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,

©2017. Japan Geoscience Union. All Right Reserved.

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

©2017. Japan Geoscience Union. All Right Reserved.