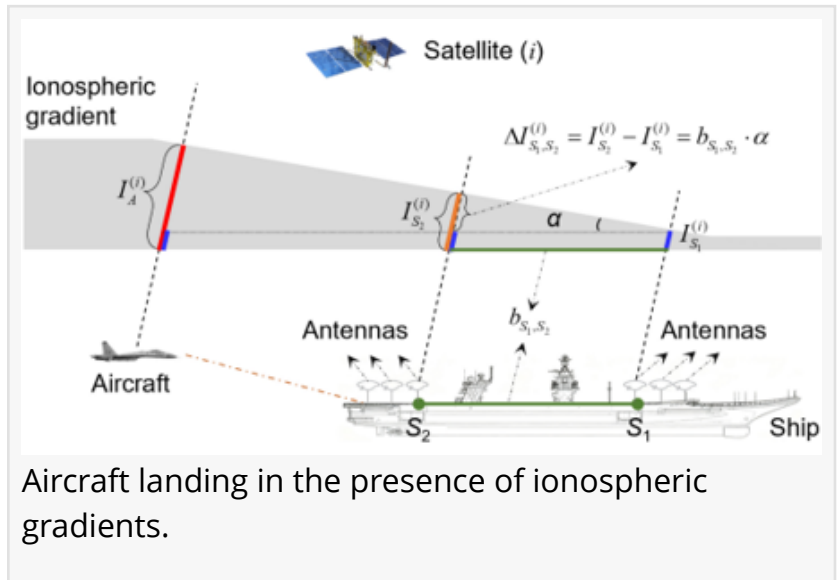


Boolean collaborative decision rule eliminates hidden ionospheric dead zones at sea

FAYETTEVILLE, GA, UNITED STATES, July 20, 2026 /EINPresswire.com/ --

Precision landing at sea depends on a simple question with high stakes: can a shipboard navigation system tell when the ionosphere is quietly bending satellite signals enough to endanger an approaching aircraft?

[Solar activity](#) can disturb the spatial distribution of electron density in the ionosphere, causing satellite GNSS signals to experience different delays over short distances. For precision approach and landing, such ionospheric gradients can translate into ranging errors and threaten navigation integrity. Carrier-phase monitoring is more sensitive than pseudorange-based monitoring, but it depends on reliable ambiguity resolution, and incorrect ambiguity estimates can mask dangerous gradients or trigger false alarm. The challenge is harder at sea, where ship flexure, antenna motion, installation errors, and Inertial Navigation System (INS) drift can degrade geometric calibration. Based on these challenges, deeper research into ionospheric gradient monitoring for SB-JPALS is needed.



Researchers from the College of Intelligent Systems Science and Engineering at Harbin Engineering University published (DOI: [10.1186/s43020-026-00204-0](https://doi.org/10.1186/s43020-026-00204-0)) the study on July 7, 2026, in [Satellite Navigation](#). The paper presents a multi-reference carrier-phase monitoring framework for SB-JPALS that is designed to bound both integrity risk and continuity risk caused by incorrect ambiguity resolution. This capability is essential for preventing hazardous measurements from being broadcast to airborne users and is a critical step for automatic landings that depend on uninterrupted, high-confidence satellite navigation.

The proposed method first reformulates the Carrier Phase Residual Monitoring (CPRM) statistic into a Geometry-Free (GF) form, reducing the impact of geometric calibration bias caused by changing antenna baselines and attitude-estimation errors. The team then analyzed how this bias affects ambiguity resolution failure and set conditions under which the failure risk can be

bounded. Instead of averaging test statistics or reacting to a single threshold exceedance, the proposed Boolean collaborative decision rule counts how many baselines raise an alert. An ionospheric gradient is declared only when that count reaches a chosen decision threshold; otherwise, abnormal test statistics can be treated as likely ambiguity resolution failures and excluded. This design also relaxes strict baseline-topology requirements, an important advantage for crowded ship decks. Simulations using BDS triple-frequency signals showed that an ambiguity-resolution failure rate below 5.8×10^{-5} is sufficient to eliminate undetectable dead zones under three-baseline configurations. Real-world experiments used a moving ship equipped with six BDS reference receivers and an INS, forming three independent baselines during about 10 hours of motion over 96.3 km. The F2/3 Boolean rule delivered the strongest performance, improving sensitivity by 12.0% compared with conventional monitoring and by 30.8% compared with single-baseline monitoring.

The authors stated that the advancement is not simply the use of more receivers, but that the receivers are required to make a shared decision. They explained that this collaborative rule helps prevent a single failed ambiguity resolution from dominating the safety assessment, while still allowing the rapid detection of genuine true ionospheric threats. For shipboard automatic landing, they emphasized that this balance is essential: the system must avoid missed hazards while minimizing unnecessary alarms that interrupt continuity during safety-critical operations, especially when there is little margin for delay or manual intervention.

The findings suggest a practical approach to improving SB-JPALS performance under realistic shipboard conditions, where navigation systems must operate amid motion, vibration, and varying antenna geometries. Although instantaneous Minimum Detectable Ionospheric Gradient (MDIG) performance remains strongly influenced by observation noise, the study shows that averaging four statistically independent epochs can reduce the MDIG from 757 mm/km to 379 mm/km, nearing JPALS requirements. Future research should test the framework under more sea states, antenna configurations, and noise conditions, with practical real-time implementation constraints in mind. This monitoring principle may also support Ground-Based Augmentation System (GBAS) and Land-Based Joint Precision Approach and Landing System (LB-JPALS) applications, where spatial ionospheric delays threaten high-integrity navigation.

References

DOI

10.1186/s43020-026-00204-0

Original Source URL

<https://doi.org/10.1186/s43020-026-00204-0>

Funding Information

This research was jointly funded by the National Natural Science Foundation of China (Grant 20 No. 62373117, 62403158, 62573150) and the China Postdoctoral Science Foundation (Grant 21 No. 2024M754152, 2024M754064).

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