Array positioning analysis of GPS-Acoustic observation data considering lateral gradient of the sound speed in seawater

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In each geodetic benchmark on the seafloor for GPS-Acoustic observation, 3–6 precise precision transponders (PXPs) are settled to form a triangular or square array. The array positioning is an analysis to determine array displacements assuming that relative positions between the PXPs are unchanged, i.e. the array moves rigidly [e.g., Spiess et al., 1998]. One of the most important parameters in the analysis is the sound speed in seawater. Usually, a reference profile of the sound speed, which is a function of water depth, is constructed based on oceanographic observations such as Conductivity-Temperature-Depth (CTD) measurements, and then small fluctuation of the sound speed structure is solved together with the array displacement. We, the Tohoku University group, have used a quantity called 'Nadir Total Delay (NTD)' to represent the fluctuation of the sound speed [e.g., Kido et al., 2006; Honsho & Kido, 2017]. The NTD is analogous to 'Zenith Total Delay' in the GNSS analysis and defined as a vertically normalized traveltime residual, i.e. a difference between observed and synthetic traveltimes normalized onto a hypothetical vertical path according to the slant of the acoustic path. When a laterally stratified structure is assumed for the sound speed, the NTD is a function of time only and independent of an azimuth and an emission angle of the acoustic path. Then, we have adopted a method in which the time variation of the NTD and the array position are solved simultaneously.

The assumption of laterally stratified structure is primarily valid. However, there are lateral variations in actual, which can result in systematic errors as much as several centimeters in the array positioning. In this study, we consider a lateral gradient of the sound speed as a first-order approximation of lateral variations. Then, we introduce an array positioning method considering the gradient and report the results of its application to actual data.

We can obtain two kinds of information on the gradient from traveltime data. First, the gradient and the array displacement give changes to traveltime in different manners; therefore, they can be theoretically distinguished using traveltime data with various emission angles. Second, the NTD variation observed while a ship moves around above the array often shows a distribution which seems to be related to the ship positions. One example is the case where the NTDs observed when the ship is located in the north of the array are generally larger than those in the south of the array; this may indicate that the sound speed is generally smaller in the north than in the south. The above two kinds of information, however, have disadvantages respectively. As for the former, the effects of the gradient and array displacement on traveltimes are different but quite similar, and thus the results can be easily affected by data or modeling errors. As for the latter, the NTD variation that is observed while the ship moves around cannot be distinguished as a temporal or spatial variation in principle.

From numerical experiments and analyses using actual data, we concluded that more reasonable results were obtained when both kinds of information were utilized together, rather than using either of them. Then, we applied the analysis considering the gradient to the actual data obtained from ~120 campaigns conducted during 2012–2016 at the 20 observation sites off the Tohoku region. Some artificial, zig-zag movements of horizontal array position recognized in the previous results [Tomita et al., 2017] tend to be suppressed. Accordingly, the estimated displacement rates were slightly changed and showed more similar rates among neighboring sites.

It remains an issue of the method how the depth of the fluctuating layer, which has significant effects on the results, is chosen. It is tentatively set to 500 m for several reasons, but each of them lacks a decisive ground. We will continue discussions on the matter in the future.

Keywords: GPS-A observation, Lateral gradient of the sound speed in sewater