NOAA NESDIS
Space Weather Data Pilot Project

2025 Space Weather Roundtable

National Environmental Satellite, Data, and Information Service

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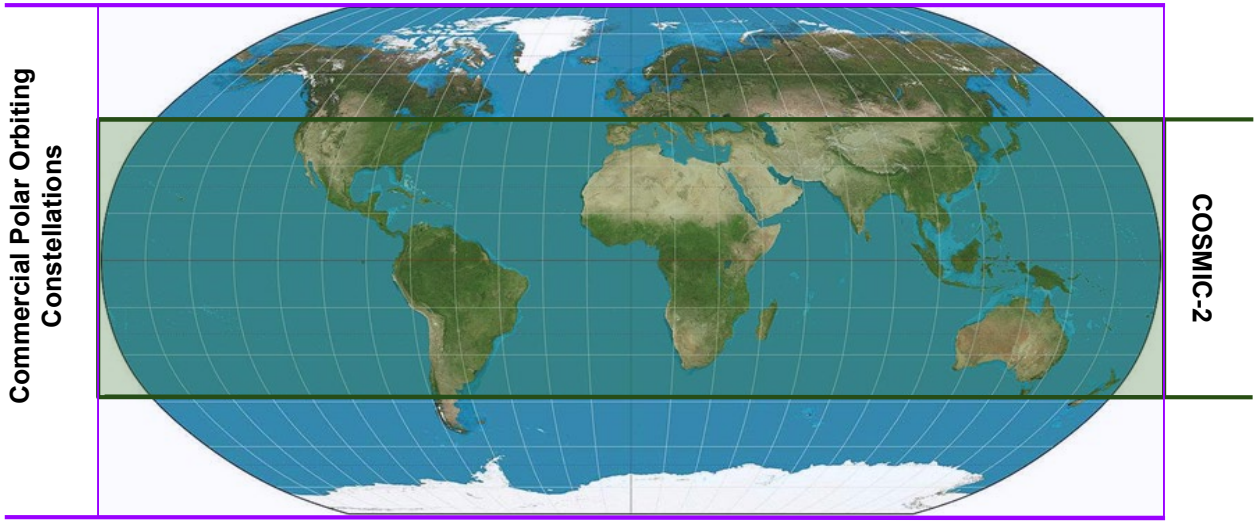
NESDIS/Systems Architecture and Engineering (SAE)

Why Commercial Space Weather Data is Necessary

Commercial RO data is necessary to reach full global coverage (COSMIC-2 is not enough)

- Adding Commercial GNSS-RO data improves ionospheric model performance, coverage and nowcasting abilities
  - Greatly improves in regions without ground-based observation data
  - Complements COSMIC-2 coverage
  - Allows creation of global ionospheric products that rely less on just background models and more on observations
- Commercial satellites provide high-rate GNSS derived data when a scintillation event is detected
- Commercial GNSS-RO ionospheric data provides critical information for users of GNSS applications
  - Geomagnetic Storms can induce errors of: ***tens of meters***
  - User precision needed: ***several millimeters - one centimeter***

Global GNSS-RO Data Coverage



GNSS Use Case Applications

- Precision Agriculture
- Industrial Construction
- Precision Geodetic and Surveying
- Aviation, Drone and Maritime Operations
- Autonomous Vehicles
- Military Applications

Space Weather Data Pilot: Overview

- **Objective:** Derive ionospheric products that meet current and anticipated operational space weather model and application needs.
  - Total Electron Content (TEC)
    - TEC observations help specify the electron density structure in the ionosphere/plasmasphere
    - From TEC vertical profiles, can derive vertical electron density profiles - TEC affects GNSS navigation applications
  - Scintillation Phase (sigma-phi) and Amplitude (S4) - High rate data ($\geq$ 50 Hz)
    - Scintillation refers to rapid, localized, intense fluctuations in the ionospheric state
    - Scintillation affects the power and phase of radio signals propagating through the ionosphere
    - Can significantly disrupt GNSS-based positioning and satellite navigation applications (e.g. loss of signal)
  - TEC and Scintillation indices calculated from GNSS pseudorange, carrier phase, and signal-to-noise (SNR) measurements
  - Maximum daily median latency 30 minutes
- NOAA Congressional Direction:
  - PROSWIFT Act (2020) and Consolidated Appropriations Act (2022)
- Spire Global and PlanetiQ awarded one year contracts; completed in August 2023
- Government team concluded their assessment and evaluation in Spring 2024

Space Weather Data Pilot Team

National Environmental Satellite, Data, and Information Service

DEPARTMENT OF COMMERCE

SPACE WEATHER PREDICTION CENTER

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

UCAR

UNIVERSITY CORPORATION FOR ATMOSPHERIC RESEARCH

University of Colorado Boulder

BOSTON COLLEGE ISRO INSTITUTE FOR SCIENTIFIC RESEARCH

AEROSPACE

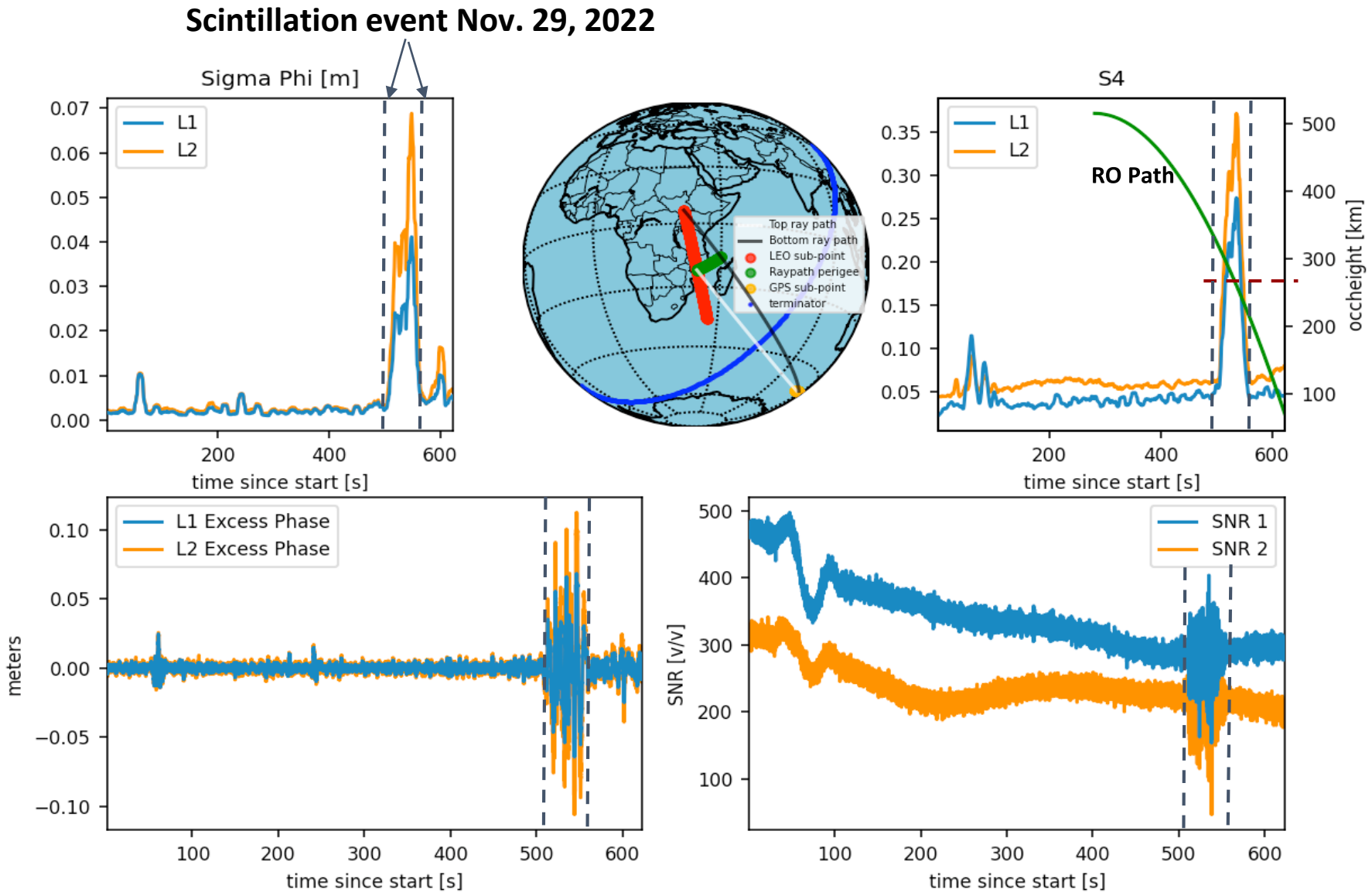
EUMETSAT

spire

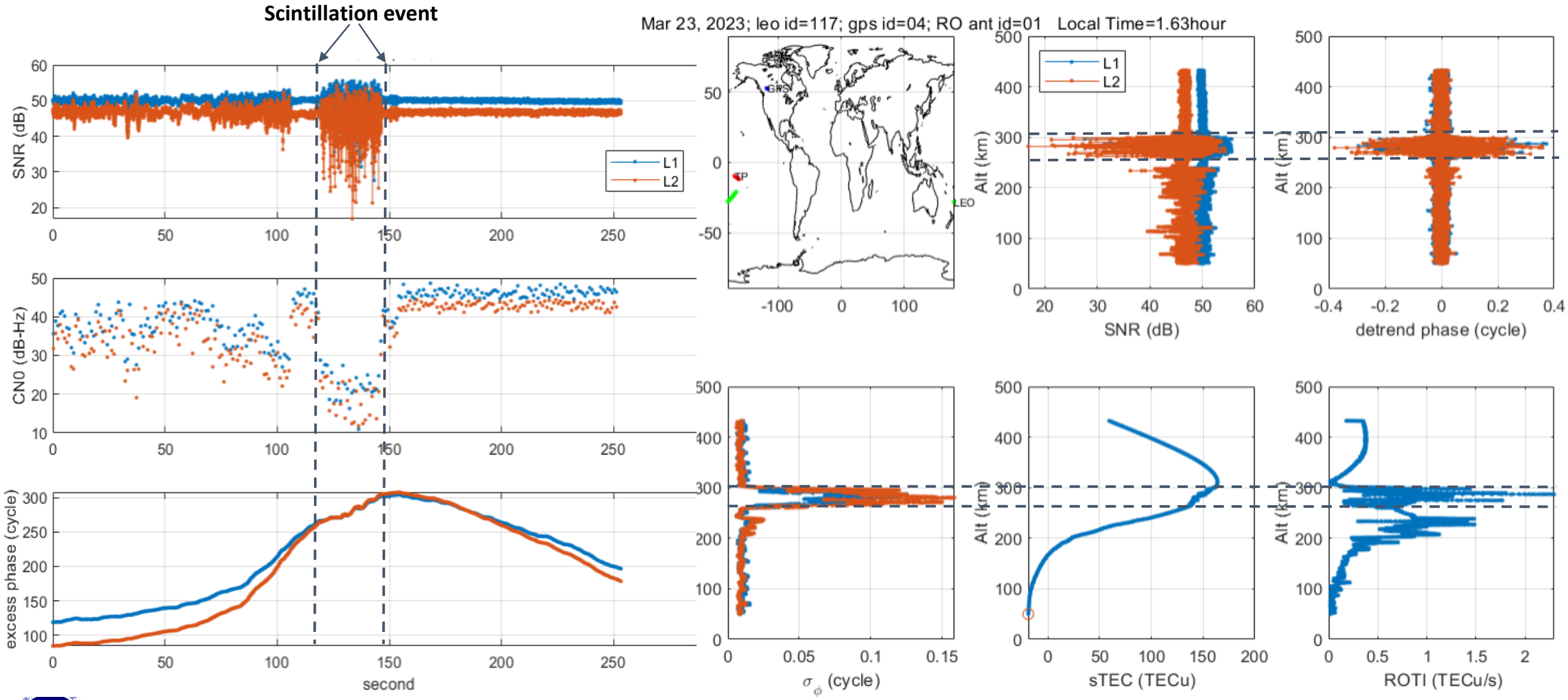
PLANETiQ

Example (PlanetiQ): F-layer Scintillation

- Processed high sampling-rate observations to derive scintillation amplitude (S4) and phase (sigma-phi) indices
- Example shows scintillation event from ~510-570 sec.



Example (Spire): F-layer Scintillation During Mar 23, 2023 Storm



Findings and Lessons Learned

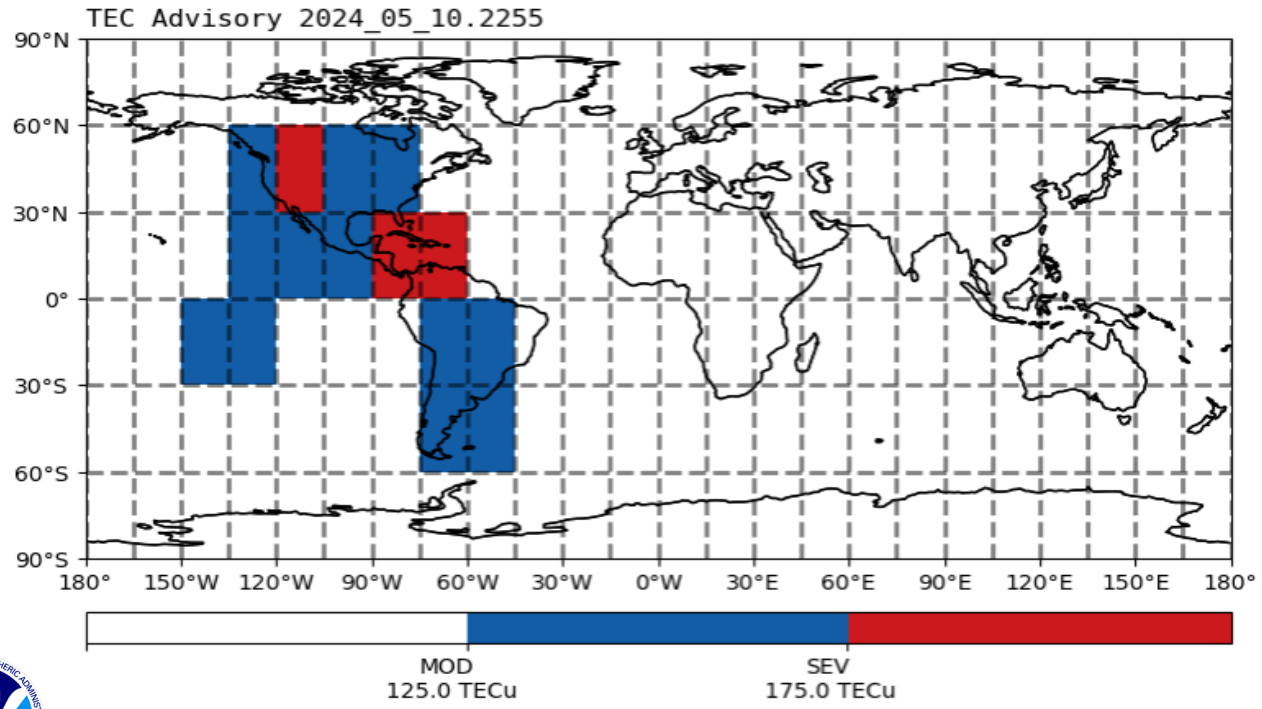
- Technical Findings:
  - High-latitude scintillation behaves different than equatorial regions; needs further understanding
  - Algorithm to identify scintillation events (triggers high-rate data download from satellite) needs updating
    - Requirement was too restrictive; Gov Team did not obtain enough data from high-latitude scintillation events
  - Developed new methods for scintillation geolocation and validation
    - Traditional method of geolocating GNSS-RO measurements does not work with ionospheric irregularities
  - Built ML algorithms to identify and filter data anomalies (e.g. RFI); avoid false positives
- Vendor Performance:
  - Electron density & TEC demonstrated mostly acceptable quality
  - Low-latitude TEC and scintillation data compares well with existing data sources (COSMIC-2 & ground data)
  - Commercial TEC and scintillation data coverage complements COSMIC-2 data very well
    - Improves global coverage of data, especially away from ground stations
  - TEC data coverage: Spatial – Good ; Temporal – Needs some improvement
  - Data latency needed some improvement
  - Data packaging methods needed streamlining in order to process data in a timely fashion

First comprehensive analysis/research on measuring high-latitude scintillation w/ GNSS-RO data

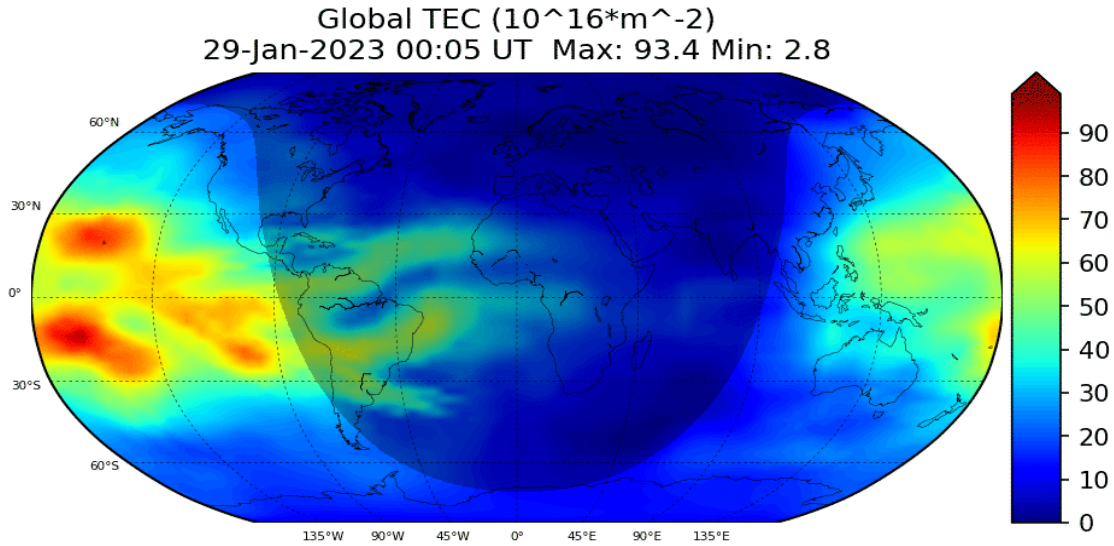
Products and Use Cases - TEC

- Current uses:
  - Incorporated into GloTEC model (ground, COSMIC-2)
  - Issue ICAO-mandated advisories (see below)
  - Bias-correction in WAM-IPE model (GFS-coupled)
  - Supports USSF operational tools & general community

TEC Advisory Map from the May 10, 2024 Geomagnetic Storm



- Future uses:
  - Extend GloTEC to incorporate Comm RO
    - TEC latency must be ≤ 30 mins

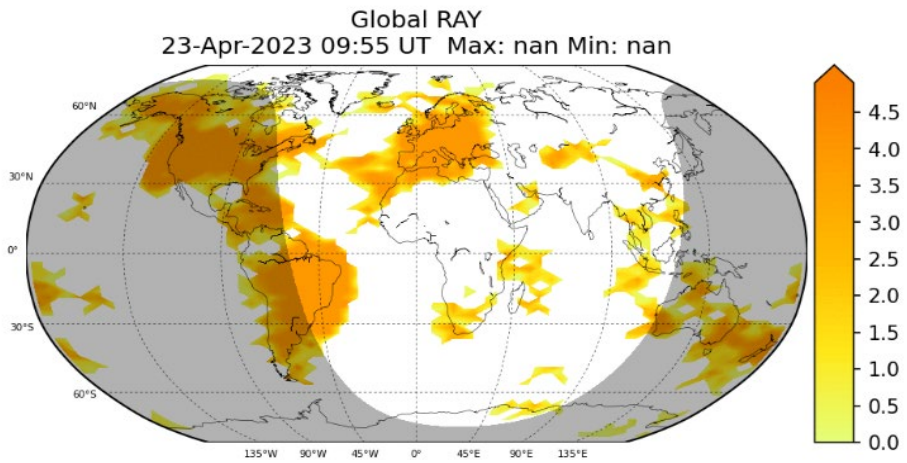


Global Total Electron Content (GloTEC) Model (ground+Spire+PlanetIQ)

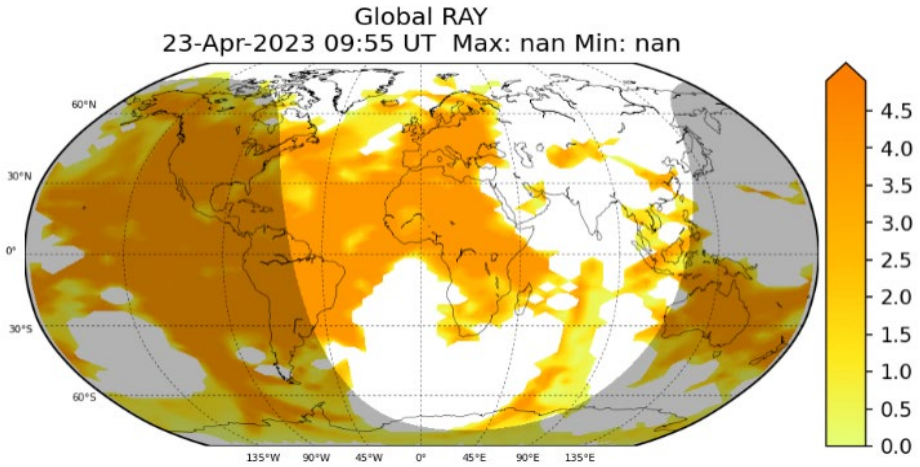
TEC Impact Assessment & Coverage

- TEC from all RO improves global coverage

GloTEC Model observation density (Ground data only)

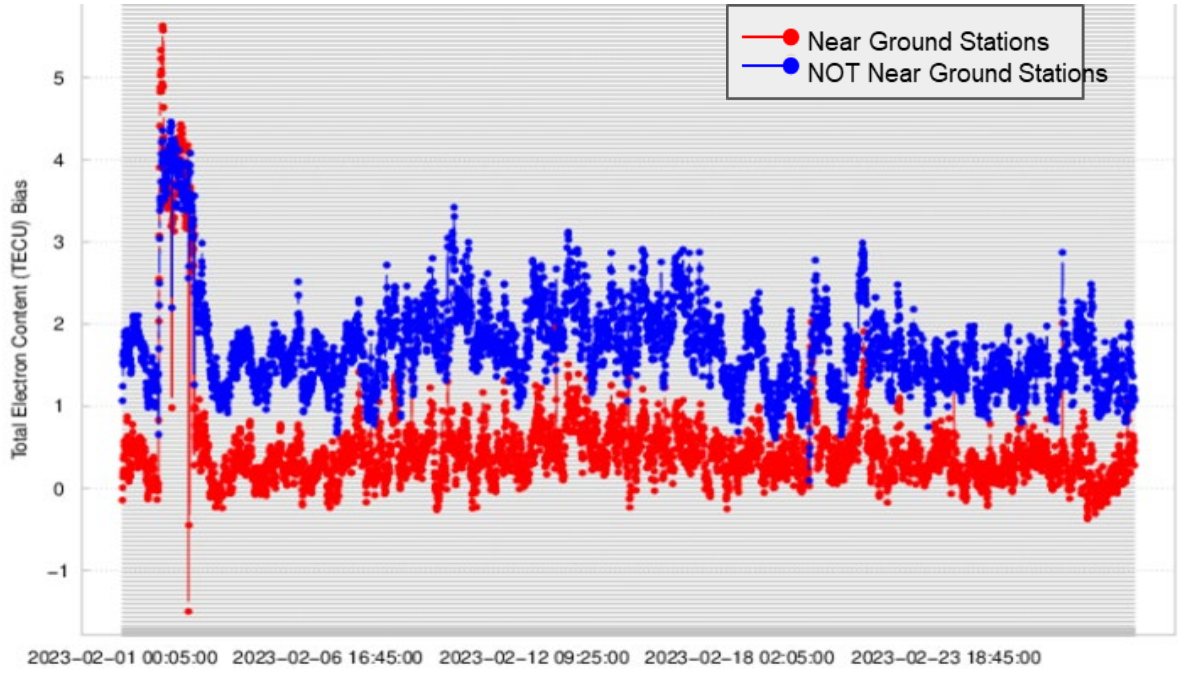


GloTEC Model observation density (Ground + all GNSS RO data)



- TEC from RO contributes more to model bias away from ground stations
  - RO contributes more to model performance in areas with less-dense ground station coverage
  - This is what we want to see

GloTEC Mean Bias between with and without RO in regions near vs. not near ground stations (does not include PiQ data)



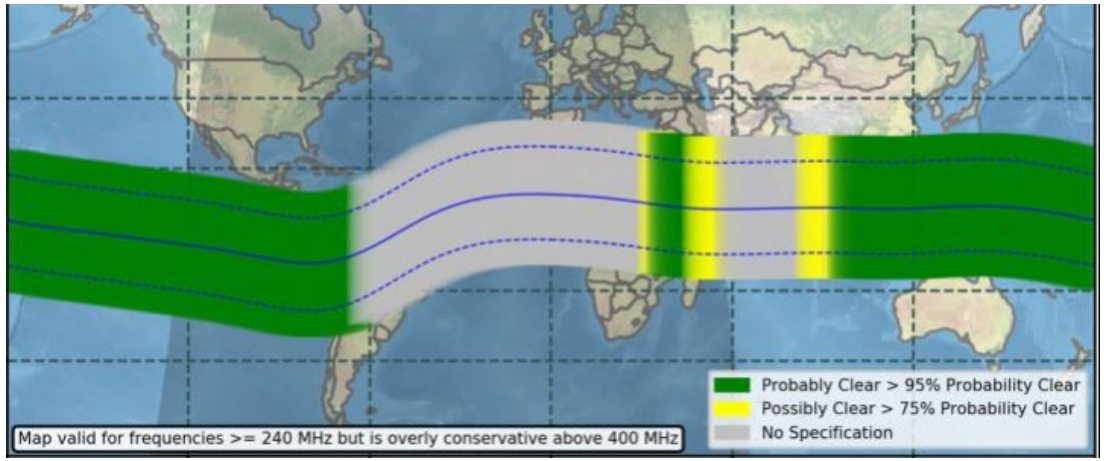
Commercial RO data improves TEC model performance – contributes to more useful TEC products

Products and Use Cases - Scintillation

- Current uses:
  - Products built from ground receivers only
  - Issue ICAO-mandated advisories (similar to TEC)
  - Supports GNSS Receiver companies, FAA, USSF/USAF, Space companies, SatCom users
- Ongoing Development:
  - SWPC leveraging COSMIC-2 Program for product development (see right)
    - **Bubble Map:** Indicates regions where scintillation-causing plasma irregularities ("bubbles") are occuring ; maps scintillation longitudinally along magnetic field lines
    - **All Clear Map:** Indicates when scintillation is *not* a factor to consider ; useful for RFI attribution
    - **Geolocation and Magnitude:** Indicates location and magnitude of scintillation events
    - Future work: Expand All Clear Map to L-Band frequencies ; explore adding of commercial RO

Bubble Map Product

All Clear Product



Summary and Future Efforts

- Pilot Team made substantial advancements; groundbreaking work w/ high-lat scintillation
  - Final Pilot report available: Space Weather Data Pilot Executive Summary
- Operational Readiness:
  - TEC is near an operationally-ready state
  - Low-latitude Scintillation not far from operational readiness
  - High-latitude Scintillation needs more extensive analysis, assessment, and evaluation
- Ongoing and near-term efforts:
  - NESDIS CDP exploring TEC operational purchases w/ IDIQ-2 vendors PlanetiQ and Spire Global
    - NESDIS CDP could begin purchasing of TEC data as soon as Delivery Order 5 (begins Sept 2025)
  - SWPC development of scintillation products using COSMIC-2 data ~ 75% complete
- NESDIS CDP will continue to explore avenues to further ionospheric measurement readiness and incorporate this into their planning process
  - Continue to coordinate with SWPC & SWO in defining civil use cases for TEC and scintillation and in the development and refinement of end-user global products

Questions on Space Weather?

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Thank You!