Spire Operational GNSS-R Constellation: Missions and Products

Philip Jales , Jake Mashburn, Jessica Cartwright, Vahid Freeman, Matthieu Talpe, Takayuki Yuasa, Oleguer Nogues - Correig, Vu Nguyen

ESA Living Planet Symposium

23rd - 27th May 2022

B7.05.1 GNSS Radio Occultation and Reflectometry in the NewSpace context

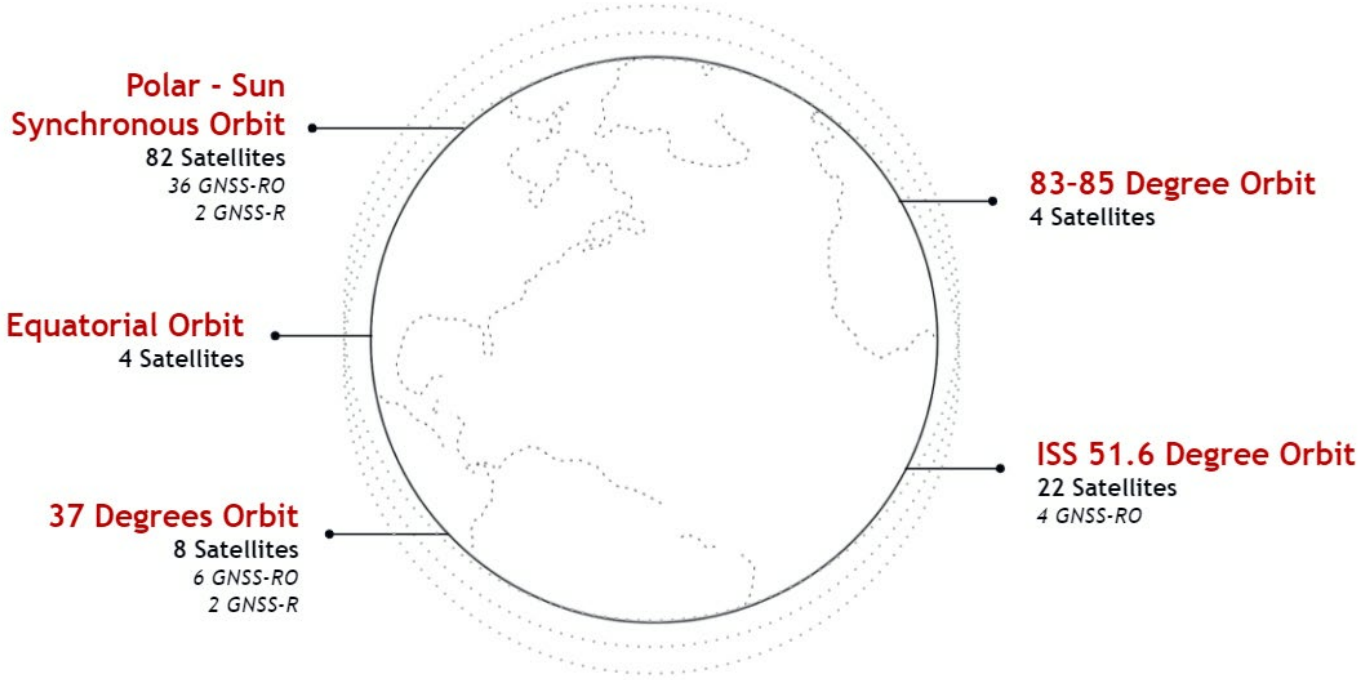
Spire Earth Intelligence Constellation

Data from a constellation of many Spire EO satellites is a resilient and sustainable solution for Earth observation

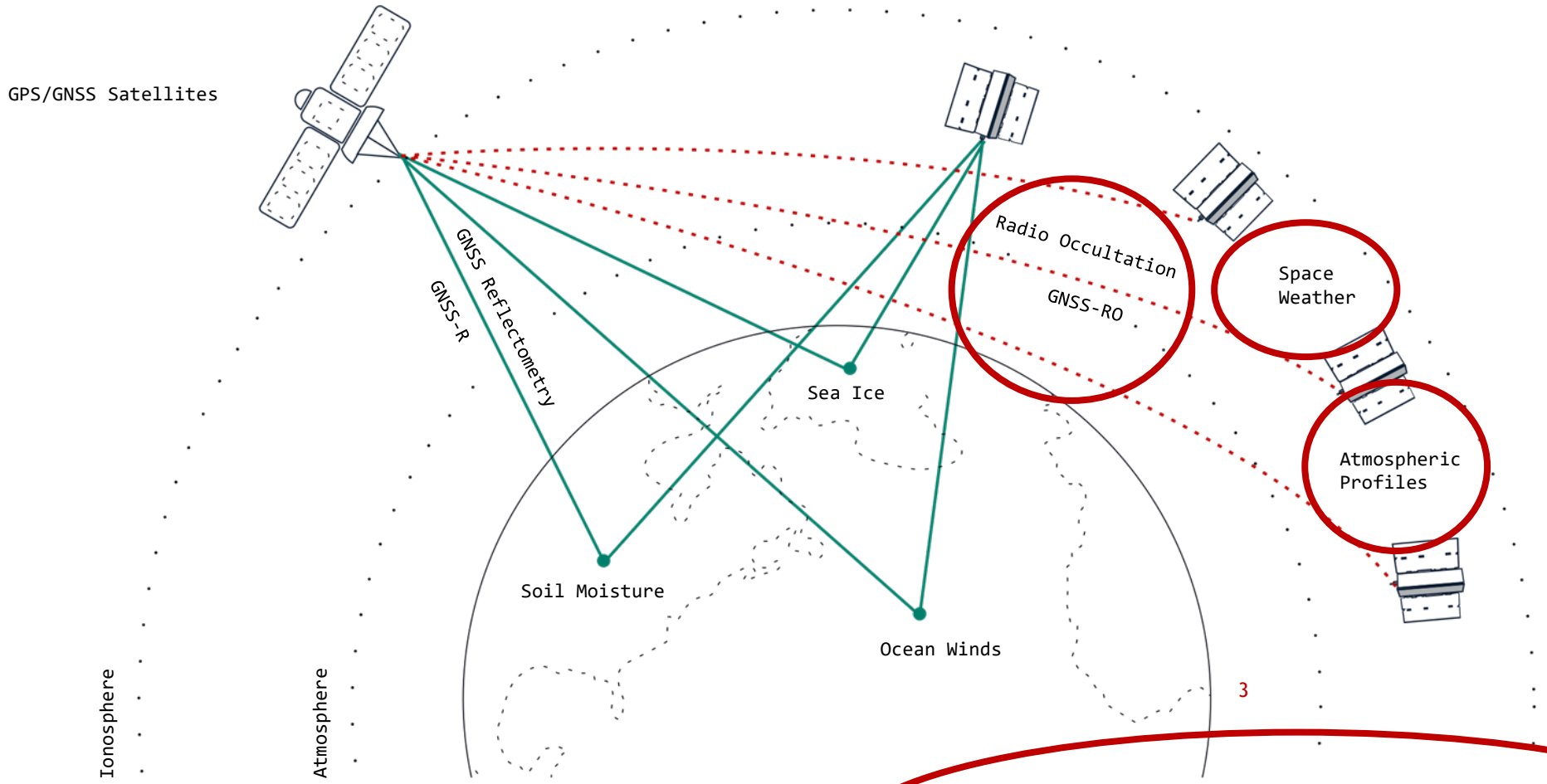
- 120+ LEO nanosatellites in diverse orbits for global coverage, high spatial and temporal sampling, and system redundancy

Earth observation

- 40+ GNSS-RO-capable sats and 25+ in GNSS-RO production
- 4 GNSS-R sats in 37° and SSO orbits



Spire GNSS-Based Earth Observations



GNSS-Reflectometry (GNSS -R)

- Surface measurements of: soil moisture, sea ice and ocean roughness

GNSS-Radio Occultation (GNSS -RO)

- Atmospheric sounding for NWP, climate
- Ionospheric so unding for space weather monitoring

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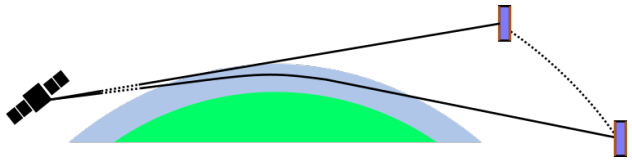
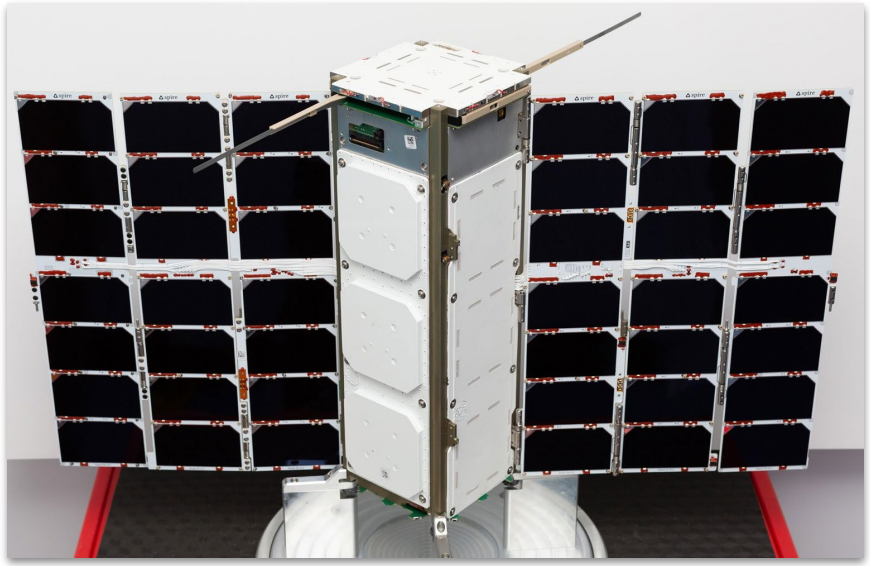
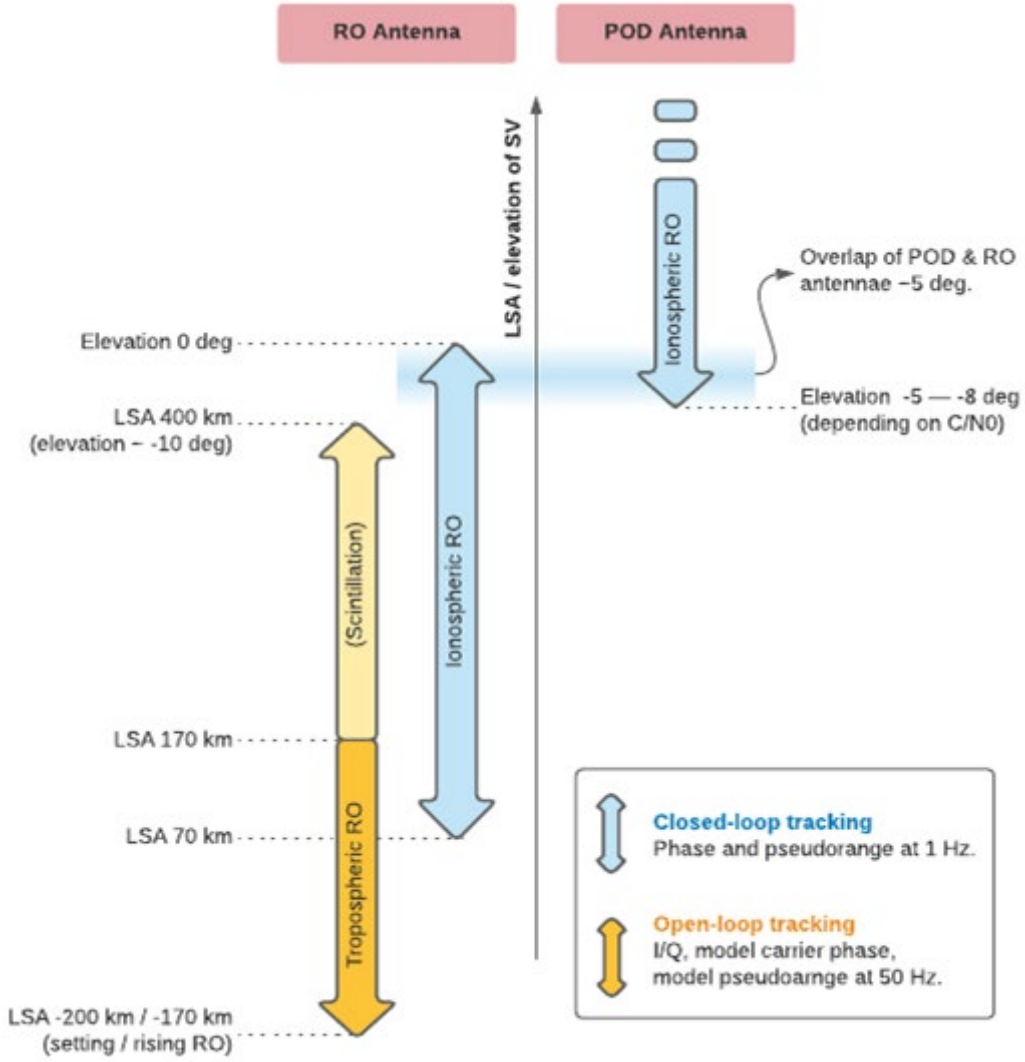
GNSS-RO Collection



Spire GNSS-RO satellites

- 3U form factor
- Moderate gain, dual antennas (rising/setting RO)
- Multi -GNSS signals tracked in open-loop
- Collection strategy also valuable for ionospheric studies





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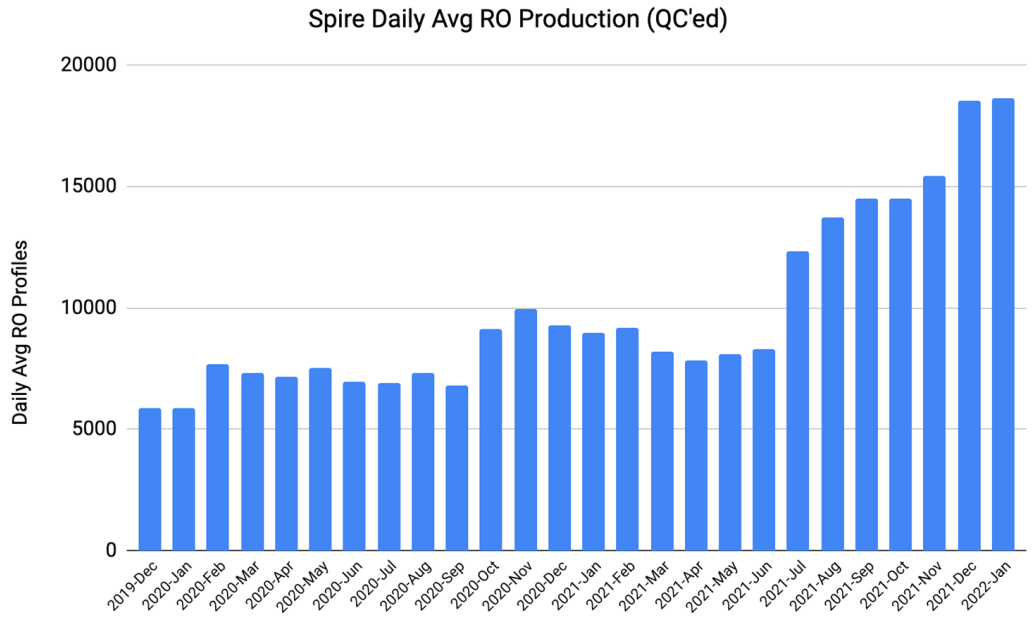
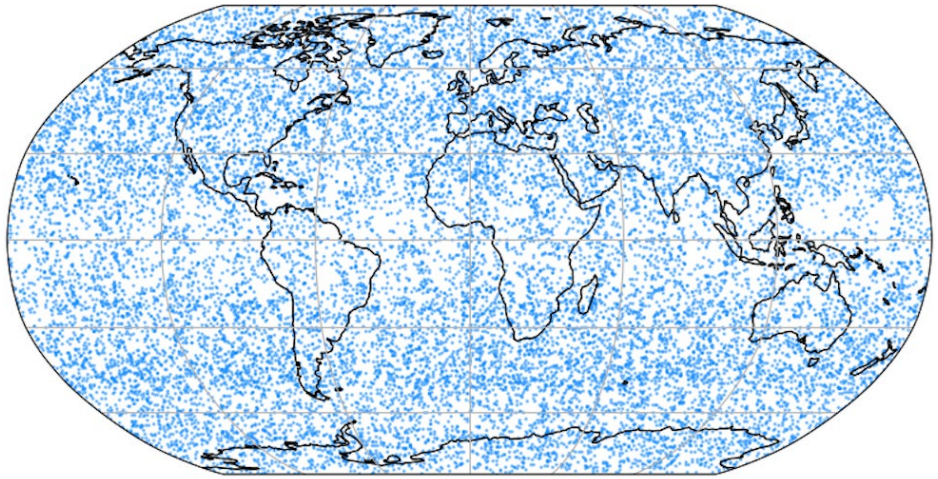
Growing GNSS-RO Volume and Coverage

- Spire constellation is currently producing **18000+ quality - controlled profiles per day** and within reach of IROWG/CGMS long-term goal of 20000 per day
  - More Spire RO profiles in the past 24 months than the *entire* COSMIC-1 14 yr mission
- Continual spacecraft bus and ground station additions and improvements to increase efficiency and decrease data latency

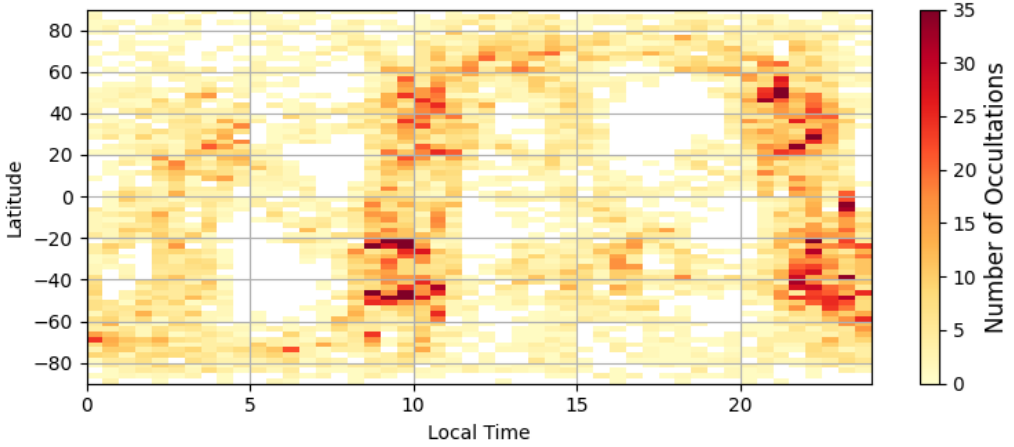
Long-term RO production increase



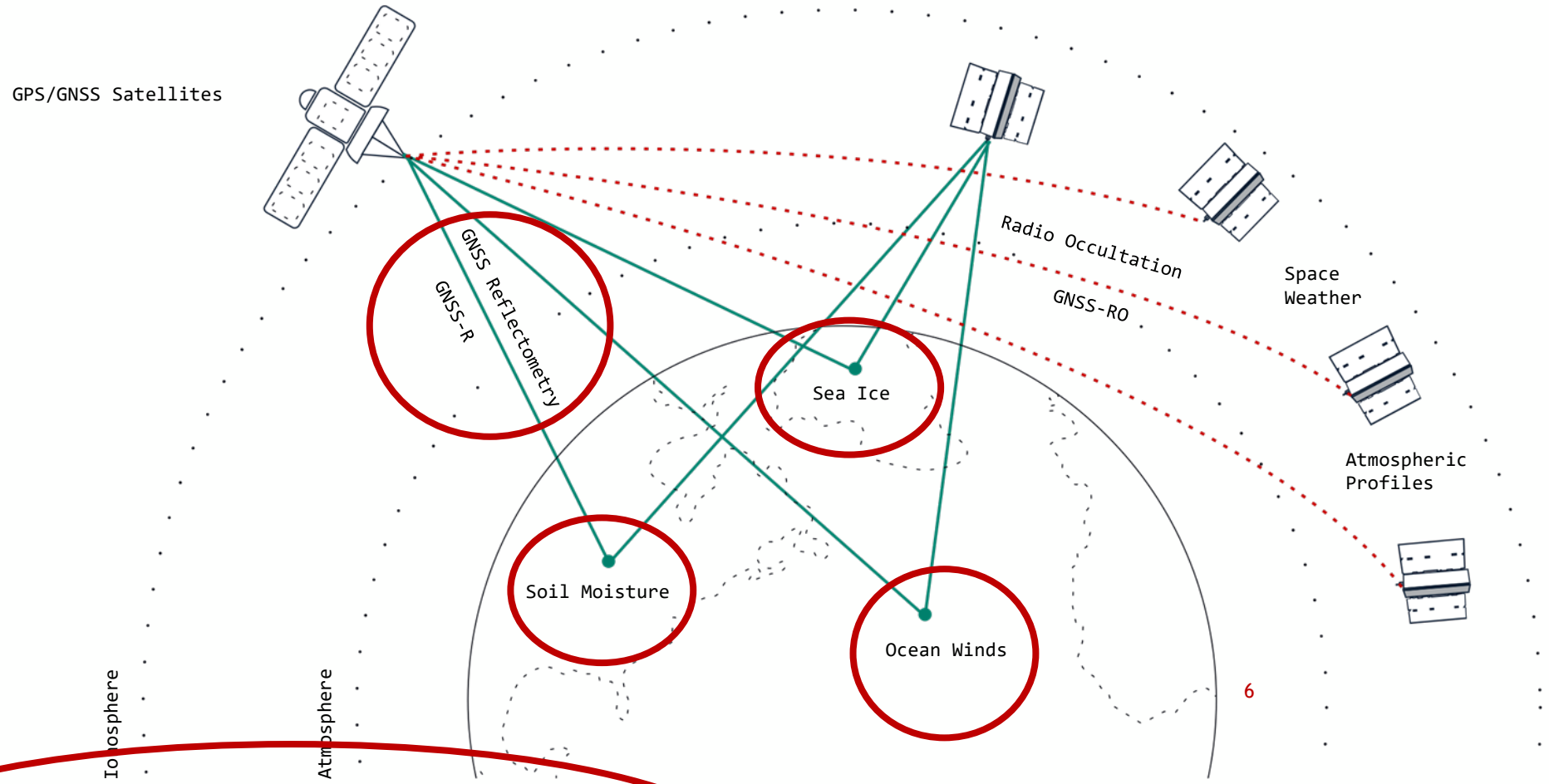
World's largest producer of RO profiles



Diverse local time coverage



Spire GNSS-Based Earth Observations



GNSS-Reflectometry (GNSS -R)

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- Atmospheric sounding for NWP, climate
- Ionospheric so unding for space weather monitoring

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Spire GNSS-Reflectometry Constellation

Conventional GNSS-R

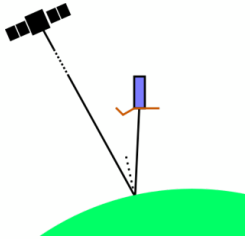
- Collaboration with ESA through the ARTES Pioneer Programme
- **4 satellites** launched in 2 batches

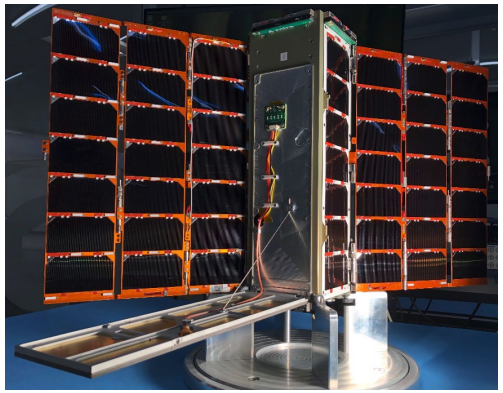
Antennas

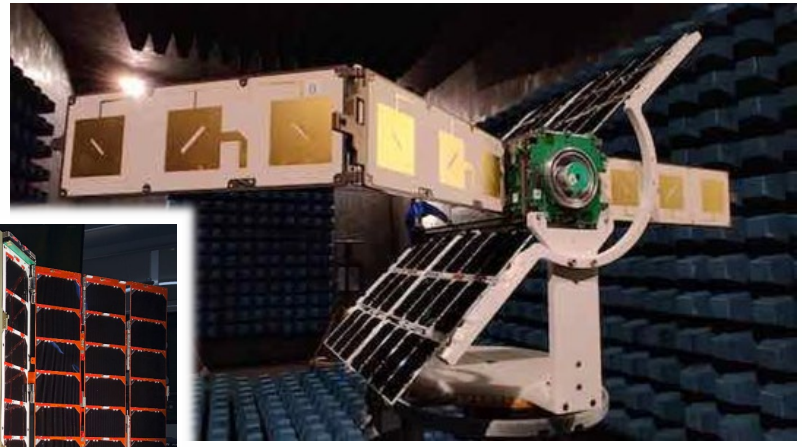
- **LHCP** antennas (x2 or x3) pointing near to nadir
- Antenna beamforming
- Advanced relative calibration

Processing

- Multi-GNSS (GPS, Galileo, QZSS, Beidou.)
- DDM signal processing (upto 30 channels)







Grazing angle GNSS-R

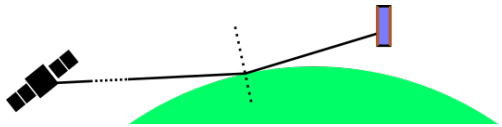
Uses Spire's existing GNSS-RO constellation with added software for grazing angle GNSS-R. **Mature and operational on 25+ satellites**

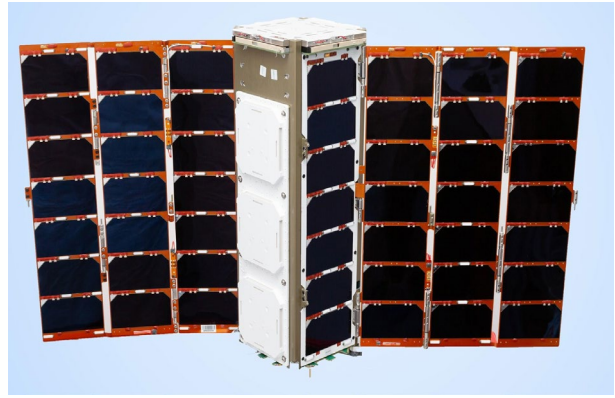
Antennas

- **RHCP** antennas: dual antennas for rising/setting Radio Occultation (RO)

Processing

- Multi-GNSS (GPS, Galileo, GLONASS, QZSS, Beidou.)
- Coherent signal processing





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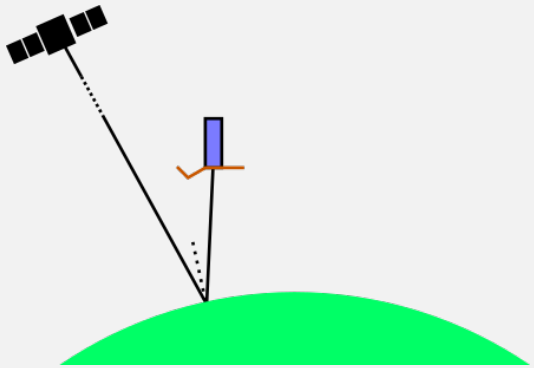
Spire Conventional GNSS -R



- Around nadir GNSS-R (20°-90 ° elevation)
  - LHCP polarisation
  - DDM observations

Spire GNSS-R Reflectivity

- The reflectivity measurements are sensitive to:
  - Dielectric constant => **soil water content, freeze/thaw**
  - Roughness => **ocean wind/wave, ice characterisation**
- Here we show L-band reflectivity (gridded mean land BRCS and ocean nBRCS) for October 2021
- **Combining all FMs** to give dense global coverage
- Operational coverage of high latitudes
  - `L1 gbrRCS, gbrNRCS`

FM109, FM110, FM146, FM147
With all QC applied

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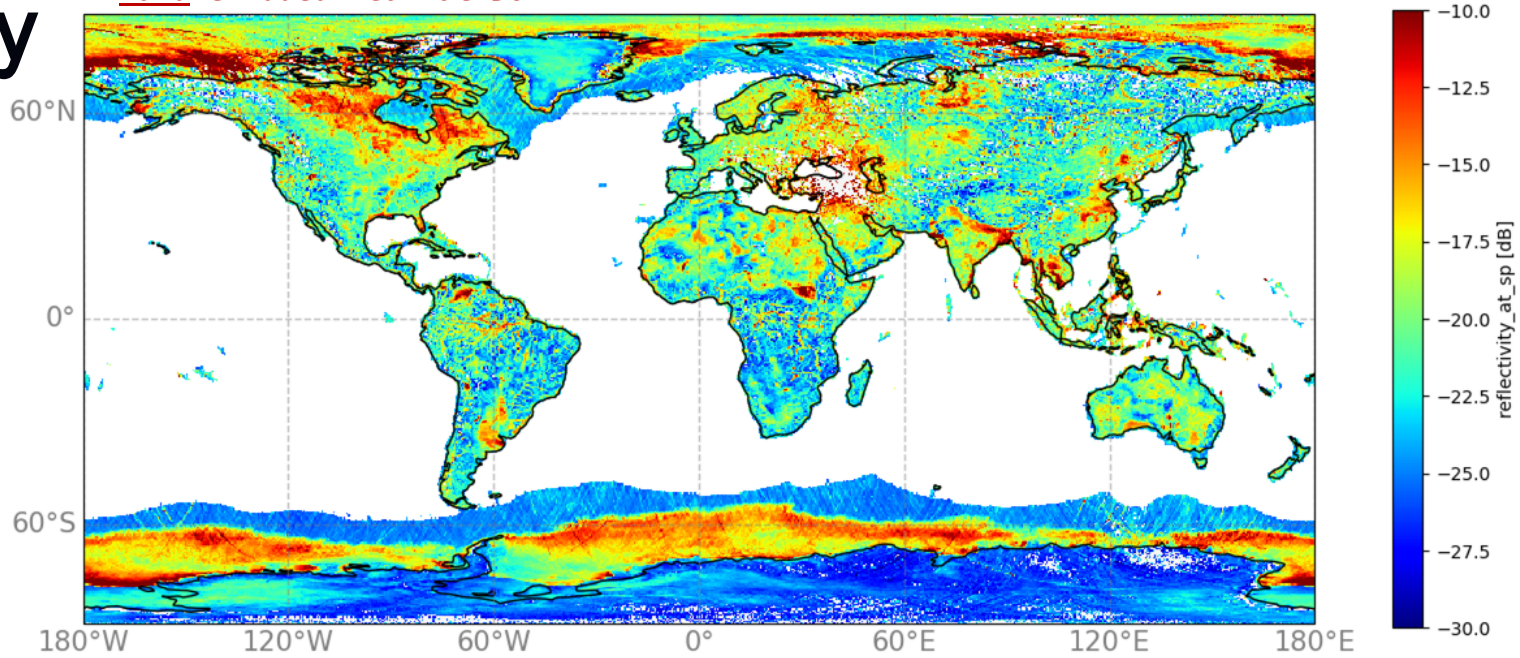
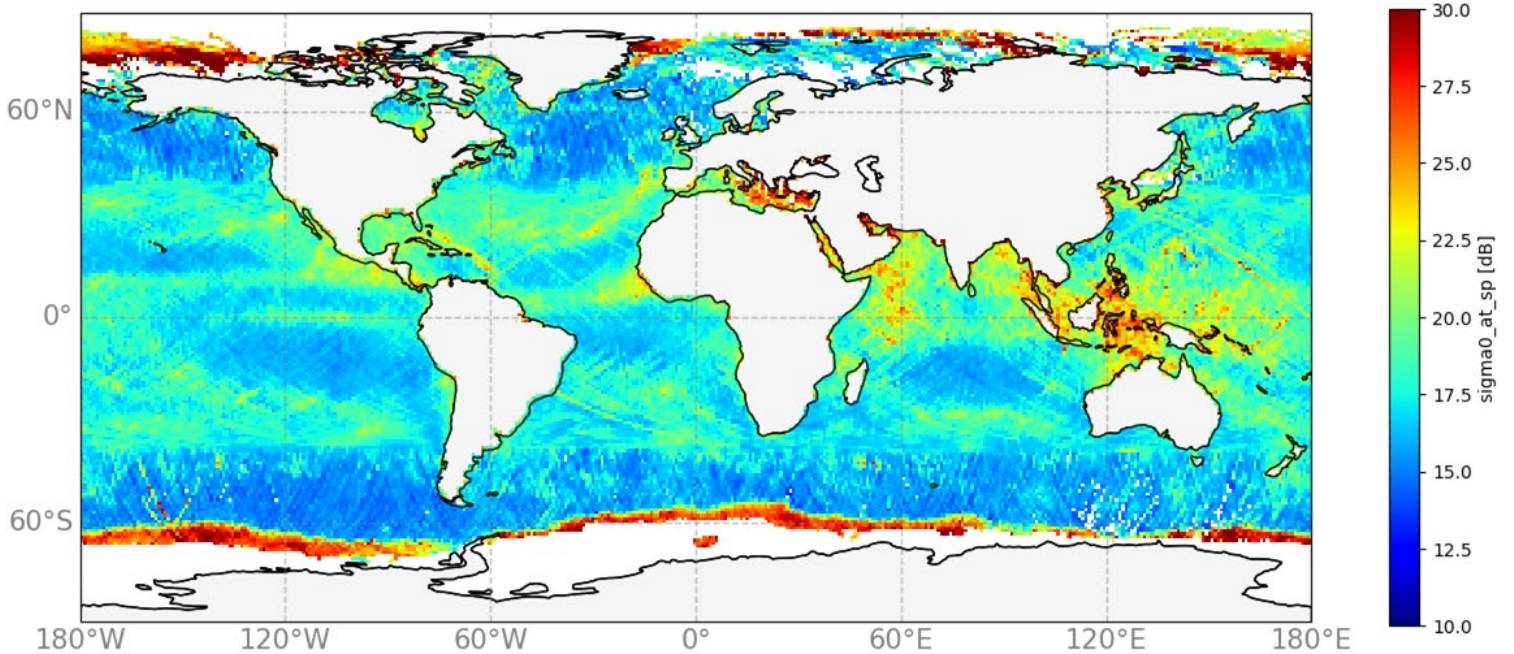
Reflectivity of all data for Oct 2021. (GPS+GAL+BEIDOU+QZSS)

Land Gridded mean at 50 km



Ocean Gridded mean at 100 km

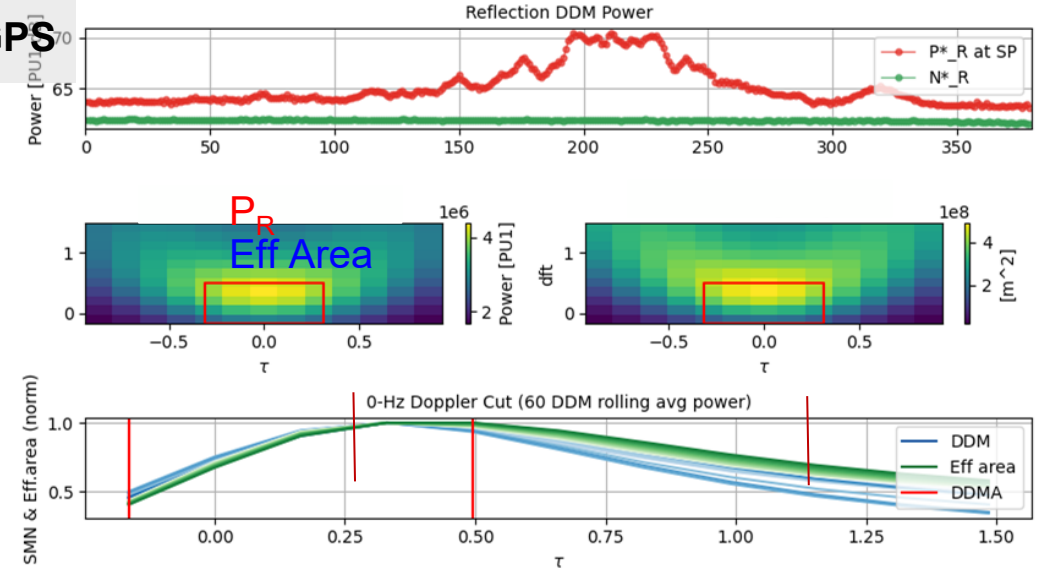


Multi -GNSS Tracking

- For GNSS remote sensing applications, **using more transmitters** improves coverage per receiver
- Spire utilises: GPS+Galileo+Beidou+QZSS
- Require **comparable reflectivity** despite **differing signal characteristics** (modulation, signal power)

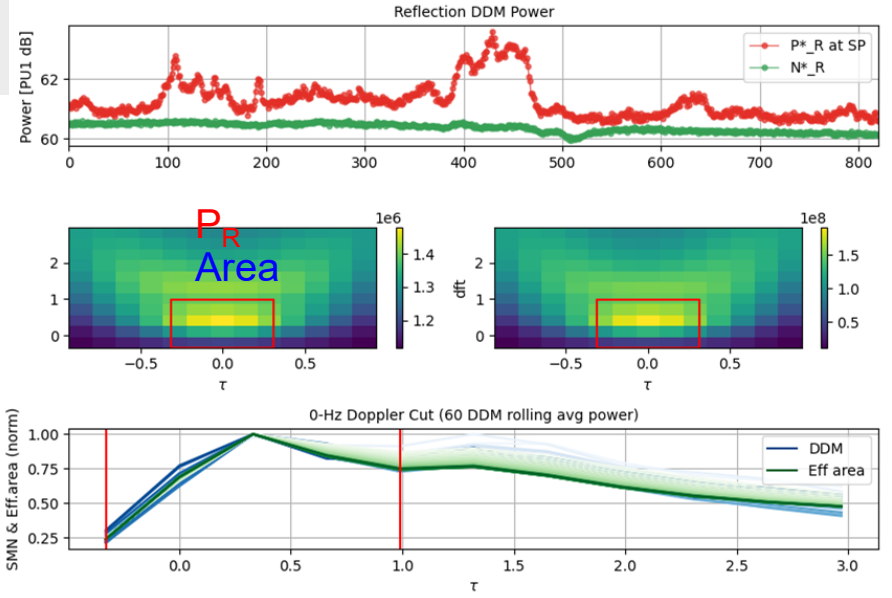
- **Spire relative calibration system compensates for differences among GNSS transmitter power**

GPS



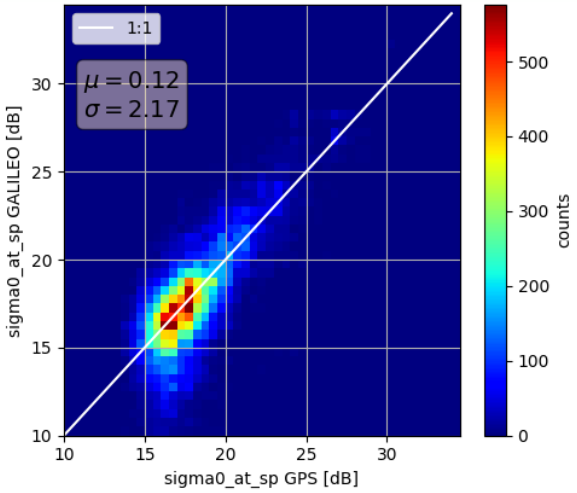
Example ocean tracks

Galileo
BOC(1,1)

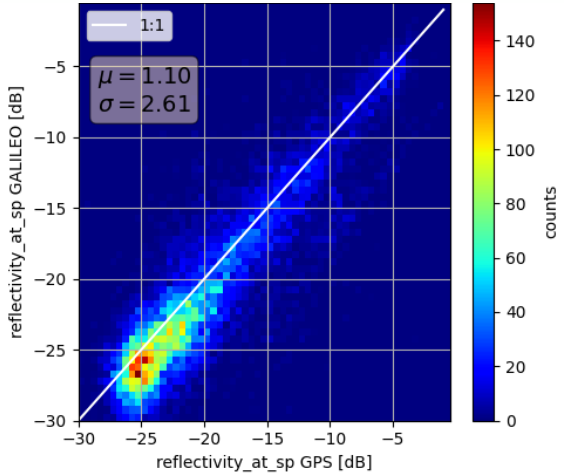


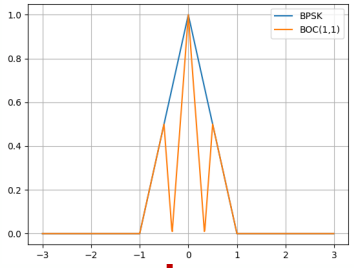
Paired GPS-Galileo reflectivity observations (Jan-Feb 2022 FM147)

Ocean nBRCS
1 hr and 50 km



Land BRCS
1 hr and 1 km



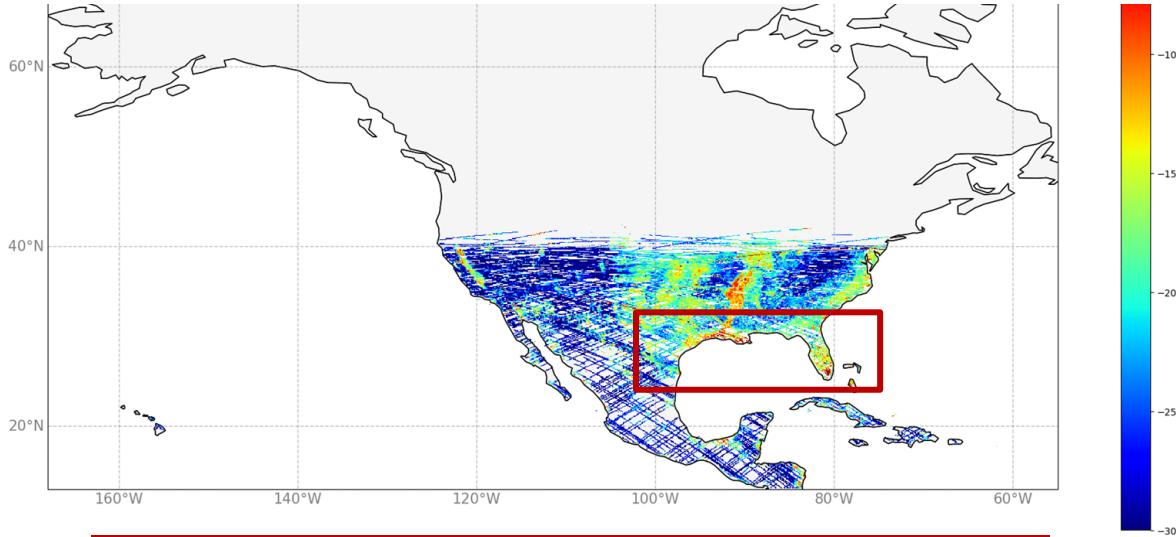


GNSS-R Sensitivity to Soil Moisture

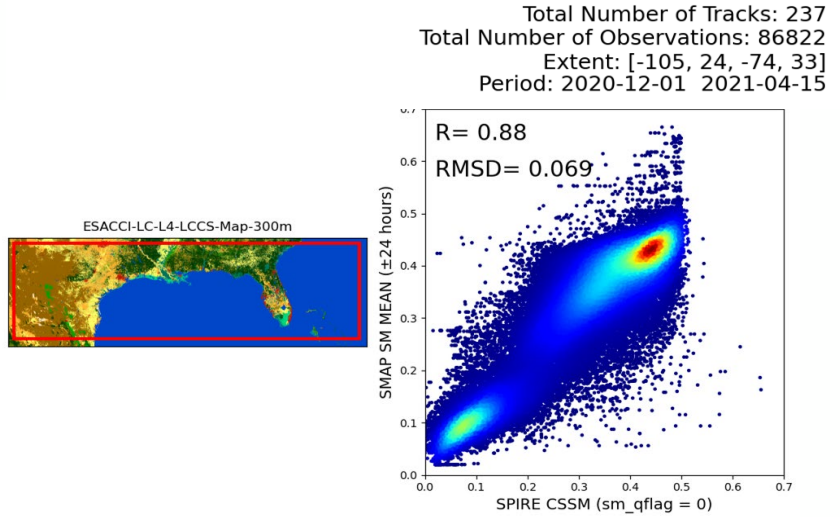
Spire GNSS-R reflectivity (10 km grid) over 2021 - monthly frames

- Compared to the other active and passive remote sensing methods used to monitor soil moisture, **GNSS-R has the advantages of increased moisture sensitivity and better penetration of foliage** by L-band signals due to forward scattering.
- Spire GNSS-R L2A Surface Soil Moisture
  - change detection calibrated soil moisture that retains the along-track structure of GNSS-R sampling characteristics.

L2A gbrSSM



The image above shows seasonal changes in Spire reflectivity measurements



@LPS 2022 Friday 12:20 pm

Poster Session Day 5

Global monitoring of soil moisture using a constellation of GNSS-R satellites

Dr. Vahid Freeman | Spire Global | Luxembourg

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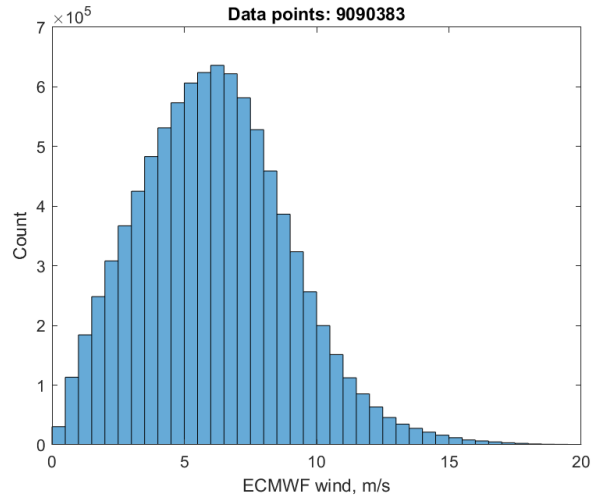
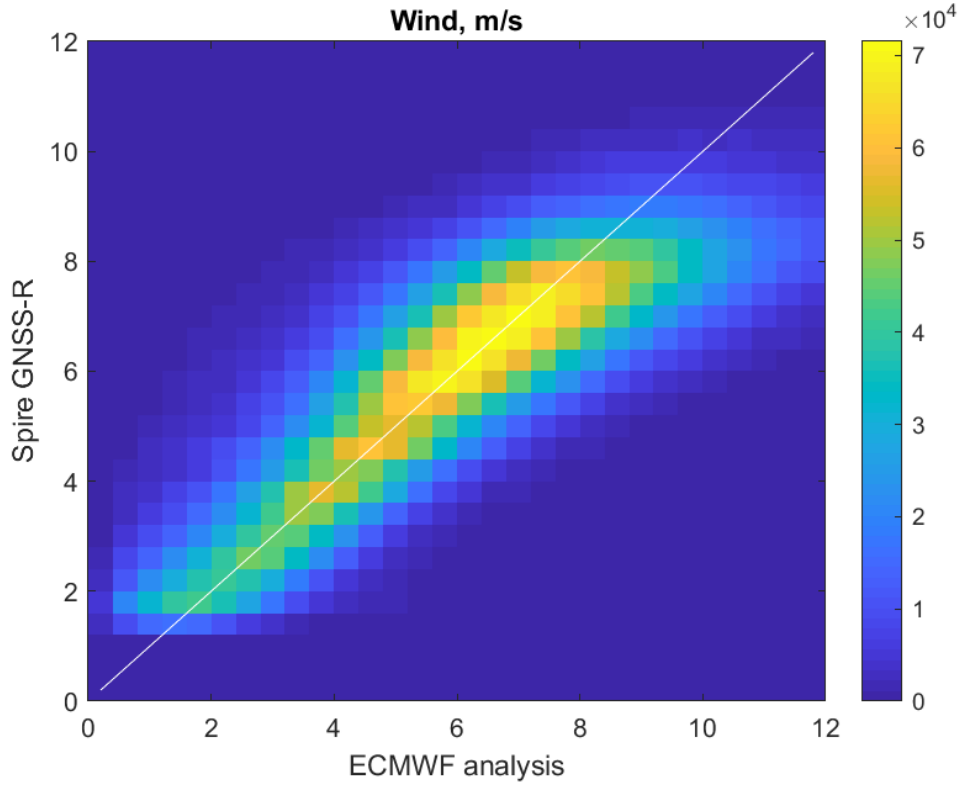
Spire Ocean Wind

- Ocean wind and MSS product: `L2 gbrOcn`
- Ocean wind and mss GMF developed from Spire GNSS-R sigma-0 using gridded ECMWF analysis



Distribution of ECMWF wind speed used in GMF update



2D histogram of GNSS-R retrieved wind vs. ECMWF wind

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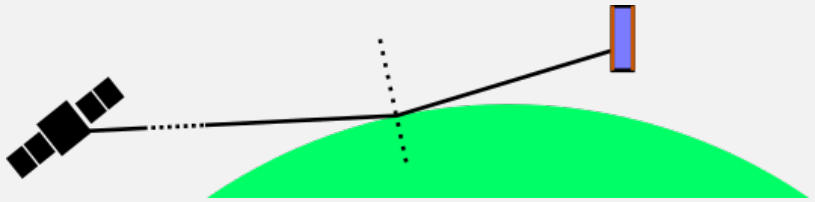
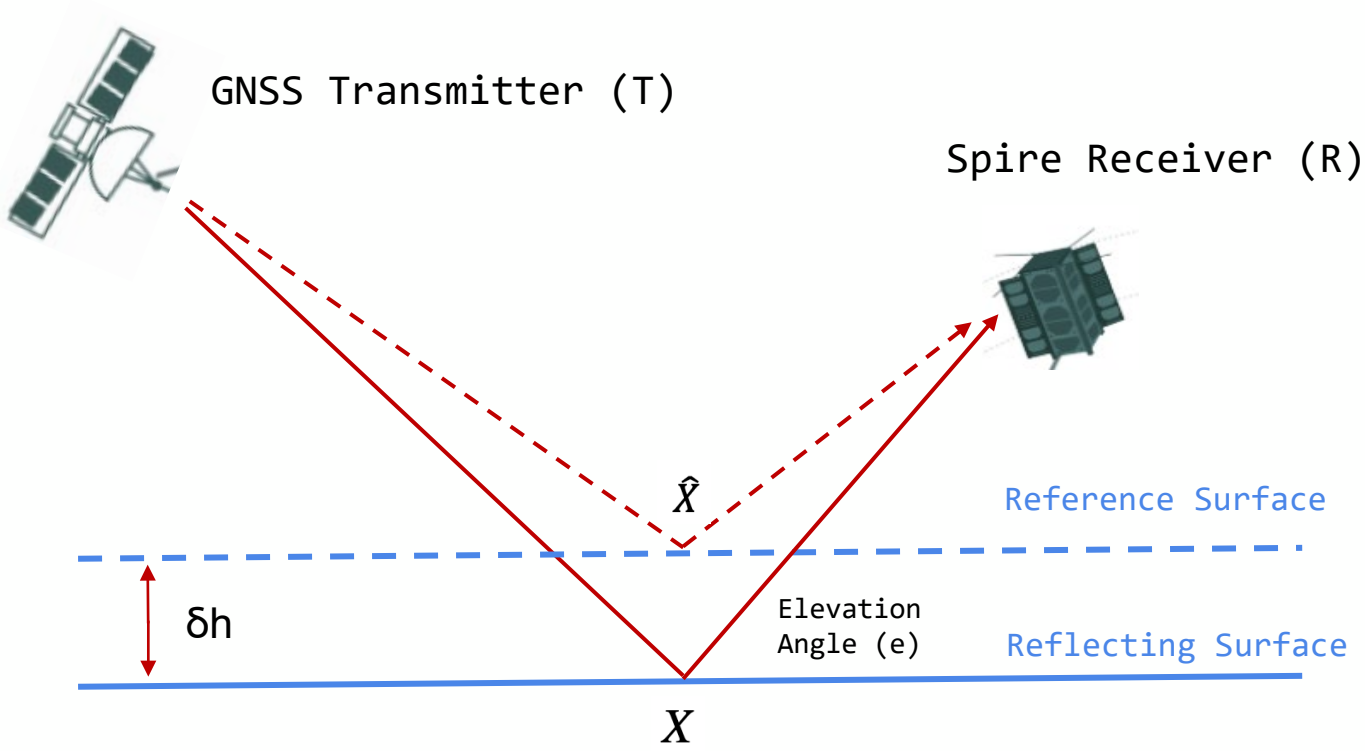
Spire Grazing Angle GNSS-R



- Grazing angle (5°-30° elevation)
  - RHCP polarisation
  - Coherent 50 Hz observations

Grazing Angle GNSS-R: Altimetry



Modeled Signal Path $T\hat{X}R$

Computed distance based on transmitter, receiver positions and specular point on ellipsoid

Actual Signal Path TXR

Based on GNSS receiver measurements of phase

Target Measurement → $\delta h \equiv \frac{T\hat{X}R - TXR}{2 \cdot sin(e)}$

Receiver Processing

- Data collection **50 Hz IQ** measurements
- Open-loop tracking of **direct and reflected** signals
- Elevation angles 5 -30 °
- Dual frequency **L1 and L2 (E1 and E5 for Galileo)**

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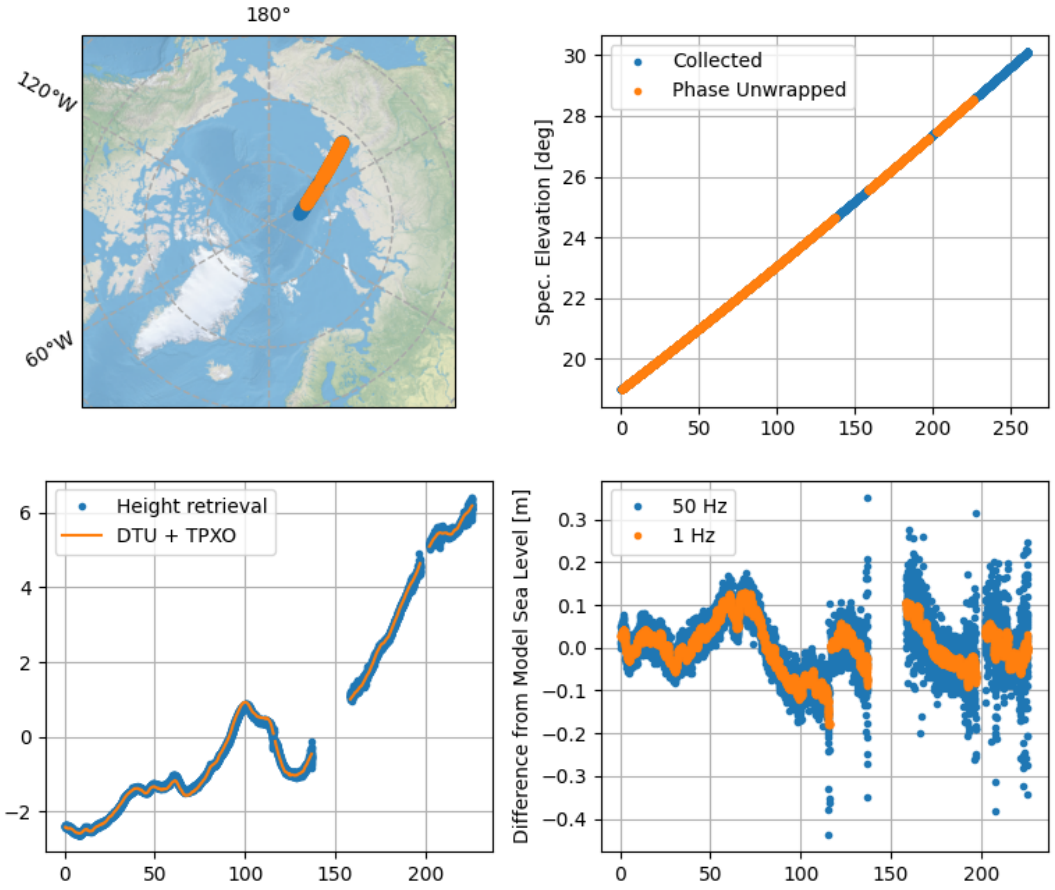
Sea ice facilitates altimetry retrievals

Surface Height Retrieval

L2 grzAlt



Applications

- Ice freeboard
- Open ocean altimetry (when low winds)
- Land ice altimetry
- River slope and width

6.9 cm RMS

@LPS 2022 Tuesday
A10.02.2 Geodetic Satellite Missions and Their Applications - 2
02:30 pm
GNSS-R Grazing Angle Altimetry from the Spire Constellation
Matthieu Talpe | Spire Global, Inc.

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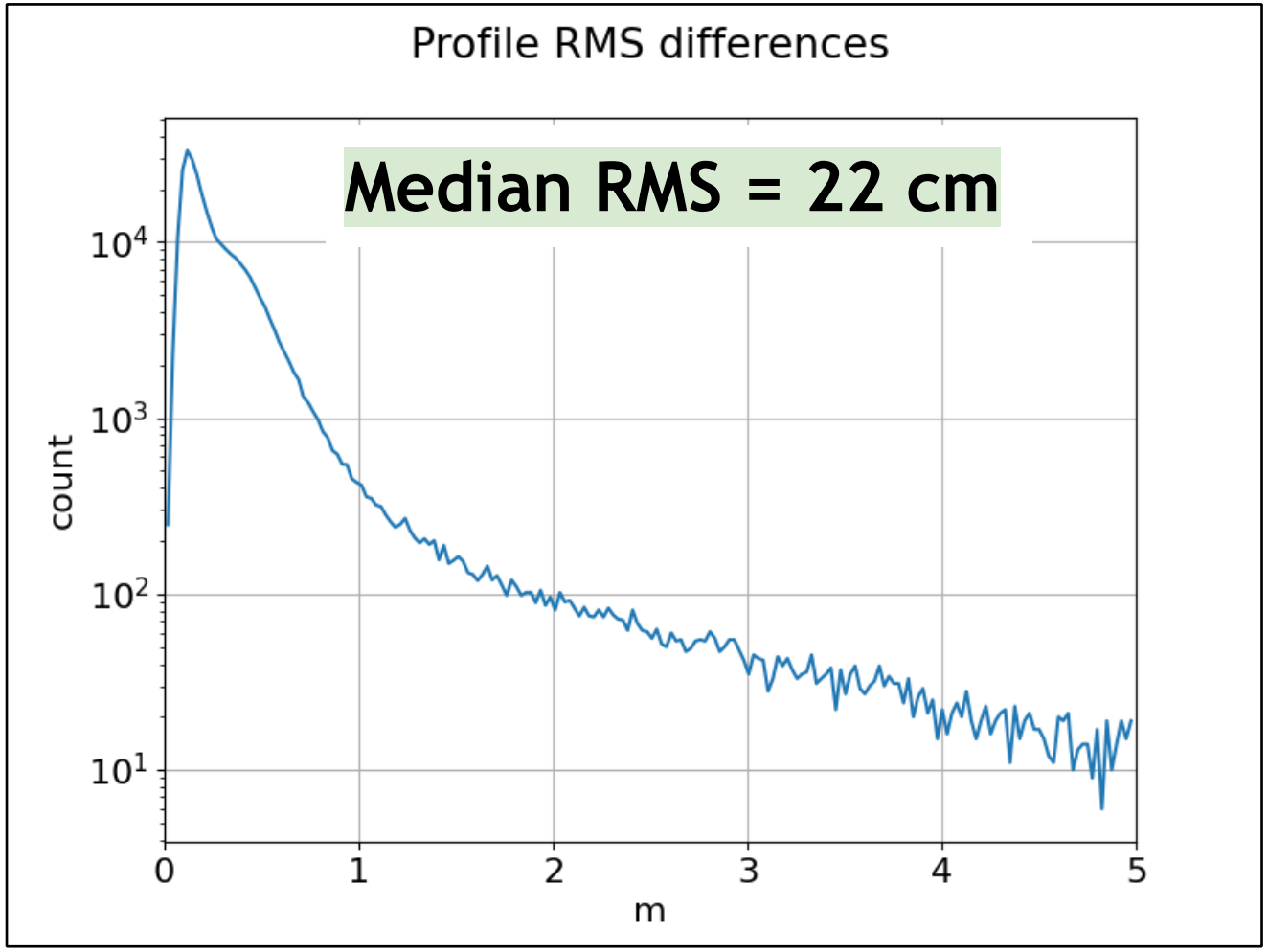
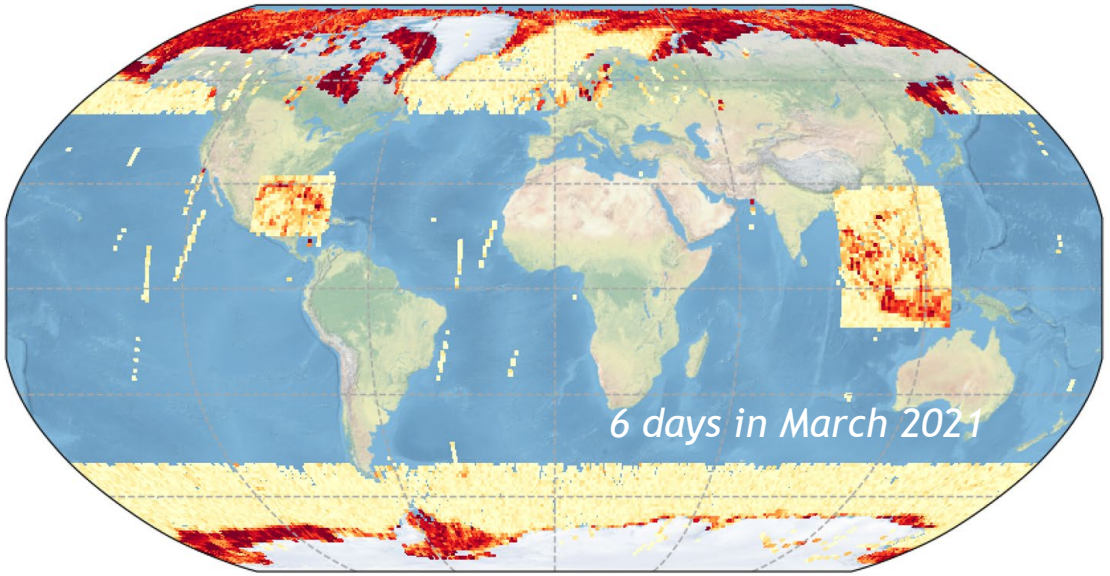
Altimetry Data Production



300,000 profiles

01-June-2020 → 07-Jan-2022

- 1000+ profiles are added everyday
- 90+% at high latitudes



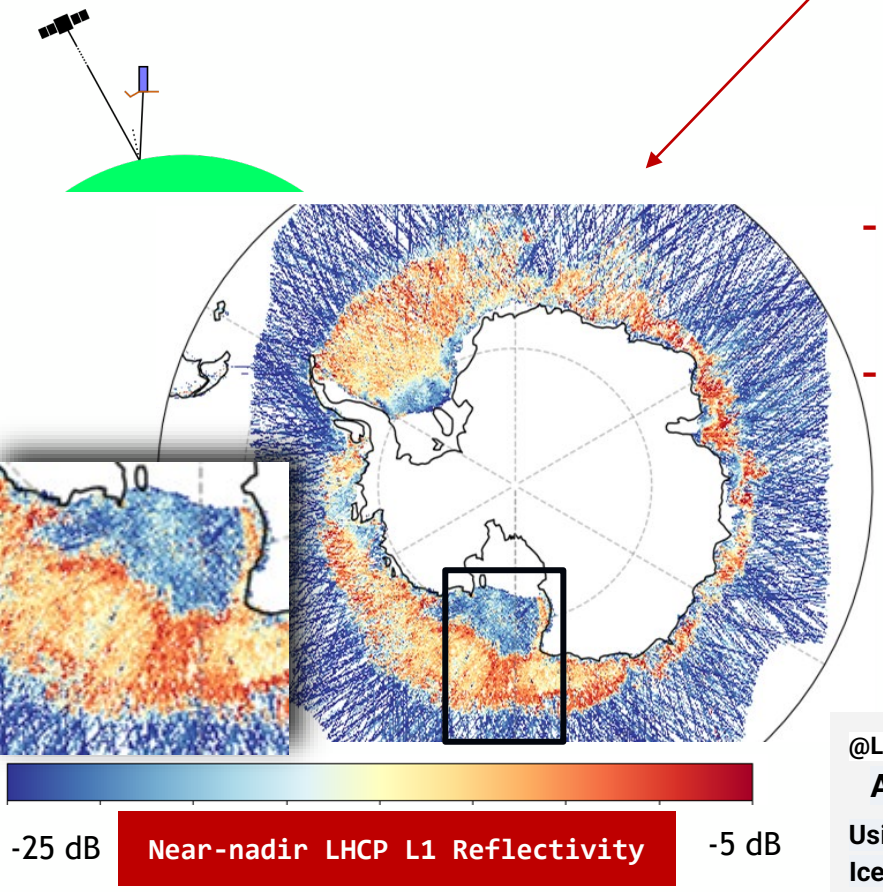
spire ⇒ 83% of height retrievals agree within 50 cm wrt a reference surface model

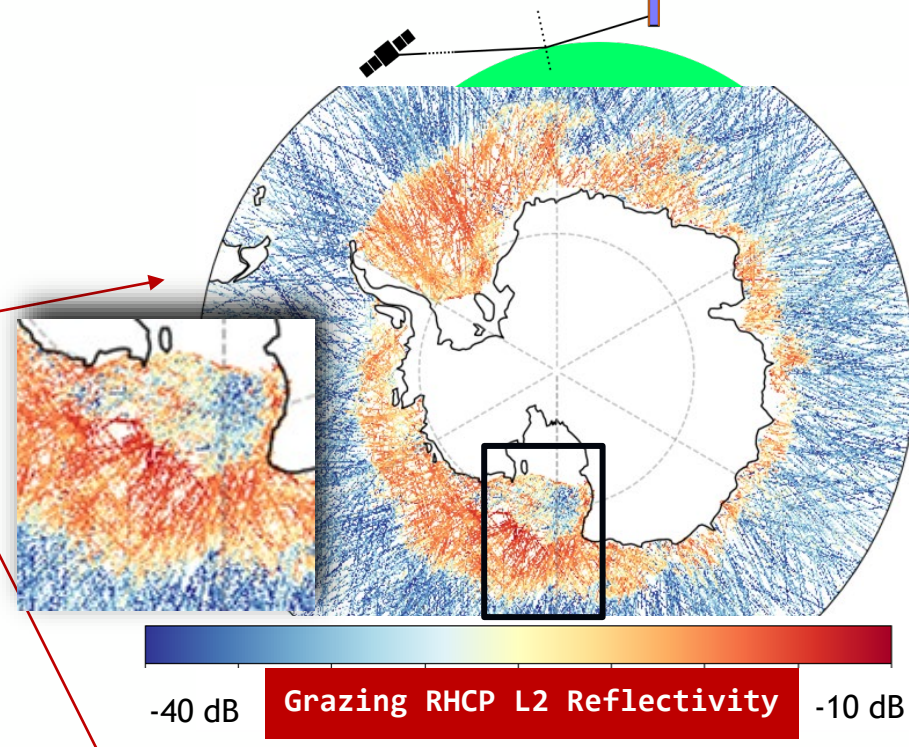
Ice Surface Classification

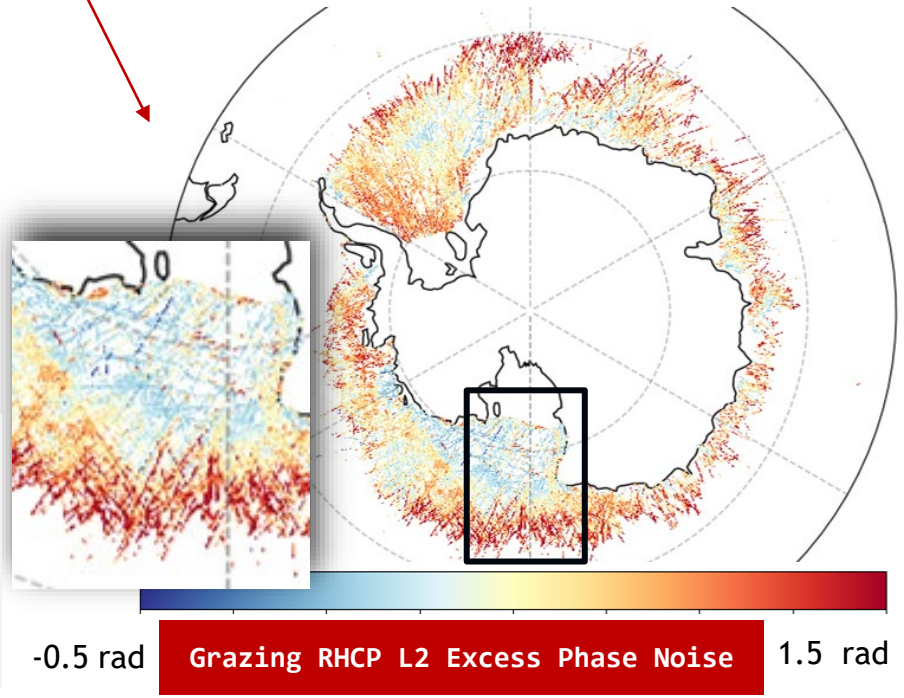
[14 days from 2021-12-16]
[10 km grid]

- **Combining** Conventional and Grazing-angle GNSS-R offers a rich set of observables
  - Dual **polarisation** , dual **frequency** , **coherent & incoherent** and diversity of **geometry**
- Provides **unique information** for characterisation of ice surfaces
- **High resolution** data products: ice extent and **ice type**

L2 grzIce







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A9.06.3 Sea Ice Remote Sensing - 3

Using GNSS-Reflectometry for sea ice classification and Marginal Ice Zone characterisation from the Spire nanosatellite constellation

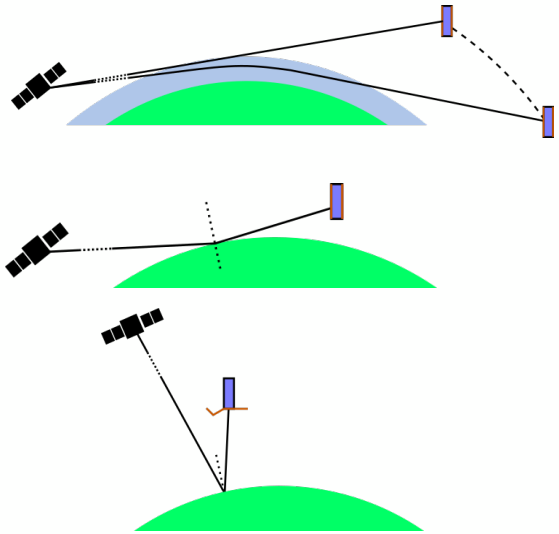
Dr. Jessica Cartwright | Spire Global | Luxembourg

Spire EI Production for NWP and Research

- Spire is delivering **GNSS-RO** raw and processed data in **near-real-time** to major processing centers for further dissemination to **NWP centers and users**
  - Delivering 1000+ to EUMETSAT and European weather centers
  - Delivering 5500+ profiles to NOAA/UCAR for CWDOB Delivery Order 4
- Delivering all data types for intended **research use** with a 30-day delay. Historical data available at no cost to users.
  - NASA CSAP (Commercial Smallsat Data Acquisition Program) - open access for NASA funded researchers
  - ESA Earth Online. - Access via research proposal for limited data quantities
  - Seeking routes for further adoption of Spire data

Spire Earth Intelligence Data Products

- Operational GNSS-RO
  - Raw and processed
  - Tropospheric and ionospheric atmosphere
- Grazing angle GNSS-R
  - L1: grzObs, grzRfl: **Coherent 50 Hz**
  - L2: grzAlt: **Altimetry**
  - L2: grzIce: **Ice Classification**
- Conventional GNSS-R
  - L1: gbrRCS, gbrNRCS: **Reflectivity DDMs**
  - L2: grbOcn: **Ocean wind and MSS**
  - L2: gbrSSM: **Soil Moisture (Preview product)**



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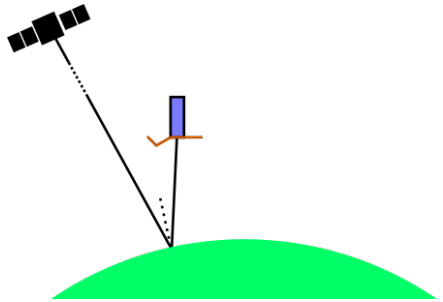
Plans for the Spire GNSS -R Constellation

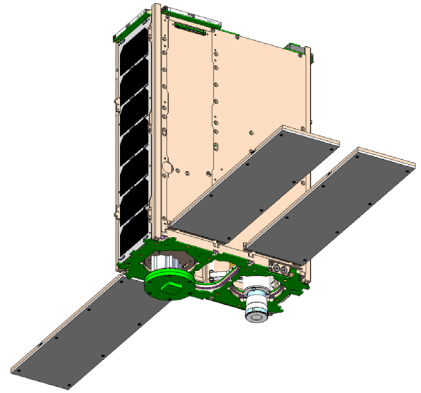


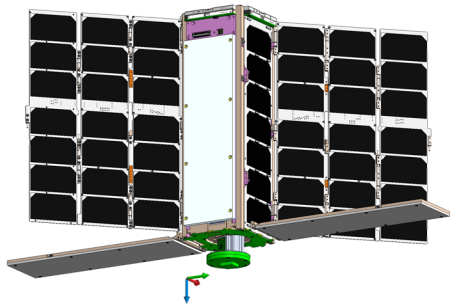
Expanding the conventional GNSS-R constellation:

- Payload and processing improvements
- Spire plans to launch an additional 3 conventional GNSS-R satellites in 2022/3

Challenges:

- GNSS-R observations have very high spatial resolution (1-2 km over land), but to exploit this resolution with timeliness requires 10s of GNSS-R satellites
- Like others in commercial Earth Observation. There is a gap between funded R&D and funding through the sale of operational data. GNSS-RO has bridged this gap, but GNSS-R is still navigating it.





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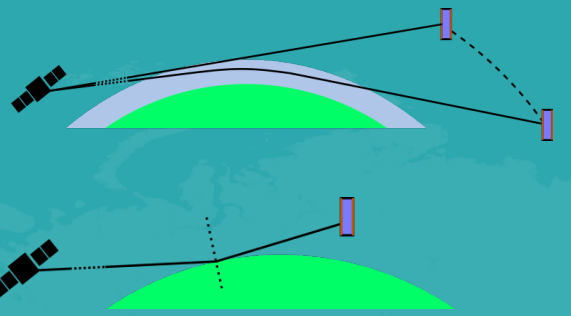
Key Takeaways

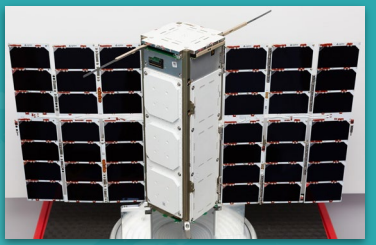
MATURE GNSS-RO CONSTELLATION
- Commercial GNSS-RO data is being ingested into operational NWP

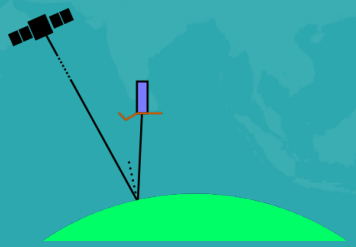
SPIRE INNOVATION IN EARTH OBSERVATION
- Multi-GNSS
- Grazing angle GNSS-R with coherent observations
- Beamforming for increased sensitivity
- Advanced calibration system

EXPANDING THE GNSS-R CONSTELLATION
- Seeking routes to expand the GNSS-R data collections and develop new applications

CONTINUED IMPROVEMENT
- Spire aims for continuous scaling, replenishment, and improvement for sustained, long-term Earth observations







Spire actively supports research and innovation, and data are available through the NASA CSDAP (all US-gov funded researchers) and ESA Earthnet programs. For more info, contact earth-obs@spire.com.

Thank you!

Dr. Philip Jales

Spire Global Ltd.

philip.jales@spire.com

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