NASA Precipitation Measurement Missions (PMM) Science Team Meeting, Annapolis, Maryland, 18-21, March, 2013

Simulations of a Midlatitude Wintertime Precipitation Event Using Bulk and Spectral Microphysics Schemes in WRF and G-SDSU as Compared to AMSR-E and a Ground Based Radar

Mei Han[1,2], Scott A. Braun[2], Toshihisa Matsui[3,2], Takamichi Iguchi[3,2], Christopher R. Williams[4,5],

[1]GESTAR, Morgan State University; [2]Mesoscale Atmospheric Process Laboratory, NASA/GSFC; [3]ESSIC, University of Maryland; [4]CIRES, University of Colorado; [5]NOAA/Earth System Research Laboratory

I. INTRODUCTION

Microphysics schemes in the Weather Research and Forecast (WRF) model use different assumptions of particles size distributions, number concentrations, shapes, and fall speeds etc., which generally produce large contrasts in precipitation forecasts. We use observations from the Advanced Microwave Scanning Radiometer – Earth Observing System (AMSR-E) and a ground-based S-band precipitation profiling radar (S-PROF) to study the impact the different assumptions in the schemes on the simulation of microwave brightness temperature (T_b), radar reflectivity, and Doppler velocity (V_{dop}) for a winter storm in California.

II. OBSERVATIONS

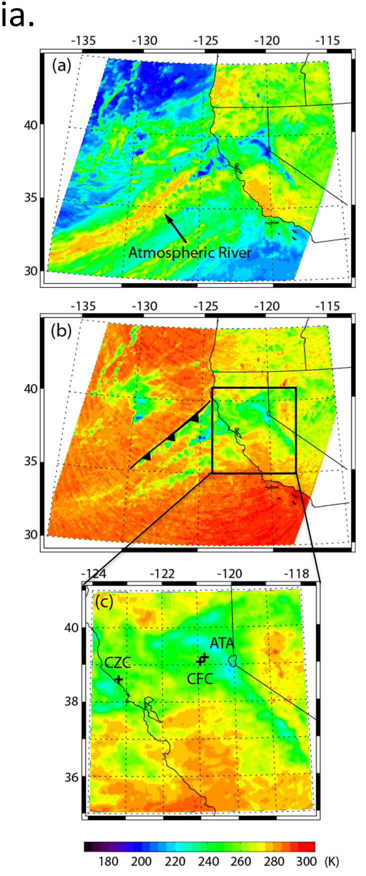


Fig. 1 (right): AMSR-E 89 GHz Tb (a) and Polarization-Corrected Temperature (PCT) (b and c) at 10:16 UTC 31 Dec 2005

- Tb data shows a plume of strong water vapor flux (the Atmospheric River, AR) reaching the CA coastal region
- PCT depression indicates the distinct scattering signature of the precipitation system
- Bands of PCT depression occur along the AR, parallel to a cold front
- Precipitation enhancement occurs over Sierras.

Three S-PROF radars were deployed at Alta (ATA, 1085 m MSL) Colfax Water (CFC, 636 m MSL), and Cazadero (CZC, 475 m MSL) by NOAA's HMT program; see Fig. 1c for locations of the sites.

Fig. 2: S-PROF observations on 31 Dec 2005

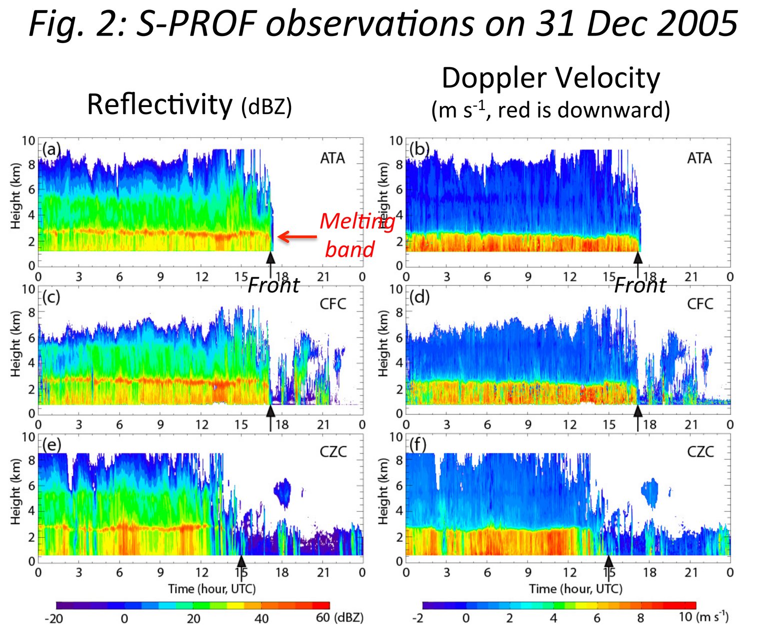
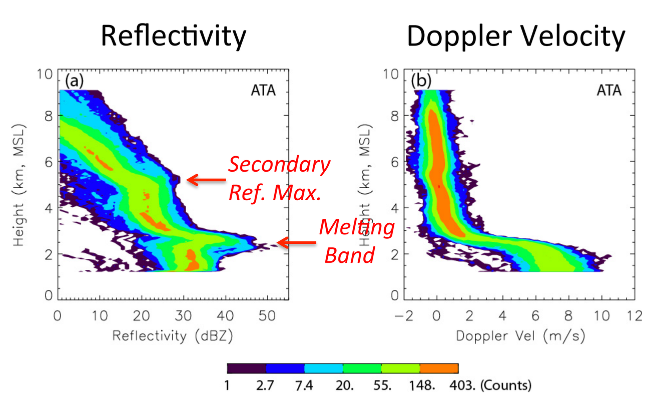


Fig. 3: Histogram for ATA



- Reflectivity magnitude: Rain layer: 25 – 45 dBZ; Snow layer: < 30 dBZ
- Doppler velocity magnitude: Rain layer: 5 – 10 m s^{-1} ; Snow layer: < 1 – 2 m s^{-1}
- Wide-spread moderate precip. and periods of intense precip. before the frontal passage (black arrows).
- Evident bright band (@ ~3km MSL) and secondary reflectivity maximum (@ ~5-6 km MSL).

III. SIMULATIONS WITH BULK SCHEMES

High resolution simulations (1.3 km horizontal spacing) with four different schemes in the WRF model, including Goddard (GSFC), WSM6, Thompson (THOM), and Morrison (MORR), are carried out.

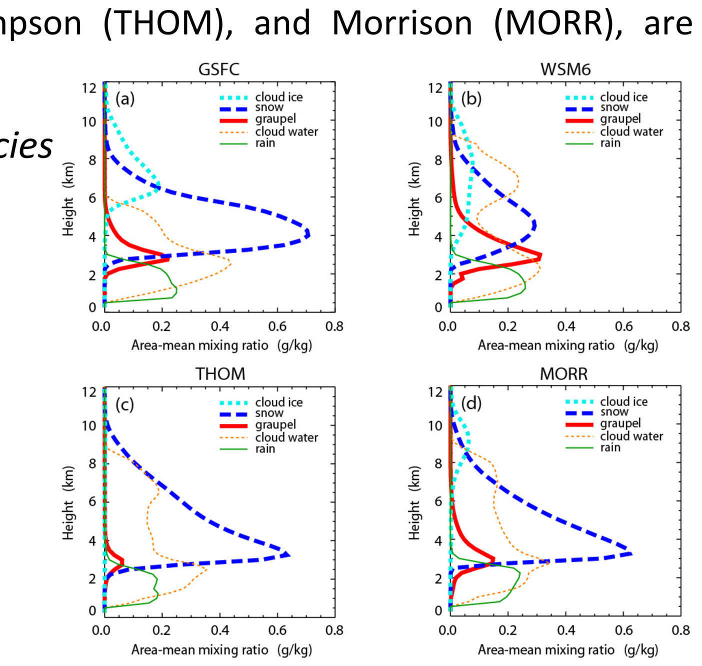


Fig. 4 (right): Mean profiles of hydrometeor species at 10 UTC 31 Dec. 2005.

- GSFC: more snow, shallower cloud liquid water
- WSM6: least snow, most graupel
- THOM: least cloud ice, least graupel
- MORR: similar snow and cloud liq. to THOM, moderate amount of graupel

a. Simulated PCTs

The WRF outputs are ingested into the Goddard Satellite Data Simulation Unit (G-SDSU) to calculate the brightness temperature at 89 GHz.

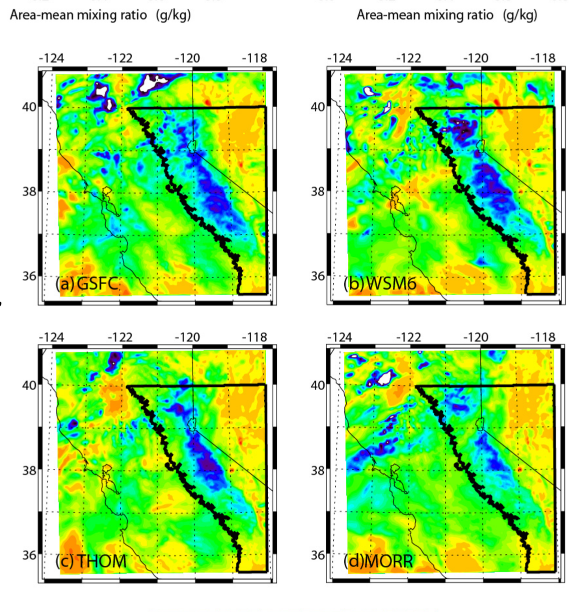


Fig. 5 (right): Simulated PCT89 at 10 UTC 31 Dec. 2005.

- Simulated PCT89 show a low bias of ~ 20 K or more compared to the obs. for every scheme --- scattering is too strong.
- Scattering is attributed mainly to snow in GSFC and MORR, and graupel in WSM6.

b. Simulated Reflectivity

Reflectivity is calculated for each simulation based upon microphysical assumptions in the different microphysics schemes.

Fig. 6: Simulated reflectivity on 31 Dec 2005 at ATA

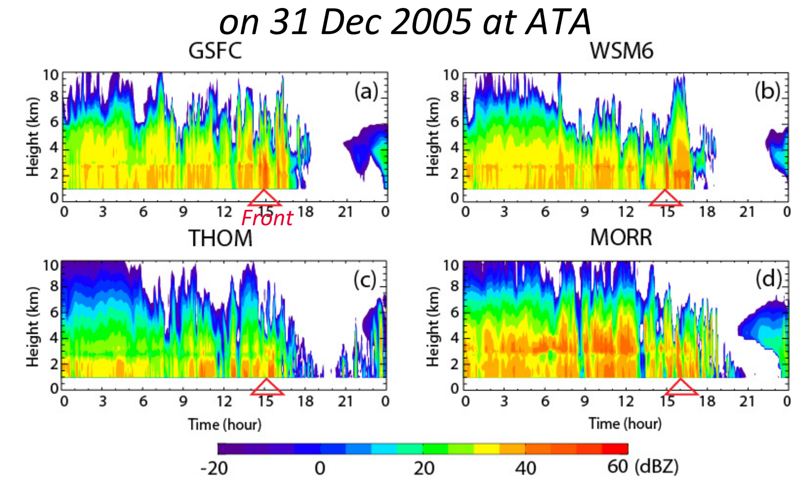
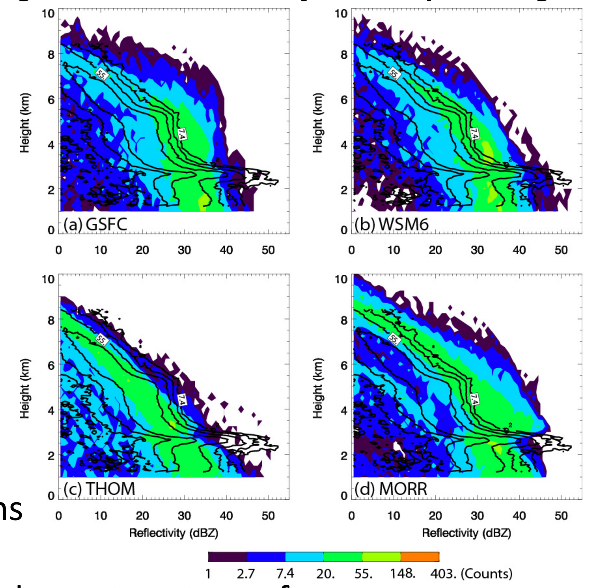


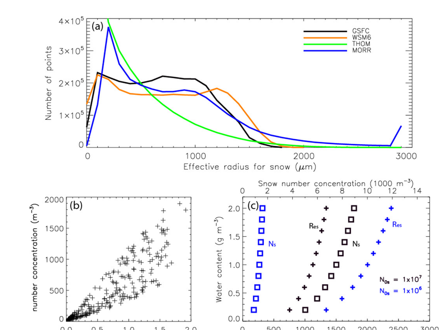
Fig. 7: Simulated reflectivity histogram



- The melting band is not captured in the simulations
- Reflectivity magnitudes:
  1) GSFC and WSM6 agree with obs. well in the rain layer, too strong for snow.
  2) THOM agrees well with the obs.
  3) MORR reflectivity too strong in rain and snow layers.

To understand why the simulated reflectivities have large differences among these schemes, we calculated the effective radius for snow (R_{es}) and compared with N_s and N_{0s} (Fig. 8).

Fig. 8: (a) Histogram of sim. R_{es}, (b) MORR N_s vs. q_s, (c) Idealized calculation for specified N_{0s}



- GSFC, WSM6 and MORR have more larger snow particles; THOM has more small ones.
- MORR has more particles larger than 2 mm with small N_s.
- Given water content, idealized calculation indicates that N_s in MORR is too small.

c. Simulated Doppler Velocity

The Doppler velocity (V_{dop}) is the sum of hydrometeors' terminal velocities and the vertical air motion for the vertically pointing radar. The total terminal velocity is weighted by reflectivity.

Fig.9: V vs. D

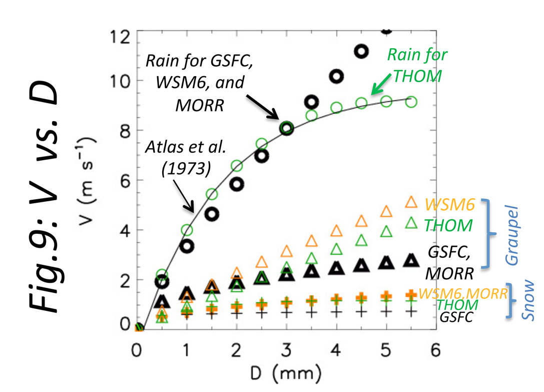


Fig. 10: Sim. V_{dop} on 31 Dec 2005 at ATA

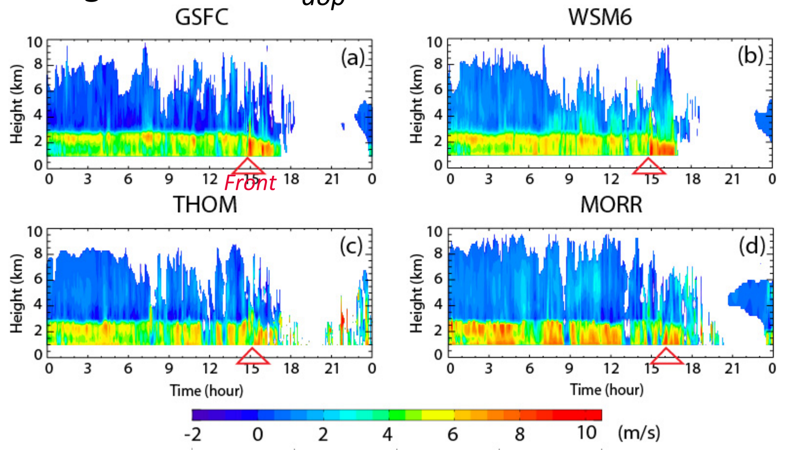
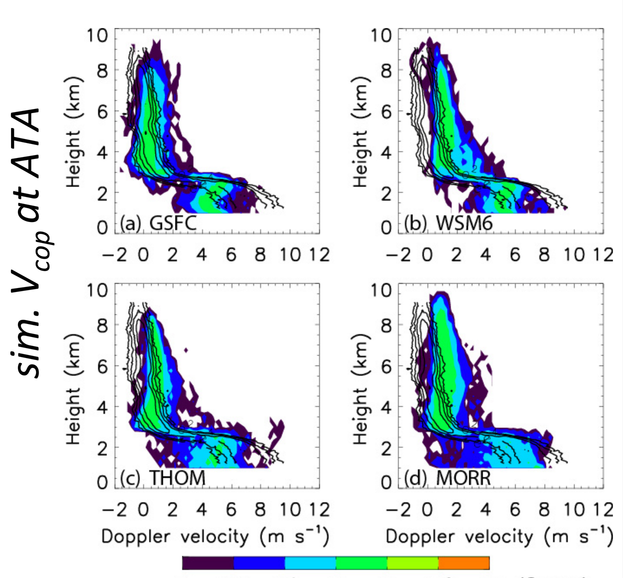


Fig. 11: Histogram for sim. V_{dop} at ATA



- WSM6 and MORR have faster V_{dop} than GSFC in snow layer
- GSFC V_{dop} is comparable to obs. in snow layer
- Simulated V_{dop} in rain layer shows low bias compared to obs. at ATA. The biases vary w. r. t. locations (not shown)

IV. CONCLUSIONS FOR BULK SCHEMES

This study (Han et al. 2013) uses observations from space-borne and ground-based microwave instruments to evaluate 4 microphysics schemes in WRF model. Simulations show too strong scattering. Large differences in reflectivity magnitudes and apparent contrasts in V_{dop} are found, which are attributed to the assumptions related to their PSDs, m-D, v-D relationships. The shape of snow, i.e., its m-D, is of great importance in reflectivity calculations.

V. SIMULATIONS WITH HUCM

A spectral microphysics scheme, HUCM, is recently implemented into the WRF model and G-SDSU. This scheme includes 7 cloud and precipitation hydrometeor species: droplet (cloud water and rain), column, plate, dendrite, snowflake, graupel, and hail. Droplet, snowflake, graupel, and hail are assumed to be spheres, while column, plate, and dendrite are non-spheres. There are 43 bins for each species. The simulation was conducted for 48 hours with 4 nested domains at finest horizontal spacing of 1.3 km.

- Doubling mass bin ranged from 3.35 x 10^{-11} to 147 g.
- Bulk density are assumed constants for droplets, plate, graupel, and hail.
- Bulk densities of dendrite, snowflake, and column vary w.r.t. size.

Fig. 12: 43 bin grid (a) mass; (b) density vs. radius

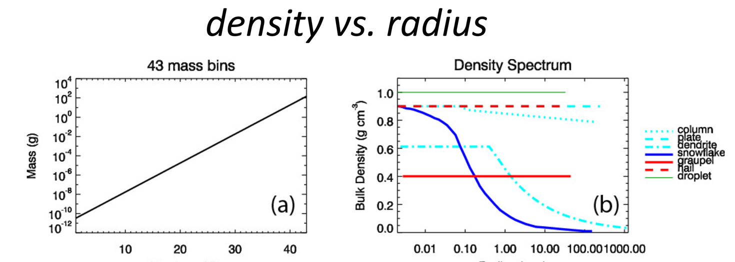
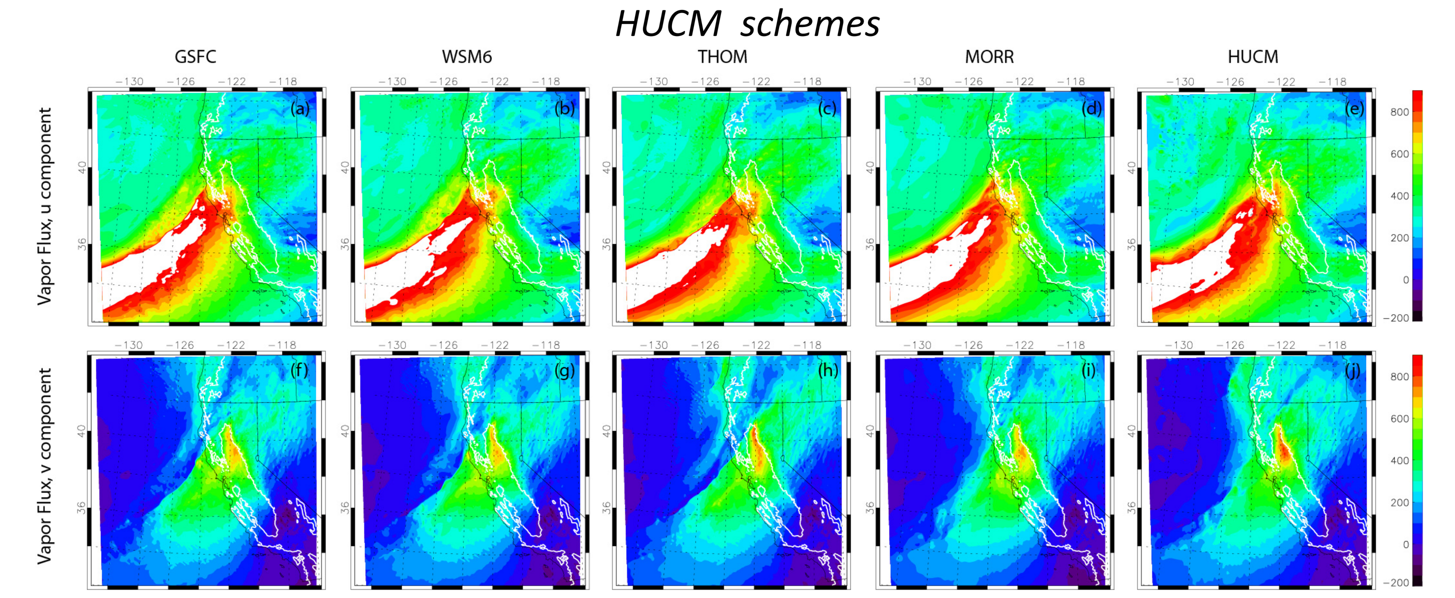


Fig. 13: Vertical integrated water vapor flux (u and v components, kg/m/s) for 4 bulk and HUCM schemes



- u component of the water vapor fluxes show similar magnitudes
- v component show a local maxima in the northern Central Valley --- Sierra barrier jet
- HUCM has the strongest Sierra barrier jet

Fig. 14: Mean profiles of hydrometeor species. (a) Same as Fig. 4, but for HUCM; (b)-(h) Spectral profile for each species.

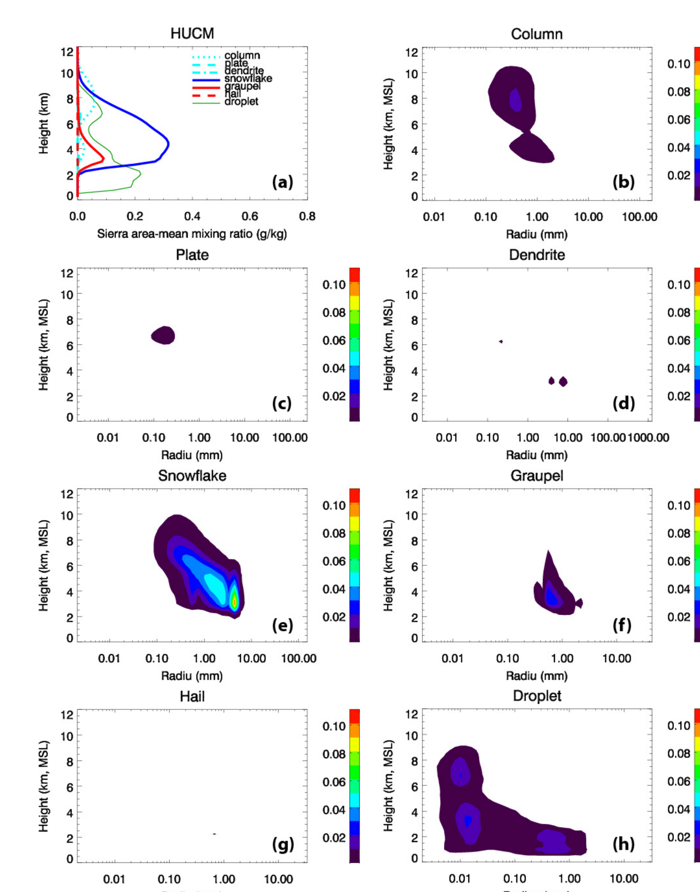


Fig. 15: Mean spectral profiles of rimed (a) and melted (b) portions of Snowflakes

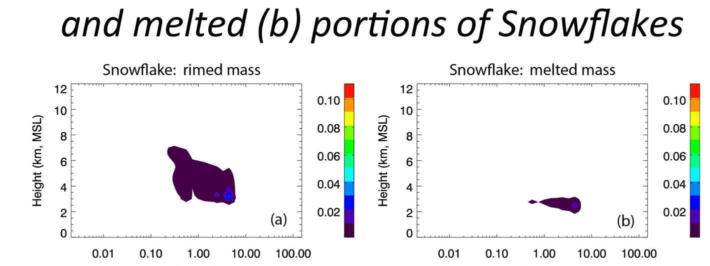
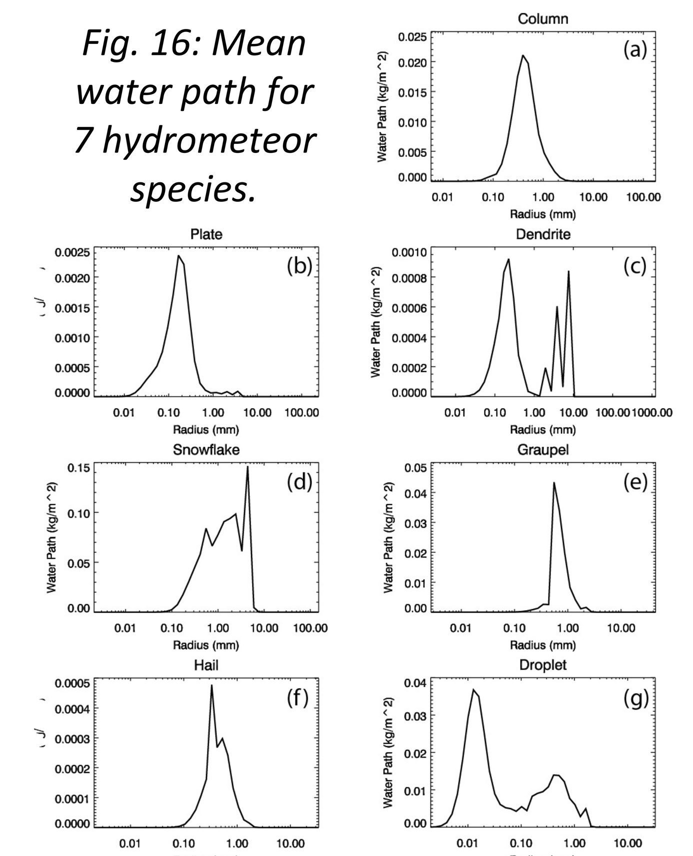


Fig. 16: Mean water path for 7 hydrometeor species.



- Snow and graupel mass total is ~ 30 % less than that in the bulk schemes
- Column is the primary ice crystal
- Snowflake (aggregates) dominates
- Droplets show two modes: cloud and rain
- Rimed portion of snow is up to ~ 20–30 % of the total snow mass
- Melted portion of snow is important at the melting level

The brightness temperature and radar reflectivity are calculated with G-SDSU (Fig. 17).

- PCT89 magnitudes over Sierra are much less than simulations with bulk schemes.
- Reflectivity peak magnitudes in snow layer are greater than 30 dBZ.
- A radar brightband is apparent.

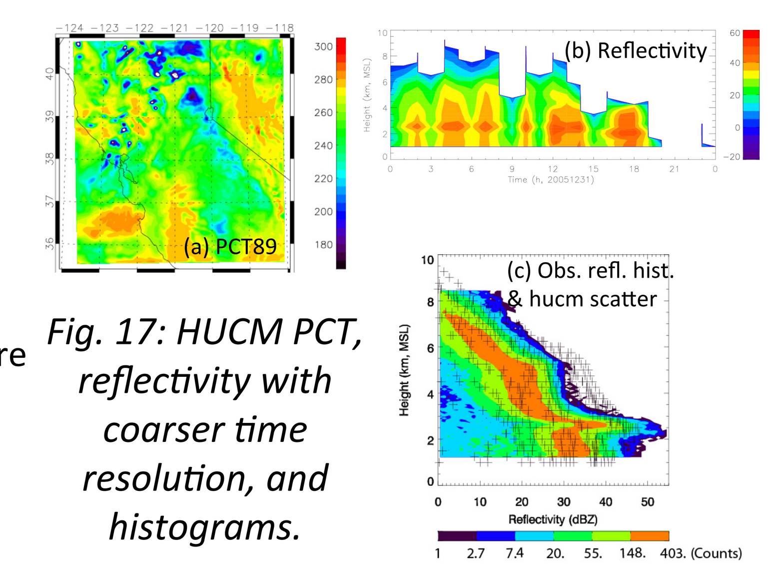


Fig. 17: HUCM PCT, reflectivity with coarser time resolution, and histograms.

VI. SUMMARY FOR HUCM

The WRF simulation with the HUCM spectral microphysics scheme captured the basic thermodynamic environment of the Atmospheric River event. It illustrates the distribution of hydrometeor species in 43 bins. The total mass of snow and graupel in HUCM is ~ 30% less than that in the 4 simulations with bulk schemes. The simulated PCTs show less bias in HUCM than the bulk schemes. Reflectivity magnitudes in the snow layer show a high bias as compared to the S-PROF observations, whereas its radar bright band is well defined. Future research will be carried out to understand the difference of snow and graupel mass, to compare the size and density of hydrometeor species in HUCM and the bulk schemes.

Acknowledgements: The authors want to thank Drs. Lin Tian, Liang Liao, Xiaowen Li, and Bill Olson at NASA/GSFC for many beneficial discussions related to radar algorithms and cloud modeling. Model simulations were performed on NASA's Discover Cluster. This work was supported by NASA Precipitation Measurement Mission science program. .

References: Han, M., S. A. Braun, T. Matsui, C. R. Williams, 2013: Evaluation of cloud microphysics schemes in simulations of a winter storm using radar and radiometer measurements, *J. Geophys. Res. Atmos., 118, doi: 10.1002/jgrd.50115.*