HIERARCHY OF MICROPHYSICAL PARAMETERIZATIONS SUITABLE FOR CLOUD AND MESOSCALE MODELS.

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1. Introduction

There has been a considerable amount of research on the modeling of microphysical processes that lead to the formation of precipitation within meso-scale and cloud-scale dynamical models. This research has been concerned with many time and spatial scales, and physical mechanisms. While the most general theme often is to understand the role of natural and anthropogenic aerosols on precipitation formation, other purposes such as the prediction of specific physical phenomena such as rain, snow, and hail on the ground, aircraft icing conditions aloft, and precipitation enhancement potential remain important goals. This paper will present a hierarchy of microphysical parameterizations schemes to represent the major physical process characteristics of precipitation development in wintertime mid-latitude storms with the particular emphasis on the problem of predicting freezing drizzle events.

The present approach utilizes classical spectral functions to represent each hydro-meteor class (i.e. cloud water, rain water, pristine ice, snow ,and graupel) in an explicit equation set. The hierarchy of schemes range from more complex two parameter functions to simplified one parameter representations of each class. The present work examines the suitability of the spectral assumptions commonly used to reduce the number of variables from two parameter to one parameter representations.

The bulk physical microphysical parameterization schemes for the ice phase used in this paper follows the work of Reisner *et. al.* (1998) and Thompson *et. al.* (2004). These schemes are based upon the earlier works of Rutledge and Hobbs (1983,1984), Lin, Farley and Orville (1983), and Murakami (1990). The small cloud droplet nucleation and condensational growth utilizes the analytical work of Cohard *et. al.* (1998). Four different collision-coalescence schemes that convert cloud water to rain water are tested. These include the one parameter rain methods of Kessler (1969), and Berry and Reinhardt (1974) and the two parameter rain methods of Khairoutdinov and Kogan (2000) (KK), and Seifert and Beheng (2001) (SB). The purpose of this hierarchy is to systematically compare different microphysical approaches within the identical dynamical framework in order to determine the most suitable approach for the prediction of freezing drizzle conditions in wintertime mid-latitude storms.

2. Model Description

The present dynamical framework is the non-hydrostatic Weather Research and Forecast Model (WRF), (WRF,2003). The hierarchy of microphysical schemes contains a number of different treatments of the microphysical processes for both liquid and ice phase processes. The warm rain procedures include the cloud condensation nucleation activation from a background activation spectrum to be used when the vertical motions can be explicitly resolved and a simple cloud number concentration prescription method for larger scales where the horizontal resolution is larger the about 1 km.

3. DEC 13-14, 2001 Improve 2 Field Study

The present hierarchy of microphysical schemes is currently being employed in the WRF, MM5, and RUC models. This paper will present results using the WRF model with grid nesting on the well documented case study of Dec 13-14,2001 from the IMPROVE 2 field experiment, Garvert *et. al.* (2004), Woods *et. al.* (2004).

The model was set up to run with 4 interactive grids with horizontal resolutions of 27, 9, 3, and 1 km. This allow the model to simultaneously solve

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for the larger scale storm system and focus on the smaller scale processes that could be directly compared with the in-situ observations. The model initial and time dependent boundary conditions were derived from the NCEP ETA model using the WRF Standard Initialization program. Each WRF model run presented here included a 24 hour simulation. The model was first started only with the coarsest grid and the finer scale grids were subsequently included as the 24 hour run progressed. The outer domain began at 12 Z UTC Dec 13 and was first run for 3 hours and then the second domain was introduced 3 hours into the simulation followed by third and forth domains respectively at 9 and 12 hours.

Some of the observations are presented in figures 1 through 4. Figure 1 show the aircraft and times of 2 research flights by the NOAA P-3 and University of Washington Convair during the IMPROVE II field experiment. These flights were taken in a post frontal period. In figure 2 show the liquid water content measured from the PMS-FSSP probe. The probe indicated significant super-cooled water above 0.1gm/kg at altitudes above 4 km where the temperature approached -20°C in the stronger updrafts. Figure 3 shows a few particle PMS-2DC images at selected levels from the Convair. These images indicate the presence of large drizzle droplets when the FSSP probe detected the larger liquid water contents. Ice particles were evident at lower altitudes. Figure 4 show a cross barrier plots of vertical velocity, liquid water content,temperature and dew-point, and terrain elevation from the P-3 aircraft at 3 km altitude (-10°C). These figures clearly show a strong correlation between the vertical velocity, liquid water content, and terrain below.

The simulation time of 5:00Z 14 Dec was chosen for the present analysis to compare to available aircraft flight data near this time.

' 4. Model Simulation Results

Results from 5 simulations are presented. These runs have the same dynamical setup with varying microphysical options within the present hierarchy. The 5 model runs are:

1. from the work of Thompson *et. al.* (2004) using the Berry and Reinhardt one moment coalescence and a one moment snow parameterization.

2. with Kessler (1969) one moment coalescence with an auto coalesce threshold of 0.35 g/kg and Thompson one moment snow parameterization.

3. with Seifert and Beheng (2001) 2 moment coalescence and Reisner *et. al.* (1998) two moment snow parameterization.

4. with Khairoutdinov and Kogan (2000) two moment coalescence and Reisner *et. al.* (1998) two moment snow parameterization.

5. with Lin microphysics (WRF default) one moment cloud, rain, small ice, snow, graupel.

Figure 5 is shows the model vertical velocity field along a cross-section that overlays the observations. The zero point on the observations axis corresponds to the 205 km point along this south-west to north-east cross-sectional plot. Noted here it that the model vertical velocities and magnitude are highly correlated with the terrain and are very similar to the P-3 aircraft observations.

In Figures 6 through 10 are cross-sectional plots of the cloud liquid content for each of the 5 runs. Runs 1,2, and 5 gave significant liquid cloud water content above the -10°C level. In Figures 11 through 15 are similar cross-sectional plots of the drizzle and rain content for each of the 5 runs. Only runs 1 and 2 gave significant super cooled drizzle above the -10°C level indicating that there may be some problems with the two moment snow. Case 4 over predicted the amount of drizzle in the lowest layers. It is worth noting that in previous icing case studies the two moment KK rain scheme had performed very well. In the present case with very strong orographic flow, the physical conditions exceeded the recommended stratiform conditions for the KK scheme. After modifying the KK scheme by correcting the terminal rain fall speed and including a rain self collection term from the SB scheme which was not present in the original KK scheme, the modified KK rain scheme resulted in satisfactory results compared with observations (not shown here).

Figures 16 through 20 show the snow fields along the same cross-sections. The two moment snow produced more snow than the one moment snow and the Lin scheme produced very little. This over production of the two moment snow was the reason for the lower super cooled water for cases 3 and 4.

5. Future Work

Many questions remain as to the suitability of using explicit bulk parameterization schemes to predict the characteristics of precipitation that lead to freezing drizzle events in wintertime mid-latitude storms. Work continues to test the hierarchy of bulk microphysical schemes for cases where verification observational data are available. Future work will include field studies from the AIRS II (2003) field experiment. Further testing and modifications of the various spectral distribution functions that represent each cloud physical field are planed.

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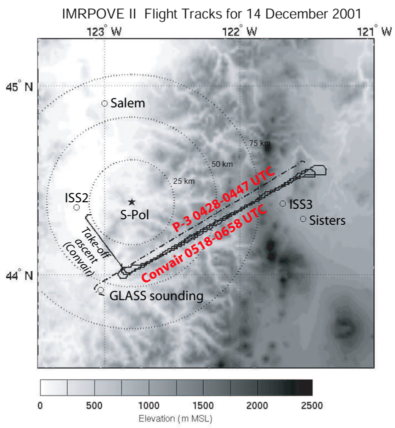

Figure 1: Aircraft Flight Tracks for 14 Dec post frontal flights.

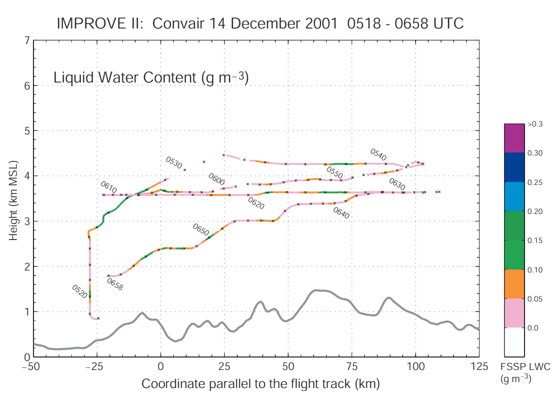

Figure 2: FSSP liquid water observations from the Convair.

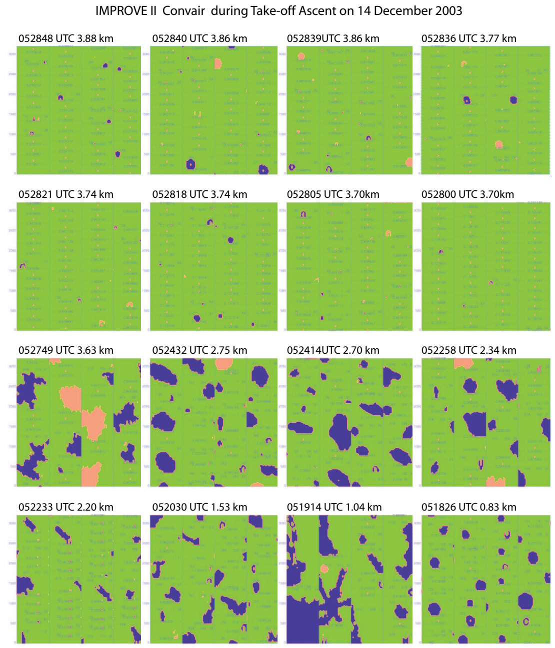

Figure 3: PMS-2DC images at selected heights from Convair.

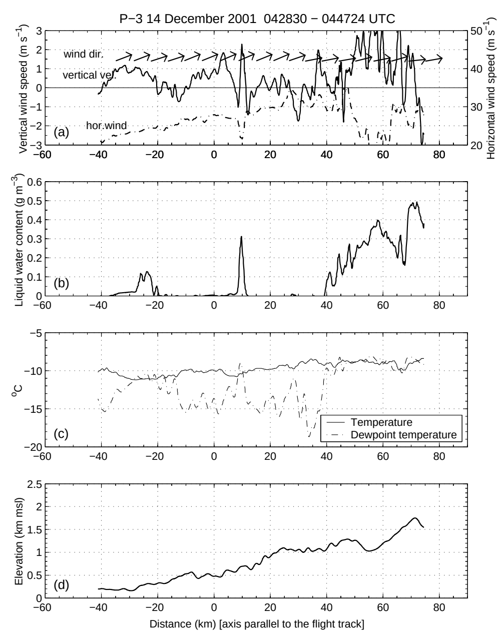

Figure 4: P-3 observed vertical velocity, liquid water, temperature and dewpoint, and altitude along crossection.

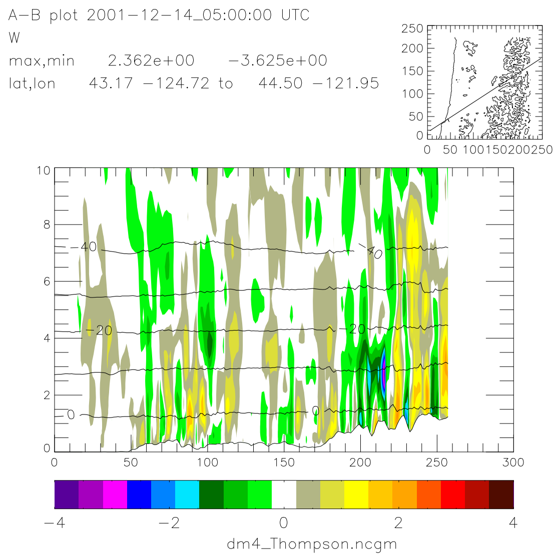

Figure 5: Model 1 km. grid vertical velocity (m/s) after frotal passage at 5Z UTC from .

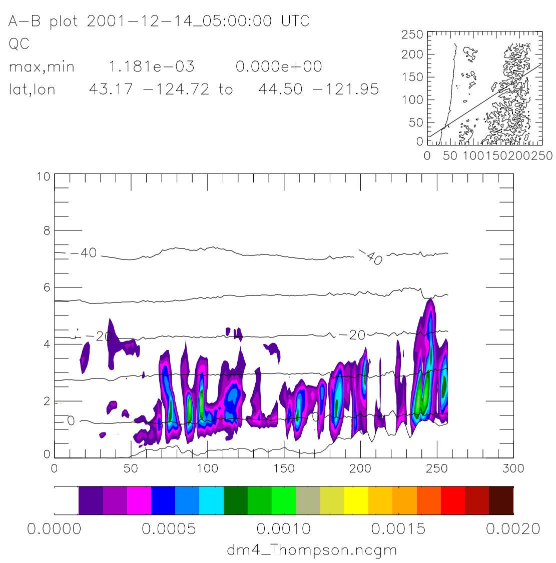

Figure 6: Model 1 km. grid Run 1 cloud water (g/g) at 5Z UTC.

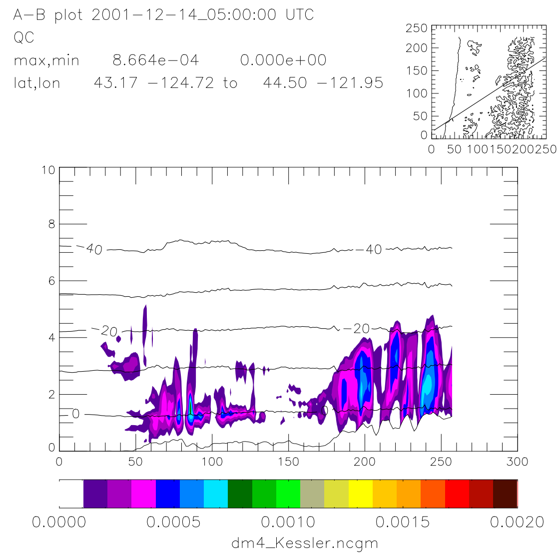

Figure 7: Model 1 km. grid Run 2 cloud water (g/g) at 5Z UTC.

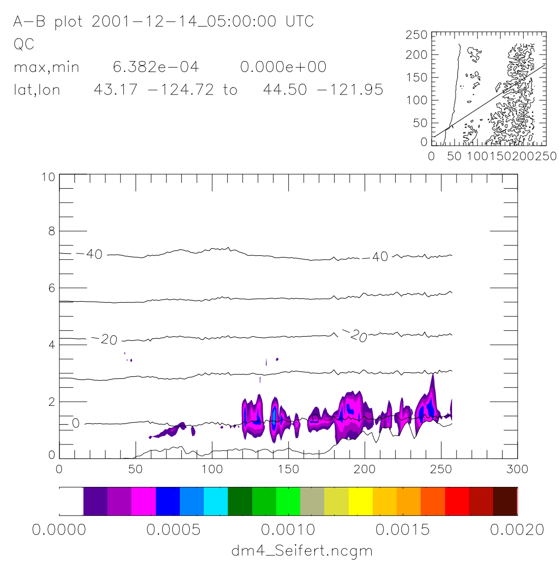

Figure 8: Model 1 km. grid Run 3 cloud water (g/g) at 5Z UTC.

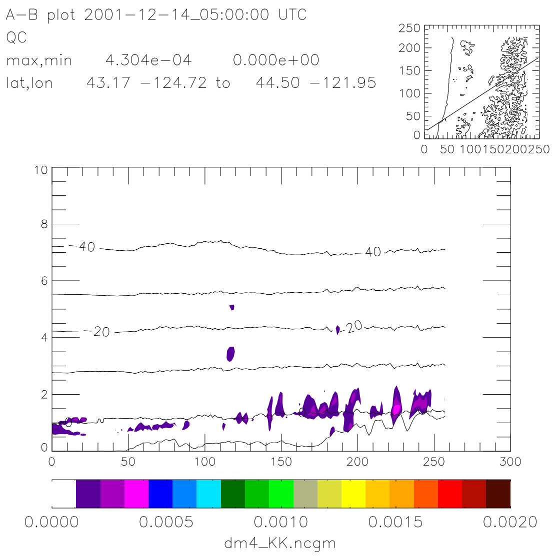

Figure 9: Model 1 km. grid Run 4 cloud water (g/g) at 5Z UTC.

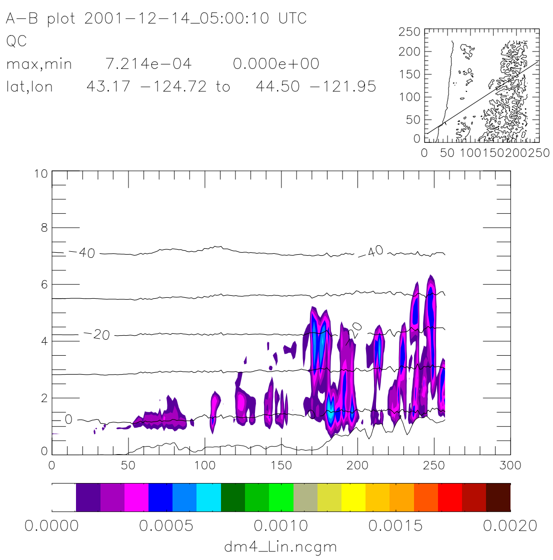

Figure 10: Model 1 km. grid Run 5 cloud water (g/g) at 5Z UTC.

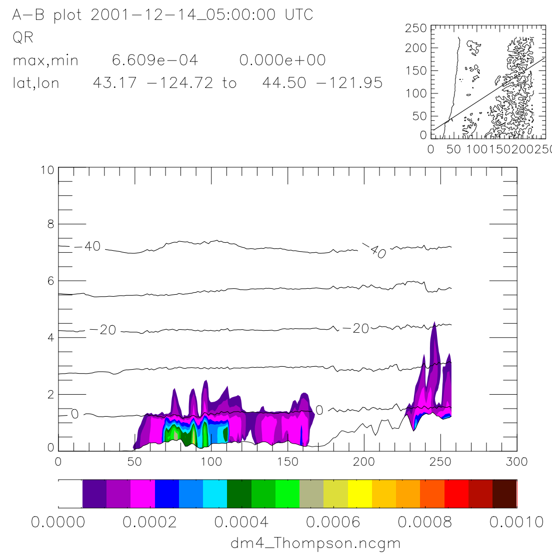

Figure 11: Model 1 km. grid Run 1 drizzle and rain water (g/g) at 5Z UTC.

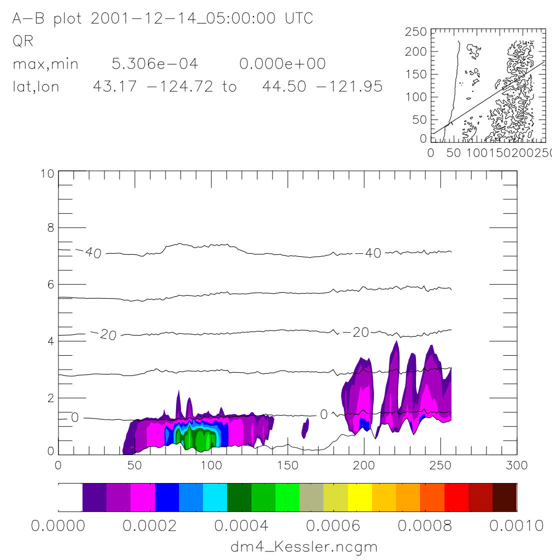

Figure 12: Model 1 km. grid Run 2 drizzle and rain water (g/g) at 5Z UTC.

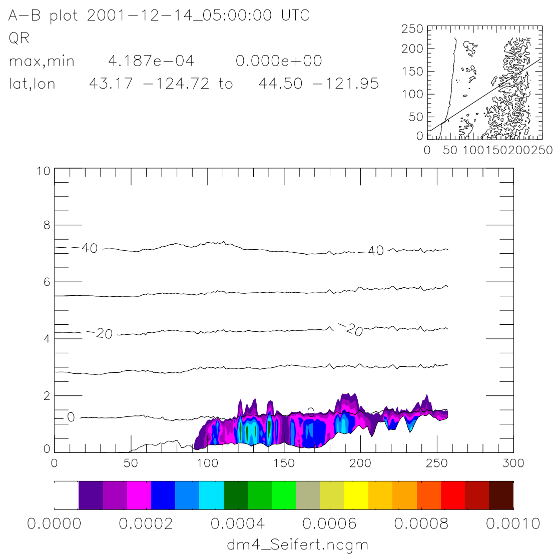

Figure 13: Model 1 km. grid Run 3 drizzle and rain water (g/g) at 5Z UTC.

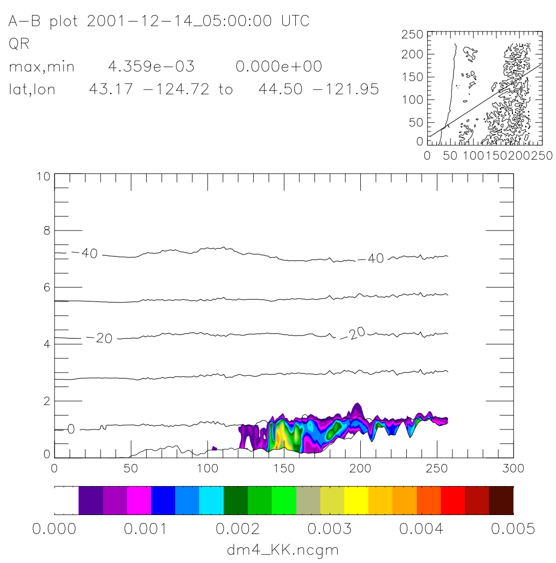

Figure 14: Model 1 km. grid Run 4 drizzle and rain water (g/g) at 5Z UTC. Note the change in scale.

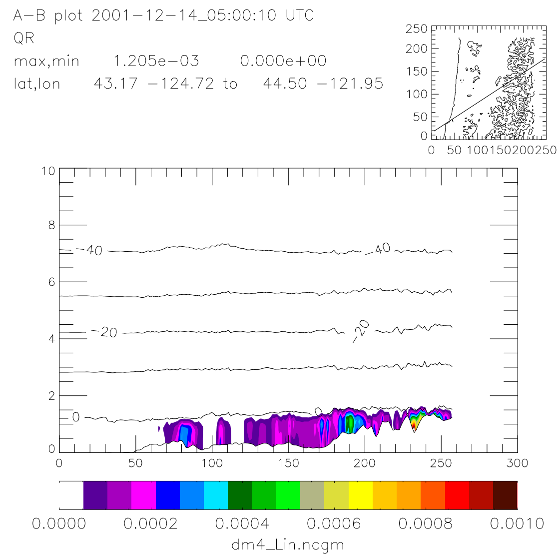

Figure 15: Model 1 km. grid Run 5 drizzle and rain water (g/g) at 5Z UTC.

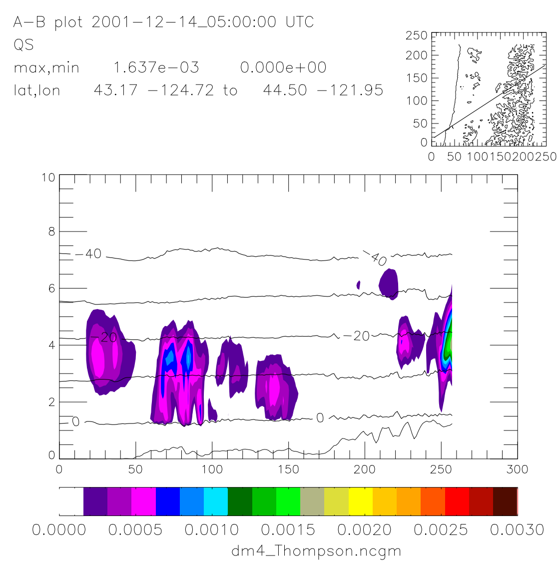

Figure 16: Model 1 km. grid Run 1 snow (g/g) at 5Z UTC.

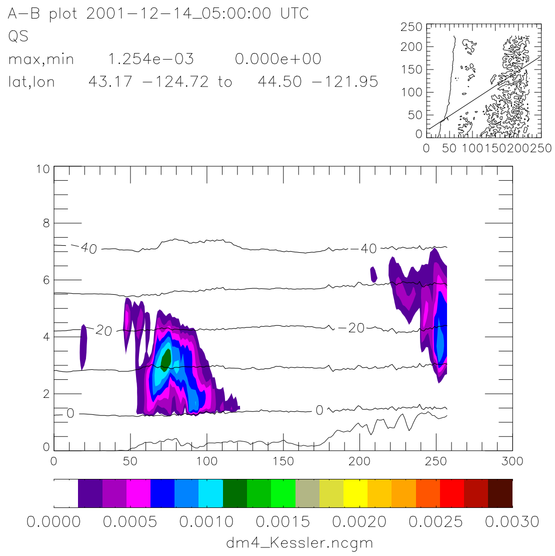

Figure 17: Model 1 km. grid Run 2 snow (g/g) at 5Z UTC.

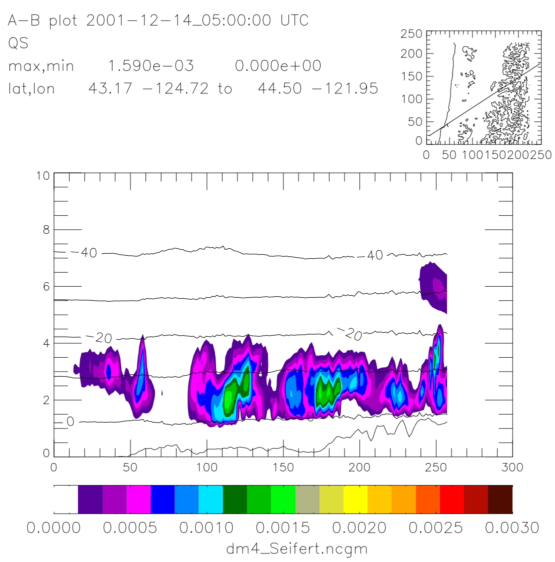

Figure 18: Model 1 km. grid Run 3 snow (g/g) at 5Z UTC.

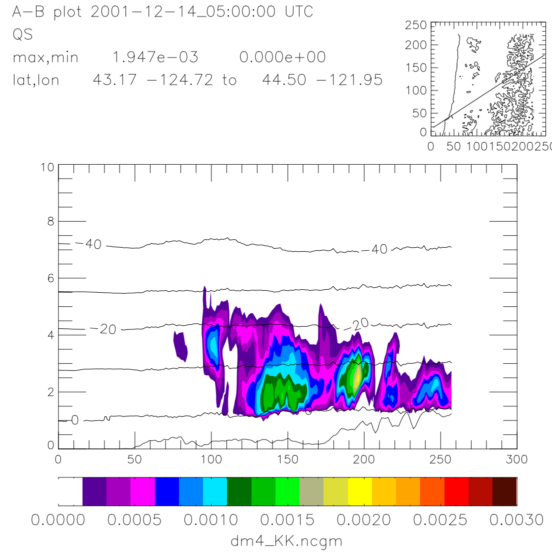

Figure 19: Model 1 km. grid Run 4 snow (g/g) at 5Z UTC.

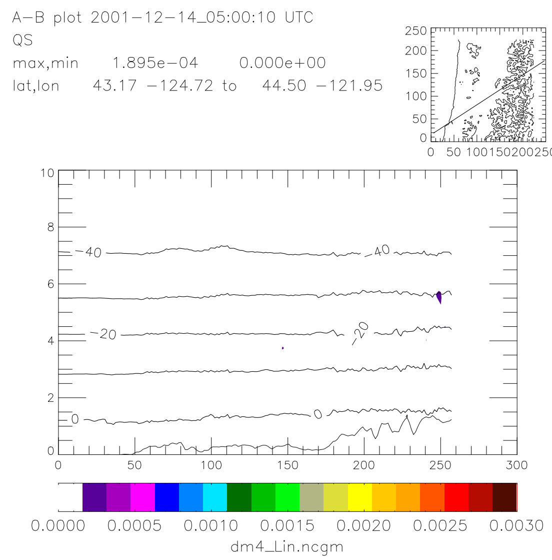

Figure 20: Model 1 km. grid Run 5 snow (g/g) at 5Z UTC.