Improving MODIS Cloud Cover Properties Algorithm through comparisons with CALIOP and merging with AIRS Data

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1. Cloud Top Properties Algorithm Overview

Cloud-top properties (temperature, pressure, and effective emissivity) are derived using the IR window and longwave CO2 absorption bands (both day and night) at 5-km spatial resolution. Cloud top pressure is derived from ratios of differences in radiances between cloudy and clear-sky regions at two spectrally close channels. Adjustments are made for radiance biases so that clear (calculated) and cloudy (observed) radiances are both referenced to the NCEP/NCAR Reanalysis forward calculated radiances. The cloud-top pressures selected minimizes the difference between the observed and calculated cloud radiances in the most opaque channel pair that senses the cloud. For low clouds (> 650 hPa), the IR window 11 µm brightness temperature is assumed to be the opaque cloud-top temperature. Effective cloud amount is derived using the inferred cloud top pressure and the radiative transfer equation for the 11 µm band.

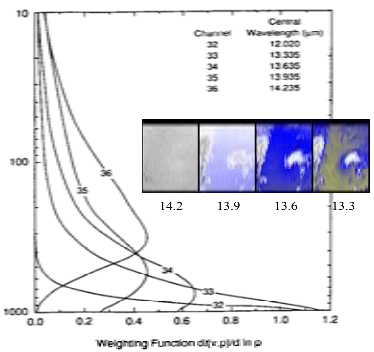
Different ratios reveal cloud properties at different levels

hi - 14.2/13.9
mid - 13.9/13.6
low - 13.6/13.3

Meas **Calc**

$$\frac{(I_{\lambda1}-I_{\lambda1}^{clr})}{(I_{\lambda2}-I_{\lambda2}^{clr})} = \frac{\eta\varepsilon_{\lambda1}\int_{p_s}^{p_c}\tau_{\lambda1}\,dB_{\lambda1}}{\eta\varepsilon_{\lambda2}\int_{p_s}^{p_c}\tau_{\lambda2}\,dB_{\lambda2}}$$

if $(I_{\lambda}^{clr} - I_{\lambda}) < \Delta$ then IRW is used



2. MODIS Algorithm Improvements before Collect 6

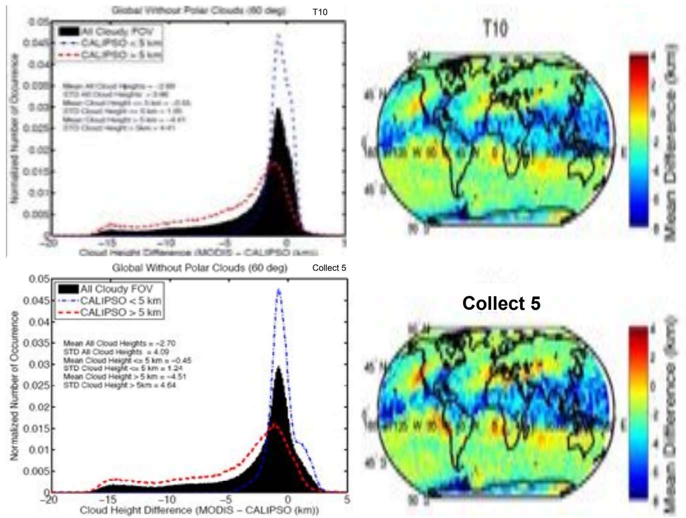
Collect 3. night-time cloud phase introduced
Collect 4. destriping started, instrument IR calibration improved
Collect 5. cloud mask improved (deserts, poles, night), radiance bias adjustment for measured versus calculated introduced

3. MODIS Algorithm Adjustments for Collect 6

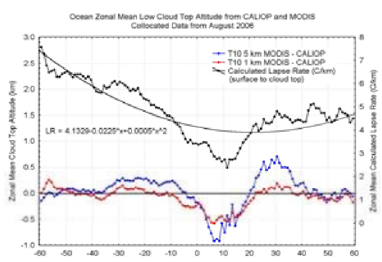
A: Use "top-down" method with channel pairs 36/35, 35/34, 34/33 in that order to select CTP.
B: Restrict CO2 channel pair solutions to the appropriate portion of troposphere (determined by their weighting functions – 36/35 less than 450 hPa, 35/34 less than 550 hPa, and 34/33 less than 650 hPa).
C: Prohibit CO2 slicing solutions for water clouds; use only IRW solution. Avoid IRW solutions for ice clouds; use CO2 slicing whenever possible.
D: Lower the "noise" thresholds (clear minus cloudy radiances required to indicate cloud presence in bands 33 to 36) to force more CO2 slicing solutions for high thin clouds.
E: Adjust ozone profile between 10 and 100 hPa to GDAS values instead of using climatology (so that CO2 radiances influenced by O3 profiles are calculated correctly).
F: Implement Band 34, 35, 36 spectral shifts suggested by Tobin et al. (2005).
G: Add marine stratus improvement where a constant lapse rate is assumed in low level inversions – lapse rate is adjusted according to latitude region.

4. MODIS vs CALIOP (Aug 2006)

The figure below, bottom left shows the histogram of the cloud height differences of over 2 million MODIS Collect 5 cloud products minus the CALIPSO cloud measurements distributed globally between 60 N and 60 S. In the mean CALIPSO is higher than MODIS by 2.7 km with a scatter of 4.1 km. High cloud determinations from MODIS are hindered by thin cloud heights defaulting to infrared window estimates; MODIS also errs on low marine stratus clouds by placing them above the inversion height. The results of all the tests are shown as T10 in top left. The high cloud height difference dropped by 0.1 km and the scatter by 0.2 km. The geographical distributions of the differences are shown in the right panels; the tropics have been improved and that marine stratus problems along the west coasts of North and South America and Africa have been largely mitigated. While these improvements are modest on the global scale, they represent significant improvement for problem regions and for high thin cirrus.



5. Marine Stratus Cloud Improvement



Zonal mean calculated lapse rate (black) along with differences of cloud top altitude for the t10 algorithm applied at 5 km resolution (blue) and 1 km resolution (red). Application at 1 km resolution is pending beyond Collect 6.

6. Combining Imager (MODIS and Sounder (AIRS) Radiances

AIRS calculations of MODIS radiances at 15 km resolution were used to investigate broadband CO2 spectral band correlations with AIRS CTPs; the resulting regressions were then used with MODIS 1 km radiances to create combined AIRS plus MODIS CTP retrievals.

The algorithm is summarized below. Pseudo MODIS radiances (AMODIS) calculated from AIRS measurements are used to establish a regression relationship for CTPs and measured MODIS infrared radiances (from channels 20 through 36). Thus, at 15 km resolution, we have regression coefficients ai for calculated AMODIS radiances for high (CTP<440 hPa), mid (CTP<680 hPa), and low (CTP> 680 hPa) AIRS CTPs where

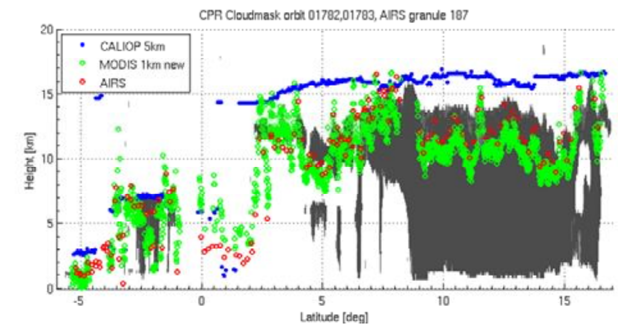
$$CTP(AIRS) - CTPmean(AIRS) = \sum ai\ [R(AMODIS)i - Rmean(AMODIS)i]$$

And at 1 km resolution within the 15 km AIRS pixel we apply the ai on measured MODIS radiances to get

$$CTP(AIRS+MODIS) - CTP(AIRS) = \sum ai\ [R(MODIS)i - Rmean(MODIS)i]$$

In all approaches, cloudy pixels are indicated by the MODIS cloud mask (CM) (MYD35).

The regression coefficients are applied to the MODIS 1 km radiances associated with the nearest AIRS pixel CTP. The figure below shows a comparison with CALIOP of the AIRS plus MODIS CTH retrievals for one granule.



CALIOP (blue), AIRS (red) , and MODIS plus AIRS combined (green) Cloud Top Heights (in km) for granule 187 on 28 August 2006. In the region from 0 to 4 deg latitude MODIS plus AIRS is obviously comparing better with CALIOP than AIRS alone.

7. Pending Work

* Collect 6 MODIS cloud products must be used to establish a ten year benchmark
* Sensor spatial resolution issues must be resolved confidently by using the same algorithm (refined via CALIOP cloud product intercomparisons) on spatially averaged MODIS data; implications for adjustments to the HIRS cloud records must be noted.
* Efforts to combine the vertical skill of AIRS with the horizontal and visible / NIR advantages of MODIS for cloud detection and characterization must be refined for global application in order to prepare for VIIRS plus CrIS cloud products (that will be derived without high spatial resolution H2O or CO2 sensitive bands).
* AVHRR cloud properties (PATMOS-X at 4 km resolution) must be supplemented with HIRS cloud top property estimates (at 20 km resolution); testing must start with NOAA 14 data.