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ON THE IMPACTS OF MICROPHYSICAL SCHEMES AND PARAMETER CHOICES ON MM5 SIMULATIONS OF WARM-SEASON HIGH LATITUDE CLOUD AND PRECIPITATION SYSTEMS

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1.Introduction

In Alaska, a large number of short-range general aviation flights related to shipping, tourism and transportation occur daily. Combined with a complex geophysical environment, leads to especially hazardous situations that still sometimes elude even experienced aviation weather forecasters.

As documented by Politovich (1989), Taffener (2001) and others, the most dangerous situations involve ice accumulation through contact freezing of large supercooled water droplets (SLDs; 30-400 μm diameter). Droplets of this size can spread along the airframe forming clear ice on unprotected surfaces (including the underside of the wings) resulting in a great increase in aircraft drag (e.g., Politovich, 1989). Knowledge of the spatial and temporal distribution of supercooled droplets is therefore very important in icing diagnosis and prediction. Unfortunately, meso- and micro-scale topography, a preponderance of conditions conducive to mixed phase clouds and sparse observational data coverage lead to a challenging environment for predicting SLD distributions and attendant icing in Alaska.

We have developed an Alaska-specific icing diagnostic algorithm (UAF IIDA) derived from the NCAR/RAP IIDA *(*McDonough and Bernstein, 1999*)* recently accepted for operational implementation at the Aviation Weather Center. We refer the reader to Tilley et al., (2002a) and (McDonough and Bernstein, 1999) for a description of UAF IIDA, but summarize by noting that UAF IIDA utilizes infrared satellite observations, pilot reports (PIREPs), surface observations and numerical forecast data from the PSU/NCAR MM5 mesoscale model version 3 (MM5v3; Chen and Dudhia 2001). Therefore, the quality of the simulated atmospheric fields of temperature and relative humidity, as well as associated cloud microphysical processes, can have a substantial impact on the skill of the algorithm.

For this reason, it is important to evaluate the degree of impact that the various MM5 microphysics schemes can have on high latitude simulations of fields important to the UAF IIDA, as well as on the IIDA output itself. In this paper we present a comparison of fields from a suite of simulations using different microphysical schemes and/or parameter settings. In a companion paper (Tilley et. al, 2002b) we feed the output from the simulations into the UAF IIDA and perform a similar comparison.

2. Experiment Design

A suite of simulations were performed with MM5v3 in which all model physics schemes were the same save the microphysical treatment. The simulation domain (Figure 1)covers most of Alaska at 18 km horizontal resolution, with 41 vertical sigma coordinate levels. All simulations utilized the Grell (Grell et al. 1991) cumulus scheme, the Burk and Thompson (1989) turbulence closure scheme, a force-restore

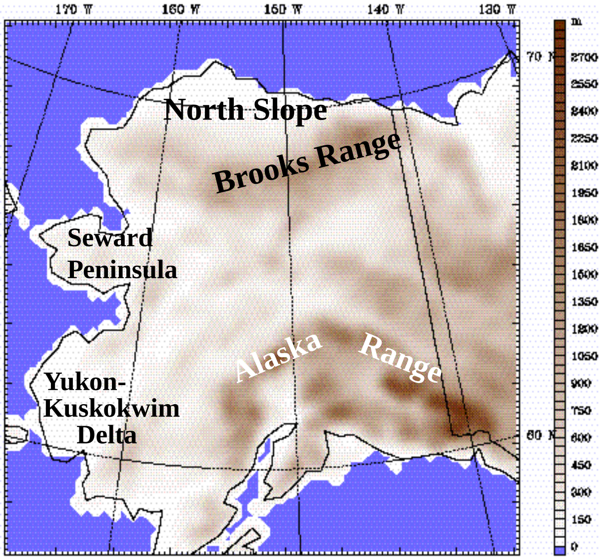


Figure 1. Domain of MM5 simulation experiments. Grid resolution is 18 km; major terrain features are marked.

treatment of the soil, and an improved version of the CCM2 radiative transfer scheme (Cassano et. al 2001).

With the above physics schemes, four simulations were conducted using the following standard microphysics options in MM5:

- the Dudhia (1989) simple ice scheme that does not include mixed phase processes,
- the Reisner et al. (1998; referred to as Reisner 1) scheme including cloud and rain water, ice and snow, but not considering riming processes or graupel formation,
- the Tao et al. (1993; referred to as Goddard) scheme that includes the above and also graupel formation,
- the Reisner et al. (1998) scheme that includes graupel formation and prognostic equations for number concentrations of graupel and ice (referred to as Reisner 2),
- the efficient scheme of Schultz (1995) that includes the formation of ice, graupel and hail.

The prediction of ice nuclei (IN) number concentration in the Reisner 1 scheme and ice initiation in the Reisner 2 scheme is based on the Fletcher (1962) empirical temperature-dependent formulation. This formulation has several shortcomings, particularly in high latitudes, as it tends to overpredict IN concentration in very cold clouds; and is insensitive to saturation conditions (e.g. Meyers et al., 1992). To compensate, Reisner et al. (1998) limited the use of the Fletcher formula to a minimum temperature threshold (T_{min})of 246K (though this is not done in the standard MM5 implementation). The 246 K limit, however, disagrees with the minimum temperature at which ice and supercooled water may coexist, usually taken as 238K but which may be colder in high latitudes (Storvold, pers. comm). To test the sensitivity of the simulations to this parameter, additional simulations (denoted R1-238 and R1-246) using the Reisner 1 scheme were carried out with T_{min} = 246K and 238K.

The Fletcher formula also underestimates IN concentration between 263-273K by as much as four orders of magnitude (e.g., Pruppacher and Klett, 1980). Molders et al., (1995) found it necessary to specify a much higher threshhold value than the ~ 0.01 m^{-3} value of Fletcher to avoid this problem, which can result in the calculated size of ice crystals becoming too large.

As a result, simulations were conducted with both Reisner schemes (denoted R1-M and R2-M) where the Fletcher formula was replaced by the empirical Meyers et al. (1992) formula which only depends on ice supersaturation, in accord with previous studies; (e.g., Pruppacher and Klett 1980). The Meyers formula, also used in the Schultz scheme, guarantees a minimum amount of pristine ice crystals (about 530 m^{-3} and allows a maximum concentration of 10000 m^{-3}. To check the sensitivity of the simulation to the value of this upper limit, a simulation (denoted R1-M2) was carried out with a maximum IN concentration of 5000 m^{-3}. Since the formula of Meyers et al. (1992) may also overpredict the IN number concentration in high latitudes (Harrington, pers. comm.), a further simulation (denoted R1-H) was performed, where the initial IN concentrations produced were reduced by a factor of ten.

3. Case study

The case study period considered here (15-17 June 1998) falls during early summer over effectively the entire domain. This period is ideal for testing many aspects of the UAF IIDA since during this part of the year several different cloud and in-flight icing environments typically are present over Alaska. Convection occurs in Interior Alaska while low stratus clouds dominates the North Slope and maritime cloud systems, with a mixture of cloud types, occur over the southern third of the state. Such a variety of conditions represent different icing forecast problems and scenarios and are a good test for any algorithm intended for regional application.

The period also corresponds to the latter half of the Surface Heat Balance of the Arctic Ocean (SHEBA) field program centered in the Beaufort Sea. As a result, there are additional special observations available for validation, featuring an integrated dataset of retrieved satellite quantities specially prepared by SHEBA investigators.

As a first test case for investigations, the period from 15th, 0 GMT, to 17th, 12 GMT, of

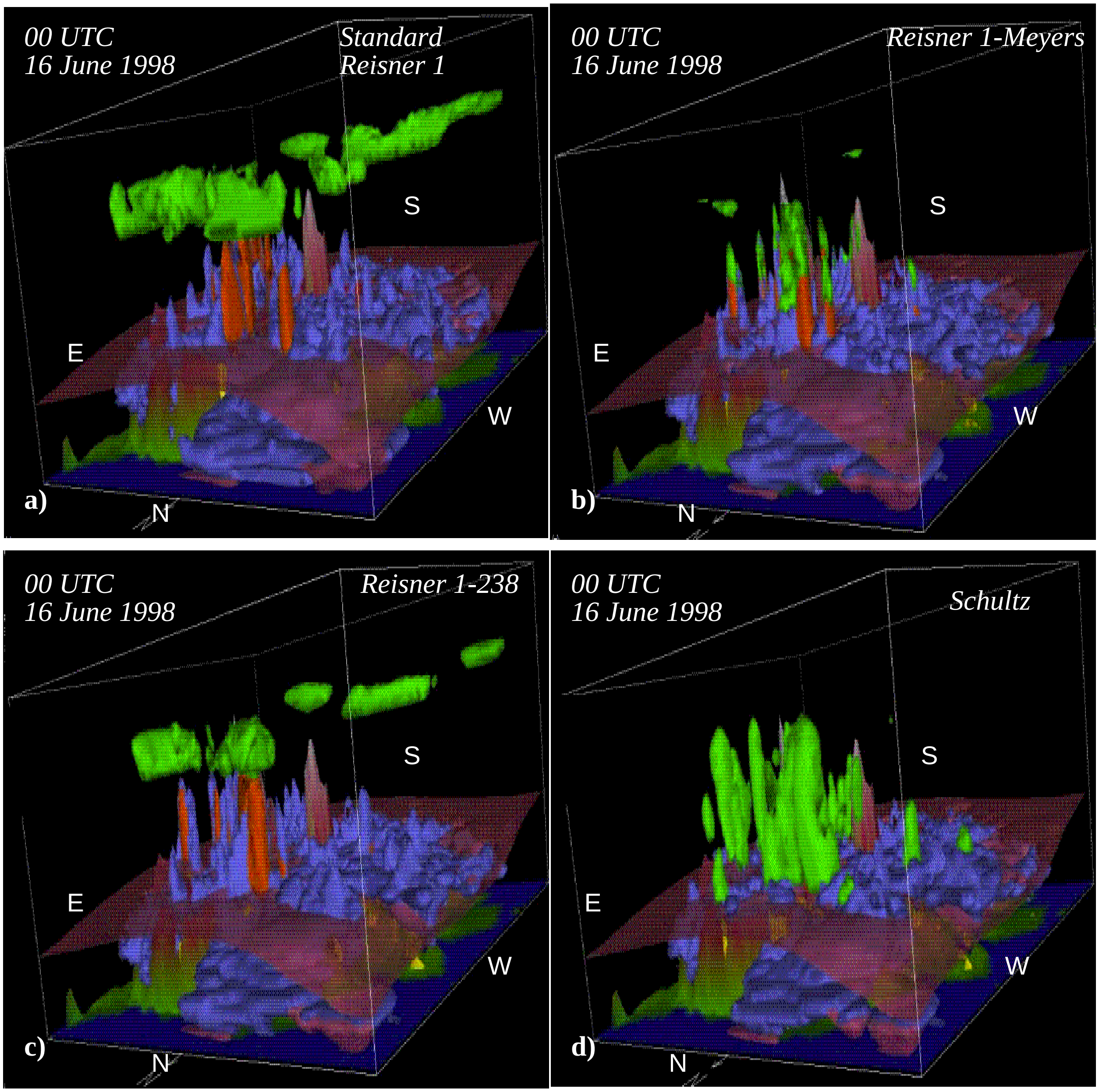
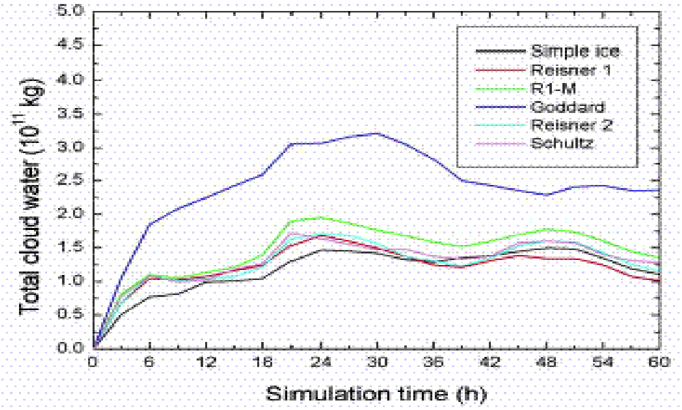


Figure 2. Cloud liquid water (violet), rain water (yellow), ice (green), and snow (red-orange) mixing ratios plus the freezing level (mauve) at 00 UTC 16 June 1998 for simulations a) Reisner 1; b) R1-M; c) R1-238; d) Schultz. The 0.05 g/kg surface is shown for cloud liquid and rain water; the 0.02 g/kg surface is shown for cloud ice and snow.

Figure 3. Time series of total cloud liquid water mass (10^{11}kg) over the 18 km simulation domain produced by the Simple Ice (black), Reisner 1(red), R1-M (green), Goddard (blue), Reisner 2 (cyan) and Schultz (mauve) simulations. 3-hourly otuput data are used to generate the time series.



June 1998 was chosen, and the data of the NCEP/NCAR Reanalysis Program (NNRP) for that period were used to create the first-guess meteorological fields on the grid of MM5 which serve as initial and boundary conditions. All predictions were carried out for that 60 h period without any form of nudging to meteorological analysis or observation data.

4. Preliminary Results

Figures 2 and 3 show a brief sample of results from the various simulations. In Figure 2, the various cloud hydrometeor fields and the freezing level for four of the experiments are visualized as isosurfaces, whereas in Figure 3 we show domain-integrated cloud liquid water mass from a subset of the experiments.

Figure 2 illustrates some significant differences in the cloud morphology amongst the experiments. Substantial differences are present in the cloud ice and snow fields amongst the simulations and there are areas of significantly differing vertical extent of supercooled water (evidenced by cloud water above the freezing level) as well. In particular, it appears clear that the use of the Meyers et al (1992) formulation for ice nucleation in the R1-M and Schultz schemes results in less high cirrus cloudiness and more cloud ice associated with convective systems in interior Alaska.

Figure 3 indicates the potential for some schemes, in particular the Goddard scheme, to systematically produce much greater levels of cloud liquid water than the other schemes. Satellite-based validation of the results is required to determine if the Goddard scheme cloud water is excessive or the other schemes' cloud water is insufficient. At the conference we will present more detailed analysis of our results as well as satellite and conventional data based-validation.

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