IMPLEMENTATION OF THE TWO-MOMENT RAMS CLOUD MICROPHYSICS IN ARW: COMPARISONS AGAINST TWO-MOMENT SCHEMES

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1. SUMMARY

Our proposal focused on testing the implementation of the two-moment cloud microphysics scheme developed for the Regional Atmospheric Modeling System (RAMS; Walko et al. 1995, and Meyers et al. 1997) in the Weather Research Forecast (ARW 2.2.1; Skamarock et al. 2007) model, and comparing its performance against cloud schemes that are currently available in ARW. We limited our comparison of the RAMS cloud microphysics parameterization against the Thompson (Thompson et al. 2004, 2008) and the Morrison (Morrison et al. 2005) schemes because both include prognostic number concentrations, at least for several hydrometeor categories.

Our comparison is based on the outputs of idealized two-dimensional squall line simulations for two sets of initial conditions. In the first case, the model was initialized with temperature and moisture profiles used by Weisman and Klemp (1982; 1984). In the second case, initial temperature and humidity profiles were interpolated from measurements taken during the International H_2O project (Weckwerth et al. 2004). In this report, we limit our comparison between the three cloud microphysics parameterizations to the set of simulations initialized with the Weisman and Klemp soundings. Further comparisons will be discussed in Fowler et al. (2008).

2. IMPLEMENTATION OF THE RAMS CLOUD MICROPHYSICS IN ARW

The RAMS cloud microphysics scheme has been implemented in the Advanced Research version of the Weather Research Forecast model (ARW 2.2.1; Skamarock et al. 2007) and tested with idealized cases. In ARW 2.2.1, the existing *moist* prognostic variables were the water vapor, cloud water, cloud ice, rain, snow, and graupel mixing ratios. The existing *scalar* variable was the number concentration for cloud ice. The following prognostic variables were added to Registry.EM:

1. In Registry.EM, the following prognostic variables were added under the *moist* section:
   - QCLOUD2 : mixing ratio of second mode of cloud water droplets (kg per kg).
   - QAGGR : mixing ratio of aggregates (kg per kg).
   - QHAIL : mixing ratio of hail (kg per kg).
2. In Registry.EM, the following prognostic variables were added under the *scalar* section:

- QNCLOUD : number concentration of first mode of cloud water droplets (# per kg).
- QNCLOUD2 : number concentration of second mode of cloud water droplets (# per kg).
- QNRAIN : number concentration of rain drops (# per kg).
- QNSNOW : number concentration of snow (# per kg).
- QNAGGR : number concentration of aggregates (# per kg).
- QNGRAUP : number concentration of graupel (# per kg).
- QNHAIL : number concentration of hail (# per kg).
- Q2_MP : internal energy of rain (Joules per kg).
- Q6_MP : internal energy of graupel (Joules per kg).
- Q7_MP : internal energy of hail (Joules per kg).
- QCCCNP : number concentration of cloud condensation nuclei (per kg).
- QGCCNP : number concentration of giant cloud condensation nuclei (per kg).
- QCCCMP : mass of cloud condensation nuclei (kg per kg).
- QGCCMP : mass of giant cloud condensation nuclei (kg per kg).

3. In the *mp_physics* section, we added the cloud microphysics option *rams*:

- Package rams mp_physics = 9
  moist :qv,qc,qc2,qr,qi,qs,qa,qg,qh
  scalar :qnc,qnc2,qnr,qni,qns,qna,qng,qnh,qp2_mp,qp6_mp,qp7_mp,qcccnp,qgccnp,
  qcccmp,qgccmp,qcifnp

The RAMS cloud microphysics package was added to the module module_microphysics_driver.F. RAMS uses the ice-liquid potential temperature instead of the potential temperature as its main thermodynamic variable. Tripoli and Cotton (1981) showed that using the ice-liquid potential temperature in conjunction with total water was a viable and powerful alternative to using the potential temperature, water vapor, and liquid and ice hydrometeors as time-dependent prognostic variables in cloud-resolving models. One main advantage is that the ice-liquid potential temperature is a conservative variable under phase changes, as is the total water content. Implementing the RAMS cloud microphysics parameterization in ARW required to replace the ice-liquid potential temperature by the potential temperature as the thermodynamic prognostic variable in order to accommodate the eulerian-mass dynamical core. In ARW, we saved the tendencies for the mass mixing ratio and number concentration of each hydrometeor categories due to each microphysics process before computing the mass, number, and thermodynamic budgets, following the structure of other cloud microphysics schemes. In contrast, the original RAMS cloud microphysics parameterization updates the mass and number mixing ratios of individual hydrometeor immediately after a microphysics process is applied. In ARW, we restructured the RAMS cloud microphysics driver so that each parameterized process carried the same weight in the mass, number, and heat budget equations.

3. RESULTS

The idealized case *em_squall2d_x* was run for 8 hours with the RAMS, THOMPSON, and MORRISON cloud microphysics parameterization. As in all inter comparisons between physical parameterizations, it is difficult to compare cloud microphysics schemes because they use different criteria to define hydrometeor categories and different parameterizations to describe microphysics processes between these hydrometeor categories. Here, we highlight a few of the chief differences that we observed between the three schemes. The major differences between the RAMS and the other two cloud schemes are related to the development of the stratiform anvils and the strength of the cold pool. Figures 1 and 2 show longitude versus pressure cross sections of the total amount of condensates simulated after 4 and 8 hours, respectively. It is obvious that the horizontal extent of the stratiform anvil simulated with RAMS is reduced relative to the other two cloud microphysics schemes. Comparing Fig. 2 against Fig. 1 reveals that the location of the updraft core simulated with RAMS has moved eastward, but that the structure of the cloud has not significantly varied after 4 hours of simulation. In contrast, the THOMPSON and MORRISON schemes yield convective cores that have moved further east in conjunction with rear decaying stratiform anvils. Figures 3 and 4 display longitude versus pressure cross sections of the change in the water vapor mixing ratio after 4 and 8 hours of simulations relative to the initial water vapor sounding. Figures 5 and 6 are as Figs. 3 and 4, but for the temperature. Relative to the THOMPSON and MORRISON cloud schemes, the RAMS cloud scheme yields a decreased moistening between 700 and 400 hPa. This result is in accordance with the decreased amount of condensates depicted in Figs. 1 and 2. Looking at Fig. 1, it is important to note that the base of the base of the convective updraft simulated with the MORRISON cloud scheme is wider than those simulated with the THOMPSON and RAMS schemes. This difference yields the maximum drying at lower levels to occur further west of the convective updrafts in the MORRISON cloud scheme, relative to the THOMPSON and RAMS parameterizations. The decreased intensity of the cold pool simulated in RAMS is obvious in Figs. 5 and 6. Detailed analyses of the contribution of each hydrometeor category to the evaporation cooling of the lower troposphere are being conducted.

4. SUMMARY AND FUTURE WORK

Results show that the RAMS cloud microphysics scheme has been implemented successfully in ARW, and is running correctly for idealized squall-line simulations. As discussed in Section 3, the evolution of a convective squall line simulated with RAMS is quite different from those simulated with the THOMPSON and MORRISON schemes, both dynamically and thermodynamically. Explaining the origins of the weaker cold pool and decreased stratiform anvils simulated with RAMS is a priority.

Depending on future funding opportunities, future research will focus on real case simulations with the aim to further evaluate the RAMS cloud microphysics in ARW.

ACKNOWLEDGEMENTS: The present work could not have been done without the support of the WRF DTC. I would like to thank Dr. Bob Gall for selecting my application as a visiting scientist at the WRF DTC in April-May 2008. I also would like to thank Louisa Nance, Pam Johnson, and Jamie Wolf for their generous help during those two months. I also would like to thank Greg Thompson and Hugh Morrison for their on-going collaboration in this project.

LIST OF FIGURES

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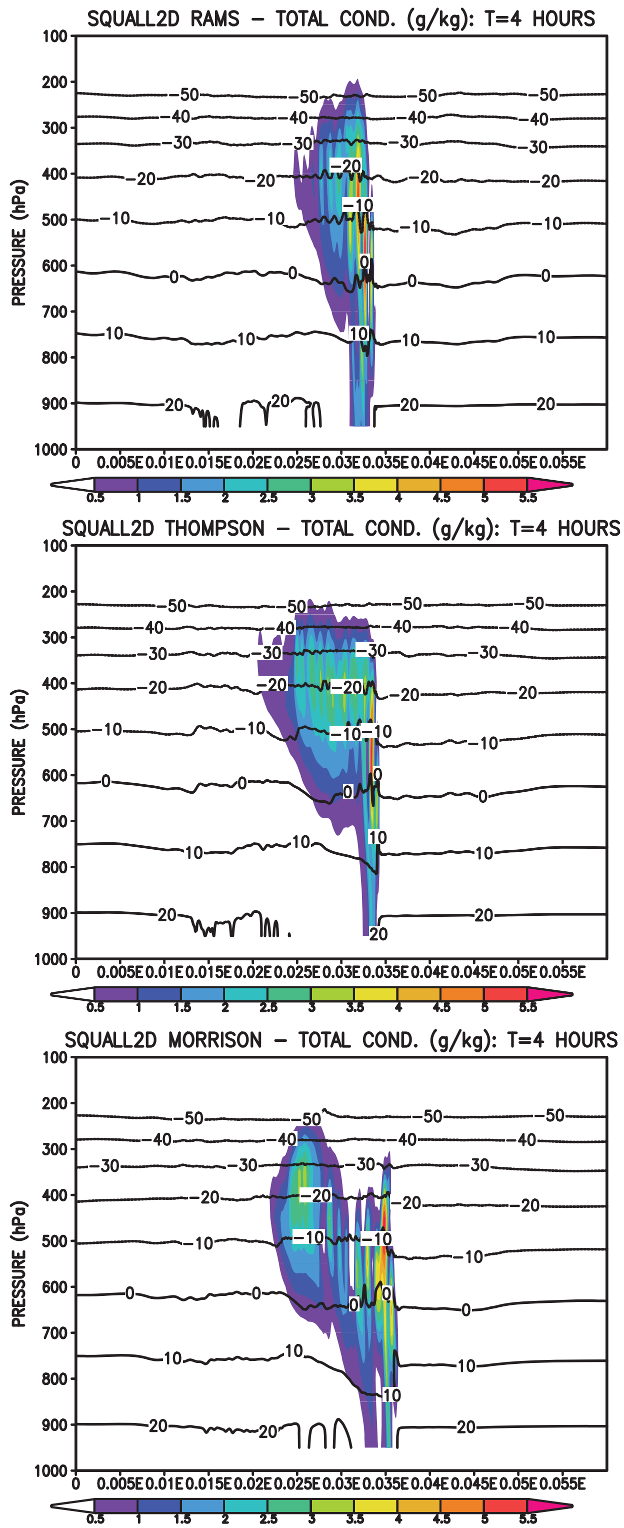

Figure 1: Longitude versus pressure cross sections of the total condensate (shaded) and temperature (contour) simulated at time t = 4 hours using the RAMS (top), THOMPSON (middle), and MORRISON (bottom) cloud microphysics schemes. Units are g per kg for the total condensate and °C for the temperature.

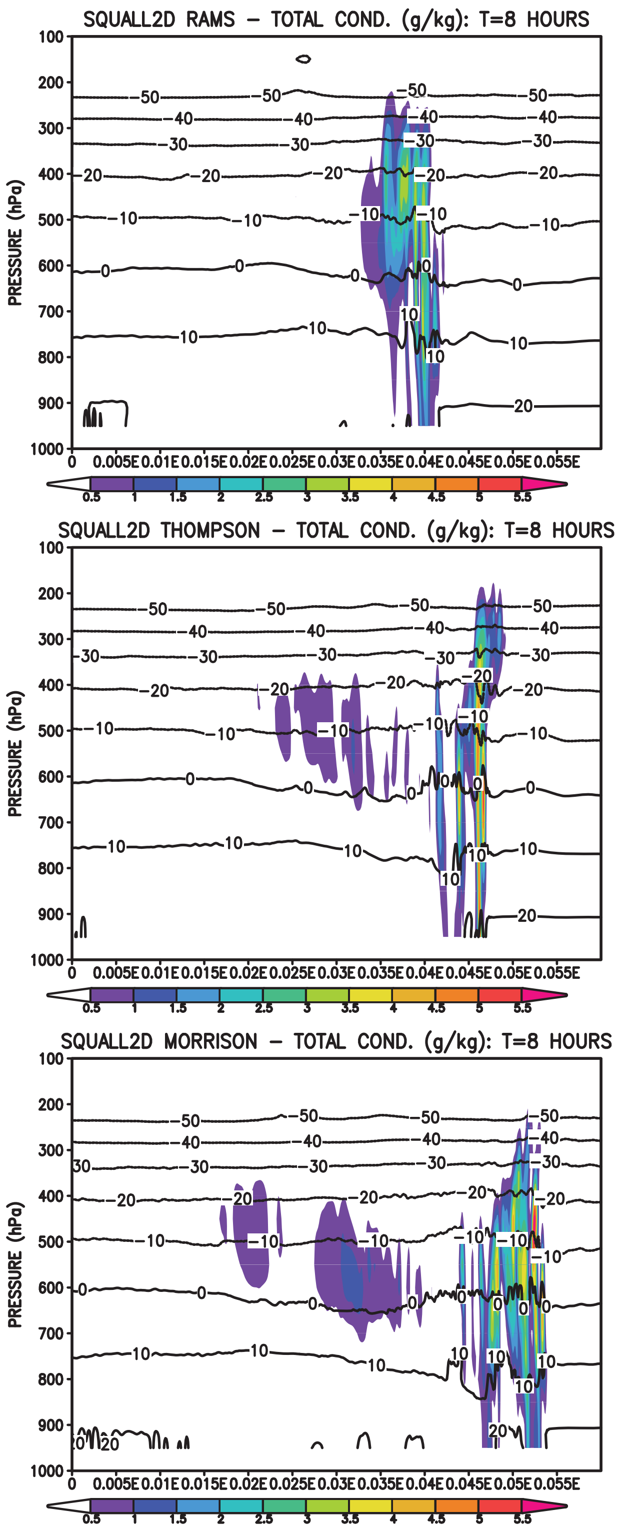

Figure 2: As Figure 1, but at time t = 8 hours.

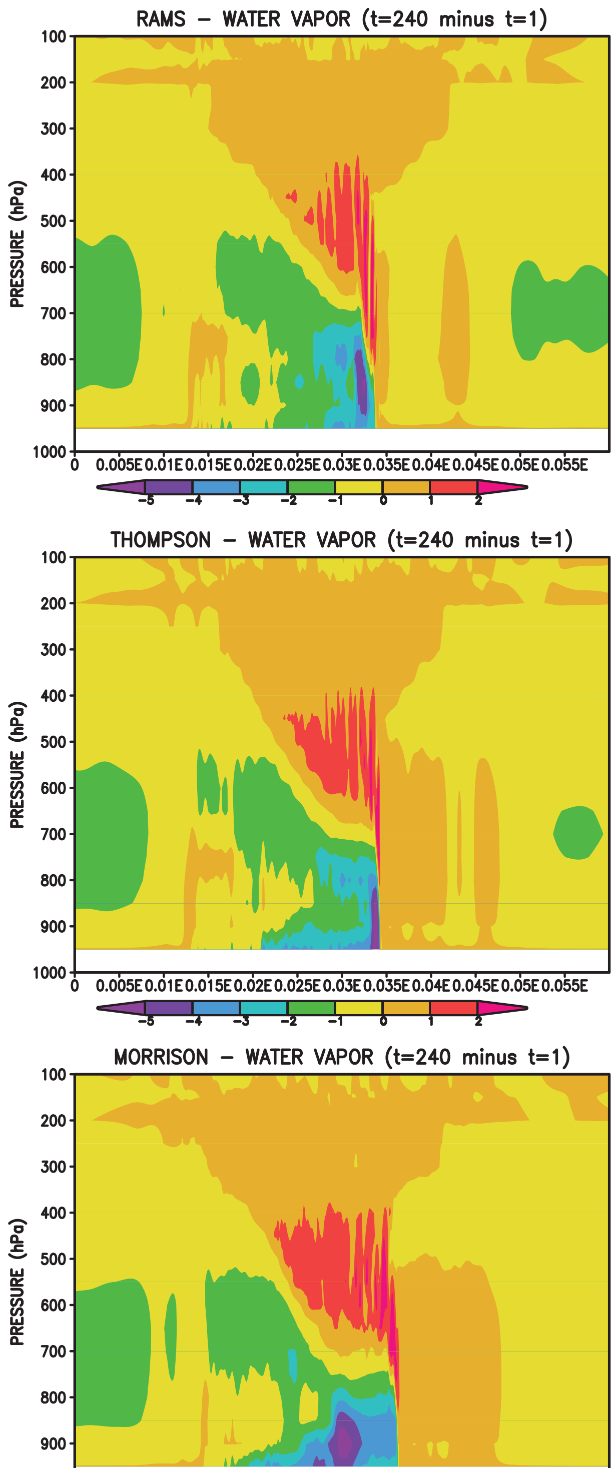

Figure 3: Longitude versus pressure cross sections of the water vapor difference between t = 4 hours and t = 0 simulated with the RAMS (top), THOMPSON (middle), and MORRISON (bottom) cloud microphysics schemes. Units are g per kg.

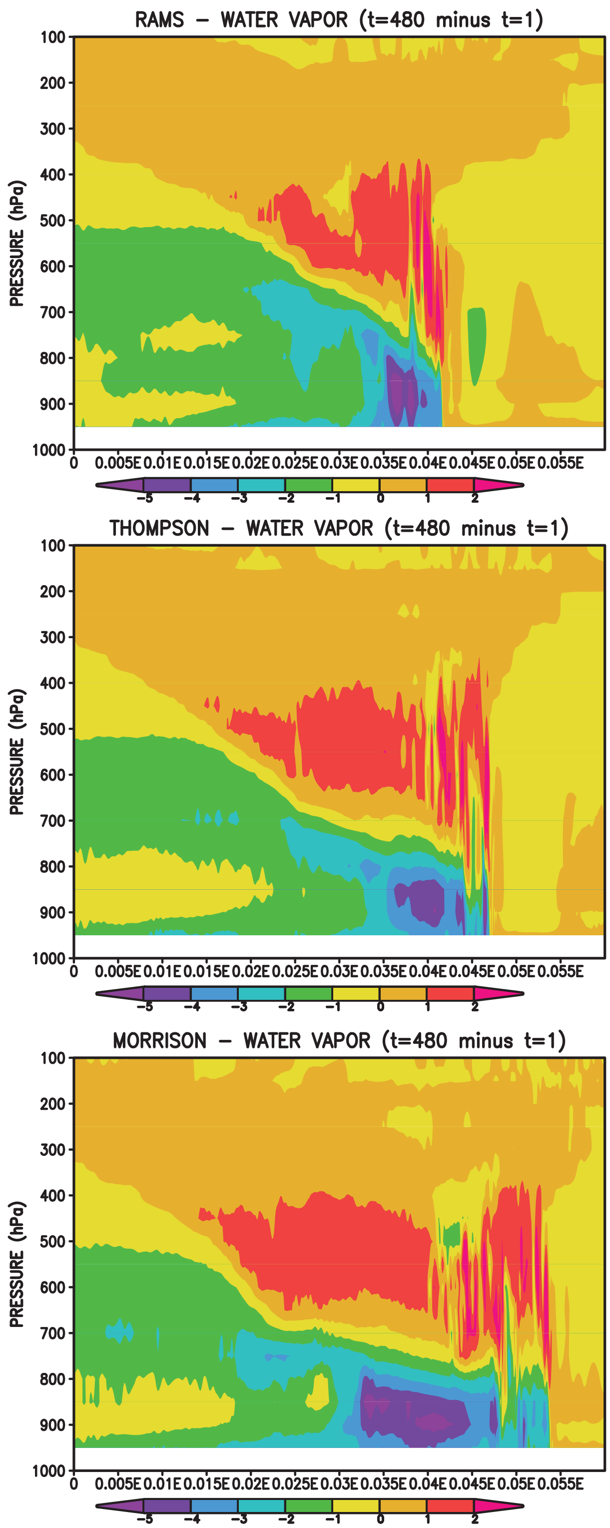

Figure 4: As Figure 3, but at time t = 8 hours.

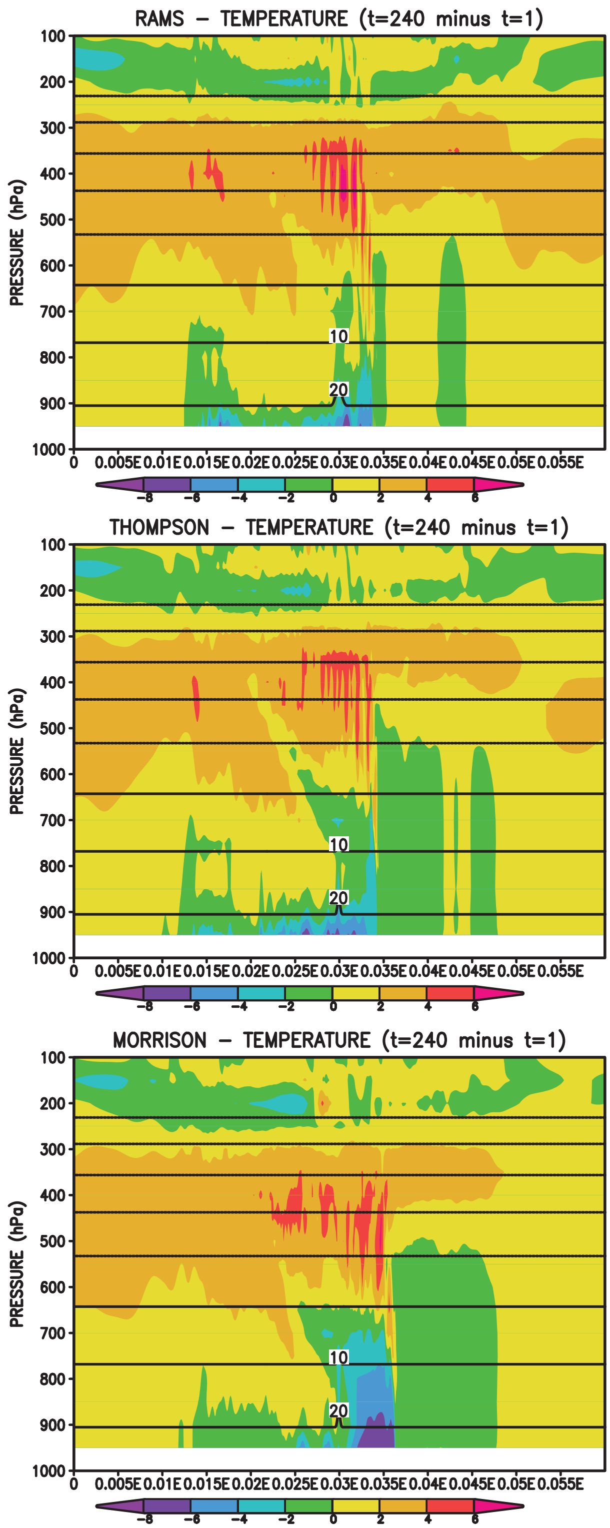

Figure 5: Longitude versus pressure cross sections of the water vapor difference between t = 4 hours and t = 0 simulated with the RAMS (top), THOMPSON (middle), and MORRISON (bottom) cloud microphysics schemes. Units are °C.

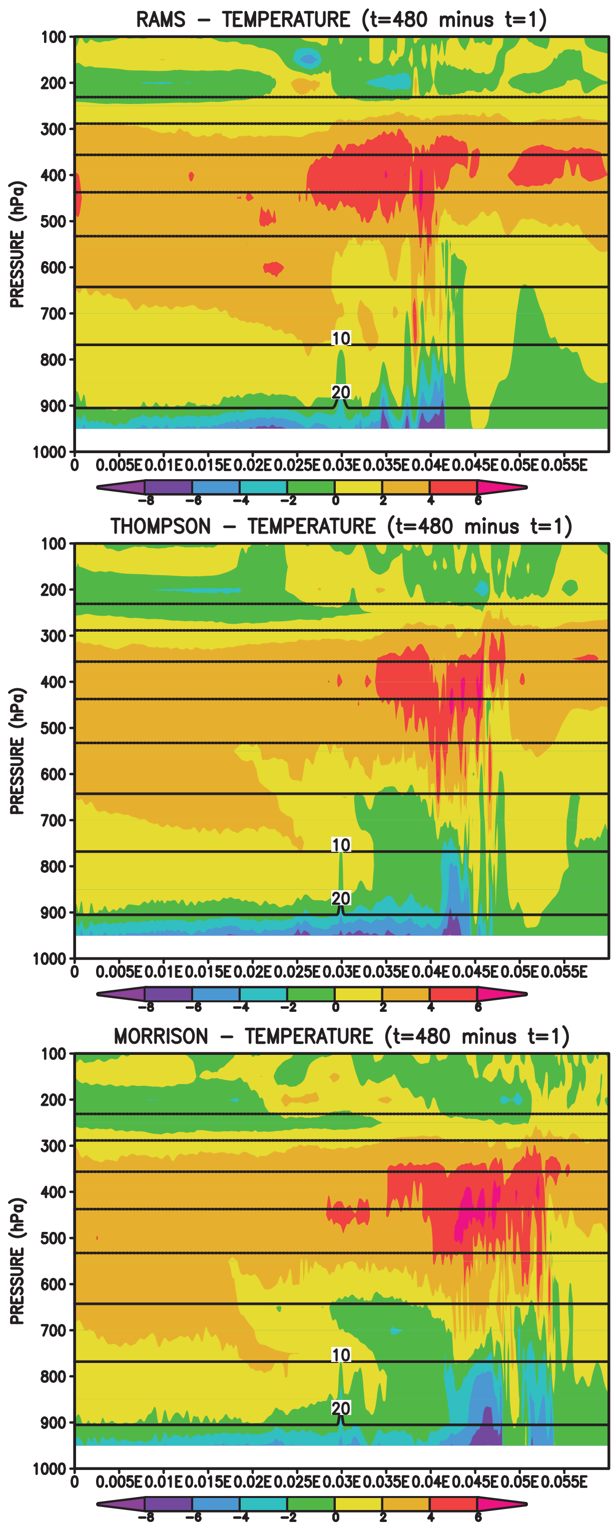

Figure 6: As Figure 5, but at time t = 8 hours.