Evaluation of the Impact of CYGNSS Wind Speed Data on Tropical Cyclone Structure Analyses and Forecasts in a Regional OSSE

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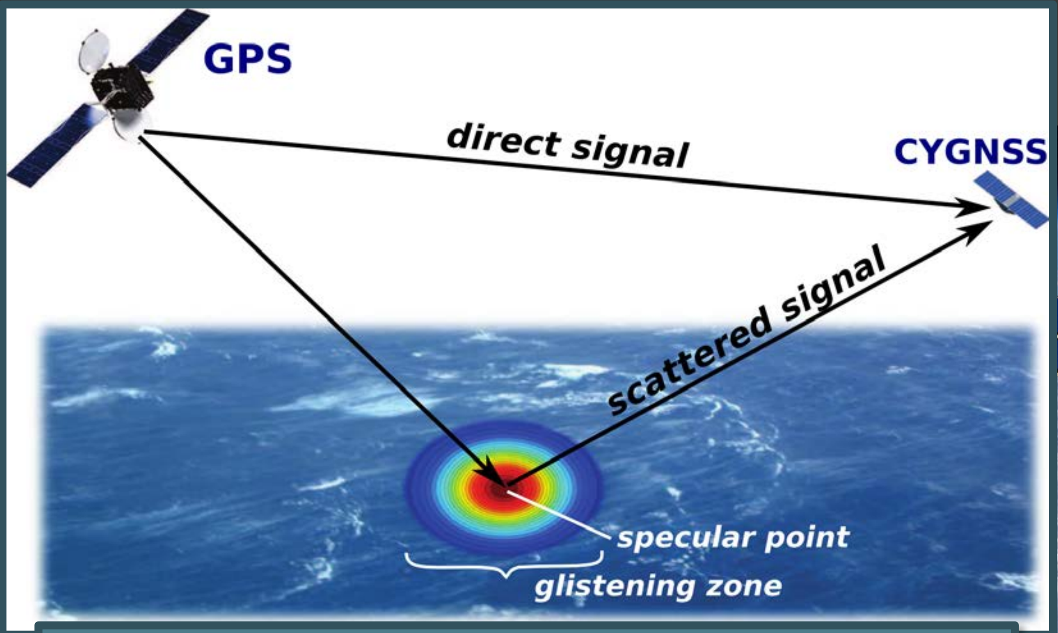
Motivation

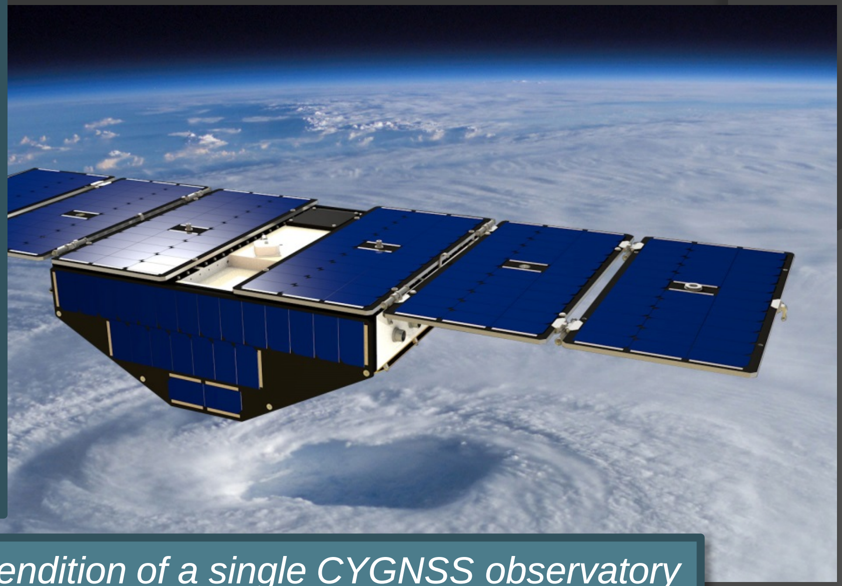
- OSSEs allow the impact of future observing platforms on models to be assessed
- CYGNSS is a future platform well-suited for observing the surface wind field of tropical cyclones (TC)
- Accurate assessment of the size of a TC's wind field is important for forecasters, models, marine interests
- A TC's storm surge potential at landfall is most strongly correlated with integrated kinetic energy (IKE), not peak wind speed

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 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



Basic geometry of bi-static quasi-specular scatterometry.



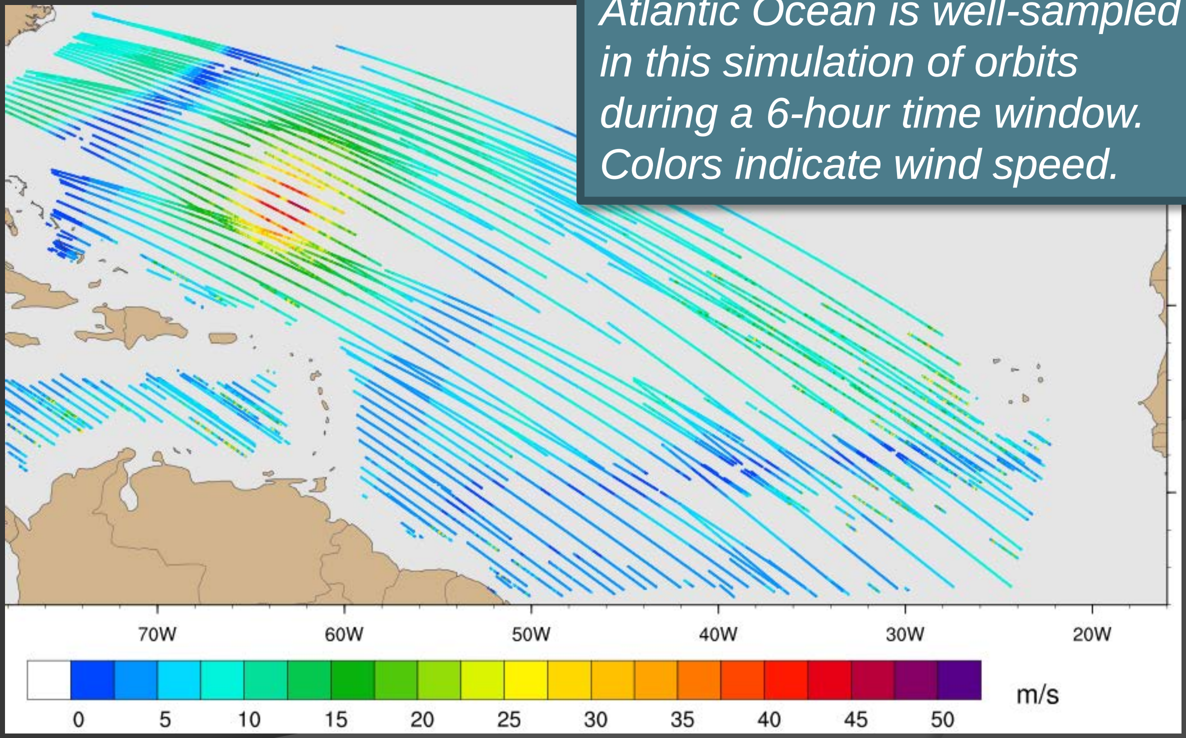
Rendition of a single CYGNSS observatory in orbit over a hurricane. (NASA)

What is CYGNSS?

- Capable of retrieving usable data over a large range of surface wind speeds in all precipitating conditions throughout the tropics and subtropics with frequent revisit times

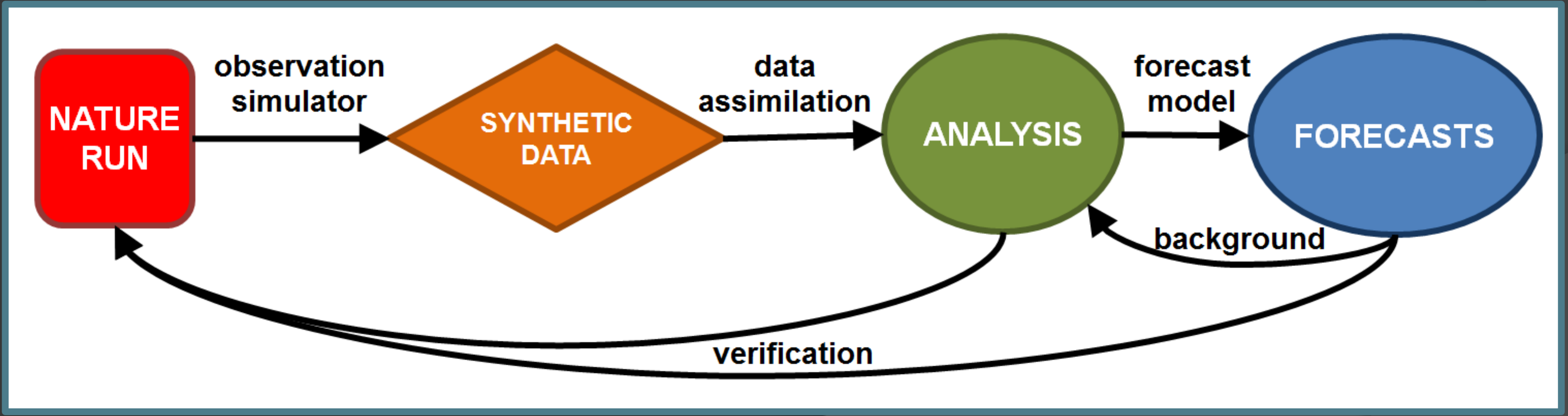
A hurricane over the western Atlantic Ocean is well-sampled in this simulation of orbits during a 6-hour time window. Colors indicate wind speed.

- 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



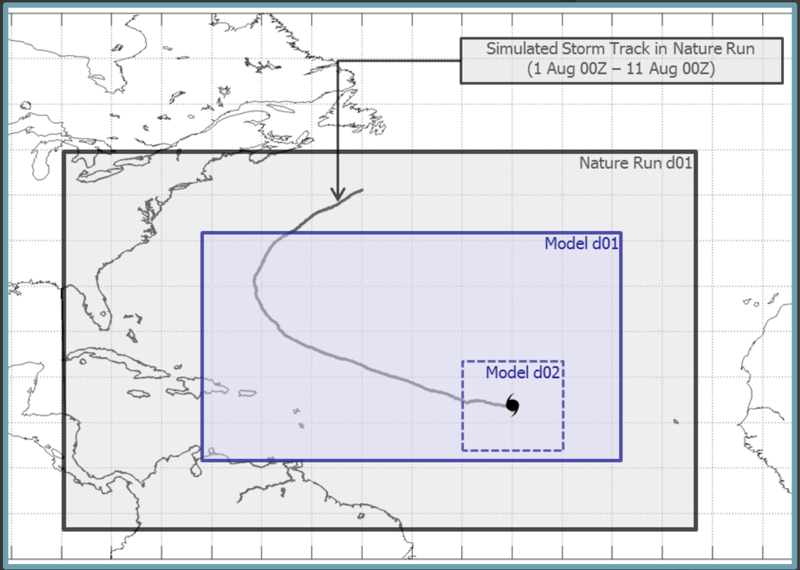
OSSE Framework

- 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 (~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.

- 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)
- Total of 16 model runs, but first 4 runs omitted from verification to allow for model spin-up (***12 total cases***)

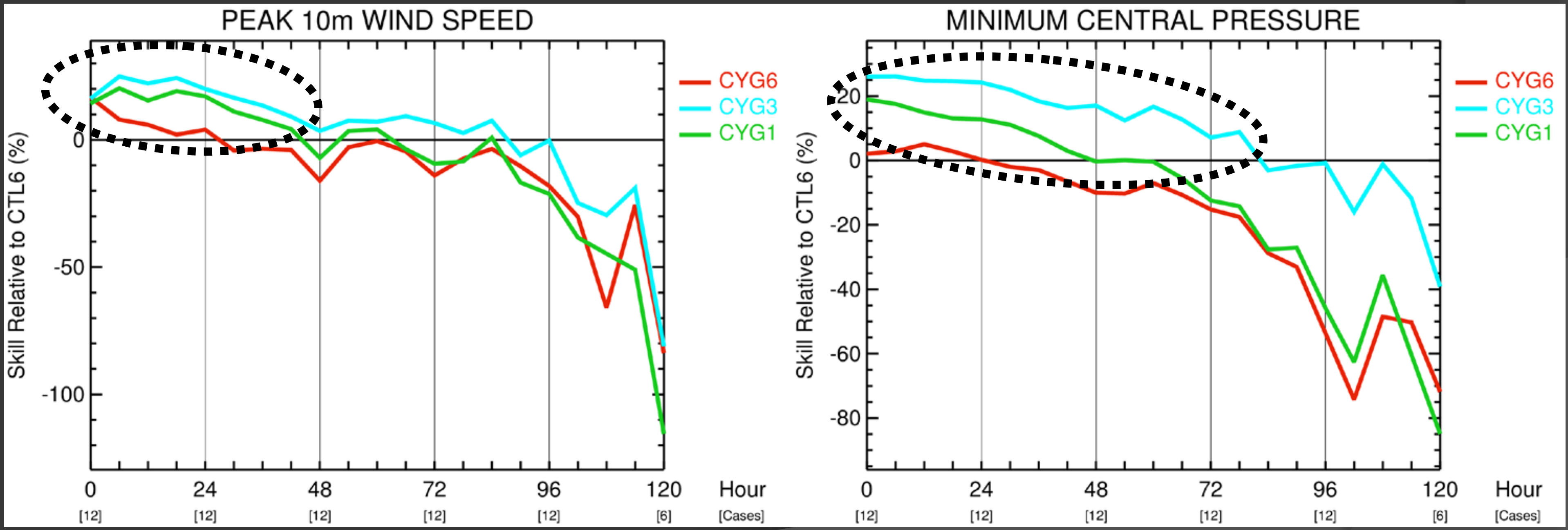
Experiments

- **CTL6**: "control" run with conventional satellite/ surface/sounding data, no CYGNSS, 6-hourly DA cycling
- **CYG6**: **CTL6** + CYGNSS wind speeds, 6-hourly DA cycling
- **CYG3**: **CTL3** + CYGNSS wind speeds, 3-hourly DA cycling
- **CYG1**: **CTL1** + CYGNSS wind speeds, 1-hourly DA cycling

- Results are from single TC in the nature run
- ***Errors are shown as skill relative to CTL6***

Traditional Metrics: Intensity & Pressure

- The addition of CYGNSS data generally improves analyses and forecasts of maximum wind and minimum pressure, mostly limited to 0-48 h timeframe, particularly with CYG3



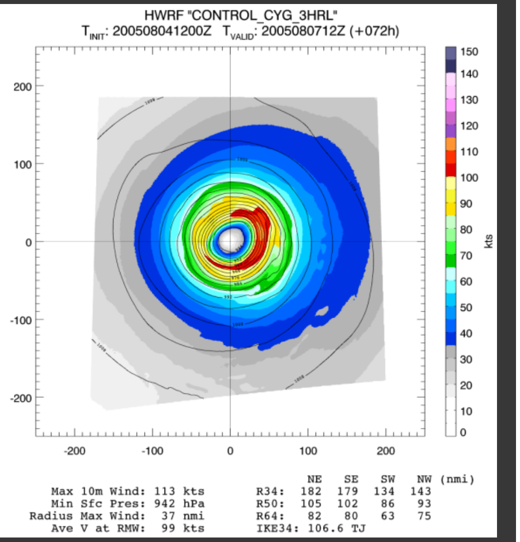
Storm Structure Metrics

- Inner core parameters include azimuthally-averaged radius of maximum wind (**RMW**) and wind speed at the RMW (**VRMW**)
- Critical wind radii defined to be maximum radial extent of 34, 50, and 64-knot winds (**R34**, **R50**, **R64**) from storm center
  - Conventionally reported in each quadrant (NE, SE, SW, NW), measured in nautical miles (1 n mi ≈ 1.15 mi ≈ 1.85 km)
  - Cartesian model grid interpolated to cylindrical grid with 2-km radial and 5º azimuthal spacing
  - Non-zero values of each critical radius averaged together to get single R34, R50, R64 (e.g. Knaff et al. 2016)
- Integrated kinetic energy (**IKE**) is calculated on model grid anywhere $r \leq R34$ and $U_{10} \geq 34$ kt:

$\int \frac{1}{2}\rho U_{10}^2 dV$ (assume $\rho = 1.15$ kg m^{-3}) (Powell and Reinhold 2007)

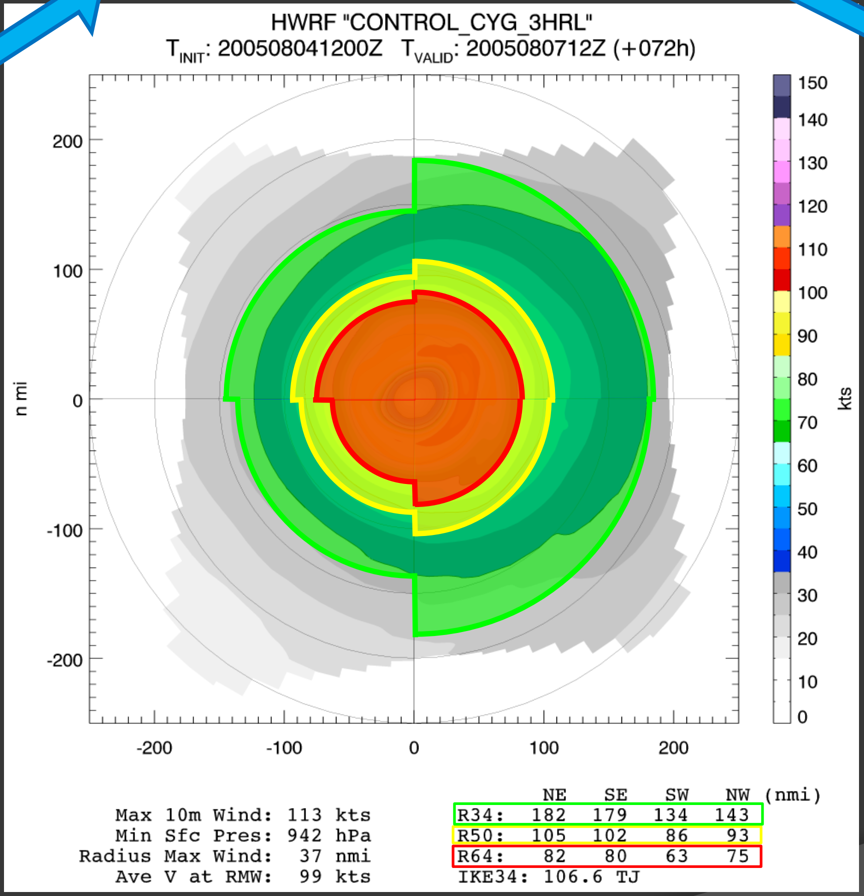
Calculating Storm Structure Metrics

Model 10-m wind
Calculate IKE



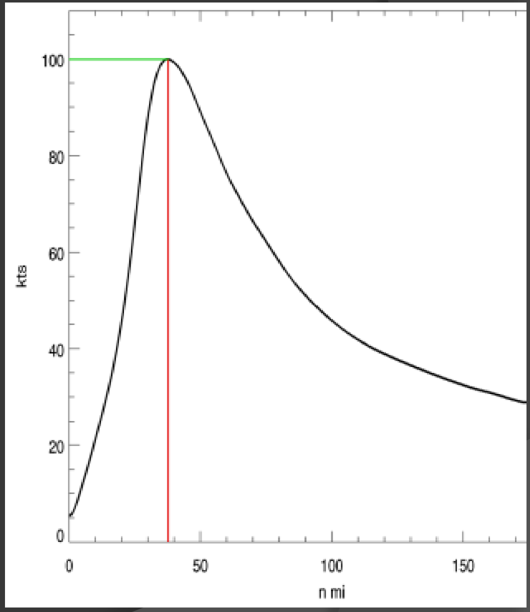
VMAX: 113 kt
PMIN: 942 hPa
IKE: 107 TJ

Interpolate to cylindrical grid
Calculate R34,R50,R64



R34: 160 nmi, R50: 97 nmi, R64: 75 nmi

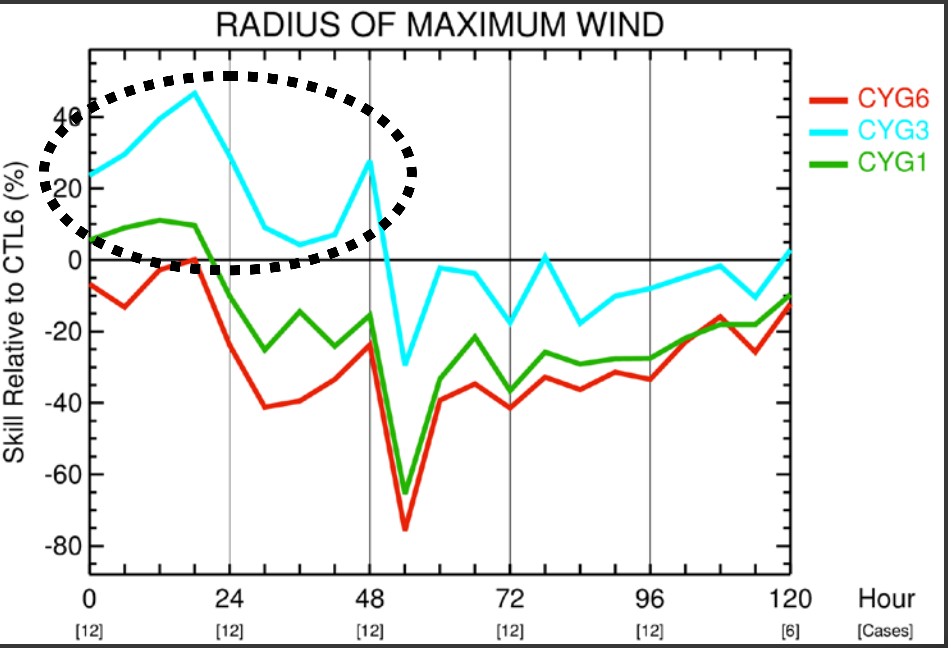
Azim-ave wind profile
Calculate RMW, VRMW

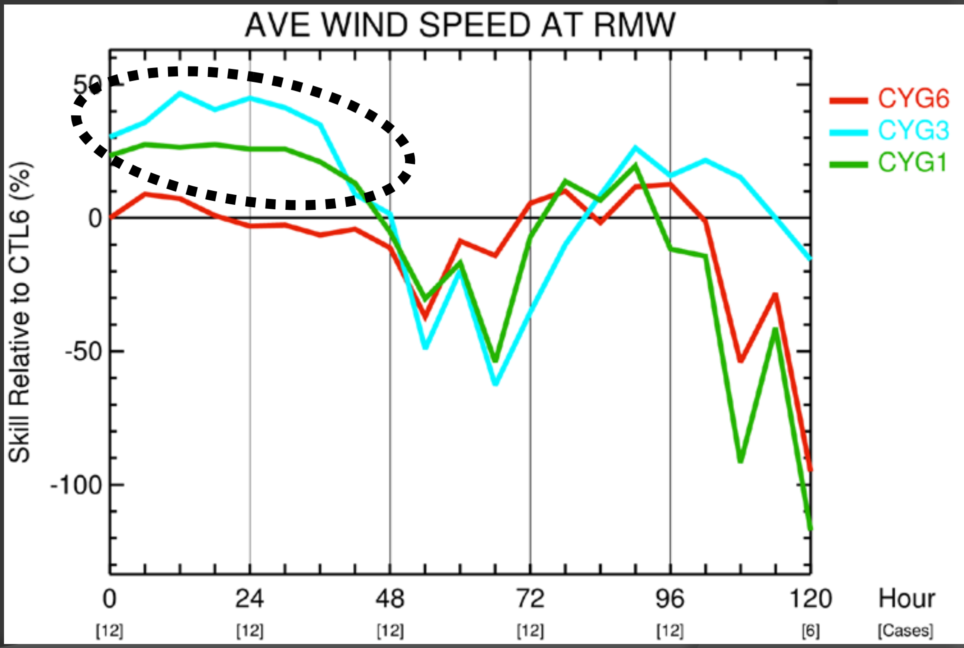


RMW: 37 nmi
VRMW: 99 kt

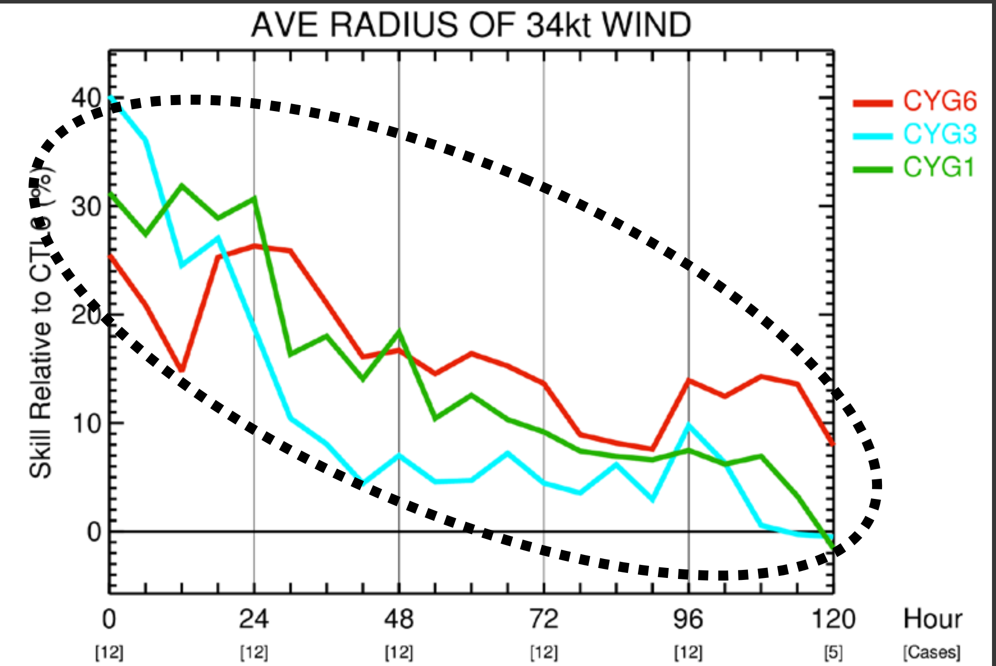
Storm Structure Metrics: Inner Core

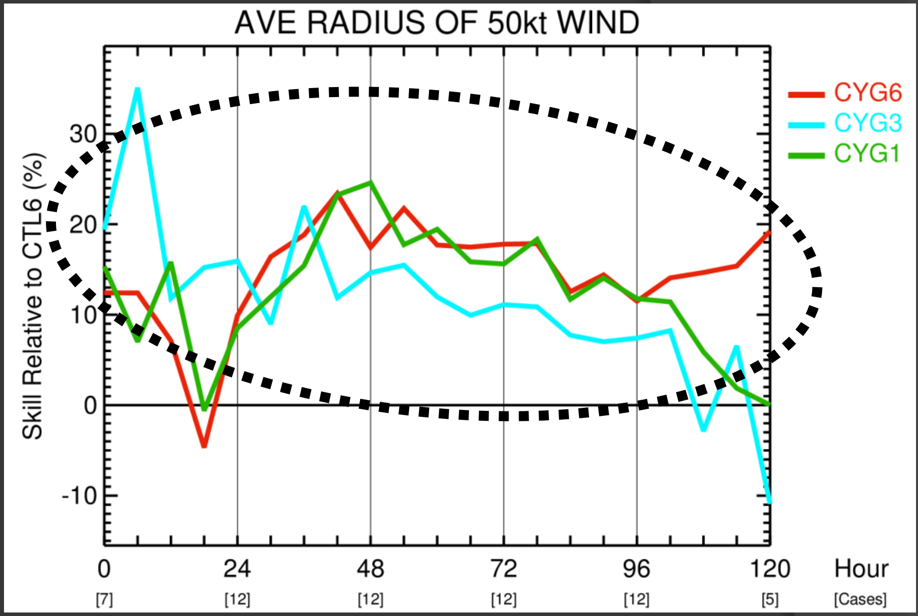
- CYGNSS data have negative impact on radius of maximum wind (RMW) errors in this sample, except for CYG3 which adds skill out to 48 h
- Positive impact on wind speed at RMW (VRMW) in 0-48 h timeframe with CYG3 and CYG1

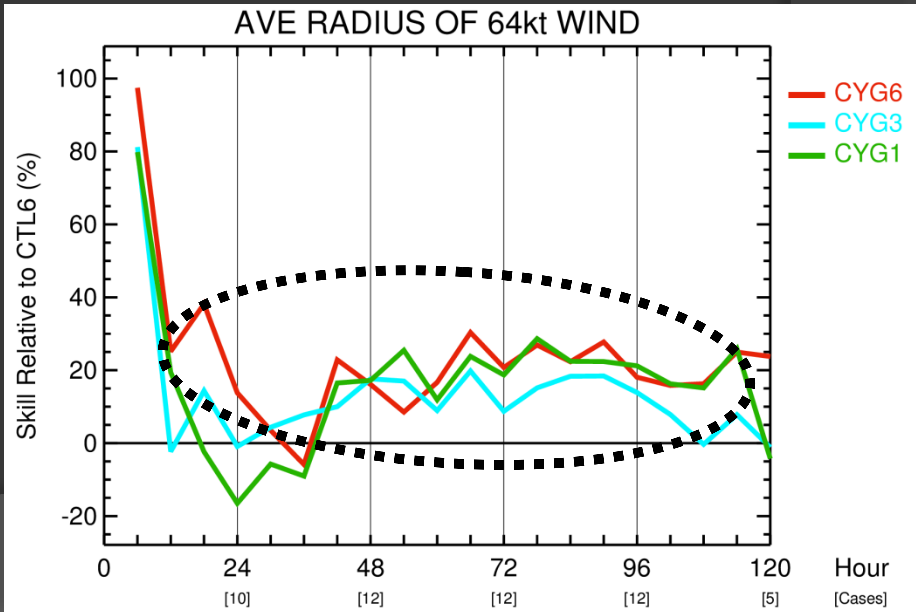




Results: Critical Radii



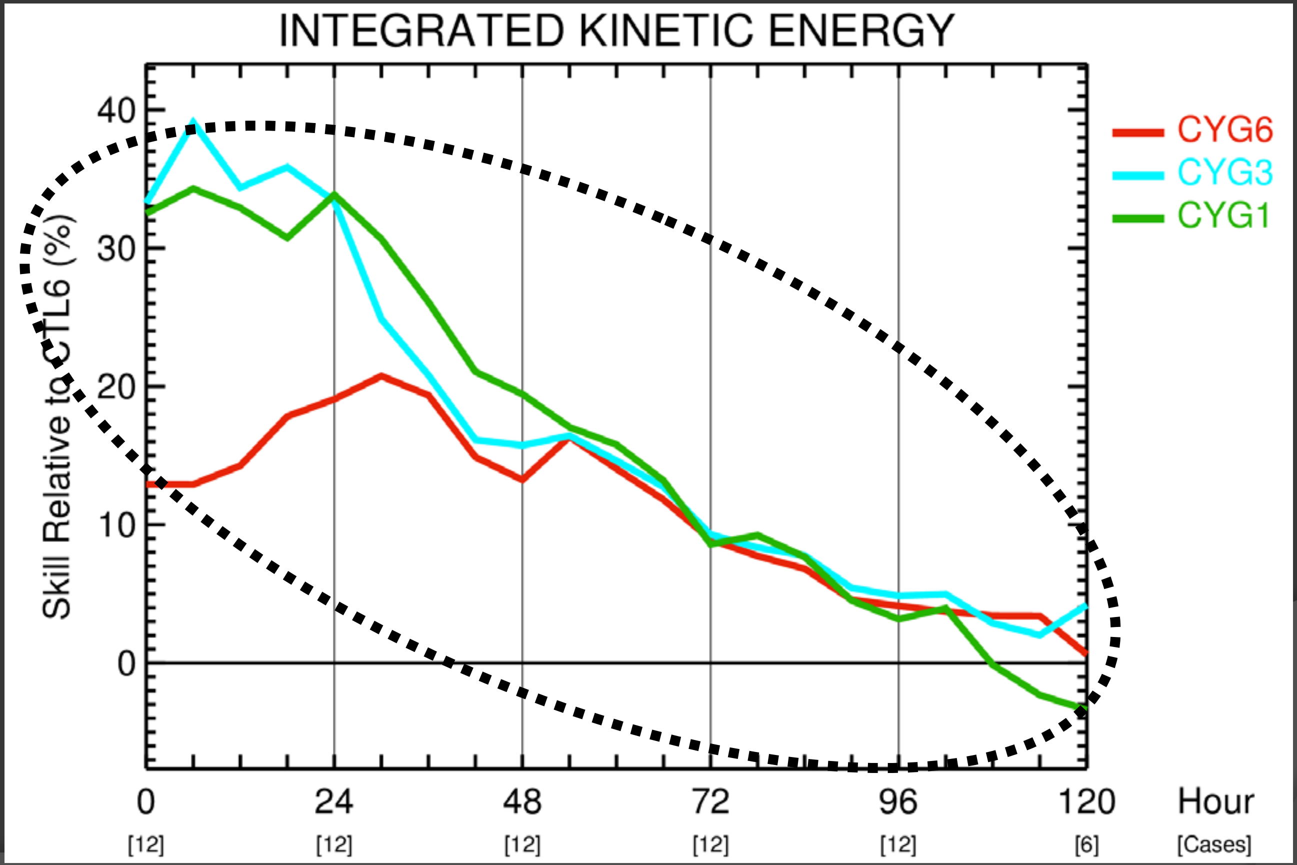




- Analyses & forecasts of all critical radii improved with CYGNSS data at all DA frequencies

Storm Structure Metrics: IKE

- Significant skill added for IKE from 0-120 h with all CYGNSS experiments, especially CYG3 and CYG1



Conclusions

- CYGNSS data have greatest impact on storm structure metrics such as critical wind radii and integrated kinetic energy
- CYGNSS data improve hurricane intensity analyses and short-range forecasts, but *inner-core-scale metrics limited by spatial resolution*
- DA cycling frequency affects quality of analyses and longevity of skillful forecasts (1 hr too short, 6 hr too long, 3 hr just right?)
- We have relatively few samples from one TC in one nature run, so error statistics are not robust, but provide guidance

Questions?

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- CYGNSS Mission Website:
  - http://cygnss-michigan.org

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