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Accuracy due to ray tracing and velocity structure in acoustic ranging to develop seafloor geodetic observations

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On-land geodetic observations are not enough to monitor crustal activities in and around the subduction zone, so seafloor geodetic observations have been required. However, present accuracy of seafloor geodetic observation is an order of 1 cm or larger, which is difficult to detect differences from plate motion in short time interval, which means a plate coupling rate and its spatio-temporal variation. Our group has developed the observation system and methodology for seafloor geodesy, which is combined kinematic GPS and ocean acoustic ranging. One of influence factors is acoustic velocity change in ocean, due to change in temperature, ocean currents in various scale, and so on. A typical perturbation of acoustic velocity makes an order of 1 ms difference in travel time, which corresponds to 1 m difference in ray length. In modeling, due to approximation, there are some differences between modeled ray paths and actual ones, which cause modeling errors in travel times. We have investigated these effects in seafloor geodesy using both observed and synthetic data to reduce and evaluate estimation errors of benchmarker (transponder) positions and to develop our strategy for observation and its analyses. Estimation procedure for benchmarker positions is similar to those used in earthquake location method and seismic tomography. So we have applied methods in seismic study, especially in tomographic inversion.

For observed data, we use the method of a one-dimensional velocity inversion with station corrections, proposed by Kissling et al. [1994], to detect spatio-temporal change in ocean acoustic velocity during observations over the Suruga-Nankai Trough, Japan. From these analyses, some important information has been clarified in travel time data. We found significant changes in ocean acoustic velocity with various spatial scales. Most of travel time changes and/or modeled acoustic velocity changes can explain small velocity changes/anomaly(s) at a depth of 600m or shallower, through forward modeling of travel time data using simplified velocity structure. However, due to simple data acquisition procedure, we cannot detect velocity anomaly(s) precisely in space and time, that is a size of anomaly and its (their) movement.

Through forward modeling of acoustic travel time data, we demonstrate various modeling to verify detected changes in observed data and to evaluate model error due to difference between velocity models and between modeled and real ones. And also, we estimate differences in pseudo-bending ray tracing and actual ray under basic ray theory, which include comparison between precise and approximate solutions.

Through these analyses, we have tried to evaluate recovery of benchmarker positions in tomographic inversion using synthetic data including anomalous travel time data to develop idea to calculate benchmarker positions with high-accuracy. In the tomographic inversion, we introduce some constraints corresponding to realistic conditions. This step gives us new developed system to detect crustal deformation in seafloor geodesy and new findings for understanding these in and around plate boundaries.

Keywords: seafloor crustal deformation measurement, acoustic ranging, ocean acoustic velocity structure, ray tracing method, tomographic inversion