Hurricane and Severe Storm Sentinel (HS3) Mission

HS3 2014 14-15 Sept Flight Report: GLOBAL HAWK AV-6 Edouard Flight

Flight Scientists:
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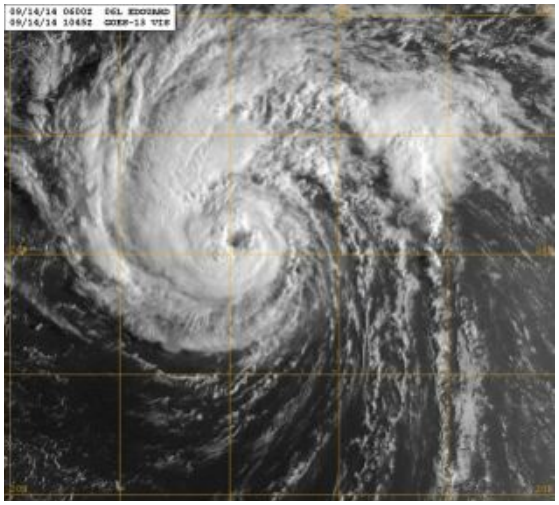
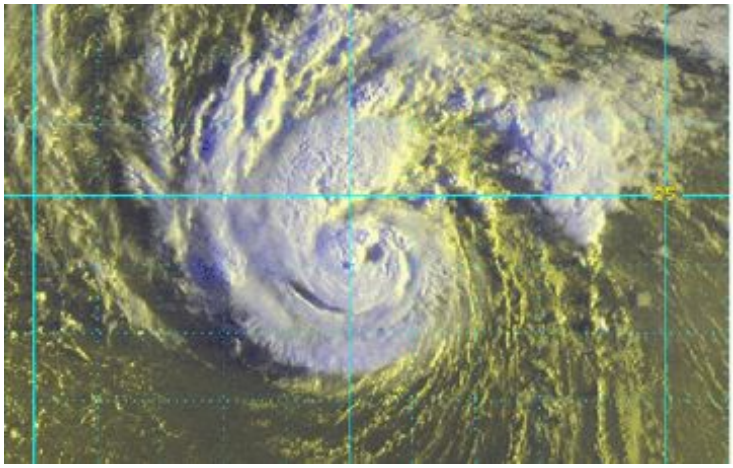
Shift 2 (1200-2100 EDT): Deanna Hence, Paul Neuman, Jon Moskaitis
Shift 3 (2000-0500 EDT): Jon Zawislak, Mike Black, Mike Montgomery
Shift 4 (0400-2100 EDT): Anthony Didlake, Pete Colarco

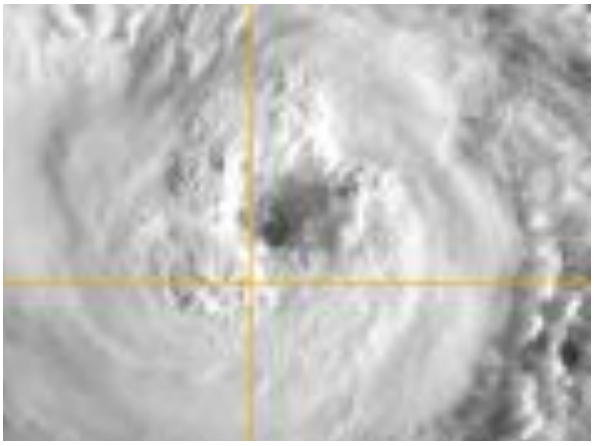
Takeoff: 14/1102Z
Landing: 15/

Mission goal: Science flight to investigate Hurricane Edouard as it undergoes rapid intensification to CAT2/CAT3.
VIS images at 0945-1045Z

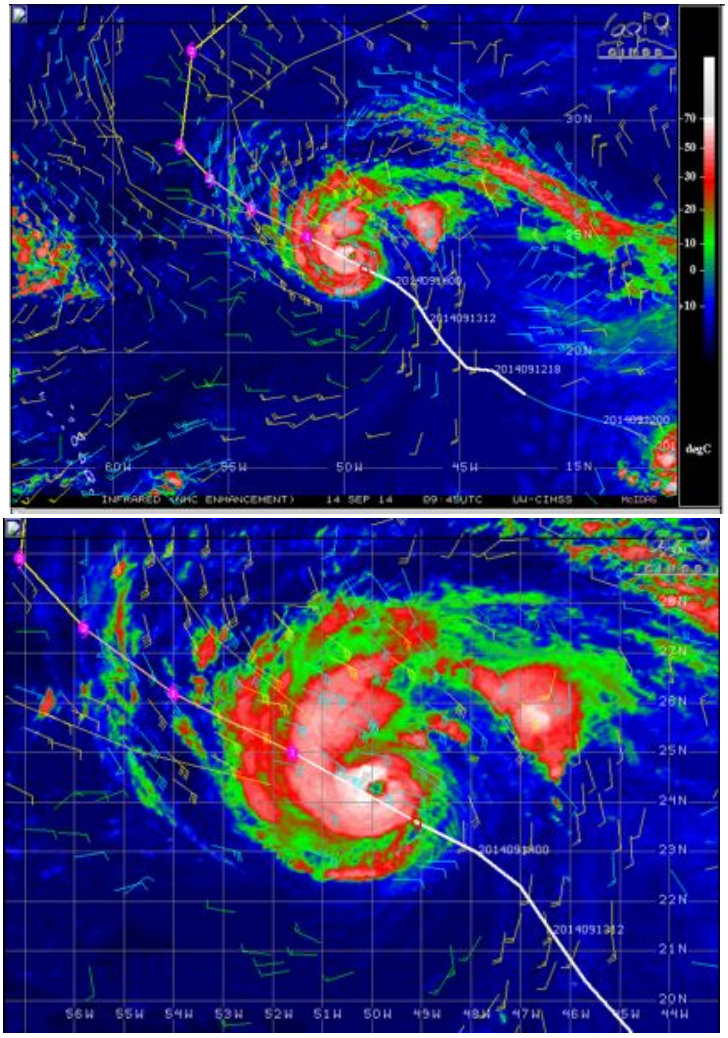




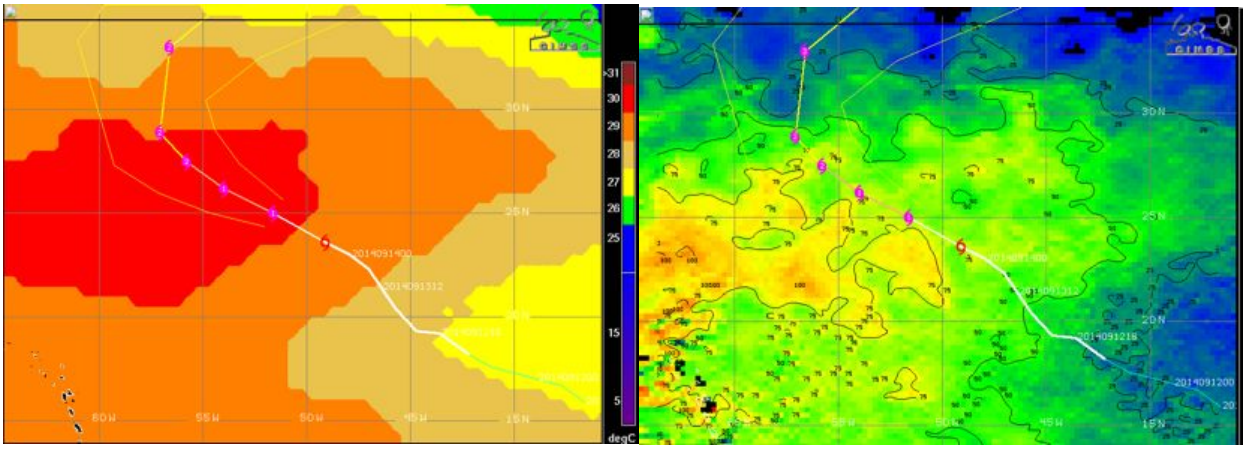
Eye appeared rapidly just before sunrise: 0745-0845Z- clear to surface. Estimate Vmax 90-100 kt.
Apparently RI is underway. Below 1045Z zoom.

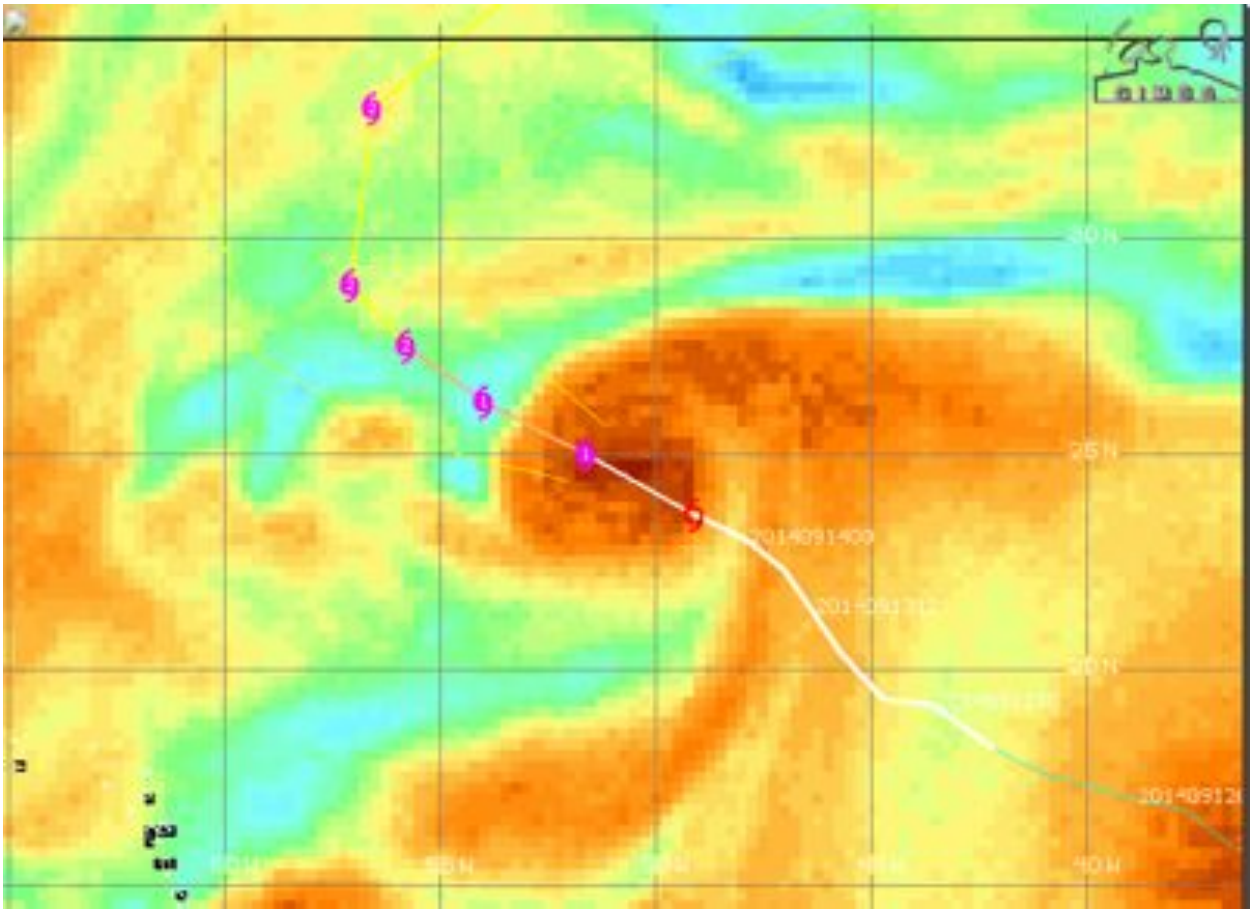


Main outflow jet extending west 350 nm from center: 56W, 25-35N. Upper AMVs at 14/1000Z, 0945 IR. 0945 IR image suggests the formation of an eye. Good outflow pattern with strong winds along the western edge of the diffuse cirrus.



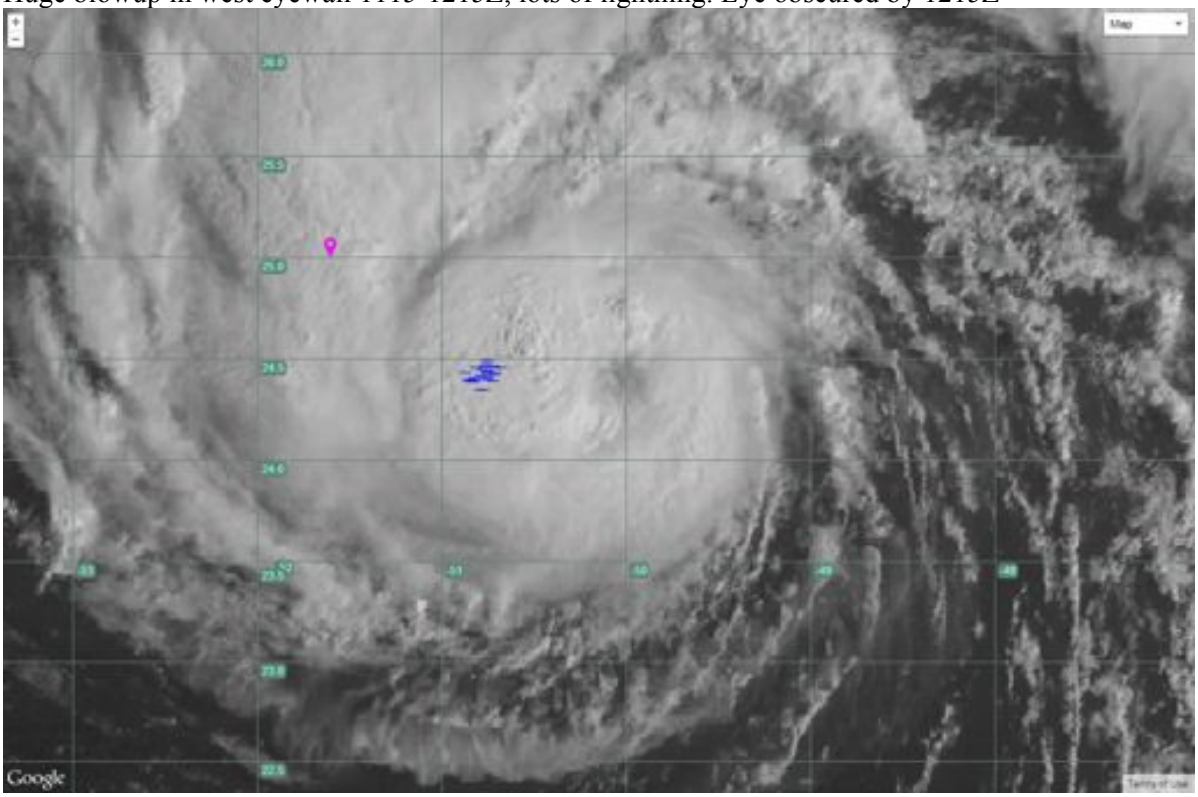
Edouard entering region of higher SSTs and larger OHC. Dry tongue wrapping around from SW to SE.

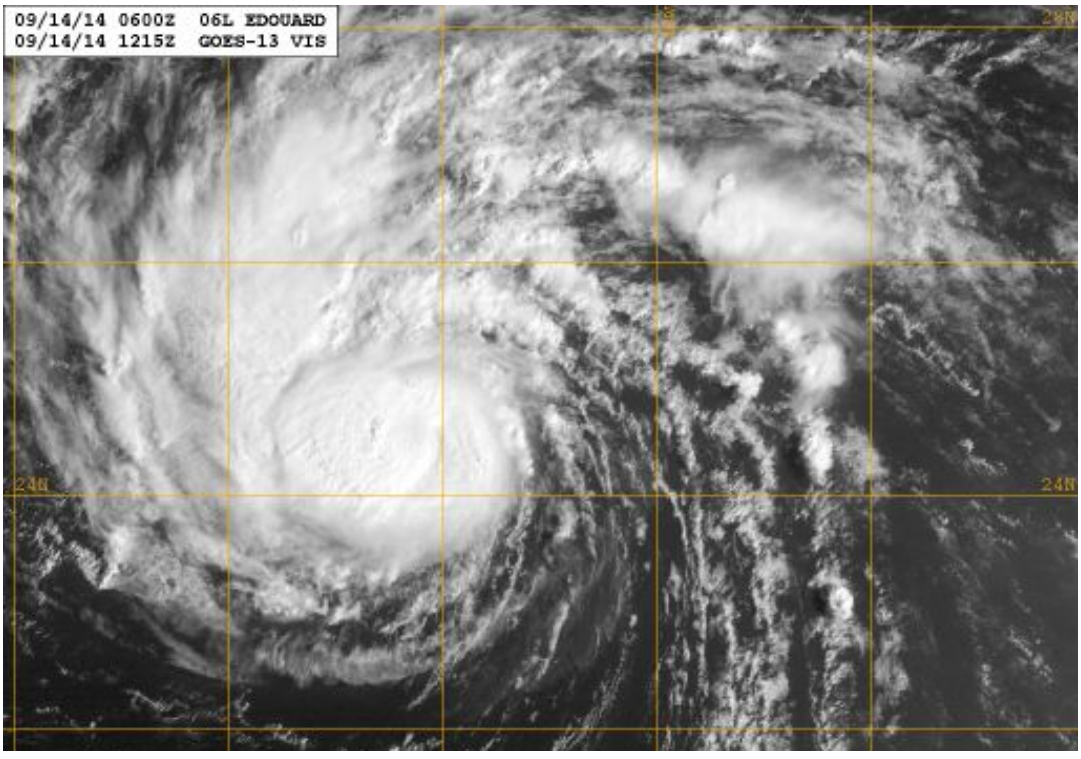




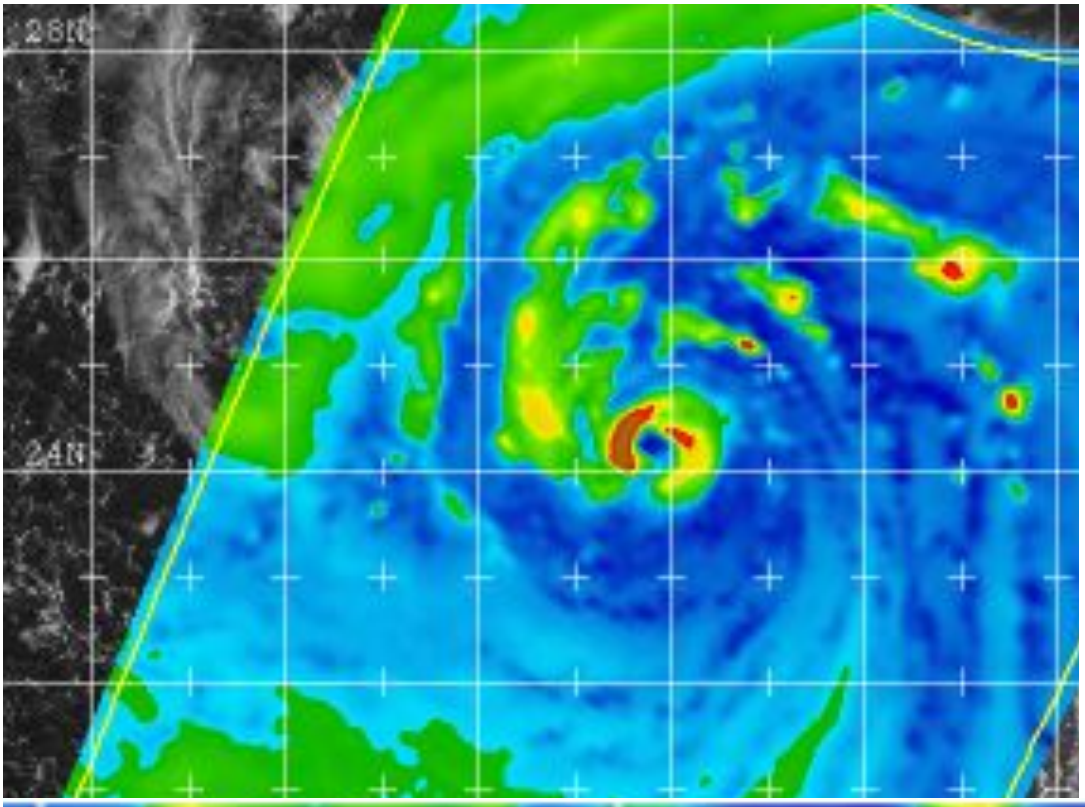
TPW 14 Sep 12Z- Dry tongue to south of center.

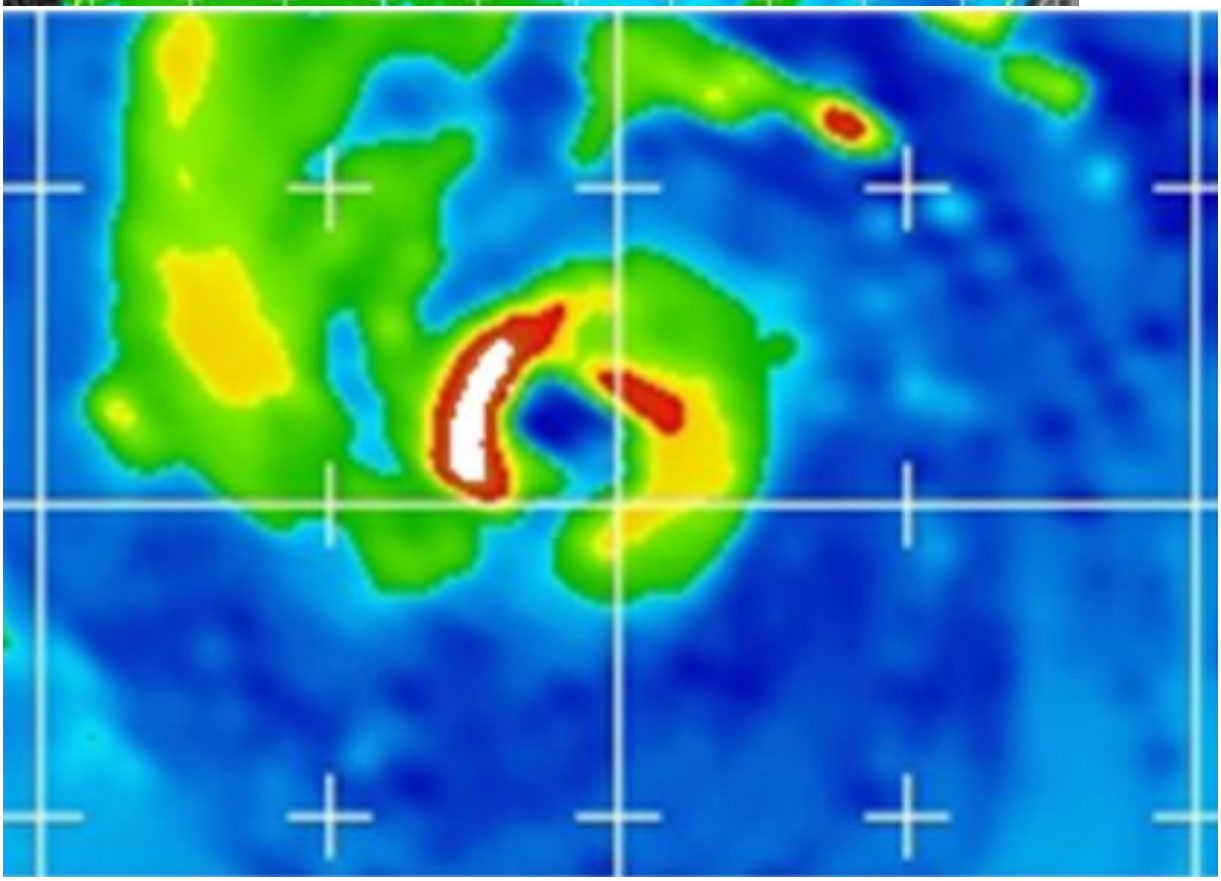
Huge blowup in west eyewall 1115-1215Z, lots of lightning. Eye obscured by 1215Z

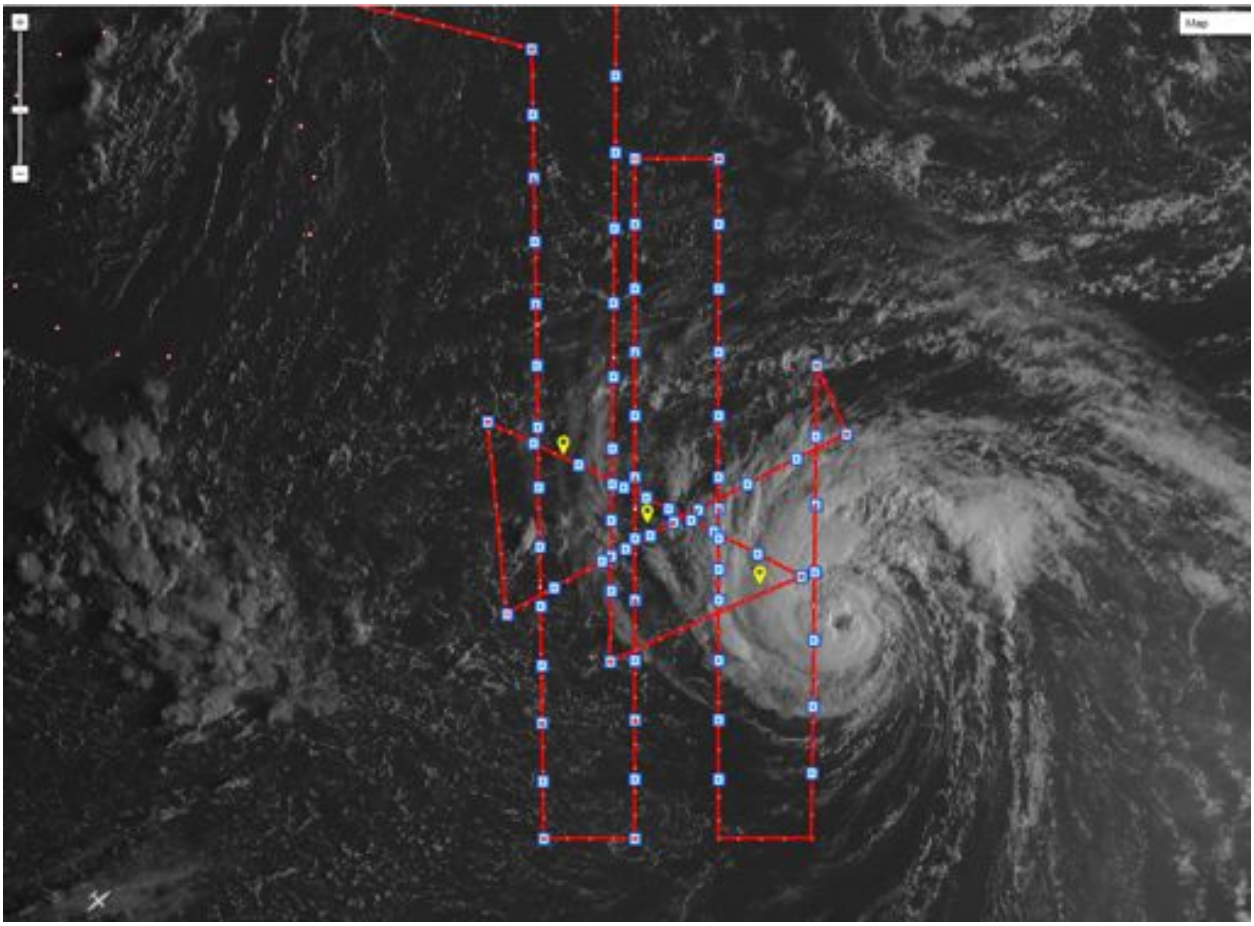




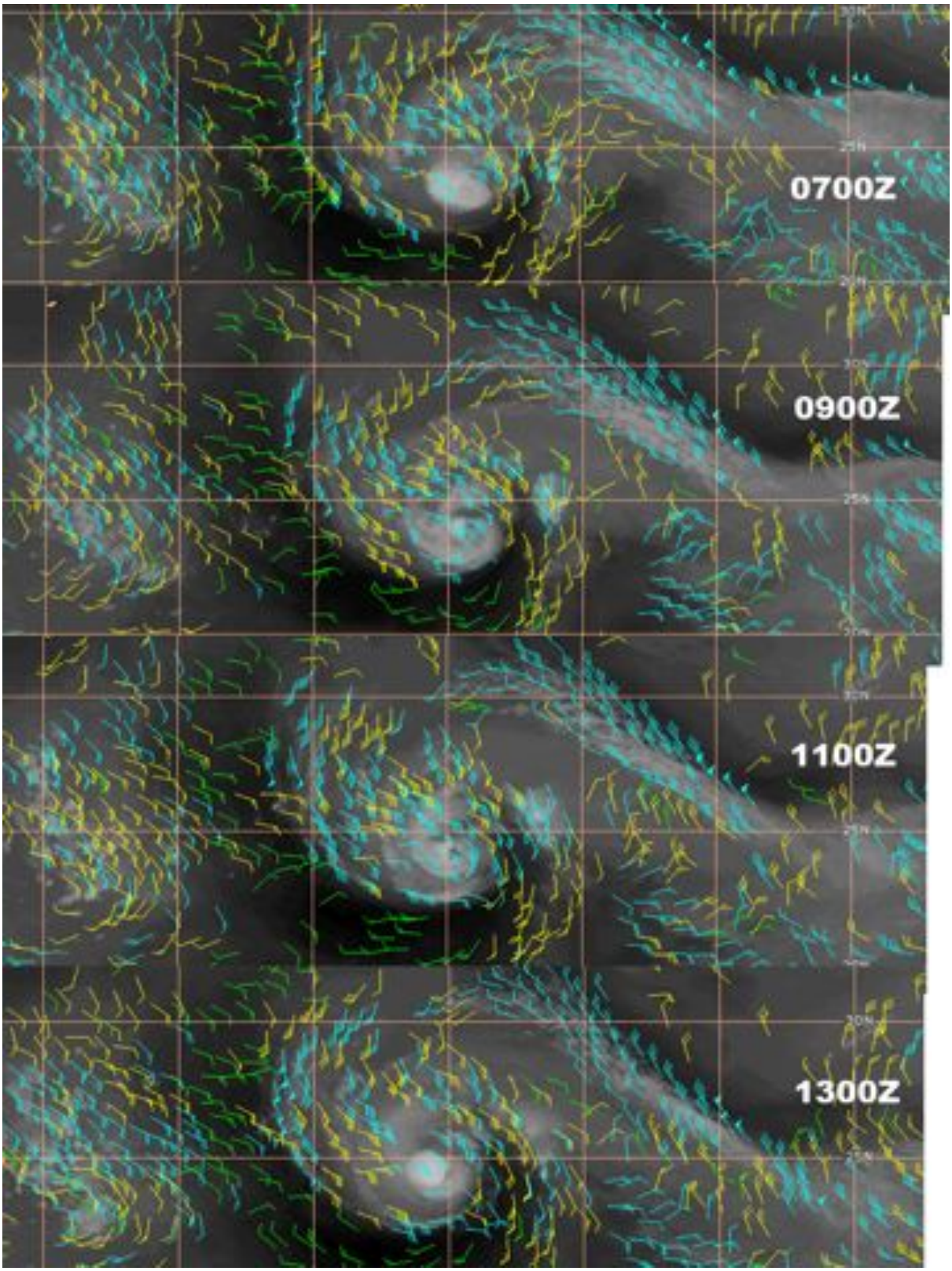
GPM 89H 14_1126Z- Well defined eye.


28N
24N

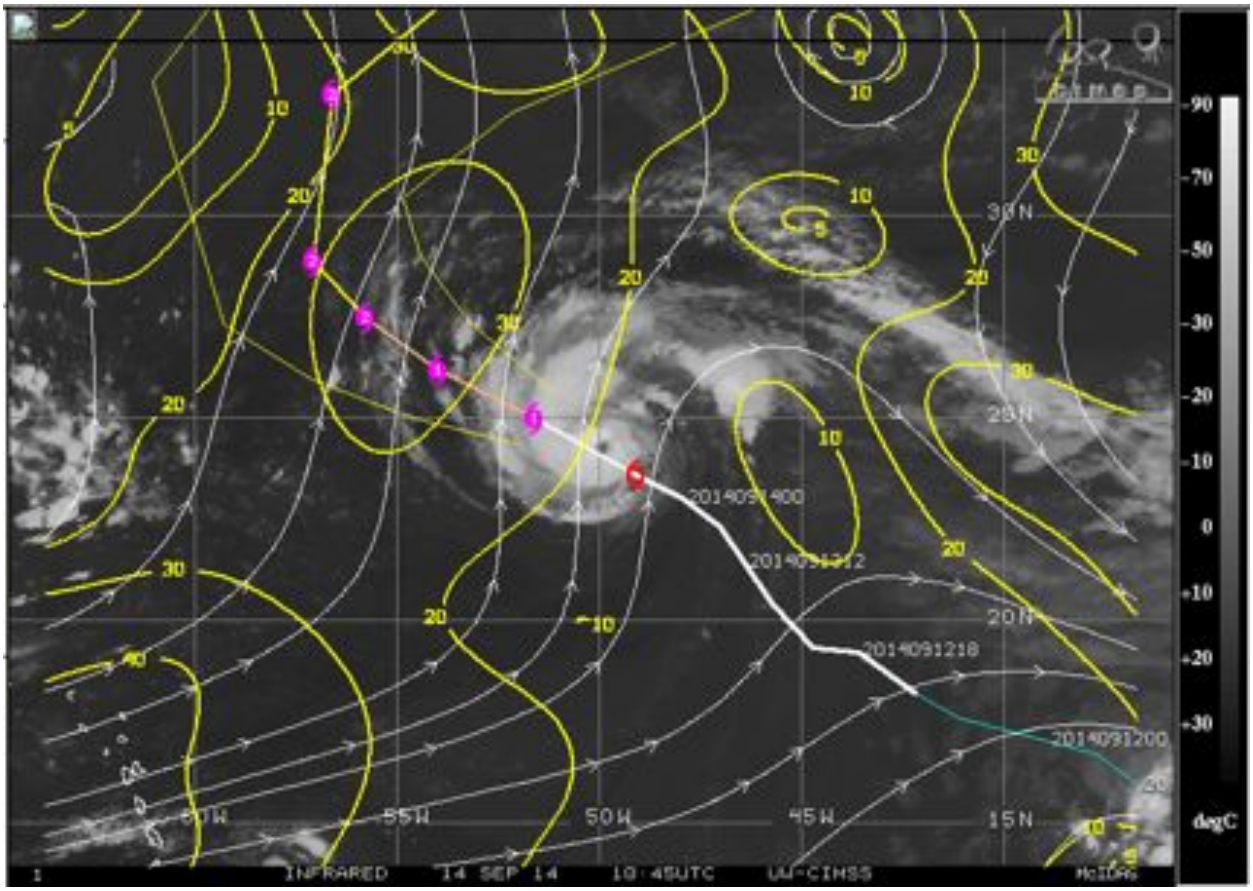




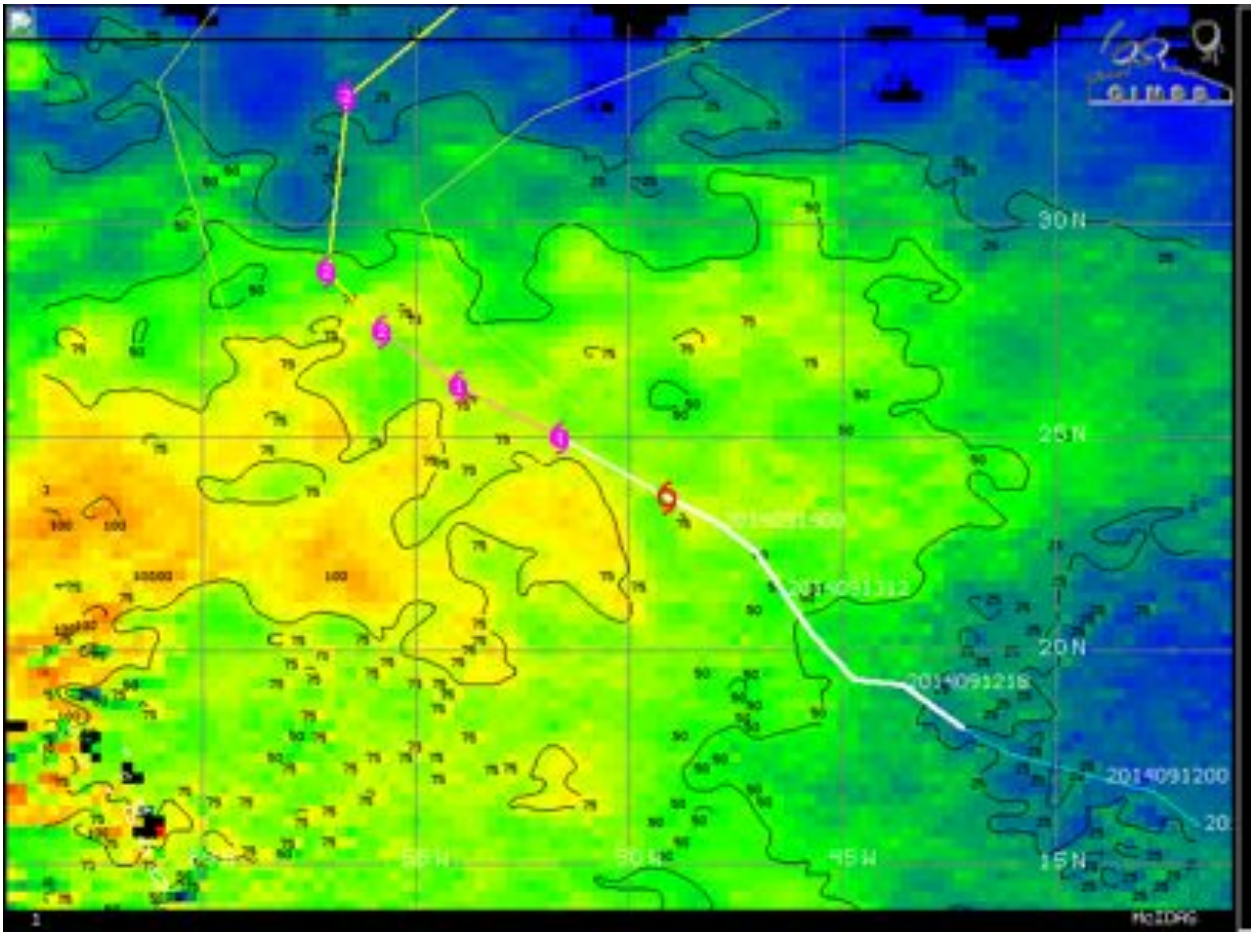
1149 Current flight track overlaid on GOES VIS image. Yellow markers show the 9/14 18Z, and 9/15 06 and 18Z forecasted positions.



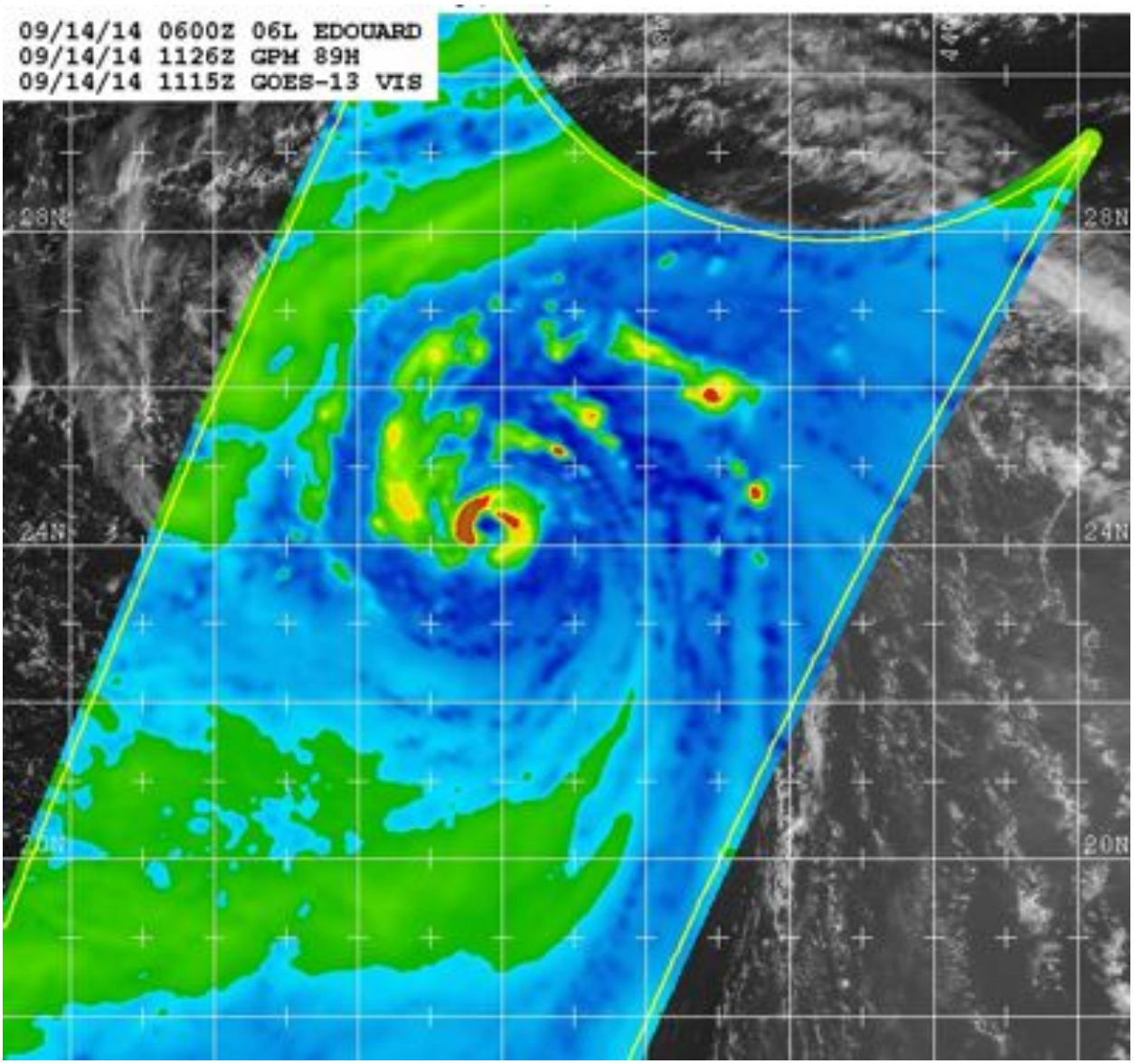
Outflow expanding slower than center motion. Outflow squeezed between digging long-wave trough to east and upper cold low moving ENE toward Edouard.



1203 Strong shear of 30 knots evident with the outflow zone ahead of the storm.



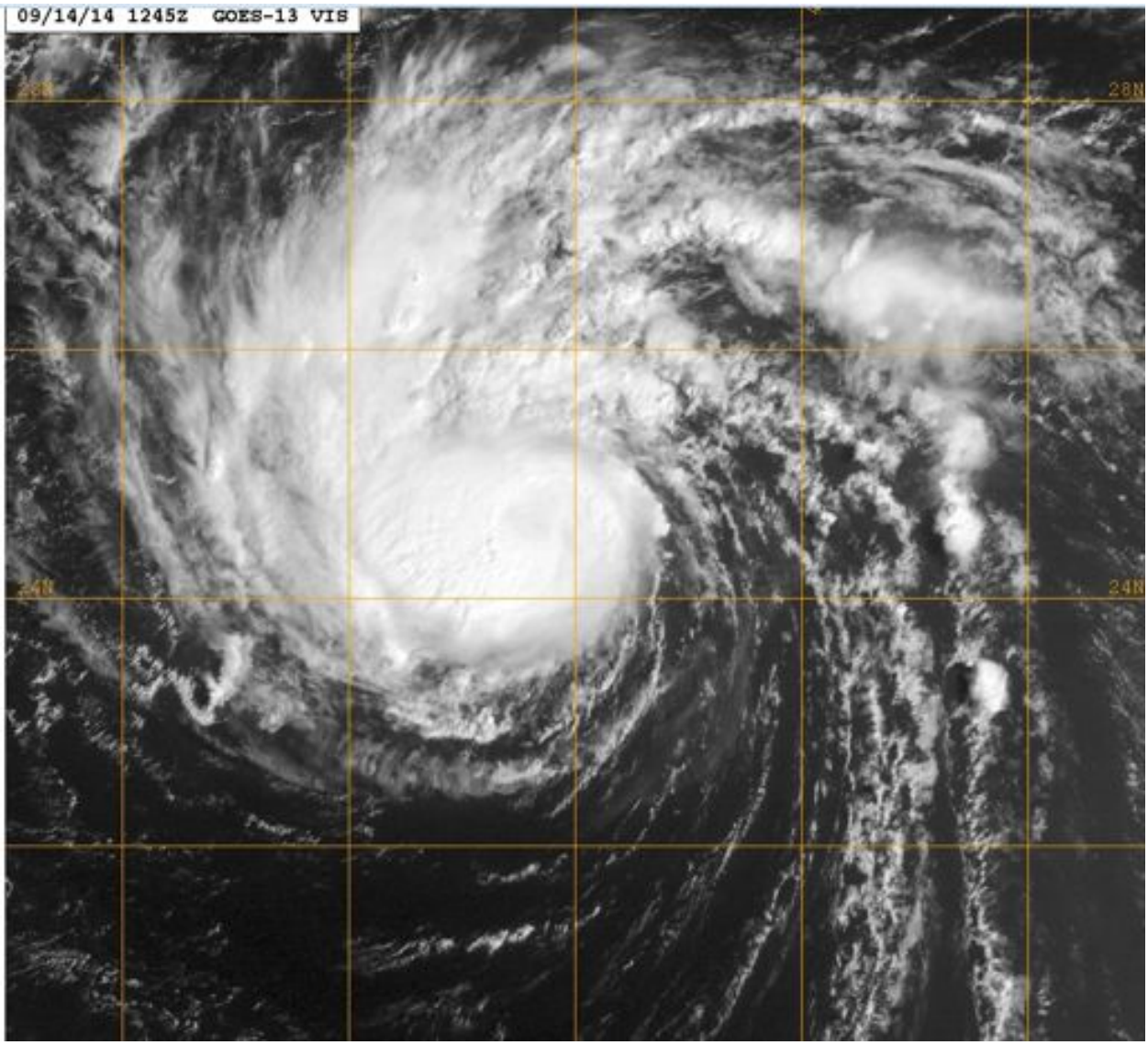
1217Z Storm is definitely a hurricane now, and moving into area of greater ocean heat content.



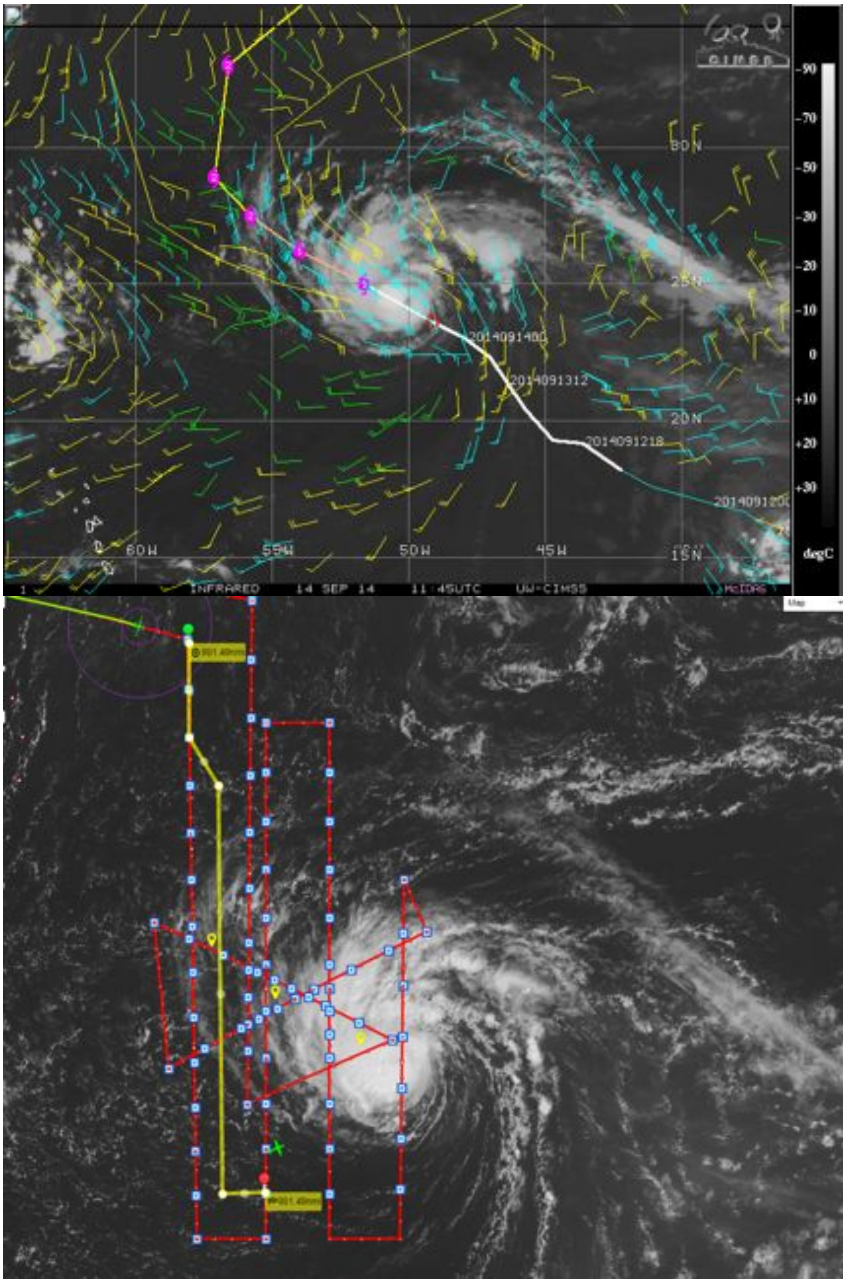
1126Z GMI 85 GHz shows clear eyewall and eye.

1258 D01 sonde released, drop good

1308 D02 sonde released



1245Z GOES visible. Convection bubbling in the eyewall made the eye overcast.



1342 Shifting first leg of the lawnmower slightly east to -55.5 and shifting southernmost part up to ~20.8N. This is to put the first leg centrally in the outflow jet. The plane will turn at the original lawnmower leg longitude, then shift over to the new longitude leg after 3 drops. The next three legs will also be changed as the plane approaches.

1419 D03 sonde released

1429 D04 sonde released

1442 D05 sonde released

1457 D06 sonde released

1500 NHC upgraded to a Cat-1 Hurricane with 15Z advisory.

1508 D07 sonde released

1521 D08 sonde released

1534 D09 sonde released

1549 D10 sonde released

1557 D11 sonde released

1610 D12 sonde released

1623 D13 sonde released

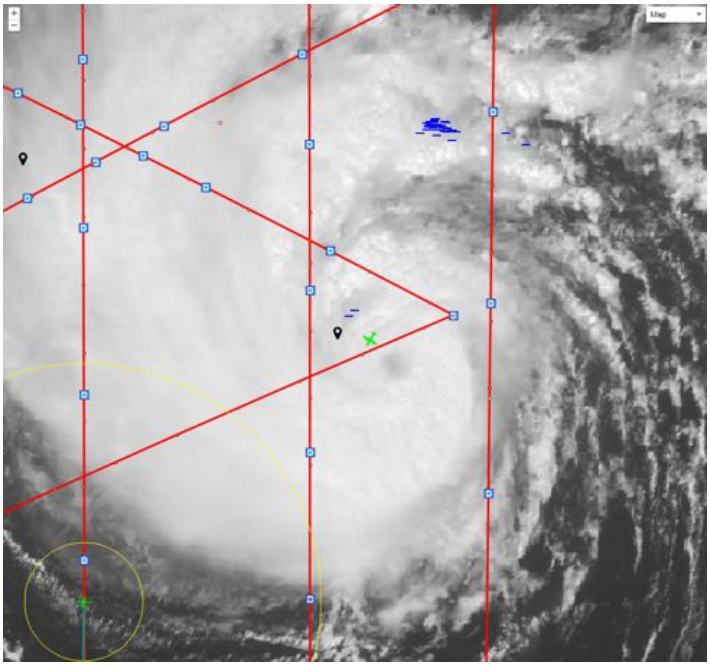
1635 D14 sonde released

1637 N43 SFMR Indicates 66 kt wind at surface, and flight level winds (750 hPa) are 90 kts.

1648 D15 sonde released

1707 D16 sonde released

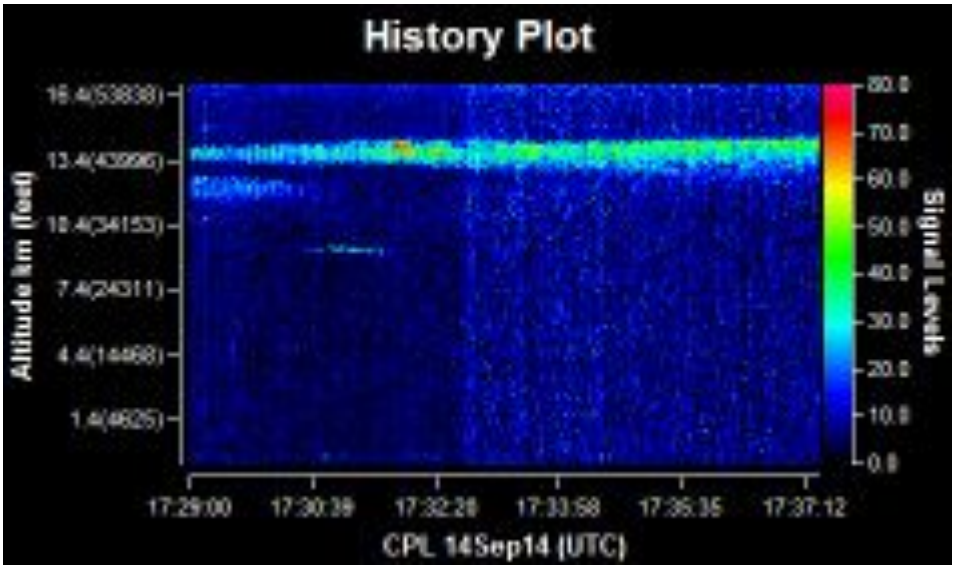
1719 D17 sonde released



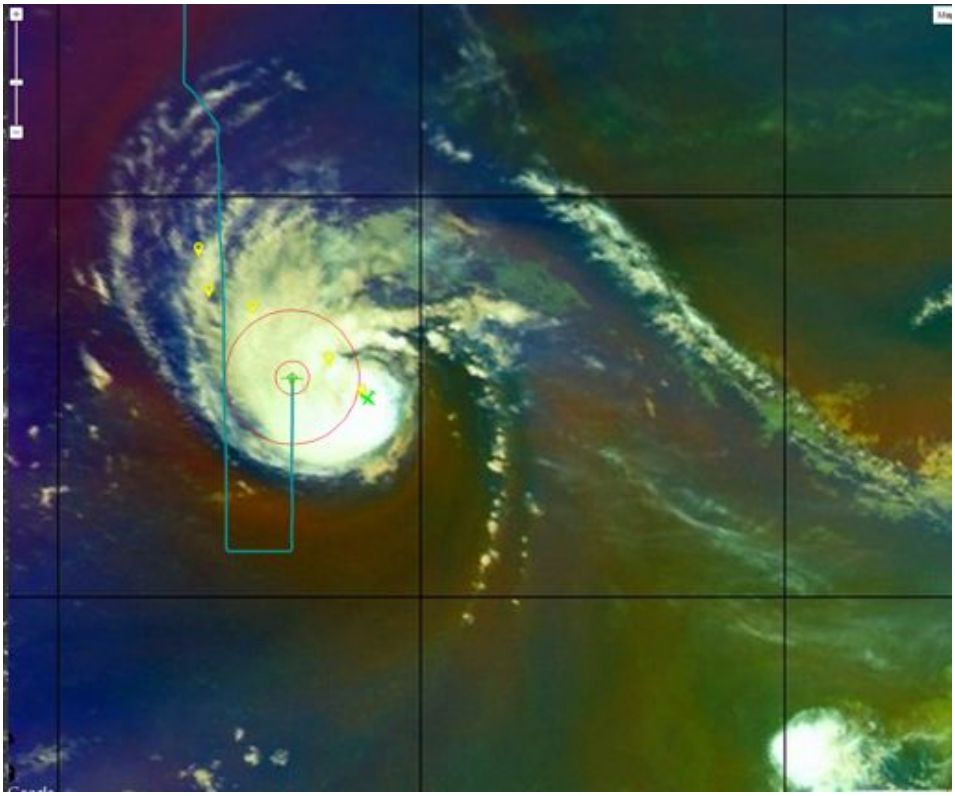
1731Z New burst of lightning in rainband regions on boundary of the dry slot.

1731 D18 sonde released

1744 D19 sonde released



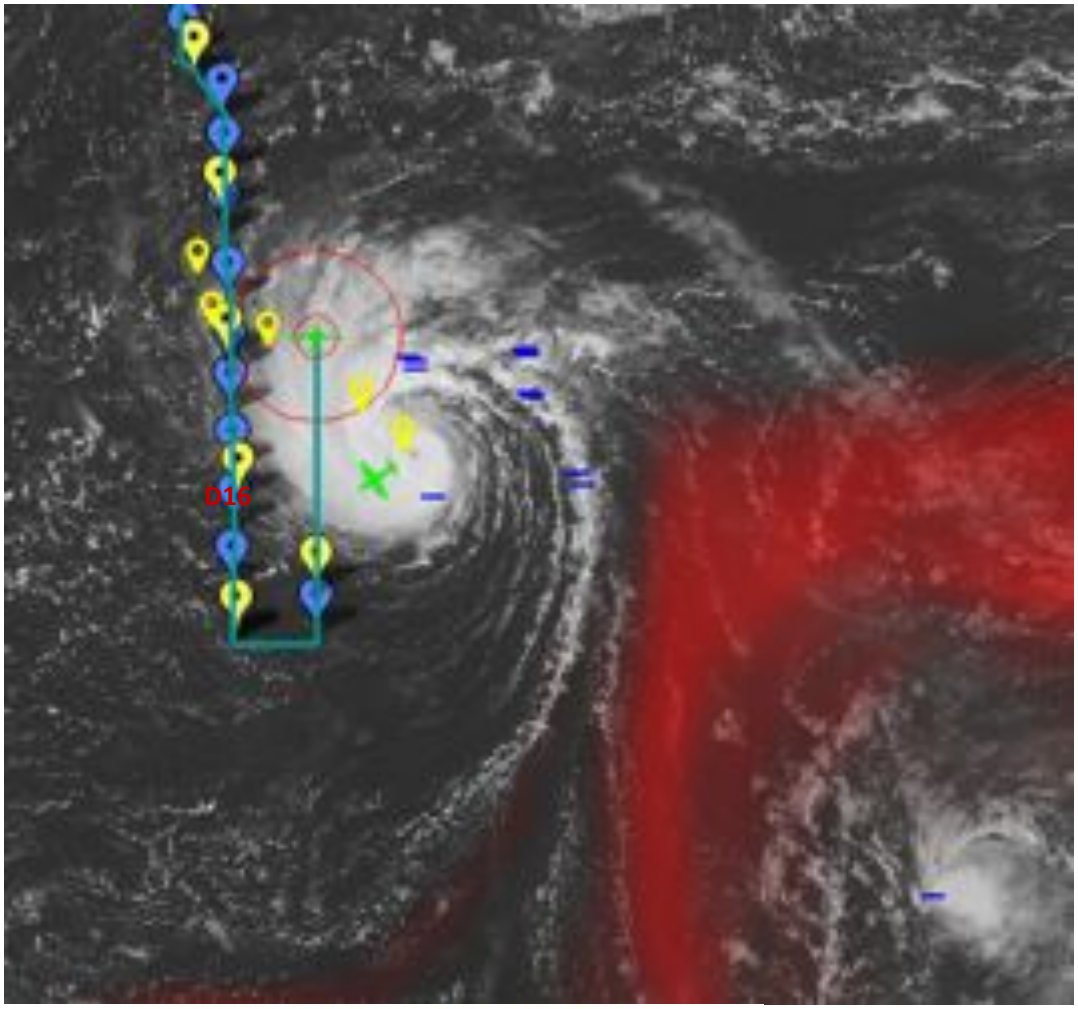
1744 CPL Quicklook indicating edge of cirrus shield currently ~47 kft.

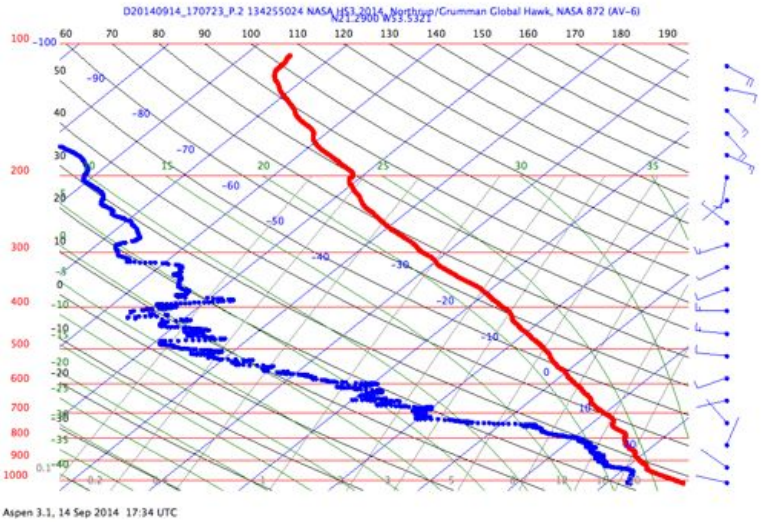


1755Z Flight path time, 1715 RGB-Airmass product. Still strong indication of dry tongue wrapping into the circulation. Northernmost extent where lightning is most prevalent in rainbands.

1756Z D20 sonde released

1802 D16 sonde indicates incredibly dry air in the dry slot. Lightning continues to fire along elongated rainband bordering between the dry slot and possible dusty layer to the SW. Red area indicates dust AOT from GEOS-5.



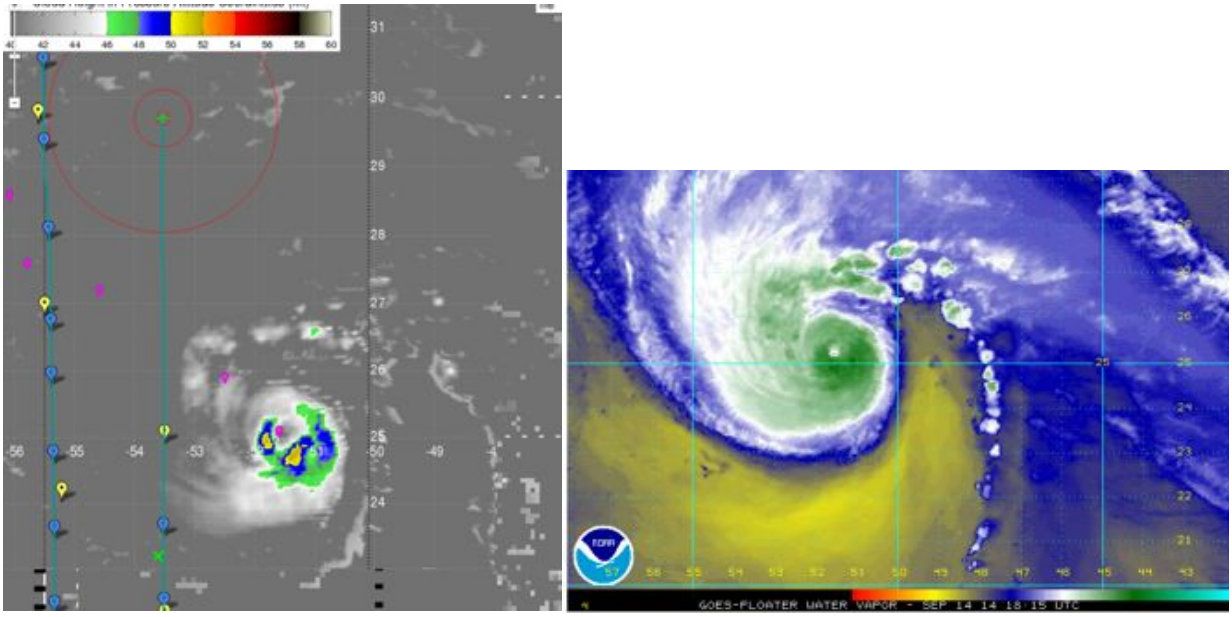


1809 D21 sonde released
1818 AVAPS indicating possible problem with launcher.

1819 AVAPS recovered.

1823 D22 sonde released.

1834 D23 sonde released.



1841 CTH at 1820 UTC, WV at 1815 UTC. Indicates eye is attempting to clear again, convective tops are axisymmetrizing around the center. Convection seems to be becoming more symmetric.

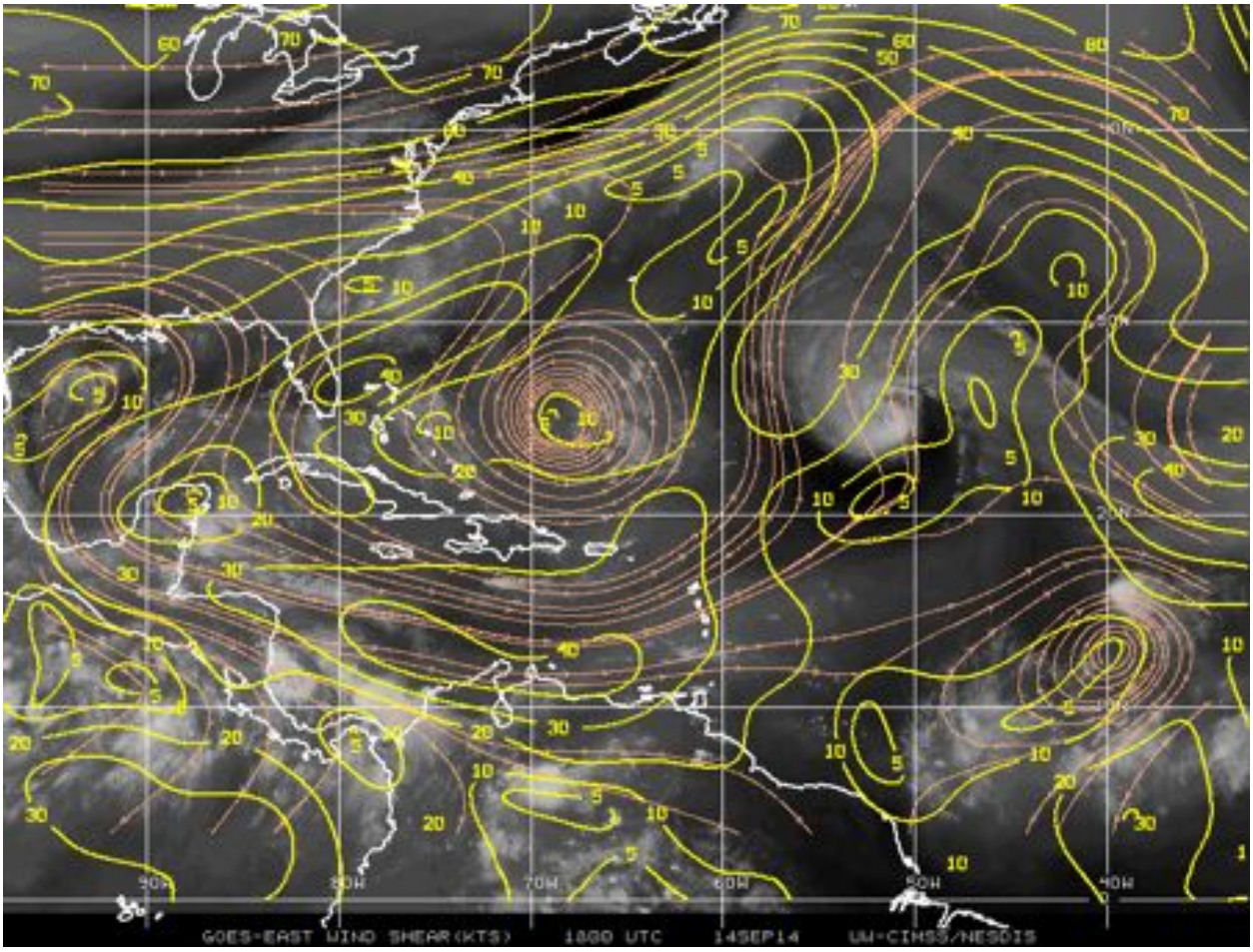
1846 D24 sonde released.

1851 NHC 18Z fix determined to be at 25.1N, 51.5W at 75 kts.

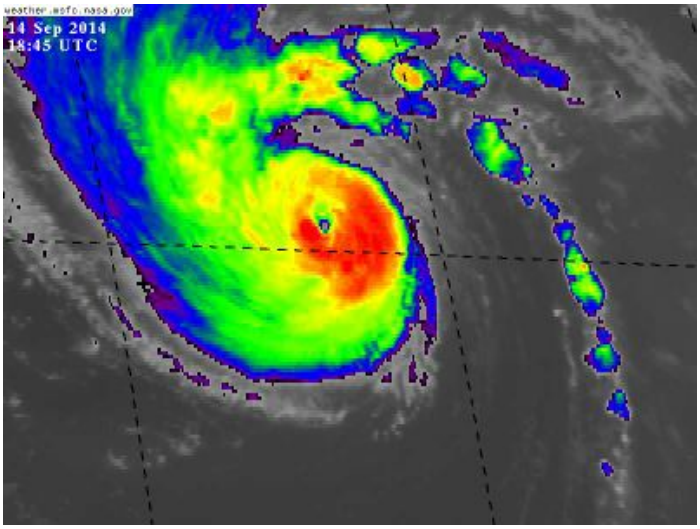
1859 D25 sonde released

1900 Flight track adjusting southern track 25 nm to the west, cutting the southern end short.

1911 D26 sonde released

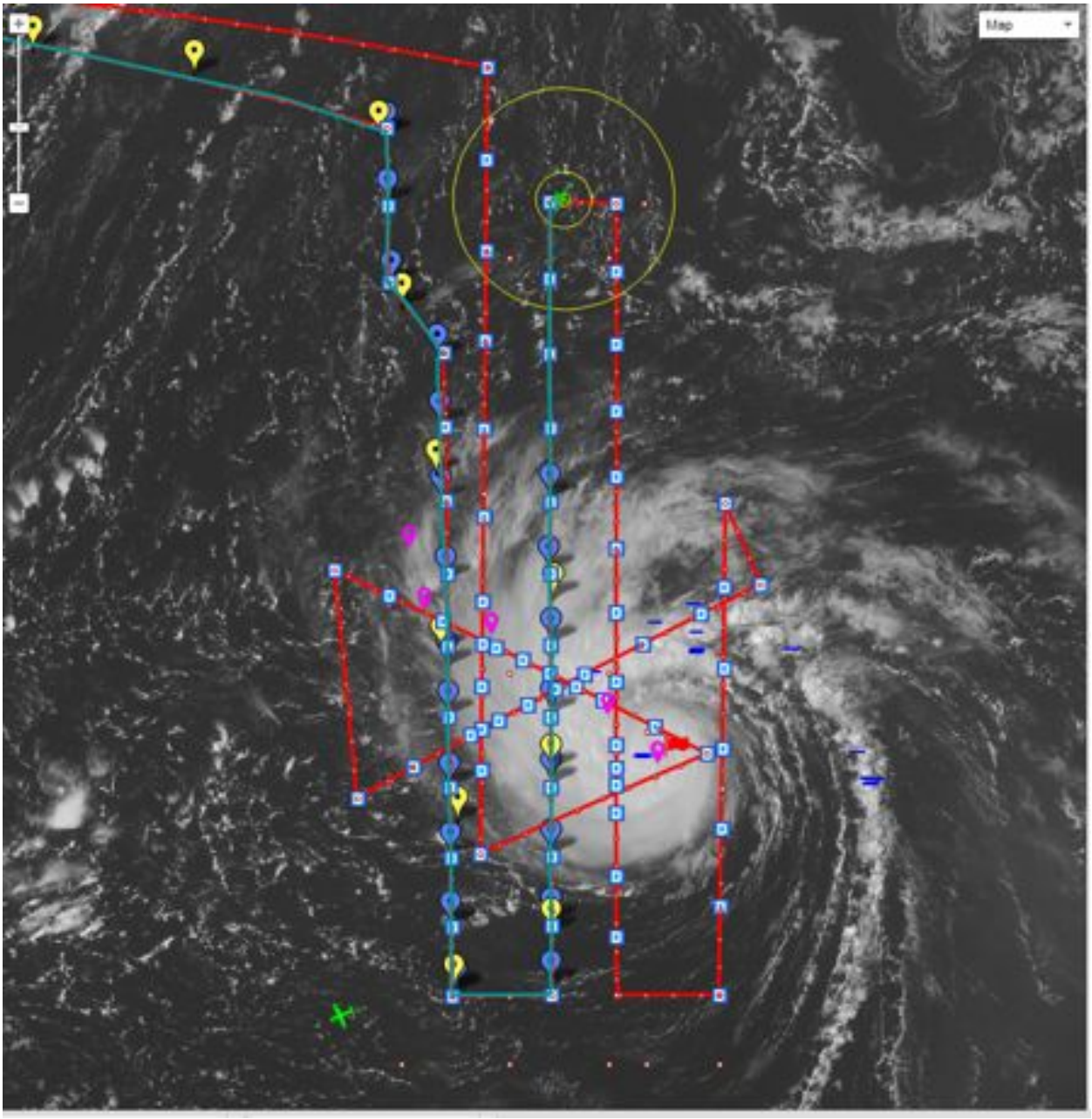


1915 The 1800Z CIMSS wind shear product indicates shear is still mostly southerly, with a sharp gradient across Edouard. Possible bit of a wobble to the SE. Rainband structure still largely asymmetric with most of the most actively convective elements in the downshear and right of shear regions, but the eyewall convection is becoming more symmetric.

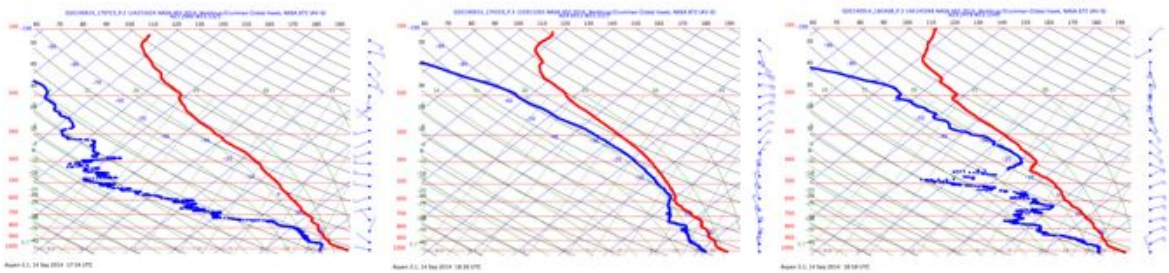


1924 GOES imagery indicating much more symmetric cloud shield over the inner core, as well as deep penetration of the dry slot.
1925 D27 sonde released

1926 New flight track, cutting off southern portion and adjusting the southbound leg westward.



1934 D28 sonde released

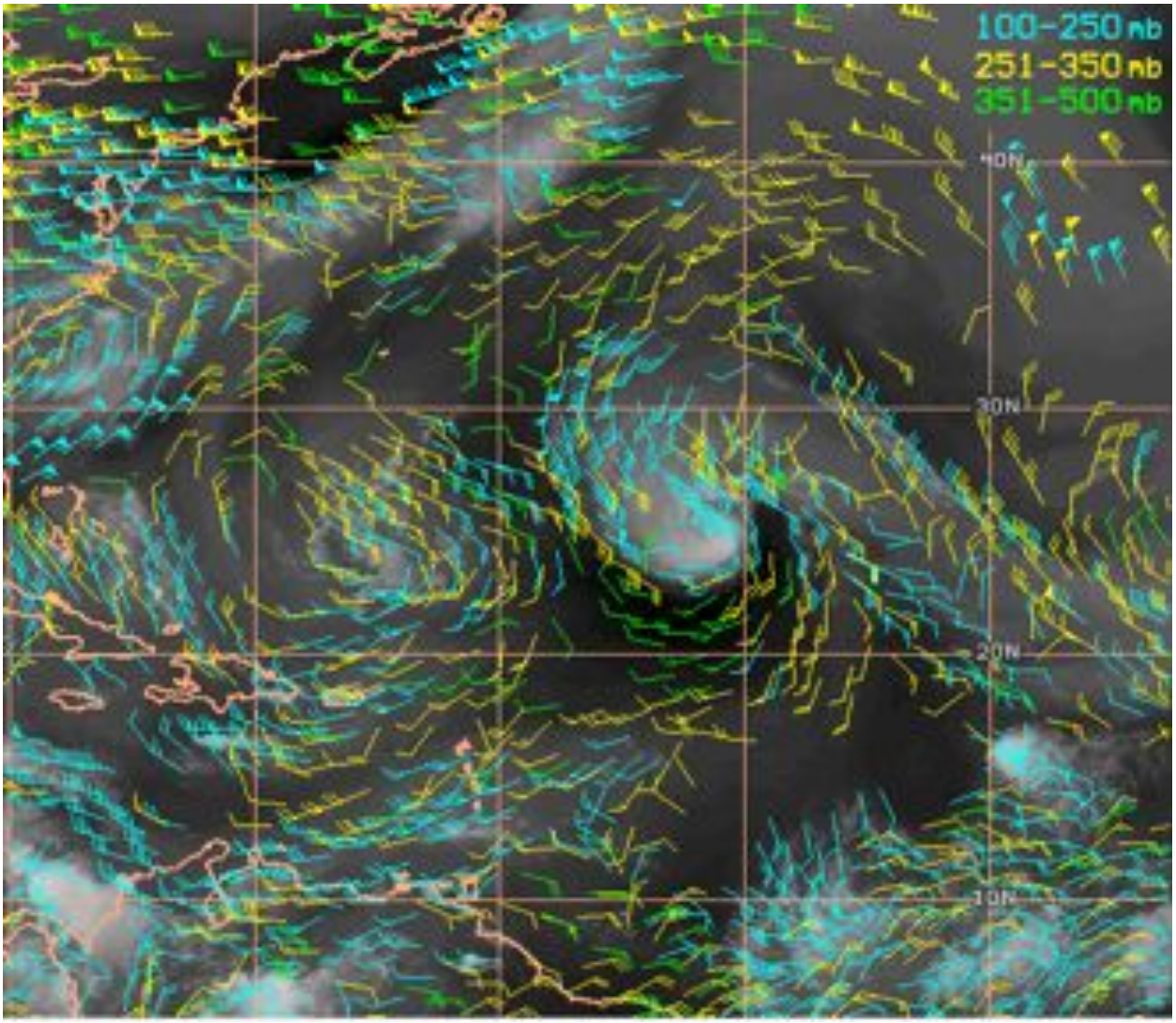


1942 The 1707Z, 1743Z, and 1834Z sondes. Indicates transition from very dry inflow to western rain region to outflow region. Winds below 400 hPa indicate cyclonic circulation. Outflow layer strongly southerly.

1944 D29 sonde released

1957 D30 sonde released

2007 D31 sonde released



2015 The CIMSS Upper level wind tracker for 1800 UTC confirms the very sudden wind shift from westerly to easterly on the border between the dry slot and Edouard's outflow. Lower level wind product indicates that the flow for the dry slot extends all the way down to 950 hPa.

2019 D32 sonde released.

2031 D33 sonde released.

2047 D34 sonde released. Pattern being adjusted about 10 nm eastward to get closer to center. Going to do D35 at the same latitude, but will do D36-38 on the fly.

2049 Gap in the clouds ahead, possible eyewall?

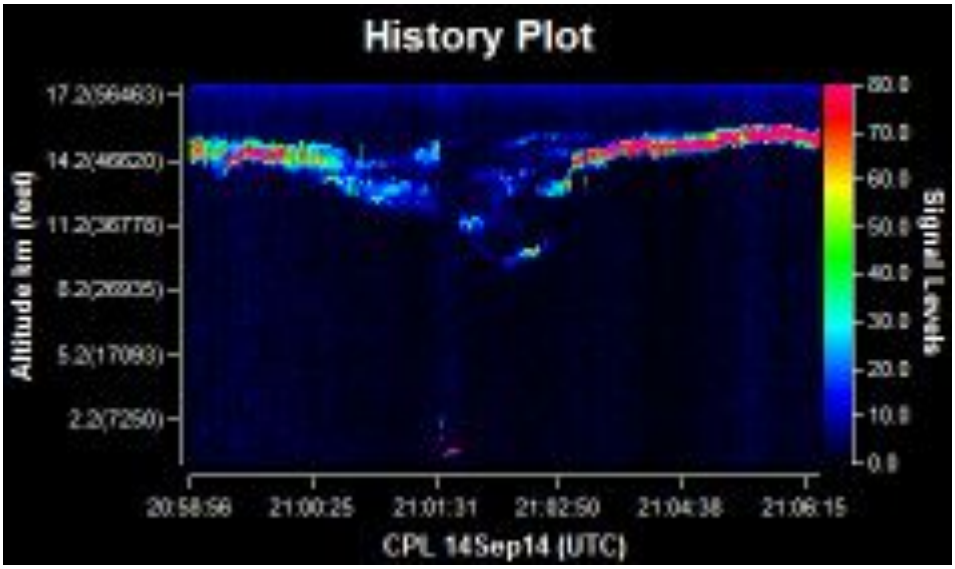
2053 Sonde #35 released at D35

2057 Sonde #36 released

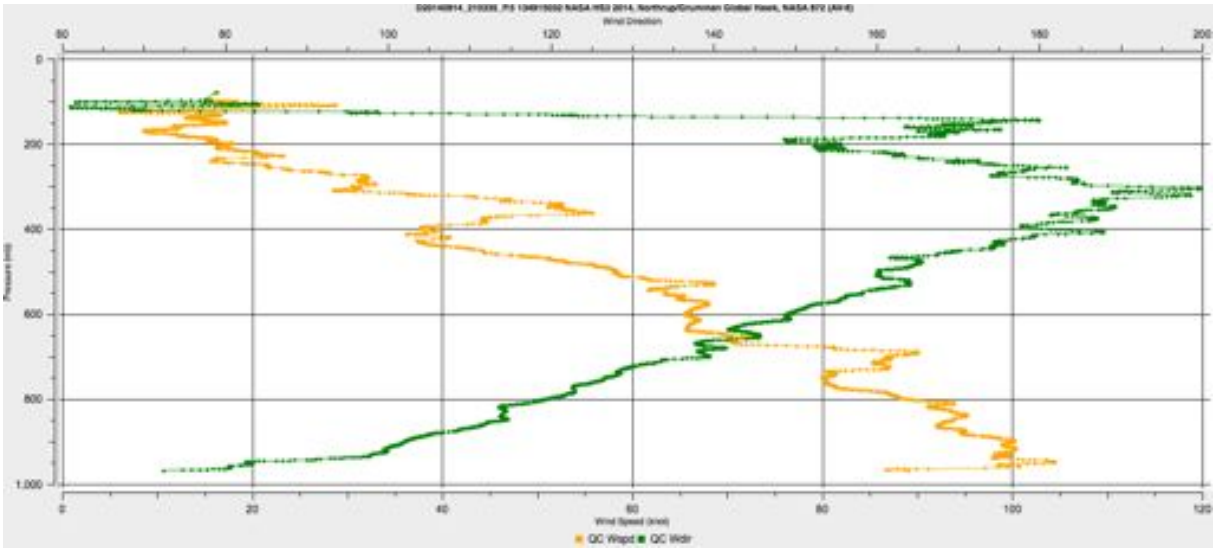
2100 Sonde #37 released at estimated center

2103 Sonde #38 released

2111 CPL showing the break in the clouds corresponding with the eye. Sonde #39 released at latitude of D38.

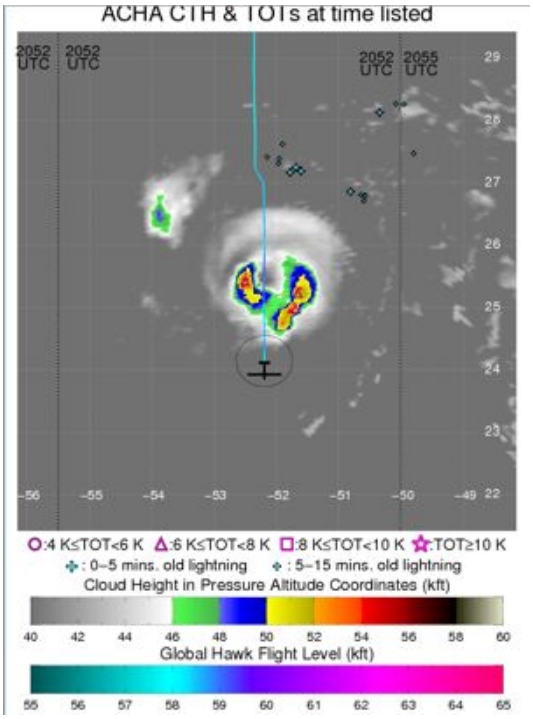


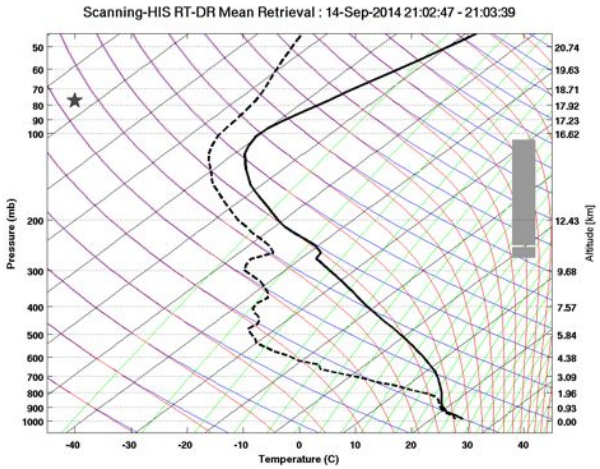
Dropsonde#38A (along first north-south leg across center) shows winds speed maximum exceeding 105 knots at approx. 950 mb; near-surface wind speed of 85 knots at splash down.

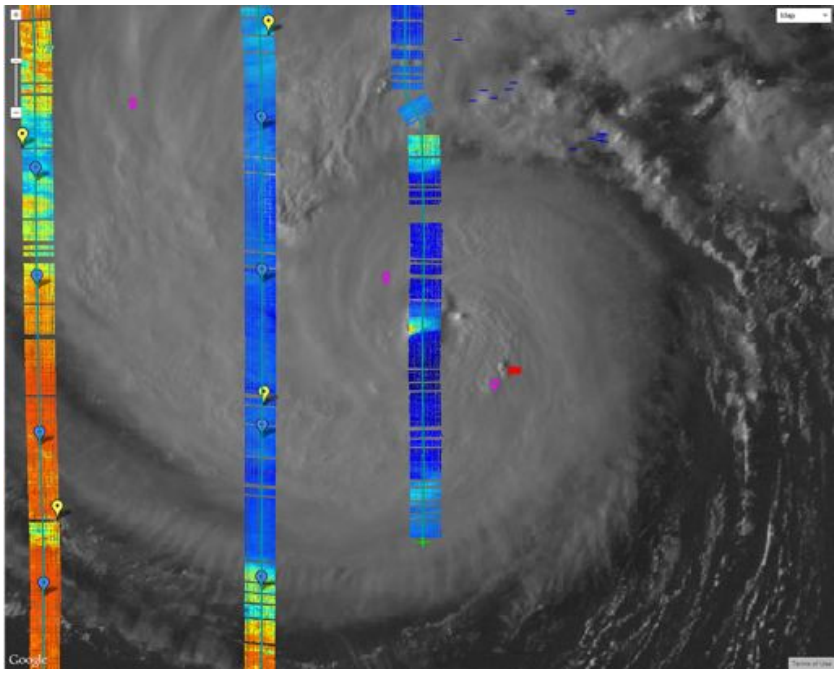


2121 Sonde #40 released between D39 and D40

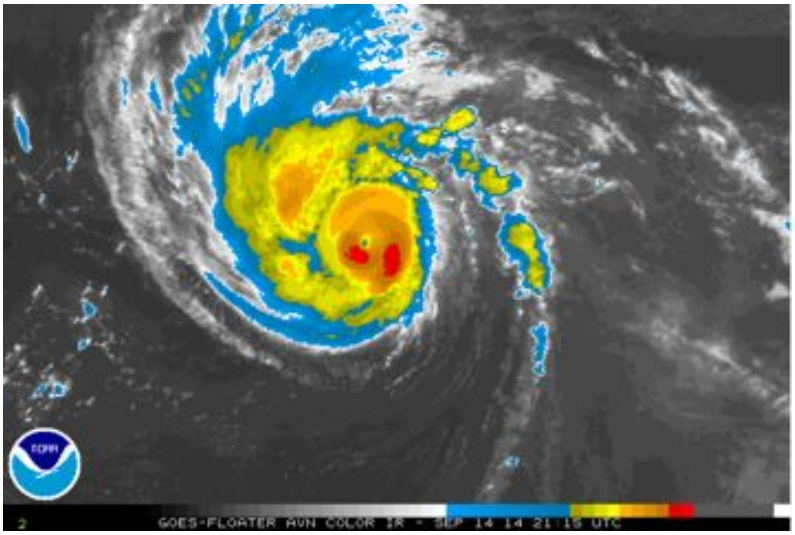
2122 Beautiful pass over the eye! Missed the max descent/warming region by a few nautical miles

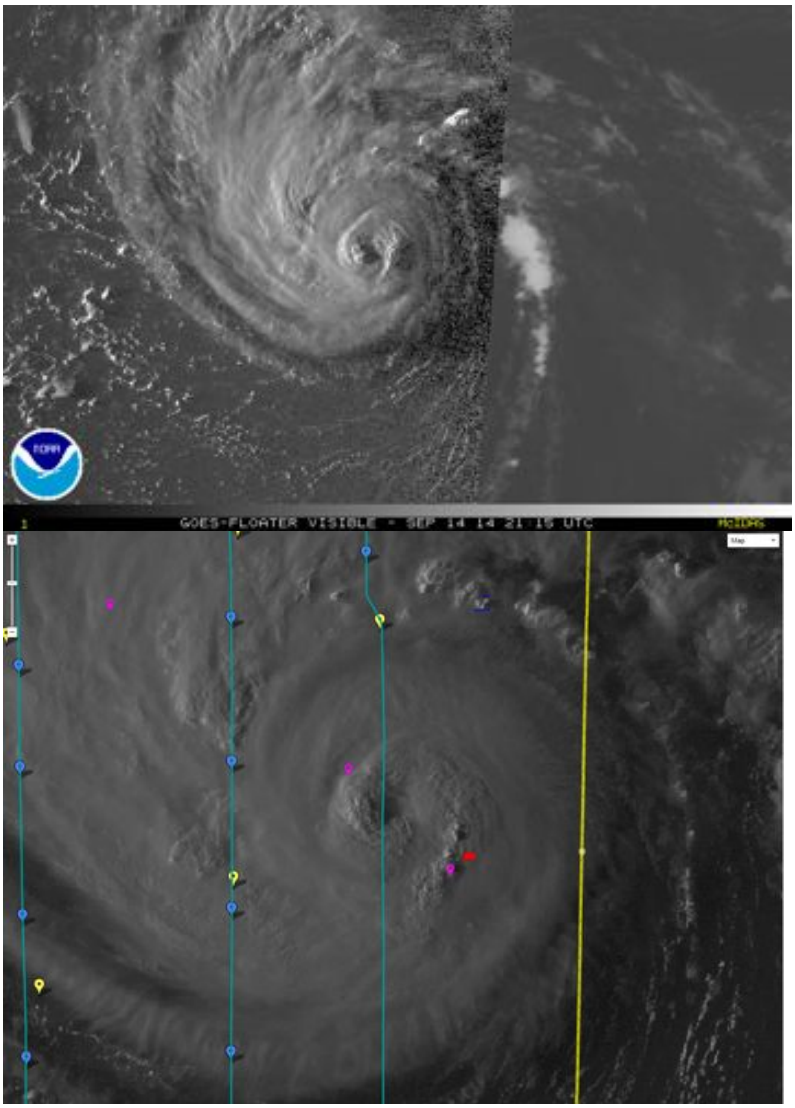




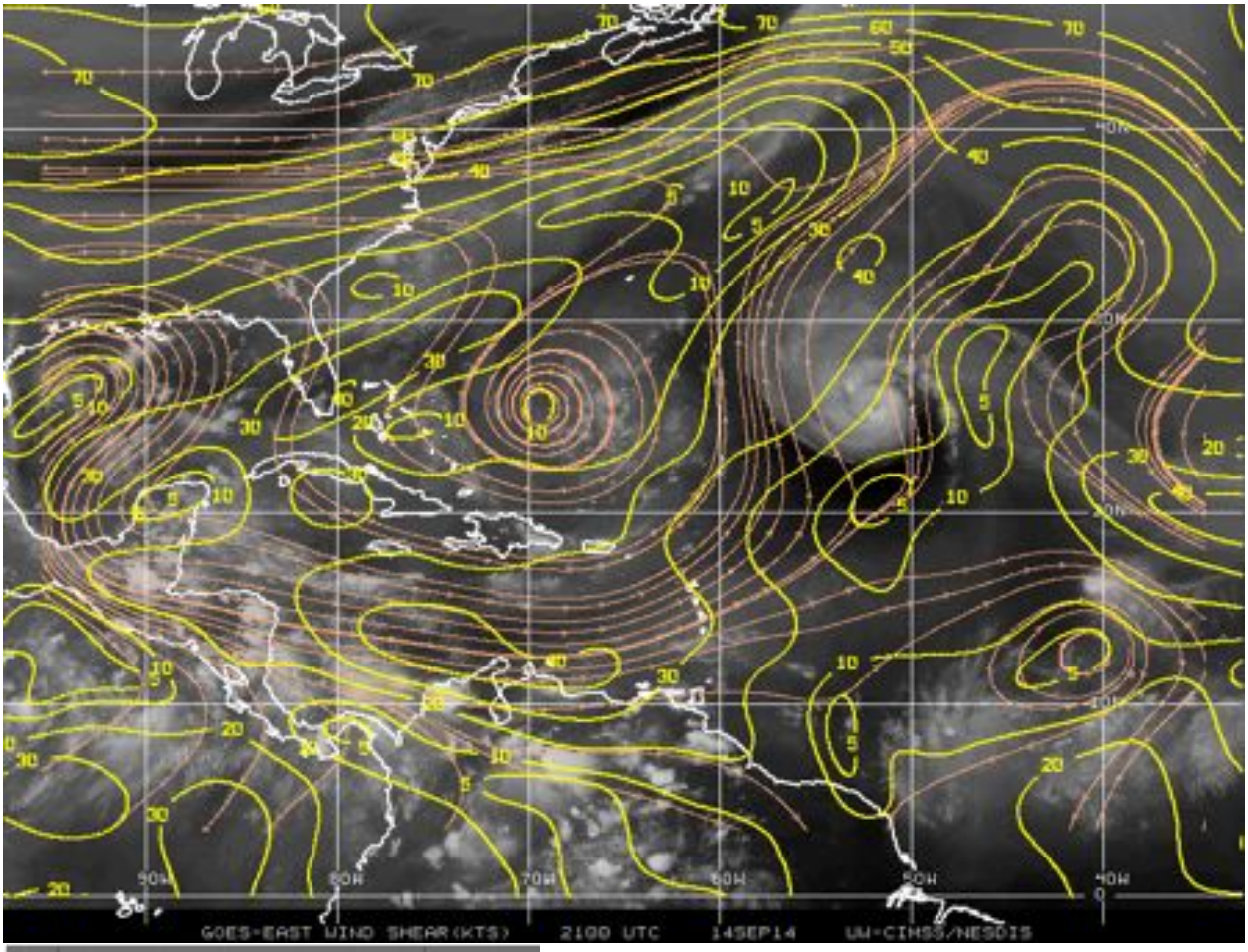


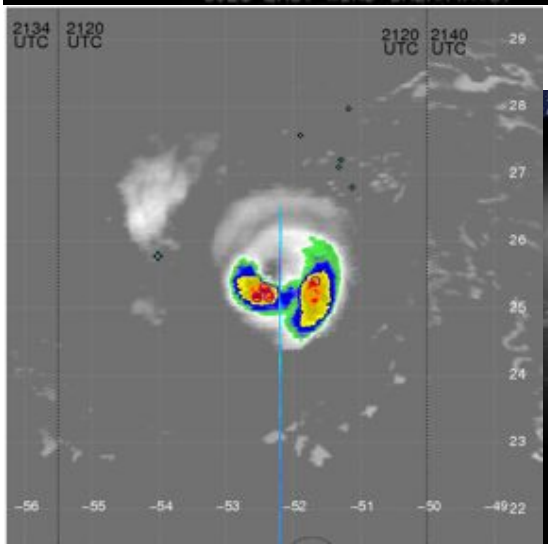
2133 The 2115 IR imagery indicates a very small eye. AVAPS preliminary data indicate surface pressure may be as low as 969 hPa.



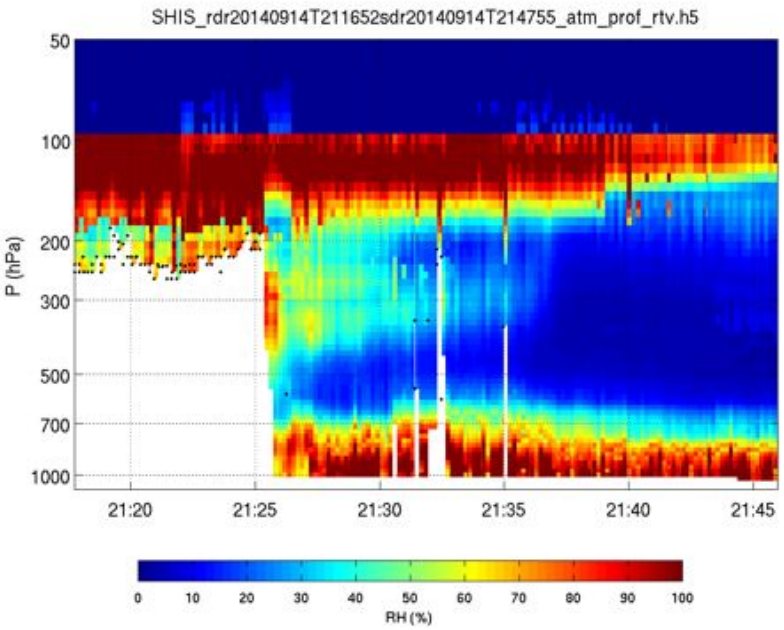


2138 Sonde #41 released at latitude of D41. 2100 UTC CIMSS shear indicates strong gradient of vertical wind shear across Edouard…if this is to be believed, Edouard doesn't seem to care. Massive convective blowup happening in eyewall, scooted through just in time! Also, some nice cloud streets in the dry slot.

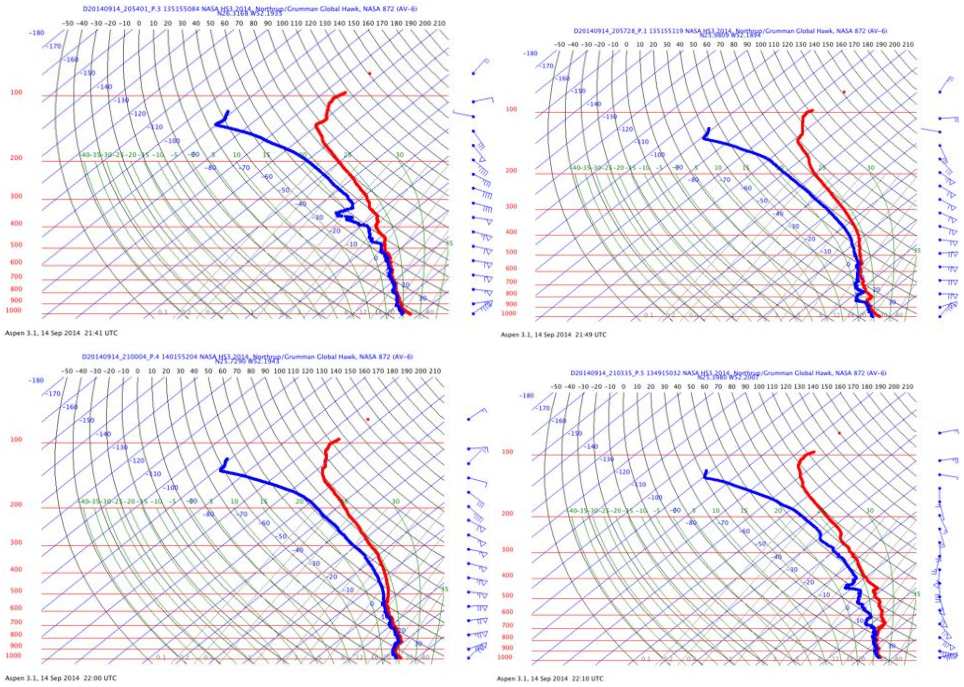




2203 SHIS indicating sudden dropoff of cloud and moisture in transition from inner core to the dry slot.



2205 Eye/eyewall sondes! Drops 35-38



The last sonde in particular looks like it snuck into the eye from the southeastern side of the eyewall…the other sondes seemed to predominately stay on the northern side of the eyewall. 85 kts at the surface, surface pressure was about 969 hPa, 95 kts just above the surface.

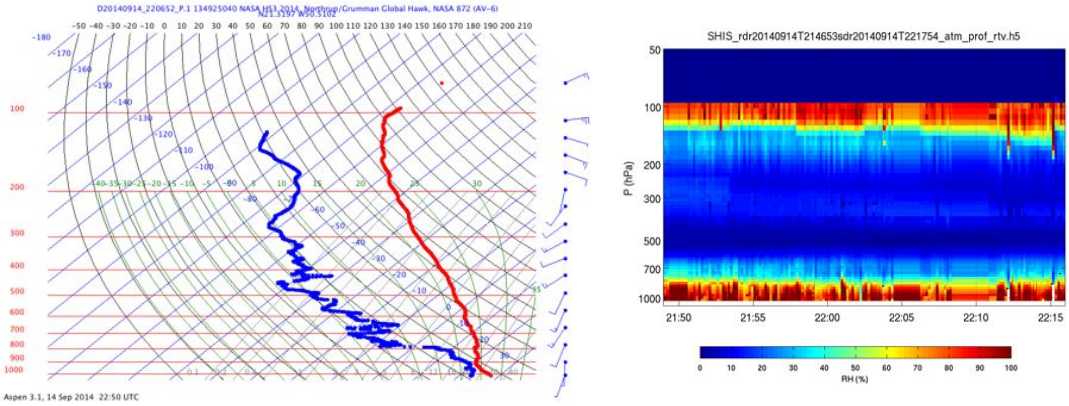
2206 Sonde #42 released at D42

2221 Sonde #43 released at D43

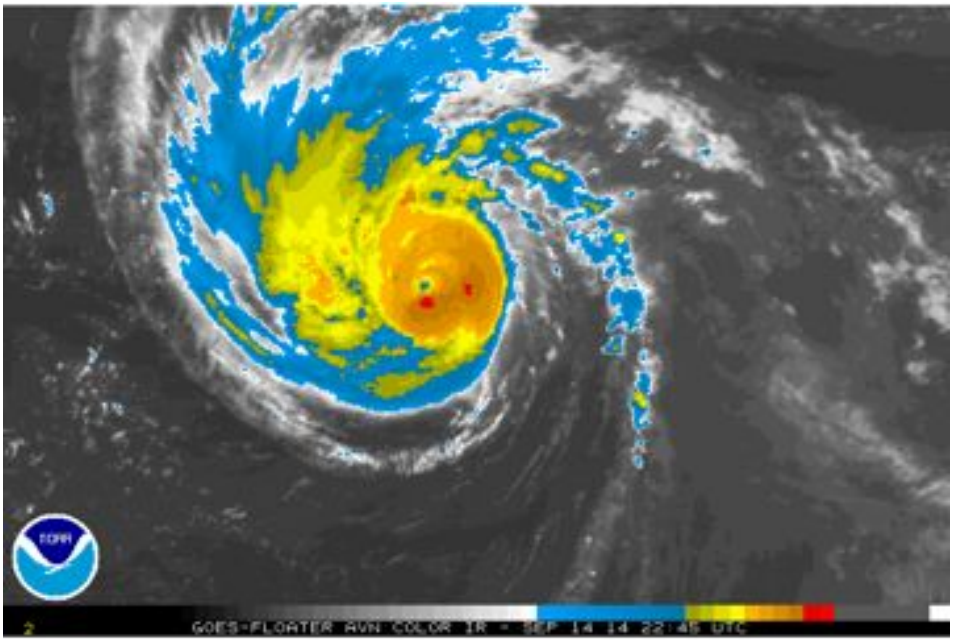
2235 Sonde #44 released at D44

2250 Sonde #45 released at D45

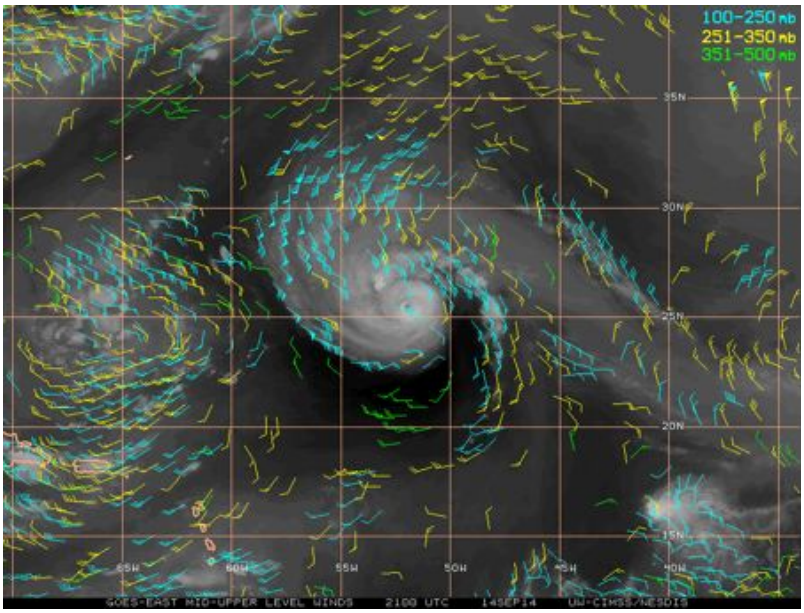
2304 Dry slot seems…well…dry. And very calm at this distance from the circulation.



Also, the storm shoots off a possible inner rainband between the persistent stationary (dare I say principal?) rainband and the inner core.



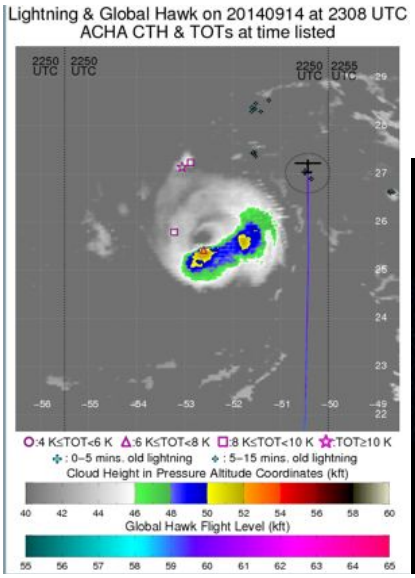
The outflow persists in the orientation as before, pushing away towards the northwest and turning anticyclonically.

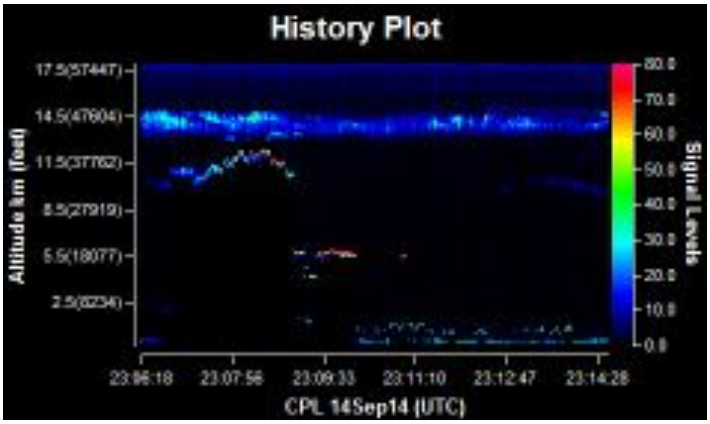


2304 Sonde #46 released at D46

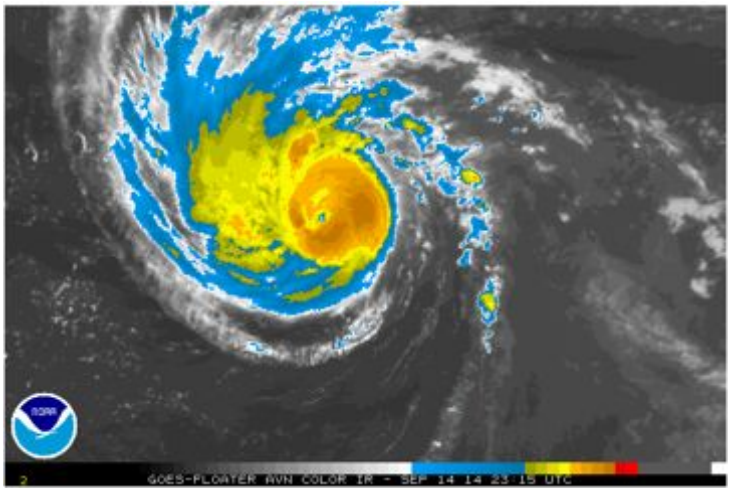
2318 Sonde #47 released at D47

2318 Classic example of a cell with lightning remaining quite low, well below flight level. Cloud tops appear to be about 38-39 kft at 2308 UTC.





2337 Cloud asymmetry is lessening, it appears that rainbands may be trying to form on the western side of the storm as the persistent eastern rainband seems to be diminishing somewhat.



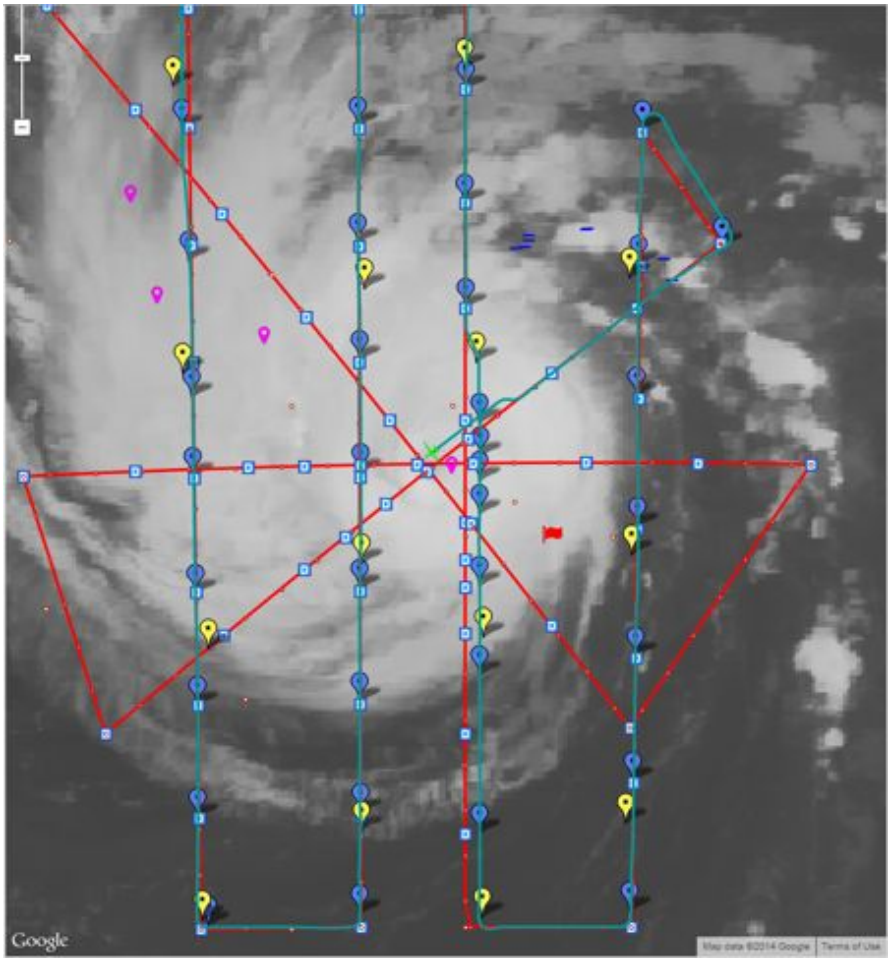
2332 Sonde #48 released at D48

2352 Sonde #49 released at D49

0002 Sonde #50 released at D50

0013 Sonde #51 released at D51

0027 Adjusted flight path for new center, attempting again high density sondes in the eye and eyewall. AVAPS has been having faults lately that makes it slower to recover and reload sondes.

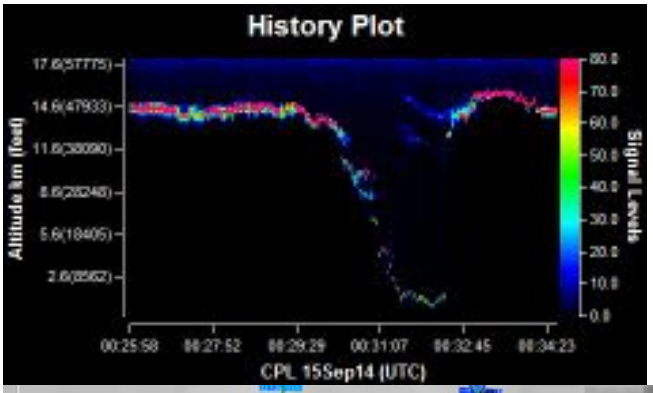


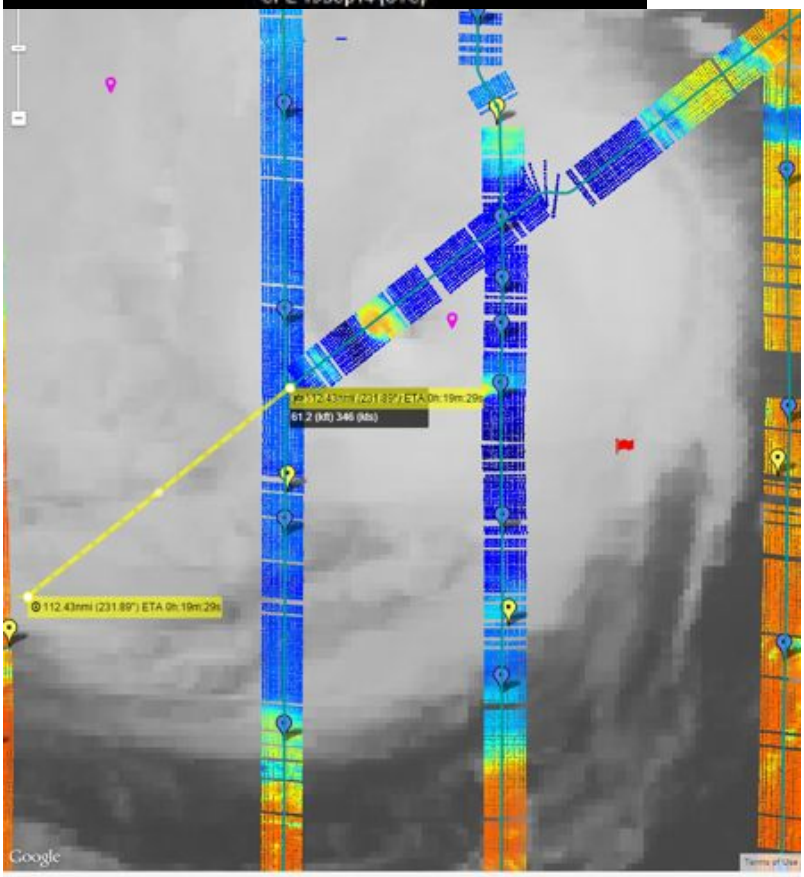
0029 AVAPS fault preventing eye drop. Attempting eyewall drop in 4 minutes, if AVAPS can recover.

0032 Sonde #53 released

0034 Sonde #54 released

0035 CPL and SHIS both were able to see down to the near-surface in the eye.

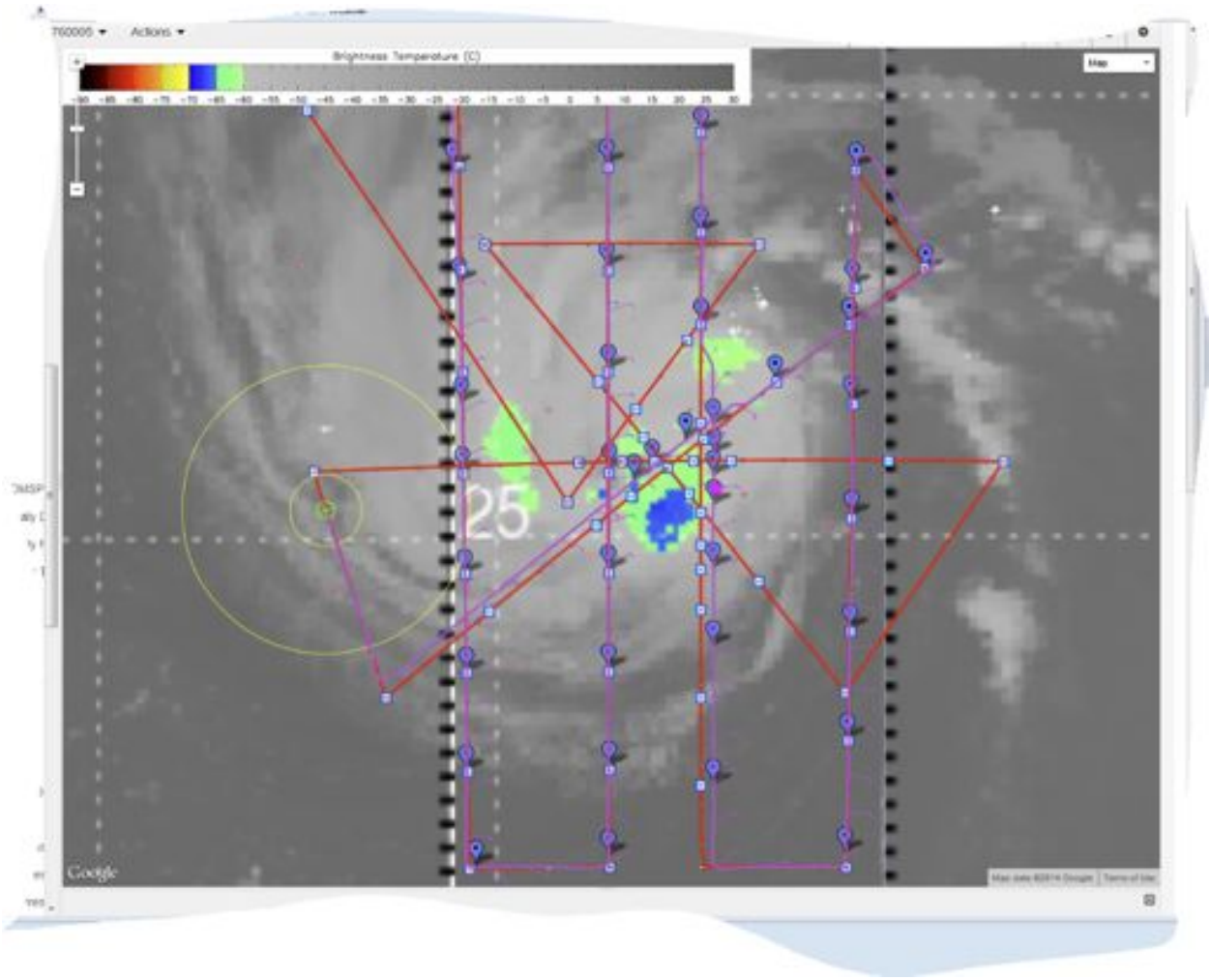




0110Z: Must skip Drop D57 to re-cycle power on AVAPS – reading too warm again. With the skip of D55 and miss of D57, now have 2 extra drops, which we will add to the SE-NW leg later through the center; add those 2 to increase density on that leg.

Revised flight plan now sent.

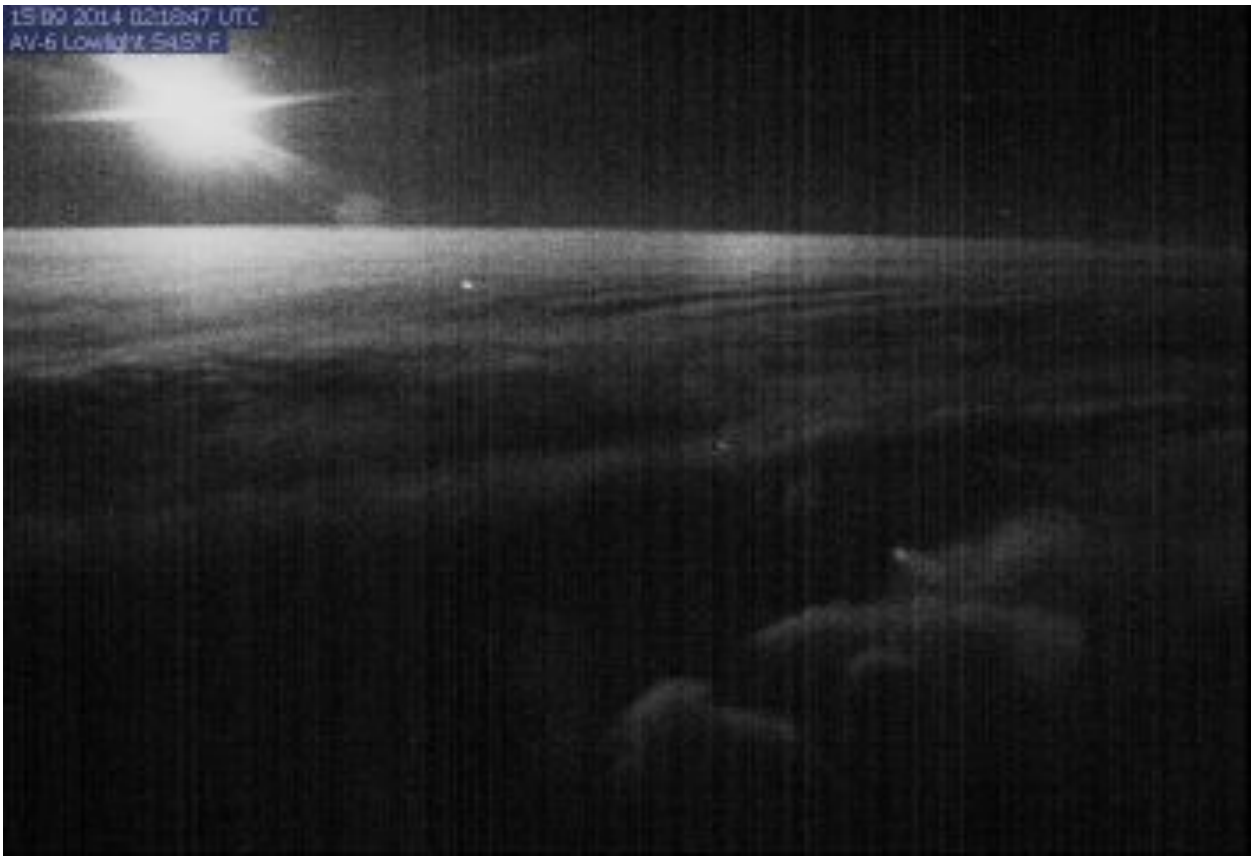
Starting high-density drop sequence: west-to-east.



Moved west-east track 4 naut. miles northward to give an improved center crossing (not shown).

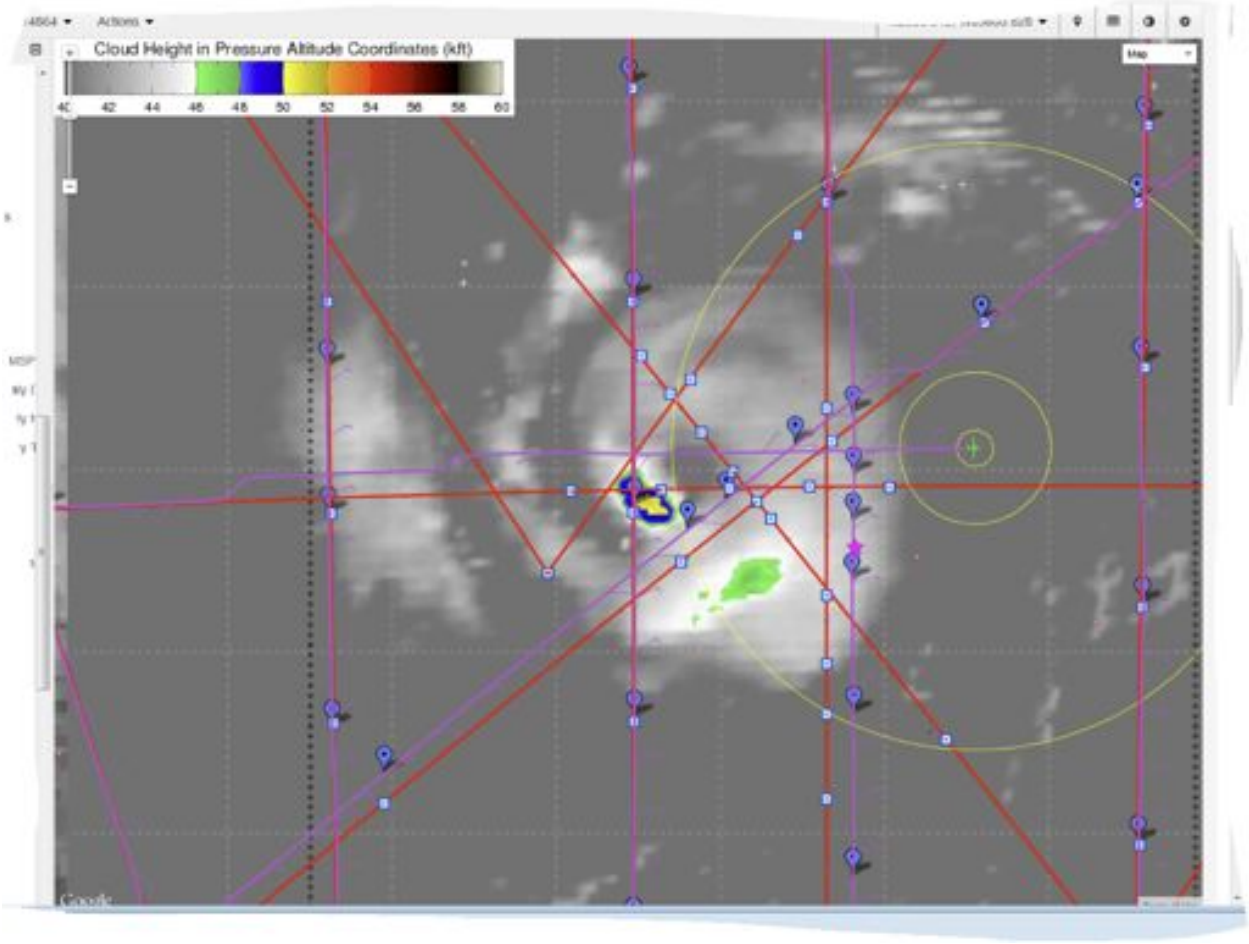
Lowlight camera image as plane flies due east towards center crossing.

Lowlight camera image as plane flies towards upper-level eye (center of image).



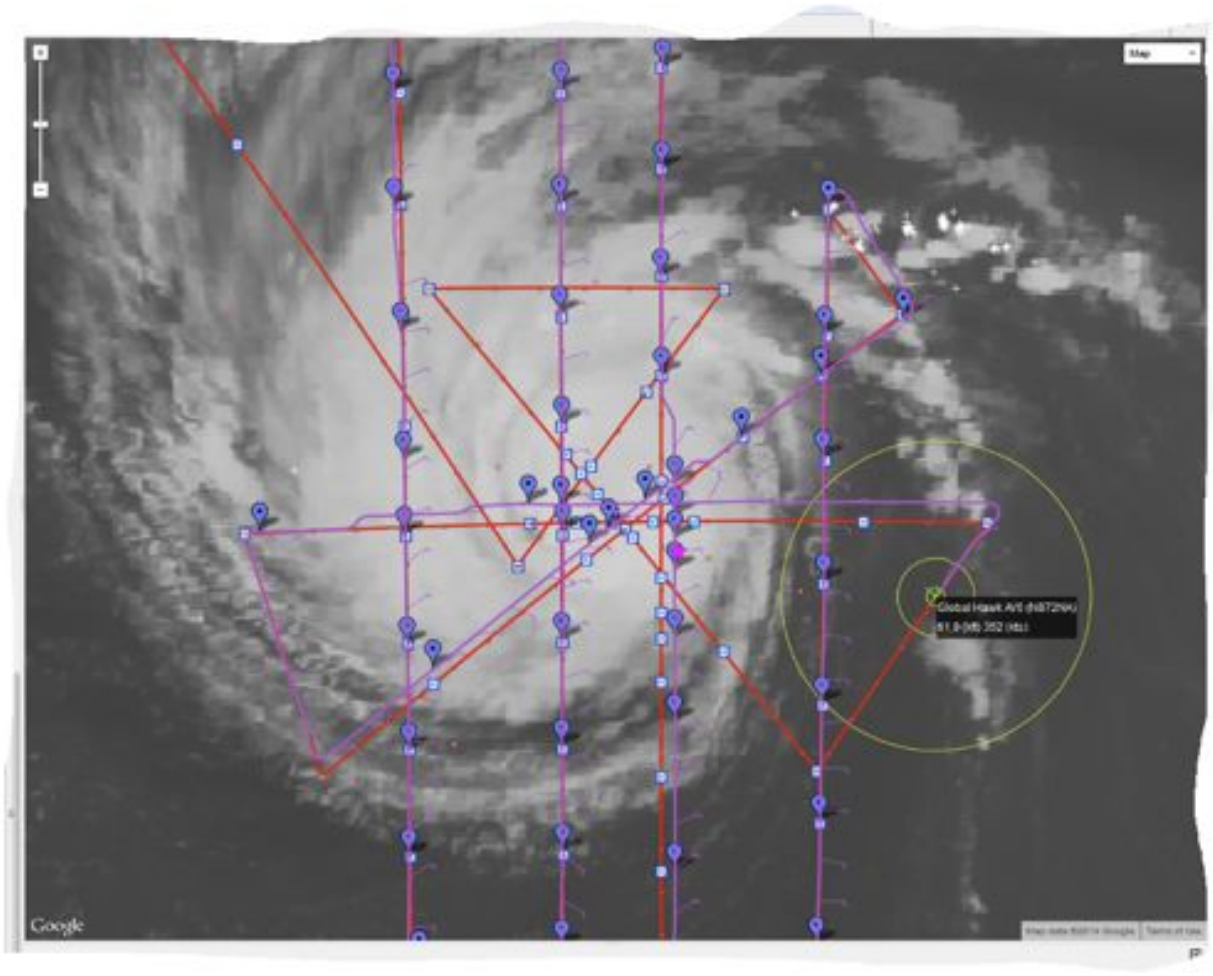
Lowlight camera image directly over eye as plane heads east. Small-scale striations in the upper-level clouds (possibly radiating gravity-inertia waves) from the convective region.

Updated IR image with flight track of AV-6:



0320 Z Updated flight track and IR image showing position of rapid drop points.

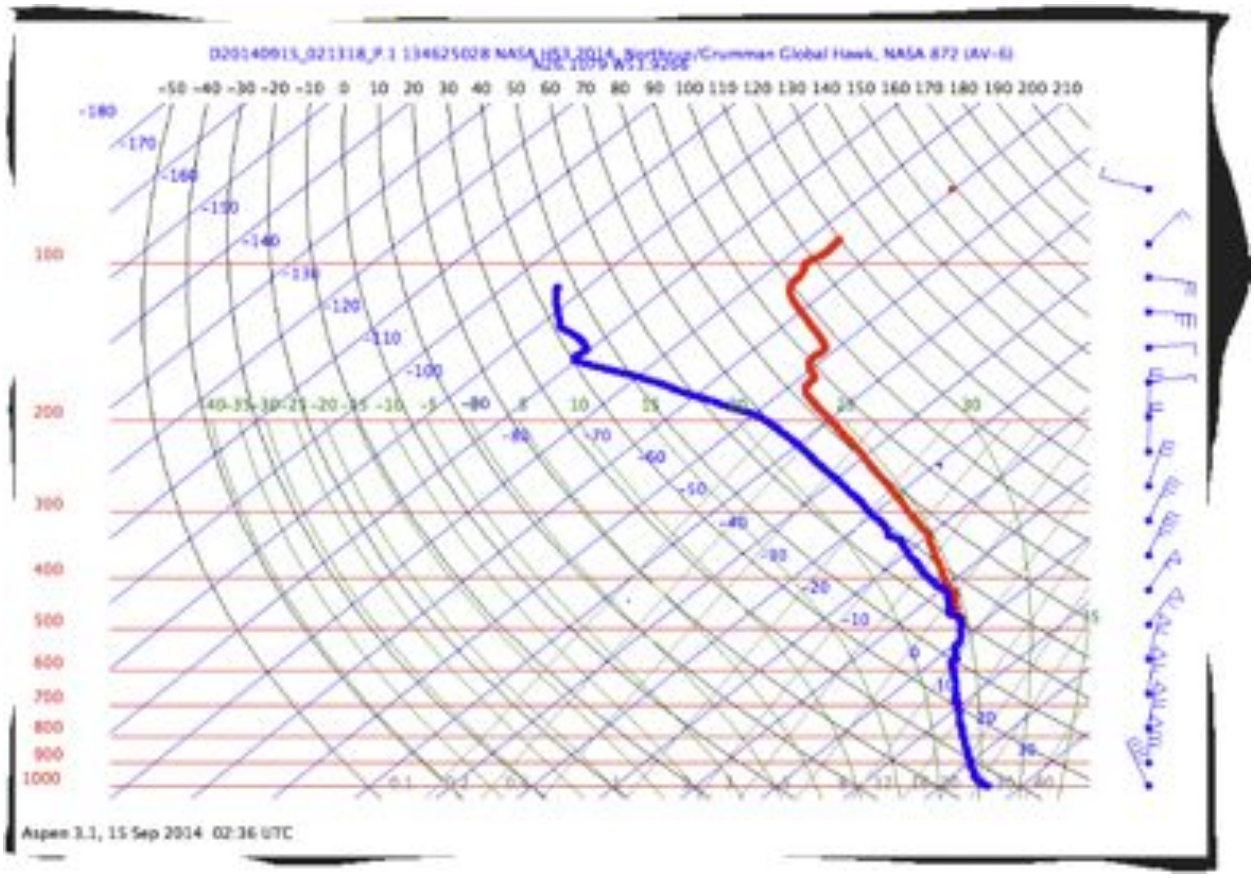
(The scientific motivation for this flight-drop sequence is to help represent low-level inner-core radial pressure gradient near and outside the RMW. This data can be used to estimate BL inflow and low-level swirling wind structure following Montgomery et al. 2014 (QJRMS) and Rogers et al. 2014 (MWR) during the storm spin up phase.)



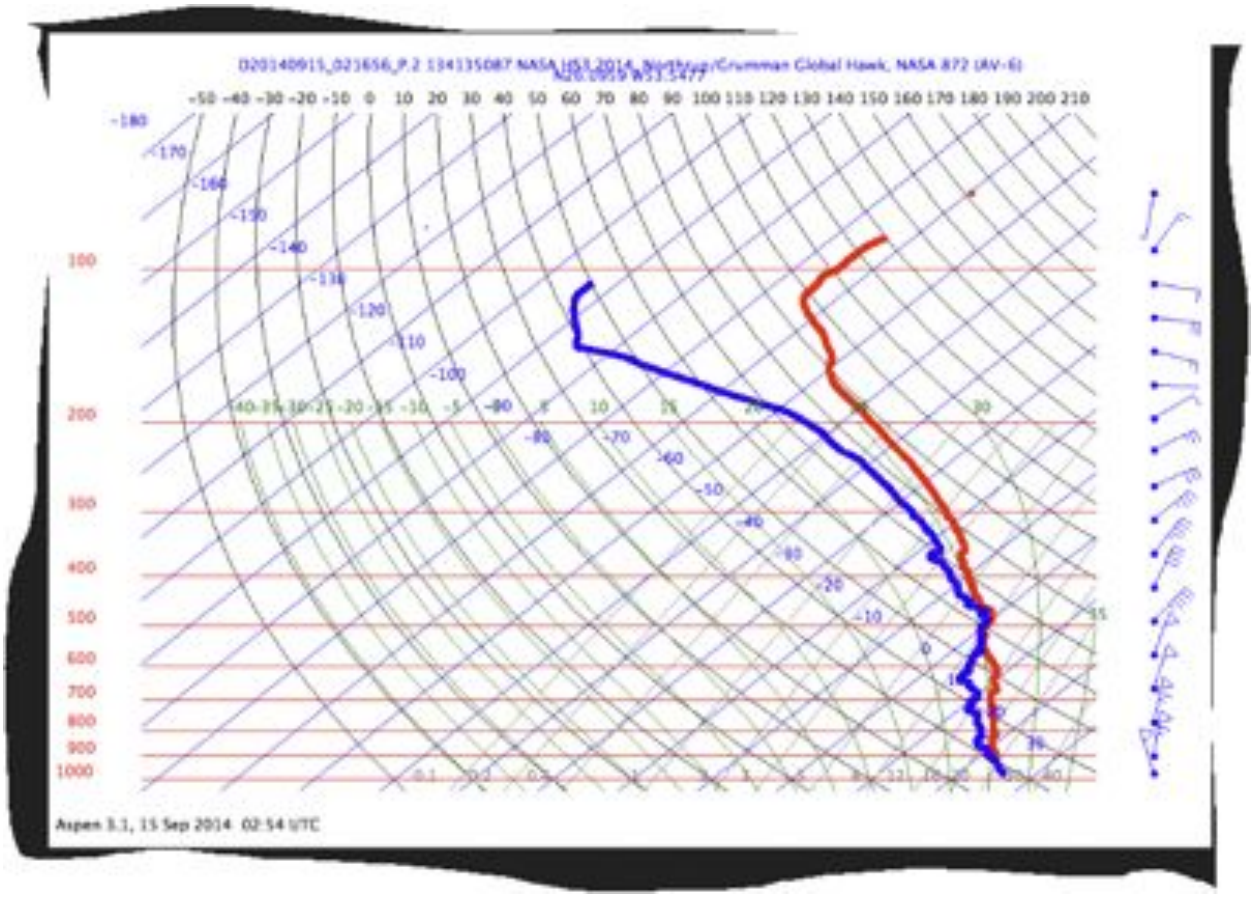
West-to-east, rapid deployment sequence.

2 Drops left of center.

(First approx. 4 RMW (40 naut. miles west of center); 0213 Z)

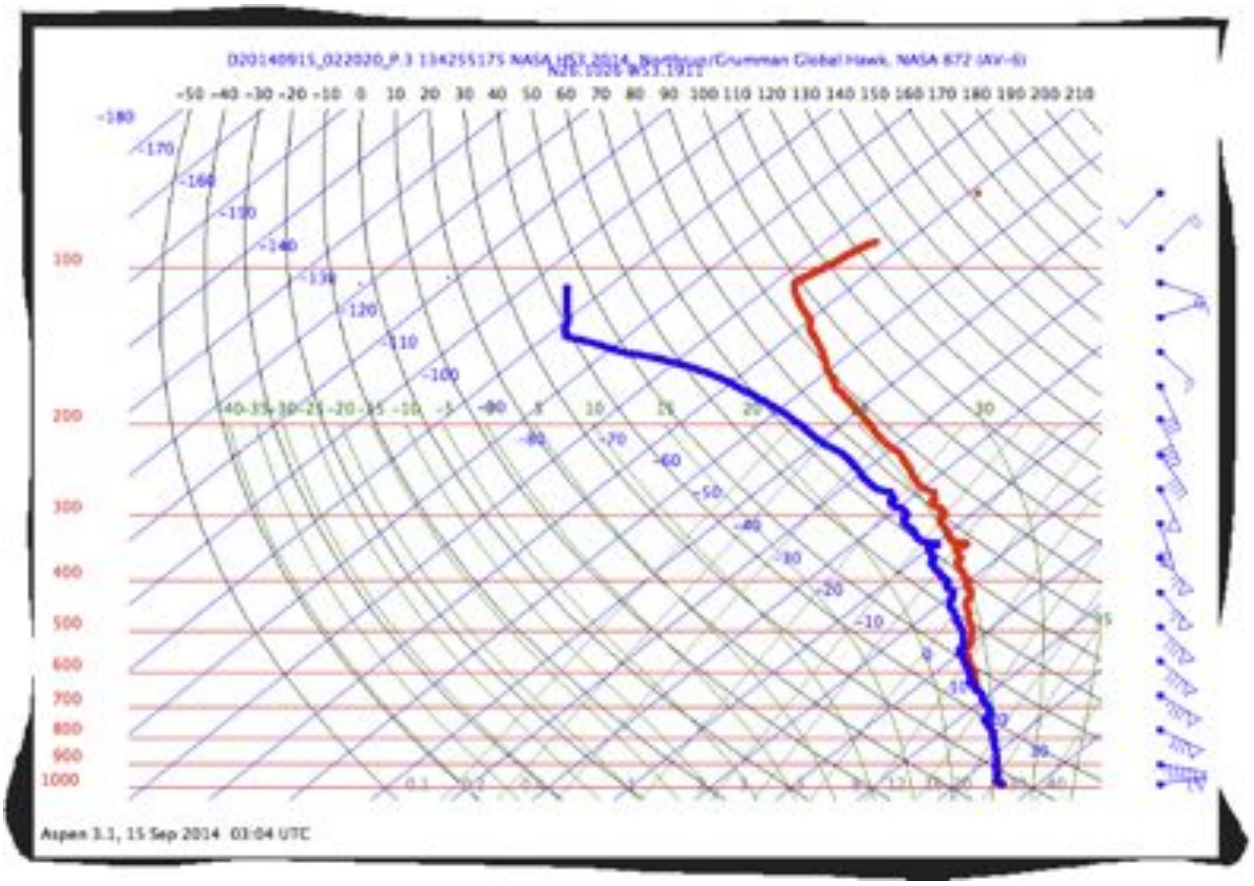


Second drop at approx. 2X RMW (20 naut. miles) west of center. (0216 Z)

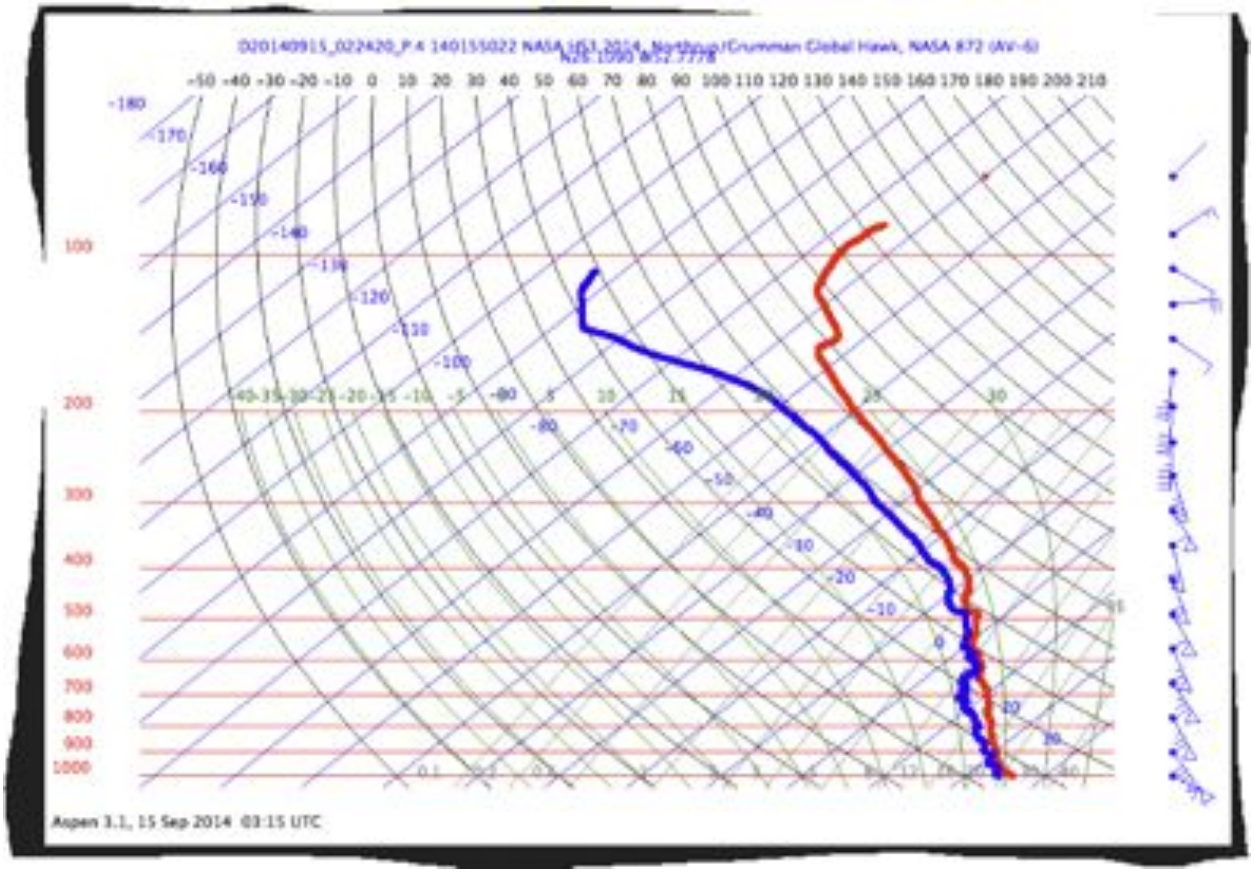


Two sondes just to east of center in rapid west-to-east drop sequence. 0220 Z and 0224 Z.

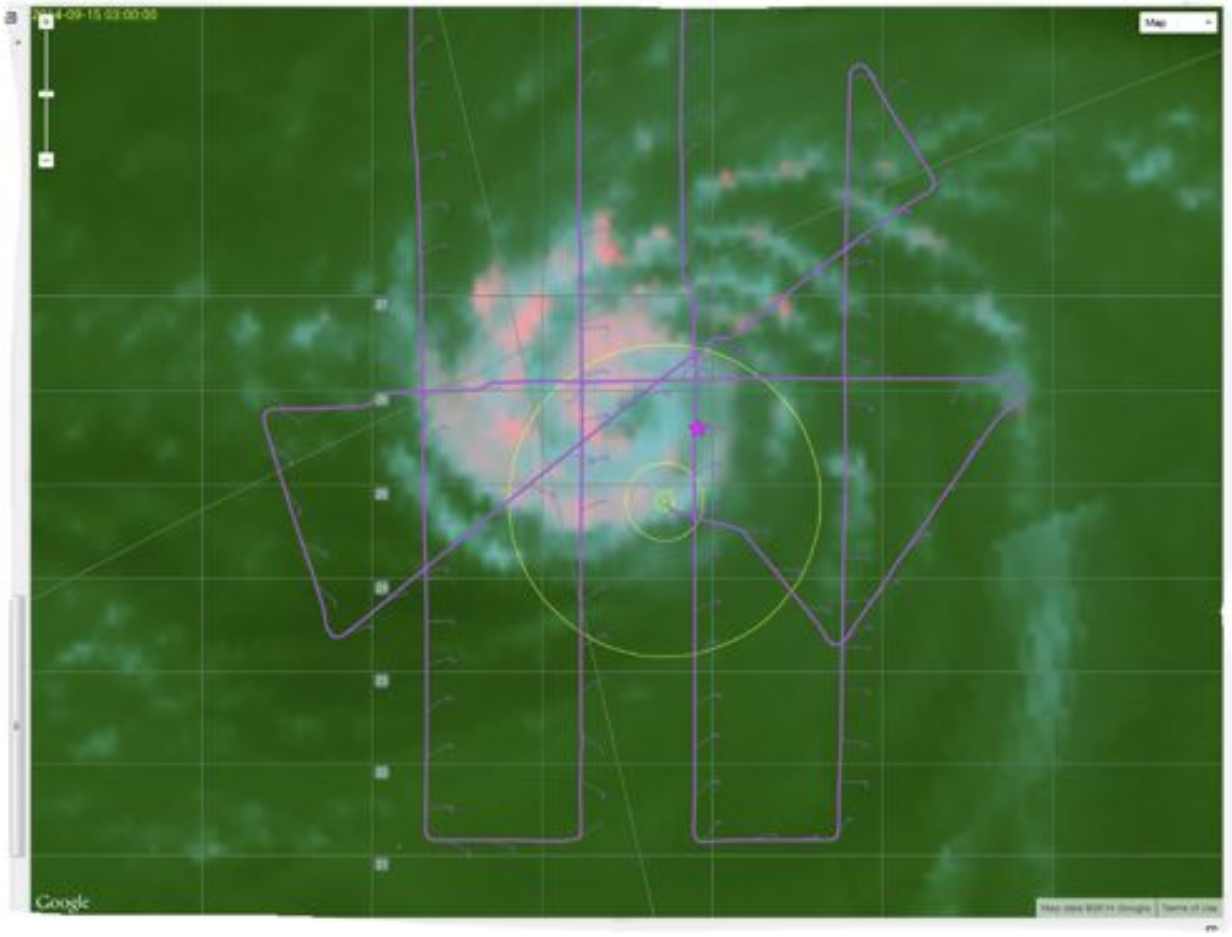
0202 Z



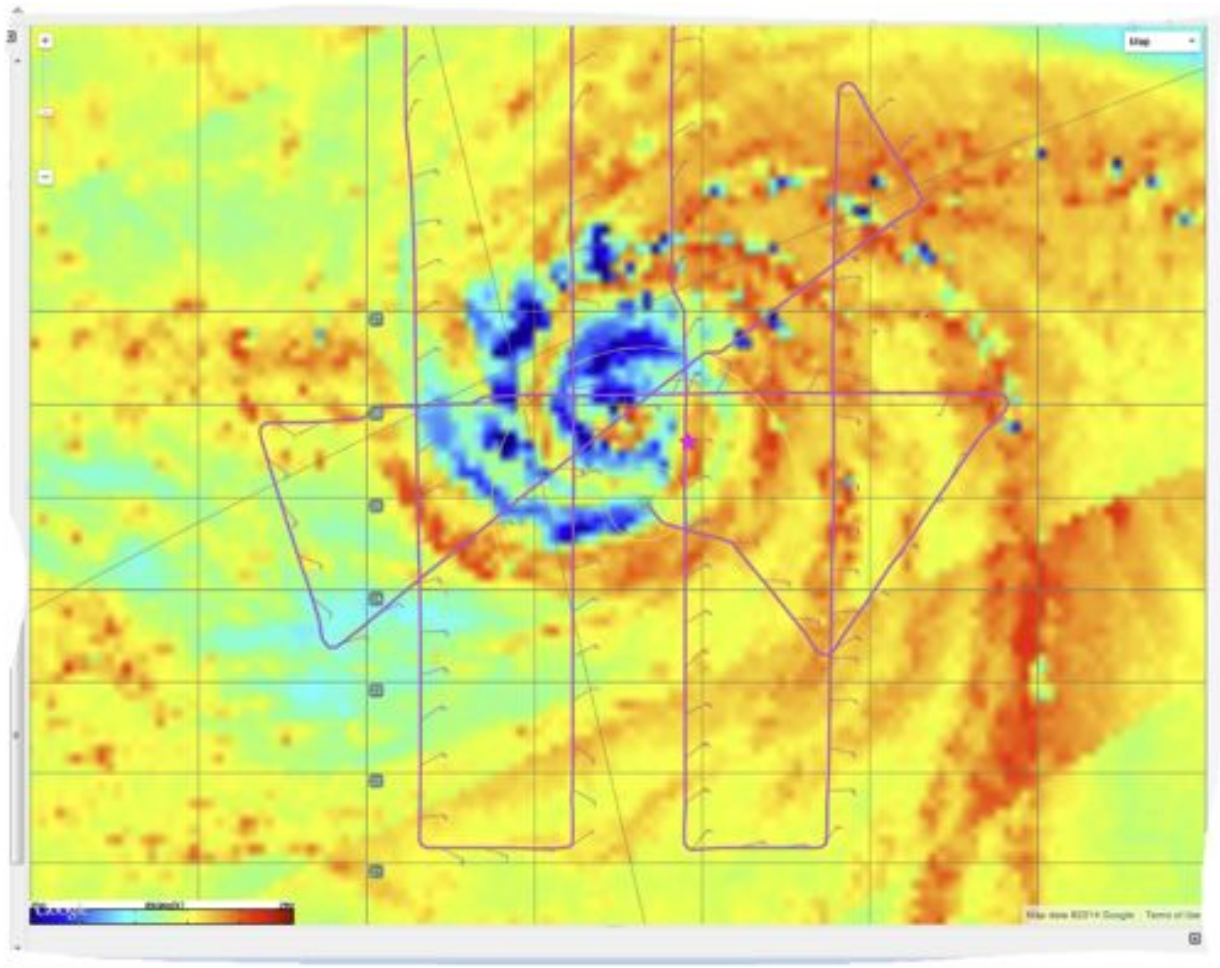
0224 Z


D20140915_022420_P-3 140155022 NASA 051 2014 Northrop/Grumman Global Hawk, NASA 872 (AV-6)
Aspen 3.1, 15 Sep 2014 03:15 UTC

37 Ghz Brightness temperature (0300 Z)



85 Ghz Brightness temperature (0300 Z)

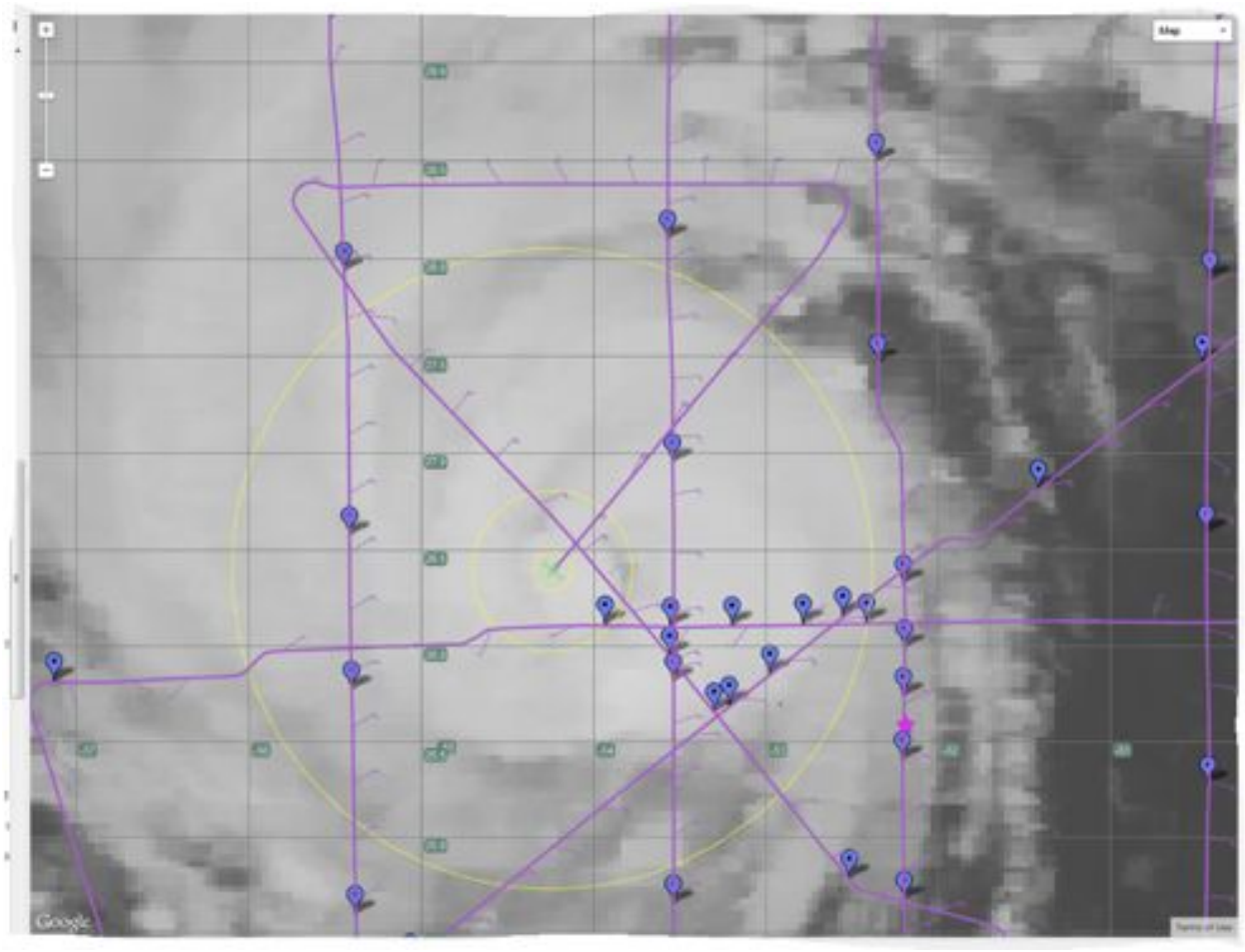


Adjusted waypoints of last part of butterfly to keep consistent. Each waypoint, W14, W15, W16 shifted about 38 nmi to the west. The exit point W16 was adjusted to make a pass through the center.

0530Z: Turning in towards the final inbound leg…center estimate is 26.5N/54.15W. Another 3 minute drop sequence (3 total) is setup. One inbound, center, one outbound. Then, the turn northwestward towards home and the sequence of 5 drops in the outflow layer.

Last drop on the SW side of final transect delayed due to clearing system fault.

Updated flight track incorporating last segment.

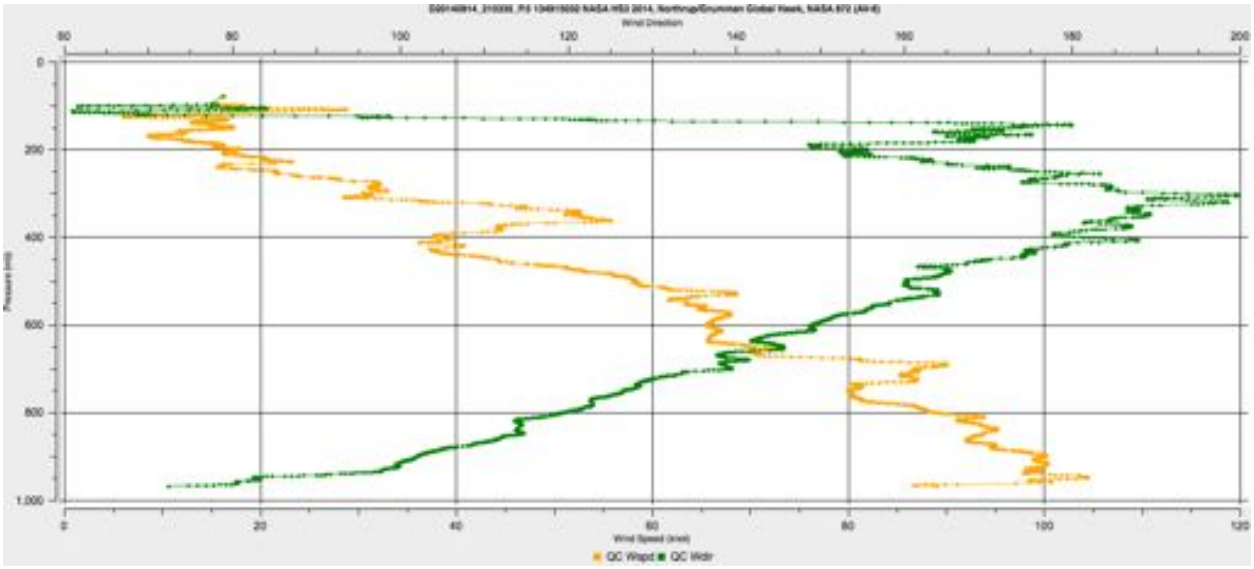


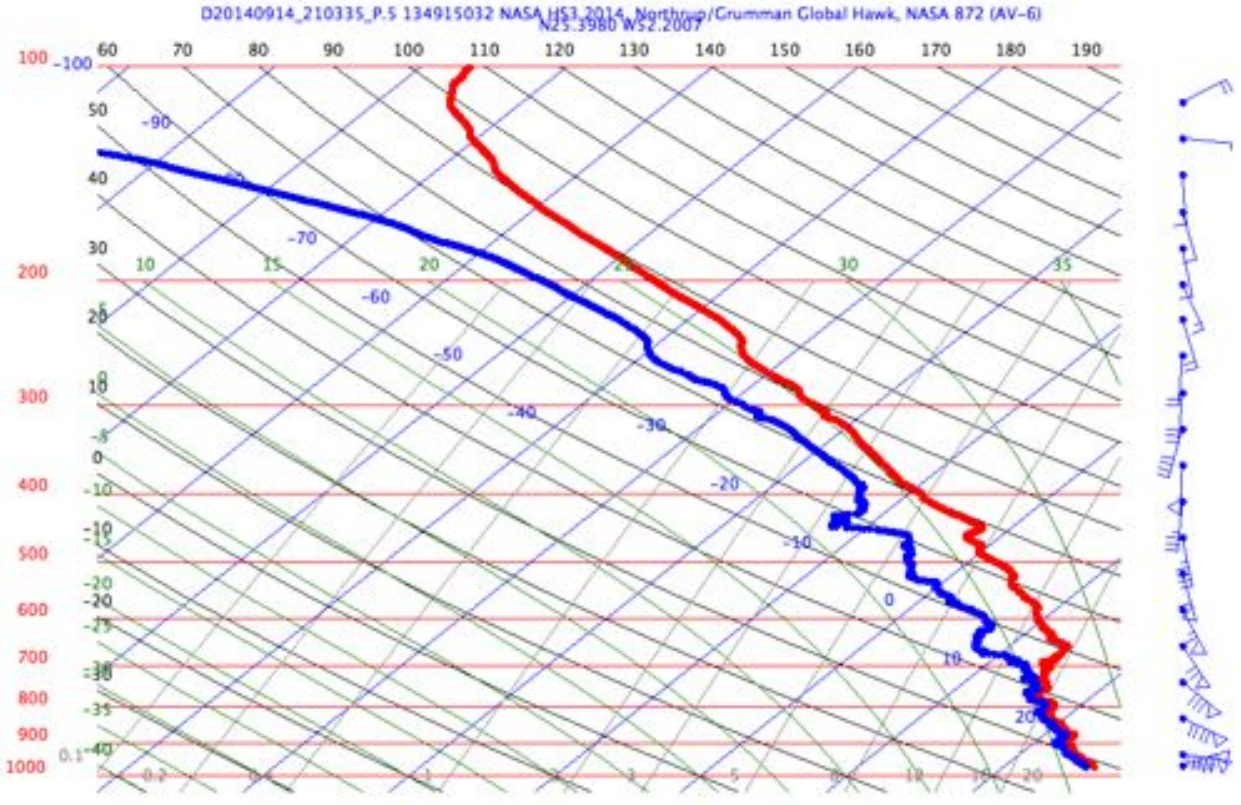
Mike Black just sent out a nice summary of the inner-core sondes from this afternoon and evening's flight.

Hi Folks:

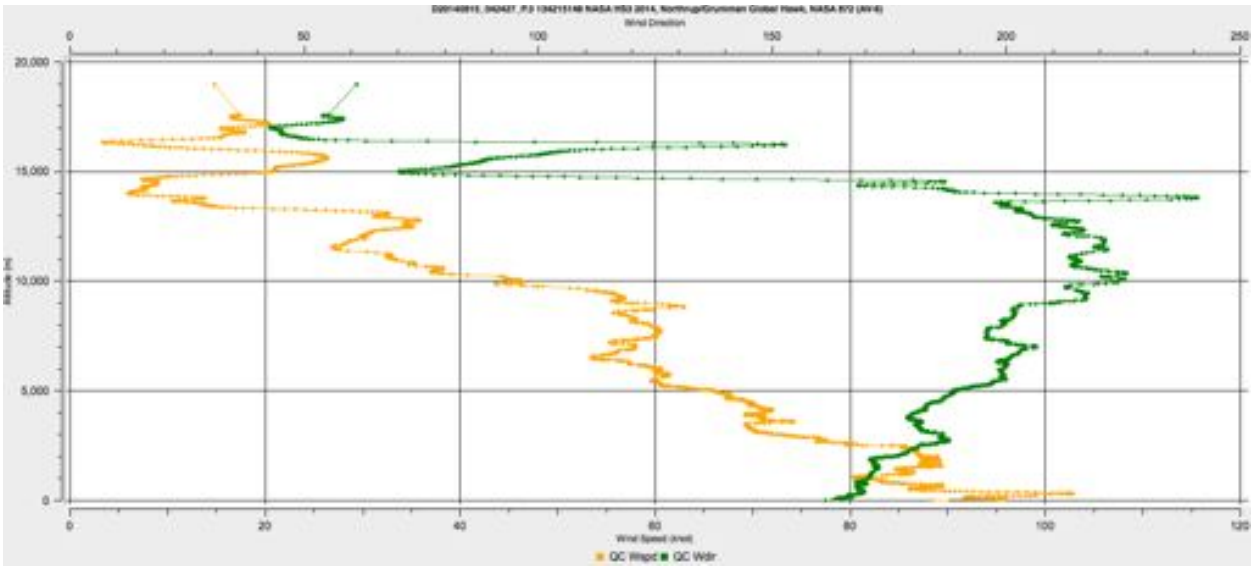
I've been working the overnight shift as mission scientist for the NASA Global Hawk mission into Hurricane Edouard. Evidently, Edouard has been undergoing a period of fairly substantial rapid intensification. We have had several drops near the eye/eyewall interface (2 Skew-ts and wind speed plots attached) that have reported a sea-level pressure of 969-970 mb. These sondes had surface winds near 90 kt, so obviously the central pressure in the eye would be lower, perhaps as low as 960 mb. Thought you might be interested. I'll send out a few synoptic plots of the sonde obs once we finish the pattern.

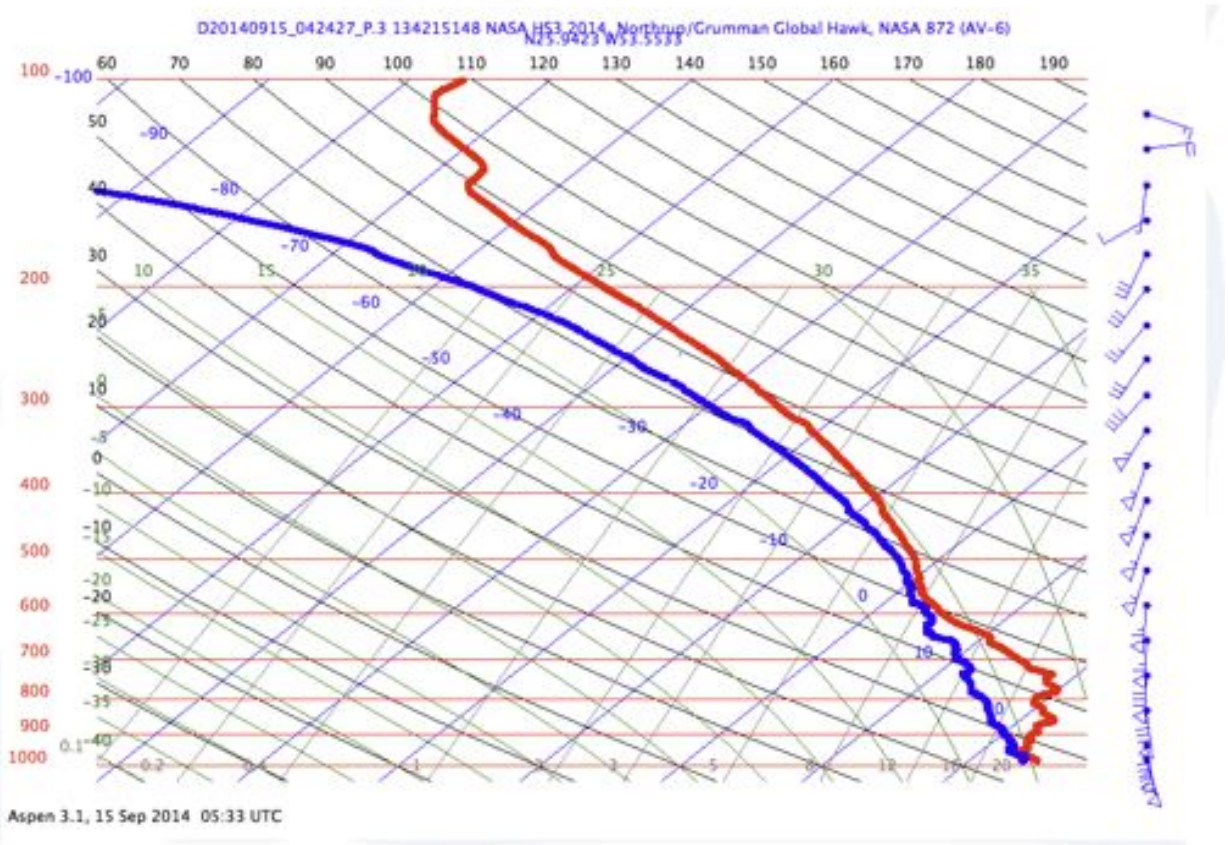
Mike





Aspen 3.1, 15 Sep 2014 01:06 UTC


Wind Direction
0
50
100
150
200
250
20,000
15,000
10,000
5,000
0
Altitude [m]
0
20
40
60
80
100
120
Wind Speed (knot)
QC Wspd
QC Wdir


D20140915_042427_P.3 134215148 NASA HS3 2014, Northrup/Grumman Global Hawk, NASA 872 (AV-6)
N25.9423 W53.5533
60
70
80
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100
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500
600
700
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-80
-70
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-50
-40
-30
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0
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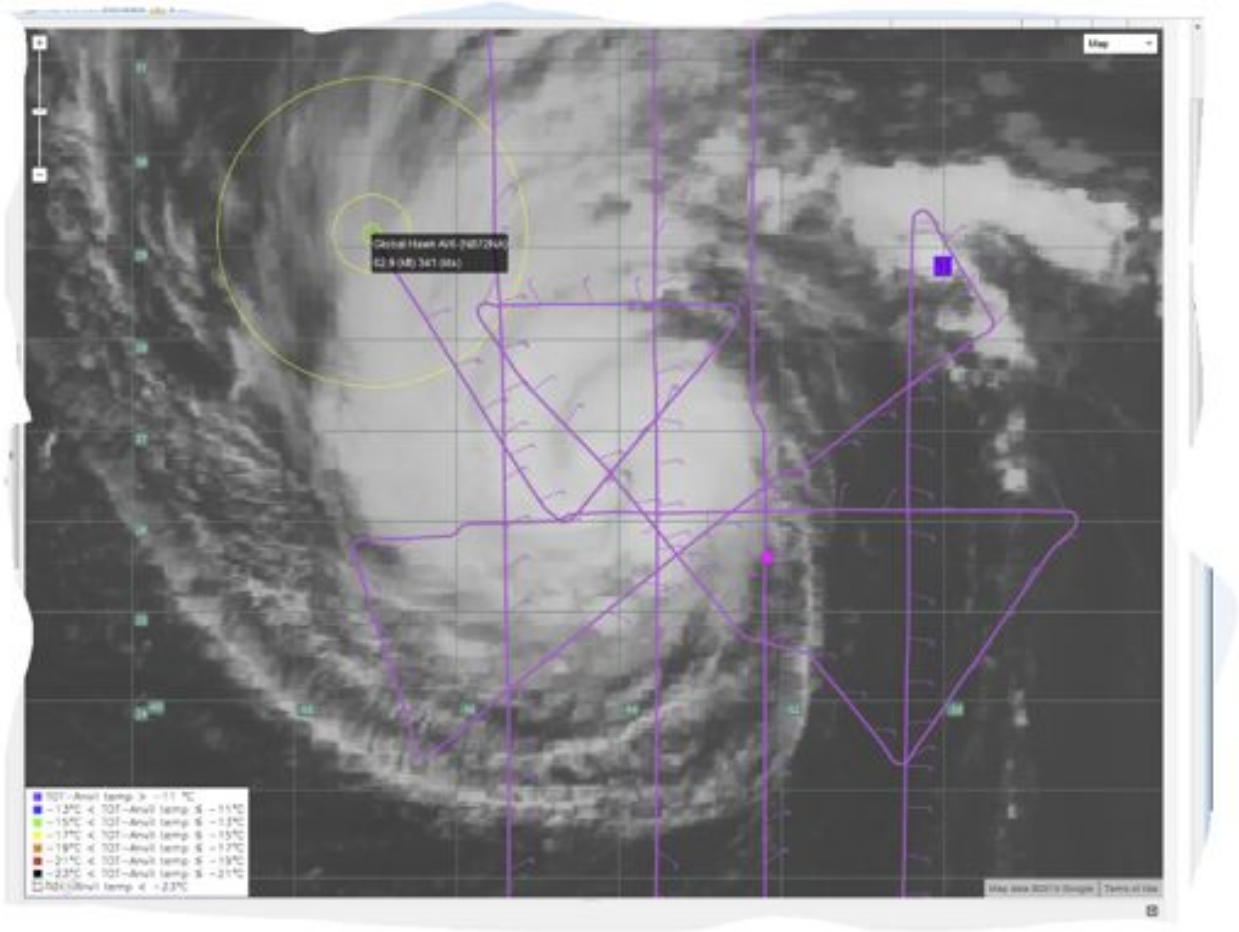
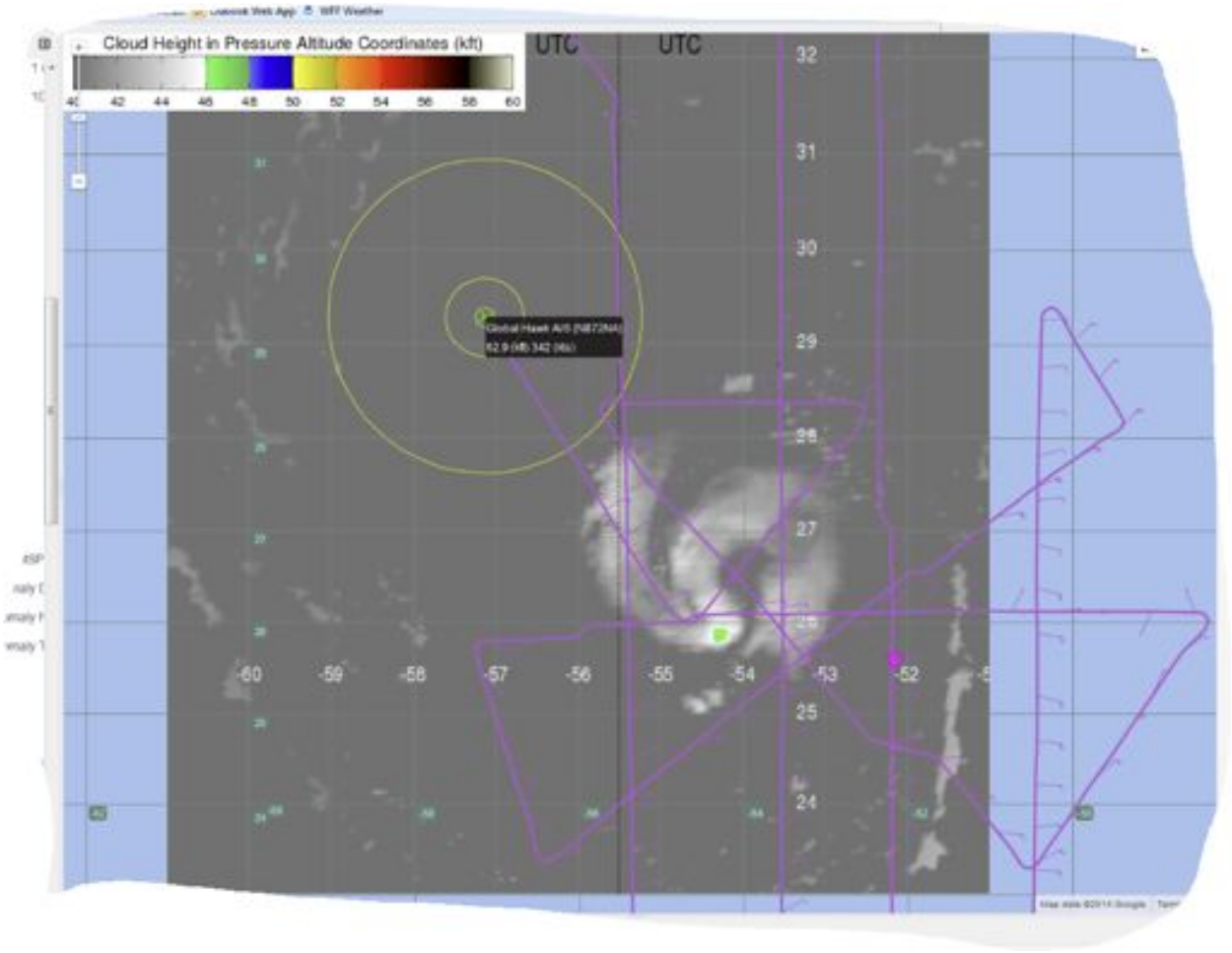
Aspen 3.1, 15 Sep 2014 05:33 UTC

At this time the storm does not appear to be very convectively active, with overshooting tops(TOT) confined at this time only to northeast sector. The cloud tops heights (CTHs) only approach 48 kft in SW portion of eyewall at 0642 Z (below).

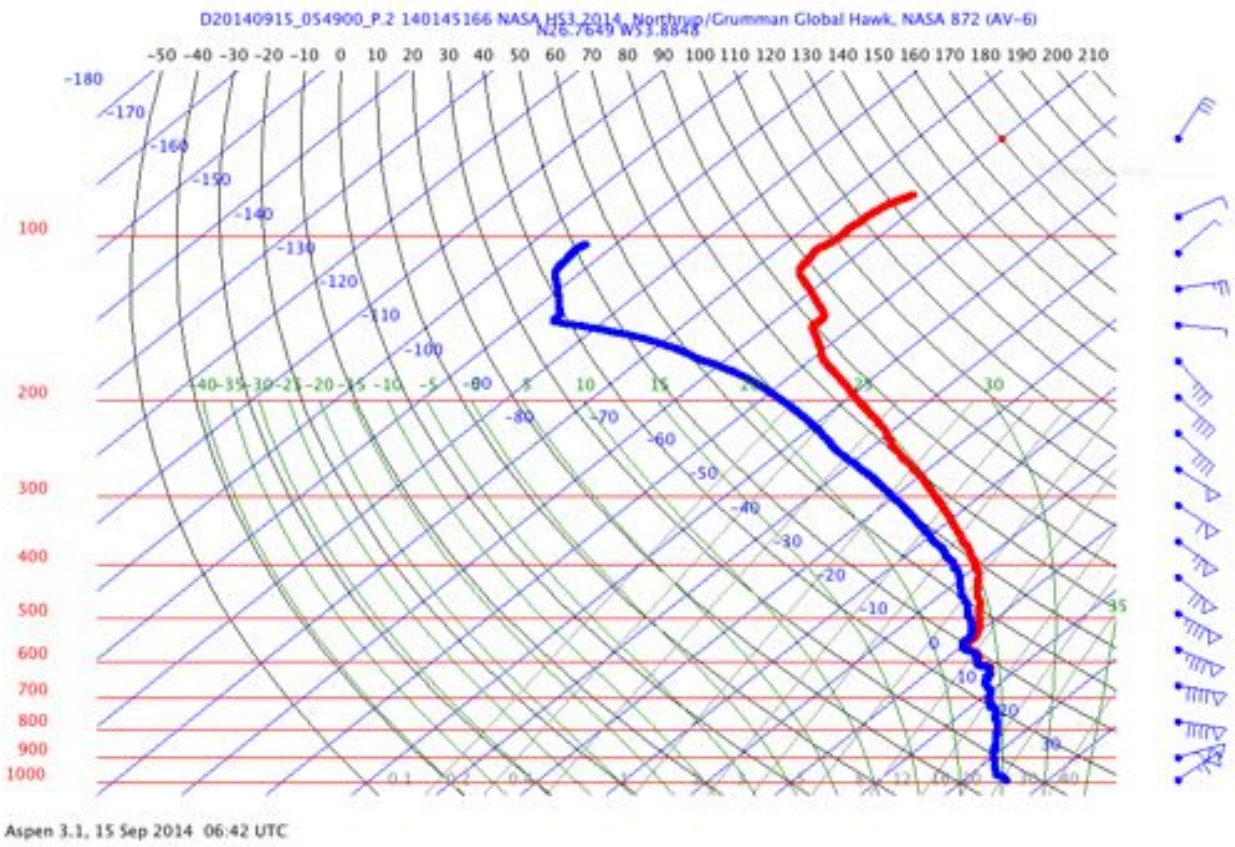


0642 Z

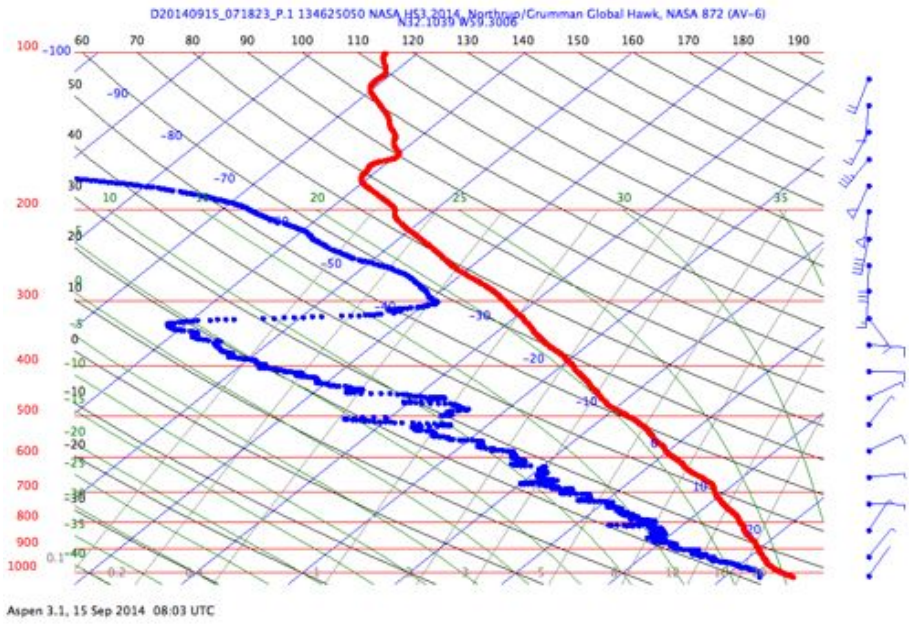


Summary: During shift 3 the convection appears to have changed dramatically. Earlier yesterday afternoon near the beginning of the pattern, there was frequent deep convection and high cloud tops near the center of Edouard. The storm was contracting and intensifying rapidly during this time (see above highlights and summary from Mike Black). During this evening, the characteristics of convection changed to a regime of moderate convection with only a few overshooting tops. The microwave imagery suggests the storm was undergoing secondary eyewall formation and eyewall replacement.

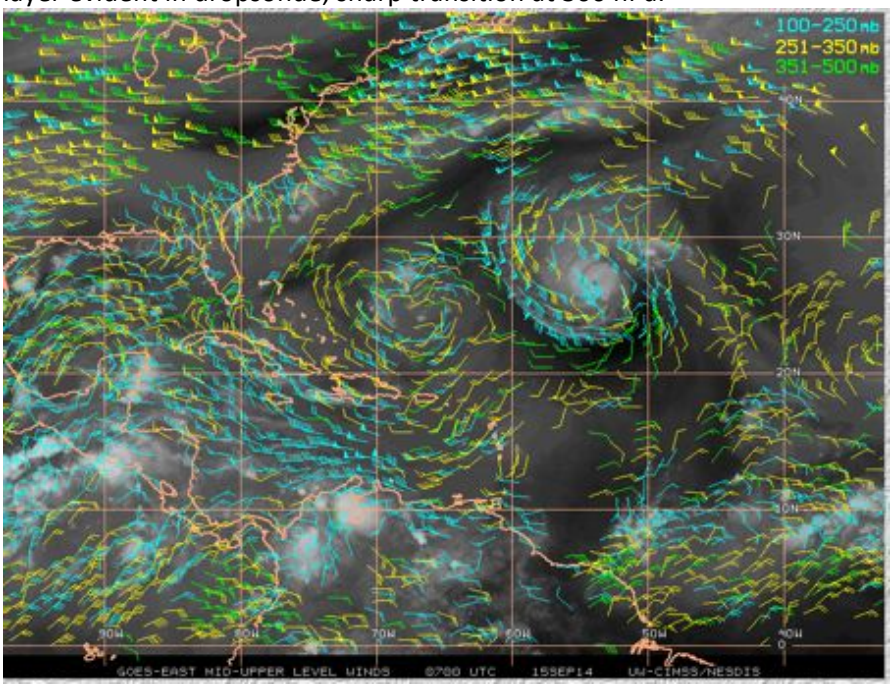
0844Z – Colarco and Didlake take over in MS for ferry back to base.



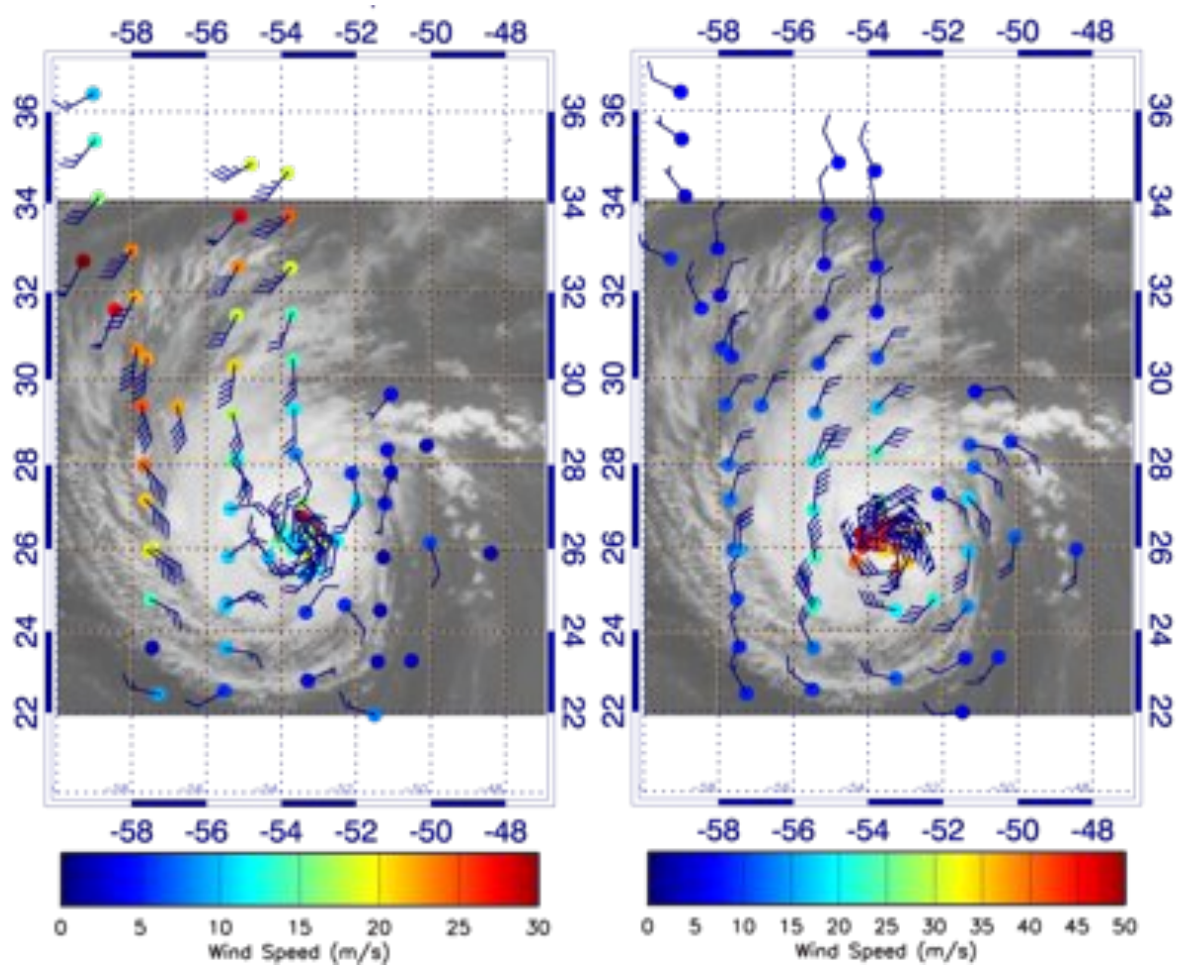
(above) 0549 z drop near storm center on last butterfly



(above) 0718 drop on outbound leg, with (below) comparison to 0700 UTC satellite winds. Outflow layer evident in dropsonde, sharp transition at 300 hPa.



1050 z landing on runway 4



The above figures show the sonde distribtion in a storm-relative reference frame. Wind barbs show storm-relative winds. Color filled circles show total ground-relative wind speed at 200 and 924 hPa. Low-level winds are as high as 45 m/s near the core, tropical storm force out to 200+ km. At upper levels, the outflow is primarily to the NW at up to 30 m/s, and weak winds on the eastern side of the storm.

Instrument summaries

AVAPS

AVAPS loaded and successfully deployed 80 sondes during RF07 into Hurricane Edouard. Operationally this was an extremely challenging flight for AVAPS. System faults associated with the shuttle mechanism for ejecting the sondes occurred following the launch of many of the drops. The frequency of the faults and difficulty in clearing them increased throughout the flight. The faults did not directly affect the launching of the sondes, but rather the time required to reset and prepare for the following launch. Despite the problems, only one set of the rapid drop sequences desired was affected and a couple of other planned drops delayed. Once deployed, data from the sondes was very good. Because of the mechanical issues, AVAPS operators did not monitor data quality as closely in real-time as usual, but no

major issues were detected. Data from the sondes provided strong evidence for the intensification of Edouard that was originally doubted by the National Hurricane Center but later accepted. All data were processed in near-real-time by NOAA HRD personnel. Automated transfer scripts have now been fully implemented and are functioning extremely well.

Following the flight, inspection of the system revealed that a sprocket had come loose from the motor that drives the shuttle. Additionally sensors detecting the shuttle position appeared to have become slightly displaced. The sprocket was repaired and reattached to the motor drive shaft and the sensors realigned. These two issues are fully consistent with the problems encountered during the flight and the AVAPS team believes the system is now fully operational again for the next flight.

Sondes Allocated		**750**	
Remaining		**352**	**46.9%**
Released		**398**	**53.1%**
Flight	**Take off Date**	**Sonde Usage**	**Sondes Left**
RF01	8/26/2014	75	675
RF02	8/28/2014	70	605
RF03	9/3/2014	50	555
RF04	9/5/2014	59	496
RF05	9/11/2014	64	432
RF06	9/14/2014	80	352

S-HIS Summary

A. Merrelli, J. Taylor; SSEC, University of Wisconsin-Madison

The sixth science flight for HS3 2014 took the aircraft over TS Edouard during a period of strong intensification. The system was upgraded to a Category 1 hurricane on the morning September 14, and appeared to stay at this strength, or intensify further, during the flight. The flight pattern consisted of a lawnmower pattern with 4 long north-south segments. One segment passed very near the eye so that S-HIS detected the cloud-free eye from the edge of the swath ("Eye Pass 1"). After the lawnmower, the aircraft passed over the eye 4 more times in a series of crossing segments that specifically were selected to intersect the eye. Of these, pass 2 occurred with a cloud free eye, and the remainder showed a partially or fully cloudy eye.

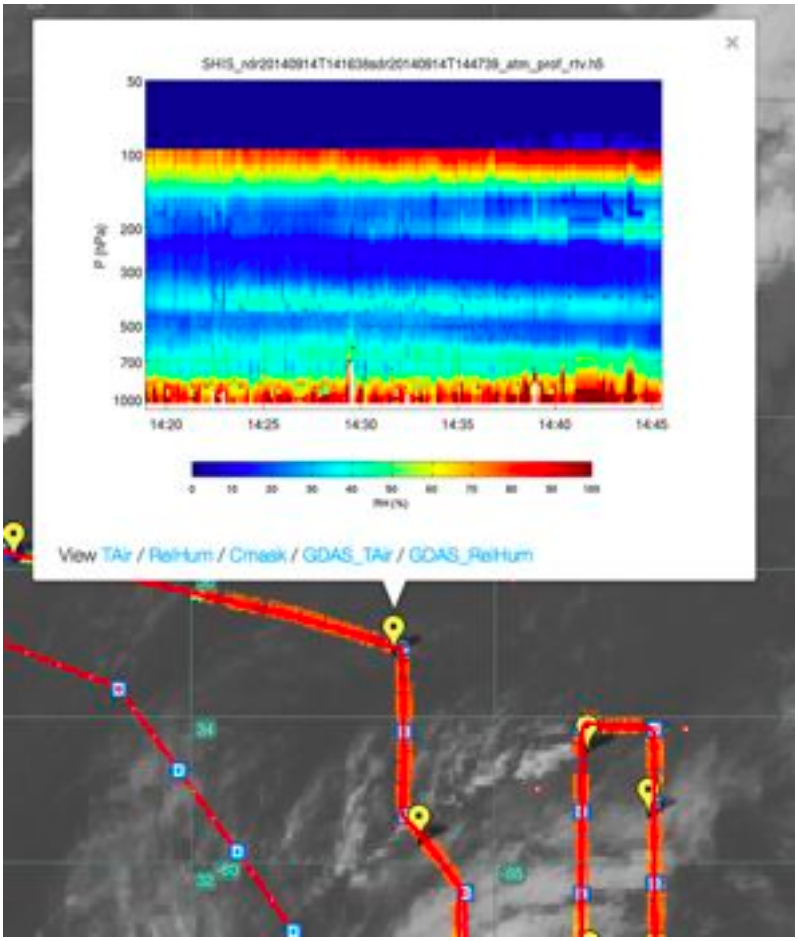


Figure 1. Relative moist middle to upper troposphere to the North – Northwest of the storm, from the inbound flight segment.

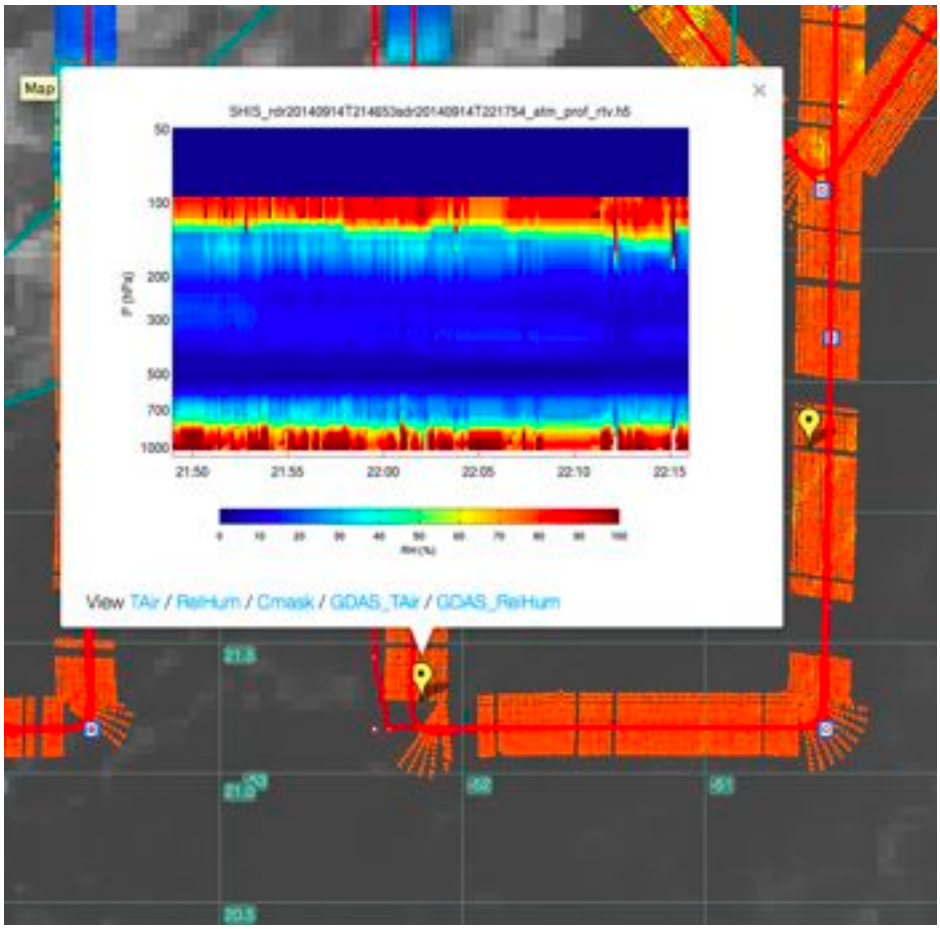


Figure 2. Dry middle and upper troposphere to the southeast of the storm.

During the lawnmower pattern, the area around the storm was nearly cloud free and many full atmosphere profiles were retrieved from the S-HIS data. Figures 1 and 2 show examples. Figure 1 shows a RH cross section from the inbound flight segment, northwest of Edouard. This region shows higher moisture levels, with the lowest levels (P > 800 hPa) saturated, and a deep layer with RH ~ 50% up to 600 hPa and again at 400 hPa. To the southeast of the storm, the dry layer had wrapped around the storm, and Figure 2 shows the drier environment, with very low RH above 800 hPa.

Figure 3 shows a summary of all 5 passes over the eye of Hurricane Edouard. The brightness temperature image shown here is the 750 cm^{-1} wavenumber image, which is displayed with a narrow colorbar range in brightness temperature, 200 – 230 K. This wavenumber is not a window channel, but the gas absorption and emission is mostly below the high altitude clouds. So this image mainly shows the cloud top temperatures for the tallest convective clouds, and is useful for identifying the eye, since in the cases where the eye was cloudy the very central clouds were usually warmer. Pass #2 was the most interesting within the S-HIS data. Figure 4 shows the RH retrieval cross section through the eye for

pass #2, showing the retrieved water vapor profile in the center of the eye. Figure 5 and 6 show a close up of the IR-window (895 – 900 cm^{-1}) brightness temperatures right around the eye during pass #2. Figure 5 has a wide display range (190 – 310 K), to highlight the cloud free center. This view also shows the relative sharpness of the southwest eyewall compared to the northeast side. Figure 6 is the same data but shown with a very narrow brightness temperature range (190 – 220 K) to highlight the very cold cloud tops around the eye. The southwest clouds show much colder temperatures, with a few fields reaching 200 K. Figures 7 and 8 are the same views for eye pass #4, showing a much cloudier eye (only a few FOV are close to 300 K) and slightly warmer cloud tops (minimum of 205K).

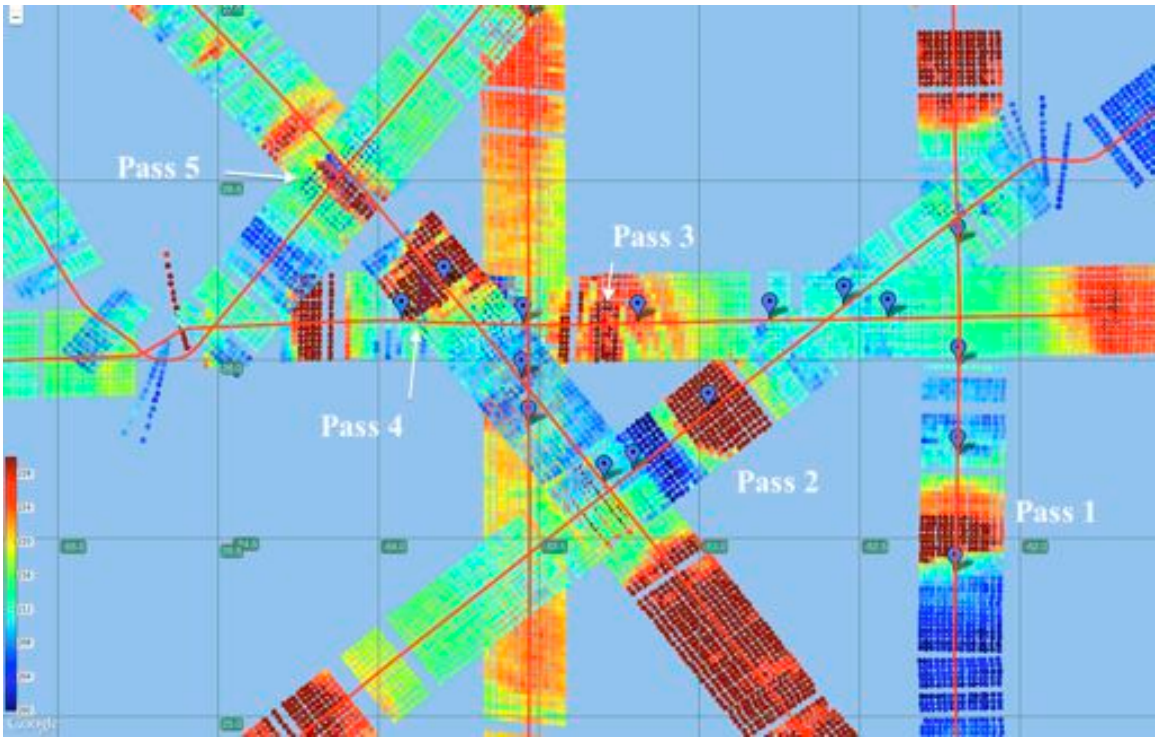


Figure 3. S-HIS brightness temperatures for the 750 cm-1 channel. Warmest temps displayed are 230 K (red) and coldest are 200 K (blue).

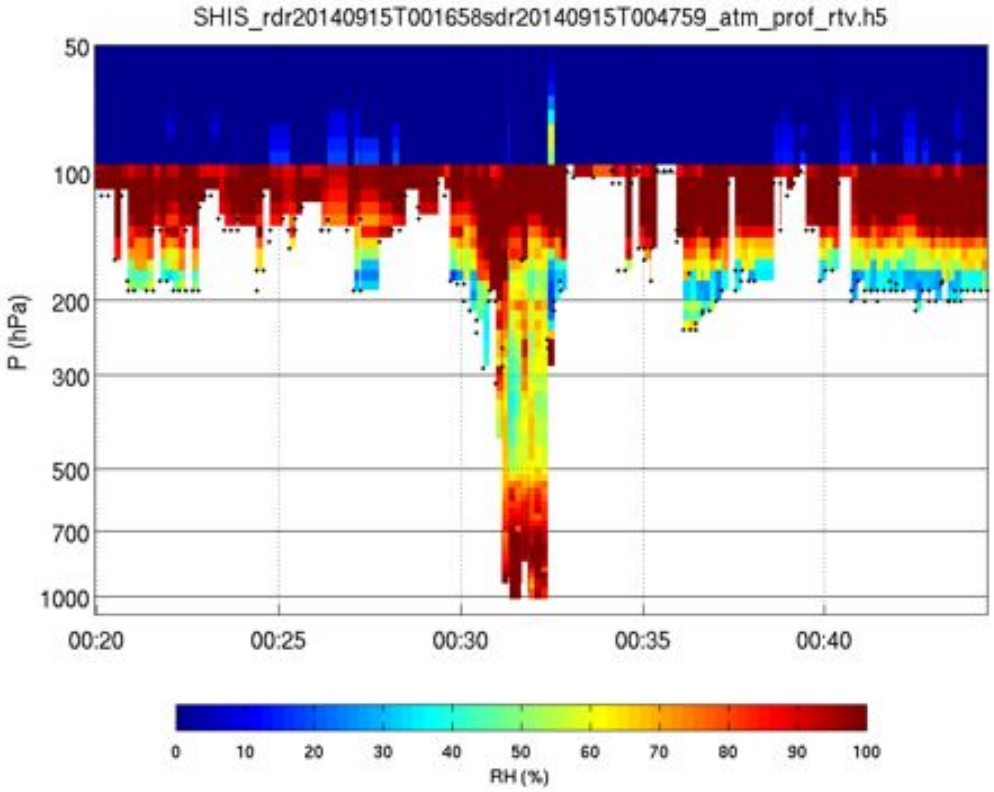


Figure 4. RH retrieval in the interior of the eye on Pass #2.

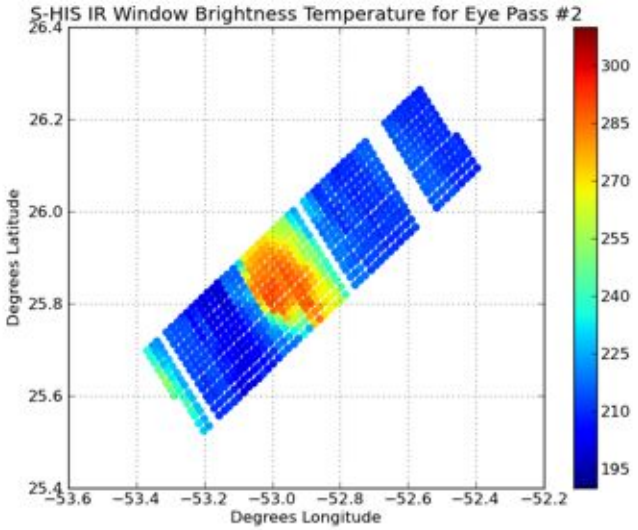


Figure 5. IR-window brightness temperatures for Eye Pass #2.

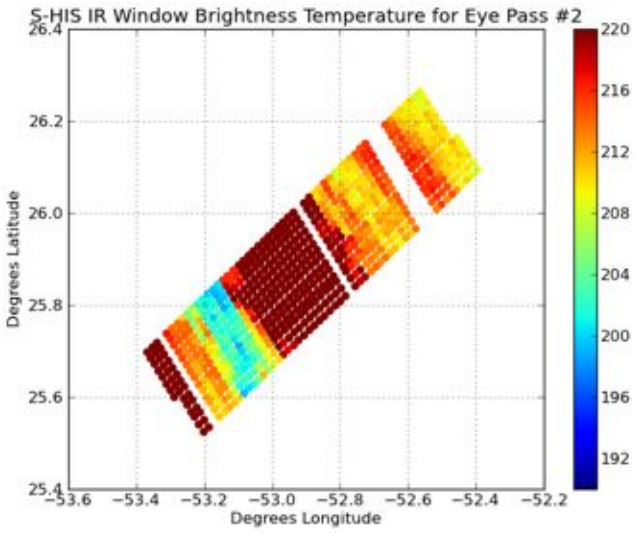


Figure 6. IR window brightness temperatures for Eye Pass #2. (Same as Figure 5, but with a narrow display range to highlight the coldest convective cloud tops.)

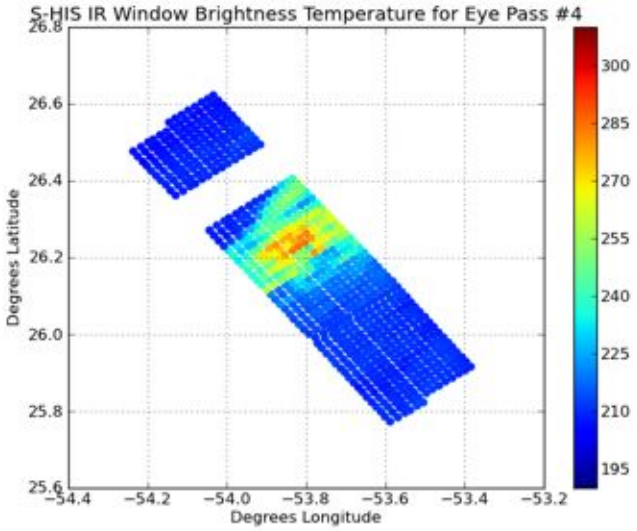


Figure 7. IR-window brightness temperatures for Eye Pass #4.

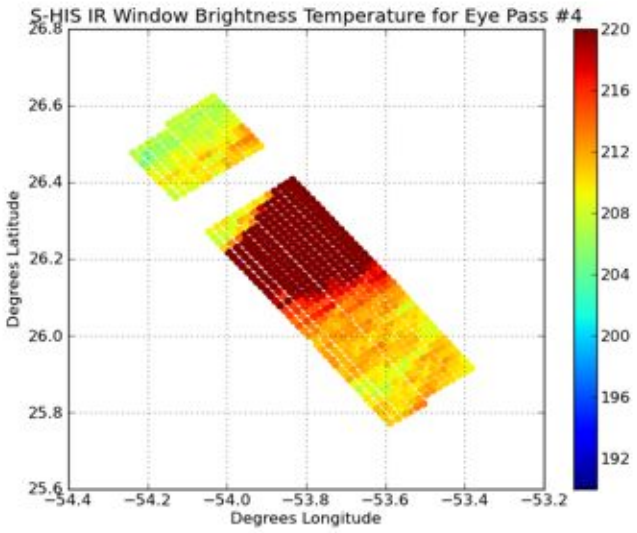


Figure 8. IR window brightness temperatures for Eye Pass #4. (Same as Figure 7, but with a narrow display range to highlight the coldest convective cloud tops.)

Instrument Summary

The Scanning-HIS operated nominally throughout the flight. An instrument power cycle (15 minutes off) at 45 minutes prior to the first science waypoint was implemented. Near the beginning of the flight, NASA IT noticed that times aboard the aircraft were incorrect (~7 minutes behind). This affects almost every computer system onboard the aircraft including the payload instruments. Usually the aircraft's GPS sends a time signal to the NASDAT (NASA Airborne Science Data Acquisition and Telemetry) system, but something caused the NASDAT to consider the GPS's time signal as not reliable and so it ignored it as a time source. Since NASDAT has no other time source aboard the aircraft this caused the time to drift for S-HIS and other computers aboard. Theoretically once the time was corrected by NASA IT the NTP clients on all the computer systems should have slowly shifted to the correct time, but NASA IT (and S-HIS) observed a sudden jump in time on some systems. This jump shows up around 1250UTC in the S-HIS data.

Timeline (All times are UTC and approximate):

- 1011 GH engine start
- 1035 Ku ON and transmitting
- 1057 S-HIS Power on
- 1102 Takeoff
- 1119 S-HIS detectors cooled
- 1330 S-HIS power cycle; ~45 minutes prior to science waypoint 1 (15 minutes off)
- 1345 S-HIS power cycle complete, IL41 on
- 1404 S-HIS detectors at 77K (nominal)
- 2100 Eye pass #1
- 0032 Eye Pass 2

- 0219 Eye Pass 3
- 0430 Eye Pass 4
- 0552 Eye Pass 5
- 0909 S-HIS descent heaters on
- 0932 Instrument power OFF before descent (IL42, IL41, DC42, DC41)
- 0945 Instrument power ON (DC41, DC42, IL41, IL42)
- 1034 Instrument power OFF (DC41, DC42, IL41, IL42)
- 1050 Landing

CPL

CPL worked well during the entire flight and data were recorded on the flight disk. The data have been processed (up through layer boundaries) and the data are on the cpl website (http://cpl.gsfc.nasa.gov/). The problem we have had in prior flights persists with the 1064 channel, where pre or multi-pulsing of the laser produces a ringing effect in the data, most evident from very strong signals like the ground return. However, the 1064 data over high clouds and the storm itself is OK. The 532 channel was fine, though the 532 laser energy is a little lower than optimal which makes the daytime data a little more noisy than we would like. Night data is unaffected. Data start: 12:30 UTC 9/14; Data end: 10:03 UTC 9/15