

Miami Polar Orbiter Workshop: Satellite Direct Broadcast in Support of Real-Time Environmental Applications February 9-13, 2015

February 12, 2015 – Tropical Cyclone Suomi-NPP Microwave Lab

This lab will use S-NPP VIIRS and microwave channels to evaluate tropical cyclone intensity, environment and structure.

Channel	Center Frequency (Ghz)	Sensitivity NEΔT (K)	Resolution at nadir (km)	Characterization at nadir
1	23.8	0.9	75	Window-water vapor 100 mm
2	31.4	0.9	75	Window- water vapor 50 mm
3	50.3	1.2	32	Window-surface emissivity
4	51.76	.75	32	Window-surface emissivity
5	52.8	.75	32	Surface air
6	53.596	.75	32	4 km ~ 700 mb
7	54.4	.75	32	9 km~ 400 mb
8	54.94	.75	32	11 km ~ 250 mb
9	55.5	.75	32	13 km ~ 180 mb
10	57.290344	.75	32	17 km ~ 90 mb
16	88.2	.5	32	Window H ₂ O 150 mm
17	165.5	.6	16	H ₂ O 18 mm
18	183.31 +/- 7.0	.8	16	H ₂ O 8 mm
19	183.31 +/- 4.5	.8	16	H ₂ O 4.5 mm
20	183.31 +/- 3.0	.8	16	H ₂ O 2.5 mm
21	183.31 +/- 1.8	.8	16	H ₂ O 1.2 mm
22	183.31 +/- 1.0	.9	16	H ₂ O 0.5 mm

Table 1 – S-NPP ATMS channels

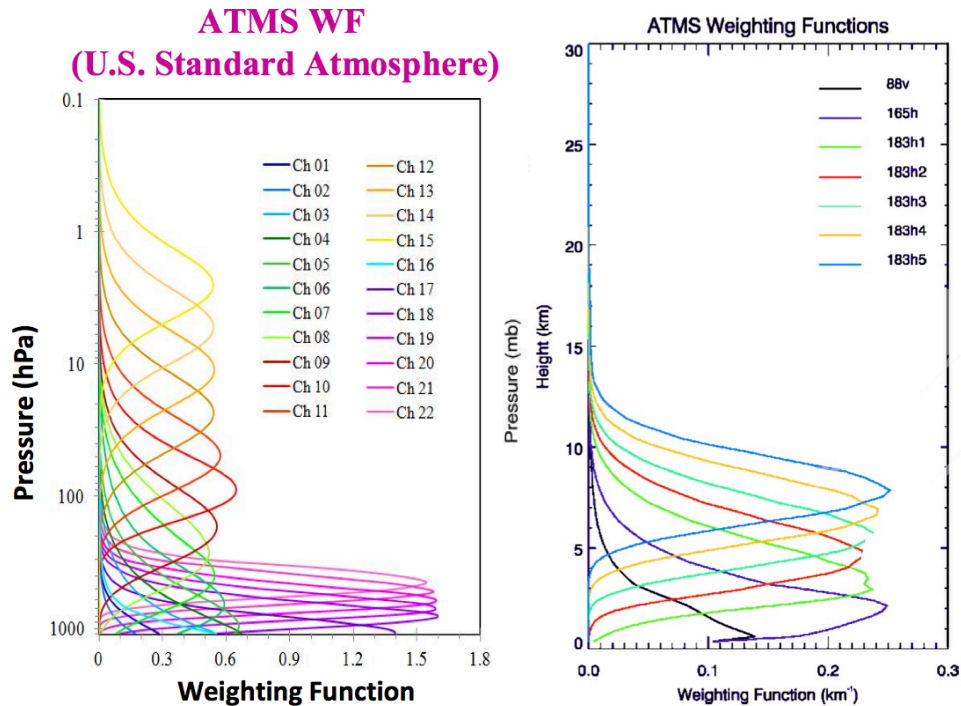


Figure 1. ATMS weighting functions for channels 1-22 (left) and moisture sounder channels (16-22)

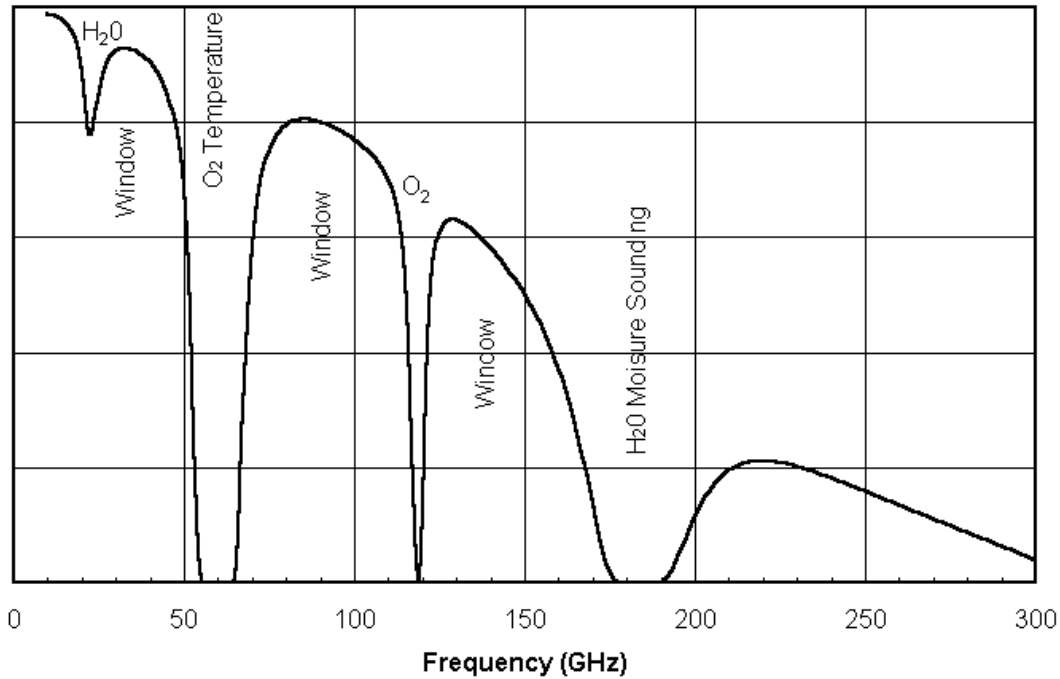


Figure 2. Microwave absorption spectrum

Section 1.0

We will start by looking at some conventional imagery of Hurricane Gonzalo for October 14, 2014. In Hydra open the VIIRS Channel 14 files under the Gonzalo directory:

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SVM14_npp_d20141014_t1730230_e1731472_b15356_c20141015000208665191_noaa_ops.h5
SVM14_npp_d20141014_t1731484_e1733126_b15356_c20141015000208665191_noaa_ops.h5
SVM14_npp_d20141014_t1733138_e1734380_b15356_c20141015000208665191_noaa_ops.h5
SVM14_npp_d20141014_t1734392_e1736034_b15356_c20141015000208665191_noaa_ops.h5
SVM14_npp_d20141014_t1736046_e1737288_b15356_c20141015000322853125_noaa_ops.h5
```

Click the Display button to display the channel 14 infrared image. Switch the enhancement to Rainbow. In this enhancement dark blues represent very cold cloud tops associated with deep convection. Lighter blues and greens indicate cold cloud tops that could be high cirrus clouds and or convection. Note that the coldest cloud tops are associated with deep convection around the eye of Hurricane Gonzalo. The eye itself is fairly warm in comparison. Also note that bands of thunderstorms with cold cloud tops are wrapping into the hurricane with prominent bands to the east of the hurricane. Cirrus clouds at the outflow level of the hurricane are noted as finely banded structures that are best seen south through west of the hurricane.

Using the cursor tool measure the temperature of the eye of Gonzalo as well as the cold cloud tops associated with the convection surrounding the eye.

Eye temperature: _____ Coldest temperatures of the eyewall: _____

Using the transect tool measure the diameter of the eye of Gonzalo. Start and end your transect near the strongest Tb gradient within the eye. Eye Diameter: _____

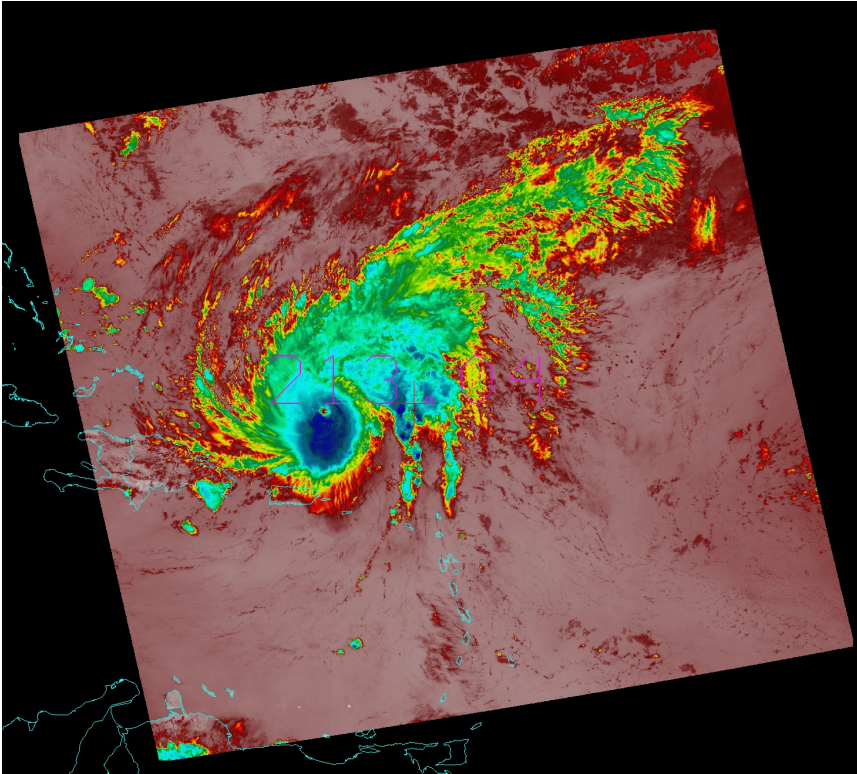


Figure 3. VIIRS Ch14 infrared image of Hurricane Gonzalo Oct 14, 2014 1733 UTC

Satellite imagery is frequently used to estimate the intensity of tropical cyclones (TCs). In fact more than 80% of the TCs that occur around the world are analyzed by some type of satellite imagery. One of the primary tools for estimating TC intensity is the Dvorak Technique (DT). This method was developed in the 1970s and is still used today. The method uses enhanced infrared imagery (typically using a temperature enhancement called the BD curve) to determine the pattern type of the tropical cyclone. Some example TC enhanced IR patterns are shown below. CDO = Central Dense Overcast.

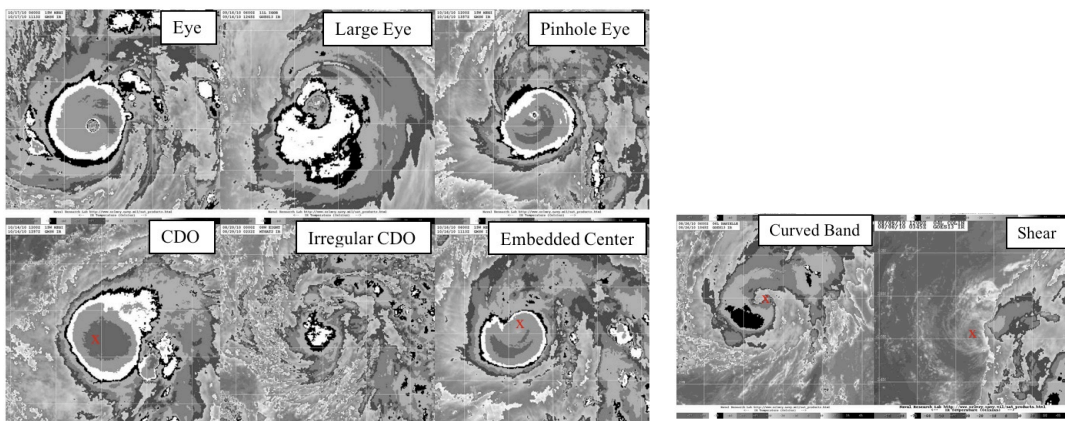


Figure 4. Enhanced infrared Dvorak pattern examples.

Once the analyst has determined the pattern the convective structure is analyzed to assess where the central convective features are in relation to the TC center. If the TC has an eye the eye temperature is estimated along with the coldest ring of convection surrounding the eye to get the intensity. The intensity is then adjusted upward/downward for very warm eye temperatures and or very cold/warm surrounding convection temperatures. Another more simplified technique in the DT is to compare the imagery to typical TC structures that can be related to intensity. Compare the VIIRS IR image for Gonzalo to the pattern chart below and estimate the intensity of the storm. Dark blues in the IR image represent white (inner core) regions in the table and light blues represent gray in the table. Rows a-c represents storm evolution types.

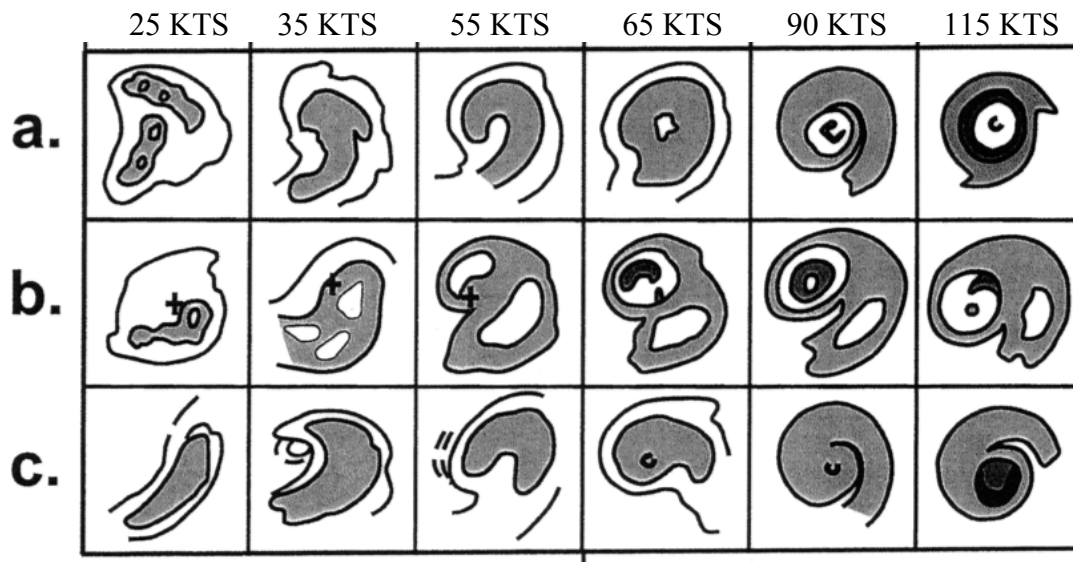


Figure 5. Dvorak pattern intensity chart.

Gonzalo intensity using enhanced infrared pattern method: _____

Section 1.1

Now we will shift from the infrared portion of the spectrum to the microwave. Microwave imagery can often reveal features of a TC that infrared and visible cannot. Often times the extensive cirrus shield of a TC can mask important features such as banding, a developing eye, or the low level center. Because several frequencies in the microwave spectrum are transparent to cirrus clouds the microwave imagery can reveal these features beneath the extensive cloud cover. Microwave imagery in the 36-37 Ghz and 88-92 Ghz ranges are frequently used along with the Dvorak Technique by TC analysts to subjectively determine the TC intensity. For example the IR may show a CDO structure (see Figure 4) while the microwave imagery may indicate an eye is present. In addition microwave sounders in the ~55 Ghz range can measure the TC warm core anomaly and objectively estimate the intensity using statistical methods.

In Hydra open the S-NPP ATMS file in the Gonzalo directory called:

SATMS_npp_d20141014_t1727166_e1735163_b15356_c20141014233515774904_noaa_ops.h5

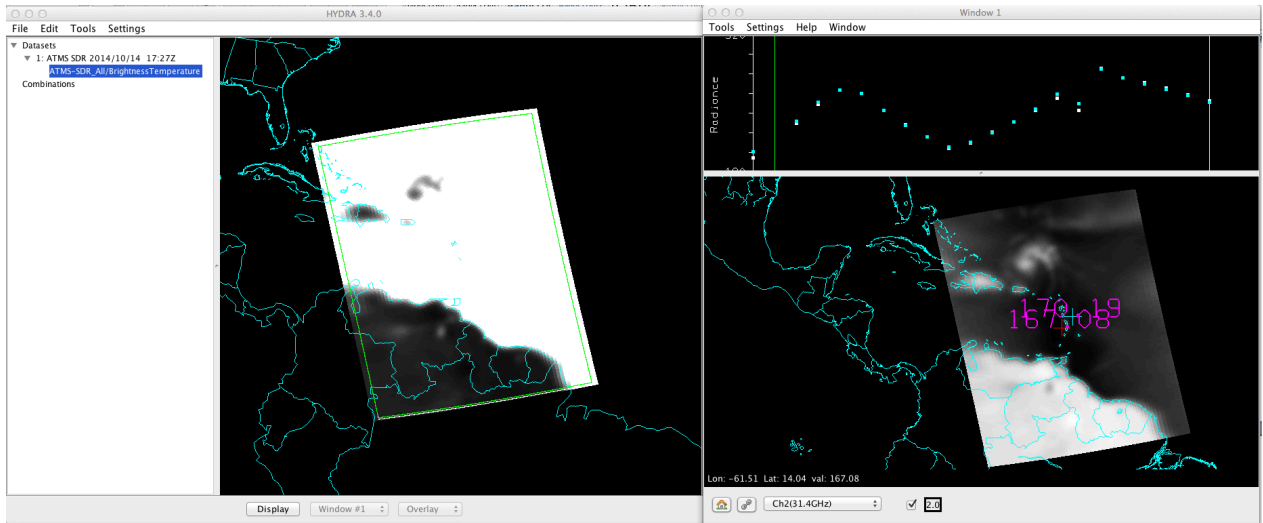


Figure 6. S-NPP ATMS display in Hydra for Hurricane Gonzalo October 14, 2014 1733 UTC

When you open the file you will get the image on the left above in Figure 6. Click “Display” and you should see the image on the right. The display default will be ATMS Channel 2. Next click on the box to the left of the check mark to change the image enhancement. Select the Rainbow enhancement. Channel 2 is a water vapor channel and has the coarsest resolution of the ATMS channels. Note in Figure 1 above that a significant portion of this channel’s weighting function is at or near the surface. As such surface temperatures and strong near surface temperature gradients can dominate the signal. Drag the cursor over the image noting the highest and lowest values (or use the min/max tool).

Highest brightness temperature: _____ Lowest brightness temperature: _____

Where are the warmest brightness temperatures located? Over the land or the water?

Looking only over the open ocean areas note that green, yellow and red indicate regions of greater moisture concentration while blues and purples represent regions of dry air in the lower levels of the atmosphere. Hurricane Gonzalo is located north of Puerto Rico near 20.8N 65.5W. Describe the moisture environment of this system and the near environment.

A tropical cyclone needs a moist environment to maintain convection and to strengthen. Based on your analysis of this channel alone would you expect

Strengthening/No Change or Weakening

Using the channel selection window select channel 16 (88.2 GHz). Note that the resolution of this channel is more than twice that of channel 2 and the features associated with the tropical cyclone become more distinct. Switch the enhancement curve to inverse rainbow. Scattering of radiation by mixed-phase hydrometeors acts to strongly suppress Tbs in this channel. Strong convection will show up in deep reds and whites. These cooler Tbs will stand out against the much warmer surface background. The channels in the 88-183 GHz range can be helpful for identifying areas of deep convection.

Now switch to the 183.3101GHz Channel 18. This is the first of a suite of 183 GHz channels that are located in a strong water vapor absorption band around 183 GHz. High concentrations of water vapor in the atmosphere act to suppress the Tb received by the sensor. Note in Figure 1 that each of the 183 GHz channels “peaks” at a different level. Note also from Figure 1 that these channels have no surface contribution in their weighting functions. Thus the “signal” over land and water are similar. How do the areas of moist air and dry air compare in this channel to Channel 2?

This is the highest resolution of the sounder channels. What resolution differences can you see?

When viewing deep convection in conventional infrared imagery cold cirrus clouds can often “mask” the details of the convective structure of a system. Looking at Hurricane Gonzalo near 20.8N 65.5W what details can you see in the microwave that are not apparent in the VIIRS infrared?

Now zoom into the tropical cyclone. Using the transect tool measure the diameter of the small eye of this hurricane in at least 2 directions for each of the 183 Ghz channels and take an average of those 2 values. Note your results.

183.3101 GHz _____ (km)
183.3102 GHz _____ (km)
183.3103 GHz _____ (km)
183.3104 GHz _____ (km)
183.3105 GHz _____ (km)

We will now shift our attention away from the moisture sounding channels to the temperature sounding channels (channels 7-10). During the lecture we discussed how the temperature sounders could be used to estimate TC intensity. ATMS channels 7-10 are located in the portion of the troposphere that typically contains the bulk of the TC warm core anomaly.

We will start by taking a look at Channel 7 (54.4 GHz). The rainbow enhancement will result in warm anomalies being red to white with cold anomalies in greens and blues. Looking at Hurricane Gonzalo you can see a weak warm anomaly at the center of the storm. Surrounding this warm anomaly are bands of colder anomalies. The cold anomalies are artifacts of hydrometeor scattering produced by heavy convection that contain significant concentrations of ice at the location of this channel (refer to Table 1 or Figure 1 and see that this channel peaks near 400 mb). Use the transect tool to create a transect plot through the warm core anomaly. The length of the transect should include as much of the undisturbed environment as possible. The goal is to capture the environmental temperatures surrounding the warm core at a distance of at least 400 km from the storm center. You will note that this channel appears fairly “noisy” and that your transect will show significant peaks and troughs. The lowest Tb values will be associated with the cold anomalies produced by the strong convective bands. Ignoring these values make your “best guess” of the environmental Tb. Next determine the maximum Tb of the warm core associated with Gonzalo. The difference $Tb_{env} - Tb_{Max}$ is the temperature anomaly for Gonzalo for this ATMS channel

Environmental Tb: _____ Maximum Tb: _____ Tb Anomaly: _____

The equation for determining the associated minimum sea level pressure (MSLP) for this channel is given by:

$$MSLP = 1010 - (12.23 * Tb_Anomaly_CH7 - 1.87)$$

Compute the MSLP: _____ (hPa)

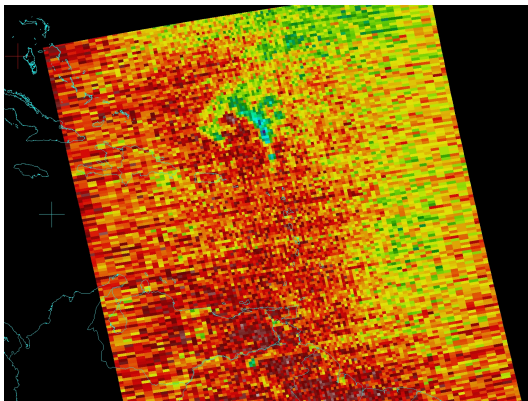


Figure 7. ATMS Channel 7 for Gonzalo October 14, 2015 1733 UTC

Thinking about your MSLP estimate and considering the resolution of the channel along with your estimates of the eye size would you expect your MSLP estimate to over-estimate or under-estimate the MSLP using this channel alone?

What impact might you expect intense eyewall convection to have on the warm anomaly sensed by the instrument?

Next we will look higher into the atmosphere with Channel 8 (54.94 GHz). Switch the channel to this channel. You will note that the warm anomaly associated with Gonzalo is more apparent in this channel. Also note that the cold anomalies that were present in Channel 7 are nearly non-existent in Channel 8. Why?

In addition to the warm anomaly associated with Gonzalo there is a much larger warmer anomaly to the west. Thinking about where this channel peaks and keeping in mind that the peak increases in height away from nadir what might be the source of this anomaly?

What potential impacts on Gonzalo could this feature have?

Using the transect tool create a transect through the warm anomaly. As you did with Channel 7 compute the environmental Tb and maximum Tb to get the Tb anomaly. Do NOT include the anomaly to the west in your transect.

Environmental Tb: _____ Maximum Tb: _____ Tb Anomaly: _____

CH8 MSLP equation is: $MSLP = 1010 - (12.85 * Tb_Anomaly_CH8 + 5.33)$

Compute the MSLP: _____ (hPa)

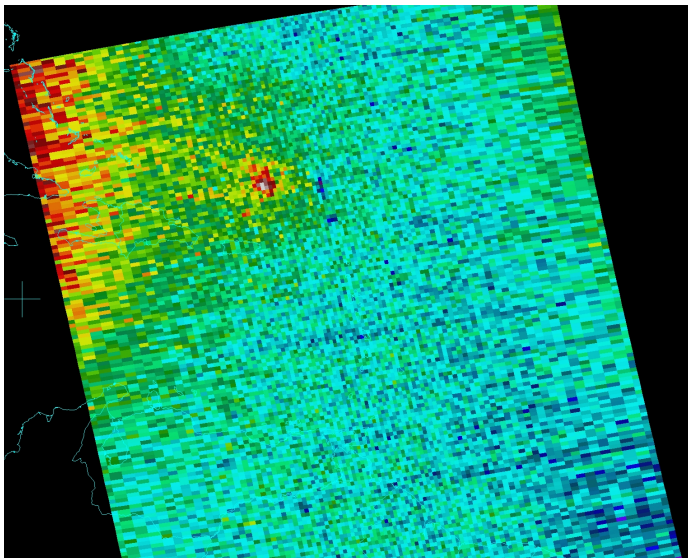


Figure 8. ATMS Channel 8 for Gonzalo October 14, 2015 1733 UTC

As you examine the Tb anomaly in channel 8 make note of the horizontal extent of the anomaly in this channel. In fact the transect tool can be used to get an estimate of the size of the tropical cyclone.

Next we will continue higher to Channel 9. Note that in this channel the large warm anomaly to the west has expanded. Using the same procedures as before, and again keeping you transect away from that feature to the West, compute the Tb anomaly and estimate the MSLP contribution for this channel.

Environmental Tb: _____ Maximum Tb: _____ Tb Anomaly: _____

CH9 MSLP equation is: $MSLP = 1010 - (11.69 * Tb_Anomaly_CH9 + 10.46)$

Compute the MSLP: _____ (hPa)

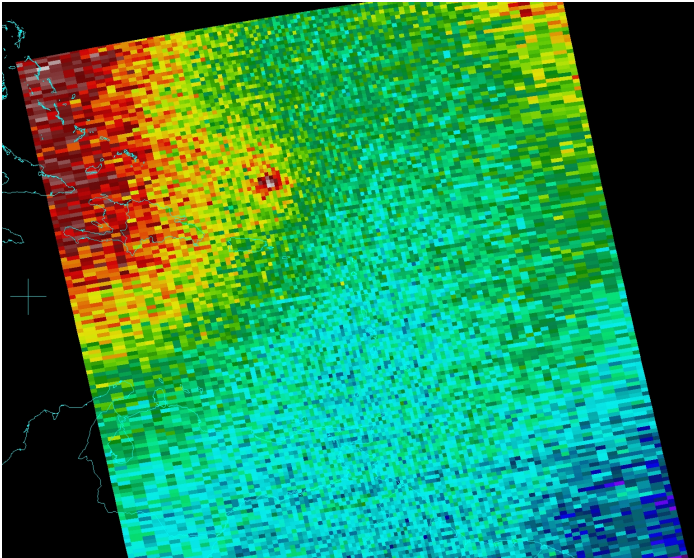


Figure 9. ATMS Channel 9 for Gonzalo October 14, 2015 1733 UTC

Just for completeness take a look at Channel 10. You will see that the warm core associated with Gonzalo does not extend to this level (at least not that the instrument can detect). Since the tropical cyclone warm core is related to the depth of the convection and height of the TC eyewall only the strongest storms tend to show up in this channel.

You now have MSLP estimates for three different ATMS channels.. How might you use the information you have to estimate the intensity of Gonzalo?

- 1) Take an average of all channel contributions
- 2) Weight each channel based on it's expected contribution/quality
- 3) Select a single channel that best represents the intensity

Final MSLP estimate: _____ Maximum Sustained Wind: _____

If you are interested you can use the table below to get the corresponding maximum sustained wind estimate.

CI Number	MWS (Knots)	MWS (MPH)	MSLP (Atlantic)	MSLP (NW Pacific)	Saffir-Simpson Category (Approximate)
1	25 KTS	29 MPH			
1.5	25 KTS	29 MPH			
2	30 KTS	35 MPH	1009 mb	1000 mb	
2.5	35 KTS	40 MPH	1005 mb	997 mb	
3	45 KTS	52 MPH	1000 mb	991 mb	
3.5	55 KTS	63 MPH	994 mb	984 mb	
4	65 KTS	75 MPH	987 mb	976 mb	1 (64-83 KTS)
4.5	77 KTS	89 MPH	979 mb	966 mb	1 (64-83 KTS); 2 (84-96 KTS)
5	90 KTS	104 MPH	970 mb	954 mb	2 (84-96 KTS); 3 (97-113 KTS)
5.5	102 KTS	117 MPH	960 mb	941 mb	3 (97-113 KTS)
6	115 KTS	132 MPH	948 mb	927 mb	4 (114-135 KTS)
6.5	127 KTS	146 MPH	935 mb	914 mb	4 (114-135 KTS)
7	140 KTS	161 MPH	921 mb	898 mb	5 (136+ KTS)
7.5	155 KTS	178 MPH	906 mb	879 mb	5 (136+ KTS)
8	170 KTS	196 MPH	890 mb	858 mb	5 (136+ KTS)

CI -- Current Intensity
MWS -- Mean Wind Speed
MSLP -- Mean Sea Level Atmospheric Pressure in Millibars

Table 2. Dvorak Current Intensity (CI) number to intensity scale

Section 1.2

We will now take a look at Gonzalo 4 days later on October 18. Open the S-NPP ATMS file named:

SATMS_npp_d20141018_t0638473_e0646469_b15406_c20141018124646799604_noaa_ops.h5

Using channels 16-22 evaluate the storms convective structure. How has the structure changed since the 14th?

Use the transect tool to measure the eye diameter in each of the 183 GHz channels.

183.3101 GHz _____ (km)

183.3102 GHz _____ (km)

183.3103 GHz _____ (km)

183.3104 GHz _____ (km)

183.3105 GHz _____ (km)

How does this compare to the eye diameter on the 14th?

Using the same procedure with the transect tool you used for the Oct 14th data determine the temperature anomaly for channels 7 – 9 and compute the intensity.

Channel 7

Environmental Tb:_____ Maximum Tb:_____ Tb Anomaly: _____

The equation for determining the associated minimum sea level pressure (MSLP) for this channel is given by:

$$\text{MSLP} = 1010 - (12.23 * \text{Tb_Anomaly_CH7} - 1.87)$$

Compute the MSLP:_____

Channel 8

Environmental Tb:_____ Maximum Tb:_____ Tb Anomaly: _____

The equation for determining the associated minimum sea level pressure (MSLP) for this channel is given by:

$$\text{MSLP} = 1010 - (12.85 * \text{Tb_Anomaly_CH8} + 5.33)$$

Compute the MSLP:_____

Channel 9

Environmental Tb:_____ Maximum Tb:_____ Tb Anomaly: _____

The equation for determining the associated minimum sea level pressure (MSLP) for this channel is given by:

$$\text{MSLP} = 1010 - (11.69 * \text{Tb_Anomaly_CH9} + 10.46)$$

Compute the MSLP:_____

Compare the warm core presentation on this day to the imagery from October 14. What changes do you notice in the structure?

Are there any other significant features in the imagery? And if so what impact might they have on the TC?

SECTION 1.3

Finally we will take a look at some of the challenges in locating the center of a tropical cyclone. The current location of the tropical cyclone is compared to the previous 6-hour old position to estimate the current storm motion and speed. The position 6 hours ago was 26.8N 64.8W. Under the “Fay” directory open the VIIRS infrared Channel 14 files:

SVM14_npp_d20141011_t1647352_e1648594_b15313_c20141011231507833579_noaa_ops.h5
SVM14_npp_d20141011_t1649006_e1650248_b15313_c20141011231507833579_noaa_ops.h5
SVM14_npp_d20141011_t1650260_e1651502_b15313_c20141011231507833579_noaa_ops.h5
SVM14_npp_d20141011_t1651514_e1653156_b15313_c20141011231743829252_noaa_ops.h5
SVM14_npp_d20141011_t1653168_e1654410_b15313_c20141011231743829252_noaa_ops.h5

Select the region where Tropical Storm Fay is located and Display the image. Use whatever enhancement you feel comfortable with. Focus your attention on the large area of thunderstorms on the left side of the image. Move the cursor tool to the location you feel is your “best guess” of the surface center position of Fay. Note the latitude and longitude.

VIIRS Channel 14: Latitude: _____ Longitude: _____

Next we will look at the visible channel I1. Open files:

SVI01_npp_d20141011_t1647352_e1648594_b15313_c20141011231633164839_noaa_ops.h5
SVI01_npp_d20141011_t1649006_e1650248_b15313_c20141011231633164839_noaa_ops.h5
SVI01_npp_d20141011_t1650260_e1651502_b15313_c20141011231633164839_noaa_ops.h5
SVI01_npp_d20141011_t1651514_e1653156_b15313_c20141011231721525819_noaa_ops.h5
SVI01_npp_d20141011_t1653168_e1654410_b15313_c20141011231721525819_noaa_ops.h5

Again highlight the area of Fay and display the image. As you did with the infrared channel 14 image move the cursor tool to the location you feel is the most likely surface center location of Fay and note the latitude and longitude.

VIIRS Channel I1 Latitude: _____ Longitude: _____

Are the two positions you selected for the two channels different? Yes No

If there is a difference how significant is the difference? For example what impact might the difference have on the short term forecast of the motion of the storm?

Is there a channel that you felt more comfortable in assessing the position and if so which one?