Mozambique Channel eddies as transport mechanisms: The case of Red Sea Water

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Outline

• The Indian Ocean and Mozambique Channel circulation
• Red Sea Water – how is it thought to be transported through the Mozambique Channel and why is it so important?
• Argo and SLA Altimetry historical data analysis – what does our data show?
• Future Argo Projects
• **Southern Ocean**
  - Antarctic Circumpolar Current
  - Flow around the globe completely unhindered
  - Fronts and areas of convergence
  - Source of Antarctic Intermediate Water (AAIW)

• **Indian Ocean**
  - Seasonal monsoonal circulation
  - No temperate and polar region to the north
  - South Equatorial Current (SEC) flows east to west, strengthening en route
  - Fed by throughflow of Pacific water through the Indonesian Sea
  - SEC bifurcates around Madagascar: NEMC – Northeast Madagascar Current (S)EMC – (South)East Madagascar Current

Black – mean current flows without seasonal trends
Gray – Monsoonal reversing circulation
The Mozambique Channel

• South Equatorial Current
  ❖ Bifurcates around Madagascar: NEMC and (S)EMC
  ❖ NEMC – splits flow northwards into the East African Coastal Current (EACC) and southwards around the Comoros Islands
  ❖ (S)EMC – flow retroflects south of Madagascar shedding eddies to the west and flow eastwards as an equatorial counter current

• Mozambique Channel
  ❖ Flow southwards is dominated by train of mesoscale eddies
  ❖ Northward flowing undercurrent through the channel carrying AAIW and North Atlantic Deep Water (NADW)
  ❖ Water from the Channel and (S)EMC flows into the Greater Agulhas Current
Red Sea Water – The Source

- Red Sea Water forms as a high-salinity water mass due to intense evaporation
- It flows over the 160 m deep sill at Bab al Mandeb and sinks into the Gulf of Aden
- On leaving the Red Sea: Temperature of 22°C and a salinity of 39
- Seasonal outflow: 0.6-0.7 Sv during Winter Monsoon, near zero during Summer Monsoon
- Transport through Gulf of Aden by means of mesoscale eddies
- On leaving Gulf of Aden, Red Sea Water has a salinity of 35.7
Red Sea Water – The distribution

- Flow out from Gulf of Aden into Arabian Sea
- Monsoonal driven circulation in northern Indian Ocean
- Extends eastwards into Indian Ocean
- Southwards into Mozambique Channel
- Red Sea Water has been recorded within the southward flowing Agulhas Current and even in Agulhas Rings shed into the South Atlantic Ocean

- The Agulhas Current contributes significantly to the Thermohaline Circulation
- The salt from Red Sea Water travels along this powerful current and enters the South Atlantic, in a less pure form, but contributing to the salt budget nonetheless
Is Red Sea Water transported through the Mozambique Channel by means of mesoscale eddies as suggested by previous studies in the region?
Argo and SLA historical data analysis

Methods

- Argo data downloaded from all data centers from the USGODAE website for the area: 7° - 29° S, 32° - 50° E
- October 2002 – December 2010
- Float profile data plotted in Ocean Data View and analyzed for Red Sea Water:
  Salinity: 34.7 – 34.9
  Temperature: 5 – 7°C
- Red Sea Water positive profiles extracted out along with latitude, longitude and date

Mozambique Channel Water Masses:
STSW – Sub-tropical Surface Water
SICW – South Indian Central Water
AAIW – Antarctic Intermediate Water
RSW – Red Sea Water
NADW – North Atlantic Deep Water

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Methods

• Automatic eddy detection script developed by Alexis Chaigneau, IRD (Chaigneau et al, 2008)
• ¼ degree delayed time SLA product, using re-processed AVISO data
• Mean dynamic topography is RIO9 processed
• Eddy detection scheme used for 1992 - 2010
• Red Sea Water positive profiles were matched up to the closest SLA date and plotted to determine where the Argo profile was collected in relation to the eddy field
• Three possible areas within the eddy field:
  • Anti-cyclones (+ve SLA)
  • Cyclones (-ve SLA)
  • Background flow

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Data Limitations

- Argo floats drift for 9 days between profiles
- Depth of float during drift may be underneath the eddy

- SLA delayed time data every 7 days
- Some Argo profiles and SLA plots link up for the same day (10% of data), but the rest are mismatched (maximum of four days)
Argo and SLA historical data analysis
Results - Total RSW positive profiles

All data
76 floats
(8 bad data)
1817 profiles

RSW positive
510 profiles
28.06 %
Argo and SLA historical data analysis

Results – RSW water structure

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Results – Eddies vs. background flow

RSW positive profiles within anti-cyclonic eddies
113 cases
22.15 %

RSW positive profiles within cyclonic eddies
111 cases
21.75 %

RSW positive profiles outside of mesoscale eddies, i.e. within background flow
277 cases
54.30 %

9 cases (1.8 %) of RSW positive floats cannot be linked to SLA images (end December 2010)
Argo and SLA historical data analysis
Results – Seasonality of RSW in eddies?

Cyclones are more prominent in winter, mirroring a decrease in anti-cyclones over the same time period, suggesting some seasonality to eddy transport of RSW water through the Mozambique Channel.

Seasonality of mesoscale eddies linked to RSW positive profiles:

a) Cyclones (n=111)
b) Anti-cyclones (n=113)
Argo and SLA historical data analysis
Results – RSW transport within eddies

8 scenarios of this RSW positive Argo float entrapped within mesoscale eddies for an extended period of time (minimum 28 days):

<table>
<thead>
<tr>
<th>Cyclones</th>
<th>Anti-cyclones</th>
</tr>
</thead>
<tbody>
<tr>
<td>July – September 2005: 64 days</td>
<td>November/December 2004: 43 days (example next slide)</td>
</tr>
<tr>
<td>January/February 2006: 31 days</td>
<td>May – July 2005: 32 days</td>
</tr>
<tr>
<td>May/June 2007: 33 days</td>
<td>November/December 2008: 43 days</td>
</tr>
<tr>
<td>July – September 2009: 48 days</td>
<td>April – June 2009: 42 days</td>
</tr>
</tbody>
</table>

One float (1900180) became entrapped first in the anti-cyclone for 32 days, before moving into the cyclone for effectively 64 days, showing a strong example of RSW being transported between eddies through the Mozambique Channel.
Argo and SLA historical data analysis
Results – RSW transport within eddies
Results Summary

- **RSW positive profiles** were found primarily in the north and central Mozambique Channel and accounted for **28.06 %** of the total Argo profiles of the study area.

- RSW was found **54.30 %** of the time in the background flow of the Mozambique Channel with the remaining time divided between **cyclonic (21.75 %)** and **anti-cyclonic (22.15 %)** mesoscale eddies.

- **Seasonality** of mesoscale eddy transport is **suggested** with **cyclonic eddies** dominating mesoscale eddy flow in **winter** and **anti-cyclonic eddies** in **summer**.

- **Eight scenarios** of transport of RSW with mesoscale eddies exist – four for anti-cyclones and four for cyclones – with **one scenario of a float being transported from an anti-cyclone to a cyclone**.

Results suggest that RSW is not transported primarily by mesoscale eddies through the Mozambique Channel as concluded by previous work, given the limitations of both the Argo profile data (9 day drift) and delayed SLA data (7 day gap).
Future Argo Projects

Western Indian Ocean Argo Deployments

Historical Argo deployments*:

- Global Ocean: 8871
- Western Indian Ocean (WIO): 340
- Mozambique Channel (MC): 17

*As at 31 August 2012. Source: JCOMMOPS website

In partnership with Agulhas Somali Current Large Marine Ecosystem (ASCLME) Project and the Western Indian Ocean Sustainable Ecosystem Alliance, the objective is to build on deployments within these two regions, particularly where piracy has put a stranglehold on oceanographic observations in the north.
Future Argo Projects
Mesoscale eddy aging

Work planned:
• CTD and S-ADCP survey
• XBT
• Underway CTD
• Satellite drifters
• Argo survey (detail below)
Future Argo Projects
Mesoscale eddy aging

“Argo Dance”
• 6-8 (Bio)Argo floats
• 1 day profiles
• ~300 m depth
• Deployed in a transect across eddy
• Aim: to capture the euphotic zone pumping of a cyclonic eddy and thus its sustainability
These data were collected and made freely available by the International Argo Program and the national programs that contribute to it (http://www.argo.ucsd.edu, http://argo.jcommops.org). The Argo Program is part of the Global Ocean Observing System.