Validation of the Community Radiative Transfer Model (CRTM)

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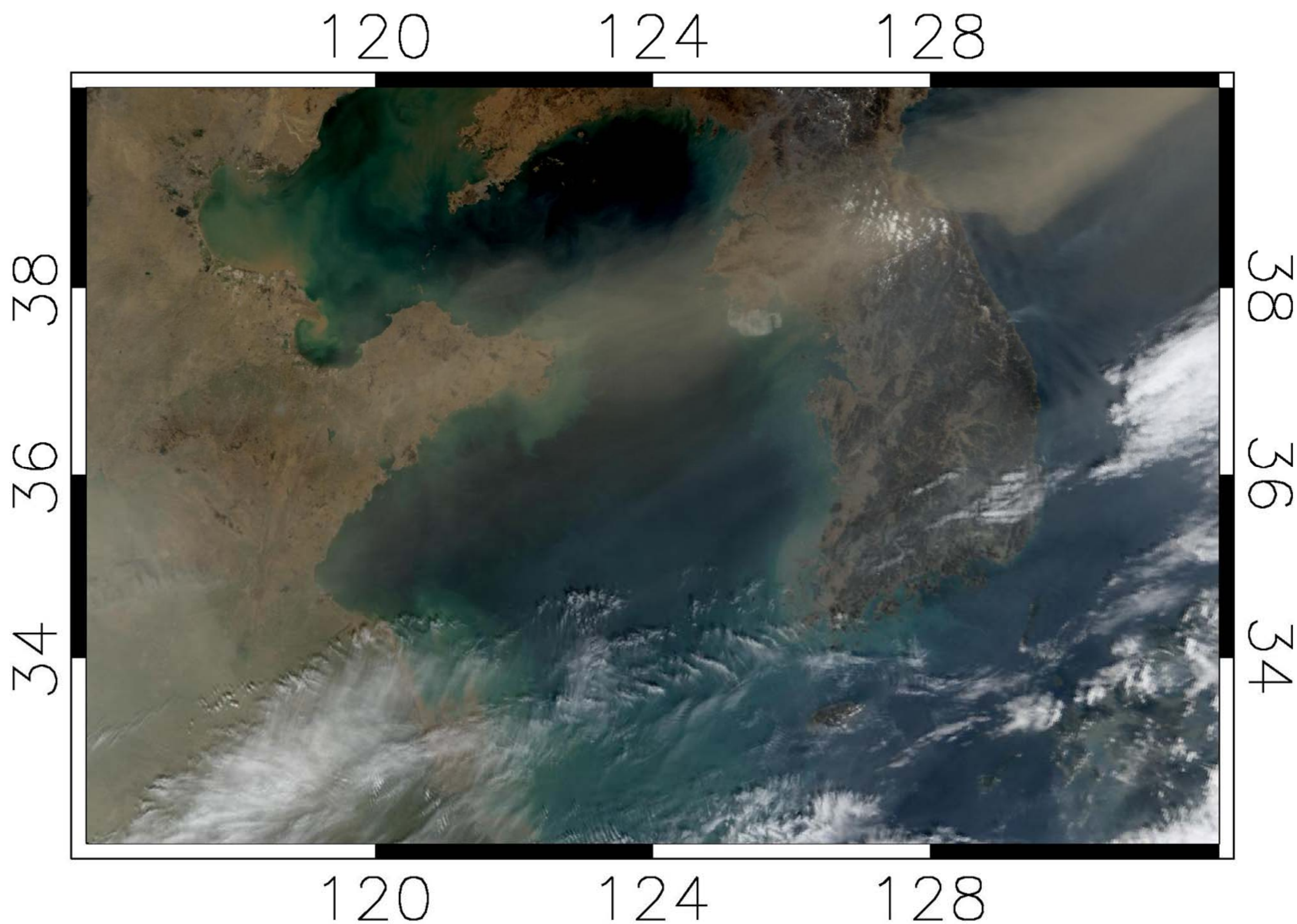
In collaboration with the JCSDA CRTM team

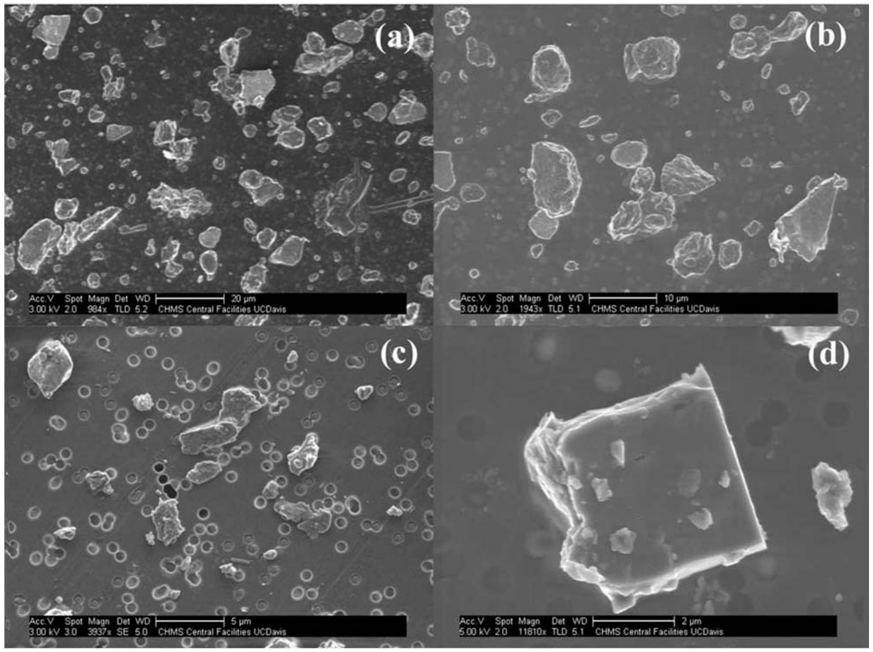
Outline

- Deliveries to enhance the CRTM
  - Science background
  - Delivered data sets
- Validation of the CRTM
  - Hyperspectral applications
  - Narrow-band applications
- Follow-up effort
- Summary

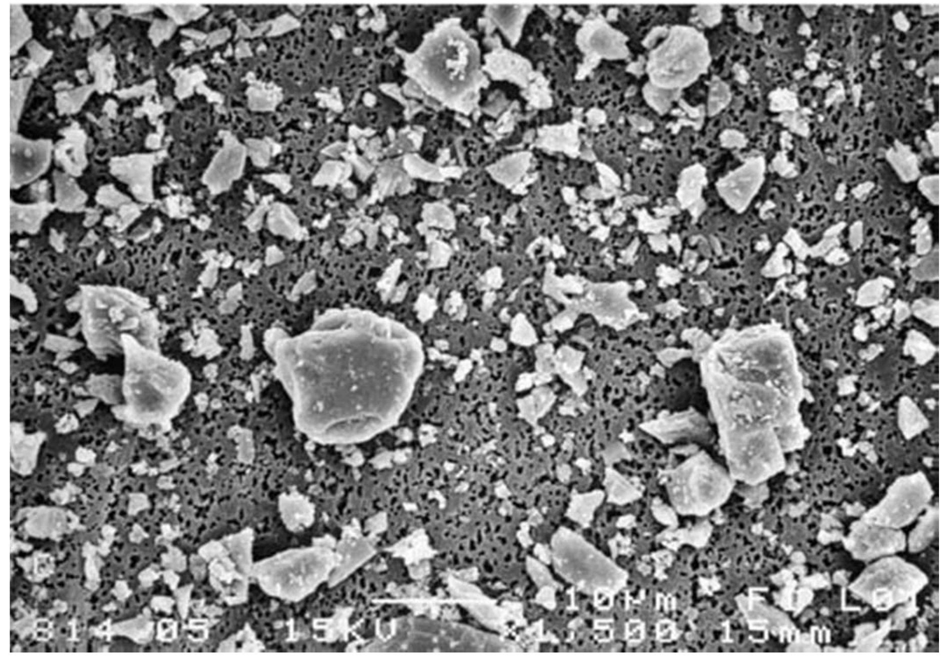
A major component of atmospheric aerosols is airborne dust that has significant opacity (particularly over arid and semi-arid areas) in certain spectral bands and can thus have a substantial impact on atmospheric radiation energy budget and climate



Asian Dust, MODIS RGB (0.65µm, 0.55µm, 0.47µm) Image

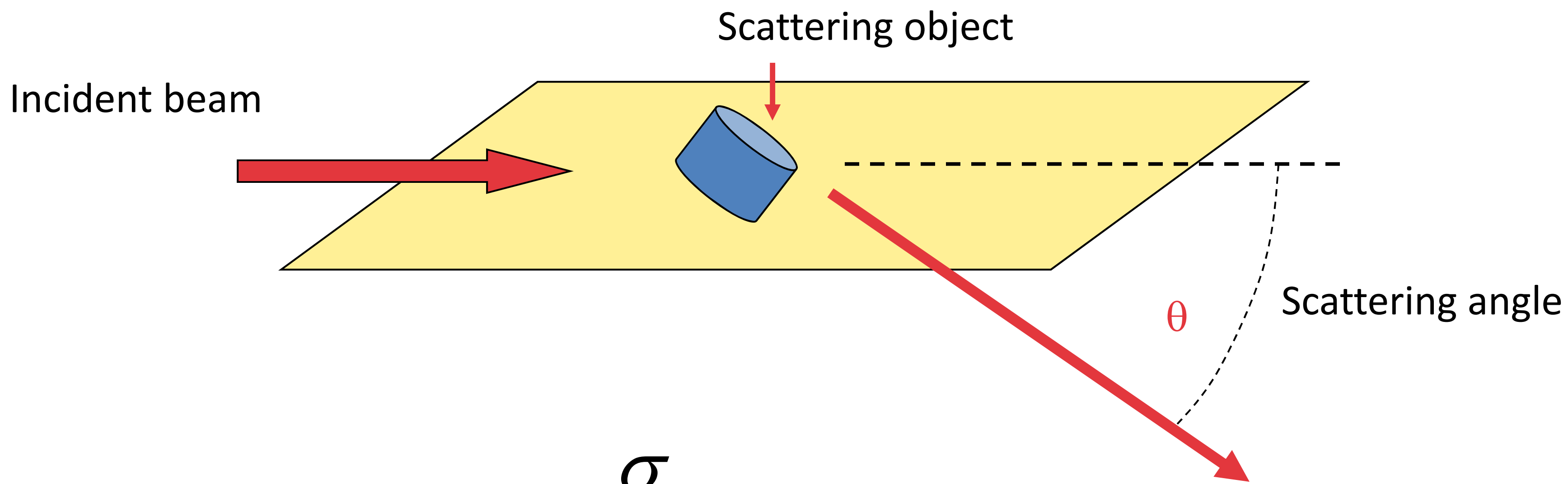


Reid et al., 2003



Volten et al., 2005

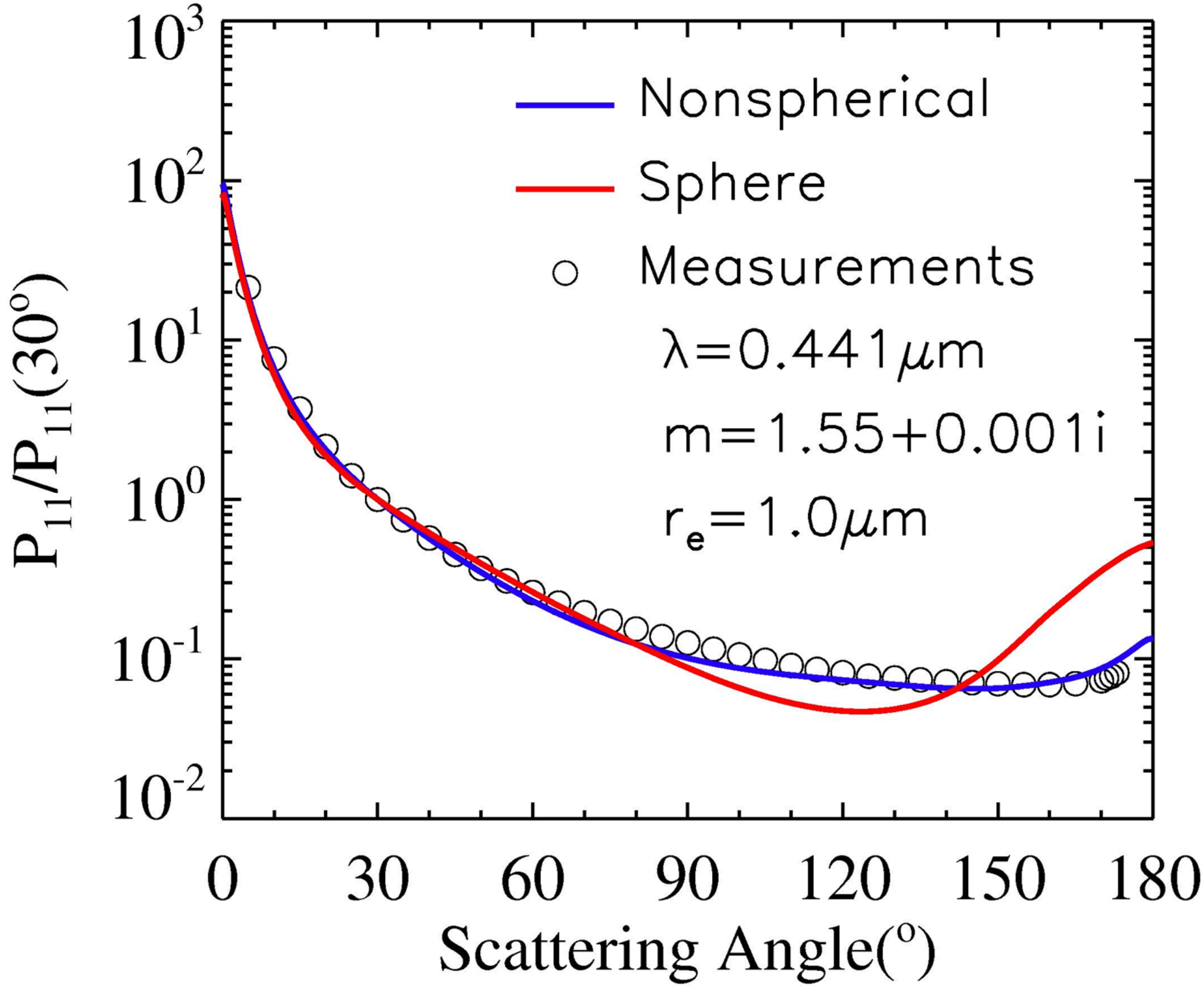
Scattering Geometry



$$I_s = \frac{\sigma_s}{4\pi r^2} P_{11}(\theta) I_i$$

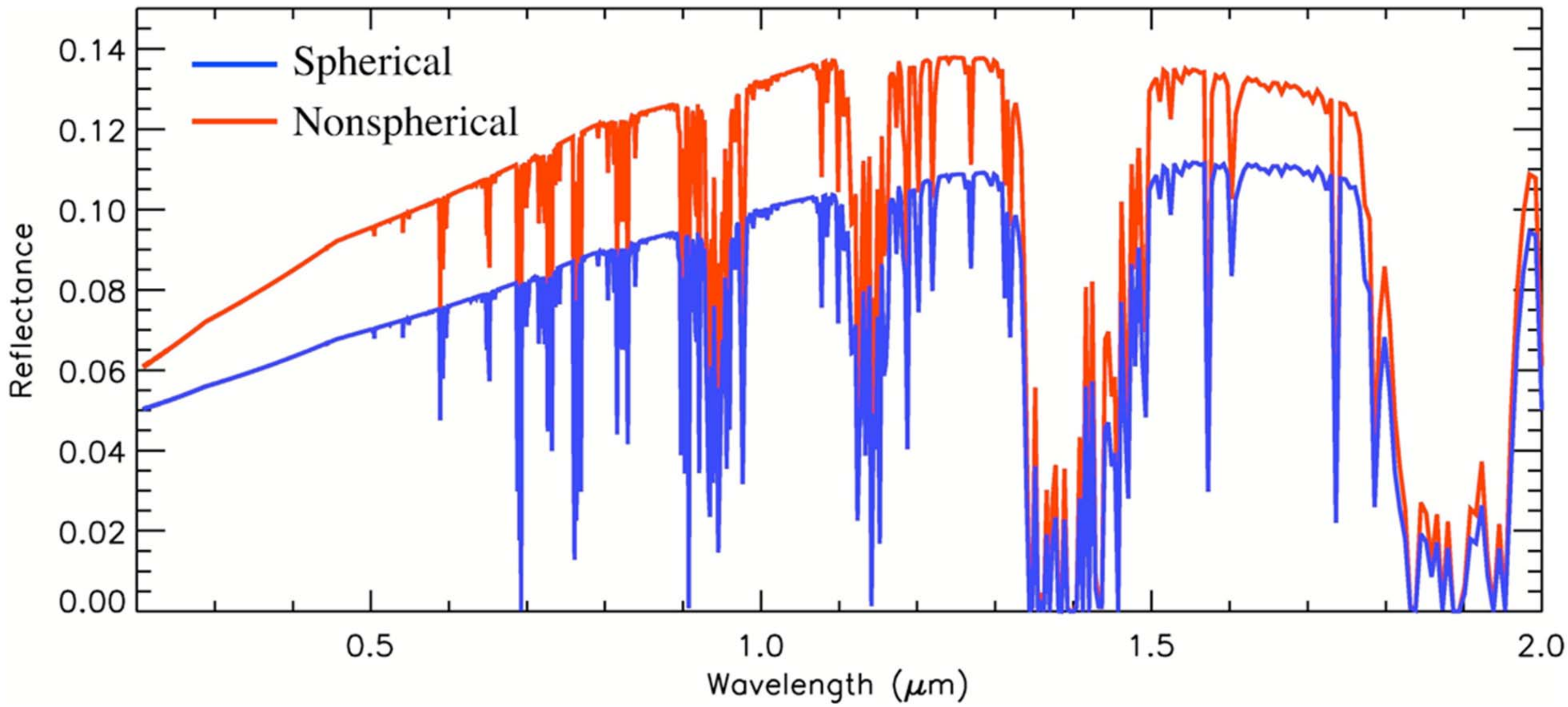
$\sigma_s = scattering\ \ cross\ \ sec\,tion$

$P_{11}(\theta) = Phase\ \ \ function$



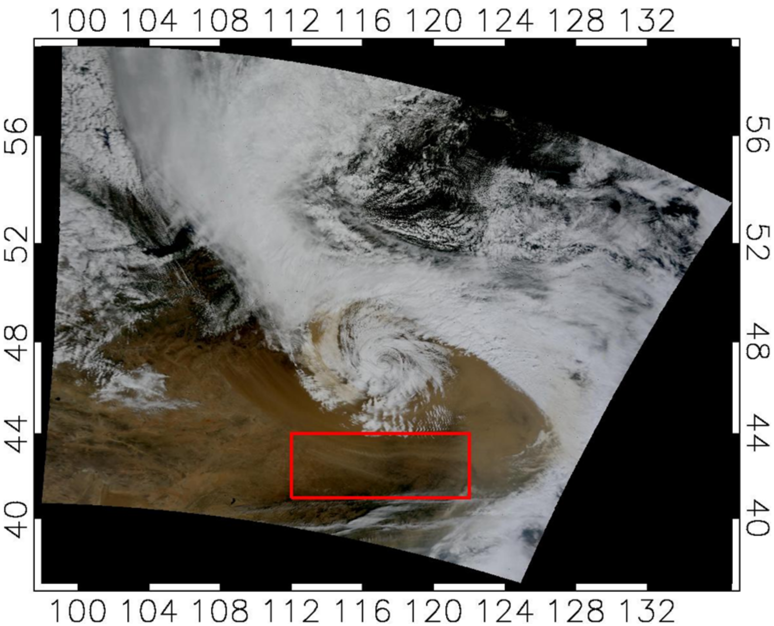
Comparison between the phase functions computed for spherical and nonspherical dust particles (Feng, Yang, Kattawar, Hsu, Tsay and Laszlo, 2009). The symbols indicate laboratory measurements (Volten et al. 2001).

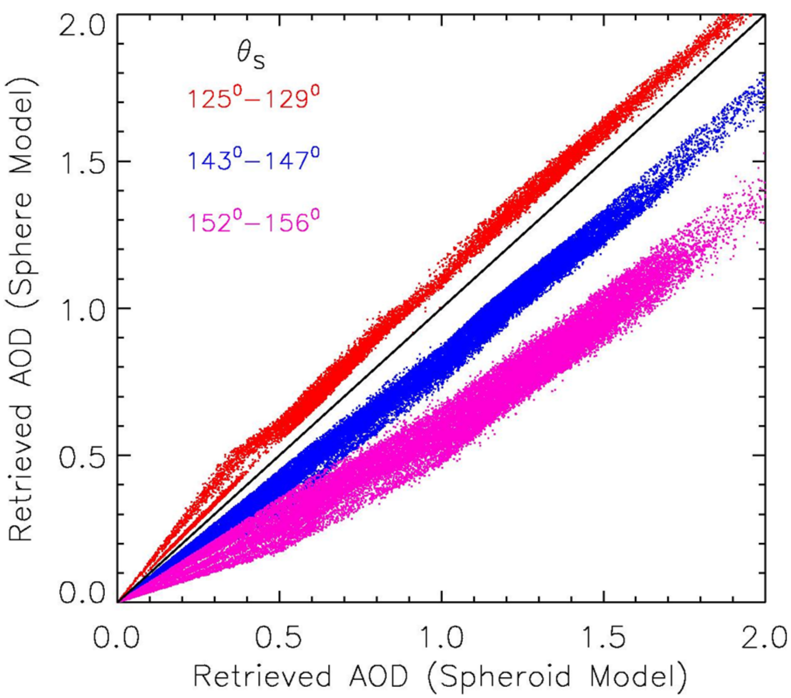
Simulated solar reflectance at the top of a dusty atmosphere. Spherical and nonspherical (spheroidal) shapes are assumed for dust particles (Yang et al., 2007)



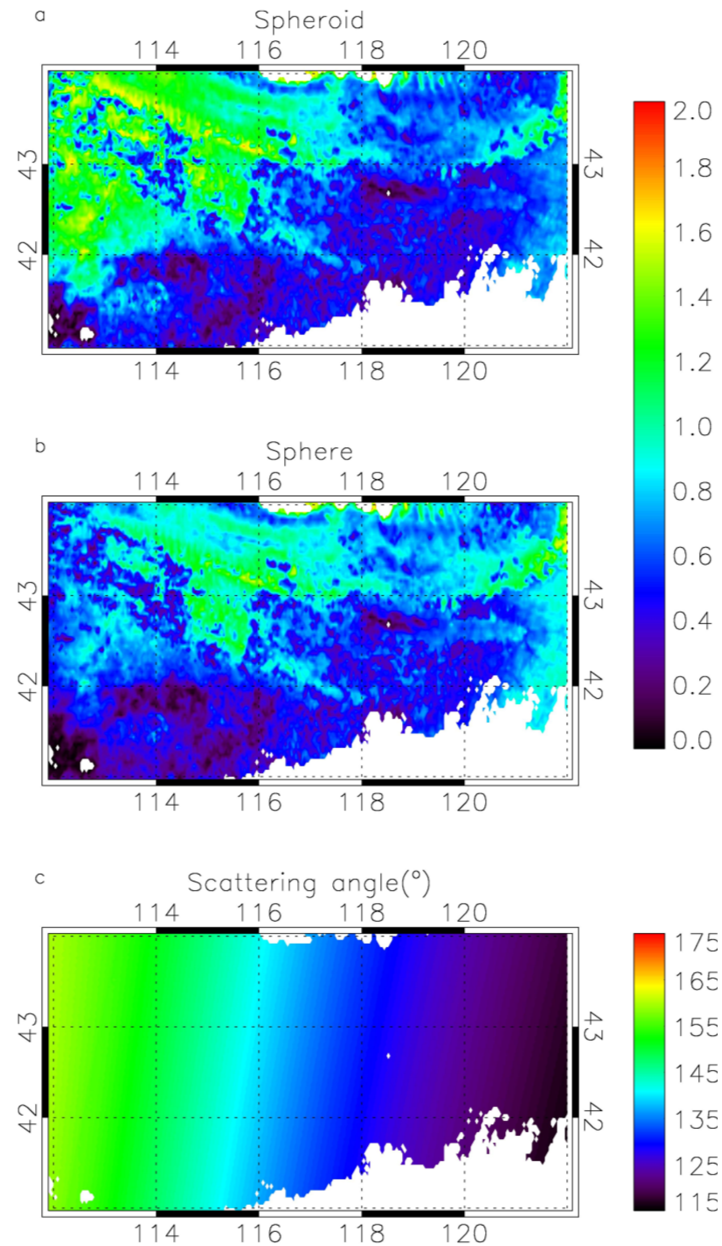
- These results indicate that the equivalent sphere approximation leads to an underestimate of the albedo of a dusty atmosphere. This underestimate has an important implication to the study of the effect of airborne dust on the radiation budget within the atmosphere.

MODIS RGB image (05/27/2008)





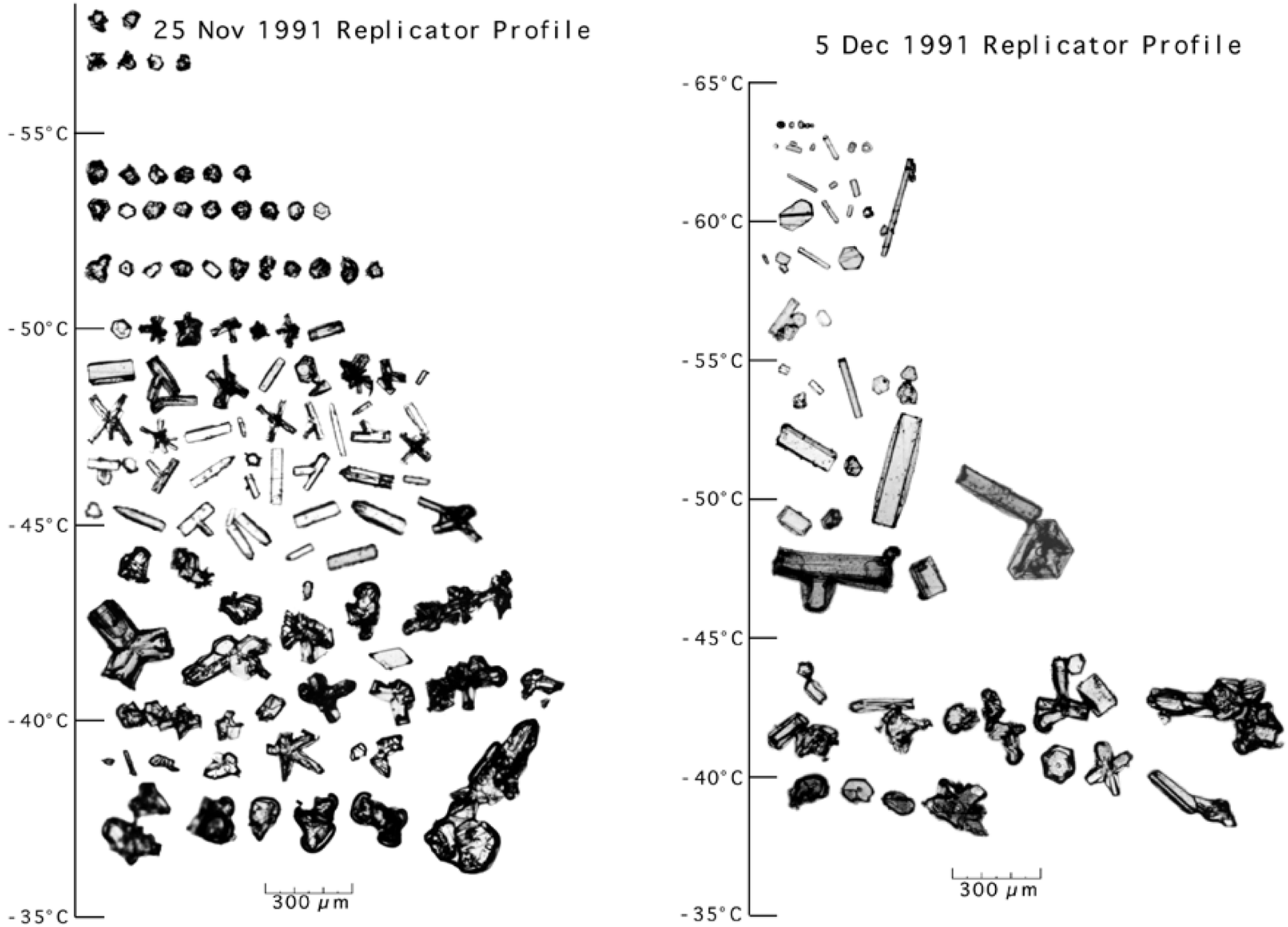
Retrieved dust optical depths

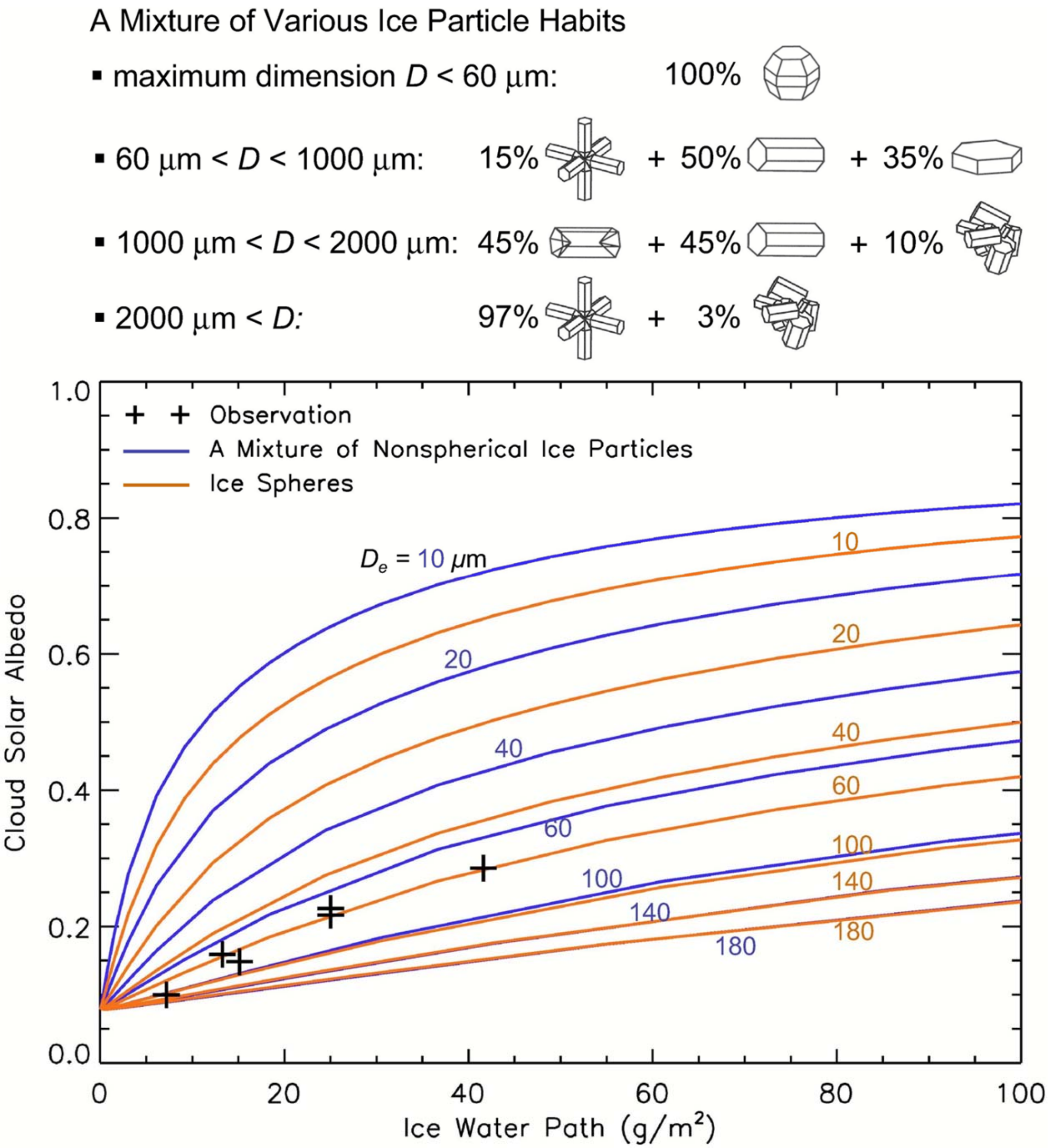


(Courtesy of Q. Feng)

Replicator Ice Crystal Profiles for FIRE Cirrus II Campaign

(Data courtesy of A. Heymsfield, L. Miloshevich, S. Aulenbach, NCAR)

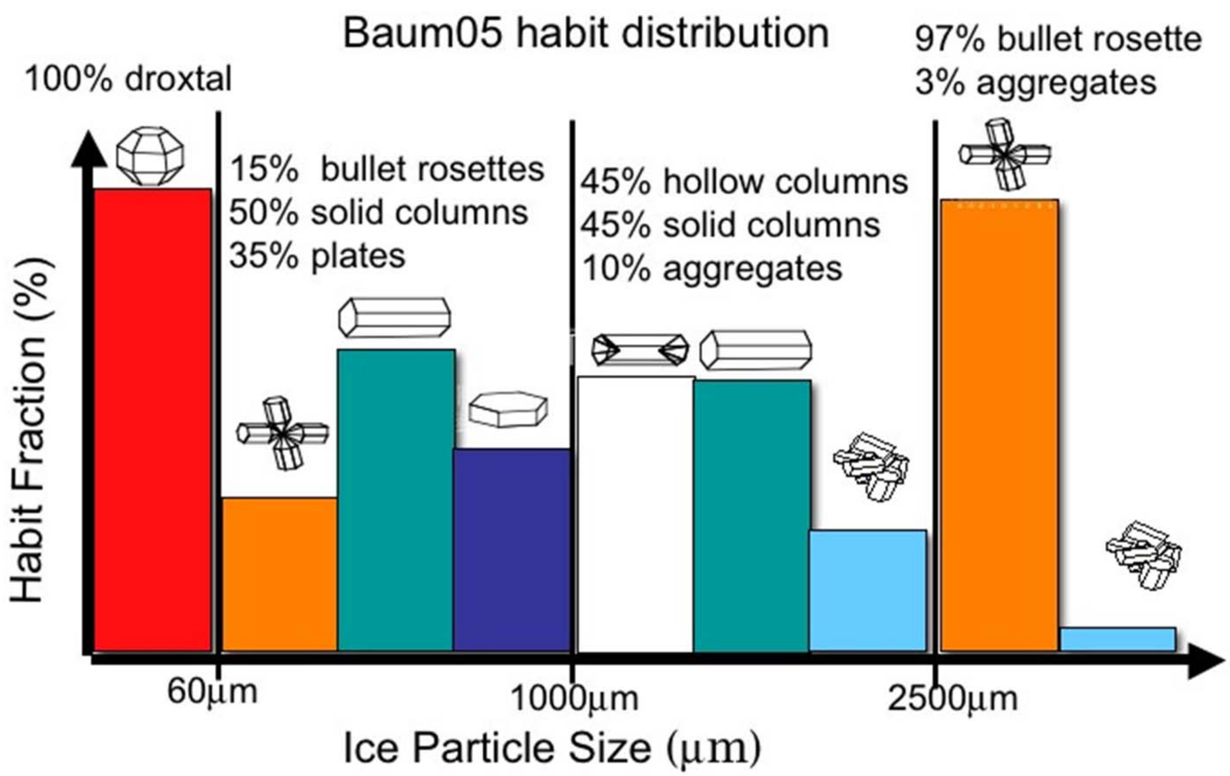




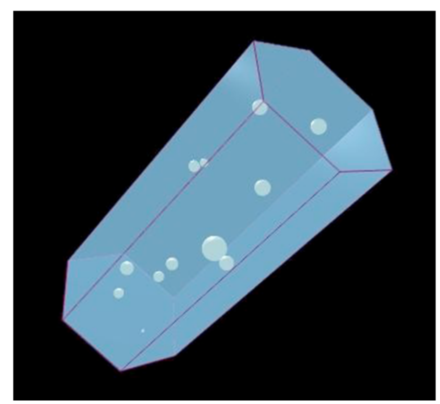
Solar albedo as a function of ice water path determined from broadband flux observations (cross dots) from aircraft for cirrus clouds that occurred during the FIRE experiment, Wisconsin, November-December, 1986 (Stackhouse and Stephens 1991). The blue lines represent the theoretical results computed with a mixture of various ice habits (Baum et al. 2005). The red lines represent the results with an assumption of ice spheres. Adapted from Yang et al. (2010)

Differences between the MODIS and POLDER ice cloud models

- Bulk scattering model
  - MODIS: Baum05 model (Baum et al 2005; Yang et al. 2000; Yang et al. 2005)
  - POLDER: IHM model (C.-Labonnote et al. 2000)

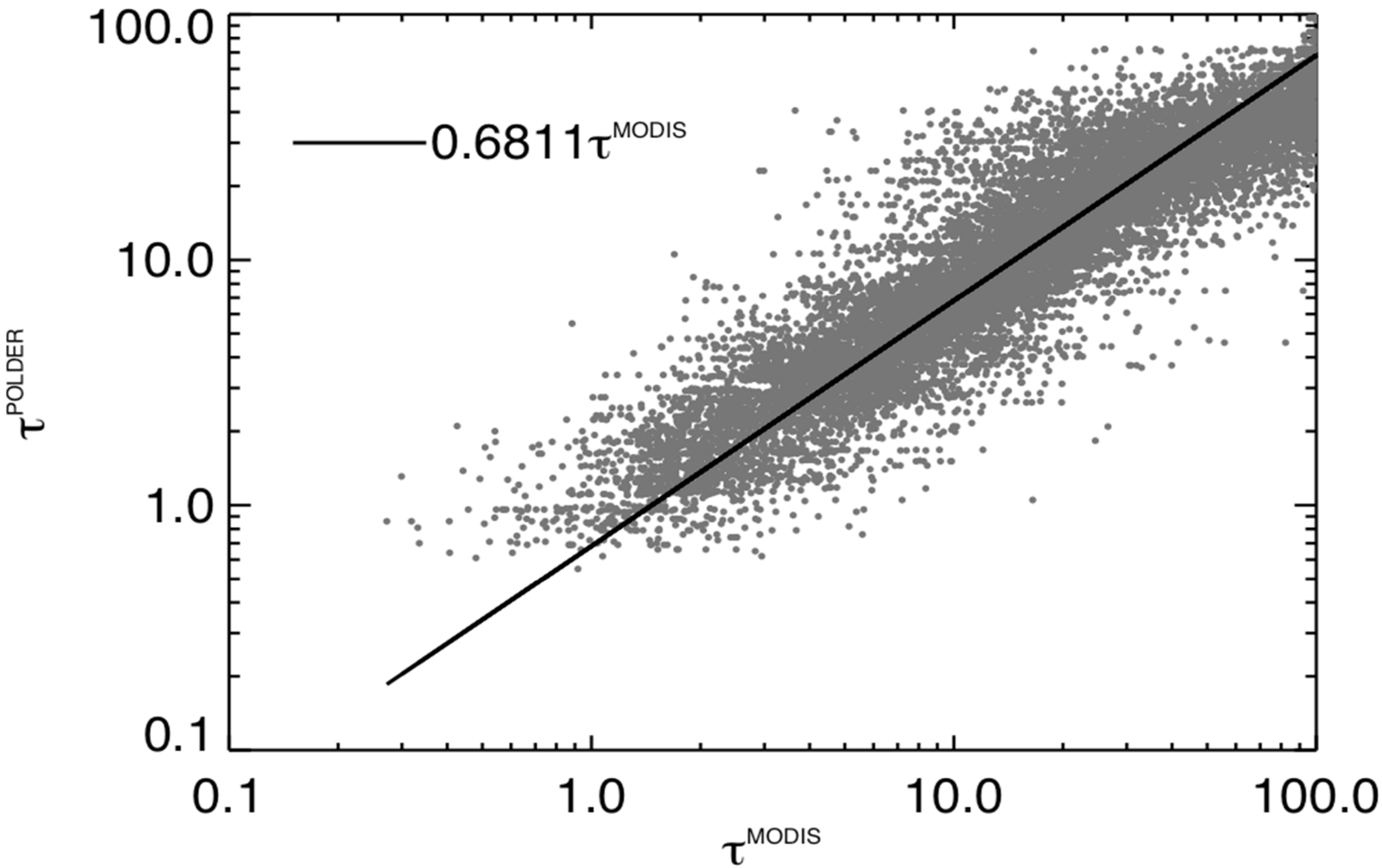


IHM model



Courtesy of
Dr. Jerome Riedi

Comparison between MODIS and POLDER Retrievals (Zhang, Yang and co-authors, 2009)



Delivered three bulk-scattering property databases

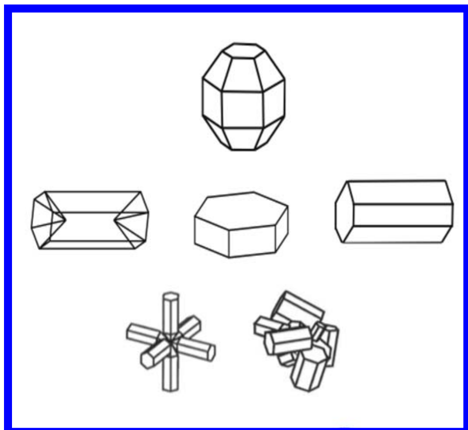
- The bulk scattering properties.
- Interpolate the bulk scattering property database to 3001 wavelengths between 0.225 and 20.0 μm
- Truncate the scattering phase function

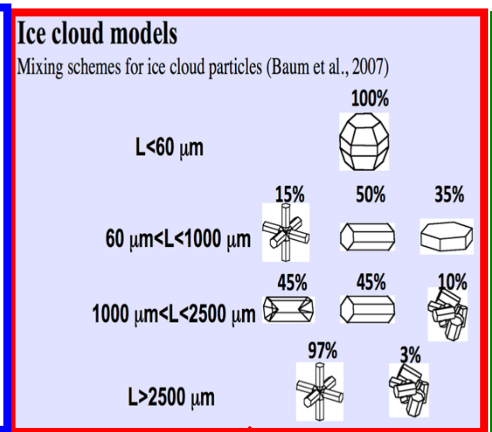
- Dust aerosols: Randomly oriented spheroidal dust particles

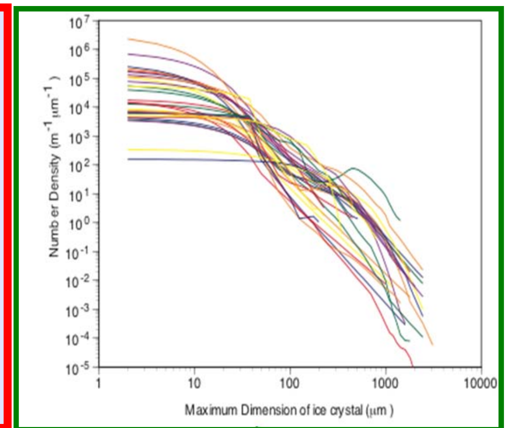
- Ice clouds: Ice crystals with a mixture of various habits

- Water clouds: Spherical water droplets

Spectral bulk scattering properties of ice clouds

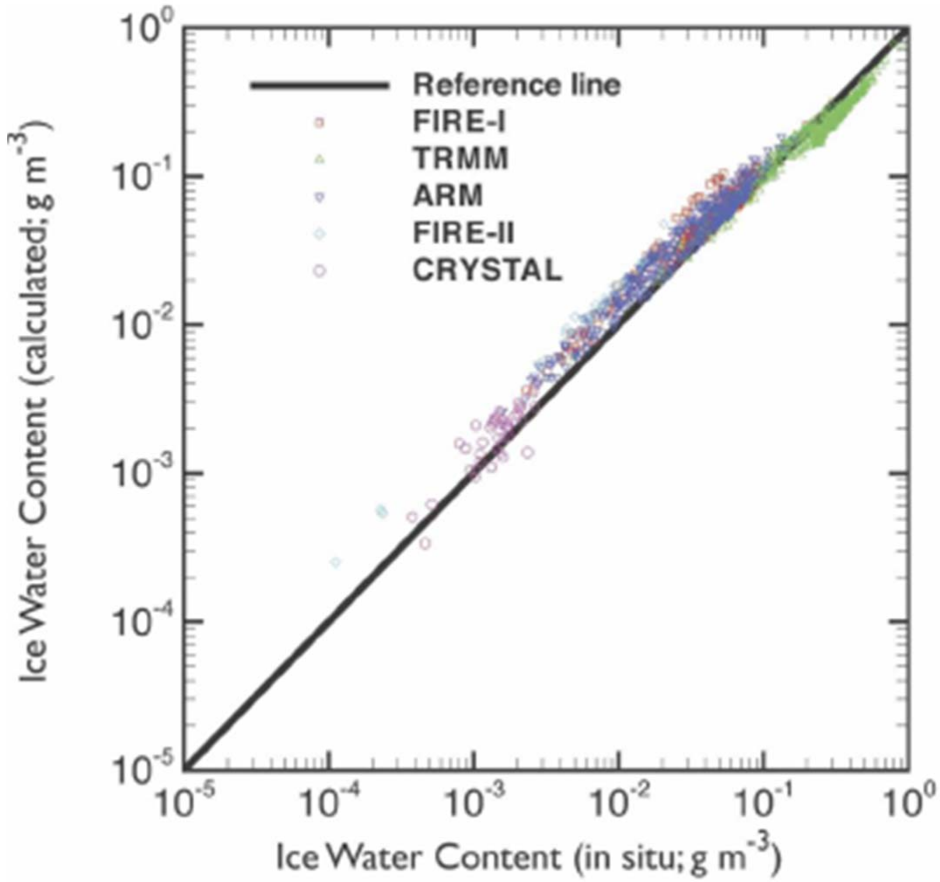




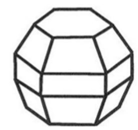


$$\overline{P}(\Theta,\nu)=\frac{\int_{D_{\min}}^{D_{\max}}\left[\sum_{h=1}^{M}P_h(\Theta,D,\nu)\sigma_{sca,h}(D,\nu)\,f_h(D)\right]n(D)dD}{\int_{D_{\min}}^{D_{\max}}\left[\sum_{h=1}^{M}\sigma_{sca,h}(D,\nu)\,f_h(D)\right]n(D)dD}$$

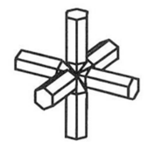
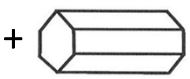
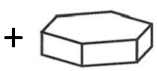
Ice Cloud Microphysical Model



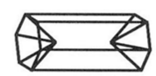
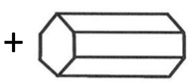
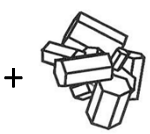
- Particle's maximum dimension D < 60 μm

 100%

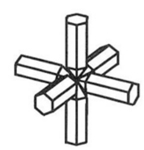
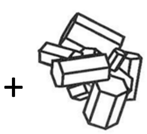
- 60 μm < *D* < 1000 μm

 15% +  50% +  35%

- 1000 μm < D < 2500 μm

 45% +  45% +  10%

- 2500 μm < D

 97% +  3%

$$IWC = \rho_{\mathrm{i}} \int_{D_{\min}}^{D_{\max}} \left[\sum_{i=1}^{N} f_i(D) V_i(D) \right] N(D) \mathrm{d}D$$

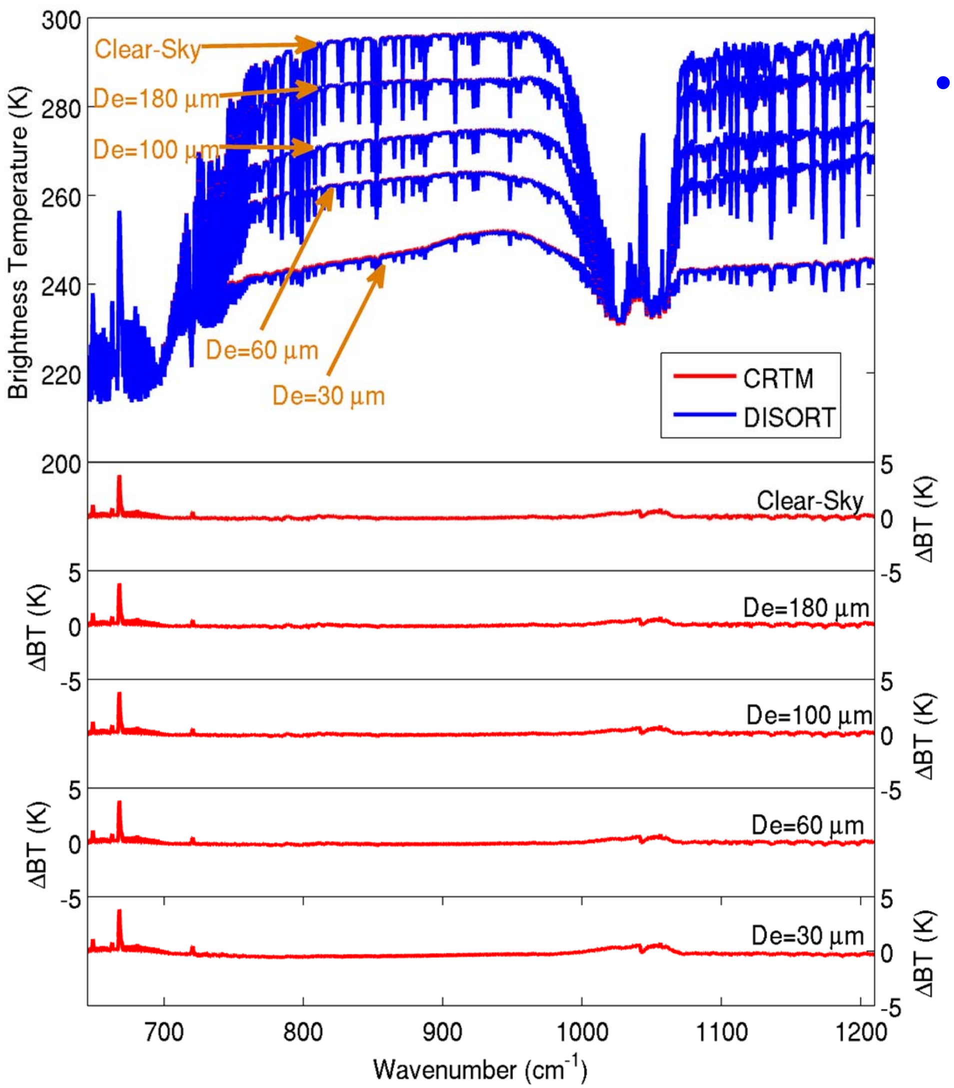
Mixing schemes for ice cloud particles
(*Baum et al. 2005)*

Validation of CRTM: Methodology

Two methods were used to validate the CRTM:

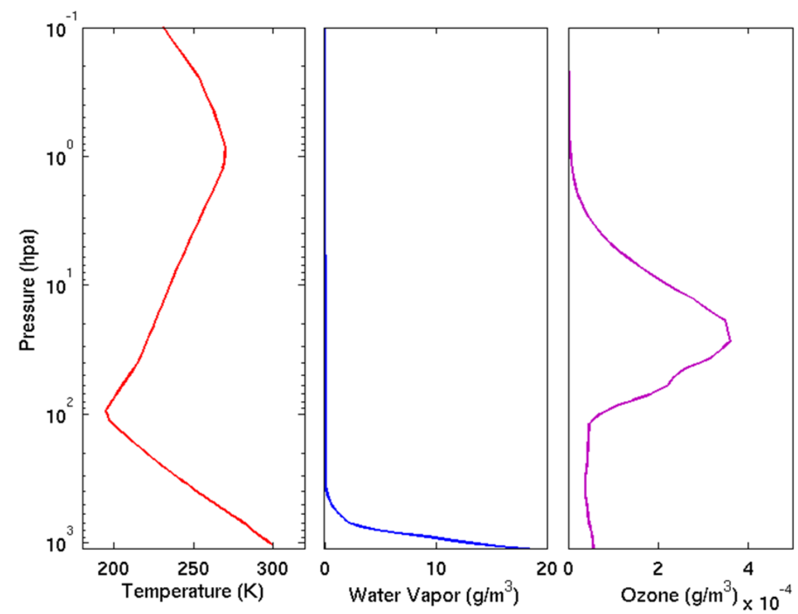
- Model-to-model method: LBLRTM+DISORT and CRTM
  - IASI, AIRS and CrIS
- The CRTM simulated high spectral resolution BTs and narrow-band BTs are compared directly with observations.
  - The ECMWF atmospheric profiles are used.

Validation of the CRTM



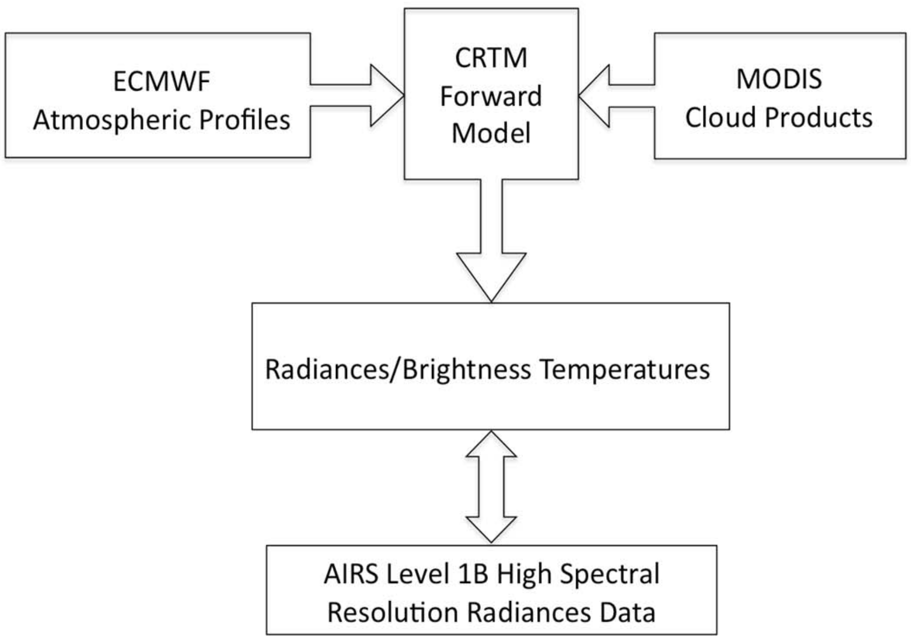
IASI band 1

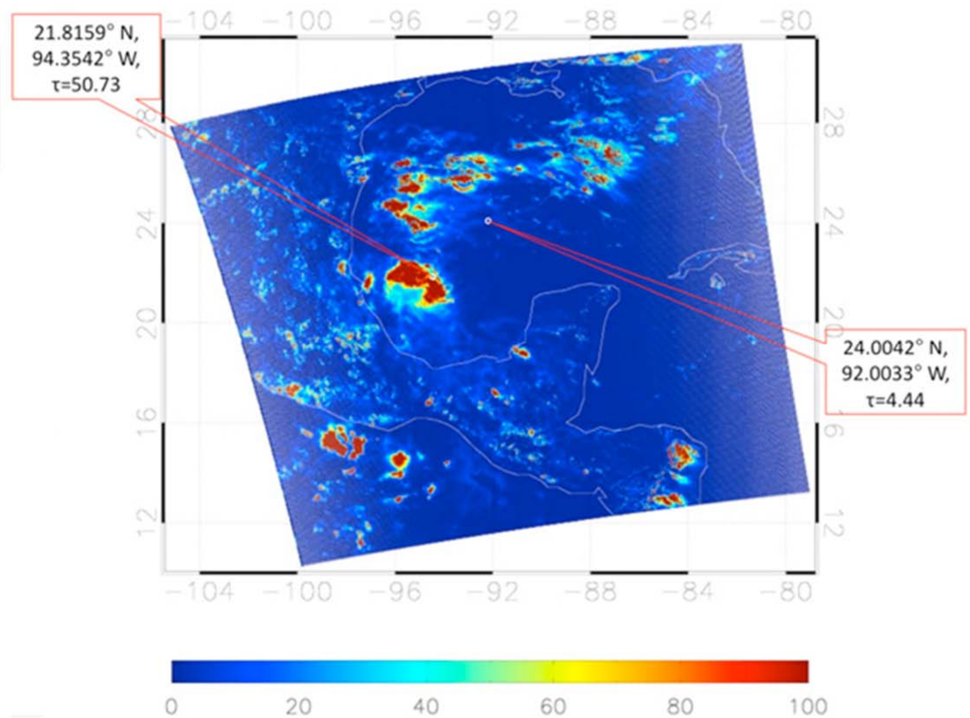
- The tropical standard atmospheric profile



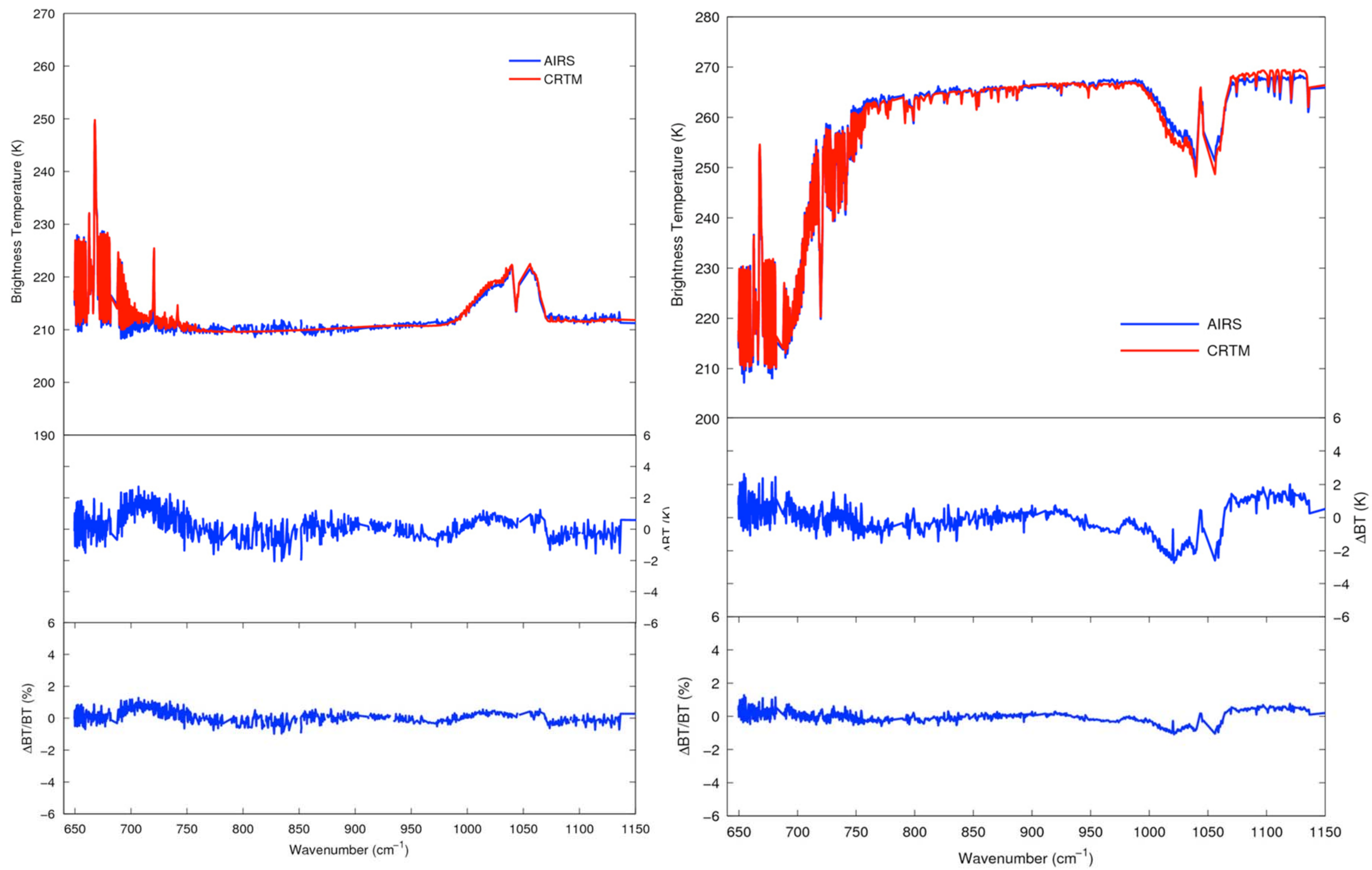
	De=30 µm	De=50 µm	De=100 µm	Clear sky
RMS of ΔBT (K)	0.1804	0.1686	0.1680	0.1595

For the purpose of validation of the CRTM, we compared the CRTM simulated brightness temperatures (BTs) with the AIRS level 1B radiance data by using the MODIS cloud products and ECMWF atmospheric profile as input.





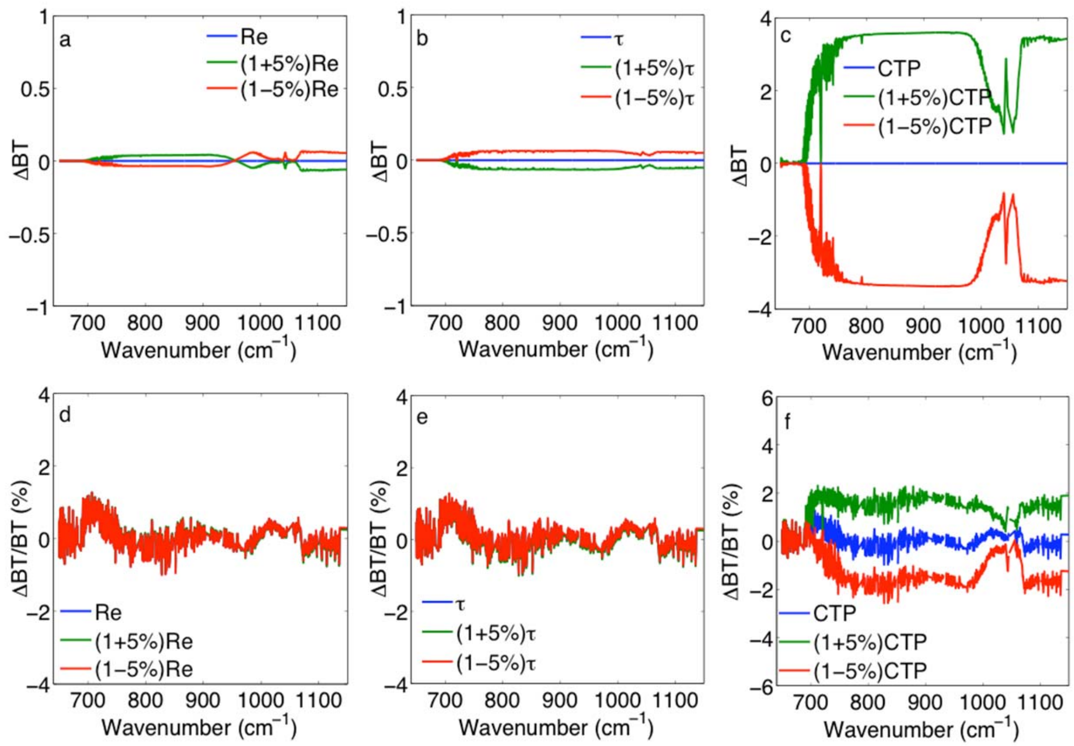
Comparison between the high-spectral-resolution BTs simulated from the CRTM and those observed by AIRS for selected MODIS pixels having a small (left) and large (right) optical thickness.



Possible Sources of Error

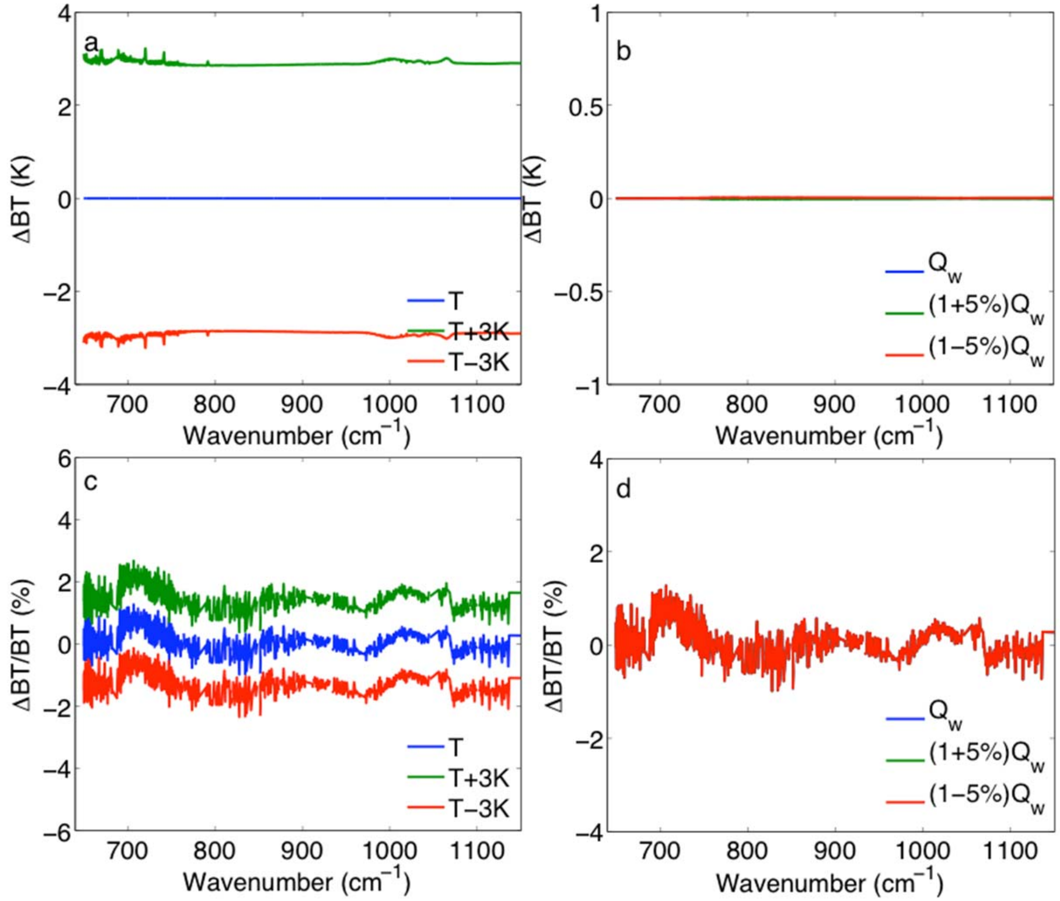
- The inaccuracies of cloud optical thickness and effective particle size
  - The MODIS cloud optical thickness and particle size are derived from MODIS visible and near-infrared bands, whereas the simulations are performed in the infrared spectrum.
- Lack of cloud base height information
- The inaccuracies in atmospheric temperature and humidity profiles
  - The time of the chosen granule of MODIS and AIRS measurements is not exactly the same as the ECMWF data, and errors may be incurred in temporally interpolating the ECMWF atmospheric profiles.

Sensitivity and Uncertainty Studies (1)



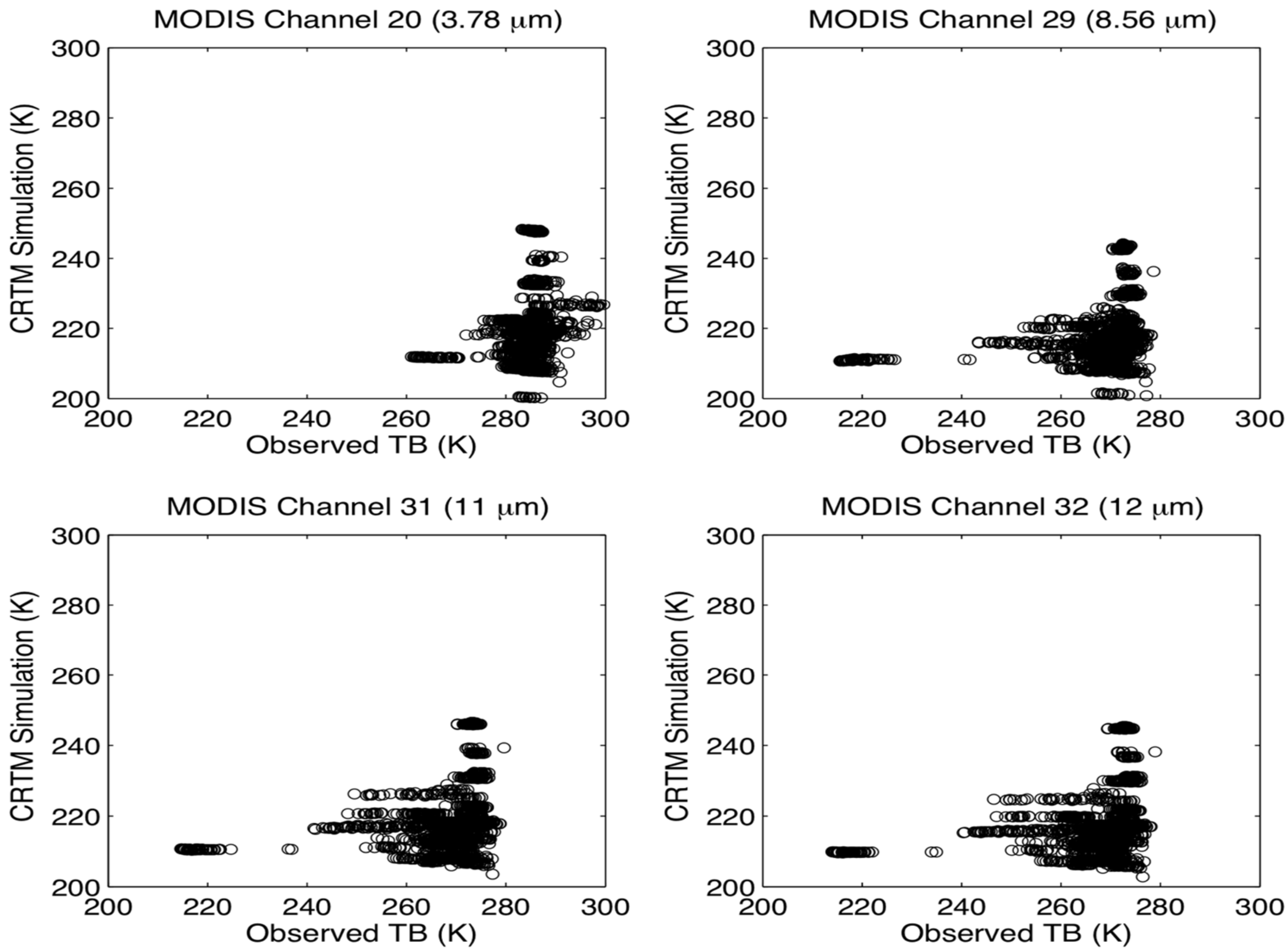
The CRTM-based brightness temperature differences associated with the perturbation of the various ice cloud properties for the optical thick cloud case.

Sensitivity and Uncertainty Studies (2)



The CRTM-based brightness temperature differences associated with the perturbation of atmospheric profile for the optical thick cloud case.

Scatter plots of the CRTM simulated and MODIS observed brightness temperatures for 4 MODIS channels

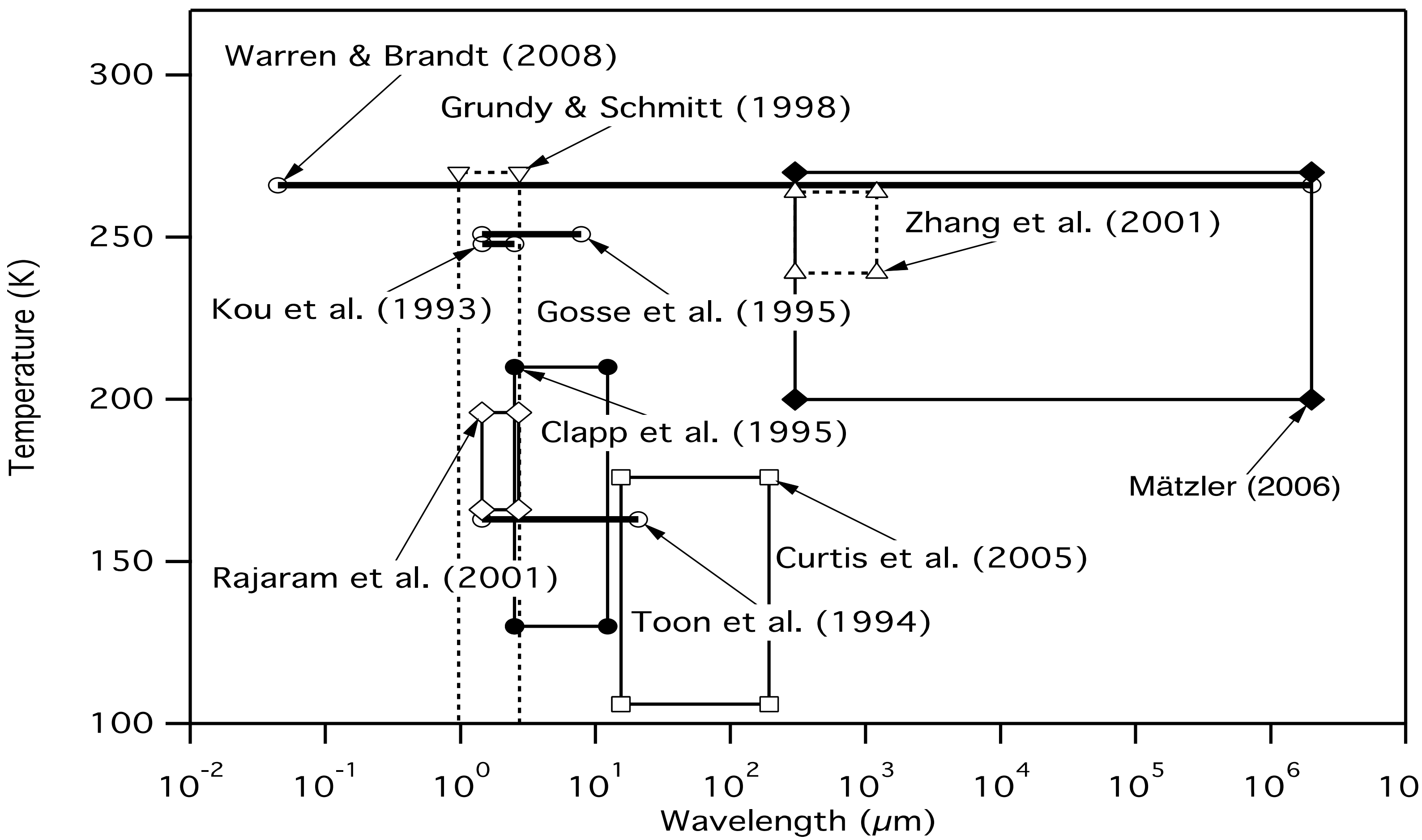


Follow-up Effort

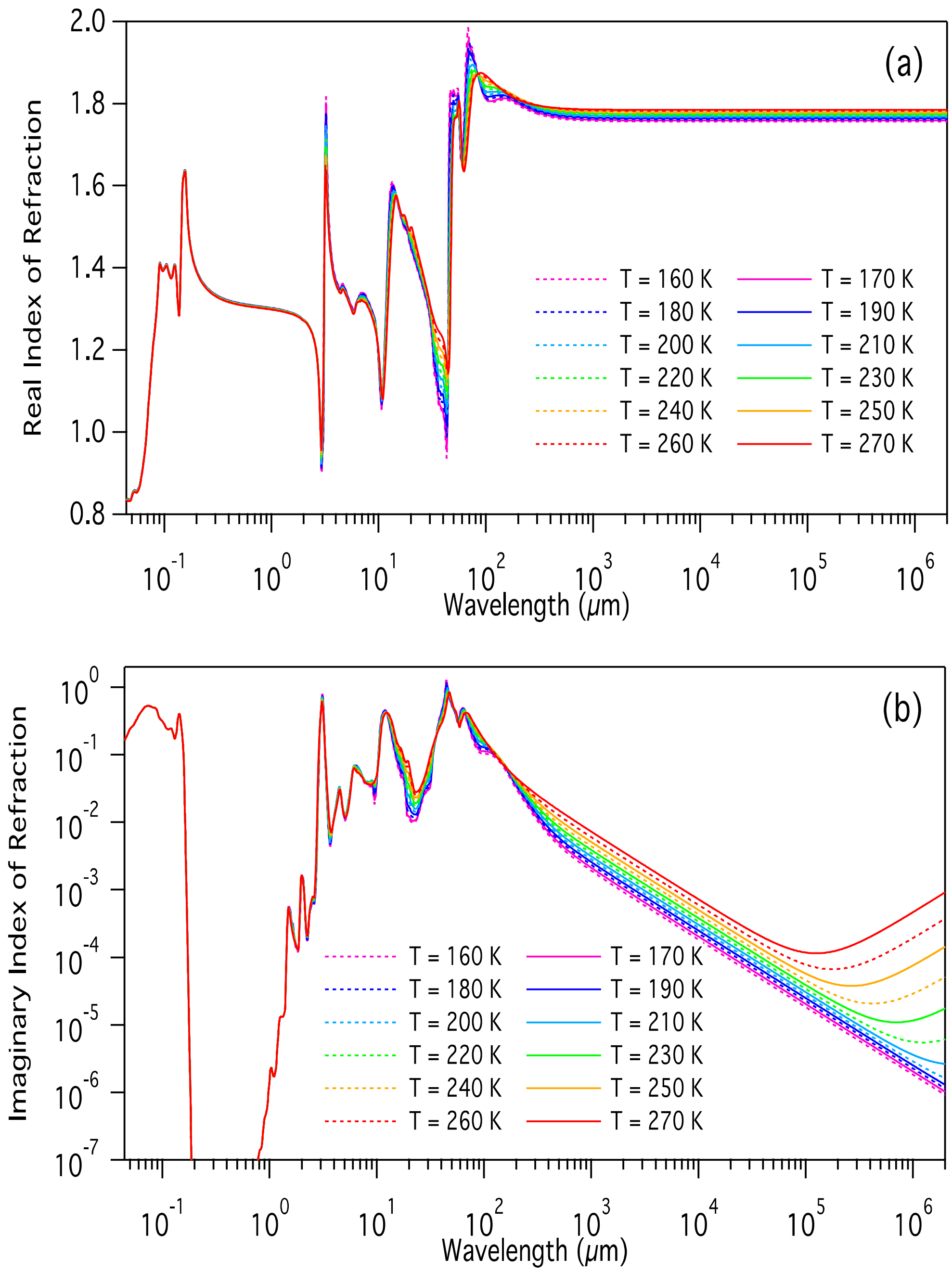
- Temperature dependence of the optical properties of ice clouds at microwave wavelengths
- The optical properties of snow

  The mass density of snow can be much smaller than that of pure ice because of porous structure. At present, the optical properties of pure ice crystals are used as the surrogates for snow. This simplification can lead to significant errors in various downstream applications.
- Validate the CRTM for narrow band applications (e.g., MODIS and ABI), particularly, in the aspect of spectral consistency based on synergetic use of satellite observations and reanalysis data (e.g., CALIOS-CALIOP cloud height, MODIS cloud properties, and MERRA atmospheric profile).

Temperature range of existing data sets of ice refractive index



Iwabuchi and Yang (to be submitted)



Iwabuchi and Yang (to be submitted)

Summary

- Three bulk-scattering property datasets were computed for the wavelengths between 0.225 to 20.0 μm.
- The ability of the CRTM to accurately simulate the IASI brightness temperature has been tested in comparison with model-to-model for both clear-sky and ice cloudy conditions.
- The sensitivity study shows that the simulated BTs are very sensitive to the cloud geometrical thickness, particularly, in the window region.
- Using ECMWF atmospheric profiles and MODIS ice cloud properties as input to the CRTM, the high spectral resolution brightness temperatures are simulated for optical thick and thin ice clouds. On the basis of the comparisons between simulated and observed brightness temperatures for AIRS, we have validated the ice cloud scattering model of the CRTM