spire | earth information

Commercial RO Becomes Reality: Rapid Growth, External Validation, and Operational Assimilation of Spire RO

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IROWG 2021

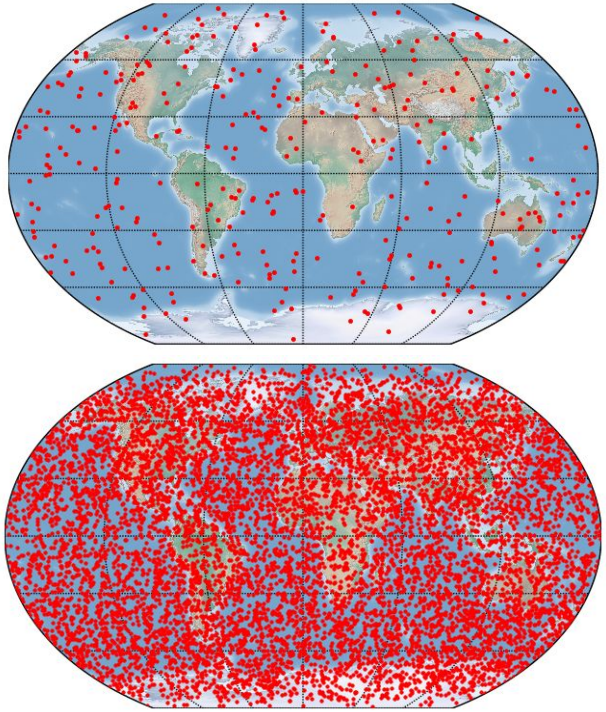
Spire EO: Agile, Operational, & Sustainable

Spire has pioneered a **new, faster, and more agile paradigm** for Earth observations

We cost-effectively harness nanosatellites to collect large quantities of Earth observations to positively impact applications that **benefit from high spatial and temporal sampling and low-latency**

Spire aims for continuous scaling, replenishment, and improvement for **agile, sustained, long-term Earth observations**

Spire innovation: First commercial company to collect radio occultation data, **pioneering RO using multiple GNSS (Galileo, QZSS, etc.)**, and developing new grazing angle **GNSS-R using RO satellites**



June 2018: 100s RO profiles/day

Feb. 2020: ~10K raw RO profiles/day (100x increase)

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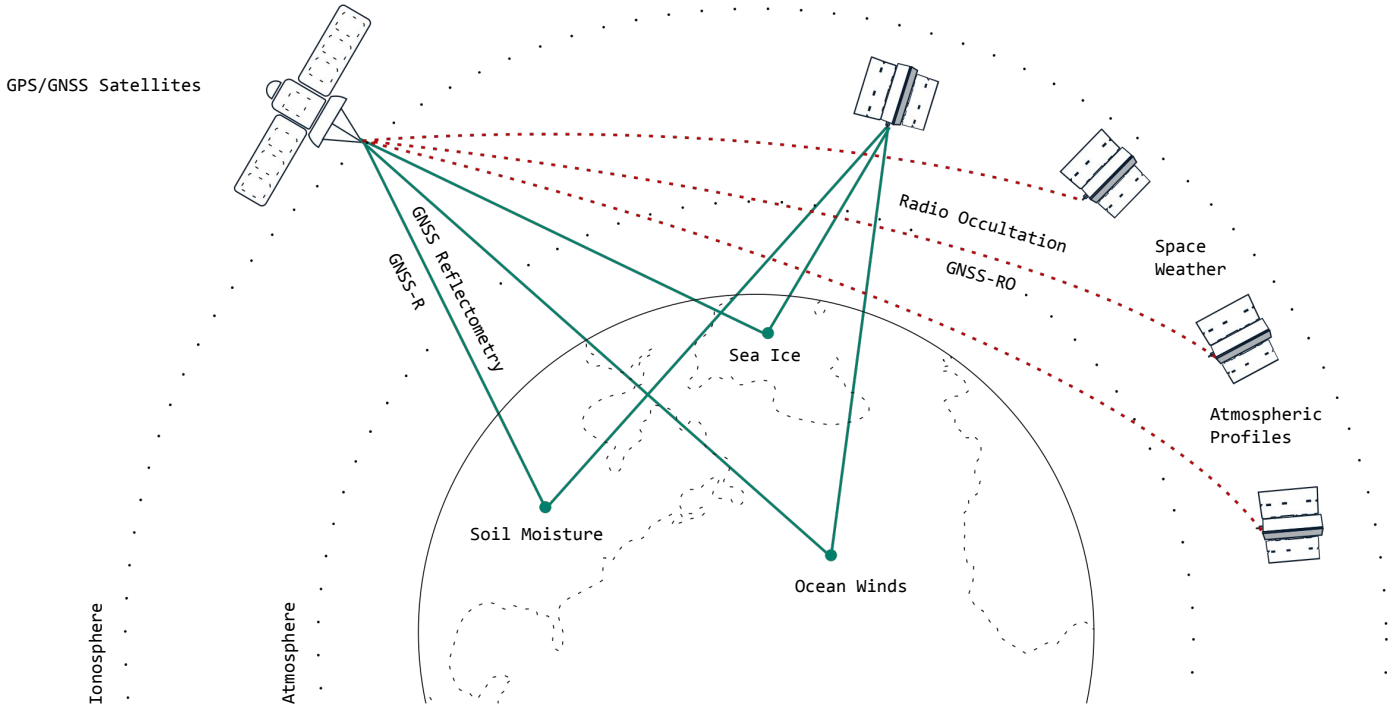
Spire GNSS-Based Earth Observations



- Atmospheric sounding for NWP, climate
- Ionospheric sounding for space weather monitoring*
- Thermospheric density through precise orbit determination (see Will McCarty's talk)

- GNSS-R scatterometry: soil moisture, ocean winds, sea ice
- Grazing angle GNSS-R for sea ice altimetry and classification **using RO sats**

*See presentation: Session 1, Fri., 9:35 EDT: Ionospheric Data Products Measured from Spire's Nanosatellite Constellation, Vu Nguyen

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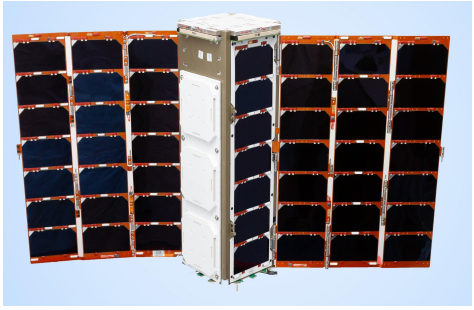
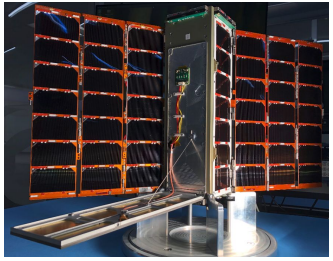
Spire EO Satellites and Constellation

Spire RO satellites

- 3U bus to scale constellation
- Moderate-gain, dual antennas (rising/setting RO)
- **Multi-GNSS signals tracked**
- **New, advanced wide-band receiver (DCB estimation and relative amplitude calibration**
- Rapid on-orbit innovation: grazing angle GNSS-R, hybrid electron density profiles





Spire GNSS-R Batch-1

- Dual nadir antennas
- Multi-GNSS tracked (minus GLO)
- **30 simultaneous reflections**
- Launched in Dec. 2019
- **Operational production now and data assimilation testing soon (ocean winds, soil moisture)**

Spire GNSS-R Batch-2

- Triple GNSS-R antennas
- **45 simultaneous reflections**
- Advanced calibration
- Launched in Jan. 2021
- Under validation

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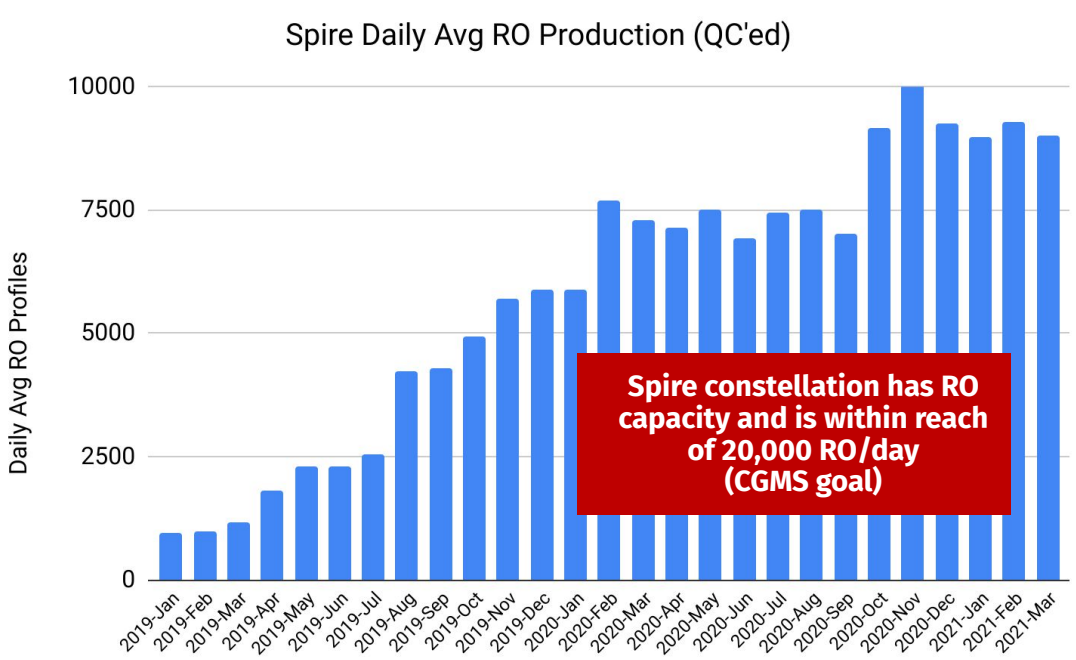
- 110+ LEO nanosatellites in diverse orbits for **global coverage, high spatial and temporal sampling**, and redundancy
- 40+ sats RO-capable and **25+ in RO production**
- **New GNSS-R sats** in 37 deg and SSO orbits

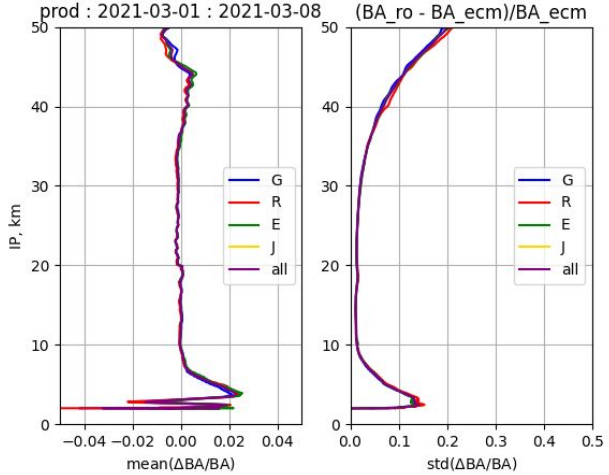
Data from a constellation of many Spire RO satellites is a resilient and sustainable solution for Earth observation

Spire GNSS-RO Production Status

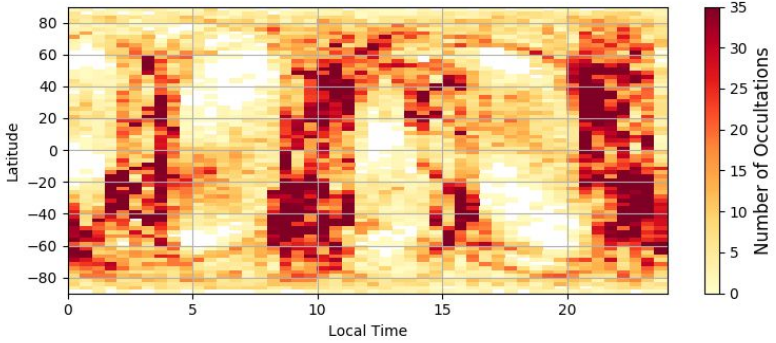


Continual growth in RO production

- New receiver in validation to become operational in 2021 to track all RO in view
- Continual bus and ground station latency performance improvements



Similar quality rising/setting profiles from multiple GNSS



Already improving local time sampling through orbit diversity

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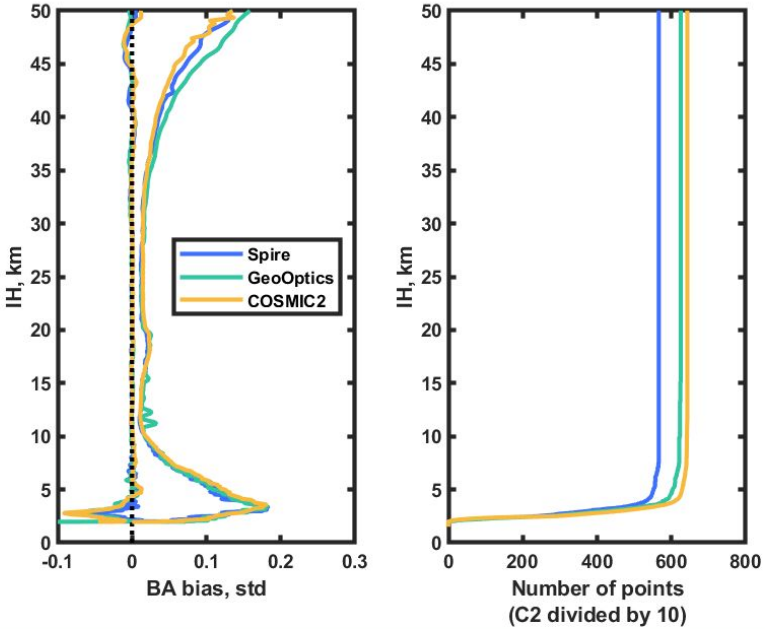
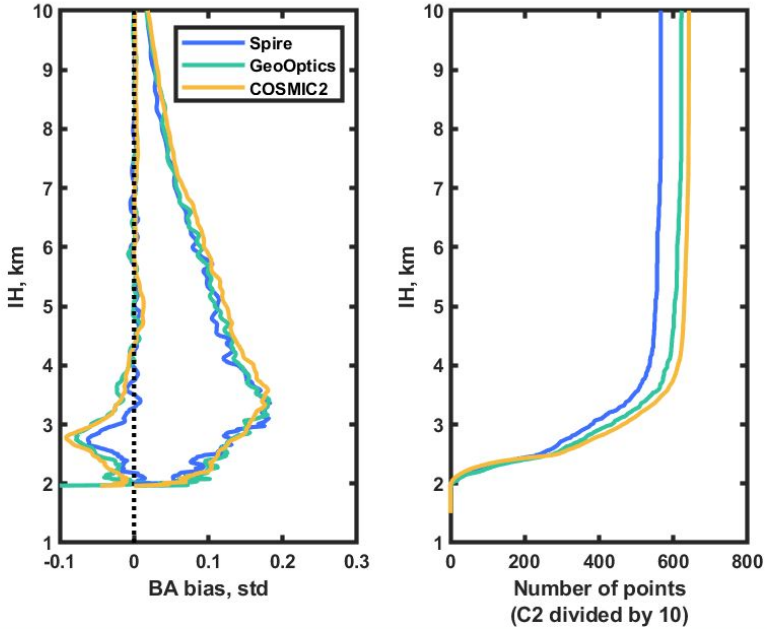
Comparison of UCAR-Processed RO Profiles

Comparison of COSMIC-2, Spire, and GeoOptics BA profiles (data processed by UCAR for NOAA Delivery Order 1, Dec. 2020 - Jan. 2021) show comparable statistics against the UCAR-provided background and no significant statistical improvement due to higher SNR RO payloads



Bias and STD of the bending angle of the profiles collected by the three RO systems **limited to the region sampled by C2** (bias scaled 10x)



Bias and STD of the bending angle of the profiles in the impact height range from **1 to 10 km** (bias scaled 10x)

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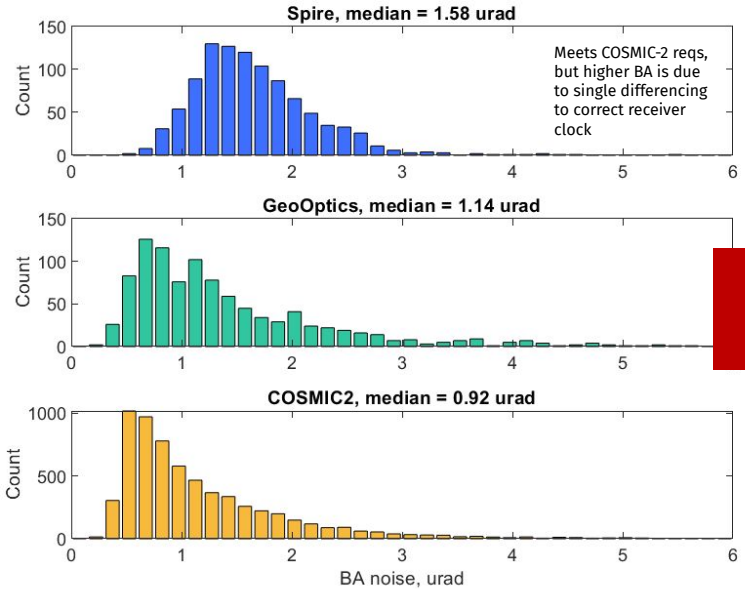
See poster: Comparison of Spire RO profiles Processed by UCAR and Spire, Vladimir Irisov

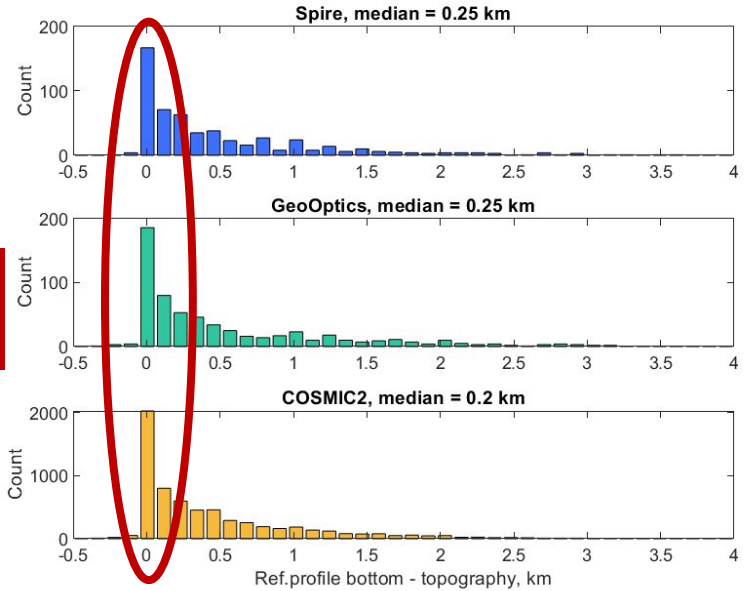
Comparison of UCAR-Processed RO Profiles

Averaged BA bias, STD, and median penetration depth are similar for all three systems (as processed by UCAR) despite strong differences in instrument SNR and minor to moderate difference in BA noise



Distributions of the BA noise estimated from ionosphere-compensated BA at 70-80 km height

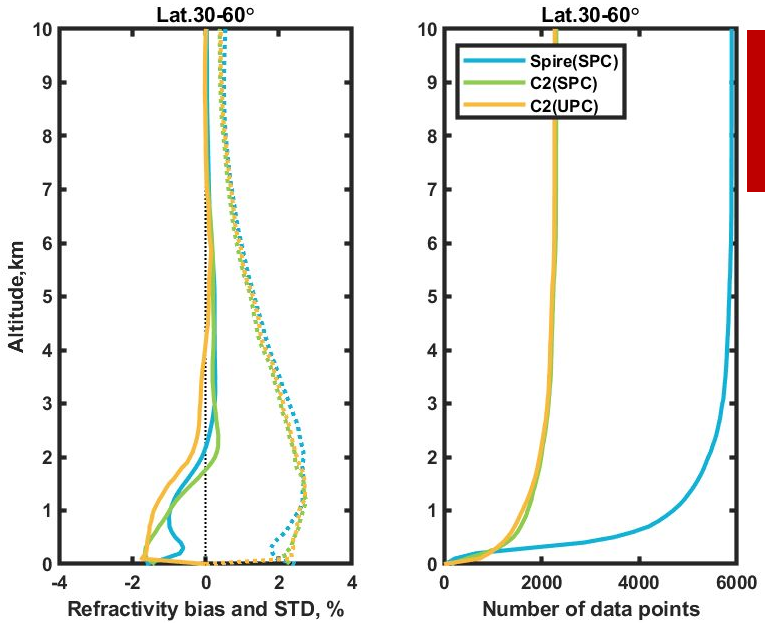
Similar penetration depths are independent of SNR



Distributions and median values of profile penetration depths for all systems (supported by UCAR results in NASA study; see Will McCarty's talk))

RO Processing Between Spire and UCAR

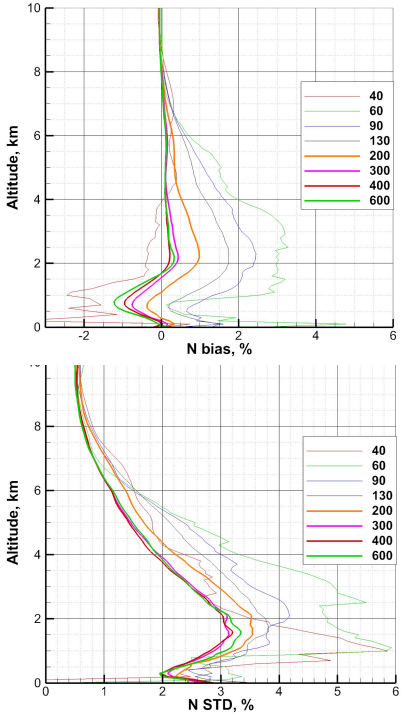
Spire and UCAR processing of the same COSMIC-2 profiles show comparable refractivity statistics



Refractivity bias and STD (left) and number of data points (right) for mid-latitude region data (Spire satellite RO also included)

Directly-sourced Spire L2 products are comparable to UCAR products and have lower processing latency

Increasing SNR above ~ 200 V/V does not significantly improve RO statistical quality



Recommend SNR thresholds be applied based on altitude to not discard valid obs >8 km

Refractivity bias and STD versus altitude and SNR (V/V)

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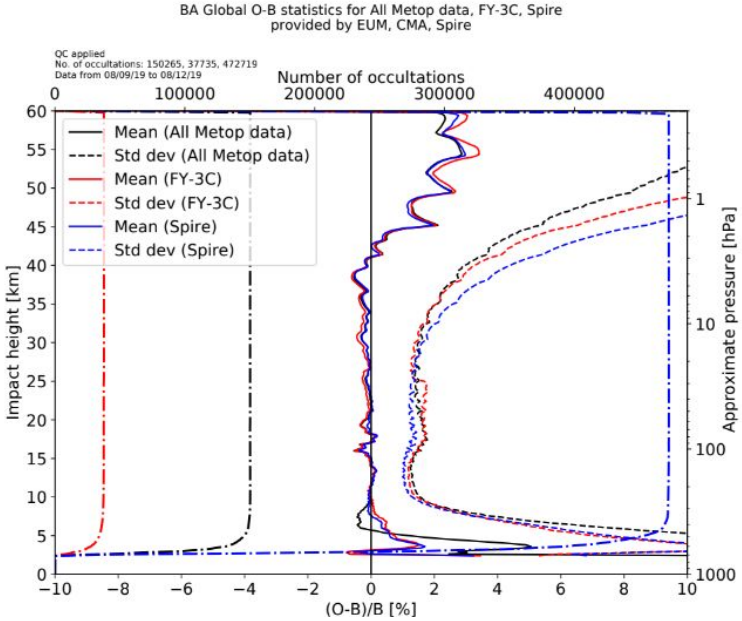
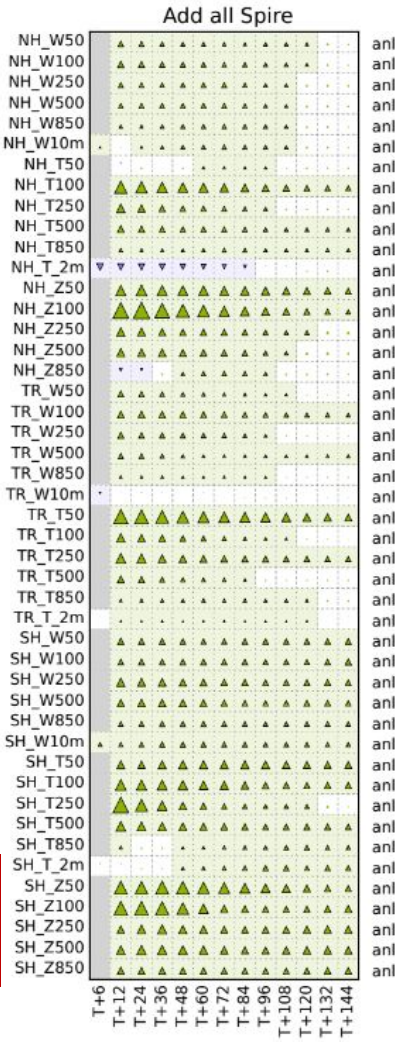
See poster: Comparison of Spire RO profiles Processed by UCAR and Spire, Vladimir Irisov

MetOffice Forecast Impact Study

- UK MetOffice performed a comprehensive study of the impact of 3 months of **Spire RO L2 BUFR data** assimilated into its forecast
- Spire RO bending angle profiles had **comparable statistics to operational systems**
- ***"Removing data from Metop-C and at the same time including an equivalent number of observations from Spire leaves the system approximately unchanged. Therefore we conclude that the two data sources are of similar quality"*** *- Bowler, 2020*



Spire bending angle profile stats compared to Metop and FY-3C



Spire RO L2 BUFR data positively impacted almost all UKMO variables out to 6 days

[(Bowler, 2020)]

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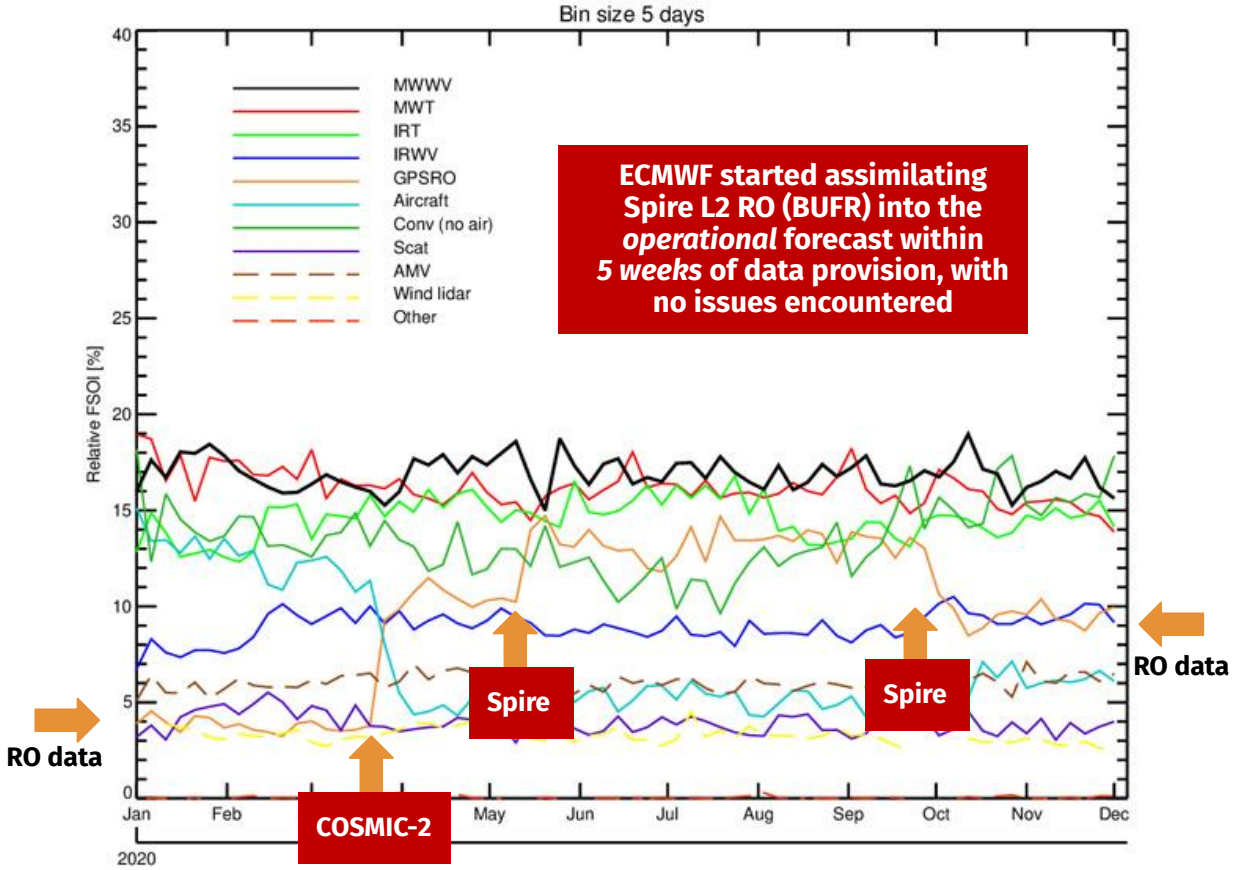
Spire RO in ECMWF Operational NWP

- Spire provided all **(>7000) daily L2 RO prfs (BUFR)** to the **ECMWF, UK Met Office, and US Air Force during the COVID-19 pandemic** to compensate for the lack of aircraft measurements (included QZSS and Galileo RO)

- **ECMWF saw significant increases in relative forecast sensitivity to observation impact (FSOI)** when COSMIC-2 RO was assimilated in March and again when **Spire RO was assimilated in May**



(Sean Healy, ECMWF) See also Katrin Lonitz's talk

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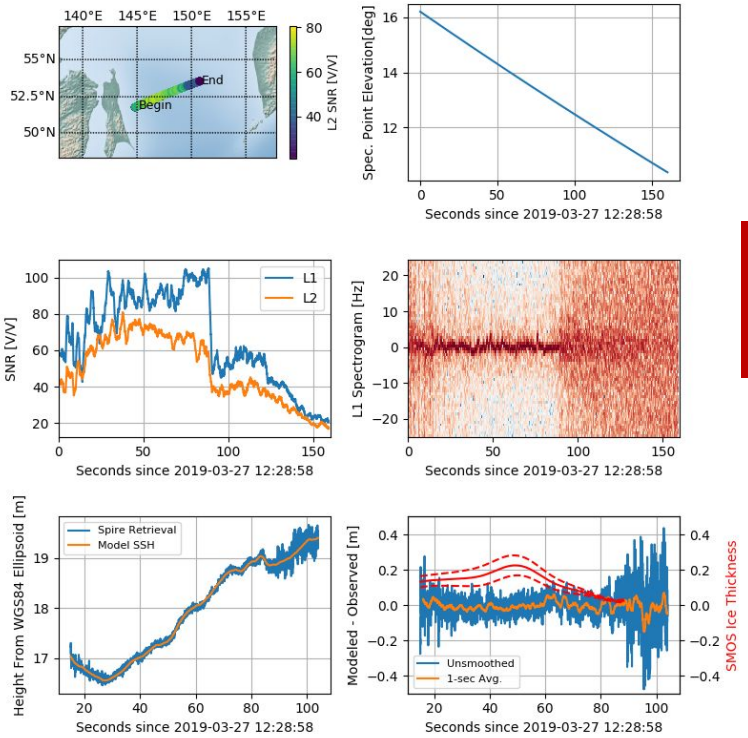
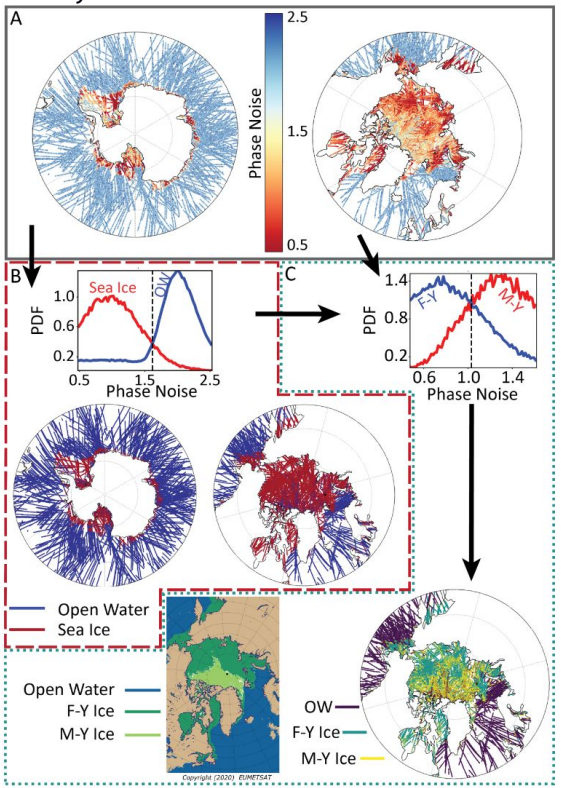
Spire Innovations: Grazing Angle GNSS-R

Grazing angle reflections are now collected on most **Spire RO satellites** to perform **altimetry over sea ice and some open ocean surfaces, achieving precisions of < 10 cm RMSE** with respect to mean sea surface



Spire rapid innovation is creating added value from traditional RO infrastructure

Spire grazing angle measurements are creating **valuable sea ice products,** achieving 95% of OSI SAF ice/water classification and 75% of first year versus multi-year ice classification



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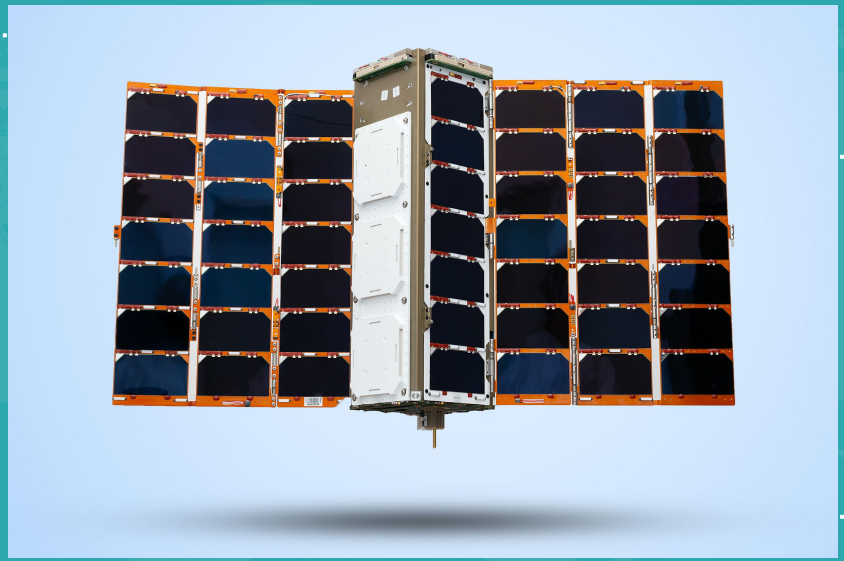
See poster: [Sea Ice Altimetry and Classification using Grazing Angle Reflected GNSS Signals Measured by Spire's RO Constellation](), Vu Nguyen

Key Takeaways

1. GLOBAL & SUSTAINABLE CONSTELLATION

Spire has built a resilient, operational Earth observations constellation to **improve weather forecasting today through assimilation of >10,000 prf/day and growing,** and **external analyses (UKMO, ECMWF, EUMETSAT, USAF, NRL, NASA, NOAA, and UCAR) have shown comparable data quality to "institutional" missions** and **the positive impact of operational assimilation of Spire-produced L2 RO data**



2. INCREASED SAMPLING & COVERAGE

Spire harnesses nanosatellites to collect large quantities of Earth observations to positively impact applications that **benefit from high spatial and temporal sampling and low-latency**

3. CONTINUED IMPROVEMENT

Spire aims for continuous scaling, replenishment, and improvement for sustainable and cost-effective long-term Earth observations

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