Retrievals of Mixed-Phase Cloud Properties During NPOESS

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Scientific Objective:

To develop a conceptual approach for the NPOESS/VIIRS to simultaneously retrieve pixel-level, ice and water cloud optical thicknesses (τ_i, τ_w) and effective particle sizes (D_e, r_e) for mixed-phase clouds from the 0.67, 1.6, 2.25 and 3.7μm bands radiances.

To apply the methodology to MODIS proxy data during the 9th Cloud Layer Experiment (CLEX-9)

To evaluate the performance of the approach by comparing retrieval results with collocated and coincident in-situ measurements.

Optical Property Models

We have developed microphysics and optical properties for mixed-phase clouds. The microphysics models for ice clouds are based on in-situ size distributions collected during field campaigns (Ou et al 2002). The microphysics models for water clouds are based on the functional form of modified Gamma size distributions (Hansen and Travis 1974). The optical properties models are based on light-scattering computations (Takano and Liou 1989) of ice and water cloud particles in the mixed-phase clouds. The single-scattering properties for an ice-water cloud layer are parameterized based on principle similar to Fu and Liou(1993):

$$\tilde{\omega} = \frac{\Delta\tau_s}{\Delta\tau} = \frac{\Delta\tau^i\tilde{\omega}^i + \Delta\tau^w\tilde{\omega}^w}{\Delta\tau^i + \Delta\tau^w} = \frac{\beta^i\tilde{\omega}^i + \beta^w\tilde{\omega}^w}{\beta^i + \beta^w}\,. \qquad (1)$$

$$\tilde{\omega}_l = \frac{\Delta\tau^i\tilde{\omega}^i\tilde{\omega}_l^i + \Delta\tau^w\tilde{\omega}^w\tilde{\omega}_l^w}{\Delta\tau^i\tilde{\omega}^i + \Delta\tau^w\tilde{\omega}^w} \qquad (2)$$

$$f = \frac{f^i\Delta\tau_s^i + f^w\Delta\tau_s^w}{\Delta\tau_s}\,, \qquad (3)$$

where $\tilde{\omega}$, $\tilde{\omega}_l$, and f are single scattring albedo, legendre polynomial expansion coefficient and phase function truncation factor for mixed clouds. $\Delta\tau_s$ $\Delta\tau$ and β are the scattering optical thickness, total optical thickness and extinction coefficient. The superscript *i* and *w* indicates ice and water clouds respectively.

Fig 1 (a)-(d) shows the single scattering co-albedos (1-$\tilde{\omega}$) plotted as functions of D_e for (a) 0.67, (b)1.6, (c)2.25 and (d) 3.7 μm bands. The curves denote constant co-albedo values. It is noted that the co-albedo increases with increasing ice and water cloud particle size due to increased absorption. Moreover, these co-albedo values are sensitive to each combination of D_e and r_e forming the basis for the simultaneous retrieval of ice and water particle sizes. Fig 1 (e)-(h) shows phase functions [P(Θ)] plotted as functions of scattering angle for (e) 0.67, (f)1.6, (g)2.25 and (h) 3.7 μm bands. In each frame, P(Θ)s for pure ice cloud (D_e = 42 μm), pure water cloud (r_e=8 μm) and a mixed-phase cloud (D_e = 42μm and and r_e=8 μm) are plotted. It is noted that the mixed-phase P(Θ) for the side-scattering range is between the P(Θ)s for pure ice and for water, but the mixed-phase P(Θ) for the back-scattering range is closer to pure water than to ice.

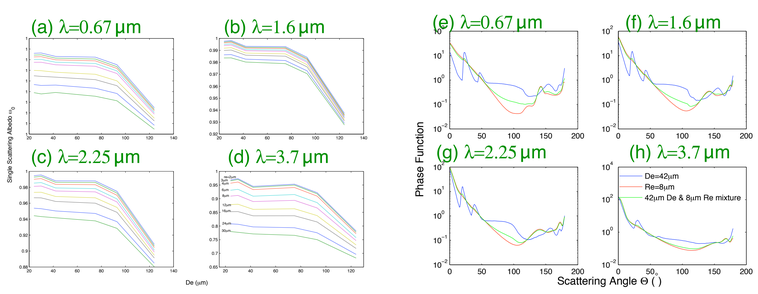

Fig 1: (a)-(d) Single-scattering co-albedo as function of D_e and r_e. (e)-(h) Phase functions for a pure ice (D_e=42 μm), water (r_e=8 μm) and a mixed phase cloud (D_e=42 μm and r_e=8 μm).

Retrieval Methodology:

The mixed-phase cloud parameters (τ_i, τ_w) and (D_e, r_e) are retrieved from a numerical search method using look-up tables of pre-computed reflectances for ice-water optical property models.

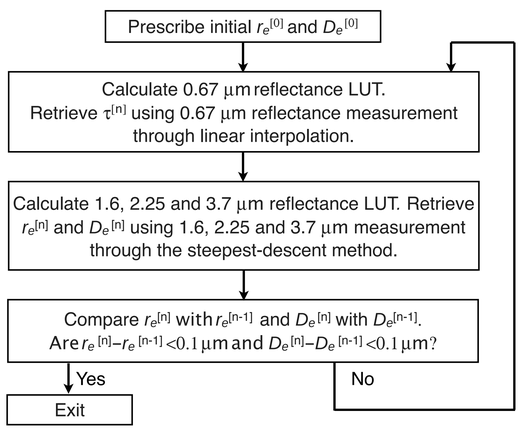

Fig 2: Flowchart of the mixed-phase cloud retrieval approach.

Application to a MODIS Proxy Scene:

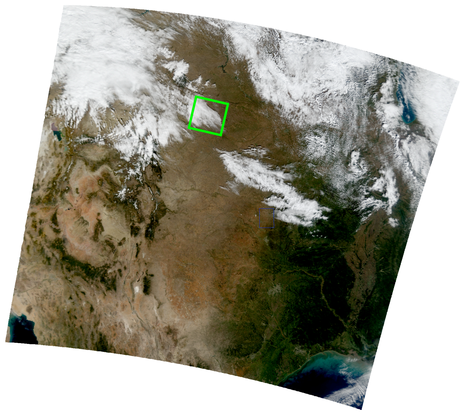

Fig 3: True color MODIS composite image for Oct 14, 2001 over North Platte (green box), Nebraska.

The capability of this new approach has been demonstrated using MODIS 0.645, 1.64, 2.13 and 3.75 μm bands reflectance/radiance data as a proxy to VIIRS. A proxy scene (Fig 3 green box), October 14, 2001 over North Platte, Nebraska during the ninth Cloud Layer Experiment (CLEX-9) has been analyzed. Fig 4 shows images of mixed-phase retrieved (a) τ_i ,(b) D_e, (c) τ_w, (d) r_e. It is noted that in general $\tau_i < \tau_w$, and this is physically reasonable, since the observed mixed-phase cloud might have been in its initial glaciation stage, whereby ice crystals were beginning to form through the Bergeron-Findeison process. It is also noted that in general $D_e > 2r_e$, and this is consistent with typical measurements of water and ice cloud particle distributions. Also shown are (e) retrieved τ_i and τ_w vs. MODIS τ within the pink box, and (f) retrieved D_e, and r_e vs. MODIS r_e within the pink box. These comparisons show that the sum of τ_i and τ_w are roughly equal to the MODIS r_e. On the other hand, the mixed-phase r_e is smaller than MODIS r_e, while many mixed-phase De are larger than two times MODIS r_e.

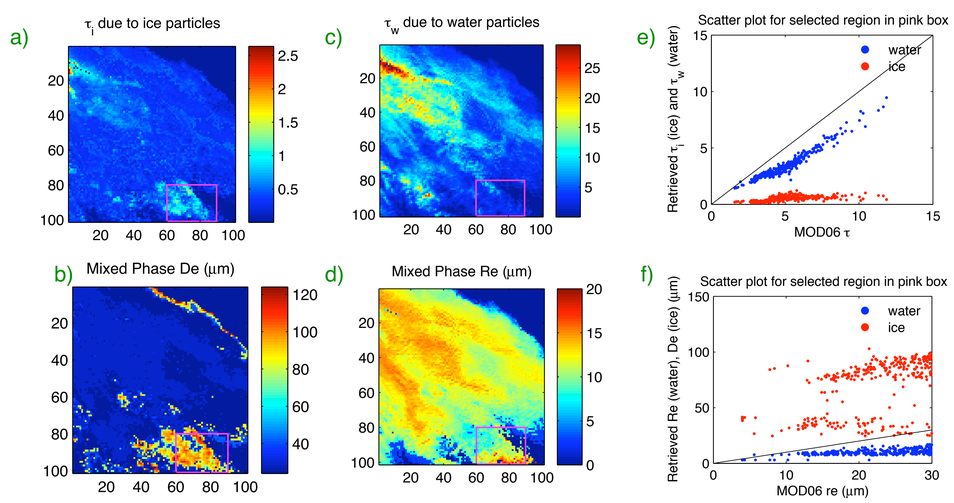

Fig 4: Images of mixed-phase retrieved (a) τi, (b) De, (c)τw, and (d)re, for the Terra/MODIS scene of October 14, 2001 over North Platte, Nebraska. Also shown are (e) retrieved τi and τw vs. MODIS τ within thegreen box of Fig (3) .

Comparison with In-Situ Observations:

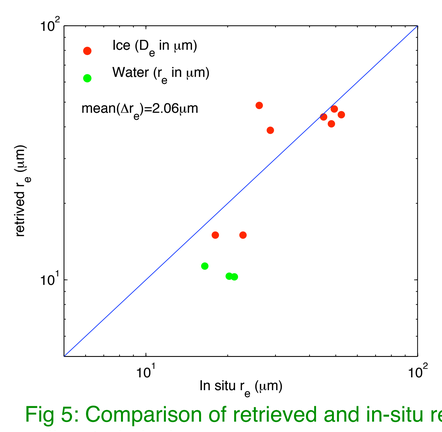

Fig 5: Comparison of retrieved and in-situ re for collocated pixels.

Airborne in situ observations by the University of Wyoming King Air cloud research aircraft (UWKA) were collected during CLEX-9. Layers of mixed-phase clouds were detected through these in-situ measurements. The UWKA cloud research aircraft sampled the southern edge of the cloud feature at about 5300 m near cloud top heights. The aircraft observations closely coincided with the Terra satellite overpass. The aircraft was equipped with variety of observational instruments and probes. In situ measurements of ice particle distribution were made by 2-DC and 2-DP probes. Simultaneous observations of liquid water content and droplet size distribution were made by FSSP. Figure 5 shows comparison of MODIS retrieved in-situ re for collocated pixels. Because of the limitation in the collocation process, there are only a total of 11 comparisons. The mean differences are around 2 μm, which meets the accuracy requirement of VIIRS, indicating preliminary success fro the retrieved approach.

Summary:

A conceptual approach for the NPOESS/VIIRS to simultaneously retrieve ice and water optical thickness and effective particle sizes in in a mixed-phase cloud layer has been developed. This approach was applied to a MODIS proxy scene with the support of collocated in-situ observations. Comparison between retrieved and in-situ re shows a small difference, indicating a preliminary success of the approach.