SPACE WEATHER OBSERVATIONS FROM SPIRE'S GROWING CUBESAT CONSTELLATION

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Spire is a satellite and data analytics company, collecting and analyzing a wide range of remote sensing observations from a growing constellation of 80+ operating LEO 3U CubeSats:

1. **GNSS**
   - Radio Occultation (RO)
   - Ionosphere (TEC, electron density)
   - Surface reflections (GNSS-R)

2. **Hosted payloads / Orbital Services**

3. **AIS** (ship tracking)

4. **ADS-B** (airline tracking)

3U LEMUR CubeSat

- **Collecting ~5,000 RO per day and growing each launch**
- Rising & setting occultations (2 RO antennas)

**GNSS constellations tracked:**
- GPS
- GLONASS
- Galileo (first commercial producer)
- QZSS
Each satellite is equipped with a compact, low power, Spire-built GNSS radio occultation (RO) receiver.

Upward-facing antenna for precise orbit determination (POD).

Dual-frequency observations also allow for derivation of ionospheric measurements.
SPACE WEATHER MEASUREMENTS

- Ionospheric information is derived from dual frequency GNSS signals
  - Slant total electron content (TEC)
  - Scintillation events
  - Electron density profiles

- Spire constellation provides these observations at unprecedented coverage
  - Data denied areas
  - Low latency

- Assimilation into upper atmospheric models for improved space weather forecasting predictions
GROWING DATA VOLUME

- Ionospheric production has increased by 10x over the past year due to launching of new satellites with enhanced capability
- New orbital planes result in better local time coverage
• Closed-loop dual-frequency observations are collected through the POD and RO antennas
  o 1-Hz pseudorange and phase
  o GPS-only

• Line-of-sight TEC data are processed by individual arcs
  o Leveling procedure minimizes the pseudorange-phase differences using a weighted scheme (Pedatella, 2011)
  o Cycle slip detection and correction algorithm applied
  o Stored in CDAAC podTec netcdf format
Electron density profiles spanning up to orbit altitudes are derived from low elevation GNSS links.

A standard Abel inversion technique is currently applied. Model-aided approaches may be used in the future.

Example of electron density profile

Nmf2 Spire-IRI comparison

Mean peak ionospheric electron density over 1 month
ELECTRON DENSITY PROFILES

- V. Forsythe et al. retrieved electron density profiles from Spire TEC measurements
- Horizontal asymmetries were corrected by using the NeQuick model
- Strong agreement was obtained between the retrieved electron density profiles and nearby measurements from digisondes and incoherent scatter radars

Full results will be published at
High rate (50 Hz) phase data are collected through the RO antennas

- Currently spans the lower E-region ionosphere (< 150 km)
- Considering increasing the altitude range to span the F-region
- High vertical resolution: < 100 m

Data are valuable for studies investigating features of the MLT/E-region

- Gravity waves
- Atmospheric tides
- Sporadic E-layers

E-region contributions to slant total electron content and electron density measurements can be derived from 50 Hz measurements (Wu, 2018)
E-REGION ANOMALY DETECTION

- Spire E-region profiles were processed to detect anomalies using Hilbert-Huang transform likely caused by TIDs and sporadic-E layer events
- Enhancement of anomalies detected at summer-time mid-latitudes, which agrees with past phenomenology
DEVELOPMENT OF IONOSPHERIC MODEL

- **Spire TEC Assimilative Model (STEAM):**
  - Combines NeQuick ionospheric model with a local ensemble transform Kalman Filter (LETKF) data assimilation scheme
  - TEC data is derived from Spire LEO constellation and GNSS ground networks
  - Extendable to use in-situ data, ionosondes, etc.
  - 15 minute assimilation window

- Spire LEO data provides valuable information on the vertical structure of the ionosphere and helps compensate for data-poor regions such as oceans
Example STEAM TEC maps for 2019-08-21
External users have also utilized Spire data to improve SPWX modeling and understanding

K. Kramer et al. (NWRA) conducted a study that highlights the promise of using Spire ionospheric data in an assimilative system (GPSII)

**Figures courtesy of K. Kramer**

**Assimilation of Spire ionospheric data improves the comparison to ground-based digisondes**
DATA & PAYLOAD OPPORTUNITIES

Data available to researchers and operations via:

- **Current NASA Bulk Purchase Agreement (BPA):**
  - NASA PIs can request Spire RO/SpWx data
- **ESA Earthdatanet in trial phase**
- Data samples available upon direct request
- Near real-time access via cloud-based API

**Spire is offering “Space-as-a-Service” for rapid, cost-effective hosted Earth observation payloads**

- 1U or more available
- 6-12 months from idea to launch
- Launches every 6 weeks on average
KEY TAKEAWAYS

● Spire’s current constellation is one of the largest producers of RO and SpWx measurements ever
  ○ Currently producing 5M+ TEC measurements per day and increasing
● Internal and external analyses have highlighted the **positive impact of Spire ionospheric data**
● Ionospheric data available now to researchers and operations via NASA BPA
● **Spire will provide consistent, long-term SpWx data as a service**

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