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

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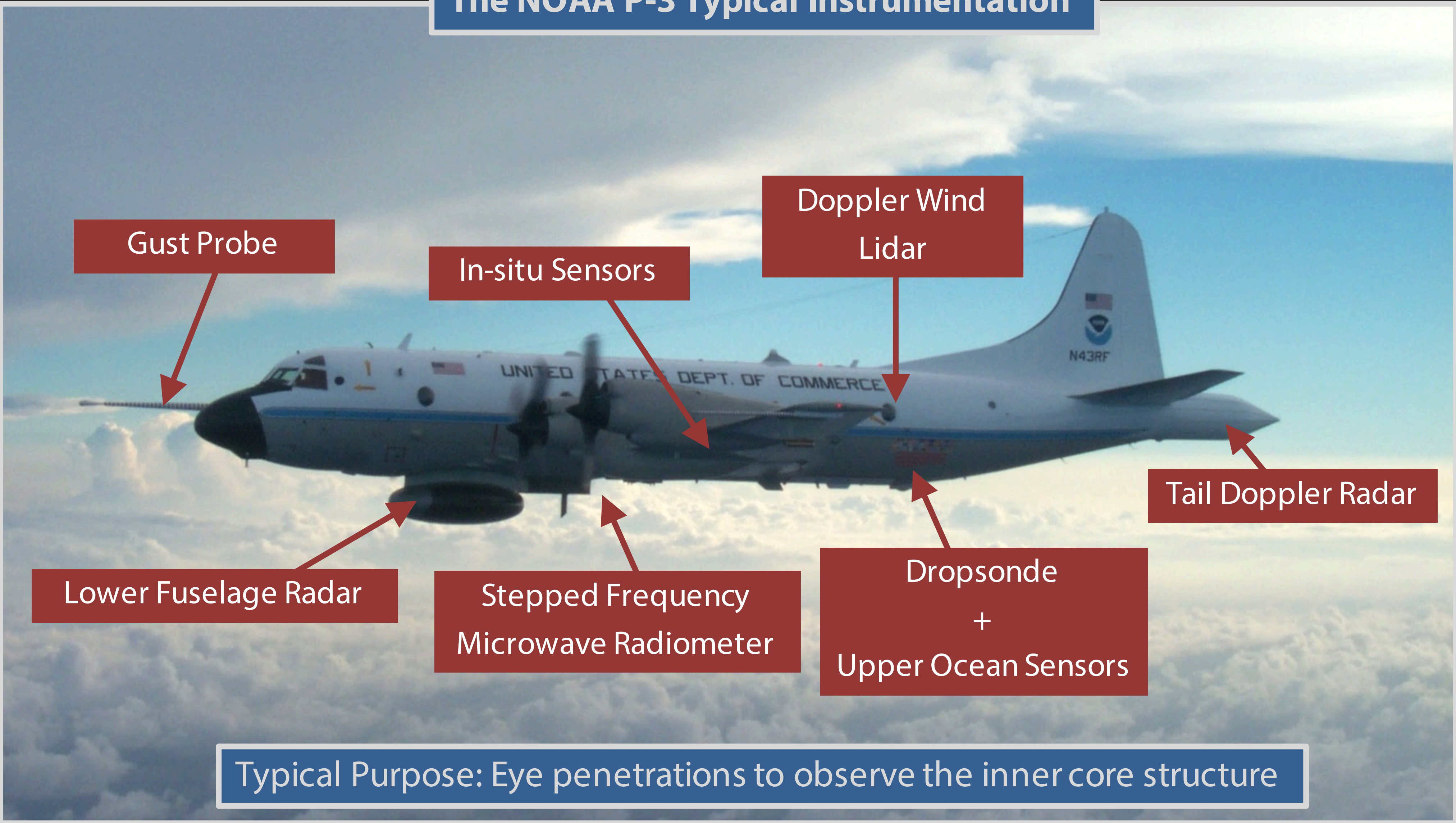
7th Ensemble Kalman Filter Workshop – State College, PA

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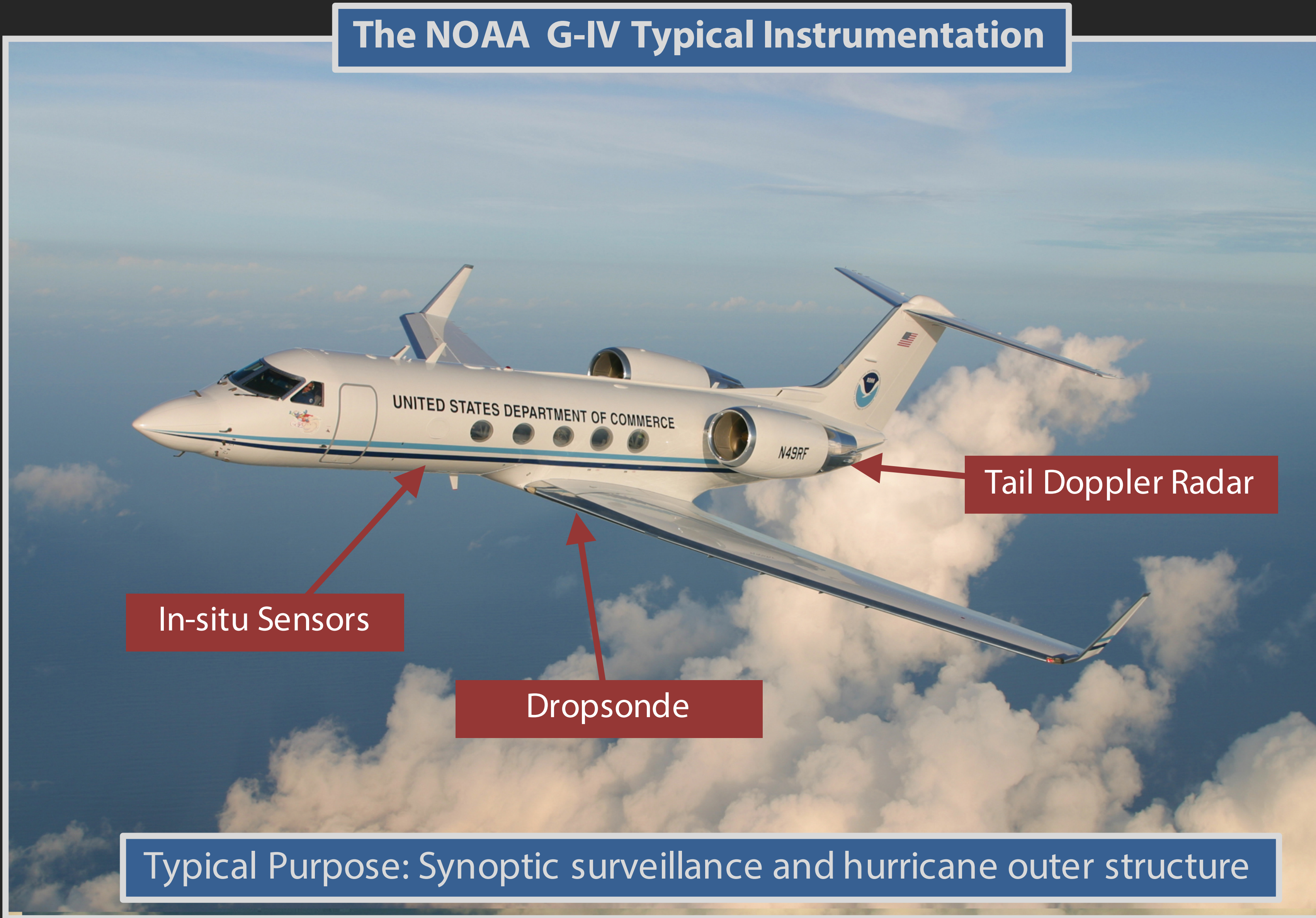
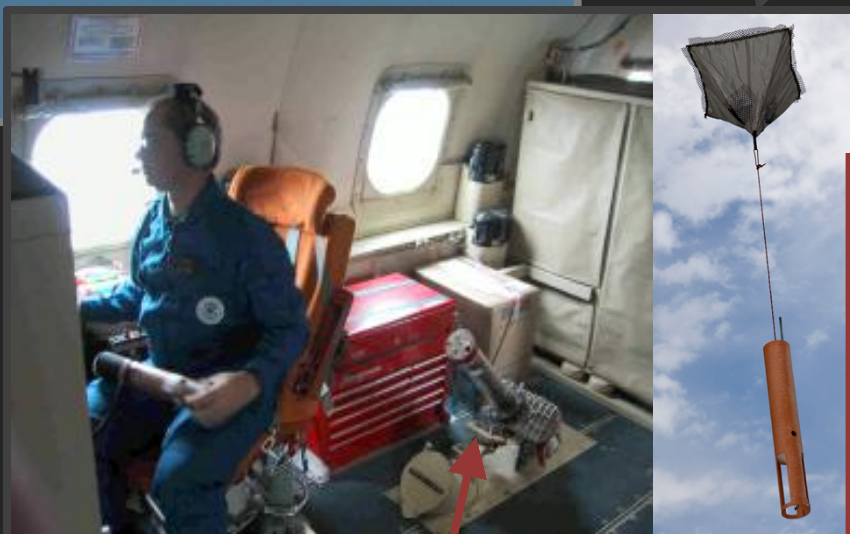
Hurricane Observing Platforms: NOAA P-3 and G-IV



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

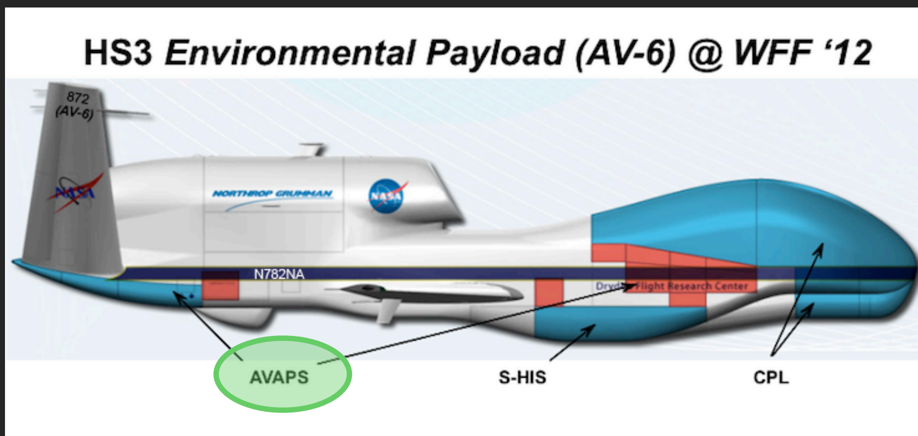
Hurricane Observing Platforms: UAS – Global Hawk

- 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)

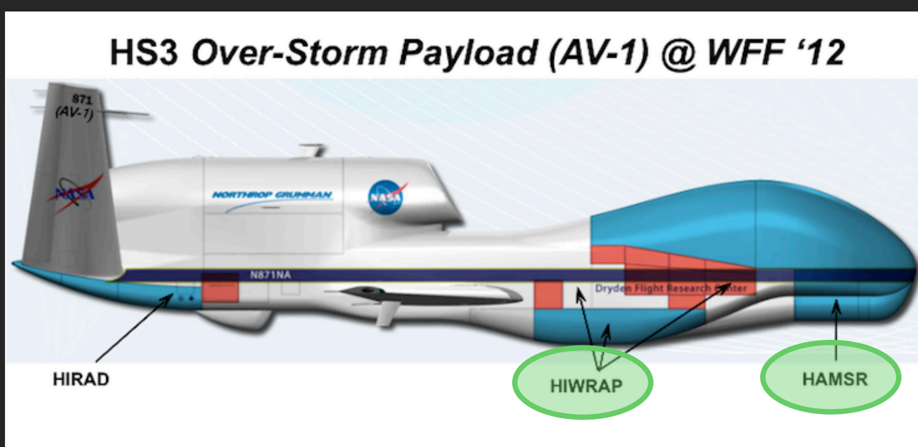
Hurricane Observing Platforms: UAS – Global Hawk

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)

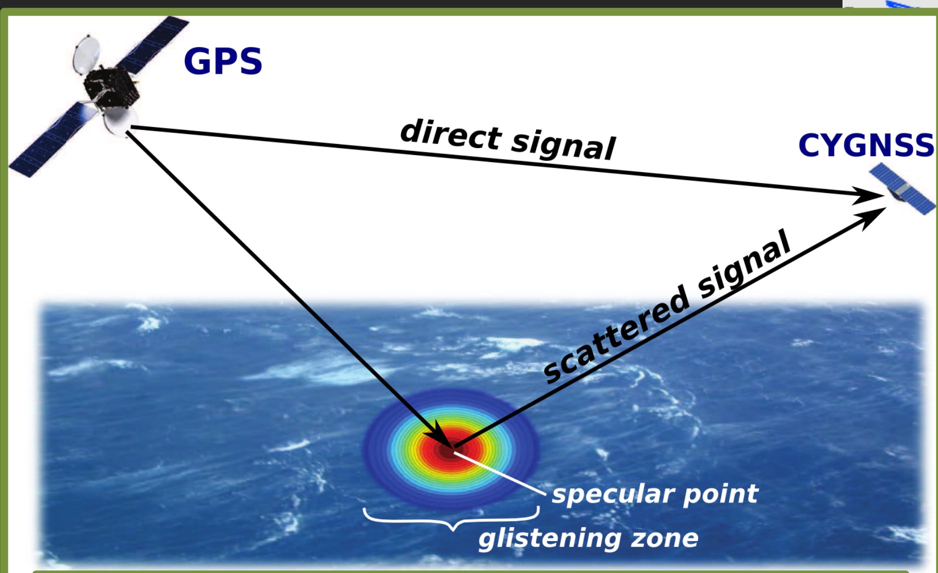
NOAA SHOUT Program Instrumentation: Dropsonde, HIWRAP, HAMSR

Courtesy: Gary Wick (NOAA)

Hurricane Observing Platforms: Satellites (CYGNSS)

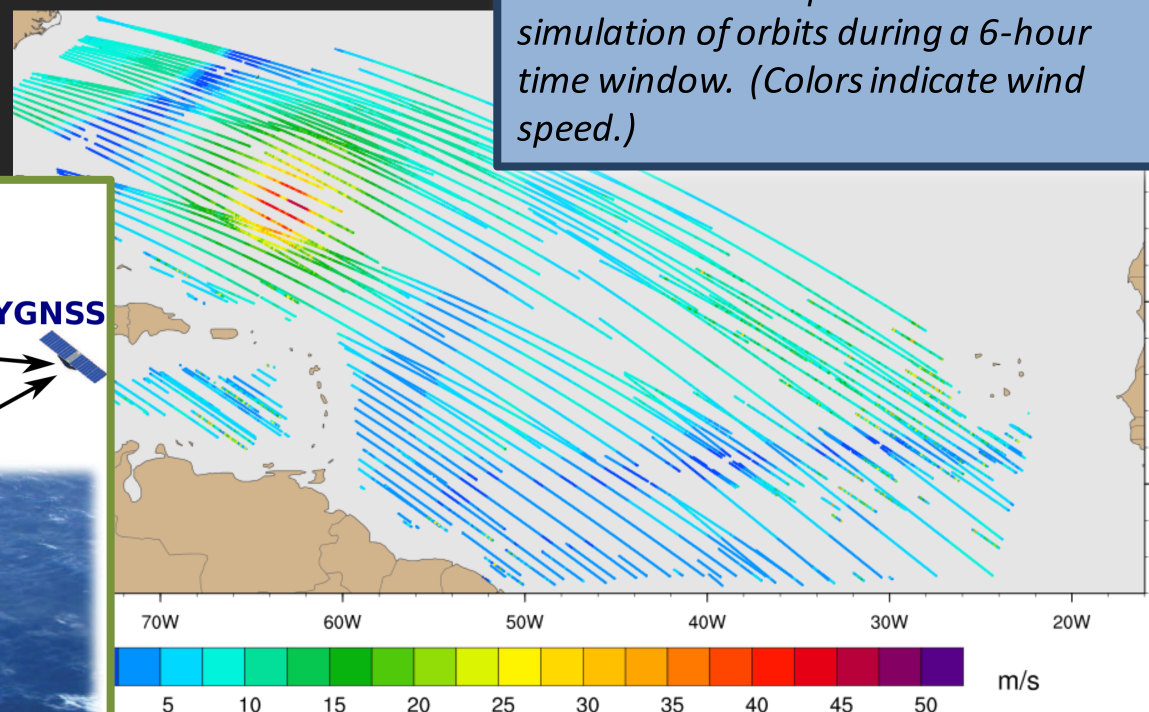
- The **CY**clone **G**lobal **N**avigation **S**atellite **S**ystem is a constellation of 8 micro-satellites scheduled for launch in late October 2016… a NASA Earth Venture Mission (Ruf et al. 2016)
- Utilizes signals from existing GPS satellites to retrieve ocean surface wind speed… surface roughness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

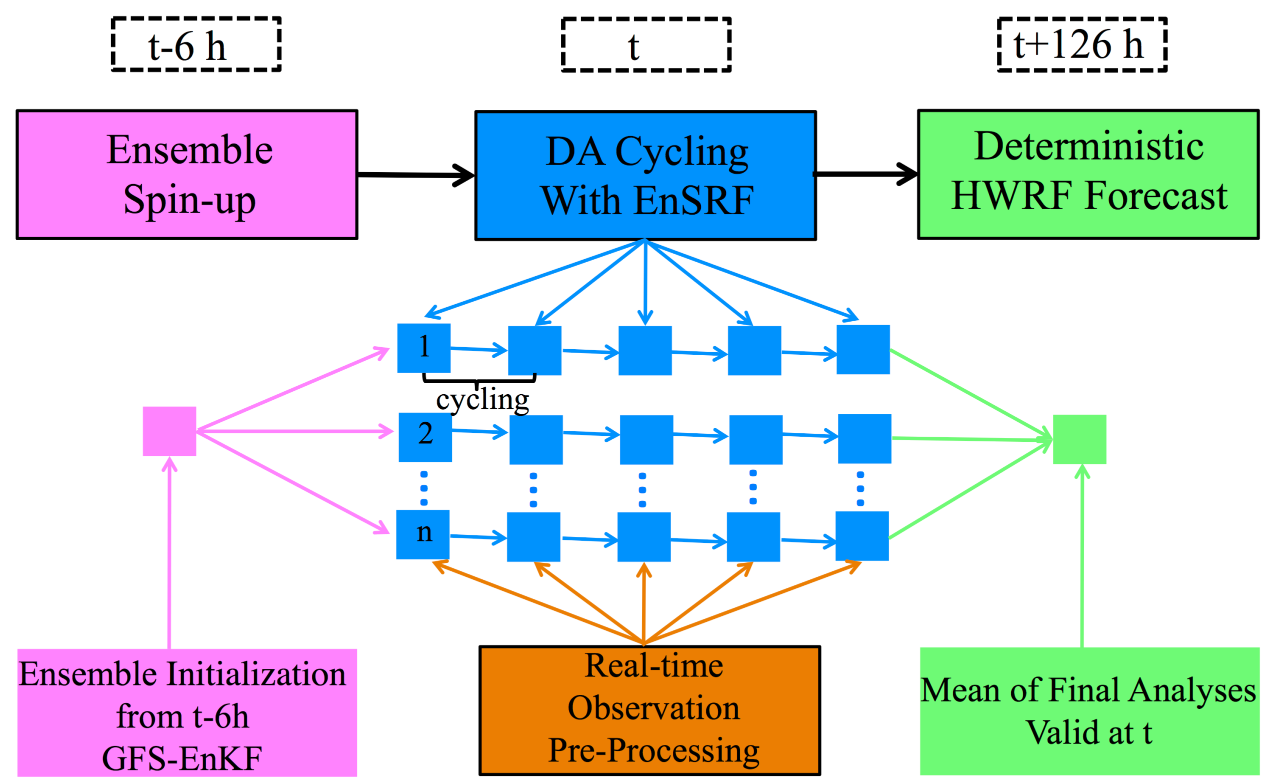


Courtesy: Brian McNoldy & Bachir Annane (U. Miami)

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

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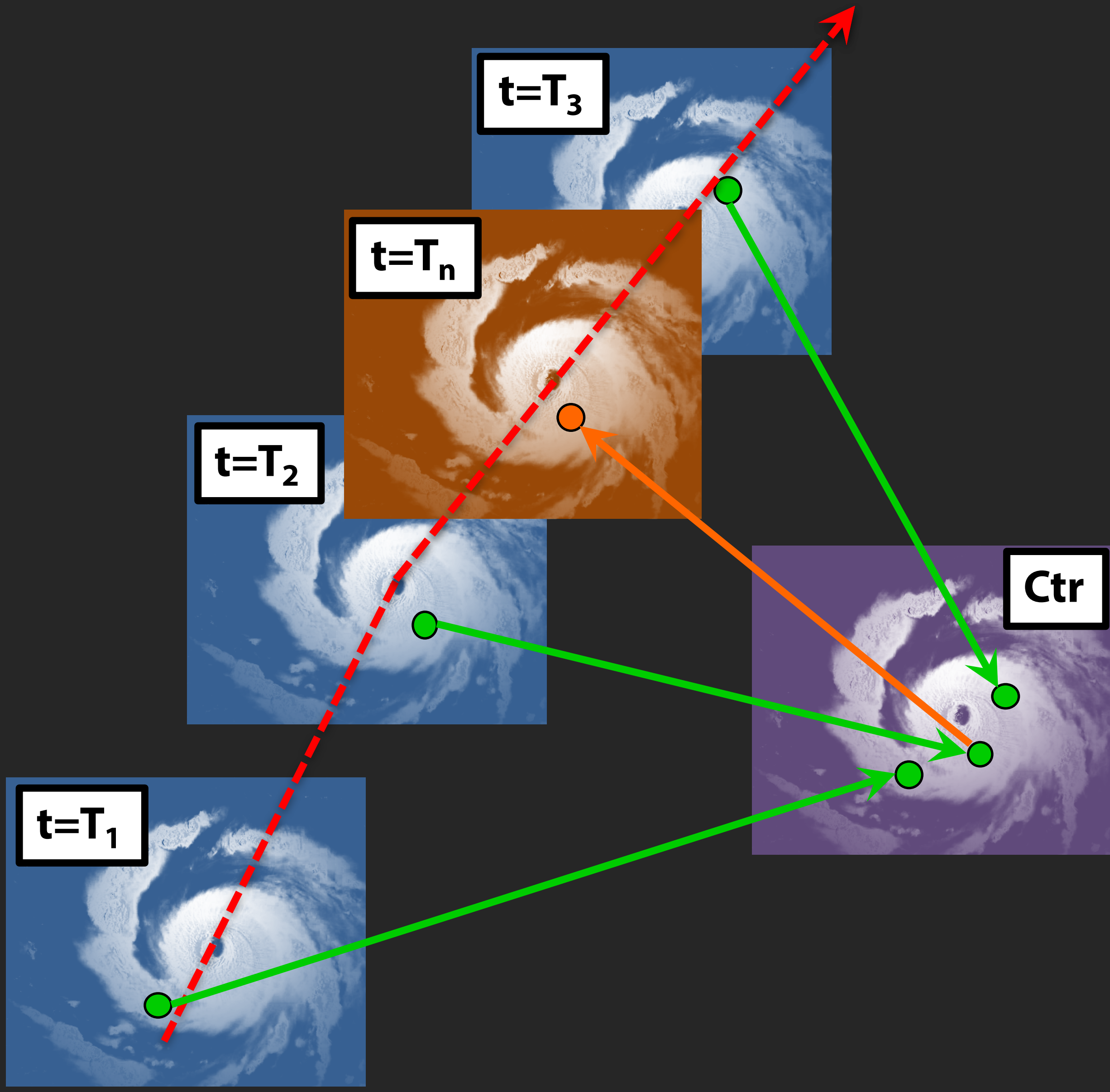
Storm-Relative Observation Processing



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

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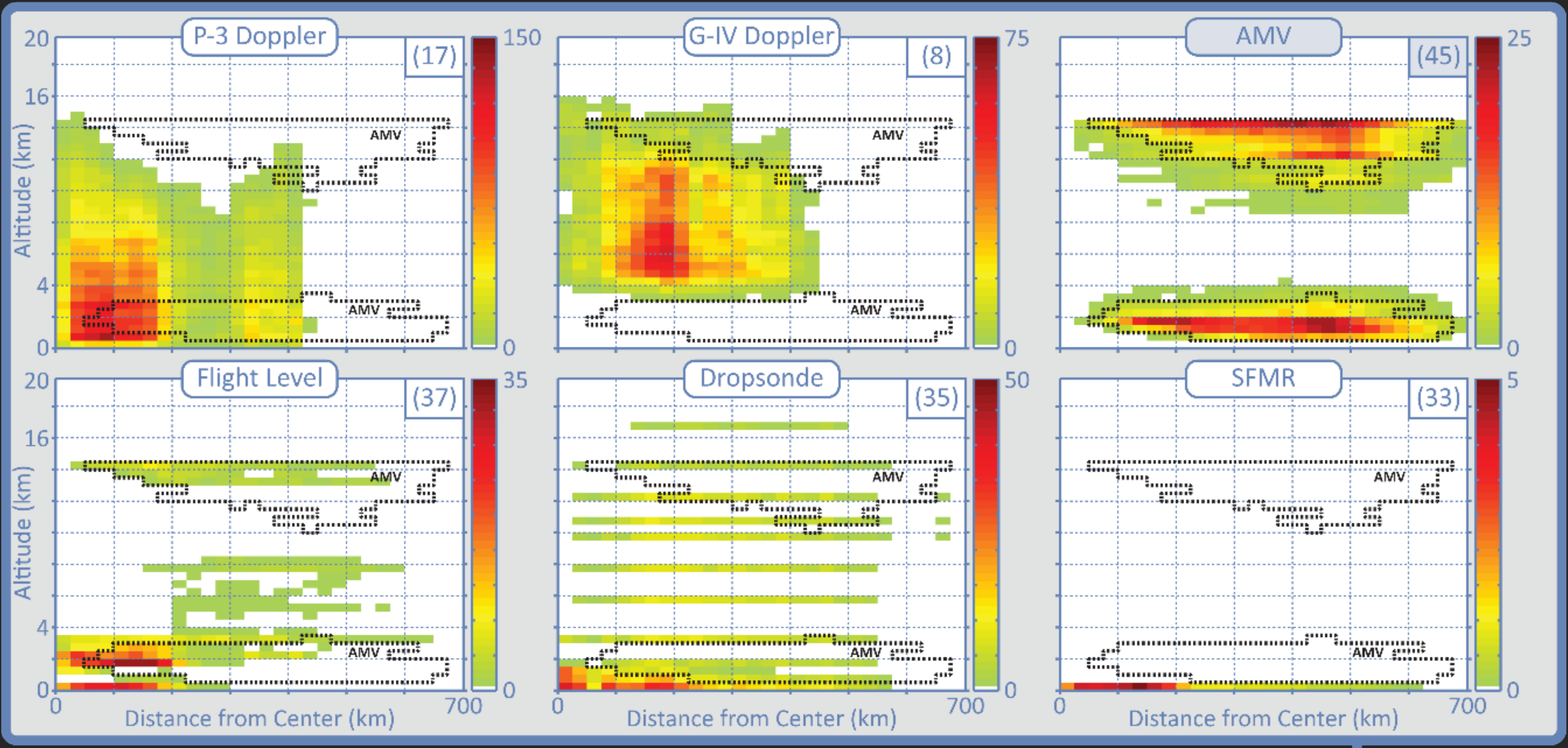
Where Are We Lacking Observations?

Example: All HEDAS Cases in 2013

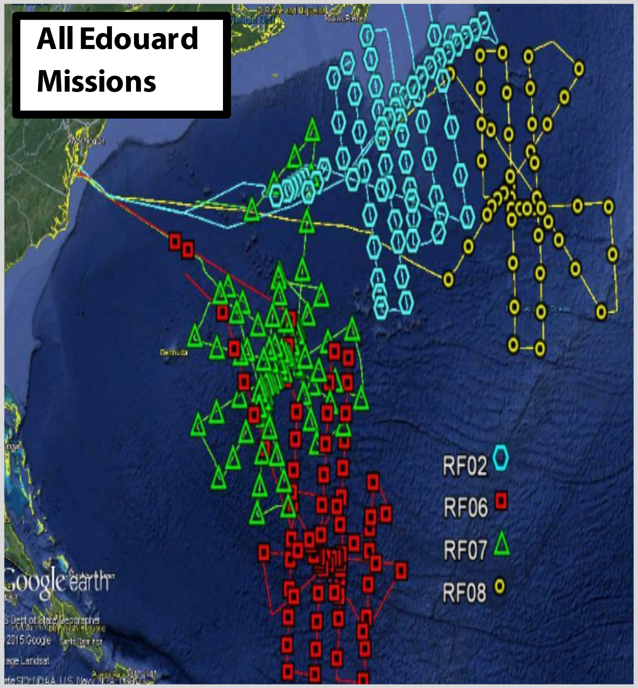
Wind Observations

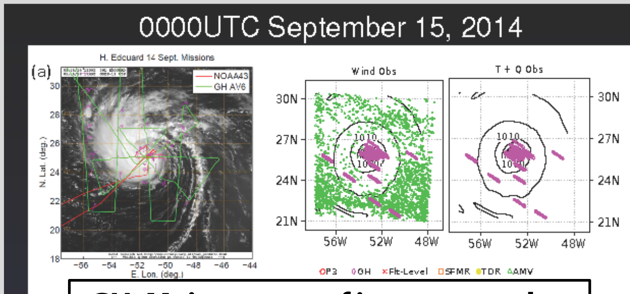


Observation Density: Azimuthally Averaged within 500-m Height x 25-km Radius Boxes
(Number of Cases: Upper Right in Parantheses)

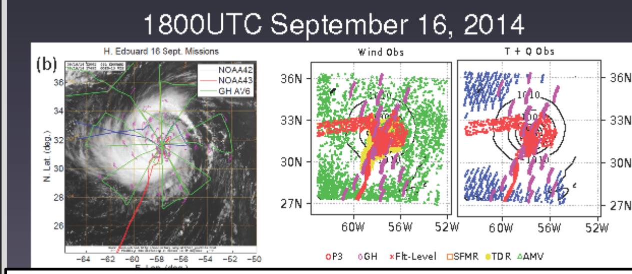
Ongoing Projects: Global Hawk Dropsonde - HEDAS

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

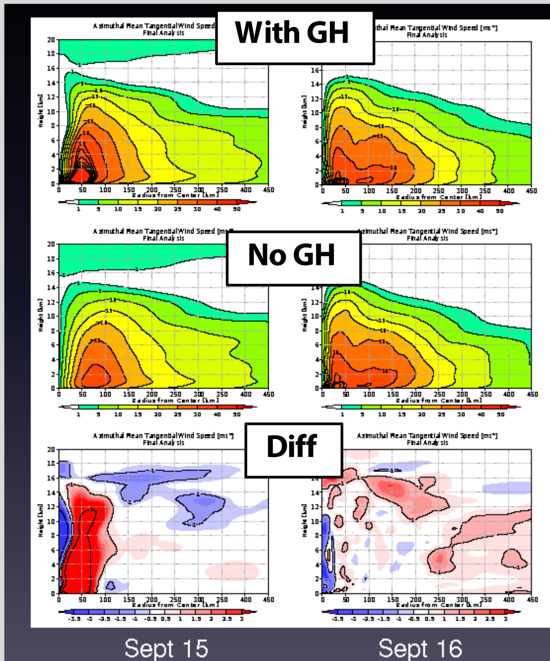




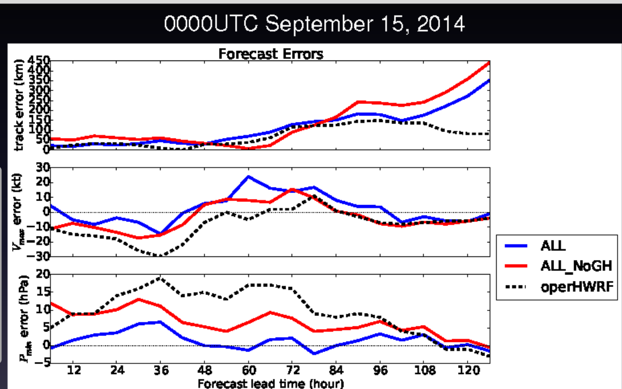
GH: Main source of inner-core obs.

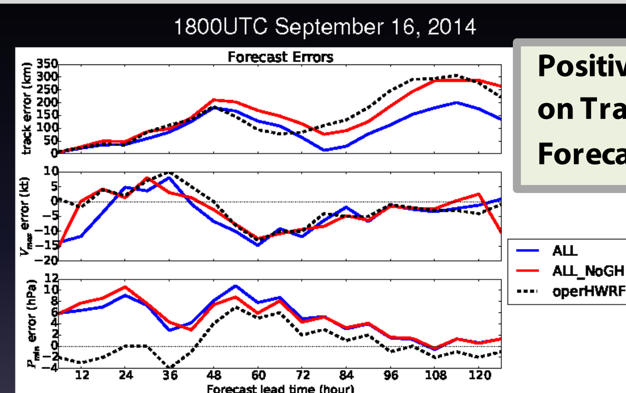


GH: Competes w/ other aircraft in inner core



Positive Impact on Intensity Forecast



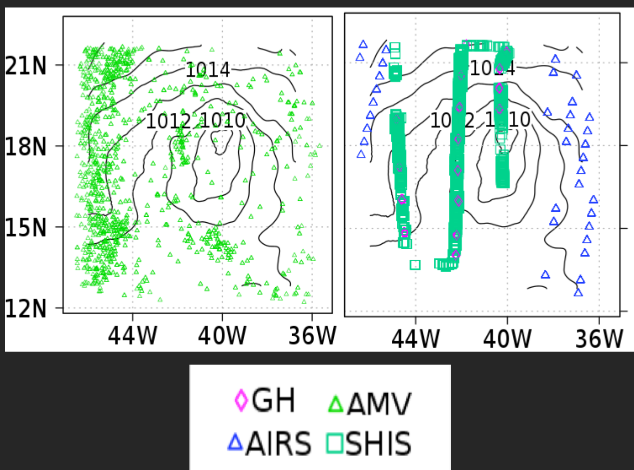


Positive Impact on Track Forecast

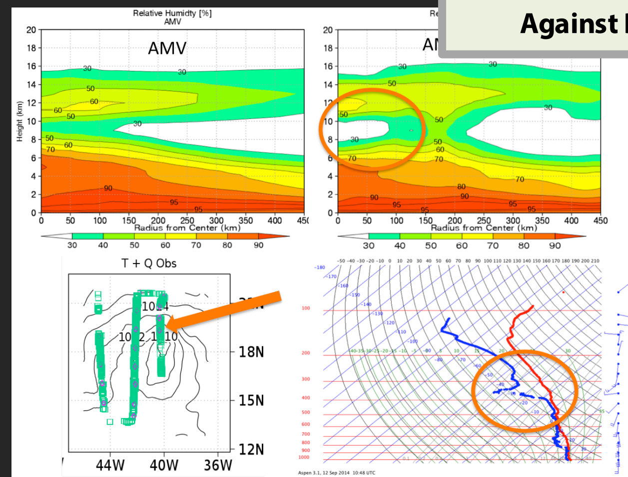
Courtesy: Hui Christophersen (HRD)

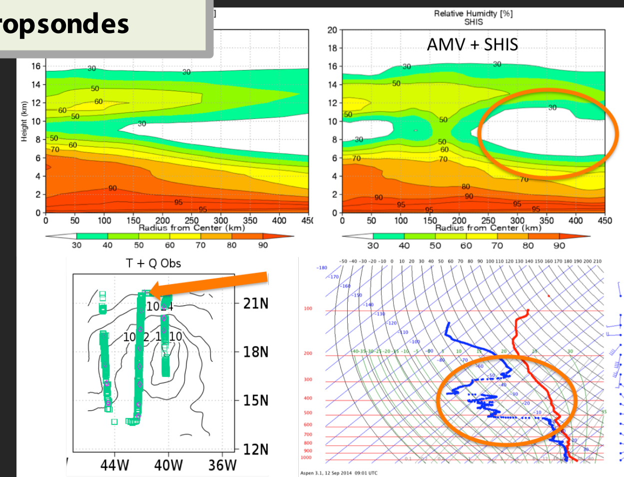
Ongoing Projects: Global Hawk T/Q vs AIRS - HEDAS

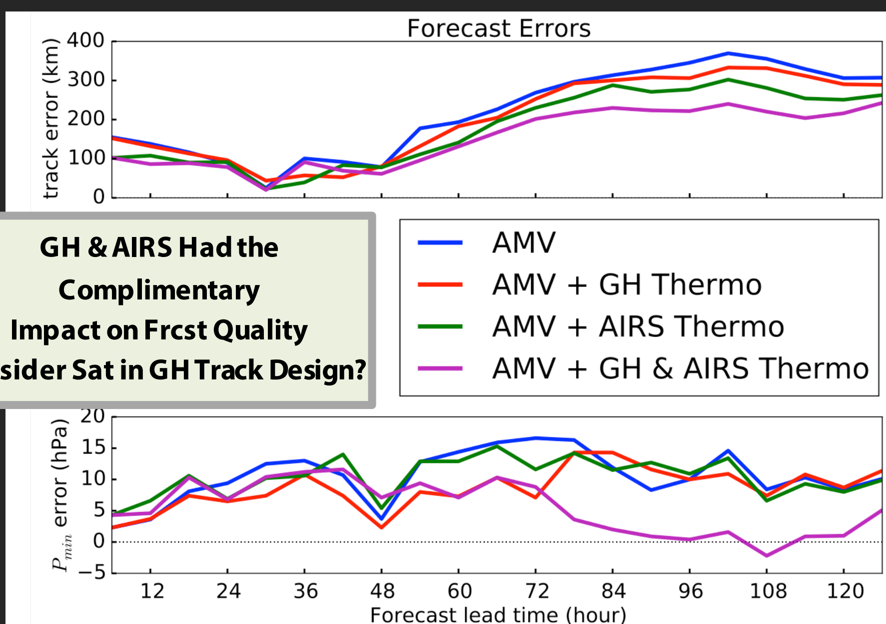
Hurricane Edouard (2014) Sep. 12 Case Study



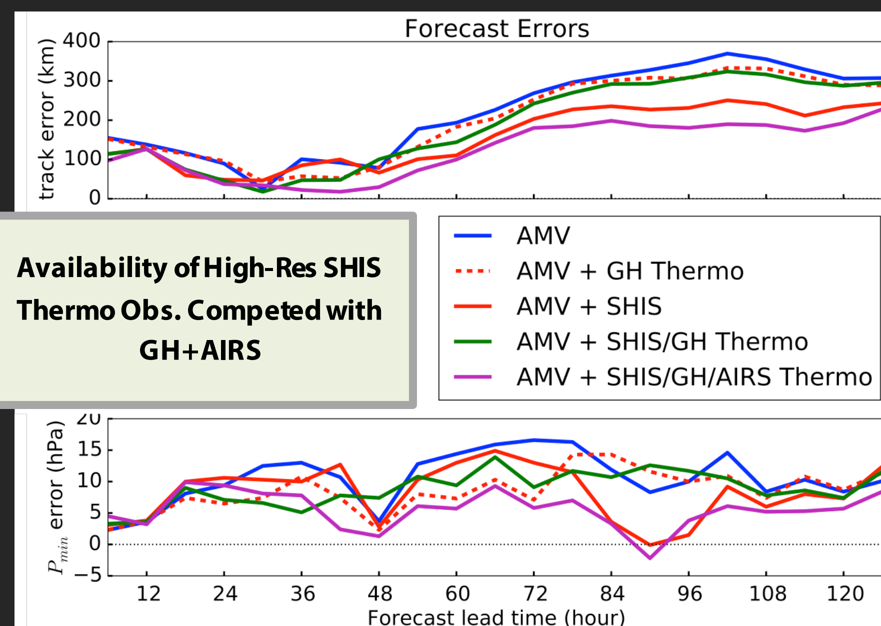
SHIS Assimilation Verifies Well Against Dropsondes







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



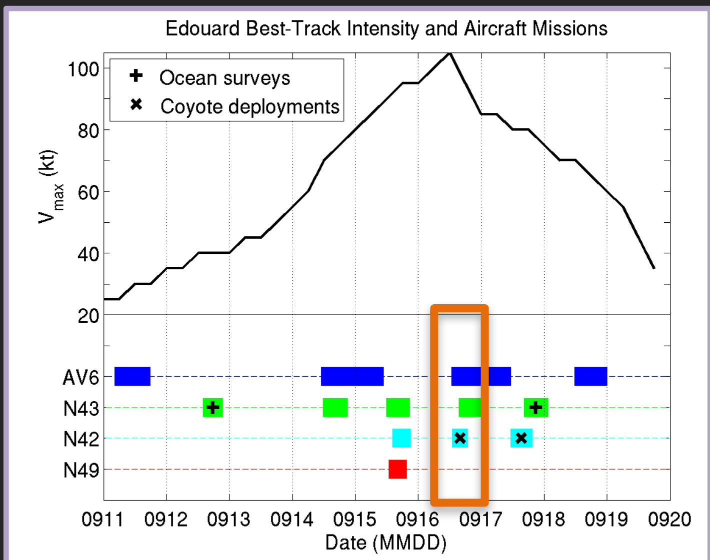
Availability of High-Res SHIS Thermo Obs. Competed with GH+AIRS

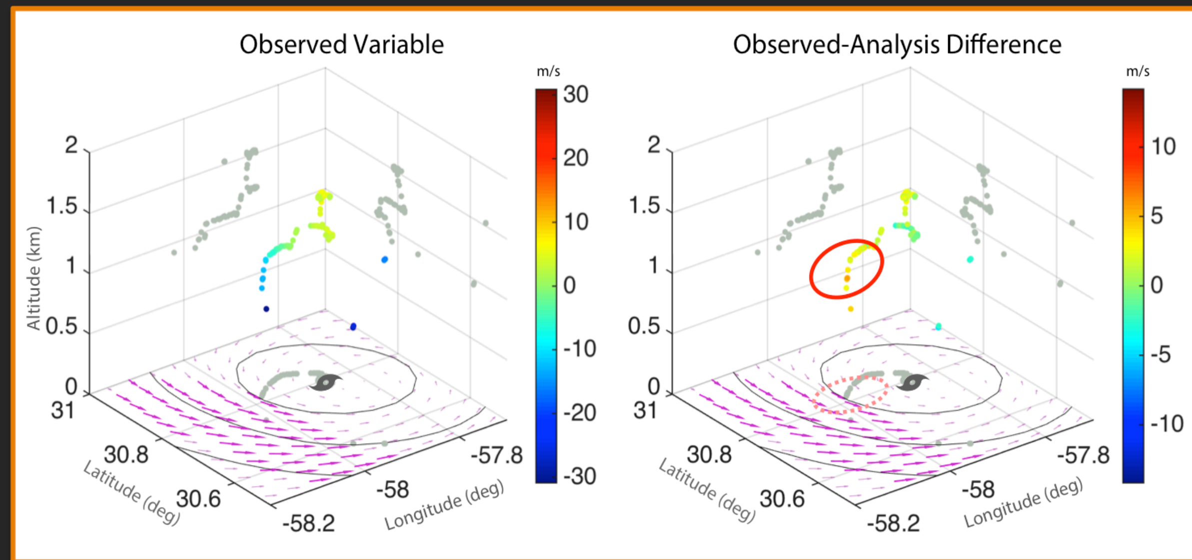
Courtesy: Hui Christophersen (HRD)

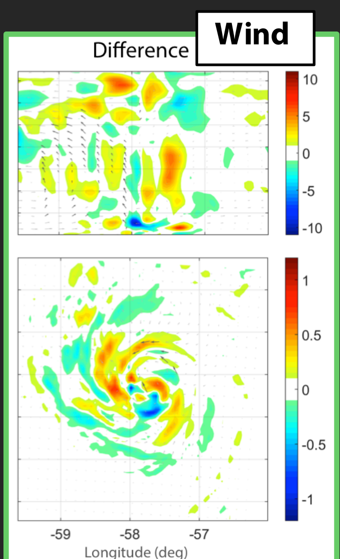
Ongoing Projects: Impact of Coyote Observations

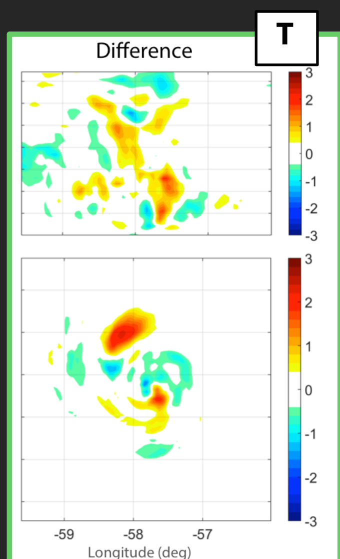
16 September 2014 1432Z: First of Only Two Successful Missions of Coyote

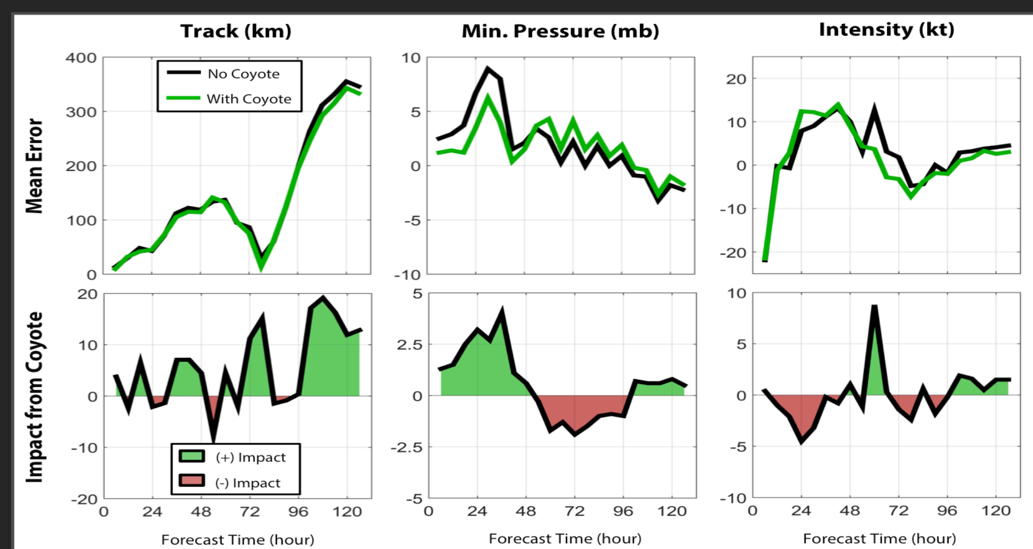
Eye/Eyewall Sampling | 28-minute Mission | Min. Altitude 896 m | Max. Wind Speed 100 kt



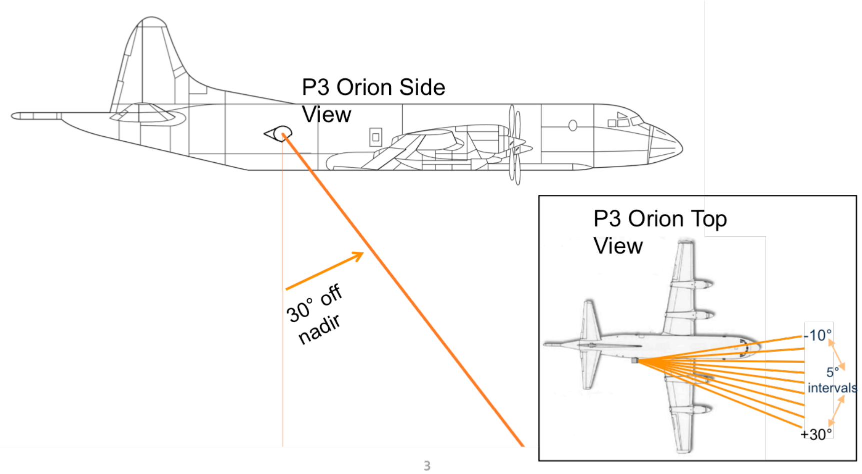


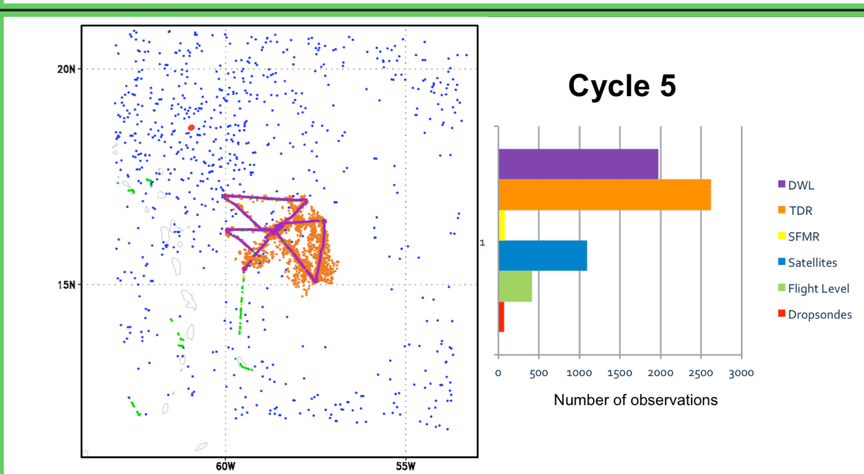


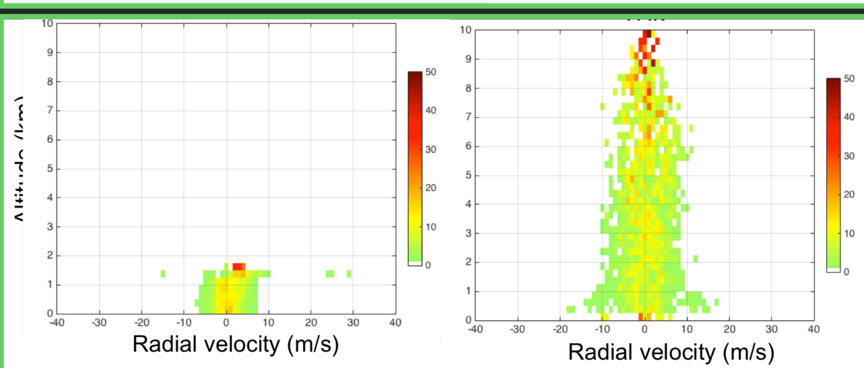




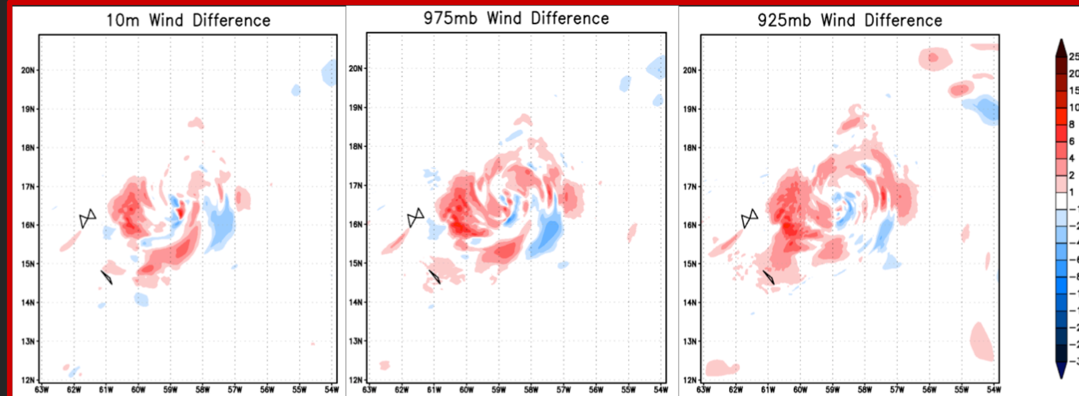
Ongoing Projects: Impact Doppler Wind Lidar

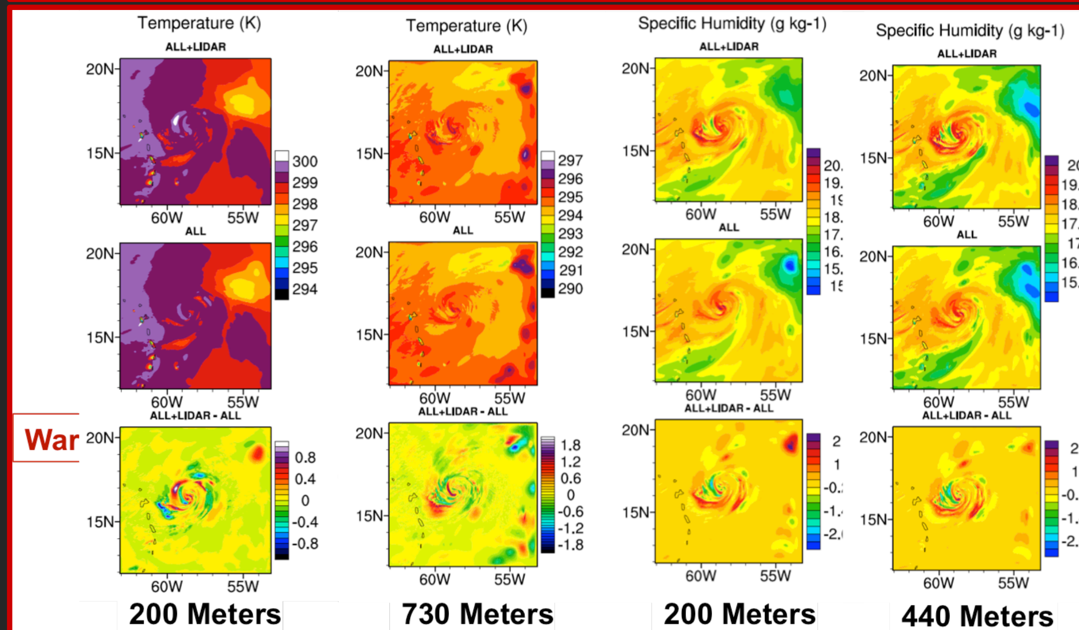






7 DWL Missions into TS Danny and Erika (2016)



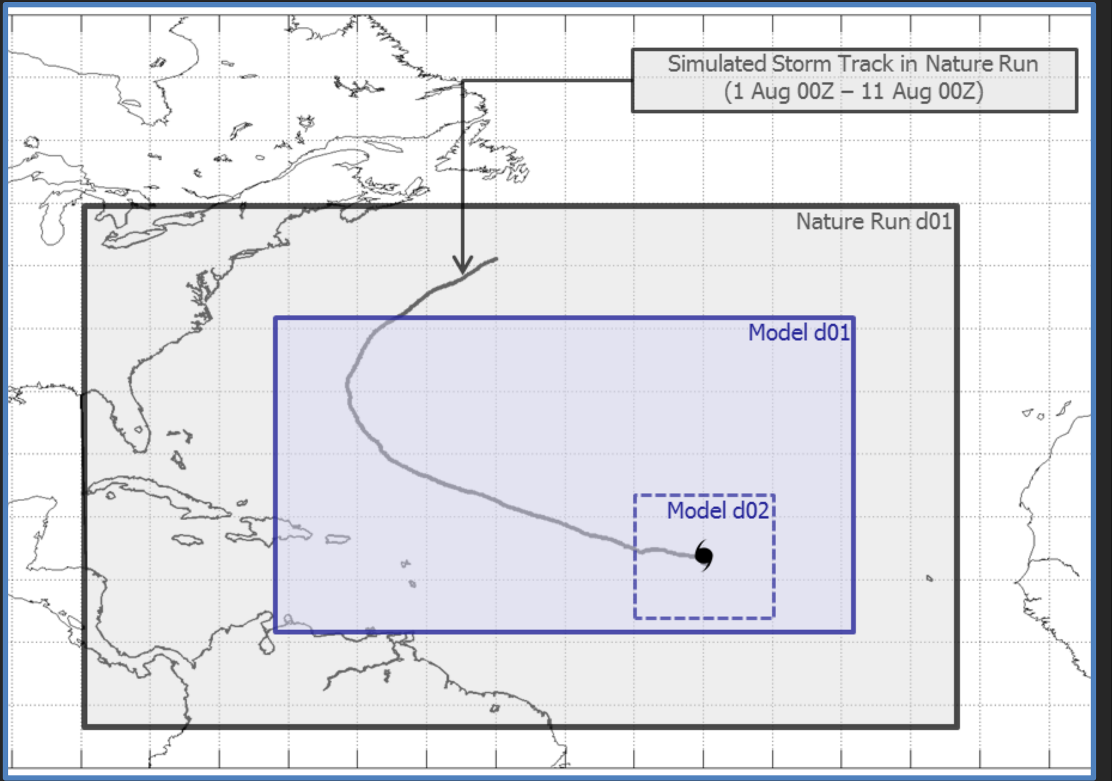


Lidar Data Had Significant Impact on Wind and Thermodynamic Analysis of the Vortex Structure

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)

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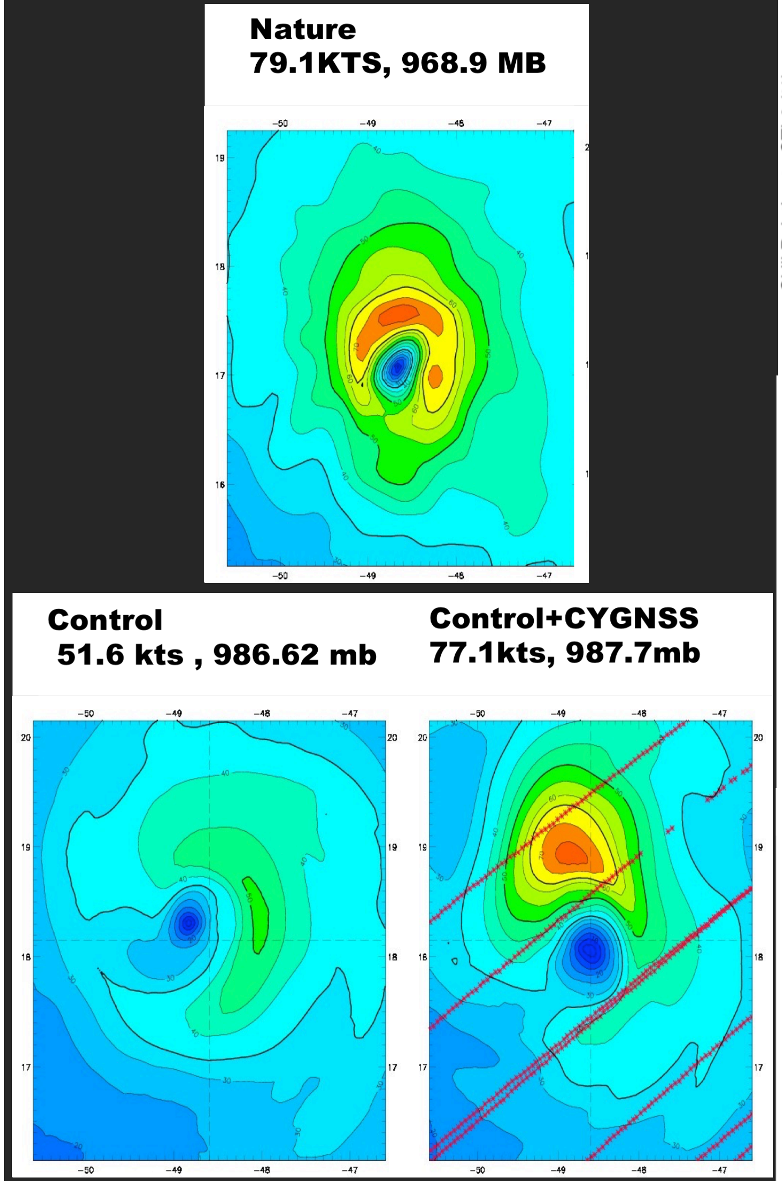
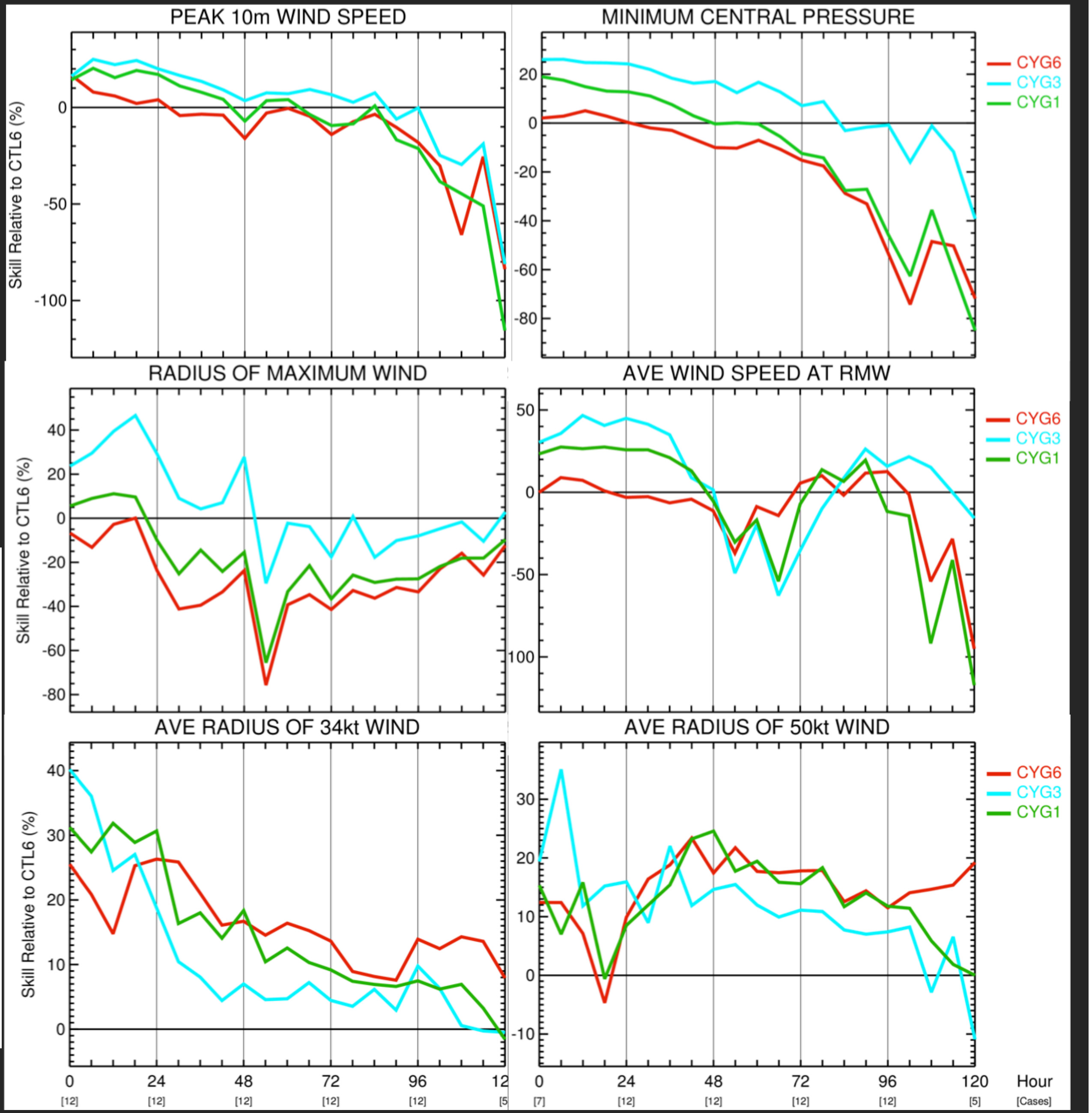
Ongoing Projects: Impact of CYGNSS Wind Speed





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

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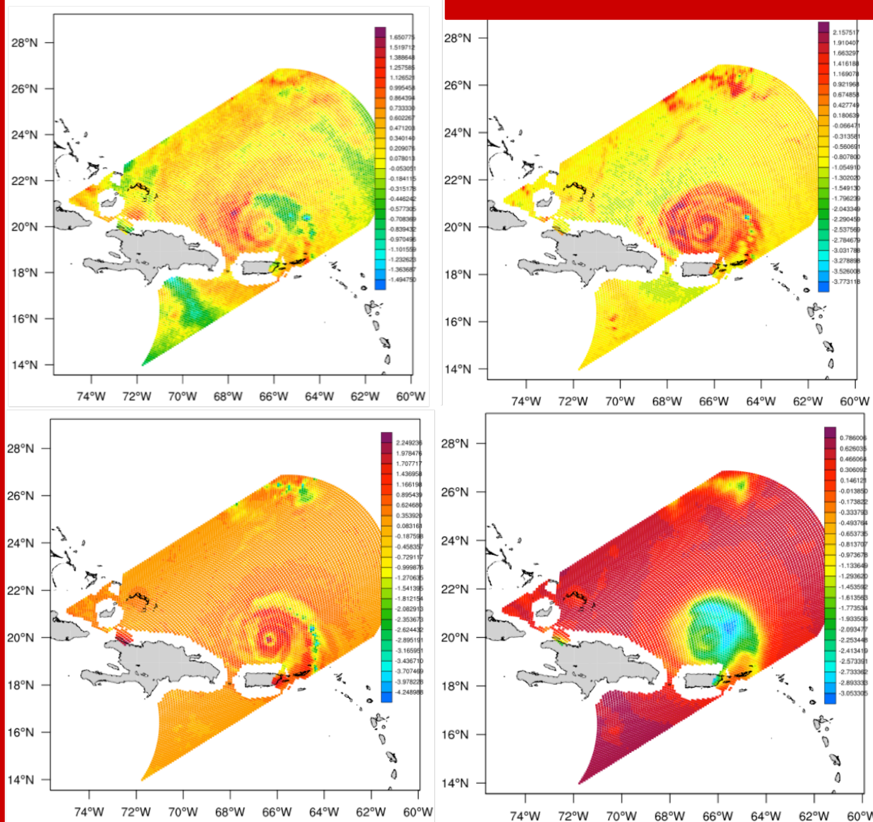
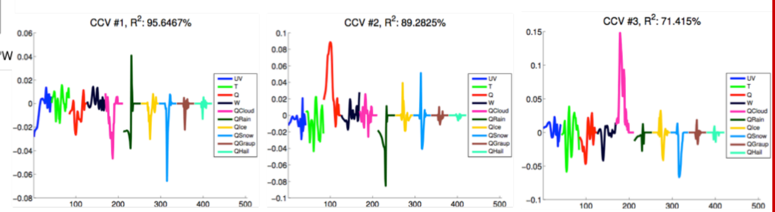
Ongoing Projects: Canonical Correlation Vectors

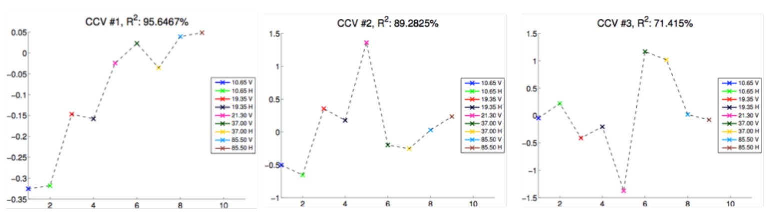
Please See Jeff Steward's Poster



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."

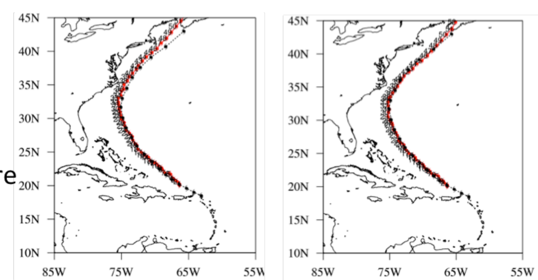
As part of the HFIP, JPL/UCLA collaborates with HRD to implement a novel observation operator based on the statistical extraction of maximally certain information from satellite observations. This information is especially amenable to data assimilation. This is potentially a way to recover massive amounts 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)