HYDRA2 – A Multispectral Data Analysis Toolkit for sensors on Suomi NPP and other current satellite platforms

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Abstract

The HYper-spectral data viewer for Development of Research Applications version 2 (HYDRA2) is a freeware-based multispectral analysis toolkit for satellite data that assists scientists in research and development as well as education and training of remote sensing applications. HYDRA2 users can explore and visualize relationships between sensor measurements (brightness temperatures for infrared and reflectances for visible/near infrared wavelengths) using spectral diagrams, cross sections, scatter plots, multi-band combinations, and color enhancements on a pixel by pixel basis.

HYDRA2 can be used with direct broadcast and archived data from sensors onboard the NOAA/NASA Suomi National Polar-orbiting Partnership (S-NPP), NASA Aqua/Terra, EUMETSAT MetOp, and Chinese Feng Yun-3 platforms.

This paper describes HYDRA2 and presents some examples using data retrievals from

the S-NPP Visible Infrared Imaging Radiometer Suite (VIIRS), Cross-track Infrared Sounder (CrIS), Advanced Technology Microwave Sounder (ATMS), as well as Terra/Aqua Moderate resolution Imaging Spectro-radiometer (MODIS) instruments.

1. Overview of HYDRA2

HYDRA2 (Hyper-spectral data viewer for Development of Research Applications version 2) is an update to the capabilities of HYDRA (Rink et al., 2007). The "HYDRA" concept is based on over 10 years of continued development of interactive satellite data interrogation and visualization tools offered at the University of Wisconsin's (UW) Space Science and Engineering Center (SSEC) remote sensing workshop series (http://cimss.ssec.wisc.edu/rss/) and direct broadcast seminars (http://cimss.ssec.wisc.edu/dbs/). The salient requirements for HYDRA2 remain similar to those of its predecessor: it must be (a) freely available to the global community, (b) computer platform independent, and (c) extendable. Essentially, HYDRA2 is a stand-alone app based on the VisAD (Visualization for Algorithm Development, Hibbard et al., 2002) Java library to integrate data from various satellite sensors, ground based instruments, and forecast models into very interactive, high performance, 2D/3D displays.

A primary motivation of this new effort is to support the Suomi National Polar orbiting Partnership (S-NPP) and the upcoming Joint Polar Satellite System (JPSS) missions, as well as maintaining existing support for the MODIS sensors onboard the Terra and Aqua platforms.. To achieve this, HYDRA2's custom VisAD data adapters for cross-track polar swath were improved to have greater flexibility and a more clearly defined programmatic interface. These improvements also facilitated the transitioning of datasets onboard the MetOp and FengYun (FY) satellite series into HYDRA2 with only a modest level of effort.

HYDRA2 enables the user to inspect multispectral (broad band and hyperspectral) fields of data so that (a) spectral measurements can be easily displayed at pixel locations; (b) colors can be assigned to pixel values and false color images can be viewed; (c) images of spectral band combinations can be constructed; (d) scatter plots can be determined from imagery containing individual or combined spectral bands; individual pixel values can be obtained either from scatter plots or imagery; (e) transects of measurements from imagery can be displayed, and (f) measured spectra and the derived temperature and moisture profiles from individual pixels can be displayed and studied.

Many improvements in the user interface and analysis tools have been implemented in HYDRA2 based on ongoing user feedback. These include: (1) linking the zooming, roaming, and interrogation between multiple image display windows, (2) combining spectral bands or linear combinations of spectral bands from multiple sensors (e.g., MODIS and VIIRS) onto a single image display, (3) managing datasets in a consistent manner, (4) eliminating VIIRS and MODIS cross-track scan “bowtie” artifacts in the re-gridding process, (5) aggregating consecutive and separate file granules into a single cohesive image, and (6) enabling image display export to KML/KMZ for transport to Google™ Earth.

The evolution from HYDRA to HYDRA2 has been motivated, in part, by rapid advancements in software development technology over the last decade. HYDRA2 consists of a higher functioning Java class-only application compared to the slower performing Jython scripting language used in HYDRA. Perhaps more importantly, the software components that comprise HYDRA2 have been generalized so that any scripting language that supports Java (e.g. Jython or JRuby) can be used to develop, for example, a user-defined computation interface. HYDRA2 employs the Java-NetCDF library, which is the Java implementation of Unidata's CDM (Common Data Model), for access to HDF4/5 format data which is currently used in MODIS and several S-NPP instruments. The Java-NetCDF library merges the storage data models of many file formats, including, but not limited, to NetCDF3/4, GRIB1/2 and WMO BUFR, to create a common application program interface (API) for many types of scientific data including multi-dimensional arrays. This updated version effectively provides computer platform and storage format independent access from a single library.

HYDRA2 uses the NetBeans© IDE (Integrated Development Environment) from Oracle®, which improves the processing efficiency of more robust source code development. HYDRA2 is deployed with platform-specific point and click installers generated by Install4j© from EJ-Technologies. The YourKit Java profiler is employed to reduce any excessive and wasteful allocation of CPU memory during runtime.. Source code revision management is handled within a GitHub repository via Git integration in NetBeans©. Unlike HYDRA, HYDRA2 is entirely self-contained within the installer, i.e., no additional libraries are needed. Graphics card drivers still require upgrades, when necessary.

The following sections provide some examples of HYDRA2 analyzing data from S-NPP that include VIIRS, CrIS, and ATMS – see eoPortal https://directory.eoportal.org/web/eoportal/satellite-missions/s/suomi-npp. HYDRA2 is also capable of viewing and interrogating data from the Terra and Aqua platform sensors that includes MODIS and the Atmospheric Infrared Sounder (AIRS) – see eoPortals https://directory.eoportal.org/web/eoportal/satellite-missions/a/aqua and https://directory.eoportal.org/web/eoportal/satellite-missions/t/terra. In addition, data from the MetOp (Klaes et al. 2007) Infrared Atmospheric Sounding Interferometer (IASI), Advanced Very High Resolution Radiometer (AVHRR), High resolution Infrared Radiation Sounder (HIRS), and Microwave Humidity Sounder (MHS) can also be displayed – see eoPortal https://directory.eoportal.org/web/eoportal/satellite-missions/m/MetOp. And recently, data from the FY-3 (see https://directory.eoportal.org/web/eoportal/satellite-missions/pag-filter/-/article/fy-3) Medium Resolution Spectral Imager (MERSI) was also added to the HYDRA2 capabilities.

2. Examples of Spectral Band Applications with HYDRA2

Expanding on the capabilities of HYDRA, HYDRA2 enables display and interrogation of the available spectral bands (22 for VIIRS and 36 for MODIS) for any pixel within a granule of data. Reflectance or brightness temperatures can be displayed for individual pixels within the granule. Red-green-blue (RGB) composites using any combination of single and/or multiple spectral bands can be created. Transects from one location to another can be constructed for a given spectral band to determine a variety of remote sensing characteristics, e.g., min/max values, pattern matching (clouds vs other features), gradients, etc.

Figure 1 shows the VIIRS infrared window I5 (11.45 μm) brightness temperature image of the eye of Typhoon Vongfong from 7 October 2012 in false color (with red colder and blue warmer in an inverse rainbow color enhancement). The high spatial resolution (375 m) of VIIRS shows the eyewall structure in excellent detail. Using HYDRA2 commands, brightness temperature for each spectral band with corresponding locations (latitudes/longitudes) for each pixel can be displayed.

Figure 2 demonstrates the transect capability of HYDRA2. A transect is superimposed on the VIIRS infrared window M15 (10.8 μm) image and the associated brightness temperature values are plotted from west to east along a 1500 km line centered on the eye of Typhoon Vongfong; brightness temperatures range from 190 K (cold, clouds near the eye) to 290 K (clear skies in the eye and further away over warm ocean surfaces).

Differences of spectral bands are often useful in highlighting atmospheric or surface features. In Figure 3, a VIIRS-derived split window image was created using Band Math (IR window M15 at 10.8 μm minus the water vapor sensitive IR window M16 at 12.0 μm); the brightness temperature difference is sensitive to atmospheric moisture with larger differences usually indicating more moisture. The highest clouds associated with the typhoon on the southwest perimeter are readily apparent because of the dryness above the clouds (indicated by differences of less than 1 K).

The VIIRS Day-Night Band (DNB, centered at 0.7 μm) is shown in Figure 4 capturing the night-time illumination over a segment of the Korean peninsula on 26 August 2012 at 1619 UTC; the stark contrast between the brightly reflective industrialized regions covering South Korea versus the unlit dark environment over North Korea is readily evident. In addition, fishing activity is also noticeable within the open water region to the east and southeast of South Korea. The DNB offers a new dimension of imaging capability, that of low light visible reflectances at night. Miller et al. (2012) provide more details on the new remote sensing opportunities offered by the VIIRS DNB.

HYDRA2 has the capability to compare measurements between any two sensors. Figure 5 shows a comparison of the brightness temperatures measured by MODIS (band 31, 11.0 μm) in the lower left and the VIIRS high resolution imager (band I5, 11.5 μm) in the lower right on 30 August 2012 over the southern portion of South Korea, the island of Jeju-do, and the open waters nearby. The overpass times are separated by less than 20 minutes. The higher spatial resolution of the VIIRS measurements (0.375 km) reveals sharper details than MODIS (1 km at nadir) across the coastline; this is evident in the annotated transect where the corresponding brightness temperature plot reveals a more detailed VIIRS profile (shown in magenta) versus the smoother MODIS profile (shown in green). The finer detail provided by VIIRS is most apparent away from nadir; VIIRS nadir resolution is constrained to grow by a factor of 2 across the entire swath, while the MODIS pixel size grows unconstrained to roughly 6 times by the edge of a narrower swath. In summary, HYDRA enables detailed comparisons of measurements between different sensors in transects, overlays, and scatter plots.

Figure 6 shows a scatter plot of visible (0.55 μm) reflectances plotted on the y-axis against infrared window (10.8 μm) brightness temperatures on the x-axis. Different colors highlight pixels in the scatter plot that are associated with regions circled in the visible reflectance image (purple shows cold and reflecting cloud pixels, green warm and non-reflecting vegetated surfaces, and blue warm and non-reflecting ocean). When two HYDRA windows have been established (containing a spectral band image, or spectral band combination image, or a derived product image) a scatter plot of the values in both windows can be compared against each other. In the scatter plot configuration, one can locate values either within the scatter plot or its corresponding imagery. Locating pixels in the scatter plot and associating them with pixels in the window display image as well as vice versa enables users to estimate threshold values for discriminating certain land, ocean, or atmospheric features.

Figure 7 shows the HYDRA2 display of the VIIRS DNB image over Columbia, South America on 30 January 2015 transferred to Google Earth mapping; this enables the colocation tools from Google Earth to be applied to the HYDRA2 data set. This example further demonstrates the ability to differentiate lightning versus city lights; west of the city lights around Medellin one finds illumination that cannot be associated with any city and is likely caused by cloud to cloud lightning.

HYDRA2 also has the capability to display several MODIS Level 2 Atmospheric product files; they include the following:

MOD04: Aerosol products

MOD06: Cloud products

(see Figure 8 for an example display of the MODIS cloud top pressure)

MOD14: Thermal Anomalies - Fires and Biomass Burning

MOD28: Sea Surface Temperature

MOD35: Cloud Mask

Figure 8 shows the derived product image of the Aqua MODIS cloud top pressure associated with 30 August 2012 at 440 UTC; two cloud groups, the first at ~300 hPa and the second at ~800 hPa, are evident. HYDRA2 will incorporate the display of VIIRS Environmental Data Record (EDR) products in the near future.

3. Hyperspectral and microwave data analysis with HYDRA2

HYDRA2 can also be used to analyze granules of hyperspectral CrIS data in much the same way AIRS data were analyzed with HYDRA (Rink et al., 2007). Colocation in space and time is readily displayed with HYDRA2 for the VIIRS, CrIS, and ATMS sensors on S- NPP (as well as with MODIS and AIRS sensors on Terra and Aqua and the IASI sensors on MetOp). This section will demonstrate HYDRA2 analysis tools for viewing CrIS and ATMS data separately and together.

Figure 9 shows the HYDRA2 display of CrIS data over Typhoon Vongfong on 7 October 2012. The top panel displays a spectrum measured by CrIS over a clear pixel well away from the typhoon center (shown in aqua) and another spectrum measured over clouds near the eye of the typhoon (shown in black). The brightness temperature infrared window image at 902.25 cm-1 (bottom panel) shows warm and cold regions. Within the spectrum plot, the clear brightness temperature spectrum (in black) shows the absorption of CO_2 at ~660 cm-1, O_3 at ~1050 cm-1, and H_2O at ~1500 cm-1 (causing notably cooler brightness temperatures in the positive lapse rate troposphere). The cloudy brightness temperature spectrum is remarkable for the near constant temperature regardless of wavenumber, indicating that the observed cloud is so high that above it there is very little H_2O and only small amounts of CO_2 and O_3 (causing somewhat warmer brightness temperatures in the negative lapse rate stratosphere).

CrIS measurements (at roughly 15 km spatial resolution) are used to derive temperature and moisture profiles in clear skies and above clouds (portions of the atmosphere where the measurements of at least some of the CrIS spectral bands are not affected by clouds). Figure 10 shows the stratospheric temperatures at 96.1 hPa (above the typhoon) derived using a Dual Regression profile retrieval (Weisz et al., 2013) along with a sounding of air temperature along the vertical pressure axis above the clouds at a position (annotated by 187.73 K) northwest of the typhoon and another position (annotated by 198 K) in the center of the eye. This remarkably well-formed eye, captured in a near perfect nadir view by CrIS on Suomi-NPP, reveals warm temperatures (290 to 300 K) for the lowest 400 hPa in the troposphere.

ATMS measurements provide a sounding capability in clear and cloudy (non-precipitating) conditions, albeit at relatively coarse (~50 km) spatial resolution. Figure 11 shows the image of ATMS brightness temperatures measured at 31.4 GHz (channel 2) over Typhoon Vongfong coincident with the VIIRS and CrIS data (shown in Figure 10) along with brightness temperature spectra covering clear conditions (annotated by 262.56 K) within the eye and cloudy features (annotated by 186.09 K) to the northwest of the eye. The absorption features in the spectrum caused by O_2 (centered on channel 10 at 57.3 GHz) and H_2O (centered on channel 18 at 183.3 GHz) are evident as colder temperatures within the clear eye region. An additional contribution to the radiation in the microwave spectrum is the reflection from the surface (especially the ocean) in the more transparent spectral channels.

Figure 12 shows a scatter plot of ATMS 31.4 GHz brightness temperatures (x-axis) versus CrIS derived temperatures retrieved for 96.1hPa (y-axis) over Typhoon Vongfong. Different colored boxes highlight pixels in the scatter plot that are shown in the CrIS retrieval image; the cold ATMS temperatures reveal a ring of clouds in the northwest quadrant of Typhoon Vongfong while the warm ATMS temperatures isolate the ring of clouds around the eye.

4. Summary

HYDRA2 enables users from a variety of educational backgrounds to explore and investigate satellite sensor measurements. Starting from HYDRA, HYDRA2 has been adapted to accommodate data from more sensors, including those on SNPP. HYDRA2 has become a part of the Community Satellite Processing Package (CSPP) that can be found at http://cimss.ssec.wisc.edu/cspp. The HYDRA2 command structure and enhanced visualizations tools are described in more detail at:

http://cimss.ssec.wisc.edu/cspp/download/. Instructions for downloading this freeware are also provided within the website.

Acknowledgements

This paper relied on extensive user participation that consisted of many students and international colleagues in beta testing the HYDRA2 freeware. We thank them for their enthusiasm and useful feedback. Funding from the NASA IMAPP (International MODIS and AIRS Processing Package) and the NOAA CSPP (Community Satellite Processing Package) programs is also gratefully acknowledged.

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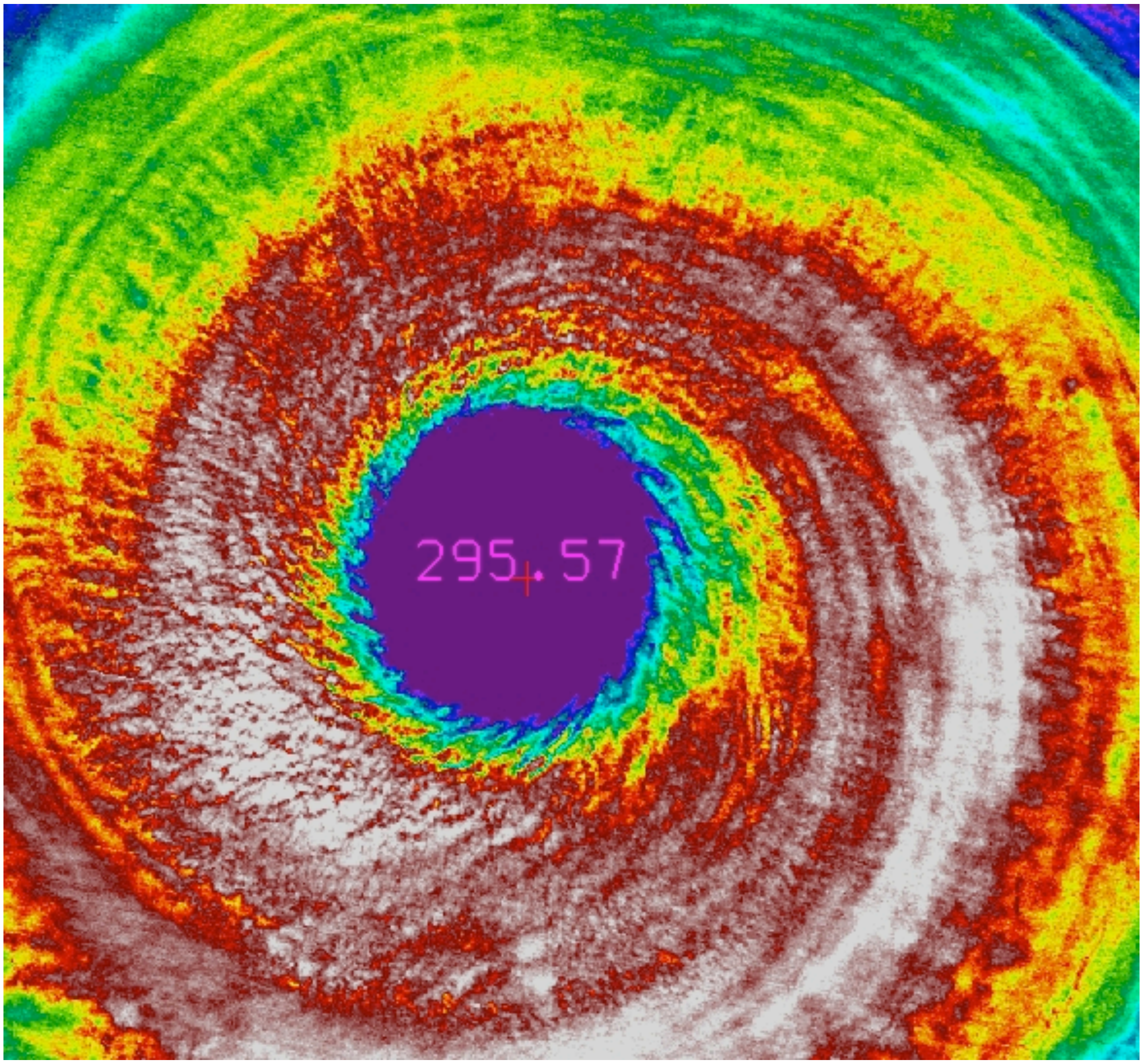


Figure 1: VIIRS infrared window image (I5, 11.5 µm) of the eye of Typhoon Vongfong on 7 October 2014 with inverse rainbow color enhancement (reds start at 190 K, greens at 195 K, and blues end at 205 K). The brightness temperature in the eye of Typhoon Vongfong is 295.6 K.

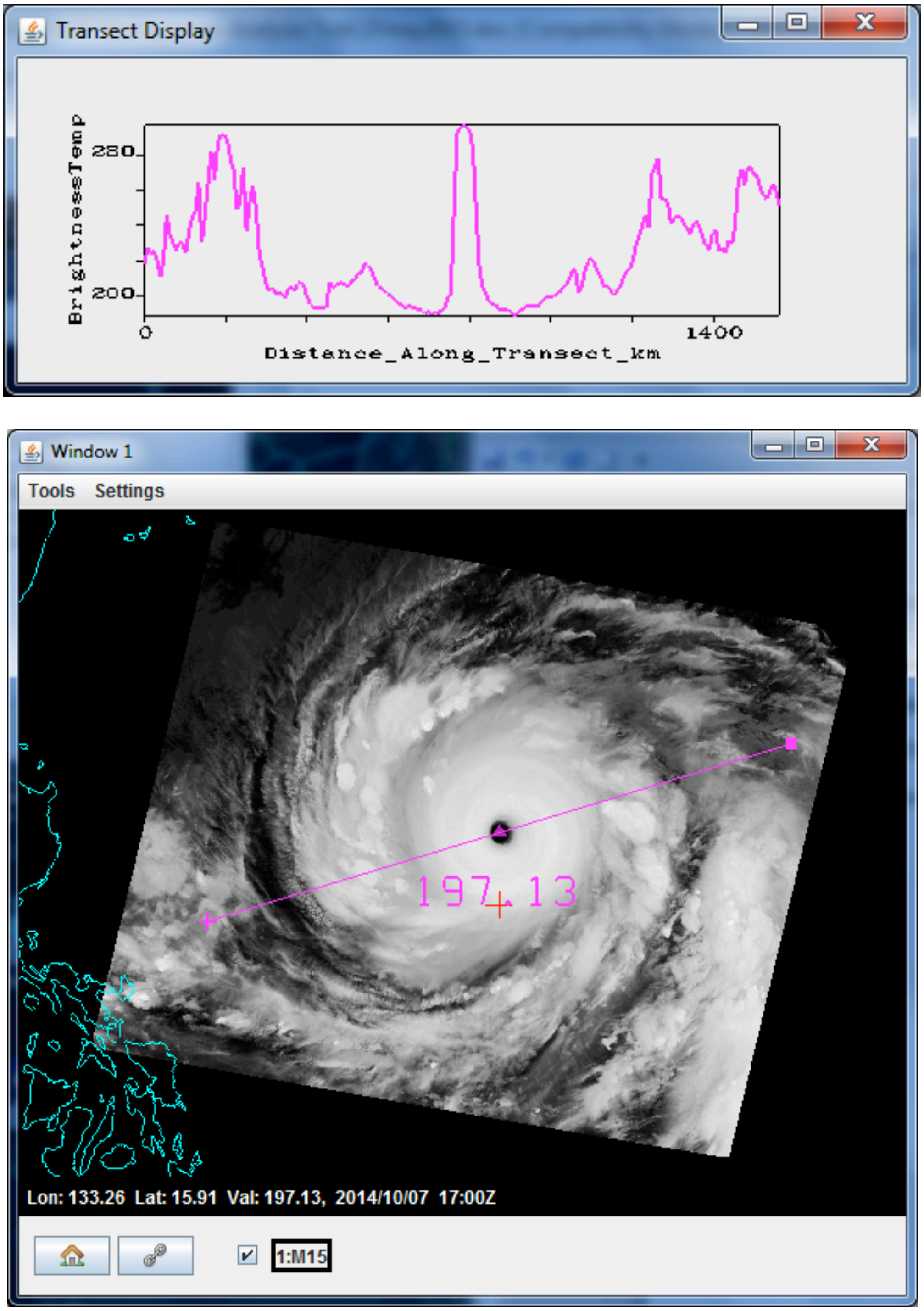


Figure 2: Infrared window brightness temperatures (top) in degrees Kelvin for the indicated transect in the 10.8 μm brightness temperature M15 image (bottom) proceeding from left (west) to right (east). Distance along the transect is indicated in kilometers.

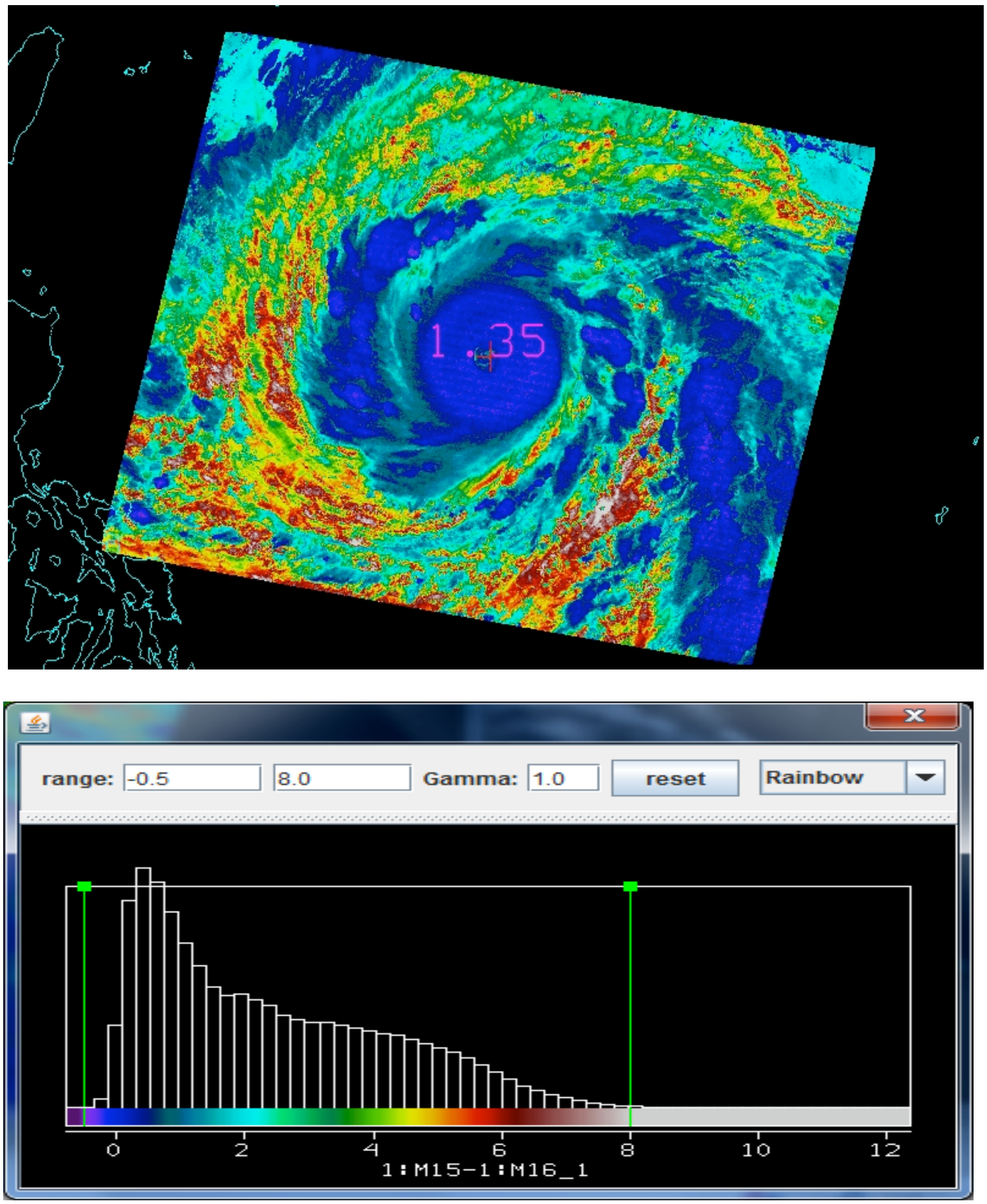


Figure 3: (top) False color image of brightness temperature difference (degrees K) between the water vapor insensitive IR window (M15) and the water vapor sensitive IR window (M16). (bottom) Color scale indicates the temperature difference along with histogram distribution within the image. Higher amounts of atmospheric moisture will produce larger differences; note the relative dryness above the high typhoon clouds.

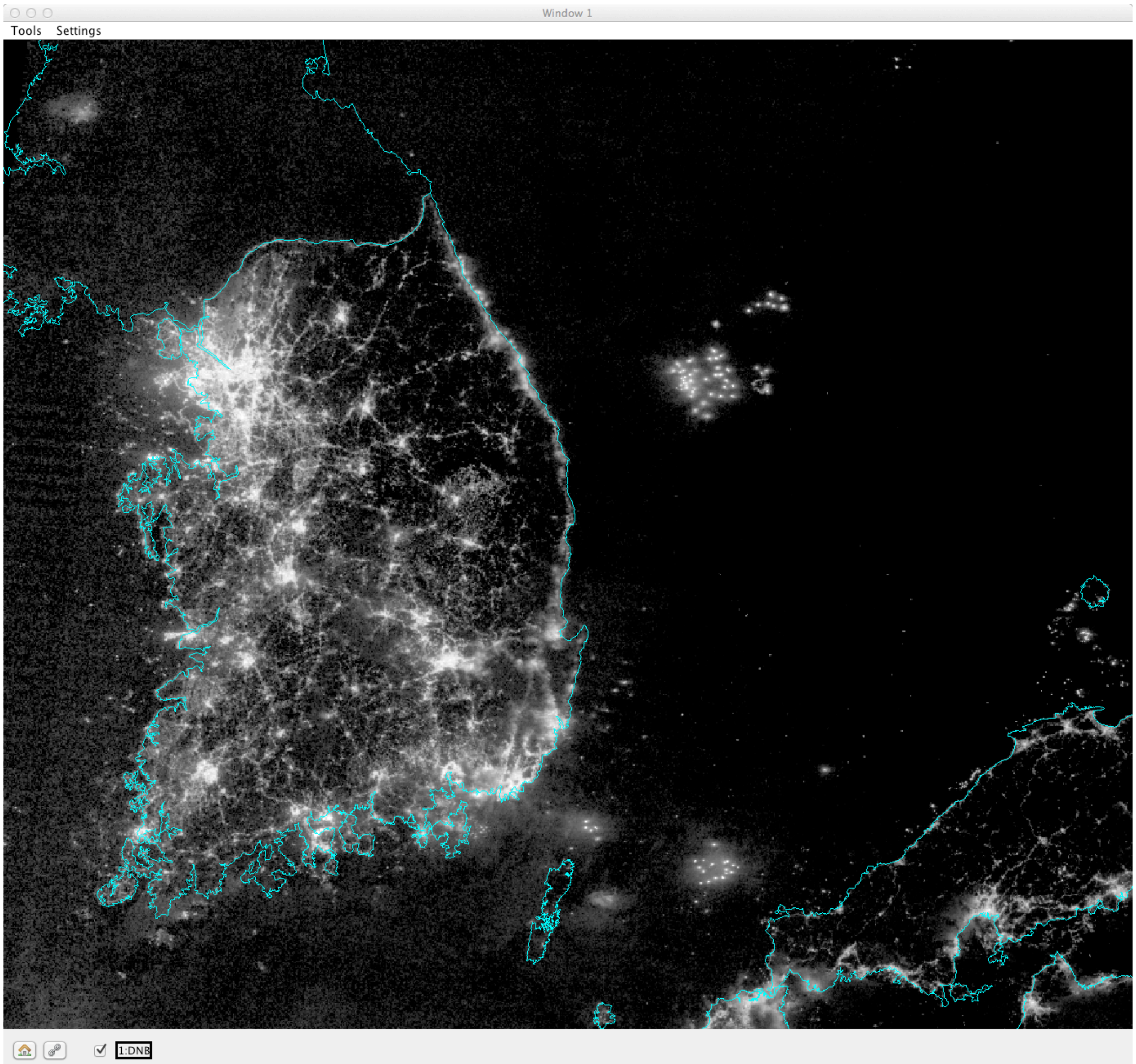


Figure 4: VIIRS DNB image of the Korean peninsula from 26 August 2012 at 1619 UTC. Lights from the cities and night time fishing are evident, as well as the stark contrast in lighting between North and South Korea.

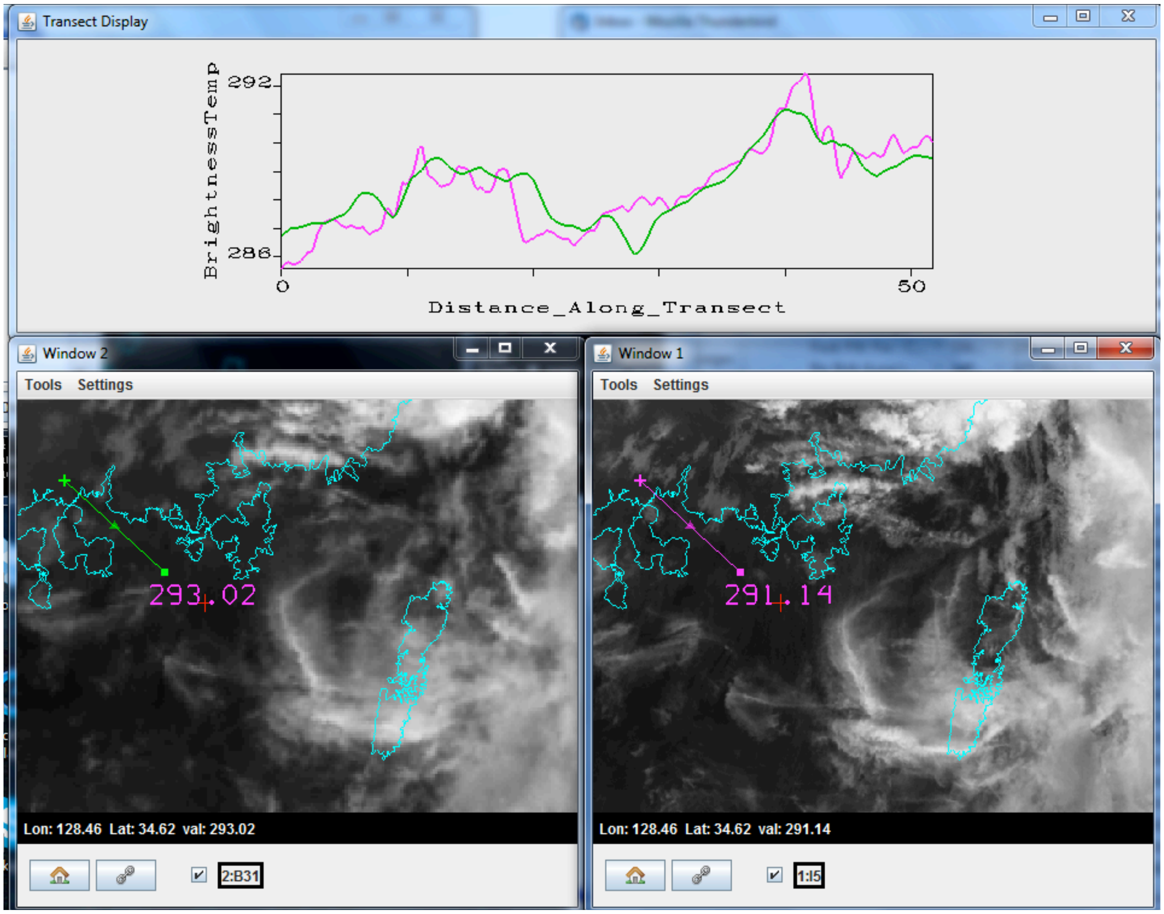


Figure 5: Comparison of 30 August 2012 VIIRS 11.5 µm infrared window I5 at 375 m nadir resolution (bottom right) from 422 UTC and corresponding MODIS 11.0 µm infrared window Band 31 at 1 km nadir resolution from 440 UTC (bottom left) along with a transect over clear skies (top). All units are in degrees Kelvin.

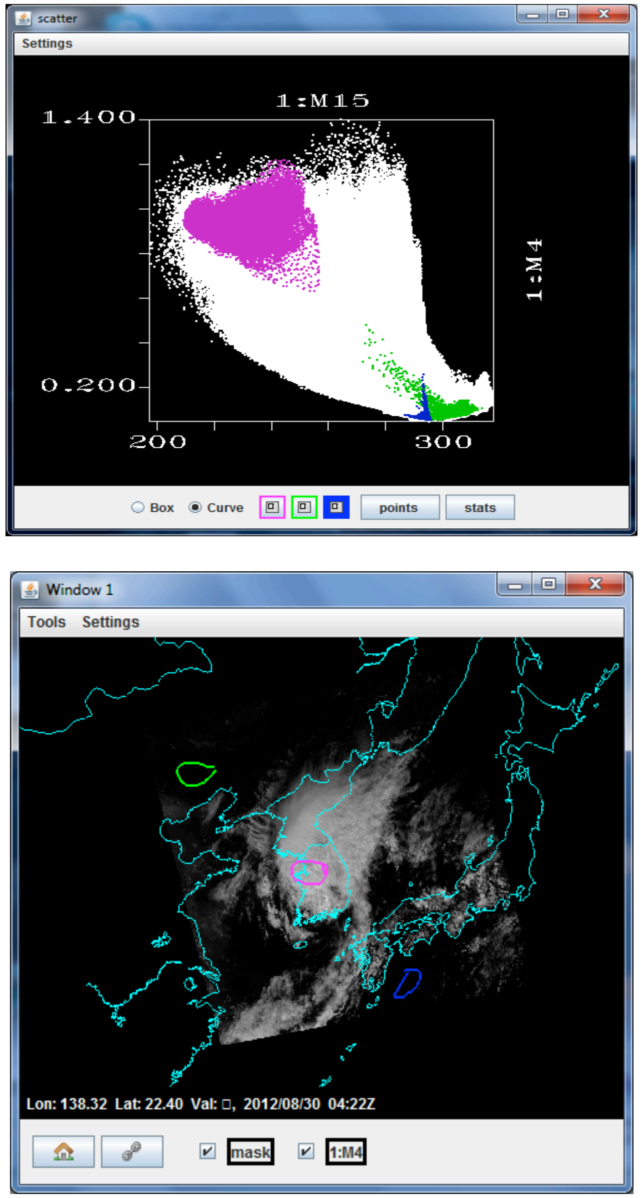


Figure 6: (top) Scatter plot of visible band M4 0.55 μm reflectances (y-axis) against infrared window band M15 10.8 μm brightness temperatures (x-axis). Pixels in the scatter plot are high-lighted in different colors and their locations are marked in the visible 0.55 μm reflectance image (bottom). Purple highlights cold and reflecting cloud, green warm and non-reflecting land, and blue less-warm and non-reflecting ocean. The color mask can be clicked on and off with the check mark.

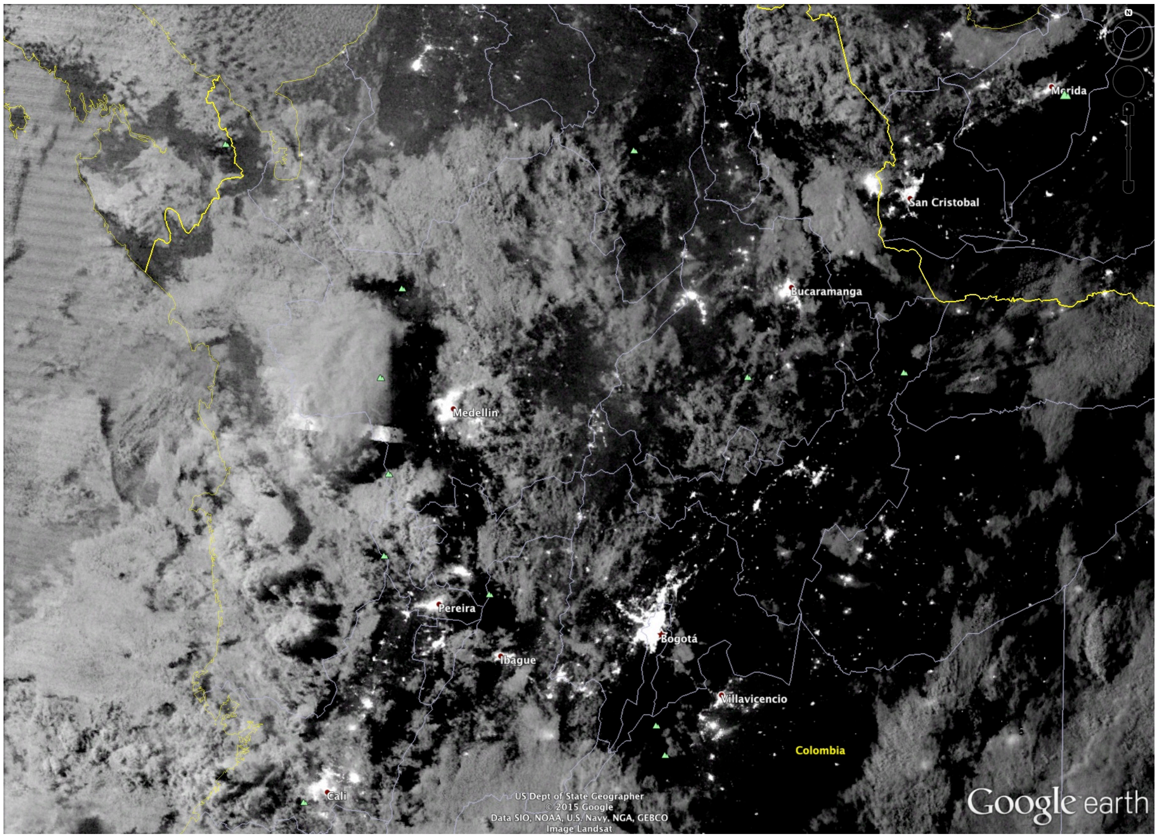


Figure 7: An example of a nighttime VIIRS visible image on 30 January 2015 over Columbia, South America as displayed over Google Earth, as part of HYDRA2 functionality.

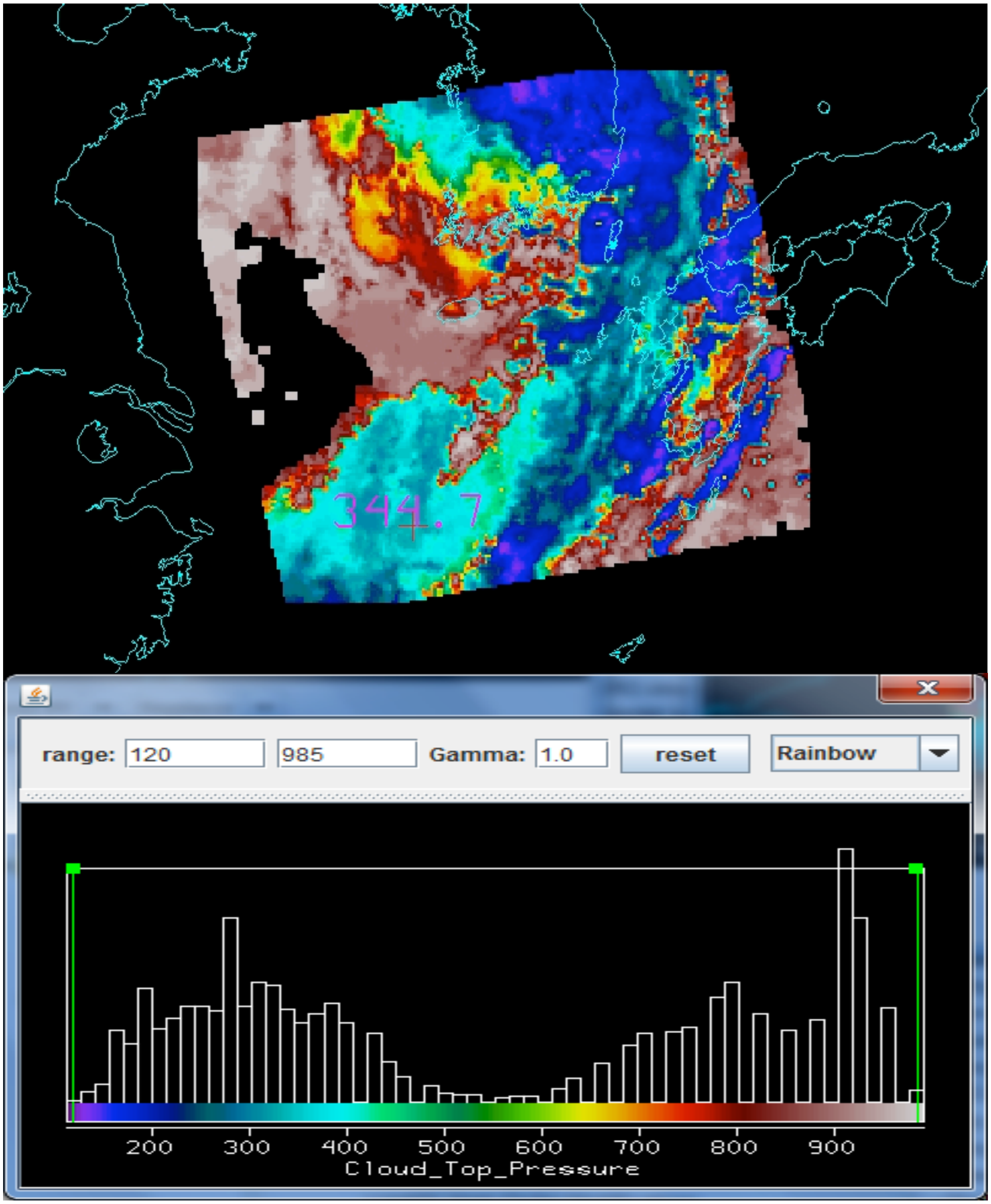


Figure 8: (Top) Derived image product of Aqua MODIS cloud top pressure levels (in hPa) from the MODIS Level 2 (MOD06) cloud properties for 30 August 2012 at 440 UTC. (Bottom) Corresponding histogram and color code of cloud top pressure levels within the entire image and associated color bar.

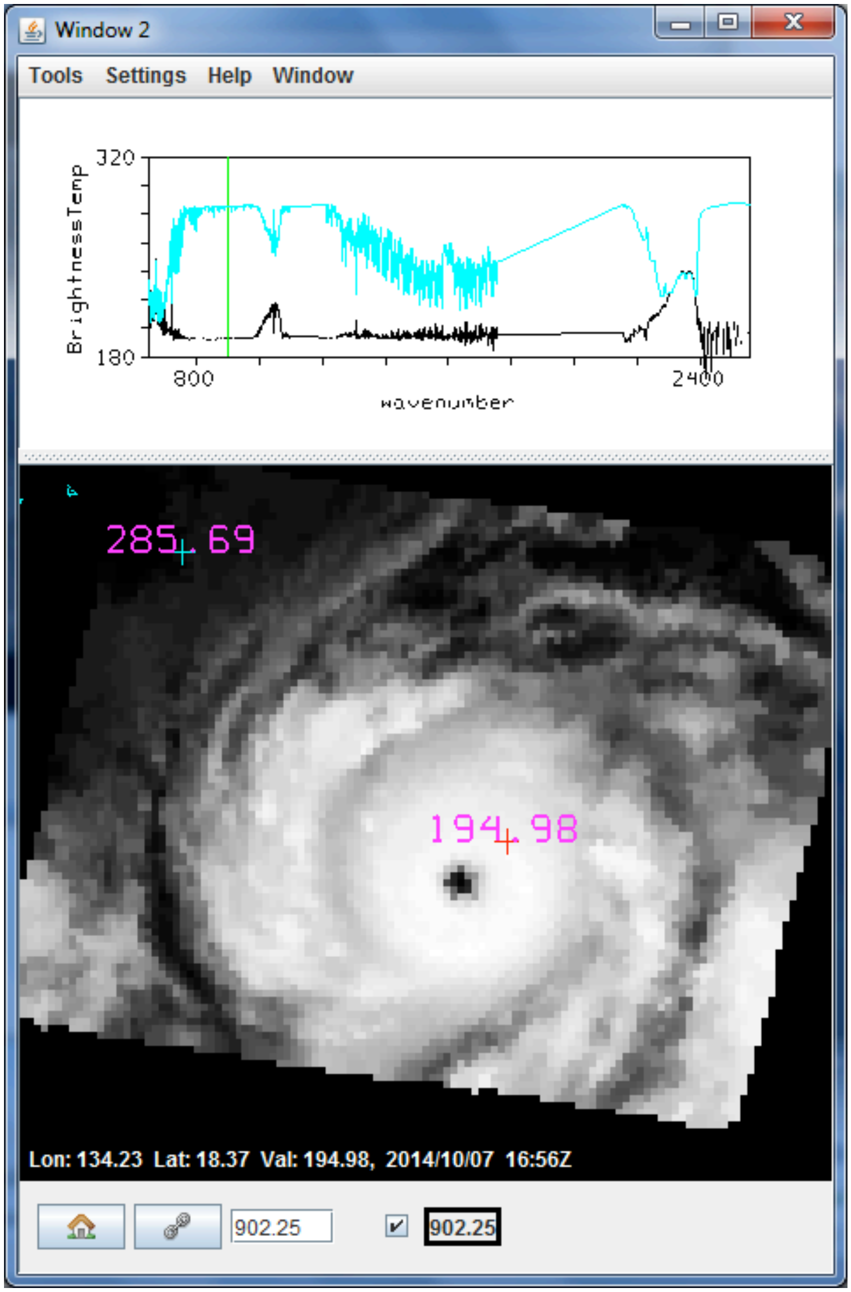


Figure 9: (bottom) Image of CrIS measurements (902 cm-1 brightness temperatures in degrees K) over Typhoon Vongfong on 7 October 2012 indicating the locations of the black spectrum (top) from clouds near the eye (marked by the red cross) and the turquoise spectrum (top) from clear sky northwest of the typhoon (marked by the turquoise cross).

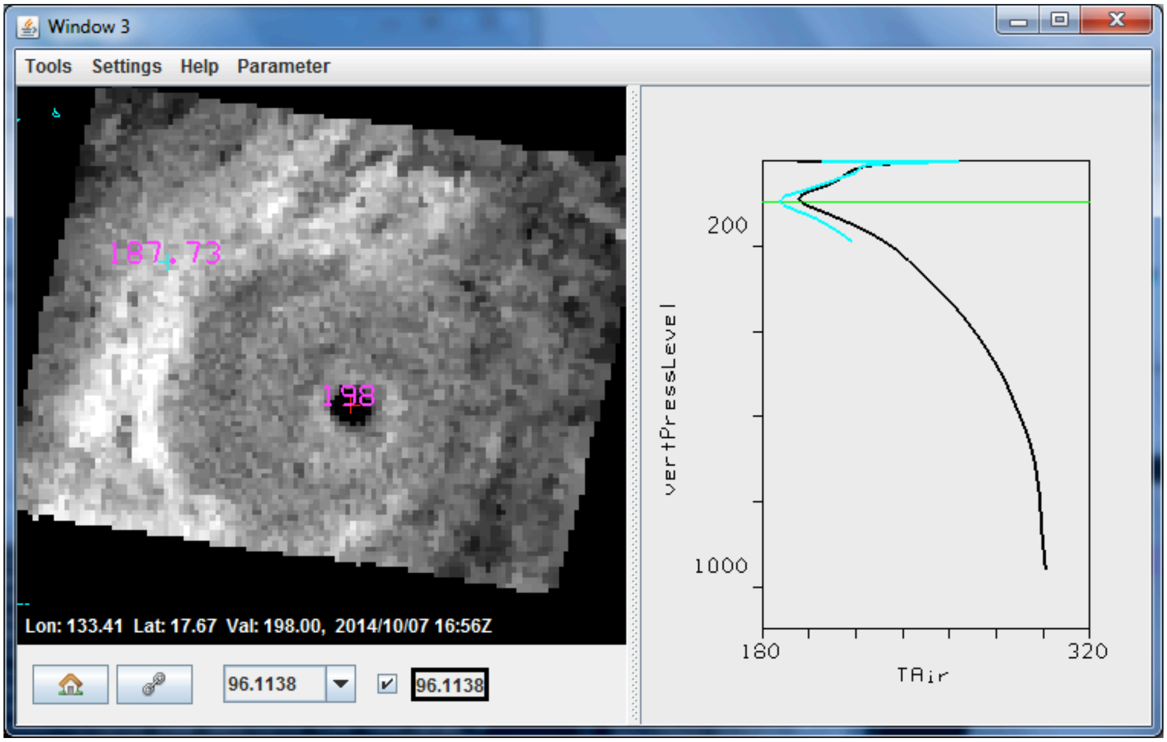


Figure 10: (left) Display of temperatures at 96.1 hPa over Typhoon Vongfong on 7 October 2012 using the Dual Regression Retrieval where white shades start at 185 K and black shades start at 195 K. (right) Temperature profile retrievals down to cloud top in the northwest sector of the typhoon (where the 96.1 hPa retrieved temperature is 187.73 K) is shown in black; the retrieval in the eye of the typhoon down to the ocean surface (where the 96.1 hPa temperature is 198.0 K) is shown in turquoise. The green line indicates the 96.1 hPa level.

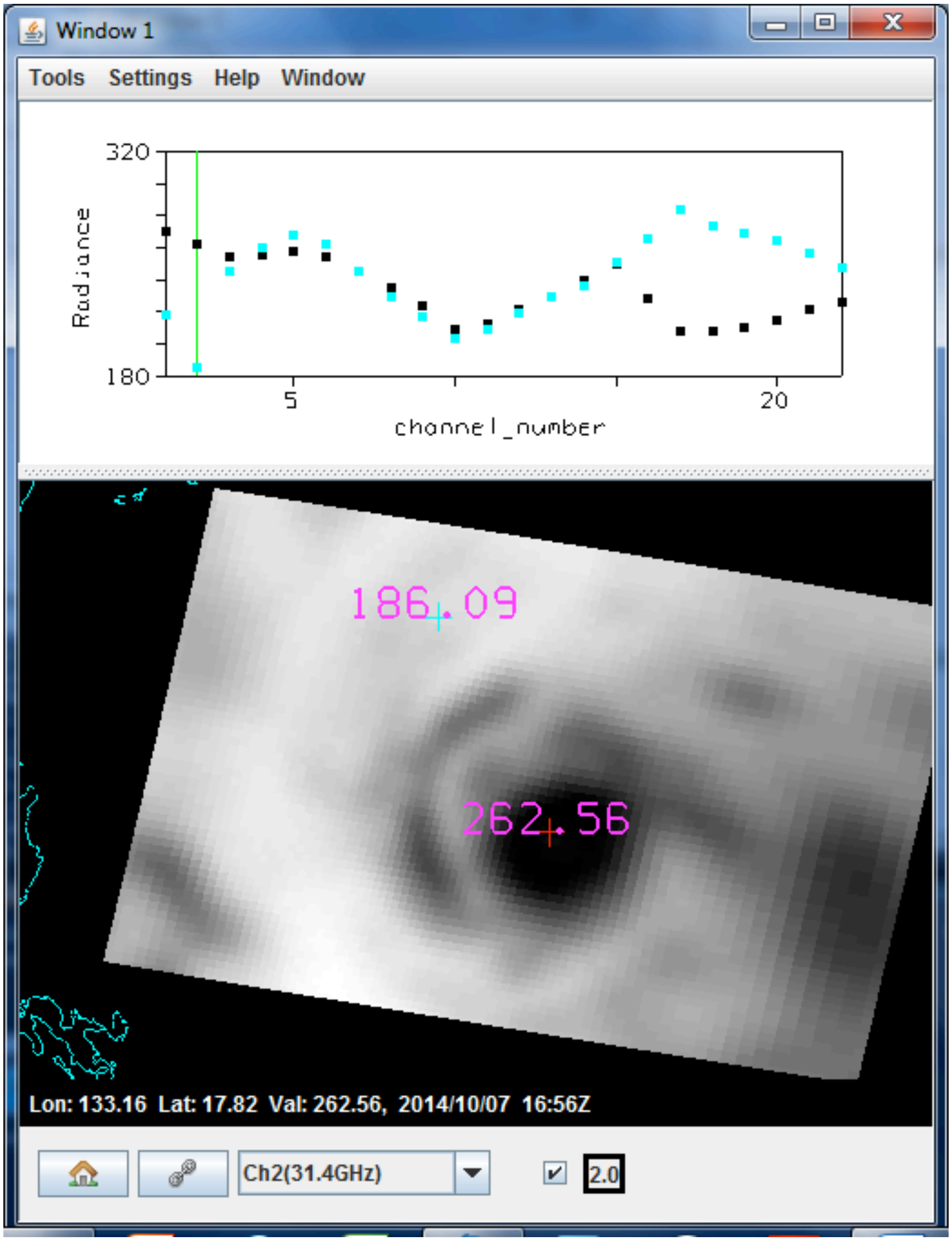
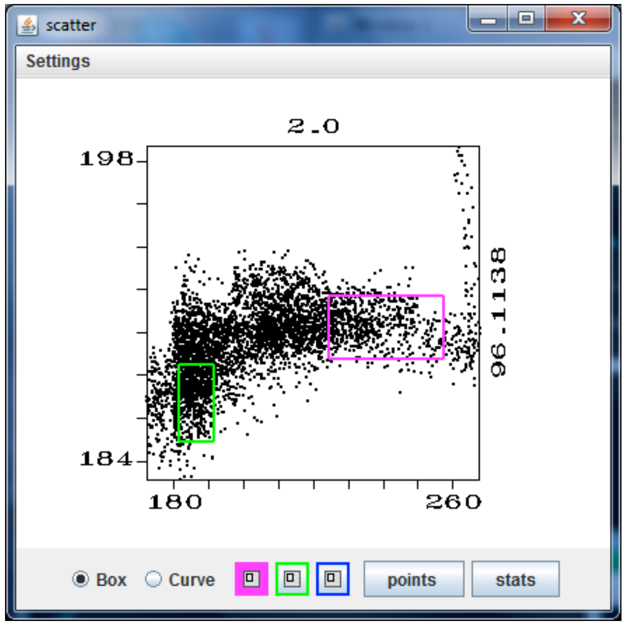


Figure 11: (Bottom) ATMS brightness temperature image for measurements over Typhoon Vongfong on 7 October 2012 at 31.4 GHz (channel 2) along with (top) microwave spectra from channel 1 at 23 GHz to channel 22 at 183.3 GHz in clouds northwest of the typhoon center (turquoise dots) and in the eye (black dots).



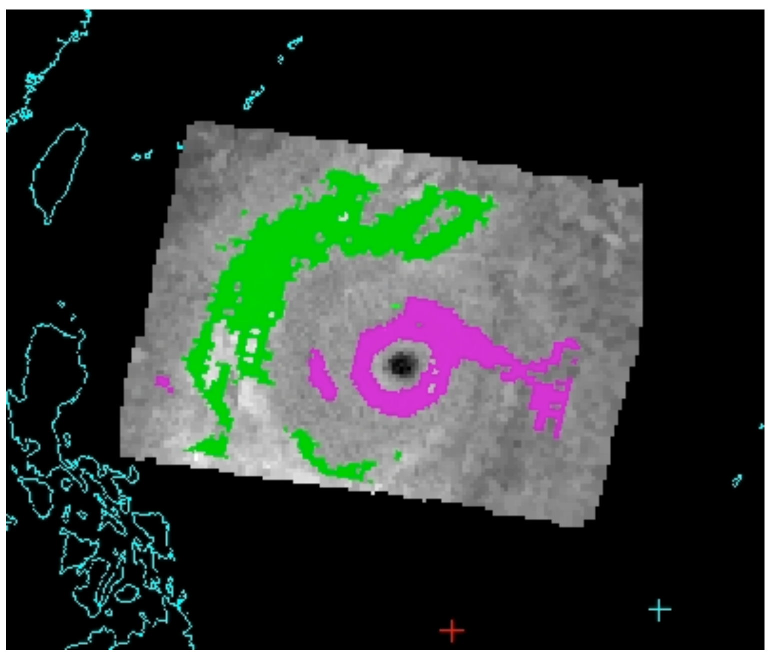


Figure 12: (Top) Scatter plot of ATMS 31.4 GHz (Ch2) brightness temperatures on the x-axis versus Dual Regression CrIS temperature retrievals at 96.1 hPa on the y-axis. (Bottom) Green and purple pixels from scatter plot located in the 96.1 hPa temperature image. All units are degrees Kelvin.

Appendix 1. Getting and Setting Up HYDRA2

The latest stable version of HYDRA2 can be obtaining from the following ftp site:

ftp://ftp.ssec.wisc.edu/pub/CSPP/HYDRA2/

For Windows Operating Systems (OS) (XP, VISTA 7 and 8) download the 'exe' file for latest version using 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\HYDRA2. Start the program by selecting Start | All Programs | HYDRA2 | runHYDRA. A window named "HYDRA" will appear (Figure A1); it will indicate the version you are using. A window named "runHYDRA" will also appear (this window may be minimized, but do not close it).

For Mac OSX use the 'dmg' installer and simply double-click to install into the /Applications folder. To start HYDRA2, double-click the icon in that folder. The icon can also be dragged to the applications docking station after which a single click of the icon will start the application.

For the Linux OS (64bit), the 'sh' installer will extract into the directory of choice, or use the 'tar.gz' 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.

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 3.5 Commands

In all windows

Shift-right click-drag to zoom in image within display

Right click-drag to move image or roam within display

In HYDRA window (see Figure A1)

Under File, select the VIIRS directory (a VIIRS folder) or File(s) (MOD02 or MYD02 for MODIS, AIRS for AIRS, SCRIS for CrIS, SATMS for ATMS) that is to be studied. (1) For VIIRS and MODIS, file selection will result in a listing of spectral bands available, an image of the IR window with coastlines, and a default subset of the granule that will be displayed in a new window upon clicking on display. The subset of the image can be adjusted with a right click and drag. The spectral band can be changed with a left click on another choice. (2) For CrIS, AIRS, and ATMS, a new window opens showing the spectral band brightness temperatures and a spectral window image showing the data coverage. Left click a drag on the green line in the top display to change the spectral band displayed below.

Left click on spectral band desired (default is IR window)

Left click-drag to highlight subset of image for display

Left click on Display at bottom to create a new image in window #1. Once Window#1 is established you can choose to replace the image in Window#1, to overlay a another image in Window#1, or to open a new Window#2 by using the arrows next to the Display command.

Tools/RGB Composite will open new a box where you have to select the R, G, and B spectral bands desired by left clicking on the color and then on the spectral band. When all three have been selected, left click on Create in the RGB Composite window to establish the RGB image. Left click on Display in the main HYDRA window to open a new window wherein the RGB image is displayed.

Tools/Band Math will open a new display where you have to select two, three, or four spectral bands that you wish to combine with + , -, x, or / operations. Spectral bands are selected by left clicking on the spectral band and then the appropriate box in the Band Math equation. After selecting the desired Band Math click on create and the pseudo image dataset will appear under Combinations in the main HYDRA window. Click on Display to see the Band Math result in a new Window.

In Window and Band Math Display (see Figure A2)

Left click-drag to move cursor within display

Left click on bottom left icon (house) to restore original display

Left click on bottom box (indicating band number) to open range, gamma, reset, and B&W vs color options (see Figure A3)

> Range can manually set BTmin (rmin) and BTmax (rmax). Range entries can be typed in to enhance low or high reflectances or BTs or they can be set by right click and sliding the top of the green bars in the reflectance/BT histogram. For the VIIRS DNB try very small values for your initial min to max range

> Gamma can be adjusted to stretch the dynamic range. It is a non-linear mapping from color to value. For infrared, color_value = BT**gamma. For visible, when gamma = 0.5, this is the square root enhancement popular with VIS.

> Reset restores the dynamic range to the min and max values in the display.

> Color options include inverse gray (BTmax is black, BTmin is white), gray,

rainbow (BTmax is red, BTmin is blue), and inverse rainbow. Contrast from white to black (or blue to red) can be adjusted in the range.

When overlays exist in a window, display can be moved from one overlay to another by clicking on the arrow at bottom of window. The check next to the band (or Band Math) identifier controls whether that image is contained in the loop controlled by the arrow at the bottom of the window. An overlay can be removed by clicking on the red circle to the right of the band identifier. (see Figure A4)

When two displays are open, toggle on link button in lower left to link zoom and roam in two displays (default is to have the windows linked)

After engaging Tools/Transect, one can left click-drag to change end point of the transect. Note that Transect can be opened in several windows simultaneously. (see Figure A5)

To engage Tools/Scatter, left click on Tools/Scatter in a first window to establish the x-axis and then left click on Tools/Scatter in a second window to establish the y-axis of scatter plot. The scatter plot will appear in a separate display. Two windows are necessary; Scatter is not properly initiated when using the overlay from one window alone.

Under Settings, options include coastlines (toggle for on and off), min/max display (toggle for on and off), probe readout (toggle for on and off for numerical value at cursor location), and color scale (toggle for on and off of numerical values associated with the colors in the display)

In Scatter Display (see Figure A6)

Selecting purple, green, and blue points (with box or curve) in the scatter window will show the associated pixels in the two image windows; conversely selecting pixels in either image window will show the associated points in the scatter window.

Left click on the points box (bottom of scatter window) to create density scatter plot; toggle back and forth between points and density

Left click on stats to see stats for purple, green, and blue selections.

Under Settings, Background Color allows selection of white or black background for the scatter plot and Axes allows resetting of x- and y-axes.

In AIRS, CrIS, or ATMS SDR (Sensor Data Record) Display

Select the file(s) to be displayed (AIRS for AIRS, SCRIS for CrIS, SATMS for ATMS)

Move the green line in the spectrum (left click drag) to change the spectral band displayed below.

When viewing the AIRS/CrIS/ATMS spectrum, zoom using shift- left click–drag. Restore to full spectrum using control-left click.

When viewing AIRS/CrIS/ATMS spectral band image left click drag to move cursor within image (note if VIIRS data over same area is open then cursor will move in both VIIRS and CrIS/ATMS images; same for AIRS and MODIS)

Click on Tools to have the option for Transect, Scatter, and FourChannelCombine. In FourChannelCombine the colored lines have to be moved (left click drag) to the desired wavenumber (GHz). Expanding beyond two spectral bands is initiated by completing the mathematical operator desired in the FourChannelCombine equation.

When viewing AIRS or CrIS profile retrievals (temperature, water vapor, and ozone can be found under the parameter), transect and scatter (under Tools) can be used in the same way as before.

In the AIRS or CrIS Retrvl Display left click and drag on the green line in the vertical profile to change the altitude of the parameter being displayed.

The red cursor in the CrIS Retrvl Display will move in synch with the red cursor in CrIS or VIIRS or ATMS spectral band displays; the blue cursor moves independent of any cursor in the other images.

Under Settings, in addition to the usual options, under Spectrum the background color can be switched from black or white.

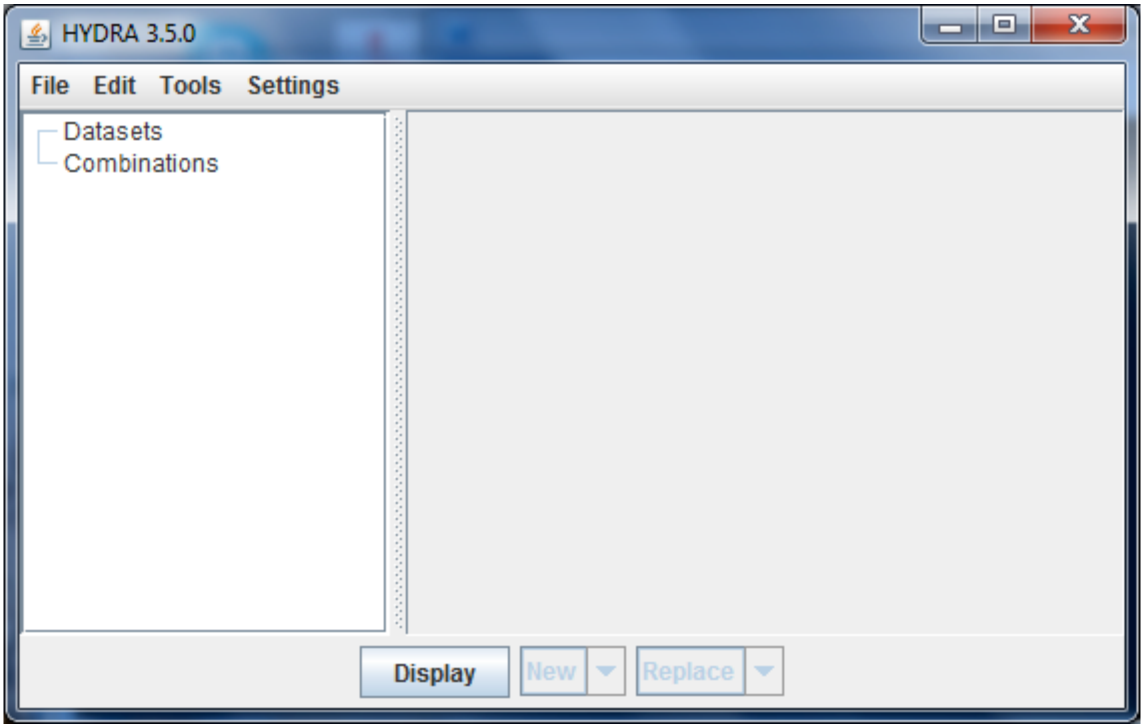


Figure A1: The HYDRA window before data set selection.

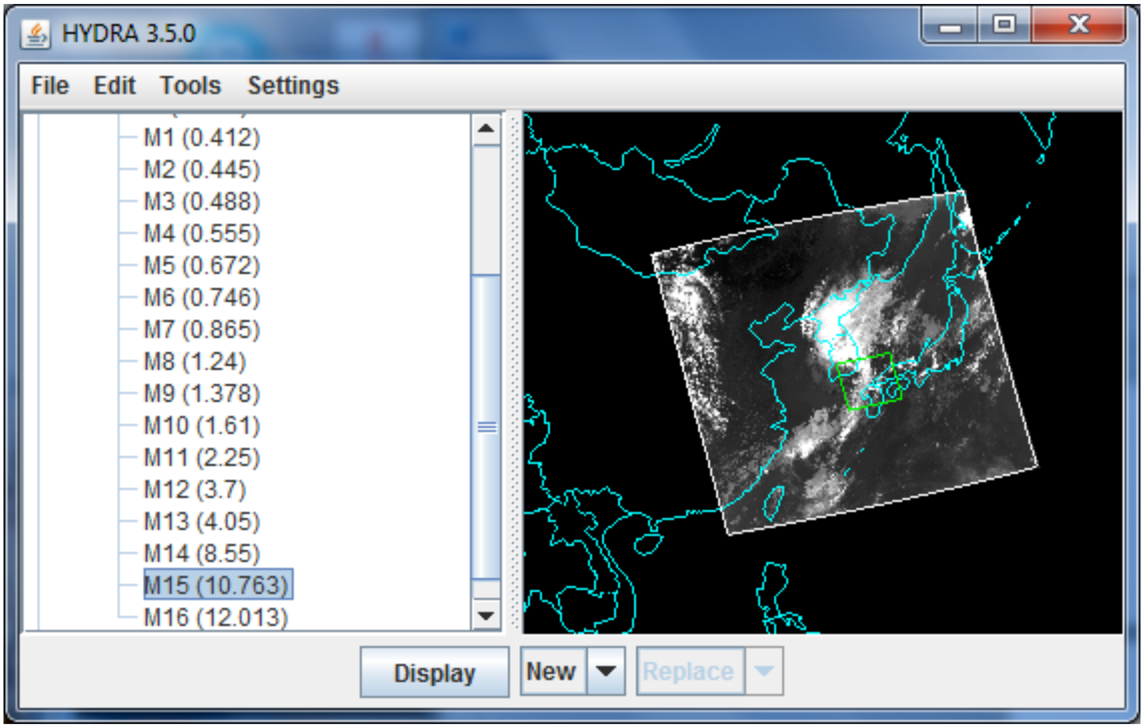


Figure A2: HYDRA window after selection of VIIRS data from 422 UTC on 30 August 2012 over Korea.

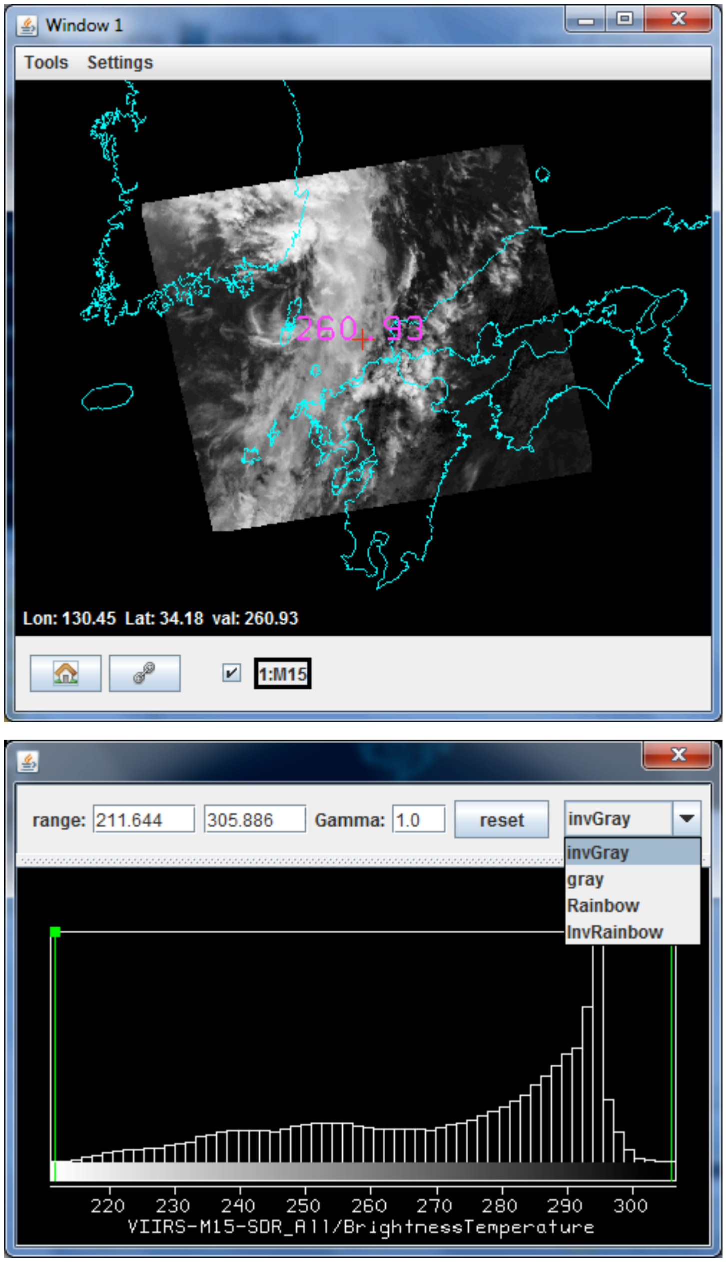


Figure A3: Image enhancement options opened by clicking on the box at the bottom of the window indicating the spectral band. Range entries can be typed in to enhance low or high reflectances or BTs or they can be set by right click drag on the top of the green bars in the reflectance/BT histogram. Reset restores the dynamic range to the min and max values in the display. Color options include inverse gray (BTmax is black, BTmin is white), gray, rainbow (BTmax is red, BTmin is blue), and inverse rainbow.

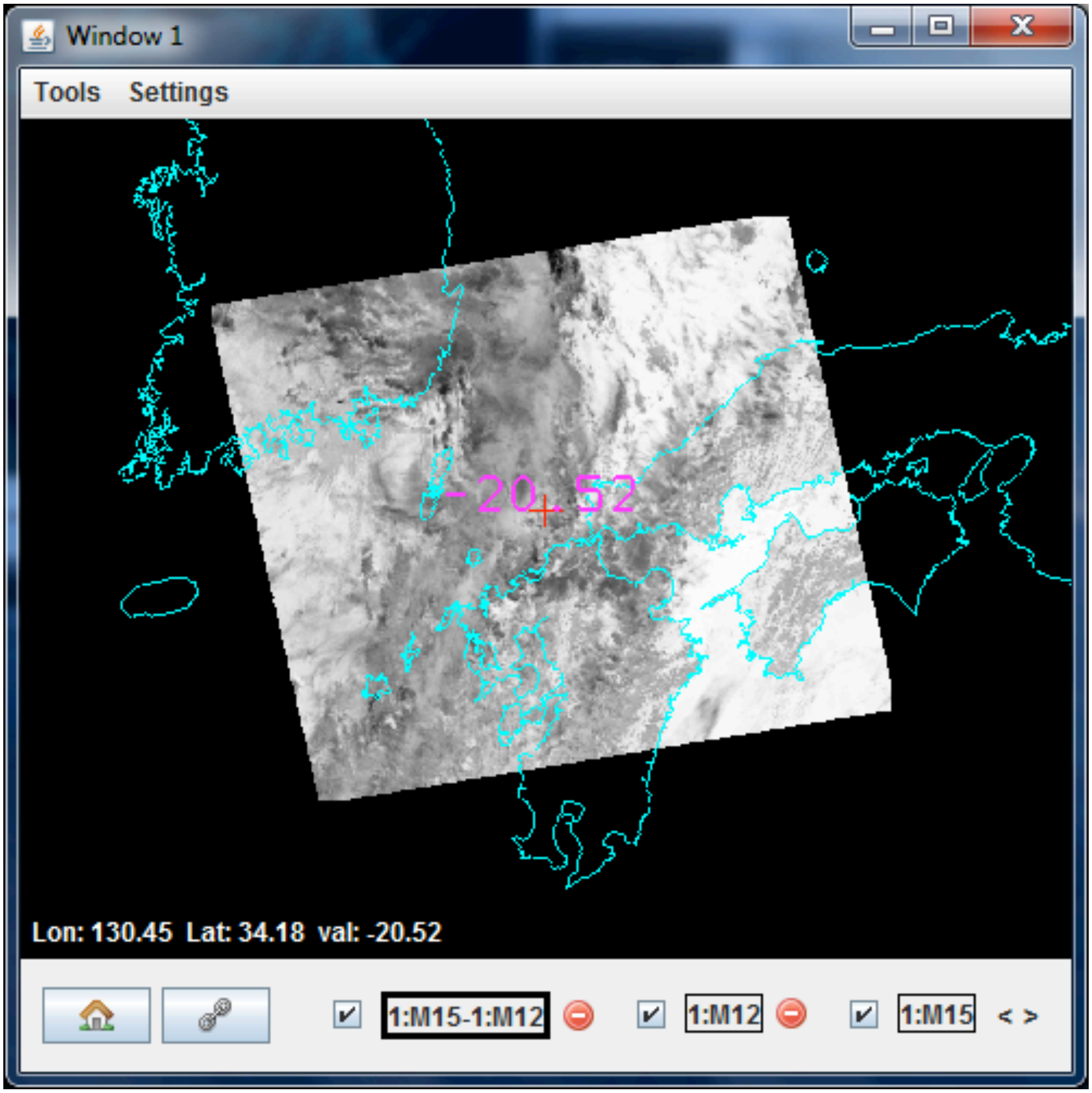


Figure A4: Window with overlay of three VIIRS brightness temperature images (BT(M15) at 10.8 μm minus BT(M12) at 3.7 μm, BT(M12) at 3.7 μm, and BT(M15) at 10.8 μm). The bold outline indicates which of the overlays is on display. When overlays exist in a window, the display can be moved from one overlay to another by clicking on the arrow at bottom right of the window. The check next to the band (or Band Math) identifier controls whether that image is contained in the loop controlled by the arrow at the bottom of the window. An overlay can be removed from the window by clicking on the red circle to the right of the band identifier.

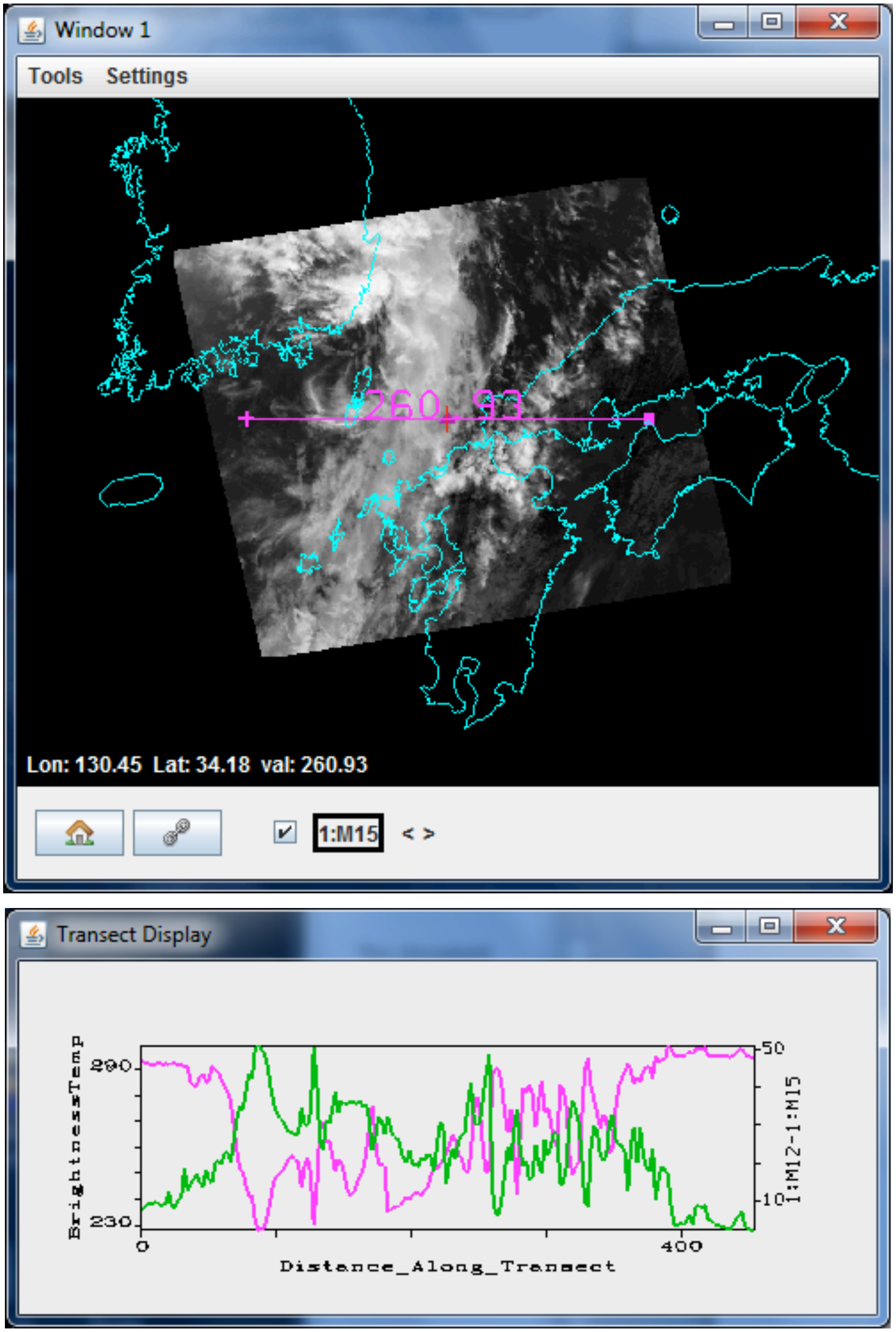
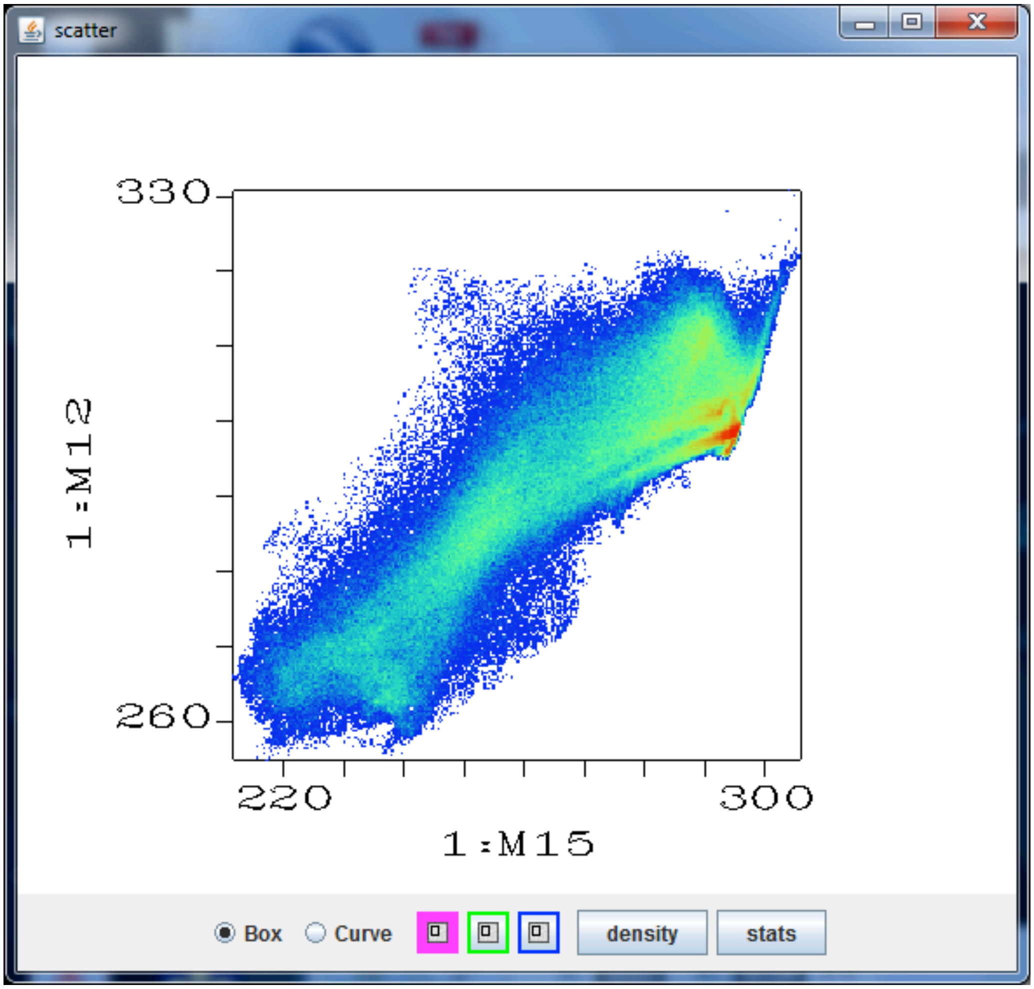


Figure A5: Transect Display of BT(M15) shown in the purple plot and [BT(M12)-BT(M15)] shown in the green plot for M12 at 3.7 μm and M15 at 10.8 μm. The reflected solar contributions often make BT(M12) greater than BT(M15).



Scatter Statistics

Stats Parameter	NPP VIIRS 1:M15 2012/08/30 04:22Z	NPP VIIRS 1:M12 2012/08/30 04:22Z
Maximum	305.89	330.77
Minimum	211.64	254.83
Number of points	592620	592620
Mean	272.28	294.40
Median	279.88	298.07
Variance	475.31	173.39
Kurtosis	-0.71587	-0.06323
Std Dev	21.80	13.17
Correlation	0.84746	
Difference Maximum	-1.427	
Difference Minimum	-78.91	
Difference Mean	-22.11	
Area [km^2]		

Figure A6: (Top) Scatter window (in density mode) showing BT(M15 or 10.8 µm) on x-axis versus BT(M12 or 3.7 µm) on y-axis. Red points show highest occurrence and blue points show least. (Bottom) Scatter statistics for the pixels shown in the scatter plot.