Reconstruction of temperature and salinity profiles using vertically coupled temperature-salinity EOF modes incorporating eddy information

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1. Introduction

Reconstructing temperature and salinity structure in the ocean interior from sea surface parameters obtained from satellites and other sources is an important issue and is used in operational-based ocean data assimilation systems. Sea surface height (SSH) is the most important parameter in the estimation of internal structure because it is the integral information of water temperature and salinity. In this study, a method for reconstructing temperature and salinity profiles using vertically coupled temperature-salinity EOF modes that take into account eddy information was investigated using ARGO float data in the Northwestern Pacific Ocean.

2. Data

The ARGO float data used was provided by the University of Tokyo website (https://ocg.aori.u-tokyo.ac.jp/member/eoka/data/NPargodata/index-jp.html). (Oka et al., 2007). The period is from 2001 to 2019, and the area is the Northwest Pacific Ocean (120°E to 180° , 0°N to 60°N). The data was divided into 20 layers at up to 1100 m according to Fujii and Kamachi (2003), and the value at each depth was interpolated using the Akima method.

For the eddy information, the Mesoscale Eddy Trajectory Atlas Product provided by AVISO was used. The eddy amplitude and strength at the ARGO float observation point were calculated and used for analysis.

3. Sea area classification

3.1 Unsupervised classification of ARGO data

The normalized temperature and salinity anomalies were calculated from the average and the standard deviation of each layer. With reference to Guillaume et al. (2017), an unsupervised classification using a Gaussian mixture model (GMM) was applied on the anomaly profiles. Clustering was performed by setting the number of classes from 3 to 9. The results for classes 6 to 8 are shown in Fig. 1.

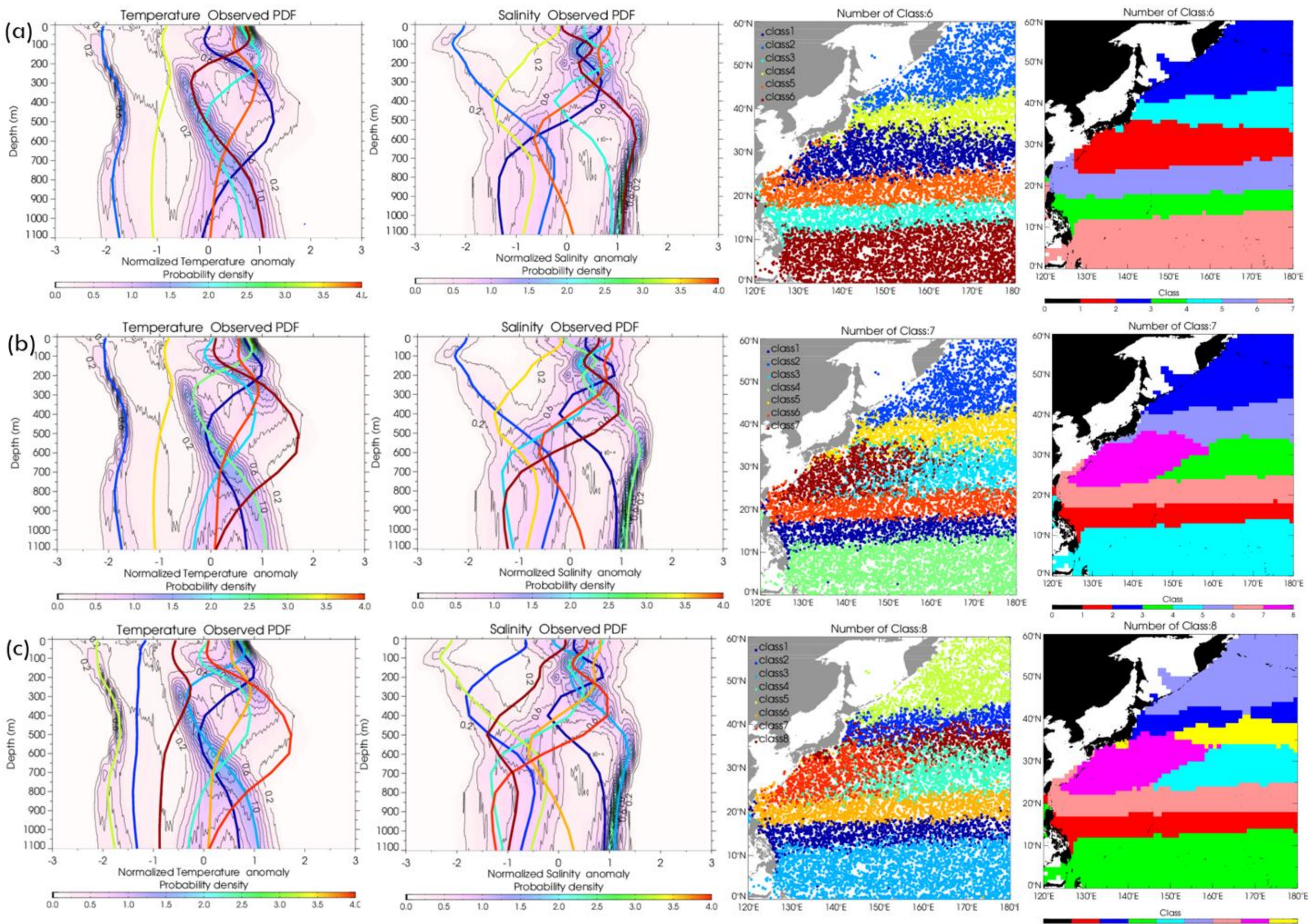

Fig. 1 Classification/clustering results for 6 to 8 classes. A diagram of the average profile of each GMM class superimposed on the probability density distribution of water temperature and salinity anomalies(left 2 figs.), a distribution map of the clustering results of the Argo data (third from the left), and Class mask calculated as the class with the highest frequency for each 1 degree grid (right fig.).

3.2 Determination of sea area classification by error analysis

With reference to Fujii and Kamachi (2003), temperature and salinity profiles were reconstructed from SSH and SST using the calculated EOF modes. The normalized errors decrease as the number of classes increases (Fig. 2(a)). The area classification with 7 classes was adopted in this analysis because it is consistent with the generally recognized water mass distribution and current systems. Figs. 2(b)-(d) show the RMS error profiles of temperature and salinity for each class, and the spatial distribution of the errors in the case of 7 classes. Table 1 shows the area and current systems corresponding to the 7 classes.

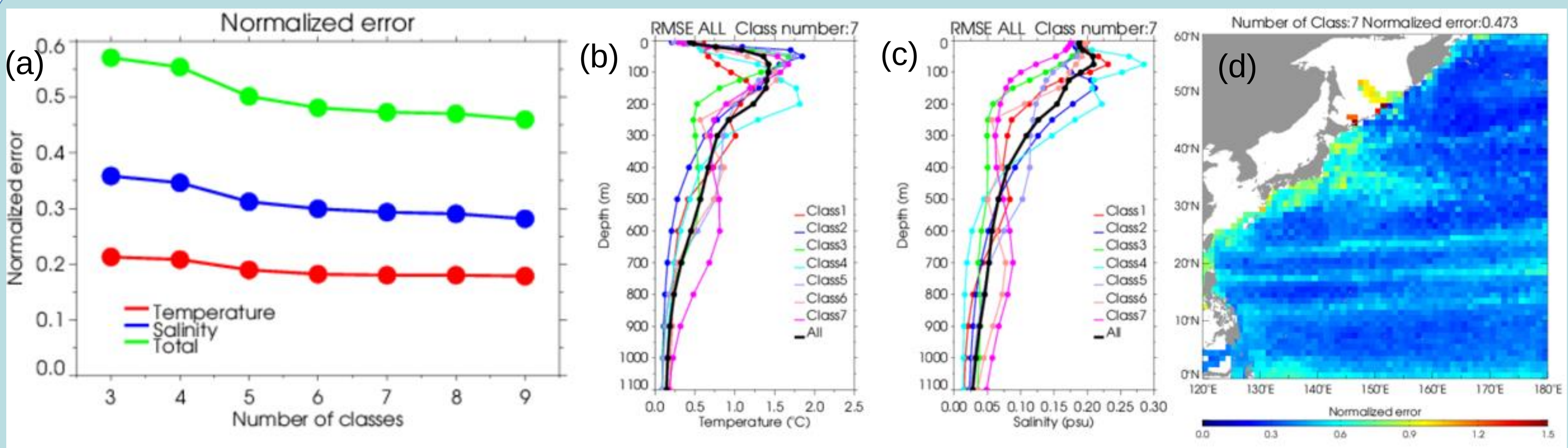

Fig. 2 (a) Normalized error as a function of number of classes, the RMS error profiles of (b) temperature and (c) salinity for each sea area, and (d) the spatial distribution of the errors in the case of 7 classes.

Table 1 Sea area and ocean current system corresponding to each class in the case of 7 classes (Fig.3).

Class1	Class2	Class3	Class4	Class5	Class6	Class7
North Equatorial Current	Subarctic	Subtropical	Tropical	Mixed Water Region	Subtropical Countercurrent	Kuroshio Recirculation
NEC	SAR	STR	TRO	MWR	SCC	KRC

4. Temperature and salinity reconstruction with eddy information

4.1 SSHa (Eddy)-related errors

Eddy amplitude and SSH anomaly (SSHa) from climatology were used as an indicator of eddy strength. Fig. 3 shows the RMS error profiles for the absolute value of SSHa. Classes 2, 5, and 7, which correspond to the subtropical to subarctic regions, exhibit the characteristic that the larger the SSHa, the larger the RMS error. Similar trend was obtained for eddy amplitude, but since the dependence on SSHa was clearer, the influence on SSHa was investigated below.

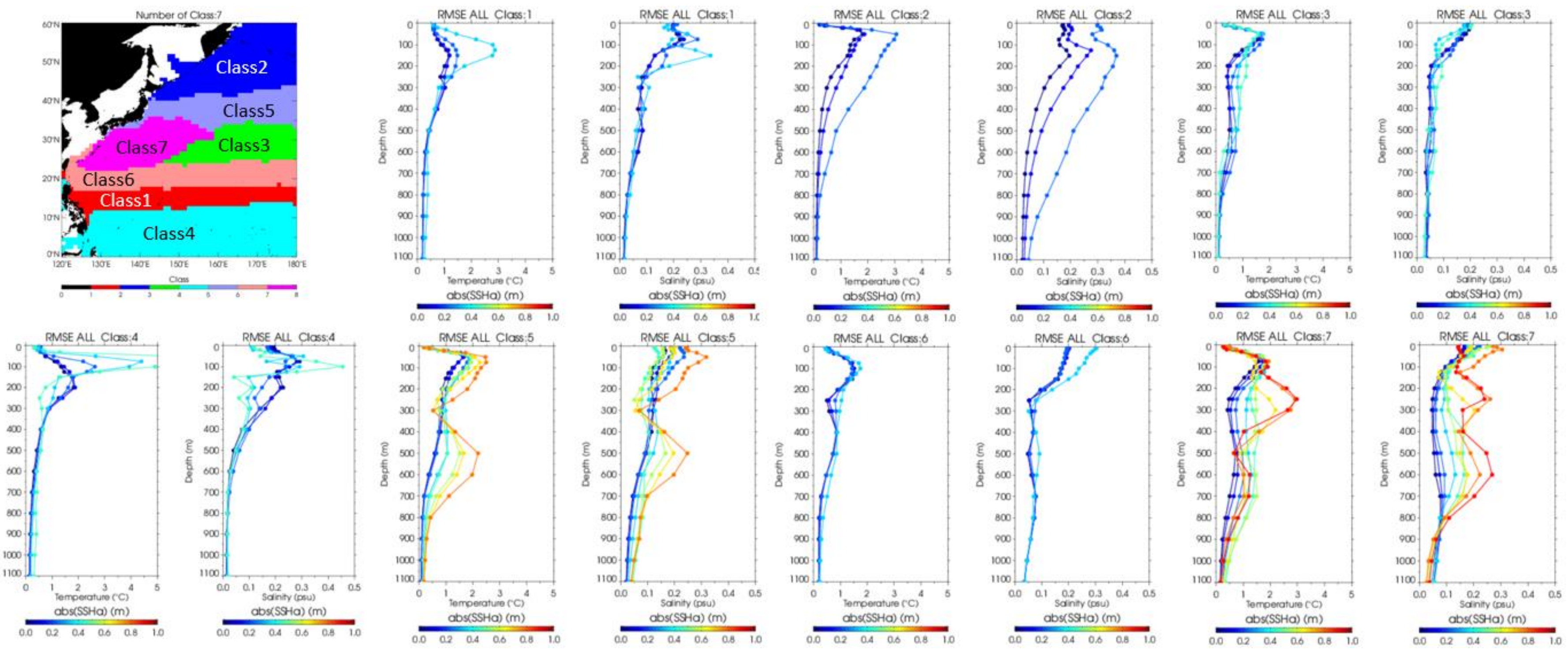

Fig. 3 RMS error profiles for the absolute value of SSHa.

4.2 Reconstruction method using density gradient

As a result of investigating the correlation between SSHa and density gradient anomalies (DGa) in each layer, there is a correlation between DGa at depths of 600 m to 1100 m and SSHa, especially in the above classes 2, 5, and 7 (Figs. 4). The approximate curves shown by the black line in Figs. 4 were defined as a linear function of DGa. The obtained relationship corresponds to the fact that an anticyclonic eddy has a downwardly structure, and the pycnocline is pushed down and the density gradient becomes larger between 600 m and 1000 m.

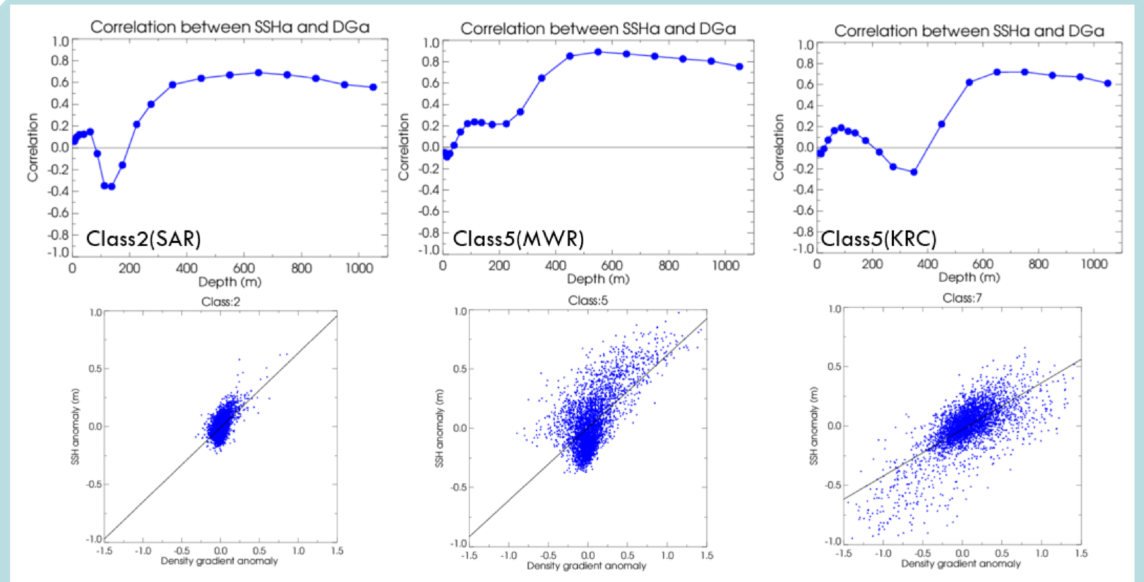

Fig. 4 (upper) Correlation between SSHa and DGa at each layer and (lower) Scatter plots of DGa averaged from 600m to 1100m and SSHa.

As a detection method using density gradient, a term of SSHa is added to the cost function.

$$J = \frac{1}{2}(x - x_f)^T B^{-1}(x - x_f) + \frac{1}{2}(Hx - x_o)^T R^{-1}(Hx - x_o) + \frac{1}{2r_h^2}[h(x) - h_o] + \frac{1}{2r_h^2}[SSHa(DG(x)) - SSHa_o]$$

Here, SSHa() is the operator for calculating SSHa from DGa, DG() is the DGa calculation operator from the state vector, and $SSHa_o$ is the observed SSHa. Fig. 5 shows the comparison of reconstructing temperature and salinity sections by hydrographic observation in Class 7 (KRC) waters using the density gradient method.

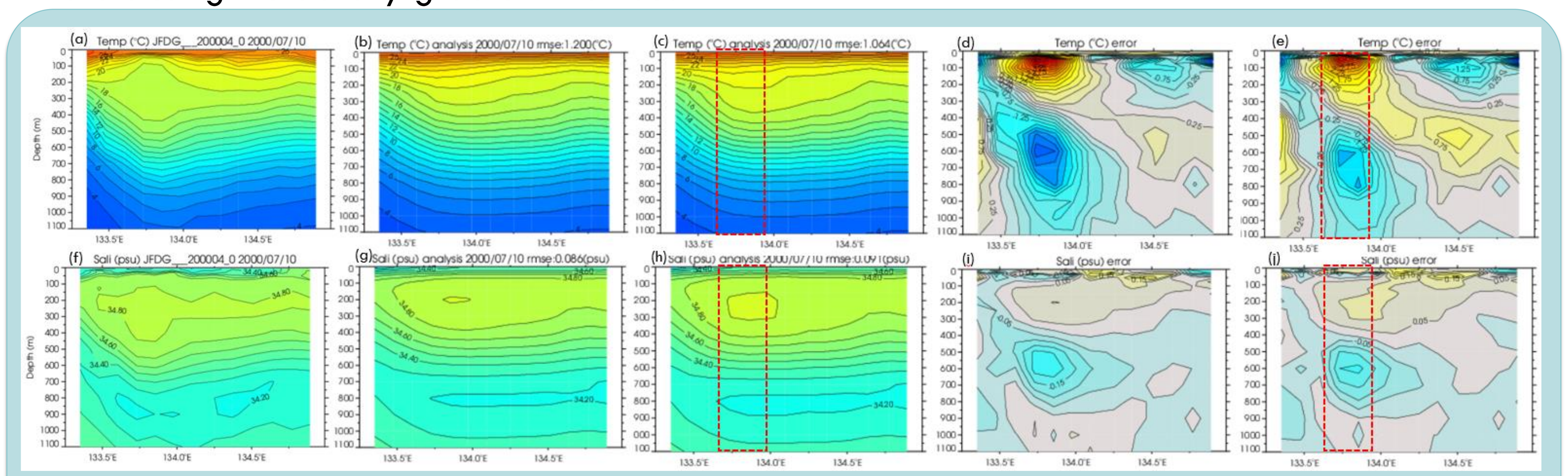

Fig. 5 (a) temperature, (f) salinity observation data, (b)(g) reconstruction using conventional method, (c)(h) reconstruction using a method that adds a density gradient term, (d)(i) errors by conventional method, and (e)(j) errors by the density gradient method.

The temperature analysis (Fig.5(c)) more clearly show the downward convex structure associated with anticyclonic eddies, closer to ship observation (Fig.5(a)). On the other hand, the lens-shaped convex structure in the subsurface layer (100m to 200m) has not been reproduced. Although the ARGO float data were similarly reconstructed using the density gradient method. no major improvement was confirmed except some cases.

5. Summary and next step

Northwestern Pacific was classified 7 areas using unsupervised classification from ARGO float data, and temperature and salinity were reconstructed using the EOF mode for each area. The dependence of errors on eddy activity (SSHa) was confirmed, and a reconstruction method using density gradients was proposed. While there were cases where the water mass structure related to eddies was improved, no significant improvement was observed in the overall error statistics. In the current method, SSHa, one-dimensional information on the sea surface, was used. By incorporating 2D SSH by SWOT and applying it to the cost function, it is thought that reconstruction that more closely reflects the real stratification structure will be possible.

Acknowledgment

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References

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