

Software Tools Useful for Image Enhancement and Analysis In response to CGMS Recommendation 34.04

A freeware based multispectral data analysis toolkit for satellite data has been developed to assist research and development of remote sensing applications as well as education and training of remote sensing scientists; it is called HYDRA - HYper-spectral data viewer for Development of Research Applications. HYDRA provides a fast and flexible interface that allows users to explore and visualize relationships between radiances (or reflectances and brightness temperatures) and wavelength (or wavenumber) using spectra diagrams, cross sections, scatter plots, multi-channel combinations, and color enhancements on a pixel by pixel basis with full access to the underlying metadata of location and time.

HYDRA enables interrogation of multispectral (and hyperspectral) fields of data so that (a) pixel location and spectral measurement values can be easily displayed; (b) spectral channels can be combined in linear functions and the resulting images displayed; (c) false color images can be constructed from multiple channel combinations; (d) scatter plots of spectral channel combinations can be viewed; (e) pixels in images can be found in scatter plots and vice versa; (f) transects of measurements can be displayed, and (g) soundings of temperature and moisture as well as spectra from selected pixels can be compared.

The World Meteorological Organization (WMO) has added HYDRA to its Virtual Laboratory for Satellite Training and Data Utilization to enable research with satellite data and to enhance training capabilities. The Virtual Laboratory is designed to provide the instructors and students with a set of easy to use tools for creating and conducting training sessions. HYDRA is now part of this international toolkit.

This paper describes some of the procedures for displaying multispectral data using HYDRA and presents some examples with MODIS and AIRS data.

Software Tools Useful for Image Enhancement and Analysis

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1. Design Philosophy of HYDRA

HYDRA (Hyper-spectral data viewer for Development of Research Applications) grew out of the necessity to provide research scientists and educators with freely available software that could display and analyze remotely sensed multispectral and hyperspectral data. HYDRA is a third generation application for hyperspectral data produced at the University of Wisconsin's Space Science and Engineering Center (SSEC) and CIMSS. The first two were based on commercial packages IDL and Matlab and served as a testbed to refine the operations and functionality required by the users.

When considering the design of HYDRA, the most important requirements were that the software must be (a) freely available to the global community, (b) computer platform independent, and (c) extendable. Computer platform independence has been elusive in so far as hdf libraries still are required to view the data. It was also important that the toolkit be coded in an easy-to-use scripting language, so that users could modify and extend the capabilities as needed. The VisAD (Visualization for Algorithm Development) Java library was selected as the basis for HYDRA; Hibbard et al (2002) has more information about VisAD. This library allows applications to be written in either Java or Jython, the Java implementation of the popular Python scripting language; more details are available in Bill (2002) and Lutz et al (1996). The core of the VisAD library is a unified Data Model, which allows for the representation of literally any numeric data in a consistent manner. This is very important when integrating data from a variety of sources that may have different sampling topologies in space or time. The Data Model also has built-in metadata for parameters such as units and error estimates. Because these metadata are an integral part of the data means they can be easily used to verify the validity of computations (the software detects invalid combinations, such as adding a temperature to a pressure) and to estimate the reliability of computations.

HYDRA has been developed using the Jython (the Java implementation of Python) scripting language. The syntax of this language is simple enough that it lends itself to easy modifications by end users who are either more familiar with scripting languages or are already competent Java programmers. Like other scripting languages, Jython suffers from poor computing performance; however, this is not an issue as nearly all "heavy" computing is handled by the VisAD library.

The programmatic interface to the data files has been designed so that emerging new file types or formats will be easy to support without changing the core of the applications. The key was to abstract the reading of the files so that the application makes the same function or method calls regardless of the file being read. This same philosophy is used in packages such as OpenDAP and ESML, which have the notion of a plug-in.

Appendix 1 and 2 offer more details on getting HYDRA started and how to use the command structure to stage and interrogate multispectral data. The following sections illustrate some of the capabilities for analyzing multispectral Moderate resolution Imaging Spectroradiometer (MODIS) and hyperspectral Atmospheric Infrared Sounder (AIRS) data with HYDRA. HYDRA is also capable of viewing and interrogating data from the Geostationary Operational Environmental Satellite (GOES) imager data as well as the European Meteosat Spinning Environmental Visible and InfraRed Instrument (SEVIRI).

2. Examples of Multi-Channel Viewing with HYDRA

The Multi-Channel Viewer enables display and interrogation of the 36 spectral channel values for any pixel within a granule of MODIS data (consisting of 335.3 mega bytes); more information about MODIS can be found in King et al (1992) and Barnes et al (1998). Measurements values (in radiance or reflectance or brightness temperature as selected) can be displayed for individual pixels within the granule; transects from one location to another can be constructed for a given spectral channel to determine min/max values as well as gradients in between. Figure 1a shows the water vapor channel (6.78 microns) brightness temperature image from a granule of MODIS data for 1030 UTC on 29 May 2001 over Europe (dark is warm and white is cold) below a plot of the reflectances (for the visible and near infrared channels) and the brightness temperatures (for the infrared channels) associated with a selected pixel in the granule (marked by the blue x). Using the HYDRA commands, measurement values and latitude/longitudes for any of the pixels for all of the spectral channels can be displayed. Figure 1b demonstrates the RGB option where a false color image can be composed in the “Multi-Channel Viewer” using the RGB option under “Tools.” This MODIS channel combination (channel 1 at 0.65 microns in the red, channel 4 at 0.56 microns in the green, and channel 3 at 0.47 microns in the blue) comes closest to providing an image akin to what the human eye would see; note the reflected solar contributions over the Mediterranean Sea. RGB allows any three channels to drive the red, green, and blue enhancements. Figure 1c shows a transect superimposed on the water vapor image and the associated brightness temperature values going from north to south; it is readily apparent that the two dry regions are more than 10 K warmer than the moister region in between.

The Channel Combinations Tool allows one to generate scatter plots of one set of channel combinations versus another. The values within the scatter plot can be located in the multi-channel images and conversely regions within the multi-channel image can be displayed in the scatter plot. This is very useful in locating features in the images and determining threshold values for discriminating them from the rest of the image (e.g. clear sky versus cirrus clouds).

Figure 2 shows screens enabled by the Channel Combinations tool. Visible reflectances (left) are plotted on the y-axis against infrared window 11 micron brightness temperatures (right) on the x-axis in a scatter plot (center). Pixels in the scatter plot are high-lighted in different colors and their locations are marked in the visible reflectance and infrared window brightness temperature images. Coldest temperatures and low reflectances indicate clouds (blue), highest reflectances and freezing temperatures indicate snow in the Alps and elsewhere (red), near zero reflectances and temperatures around 290 K indicate near shore waters (purple), and hottest temperatures and modest reflectances indicate desert (turquoise). Conversely, pixels in the images can also be high-lighted and their locations in the scatter plot marked (not shown).

Figure 3 shows an example of an image created from linear combinations of spectral channels with HYDRA; the normalized vegetation index is shown as calculated from reflectances [band 2 (0.86 μm) – band 1 (0.65 μm)] / [band 2 (0.86 μm) + band 1 (0.65 μm)]. The vegetation index is based on the relatively low leaf and grass reflectance from spectral bands below 0.72 μm and relatively high reflectance from spectral bands above. Regions with some vegetation are clearly distinguished from those with little. Regions without significant vegetation have indices below 0.3; vegetated regions show indices above 0.6.

3. Hyperspectral data analysis with HYDRA

HYDRA is also used to analyze granules of hyperspectral AIRS data (consisting of about 63 mega bytes each); the spectral selection is now indicated by wavenumber, a prevalent indicator in the infrared region of the spectrum which equals the number of wavelengths that fit into one centimeter. AIRS takes infrared measurements from 650 to 2550 cm^{-1} (15.4 to 3.9 microns) in 2300 spectral bands at spectral resolutions as high as 0.5 cm^{-1} ; Aumann et al (2003) provides more information on the instrument and its characteristics. Figure 4a shows the Multi-Channel Viewer display of AIRS data over the Black and Caspian Seas on 28 August 2005. The top panel displays two spectra measured by AIRS over a pixel in clear skies in the Black Sea (marked by the cross and displayed as the black spectra) and over a nearby pixel in high clouds (marked by the red dot and displayed by the red spectra); the spectral gaps in AIRS between 1136 to 1265 cm^{-1} (8.8 to 8.2 microns) and 1629 to 2169 cm^{-1} (6.2 to 4.6 microns) are bridged by HYDRA with a straight line. The clear sky spectrum shows those regions where the atmosphere has CO₂ absorption (between 650 and 750 cm^{-1} as well as between 2350 and 2450 cm^{-1}), H₂O absorption (between 1265 and 1625 cm^{-1}), and O₃ absorption (near 1050 cm^{-1}). Black Sea brightness temperatures in the infrared window regions are near 300 K while the cloud top temperatures are about 220 K. The spectral brightness temperatures measured over the cloud are relatively constant as one would expect over an opaque blackbody-like cloud in the long wavelength region (the spectra is relatively flat between 650 and 1150 cm^{-1}). No significant moisture is being evident above the cloud (indicated by the flatness in the water vapor sensitive region between 1265 and 1625 cm^{-1}). In contrast there is strong absorption by atmospheric water vapor over the surface of the Black Sea (resulting in significantly colder brightness temperatures from 1300 to 1600 cm^{-1} since the sensor is seeing less deeply into the troposphere) and absorption by atmospheric ozone (seen in the colder temperatures near 1050 cm^{-1}). The reflected solar

contribution over the cloud in the short wavelength region is evident by the temperature increase from 220 to 260 K (going from 2450 to 2550 cm^{-1}). However there is no significant solar contribution from the Black Sea pixel.

Figure 4b demonstrates the capability to zooming in on a portion of the spectra. As one nears the center of the ozone absorption region it is expected that the satellite is sensing less deeply into the atmosphere. As the cloud temperatures get warmer by about 3 K in going from the periphery of the ozone absorption band at 1020 cm^{-1} to the center of the absorption band at 1055 cm^{-1} , it is suspected that the cloud top is likely in the stratosphere where temperatures get warmer with altitude (unlike the troposphere where they get colder with altitude).

Figure 5 shows the Channel Combinations tool enabling investigation of spectral channels on and off water vapor absorptions features; this illustrates how the spectral and spatial sensitivity of the AIRS measurements is readily explored with HYDRA. Brightness temperature differences between 1384.5 cm^{-1} (off the water vapor rotational absorption line hence sensing mostly the sea surface) minus 1387.2 cm^{-1} (on the water vapor rotational absorption line hence sensing some of the lower tropospheric moisture) of more than 40 K (red regions in lower left image) indicate very moist regions of the lower troposphere; dry regions (blue) with less than 1 K difference are evident over the desert and in opaque high clouds.

HYDRA also enables comparison soundings of temperature and moisture (generated from non-HYDRA software and staged in to a file that HYDRA can read) with spectra from selected pixels. Figure 6 shows an example; moisture profiles and spectra in the eastern and western parts of the Black Sea demonstrate that deeper water vapor absorption lines are associated with moister atmospheres. The profile retrievals have been accomplished with a principal component retrieval algorithm trained with AIRS spectra calculated from radiosonde observations (Weisz et al, 2005).

4. Summary

As these few examples illustrate, HYDRA offers several tools to interrogate multispectral and hyperspectral remote sensing data quantitatively and to explore the correlations between radiance measurements and features in the images. Continued development over the next several years is planned in order to incorporate more multispectral and hyperspectral instrument systems into the HYDRA menu. In addition several improvements will be added including (1) improving the user interface, (2) adding the capability to animate sequences in time or wavenumber, (3) introducing a state saving device (ie. a persistence mechanism), (4) enhancing collaboration at remote sites through granule sharing, (5) enabling more high-spectral data analysis (ie principal component analyses), and (6) providing more interaction between scripting and the application.

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the instructors and students with a set of easy to use tools for creating and conducting training sessions – HYDRA is now part of this international toolkit.

The HYDRA project is an on-going development effort. Planned future developments include features that will enable remote multiple site viewing of and interaction with the same data set; this will enhance use in the Virtual Laboratory and collaborations at remote sites.

More information and the freeware may be found at: <http://www.ssec.wisc.edu/hydra/>.

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Appendix 1. Getting and Setting Up HYDRA

For Windows, HYDRA can be downloaded from the web site mentioned above. Download the latest version in binary ftp mode, and then run it by double-clicking the file icon. The installer will ask where you wish to install the program. Accept the default, C:\Program Files\hydra. Start the program by selecting Start | All Programs | hydra | Run HYDRA. A window named “HYDRA” will appear (Figure A1); it will indicate the version you are using. A window named “Run HYDRA” will also appear (this window may be minimized, but do not close it).

For Linux, download the file “hydra_v1.6_linux.tar.gz” or a later version in binary ftp mode and install by entering “gzip -cd hydra_v1.5_linux.tar.gz| tar xvf -” at a command prompt. This will create a sub-directory named “hydra” into which everything required to run will be installed. To run HYDRA, first change directory into the 'hydra' directory, and enter “./runHydra” at the command prompt.

For Macs, OSX 10.4 (Tiger) or later, repeat the procedure above for Linux, except use the file 'hydra_v1.6_mac.tar.gz.' Earlier versions of Mac, 10.3 (Panther) require a separate installation of Java3D.

The HYDRA window enables you to load new files and to select regions within the current file. HYDRA is designed to read MODIS Level-1B 1KM files in HDF4 format. Files obtained from the NASA DAAC, or those produced locally by a direct broadcast ground station (including IMAPP), can also be used.

Appendix 2. Summary of HYDRA Commands

HYDRA main window

Displays a world map and shows *File, Load, Tools, Settings,* and *Start* at top.

File offers

Exit to closes this window

Load has the options

Local Data allows you to search local directories to find MODIS, AIRS, GOES or Meteosat data.

Remote Data allows you to get data from a remote server

(a) Terra or Aqua Direct Broadcast or (b) Goddard DAAC

GOES/MSG allows you to get geostationary satellite data from an ADDE server

After a data granule is selected HYDRA displays the infrared window (at reduced resolution 4 km for MODIS) on a world map.

Tools offers

Capture Display to save the image as a jpeg

Settings has

Set Color Range where the histogram of brightness temperatures or radiances can be adjusted to maximize contrast – the color range can be altered with a right click plus drag at either end of the color scale

Set Color Scale where *Color*, *Gray* and *Inverse Gray* gives choice of color, grey, or inverse grey (which produces white clouds for infrared channels)

The toolbar at the top enables reset, zoom in, zoom out, translate, box magnify, find location, and subset at full resolution functions

Reset (left click on reset and then click on image to restore original image)

Zoom in (left click on zoom in plus click on image enables enlargement)

Zoom out (left click on zoom out plus click on image enables far view)

Translate (left click on translate plus click on image enables moving the image within the window)

Box magnify (left click on box plus click and drag to create box for enlargement)

Find location (left click on arrow plus click on image displays location of the chosen pixel)

Subset at full resolution (only after Multi-Channel Viewer is engaged, then left click on subset plus click and drag on image creates a subset of image at full resolution; this is automatically transferred from HYDRA into the Multi-Channel Viewer when both are engaged – data is displayed at reduced resolution by default unless subset function is used)

Start opens *Viewer*

wherein the measured spectra (wavenumber on x-axis and radiance or brightness temperature on y-axis) is displayed along with a spectral band superimposed on a world map. Left click on arrow icon in the bottom toolbar allows you to see the pixel value for a given lat-lon (using left click and drag).

Tools menu (appears in *Multi-Channel Viewer* window)

Linear Combinations opens the **Channel Combination Tool** display where you can specify linear combinations of spectral bands a,b,c and d
(a +-x / b) +-x / (c +-x / d).

RGB allows you to select a spectral channel for each color in the RGB display

Transect allows you to create a line on the image and see the temperatures or radiances along the transect marked by shift plus right click and drag.

Capture Display allows you to save the image as a jpeg

Statistics displays the min and max values in the image

Reference Spectrum allows you to compare spectral measurements from two selected pixels (controlled by the arrows in the bottom toolbar)

Settings (on the Viewer) has

Set Color Range where the histogram of brightness temperatures or radiances can be adjusted to maximize contrast – the color range can be altered with a

right click plus drag at either end of the color scale
BT->radiance allowing you to toggle from brightness temperatures to radiances in the infrared spectral channels
Projection offers **Lambert Equal Area** or **Instrument** projections of the data
Set Color Scale where **Color**, **Gray** and **Inverse Gray** gives choice of color, grey, or inverse grey (which produces white clouds)
Lat/Lon Grid can be superimposed on the image by using the toggle
Image Label labels the image with the instrument and day/time of the data

The **Channel Combination Tool** offers the usual tool bar and

Compute to create an image of the selected linear combination (you can indicate at the bottom your preference for this linear combination to be on the x- or y-axis in the scatter plot) and displays a toolbar for image manipulations (five color boxes are available in the toolbar to select regions by boxes or curves in the image that will be displayed in the scatter plot; a left click drag in the image highlights the chosen points in the scatter plot).

Scatter creates a scatter plot of the chosen x- and y-axis linear combinations. Five color area boxes (or area curves) in the bottom toolbar of the scatter plot allow you to select points in the scatter plot that will be displayed in the x-axis and y-axis images; a left click drag in the scatter plot highlights the chosen points in the scatter plot and simultaneously in the x- and y-axis images. Conversely (as indicated before) left click drag in the x- or y- axis images shows the locations of the chosen pixels in the scatter plot. Each color area box (or area curve) can be erased with a left click when the color box is engaged; after erasure another area box (or area curve) can be selected for this color. The zoom capability in the scatter plot (on the bottom right of the toolbar) allows you to enlarge special features in the scatter plot and investigated them in more detail.

After engaging version 1.7.4 of HYDRA, the HYDRA window appears (Figure A1). To load a MODIS Level-1B 1 km resolution file from disk, click on “data | local” and select the file to be loaded (e.g., MYD021KM.A2004144.0510.004.2004145120621.hdf to load the 29 May 2001 data set). When the file is loaded, an image of the 11 μm radiances appears, as shown in Figure A2.

Appendix 3. Viewing Level 2 Products

When viewing level 2 products (staged in a separate file), HYDRA generates a display of that product. Current choices include the cloud mask (from MOD35), total column ozone and water vapor (from MOD07), cloud top properties (from MOD06), and AIRS profile retrievals (generated using a statistical regression retrieval algorithm trained with AIRS spectra calculated from radiosonde observations). Figure A3 shows the MODIS level 2 cloud mask product associated with the 29 May 2001 granule over Europe.

When viewing MOD07 or AIRS profiles, **Variables** offers the choice to display air temperature profiles

total ozone
precipitable water
surface temperature
water vapor profiles
surface pressure
ozone profiles

Levels offers 17 levels between 1100 and 50 hPa for the retrieval field display.

Settings offers a choice to *Set Color Range*, *Set Color Scale*, and *Show Color Bar*. The last choice enables superposition of a color bar label that identifies the values of the product associated with each color.

Tools offers the option of *Reference Profile* that allows you to compare level 2 products from two selected pixels (controlled by the arrows in the bottom toolbar where the red dot indicates the location of the second profile) and *Transect* that allows you to construct a transect across the level 2 product image (see above).

HYDRA also offers the capability to co-locate MODIS and AIRS gathered from Aqua. The MODIS and AIRS granules are opened separately with the HYDRA and the position arrows automatically start tracking in each display. Figure A4 shows an example where co-located MODIS data is suggesting sub-pixel cloud presence in the AIRS data.

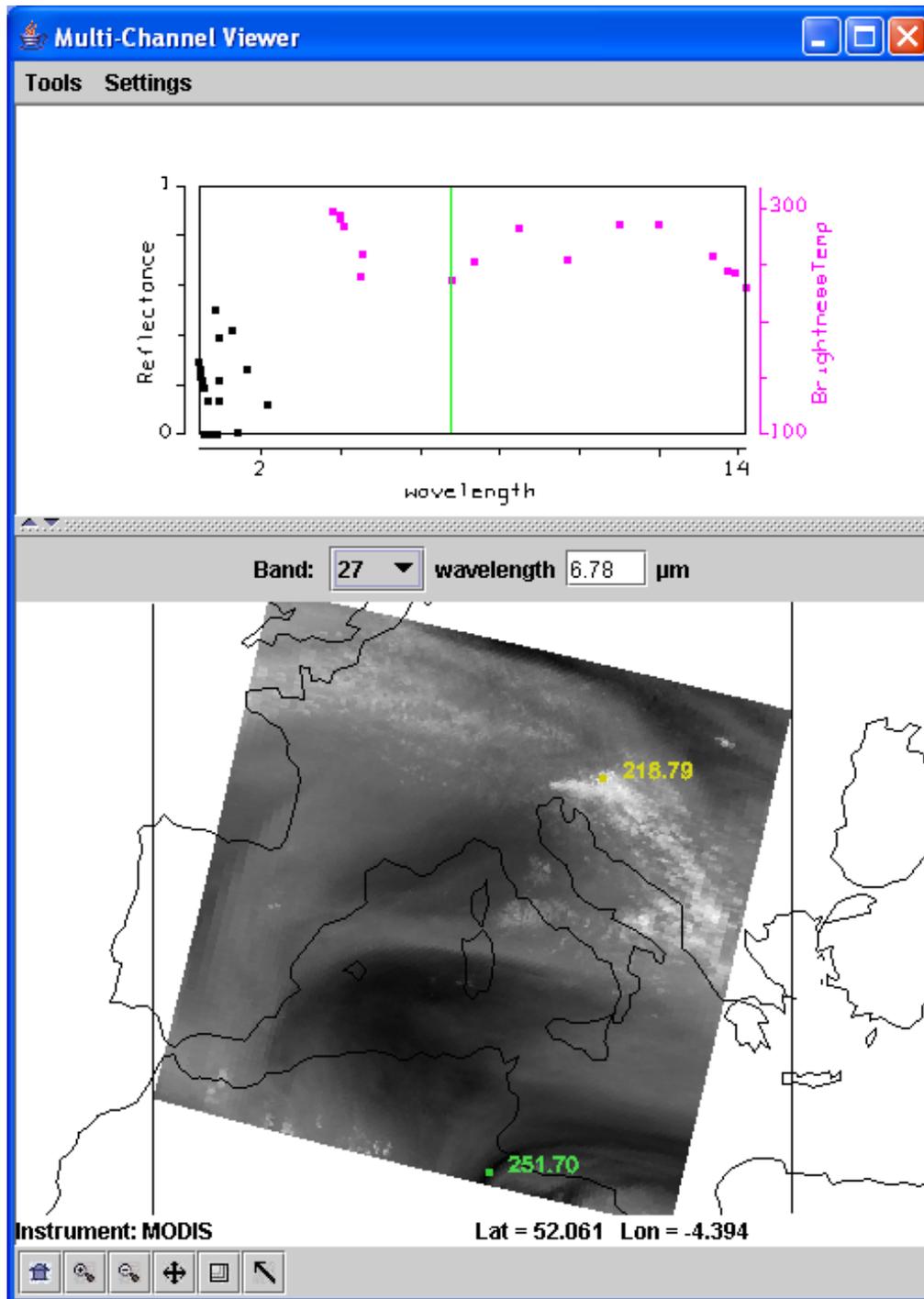


Figure 1a: “Multi-Channel Viewer” of a MODIS granule from 29 May 2001 over Europe at 1030 UTC. The upper panel shows the 36-channel spectrum of the reflectance measurements in the visible and near infrared channels (black dots referenced to the left y-axis) and the brightness temperature measurements in the infrared channels (purple dots referenced to the right y-axis) as a function of wavelength (microns). The lower panel shows the water vapor image with minimum (219 K) and maximum (252 K) superimposed.

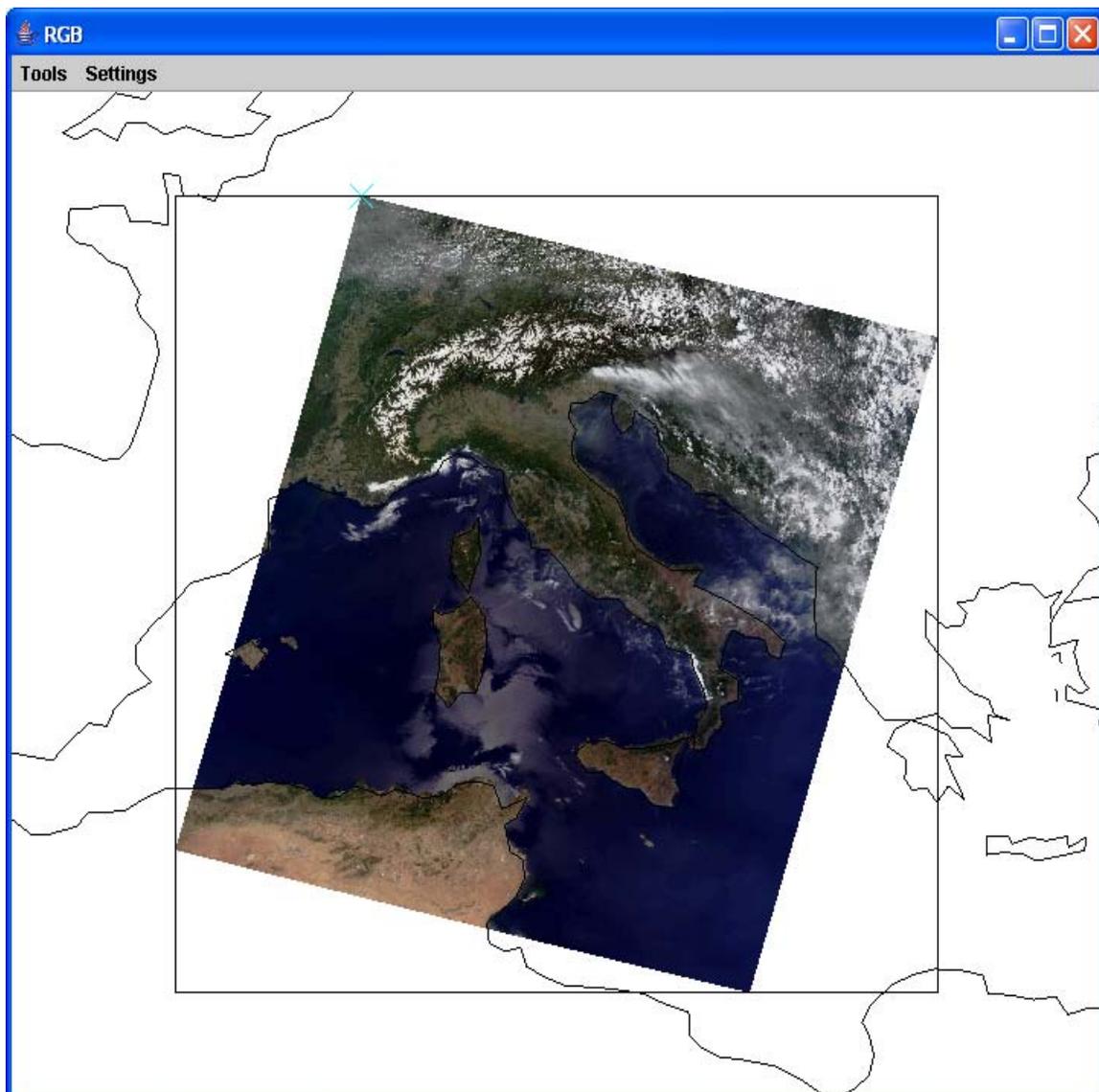


Figure 1b: A pseudo RGB image composed in the “Multi-Channel Viewer” using the RGB option under “Tools.” The red channel is using channel1 (0.65 microns), the green channel is using channel 4 (0.56 microns), and the blue channel is using channel 3 (0.47 microns). The reflected solar contributions in the Mediterranean Sea are clearly visible.

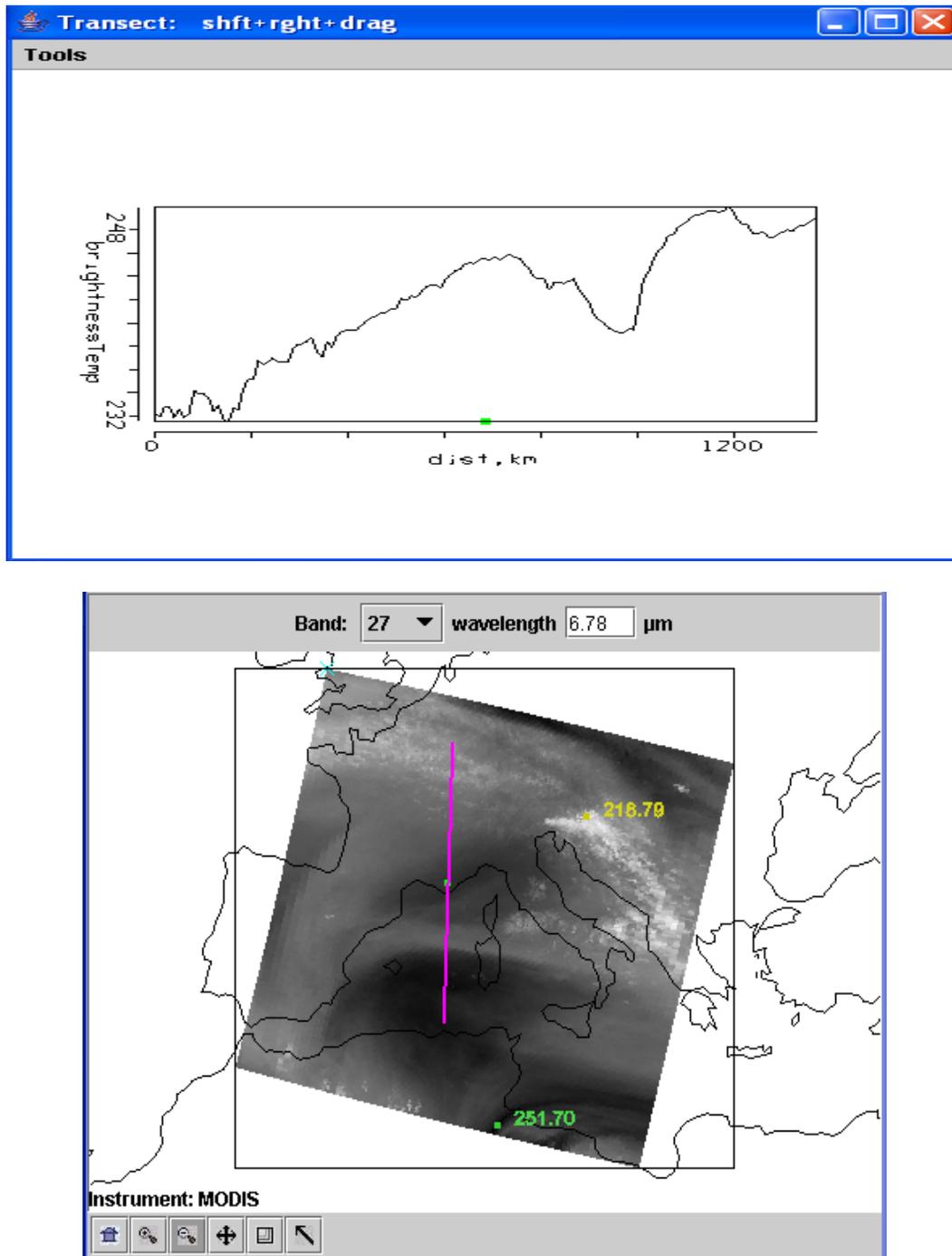


Figure 1c: Water vapor brightness temperatures (top) for a transect in the 6.78 micron water vapor brightness temperature image (bottom) starting at clouds in northern Europe and progressing through the Alps and then through two dry regions west of Italy. The two dry regions are more than 10 K warmer than the moister region.

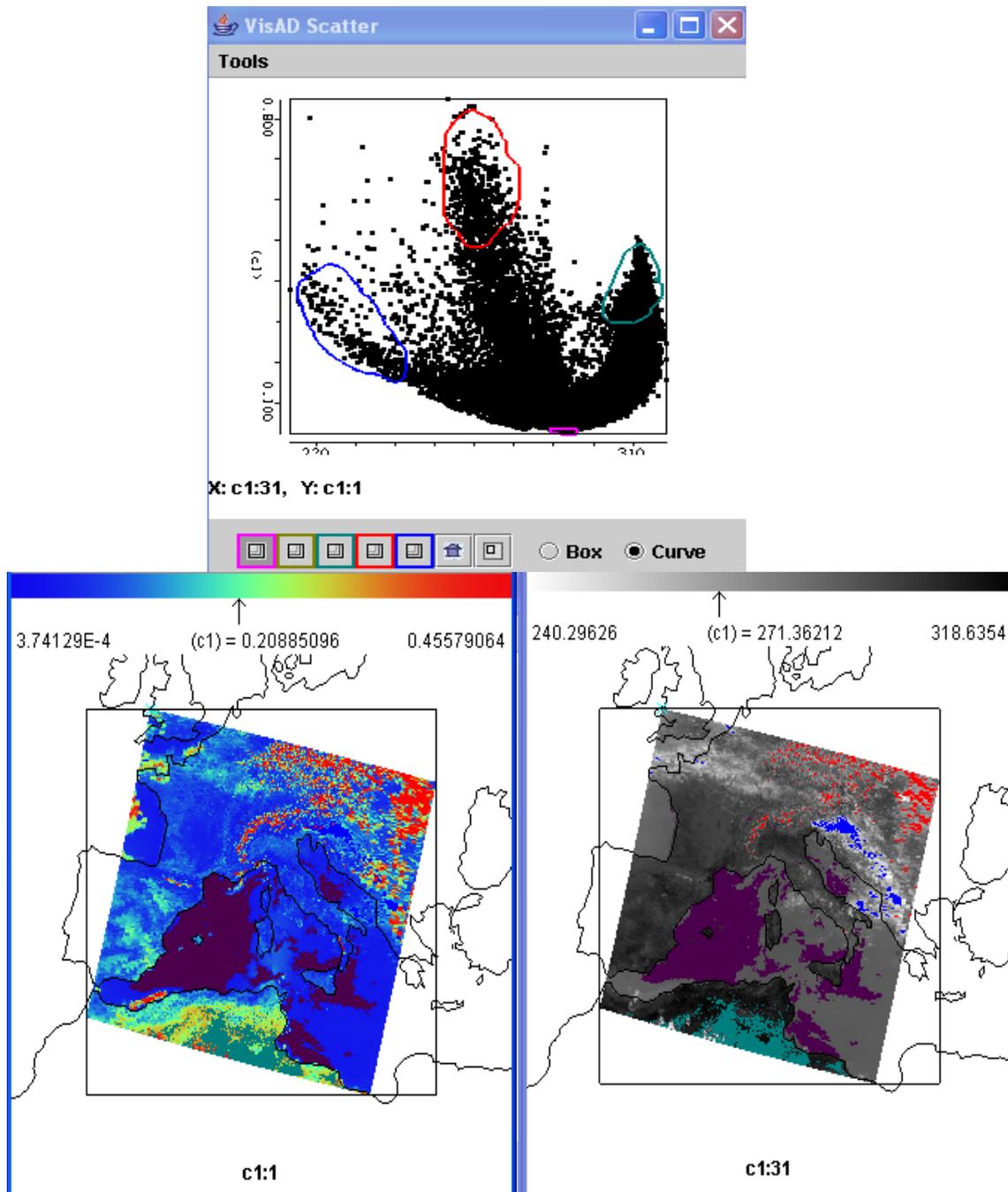


Figure 2: Screens enabled by the Channel Combinations tool. Visible reflectances (color enhanced in the bottom left panel with near zero reflectance blue, 20% reflectance green, and 50% reflectance red) are plotted on the y-axis against infrared window 11 micron brightness temperatures (in the bottom right panel where cold temperatures of 240 K are white and hot temperatures of 319 K are black) on the x-axis in a scatter plot (top panel). Pixels in the scatter plot are high-lighted in different colors and their locations are marked in the visible reflectance and infrared window image.

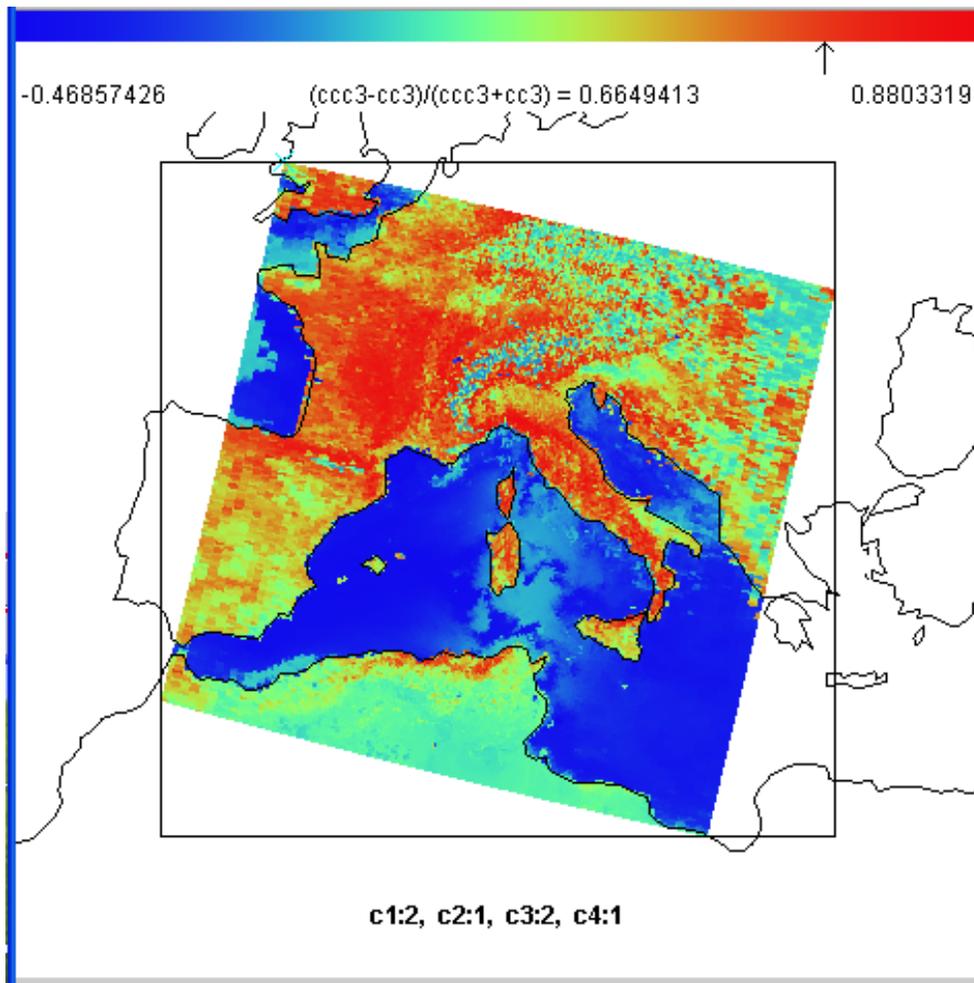


Figure 3: A pseudo image of normalized vegetation index constructed with MODIS reflective bands [band 2 (0.86 μ m) – band 1 (0.65 μ m)] / [band 2 (0.86 μ m) + band 1 (0.65 μ m)]. Dry desert-like regions in the northern regions of Africa show vegetation indices below 0.2 (turquoise); fertile river valleys and coastal regions show indices above 0.6 (red). Ocean areas show negative values (blue). The arrow indicates the median value in the scene.

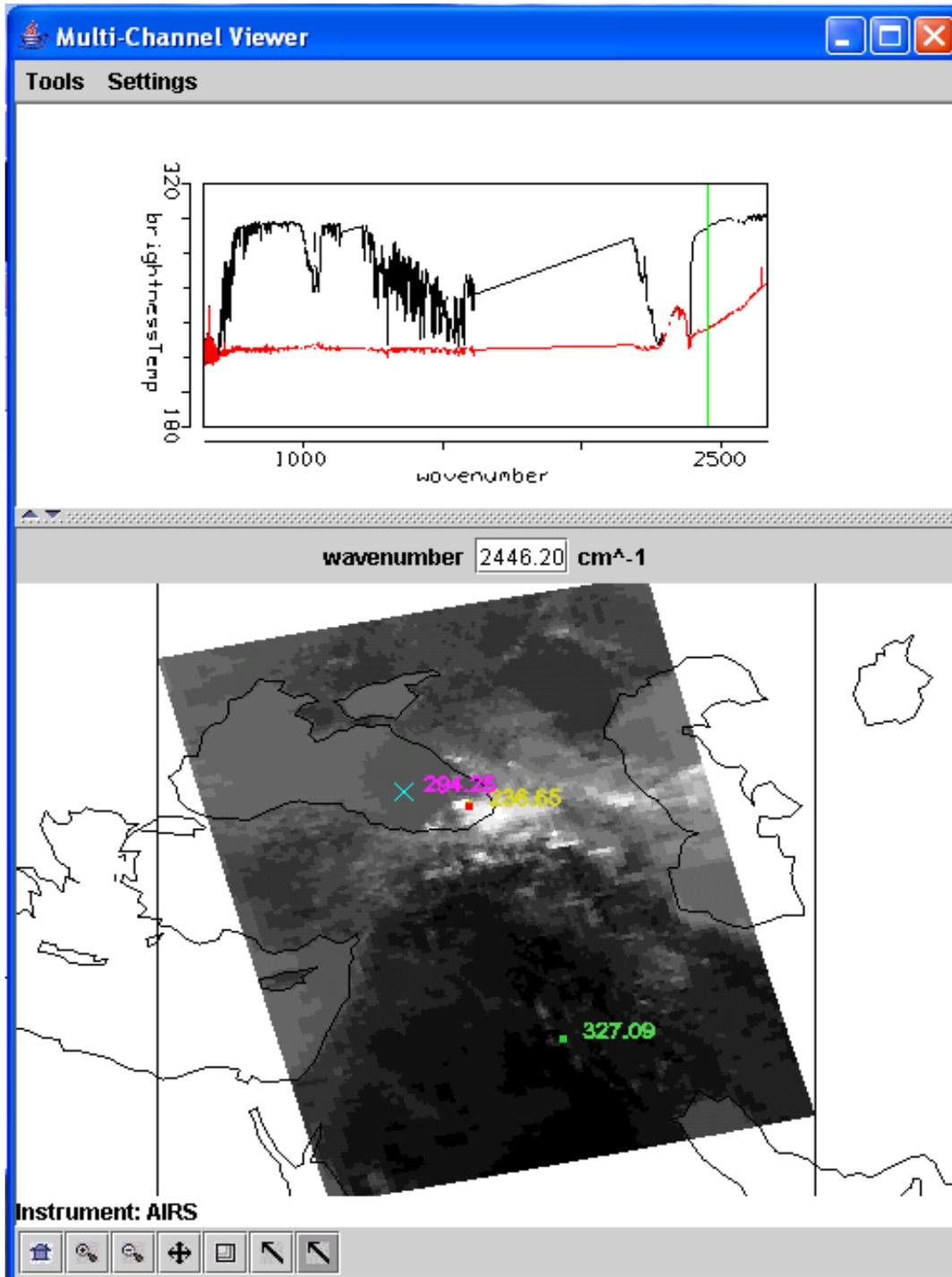


Figure 4a: Multi-Channel Viewer display of AIRS data over the Black and Caspian Seas on 28 August 2005 showing spectra (top) and short wave (2446 cm⁻¹) infrared window image (bottom). Brightness temperature spectra from 650 to 2550 cm⁻¹ are measured by AIRS over the pixel in the Black Sea (marked by the cross) and over the nearby pixel in the high clouds (marked by the red dot). Straight lines in the spectra cover the spectral gaps in the AIRS measurements. Black Sea brightness temperatures in the infrared window regions are near 300 K while the cloud top temperatures are about 220 K.

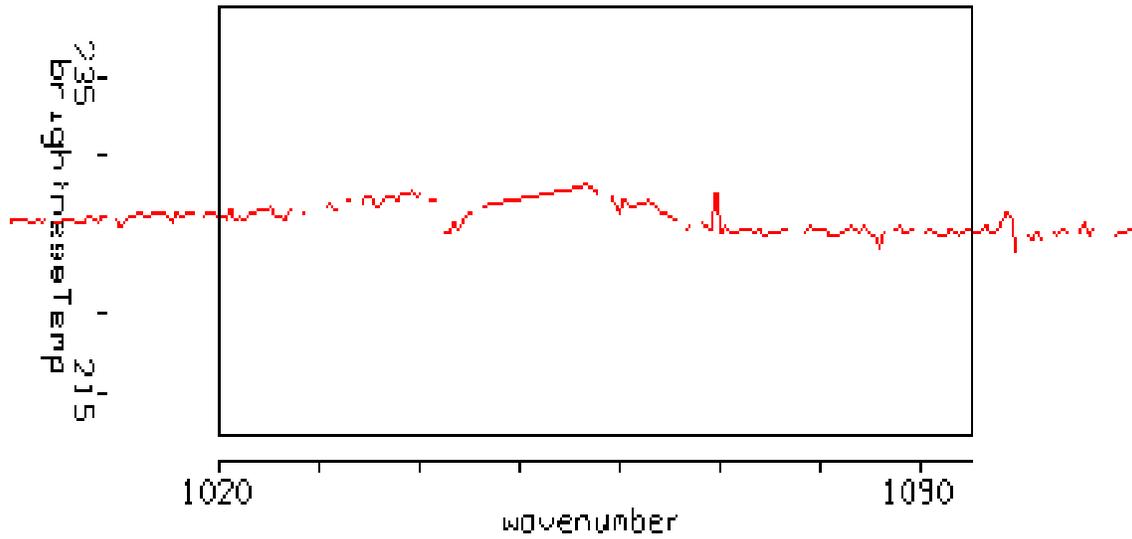


Figure 4b: Zoom to the ozone absorption region near 1050 cm⁻¹ in the spectra observed over the cloudy pixel (marked by the red dot in Figure 4a). Cloud temperatures get warmer by about 3 K in the spectral region that is more opaque to ozone indicating that the cloud top is likely in the stratosphere.

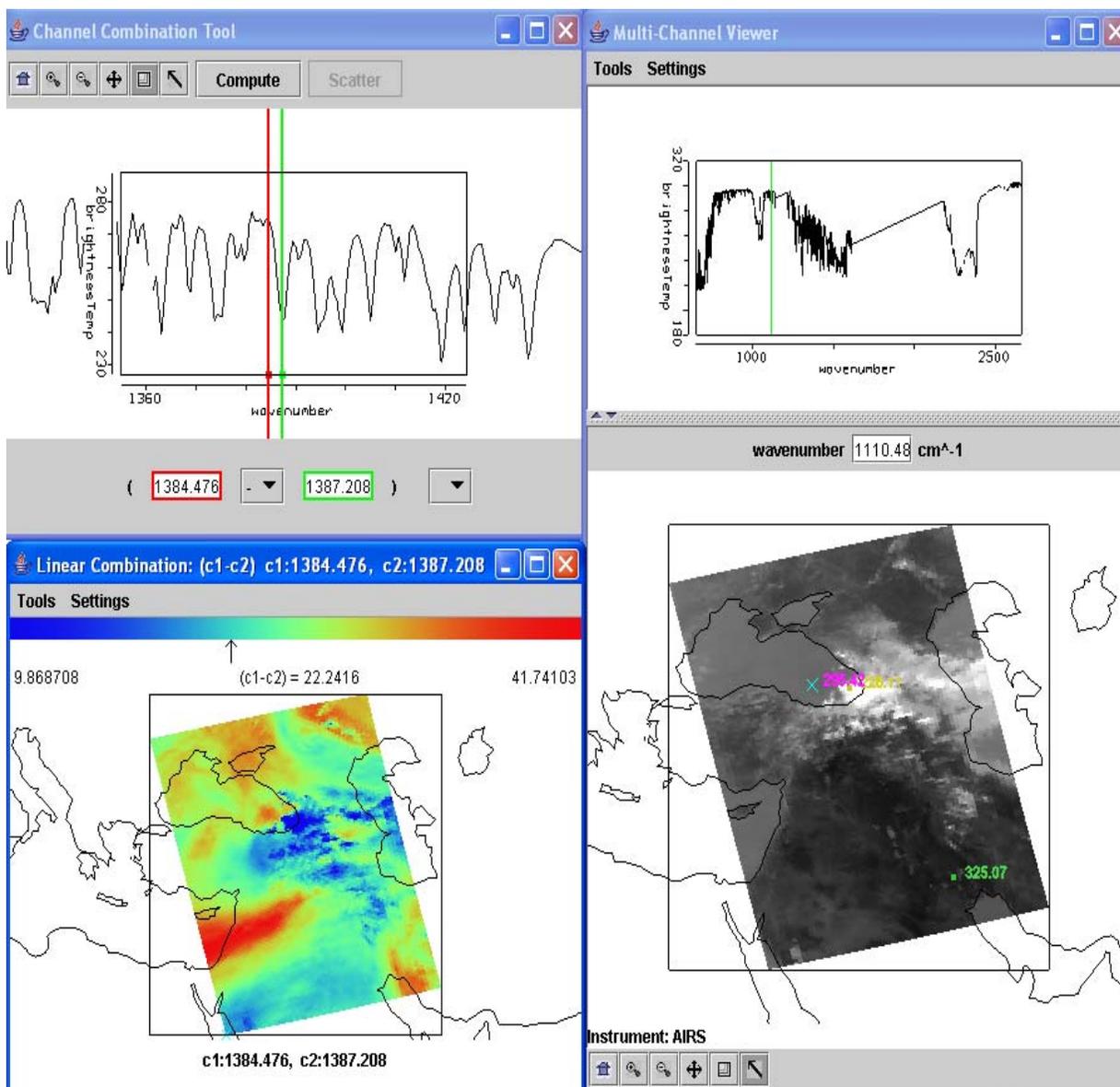


Figure 5: (Right) AIRS measured spectrum in western part of Black Sea (marked by x) and the infrared window image from 1110.5 cm^{-1} . (Top left) Channel Combinations display of brightness temperature spectrum between 1420 and 1360 cm^{-1} in the water vapor absorption spectral region. (Bottom left) Brightness temperature differences between 1384.5 cm^{-1} (off the water vapor rotational absorption line) minus 1387.2 cm^{-1} (on the water vapor rotational absorption line). Brightness temperature differences of more than 40 K are seen in clear regions and less than 1 K in opaque high cloudy regions, indicating the spectral and spatial sensitivity of the AIRS measurements.

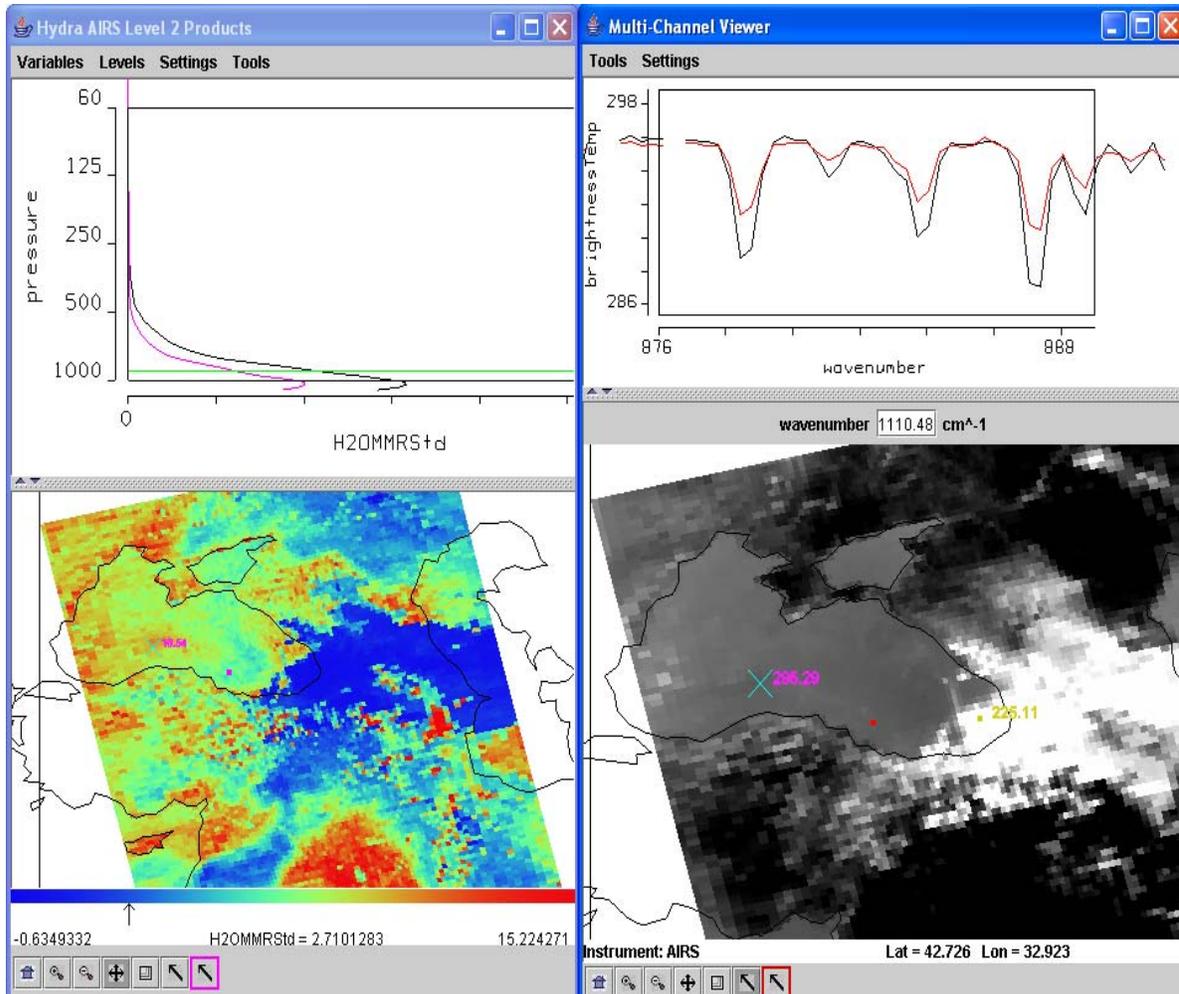


Figure 6: (Top right) AIRS measured spectra from 876 to 888 cm⁻¹ in western (marked by x) and eastern (marked by red dot) locations in the Black Sea in the infrared window image from 1110.5 cm⁻¹. The on-line off-line brightness temperature difference is greater in western location of the Black Sea. (Bottom right) AIRS 1110.5 cm⁻¹ brightness temperature image indicating the two locations in the Black Sea for the measured spectra shown top right. (Top left) Water vapor profiles in mm associated with the western (black profile) and eastern (purple profile) locations in the Black Sea. The western location is substantially moister. (Bottom left) Image of water vapor retrieval field at 900 hPa for the AIRS granule showing the gradients more clearly (with blue indicating little or no 900 hPa moisture and red indicating 15 mm) .

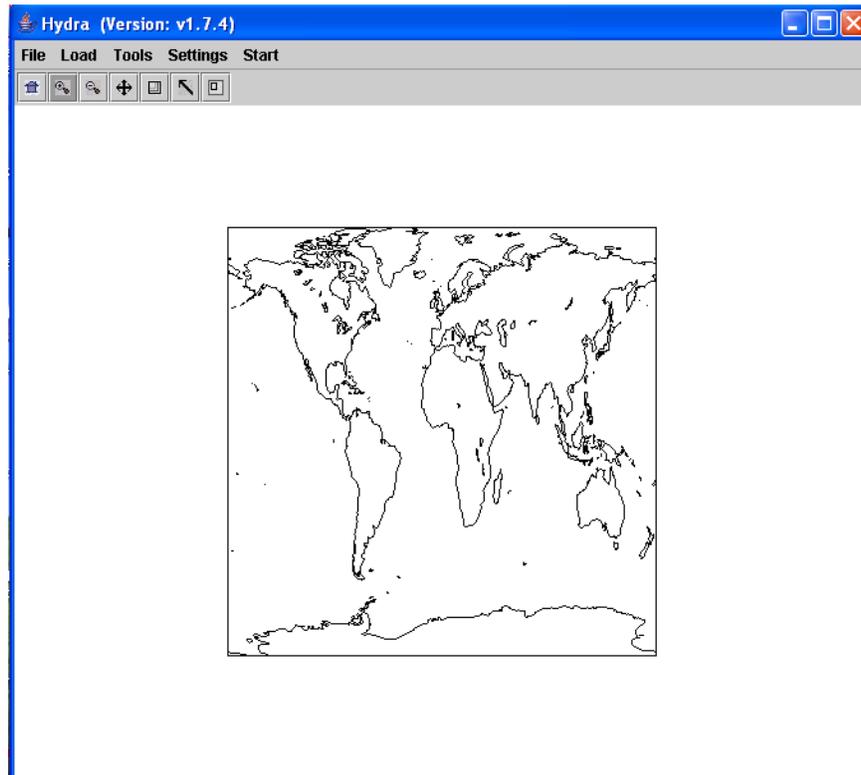


Figure A1: The HYDRA window.

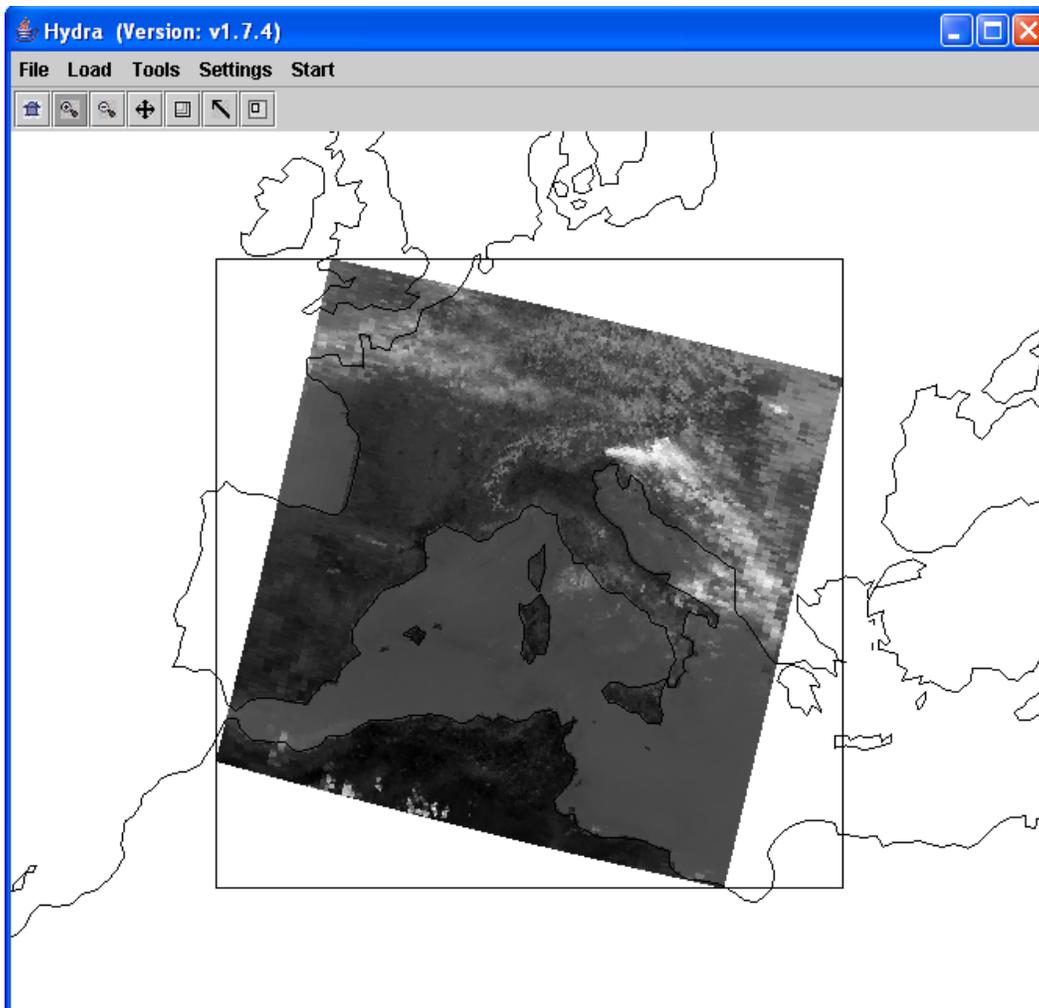


Figure A2: HYDRA window with the 29 May 2001 MODIS L1B 1KM granule loaded.

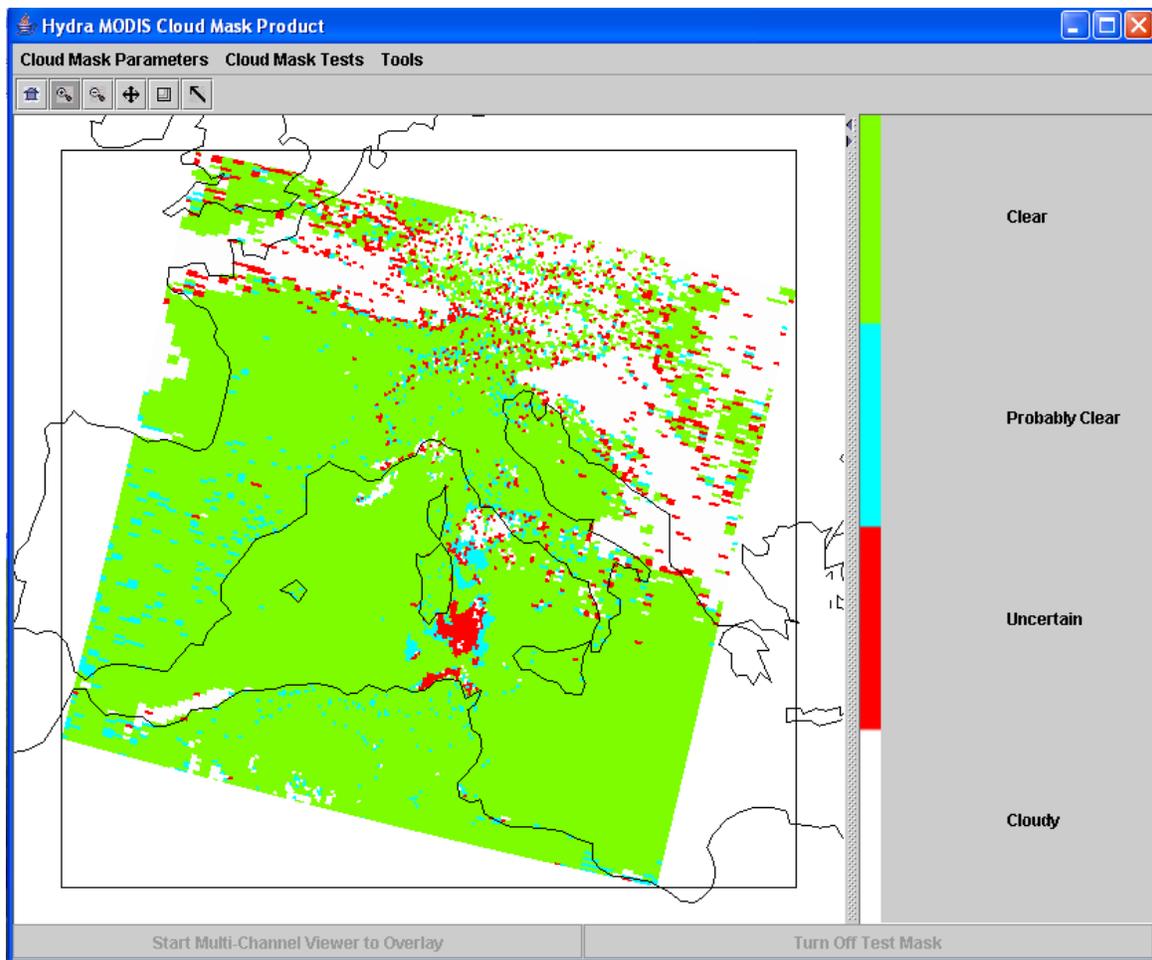


Figure A3: HYDRA MODIS level 2 products display of the cloud mask for 29 May 2001 granule over Europe. Clear is indicated by green, probably clear (95% certain) by turquoise, uncertain by red (prevalent around cloud edges), and cloudy by white.

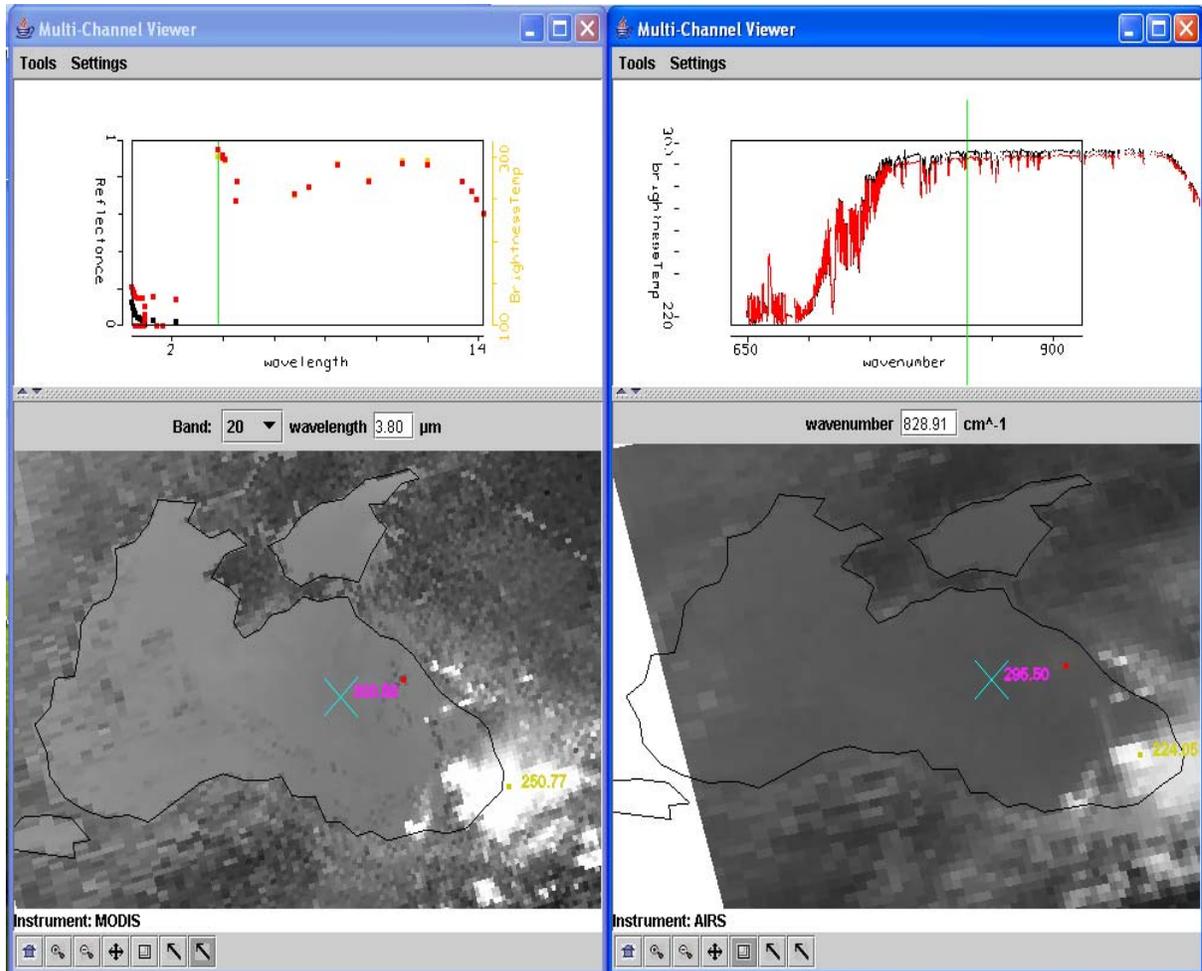


Figure A4: HYDRA with AIRS (right) and MODIS (left) co-located display of spectra. The MODIS 3.8 micron image is indicating some cloud contamination in the location of the red dot; the cloudy spectra (red) is cooler than the clear sky spectra in the location of the cross (yellow). The AIRS 828 cm⁻¹ (~12 micron) image does not reveal the cloudiness but the clear sky spectra (black) is slightly warmer than the suspected cloudy spectra (red).