Uncertainty in ATMS Radiance Simulation Associated with CRTM Scattering Database

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Introduction

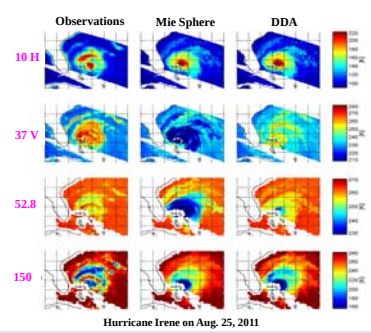
Cloudy radiances provided by satellite instruments naturally contain useful information about clouds and precipitation presented in the filed-of-vies (FOVs) of the instruments, and should be desired by numerical weather prediction (NWP) models. In order to benefit from the assimilation of cloud- or rain-affected microwave radiance data, it requires to have a better characterization of the observation errors for satellite radiances under cloudy conditions than that used in the current GSI. To achieve that, it is necessary to first understand the biases from the satellite observations and corresponding simulations. To simulate passive microwave radiances in cloudy or precipitating conditions requires better knowledge of the scattering properties of frozen hydrometeors. Typically, snow particles are represented as spheres and their scattering properties are calculated using Mie theory, but this is unrealistic and particularly in deep-convective areas, it produces too much scattering in mid frequencies and too little scattering at high frequencies. These problems make it hard to assimilate microwave observations in NWP models, particularly in situations where scattering effects are most important such as over land surfaces or in moisture sounding channels. In this study, Mie and the discrete dipole approximation (DDA) scattering data base are compared for the simulation of brightness temperatures from the Advanced Technology Microwave Sounder (ATMS) using the Community Radiative Transfer Model (CRTM) developed by the US Joint Center of Satellite Data Assimilation (JCSDA).

Comparison of Mie Sphere and DDA for Hurricane Irene

- Liu (2008) produced scattering database that contains pre-computed optical properties of non-spherical ice particles, and made it practical to incorporate discrete dipole approximation (DDA) results into fast radiative transfer models for microwave data assimilation.
- Geer and Baordo (2014) implemented Liu's scattering database in RTTOV-SCATT.

Liu, 2008: "A database of microwave single-scattering properties for nonspherical ice particles", Bull. Amer. Meteor. Soc., 89, 1563-1570. DOI: 10.1175/2008BAMS2486.1

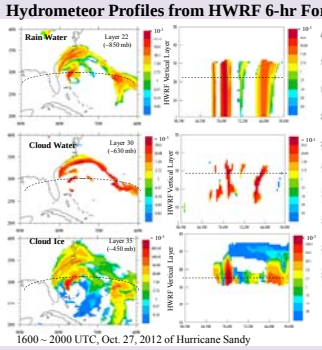
Geer A. J., and F. Baordo, 2014: "Improved scattering radiative transfer for frozen hydrometeors at microwave frequencies", Atmos. Meas. Tech. Discuss., 7, 1749-1805, 2014. DOI:10.519/AMTD-7-1749-2014



Hurricane Irene on Aug. 25, 2011

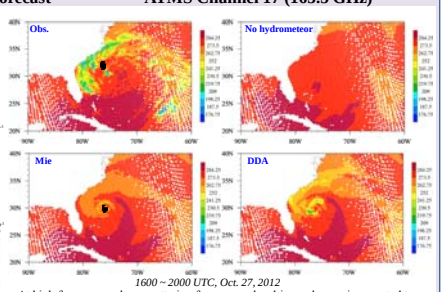
Comparison of Mie Sphere and DDA for Hurricane Sandy

Hydrometeor Profiles from HWRF 6-hr Forecast



1600 ~ 2000 UTC, Oct. 27, 2012 of Hurricane Sandy

ATMS Channel 17 (165.5 GHz)



1600 ~ 2000 UTC, Oct. 27, 2012

At high frequency, where scattering from upper-level ice and snow is expected to depress the brightness temperatures, the Mie simulations did not provide enough scattering as DDA did.

Characterization of ATMS Observation Error under Cloudy Conditions Using Collocated TMI Data

ATMS and TMI Collocation Criteria

- Temporal Collocation: temporal difference of ATMS pixel and TMI pixel is less than 15 minutes;
- Spatial Collocation: TMI pixels are within the FOV of ATMS pixel.

Determination Index (DI)

The elliptical equation of ATMS FOV boundary is :

$$\frac{(x-x_0)^2}{a^2}+\frac{(y-y_0)^2}{b^2}=1$$

x and y: the longitude and latitude of ATMS FOV center;

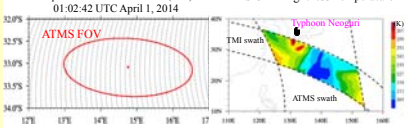
$(x-x_0)$ and $(y-y_0)$: the distance between ATMS and TMI centers along the ATMS FOV major and minor axis;

a and b: the length of semi-major and semi-minor axes.

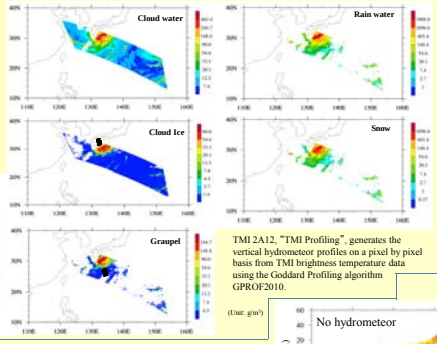
If DI ≤1: TMI pixel is within ATMS FOV

TMI pixels within ATMS FOV (5.2°) at 01:02:42 UTC April 1, 2014

ATMS Ch1 Brightness Temperature



Vertically-Integrated Hydrometeor Content from TMI



(Unit: g/m²)

TMI 2A12, "TMI Profiling", generates the vertical hydrometeor profiles on a pixel by pixel basis from TMI brightness temperature data using the Goddard Profiling algorithm GPROF2010.

Simulation of ATMS Brightness Temperature Under Cloudy Conditions

Observed brightness temperature (O)

Simulated brightness temperature (B) under cloudy condition

Inputs to CRTM Simulations

- Atmospheric profiles from ECMWF analysis data

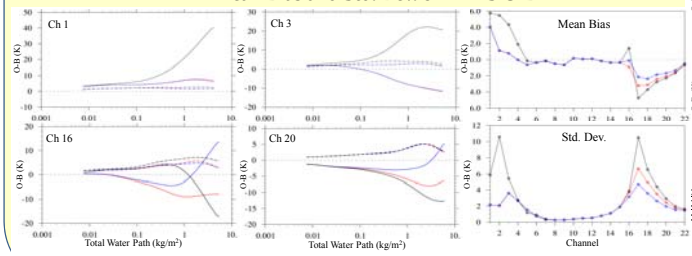
  Temperature, pressure, water vapor, ozone profiles
- Hydrometeor profiles from TMI retrieval products

  Cloud water (q_c), cloud ice (q_i), rain water (q_r), snow (q_s), graupel (q_g)
- Values of empirical effective radius and default volume density

Hydrometer		Cloud water	Cloud ice	Rain water	Snow	Graupel
Effective radius (μm)		10	50	300	300	200
Volume density (g/cm³)	Mie	1.0	0.916	1.0	0.1	0.4
	DDA		0.916			

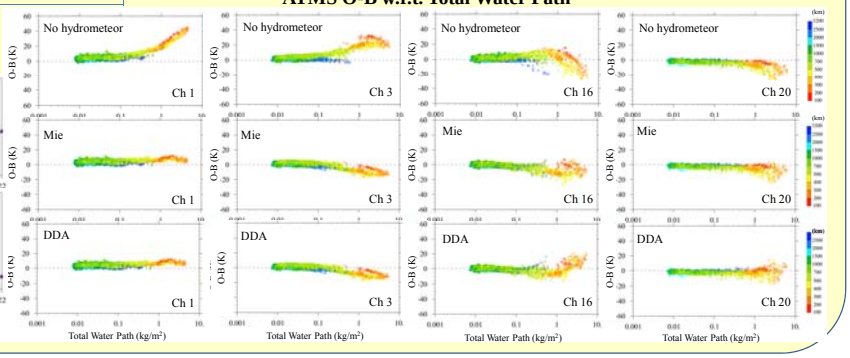
Using a combination of the ECMWF analysis data and the TMI retrieved cloud information as the atmospheric state input to the CRTM, radiances are simulated at the ATMS footprint resolution. To directly compare with the observed ATMS microwave radiances, the averaged vertical profile of each hydrometeor specie is generated for the ATMS footprint under the assumption that the cloud distribution within the entire ATMS FOV is the same as the TMI retrieved cloud distribution.

Mean Bias and Std. Dev. of ATMS O-B



Solid: Mean Dashed: Std. Dev. — No hydrometeor — Mie — DDA

ATMS O-B w.r.t. Total Water Path



Summary

- The simulated ATMS brightness temperature is very close to observation in upper level temperature sounding channels. (not shown)
- The ATMS bias of channels 1-4 shows the LWP/IWP-dependency.
- The brightness temperature simulations from the two scattering coefficients display obvious difference in channels 16-22. DDA can correct the underestimation of scattering at those channels.