Pathways and effects of the Indonesian Throughflow water in the Indian Ocean using Particle trajectory and tracers in an OGCM

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Abstract

As the Indonesian Throughflow (ITF) brings large amount of heat from the Pacific Ocean to the Indian Ocean it has a significant role in determining the climatology of the Indian ocean as well as the Atmosphere above it. In this study we are intended to find the pathways of the ITF in the Indian Ocean and its effects in the Indian Ocean Temperature and Salinity. The pathways of the ITF are traced in an OGCM using Lagrangian type particle trajectories as well as using "passive tracers". At the immediate entrance region the surface ITF advects along the Australian coast and subduct at the north-west coast of Australia, while sub-surface (> 60m) ITF advect across the Indian Ocean from west to east. At the western Indian Ocean the majority of the ITF turns to the north and re-directed into three distinct depth ranges. They are (1) across the Indian Ocean along the south of the equator (200m-300m) (2) across the Indian Ocean along the north of the equator (100m-200m) and (3) up-wells at the Somali coast and spread all over the surface (0-100m). The pathways of the passive Tracers show that the ITF mixes vigorously at the entrance region and this implies a heat release of the ITF to the atmosphere. In a model run with "no ITF" revealed that the ITF induced temperature and salinity prints are accompanied with its major pathways.

1 Introduction

The ITF is the warm route of the Global Conveyor belt from the Pacific Ocean to the Atlantic, crossing the Indian Ocean. During this journey, the ITF spreads significantly in the Indian Ocean and modifies its water types. Thus the spreading pathways of the ITF in the Indian Ocean are important to investigate. Apart from the conventional methods of identifying the watermass using the classical T-S analysis, here we make use of a set of tools in an OGCM, which has advantages of its own. They are 1) Lagrangian type particle trajectories, which are neutrally buoyant, efficient in representing the large scale circulation, whereas devoid of horizontal diffusion and vertical mixing, 2) passive tracers with no surface forcing, which undergo advection, horizontal diffusion and vertical mixing 3) temperature and salinity.

2 OGCM and method of study

In this study, we use ACOM2.0 (Australian Community Ocean Model), which is an OGCM based on MOM2.0. The model domain contains the Indian Ocean and Pacific Ocean with a northern boundary at 40°N and southern boundary at 65°S and with a constant resolution of 0.5° in both the x and y directions. The model has 25 vertical levels with first 16 in the upper 300m. The model is spun with monthly climatological surface forcing to attain a steady state solution. From this steady state, the following experiments are done. 1) Lagrangian Trajectories of the particles representing the ITF are tracked using the instantaneous velocity fields derived from the model. For this experiment, twenty thousand particles are released on January month at the Indonesian straits at every 15m vertical level. Particles are tracked for 20 years. 2) Passive tracers are released at the same domain as the particles and integrated using the same time step as the model integration (900 Sec). It is run for 10 years. 3) An artificial run is produced by closing the ITF by a land bridge and allowing no throughflow to the Indian Ocean. A comparison of the reference run with this artificial case is used to find out the effects of ITF in the Indian Ocean temperature and salinity.

3 Pathways of the ITF in the Indian Ocean

3.1 Lagrangian particle trajectories

The major routes of the ITF in the Indian Ocean revealed from the particle trajectories are shown in the Figure 1. The depth information of the particles is coded by different color. At the entrance region, the surface particles (<60m) travel to the south and subducts at the north-west coast of Australia, while the sub-surface particles advect straight across the Indian Ocean as a narrow jet following the south equatorial current. Upon reaching the western coast of the Indian Ocean, the majority of the ITF turns to the northern Indian Ocean and reroutes into three distinct depth ranges. They are Route-1: across the Indian Ocean along the south of the equator (200m-300m), Route-2: across the Indian Ocean along the north of the equator (100m-200m) and Route-3: upwells at the Somali coast and spreads all over the surface Indian Ocean (0-100m). These distinct routes are shown in Figure 1.

After reaching the eastern Indian Ocean, the particles in the Route-1 turn to the south and reach the subduction of the Southern Tropical Indian Ocean (20°S-30°S). These particles subduct there and further they take a deeper route across the Indian Ocean and exit via Agulhas channel in the western Indian Ocean. The particles in the Route-2 upwells at the Bay of Bengal. These particles cross the equator from north to the south by following the annual mean southward Ekman transport, which is linked by a shallow meridional overturning circulation at the equator. After reaching the southern Indian Ocean, these particles follows the same pathway as the Route-1 particles. The particles in the Route-3 are spread all over the surface Indian Ocean and undergo chaotic pathways owing the the seasonal reversal of the surface Indian Ocean. These particle eventually crosses the equator as the same way as the particles in Route-2.

3.2 Tracer pathways

The pathways of the ITF revealed from the tracers are shown in Figure 2 for the first two tracers. (Tracer-1 released at 0-60m and Tracer-2 released at 60m-120m). Tracers are vertically mixed at the ITF entrance region. This additional property shown by the tracers imply that the ITF undergo vigorous mixing at the entrance region and loses its T-S characteristics. In addition to this vertical mixing, the tracer shows the spreading of the ITF across the latitude to the south owing to the horizontal diffusion. This diffusive erosion causes the ITF to spread out of the main jet, than shown by the particle trajectories.

At the western boundary majority of the tracers advects to the northern Indian Ocean, owing to the strong northward boundary currents. This is consistent with the particle trajectories. Additional features of the pathways revealed in tracer are, 1) vertical mixing at the entrance region in the eastern Indian Ocean 2) the upwelling along the Java-Sumatra coast and 3) spreading of the ITF related to the annual Rossby waves in the Southern Tropical Indian Ocean.

3.3 Effect of ITF in the Indian Ocean Temperature and Salinity

The ITF is relatively warmer and fresher than the Indian Ocean. The effect of ITF water in the temperature and salinity of the Indian Ocean are shown in the Figure 3. The figure shows the "difference" between two model runs (reference case and closed throughflow case). The resulting "anomaly" fields are shown for the temperature and salinity in the surface and sub-surface(100m) levels. The ITF warms and freshes the sub-surface Indian Ocean. In the sub-surface level the temperature and salinity signature of the ITF are consistent with its major pathways. However in the surface, there are remote regions (eg. south of 40°S) where the ITF influences the temperature and salinity of the Indian Ocean. These are generated due to the modification in the circulation of the Indian Ocean due to the presence of fresh and warm ITF.

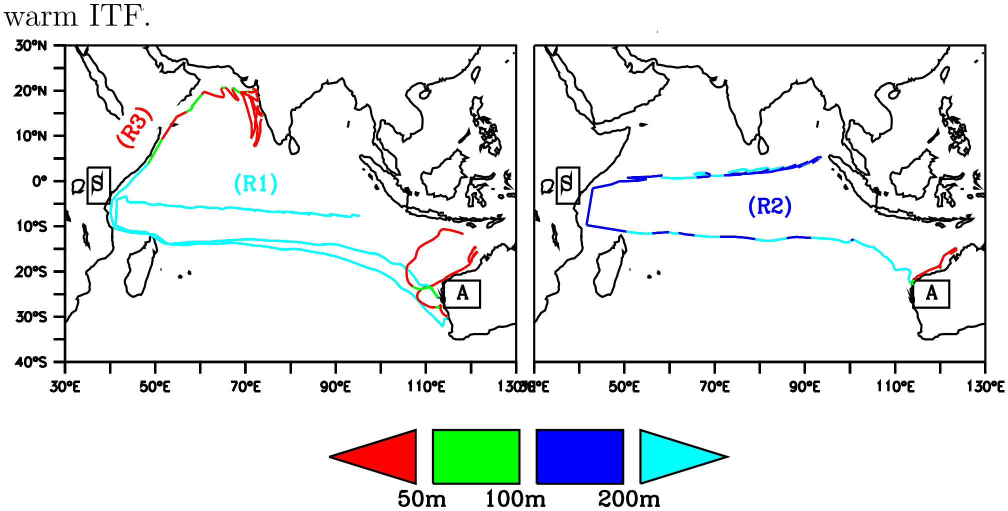

Figure 1: The distinct routes of ITF in the Indian Ocean in 20 years as revealed from the Lagrangian particle trajectories.

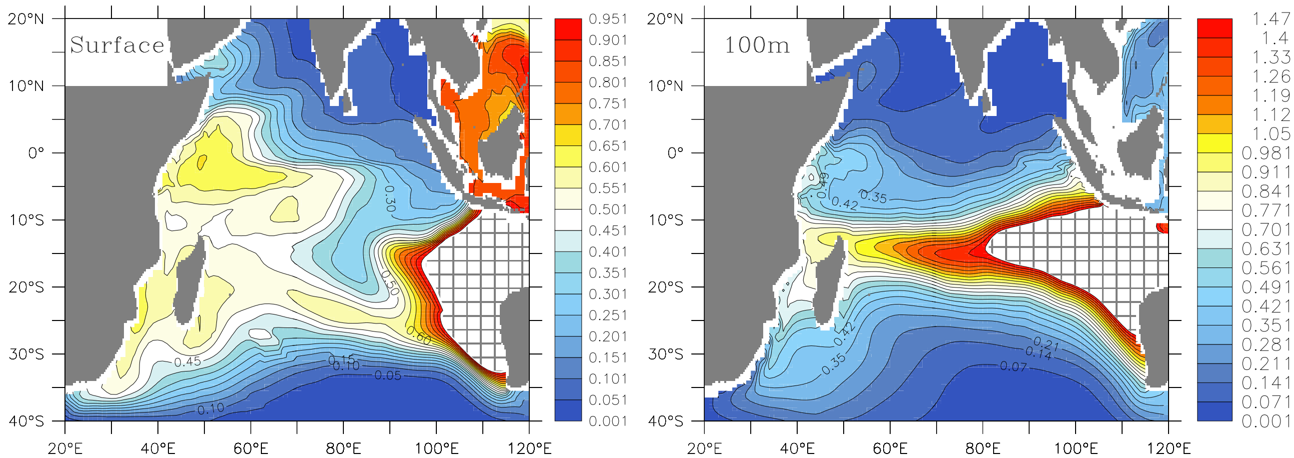

Figure 2: Pathways of ITF revealed from the Tracers are shown for the surface and subsurface (100m). Tracer-1 and Tracer-2 are summed together. The presence of ITF at the major upwelling zones in the Indian Ocean are apparent. Subsurface ITF travels as a jet across the Indian Ocean and spreads around due to the horizontal diffusion.

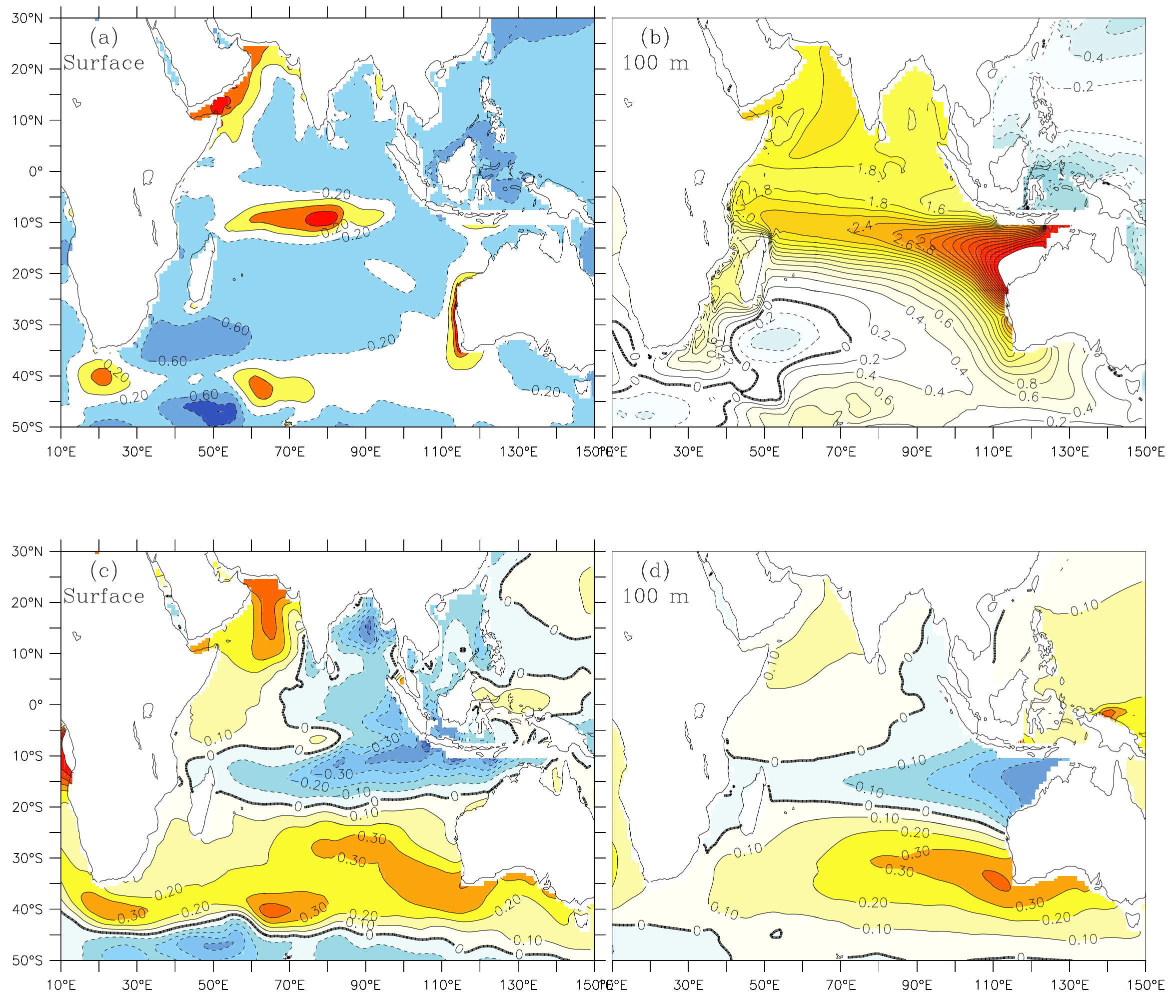

Figure 3: Influence of ITF in the Indian Ocean (a,b) temperature and (c,d) salinity are shown for the surface level and sub-surface (100m) level.