Use of CALIOP Cloud Data for VIIRS and MODIS Cloud Mask Validation

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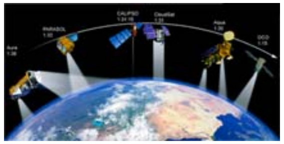
Introduction



The afternoon "A-Train" satellite constellation, for the first time ever, is making near simultaneous measurements of aerosols, clouds, temperature, relative humidity, and radiative fluxes over the globe during all seasons. Aqua was launched on May 4, 2002, and has six Earth-observing instruments on board, including MODIS (Moderate Resolution Imaging Spectroradiometer). MODIS measures upwelling radiation from the Earth-atmosphere system in 36 spectral bands. The Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO) satellite was launched in April 2006 and provides new insight into the role that clouds and atmospheric aerosols (airborne particles) play in regulating Earth's weather, climate, and air quality. Onboard CALIPSO is the Cloud-Aerosol Lidar with Orthogonal Polarization (CALIOP) that measures backscatter at 532 and 1064 nm, providing very accurate cloudy-sky vs. clear-sky discrimination and height information.

CALIPSO trails Aqua by 45 to 135 seconds and therefore allows MODIS and CALIOP to observe cloud scenes at very nearly the same time. A collocation algorithm has been developed at CIMSS that associates 1-km MODIS pixels with CALIOP 1-km lidar cloud boundary retrievals.

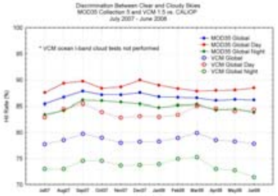
Use of CALIOP Cloud Data for Cloud Mask Validation

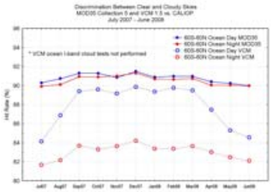
A year's worth of CALIOP cloud data and MODIS radiance and cloud mask data were collocated and analyzed (July 2007 through June 2008). This allowed comparisons between MODIS Collection 5 cloud mask (M35) and Version 1.5 VIIRS Cloud Mask (VCM) results. MODIS radiance and geo-location data were used as proxies for the future VIIRS inputs. The VCM was generated with Version 1.5 science code using the Low Earth Orbiter Cloud Algorithm Testbed (LEOCAT) software to stage and prepare all radiance, geo-location, and ancillary data sets. Note that the 375-meter imagery resolution 0.64 and 0.87 µm variability tests are not performed as there is no way to simulate these bands using proxy MODIS L1b inputs. It is anticipated that these tests will increase the VCM accuracy over oceans, especially at night.

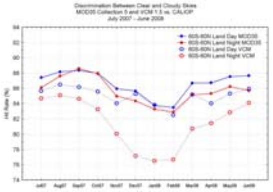
The table at right shows percent agreement ("hit rate") between CALIOP and the VCM and M35 over various scene types. ***It is expected that the VCM should show less agreement than MODIS, given that MOD35 has benefited from over ten years of research and development.***

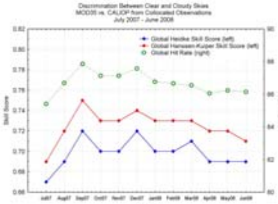
Shown below are plots of hit rate as a function of month from July 2007 through June 2008. In the top row, VCM and MOD35 (MODIS cloud mask) agreements with CALIOP are shown for global data, global day and night, and 60S to 60N latitude day and night for ocean and land separately. It appears that the most developed VCM algorithm is non-polar daytime land, where the difference in agreement from MOD35 is only 1.6 percent (see table). Note the differing scales on Y-axes.

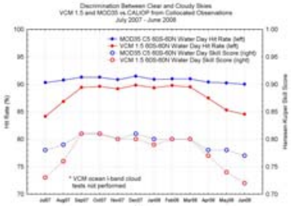
Scene Type	VCM Cloud Agree	VCM Clear Agree	VCM Over-all	M35 Cloud Agree	M35 Clear Agree	M35 Over-all
Global, day and night	74.7%	89.9%	79.2%	87.6%	84.8%	86.8%
60S-60N, day and night	81.2	94.1	85.1	90.5	87.9	89.8
Global, day	83.4	90.2	85.3	90.5	87.6	89.7
60S-60N, day	*84.8*	91.5	87.0	90.0	89.7	89.9
Global, night	67.1	89.6	73.9	85.0	82.5	84.3
60S-60N, night	77.8	97.1	83.3	91.0	86.0	89.6
Global, water	77.6	90.8	80.7	90.2	84.4	88.9
Global, water, day	83.7	90.1	85.3	92.8	84.8	90.8
60S-60N, water, day	*85.6*	92.1	87.4	92.2	*87.4*	90.9
Global, water, night	71.9	91.6	76.2	87.8	83.8	86.9
60S-60N, water, night	78.9	97.2	82.9	92.1	85.1	90.5
Global, land	67.1	88.8	76.2	80.7	85.4	82.7
Global, land, day	82.2	90.3	85.3	83.9	92.3	87.1
60S-60N, land, day	*82.0*	90.1	85.8	*82.5*	93.5	87.4
Global, land, night	55.7	87.9	70.0	78.3	81.4	79.7
60S-60N, land, night	74.1	96.9	84.3	87.2	87.2	87.2

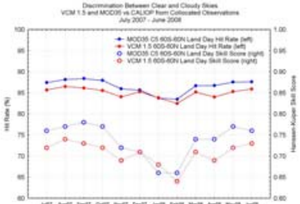








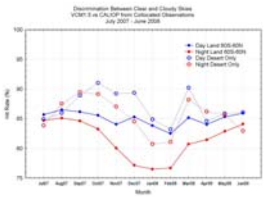


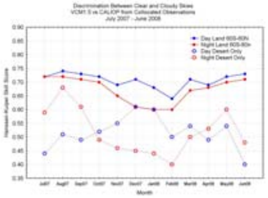


Shown above is a comparison of three estimates of agreement between MOD35 and CALIOP. Note that the hit rate shown in green (RHS) is generally more forgiving than the two skill scores in red and blue (LHS). In the plots shown at above and below right, we contrast the hit rate and the Hanssen-Kuiper Skill Score (HKSS) for the VCM and MOD35 vs. CALIOP. The HKSS ranges from -1 (perfect negative correlation) to +1 (perfect positive correlation) and addresses how well cloudy and clear sky are discriminated. The HKSS is an appropriate measure of accuracy for data sets that are not normally distributed, such as clouds.

The two plots above show hit rates (LHS) and skill scores (RHS) for daytime non-polar water (left) and land (right). HKSSs for the VCM are very similar to those of MOD35 for daytime water during September, 2007 to April, 2008. It is puzzling why the VCM HKSS drops off during the NH summer. The impact of NH winter conditions are seen for land data in both cloud masks where the VCM and MOD35 show very similar results. Note that the decrease in accuracy is seen much more clearly in the HKSS than in the hit rate.

At right are plots of VCM hit rate (first right) and HKSS (second right) for non-polar daytime and nighttime land and desert surfaces. The plots highlight the differences between the two measures of accuracy. Contrary to expectations, the hit rates show higher accuracy for desert surfaces in comparison to all daytime land regions. In contrast, the HKSS scores are significantly lower for deserts than for all scene types. Also detailed are the changes in seasons of maximum accuracy between day and night for deserts where winter shows better agreement with CALIOP during daytime, but summer is better for night scenes. Hit rates have been proposed as the metric for evaluation of the VCM. ***We extend a note of caution here, that additional measures of accuracy should be computed along with the hit rate.***

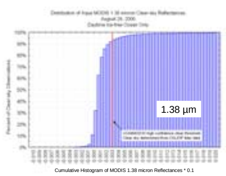


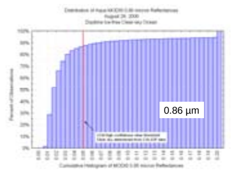


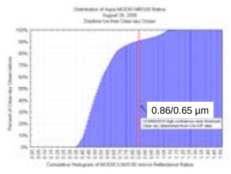
Use of CALIOP Cloud Data for VCM Cloud Test Thresholds Validation

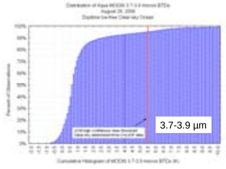
CALIOP cloud boundary data may be utilized for validation of individual cloud mask test thresholds. At right are cumulative histograms showing several *clear-sky* distributions of commonly used spectral cloud test measures. Proxy MODIS reflectance and brightness temperatures were collocated with CALIOP data that were used to define clear sky pixels. In each histogram, the vertical red line shows the test threshold used in the VCM and chosen before CALIOP data was available. Generally, the thresholds are placed such that about 95% of clear pixels are to the "clear" side of the threshold (e.g., to the left of the red line in the 1.38 µm histogram). The 0.86 µm threshold is found at about 87% of the clear pixels because of solar zenith and sun-glint effects. Setting this threshold higher would result in some false clear-sky (missed clouds).

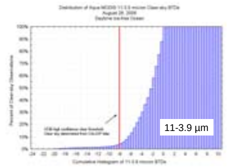
The 11-12 µm histogram (second row, far right) shows an example of a cloud test with dynamic (calculated) thresholds. Therefore, this plot shows the distribution of observed 11-12 µm brightness temperature differences minus the calculated thresholds. Since a measured BTD greater than the threshold indicates transmissive cirrus cloud (positive difference), the clear-sky histogram shown here indicates that the thresholds will not lead to false alarms (false clouds).

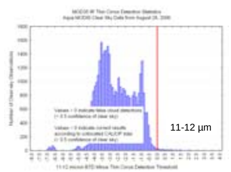






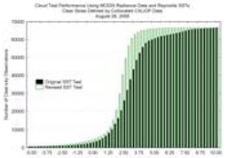


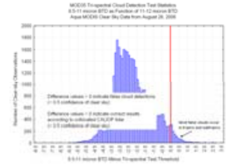


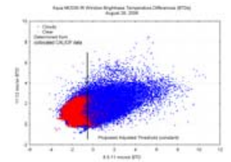


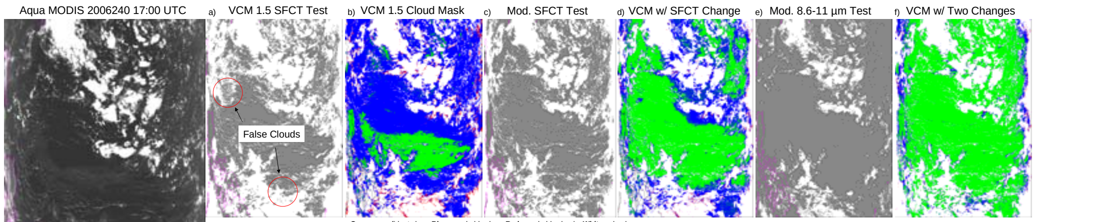
Cloud Test and Test Thresholds Tuning

Some examples of cloud test and test threshold "tuning" are shown here. Potential changes to the surface temperature, 8.5-11 µm BTD, and 11-3.7 µm BTD cloud tests in the night ocean VCM algorithm are being tested. An improved "SST" test yields the figure at near right. The histogram at center right shows some false cloudiness predicted by the 8.5-11 µm BTD test and a new, simpler threshold at far right. A night ocean tropical western Pacific scene is shown below. VCM results are shown below right, before (a, b) and after the changes (c-f). Improvements are seen in the number of confident clear pixels identified (f). Cloud test changes shown here are being implemented in the Collection 6 MODIS cloud mask.





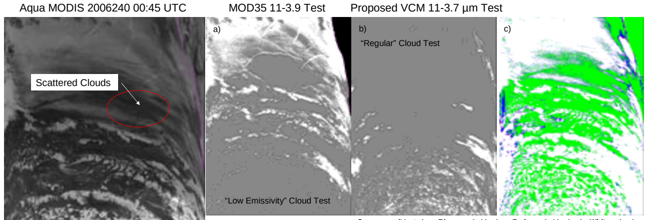




MODIS 3.75 µm BT

Green – confident clear, **Blue** – probably clear, **Red** – probably cloudy, **White** - cloudy

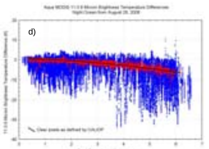
A night ocean scene (below) shows the utility of using two 11-3.7 µm BTD cloud tests. A "low emissivity" cloud test (a) is appropriate for marine stratus clouds where this BTD is typically > 0 for cloudy pixels (cloud threshold ~ +1.0). The results of a "regular" low cloud test is shown in b where the cloud thresholds are a function of total precipitable water shown in the plot labeled d) below. Final VCM result shown in c. Use of VIIRS I-band cloud tests is expected to improve the detection of scattered and broken stratus clouds like those circled in the BT image below, left.



Green – confident clear, **Blue** – probably clear, **Red** – probably cloudy, **White** - cloudy

MODIS 3.75 µm BT

Southern Atlantic night ocean scene off the SW coast of Africa. Northern (top) region characterized by subtropical marine stratus.



Derivation of 11-3.7 µm cloud test thresholds (left) as a function of TPW. Pixels identified as clear by collocated CALIOP data are shown in red, cloudy ones in blue. High confidence in lidar cloud vs. clear-sky discrimination allows higher confidence in setting cloud test thresholds. Example application is shown in b) above.

Main Points

1. MODIS Collection 5 cloud mask (MOD35) results compare reasonably well with CALIOP lidar (global hit rate = 87%).
2. VCM daytime algorithms are reasonably well developed (hit rate = 85%).
3. VCM nighttime algorithms are less developed than daytime and will require more work than simple threshold tuning.
4. Daytime VCM cloud test thresholds are reasonable according to collocated CALIOP data and should require only post-launch tuning to the VIIRS instrument.
5. Some nighttime VCM cloud tests and test thresholds may need to be changed or adjusted (beyond threshold tuning). MODIS cloud mask (MOD35) development could be used as a guide.
6. Hit rate calculations need to be supplemented with other measures of validity for accurate depictions of VCM performance, particularly in regions where either clouds or clear-skies are relatively rare (e.g., deserts, marine stratus regimes).