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Microphysical Observations and Mesoscale Model Simulation of a Warm Fog Case during FRAM Project

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Abstract—The objective of this work is to apply a new microphysical parameterization for fog visibility for potential use in numerical weather forecast simulations, and to compare the results with ground-based observations. The observations from the Fog Remote Sensing And Modeling (FRAM) field which took place during the winter of 2005 – 2006 over southern Ontario, Canada (Phase I) were used in the analysis. The liquid water content (*LWC*), droplet number concentration (N_d), and temperature (*T*) were obtained from the fog measuring device (FMD) spectra and Rosemount probe, correspondingly. The visibility (*Vis*) from a visibility meter, liquid water path from microwave radiometers (MWR), and inferred fog properties such as mean volume diameter, *LWC*, and N_d were also used in the analysis. The results showed that *Vis* is nonlinearly related to both *LWC* and N_d. Comparisons between newly derived parameterizations and the ones already in use as a function of *LWC* suggested that if models can predict the total N_d and *LWC* at each time step using a detailed microphysics parameterization, *Vis* can then be calculated for warm fog conditions. Using outputs from the Canadian Mesoscale Compressible Community (MC2) model, being tested with a new multi-moment bulk microphysical scheme, the new *Vis* parameterization resulted in more accurate *Vis* values where the correction reached up to 20 –50%.

Key words: Fog microphysics, fog parameterization, fog forecasting, fog remote sensing.

1. Introduction

Fog formation is directly related to thermodynamical, dynamical, radiative, aerosol, and microphysical processes as well as surface conditions. Extinction of light at visible ranges within the fog results in low visibilities that can affect low-level flight conditions, marine traveling, shipping, and transportation. Fog occurrence of more than 10% of time in some regions of Canada (Whieffen, 2001) demands that fog nowcasting and/or forecasting models should be improved. Particularly, fog intensity, represented with visibility *(Vis),* should be more accurately simulated to reduce the costs of fog-related accidents and delays in transportation.

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The earlier studies on droplet number concentration (N_d) and liquid water content (*LWC)* relationships showed that there is usually a large variability in N_d for a given *LWC* (GULTEPE *et al.*, 2001; GULTEPE and ISAAC, 2004a). The work by GULTEPE *et al.* (2006) on fog microphysics suggested that N_d can change from a few droplets per volume to 100 cm^{-3} for a fixed *LWC* and that visibility should be a function of both N_d and *LWC*. These works indicated that N_d should be considered in visibility parameterizations. Previously, BOTT and TRAUTMANN (2002), using prognostic equations, developed a model that predicted both N_d and *LWC*. Under saturated conditions, more cloud concentration nuclei (*CCN)* leads to the formation of a large number of small droplets (GULTEPE and ISAAC, 1999), resulting in slower gravitational settling of droplets and thus low visibility. As shown by the experimental relation of JIUSTO (1981), visibility is directly related to the average cloud droplet radius, which in turn is directly proportional to the *LWC* and inversely proportional to the total number concentration. Hence, visibility parameterizations should also include the total number concentration of droplets as an independent variable.

Fog forecasting/nowcasting cannot be successful until a better understanding of fog microphysics and the large/small-scale dynamical effects on its formation is provided.

The current parameterization for fog visibility in numerical weather prediction (NWP) models is not accurate due to the neglect of N_d in parameterizations (STOELINGA and WARNER, 1999; GULTEPE *et al.*, 2006). ELLROD (1995) stated that satellite observations based on a channel differencing method (ch2-ch4) can facilitate fog forecasting at night because SW radiation is absent. On the other hand, the day-time algorithm needs to take away the SW contribution from the ch2. GULTEPE *et al.* (2007) suggested that integration of satellite observations together with a forecasting model output can improve fog forecasting up to 30%. An integration of surface-based sensors, remote sensors and model data, as proposed by ISAAC *et al.* (2006) and GULTEPE *et al.* (2007) for airport winter weather, might help provide improved predictions/nowcasts for fog occurrence.

The visibility for fog and other microphysical elements used in forecasting models was calculated using equations given by KUNKEL (1986) and STOELINGA and WARNER (1999). The fog visibility parameterization for warm temperatures is only a function of *LWC* and it has been commonly used in *NWP* models (BENJAMIN *et al.*, 2004). GULTEPE *et al.* (2006) suggested that the *Vis* parameterization for fog should also include N_d; otherwise, a possible uncertainty in model results can reach up to 50%.

In the present work, the observations collected during Fog Remote Sensing And Modeling (FRAM) field project which took place during the winter of 2005–2006 at the Center for Atmospheric Research Experiment (CARE) site, Toronto, Ontario, were used in the analysis. A new parameterization scheme for warm fog visibility as a function of both *LWC* and N_d, suggested by GULTEPE *et al.* (2006), is used to predict *Vis*. The Canadian Mesoscale Compressibility Community (MC2) model (BENOIT *et al.*, 1997) is used to simulate the 4 January, 2006 fog case. The microphysics scheme