# An Overview of the Tropical Cyclone Data Assimilation Activities at NOAA's Hurricane Research Division


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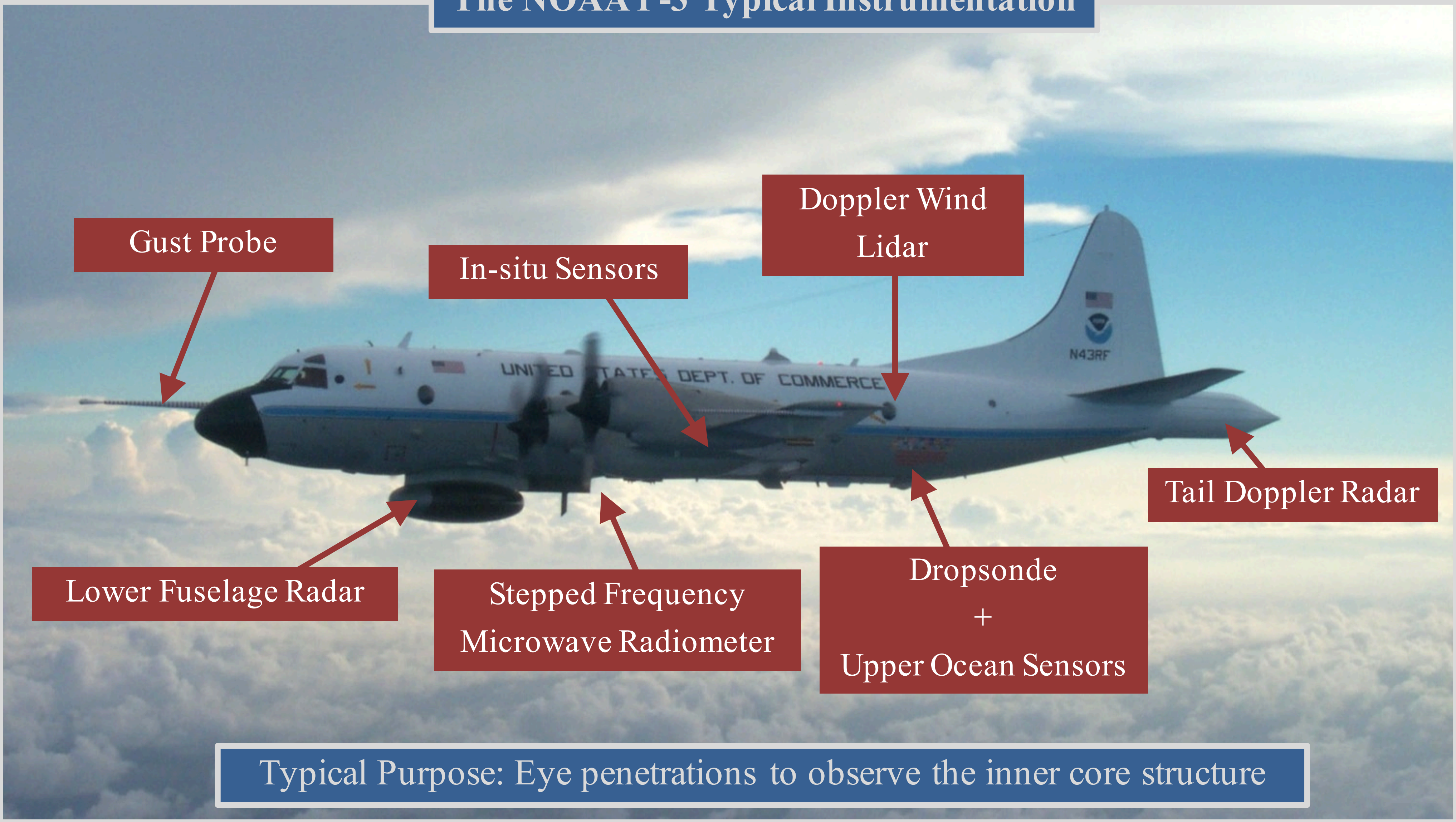
**7th Ensemble Kalman Filter Workshop – State College, PA**

# Hurricane Observing Platforms: NOAA P-3 and G-IV

## The NOAA P-3 Typical Instrumentation




Typical Purpose: Eye penetrations to observe the inner core structure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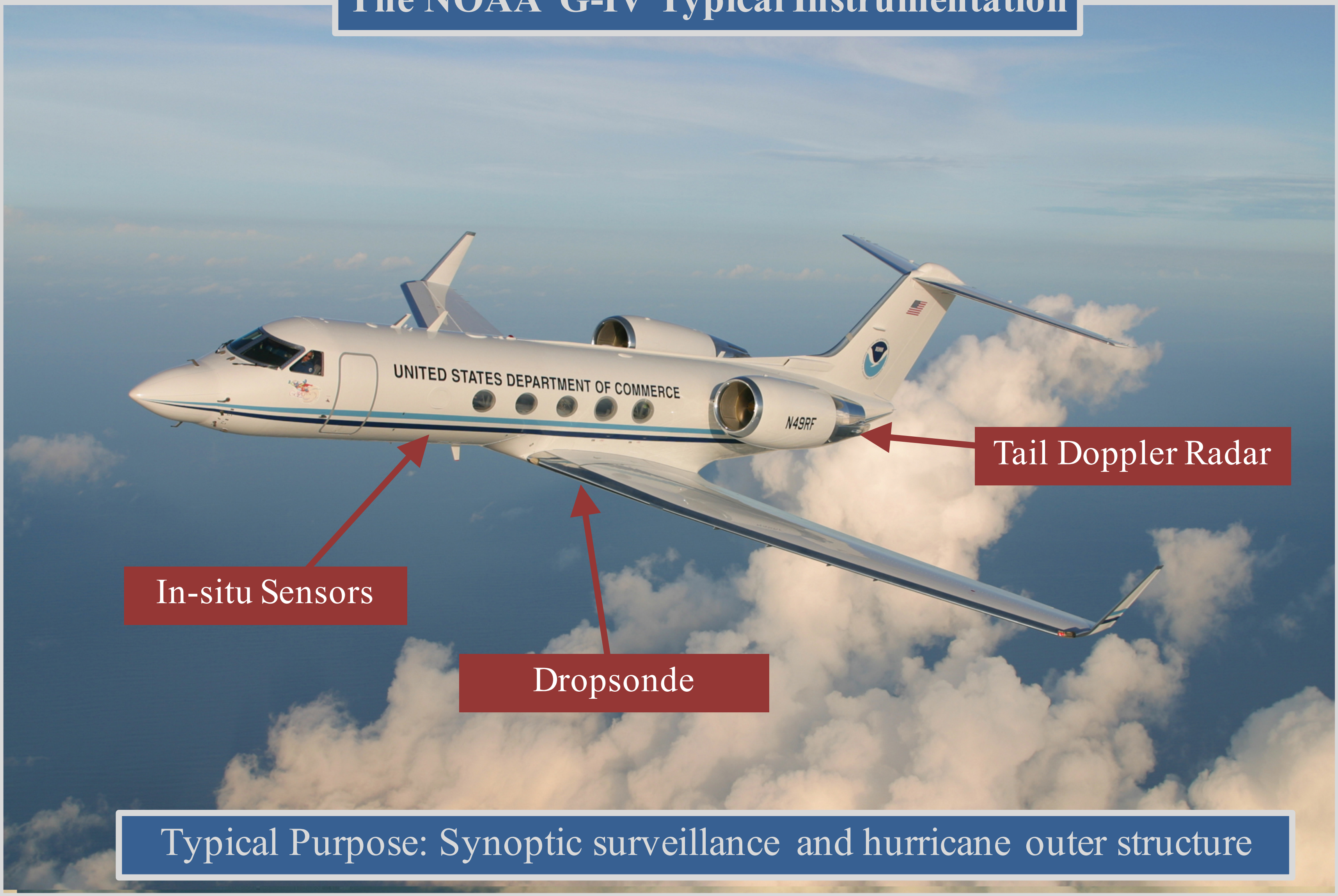
# Hurricane Observing Platforms: NOAA P-3 and G-IV

## The NOAA G-IV Typical Instrumentation

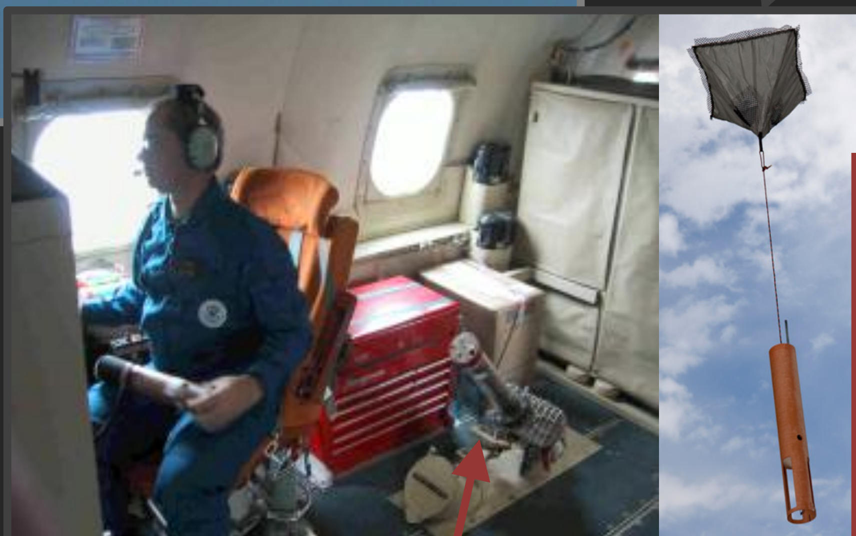



Typical Purpose: Synoptic surveillance and hurricane outer structure

# Hurricane Observing Platforms: UAS – Coyote


The NOAA P-3 Aircraft Typically Penetrates Tropical Cyclones and Collects Data with a Suite of Instruments

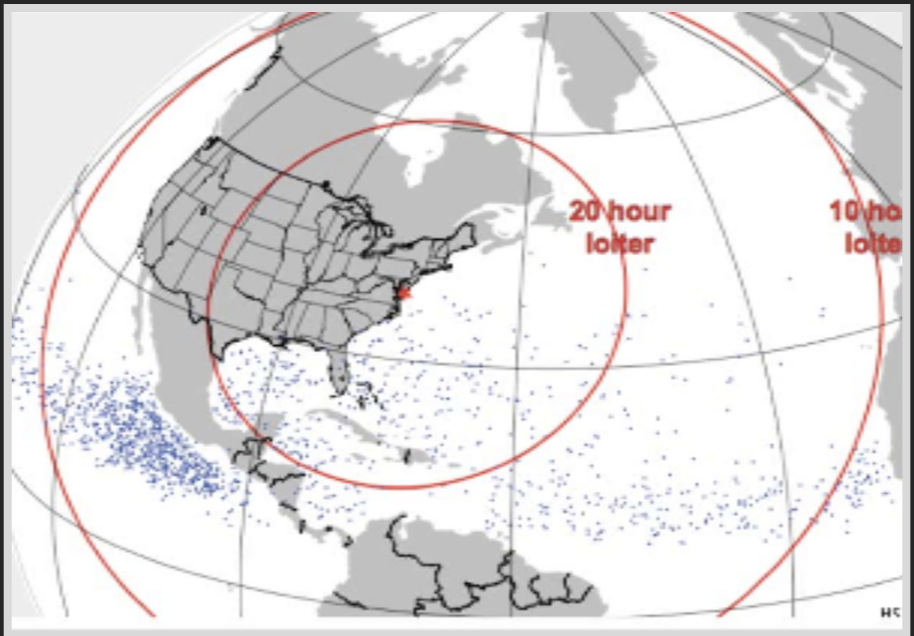
The Dropsonde System is Designed to Measure the Vertical Variations in the Atmosphere



The Coyote is a Small Aircraft that Uses the Dropsonde Deployment System and Sensor Suite and is Capable of Remaining Airborne for ~1 h or Longer

# Hurricane Observing Platforms: UAS – Global Hawk

- Flight Level: ~55-63,000 ft
- Duration: ~26 hr
- Range: 11,000 nm
- Payload: 1,500+ lbs
- Deployment Sites:
  - NASA Wallops Flight Facility (Wallops Island, VA)
  - NASA Armstrong Flight Research Center (Edwards AFB)




Courtesy: Gary Wick (NOAA)



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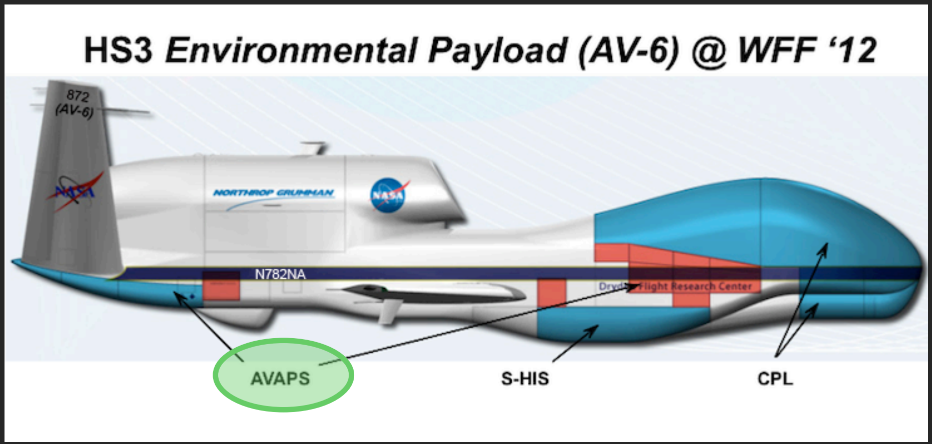
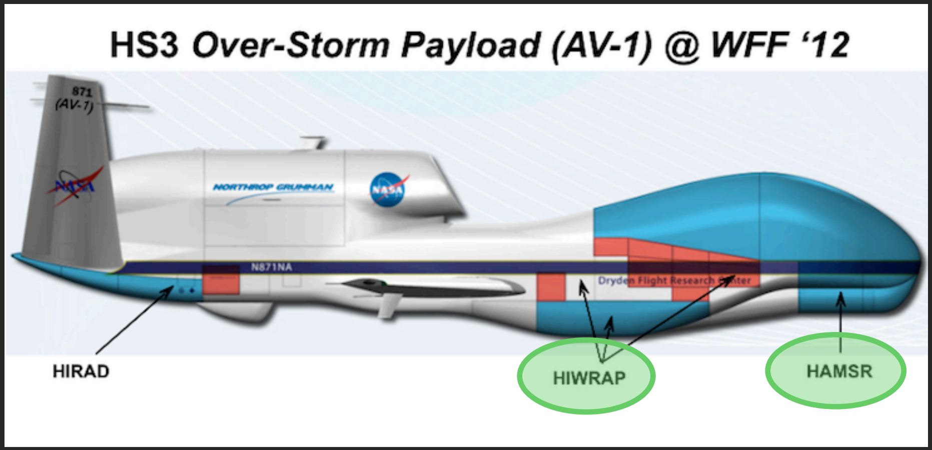
# Hurricane Observing Platforms: UAS – Global Hawk

## NASA Hurricane Severe Storm Sentinel (HS3) Experiment
## Two-Aircraft Configuration




***Environment Observations***

- Profiles of temperature, humidity, wind, and pressure (AVAPS - Dropsonde)
- Cloud top height (CPL)
- Cloud top temperature and profiles of temperature and humidity (S-HIS)




***Over-storm Observations***

- Doppler velocity, horizontal winds, and ocean surface winds (HIWRAP)
- Profiles of temperature and humidity and total precipitable water (HAMSR)
- Ocean surface winds and rain (HIRAD)

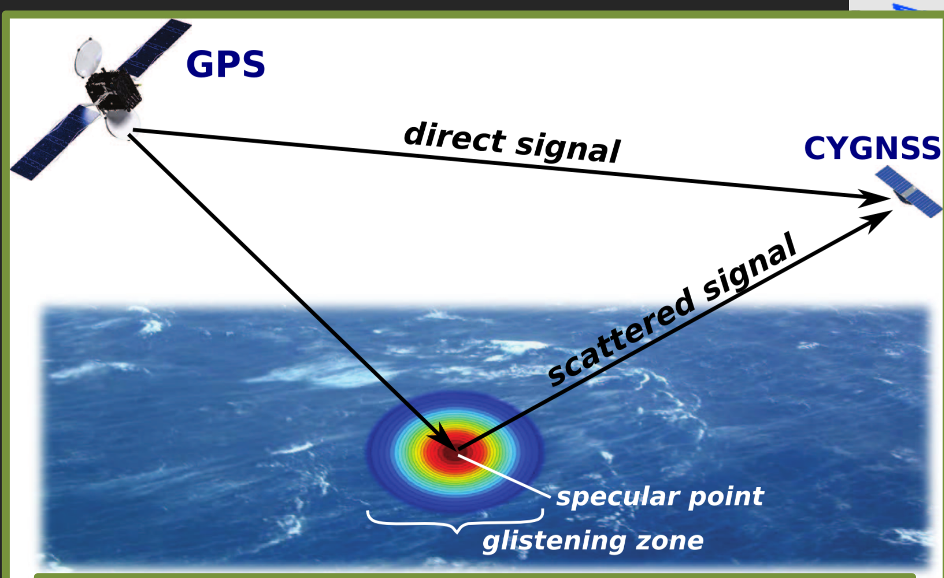
**NOAA SHOUT Program Instrumentation: Dropsonde, HIWRAP, HAMSR**

Courtesy: Gary Wick (NOAA)

# Hurricane Observing Platforms: Satellites (CYGNSS)

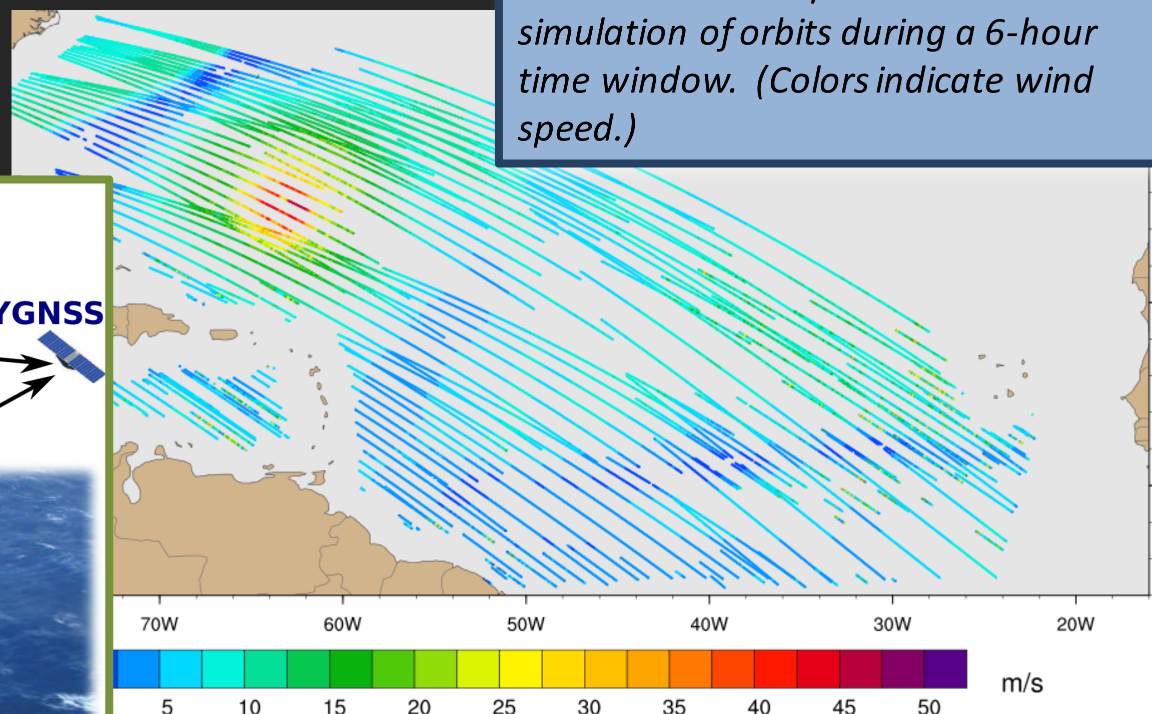
- The **CY**clone **G**lobal **N**avigation **S**atellite **S**ystem is a constellation of 8 micro-satellites scheduled for launch in late October 2016… a NASA Earth Venture Mission (Ruf et al. 2016)
- Utilizes signals from existing GPS satellites to retrieve ocean surface wind speed… surface roughness (mean square slope) affects forward-scattered signal

Receives GPS L-band signals at 19-cm wavelength | Low-Earth orbit covers 35S-35N | 25-km spatial resolution | Retrieved wind speed dynamic range 0-70 m/s | Median / mean revisit time is 2.8 h / 7.2 h




*Basic geometry of bi-static quasi-specular scatterometry.*

*A hurricane over the western Atlantic Ocean is well-sampled in this simulation of orbits during a 6-hour time window. (Colors indicate wind speed.)*

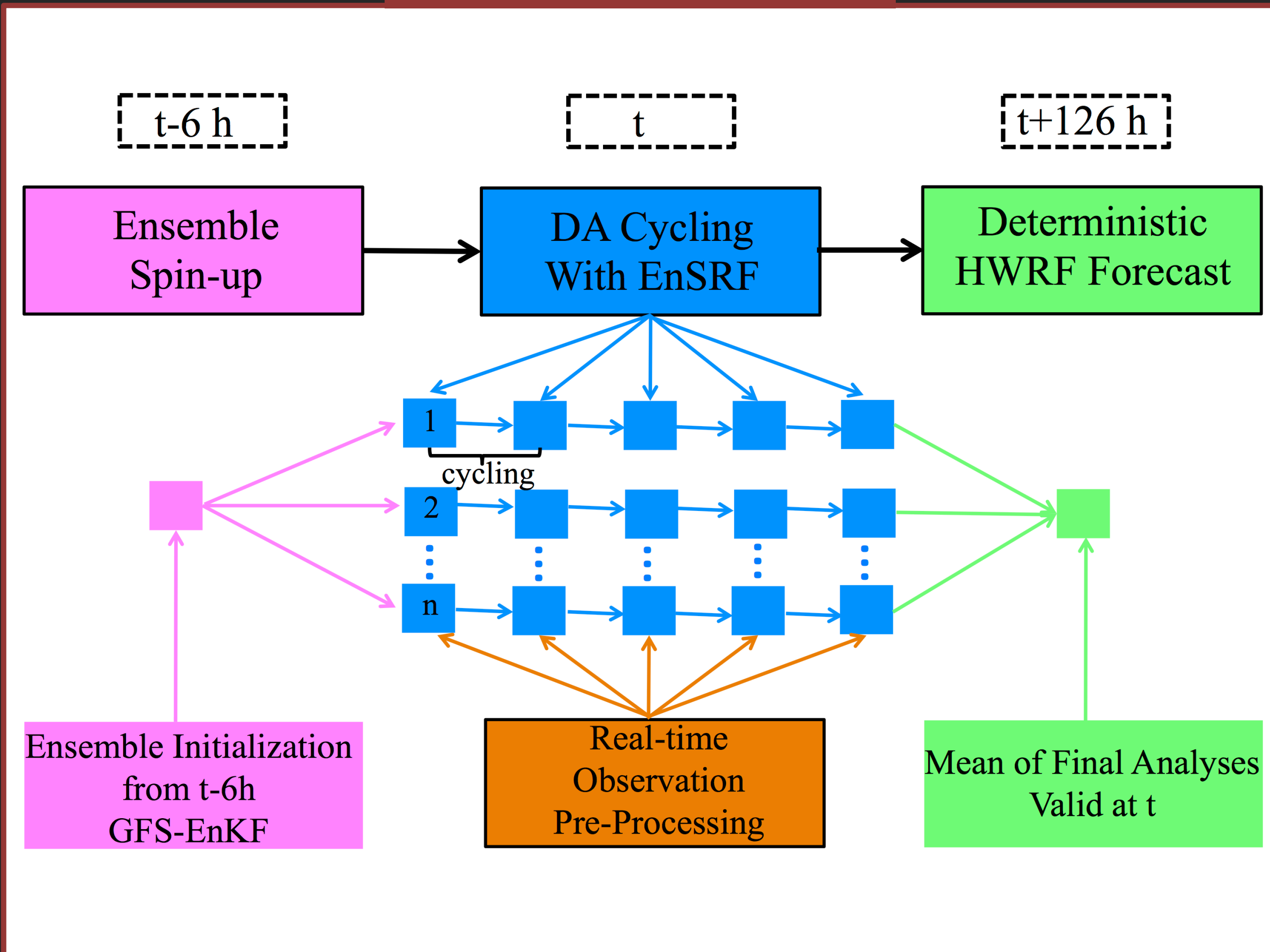



Courtesy: Brian McNoldy & Bachir Annane (U. Miami)

# Hurricane Ensemble Data Assimilation System (HEDAS)

## NOAA/AOML/HRD's Vortex-Scale Data Assimilation System

### HEDAS Schematic



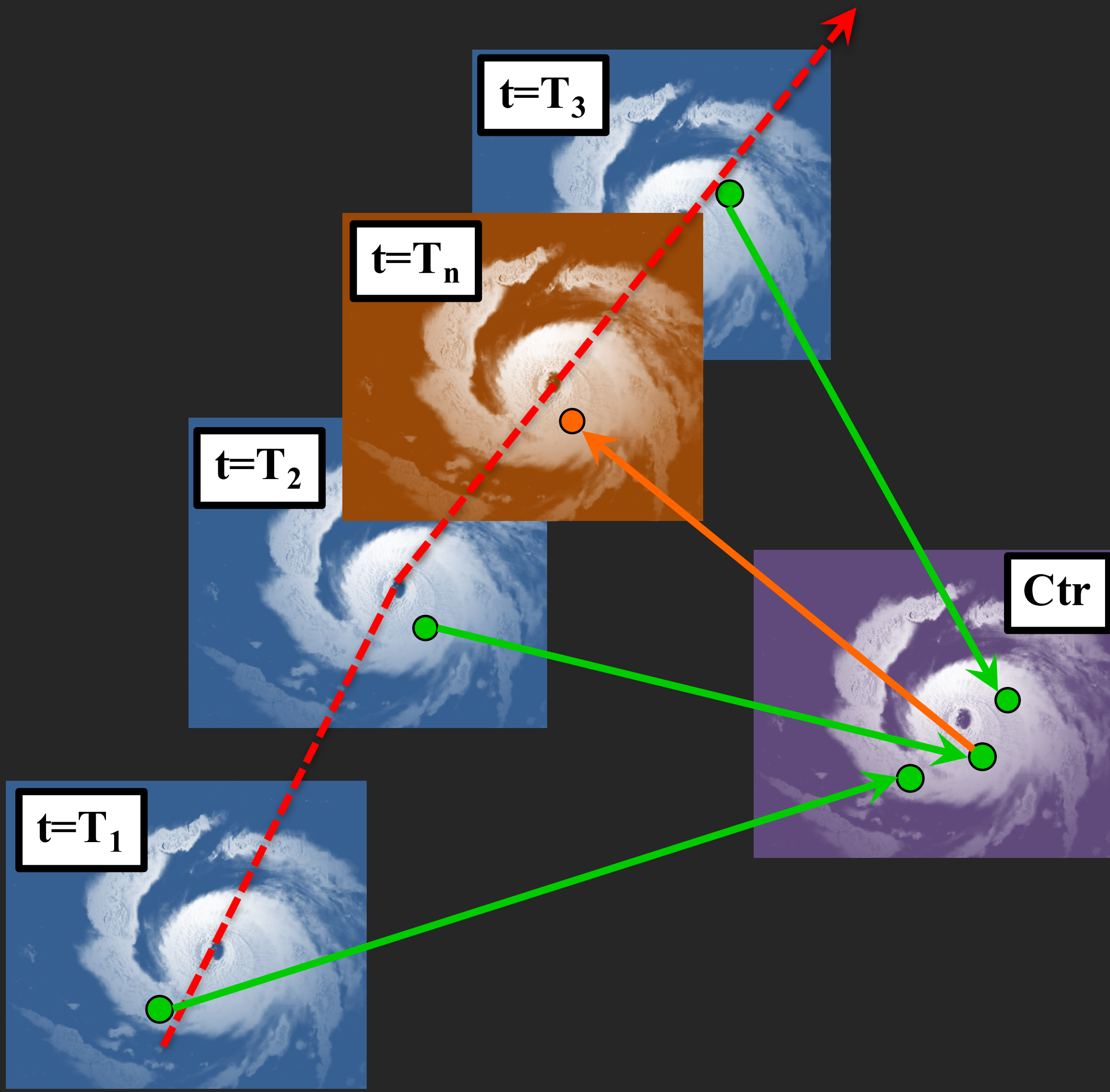

### HEDAS Characteristics

- Focus on tropical cyclone inner-core data assimilation for high-resolution vortex initialization
- Uses the ensemble square-root Kalman filter (Whitaker and Hamill 2002)
- Storm-relative observation processing capability (Aksoy 2013)
- Interfaced with NOAA's HWRF model
- Deterministic HWRF forecasts initialized with the HEDAS mean vortex analysis

### Aircraft/Platforms Processed:

NOAA P-3
NOAA G-IV
Air Force Reserve C-130
NASA Global Hawk
Coyote
Satellite AMVs
AIRS & GPS-RO Retrievals

# Storm-Relative Observation Processing



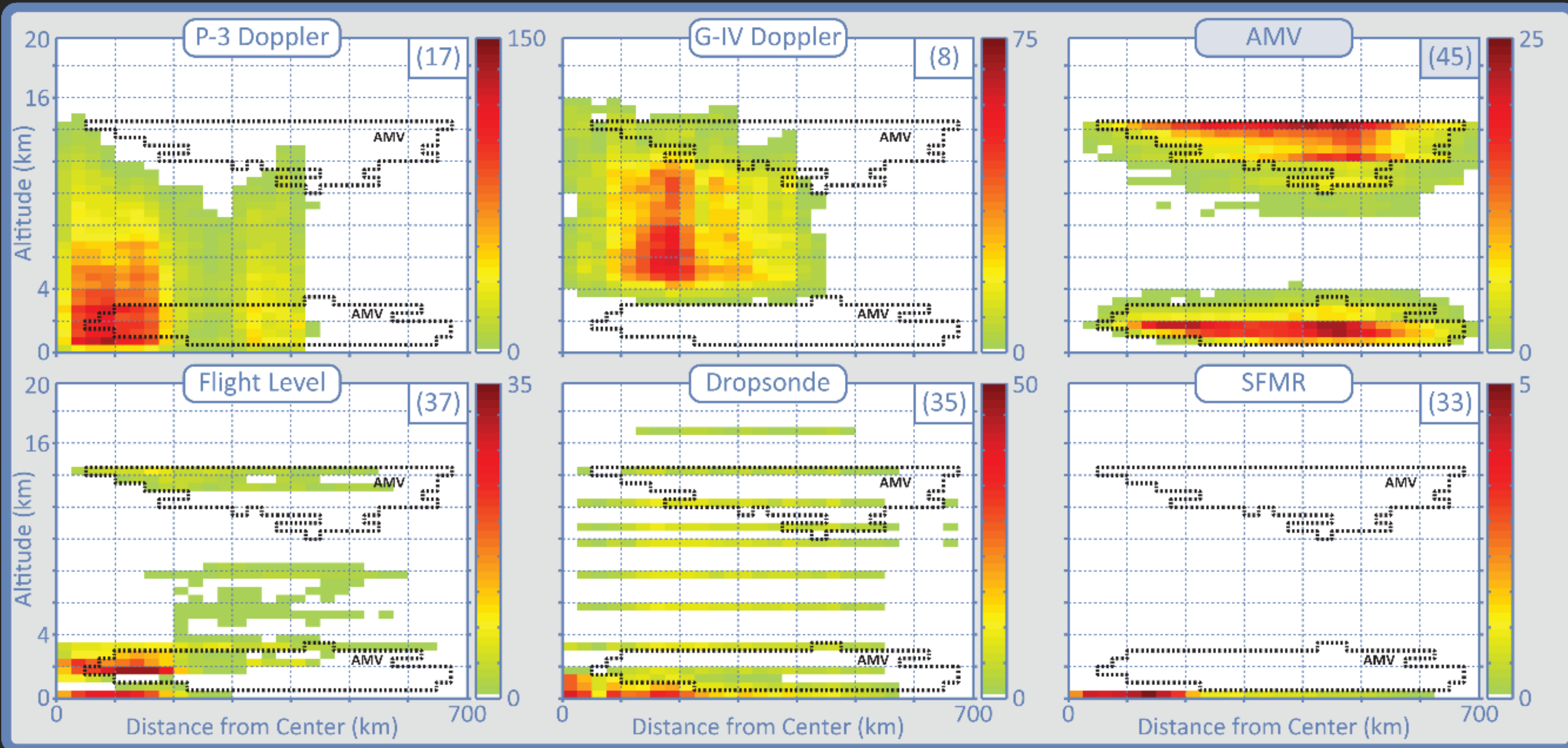

**Assuming a Steady-State Tropical Cyclone:**

- **Allows observations to be randomly assigned to any number of DA cycles**
- **Provides homogeneous observation coverage in all DA cycles**
- **Allows for frequent "sub-cycling" to obtain a vortex-scale analysis with better balance**

# Where Are We Lacking Observations?

## Example: All HEDAS Cases in 2013

**Wind Observations**

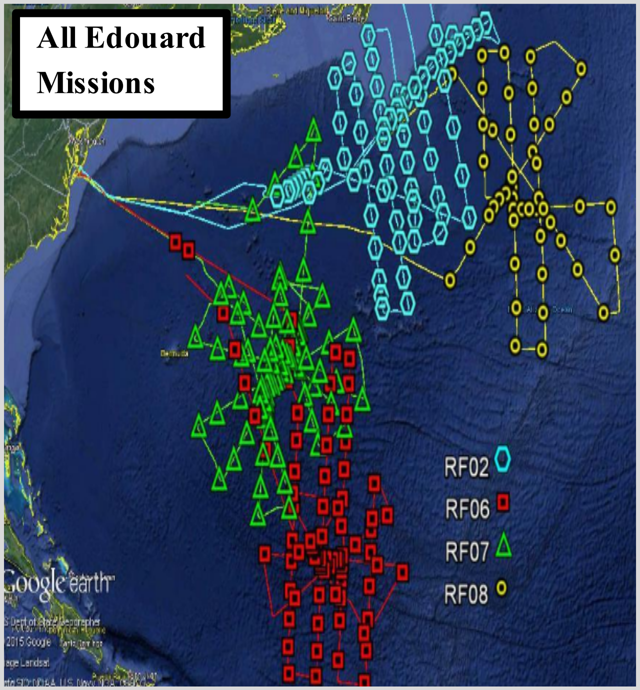



Observation Density: Azimuthally Averaged within 500-m Height x 25-km Radius Boxes
(Number of Cases: Upper Right in Parantheses)

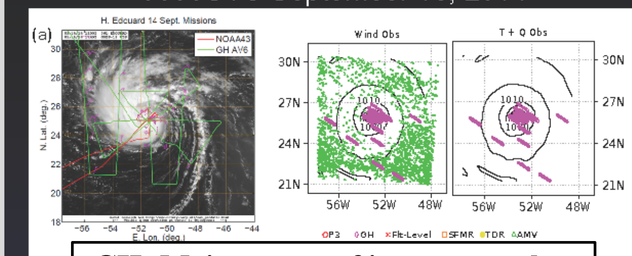
# Ongoing Projects: Global Hawk Dropsonde - HEDAS

## Hurricane Edouard (2014) Sep. 15 vs 16 Case Study

**All Edouard Missions**

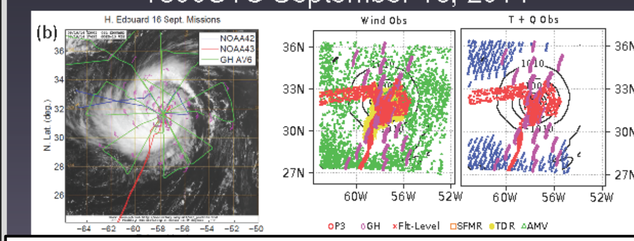



0000UTC September 15, 2014

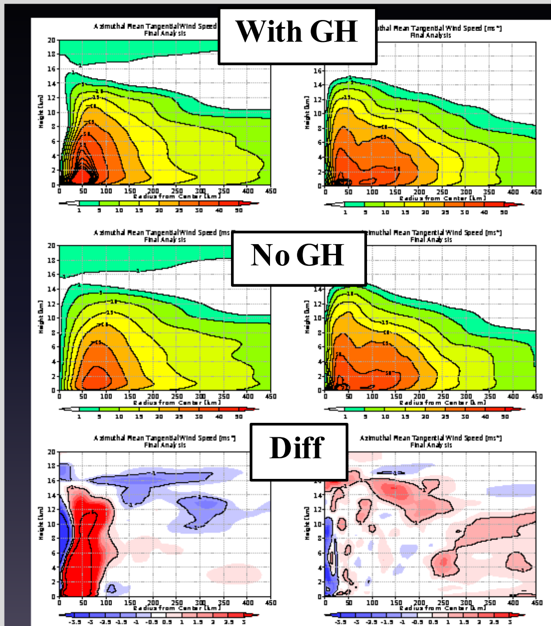



**GH: Main source of inner-core obs.**

1800UTC September 16, 2014

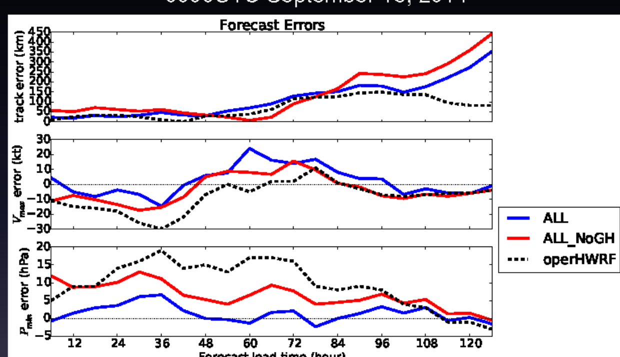



**GH: Competes w/ other aircraft in inner core**



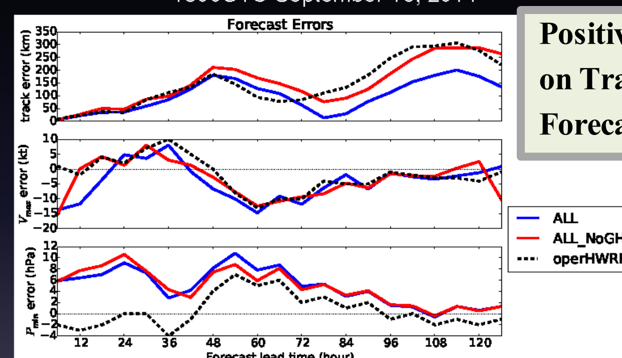

Sept 15 Sept 16

0000UTC September 15, 2014




**Positive Impact on Intensity Forecast**

1800UTC September 16, 2014

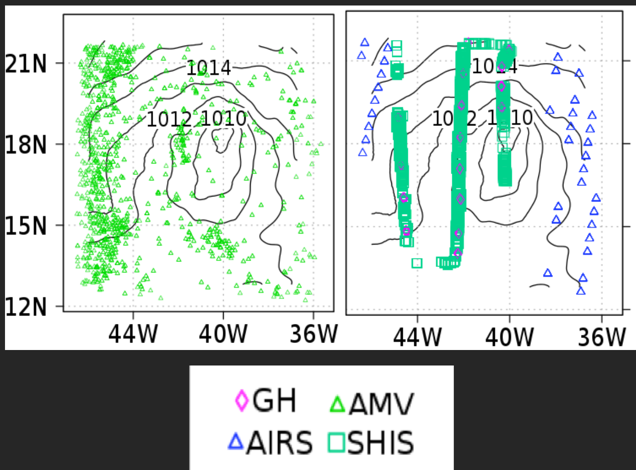



**Positive Impact on Track Forecast**

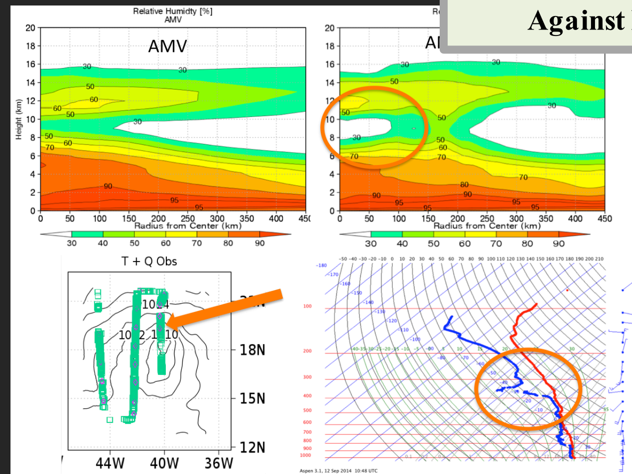
Courtesy: Hui Christophersen (HRD)

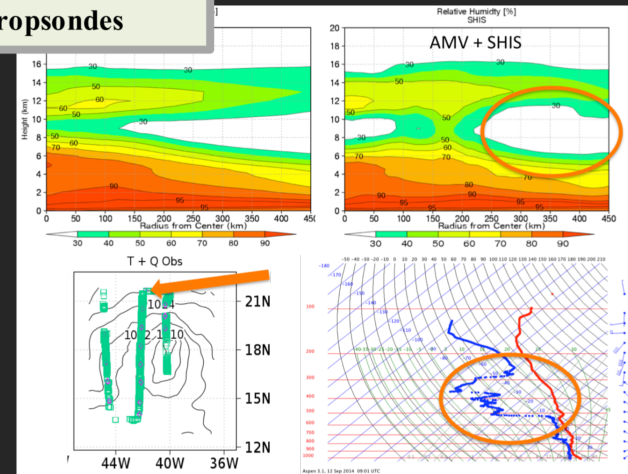
# Ongoing Projects: Global Hawk T/Q vs AIRS - HEDAS

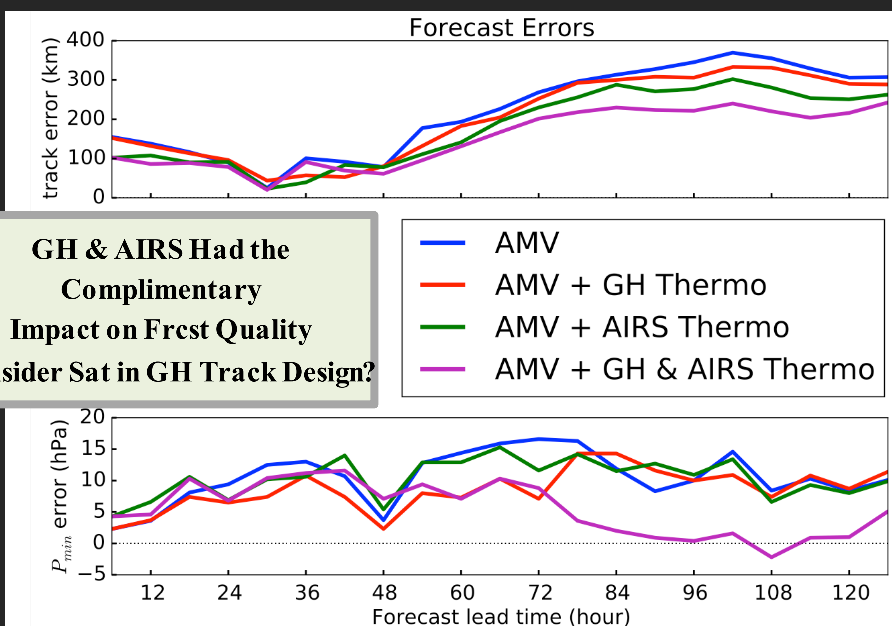
## Hurricane Edouard (2014) Sep. 12 Case Study



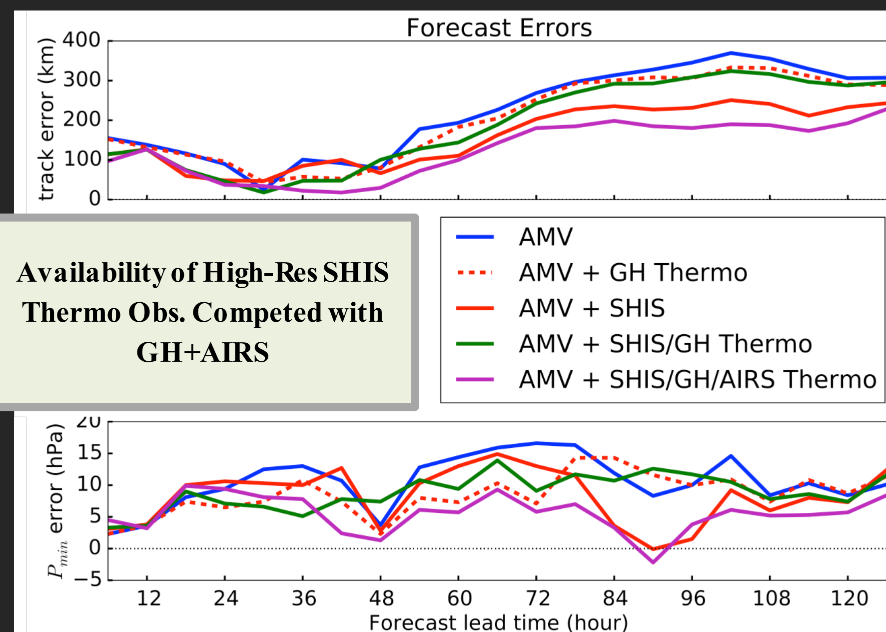

**SHIS Assimilation Verifies Well Against Dropsondes**




**GH & AIRS Had the Complimentary Impact on Frcst Quality**
**Consider Sat in GH Track Design?**



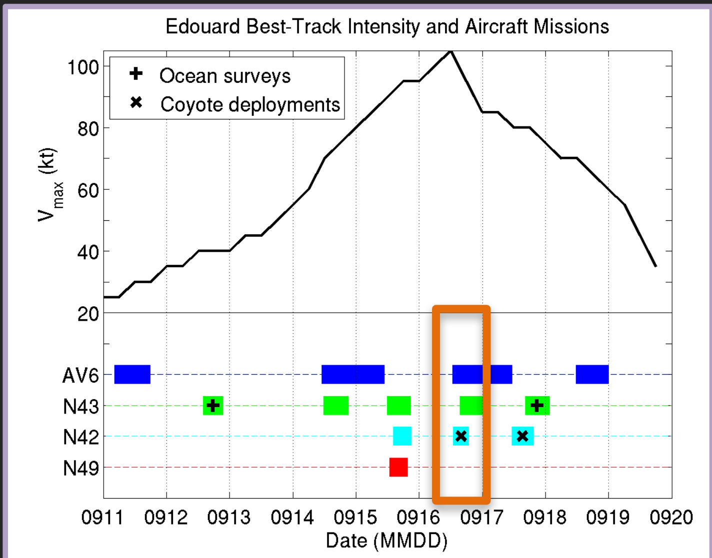

**Availability of High-Res SHIS Thermo Obs. Competed with GH+AIRS**

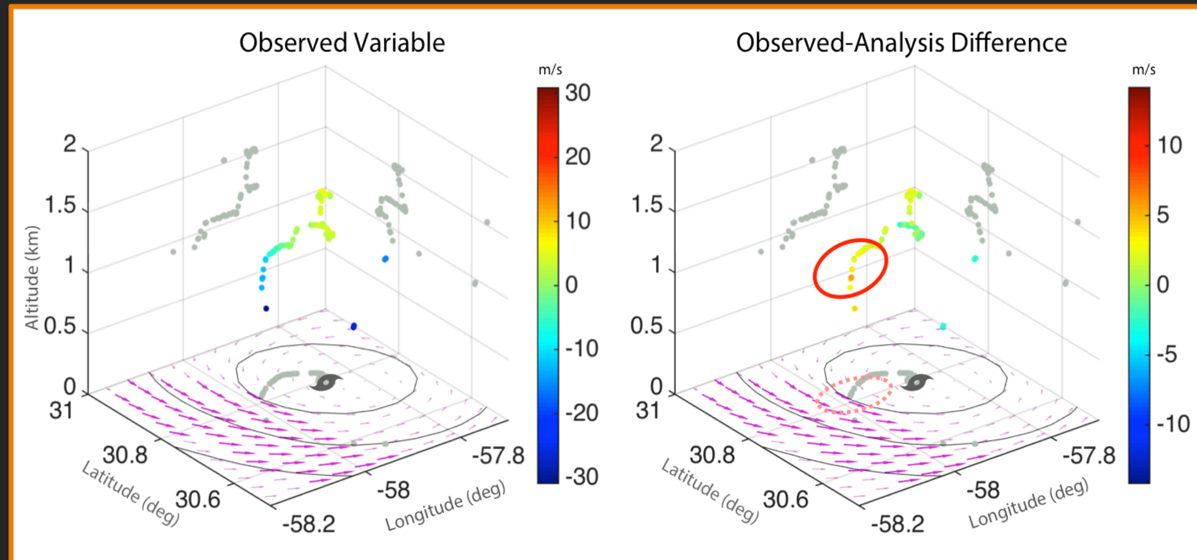
Courtesy: Hui Christophersen (HRD)

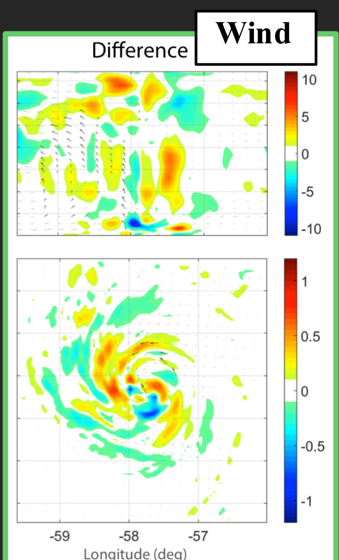
# Ongoing Projects: Impact of Coyote Observations

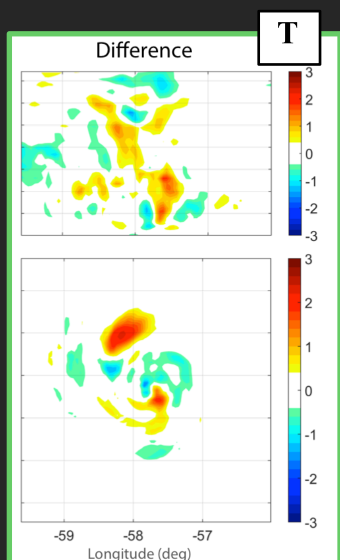
**16 September 2014 1432Z: First of Only Two Successful Missions of Coyote**

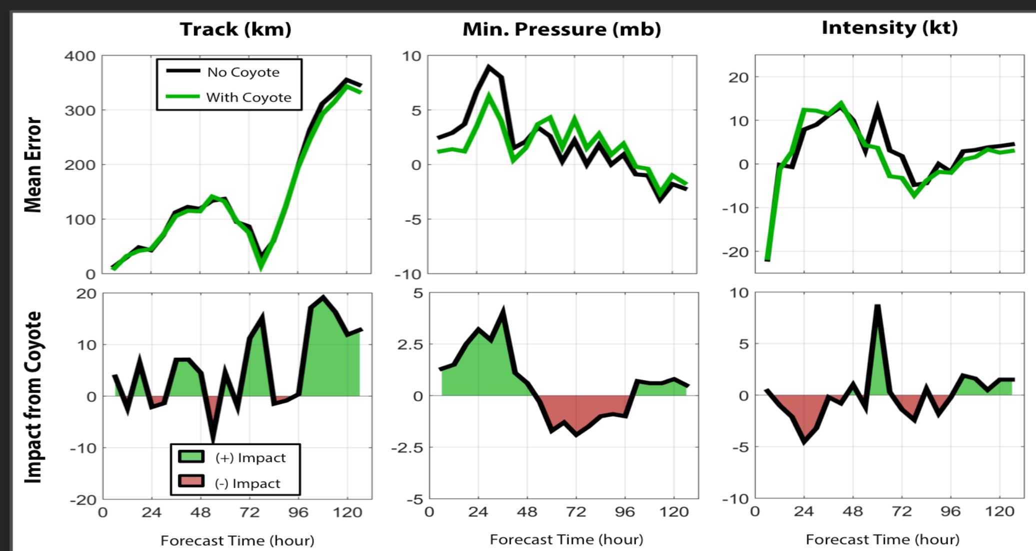
Eye/Eyewall Sampling | 28-minute Mission | Min. Altitude 896 m | Max. Wind Speed 100 kt



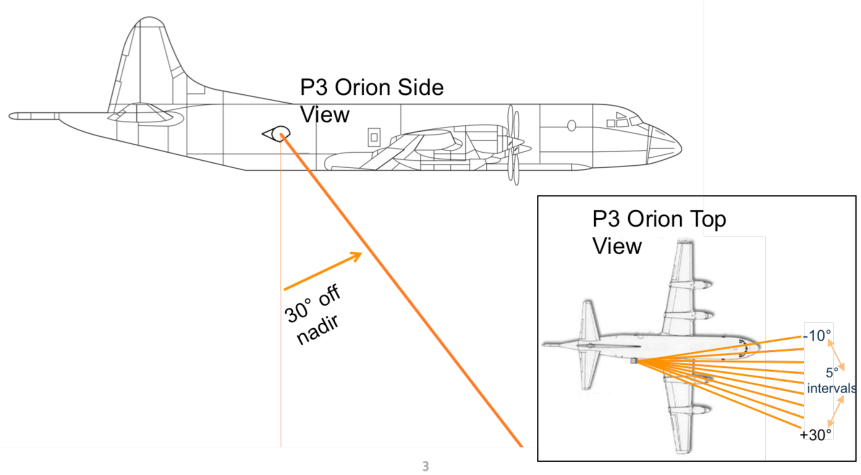



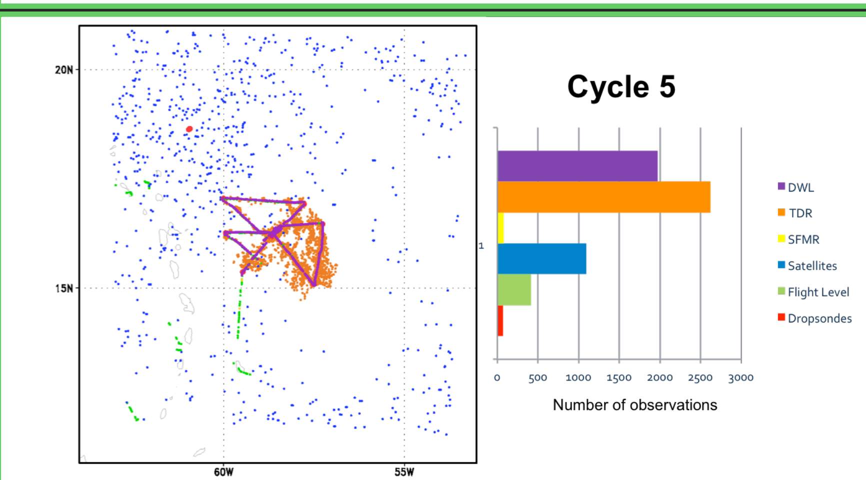



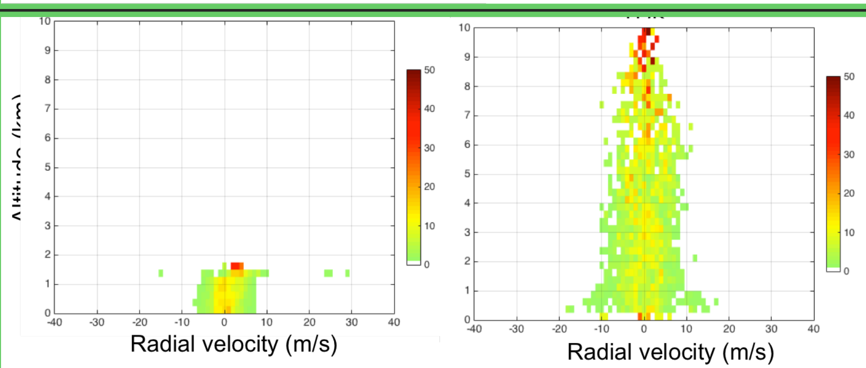



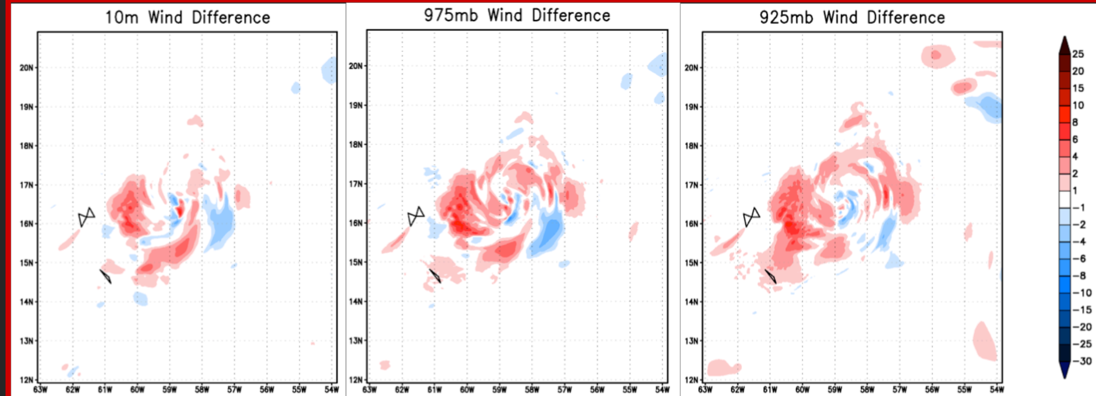
# Ongoing Projects: Impact Doppler Wind Lidar

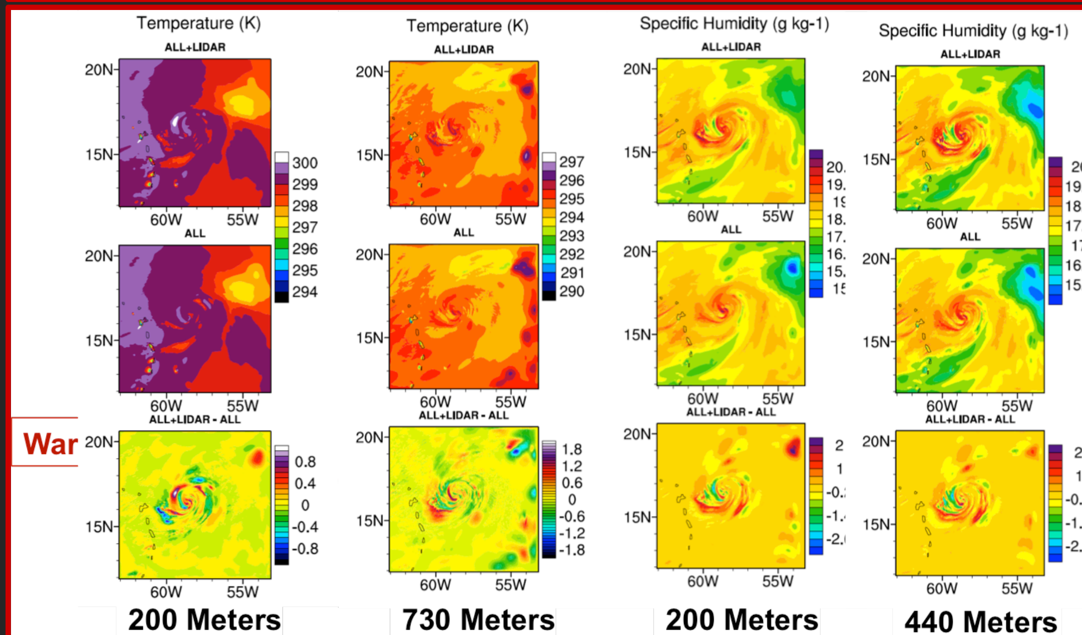



**7 DWL Missions into TS Danny and Erika (2016)**



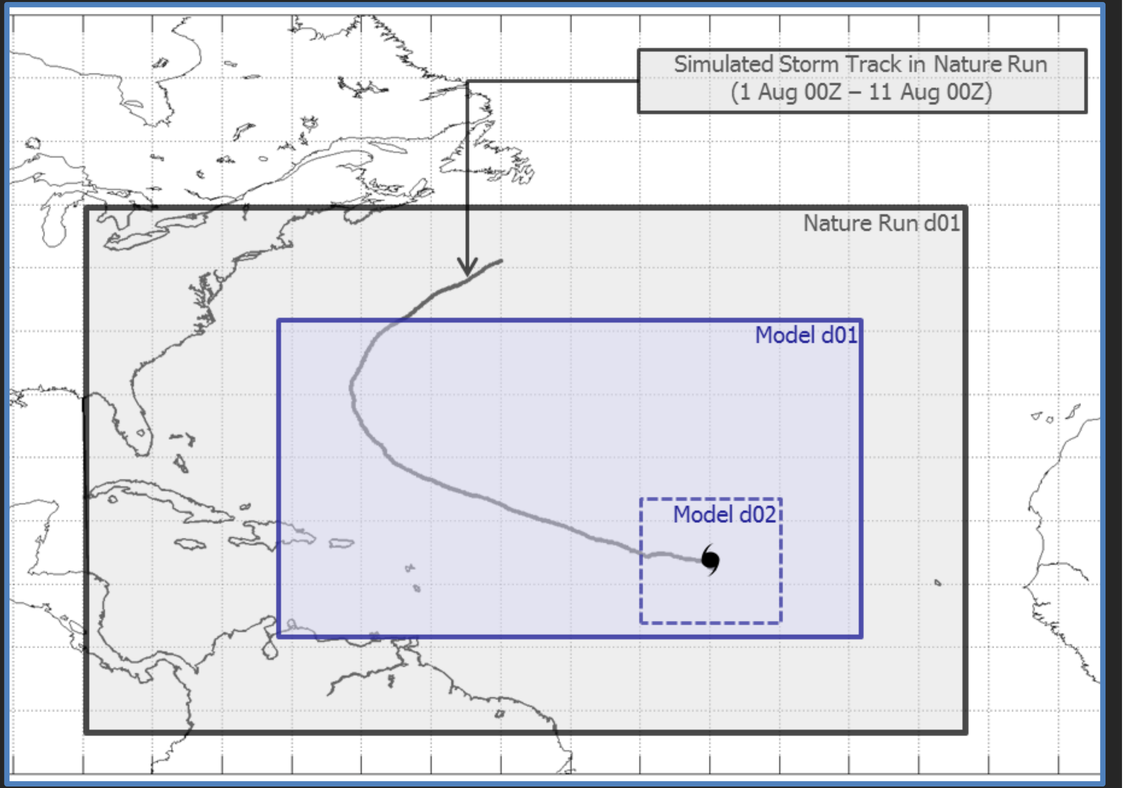




Lidar Data Had Significant Impact on Wind and Thermodynamic Analysis of the Vortex Structure

Courtesy: Lisa Bucci (HRD)

# HRD's Hurricane OSSE Framework

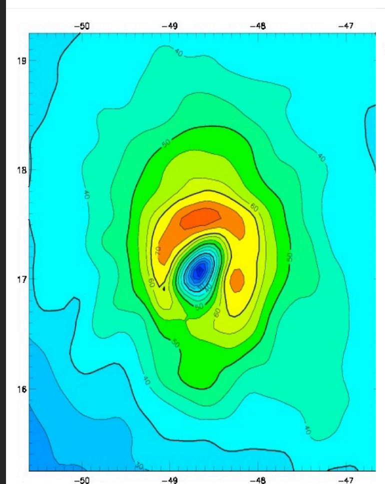
- Nature Runs
  - **Global:** ECMWF: low-resolution (~40 km) "Joint OSSE Nature Run"
  - **Regional (North Atlantic):** WRF-ARW: high-resolution (27 km) regional domain, 9/3/1-km nests (v3.2.1)
- Data Assimilation Scheme
  - **GSI:** Gridpoint Statistical Interpolation… standard 3D variational assimilation scheme (v3.3). Analyses performed on 9-km grid.
- Forecast Model
  - **HWRF:** the 2014 'operational' Hurricane-WRF model (v3.5). Parent domain has 9-km resolution, single storm-following nest has 3-km resolution.




Courtesy: Brian McNoldy & Bachir Annane (U. Miami)

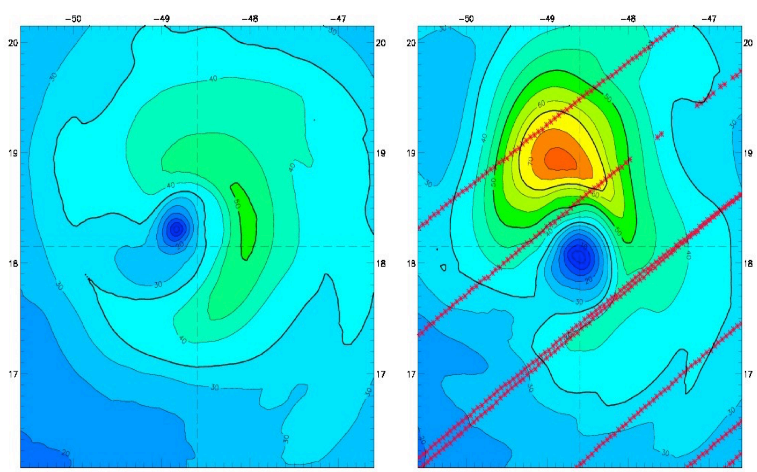
# Ongoing Projects: Impact of CYGNSS Wind Speed

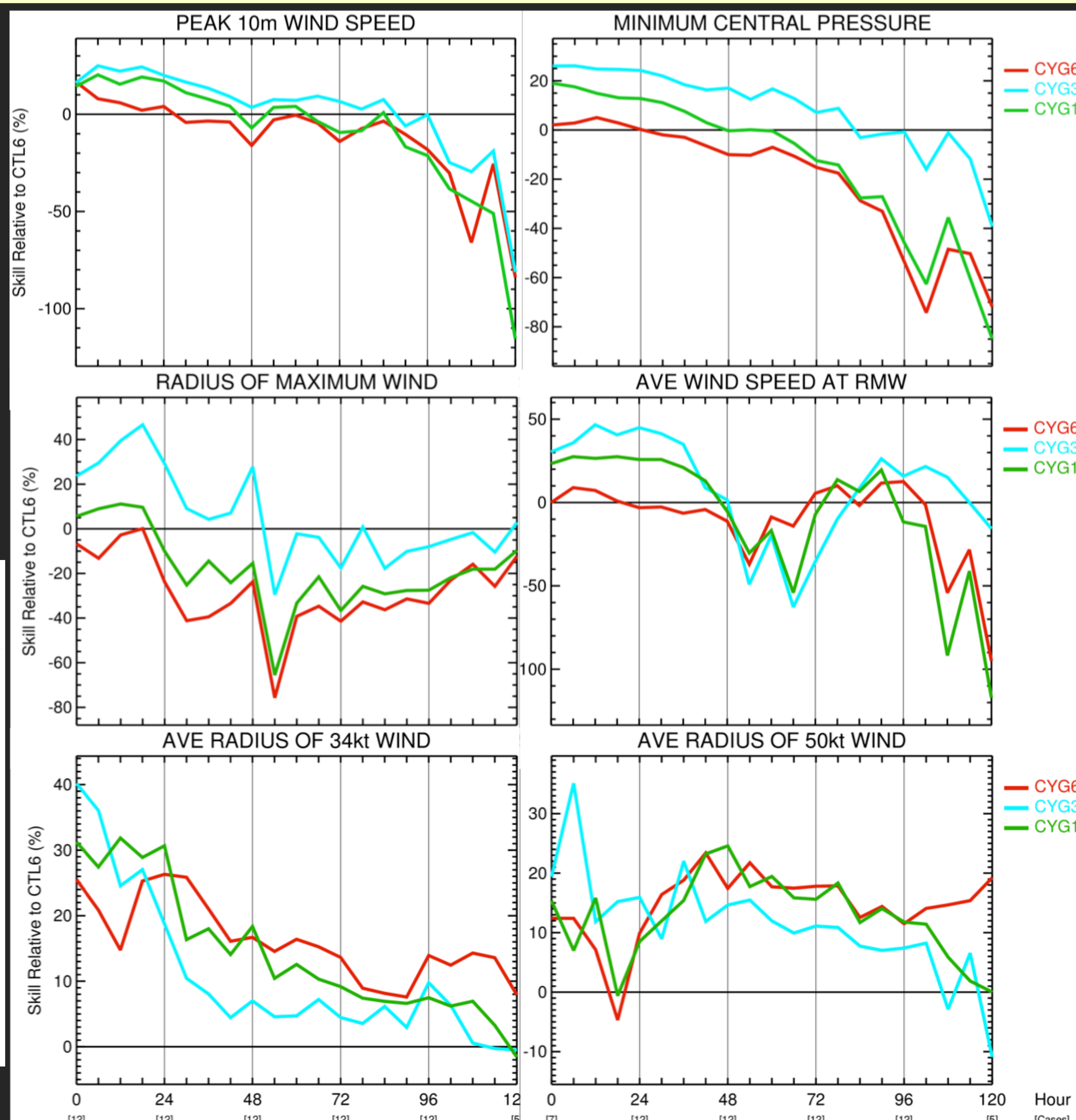
**Nature**
**79.1KTS, 968.9 MB**



**Control**
**51.6 kts , 986.62 mb**

**Control+CYGNSS**
**77.1kts, 987.7mb**






Courtesy: Brian McNoldy & Bachir Annane (U. Miami)



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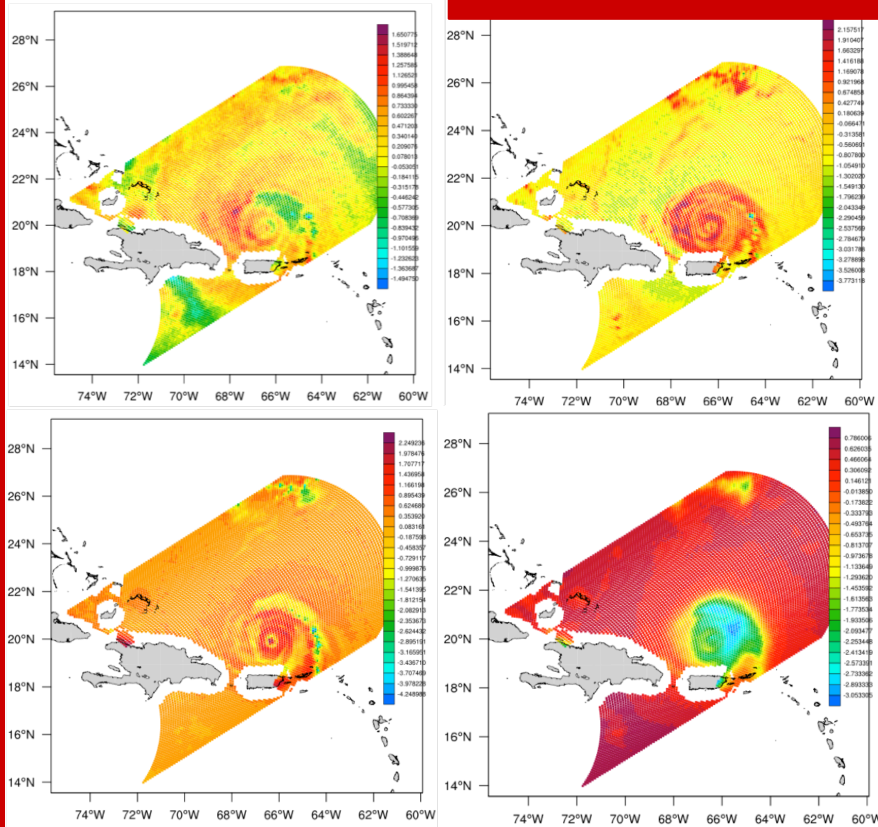
# Ongoing Projects: Canonical Correlation Vectors

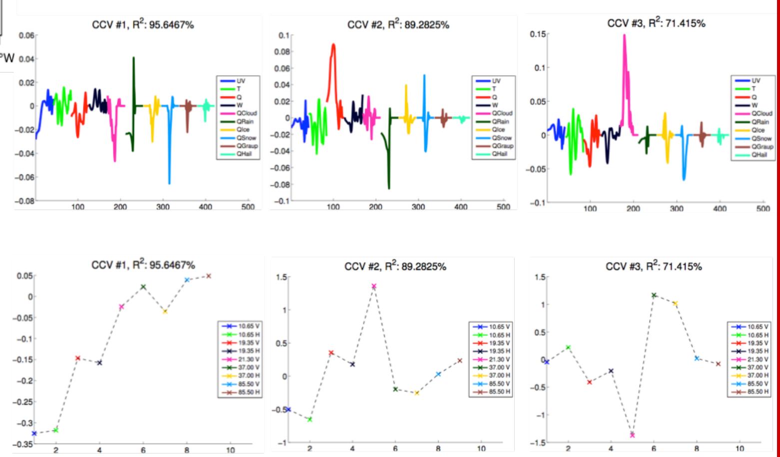
Please See Jeff Steward's Poster



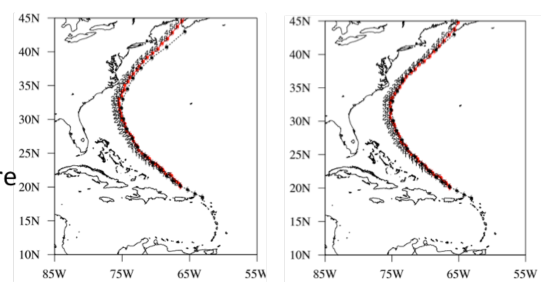

Satellites have good spatial and temporal coverage but remain underutilized in data assimilation especially in cloudy areas. Satellites make up around 90% of the available observations but currently more than 75% are thrown away due to issues with "cloud contamination."

As part of the HFIP, JPL/UCLA collaborates with HRD to implement a novel observation operator based on the statistical extraction of maximally certain information from satellite observations. This information is especially amenable to data assimilation. This is potentially a way to recover massive amounts of useful data for hurricane DA. Below: the CCV obs/model vectors.

Above: CCV Observations of Earl during eyewall replacement from TRMM/TMI, giving uncorrelated "views" of the storm. only the first 3 have a high enough $R^2$ enough to warrant inclusion.




Right: Track before and after DA with these observations v/ best track (left: no obs). More testing is needed.




Courtesy: Jeff Steward (NASA/JPL)

# Thank You!

For HRD data, please visit:
http://www.aoml.noaa.gov/hrd/data_sub/hurr.html

Flying in a Hurricane -- Hurricane Patricia 23 Oct 2015 NOAA P-3 Flight
(Experienced ~2000 ft / 650 m drop flying through the eye)

# Ongoing Projects

## Data Impact

### OSEs

- Tail Doppler Radar
- Doppler Wind Lidar
- Coyote
- Global Hawk Dropsondes
- Global Hawk S-HIS
- Atmospheric Motion Vectors
- AIRS Retrievals

### OSSEs

- G-IV Dropsonde Impact
- Coyote Impact
- Global Hawk Impact
- CYGNSS

## New/Improved DA Methods

- Parallel EnKF Methods
- Canonical Correlation Vectors
- EnKF Optimization for New Datasets
- Background QC Methods