

Editorial

Observation, Simulation and Predictability of Fog: Review and Perspectives

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Fog affects human activities in various ways, but the societal impact of fog has significantly increased during recent decades due to increasing air, marine and road traffic. The financial implications of the aviation industry can be large; for example, the financial losses for the Gandhi International Airport in India, between 2011 and 2016, reached approximately 3.9 million USD for airlines [1]. In Canada, reduced visibility accounted for one-half of all weather-related accidents at the airport [2]. For land transportation, the first impact concerns road safety [3]. The presence of fog leads to an increase in the number of accidents at night and doubles the number of fatalities per 100 accidents. Studies show that 32% of all accidents at sea worldwide and 40% in the Atlantic occur in the presence of dense fog. The economic and human losses associated with fog are comparable to losses due to extreme weather phenomena such as tornadoes and hurricanes.

Better forecasts would help to mitigate the financial losses associated with delays at airports [1], and human losses due to accidents in both marine and terrestrial transportation. The forecasting of fog remains very incomplete due to the time and space scales involved in the processes driving fog formation and fog's life cycle. Recent studies highlighted the remaining difficulties in predicting and measuring fog at various scales of time and space [4,5].

This Special Issue is expected to represent an important step in the direction of addressing new scientific challenges in fog-related research and operational applications. This Special Issue contains 17 papers related to the observation, simulation and predictability of fog, and the papers cover a wide spectrum of research. We would like to thank all the authors for the hard work that they have done on writing articles and modifying them based on reviewers' comments, and the reviewers for constructive comments.

Observation

Several comprehensive observational program measurements have been carried out since the 1970s. The main processes leading to fog formation are now well-known: cooling due to radiation, turbulence and land–atmosphere interactions. Satellite detection of clouds and fog, and consequent data analysis and interpretation are emerging tools with great potential for regional and worldwide spatial and temporal properties of fog. However, there are still significant problems and uncertainties related to detection algorithms that do not fully resolve fog layers.

Fog formation involves a myriad of interactions between physical processes, generating fog variability in time and space. Once a fog layer has been formed, the number of fog droplets and their size distribution can have a large impact on the development of the fog layer due to their feedback on gravitational settling and radiative cooling at the fog top, which are key processes for fog [6–9]. In the past 30 years, more and more attention has been paid to the study of the microphysical characteristics of fog, and continuous progress had been made in the development of observation instruments of fog microphysical parameters [6]. Significant variability has been observed in the droplet size distribution in fog [9].



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Although all these studies based on microphysical observations have contributed valuable insights to fog research [10], these studies cannot overcome the problems of fog forecasting.

Many important processes occurring in fog evolution do not produce any conclusive signal in the classical meteorological measurements. For example, the complex processes occurring in a small-scale valley could not easily be deduced from classical meteorological observations [4,5]. New observing systems, such as imagery from IR cameras [5], can provide great insights into fog processes and dynamics, identifying interesting features not previously seen. Comparison of imagery with conventional meteorological observations showed that the observations were often not capable of being used to delineate all of the processes affecting fog, due to their incomplete and local nature. This method of research seems very interesting to study small-scale processes involved in fog and could perhaps help us to improve fog forecasting.

Furthermore, with discrete observations made from meteorological towers, fog depth cannot always be accurately determined [11]. However, understanding how and why a shallow fog layer transitions to a deep layer is essential. It has been shown that shallow fog layers can exist long before the evolution, and even in the absence of a deeper fog layer. The need to identify when and why these fog layers ultimately deepen was highlighted as an important follow-up. Unfortunately, accurately characterizing fog depth with conventional observations is not always straightforward [12]. The future fog field experiments should focus on shallow fog in order to better understand the transition between a formation phase and mature fog layer. Studies of fog events in relation to short-term climate variability are also providing valuable insights into climate aspects of fog, and this kind of study needs to be developed [10,13].

Numerical simulation and forecasting

The current numerical weather forecasting models are not capable of simulating the gradual transition from mist to dense fog, and fail to accurately simulate the life cycle of fog. This leads to many false alarms. One can also notice that errors in one process could easily be hidden by errors or uncertainties in another. Moreover, the dominant process may change during the fog's life cycle, making things even more complex. Presently, numerical forecast models lack sufficient resolution, both vertically and horizontally, to accurately represent fog. It should be noted that forecast models should ideally resolve a huge span of physical processes, ranging from an aerosol scale (10^{-7} m) to synoptic processes with scales of 10^6 m or more. Hence, a successful fog forecast might be difficult or even impossible as long as the numerical model is not capable of simulating these processes with the required accuracy. Moreover, numerical forecasting models are incapable of representing different microphysical stages of the fog associated with various spectral shapes. Very detailed microphysical simulations suggest that the droplet size distribution develops during the life cycle (gamma shaped, bi-modal and platykurtic), which was also found in observations of fog cases [8]. However, an accurate simulation of the fog layer needs the consideration of the typically observed small-scale heterogeneities of the soil properties. Many studies show that insufficient fog forecast skills of numerical weather prediction models must not necessarily be caused by an inadequate microphysics parametrization of fog.

Moreover, initial conditions have great impacts on the accuracy of the forecast. It is obvious that an important component for the success of numerical fog forecasting is the capability to initialize at their best, numerical models using specific observations and assimilation schemes [14,15]. Accurate boundary conditions for regional, mesoscale and microscale models might also have significant impacts on the success of fog forecasts under evolving synoptic processes. Fog-top height is considered to be very useful information [11,12]. There is no doubt about the importance of accurate information of fog thickness for data assimilation, due to the significant impact of this parameter on the fog life cycle. The estimation of observed fog-top height is also useful for the validation of model simulations. Moreover, the height of the fog top at the end of the mature phase is useful information for estimating the beginning and duration of the fog dissipation phase.

The wind profile inside the nocturnal boundary layer and particularly at the top of the nocturnal boundary layer plays a significant role during the evolution from formation to mature phases of the fog layer. In fact, by modifying the mixing between the nocturnal boundary layer and the residual layer, modestly stronger wind can alter the development of the fog layer and keep fog in a shallow patchy state.

To conclude, Kelvin–Helmholtz waves at the top of the fog layer [16], the role of exchanges with the surface at very fine scale, shorter time-scales of regulating feedback in fog and its highly transient nature need to be simulated by very high resolution models (between the centimeter and meter scales). At this scale, a coupled large-eddy simulation and Lagrangian cloud model approach seems very promising to better understand the interactions inside the fog layer. By simulating several hundred million fog droplets as Lagrangian particles explicitly, this approach could resolve explicitly the diffusional growth of fog droplets, including Köhler theory and gravitational sedimentation representation [8]. Direct numerical simulations have also emerged as a valuable tool in resolving fog on scales in the order of a meter or less [17]. This type of simulation can provide insights into small scale radiation and turbulence interactions and the entrainment on fog evolution and dissipation. However, these type of approaches can be used for particular numerical studies and not in numerical weather forecast models.

Predictability

The evolution of fog, e.g., from a shallow fog to a deep adiabatic one, seems very chaotic and is still unpredictable. Numerical simulations also show that the occurrence and type of fog could be very different over a small but heterogeneous area. It is also interesting to note that the spread of the observation or simulated parameters at a very fine scale (above 1 m) were very high during some phase of the fog life cycle, e.g., the transition from shallow fog to a deep fog layer. This appeared to be the result of the complex interplay of processes at numerous ranges of scale. New concepts need to be developed to better understand this chaotic nature of fog. One illustration was done with pseudo-process diagrams, which seem to be very good tools to analyze fog, and allow a good illustration of the spread of fog during chaotic phases [4]. The evolution of a fog layer can be summarized by few attractors, defined, for example, by no fog and deep fog states. The trajectories in the phase space between these attractors correspond to bifurcations during the fog life cycle. Ensemble forecasts using suitable perturbations in initial and boundary conditions and physics parameterizations representative of the sensitivities of fog forecasting appear to be essential if progress is to be made in the domain of fog prediction. The wind inside the nocturnal boundary layer seems to have a significant impact, and it will be necessary that the fog ensemble forecast system represents the wind spread inside the boundary layer well.

Finally, we must ask the following questions in order to understand the information that must be provided for operational meteorologists and end-users: (a) How can one best display information from fog condition uncertainties in a way that maximizes value for the end-users? (b) How can one minimize the societal impacts of fog? These questions should be the primary questions for our future research.

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