MODIS Collection 6 Ice Model Assessments with POLDER and CALIPSO

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Ice Refractive Index

Warren & Brandt 2008
Warren 1984

32 µm

Wavelength (µm)
**Novel Invariant Imbedding T-Matrix Method**

\[ \bar{E}(\vec{r}) = \bar{E}_{\text{inc}}(\vec{r}) + k^2 \int (m^2 - 1) \bar{G}(\vec{r} - \vec{r}') \cdot \bar{E}(\vec{r}') d^3 \vec{r}' \]

\[ T_{mnmn}(r + dr) = Q_{11}^m(r + dr) + \left[ I + Q_{12}^m(r + dr) \right] \left[ I - T_{mnmn}(r) Q_{22}^m(r + dr) \right]^{-1} T_{mnmn}'(r) \left[ I + \hat{Q}_{12}^m(r + dr) \right] \]

Johnson (1988); Bi, Yang, Kattawar, and Mishchenko (2013), Bi and Yang (2014)
What is a nonspherical particle?

A nonspherical particle is a certain distribution of the refractive index within a spatial domain of interest.

A nonspherical particle = an inhomogeneous sphere

= a multi-layered sphere

Note that the T-matrix corresponding to $r=0$ is zero.
Comparison between II-TM and ADDA (Bi and Yang, 2014)

In the Discrete-dipole-approximation (DDA) simulation, 1056 orientations with 128 scattering planes are set to achieve the randomness. ADDA is a public DDA software developed by Yurkin and Hoekstra.
Yang and Liou (1996)

\[ E_s(r) |_{kr \to \infty} = \frac{\exp(ikr)}{-ikr} \frac{k^2}{4\pi} \mathbf{n} \times \int \int_S \{ \mathbf{n}_S \times \mathbf{E}(r') - \mathbf{n} \times [\mathbf{n}_S \times \mathbf{H}(r')] \} \times \exp(-ik \mathbf{n} \cdot r') d^2 r', \]
MODIS C5 (Baum et al. 2005) and MODIS C6 (Platnick et al. 2014) Ice Models

a. MODIS Collection 5

b. MODIS Collection 6

c. 

C.  

Asymmetry Factor

Effective Diameter (\( \mu m \))

MODIS C5

MODIS C6

d. 

Phase Function

Scattering Angle (°)

10^4

10^3

10^2

10^1

10^0

“*The asymmetry parameter had to be adjusted from* the broadband Mie value of $g=0.87$ for the size distribution chosen to a lower value of $g=0.7$ in order to *bring the observations and theory into broad agreement.*”

“*Cirrus clouds characterized by* $g=0.87$ warmed *approximately twice as much as* cirrus clouds modeled with $g=0.7$. ”
Consistency of spectral retrievals

- MODIS operational retrieval algorithm (Nakajima and King, 1990)

- Infrared techniques: 8.5 µm, 11 µm, and 12 µm (e.g., Wang et al. 2011)

- The cloud property retrievals based on the two techniques should be consistent.
Scatter plots of MODIS observed TOA BTs and BTD (8.5-11mm) vs. simulated BTs and BTD by using the optimal $t$ and $D_{eff}$ (after Wang et al. 2011).
Spectral Consistency: MODIS C5 versus MODIS C6
Ranges of POLDER Observations
(5%-95% quantile)

Polarized Reflectivity

Scattering Angle (°)

T < 208 K

208 K < T < 228 K

T > 228 K
Polarimetric property consistency: POLDER observations (color contour) versus simulations (lines) with $D_e=60 \ \mu m$
Enhanced backscatter for roughened particles (Zhou and Yang 2015):

\[ \zeta = 1 + \frac{\sin \delta_c}{\delta_c} R \]

where \(0.3 < R < 0.7\) and \(\delta_c = 2\pi D(\pi - \theta)/\lambda\).
Comparison of Integrated Attenuated Backscatter-Optical Depth relations of MODIS C5 and MODIS C6 model ice particles in different latitudinal areas

20N-20S

20N-40N and 20S-40S

40N-60N and 40S-60S

Southpole
Conclusions

• With the newly developed MODIS C6 ice cloud optical property model, improvements have been achieved from several perspectives:
  - Spectral consistency in cloud property retrieval (VIS/NIR vs IR)
  - Polarimetric property consistency: POLDER observations vs simulations
  - Consistency in a combination of passive (MODIS) and active (CALIPSO) observations.

• MODIS C6 ice cloud optical property model has been extended to the generation of ice cloud properties in the Community Radiative Transfer Model (CRTM)

• Will apply the MODIS C6 model to RT models in GCMs (e.g., CESM).