SSTDM2014, International Workshop on
Small Satellites and Sensor Technology
for Disaster Management

THE CYGNSS NANOSATELLITE CONSTELLATION HURRICANE MISSION

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CYGNSS Mission Overview

- CYGNSS is the NASA Earth Venture 2 Mission (selected in June 2012)
- Consists of 8 GPS bi-static radar receivers deployed on separate nanosatellites
- The primary science driver is rapid sampling of ocean surface winds in the inner core of tropical cyclones

CYGNSS Schedule

CYGNSS has successfully completed its Preliminary Design Review (PDR) in January 2014, and has started Phase C.

CYGNSS Science Motivation

- **Tropical cycle track forecasts have improved in accuracy by ~50% since 1990, largely as a result of improved mesoscale and synoptic modeling and data assimilation. In that same period, there has been essentially no improvement in the accuracy of intensity forecasts.**

Irene forecasts on track; not up to speed on wind

(A.P. wire service, August 29, 2011)

by Seth Borenstein & ChristineAmario:

Hurricane Irene was no mystery to forecasters. They knew where it was going. But what it would do when it got there was another matter. Predicting a storm's strength still baffles meteorologists. Every giant step in figuring out the path highlights how little progress they've made on another crucial question: How strong?

…the forecast after Irene hit the Bahamas had it staying as a Category 3 and possibly increasing to a Category 4. But it weakened and hit as a Category 1…"We're not completely sure how the interplay of various factors is causing the strength of a storm to change," [National Hurricane Center Director Bill] Read said. One theory is that a storm's strength is dependent on the storm's inner core. Irene never had a classic, fully formed eye wall even going through the Bahamas as a Category 3. "Why it did that, we don't know," Read said. "That's a gap in the science."

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CYGNSS Science Goals & Objectives

- **CYGNSS Science Goal**
  - Understand the coupling between ocean surface properties, moist atmospheric thermodynamics, radiation, and convective dynamics in the inner core of a tropical cyclone (TC)
- **CYGNSS Objectives**
  - Measure ocean surface wind speed in all precipitating conditions, including those experienced in the TC eyewall
  - Measure ocean surface wind speed in the TC inner core with sufficient frequency to resolve genesis and rapid intensification
- **Questions to be Answered by CYGNSS**
  - How do the dynamics within TCs determine their intensity at landfall?
    - CYGNSS measures surface winds in the TC inner core with a 2 hr median & 4 hr mean revisit time, enabling investigation of rapid intensification
  - How do moist atmospheric thermodynamics, radiation and convection interact to control the development of TCs?
    - CYGNSS + coincident Global Precipitation Measurement (GPM) mission rainfall measurements will constrain both boundaries of air/sea interaction

CYGNSS Team

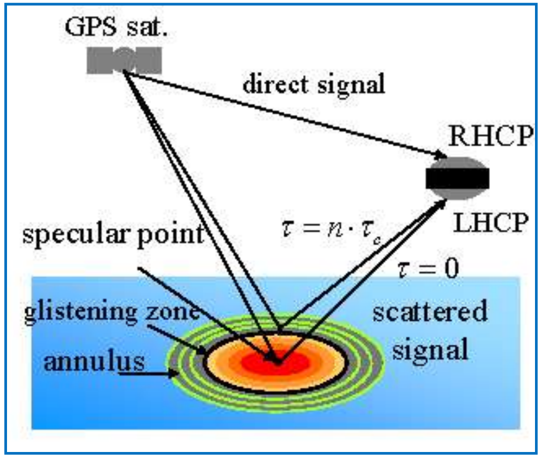
- **University of Michigan**
  - Chris Ruf (PI), Aaron Ridley (Project Scientist)
- **Science Team**
  - Bob Atlas <NOAA>, Paul Chang <NOAA>, James Garrison <Purdue>, Scott Gleason <SwRI>, Stephen Katzberg <NASA LaRC, retired>, Sharan Majumdar <U-Miami>, Derek Posselt <U-Michigan>, Donald Walter <S. Carolina State Univ>, Valery Zavorotny <NOAA>, Zorana Jelenak <NOAA>
- **Southwest Research Institute**
  - John Scherrer (PM), Randy Rose (Sys Eng)
- **Surrey Satellite Technology US**
  - Gene Hockenberry (DDMI)
- **Sierra Nevada Corporation**
  - Deployment Module

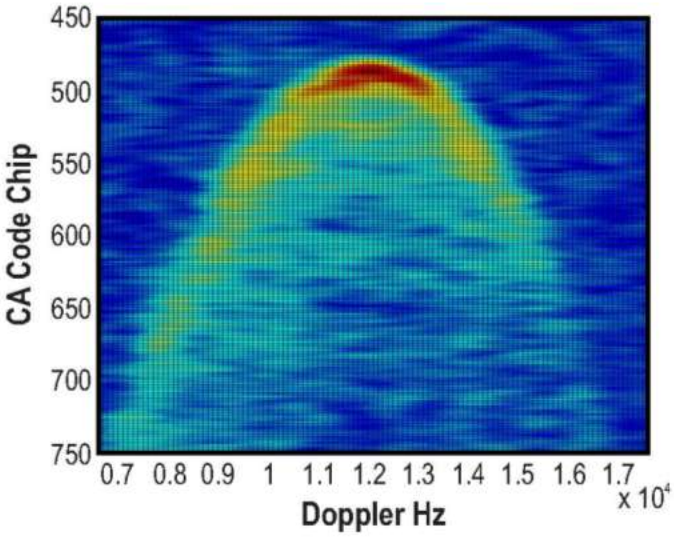
GNSS Scientific Measurements

Science Objective	Scientific Measurement Estimated Performance	
	Observable	Physical Parameter
Measure ocean surface winds under TC conditions	Precip	< 100 mm/hr (25 km footprint)
	Windspeed uncertainty	Greater of 2 m/s or 10% of windspeed
	Spatial resolution	Variable 5-50 km (ground processing)
	Windspeed dynamic range	< 70 m/s (Cat 5)
Measure ocean surface winds in TC inner core with high temporal frequency	Mean revisit time	5 hr
	Earth coverage	> 70% coverage of all historical TC storm tracks

Bi-Static Quasi-Specular Ocean Surface Scatterometry

- Bi-static scattering geometry with GPS direct signal proving reference and quasi-specular forward scattered signal containing ocean surface roughness information
- Scattering cross-section image measured by UK-DMC-1 demonstration spaceborne mission with variable lag correlation and Doppler shift enabling resolution





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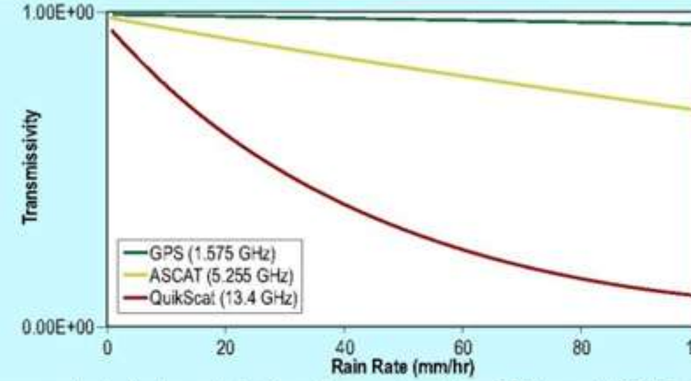
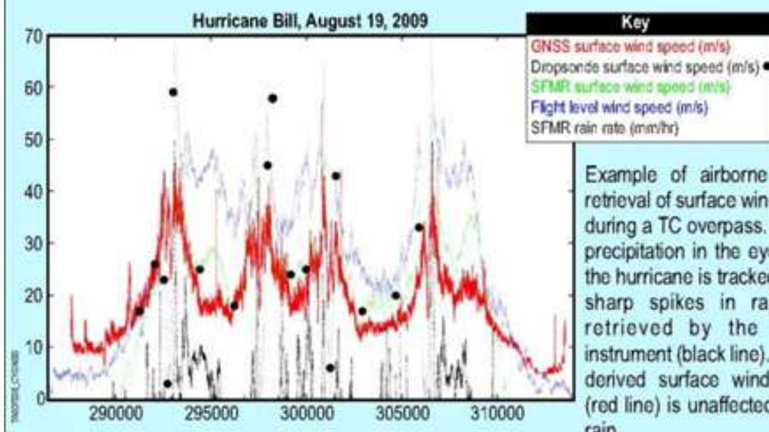
Performance in Intense Precipitation

- One-way transmissivity through typical tropical storm (5 km freezing level) for: GPS (1.575 GHz), ASCAT (5.255 GHz), QSCAT (13.4 GHz)
- Airborne GNSS wind speed retrieval during overpass of Hurricane Bill on 19 Aug 2009. Strong rain bands (black) do not noticably affect the GNSS retrieved wind (red)



The one-way slant path atmospheric attenuation experienced by a GPS (green), ASCAT (yellow) and QuikScat (red) signal propagating through a typical tropical storm (5 km freezing level) as a function of surface rain rate. Rain has a negligibly small effect on the GPS signal, even at the highest rain rates. ASCAT is attenuated enough at the highest rain rates to severely impact its ability to retrieve surface winds. QuikScat signals are effectively blocked by heavy rain and cannot sense the surface at all.



Example of airborne GNSS retrieval of surface wind speed during a TC overpass. Intense precipitation in the eyewall of the hurricane is tracked by the sharp spikes in rain rate retrieved by the SFMR instrument (black line). GNSS-derived surface wind speed (red line) is unaffected by the rain.

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CYGNSS Science Payload

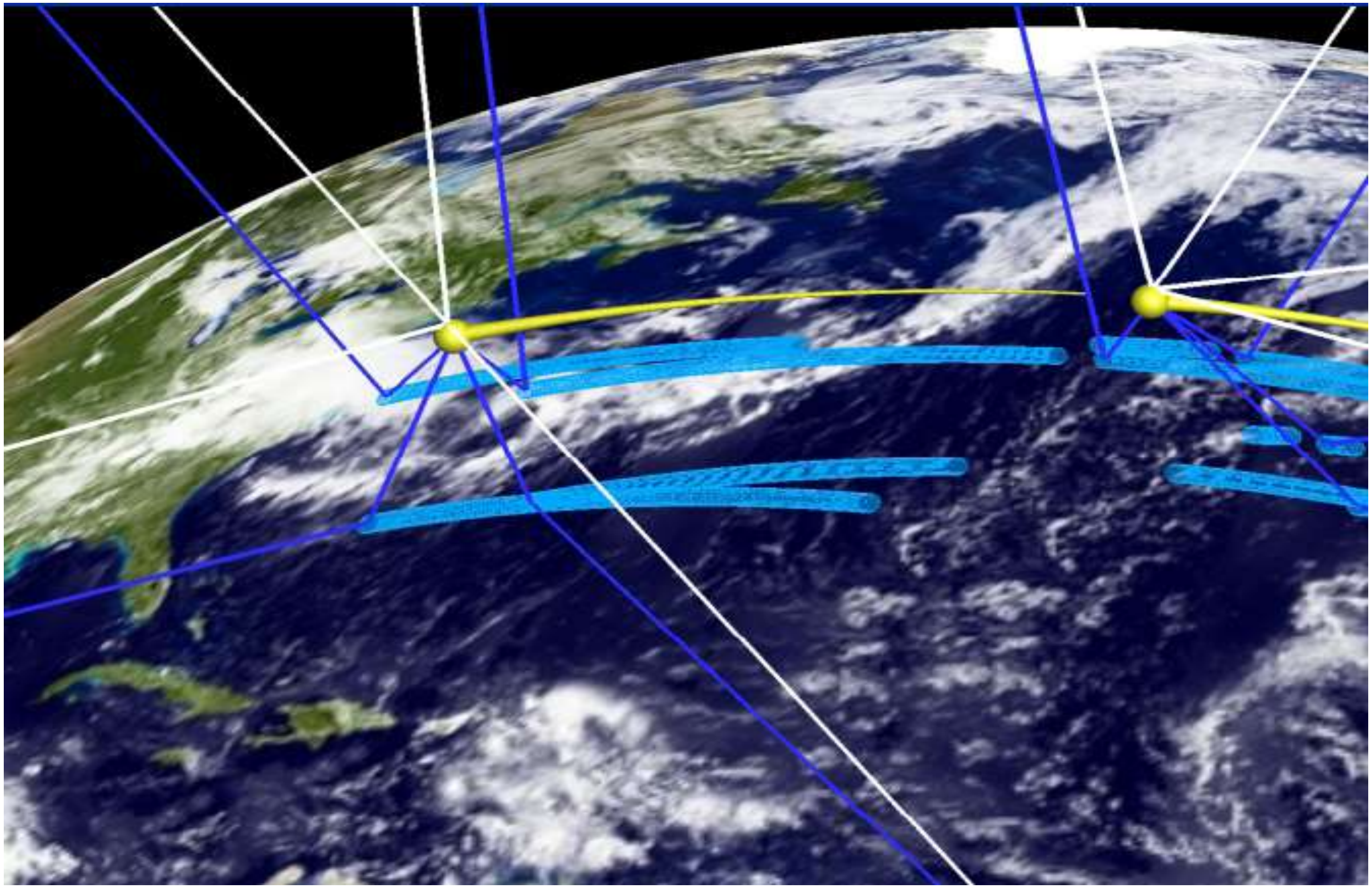
- Next generation version of the UK Surrey Delay Mapping Receiver flown on the UK-DMC-1 mission
- Simultaneously tracks and generates Delay Doppler Maps from up to 4 GPS s/c transmitters
  - 60 ns Delay res
  - 250 Hz Doppler res

Delay Mapping Receiver (DMR)

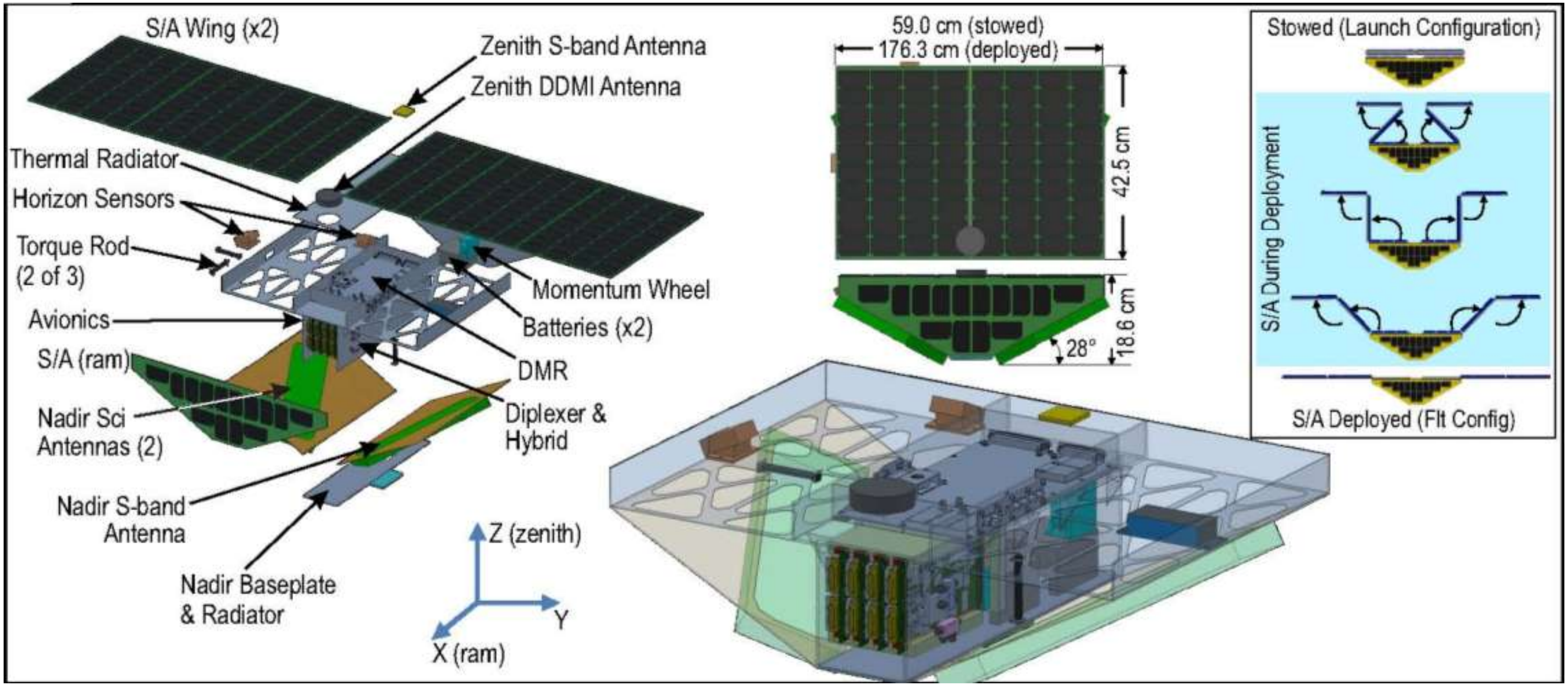
Zenith S-band Ant

Nadir Science Antennas

CYGNSS Measurement Tracks



CYGNSS Observatory



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CYGNSS Software Simulator

- **End-to-end model of all critical steps in the wind speed retrieval process:**
  - Dynamic orbit propagators for GPS and CYGNSS constellations
  - Signal generation by GPS transmitter satellites
  - Free space propagation to the specular reflection point on the Earth surface
  - Bi-static forward scattering from the wind driven, roughened ocean surface
  - Receive antenna gain pattern projected onto the Earth surface
  - Link budget for received signal strength
  - Fading and thermal noise statistics of received signal
  - Accuracy, precision and resolution of Delay Doppler Map data product
  - Wind speed retrieval algorithm

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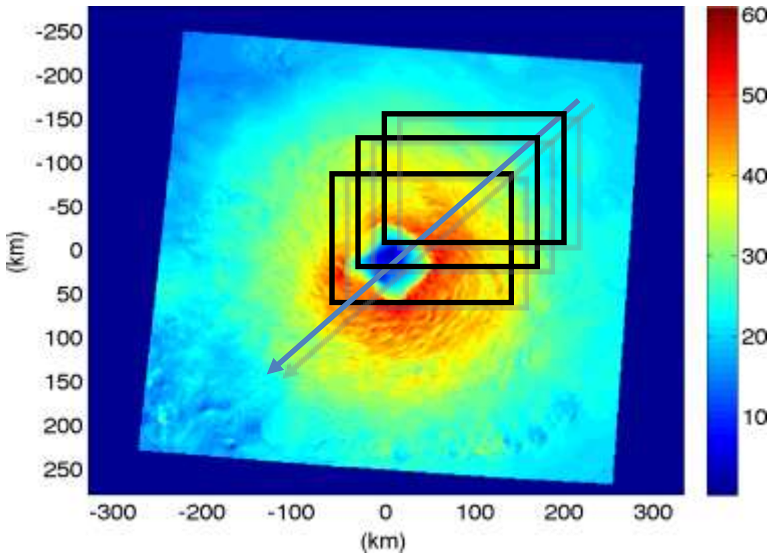
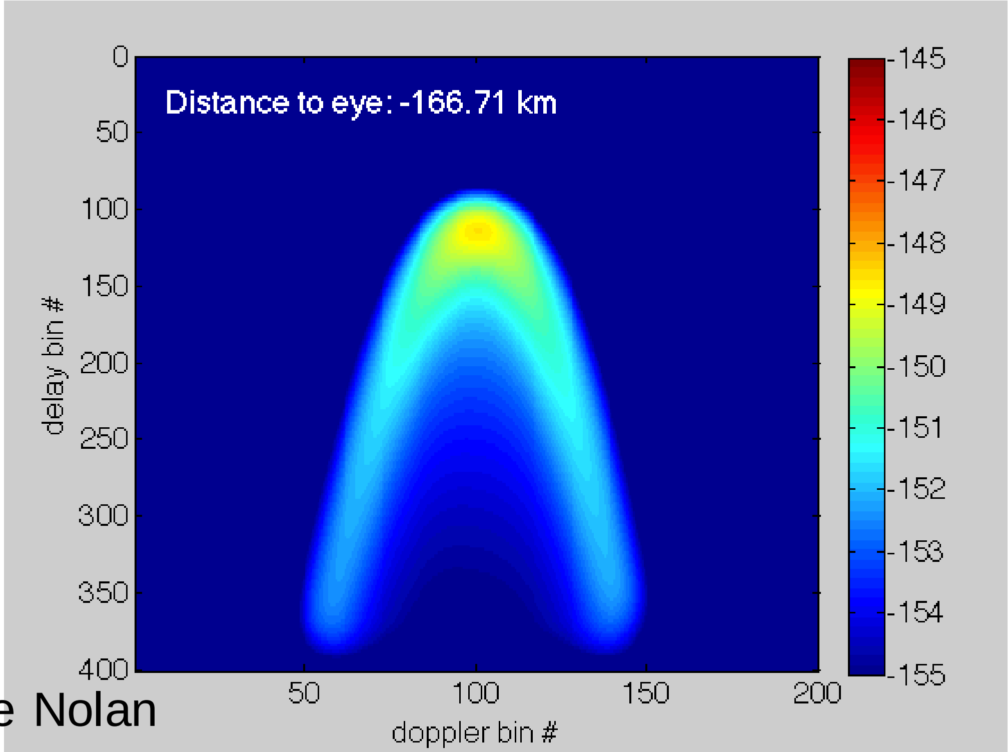
Simulation of Reflection Passing Through Hurricane Eye

- Region of the full image is selected and re-sampled (100km x 100km at 0.1km resolution)
- Wind fields converted to mss using Katzberg model and adjusted for wind direction
- DDM taken as the region crosses the eye. Note that in these simulations, TX and RX are fixed (the surface moves)



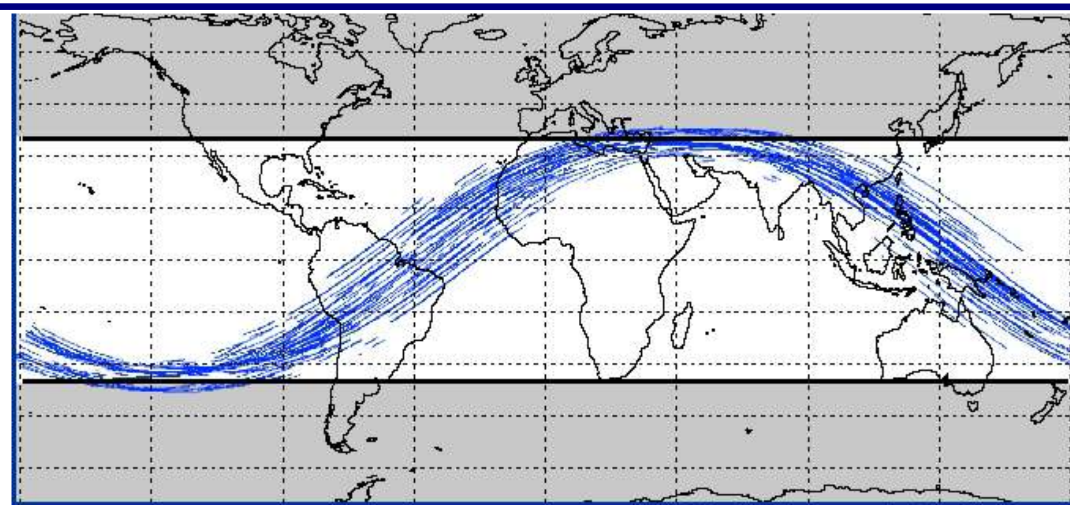


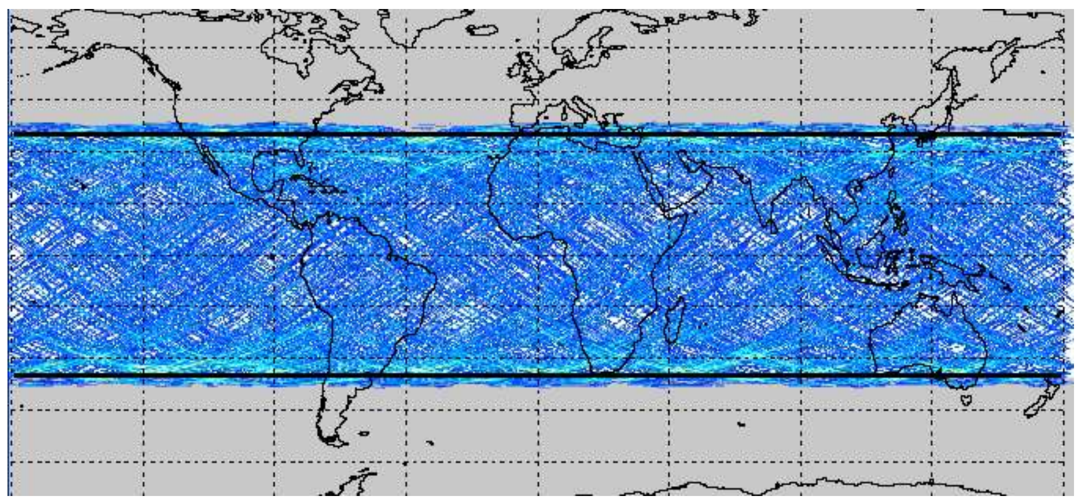
Hurricane Nature Run Provided by Dave Nolan

Simulation Performed by Andrew O'Brien and Yuchan Yu at OSU

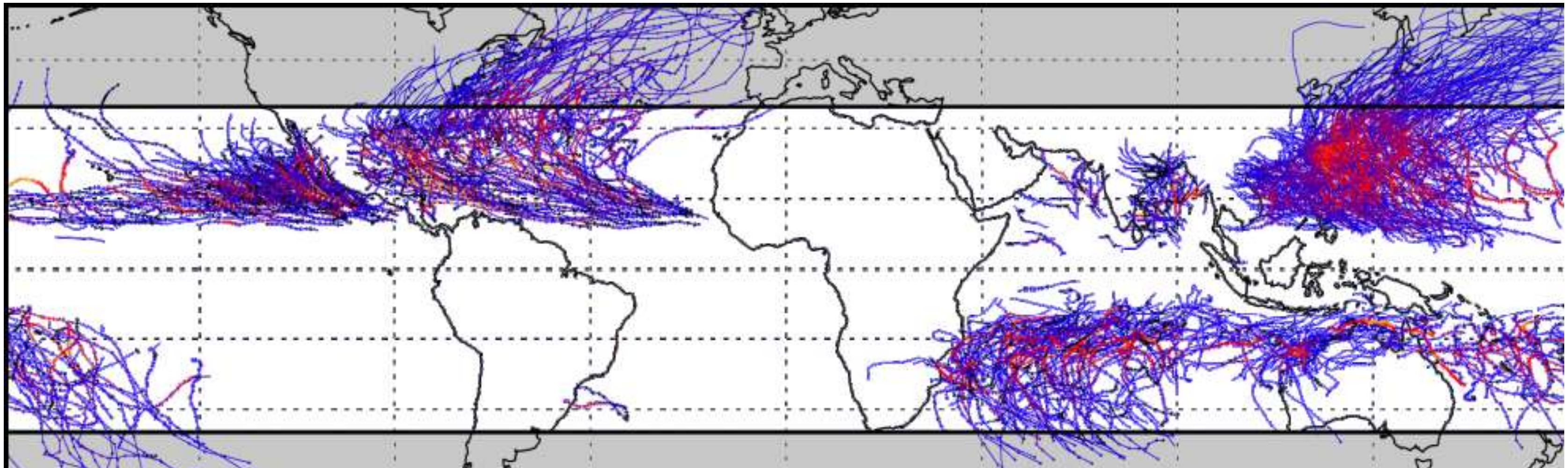
CYGNSS Earth Coverage

- 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





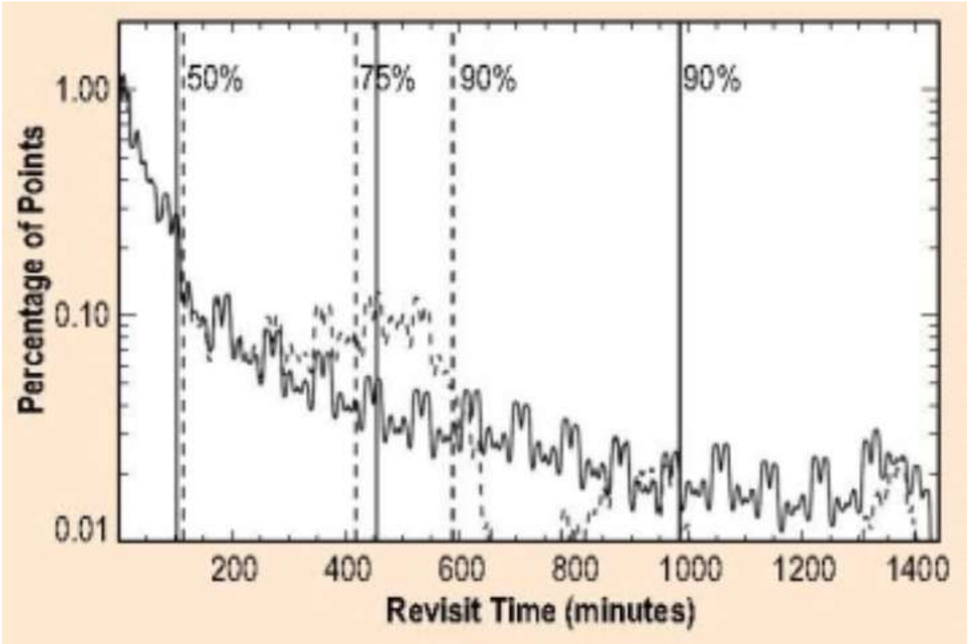
CYGNSS Historical Storm Track Overlay



CYGNSS coverage map overlaid on historical record of all named (wind speed >30 kt) storm tracks during 2000-2009. Red indicates Cat 1 or higher TC.

CYGNSS Revisit Time Statistics

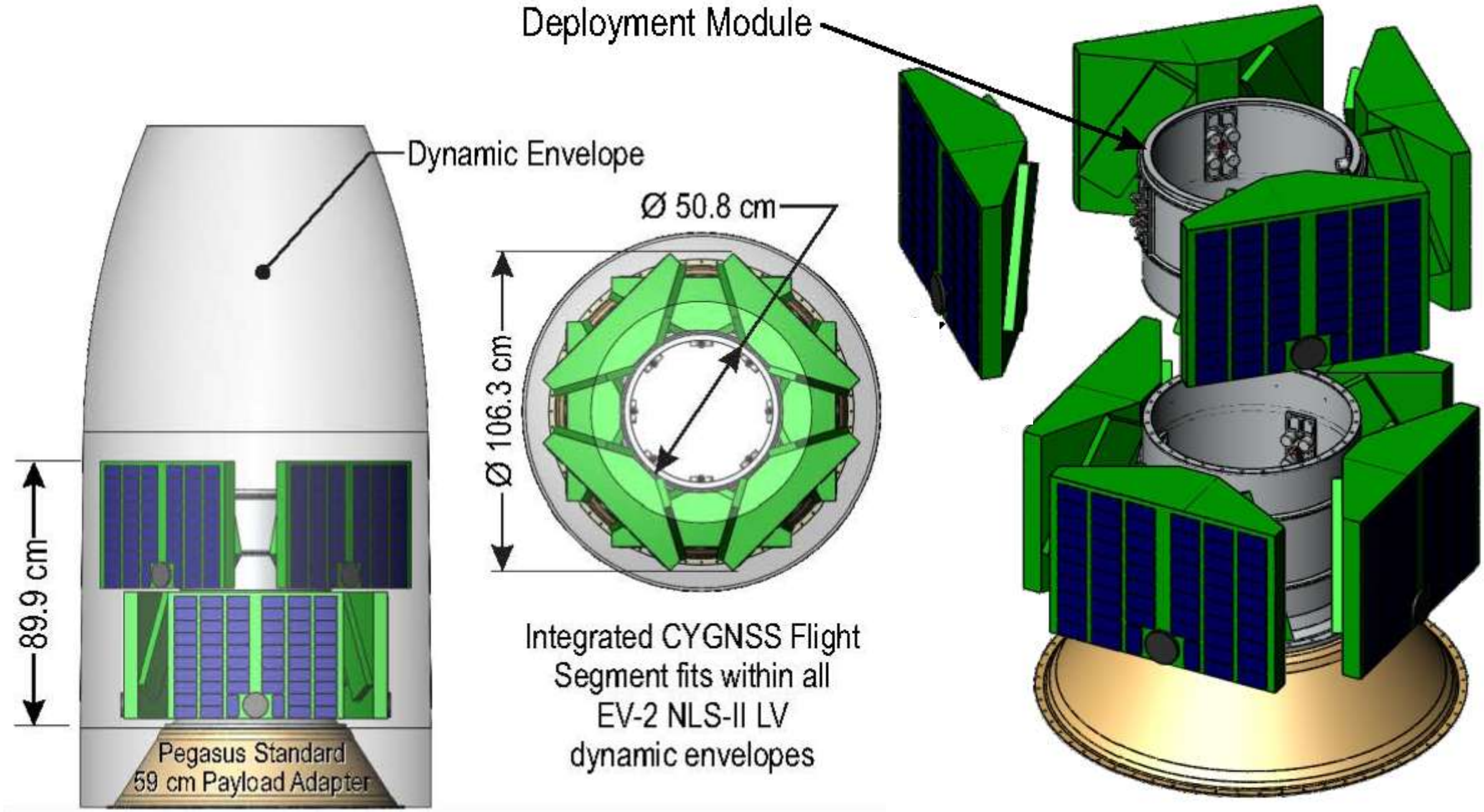
- Probability distribution of revisit time for all Earth samples within +/-35^{o} (solid) and for samples of historical storm tracks (dashed).
- Revisit stats derived from PDF demonstrate 4 hr mean storm revisit and ~9 hr to revisit 90% of all storms



Revisit Statistics	Median	Mean	90% Cumulative
All Samples	1.6 hr	4.8 hr	14.4 hr
Storms Only	1.5 hr	4.0 hr	9.3 hr

Complete Flight Segment with Deployment Module

vid-1
vid-2



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The End

Play CYGNSS Hurricane End-to-End Simulation Video!