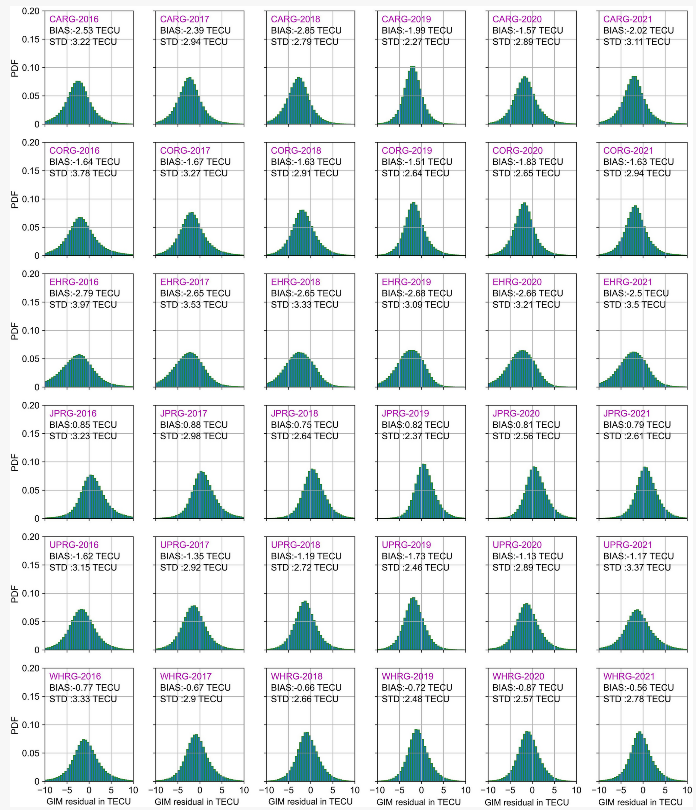
Adaptive ionospheric uncertainty maps speed up reliable GNSS positioning

GA, UNITED STATES, July 27, 2026 /EINPresswire.com/ -- Global Navigation Satellite System (GNSS) positioning depends on accurate ionospheric corrections and realistic estimates of their uncertainty. A new residual-based framework, called Factor-Adjusted Ionospheric Residual Statistics (FAIRS), makes the Root-Mean-Square (RMS) information accompanying Global Ionospheric Maps (GIMs) more consistent with observed correction errors. By accounting for non-Gaussian residual behavior and the local availability of GNSS observations, FAIRS improves the responsiveness and statistical bounding performance of the uncertainty maps without applying uniform overinflation. Tests in ionosphere-constrained Precise Point Positioning (PPP) further showed faster convergence in the evaluated cases while maintaining reliable weighting of the ionospheric corrections.



Histogram distributions of ionospheric errors for different GIM products.

Global Ionospheric Maps (GIMs) describe Total Electron Content (TEC) and are widely used to correct ionospheric delay in satellite navigation. GIM products are generally accompanied by root-mean-square (RMS) maps that describe the estimated accuracy of the TEC values. However,Each map is accompanied by a Root-Mean-Square (RMS) layer intended to describe uncertainty, but Ionospheric Associated Analysis Centers (IAACs) of the International GNSS Service (IGS) generate these mapslayers with different algorithms and statisticalphysical interpretations. Some estimates reflect only internal model fitting and can understate real errors; others are inflated so strongly that they lose value for precision applications. GIM Rresidual errors also contain heavy tails, spatialregional differences and repeatable sub-daily signals that are not adequately captured by a simple Gaussian modelsimple Gaussian assumptions may miss. These limitations motivate a closer examination of ionospheric residual behavior and the methods used to generate reliable GIM accuracy informationGiven these challenges, deeper investigation is needed into how ionospheric residuals behave and how GIM uncertainty should be constructed.

Researchers led by the Aerospace Information Research Institute, Chinese Academy of Sciences (CAS), with collaborators from institutions in Germany, Spain, Poland, Italy, Canada and China, published the study on July 15, 2026, in Satellite Navigation. The team examined unmodeled ionospheric errors across multiple rapid GIM products and developed Factor-Adjusted Ionospheric Residual Statistics (FAIRS) to generate more credible RMS maps. By combining distribution-aware scaling with station-based residual information, the method aims to align reported precision more closely with actual ionospheric variability and improve the use of GIM corrections in high-precision positioning.

The team analyzed rapid GIM products from seven IAACs using observations collected at 26 globally distributed IGS stations from 2016 to 2021. Carrier-to-Code Leveling (CCL) extracted TEC from Global Navigation Satellite System (GNSS) data, while spatial and temporal interpolation matched map values to each observation. Most residuals fell between approximately -5 and 5 Total Electron Content Units (TECU), but the distributions were generally symmetric and leptokurtic: errors clustered near the center while unusually large values occurred more often than a normal distribution predicts. After three-standard-deviation filtering, the central residual distribution could be approximated as normal. Fast Fourier Transform (FFT) and Allan variance analyses identified deterministic components with periods of one-sixth, one-third and two-thirds of a day, alongside changing noise regimes. FAIRS then adjusted uncertainty using skewness, kurtosis and residuals around Ionospheric Pierce Points (IPPs). It distinguished monitored grid points, where nearby observations supported adaptive updates, from unmonitored points, where more conservative estimates were retained. Validation with the Ionospheric Error-Accuracy Diagram (IEAD) and RMS Bounding Percentage (RMSBP) showed 81.78%, 96.85% and 98.96% coverage within one, two and three RMS bounds for Slant Total Electron Content (STEC) residuals. For differential Slant Total Electron Content (dSTEC), coverage reached 97.96%, 98.96% and 99.04%.

The authors said the key advance is not simply making uncertainty values larger, but making them respond to what the ionosphere and the observing network are actually doing. They said a useful RMS map should protect users from underestimated errors while still revealing where and when the model is performing well. By incorporating residual shape and local data density, FAIRS offers a practical balance between reliability and sensitivity. This allows uncertainty information to become an active part of positioning decisions rather than a static safety margin applied uniformly across regions and conditions.

The approach could strengthen navigation services that depend on fast and reliable positioning, including surveying, geodesy, precision agriculture, autonomous systems and other real-time GNSS applications. In single-frequency PPP with ionospheric constraints (PPP-IC), FAIRS-based weighting reduced early positioning errors and shortened convergence under both quiet and geomagnetically active conditions, while maintaining dependable error bounds. The method has already been applied to CAS rapid and final GIM production, providing a route toward uncertainty maps that better reflect sparse observations and rapidly changing ionospheric conditions. Future work will test FAIRS with multi-GNSS and multi-frequency data and explore its use in adaptive smoothing, dynamic parameter tuning and improved TEC modeling.

References
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