Development of a High Resolution Ocean Model for ENSO Forecasting

Naoyuki Hasegawa
n-hasegawa@met.kishou.go.jp
Japan Meteorological Agency
1-3-4, Otemachi, Chiyodaku, 100, Tokyo Japan

1. Introduction

The Japan Meteorological Agency (JMA) operates a coupled ocean and atmosphere model for the ENSO prediction. The oceanic part of this model is identical to that used in the Ocean Data Assimilation System (Kimoto et al., 1997), which provides the oceanic initial conditions for the coupled model. A high resolution version of this ocean model was developed to assess the impact of the resolution on the model performance.

2. Model

The horizontal resolution was enhanced from 2.0° latitude (0.5° between 10°S and 10°N) by 2.5° longitude to 1.25° latitude (0.25° for 10°S -10°N) by 1.25° longitude. The model was modified from a rigid lid model which follows Bryan (1969) to a free surface model based on Killworth et al. (1991) to avoid the solution of a Poisson-type equation. The vertical resolution was also improved from 20 levels to 30 levels and the layer spacing around the equatorial thermocline was reduced from 30m to 15m. The models have realistic bottom topography, but the maximum depth of the bottom is set to 4000 meters. The computational domain is global, excluding the Arctic Ocean.

In a z-coordinate free surface model, when the thickness of the top layer is less than the range of the sea surface displacement (2 to 3 m), the sea surface may be moved beyond the bottom of the top layer, and this would cause the complication in the algorithm. Therefore, a new vertical coordinate was introduced in the high resolution model. The vertical coordinate ζ is defined as;

$$z = z_0\left(\frac{z+dh}{z_0+dh}\right), \text{ where } \begin{cases} d=1 & (z<z_0) \\ d=0 & (z \ge z_0) \end{cases} \quad \text{(see Fig. 1)}$$

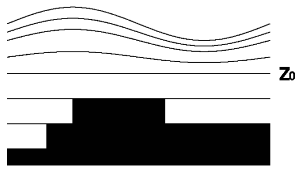

Fig.1 Vertical coordinate used in the high resolution model.

Note that z and ζ are in the downward direction and η (sea surface displacement) is in the upward. z_0 is set to be a depth above which no bottom topography is present (e.g. 50m) . This coordinate allows the top layer to be very thin (1.6m in the high resolution model), while keeping the virtue of the z-coordinate in the pressure gradient calculation. This modification of the dynamical frame was found not to give significant difference in the performance when run at the same resolution as the present model.

The both models employ the vertical mixing of Pacanowski and Philander (1981). A Smagorinski-type second order horizontal diffusion is used in the present model and the high resolution model has the forth order horizontal diffusion with a constant diffusion coefficient.

3. Experiment

The impact of the resolution was assessed by integrating the present and the high resolution models with fluxes based on observation from 1980 to 1996. After 15 year spinup runs with climatological wind stress and restoring force to the climatological SST, the models were given the fluxes calculated from the atmospheric fields of the European Centre for Medium-Range Weather Forecasts (ECMWF) reanalysis (provided to JMA by courtesy of ECMWF) and JMA operational atmospheric analysis (1994-1996). The short and long wave radiation fluxes were based on Reed (1977) and Budyko (1974), respectively. The momentum, latent heat and sensible heat fluxes were calculated with the formulae given by Bunker (1976). The cloudiness in the calculation was estimated from the relative humidity with a statistical relation by

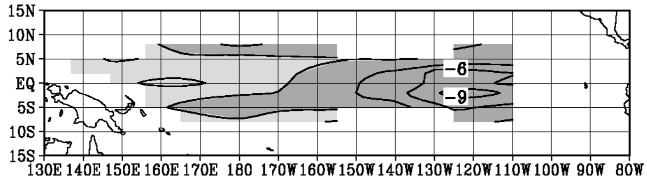

Fig.2 Difference of RMSEs of 5 day mean 20°C depth for 1984-1996 (m). Dark shade indicates the negative difference (high resolution is better) and light shade indicates the positive difference. The contour interval is 3m.

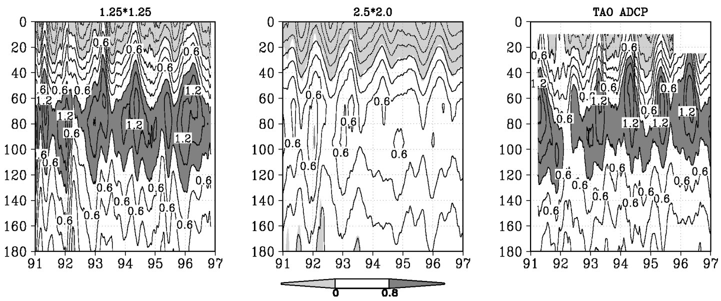

Fig.3 Time- depth diagram of the eastward currents at 0°N, 110°W (m/s) from January 1990 to December 1996 for the high resolution model (left), the present model (center) and TAO ADCP (right).

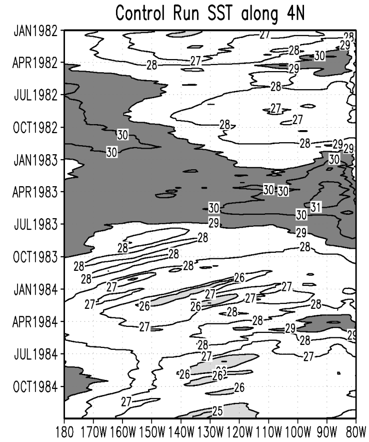

Fig.4 Time-longitude diagram of the SST (°C) along 4°N by the high resolution model from Jan. 1982 to Dec. 1984.

Saito and Baba (1988). The model SST was used in the flux calculation. Salinity was restored to the climatology for all the model runs. The temperatures were restored to the climatology in the entire region for the first 10 years of the spinup and below 1500m and poleward of 50° for the rest of the experiment.

4. Results

When compared with the TAO data, the models showed warm SST bias (around 1°C) in the equatorial Pacific, and its magnitude was not reduced by the high resolution model (figures not shown). However, some improvements were seen in the subsurface structure, which is important for ENSO prediction. The high resolution model gave better thermocline depth (20°C depth) in the eastern equatorial Pacific (Fig. 2). This was mostly brought about by the reduction of the deepening bias of the 20°C depth in the low resolution model. The high resolution model also gave better (sharper) vertical temperature gradient within the thermocline (figures not shown). The present model gave substantially weaker Equatorial Undercurrent, but this was remedied by the high resolution model (Fig. 3). The high resolution model reproduced the tropical instability waves (Legeckis, 1977, etc.) which was absent in the present model (Fig. 4), though the effect of this wave on ENSO is yet to be studied.

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