Geoinformation Science Journal, Vol. 10, No. 2, 2010, pp: 52- 61

SURFACE CIRCULATION AND TRANSPORT IN THE MOZAMBIQUE CHANNEL

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ABSTRACT

Surface circulation and transport in the Mozambique Channel have been determined using altimetry and the hydrographic section along 25 °S covered during the World Ocean Circulation Experiment. Vertical sections of potential temperature and salinity are prepared to understand the water characteristics. The meridional component of geostrophic velocity is computed referring to the deepest common depth between stations. The mean circulation field exhibits the strong Mozambique current in the northern part of the Channel. But, it is weakened and embedded with anticyclonic eddies towards south. The geostrophic flow reveals the eddy circulation in the Mozambique Channel. The meridional volume and heat transports have been estimated and presented with respect longitude. Both the net volume transport and the heat transport are towards south and are 22.8 Sv and 0.7 pw respectively.

Keywords: Circulation, Transport, Mozambique Current, Eddies

1.0 INTRODUCTION

The Mozambique Channel in the south-western Indian Ocean is receiving much attention from oceanographers as it is an important region of mesoscale eddy activity. The Mozambique Current has been perceived as a western boundary current to the wind-driven system in the southwest Indian Ocean. It is supposed to be a key link in the, climatically important, global thermohaline circulation by carrying tropical surface and thermocline water poleward through the Mozambique Channel and eventually into the South Atlantic. Africa, as the western boundary of the Indian Ocean subtropical region, does not extend southward to the edge of the wind stress region, that would define a complete subtropical gyre and so the gyre "runs out of western boundary". This results in the reteroflection of the Agulhas Current when it reaches the southern end of Africa, distinguishing the Aglhas from the subtropical western boundary currents of the other oceans.

Earlier studies of Grundlingh (1997) reports the circulation of the Mozambique Channel using drift buoys data. The South Equatorial Current on approaching the African Coast, it bifurcates in to north and south. The southward branch continues poleward as the Mozambique Current. The satellite and in situ observations have shown that the Mozambique Current does not proceed as a continuous western boundary current but, instead, breaks up into a train of anticyclonic eddies around the narrow section of the of the Channel (de Ruijter et. al., 2002). Satellite altimetry data showed inter-annual variability of the rate of formation of Mozambique Channel eddy probably related to the large scale climate anomalies over the equatorial Indian Ocean (Schouten et al., 2002)

ISSN 1511-9491© 2009 FKSG

Current meter observations across the channel at 17°S have shown large fluctuations of the transport between 20 and 50 Sv (Ridderinkhof and de Ruijter,2002). Benny (2002) derived the long-term average bimonthly flow pattern employing thermal field. Using SeaWifs data Quartly and Srokosz (2003) presented a visible record of eddies in the southern Mozambique Channel. A large portion of these eddies propagated all the way into the Agulhas retroflection region, where they seem to trigger the shedding of Agulhas rings (Van Leeuwan et al., 2000). Further, these Agulhas rings carry warm and salty Indian Ocean waters into the South Atlantic Ocean (Gordon et al., 1987). A recent study of Roshin et al. (2010) describes the role of eddies in the biological productivity of the Mozambique Channel.

2.0 METHOD

The surface circulation is obtained from the high resolution Eulerian velocity field estimated by combining satellite altimetry and surface drifter data by Benny et al., (2008). The mean field, anomaly field and seasonal patterns have been constructed.

The hydrographic section between Africa and Madagascar approximately along 25 °S covered during the World Ocean Circulation Experiment in June 1995 is used in the present study to estimate the meridional transport. Vertical sections of temperature and salinity are also prepared using the CTD data. The meridional geostrophic velocity, volume transport and heat transport have been estimated. The location of hydrographic section is shown in **figure 1**.

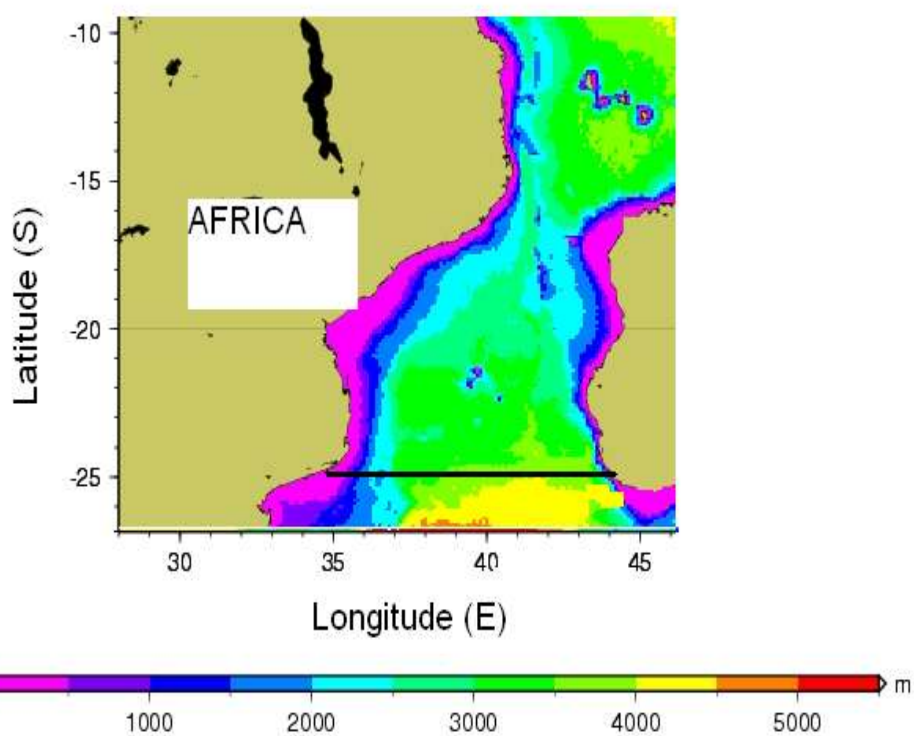


Figure 1. Bottom topography of the study region and the location of hydrographic section (black solid line)

The geostrophic velocity at standard depths up to the surface is computed with reference to the deepest common depth between the adjacent stations. The volume transport and heat transport are estimated using the computed geostrophic velocity. The unit Sverdrup (Sv) is used to denote the volume transport (1Sv= 10^6 m^3/s).

2.1 Geostrophic velocity

The geostrophic velocity between two stations is computed using the Helland-Hansen equation,

$$v = (10/fL)\,(\Delta D_A - \Delta D_B)$$

Where; v = average current velocity normal to a line between stations A and B.

$(\Delta D_A - \Delta D_B)$ = Dynamic height anomaly difference between stations A and B

L= distance between stations A and B

f = Coriolis parameter

2.2 Volume transport

The volume transport is given by,

$$\text{Volume Transport} = \int_{x_w}^{x_e} \int_{-D}^{0} v.dx.dz$$

The integration is made from bottom (-D) to the surface, and from the west (x_w) to the east(x_e)

Where, v= average current velocity normal to a line between stations A and B.

dz= difference between the consecutive depths

dx= distance between stations A and B

2.3 Heat transport

The meridional heat transport is estimated using the equation,

$$\text{Heat Transport} = \int_{x_w}^{x_e} \int_{-D}^{0} \rho.c_p.v.\theta.dx.dz$$

Where, ρ = denisity of sea water =1025 kg/m^3

C_P = specific heat of sea water at constant pressure=3998 J kg^{-1} °C

θ = mean potential temperature

v = meridional velocity

The equation is integrated from bottom (-D) to the surface and from west (x_w) to east (x_e).

3.0 RESULTS

3.1 Surface circulation

The Eulerian mean velocity field, anomaly field as well as the average absolute velocity fields of January and July is shown in f**igure 2**.

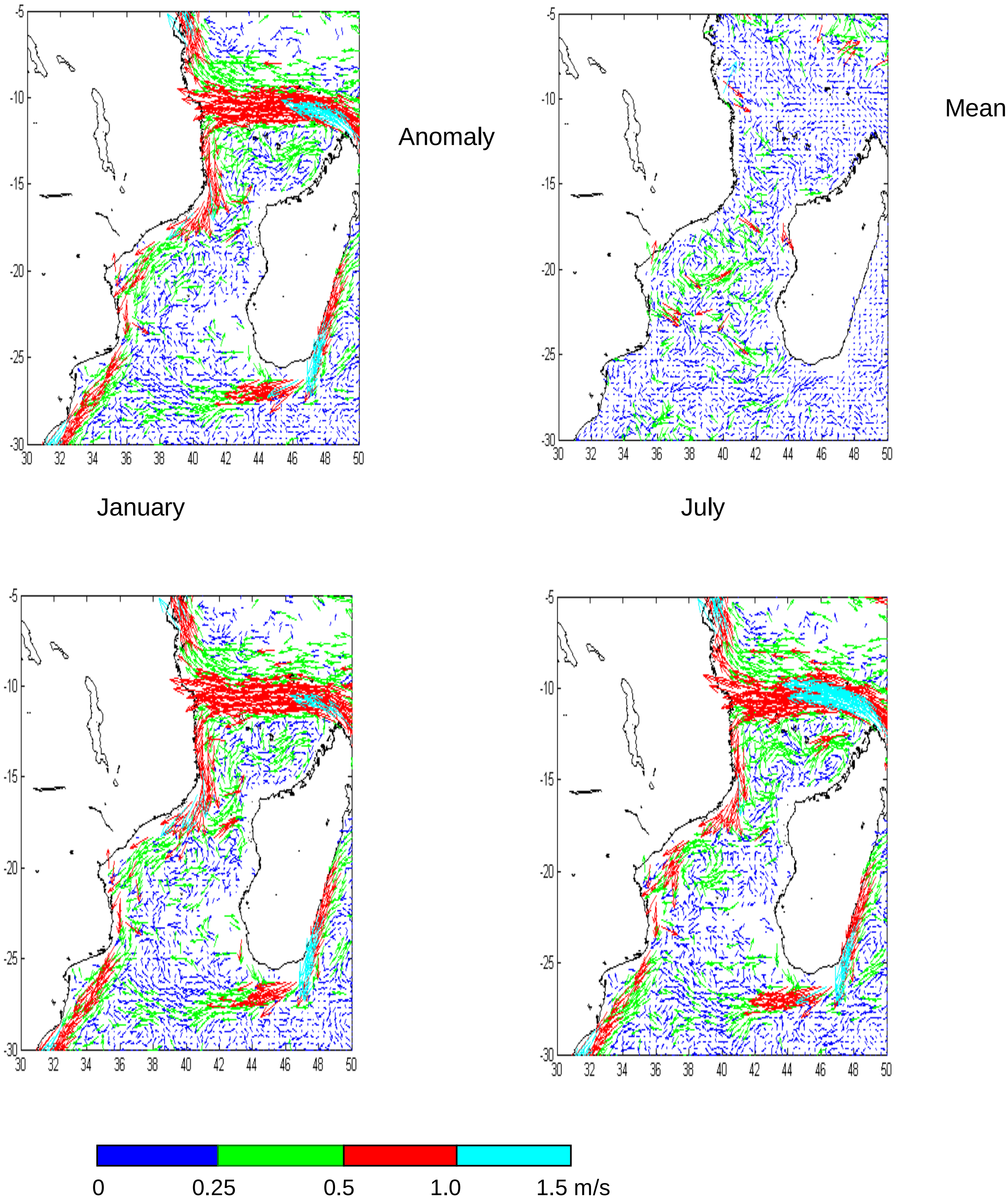


Figure 2. Surface velocity field

The mean surface velocity field exhibits active circulation in the northern part of Mozambique Channel, where the zonal South Equatorial current branches at the African coast towards north and south components. The southward component flows along the eastern boundary of Mozambique and joins with the westward component of East Madagascar Current and forms the strong western boundary Agulhas Current. The Mozambique Current generates number of eddies during its southward flow owing to the instabilities developing from coastal and bottom topographical constrains.

The anomaly field is quite strong in the southern part of Mozambique Channel where current speed varies above 50 cm/s. It also reveals presence of vortices in different parts of the Mozambique Channel. The seasonal (January and July) absolute current field shows slight variations in the Mozambique Channel. The Mozambique Current is more stable and continuous in January compared to July. But, eddy activity dominant in July. It seems that seasonal variations are related to the changes in the zonal South Equatorial Current.

3.2 Water characteristics

The vertical sections of potential temperature, salinity and geostrophic velocity along 25°S are presented to understand the watermass assembly of the region. Since strong variations are observed in the surface layers, the vertical section is prepared separately up to 500m in a magnified scale to bring out the maximum information possible.

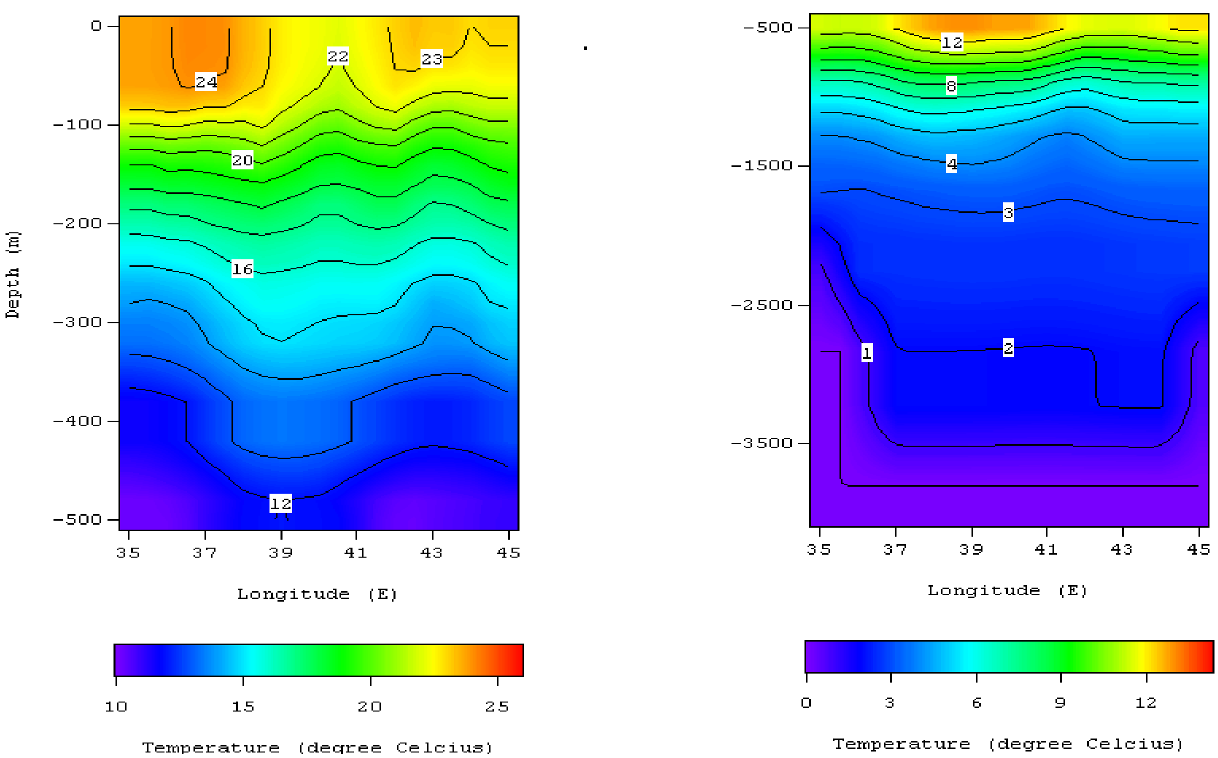
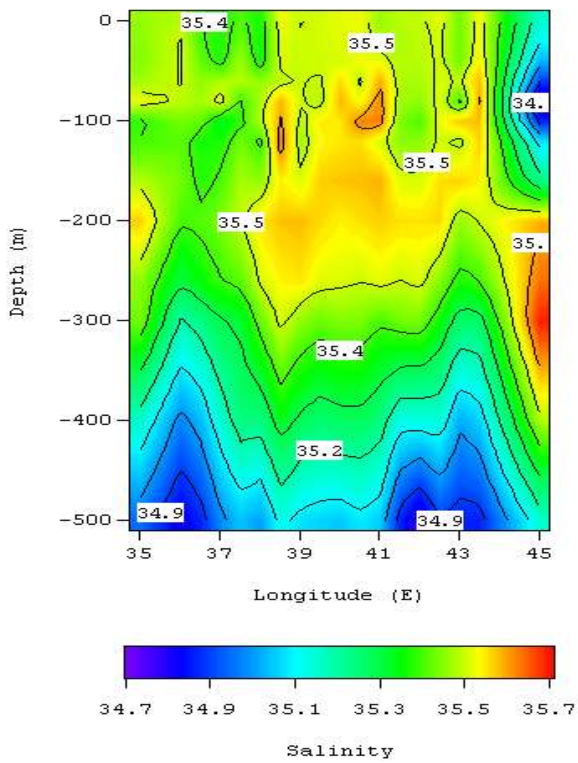


Figure 3. Vertical section of potential temperature

3.2.1 Potential temperature

The vertical section of potential temperature (**figure 3**) between Africa and Madagascar shows conspicuous horizontal variation in the surface layers. In the eastern and western parts of the section warm surface waters are present, whereas comparatively cool waters are noticed in the central part between 38 and 42 °E. The surfacing of isotherms at this region suggests upwelling of subsurface cool waters. The temperature structure around 37 °E shows a possible surface sinking. A weak thermocline is present between 80 and 200m, where a temperature variation of 5 °C is observed. The orientation of the isotherms (opposing slopes) below 200m suggests the opposing flow pattern in the surface and subsurface levels. The wave like pattern of isotherms indicates deep reaching (up to 2000m) eddy activity in the region.



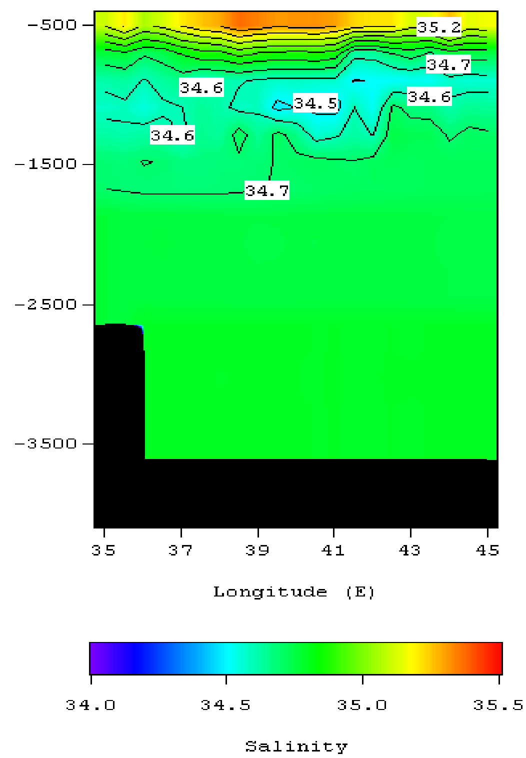


Figure 4. Vertical section of salinity

3.2.2 Salinity

Vertical section of salinity shows heterogeneous surface distribution (**figure 4**). Strong horizontal variation is observed in the surface layers up to 250m. High salinity water is observed in the eastern part, near Madagascar compared to the west. Salinity is minimum around 37 °E, where sinking is noticed. The high salinity layer extends from surface to 250m depth between 38 and 40 °E supports the upwelling indicated in the temperature distribution. Below the surface, 200-600m depths a weak halocline is present, where a salinity variation of 1 psu is noticed. The low salinity water observed at around 1000m in the west and east is the intrusion of Antarctic Intermediate Water in the Mozambique Channel. In the deeper levels the salinity characteristics confirms the presence of Indian Ocean Deep Water. Antarctic Bottom Water is not found in this region.

The water characteristics indicate that the surface water is a mixture of different watermasses, its formation are highly influenced by the coastal processes as well as the eddy circulation occurring in this region.

3.3 Geostrophic Velocity

The meridional component of geostrophic velocity determined with respect to the common deepest depth between the adjacent stations along the section is shown in **figure 5**. The positive and negative values represent the southward and northward flows respectively. It is interesting to note that along this section strong southward flow is taking place at the western and eastern part, while northward flow prevails at the central region, which indicates the eddy circulation occurring in the Mozambique Channel. Strong southward flow is occurring near the Madagascar Coast. Below 1000m, strong counter current (northward) is occurring between 35 °E and 38 °E. The flow is very weak below 3000m.

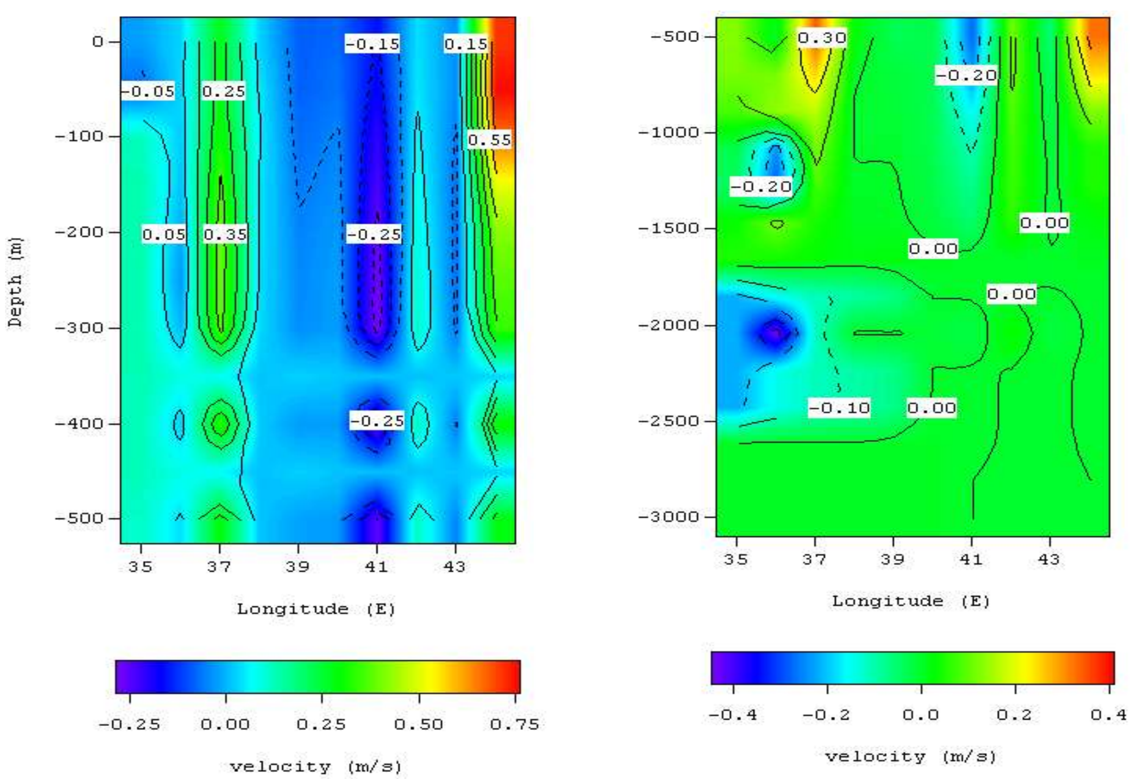


Figure 5. Vertical section of meridional geostrophic velocity

3.4 Volume Transport

The volume transport between Africa and Madagascar is represented with respect to longitude is shown in **figure 6**. Alternate southward and northward flows are observed. The transport estimated is 76.8 Sv and 54 Sv towards south and north respectively. The net transport is towards south and is 22.8 Sv. The major southward transports are occurring around 37 °E and 42 °E, whereas the northward transport is concentrated between 40 °E and 42 °E. The alternate cores of southward and northward flows are due to the prevailing eddy circulation in the Mozambique Channel.

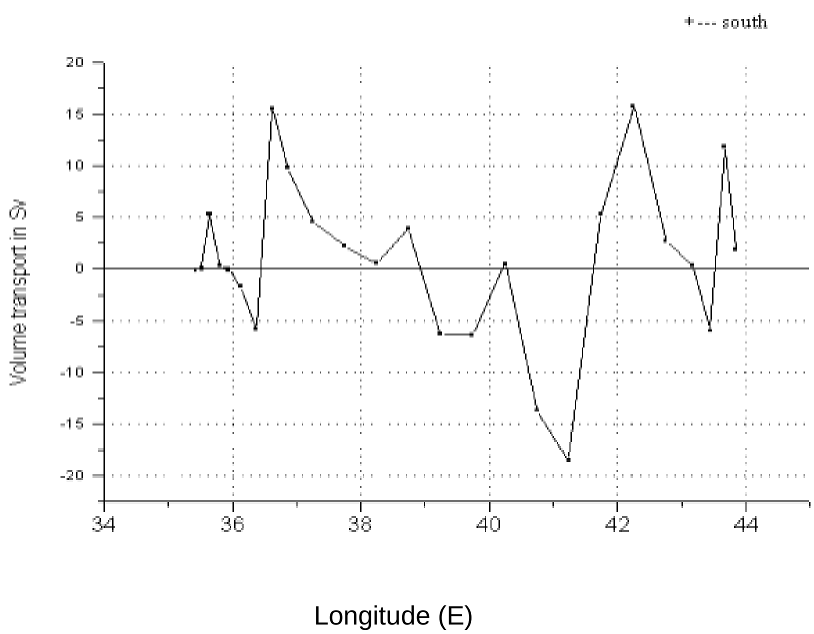


Figure 6. Volume transport with respect to Longitude

3.5 Heat transport

The heat transport distribution is similar to the volume transport. The net meridional heat transport obtained is 0.7 pw towards south (**figure 7**). The longitudinal distribution shows the major southward cores around 37 °E, 42 °E and 43 °E. Whereas, the northward heat transport cores are at about 39 °E and 41 °E. The quite low transport off Africa shows the opposing flows in the region.

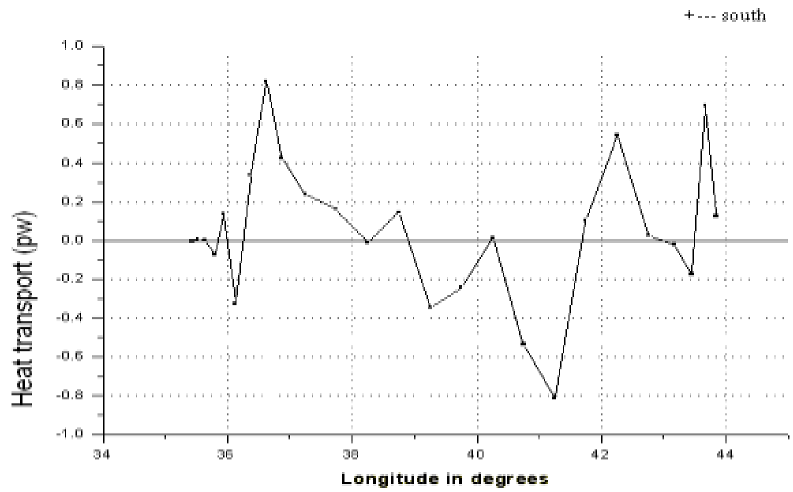


Figure 7. Heat transport distribution with respect to longitude

4.0 CONCLUSIONS

Significant spatial and temporal variations are found in the surface circulation of the Mozambique Channel. Southward flowing Mozambique Current is strong in the northern part of the channel, where, the current speed even reaches 1m/s. Towards south the current is weakened and embedded with eddies. The Mozambique Current is more stable and continuous in southern summer (January) compared to winter (July). During winter, high eddy activity is occurring throughout the Channel. The anomalous velocity field is strong in the southern part of the Channel.

The water characteristics exhibit vertical and horizontal variation across the Channel. Horizontal variation is prominent in the surface layer. The surface water characteristics are much influenced by the coastal processes and the vertical motion due to the eddy activity. The low saline Antarctic Intermediate Water is present in the channel at around 1000m depths. The Indian Deep Water resides below the Antarctic Intermediate Water. The water characteristics reveal that the Antarctic Bottom water is not reaching in this region.

The geostrophic velocity distribution confirms the eddy circulation. Below the Mozambique Current, strong return under current is present. The net volume transport through the Mozambique Channel at 25 °S is 22.8 Sv, towards south. Southward transport is mainly occurring in the western and eastern parts, while the northward transport is at the central region. The net heat transport is also southward and is 0.7 pw.

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