Pathways and effects of ITF in the Indian Ocean: A model study

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Abstract

Indonesian Throughflow (ITF) is a system of currents flowing from the Pacific to the Indian Ocean via Indonesian Straits. The ITF is the upper (warm) branch of the Global Conveyor Belt, while much less is known on its pathways within the Indian Ocean, whose understanding is necessary, to find the impact of the ITF in the Indian Ocean climate as well as the response of the conveyor belt in long term climate change. This research is focused on the detailed three dimensional trajectories of the ITF in the Indian Ocean and to categorize its impact on the Indian Ocean climatology.

The 3-Dimensional pathways of the ITF in the Indian Ocean are identified using an OGCM, with a combined set of tools (1) Lagrangian particle trajectories, (2) passive tracers and (3) active tracers (temperature and salinity). Each of these tools has its own advantages and limitations to represent the water mass pathways. The Lagrangian particles, without horizontal and vertical mixing, suggest that at the entrance region the surface ITF ($<$ 60m) subducts off-northwestern coast of Australia (releasing $\sim$40 Wm^{-2}), and then travels across the Indian Ocean along the thermocline depths. The subsurface ($>$60m) ITF more directly departs westward and crosses the Indian Ocean. Using the passive tracers, which are mixed vertically under convection as well as horizontally due to diffusion, the ITF is shown to undergo vigorous mixing as soon as it enters the Indian Ocean and modifies its upper T-S characteristics. The ITF partially upwells along the southern Java-Sumatra coast and spreads southwestwards owe to the planetary waves in the Southern Tropical Indian Ocean.

Upon reaching the western boundary, more than 70% of the ITF turn northward and reroutes into three distinct depth ranges, owing to the seasonal reversal of the Somali region, as Route-1 (26%): across the Indian Ocean just to the south of the equator (200m-300m), Route-2 (24%): across the Indian Ocean to the north of the equator (100m-200m) and Route-3 (20%): upwells in the Somali region and spreads all over the surface of the northern Indian Ocean. Route-3 dominates during summer monsoon (Apr-Oct) while Route-2 dominates during winter monsoon (Nov-Mar). The basin-wide spreading is responsible for a long residence time of the ITF in the Indian Ocean to be at least 20 years.

The effects of the ITF on the temperature and salinity are mainly accompanied with the major pathways shown by the Lagrangian particles and the passive tracers. These effects are categorized into, direct effects, those related to the direct advection of the ITF, and indirect effects, those related to the modification of basin wide circulation associated with the fresh and warm ITF. The direct effect of the ITF is responsible for a warming ($\sim$3°C) and freshening ($\sim$0.2 psu) of the thermocline depths (100 m) along the main stream (10°S to 20°S). However, indirect effects are visible in a few spots: i.e., the warm and saline feature is produced off-southwestern coast of Australia around 30°S caused by the eastward surface current, which is under the thermal wind relationship owing to the warm and fresh ITF component. The same character enhances vertical convection and warms the surface around 40°S.

1 Introduction

The Indonesian Throughflow (ITF) is a system of currents flowing from the Pacific to the Indian Ocean via Indonesian Straits. It is the only low latitude connection between the world Oceans. The ITF is considered as the surface route of the Global Conveyor Belt, which carries warm water from the Pacific to the Atlantic through the Indian Ocean. Previous studies had shown that if the entire ITF is supposed to release the heat to the atmosphere over the Indian Ocean, the net heat flux would rise by 11 Wm^2 and it is 25% of the net heat flux of the Indian Ocean north of 30^{0}S. There are numerous studies discussing about the effects of the ITF in the Indian Ocean temperature and salinity, without considering the fundamental question 'Where does the ITF go into the Indian Ocean?'. Thus, here we examine the detailed 3-D trajectories of the ITF.

2 Methods

An OGCM is simulated with Pacific and Indian Ocean domain. Lagrangian particles and passive tracers are released at the ITF entrance region (Indonesian straits). Particles are tacked for 20 years using instantaneous model velocity fields. Passive tracers are traced for ten years. Lagrangian particles are merely a representative of advection while passive tracers also undergo vertical mixing and horizontal diffusion. An artificial case is run with closed ITF channel, and comparison is made between this artificial case against the control run and effects of the ITF in temperature and salinity are found.

3 Pathways and effects of the ITF in Indian Ocean

3.1 Particle Trajectories

Our main findings are given here. At the entrance region, the surface particles (initialized <60m) flow southwestward and subduct off-northwestern coast of Australia and later they return northwestward at a depth >300m and travel across the Indian Ocean. While the thermocline particles (>60m) directly depart from the entrance region and reach the western boundary. The subduction of surface ITF shows an enhanced vertical mixing and cooling during the austral winter. In addition to that the onshore geostrophic current impinging on the western coast of Australia also enhances the subduction of the surface ITF

At the western boundary the ITF undergoes seasonal re-routing as shown in Figure 1. The percentage contributions of particles on each of the routes are also shown. The particles in Route-2 and 3 cross the equator and upwell at various pockets in northern Indian Ocean, namely, Somali Coast, Bay of Bengal and Arabian Coast and return to southern Indian Ocean following annual mean southward Ekman transport. These particles are connected from north to south at the equator by means of a shallow overturning roll existing at the equator. These particles undergo subduction at the subduction zone (~25^{0}S) and exit via Mozambique Channel.

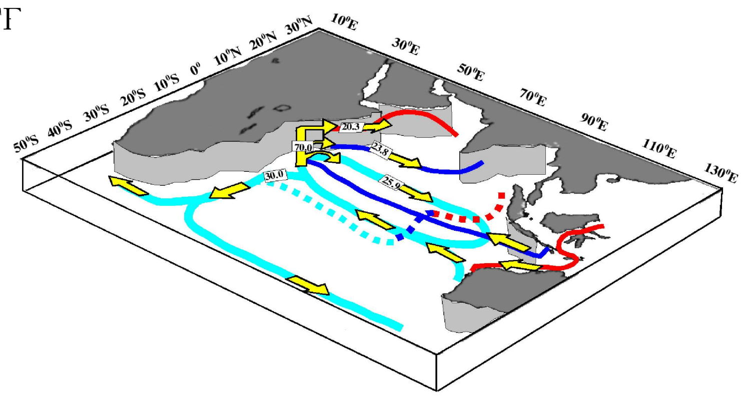

Figure 1: Schematic view (Valsala and Ikeda, 2005b).

3.2 Tracer pathways

The tracer pathways are generally in conformation with the particle trajectories however they are spread horizontally due to diffusion. At the entrance region, the subsurface tracer (released 60m to 120m initially) reached to the surface by vertical mixing, which shows that the ITF undergoes vigorous mixing as soon as in enters the Indian Ocean. A few additional pathways are turned out from the tracers, especially the upwelling of subsurface ITF at the southern Java coast. It is confirmed with backward particle trajectories. The tracer concentration shows that about 1.6 Sv of Lombok throughflow upwell at the south Java coast during the boreal summer (Aug-Sep).

3.3 Effect of the ITF in temperature and salinity

The control model run is compared with an artificially closed ITF run. The difference between these cases shows that the thermocline of the Southern Tropical Indian Ocean (STIO) is largely influenced by the warm and fresh component ITF. The dynamic topography across the STIO is elevated and it owe to the fresh and warm ITF there. This causes geostrophic current to be stronger in the real case and affect the thermal structure of below the thermocline off-southwestern coast of Australia.

The ITF is found to have a significant signature in the surface Indian Ocean, mainly at (1) the entrance region (2) Somali-Arabian coastal upwelling region, (3) equatorial upwelling region and (4) south of 40^0S. The first three of these regions have direct influence of ITF advection. However in the region-4, there is no confirming surface pathways of the ITF and it is found that the enhanced convective overturning associated with the fresh ITF below 300m at that region is the reason for such anomalies. The signature in the surface salinity shows that the ITF has more direct effects on the upwelling zone of south of Java. There are some positive sea surface salinity anomalies which are not due to the direct presence of the ITF instead they are produced by the modification of thermohaline circulation due to the closure of the ITF.

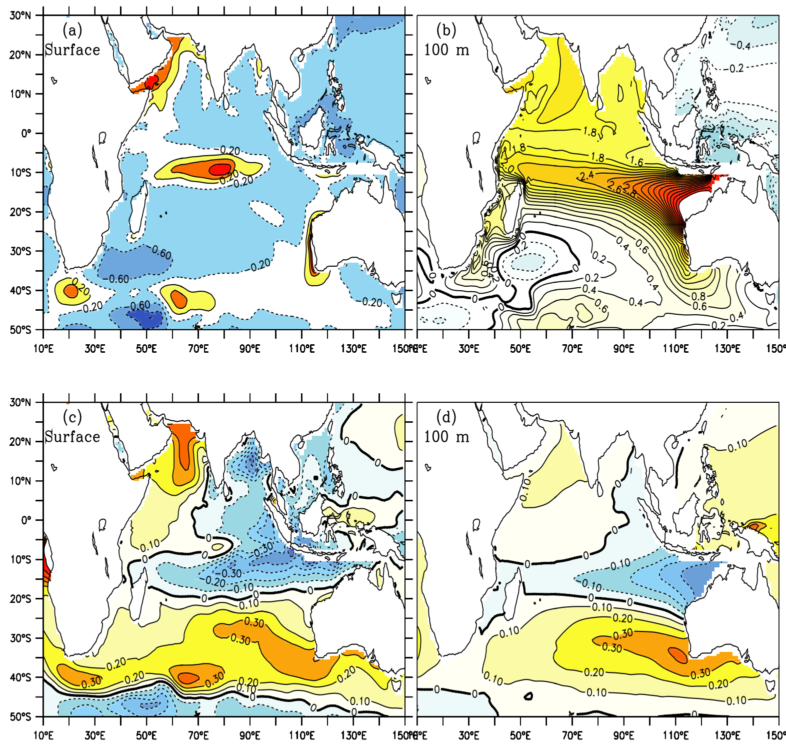

Figure 2: Temperature (upper) and Salinity (lower) signature of the ITF in the Indian Ocean is shown for surface and subsurface (100m).

The thermocline signature of the ITF in temperature and salinity (100m) are in confirmation with the ITF pathways. The ITF causes the warming and freshening of the thermocline of STIO. The ITF interacts with the atmosphere at various pockets, namely, the entrance region close to the northwestern coast of Australia, Somali upwelling region, and equatorial Indian Ocean and has influence on the climate. In addition, the ITF modifies the basin wide circulation of the Indian Ocean by affecting the water mass properties. Thus the understanding of 3-D pathways helped us to find the impact of the ITF on the Indian Ocean climate in more detail.

List of Publications, (Valsala and Ikeda, 2005a,b)

Valsala, V. K. and M. Ikeda, 2005a: An Extreme Drought Event in the 2002 Summer Monsoon Rainfall and its Mechanism proved with a Moisture Flux Analysis. *Scientific Online Letters on the Atmosphere*, **1**, 173–176.

— 2005b: Pathways and effects of the Indonesian Throughflow water in the Indian Ocean using Particle trajectory and Tracers in an OGCM. *J. Climate*, (in press).