

論文の要旨

Title: Advanced study of coastal acoustic tomography with a focus on data assimilation

(データ同化法に注目した沿岸音響トモグラフィーの先進的研究)

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Coastal seas are transition zones between the continents and open ocean and characterized by variable dynamic phenomena which vary with time, such as coastal upwelling, tide and waves. However, systemic monitoring of coastal environments is so difficult for traditional field observation owing to heavy fishing activity and shipping traffic. Coastal acoustic tomography (CAT) is proposed as an innovative technology to enable the mapping of coastal-sea environments, using sound transmission from acoustic stations. Data assimilation (DA) is a prosperous method to take the most advantage of CAT data, which hold the information on sound speed (mainly related to temperature and salinity) and current velocity along sound transmission paths. The prediction accuracy of oceanic variables (temperature, salinity and current velocity) from ocean model has been significantly improved through the assimilation of acoustic tomography data with temporal growth. The Ensemble Kalman filter (EnKF) method may be preferable in assimilation of CAT data pronounced with time varying characteristics rather than variational method with heavy time consumption. However, computational burden still exists in the conventional EnKF method with model error covariance calculated by a large number of ensemble forecast of model states and updated at every data assimilation step. Further time reducing method is required for

quick assimilation of time varying coastal acoustic tomography data.

In this study, a time-efficient data assimilation scheme based on Ensemble Kalman filter was newly proposed. For this time-efficient data assimilation scheme, the model error covariance is determined from the perturbed model state vectors at each DA time without forecasting the ensemble model state vectors using a N-ensemble of pseudorandom noises. The pseudorandom noises are characterized by isotropic covariance with a specified decorrelation length. A smooth correlation function is also introduced to model error covariance to localize the data assimilation effect on tomography domain. Furthermore, barotropic and baroclinic assimilation are applied to CAT multi-arrival peak data.

This thesis is intended to study the environmental variations of the Hiroshima Bay and Bali Strait, by applying the newly proposed data assimilation method and vertical-slice inversion to obtain the vertical profiles of current and temperature from CAT data. Furthermore, a newly developed CAT system with mirror functionality (MCAT) is proposed to collect offshore subsurface data from shore station.

Hiroshima Bay, located at the western part of the Seto-Inland Sea, Japan, is elliptical in shape with a north-south length of 50 km and an east-west length of 20 km. The northern part of the bay is further semi-enclosed (about 10-km) by the south coast of Hiroshima City on the northern side and three islands (Miyajima, Etajima and Ninoshima) on the southern side. A typhoon driven coastal upwelling occurred on September 16-17 was measured by four CATs system in the northern part of Hiroshima Bay. The three-dimensional mapping of typhoon driven current and associated reverse flow was well reconstructed in a 2-layer system of current and salinity by applying the time-efficient data assimilation scheme. The upwelling was generated near the northern shore of Hiroshima Bay from 00:00 to 12:00 on September 17. During this period, a subtidal southward-flowing current formed in the upper layer and a northward-flowing current formed in the lower layer. The salinity in the upper layer increased up to values equal to the lower-layer salinity. As time proceeded, the upwelling was followed by a period of reverse flow with a northward subtidal current in the upper layer and a

southward subtidal current in the lower layer. The upper-layer saline water gradually retreated northeastward with the northward subtidal current. During the upwelling, the total transported volume was balanced between the upper and lower layers, demonstrating this continuity of the upper- and lower-layer currents and the reliability of data assimilation. The total northward transported volume for the upper layer in the reverse-flow period was significantly smaller than the total southward transported volume for the upper layer in the upwelling period. Furthermore, the total northward transported volume for the upper layer was significantly larger than the total southward one for the lower layer in the reverse-flow period. These transported volume imbalances implied the existence of two types of water mixing: offshore mixing during the upwelling and nearshore mixing during the reverse-flow period. The mixing fractions, estimated from the volume imbalances were 24% for the offshore mixing and 30% for the nearshore mixing. The assimilation results were compared to CAT and CTD results. The DA errors were significantly smaller than the variation ranges of current and salinity associated with the upwelling.

The Bali Strait, located between Java and Bali, is connected to the Java Sea through a narrow northern inlet of width about 2 km, which broadens southward in a trumpet shape toward the outlet to the Indian Ocean. The northern part with channel widths of about 5 km is characterized by a strong tidal current, which makes the scheduled operation of ferry boats difficult. The tidal current in the northern part of Bali Strait was investigated from two CAT experiments using vertical-slice inversion and barotropic data assimilation. The tidal current was characterized by semi-diurnal oscillation superimposed on high frequency oscillation. The maximum tidal current reached 2 ms^{-1} in high tide time. Various vortices of diameter 3-km with different directions were generated in high tide or low tide. The vortex center was always placed at 1- 2 km from B1 (CAT station in Bali side). Furthermore, the amplitudes of high-frequency oscillation were large especially at the mean tide, implying the same phenomenon of a standing-wave type.

In OAT/CAT, travel-time data are generally stored in individual subsurface stations and data analyses are performed after the recovery of the subsurface systems.

Shoreward transfer of subsurface CAT data can enable the monitoring of offshore environments from the shore and making the real-time prediction of offshore environmental changes possible. CAT with mirror-transpond functionality (MCAT) is here proposed to monitor offshore subsurface environments from the shore, measuring both current and sound speed between instruments. The newly developed MCAT system was well validated by two feasibility experiments which were carried out in the Nekoseto Strait of the Seto Inland Sea. The various path-average currents along the sound transmission line, crossing the vortex-embedded tidal currents, were successfully calculated from the regular and mirror data. The hourly-mean path-average currents obtained from mirror and regular data, were dominated by semi-diurnal tides which have amplitude of 0.2-0.3 ms⁻¹ in both two experiments. The indices of observation error were estimated using RMSEs for different kinds of path-average current. The errors were significantly smaller than the variation ranges of current, implying the accuracy of MCAT measurement.