

Ionospheric Data

Products Measured from Spire's Nanosatellite Constellation

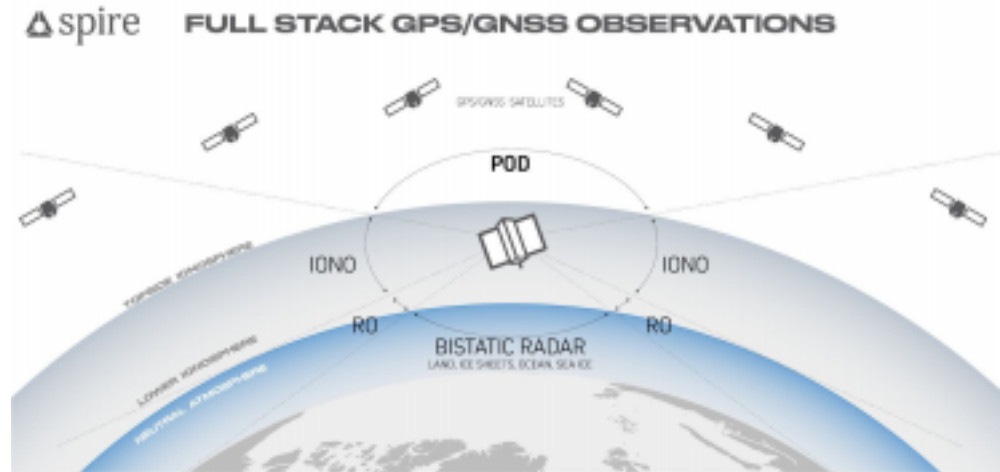
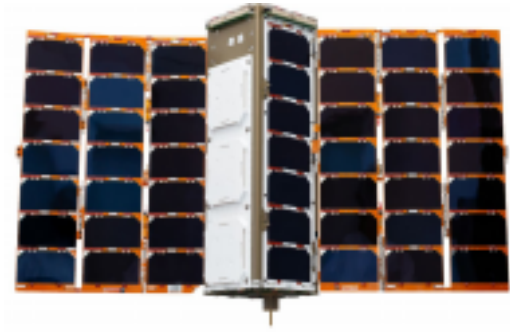
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Yuasa

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IROWG 2021

Spire EO Experience

- Spire operates one of the largest constellation of satellites (100+ nanosatellites and growing)
- First commercial company to collect radio occultation data and leads in GNSS-based Earth observations and innovations
- STRATOS GNSS Receiver for remote sensing and precise orbit determination
 - Software-defined
 - Dual-frequency (L1, L2, E5b)
 - Processes all GNSS constellations (iono measurements based currently only on GPS but will soon include other GNSS)
 - 9000+ quality-controlled RO profiles per day



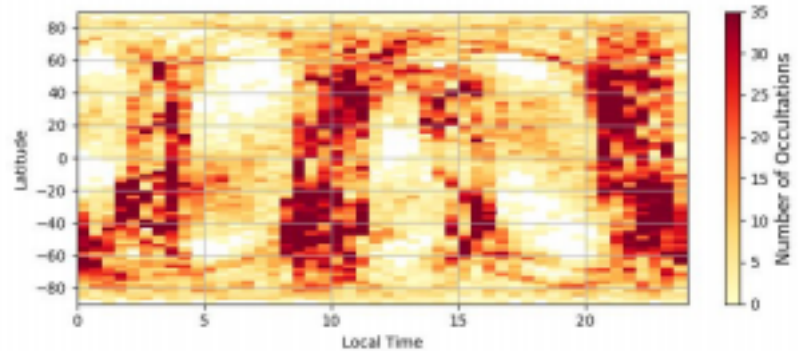
SpWx Data Collection

- SpWx relevant data collected from both POD and RO antennas
- POD antenna
 - 1 Hz, closed loop tracking
- RO antenna
 - 1 Hz, closed loop tracking
 - 50 Hz open loop tracking

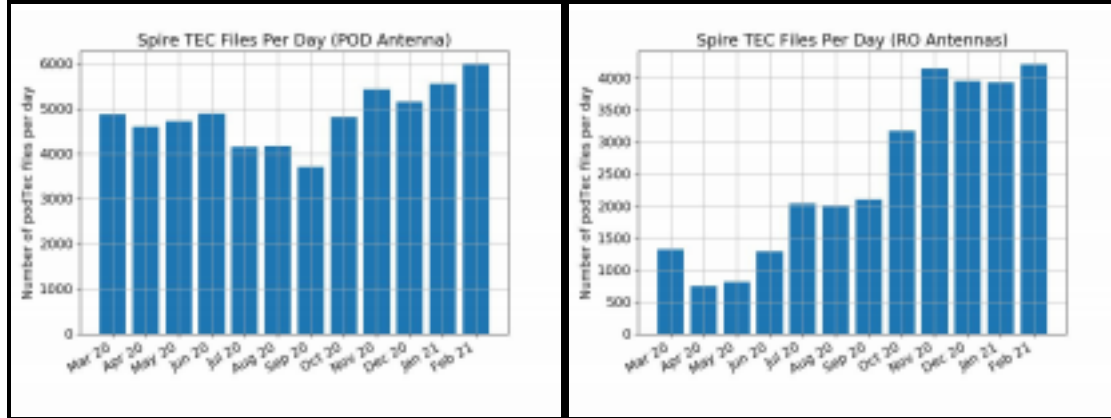


SpWx Data Production

- Spire satellites are mostly located in a mixture of sun-synchronous and mid-latitude orbits
- 5000+ continuous, closed-loop GPS links are processed into TEC measurements per day through the POD antenna
 - 8 million TEC points per day



- Increasing number of ionospheric events collected through the RO antennas
- ~4000 events per day

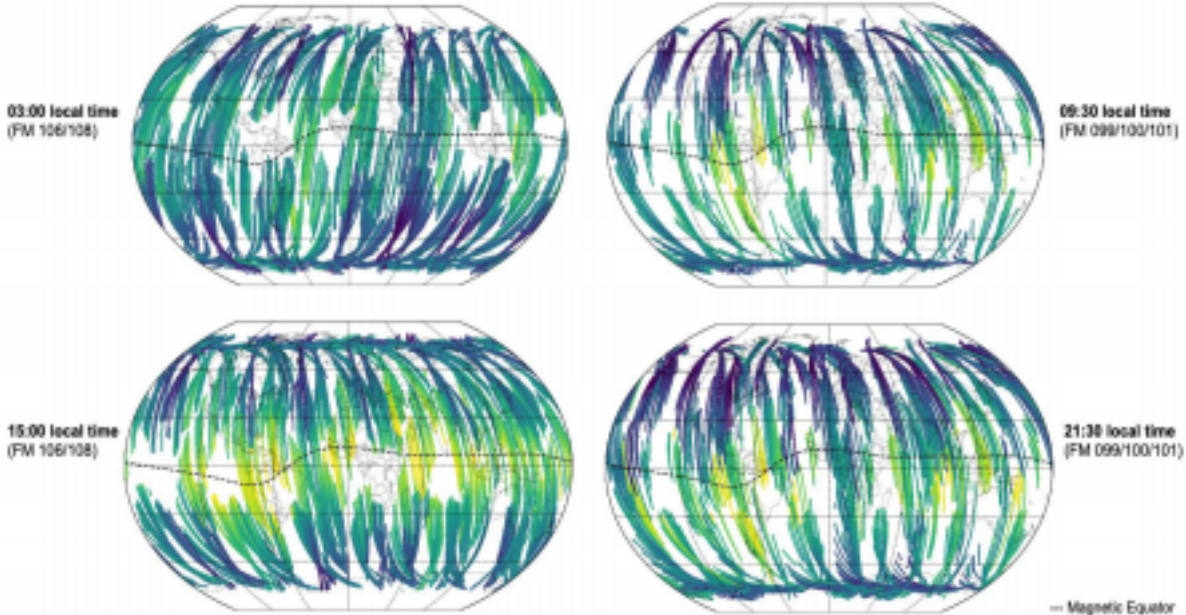
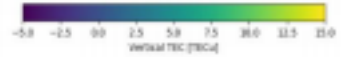


Total Electron Content

- Closed-loop dual-frequency pseudorange and phase observations used to derive TEC measurements
- Standard procedure applied
 - Weighted levelling procedure to minimize pseudorange-phase differences
 - Cycle slip correction
 - Estimation and removal of differential code biases (DCBs)
- Receiver DCBs estimated only for POD antenna measurements
 - Absolute TEC values available for topside ionosphere

Spire absolute TEC mapped to zenith (2019-12-01 to 2019-12-08)

* For all rays above 40 degrees elevation and greater than 10 minute duration



TEC During NOAA CWDOB D01

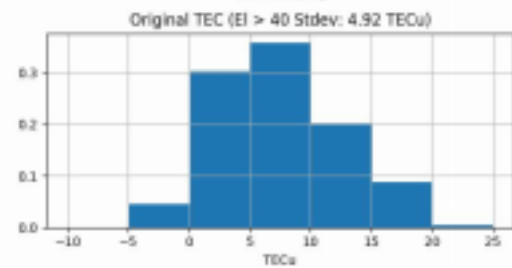
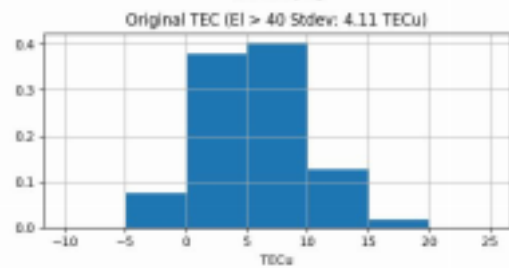
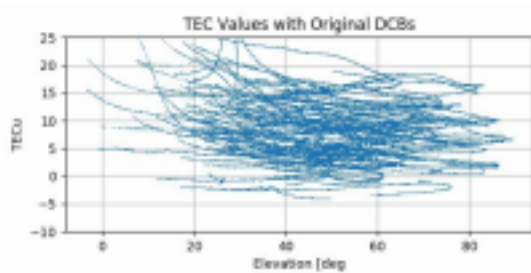
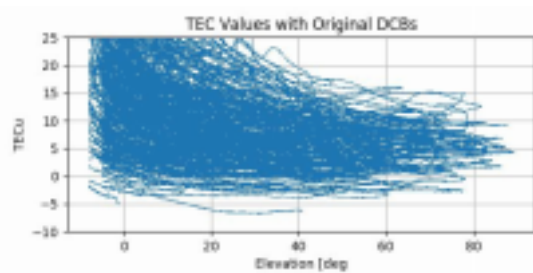
- UCAR processed raw Spire observations into TEC estimates for NOAA CWDOB D01 •

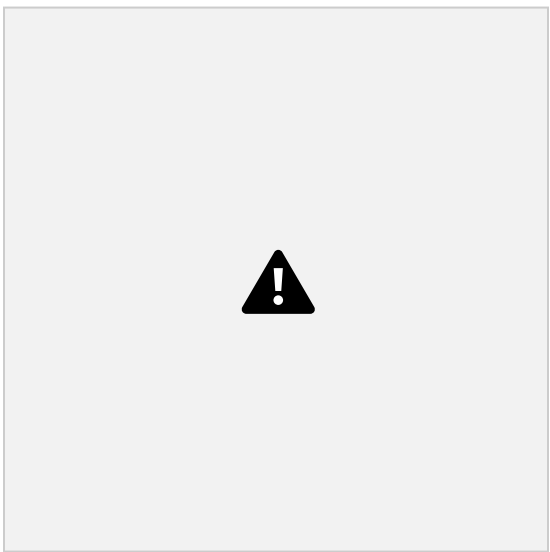
UCAR estimates compared to Spire-processed measurements

- Lower number due to smaller subset of Spire data delivered to UCAR
- Larger TEC standard deviation seen at high latitudes possibly due to differences in GNSS

DCBs



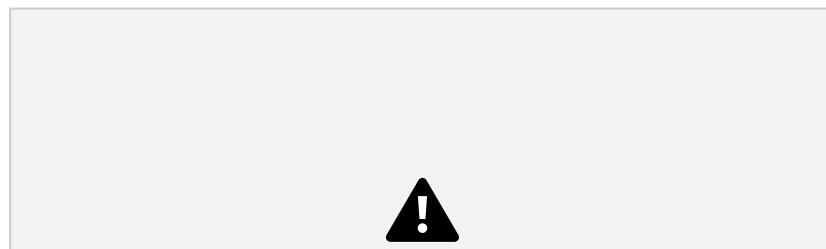




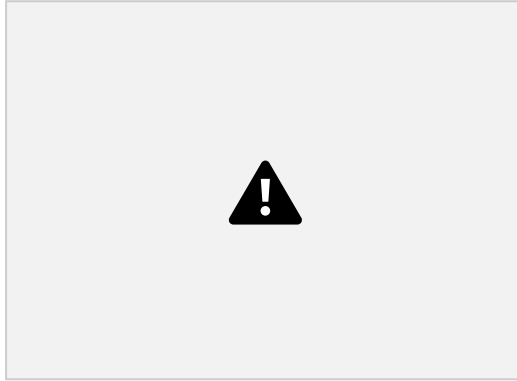
Electron Density Profiles



- Electron density profiles spanning up to orbit altitudes are currently derived using low-elevation GPS links through POD antenna
- Standard Abel-inversion technique is applied



- Strong agreement obtained between electron density profiles and nearby measurements from digisondes and ISRs





New Merged TEC Product

- Combined ionospheric TEC from both POD and RO antennas
- Level RO antenna TEC to POD antenna TEC
 - Calibrated data across extended height range
- Allows for more reliable retrieval of electron density

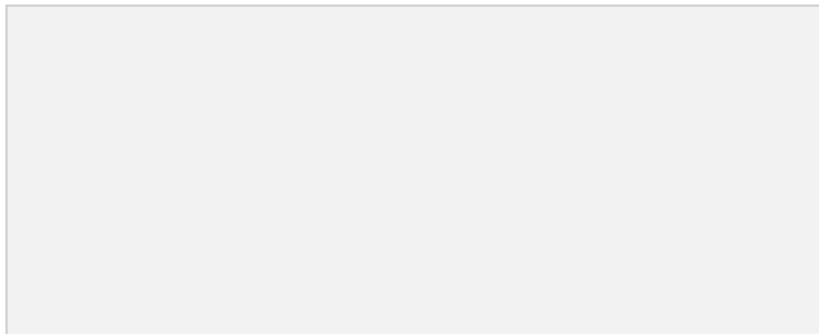


8

High-Rate Data and Scintillation

- High-rate (50 Hz) open-loop phase data are collected through RO Antennas
- Spans at least from 150 km and downward
- Multi-constellation

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On-board estimation of S4

- 50 Hz data from orbit altitude downward is downlinked if S4 exceeds threshold (like COSMIC-2)

9

GNSS-RO Receiver Advancements

- Spire has recently launched a **highly advanced GNSS receiver** on several satellites
- STRATOS v2 is a wide-band, direct sampling receiver

with a sophisticated, **amplitude and phase calibration system**

- The receiver is perfected for all GNSS applications for accurate differential code bias estimation, as well as relative channel calibration to within 0.1 dB
- Opportunity to add more constellations in closed-loop tracking for greater TEC production
- Currently undergoing checkout and commissioning

10

Ionospheric Data Assimilation

- Spire TEC data is suitable for use in data

assimilation models

- Spire TEC Environment Assimilation Model (STEAM)
 - 4D Local Ensemble Transform Kalman Filter
 - Routinely uses ground and Spire data
 - Experimental Spire/COSMIC2 DA
- International Civil Aviation Organization (ICAO) provides space weather advisories to aviation users
 - STEAM ensemble can be used to estimate probability of VTEC falling in defined bands

11

Key Takeaways

- Spire nanosatellite constellation is continuously



producing space-weather products

- Absolute and relative TEC
 - Electron density profiles
 - High-rate scintillation data
- Internal and external analyses have highlighted the positive impact of Spire ionospheric data
 - Improvements expected through updated receiver and ground processing
 - Ionospheric data products (podTec, scnLv1, ionPrf) available now to researchers and operations through the NASA Commercial Smallsat Data Acquisition (CSDA) Program

