IPR (Indirect Path Ranging): a new approach for long-distance acoustic ranging with a moored relay node

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Seafloor geodetic techniques such as GNSS-Acoustic measurement (GNSS-A), ocean bottom pressure-gauge (OBP) and direct path ranging (DPR) provide in-situ measurement of seafloor deformation. Especially, DPR is a specialized way to preciously measure relative horizontal motion continuously. It measures two-way travel time between a pair of acoustic transducers. The precision of DPR is typically 1–2 mm per 1 km baseline. Observation period is as long as ~3 years so far. However, difficulty in DPR is to ensure direct acoustic paths among transducers not interfered with seafloor as the distance being longer; e.g., an acoustic path bends downward by 142 m for 10 km baseline in a typical sound speed gradient. Unrevealed local topographic bump around the transducer often hinders paths, too.
In extricating such obstacles, we employed a new approach that uses an acoustic relay node, called interrogator, at the halfway of a baseline to reliably pass acoustic paths; we call it "Indirect Path Ranging (IPR)". Sweeney et al. (2005, *Mar. Geod.*) introduced a ship-hanging interrogator ~500 m above the seafloor and reported that baseline length of 5 km can be measured with several centimeters precision. On the other hand, we moored the interrogator at midwater for long-term continuous observation. A moored interrogator is much advantageous than hanging type, which pumps according to ship's heave; displacement of the interrogator during individual ranging degrades the measuring accuracy.
IPR/DPR observation was conducted during October 2017–August 2018 off Fukushima region, where massive postseismic slip seems to be occurred in the shallow subduction zone (e.g., Iinuma et al., 2016, *Nature Comm.*). We installed five seafloor transponders at trench slope and moored an interrogator at the center of them (i.e., close to the trench axis). All the five baselines for IPR were available, while only one was available for DPR combination due to long distance. We confirmed that rangings were properly carried out over 80% of total period for IPR even the longest beseline of 9180 m.
As the first step, we estimate the 3-D position of the interrogator using four seafloor stations that can be simultaneously called from the interrogator. The interrogator was in motion within the radius of 50 m during most of the period, while it excursed by 300 m at the longest. Traveltime residuals were in order of ~10 cm in terms of distance. Since the acoustic paths were almost horizontal, vertical motion of interrogator may be poorly resolved. Therefore, the vertical motion should be determined form pressure data rather than being solved as an unknown. Anyway, uncertainty of the vertical position of the interrogator has less contribution in total ranging accuracy for its geometry. In the next step, we plan to evaluate interrogated baseline length changes with more precise interrogator position by applying sound velocity correction.
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