



Present status and future directions of GNSS assimilation at NRL

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Summary of Operational Status

- Operational Procedure
 - Forward Operator (ROPP)
 - Observation error specification
 - Tangent point drift considerations
- Sensors assimilated
 - List of sensors and any caveats
- Impact assessment
 - Monitoring
 - FSOI (Forecast Sensitivity to Observation Impact)
 - Shown to the right (GPS highlighted in red)

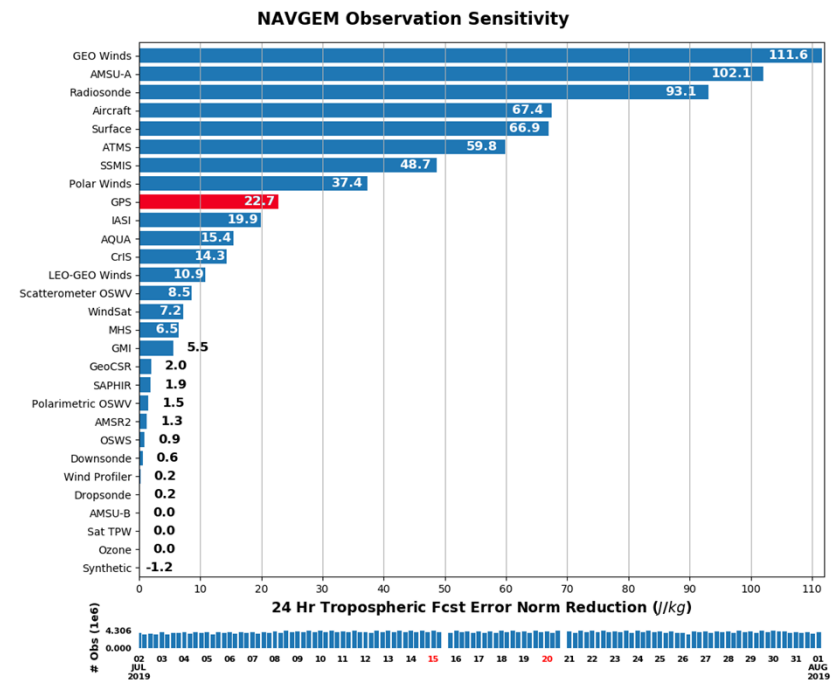
New Observations

- KOMPSAT-5, GRAS MetOp-C, PAZ,
- SPIRE, GeoOptics
- CYGNSS (CYclone Global Navigation Satellite System)
 - GNSS-Reflectometry growth will be rapid

Future Directions

- Improved observation error (based on humidity)
- 2D Operator

https://www.nrlmry.navy.mil/metoc/ar_monitor/

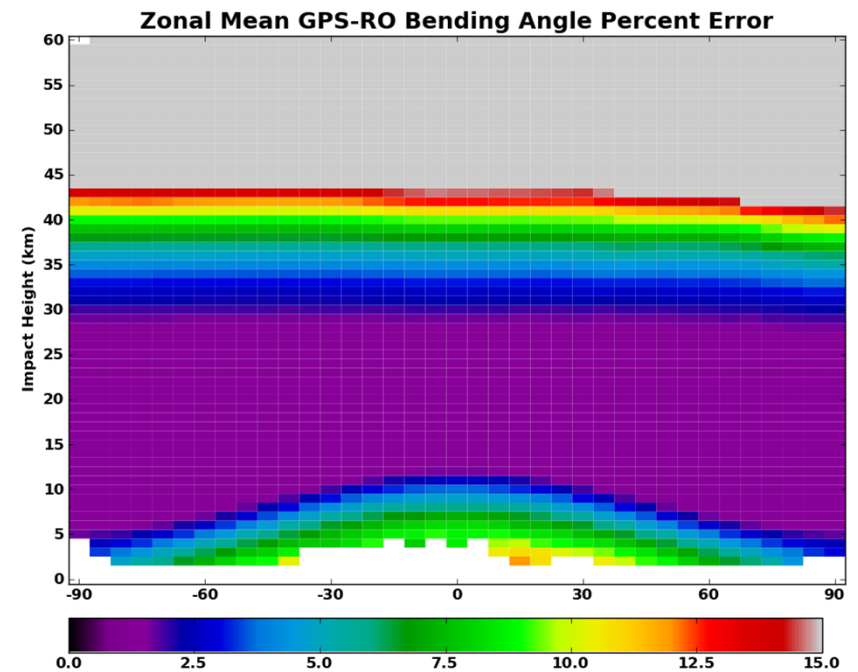


Summary of Operational Status

- Details of GNSS-RO assimilation
 - Assimilation of bending angle
 - 60km cap
 - Occultation points treated as independent tangent points

- Quality control checks
 - Check on the vertical bending angle gradient

- Observation error specification
 - Based on observed RMS statistics from assimilation system
 - Surface maximum 25% at Equator, 16.5% at pole
 - Decline throughout tropopause to 1.5%
 - 1.5% bulk of stratosphere
 - Use max of 0.6 μ rad –or– 1.5% of observation



Operational Status: Sensor Availability

Sensors recognized in Operations

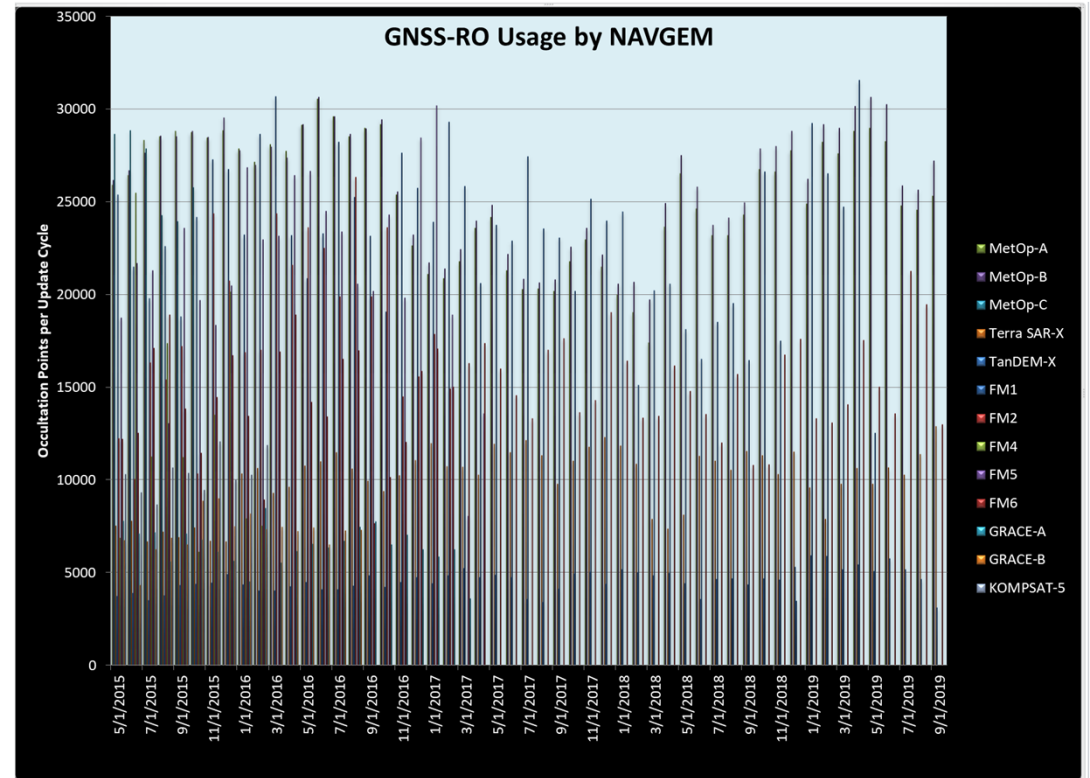
- C/NOFS
 - CORISS (x)
- COSMIC
 - FM1
 - FM2 (x)
 - FM3 (x)
 - FM4 (x)
 - FM5 (x)
 - FM6
- GRAS
 - MetOp-A
 - MetOp-B
 - MetOp-C
- GFZ
 - TerraSAR-X
 - TanDEM-X
 - GRACE-A (x)
 - GRACE-B (x)
- KOMPSAT5
 - AOPOD

“Plumbed” but not Operational

- SPIRE
- PAZ
 - ROHPP

Expected in near Future

- COSMIC-2
- GRACE-FO



Operational Monitoring: Innovation (O-B)

Summary of Operational Status

2014 NAVGEM v1.2

- T359L50
- EDMF

2015 NAVGEM v1.3

- T425L60
- Θ_v dynamics

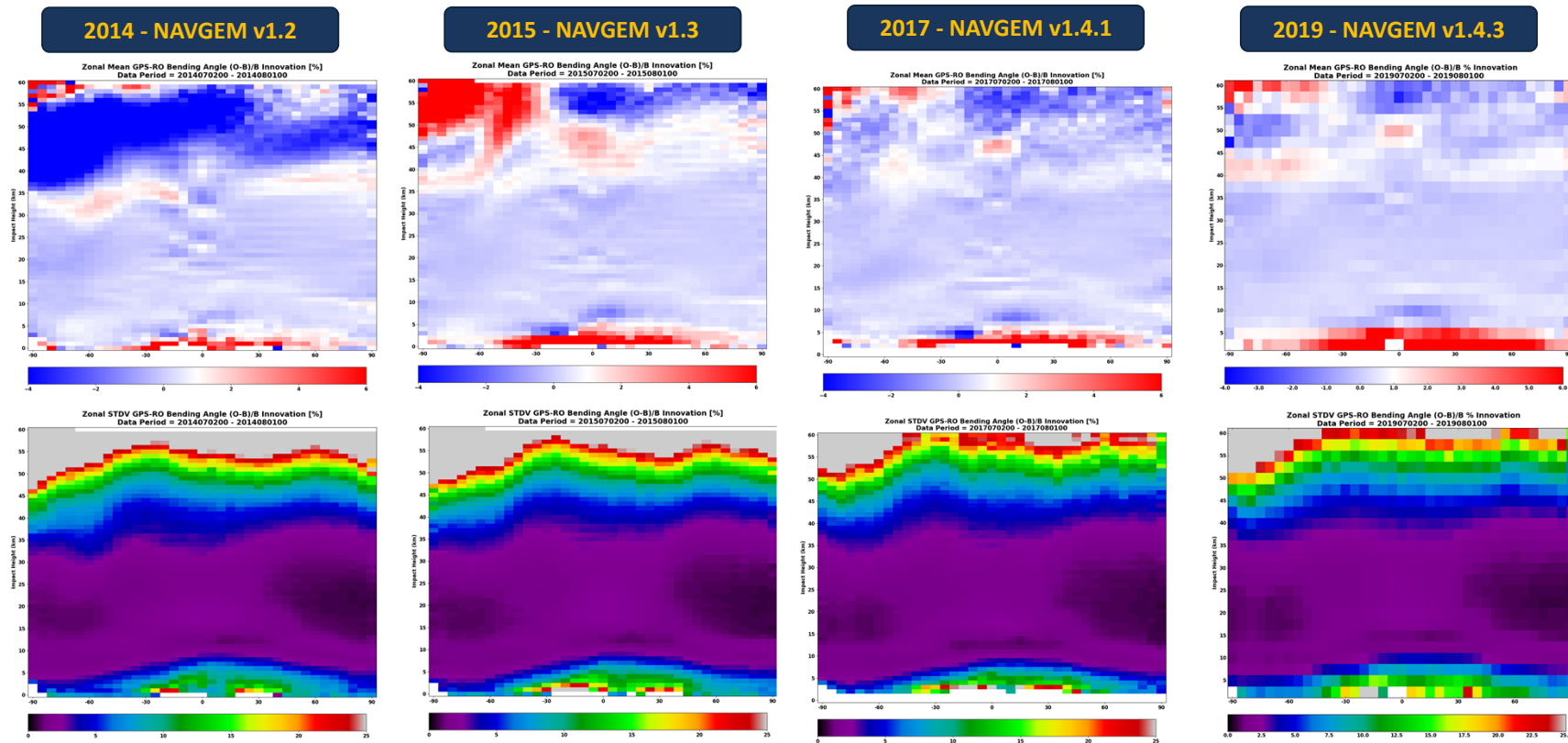
2017 NAVGEM v1.4.1

- Hybrid DA
- CrIS

2019 NAVGEM v1.4.3

- Correlated Ob Error

Evolution shows gradual improvement near model upper boundary



Upper plots: $\text{mean}[(O-B)/B]$

Lower Plots: $\text{stdv}[(O-B)/B]$

Operational Monitoring: FSOI

Summary of Operational Status

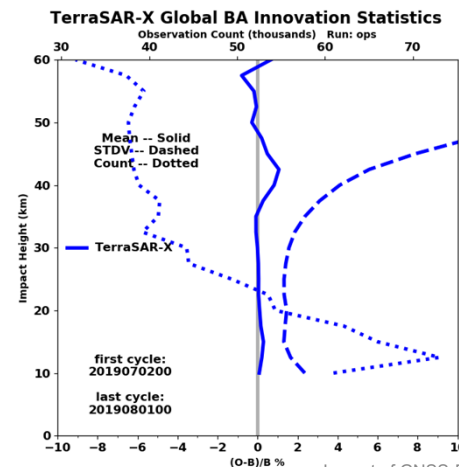
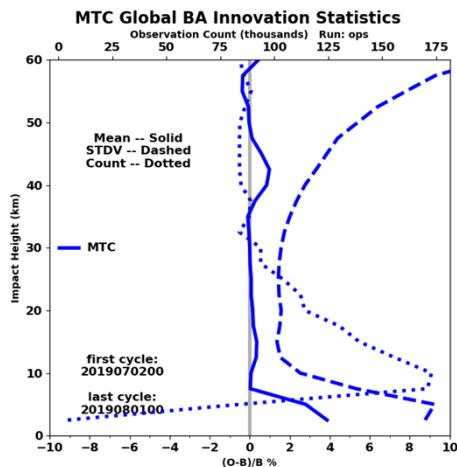
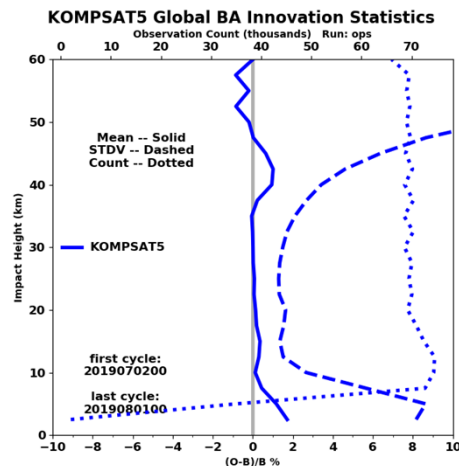
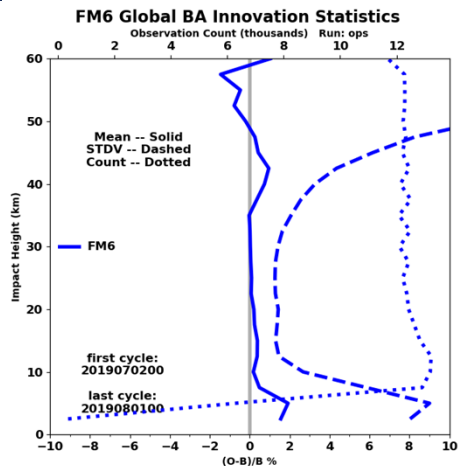
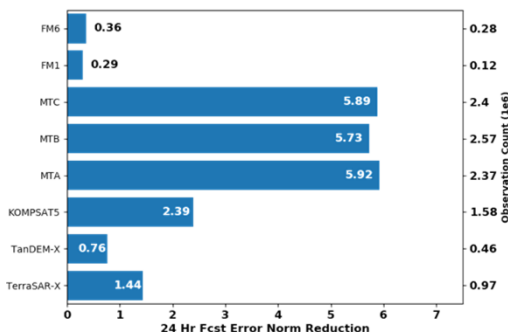
Forecast Sensitivity to Observation Impact (FSOI)

- Consistent impact
- Metric weighted towards troposphere
 - Norm is a total energy norm
 - Combines temperature, humidity, divergence and vorticity

GNSS-RO network

- Most sensors used up to 60km
- Attempt to use in troposphere large dropoff due to conservative quality control

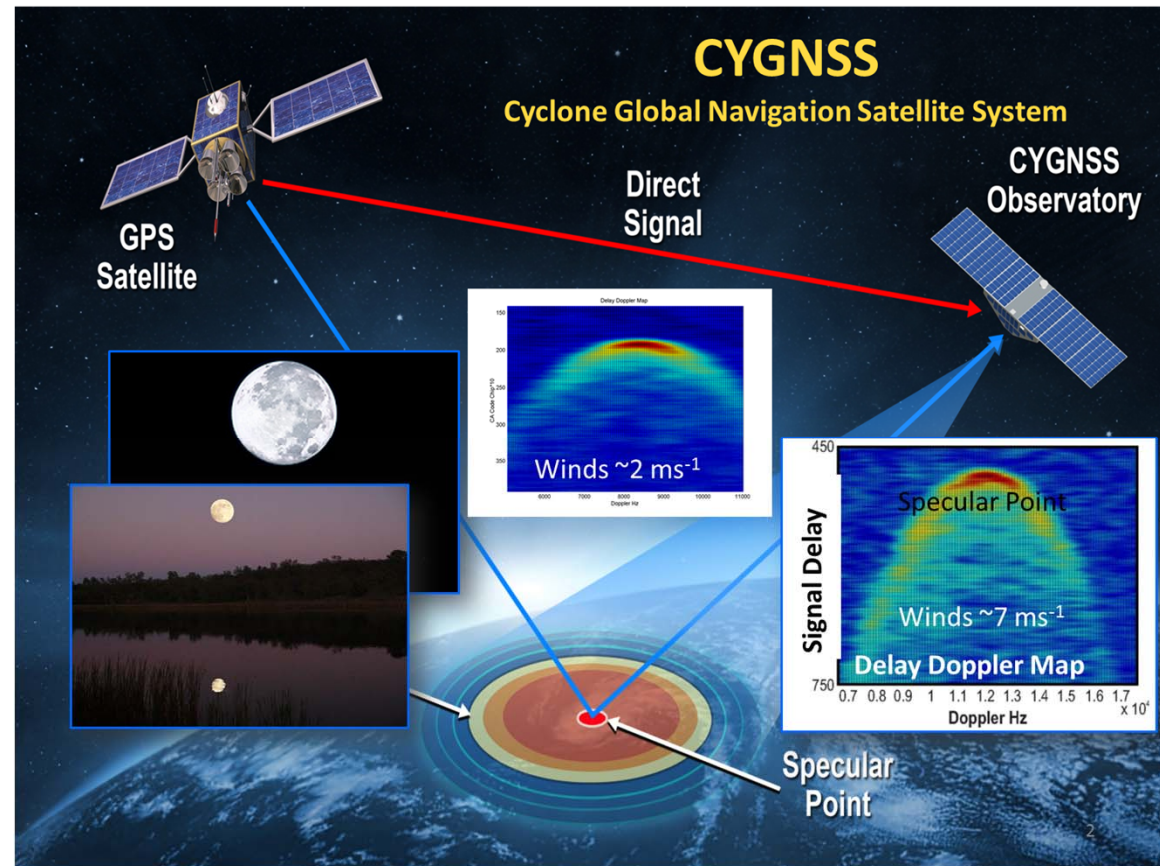
NAVDAS-AR GPS Ob Sensitivity



GNSS-Reflectometry: CYGNSS

CYclone Global Navigation Satellite System

- 8 micro-sats launched Dec. 16, 2017 in LEO
- High frequency temporal sampling of inner TC structure and low spatial observation revisit time (mean ~7 hrs)
- Unprecedented spatial coverage and observation count in any weather condition due to use of microwave L-band
- Delay Mapping Receive (DMR) processes direct and reflected GPS signals to produce Delay Doppler Maps (DDMs), a representation of sea surface roughness due to a winds
- **Forward Model needed!**



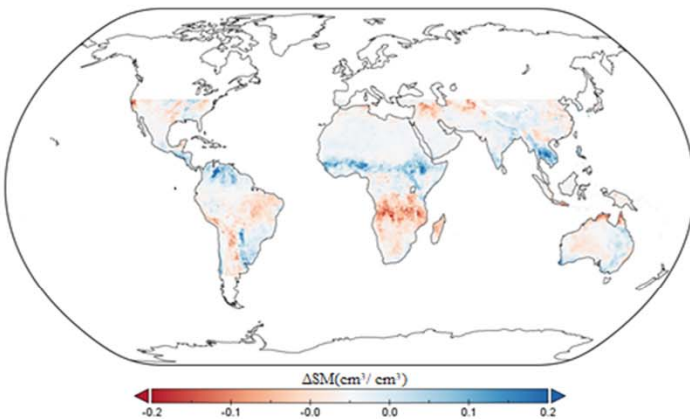
Soil Moisture Signal

(Courtesy Mohammad Al-Khaldi, Ohio State)

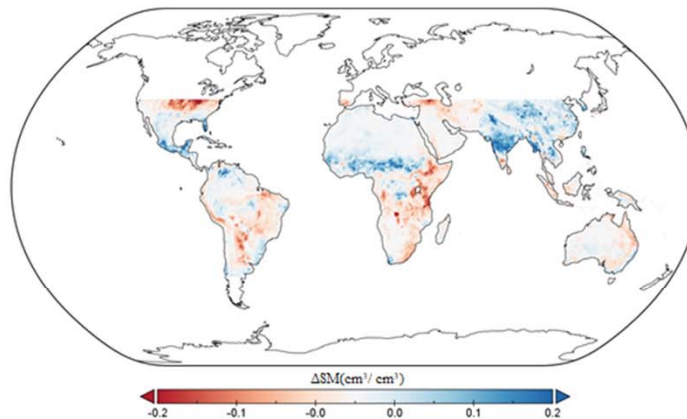


- Difference monthly mean CYGNSS signal to noise ratio over land (no soil moisture retrieval algorithm... yet) – 1 month change in SNR
- Compare with SMAP 1-month difference in soil moisture

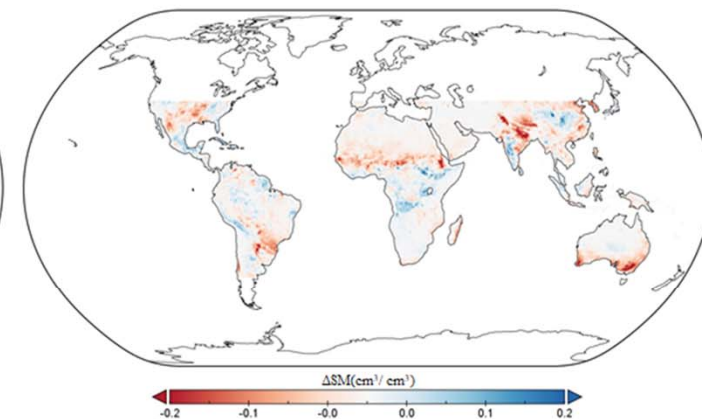
SMAP, Apr - May



SMAP, May - June



SMAP, Aug - Sept



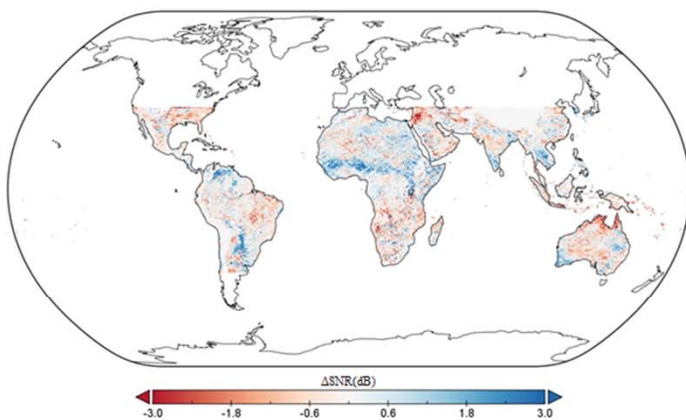
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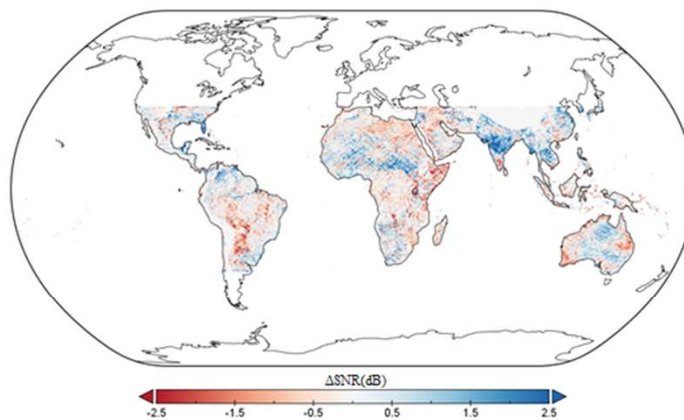


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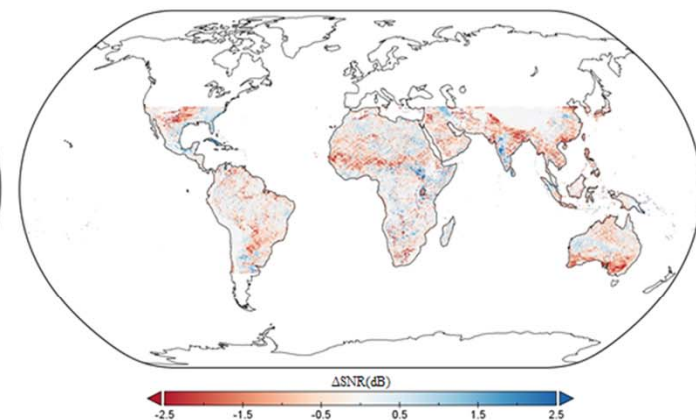
CYGNSS, Apr - May



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CYGNSS, Aug - Sept

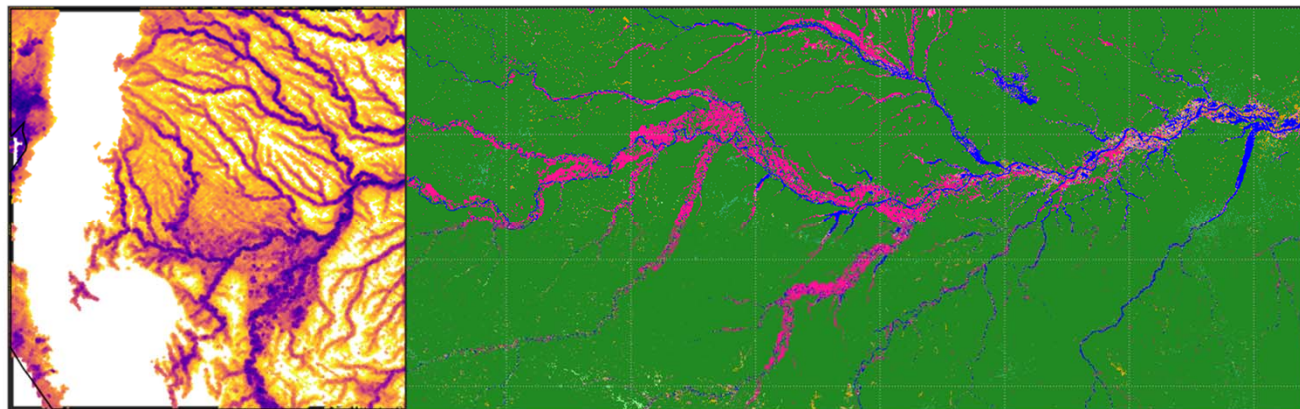


Land Surface Inundation

(Clara Chew, Talk 4.4, Tues 8 Jan, 9:15 AM)



- CYGNSS signal sensitive to surface water – examine Amazon



- Open water
- Flooded woody vegetation
- Flooded broadleaved forest
- Closed to open broadleaved forest (>5 m)



<https://data.cosmic.ucar.edu/gnss-r/soilMoisture/cygnss/level3/>

Plans and Investigations

PAZ

- 13Aug2019 available from NOAA, but not yet on GTS

COSMIC-2

- Ready to evaluate and use the data upon release

Observation Error

- Error estimate based on atmospheric humidity profile
- Additional investigations into error modeling in lower troposphere could bring more improvements

2D Observation Operator

- Begin testing 2-dimensional bending angle operator
- Plan is to treat occultation in segments to alleviate the condition of crossing covariance volumes

