Agulhas Leakage in the CCSM4

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Agulhas Leakage

- Exchange of water between South Indian and Atlantic Oceans
- Takes part in
  - Supergyre
  - Meridional Overturning Circulation

Beal et al. (2011)
Agulhas Leakage

- **Main mode of exchange**
  - Agulhas Rings
  - Instability of Agulhas Retroflection
  - ~ 6 per year
  - Filled with warm and salty water
Agulhas Leakage: Impact

- Gordon (1985)
  - “Such a warm water link between the Atlantic and Indian oceans would strongly influence global climate patterns”
Agulhas Leakage: Impact

- **Gordon (1985)**
  - “Such a *warm water link* between the *Atlantic and Indian oceans would strongly influence* global climate patterns”

  - Heat and salt injection through Agulhas Leakage
    - Strengthens MOC
    - Stabilizes MOC
Agulhas Leakage: Impact

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  - Heat and salt injection through Agulhas Leakage
    - Strengthens MOC
    - Stabilizes MOC

- **Biastoch et al. (2008)**
  - High-resolution model of Agulhas region, nested in global model
  - "Dynamical signals from Agulhas region contribute MOC signal of same order of magnitude as those arising in the north"
Agulhas Leakage: Implications

- No conclusive proof yet of AL ↔ MOC link
  - Models too simplistic
  - More realistic models
    - Ocean-only, no atmospheric feedbacks
    - Too short integration
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- Our best hope: Coupled climate models
  - Coupled ocean-atmosphere
  - Long integrations
Agulhas Leakage: Implications

- No conclusive proof yet of AL ↔ MOC link
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- Our best hope: Coupled climate models
  - Coupled ocean-atmosphere
  - Long integrations

- But: Low-res models do not represent Agulhas Leakage well
  - CCSM4 overestimates Agulhas Leakage by factor 3 (Weijer et al. 2012)
Research Goal

- Can we find evidence for Agulhas Leakage ↔ MOC link in CCSM4?
Does Agulhas Leakage influence MOC in CCSM4?

- 1850 pre-industrial control
  - Final 500 yr of 1300 yr integration
Does Agulhas Leakage influence MOC in CCSM4?

- 1850 pre-industrial control
  - Final 500 yr of 1300 yr integration

- Agulhas Leakage: Lagrangian analysis
  - Monthly 3D velocity fields
  - Release 2M+ numerical floats in Agulhas Current
  - Diagnose floats crossing GoodHope line
Does Agulhas Leakage influence MOC in CCSM4?

- **1850 pre-industrial control**
  - Final 500 yr of 1300 yr integration

- **Agulhas Leakage: Lagrangian analysis**
  - Monthly 3D velocity fields
  - Release 2M+ numerical floats in Agulhas Current
  - Diagnose floats crossing GoodHope line
  - Diagnose associated salt flux $F_S$

![Graph showing time series of $F_s$ (Sv psu)]
Mechanisms

- Wave adjustment
  - Kelvin/Rossby waves

Weijer et al. (2002)
Mechanisms

- **Wave adjustment**
  - Kelvin/Rossby waves

- **Advective adjustment**

  Weijer et al. (2002)
Agulhas Leakage vs. MOC

- Coherence

$F_s$ vs. MOC at 15N (black), 15S (red), and 30S (blue)
Agulhas Leakage vs. MOC

- **Coherence:** Multidecadal (50-100 yr)
  - $F_S$ is marginally coherent with MOC

![Graph showing coherence between $F_S$ and MOC](image)
Agulhas Leakage vs. MOC

- **Coherence:** *Multidecadal (50-100 yr)*
  - $F_S$ *is marginally coherent* with MOC
  - Very small lag/lead, southward propagation, so causality…?

  ![Graph showing coherence and phase lag between $F_S$ and MOC](image)

Coherence between $F_S$ and MOC averaged for $50 < T < 100$ yr
Agulhas Leakage vs. MOC

- **Coherence**: Decadal (10-50 yr)
  - $F_S$ not coherent with MOC, except at 25 yr
Agulhas Leakage vs. MOC

- **Coherence:** *Decadal (10-50 yr)*
  - $F_S$ *not* coherent with MOC, except at 25 yr
  - At 25 yr, $F_S$ *leads* MOC

Coherence between $F_S$ and MOC averaged for $20 < T < 33$ yr
Signal Propagation: Lagged Correlation

Optimal Correlation

Lag
Signal Propagation: Lagged Correlation

Optimal Correlation

Lag

0-5 yr lag
Signal Propagation: Lagged Correlation

Optimal Correlation

Lag

30-40 yr lag
Signal Propagation: Lagged Correlation

Optimal Correlation

Lag

40-50 yr lag
Signal Propagation: Lagrangian Floats

All 1258 trajectories into box, color coded for transit time [years]

South Caribbean
Signal Propagation: Lagrangian Floats

South Caribbean

Mean arrival time: 34 yr
Conclusions

- No discernible impact of Agulhas Leakage variability on MOC
  - Study is inconclusive: salinity variability too weak
- Advective pathway is present
CCSM4: Analyses

- 1850 Pre-industrial control
  - Spun up from rest
  - Fixed 1850 conditions
  - Last 500 yr of 1300 yr simulation

- 20th century runs
  - Initialized at 1850
  - Time-varying forcing
    - Greenhouse gases
    - Solar output
    - ...
  - Last 26 yr of 156 yr simulations
  - 5 ensemble members
Agulhas Leakage in CCSM4

- 20th century runs
- Lagrangian analysis
  - Monthly 3D velocity fields, 1980-2005
  - Release 110,000 numerical floats in Agulhas Current
    - How many make it into South Atlantic?
    - How many make it across 21°S?
Agulhas Leakage in CCSM4: Mean Transports

Weijer et al. (2012)
Agulhas Leakage in CCSM4: Mean Transports

Agulhas Current transport

69 Sv

70 Sv (Bryden et al. 2005)

Weijer et al. (2012)
Agulhas Leakage in CCSM4: Mean Transports

Good Hope line transport

43 Sv

14-17 Sv (Doglioli et al. 2006; van Sebille et al. 2009; Richardson 2007)

Weijer et al. (2012)
Agulhas Leakage in CCSM4: Mean Transports

21ºS transport

10 ± 1 Sv

10 Sv (Donners and Drijfhout 2004)

4 Sv (Biastoch et al. 2009)
Agulhas Leakage in CCSM4: Trends

Weijer et al. (2012)

3.6 ± 1.3 Sv/decade

-0.1 ± 0.6 Sv/decade
Agulhas Leakage in CCSM4: Conclusions

- Agulhas Current okay
- Agulhas Leakage overestimated by factor \(~3\)
- 75% recirculates in super-gyre
- Why?
  - Agulhas Retroreflection *inertial* process
  - Not captured by low-resolution 1° models
  - Instead, leakage takes place in *viscous* boundary layer

De Ruijter (1982)
Meridional Coherence of the AMOC

Coherence MOC at 26N with 60N (black), 45N (red), and 30N (blue)

Coherence MOC at 26N with 15N (black), 15S (red), and 30S (blue)

$T > 50$ yr
Good Metric of Agulhas Leakage Impact?
CCSM4

Atmosphere Model
(Community Atmosphere Model: CAM4)

Land Model
(Community Land Model: CLM4)

Ocean Model
(Parallel Ocean Program: POP2)

Sea Ice Model
(Community Ice Code: CICE4)
Does Agulhas Leakage influence MOC in CCSM4?

- Coherence
  - Salinity in southeastern Atlantic coherent with $F_S$ but not with $V_{ag}$
Joint Response to ENSO: AMOC
CCSM4

- Community Climate System Model, version 4
  - Joint NSF/DOE funded project
    - National Center for Atmospheric Research (NCAR)
    - Los Alamos National Laboratory (LANL)

- CMIP5: Coupled Model Intercomparison Project
  - World Climate Research Program (WCRP)
  - Standard experimental protocol for climate model comparison
  - Science input into IPCC’s 5th assessment report (AR5; 2013)
Agulhas Leakage vs. MOC

- Coherence: *Interannual (1-10 yr)*
  - $F_S$ *not* coherent with MOC
  - At 4-5 yr, joint response to ENSO
Salinity Bias

\[ \Delta S = 0.24 \text{ psu} \]
\[ \sigma(S_{34S}) = 0.11 \text{ psu} \]

\[ \Delta S = -0.04 \text{ psu} \]
\[ \sigma(S_{34S}) = 0.02 \text{ psu} \]
Wave Adjustment

- Kelvin/Rossby waves

Weijer et al. (2002)
Wave Adjustment

- Kelvin/Rossby waves
  - No cross-equatorial transport of MOC anomalies
  - Time scales shorter than decadal
  - *Equatorial Buffer*

*Weijer et al. (2002)*
Wave Adjustment

- **Meridional coherence of the AMOC**
  - MOC at 26°N with MOC at 15°N, 15°S, 30°S

![Coherence MOC at 26N with 15N (black), 15S (red), and 30S (blue)]

\[ T > 50 \text{ yr} \]
Advective Adjustment

- Advection of density anomalies

Weijer et al. (2002)