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The Impact of Vertical Resolution in the Explicit Numerical Forecasting of Radiation Fog: A Case Study

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Abstract—Numerical experiments are performed with a comprehensive one-dimensional boundary layer/fog model to assess the impact of vertical resolution on explicit model forecasts of an observed fog layer. Two simulations were performed, one using a very high resolution and another with a vertical grid typical of current high-resolution mesoscale models. Both simulations were initialized with the same profiles, derived from observations from a fog field experiment. Significant differences in the onset and evolution of fog were found. The results obtained with the high-resolution simulation are in overall better agreement with available observations. The cooling rate before the appearance of fog is better represented, while the evolution of the liquid water content within the fog layer is more realistic. Fog formation is delayed in the low resolution simulation, and the water content in the fog layer shows large-amplitude oscillations. These results show that the numerical representation of key thermo-dynamical processes occurring in fog layers is significantly altered by the use of a grid with reduced vertical resolution.

Key words: Radiation fog, explicit numerical forecasting, vertical resolution.

1. Introduction

In the numerical weather prediction (NWP) literature, numerous studies have aimed at determining the influence of horizontal resolution on the representation of various weather phenomena, such as convection (Weisman *et al.*, 1997), sea-breeze (Colby, 2004), and fog (Pagowski *et al.*, 2004); as well as the overall accuracy of numerical weather forecasts (Mass *et al.*, 2002). Certain phenomena have limited vertical scale while exhibiting strong vertical gradients, such as the stably stratified nocturnal boundary layer, fog and other boundary layer clouds. This suggests the importance of the vertical resolution needed to accurately represent such features, as briefly discussed by Bechtold *et al.* (1996) for the stratocumulus-topped boundary layer.

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A greater need for accurate fine-scale very short-term forecasts of low cloud ceiling and fog at airports exists as the volume of air traffic continues to increase. For the explicit numerical forecasting of fog and low clouds, two approaches are considered. One relies on the use of three-dimensional (3-D) mesoscale models such as the Rapid Update Cycle (BENJAMIN *et al.*, 2004), while another is based on the use of high vertical resolution one-dimensional (1-D) models as in CLARK and HOPWOOD (2001), BOTT and TRAUTMANN (2002) and BERGOT *et al.* (2005). Both approaches have strengths and limitations. The operational 3-D models cannot use a very high vertical resolution due to prohibitive computational cost, while 1-D models typically incorporate more sophisticated parameterizations and higher vertical resolution. However, 1-D models cannot represent the effect of spatial heterogeneities that may exist at the mesoscale as their 3-D counterpart can. Nevertheless, high-resolution 1-D models have advantages in situations characterized by the dominant role of local scale vertical exchanges of momentum, heat and moisture as in the case of radiation fog over flat terrain.

In this study, a comprehensive one-dimensional (1-D) boundary layer/fog model is used to perform numerical sensitivity experiments aimed at illustrating the impact of the vertical resolution used to generate explicit short-term forecasts of radiation fog formation and evolution. These experiments provide insights into the resolution dependence of the parameterizations of key physical processes influencing the characteristics and evolution of fog layers, such as radiative cooling, dew deposition and fog water transport by gravitational settling (ROACH, 1995). By the same token, some limitations of 3-D models related to limited vertical resolution are illustrated. For the sake of brevity, only stages corresponding to the pre-fog, formation and early evolution of the fog layer are considered. A discussion concerning fog dissipation is relegated to future efforts.

2. Description of Model and Numerical Experiments

The numerical model used to perform the sensitivity experiment is a version of the COBEL (Code de Brouillard à l'Échelle Locale) 1-D boundary layer/fog model described in BERGOT and GUÉDALIA (1994) and used at the Paris-Charles De Gaulle airport in France (BERGOT *et al.*, 2005). The model was originally developed through a collaboration between the Laboratoire d'Aérologie, Université Paul Sabatier/ Centre National de la Recherche Scientifique and Météo-France/Centre National de Recherches Météorologiques. Additional modifications were implemented at the Université du Québec à Montréal and at the National Center of Atmospheric Research (NCAR). The main features of the model are a detailed parameterization of radiative transfer in the longwave part of the radiation spectrum (VEHIL *et al.*, 1989), as well as a simple parameterization of shortwave (solar) radiation (FOUQUART and BONNEL, 1980). The parameterization of turbulent mixing incorporates a prognostic