Interannual variability and decadal change of thermocline depth and upper ocean heat content in the Indian Ocean

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1. BACKGROUND

The climatic importance of the tropical Indian Ocean has been receiving increasing attention. Compelling observational evidence and climate model studies in recent years show that the Indian Ocean plays a crucial role in affecting global and regional climate. Although variability and change of thermocline depth and upper-ocean heat content are important parameters for regulating climate, processes that cause their variability and change in the Indian Ocean during recent decades is unclear. How eddy activities impact the variability and change of thermocline depth and heat transport is not well known.

2. GOAL AND APPROACH

The overall goal of the proposed research is to utilize the over decade long multiple satellite altimeter data, other satellite data, in situ observations combined with ocean general circulation model (OGCM) and coupled global climate model (CGCM), to provide a thorough understanding of the causes for the interannual variability and decadal change of thermocline depth and the upper-ocean heat content in the Indian Ocean. Our main period of interest is 1992-present, when satellite altimeter data are available. Results for this period will also be analyzed in conjunction with available data and model solutions during 1960-present, in order to understand whether the trend during the altimetry era represents longer-term trend or multi-decadal variability.

3. PRELIMINARY RESULTS

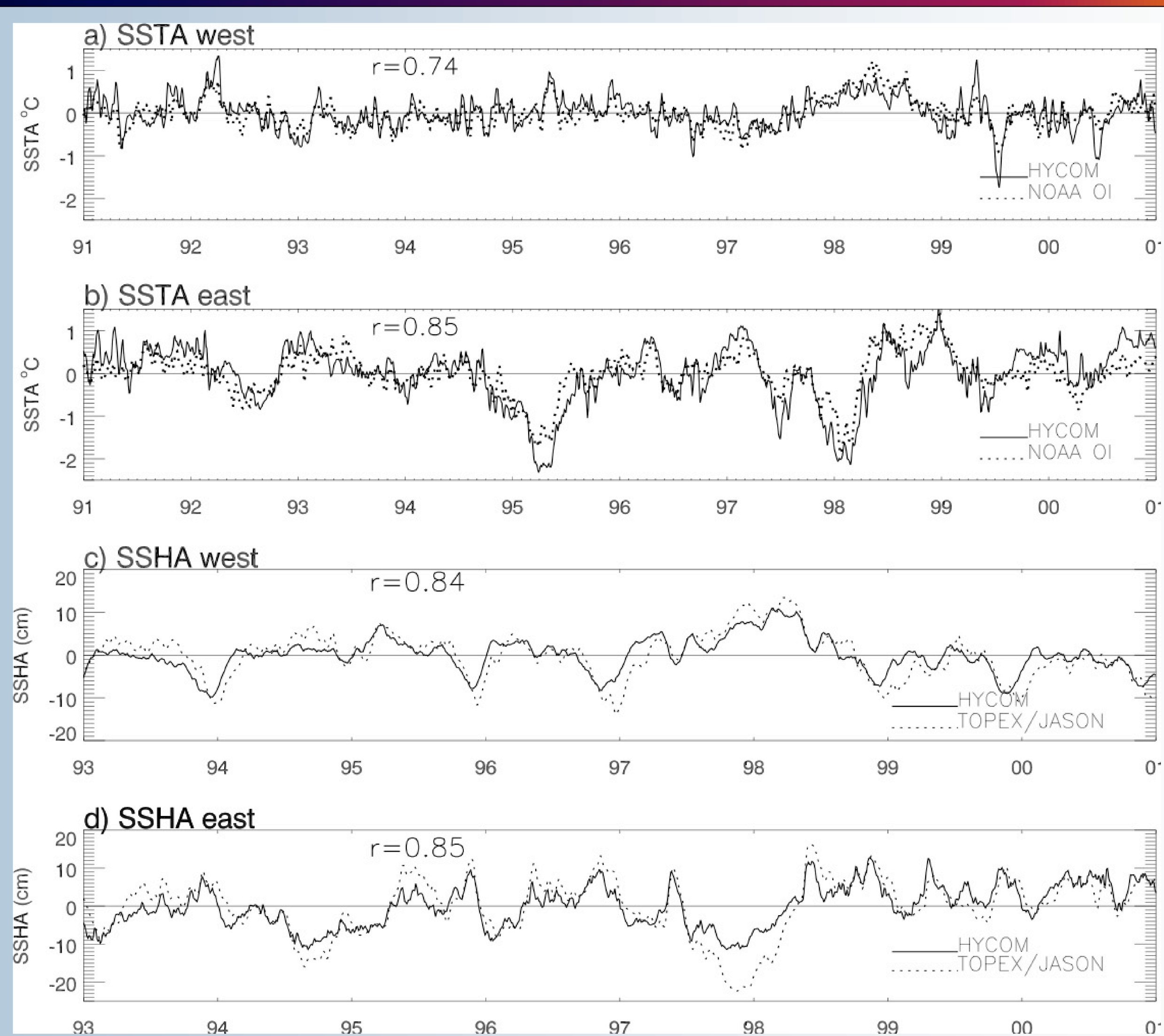

Fig. 1. Model/data comparison. a) Time series of NOAA OI weekly SSTA (dashed curves; *Smith and Reynolds 2004*) and modeled (solid curves) SSTA from the Hybrid Coordinate Ocean Model (HYCOM) 3-day mean solution averaged over the western antinode region (10S–10N, 50E–70E) of the IO zonal dipole mode during 1991–2000. b) Same as a), but for the SSTA averaged over the eastern antinode region (10S–0N, 90E–110E). c) Time series of SSHA from TOPEX/Poseidon/Jason altimeter data with a 3-day resolution (dashed curve) in the western antinode region, and from the 3-day-mean HYCOM solution (solid curves). d) Same as in c), but for the eastern antinode region. Figure from Han et al. JPO, 2006.

This figure demonstrates that HYCOM reasonably simulated the intraseasonal, seasonall and interannual variability of SST and SSH in the Indian Ocean.

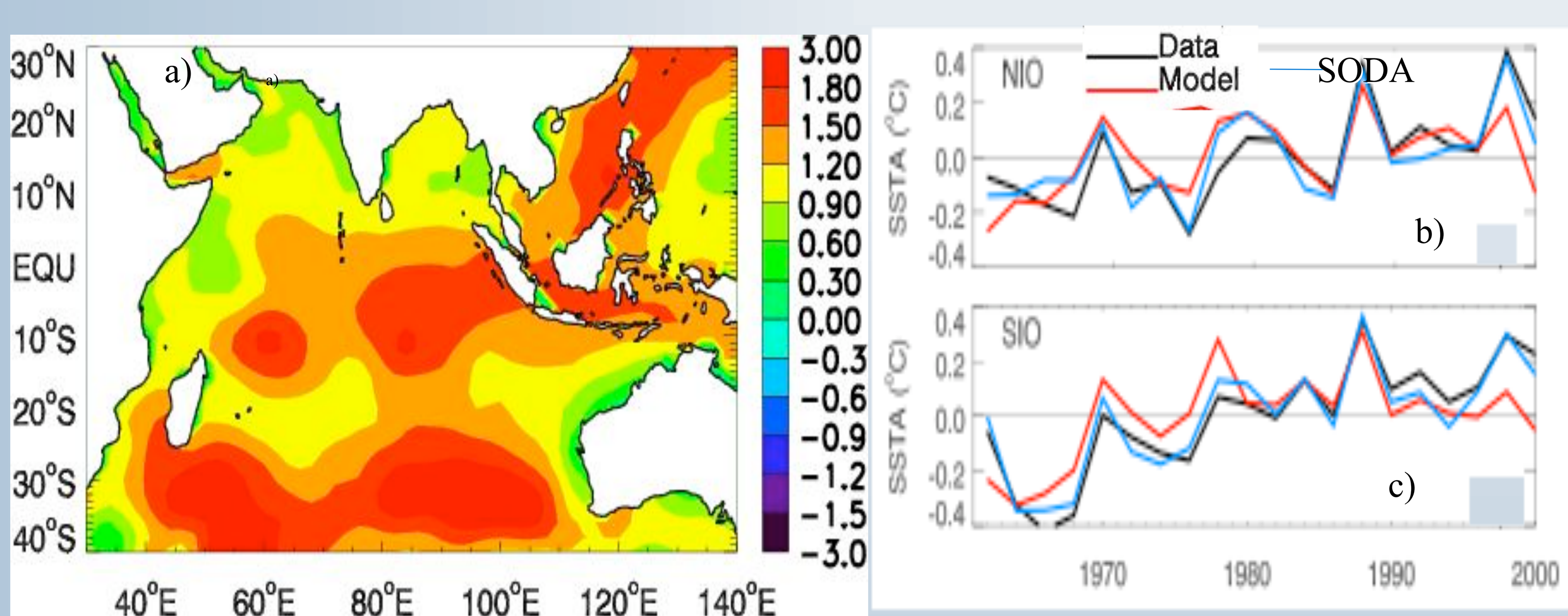

Fig. 2. a) Linear trend of observed SST (*Smith and Reynolds 2004*) for the period of 1960-2005 over the Indian Ocean (IO). Units: ^{o}C/century. b) 2-year-mean, basin-averaged SSTA Over the north IO (NIO) and south IO (SIO) during 1961-2000 from the observed SST (black), HYCOM (red; see Trenary and Han 2008) and Simple Ocean Data Assimilation (SODA) product (blue; Carton and Giese 2008).

This figure shows that warming trend and decadal variations of the surface Indian Ocean in the past few decades are detected by the reconstructed data and data assimilation product; they are well simulated by HYCOM.

Does the sea surface height anomaly (SSHA) have similar trend? In another word, is the sea level change in the Indian Ocean in the past few decades caused by the upper ocean warming? To what extent and on what timescale the SSHA of the Indian Ocean can be used to detect warming signals?

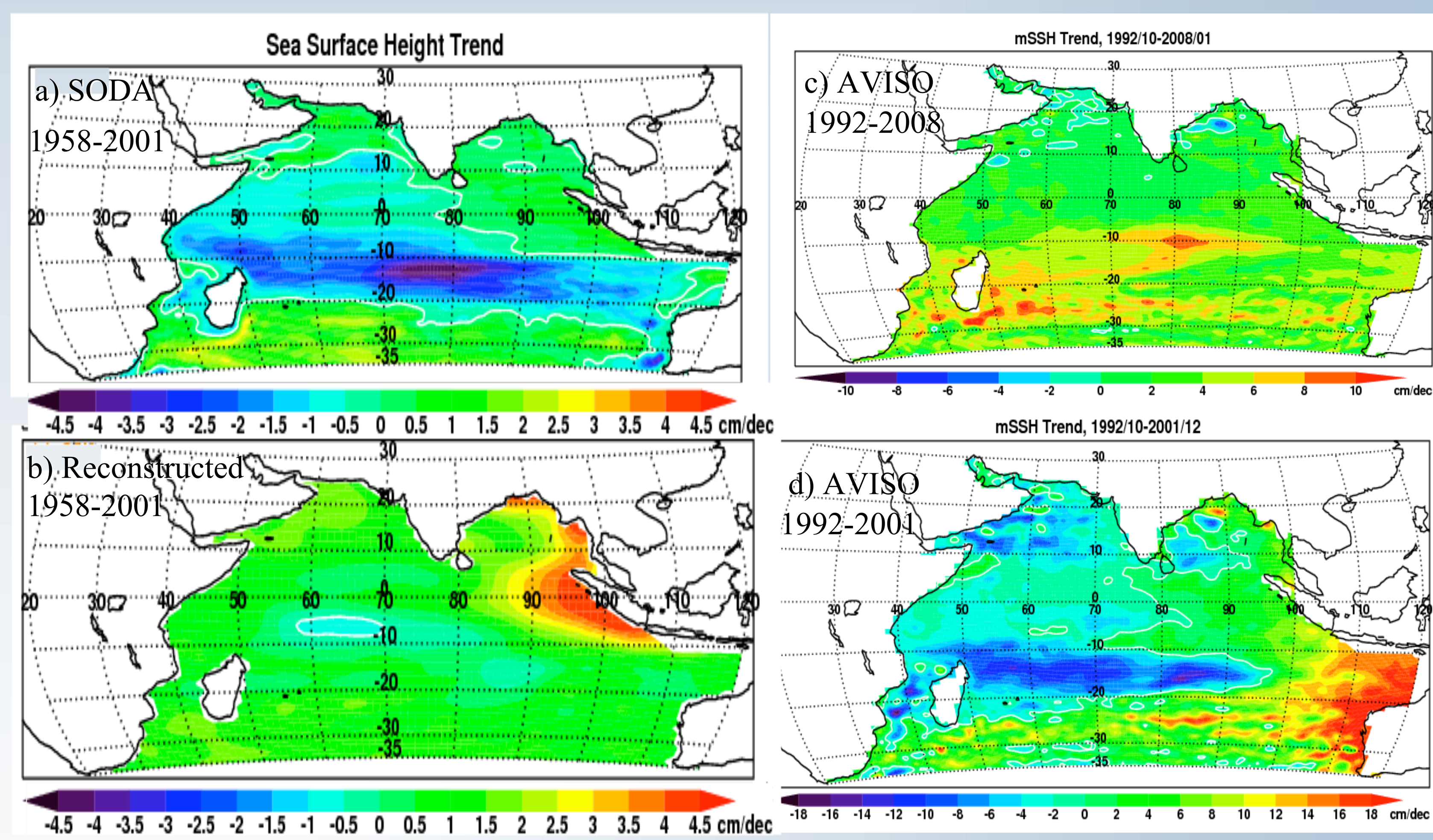

Fig. 3. a) SSH trend for 1958-2001 from SODA data; b) SSH trend for 1958-2001 from the reconstructed SSH data of *Church et al.* 2004. The seasonal cycle has been removed before the linear trend is calculated. The white contours indicate zero; c) SSH trend from AVISO weekly data for the period of 1992-2008; d) Same as c) but for the period of 1992-2001.

This figure shows that linear trend of SSH has a very different spatial structure than that of the SST (compare Figs 3 and 2). Church et al. reconstructed SSH shows a much stronger positive SSHA in the eastern tropical IO and weaker negative SSH trend in the central-western SIO comparing to SODA data. There is a strong decadal change between 1992-2001 and 2001-2008 periods (Figs 3c and 3d).

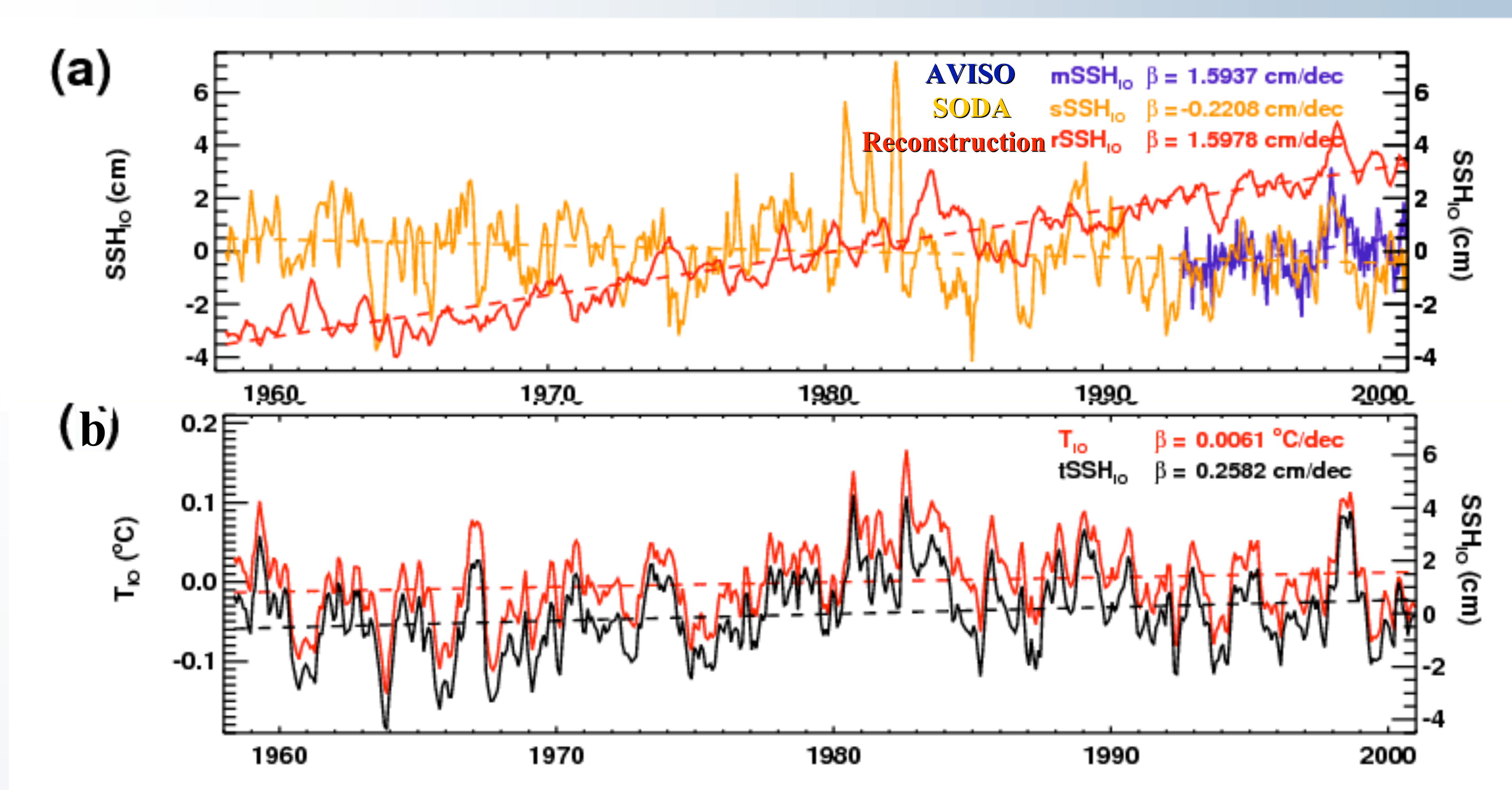

Fig. 4. **:** (a) The solid lines show deseasoned SSHA averaged over the Indian Ocean (20° E - 120° E, 35° S - 30° N) from AVISO satellite data (blue), SODA (yellow), and reconstruction (red); the dashed lines are their linear fits. The upper right corner shows their linear trend values; (b) Same as (a) but for the deseasoned mean temperature in the upper 1498m from SODA data (red) and the deseasoned SSHA due to thermal expansion (temperature change only) calculated from the SODA data (black).

Fig. 4a shows that SODA SSHA agrees reasonably well with AVISO SSHA (yellow and blue) for the period of 1992-2001, when all three datasets overlap. The Reconstructed SSHA seems to be systematically higher. All datasets show increasing SSHA trends for the 1992-2001 period. During 1958-2001, SODA SSHA averaged over the Indian Ocean shows a slightly decreasing trend due to the negative SSHA in the tropical SIO (Fig. 3). The reconstructed SSHA, however, shows a strong increasing trend.

Like the SST, temperature in the upper 1498m of the Indian Ocean from SODA (red line of Fig. 4b) shows an warming trend. The corresponding SSHA calculated from the upper ocean temperature anomaly also shows an increasing trend (black line of Fig. 4b), which is in contrast to the slightly decreasing trend of "total" SSHA from SODA (Fig. 4a, yellow). These results indicate that thermal expansion may not be the only cause for the SSH change. Changes of salinity, mass convergence/divergence due to oceanic circulation, etc. may be also important in causing the multi-decadal sea level change of the Indian Ocean.

4. PROJECT PLAN

The project will utilize the multi-year satellite SSH data, other satellite data, in situ observations, ocean data assimilation products, combined with OGCM and CGCM experiments to:

- Explore the interannual variability of thermocline depth and heat content especially in the upper ocean; develop a detailed understanding of the processes involved, including wind-driven circulation, waves, surface heating and remote forcing from the Pacific;
- Investigate the intradecadal variability and decadal change of upper-ocean heat content, and examine the relative effects of winds, surface heat fluxes and remote forcing from the Pacific via the Indonesian Throughflow;
- Identify and document mesoscale eddies, and explore the effects of wind-driven eddies and instabilities on the thermocline depth, heat transports and thus upper-ocean heat content.