Application of a non-spherical snow aggregate DDA database to assimilation of GPM data in meso-scale NWP

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INTRODUCTION

GPM broadens the observing coverage of global precipitation to mid-latitudes with more higher frequency microwave channels, and dual frequency radar. Assimilation of these observations in NWP and reanalysis requires a physically-consistent forward model for the absorption and scattering properties of precipitation particles spanning the range of active and passive channel frequencies (Chambon et al 2014). One of new frontiers is to assimilate GPM data where frozen precipitation scattering is most important, such as winter storms and over land surface in mid-latitudes. There are larger uncertainties in simulating optical properties of frozen hydrometeors dependent of assumptions and models of particle geometry, orientation and size (mass) distribution (Geer and Baordo 2014). The biases caused by these uncertainties in radiance observation operator could affect accuracy of analysis and consequentially forecast skills [Figure 1].

A non-spherical snow aggregate DDA database is developed for GPM physically-based retrieval algorithm [Figure 2]. We explore its application in the radiance observation operator to assimilate GPM level-1 data in NASA-Unified WRF Ensemble Data Assimilation System. Three snow models are implemented: Mie soft sphere, single crystal DDA, and aggregated crystal DDA. Observation simulations are carried out to investigate relative biases using different single-scattering parameter calculations [Figure 3], different particle density functions and particle size distributions in bulk optical property calculation [Figure 4], and observation departures comparing to GPM data [Figure 5]. The goal is to evaluate and incorporate a realistic snow particle model in DA system that can capture the radiative properties in a range of microwave frequencies under various precipitation conditions, and be physically consistent with microphysics in mesoscale NWP.

Assimilation of GPM snow-sensitive channels using Mie sphere model

underestimated brightness temperature depression
bias affected snow storm forecasts (2014 Thanksgiving week)

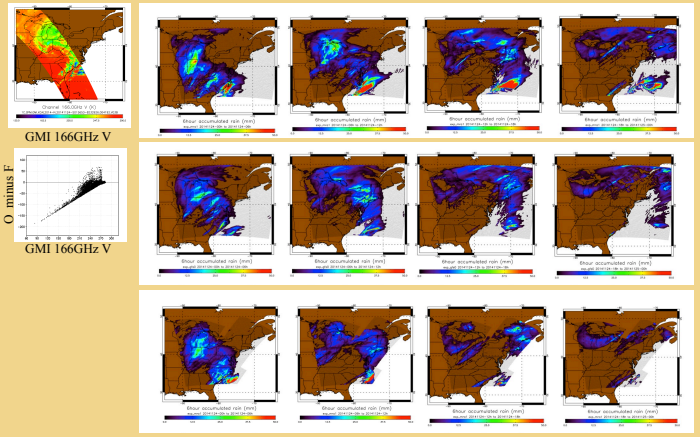


Figure 1. top: precipitation forecasts with assimilation of GPM high frequency channels using Mie sphere snow modeling, middle: forecasts without GPM data assimilation, and bottom: ground-based verification data (Stage IV) 6h surface precipitation accumulation.

PSDs and mass-size relations for bulk optical property calculation

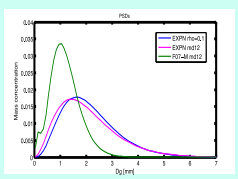


Figure 4(a) snow PSD (in mass concentrations)

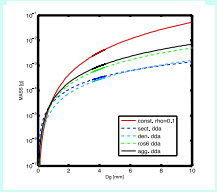


Figure 4(b) snow mass-size relation. Aggregate DDA uses $M=0.007\ D^{2.2}$ (solid black in fig. 4(b) and fig. 2(c)).

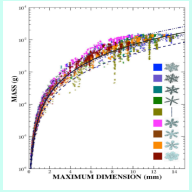


Figure 2(c) mass-size relation of multi-crystal particles. Black dotted curves are derived from field campaigns (Heymsfield et al. 2010)

a non-spherical snow aggregate DDA database

(Kuo and Olson et al. 2015)

A 3-D growth model is used to simulate pristine ice crystals, which are aggregated using a collection algorithm to create larger, multi-crystal particle, shown in Figure 2(a). The growth/collection model is used to generate a large database of snow particles, and the single-scattering properties of each particle are computed using the discrete dipole approximation to account for the non-spherical geometries of the particles, shown in Figure 2(b). The simulated crystals and aggregates have mass vs. size and fractal properties that are consistent with field observations, shown in Figure 2(c).

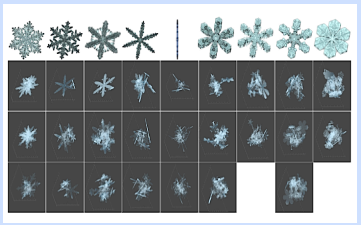


Figure 2(a) Pristine crystal simulated using *Snowfake* algorithm (Gravner and Griffeath, 2009), and snapshots of aggregation simulation based on each crystal type using a collection algorithm.

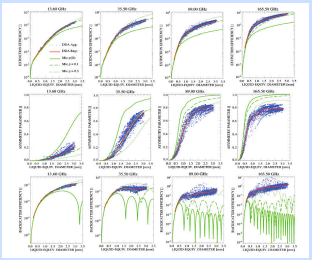


Figure 2(b) single-scattering parameters of snow aggregate particles in the database, in blue dots, ensemble regression in red.

Single scattering properties

(aggregate DDA ensemble-average vs. soft Mie sphere and single crystal DDA)

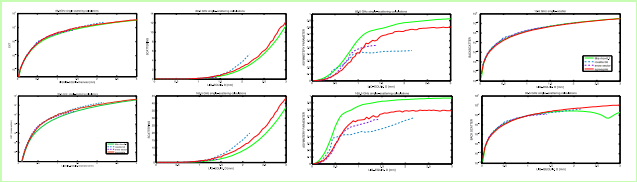


Figure 3. single scattering properties in the DA observation operator with different snow geometry options: soft sphere, secter snowflake, dendrite snowflake, and ensemble average of aggregated snow particles.

GPM observation simulations and observation-departures in DA

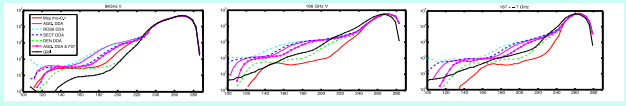
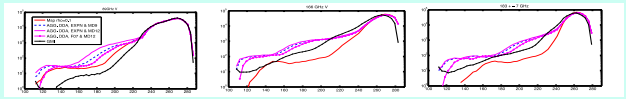
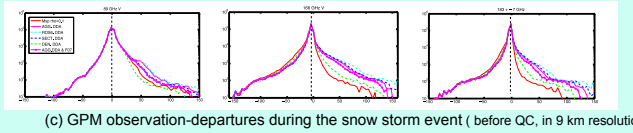


Figure 5 (a) GPM observation simulations using soft sphere, single crystal and aggregate DDA



(b) GPM simulations using aggregate DDA with different PSD or mass-size relations



(c) GPM observation-departures during the snow storm event (before QC, in 9 km resolution.)

SUMMARY

- ❑The soft Mie sphere model in the all-sky radiance observation operator underestimated brightness temperature depression in high frequency channels. Assimilation of data from these channels led to biased snow storm forecasts.
- ❑ Non-spherical snow models are implemented in the radiance operator in NU-WRF EDA. A snow aggregate DDA is applied to GPM data simulations and improves the observation departure statistics comparing to that of soft Mie sphere model.
- ❑ More systematic evaluation in snow-sensitive radiance data assimilation is underway on single and bulk optical property calculations of frozen precipitation in different combinations of DDA and PSD in connection with microphysics models.

References:

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Chambon, P., S. Q. Zhang, A. Y. Hou, M. Zupanski, and S. Cheung, 2014: Assessing the impact of pre-GPM microwave precipitation observations in the Goddard WRF ensemble data assimilation system. Q. J. Roy. Meteorol. Soc..**140**: 1219–1235

Geer, A. J. and Baordo, F., 2014: Improved scattering radiative transfer for frozen hydrometeors at microwave frequencies. Atmos. Meas. Tech., 7, 1839–1860, doi:10.5194/amt-7-1839-2014