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Role of Indian Ocean SST variability on the recent global warming hiatus

Anika Arora [a], Suryachandra A. Rao [a,*], R. Chattopadhyay [a], Tanmoy Goswami [a], Gibies George [a], C.T. Sabeerali [a,b]

[a] Indian Institute of Tropical Meteorology, Pune 411008, India
[b] Center for Prototype Climate Modeling, New York University, Abu Dhabi, UAE

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ABSTRACT

Previous studies have shown a slowdown in the warming rate of the annual mean global surface temperature in the recent decade and it is referred to as the hiatus in global warming. Some recent studies have suggested that the hiatus in global warming is possibly due to strong cooling in the tropical Pacific. This study investigates the possible role of the Indian Ocean warming on the tropical Pacific cooling. Despite the continued rise in sea surface temperature (SST) over the tropical Indian Ocean, SST over the tropical Pacific has shown a cooling trend in the recent decade (2002 − 2012). It is well known fact that the Indian Ocean and the Pacific Ocean are strongly coupled to each other and the Indian Ocean basin wide warming is triggered by El Niño on interannual time scale. However, in the recent decade, this relationship is weakening. The recent Indian Ocean warming is triggering a Matsuno-Gill type response in the atmosphere by generating anomalous cyclonic circulations on either side of equator over the tropical Indian Ocean and anomalous easterlies along the tropical Pacific Ocean. These anomalous easterlies result in Ekman divergence in the equatorial Pacific and produce upwelling Kelvin waves, cools the tropical Pacific and therefore indirectly contributes to the hiatus in global warming.

1. Introduction

The continued rise in anthropogenic greenhouse gases in the atmosphere is expected to provide a long term warming trend in the global mean surface temperature. Although the long term global warming trend seems to be persistently evident in surface temperature, there is also evidence of slowing down of warming trend (hiatus) in the recent decade (2002–2012) as reported by the previous studies. At the same time, top of the atmosphere radiative flux still showing an imbalance raises concern about the extra heat added to the earth climate system but the same not being reflected as rise in global mean surface temperature. Extra heat added to the climate system could be responsible for the rise in temperature of the atmosphere or the ocean or both (Kosaka and Xie, 2013; England et al., 2014; Easterling and Wehner, 2009). Previous studies have suggested different theories of the recent hiatus in global mean surface temperature and can mainly attributed to decrease in stratospheric water vapor (Rosenlof and Reid, 2008; Solomon et al., 2010) and increase in stratospheric aerosol effect (Solomon et al., 2011; Xie et al., 2013). This hiatus in global mean surface temperature has posed a challenge to the prevailing view of the role of the increasing trend in anthropogenic greenhouse forcing related to the global warming (Easterling and Wehner, 2009; Foster and Rahmstorf, 2011). Although the regional variation, seasonality of global warming signatures and stratospheric link are the commonly described mechanisms in literature (Solomon et al., 2010, 2011; Meehl et al., 2011; England et al., 2014), the role of dynamical feedback has started evolving in recent only. Kosaka and Xie (2013) have reported strong association between the eastern tropical Pacific Ocean cooling and the recent hiatus seen in global warming but whether cooling is a consequence of internal dynamics or externally forced remains unclear. Intensification of trade winds in the tropical Pacific Ocean is partly attributed to observed cooling trend in SST (Ding et al., 2013; England et al., 2014). In hiatus period, amount of heat missing from the atmosphere is trapped in the form of global ocean heat content and out of this about 70% of this heat is stored in the Indian Ocean (Lee et al., 2015). They also show that increase in heat content of the Indian Ocean cannot be explained through surface fluxes. Discharge of warm water from the Pacific Ocean into the Indian Ocean through Indonesian Passage is responsible for an abrupt change in heat content of the Indian Ocean. Indian Ocean seems to work as a giant reservoir in maintaining global mean temperature in the recent decades. This study advocates the role of wind anomaly associated with La-Nina like conditions in intensification of Indonesian Through Flow (Lee et al., 2015) but atmospheric response generated by increased heat content in the Indian Ocean and its role in modulating global mean temperature through the Pacific Ocean SST remains a puzzle. Roemmich et al. (2015) also claimed that imbalance in heat in the climate system can be explained by heat uptake by subsurface ocean. Using coupled model experiment with similar

* Corresponding author at: Indian Institute of Tropical Meteorology, Dr. Homi Bhabha Road, Pashan, Pune 411008, India.
E-mail address: surya@tropmet.res.in (S.A. Rao).

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energy imbalance at the top of the atmosphere as observed, Meehl et al. (2011) showed that warming in subsurface ocean below 300 m is accelerated and upper ocean seems to warm at much reduced rate during hiatus period. Balmaseda et al. (2013) also supports similar hypothesis to explain the recent hiatus. The recent hiatus has created a significant interest in dynamically explaining the cause associated with it and its implications on the future trend of global warming.

In the recent decade, strong cooling trend is observed in the tropical Pacific in contrary to the warming trend in the Indian Ocean (Fig. 1(b)). The rapid Indian Ocean warming (Levitus et al., 2000; Hoerling et al., 2004; Du and Xie, 2008; Rao et al., 2012; Roxy et al., 2014; Sabeerali et al., 2014; Swapna et al., 2014 and references there in) and the recent tropical Pacific cooling is quite interesting as this can have several implications in the modulation of teleconnection between these two oceans (Trenberth et al., 1998). It is now well known that the feedback between the Pacific and the Indian Ocean determines the variability of coupled modes in these two basins. El Niño southern oscillations (ENSO) can have important implications in determining SST patterns over the Indian Ocean (Bjerknes, 1969; Rasmusson and Carpenter, 1983; Venzke et al., 2000; Alexander et al., 2002; Wu and Kirtman, 2004). Similarly, it is shown by various studies that the Indian Ocean variability may have significant role in ENSO transitions and the tropical Indian Ocean can contribute significantly to ENSO variability (Meehl, 1987; Saji et al., 1999; Annamalai et al., 2005; Xie et al., 2009). Thus, the change in basic state of SST and variability over both the basins can have a significant impact on teleconnection relationship between the Pacific and the Indian Ocean as well as the Pacific and the Indian summer monsoon (Krishna Kumar et al., 1999; Kumar et al., 2000; Kinter et al., 2002; Turner et al., 2005).

With this background, it becomes important to explore how the recent tropical Pacific cooling and the Indian Ocean warming are dynamically related to each other. The cooling trend in the tropical Pacific is explained through several factors, but the role of inter-basin teleconnection between the Indian Ocean and the Pacific Ocean on the hiatus in global temperatures has not been examined so far. The teleconnection between these two basins may be an important link to explain the hiatus since the Indian Ocean and the Pacific Ocean are connected through an atmospheric bridge named Walker Circulation (Julian and Chervin, 1978; Webster and Yang, 1992). In this study our objective is to explore the possible role of the Indian Ocean warming in maintaining the observed Pacific cooling trend in the recent decade through observational analysis and model experiment. It will also help to establish a mechanism of change in inter-basin teleconnection on decadal scale.

Section 2 provides the details of the dataset used for this study and details of the experiments carried out using an Atmospheric General Circulation Model (AGCM) ECHAM5. Detailed discussion on the result is presented in Section 3. Finally Section 4 concludes the study.

2. Data and method

2.1. Data

In order to study temporal variation and linear trend of SST we have used monthly mean Hadley Center Sea Ice and Sea Surface Temperature dataset (HadISST; Rayner et al., 2003, 2006). For cross validation of SST trend, TMI AMSR-E fused daily SST for the period June 2002–December 2012 is also analyzed (Wentz et al., 2000, 2001). The TMI AMSR-E data is obtained via http://data.remss.com/sst/daily/tmi_amsre. This study also uses NCEP/NCAR Reanalysis 2 zonal and meriodional winds (Kanamitsu et al., 2002), Modern-Era Retrospective Analysis for Research and Applications (MERRA) net surface heat flux (Rienecker et al., 2011) and Met Office Hadley Centre subsurface ocean temperature observations (version EN.4.1.1.; Good et al., 2013) for the period January 1979 to December 2012. NOAA interpolated outgoing longwave radiation (OLR) dataset for the period June 1974–December 2012 (Liebmann and

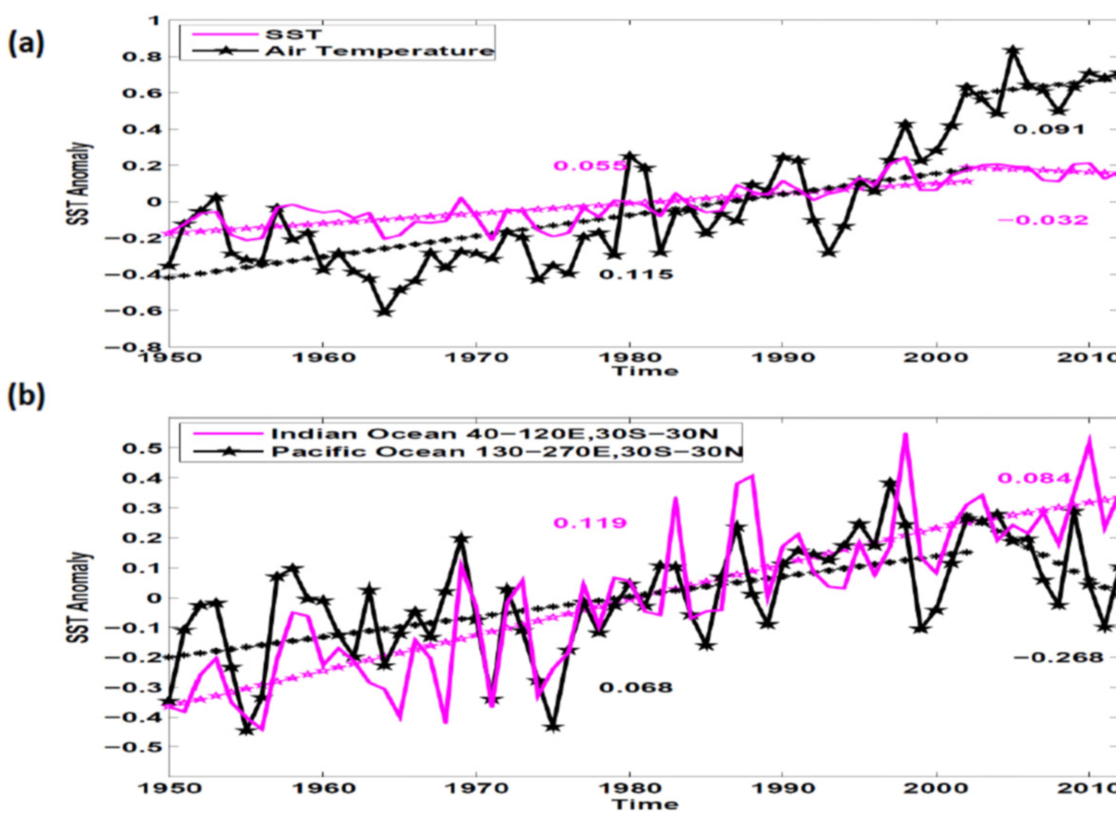

Fig. 1. Time series of (a) annual mean global sea surface temperature (°C; magenta) and 2 m air temperature (°C; black) (b) SST (°C) averaged over the tropical Indian Ocean (40°E-120°E, 30°S-30°N; magenta) and tropical Pacific Ocean (130°E-90°W, 30°S-30°N; black) for the period 1950 to 2012, along with linear trend (dashed line) calculated for two different periods (1950–2002 and 2002–2012).Slope of each trend line is labeled in respective line color.