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Reconstructing Sound speed profiles worldwide with Sea surface data

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ABSTRACT

Sound Speed Profile (SSP) is the key factor affecting underwater acoustics and it is of great value to obtain SSP in near real-time. In this paper, the sea surface data were used to reconstruct the SSP with the single empirical orthogonal function regression (sEOF-r) method in a global scale. Argo floats data as well as the altimeter data and sea surface temperature (SST) in the year 2010–2013 were used to establish the regression dataset. Argo profiles worldwide were grouped into $2^\circ \times 2^\circ$ longitude/latitude grid cells. Then EOF vectors were obtained in each grid, and the regression coefficients for the vectors were obtained with the sea surface data. Analysis showed that SSP anomalies differ from place to place. An assumption was made that the difference was due to the dynamic eddy activity and the eddy kinetic energy (EKE) map was pictured. Results suggested that the two variables correlated with each other. The larger the EKE, the larger the SSP anomalies. However, compared to the absolute value of the SSP anomalies, the error estimation improvement ratio remained relatively stable in most places.

1. Introduction

Ocean acoustic propagation properties are highly correlated with the ocean environment. Many studies have been conducted on acoustic propagation in different parts of the world's oceans [1–10], and detailed ocean researches related to the Sound Speed Profile (SSP) have been made [11–16]. Given that the underwater acoustic propagation properties are highly correlated with the sound speed profile, it is of key value to obtain the sound speed field in real-time. Sound speed is a function of temperature, salinity and the static pressure of the immediate ocean water column, which could be calculated with the empirical sound speed formula [17]. Researches have shown that the temperature and salinity profile could be inferred from the sea surface field which could be obtained in real time, an assumption was made that the SSP field could also be reconstructed directly with the sea surface field.With the advantage of wide coverage and high resolution, the satellite has been a major method to observe the ocean. However, the satellite could only figure out the surface field of the ocean, while the subsurface field remains unknown. Thus, projecting the sea surface field downward into the ocean has been a hot topic for quite a time. Early studies suggest that the satellite altimeter signal mainly reflects the interior barotropic and first baroclinic modes. Stammer [18] suggests that the surface height deviations are linked to those of the thermocline. Wunsch [19] found that the barotropic and the first baroclinic modes constituted the largest part of the depth-averaged energy, while the first baroclinic mode dominated surface variability. Carnes et al [20] found the statistical relationship between steric heights (SH) and temperature at standard levels for a region in the Gulf Stream. Later, they determined the empirical orthogonal function (EOF) amplitudes as functions of both sea surface temperature (SST) and SH with the linear regression method in the northwest Pacific and northwest Atlantic Oceans [21], namely the sEOF-r method. The method has been adopted by the US Navy ocean forecast system [22]. Later efforts have been devoted in the method to propagate downward the surface info. Pascual and Gomis [23] proposed an approach to estimate vertical profiles without introducing statistical regression for the computation of the amplitudes. Bruno and Rosalia [24] proposed a multivariate method to couple temperature and steric height profiles, which allowed the reconstruction of both from a combination of SST and surface SH. By linking the surface density with the subsurface field via the surface quasigeostrophic (SQG) formalism, researchers now extrapolate subsurface velocity and density fields from SST and sea surface height (SSH) data [25–27]. Despite the extensive researches over reconstruction, few studies concern about the reconstruction performance in a global scale. But this issue matters due to the highly dynamical ocean environment worldwide.

In this paper, the SSP were reconstructed in a global scale with SST and altimeter data via the sEOF-r method. Given that ocean

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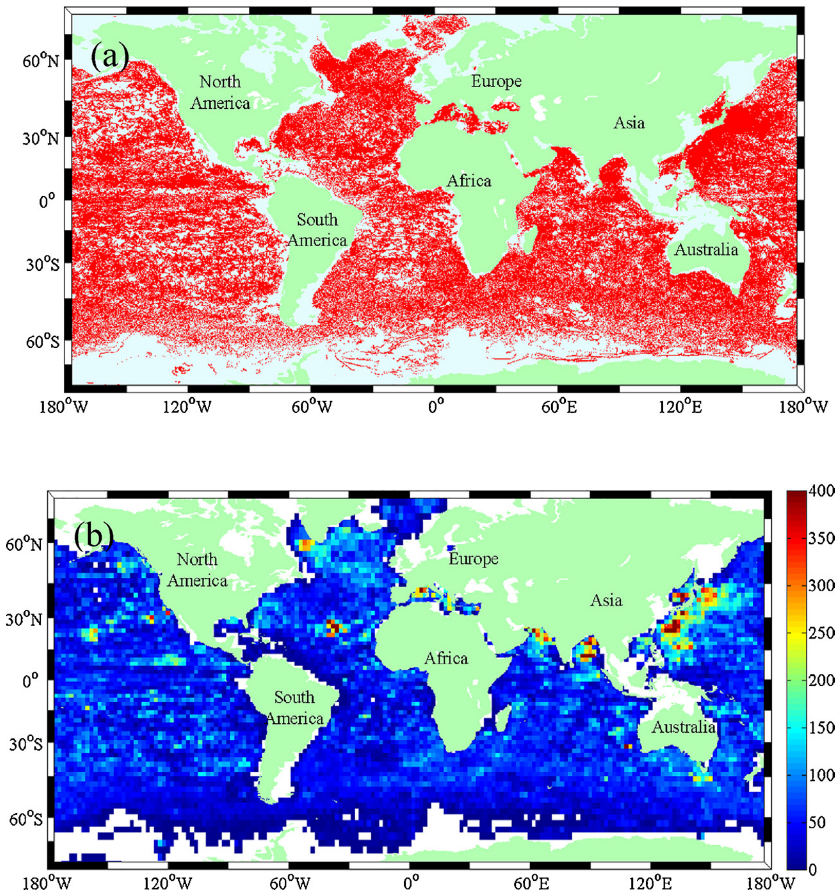

Fig. 1. (a) Argo distribution for the year 2010–2013 with a total about 479 000 profiles (b) Density of the Argo distribution (The colour refers to number of profiles in each $2^{\circ} \times 2^{\circ}$ grid cell).

environment differs from place to place worldwide, the performance of the reconstruction method might differ largely in different ocean areas. Argo profiles were used to provide the SSP fields. Since the Argo floats mainly distribute in the deep ocean, the shallow water was not included in this paper.

2. Data preparation

The regression database was to be established with the SSP subsurface and the sea surface data. Argo profiles were used to establish the SSP field subsurface. The sea surface data include the SLA data and the SST anomaly.

2.1. Argo data

The data from Argo floats consist of about 479,000 temperature and salinity (T/S) profiles in the upper 2000 m between years 2010 and 2013. Fig. 1(a) shows the Argo floats distribution over the years 2010–2013. Fig. 1(b) shows the density of the Argo profiles on the $2^{\circ} \times 2^{\circ}$ longitude/latitude grid, where the colors refer to the number of profiles in each grid. Fig. 1(b) suggests that the Argo floats were more densely distributed in the Northwestern Pacific Ocean, in the Northern Atlantic Ocean and in the north part of Indian Ocean.

Given that the SSP could be obtained via the empirical sound speed formula with the temperature profile and the salinity profile, and that the Argo floats measure the two profiles at the same time, the Argo profiles could provide SSP during each measurement. The SSP anomalies were obtained by removing the climatology profiles, which were obtained by interpolating WOA09 data to floats position.

2.2. Sea surface data

The altimeter data contain SSH and SLA products provided by Archiving, Validation, and interpretation of Satellite Oceanography data (AVISO). The data were daily data on a $0.25^{\circ} \times 0.25^{\circ}$ longitude/latitude grid. The SST data were NOAA 1/4° daily optimum interpolation sea surface temperature (or daily OISST) which uses satellite SSTs from AVHRR. Fig. 2(a) is the global map of the SLA field and Fig. 2(b) is the global map for SST on 3rd August in 2003. As shown in Fig. 2(a), the sea state remains relatively calm for the majority part of the ocean, while some areas show significant deviation from the average state.

To establish the regression database between the sea surface data and the SSP field, the SST anomaly field was necessary. Thus the average SST field of the years 2003 ~ 2013 were calculated and the average SST field was shown in Fig. 2(c). With the average SST field, the SST anomaly field each day was obtained. The average SST field shown in Fig. 2(c) was a spatially smooth one, while the SST field each day in Fig. 2(b) shows more regional details.

3. SSP reconstruction

Sound speed C (m/s) is a function of temperature T (°C), salinity S (‰) and the static pressure P (kg/cm²) of the immediate ocean water column, which yields the empirical formula:

$$C = 1449.22 + \Delta C_T + \Delta C_S + \Delta C_P + \Delta C_{STP} \qquad (1)$$

Here, $\Delta C_T = 4.6233T - 5.4585(10)^{-2}T^2 + 2.822(10)^{-4}T^3 - 5.07(10)^{-7}T^4$

$\Delta C_P = 1.60518(10)^{-1}P + 1.0279(10)^{-5}P^2 + 3.451(10)^{-9}P^3 - 3.503(10)^{-12}P^4$

$\Delta C_S = 1.391(S-35) - 7.8(10)^{-2}(S-35)^2$