Forecast Impact Experiments To Optimize Utilization of CYGNSS Wind Observations

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Overview

- Introduction
- Early OSSEs
- Components of an Observing System Experiment (OSE)
- Case Study
- Experiments
- OSE Results
- Deriving CYGNSS Vector Winds
- Summary
- Future Work

Atlantic Oceanographic and Meteorological Laboratory (NOAA/AOML)

Miami, FL

AOML's research spans hurricanes, coastal ecosystems, oceans and human health, climate studies, global carbon systems, and ocean observations.

Three scientific research divisions:

1. **Hurricane Research Division**
2. **Ocean Chemistry and Ecosystems**
3. **Physical Oceanography**

Hurricane Research Division

Observing Techniques:

design, test and automate optimal data collection

Modeling and Prediction:

develop and improve both multi-layer numerical and statistical-dynamical models

Data Assimilation:

state analysis of tropical systems and their near environments

Dynamics and Physics:

improving our understanding of of air motion, moist thermodynamics, and radiation of tropical cyclones

Impacts:

multi-faceted nature of hurricane hazards (winds, storm surge, waves, heavy rainfall, flooding, mudslides, etc.)

Observing System Experiments:

The QOSAP program evaluates both new and proposed observing systems by conducting experiments to determine the impact of observational data on models (existing or proposed). The QOSAP program has two primary evaluations: Observing System Experiments (OSEs) and Observing System Simulation Experiments (OSSEs). Together, these experiments can help managers make decisions about the effectiveness, impact, and viability of new and proposed observing systems.

Surface Wind Impact Analysis

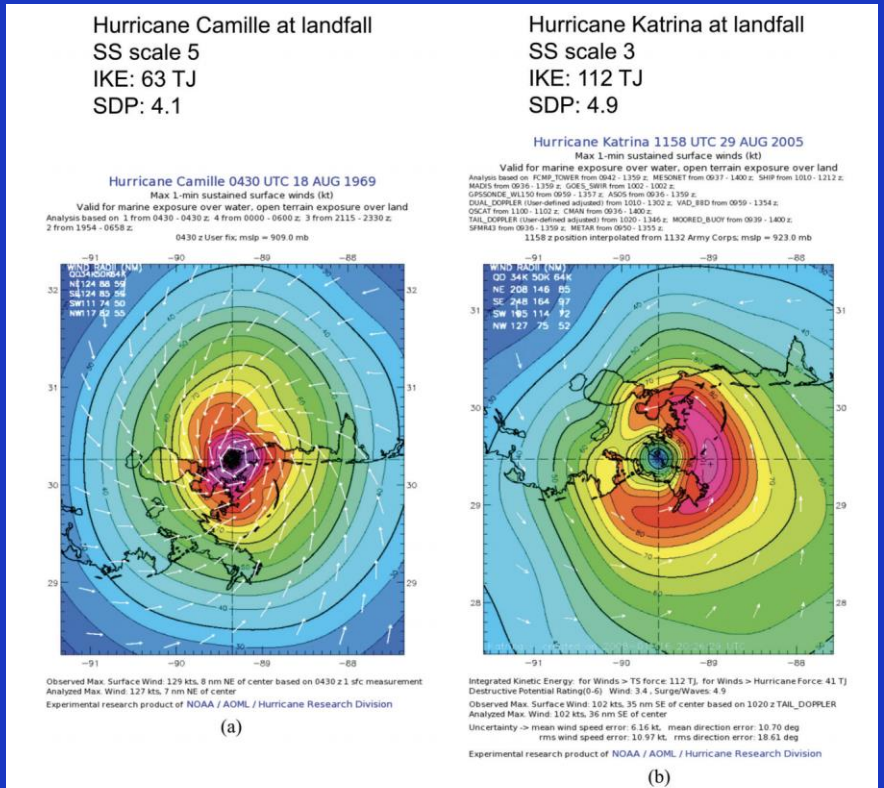


Fig. 5. H*Wind surface wind analysis (shaded, kt, values corresponding to accompanying contours) for (a) Hurricane Camile (1969) and (b) Hurricane Katrina (2005) showing the IKE for winds greater than TS force, the surge/wave destructive potential (SDP), and the SS scale.

Impacts:

- **Hurricane wind field analyses to support research and model validation**

Powell et al "Reconstruction of Hurricane Katrina's wind fields for storm surge and wave hindcasting" Ocean Engineering

- **Development of new forecast model metrics that attribute physical storm impacts**

Powell et al "Tropical Cyclone Destructive Potential by Integrated Kinetic Energy" BAMS 2007

- **Hurricane risk**

S. Hamid et al 2010: "Predicting losses of residential structures in the state of Florida by the public hurricane loss evaluation model", Statistical Methodology, 7, 552-573.

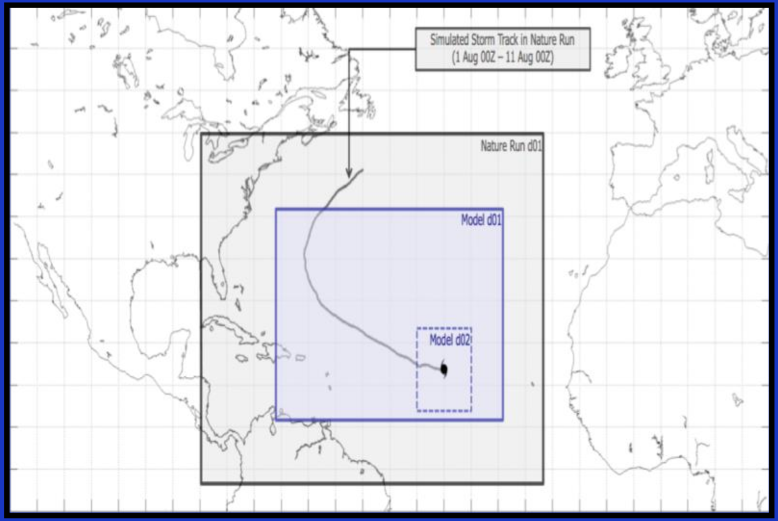
Past Observing System Simulations Experiments (OSSEs)

OSSE Framework Details

Nature Runs
- ECMWF: low-resolution T511 (~40km) “Joint OSSE Nature Run”
- WRF-ARW: high-resolution 27 km regional domain with 9/3/1 km storm-following nests (v3.2.1)

Data Assimilation Scheme
- GSI: Gridpoint Statistical Interpolation. a standard 3D variational assimilation scheme (v3.3).

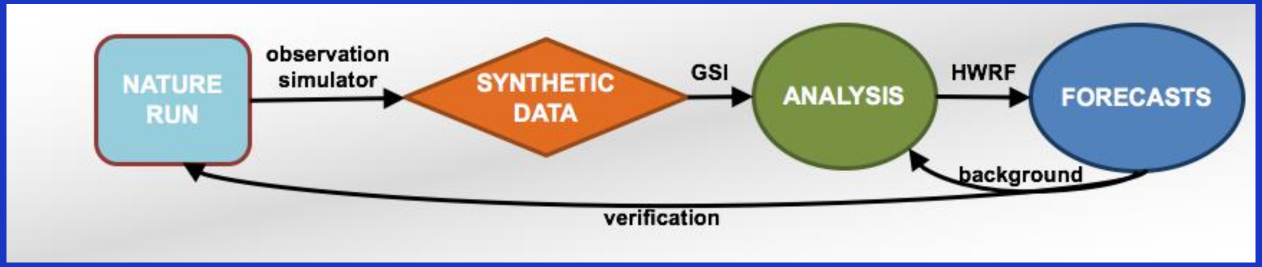
Analyses performed at 9km resolution.



Forecast Model
- HWRF: the 2014 operational Hurricane-WRF model (v3.5).

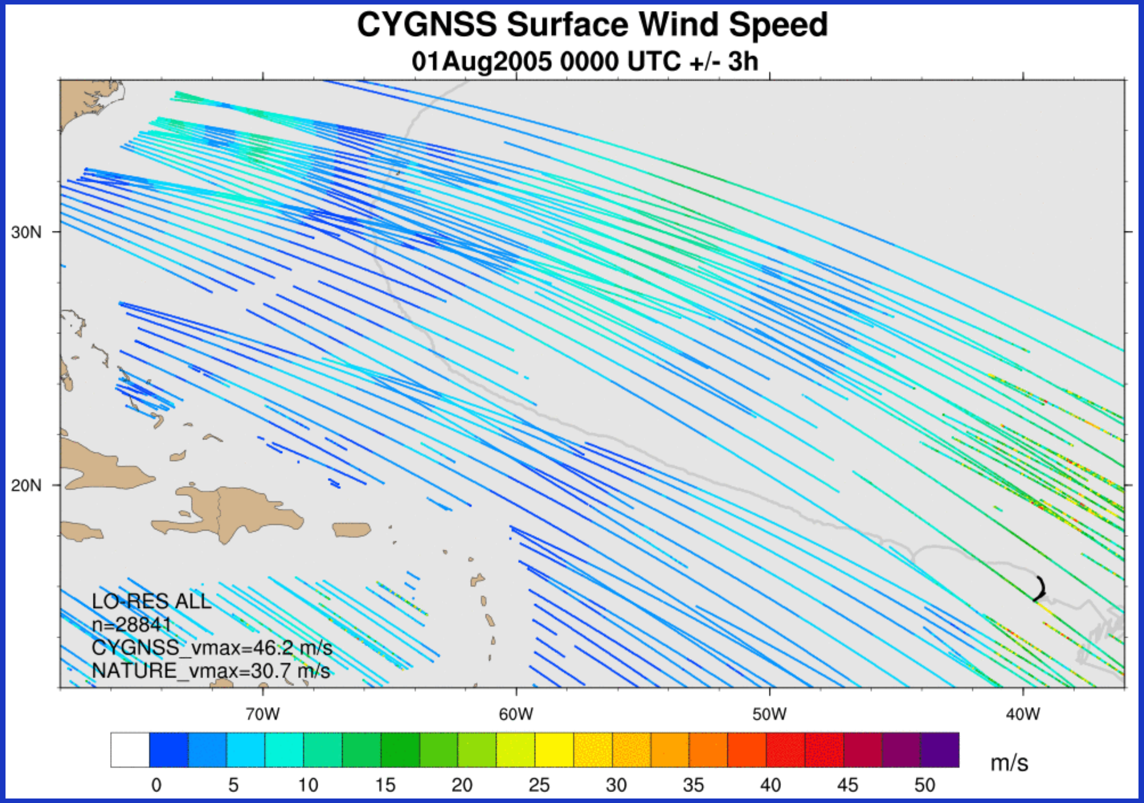
Parent domain has ~9km resolution, single storm-following nest has ~3km resolution.

DA and model cycling performed every 6,3, 1 hours, each run producing a 5-day forecast.



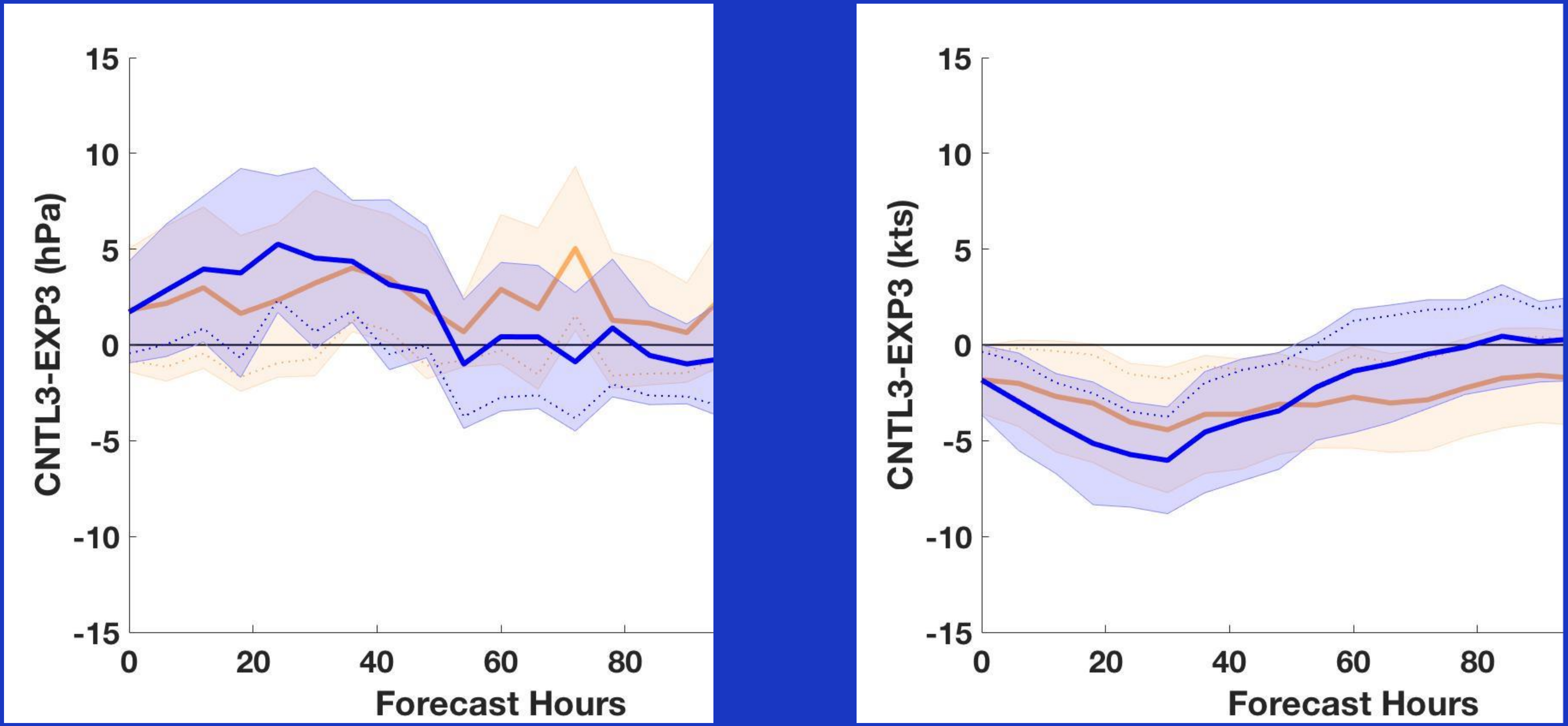
Simulated CYGNSS Data

Synthetic CYGNSS dataset generated to span from the WRF nature run.



0801 00z - 0805 00z

OSSE Results



(a) Minimum sea-level pressure forecast error and (b) maximum wind speed forecast error of experiments CYG3 (orange) and VAM3 (blue) with respect to CNTL3. 95th percentile confidence intervals (CI) are plotted: 2-sided CIs are plotted in transparent colors and 1-sided CIs are plotted with thin dotted lines.

OSSE Result Summary

Assimilation of CYGNSS data almost always improves hurricane intensity, track analyses, and short range forecasts (0-48 hrs).

DA cycling frequencies affects analyses and forecast errors.
- 3-hrly cycling produced minimum errors in our study

There are relatively a few samples from one storm, so error statistics are not robust but provide guidance.

Observing System Experiments (OSEs)

HWRF CYGNSS OSEs

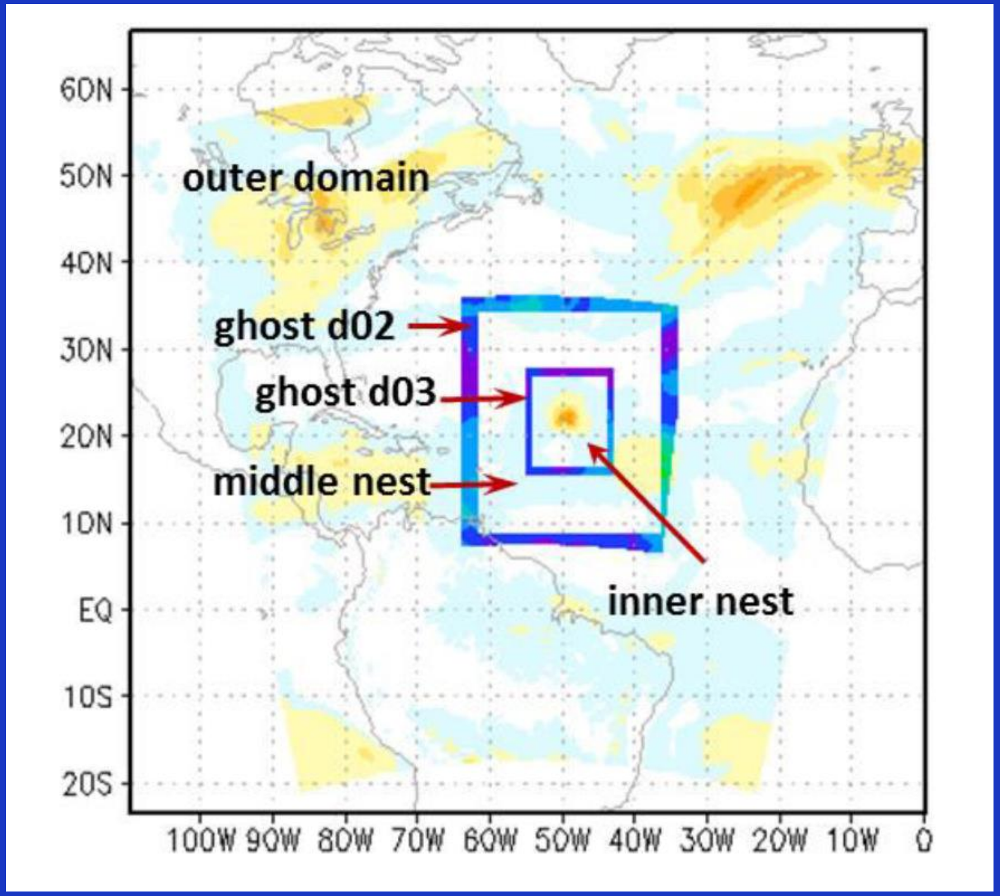
- **Atmospheric forecast model (Operational HWRF, “H219”)**
- **Control experiment: NCEP operational HWRF, H219**
- **Data assimilation system**
  - Hybrid 3d-Variational/Ensemble Kalman Filter data assimilation system in the Gridpoint Statistical Interpolation (GSI) framework
- **Experiments using different treatments of CYGNSS data**
  - Assimilate CYGNSS wind speed in HWRF operational configuration
  - Investigate different thinning alternatives
- **OSEs will focus on:**
  - Sparsely observed periods of TC lifecycles (TD/genesis)
  - Operational HWRF forecasts with relatively high intensity error
- **One of the high impact storms of 2017/2018:**
  - Hurricane Michael (2018)
  - Short-term forecasts of hurricane intensity are a focus

OSE Framework Details

•**Global forecast system initialization and lateral boundary conditions**
- FV3GFS Operational analyses and forecasts (“H219”)

• **Data Assimilation Scheme**
- Hybrid 3d-Variational/Ensemble Kalman Filter data assimilation system in the Gridpoint Statistical Interpolation framework
- Analyses performed at 1.5 and 4.5 km resolution.

• **Forecast Model**
- HWRF: the 2019 operational Hurricane-WRF model (v3.9). Parent domain has ~14.5-km resolution, two storm-following nests with ~4.5-km and ~1.5-km resolution.



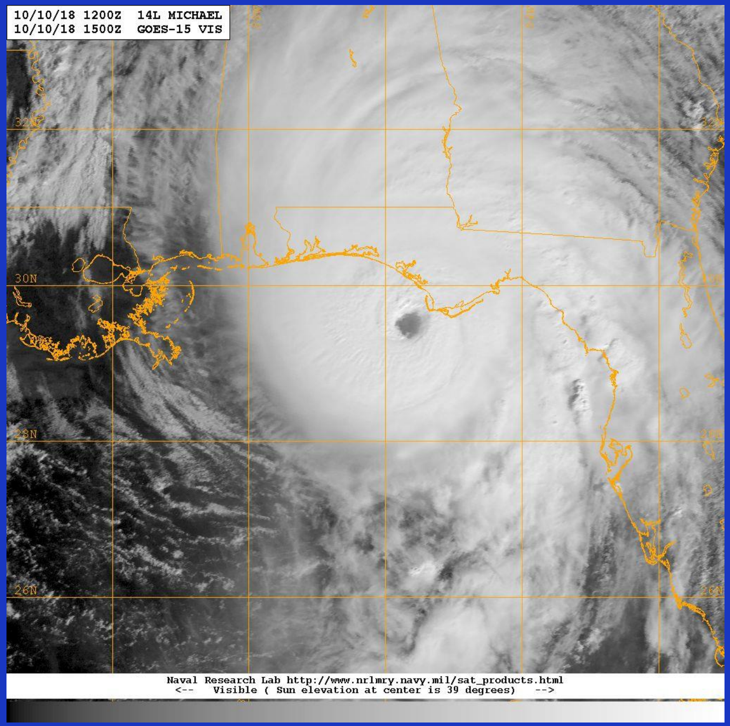
Compare Experiment treatments to Control to assess impact on hurricane metrics (minimum sea-level pressure, maximum wind, track error).

DA and model cycling performed every 6 hours, each cycle produces a 5-day forecast.

Tropical Cyclone Michael

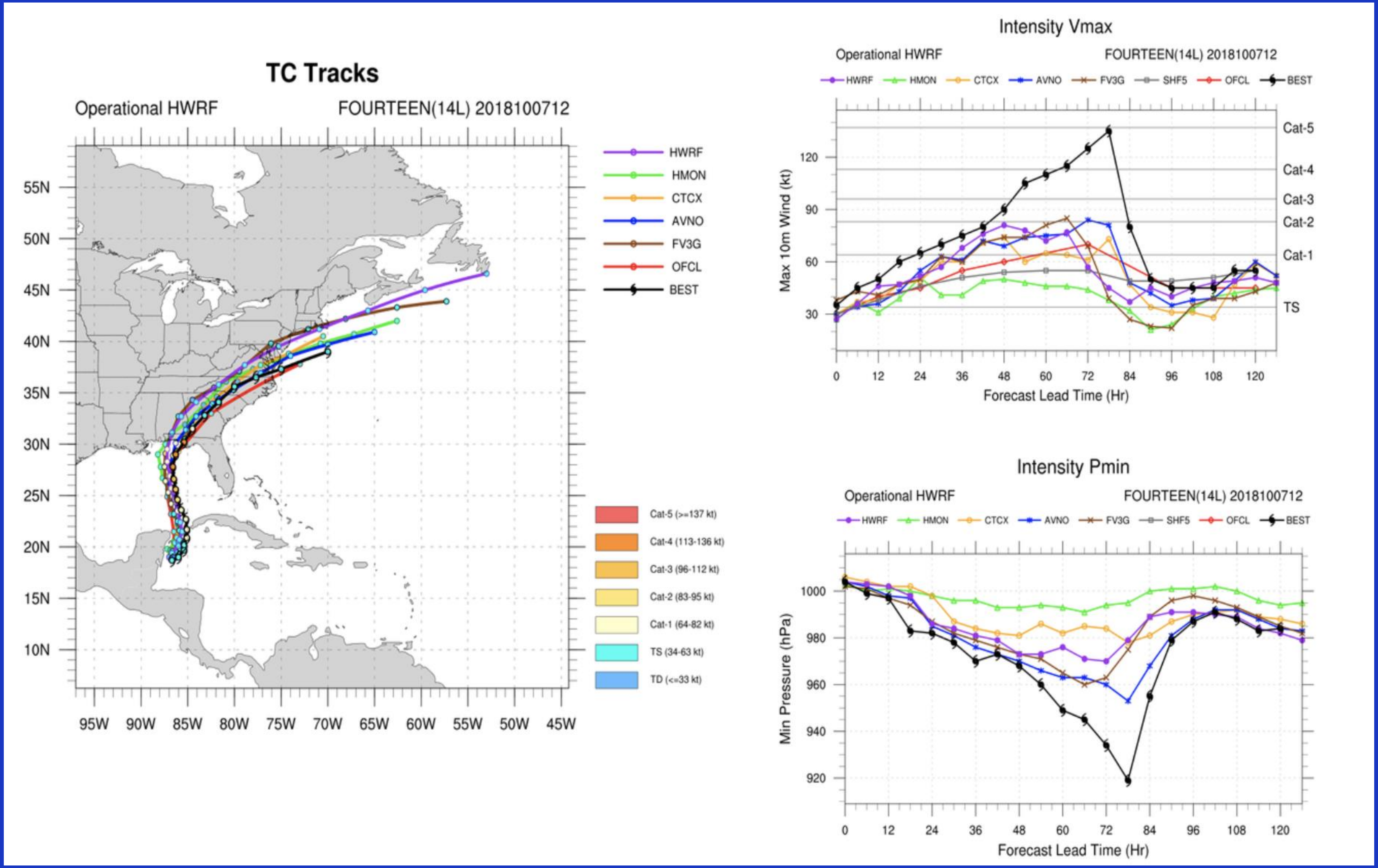
10/07 00Z- 10/10 18Z

- Hurricane Michael was the first Category 5 hurricane to strike the contiguous United States since Andrew in 1992.
- The third-most intense Atlantic hurricane to make landfall in the contiguous United States in terms of pressure, behind the 1935 Labor Day hurricane and Hurricane Camille of 1969
- Date: October 7, 2018 – October 16, 2018
- Affected areas: Landfall at Mexico Beach Florida Michael
- Michael is the 10th-costliest Atlantic hurricane



Case Study: TC Michael

10/07 00Z- 10/10 18Z

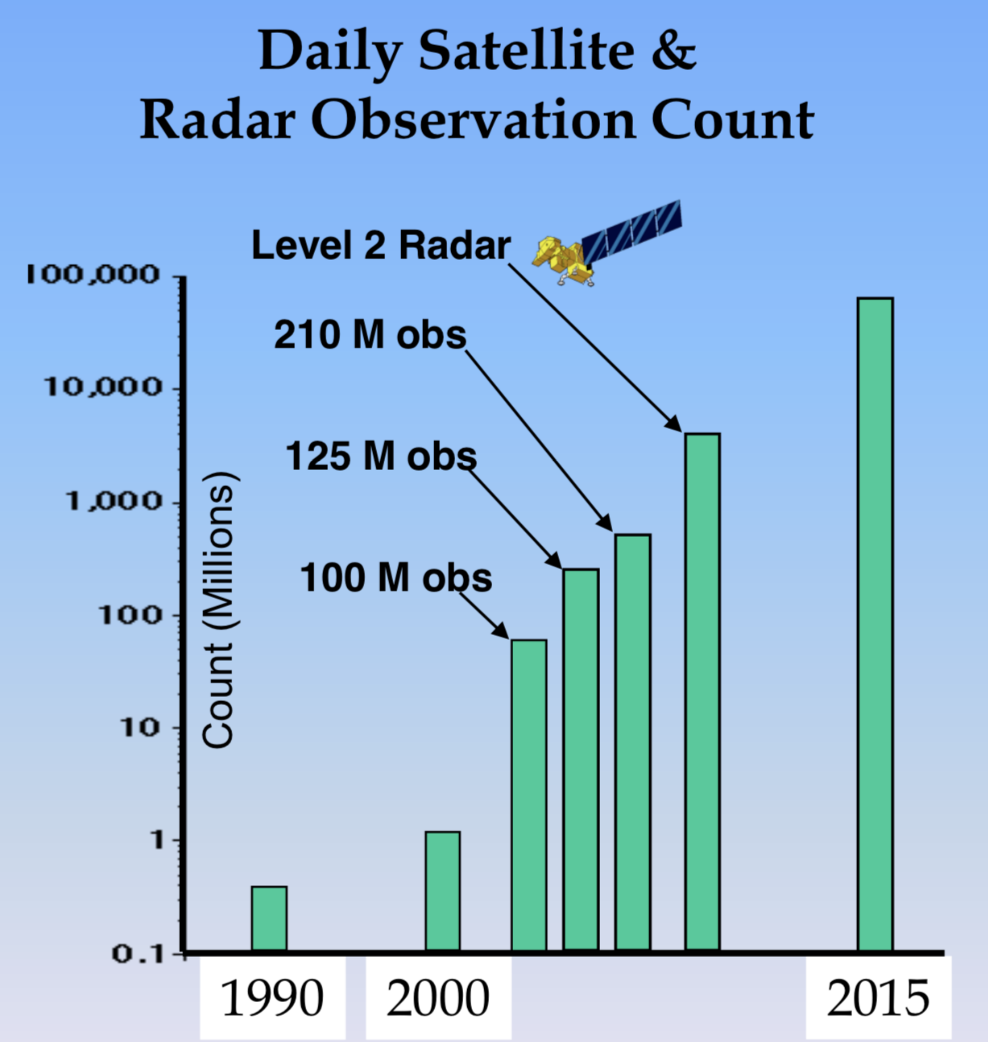


EMC

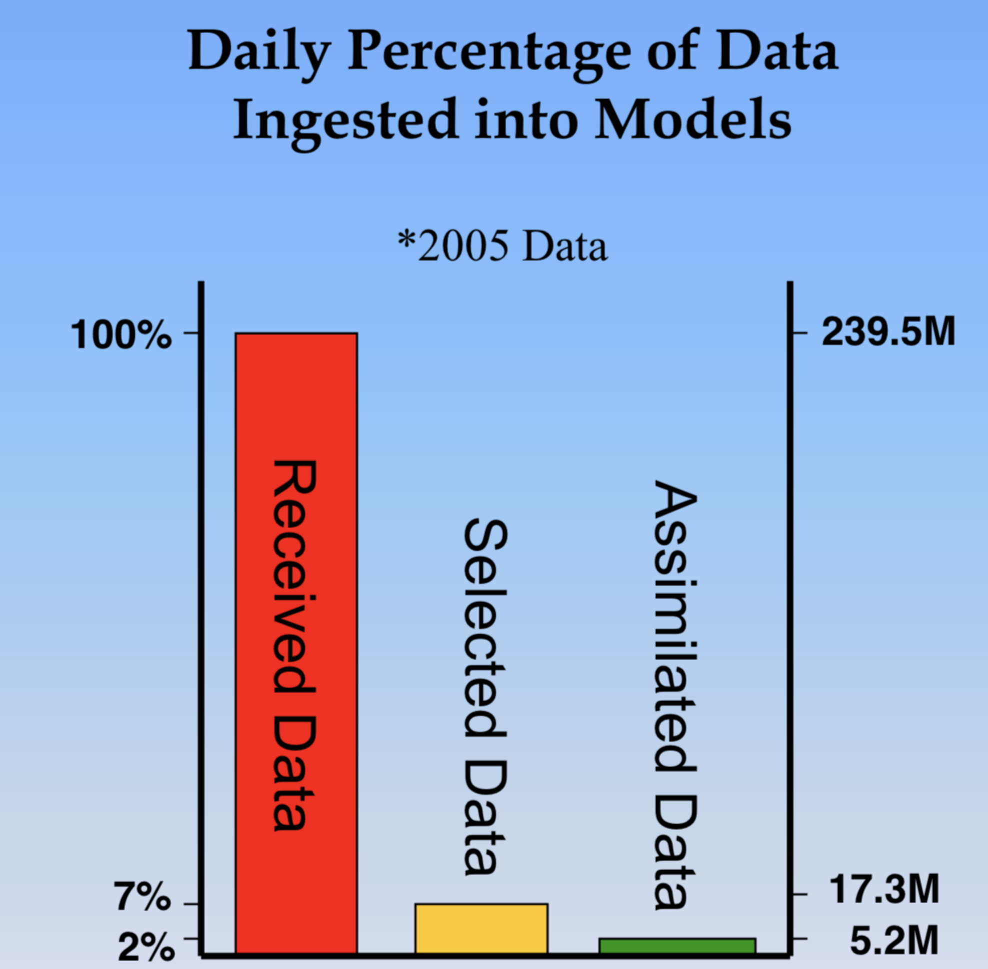
List of Experiments

Experiment name	Assimilated Data set 15 cycles (10/07 00Z- 10/10 18Z)		
	Conventional	Radiances	CYGNSS
Control	Yes	Yes	<u>No</u>
No Thinning	Yes	Yes	Yes
Thinning at 50km	Yes	Yes	Yes
Thinning at 100 km	Yes	Yes	Yes (up to 15 m/s)

Thinning



Five Order of Magnitude Increases in Satellite Data Over Fifteen Years (2000-2015)



Received = All observations received operationally from providers
Selected = Observations selected as suitable for use
Assimilated = Observations actually used by models

DtCenter

Assimilated CYGNSS Data

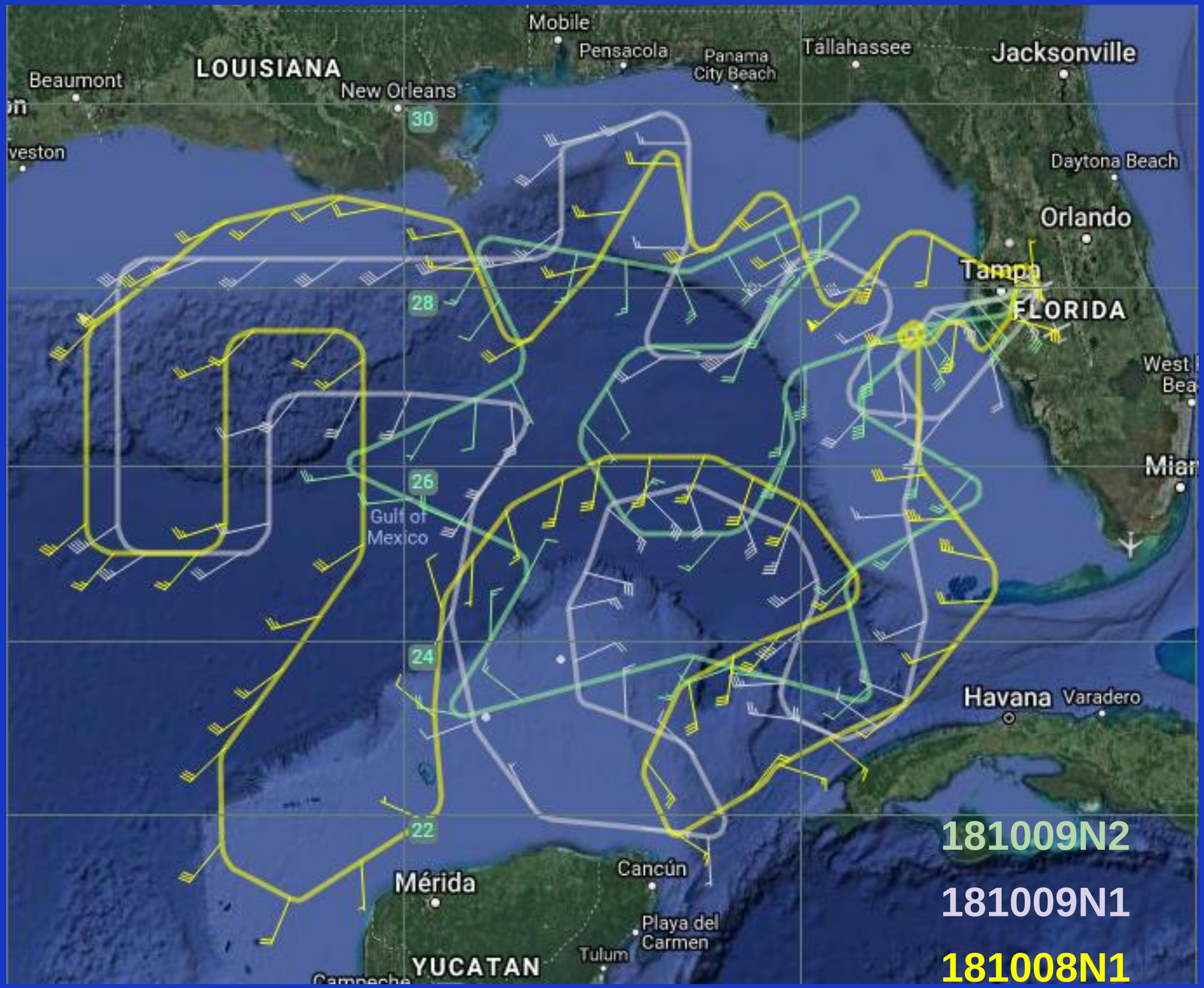
- CYGNSS v2.1 QC'd and converted to prepbufr
- Only Young Seas with Limited Fetch (YSLF) winds up to 15 m/s used
- Observation error: 2.5-3 m/s

	Average Assimilated CYGNSS Counts 15 cycles (10/07 00Z- 10/10 12Z)		
	No Thinning	Thin 50km	Thin 100km
CYGNSS	4568	608	246

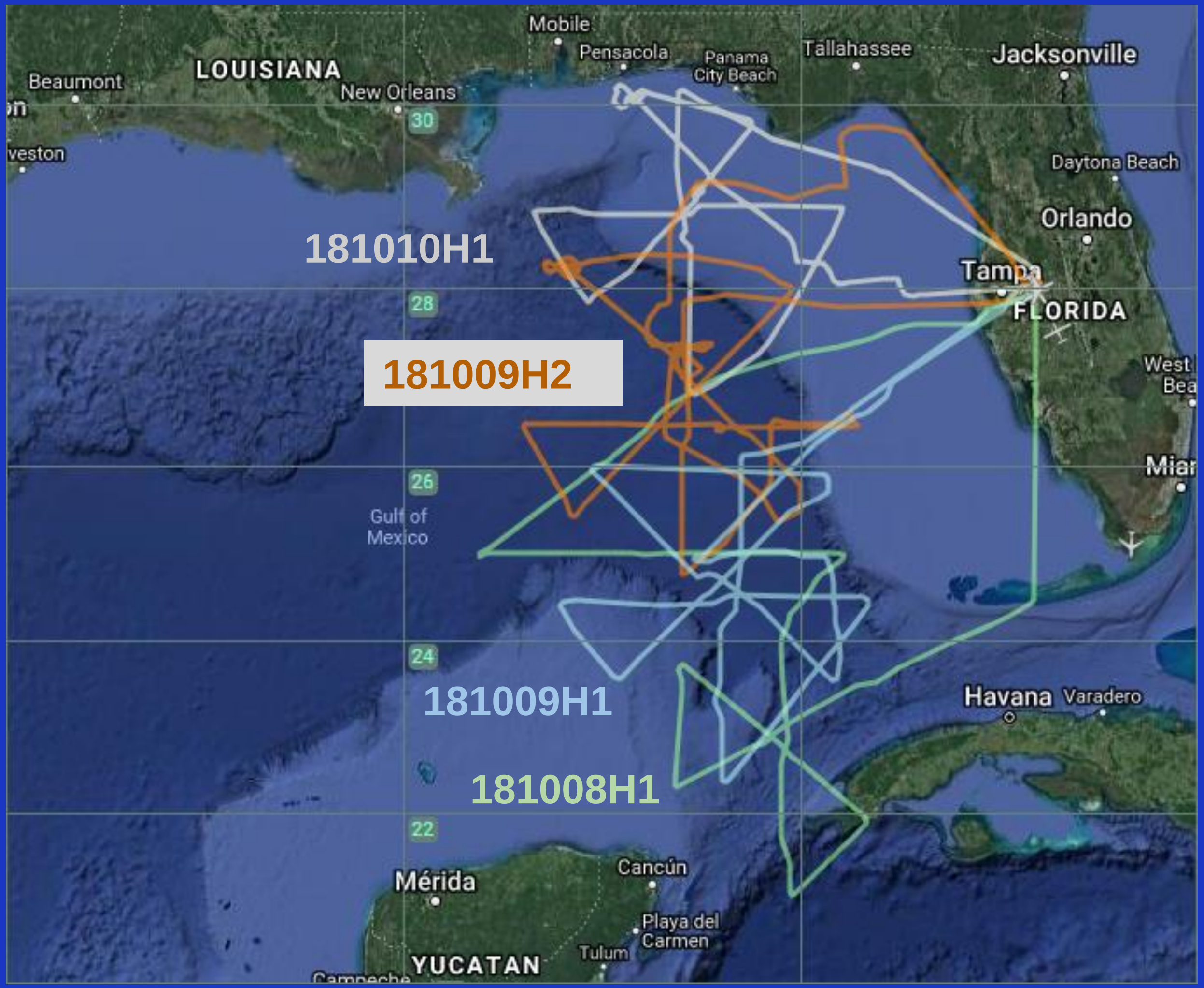
Michael

NOAA Hurricane Hunter Aircraft Flight Patterns: Gulfstream IV and P3

G-IV Flight Tracks

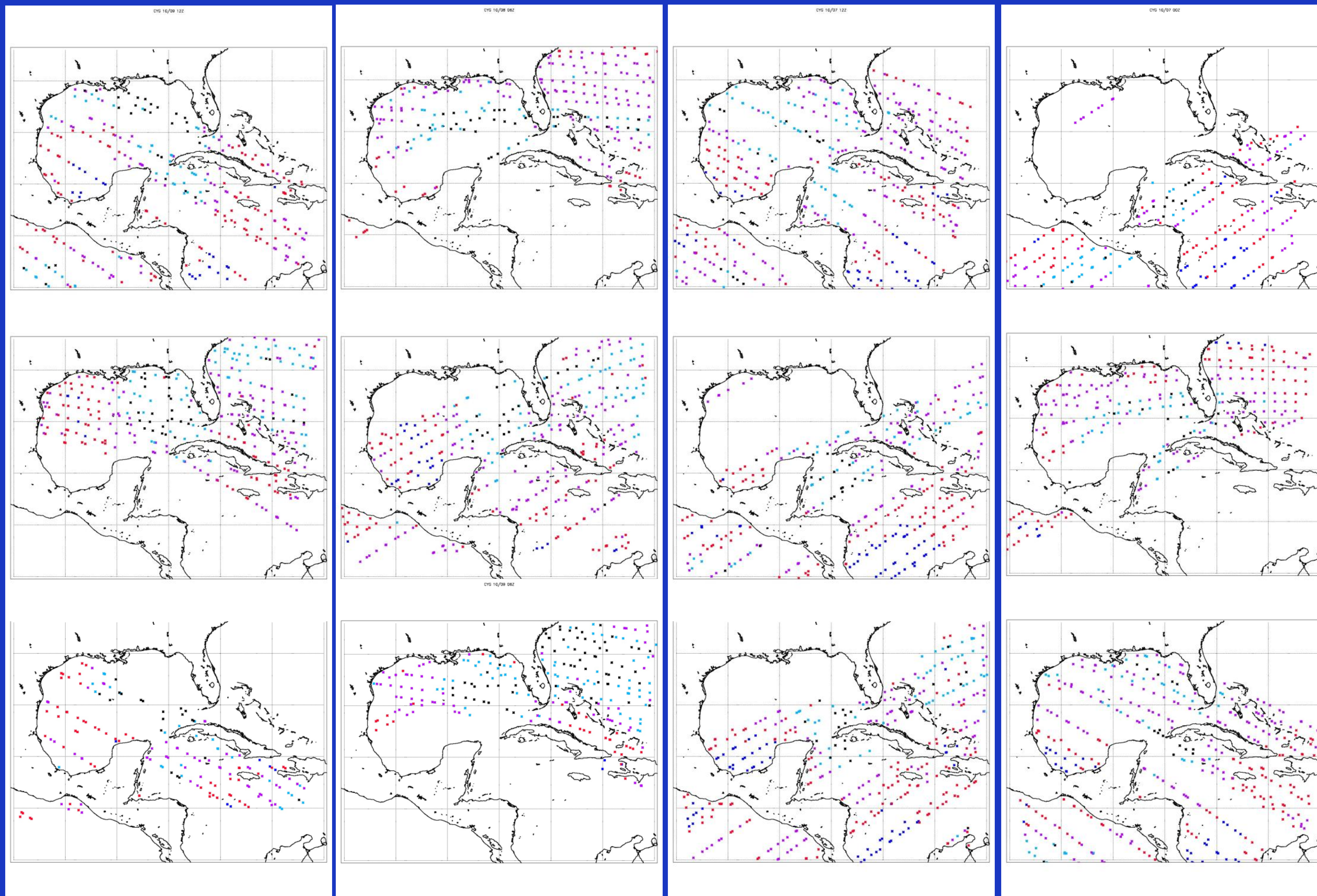


P-3 Flight Tracks



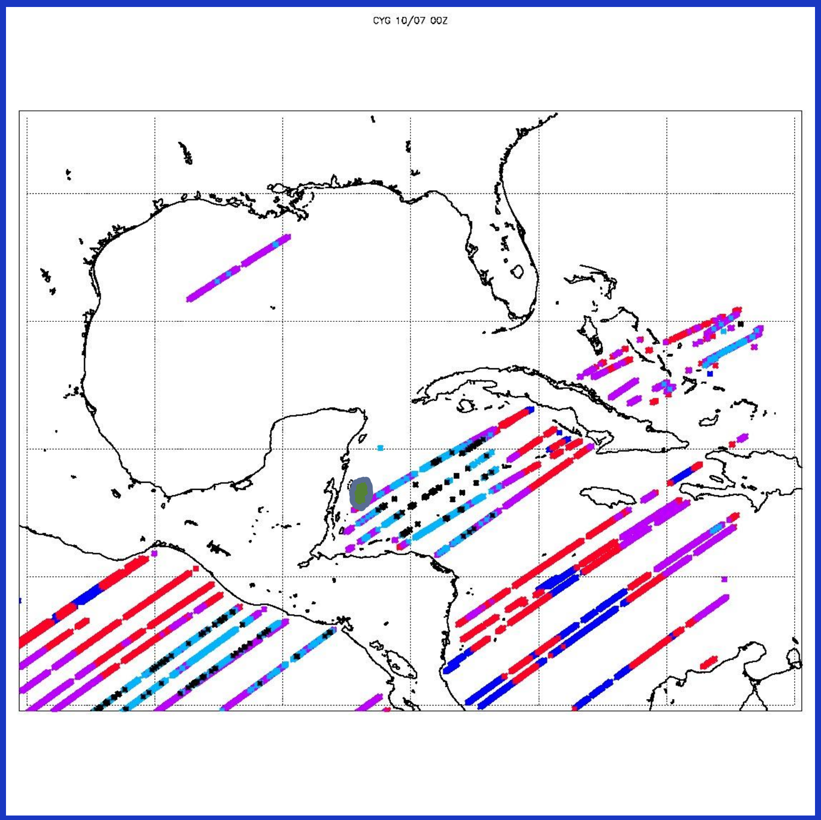
CYGNSS COVERAGE

10/07 00Z- 10/10 18Z

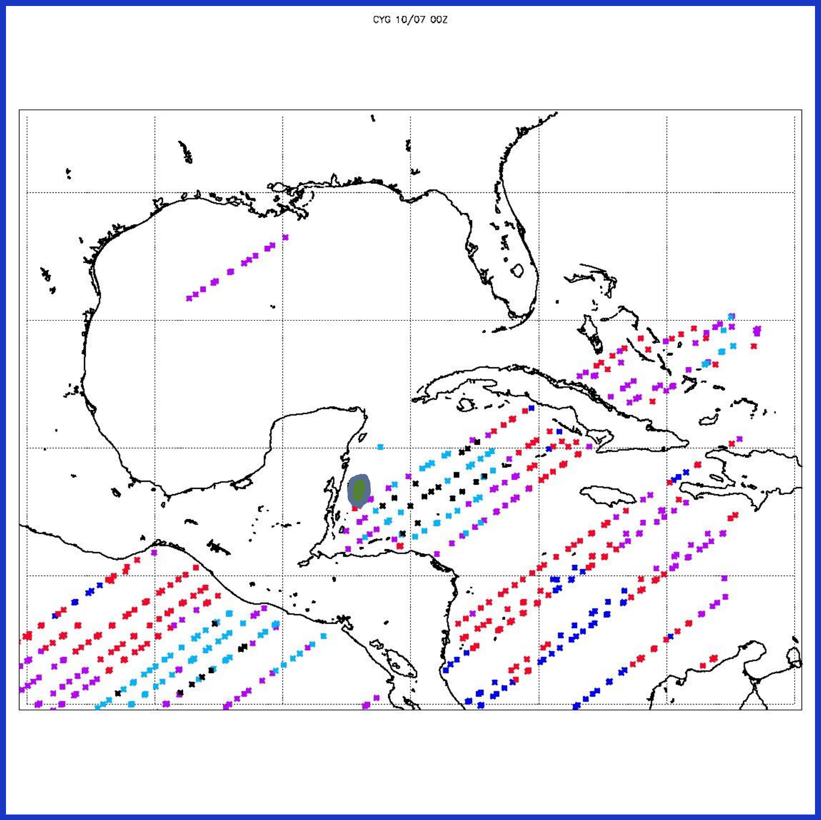


CYGNSS COVERAGE 10/07 00Z, +/- 3 hrs Michael

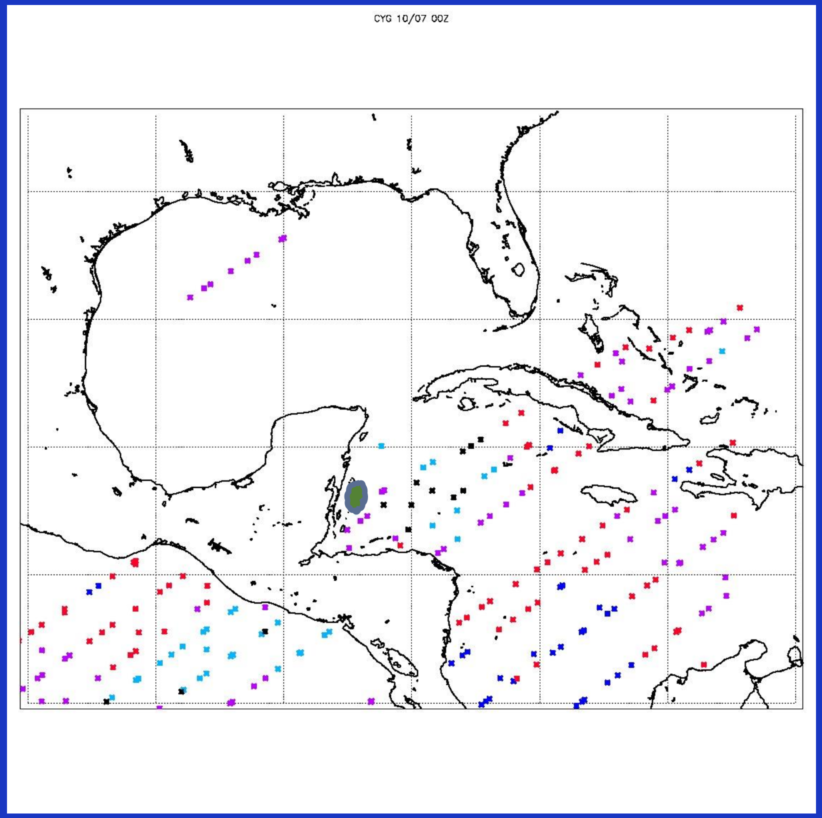
No Thinning

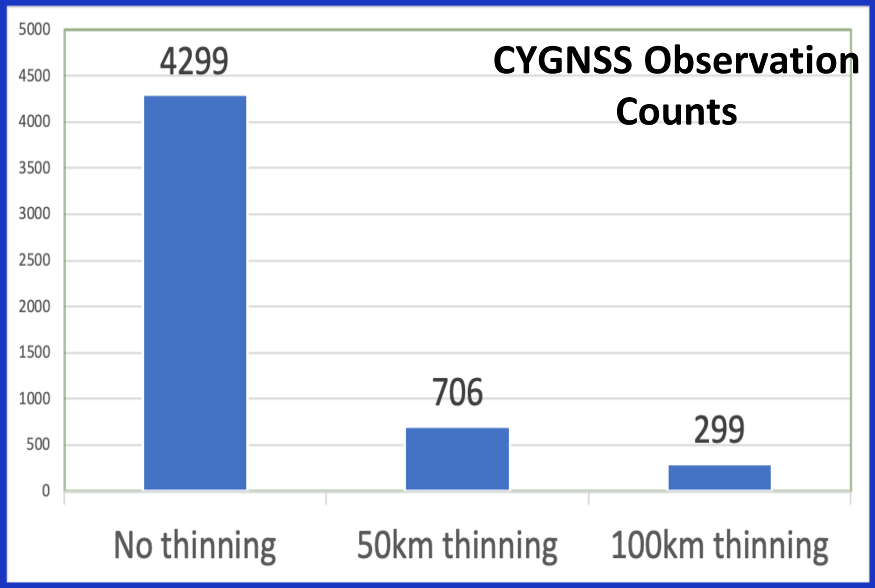


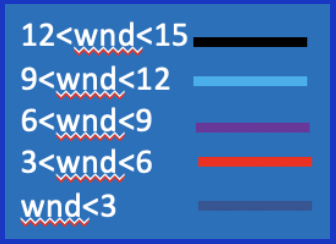
50km Thinning



100km Thinning



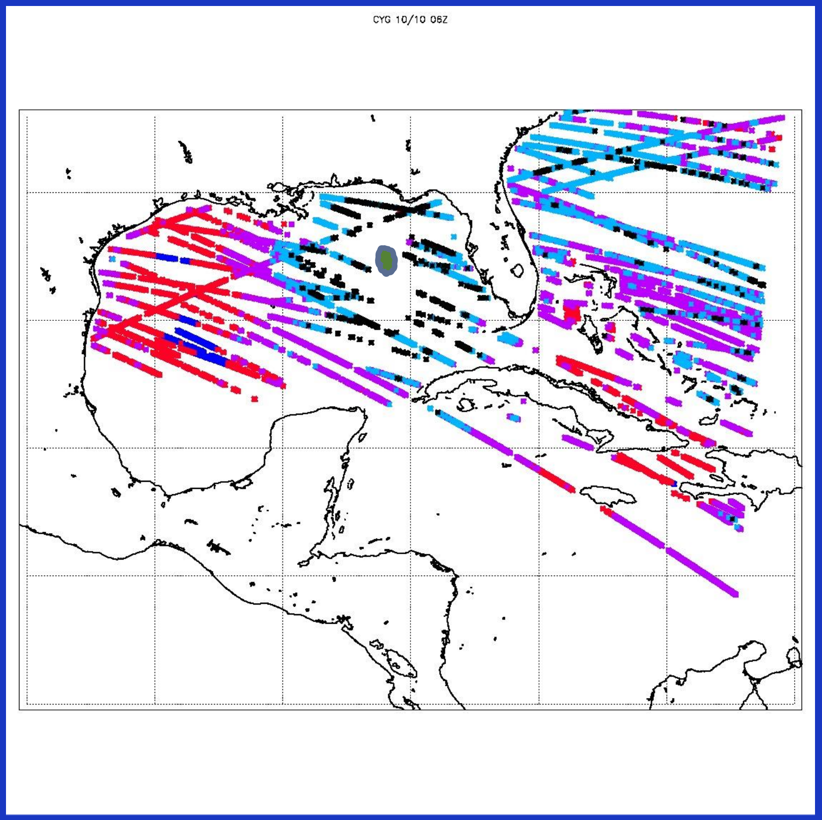




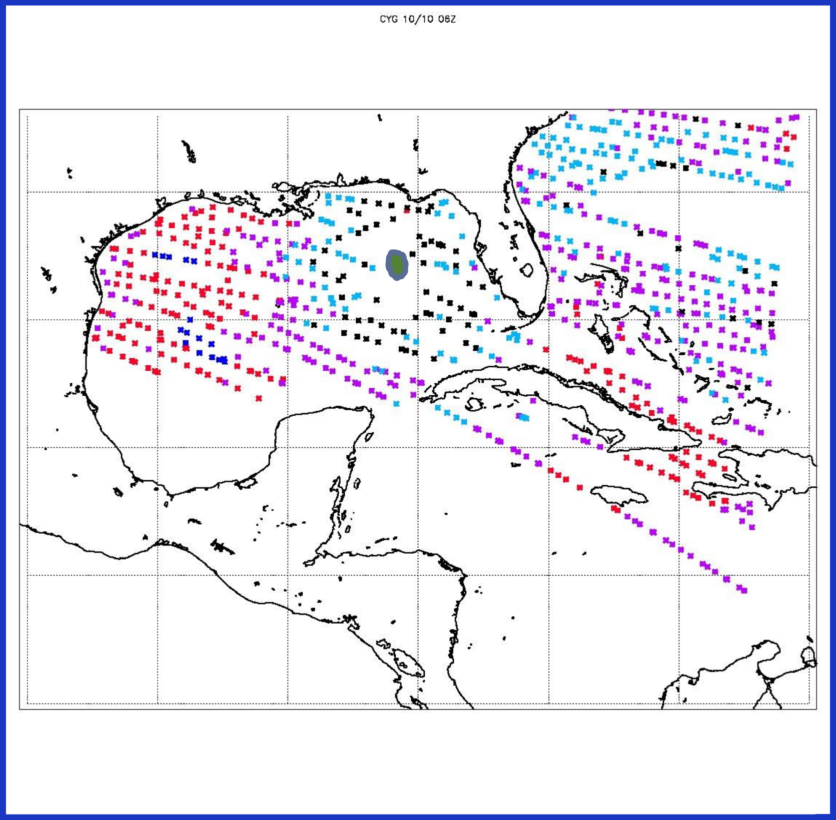
Partial coverage on the southern part of the storm

CYGNSS COVERAGE 10/10 06Z, +/- 3 hrs Michael

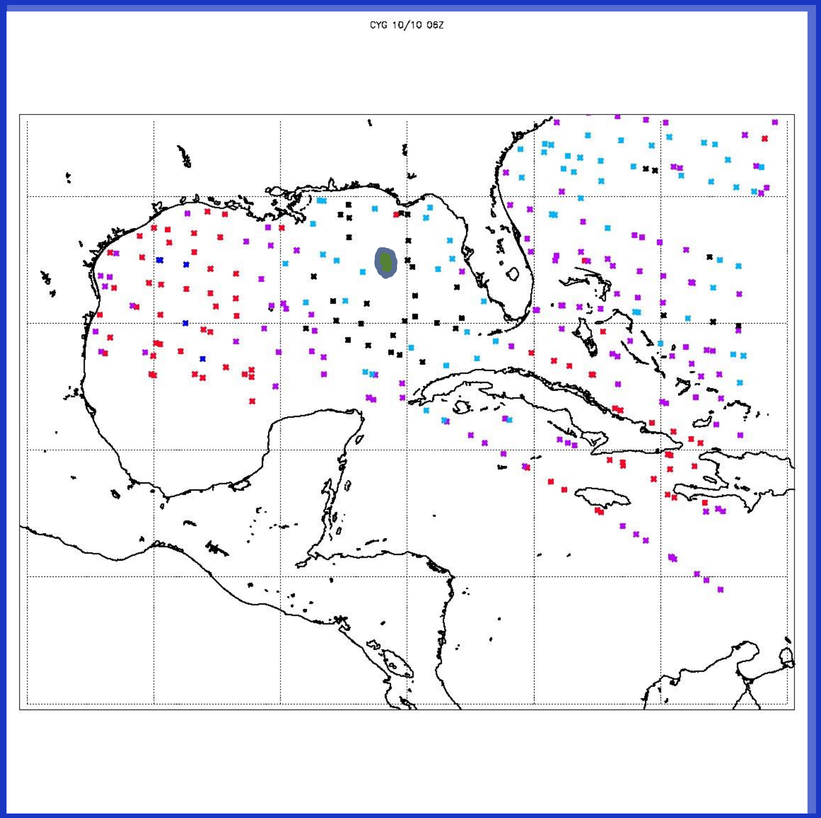
No Thinning

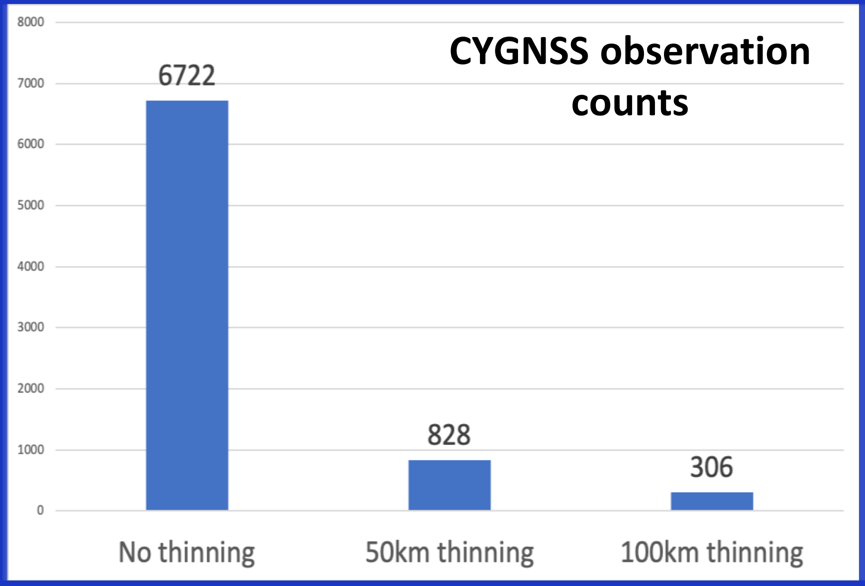


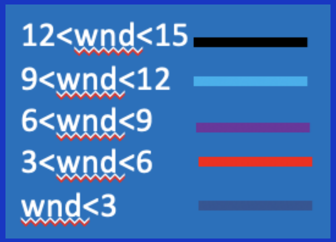
50km Thinning



100km Thinning



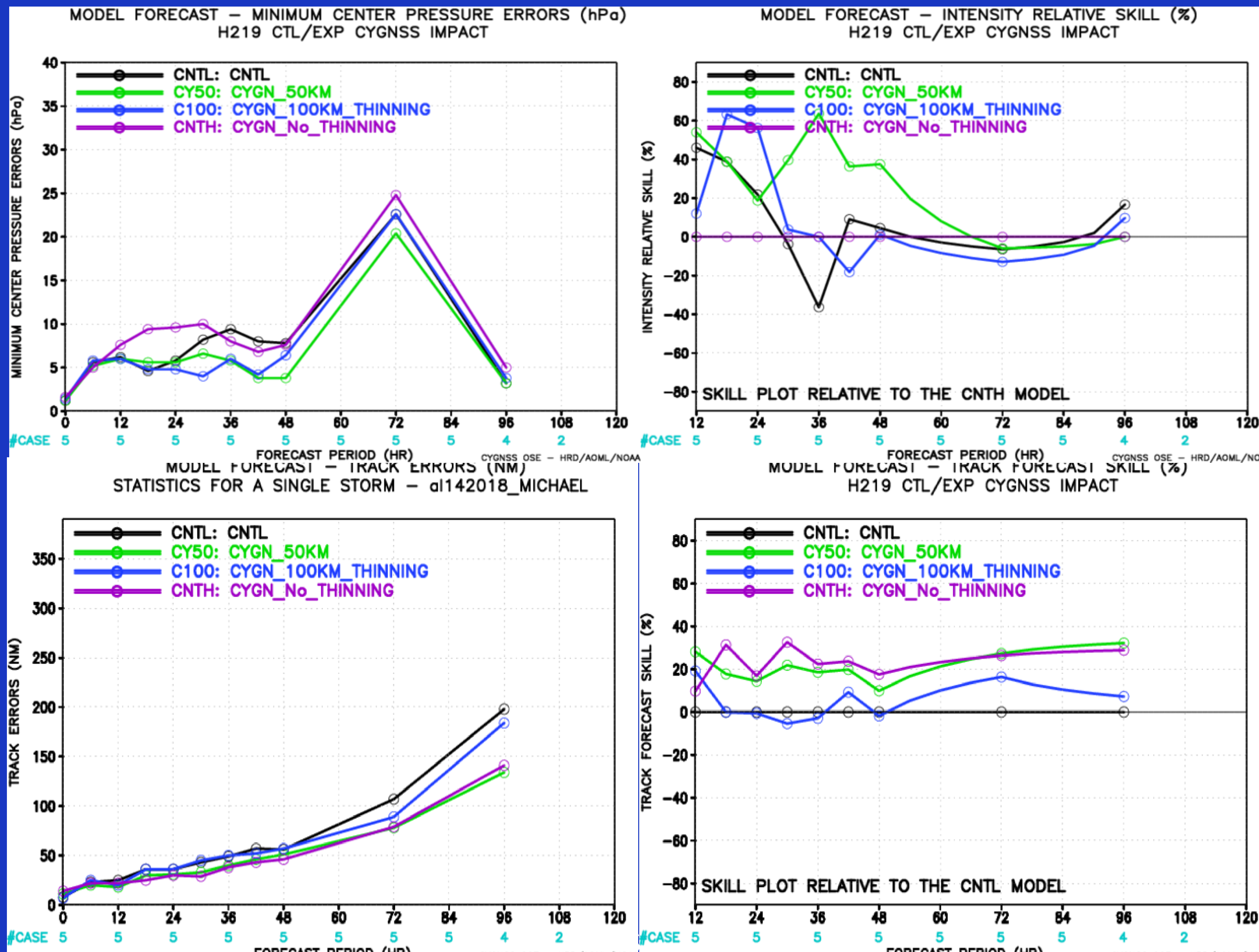




No CYGNSS data in the core of the storm

Michael
Average Track and Intensity Forecast Errors

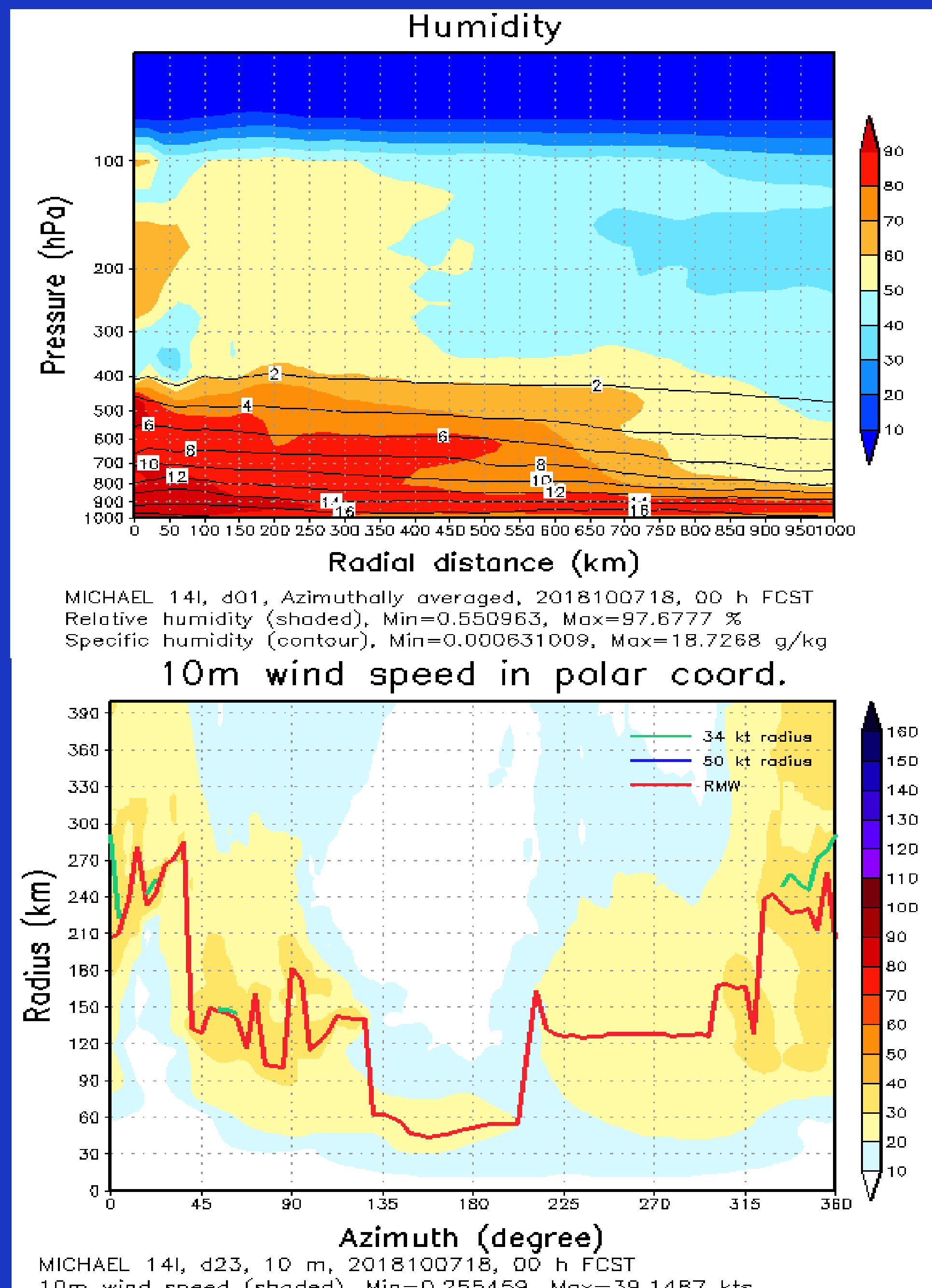
Observation (NHC Best Track) and Experiment Difference

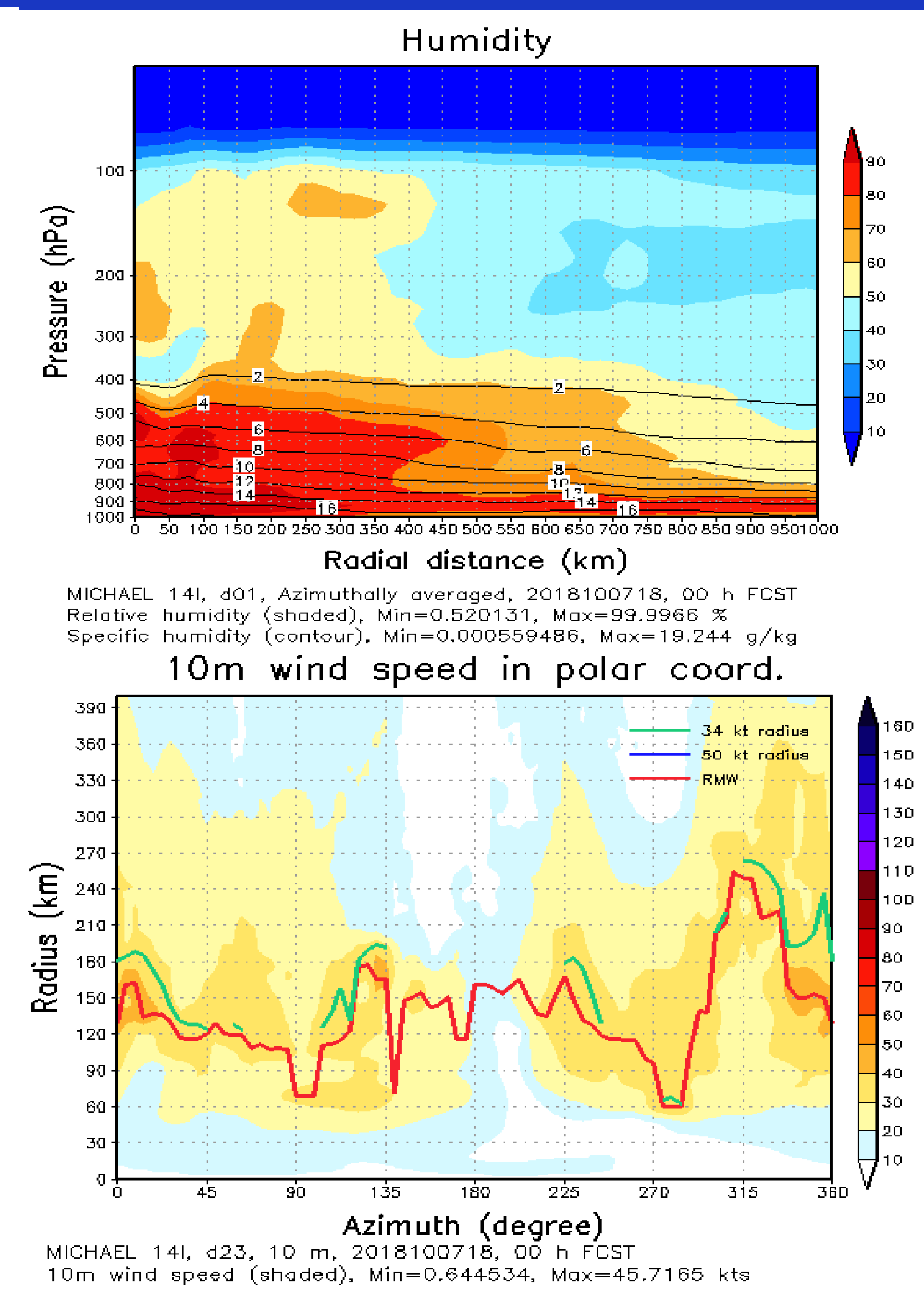


Michael
10/07 18Z (Analysis)

CONTROL

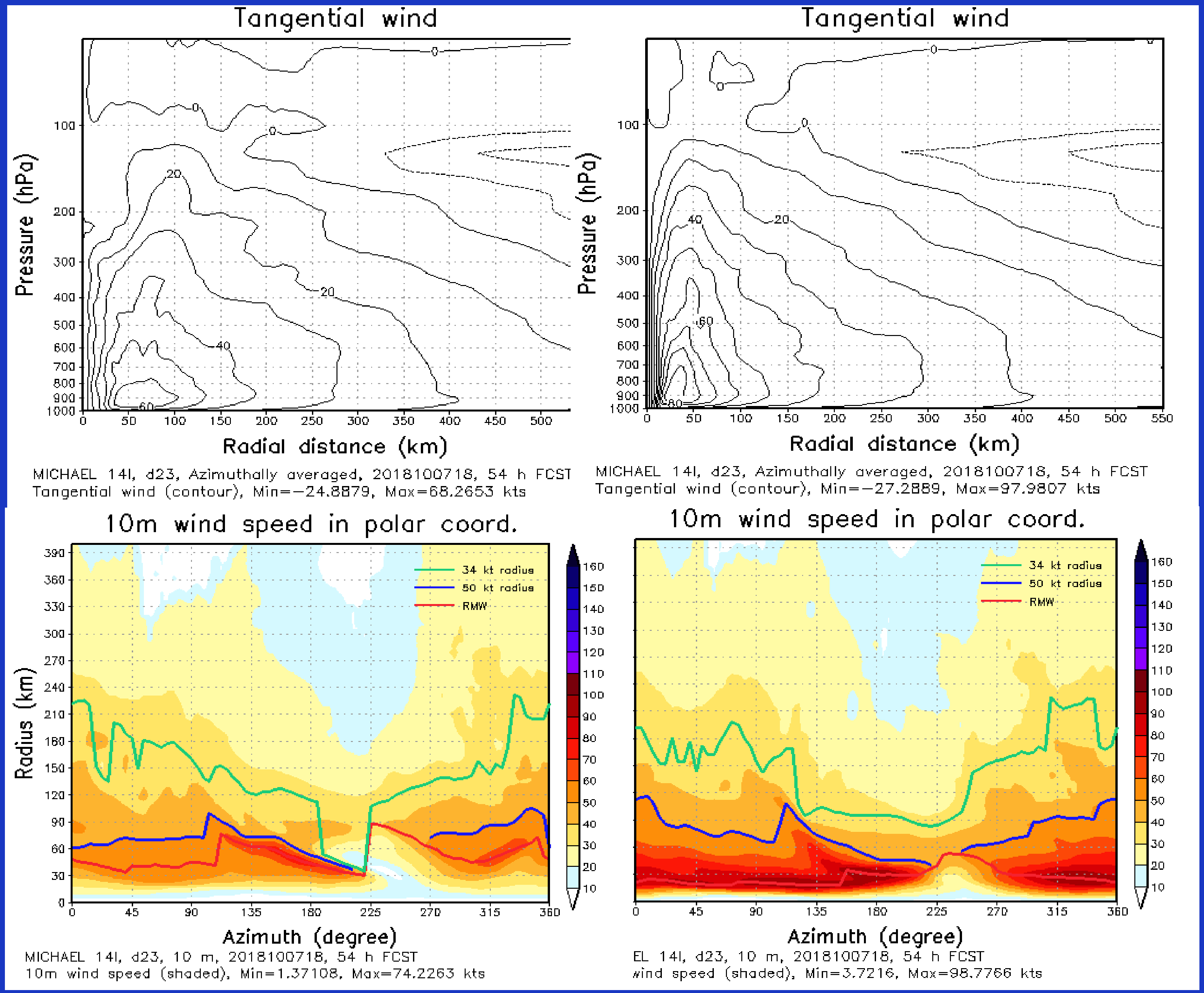
CYG50





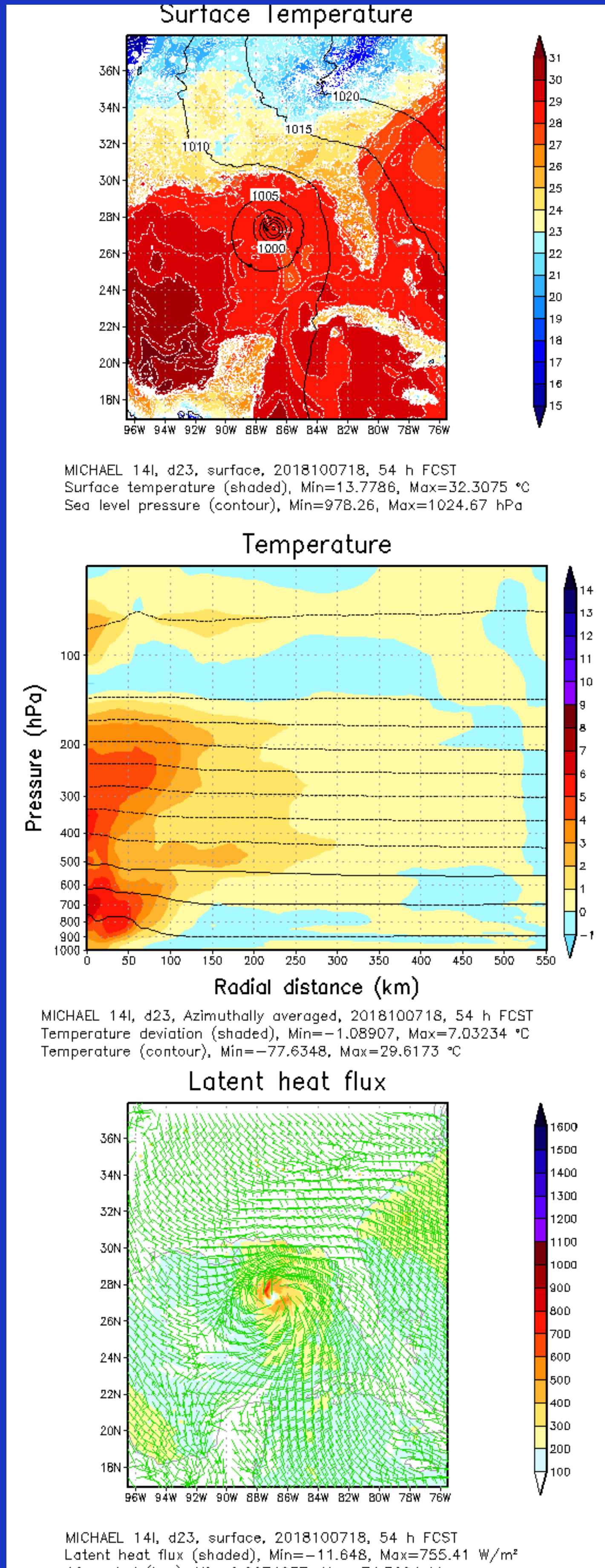
Michael (10/07 18z)
54hr forecast

CONTROL | CYG50

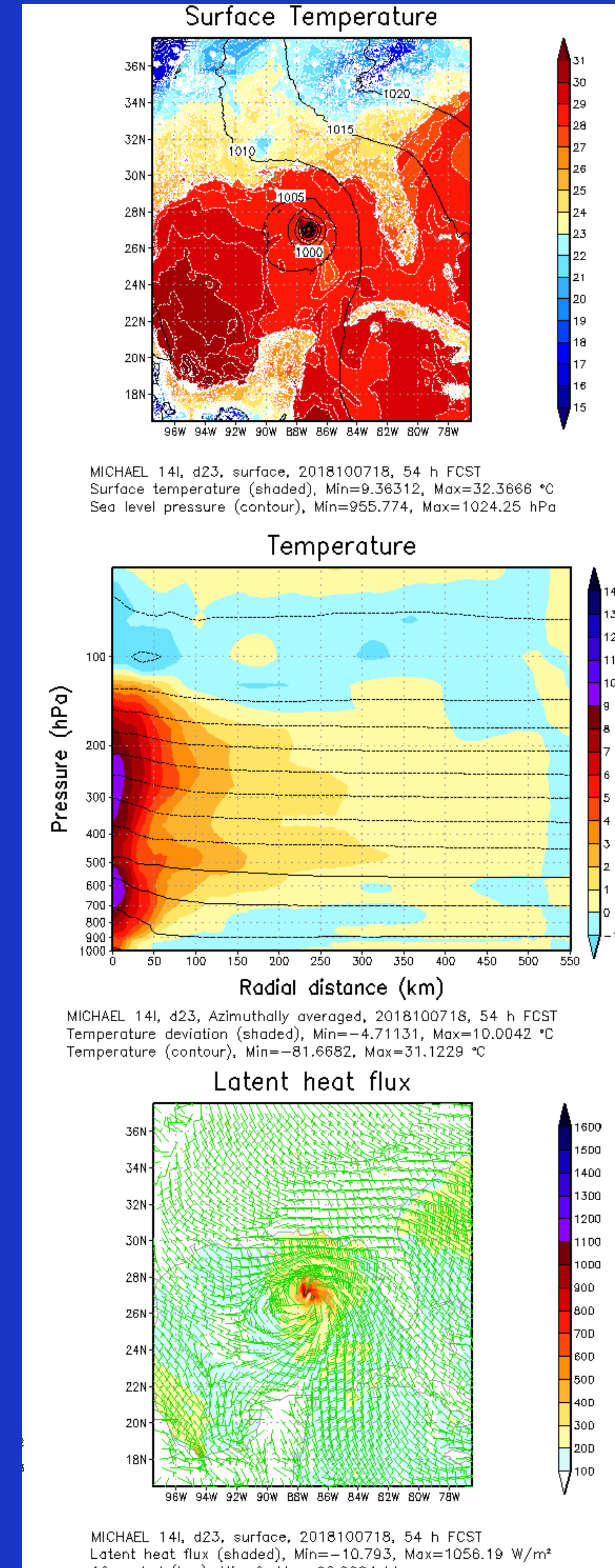


Michael (10/07 18z)
54hr forecast

CONTROL



Var	CNTRL	CYG50
MSLP hPa	978	955
MAX(TD) Celsius	7	10
MAX(LH) W/m^2	755	1056



CYG50

Deriving CYGNSS Vector Winds

Vector wind analysis method (VAM)
2-D Variational Wind Analysis

An optimal fit to CYGNSS observations is constrained by:

J_b: analysis should be "close" to the *a priori*, or "Background", wind field

J_o: ensure the analysis is close to CYGNSS wind speeds

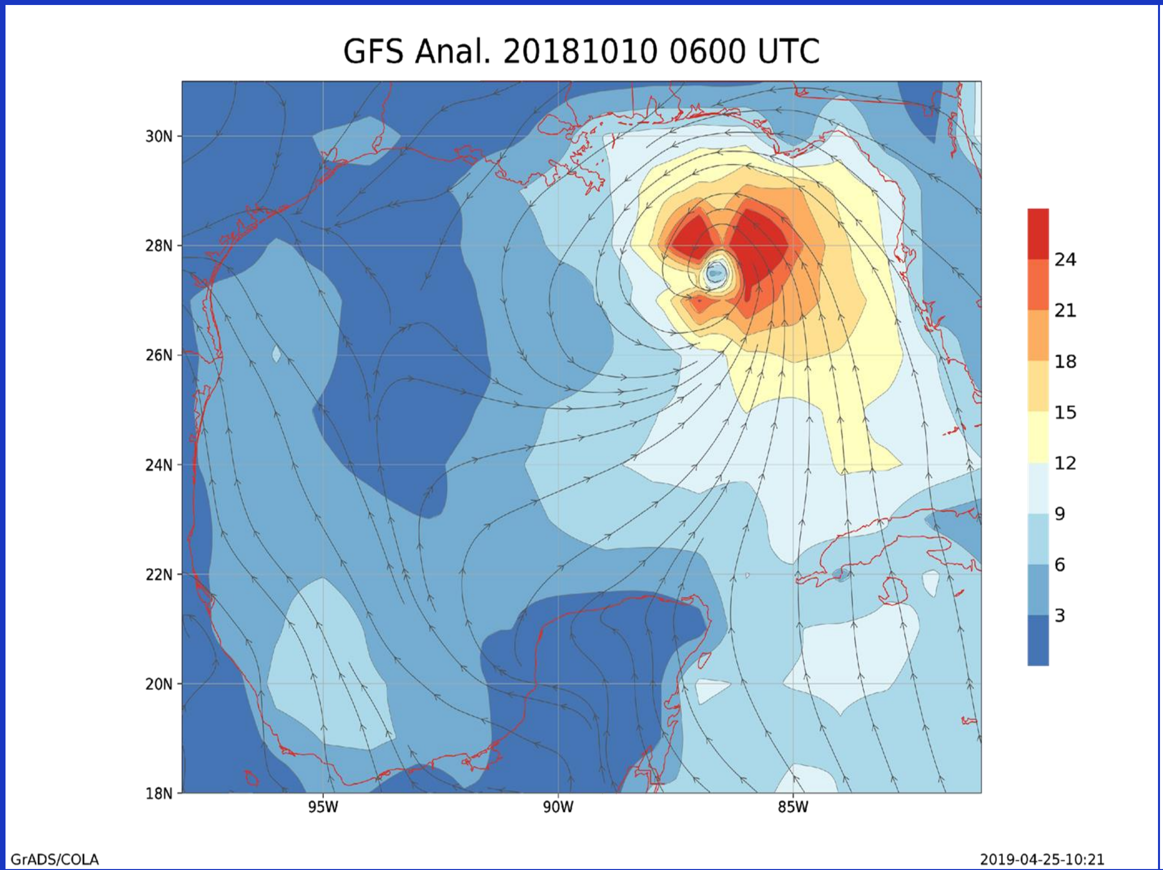
J_c: impose fluid dynamical constraints on the solution (vorticity, divergence)

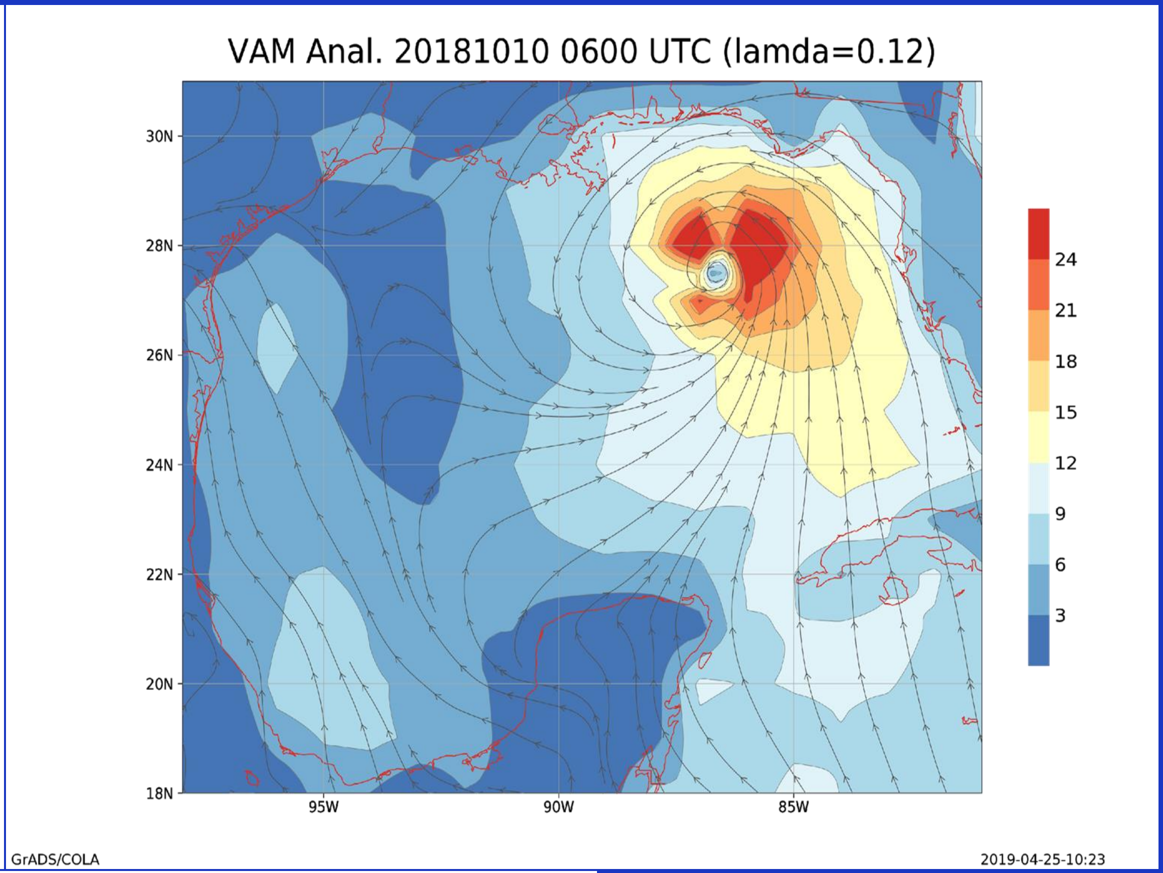
$$MIN(J = J_b + J_o + J_c)$$

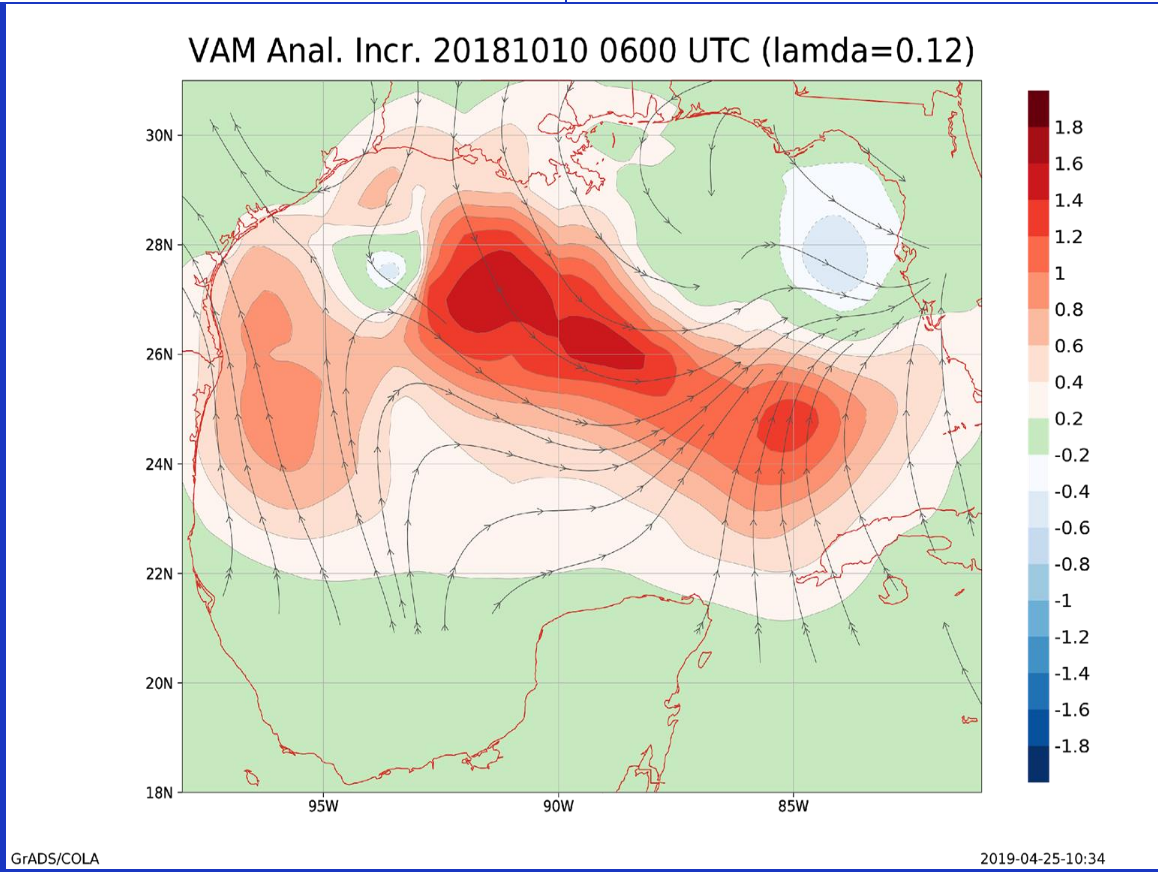
Background winds are GFS operational analyses (0.25 x 0.25 degree).
Relative weights in minimization are consistent with CCMP analyses.

Hoffman, R. N., S. M. Leidner, J. M. Henderson, R. Atlas, J. V. Ardizzone, and S. C. Bloom, 2003: A two-dimensional variational analysis method for NSCAT ambiguity removal: Methodology, sensitivity, and tuning. *J. Atmos. Oceanic Technol*., **20** (**5**), 585–605.

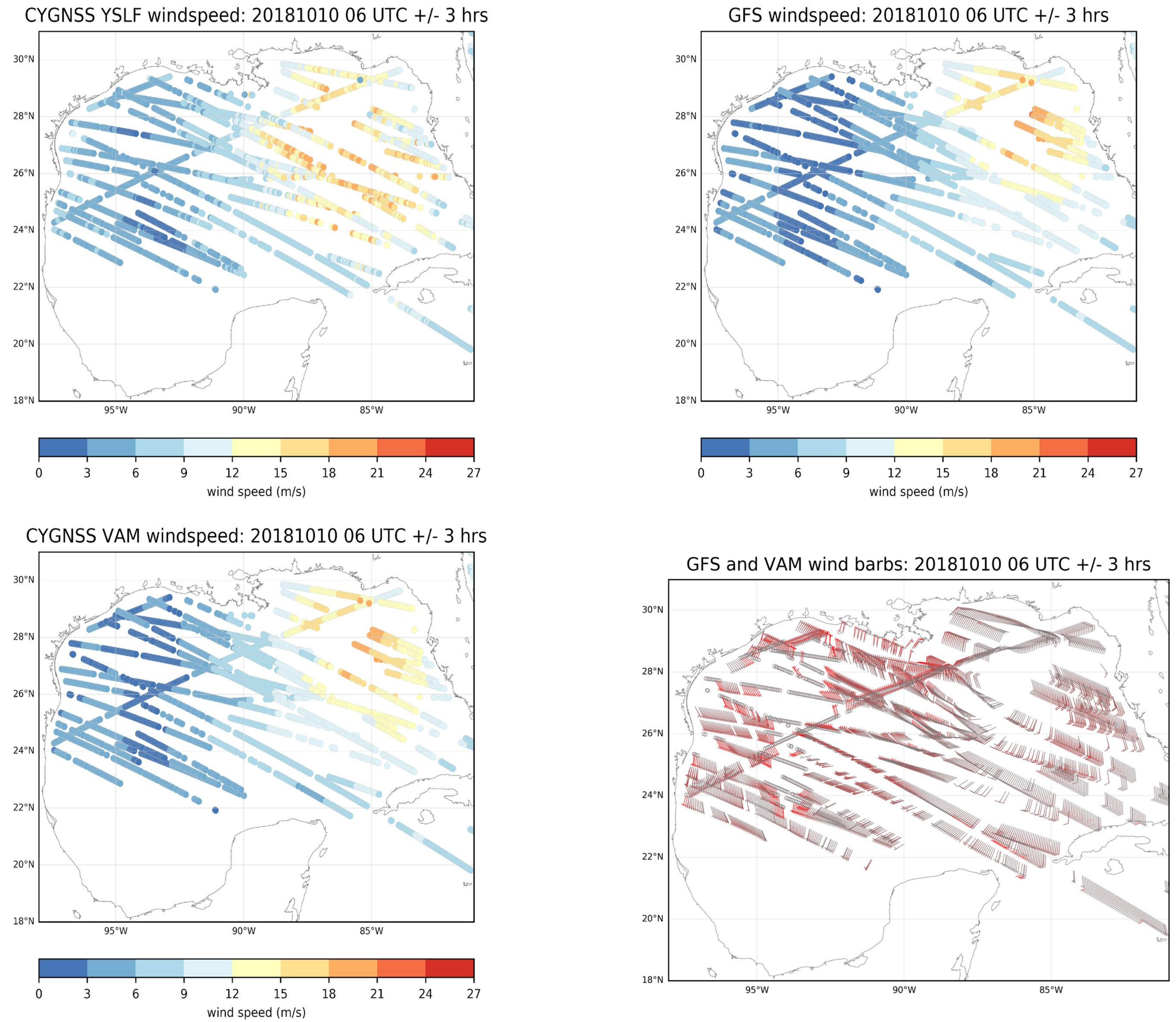
Vector wind analysis of CYGNSS: Michael







Vector wind analysis of CYGNSS: observation locations

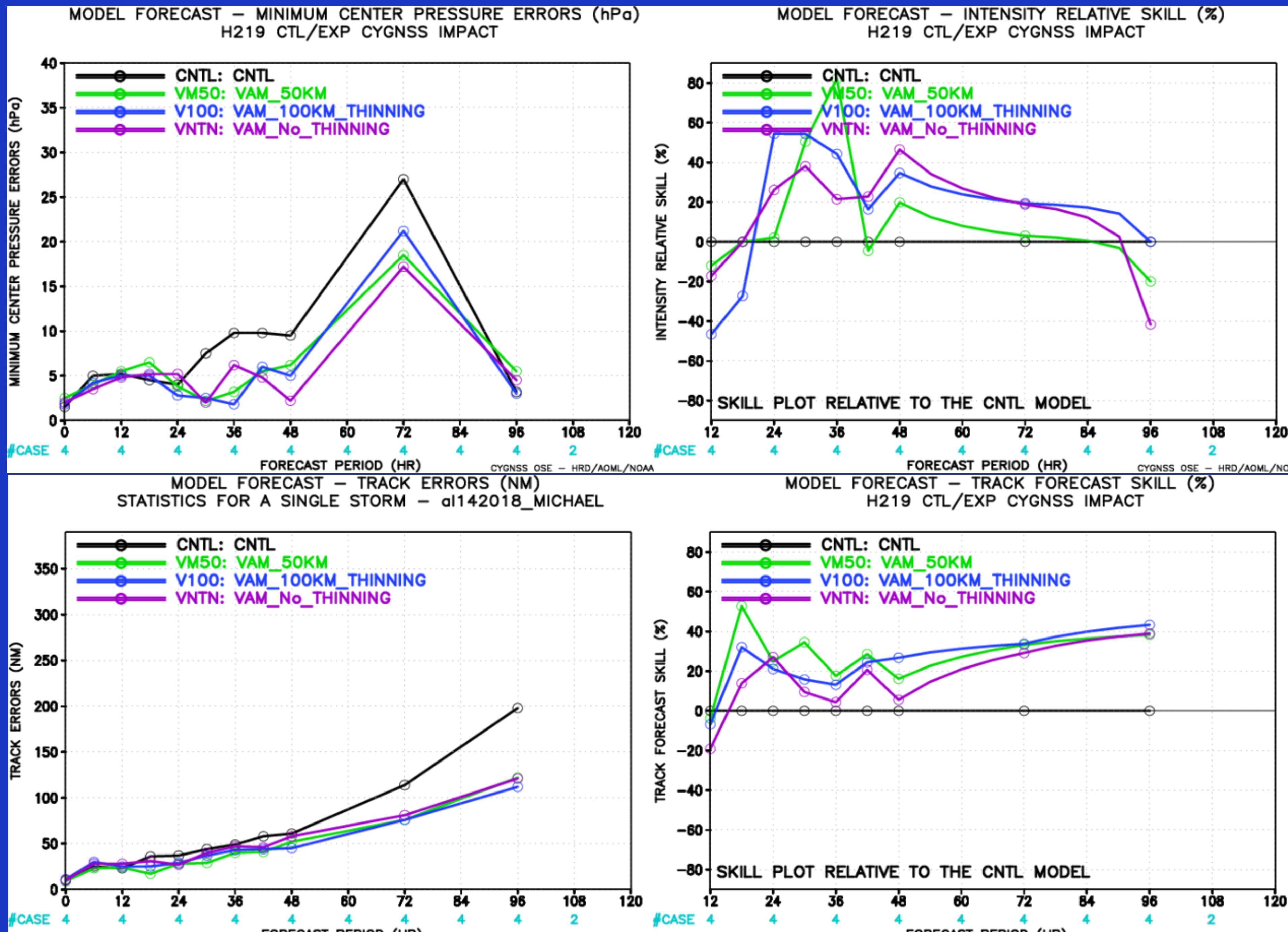


List of Experiments (VAM)

Experiment name	Assimilated Data set 15 cycles (10/07 00Z- 10/10 18Z)		
	Conventional	Radiances	VAM
Control	Yes	Yes	No
No Thinning	Yes	Yes	Yes
Thinning at 50km	Yes	Yes	Yes
Thinning at 100 km	Yes	Yes	Yes

Michael
Average Track and Intensity Forecast Errors

Observation (NHC Best Track) and Experiment Difference



N=5 forecasts, TD to

SUMMARY

OSEs setup:

- Using strict CYGNSS observation quality filtering
- Using CYGNSS wind speeds 0-15 m/s

Intermediate OSEs results:

- Thinning is important to avoid correlated information/error
  - OR account for oversampling via inflated obs error
- Early life cycle impact on intensity and track is positive
- Testing only a portion of eventual CYGNSS wind speed range
- Vector winds improve analyses and forecasts more than scalar
- These results are only for one storm

Future work

- Regenerate current results for all hurricanes 2017-2018 using future releases of CYGNSS, and extend to assess full TC lifecycle impacts.

- Investigate the impact of hybrid 3dVar- ensemble covariances on distributing wind speed information in the vertical and to unobserved variables.

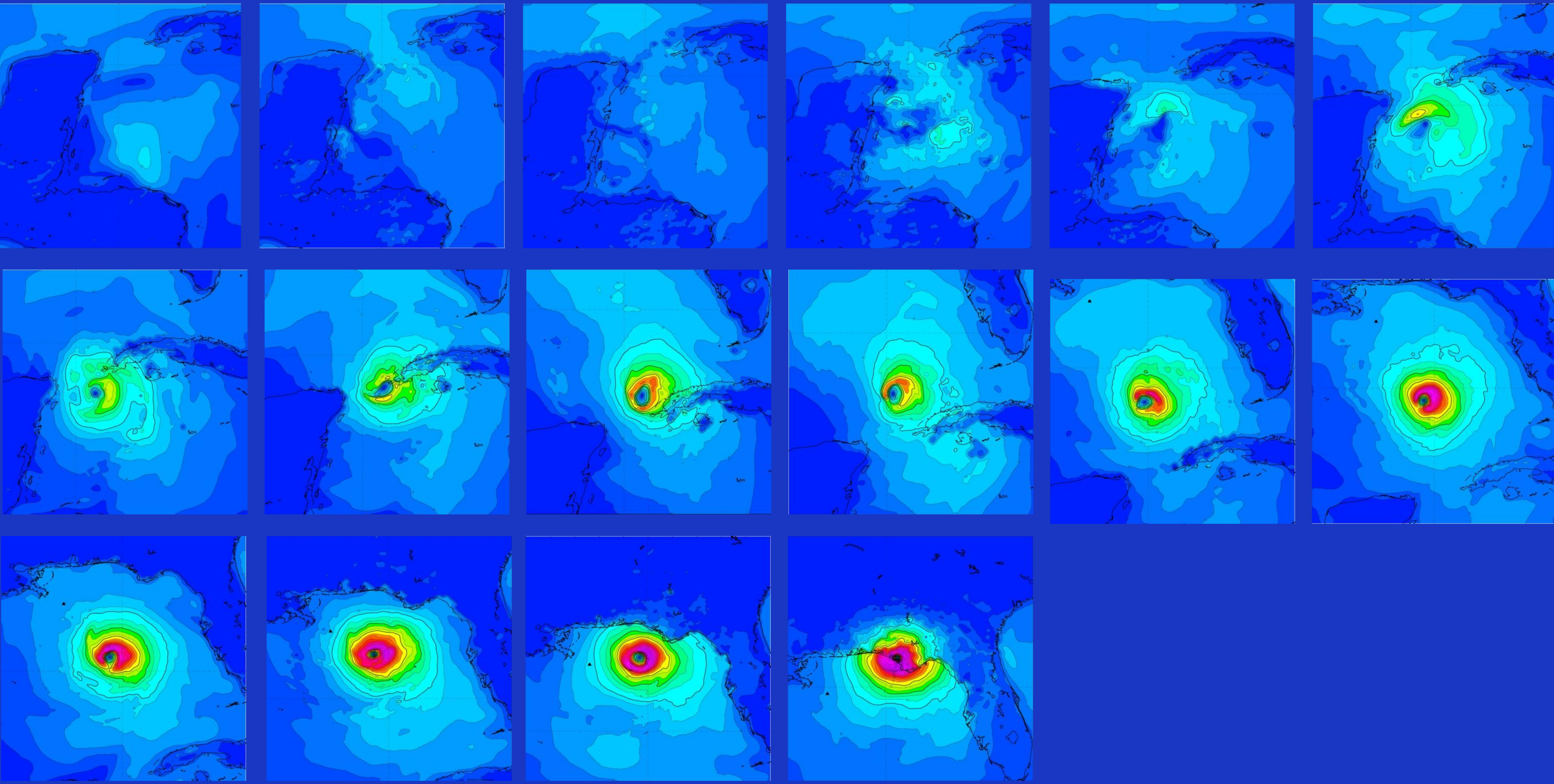
- Use a 2D-Var (VAM) to generate CYGNSS wind vectors for all tropical cyclones.

- Assimilate all QC'd CYGNSS data (no thinning; H219) with greatly reduced observation weight.

QUESTIONS?

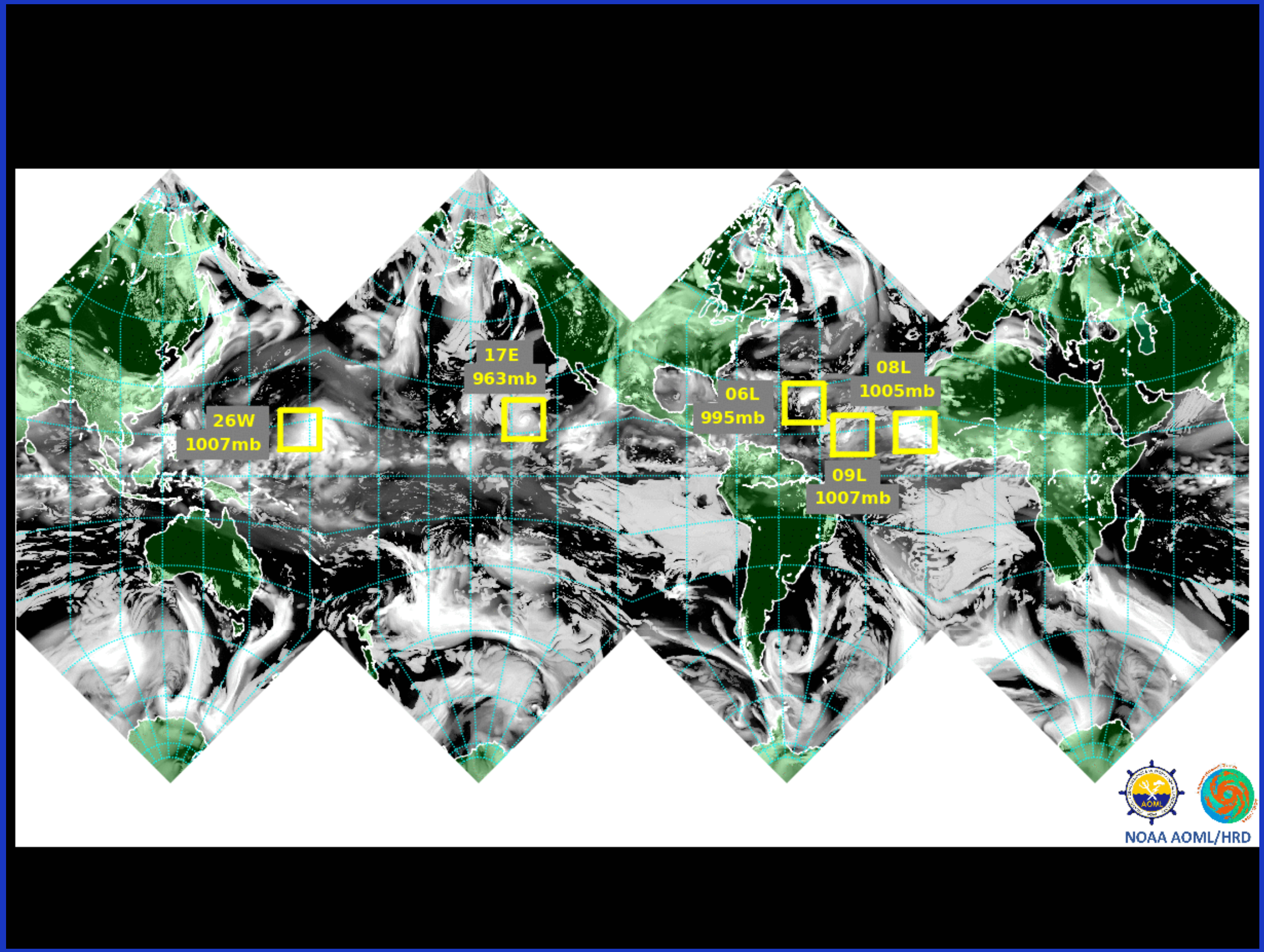
Backup Slides

Surface wind analyses every 6 hours for TC Michael
1007 00Z to 1010 18Z



Next Generation
Moving Nest implementation for FV3GFS

- Current and Upcoming Efforts
  - Multiple static nests
  - Flexible grid refine ratios
  - Validation of identical results
  - Simple moving nests – defined motion
  - Moving nests with storm tracking
  - Moving nests crossing between cube faces



Ramstrom et al.

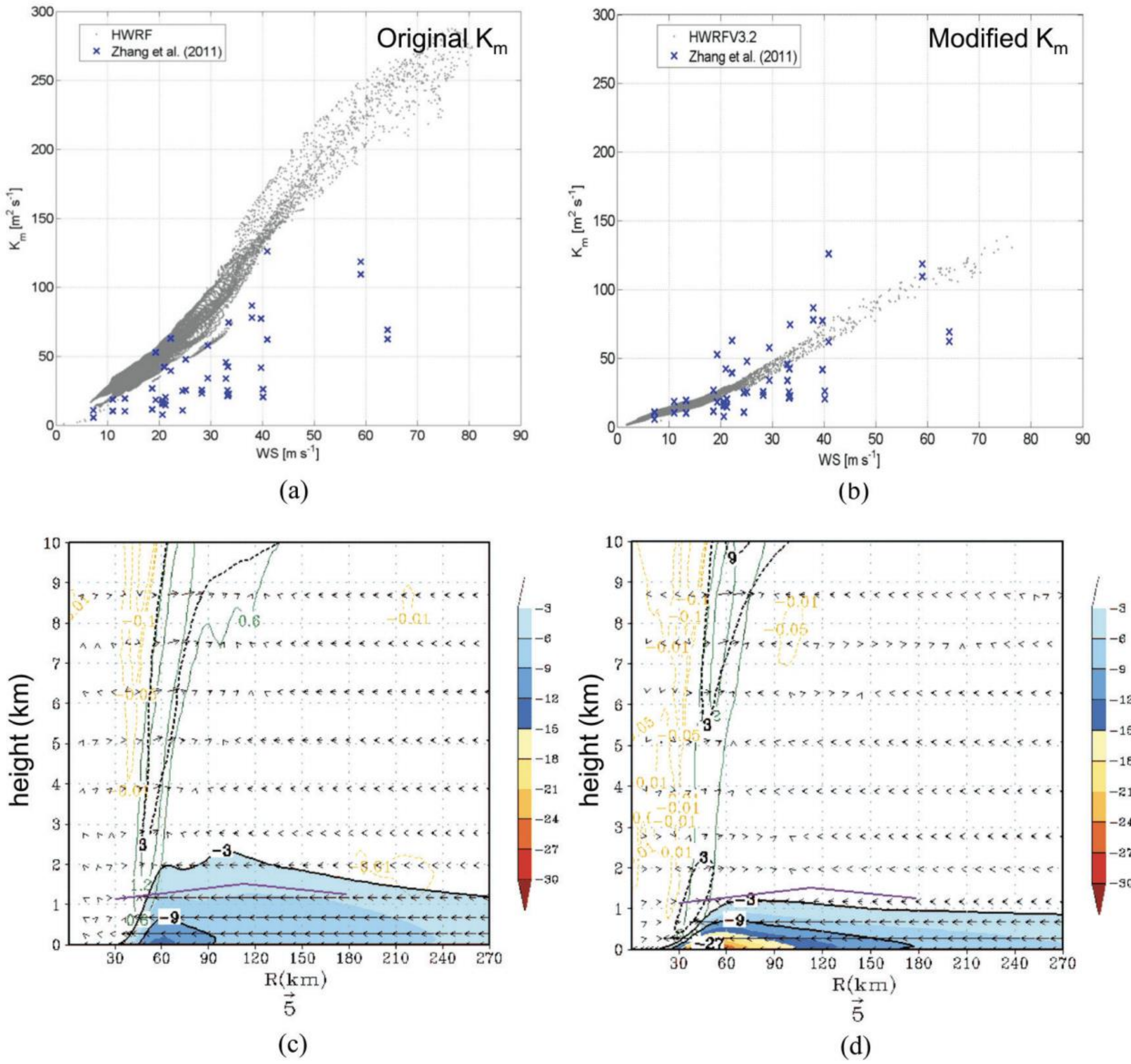


FIG. 4. (a) Aircraft-derived measurements of vertical eddy diffusivity from several flight legs (X marks; from J. A. Zhang et al. 2011a) and calculated model vertical eddy diffusivity from HWRF (gray dots) as a function of 10-m wind speed. (b) As in (a), but for values of model vertical eddy diffusivity reduced by 75%. (c) Radius–height plot of axisymmetric radial wind (shaded, m s^{-1}) and axisymmetric vertical velocity [green (positive) and brown (negative) contours; m s^{-1}] for idealized HWRF simulation using default value of K_m shown in (a). (d) As in (c), but for modified values of K_m shown in (b). Panels (c),(d) adapted from Gopalakrishnan et al. (2013).

Averaging Time

http://www.aoml.noaa.gov/hrd/tcfaq/D4.html

The Hurricane Center uses a 1 min averaging time for reporting the sustained (i.e. relatively long-lasting) winds. The maximum sustained wind mentioned in the advisories that NHC issues for tropical storms and hurricanes are the highest 1 min surface winds occurring within the circulation of the system. These "surface" winds are those observed (or, more often, estimated) to occur at the standard meteorological height of 10 m (33 ft) in an unobstructed exposure (i.e., not blocked by buildings or trees).

Conversion factors in TC conditions

GUIDELINES FOR CONVERTING BETWEEN VARIOUS WIND AVERAGING PERIODS IN TROPICAL CYCLONE CONDITIONS
https://www.wmo.int/pages/prog/www/tcp/Meetings/HC31/documents/Doc.3.part2.pdf

Table 1.1 Recommended wind speed conversion factors for tropical cyclone conditions.

Exposure at +10 m		Reference Period	Gust Factor $G_{\tau,To}$				
			Gust Duration τ *(s)*				
Class	Description	T_o (s)	*3*	*60*	*120*	*180*	*600*
In-Land	Roughly open terrain	3600	1.75	1.28	1.19	1.15	1.08
		600	1.66	1.21	1.12	1.09	1.00
		180	1.58	1.15	1.07	1.00	
		120	1.55	1.13	1.00		
		60	1.49	1.00			
Off-Land	Offshore winds at a coastline	3600	1.60	1.22	1.15	1.12	1.06
		600	1.52	1.16	1.09	1.06	1.00
		180	1.44	1.10	1.04	1.00	
		120	1.42	1.08	1.00		
		60	1.36	1.00			
Off-Sea	Onshore winds at a coastline	3600	1.45	1.17	1.11	1.09	1.05
		600	1.38	1.11	1.05	1.03	1.00
		180	1.31	1.05	1.00	1.00	
		120	1.28	1.03	1.00		
		60	1.23	1.00			
At-Sea	> 20 km offshore	3600	1.30	1.11	1.07	1.06	1.03
		600	1.23	1.05	1.02	1.00	1.00
		180	1.17	1.00	1.00	1.00	
		120	1.15	1.00	1.00		
		60	1.11	1.00			