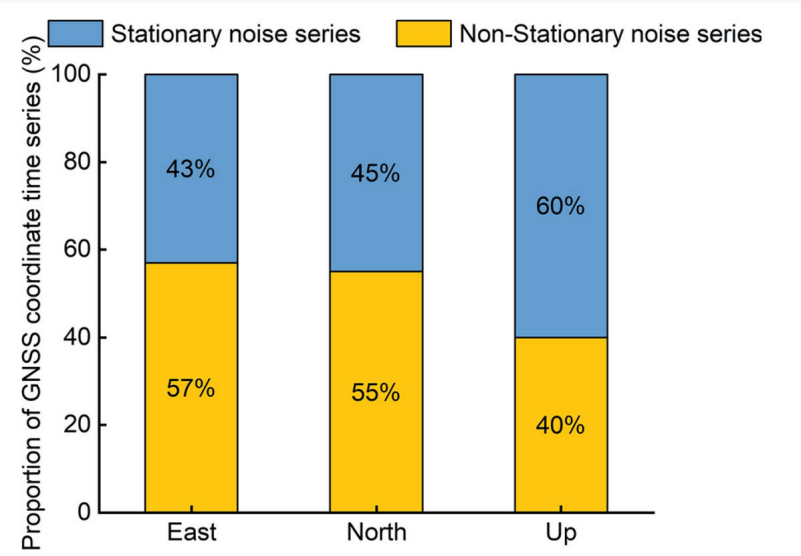
Preserving cross-gap differences improves GNSS noise analysis with missing values

GA, UNITED STATES, October 17, 2026 /EINPresswire.com/ -- A new study presents two information-preserving maximum likelihood methods for analyzing Global Navigation Satellite System (GNSS) coordinate time series when colored noise is non-stationary and observations are missing. Standard first-order differencing can stabilize non-stationary noise, but it discards differenced observations involving missing epochs, losing valid information and biasing noise parameters and velocity uncertainty. The proposed methods retain cross-gap differences through either a linear transformation matrix or marginalization of missing values in the original series. Tests on simulated and real GNSS data show consistent, more accurate noise parameter and velocity uncertainty estimates, with computational efficiency depending on the percentage of missing values.



Proportion of GNSS coordinate time series containing non-stationary noise in the East, North and Up components obtained at 60 global GNSS sites.

High-precision Global Navigation Satellite System (GNSS) coordinate time series underpin studies of plate motion, earthquakes, terrestrial water storage, sea level change, and landslides. Their noise is often temporally correlated colored noise, and power-law (PL) noise with spectral index alpha ≤ -1 is non-stationary, making covariance matrices non-Toeplitz. First-order differencing can transform such noise into stationary processes, but missing values cause extra loss: one missing epoch removes two adjacent first differences. This loss can bias noise model parameters and velocity uncertainty, especially when non-stationary noise and many gaps coexist. Given these challenges, in-depth research is needed on information-preserving noise analysis for GNSS coordinate time series with missing values in the first-differenced domain.

Researchers from the China University of Mining and Technology, the State Key Laboratory of Spatial Datum, the Jiangxi University of Science and Technology, and the University of Beira

Interior published (DOI: 10.1186/s43020-026-00220-0) their study in Satellite Navigation on 05 October 2026. The work develops two modified first-differenced maximum likelihood estimation (MLE) algorithms for GNSS coordinate time series with missing values. One uses a linear transformation matrix; the other uses a marginal likelihood function. Both aim to preserve valid differenced information that standard first-differenced MLE discards.

The first algorithm constructs free differenced observations from consecutive available epochs, even across missing segments, using a linear transformation matrix. The second treats missing original observations as latent variables and integrates them out through a marginal likelihood, while preserving the Toeplitz structure of the complete first-differenced covariance matrix. The authors evaluated the methods using 10,800 simulated GNSS coordinate time series covering stationary, weakly non-stationary, and strongly non-stationary power-law noise. Missing values percentages ranged from 0% to 50% in the main comparative experiments and were extended to 65% for the computational efficiency analysis. The evaluation also included 180 real GNSS coordinate time series from 60 global GNSS sites. The two modified algorithms produced highly consistent estimates, with Pearson correlation coefficients of 0.9999 for key noise parameters and velocity uncertainty and near-zero mean differences. Their main difference was speed. The marginal likelihood algorithm was generally faster when missing values were below about 60%, whereas the linear transformation algorithm became more efficient at higher missing percentages. In real data, 12% of series favored the linear transformation approach, close to the share with more than 60% missing values. Both modified algorithms outperformed normal MLE and standard first-differenced MLE under non-stationary noise and high missingness.

The authors said the key advance is not filling gaps but keeping valid differences that span them. They said that instead of treating every difference near a missing epoch as unusable, their methods preserve the information already present in available observations. They explained that the two algorithms are statistically equivalent in parameter estimates but differ in speed: the marginal likelihood approach is often faster with low-to-moderate missing data, while the linear transformation approach gains an edge when gaps are extensive. They added that this makes the framework practical for large global GNSS archives.

More reliable GNSS velocity uncertainty can improve interpretations of plate motion, earthquake deformation, sea level change, water storage, and landslide monitoring. The framework also offers a complementary first-differenced extension to existing fast Toeplitz-based MLE tools, rather than replacing them. Likelihood values from the proposed algorithms can support model selection criteria such as the Akaike information criterion (AIC) or Bayesian information criterion (BIC). The authors caution that applying the methods to other geophysical time series may require adapting the functional model, sampling interval, and covariance construction, especially for irregular sampling, non-Gaussian errors, or noise processes different from white noise plus power-law (WN+PL).

References
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