Sensitivity Analysis of Radiation Fog with a Single-Column Model

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Introduction

Fog is an important meteorological phenomenon, which can have serious negative impacts on air quality, airport operations, and highway safety. A radiation fog event is a result of the complex interaction between the land surface and the lower layers of the atmosphere. Its development is primarily controlled by a balance between radiative cooling and turbulence. Meanwhile, the role of cloud microphysics also emerges as important factor.

The single-column model (SCM) used is the diagnostic model resembling a single vertical column of a 3-D CFD model, *Mercure_Saturne*. The SCM is compared with detailed observations made in a shallow radiation fog that formed on the night of 18-19/02/2007 (IOP-13) at SIRTA site (Fig. 1). A important purpose of this study was to assess the ability of our SCM to produce a reasonable simulation of fog variables, in particular liquid water content (LWC), horizontal visibility and cloud droplets spectrum. The results are used for forecasting study over a long period. The advantage of running a SCM is twofold. Firstly, when developing and testing new parameterization it can be useful to keep the large-scale atmospheric circulation fixed so that a better assessment can be made of the impact on the local climate without the complication of large-scale feedback [3]. Secondly, the SCM uses far less computer storage and time to run.

Fig. 1: The location of the ParisFog campaign (10/2006-03/2007). SIRTA-Palaiseau, France [48.713N, 2.204E].

Model description

The SCM contains 69 vertical layers and a time step of 60 seconds, which is nudged with advective tendencies derived from MM5. The main physics schemes used have been given detailedly in [4], including shortwave-longwave radiation parameterization, warm-cloud microphysics, and boundary-layer turbulent mixing parameterization. In this study, all the simulation has been performed in *nudging mode*.

1. *Nudging technique*

$$\frac{\partial X}{\partial t} = model(X) + C_n(X_{meso} - X) \quad (1)$$

2. *Microphysics* In summary, the prognostic parameters include liquid potential temperature, cloud water (sum of water vapor and liquid water), and cloud droplet number concentration.

$$\rho\frac{D\theta_l}{Dt} = \triangle\theta_l - \text{Rad} - \text{Sedim} \quad (2)$$

$$\rho\frac{Dq_w}{Dt} = \triangle q_w + \text{Sedim} \quad (3)$$

$$\rho\frac{DN_c}{Dt} = \triangle N_c + \text{Cond/Evap} + \text{Nuc} + \text{Selfcol} + \text{Sedim} \quad (4)$$

3. *Turbulence closure* $k-\varepsilon$ closure (from [1]) for control simulation.
4. *Radiation* The SCM includes SW/LW schemes. We take into account the charge in pollutant for cloud droplets albedo and aerosols albedo, respectively.
5. *Boundary and initial conditions* A symmetry condition at the top-surface. T and H are forced at the ground using a Atmospheric Surface Layer method. The reconstruction of initial field were performed by the assimilated data from the surface and soundings data.

Control simulation

The control simulation of the event began at 1200 UTC 18/02/2007 with surface forced condition and then continued until 1200 UTC 19/02/2007 when the fog disappeared completely. The nucleation spectra is initiated through a fitting procedure using scanning mobility particle sizer (SMPS) measurements of aerosol number size distribution at the SIRTA site.

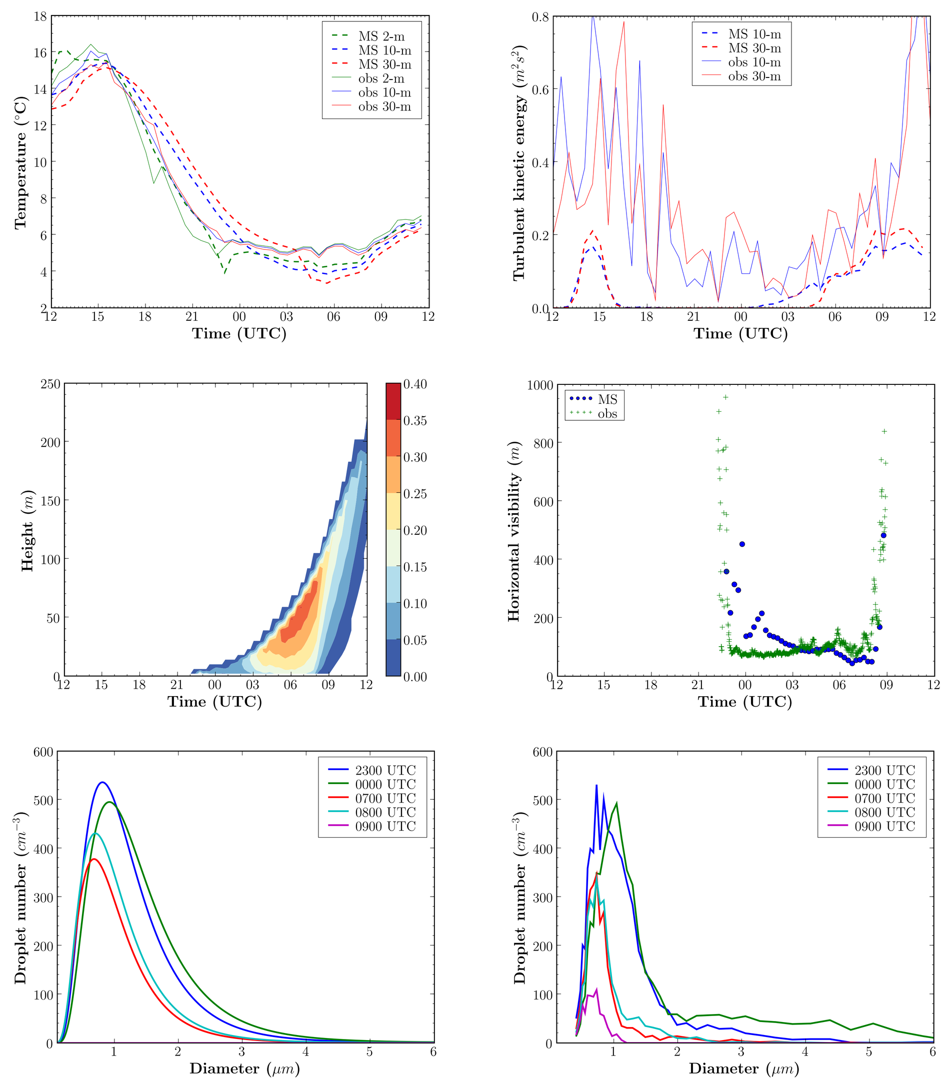

Fig. 2: Temperature at surface, 2m, and 10m (left-top), Turbulence kinetic energy at 10m and 30m (right-top), Liquid water content in g/kg (left-mid), Horizontal visibility at 2m (right-mid), Droplet size distribution measured (left-lower), and Droplet size distribution simulated (right-lower).

Sensitivity of turbulence closure

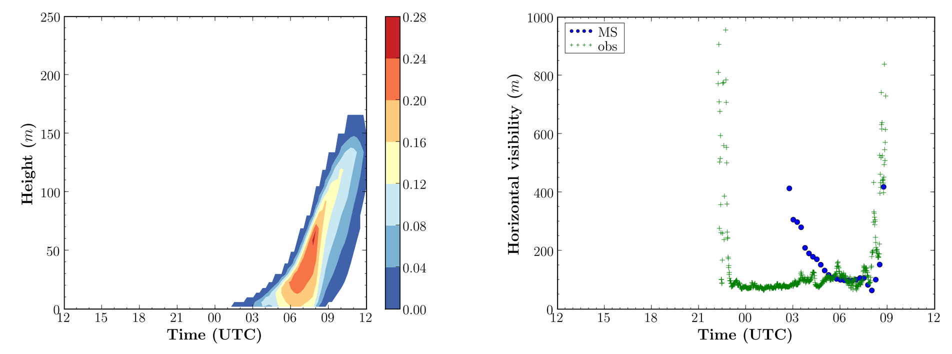

Fig. 3: With Louis closure. Liquid water content (left) and visibility (right).

Sensitivity of Microphysics

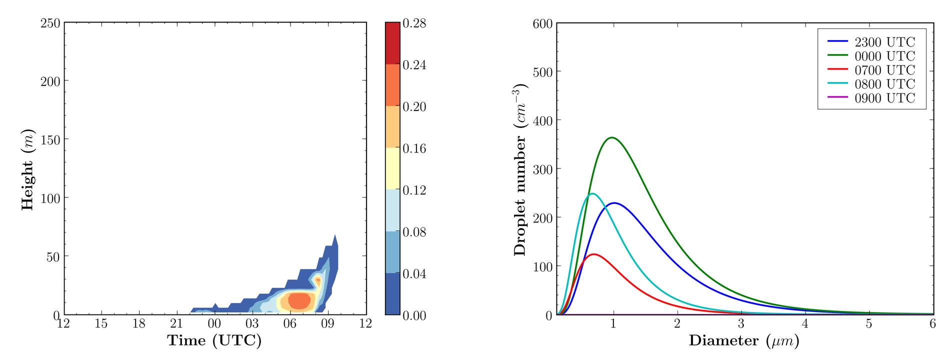

Fig. 4: Effet of sedimentation. Liquid water content (left) and droplet spectra (right).

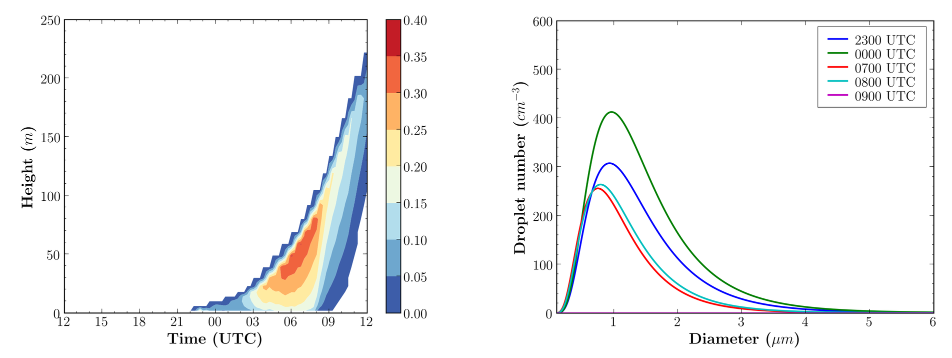

Fig. 5: Effet of nucleation. Liquid water content (left) and droplet spectra (right).

Land surface processes

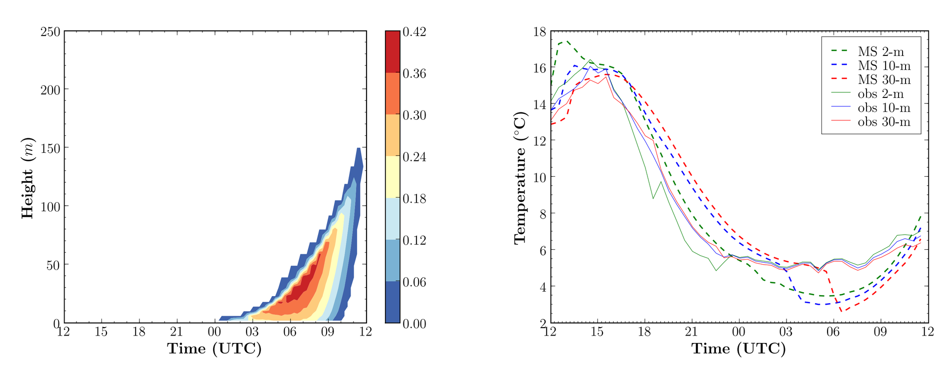

Fig. 6: With a land-surface-atmosphere model. Liquid water content (left) and temperatures (right).

36-h Radiation Fog Forecast

1. *Verification method - Contingency table* a is "hit" number, b is "missed" number, c is "false alarm" number, and d is "correct rejections" number [2].
   - Percent correct (PC). Range: 0 to 1. Perfect score: 1:

   $$PC = \frac{a+d}{a+b+c+d}$$

   - Probability of detection (POD). Ranges: 0 to 1. Perfect scores: 1. False Alarm Rate (FAR).

   $$POD = \frac{a}{a+b},\ FAR = \frac{c}{a+c}$$

   - Threat Score or Critical Success Index (CSI). Range: 0 to 1. Perfect score: 1.

   $$CSI = \frac{a}{a+b+c}$$

   - True skill statistic (TSS) or Hanssen-Kuiper Score. Range: -1 to 1, 0 indicates no skill (when forecasts are totally missed). Perfect score: 1.

   $$TSS = \frac{ad-bc}{(a+b)(c+d)} = POD - FAR$$

2. *Result*

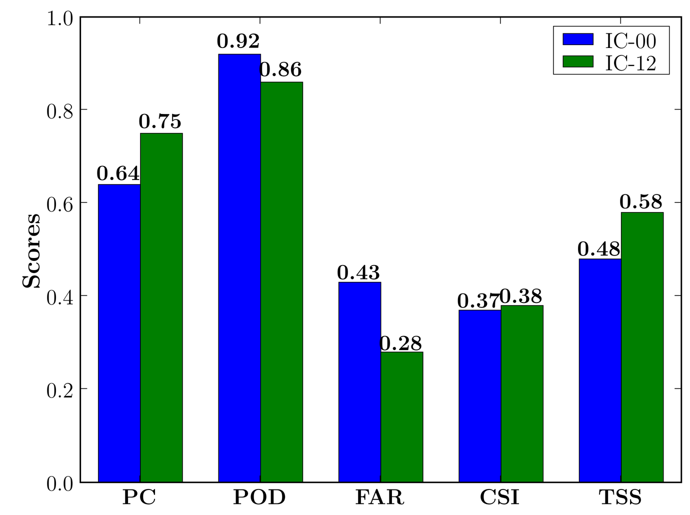

Fig. 7: The scores from the contingency tables for the case whose simulation starting at 0000 UTC (referred to as IC-00) and the case starting at 1200 UTC (referred to as IC-12) during the ParisFog period.

Conclusion

The analysis of the behavior of the different parameterizations suggests that the subtle balance between the various processes is nearly achieved. This study also reveals that the fog evolution strongly depends on the turbulent exchange coefficients, the condition of cloud droplet activation, and the sedimentation velocity.

We have performed forecasts in short-range by applying mesoscale forcing and nudging technique. From the scores associated with a 2×2 contingency table, we have found a good level of agreement between the forecast and the truth: $TSS > 0.5$. By using nudging, we can always have a good forecast for the fog/no-fog decision, moreover, that can be made about 36-h in advance. In addition, it will be helpful to apply this method for fog forecast under the conditions where spatial heterogenetity is significant.

Some additional analyses of these model forecast outputs will be performed to consider the model results with different coupling of mesoscale model, such as ECMWF or ARPEGE. This may conduct task analysis in reduction of prediction error.

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