Impact of CYGNSS Data on Tropical Cyclone Analyses and Forecasts in a Regional OSSE Framework

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aer — Atmospheric and Environmental Research

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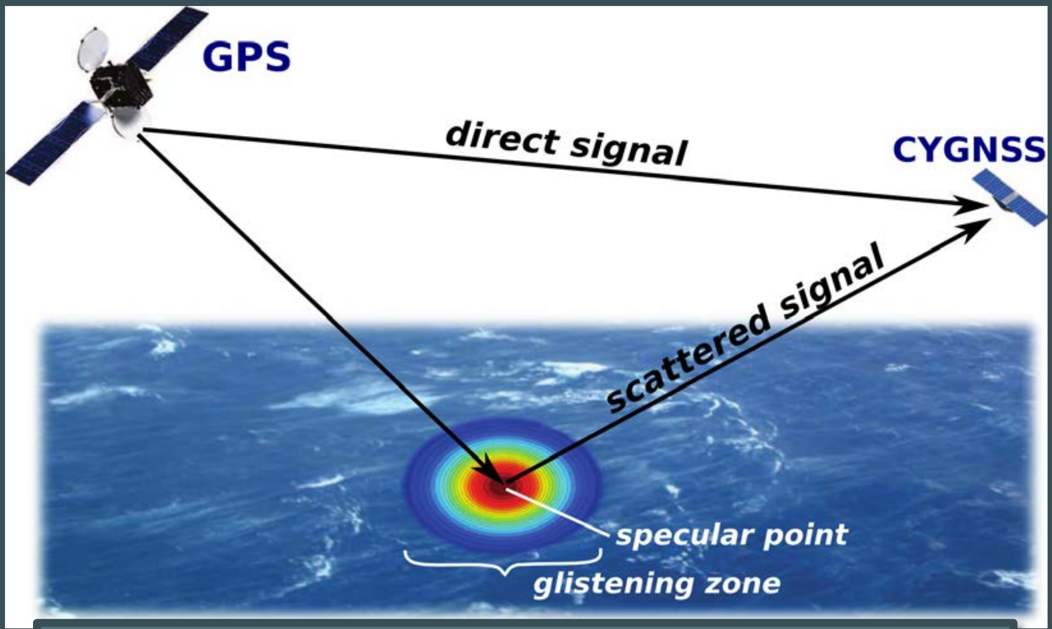
Motivation

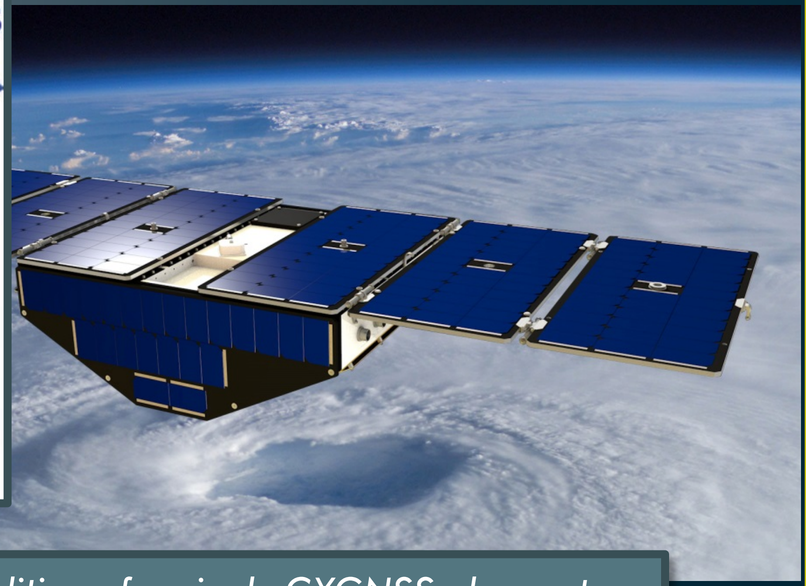
- *Inform* the design of orbit and data collection strategies prior to launch of new instrument
- *Prepare* data assimilation systems to handle real data after launch in an optimal way
- CYGNSS is a new and unique platform well-suited for observing the surface wind field of tropical cyclones

What is CYGNSS?

- The *<u>C</u>yclone <u>G</u>lobal <u>N</u>avigation <u>S</u>atellite <u>S</u>ystem* is a constellation of 8 micro-satellites scheduled for launch in October 2016… a NASA Earth Venture Mission
- Utilize signals from existing GPS satellites to *measure ocean surface wind <u>speeds</u>* (surface roughness affects forward-scattered signal)



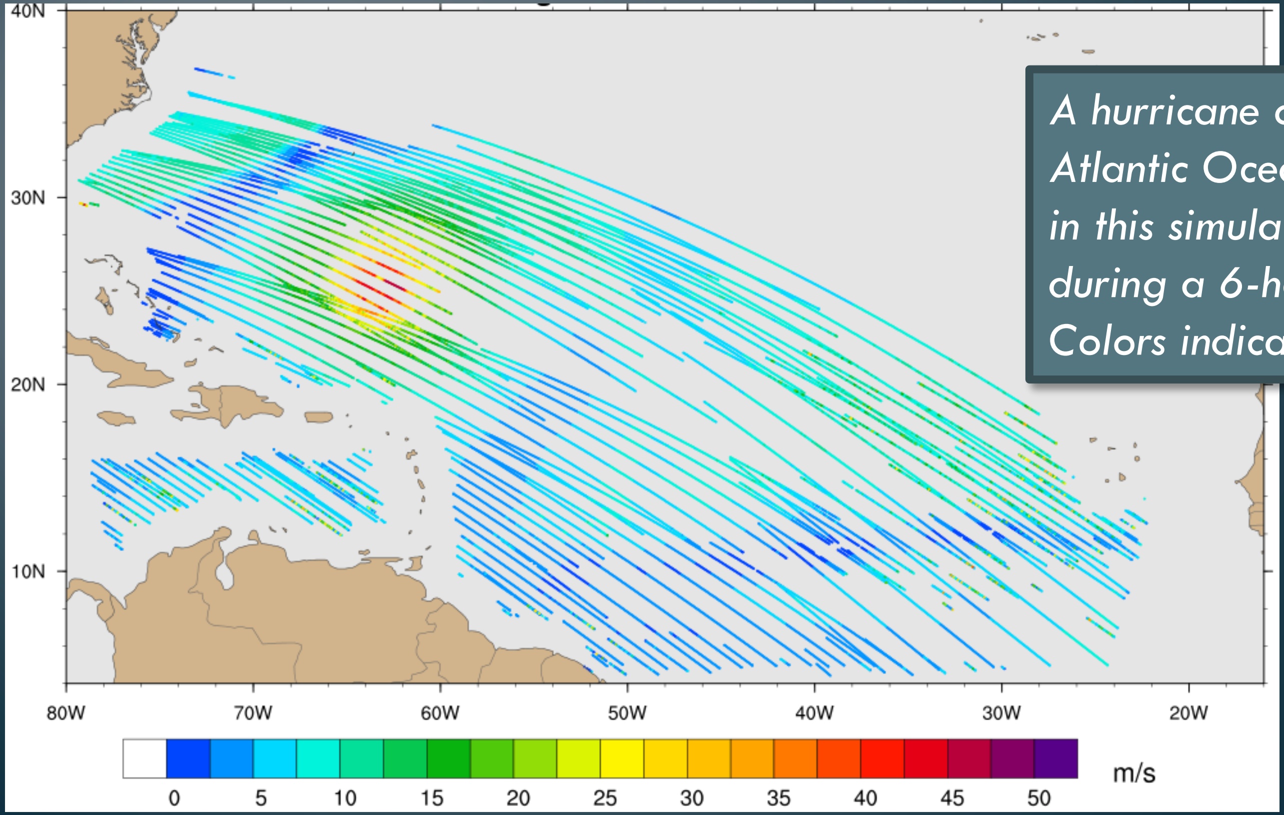
Basic geometry of bi-static quasi-specular scatterometry.



Rendition of a single CYGNSS observatory in orbit over a hurricane. (NASA)

What is CYGNSS?

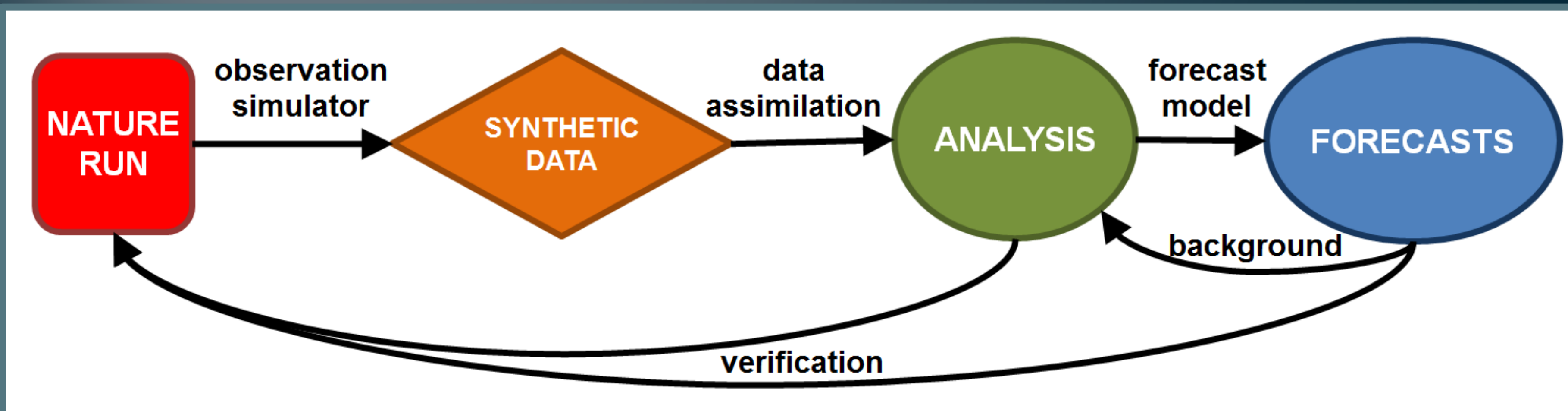
- Capable of retrieving usable data over a large range of wind speeds (0-70 m/s) in all precipitating conditions throughout the tropics and subtropics with frequent revisit times (~2-6 hours)



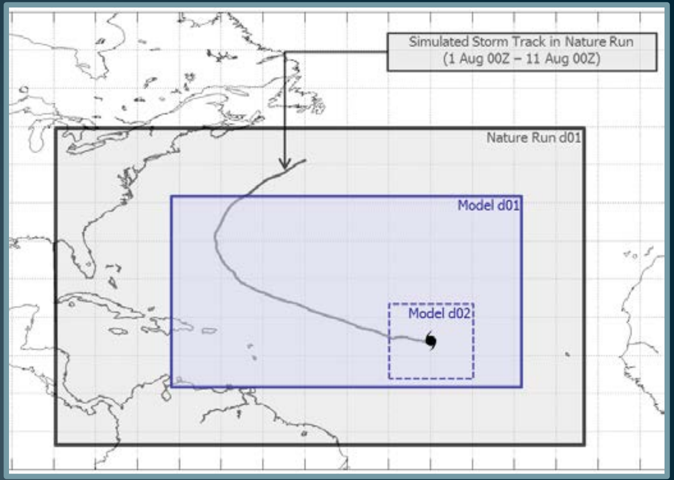
A hurricane over the western Atlantic Ocean is well-sampled in this simulation of orbits during a 6-hour time window. Colors indicate wind speed.

OSSE Framework

- Regional Hurricane OSSE (Observing System Simulation Experiment) framework developed at NOAA/AOML
- A robust, realistic, vetted *nature run* is the foundation and "truth"
  - High-resolution regional nature run (1-km inner domain) embedded within lower-resolution global nature run.
- Simulated observations from a variety of instruments/platforms are generated and provided to a data assimilation scheme which provides an analysis to a regional forecast model.



Hurricane OSSE Framework Details



- Nature Runs
  - Global
    - ECMWF: low-resolution (~40km) "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… a 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.

- For results shown here, DA cycling performed every 6/3/1 hours, forecast model run every 6 hours (each run producing a 5-day forecast)
- There are a total of 16 runs, but first 4 model runs omitted from verification to allow for model spin-up (***12 total cases***)

Overview of Experiments

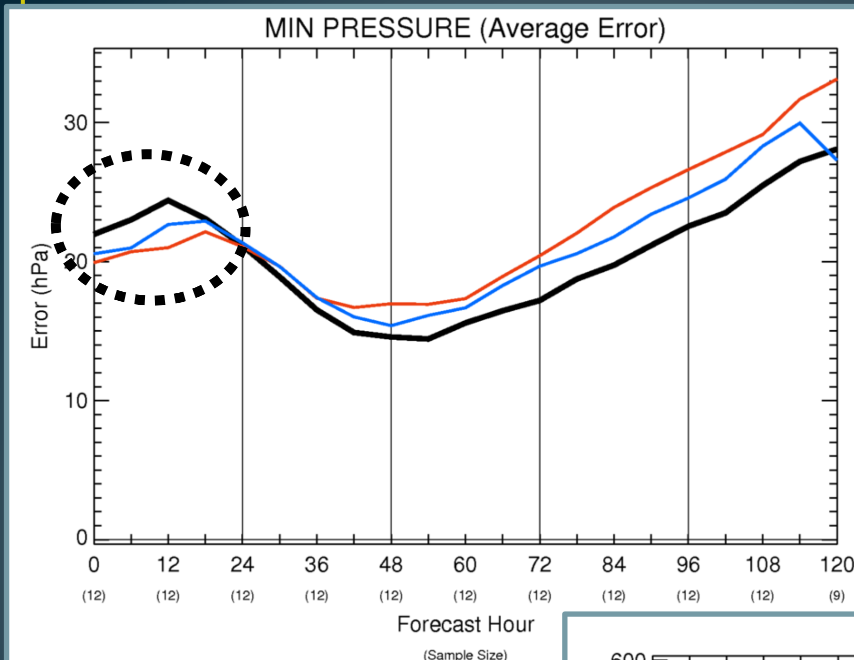
- Nominal CYGNSS wind speeds
- Direction information added to CYGNSS wind speeds using 2D Variational Analysis Method (**VAM**)
  - VAM creates gridded wind analysis by minimizing an objective function which measures the misfit of the analysis to the background, the data, and *a priori* constraints… the analyzed dynamical balance must be close to that of the background (GFS global model in our case)
  - Used for 30+ years to create high-quality ocean surface wind datasets
- Vary data assimilation cycling frequency

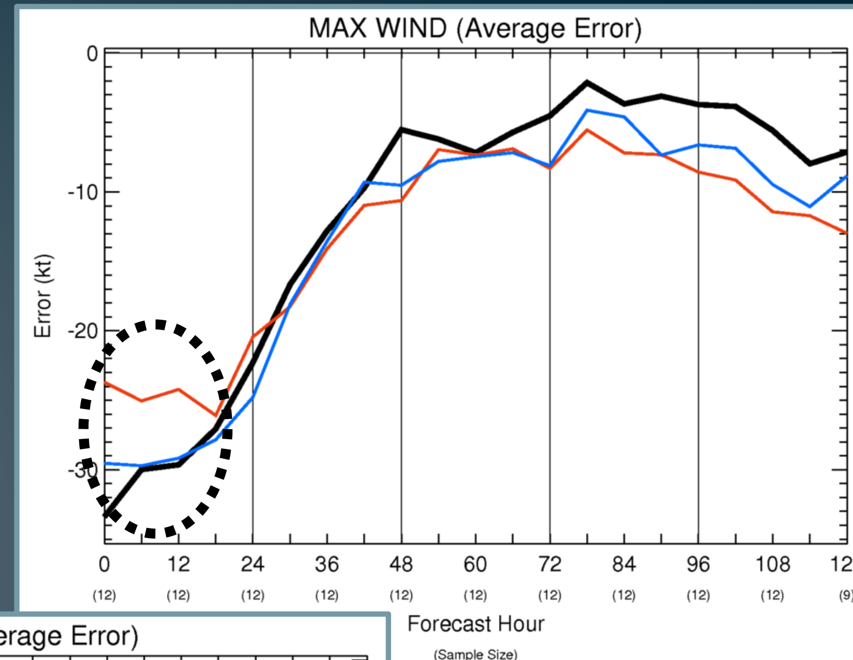
- Results shown include: 0-5 day average error of minimum central pressure, maximum surface wind, and track from a single tropical cyclone in the nature run

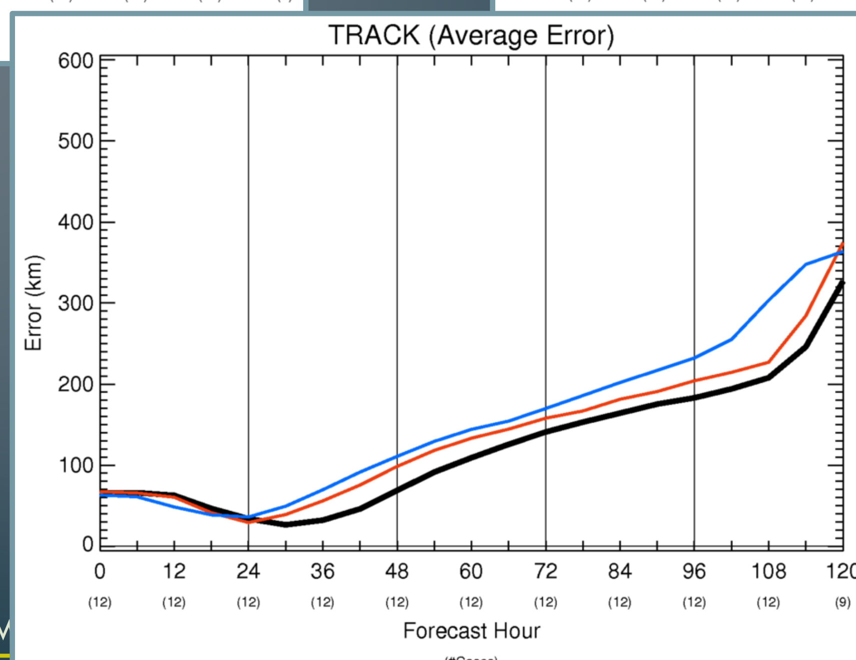
Experiments

- **CONTROL**: conventional satellite/surface/sounding data, no CYGNSS
- **CYG SPD**: **C** + CYGNSS wind speeds, no direction; nominal CYGNSS product
- **VAM VEC**: **C** + VAM wind vectors at CYGNSS retrieval coordinates

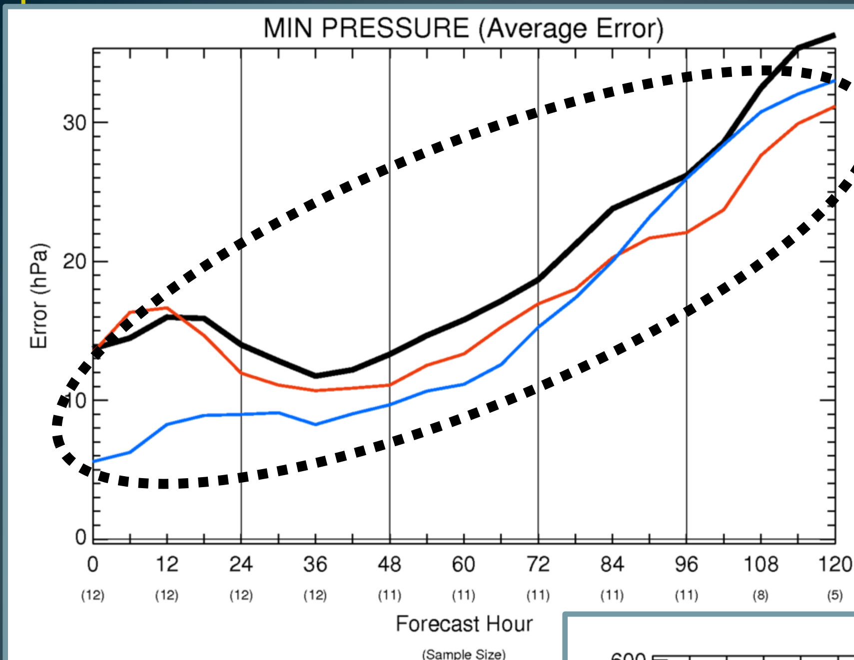
6-hourly DA Cycling

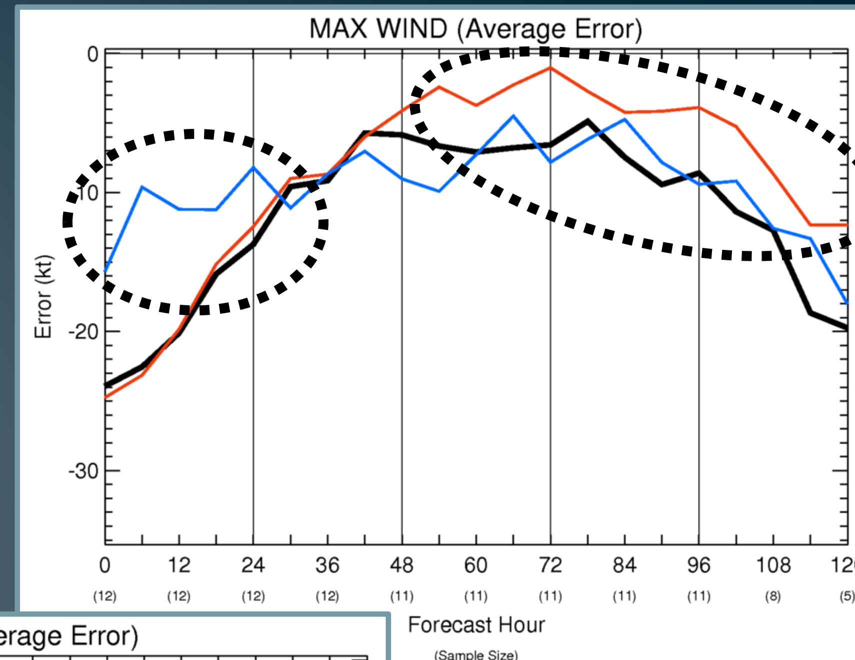






3-hourly DA Cycling

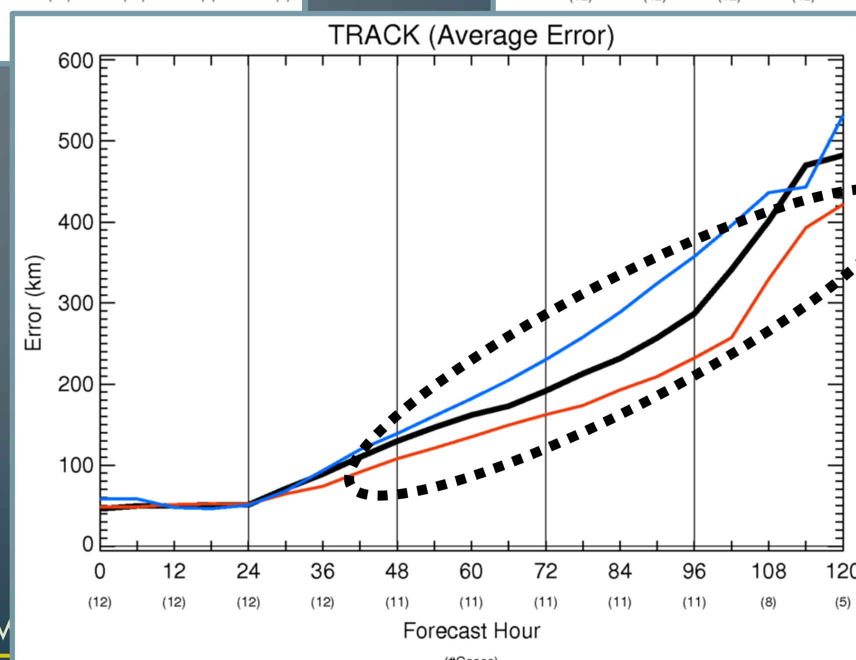




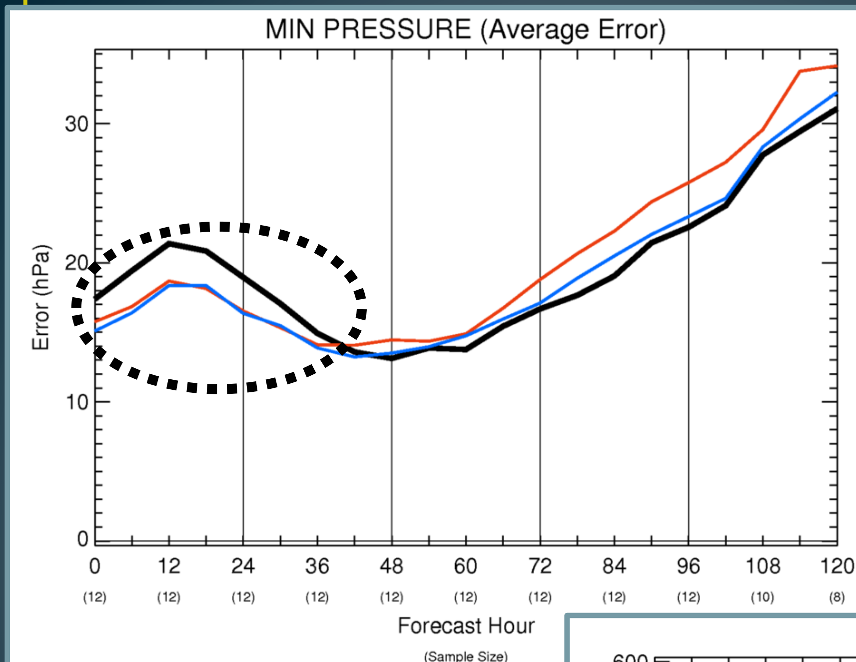
CONTROL 3HR

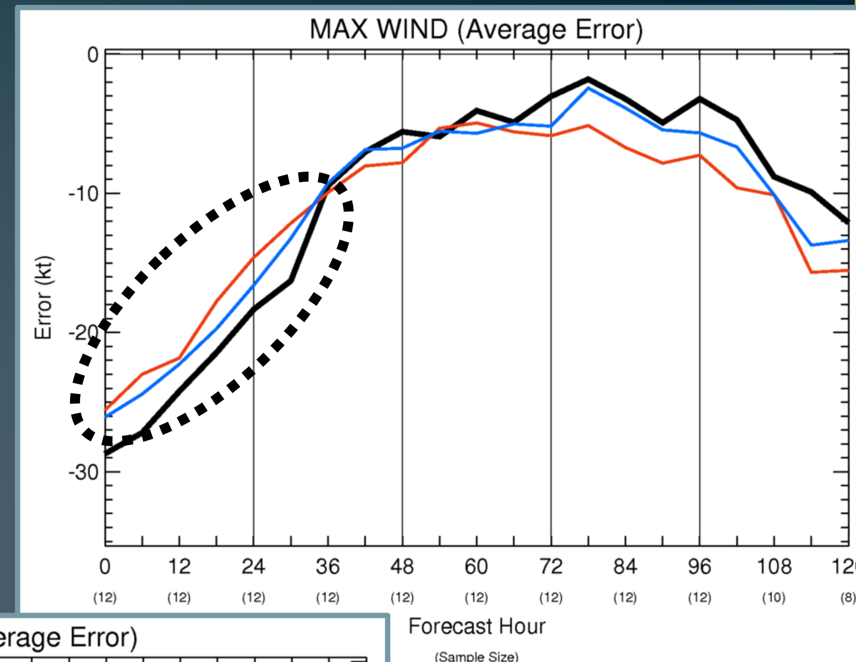
CYG_SPD 3HR

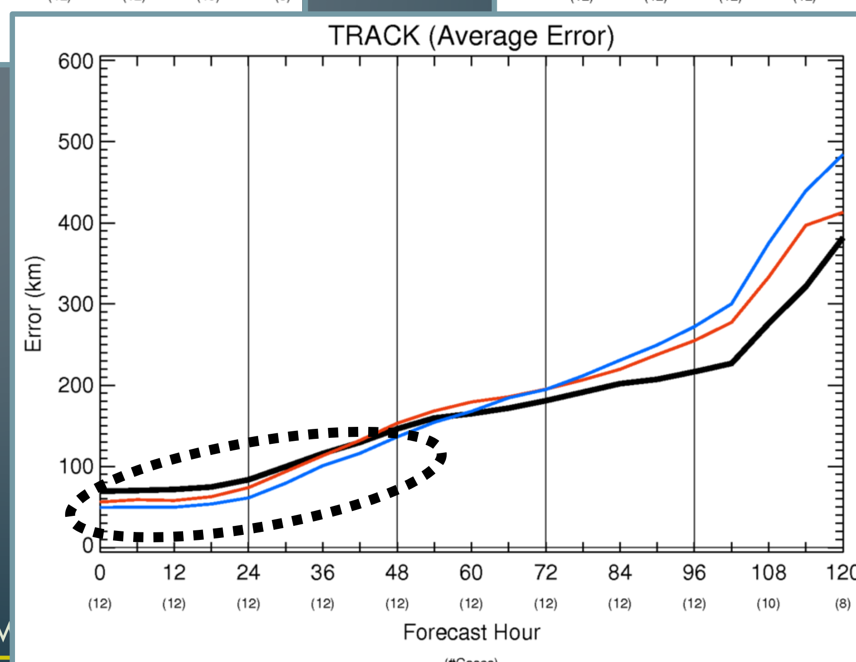
VAM_VEC 3HR



1-hourly DA Cycling





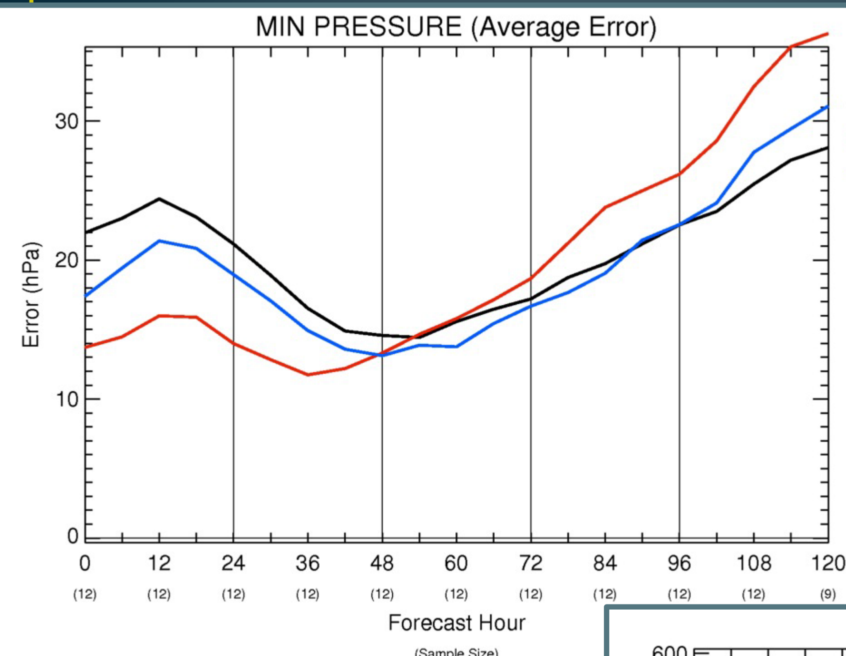


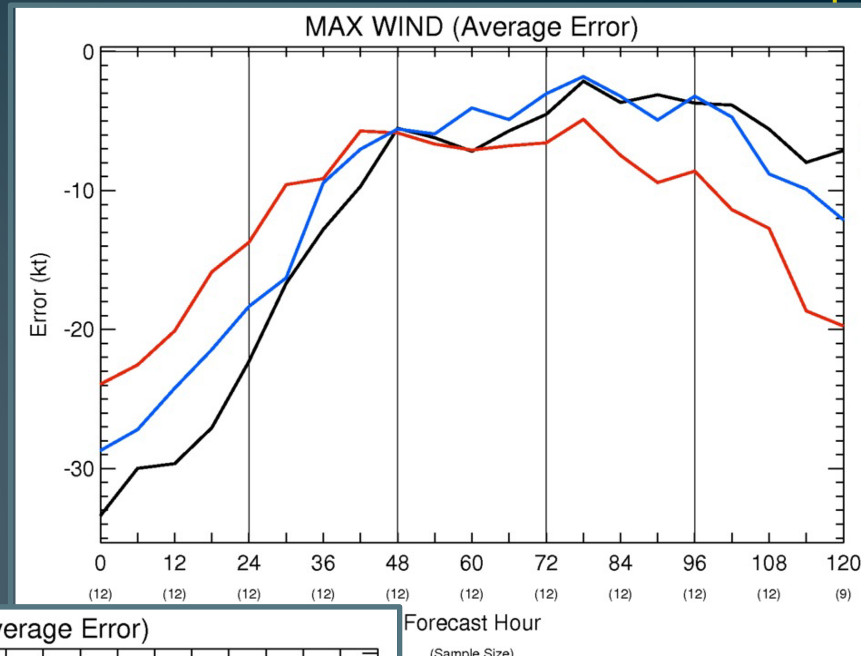
CONTROL 1HR
CYG_SPD 1HR
VAM_VEC 1HR

Same Experiments –
Different Cycling Frequencies Plotted Together

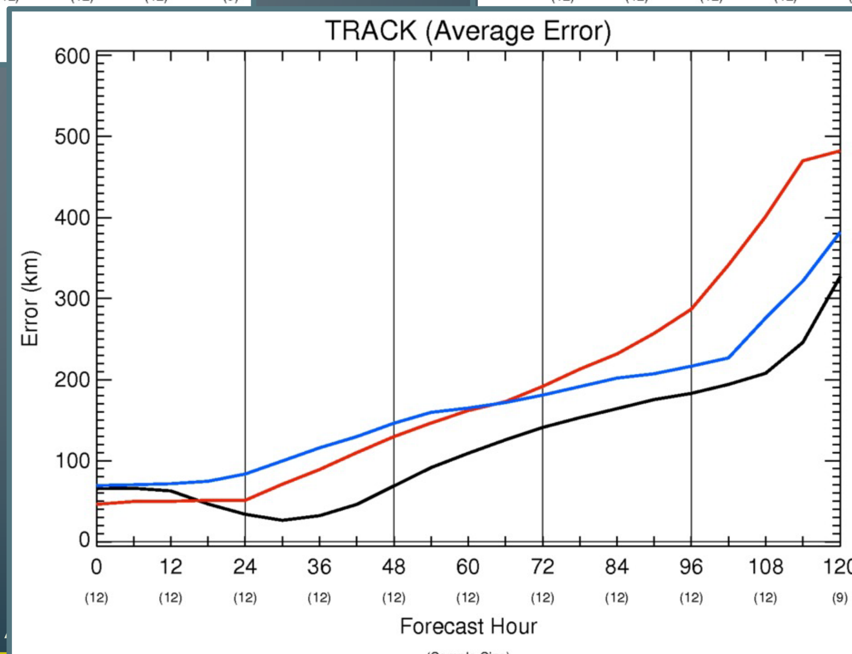
- **6 HOURLY**: observations binned into 6-hour windows (cycle time +/- 3 hours), DA performed every 6 hours, 5-day forecasts produced every 6 hours
- **3 HOURLY**: observations binned into 3-hour windows (cycle time +/- 1.5 hours), DA performed every 3 hours, 5-day forecasts produced every 6 hours
- **1 HOURLY**: observations binned into 1-hour windows (cycle time +/- 0.5 hours), DA performed every hour, 5-day forecasts produced every 6 hours

CONTROL

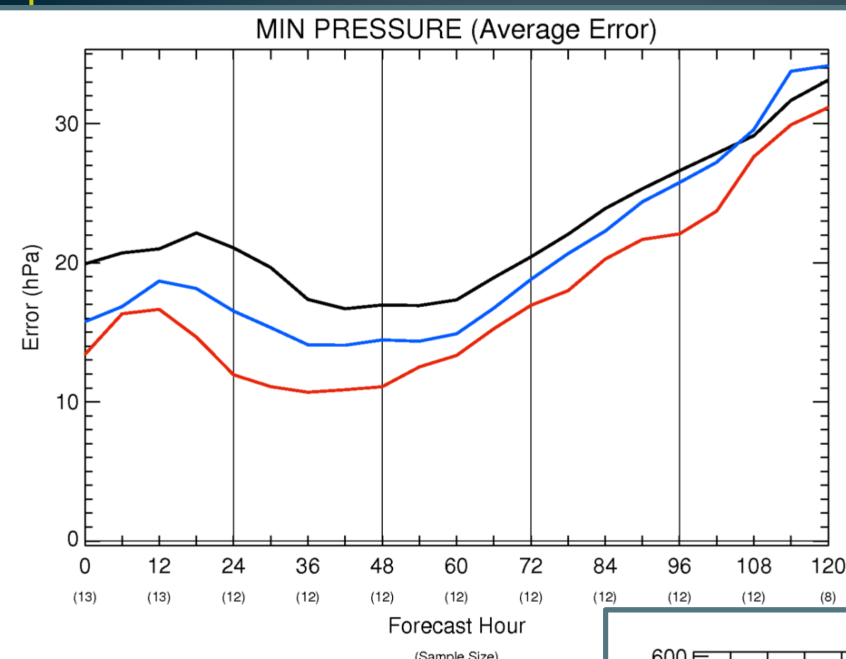


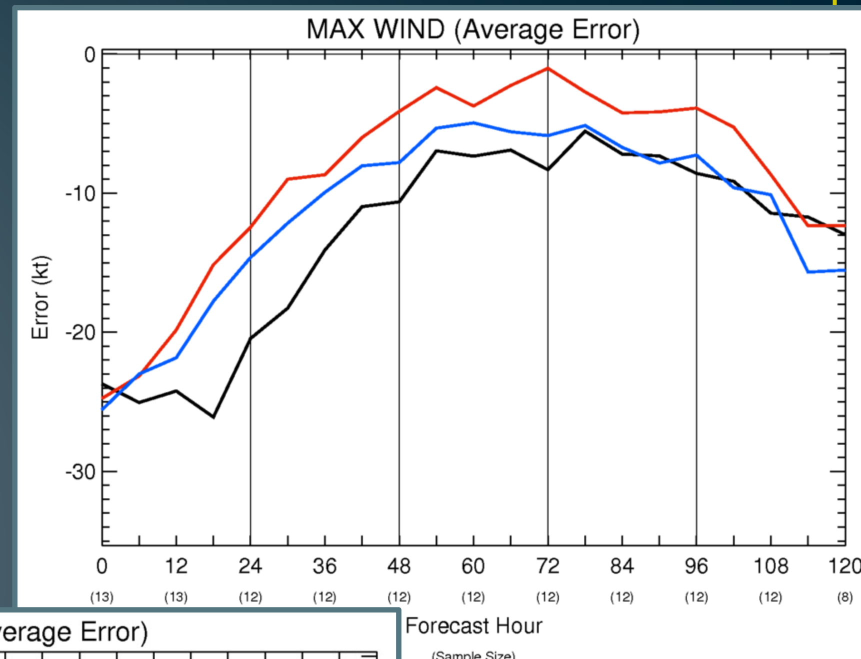


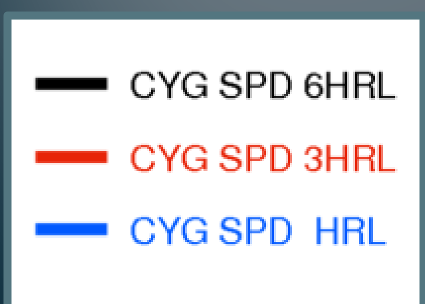
CONTROL 6HRL
CONTROL 3HRL
CONTROL HRL

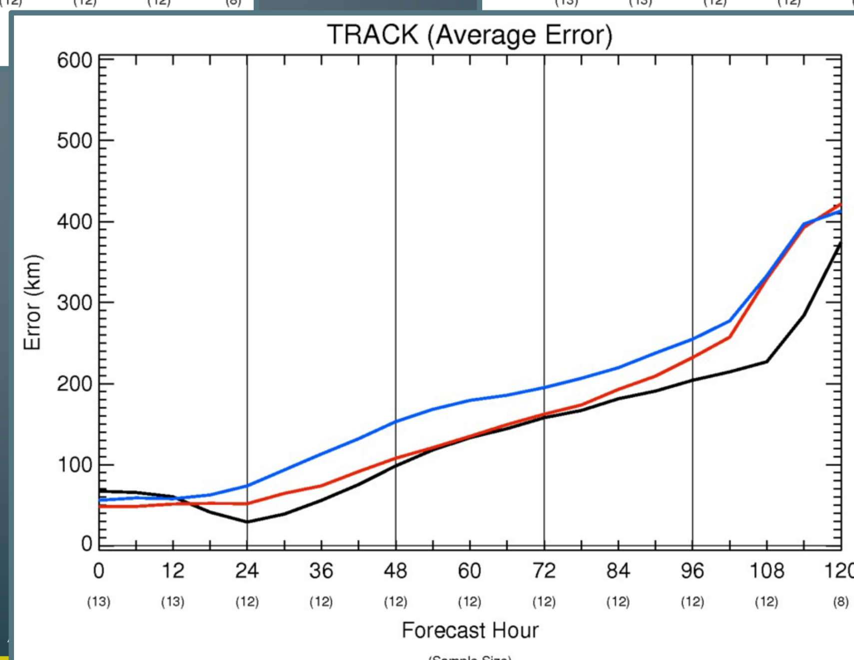


CYG_SPD

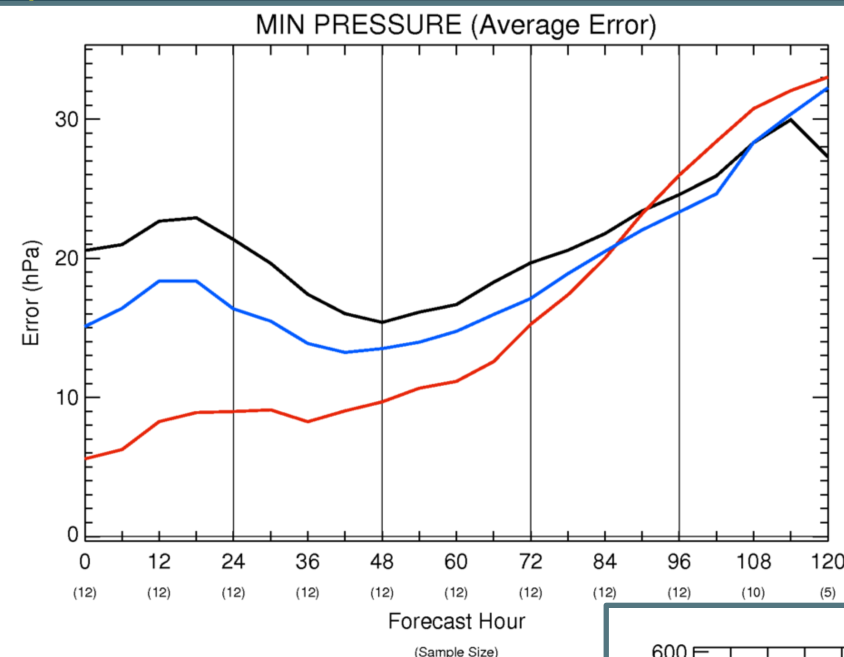

MIN PRESSURE (Average Error)
Error (hPa)
0
10
20
30
0 12 24 36 48 60 72 84 96 108 120
(13) (13) (12) (12) (12) (12) (12) (12) (12) (12) (8)
Forecast Hour
(Sample Size)

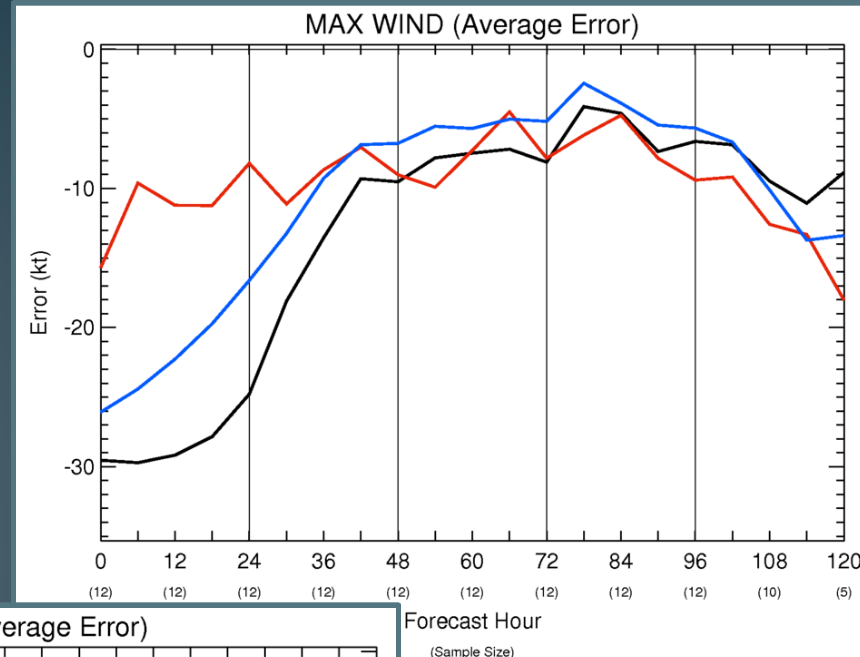

MAX WIND (Average Error)
Error (kt)
0
-10
-20
-30
0 12 24 36 48 60 72 84 96 108 120
(13) (13) (12) (12) (12) (12) (12) (12) (12) (12) (8)
Forecast Hour
(Sample Size)

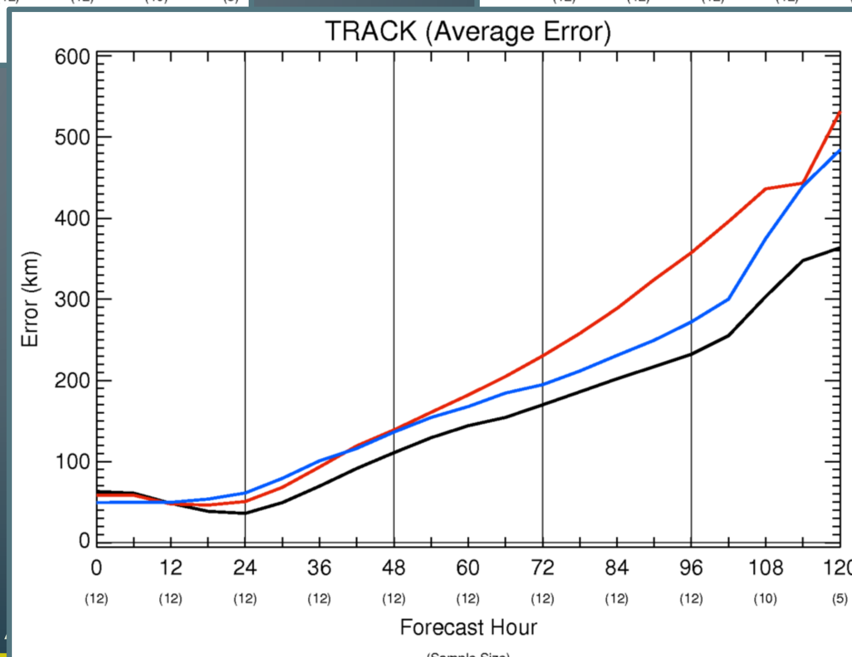

CYG SPD 6HRL
CYG SPD 3HRL
CYG SPD HRL


TRACK (Average Error)
Error (km)
600
500
400
300
200
100
0
0 12 24 36 48 60 72 84 96 108 120
(13) (13) (12) (12) (12) (12) (12) (12) (12) (12) (8)
Forecast Hour
(Sample Size)

VAM_VEC







VAM VEC 6HRL

VAM VEC 3HRL

VAM VEC HRL

Results

- *Analysis of TC intensity* (pressure, wind) improved with addition of CYGNSS data at any cycling frequency
  - greatest improvement from 3-hourly cycling with VAM_VEC data
- *Forecasts of TC intensity* improved, though lead time varies with DA cycling frequency
  - 6-hourly cycling benefits extend ~0-24 hr, 1-hourly cycling benefits extend ~0-36 hr, 3-hourly cycling benefits extend out to 5 days in many cases
  - 3-hourly seems optimal… data too washed out in time with 6-hourly?, insufficient volume of data or model "spin-up" time with 1-hourly?
- *Track at 0-24 hr* very slightly improved with addition of CYGNSS data
  - CYGNSS impacts on track forecasts are small and typically gone by ~24h… they are only surface winds, and a small fraction of all assimilated observations

General Conclusions

- Assimilation of CYGNSS data with GSI almost always improves hurricane intensity and track *analyses and short-range forecasts*
- Processing retrieved CYGNSS wind speed data with VAM to get vectors generally produces better analyses and forecasts
- DA cycling frequency affects quality of analyses (1hr too short, 6hr too long, 3hr just right?)
- We have relatively few samples from one storm, so error statistics are not robust, but provide guidance

Questions?

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- Upcoming CYGNSS presentations:
  - Maria-Paola **Clarizia**, *Wednesday 11:15am*
  - Chris **Ruf**, *Thursday 1:45pm*

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