Ionospheric Irregulates Response to the April 2023 Major Geomagnetic Storm: A European Perspective

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ABSTRACT

The ionosphere plays a critical role in the propagation of Global Navigation Satellite System (GNSS) signals. However, ionospheric irregularities, such as scintillation and electron density fluctuations, can significantly impact the performance of GNSS applications. Scintillation in trans-ionospheric signals, such as those used by the Global Positioning System (GPS), is caused by electron-density irregularities in the ionosphere. As these signals pass through the irregularities, they experience rapid and unpredictable changes in signal strength, resulting in amplitude and phase fluctuations. These fluctuations can lead to degraded receiver performance in several ways, from accuracy issues, such as range errors, to the loss of signal tracking [Paula et al. 2003]. Thus, obtaining reliable information about key parameters that describe the ionosphere's perturbation level is crucial for ensuring the required safety standards. The occurrence and intensity of ionospheric scintillation depend on factors like location, time, and the Earth's magnetic field. Despite decades of study, research gaps persist, primarily due to the need for specialized high-rate GNSS receivers.

This study examines ionospheric scintillation, total electron content (TEC), and Rate of TEC Index (ROTI) variability during the 23 April 2023 geomagnetic storm over Europe. We use the LOFAR (Low-Frequency Array) dataset to calculate scintillation in the megahertz range and gain insights into small-scale ionospheric irregularities. ROTI, calculated and provided from real-time GNSS measurements of a global network of receivers by the Universitat Politècnica de Catalunya (UPC-IonST), is used to assess large-scale ionospheric disturbances by measuring rapid TEC fluctuations. Additionally, we analyze ROTI and VTEC datasets from DLR for 29 LOFAR stations, and evaluate the Gradient Ionosphere Index (GIX) to estimate ionospheric perturbations.

By combining data from LOFAR, UPC, and DLR, we explore the relationship between scintillation indices and ROTI values, providing a comprehensive analysis of ionospheric irregularities during storm conditions. This research enhances our understanding of space weather impacts on GNSS systems and communication infrastructure across Europe. The findings will improve predictive capabilities for geomagnetic events and define strategies to mitigate the risks associated with ionospheric disturbances.

Key Findings:

- We observed temporal and spatial characteristics of scintillation, VTEC, and ROTI.
- We present characteristics of ionospheric scintillation in association with ROTI, VTEC and GIX.
- We study characteristics of small-and large-scale irregularities during major geomagnetic storm on 23-25April 2023.