Tropical Cyclone Forecast Skill Impact Simulations with the NASA CYGNSS Constellation

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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.
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
• 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
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

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

- 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

6 HRL storm statistics
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° inclination
  – Begin deployment of 8 Observatories at ~L+12 min
• Phase E (science operations) to begin at L+60 days
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

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