Improving MOD06 Thin Cirrus Cloud Optical Thickness Retrievals Using 1.38 µm

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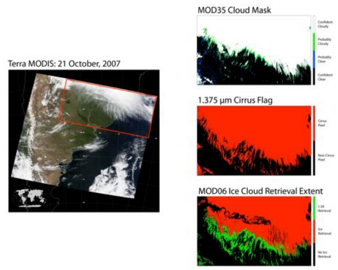
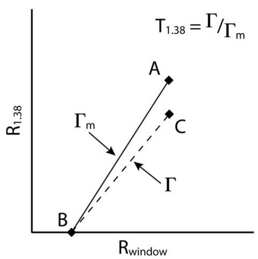
BACKGROUND

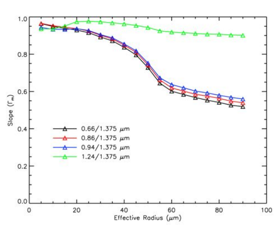
Thin cirrus are often difficult to detect, and their optical properties difficult to retrieve, using passive sensors such as MODIS. Indeed, the MODIS cloud products (MOD06) often fail to retrieve such clouds (see right). To potentially improve upon the capabilities of these products, a new optical thickness retrieval method, employing the MODIS 1.38 µm channel, has been developed for thin cirrus conditions. The 1.38 µm channel, centered within a strong water vapor absorption band, is quite sensitive to cirrus, or more specifically, to cirrus optical thickness. However, its signal suffers non-negligible attenuation due to atmospheric water vapor above and within the cloud. This attenuation can be estimated by pairing 1.38 µm with a window channel, namely 1.24 µm. After correcting for attenuation, cirrus optical thickness is derived from 1.38 µm reflectance using a look-up table approach.

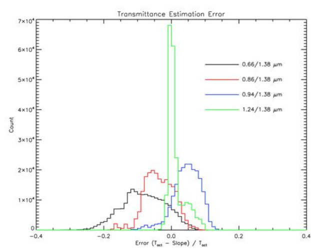


TRANSMITTANCE ESTIMATION

We employ a two-band approach (a window channel with band 26) to estimate above/in-cloud transmittance at 1.38 µm. Conceptually, the method involves two slopes (below, left): 1) Γ (line B-C), the slope of the line connecting MODIS observations (C) with estimated "clear sky" reflectance (B), and 2) Γ_m (line B-A), the slope of the line connecting the estimated "clear sky" reflectance with that estimated for a cloud without above/in-cloud water vapor (A) (note: the window channel reflectance is the same for both cloud scenarios A and C). We have selected 1.24 µm (band 5) as the window channel to minimize slope dependence on effective size (below, center), as well as uncertainties in estimated transmittance (below, right).





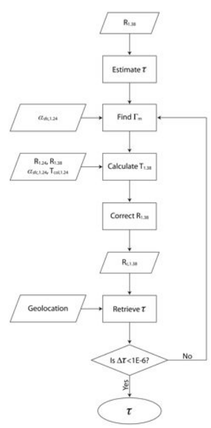


RETRIEVAL METHODOLOGY

Once the above/in-cloud water vapor attenuation is estimated, and the 1.38 µm reflectance is corrected, cloud optical thickness is derived using a bi-directional reflectance look-up library (computed with DISORT from the bulk-scattering properties for ice clouds of Baum et al. [2005]). Because 1.38 µm is also sensitive to particle effective size, we assume an effective radius of 30 µm for all aspects of the retrieval. Additionally, because the slope Γ_m cannot be directly calculated, we have constructed a pre-computed slope library for various combinations of surface reflectance, effective size, and optical thickness. The small sensitivity to optical thickness is accounted for by iterating over τ until the retrieval converges.

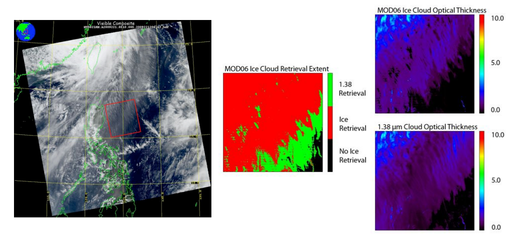
The retrieval algorithm operates in a straightforward manner (flow diagram at right):

1. Input MODIS observations ($R_{1.24}$ and $R_{1.38}$).
2. Compute a first-guess optical thickness from measured reflectance, $R_{1.38}$. Here, we use the single-scatter approximation.
3. Select appropriate Γ_m from the pre-computed slope library.
4. Calculate estimated above/in-cloud transmittance ($T_{1.38}$) from observations, estimated "clear sky" reflectance (surface albedo, column transmittance using NCEP re-analyses), and Γ_m.
5. Compute corrected 1.38 µm reflectance ($R_{c,1.38}$).
6. Derive optical thickness from $R_{c,1.38}$, geolocation, and the pre-computed bi-directional reflectance look-up library.
7. Decision: Is Δτ ($\tau_{retrieved} - \tau_{estimated}$) less than 1E-6? Yes: retrieval successful. No: return to 3.



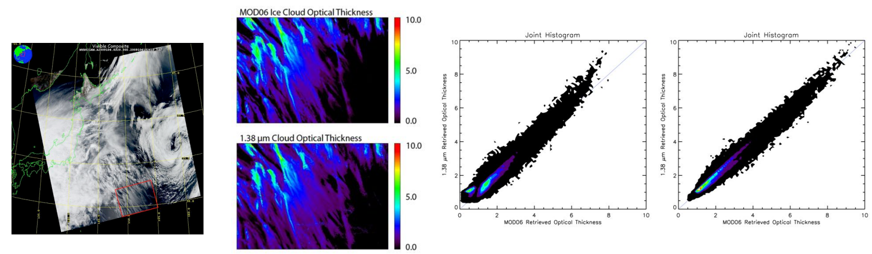
RESULTS

Here we show results for a sample Aqua MODIS granule from 9 August, 2009 (true-color RGB at right). We'll focus on the region of thin cirrus clouds in the center of the image (outlined in red). The MOD06 ice cloud retrieval extent (right, center) shows that the 1.38 µm retrieval can potentially add a significant number of pixels. Indeed, comparing results from the two retrievals (far right) reveals that the 1.38 µm retrieval can recover much of the "missing" thin cirrus.



RETRIEVAL EVALUATION/CONSISTENCY WITH MOD06

Integrating the 1.38 µm retrieval into MOD06 requires continuity between the two methods. Here, we compare results from both retrievals for moderately thick cirrus using an Aqua MODIS granule from 14 April, 2009 (true-color RGB below, far left). A cursory analysis reveals that, for this case, the retrievals appear quite similar (below, left). However, plotting the 1.38 µm retrieval vs MOD06, there are in fact discrepancies (below, right). These can be accounted for by conforming the retrieval assumptions (i.e., forcing MOD06 to 30 µm effective radius) and by lowering the ocean surface albedo to 0.02 (rather than 0.05 for diffuse illumination) (below, far right).



RETRIEVAL UNCERTAINTIES

It is important when providing a retrieved value to also provide an estimate of its usefulness. To that end, we are currently developing a robust method for estimating the uncertainties in the 1.38 µm retrieval. At right is a graphical representation of the major uncertainty components that we have identified. These uncertainty components can be combined by means of the propagation of errors technique to estimate the retrieval uncertainty on a pixel-level basis. For instance, the total uncertainty in optical thickness due to all first-order uncertainties, assuming independence, can be defined as:

$$\sigma^2_{\Delta\tau} = \sigma^2_{\Delta\tau_{R_{c,1.38}}} + \sigma^2_{\Delta\tau_{re}} + \sigma^2_{\Delta\tau_{m/m}}$$

Furthermore, focusing on the corrected 1.38 µm reflectance, we can write its uncertainty in terms of the variance in $\Delta R_{c,1.38}$ and its sensitivity derivative:

$$\sigma^2_{\Delta\tau_{R_{c,1.38}}} = \left(\frac{\partial\tau}{\partial R_{c,1.38}}\right)^2 \sigma^2_{\Delta R_{c,1.38}}$$

And so forth. This uncertainty analysis is similar to that already present in the current operational MOD06 cloud retrieval algorithms.