Diagnostics of the Agulhas Eddies Propagation in Ocean Reanalyses, OGCMs and Satellite Altimetry

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Motivation

- **Agulhas Current** is a classic **western boundary current**

- It is also known as **“Sea of Eddies”**

- **Agulhas** position is controlled by the bottom topography - continental shelf and Agulhas Plateau

- **Surface velocities** in the core are up to 100 cm/s (6km/h), with the peaks up to 245 cm/s

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Motivation

- Agulhas Current plays a **key role** in the global conveyor belt being the strongest WBC:
  - at 32N and S latitude
  - Agulhas: 70 Sv
  - Gulf Stream: 34 Sv
  - Kuroshio: 42 Sv

- Model drifters and **40%** of the Agulhas leakage volume transport reach the North Atlantic within 12 years supporting the dynamics of AMOC circulation

- Agulhas leakage responds to changes in the position and intensity of the westerly winds band in the SH

- It affects decadal variability of the Atlantic Overturning Circulation (r=0.74 - 15 yrs lag)

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Ruhs et al., 2015 - NEMO based study

Durgadoo et al., 2013 - NEMO based study

Biastoch et al., 2008; Biastoch et al., 2015; Kelly et al., 2016
Model experiments design - hindcast 1958-2009

**NEMO INALT**
(Indian Ocean Atlantic Nest)

**FESOM**
(Finite Element Sea-Ice Ocean Model)

(i) The time scales of SSH variability across the Agulhas regions
(ii) Comparison of the SSH variability across the model experiments, ocean reanalyses and satellite altimetry
## Datasets

### Ocean reanalyses

<table>
<thead>
<tr>
<th>Dataset</th>
<th>Resolution</th>
<th>Frequency</th>
<th>Model</th>
<th>Time period</th>
</tr>
</thead>
<tbody>
<tr>
<td>GLORYS 040 (1/4°)</td>
<td>Daily mean</td>
<td>NEMO (MERCATOR)</td>
<td>1993 - pr.</td>
<td></td>
</tr>
<tr>
<td>GLORYS 012 (1/12°)</td>
<td>Daily mean</td>
<td>NEMO (MERCATOR)</td>
<td>1993 - pr.</td>
<td></td>
</tr>
<tr>
<td>SODA (Simple Ocean Data Assimilation)</td>
<td>1/4°</td>
<td>MOMS (University of Maryland)</td>
<td>1980 - 2015</td>
<td></td>
</tr>
<tr>
<td>SOSE (Southern Ocean State Estimate)</td>
<td>1/6° regional SO</td>
<td>Daily mean</td>
<td>MIT GCM</td>
<td>2005 - 2010</td>
</tr>
</tbody>
</table>

### Model experiments

<table>
<thead>
<tr>
<th>Model</th>
<th>Resolution</th>
<th>Frequency</th>
<th>Model Type</th>
<th>Time period</th>
</tr>
</thead>
<tbody>
<tr>
<td>FESOM</td>
<td>unstr. (1/10° highest)</td>
<td>5-daily mean</td>
<td>FESOM (AWI)</td>
<td>1958 - 2009</td>
</tr>
<tr>
<td>NEMO</td>
<td>1/4° global</td>
<td></td>
<td>NEMO (GEOMAR)</td>
<td></td>
</tr>
<tr>
<td>INALT10</td>
<td>1/10° nest</td>
<td>5-daily mean</td>
<td></td>
<td>1958 - 2009</td>
</tr>
<tr>
<td>INALT20</td>
<td>1/20° nest</td>
<td>5-daily mean</td>
<td></td>
<td>1958 - 2009</td>
</tr>
<tr>
<td>INALT60</td>
<td>1/60° nest</td>
<td>5-daily mean</td>
<td></td>
<td>separate years</td>
</tr>
</tbody>
</table>

### Remote sensing

<table>
<thead>
<tr>
<th>Dataset</th>
<th>Resolution</th>
<th>Frequency</th>
<th>Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>AVISO 1/4</td>
<td>ssh, U, V</td>
<td></td>
<td>FESOM, unstr. mesh</td>
</tr>
<tr>
<td>NOAA SST 1/4</td>
<td>(Reynolds SST)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Bandpassing

Adaptation of the methodology, widely used in diagnostics of the atmospheric dynamics:

\[ f(x, y, t) = f_1(x, y, t) + f_2(x, y, t) + f_h(x, y, t) \]

Jones and Simmonds 1993
Zolina and Gulev, 2003
Gulev et al., 2002
Kravtsov et al., 2016
among many others

Example for Sea Level Pressure (Kravtsov et al.,...)

Time series of the band passed
SSH at the point 24.8E;43.4S
Bandpassed SSH in different time ranges, AVISO, 1993-2009

(a) 0 - 20 days
(b) 20 - 40 days
(c) 40 - 60 days
(d) 60 - 80 days
(e) 80 - 100 days
(f) > 100 days

100 m currents, FESOM

(courtesy of Nikolay Koldunov, AWI)
Leading frequency in temporal spectra, AVISO, 1993-2009

First leading freq. in temporal spectra, AVISO, bandpassed

AVISO, 5 years running spectra, 24.8E;43.4S
FESOM, 5 years running spectra
INALT 1/20, 5 years running spectra

Period (days)
80-100 days
60-80 days

spectral power

period (days)

frequency

spectral power

frequency

spectral power

frequency

spectral power

frequency

spectral power

frequency

spectral power

frequency

spectral power

frequency

spectral power

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spectral power

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spectral power

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spectral power

frequency

spectral power

frequency

spectral power

frequency
40-60 days, 1993-2009, focus on Agulhas retroflection

AVISO - INALT 1/10

AVISO - GLORYS2V4_1/4

AVISO - GLORYS012V1_1/12

AVISO - INALT 1/20

AVISO - SODA_1/4

AVISO - SOSE 1/6

AVISO - FESOM

(c) 40 - 60 days
60-80 days, 1993-2009, focus on Mozambique channel

AVISO - INALT 1/10

AVISO - GLORYS2V4_1/4

AVISO - GLORYS012V1_1/12

AVISO - INALT 1/20

AVISO - SODA_1/4

AVISO - SOSE 1/6

AVISO - FESOM

AVISO - GLORYS2V4_1/4

(d) 60 - 80 days
80-100 days, 1993-2009, focus on Central South Atlantic
Diagnostics of the propagating patterns, 60 - 80 days, yr. 2000

Time series of the PC1 and PC2, reg. Mozambique

12 days - 120 km
1 day - 10 km
0.4 km/h

EOF1 (color, 25%)
EOF2 (lines, 23%)

EOF 1 negative values
EOF 1 positive values
EOF 2 negative values
EOF 2 positive values

Principal components analysis
EOF 1 negative values
EOF 1 positive values
EOF 2 negative values
EOF 2 positive values

EOF1 (color, 21%)
EOF2 (lines, 20%)

EOF1 (color, 37%)
EOF2 (lines, 32%)

EOF1 (color, 43%)
EOF2 (lines, 41%)

AVISO

AVISO - INALT 10

FESOM

INALT 10

2000-2001, 80-100d
2000-2001, 80-100d

AVISO 1/4

GLORYS 1/4

SODA 1/4

GLORYS 1/12

EOF 1 negative values
EOF 1 positive values
EOF 2 negative values
EOF 2 positive values
2000-2001, 80-100d, anticyclonic eddies only

AVISO - INALT 10

Griffa et al. 2008

Frenger et al., 2015
2000-2001, 80-100d, cyclonic eddies only

Frenger et al., 2015

Griffa et al. 2008

AVISO

EOF1 (color, 21%)
EOF2 (lines, 20%)

FESOM

EOF1 (color, 35%)
EOF2 (lines, 31%)

INALT 10

EOF1 (color, 43%)
EOF2 (lines, 39%)

AVISO - INALT 10
2000-2001, regional probability distribution of relative vorticity

Figure 5. Trajectories of (a) cyclonic, and (b) anticyclonic eddies first identified in the AC system between October 1992 and April 2012. Insets in (a) and (b) show the South Atlantic crossing eddies’ first locations.
Summary

(i) We present a methodology for the fast Eulerian OCMs diagnostics

(ii) After the time scales of 80 days agreement in SSH variability between datasets is better comparing to the higher frequencies

(iii) FESOM and INALT models generally agree in size, speed and the shape of propagating mesoscale eddies over the Agulhas Current with AVISO data

(iv) Two independent OGCMs provide the same deflection of the anticyclonic eddies path in the Central South Atlantic from both AVISO and ORS (assimilating AVISO)

   (i) AVISO gridded dataset might not be resolving eddies equatorward from the certain latitude
   (ii) Common bias for OGCMs (vorticity balance?)
   (iii) How important is this bias for the global Agulhas influence

To do
   (i) Check this with along track data
Diagnostics of the propagating patterns, 60-80 days, yr. 2000

EOF1 (color, 25%)  EOF2 (lines, 23%)

AVISO

d ~2.5 deg.
~ 240 km.

EOF1 (color, 24%)  EOF2 (lines, 23%)

FESOM

EOF1 (color, 23%)  EOF2 (lines, 23%)

INALT 1/20

R corr

Lag (5 days)
Agulhas Rings trajectories from altimetry 2000-2014

Figure 4. Bathymetric map of the area of study, with the locations of the Cape (C), Agulhas (A), and Agulhas Bank (AB) and isopachic lines from 2000 to 2014. The colour here shows the maximum depth of the Agulhas Current (AC). Agulhas Bank (AB), and Agulhas Rings.

Dencausse et al., 2010

Master2 Thesis of Rémi Laxenaire, 2015

Pilo et al., 2015

Figure 5. Trajectories of (a) cyclonic and (b) anticyclonic eddies first identified in the AC system between October 1992 and April 2012. Insets in (a) and (b) show the South Atlantic crossing eddies' first locations.