OSSE Evaluation of the Impact of Aircraft Observations on Hurricane Analyses and Forecasts

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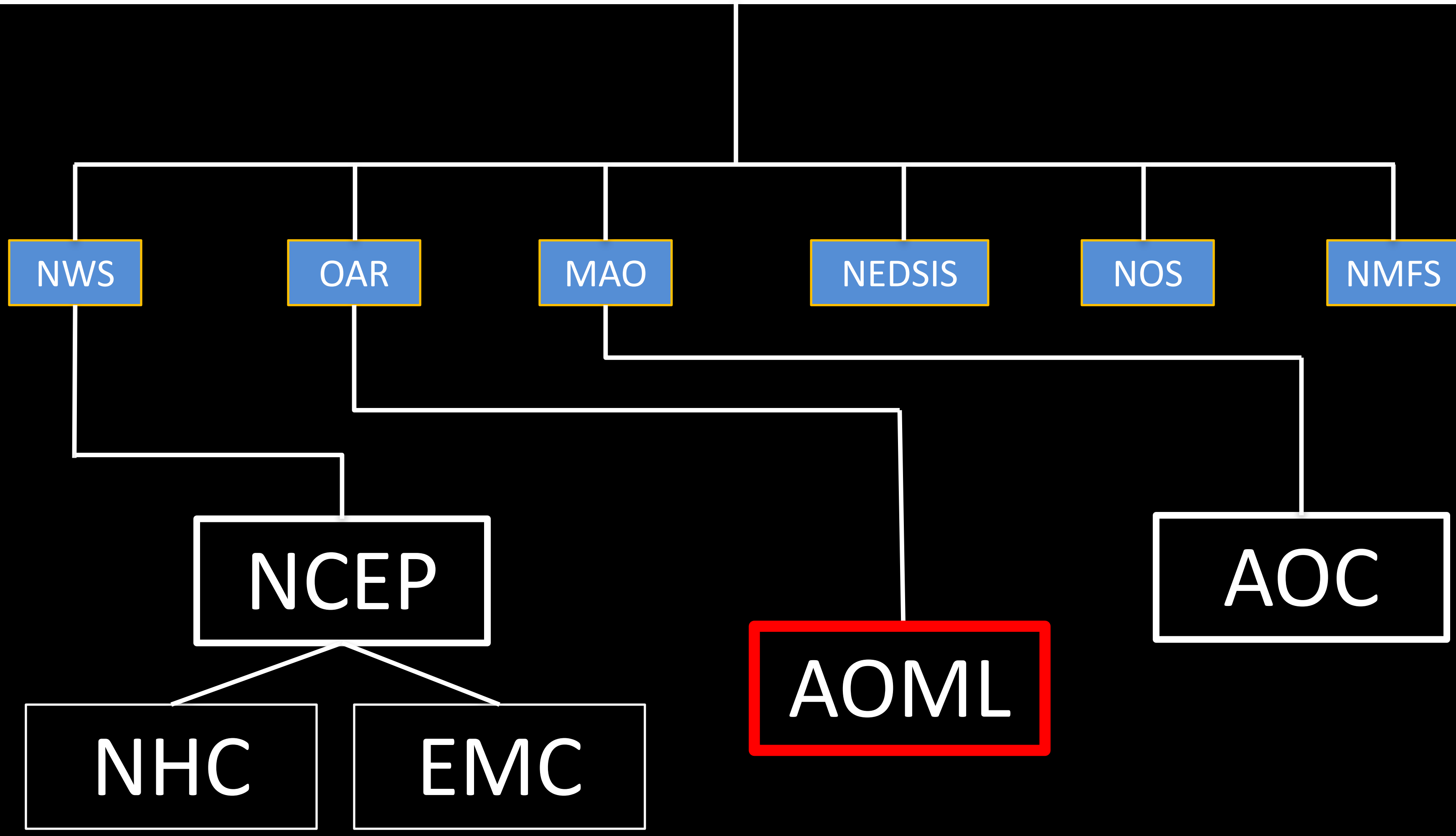
NOAA

- Advance understanding and prediction of changes in the environment through world class science and observations
- Improve preparedness, response, and recovery from weather and water events by building a **Weather-Ready Nation**



Atlantic Oceanographic and Meteorological Laboratory

Virginia Key Science Community

- Hurricane Research
- Oceans and Climate
- Coastal Oceanography

Hurricane Research Division

HRD Research Mission Statement:

Advance the prediction of hurricanes through observations, modeling, and theory, with an emphasis on inner core processes.

- Develop and refine tools used for operational hurricane forecasting (NHC, EMC)
- Expand fundamental understanding of physical processes that drive TC formation and evolution

NOAA HURRICANE FORECAST IMPROVEMENT PROJECT

Unified NOAA approach to guide and accelerate improvements in TC forecasts; created in 2009

- Reduce errors by 50% in track and intensity forecasts in 10 years
- Detect rapid intensity change
- Improve storm surge prediction
- Quantify, bound, and reduce forecast uncertainty
- Extend forecast reliability to 7 days

HRD

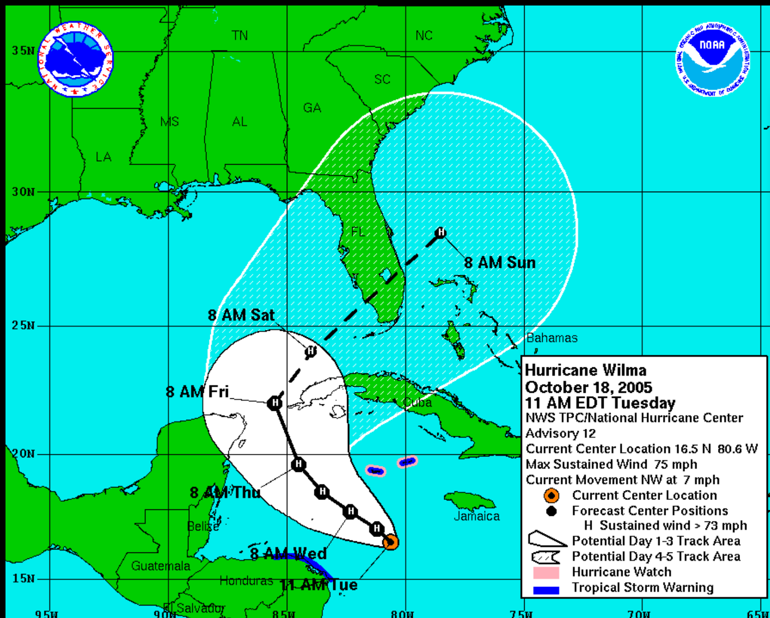
Research Groups:

Observations

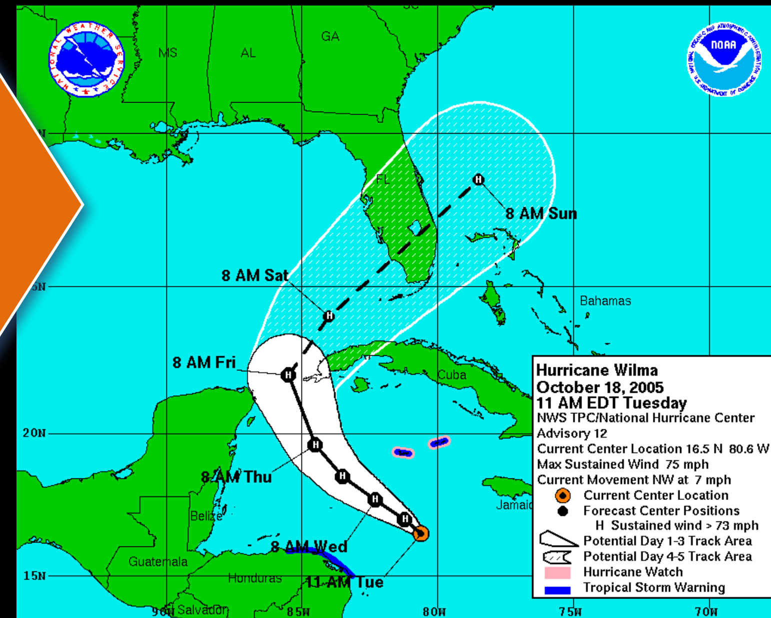
Modeling

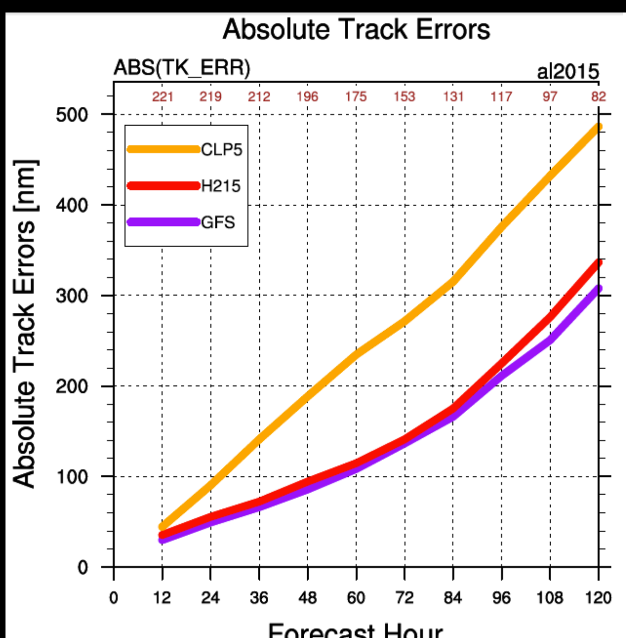
Data Assimilation

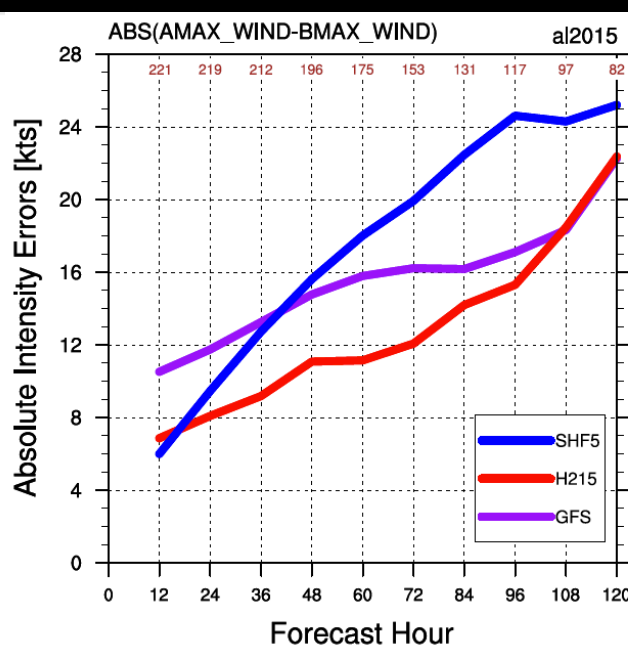
OSE/OSSE



> 50% reduction in uncertainty





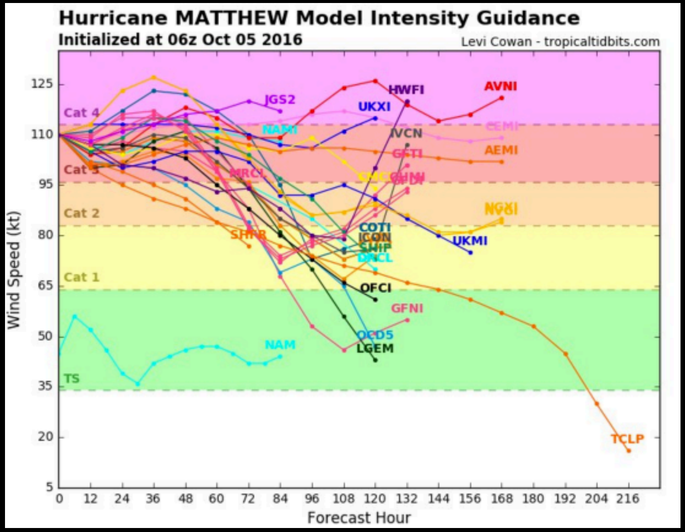


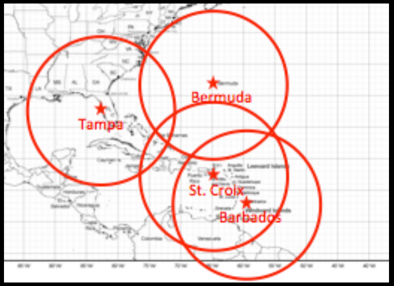
HRD's Hurricane Field Program

- allows for the annual collection of aircraft reconnaissance data in the E. Pac and Atlantic basins (AOC)
- provides real-time aircraft observations to be assimilated in the operational models during hurricane season

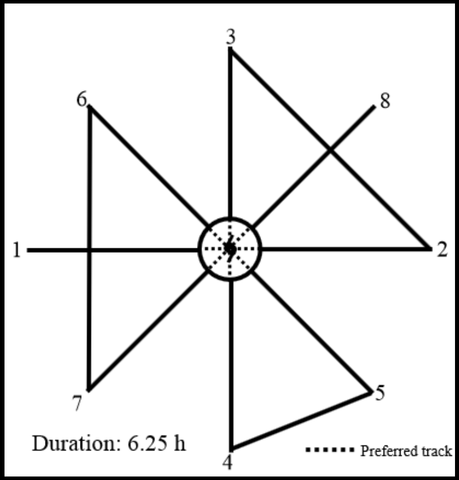
Hurricane Field Program

- IFEX Goals (Rogers et al. BAMS 2006, 2013)
  1. Collect observations that span TC lifecycle in a variety of environments for model initialization and evaluation
  2. Develop and refine measurement technologies that provide improved real-time monitoring of TC intensity, structure, and environment
  3. Improve understanding of physical processes important in intensity change at all lifecycle stages
- Preparation
  - Mission experiments
  - Map discussion/targeting
  - Project coordination

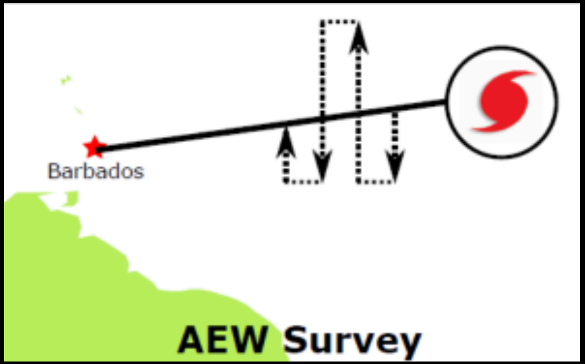


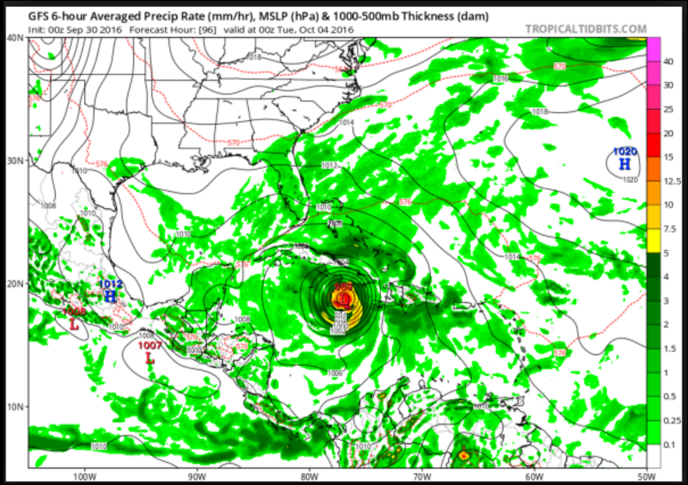


Range of P-3 aircraft



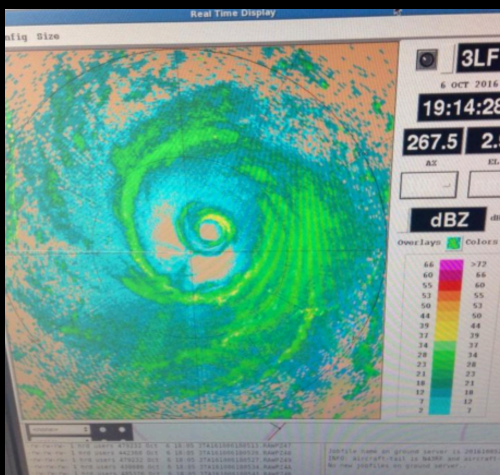
Rotated Figure 4





Hurricane Field Program

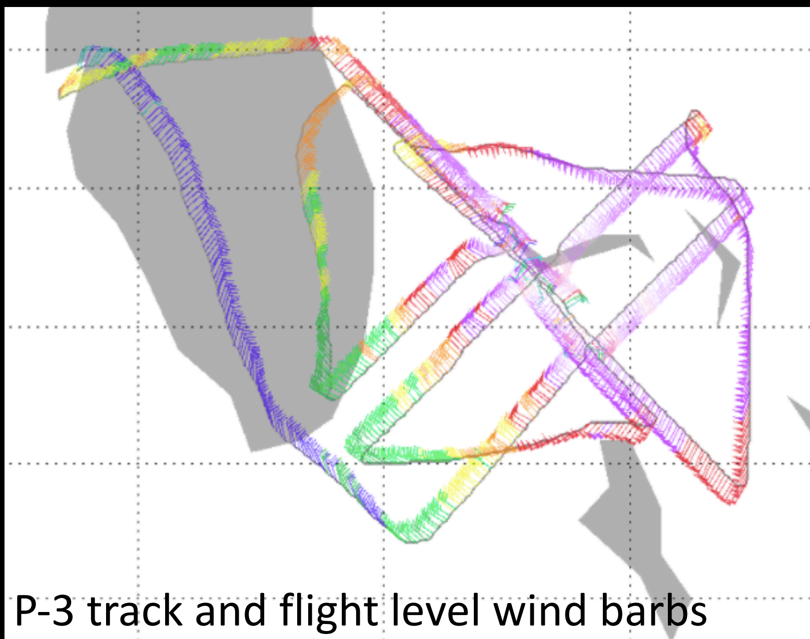
- Field experiment process
  - airborne crew
  - ground crew
  - typical deployment

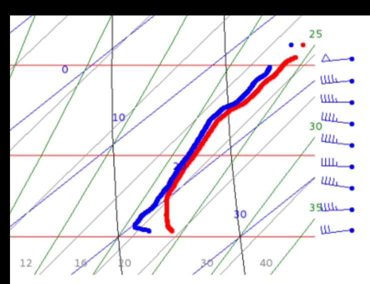


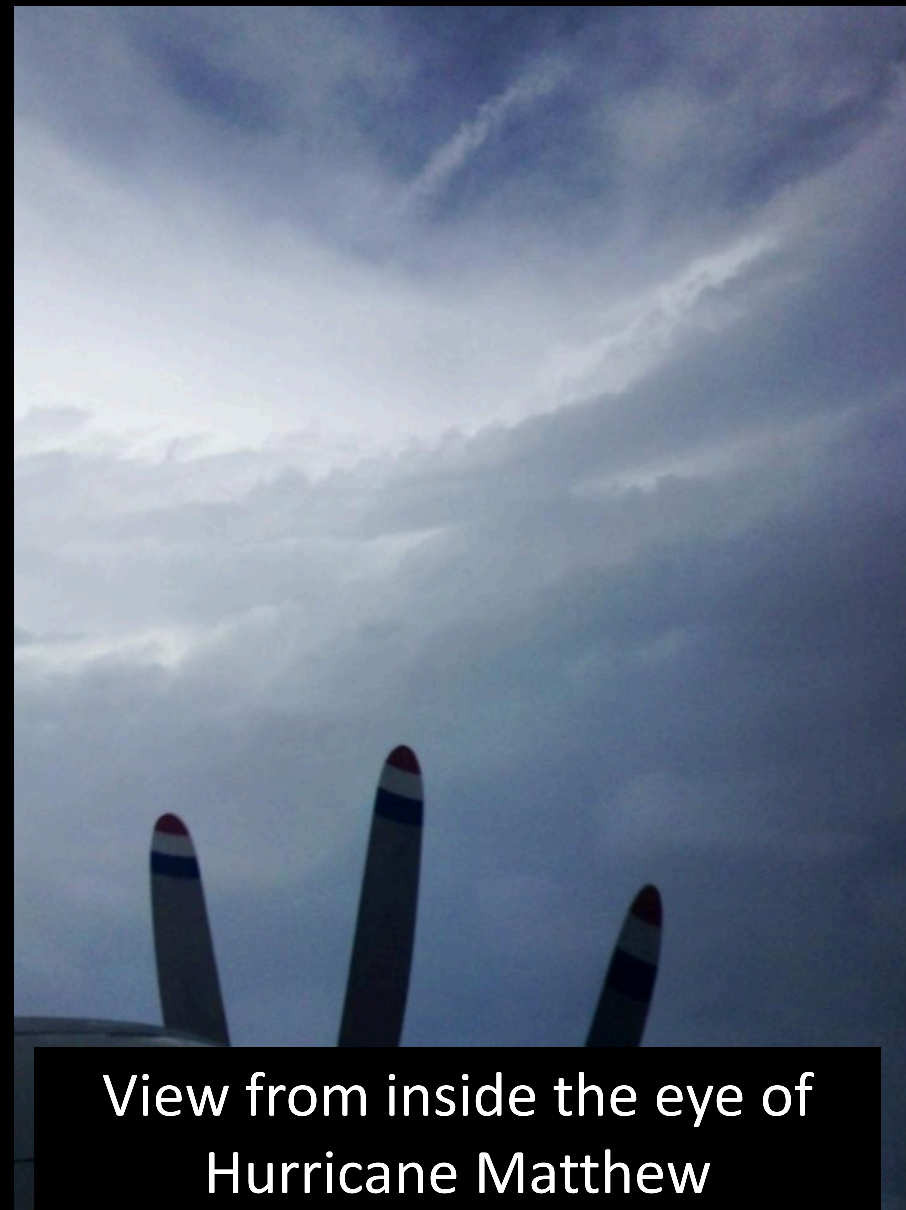
- 8-12 hours per mission
- 12-15 people per mission
- Missions every 12 hours

Hurricane Field Program

- Debrief of missions
  - Evolution of sampled TC
  - Data collected


P-3 track and flight level wind barbs



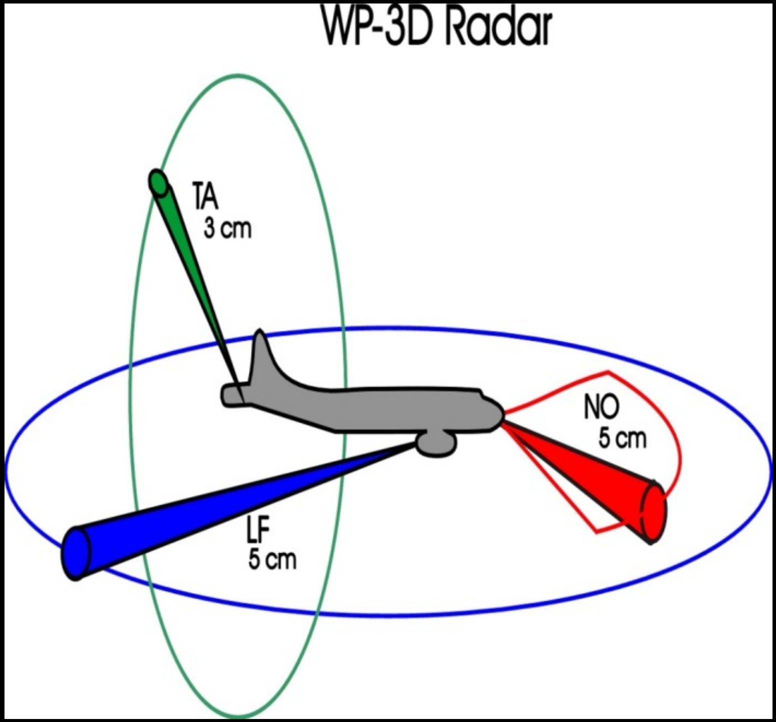

View from inside the eye of Hurricane Matthew

Aircraft Instruments

Measurements: temperature, pressure, humidity, wind, precipitation, cloud microphysics, sea surface temperature, ocean heat content, sea spray

Airborne Instruments:

Flight level sensors
Dropsondes
IRsondes
AXBTs
SFMR
Tail Doppler Radar
Lower Fuselage Radar
Doppler Wind LIDAR
IWRAP
Precipitation Imaging Probe
HAMSR
HIRAD
HIWRAP
Scanning HIS



NOAA Aircraft

P-3

5-10 kft
through core

G-IV

45 kft through
environment

UASonde

(Coyote)

2 kft through core
in Boundary Layer

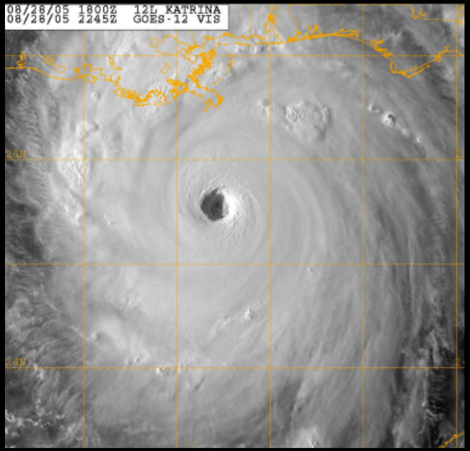
Global Hawk

65 kft above core
and environment

Tropical Cyclones

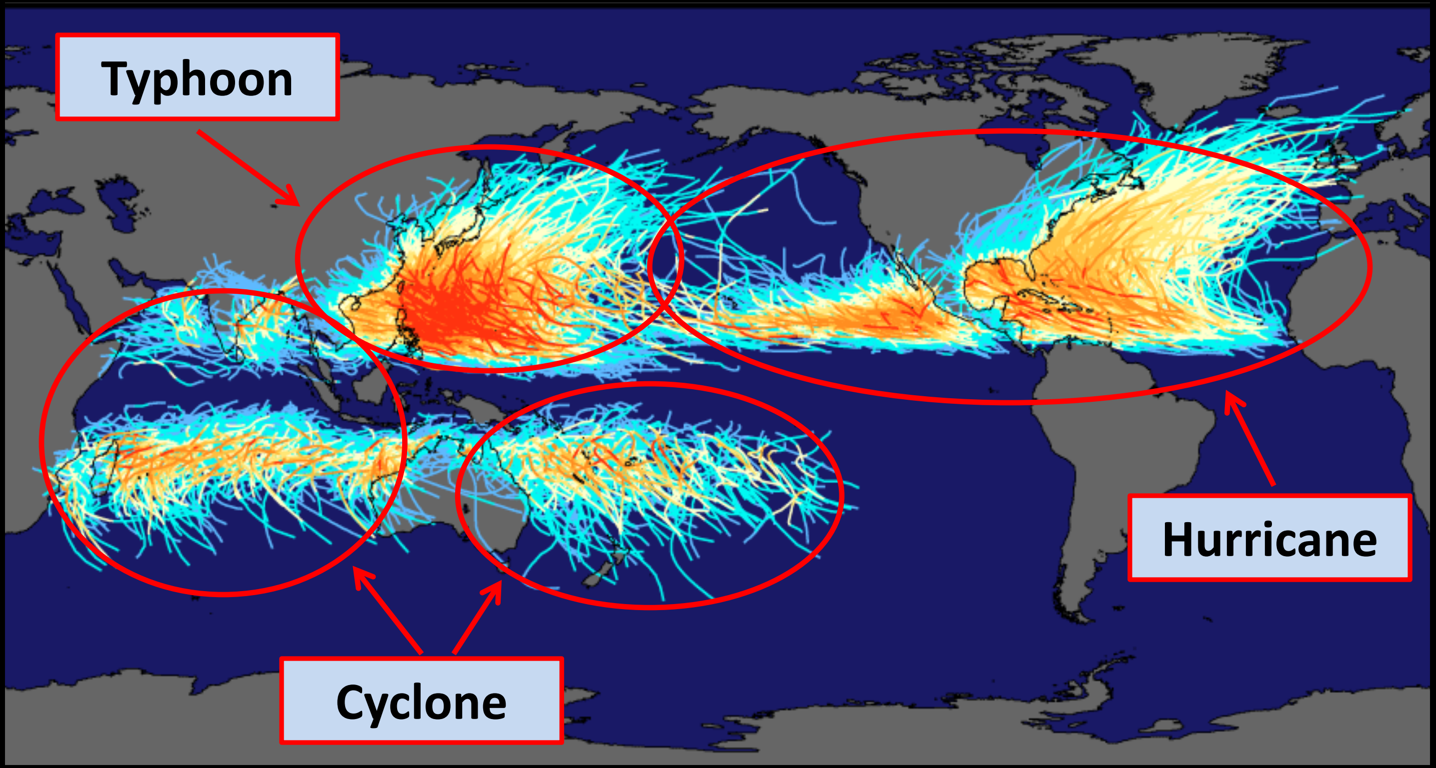
Defined by:

- Deep convection near a warm-cored low pressure center
- Closed surface circulation > 35 knots



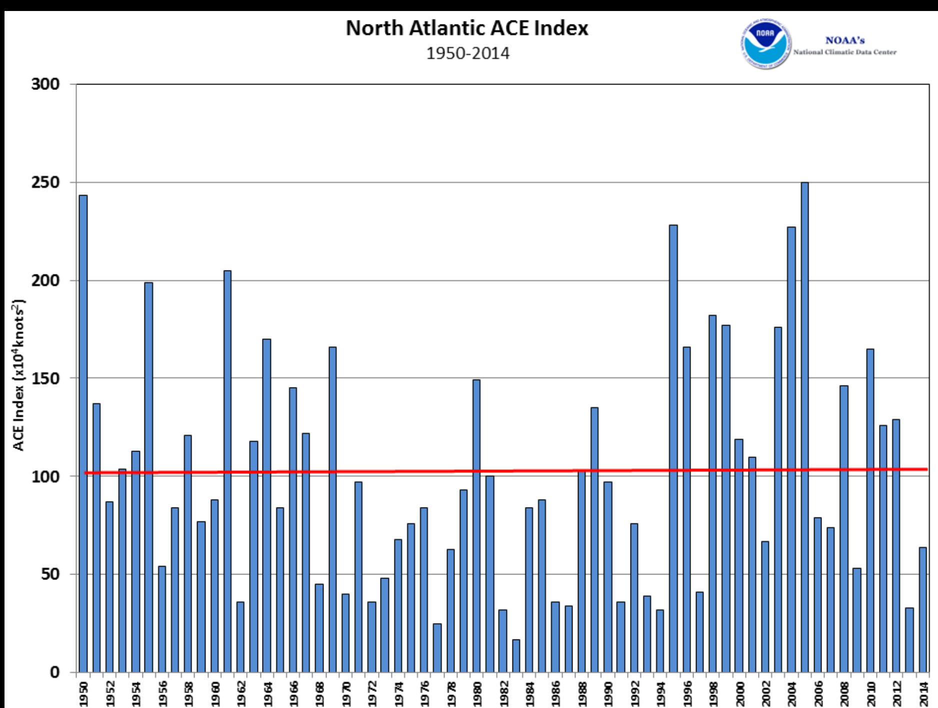
Impacts:

- Strong Winds
- Storm Surge
- Heavy Rain
- Tornados

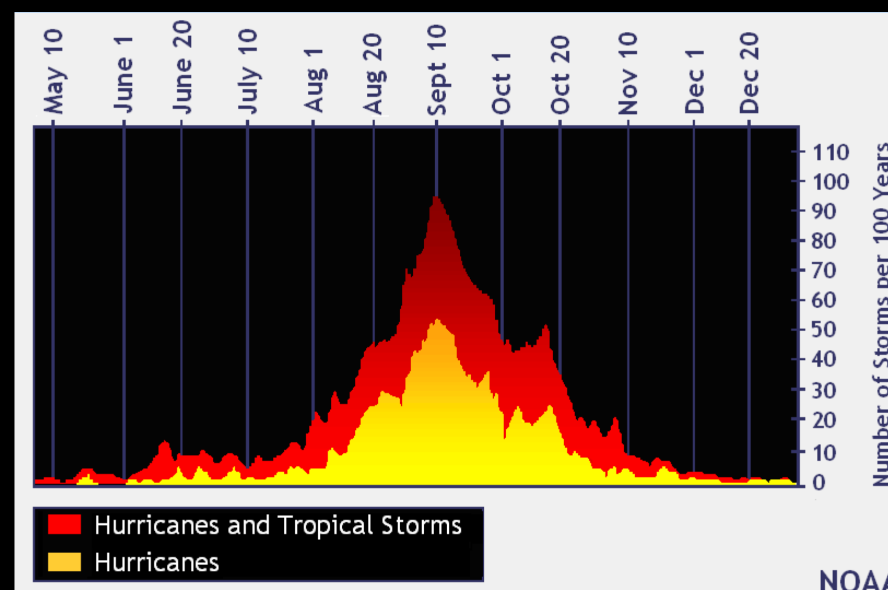


Tropical Cyclones

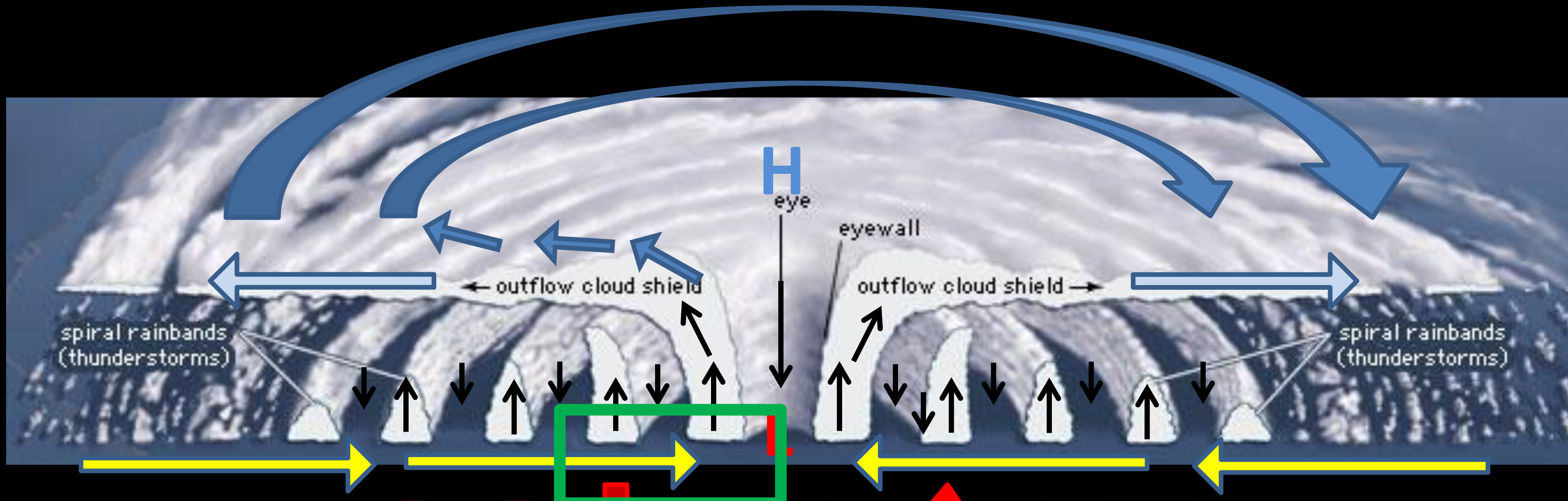
Saffir-Simpson Hurricane Scale				
Category	Sustained Winds (mph)	Storm Surge	Central Pressure	Potential Damage
1	74-95	4-5 ft.	980 mb	Minimal
2	96-110	6-8 ft.	965-979 mb	Moderate
3	111-130	9-12 ft.	945-964 mb	Extensive
4	131-155	13-18 ft.	920-944 mb	Extreme
5	>155	>18 ft.	<920 mb	Catastrophic

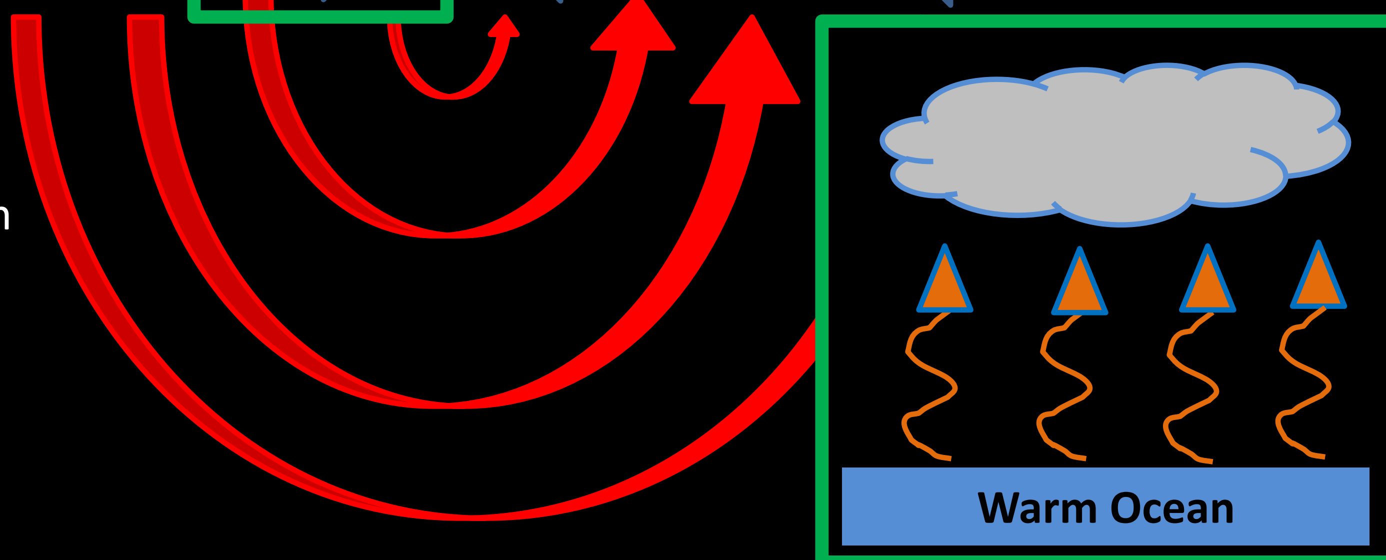


Negative correlation between Atlantic and Pacific ACE indices



Anatomy of a Mature Hurricane





Positive feedback loop:

Energy evaporated from ocean ("surface flux")

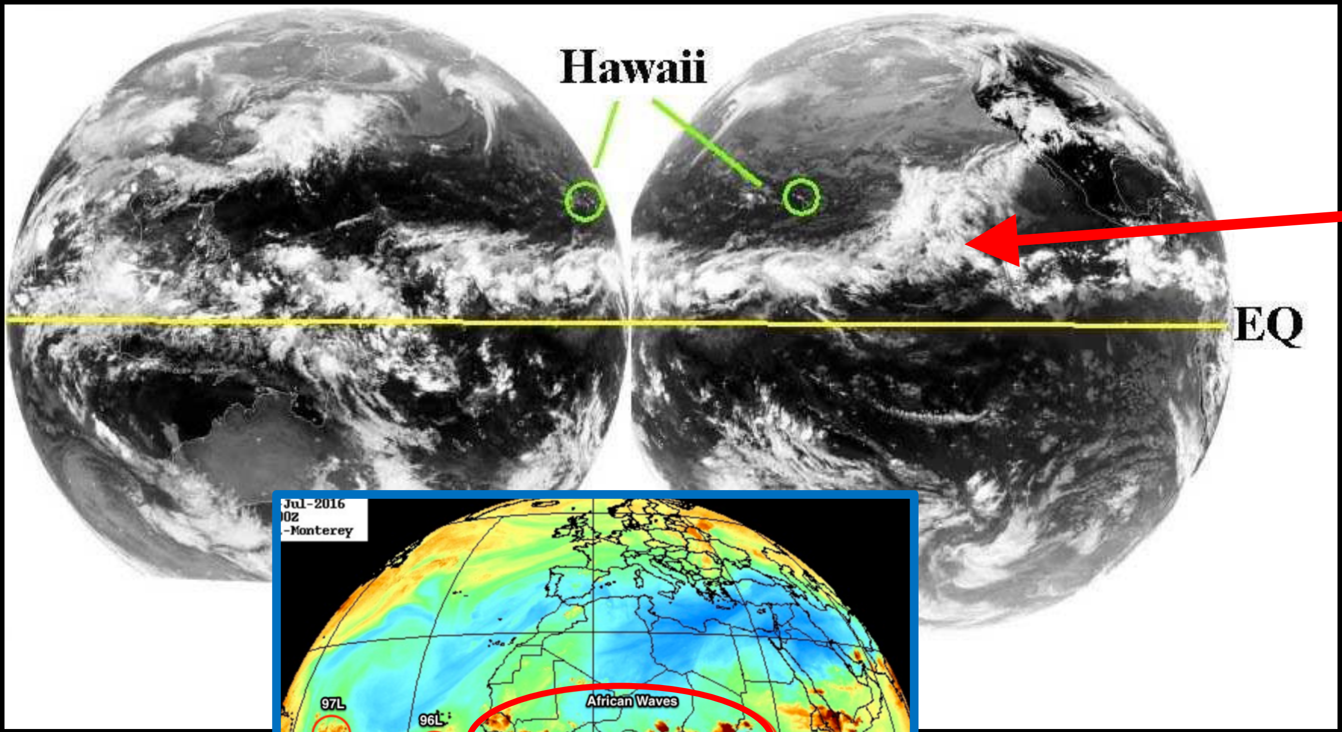
→ Enhances convection

→ Lowers pressure

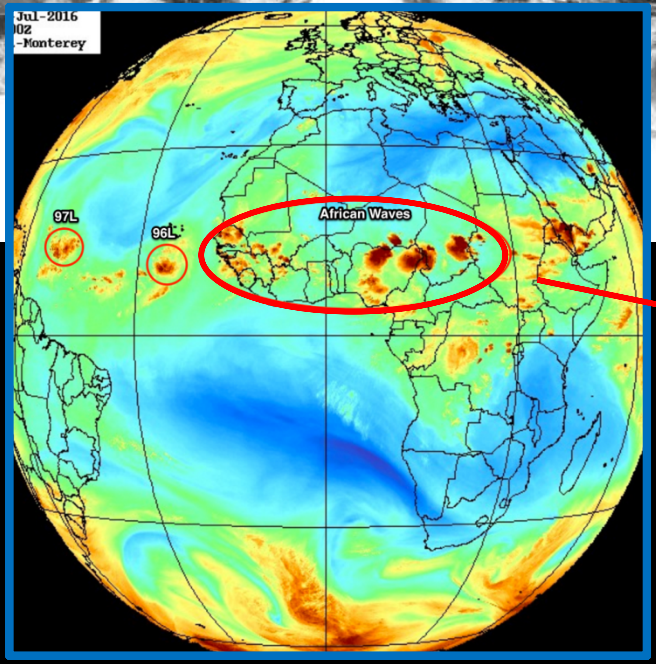
→ Increases winds

→ Increases flux

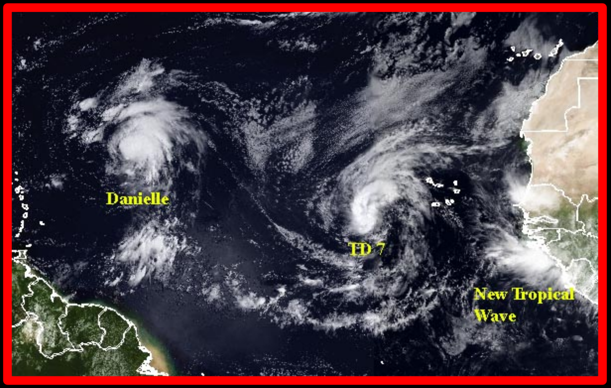
Development (Genesis)



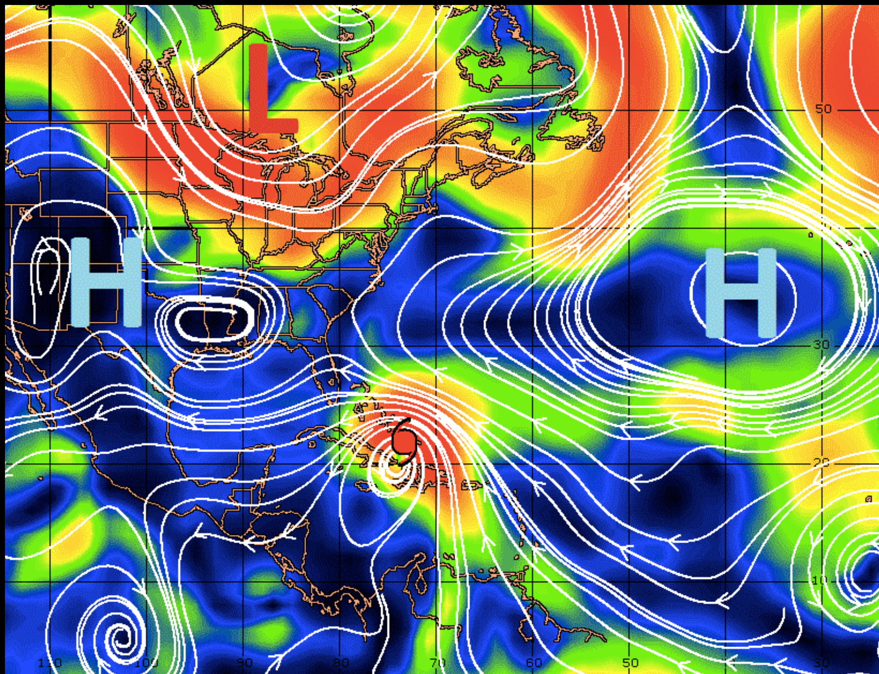
ITCZ



African Easterly Waves



Interaction with Environment

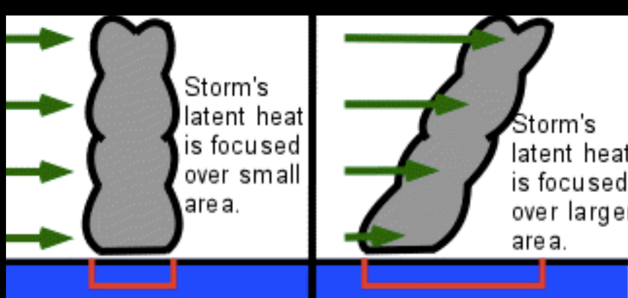


Hurricanes are steered by wind flow around high and low pressure regions

→ May track into unfavorable conditions

Unfavorable conditions:

- Dry air decreases buoyancy
- Vertical Wind Shear prevents vertical alignment

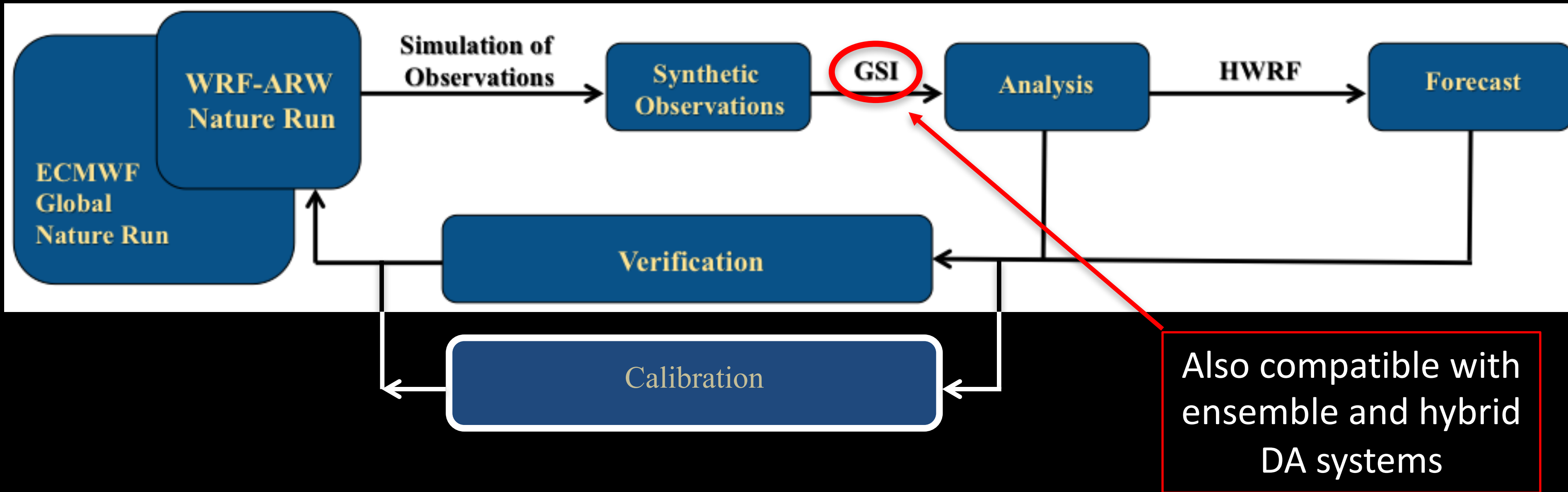


Observing System Simulation Experiments (OSSEs)

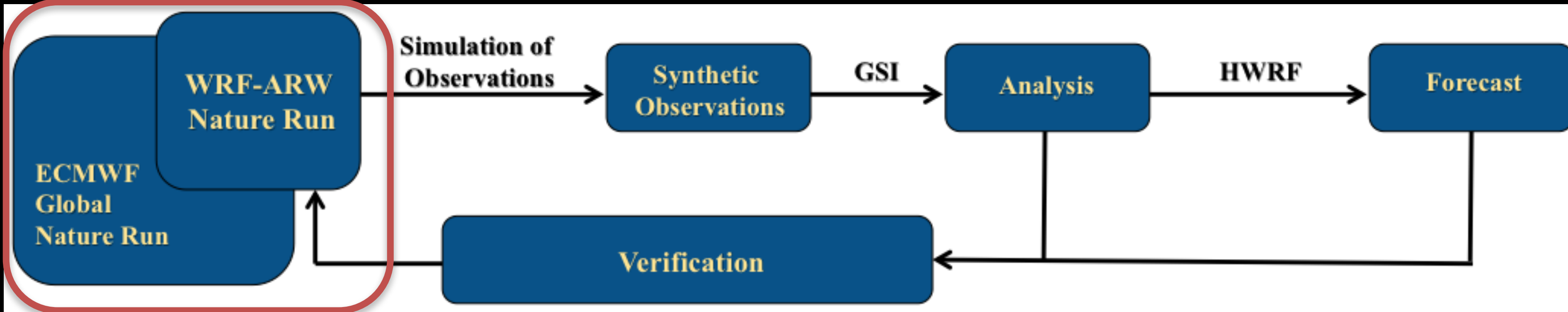
- Quantify the potential impact of current/proposed observing systems on forecasts and analyses by assimilating synthetic observations obtained from a Nature Run

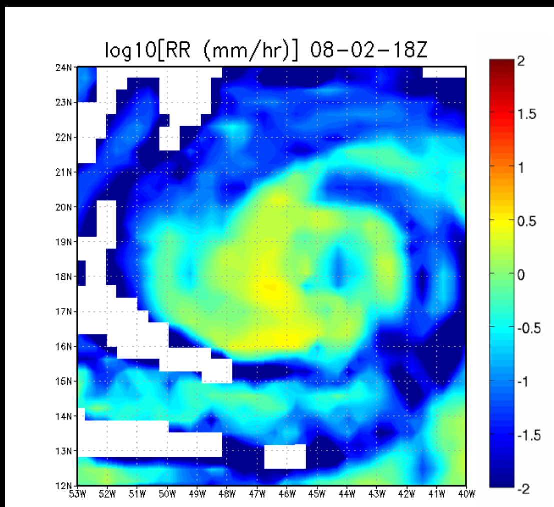
HRD's Regional OSSE System for Hurricanes

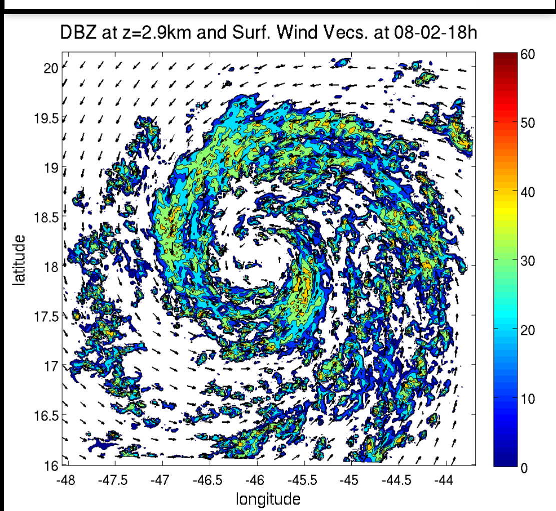
- Utilizes a regional Hurricane Nature Run (Nolan et al., 2013) and creates analyses used by the high-resolution regional forecast model HWRF

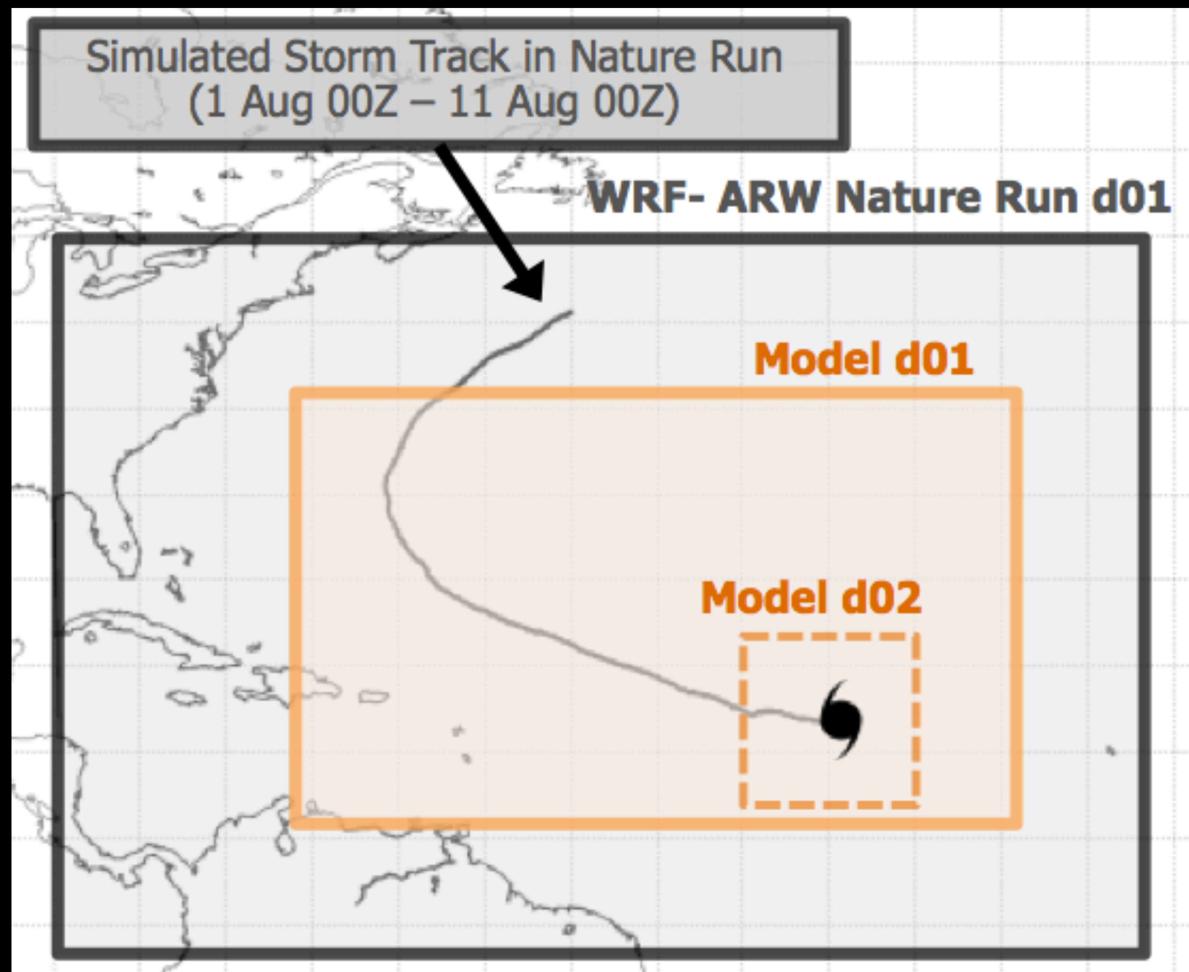


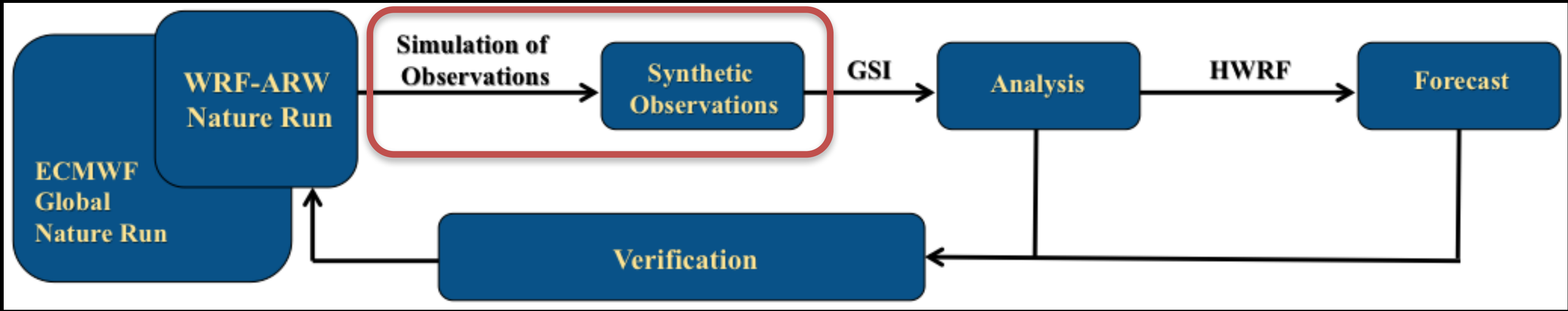
- forecast impact experiments
- model and OSSE system Validation
- optimize airborne sampling flight patterns and instrumentation coverage
- test new instruments before installation
- assess and improve data assimilation and vortex initialization methodology for hurricane prediction

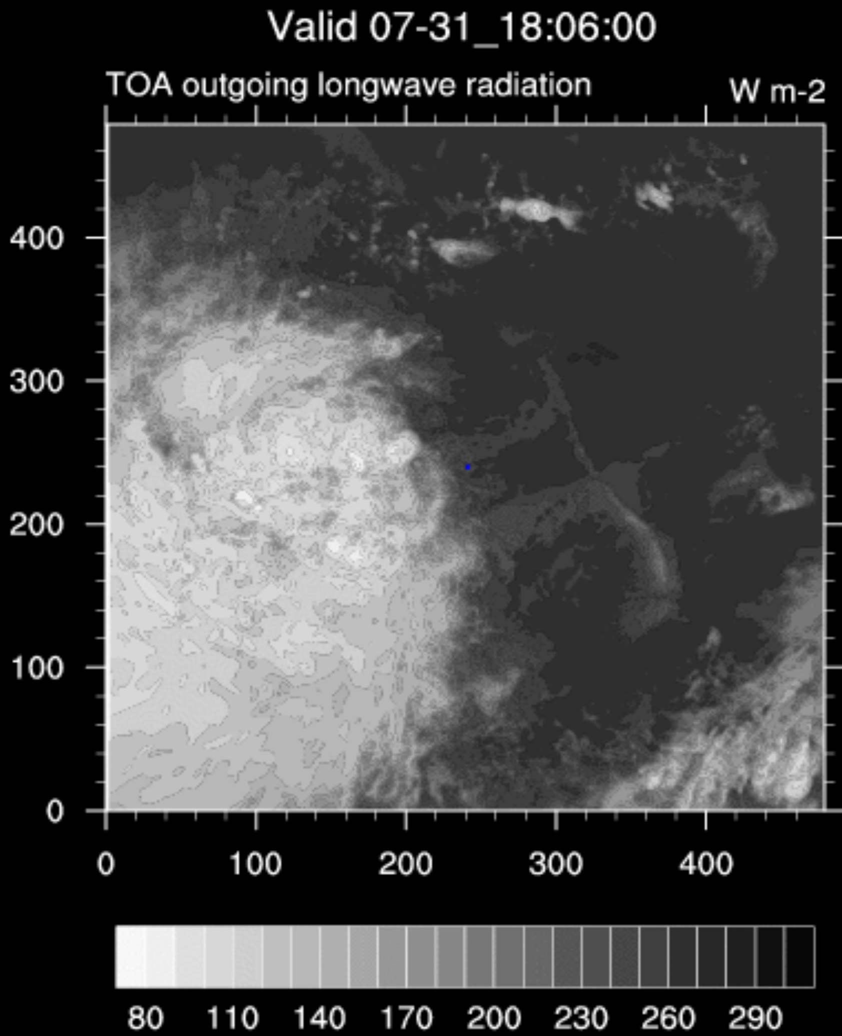

ECMWF Global Nature Run
WRF-ARW Nature Run
Simulation of Observations
Synthetic Observations
GSI
Analysis
HWRF
Forecast
Verification

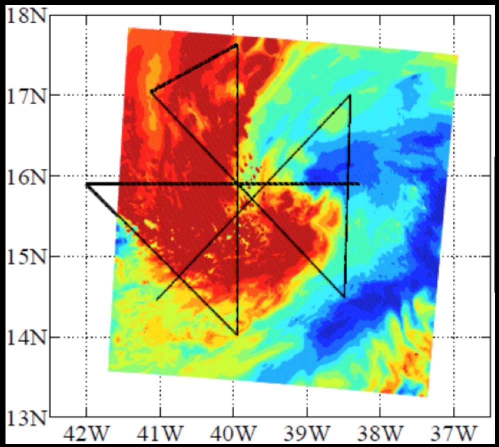

log10[RR (mm/hr)] 08-02-18Z
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2


DBZ at z=2.9km and Surf. Wind Vecs. at 08-02-18h
latitude
longitude
20
19.5
19
18.5
18
17.5
17
16.5
16
-48
-47.5
-47
-46.5
-46
-45.5
-45
-44.5
-44
60
50
40
30
20
10
0

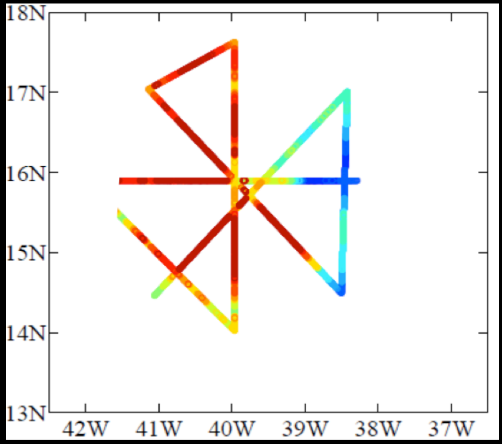

Simulated Storm Track in Nature Run
(1 Aug 00Z – 11 Aug 00Z)
WRF- ARW Nature Run d01
Model d01
Model d02



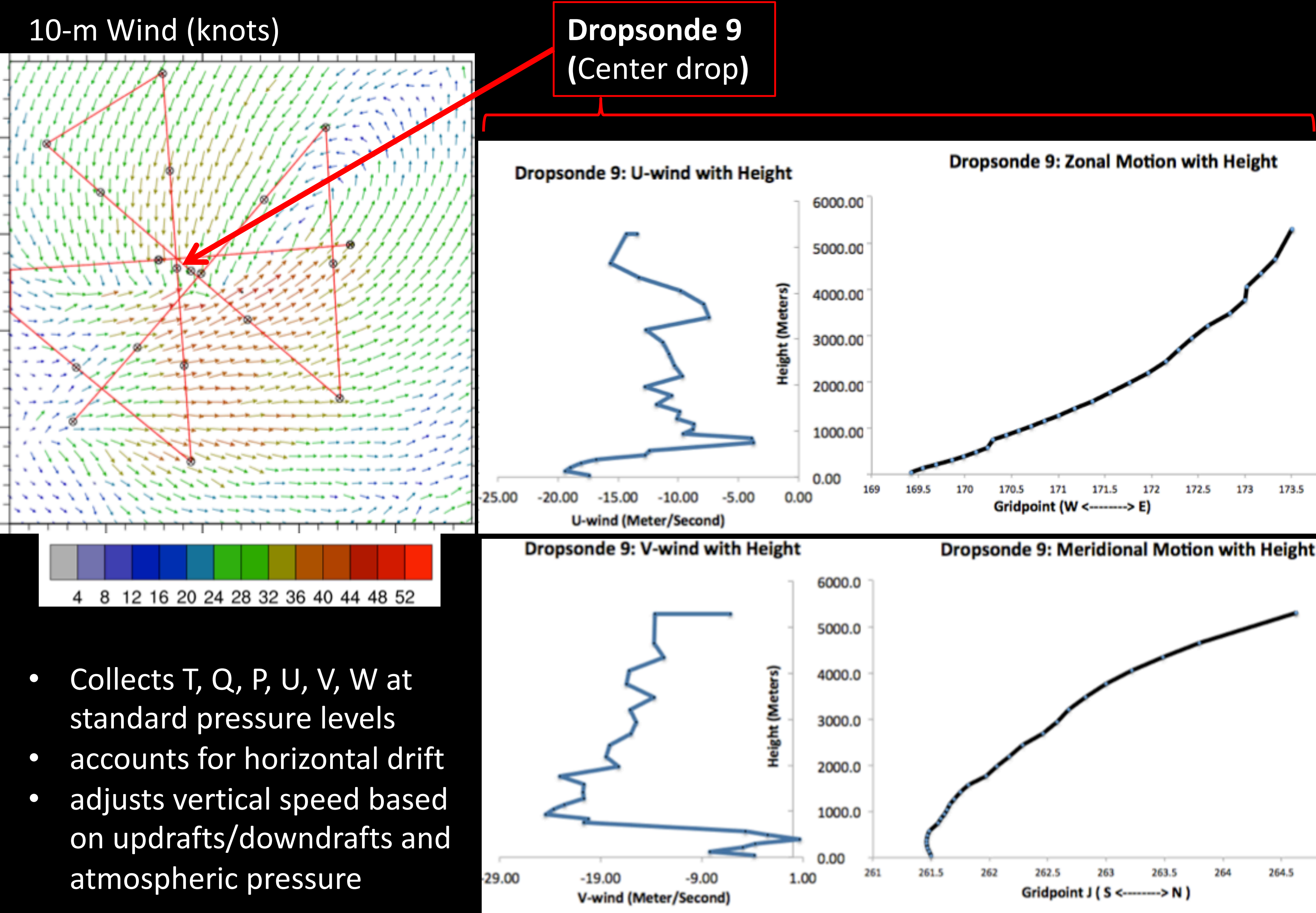




Flight level moisture sample

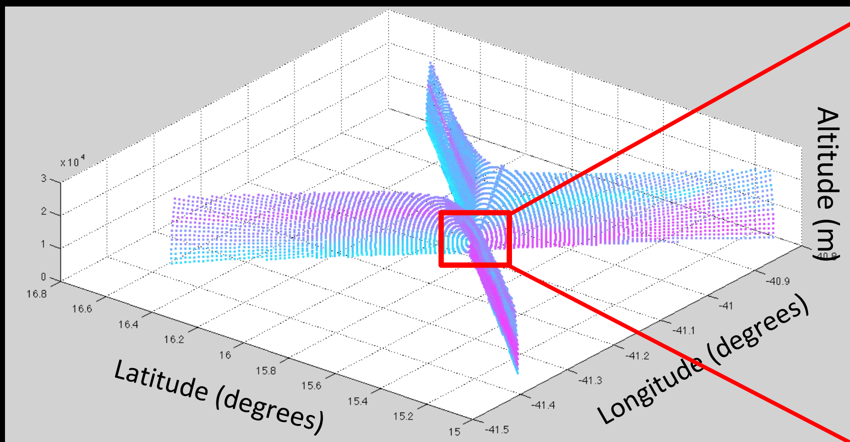


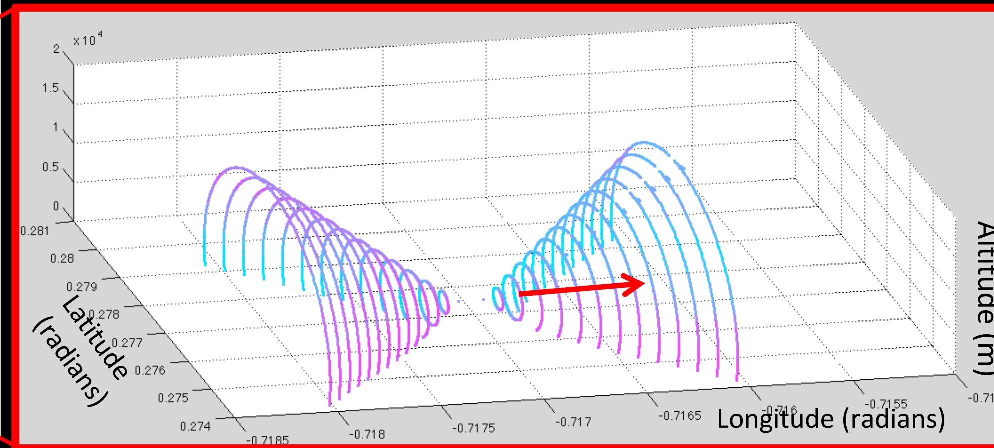
Dropwindsonde Simulation



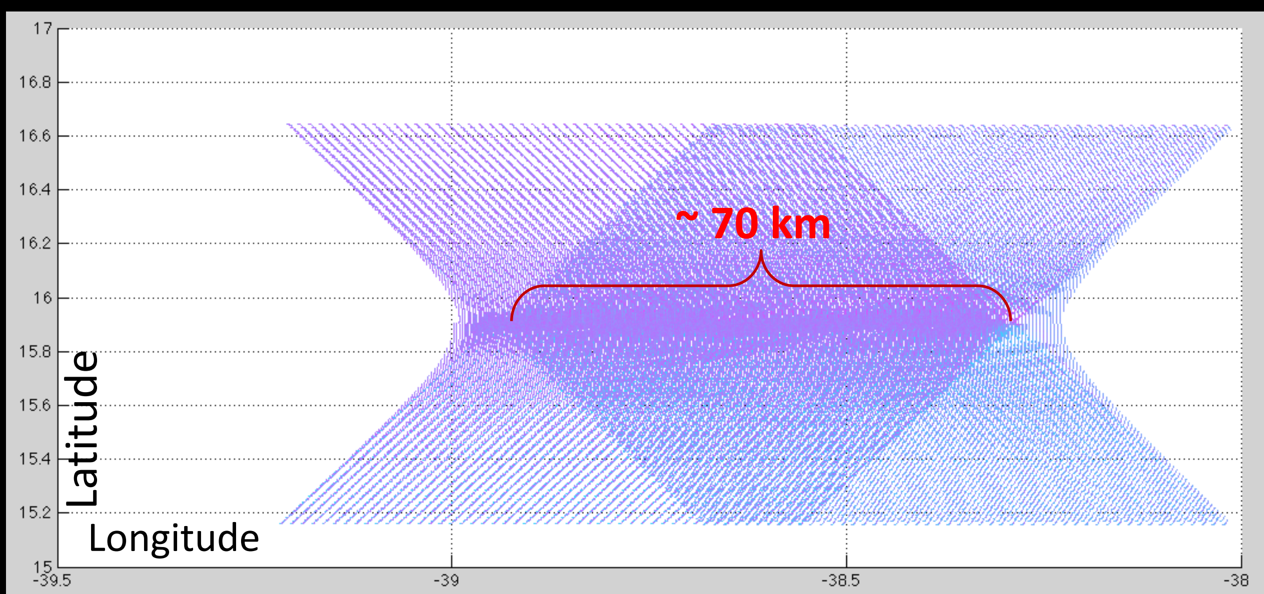
- Collects T, Q, P, U, V, W at standard pressure levels
- accounts for horizontal drift
- adjusts vertical speed based on updrafts/downdrafts and atmospheric pressure

Tail Doppler Radar Simulation

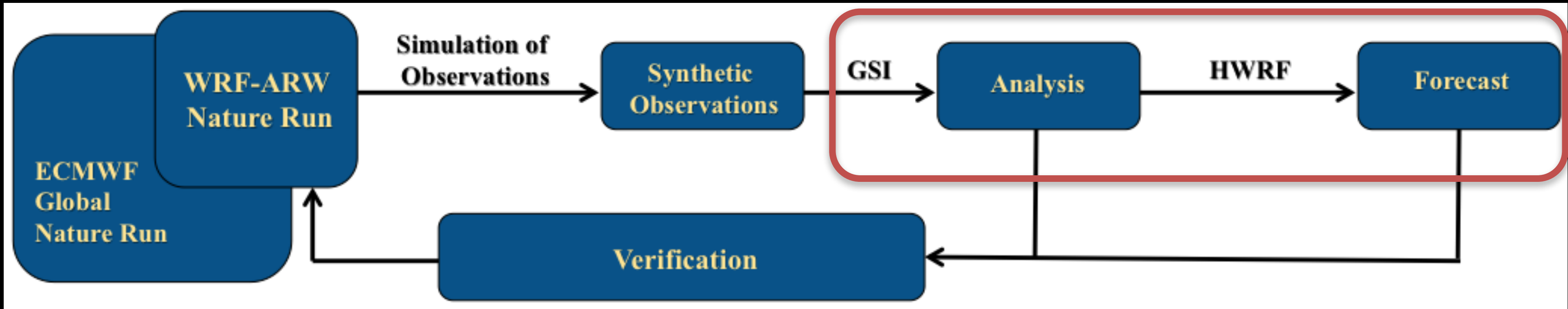




Can simulate both single antenna and dual-antenna X-band TDR



- Range: 90 km
- Horizontal Res: 3 km
- 60 rays/second
- cwm_thresh = 7.51e-5
- Includes operational superobbing routine



High-resolution forecast model

- NOAA's Hurricane-WRF model (v3.5)
  - 9km parent domain (d01)
  - 3km storm-following nest (d02)
    - only active during forecasts
  - 61 vertical levels
  - no vortex initialization/relocation
  - no ocean coupling
- 6-hour forecasts for 5 days

Data Assimilation

- GSI (v3.3) performs analysis over 9km parent domain (d01) of HWRF
  - 3D Var scheme
  - 6 hourly cycling
  - 6 hour spin up (cold start)

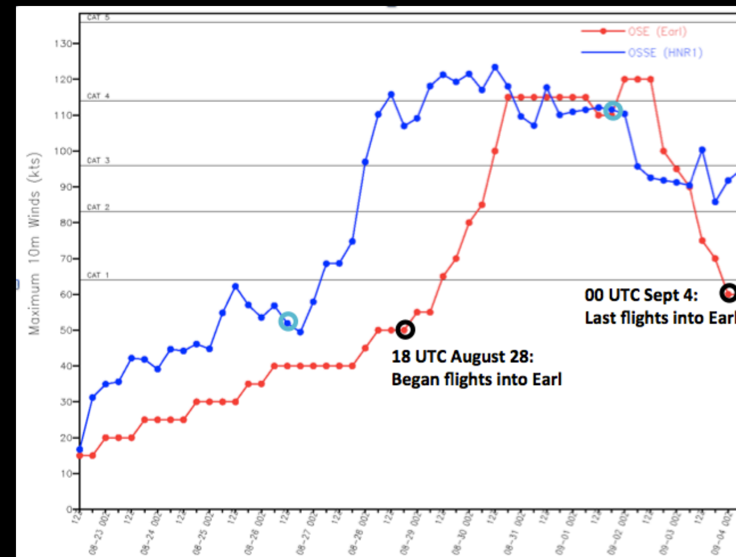
Operationally assimilated data:

- used as **control** observations for OSSEs
- Conventional Observations
  - radiosondes/dropwindsondes
  - aircraft reports & buoy/ship observations
  - land surface observations
  - pibal winds & wind profilers
  - radar-derived Velocity Azimuth Display (VAD) wind
  - WindSat scatterometer winds
  - GPS-derived integrated precipitable water
- Satellite Observations
  - IR Radiances from: HIRS, AIRS, IASI, GOES
  - MW Radiances from: AMSU-A, MHS, ATMS
  - Satellite derived wind: IR/VIS cloud drift & water vapor winds

Validation of Regional OSSE System for Hurricanes

Motivation:

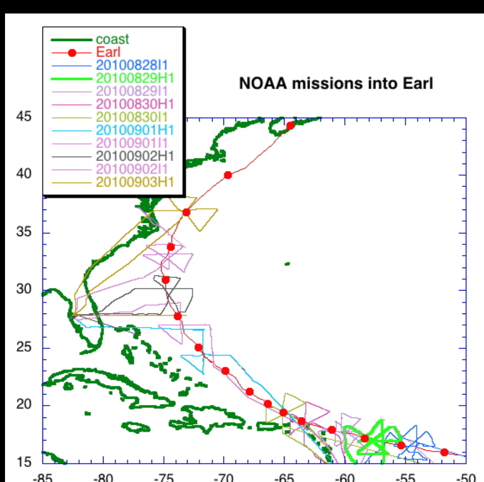
- Make OSSE system results relatable to real world by setting a baseline
- Identify deficiencies in OSSE system and calibrate
- Develop a standardized approach to validation for hurricane OSSE systems

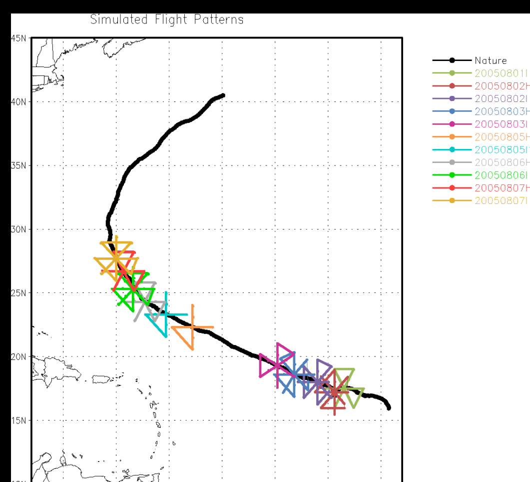


Experiment Setup

- 6 hour cycling for 26 cycles
- Assimilate control data on 9km d01

OSE (Hurricane Earl)	OSSE (Nature Run)
P-3 FL + drops	Synthetic FL + drops



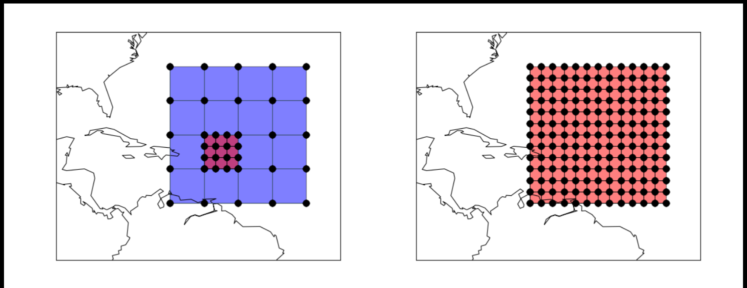


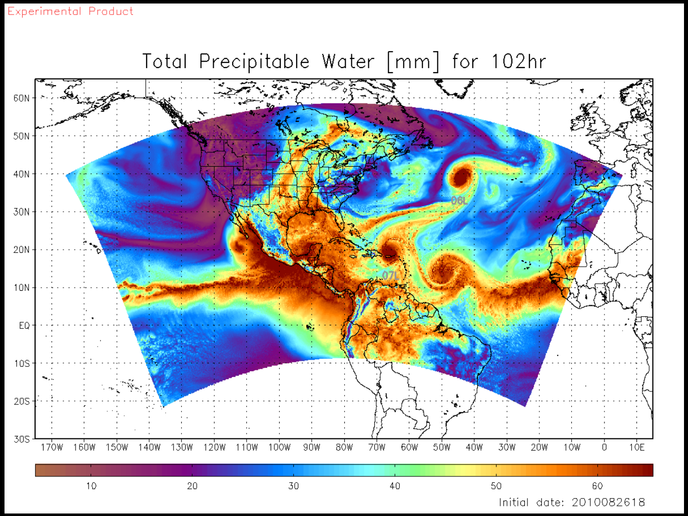
Conclusions:

- Comparable O-B values
- similar track and intensity error trends

Need multiple cases for a more robust validation

Basin Scale Nature Run





Objective:

Create a uniform high-resolution hurricane Nature Run

- utilize new GEOS-5 G5NR Global Nature Run (7km)
  - 72 vertical levels
- capture small scale features of multiple hurricanes

Regional Nature Run

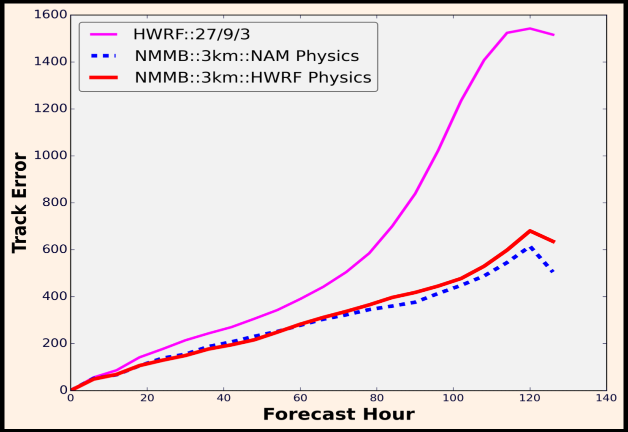
- NMM-B with NAM physics
  - embedded in G5NR
- 3 km uniform resolution
- 61 vertical levels

Conclusion:

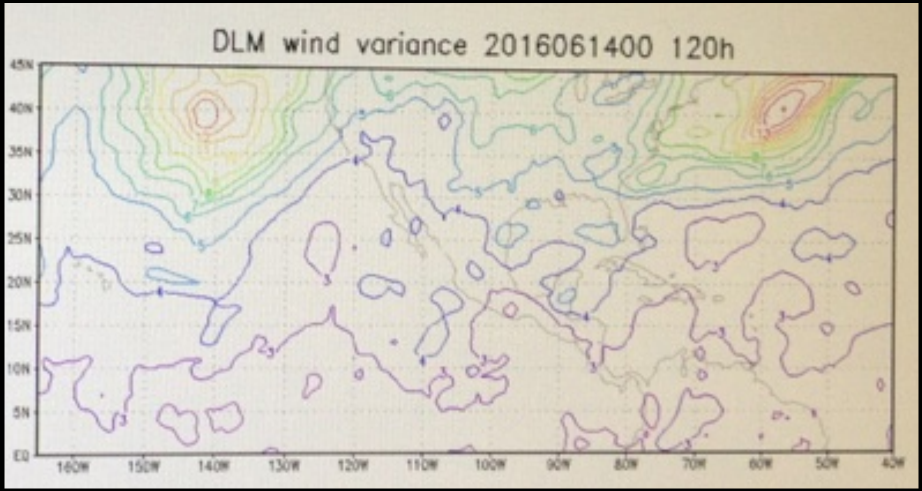
Uniform-3km resolution provides significant forecast improvement, especially for track

Ongoing work:

- Increase resolution to 1km
- Evaluation/validation of Nature Run output



G-IV Synoptic Surveillance Targeting



Motivation:

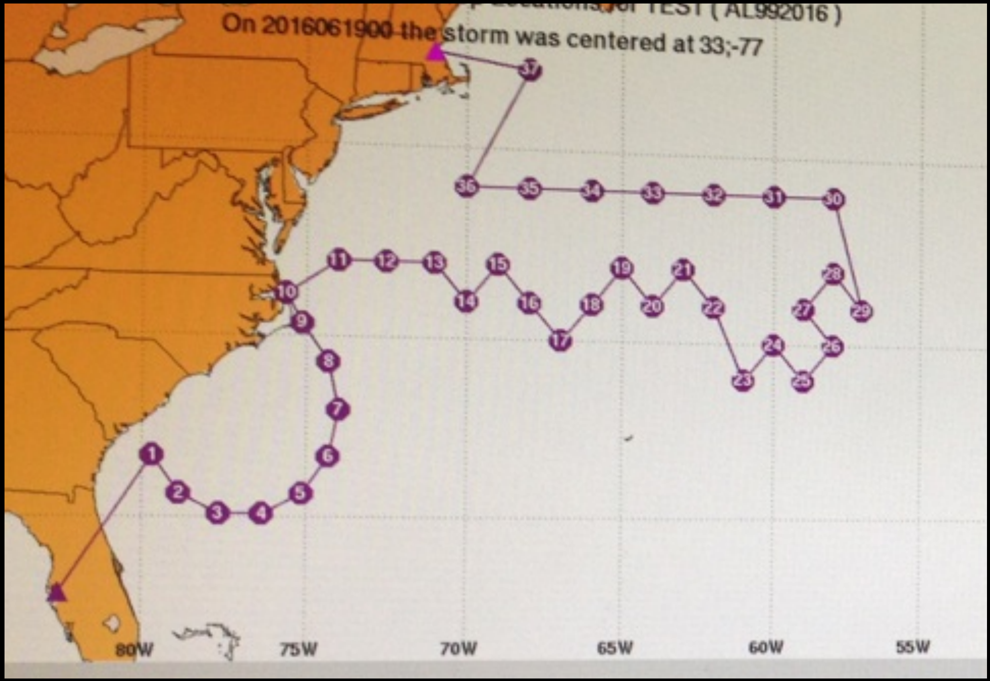
Investigate targeting procedure for synoptic surveillance sampling using NOAA G-IV (NHC)

- Near-hurricane environment
- Synoptic scale features

Current Procedure:

- Use generic circumnavigation pattern around hurricane
- Sample regions of highest variance in GEFS deep layer mean wind within 20 degrees of hurricane center location
- Deploy sondes every 1-1.5 degrees
- Performed 2-3 days before expected landfall

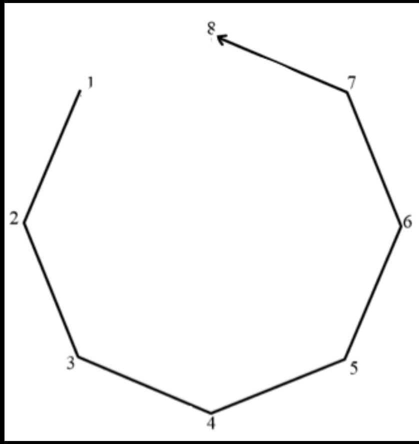
Extremely subjective

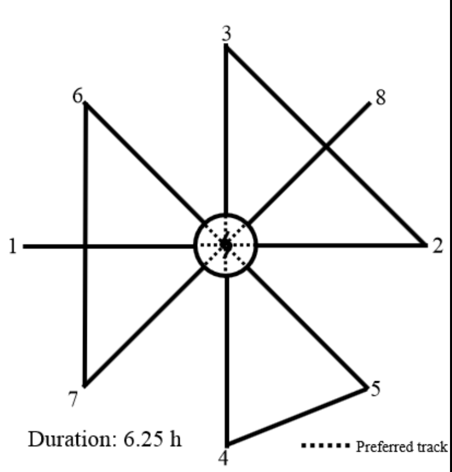


Objectives:

Near-storm environment:

- Sensitivity to
  - Storm relative location
  - Pattern shape
  - Dropsonde distribution





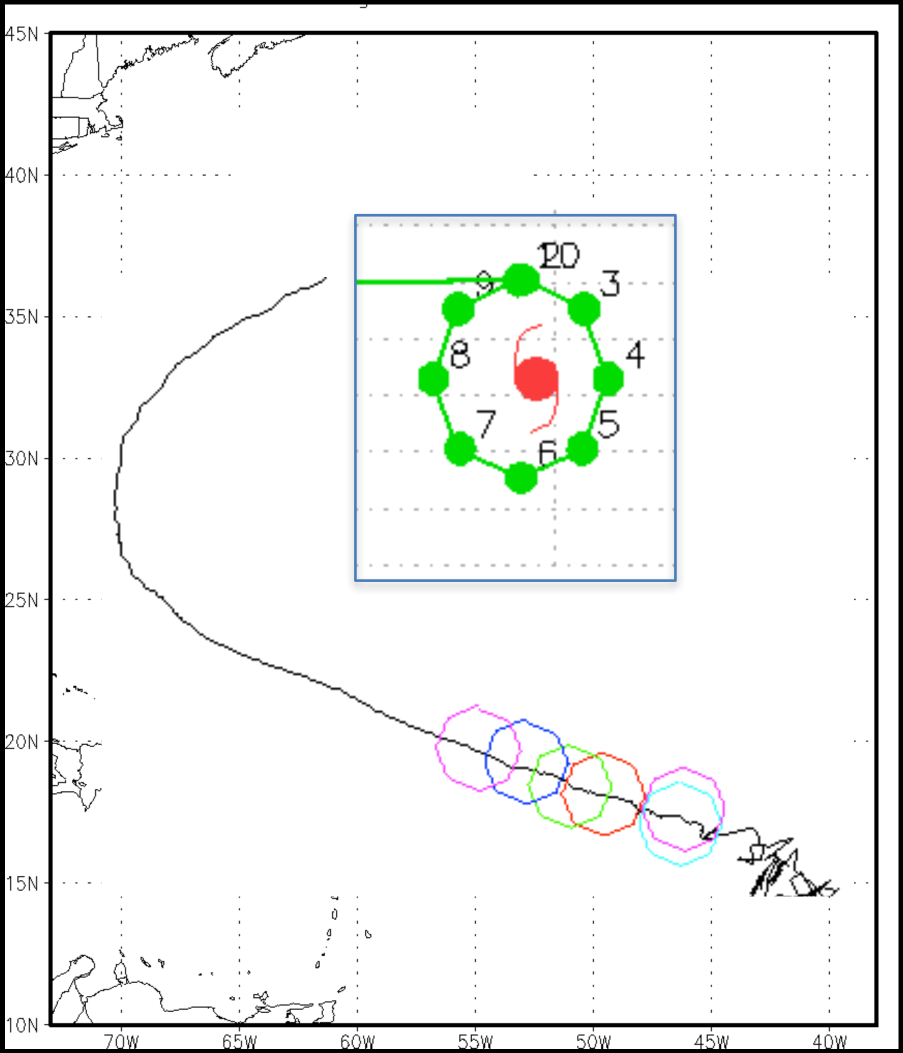
Synoptic features

- Sensitivity to
  - Uncertainty in variable fields from ensemble forecasts
  - Dropsonde distribution

Evaluate using both regional and global forecast models

- HWRF and GFS

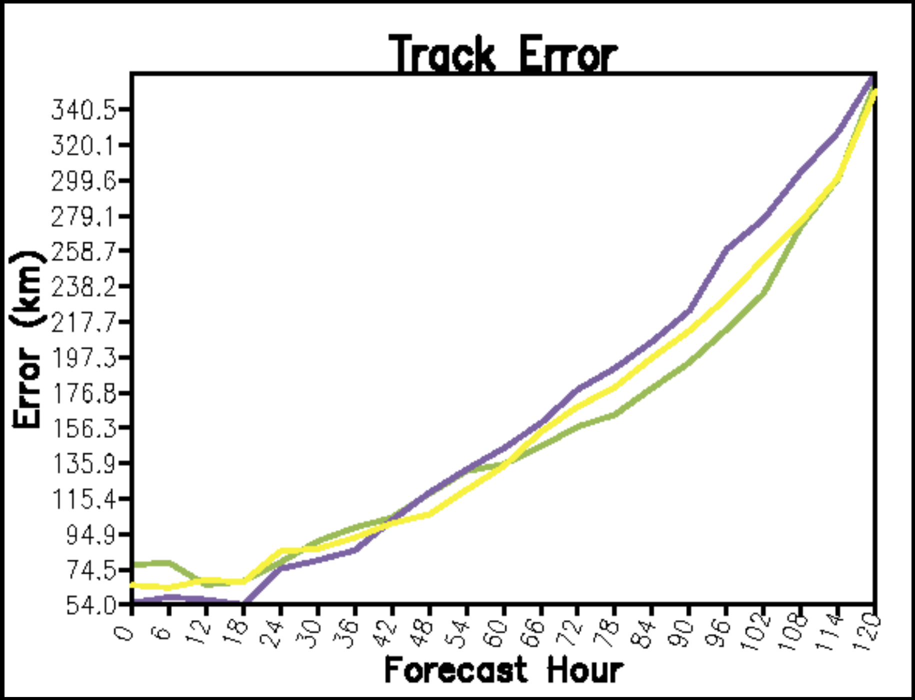
Sensitivity to Radial Distance from Center



Mission ID	Take off time (local)
20050801N1	2am
20050801N2	2pm
20050802N1	2am
20050802N2	2pm
20050803N1	2am
20050803N2	2pm

Dropsonde coverage:
every 40 degrees (storm relative)
Total Dropsondes: 60

 # observations assimilated in experiment: 27215
 # observations assimilated in control: 26200



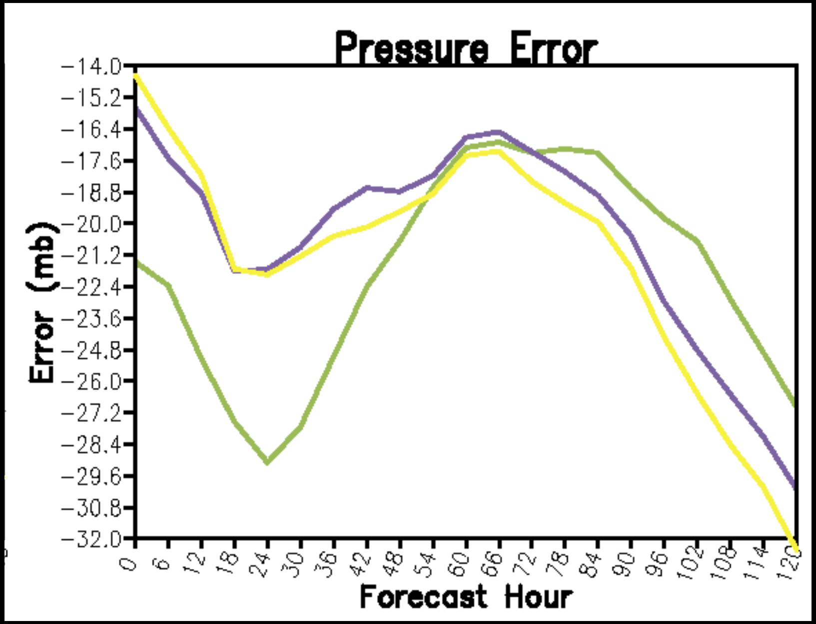
Control
g4_1.5xR34_drops
g4_3xR34_drops

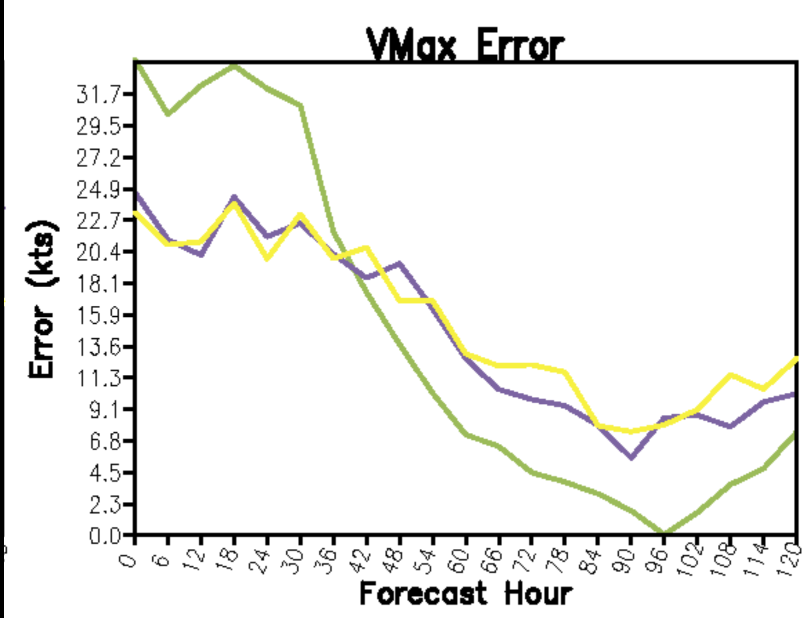
Minimal impact (20 km) on track out to

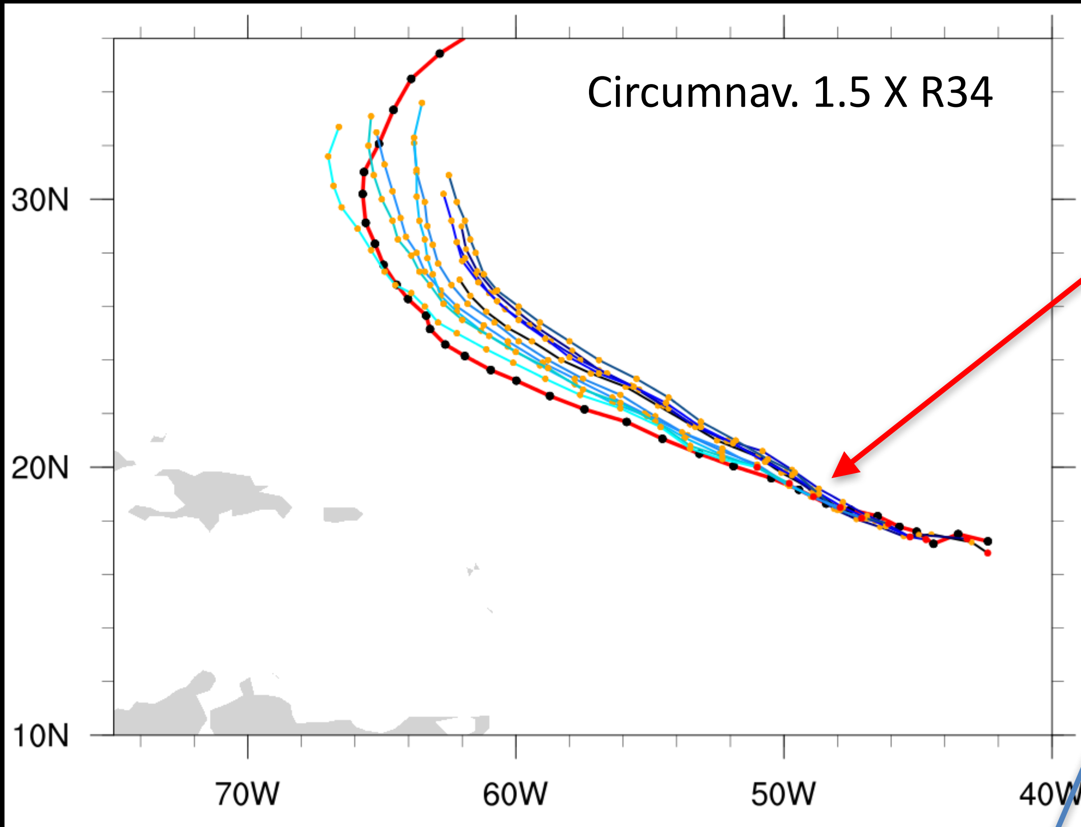
- 18 hours for 1.5 x R34
- 9 hours for 3 x R34

~10 knot (~ 7mb) improvement in intensity out to 42 hours

- Little difference between regions
- Does not mitigate "spin down"
- Does not capture rapid intensification



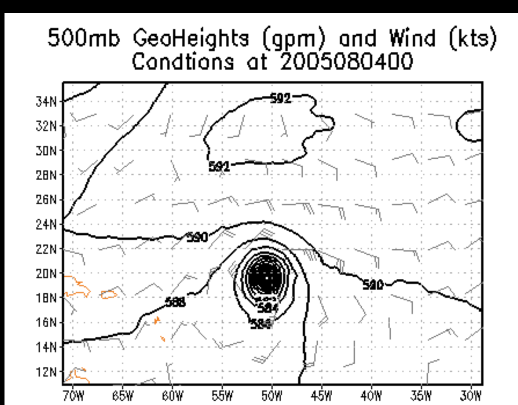




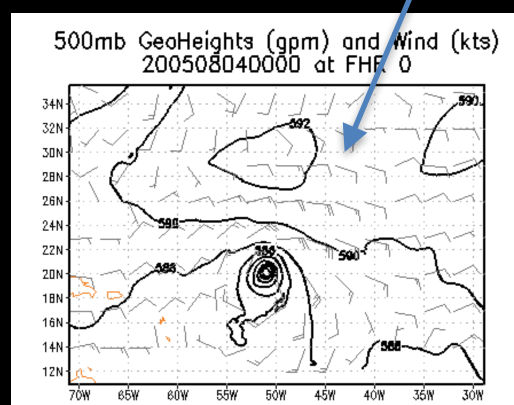
Forecast tracks diverge at ~ August 04 00Z

Subtropical ridge more robust **AND** Vortex much weaker

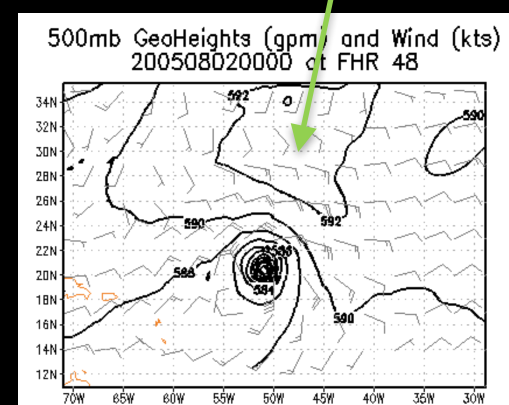
Vortex embedded within ridge → Feels stronger steering



Nature Run

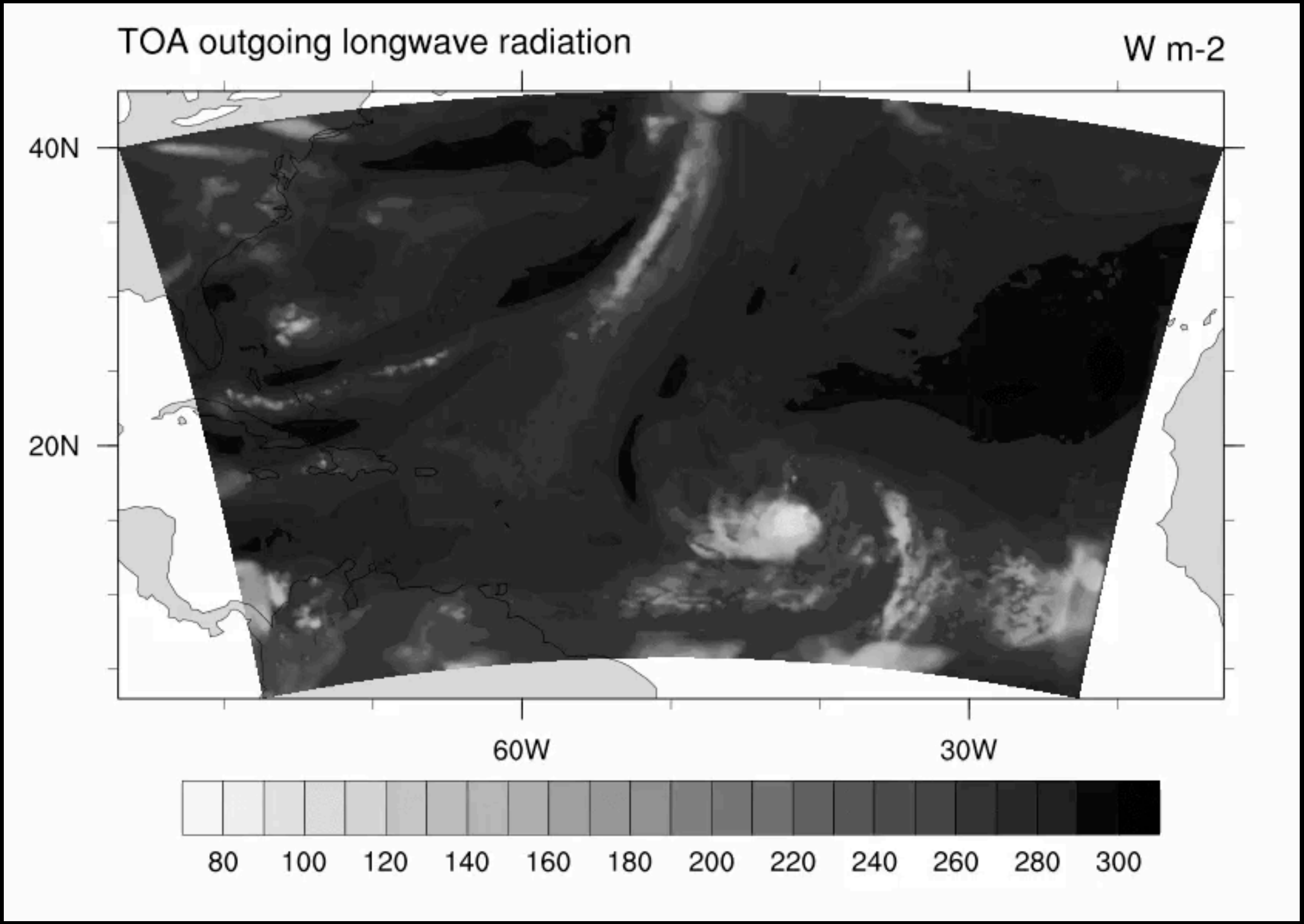


Analysis



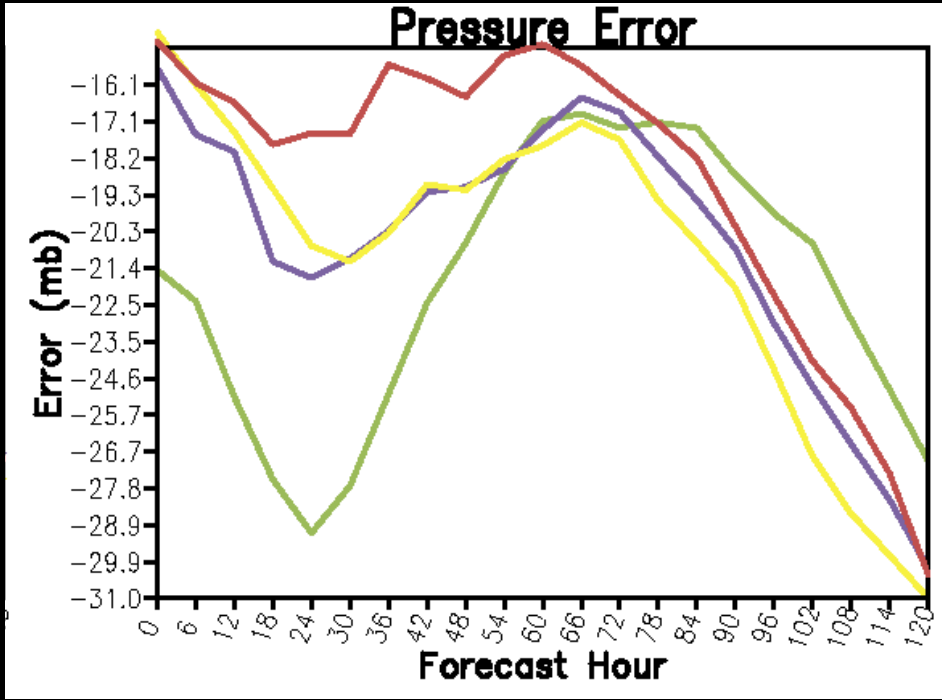
48-hr forecast init @ 0802 00Z

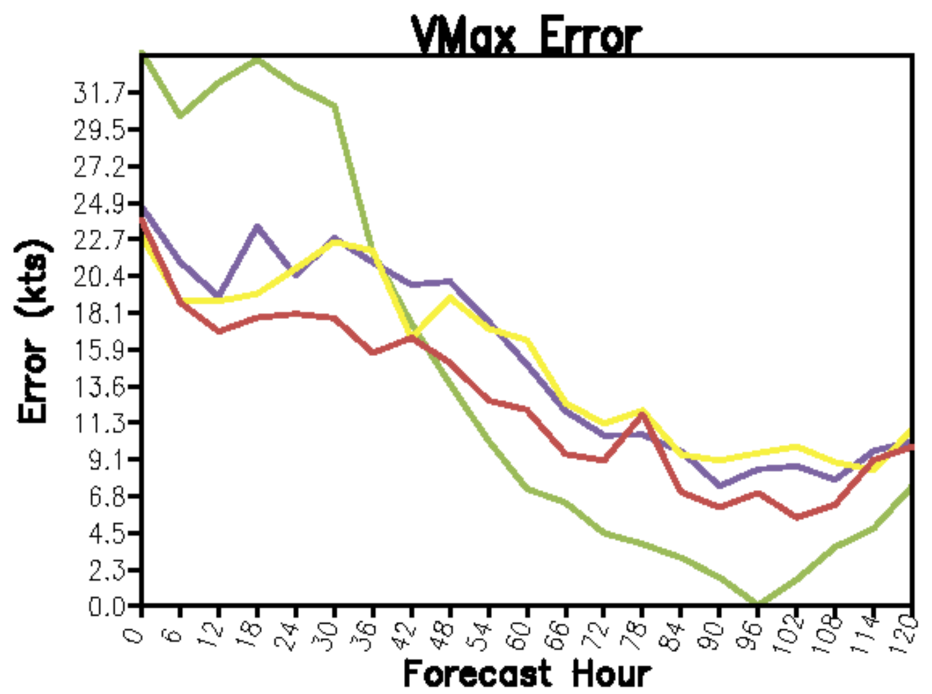
Impact of G-IV Flight Level Observations

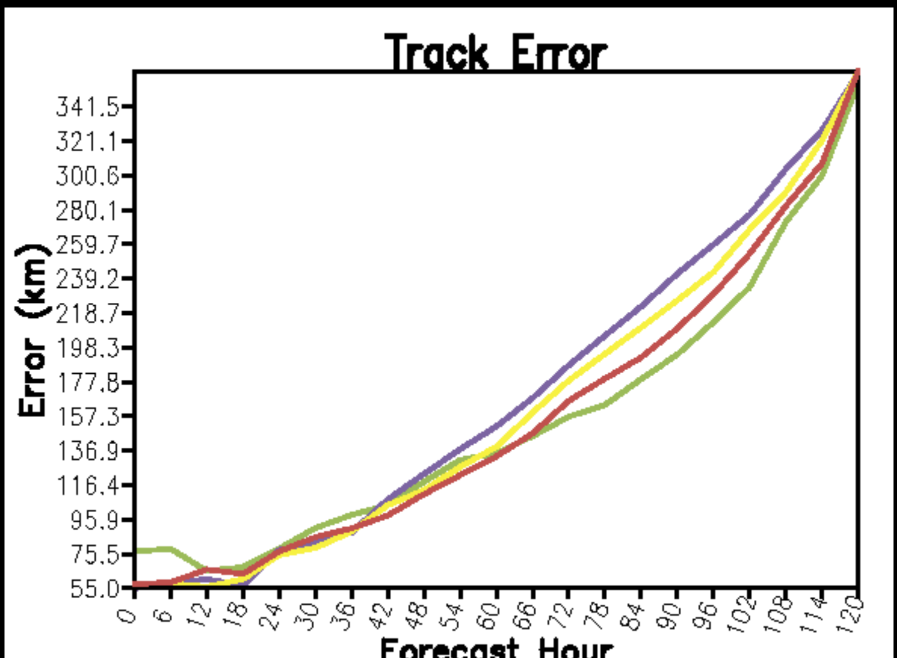


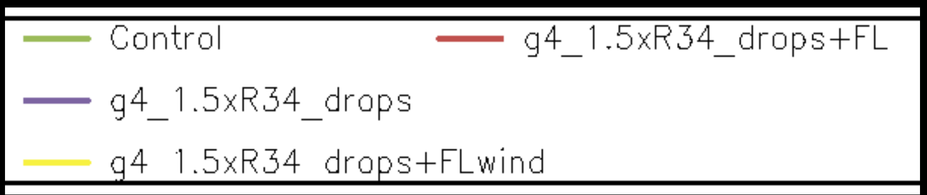
Data used:
60 dropsondes + flight level

 # observations assimilated in control: 26200
 # observations assimilated in experiment: 60000





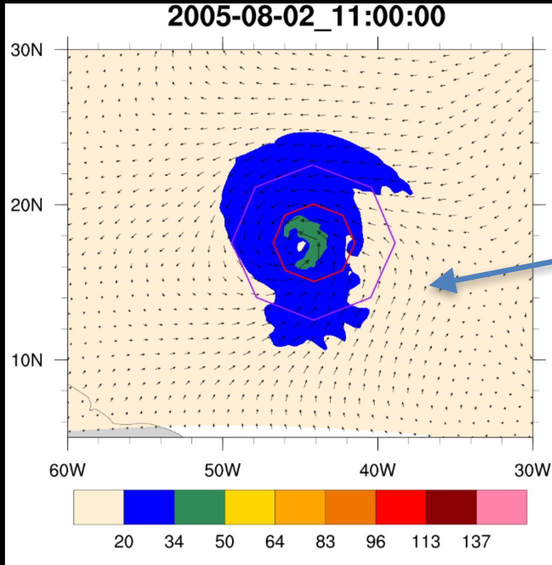




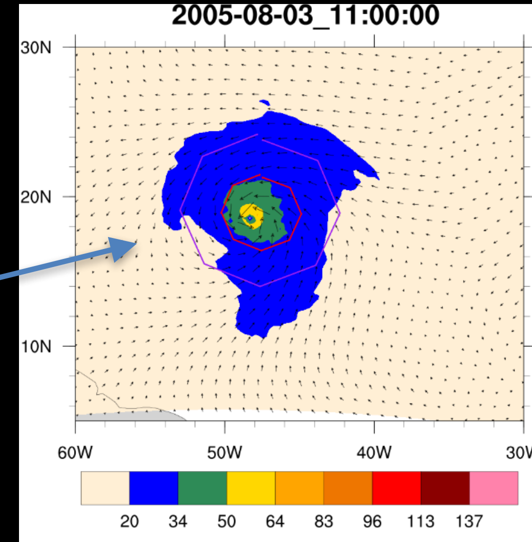
No significant impact on track forecast
Intensity forecast consistently improved out to

- 42 hours in vmax
- 72 hours in mslp
- "spin down" almost diminished
- Distinct impact differences before/after onset of RI

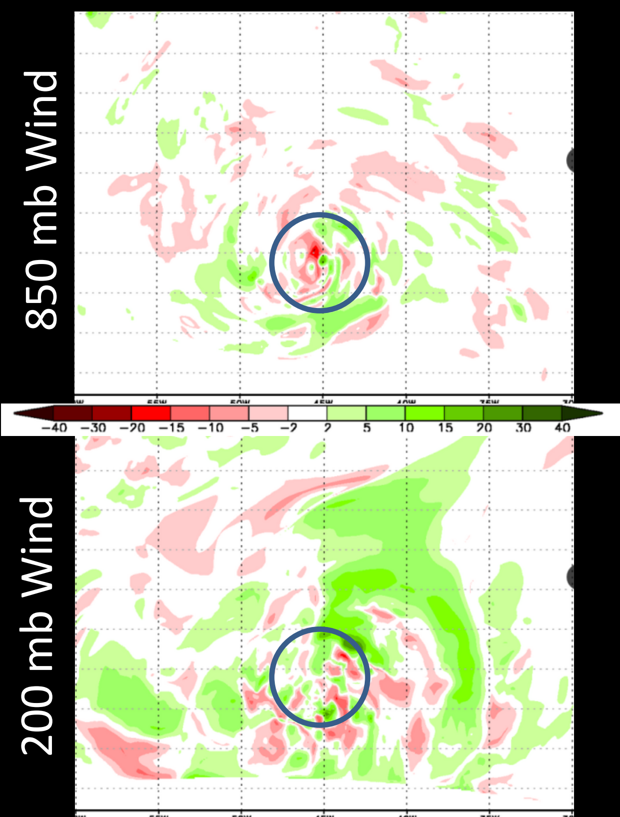
Nature Run



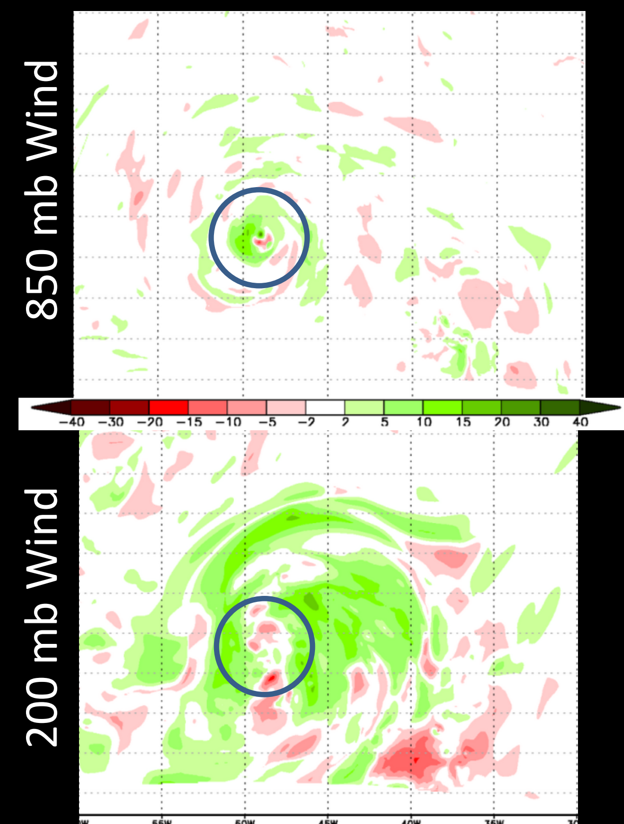
Before onset of RI



After onset of RI



Location of UL center is displaced from LL center



UL winds captured in analysis
→ Additional core information improves intensity forecast

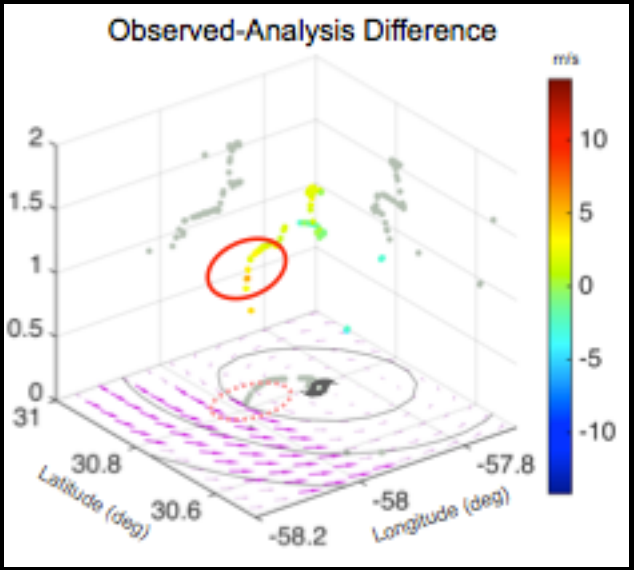
Preliminary Summary of G-IV Experiments

- If dropsondes are limited, deploy close to radius of 34 knot winds to improve track forecast
- Assimilating flight level measurements improves intensity forecast despite lack of vortex init/reloc or ensemble DA
  - Does not affect track forecast
- Different techniques may be more beneficial before/after onset of rapid intensification

Optimization of Coyote UAS

What is a Coyote?

- similar to dropsonde
- collects T, Q, P, and wind measurements in the BL
- deployed from NOAA P-3
- 1 hour duration
- NOT reusable



Case Study: Hurricane Edouard
16 September 2014

- sampled eye/eyewall region over 28 minute flight
- observations were assimilated using Hurricane Ensemble DA System (HEDAS)
  - slightly positive impact on vortex analysis
  - slightly positive forecast impact
  - strongest analysis errors within the High Gradient Region

Ongoing work: **OSSEs**

- verify impact using OSSE validation
- evaluate analysis and forecast impact of various configurations (up to 3 coyotes/mission)
  - assess trade-offs in duration and coverage
- develop optimal coyote framework for hurricanes
  - Evaluate and improve hurricane model land-sea interaction and boundary layer physics

Additional Ongoing Aircraft Experiments

- In-house regional OSSE system upgrade (including NR and DA)
- Evaluation of P-3 instrumentation for Hurricane Field Program
- Assessment of multi-aircraft missions
- Impact of Tail Doppler Radar radial velocities
  - Superobbing / density of observations
  - Orientation of aircraft
- Optimization of Doppler wind LIDAR scanning patterns
- Potential impact of Global Hawk Observations on hurricane track & intensity forecasts
- Coordination of data collection with satellite passes
- Assessing ensemble and hybrid DA methods for inner core

Questions?????

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shirley.murillo@noaa.gov
frank.marks@noaa.gov

Rigorous OSSE Checklist: http://www.aoml.noaa.gov/qosap/osse-checklist/

HRD website: http://www.aoml.noaa.gov/hrd/

Twitter: https://twitter.com/HRD_AOML_NOAA

Facebook: https://facebook.com/noaahrd