P2B.10 Comparison and validation of WRF-ARW cloud microphysics schemes during C3VP/CLEX-10 field experiment

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1. Introduction*

Better understanding of the vertical structures of clouds in the atmosphere is essential for more accurate radar, lidar, satellite retrievals, climate/weather numerical modeling, and even aviation safety issues regarding icing conditions (Fleishauer et al., 2002). However, an accurate estimate of liquid and ice phase hydrometeors in the clouds is still very challenging, and our limited knowledge of cloud microphysical structures and characteristics has caused clouds to be poorly represented in weather/climate models and satellite retrievals. In general, quantitative studies of cloud phase-composition and distribution in numerical modeling have been significantly limited by a lack of intensive in-situ measurements that can directly evaluate the simulated results.

In this study, three different cloud microphysics schemes in the Advanced Research WRF (WRF-ARW; Skamarock et al. 2008) dynamic core are evaluated for non-precipitating midlevel cloud and snowfall cases. In order to validate the simulations, we take full advantage of rich data sources from various satellite and intensive aircraft in-situ observations. For each case, the horizontal cloud patterns from the WRF simulations are compared with MODIS (Moderate-Resolution Imaging Spectroradiometer) IR images. In particular, the vertical structures and properties of liquid and ice phase hydrometeors from two microphysics schemes are validated by using Convair-580 aircraft measurements and CloudSat products.

2. Observational analysis

In this study, intensive aircraft in-situ observations and various satellite data are utilized to examine the model simulation results during C3VP/CLEX-10 (the Canadian CloudSat/CALIPSO Validation Project / the tenth Cloud Layer Experiments). CLEX-10, which is part of an ongoing field experiment effort for a study of non-precipitating, mid-level, mixed-phase clouds funded by the Department of Defense's Center for Geosciences/Atmospheric Research at CIRA-Colorado State University (Fleishauer et al. 2002; Carey et al. 2007), collaborated with C3VP that took place from 31 October 2006 to 1 March 2007 over Southern Ontario and surrounding areas. C3VP is the extensive validation project of the satellite products performed by the Meteorological Service of Canada as part of the international CloudSat program (see http://c3vp.org) with the primary objective to validate measurements and retrieved products from the CloudSat and CALIPSO satellites. In particular, for studying the vertical structure of clouds, data from the recently launched CloudSat (Stephens et al. 2002) are used together with coincidental aircraft observations, which was designed to measure the vertical structure of clouds and precipitation from space with a 94-GHz cloud profiling radar (CPR), which observes most of the cloud condensate and precipitation within its nadir field of view and provides profiles of these properties with a vertical resolution of 240m. CloudSat release-version 04 data are used in this study (refer to http://cloudsat.cira.colostate.edu/ for more details).

In Fig. 1, MODIS images (12 μm) of the Aqua satellite show cloudy areas of interest for non-precipitating midlevel cloud and snowfall cases on 5 November 2006 and 22 January 2007 in the Great Lakes region, respectively. During C3VP/CLEX-10, the microphysical structure of the clouds over the target regions shown in Fig. 1 were sampled using in-situ probes and remote sensing instruments onboard the National Research Council of Canada's Convair-580 aircraft (Barker et al., 2008).

On 5 November 2006, a warm front had moved over Southern Ontario leaving behind a large area of mid-level cloud cover. As shown from CloudSat cloud classification and CPR reflectivity data in Fig. 5, the aircraft flew over altocumulus between 1.5 km and 5 km and some cirrus clouds above. It was reported that during the flight targeting the CloudSat overpass around 1830 UTC, a mixed phase cloud layer, with nearly 3 km of thin cirrus above and scattered clouds below, was observed. The vertical profiles of temperature/dew point and LWC/IWC are represented in Fig. 3. It is noted that a significant amount of liquid up to 0.3 gm^{-3} is observed in the cloud (4-4.7 km), although the target mixed-phase cloud has cloud top temperatures down to -22°C. Here, liquid and ice water contents (LWC and IWC) are from

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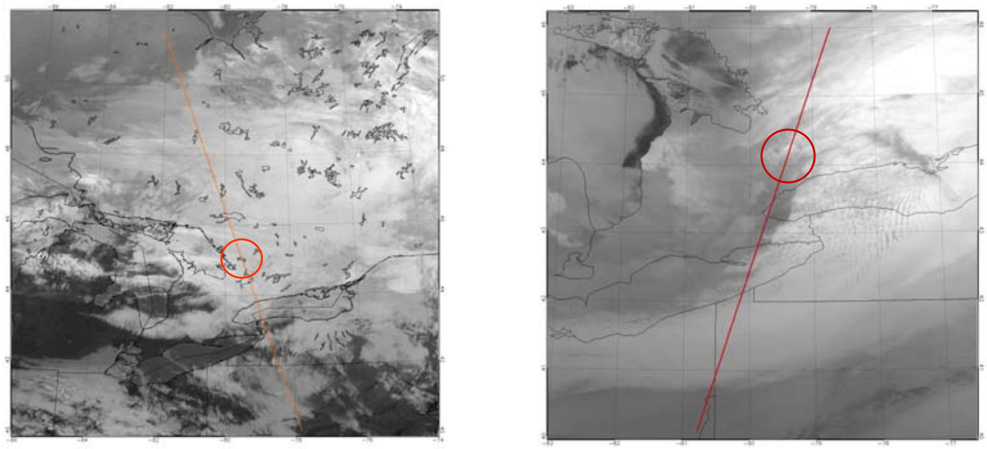
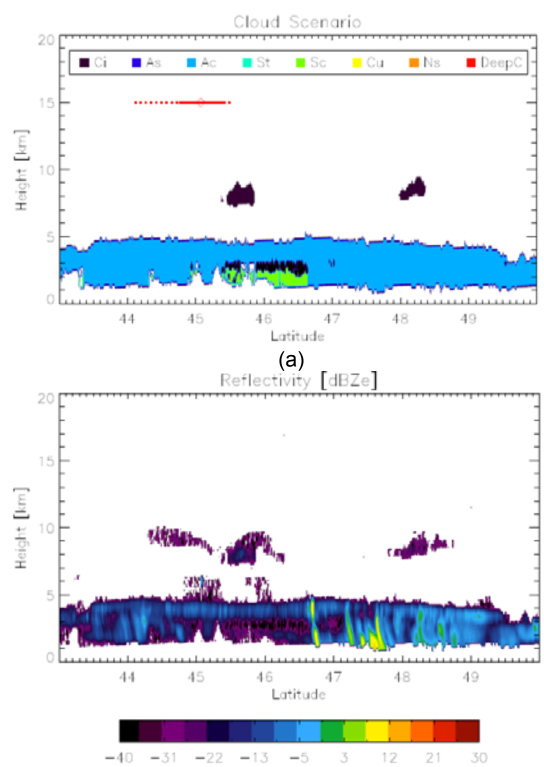


(a) (b)

Figure 1. MODIS 12 μm images (a) at 18:25 UTC on 5 November 2006 and (b) at 0730 UTC on 22 January 2007 plotted with each CloudSat ground track (solid line) and C3VP/CLEX-10 target region (circle)

the King liquid water and Nevzorov LWC-TWC probes.



(a)

(b)

Figure 2. Contour plots of (a) CloudSat cloud classification with CLEX10 area (whole flight: red dotted, the main target during the CloudSat overpass: red solid) and the aircraft location (red diamond) and (b) CPR reflectivity (dBZ) for the 5 November 2006 case.

On 22 January 2007, a big storm system passed over southern Ontario during the overnight hours and brought light to moderate snowfall at the surface over the area of interest. The aircraft sampled a region of deep ice cloud during the CloudSat overpass around 0730 UTC (Fig. 4). Figure 5 shows the vertical profiles of temperature/dew point saturated and decreased down to -35°C near 7 km. It also shows that ice is dominant over the target region.

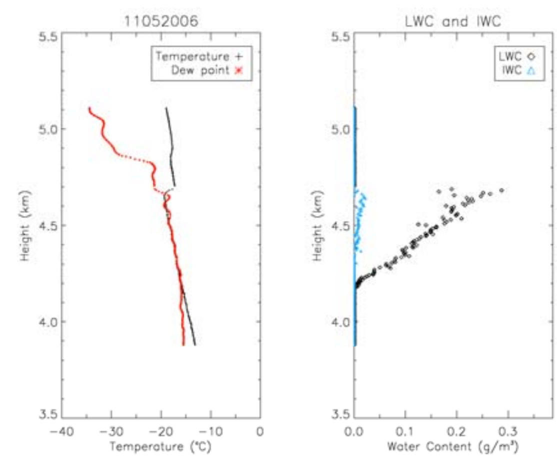
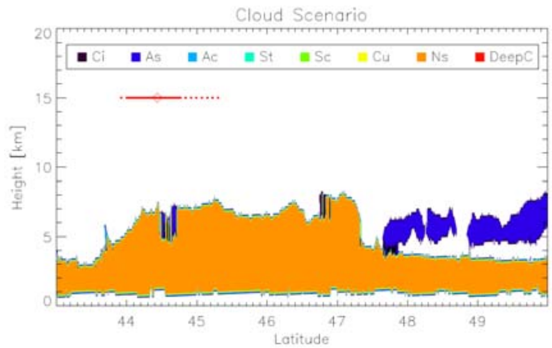


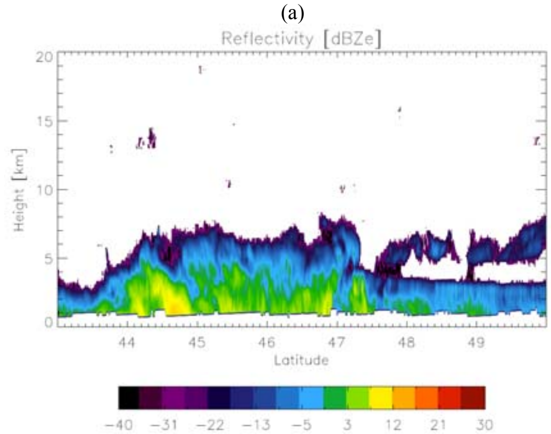
Figure 3. Aircraft measurements of temperature/dew point and LWC/IWC from 184100 to 184500 UTC on 05 November 2006.

3. Comparisons between model simulations and observations

In the present study, three different cloud microphysics schemes, Thompson, WSM6, and Goddard schemes, are evaluated for the two cases. All the microphysics schemes partition condensed water into five species: cloud liquid, cloud ice, rain, snow and, graupel. WRF-ARW (Ver. 3.0.1.1) is run in a one-way nesting configuration of 9-km and 3-km grid spacing with 32 vertical levels. The domain setup is shown in Fig. 6. Yonsei University (YSU) planetary boundary layer (PBL) scheme and Dudhia rapid radiative transfer



(a)



(b)

Figure 4. As in Fig. 2 but for the 22 January 2007 case.

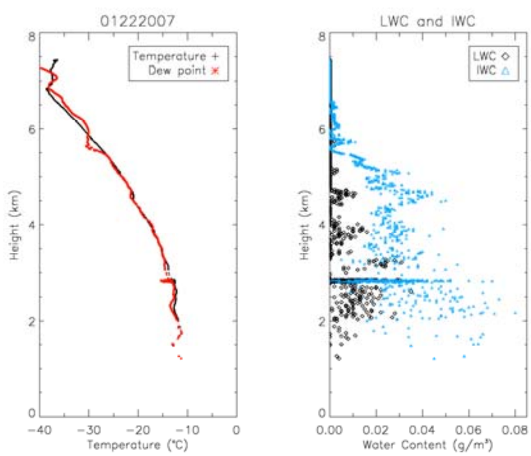


Figure 5. As in Fig. 3 but for 0643 UTC to 0713 UTC on 22 January 2007.

model (RRTM) radiation are employed in the simulation. The Global Forecast System (NCEP/GFS) output (0.5°) is used for initialization and lateral boundary condition information, and the simulations were integrated for 36 hrs starting from 1200 UTC on 04 November 2006 and 1200 UTC on 21 January 2007, respectively.

Figure 7 represents vertical profiles of liquid- and ice-phase hydrometeors generated from the WRF simulation with each microphysics scheme, valid at 1800 UTC on 05 November 2006. It is noted that the

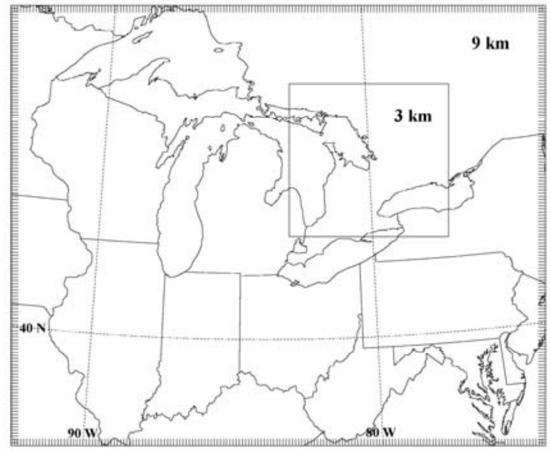


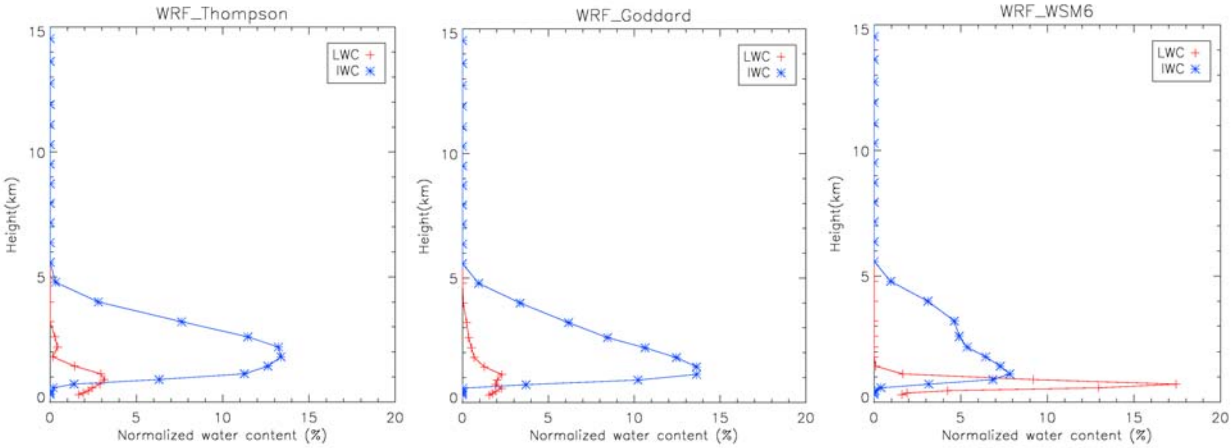
Figure 6. WRF model domain setup with an outer 9-km domain and a nested 3-km domain.

results of mixing ratios were converted to liquid and ice water contents (LWC and IWC) and normalized by total water contents (TWC=LWC+IWC) after averaging over C3VP/CLEX-10 target area as shown in Fig. 1. In the figure, we can see that the patterns of both phase profiles from the results with Thompson and Goddard schemes look similar but quite different particularly for WSM6 scheme. However, when compared with the aircraft measurements during C3VP/CLEX-10 (not shown), all these schemes failed to simulate the real vertical distributions of liquid and ice hydrometeors for this mixed-phase cloud having plenty of supercooled liquid water near cloud top, although WSM6 simulates the significant amount of LWC around 1 km. The aircraft measurements (1750-1845 UTC) showed that water contents existed only between 4 and 5 km, and ~94% of TWC was liquid and ~6% was ice.

For the snowfall case, each simulation result is represented in Fig. 8. They all simulate a large amount of ice-phase particles. The pattern of the results is quite consistent with the aircraft observation, but liquid water contents are still underestimated, even though further quantitative analyses should be performed.

4. Summary and future work

The present study shows preliminary results from the comparisons of three WRF microphysics schemes using satellite and aircraft measurements. The main goal is to evaluate the performance of WRF model using three different microphysics schemes for two cases that were associated with non-precipitating mixed-phase cloud and snowfall, respectively. Satellite radar observations and aircraft in situ measurements during the C3VP/CLEX-10 field experiment are used to understand the characteristics of the clouds from various remote sensors and compare with WRF simulations. From the analysis of CloudSat standard data products and C3VP/CLEX10 measurements, it first is found that the amount of cloud water content (LWC and IWC) varies significantly in each case. It is noted that a significant amount of liquid water up to 0.3 g/m^3 is



(a) (b) (c)

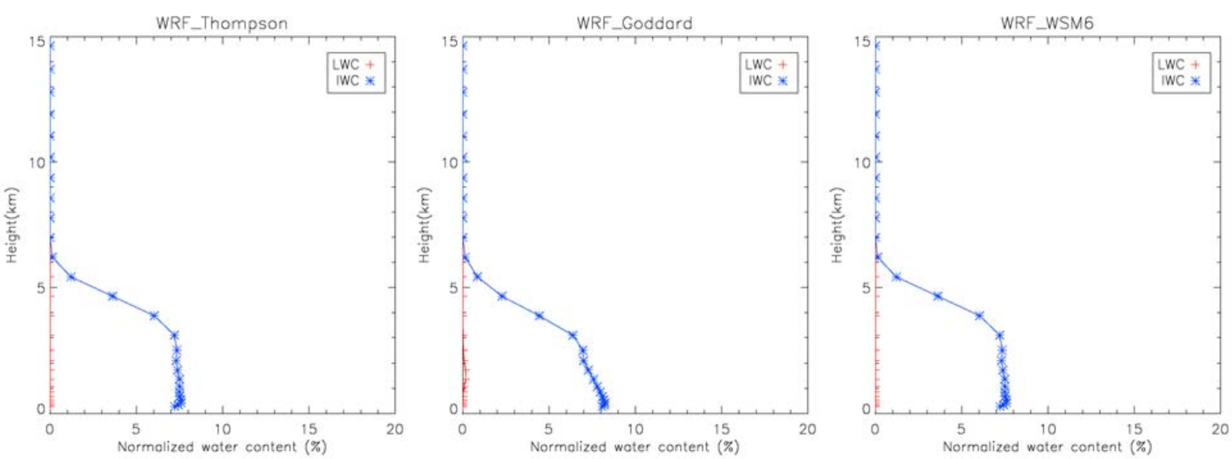
Figure 7. Normalized vertical profiles of liquid- and ice-phase hydrometeor from WRF simulations with (a) Thompson, and (b) Goddard, (c) WSM6, schemes at 1800 UTC on 05 November 2006. Mixing ratios (g/kg) in the 3-km domain were converted to water contents (LWC and IWC) and normalized by total water contents (TWC) after averaging over the C3VP/CLEX-10 target region.

obtained from the aircraft observation in very low temperature conditions (< -20°C) near cloud top for the mixed-phase cloud case, and supercooled liquid water still exists for the snowfall case (-10°C ~ -30°C). However, all simulation results vary among the three microphysics schemes particularly in WSM6 and show significantly different vertical structures of hydrometeors for the non-precipitating mixed-phase cloud case when compared with the aircraft observations, although they represent very similar patterns for the snowfall case. As

From the present study, it is apparent that more intensive observations are necessary to improve our understanding of the detailed cloud microphysical features. CloudSat and intensive in-situ observations such as C3VP/CLEX-10 data will provide an important basis in improving cloud microphysics schemes. As more datasets from the C3VP/CLEX-10 field experiment become available in near future, further detailed studies

indicated by Deeter and Vivekanandan (2004), the result shows that the accurate simulation of mixed-phase clouds is still challenging. The complex nature including fall speed, shape, latent heat release, and conversions among various types of frozen particles may cause greater differences. More detailed information of ice-phase particle formation and growth associated with temperature should be utilized to improve the accuracy of cloud simulations (Woods et al., 2008).

will continue using various airborne and satellite measurements. In addition, future study will be targeted toward identifying more cases to assess the performance of the model microphysics schemes. In evaluating the model ability to simulate the structure and amount of hydrometeors, sampling and sensitivity issues must be considered when comparing the results to in-situ observations.



(a) (b) (c)

Figure 8. As in Fig. 7 but for 0700 UTC on 22 January 2007.

5. Acknowledgments

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6. References

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