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# Tropical Cyclone Forecast Skill Impact Simulations with the NASA CYGNSS Constellation

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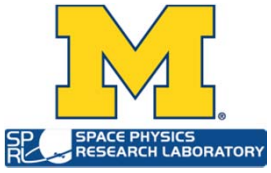
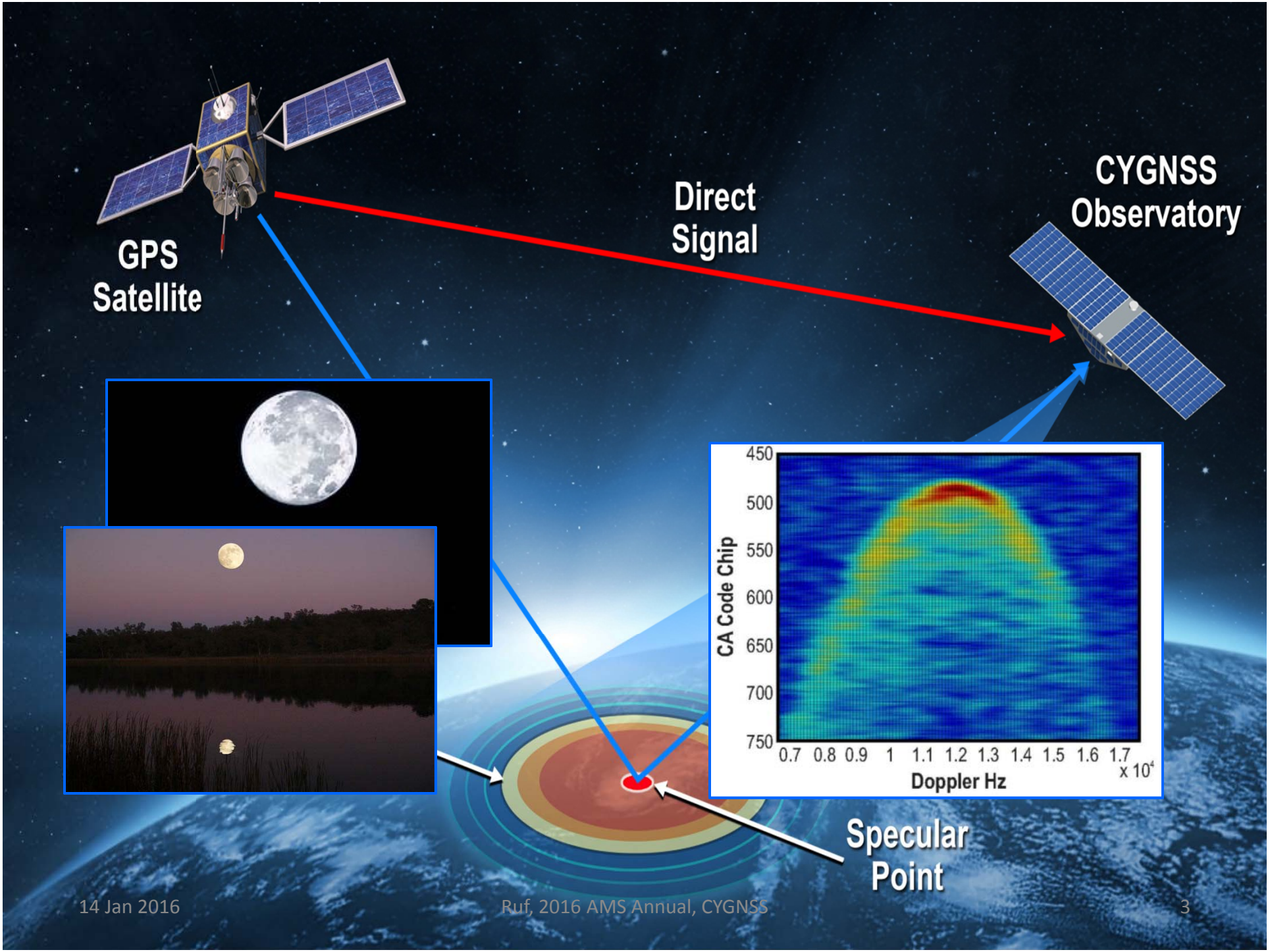






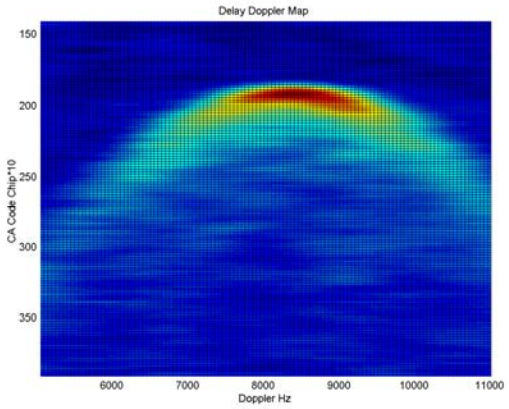
# CYGNSS Mission Overview

- The Cyclone Global Navigation Satellite System (CYGNSS) is the first NASA Earth Venture Mission
- CYGNSS consists of 8 microsatellites, each with a 4-channel GPS bi-static radar receiver
  - Mission lead/Science Ops (University of Michigan)
  - Spacecraft/Integration/Mission Ops (Southwest Research Institute)
- The driving science objective is rapid sampling of ocean surface winds in the inner core of tropical cyclones
- CYGNSS uses a new measurement technique and a new satellite mission architecture
  - Measure the distortion of GPS signals scattered from the ocean surface to determine ocean surface roughness and wind speed
  - Use small satellites so many can be flown to improve sampling

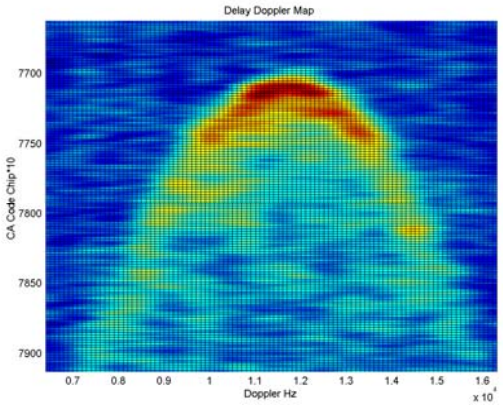

GPS
Satellite
Direct
Signal
CYGNSS
Observatory
CA Code Chip
450
500
550
600
650
700
750
0.7 0.8 0.9 1 1.1 1.2 1.3 1.4 1.5 1.6 1.7
x 10^4
Doppler Hz
Specular
Point

# Spaceborne Empirical Demonstration of Ocean Wind Speed Retrievals by GNSS-R

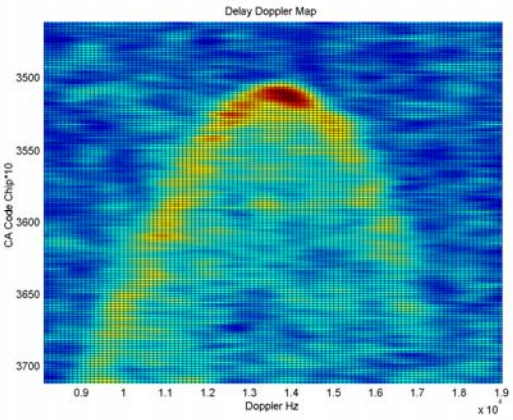
GNSS-R instrument (early version of CYGNSS science payload) deployed on UK-DMC-1 mission, launch 2003




- Winds ~ 2 m/s

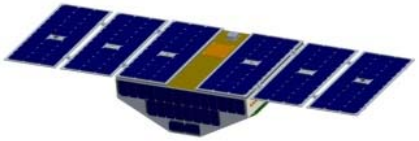


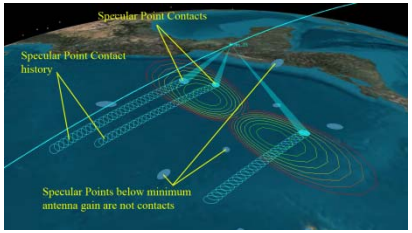

- Winds 7 m/s

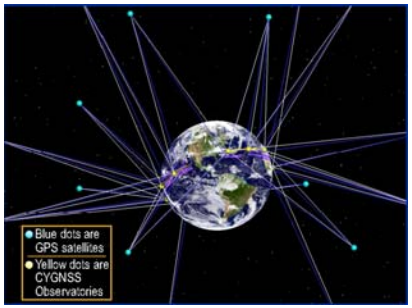



- Winds 10 m/s

# CYGNSS Specular Point Contacts and Spatial Sampling

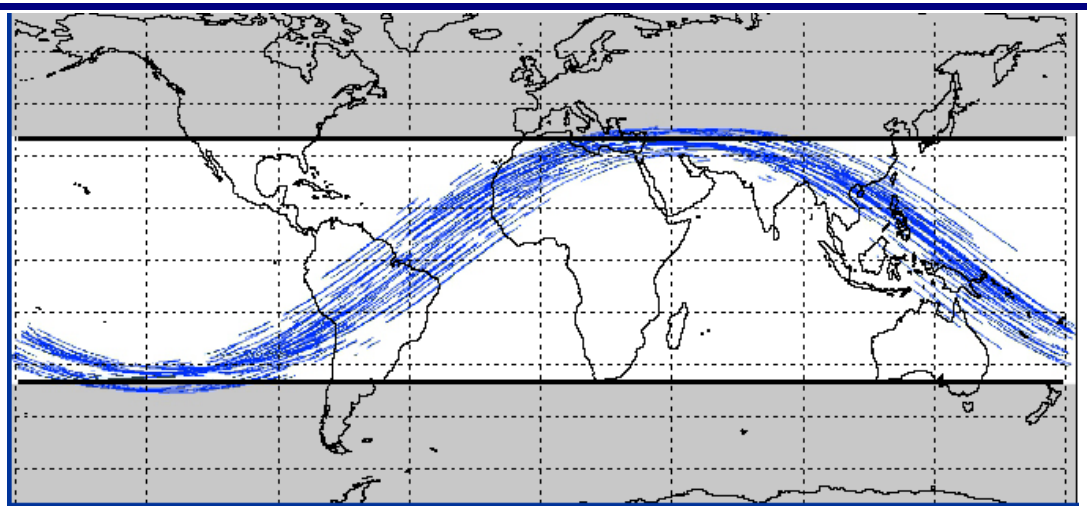


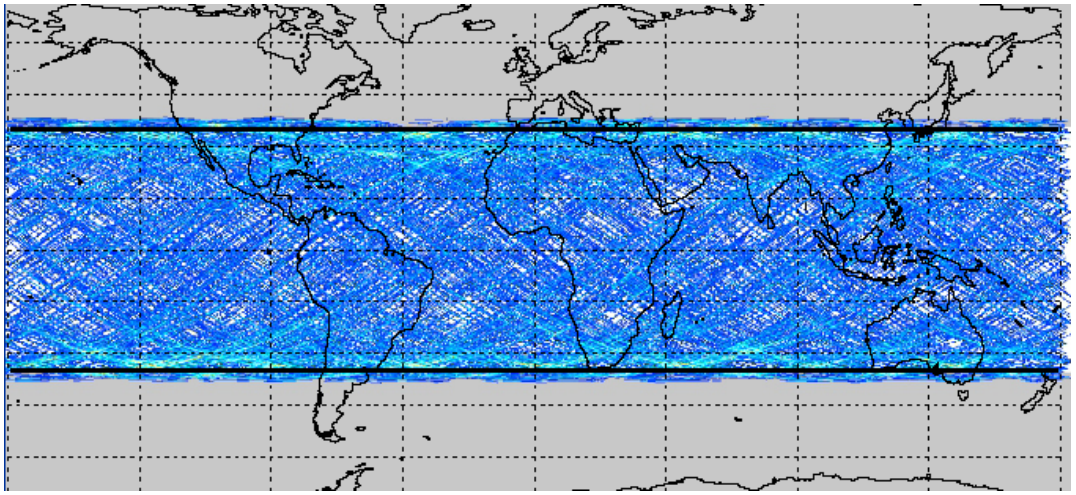


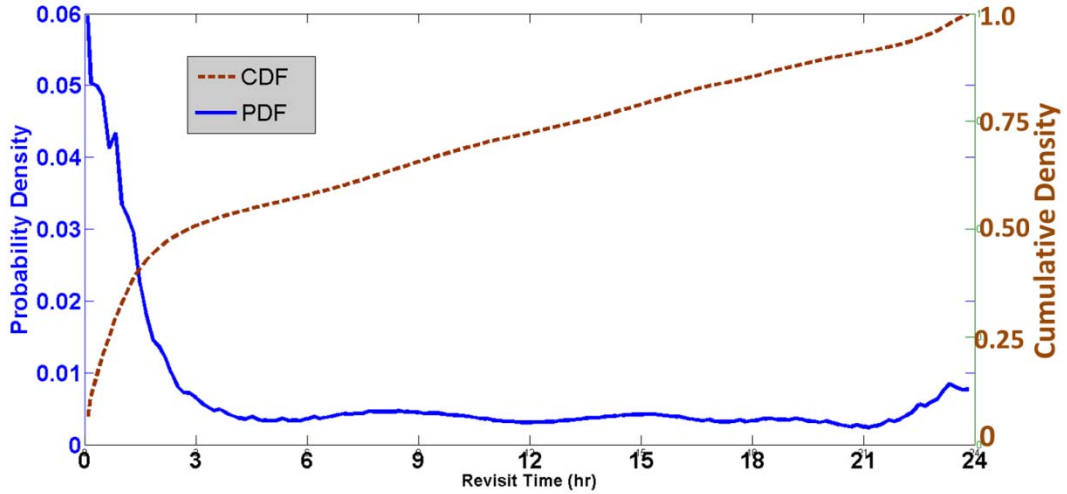

# CYGNSS Spatial Sampling

- 90 min (one orbit) coverage showing all specular reflection contacts by each of 8 s/c
- 24 hr coverage provides nearly gap free spatial sampling within +/- 35 deg orbit inclination





# CYGNSS Temporal Sampling




- Sampling occurs randomly due to the asynchronous nature of the CYGNSS and GPS satellite orbits
- Revisit time is characterized statistically from these distributions
- The median and mean revisit times are, respectively, 2.8 and 7.2 hours.

# Level 1 Baseline
# Mission Science Requirement

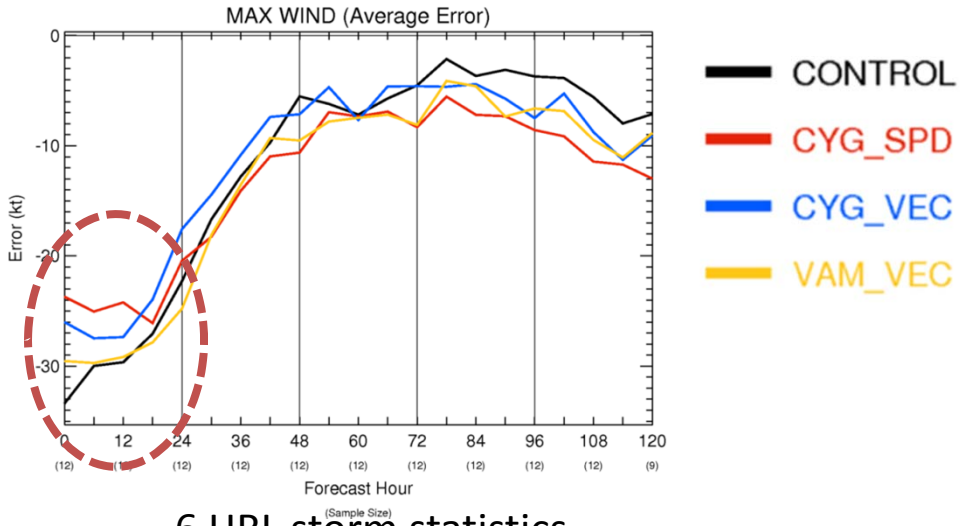
| Sci Rqmt # | Requirement | Verification Approach |
|---|---|---|
| 1 | 3 m/s to 70 m/s at 5 km x 5 km resolution | Simulation/Analysis/Test |
| 2 | Operation in presence of rain | Analysis |
| 3a | 10% retrieval uncertainty for winds > 20 m/s | Simulation/Analysis/Test |
| 3b | 2 m/s retrieval uncertainty for winds < 20 m/s | Simulation/Analysis/Test |
| 3c | Spatial Resolution of 25 km x 25 km or better | Simulation/Analysis |
| 4a | 100% duty cycle during science operations | Analysis/Test |
| 4b | Mean temporal resolution less than 12 hours | Simulation/Analysis |
| 4c | 24 hour spatial sampling covering 70% or more of the cyclone historical track | Simulation/Analysis |
| 5 | Calibrate and validate CYGNSS data in individual wind speed bins above and below 20 m/s | Simulation/Test |
| 6 | Support operational hurricane forecast community | Demonstration |

# OSSE Forecast Skill Impact Assessment (Atlas and Majumdar)

**OSSE Framework Details**

- Nature Runs: ECMWF low-res T511 (~40km); WRF-ARW hi-res 27km regional domain, 9/3/1 km storm-following nests (v3.2.1)
- Data Assimilation: GSI: Gridpoint Statistical Interpolation, standard 3D variational assimilation scheme (v3.3)
- Forecast Model: 2014 'operational' Hurricane-WRF model (v3.5). Parent domain has 9km res, single storm-following nest @ 3km
- DA and model cycling every 6 hr, each run producing a 5-day forecast (except for higher-freq cycling exp)

- **CONTROL**: conventional data sans scatterometers
- **CYG SPD**: (C + CYGNSS wind speeds, no direction)
- **CYG VEC**: (C + CYGNSS wind speeds with VAM analysis directions)
- **VAM VEC**: (C + VAM analysis wind speeds and directions at CYGNSS retrieval coordinates)



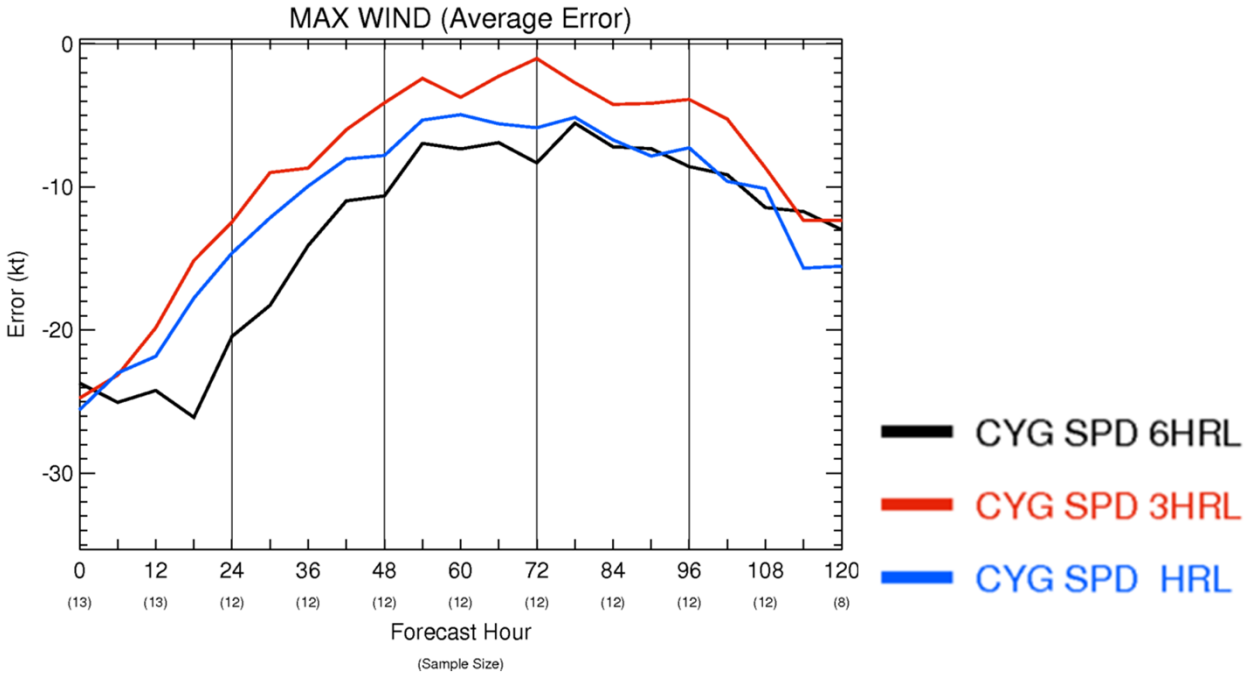

6 HRL storm statistics

- Directional information added to CYGNSS wind speeds using 2D Variational Analysis Method (VAM); Creates gridded wind analysis by minimizing a cost function that measures the misfit of the analysis to the background, data, and *a priori* constraints

# Cycling Frequency Statistics (CYG SPD)
## (Atlas and Majumdar)

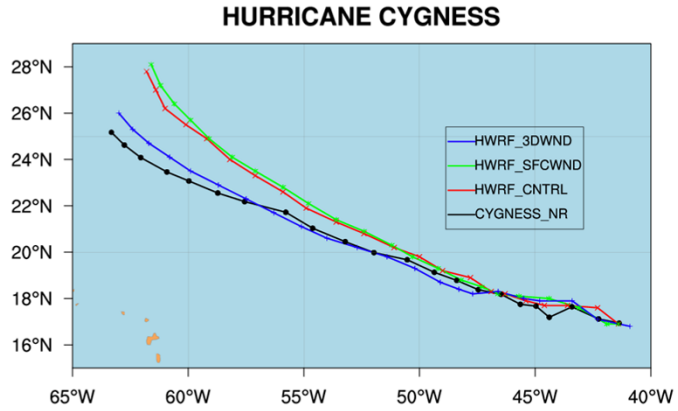
Observations binned into X-hour windows (synoptic time +/- X/2 hours), DA performed every X hours, 5-day forecasts produced every 6 hours

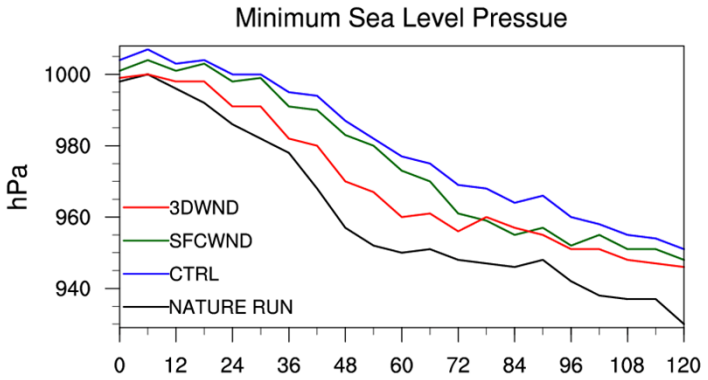
- **6 HOURLY**
- **3 HOURLY**
- **1 HOURLY**

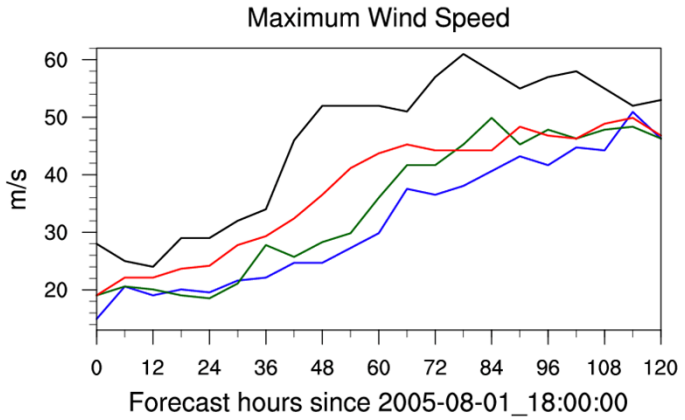


# OSSE Study: CYGNSS surface winds v. Lidar 3-D wind profiles (Zhaoxia Pu)

**HWRF track and intensity forecasts** (18 UTC 01 – 18 UTC 04 Aug 2005) **with HWRF/GSI data assimilation** (12-18 UTC 01 Aug, 2005)



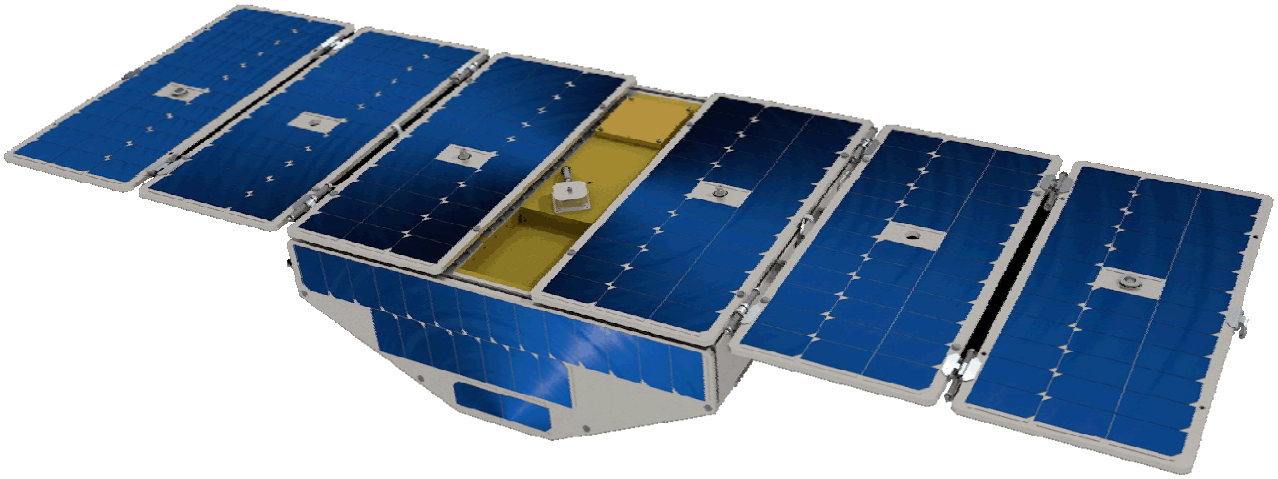




- Both ocean surface wind and 3D wind have positive impact on tropical cyclone forecasting in terms of track and intensity.
- 3D winds outperform ocean surface winds. However, since CYGNSS can see through the clouds, its benefit is still obvious.

# CYGNSS Mission Status

- Phases A/B/C complete
  - Define requirements (A), Preliminary flight segment design (B), Critical flight segment design (C)
- Currently in Phase D
  - 8 observatories being assembled, integrated and tested at SwRI in San Antonio, TX
  - Mission Operations Center coming online at SwRI in Boulder, CO
  - Science Operations Center coming online at UM in Ann Arbor
- T-minus 276 days + 23 hours to launch
  - Launch window opens at 13:00 EDT on 17 Oct 2016
  - L-1011 aircraft takes off from Kennedy Space Center
  - Pegasus dropped over mid-Atlantic, launched into 510 km circular orbit at 35$^{o}$ inclination
  - Begin deployment of 8 Observatories at ~L+12 min
- Phase E (science operations) to begin at L+60 days

# CYGNSS Observatory

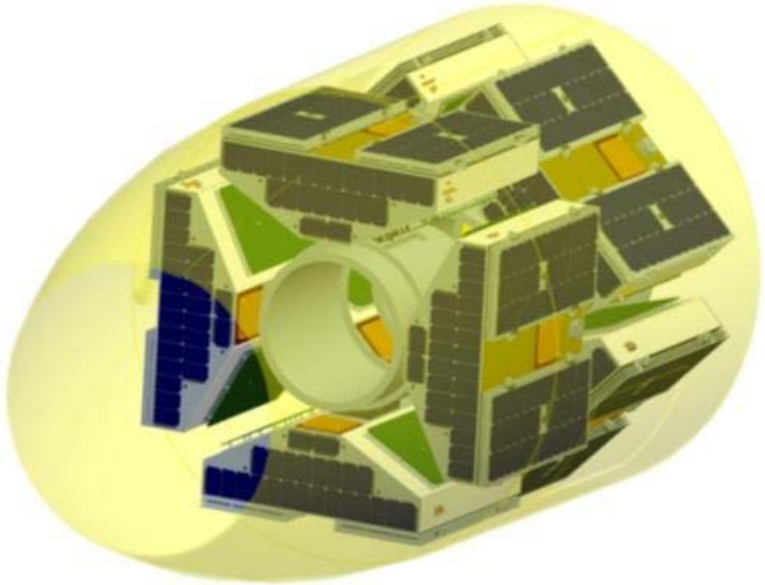


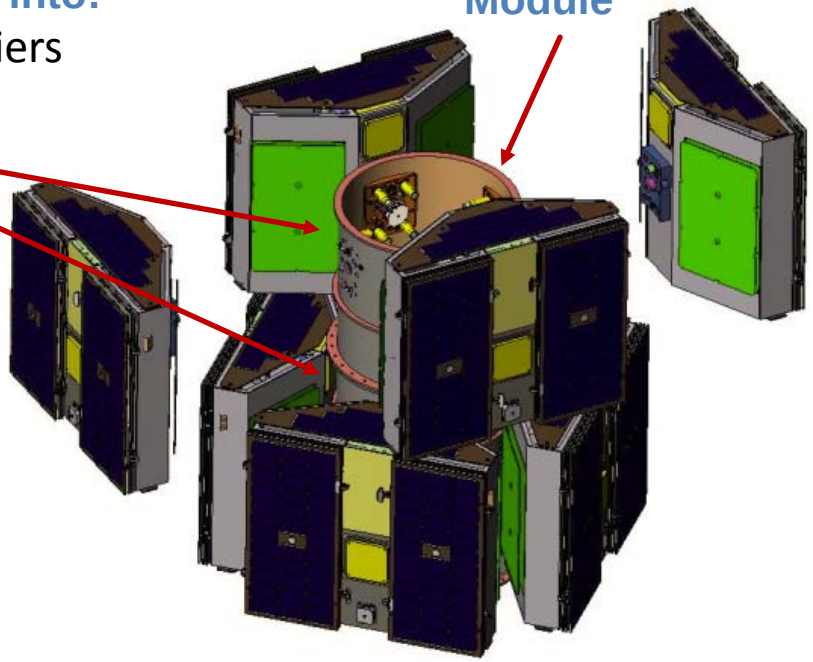
Power: 38.3 W; Mass: 24.8 kg

# Observatory #1 Assembly, Integration & Test

# Launch and Deployment Concept

**Observatories Integrated into:**
(2) Deployment Module Tiers
(4) Vehicles Per Tier





# Pegasus Installed on L-1011 Aircraft

# *Thank You*

for more information visit **http://cygnss-michigan.org**

or contact Chris Ruf, **cruf@umich.edu**