The role of the Agulhas Current system in the global overturning circulation

or: The brawniest retroflection
The brawniest retroflection

Arnold L. Gordon

The influence of the Agulhas system of currents and eddies around southern Africa extends far beyond that region. Hence the especial need for a better understanding of the complex phenomena involved.

Gordon (Nature 2003)

The Agulhas system and associated flow patterns.
Sources of the Agulhas Current
The Agulhas Current system and Agulhas leakage
An observationally-based timeseries of Agulhas leakage
Cold vs. warm water route
Summary

The Agulhas system and associated flow patterns.
Sources of the Agulhas Current
Indonesian Throughflow and Tasman leakage

Lagrangian transports by Indonesian Throughflow (ITF) and Tasman leakage (TL)

Timeseries of Indonesian Throughflow and Tasman leakage

Van Sebille et al. (J. Geophys. Res. 2014)
Pathways through the Indian Ocean

ITF and TL
- Cross the Indian Ocean in ~20 years
- Contribute equally to Agulhas leakage

Durgadoo et al. (J. Geophys. Res., 2017)
The Agulhas Current system and Agulhas leakage
Nested high-resolution ocean modelling

- Global ocean/sea-ice model (NEMO) with 1/10° nest
- 46 vertical levels
- Atmospheric forcing of the past 60 years
The Agulhas Current system

Lutjeharms and Ansorge (2007)
Agulhas rings

Chelton et al. (2011); van Aken et al. (2000)

Trajectories of long-lasting eddies

Velocity structure of an Agulhas ring
The Agulhas Current system

Agulhas leakage = Amount of Agulhas Current entering the South Atlantic (~15 Sv in upper 1000 m)

Lutjeharms and Ansorge (2007); Richardson (2007)
Increase of Agulhas leakage in the past decades

Biastoch et al. (Nature 2009), Durgadoo et al. (J. Phys. Oceanogr. 2013)

33 atmospheric forcing from similar datasets, leakage show an increase of about 1.2 Sv / decade since the late 1960s (Biastoch et al. 2009b; Rouault et al. 2009).

FIGURE 2.9: Illustration of the Lagrangian analysis used for Agulhas leakage measurement. (a) Water parcel density (shading, normalised number of occurrences per 0.25° x 0.25° grid box) overlaid by 25 exemplary parcel trajectories. Water parcels were released across the Agulhas Current at 32°S (green section) and integrated forward within all four configurations. The Good-Hope line in the Cape Basin was used to capture parcels exiting the domain as Agulhas leakage. Time means and annual standard deviations (in brackets) of leakage for ORCA05, AGIO, INALT01 and ARC hindcast experiments are also shown. (b) Time-series of Agulhas leakage anomaly (respective mean values removed) within the four model configurations for period 1948–2003.

Illustration of the Lagrangian calculation used to quantify Agulhas leakage

$O(10^6)$ Floats seeded in the Agulhas Current over 1 year

~65 Sv

~13-17 Sv

Amount entering the Atlantic over 1+3 years
Wave response of Agulhas (leakage)

Signal propagation by Rossby and topography shelf waves

AMOC response due to Agulhas mesoscale

Biastoch et al. (Nature 2008)
40% of Agulhas leakage arrives at 26°N, most probable after 12-13 years, half of the water after 23 years.
Increase of Agulhas leakage in the past decades

- Biastoch et al. (Nature 2009), Durgadoo et al. (J. Phys. Oceanogr. 2013)

Agulhas leakage (Agulhas transport crossing Goodhope section)

Atlantic-Indian Ocean supergyre and winds

Agulhas leakage vs. wind stress change in hindcast & sensitivity experiments

1.2 Sv/decade (30%)
Future increase of Agulhas leakage

Biastoch and Böning (Geophys. Res. Lett. 2013)

Zonally averaged wind stress from CMIP-type model

Agulhas leakage for reference (dark gray bars) and shifted wind (light gray) experiments
A long observationally-based timeseries of Agulhas leakage

Sea surface temperature and Agulhas leakage

Sea surface temperature (SST) and sea surface height (SSH)

Linear SST trend (1965-2000) and SSH standard deviation

Biastoch et al. (Nat. Commun. 2015)
High-resolution models to simulate Agulhas leakage

1/10° INALT01 nested ocean model with CORE forcing

1/10° quasi-global ocean model OFES with NCEP/NCAR forcing

Global coupled model CM 2.6 (1/10° ocean and 50-km atmosphere/land)

Biastoch et al. (Nat. Commun. 2015)
Agulhas leakage vs. SST

Correlation between Agulhas leakage and near-/sea surface temperature

Biastoch et al. (Nat. Commun. 2015)
Annual Agulhas leakage vs. NST/SST difference (Atlantic Ocean minus Indian Ocean) for INALT01, OFES and CM2.6
A long observationally-based time series of Agulhas leakage

Agulhas leakage at annual resolution and decadally filtered

Southern Annular Mode (SAM)
(decadally correlated, $r = 0.9^*$)

Atlantic Meridional Oscillation (AMO)
(multi-decadal lag correlation, 15 yrs, $r = 0.75^*$)

* All trends are performed on detrended data and are statistically significant

Biastoch et al. (Nat. Commun. 2015)
Cold vs. warm water route

Rühs, Schwarzkopf, Speich, and Biastoch (Ocean Sci., 2019)
Cold vs. warm water route

Global ocean/sea-ice model (NEMO) with 1/20° nest
- 46 vertical levels
- Atmospheric forcing of the past 60 years
Monitoring the NBC at 11°S
(Dept. Physical Oceanography at GEOMAR)
Cold vs. warm water route

Rühs et al. (Ocean Sci., 2015)

Lagrangian backward experiment

- released virtual fluid particles in NBC (5-daily between 2000-2009)
- each particle tagged with fraction of current NBC transport (max. 0.01 Sv)
- advected backwards in time to source sections (max. 40 yrs)

→ $O(10^6)$ particle trajectories
Cold vs. warm water route

Lagrangian streamfunction and volumetric amounts of individual sources

DP contribution to AMOC ≥ 40%
- higher than previously estimated
- fits to ARGO float observations

Rühs et al. (Ocean Sci., 2015); Rodrigues et al. (2010)
Modal (median) transit times
- Agulhas Current: 7 yrs (9 yrs)
- Drake Passage: 12 yrs (18 yrs)
Cold vs. warm water route

Rühs et al. (Ocean Sci., 2015)

Lagrangian streamfunctions of individual contributions

AC → NBC (6.3 Sv)

DP → NBC (4.7 Sv)
Cold vs. warm water route

Depth distribution of AC and DP particles in NBC

Rühs et al. (Ocean Sci., 2015)
Cold vs. warm water route

- at source no clear separation in $\theta$
  $T_{AC} > 4.0^\circ C$, $T_{DP} < 8.5^\circ C$
- BUT separation in S
  $S_{AC} > \sim34.5 > S_{DP}$

Rühs et al. (Ocean Sci., 2015)
Cold vs. warm water route

Rühs et al. (Ocean Sci., 2015)

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- BUT separation in $S$
  $S_{AC} > \sim34.5 > S_{DP}$

- in NBC
  - AC and DP nearly same $\theta$-$S$ spectrum

Net along-track property changes:
- AC: salinification, slight density gain
- DP: salinification, warming, density loss
Cold vs. warm water route

Rühs et al. (Ocean Sci., 2015)

Last mixed layer contact of contributions to NBC

Last MLD contact on AC → NBC transit

Last MLD contact on DP → NBC transit

Relative number of particles in %
Agulhas leakage is subject to highly interannual variability, but decadally correlated with Southern Hemisphere winds

Model experiments and an SST-based index show that Agulhas leakage has increased

- lag-correlated with AMO on multi-decadal timescales

Inflow from the Drake Passage: ≥ 40 %

- “warm vs. cold” → “saline vs. fresh”
- both contributions mix in the South Atlantic → arrive at similar density space
Future Directions in Basin & Global High-resolution Ocean Modelling

7-9 October 2020 | Kiel | Germany

- Robustness of decadal variability
- Influence of individual modelling strategies
- What are additional critical processes to consider
- Role of internal variability on global warming
- Linking modeling and observations, physics and biogeochemistry

Celebrate with us the achievements and contributions of Prof. Claus Böning who will retire in autumn this year

https://events.geomar.de/~OM2020

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