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Advances in Fog Microphysics Research in China

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Fog microphysical research in China based on field experiments obtained many important results in recent 50 years. With the fast development of China's economy, urbanization in the last 30 years, special features of fog microphysical structure also appeared, which did not appear in other countries. This article reviews the fog microphysical research around China, and introduces the effect of urbanization on fog microphysical structure and the microphysical processes as well as macroscopic conditions of radiation fog droplet spectral broadening. Urbanization led to an increase in fog droplet number concentration but decreases in fog liquid water content (LWC) and fog droplet size, as well as a decrease in visibility in large cities. Observations show that the radiation fog could be divided into wide-spectrum one, which is all extremely dense fog with the spectral width more than 40 μm, and narrow-spectrum one, most of which is dense fog with the spectral width less than 22 μm, according to droplet spectral distribution. During developing from dense fog to extremely dense fog, the wide-spectrum radiation fog is characterized by explosive deepening, that is, within a very short time (about 30 min), the droplet concentration increase by about one order of magnitude, droplet spectral broadening across 20 μm, generally up to 30-40 μm, or even 50 μm. As a result, water content increased obviously, visibility decreased to less than 50 m, when dense fog became extremely dense fog.

We believe in the near future, the following several aspects need to strengthen: (1) The measurements of fog microstructure characteristics: extensive fog microphysics measurements are needed, although there are many efforts focusing on fog microphysics, their physical understanding is still in question in different cases and different environments. (2) The fog-haze transformation microphysical processes and mechanisms need be revealed. Most of the past researches divided the fog and the haze, however the haze transformed to fog need further observation and analysis. (3)The fog spectral widening is another question need to be revealed. Since the explosive features would appear in larger areas, the synchronous observations in larger ranges would be carried out in the future. (4) The relationship between fog microphysics, radiation, nocturnal boundary layer, turbulence, and pollutions need to be further uncovered. (5) Artificial influence fog microstructure could achieve the goal of weakening or even dispersing fog and haze. (6) Further studies could use the acquired microphysical parameters to improve the numerical models which could further improve the fog forecast.
Key words: Fog microphysics, China, droplet spectral broadening, urbanization effect;

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The relationship between radiation fog, dew formation and turbulence, determined using data from the LANFEX field campaign.

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The LANFEX campaign included an 18 month long field trial in a region of small hills (Shropshire, UK), that were extensively instrumented at a number of sites, to investigate how subtle interactions between processes affected the formation of radiation fog and dewfall. Given sufficient clear-sky nocturnal radiative-cooling, the data have quantified three turbulence regimes which favour either fog or dew formation, or when neither are likely to form. For example, radiation fog was never observed to form in these regions when the vertical velocity variance, σ_w^2, exceeded 0.005 m^2s^2. In contrast, dew deposition was measured to be greatest when vertical velocity variance $0.005 < \sigma_w^2 < 0.01$ m^2s^2. This result appears to be a response to how efficiently saturation (i.e. RH of the air) is transported to the surface. When turbulence intensity was relatively high, downward sensible heat fluxes, offsetting the nocturnal radiative cooling, were sufficient to prevent the surface reaching the dewpoint temperature of the air, such that dewfall was not instigated. At lower turbulence intensity, the sensible heat fluxes to the surface were reduced, and the surface reached dew point temperature, allowing dewfall to occur, but the air above the surface remained sub-saturated and fog did not form. When turbulence intensity levels fell to very low values, the efficiency of transport of air to the surface reduced, such that dewfall rates reduced. This allowed air at higher levels to saturate and fog to form. Various data are presented to quantitatively illustrate these findings.

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Deformation characteristics of a continuous Sea Fog process in the Yellow Sea and Bohai Sea and its Genesis Analysis

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On March 3rd-5th of 2016, a large sea fog continuously appeared over the most areas of Yellow and Bohai Seas. In this article, the satellite remote sensing monitoring data is used to analysis the morphological variation of the sea fog event during the three stages: generation, development, and extinction. It reveals the lack of sea fog over southeast coast of Shandong Peninsula and the evolution of the event. The results show that: 1) Early in the formation of the sea fog, there is no sea fog under the southerly wind on the southeast coast of Shandong Peninsula. Because of the weak cyclone, instability of atmospheric layer, and low humidity. Affected by low pressure, no water vapor convergence. 2) The period of maturity of the sea fog, the air temperature is lower than that on the sea surface. This condition is caused by the radiation from the top of the fog within the 0-1oC of the temperature difference of the air and sea surface. The southerly heating low air from the northwest Pacific Ocean is beneficial to the formation of sea fog. It is monitored the obviously water vapor convergence in this area. 3) The effect of vertical wind shear especially from 925hPa to 1000hPa is positive to the maintenance of inversion layer and promote the development of vertical height of the sea fog. Eventually it forms the typical sea fog with the certain thickness.
Key words: sea fog, morphological variation, the temperature difference of the air and sea surface, inversion layer, vertical wind shear

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Analyses of Physical Processes Driving Continental Fog and Low Stratus Life Cycle Based on Large-Eddy Simulations and Detailed Remote Sensing Measurements

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Context/purpose. Continental fog and low stratus (FLS) clouds can have high impact on human transport planning and safety, yet forecasting the location and timing of such events remains a challenge to current day numerical weather prediction models. Predictions suffer from imprecise initial and boundary conditions, parametrized representations of processes, poorly understood processes, and limitations in spatial resolution. To make progress in this field, radiative, dynamical and microphysical processes driving the FLS life cycle must be better-understood and key variables and their variability must be better quantified. Our study brings new quantified insights on the processes that affect FLS liquid water content, FLS top and bottom boundaries, and FLS dissipation time (i.e. when the FLS no longer touches the surface).

Method. To do so, we rely on information from analyses of high-resolution Large-Eddy Simulations (LES) and detailed in-situ and remote sensing measurements of FLS occurring in the Paris continental basin (France). Using the LES, we conduct sensitivity studies to quantify how radiative and dynamical processes contribute to accelerating or delaying FLS dissipation. Using 45 observed fog events, we study how the observed variability in key variables may affect the time of dissipation.

Results. Our research confirms that longwave radiative cooling is the dominant process to maintain FLS liquid water, and allows us to quantify this for both thin and opaque FLS, and to quantify the role of overlying cloud layers. We also find that during daytime solar radiation is responsible for several processes that are the main drivers, among local processes, reducing FLS liquid water and increasing FLS top height, such as in-cloud absorption, surface turbulent heat fluxes, and entrainment due to buoyancy. Differences in dissipation time up to 90 min are found by varying surface conditions, or humidity and thermal stability of the air just above the FLS.

Interpretation. Our results show that the dissipation time of continental well-mixed FLS can be defined as the time when the (vertically integrated) liquid water path drops below a critical value so that it is no longer sufficient to fill the layer between surface and FLS top. Tracking FLS top height and FLS liquid water path can be done most accurately with a profiling cloud radar and microwave radiometer. These measurements show that the observed variability in radiation, entrainment at FLS top and surface heat fluxes can explain part of the variability in FLS dissipation time.

Conclusions. Our findings show that real-time analysis of Doppler cloud radar, microwave radiometer and ceilometer measurements can support detailed diagnosis of processes responsible for FLS evolution, and could potentially find applications in FLS nowcasting.

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Observational Study on the Supercooled Fog Droplet Spectrum Distribution and Icing Accumulation Mechanism in Lushan, Southeast China

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A fog monitor, hotplate total precipitation sensor, weather identifier and visibility sensor, ultrasonic wind speed meter, an icing gradient observation frame, and an automated weather station were involved in the observations at the Lushan Meteorological Bureau of Jiangxi Province, China. In this study, for the icing process under a cold surge from 20–25 January 2016, the duration, frequency, and spectrum distribution of agglomerate fog were analyzed. The effects of rain, snow, and supercooled fog on icing growth were studied and the icing and meteorological conditions at two heights (10 m and 1.5 m) were compared. There were 218 agglomerate fogs in this icing process, of which agglomerate fogs with durations less than and greater than 10 min accounted for 91.3% and 8.7%, respectively. The average time interval was 10.3 min. The fog droplet number concentration for sizes 2–15 μm and 30–50 μm increased during rainfall, and that for 2–27 μm decreased during snowfall. Icing grew rapidly (1.3 mm/h) in the freezing rain phase but slowly (0.1 mm/h) during the dry snow phase. Intensive supercooled fog, lower temperatures and increased wind speed all favored icing growth during dry snow (0.5 mm/h). The maximum ice thickness at 10 and 1.5 m was 20.7 and 1.2 mm, respectively, while the duration was 102 and 61 h, respectively. The density of icing at 10 m was lower than that at 1.5 m, and the accumulation rate of icing on the tower was closely related to the precipitation rate and microphysical characteristics of supercooled fogs. The ice thickness at 1.5 m was sensitive to daily variations in temperature and relative humidity, indicating diurnal variation. Differences in temperature and wind speed between the two heights were the main reasons for the differences in icing conditions, which indicated that icing was strongly affected by height.

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The Interaction of Aerosol Composition, Properties and Fog Formation

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Hygroscopic aerosol particles can act as cloud condensation nuclei in the atmosphere to affect the fog and cloud formation. The possible aqueous phase reactions can be enhanced with the formation of the cloud (or fog) droplets and further modify their chemical composition. To investigate the interaction of different types of fog, aerosol hygroscopicity and aerosol major chemical composition, the results from two field studies, Kinmen in April 2017 and Xitou Experimental Forest of National Taiwan University in December 2018 were discussed. The fog formation mechanism for these two sites is different: fog in Kinmen tends to be advection fog caused by moist air from the sea while the fog in Xitou is upslope fog formed by local land-sea breeze. The single hygroscopicity parameter, κ, of aerosol as a function of aerosol diameter was derived based on the measurements of a cloud condensation nuclei counter (CCNc), an ultrafine condensation particle counter (UCPC) and a scanning mobility particle sizer (SMPS). The major aerosol composition was determined based on the absorbance of selected functional groups measured by a Fourier transform infrared spectroscopy-attenuated total reflection (FT-IR-ATR) for the filter samples collected using a multi-orifice uniform deposit impactor (MOUDI). The preliminary result suggests that κ in Kinmen shows an increasing trend with the dry aerosol diameter for the size range of 50-200 nm. For both Kinmen and Xitou cases, κ value during the fog event is slightly higher than that of non-foggy days. During the strong new particle formation event, the particle with its diameter less than 100 nm might have κ value of less than 0.1. That might be caused by the composition was less aged and had lower hygroscopicity. With the differentiation of carbonyl groups at 1520-1820 cm^{-1} to determine the neutralization level using FT-IR-ATR, small particles tend to have higher acidity whereas large particles are more neutralized as carboxylates. The size, composition, and the hygroscopicity of aerosol may affect fog formation but can be further modified by the aqueous chemical reactions inside the fog droplets. More detail analysis of the interaction between aerosol particles and fog droplets will be discussed during the conference.

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Impact of the Pacific–Japan Teleconnection Pattern on July Sea Fog over the Northwestern Pacific: Interannual Variations and Global Warming Effect

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The northwestern Pacific (NWP) is a fog-prone area, especially the ocean east of the Kuril Islands. The present study analyzes how the Pacific–Japan (PJ) teleconnection pattern influences July sea fog in the fog-prone area (where sea fog occurrence frequency is high) using independent datasets. The covariation between the PJ index and sea fog frequency (SFF) index in July indicates a close correlation, with a coefficient of 0.62 exceeding the 99% confidence level. Composite analysis based on the PJ index, a case study, and model analysis based on GFDL-ESM2M, show that in high PJ index years the convection over the east of the Philippines strengthens and then triggers a Rossby wave, which propagates northward to maintain an anticyclonic anomaly in the midlatitudes, indicating a northeastward shift of the Northwestern Pacific subtropical high. The anticyclonic anomaly facilitates the formation of relatively stable atmospheric stratification or even an inversion layer in the lower level of the troposphere, and strengthens the horizontal southerly moisture transportation from the tropical–subtropical oceans to the fog-prone area. On the other hand, a greater meridional SST gradient over the cold flank of the Kuroshio Extension, due to ocean downwelling, is produced by the anticyclonic wind stress anomaly. Both of these two aspects are favorable for the warm and humid air to cool, condense, and form fog droplets, when air masses cross the SST front. The opposite circumstances occur in low PJ index years, which are not conducive to the formation of sea fog. Finally, a multi-model ensemble mean projection reveals a prominent downward trend of the PJ index after the 2030s, implying a possible decline of the SFF in this period under the conditions of RCP4.5 scenario from CMIP5 data.

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Missed Fog: Understanding the Growth of Fog from the Ground Up.

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Conventional in situ observations of visibility and other meteorological variables are restricted to a limited number of heights near the surface, with the lowest observation often made above 1 m. This can result in missed observations of shallow fog as well as the initial growth stage of thicker fog layers. At the same time, numerical experiments have demonstrated the need for high vertical grid resolution in the near-surface layer to accurately simulate the onset of fog; this requires correspondingly high-resolution observational data for validation.

In November 2017, a field experiment was conducted at the Cabauw Experimental Site for Atmospheric Research (CESAR) in the Netherlands with the aim of observing the growth of shallow fog from the ground up, assessing the applicability of emerging high-resolution methods for observing shallow fog. Two innovative, high-resolution techniques were employed: distributed temperature sensing (DTS), providing temperature and relative humidity observations at vertical resolutions as fine as 1 cm, and a novel camera-LED method to observe near-surface visibility below the conventional sensor height of 2.0 m. These observations were supplemented by the existing observations at the site, including those along a 200-m tall tower.

Comparison between the high-resolution observations and their conventional counterparts shows the errors to be small, giving confidence to the reliability of the techniques. The high resolution of the observations subsequently allows for detailed investigations of near surface processes. The growth of fog layers from the ground up was observed with very strong temperature inversions in the lowest metre (up to 5 K), and corresponding region of (super)saturation where the fog formed and grew. Throughout the two-week observation period, fog was observed twice at the conventional sensor height of 2.0 m, but up to four times in the lowest 0-0.5 m using the camera estimates, with the shallow fog also forming up to two hours before it was observed by the conventional sensor.

The observations are supplemented by high-resolution numerical simulations of the experimental period, highlighting the sensitivity of the fog layer to surface properties and ambient conditions, providing greater insight into what drives the growth of a very shallow fog layer (i.e. < 1 m) into a deeper, and therefore more dangerous, layer.

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Understanding Fog in a Coastal Desert: The Namib Fog Life Cycle Analysis (NaFoLiCA) Project

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This contribution introduces insights gained on fog in a coastal desert obtained from a combination of in-situ observations, satellite observations and numerical modeling.

The Namib desert is one of the driest regions on Earth. Fog is suspected to play an important role in the hydrological cycle of the area. However, existing observations are sparse in space and time, and address only selected aspects of fog. The Namib Fog Life Cycle Analysis (NaFoLiCA project) is a three-year coordinated effort to improve the understanding of fog in the region, with a particular focus on the life cycle of fog. In particular, the aim is to understand how, when and by what pathways fog develops, what its properties are, and how, when and where it dissipates.

An Intensive Observation Period (IOP) took place in September 2017, during which we were able to comprehensively characterize several fog events with respect to their duration, extent, radiative effects, vertical stratification and water deposition. The systematic analysis of these individual cases helps us understand processes occuring in Namib fog. This in turn, is a requirement for the improvement of numerical weather prediction models in the region. The PAFOG fog model is being integrated into the COSMO weather model to adequately represent fog conditions in the region. This effort profits from the intensive observations for evaluation, but also from the process insights gained. The spatial extent of fog modeled is in turn compared to satellite observation. With a newly developed 24-hour robust fog detection algorithm on geostationary satellite data, we have been able to track the development of fog events, but also to study its climatological patterns, and relate them to the atmospheric dynamics of the wider region.

Results from all parts of the project, and how they combine to paint a coherent picture of fog in the Namib, are presented in this contribution.

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New insights on fog and low clouds in the Namib

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This contribution presents spatiotemporal patterns of fog and low clouds (FLC) in the Namib region and uses a statistical learning technique to show that most of the spatiotemporal variability of FLC in the central Namib can be explained by large-scale dynamics.
Fog is a defining element of the Namib-region climate and a crucial source of water for many species and ecosystems. Still, little is known on the patterns and processes of Namib-region FLC, in large parts due to the very sparse observational records. Specifically, there is an ongoing debate in the scientific literature concerning the relevance of different mechanisms responsible for fog formation in the region. In this contribution, data from multiple satellite platforms and station measurements are used to paint a coherent picture of the spatial and temporal patterns of Namib-region FLC. Observations are analyzed on different scales and combined with reanalysis data and modelled air-mass backtrajectories. The main findings are:
1) There are distinct seasonal patterns in FLC height.
2) The timing of the start of the diurnal FLC cycle and the distance to the coastline are strongly correlated.
3) The variability of the overall FLC coverage in the central Namib is driven by the large-scale dynamics.
The findings give a complete picture of FLC in the Namib and point to a regime that is dominated by advective processes. This provides a relevant framework for the interpretation of findings of recent studies that rely on the chemistry of Namib-region fog. The findings lead to a better understanding of Namib-region FLC and help broaden the understanding of low clouds along the southwestern African coastline and the southeast Atlantic.

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In-cloud scavenging influence on atmospheric aerosol as measured in fogs

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Atmospheric aerosol (AA) influences cloud formation, lifetime and other properties; at the same time, however, it is influenced by the cloud processing as well. Processes between AA and clouds, source of large uncertainty in weather and climate changes estimations, can be described on fogs, or on low clouds present at a suitable station. An example of such a station is Milešovka in Czechia, Central Europe, where fog is present for almost 55 % of the time, giving a great opportunity to explore the changes in the aerosol particle size distributions due to the cloud processing, and vice versa.

The measurements took place at the meteorological observatory of the Institute of Atmospheric Physics of the Czech Academy of Sciences, located on the top of the Milešovka Mtn. At the station, full meteorological data are measured continually, with additional measurements on fog/cloud characterization and vertical cloud profile. For the description of the AA properties, online measurement of outdoor particle number size distributions (PNSD) in the size range 10 nm – 20 μm was conducted using SMPS and APS spectrometers. The PNSD were measured as dry, after passing diffusion dryer. Total number AA concentration, concentrations of equivalent black carbon (EBC), and CO were also recorded as a proxy for air mass history. The sampling system consisted of a heated whole air inlet, and PM2.5 sampling head, being switched by an automatic valve. The time resolution was set up to 5 min, to be able to describe the real-time changes in the PNSDs. First data were sampled during a month-long autumn/winter campaign and another campaign is foreseen during spring.

From the difference between PNSD sampled by whole air inlet and by PM2.5 inlet, dry PNSD of activated particles nuclei can be calculated. During fog, a significant mode ($\sim$600 #/ccm) with mean diameter of 230 nm was found in submicron sizes, and a secondary peak ($\sim$0.5 #/ccm) was located at about 1.5 μm. For non-fog periods, the sub-micron mode is missing, suggesting its connection to fog processing of AA.

Preliminary results (the campaign has finished at the end of the year, so most of the analyses are still ongoing) also suggest a connection between the mode intensity and air mass history/fog type. This will be confirmed/rejected by back trajectories analysis and synoptic classification, as well as by application of Positive Matrix Factorization and by comparison with auxiliary data (total concentrations, EBC, CO, and fog properties).

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Atmospheric Conditions for Advection-Radiation Fog Over the Western Yellow Sea

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Advection fog occurs usually when warm and moist air flows over cold sea surface. The classic view thinks that cooling of unsaturated air by relatively cold sea surface causes advection fog and thus the air temperature is usually higher than sea surface temperature in advection fog. However, it is occasionally reported that the fog air temperature falls below sea surface temperature (called here the sea fog with sea surface heating [ssH]) due to longwave radiation cooling at fog top. Using 8-year buoy observations, this study reveals that about 33% of the time, the advection fog is with ssH in the western Yellow Sea. By synthesizing long-term observations from meteorological stations, atmospheric soundings, and offshore buoys, this study further investigates the marine atmospheric boundary layer (MABL) structure and atmospheric circulation associated with the ssH sea fog. Composite analysis shows that a local anomalous high pressure favors widespread formation of the ssH sea fog. The subsidence in the high pressure intensifies the thermal and moist stratification between the MABL and free atmosphere through adiabatic warming. The dry air above helps cool the fog layer by enhancing the longwave radiative cooling at the fog top and the vertical mixing beneath, causing air temperature to drop below sea surface temperature. The ratio of sea fog with ssH to total sea fog decreases from spring to summer as the descending motion and MABL stratification both weaken. This study highlights the importance of longwave radiative cooling at the advection fog top and suggests a way to improve sea fog forecast in the Yellow Sea.

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Analysis of the boundary layer characteristics and cause for a spring sea fog over Fujian

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Abstract: A large-scale sea fog developed from south to north in Fujian coastal area and Taiwan Strait on March 3-4 2018. Fujian coastal automatic station, buoy station data, microwave radiometer, wind profiler radar, FY-2F satellite data and ERA-Interim reanalysis data are used to analys the causes, formation and elimination mechanism of sea fog, the boundary layer characteristics and the air-sea interaction are analyzed intensively. The results show that the maintenance of near-surface inversion layer, the humidity area, the middle dry and warm cover layer, small wind speed and temperature dew point, the increase of liquid water content and integrated water vapor are beneficial to the formation of sea fog. The reduction of vertical wind shear contribute to the warm and humid air in the lower layer difficult to transport upward, which is beneficial to the formation and development of sea fog. Water vapor from the western Pacific is transported to Fujian coast and the Taiwan Strait, the high value area of 925∼1000 hPa water vapor flux is over the sea, the vapor flux convergence between Fujian coast and Taiwan Strait are different . The air-sea temperature difference in the range of 0-3 centigrade is favorable for the formation and development of sea fog, which makes the cooling of warm and humid air above the cold sea surface reach saturation to form sea fog. Turbulent heat transfer between air and sea is the cooling mechanism of sea fog , there are negative latent heat flux and and positive sensible heat flux during the occurrence, development and maintenance of sea fog.
Keywords: sea fog, air-sea temperature difference, boundary layer characteristics, heat flux

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Analysis of the Yellow Sea fog cases using turbulent flux observations

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Sea fog is one of the most problematic factors in marine activity and the environment. A substantial portion of automobile accidents, problems with aviation, and marine accidents are related to low visibility in the presence of dense fog. The Yellow Sea is the most frequently foggy area along Korea coast. Therefore, it is important to accurately predict the sea fog over the Yellow Sea. In this study, we focus on the microphysical effects of turbulent fluxes on sea fog prediction using direct observation data of turbulent fluxes at Socheongcho Ocean Research Station (SORS) during 2016-2018. The SORS is steel-framed tower-type platform which is located at 37°25' N, 124°44' E over the Yellow Sea and designed to monitor long-term oceanic variance, enabling interdisciplinary scientific investigation. Collection of fog case was performed with a present weather detector to monitoring visibility and vertical sounding measured at the synoptic station to the 60 km northwest of SORS. Turbulent fluxes have been observed by an open path eddy covariance system composed of sonic anemometer and an open path infrared gas analyzer. The sonic anemometer is installed on the intermediate deck at the height of 7m, 10m from mean sea level to obtain direct air-sea interaction process. All data were subject to quality control in order to detect any unrealistic value check prior to analysis. The quality of fast-response (10Hz) data collected from an open ocean research platform was controlled using algorithms of Vickers and Mahrt (1997) and Oh et al. (2010). Quality controlled sensible, latent heat fluxes and radiative fluxes were examined to analysis of microphysical structure of fog cases. Detailed results will be shown at the conference.

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Fog due to stratus lowering: experimental and modelling case study

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Fog strongly perturbs aviation, marine and land transportation and accurate forecasts are thus required to reduce its impact on human activities. However there are still many unknowns in the physical mechanisms driving fog variability and how they interact, especially for fog formed by stratus lowering. The Numerical Weather Prediction (NWP) model AROME has some difficulties to correctly forecast this type of fog (Philip et al, 2016). Thus, the purpose of our study is to better understand the key processes involved in the fog formed by stratus lowering over continent.

We analyze here data collected during a field campaign that took place during autumns 2015 and 2016 in the north-east of France at the OPE station (Observatoire Perenne de l'environnement), Extensive measurements were performed with in-situ and remote sensing instruments. During the intensive observation periods (IOP), in situ vertical profiles have been carried out with a tethered balloon and Unmanned Aerial Vehicles (UAV) in addition to classical soundings. Sampled fog events during this experiment are mainly radiation (RAD) fog and stratus-lowering (STL) fog.
This work first documents, from analysis of detailed observations, the differences between STL, RAD and quasi-fog formation by stratus lowering (cloud base varies between 120m and 50m) in terms of the thermodynamical conditions and microphysical properties.
Then, we present results from a 3D numerical simulation performed with Meso-NH model (Lac et al, 2018) applied at 100 m resolution with a downscaling approach from AROME analysis. We focus on IOP2 (1-2 Dec 2016) in order to investigate the physical mechanisms involved in the fog formed by stratus lowering. We use a 2-moment microphysical scheme (LIMA) (Vié et al, 2016) to lead an accurate analysis of the microphysical properties of the stratus and fog, and to compare with in-situ droplet size distribution measurements.

The budget analysis shows that advection processes seem crucial to feed the stratus, in order to favor the stratus top rising and the stratus base lowering. Both experimental and modelling studies underline the complexity of this type of fog and the necessity to better understand the key processes driving the cloud life cycle.

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The surface heat fluxes-atmosphere relations in Chi-Lan montane cloud forest in Taiwan

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Variations in surface fluxes can alter the development of the planetary boundary layer, thus potentially affecting the convective initiation through land-atmosphere interactions. Chi-Lan montane cloud forest, located at 1650 m above mean sea level at northeastern Taiwan, possesses low latent heat flux compared with other forests around the world. Both frequent afternoon fog water and more than 3000 mm annual precipitation serve as plentiful water sources to Chi-Lan's ecosystem, horizontally and vertically, respectively. In addition, tropical montane cloud forests may suffer from vegetation mortality or species invasion due to the uplift cloud base height resulting from local and regional hydroclimatological changes. However, the interactions between surface fluxes and atmosphere in such wet montane cloud forests remain unclear. In this study, flux tower observations and Community Land Model (CLM) simulations are utilized to explore the role of fog in Chi-Lan. An asymmetric diurnal latent heat flux was found in observations: an early peak of the diurnal latent heat fluxes. However, this characteristic is not shown in Lien-Hua-Chih in central Taiwan. The high canopy evaporation in early morning is found to potentially result in the increased latent heat flux through CLM simulations. We also found that the intercepted fog water and dew at night reform canopy water, contributing to evaporation after the next sunrise, modifying the diurnal water cycle in Chi-Lan. The surface fluxes response to the atmosphere may change under global warming, and thus, to understand the change in Chi-Lan montane cloud forest in the future climate is necessary.

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Covariation of droplet size distribution and air humidity in fog: A methodological approach

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The dynamics of a particle, for example of a fog droplet, depends on its size. Further, we see that clouds or fogs are not homogeneous bodies, but contain air masses with higher-than-average relative humidity (RH) and other air masses with lower-than-average RH. Therefore, it is interesting to analyze the droplet size distribution (DSD) in clouds and fog in covariation with the air humidity. However, some instrumental challenges arise, particularly with respect to the high-precision measurement of RH. The approaches made so far include, for example, infrared absorption techniques in airborne cloud physics studies.

A new method was developed and employed for the first time in March and April 2017 on Mt. Lulin, Taiwan. This method allows the calculation of relative humidity in the droplet-free air of fog and, in a further step, links this data to the DSD as measured with a FM100 Fog Monitor. The setup consists of a newly developed fog droplet separator with an attached H_2O gas analyzer and precision thermometer. The fog droplet separator works similar to an active fog collector, yet with a high collection efficiency of 98.3 % for the liquid water content. The water vapor concentration and the temperature can be measured precisely and without essential disturbance by fog droplets at a frequency of 1 Hz in the droplet-free air. The DSD was analyzed and its covariation with RH was studied.

Regarding a single fog event, there are differences in the DSD between data with high RH ($>$ 100.3 %) and low RH ($<$ 99.7 %). However, when considering all data of a fog event, the DSD is quite similar. Note that the droplet diameters are generally high regarding the Köhler curves. The geometrical means of the droplet diameters are 9.2 μm and 9.3 μm for the DSD of the two analyzed fog events, respectively. This may implicate that the dry diameters of the condensation nuclei and the salinity are relatively high. The hypothesis of the Köhler curve stating that droplets are smaller at a low RH than at a high RH is confirmed in one of the two analyzed fog events.

The results show that the developed method is appropriate to analyze the DSD in covariation to the air humidity in fog. However, this covariation is complex: the analysis of more fog events and measurements with a higher resolution, especially for the DSD of the smaller droplets, is inevitable.

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Fog droplet distributions and liquid water fluxes in the hyperarid Namib

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The quasi-permanent stratocumulus deck over the South Atlantic is regularly advected into the hyper-arid Namib, where it appears as fog upon interception with the gradually ascending terrain and provides a water input for plants and animals besides scarce rain. The governing processes and dynamics are not properly studied and recent literature proposes radiation fog rather than an advection as partial origin process. fog precipitation, measured by various fog collectors is not necessarily the final water input received by the system and tells us little about the dynamics within the fog. Within the scope of the Namib Fog Life Cycle Analysis (NaFoLiCA) project, a cloud droplet probe sampled the fog droplet distribution at a higher rate than the fog collectors could. Liquid water content and flux were then derived by the eddy covariance method using an adjacent IRGASON. After a few months, the setup was moved to another location to investigate spatial variability in droplet distributions.

Before fog events, the background concentration consisted primarily of droplets smaller than 10 μm. The size of droplets during fog events was mainly between 10 and 40 μm with few droplets larger than this. The increase in droplet numbers, and thus liquid water content, occurs simultaneously with a decrease in visibility and a sudden change in longwave downward radiation. The first measurements of fog precipitation lagged by roughly 30 minutes compared to detection by the cloud droplet probe. Short decreases in droplet numbers were found to reduce the intensity of fog precipitation. Liquid water content was up to three orders higher during fog events compared to days without fog. Cumulative liquid water flux during one event was around 60 mg (0.06 ml) not including gravitational settlement of droplets. The analysis of droplet distribution and fluxes allowed detailed analysis of fog events, more so than by fog collectors alone. Selected fog events, their stages and links to the droplet distributions help to better understand the role of fog in the hyperarid Namib.

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Lifting the fog in the central Namib – where did it come from?

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The interplay between wet and dry is a distinct climatological characteristic of the hyper-arid coastal strip in the Namib. Moisture in form of low clouds/fog provides an important input of water to the Namib's biota via the atmosphere. Advection of low clouds/fog of marine origin is thought to be the dominant mechanism for fog, which, in the case of low clouds, occurs as fog where the cloud layer intercepts the land. This advection-dominated fog regime was questioned recently based on isotope analyses and led to the suggestion that it might be rather a radiation-dominated fog regime in the coastal Namib. Against this background we present a ground-based meteorological view to this debate. Net radiation and fog precipitation measurements from the FogNet in the central Namib are used to detect and distinguish low clouds/fog and the spatio-temporal patterns are analyzed.
The interplay between wet and dry is a distinct climatological characteristic of the hyper-arid coastal strip in the Namib. Moisture in form of low clouds/fog provides an important input of water to the Namib's biota via the atmosphere. Advection of low clouds/fog of marine origin is thought to be the dominant mechanism for fog, which, in the case of low clouds, occurs as fog where the cloud layer intercepts the land. This advection-dominated fog regime was questioned recently based on isotope analyses and led to the suggestion that it might be rather a radiation-dominated fog regime in the coastal Namib. Against this background we present a ground-based meteorological view to this debate. Net radiation and fog precipitation measurements from the FogNet in the central Namib are used to detect and distinguish low clouds/fog and the spatio-temporal patterns are analyzed.
FogNet is a network of 11 meteorological stations which form a west-east transect from the coast to 733 m asl at 85 km inland, and a north-south transect at around 50 km inland at 400 to 500 m asl, where the inland-reaching stratus frequently intercepts. At all stations the following meteorological measurements are recorded: wind speed and wind direction at 10 m, air temperature and humidity at 2 m, net radiation, global radiation, surface temperature, soil moisture and soil temperature, leaf wetness, precipitation and fog precipitation using a Juvik-type fog collector. At three stations only: air pressure, net radiation and visibility. The measurements started in July 2014 with nine stations. Two additional stations were added 2015 and 2016 close to the coast.

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Vertical profile of fog microphysics experiments

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Fog has a significant impact on human activities in particular with respect to air transport operations. To improve fog simulation and forecast the CNRM conducted two field campaigns during Fall 2015 and 2016 in collaboration with IRSN (Institut de Radioprotection et de Sûreté Nucléaire). Realized at the Observatoire Pérenne de l'Environnement (OPE) of ANDRA (Agence Nationale pour la gestion des Déchets Radioactifs) located in the East of France (250 km from Paris) in a deep rural area, an innovative instrumental set-up was deployed to gain insights on the following objectives :
- document typical features of the vertical profiles of fog microphysical properties (droplet size and number concentration, liquid water content (LWC) and visibility) in order to to constrain and validate numerical simulations ;
- asses the impact on fog forecast of the assimilation of humidity and temperature profiles retrieved from a ground-based microwave radiometer into the AROME numerical weather prediction model ;
- evaluate the amount of fog water deposition on plants by turbulent mixing which is a substantial sink of water at the surface.

Numerous instruments were installed on a mast at different altitude levels (2, 10, 50 et 120 m). During intensive observation periods in situ vertical profiles up to 500 m height above the ground were performed with a tethered balloon equipped with microphysics (modified DMT Cloud Droplet Probe) and turbulence (sonic and inertial sensors) measurements. Ultra-light (650 g) remotely piloted aircraft systems were also used to characterize the boundary layer properties evolution in complement to radiosonde measurements.

The instrumental set-up deployed during this campaign is presented and data collected during fog events are analysed to investigate the variability of the different parameters along the vertical. We show that LWC values are much higher that those usually measured at the ground during past experiments. We analyse a developed fog, a thin fog (< 50 m) and a stratus to fog transition that occurred successively during the nights from 27 to 30 October 2016. This study underlines the interest to document the time evolution at different altitude levels. We also investigate in details the fog formed due to stratus lowering that was sampled during the night of 1-2 December 2016. The vertical profiles of the droplet size distributions collected with the tethered balloon are investigated. They reveal noticeable differences between the stratus and the fog formed below.

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The effect of soil type and crust cover on the absorption of atmospheric water vapor – laboratory and field trials

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In arid and semiarid environments non-rainfall water inputs (NRWI) are an important source of water. In Israel's Negev desert direct absorption of atmospheric water vapor is the dominant NRWI and is strongly affected by soil properties, in particular clay content. The presence of a surface crust layer, whose physical and physico-chemical properties are substantially different from those of the underlying undisturbed substrate will likely affect the absorption patterns. The objective of our study was to quantify the effect of soil type (loess vs. sand) and crust cover (crust vs. crust removed) on direct atmospheric water absorption.

The loess soil samples were obtained in an open field adjacent to the Jacob Bluestein Institutes for Desert Research (BIDR), Ben-Gurion University of the Negev (30˚51' N, 034˚46' E, 470 m a.s.l); and the sand samples from the Nizzana Sand Dune area (30˚58'N, 034˚24'E, 226 m a.s.l.). The loess crusts were physically induced while those present on the sand samples were of biological origin.

A field experiment was carried out in the open field adjacent to the BIDR. Four undisturbed 50 cm depth soil samples (sand and loess with crust and with crust removed) were placed in micro-lysimeters and automatically weighed at 30 min. intervals. This field experiment was carried during the dry season of May to October 2016.

The field study was supplemented with a laboratory experiment in which undisturbed samples (1, 3, 7 and 10 cm) obtained from the above-mentioned sites were used. Oven-dry samples were exposed during 6 days to constant temperature and relative humidity conditions (25±1 oC and 85±5 %, respectively) in sealed chambers. Mass changes were recorded at varying time intervals.

The adsorption process in the field started in the late afternoon with the arrival of the sea breeze and ended with sun rise. On a daily basis, the crusted loess sample adsorbed more water than the crusted sand sample, and the crust removed loess soil absorbed more water than the crust removed sand. The crusted samples generally absorbed less water than the corresponding non-crusted ones.

The results of the laboratory tests showed that loess samples with crust and with crust removed absorbed similar water amounts for all sample depths throughout the study period. The crusted sand samples however absorbed systematically more water than the crust removed samples for all sample depths.

We conclude that the higher resistance of crusts to gaseous flux, a result of their higher bulk density and smaller pores, does not limit water vapor flux into the deeper soil layers and does not explain the field results.

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Microphysics of Coastal Fog from a Field Study on the Canadian East Coast

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The interactions between aerosols and water vapour can be a determining element in the formation, density and persistence of fog, which makes fog forecasting a challenge. Although fog is rather common, models fail at accurately predicting visibility, notably due to issues with the microphysical parameterization. The cold waters off the Canadian east coast are one of the foggiest places on the planet due to the close proximity of a warm current advecting a high amount of moisture in the lower troposphere. The development of a semi-permanent high pressure system over the North Atlantic combined with a high sea-surface temperature gradient makes May, June and July the foggiest months of the year in that region. Our research group conducted a field study near Halifax, on the Canadian east coast in the early summer of 2016 to collect data on the microphysics of coastal fog. Using back trajectories, we associated each of the 7 selected fog events with a continental or purely marine origin. We observed a bimodal droplet size distribution during all events, with a higher concentration of small droplets during events that were continentally influenced (more polluted). A comparison between dry particles before and after the events also revealed a scavenging of coarse mode aerosol and an enrichment of accumulation mode particles, proportional to the duration of each event. In one case, we hypothesize that a lack of large particles may have played a significant role in the dissipation of fog. Our results will be compared with past studies and their implications will be discussed.

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Experimental study of fog physical response to chemical compounds dissolved in pure water

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The goal of this work is to study the impact of aerosols on fog formation in lab environments. Physical and chemical properties of aerosol affect droplet formation and its size spectra, which are dependent on thermodynamical conditions. Fog, as a natural phenomenon, is widely studied because it can affect visibility, air quality, climate, agriculture, and human health. In order to better understanding of fog prediction, earlier works have extensively studied natural fog with respect to its formation and dissipation processes. Similarly, artificially produced fog types have been studied improve firefighting, agriculture, and transportation capabilities and to understand conditions that lead to deterioration of air quality. Both fog and rain are natural “cleaners” of the lower atmosphere because their droplets attract or wash out various aerosol particles as they fall at varying speeds to the ground. Lab experiments related to artificial fog studies are limited, therefore, this study will evaluate aerosol effects on fog physical properties in a lab environment. To reach the goal, an automated fog generating system was designed and that includes controlled chemical compounds dissolved in pure water. The results suggested that increasing the concentration of potassium dihydrogen phosphate (KH_2PO_4), urea ($CO(NH_2)_2$), and potassium hexacyanoferrate trihydrate ($K_3(Fe(CN)_6)$), as well as aerosol types (chemical compounds) can lead to changes in number concentration of fog droplets; therefore reducing visibility. In the analysis, various physical conditions, such as fog droplet size and concentration, were analysed using changing aerosol composition. The results obtained showed that the particle size distribution of fog droplets changes with the addition of chemical impurities and their mass concentration. Overall, both issues and challenges of the experimental fog generating system used in this study are provided and future work is described.

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Critical Liquid Water Path as a possible indicator of Fog Dissipation

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Fog has a significant impact on human transport activities due to the strong reduction of visibility at the surface. An accurate estimation of fog dissipation time could aid decision making for the transport sector, significantly reducing related costs and risks. However, the location and time of appearance and dissipation of fog are still difficult to forecast with sufficient accuracy by numerical weather prediction models.

It has been observed that a significant part of fog evolution can be explained using local parameters, especially when its dissipation happens due to lifting of the cloud base, transitioning it into a low stratus cloud. Fog-base lifting accounts for more than half of the fog dissipations recorded at the SIRTA atmospheric observatory located in Palaiseau, France, during the past 7 years.

It has also been found that fog lifting and dissipation seem to be correlated with the Critical Liquid Water Path (CLWP) parameter first introduced by Cermak and Bendix in 2011 as a method to determine the presence of fog at the surface from satellite observations. The CLWP provides a measure of the minimum amount of liquid water that is needed to fill a fog layer from the fog top height down to the surface, assuming a particular subadiabatic profile of vertical liquid water content.

Our hypothesis is that a nowcasting method based on comparing real time observations of Liquid Water Path (LWP) with the estimated CLWP at a site of interest could improve the accuracy on the estimation of fog dissipation time.

Instead of satellite measurements our approach calculates CLWP by using ground based instruments. Cloud Top Height is retrieved by a Cloud Radar BASTA and Cloud Base Height by a CL31 Ceilometer. Alongside these instruments we include standard observations of temperature, pressure and visibility at screen level. LWP is retrieved with a HATPRO Microwave Radiometer.

Uncertainties in elements such as the layer temperature and the subadiabaticity profile will have an impact on the quality of the CLWP estimation. Hence we studied a large number of cases to get a better understanding of the method and to assess the impact of other atmospheric variables on its performance.

The presentation will include an introduction to the CLWP concept and an evaluation of its performance as predictor of fog dissipation for 40 fog events observed at the SIRTA observatory, analyzing the relevance of parameters such as temperature or fog top height. Single case studies will also be shown to illustrate how CLWP evolves over time. Finally, detected limitations and proposals to improve CLWP estimation will be discussed.

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Cloud Microphysics Affected by Dry Air Entrained from above Cloud Top in Stratocumulus

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Fog is quite similar to low-level clouds, especially for stratocumulus. Both of them occur in the low troposphere and they are affected by dry air entrained from above the cloud top. Different turbulent entrainment-mixing processes are critical to cloud-related processes which have been studied with many conceptual models based on the relationship between cloud droplet size and cloud number concentration. However, few studies focus on the vertical evolutions of entrainment mixing mechanisms. To fill this gap, the stratocumulus clouds observed during the Physics of Stratocumulus Top (POST) project are analyzed to improve the understanding of the entrainment-mixing processes in the stratocumulus top region. Based on the sawtooth flight pattern, the cloud data are studied for each 1m as the height interval, which ensures the high vertical resolution. In 3 non-drizzling cases, there is a tendency for entrainment mixing to change from homogeneous to extremely inhomogeneous. First, microphysics analysis shows that homogeneous mixing degree (i.e., how much of mixing is homogeneous) decreases with the increasing height. Second, dynamics analysis shows that Damkohler number (the ratio of mixing time scale of dry air to evaporation time scale of droplets) increases with the increasing height. The reason is that the size of entrained dry air is large near cloud top. When the dry air goes deep into the cloud, the size of dry air decreases and relative humidity of dry air increases. The smaller dry air size and higher relative humidity cause more homogeneous mixing in the middle of cloud than near cloud top.

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A role of turbulence transfer in predicting radiation fog using the regional Eta model

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Understanding mechanisms for fog formation, evolution, and dissipation is fairly difficult due to complexity of physical processes and their interplay. Consequently, fog predictions represent a great challenge which is generally further amplified by a lack of detailed measurements. Accurate fog predictions require high-resolution models and detailed physical parameterizations. One of the essential parameterizations is treatment of turbulence transfer and its interplay with microphysics and general structure and stability of the PBL. Regional Eta model driven by the control and the first four of the ECMWF ensemble members has been used to investigate the formation, evolution, and dissipation of radiation fog over plain terrain in France. A series of sensitivity tests conducted to investigate the role of turbulence closure schemes on prediction accuracy was completed using liquid water content, temperature and wind speed data. The results of the two Eta ensembles which differ only in turbulence scheme (Mellor-Yamada-Janjić boundary layer scheme, used in the original Eta model, and Nakanishi-Nino scheme (NN2009)) are compared. Preliminary results show that the improved parameterization of turbulence transfer that is calibrated by results from large-eddy simulations (NN2009) can significantly improve prediction accuracy. One of the main causes for the improvement appears to be formulation of the turbulent length scale that realistically increases for decreasing stability. The NN2009 scheme also allows for increased level of the turbulent kinetic energy which is important for complex interaction of radiation, microphysics, and turbulence for fog formation, evolution and dissipation. In particular that becomes essential in balancing the effect of subsidence vs. fog vertical growth. Since saturation conditions leading to fog formation are sensitive to initial thermodynamic conditions, results from the ensemble predictions justified the use of probabilistic fog forecasting.

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Isotopic investigation of dew origins and formation mechanisms under different climate conditions

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Dew is an important hydrological input to many ecosystems especially in the arid and semiarid regions. Few studies investigate the sources and formation mechanisms of dew under different climatic conditions. ^{17}O-excess, as a new tracer, is reported to preserve information about water sources and precipitation formation mechanism. Therefore, to fill the knowledge gap in dew sources and formation mechanisms, we investigated the dew and precipitation isotope variations (δ^2H, δ^{18}O and δ^{17}O) including ^{17}O-excess under three different climate regions (i.e., Gobabeb in the central Namib Desert, Nice in France with Mediterranean climate, and Indianapolis in the central United States). We also analyzed and modeled (Rayleigh evaporation model) the effects of meteorological factors (temperature and relative humidity) on ^{17}O-excess variations. The results showed that the dew in the Gobabeb were from three sources: ocean (advective dew), groundwater and shallow soil water, through comparing the local dew water line with local meteoric water line (LMWL) and global meteoric water line (GMWL). The dew in Nice had both ocean-derived dew and local-derived dew. The dew in Indianapolis was likely local-derived. In addition, informed by the $\delta\prime^{18}$O-$\delta\prime^{17}$O relationship and the positive correlation between^{17}O-excess and d-excess, dew in the Gobabeb (0.5191) experienced kinetic fractionation effect, while the dew in the other two sites, were mainly affected by equilibrium fractionation effect. The difference of dew formation under the three different climatic conditions was mainly affected by the local relative humidity, which was also verified by Rayleigh evaporation model. This study provides a practical method to distinguish dew sources and provides mechanistic understanding of dew formation mechanisms in different ecosystems.

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Influence of aerosol on fog microphysics over suburban area in Taoyuan, Taiwan

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In this presentation, we will present our preliminary results on the interactions of aerosol and fog based on in-situ observations carried out at the National Central University, Taoyuan, Taiwan during the period of December 2018 – January 2019. During the experiment, a cloud drop spectrometer (FSSP-100) was used to observe the particle size distribution of fog droplets and further to estimate the liquid water content (LWC). Data collected from the Thermo Scientific TEOM 1405 PM2.5 and PM10 monitor, Joss-Waldvogel Disdrometer (JWD) raindrop spectrometer, and automatic meteorological towers were applied in this study. Based on assessments of visual observation and auxiliary data, total 5 fogging events (2 radiation fog and 3 advection fog) were selected during the period. Our results show that with the number of fog drops greater than 5 μm increased, the concentration of PM10 and PM2.5 has a tendency to decrease. This phenomenon may cause by the particle size of the droplets increased with nucleation process of the fog, and the concentration of PM10 and PM2.5 may decrease, which so-call nucleation scavenging. According to previous study, sedimentation and collisional coagulation may also cause above mentioned phenomenon, but we suggest they can be ignored in most cases. Finally, we found that in the suburban area of Taoyuan, when PM10 is between 10 μg m-3 and 45 μg m-3, it is easier to form larger fog droplets. On the other hand, when PM10 is less than 10 μg m-3 or greater than 45 μg m-3, the fog droplets are not easy to form.

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The Interactions between Aerosols and Fogs Based upon Long-Term Satellite Products from MODIS and VIIRS

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The impact of natural and anthropogenic sources of air pollution has gained increasing attention from scientific communities in recent years. In particular, over East and South Asia during winter months, the formation of fogs often coincides with extreme haze events. These tropospheric aerosols not only perturb radiative energy balance by interact-ing with solar and terrestrial radiation, but also by changing fog properties and lifetime. With the launch of Terra/MODIS in 1999, Aqua/MODIS in 2002, and SNPP/VIIRS in 2011, high quality comprehensive aerosol climatology is becoming feasible for the first time. As a result of these unprecedented data records, studies of the radiative effects on fogs due to tropospheric aerosols are now possible. In this study, we will investigate the interactions between aerosols and fogs over East and South Asia. We will examine the diurnal evolutions of the physical and optical properties of fogs and aerosols by compar-ing the observations derived from the morning satellite (i.e. Terra) with those from the afternoon satellites (i.e. Aqua and SNPP). Finally, by combining these analyses with the MERRA-2 products the effect of atmospheric dynamics and water vapor in modulating the variability of aerosol and fog properties in Asia will be discussed.