

**MODIS and AIRS Workshop**

**5 April 2006**

**Pretoria, South Africa**

**LAB 2**

**Lab on MODIS Cloud spectral properties, Cloud Mask, NDVI and Fire Detection**

This Lab was prepared to provide practical insight into MODIS IMAPP level 2 product retrieval theory and technique.

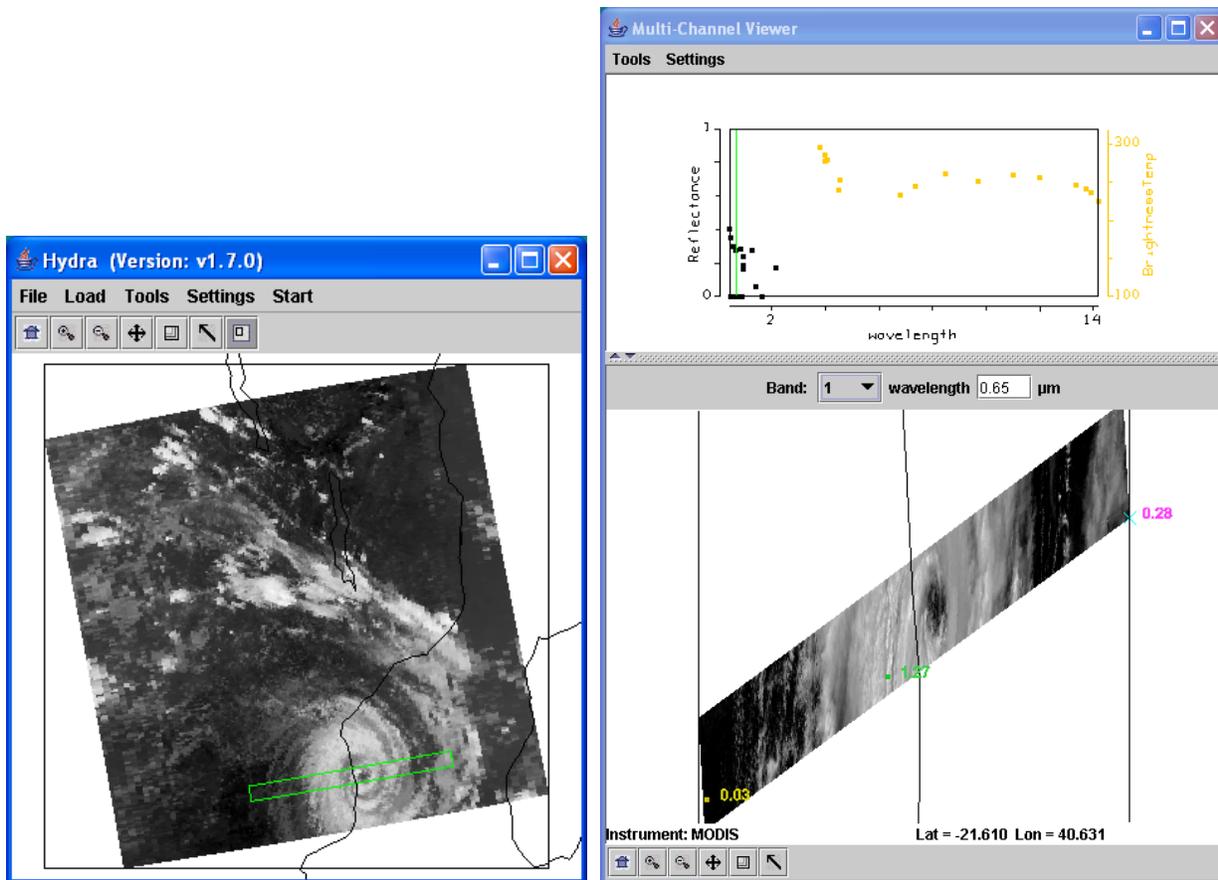
**Exercise 1: Exploring clouds in the MODIS scene**

*This exercise aims to provide the user with a basic understanding of cloud radiative properties. By the end of this exercise, you should be able to describe how you expect high and low clouds to affect radiances in several different MODIS bands.*

1. Analyze the cloud scene over South Eastern Africa and the Mozambique Channel from 2 March 2003 (day 61), at 11:30 UTC detected by Aqua MODIS using the Hydra software. Proceed in the following steps. Start up Hydra and load local image file MYD021KM.A2003061.1130.004.2004079065535.hdf.

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

(b) Select the following region (outlined approximately by green box) from the Hydra window as shown in Figure 1.



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

(c) Investigate the radiances emanating from the cloud within the scene in different wavelengths; look at the following bands:

- Band 1 (0.65  $\mu\text{m}$ ) – clouds and snow reflecting
- Band 2 (0.86  $\mu\text{m}$ ) – contrast between vegetation and clouds diminished
- Band 26 (1.38  $\mu\text{m}$ ) – only high clouds and moisture detected
- Band 20 (3.7  $\mu\text{m}$ ) – thermal emission plus solar reflection
- Band 31 (11  $\mu\text{m}$ ) – clouds colder than rest of scene
- Band 35 (13.9  $\mu\text{m}$ ) – only upper atmospheric thermal emission detected.

Once you are done close the Multi-Channel Viewer window.

## Exercise 2: Exploring the MODIS Cloud Mask Algorithm

*The goal of this exercise is to gain an understanding of cloud characteristics in terms of reflectances and brightness temperatures and how this information is used in the MODIS cloud mask algorithm. By the end of this exercise, the user should be able to identify which MODIS bands are used to detect clouds and why they are used, how to choose cloud/no cloud thresholds for individual spectral tests, and how the user can improve the cloud mask over a local region if it is not performing optimally.*

1. From the Hydra window reload the same MODIS data file, and start the Multi-Channel viewer examining the entire scene at lower resolution. Proceed in the following steps.

(a) What are some reasons why the cloud Brightness Temperatures (BT) are different in different infrared bands and reflectances (also indicated with  $r$ ) different in different visible channels?

(b) Now overlay the cloud mask product over the image displayed in the Multi-Channel Viewer by loading local image file MYD35\_L2.A2003061.1130.hdf. The 4 category cloud mask will be displayed over the image and a new cloud mask window will be displayed. Please note that the highest confident clear category (green) is not displayed, you will see the underlying image for this category. Select **Cloud Mask Window, Cloud Mask Parameters, Unobstructed\_FOV\_Quality\_Flag**. The Cloud Window will reformat with a button appearing at the bottom that will allow you to toggle the mask off and on. Comment on the performance of the mask at this reduced resolution.

(c) Are there regions where it appears to do better/worse?

(d) From your examination of the data, can you explain why the cloud mask might have failed in some regions?

(e) Go back and look at the data again in different bands if you need to. When you have finished, make sure the cloud mask is toggled off and close the Cloud Mask Window.

2. Go to the main Hydra window, click on the bottom menu toolbar **subset image** icon (last one on the right) and select the following region by holding down the right mouse button and dragging it over the region of interest (outlined approximately by green box in Figure 2):

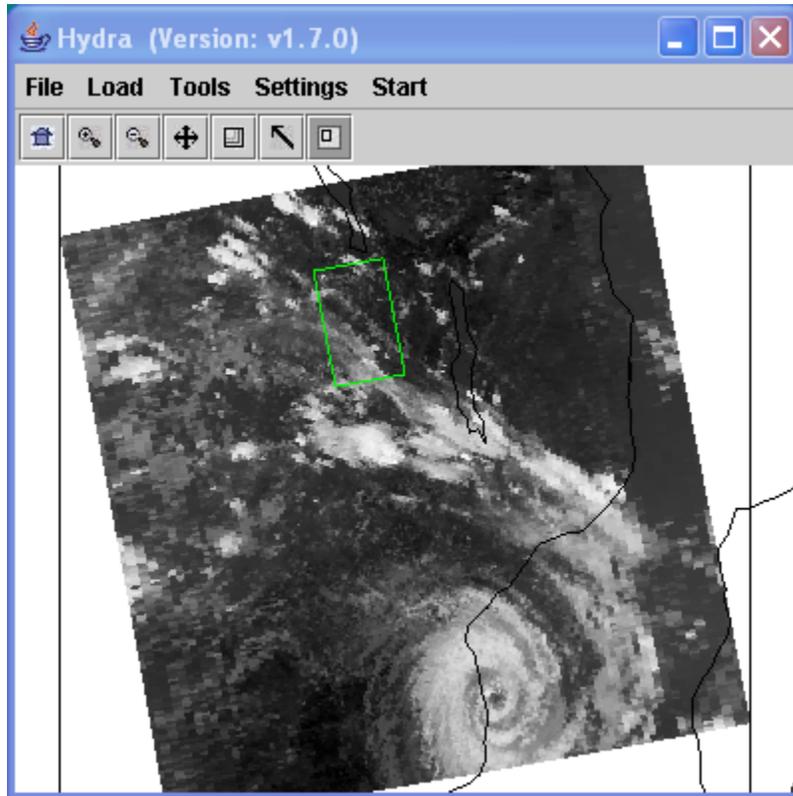


Figure 2: Land, sea, clouds and clear sky. As observed by Aqua MODIS on 2 March 2003 at 11:30 UTC.

The MODIS cloud mask algorithm combines the results of a series of individual spectral cloud tests to determine a final confidence in clear value. Investigate the radiances, BT and reflectance emanating from the scene in different wavelengths; make sure you look at Bands 1 ( $0.65 \mu\text{m}$ ), 2 ( $.86 \mu\text{m}$ ), 26 ( $1.38 \mu\text{m}$ ), 7 ( $2.1 \mu\text{m}$ ), 20 ( $3.8 \mu\text{m}$ ), 27 ( $6.5 \mu\text{m}$ ), 31 ( $11 \mu\text{m}$ ) and 35 ( $13.9 \mu\text{m}$ ).

(a) Comment on the cloud and clear sky characteristics in each of these spectral bands.

(b) Which three bands would you choose to determine a cloud / no cloud “mask”; why?

(c) What reflectance or brightness temperature thresholds would you use (cloud/no cloud) for bands 1 ( $0.65 \mu\text{m}$ ), 26 ( $1.38 \mu\text{m}$ ), 27 ( $6.5 \mu\text{m}$ ), 31 ( $11 \mu\text{m}$ ) and 35 ( $13.9 \mu\text{m}$ )? (Use the pick image button (*Arrow*) from the bottom toolbar, and then hold down the right mouse button as you roam around the image to get the pixel values, or the *Select Color Range* option from the *Settings* drop down menu). Save your thresholds.

3. Now select **Linear Combinations** from the **Tools** menu at the top of the Multi-Channel Viewer window. A new window (**Channel Combinations Tool**) will open. You can create combined channel images and scatter plots which can be used to investigate the scene and infer atmospheric and surface properties by selecting the channels and mathematical operations located at the bottom of the window. To select a channel, you can either type the wavelength into the equation boxes at the bottom or move the colored bars to the desired wavelength using the **Grab** tool (**Arrow**) on the main toolbar and holding down the right mouse button while located on the color bar. Try the following band combinations to create combined images (once the channels and operations are correctly selected, click on the **compute** button), and indicate the advantages and disadvantages of each combination for cloud detection. It may help to set the color scale to grey (the default is inverse grey). Try to think globally.

- Band 20 (3.80  $\mu\text{m}$ ) – Band 31 (11  $\mu\text{m}$ ) (BT)
- Band 2 (0.855  $\mu\text{m}$ ) / Band 1 (0.650  $\mu\text{m}$ ) (r)

(a) Using both the select image tool (**Arrow**) along the bottom combined image window and the **Select Color Range** option from the **Settings** drop down menu to enhance different regions, estimate what threshold values you would use in each test to indicate the presence of clouds?

Band	Threshold values
Band 20 (3.80 $\mu\text{m}$ ) – Band 11 (11 $\mu\text{m}$ ) (BT)	
Band 2 (0.855 $\mu\text{m}$ ) / Band 1 (0.650 $\mu\text{m}$ ) (r)	

(b) Values under the cursor can be obtained by selecting the **select image** tool (**Arrow**) from the bottom toolbar and roaming around the image while holding down the right mouse button. When you choose **Select Color Range**, you can move the limits of the enhancement around (or type the values in) and see how your thresholds work at detecting clouds. It may help to create a scatter diagram of the images. By displaying the band you wish to have on the x and y axes as an individual combined image (**deselect the mathematical operator**) you can then select the **axis button** at the bottom of the combined image window and then click on the **Scatter** button in the Channel Combination window. A separate window containing the scatter diagram will appear. You can then map the scatter points onto the axes image windows by selecting a region of points using the **select buttons** on the bottom and the **right mouse button**, or you can draw a region by hand by selecting the **Curve** button and moving the mouse while holding down the right mouse button. For instance, you can create a single band image of Band 31 (11  $\mu\text{m}$ ) (BT) on the X axis and Band 2 (0.855  $\mu\text{m}$ ) / Band 1 (0.650  $\mu\text{m}$ ) (r) on the Y axis, and map the points that you use as a threshold onto the individual combination windows.

(c) The cloud mask threshold tables consist of 4 values; here are the thresholds files for day time land and where indicated, desert:

Test bands (Name)	0 percent chance Clear Threshold	50 percent Clear Threshold change	100 percent Clear Threshold chance	Power (Linear Slope between 0% and 100% clear conf.)
Band 31 – Band 20 11-4 $\mu\text{m}$ BT (low) (lds11-4lo) desert	-20.00	-18.0	-16.0	1.0
Band 35 13.9 $\mu\text{m}$ BT (ldsco2)	222.0	224.0	226.0	1.0
Band 27 6.5 $\mu\text{m}$ BT (ldsh20)	215.0	220.0	225.0	1.0
Band 2 .86 $\mu\text{m}$ r (ldsref2) desert	0.34	0.30	0.26	1.0
Band 26 1.38 $\mu\text{m}$ r (ldsref3)	0.04	0.035	0.03	1.0
Band 2/Band 1 .86 $\mu\text{m}$ r / .65 $\mu\text{m}$ r (dlvrat)	1.85	1.90	1.95	1.0
Band 31 – Band 32 11-12 $\mu\text{m}$ BT (lds11-12lhi) desert	3.50	3.00	2.50	1.0

(d) How do the thresholds that you set compare with these?

(e) Can you think of reasons why they might be different?

(f) Which thresholds would you change for this scene, and how would you implement these changes?

(g) Now overlay the MODIS cloud mask file on our local subset. How do you think it performed?

When you have finished, close the Linear Combinations window.

### Exercise 3 NDVI

*The goal of this exercise is to gain an understanding of the basic technique used to retrieve surface vegetation amount.*

1. Start up Hydra and load local image file MYD021KM.A2006073.1240.005.2006075012425.hdf, and open the Multi-Channel Viewer. Subselect the following region:

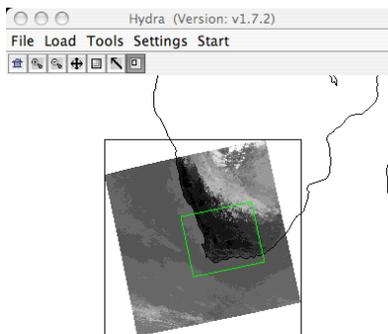


Figure 3: Vegetation Index Subset Region

(a). Demonstrate some of the spectral signatures for vegetated and barren soil in band 1 (0.68 micron) and band 2 (0.86 micron) as indicated in the handout. In each case identify which spectral signature you are demonstrating.

Band 1:

Band 2:

2. Select Band 1 in the Multi-Channel Viewer and create a transect as shown in figure 4:

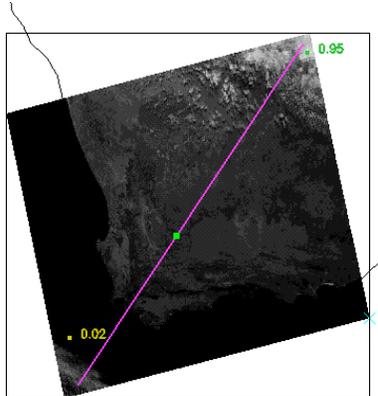


Figure 4: Vegetation Index Transect Selection

In the Transect window *select Settings->last two* and then in the Multi-Channel Viewer change to band 2 without moving the transect line. This will show both transect lines in the transect window.

(a) Examine the transects, can you identify the clouds in the transect windows? Describe the behavior of the reflectances in the presence of clouds.

(b) Do the same for ocean.

(c) Do the same over land: can you identify regions that are highly vegetated? Sparsely vegetated? Barren soil?

3. Use **Linear Combination** combine spectral bands to explore the vegetation indices that are based on the relatively low leaf and grass reflectance from spectral bands below  $0.72 \mu\text{m}$  and relatively high reflectance from spectral bands above.

(a) Construct a pseudo image of Band 1, and then another with Band 2. Create a scatter plot of the two with Band 1 on the x-axis and Band 2 on the y-axis. Can you identify the points for which band 1 and band 2 reflectances are almost the same (slope=1)? Among this subset of points: what distinguishes the points in the lower reflectance range from those in the high range?

(b) Can you identify the densely vegetated regions by selecting points in the scatter-plot window? According to the theory where should you start your search from?

(c) Construct a pseudo image of the Simple Ratio (SR)  $[\text{Band 2 (0.86}\mu\text{m)} / \text{Band 1 (0.65}\mu\text{m)}]$ . What are the SR values in regions without significant vegetation; what are they in vegetated regions? Playing with color scale and range try to identify the more vegetated regions. What would you expect to happen to the SR in extremely vegetated areas (high biomass)? Why?

(d) Construct a pseudo image of normalized vegetation index  $[\text{Band 2 (0.86}\mu\text{m)} - \text{Band 1 (0.65}\mu\text{m)}] / [\text{Band 2 (0.86}\mu\text{m)} + \text{Band 1 (0.65}\mu\text{m)}]$ . Can you discriminate regions with some vegetation from those with little? What are the NDVI values in regions without significant vegetation; what are they in vegetated regions?

4. In this exercise you did not correct for atmospheric scattering and for the canopy characteristics.

(a) How does scattering affect your results?

(b) Do SR and NDVI in general take into account the canopy effect? If yes, how? If not, what vegetation index does take it into account?

## Exercise 4 Fire Detection

*The goal of this exercise is to gain an understanding of fire radiative characteristics specifically of the MODIS bands used in the fire detection algorithm. By the end of this exercise, the user should be able to identify which MODIS bands are used to detect fires and why they are used, understand the basic steps that are taken by the MODIS fire product to detect clouds, and gain an understanding of the strengths and weaknesses of the algorithm.*

1. Load into hydra the local Aqua MODIS file from 20 August 2003 covering Southeastern Africa and Madagascar, MYD021KM.A2003232.1110.004.2004148203517.hdf. Start the Multi-Channel Viewer, and then select the small region displayed in Figure (5). Load Band 22 (3.99  $\mu\text{m}$ ) into the Multi-Channel Viewer window.

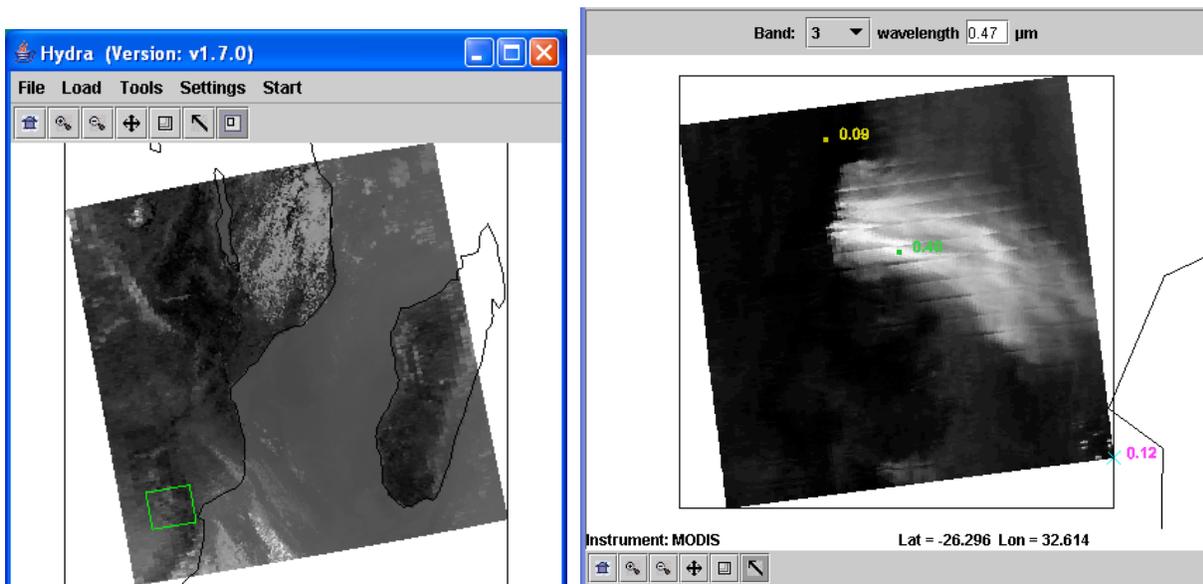


Figure 5. Main hydra window with selection of image from Aqua MODIS on 20 August 2003 at 11:10 UTC (left) and high resolution band 3 (.45  $\mu\text{m}$ ) reflectance image in the Multi-Channel Viewer (right).

(a) Create a transect across the hottest pixels in the scene. Try to overlay your transect across the source of the smoke plumes seen in band 3 ( $0.47\ \mu\text{m}$ ). What range of values do you observe in the transect? Do you notice anything that looks strange to you? Grab the transect point locator by right clicking and holding down the mouse button on the green point located at the bottom of the transect window X-axis. Move the position to the location along the transect where there seems to be missing data. Do the same for other missing data points. Where do these point lie in the image? Why do you think the values are missing?

(b) Leave the transect window open, and load band 21 ( $3.99\ \mu\text{m}$ ) into the Multi-Channel Viewer. How do the range of values compare? Are there missing values? Now repeat for band 31 ( $11\ \mu\text{m}$ ).

(c) What could be some of the causes of the differences that you have found between the three channels?

(d) Open the Linear Combinations Window and make a single image of Band 21 ( $3.99\ \mu\text{m}$ ) and a combination window of BTDIF4-11 (Band 21( $3.99\ \mu\text{m}$ ) – Band 31( $11\ \mu\text{m}$ )). Choose the band 21 image as the X-axis and the BTDIF4-11 image as the Y-axis, and create a scatter diagram. The MODIS fire algorithm uses a series of tests to determine if a pixel contains a fire. The first step is to identify potential fire pixels. This involves testing a pixel to see if the BT4 (Band 21  $3.99\ \mu\text{m}$ )  $> 310\ \text{K}$  and BTDIF4-11 ((Band 21( $3.99\ \mu\text{m}$ ) – Band 31( $11\ \mu\text{m}$ )))  $> 10\ \text{K}$ . Try out these thresholds by grabbing the points which meet this criteria within the scatter diagram (drag the box over the region which satisfies both thresholds). How do you think this preliminary test performs? Do you think it captures all of the fire pixels? Too many?

(e) Once the potential fire pixels are identified, other tests are applied to this subset of data points. The first is a simple Band 21 ( $3.99\ \mu\text{m}$ ) brightness temperature threshold test: BT4 (Band 21  $3.99\ \mu\text{m}$ )  $> 360\ \text{K}$ . Try out this threshold test in the scene you are looking at. You may wish to set the Set Color Range window to help you with this. How many of the previously chosen pixels does this find? If this test is passed, then the pixel is labeled as a fire pixel.

(f) Next, the technique attempts to differentiate the fire pixel from the non-fire pixel background region. This involves comparing the potential fire pixel to the surrounding pixels. This contextual approach uses

the average brightness temperature of the non-potential fire pixels in Band 21(3.99 μm) that surround the fire pixel along with the Mean Absolute Deviation (the mean of the absolute value of the differences between the average and the deviation from the average:  $MAD = \frac{1}{N} \sum_i |x_i - \bar{x}|$  where  $i$  is the number of points you are summing). For pixels that did not pass the first BT4 test, they must pass the next 3 dynamic thresholds to be labeled a fire pixel.

Threshold tests	Thresholds for the section of data displayed in Figure 5 from 20 August 2003
BTDIF4-11 > Average BTDIF4-11 + 3.5 (MAD BTDIF4-11)	BTDIF4-11 > 3.2 K + 3.5 * (.63) K BTDIF4-11 > 5.40
BTDIF4-11 > Average BTDIF4-11 + 6 K	BTDIF4-11 > 6K + 3.2 K BTDIF4-11 > 9.2 K
BT4 (Band 21 3.99 μm BT) > Average BT4 + 3(MAD BT4)	BT4 > 298.52 K + 3 * 16.57 K BT4 > 348.23 K

Apply these tests to our scene (you can use the scatter diagram if you would like). How do you think this detection algorithm performs in this region? Are there places that it fails?

(g) How do you think clouds would affect the results?

When you are finished, close the Channel Combination Tool Window.

(g) Now select the region outlined in Figure 6.

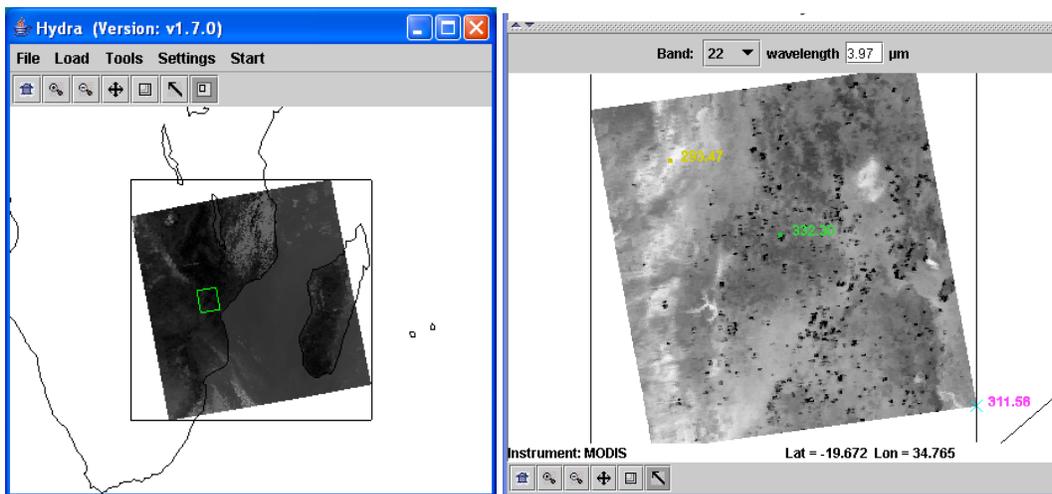


Figure 6. Main hydra window with selection of image from Aqua MODIS on 20 August 2003 at 11:10

UTC (left) and high resolution band 22 (3.99  $\mu\text{m}$ ) reflectance image in the Multi-Channel Viewer (right).

(h) Repeat steps (d) and (e) for this new scene. Comment on the results.

(j) Looking at the variability of the scene, can you think of some reasons why you would not want to use one set of thresholds for the entire scene? Are there some types of backgrounds where it would be easier to detect fires? Harder?

(k) Load Band 22 (3.99  $\mu\text{m}$ ) into the Multi-Channel Viewer. Now overlay the MODIS fire Level 2 product over the image displayed in the Multi-Channel Viewer by loading local image file MYD14.A2003232.1110.004.2004152085610.hdf. The fire product will be displayed over the image and a new MODIS Fire Mask Product window will be displayed, with a button at the bottom that allows you to toggle the mask off and on (you may have to re-size the window to see it). How do you think the official fire product performs on this scene?

We have not examined all the tests that go into a final fire pixel determination, but we have gone through most of them. There are also tests that discriminate clouds from fire pixels, and special algorithms for differentiating desert boundaries, sun glint and coastal regions.

#### **Extra: Compute and apply contextual thresholds**

(l) Now pick a potential fire region, and determine a BT4 average and BT4 MAD and a BTDIF4-11 average and BTDIF4-11 MAD. Use 4 pixels to determine the statistics and remember not to choose any in your background calculation that are included as potential fires. You can either do the calculations by hand or with a calculator that may be included as software on your PC. Calculate what the contextual fire thresholds should be for the pixel as was done in step (f). Now apply the thresholds to the pixel you are working on and all the pixels in the scene. How did your fire thresholds perform on (1) the current pixel, (2) on the whole scene?

#### **Extra: Thermal Sensitivity**

1. From the Hydra window re-load the same granule used in Exercises 1 and 2.. Sub-select a region with clouds and clear sky and load the full resolution image at 4 and 11 microns.

(a) Do you notice any change in the cloud spatial dimensions? If yes, in which band does the cloud appear bigger?

(b) Can you guess why?