The effects of a single layer horizontal underwater sound speed gradient on GNSS-A seafloor geodetic observation evaluated by numerical simulation

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The GNSS-Acoustic ranging combination technique (GNSS-A) measures the position of a seafloor benchmark in precision of centimeters by combining GNSS observation and underwater acoustic ranging on a sea surface platform (e.g. survey vessel, buoy, autonomous vehicle). One of the largest error sources of GNSS-A is the acoustic ranging error due to the perturbations in the underwater sound speed structure (SSS). Numerous data analysis schemes have been developed by researchers to correct the effects on the GNSS-A positioning accuracy caused by perturbations in the SSS.
Recently, our research group has developed an open source GNSS-A analysis software "GARPOS" (Watanabe et al. 2020) which implements empirical Bayesian approach to simultaneously estimate the seafloor benchmark positions and the sound speed perturbation. The algorithm of GARPOS decomposes the SSS to a horizontally stratified reference sound speed profile and the sound speed perturbation. The sound speed perturbation model consists of three components; component $\delta V0$ which indicates the temporal change of the average sound speed, component $\mathbf{g}_1$ which depends on the position of the surface platform, and component $\mathbf{g}_2$ which depends on the seafloor transponder positions. The components $\mathbf{g}_1$ and $\mathbf{g}_2$ can be interpreted as terms that represent the horizontal sound speed gradient in the relatively shallower and deeper portions of the sea, respectively, and can be applied to evaluate the physical oceanography around the seafloor site.
In this study, we evaluated the sound speed perturbation extracted from GARPOS by using synthetic GNSS-A data generated by numerical simulation. We constructed a numerical simulator using the Eikonal equation repository PyKonal (White et al. 2020) to simulate acoustic travel times in a simple SSS with a horizontal sound speed gradient. We generated synthetic GNSS-A data using the simulated travel times, which were analyzed using GARPOS. The sound speed perturbations obtained from GARPOS were evaluated by comparing with the SSS parameters that were set in the numerical simulation.
The results of the analyses of the synthetic GNSS-A data indicate that GARPOS successfully reproduces SSSs with a single horizontal sound speed gradient. For example, in the case of a single layer of sound speed gradient extending from the sea surface to a certain depth, the sound speed perturbation components extracted with GARPOS agrees with the simpler sound speed perturbation schemes proposed by Honsho et al. (2019) and Kinugasa et al. (2020). We will also discuss on the effects of the layer thickness, layer depth, and magnitude of a single layer sound speed gradient on the sound speed perturbation components $\mathbf{g}_1$ and $\mathbf{g}_2$ of GARPOS, to show how $\mathbf{g}_1$ and $\mathbf{g}_2$ can be interpreted in such simple SSSs.
Since there are two components representing the horizontal sound speed gradient ($\mathbf{g}_1$ and $\mathbf{g}_2$), GARPOS is capable to extract SSSs that are more complex than SSSs with only a single sound speed gradient layer, such as those evaluated in this study. In the future, we are looking to investigate the interpretation of sound speed perturbation components of GARPOS by using synthetic data simulated with complex SSSs.

Keywords: GNSS-A, Seafloor geodesy, Sound speed structure, Sound speed gradient

