Remote and local forcing of decadal sea level and thermocline depth variability in the south Indian Ocean

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1. BACKGROUND

Multi-decadal trend of the Indian Ocean vertical warming structure shows a complex pattern: near-surface warming is accompanied by thermocline cooling in the tropical south Indian Ocean. This intricate pattern of temperature variability is consistent with the distinct spatial patterns of sea level trends since the 1960s. The sea level drops in the southwestern Indian Ocean and rises elsewhere. Overlying on the multi-decadal trend, large-amplitude decadal variability has been observed for Indian Ocean SST, sea level, and upper ocean heat content. ***What is the relative importance of winds over the Indian Ocean versus that over the Pacific in causing decadal variability of sea level and thermocline depth in the South Indian Ocean? What is the role of Indian Ocean internal variability?*** Answering these questions is important, because understanding the causes and improving the estimates of spatially varying sea level change are important research target in coming years.

2. GOAL AND APPROACH

The goal of this study is to assess the relative importance of winds over the Indian Ocean versus winds over the Pacific via the Indonesian Throughflow (ITF) in causing South Indian Ocean decadal variability of sea level and thermocline depth, and to examine the role of Indian Ocean internal variability. To achieve the goal, three sensitivity experiments (see Table 1) are performed using an Ocean General Circulation Model (OGCM), the HYbrid Coordinate Ocean Model (HYCOM).

Experiments	Forcing Fields	Assessed Processes for decadal variability
INDOPAC	3-day mean ERA40 fields from 1958-2001; 3-day QuikSCAT winds, pentad CMAP precipitation, ISCCP radiation for 2000-2008	All (remote, local, & internal variability)
IND	Same as INDOPAC except that forcing over the Pacific (Fig. 1a) is kept to climatological mean	Indian Ocean wind forcing (also includes effects of internal variability)
DIFF	Difference: (INDOPAC – IND)	Pacific forcing via the ITF
INTERNAL	ERA-Interim monthly climatology	Oceanic internal variability due to nonlinearity of oceanic system

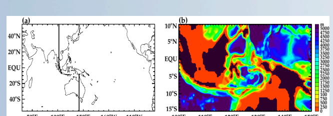

Fig. 1: (a) Basin map for HYCOM experiments; In INDOPAC experiment, the entire basin is forced. In the IND experiment, regions east of the vertical lines are forced by the 1958-2001 mean fields. (b) Topography of the Indonesian passage used for HYCOM experiments. Landmasses are shown in black.

3. RESULTS

a) Model/data comparison

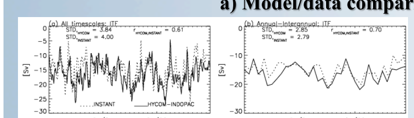

Fig. 2: (a) Comparison between 3-day mean ITF transport (Sv) from INSTANT data and 3-day snapshot from HYCOM INDOPAC. (b) Same as (a) but for monthly mean.

HYCOM ITF agrees well with INSTANT observed ITF transport, especially for their seasonal-to-interannual variations (2b).

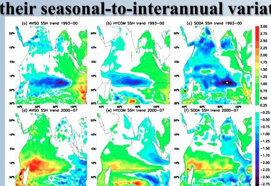

Fig. 3: Linear trends in SSHA for the period 1993-2000 (top row) for (a) AVISO, (b) HYCOM, and (c) SODA-POP; (d)-(f) Same as (a)-(c) but for the period 2000-2007. Trends are given as cm yr^{-1}. The horizontal line marks the latitude of 15°S.

Decadal change from HYCOM SSHA (Fig. 3, middle) agrees well with AVISO data (left), and to a lesser degree, with SODA data (right). Decadal changes of vertical temperature structure from HYCOM are also reasonably simulated (Fig 4).

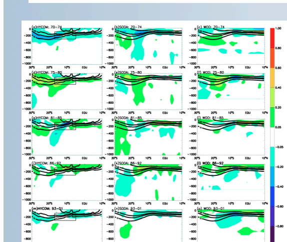

Fig. 4. Decadal zonal mean temperature anomalies for HYCOM (left), SODA (middle), and WOD05 (right) for the periods 1970-1974 (top), 1975-1980 (second row), 1981-1985 (third row), 1986-1992 (fourth row), 1993-2001 (bottom). The decadal anomalies are computed from the detrended and demeaned annual temperature fields zonally averaged from 35E to the eastern boundary. The anomalies are then averaged over each period. The color contours show temperature anomalies and the line contours show depths of the 25, 20,18, and 15C isotherms.

Fig. 3

b) Processes

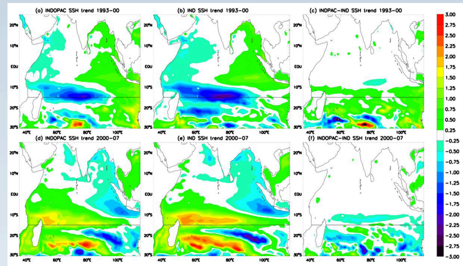

Fig. 5. Linear trends in SSHA for the period 1993-2000 (top row) for (a) HYCOM-INDOPAC, (b) HYCOM-IND, and (c) DIFF = (INDOPAC - IND.) (d)-(f) Same as (a)-(c) but for the period 2000-2007. Trends are given as cm/yr.

Decadal change of SSH from 1993-2000 to 2000-2007 results primarily from Indian Ocean wind forcing (compare left and middle columns of Fig. 5); remote forcing by winds over the Pacific via ITF has some contribution in south tropical and subtropical Indian Ocean (right column). Note that solution DIFF (right column) also includes the effects of oceanic internal variability.

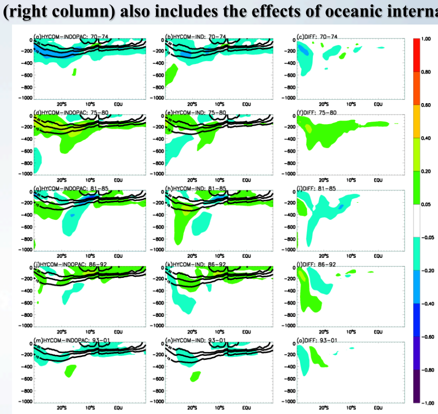

Fig. 6. Decadal zonal mean temperature anomalies from HYCOM-INDOPAC (left), HYCOM-IND (middle), and HYCOM-DIFF (right) for the periods 1970-1974 (top), 1975-1980 (second row), 1981-1985 (third row), 1986-1992 (fourth row), 1993-2001 (bottom). The decadal anomalies are computed from the detrended and demeaned annual temperature anomalies. The zonal-mean temperature fields are averaged over each period. The color contours show temperature anomalies (oC) and the line contours show depths of the 25, 20,18, and 15C isotherms.

Indian Ocean winds are the primary cause for decadal changes of the complex vertical temperature structure; with ITF contributes to the temperature variations in the thermocline region of the subtropical basin (Fig. 6).

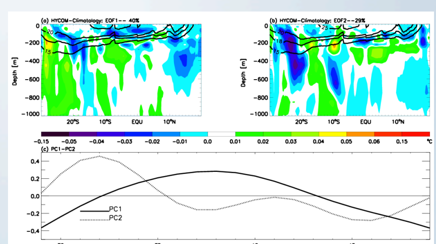

Fig. 7. The first (EOF1; a) and second (EOF2; b) leading EOFs and associated principle components (PC1 and PC2; panel c) for 8-year lowpassed zonal mean temperature anomalies using the detrended and demeaned annual temperature from the HYCOM INTERNAL run for years 20-59. The lined contours in a-c and e-g show depths of the 25, 20, 18, and 15C isotherms.

Indian Ocean internal variability due to nonlinearity can also have significant contribution to decadal scale variability of the complex temperature structure (Fig. 7) and sea level (not shown).

4. Summary & Conclusions

•The vertical structure of decadal temperature variability varies from decade-to-decade, with maximum variability peaking in the vicinity of the thermocline;

•Prior to the early 1990s, decadal variations in sea level and thermocline depth can be described in terms of a baroclinic Sverdrup balance, forced by Ekman pumping velocity associated with windstress curl acting on the Indian Ocean; beginning in the early 90's, decadal variability of the equatorial Pacific trades forces thermocline variations that modify the sea level and thermocline depth across the tropical south Indian Ocean basin;

•Farther south, between 20°S-30°S, oceanic instabilities make significant contributions to decadal variability of the thermocline.