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Spire Earth Observations

NASA CSDA Program Lunch & Learn

06 OCT 2022

Introductions

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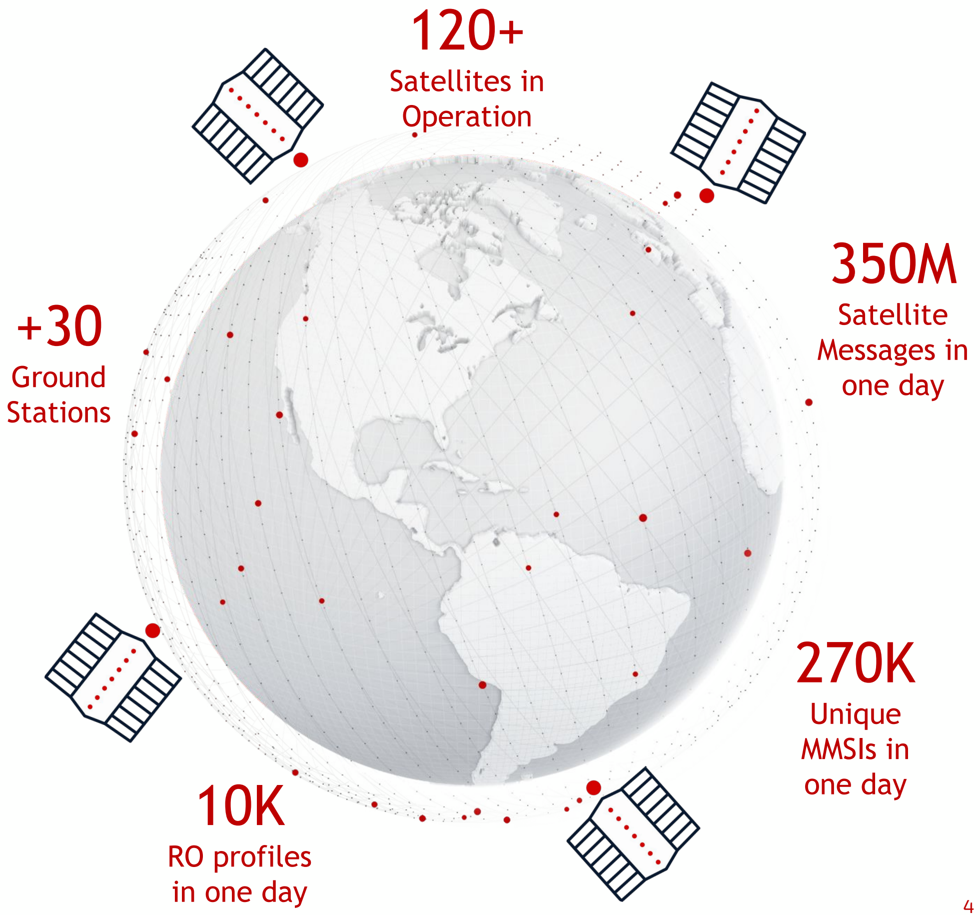
Agenda

The Spire Constellation

One of the largest private constellations in the world

- The Low Earth Multi-Use Receiver (LEMUR) is Spire's 3U CubeSat platform used to track **maritime**, **aviation**, and **weather** activity from space
- We operate the world's **largest RF sensing** fleet and are the largest producer of **radio occultation** and **space weather** data
- Our data provides a global view with coverage in **remote regions** like oceans and poles; all data can be refreshed within **15 minute** cycles
- 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**



Global Ground Station Footprint

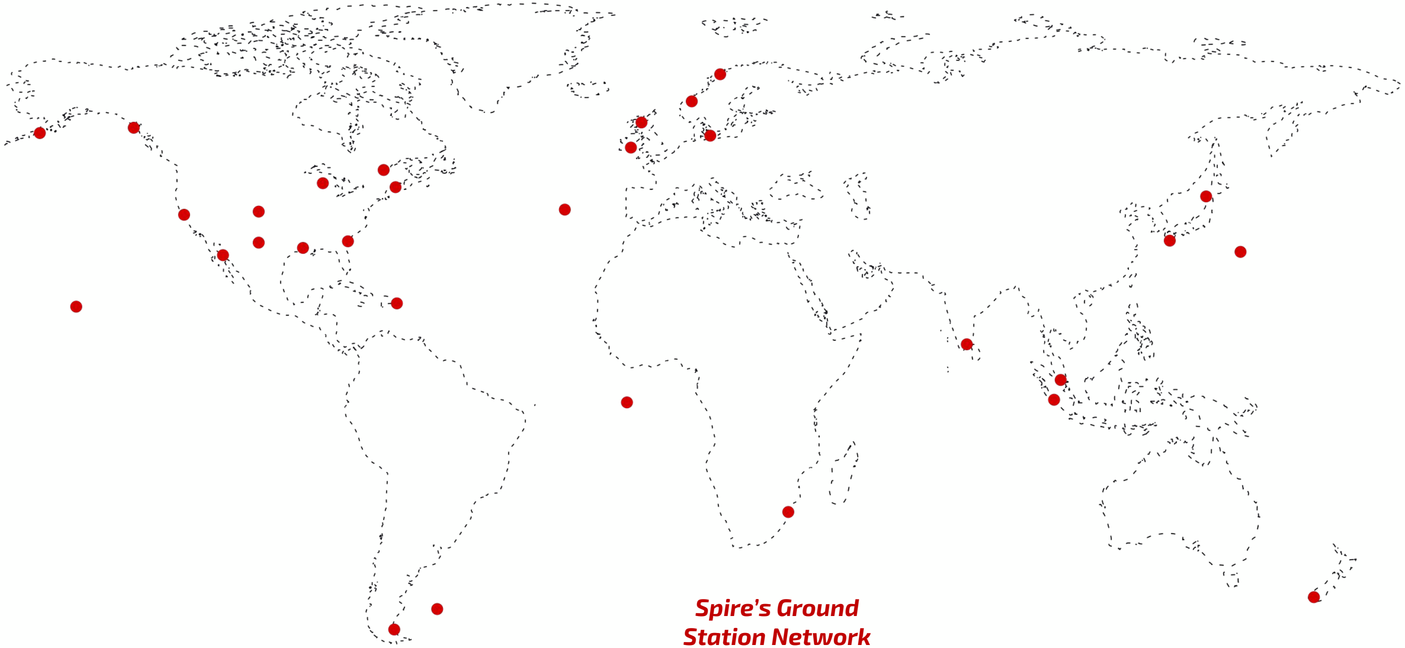
We own and operate the most geographically dispersed and largest network for ground stations, which allows us to repatriate our satellite-generated data at record speed

30+

Ground stations

70+

Antenna systems



Spire Market Sectors & Product Verticals

Earth Intelligence

Spire generates unique data sets of Earth's surface and atmospheric layers using GNSS remote sensing techniques such as radio occultation, reflectometry, and ionospheric electron density and scintillation

GNSS Interference

Spire collects and geolocates sources of GNSS interference in real-time; global GNSS spectrum monitoring and custom RF collection solutions are available for certain operational use cases

Space Services

Spire offers access to its proven LEMUR CubeSat platform and infrastructure for a wide range of customer-driven missions. Standard APIs enable customer access to Spire's cloud-based constellation management and ground stations

Maritime

Spire provides vessel tracking and information on the state of global waterways by leveraging the International Maritime Organization (IMO) Automatic Identification System (AIS) standard

Aviation

Spire collects near real-time information on the movements of civilian aircrafts across the globe, following the International Civil Aviation Organization (ICAO)-backed Automatic Dependent Surveillance-Broadcast (ADS-B) standard

Weather Forecast

Spire models global space-based weather data for hyper-localized coordinates at various vertical levels, with critical implications for severe weather events forecasting, preparation, and management

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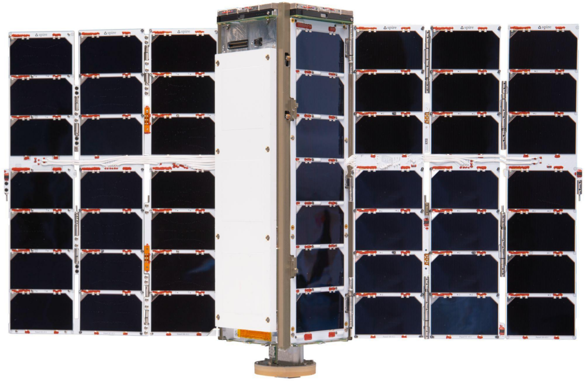
Spire's Low Earth Multi-Use Receiver

3U and 6U Spacecraft with Over 450 Years Collective Heritage

Hosted Payload Parameter	3U Carrier Specs	6U Carrier Specs
Empty Carrier Mass	4.2 kg	5 kg
Payload Mass	Up to 1.4 kg	Up to 7kg
Total Mass	Up to 5.6 kg	Up to 12 kg
Volume	Up to 1.5U	Up to 4U
Payload Power	5 W - 15 W OAP 40 W Peak	
Payload Voltage	3.3V, 5V, 12V, VBAT (6.8 - 8.4 V)	
Onboard Storage	16 GB (expandable)	
Pointing Precision	+/-3° all axes (+/- 0.05° w/ Star Tracker)	
Pointing Accuracy	+/-3° all axes (+/- 0.1° w/ Star Tracker)	
Timing Accuracy	<12 ns (w/ Time & Frequency Reference System)	
Orbit Position Knowledge	<2 m (w/ Time & Frequency Reference System)	

3U



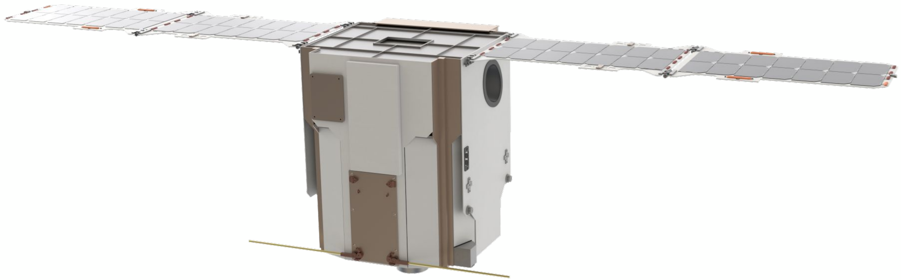
6U

12U & 16U LEMUR

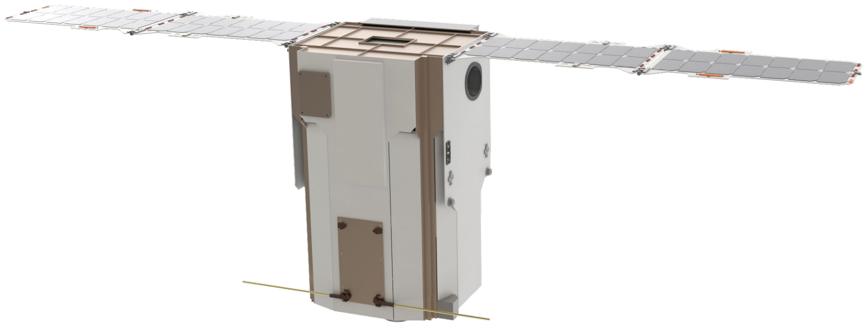
Higher SWP Platforms for Enhanced Mission Capability

- 12U & 16U LEMUR satellites under development
  - PDR complete w/ CDR scheduled for Oct 2022
  - First launch in Q3 2023
- Development timelines driven by commercial contracts
  - **NorthStar:** Six 16U satellites scheduled to launch in Q3/Q4 2023
  - **Commercial Customer:** Minimum constellation of three 16U satellites with first launch in late 2023 / early 2024
- 'Alpha' Power System under development with first launch Q1 2024

Spacecraft Parameter	12U / 16U Platform Specs
Empty Carrier Mass	10 / 12 kg
Payload Mass	Up to 14 / 16 kg
Total Mass	Up to 24 / 28 kg
Volume	Up to 8U / 12U
Payload Power	Up to 100 W OAP & 300 W Peak
Payload Voltage	3.3V, 5V, 12V, 24V, 28V, VBAT (28.8V)



12U



16U

Agenda

Data Available Under CSDA Program

Data available from both NASA CSDA Program task orders and older NASA CSDA pilot program

- NASA procured access to data types starting **01 NOV 2019** through to **17 JUN 2023**
- Data available with a 30-day delay (i.e., 30 days after collection)
- Current Spire products available under the NASA CSDA Program
- New products undergo NASA evaluation
- Product improvements made available as developed
- Conventional GNSS-R (Near-Nadir)

Data Type	Date Range
GNSS Radio Occultation (GNSS-RO) (L0-L2 Atmos. Prf)	24 SEP 2018 - 14 DEC 2018 14 DEC 2018 - 08 MAR 2019 **01 NOV 2019 - present**
Grazing Angle GNSS-Reflectometry (GNSS-R) (L0-L2 Sea Ice Type & Altimetry)	09 JAN 2019 - 18 APR 2019 **01 NOV 2019 - present**
Conventional GNSS-R L1 Bistatic Radar	**17 MAY 2022 - present**
Conventional GNSS-R L2 Ocean Winds	**01 AUG 2022 - present**
Conventional GNSS-R L2 Soil Moisture	**Est. DEC 2022**
Raw IF captures (GNSS-R)	Various
L0-L1 Precise Orbit Determination	24 SEP 2018 - 18 APR 2019 **01 NOV 2019 - present**
L0-L2 Space Weather (TEC, EDP, Scintillation)	**01 NOV 2019 - present**
L0 Magnetometer (Simple Sensor Data)	**01 NOV 2019 - present**

Data Products

GNSS Radio Occultation

Space Weather

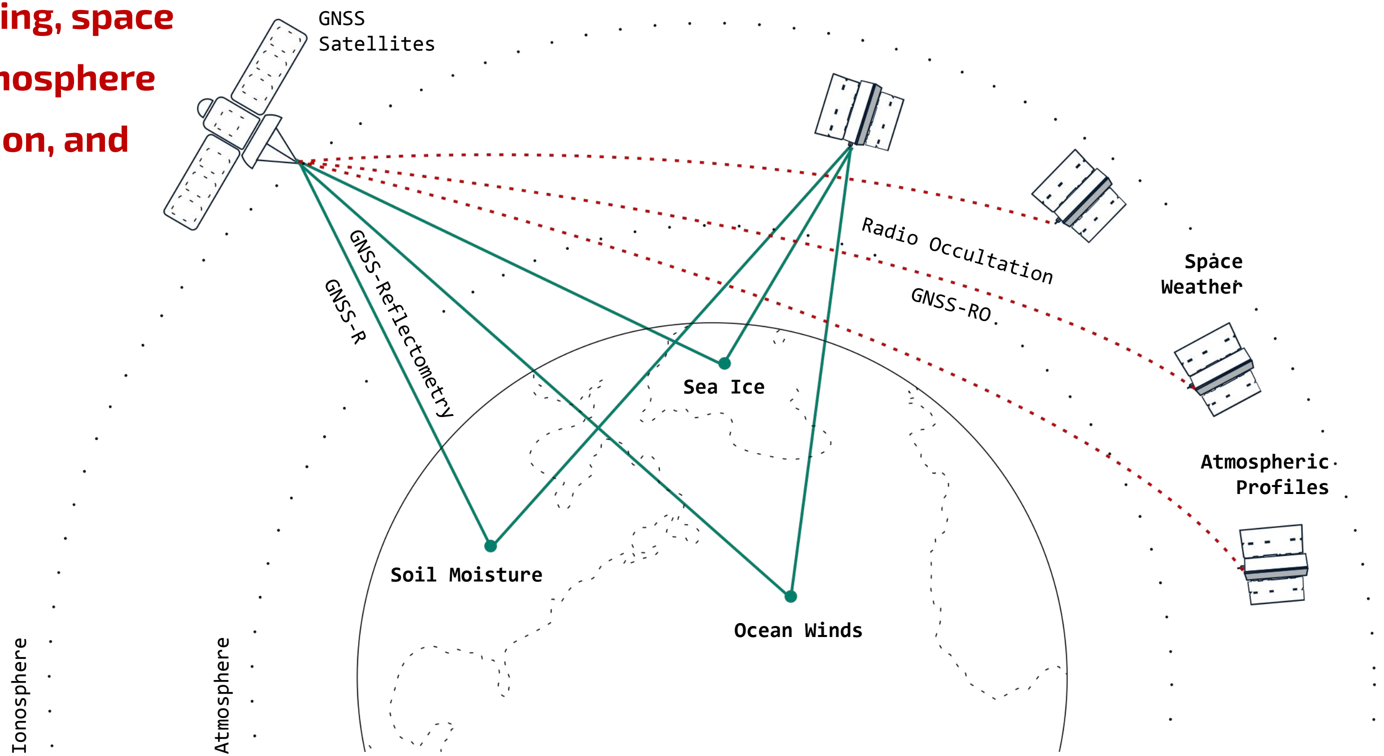
Precise Orbit Data

Grazing Angle GNSS-Reflectometry

Conventional GNSS-Reflectometry

Spire Earth Intelligence Data

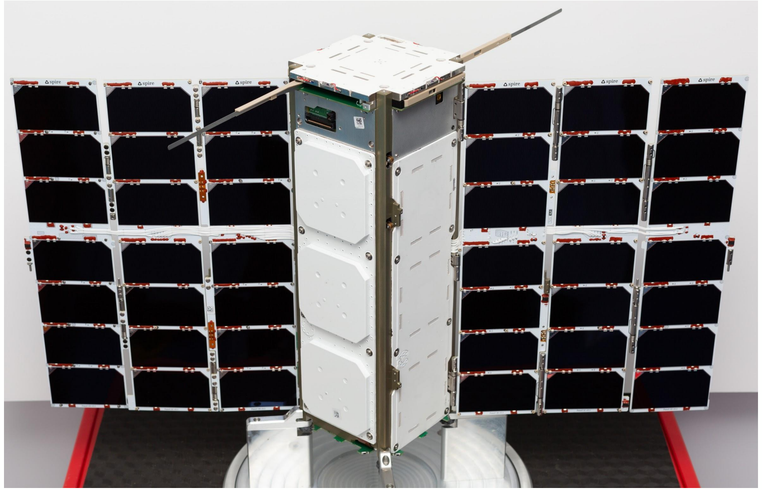
Our satellites also capture data relevant for **NWP modeling, space weather monitoring, ionosphere corrections for navigation, and thermospheric density**

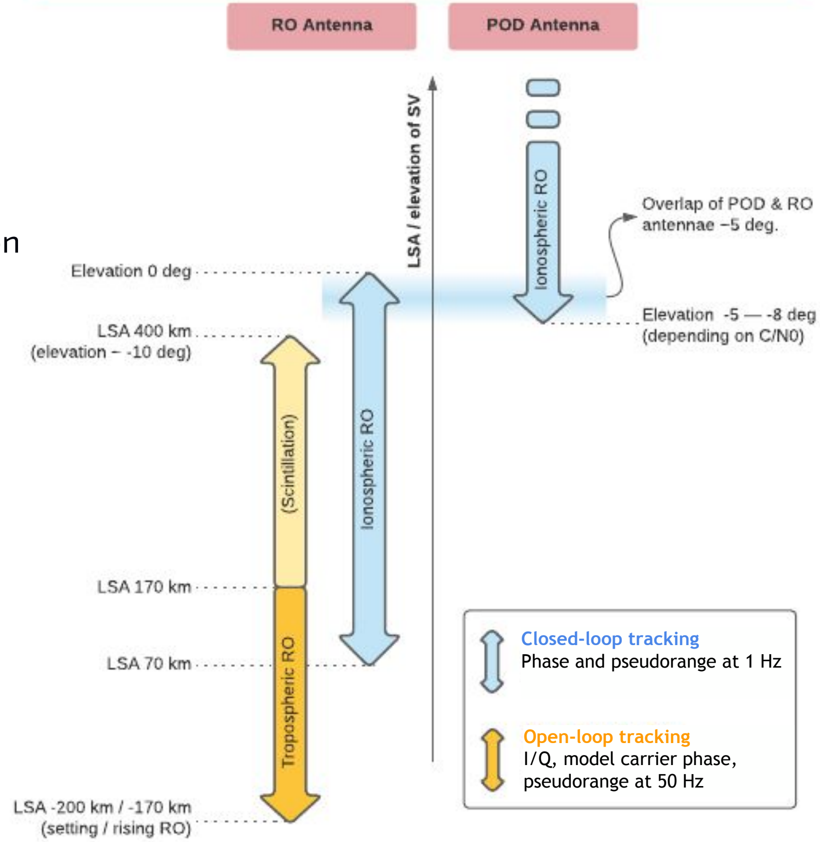


GNSS-RO Collection

Spire GNSS-RO satellites

- Moderate gain, dual antennas (rising/setting)
- Multi-GNSS signals tracked in open-loop
- STRATOS receiver v2 launched and capable of more RO collection
- 40+ RO-capable satellites, 25+ in production

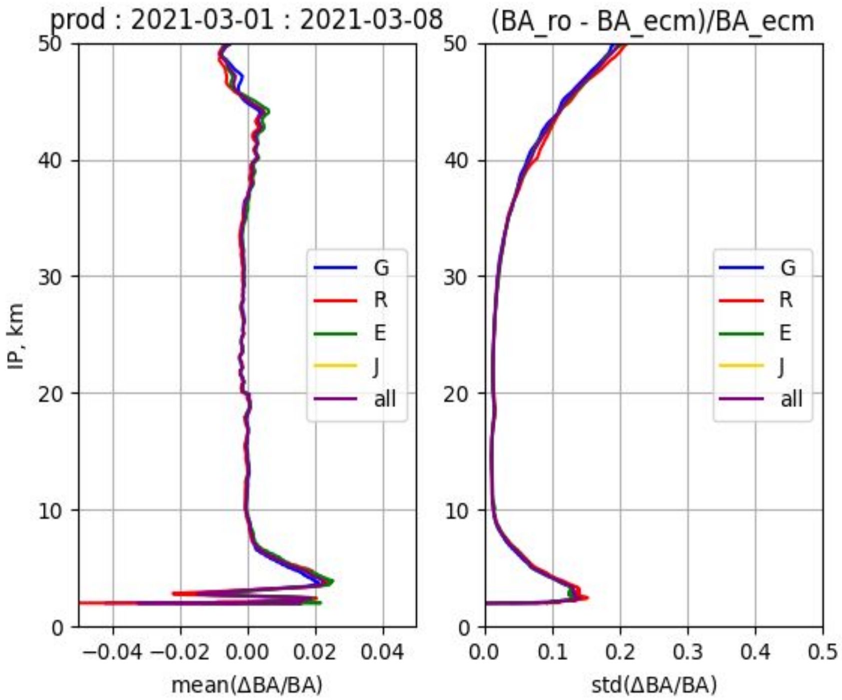




GNSS-RO Data in the CSDA Program

RO Data Processing

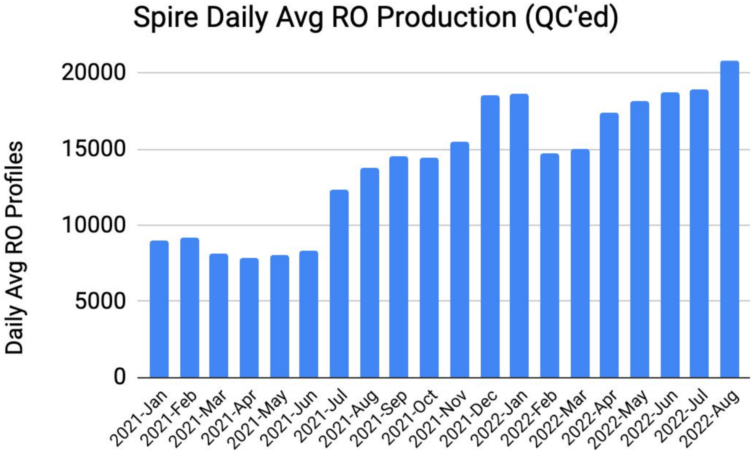
- Spire RO data are downloaded and processed into all data levels using a state-of-the-art processing system
- Mainly follows CDAAC conventions and includes:
    - Level 0 Low-level 50 Hz data (custom netCDF, opnGns)
    - Level 1B Excess phase (atmPhs)
    - Level 2 Atmospheric profiles (atmPrf, bfrPrf)
    - Navigation data
        - Level 1A RINEX data (podObs)
        - Level 1A Attitude data (leoAtt and telAtt)
        - Level 1B Precise orbit estimates (leoOrb)
    - Ancillary data available



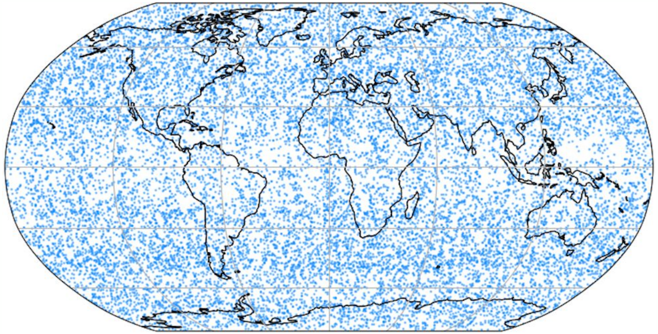
Similar quality rising/setting profiles from multiple GNSS

Growing GNSS-RO Volume & Coverage

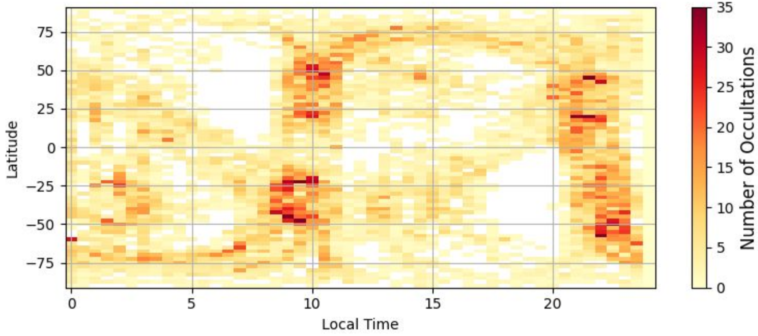
- Spire constellation is currently producing **20,000+ quality-controlled profiles per day**, satisfying the current established IROWG/CGMS target
  - *Ability to scale quickly to meet future demand*
- Delivering raw and processed data in near-real-time to major processing centers for further dissemination to NWP centers and users



Long-term RO production increase



World's largest producer of RO profiles
(24 hr coverage shown below)

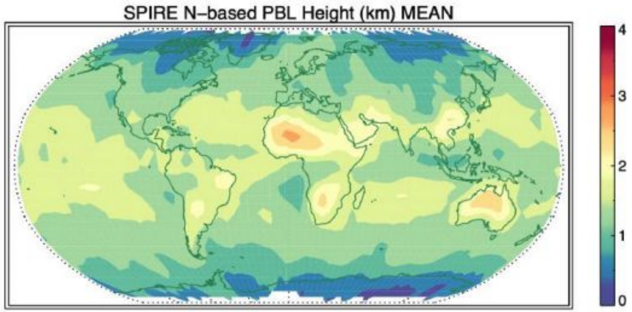


Diverse local time coverage

External Evaluations

- Several years of third-party evaluations from EUMETSAT, UCAR, NOAA** have shown Spire RO data to be of high-quality and exceeding performance of many legacy missions
  - Near real-time results available at ROMSAF and JCSDA
- Demonstrated positive impact of Spire RO data on NWP systems from evaluators at NOAA, NASA, ECMWF, UK Met Office**

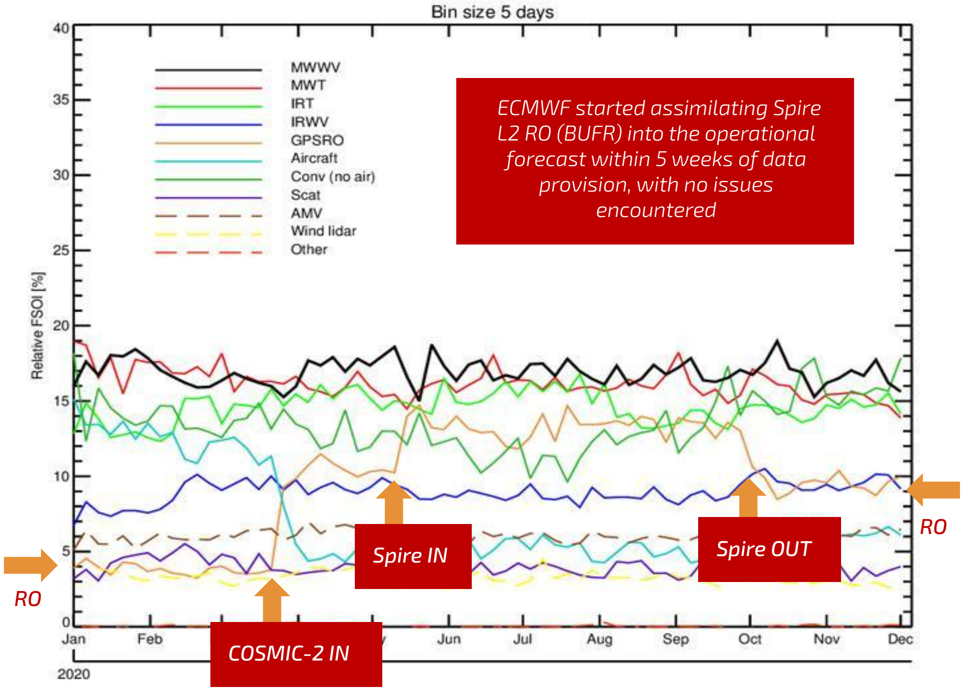
UCAR study on planetary boundary layer from Spire data



Mean PBL height as detected directly from Spire data. It is noted that Spire's penetration depth exceeds heritage, making this measurement possible.

Source: W. Schreiner, 2021 (Data Processing and Scientific Evaluation of Spire GNSS RO Data for the NASA CSDA)

ECMWF FSOI increase after assimilating Spire RO in 2020



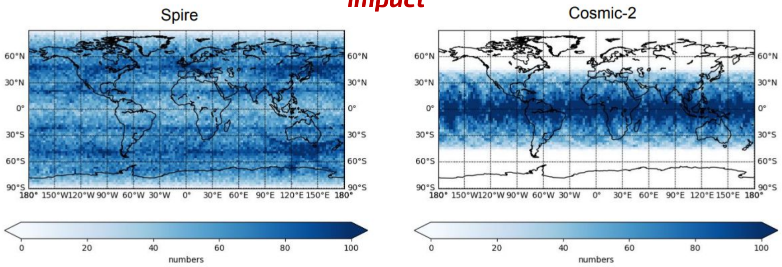
Source: S. Healy, ECMWF, 2020

** References for Schreiner, Healy, Lonitz, Ho, and McCarty evaluations listed throughout Slides 17 and 18 of this presentation

External Evaluations

At the 2021/2022 International RO Working Group meetings, independent users showed Spire RO is similar in quality and impact to institutional RO missions

ECMWF compared Spire to COSMIC-2 sampling and impact



Source: K. Lonitz, ECMWF, 2021 (link to IROWG presentation)

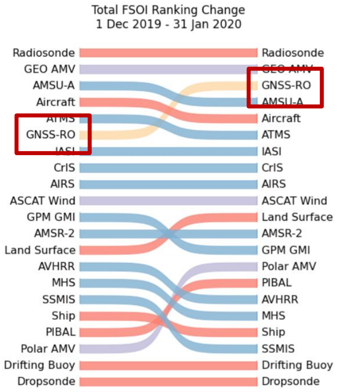
NOAA showed Spire matches COSMIC-2 penetration depths

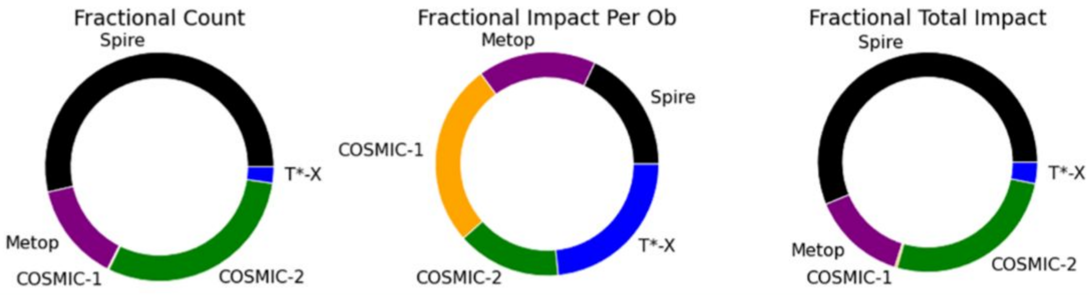
	10N-10S	10N-30N	30S-10S	30N-45N	45S-30S	45N-60N	60S-45S	60N-90N	90S-60S
COSMIC-2	0.85	0.90	0.75	1.35	1.10				
GeoOptics	0.95	1.05	1.10	0.70	0.80	0.35	0.40	0.55	0.20
SPIRE	0.90	0.90	0.75	0.80	0.55	0.45	0.25	0.45	0.20
KOMPSAT-5	1.85	1.50	1.15	0.40	0.95	0.35	0.40	0.25	0.20
PAZ	2.65	1.85	2.05	0.90	1.30	0.45	0.45	0.35	0.25

Source: B. Ho, NOAA, 2021 (link to IROWG presentation)

NASA showed Spire data moved ***RO FSOI to third place*** *among all observations and Spire led in fractional total impact*

Source: W. McCarty, NASA, 2021 (link to IROWG presentation)





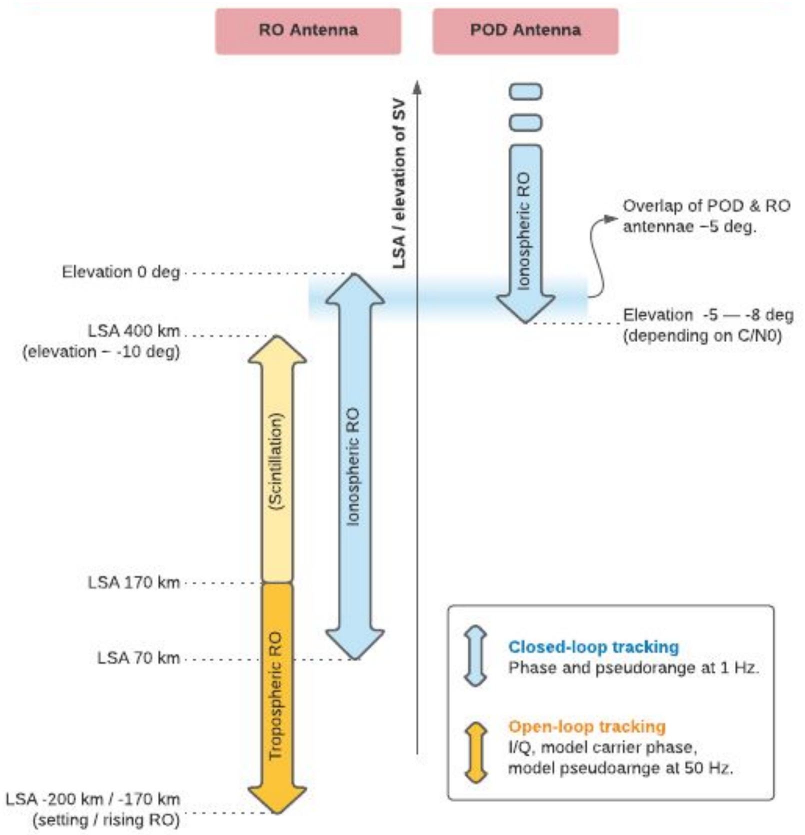
Data Products

- GNSS Radio Occultation
- **Space Weather**
- Precise Orbit Data
- Grazing Angle GNSS-Reflectometry
- Conventional GNSS-Reflectometry

Ionospheric Data Collection

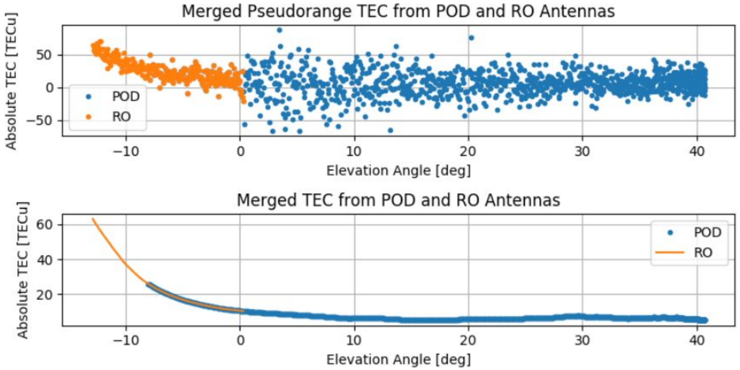
- **SpWx relevant data collected from both POD and RO antennas**
  - POD antenna: 1-Hz closed loop tracking
  - RO antennas: 1-Hz closed loop tracking and 50 Hz open loop tracking
  - Observation range overlap between POD and RO antennas
- **Data Products**
  - GNSS observables in RINEX format (podObs)
  - Total Electron Content (TEC) estimates (podTec, ionTec)
  - On-board scintillation indices (scnLv1)
  - Electron density profiles (ionDen)

More details at Angling et al. Sensing the ionosphere with the Spire radio occultation constellation, *J. Space Weather Space Clim, 2022*

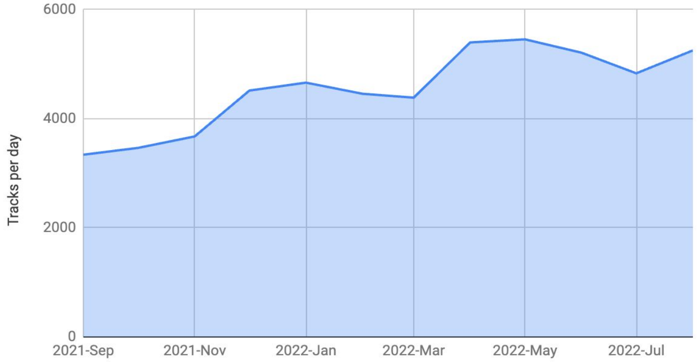


TEC Estimates

- Closed-loop dual-frequency pseudorange and phase observations used to derive TEC measurements through each antenna
    - Standard procedure applied: Weighted levelling, cycle slip correction and estimation of differential code biases
    - Stored in CDAAC podTec format
- GNSS observations/TEC estimates can be combined across POD and RO antennas to produce longer ionospheric tracks (ionTec)
    - Over 5000 ionospheric tracks per day spanning from maximum elevation to less than 90 km altitude
    - Over 500 ionospheric tracks per day satisfying median latency of 30 minutes required by NOAA SpWx Data Pilot
    - Currently only tracking GPS in closed-loop mode. Can add other constellations to increase number of ionospheric tracks.



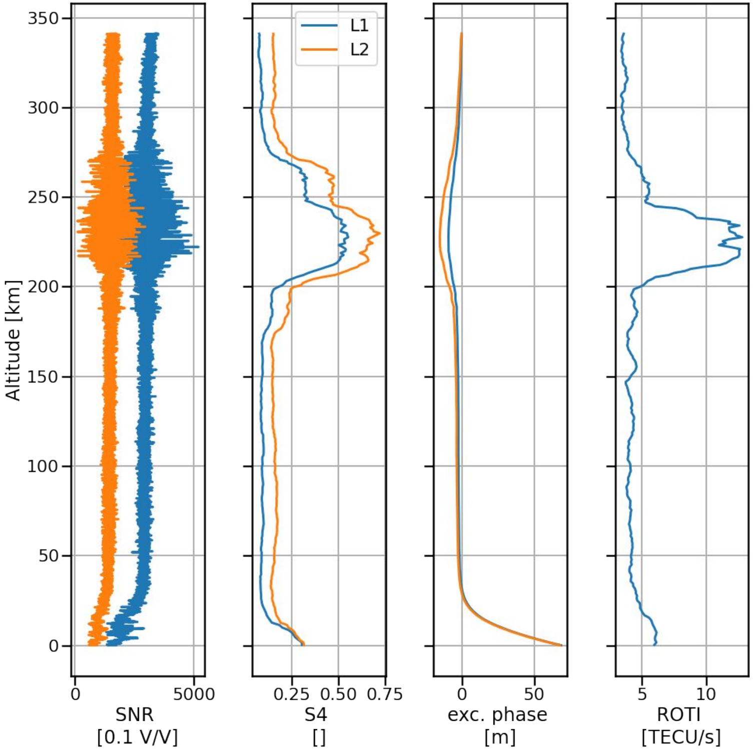
Example of combining TEC across multiple antennas



Monthly averaged ionospheric tracks per day

High-rate Data & Scintillation

- High-rate (50-Hz) open-loop phase data are collected through RO antennas
  - Spans at least from 150km and downward
  - Multi-constellation
- On-board estimate of S4
  - Computed every second from a 10 second block of I and Q data sampled at 1 kHz
  - Computed on both frequencies through the RO antennas
  - 50-Hz data from orbit altitude is downlinked if S4 > 0.3 for at least 10 seconds



F-region 50 Hz Data and Scintillation Indices

Data Products

GNSS Radio Occultation

Space Weather

Precise Orbit Data

Grazing Angle GNSS-Reflectometry

Conventional GNSS-Reflectometry

Precise Orbit Data in CSDA Program

- Spire GNSS precise orbit products are collected operationally by all sats
- The product types follow COSMIC conventions (CDAAC) and include:
  - Navigation data (leoOrb precise orbits in SP3 format, RINEX data)
- Possible applications:
  - These data have been successfully used to estimate thermospheric density through satellite drag
  - Mass change trend signals and annual signals for different recovered by GPS receivers in LEO using POD techniques (e.g., da Encarnação et al, 2019)

Space Weather®

Research Article | Open Access

Toward Accurate Physics-Based Specifications of Neutral Density Using GNSS-Enabled Small Satellites

Eric K. Sutton, Jeffrey P. Thayer, Marcin D. Pilinski, Shaylah M. Mutschler, Thomas E. Berger, Vu Nguyen, Dallas Masters

First published: 08 May 2021 | https://doi.org/10.1029/2021SW002736

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Abstract

Satellite-atmosphere interactions cause large uncertainties in low-Earth orbit determination and prediction. Thus, knowledge of and the ability to predict the space environment, most notably thermospheric mass density, are essential for operating satellites in this domain. Recent progress has been made toward supplanting the existing empirical, operational methods with physics-based data-assimilative models by accounting for the complex relationship between external drivers such as solar irradiance, Joule, and particle heating, and their response in the upper atmosphere. Simultaneously, a new era of CubeSat constellations is set to provide data with which to calibrate our upper-atmosphere models at higher spatial resolution and temporal cadence. With this in mind, we provide an initial method for converting precision orbit determination solutions from global navigation satellite system

Data Products

GNSS Radio Occultation

Space Weather

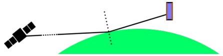
Precise Orbit Data

Grazing Angle GNSS-Reflectometry

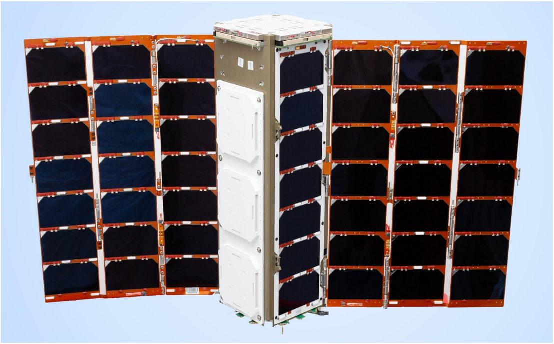
Conventional GNSS-Reflectometry

Spire GNSS-Reflectometry Constellation

Grazing Angle GNSS-R



Operational on 25+ satellites



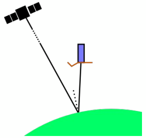
Antennas

- Two dual-frequency RHCP antennas on each satellite for rising/setting radio occultation

Processing

- Multi-GNSS (GPS, Galileo, GLONASS, QZSS, Beidou.)
- Coherent signal processing - output I/Q at 50 Hz
- Ice characterisation and altimetry

Conventional (Near-Nadir) GNSS-R



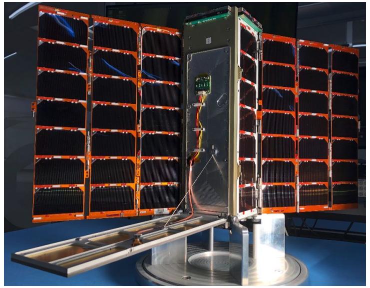
Four (4) satellites on-orbit with near-nadir antennas

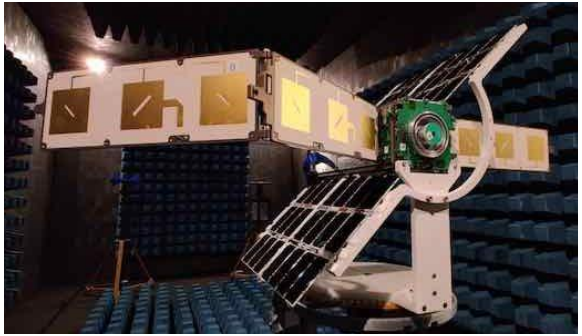
Antennas

- Single frequency LHCP nadir-pointing antennas
- Antenna beamforming and advanced relative calibration

Processing

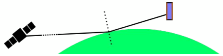
- Multi-GNSS (GPS, Galileo, QZSS, Beidou)
- DDM signal processing (up to 30 channels)
- Prototypes for long-term, high-res (3 km) soil moisture observations



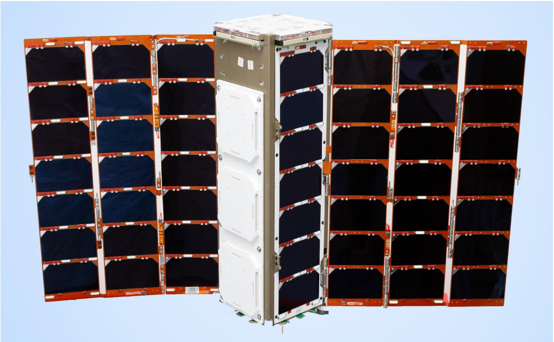


Spire GNSS-Reflectometry Constellation

Grazing Angle GNSS-R



Operational on 25+ satellites



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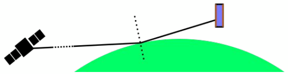
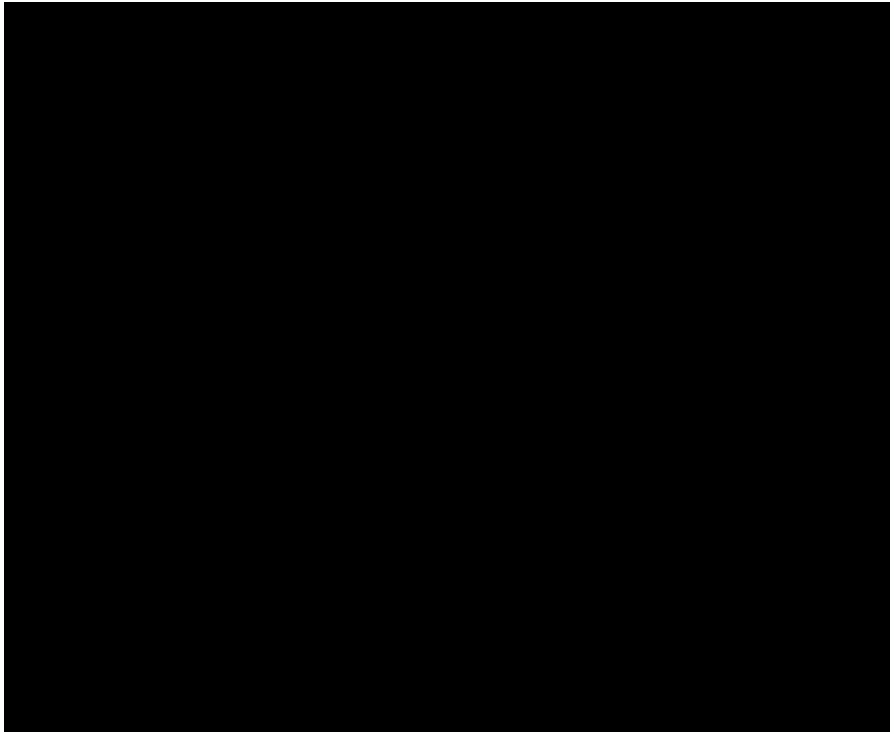
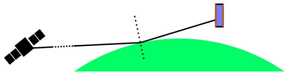
Grazing Angle GNSS-R Data Collection



- **Up to 25 satellites** in various orbital planes
- **Stable operational data collection**, averaging 2000+ L1B events per day, each ranging from several seconds to nearly 6 minutes
- Data collection **50 Hz IQ** measurements
- Open-loop tracking of **direct and reflected** signals
- Dual frequency **L1 and L2** *(E1 and E5 for Galileo)*
- **Median latency of 90 min** from data collection to Level 2 product availability
- **Products:**
  - Level 1A: Instrument data aggregation
  - Level 1B: Measurement georeferencing
  - Level 2: Ice extent and classification
  - Level 2: Height profile extraction



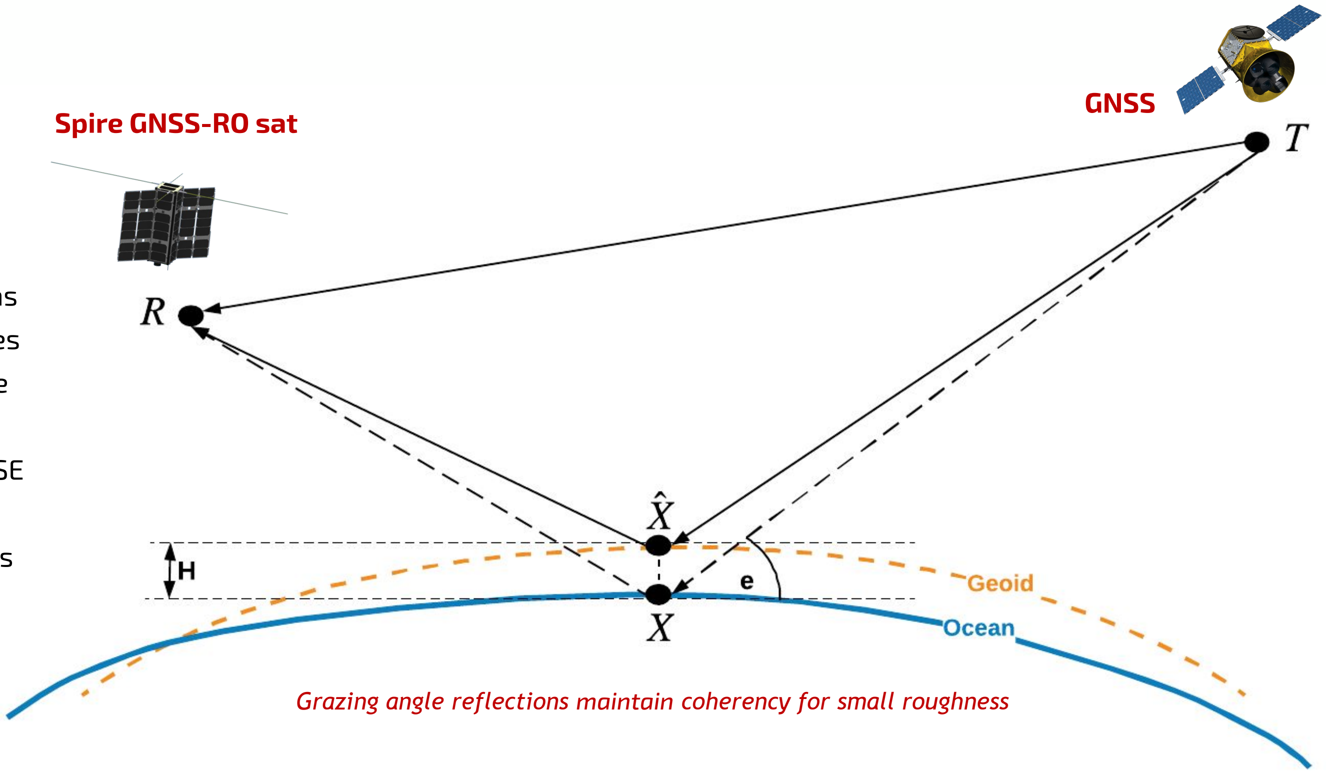
Grazing Angle
GNSS-R Technique



Phase-delay altimetry is a type of GNSS-R that uses <u>coherent</u> reflections of GNSS signals at low grazing angles (5-30 deg) to estimate cm-level heights of smooth surfaces

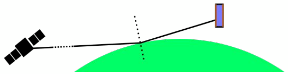
Grazing angle GNSS-R altimetry has the ability to collect large quantities of relative height profiles of sea ice with precisions that approach traditional altimeters (< 10 cm RMSE @ 50 Hz) and can potentially complement these other altimeters to fill gaps

Running operationally on up to 25 satellites

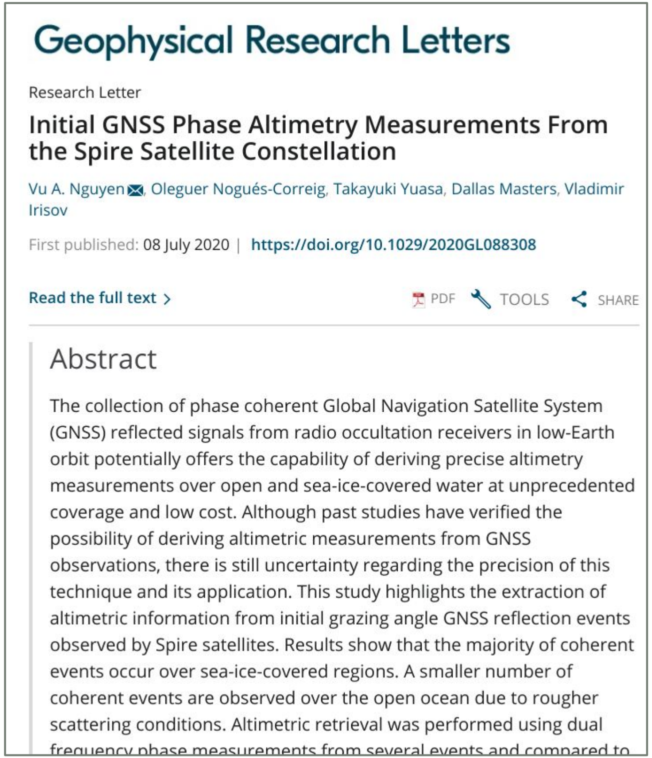


Grazing angle reflections maintain coherency for small roughness

Grazing Angle GNSS-R in CSDA Program



- Spire grazing angle GNSS-R products are collected operationally by GNSS-RO satellites (targeting polar, Gulf of Mexico, and Indonesian areas)
- The product types are Spire-defined and include:
  - Low-level 50 Hz data open-loop tracked I/Q data (direct and reflected signal in RO antenna (L1A base data in nc4 format)
  - Georeferenced reflection (L1B data nc4 format)
  - Level 2: Ice extent and classification
  - Level 2: Height profile extraction



Geophysical Research Letters

Research Letter

Initial GNSS Phase Altimetry Measurements From the Spire Satellite Constellation

Vu A. Nguyen, Oleguer Nogués-Correig, Takayuki Yuasa, Dallas Masters, Vladimir Irisov

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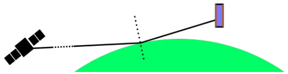
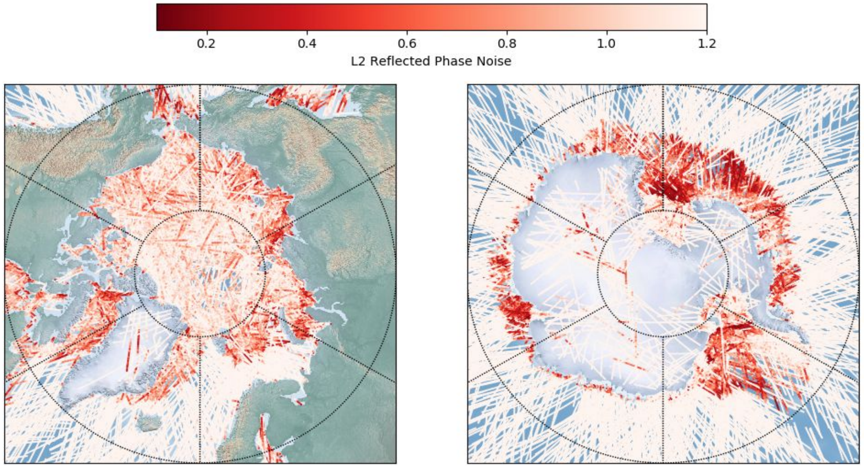
Abstract

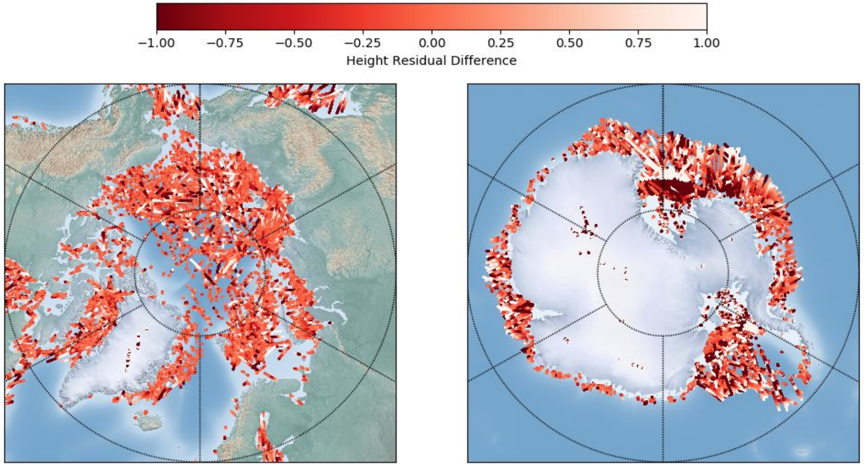
The collection of phase coherent Global Navigation Satellite System (GNSS) reflected signals from radio occultation receivers in low-Earth orbit potentially offers the capability of deriving precise altimetry measurements over open and sea-ice-covered water at unprecedented coverage and low cost. Although past studies have verified the possibility of deriving altimetric measurements from GNSS observations, there is still uncertainty regarding the precision of this technique and its application. This study highlights the extraction of altimetric information from initial grazing angle GNSS reflection events observed by Spire satellites. Results show that the majority of coherent events occur over sea-ice-covered regions. A smaller number of coherent events are observed over the open ocean due to rougher scattering conditions. Altimetric retrieval was performed using dual frequency phase measurements from several events and compared to

Grazing Angle Measurement Coverage



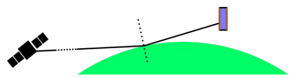


Total Measurement Coverage over 1 Week



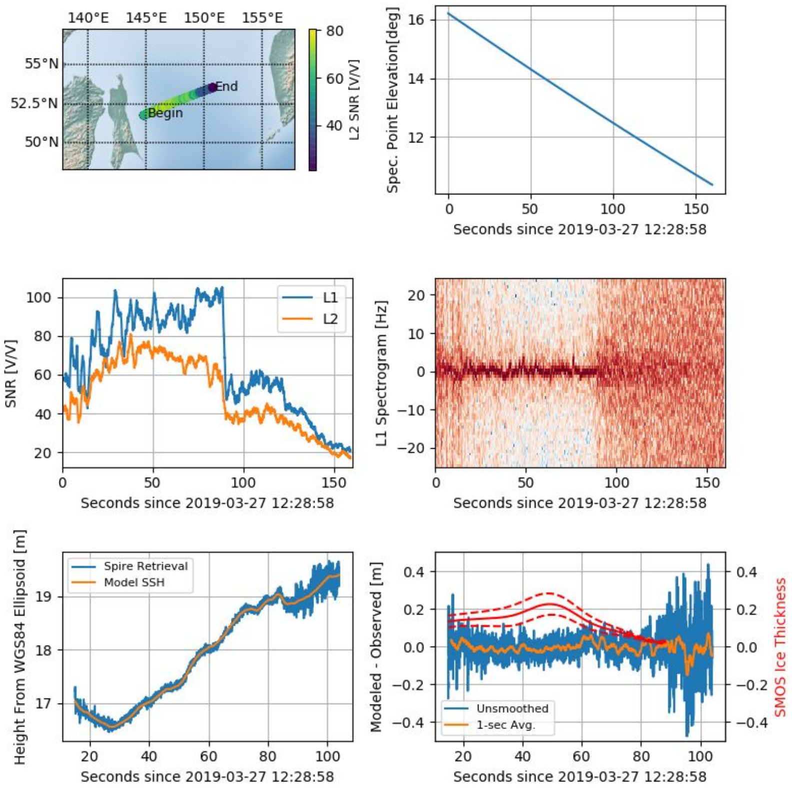
Altimetric Height Coverage over 1 Week

Grazing Angle Sea Ice Altimetry

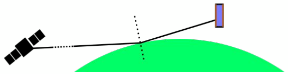


Reflection event over Sea of Okhotsk

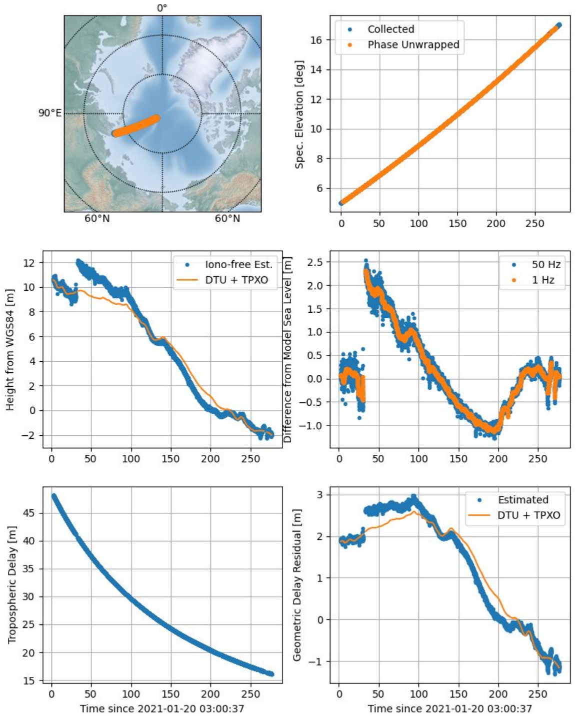
- L1 & L2 SNR correlated and show transition from sea ice to open ocean around 80 seconds
- Estimated reflector height again follows expected mean sea surface (DTU18) with tides (TPX09-atlas) removed
- Residual shows little gradient along the track *(< 3 cm RMSE)*
- SMOS thickness estimate is larger in center of track
- Reflection is likely occurring off the top of the ice or snow interface



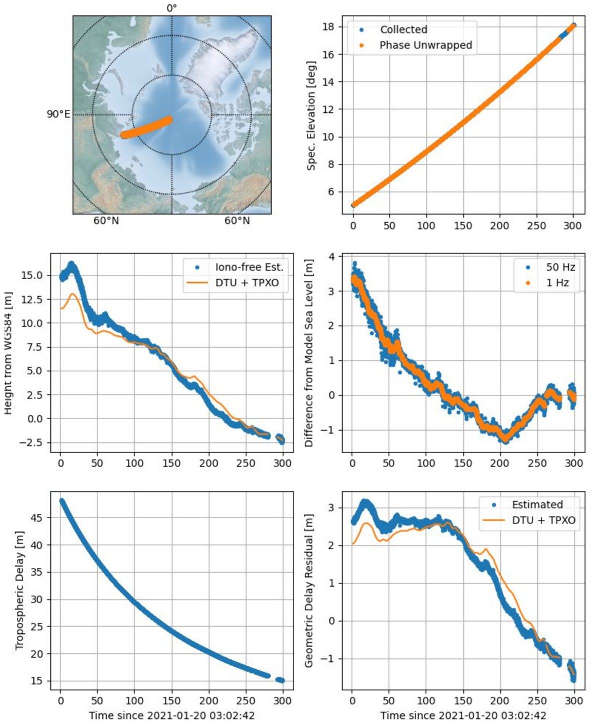
Two-Sat Validation of Sea Ice Altimetry



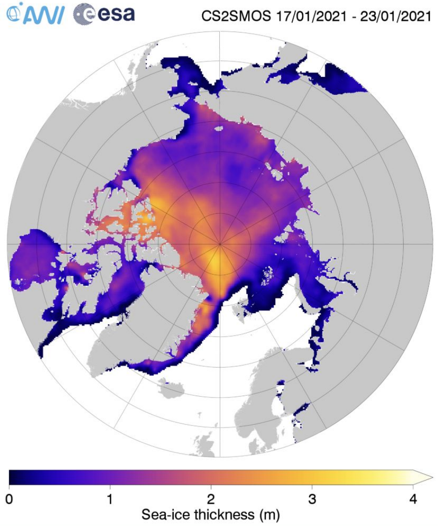
FM101 at T03:00



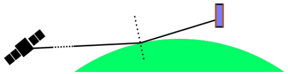
FM100 at T03:02



Sats in same orbit (2 min apart) measure similar profile gives **intrinsic method to validate data within the constellation (CS2SMOS below)**



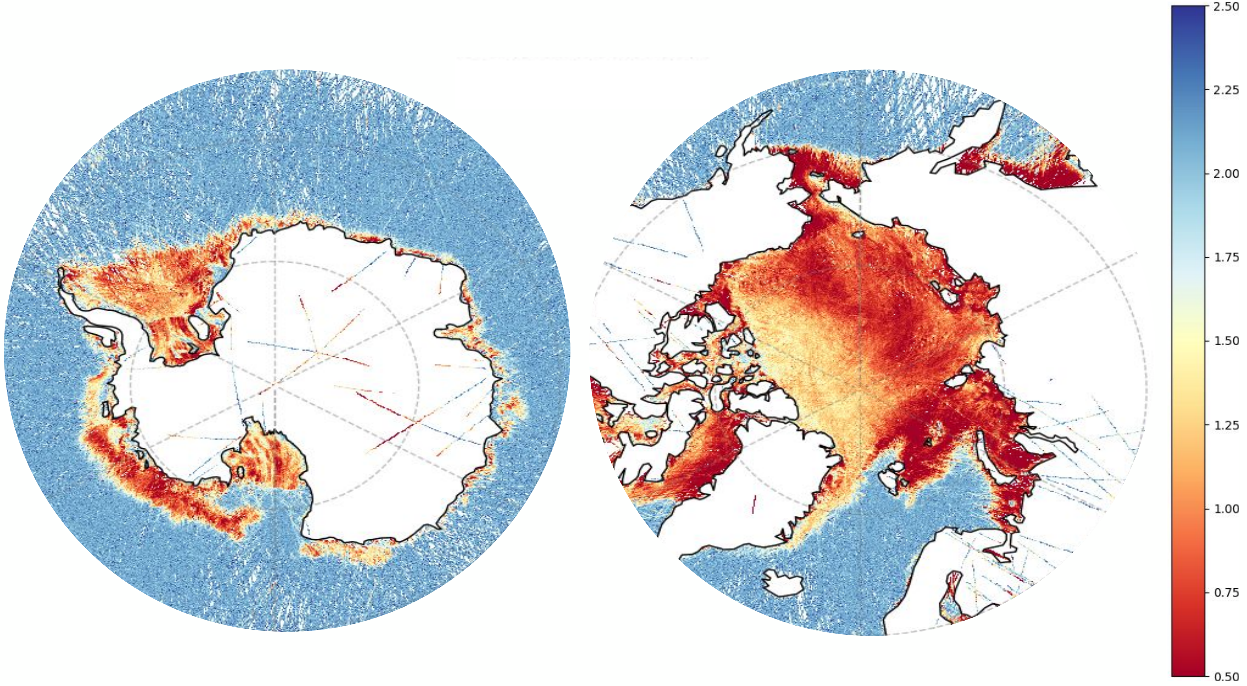
Grazing Angle GNSS-R Phase Noise



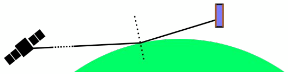
- Standard deviation of the change in the phase over a one second window

- Temporal and spatial variation in patterns in roughness

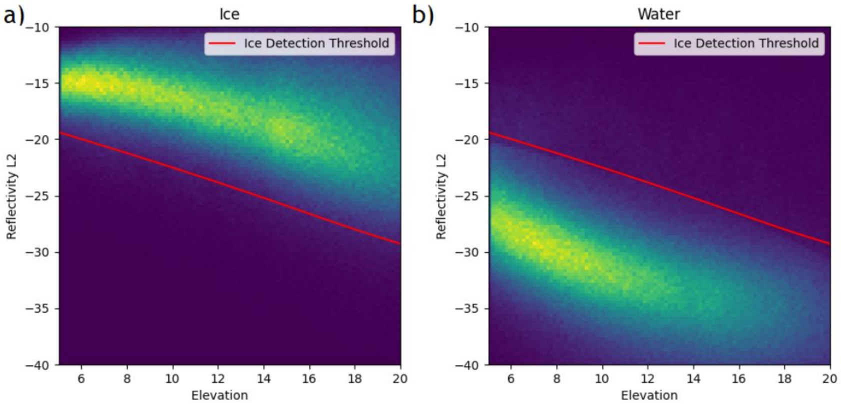
- First Year and Multi-Year ice clearly visible in Arctic data



Application to Sea Ice Extent



Simple threshold dependent on elevation angle



Thresholds trained:

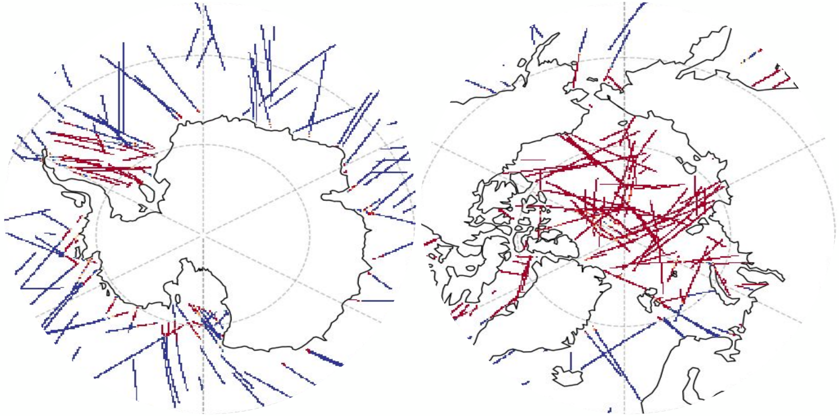
1st March 2020 - 1st March 2021

Data shown:

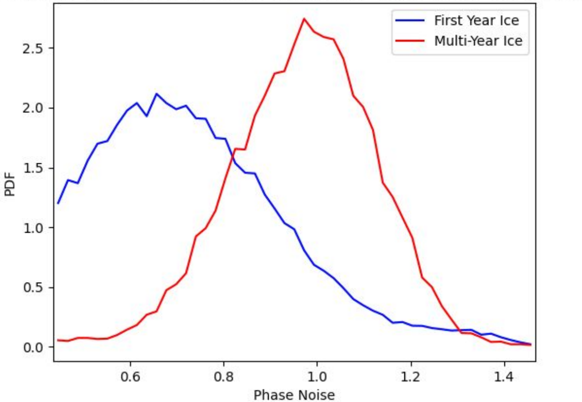
1st March 2020 - 1st March 2022

	Active	Passive	Operational
Arctic	94 %	93 %	95 %
Antarctic	98 %	96 %	

Separate training and testing datasets



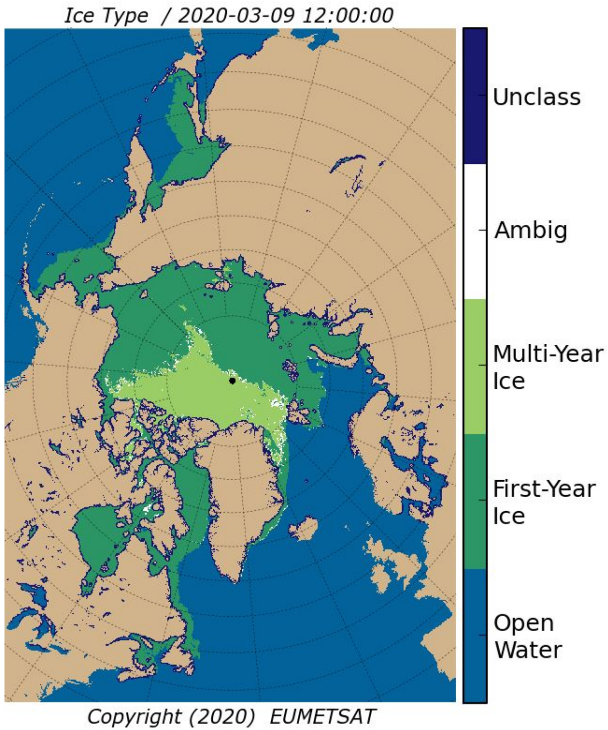
Application to Sea Ice Type

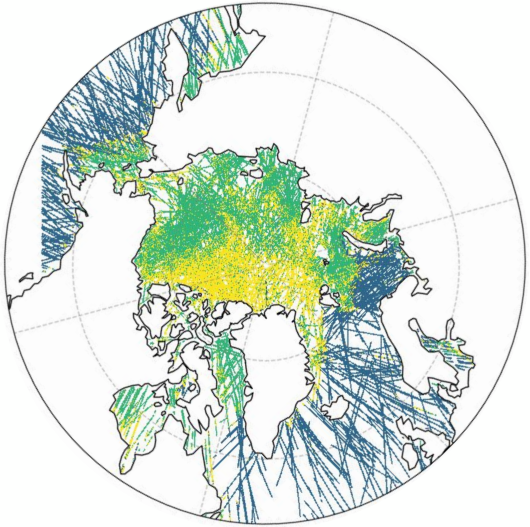


First-year Ice ⟵ ⟶ Multi-year Ice

	Weekly Ice Chart	Active Product
Arctic	74 %	77 %

Separate training and testing datasets





Data Products

GNSS Radio Occultation

Space Weather

Precise Orbit Data

Grazing Angle GNSS-Reflectometry

Conventional GNSS-Reflectometry

Spire GNSS-Reflectometry Constellation

Grazing Angle GNSS-R

Operational on 25+ satellites

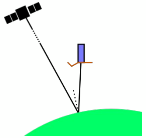
Antennas

- Two dual-frequency RHCP antennas on each satellite for rising/setting radio occultation

Processing

- Multi-GNSS (GPS, Galileo, GLONASS, QZSS, Beidou.)
- Coherent signal processing - output I/Q at 50 Hz
- Ice characterisation and altimetry

Conventional (Near-Nadir) GNSS-R



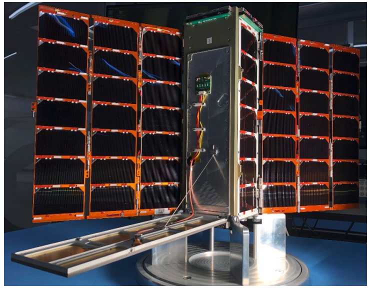
Four (4) satellites on-orbit with near-nadir antennas

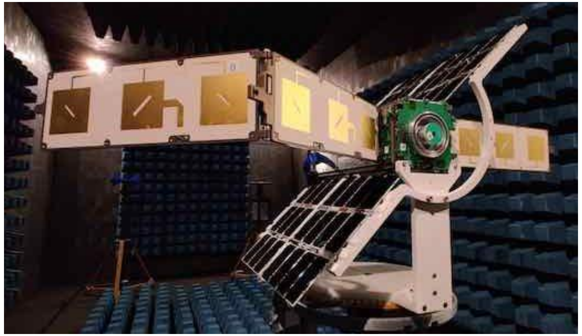
Antennas

- Single frequency LHCP nadir-pointing antennas
- Antenna beamforming and advanced relative calibration

Processing

- Multi-GNSS (GPS, Galileo, QZSS, Beidou)
- DDM signal processing (up to 30 channels)
- Prototypes for long-term, high-res (3 km) soil moisture observations





GNSS-R Data in the CSDA Catalog

- Spire Conventional (Near-Nadir) GNSS-R products are collected operationally by GNSS-R Batch-1 & Batch-2 satellites
- The product types are Spire-defined and include:

Level 1B
GNSS-R Land Surface Reflectivity
(along-track, netCDF)

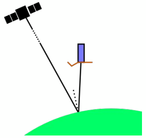
Level 1B
GNSS-R Ocean Normalized Bistatic Cross-sections
(along-track, netCDF)

L2
Ocean Wind Speed and MSS
(along-track, netCDF)

L2
Soil Moisture **
(along-track, netCDF)

*** undergoing NASA evaluation*

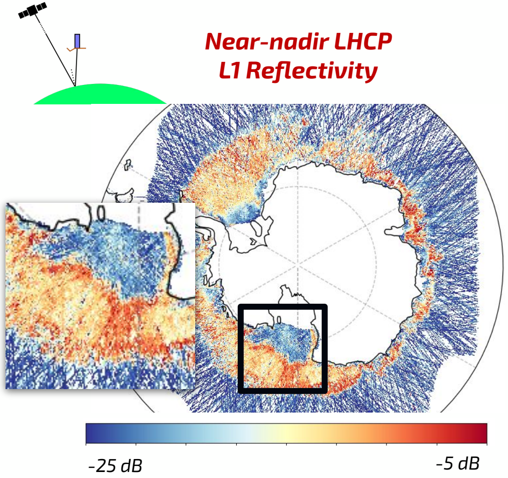
GNSS-R Ice Classification

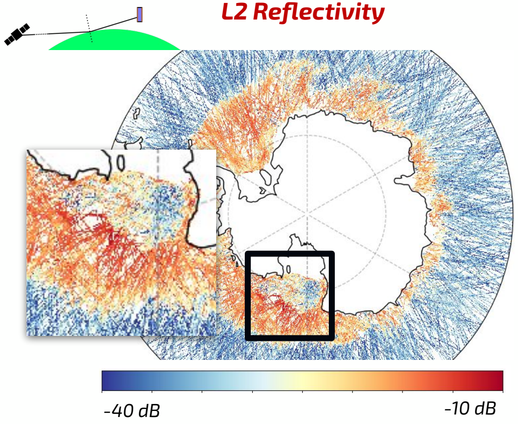


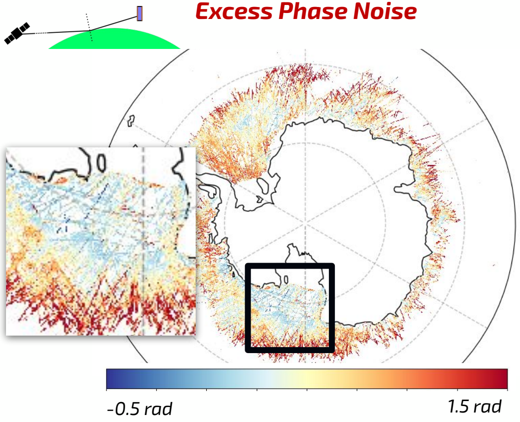
- Combining Conventional (Near-Nadir) and Grazing-Angle GNSS-R offers a rich set of observables:
  - Dual polarisation and frequency
  - Coherent & incoherent
  - Diversity of geometry

- High resolution data products: sea ice extent, ice type

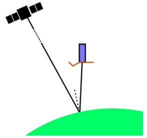
Fourteen (14) days starting 2021-12-16 over a 10 km grid



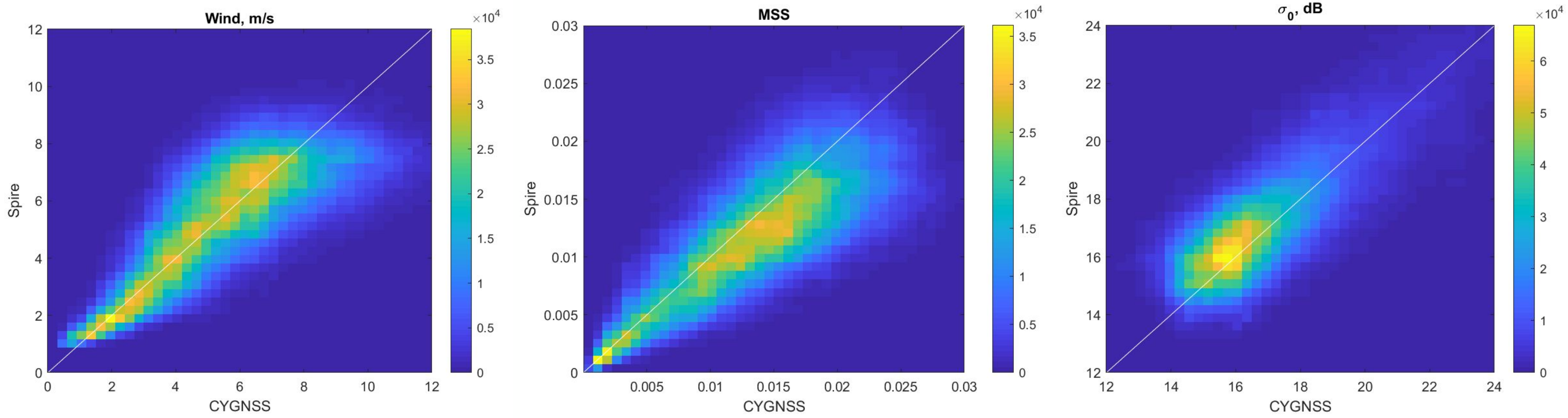




Spire L2 GNSS-R Ocean Products

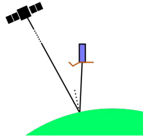


Spire vs. CYGNSS ocean products
(8.6*10^6 point pairs)

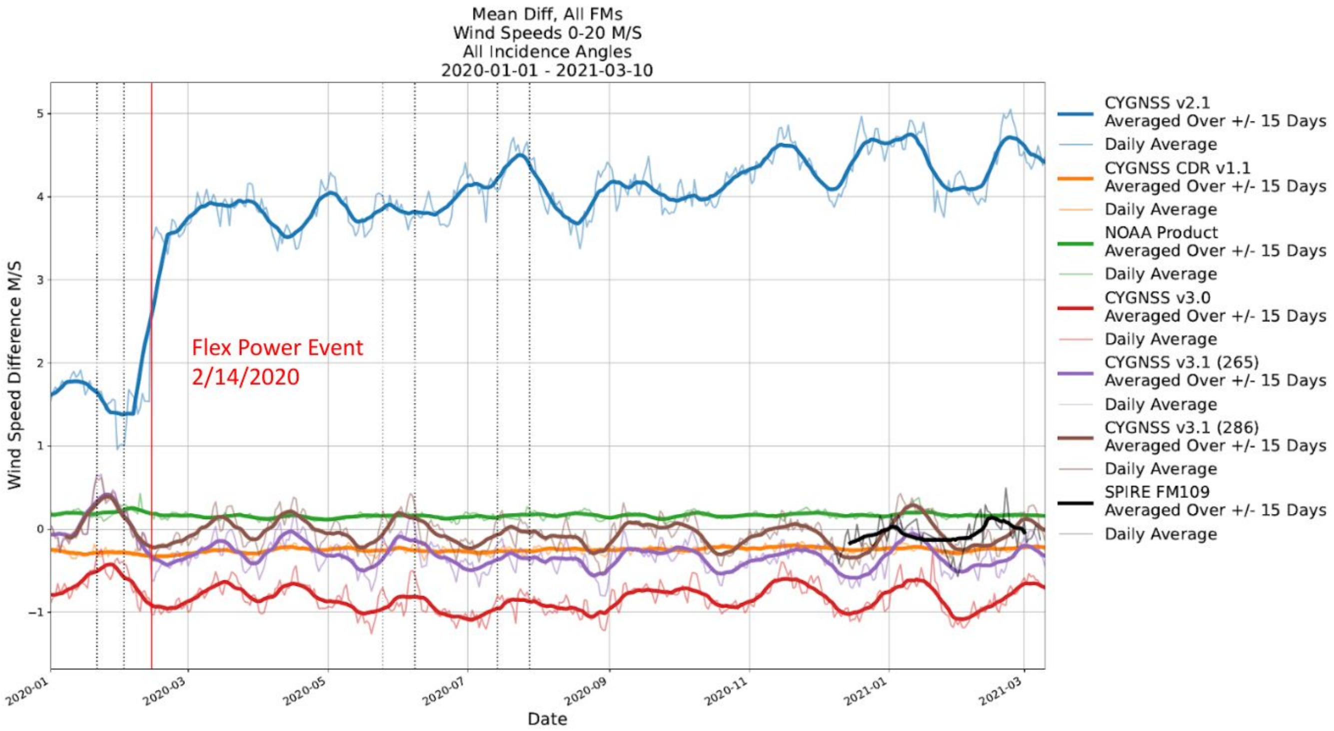


Ocean wind	Mean Square Slope	NBRCS
corr = 0.74	corr = 0.75	corr = 0.83
std(diff) = 1.60 m/s	std(diff) = 0.004	std(diff) = 1.53 dB

Spire L2 GNSS-R Ocean Products

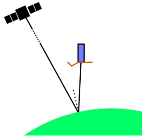


- University of Michigan 2021 evaluation of Spire L2 Ocean Wind speed

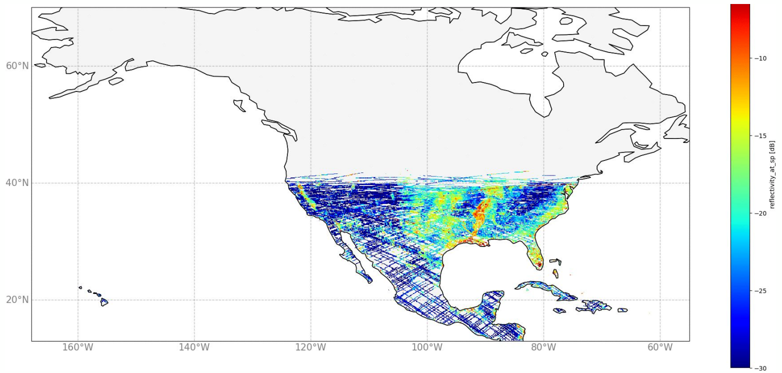


GNSS-R Sensitivity to Soil Moisture

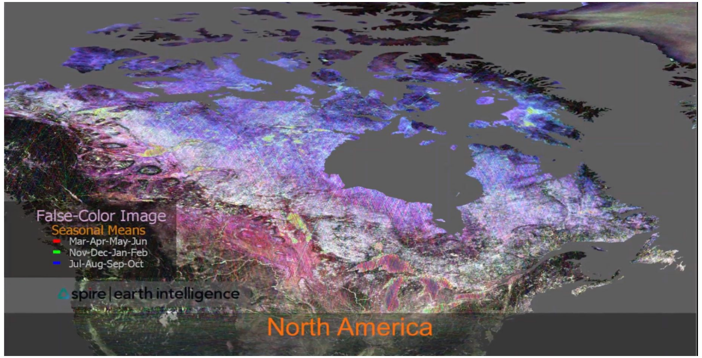
*** product undergoing NASA evaluation*



- 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.

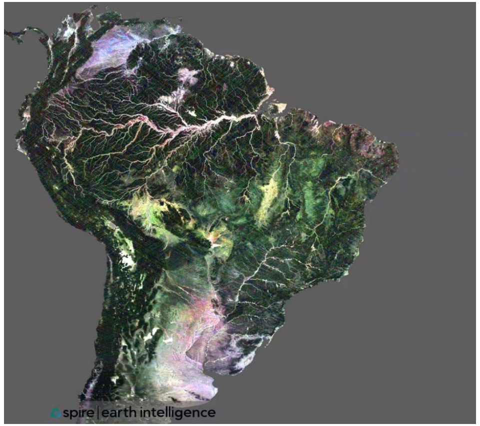


Spire GNSS-R reflectivity (10 km grid) over 2021 - monthly frames



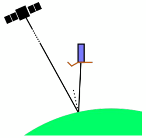
Spire GNSS-R Reflectivity over North America (top) and South America (bottom):

False-color showing seasonal changes in reflectivity

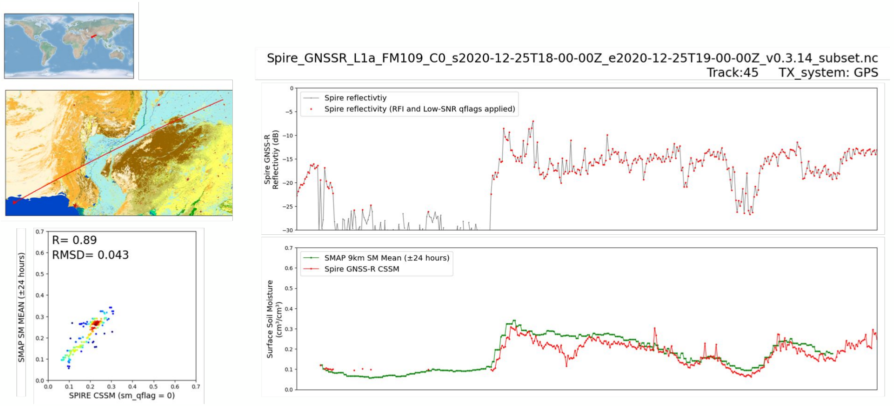


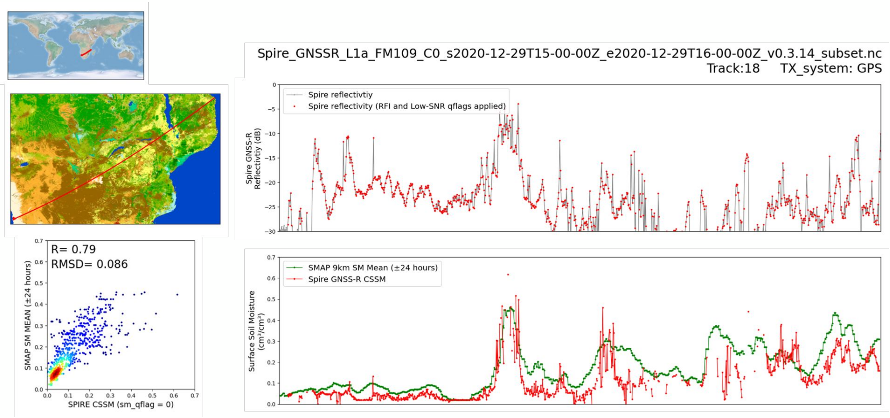
Spire L2 GNSS-R Soil Moisture

*** product undergoing NASA evaluation*



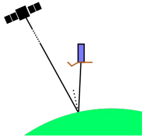
- Track-wise comparison of Spire & SMAP Soil Moisture
- GNSS-R soil moisture shows comparable quality to SMAP but has inherently smaller footprint





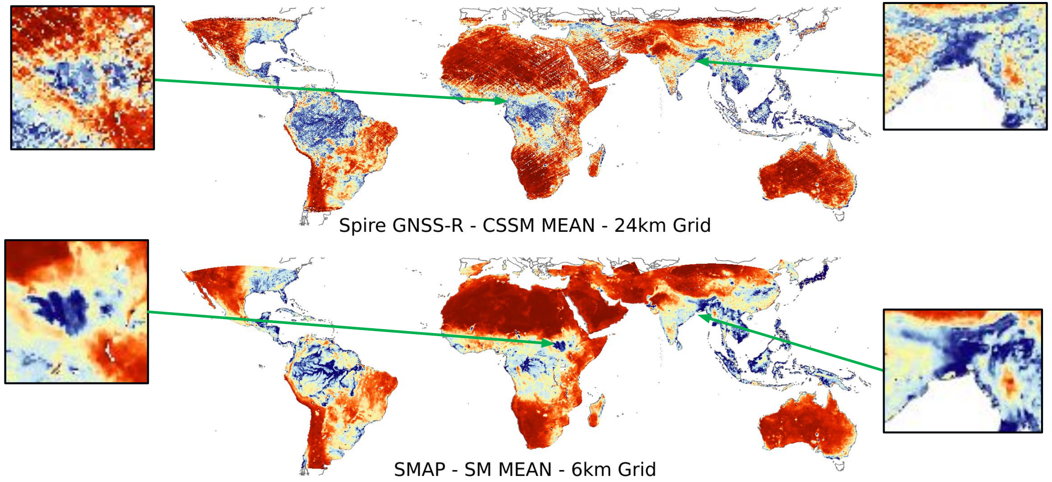
Spire L2 GNSS-R Soil Moisture

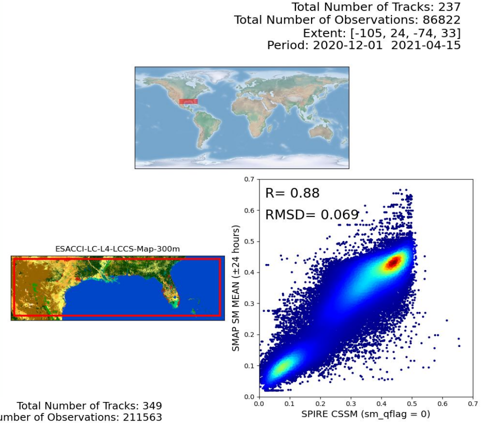
*** product undergoing NASA evaluation*

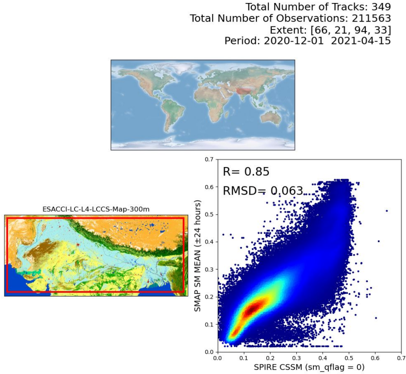


Regional and Spatial Comparison of Spire & SMAP SM

Averaging period
(2021: Jan, Feb, Mar, Apr)







Agenda

Data Available Under CSDA Program

Data available from both NASA CSDA Program task orders and older NASA CSDA pilot program

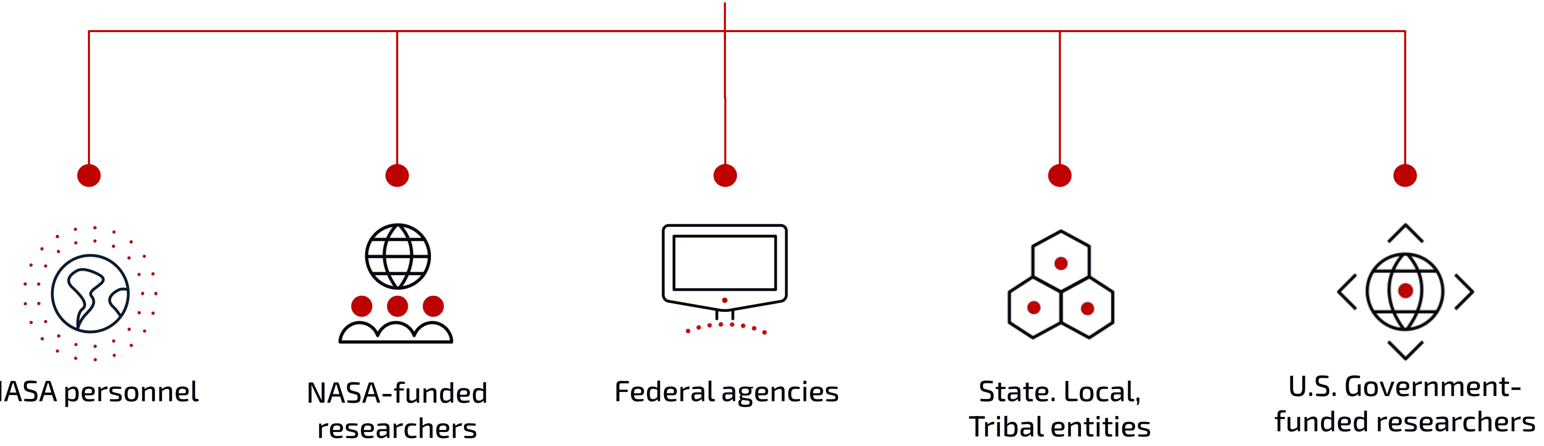
- NASA procured access to data types starting **01 NOV 2019** through to **17 JUN 2023**
- Data available with a 30-day delay (i.e., 30 days after collection)
- Current Spire products available under the NASA CSDA Program
- New products undergo NASA evaluation
- Product improvements made available as developed
- Conventional GNSS-R (Near-Nadir)

Data Type	Date Range
GNSS Radio Occultation (GNSS-RO) (L0-L2 Atmos. Prf)	24 SEP 2018 - 14 DEC 2018 14 DEC 2018 - 08 MAR 2019 **01 NOV 2019 - present**
Grazing Angle GNSS-Reflectometry (GNSS-R) (L0-L2 Sea Ice Type & Altimetry)	09 JAN 2019 - 18 APR 2019 **01 NOV 2019 - present**
Conventional GNSS-R L1 Bistatic Radar	**17 MAY 2022 - present**
Conventional GNSS-R L2 Ocean Winds	**01 AUG 2022 - present**
Conventional GNSS-R L2 Soil Moisture	**Est. DEC 2022**
Raw IF captures (GNSS-R)	Various
L0-L1 Precise Orbit Determination	24 SEP 2018 - 18 APR 2019 **01 NOV 2019 - present**
L0-L2 Space Weather (TEC, EDP, Scintillation)	**01 NOV 2019 - present**
L0 Magnetometer (Simple Sensor Data)	**01 NOV 2019 - present**

End User License Agreement

This latest version* of the EULA is effective as of 9 NOV 2020 and applies to Spire data accessible through the NASA CSDA Program

Individuals with access to Spire data
through the NASA CSDA Program



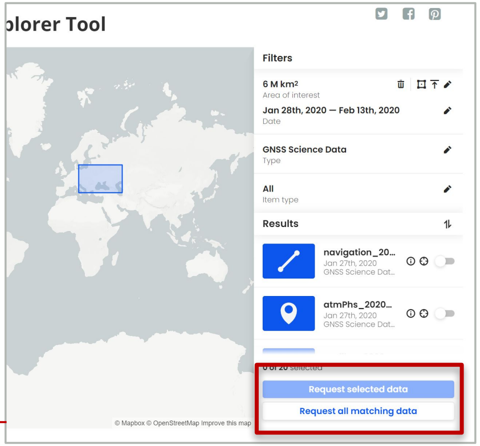
* The EULA document is available on the CSDA Program website: https://cdn.earthdata.nasa.gov/conduit/upload/16879/CSDA_Program_USG_EULA-11-09-20_Rev3.pdf

Agenda

Accessing the data

Spire data is accessible through the NASA Smallsat Data Explorer (SDX) using Earthdata login credentials

- Create an Earthdata login: https://urs.earthdata.nasa.gov/
- Navigate to the CSDA Program Smallsat Data Explorer (SDX): https://csdap.earthdata.nasa.gov/
- On the left side of the screen, login to your Earthdata account.
- Selected your filter parameters and click "Request data"
- A NASA reviewer will validate the request and, if approved, send a URL with access to the data



User Support

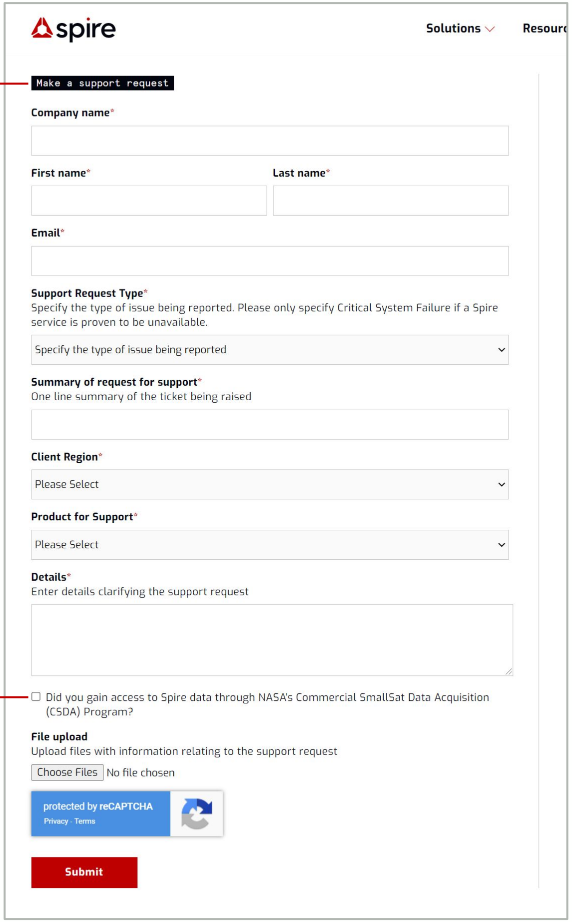
NASA can provide SDX and data access support, Spire is available for questions on the data itself

Accessing the data through SDX:

- Click the *Contact Us* link at the bottom of the SDX page

Submit a Spire Support Request:

- Navigate to https://spire.com/developers/support/
- Fill out the requested information
- Indicate on the form that you are asking about NASA CSDA Program data



Thank you

From our team, to yours.

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