Coupled Ocean and Atmosphere Simulation by Assimilating Ocean Observation Data to a Coupled Model

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INTRODUCTION

We developed a data assimilation system in which ocean observation data is assimilated to a Coupled atmosphere-ocean General Circulation Model (CGCM), i.e, "quasi coupled data assimilation system". The system is called MOVE-C here. We expect that MOVE-C is suitable for analyzing the climate variability because it explicitly calculates the interaction between the atmosphere and ocean. The initial conditions of the atmosphere and ocean for the coupled model is prepared separately by using non-coupled atmosphere and ocean data assimilation systems in current seasonal forecasting, and it is often pointed out that inconsistency between those initial conditions can degrade the forecast skill. There is a possibility that the seasonal forecasting is improved by using the coupled atmosphere-ocean analysis as the initial condition. It also enables us to make an ocean analysis which does not depend on any atmospheric reanalysis data and, therefore, is not affected by its errors.

We conducted a reanalysis experiment using this system and examined what is improved on the AMIP Run, a simulation run of the atmosphere model used in MOVE-C in which observed monthly Sea Surface Temperature (SST) is employed as the ocean boundary condition. The monsoon variability is better reproduced in the MOVE-C reanalysis (MOVE-C RA), which results in the improvement of the atmospheric fields, particularly, precipitation in the equatorial Pacific and Indian Oceans. The improvement demonstrates the importance of calculating ocean processes in the couple model for reproducing the climate variability.

In the rest of this manuscript, we introduce what MOVE-C improves on the AMIP Run. The system configuration of the MOVE-C is concisely described in the next section. The MOVE-C RA is compared with the AMIP Run in the third section. This study is summarized in the last section.

System configuration of MOVE-C

MOVE-C is a system in which ocean observation data is assimilated to a CGCM using a global ocean data assimilation scheme. The CGCM used in MOVE-C is a JMA/MRI-CGCM (Yasuda et al. 2007). It is operationally used for the ENSO forecast from March 2008 in JMA. The atmospheric component is a General Circulation Model (GCM) used in JMA (Onogi et al., 2007) with the resolution of TL95/L40. The horizontal resolution corresponds to about 180 km. The ocean component is MRI.COM, a multi-level GCM developed in MRI (Tsujino and Yasuda 2004, Ishikawa et al. 2005). It has a global domain within 75°S-75°N and 50 levels. The grid spacing in the zonal direction is 1° and that in the meridional direction is 0.3° within 5°S-5°N and 1° poleward of 15°S and 15°N.

The ocean data assimilation scheme is that used in MOVE/MRI.COM-G (Usui et al. 2006) which is also operationally used from March 2008 in JMA for monitoring of the equatorial Pacific and providing JMA/MRI-CGCM with ocean initial condition. In the scheme, temperature and salinity fields are analyzed by a multivariate 3-dimensional variational method using coupled temperature-salinity empirical orthogonal functional decomposition (Fujii and Kamachi 2003). In situ temperature and salinity profiles, satellite altimetry data, and COBE-SST (observation-based SST data in JMA, Ishii et al. 2005) are used in the analysis. The result is reflected in the model field through incremental analysis updates (Bloom et al. 1996).

The MOVE-C reanalysis (MOVE-C RA) is conducted for the period of 1992-2006. We also performed the AMIP Run, a simulation run of the atmosphere GCM used in MOVE-C. Monthly data of COBE-SST is employed as the ocean boundary condition in the AMIP Run.

Comparison between MOVE-C RA and the AMIP Run

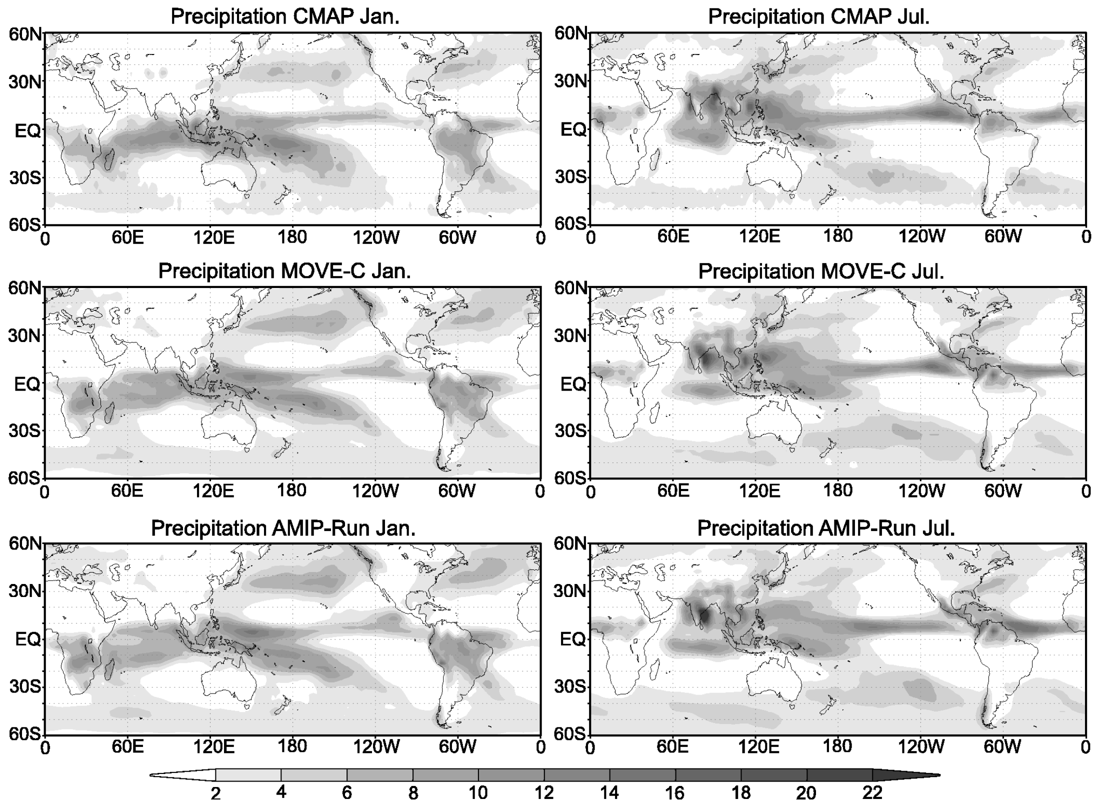

Figure 1 Global distribution of monthly mean precipitation (mm/day) in CMAP (top), MOVE-C RA (middle), and the AMIP Run (bottom). Left: January. Right: July.

First, we show the distribution of monthly mean precipitation in MOVE-C RA and the AMIP Run, as well as that in CMAP, an observation-based precipitation data (Xie and Arkin 1997), in Figure 1. In July, the AMIP Run has a too strong peak north of New Guinea and underestimates in the South Pacific Convergence Zone and the equatorial Indian Ocean. These defects are improved in MOVE-C RA. The overestimates in African continent and North Atlantic in the AMIP Run are also suppressed in MOVE-C RA. In July, the precipitation is considerably overestimated east of India and underestimated around Philippine in the AMIP Run. The overestimate east of India is mitigated and precipitation around Philippine increases in MOVE-C RA. The position of the peak in Intertropical Convergence Zone in MOVE-C RA is also much closer to that in CMAP. The overestimate in the equatorial Atlantic in the AMIP run is also suppressed in MOVE-C RA. MOVE-C thus improves the monthly mean precipitation fields on the AMIP Run.

Time series of monthly mean precipitation east of Philippine is plotted in Figure 2. From this figure, we find that MOVE-C improves variability of precipitation in this area on the AMIP Run. Particularly, the large precipitation in boreal summer is fairly underestimated in the AMIP run, but is reproduced better in MOVE-C RA. The minimums in the boreal winters in 1992 and 1998 in MOVE-C RA are also closer to CMAP. The root mean square difference between MOVE-C RA (the AMIP Run) and CMAP is 2.28 (3.00) mm/day, that is, MOVE-C RA has a smaller error in average.

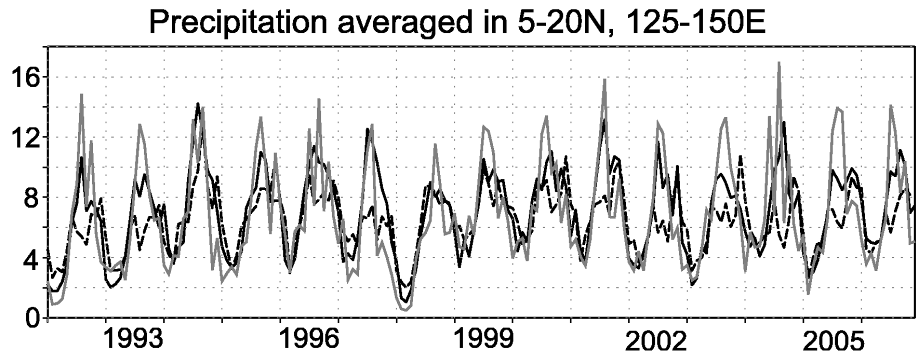

Figure 2 Time series of monthly mean precipitation (mm/day) averaged in 5-20°N, 125-150°E. Gray solid line: CMAP. Black solid line: MOVE-C RA. Black dashed line: AMIP Run.

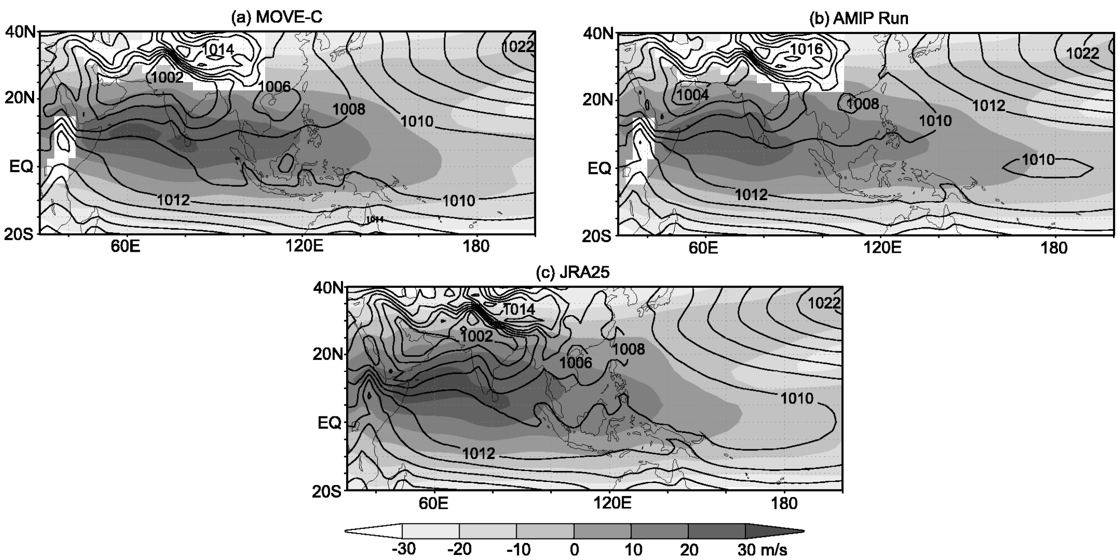

Figure 3 Distributions of monthly mean SLP (hPa, contour) and monthly mean vertical shear (850 hPa – 200 hPa) of zonal winds in July (m/s, shaded). (a) MOVE-C RA. (b) AMIP Run. (c) JRA25.

Actually, the improvement of summer precipitation east of Philippine in MOVE-C RA reflects the increase of tropical cyclones in the western tropical Pacific, which is known from the daily Sea Level Pressure (SLP) and precipitation fields (figure not shown). Then, the increase of the tropical cyclone is associated with the improvement of the monsoon trough and the zonal Walker Circulation on the AMIP Run shown in Figure 3. In JRA25, an atmospheric reanalysis data in JMA (Onogi et al. 2007), a low pressure (< 1010 hPa) area associated with the monsoon trough is extended from Southeast Asia to the east of the date line. This feature is well reconstructed in MOVE-C RA. The low pressure area, however, retreats to around 140°E in the AMIP Run although the low pressure patch remains around date line. This difference means the monsoon trough in the AMIP Run is weaker than in JRA25 and MOVE-C RA. The AMIP Run therefore induces the lower number of tropical cyclone generations. Figure 3 also shows monthly mean vertical shear of zonal winds between 850 hPa and 200 hPa in July. This shear represents the strength of the zonal Walker Circulation (e.g., Wang et al. 2003). In the AMIP Run, the shear is larger over Indian Ocean and the maritime continent than in JRA25: the maximum of the shear is larger than 30m/s in JRA25, but is smaller than 30m/s in the AMIP Run, the area where the shear is more than 20m/s extends to 110°E in JRA25, but it retreats to 90°E in JRA25, and the area where the shear is larger than 10m/s over the maritime continent is narrower in the AMIP Run. These defeats are improved in MOVE-C RA: the maximum of the shear is more than 30m/s and the area where the shear is lager than 20m/s extends to 120°E although the shear is larger over the maritime continent in MOVE-C RA. The zonal Walker Circulation is, therefore, weak in the AMIP Run, but intensified and reconstructed more properly in MOVE-C RA. Then, the intensified circulation amplified the westerly wind in the western tropical Pacific and activates the monsoon trough in MOVE-C RA.

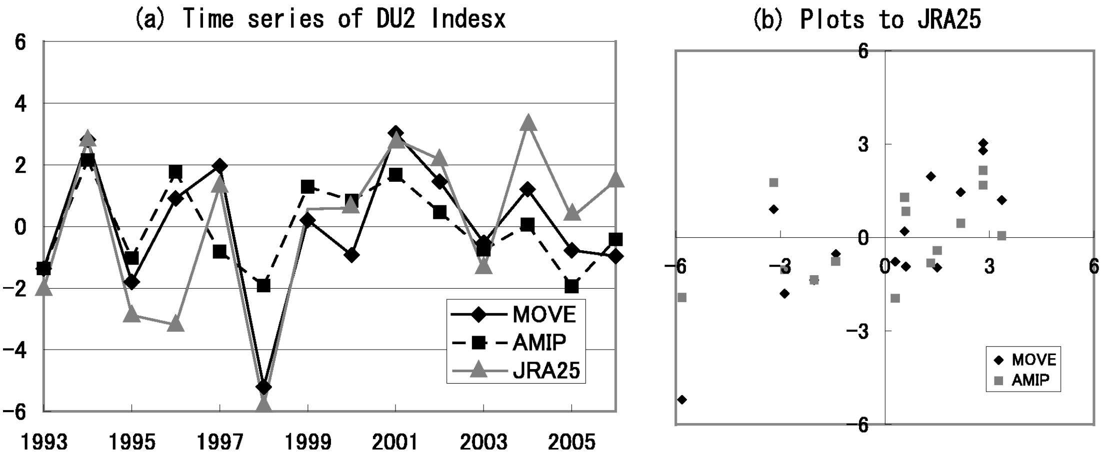

Figure 4 (a) Time series of DU2 index in MOVE-C RA (black solid line with diamonds), the AMIP Run (black dashed line with squares), and JRA25 (gray solid line with triangles). (b) Plots of DU2 index of MOVE-C RA (black diamonds) and the AMIP Run (gray squares) to that of JRA25.

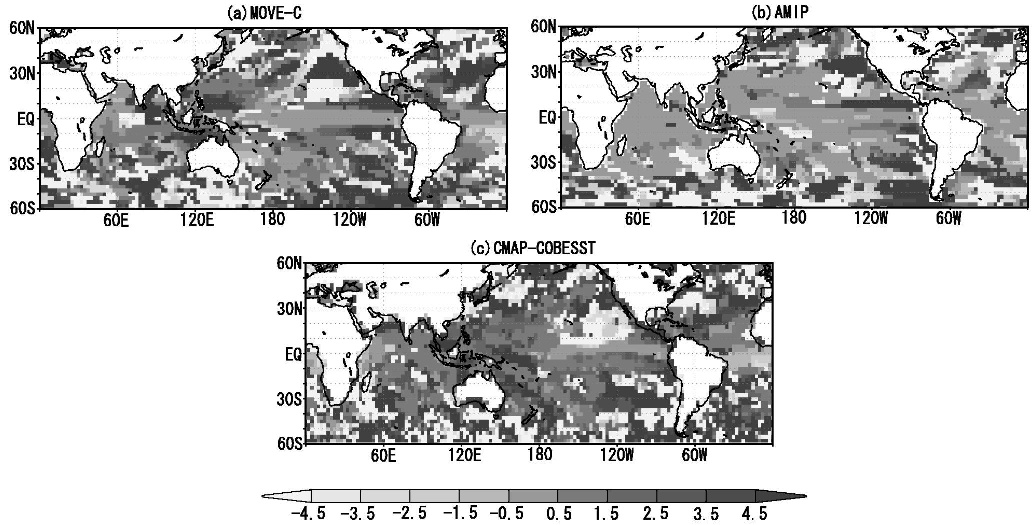

Figure 5 Maps of the time lag (month) that maximizes the correlation between SST and precipitation change. The positive value denotes that precipitation lags behind SST. MOVE-C RA and the AMIP Run are used in (a) and (b) respectively. The lag calculated from COBE-SST and CMAP is mapped in (c).

Improvement of the monsoon trough is also confirmed from the time series of DU2 index proposed by Wang and Fan (1999) (Figure 4). DU2 index is the anomaly of the difference between the monthly zonal winds averaged in 5-15°N, 90-130°E, and 22.5-32.5°N, 110-140°E from its mean in July, and represents how well the monsoon trough developed in the year. Interannual variation of DU2 index in the AMIP Run is much smaller than that in JRA25. This defeat is improved in MOVE-C RA. Particularly, the low value in 1998 in JRA25 is well estimated in MOVE-C-RA. The large values in 1994, 1997, 2001 are also recovered. The correlation of DU2 index between JRA25 and MOVE-C RA (the AMIP Run) is 0.796 (0.479). Interannual variation of the monsoon trough is, thus, improved in MOVE-C RA.

One reason for the improvement of the monsoon trough and zonal Walker Circulation is that the overestimates of precipitation east of India in the AMIP Run is suppressed by air sea interaction in MOVE-C RA. In the real world, high SST tends to activate convection, resulting in increasing precipitation in the tropical region. On the other hand, there also exists a negative feedback mechanism: increase of precipitation tends to cool SST by reducing short wave heating. This feedback has a role in adjusting precipitation. Then, the change of precipitation lags about one month behind SST because of this feedback in the tropical region as described in Arakawa and Kitoh (2004), and shown in Figure 5 (c). However, this negative feedback mechanism lacks in the non-coupled atmosphere model. Therefore, SST and precipitation is basically correlated with no lag as shown in Figure 5 (b), and the precipitation tends to be overestimated in high SST areas.

On the other hand, the negative feedback mechanism can be reestablished by the ocean model in MOVE-C although the effect might be reduced by the ocean data assimilation, particularly by assimilating SST data. Figure 5 (a) illustrates that, in MOVE-C RA, the one month lag of precipitation behind SST is better estimated than in the AMIP Run, which implies the negative feedback mechanism works in MOVE-C. This feedback suppresses the overestimate of precipitation east of India: the convective cloud cools SST by cutting sunshine and the cool SST deactivates the convection in turn. The reduction of the upward transport of the air mass by the convection east of India increases the lower westerly wind and intensifies the zonal Walker Circulation over the eastern part of the Indian Ocean and the maritime continent, resulting in the improvement of the monsoon trough.

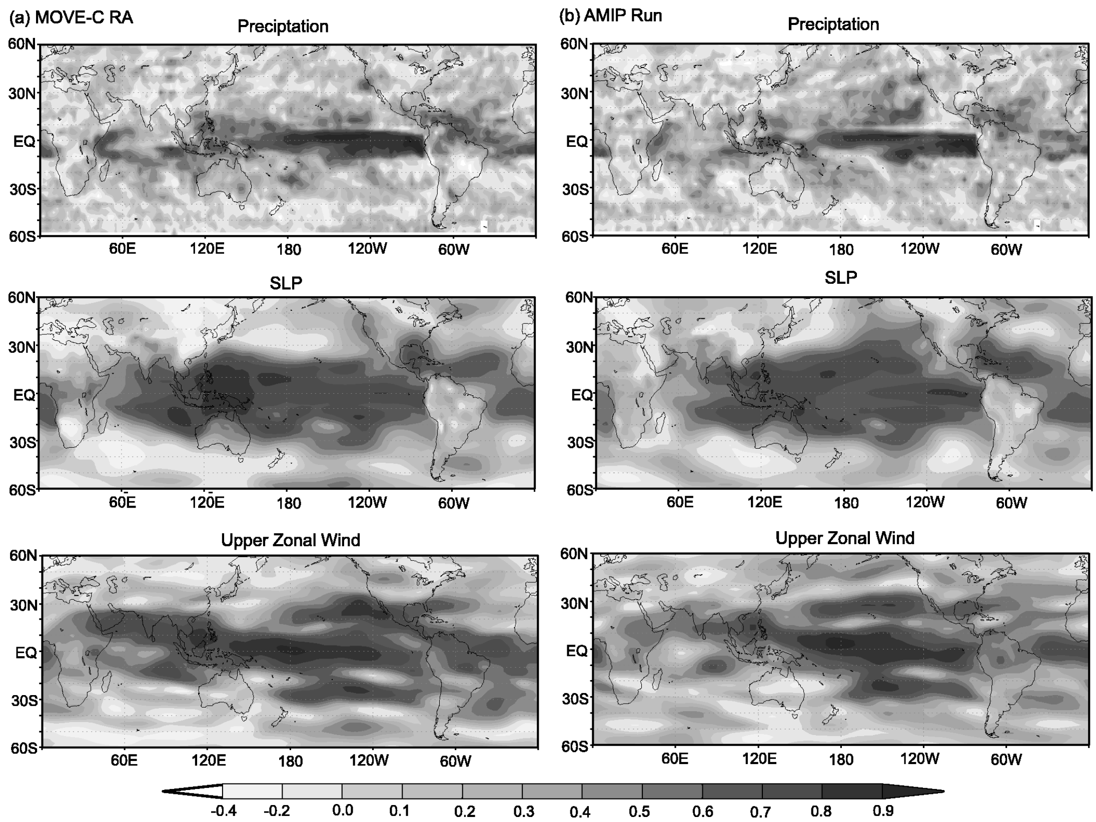

Figure 6 Maps of ACCs of precipitation (top), SLP (middle), and the upper zonal wind at 200 hPa (bottom) in (a) MOVE-C RA and (b) AMIP Run. The ACC of precipitation is calculated with CMAP. The ACCs of SLP and the upper zonal wind are calculated with those in JRA25.

Figure 6 shows maps of the Anomaly Correlation Coefficient (ACC) of precipitation, SLP, and the upper zonal wind at 200 hPa of MOVE-C RA and the AMIP Run. The ACC of precipitation is calculated with CMAP and others are calculated with JRA25. A 5-month running mean is applied to the monthly data before calculating ACC in order to remove intraseasonal variability. The ACC of precipitation shows that, in MOVE-C RA, not only the mean state but also the variability of precipitation in the tropical region is improved on the AMIP Run: the area where the ACC is larger than 0.5 is wider in the Indian, western Pacific, and Atlantic Oceans, and the area where the ACC is lager than 0.8 is extended in the eastern tropical Pacific. The ACC of SLP is also increased around the maritime continent: the area where the ACC is larger than 0.8 does not exist in the map of the AMIP Run, but the area extends in that of MOVE-C RA. Although the ACC of the upper zonal wind in the Pacific seems to be similar in average, the larger value in MOVE-C RA implies the better reproduction of the upper zonal wind in the tropical Indian Ocean, reflecting the improvement of the zonal Walker Circulation. Thus, in MOVE-C RA, atmospheric features are improved on the AMIP Run.

Summary

We developed MOVE-C, a data assimilation system in which ocean observation data is assimilated to a CGCM. The negative feedback mechanism in which the large precipitation decreases SST works in MOVE-C, which mitigates the overestimate of precipitation east of India, and improves the zonal Walker Circulation and the monsoon trough on the AMIP Run, a simulation run of the non-coupled atmosphere model with monthly observation-based SST data. This improvement leads better estimation of the precipitation, SLP, and zonal wind fields. Thus, assimilating ocean data to the coupled model is a potential way to reconstruct the climate variability.

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