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Cyclone Global Navigation Satellite System (CYGNSS) – Mission Status and Results

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SPACE PHYSICS RESEARCH LABORATORY

CYGNSS Mission Overview

- Eight satellites in low earth orbit at 35^o inclination, each carrying a 4-channel bistatic radar receiver for surface reflections of GPS L1 signals
- Mission Objectives
  - ORIGINAL: Measure ocean surface wind speed
  - EXPANDED: Land observations of soil moisture and inland waterbodies
- Launch: 15 Dec 2016
- Initial Phase E: Mar 2017 – Feb 2019
- Extended Phase E confirmed through Sep 2023
  - Expect to continue Phase E mission extensions as long as at least one spacecraft is producing useful science data

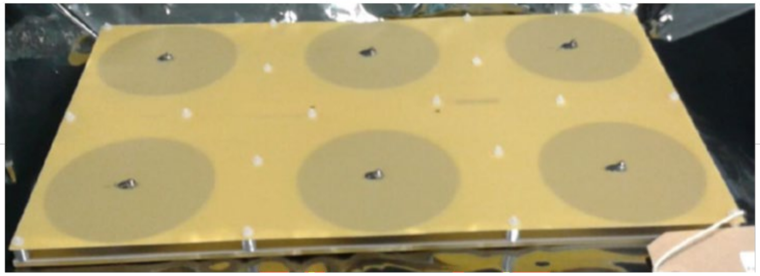
CYGNSS GNSS-R Payload

- Provided by Surrey Satellite Technology Ltd.
- Receiver is their SGR-ReSI
  - Almost identical to receiver on TDS-1
  - On-board Delay Doppler Maps from up to 4 GPS transmitters using L1 C/A signal
- Pair of nadir science antennas pointed cross-track in port and starboard directions

Delay Mapping Receiver (DMR)

Zenith S-band Ant

Nadir Science Antennas



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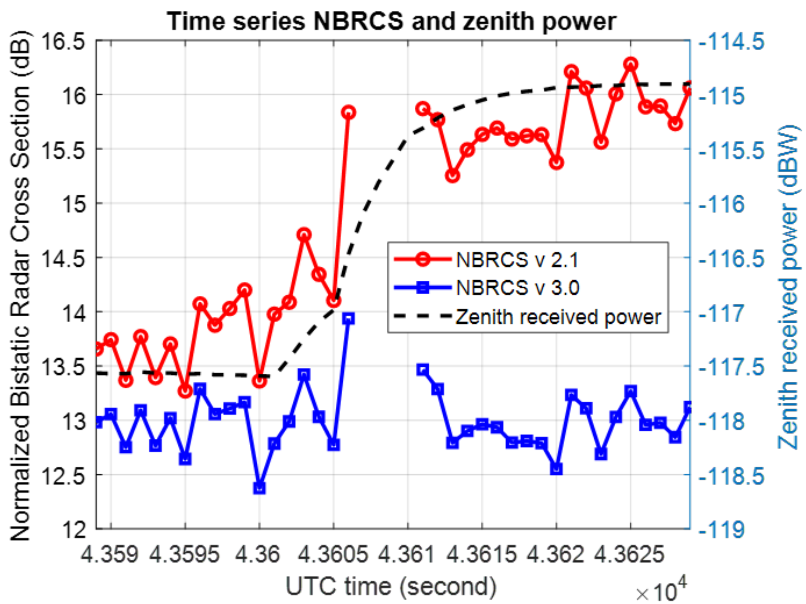
5 of 8 Observatories in Integration and Test

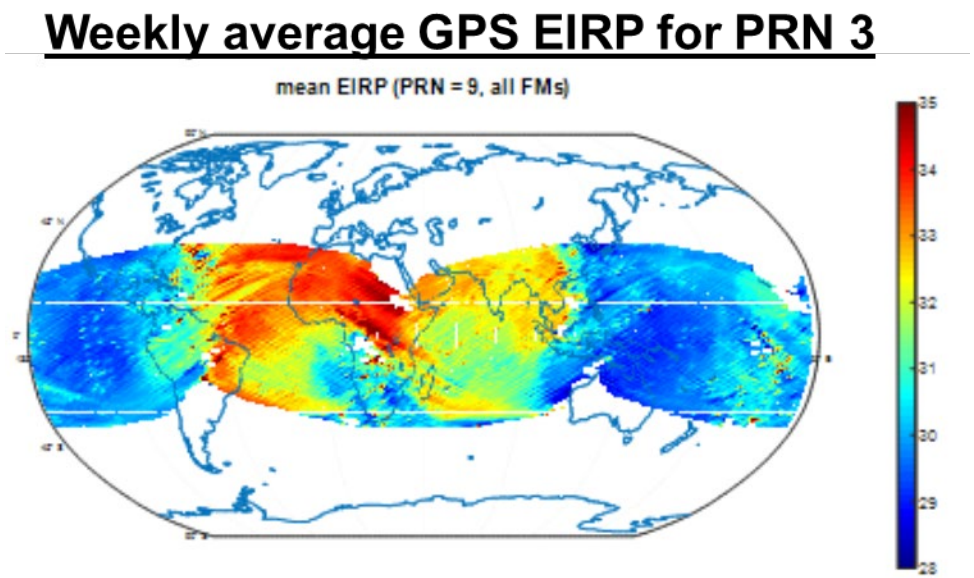
Post-Launch Engineering Change

- Reprogram flight navigation receivers to measure direct GPS signal strength received by zenith navigation antenna (Aug 2018)
- Revise calibration approach to account for GPS transmit power changes
- Release new science data products with dynamic real time GPS EIRP correction (Sep 2020)

Real Time GPS EIRP Correction

- **Derived scattering cross section of ocean surface with ~uniform wind speed during GPS "flex power" event**
  - Dashed line: direct signal received power
  - Red: NBRCS calibrated assuming constant GPS transmit power
  - Blue: NBRCS with dynamic GPS EIRP correction is ~uniform



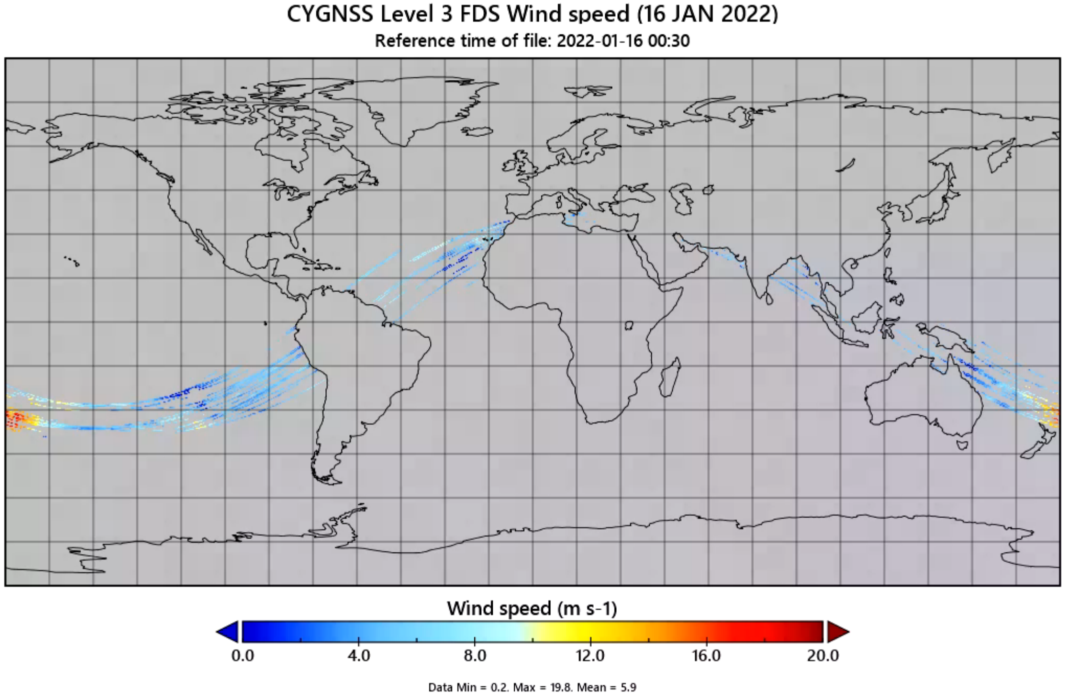


CYGNSS Released Data Products

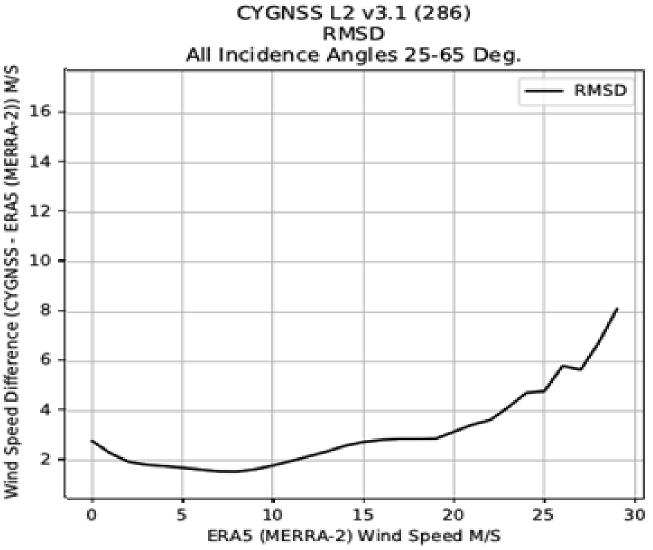
- Level 1 Engineering Data Products
  - Scattering Cross Section of the ocean and land for incoherent scattering from rough surfaces
  - Reflectivity of land for coherent scattering from smooth surfaces
- Level 2 Science Data Products
  - Ocean surface roughness (mean square slope)
  - Ocean surface wind speed (10 m ref height)
  - Ocean surface heat flux (latent and sensible)
- Level 3 Science Data Products
  - Hourly gridded (in lat/lon) versions of L2 products
  - 6-hourly and daily soil moisture
  - 6-hourly tropical cyclone overpasses in storm-centric coords

CYGNSS Global Wind Speed Product

Typical 24 hours of v3.1 L3 FDS Winds



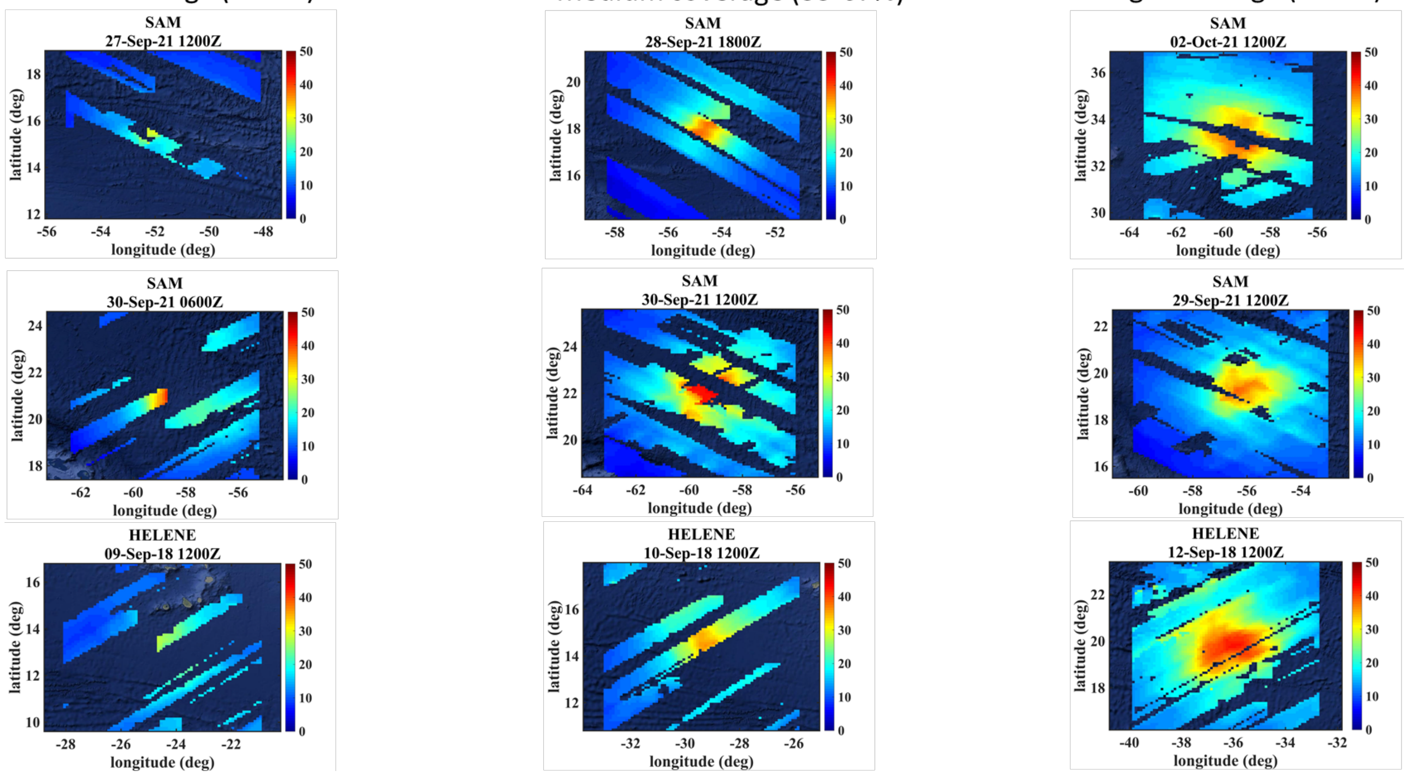
RMS Difference between CYGNSS L2 FDS and ERA5 Winds



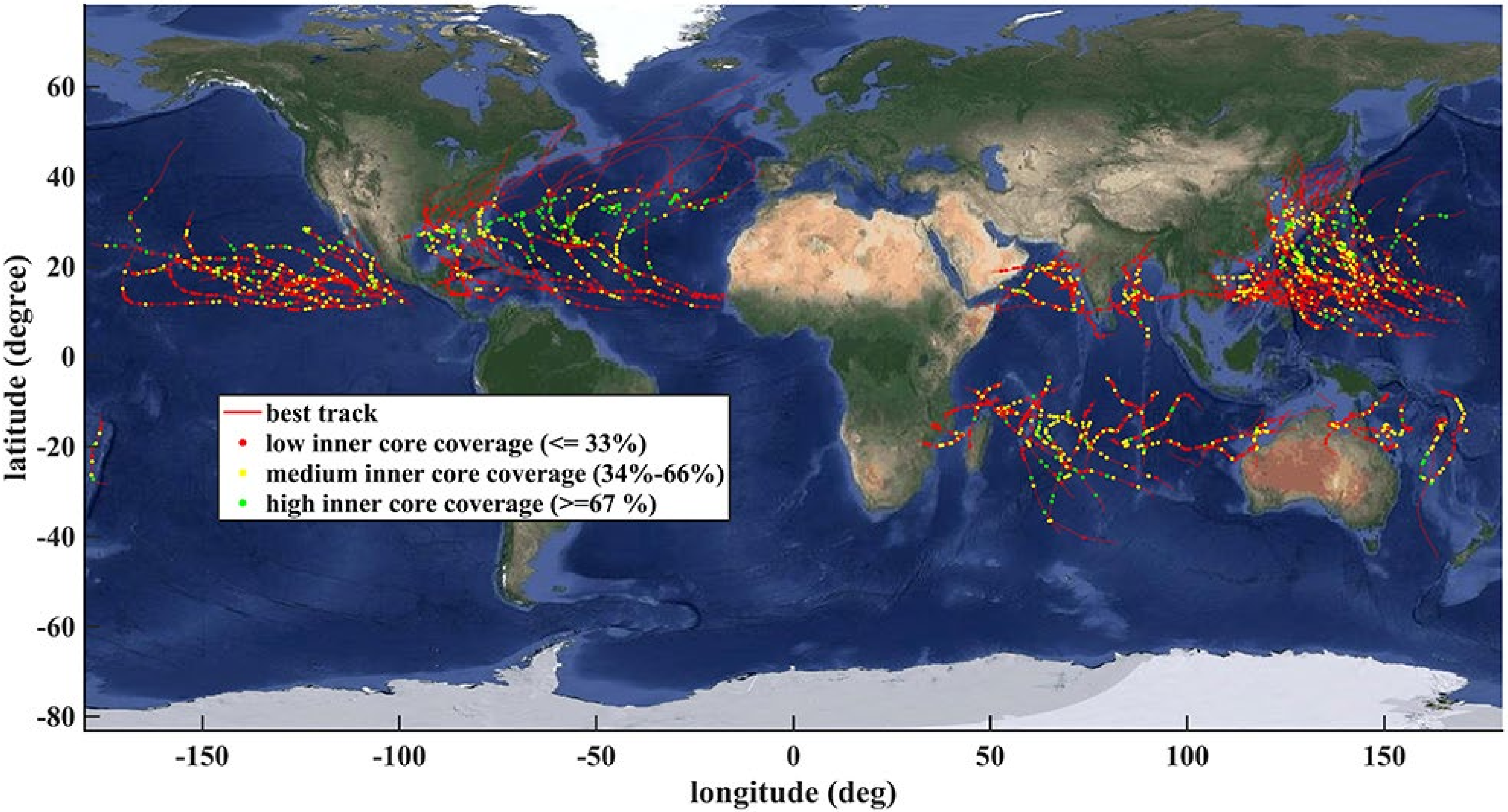
CYGNSS L3 Storm-Centric Gridded Wind Speed Product

- Wind fields that have <33%, 33-67% and >67% coverage of inner core (within R34)

Low coverage (< 33%) | Medium coverage (33-67%) | High coverage (>67%)



CYGNSS Overpasses of all Cat 3+ Storms During 2018-2020

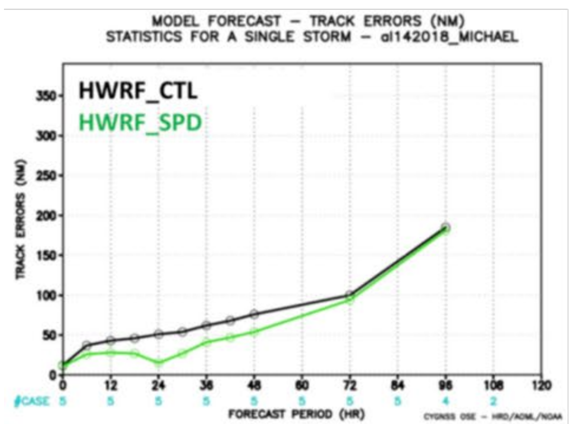


Hurricane Prediction Skill Impact

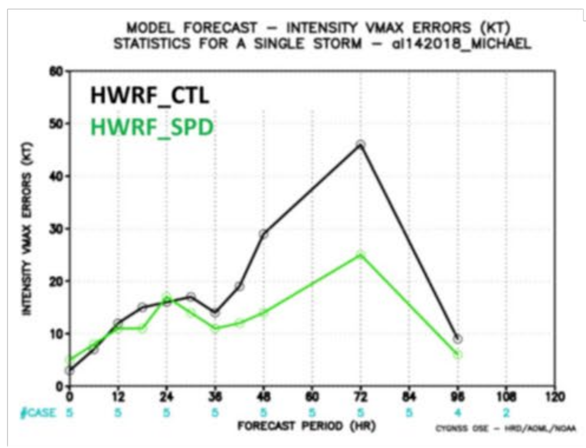
(NOAA HRD, Univ. of Miami, AER)

- Observing system experiment (OSE) to assess the impact of CYGNSS wind products on TC track, Vmax, and minimum sea level pressure (MSLP) forecasts
- Examine impact of adding CYGNSS winds on forecast skill relative to control (no CYGNSS) forecast
- Case study is developmental phase of Hurricane Michael (2018)

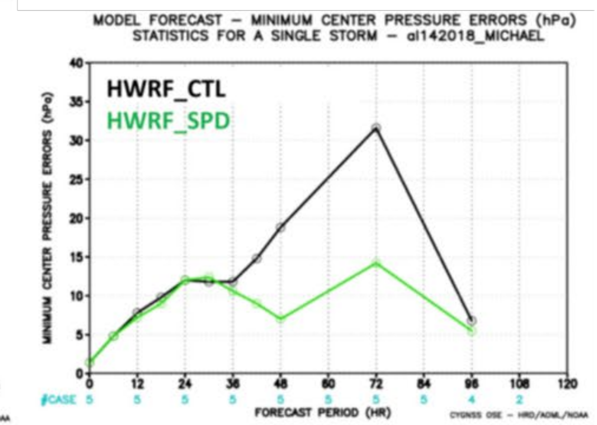
TRACK FORECAST



VMAX FORECAST



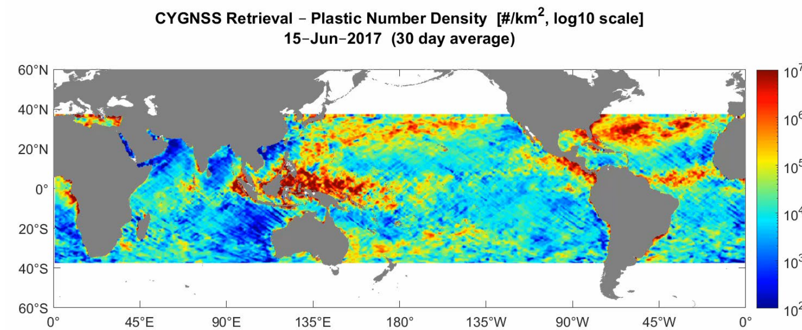
MSLP FORECAST

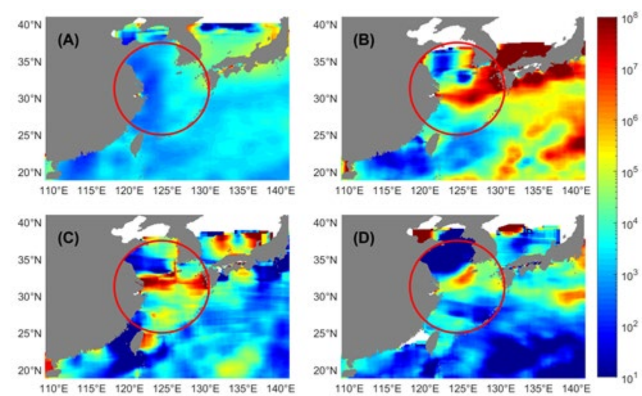


Mueller, M, B. Annane, M. Leidner, L. Cucurull (2021). Impact of CYGNSS-derived Winds on Tropical Cyclone Forecasts in a Global and Regional Model. Monthly Weather Review, DOI:10.1175/MWR-D-21-0094.1.

Ocean Microplastic Detection and Imaging

- **Measurement of ocean roughness anomaly by CYGNSS**
  - Anomaly = Deviation of measured roughness from that predicted by scattering model forced by reanalysis wind speed
  - Highly correlated with ocean microplastic concentration
- **Global dynamics imaged**
- **Episodic river outflow detected**
- **Two field campaigns to North Pacific Gyre in Summer 2022**
  - The Ocean Voyage Institute
  - The Ocean Cleanup



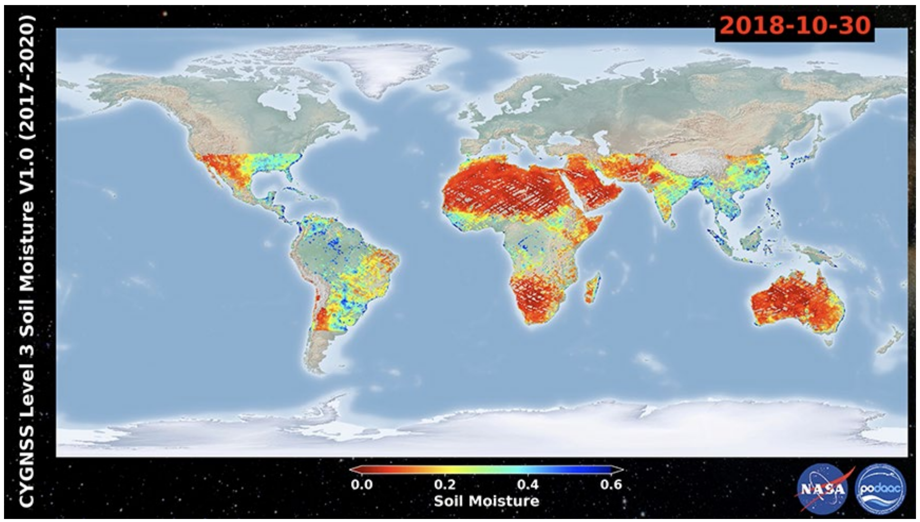


Evans, M. C., C. S. Ruf (2021), Towards the Detection and Imaging of Ocean Microplastics with a Spaceborne Radar. IEEE Trans. Geosci. Remote Sens., DOI: 10.1109/TGRS.2021.3081691.

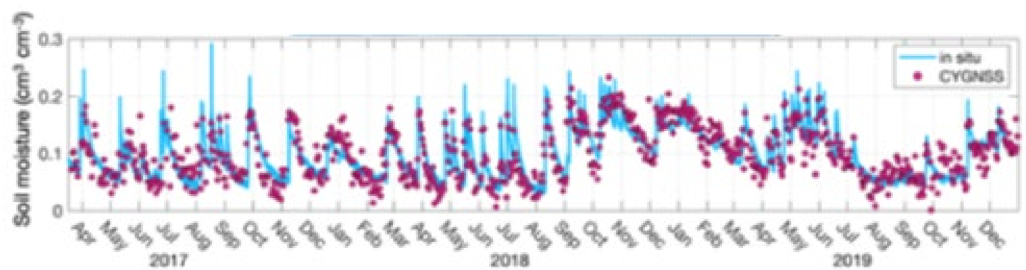
Released Soil Moisture Data Product (6 hr and daily versions available)

❖ **There is currently one CYGNSS soil moisture data product in release by the PO.DAAC**

Daily Soil Moisture Data Product



Ground truth validation of soil moisture product

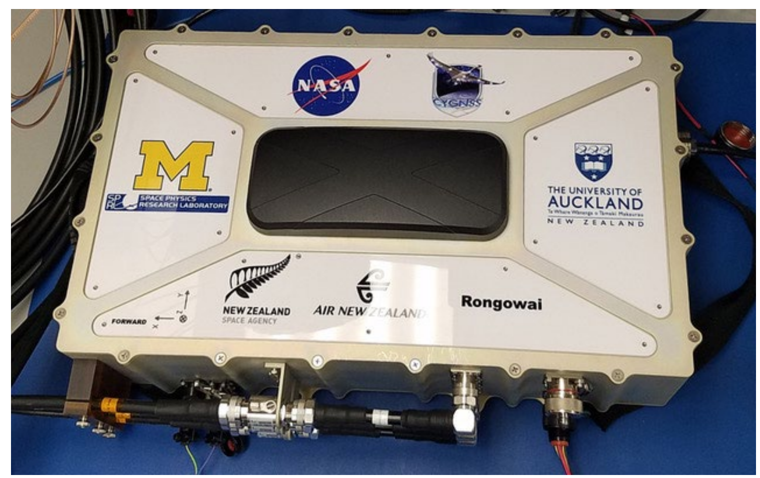


New Soil Moisture Products in Development

- **CYGNSS Soil Moisture by Xiaolan Xu, Simon Yueh, et al. (JPL)**
  - Physical Model Inversion
- **CYGNSS Soil Moisture by Fangi Lei (Mississippi State University).**
  - Machine-Learning algorithm
- **CYGNSS Soil Moisture and Biomass by Emanuele Santi (CNR Institute of Applied Physics)**
  - Soil moisture and biomass data parameters derived from CYGNSS Level 1 data

Airborne Soil Moisture Cal/Val
(with Delwyn Moller, Univ. Aukland)

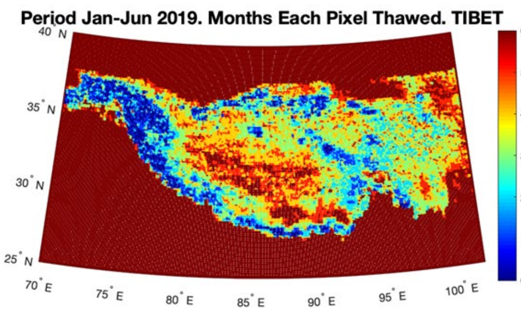
- **Next Gen GNSS-R Extended Duration Airborne Field Campaign**
  - Partnership with New Zealand Space Agency, Univ. of Auckland, and Air New Zealand
- **Status**
  - Installation on ZK-NFA, expected August 2022
  - Immediate return to normal domestic commercial service

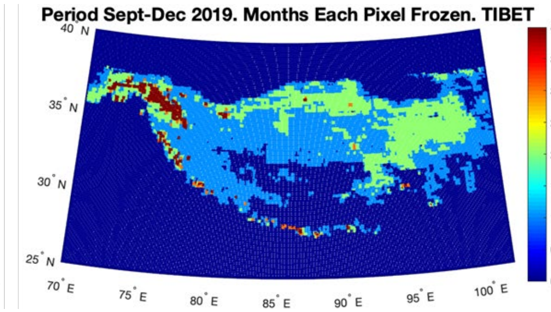


Freeze/Thaw Detection

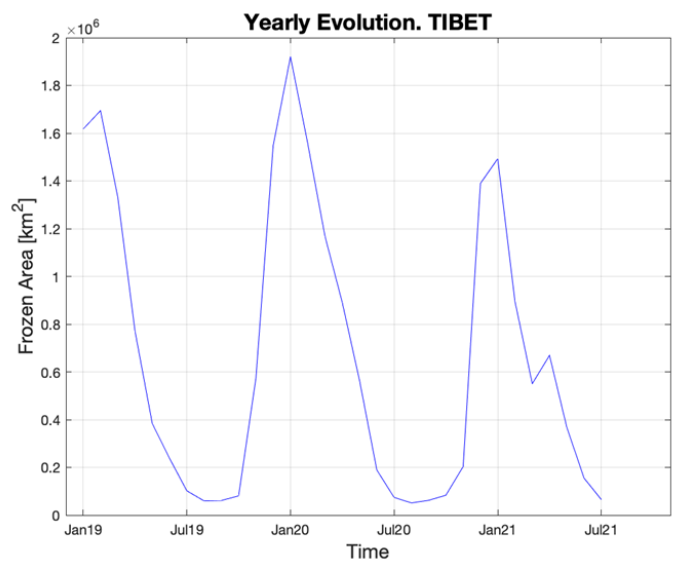
(with Hugo Carreno Luengo, Univ. Michigan)

- **Surface reflectivity responds strongly to changes in water phase**
- **CYGNSS coverage of Tibetan Plateau tracks F/T transitions in spring and fall**





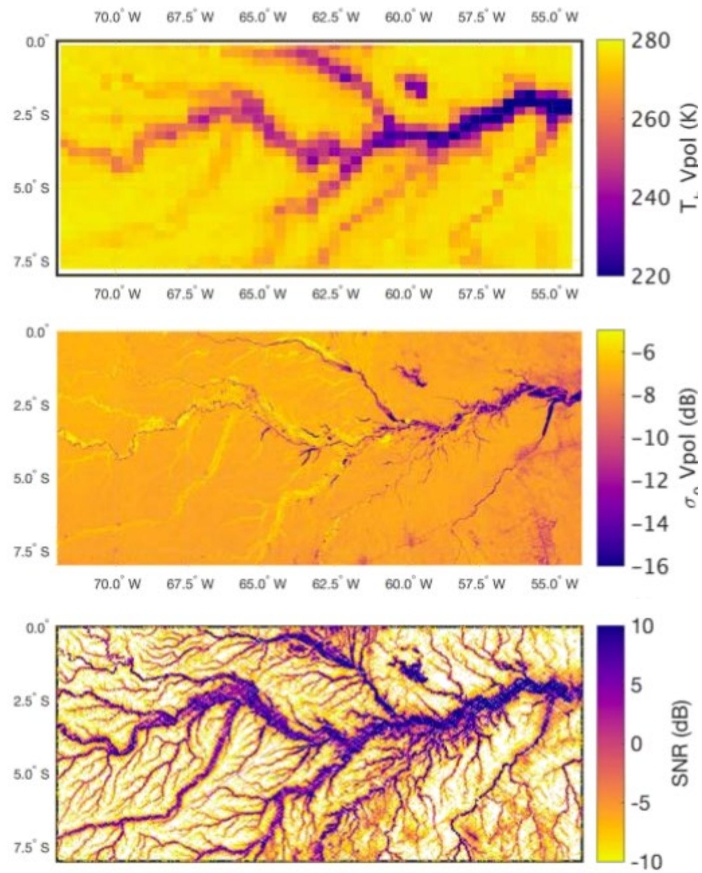
- **Area extent of frozen ground can be tracked vs. time to monitor climatic trends**



Carreno Luengo, H., C. S. Ruf (2021). Retrieving Freeze/Thaw Surface State from CYGNSS Measurements. IEEE Trans. Geosci. Remote Sens., doi: 10.1109/TGRS.2021.3120932, 2021.

CYGNSS Inland Waterbody Imaging

- High res limaging from coherent specular scattering
- Images of the same section of the Amazon River by:
  - SMAP passive microwave
    ~30 km resolution
  - SMAP active radar
    ~3 km resolution
  - CYGNSS GNSS-R
    << 3 km resolution



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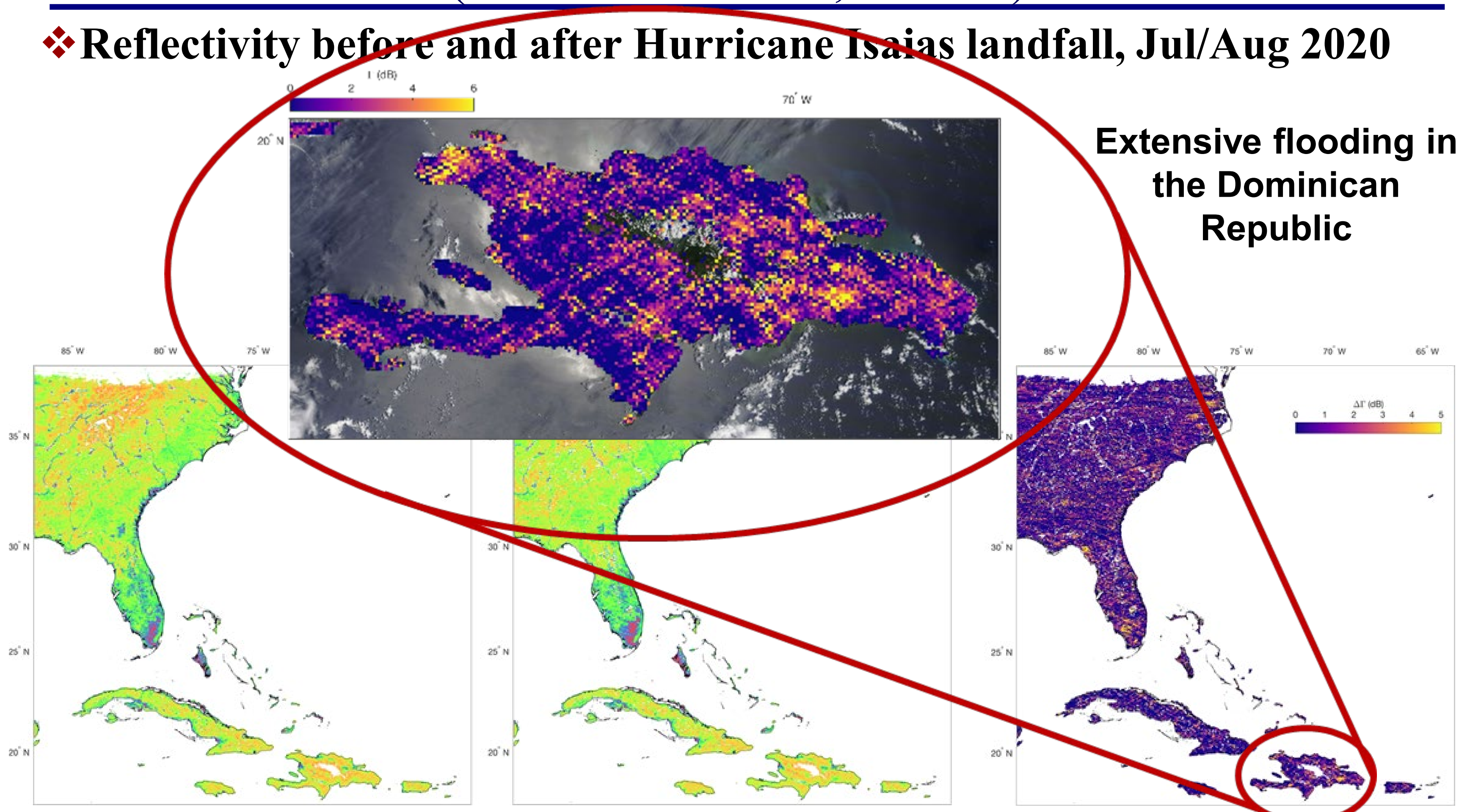
Imaging Flooding Inundation after Hurricane Landfall

(with Clara Chew, UCAR)

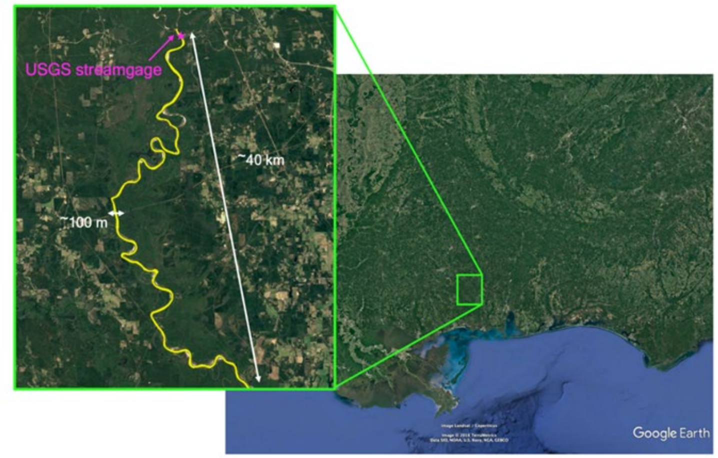
❖ **Reflectivity before and after Hurricane Isaias landfall, Jul/Aug 2020**

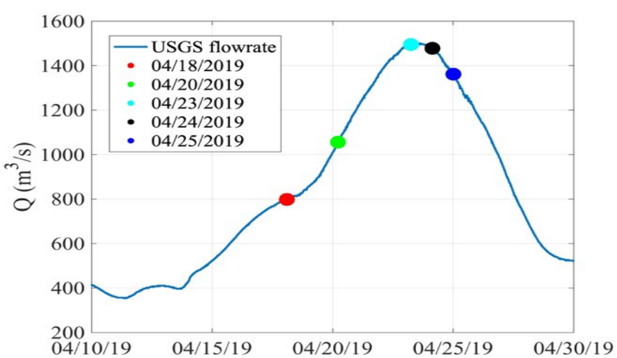


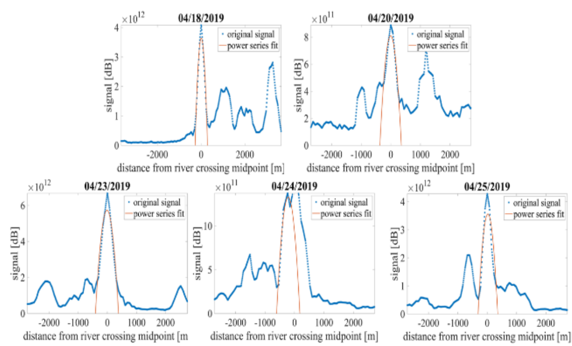
Extensive flooding in the Dominican Republic

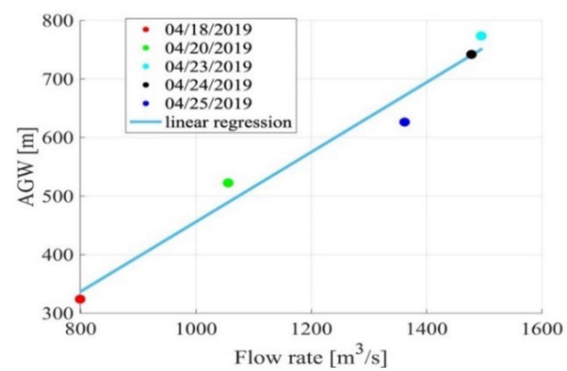
Tracking River Flow Rate
(with April Warnock, SRI)

- CYGNSS overpasses during surge in Pascagoula River flowrate
- CYGNSS tracks of scattered signal power with river crossing highlighted
- Associated GNSS-R Width (AGW) of river is correlated with flow rate









Warnock and Ruf (2019). Response to Variations in River Flowrate by a Spaceborne GNSS-R River Width Estimator. Remote Sens., 11(20), 2450, doi: 10.3390/rs11202450.

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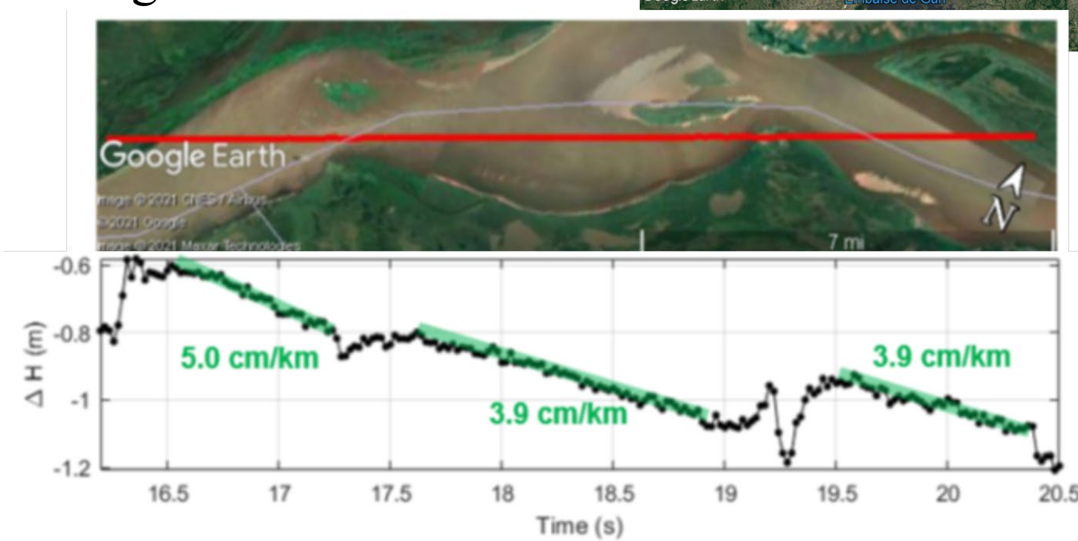
Measuring River Surface Slope

(Prof. Jade Morton & group, CU Boulder)

- Carrier phase altimetry during river overpasses
- Relative altimetry can determine changes in height with common mode error cancellation
- Precision of ΔHeight measurement is several cm

Orinoco River Track



Summary

- CYGNSS science applications have expanded since launch in 2016 to include
  - Wind speed assimilation for hurricane forecasting
  - Soil moisture retrieval
  - Freeze/thaw detection
  - Flood inundation
  - River width and slope

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