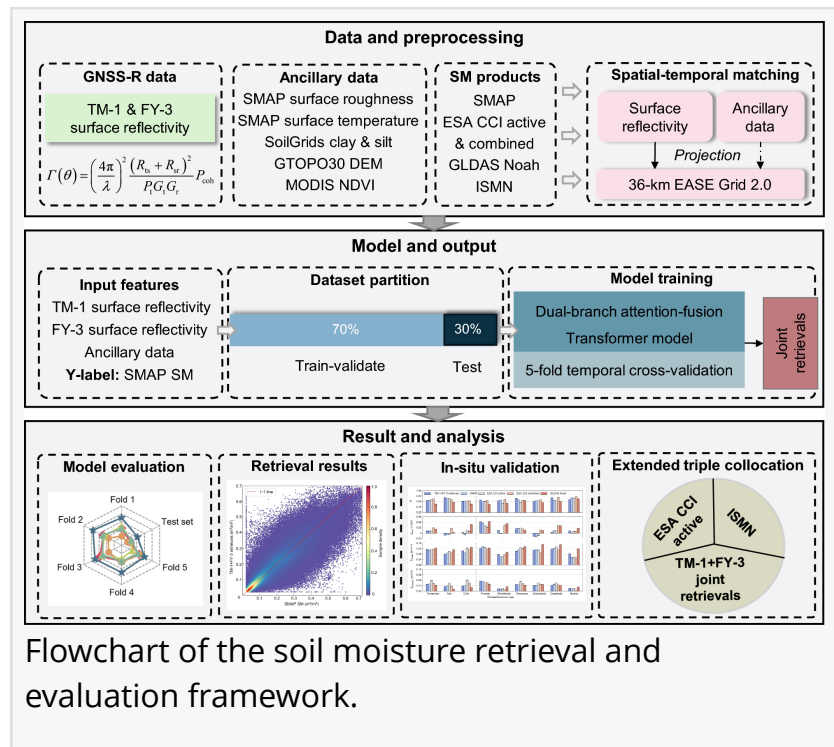


Satellite fusion sharpens the global view of soil moisture

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/EINPresswire.com/ -- Soil moisture is a small signal with a large influence: it shapes crop growth, drought development, flood risk, and the exchange of water and heat between land and atmosphere. Yet this hidden variable remains difficult to track continuously at a global scale. A new study shows how reflected navigation signals from space can be combined to map soil moisture more consistently across diverse landscapes. By integrating observations from Tianmu-1 and Fengyun-3, the researchers developed an attention-guided Transformer model that learns the unique strengths of each satellite mission before fusing them. The approach improves the accuracy, stability, and coverage of [Global Navigation Satellite System-Reflectometry](#) (GNSS-R)-based soil moisture monitoring, offering a stronger foundation for hydrology, agriculture, and climate-risk applications.



Soil moisture (SM) monitoring has traditionally depended on ground sensors or conventional remote sensing products, each with practical limits. In-situ networks provide direct measurements but are expensive and sparse, while optical and microwave satellite methods can be affected by clouds, vegetation, cost, or coarse spatial details. Global Navigation Satellite System-Reflectometry (GNSS-R) offers a promising alternative by using reflected signals from navigation satellites, but many studies still rely on single missions. Simple fusion of multiple missions can also blur differences in orbit, geometry, and signal response. Based on Considering these challenges, there is an urgent need for in-depth research into intelligent multi-mission GNSS-R fusion methods for global soil moisture retrieval.

The study was published on July 8, 2026, in Satellite Navigation. The work was conducted by researchers from the School of Geodesy and Geomatics, Wuhan University, and the Chinese

Antarctic Center of Surveying and Mapping, Wuhan University. It presents a dual-branch attention-fusion Transformer model that integrates Level-1 observations from the complementary Tianmu-1 (TM-1) and Fengyun-3 (FY-3) missions to retrieve global soil moisture with improved spatiotemporal continuity and stronger robustness across changing surface conditions.

The research team first gridded TM-1 and FY-3 GNSS-R observations to the 36-km Equal-Area Scalable Earth Grid, Version 2.0, (EASE-Grid 2.0) respectively, using surface reflectivity as the primary satellite observable. The model also incorporated auxiliary environmental information, including Soil Moisture Active Passive (SMAP) surface roughness and temperature, Moderate Resolution Imaging Spectroradiometer (MODIS) Normalized Difference Vegetation Index (NDVI), GTOPO30 Digital Elevation Model (DEM), and SoilGrids clay and silt content. Instead of forcing all satellite inputs into one stream, the model uses two mission-specific branches to learn TM-1 and FY-3 features separately, preserving differences in constellation design, observation geometry, and signal behavior. An attention-based module then adaptively balances cross-mission information before a Transformer captures temporal dependencies. The integrated TM-1 + FY-3 dataset achieved 79.7% average global monthly temporal coverage. Against SMAP soil moisture references, the model reached a correlation coefficient of 0.88 and root mean square error (RMSE) of 0.053 m³/m³. Independent validation with International Soil Moisture Network (ISMN) measurements yielded a correlation of 0.67 and unbiased RMSE (ubRMSE) of 0.041 m³/m³, while Extended Triple Collocation (ETC) analysis showed a correlation of 0.75 and random error standard deviation of 0.030 m³/m³. The model performed especially well in arid and sparsely vegetated regions, where reflected signals can more directly capture surface moisture changes.

The authors said the study shows that multi-mission GNSS-R is not simply a matter of collecting more satellite tracks, but of learning how different missions sense the land surface. They said the attention mechanism allows the model to draw useful information from each mission under changing vegetation, climate, and land-cover conditions, rather than treating all observations as equivalent. In their view, this makes the framework better suited for operational hydrological monitoring, where missing data, surface complexity, and mission differences must be handled together.

The findings could support more continuous soil moisture products for drought early warning, flood forecasting, irrigation planning, water-resource management, and land-atmosphere research. Because GNSS-R can use reflected signals from existing navigation satellites and relatively low-cost receivers on Low Earth Orbit platforms, the approach may complement conventional microwave missions while extending coverage in regions where ground observations are limited. As more GNSS-R constellations become available, attention-guided fusion could help reduce spatial and temporal gaps, improve global hydrological monitoring, and support higher-resolution environmental applications. Future work may expand the framework to additional missions, improve uncertainty-aware fusion, and strengthen validation in tropical, Asian, African, and Oceanian regions.

References

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