Earth Remote Sensing using Surface-Reflected GNSS Signals (Part II)

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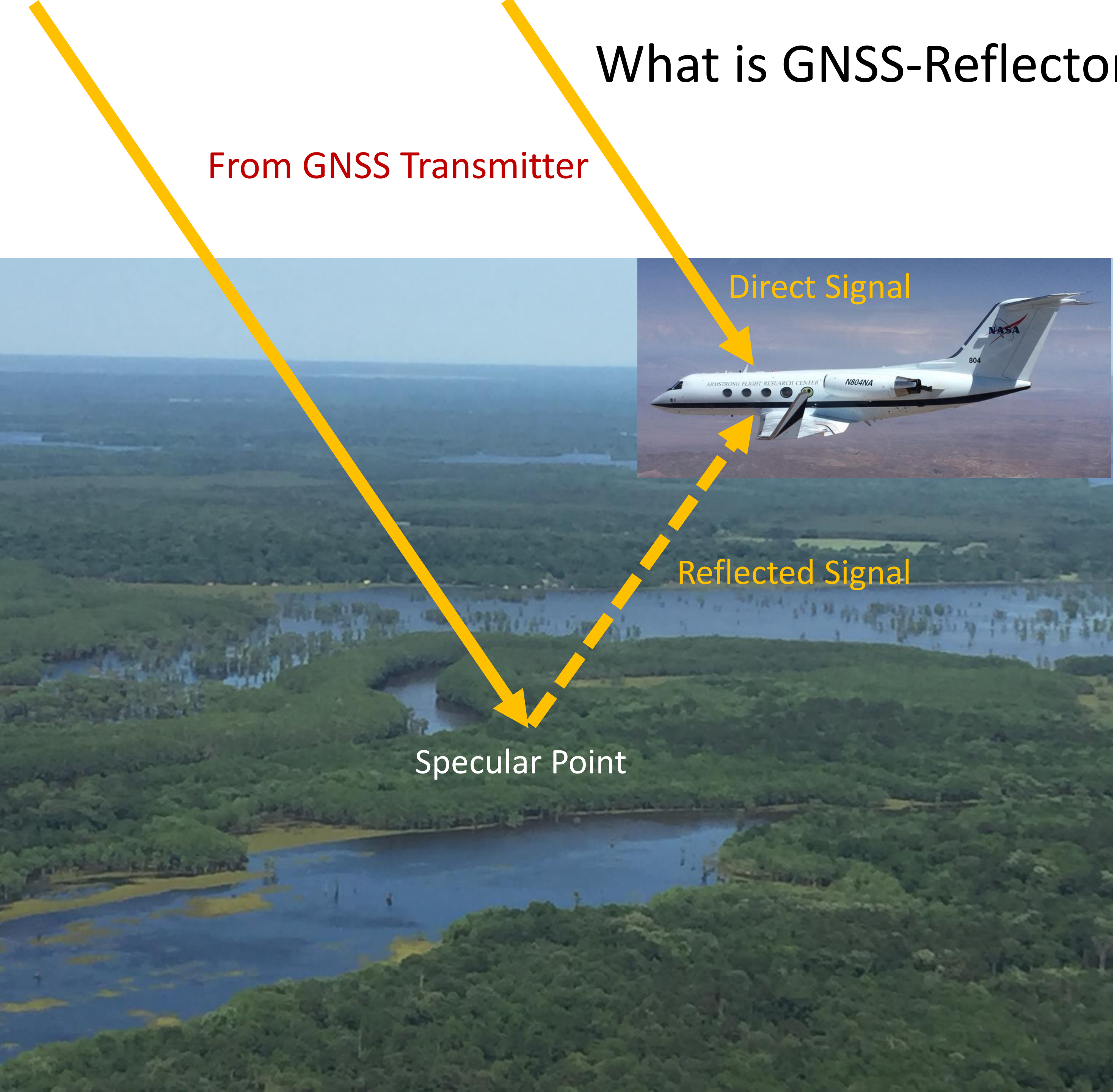
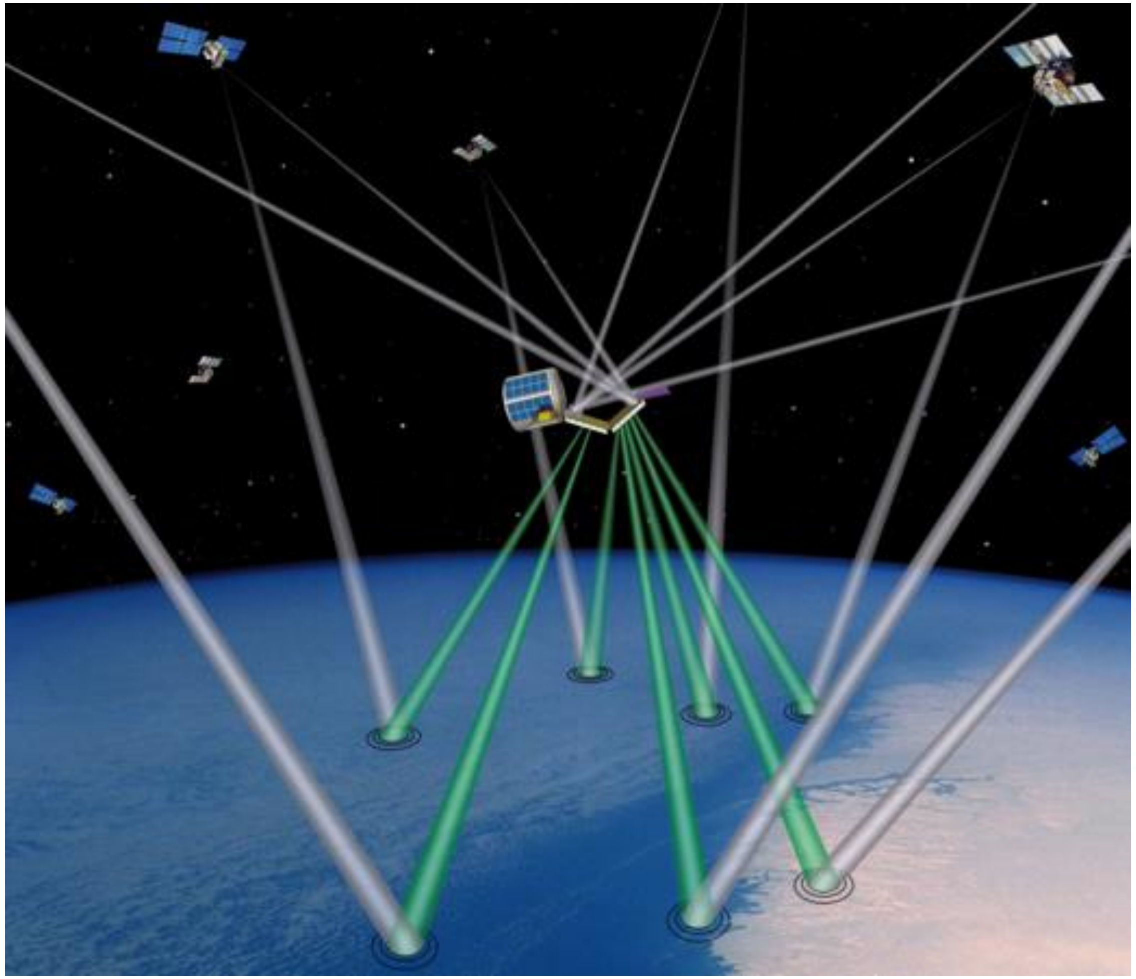
What is GNSS-Reflectometry (GNSS-R)?



GNSS-R

- Radar with separate transmitter and receiver (bistatic radar)
- Forward-scattering
- Specular Point: Earliest arrival at receiver

Space-Based GNSS-R System



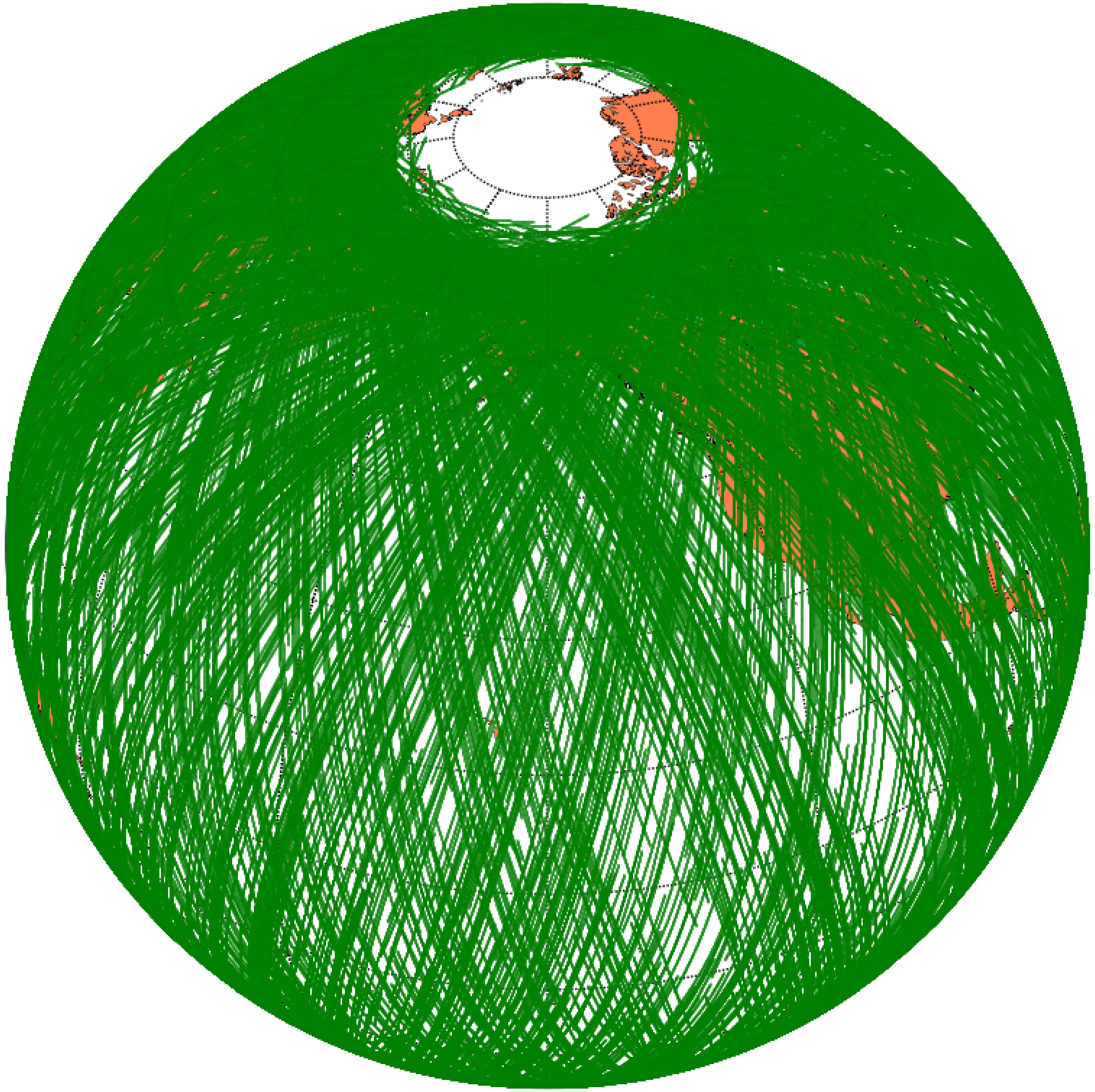
<u>GNSS-R</u>

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

<u>Many Advantages</u>

- 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’

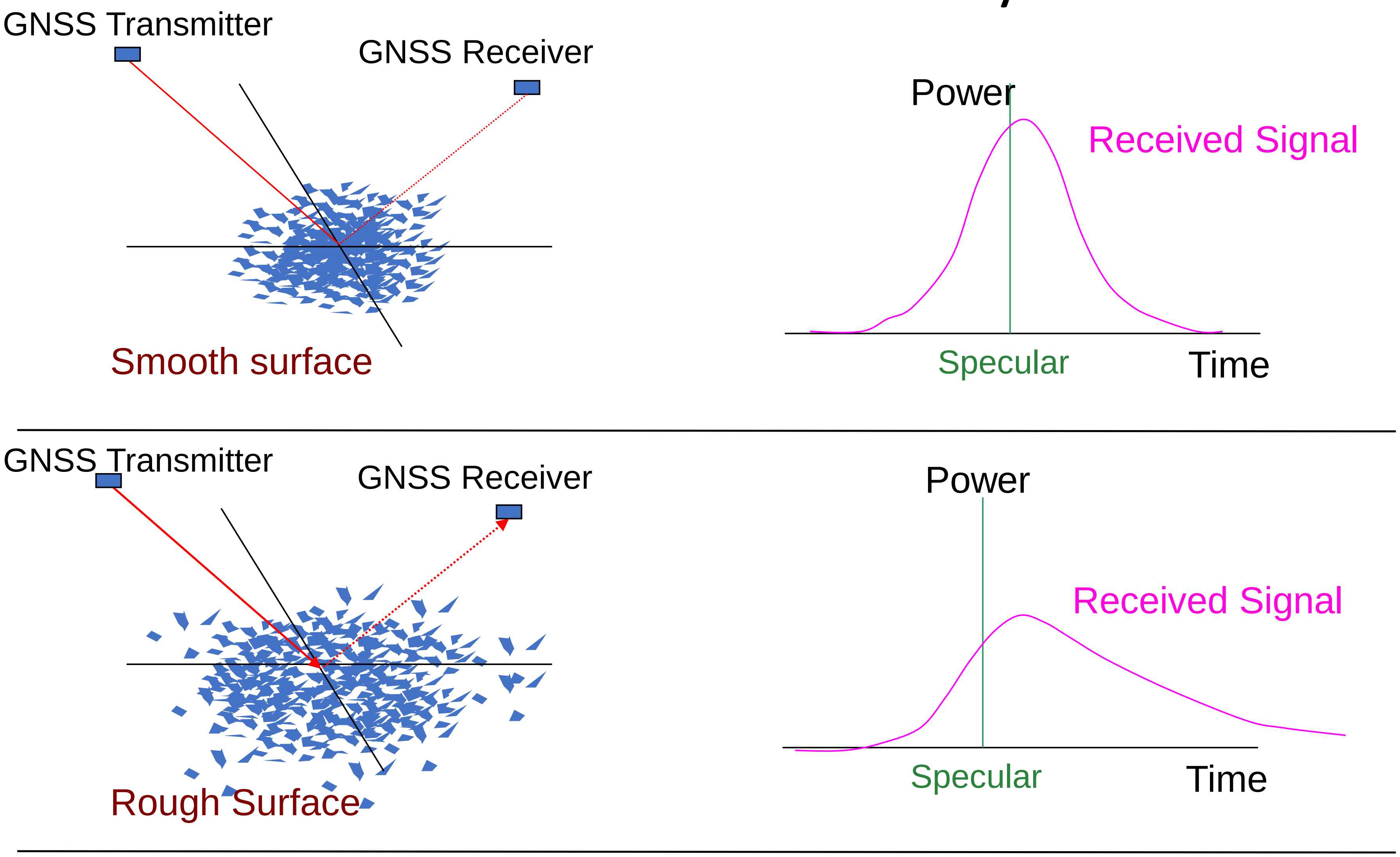
Surface Coverage



Coverage Simulation:

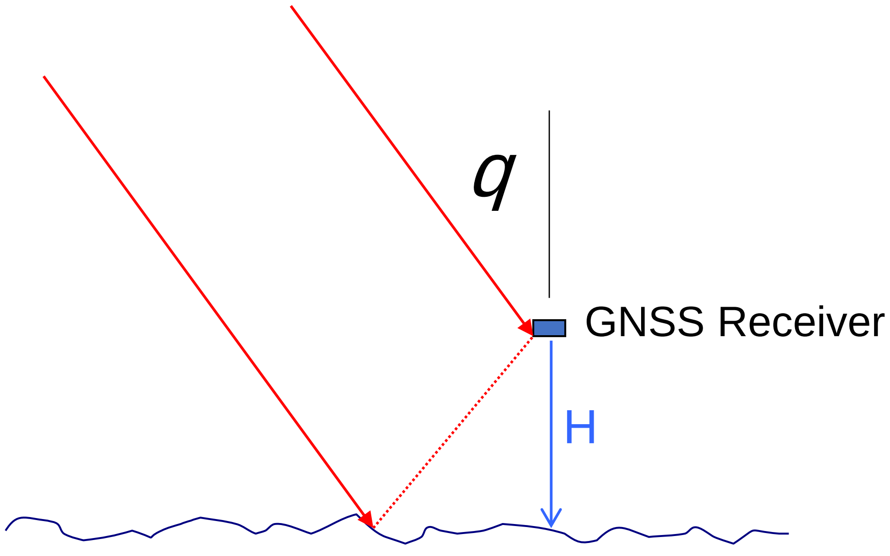
- 6-satellite constellation
- High inclination orbit (72 deg)
- 1 day
- GPS + Glonass + Galileo

GNSS-R Scatterometry

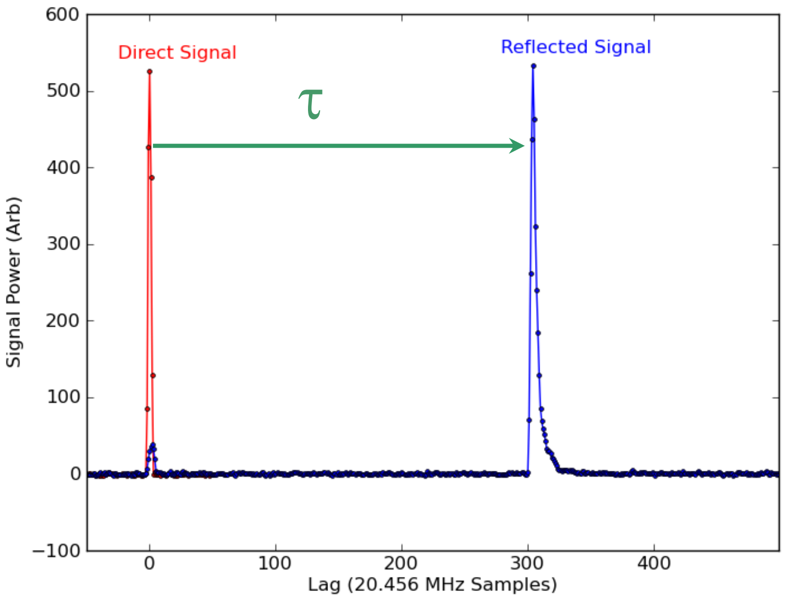


Smooth surface: Higher peak, faster rise
Rough surface: Lower peak, slower rise

GNSS-R Altimetry

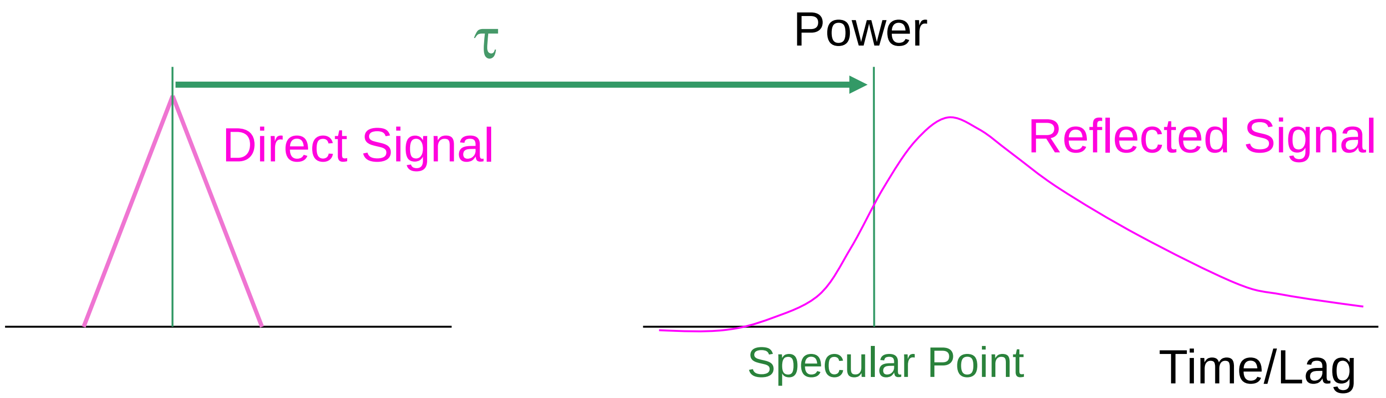


$$t = 2H\cos q$$



JPL 2003 Monterey-Bay aircraft test

Time delay (τ) between direct and ocean-reflected signal gives information on receiver height over surface



GNSS-R Bistatic Radar Equation

$$W(t) = c_0 \int_s \frac{G(\rho)\Lambda^2(t - t_{spec})\,\mathrm{sinc}^2(T_I \Delta f(\rho))}{4\pi R_t^2 R_r^2} \sigma_o^p(\rho)\, ds$$

Antenna pattern on surface
Autocorrelation Fcn
Receiver Integration
Scattering
Related to PDF of surface slopes
Geometry
Altimetry
Scatterometry

Zavorotny, V. U. and A. G. Voronovich, Scattering of GPS Signals from the Ocean with Wind Remote Sensing Application, *IEEE Transactions on Geoscience and Remote Sensing*, Vol. 38, No. 2, 951-964, 2000.

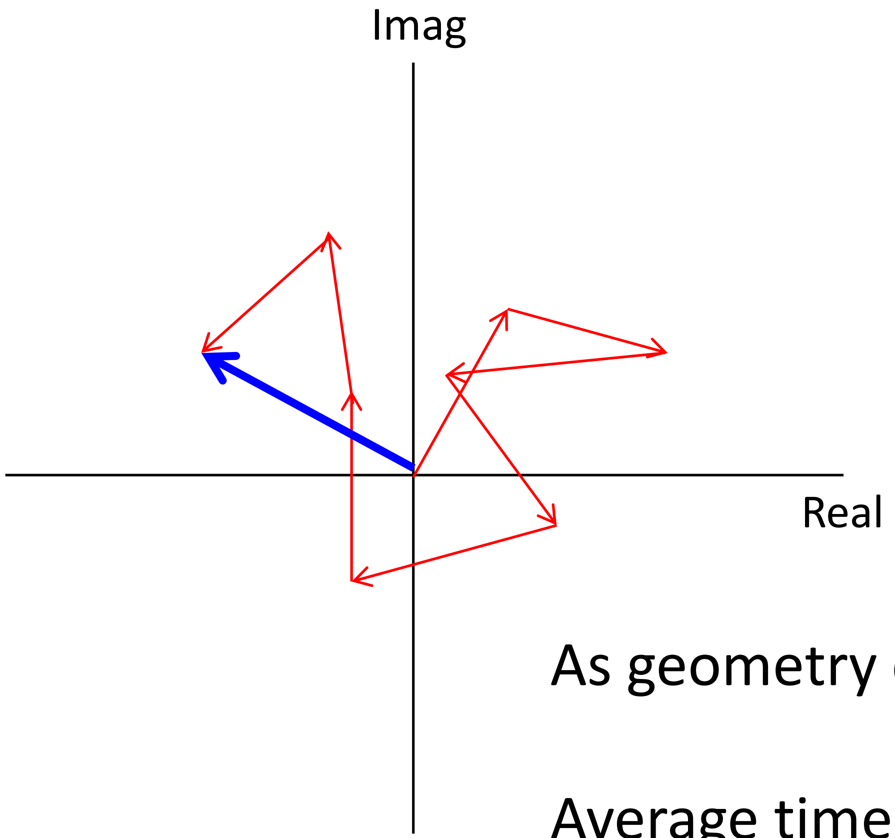
Scatterometry (oceans)

- This technique measures surface Mean-Squared Slopes (MSS)
- MSS related to wind speed through empirical model

Altimetry

- Specular timing relative to direct-signal reception

Signal Incoherence



- Received signal is sum over all surface facets
- Rough surface: resulting phasor has random phase
- Resulting power is exponentially distributed

  => Power SNR = 1   (speckle)

As geometry changes (receiver movement) the phasor sum changes.

Average time for phasor sum to be uncorrelated to previous sum is the signal's correlation time.

Aircraft: ~10 msec
Spacecraft: ~1 msec

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

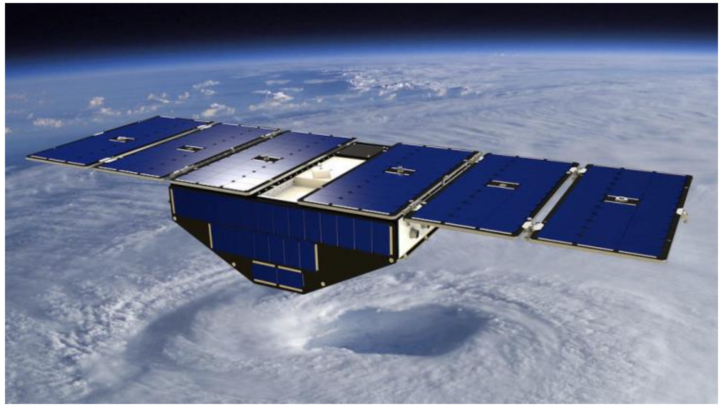
What’s Happening in the GNSS-R Field?

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?

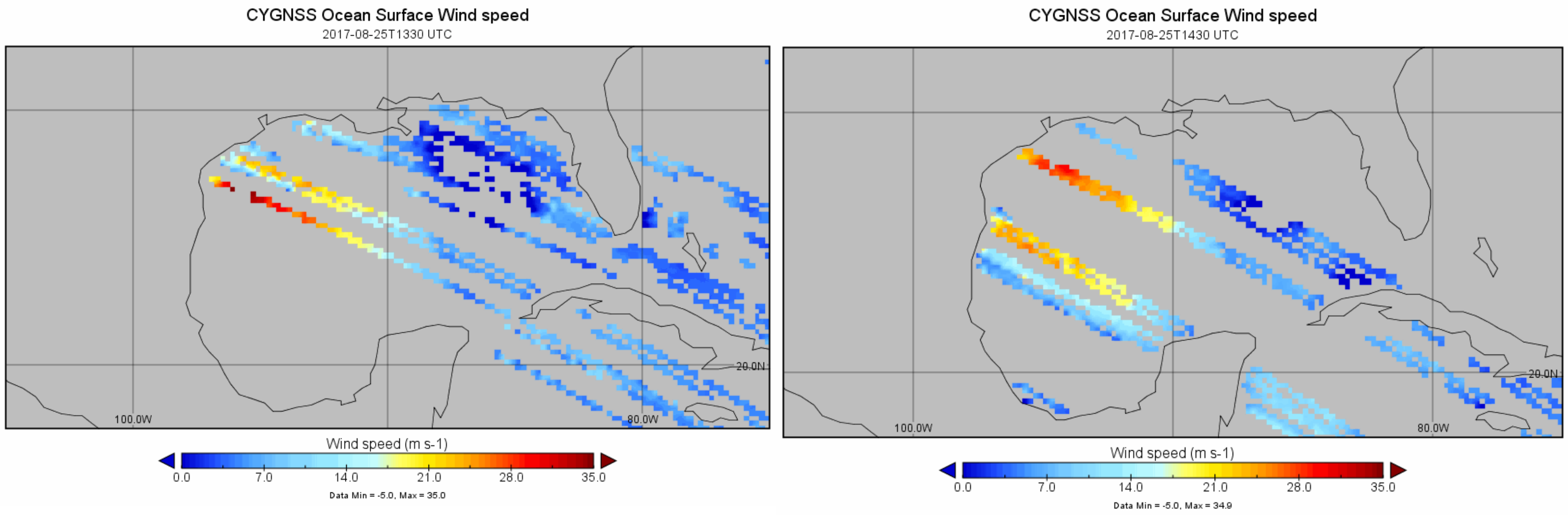
CyGNSS Satellite



<u>CyGNSS: NASA Earth Venture Mission</u>

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

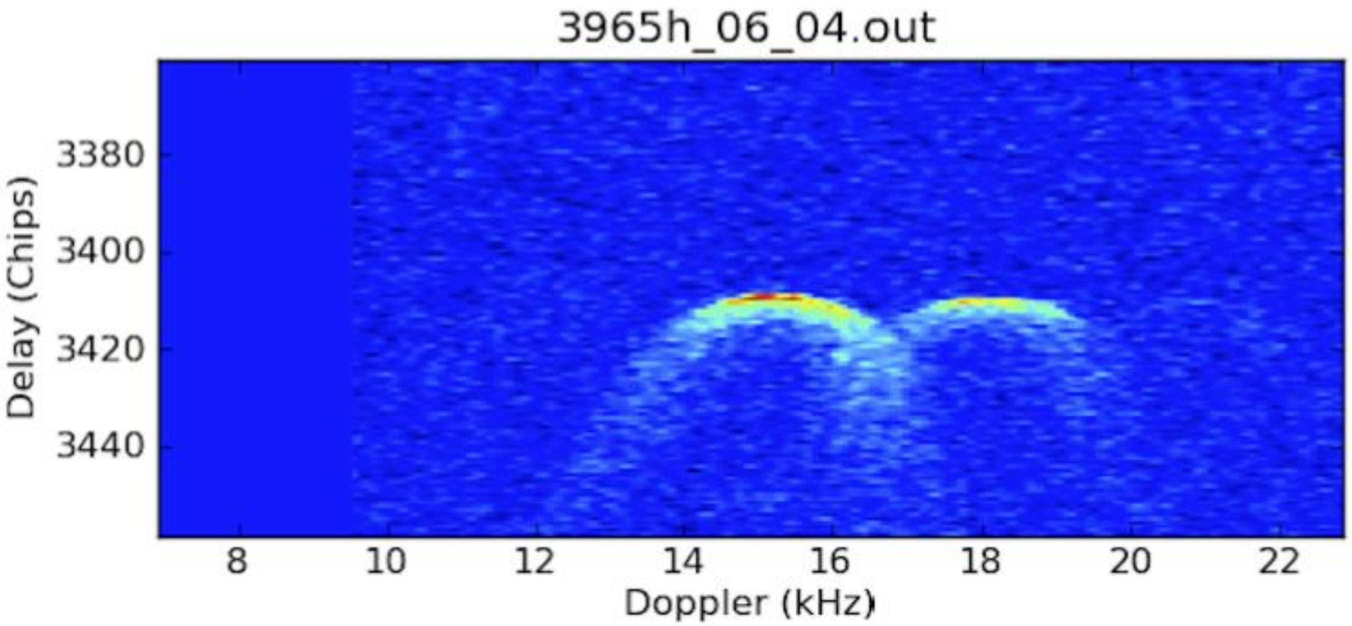
Observations of Hurricane Harvey Prior to Landfall on August 25, 2017



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?



Delay-Doppler Map (DDM) has aliased images due to data blanking

NASA's Soil Moisture: Active & Passive (SMAP)

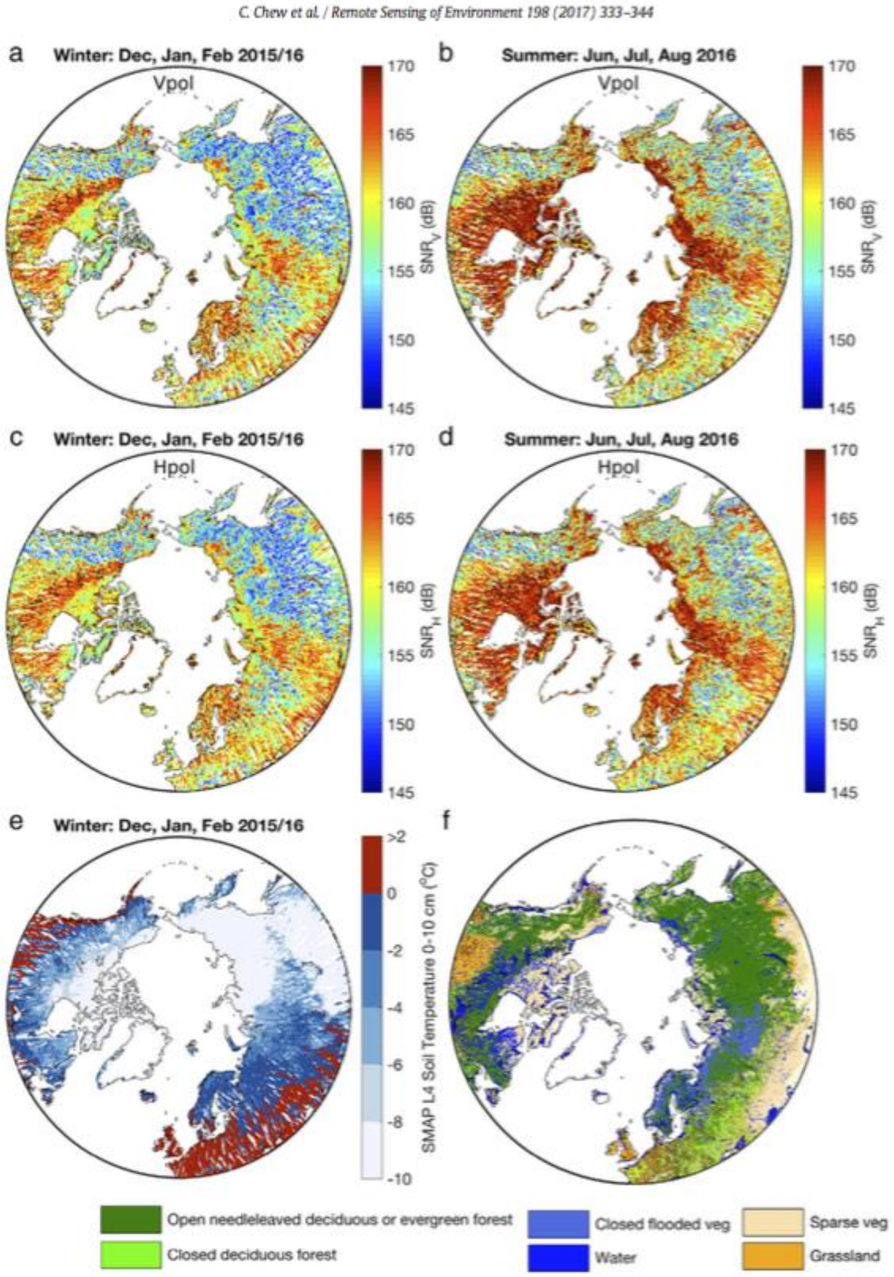
- Dedicated soil-moisture mission
- Active L-band radar + passive radiometer
- Radar transmitter failed 7/7/15
- On 8/20/15, radar receiver moved to collect GPS L2

Unique GNSS-R data set

- High gain antenna (~30 dB)
- Dual polarization (H/V)
- Raw sampled data downloaded
  - Look at phase, coherence, integration times, etc
- Hope to make DDM + metadata public soon

Created unique GNSS-R data set from failed radar system

What's Happening in the GNSS-R Field?



SMAP GNSS-R Observes Freeze/Thaw

Vertical Polarization

Winter Summer

Horizontal Polarization

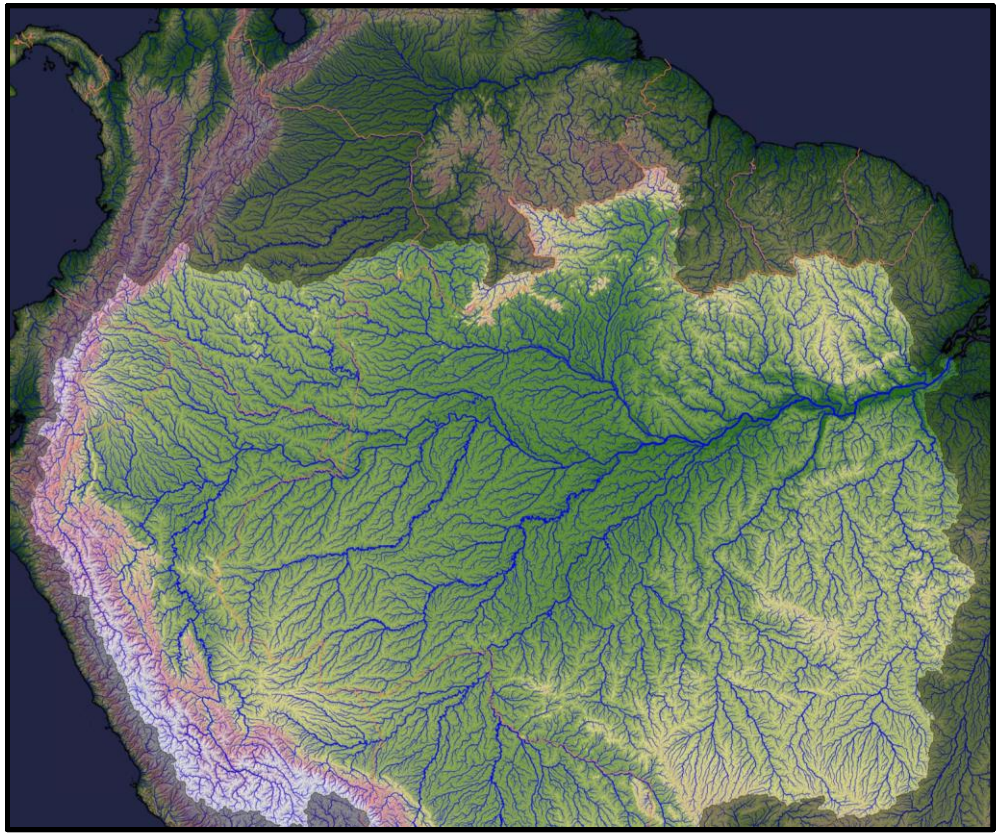
Winter Summer

Winter Temp (blue frozen) Vegetation Type

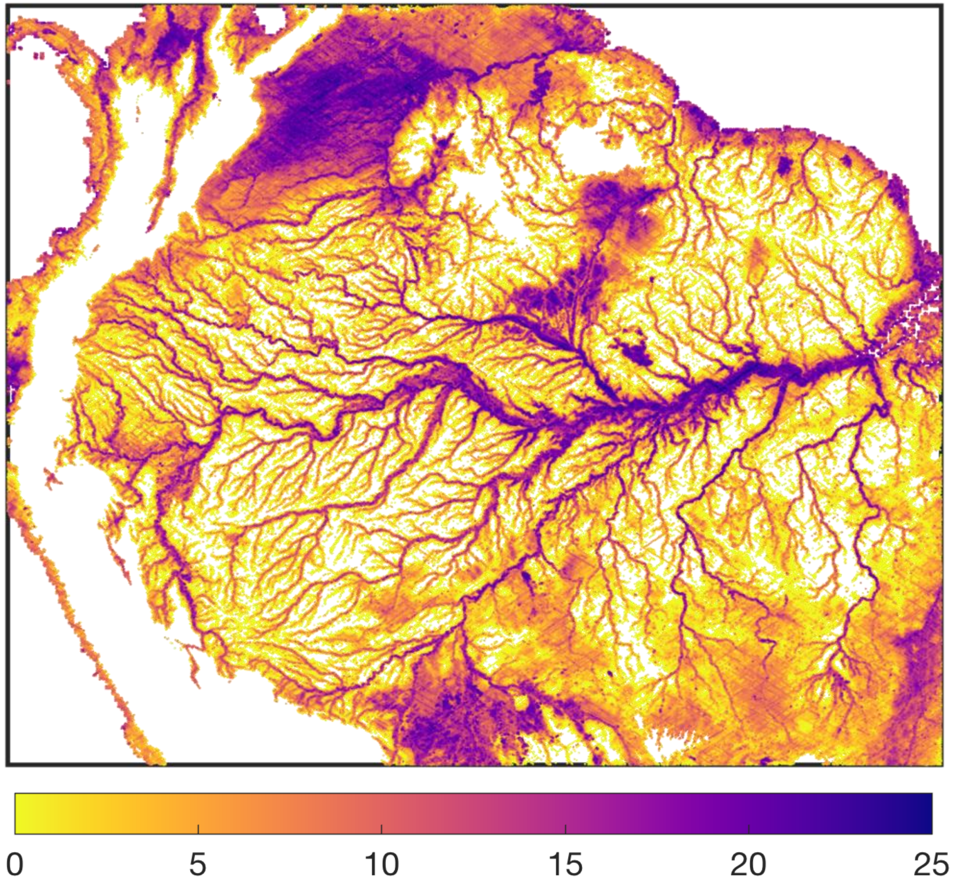
From Chew et al, Remote Sen Env 198, 2017

What's Happening in the GNSS-R Field?

HydroSheds Database



CyGNSS Data: SNR vs location



White: Outside CyGNSS delay window

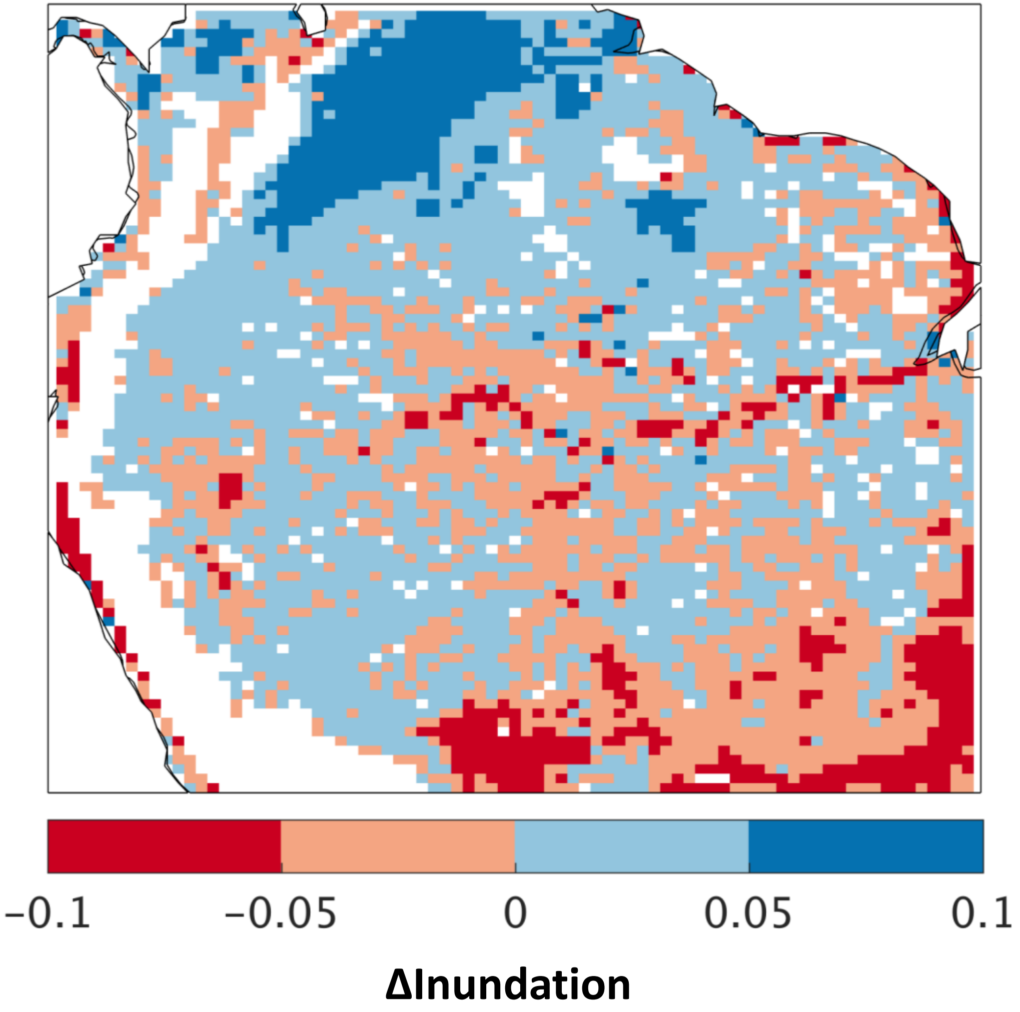
Amazon Rainforest

Courtesy Clara Chew (UCAR)

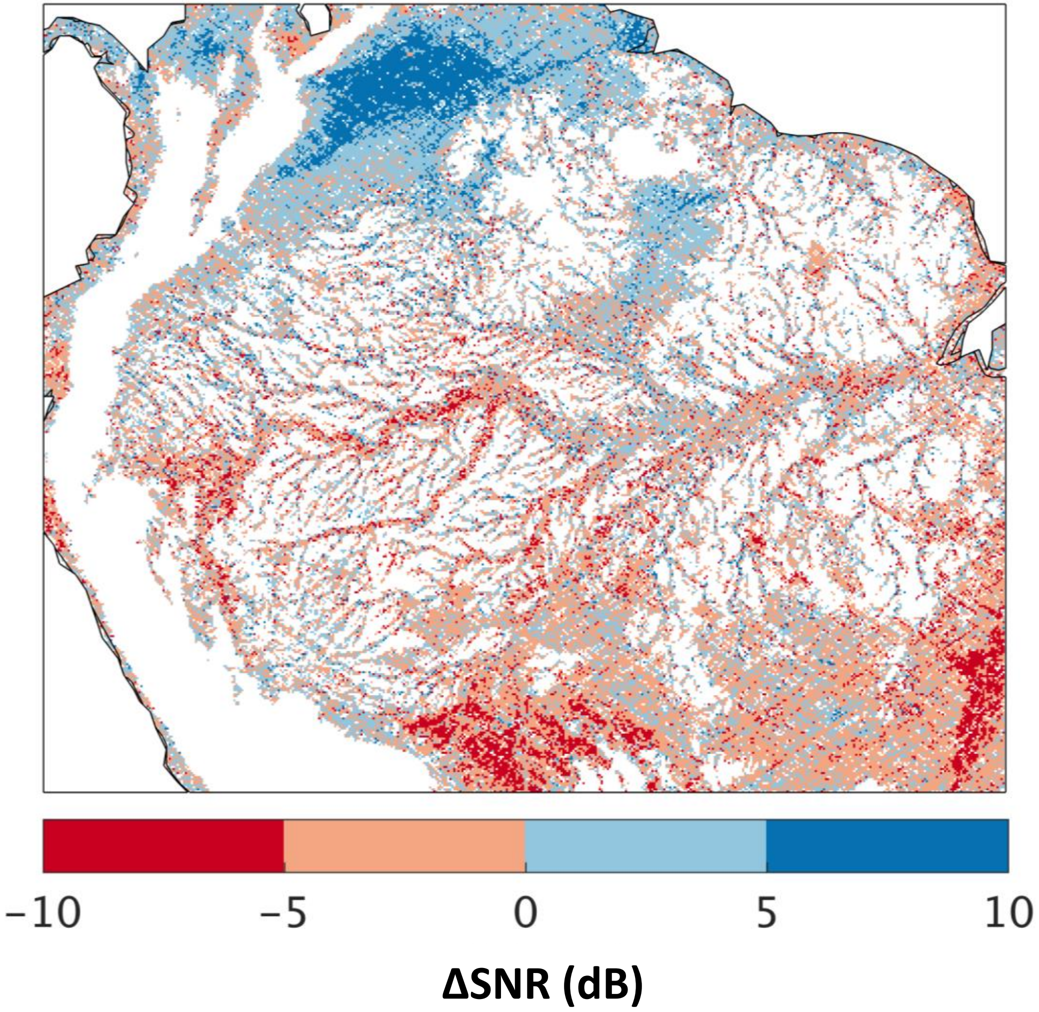
What’s Happening in the GNSS-R Field?

Change in SNR: Aug - Mar

SMAP Radiometer (J. Du, et al)



CyGNSS Data



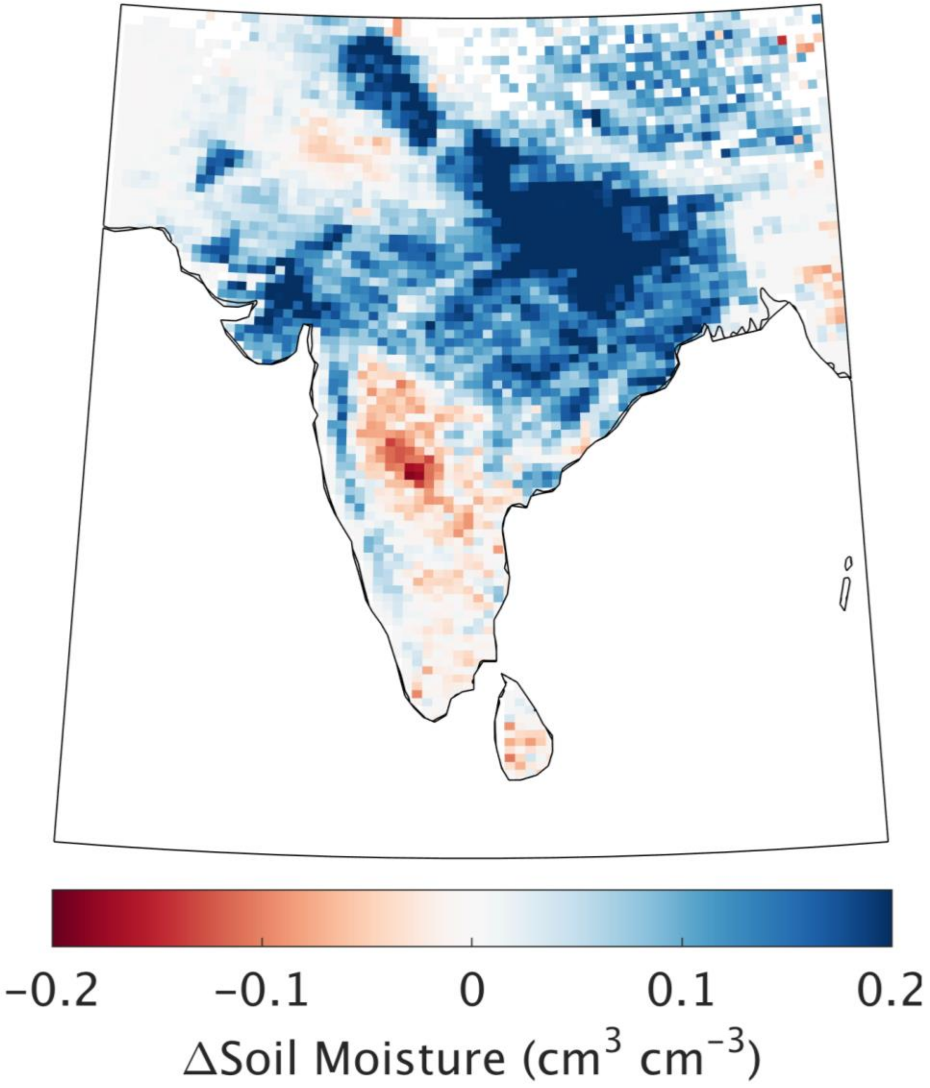
Amazon Rainforest

Courtesy Clara Chew (UCAR)

What’s Happening in the GNSS-R Field?

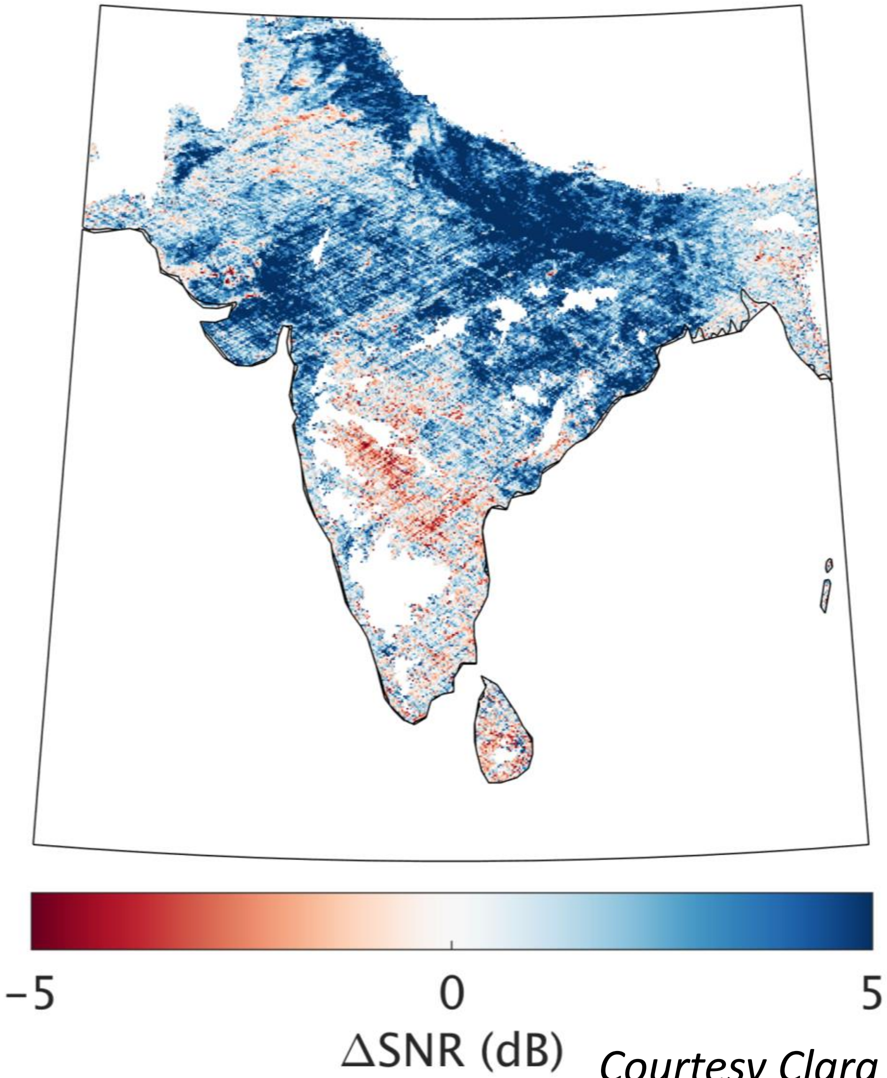
Change in SNR: Apr - Mar

SMAP Radiometer: Level 3



India

CyGNSS Data: SNR Change



Courtesy Clara Chew (UCAR)

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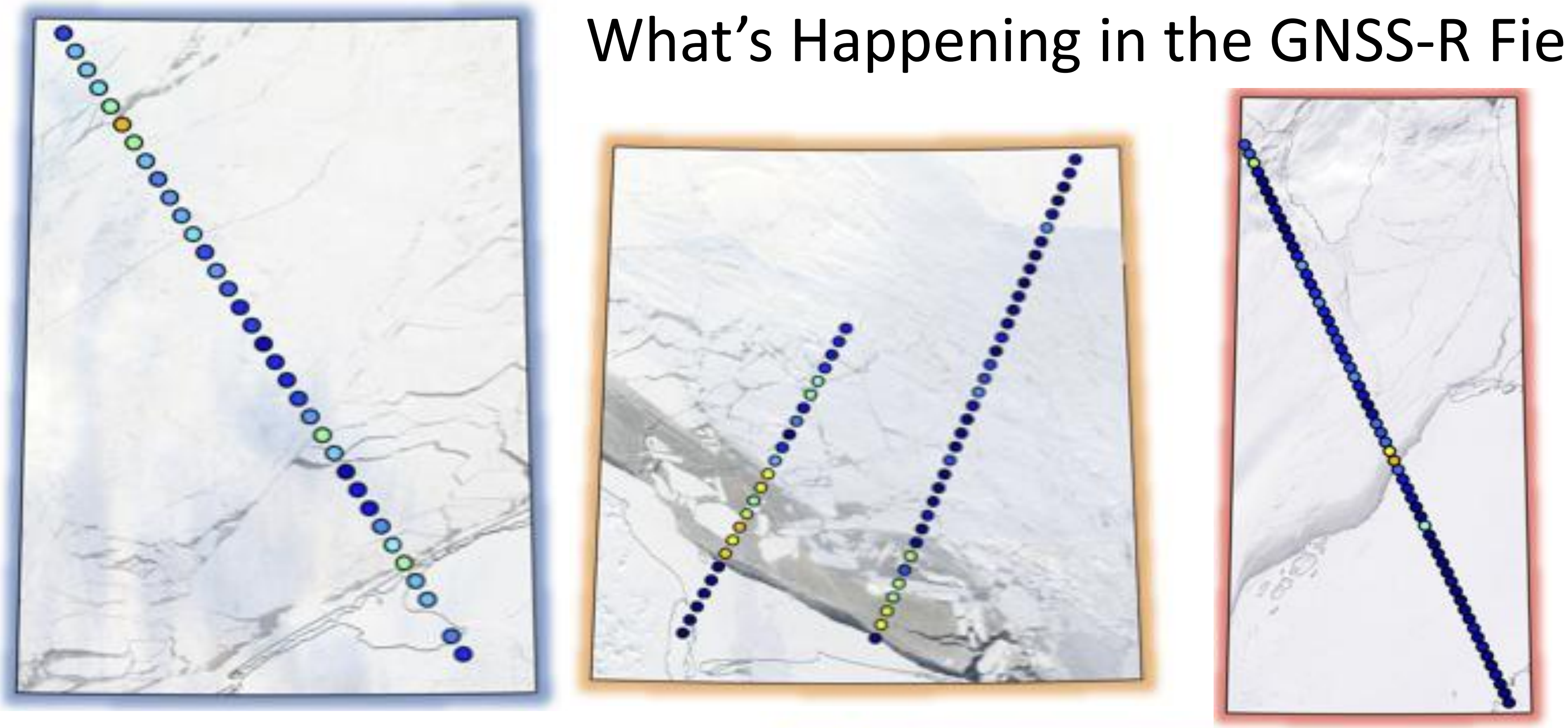
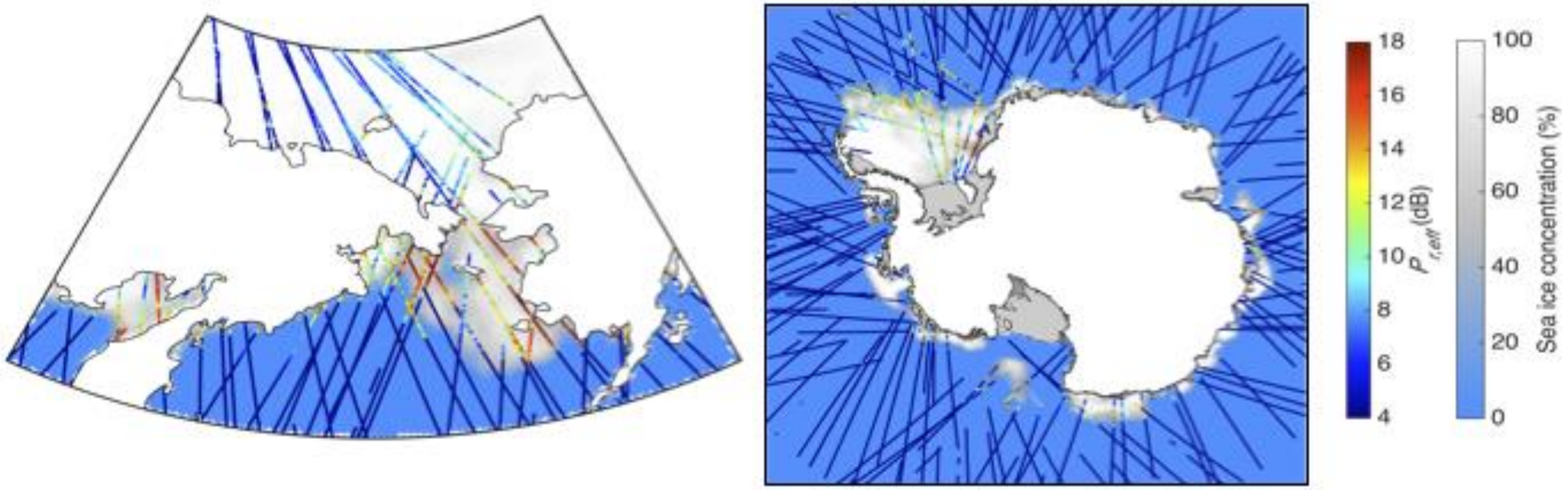


<u>TechDemoSat-1 Data</u>

- 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

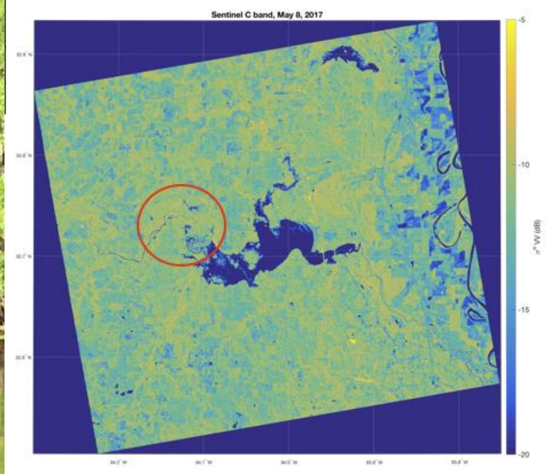
Courtesy Clara Chew (UCAR)

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

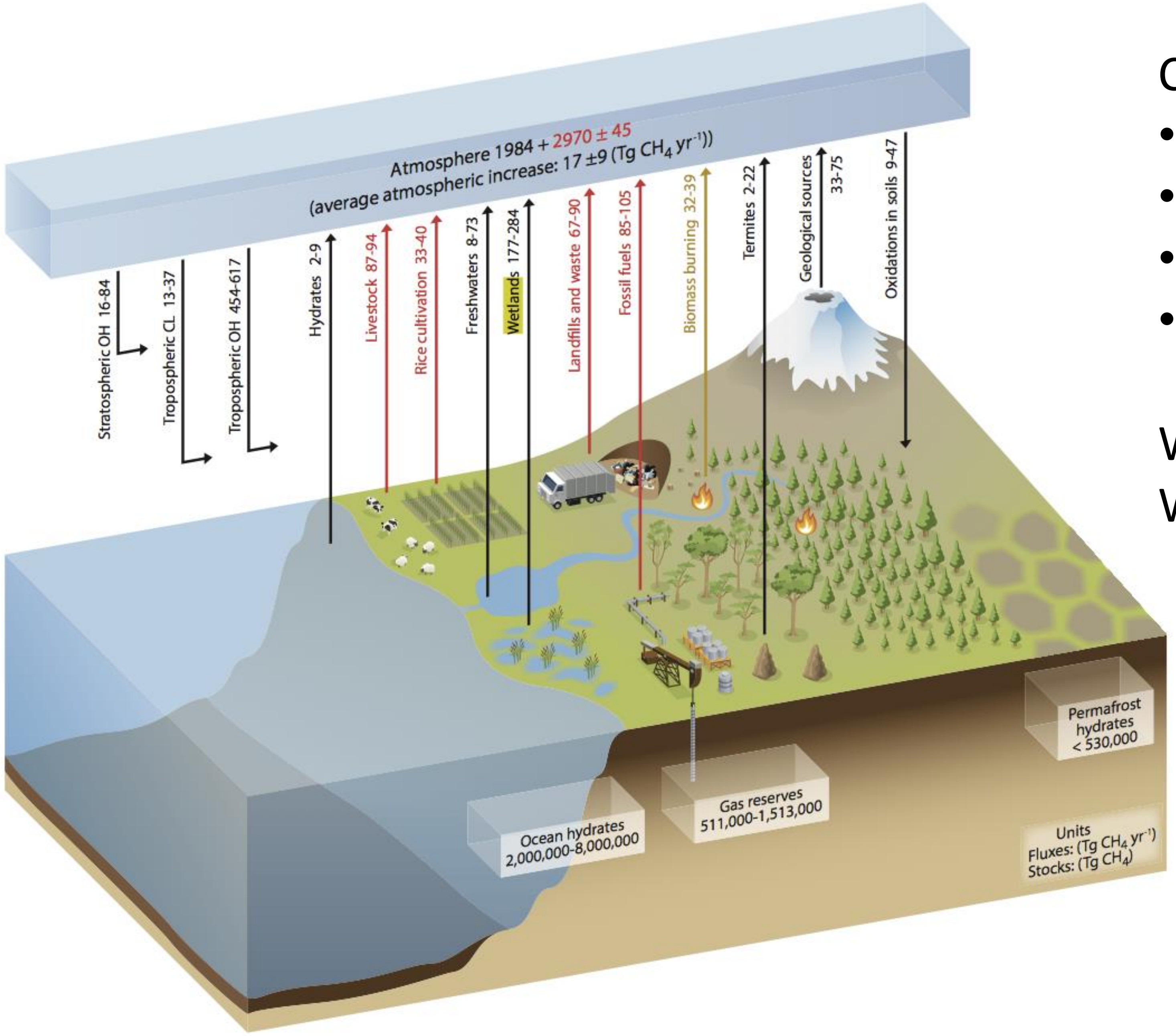


Summary

- 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

Backup Slides

Global Methane Cycle



Contributions to Atmospheric Methane

- Wetlands (177-284 Tg/yr)
- Fossil Fuels (85-105 Tg/yr)
- Livestock (87-94 Tg/yr)
- Landfills (67-90 Tg/yr)

Wetlands has largest contribution
Wetlands has largest uncertainty range

IPCC (2013), Climate Change 2013: *The Physical Science Basis*, Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change