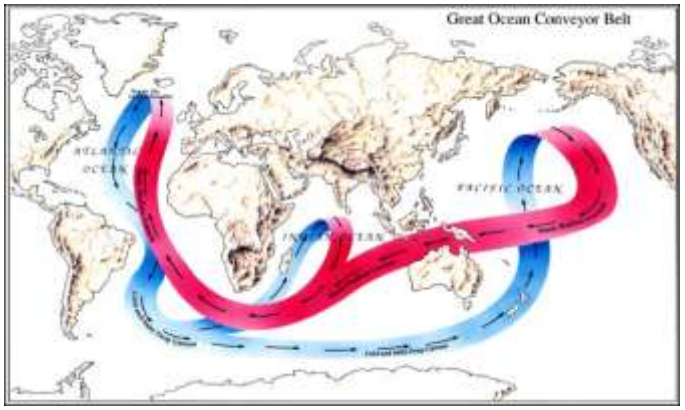
Arne Biastoch | GEOMAR Helmholtz Zentrum für Ozeanforschung Kiel

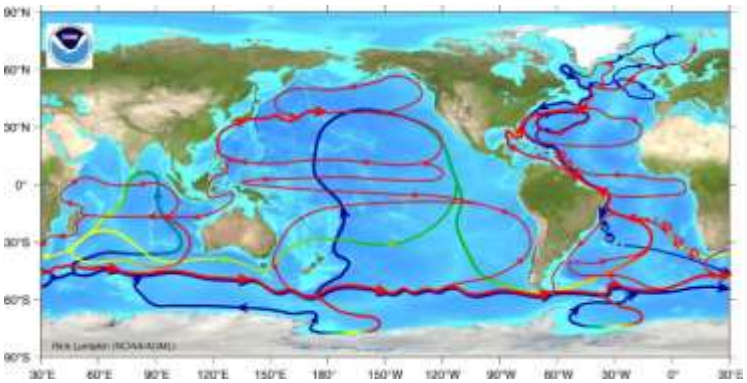
Understanding Ocean Variability

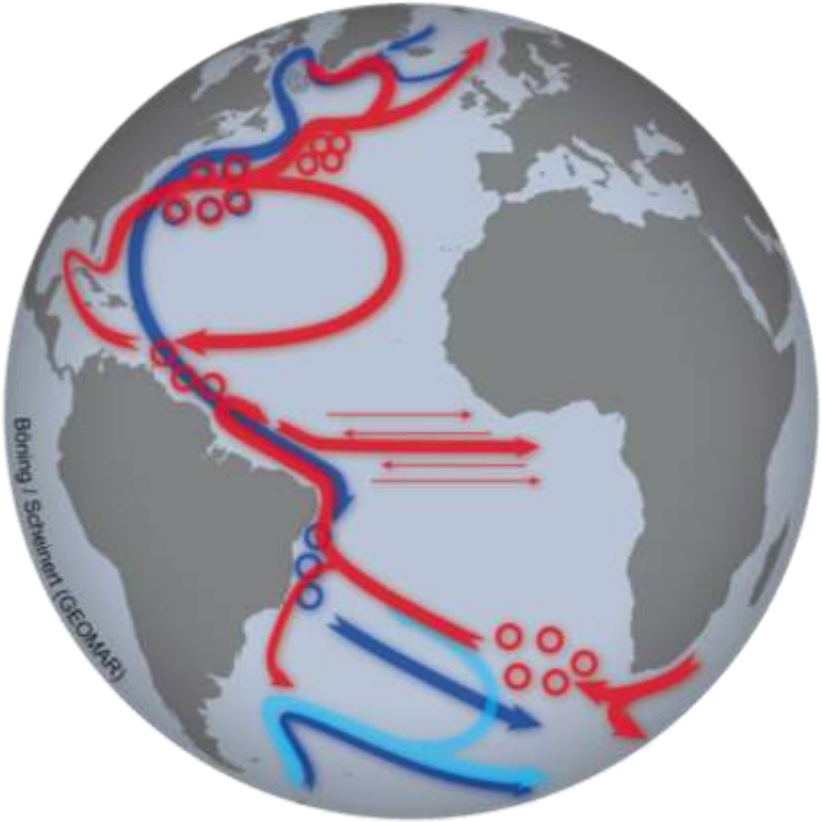
Using OGCMs and satellite data to understand the Atlantic meridional overturning circulation

GEOMAR

The global overturning circulation



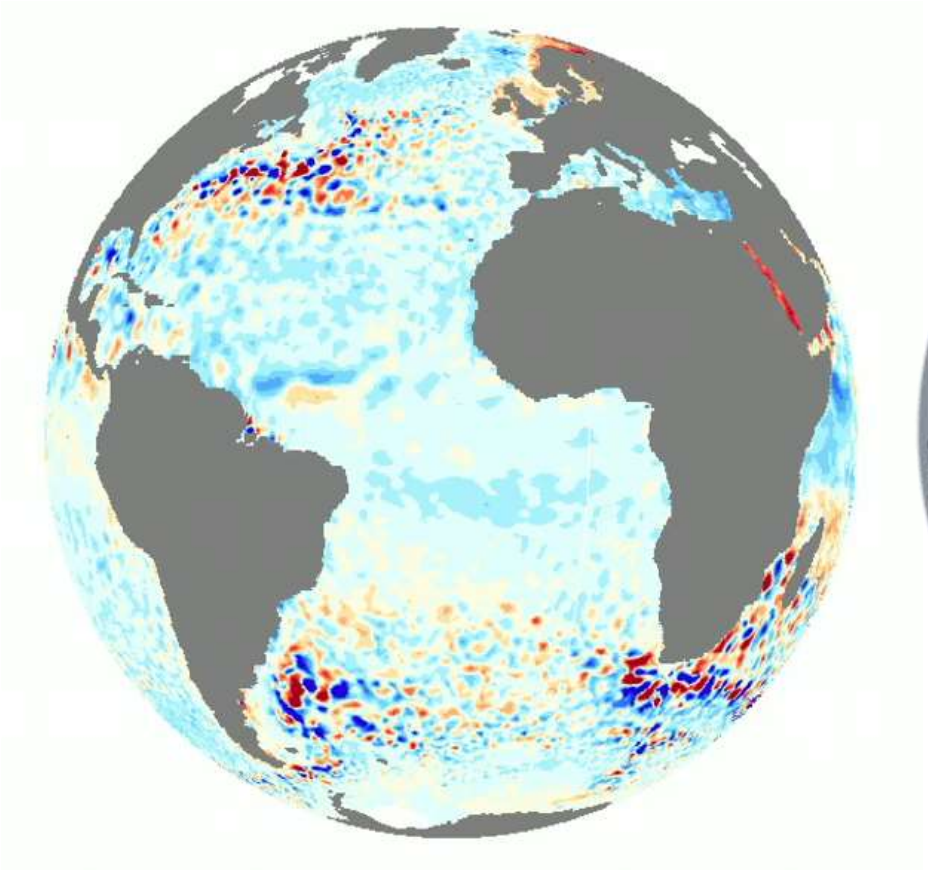




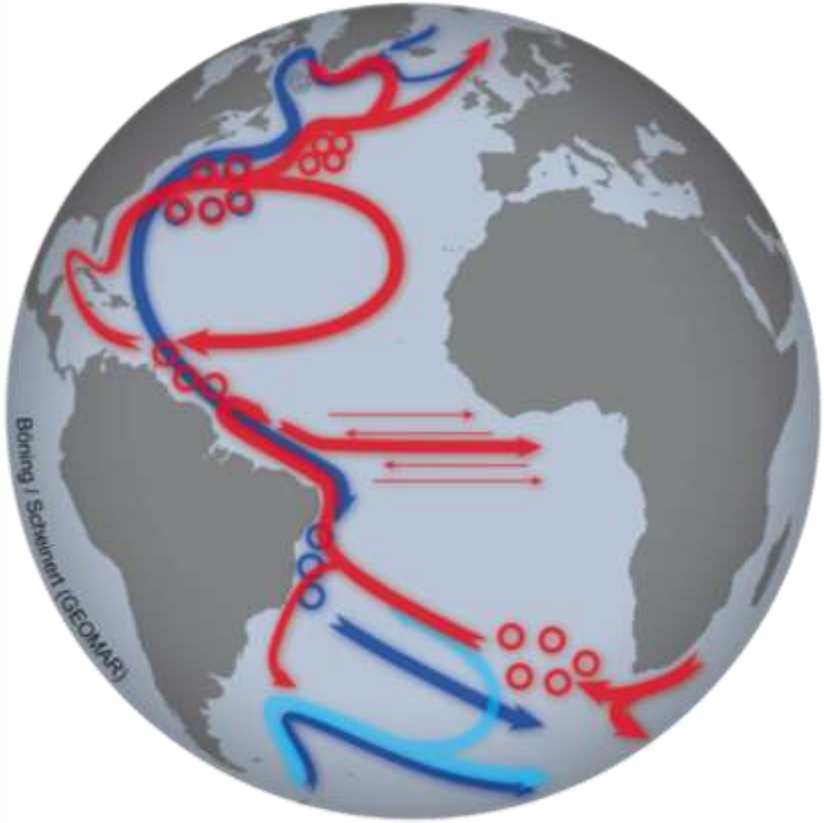
Large-scale circulation in the Atlantic
(cold and warm flows)

Schematics by Broecker/Deacon, Lumpkin, Böning and Scheinert

The global overturning circulation



Mesoscale variability in the Atlantic
(from satellite altimetry)



Large-scale circulation in the Atlantic
(cold and warm flows)

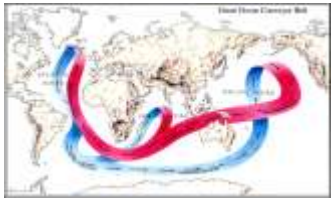
Schematics by Böning and Scheinert

The Agulhas Current System

...and its embedding in the large-scale circulation

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)

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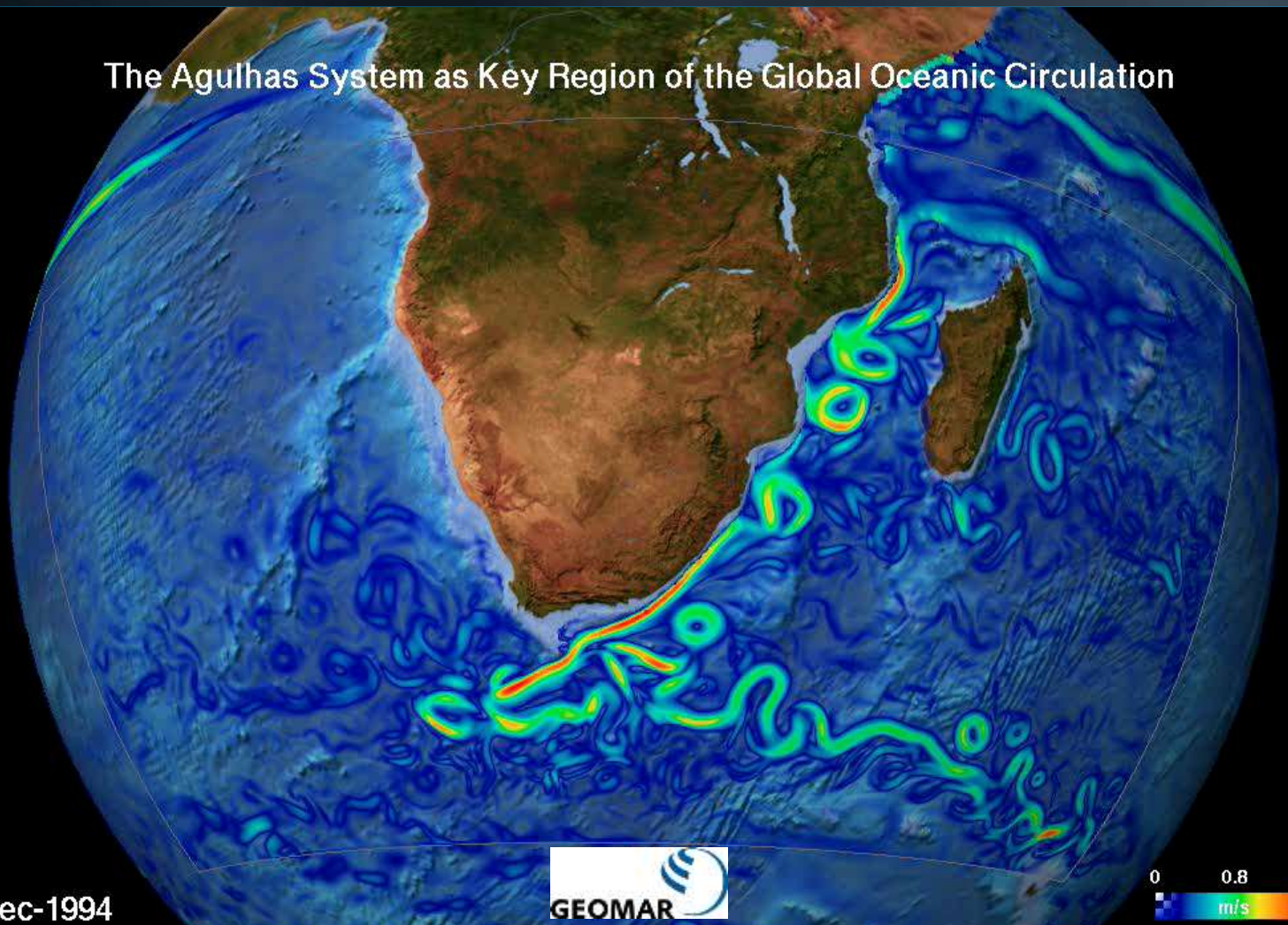
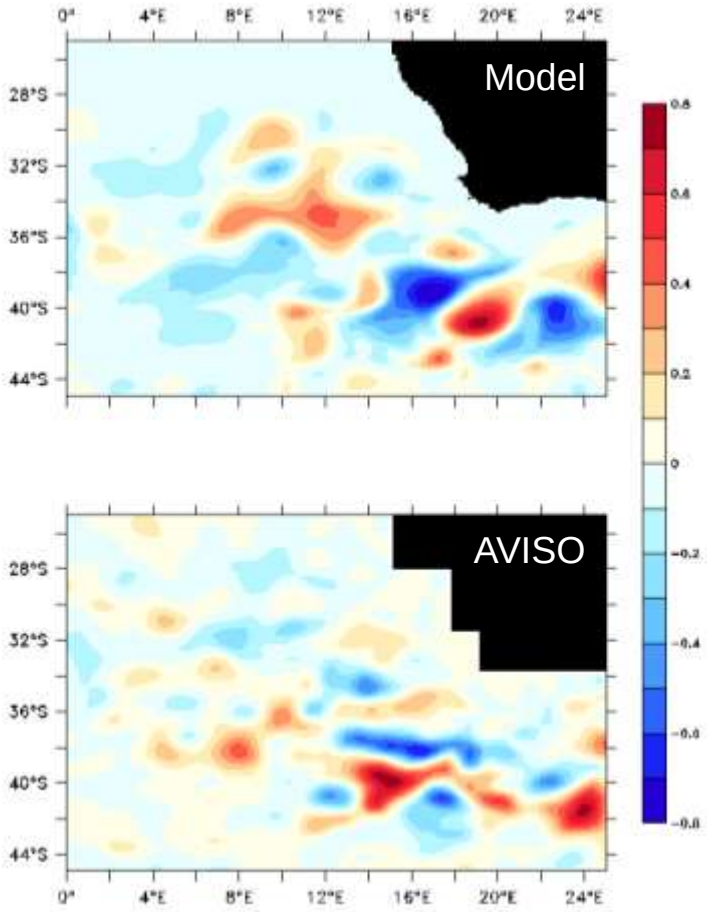
Modelling the Agulhas Current System



The Oceanic Mesoscale

Sea surface height (SSH) of modelled and observed for 1 July 2000

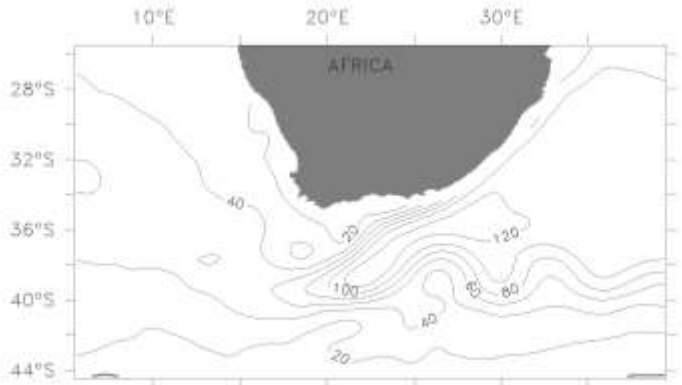


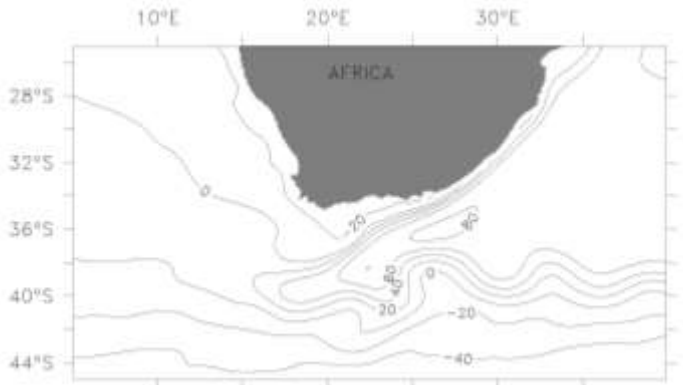
AVISO SSH data : gridded product
(absolute and relative sea level)
daily, 1/4° resolution, 1993-now

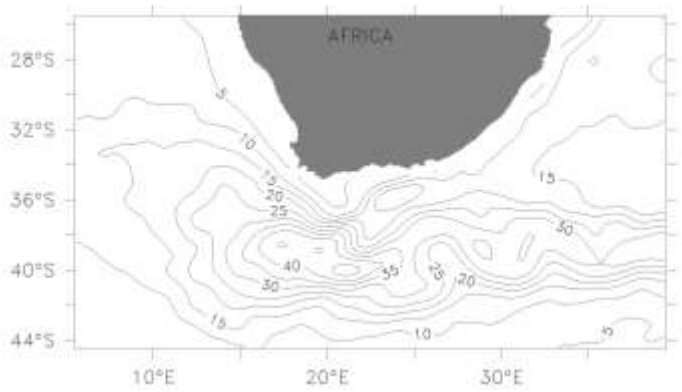
Verification through Sea Surface Height

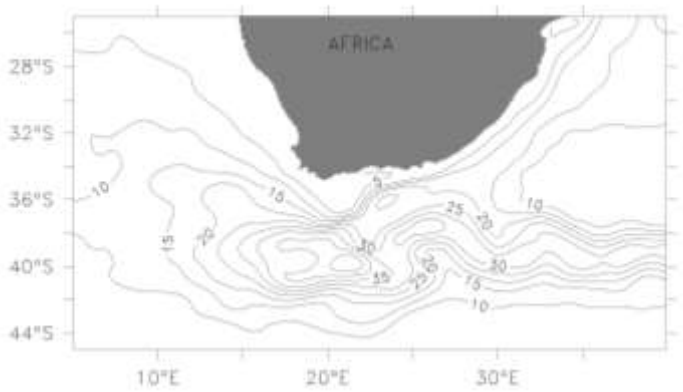
Time-mean SSH [cm]

SSH s.t.d. [cm]









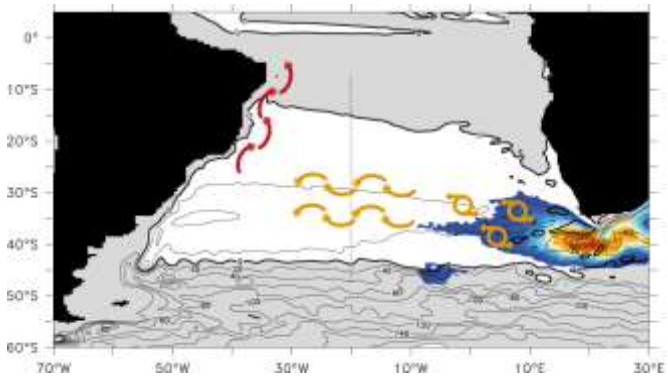
Caution: different scales for absolute and relative SSH

Observed SSH (AVISO)

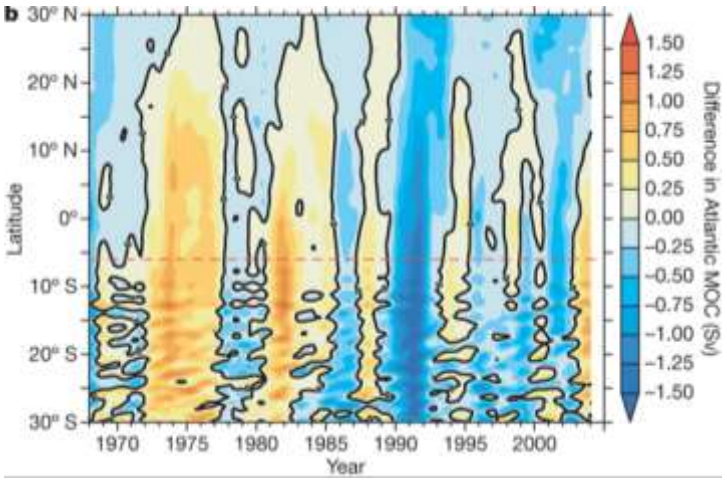
Modelled SSH (INALT01)

Biastoch et al. (2015)

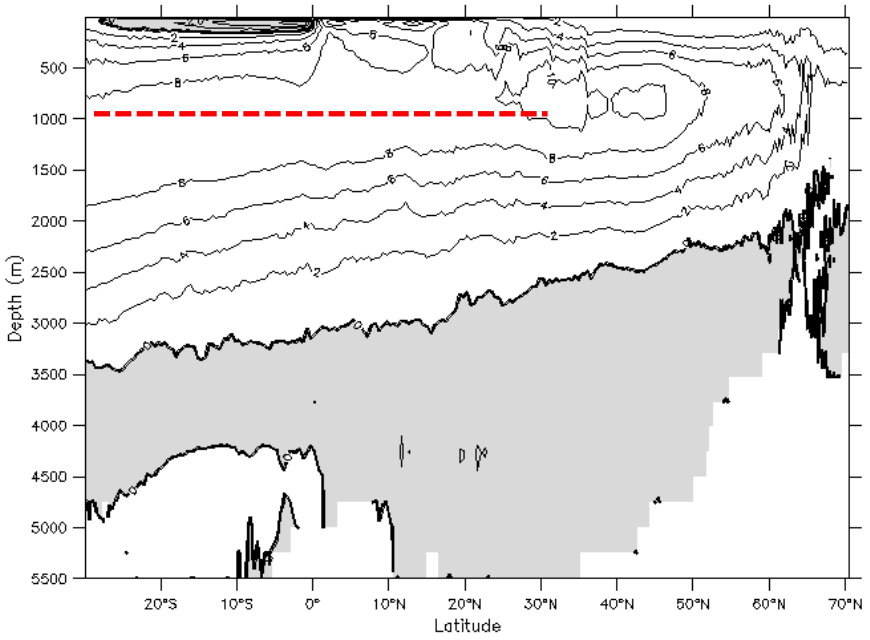
Large-scale impact from the Agulhas System: wave processes



Propagation by Rossby and Kelvin waves



AMOC response due to Agulhas mesoscale



Atlantic meridional overturning circulation (AMOC)

Biastoch et al. (2008), Weijer et al. (2002)

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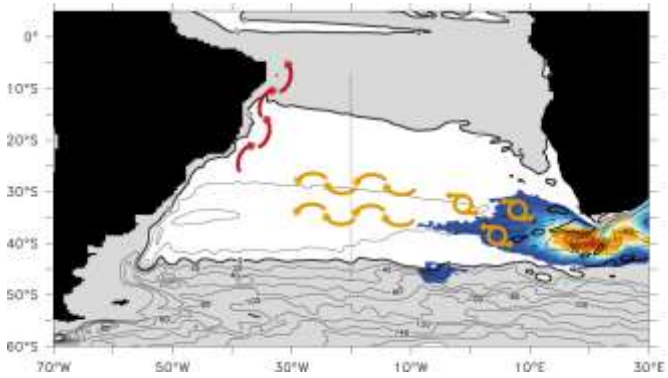
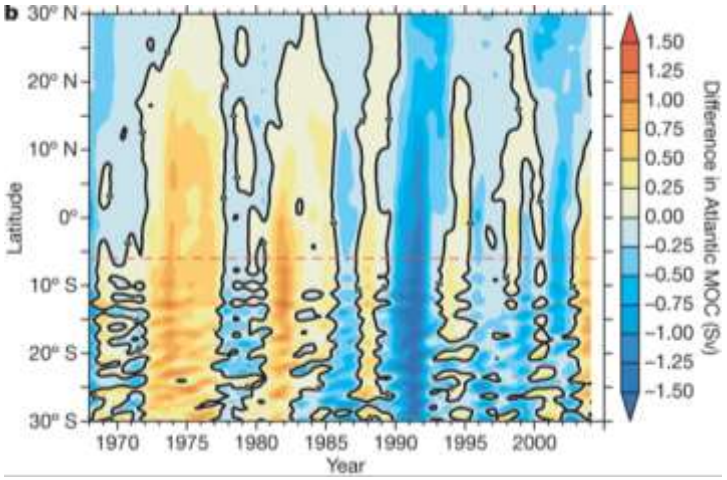
Large-scale impact from the Agulhas System: wave and advective processes



Propagation by Rossby and Kelvin waves



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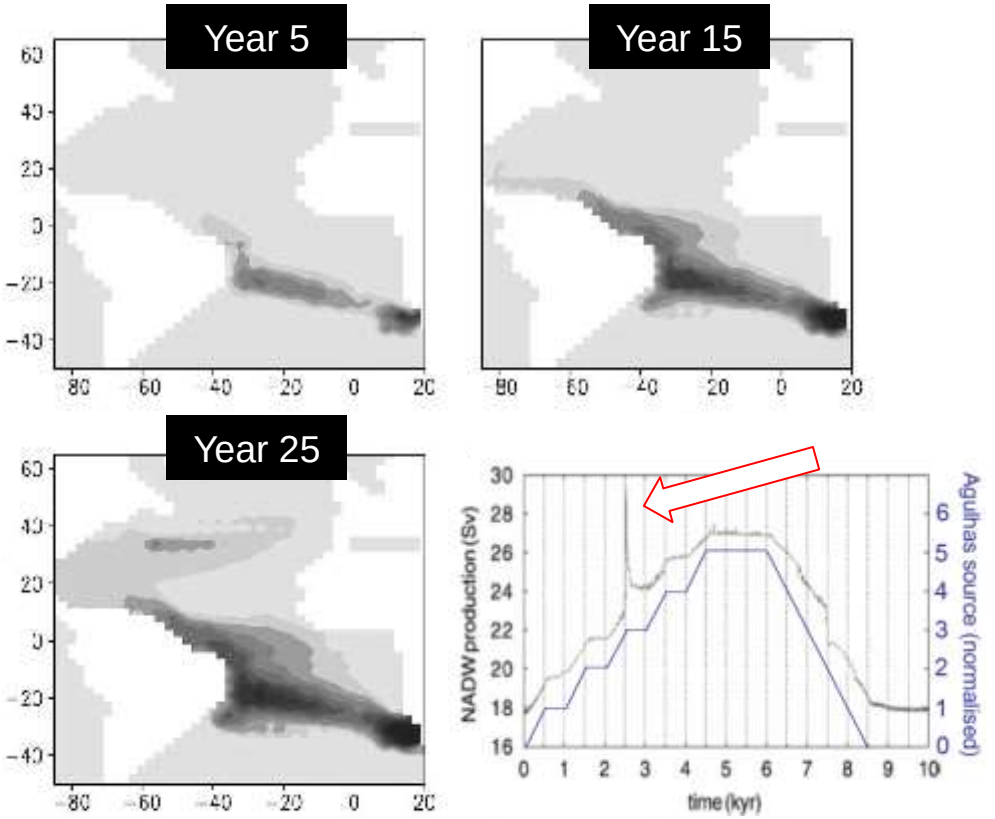
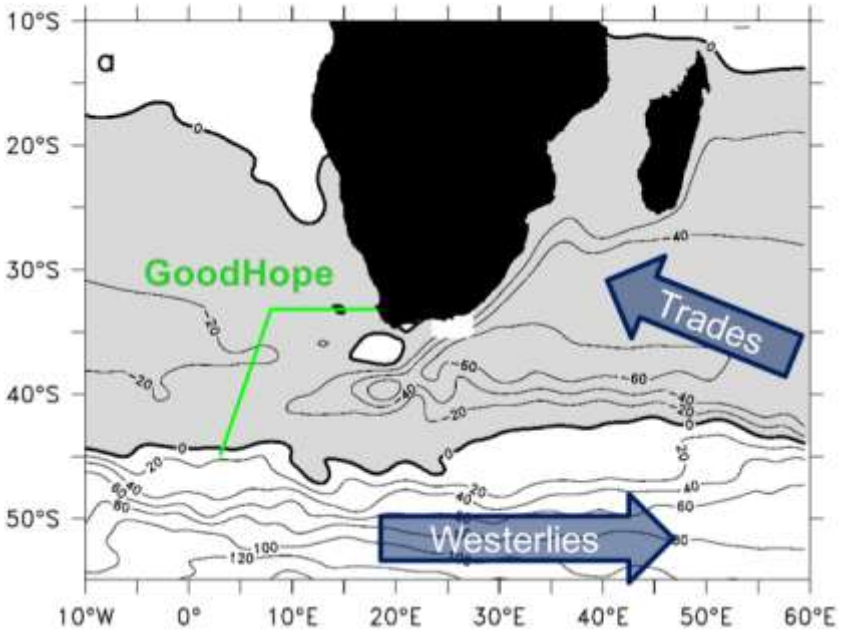


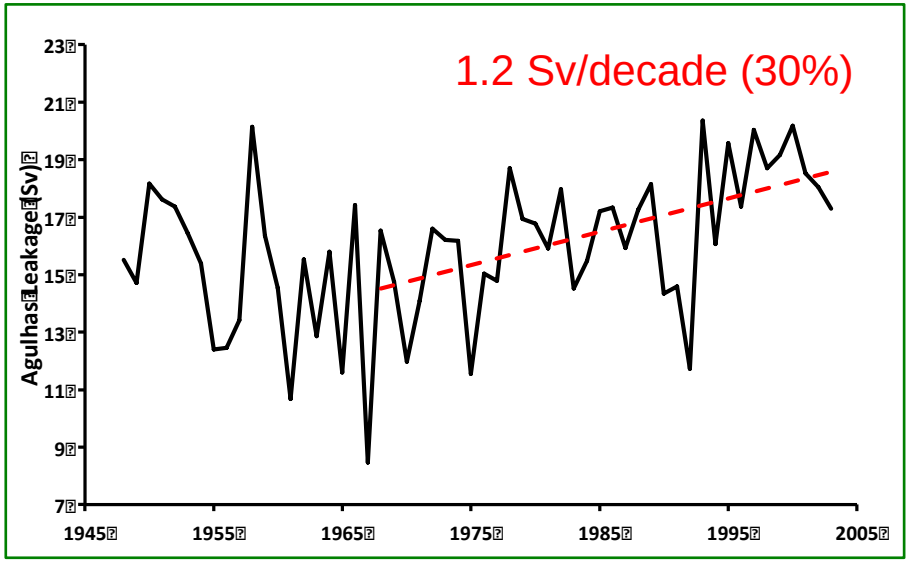
Salt anomaly (250 m depth) and AMOC response

Biastoch et al. (2008), Weijer et al. (2002)

Increase of Agulhas leakage in the past decades



Atlantic-Indian Ocean *Supergyre*
(indicated by horizontal streamfunction)

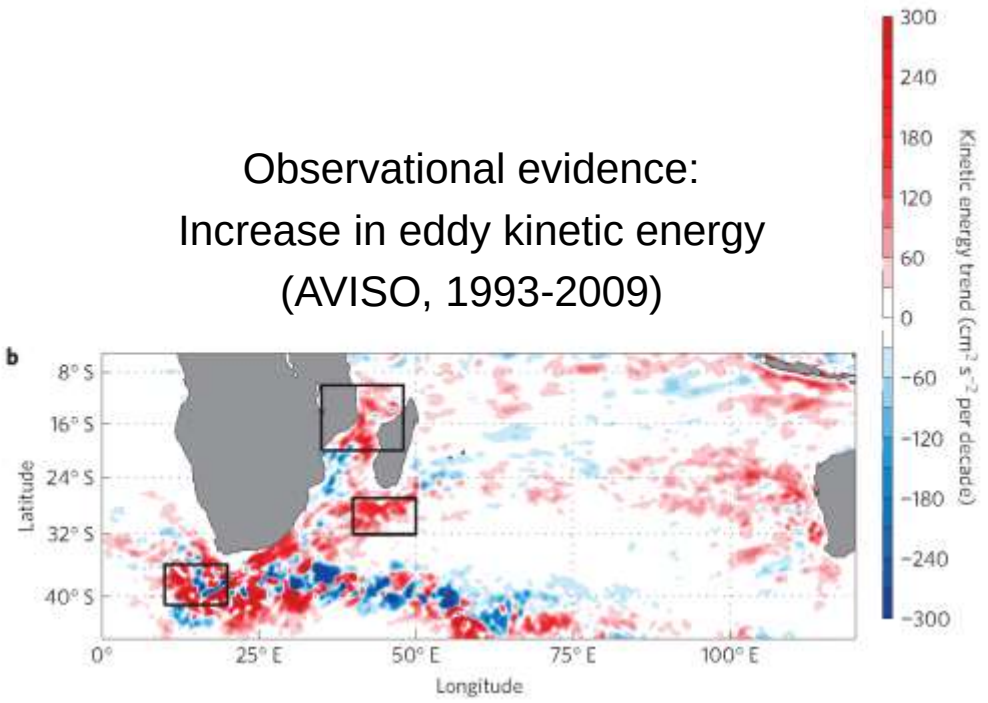


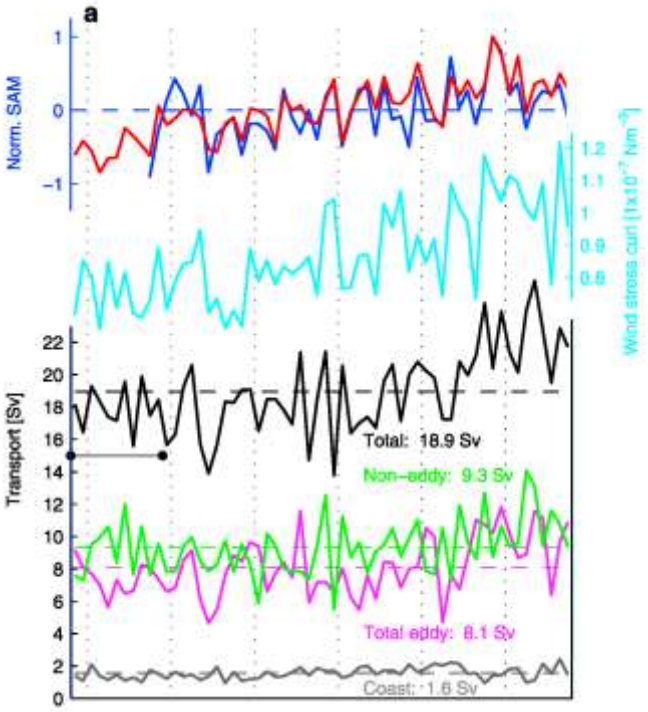
Modeled increase in Agulhas leakage
(Agulhas transport crossing GoodHope section)

Biastoch et al. (2009), Durgadoo (2013)

Increase of Agulhas leakage in the past decades

Observational evidence:
Increase in eddy kinetic energy
(AVISO, 1993-2009)





Southern Annular Mode (SAM) and
contributions to Agulhas leakage in a 1/12° model

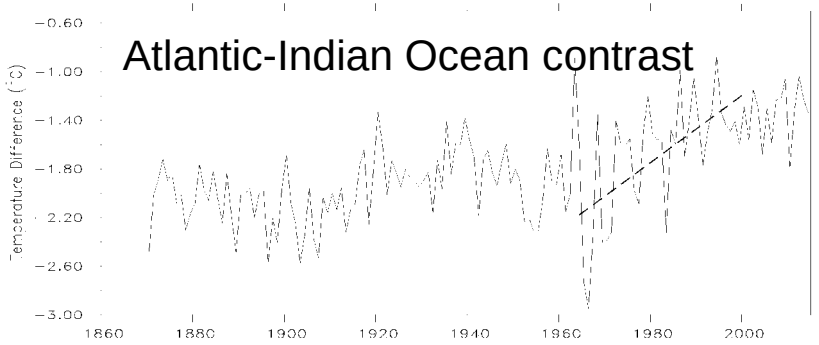
Backeberg et al. (2012), Loveday et al. (2015)

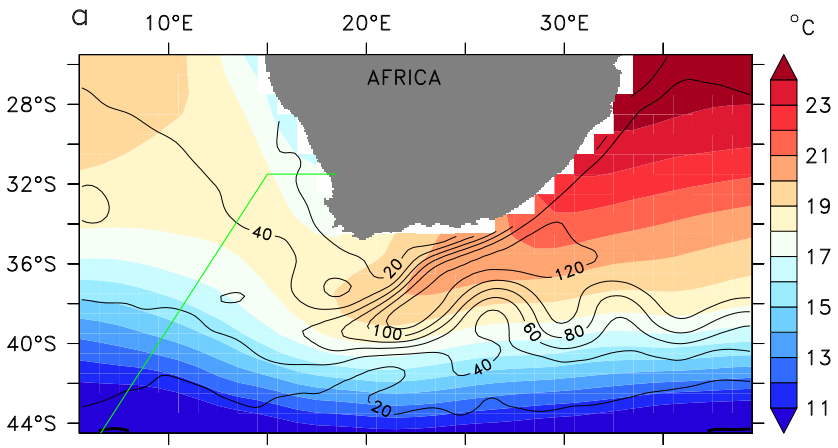
A 145-year long timeseries of Agulhas leakage

Biastoch, Durgadoo, Morrison, van Sebille, Weijer, and Griffies (*Nature Commun.*, 2015)

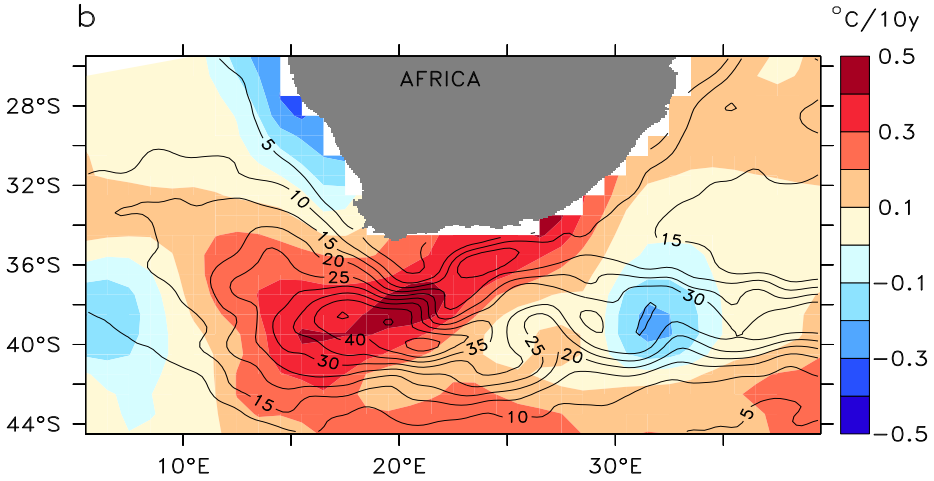
Sea Surface Temperature and Agulhas leakage

HadISST data set: compilation
(simple buckets to satellite data)
monthly, 1° resolution, 1870-2015





Time-mean SST and SSH

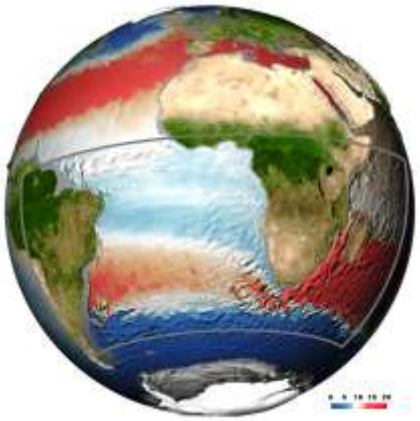


Linear SST trend (1965-2000) and SSH s.t.d.

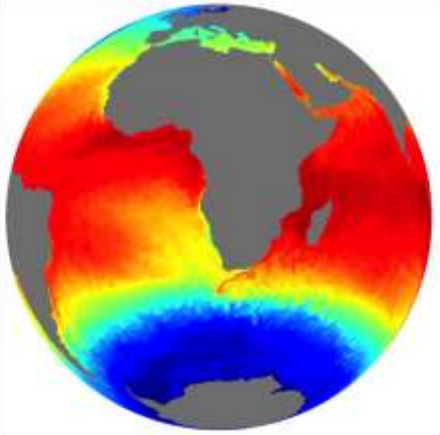
Biastoch et al. (2015)

High-resolution models to simulate Agulhas leakage

1/10° INALT01 nested ocean model with CORE forcing



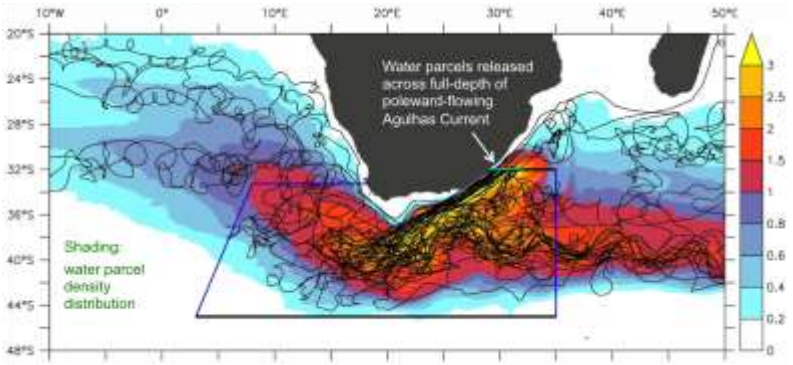
1/10° quasi-global ocean model OFES with NCEP/NCAR forcing



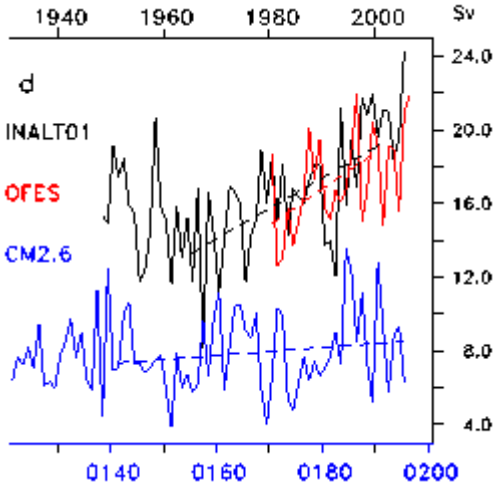
Global coupled model CM 2.6 with 1/10° ocean and 50-km atmosphere/land

Biastoch et al. (2015)

Lagrangian quantification of Agulhas leakage



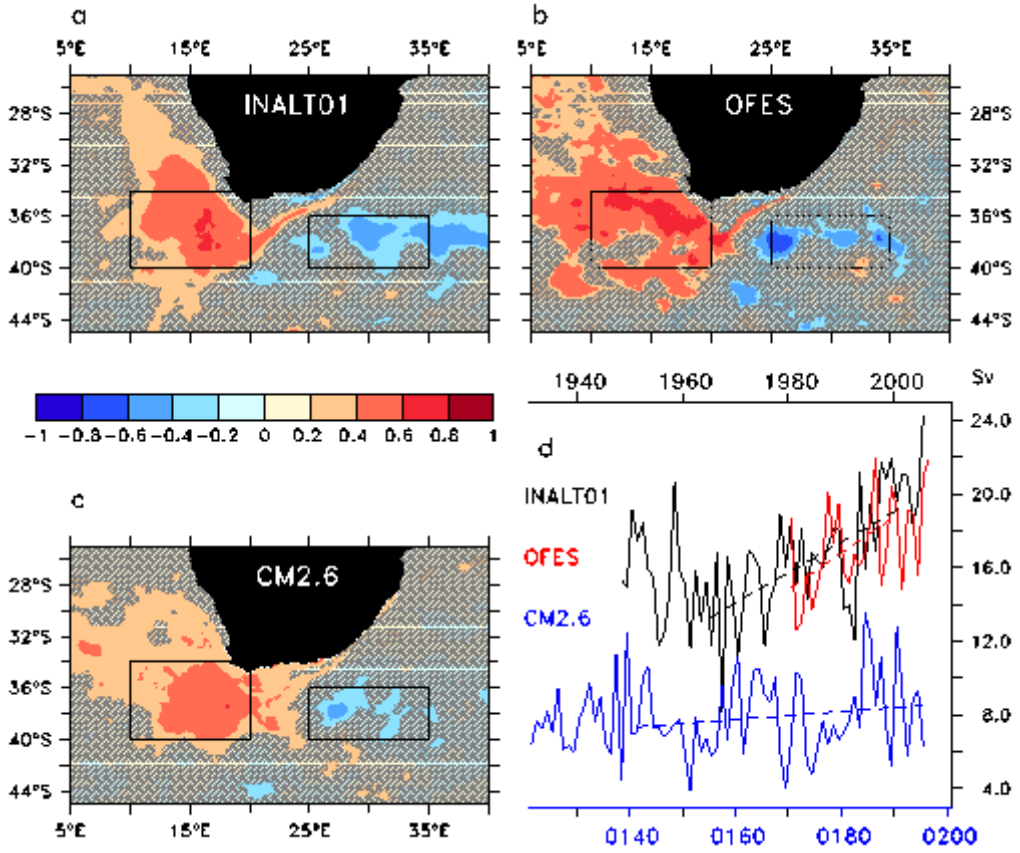
Lagrangian particles (example trajectories) to quantify Agulhas leakage



Agulhas leakage

Biastoch et al. (2015)

Correlation of Agulhas leakage and Indian Ocean – Atlantic SST gradient



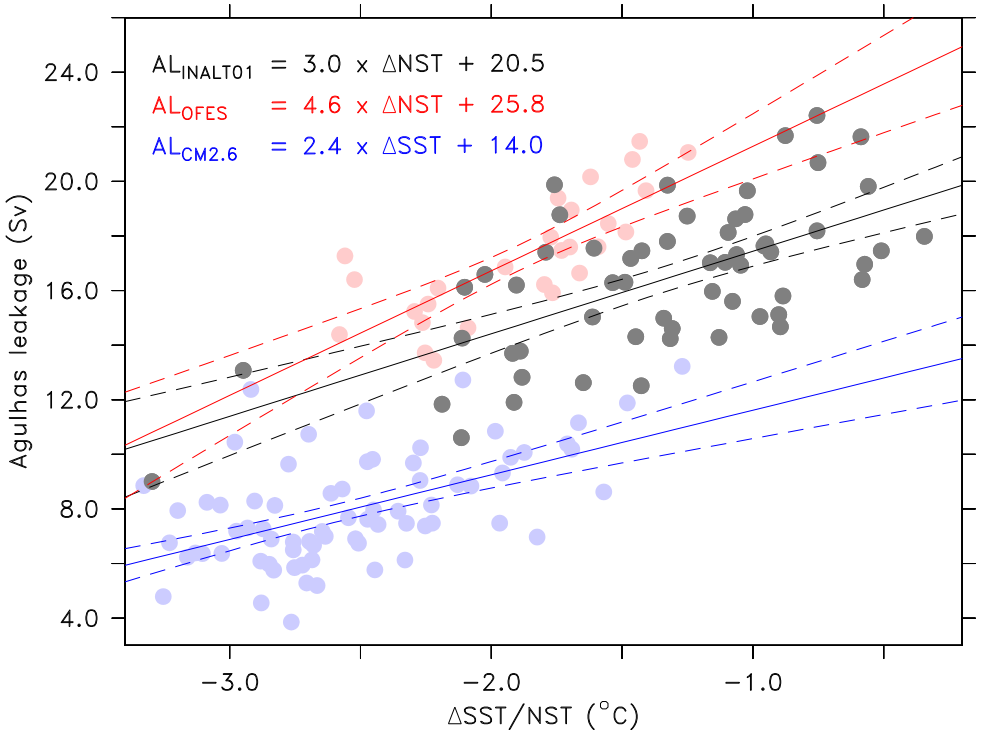
Agulhas leakage

Correlation between Agulhas leakage and NST* in the high-resolution ocean models INALT01 and OFES, and SST in the coupled climate model CM 2.6

Biastoch et al. (2015)

* NST = near-surface temperature (~15 m)

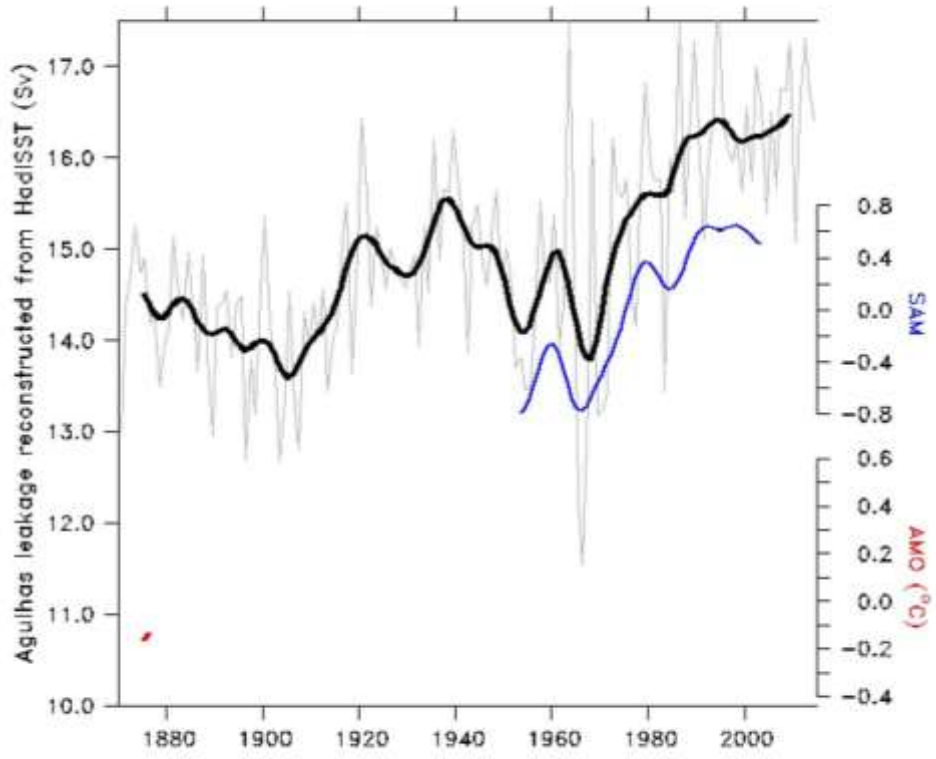
Correlation of Agulhas leakage and Indian Ocean – Atlantic SST gradient



Annual Agulhas leakage vs. SST/NST (Atlantic Ocean minus Indian Ocean) for INALT01, OFES and CM2.6

Biastoch et al. (2015)

A 145-year long historic time series of Agulhas leakage



Agulhas leakage at annual resolution and decadally filtered

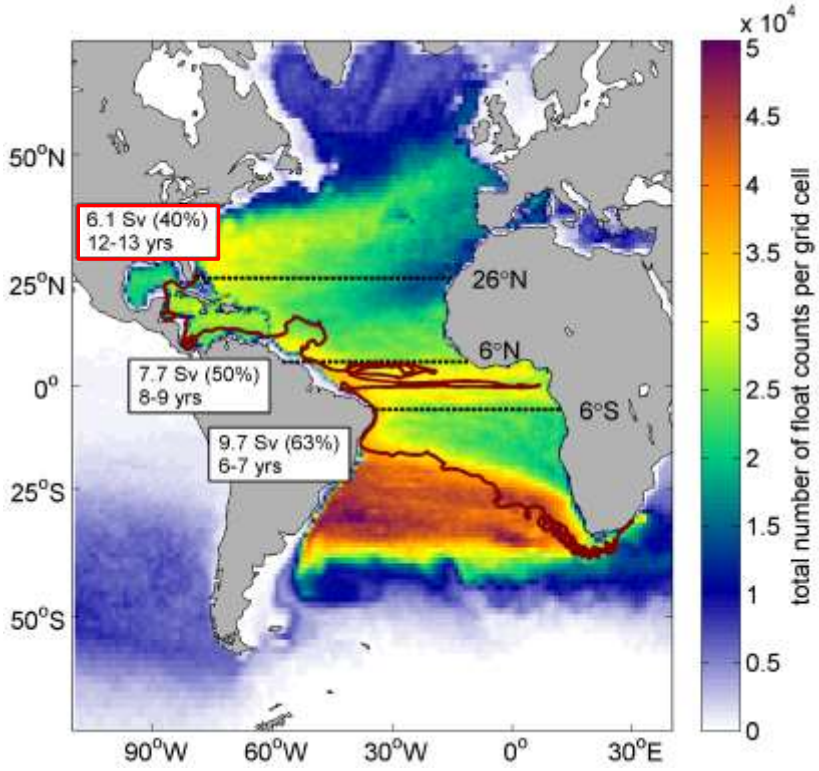
Southern Annular Mode (SAM)
(decadally correlated, r = 0.9*)

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. (2015)

Spreading of Agulhas leakage

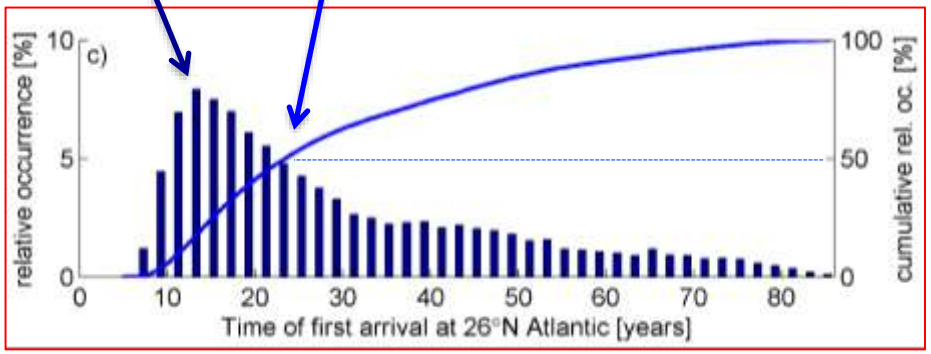


Probability density map of Agulhas leakage floats

40% of Agulhas leakage arrives at 26°N,

most probable after 12-13 years,

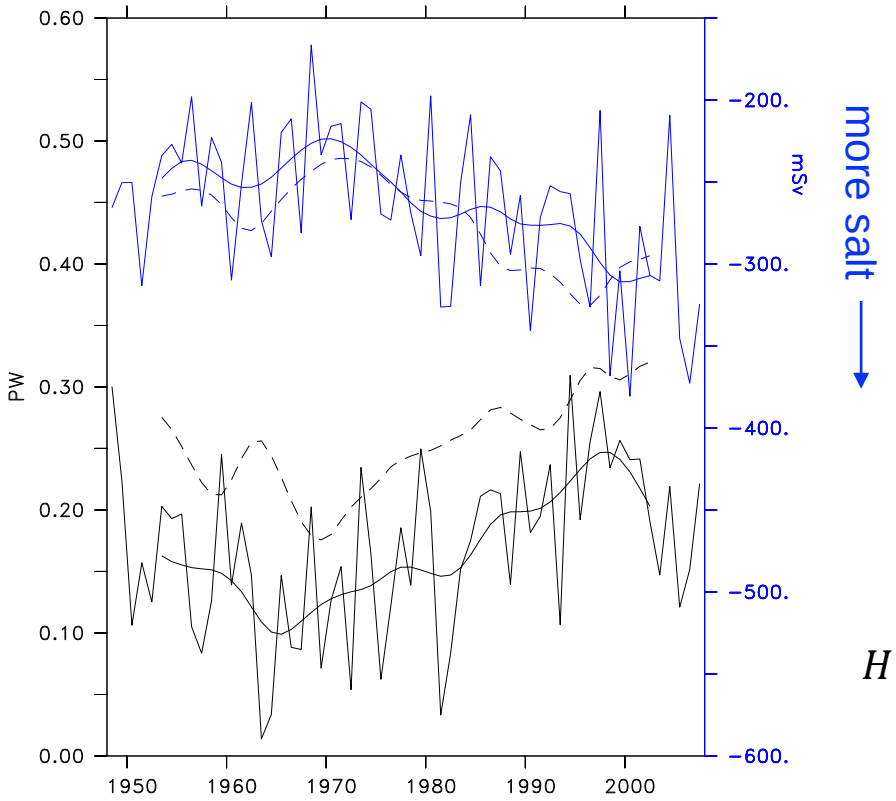
half of the water after 23 years



Transit time distributions at 26° N

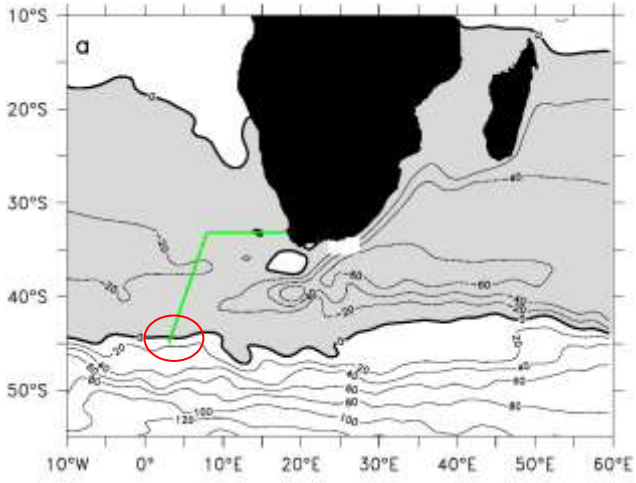
Rühs et al. (2013)

Import of heat and salt through Agulhas leakage



more heat ⟶

more salt ⟶



$$H(t) = \varrho c_p \int_{\psi(t)=0}^{Africa} \int_{-H}^{0} u_{\neg}(x,z,t)\,\theta(x,z,t)\,dz\,dx$$

Heat and Freshwater transports through Agulhas leakage and as Atlantic meridional transports (10°-5°S)

Biastoch et al. (2015)

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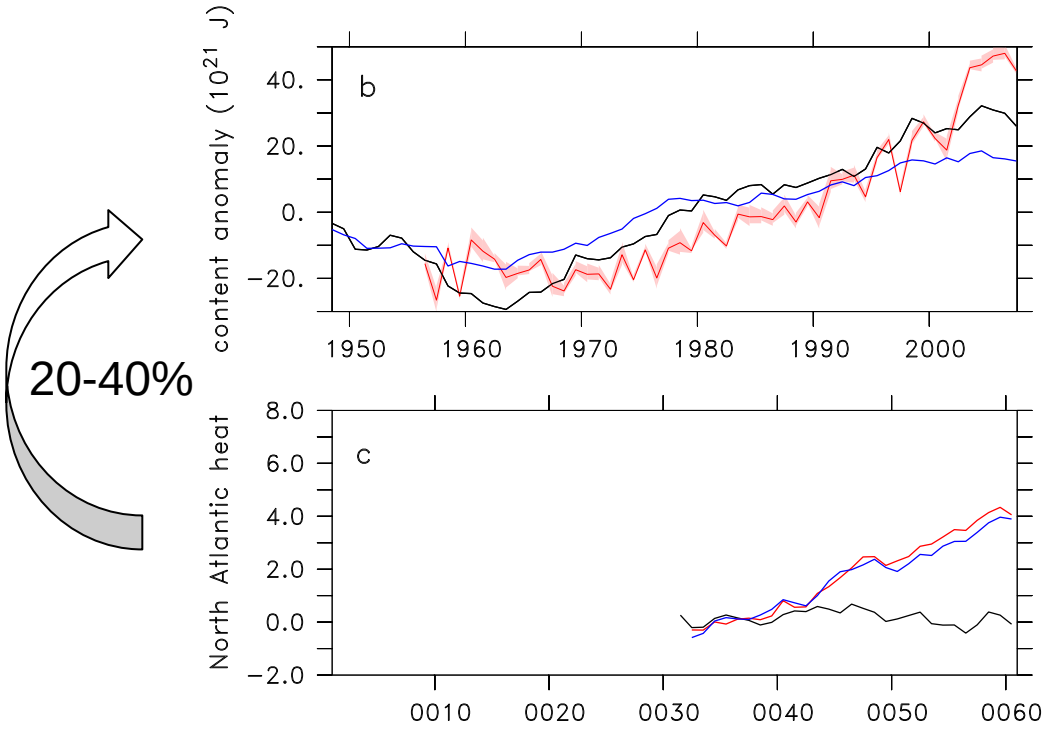
Agulhas leakage and North Atlantic heat content



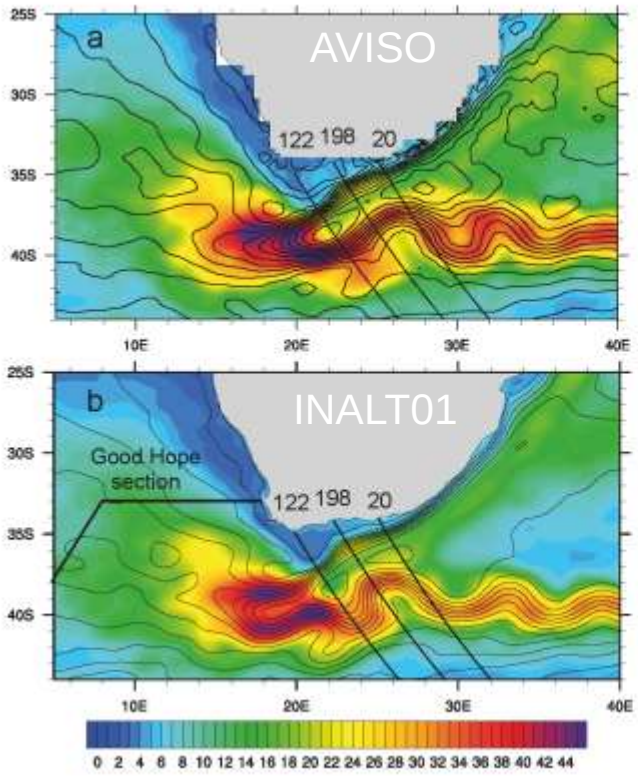
North Atlantic heat content anomaly in INALT01 (0-700 m, 200-700 m) and in observations (0-700 m)

North Atlantic heat content anomaly (0-700 m, 200-700 m) in a sensitivity experiment with **increased Agulhas leakage (2.5 Sv)**

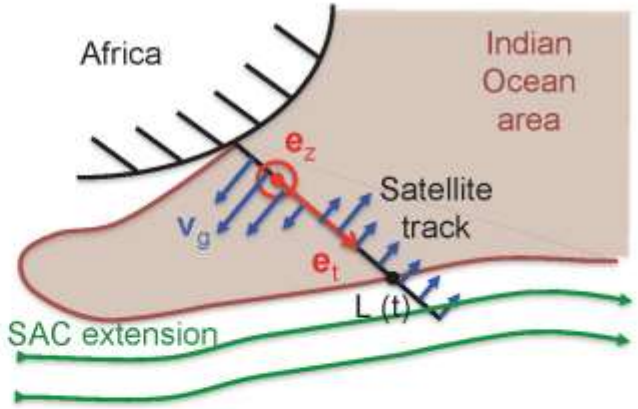
Biastoch et al. (2015), Levitus et al. (2012)

Current and future evolution of Agulhas leakage

Agulhas leakage in the past decades



Mean and s.t.d. of SSH
in observations and model

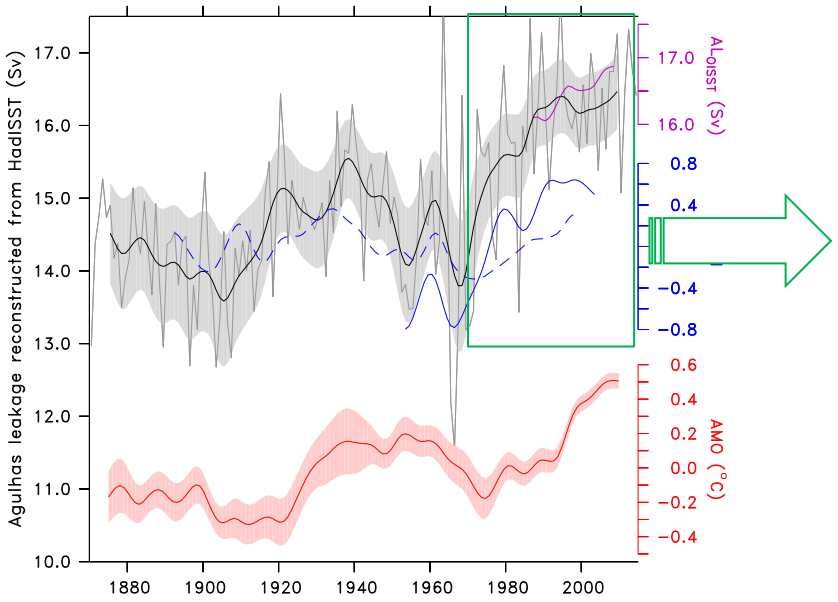


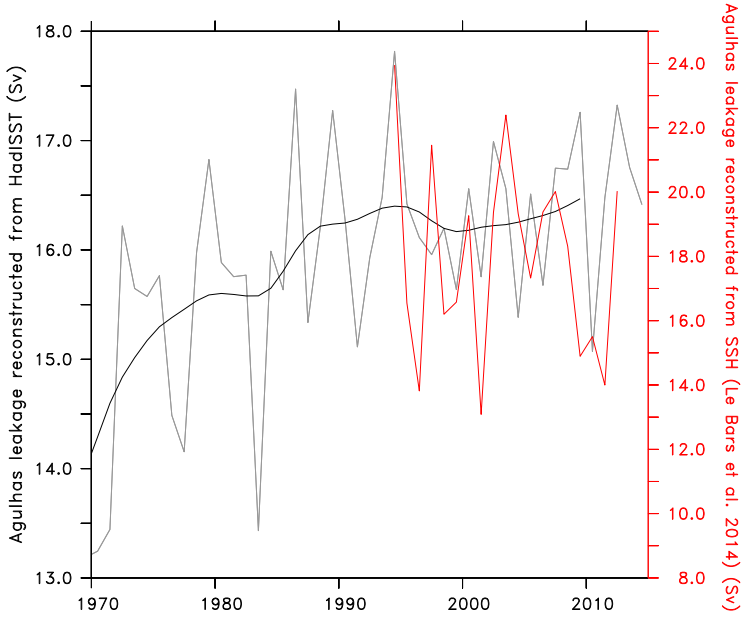
Schematic of vectors along satellite track used to separate Indian Ocean from South Atlantic Current (SAC)

AVISO SSH data: along-track data
10-day, ~6 km resolution, 1993-2015

Le Bars et al. (2014)

Agulhas leakage in the past decades



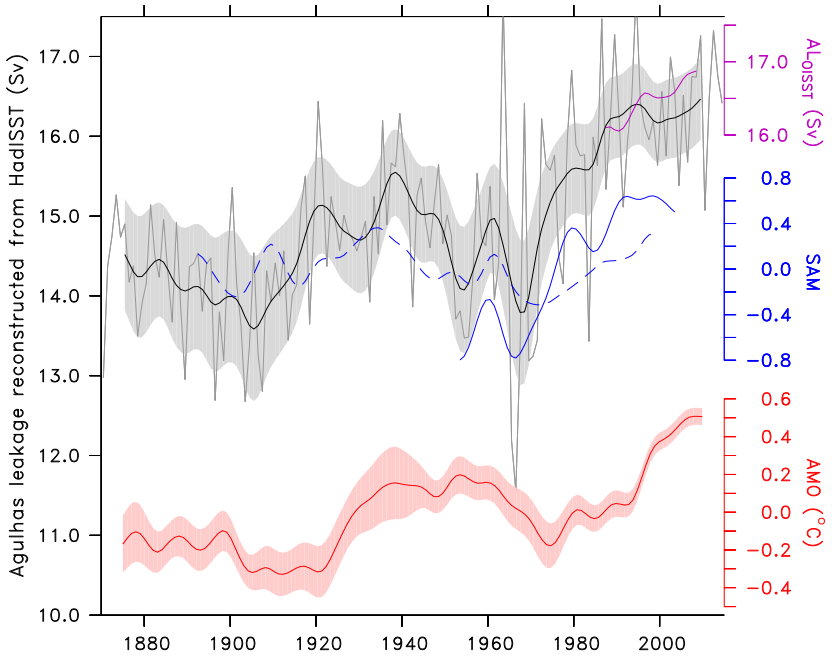


Agulhas leakage regressed from HadISST, SAM and AMO

Annual and decadally filtered Agulhas leakage regressed from HadISST, and derived through a dynamical criterion from SSH

Biastoch et al. (2015), Le Bars et al. (2014)

Summary



Biastoch, Durgadoo, Morrison, van Sebille, Weijer, and Griffies, 2015, Atlantic Multi-decadal Oscillation covaries with Agulhas leakage, *Nature Commun.*, 6:10082

The strength of the global over-turning circulation south of Africa, 'Agulhas leakage'

is linked with Southern Hemisphere winds (SAM) on decadal timescales

is lag-correlated with North Atlantic variability (AMO) on multidecadal timescales (15 yrs lag)

Satellite data sets (SSH and SST):

- Model and observations decoupled because of oceanic mesoscale
- SSH statistics used for verification
- Satellite record too short for decadal timescales → combination with *in situ* data