DISCRIMINATING CLEAR SKY FROM CLOUD WITH MODIS
(version Sep 94)

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Definition of MODIS Cloud Mask

* indicates unobstructed view of the earth surface for given FOV

* indicates whether clear FOV is affected by cloud shadows

* will be generated at 1 km and 250 m resolutions of the MODIS data
  (500 m to be inferred from 250 m)

* input is assumed to be calibrated and navigated level 1B data

* cloud mask will be determined for good data only
  (ie. FOVs where ch 1, 2, 3, 5, 6, 18, 22, 26, 27, 29,
  31, 32, and 35 have radiometric integrity)

* incomplete or bad data will create holes in the cloud mask.

Channels used in generation of MODIS Cloud Mask

Channel Number	Wavelength (microns)	Used in Cloud Mask (B indicates backup to another channel)	

Reflected radiation

Channel Number	Wavelength (microns)	Used in Cloud Mask	
1	0.659	Y	clouds
2	0.865	Y	clouds
3	0.470	Y	shadows
4	0.555	B(3)	
5	1.240	Y	snow
6	1.640	Y	snow
7	2.130	B(6)	
8	0.415	N	
9	0.443	N	
10	0.490	N	
11	0.531	N	
12	0.565	N	
13	0.653	N	
14	0.681	N	
15	0.750	N	
16	0.865	N	
17	0.905	N	
18	0.936	Y	low clouds
19	0.940	N	
26	1.375	Y	thin cirrus
20, 21	3.750	B(22)	
22	3.959	Y	window
23	4.050	N	
24	4.465	N	
25	4.515	B(35)	

Emitted radiation

Channel Number	Wavelength (microns)	Used in Cloud Mask	
20, 21	3.750	B(22)	
22	3.959	Y	window
23	4.050	N	
24	4.465	N	
25	4.515	B(35)	
27	6.715	Y	high moisture
28	7.325	B(27)	
29	8.550	Y	mid moisture
30	9.730	N	
31	11.030	Y	window
32	12.020	Y	low moisture
33	13.335	N	
34	13.635	B(35)	
35	13.935	Y	high cloud
36	14.235	N	

Outputs (32 bit word for each FOV)

bit   content

decision
1   1 mask determined
     0 no decision

summary of all algorithms
2   unobstructed fov (quality flag)
     11 > 99% prob of clear
     10 > 95% prob of clear
     01 > 66% prob of clear
     00 cloud

ancillary information
1   day/night (visible data usable or not)
1   snow/ice
2   land/water (11 land, 10 wetland, 01 coastal, 00 water)

results from cloud algorithms
1   IR threshold found cloud
1   IR temperature differences found cloud
1   vis threshold found cloud
1   vis ratio found cloud
1   near IR test found thin cirrus
1   CO_2 high cloud test found high cloud
1   cloud shadow found

additional tests if not sure of unobsrtucted fov (prob less than 95%)

1   temporal consistency check indicated cloud
1   spatial continuity test indicated cloud

250m mask from visible tests
16   1 clear and 0 cloudy for 16 fovs within 1 km fov

MODIS Cloud Mask Algorithm

1. Identify characteristics of FOV (lat-lon, sunglint,..)

2. Apply masking tests in the following order:

a. IR temperature threshold and difference tests with chs 20, 22, 29, 31, 32

b. Reflectance threshold test with ch 22

c. CO_2 test for high clouds with ch 35

d. Near IR thin cirrus test with ch 26

e. Reflectance 1 ratio test with ch2/ch1.
   this test will not be applied to desert regions
   apply to pixels labeled as cloud to reclassify as snow/ice; set snow flag

3. Check for consistency

a. temporal consistency tests
   IR clear-sky composite (ascending, descending) consistency test
   VIS/NIR clear-sky composite consistency test

b. spatial consistency within same ecosystem

4. Pass uncertain pixels/subregions to multivalent logic (automated classification algorithms).

5. Apply spatial uniformity test to several 10 km x 10 km regions totally contained in one swath from the same or adjacent swaths

a. Spatial IR uniformity test applied with ch 31

b. Spatial reflectance uniformity test applied to ch 1 or 2.

c. IR and vis 2-D histogram tests with chs 1 and 31

Single Pixel Tests

Infrared Window Brightness Temperature Threshold and Difference Tests

$$BT_{11} < 270$$
$$BT_{11} + a_{PW} * (BT_{11} - BT_{12}) < SST$$
$$BT_{11} + b_{PW} * (BT_{11} - BT_{8.6}) < SST$$

where a_{PW} and b_{PW} are determined from a lookup table as a function of total precipitable water vapor (PW).

$BT_{3.9} - BT_{11} > 3$ indicates presence of partial of thin cloud cover

$BT_{11} - BT_{6.7}$ show large negative difference for clear sky over the Antarctic Plateau winter

IR threshold and difference tests sensitive to surface emissivity and atmospheric PW, dust, and aerosols

Reflectance Threshold Test

$r_{3.9} > 6\%$ considered to be cloudy and $< 3\%$ considered to be snow/ice

problems in bright deserts

CO_2 Channel Test for High Clouds

$BT_{13.9} <$ threshold

possible problems in high terrain

Near IR Thin Cirrus Test

$r1.38 >$ threshold indicates presence of thin cirrus cloud

ambiguity of high thin versus low thick cloud (resolved with $BT_{13.9}$) problems in high terrain

Reflectance Ratio Test

$r_{.87}/r_{.66}$ is between 0.9 and 1.1 for cloudy regions
if true then further tests should be performed to test for cloud

must be ecosystem specific

Multivalent Logic

Automated Classification Methods

used for uncertain pixels

Spatial Uniformity Tests

Infrared Window One-Dimensional Histogram Tests

$$BT_{thres} = BT_{max} - \text{sigma}$$

need surface uniformity

Reflectance Uniformity Test

max and min values close indicate cloud free scene uniformity
$r_{.66}$ over land and $r_{.87}$ over ocean

daytime only, must be ecosystem specific
must account for satellite zenith and view angle

Infrared Window Radiance Spatial Uniformity
Infrared Window plus Visible Threshold Tests
Two-Dimensional Infared and Visible Histogram Analysis

best over oceans, must be characterized by ecosystem

Validation Plan

1. ER2 field campaigns with MODIS Airborne Simulator (MAS)

   winter deployment over Great Lakes, Hudson Bay, sea ice, lake ice
   (out of Madison, WI)

   summer deployment over ocean, mountains, and desert
   (out of Mountain View, CA)

2. ground campaign with all sky camera (Fujita)

   winter and summer in Midwest

3. Comparison with ASTER cloud maps (also on AM platform)

   selected swaths (60 km wide with 30m res)
   available in diffeent ecosystems every 16 days

Thoughts on QC

1. Monitor percentage of cloud detection with various tests
   look for consistency

2. Monitor consistency of global cloud cover from day to day
   should maintain 5% consistency

3. perform regional statistics
   persistence of marine stratus

4. correlate cloud mask with independent SST and OLR determinations
   should find good correlations

Cloud Mask Data Sets

AVHRR/HIRS Global

 oceans only

 4Q 1994

AVHRR Local Area Coverage

 land

 1Q 1995

MAS 50 Channel

 Gulf of Mexico and Coastal Zone

 2Q 1995

 Summer Ocean, Mountain, and Desert

 4Q 1995

 Midwest and Hudson Bay Winter

 2Q 1996