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Tropical Indian Ocean simulation by NEMO Ocean model using the AGRIF nesting tool

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ABSTRACT

An effort is made to demonstrate performance of the Nucleus for European Modeling of the Ocean (NEMO) model for the Tropical Indian Ocean simulation around [65E-95E; 5S-20N] during 2002-2007. The NEMO is a primitive equation model adapted to regional and global ocean circulation problems. This model is intended to be a flexible tool for studying the ocean and its interactions with the other components of the earth climate system over a wide range of space and time. The model configuration is based on the ORCA tripolar grid. The refinement over the Indian Ocean is made using the AGRIF nesting tool. The horizontal resolution is taken as 1^o for the global simulation and 0.25^o for the tropical Indian Ocean (TIO) simulation using AGRIF. The vertical structure of the ocean is divided into 46 levels. The initial conditions of temperature and salinity are taken from the Levitus climatological data. The model is forced with monthly precipitation and runoff, daily downward shortwave and long wave radiation, 6-hourly zonal and meridional winds, specific humidity and air temperature. These forcing are derived from the Coordinated Ocean-sea Ice Reference Experiments (CORE.v2). Both the global and TIO runs are carried out simultaneously and the boundary conditions for the TIO run are derived

from the global run. The model simulated surface as well as sub-surface variables are compared with the available in-situ and satellite observations. It has been found that the model is able to realistically simulate the hydrography and circulation features over the TIO. The seasonal variability of the mixed layer depth is also studied.

Keywords: NEMO; AGRIF; TIO; hydrography; CORE.v2

1. INTRODUCTION

Oceans play a major role in the modulation of global climate. They are complex systems on the earth which are never at rest. The oceans have high heat holding capacity. The ocean currents help in maintaining circulation of water mass across the world oceans. The tropical Indian ocean (IO) builds the major portion of the largest warm pool on the earth and its interaction with the atmosphere plays a key role in the climate change on both the regional and global scales. The IO has a unique feature among the three tropical oceans due to seasonal reversal of upper ocean current and are quite different from the Atlantic and Pacific in a number of important ways. Large seasonal variations in the IO currents are mainly governed by the monsoonal winds, many of which display annual reversals, such as the southwest/northeast monsoon current and the Somali current south of India/Sri Lanka.

The Arabian Sea (AS) and the Bay of Bengal (BoB) are interesting tropical basins in the Indian ocean. The temperature and salinity over the AS and BoB are highly incoherent in nature, both in the horizontal (surface) and on the vertical (sub-surface) directions. Although both the AS and BoB are located at nearly the same latitude, but their water mass characteristics are quite different. The unique feature of the BoB is a large seasonal freshwater surplus, which makes the waters of the upper layers less saline and highly stratified. In general, the BoB receives about twice as much freshwater (approximately 80% from oceanic precipitation and 20% from continental runoff) as it evaporates back to the atmosphere (de Boyer Montegut, 2005). Similarly, the water properties in the Arabian sea are also influenced by the various processes. The runoffs from rivers like Periyar and Muvatupuzha, seasonally reversing currents, intrusion from the BoB, coastal upwelling etc. produces notable changes in the spatial and temporal variability of salinity and temperature over this AS region.

The BoB displays a very strong seasonal cycle in the sea surface salinity (SSS), particularly near the mouths of the Ganges-Brahmaputra and along the east coast of India (Akhil et al. 2014). The oceanic parameters like temperature, density and salinity are homogeneous due to well mixing process. They show a sudden change from their respective value at the surface at a particular depth thus creating a separation layer referred to as the mixed layer depth (MLD). The MLD in the BoB is associated with freshening due to the continental river runoffs (i.e. Ganga, Brahmaputra, Meghna, Mahanadi, and Godavari) as well as excess precipitation over the tropical Indian Ocean during summer. The BoB MLD is usually shallow and forms a barrier layer (Lukas and Lindstrom 1991; Sprintall and Tomczak 1992) which is often controlled by salinity stratification.

The TIO covering the AS and BoB is an interesting region of study. Several studies have already been carried out for understanding the TIO circulation and climate variability (Schott and McCreary 2001; Yamagata et al. 2004; Annamalai and Murtugudde 2004; Chang et al. 2006). We tried to realistically simulate the circulation and variability in the temperature and salinity of the region using an ocean circulation model, NEMO. Our study uses application of Adaptive Grid Refinement in Fortran (AGRIF) over the tropical IO to perform the simulation at an eddy permitting resolution. We give the detailed description on NEMO, its experimental design, the forcing files used, the initial and boundary conditions etc. in Section 2. Section 3 discusses the model simulation results for the seasonal variability of the surface hydrograpy (temperature and salinity) and mixed layer depth over the eastern AS and BoB. The conclusions are given in Section 4.

2. MODEL, DATA SETS AND EXPERIMENTAL DESIGN

NEMO version 3.4, which is used for the present analysis, is an updated version of the Nucleus for European Modelling of the Ocean (NEMO; Madec et al. 2012) ocean general circulation model (OGCM). The model has been extensively used for various modeling studies over different oceans (Barnier et al. 2006; Penduff et al. 2007, 2010). The model uses the tripolar ORCA grids. It has 46 levels in the vertical with partial cells parametrization for a better representation of the topographic floor. The model configuration has a global 1 degree resolution with a tropical refinement using AGRIF nesting tool over the Indian ocean. We use 1/4 degree eddy permitting resolution over the AS and BoB using AGRIF. The model is initialized with the temperature and salinity climatology of Levitus et al. (1998). The surface forcing data for the NEMO model integration is taken from Coordinated Ocean-sea ice Reference Experiment version 2 (CORE v.2) of Large and Yeager (2009). In this study, the model is integrated for 6 years (2002-2007) including one year of spinup run. The seasonal circulation and variability of model's surface variables is analysed during (i) winter monsoon (DJF: December-January-February) (ii) pre-monsoon (MAM: March-April-May) (iii) summer monsoon (JJA: June-July-August), and (iv) post- monsoon (SON: September-October-November) seasons over the AS and BoB. For the validation of model output, the observed temperature from HadISST, MLD from ORAS4 (Ocean Reanalysis System 4) and salinity from North Indian Ocean Atlas (NIOA: Chatterjee et al., 2012) are used.

3. MODEL VALIDATION AND DISCUSSION

In Figure 1, the model simulated SST is compared with observational HadISST data. The model (lower panel) shows good agreement with the observations (upper panel) for all four seasons. We observe the SST maximum during MAM and minimum during DJF. The model overestimates the SST over the AS, whereas, it is underestimating the SST over the BoB in all the seasons. We see lower SST values at the interface of AS and BoB (along the lower coasts) during JJA and SON seasons.

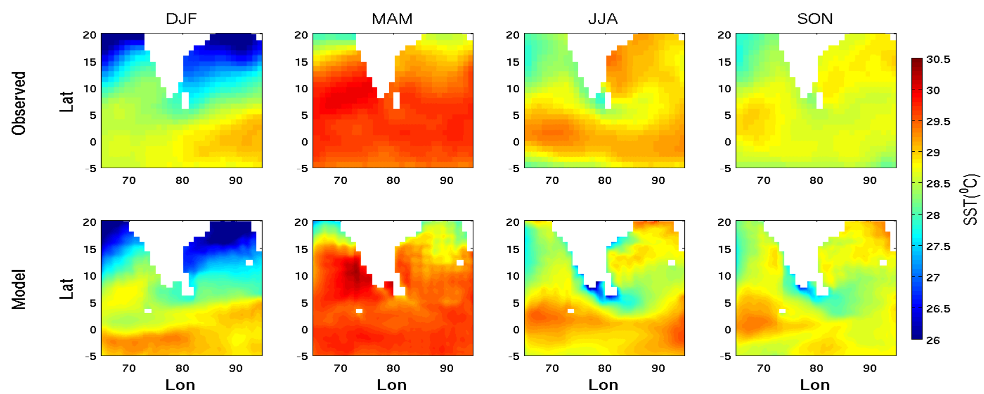

Figure 1 SST of the northern Indian Ocean during DJF, MAM, JJA, and SON seasons. The upper panel shows the observed HadISST SST, whereas, the lower panel shows the corresponding model SST during 2002-2007.

The overall seasonal performance of the model is found to be far better during the DJF and MAM seasons as compared to JJA and SON seasons of the year over the region of study.

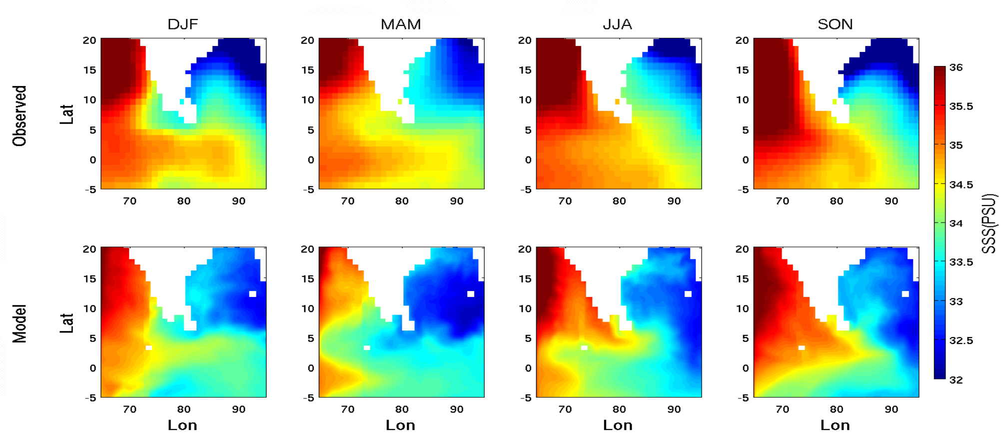

Figure 2 SSS of the northern Indian Ocean during DJF, MAM, JJA, and SON seasons. The upper panel shows the observed NIOA SSS, whereas, the lower panel shows the corresponding model SSS during 2002-2007.

In Figure 2, we compare the model SSS (lower panel) with the NIOA observed salinity data (upper panel). The model is able to simulate the SSS spatial variability of the region. For example, the low salinity and high salinity regions in the BoB and eastern AS are well simulated by the model. Fresh water comes from the BoB and enters into the AS, in two ways: (i) due to southward flowing East India Coastal Current (EICC) and (ii) due to westward advection by the Northeast Monsoon Current (NMC). On the other hand, the high salinity water from the AS flowing into the BoB due to the Southwest Monsoon Current (SMC) during summer and post-monsoon seasons (Vinayachandran et al., 1999) generates a salty tongue south of India and east of Sri Lanka. Our model is able to capture this feature during summer and post-monsoon seasons over the above mentioned location. However, the model SSS values are slightly overestimated over the head BoB, whereas, underestimated along the equator and south of equator in all the seasons.

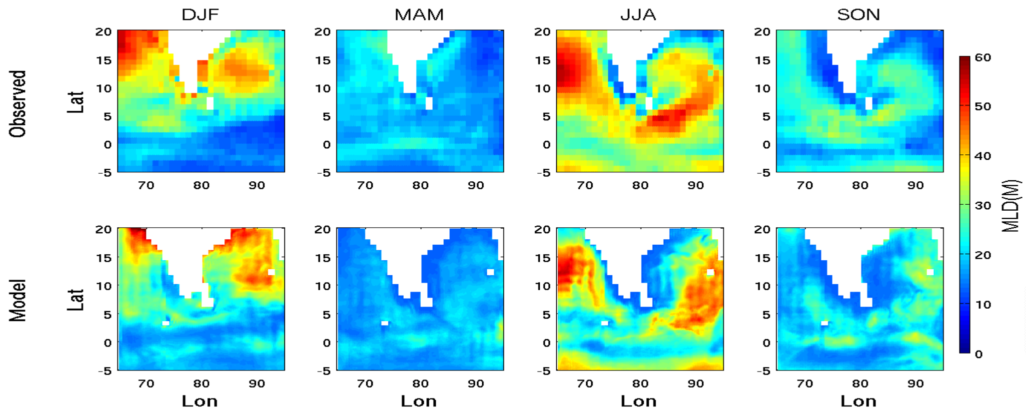

Figure 3 MLD of the northern Indian Ocean during DJF, MAM, JJA, and SON seasons. The upper panel shows the observed ORAS4 MLD, whereas, the lower panel shows the corresponding model MLD during 2002-2007.

Figure 3 depicts the spatial pattern of mixed layer depth over the AS and BoB. The model simulated values are given in the lower panel, whereas ORAS4 observed MLD values are shown in the upper panel for comparison. Our MLD results are in conformity with the seasonal and interannual variability of the MLD obtained by Montegut et al. (2007) and Uddin et al. (2014) for the AS and BoB regions, respectively. The model simulated maximum MLD during DJF is 60 m and during JJA is nearly 50 m over the eastern AS and BoB. The maximum MLD in winter and summer monsoon is due to a high monsoonal wind speed over this region. The MAM and SON seasons are marked with shallow MLD values with the MLD maximum of 20m and 25m, respectively. These values show good agreement with the observed ORAS4 values. These results are also consistent with the seasonal evolution of the mixed layer depth studied by Rao et al. (1989). During the monsoon and post-monsoon seasons, the MLD shoaling along the coastal regions is also well matched with the observations.

4. CONCLUSIONS

In this study, we investigate the seasonal variation of SST, SSS, and MLD using the NEMO-AGRIF nesting tool at a high resolution of $1/4^{o}$ over the tropical Indian Ocean covering the AS and BoB. The model simulates the SST quite well in all the seasons except in the monsoon season. The model, however, fails to get the correct magnitude of the SSS though the seasonal spatial structure of the SSS is somewhat better simulated. The MLD seasonal variability, on the other hand, is correctly simulated by the model both in terms of spatial pattern as well as magnitude.

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