Mesoscale eddies & their role in the formation & transformation of Indian Ocean water masses

A. Koch-Larrouy1, R. Morrow1, T. Penduff2, M. Juza2

Abstract

The sources and pathways of mode waters entering the subtropical gyres of the Indian Ocean are examined. A Lagrangian analysis is performed on an eddy resolving model of the Southern Ocean (DRAKKAR, ¼° Mercator grid), where we trace the subducted mode water’s pathways, identify their formation regions, and trace back whether their source waters come from the Atlantic, Pacific or Indian sectors of the Southern Ocean. We also quantify how the mode water characteristics are modified after subduction, due to internal mixing effects.

Mode Water Definition

We take a large range for mode waters, defined as below 200m, Potential Vorticity (PV) < 0.2 and potential density in the range 26-27.4.

Pathways and volume transport of mode waters which cross the 30°S line

Millions of tiny water mass particles are released within the defined mode waters at 30°S, revealed throughout the time period. We then track the particles back in time and store their changing characteristics along the route. We identify when they were last in contact with the mixed layer. We stop the integration when they reach the analysis boundary at 20°E, 150°E or recirculate through 30°S.

Waters ventilated in the Indian Sector (top panels)

23 Sv of mode waters are ventilated in the Indian sector of the model, and then exit into the subtropical gyre crossing the 30°S line. Of these waters, the major branches come from the Agulhas Retroflection and the northern ACC (19.5 Sv – in pink and blue). There is a small recirculation of Leeuwin Current waters (2.4 Sv – green) and from the Tasman Leakage (1.5 Sv – yellow).

Non-ventilated mode waters crossing 30°S (bottom panel)

44.5 Sv of mode waters exiting at 30°S in the Indian Ocean are non-ventilated – either advected from the Pacific or south Atlantic (5 Sv) or in deeper recirculation cells (mainly eddies at 30°S).

Modification of mode water properties by internal (eddy) mixing AFTER subduction

This figure shows the salinity distribution of the mode waters at each of the main ventilation site (LEFT) at the moment of ventilation and (RIGHT) when they exit at 30°S. The initial salinity distribution is not shown. At 30°S, the salinity distribution is mixed across the whole model domain. The extrema boundaries have been entered.

- The bi-modal or tri-modal structure at the ventilation site has become more homogeneous through eddy mixing.

> Homogeneous mode water properties are created AFTER subduction !

Density distribution of mode waters which cross the 30°S line

Waters ventilated in the Indian Sector

Of the 23 Sv of mode waters ventilated in the Indian sector of the model, which then exit into the subtropical gyre crossing the 30°S line, 8.4 Sv are in the STMW density class, 13.8 Sv are in the SAMW class, and only 1.3 Sv in the AAIW density class. Most of the AAIW which cross 30°S are advected at deeper levels from the Atlantic and Pacific Oceans, and are not ventilated in the Indian Sector.

Waters ventilated in the Indian Ocean

40 Sv of mode waters are ventilated in the Indian sector of the model, which then exit into the subtropical gyre crossing the 30°S line. Of these waters, the major branches come from the Agulhas Retroflection and the northern ACC (39 Sv – in pink and blue). There is a small recirculation of Tasman Leakage (1.5 Sv – yellow).

25 Sv of denser and deeper mode waters transit the Indian Ocean from the Atlantic to the Pacific without touching the surface mixed layer (ADIPac).

SAMW properties at the last ventilation site in the Indian Ocean

Lagrangian particle analysis of SAMW (density class 26.4 – 26.8) for waters formed in the Indian sector of the Southern Ocean, which then exit north at 30°S in the Indian Ocean. These tracers show the SAMW characteristics at the location where these waters were last ventilated properties at the base of the mixed layer. Water mass pathways are varied: the Agulhas Retroflection, Antartic Surface waters, and Leeuwin Current waters.

Summary and Conclusions

The major conclusions of this study are:

1) We have quantified that only one-third of the water exported at 30°S between 20°E and 27.5°E is subducted locally in the Southern Indian Ocean.

2) AAIW exported across 30°S in the Indian Ocean are not ventilated in the South Indian Ocean but advected from other oceans.

3) Three main ventilation sites for SAMW have been identified in the Indian Ocean:
   - WEST: 3.5 Sv lighter SAMW, north of Kerguelen
   - CENT: 6.5 Sv SW of Australia – EAST: 3.5 Sv SW of Tasmnias.

4) The model highlights new important ventilation sites for the deepest and densest SAMW in the TAG and COAST sites.

5) This study modifies the classical vision of MIB ventilation. We find that the last ventilation “leaving” the ML occurred on the adjacent downstream side of the deep WML, mainly due to horizontal advection.

6) Winter re-emergence can occur many years after water leaves the deep WML north of the SAF.

7) Eddies play an important role in the formation of these SAMW
   - Firstly, upstream of the last ventilation site, eddies contribute to mixing different branches together.
   - Secondly, at the last ventilation site, the model shows isolated deep mixed layers (chimneys), mainly created by mesoscale activity.

8) Finally, this study shows that eddies are crucially after the last ventilation in homogenising the T,S properties.

Further Information

Contact : Ariane.Koch-Larrouy@legos.obs-mip.fr
Or Rosemary.Morrow@legos.obs-mip.fr

1. LEGOS: OMP, 16, av. E. Belin, 31400 TOULOUSE, FRANCE
2. LEGOS, BP53, 38401 GRENoble, FRANCE