

PREDICTION OF SOUTHERN OSCILLATION USING THE INDONESIAN THROUGHFLOW VARIABILITY

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ABSTRACT

Atmospheric boundary layer derived from NCEP/NCAR reanalyses for the period of 1974 to 2002 has been used as boundary forcings for the global ocean model Max Planck Institute Ocean Model (MPIOM). The ocean model is a curvilinear grid model, whose poles are located over mainland China and over the Australian continent, thus focusing on the maritime continent. The model simulates major Indonesian throughflow passages that focus on six canals representing three inlets and three outlets (the Makassar, Lifamatola, Halmahera, Lombok, Ombai and Timor Straits). The model results have been validated using the Arlindo observation Project over the Makassar Strait in the period of January 1997 to February 1998, which fortunately was during a strong El Niño episode. The model simulation results were then investigated for their prediction capabilities of any of those channels in foreseeing the incoming southern oscillation events. Temporal correlation analysis with lag and advance time correlation methods were performed against simulated data at all levels on those channels. Variabilities in depth of 74 to 200m (thermocline depth) show the strongest correlation with SOI index (Darwin minus Tahiti mean sea level pressure). The temperature and salinity correlations with SOI are the highest with one-month in advance over Lifamatola Strait (0.77) and two-month in advance over the Makassar Straits (0.74). These significant correlations highlight the important of those two straits in prediction of incoming southern oscillation that usually leads to ENSO episode which brings most of the time devastating impact to economy, agriculture and ecosystem.

1. INTRODUCTION

The inter-ocean transport from the tropical and subtropical Pacific Ocean to the Indian Ocean, known as the Indonesian Throughflow (ITF), plays major roles in heat and freshwater fluxes between the two oceans and influence the strength and timing of Asian-Australian Monsoon and may feedback to global climate (i.e. Bryden and Imawaki, 2001). Observations and models indicate that the primary ITF source come from the north Pacific thermocline water through Makassar Strait and some additional contributions from the south Pacific through the Maluku and Halmahera Sea (Gordon and Fine, 1996; Godfrey, 1996). The ITF exits into the eastern Indian Ocean through major passages along the Java-Nusa Tenggara Island chain: Lombok Strait, Ombai Strait and Timor Passage (Murray and Arief, 1988; Molcard *et al.*, 2001). Because there were no simultaneous direct measurement of ITF in both inflow and outflow passages, the long term ITF magnitude and

variability are less understood. In this study, we use the velocity and temperature profiles from two moorings deployed in Makassar Strait from November 1996 to July 1998 (Gordon *et al.*, 1999; Ffield *et al.*, 2000; Susanto and Gordon, 2004) and compare with our numerical model result.

Because of complex coastline geometry and narrow straits, a high resolution numerical model should be used in this region. First we used a global ocean model with a regional detail capability. There have been several modeling studies of the ITF. Most of them use regional models (i.e. Potemra *et al.*, 1997; Kamenkovich *et al.*, 2003), while some authors use the global ocean model (i.e. Rodgers *et al.*, 2000). The regional model experiences problems with the subsurface boundaries because they use ocean climatology for the boundary values, for example from Levitus *et al.* (1998) or other gridded climatological data set. With this setup, the large scale phenomena signals such as the El Niño Southern Oscillation (ENSO) and the Indian Ocean dipole (Saji *et al.*,

2001) could not be captured. On the other hand, a global model has problem with its coarse resolution, which could not resolve complex coastline and straits of Indonesian Seas. In this study, we introduce a new approach using a global ocean model with a curvilinear grid system that considers the whole globe with a detail view over a specific region, in this case the Makassar Strait. With this setup, we will have not only a better representation of the Makassar Strait but also the Maluku Halmahera region, where numerous small islands are present, which are important to describe a correct pathway to the Indonesian throughflow (i.e. Morey *et al.*, 1999). However, this setup may still not adequate to cover the local detail of orography, thus the second model combination approach is proposed. With the second approach, a combination of the global and local ocean models is employed to simulate a better throughflow.

We applied the Max Planck Institute ocean global circulation model (OGCM), the MPI-OM (Marsland *et al.*, 2003). MPIOM is the latest development of the Hamburg Ocean Primitive Equation (HOPE) model (Wolff *et al.*, 1997) with a major improvement of transition from a staggered E-grid to an orthogonal curvilinear Arakawa C-grid (Arakawa and Lamb, 1977). So far, the MPIOM model use only the climatology, i.e. salinity and temperature data from Levitus *et al.* (1998) at the open boundaries for the initialization, even for the long term realistic calculation. Therefore it is very difficult to achieve high level results on a shorter time scale as the available climatology boundary conditions. In order to achieve better results of simulation, we need high resolutions boundaries values in time and space. Those boundaries values will be supplied from an ocean atmosphere simulation using the MPI-OM.

Due to limited observations both in time and space, only few studies have addressed the oceanic variation in this region. In this study we show the simulated ocean current and temperature variability within the Makassar Strait and their comparisons to the in-situ observation during the mooring period from November 1996 to July 1998 of the transport (Gordon *et al.*, 1999; Susanto and Gordon, 2004) and of the temperature profile (Ffield *et al.*, 2000) from the Arlindo project. The time scale is limited to monthly, seasonal and interannual variability from that period. In addition, the variability of ITF and the impact ENSO will also be presented. Next, we will discuss possible improvement of the model

simulation over this area and a preliminary result of data interfacing between the two models.

2. MODEL DESCRIPTION

The MPI-OM model uses topography from a 5 minute global ocean bathymetry, corresponding to about 9 km resolution at the equator. The MPI-OM uses a bipolar orthogonal spherical coordinate system, which allows irregular positions of the poles. This study uses a special conformal grid where the north pole is located in China and south pole in Australia. This pole placement offers two major advantages over regular latitude-longitude grids. Firstly, the placement of the poles over land removes the numerical singularity associated with the convergence of meridians at the geographical north pole. Secondly, the choice of non-diametric poles allows for the construction of regionally high-resolution models that maintain a global domain and thus avoid the problems associated with either open or closed boundaries. However, it should be noted that this approach has the disadvantage of globally constraining the model time step to be small enough to be appropriate for the highest resolution region. Fig. 1 illustrates this conformal grid with a global and regional view of adjusted bathymetry. With such a setup the resolution over the Makassar Strait would reach about 40 km wide with the smallest horizontal cell size is located near the poles. The grid is characterized by 30 vertical levels with increasing level thickness from surface to bottom. MPI-OM is a hydrostatic ocean model, which uses z -coordinates for vertical discretisation. For a detailed description of MPI-OM, the readers are referred to Marsland *et al.* (2003).

The model was initialized with the annual mean data from the gridded World Ocean Atlas 1998 (Levitus *et al.*, 1998). Then the model was run for the first initial year, during which three dimensional Newtonian (linear) relaxation of the thermohaline fields was applied to all wet grid cells below the fourth layer. In the later simulation years, the model uses surface boundary forcings from the the National Centers for Environmental Prediction and National Center for Atmospheric Research reanalysis (NRA; Kalnay *et al.*, 1996) for a period from 1948 to 1999, which include 2m air temperature, short-wave radiation, precipitation rate, cloud cover, dew point temperature, zonal (u) momentum surface flux, meridional (v) momentum surface flux and 10 m wind velocity. MPI-OM

receives at every 6 hours the global, predefined atmospheric fields, which are recalculated in heat, freshwater and momentum fluxes using bulk formulae. The first 30 years from the MPI-OM-NRA run was skipped due to spin-up.

For the long term ocean atmosphere simulation, we used a regional climate model REMO for the atmosphere and MPI-OM for the global ocean model and NCEP/NCAR reanalyses (at 2.5 degree resolution). Detail description of the model setup of the coupled ocean atmosphere model on regional scale is given in Aldrian et al. (2005). Although previous study (Aldrian et al., 2005) have shown a well established long term ocean atmosphere simulation within the Indonesian

region, the current simulation advances further with better topography over the Molucca, longer time period from 1968 – 1999 and improved new dataset for surface library for REMO and better river runoff data for MPI-OM. In this simulation, MPI-OM uses 6366 major river data over the whole globe. The river data was calculated using a hydrology model, which considers precipitation rate from NCEP NCAR reanalyses.

3.MODEL RESULTS

3.1 Model Output validation

For model output validation, observed data from the Arlindo project between 1996 to 1998

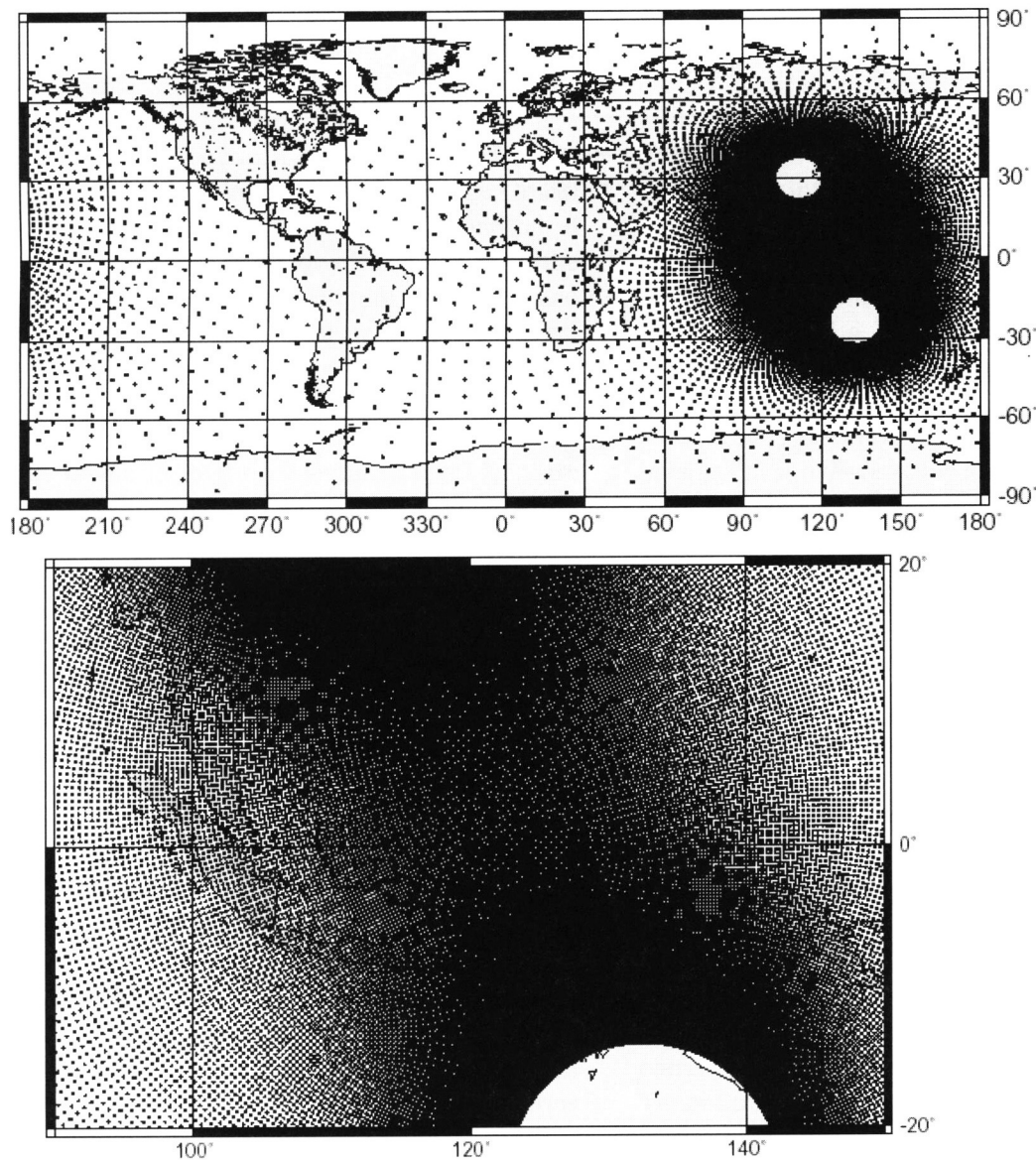


Figure 1. High resolution MPIOM with curvilinear orthogonal grid (above) and localized regional view of high resolution grid system of MPIOM (below) with grid pixel 326 x 210. (Marsland *et al.*, 2003).

in each layer during the ENSO period, there are strong correlations on each channel up to the thermocline depth. The correlation coefficient of temperature at depth of 150m after 12-months smoothing over the throughflow during the period of 1974 to 2002 with SOI, respectively for the Makassar, Lifamatola, Halmahera, Lombok, Ombai and Timor Straits are 0.64, 0.68, 0.63, 0.50, 0.62 and 0.64.

In comparison of the model output and SOI index from the 12-months smoothing, there are various correlation for each depth. In general the correlation increase along with the increase depth from the surface and reach its maximum at the thermocline depth, then the correlation decrease until reaching the depth ocean layer.

The highest correlations of the model output occurs at each throughflow channel are 0.82 in the Lifamatola Strait at depth of 47 m, 0.77 in the Makassar Strait at 69 m, 0.75 in the Halmahera Strait at depth between 47 to 69 m, 0.73 in the Lombok Strait at depth of 69, 0.64 in the Ombai Strait at depth of 57 and 0.64 in the Timor Strait at depth of 47 m. At depth of about 800 m the correlation between temperature variability and SOI index are insignificant and not systematic, however there is an increase of correlation value in the intermediate level below the thermocline layer in the Lifamatola channel that has a deep sill. In the throughflow outlets correlation are relatively stable with decreasing pattern up to the ocean bottom. Besides, high correlations tend to persist up to depth of 150 m and then decrease.

In general, the correlation of the thermocline and intermediate layers increase a little when the SOI index lagging by several months. For example in the Lifamatola Strait, the SOI and temperature time series correlation at depth of 57 m will increase from 0.78 in concurrent correlation into 0.83 and 0.86 when SOI lag by one and two months. Meanwhile in the throughflow outlet of Ombai Strait, the time series correlation between SOI and temperature will increase from 0.64 of zero lag into 0.68 and 0.70 when SOI lag by one or two months at depth of 57 m. Eventhough correlation values vary among channels at different lag time, there are common correlation pattern within depth and lag periods, where the highest correlations occurs in the thermocline layers.

From the observed six channels of the model result, there are two regimes of lag and lead SOI correlations. In the first regime, the correlation

increase if SOI lag and the depth increase in the thermocline layers. This pattern occurs in the Makassar, Lifamatola, Halmahera and Lombok Straits. These results indicate that thermocline layers on those channels are modulated by the SOI phenomenon with stronger characters in increase depth. The second regime when SOI lead will increase the correlation, however at certain depth in the thermocline layers are weaker correlations than above and below layers. The explanation of this phenomenon is related to the influx of the south Pacific from the depth Lifamatola channels that spill over deeper thermocline in the Banda Sea and then dominate those deeper layers due to density differences (Gordon and Fine, 1996; Hautala *et al.*, 1996; Ilahude and Gordon, 1996). The latter phenomenon does not occur in the Lombok Strait, which is one of the throughflow outlets that is dominated by the variability in the Makassar strait.

In relation with the position of the Indonesian water which influenced by the condition over the Pacific Ocean, during the El Niño episode water temperature over Indonesia is cooler than normal, thereby reducing the rainfall amount. On the other hand, during La Niña episode, the water temperature over Indonesia is higher than normal, thereby increasing the rainfall amount. Thus, a climate early warning system in relation to those phenomena is indispensable for Indonesia because El Niño episode mostly follow by long drought. With regard to that, correlations between SOI index and temperature of ocean layers as chosen as main indicator to detect potency of incoming ENSO phenomenon. For this purpose, lead SOI index are correlated with the temperature of ocean layers.

In general, correlations between lead SOI and ocean temperature will increase by leading the SOI index by one up to six months. Physical parameter of Indonesian water that is modulated by the variability over the Pacific Ocean has roles in reducing those correlations. These results, in turn, provide chances of predicting ENSO through observing changes in several major throughflow channels. The Makassar, Lifamatola, Halmahera and Lombok Straits are grouped into a higher correlation group than the one with Ombai and Timor Straits for every SOI+n (where n is leading months). On other words, the former four channels have stronger characters than the Ombai and Timor in detecting the incoming ENSO. With SOI+1 the correlation of four channels are still strong between

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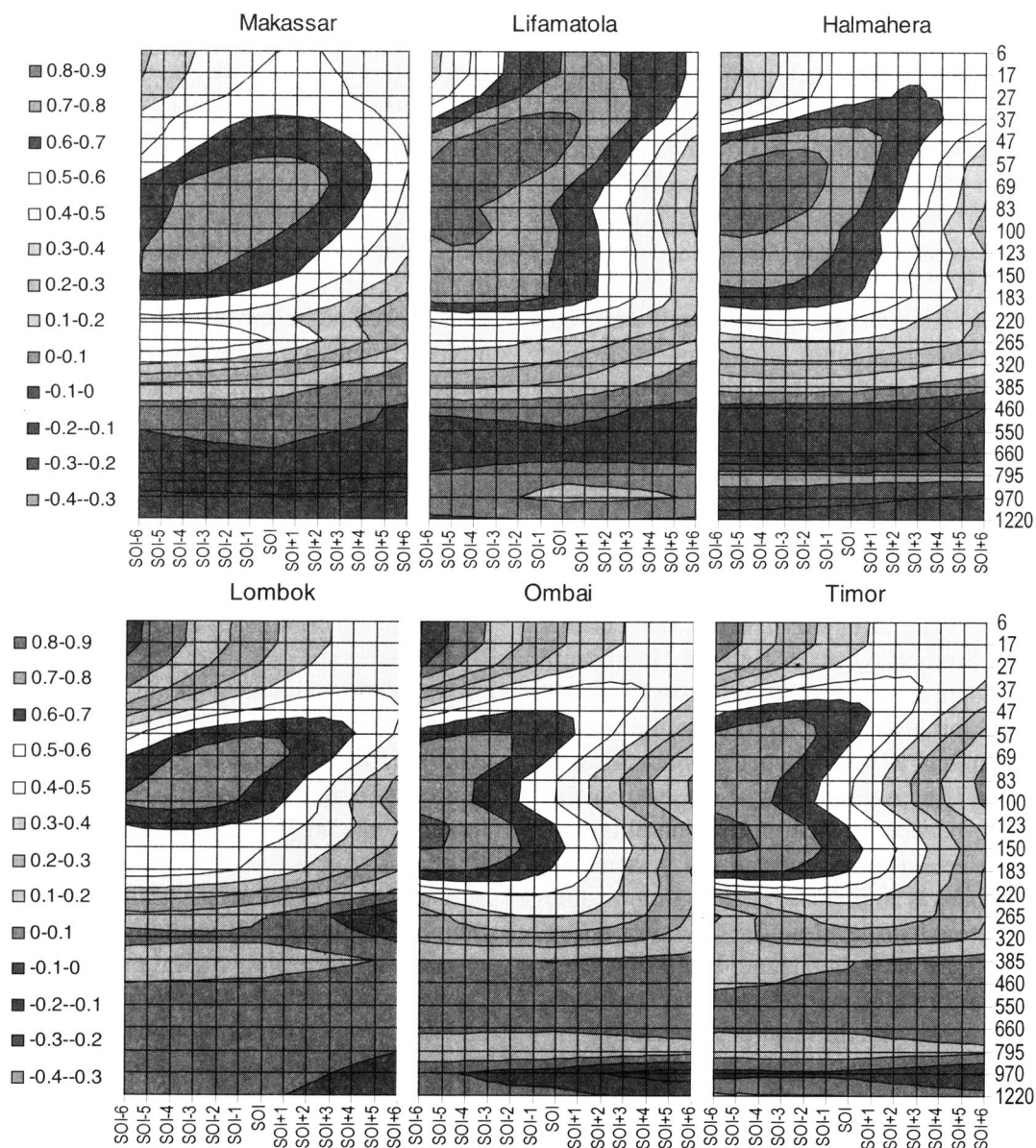


Figure 4. Correlation coefficient between temperature and SOI index with lag and lead relationship over the period 1974-2002 and after 12-months *smoothing*

0.71 in the Lombok Strait to 0.77 in the Lifamatola Strait. With SOI+2 the correlations decrease but still significant between 0.67 in the Lombok and

Halmahera Straits and 0.74 in the Makassar Strait. Hence, the water temperature over the Makassar strait at depth of 69 m and over the Lifamatola at

Tabel 1. The highest correlation values and lead SOI index over six throughflow channels over the period 1974-2002.

No	Throughflow channel	Depth	SOI	SOI+1	SOI+2	SOI+3	SOI+4	SOI+5
1	Makassar Strait	69 m	0.77	0.75	0.74	0.68	0.62	0.56
2	Lifamatola Strait	47 m	0.81	0.77	0.70	0.63	0.54	0.45
3	Halmahera Strait	47 m	0.75	0.72	0.67	0.61	0.55	0.48
4	Lombok Strait	69 m	0.73	0.71	0.67	0.61	0.55	0.47
5	Ombai Strait	57 m	0.64	0.59	0.53	0.46	0.39	0.31
6	Timor Strait	47 m	0.64	0.60	0.54	0.48	0.42	0.34

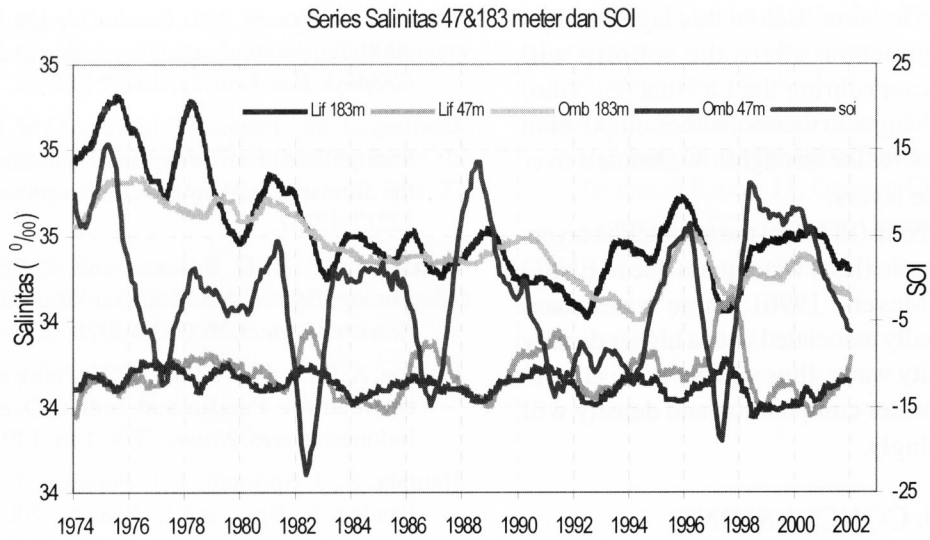


Figure 5. Interannual salinity variability over the Lifamatola and Ombai Straits after 12-months smoothing.

depth of 47 m could be used as an indicator of incoming ENSO.

3.3 Salinity variability

Beside temperature profile, the variability of salinity over the throughflow channels will also be investigated. The vertical profile of salinity follow the common profile of water density over the tropics with increase salinity with increasing depth. In relation with ENSO, the upper layer up to the thermocline layer have strong responses with

climate modulation over Pacific and the ocean atmosphere boundary variability. As a result, in the upper layer, during high (low) SOI period or during the La Niña (El Niño) the upper salinity will decrease (increase). This phenomenon is in relation with the sea air interaction when during La Niña (El Niño) there is an increase (decrease) of rainfall over the ocean. Thus, in turn, the rainfall or precipitating fresh water will decrease (increase) salinity in the upper layer. Changes over the upper layer will be transferred into deeper layer although

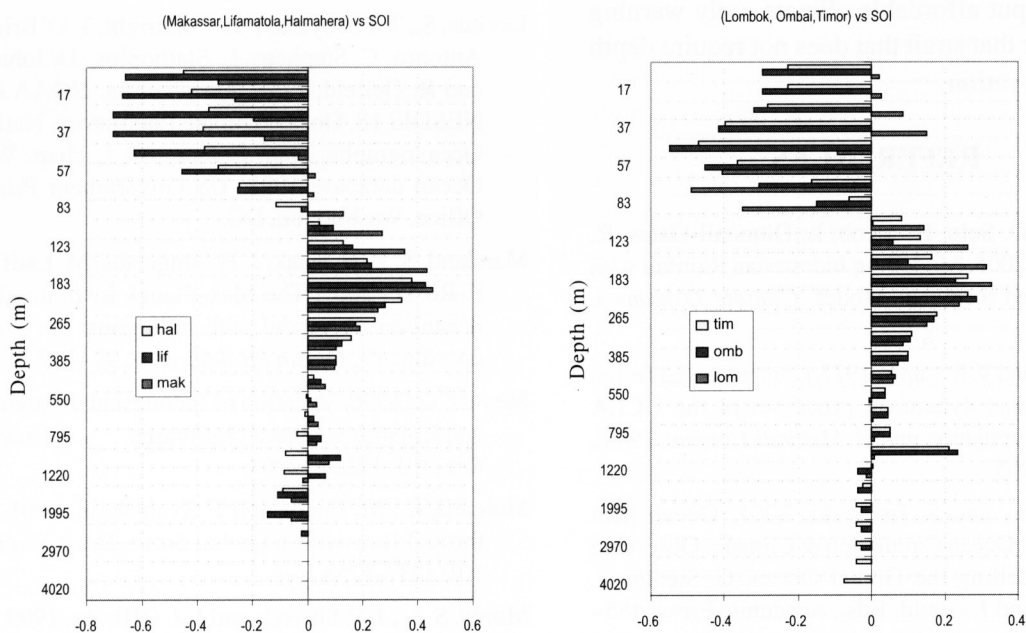


Figure 6. Correlation coefficients between salinity and SOI index with depth without lag relationship over the period 1974-2002 after 12-months smoothing.

not uniform up to 83 m. Below this layer there is reversal phenomenon where the salinity will increase (decrease) during the La Niña (El Niño) period due to changes in thermohaline composition after advection over the throughflow channels over the thermocline layers.

During La Niña (El Niño) the thermocline layers will transport more (less) water mass due to ENSO modulations (Meyers, 1996). Large water mass transport is usually associated with a higher density or higher salinity water, thus whenever this layers is modulated, water composition and density will change accordingly.

4. CONCLUSIONS

The MPIOM has capability on performing simulation of the variability of the Indonesian throughflow. The variability of temperature from the model is highly correlated with the observed one along the Labbani channel of the Makassar Strait. Both temperature and salinity profile across the major inlet passage of the Indonesian throughflow show significant correlation against SOI index, thus showing predictability potency of the deep ocean variability. The Lifamatola Strait shows the best potential candidate for detecting the incoming ENSO as the strait is sensitive up to two months ahead before the SOI signal over Pacific strengthens and the correlation goes up to the upper ocean layer. The latter fact is very useful in order to put affordable climate early warning system over that strait that does not require depth ocean observation.

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