Inversion method counting the spatial variation of sound speed structure in the measurement of Ocean Base Crustal Deformation

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We developed a new geodetic method of monitoring crustal deformation on the ocean floor. The measurements were conducted at two sites beneath the Pacific Ocean, near the Nankai trough, where the Philippine Sea plate subducts into the Pacific plate. We have conducted repetitive measurement for about 5 years at the two sites, one is in Suruga Bay and the other at the Kumano Basin. At each survey site, three seafloor transponders, whose positions were repetitively measured, were deployed to define a benchmark unit. We combined GPS and acoustic technique to determine the positions of the transponders. A surface vessel, whose position was precisely determined by kinematic-GPS technique, drifted over the benchmark unit transmitting an ultrasonic signal to the seafloor transponders. The signal was reproduced by the transponders replying to the vessel. Positions of the transponders and the sound speed structure of the sea water were determined simultaneously from the round-trip travel time of the signal using a tomographic technique.

We repeatedly carried out measurements over the two sites. For the Kumano Basin, the horizontal precision of the benchmark location was d_h=5 cm and its vertical precision was d_v=10 cm through the repetitive measurements. At the Kumano Basin, a 21.5-cm southward displacement of the benchmark unit was detected just below the site before and after a large earthquake (Mw 7.5). Our observation system therefore proved itself capable of detecting seafloor crustal deformation associated with crustal activities in offshore areas.

The benchmark location was determined by inversion method using the precisely determined vessel position and the travel time of the ultrasonic signal. The lateral variation of the sound speed structure is very large reaching to several tens cm as a sound path so that we need to estimate the sound speed structure as well as benchmark locations. In the present analysis, we assume that the sound speed does not change horizontally but only in time. This is based on the nature that the lateral variation of the sound speed is limited only in the shallower part than 500m deep.

We can neglect the effect of the variation on the sound path because the sound path generated by the vessel is very close to each other in the shallower part. Therefore, we can solve the inverse problem, whose equation number is 3N (N shots for each benchmark) and unknown is N (sound speed structure for each moment) plus 9 (positions of three benchmarks), as an over determined system.

However, the actual sound speed structure has lateral variations. Larger variance of the benchmark positions corresponding to larger variance of the sea surface temperature suggests that the spatial variation in the sound speed affects the solution. We must estimate the lateral variation of sound speed structure to improve the benchmark positioning.

We conducted several numerical experiments to find the suitable design of the measurement to solve the lateral sound structure. We present the result of the numerical experiment and the benchmark positions solved with the new approach.