Relationship between Ocean Bottom Pressure Variations and Baroclinic Eddy off Kushiro-Tokachi

*Takuya Hasegawa[1], Akira Nagano[1], Hiroyuki Matsumoto[1], Keisuke Ariyoshi[1]

1. Japan Agency for Marine-Earth Science and Technology

The scope of this study is to explore relationships between ocean bottom pressure variations and oceanic climate changes. We analyzed ocean bottom pressure data at stations PG1 and PG2 obtained from the Long-Term Deep Sea Floor Observatory off Kushiro-Tokachi by JAMSTEC, satellite- observed sea surface height (SSH) data provided by AVISO, and conductivity-temperature-depth (CTD; i.e., temperature and salinity vertical profile) data at a repeated observation line (A-line) from 2004 to 2013. The result shows that ocean bottom pressure variations at PG1 and PG2 are almost in phase in most of the analysis period, but from the early 2006 to the end of 2007, are quit discrepant. Expecting a peculiar hydrographic feature at the occasion, CTD data along the A-line in January 2007 are analyzed. A lenticular eddy was found to exist in a layer between 1500 and 3000 dbar. Probably due to the baroclinic eddy feature, ocean bottom pressure at PG2 is not in phase with the SSH, in contrast to PG1. The present results imply that oceanic temperature and salinity observations like CTD, in addition to SSH, are required to understand the mechanism of ocean bottom pressure changes.

Keywords: ocean bottom pressure variation, oceanic eddy

Comparison between temporal variation of sound velocity derived from GPS/acoustic and CTD measurements

*Ryo Matsui[1], Motoyuki Kido[2], Chie Honsho[2], Fumiaki Tomita[1]

1. Graduate School of Science and Faculty of Science, Tohoku University, 2. International Research Institute for Disaster Science, Tohoku University

The GPS/acoustic (GPS/A) technique enables us to detect the seafloor crustal deformation by combining Global Positioning System and acoustic ranging. In the GPS/A technique, horizontal displacement of a seafloor transponder array, which composed of at least three instruments, can be estimated for each of single ranging shot (e.g., Spiess, 1985; Kido et al., 2006). The traveltime residual in the estimate is related to sound speed variation when it is normalized to nadir total delay (NTD), which is equivalent to zenith total delay (ZTD) in GNSS analysis. The equivalent quantity can be also obtained from in-situ measurements of sound speed profiles by integrating its slowness throughout the profile. Kido et al. (2008) compared the two quantities and found that they are in good agreement at least for the semidiurnal variation. In this study, we investigate two subjects as applications of Kido et al. (2008).
First, we investigated whether the shorter (~1 hour) timescale variation of NTD obtained through GPS/A analysis also reflect the sound speed variations. For this purpose, we conducted intensive XBT casts every six minutes for one hour and calculated corresponding NTD. After adapting proper correction for sensor bias of each XBT cast, we confirmed that the GPS/A analysis well resolves the sound speed variation even in a short timescale.
Second, we investigated the potential accuracy to resolve vertical crustal displacements using precise sound speed profile obtained by CTD measurements. In the GPS/A analysis, absolute NTD intrinsically contains uncertainty of the transponder depth. However, this NTD must be unchanged through campaigns; therefore, relative change between campaigns may indicate vertical movement of the transponders. For this context, we evaluated the potential accuracy by comparing the discrepancy between up and down CTD casts relative to GPS/A estimates of NTD for several observation sites. Considering CTD errors both in temperature and time axes (because each CTD cast takes finite time), we found the detectable level of the vertical movement is about 15 cm.

Keywords: seafloor geodesy, GPS/acoustic observation, sound velocity, CTD measurements

Evaluation of the sound speed equations for seawater proposed by Chen-and-Millero and Del-Grosso using GPS/Acoustic observation data

*Chie Honsho[1], Motoyuki Kido[1], Fumiaki Tomita[2]

1. International Research Institute of Disaster Science, Tohoku University, 2. Graduate School of Science, Tohoku University

There are two widely accepted equations for the computation of the speed of sound in seawater: the Chen and Millero's (CM) equation (*Chen and Millero*, 1977), which is also known as the UNESCO equation, and the Del Grosso's (DG) equation (*Del Grosso*, 1974). They are polynomial functions of pressure, temperature, and salinity defined by 42 and 19 coefficients for the CM and DG equations, respectively. For typical ocean temperatures and salinities, the DG equation generally gives smaller values than the CM equation. Though the difference is small near the sea-surface, it becomes larger as the pressure (or depth) increases and reaches as much as 0.6 m/s at depths greater than 3000 m. The two equations are empirically deduced from laboratory measurements and then have been examined by actual measurements in the ocean (*Spiesberger and Metzger*, 1991a; 1991b; *Dushaw et al.*, 1993; *Meinen and Watts*, 1997). These studies reached the same conclusion that the DG equation is more accurate than the CM equation, though the accuracy of the DG was evaluated variously. In this study, we evaluated the two equations using GPS/Acoustic observation data that have been collected for the detection of seafloor crustal movements off the Tohoku region since 2012. Advantages of this study are a large number of traveltime data collected during repeated surveys and great water depths of the observation sites (mostly deeper than 3000 m), which is a preferable condition to distinguish differences between the CM and DG equations.

The data were collected during a total of 120 observation campaigns conducted at the 20 sites from 2012 to 2016. There is a triangle or square array in each site, which consists of 3–6 transponders settled on the seafloor. Two-way traveltimes between a transducer on a ship and the seafloor transponders were measured to an accuracy of 10 microseconds. The pulse transmission was executed at an interval of 30–60 seconds typically for ~15 hours during one campaign. The analysis was performed for each site, and the data of 3–8 campaigns which was devoted to one site were used together for an inversion procedure. Assuming that the array geometry is rigid among the campaigns, we determined the position of each transponder at the time of the first campaign and displacements of the array at the time of subsequent campaigns. In terms of the sound of speed, we first prepared a reference vertical profile for each campaign based on XBT, CTD, or XCTD measurements conducted in the campaign and converted either with the CM or DG equations. Then, assuming that the sound speed does not change in horizontal directions, time-variation of the sound-speed profile was modeled to vary at the same scale factor over all depths. Consequently, time-variations of the scale factor during each campaign were simultaneously obtained in the inversion as well as the array positions. The results with the CM equation showed that scale factors for the sound speed were significantly smaller than 1.0: time-averaged scale factors for all the campaigns have a mean of 0.9994 and a standard deviation of 0.0001, which corresponds to a correction for the reference sound-speed profiles as much as −0.9±0.2 m/s over all depths. With the DG equation, the mean scale factor of 0.9997±0.0001 was obtained, which corresponds to a correction of −0.5±0.2 m/s. It is closer to 1.0 than that with the CM equation, though it is still smaller than 1.0. Our result that smaller corrections were needed with the DG equation than the CM equation agrees with the results in the previous works, but the amounts of correction are larger than their estimates. Moreover,

when the DG equation was used the resulting scale factor had clear correlation with the depth of the sites: scale factors approach closer to 1.0 for campaigns conducted in deeper sites. This may indicate that errors in the DG equation occur in shallow parts rather than in deep parts.
* All references are in *J. Acoust. Soc. Am.*

Keywords: sound speed in seawater, GPS/Acoustic observation

Sea-level records analysis with empirical mode decomposition and its variations: Boundary effect improvement and mode reconstruction method

*Han Soo Lee[1]

1. Hiroshima University

Sea-level records analysis with empirical mode decomposition and its variations: Boundary effect improvement and mode reconstruction method

Han Soo Lee[1]

[1]Graduate School for International Development and Cooperation, Hiroshima University.
1-5-1 Kagamiyama, Higashi-Hiroshima 739-8529, Hiroshima, Japan

A common goal of most time-series analysis is to separate deterministic periodic oscillations in the data from random and aperiodic fluctuations associated with unresolved background noise (unwanted geophysical variability) or with instrument error. For many applications, the sea level records are treated as linear combinations of periodic or quasi-periodic components that are superimposed on a long-term trend and random high-frequency noise. The periodic components are assumed to have fixed or slowly varying amplitudes and phases over the length of the record. Fourier analysis is one of the most commonly used methods for identifying periodic components in near-stationary sea-level data. If the sea-level data are strongly non-stationary, then more localized transforms like Wavelet transform can be used. However, the sea-level is a naturally non-linear process and data with the non-linear interactions among the physical processes with different time scales causing sea-level changes.
Empirical Mode Decomposition (EMD) is an adaptive (data-driven) method to analyse non-stationary signals stemming from non-linear systems (Huang et al., 1998). It produces a local and fully data-driven separation of a signal in high and low frequency oscillations, called intrinsic mode functions (IMFs), and a monotonic trend (residual). Detailed information on EMD and EEMD are referred to Huang *et al.* (1998) and Wu and Huang (2009). The CEEMDAN is an important improvement of EEMD (Torres et al., 2011), achieving a negligible reconstruction error and solving the problem of different number of modes for different ensemble numbers with signal plus noise. The improved CEEMDAN is a further improvement of CEEMDAN for solving the problem of residual noise in modes and spurious modes (Colominas et al., 2014). For the sake of paper length, readers refer to the relevant literature above for detailed algorithms of EMD and its variations. For applications of EEMD, refer to Lee *et al.* (2012).
In this study, we illustrate two improvements in the signal decomposing and analysis process of EMD; the boundary effect and reconstruction method for decomposed intrinsic mode functions (IMFs). We use the mirror method for boundary effect and statistical significance test for reconstruction of IMFs to improve the statistical significance of each modes. The artificial signal test show that the proposed mirror method for boundary effect and the statistical significance test for reconstruction of IMFs improve the decomposing results dramatically compared to the original artificial signal components.

Keywords: empirical mode decomposition, boundary effect, mode reconstruction method, sea-level records

