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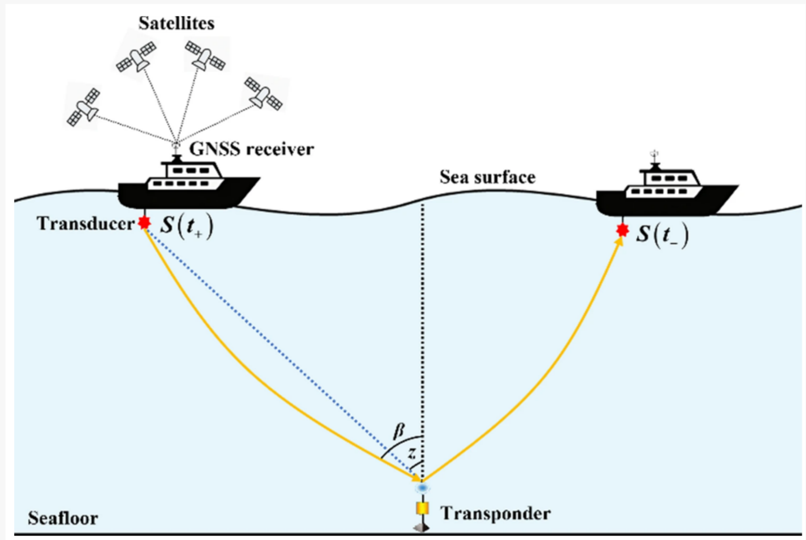
Layered ocean sound speed model improves acoustic seafloor positioning precision

FAYETTEVILLE, GA, UNITED STATES, June 23, 2026 /EINPresswire.com/ -- GNSS-A positioning, which combines satellite positioning of a sea-surface platform with underwater acoustic ranging, is essential for monitoring seafloor tectonic movements and improving global reference frames. However, the ocean's sound speed varies with depth and time in complex ways, creating errors that have long limited positioning accuracy. Researchers have now developed a layered sound speed gradient model that captures how horizontal sound speed variations differ across depth layers. By jointly estimating seafloor transponder coordinates, time varying sound speed perturbations, and layer specific gradients, the new method significantly reduces positioning errors. In simulations, the approach reduced positioning errors from the decimeter scale to the millimeter range. Field experiments further demonstrated improved acoustic residuals, stable positioning repeatability, and strong consistency with independent GARPOS solutions, offering a more reliable tool for seafloor deformation studies and ocean environment characterization.



Schematic illustration of underwater two-way acoustic positioning in a GNSS-A system.

Conventional Global Navigation Satellite SystemAcoustic (GNSSA) positioning treats the water column as having a single depthaveraged horizontal sound speed gradient. While simple and numerically stable, this assumption becomes inadequate when horizontal gradients vary strongly with depth—as they often do in real oceans, especially in the upper active layer. Prior attempts using twolayer partitions remain too coarse to capture finescale vertical structure. As a result, unmodeled sound speed heterogeneity accumulates in traveltime residuals, introducing systematic biases that can reach several centimeters in seafloor coordinates. Due to these challenges, a more realistic representation of depthdependent sound speed gradients is needed, together with a joint inversion framework that can estimate both seafloor positions and layered field parameters simultaneously.

A team led by researchers at Shandong University, Weihai, China, and the Chinese Academy of Surveying and Mapping, Beijing, presents a new GNSS-A positioning approach in Satellite Navigation, published (DOI: 10.1186/s43020-026-00197-w) online May 29, 2026. The study introduces a layered horizontal sound speed gradient model that divides the water column into multiple depth intervals, each with its own time-varying eastward and northward gradient. Adjacent layers are linked through depth-weighted continuity constraints, which help stabilize the joint inversion of both seafloor transponder coordinates and sound speed field parameters.

The key innovation lies in how the model handles vertical heterogeneity. Instead of forcing one gradient to represent the whole water column, the researchers split the column into layers—for example, 0–300 m, 300–800 m, and 800–3000 m—each with its own horizontal gradient expressed using B-spline basis functions. A depth-weighted constraint gently forces neighboring layers to behave consistently, with weaker coupling in the upper ocean (where variability is high) and stronger coupling at depth (where conditions are smoother). This design prevents unphysical layer-to-layer oscillations while allowing real vertical structure to emerge. In simulations with prescribed depth-dependent gradients, the conventional single-layer model produced 3D positioning errors of 66–231 mm, whereas the new layered model reduced errors to only 2.6–5.6 mm. In a representative MYGI field campaign, the acoustic travel-time residual standard deviation decreased from 0.1243 ms to 0.0787 ms, and the estimated transponder coordinates showed close agreement with independent GARPOS solutions, with most component-wise differences reduced to the millimeter level. Long-term analyses at four seafloor geodetic sites (MYGI, KAMS, CHOS, and FUKU) further showed stable multi-epoch coordinate time series over nearly a decade and broad consistency with GARPOS, with smaller scatter than the conventional single-layer models in several components.

The authors explained that the conventional approach essentially averages horizontal sound speed gradients across the entire water depth, which works reasonably well only when the gradients are truly depth-invariant. “In the real ocean, temperature and salinity stratify strongly, so horizontal variations in the upper few hundred meters behave very differently from those in deeper water,” they said. The authors noted that the layered model allows depth-dependent gradient variations to be estimated from the observations, while the interlayer constraints help keep the solution physically reasonable. Rather than relying on a single effective gradient for the entire water column, the model incorporates the layered nature of the ocean sound speed structure directly into GNSS-A positioning.

The new method has direct applications in seafloor geodesy, where centimeter-level stability is needed to detect slow tectonic motions or post-seismic deformation. It also offers a way to extract oceanographic information from routine GNSS-A surveys—because the estimated layer-wise gradients reveal how horizontal sound speed variability changes with depth, effectively turning positioning data into a probe for ocean structure. Beyond GNSS-A, the same layered gradient framework could potentially be extended to other underwater acoustic positioning systems, such as Long Baseline (LBL) and Ultra-Short Baseline (USBL) positioning.

Future work will focus on adaptive layer selection and integrating ocean model data to further tighten constraints, ultimately supporting long‑term seafloor monitoring and improved marine geodetic reference frames.

References
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