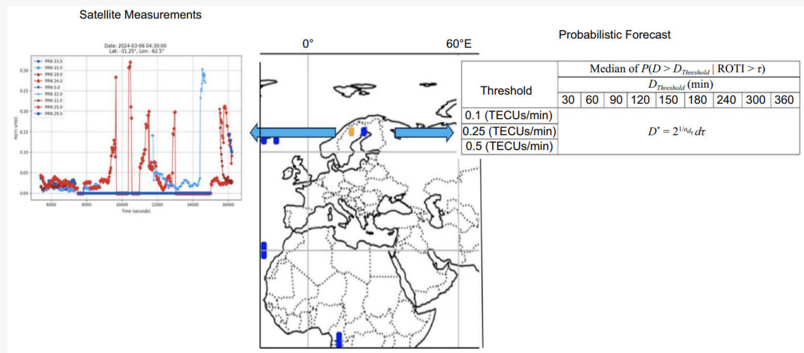
Can we predict ionospheric turbulence? A Bayesian model offers a global warning system

GA, UNITED STATES, February 19, 2026 /EINPresswire.com/ -- Space weather can disrupt satellite navigation and communication systems by triggering rapid fluctuations in the ionosphere. A new study introduces a global probabilistic forecasting model that predicts when and where ionospheric disturbances—measured by the Rate of total electron content (TEC) Index (ROTI)—are likely to persist. Unlike previous machine learning approaches, the new method embraces the bursty, heavy-tailed nature of ionospheric activity using a Bayesian framework. It also takes into account the fact that the observations in the Pierce Points between the satellites and the GNSS stations are distributed in a non-uniform way, and change in time due to the movement of the satellite. By dividing the globe into fine geographic cells and modeling disturbance duration through long-tail statistics, the system delivers robust forecasts up to six hours ahead. The approach improves the reliability of early warnings for regions where Global Navigation Satellite Systems (GNSS) performance may be compromised.



Global ROTI forecasting framework

The ionosphere, a dynamic region extending from roughly 60 to 1,000 kilometers above Earth, plays a critical role in radio signal propagation. During geomagnetic storms and solar flare events, irregularities in electron density can cause signal scintillation, leading to Global Navigation Satellite Systems (GNSS) positioning errors, signal degradation, or even loss of lock. The rate of total electron content (TEC) Index (ROTI) is widely used as a proxy to detect such disturbances. However, forecasting ROTI remains challenging. Traditional statistical models struggle with its non-Gaussian behavior, while machine learning systems often degrade when facing extreme outliers and data gaps. In light of these challenges, further in-depth research is needed to better understand and model the long-tailed behavior of ROTI signals.

In a study published (DOI: 10.1186/s43020-026-00188-x) in Satellite Navigation on 2 February 2026, researchers from the Universitat Politècnica de Catalunya and the Yangtze Normal University introduced a Bayesian probabilistic model to forecast global ROTI activity. The model predicts the probability that ionospheric disturbances will exceed defined thresholds across a 2.5° × 5° geographic grid, with forecasting horizons ranging from 30 minutes to six hours. By incorporating long-tail statistical behavior and persistence dynamics, the method aims to improve global monitoring of GNSS vulnerability under space weather conditions.

The team began by analyzing global GNSS measurements and focusing on ROTI, which quantifies rapid variations in TEC. Previous research had demonstrated that ROTI does not follow a Gaussian distribution; instead, it exhibits power-law behavior with bursty spikes and heavy tails, and with gaps in the time series due to the movement of the satellites. These extreme but infrequent events are precisely those most disruptive to navigation systems.

To address this, the researchers adopted a Bayesian persistence model grounded in long-tail statistics. For each active geographic cell, they analyzed the previous six hours of satellite observations and calculated the empirical duration of disturbance above specified thresholds (0.1, 0.25, and 0.5 TECU/min). Assuming a power-law prior, they analytically derived the posterior distribution of disturbance duration and used its median as the forecast estimate. In addition a method for doing the aggregation of the observations of different satellites at each cell was proposed.

Unlike gradient-based neural networks, which can be destabilized by extreme outliers, this approach remains robust under bursty conditions and allows for missing data segments. Validation against historical GNSS datasets showed strong predictive performance, with Weighted Kappa values exceeding 40% for horizons up to two hours and mean precision above 65% across all tested horizons.

“Our findings show that ionospheric disturbances behave more like persistent bursts than smooth periodic waves,” said the corresponding author. “By modeling ROTI using long-tail distributions, we can better capture the probability of extreme events without being misled by statistical assumptions that underestimate rare but impactful spikes.” The team emphasized that their approach provides a physically consistent framework for forecasting ionospheric persistence, rather than relying solely on black-box optimization.

The new model offers practical benefits for aviation, satellite communication, and space-based navigation systems. By identifying geographic regions where GNSS reliability may be compromised, it supports proactive mitigation strategies, including adaptive signal tracking and operational risk management. Because the algorithm runs in seconds on standard hardware and does not require extensive training data, it is suitable for real-time implementation in global monitoring systems. Beyond GNSS applications, the framework may also inform broader space weather forecasting efforts, especially in regions where geomagnetic storms and auroral processes introduce highly irregular ionospheric behavior.

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