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3.10 USE OF A MIXED-PHASE MICROPHYSICS SCHEME IN THE OPERATIONAL NCEP RAPID UPDATE CYCLE

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1. INTRODUCTION

Over the past few years, scientists at NCAR (National Center for Atmospheric Research) and NOAA (National Oceanic and Atmospheric Administration) have been collaborating to apply mixed-phase, bulk microphysics schemes to short-range operational numerical weather prediction. An important motivation for this work (under partial sponsorship of the Federal Aviation Administration) is to provide better guidance to the Aviation Weather Center of NCEP (National Centers for Environmental Prediction, part of the USA National Weather Service) for preparation of their icing forecasts.

2. BRIEF DESCRIPTION OF THE SCHEME

The particular scheme that is the subject of this paper is "Option 4" described in Reisner et al. (1998, hereafter R), but with some modifications and enhancements. The original development of the scheme was motivated by a need to improve forecasts of in-flight icing. The Reisner et al study developed a three-level bulk microphysical scheme, with each level introducing increasing complexity. Option 3 (lowest level) only predicted mixing ratios of cloud water, rain, ice and snow. Option 4 added the ability to predict number concentration of ice and mixing ratio of graupel, as well as introducing a variable N_0 (slope intercept) of snow into the scheme. The highest-level scheme was a two-moment scheme that added the ability to predict number concentrations of snow and graupel in addition to that of ice. All four schemes use the Marshall-Palmer inverse-exponential particle-size distribution for rain, snow and graupel.

These schemes were run for observed icing cases occurring during the Winter Icing and Storms Project (WISP, Rasmussen et al. 1992) with the Penn State/NCAR Mesoscale Model (MM5) and were shown to produce reasonable predictions of supercooled liquid water for two well-observed cases. Based on these favorable results it was decided to implement this scheme into the Rapid Update Cycle (RUC) model.

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3. OPERATIONAL APPLICATION

The Rapid Update Cycle (RUC, Benjamin et al 1999) is a four-dimensional atmospheric data assimilation and coupled land-atmosphere prediction system run at the National Centers for Environmental Prediction. The name RUC derives from its use as a vehicle for rapid updating and dissemination of analyses and very short term forecasts: analyses and forecasts are produced every hour by combining the latest 1-h model forecast with data received during the hour since the data cutoff for the previous analysis. Three-hour forecasts are produced every hour and 12-h forecasts every 3h. A distinctive aspect of the atmospheric component of RUC is its use of a hybrid sigma-isentropic vertical coordinate. Further, the forecast-model code has been written such that physics routines from MM5 can be easily adapted to run in RUC.

As mentioned above, it was decided to implement option 4 of the Reisner microphysics scheme into the Rapid Update Cycle operational system. This option was chosen because it was the lowest order scheme that produced reasonable forecasts in the Reisner et al study, allowing for a reasonably small impact on the operational system. In order to avoid having to "spin-up" clouds and precipitation at the start of each forecast, the 1-h forecast of the liquid and solid hydrometeor mixing ratios from the previous hour's run are passed into the next analysis without modification. (A real-time satellite-based cloud analysis is under development as discussed by Kim and Benjamin, 2000.)

4. RECENT MODIFICATIONS

Operational experience with the initial implementation of the option 4 microphysics in RUC, corroborated by real-time forecasts and case-study simulations using MM5, revealed a number of unexpected behaviors. These included:

1) excessive graupel at both high levels (temperatures below -25°C) even when vertical motions are weak, and just above the melting layer;

2) lower than expected amounts of supercooled liquid water;

3) unrealistically high cloud-ice number concentrations approaching $10^8/m^3$,

4) unrealistically small snow mixing ratios.

Careful reexamination of the code as well as use of a 2-dimensional version of MM5 capable of running either Reisner option 4 or a detailed microphysics code Rasmussen and Geresdi (2000), has led to a number of improvements to the code that have addressed these problems. In addition, the use of 10-min time steps in the operational implementation of Reisner option 4, necessary to meet operational runtime requirements on NCEP's old C90 Cray computer, was found to be a major contributor to graupel buildup.

Major changes to option 4 of R that address the above problems include the following.

1) Abandonment of the Fletcher curve (Fletcher, 1962) for ice nucleation as a function of temperature in favor of a more recent curve proposed by Cooper (1986) that leads to less aggressive ice nucleation at colder temperatures.

2) For both vapor deposition on snow and graupel, and for riming of snow or graupel by collection of supercooled cloud water, the assumed particle size distributions of both snow and graupel have been modified to a Gamma distribution in order to reduce the number of small particles. Further, as described in R (Eq A.43, Ikawa and Saito, 1991), there formerly was an explicit time-step dependence in the expression describing the rate of graupel formation as result of riming on snow. This is now replaced by a procedure of Murakami (1990) that is independent of time step: if depositional growth of snow is larger than riming growth, all riming growth of snow goes to augment snow, whereas if riming growth of snow exceeds depositional growth, riming growth of snow goes to augment graupel.

3) Extensive revision was made to calculations of cloud-ice number concentration to make this more consistent with mixing-ratio changes and to properly account for riming of cloud ice.

4) In order to more accurately simulate the production of supercooled drizzle droplets, a major icing hazard, through the collision-coalescence process, in supercooled cloud layers, the zero intercept for the size distribution of raindrops has been increased from $0.8*10^6$ to 10^{10} m^{-4} for rain water mixing ratios less than 0.1 g/kg and the autoconversion threshold from cloud water to rain water changed to 0.35 g/kg based on comparison to detailed simulations of freezing-drizzle formation.

5) Numerous other changes have been introduced to improve internal consistency.

6) We are investigating the efficacy of lookup tables in reducing computation time.

5. RESULTS

At this writing (June 2000), the revised option 4 of Reisner et al as implemented into RUC is undergoing further testing. We anticipate that by later this year an upgraded, higher-resolution version of the RUC, including the revised option 4, will be operational at NCEP. At the conference we will show comparison runs illustrating the impacts of these and other changes from the older operational version used since 1998.

6. ACKNOWLEDGMENTS

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