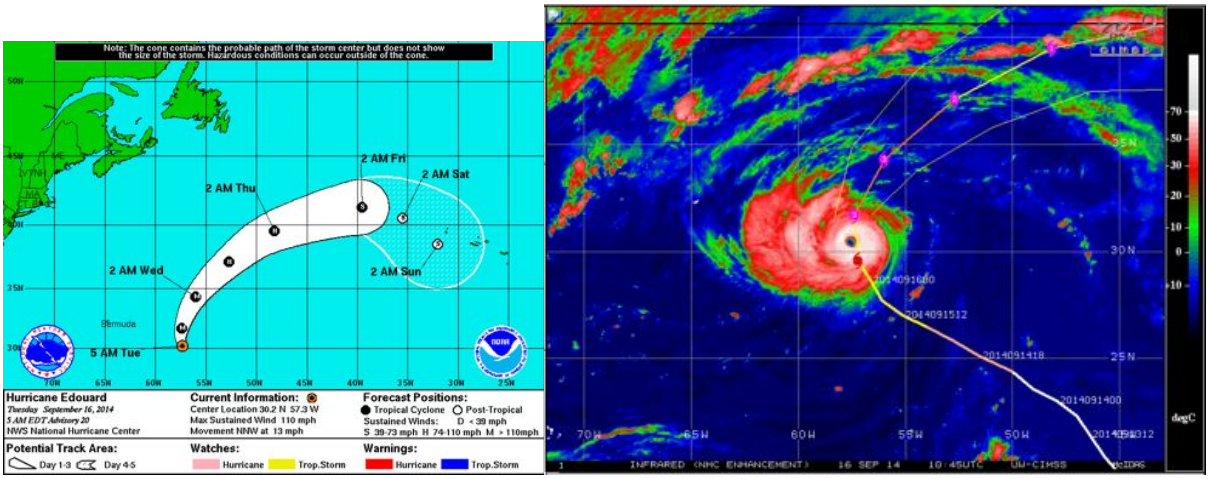
Hurricane and Severe Storm Sentinel (HS3) Mission

HS3 2014 16-17 Sept Flight Report: GLOBAL HAWK AV-6 Edouard Flight

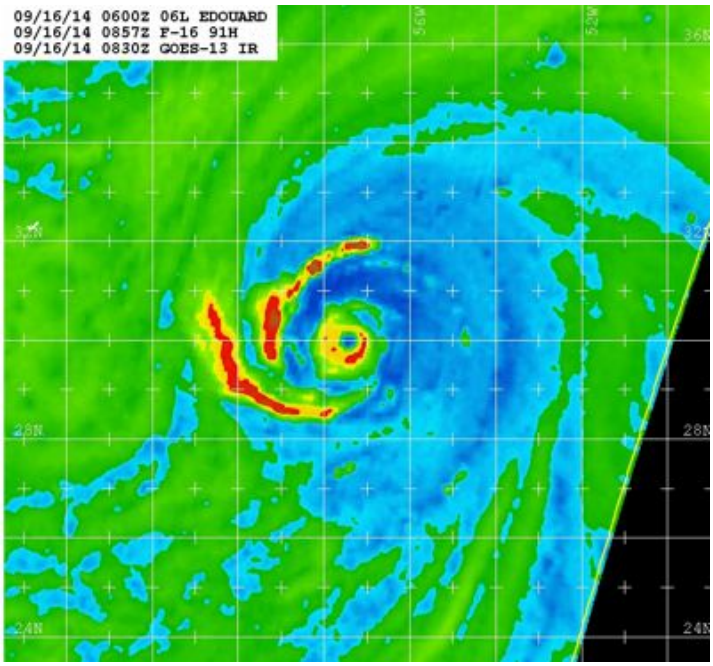
Flight Scientists:
Shift 1 (0500-1300 EDT): Anthony Didlake, Pete Colarco, Scott Braun
Shift 2 (1200-2100 EDT): Deanna Hence, Paul Neuman, Rob Rogers
Shift 3 (2000-0500 EDT): Jon Zawislak, Mike Black, Mike Montgomery
Shift 4 (0400-2100 EDT): Anthony Didlake, Pete Colarco

Takeoff: 16/1240Z
Landing: 17/

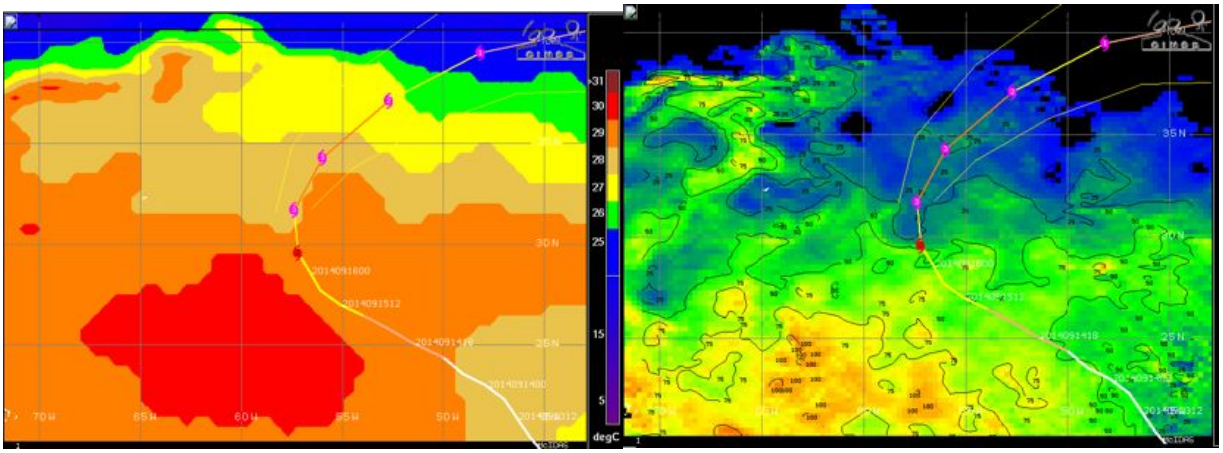
Mission goal: Science flight to investigate Hurricane Edouard at its peak intensity and begins weakening and turns to the northeast.



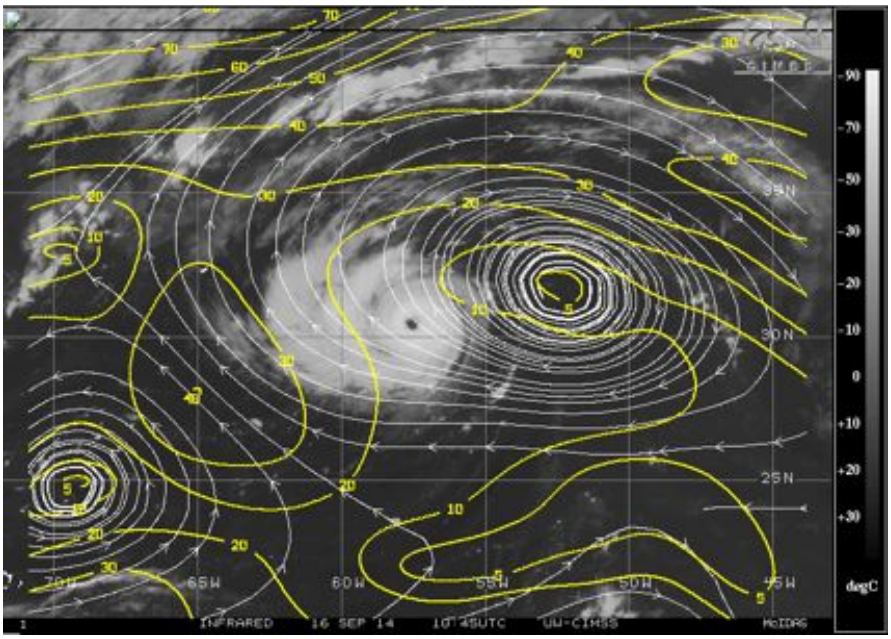
NHC 5am advisory has Edouard at 95 kts/963 mb. Currently moving NNW at 13 mph. Forecast is to strengthen just 5 more knots then begin weakening as it turns to the northeast. Infrared image shows Edouard has a clear eye with a symmetrical CDO. Large rainbands are located on the western side of the storm.



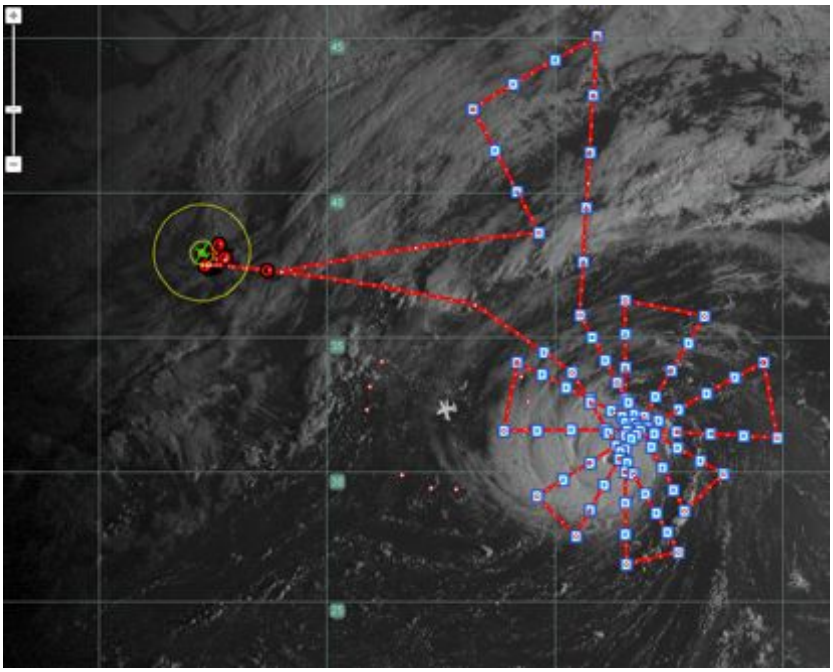
Microwave image (0857Z) shows the two clear rainbands on the western side of the storm.



The storm is entering lower SSTs and Ocean heat content. This is the reason for the initial weakening.



Edouard is experiencing moderate (~15 m/s) SE shear. The rainbands and maximum eyewall convection are occurring in the expected quadrants relative to the shear vector. According to SHIPS, shear will decreases in 12 hours, then increase again after 24 hours.

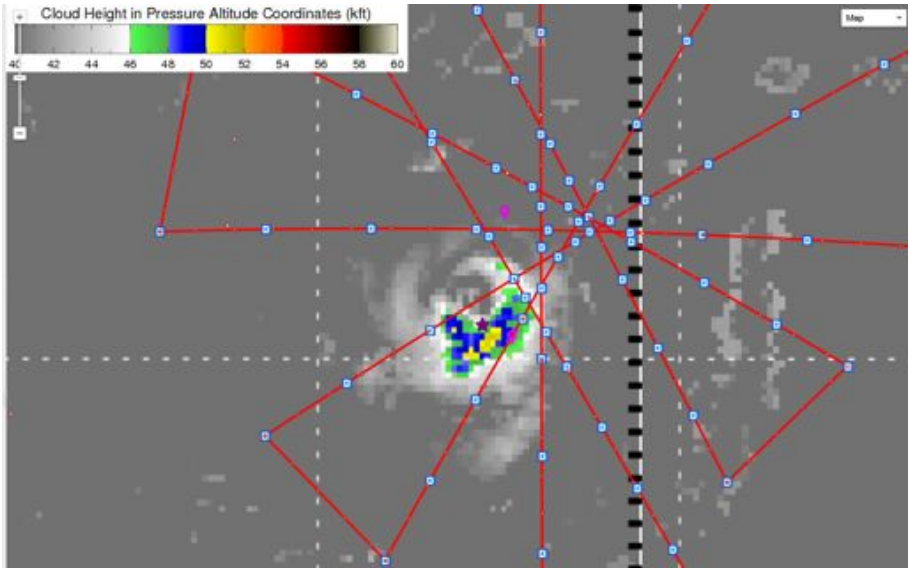


The flight plan consists of a large butterfly pattern followed by a track to the northwest to sample the storm outflow and trough to the north. These data will provide necessary information for the impending ET.

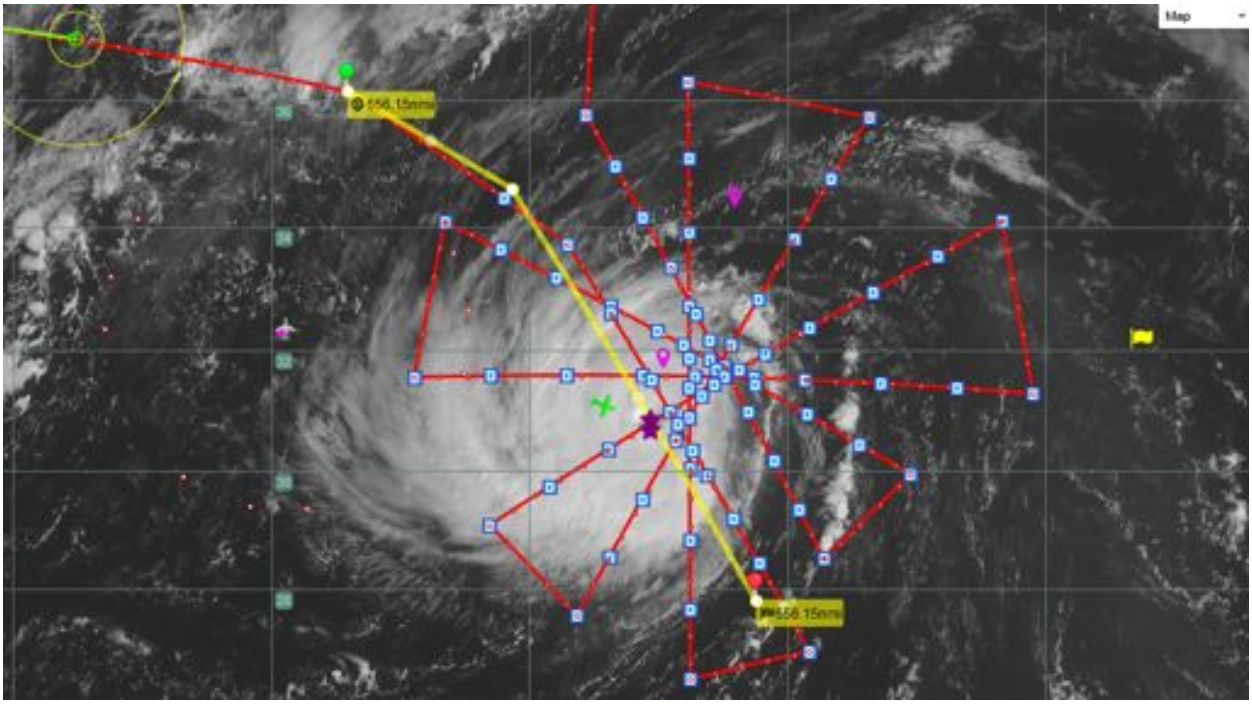
1220Z: Original 1200 takeoff is delayed due to showers passing through WFF.

1240Z Takeoff from WFF

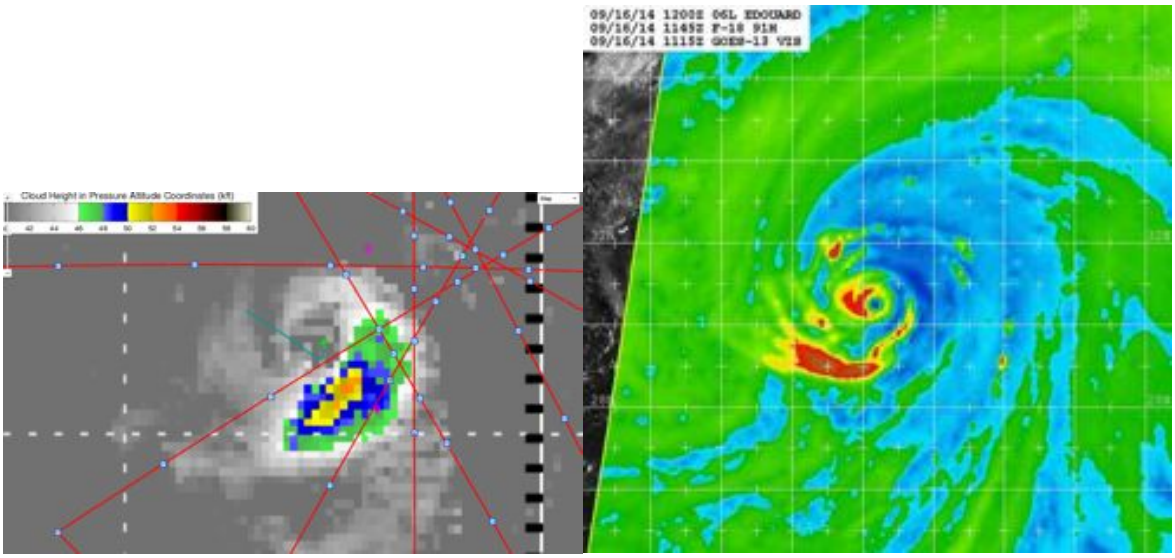
1246 It's a beautiful morning above all the clouds.



1330 Cloud top heights of the eyewall are reaching 51 kft.



1406 Storm is jogging more to the west than forecasted, so adjusting the first leg. First leg into the storm

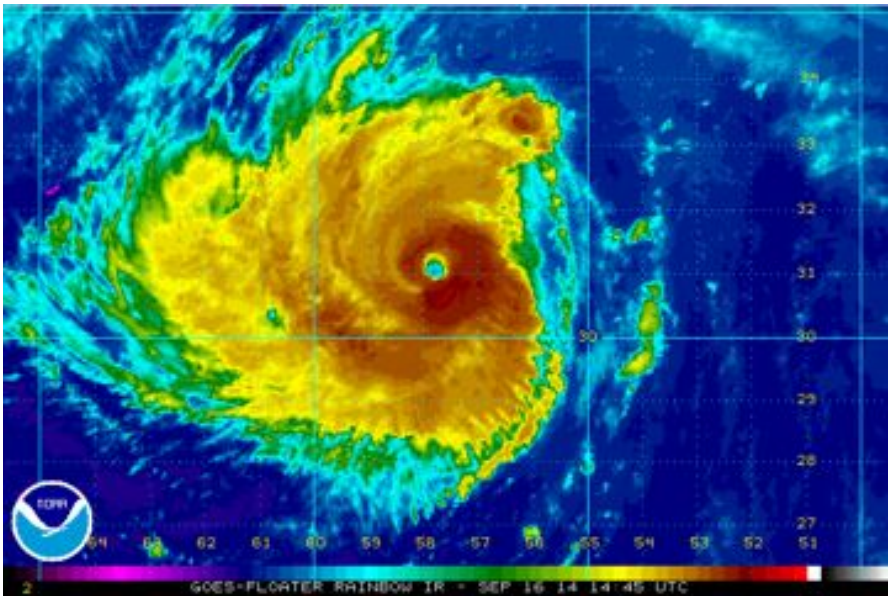


1415 N42 just reached the eye (blue line in first image above). Reports lots of banded structures on west side of storm. The cloud tops are increasing in the southeastern eyewall. Microwave image shows the rainband activity has shifted to the south and southwest.

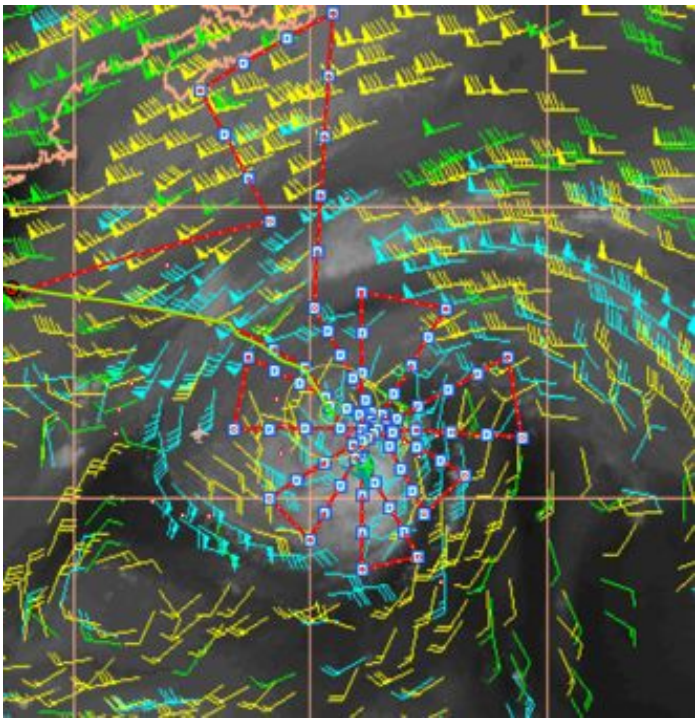
1436 N42 reports closed eyewall with stadium effect. 955 mb mslp in eye.

1500Z NHC upgrades Edouard to Cat 3. 100 kts, 955 mb. Moving NNW at 13 mph.

1506Z D01 sonde released. Looks good.

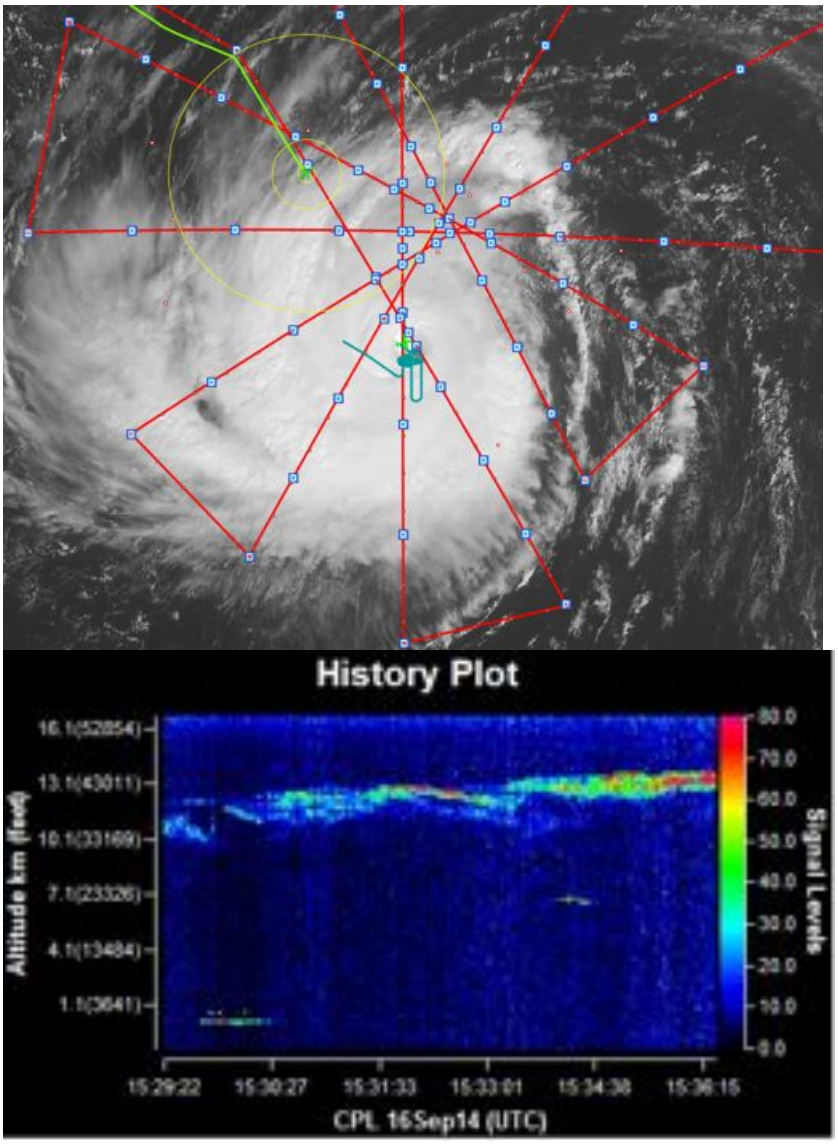


1445Z IR image of Edouard.



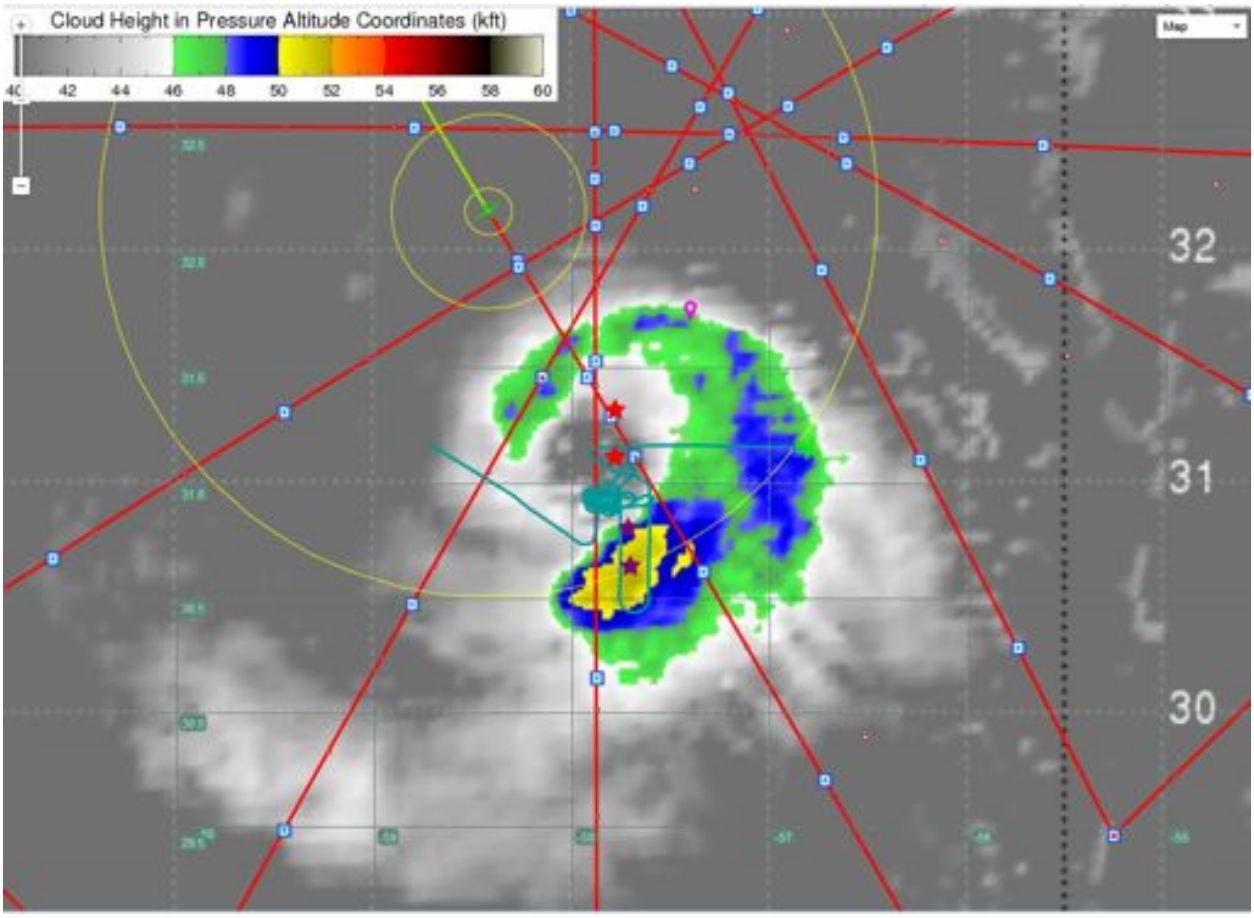
Flight track with 1445Z upper level winds. The strongest of outflow jet sits just to the west of the flight track. Last legs of planned flight track sits right in the mid-latitude jet.

1520Z D02 sonde released



1535Z First leg of flight track is shifted slightly north and east for forecasted track position at 1600Z. Now approaching the outflow cirrus canopy as seen on CPL.

1536Z D03 sonde released



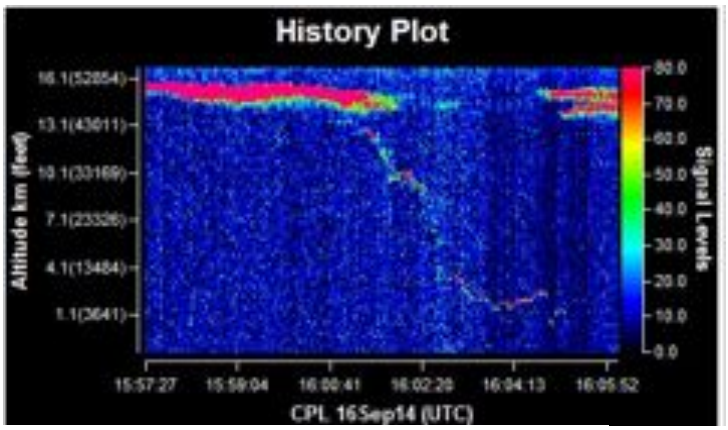
1552Z Hawk approaching the eyewall. Cloud tops around 51 kft on the SSE side of eyewall. The heights haven't changed much over time. There is no lightning and appears okay to fly over. Will be dropping three sondes in rapid succession.

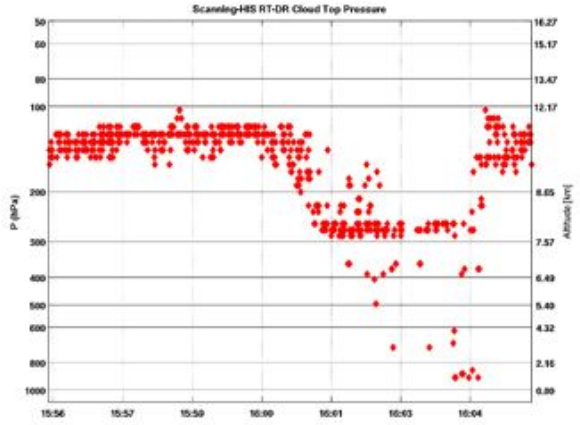
1555Z D04 sonde released and good.

1601Z D05 sonde released.

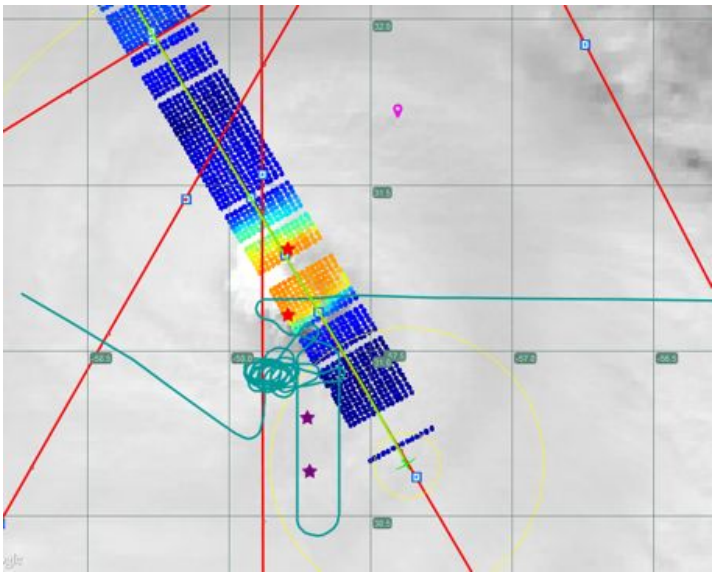
1603Z D06 sonde released

1605Z D07 sonde released





1607Z Both CPL and SHIS capture the eye.



1612Z SHIS shows warmer brightness temps in the eye.

1612Z D08 sonde released.

1624 D09 sonde released.

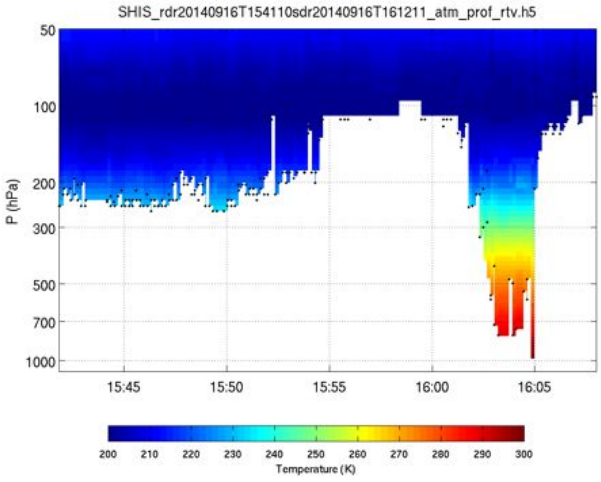
1633 Decision to do drops on pass 1, 2, 4, and 6 at 1x and 3x RMW. Pass 3, 5, 7 will be done at 2x and 4x RMW. RMW is currently 11 nm based on NOAA42 fix at 1416Z.

1635 D10 sonde released

1647 D11 sonde released

1650 Edge of the cirrus shield.

1659 SHIS temperature product in the eye overpass.

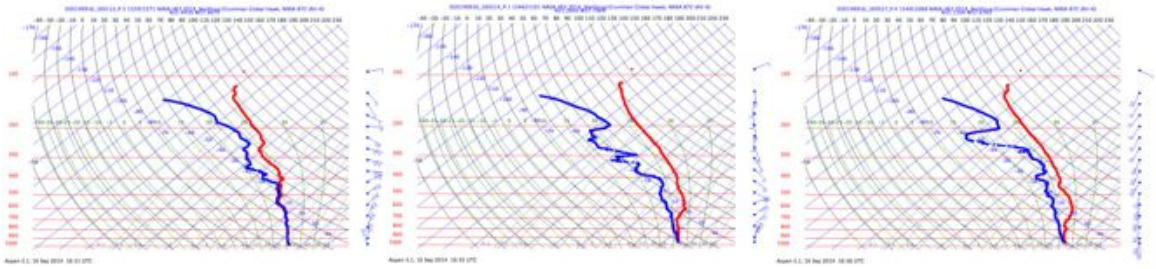


1709 D12 sonde released

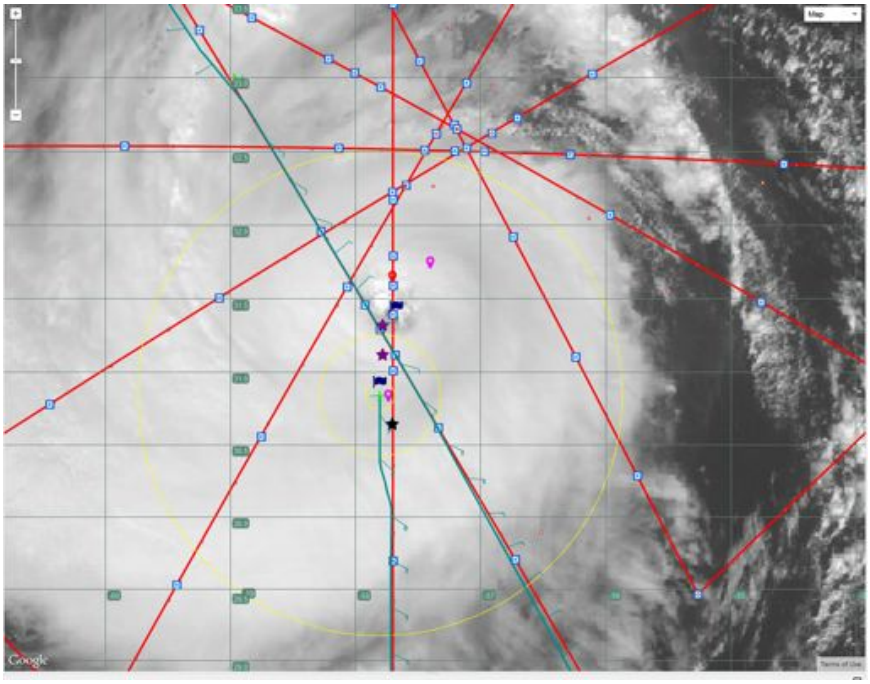
1716 N42 indicates center position: 31 deg 22.5 min N, 57 deg 44.0 min W, moving 020 at 14 kts at 1652Z. Going to keep current course since it seems it's still longitudinally correct.

1721 D13 sonde released.

1734 D14 sonde released. Also eyewall sondes from the first pass. First two sondes likely made near circuits around the eye. Moisture in upper levels indicate probably cirrus coverage. Nice warming signature.



1746 Track diverted 5 nm to the west in hope of better aligning with the center, based on satellite representation.



1748 Sonde # 15 released near D15

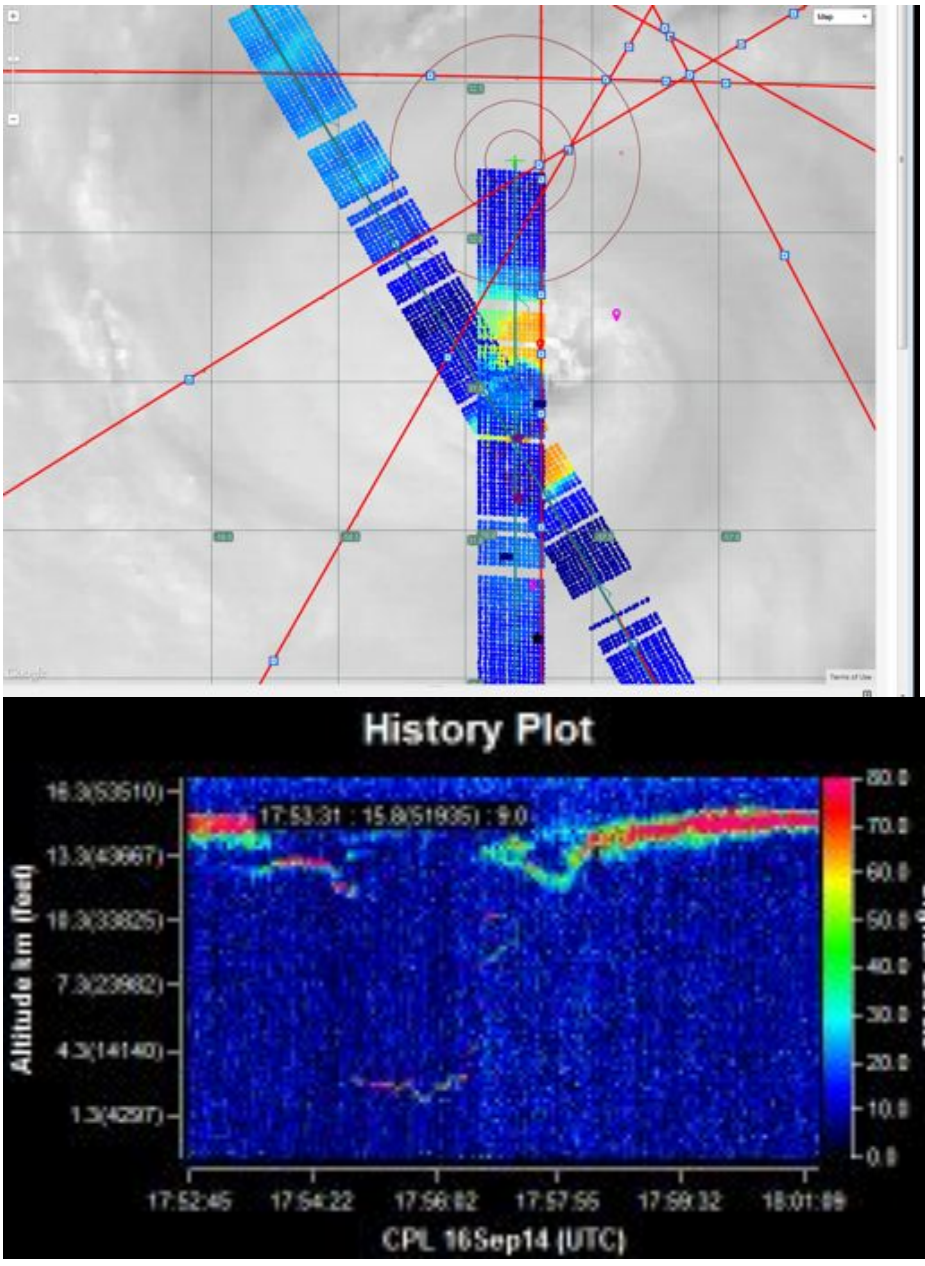
1753 Sonde #16 released via CPL signature decreasing to surface.

1755 Sonde #17 released

1757 Sonde #18 released

1801 Sonde #19 released at D19

1802 SHIS and CPL indicate course correction to the left was too much.



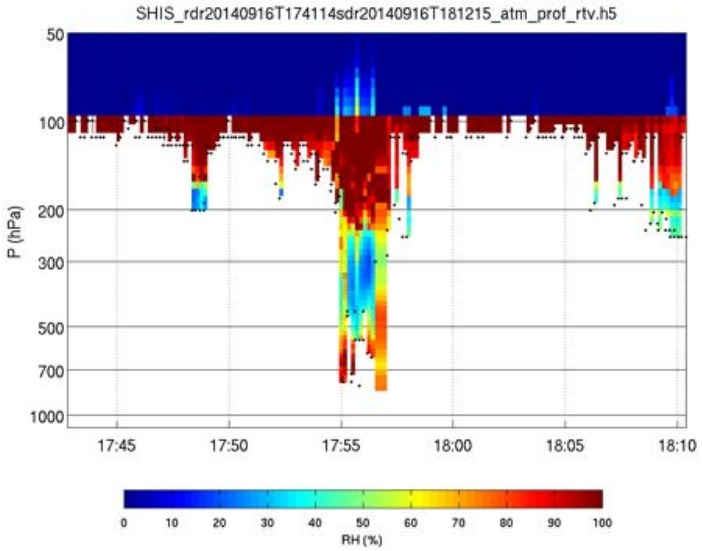
1807 N42 center position at 1720Z is 31 deg 28 min N, 57 deg 46 min W, with a radius of maximum wind of 14 nm.

1815 Sonde #20 released at D20

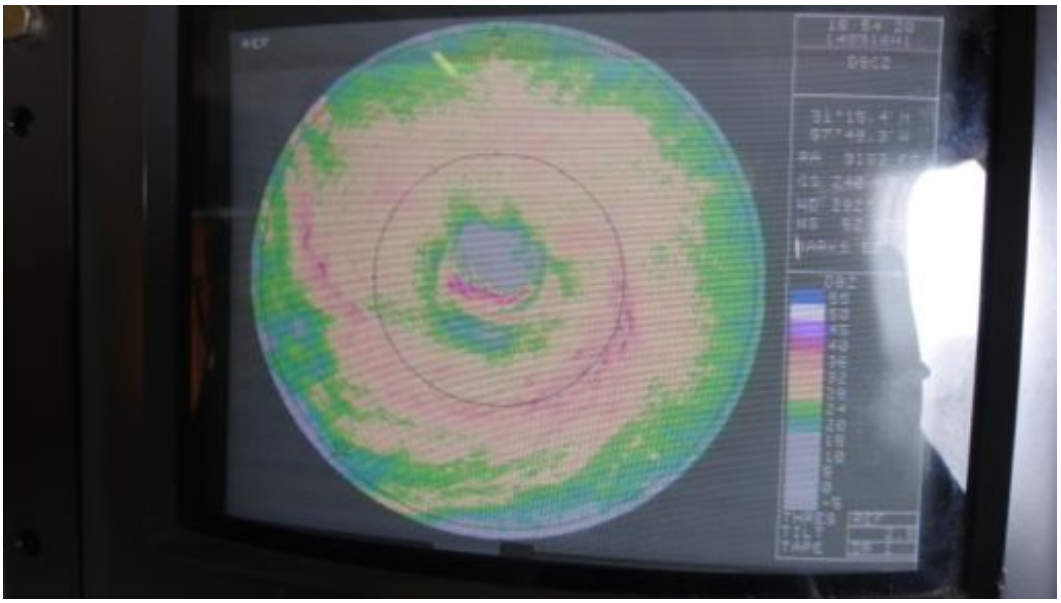
1829 Sonde #21 released at D21

1844 Sonde #22 released at D23

1847 SHIS shows nicely lowered RH in the eye.



1850 N42 indicates possible double eyewall structure in the LF radar?



1910 Sonde #23 released at D23

1925 Sonde #24 released at D24

1939 Storm to be downgraded to below major status with the next advisory, according to the NOAA folk.

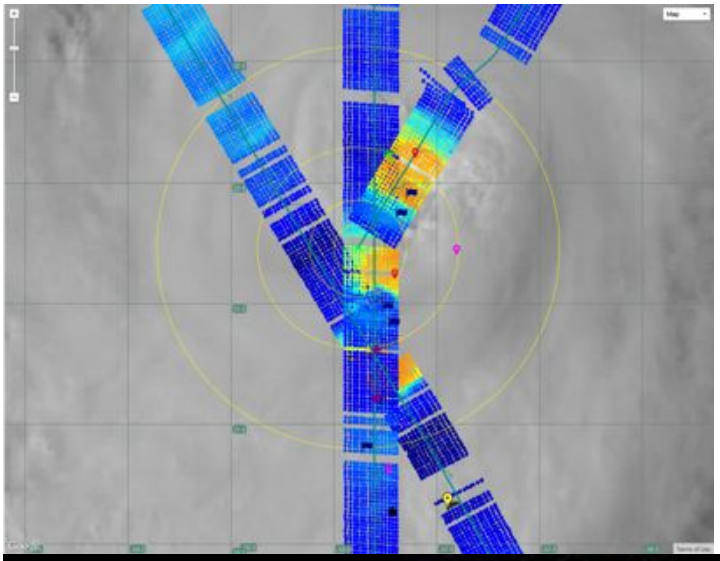
1925 Sonde #25 released at D25

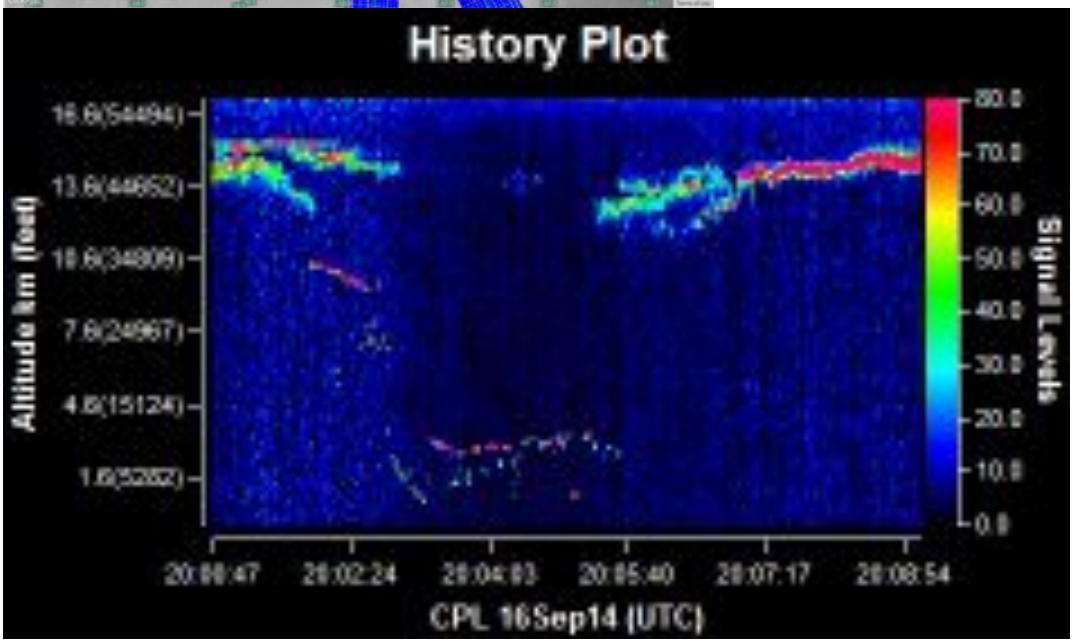
1950 Sonde #26 released at D26.

1958 Sonde #27 released early because of likely intercept of N43 in center. Suspending drops due to traffic.

2000 Sonde #28 released

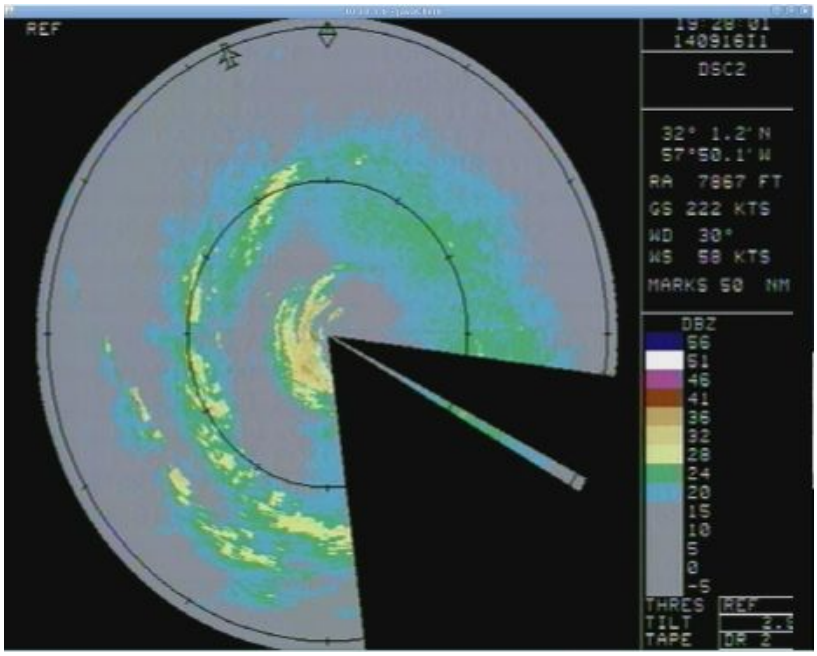
2006 Beautiful direct overpass of eye, but no dropsondes because had to suspend. SHIS and CPL show return to very low levels.





2009 Sonde #29 released at D29

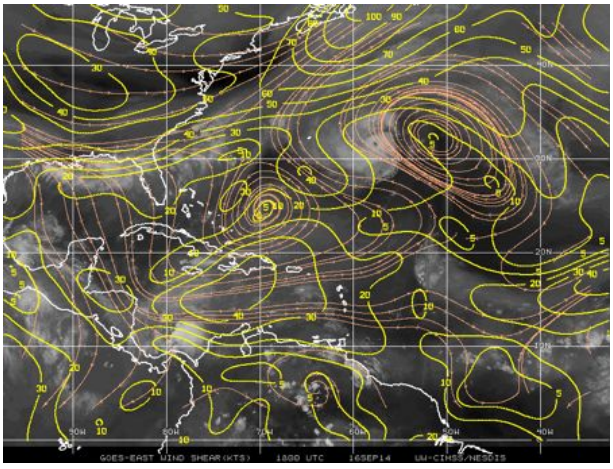
2010 N43 lower fuselage radar and flight level winds indicates double eyewall structure, with inner eyewall open to the NE.

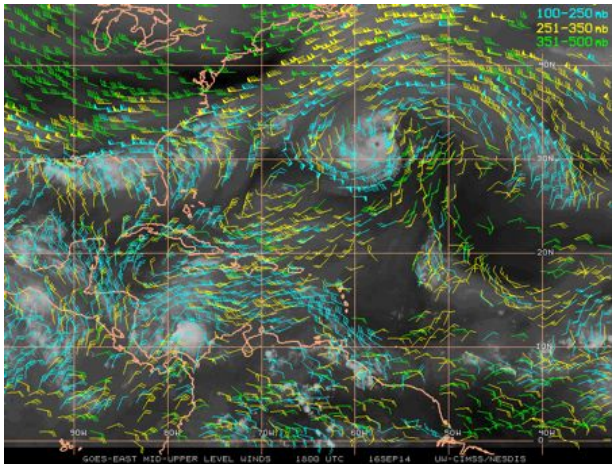


2014 Sonde #30 released at D30

2027 Sonde #31 released at D31

2028 CIMSS 1800Z shear indicates shear is still relatively light over the bulk of the system, although the outflow is likely beginning to merge with the jet to the north.





2040 Sonde #32 released at D32

2055 Sonde #33 released at D33

2120 Sonde #34 released at D34

2134 Sonde #35 released at D35

2144 Heading toward a forecasted center position of 32.5, -57.5. So far morning forecast team has been dead on in their predictions!

2150 Sonde #36 released at D36

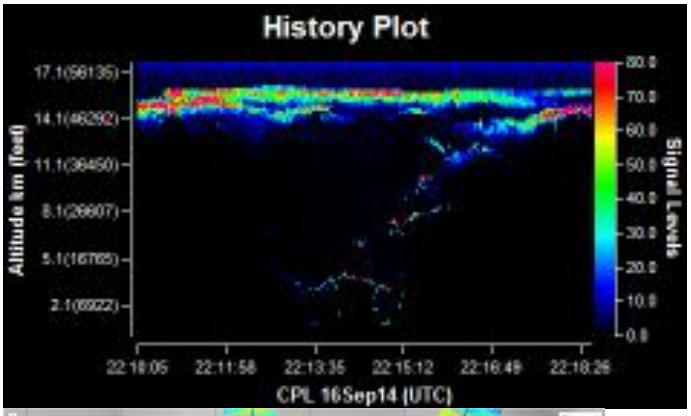
2204 Sonde #37 released at D37

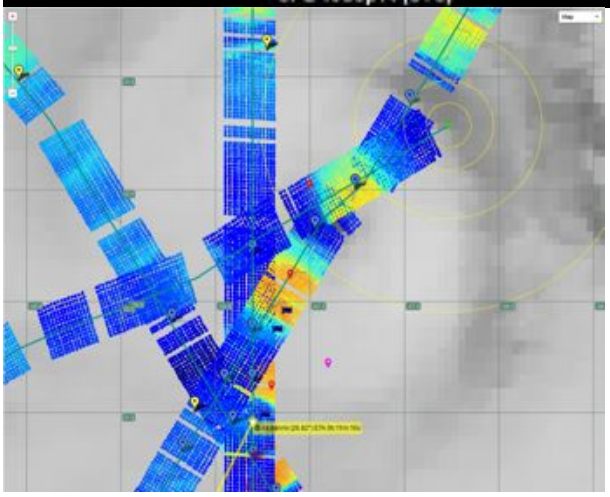
2210 Sonde #38 released at D38

2214 Sonde #39 released by science call using CPL and SHIS

2215 Sonde #40 released by D40

2219 CPL indicates cirrus over eye was relatively thick, but not too thick to see into the eye. May have been just a hair north of the center. SHIS showing the very nice recurvature of the storm path.

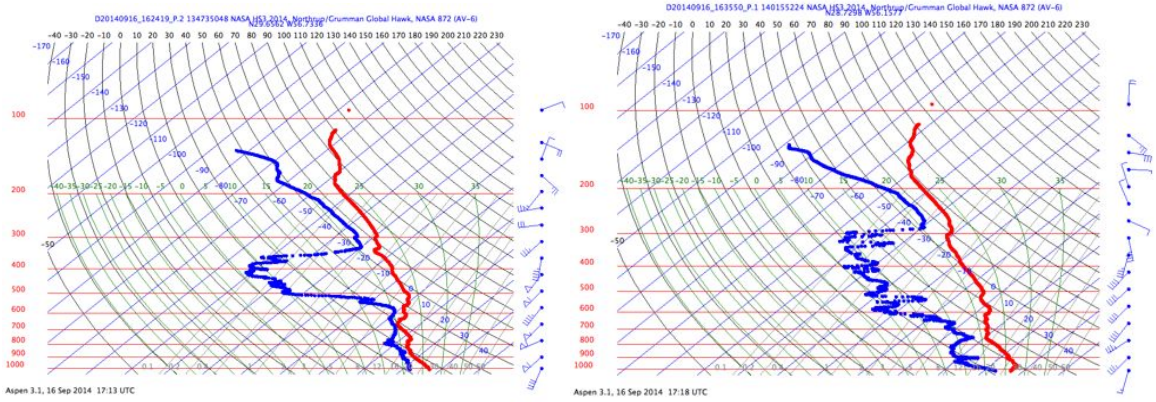




2221 Sonde #41 released at D41

2235 Sonde #42 released at D42

2244 Sondes in the rainbands to the south note drying and warming in the mid-levels, below a moist layer likely associated with the cirrus deck.



2250 Sonde #43 released at D43

2307 Sonde #44 released at D44

2335 Sonde #45 released at D45

2353 Sonde #46 released at D46

2358 Updated position to 33.1N, forecast determined that the storm has begun to pick up speed.

0003 Sonde #47 released at D47

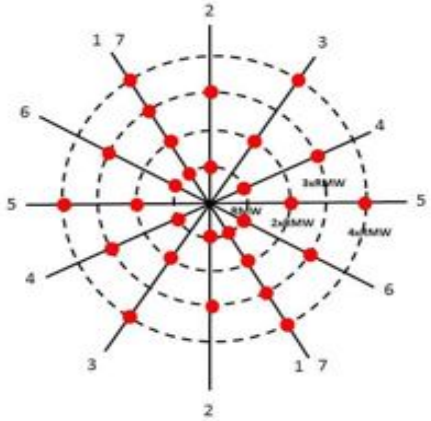


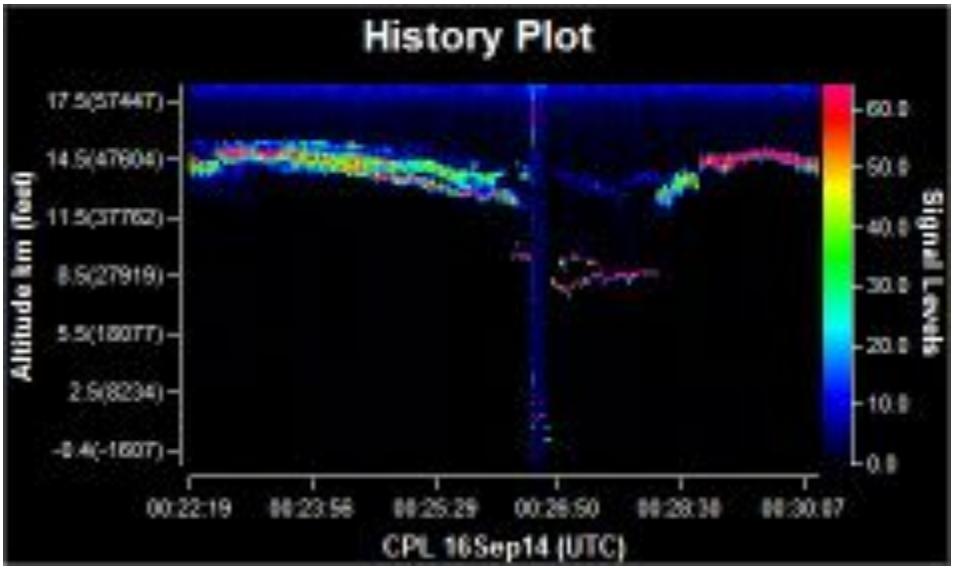
Figure: Schematic of inner-core dropsondes (red dots) in storm-relative and RMW-relative framework. RMW assumed to be 14 nm (based on vortex data message from NOAA42 earlier in day).

0017 Sonde #48 released at D48

0022 Sonde #49 released at D49

0027 Sonde #50 released at D50

0032 Sonde #51 released at D51



Went over the northern eyewall around 0027 UTC

0037 Sonde #52 released at D52

0051 Sonde #51 released

0105 Sonde #54 released at D54

0122 Sonde #55 released at D55

0153 Sonde #56 released at D56

0205 Sonde #57

0219 Sonde #58

0233 Sonde #59

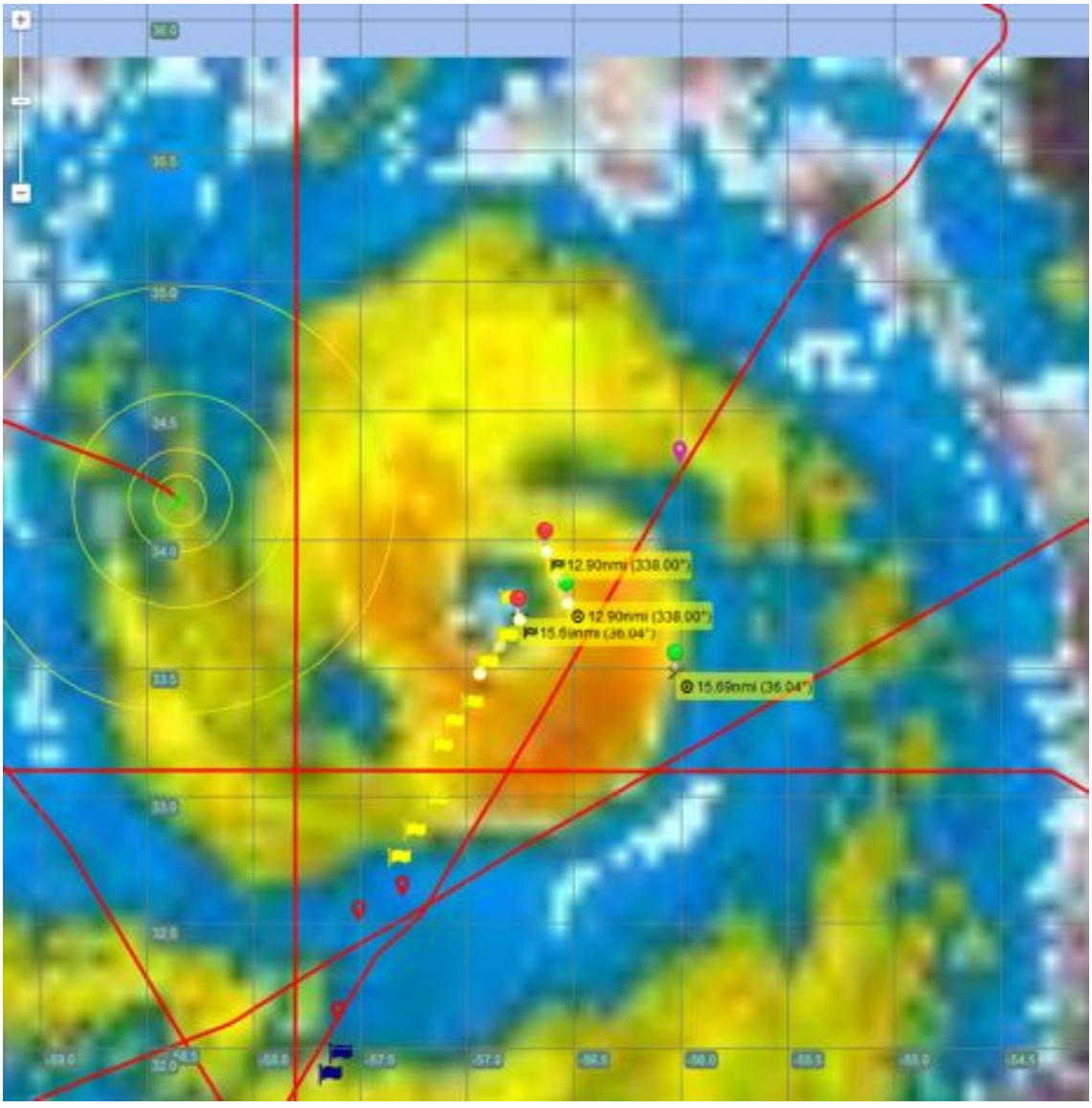
0238 Sonde #60

0241 Sonde #61

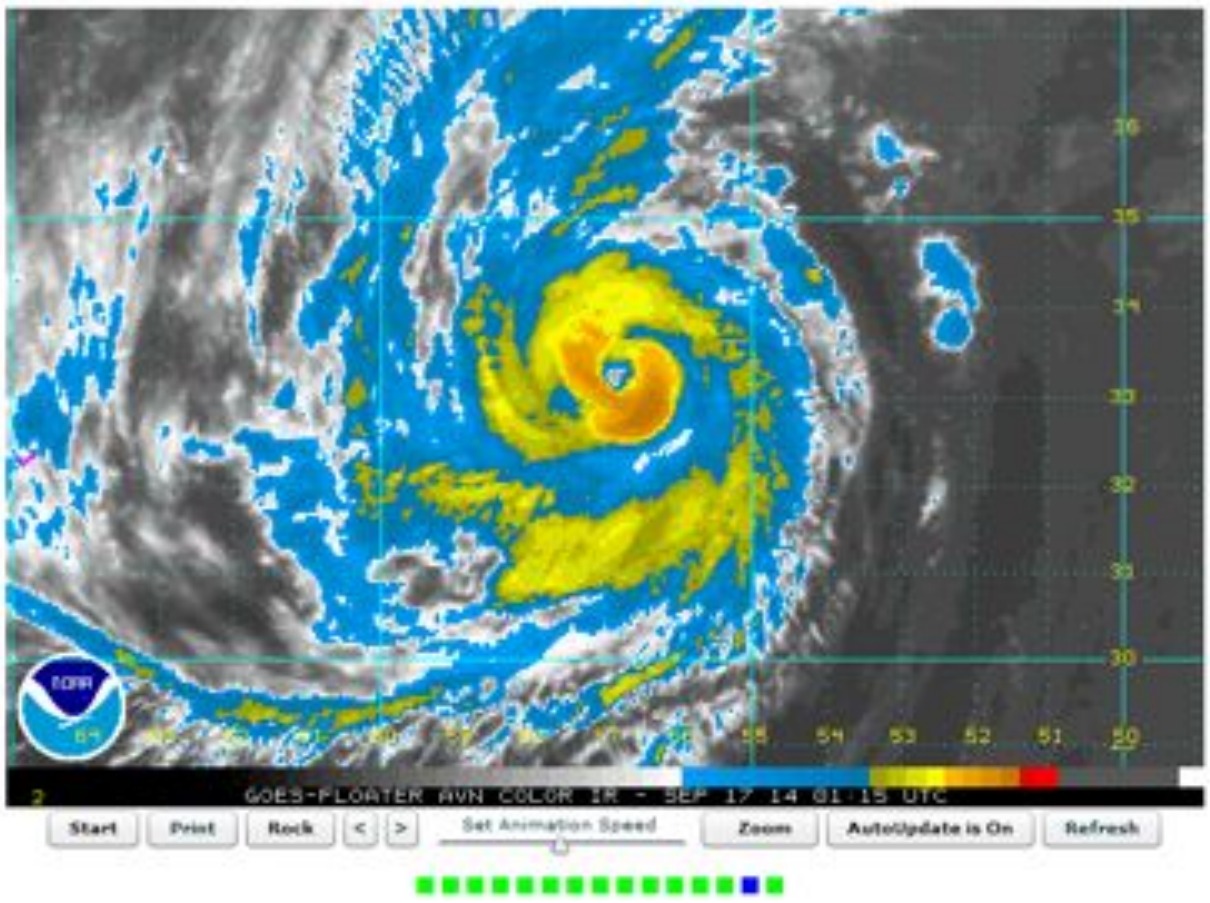
0243 Sonde #62

0248 Sonde #63

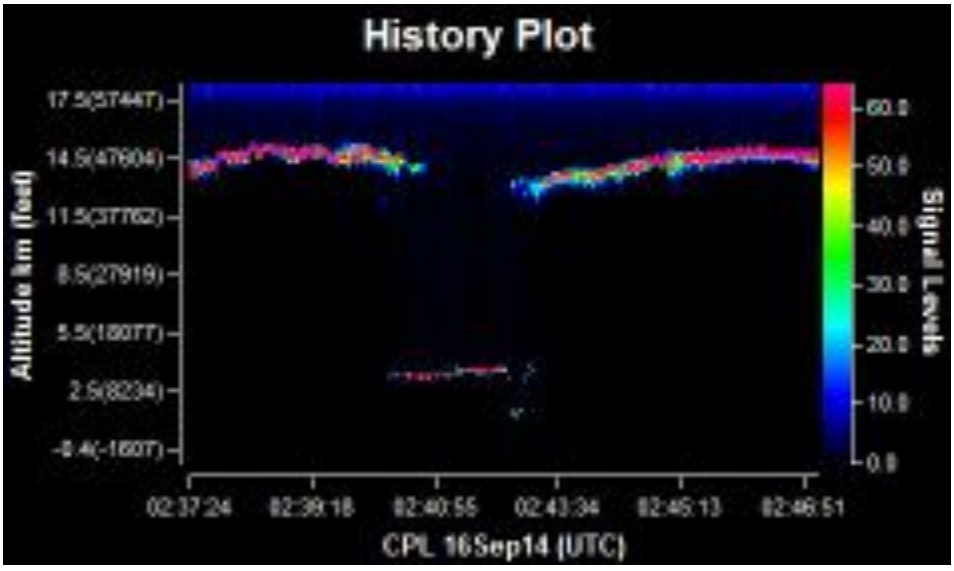
There appears to be an issue with the AVN color-scaled IR loop in MTS – it's mapped wrong. The centroid based on MTS would be up near 33.7 N, but from the NOAA SSD floater page (native grid) the center is more like 33.3 N. (see below two images). This came up when trying to vector plane towards storm center, and two mission scientists came up with different numbers depending on the product that was being used.



MTS IMAGE



NOAA SSD PAGE



Nailed the eye on this overpass! Unfortunately the center sonde failed for this one.

0302 Sonde #64

0315 Sonde #65

0329 Sonde #66

0347 Sonde #67

0357 Sonde #68

0408 Sonde #69

0419 Sonde #70

0424 Sonde #71

0428 Sonde #72

0433 Sonde #73

0438 Sonde #74

0449 Sonde #75

0502 Sonde #76

0525 Sonde #77

0537 Sonde #78

0541 Sonde #79

0612 Sonde #80

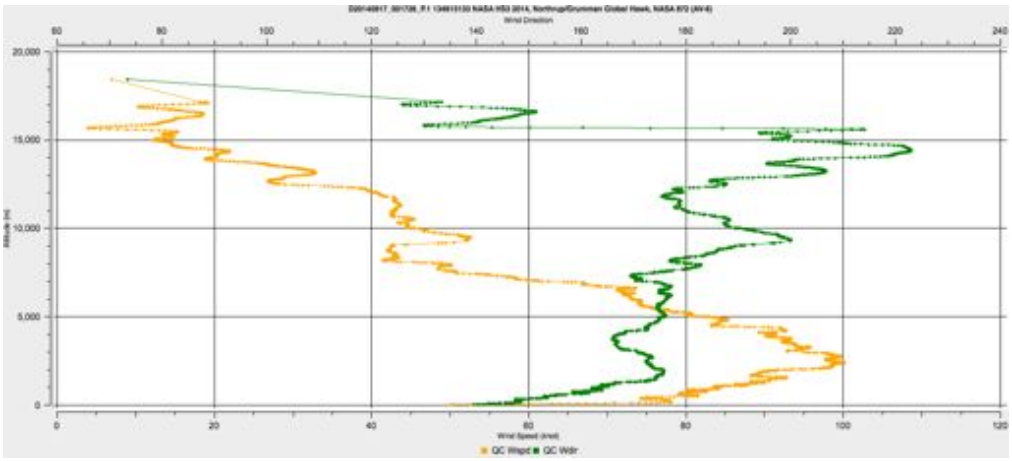
0614 Sonde #81

0637 Sonde #82

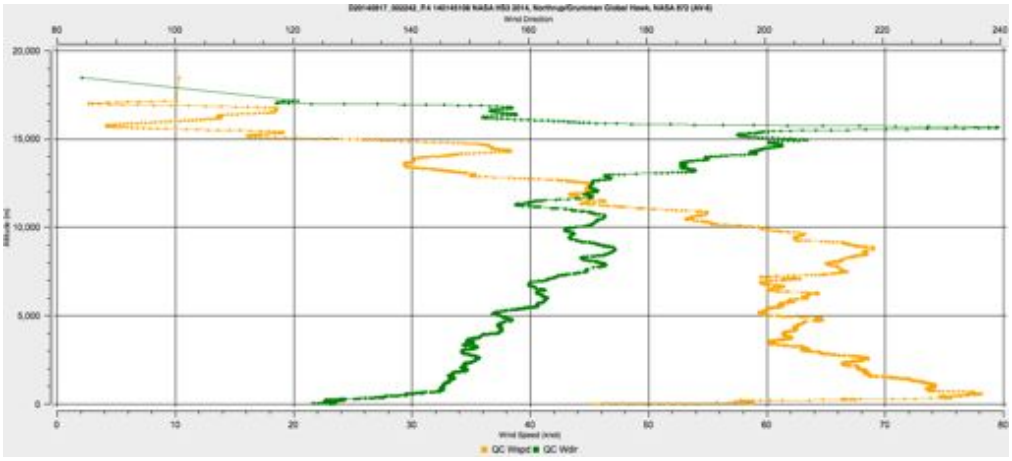
0657 Sonde #83

0715 Sonde #84

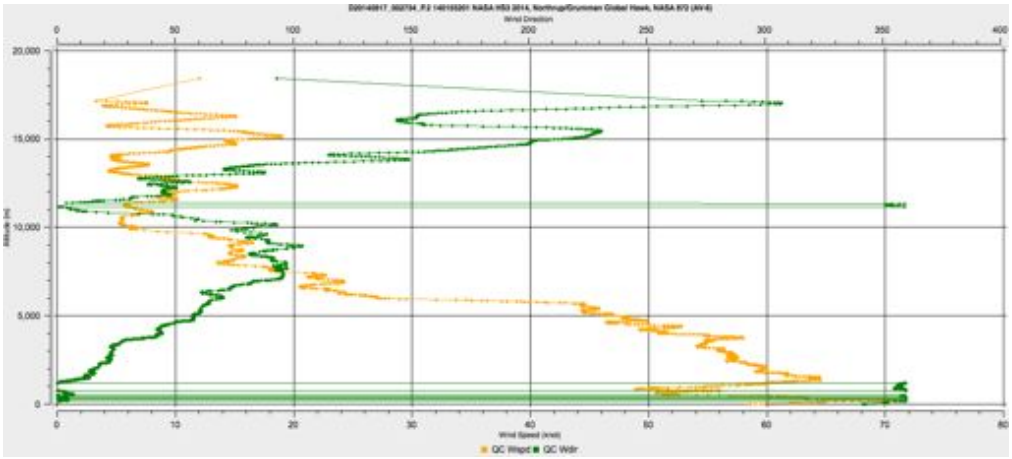
0736 Sonde #85



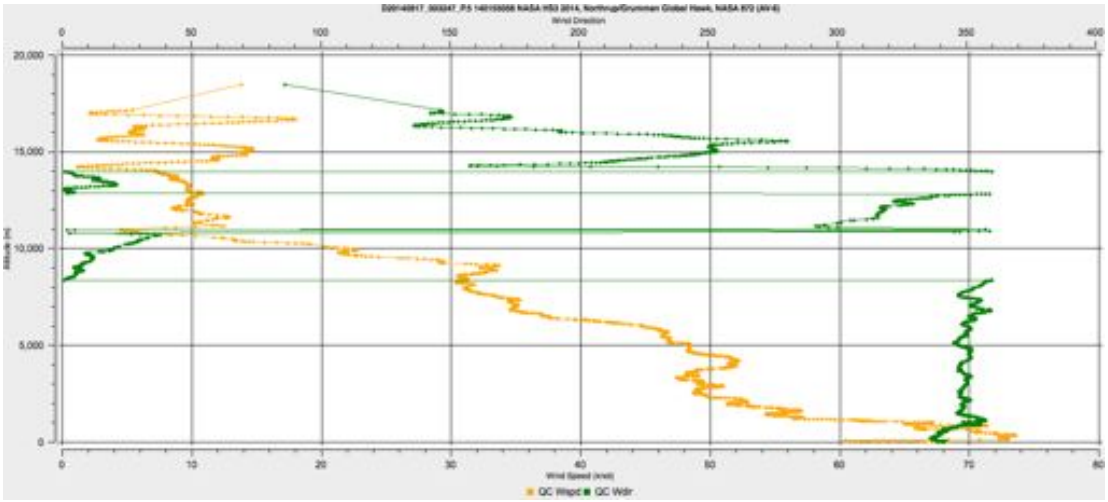
This was intended to be the 2*RMW sonde on east side for the E-W leg between 00 and 01 UTC (note it has the strongest winds)



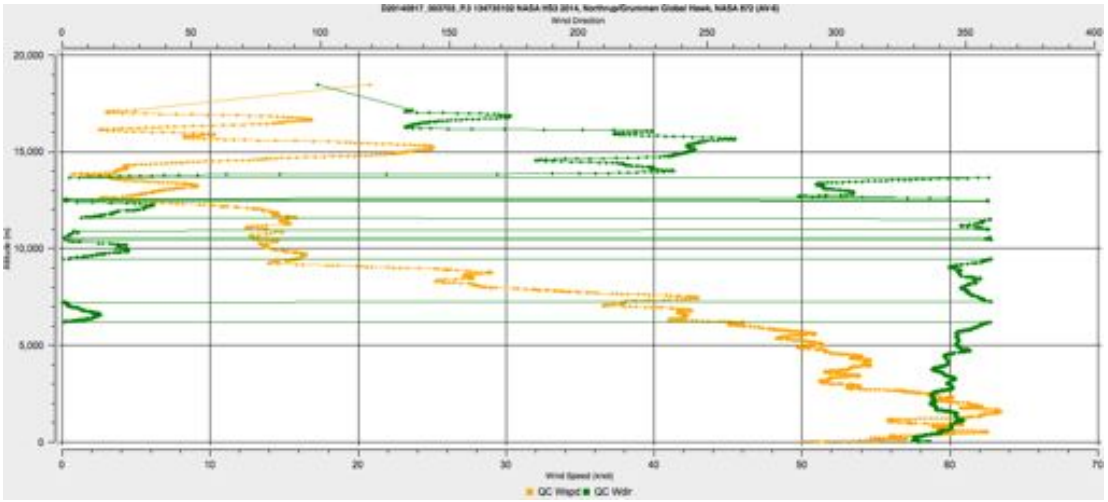
This was intended to be the RMW sonde on east side



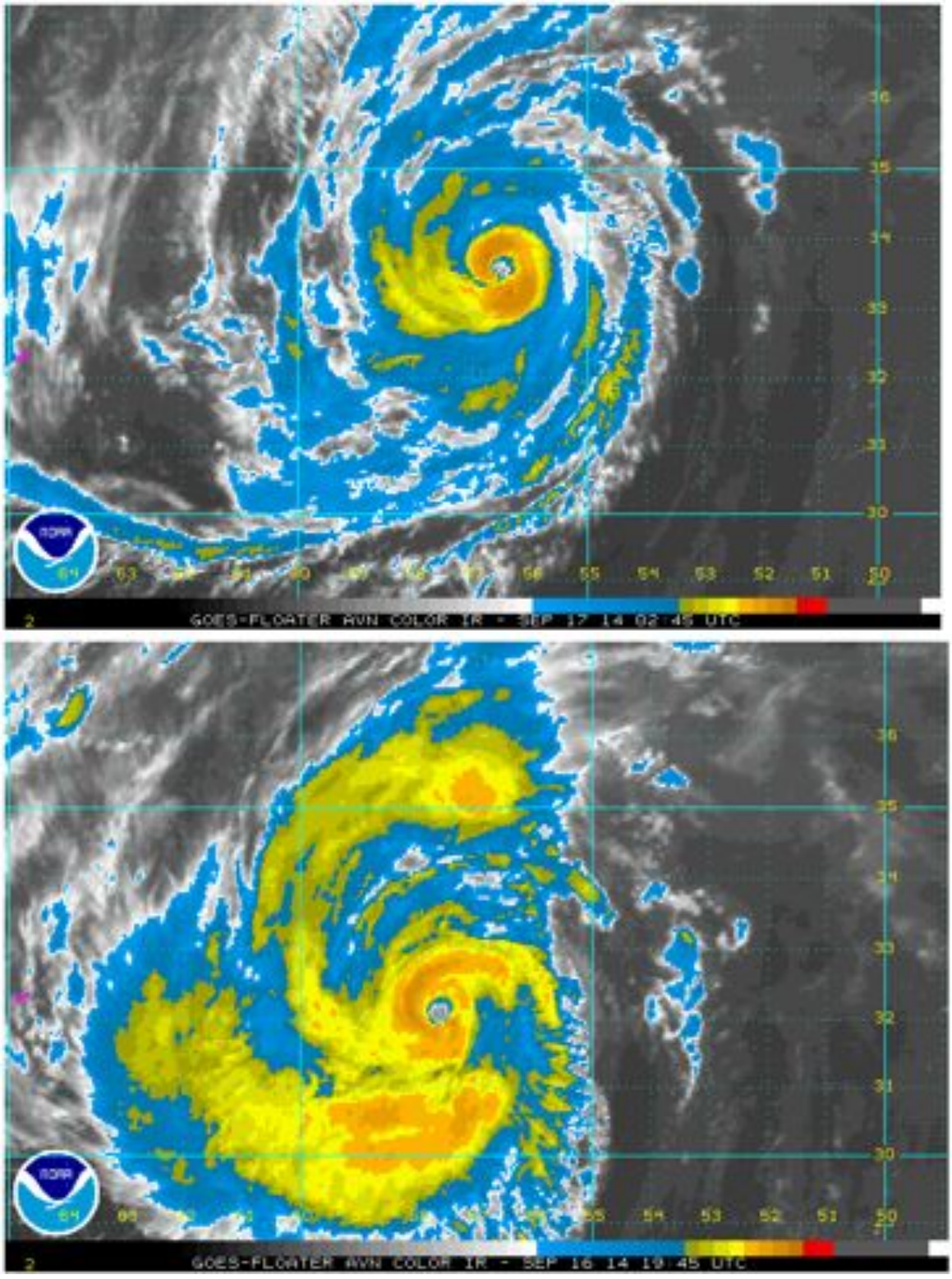
This sonde was dropped in the upper eye and fell into the northern eyewall.



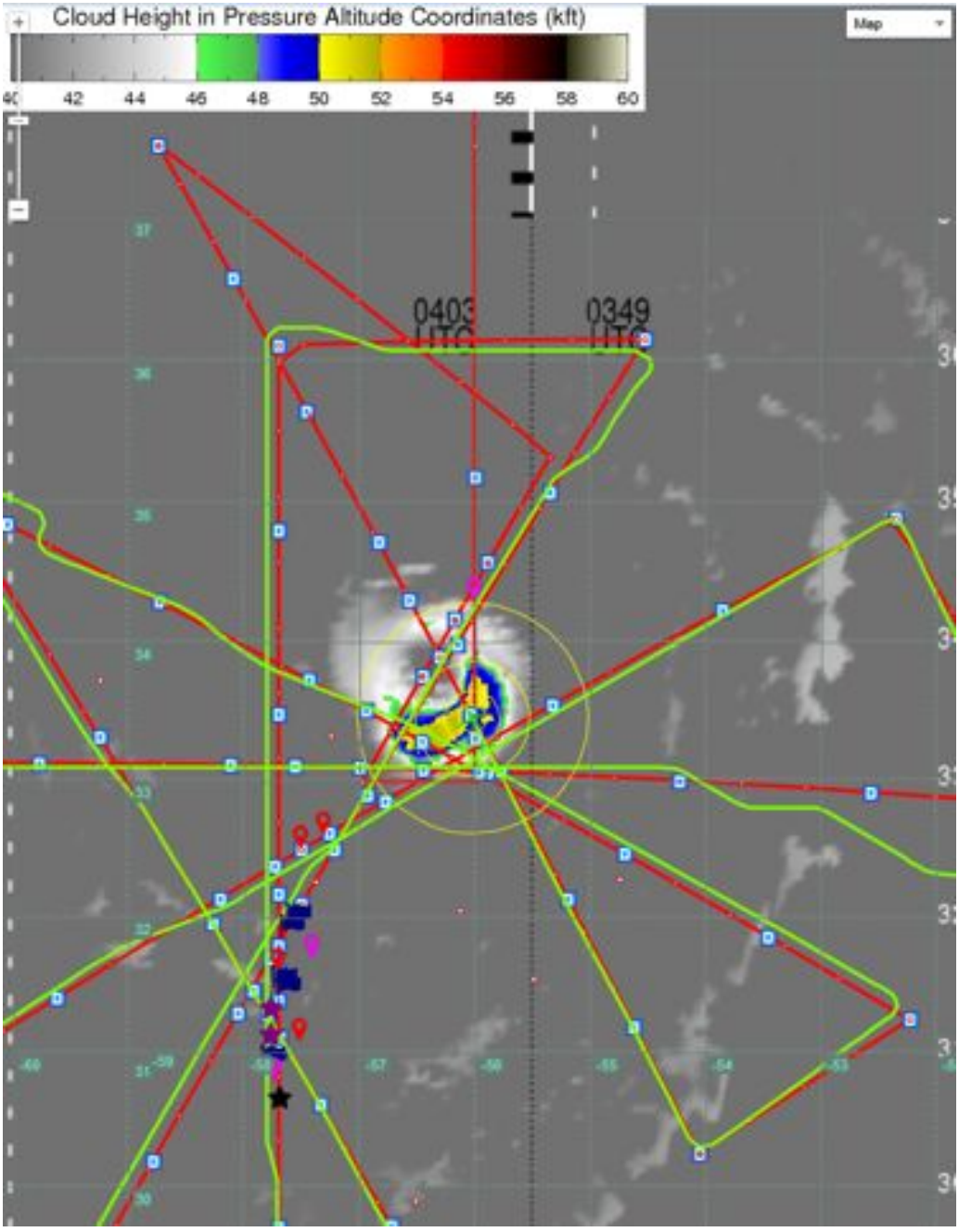
RMW sonde on west side



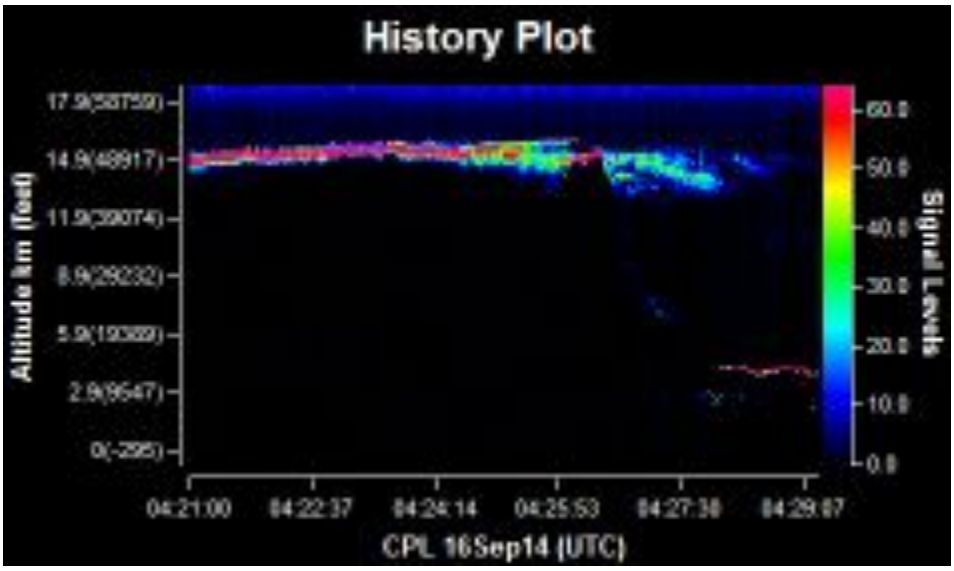
2*RMW sonde on west side



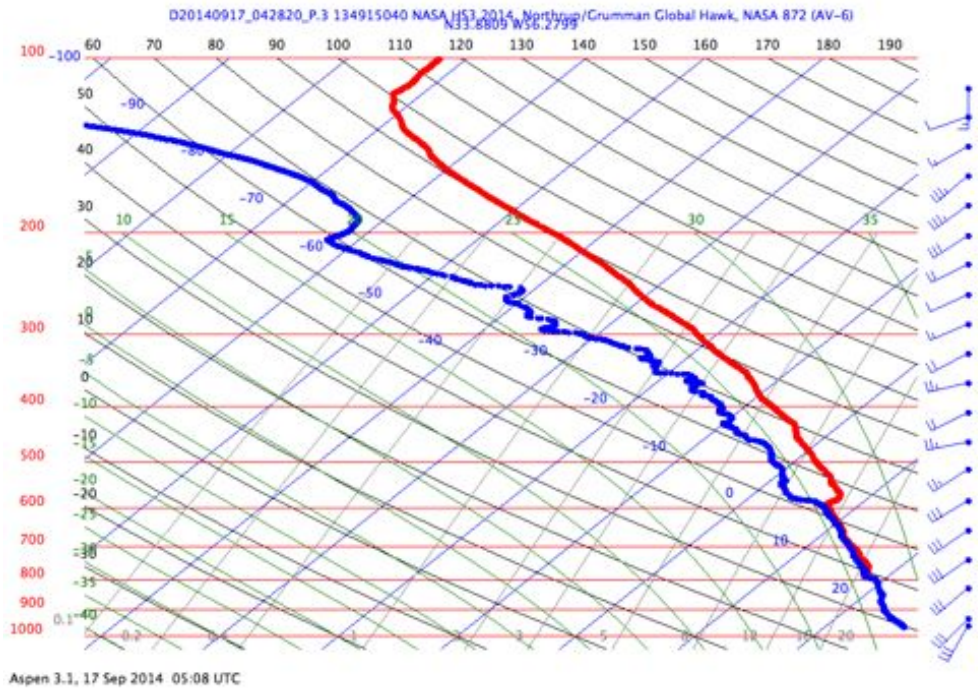
Note the large decrease in strength of outer convection through the day… inner core structure is more symmetric around 03Z than earlier as well.



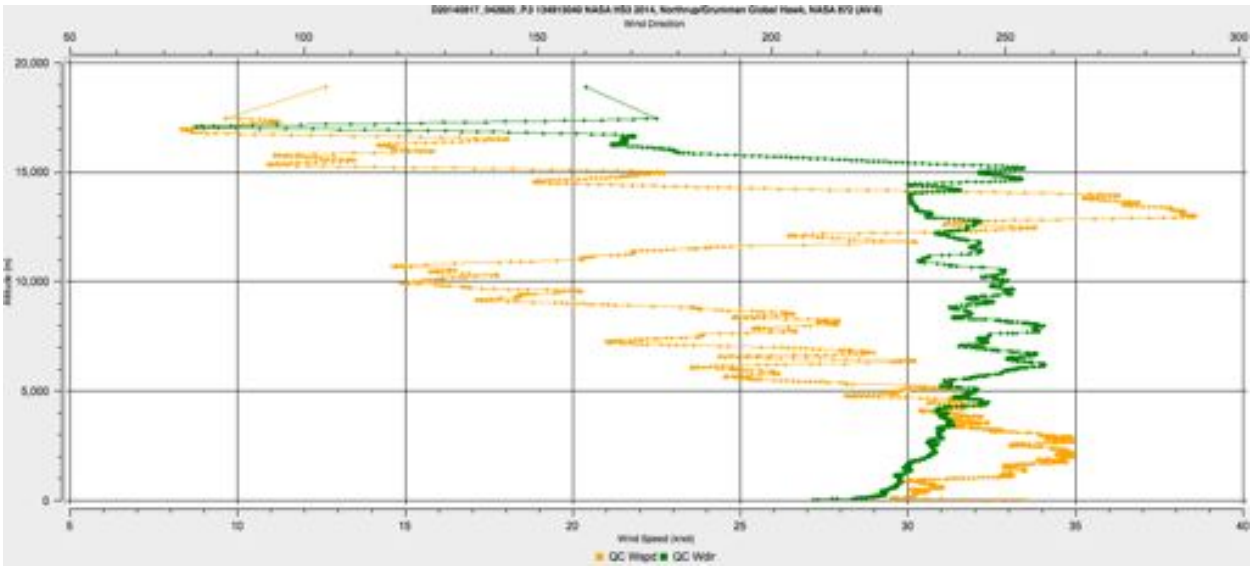
About to go over eye at 0423.

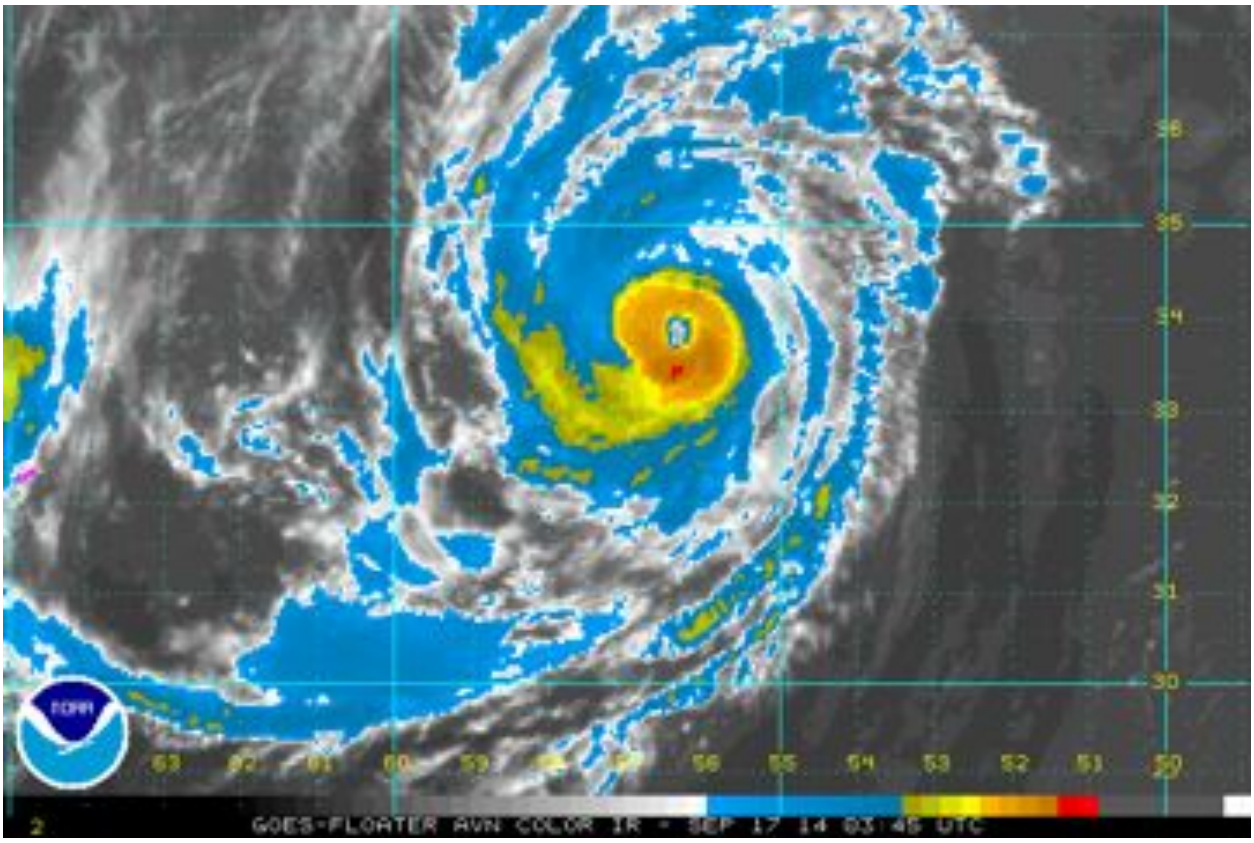


Got over the eye once more – can see the slope to the eyewall very clearly.

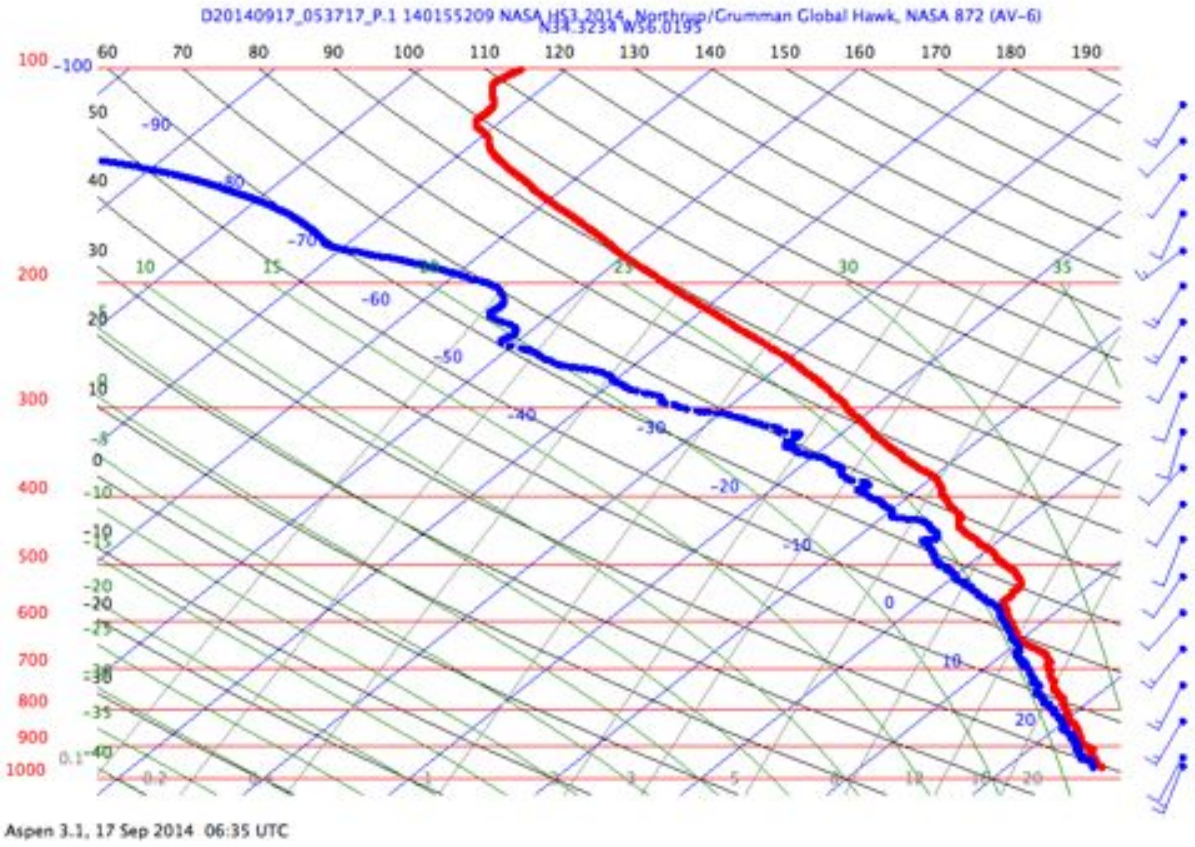


A nice drop from within the eye.

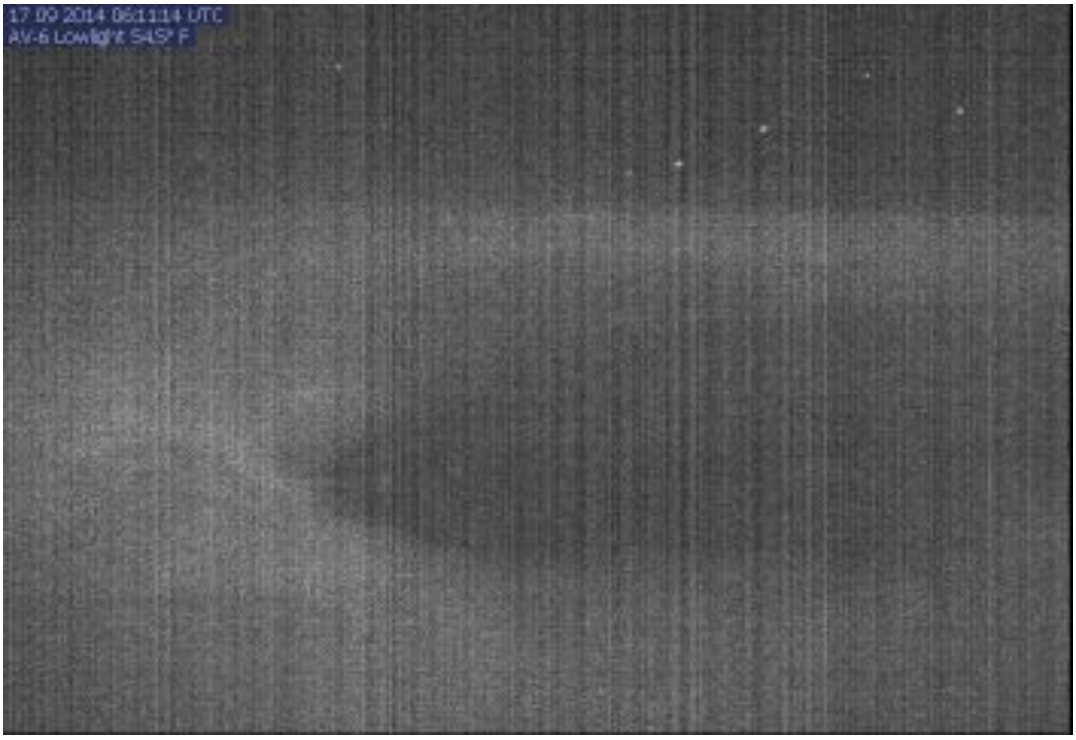




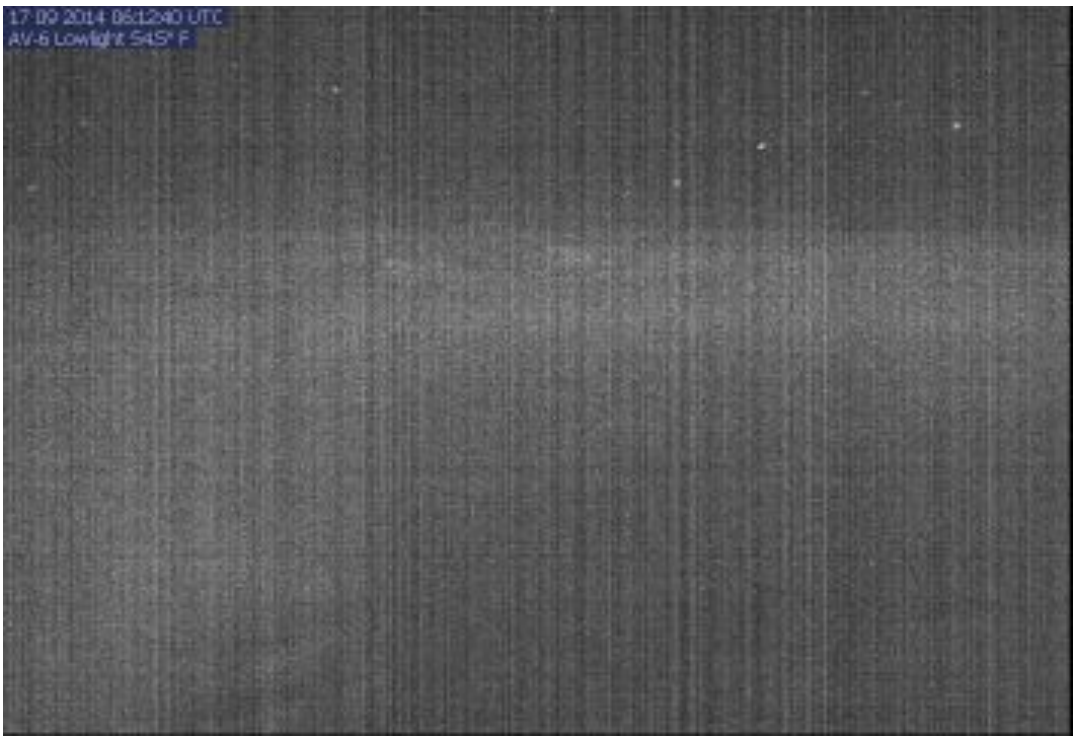
Fairly large convective blow-up on south side at this time.



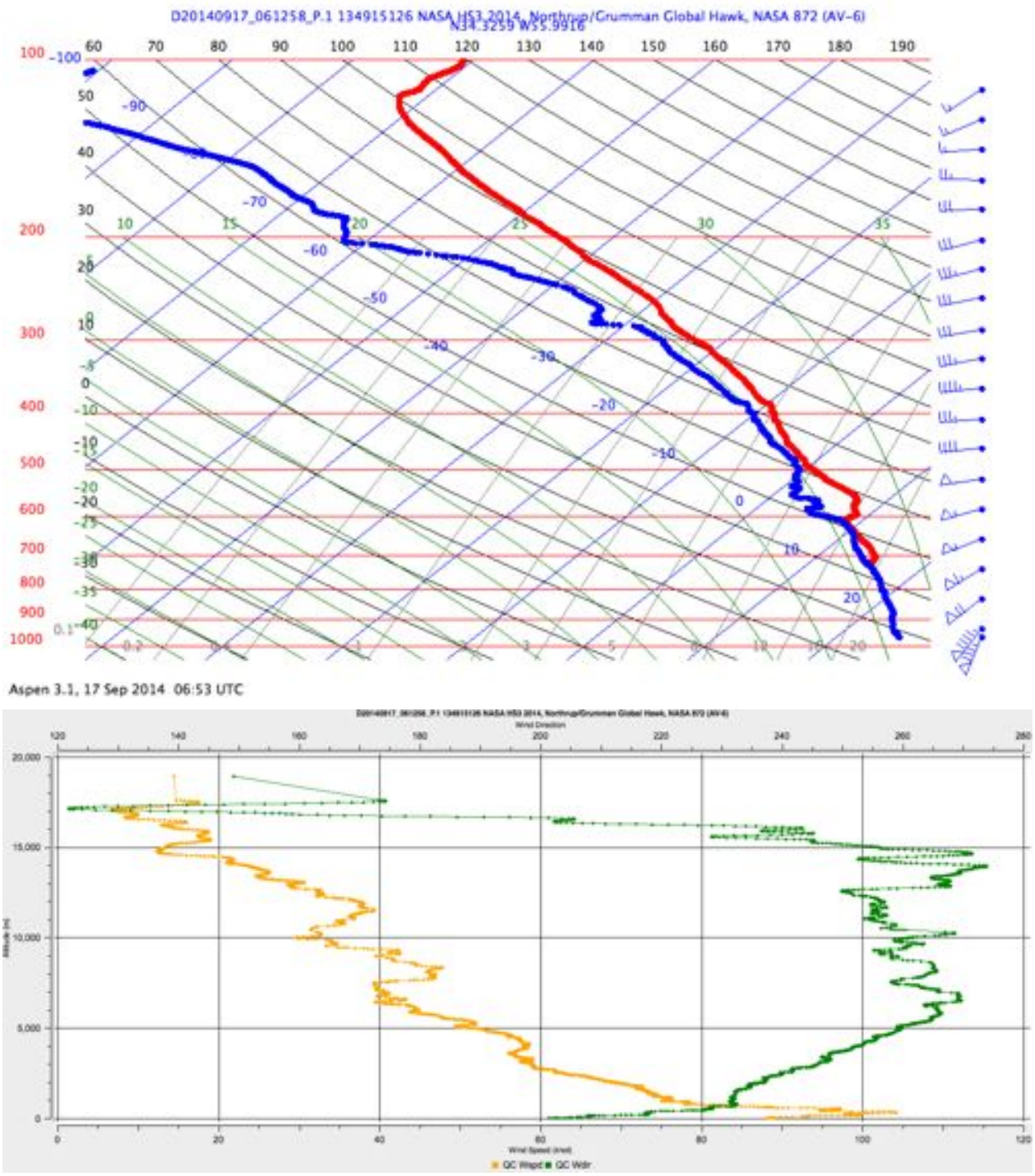
Winds about 20 kt or less from flight-level to the surface, a surface pressure of 961 mb, and a nice eye inversion between 500 and 600 mb.



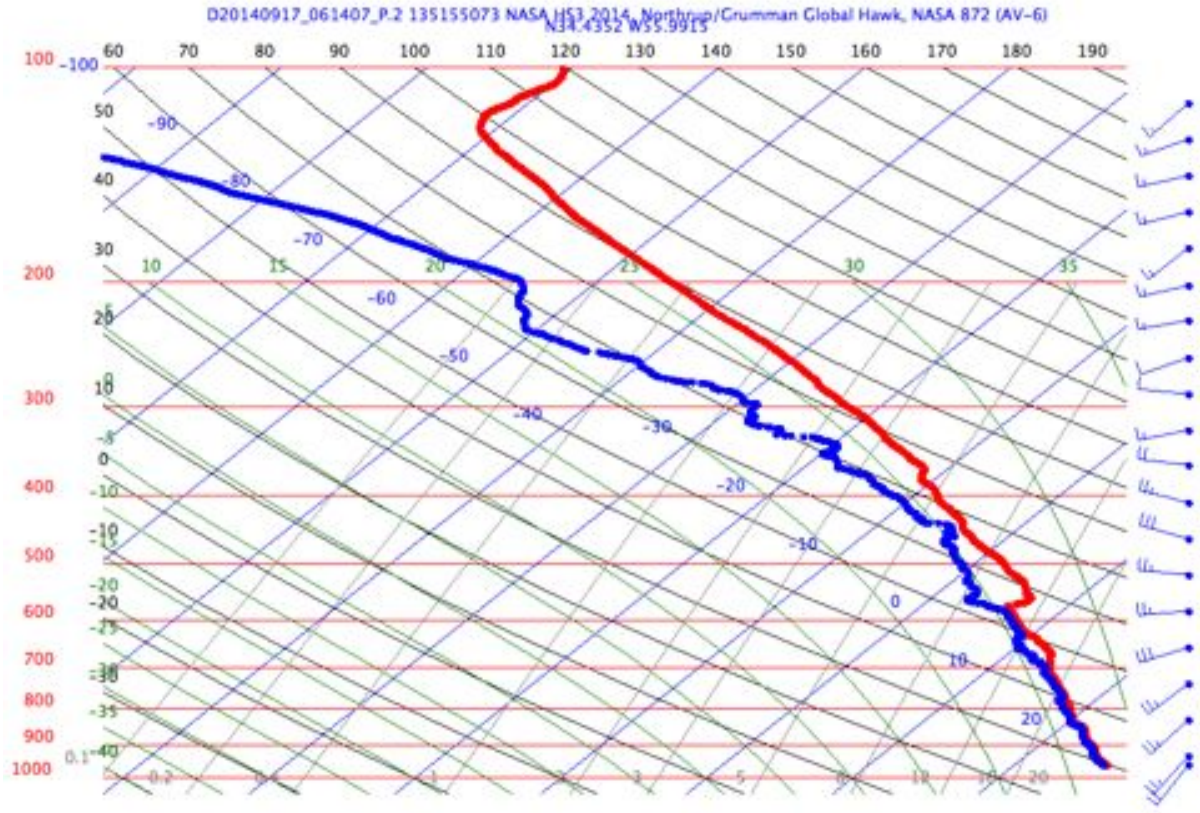
About to go over the western part of the eye on N/S transect just after 0600 UTC.

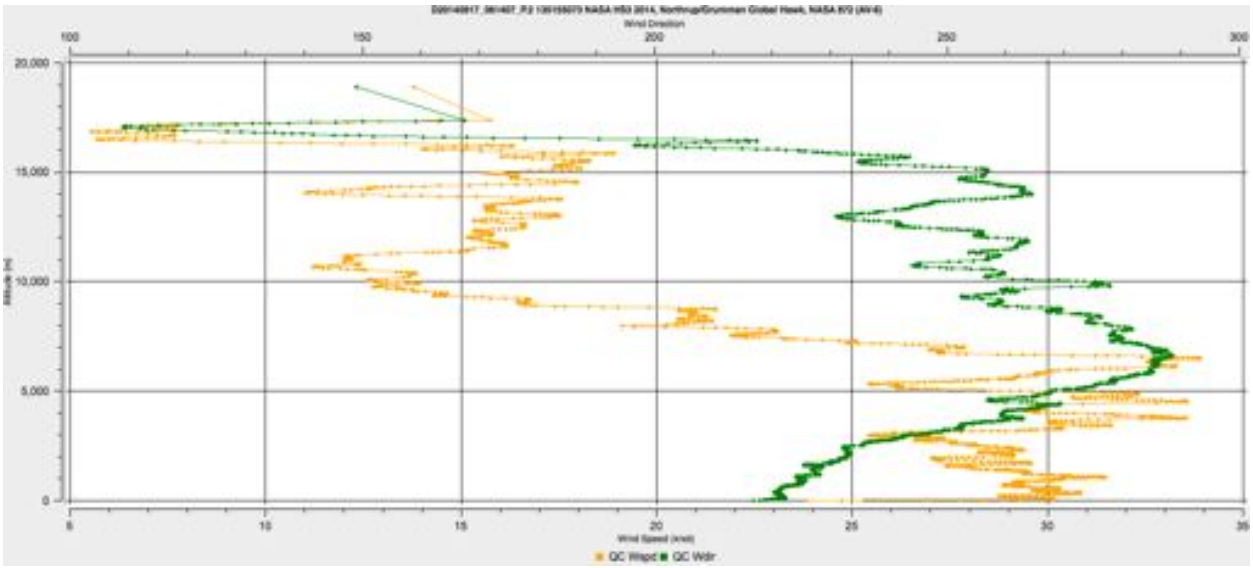


This was about the time we released that first sonde.

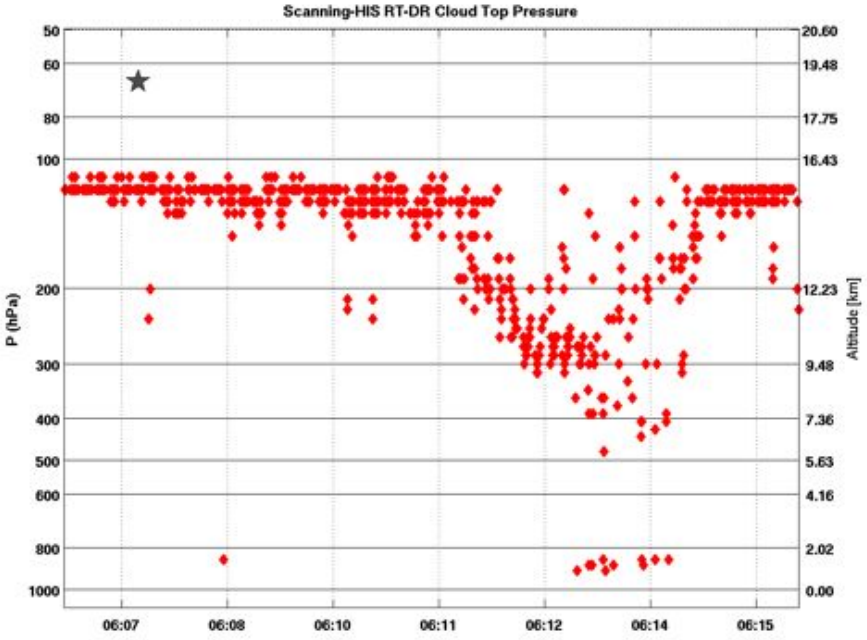


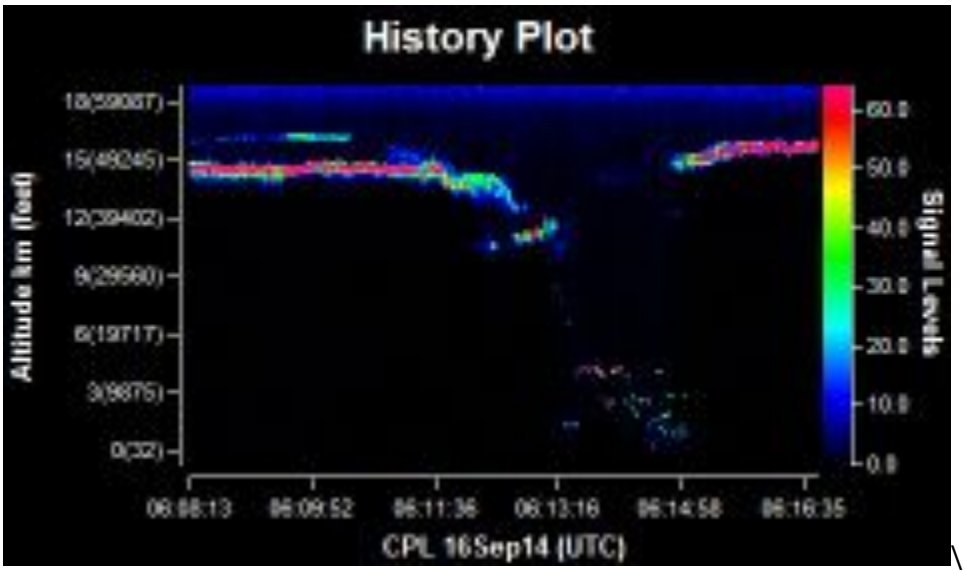
The sonde started out on the south side of the eye and rotated around to the eastern eyewall. The sonde reported a sea-level pressure of 963 mb, surface winds of 90 kt, a 105 kt wind at 300 m, a mean boundary-layer wind of 95 kt, and a lowest 150 m average wind speed of 90 kt.





This was the last drop from within Eduoard, splashing with a surface pressure of 960 mb.





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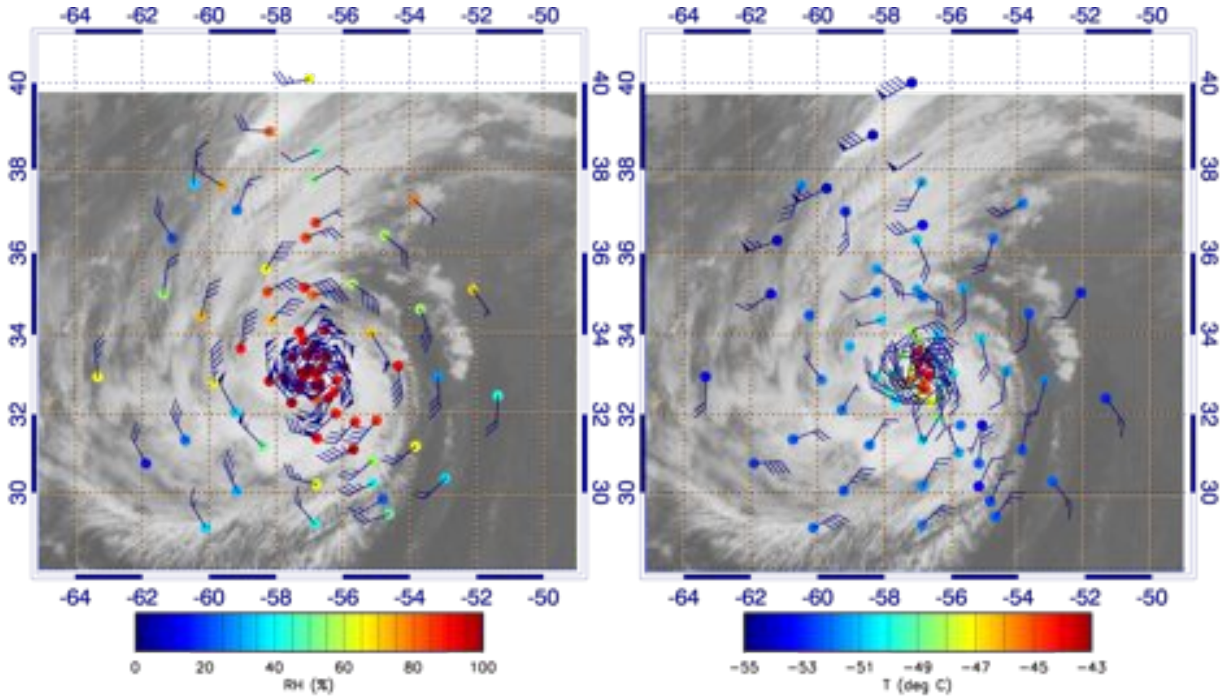
Eye penetration evident in the CPL observations.

0827 Sonde 88 released. Last sonde. Predict 1130z landing on runway 4.

1120 Landing!



The above figures show the sonde distribtion in a storm-relative reference frame. Wind barbs show storm-relative winds. Color filled circles show relative humidity (left) at 700 and temperature (right) at 200 hPa. Dry air surrounded much of the storm, but was typically located 200-300 km from the center. At 200 hPa, a clear warm core is seen with temperature perturbations of about 10-12 K relative to the near environment. Outflow was more symmetric, with a branch to the north and south.

Instrument summaries

AVAPS

AVAPS loaded and deployed 88 sondes during RF07 into Hurricane Edouard. Mechanically the system performed without fault suggesting that the repairs performed prior to the last flight were successful and addressed the previous issues. Overall data return was very good, though a small number of sondes were affected by different problems. Four sondes were affected by RFI to different degrees during the second pass over the storm eye. Data from a spectrum analyzer (see graphic at end) illustrates a period of strong interference with very sharp onset and end times. The source of the interference remains unclear. It is not likely that a significant amount of the missing data can be recovered. One sonde lost data near the surface due to sounding termination rules based on typical maximum times-of-flight. Apparent persistent strong updrafts kept the sonde aloft much longer than expected and the channel automatically terminated. The maximum allowable time-of-flight was extended, but this should be monitored when rapid drop sequences are desired. Three additional soundings lost differing degrees of

data due to a failed PTU module in flight and other data return problems. No fast falls were observed. Data from all but one of the soundings were processed in near-real-time and transmitted to the GTS and real-time display and distribution sites. Post flight inspection revealed no maintenance issues and the system is ready for the next flight.

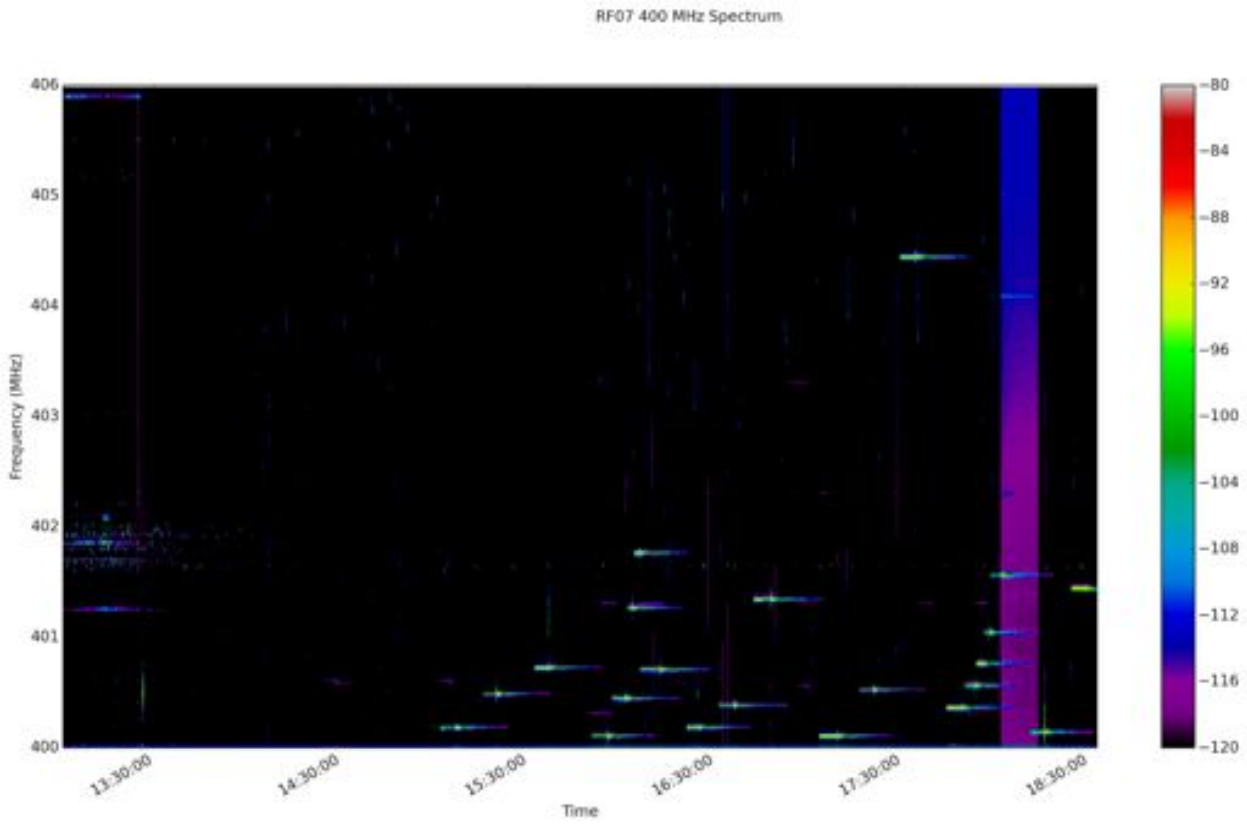


Illustration of brief discrete period of strong RFI that affected the telemetry return from four soundings. Graphic courtesy Nicholas Potts, NCAR.

Sondes Allocated		**750**	
Remaining		**264**	**35.2%**
Released		**486**	**64.8%**
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
RF07	9/16/2014	88	264

S-HIS Summary

W. Sessions, A. Merrelli; SSEC, UW-Madison

Science Flight #7 was a set of repeated crossings over the center of Hurricane Edouard. The storm developed into a category 3 at 1451 UTC before dropping to cat 2 by 2100 UTC and ultimately cat 1 by 0300 UTC Wednesday morning. The storm tracked northward to the western portion of the preflight forecast cone, curving increasingly north-eastward.

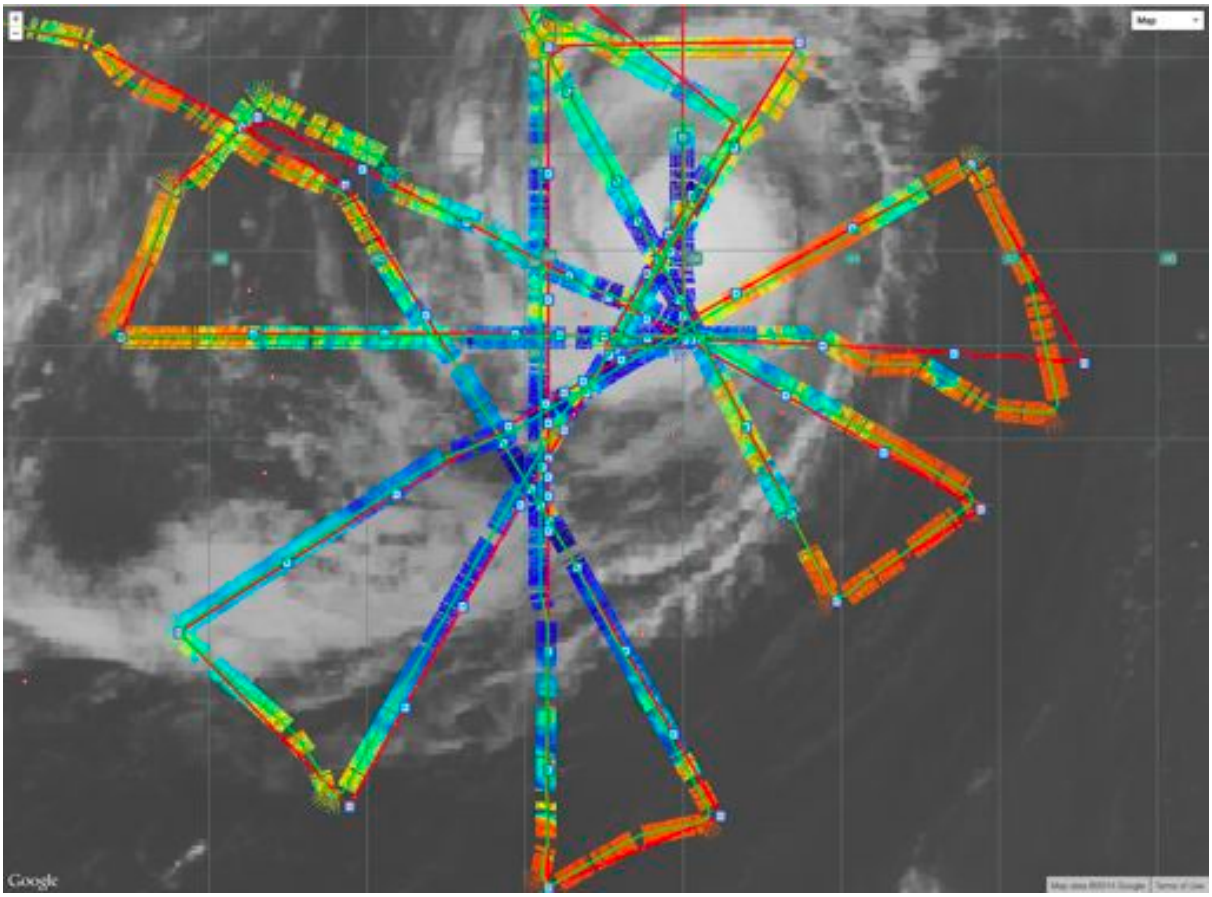


Figure 1. AV6 planned and executed transects with Hurricane Edouard after last eye crossing with S-HIS 900 cm^{-1} channel brightness temperatures and proposed dropsonde locations.

Much of the area to the west and north of the storm was partly cloudy, so the real-time temperature and water vapor profile retrievals were rarely reaching the surface. To the southeast of the storm, the area was quite clear, and the retrieved humidity profile shows moderate moisture levels (~50% RH) to 600 hPa. Figure 1 shows the RH cross section east of the storm, between eye passes 6 and 7.

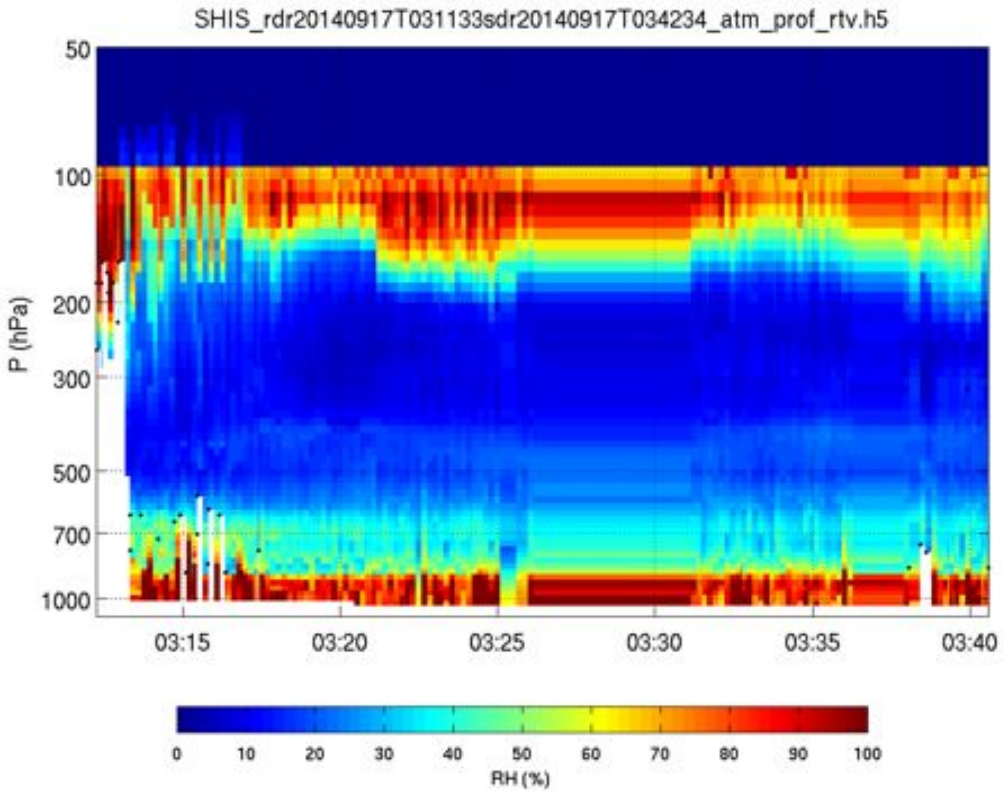


Figure 2. RH cross section to the east of Edouard.

Nine eye overpasses were completed, spanning 14 hours. During the eye approaches, the S-HIS data was used in concert with CPL to help determine when the aircraft passed over the eyewall to help time the dropsonde release. To minimize latency, there is now a text file (~shis/ctt_stars.txt) containing an ASCII representation of 900 cm^{-1} brightness temperature in degrees above 200K can be followed on dreadnaught. The brightness temperature swath display was also used to help evaluate the track positioning for each path after each crossing. Figure 3 shows a summary of eye passes with a 200 – 300 K display range. This summary collage plot clearly shows the storm track. The final two overpasses were separated by less time than the previous ones, resulting in the eighth being obscured. The eye shows varying degrees of cloud cover throughout the flight.

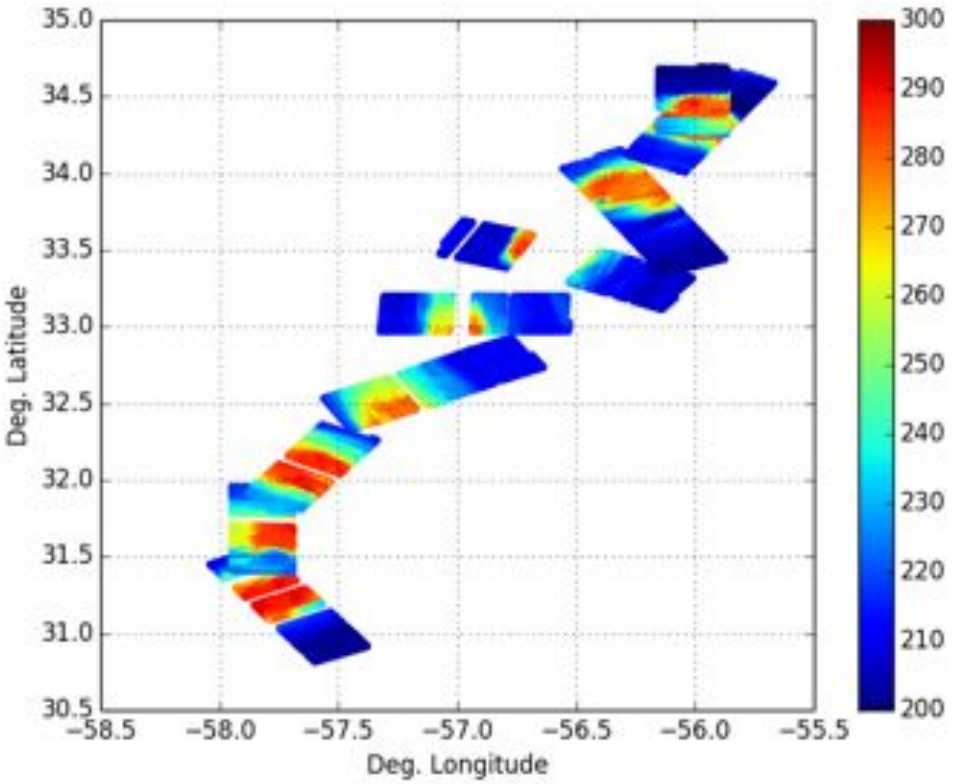


Figure 3. Collage of 9 eye passes as seen in the S-HIS 900 cm^{-1} swath.

S-HIS profile retrieval penetration was limited outside of the eye. The relative humidity profile in the eye depict dry mid-levels, saturating below 500-600 hPa (figure 4). Eye structure was also visible in the dual-regression cloud top retrieval. The character of the cloud layers within the eye differed from what was seen in CPL, however. Figure 5 shows RT-DR detecting predominantly high clouds, distinct from the primary CPL layer returns at 1.5 km. A high cloud layer (obscured in the presented CPL image) was present for this transect, possibly complicating the retrieval.

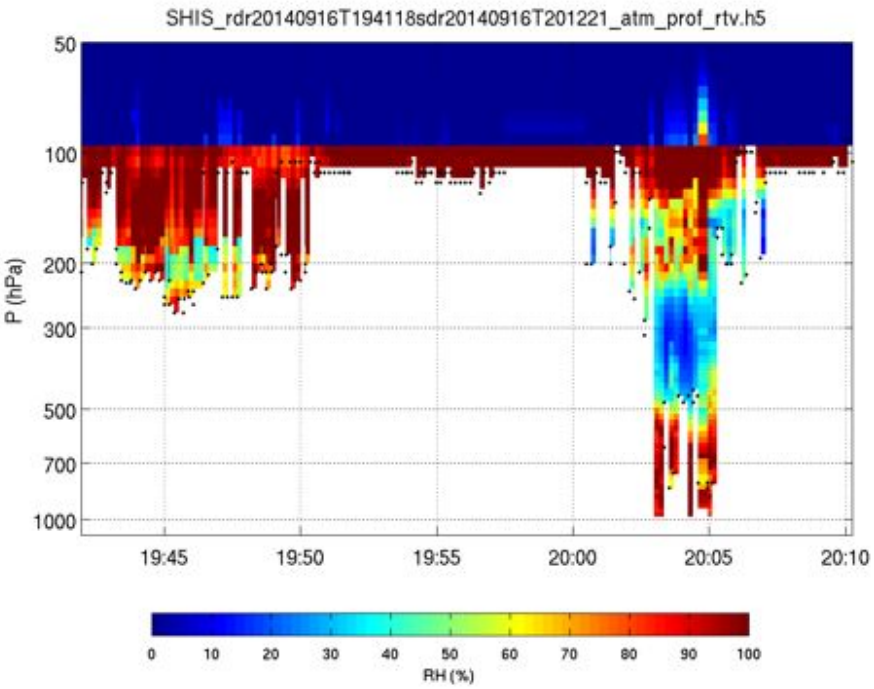


Fig 4. S-HIS relative humidity profile retrieval during the third eye transect.

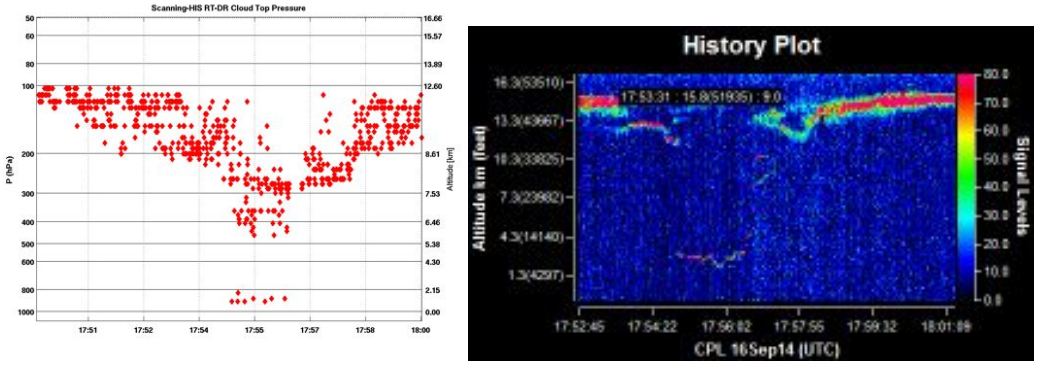


Fig. 5. S-HIS RT-DR cloud top retrieval (left) and CPL backscatter (right) during the second Edouard eye transect.

Agreement between the dropsondes and S-HIS varied. Dropsonde temperatures were consistently warmer than S-HIS by a few degrees, which was in turn warmer than GDAS, particularly at the upper levels. Figure 6 shows poor agreement during transect 4, which crossed to the NW of the eye center. Surface winds remained below 15 knots, indicating that it did not cross the eyewall. The transect 9 dropsonde was released much closer to the center but still had differed. The horizontal heterogeneity

found in an environment as complex as a hurricane eye makes these discrepancies unsurprising; sonde measurements of the lower troposphere occurred more than ten minutes after the S-HIS and cannot bas assumed to be the same air mass.

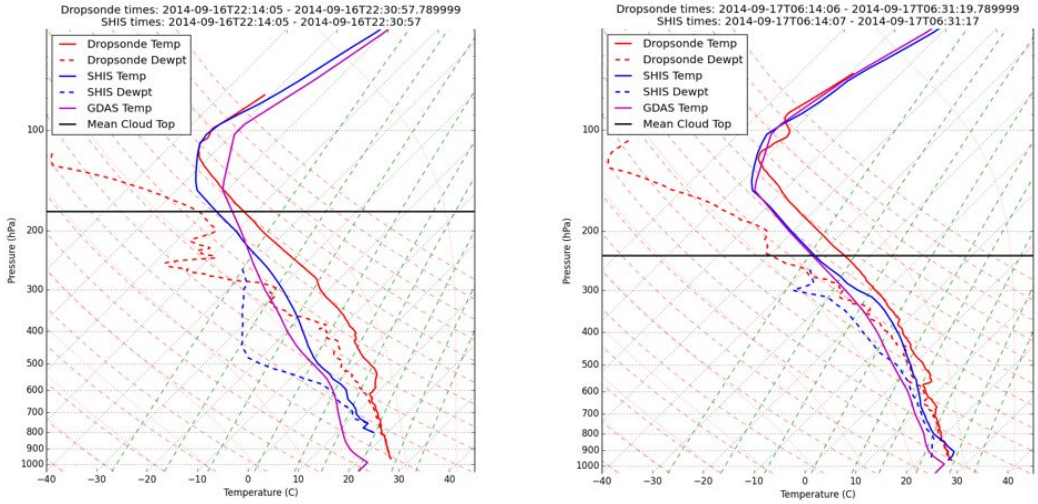


Fig. 6. Comparison between dropsonde, S-HIS, and GDAS profiles for transects 4 (left) and 9 (right).

Instrument Summary

The instrument was power cycled between 1423 and back online at 1440 UTC, about an hour before the first science waypoint. After the cycle the cooler remained in full stroke, high current mode for the remainder of the flight. However, the temperature did not increase at a rate requiring further intervention, peaking around 79. A rapid detector temperature drop can be observed at around 0200 UTC.

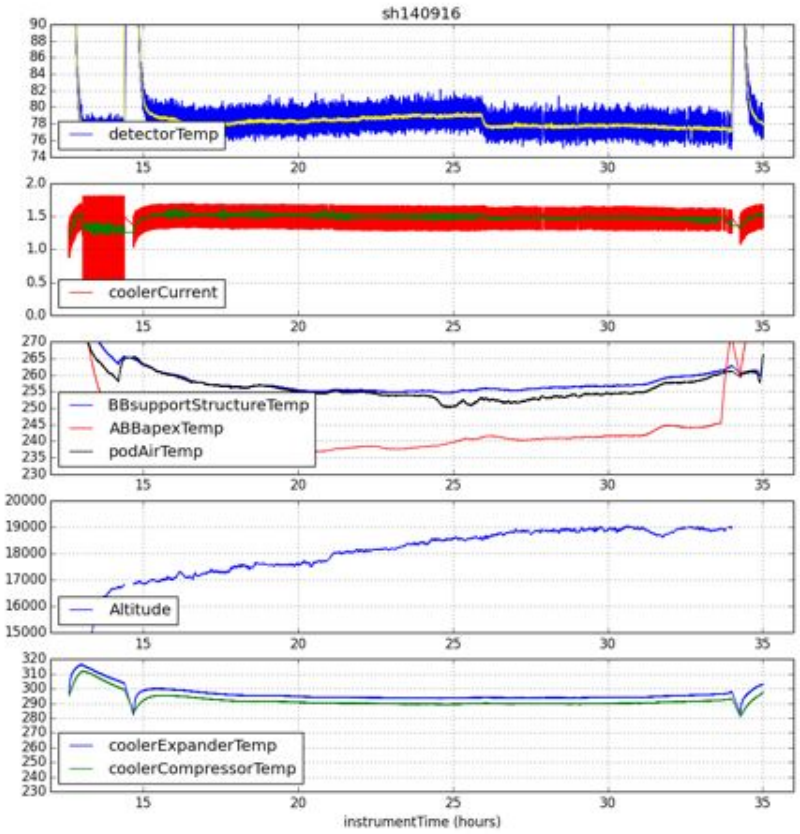


Fig 7. Flight summary for cooler behavior.

Timeline (All times UTC and approximate)

- 1126 GH engine start
- 1220 Ku ON and transmitting
- 1235 IL41 ON (SHIS Power)
- 1240 Takeoff
- 1303 Detectors cooled
- 1423 IL 41 Off, DC41 Off, DC42 Off for deep power cycle for cooler reset
- 1440 DC41/DC42/IL41 On
- 1451 Edouard upgraded to CAT3 Hurricane
- 1603 1st eye overpass
- 1756 2nd eye overpass
- 2005 3rd eye overpass. Within 25mi of NOAA P3, so no drops
- 2215 4th eye overpass
- 0029 5th eye pass
- 0242 6th eye pass
- 0429 7th eye pass

- 0536 8th eye pass
- 0614 9th eye pass
- 0827 Sonde #88 - Final Sonde
- 0941 IL42 ON (Descent heaters)
- 1000 Instrument power OFF before descent (IL42, IL41, DC42, DC41)
- 1015 Instrument power ON (DC41, DC42, IL41, IL42)
- 1100 Instrument power OFF (DC41, DC42, IL41, IL42)
- 1121 Landing

CPL

CPL performance was about identical to Flight #6, all data was captured, but we still had the 1064 ringing from strong ground returns. We had tried to reduce the laser power to see if this would reduce or alleviate the problem, but it apparently had little if any effect. These data have been processed and are on the cpl web site. For Science Flight #8, we reduced the laser power a bit more in an effort to fix the 1064 ringing problem. Data Start: 12:08 UTC 9/16; Data End: 09:49 UTC 9/17.

A nice 1064 image of Edouard's eye is attached.
Note that over the storm 1064 is fine, no ringing is seen.