Recent Progress in Tropical Cyclone Intensity Change Through Aircraft Field Campaigns





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EXperiment on Typhoon Intensity Change in Coastal Areas (EXOTICCA)
9 Oct, 2015
Shanghai, China

Intensity Forecast Experiment (IFEX)

Observing platforms and instruments

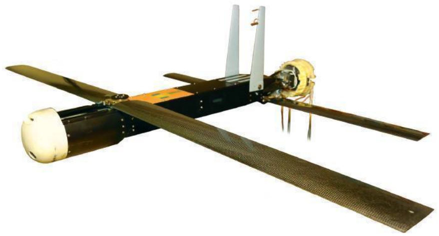
- **In-situ**
  - Wind, press., temp.

- **Expendables**
  - Dropsondes
  - AXBT, AXCP, buoy

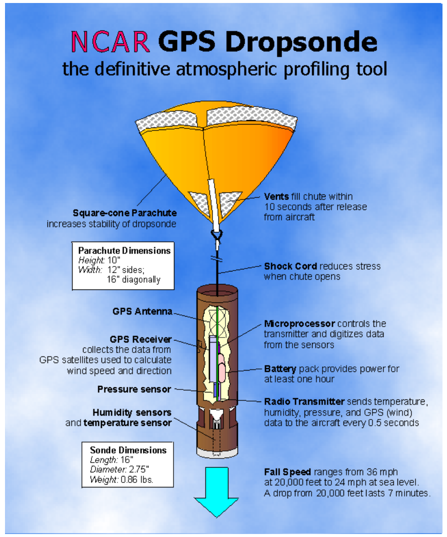
- **Remote Sensors**
  - Tail Doppler Radar(TDR)
  - SFMR/HIRAD
  - WSRA
  - Scatterometer/profiler
  - UAS

NASA Global Hawk

G-IV Tail Doppler Radar



Coyote UAS



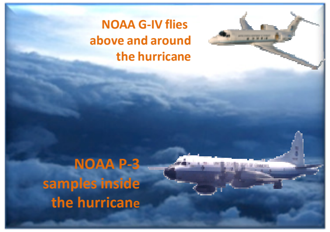
GPS Dropsonde

Doppler Wind Lidar

EXPERIMENTS- NOAA-HRD IFEX(2010-20)
Atmospheric/ Oceanic Measurement Systems

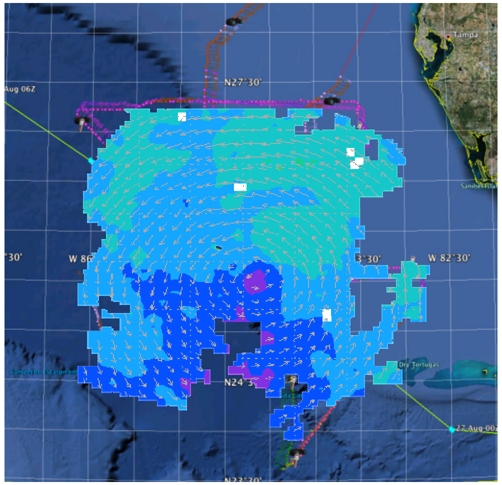
1. WP-3D
   a. Tail Doppler Radar (TDR)
   b. Doppler Wind LIDAR (DWL)
   c. Stepped Frequency Microwave Radiometer (SFMR)
   d. Imaging Wind and Rain Profiler (IWRAP- scatterometer/ Doppler profiler)
   e. Vaisala RD-94 dropsonde Advanced Vertical Atmospheric Profiling System (AVAPS)
   f. COYOTE mini-UAV deployment
   g. AXBT, AXCTD, AXCTD ocean profiling system
   h. ALAMO continuous ocean float deployment
2. G-IV
   a. Vaisala RD-94/ EOL mini-dropsonde Advanced Vertical Atmospheric Profiling System
   b. High-Altitude Tail Doppler Radar (TDR)
   c. Narrow-Beam, High-Altitude Stepped Frequency Microwave Radiometer (SFMR)

IFEX Goal 1: Assimilation of data into models

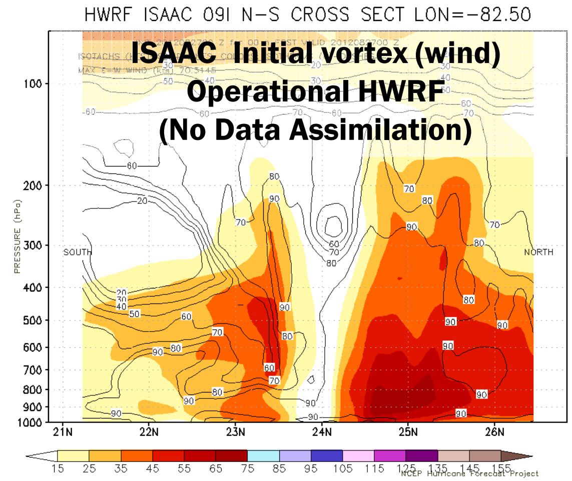


Impact Of Aircraft Observations On HWRF Forecast

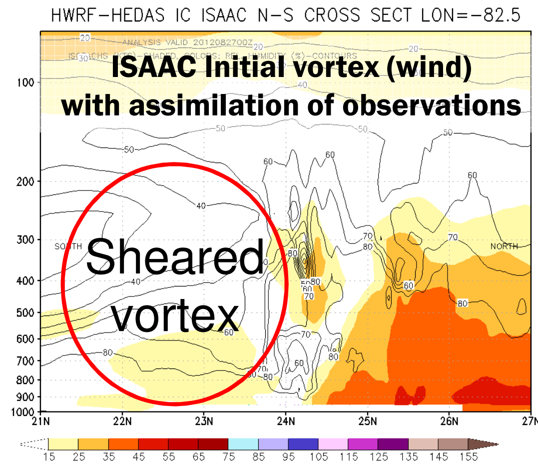
- Improving Storm Structure At Initial Time -



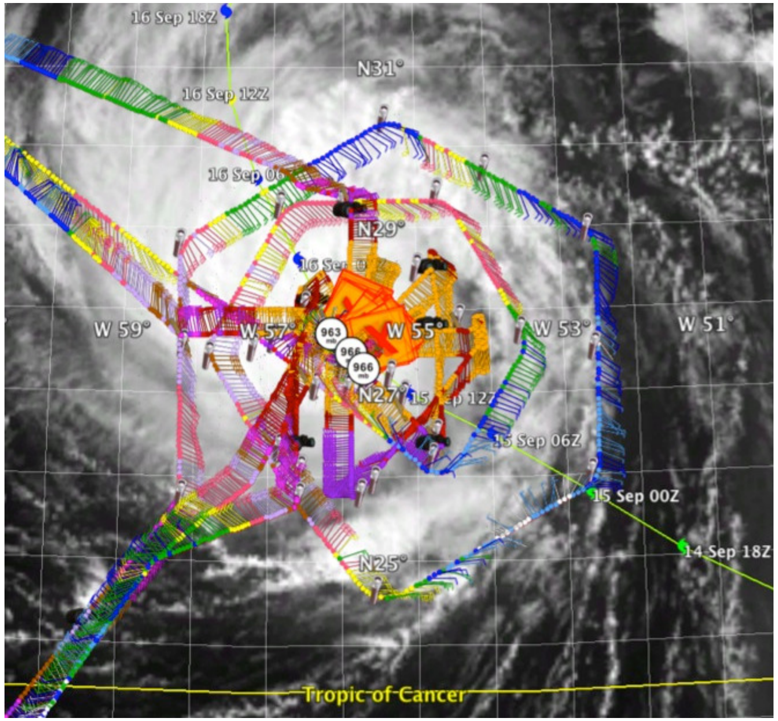
The Hurricane Research Division of AOML developed a state-of the-art inner core data assimilation system for HWRF (HEDAS)
[Runs in real-time under HFIP]



ISAAC (2012): Intensity Errors (kt)				
Forecast Hrs	12	24	36	48
Operational HWRF	13	16	26	26
With P-3 Data	8	3	9	20
# Cases	9	7	5	3

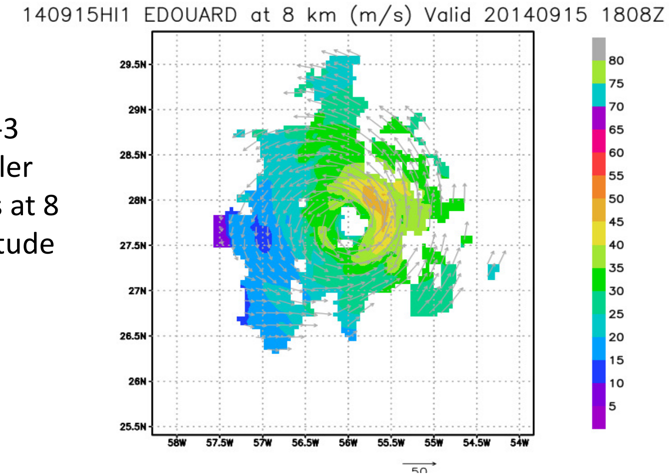


IFEX Goal 2: Develop & refine observing technologies: G-IV TDR

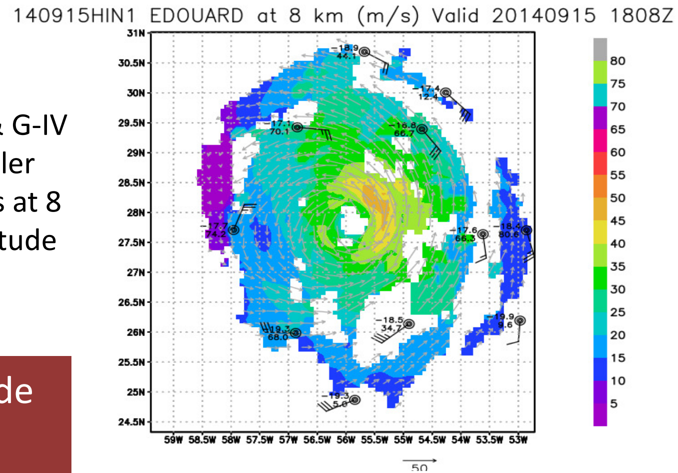


- 2 P-3 and G-IV flight track in Hurricane Edouard 15 September 2014

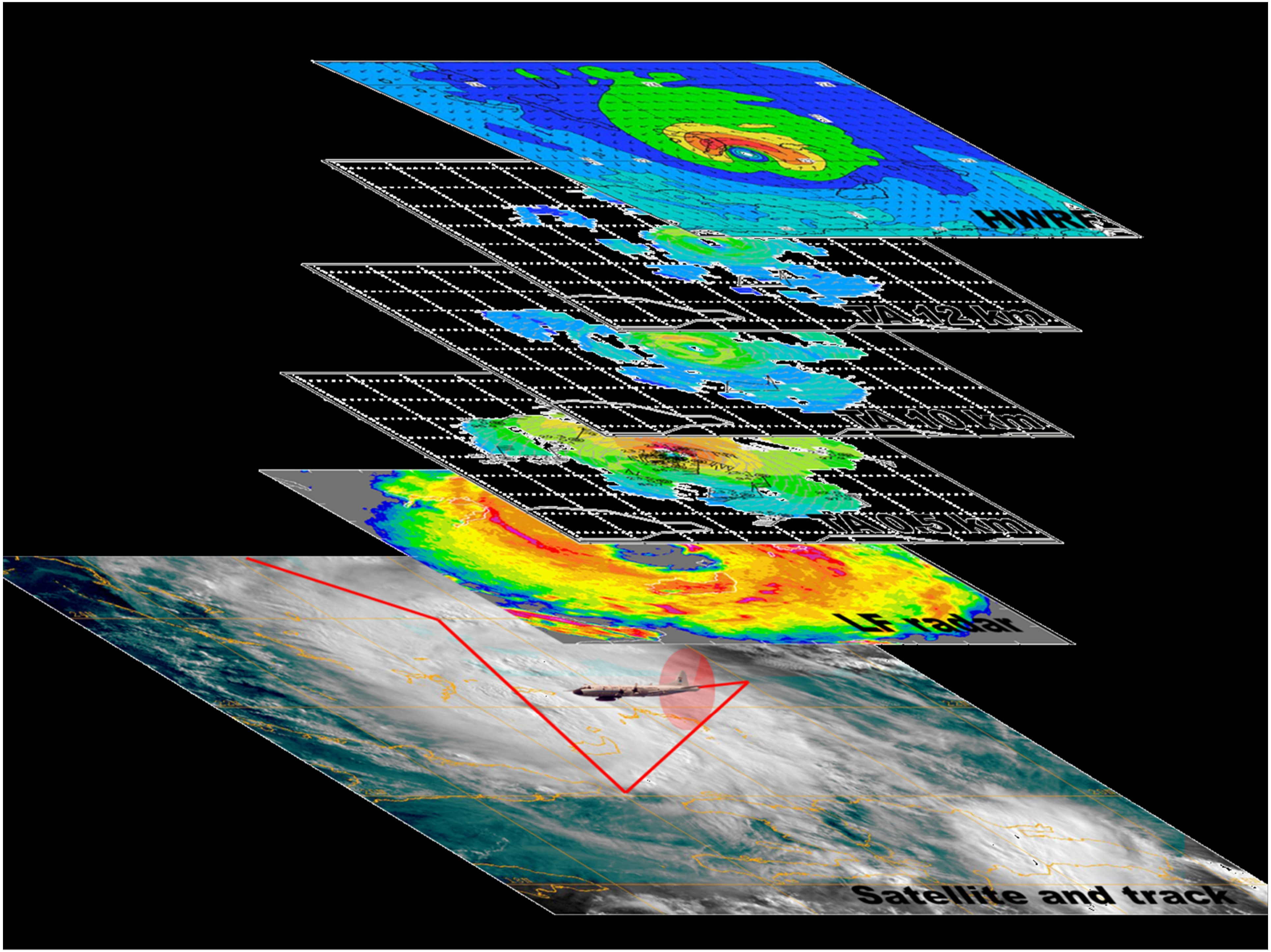
•2 P-3 Doppler analysis at 8 km altitude



•2 P-3 & G-IV Doppler analysis at 8 km altitude



• G-IV Doppler can provide enhanced coverage, especially at higher altitude
• G-IV can be flown further from center to sample environment and supplement P-3, or closer to center to "replace" P-3


HWRF
TA 12 km
TA 10 km
TA 0.5 km
LF radar
Satellite and track

EXPERIMENTS: NASA HS3*(2012-14) ONR TCI**(2014-15) NOAA SHOUT***(2015-16) Atmospheric/ Oceanic Measurement Systems

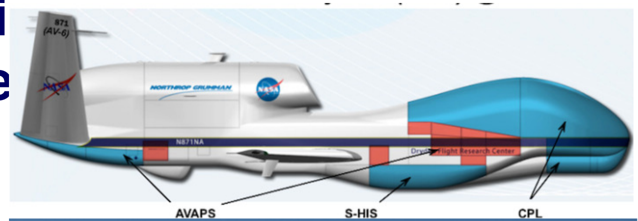
1. NASA GLOBAL HAWK UAV
   a. HAMSR
   b. Cloud Physics LIDAR (CPL)
   c. S-HIS
   d. HIWRAP
   e. EOL mini-dropsonde Advanced Vertical Atmospheric Profiling System (AVAPS3)

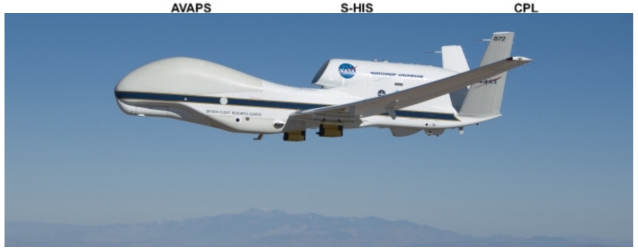
2. NASA WB-57
   a. High-Definition Sounding System (HDSS) for eXpendable Digital Dropsonds (XDDs) for SST and rapid-release atmospheric profiling
   b. Hurricane Imaging RADiometer (HIRAD)

*HS3- Hurricane and Severe Storms Sentinel
**TCI- Tropical Cyclone Intensity
***SHOUT- Sensing Hazards with Operational Unmanned Technology

NASA Hurricane and Severe Storm Sentinel (HS3):

- Science Goal: To understand hurricane genesi and intensification. NRL focused on hurricane outflow, dynamics, and predictability.
- 5-week deployments in hurricane seasons of 2012-2014 using two Global Hawks.
- Operational Implementation (SHOUT)





ONR Tropical Cyclone Intensity (TCI):

- Science Goal: To understand hurricane outflow dynamics and relationship to intensity.
- Deployments in hurricane seasons of 2014-2015 using NASA WB-57 research aircraft.

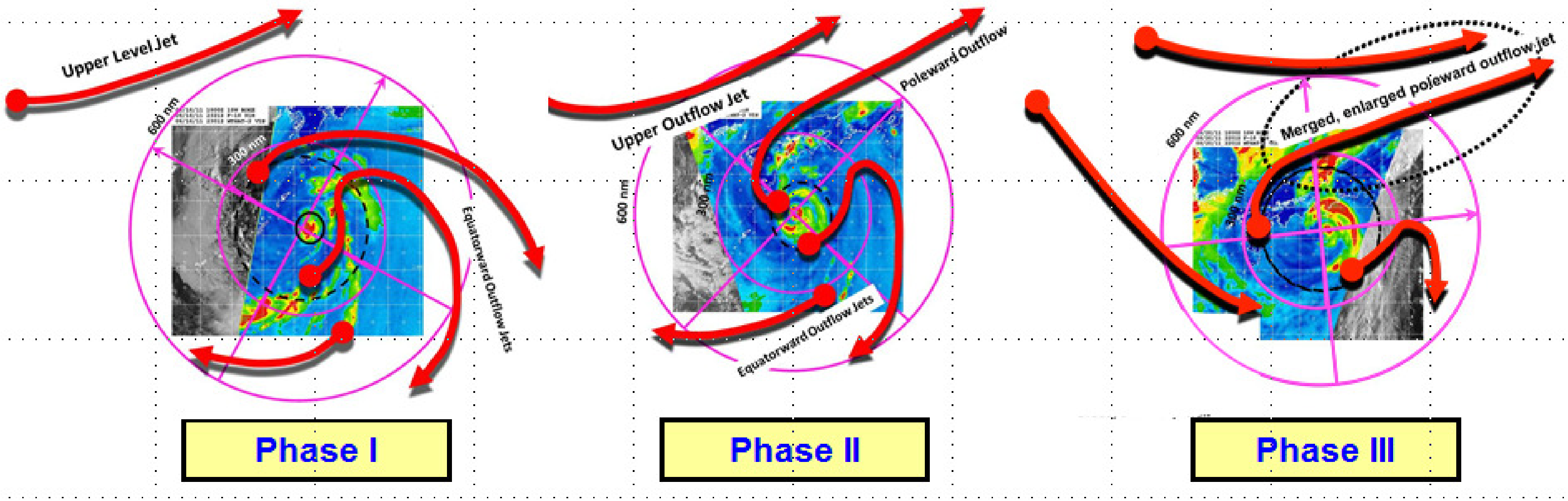
High Definition Sounding System (HDSS):

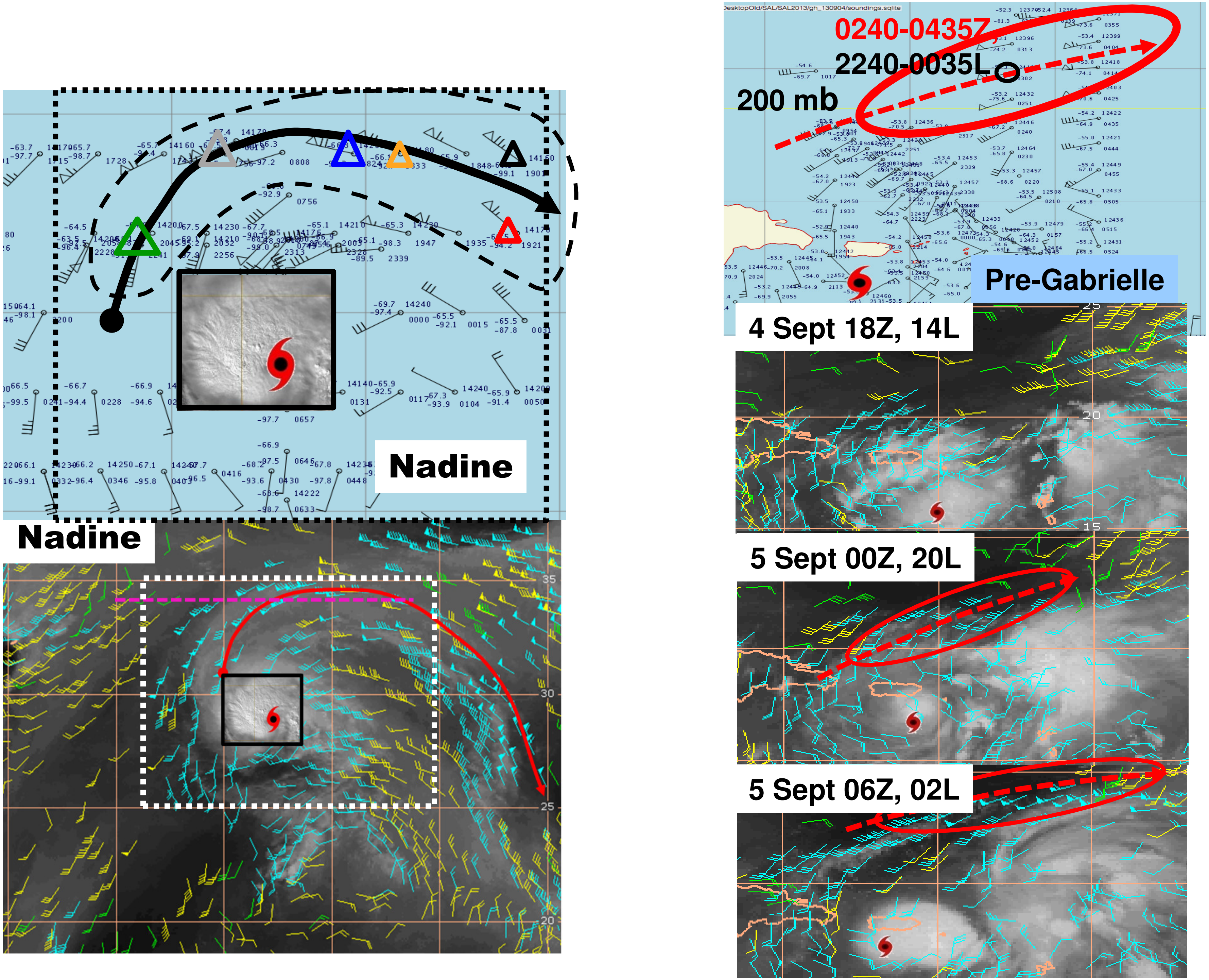
- Innovative eXpendable Digital Dropsonde (XDD) atmospheric profiling system (YES, Inc.)
- Profiles of pressure, temp., RH, winds, SST
- Capable of rapid sonde deployment (50+)

HYPOTHESIS

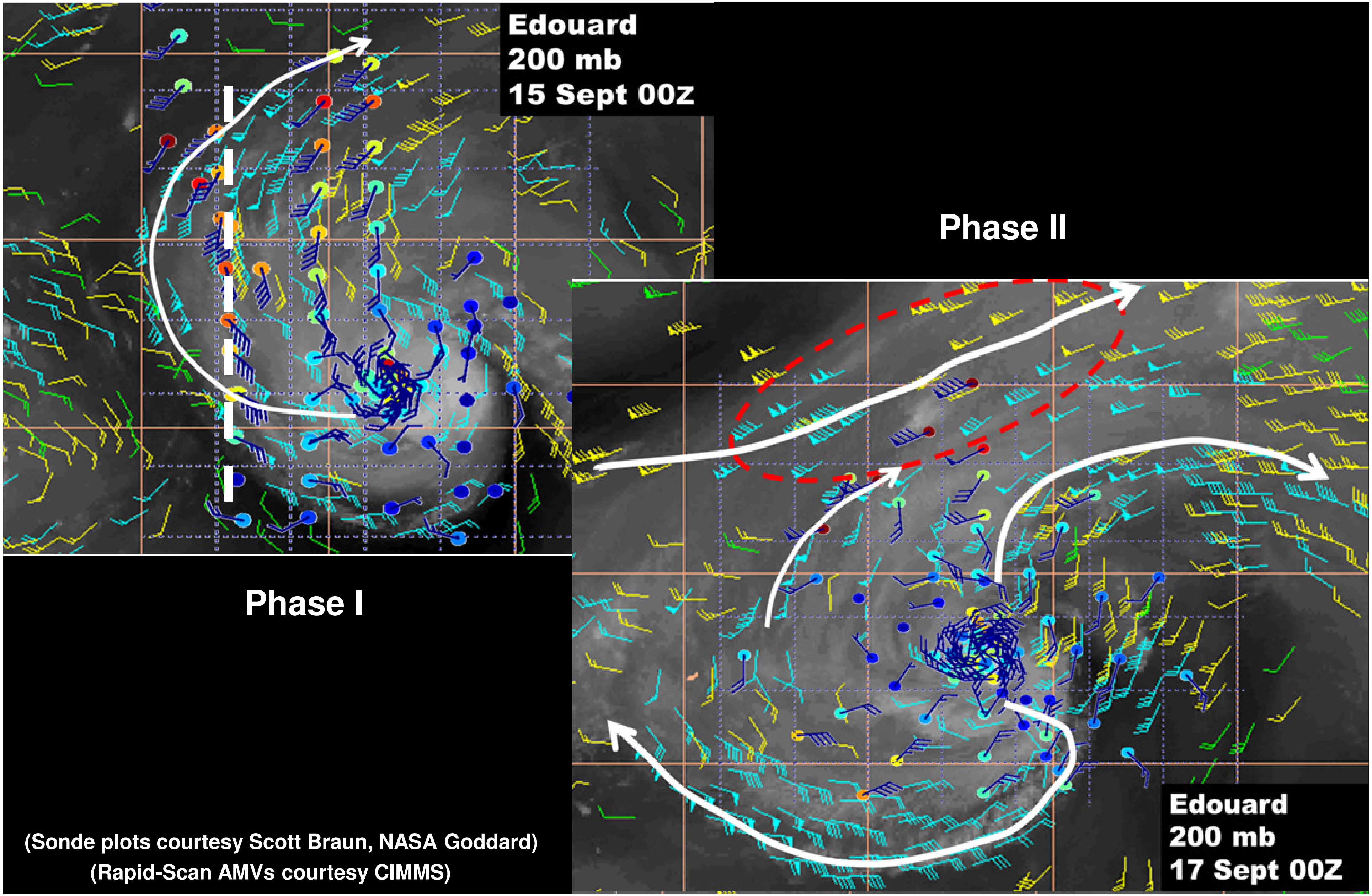
TC Life Cycle, including Rapid Intensification (RI) and Rapid Decay (RD), is associated with environmentally-forced and inner-core convectively-forced outflow jet evolution:

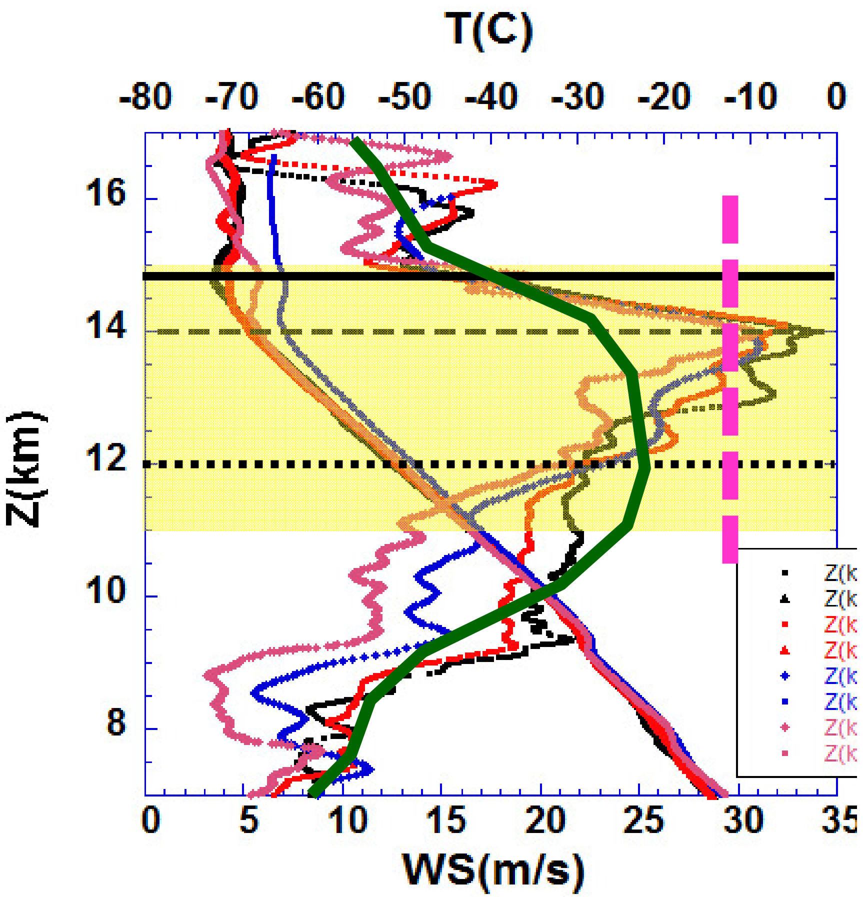
I. **TC development- Single Equatorward-directed Jet**
II. **Intensification and RI: Dual Equatorward and Poleward Jets**
III. **Mature & decay (ET): Primarily, single Poleward-directed Jet**



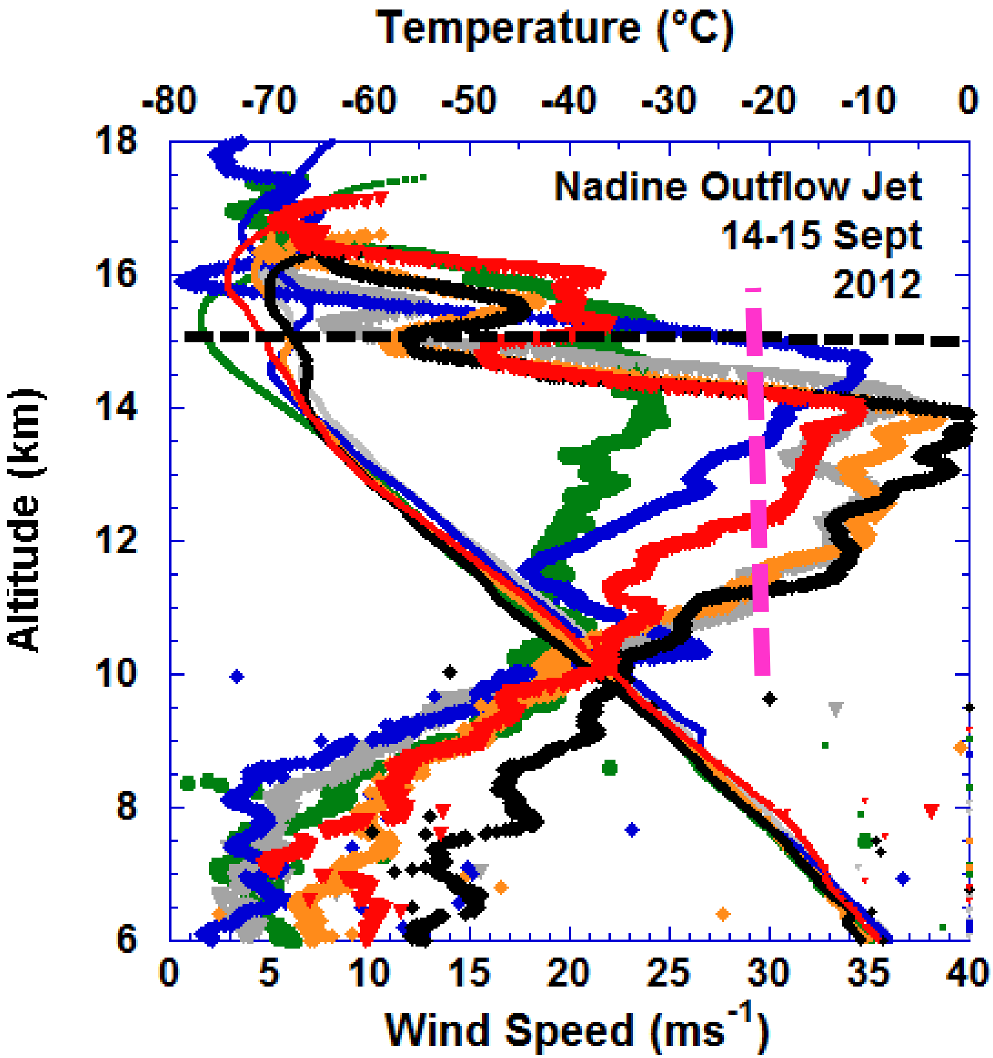


Nadine
Nadine
0240-0435Z
2240-0035L
200 mb
Pre-Gabrielle
4 Sept 18Z, 14L
5 Sept 00Z, 20L
5 Sept 06Z, 02L


Edouard
200 mb
15 Sept 00z
Phase II
Phase I
Edouard
200 mb
17 Sept 00Z
(Sonde plots courtesy Scott Braun, NASA Goddard)
(Rapid-Scan AMVs courtesy CIMMS)



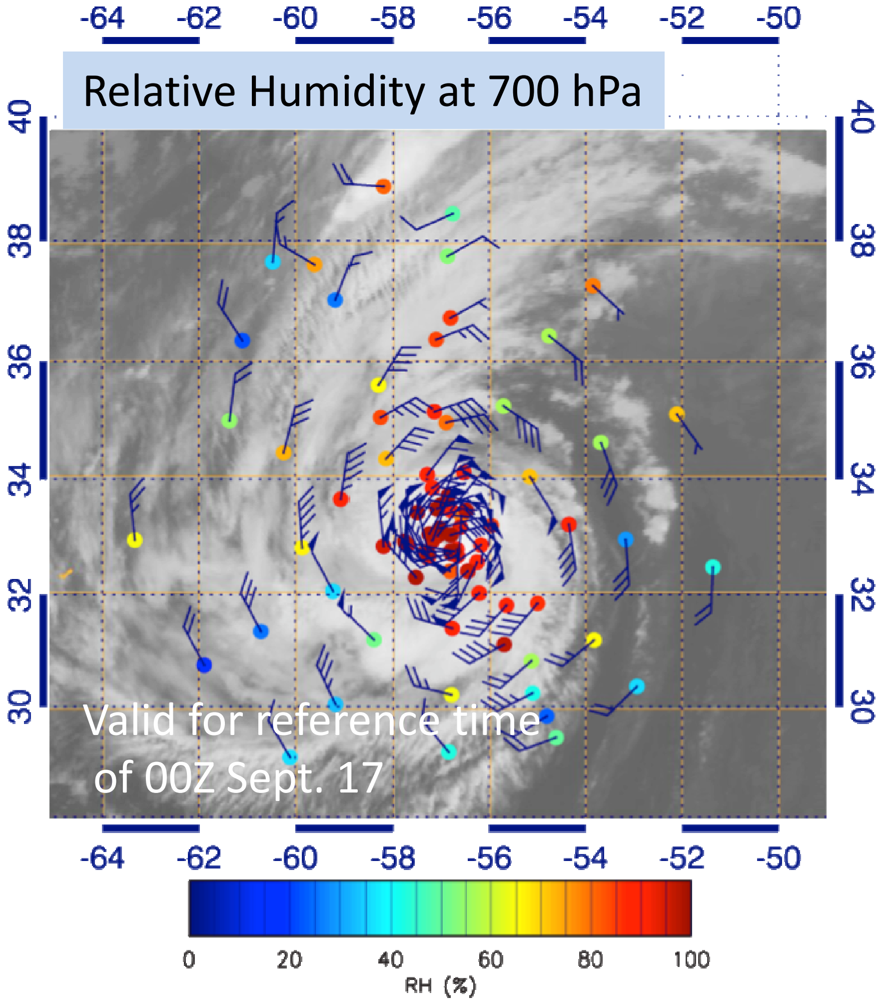
Leslie, 2010

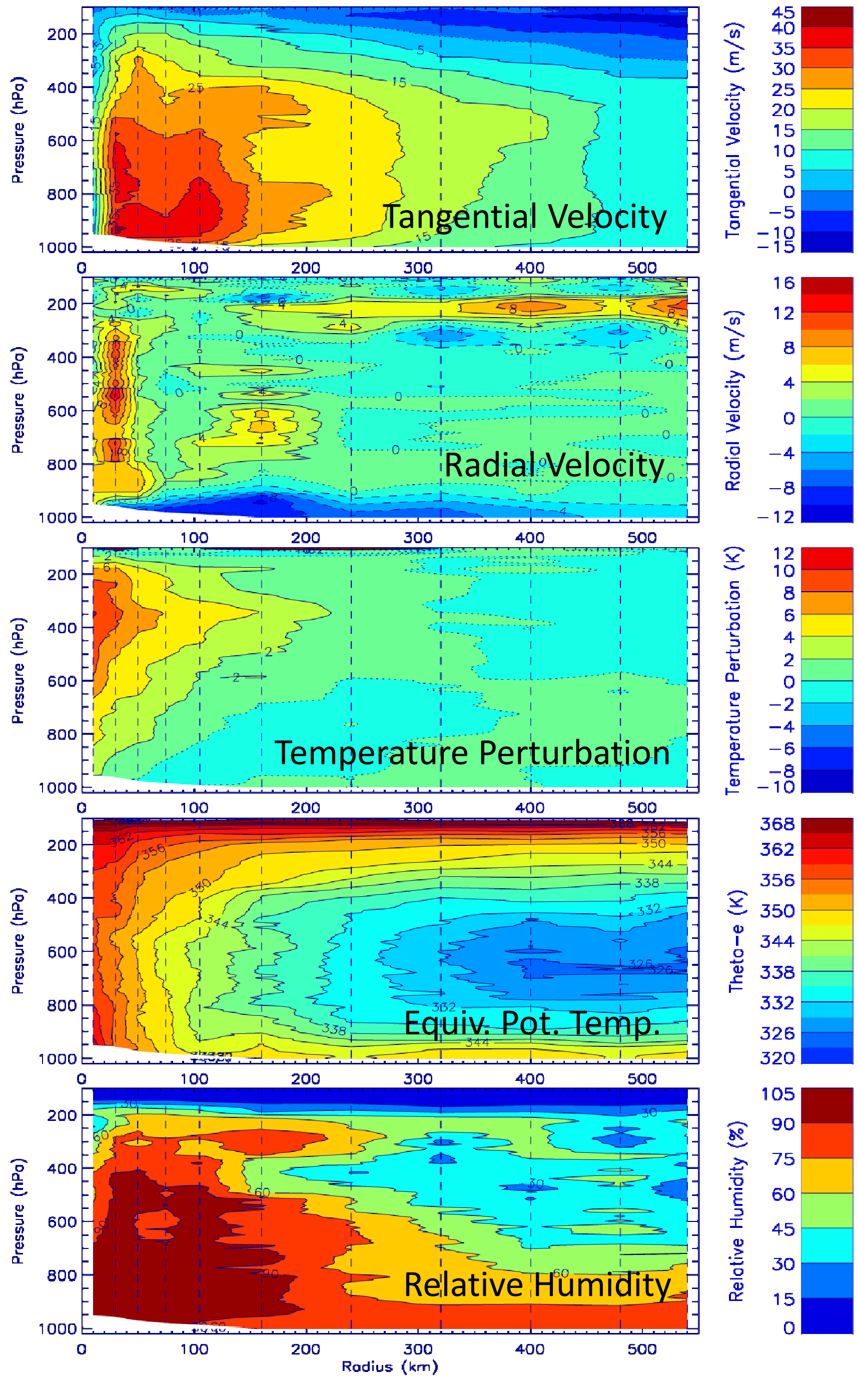


Nadine, 2010

Composite Structure At Peak Intensity

Hurricane Edouard on September 16-17





NOAA SHOUT 2015

•**GOAL**: Test prototype UAS concept of operations that could mitigate the risk of diminished high impact weather warnings in case of polar-orbiting satellite observing gaps

•Global Hawk

•Flight level: ~55-60,000 ft

•Duration: ~24 h

•Range: 11,000 nm

•Payload: 1500+ lbs

•Deployment site: NASA Wallops

•5 week deployment (late Aug through Sep)

•Instrumentation: AVAPS, HAMSR, & HIWRAP

•One successful storm flight in 2015 (due to El Nino effects)

•Extend project into 2016

XDD FACT SHEET

XDD SODA AVAPS RD-94

Observables

- Temperature
- Humidity
- Pressure/ altitude
- Wind speed/ direction
- Vertical velocity
- Sea Surface Temperature
- Photo documentation
- Dual fall speeds:
  - Fast/ ballistic: 11min to splash
  - Slow/ spiral dive: 18 min to splash

Physical Specifications

Weight: 58.0 g (2.0 oz)
Diameter: 6.6 cm (2.6 in)
Length: 17.8 cm (7.0 in)
No parachute

Comparisons

SODA can (full):
Weight: 340 g (12 oz)
Diameter: 6.4 cm (2.5 in)
Length: 12.1 cm (4.75 in)

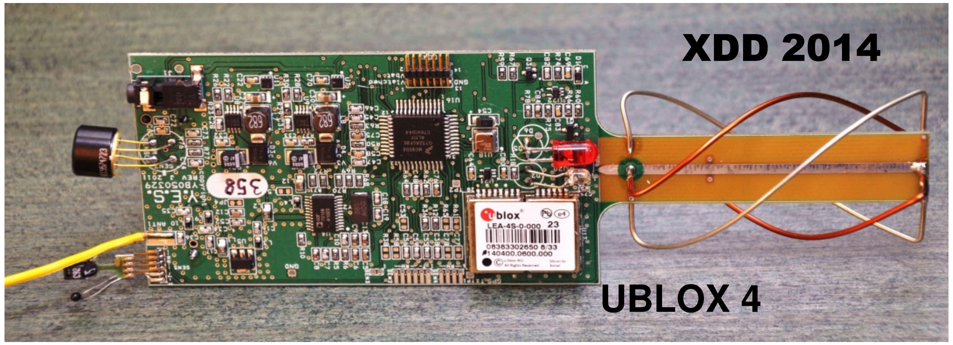
RD-94
Weight: 320 g (11.3 oz)
Diameter: 7.0 cm (2.75 in)
Length: 40.5 cm (15.9 in)
12” square cone parachute

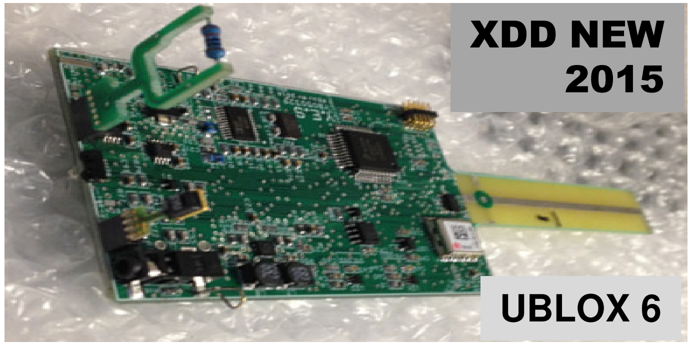
AVAPS Mini
Weight: 165 g (5.8 oz)
Diameter: 4.7 cm (1.8 in)
Length: 30.5 cm (12.0 in)
8” square cone parachute

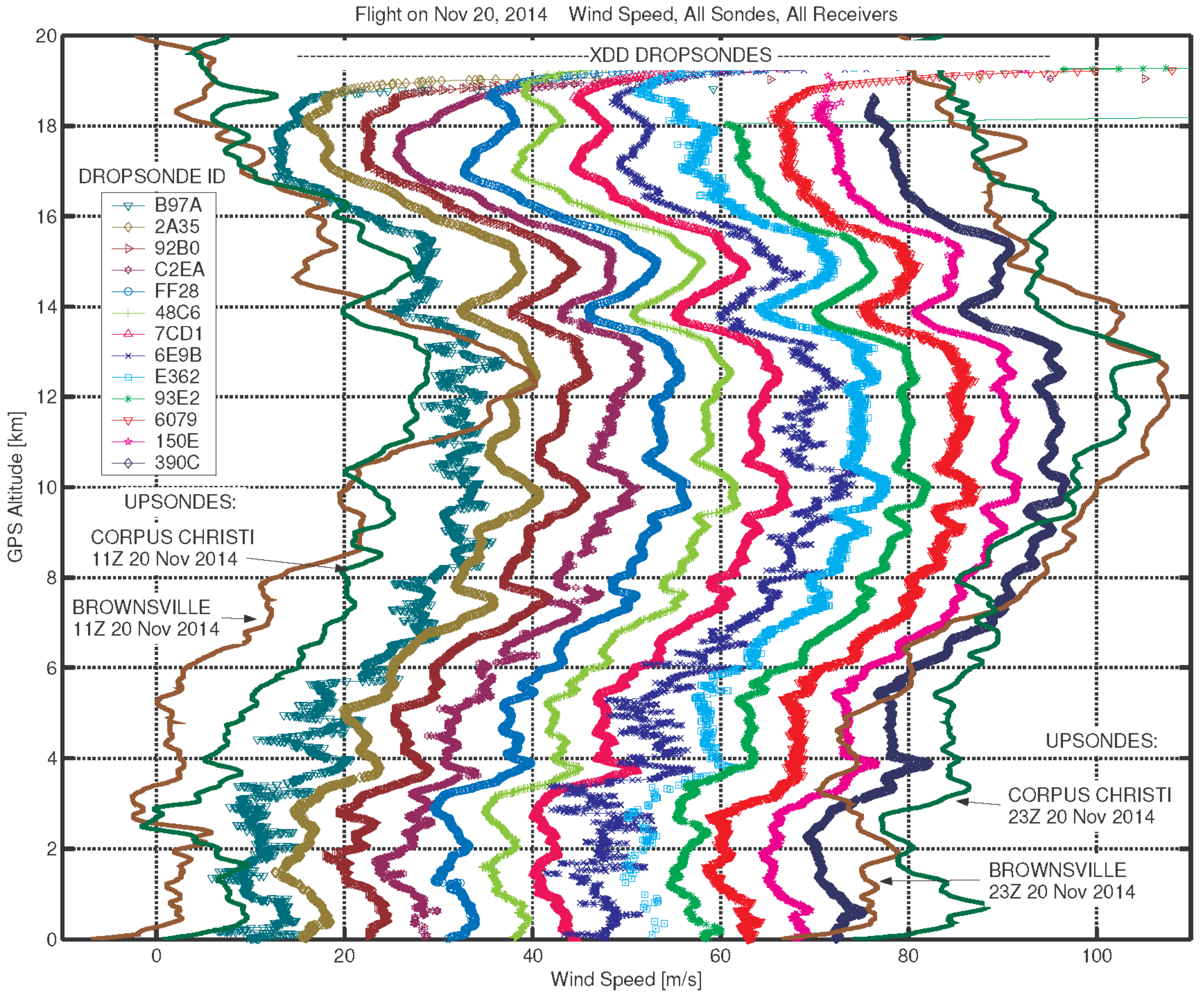
HDSS- Why so special?

1. 2 Automatic Dropsonde Dispensers (ADDs)
2. 2 receivers per ADD- 4 receivers total, 2 redundant backup
3. 4 antennas on WB-57
    a. 2 antennas on belly pallet
    b. 1 antenna on each wing tip
4. 5 Channels per receiver
5. 8 XDD's per CH
6. 2x2x5x8 = 160 XDD signals (<u>80 XDDs: 100% redundancy</u>)
7. 1 CPU per CH = 10 CPUs for gain adjustment (volumn control)
8. Minisonde: 8 receivers x 1 sonde/receiver = <u>8 sondes, 0% redundancy</u>

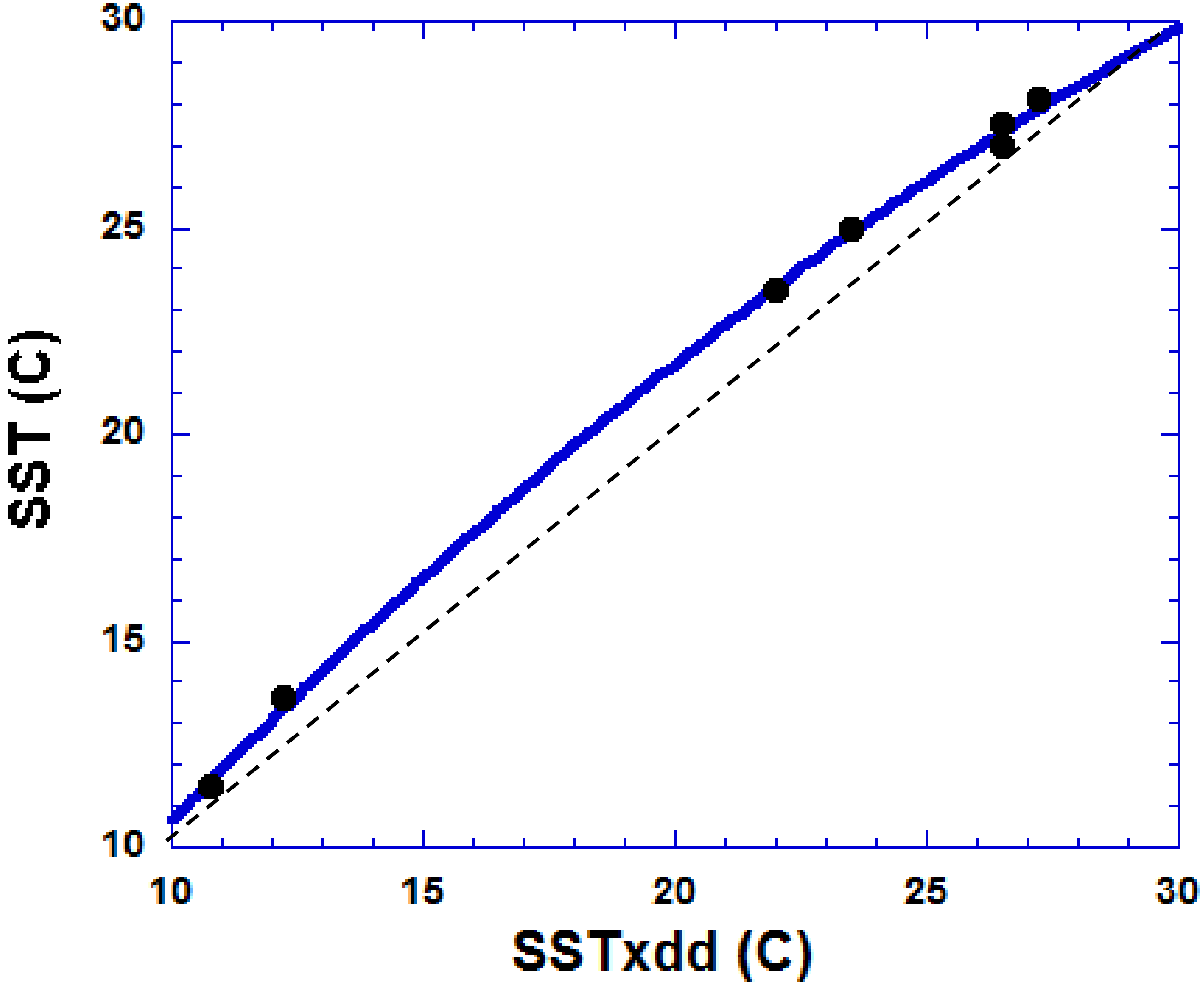
BOTTOM LINE: REVOLUTION IN SONDE DESIGN
New world for sampling strategies





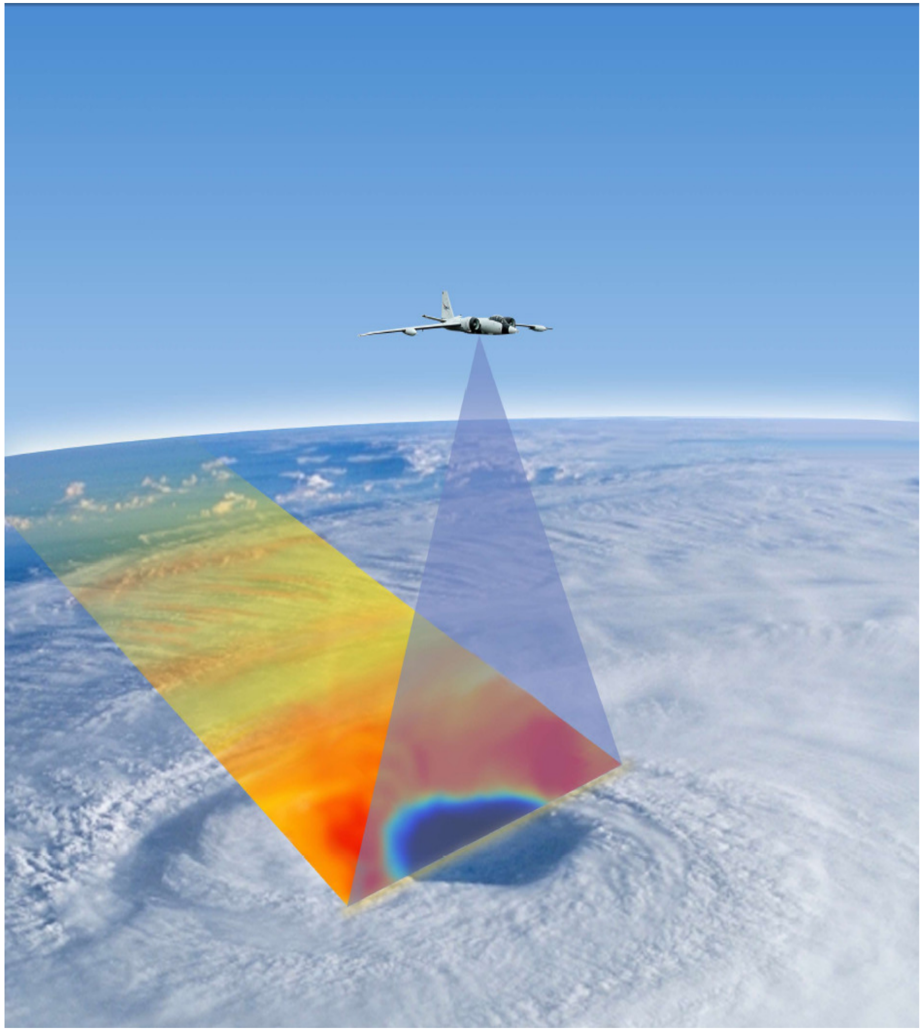


Flight on Nov 20, 2014 Wind Speed, All Sondes, All Receivers
XDD DROPSONDES
DROPSONDE ID
B97A
2A35
92B0
C2EA
FF28
48C6
7CD1
6E9B
E362
93E2
6079
150E
390C
UPSONDES:
CORPUS CHRISTI
11Z 20 Nov 2014
BROWNSVILLE
11Z 20 Nov 2014
UPSONDES:
CORPUS CHRISTI
23Z 20 Nov 2014
BROWNSVILLE
23Z 20 Nov 2014
GPS Altitude [km]
Wind Speed [m/s]
0
20
40
60
80
100
2
4
6
8
10
12
14
16
18
20


30
25
20
15
10
SST (C)
10
15
20
25
30
SSTxdd (C)

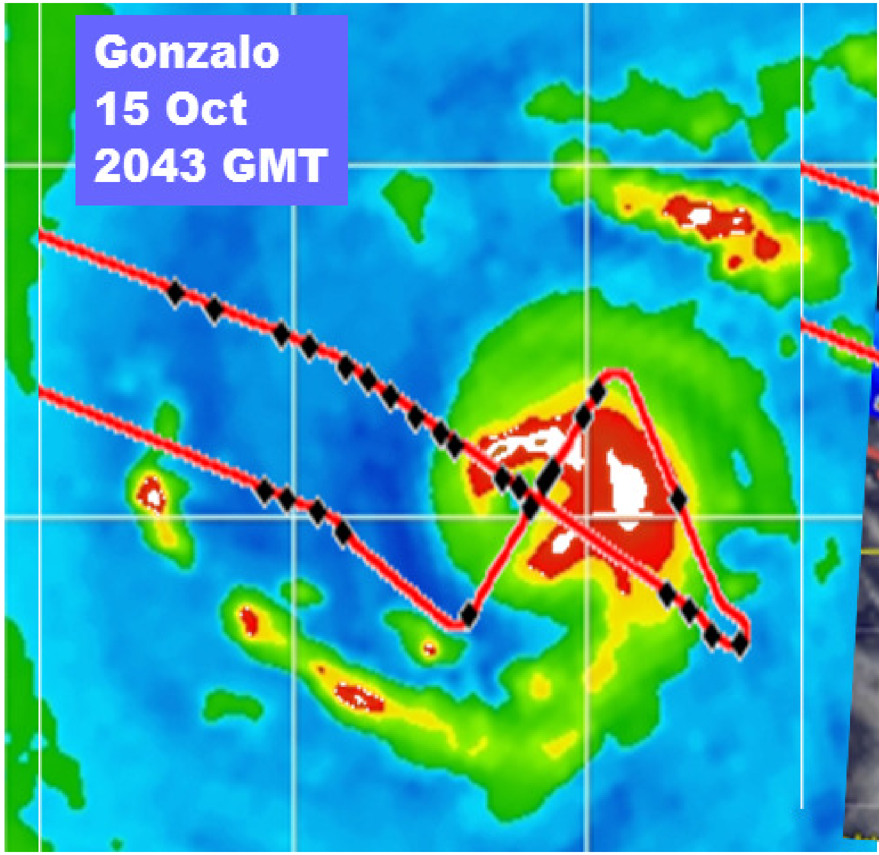
Hurricane Imaging Radiometer (HIRAD)

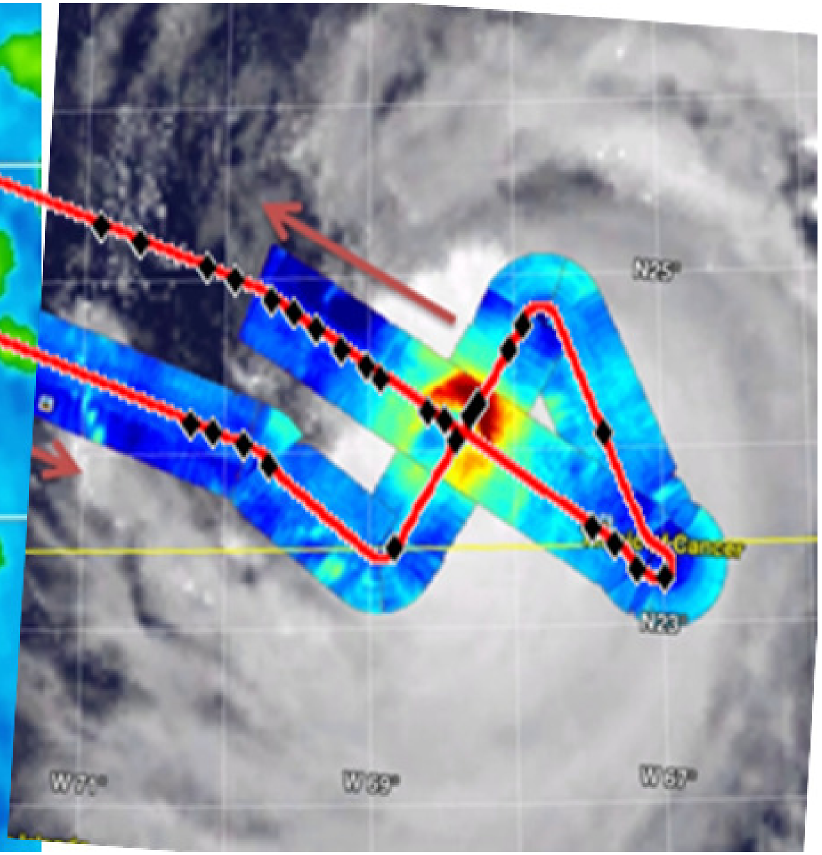
- A passive microwave radiometer (C-band, 4 frequencies), similar to SFMR: Measures emissivity and retrieves hurricane surface wind speeds and rain rates over a wide-swath:
  - Swath Width ~ 60-80 km
  - Resolution ~ 1- 5 km
  - Wind speed ~10 – 85 m/s
  - Rain rate ~ 5 – 100 mm/hr
- Synthetic Thinned Array Radiometer (*not mechanically scanning*) sees a wide swath below the aircraft
- Flight History:
- Hurricane Earl (2010 GRIP, WB-57)
- Hurricane Karl (2010 GRIP, WB-57)
- HS3 2012 Pacific Flight (AV-1)



Microwave 91GHz Tb SSMIS

HIRAD 4GHz Tb
15 Oct

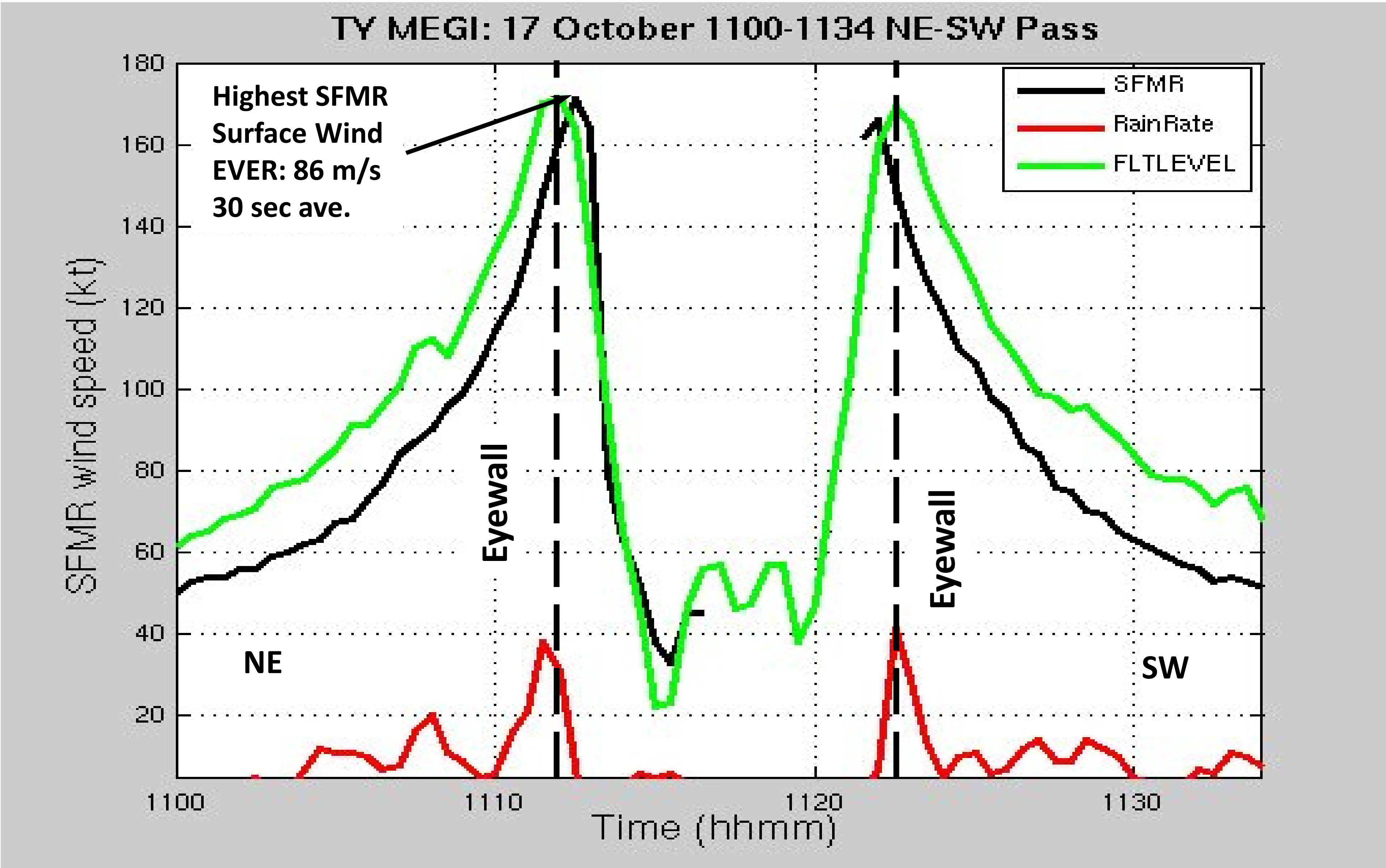




HIRAD image courtesy Dan Cecil, NASA Marshall

What is SFMR?

- **S**tepped-**F**requency **M**icrowave **R**adiometer
- Measures sea surface wind speed below aircraft
- Installed on tropical cyclone-penetrating aircraft
  - 2 NOAA WP-3D since 2004
  - 10 Air Force Reserve WC-130J since 2009
  - NOAA G-IV (currently not operational)

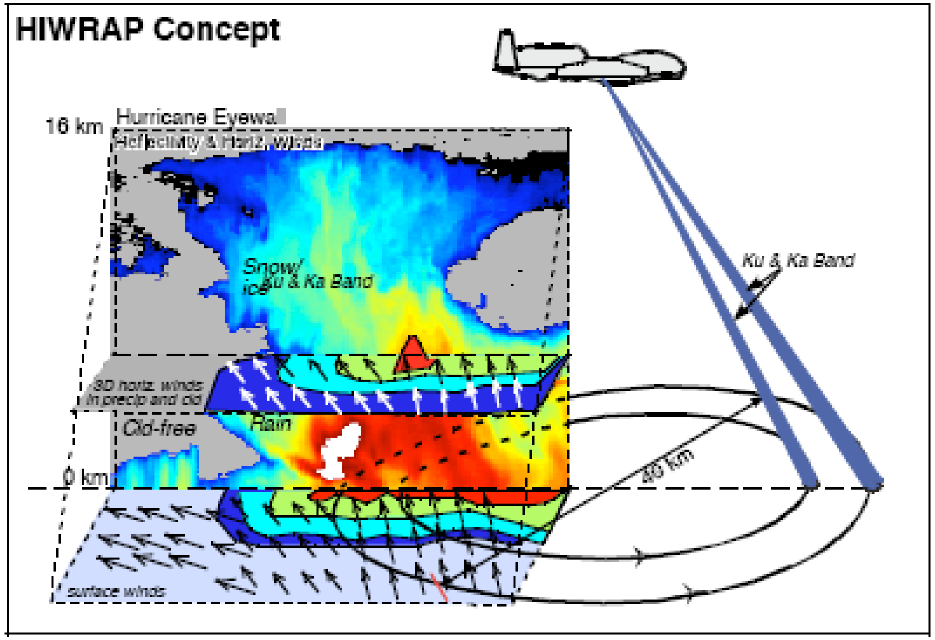

TY MEGI: 17 October 1100-1134 NE-SW Pass
Highest SFMR
Surface Wind
EVER: 86 m/s
30 sec ave.
SFMR
RainRate
FLTLEVEL
Eyewall
Eyewall
NE
SW
SFMR wind speed (kt)
Time (hhmm)
180
160
140
120
100
80
60
40
20
1100
1110
1120
1130

High-Altitude Imaging Wind and Rain Airborne Profiler (HIWRAP)

MEASUREMENTS GOALS:

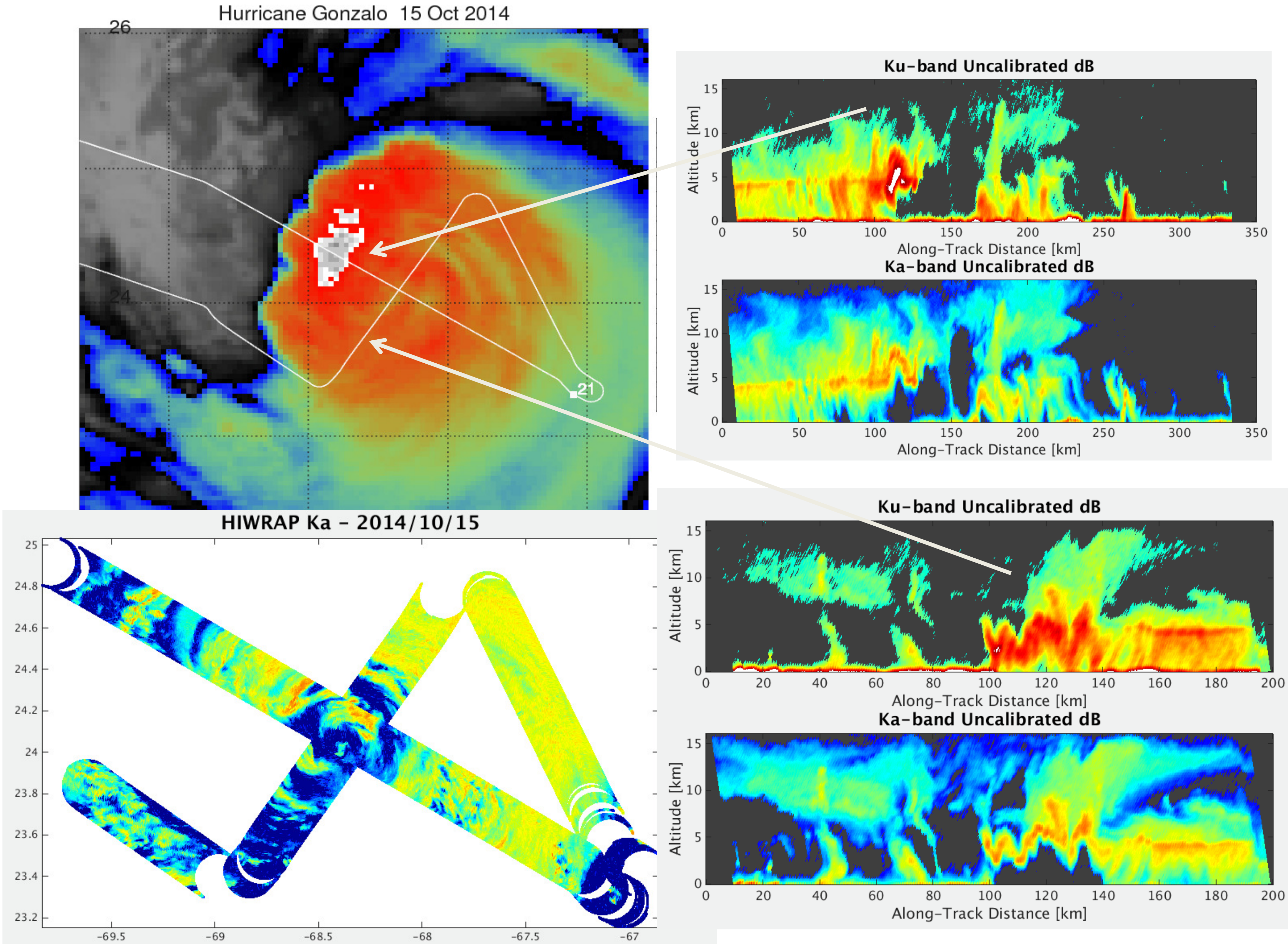
Map the 3-dimensional winds and precipitation in precipitation regions associated with tropical storms.

Map ocean surface winds in clear to light rain regions using scatterometry.



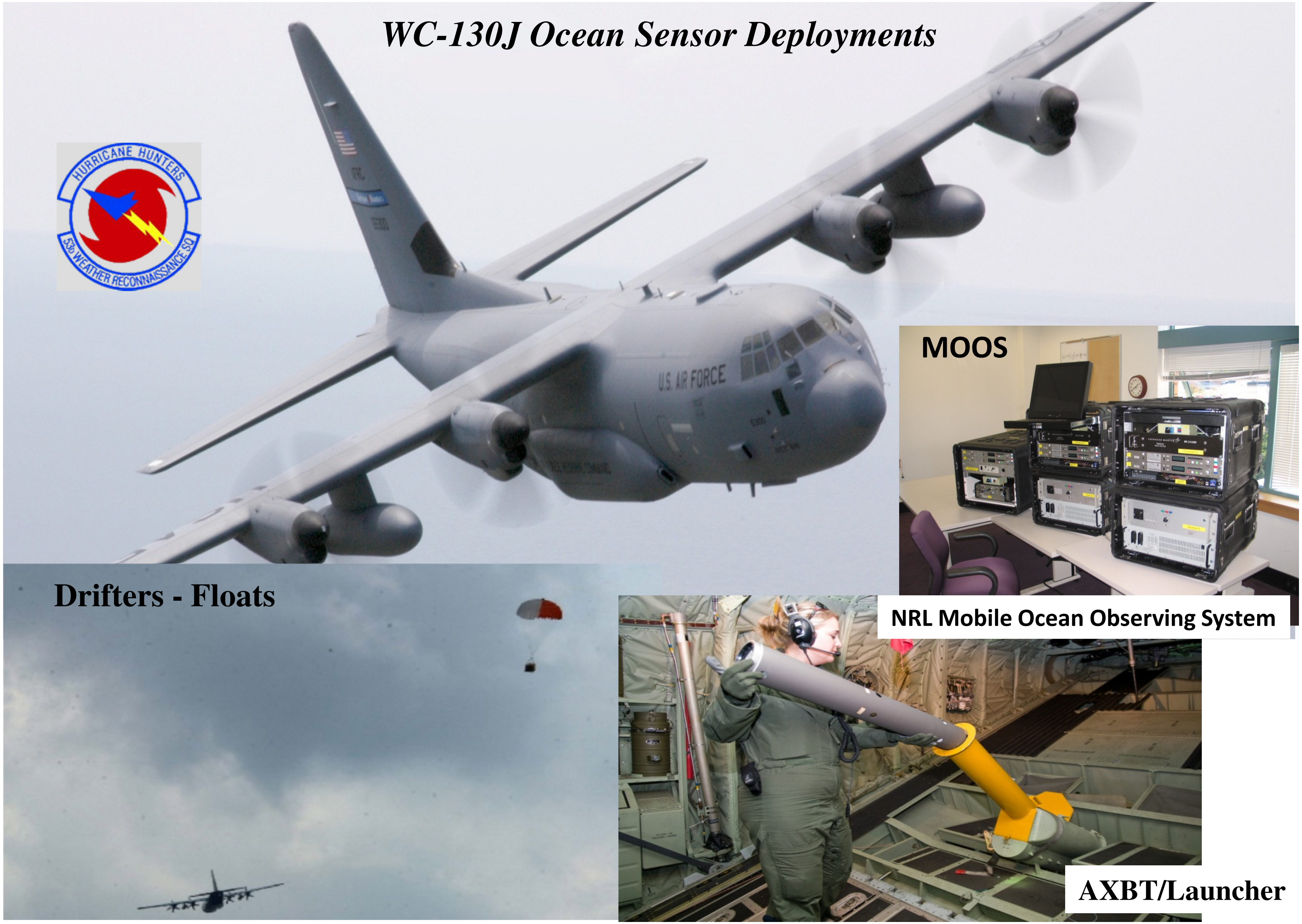
HIWRAP Characteristics:

- *Conically scanning.*
- *Simultaneous Ku/Ka-band & two beams @ 30 and 40 deg*
- *New technologies in radar: low power solid state transmitters with pulse compression, single antenna*
- *GPM radar frequencies.*


Hurricane Gonzalo 15 Oct 2014
26
24
21
Ku-band Uncalibrated dB
Altitude [km]
Along-Track Distance [km]
Ka-band Uncalibrated dB
Altitude [km]
Along-Track Distance [km]
Ku-band Uncalibrated dB
Altitude [km]
Along-Track Distance [km]
Ka-band Uncalibrated dB
Altitude [km]
Along-Track Distance [km]
HIWRAP Ka - 2014/10/15

EXPERIMENTS- ONR TCS08 NSF TPARC(2008) ONR ITOP(2010) ONR/AFRC AXBT Demo (2011-16) Atmospheric/ Oceanic Measurement Systems

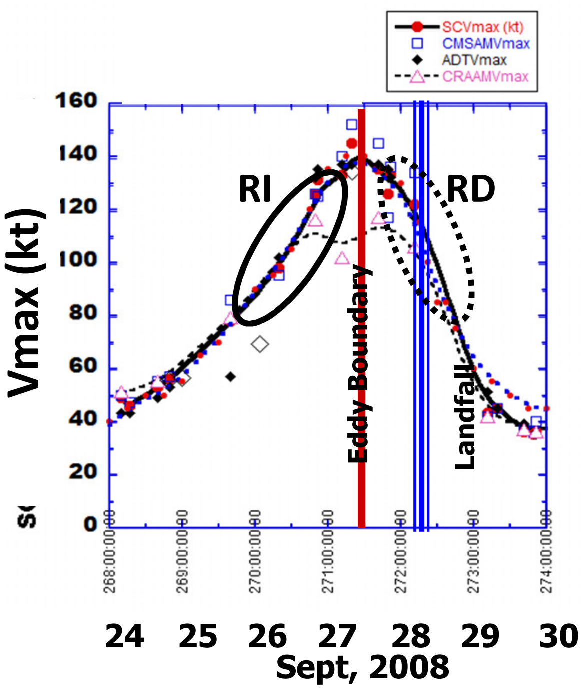
1. AFRC WC-130J
    a. Nose C-band radar
    b. Vaisala RD-94 dropsonde Advanced Vertical Atmospheric Profiling System (AVAPS)
    a. Stepped Frequency Microwave Radiometer (SFMR)
    c. Mini-met/ SVP drift buoy deployment
    d. Lagrangian profiling float deployment
    e. EM-APEX profiling floats
    f. AXBT’s
    g. Alamo minni-float deployment
2. NRL/ NCAR P-3
    1. ELDORA Tail Doppler Radar
    2. Vaisala RD-94 dropsonde Advanced Vertical Atmospheric Profiling System (AVAPS)
3. DLR Falcon
    a. Vaisala RD-94 dropsonde Advanced Vertical Atmospheric Profiling System (AVAPS)
4. DOTSTAR ASTRA twin-jet
    a. Vaisala RD-94 dropsonde Advanced Vertical Atmospheric Profiling System (AVAPS)

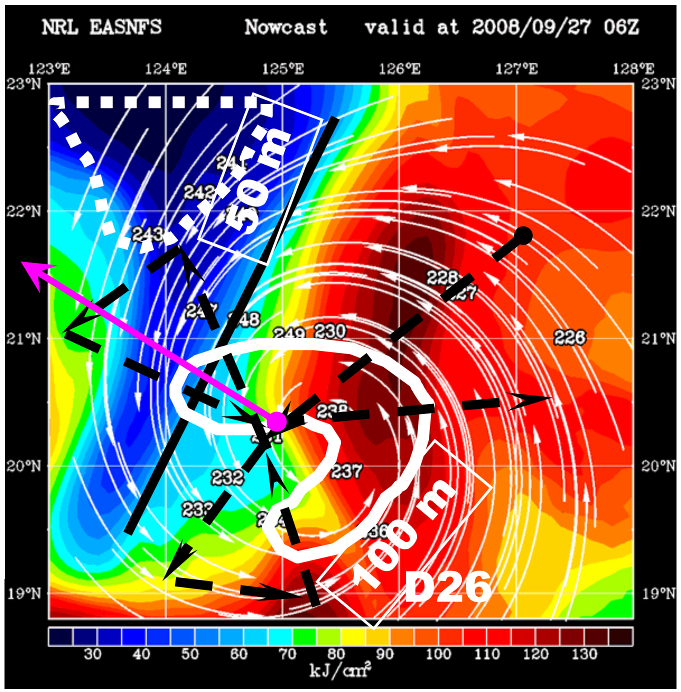

WC-130J Ocean Sensor Deployments
HURRICANE HUNTERS
53rd WEATHER RECONNAISSANCE SQ
U.S. AIR FORCE
MOOS
NRL Mobile Ocean Observing System
Drifters - Floats
AXBT/Launcher

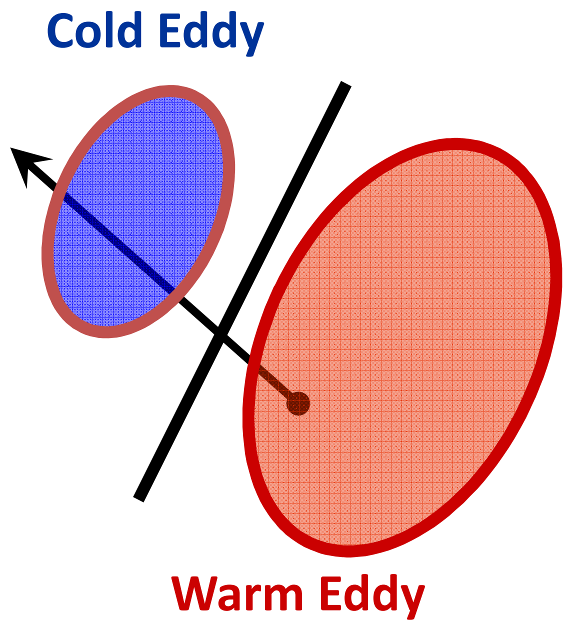
Similar to TCS08 STY Jangmi RI/RD episode

- Jangmi Rapid Intensification/Decay Coincides with passage over warm/cold eddy pair prior to Taiwan landfall

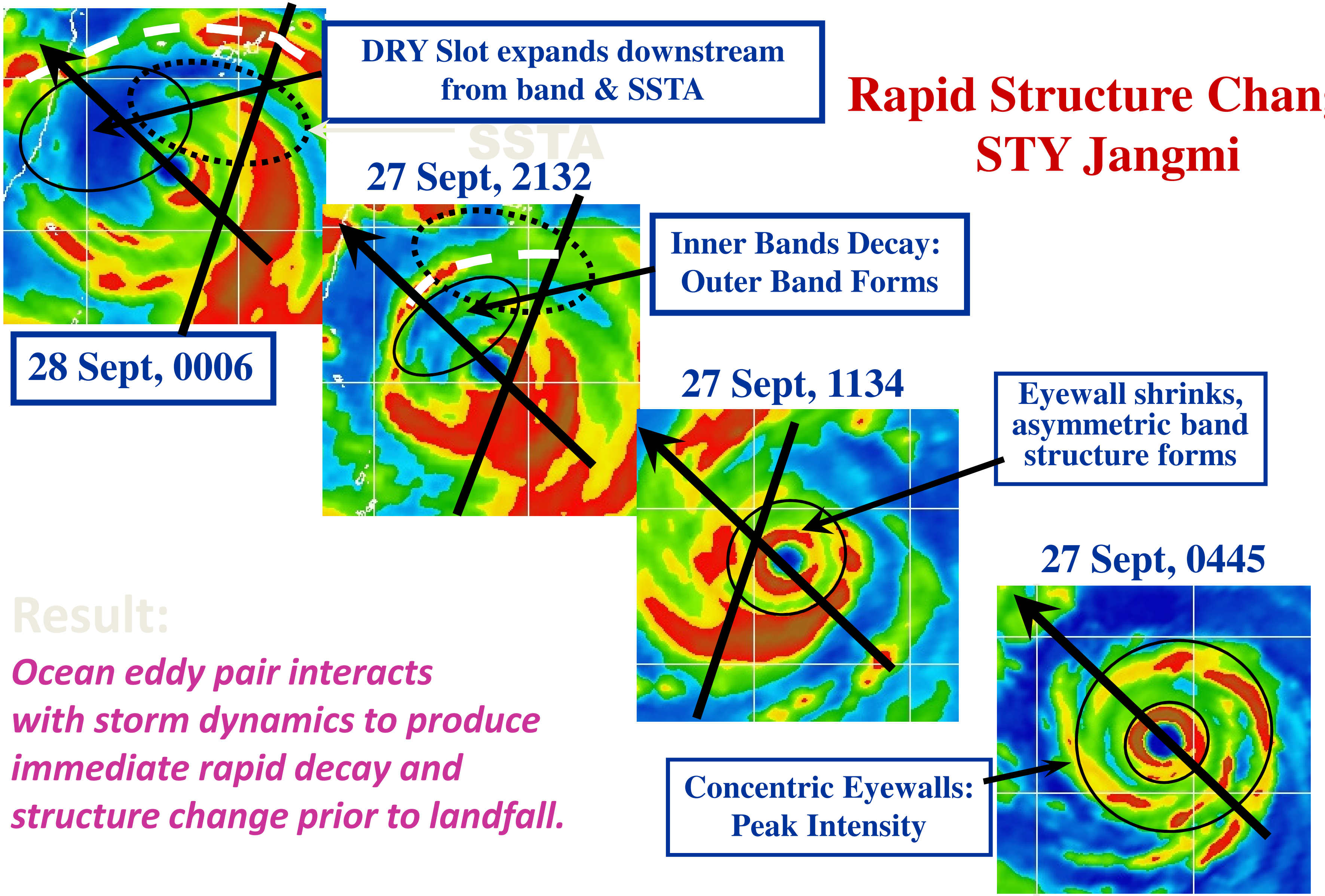
- ITOP/TCS10 STY Megi undergoes RI over large D26 and OHC26 region







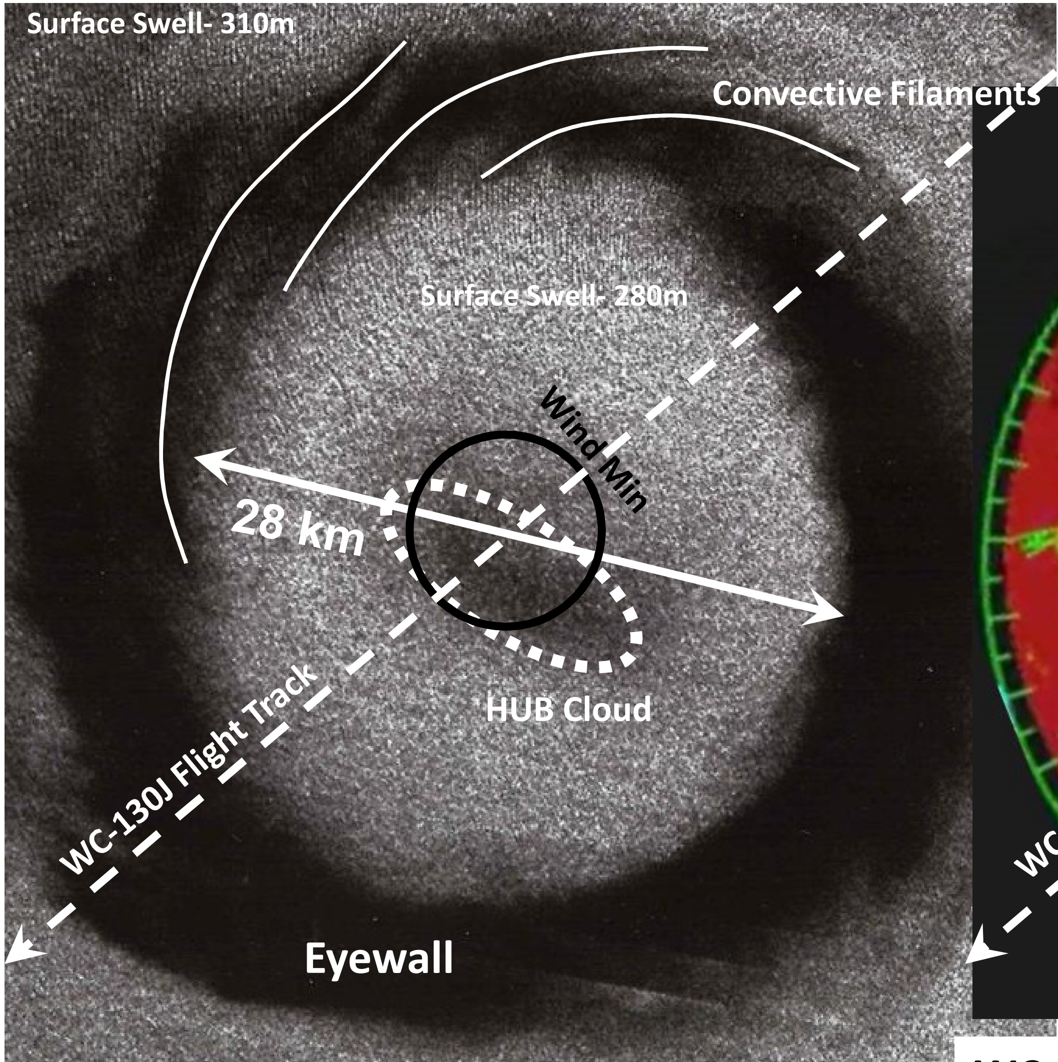
Rapid Structure Change STY Jangmi



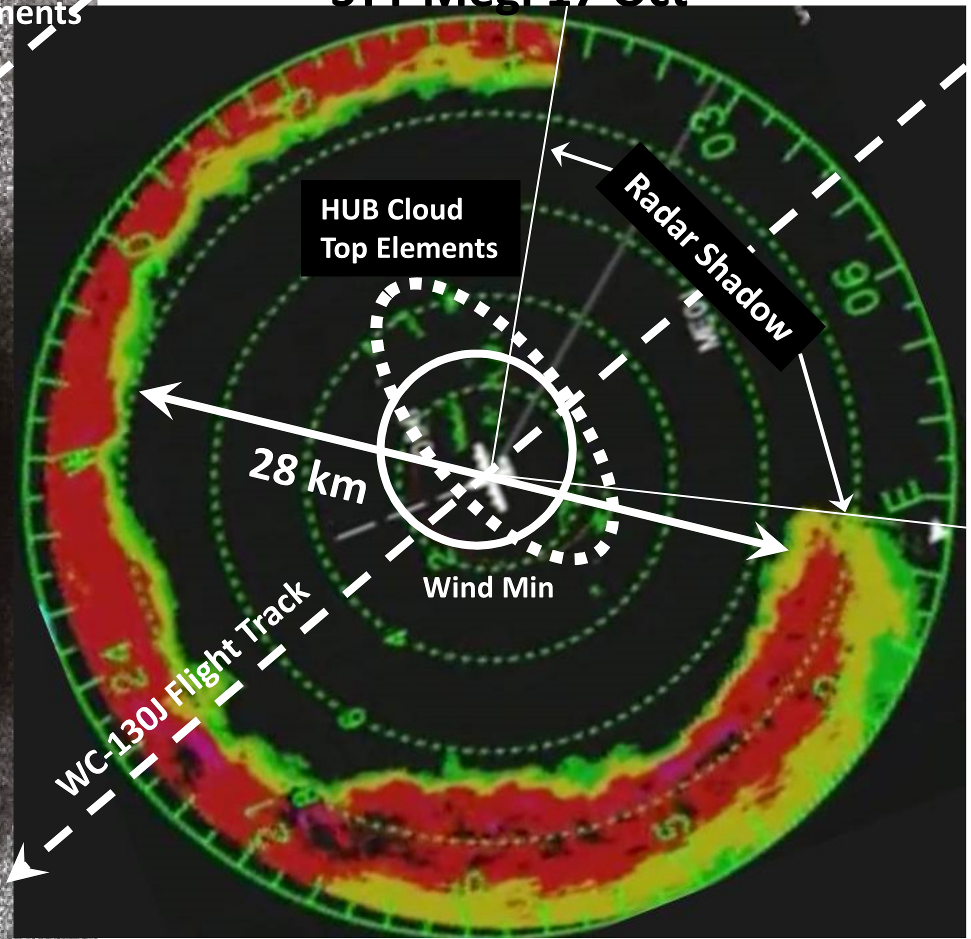
Result:

Ocean eddy pair interacts with storm dynamics to produce immediate rapid decay and structure change prior to landfall.

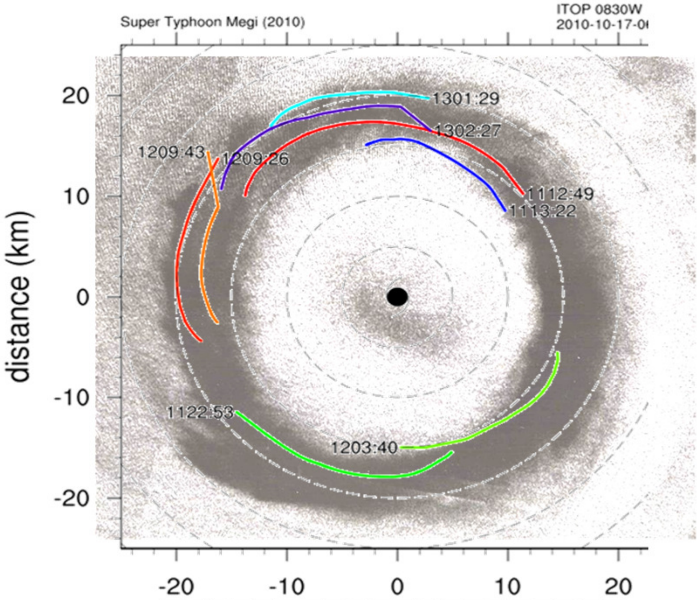
Mesoscale eyewall features: Unknown effects on ocean forcing STY Megi 17 Oct

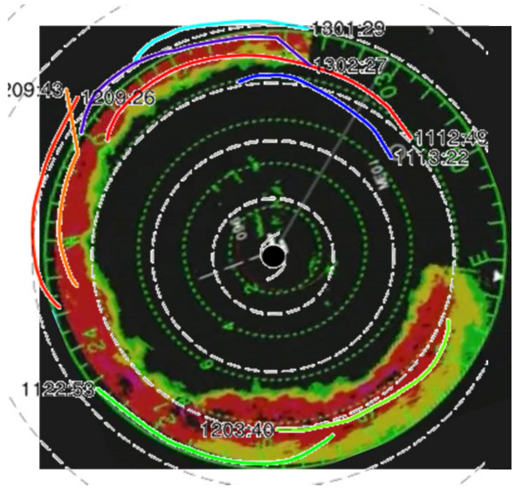


COSMO SKYMED-3 SAR: 0925 UTC



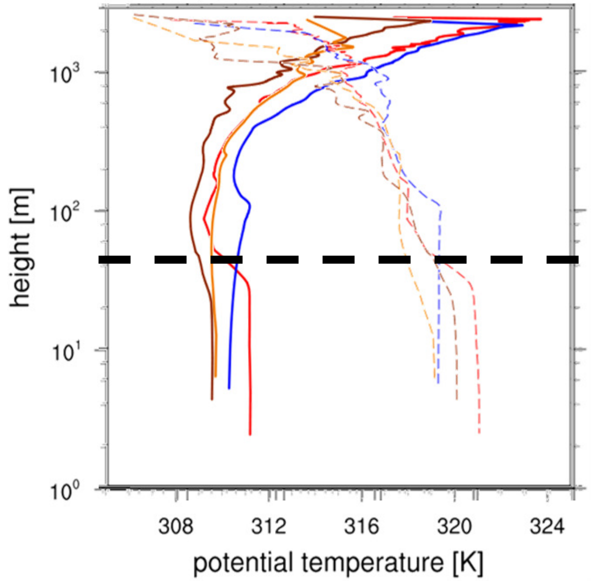
WC-130J C-band Weather Radar: 1115 UTC

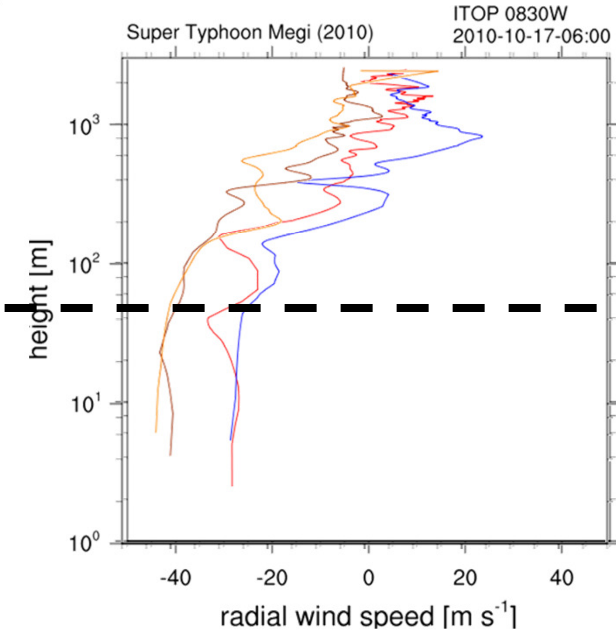


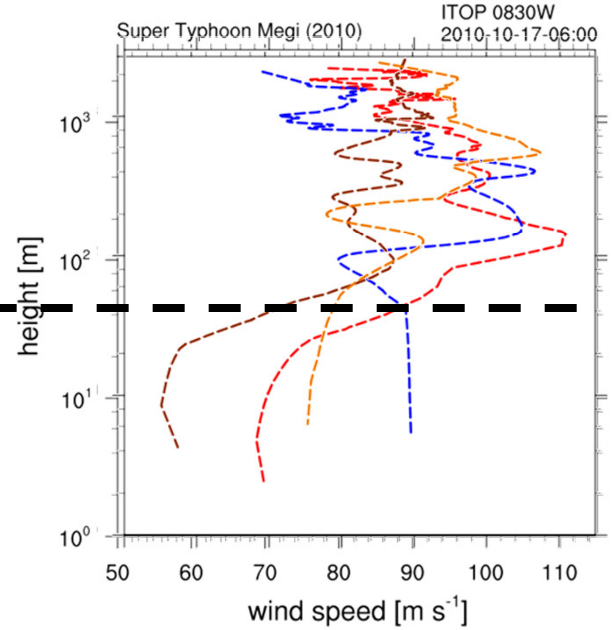


Never-before seen Boundary-layer features

1.Winds to the surface, 4m
2. Super-adiabatic surface layer, <40 m
3. Constant radial and total wind speed, sfc to 40 m; violates log
4. Highest sonde wind ever: 110m/s
5. Highest sonde sfc wind ever:90m/s







The AXBT Demonstration Project
Observing the Oceans Around TCs

Overall Objective:

Increase hurricane forecast accuracy by assimilating ocean observations from beneath tropical cyclones into coupled numerical models in near-real time

Incremental Objectives:

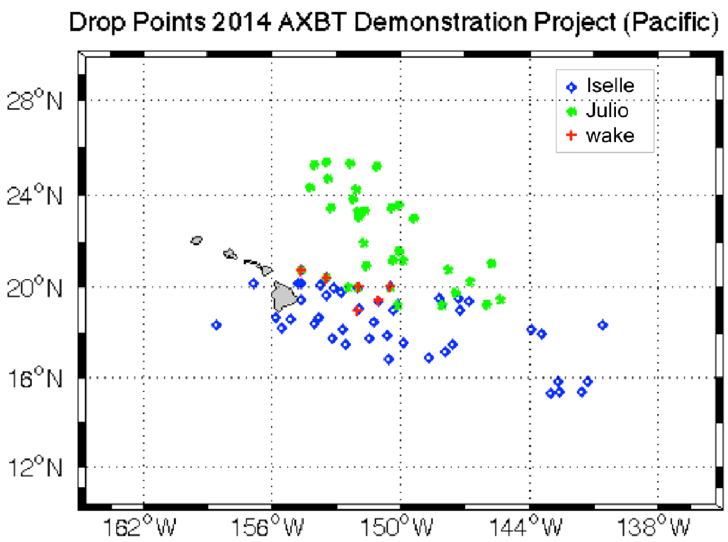
① *Collect, process, and transmit AXBT data to coupled modeling centers in near-real time*

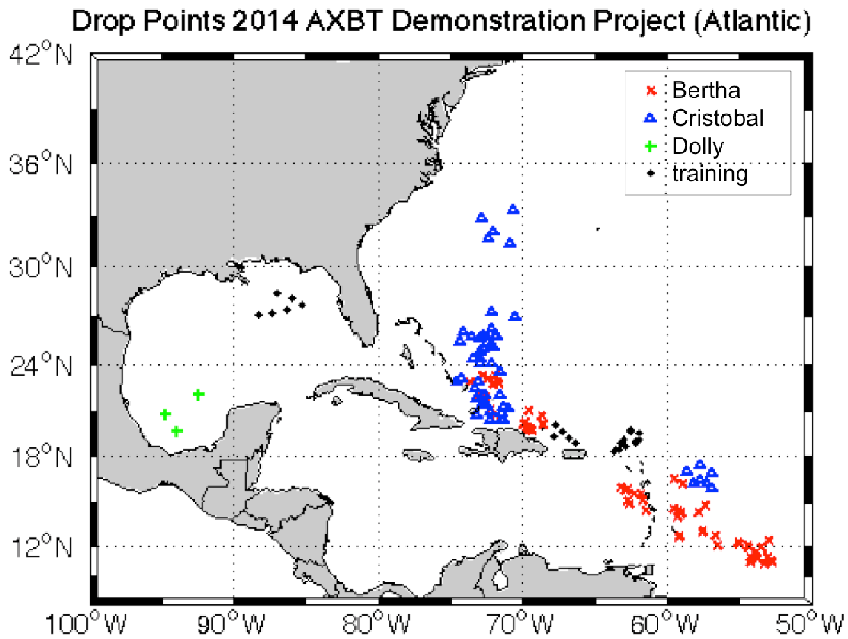
② *Assimilate AXBT data into coupled models*

③ *Demonstrate improvement to ocean model initializations and forecasts*

④ *Demonstrate improvement to hurricane track and intensity forecasts*

Deployment Activity during the 2014 Season



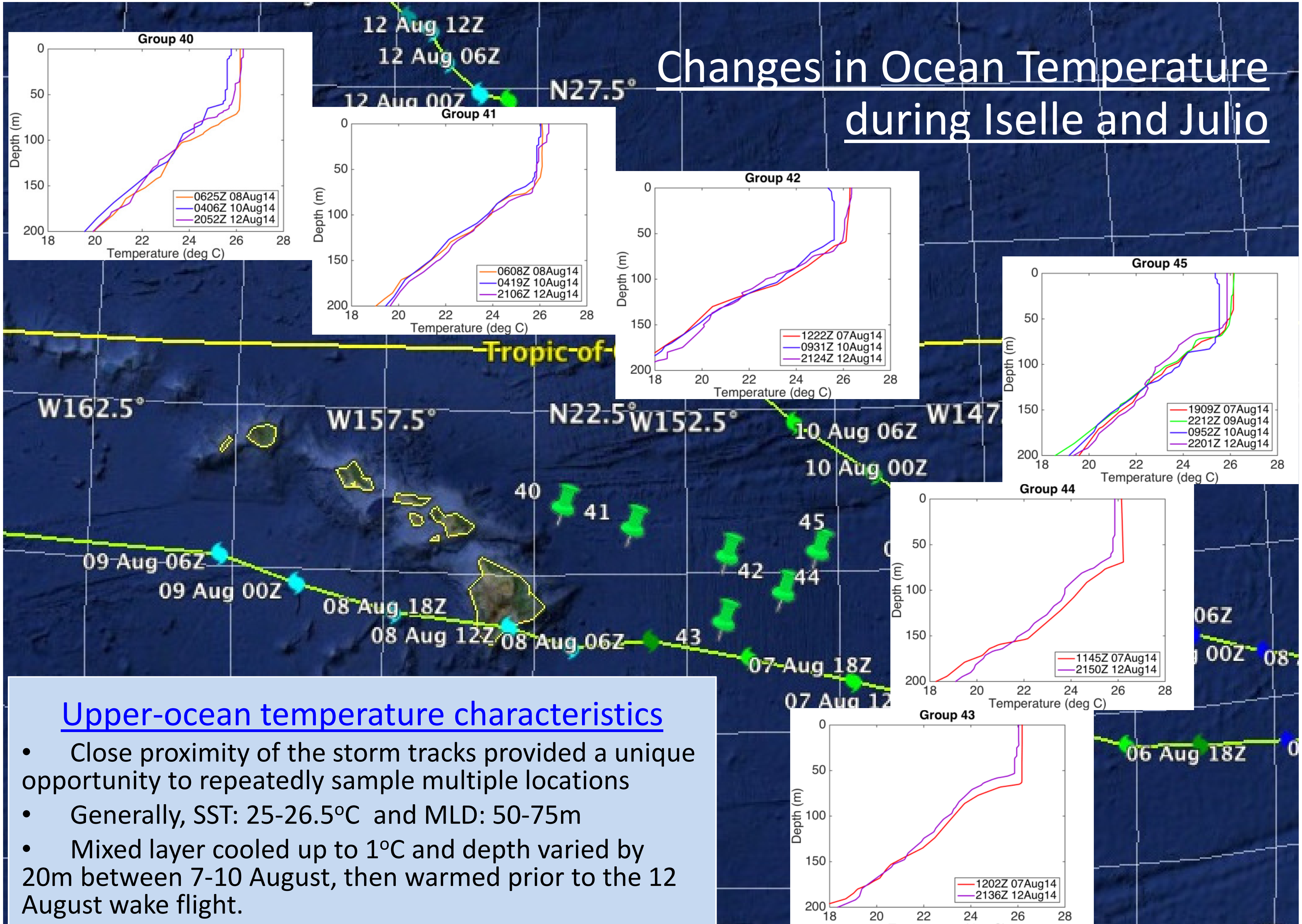


42 flights with 53rd WRS

- Hurricane Bertha (5)
- Hurricane Iselle (7)
- Hurricane Julio (5)
- Hurricane Cristobal (10)
- Other invests (2)
- Transits/Training (13)

- 20 July – 15 September 2014
- 6 personnel
  - 3 Midshipmen, 2 Officers, 1 NCO
- 257 AXBTs deployed

Changes in Ocean Temperature during Iselle and Julio



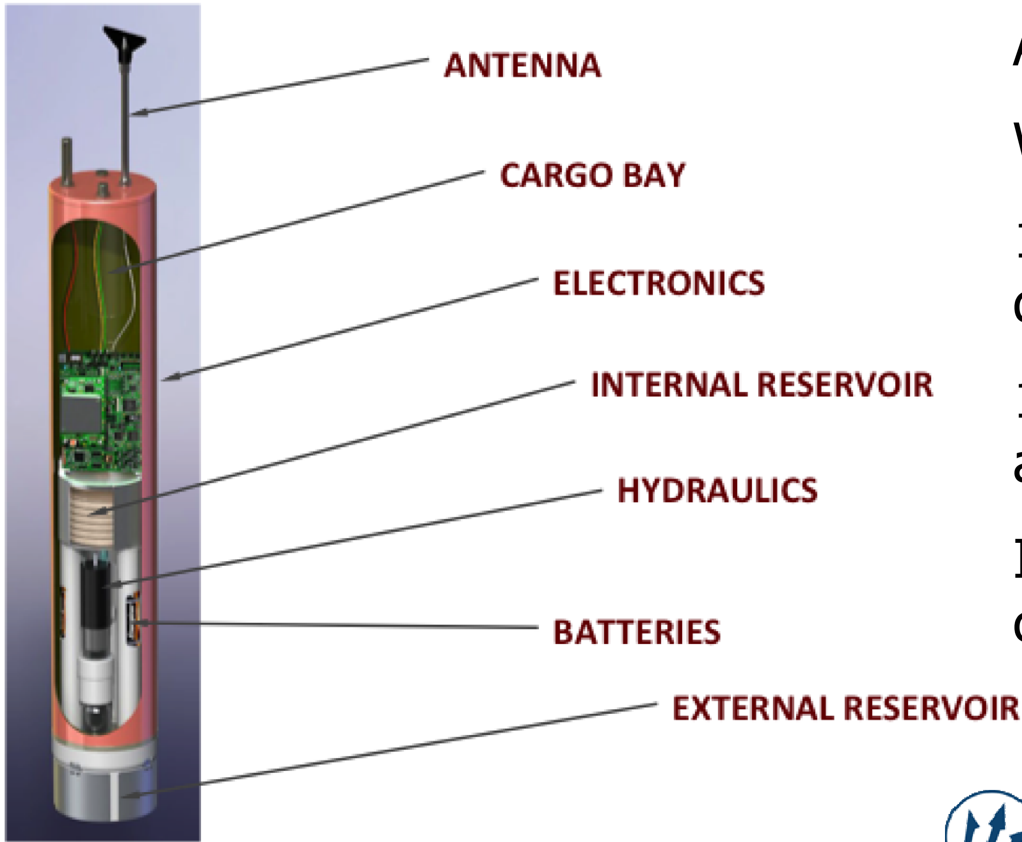
Upper-ocean temperature characteristics

- Close proximity of the storm tracks provided a unique opportunity to repeatedly sample multiple locations
- Generally, SST: 25-26.5°C and MLD: 50-75m
- Mixed layer cooled up to 1°C and depth varied by 20m between 7-10 August, then warmed prior to the 12 August wake flight.

ALAMO

Smaller profiling float that will fit in the AXBT launcher and can be used operationally by the USAF and NOAA Hurricane Hunter planes.

Advantages over AXBT include: multiple profiles, more sensors (pressure, salinity, & accelerometer for surface waves), no VHF receiver equipment on planes



A-sized case

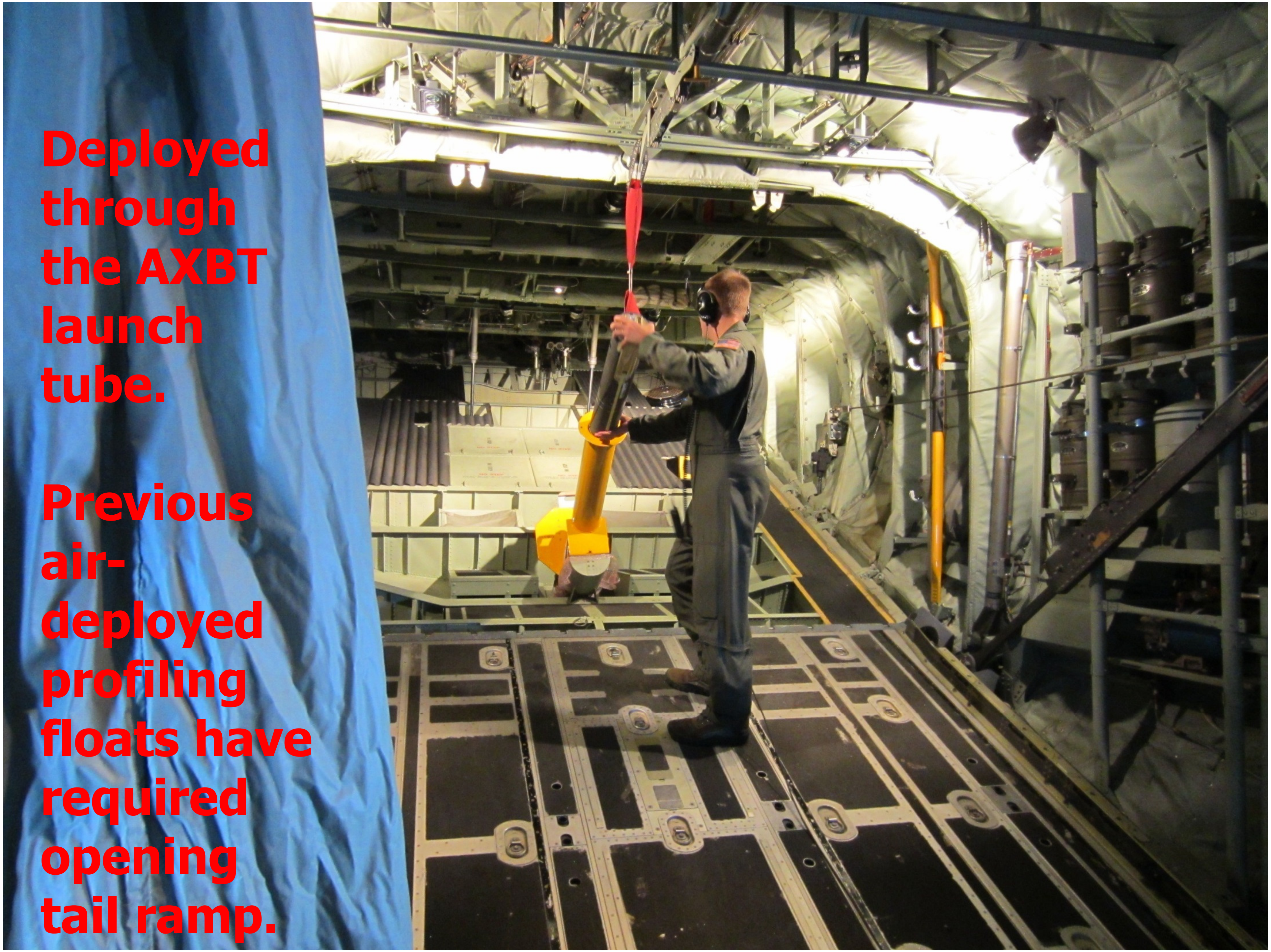
Weight ~10 kg

1200-meter depth rating

1–2 dbar bin-averaged data

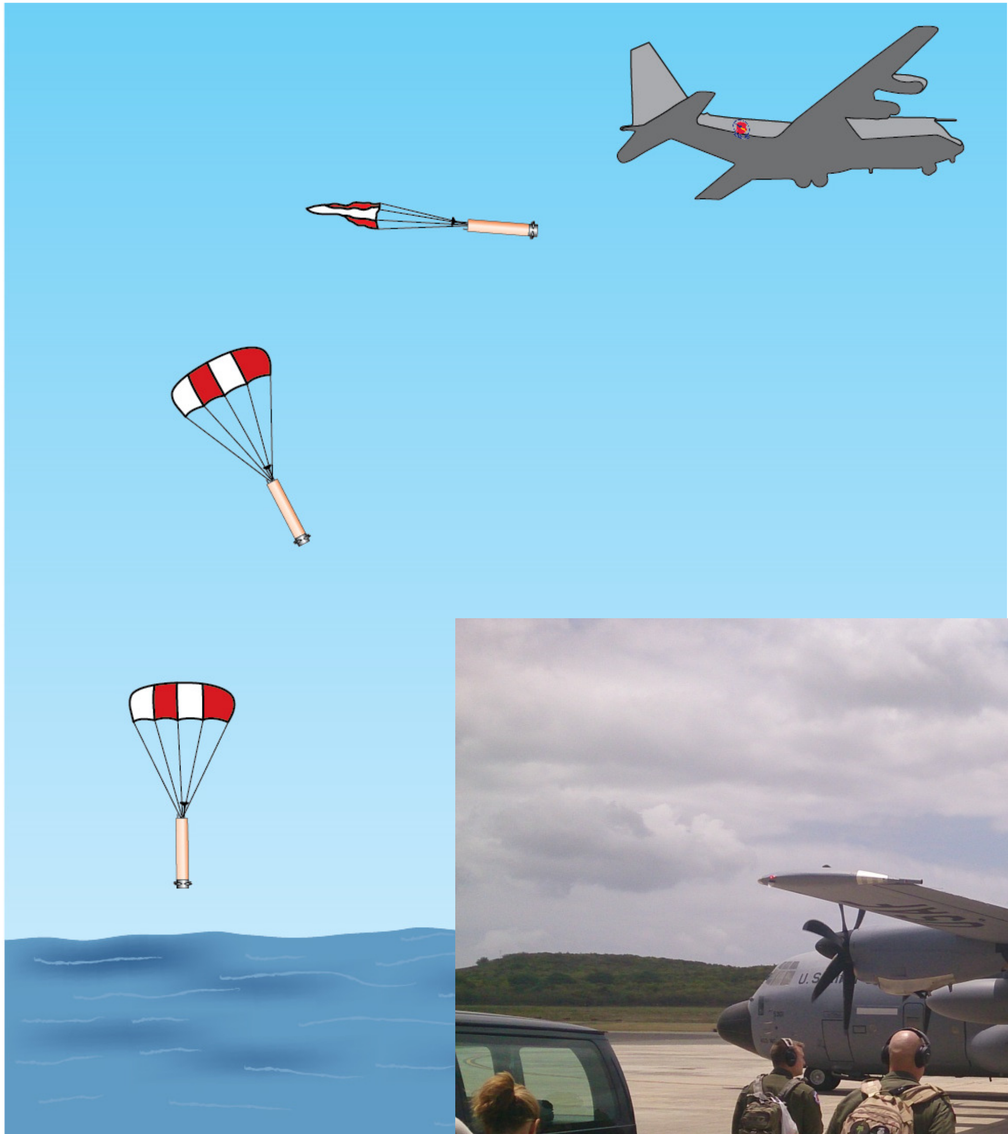
Iridium data communication

MRV SYSTEMS


Deployed through the AXBT launch tube.
Previous air-deployed profiling floats have required opening tail ramp.

A-sized profiling floats were originally developed under funding from ONR, and redeveloped under NOAA Sandy Supplemental funding

The ALAMO and Lagrangian floats have been tested and deployed in cooperation with USAFR 53rd WRS

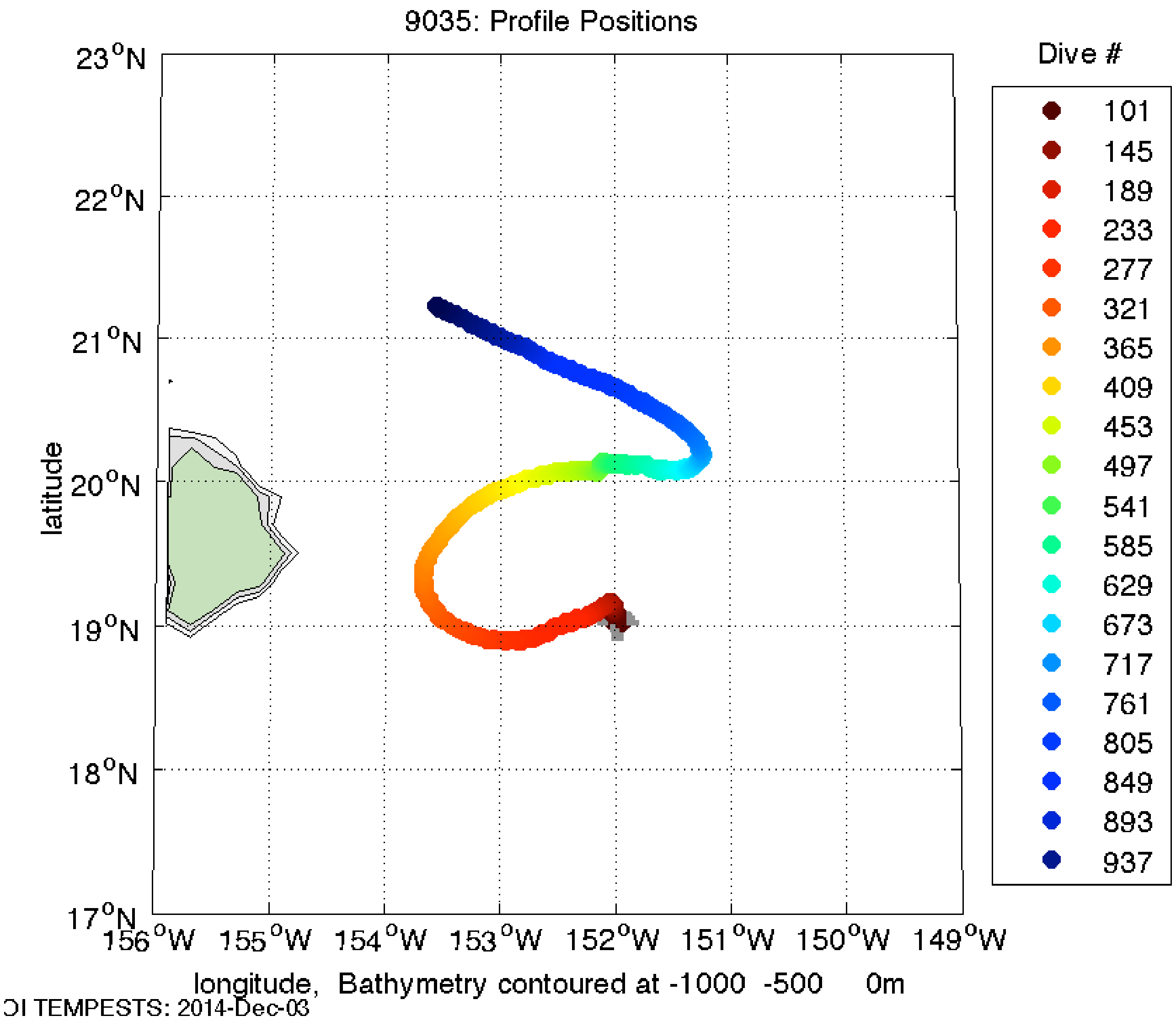


Float 9035, WMO #4901723

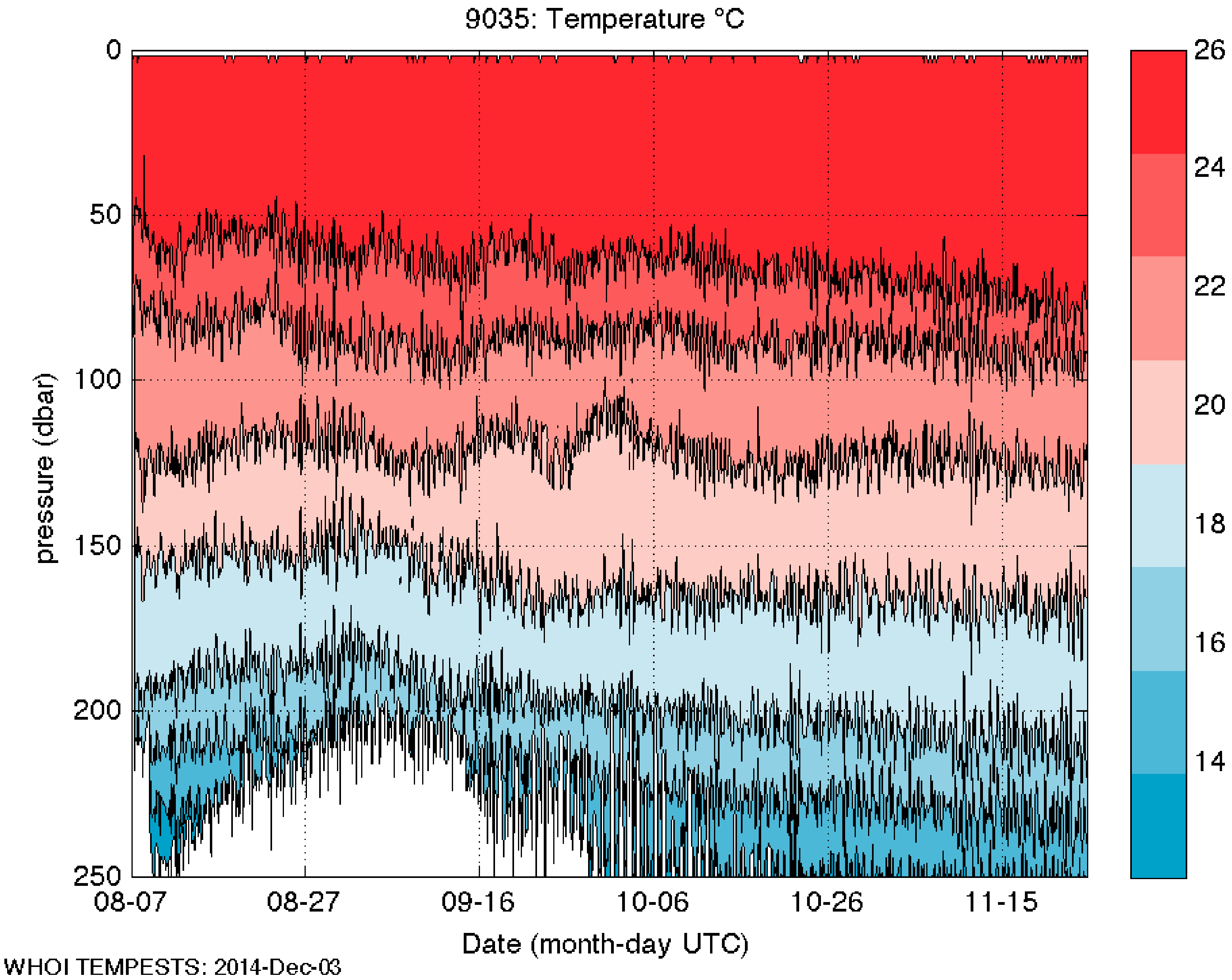
Deployed East of Hawaii, Hurricane Iselle

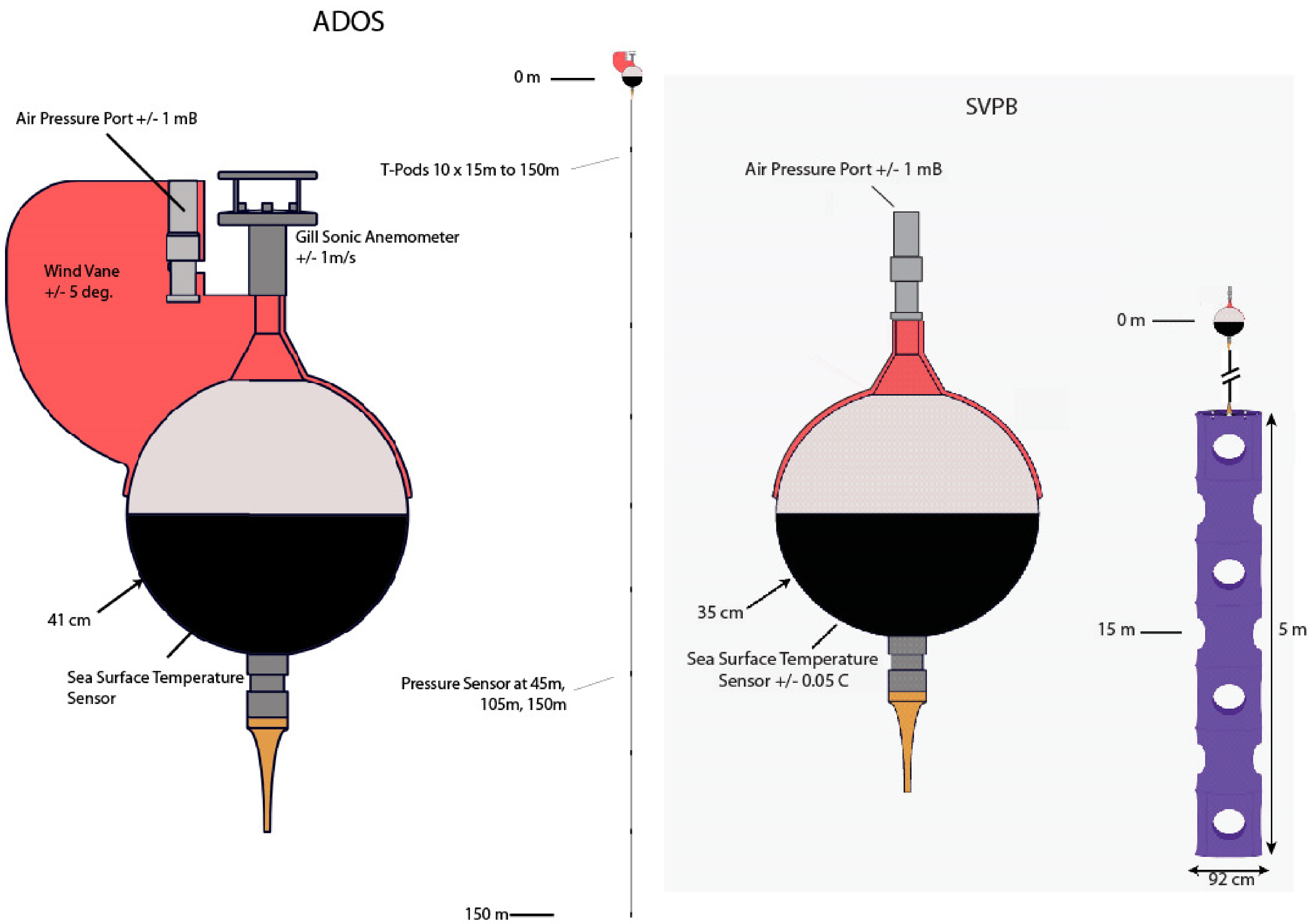
Reported 8 profiles per day from Aug 8 to Nov 25

Profile depth varied from 200 to 300 dbar



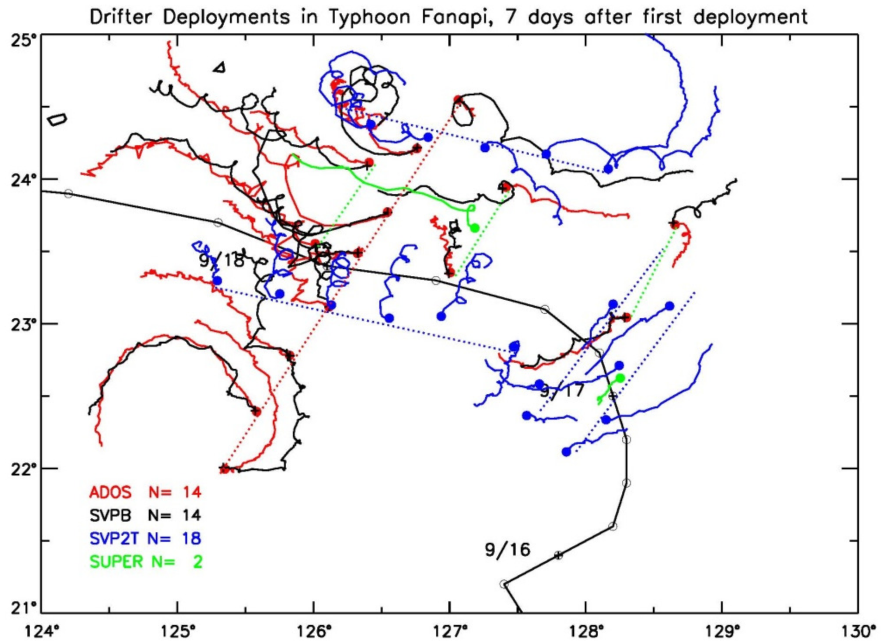
4901723 Upper Ocean Temperature

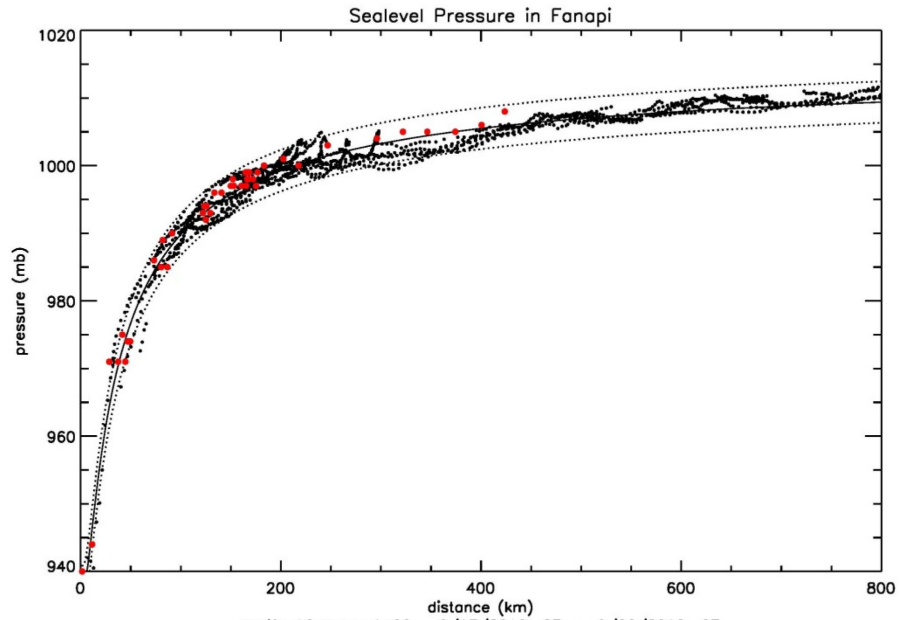




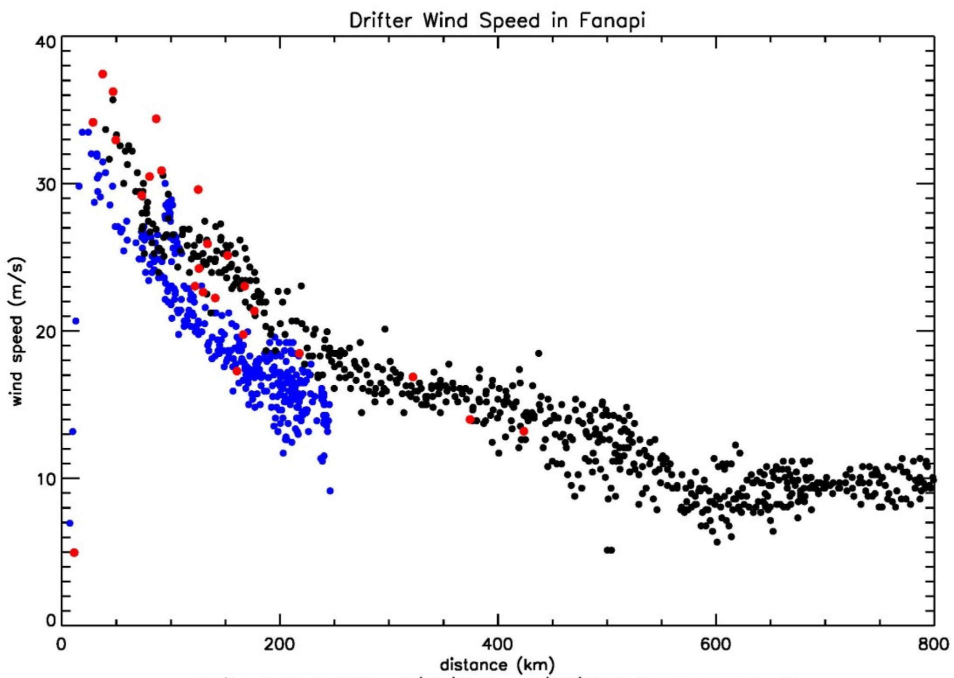
ADOS
0 m
Air Pressure Port +/- 1 mB
T-Pods 10 x 15m to 150m
Gill Sonic Anemometer
+/- 1m/s
Wind Vane
+/- 5 deg.
41 cm
Sea Surface Temperature
Sensor
Pressure Sensor at 45m,
105m, 150m
150 m
SVPB
Air Pressure Port +/- 1 mB
0 m
35 cm
Sea Surface Temperature
Sensor +/- 0.05 C
15 m
5 m
92 cm

Air-Deployment by 53rd Hurricane Hunter Squadron of Air National Guard

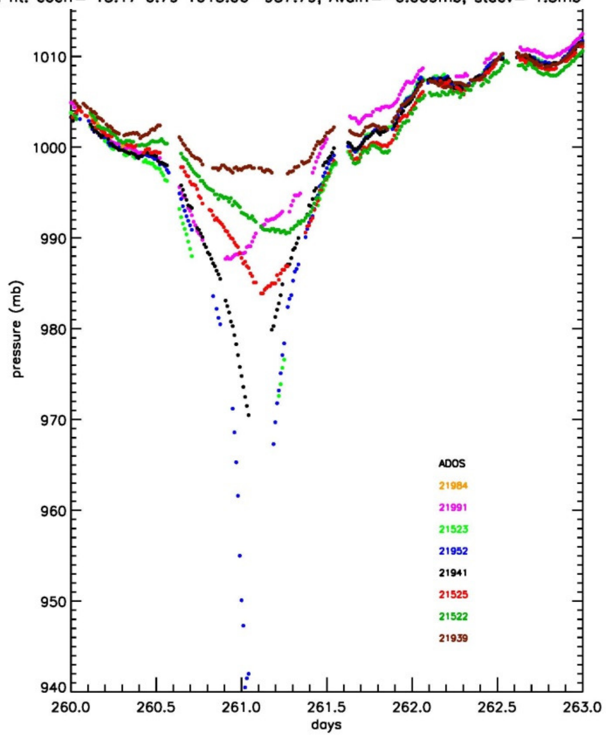




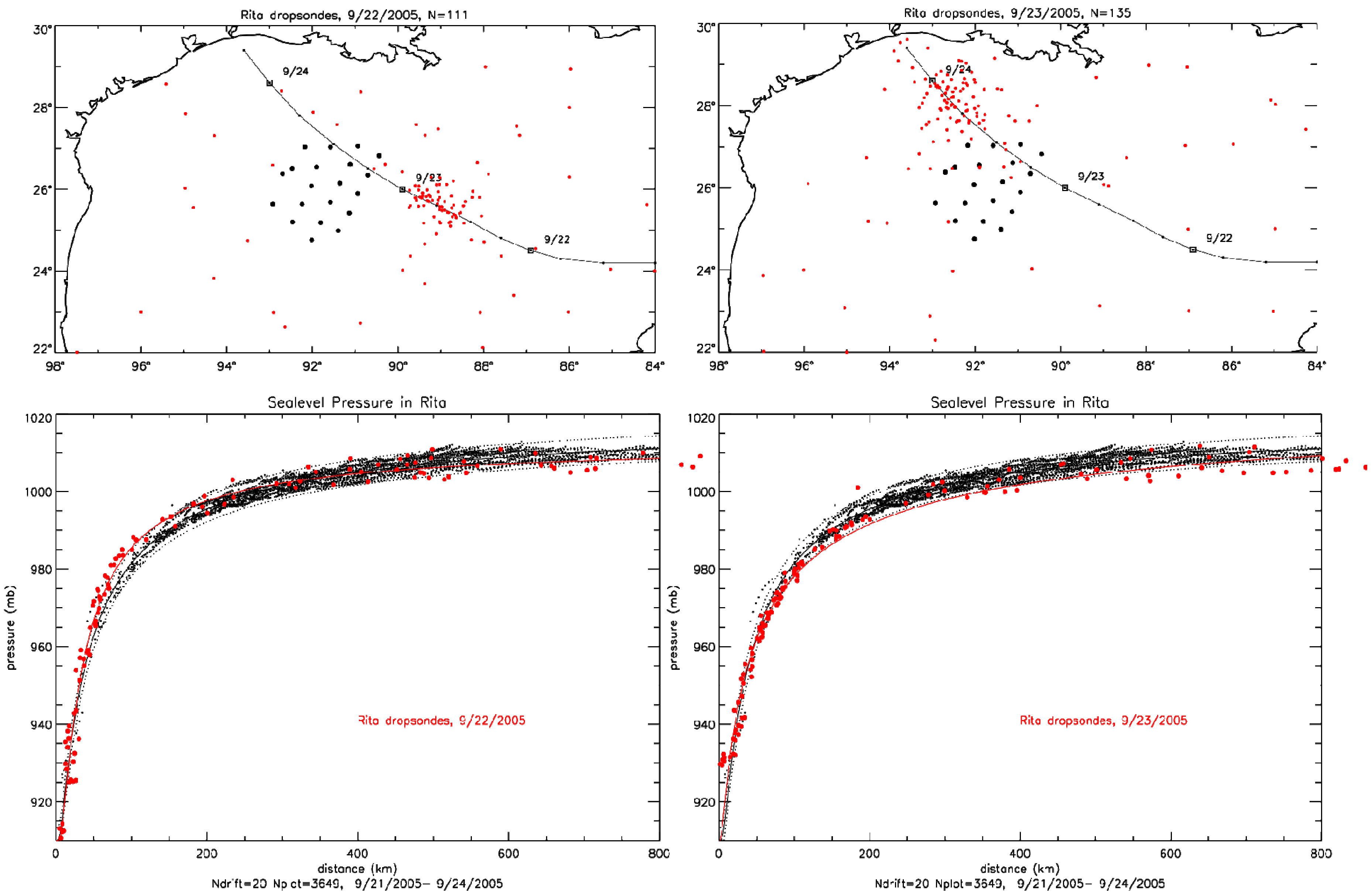
Ndrift=16 Nplot=1466, 9/17/2010 0Z - 9/20/2010 0Z
function fit: coeff= 15.17 0.79 1015.06 937.79, Avdiff=-0.009mb, stdev= 1.5mb



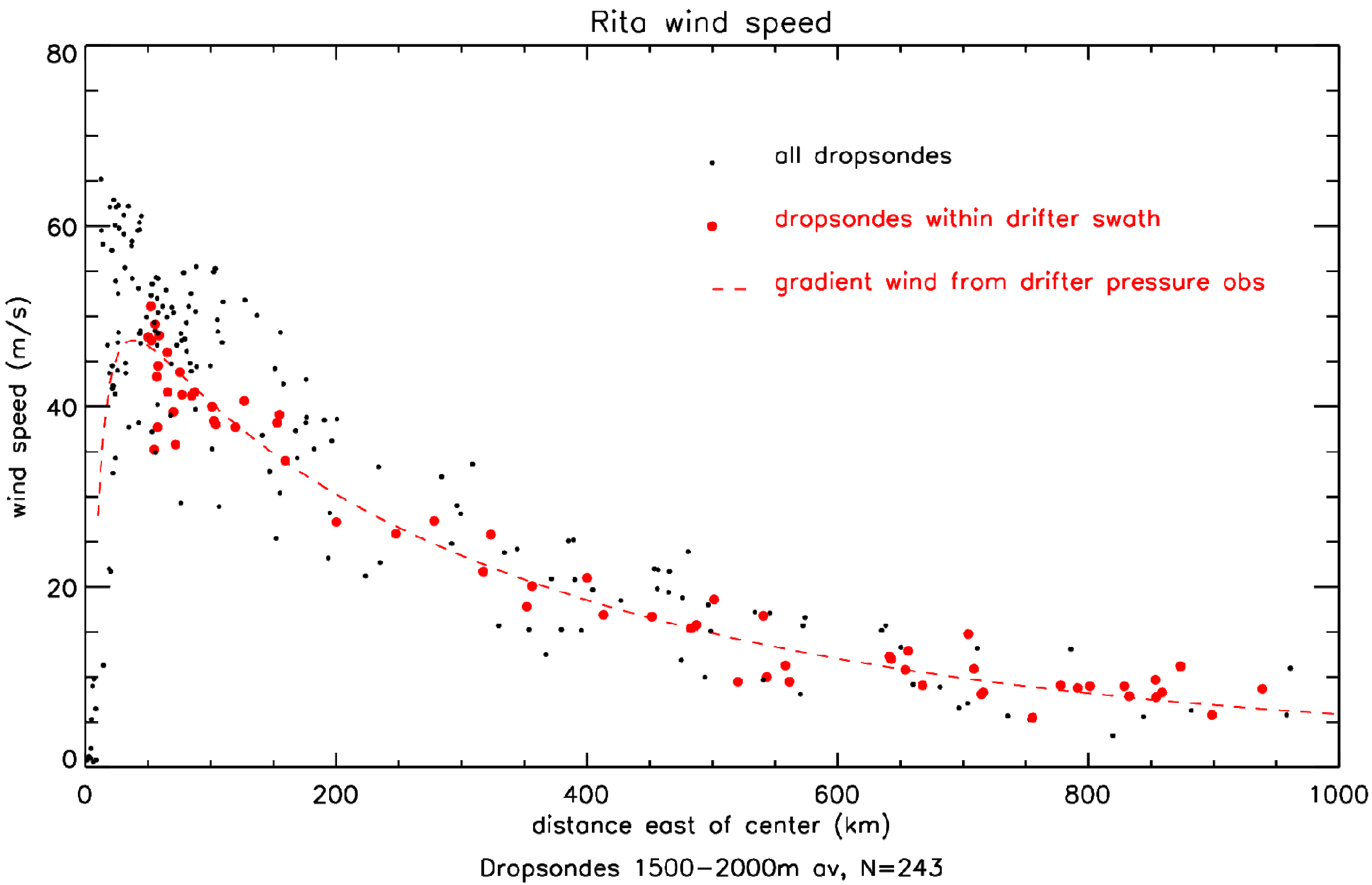
Ndrift= 8 Nplot=1804, 9/17/2010 - 9/20/2010, Dropsondes: N= 31

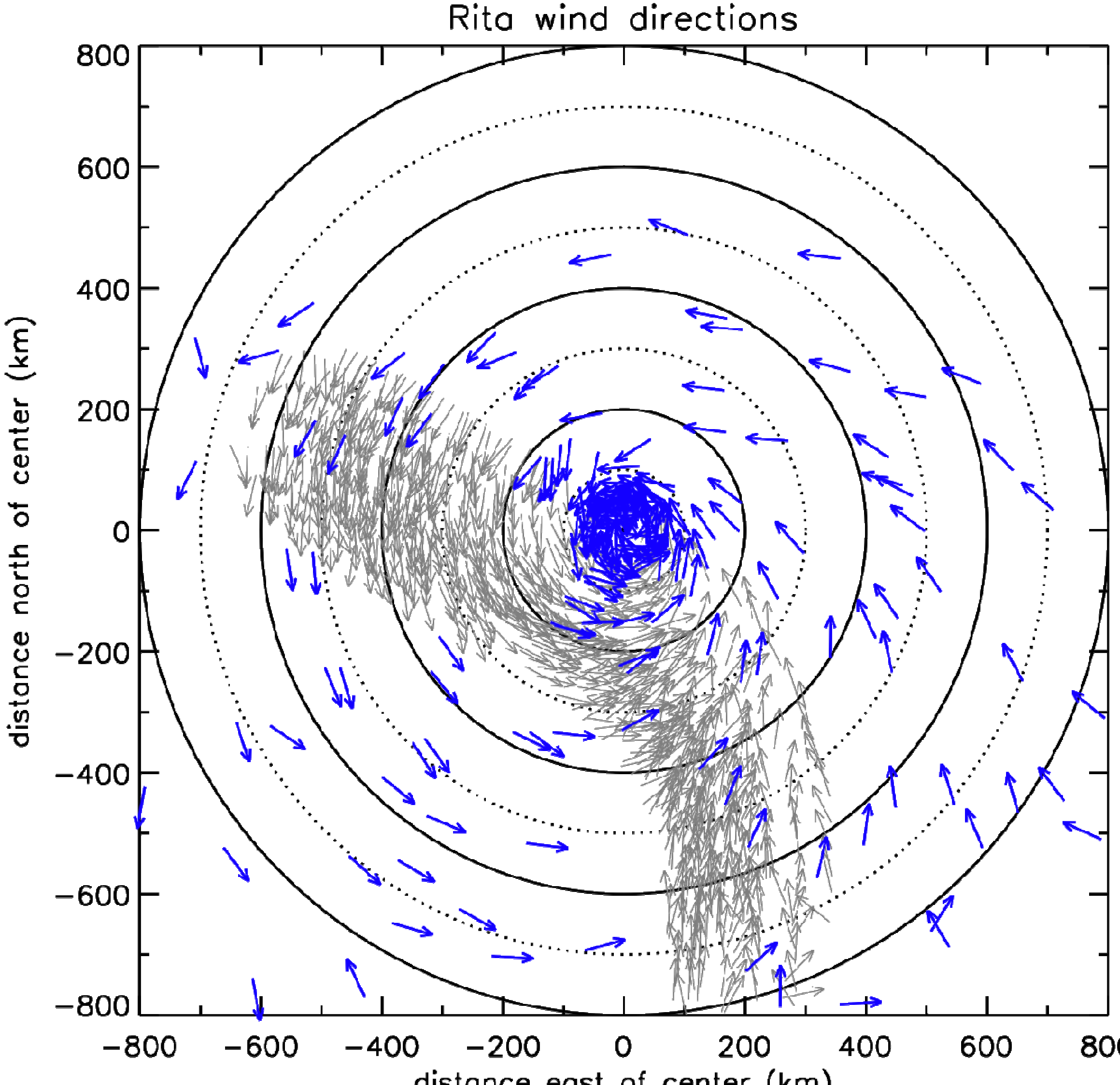


Atmospheric Pressure Comparison: Drifters vs. Dropwindsondes (Rita, 2005)



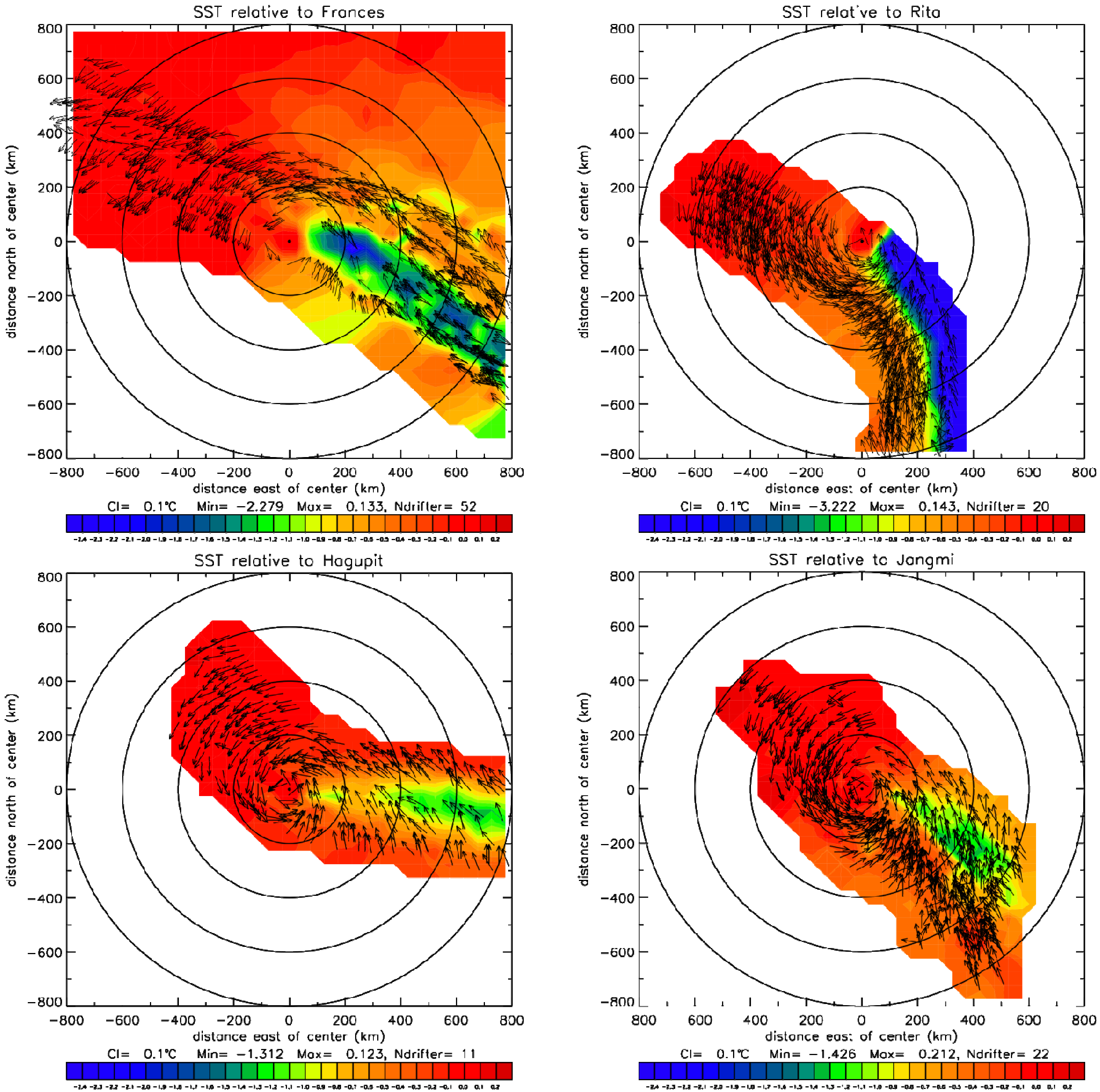
Gradient Wind Balance above Boundary Layer: Comparison with Dropsonde wind speed





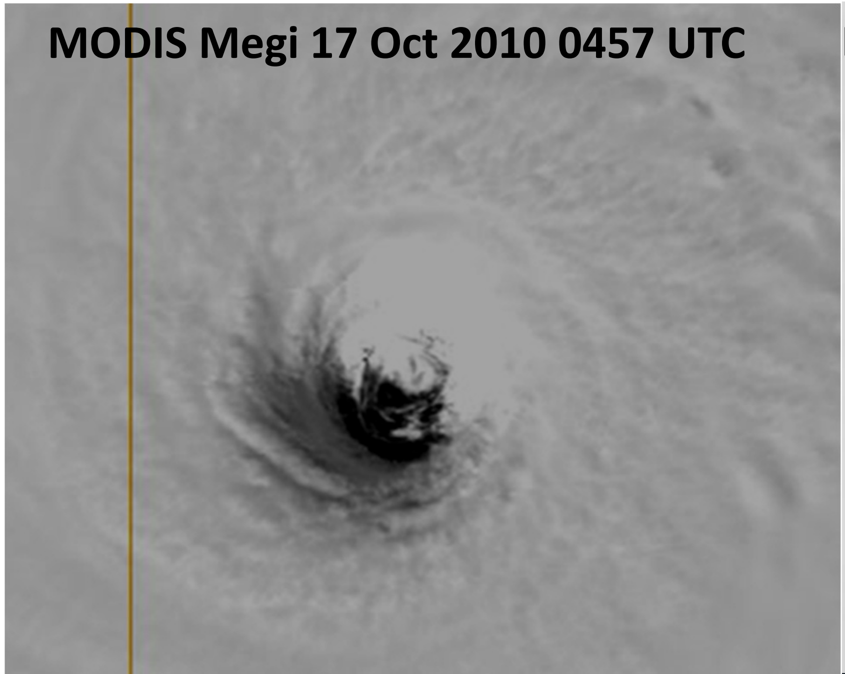
Nplot= 749, days 264.7−268.0 = 3.3, 9/21/2005 − 9/24/2005, Nskip= 4

Dropsondes 0−50m av, N=216


SST relative to Frances
CI= 0.1°C Min= −2.279 Max= 0.133, Ndrifter= 52
SST relative to Rita
CI= 0.1°C Min= −3.222 Max= 0.143, Ndrifter= 20
SST relative to Hagupit
CI= 0.1°C Min= −1.312 Max= 0.123, Ndrifter= 11
SST relative to Jangmi
CI= 0.1°C Min= −1.426 Max= 0.212, Ndrifter= 22
distance east of center (km)
distance north of center (km)

Stages in Field Program Development
HFIP HS3 TCI EXOTICA

- Conception, design, vetting- 2 yr
  - All-inclusive, multi-scale concept design
  - Multi-purpose, sub-module conceptualization
- Focus down: 2-3 key modules (very important)
- Design, testing, dry run- 2 yr
- Trial implementation- 1 yr
- Operational demonstration- 2 yr
- Operational implementation- 10 yr


MODIS Megi 17 Oct 2010 0457 UTC


MTSAT Jangmi 27 Sept 2008 0657 UTC


Randy Bynon
CMSGT, 53rd


Scott Dufreche
LTCOL, 53rd