spire | federal

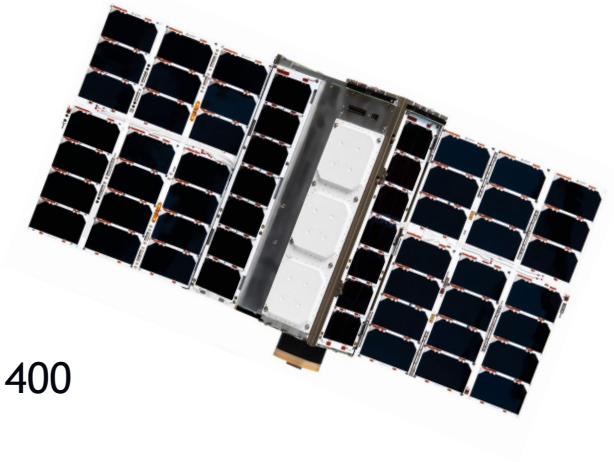
Committee on Earth Science and Applications from Space

Presented by:

Kris Lindner - Business Development, Space Programs

April 2025

Spire Global Company Overview



Building a space-powered global data network

- Spire Global, Inc. (NYSE: SPIR) is a US Company headquartered in Northern Virginia with over 400 employees
- Spire operates wholly owned subsidiaries in Canada, United Kingdom, Luxembourg, Germany, & Singapore
- Spire Federal (Cage Code: 7JE17) provides products and services to the US Federal Government market.
- Based on revenue and cost of goods, sold Spire remains a small business for Data Processing, Navigation Services, Telecommunications, and R&D NAICS codes (encompassing all commercial offerings).

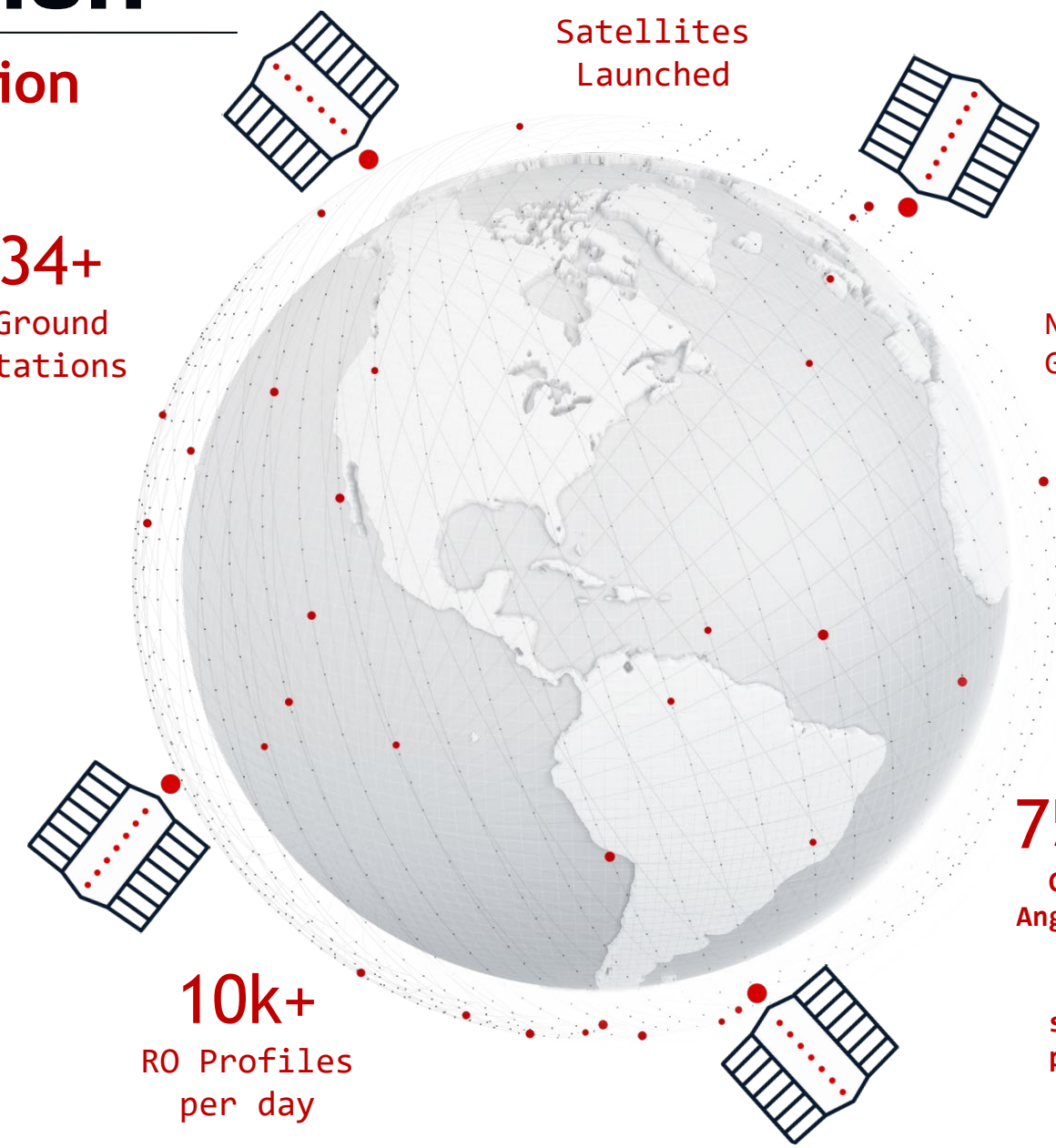
Spire Global's 5 Core Data Products & Space Services

Maritime | **Aviation** | **Weather** | **Space Reconnaissance** | **Space Services**

The Spire Constellation

The largest multipurpose constellation in the world

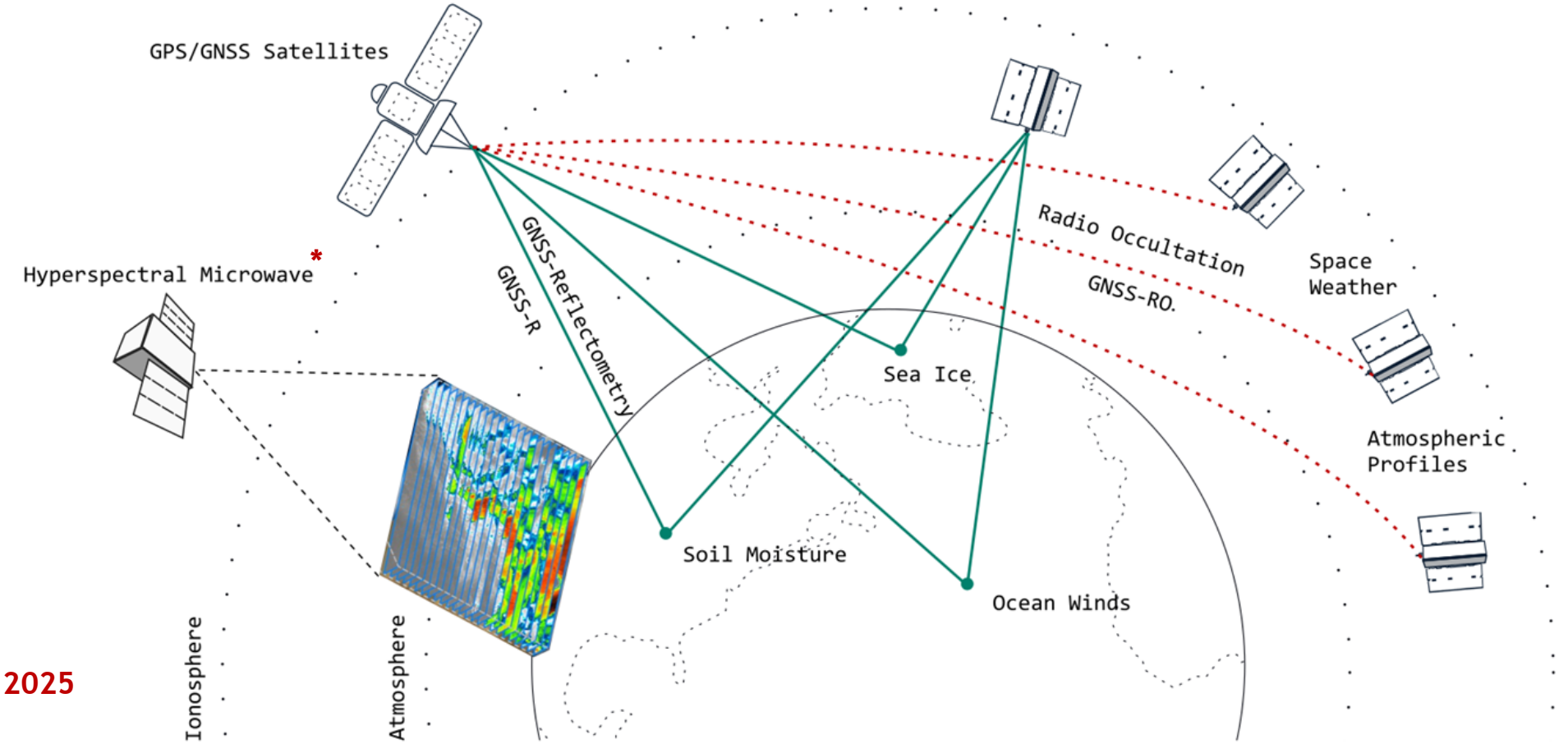
- The Low Earth Multi-Use Receiver (LEMUR) is Spire's CubeSat platform used to track maritime, aviation, and weather activity from space
- We operate the world's largest RF sensing fleet via a network of over 34 ground stations remotely operated with autonomous constellation management tools used to optimize tasking, collection, contact time & data transfer
- Our data provides a global view with coverage in remote regions like oceans and poles
- We are continuously launching improved sensors and upgrading them in-orbit
- We turn ideas into live feed from space in as little as 6-12 months



Spire Earth Intelligence Data

Our satellites capture data relevant for weather and climate monitoring

- Space weather: Ionosphere corrections for navigation and thermospheric density
- Neutral atmosphere: Profiles of temperature, pressure, and humidity
- Surface: Ocean surface wind, soil moisture, and sea ice

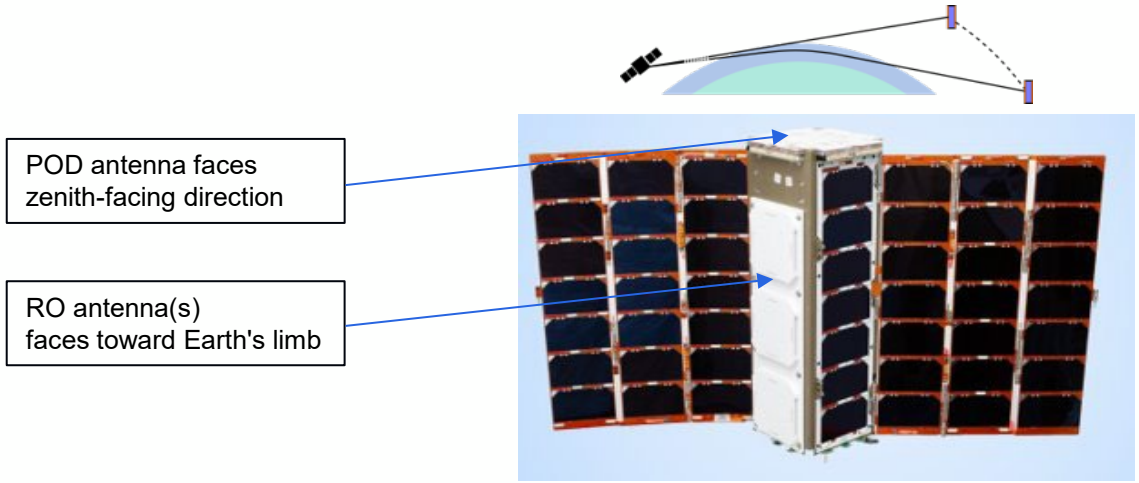


*Launching in 2025

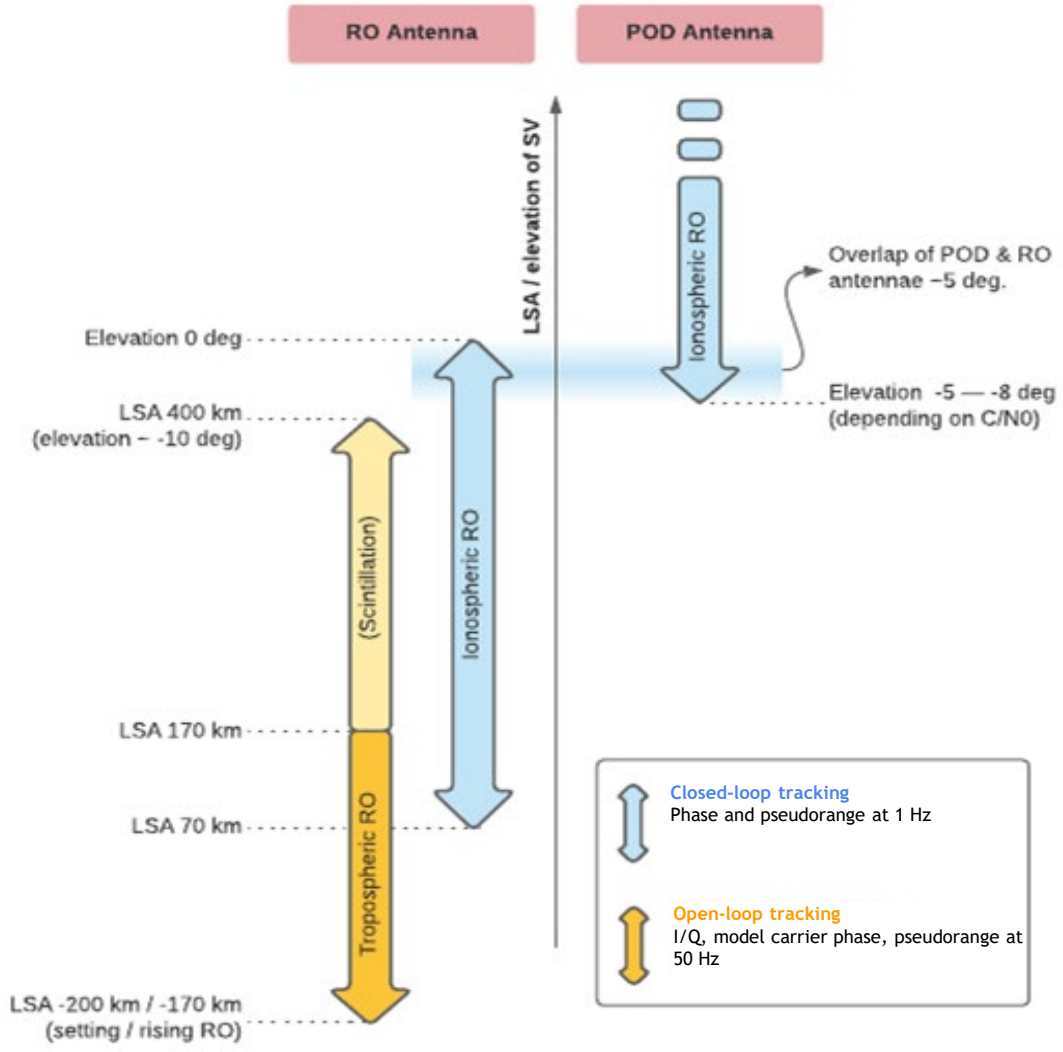
GNSS-Radio Occultation

- RO technique measures the phase change in the GNSS signal as it passes through the Earth's atmosphere
  - Amount of signal bending is sensitive to atmospheric properties (temperature, water vapor) with benefits to operational NWP
  - Setting/rising of Spire satellite produces vertical profile of Earth's atmosphere with ~100-meter vertical resolution, < 0.1 K accuracy
- GNSS signals collected with in-house built STRATOS receiver
  - Multi-GNSS, dual-frequency signals tracked in open-loop
  - Demonstrated many "firsts" for RO including producing high-quality profiles from a Cubesat, producing non-GPS profiles, etc.

Spire GNSS-RO 3U Satellite Bus



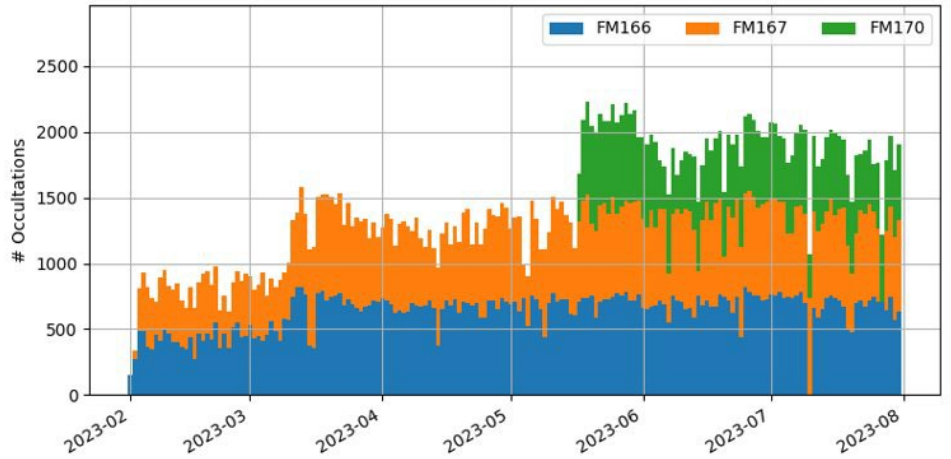
RO Measurement Configuration



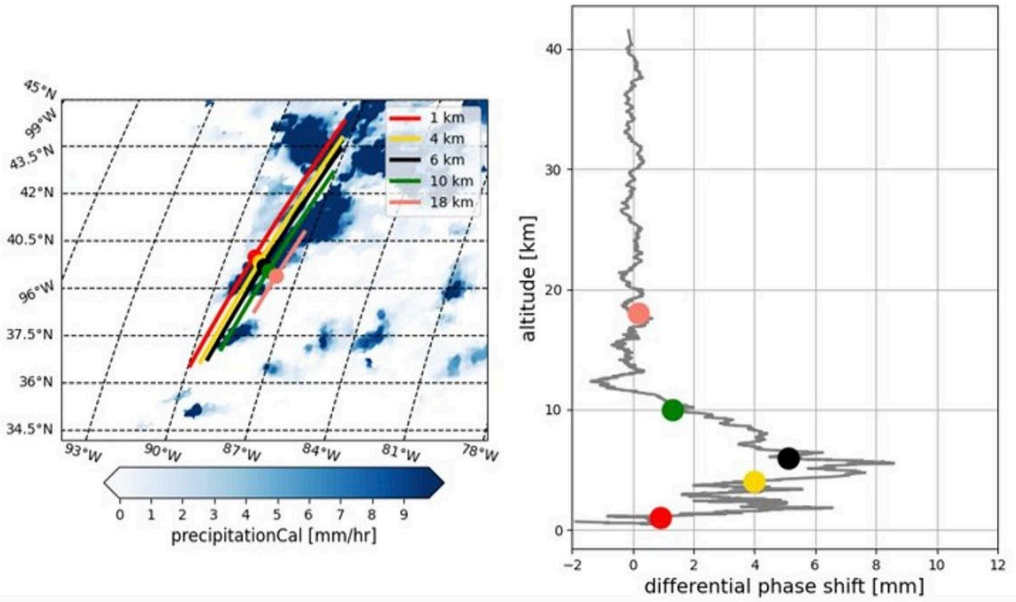
Polarimetric Radio Occultation

- First Spire PRO-capable satellites launched in 2023
- Over 2000 PRO profiles per day collected from 3 Spire satellites, 4 GNSS constellations
  - **10x** amount of data currently available from PAZ mission
- Polarization phase shifts demonstrate clear sensitivity to precipitation and are minimally affected by the antenna
- Bending angle profiles can be derived from PRO data with similar quality to Spire's operational RO

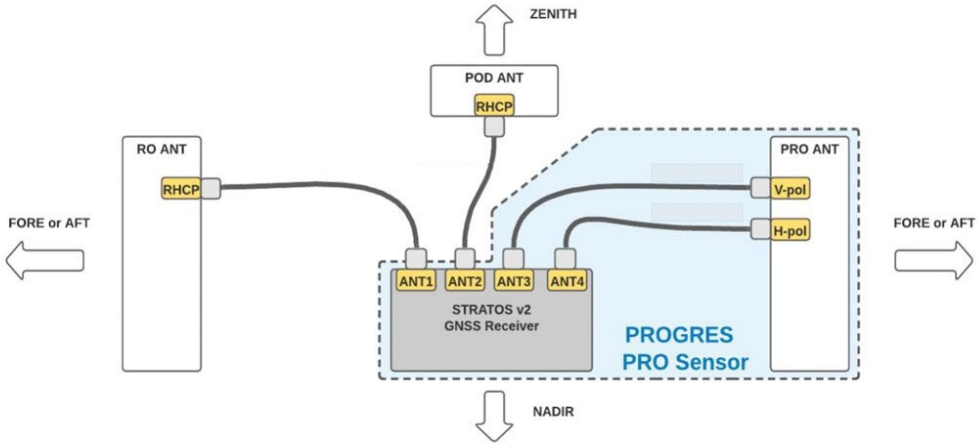
Collected PRO profiles by Spire satellite



PRO Measurements Compared to IMERG Precipitation



Spire Polarimetric RO payload



GNSS-Reflectometry

Spire deployed GNSS-R constellation

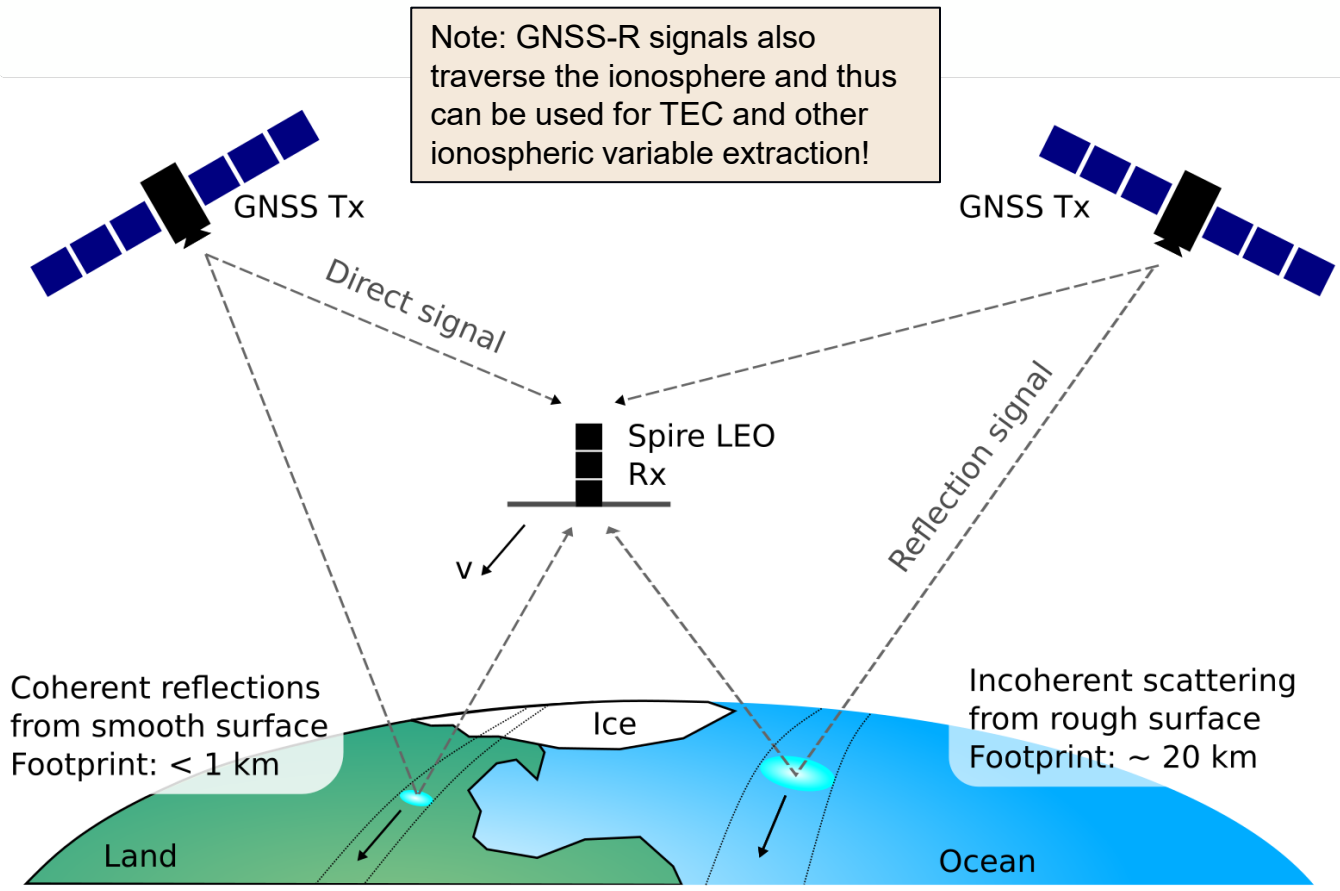
GNSS-R is a form of bistatic radar using GNSS signals of opportunity (e.g., GPS, Galileo, QZSS, Beidou) to perform Earth surface scatterometry (reflectivity and roughness estimation)

Reflectivity is sensitive to surface state

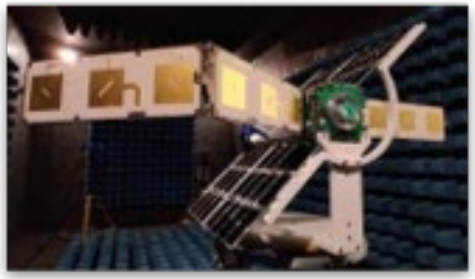
- Roughness -> **Ocean wave / wind**
- Dielectric -> **Soil moisture, flooding**
- Covering Volume -> **Biomass**
- Time delay -> **Surface altimetry**

Spire GNSS-R measurements come in two forms:

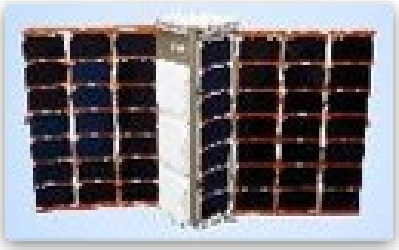
- **"Near-nadir" measurements** collected by GNSS-R satellites with deployable antennas
- **"Grazing angle" measurements** collected by GNSS-RO satellites



Near-nadir GNSS-R Satellites



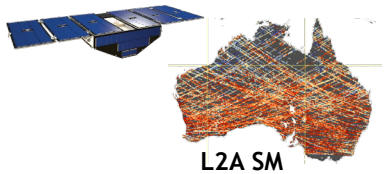
GNSS-RO Satellites can also collect grazing angle GNSS-R



From Space Data to advanced Soil Moisture information

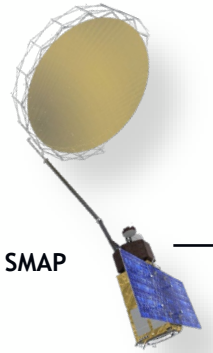
Spire Soil Moisture Monitoring System

CYGNSS



Spire GNSS-R

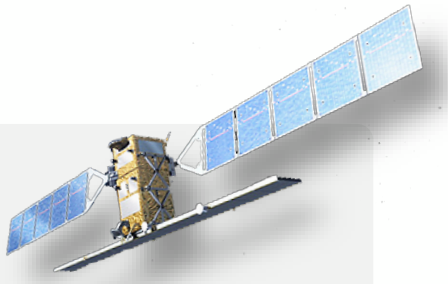
L2A SM



SMAP

Input : Trackwise soil moisture from CYGNSS and Spire GNSS-R instruments are being merged with SMAP data

Spire's Data Analytics System

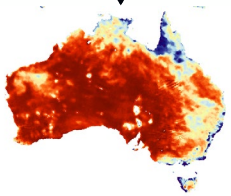


Sentinel-1
Analyzed Data
Volume: ~1.5 PB

Data Fusion

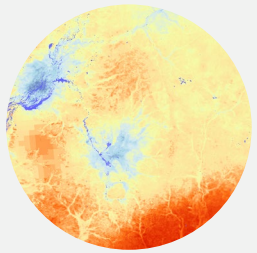
High-resolution Downscaling Engine

The soil moisture product is further refined through Spire's Downscaling Engine powered by insights derived from extensive data analytics on long-term, high-resolution (10m) Sentinel-1 Synthetic Aperture Radar (SAR) data.

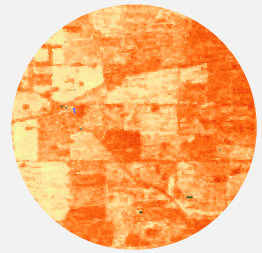


Spire 6km Soil Moisture

Output of this data fusion is the Spire 6km Soil Moisture



Spire 500m Soil Moisture



Spire 100m Soil Moisture

Output of the high-res engine is the standard 500m Soil Moisture and 100M Soil Moisture

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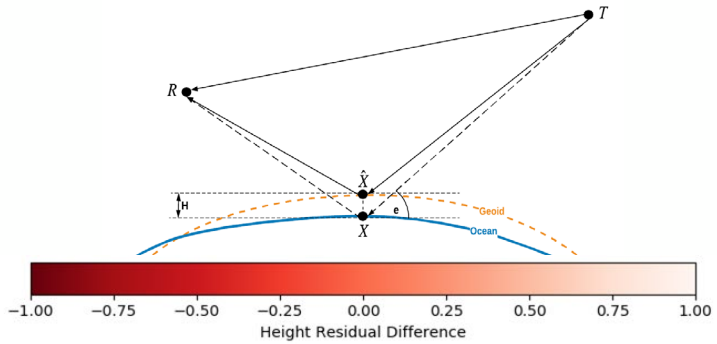
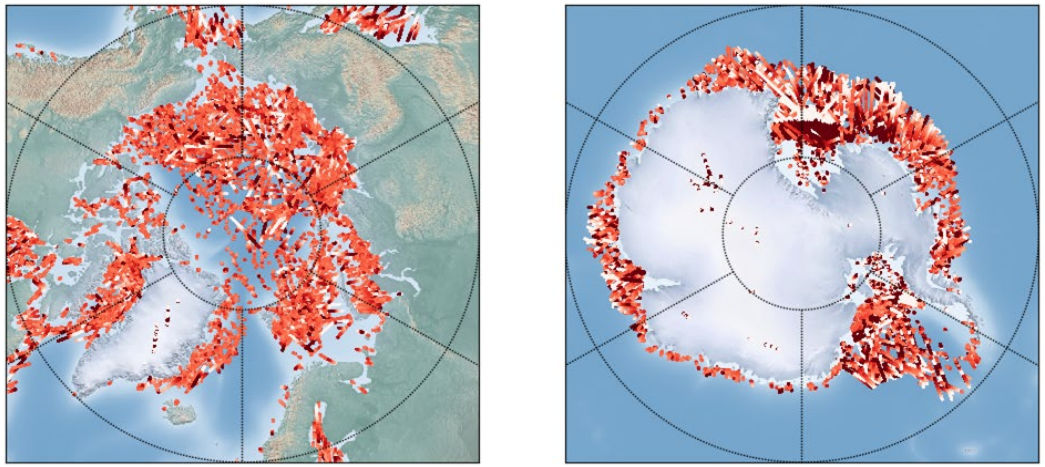
Grazing Angle GNSS-R Sea Ice

Spire produces two L2 sea ice products from grazing angle GNSS-R techniques derived from Spire GNSS-RO satellites

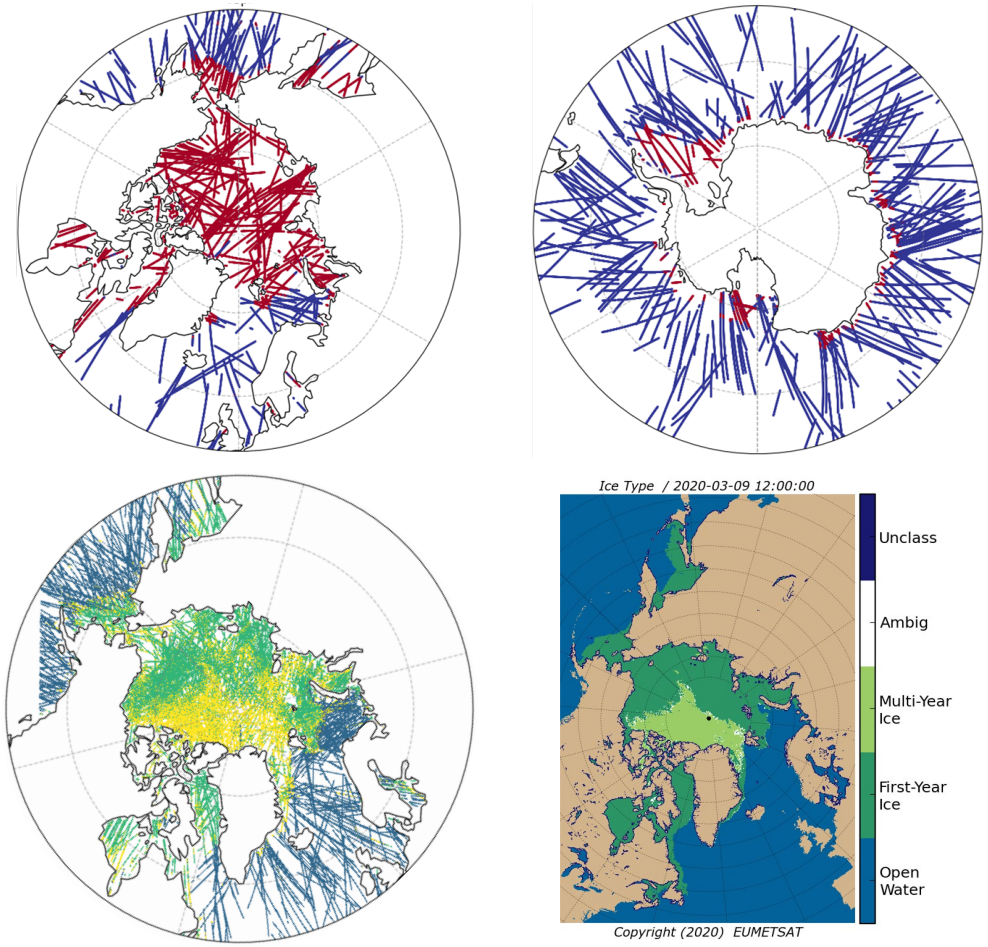
Sea Ice Altimetry





Altimetric Height Coverage over 1 Week

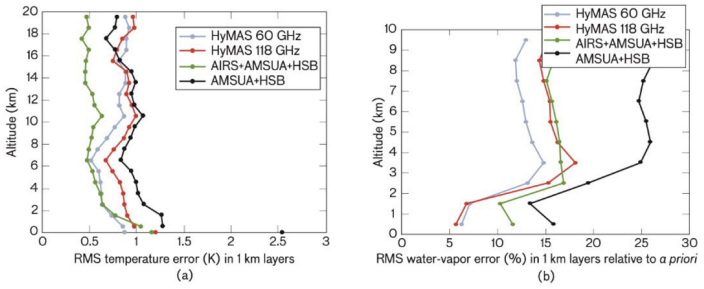
Sea Ice Detection and Classification



Hypserspectral Microwave Sounding

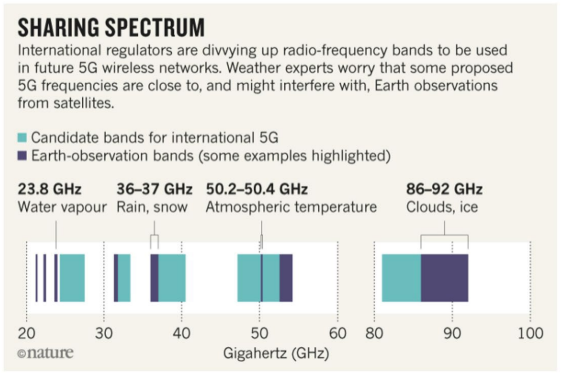
Channel volume and vertical resolution improve value of HyMS data

Retrieval Accuracy



- In simulation studies, using HyMS to sample more channels improves retrieval accuracy of water vapor, temperature profiles
- *Studies currently agree* found 0.5K temperature, 5% humidity improvements
- *Boukabara and Garrett* found temperature and water vapour improvements compared to AMSU/MHS

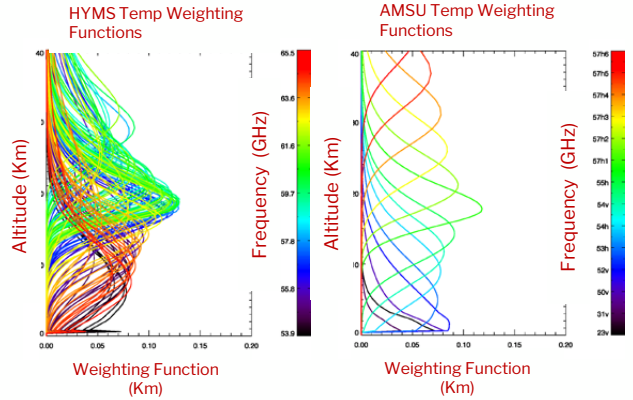
RFI Mitigation



Source: ITU

- Digital channel formation supports time-frequency domain methods and statistical methods to be applied to remove RFIs

Vertical Resolution



- Provides atmospheric layer mean temperature, and moisture profiles over geographic point
- Each sounder channel is sensitive to temperature and humidity at different atmospheric layers
- Weighting functions indicate the distribution of radiances from various atmospheric levels across frequencies.

Better Nowcasts and Forecasts

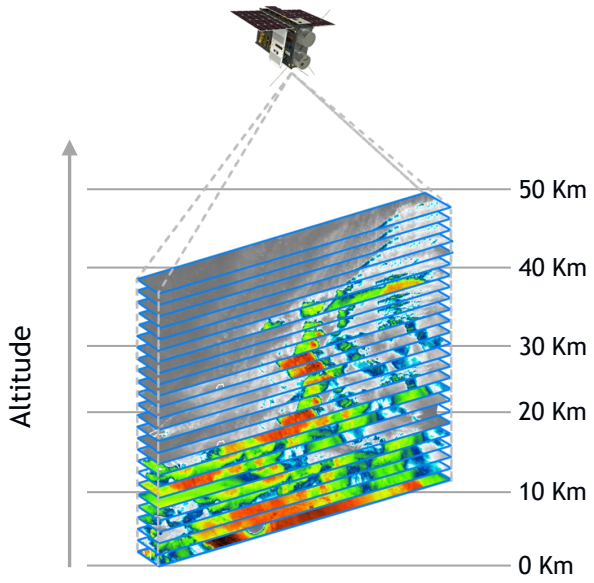
Hyperspectral Microwave Sounder (HyMS) vs. Microwave Sensors

HyMS

<40 kg Dedicated Platform

>1000 Channels

Updated every 3 Years



Benefits

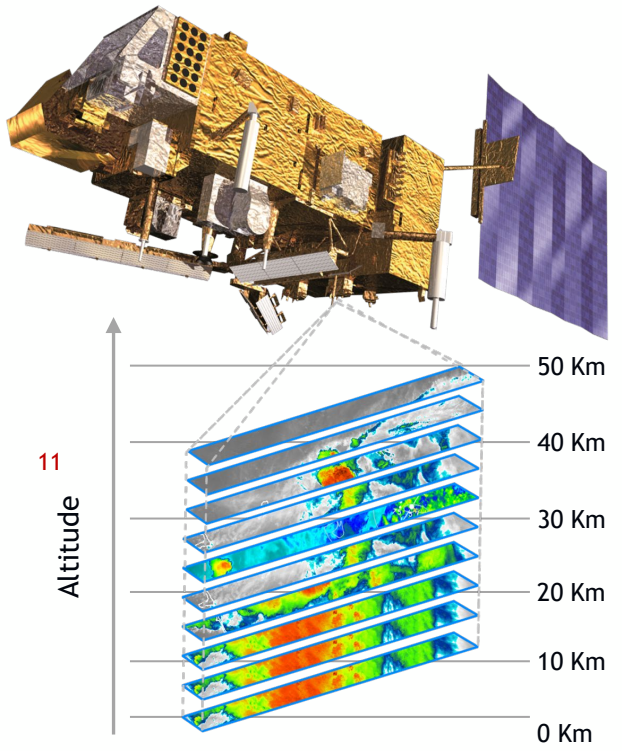
1. Improved **Accuracy**
2. Better **RFI Noise Mitigation**
3. Higher **Vertical Resolution**
4. Increased **Hydrometeor Characterization**
5. Additional Expected Benefits

MetOP SG MWS Instrument

>4000 Kg Multi-sensor Platform

24 Channels

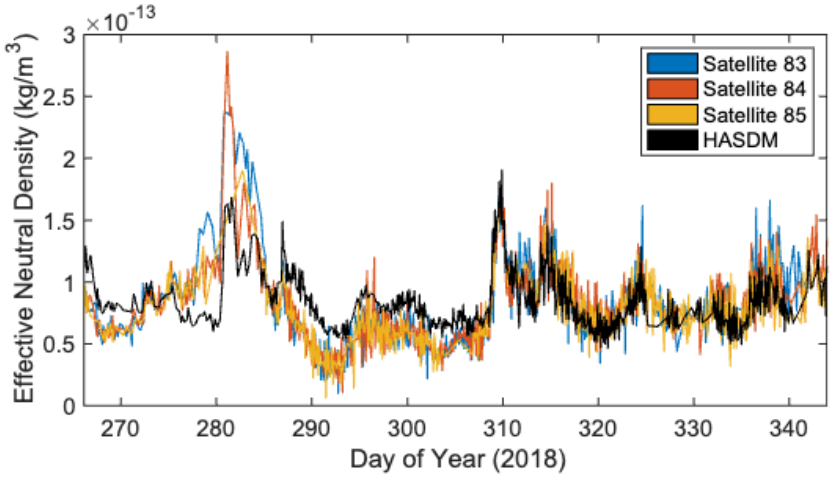
Updated every 20 Years



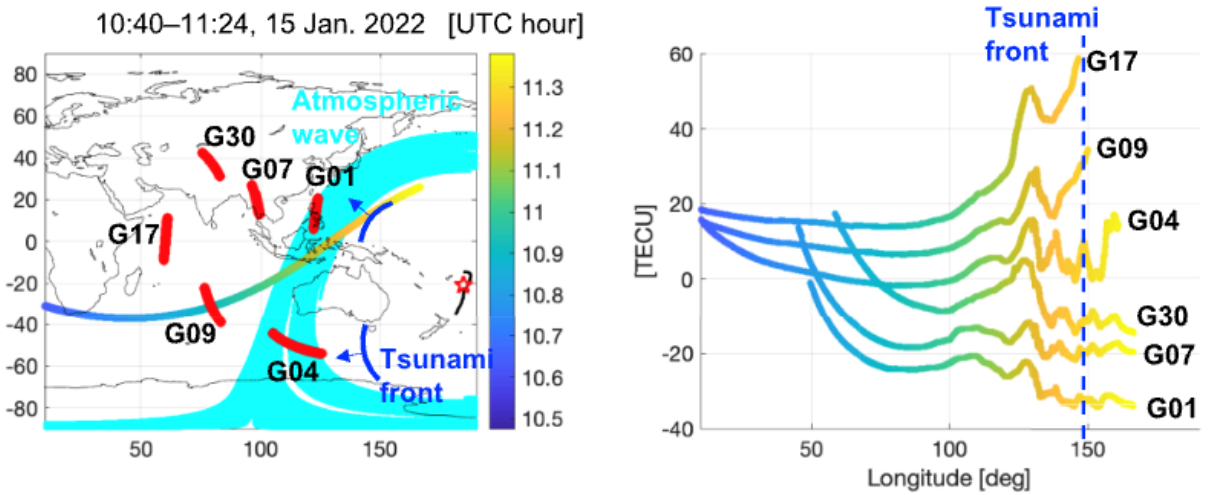
Space Weather Applications

- Spire's constellation of dual-frequency GNSS receivers in different orbital planes enables unique observations of the ionosphere-thermosphere system
- Examples of ionospheric applications include ionospheric disturbance detection, model data assimilation, climatology, storm-time analysis, etc.
- Precise orbit determination estimates can also be used for thermospheric density derivation, gravity field recovery, and potentially more

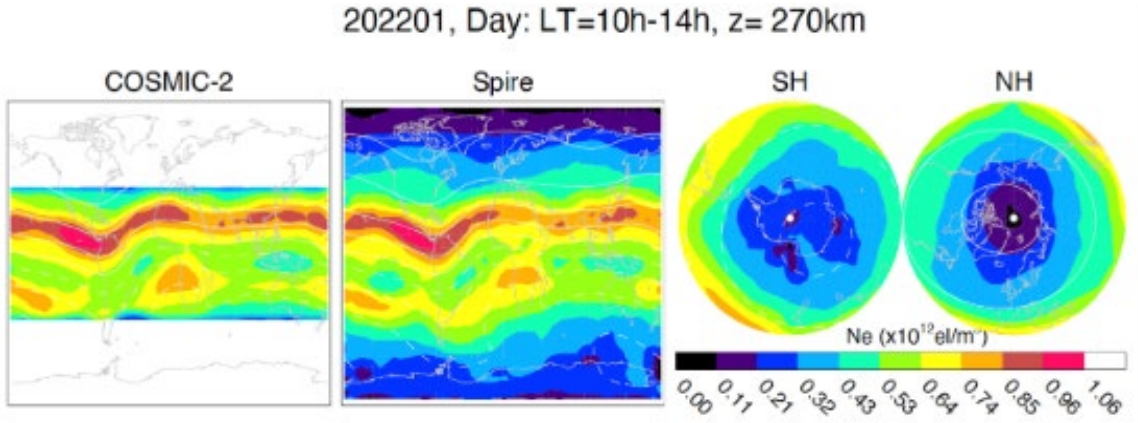
Thermospheric density estimates derived from Spire POD
(Sutton et al., 2021, https://doi.org/10.1029/2021SW002736)



Ionospheric wave detection from Spire TEC data after Hunga-Tonga Eruption
(Han et al., 2023, https://doi.org/10.1029/2022EA002586)



Ionospheric electron density estimates derived from Spire data
(Wu et al., 2023, https://doi.org/10.3390/rs15133245)



Left: Ground tracks of Spire satellites (colors representing hours of flight) and GPS satellites (red). Cyan lines represent atmospheric wave propagation. Predicted tsunami wavefront shown in blue and Hunga-Tonga volcano represented by a star. **Right**: Time series of Spire TEC measurements along the longitude of the Spire trajectory.

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Polarimetric Radio Occultation (PRO)

Credit: R. Padullés et al. (2025), Initial Polarimetric Radio Occultation Results from Spire's Nanosatellite Constellation: Independent Validation and Potential Applications, The Bulletin of the American Meteorological Society, submitted.

- PRO provides information on **the presence of rain droplets and ice crystals**, in addition to thermodynamic information common to RO, via the difference in phase of the H and V polarizations.
- The information correlates well with standard 2D precipitation products such as IMERG.
- The PRO vertical resolution is further verified when compared to advanced ground-based radars, as illustrated here for a convective cell over the Great Plains.
- This suggests that PRO can contribute globally to precipitation measurements, especially over sparsely covered regions such as oceans.
- CSDA-supported researchers are working on demonstrating the positive impact of PRO measurements on weather forecasting.

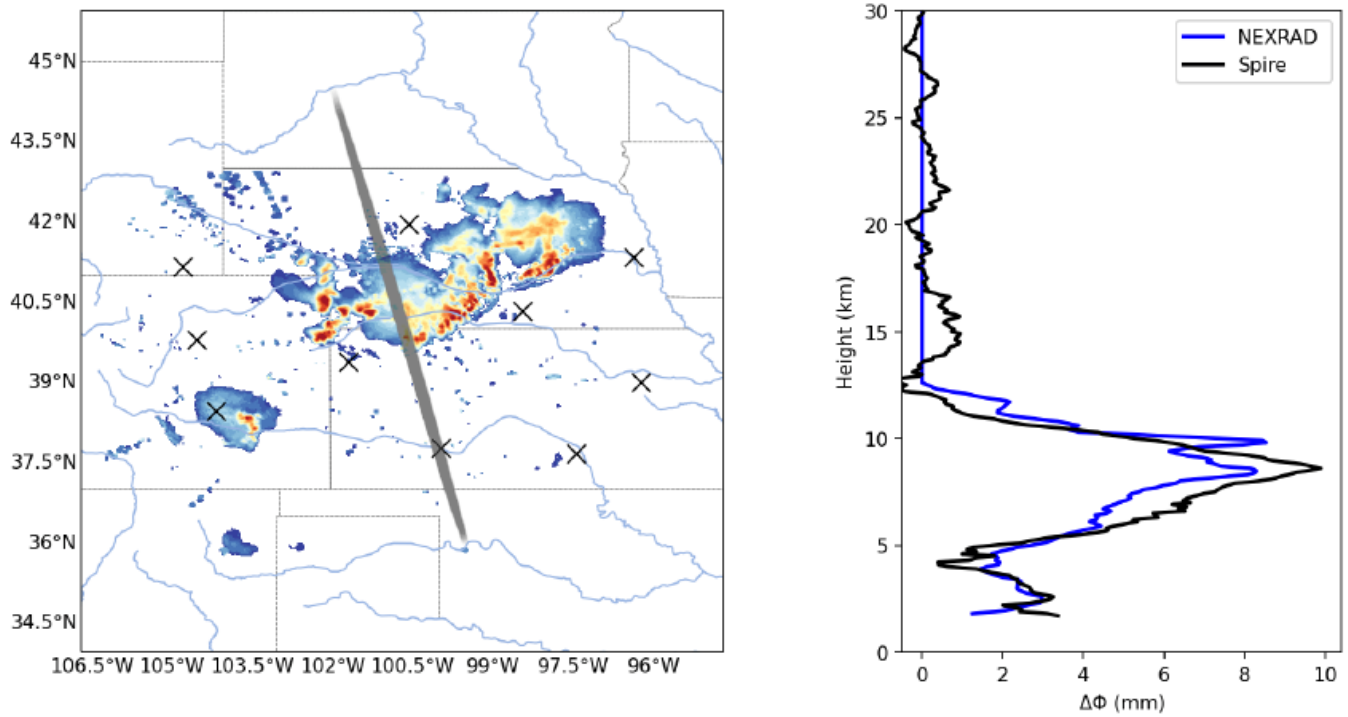


FIG. 3. Example of one Spire PRO $\Delta\Phi(h)$ observations and the corresponding NEXRAD-derived $\Delta\Phi^{Nex}(h)$. Panel a shows the projection on the surface of the PRO rays, with a composite of the radar reflectivity in the background. The crosses on the map represent the locations of the different NEXRAD radars used to simulate the K_{dp}^{RO} (see text for more details). Panel b shows the $\Delta\Phi(h)$ as a function of height, for the Spire observation (black) and that simulated using NEXRAD data (blue).

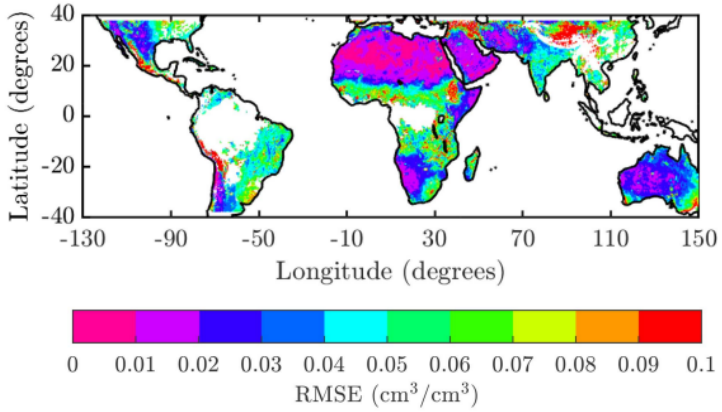
Soil Moisture Observing System GNSS-Reflectometry

Credit: M. M. Al-Khaldi et al. (2024) An Analysis of a Commercial GNSS-R Soil Moisture Dataset," in IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, vol. 17

Research Summary and Impact

- Volumetric soil moisture content plays a crucial role in a variety of land processes and can impact water resource management, agricultural productivity and crop yield forecasting.

- The product's sensitivity to large scale soil moisture variability is demonstrated using an example of a 2022 flood in Pakistan
- Overall product correlation with SMAP soil moisture of approximately 85% is determined
- No clear evidence of intersatellite biases is observed



Per pixel retrieved soil moisture assessment metrics using SMAP as a reference

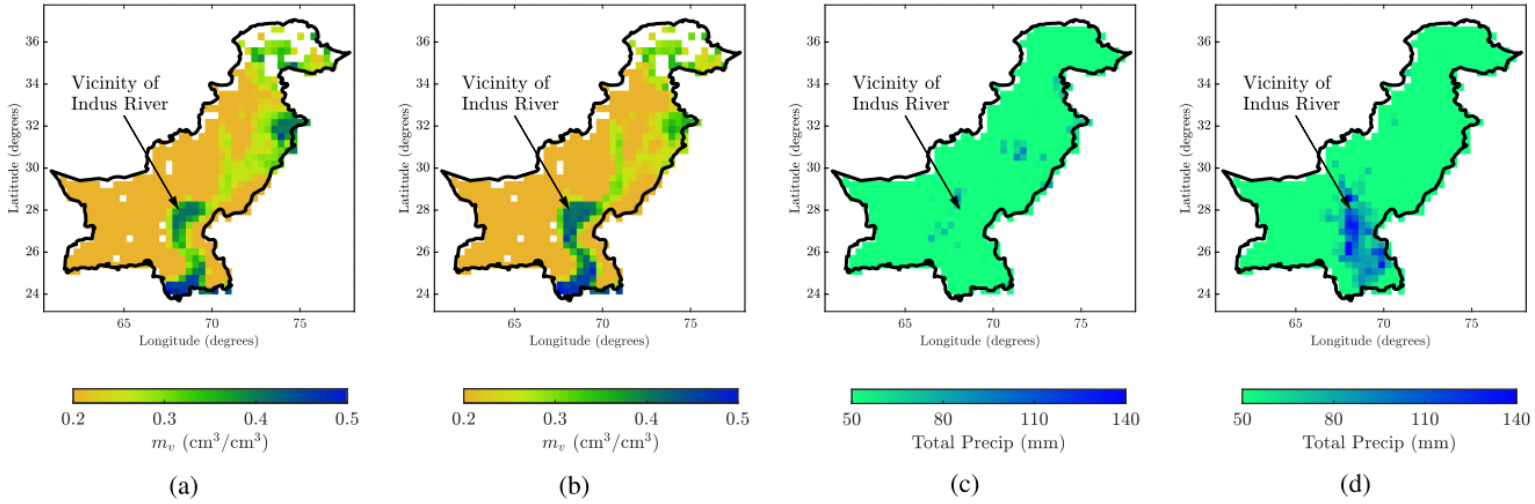


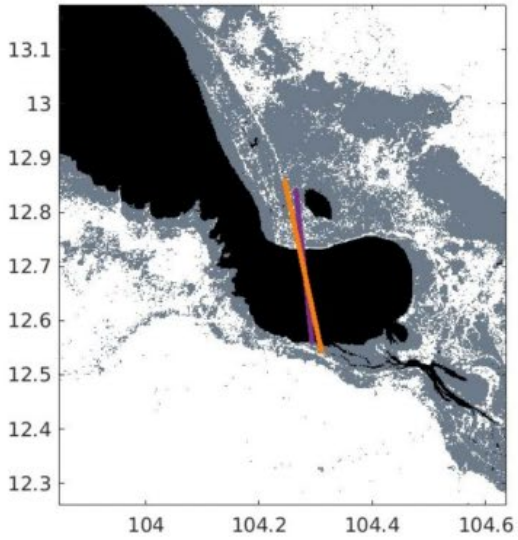
Fig. 6. Spire soil moisture averaged over 14 d "dry" (15 July 2022–1 August 2022) and "wet" (1–15 August 2022) periods coinciding with 2022 Pakistan floods with total GPM derived precipitation over the same two periods. L2 soil moisture averaged to a 36 km grid. (a) Spire, dry. (b) Spire, wet. (c) GPM, dry. (d) GPM, wet.

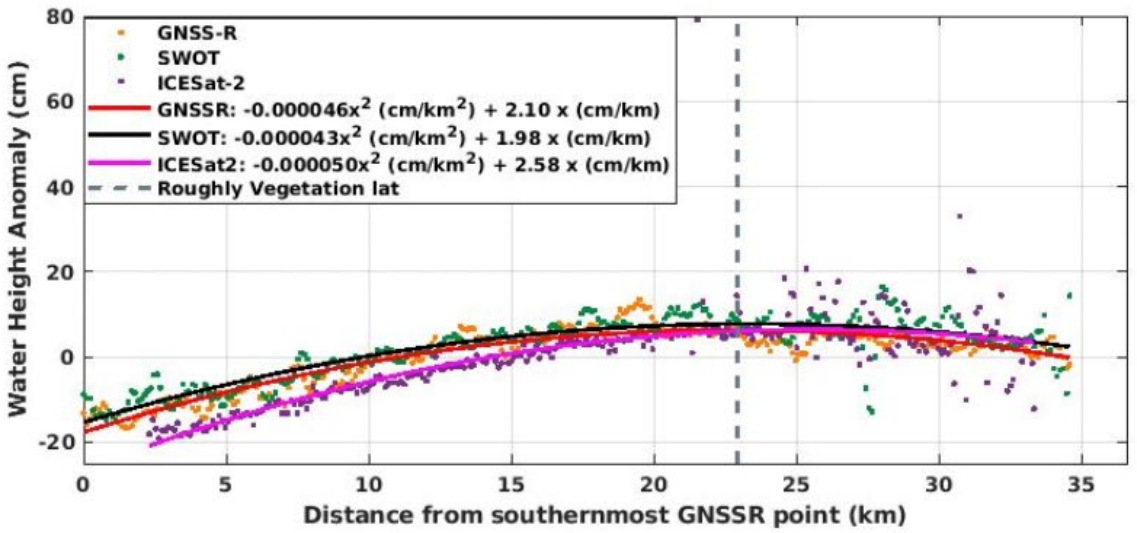
Surface Water Monitoring
GNSS-Reflectometry

Credit: M. Scott et al. (2024). Comparing ICESat-2, SWOT, and GNSS-Reflectometry Water Surface Profiles over the Tonle Sap Lake. Presented at 10th International Radio Occultation Working Group Meeting.

Research Summary and Impact

- Spire's constellation of GNSS-Reflectometry (GNSS-R) sensors can be a cost effective way to monitor inland water bodies such as lakes and rivers over short time scales.
- The figure here shows a comparison of cm-level derived surface altimetric heights derived from Spire GNSS-R measurements over Tonle Sap Lake with estimates derived from SWOT and ICESat-2, two single satellite NASA missions.





Selected Publications

Radio Occultation

- Lonitz et al. (2021). Assimilating Spire and COSMIC-2 data into the IFS. ECMWF Newsletter #169, 25-32.
- McCarty, W. (2021). Science utilizing data from Spire Global as part of the NASA Commercial SmallSat Data Acquisition Program. In 2021 IEEE Geoscience and Remote Sensing Symposium IGARSS.
- Qiu, C. et al. (2023). Comparative Assessment of Spire and COSMIC-2 Radio Occultation Data Quality. Remote Sensing.
- Weiss, J. et al. (2022). COSMIC-2: Highlights from 3 Years in Orbit. Presented at Joint OPAC-7 and IROWG-9. Leibnitz, Austria, September 8, 2022.

Space Weather

- Han et al. (2023). CubeSat GPS Observation of Traveling Ionospheric Disturbances After the 2022 Hunga-Tonga Hunga-Ha'apai Volcanic Eruption and Its Potential Use for Tsunami Warning. Earth and Space Science.
- Cheng et al. (2024). Detection of traveling ionospheric disturbances triggered by 2022 Tonga volcanic eruptions through CubeSats coherent GNSS-reflectometry measurement. Journal of Geophysical Research: Space Physics.
- Grombein, T. et al. (2023). Gravity field recovery based on GPS data of CubeSats from the Spire constellation. 28th General Assembly of IUGG, Berlin, Germany, July 11-20, 2023.
- Lei et al., (2023). Assessment of storm-time ionospheric electron density measurements from Spire Global CubeSat GNSS radio occultation constellation. GPS Solutions.
- Sutton et al. (2021). Toward Accurate Physics-Based Specifications of Neutral Density Using GNSS-Enabled Small Satellites. Space Weather.
- Wang et al. (2021). Ionospheric total electron content and disturbance observations from space-borne coherent GNSS-R measurements. IEEC Transactions on Geoscience and Remote Sensing.
- Wu et al. (2023) Optimal Estimation Inversion of Ionospheric Electron Density from GNSS-POD Limb Measurements: Part I-Algorithm and Morphology. Remote Sensing.

Selected Publications

Grazing Angle GNSS-R

- Anderson et al. (2024). GNSS-Reflectometry-Based Mapping of Antarctic Ice Shelf Surface Characteristics. Presented at IROWG-10.
- Buendia et al. (2023). Ice sheet height retrievals from Spire grazing angle GNSS-R. Remote Sensing of the Environment.
- Bhattacharya et al. (2023). Detection of Surface Water Using Spire Grazing Angle GNSS-R Data. 2023 International Geoscience and Remote Sensing Symposium.
- Roesler, C. et al. (2023). Gulf of Mexico loop-current signature observed from GNSS-R phase altimetry based on Spire Global CubeSat data. IEEC Transactions on Geoscience and Remote Sensing.
- Wang et al. (2023). Troposphere Sensing Using Grazing-Angle GNSS-R Measurement From LEO Satellites. Geophysical Research Letters.
- Wang et al. (2022). Observation of the Mississippi River Surface Gradients from Spire's GNSS-R CubeSats. 2022 International Geoscience and Remote Sensing Symposium.
- Yanez, C. et al. (2024). Lake Water Level Estimation from Grazing GNSS-Reflectometry and Satellite Radar Altimetry over the Great Lakes. IEEE Geoscience and Remote Sensing Letters.

Near-nadir GNSS-R

- Jales et al. (2023). Spire Global's Operational GNSS-Reflectometry Constellation for Earth Surface Observations. 2023 IEEE International Geoscience and Remote Sensing Symposium, Pasadena.
- Setti et al. (2023). Evaluation of Spire GNSS-R reflectivity from multiple GNSS constellations for soil moisture estimation. International Journal of Remote Sensing.

Thank you

From our team, to yours.