Modelling the Agulhas Current and its Coupling with the Atlantic Circulation
The Agulhas System as a Key Region of the Global Oceanic Circulation

Structure

- Introduction
- Modelling the Agulhas Current
- Agulhas Leakage
- Large-Scale Response I: Waves
- Large-Scale Response II: Advection
- Summary and Perspective
Satellite picture (SeaWiFS) of ocean colour

Bard and Rickaby (Nature, 2009)
Palaeoceanography: Agulhas and Climate

Ice volume decreases

Agulhas leakage peaks

STF shifts south

SST increases

MOC strengthens?
Dynamical Controls on Agulhas Leakage

Beal, de Ruijter, Biastoch, Zahn and SCOR WG 136 (Review in *Nature*, 2011)
Dynamical Controls on Agulhas Leakage

Beal, de Ruijter, Biastoch, Zahn and SCOR WG 136 (Review in Nature, 2011)
Dynamical Controls on Agulhas Leakage

Beal, de Ruijter, Biastoch, Zahn and SCOR WG 136 (Review in Nature, 2011)
Response of the North Atlantic to South Atlantic Buoyancy Input

Hamburg LSG Model
(developed for climate studies)

source of Agulhas heat and salt

sink

Input and NADW response

Weijer et al. (2002)

Spreading of salt anomaly at 250 m depth
Far-field Influence on North Atlantic Climate

Atlantic Ocean heat content

Spreading of heat anomalies under global warming

Lee et al. (2011)
Mesoscale Variability up- and downstream of the Agulhas Current

Circulation schematics

Lutjeharms and Ansorge (2007)
Agulhas Rings

Trajectories of long-lasting eddies

Velocity structure of an Agulhas ring

Chelton et al. (2011); van Aken et al. (2000)
Mesoscale Variability up- and downstream of the Agulhas Current

Circulation schematics

Lutjeharms and Ansorge (2007)
Mesoscale Dynamics in the Source Regions

Mozambique Eddies

Natal Pulses

Sea Surface Height Variability

De Ruijter et al. (1999; 2002); Schouten et al. (2002)
Modelling the Agulhas Current

... and its Embedding in the Large-scale Circulation
Nested Ocean Model

NEMO ocean/sea-ice model within European DRAKKAR collaboration

- Nested configuration with 2-way interaction (AGRIF) between both grids
  - Global coarse-resolution (1/2°)
  - High-resolution Agulhas (1/10°)
- 46 vertical levels
- Sea-ice model
- Atmospheric forcing (CORE):
  Bulk formulae at 6h/1d-resolution, inter-annual variability (1958-2004)

Madec (2006); Barnier et al. (2006); Debreu et al. (2008)
Animation of Near-Surface Speed

The Agulhas System as Key Region of the Global Oceanic Circulation

31-Dec-1994

Near-Surface Speeds in a High-Resolution Model, Nested in a Global, Coarse-Resolution Ocean Model

Bilestoch and Böning, Ocean Modelling Group
Agulhas Current

Observations (composite section) and model off Port Shepstone

Beal (2009); Biastoch et al. (J. Phys. Oceanogr., 2009)
Agulhas Current Variability

Modelled and observed Agulhas Current and Agulhas Undercurrent

Agulhas Current: -77.3 ± 13.7

Agulhas Undercurrent: 5.4 ± 3.7

-78.6 ± 19.7

5.9 ± 3.9

(Bryden et al., 2005)

5.3 ± 3.8

(Beal, 2009)

Biastoch et al. (J. Phys. Oceanogr., 2009)
Retroflection of the Agulhas Current

TIME: 01-JAN-1990 00:00 NOLEAP

Speed and velocity at 100 m depth
Agulhas Leakage

Interoceanic Transfer of Mass, Heat and Salt
Quantification of Agulhas Leakage

- O(10^6) Floats seeded in the Agulhas Current over 1 year
- Amount entering the Atlantic over 1+3 years: ~15 Sv (24%)
- Retroflection into Indian Ocean: ~37 Sv (61%)

„Agulhas Leakag“ = amount of Agulhas Current that flows into the Atlantic

Biastoch et al. (Geophys. Res. Lett., 2008); ARIANE (Blanke, Univ. Brest)
The Importance of Model Resolution

<table>
<thead>
<tr>
<th>Resolution</th>
<th>Agulhas Leakage</th>
</tr>
</thead>
<tbody>
<tr>
<td>ORCA05 (50 km)</td>
<td>29.6 ± 6.0 Sv</td>
</tr>
<tr>
<td>ORCA025 (25 km)</td>
<td>16.2 ± 4.9 Sv</td>
</tr>
<tr>
<td>AG01 (10 km)</td>
<td>14.8 ± 2.6 Sv</td>
</tr>
</tbody>
</table>

Observations (Richardson, 2007): ~15 Sv

Temperature and velocity at 450m depth (snapshot)
Large-scale Response I

Wave Effect on the Atlantic MOC
Wave Response: Dynamical Effect of Agulhas Mesoscale on MOC

Biastoch et al. (Nature, 2008)
Rossby and Kelvin Waves

Rossby waves

Kelvin waves

Hovmöller diagram of sea level anomalies (cm) in the tropical Pacific
Wave Response: Dynamical Effect of Agulhas Mesoscale on MOC

Biastoch et al. (Nature, 2008)
Wave Response: Dynamical Effect of Agulhas Mesoscale on MOC

Interannually filtered MOC-difference at 1000 m due to Agulhas mesoscale

Biastoch et al. (Nature, 2008)
Wave Response: Northern vs. Southern Influences

MOC anomalies due to Agulhas mesoscale

MOC anomalies due to Labrador Sea convection

Winter value of (modelled) mixed layer depth in the Labrador Sea

Biastoch et al. (Nature, 2008); Biastoch et al. (J. Clim., 2008)
Wave Response: Northern vs. Southern Influences

MOC anomalies due to Agulhas mesoscale

MOC anomalies due to Labrador Sea convection

Standard deviation of interannual MOC strength

Biastoch et al. (Nature, 2008); Biastoch et al. (J. Clim., 2008)
Large-scale Response II

Advective Effect on Thermohaline Circulation
Dynamical Controls on Agulhas Leakage

Beal, de Ruijter, Biastoch, Zahn and SCOR WG 136 (Review in *Nature*, 2011)
Advective Response: Agulhas Leakage and Thermohaline Circulation

Horizontal Circulation (streamfunction)

Biastoch et al. (Nature, 2009)
Advective Response:
Agulhas Leakage and Thermohaline Circulation

Biastoch et al. (Nature, 2009)
Agulhas Leakage under Global Warming

Zonal wind stress in the Kiel Climate Model (KCM)

Zonally averaged wind stress

Present-day experiment

Difference due to global warming

Park et al. (2008); Biastoch and Böning (2012, in prep.)
Agulhas Leakage under Global Warming

Zonally averaged wind stress

Agulhas leakage for reference (dark gray bars) and shifted wind (light gray) experiments

Park et al. (2008); Biastoch and Böning (2012, in prep.)
Spreading of Agulhas Leakage

Typical Spreading Rates

~14 Years
~8 Years
~6 Years

Probability density map of Agulhas leakage floats

Rühs, Biastoch, Durgadoo, Behrens (2012, in prep.)
Adveective Response: Agulhas Leakage and Thermohaline Circulation

Analysis of historic profiles in NBC core off South America

Example trajectories of virtual floats released along the GoodHope section

Biastoch et al. (Nature, 2009)
Northern vs. Southern Influences on the Atlantic Thermohaline Circulation

Increased supply of freshwater → weakening of the deepwater formation

Increased supply of saline water → stabilization of the deepwater formation

Nature cover pages 2008 and 2009, schematics by G. Holloway
Summary and Perspective
Modelling the Agulhas Current and its Coupling with the Atlantic Circulation

- High-resolution model needed to realistically represent the Agulhas system and Agulhas leakage

(I) Wave process
- Mesoscale Agulhas leakage dynamics introduces decadal MOC variations of ±1.5 Sv quickly propagating into northern hemisphere
- What causes the decadal variations?
- How important are these for the (interpretation of) North Atlantic circulation variability?

(II) Advective process
- Supergyre has extended due to poleward shift/intensification of SH westerlies
- The Agulhas Leakage has increased → 25% increase in salt export towards the north
- Climate models project a further increase in Agulhas leakage
- How does the timing and strength compare to the (Sub-)Arctic freshening?
- How do other sources (Drake Passage, Southern Ocean) contribute?
Increasing Awareness of Agulhas Regime

SCOR Working Group 136
“Climatic Importance of the Greater Agulhas Current System”

Beal, de Ruijter, Biastoch, Zahn and SCOR WG 136 (Review in Nature, 2011)
The Agulhas System and its Role in Changing Ocean Circulation, Climate, and Marine Ecosystems
Spier Hotel, Stellenbosch, Western Cape, South Africa
8–12 October 2012

De Ruijter, Zahn, Biastoch, Beal, and SCOR WG 136