

Menzel / Antonelli

Lab 3 – Understanding Multispectral Cloud Properties sensed with MODIS

March 2006

Table: MODIS Channel Number, Wavelength (µm), and Primary Application

Reflective Bands			Emissive Bands		
1,2	0.645, 0.865	land/cld boundaries	20-23	3.750(2), 3.959, 4.050	sfc/cld temp
3,4	0.470, 0.555	land/cld properties	24,25	4.465, 4.515	atm temperature
5-7	1.24, 1.64, 2.13	“	27,28	6.715, 7.325	water vapor
8-10	0.415, 0.443, 0.490	ocean color/chlorophyll	29	8.55	sfc/cld temp
11-13	0.531, 0.565, 0.653	“	30	9.73	ozone
14-16	0.681, 0.75, 0.865	“	31,32	11.03, 12.02	sfc/cld temp
17-19	0.905, 0.936, 0.940	atm water vapor	33-34	13.335, 13.635	cld top properties
26	1.375	cirrus clouds	35-36	13.935, 14.235	cld top properties

Table: Summary of some MODIS Cloud Tests

Scene	Solar/Reflectance	Thermal	Comments
Low cloud over water	$R_{0.86}$, $R_{0.67}/R_{0.86}$, $BT_{11}-BT_{3.7}$	Difficult, Compare BT_{11} to daytime mean clear-sky values of BT_{11} ; BT_{11} in combination with BT difference tests; Over oceans, expect a relationship between $[BT_{11}-BT_{8.6}]$, $[BT_{11}-$ $BT_{12}]$ due to water vapor correlation to SST	Spatial and temporal uniformity tests sometimes used over water scenes; Beware of Sun-glint regions
High Thick cloud over water	$R_{1.38}$, $R_{0.86}$, $R_{0.67}/R_{0.86}$,	BT_{11} ; $BT_{13.6}$; $BT_{6.7}$ $[BT_{11}-BT_{8.6}]$, $[BT_{11}-BT_{12}]$	Easy, good contrast in vis and IR
High Thin cloud over water	$R_{1.38}$, $\Delta R_{0.86}$, $[R_{0.65}-R_{1.6}]/[R_{0.65}+R_{1.6}]$;	$BT_{6.7}$; $BT_{13.9}$ $[BT_{11}-BT_{12}]$, $[BT_{3.7}-BT_{12}]$, $[BT_{8.6}-BT_{11}]$	For $R_{1.38}$, be careful of surface reflectance for atmospheres with low total water vapor amounts. For BT difference tests, beware of variations in surface emissivity.
Low cloud over snow	$[R_{0.65}-R_{1.6}]/[R_{0.65}+R_{1.6}]$; $R_{2.1}$ back up to 1.6 $[BT_{11}-BT_{3.7}] << 0$	Difficult, look for inversions in clr sky $BT_{11}-BT_{6.7} < 0$	NDSI (Normalized Difference Snow Index) is ratio test. $R_{2.1}$ is also dark over snow and bright for low cloud.
High thick cloud over snow	$R_{1.38}$; $[R_{0.65}-R_{1.6}]/[R_{0.65}+R_{1.6}]$	BT_{11} ; $BT_{13.6}$; $BT_{6.7}$ Look for inversions, suggesting cloud-free.	Usually easy

High thin cloud over snow	$R_{1.38}$; $[R_{0.65}-R_{1.6}]/[R_{0.65}+R_{1.6}]$	BT_{11} ; $BT_{13.6}$; $BT_{6.7}$ Look for inversions, suggesting clear sky.	
Low cloud over vegetation	$R_{0.86}$, $R_{0.67}/R_{0.87}$, $BT_{11}-BT_{3.7}$; $[R_{0.86}-R_{0.65}]$ $/[R_{0.86}+R_{0.65}]$	Difficult, BT_{11} in combination with BT difference tests.	NDVI (Normalized Difference Vegetation Index). Other ratio tests also are good. Can make tests a function of ecosystem.
High Thick cloud over vegetation	$R_{1.38}$, $R_{0.86}$, $R_{0.67}/R_{0.86}$, $[R_{0.86}-R_{0.65}]$ $/[R_{0.86}+R_{0.65}]$	BT_{11} ; $BT_{13.9}$; $BT_{6.7}$ $[BT_{11}-BT_{8.6}]$, $[BT_{11}-BT_{12}]$	Can make tests a function of ecosystem to account for variations in surface emittance and reflectance.
High Thin cloud over vegetation	$R_{1.38}$, $R_{0.86}$, $R_{0.67}/R_{0.86}$, $[R_{0.86}-R_{0.65}]$ $/[R_{0.86}+R_{0.65}]$	$BT_{13.9}$; $BT_{6.7}$ $[BT_{11}-BT_{8.6}]$, $[BT_{11}-BT_{12}]$	Beware of variations in surface emittance and reflectance.
Low cloud over bare soil	$R_{0.86}$, $R_{0.67}/R_{0.86}$, $[BT_{11}-BT_{3.7}]$	BT_{11} in combination with brightness temperature difference tests. $[BT_{3.7}-BT_{3.9}]$	Difficult due to brightness and spectral variation in surface emissivity. Surface reflectance at 3.7 and 3.9 μm is similar.
High Thick cloud over bare soil	$R_{1.38}$, $R_{0.86}$, $R_{0.67}/R_{0.86}$	$BT_{13.9}$; $BT_{6.7}$ BT_{11} in combination with brightness temperature difference tests.	
High Thin cloud over bare soil	$R_{1.38}$, $R_{0.86}$, $R_{0.67}/R_{0.87}$, $[BT_{11}-BT_{3.7}]$	$BT_{13.9}$; $BT_{6.7}$ BT_{11} in combination with brightness temperature difference tests, for example $[BT_{3.7}-BT_{3.9}]$	Difficult; be careful of surface reflectance at 1.38 μm . and variations in surface emittance.
Cloud-top pressure		Channels in absorption band of carbon dioxide (13-14 μm)	CO2 slicing
Cloud phase	Combination of $R_{0.86}$; $R_{1.6}$ and $R_{2.1}$	$[BT_{8.6} - BT_{11}] > 0$ for ice and < 0 for water. $[BT_{11} - BT_{12}]$ for water clouds $> [BT_{8.6} - BT_{11}]$. Conversely, $[BT_{8.6} - BT_{11}]$ for ice cloud $> [BT_{11} - BT_{12}]$.	Watch out for cloud overlap Determine phase by using observations that test for high cloud versus those that test for low.
Cloud particle size	Combination of $R_{0.86}$; $R_{1.6}$, $R_{2.1}$; & $R_{3.7}$	$[BT_{8.6} - BT_{11}]$ values versus $[BT_{11} - BT_{12}]$ is useful for thin high clouds.	Arches

1. Use Hydra to analyze the clouds in the scene over Italy on 29 May 2001 detected by MODIS (find MOD021KM.A2001149.1030.003.2001154234131.hdf and load it into Hydra).

1a. Look at clouds in different reflective bands. For each type (by selecting a single Field Of View) describe the changes in reflectance for different channels (top panel of Multi-channel viewer window).

1b. Look at clouds in different thermal emissive bands. For each type (by selecting a single Field Of View) describe the changes in radiance detected in different channels (top panel of Multi-channel viewer window).

2. Select the following region (outlined approximately by green box) from the Hydra window.

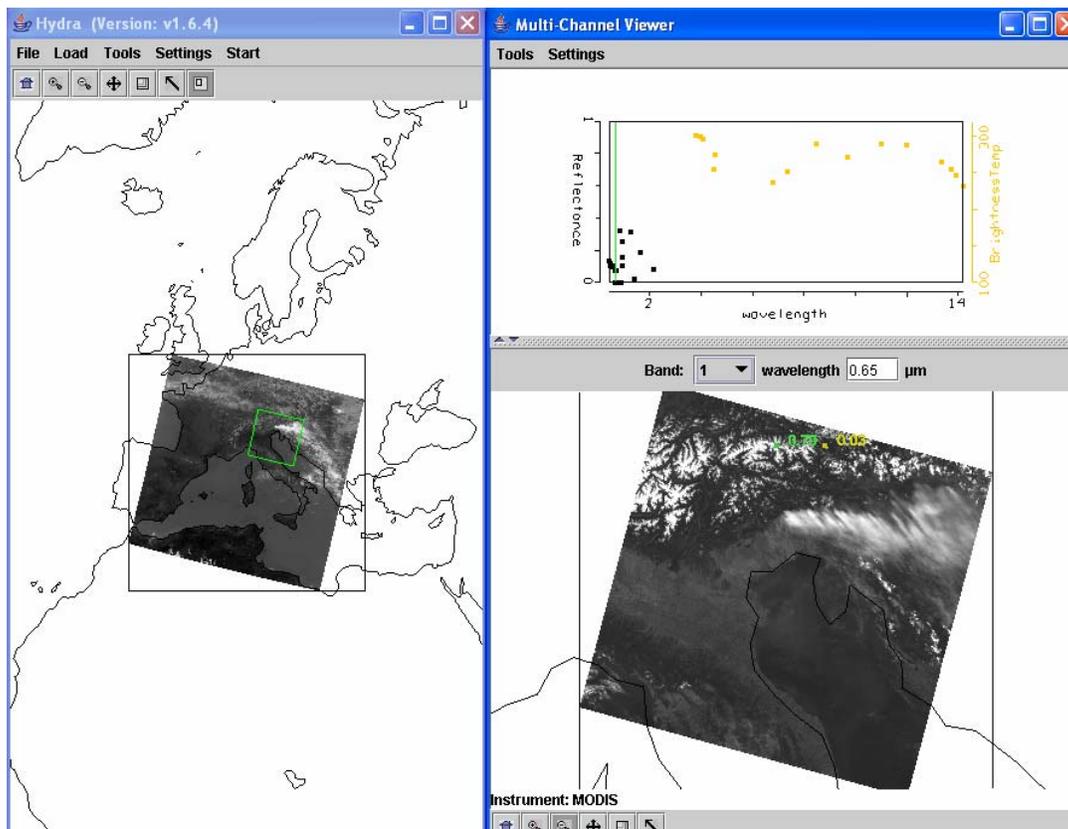


Figure 1: Subset selected for full resolution analysis of snow, clouds, and clear sky (left). Full resolution visible image of subset selected (right).

2a. Investigate the radiances emanating from the cloud within the scene in different wavelengths; look at the following bands

Band 1 (0.65 μm) – clouds and snow reflecting

Band 2 (0.86 μm) – contrast between vegetation and clouds diminished

Band 26 (1.38 μm) – only high clouds and moisture detected
Band 6 (1.64 μm) – water clouds reflecting, snow and ice clouds not reflecting
Band 20 (3.7 μm) – thermal emission plus solar reflection
Band 31 (11 μm) – clouds and snow colder than rest of scene
Band 35 (13.9 μm) – only upper atmospheric thermal emission detected.

2b. Note in BT images, clouds appear larger at 11 μm than at 3.7 μm . Can you explain why?

2c. Which three bands would you choose to determine a cloud / no cloud "mask"? What radiative characteristics of the cloud, surface and atmosphere led you to select these spectral bands? What reflectance or brightness temperature thresholds would you use?

2d. Consider the Band 31 (11 μm) image. What is the range of brightness temperatures over the land surface? What are the brightness temperatures of the different cloud types in the scene? Could you assume something about cloud phase from the cloud brightness temperatures?

2e. Using **Linear Combination** combine spectral bands that can be used to detect clouds and infer cloud properties. Try the following band combinations (by entering the suggested wavelengths in the colored boxes), and for each combination click on the compute button.

Band 2 (0.86 μm) / Band 1 (0.65 μm)
[Band 1 (0.65 μm) - Band 6 (1.6 μm)] / [Band 1 (0.65 μm) + Band 6 (1.6 μm)]
(Band 29 (8.6 μm) - Band 31 (11.0 μm)
(Band 31 (11.0 μm) - Band 32 (12.0 μm)

2f. Map each linear combination on the Y axis (by clicking the Y axis button) against Band 31 (11.0 μm) on the X axis (by clicking the X axis button). Click on **Scatter** to open a scatter plot window. Estimate what threshold values you would use in each test to indicate the presence of clouds? Select different regions in the scatter plot window and look at the corresponding points in the linear combination window.

2g. Look at the scatter plot of [Band 29 (8.6 μm) - Band 31 (11 μm)] versus [Band 31 (11 μm) - Band 32 (12 μm)]. Find where the largest differences occur in each image. Are there clouds in these brightness temperature difference images that could not be seen in the visible images?

3. Compare with the MODIS products files.

3a. Load the MODIS cloud mask (find the MOD35 file) using Hydra. How does the cloud mask compare with your own tests for cloud presence. Find three locations where you disagree and explain why you think the cloud mask is in error.

3b. Load the MODIS cloud phase product (find the MOD06 file) using Hydra. How does the cloud phase product compare with your own tests for cloud water/ice. Find three locations where you disagree and explain why you think the cloud product is in error.

4. Back in Hydra reload MOD021KM.A2001149.1030.003.2001154234131.hdf. Subselect the region shown below. Compare the cloud depiction at 0.65 and 11 μm .

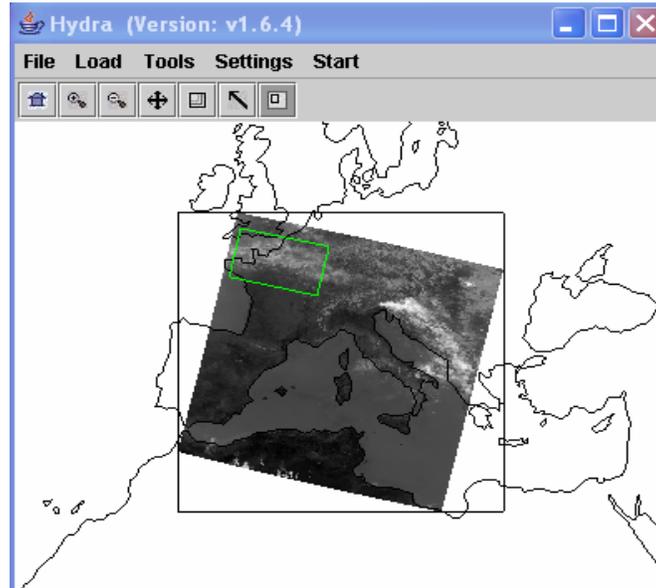


Figure 2: Cirrus clouds and clear sky

4a. Generate a scatter plot of Band 31 on the x-axis and Band 29 – Band 31 on the y-axis. Now you can select a rectangular region on the scatter plot and look at the images to determine the location of the selected points in the pseudo-images (See Figure 3a).

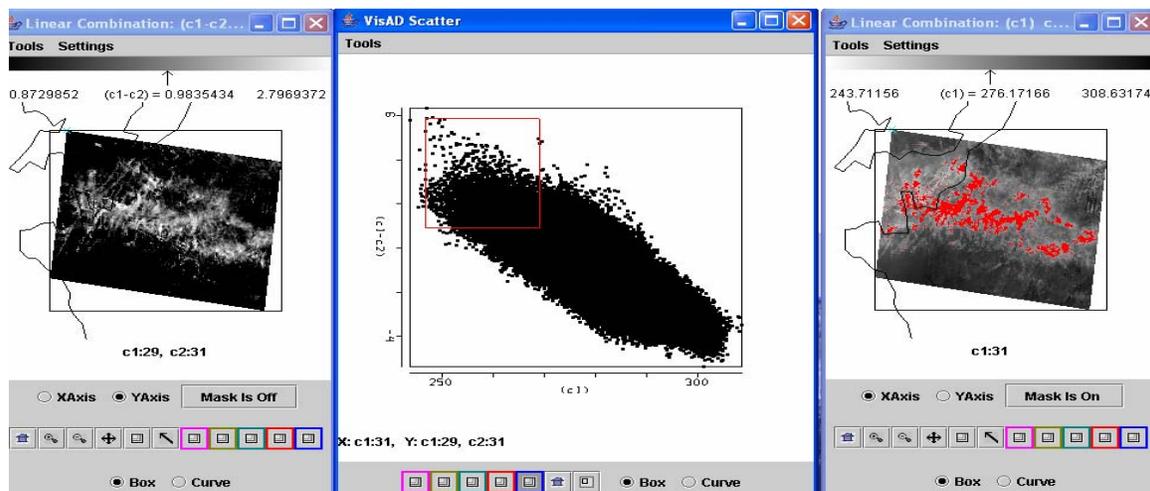


Figure 3a: Scatter plot of BT8.6-BT11 (left image) versus BT11 (right image) with BT8.6-BT11>1 and BT11>270 highlighted in red.

4b. Alternatively use the system to select a rectangular region of one of the pseudo-images that display the linear combinations and look at the position of the selected pixels in the scatter plot. (Figure 3b)

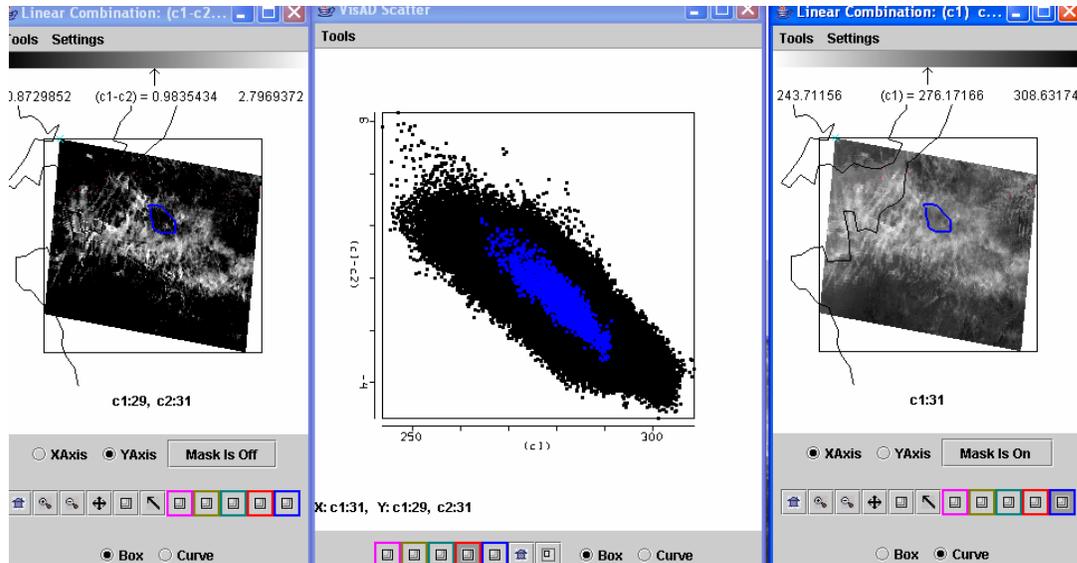


Figure 3b: Scatter plot of BT8.6-BT11 (left image) versus BT11 (right image) with selected cloud feature in BT11 image highlighted in blue and displayed on scatter plot.

4c. Try to determine the type of cloud viewed in this region. Does Band 26 ($1.38 \mu\text{m}$) support or contradict your cloud classification. If you were to design and automated algorithm to detect these cloud types, what would you include in your algorithm?

4d. Which difference is larger for this cloud, [Band 29 ($8.6 \mu\text{m}$) - Band 31 ($11 \mu\text{m}$)] or [Band 31 ($11 \mu\text{m}$) - Band 32 ($12 \mu\text{m}$)]?

4e. Try two other tests suggested for high thin ice clouds over land and comment on their correlation with the BT8.6 – BT11 test demonstrated above.

5. In the Hydra window, subselect the region shown below (Figure 4). Focus your region on the cloud and some nearby clear sky.

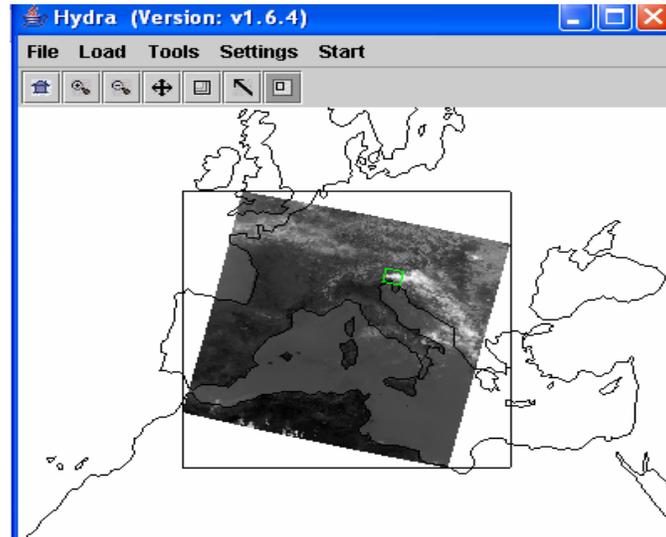


Figure 4: Subset to inspect thermal emission of clouds.

5a. Make a scatter plot of [Band 29 - Band 31] and [Band 31 - Band 32]. You should see a hook shape pattern in the scatter plot window. In this case, which brightness temperature difference signal is stronger (larger range of values). Select regions in different parts of the hook shape to see what parts of the image they correspond to – find the parts of the hook shape that correspond to clear skies, partly cloudy, and overcast cloud.

5b. To determine what causes the hook shape found in 4a, calculate the radiances at 8.6, 11, 12 μm for a scene of clear sky at 300 K and a cloud at 230 K with varying cloud amount. Let the cloud fraction vary from $N = 0.0, 0.2, 0.4, 0.6, 0.8,$ and 1.0 . Convert the radiances to brightness temperatures. Plot brightness temperature differences 8.6 - 11 versus 11 - 12 μm for the six different cloud fractions. What does this imply about the hook shape detected in the previous problem? What other factors might influence the hook shape?