GNSS+R 2019 Benevento, ITALY
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NASA CYGNSS Science Data Characterization and Applications

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1. University of Michigan, 2. Jet Propulsion Laboratory,
3. University Corporation for Atmospheric Research,
4. University of Utah, 5. University of Miami

Mission Overview

- Science Objectives
  - Measure ocean surface wind speed in all precipitating conditions, including those experienced in the TC eyewall, and with sufficient frequency to resolve genesis and rapid intensification
- Use GNSS-R measurement technique
  - Low power payload permits use of small satellites so many can be flown to improve sampling
  - The 8 s/c constellation is in a ~527 km altitude at 35^{o} inclination to concentrate measurements on tropical latitudes

Project Team Roles

- University of Michigan
  - Programmatic: Principal Investigator, Financial, Science Team management
  - Engineering: Flight torque rods, constellation deployment & orbit planning
  - Science Operations Center: Science data products, NASA DAAC interface, Support Science Team algorithm development
- Southwest Research Institute
  - Programmatic: Project Manager, Systems Engineer
  - Satellite: Bus design, Power, Comm, Flight software, Integration & Test
  - Mission Operations Center: Early on-orbit ops, Phase E ops, USN/SSC (ground station) interface
- Surrey Satellite Technology Ltd. – Science payload (GNSS-R receiver)
- Sierra Nevada Corp. – Deployment module, Solar arrays
- Draper Labs – ADCS control algorithm
- Science Team – UCAR, Ohio State U., U. Miami, Purdue U., U. Utah, NASA, NOAA

Mission Timeline

- 18 Jun 2012 CYGNSS Earth Venture Mission Selected
- 19 Jun 2013 System Requirements Review (Phase A)
- 22 Jan 2014 Preliminary Design Review (Phase B)
- 13 Jan 2015 Critical Design Review (Phase C)
- 30 Jun 2015 System Integration Review (Phase D)
- 15 Dec 2016 LAUNCH
- 23 Mar 2017 Post Launch Assessment Review (Phase E)
- 19 Mar 2019 End of Prime Mission Review (Phase E+)
- Senior Review scheduled in Fall 2020

Constellation Status (as of 2019-05-10)

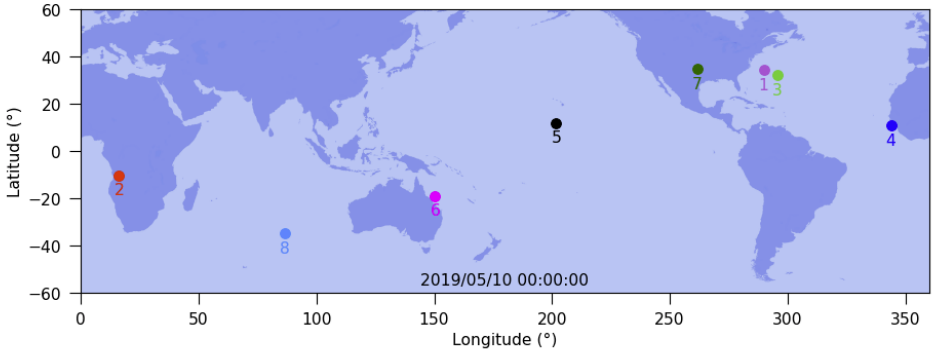


Figure 1: Snapshot of CYGNSS positions.

2019/05/10 00:00:00						
Observatory	Perigee (km)	Apogee (km)	Trailing/Leading Time (min)	Distance (km)	Trailing/Leading Separation (°)	Phase rate difference (°/day)
FM01	508.3	539.1	2.5/92.5	1155.4	10/350	2.45
FM02	519.7	534.3	72.3/22.7	10388.7	274/86	0.029
FM03	508.4	536.3	0.0/95.0	0.0	0/360	0
FM04	514.1	539.9	82.1/12.9	5887.5	311/49	0.032
FM05	508.7	548.2	24.0/71.0	10983.0	91/269	1.84
FM06	513.0	538.6	38.7/56.3	17651.6	146/214	0.013
FM07	507.6	535.2	7.4/87.6	3378.6	28/332	0.000
FM08	510.9	533.7	54.5/40.5	18477.9	207/153	1.03

Table 1: Current orbit parameters.

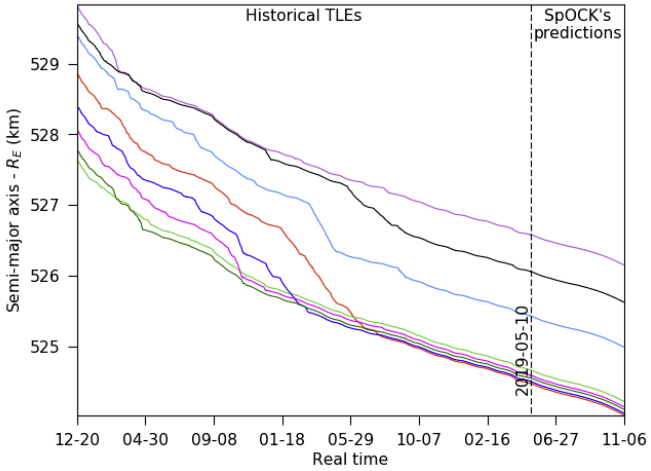
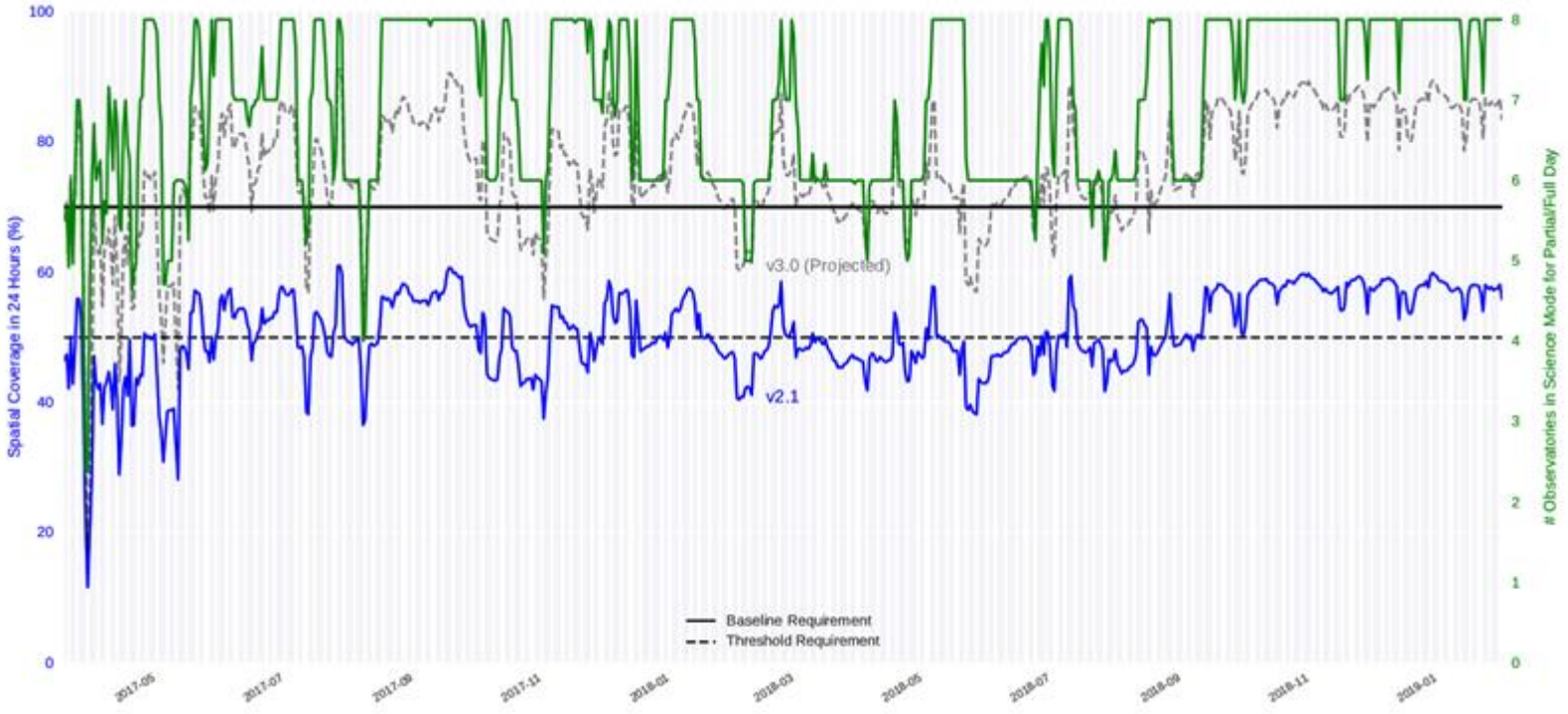


Figure 2: CYGNSS orbit decay - historical and predictions assuming the satellites are nadir pointing.

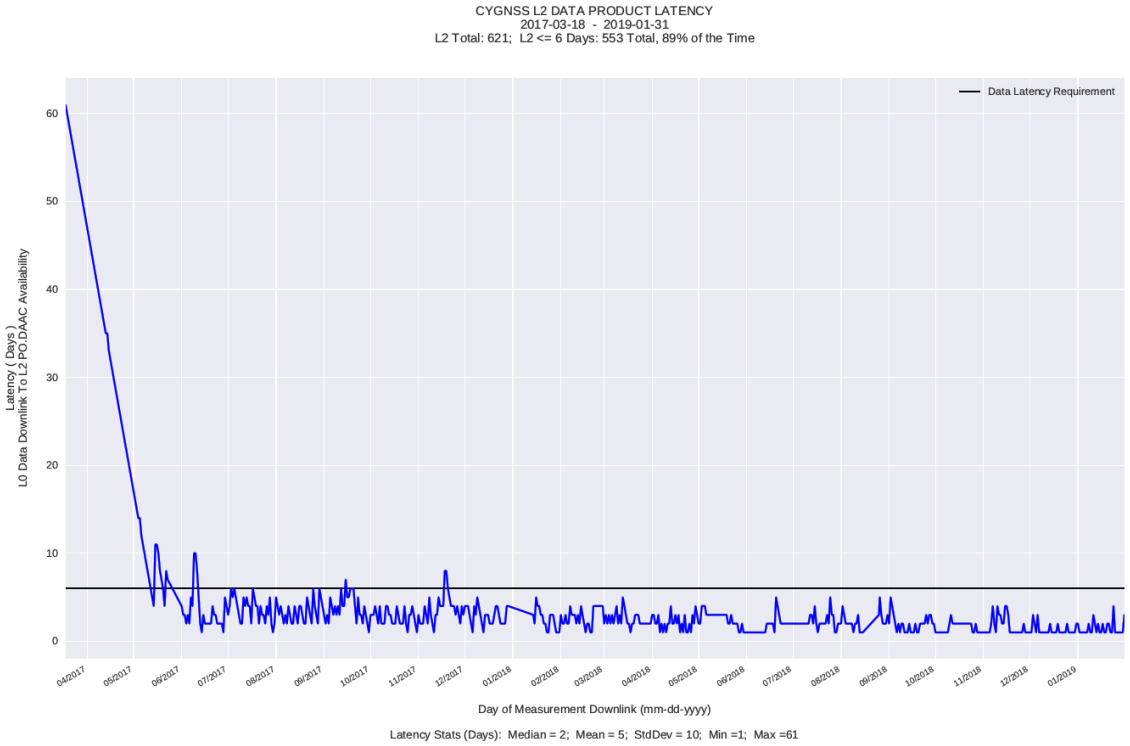
Science Data Coverage

- % of Earth between +/- 35º latitude with at least one sample in a ¼ºx¼º grid within 24 hr



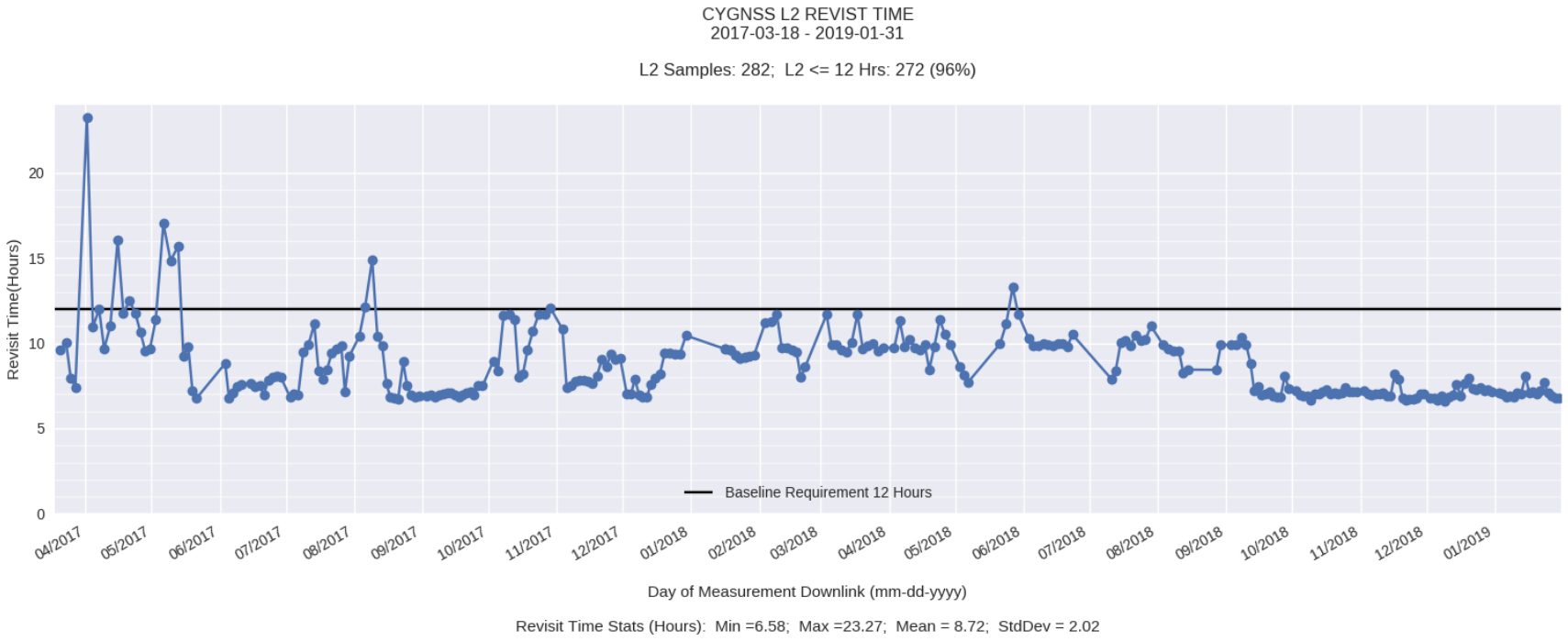
Science Data Latency

- Time between acquisition and L1, L2,L3 posted to PO.DAAC



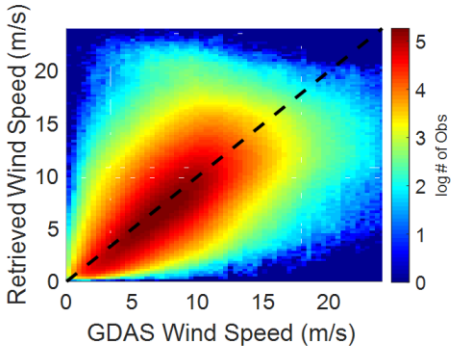
Science Data Revisit Time

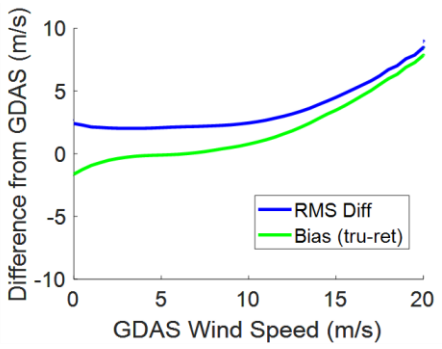
- Average time between pairs of samples in the same ¼ºx¼º grid over +/- 35º latitude



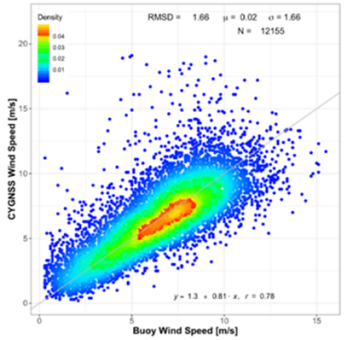
Wind Speed Retrieval Uncertainty Below 20 m/s

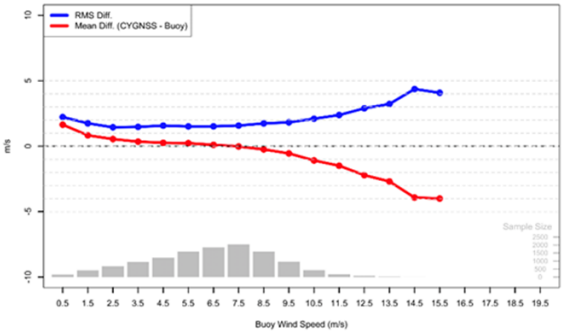
- Jun 2017 – Oct 2018 Matchups with GDAS (68E+6 samples)
  - 2.31 m/s RMS difference between CYGNSS and GDAS
  - 1.67 m/s RMS uncertainty in CYGNSS winds





- Mar 2017 – Aug 2018 Matchups with 76 tropical moored buoys (12,164 samples)
  - 1.7 m/s RMS difference between CYGNSS and buoys

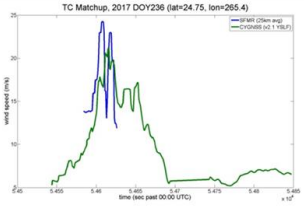




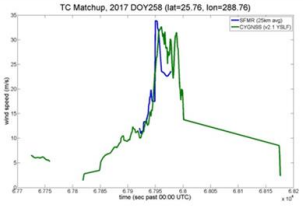
Wind Speed Retrieval Uncertainty Above 20 m/s

- 2017 Atlantic hurricane comparisons with coincident measurements by SFMR on NOAA P-3 hurricane hunters
  - 20 coincident TC overpasses: Harvey DOY 236(4), 237; Irma DOY 248; Jose DOY 258(2), 259, 264(4); Maria DOY 266(2), 267(4), 270
  - Matchup criteria: <30 min & 12.5 km separation between CYGNSS and SFMR obs
- Max wind speed measured by SFMR is 53.6 m/s (119.9 mph, Cat 3)
- Windspeed RMS Uncertainty
  - 3.2 m/s (11.3% of 28.8 m/s mean)

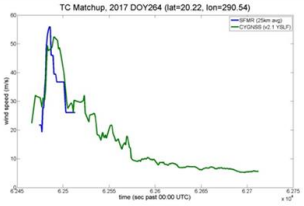
- **GREEN**: CYGNSS v2.1 YSLF wind speed before/during/after overpass
- **BLUE**: Coincident wind speed by SFMR on NOAA P-3 hurricane hunter



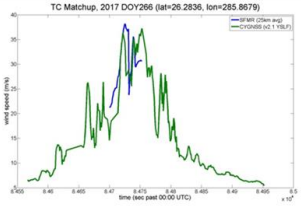
Harvey



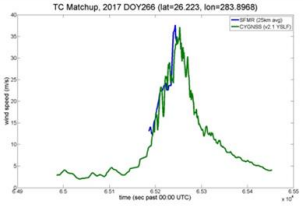
Jose, pass 1



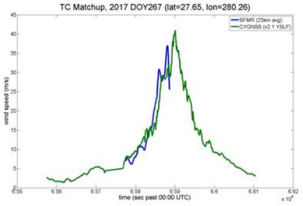
Jose, pass 2



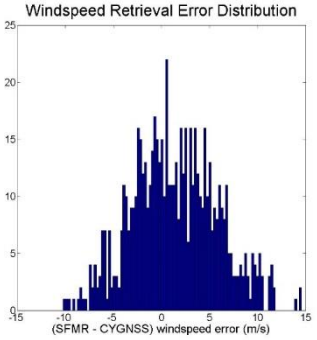
Maria, pass 1



Maria, pass 2



Maria, pass 3

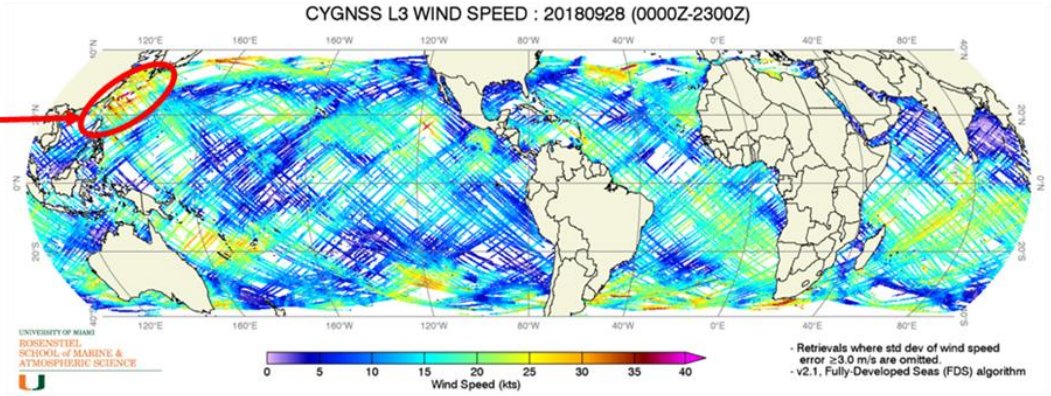


Mission Science Requirements

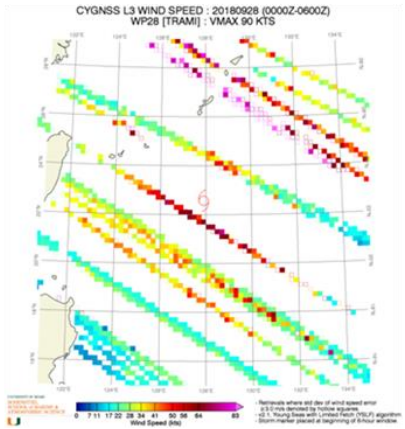
CYGNSS Level 1 Mission Science Performance			
#	Requirement	CBE	Performance
1	Wind speed dynamic range at 5 km x 5 km resolution	1-54 m/s	Exceeds 40 m/s threshold
2	Operation in presence of rain	Yes	Meets baseline
3a	Retrieval uncertainty for winds > 20 m/s	11.3%	10% requirement
3b	Retrieval uncertainty for winds < 20 m/s	1.7 m/s	Exceeds 2 m/s baseline
3c	Spatial Resolution	25.4 km	Exceeds 50 km threshold
4a	100% duty cycle during science operations	Yes	Meets baseline
4b	Mean temporal resolution	9.1 hr	Exceeds 12 hr baseline
4c	Spatial sampling coverage of cyclone historical tracks in 24 hours	50-74%	Exceeds 50% threshold
5	Calibrate and validate CYGNSS data in individual wind speed bins above and below 20 m/s	Yes	Meets baseline

Temporal Sampling Example
Overpasses of Typhoon Trami on 28 Sep 2018

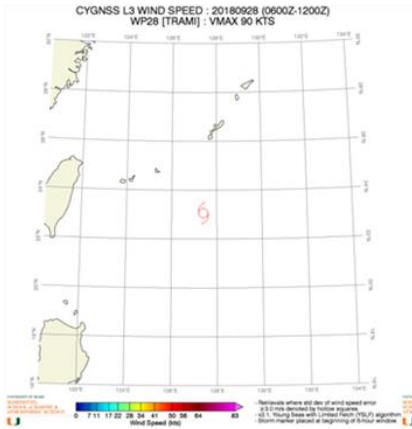
- (top) 24 hr global wind speed composite with TC Trami circled in red
- (bot) 4x6 hr 14x14deg wind speed composites centered on Tami best track storm center



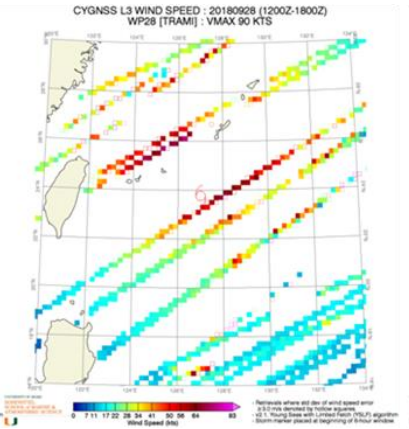
0000–0600 Z



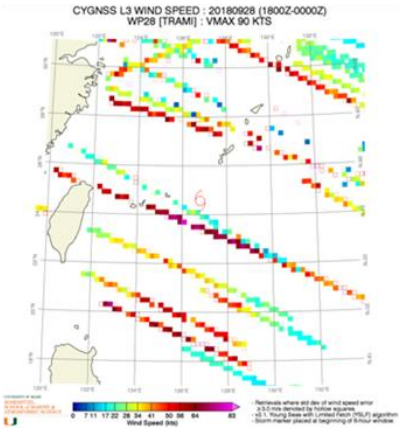
0600–1200 Z



1200–1800 Z

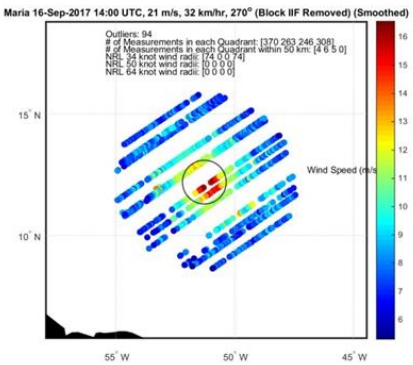


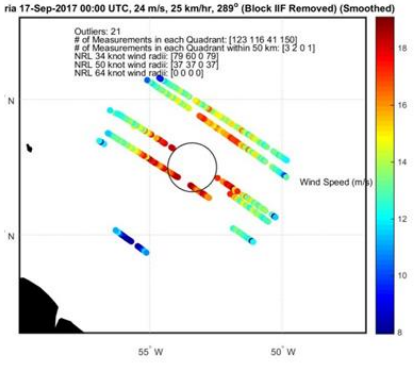
1800–2400 Z

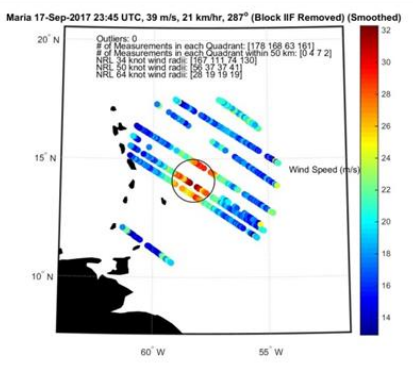


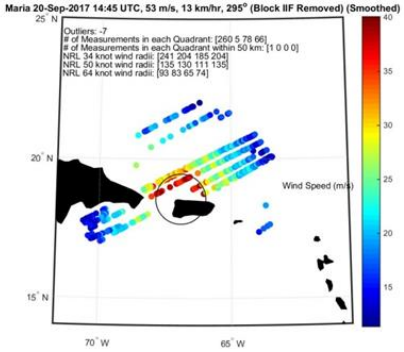
TC Overpass Examples

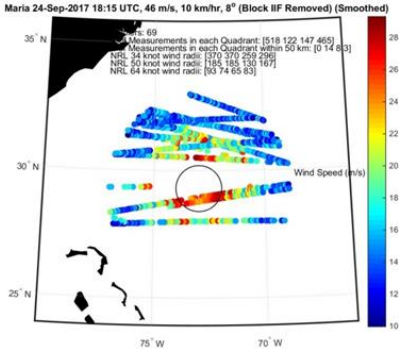
- Hurricane Maria overpasses centered on: 16 Sep @ 14:00, 17 Sep @ 00:00, 17 Sep @ 23:45, 20 Sep @ 14:45, 24 Sep @ 18:15, 25 Sep @ 18:30 UTC
- National Hurricane Center best track storm center in middle of black circle

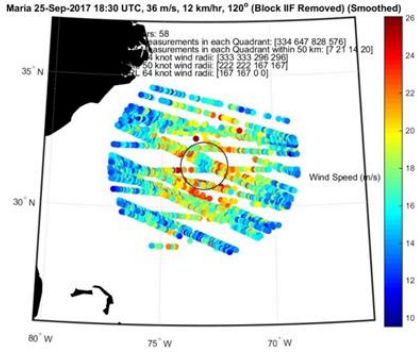






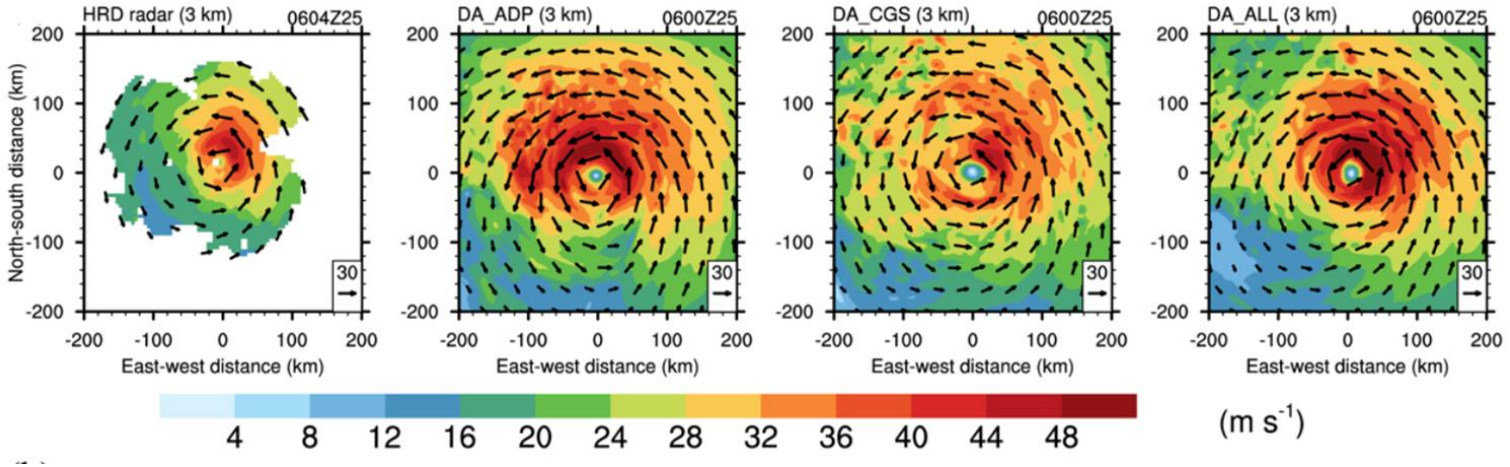






Data Assimilation Example
(Z. Pu, U-Utah)

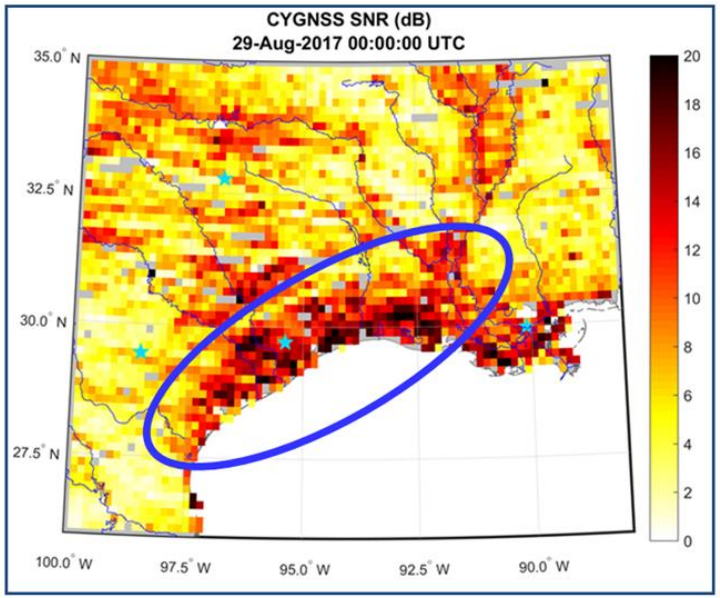
- Assimilate CYGNSS v2.1 wind speeds into HWRF for Hurricane Irma
  - Use Grid-point Statistical Interp. (GSI) hybrid ensemble 3-D variational DA
  - Three cases considered:
    - 1) ADP, assimilate routine NCEP operational obs (control)
    - 2) CGS, assimilate only CYGNSS obs
    - 3) ALL, assimilate both CYGNSS and NCEP operational obs
- Winds at 3 km altitude, measured by airborne doppler radar and predicted by HWRF
- Prediction of observed peak winds in NE quadrant improved with CYGNSS obs

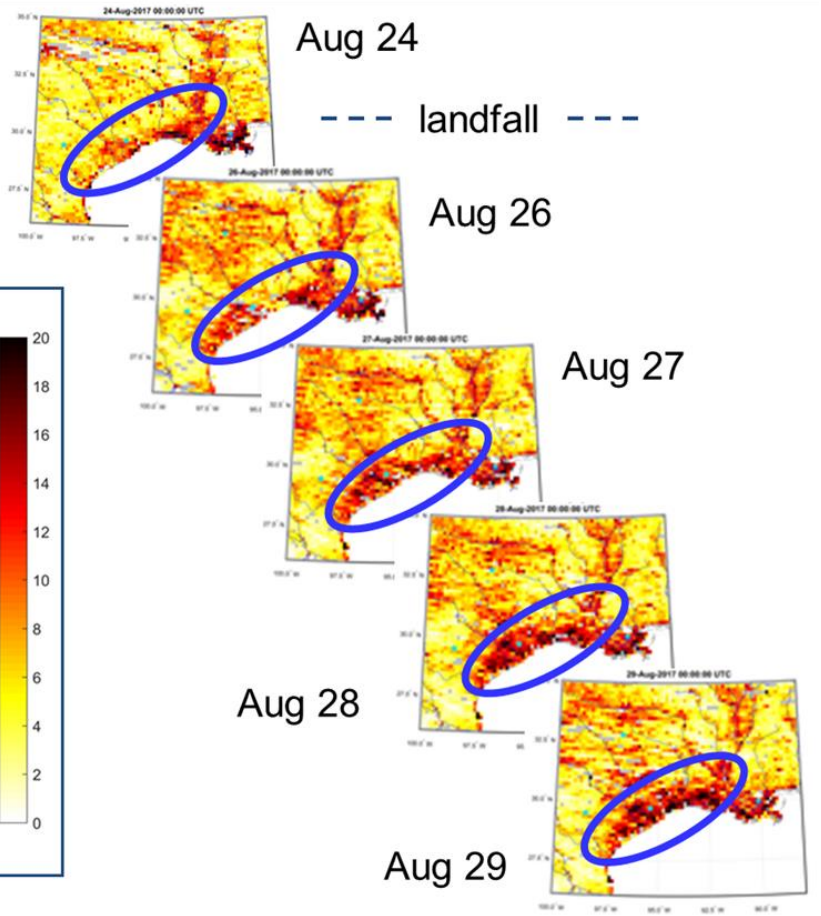


CYGNSS SNR Images of Southeast Texas

Before & After Hurricane Harvey Landfall on Aug 25, 2017

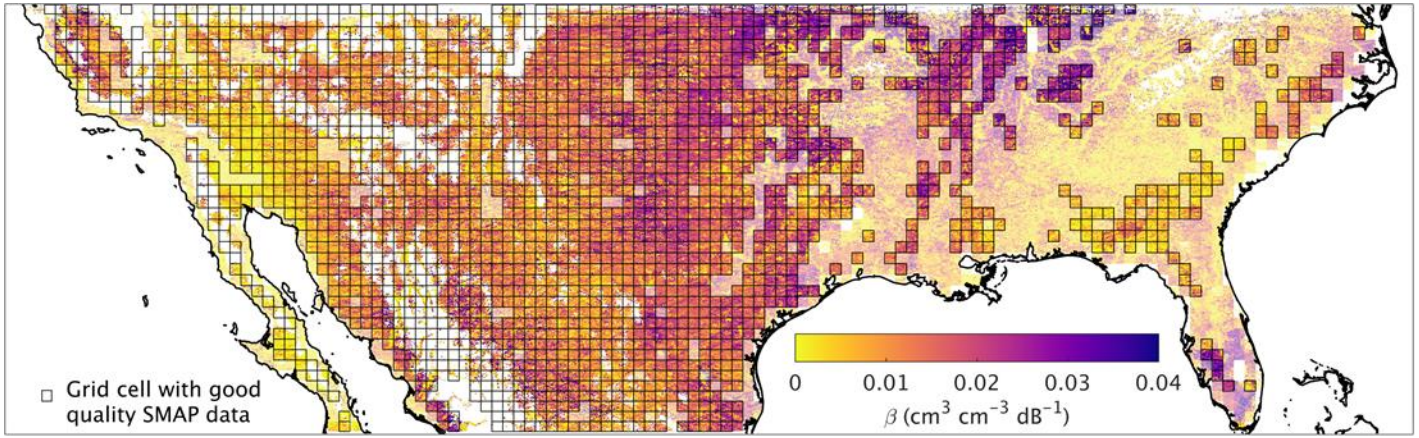
- (right) Time lapse SNR images in Houston metro region
  - Large increases in SNR indicate flooding inundation
- (below) Aug 29 SNR image with coastal flooding circled

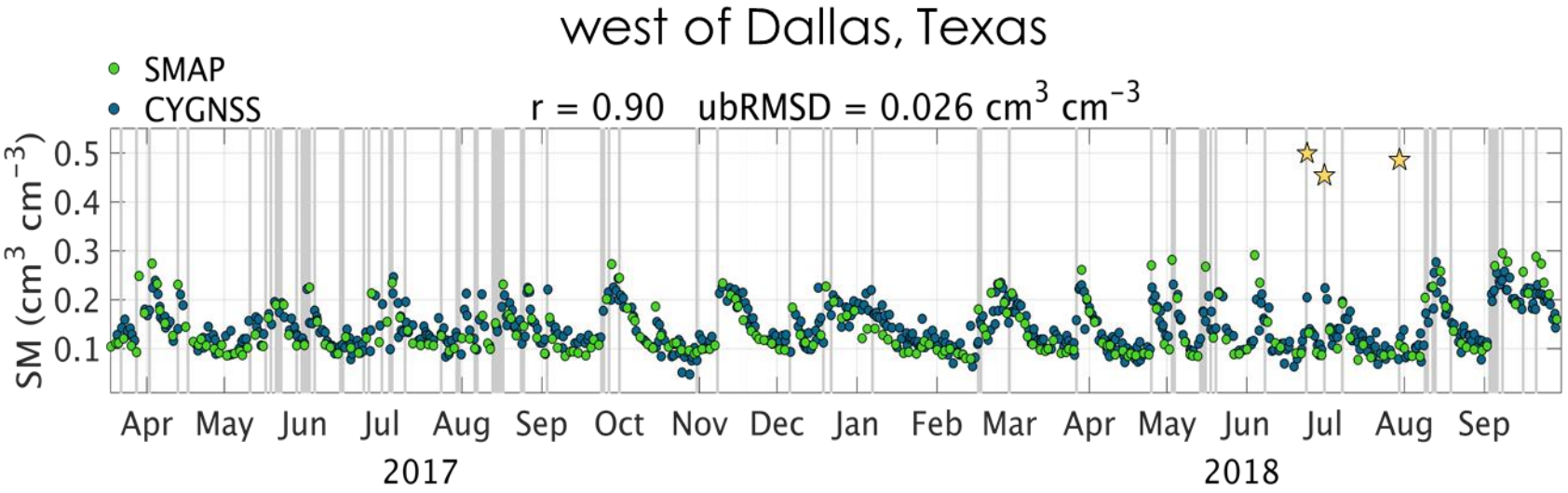




(courtesy Mary Morris, NASA/JPL)

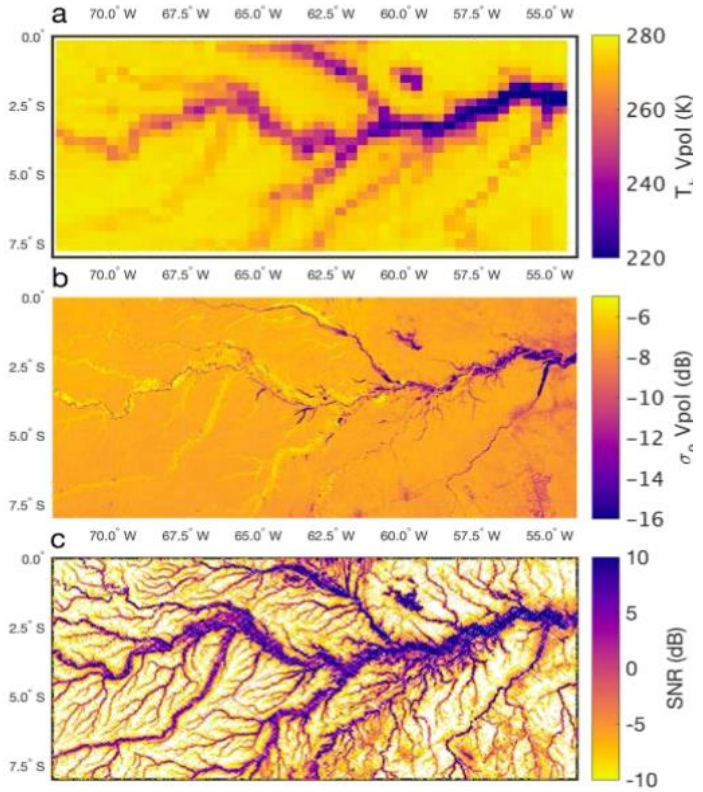
CYGNSS-Derived Soil Moisture Time Series (C. Chew, UCAR)





Spatial Resolution Over Land

- High res land imaging from coherent forward scatter
  - First Fresnel zone for CYGNSS is ~500 m
- Images of the same section of the Amazon River by:
  a) SMAP passive microwave
  ~30 km res
  b) SMAP active radar
  ~3 km res
  c) CYGNSS GNSS-R
  <500 m res)



CYGNSS Extended Mission Science Summary

- **Tropical and Extratropical Cyclones**
  - Forecast skill improvement, TC characterization, Estimates of surface heat fluxes, Ocean surface waves and current
- **Oceanography**
  - Coastal Wind and Waves Retrievals, Storm Surge Modeling, Sub-daily to Sub-seasonal Variability, Level 4 Wind Products, GNSS-R Altimetry
- **Terrestrial**
  - Modeling land reflections, Retrieval and validation of soil moisture, Mapping wetlands and inundation, Snow retrieval over land

Follow On Mission?

- NASA Designated Observables (DO) Missions
  - Science objectives, flow down to L2 data products
  - Mission architecture studies define orbiting platforms and L1 measurements by payloads
- Aerosol/Clouds Convection & Precipitation mission
  - Core satellite + Smallsat constellation
- CYGNSS demonstrated high rel/high qual science with smallsats and with a GNSS-R payload
- DO-ACCP has the potential to mainstream GNSS-R