Bipolar climatology of GNSS ionospheric scintillation under quiet geomagnetic conditions

Lucilla Alfonsi¹, Luca Spogli¹, Giorgiana De Franceschi¹, Vincenzo Romano¹, Marcio Aquino², Alan Dodson² C. N. Mitchell³

¹ Istituto Nazionale di Geofisica e Vulcanologia (INGV), Rome, Italy
² Institute of Engineering Surveying and Space Geodesy (IESSG), University of Nottingham, Nottingham, UK
³ Department of Electronic and Electrical Engineering, University of Bath, United Kingdom

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Outline

• Introduction
• Data
• Method
• Results and discussion
• Remarks
• Next steps
**Introduction**

**AIM**
Develop a “scintillation climatology” over both polar areas
- Forecast of Space Weather events

**WHERE**
Receivers in Antarctica (2) and Northern Europe (4)
- Cusp/cap and auroral latitudes

**WHEN**
Year 2008 data
- Very quiet period
  - Useful for climatology

**DATA**
Scintillation data from INGV-IESSG-UoB network of GISTM (GPS Ionospheric Scintillation and TEC Monitor) receivers
- NovAtel OEM4 dual-frequency
  - 50 Hz

**METHOD**
Scintillation occurrence maps
**ROT** (Rate of TEC) maps

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*Maps showing locations of receivers in Antarctica and Northern Europe.*
Data

- Scintillation indices computed over **60 seconds** from L1 (1.57 GHz)
  - *Phase* $\sigma_{\phi}$: $\sigma_{\phi}^2 = \langle \phi^2 \rangle - \langle \phi \rangle^2$
  - *Amplitude* $S_4$: $S_4^2 = \left( \langle I^2 \rangle - \langle I \rangle^2 \right) / \langle I \rangle^2$.

- Reducing tracking errors
  - $\alpha_{\text{elev}} > 20^\circ$ for both indices.

- Vertical quantities

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<th>Location</th>
<th>Latitude</th>
<th>Longitude</th>
<th>CGLat</th>
<th>CGLon</th>
<th>Hemisphere</th>
<th>Days of data</th>
<th>%</th>
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Method

- **Maps of percentage occurrence**
  - $M_{\text{lat}}$ vs MLT
- **Percentage occurrence**
  - 1 bin = 1h MLT x $1^\circ$ $M_{\text{lat}}$
- **Thresholds:**
  - 0.25 radians for $\sigma_\phi$
  - 0.25 for $S_4$
- **Accuracy < 2.5 %**
  - Avoid low statistics bins
- **Feldstein auroral oval superimposed**
  - Different geomagnetic activity
    - Quiet period IQ=0 to 3
  - Electron density gradients on the boundaries

\[
\frac{N(S_4 \text{ or } \sigma_\phi > \text{threshold})}{N_{\text{tot}}} = 100 \cdot \frac{\sigma(N_{\text{tot}})}{N_{\text{tot}}} = \frac{100}{\sqrt{N_{\text{tot}}}}
\]
**Results and discussion**

- **Superposition of 3 effects (mainly Phase scintillation):**
  - Auroral oval boundaries
  - Ionospheric through walls
  - Polar cap patches
ROT maps

- ROT helps in identification of regions with intense TEC gradients
  - Maps ROT and ROTrms
- ROT 1-min distribution of the whole period (ex. South Hemisphere)
- Extract sub-distribution in each bin (same segmentation of percentage occurrence)
  - Get Mean
  - Get Root Mean Square
- Fill ROT and ROTrms maps
• Identification of polar cap patches
• Cusp region well drawn especially over south hemisphere
• ROTrms almost identical between 74° and 84° MLAT
• Interesting ROT feature around MLT noon over north hemisphere (?)
Correspondences (1/2)

Phase & ROT

![Phase & ROT plots](image-url)
Correspondences (2/2)
Amplitude & ROT
Remarks

- Scintillation data from GISTMs located over a wide range of latitudes in both hemispheres
- Scintillation occurrences map for a long quiet period (2008) has been produced
  - Auroral oval boundaries, trough walls and polar cap patches host scintillation
- ROT and ROTrms maps are useful to identify TEC structures
  - SigmaPhi seems to be more related to ROT
  - S4 seems to be more related to ROTrms
    - ROTrms is a sort of numerical second derivative of TEC \( \rightarrow \) DROTI(?!)
    - DROTI (TECU/min²) = \( 8.5 \cdot 10^3v_F^2S4 \) (single phase screen assumption)
Next steps

- Enlarge the statistics to consider a significant variety of ionospheric conditions
- Seasonal variation of the scintillation occurrence
- Extend the climatology to equatorial latitudes
- Change thresholds in the scintillation occurrence definition
- Compare the maps with tomographic reconstructions by MIDAS
- Explore the information theory approach to understand ROT and ROTrms.
INGV scintillation and TEC data at: www.eswua.ingv.it

Thanks for your attention!

lucilla.alfonsi@ingv.it