Sensitivity of MODIS Cloud Detection and Property Estimation to Radiance Bias Adjustment, Sensor Resolution, and Viewing Angle

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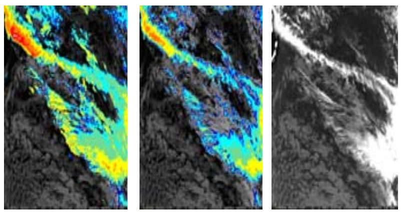
Cloud Top Properties Algorithm Overview

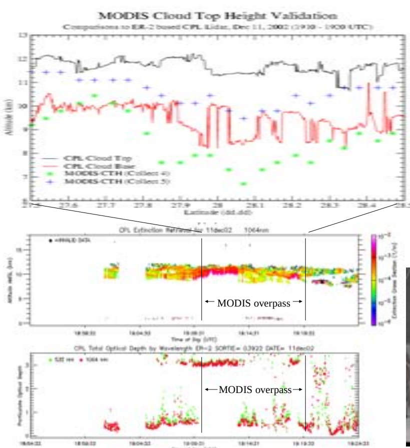
Cloud-top properties (temperature, pressure, and effective emissivity) are derived using the IR window and longwave CO2 absorption bands (both day and night) at 5-km spatial resolution. CO2 slicing infers cloud-top pressure and effective emissivity (cloud fraction times cloud emissivity at 11 µm) using differing partial absorption of several MODIS CO2 bands near 15 µm, with each band being sensitive to a different level in the atmosphere. 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/EMC Global Forecast System forward calculated radiances. The cloud top pressure (CTP) determined from the most opaque channel pair (with the weighting functions highest in the atmosphere) is selected; this optimizes the sensitivity to high thin cirrus. Thereupon, the effective cloud amount (ECA) is determined using the cloud pressure and the observed cloud signal in the infrared window channel at 11 mm. For low clouds (> 700 hPa), the CO2 channel SNR decreases, so the IR window 11 µm brightness temperature is assumed to be the opaque cloud-top temperature and a cloud-top pressure is assigned using the NCEP/EMC GFS temperature profile.

Effects of Radiance Bias Adjustment on CTP

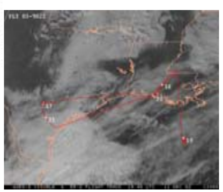


MODIS Aqua CTP results on 1 December 2004 for CTP<400 hPa after radiance bias adjustment in Collect 5 (left panel), before radiance bias adjustment in Collect 4 (middle panel), and IR image right panel). Clouds are higher in Collect 5 and more semitransparent (not shown).

White shows clouds of Pc < 125 hPa, red < 160 hPa, orange < 190 hPa, yellow < 225 hPa, aqua < 260 hPa, cyan < 300 hPa, sky < 330 hPa, blue < 360 hPa, and navy < 390 hPa.

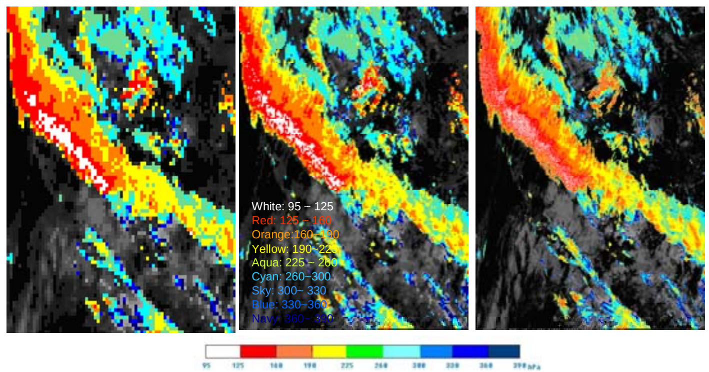


(left) Cloud Physics Lidar (CPL) cloud top and bottom and Collect 4 & 5 MODIS cloud tops (height inferred from GFS pressure profiles) for 1910 to 1920 UTC on 11 December 2002. (bottom right) ER-2 flight track on GOES-8 image. Segment from 1910 to 1920 UTC was timed to coincide with MODIS / Aqua overpass. (bottom left) CPL altitude and total optical depth determinations from 1854 to 1924 UTC. During MODIS overpass; CPL sees cloud at roughly 10 km starting with optical depths of about 3 at 1910 UTC and dropping to 0.5 at 1913 UTC.



Global Cloud Properties at 1, 5, 10, 20 km resolution

The results from processing the Aqua MODIS global data for 1 December 2004 at various resolutions are found in Table 1 (only northern mid-latitudes 20 to 60 N and tropics 20 S to 20 N are shown for simplicity). They are separated by cloud type into clear sky (infrared window optical depth τIR < 0.05), thin (τIR < 0.7), thick (τIR > 0.7), and opaque (τIR > 3.0) clouds and separated by level in the atmosphere above 440 hPa (high), between 440 and 700 hPa (middle), and below 700 hPa (low). As can be expected, clear sky detection falls off with increasing spatial resolution. At 1 km, clear skies are detected in 28.5% (33.1%) of the fields of view in the northern mid-latitudes (tropics); this drops to 19.4% (22.7%) at 5 km and further drops to 15.7% (18.4%) at 20 km. Most of the decrease in clear sky is the increased detection of low clouds. Figure 1 shows the a plot of the frequency of detection of all and high clouds in the northern mid-latitudes as a function of sensor spatial resolution on 1 December 2004 for Aqua MODIS. The biggest change occurs going from 1 to 5 km resolution; from 5 to 20 km there is not much change.



MODIS Cloud Top Pressures processed at 10, 5, and 1 km resolution (from left to right)

Global Cloud Properties at scan angles 18, 32, 41, 50 and 55 degrees

The results from processing the Aqua MODIS global data at 5 km resolution for 1 December 2004 at various scan angles are found in Table 2. They are separated by scan angles (less than 18 degrees, between 18 and 32 degrees, between 32 and 41 degrees, between 41 and 50, and between 50 and 55 degrees. Clear sky detection falls off with increasing scan angle. Near nadir (less than 18 degrees), clear skies are detected in 27.5% of the fields of view. This progressively drops to 25.2% (between 19 and 32 degrees), 22.7% (between 33 and 41 degrees), 18.7 (between 42 and 50), and 14.4% (between 51 and 55 degrees). Middle cloud detection increases the most, going from 15.6% at nadir to 23.2% at maximum scan angles. Low cloud detection increases from 36.0% to 40.4%. High cloud detection changes by one percent over the different sensor scan angles; this is possibly a result of the diffuse nature of most high clouds. Figure 2 shows the changes in high, middle, low, cloud detection as a function of sensor viewing angles.

Table 1: Aqua MODIS global CTP above 440 hPa (high), between 440 & 700 hPa (middle), and below 700 hPa (low) and ECA with clear (IRW optical depth τIR < 0.05), thin (τIR < 0.7), thick (τIR > 0.7), and opaque (τIR > 3.0) processed at 1, 5, 10, and 20 km for tropics (20 S to 20 N) on 1 Dec 2004.

%	Total	Thin	Thick	Opaque
Resolution: 1 km				
High	31.3	10.9	12.2	8.2
Middle	5.5	0.1	0.9	4.5
Low	30.2	0.0	0.0	30.2
Clear	33.1			
Resolution: 5 km				
High	31.9	11.6	13.0	7.3
Middle	5.2	0.2	1.0	4.0
Low	40.2	10.4	10.6	19.2
Clear	22.7			
Resolution: 10 km				
High	32.7	12.4	13.7	6.6
Middle	5.1	0.3	1.1	3.7
Low	41.7	0.0	0.0	41.7
Clear	20.5			
Resolution: 20 km				
High	33.5	13.4	14.5	5.6
Middle	4.7	0.3	1.0	3.4
Low	43.4	0.0	0.0	43.4
Clear	18.4			

Table 2: Aqua MODIS global CTP and ECA processed at five kilometer resolution for sensor scan angles less than 18, between 19 & 32, between 33 & 41, and between 42 & 55 degrees for global data on 1 Dec 2004.

%	Total	Thin	Thick	Opaque
scan angle: within 18° (-18° ~ +18°)				
High	20.9	6.2	10.6	4.1
Middle	15.6	0.4	4.9	10.2
Low	36.0	0.0	0.0	36.0
Clear	27.5			
scan angle: +18° to +32° and -18° to -32°				
High	21.3	6.0	11.0	4.3
Middle	16.6	0.3	4.0	12.3
Low	36.9	0.0	0.0	36.9
Clear	25.2			
scan angle: +32° to +41° and -32° to -41°				
High	21.3	5.3	11.2	4.8
Middle	17.8	0.1	2.9	14.8
Low	38.2	0.0	0.0	38.2
Clear	22.7			
scan angle: +41° to +50° and -41° to -50°				
High	21.9	4.7	11.5	5.7
Middle	20.1	0.0	1.5	18.6
Low	39.3	0.0	0.0	39.3
Clear	18.7			
scan angle: +50° to +55° and -50° to -55°				
High	21.9	3.4	11.2	7.3
Middle	23.2	0.0	0.4	22.8
Low	40.4	0.0	0.0	40.4
Clear	14.4			

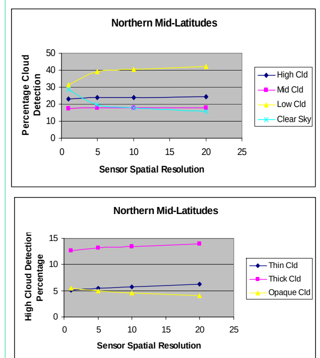


Figure 1: Detection of all and high clouds in the northern mid-latitudes as a function of sensor spatial resolution (1, 5, 10, and 20 km) on 1 Dec 2004

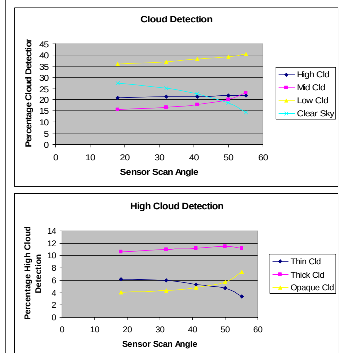


Figure 2: Detection of all and high clouds as a function of sensor viewing angle (less than 18, 18 to 32, 32 to 41, 41 to 50, and 50 to 55 degrees) when processing the MODIS cloud properties at five kilometer resolution for the global data set on 1 December 2004

Conclusions

* Radiance bias adjustment (for MODIS measured minus model calculated radiances) places CO2 slicing cloud tops higher (CTP decreases) and suggests they are thinner (ECA decreases). Agreement with Cloud Physics Lidar is dramatically enhanced (CO2 slicing clouds fall between CPL cloud top and bottom)
* Increasing sensor resolution reduces clear sky detection and increases low cloud estimation. 28.5% (33.1%) fields of view are clear at 1 km in the northern mid-latitudes (tropics) versus 15.7% (18.4%) at 20 km; correspondingly low cloud detection increases from 31.2% (30.2%) to 42.0% (43.4%). The biggest change occurs going from 1 to 5 km resolution; our goal is to provide MODIS CTPs at 1 km resolution in Collect 6.
* At high sensor scan angles clear sky detection drops off and middle cloud detection increases. Clear sky detection at 5 km resolution also falls off with increasing scan angle from near nadir at 27.5% to 14.4% at 45 degrees. Middle cloud detection increases from 15.6 % at nadir to 23.2 % at maximum scan angles. High cloud detection change less than one percent over the different sensor scan angles. Cloud trends should be catalogued by sensor scan angle; top down view at near nadir (< 18 °) is preferable.