MODIS Cloud Mask: Approach, Results and Validation

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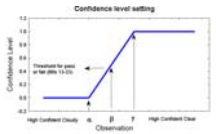
Cloud Detection Approach

Our approach to the MODIS Cloud Mask: for each pixel, provide a confidence flag that indicates how certain we are that the pixel is clear.



Each test returns a confidence (F) ranging from 0 to 1.
Similar tests are grouped and minimum confidence selected [min (F_i)]
Quality Flag is

$$Q = \sqrt[n]{\prod_{i=1}^{n} \min(F_i)}$$

Four values; 0, >.66, >.95 and >.99

Uses various spectral threshold tests to detect obstructed (cloudy) FOVS

Heritage includes APOLLO, ISCCP, CLAVR, SERCAA, collocated HIRS/AVHRR, and MAS

Tests and test thresholds are functions of "conceptual domains"
(daytime ocean, nighttime land, sun-glint, surface snow/ice, etc.)

Uses as little ancillary (non-radiance based) data as possible to avoid stops in the processing chain

Does not use MODIS products (to avoid feedback)

Makes use of several "clear-sky restoral tests" which check for unambiguous clear-sky signals

MODIS Cloud Mask
Confident Clear
Probably Clear
Uncertain
Cloudy

Cloud Mask Output:

Clear sky conservative (would rather call a clear FOV cloudy than a cloudy FOV clear)

Tries to satisfy various cloud detection needs.

Output contains 48 pieces (bits) of information for each daytime 1-km pixel (includes 16 collocated 250-m pixels)

Image analysis
Field experiments
- Aircraft missions
- Ground-based observations

Consistency Checks
Global Statistics
Comparison with other satellite analysis

MODIS cloud mask file contents (M?D35_L2*.hdf)

BYTE 1: bit field	Description	Key
0	Cloud Mask Flag	0 = Not determined 1 = Determined
2, 1	Unobstructed FOV Quality Flag	00 = Cloudy 01 = Uncertain 10 = Probably Clear 11 = Confident Clear
3	Day or Night Path	0 = Night / 1 = Day
4	Sunglint Path	0 = Yes / 1 = No
5	Snow/Ice Background Path	0 = Yes / 1 = No
7, 6	Land or Water Path	00 = Water 01 = Coastal 10 = Desert 11 = Land

BYTE 2: bit field	Description	Key
0	Non- cloud obstruction Flag	0 = Yes / 1 = No
1	Thin Cirrus Detected (Solar)	0 = Yes / 1 = No
2	Shadow Found	0 = Yes / 1 = No
3	Thin Cirrus Detected (Infrared)	0 = Yes / 1 = No
4	Adjacent Cloud Detected **	0 = Yes / 1 = No
5	Clear Sky - IR Threshold	0 = Yes / 1 = No
6	High Cloud Flag - CO2 Test	0 = Yes / 1 = No
7	High Cloud Flag - 6.7 micron Test	0 = Yes / 1 = No

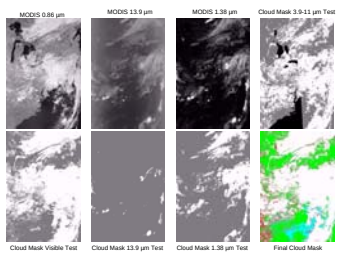
BYTE 3: bit field	Description	Key
0	High Cloud Flag - 1.38 micron Test	0 = Yes / 1 = No
1	High Cloud Flag - 3.7- 12 micron Test	0 = Yes / 1 = No
2	Cloud Flag - IR Temperature Difference	0 = Yes / 1 = No
3	Cloud Flag - 3.7- 11 micron Test	0 = Yes / 1 = No
4	Cloud Flag - Visible Reflectance Test	0 = Yes / 1 = No
5	Cloud Flag - Visible Reflectance Ratio Test	0 = Yes / 1 = No
6	Cloud Flag - NDVI Clear Sky Restoral Test	0 = Yes / 1 = No
7	Cloud Flag - Night 7.3-11 micron Test	0 = Yes/ 1 = No

BYTE 4: bit field	Description	Key
0	Cloud Flag - Spare	0 = Yes / 1 = No
1	Cloud Flag - Spatial Variability	0 = Yes / 1 = No
2	Clear Sky Restoral Tests	0 = Yes / 1 = No
3	Cloud Flag - Night Water Spatial Variability	0 = Yes / 1 = No
4	Suspended Dust Flag	0 = Yes / 1 = No
5-7	Spares	

BYTE 5: 250m Cloud Flag - Visible Tests

BYTE 6:

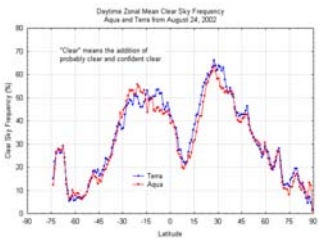
MODIS Cloud Detection (August 24, 2002)



The above figures show MODIS channels, the final cloud mask result and results from individual tests..

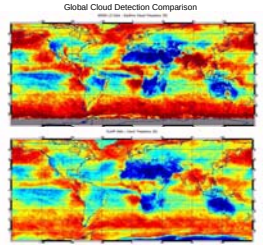
Global Cloud Mask Results

Zonal Mean Clear-sky Values of Terra and Aqua



In this analysis, we present the percentage of pixels labeled as clear or probably clear for the Terra and Aqua instrument. This comparison is for daytime and since the time difference between the two instruments is less than 3 hours, we should not expect there to be much of a temporal sampling problem for this one day. In this comparison, each instrument captures the broad scale cloud features and each zonal bin is generally only different by a few percent. This comparison, and others like it, indicate that the algorithm of the two instrument are operating similarly and yield similar results for similar cloud fields.

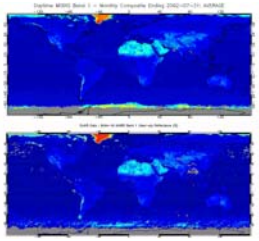
Global Cloud Detection Comparison



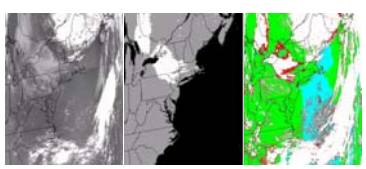
July 2002 cloud frequency from Terra MODIS Collection 3 cloud mask and NOAA-16 CLAVR.

The top panel is the global daytime MODIS cloud mask output (bits 1,2) at 0.5 degree resolution forJuly 2002.

The lower panel is the same time period for CLAVR algorithm applied to the NOAA-16.

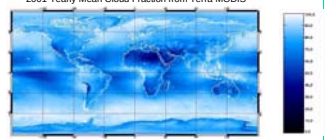


A comparison of visible clear sky reflectances from NOAA-16 AVHRR and MODIS 0.65 µm bands for the month of July 2002. The maps are very similar except for a few regions in Asia and sea-ice boundaries in the South Pole region. The latter difference likely results from the improved snow/ice detection capability of MODIS. False cloud detection over snow/ice surfaces would result in a lower mean reflectance.

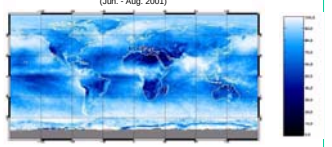


Terra MODIS band 3, "smoke mask", and cloud mask for 6 July, 2002, 15:50 UTC.

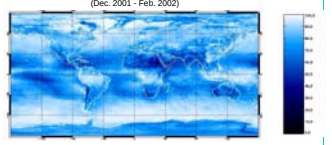
2001 Yearly Mean Cloud Fraction from Terra MODIS



Boreal Summer Mean Cloud Fraction from Terra MODIS (Jun. - Aug. 2001)



Boreal Winter Mean Cloud Fraction from Terra MODIS (Dec. 2001 - Feb. 2002)

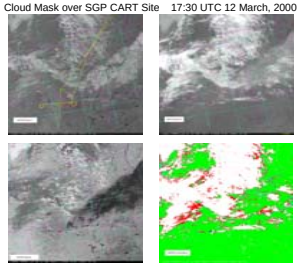


Discussion and Future Work

The daytime cloud mask is performing well as demonstrated by this poster. Current emphasis is on science issues (cloud types, amounts), comparison with other instruments and improving the nighttime cloud mask.

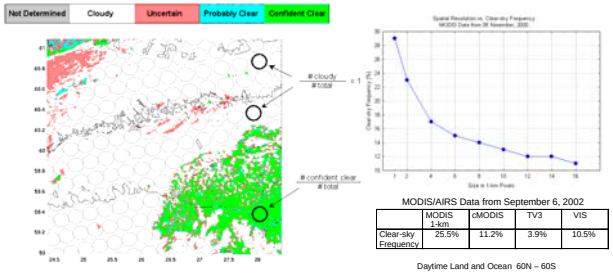
Validation Approaches

Cloud Mask over SGP CART Site 17:30 UTC 12 March, 2000



The MODIS group at UW-Madison is continuing the necessary effort to validate the MODIS cloud mask. A great many scenes have been evaluated from all regions, surface types, and seasons. For example, an analysis of multi-spectral MODIS imagery reveals that the cloud mask in the above case properly discriminates cloud from both snow and non-snow covered surfaces. The image on the bottom right shows the cloud mask result.

AIRS Clear Flag from MODIS cloud mask



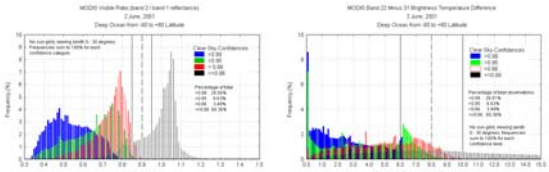
MODIS/AIRS Data from September 6, 2002

	MODIS 1-km	cMODIS	TV3	VIS
Clear-sky Frequency	25.5%	11.2%	3.9%	10.5%

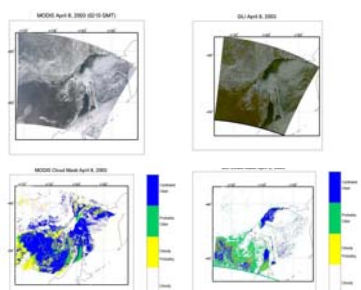
Daytime Land and Ocean 60N – 60S

Radar/lidar	MODIS Cloud	MODIS Uncertain	MODIS Probably Clear	MODIS Clear	
Clear	19	6	85	65	175
Low Cloud	82	0	4	3	89
Middle Cloud	44	3	13	0	60
High Cloud	14	1	6	3	24
	159	10	108	71	

Comparison of cloud heights from the Micropulse Lidar/ Millimeter Cloud Radar (MPL/MMCR) at the DOE ARM SGP CART site to MODIS cloud mask results. There are inherent difficulties in comparing data with vastly different spatial and temporal resolutions and sensitivities The MODIS cloud mask algorithm and MPL/MMCR agreed on the existence of clear or probably clear 86% of the time (86+ 65/175) and 92% of the time that a cloud was present. An uncertain result occurred in less than 3% of the total comparisons.



These histograms show observations of radiance data as a function of final clear sky confidences according to the MODIS cloud mask. They also define thresholds for the tests depicted. For example, the left-hand plot shows how the distribution of visible ratios changes with clear sky confidence. The vertical lines define the threshold interval for this cloud test (1.0 at left to 0.0 at right). One may conclude that the thresholds have been chosen properly as very few, if any, clear sky confidences >0.95 fall within the interval. In the figure at right, however, one sees that part of the distribution of observations denoted as clear (blue) or probably clear (green) falls inside the threshold interval. One could conclude that these thresholds should be made larger (moved right on the graph).



A comparison of the MODIS cloud mask (left) with the GLI cloud mask (right) for a scene on April 8, 2003 near Japan. The GLI and MODIS have similar spectral channels and spatial resolution. The GLI (launched in December 2002) is currently undergoing updating of thresholds.

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