizations. Next, we aim to explain model variation is explained by a process diagram approach (Sterk et al 2013) by varying the process strength in each of the parameterization schemes in a reference run.

Method
We evaluate the 1D WRF model for a diurnal cycle of the radiation fog at the Cabauw research tower (the Netherlands). We focus on the timing of the fog onset and dissipation, as well as liquid water content and fog vertical extent. To mimic a model intercomparison, multiple combinations of parameterization schemes for turbulence, longwave radiation, microphysics and land-surface coupling are permutated. Since the formulation of text physics parameterizations is known to be subject to uncertainties, the ensemble of model intercomparison results is subsequently studied in order to unravel whether the model spread is dominated along one or more of the four physical processes. This is achieved by defining a reference model setup, in which the process strength of each of the processes is varied by a factor 2 and 4 to represent the parameterization uncertainty. Results are plotted in a so-called diagram. The resulting spread due to varying parameterization strength is compared to the model ensemble spread and observations to study physical consistency.

Results
The 1D WRF model is able to represent the selected fog case study. It appears the model most sensitive to the selected boundary layer scheme for the fog onset, while the model results for the fog dissipation are most sensitive to the microphysics scheme. The strongest model sensitivity is found for mixing strength and land-surface coupling.

Conclusion
The 1D WRF model is able to forecast the selected fog case at Cabauw, and the processes diagram approach is a suitable method to study model sensitivity.
Background
Fog forecasting is challenging for Numerical Weather prediction models.

Aim
In this study we evaluate the WRF and HARMONIE mesoscale models on the forecast of two contrasting radiation fog events against observations at the Cabauw 200 m tower in the Netherlands.

Method
HARMONIE and WRF forecasts are compared to observed thermodynamic profiles at Cabauw tower (Netherlands) observations. With WRF permutations in boundary-layer scheme, microphysics schemes, nesting, domain size and model grid size are compared.

Results
To understand the role of physical processes, i.e. turbulence, radiation, land surface coupling, and microphysics, we evaluate the HARMONIE and Weather Research and Forecasting (WRF) mesoscale models for two contrasting warm fog episodes at the relatively flat terrain around the Cabauw tower facility in the Netherlands. One case involves a radiation fog that arose in calm anticyclonic conditions, and the second is a radiation fog that developed just after a cold front passage. The WRF model represents the radiation fog well, while the HARMONIE model forecasts a stratus lowering fog layer in the first case and hardly any fog in the second case. Permutations of parametrization schemes for boundary-layer mixing, radiation and microphysics, each for two levels of complexity, have been evaluated within the WRF model. It appears that the boundary-layer formulation is critical for forecasting the fog onset, while for fog dispersal the choice of the microphysical scheme is a key element, where a double-moment scheme outperforms any of the single-moment schemes. Finally, the WRF model results appear to be relatively insensitive to horizontal grid spacing, but nesting deteriorates the modelled fog formation. Increasing the domain size leads to a more scattered character of the simulated fog. Model results with one-way or two-way nesting show approximately comparable results.

Conclusion
WRF represents the radiation fog cases well, while HARMONIE develops cloud base lowering fogs. The boundary-layer formulation is critical for forecasting the fog onset, while fog dispersal depends mostly on the selected microphysical scheme.
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