Reproduction of thermohaline fields with the NEMO model assimilating ARGO data and ocean surface temperature using Kalman ensemble filter and 3D-Var method

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Introduction

Stepanov et al, 2021 presented an analysis of the test results of assimilation of various synthetic hydrological data using the LETKF filter (a Local Ensemble Transform Kalman Filter), included through the PDAF system (Parallel Data Assimilation Framework, Nerger et al., 2005, http://pdaf.awi.de) in the NEMO model (Nucleus for European Models of the Ocean) version 4, Madec, 2016). It was shown that the joint assimilation of vertical distributions of water temperature (*T*) and salinity (*S*) significantly improves the quality of reproduction of both these model fields and the level surface field, and such assimilation is more preferable in comparison with the assimilation of surface data alone, in particular, with the assimilation of the sea level surface.

The paper briefly describes the results of reproducing the thermohaline fields of the World Ocean with this version of NEMO model using two different oceanographic data assimilation systems (ODAS). The first system is based on the three-dimensional variation scheme 3D-Var, and the second one uses the ensemble Kalman filter LETKF with horizontal localization. The data of Argo floats (http://www.usgodae.org/argo/argo. html) and sea surface temperature (SST) data (NCEP Climate Data Assimilation System, https://www.ncdc.noaa.gov/data-access/model-data/model-datasets/climate-forecast-system-version2-cfsv2, hereinafter, CDAS) were assimilated in both ODAS.

Numerical experiments

Three experiments simulating the ocean-sea ice system were carried out with the same model parameters and the same atmospheric forcing data from the DFS5.2 set (Dussin et al., 2016). In the first experiment (hereinafter, the FREE experiment), no any data assimilated, in the other two, the profiles of water *T* and *S* from ARGO data are assimilated using the 3D-Var and LETKF methods (respectively, the ASSIM1 and ASSIM2 experiments). Two additional experiments assimilating ARGO data together with SST data were also carried out (ASSIM1F and ASSIM2F experiments).

In the FREE experiment, the integration started from the resting state with initial conditions for *T* and *S* of water for January from the WOA13 climatology. After spin up during 01.01.2001–31.12.2006 with atmospheric forcings DFS5.2 the integration of NEMO was continued over the time interval 01.01.2007–31.12.2014.

In the ASSIM1 and ASSIM1F experiments, the model integration was carried out over the time interval 2007–2014, starting from an initial state of rest with January climate distributions of ocean water *T* and *S* from the WOA13 atlas. The model distribution of ice cover characteristics derived in the FREE experiment by the end of December 2007 was used as initial conditions for all experiments with assimilation.

To initialize the calculations in ASSIM2 and ASSIM2F, an ensemble of 20 members was created. Each state vector field is created by adding stochastic noise (different for each ensemble member) to the initial fields. The initial fields for ocean *T* and *S* correspond to the January climate distributions from the WOA13 atlas and the other fields correspond to the state of rest. Stochastic components depending on longitude and latitude are determined according to Seidov and Marushkevich, 1988. For subsequent integration of NEMO model the first approximation ensemble is represented by the sum of the stochastic noise (different for each member of the ensemble at each step of the analysis) and the result of integrating the model equations for each of the 20 ensemble members. The assimilation window in these experiments was assumed to be 2 days.

Results

For all experiments, vertical distributions of deviations of model *T* and *S* values from Argo data were calculated and then averaged over the entire global region for the period 2010-2014. The maximum differences in model water temperature for all the Argo data experiments with assimilation are observed in the upper ~250 m layer: the temperature difference is ~0.1°C at depths of about 100–150 m, which is less than in the FREE experiment. Deeper than ~250 m, the differences in model temperature from the Argo data with assimilation experiments are approximately the same and significantly less than in the FREE experiment.

The maximum differences of model *S* from Argo for ASSIM1 and ASSIM2 are also seen in the upper ~250 m layer (~0.01 psu): the calculated salinity is less than the Argo data. For the FREE experiment, these differences are significantly larger: on the surface the model ocean is more salty (by more than 0.1 psu) and it is on average ~0.2 psu more salty than the Argo data deeper than 250 m.

Figure 1 shows the distributions of SST deviations from the CDAS data in the ASSIM1 (a, b) and ASSIM2 (c, d) experiments averaged over March and September 2010–2014. Both experiments with Argo assimilation reproduce the SST better than the calculation without Argo assimilation (Fig. 1 e, f). As can be seen from this figure, the SST in ASSIM2 in the open ocean (especially in the latitudinal zone from 40°S to 40°N) is better reproduced than in ASSIM1. The joint assimilation of the SST and *T* and *S* profiles further improves the simulated field of the SST (not shown) and does not significantly change the distribution of *T* and *S* with depth compared to ASSIM1 and ASSIM2.

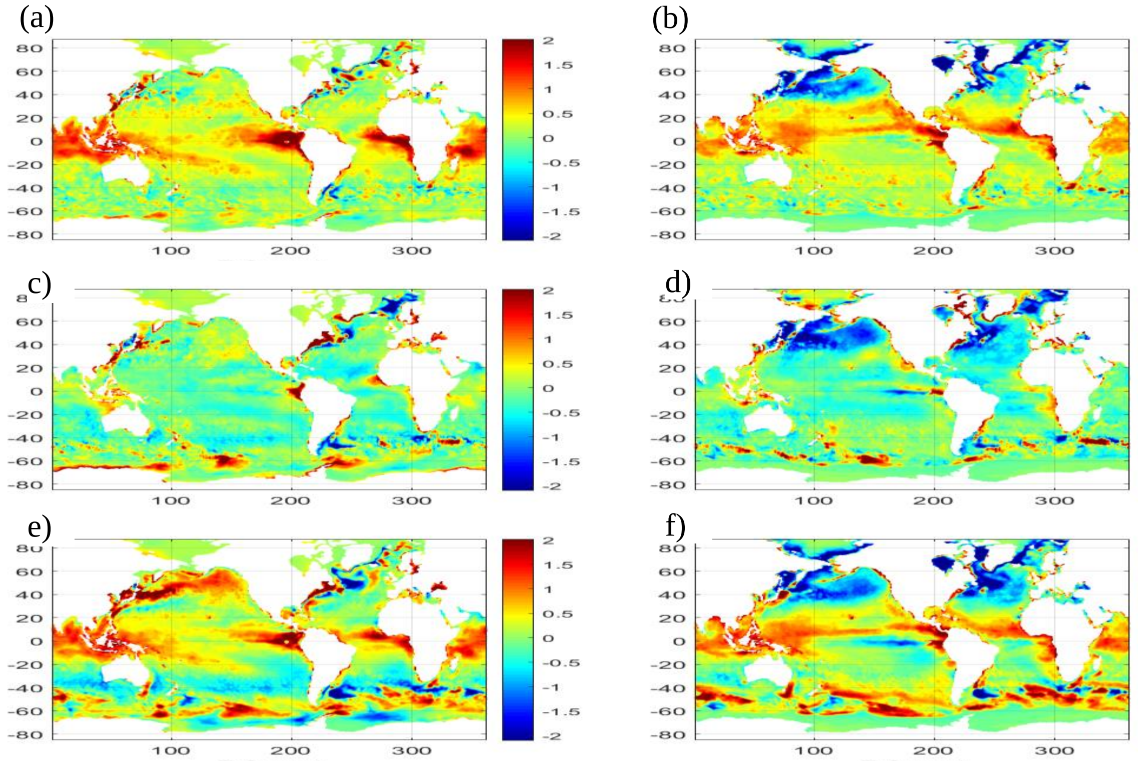

Fig. 1. Average deviations of SST from CDAS data in the ASSIM1 (a, b), ASSIM2 (c, d) and FREE (e, f) experiments in March (a, c, e) and September (b, d, f) for the period 2010–2014.

Summary

Comparing of the model results with the observational data, we can concluded that the assimilation of Argo data using two different assimilation systems yields comparable results for model *T* and *S* profiles. However, the use of an assimilation system using the ensemble Kalman filter significantly simplifies the transition from coarse to finer spatial model resolution.

It is worth noting that the implementation of ensemble Kalman filter is advantageous for reproducing the open ocean SST on a coarse computational grid compared to 3D-Var method.

References

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