Improved Analysis Fields in the Arctic Ocean with the Meteorological Research Institute Data Assimilation System (MOVE).

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1. Introduction

Recently, a sea ice retreat has been observed and the atmosphere-ocean-sea ice system has possibly entered upon a changing phase in the Arctic Ocean. It is also assumed that the variation in the Arctic Ocean influences the midlatitudes. Preparing for the study on the Arctic Ocean-midlatitude climate using an atmosphere-ocean-sea ice coupled model-assimilation system, the Multivariate Ocean Variational Estimation (MOVE) system for the global ocean, developed in MRI, has been improved in order to better describe the seasonal to interannual variability in the Arctic Ocean. In this study, the reproduction of the ocean and the sea ice fields by the MOVE system is investigated focusing on the Arctic Ocean.

2. Ocean data assimilation system in MRI: MOVE/MRI.COM-G2

Ocean general circulation model: MRI.COM (Tsujino et al., 2011)

- Sea ice model: thermodynamics, dynamics, EVP rheology, 5-category ice + snow
- Horizontally 364×394 grids, tri-polar coordinate (Fig. 1)
- Vertically 52 levels + BBL, σ-z hybrid coordinate, $\Delta z_1 \sim 2$ m
- Surface forcing from JCDAS (JRA25 follow on) daily data, use of bulk formula

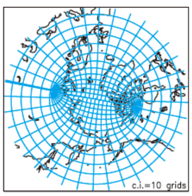

Fig. 1. Model grids on a stereographic projection from the north pole.

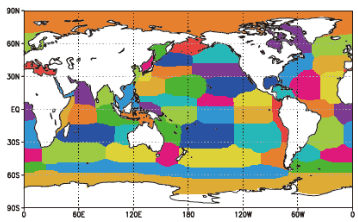

Fig. 2. Distribution of the areas defined for the T-S coupled EOF modes.

Ocean data assimilation scheme: MOVE (Fujii and Kamachi, 2003; Usui et al., 2006)

- Observational data: satellite altimetery data, SST, temperature and salinity profile data
- Analysis fields by 3DVAR based on the vertical temperature-salinity coupled EOF modes
- EOF modes: areas updated (Fig. 2); overlapping of the areas is allowed; use of monthly values
- Assimilation using the incremental analysis updates method (Bloom et al., 1996)
- Cost Function: $J=\frac{1}{2}\mathbf{w}^T\mathbf{B}^{-1}\mathbf{w}+\frac{1}{2}(\mathcal{H}(\mathbf{w})-\mathbf{y})^T\mathbf{R}^{-1}(\mathcal{H}(\mathbf{w})-\mathbf{y})+\alpha$
  $\mathbf{w}$: amplitudes of the T-S coupled EOF modes for the correction

Experiments

- Simulation experiment without assimilation for spinup and during the 1979-2008 period (SIM)
- TS assimilation experiment during the 2001-2008 period (TS-Assim) with an initial condition from the simulation run; the assimilation window of 1 month
- In addition, restoring experiments to the sea ice concentration (SIC) data based on the SSM/I observation (in which time scales for the restoring are 1, 5, 10, 30 days) (TS+Ice-Assim) and the following simulation experiments as initialized by the assimilation (TS+Ice-Ini)

3. Results

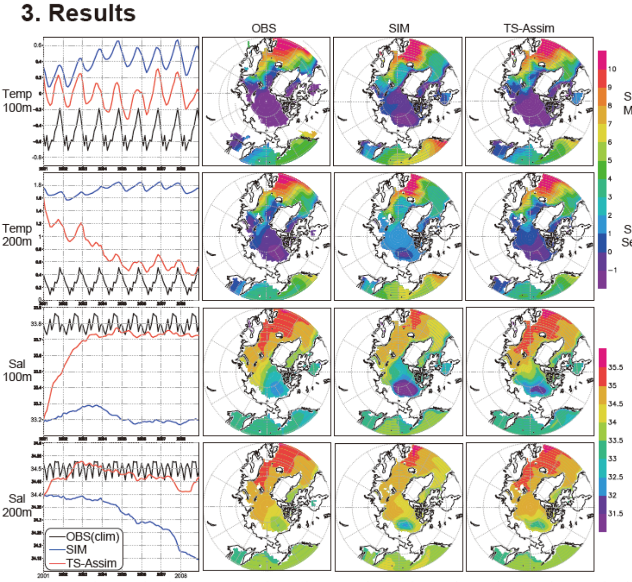

Fig. 3. Temperature/salinity in the 100/200 m depth from the observational data (climatology), the simulation run without assimilation, and the TS assimilation run. Observational distributions are from PHC 3.0 (Steele et al., 2001). Time series are averaged over 70-90°N. Distributions from our result are averaged over the period between 2003 and 2008.

- During 2001-2002 approximately, TS in the Arctic Ocean surface layer are improved by the assimilation due mainly to a realistic TS reproduction in the subarctic region (Fig. 3). (This improvement is extended via waves.)
- The improvement in the surface-layer temperature leads to a better description of sea ice area (Fig. 4), especially in summer from 2002 (Fig. 5), which in turn results in the further improvement of temperature during 2003-2004 (Fig. 3).
- A low salinity bias remained in the Pacific sector (Fig. 3) is similar to that often reported in coarse resolution models (Steiner et al., 2004).
- A decrease of the 200-m salinity in summer of 2007 (Fig. 3) is from the Pacific sector (not shown), possibly associated with the prominent sea ice decrease.

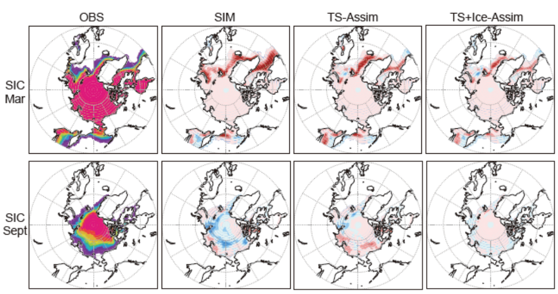

Fig. 4. SIC distributions in March and September of observational data (MGDSST/Japan GHRSST) and biases of our results in the simulation run, the TS assimilation run, and the assimilation run of TS and sea ice (10-day scale restoring), averaged over the 2001-2008 period.

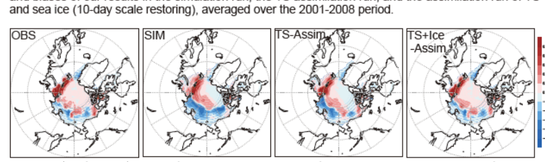

Fig. 6. Distributions of the SIC interannual anomalies in September 2003 (as an example of interannual variavility), from the 2001-2008 monthly mean fields.

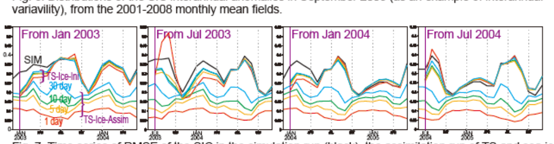

Fig. 7. Time series of RMSE of the SIC in the simulation run (black), the assimilation run of TS and sea ice, and the initialized run by the assimilation (color). Each color denotes the time scale of the SIC restoring.

- In addition to the basic annual march, both the decreasing trend and the interannual variability (e.g., minimum in 2007) in the sea ice distribution is generally reproduced even by surface forcing only (SIM; Figs. 5, 6).
- The TS assimilation and the SIC restoring both lead to further improvement (Figs. 4-6).
- The initialized runs by the TS and SIC assimilation show an initial shock effect especially in the case with a short time scale for the SIC restoration (Fig. 7). Seasonality seems to exist for the magnitude of this effect.
- Nevertheless, the RMSEs are lower in the initialized run than in the simulation run during several months.
- The assimilation of TS and SIC also affects the sea ice thickness (Fig. 8).

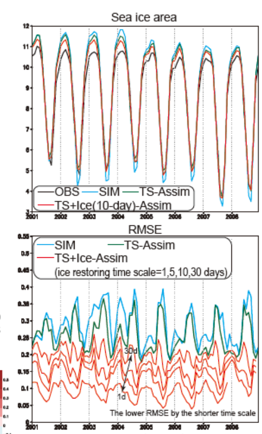

Fig. 5. Time series of the Arctic sea ice area (65-90°N; in 10^6 km^2) and RMSE of the SIC.

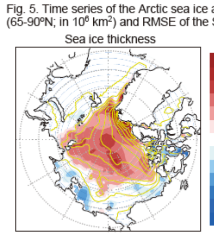

Fig. 8. Distribution of the sea ice thickness in September averaged over the period between 2001-2008 from the assimilation run of TS and sea ice (contour; 40 cm intervals) and its anomaly from the simulation run (shade; in cm).

4. Summary and discussion

The reproduction of the improved MOVE system has been investigated in the Arctic Ocean. In addition to the basic reproduction by the simulation run without assimilation in the seasonal to interannual variability, the analysis fields by the assimilation show more realistic reproduction due to the improved subarctic water and sea ice distribution. Targetting on the sea ice initialization, the restoring experiments to the SIC data have also been performed. The initialization by the SIC restoration improves the sea ice distribution for several month. However, an initial shock effect produced particularly in the case with a short restoring time scale suggests that a more sophisticated method for the data assimilation of the sea ice data is required, although the shock effect is likely to be smaller in a coupled simulation where the surface air temperature changes in response to the ice top temperature.