Earth Remote Sensing using Surface-Reflected GNSS Signals (GNSS-Reflectometry)

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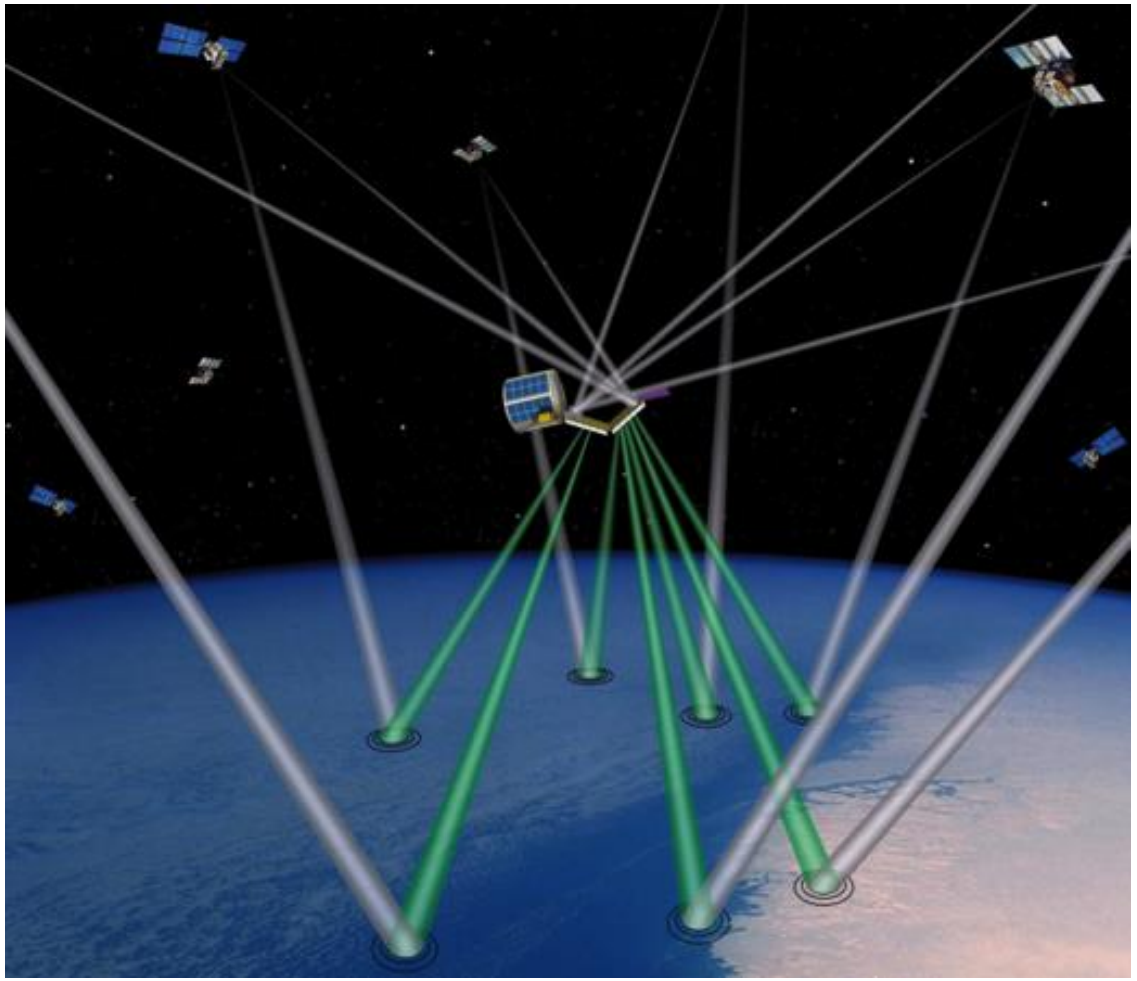
Presented 11/15/17
Space-Based Positioning, Navigation, and Timing
National Advisory Board



- What is GNSS-Reflectometry (GNSS-R)?
- What measurements can GNSS-R make?
- What's currently happening in this field?

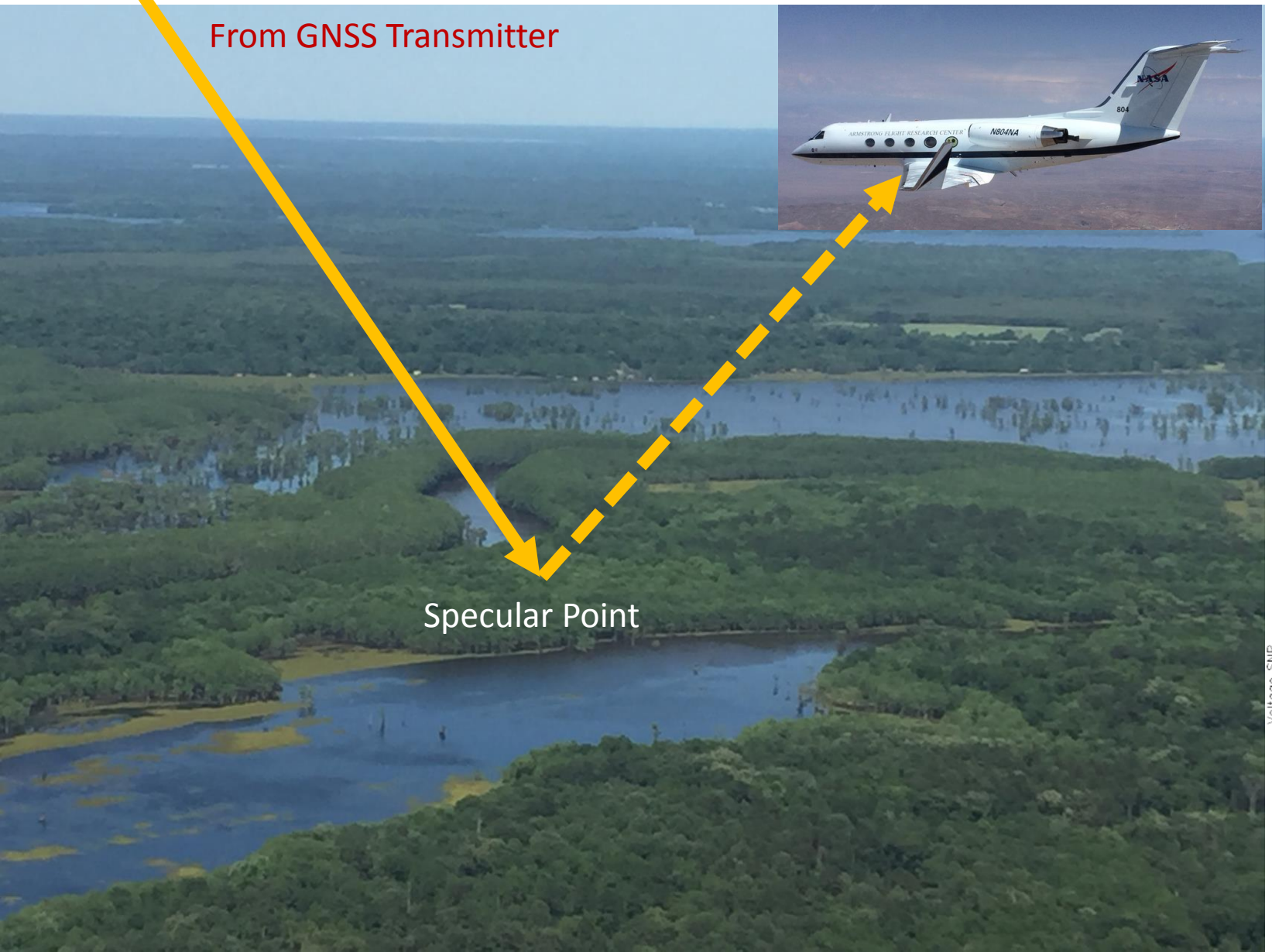
What is GNSS-Reflectometry (GNSS-R)?

Start With RADAR

<u>Radar Comparison</u>

- Transmitter & receiver co-located (Monostatic)
- Backscatter

What is GNSS-Reflectometry (GNSS-R)?

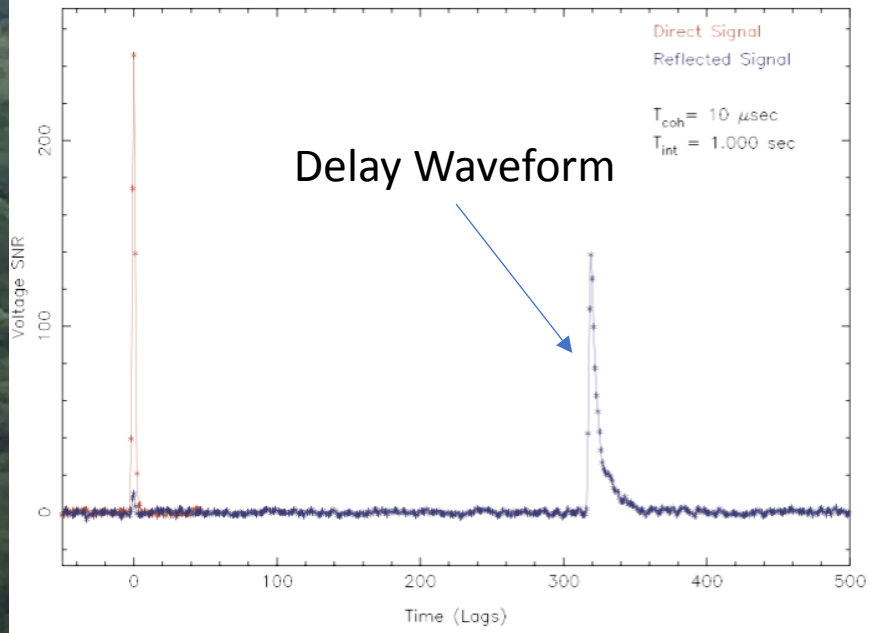


GNSS-R

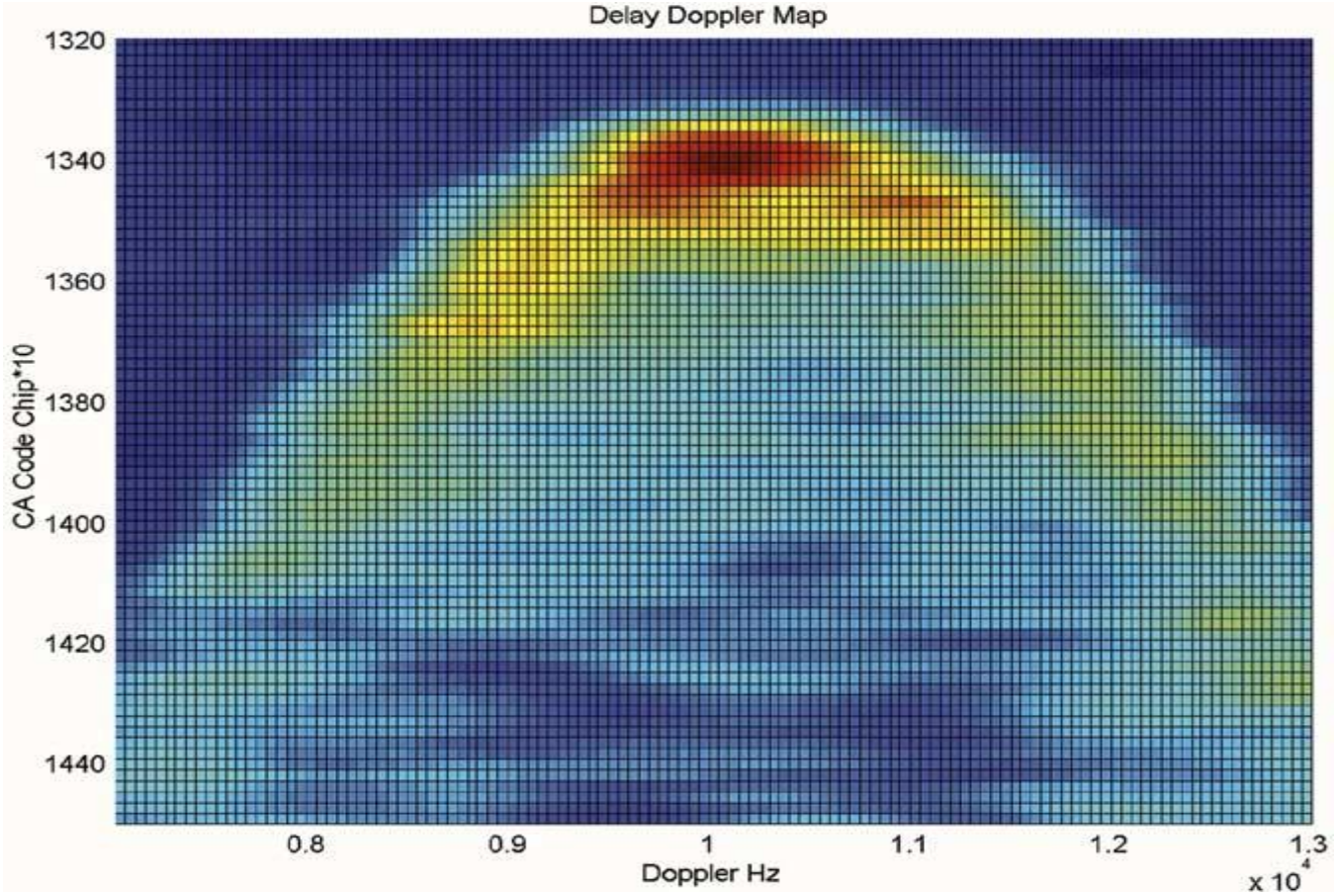
- Just radar with separate transmitter & receiver (bistatic)
- Forward-scattering

Receives Power(time)

- Shape => Roughness
- SNR => Conductivity
- Timing => Height



What is GNSS-Reflectometry (GNSS-R)?

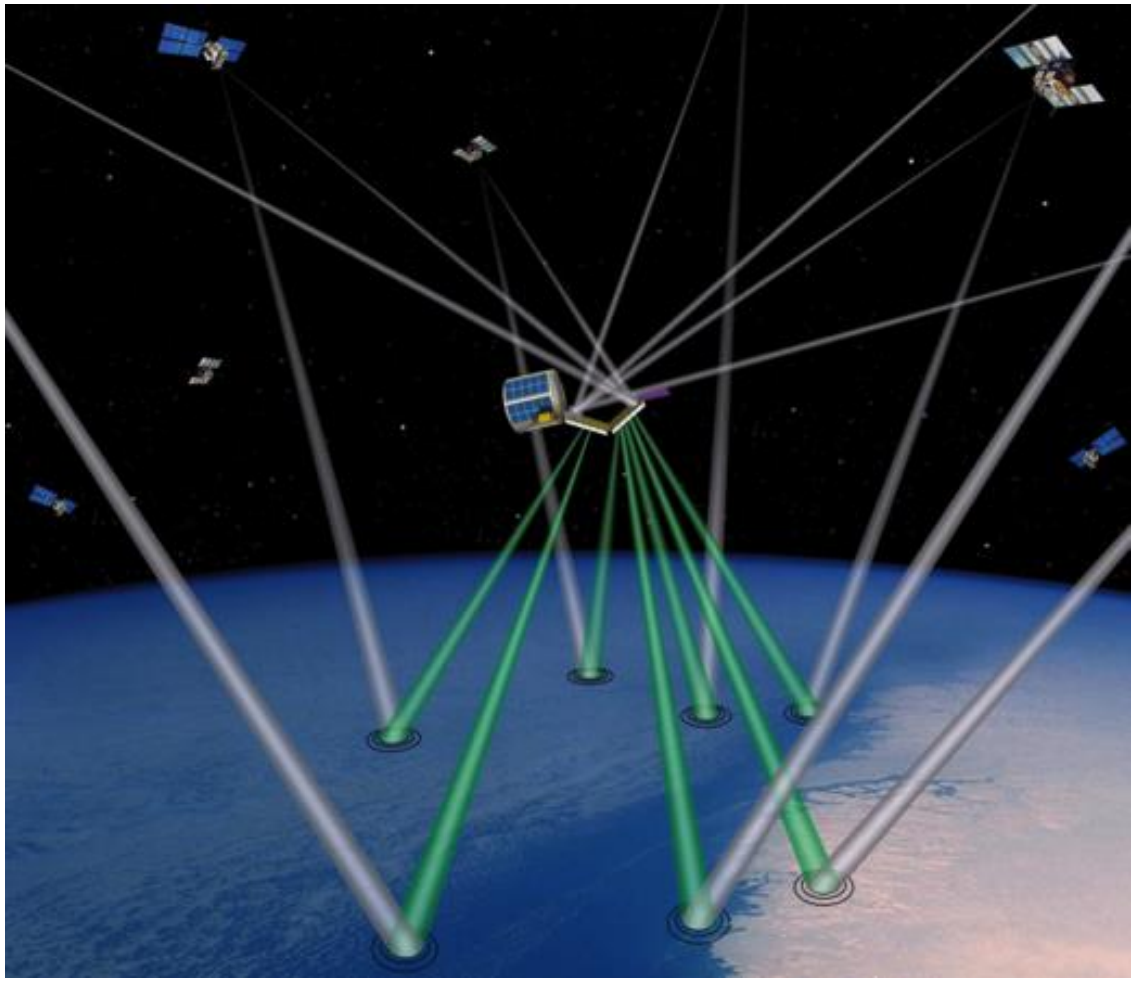


Scott Gleason, from UK-DMC experiment

Delay-Doppler Map (DDM)

- Received power vs delay/Doppler
- Primary observable for GNSS-R
- Vertical slice is Delay Waveform

Space-Based GNSS-R System

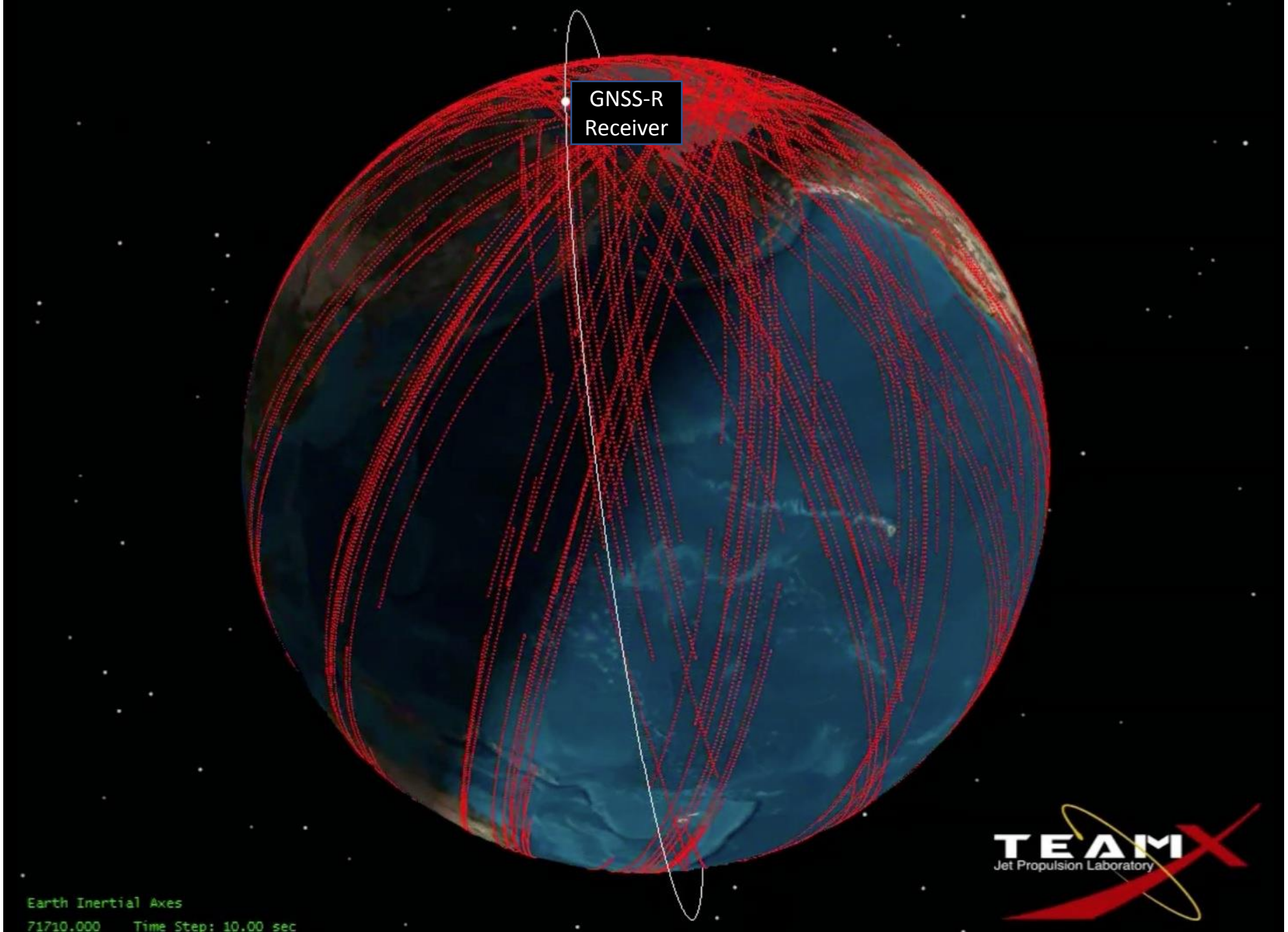


GNSS-R

- Multi-bistatic
- Next few years: >100 GNSS transmitters
- Dense surface coverage

Many Advantages

- Multiple, simultaneous observations
  - High spatial / temporal resolution
- Free high-quality signals
- Leveraging huge global infrastructure
- No transmitter
  - Relatively low cost, low power
  - Constellation possibilities (CyGNSS)
- Forward scattering (where the power goes)
- ~Same hardware as Radio-Occultations’


GNSS-R
Receiver
TEAMX
Jet Propulsion Laboratory
Earth Inertial Axes
71710.000 Time Step: 10.00 sec

What Measurements Can GNSS-R Make?

Red: Demonstrated from space

Green: Ground, aircraft experiments

Oceanography

- Surface winds (CyGNSS Mission: Cyclones)
- Mesoscale topology
- Tsunami science/warning
- Geoid / Mean Sea Surface

Land

- Soil Moisture
- Wetland Extent
- Freeze/Thaw State
- Vegetation Characteristics

Cryosphere (assuming high-inclination orbit)

- Sea-Ice Extent
- Ice freeboard
- snow depth
- Ice roughness / age

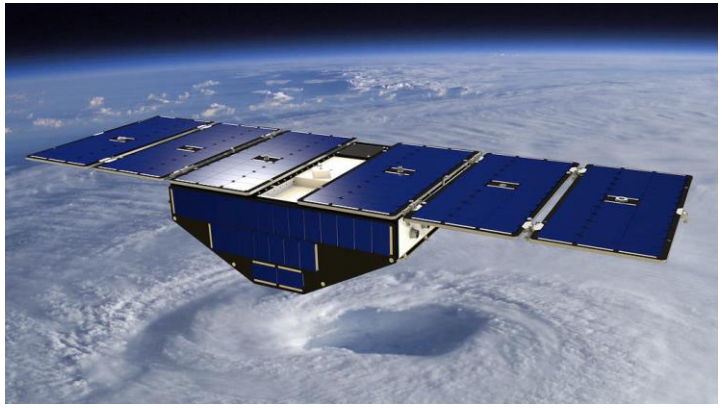
What's Happening in the GNSS-R Field?

Mission/Satellite	Year	# Space GNSS Reflections
SIR-C	2003 (obtained)	2
SAC-C	2003	~6
UK-DMC	2007	22
TechDemoSat1	2015-2017	~100M
SMAP (GNSS-R)	2015-present	>2.3M + 2900/day
CyGNSS (8 sats)	2017-present	>125M + 0.5M/day

Explosion of data in last 2 years

What's Happening in the GNSS-R Field?

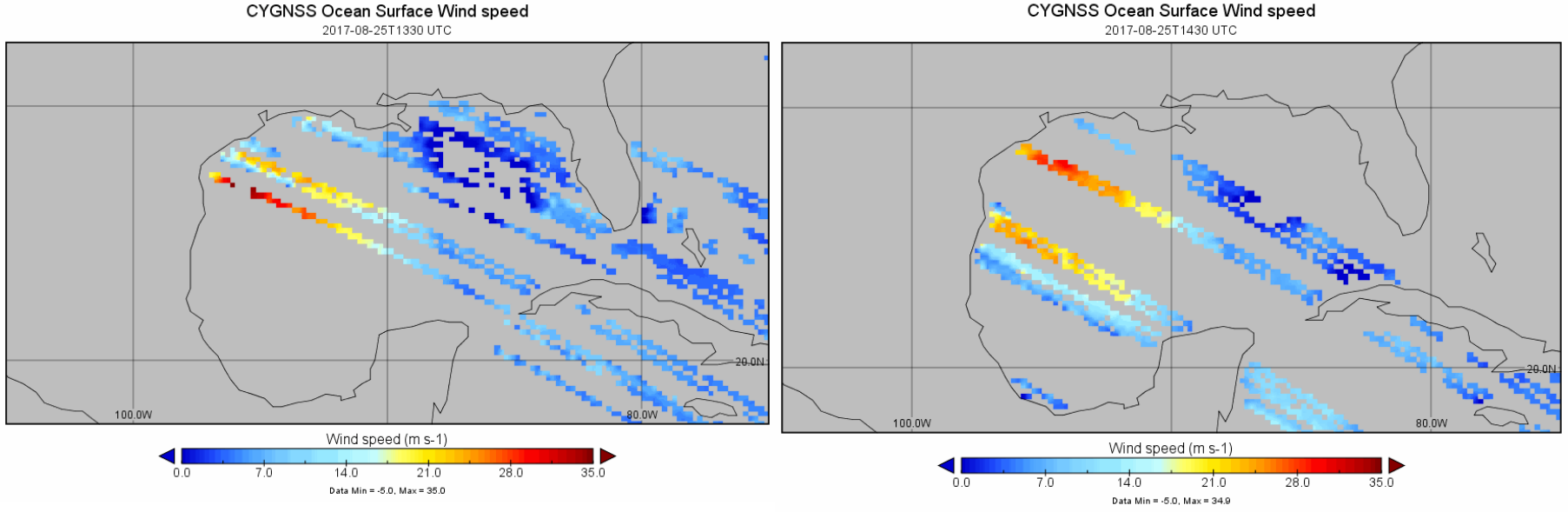
CyGNSS Satellite



CyGNSS: NASA Earth Venture Mission

- $157M to study Cyclone Science
- Goal: Improved cyclone intensity forecast
- 8 small-sats
- Observe GPS L1 C/A signals after reflecting from the ocean

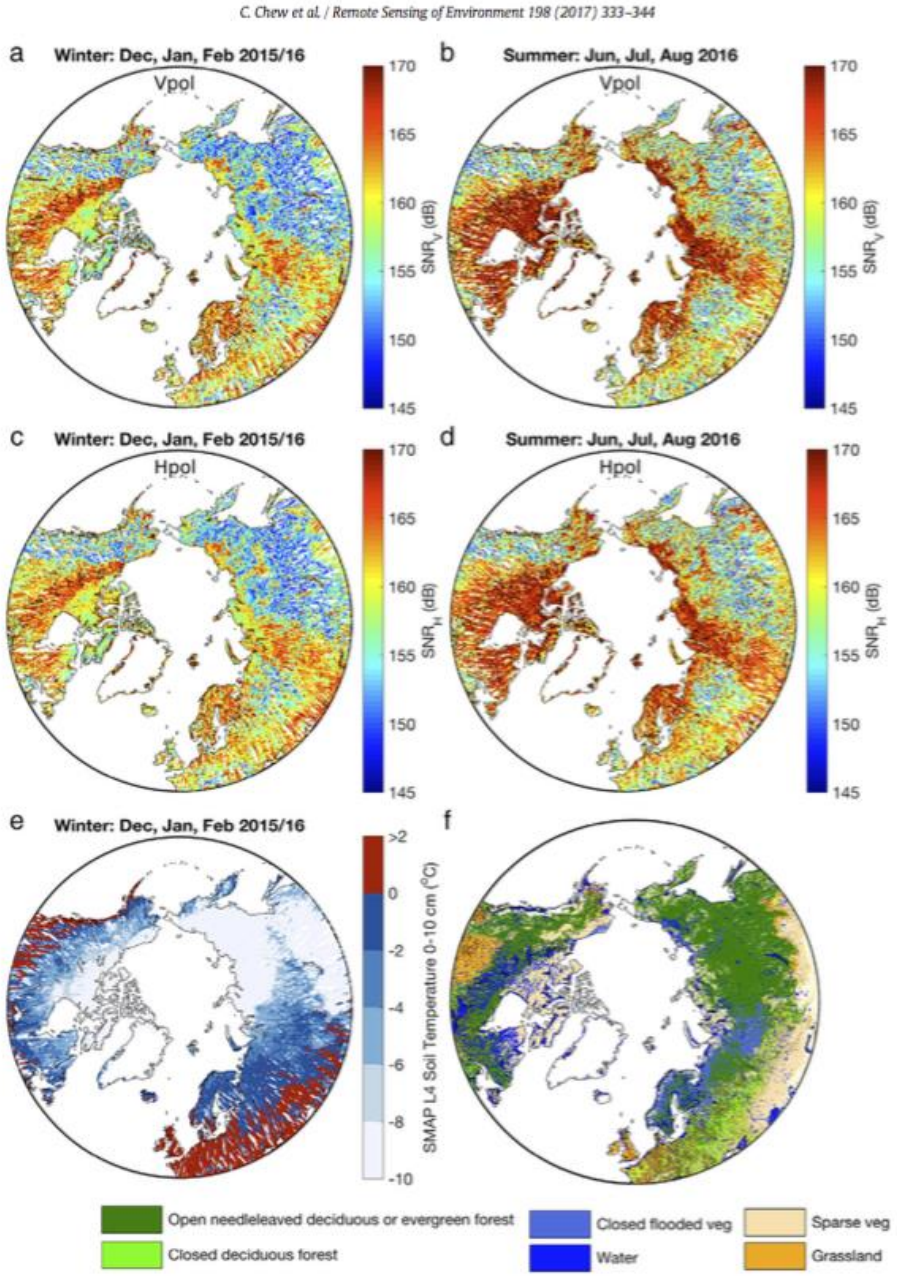
Observations of Hurricane Harvey Prior to Landfall on August 25, 2017



Courtesy Chris Ruf (PI)

CYGNSS Level 3 gridded surface wind speed data product (v1.1) at
1300-1400 and 1400-1500 UTC on 25 Aug 2017, prior to landfall at ~0300 UTC on 26 Aug 2017

What's Happening in the GNSS-R Field?



SMAP GNSS-R Observes Freeze/Thaw

Vertical Polarization

Winter Summer

Horizontal Polarization

Winter Summer

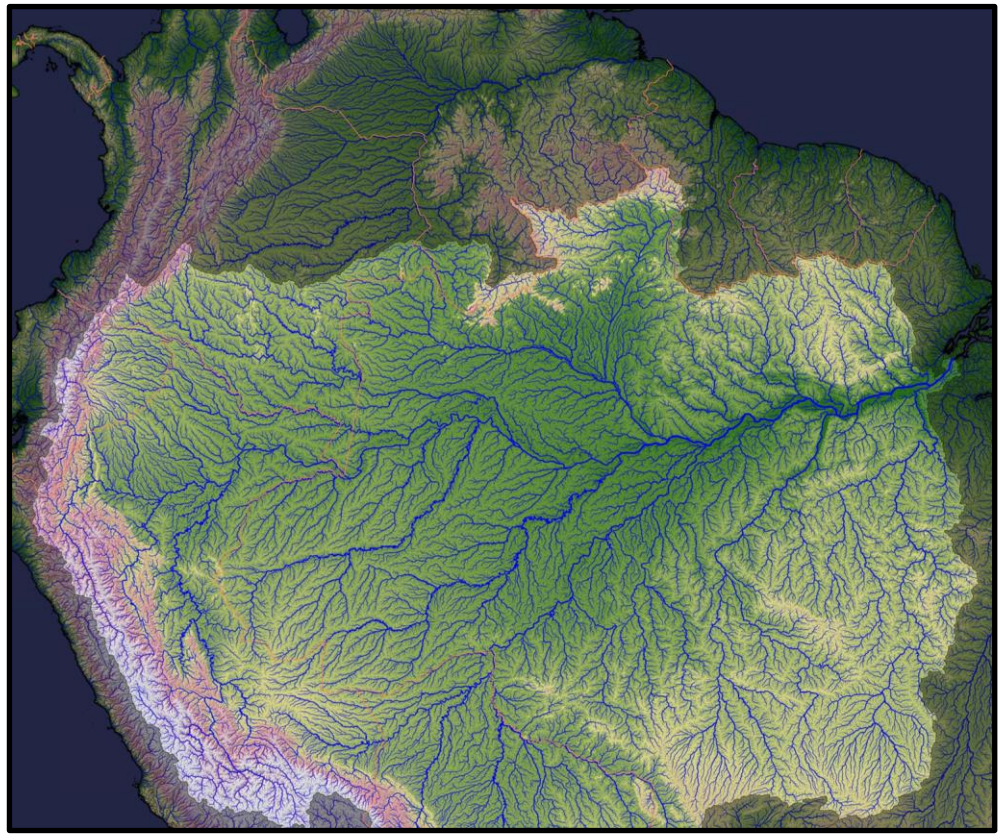
Winter Temp (blue frozen)

Vegetation Type

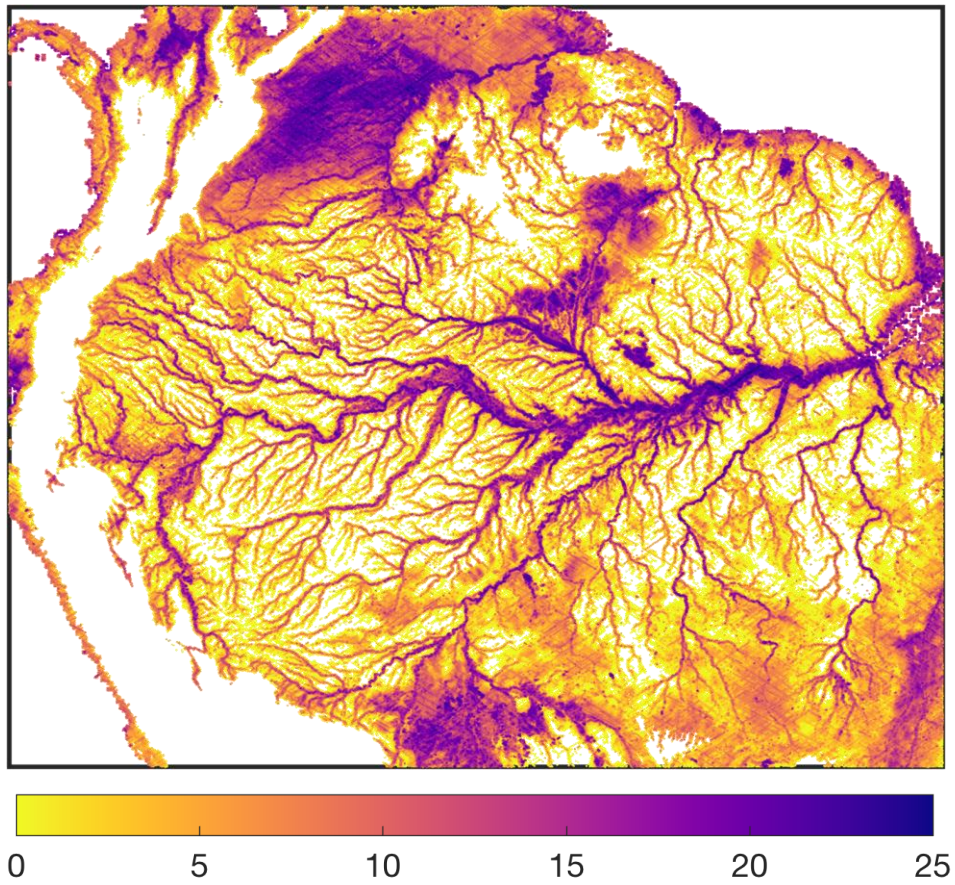
From Chew et al, Remote Sen Env 198, 2017

What's Happening in the GNSS-R Field?

HydroSheds Database



CyGNSS Data: SNR vs location



White: Outside CyGNSS delay window

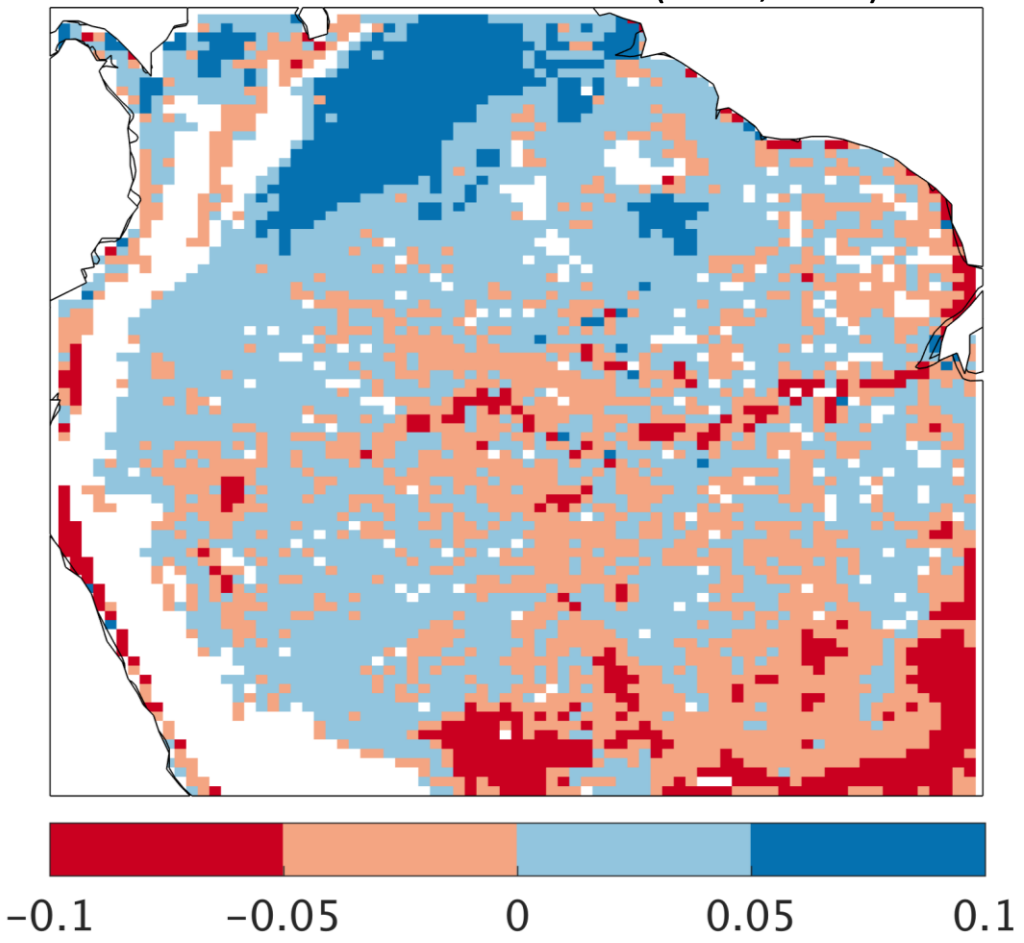
Amazon Rainforest

Courtesy Clara Chew (UCAR)

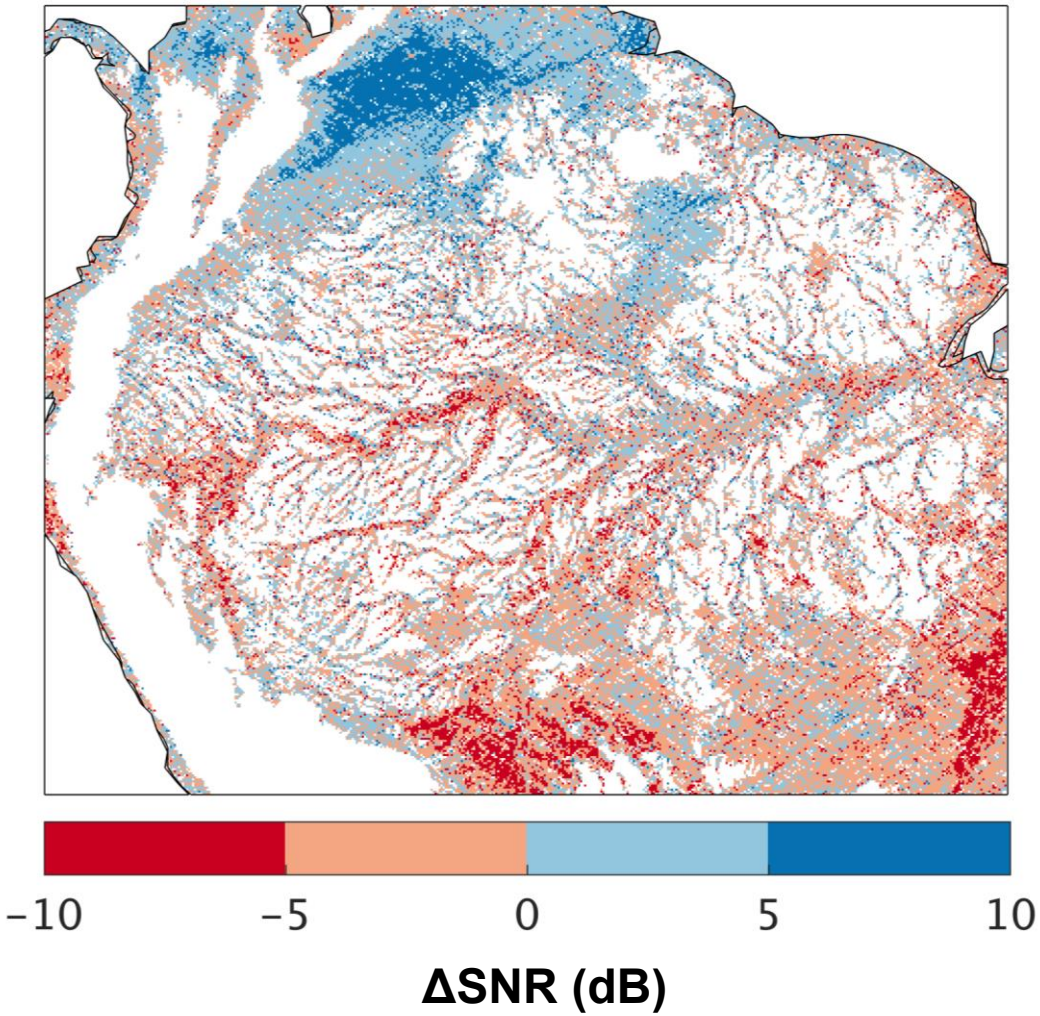
What's Happening in the GNSS-R Field?

Change in SNR: Aug - Mar

SMAP Radiometer (J. Du, et al)



CyGNSS Data



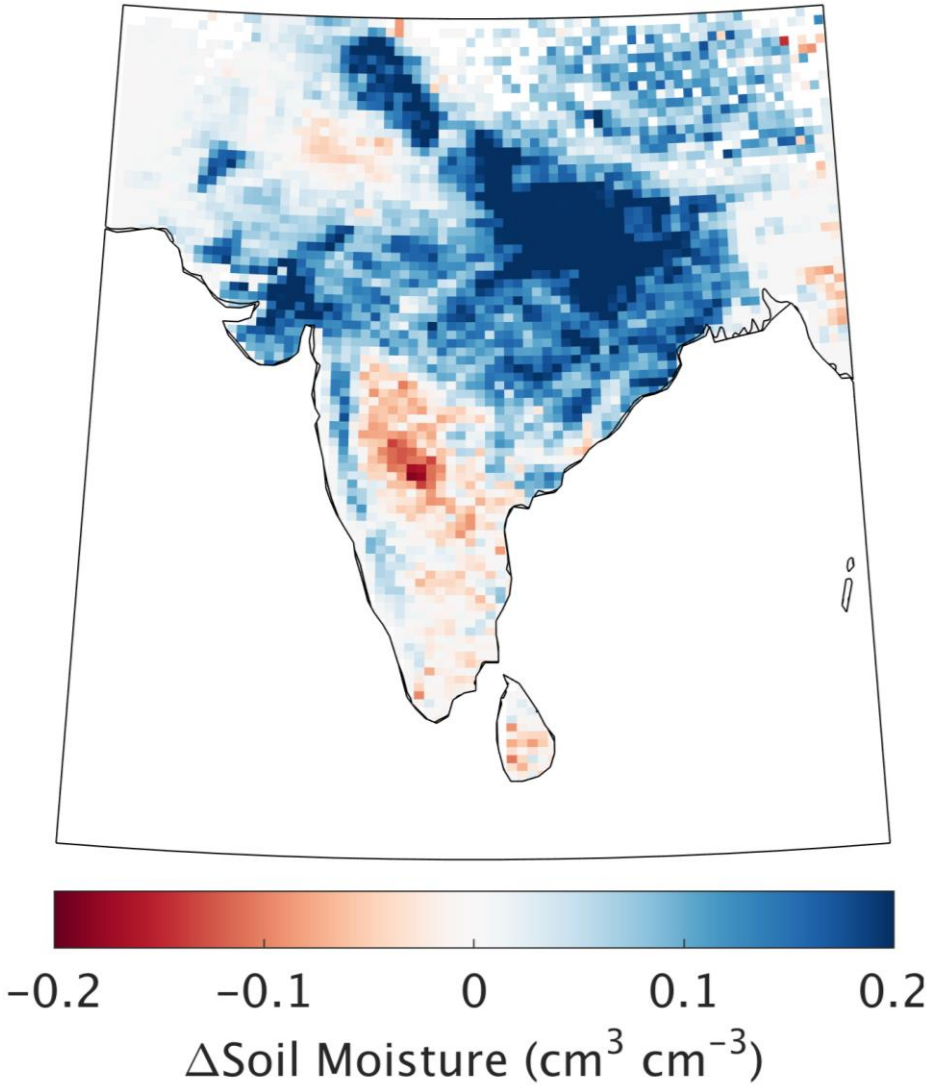
Amazon Rainforest

Courtesy Clara Chew (UCAR)

What's Happening in the GNSS-R Field?

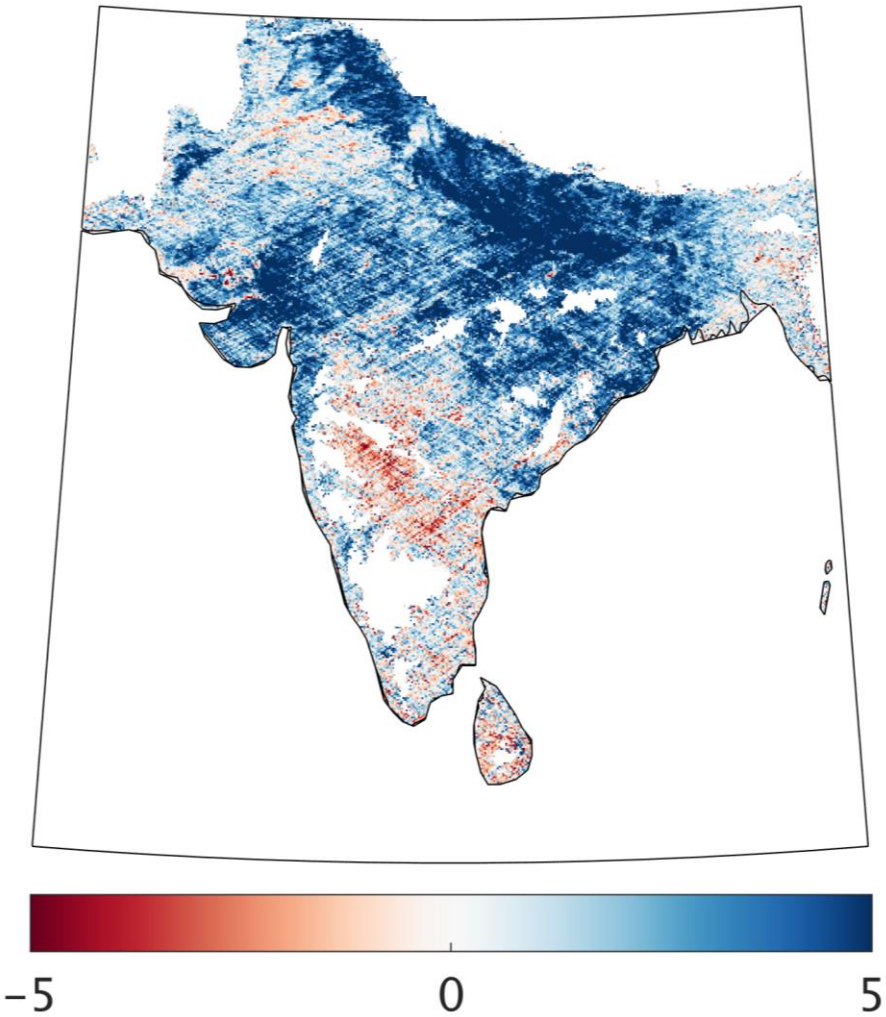
Change in SNR: Apr - Mar

SMAP Radiometer: Level 3



India

CyGNSS Data: SNR Change



Courtesy Clara Chew (UCAR)

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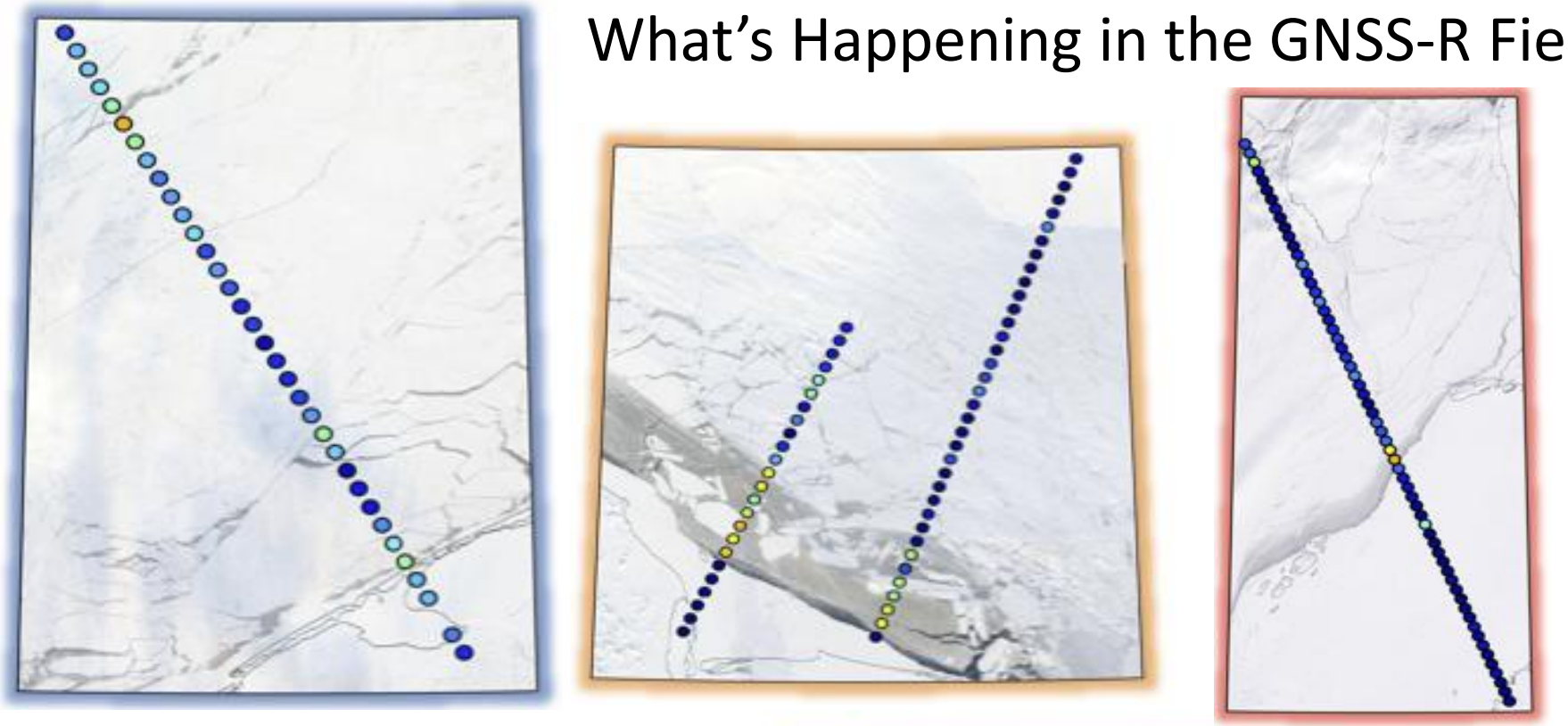
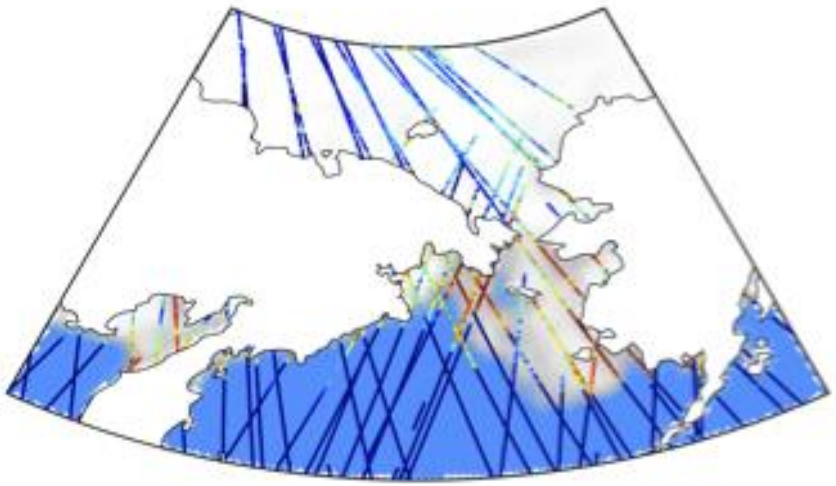
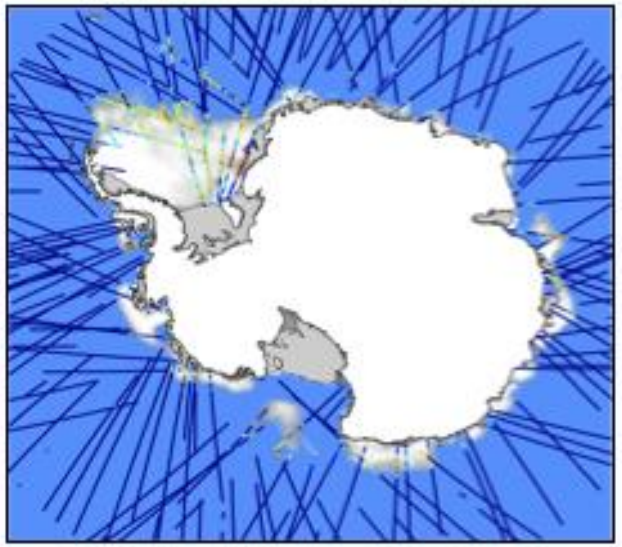
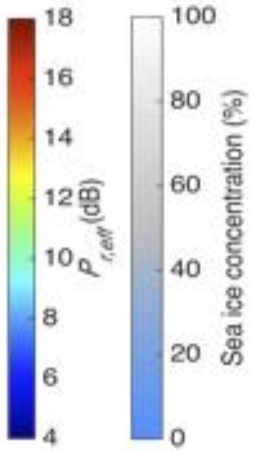


TechDemoSat-1 Data

- Higher power over ice leads and polynyas
- Up to 10 dB increase
- Not seen in passive microwave







- Increased P on ice edges
- Highest P intermediate sea ice conditions

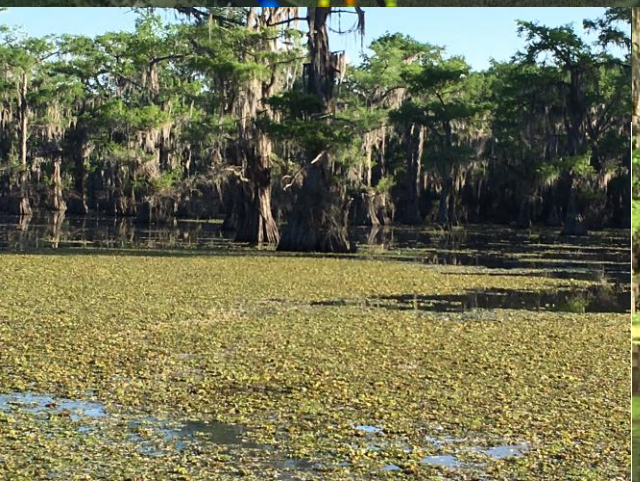
Courtesy Clara Chew (UCAR)

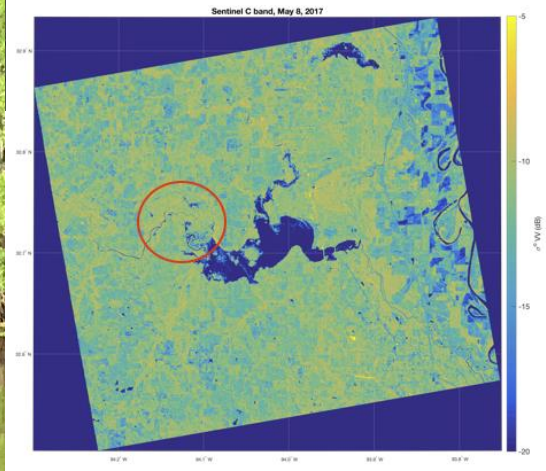
What's Happening in the GNSS-R Field?

Wetland Inundation Extent

- Connection to methane production
  - Potent greenhouse gas
- Can forward-scattered GNSS-R signals penetrate vegetation to sense underlying inundation?

- May 2017 aircraft experiment: Caddo Lake LA
  - 20 dB blue to red scale
  - Light green: Giant Salvia
  - Dark green: Cypress
  - Backscatter radar shows little water





Summary

- GNSS-Reflectometry is a new Earth-remote sensing technique
- Explosive growth since 2015: TDS-1, SMAP, CyGNSS
- Many unique advantages compared to other remote sensing techniques
  - High spatial/temporal coverage, forward scattering, GNSS-RO-compatible, long-term SI-traceable signals
- Active research underway:
  - Ocean winds, soil moisture, wetland extent, freeze-thaw state, sea ice extent, ocean altimetry