Evaluating microphysical schemes in simulating the mixed-phase processes of a winter storm during GPM-GCPEx

[1]Aaron R. Naeger, [2] Brian A. Colle, and [3]Andrew L. Molthan

aaron.naeger@nasa.gov

[1]University of Alabama in Huntsville, Earth System Science Center/NASA SPoRT, Huntsville, AL [2]School of Marine and Atmospheric Science, Stony Brook University, Stony Brook, NY

[3]Earth System Science Office, Marshall Space Flight Center, Huntsville, AL

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GPM-GCPEx field campaign

- Global Precipitation Mission (GPM) Cold-season precipitation experiment (GCPEx) took place during January and February 2012 in Ontario, Canada.
- A wealth of ground-based and in situ aircraft measurements were gathered over the field campaign region which we utilize to help validate model simulations.
- GCPEx measurements showed minimal amounts of supercooled water throughout the field campaign leading to mostly dry snow events.
- A warm frontal band on 18 February was associated with higher amounts of supercooled water which led to active mixed-phase processes and heavy snowfall.

Model configuration and cloud microphysics

- NASA-Unified WRF (NU-WRF) was the preferred modeling system for this study due to the recent implementation of the new Goddard 4ICE scheme and the coupling with the Goddard Satellite Data Simulator Unit (G-SDSU).
- We implemented Morrison's new Predicted Particle Properties (P3) scheme into NU-WRF.
- Four different NU-WRF simulations were conducted using the same model setup and configuration with the exception of the microphysics scheme and required radiation scheme linked to Goddard 4ICE.
- We conducted a 24-hour simulation beginning 18 February 2012 at 00 UTC.

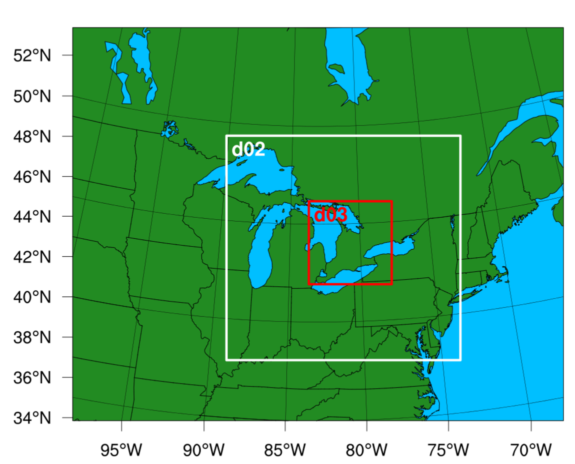

Figure 1. NU-WRF triple-nested domain configuration.

NU-WRF configuration options			
Boundary Condition Data	RUC		
Vertical Resolution	50 Levels		
PBL Physics	Mellor-Yamada-Janjic scheme		
Cloud microphysics	1) 4ICE, 2) WSM6, 3) MORR, and 4) P3		
Shortwave Radiation	RRTMG expect Goddard radiation for 4ICE		
Longwave Radiation	RRTMG expect Goddard radiation for 4ICE		
Domains	Domain 1	Domain 2	Domain 3
Horizonal Resolution	9 km	3 km	1 km
Grid Points	301x241	430x412	457x457
Cumulus scheme	Grell-Devenyi	Turned off	Turned off

Table 1. NU-WRF configuration options

- In Eq. (1), N_x(D) represents the number concentration of particles of a pre-defined hydrometeor class (x) and diameter (D), N_{os} is the intercept parameter, u_x is the shape parameter, and λ_x is the slope parameter.
- To solve Eq. (1) and (2), WSM6 varies N_{os} depending on temperature while 4ICE maps N_{os} based on variations in temperature and mixing ratio.

1) $N_x(D) = N_{ox} D^{u_x} e^{-\lambda_x D}$ **2)** $\lambda_x = \left(\frac{\pi \rho_x N_{ox}}{\rho_a q_x}\right)^{1/4}$

3) $\lambda_x = \left(\frac{\pi \rho_x N_x}{\rho_a q_x}\right)^{1/3}$ **4)** $N_{os} = N_x \lambda_x$

Scheme	N_{os} (cm^{-4})	μ_s	ρ_s (kg m^{-3})
4ICE	f(T,ρ)	0	f(snow size)
WSM6	f(T)	0	100
MORR	f(N_s,λ_s)	0	100

Table 2. Snow class parameters.

- MORR (2-moment) predicts number concentration (N_x) which is used in the calculation of λ_x (Eq. (3)) and then N_{os} (Eq. (4)). Less dependence on assumptions.
- 4ICE, WSM6, and MORR rely on pre-defined hydrometeor classes that use specified thresholds to transfer particles between classes.
- P3 uses much different approach where four prognostic mixing ratio variables (total ice mass, rime ice mass, rime volume, and total number) predict the bulk particle properties of a single ice-phase.

Cloud microphysical scheme evaluation

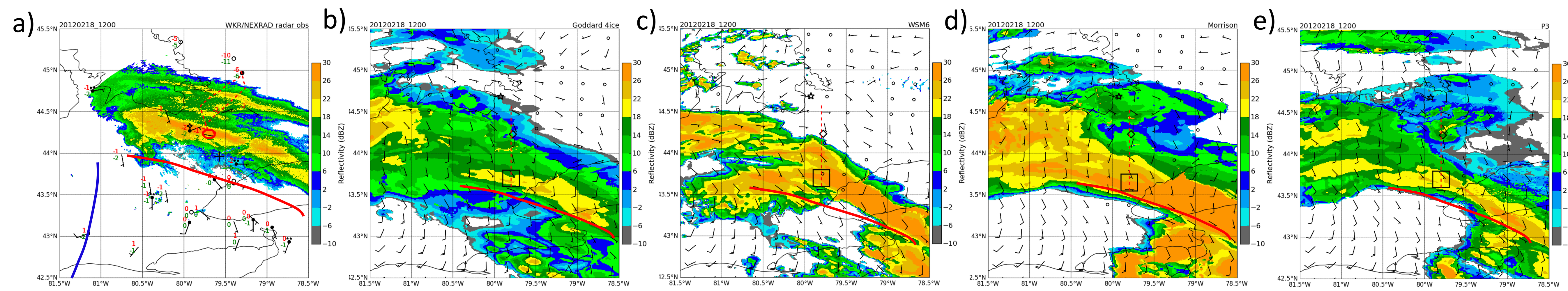

Figure 2. a) Surface weather conditions along with radar reflectivity based upon King City C-band radar at 0.3° elevation angle and Buffalo S-band radar at 0.5° elevation angle at approximately 1200 UTC on 18 Feb. Solid red and blue lines indicate estimated position of warm and cold front based on surface stations. Simulated radar reflectivity from lowest model vertical level and 10-m wind speed (knots) at 1200 UTC for b) 4ICE, c) WSM6, d) MORR, and e) P3. Solid red line shows estimated position of simulated warm front.

- Simulated warm front was slower for all schemes compared to observational analysis.
- However, schemes are able to adequately represent the alignment and structure of the frontal band as shown by radar.
- Frontal band in WSM6 shows the least agreement with radar.

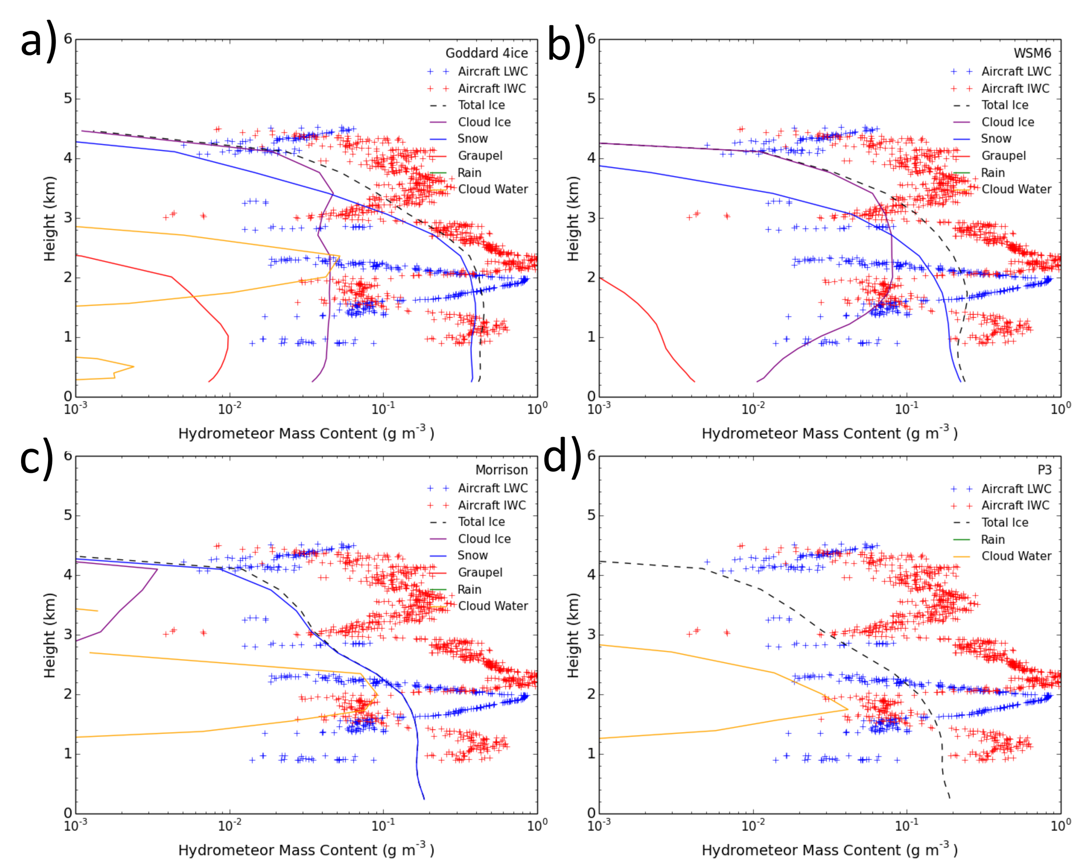

Figure 3. Mean profiles of hydrometeor mass at 1200 UTC for each scheme from box outlined in Fig. 2b-e. Aircraft LWC and derived IWC are shown for descent profile shortly after 1200 UTC. Location of aircraft profile is shown by red oval in Fig. 2a.

- Total ice from 4ICE scheme shows the closest agreement to aircraft IWC due to much higher snow mass than WSM6 and MORR.
- P3, MORR, and 4ICE adequately represent the structure of cloud water but severely underpredict the amount.
- MORR appears to perform better than P3 scheme even though P3 predicts riming processes.
- Graupel mass in 4ICE suggests the presence of riming.

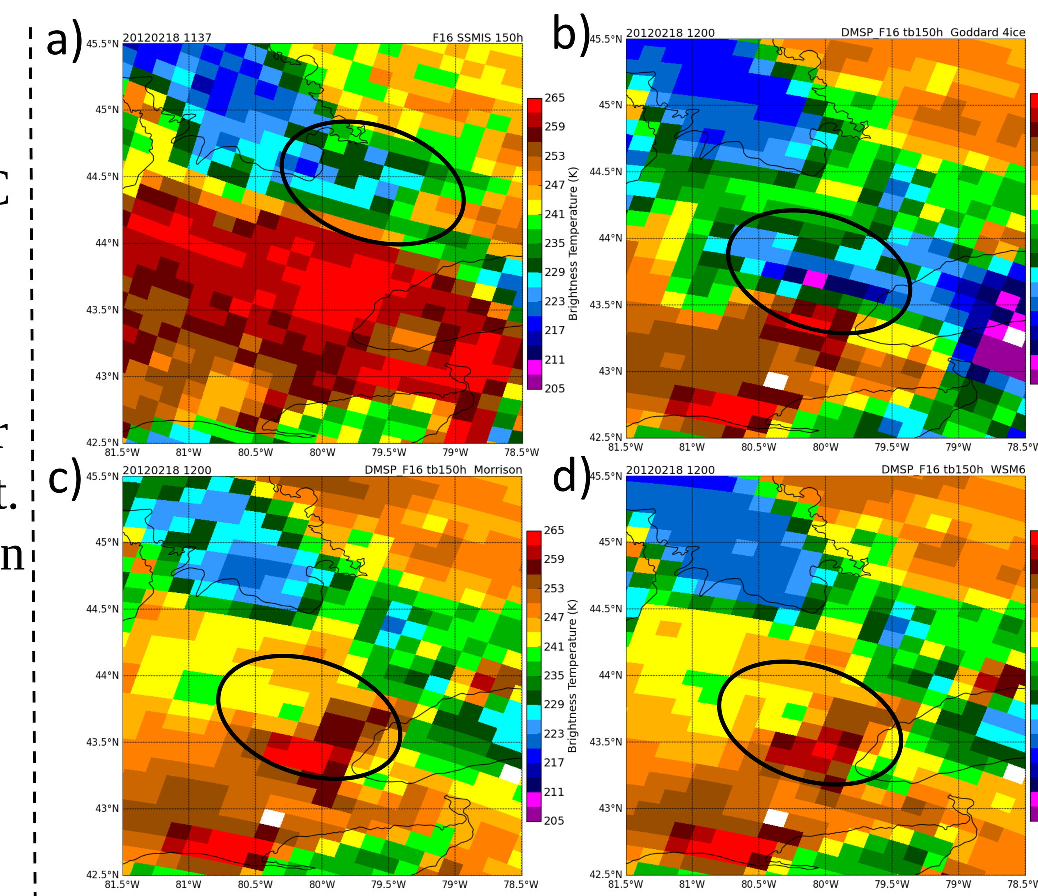

Figure 4. a) SSMIS 150 GHz brightness temperatures (BTs) in horizontal polarization at about 1140 UTC. SSMIS synthetic 150 GHz brightness temperatures at 1200 UTC calculated with G-SDSU for b) 4ICE, c) MORR, and d) WSM6.

- SSMIS shows significant reduction of 150 GHz BTs in observed frontal band region due to scattering by snow and ice particles.
- 4ICE BTs are in closer agreement to observations than MORR and WSM6.
- This further indicates that ice and snow particles are better represented by 4ICE.
- P3 not yet implemented into G-SDSU.

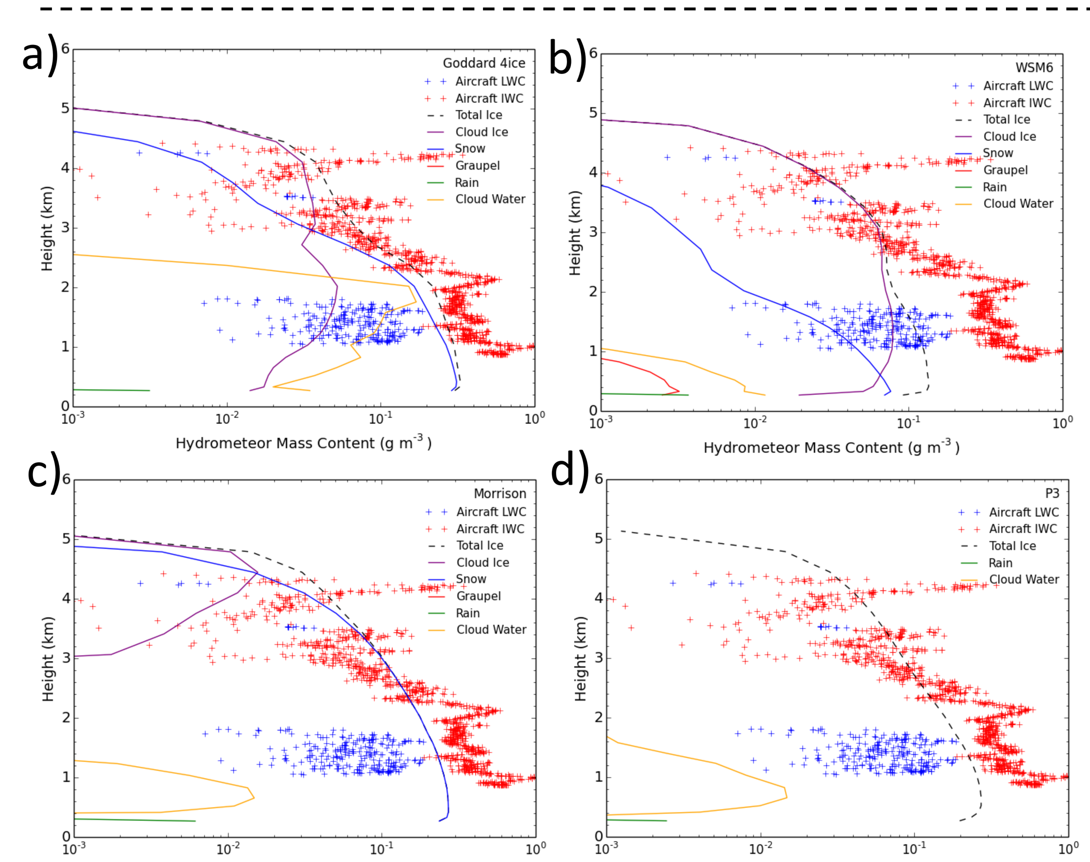

Figure 5. Similar to Fig. 3 except mean profiles of hydrometeor mass are compared to aircraft descent profile at approximately 1700 UTC. At this time, simulated frontal band was at nearly the same location as observed frontal band. Thus, mean profiles were calculated from a box surrounding the aircraft spiral location in Fig. 2a.

- P3 and MORR predict reasonable values of total ice mass but the overall structure is best represented by 4ICE.
- Aircraft LWC shows much lower values than profile at 1200 UTC.
- 4ICE predicts cloud water quite well while P3 shows much lower values.
- P3 and MORR significantly underestimate cloud water amount.

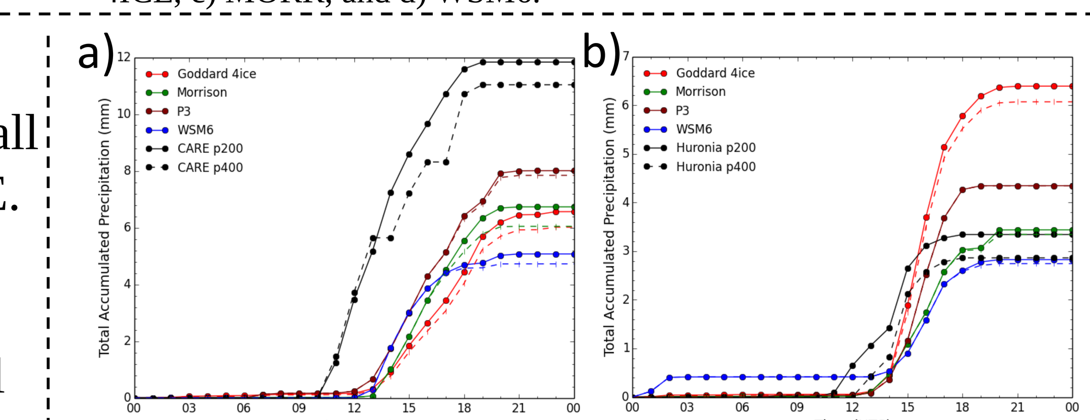

Figure 6. Total accumulated precipitation at a) CARE and b) Huronia station versus modeled precipitation for each scheme. CARE and Huronia locations are indicated by diamond and star symbols in Fig. 2b-e.

- Schemes perform better at Huronia, except for 4ICE, where precipitation is nearly 25% of that measured at CARE.
- Predicted precip is much less than measured at CARE due to minimal cloud water and riming.

Summary and Future Work

- Warm frontal band is most realistically simulated by the 4ICE scheme, especially when mixed-phase processes are weak. However, all cloud microphysics schemes drastically underpredict the cloud water mass during peak period of riming and heavy snowfall. We are currently investigating the size distribution parameters and mass-diameter relationships by comparing to aircraft profiles in order to make refinements to the schemes.
- We plan to implement P3 into G-SDSU and further utilize the simulator tools for evaluating schemes. We will also conduct simulations with the HUCM spectral bin scheme to provide a benchmark for bulk schemes.