Response of the Atlantic Ocean Circulation to Greenland Ice Sheet Melting

Wilbert Weijer, Mat Maltrud, and Matthew Hecht
Los Alamos National Laboratory (LANL)

Henk Dijkstra, Michael Kliphuis, and Matthijs den Toom
Institute for Marine and Atmospheric Research Utrecht (IMAU)

Weijer et al., GRL 2012
Atlantic Meridional Overturning Circulation (AMOC)

- How sensitive is AMOC to GrIS freshwater input?
  - 2007 mass deficit: 267 ± 38 Gt/yr (Rignot et al. 2008)
    - ~ 0.01 Sv
    - Freshwater input expected to increase
      - Surface melting
      - Precipitation
      - Calving

- Studied exclusively in low-resolution ocean models
  - No explicit eddies, effects parameterized
  - Sluggish, broad boundary currents
  - Freshwater input over large area Greenland Ice Sheet
Research Question

- **Does enhanced model resolution modify AMOC sensitivity?**
  - More accurate representation of ocean transports
    - Boundary currents
    - Eddy fluxes
  - Less reliance on parameterizations

- **Does result depend on spatial pattern of freshwater forcing?**

**Approach**

- Perform freshwater sensitivity studies in hierarchy of models
  - 1 degree and 0.1 degree
- Different freshwater flux patterns
  - Realistic distribution of freshwater around Greenland
  - Hosing
The Model

- **Los Alamos’ Parallel Ocean Program (POP 2.0)**
  - Global domain
  - Ocean-only

- **2 configurations**
  - \(1^\circ\) ("by-one")
    - non-eddying
    - IPCC class
    - 40 levels
    - Dipole, displaced pole over Greenland
  - \(0.1^\circ\) ("point-one")
    - strongly eddying
    - 42 levels
    - tripole
Forcing

- **CORE monthly-mean normal-year atmospheric climatology**
  - Large & Yeager (2004) data
  - Standard bulk formulae

- **SST**
  - Latent heat flux
  - Sensible heat flux
  - Radiation

- **SSS**
  - Precipitation
  - Evaporation
  - Run-off
  - Flux correction
    - Mixed boundary conditions
    - No relaxation
Experimental Procedure: Spin-up + 3 Branches

- **C-Mixed**: Control Integration
- **E-Greenland**: Greenland Freshwater
  - ‘Realistic’ near-coastal distribution around Greenland (*Rignot & Kanagaratnam 2006*)
  - Time-mean amplitude 0.1 Sv (*Gerdes et al. 2006*)
  - Seasonal variation
- **E-Hosing**: Traditional Hosing
  - Distribution North Atlantic 50°-70°N (CMIP)
  - Constant 0.1 Sv flux
E-Greenland Freshwater Perturbation

0.1°

1.0°
Overturning Streamfunction

0.1°

1.0°
Overturning Response: E-Greenland

\[ \Delta \text{MOC (Sv)} \]

\[ \text{Time (yr)} \]

\[ R_{0.1} \]

\[ x1 \]
Overturning Response: E-Greenland

Overturning response: $x1$ rapid initial adjustment
Overturning Response: E-Greenland

Overturning response:
- x1 rapid initial adjustment
- $R_{0.1}$ more gradual, persistent
Surface Salinity: E-Greenland

Labrador surface salinity:
- Similar evolution
Surface Heat Flux: E-Greenland

Surface Heat Flux Anomaly

- Lab R_{0.1}
- Lab x1

% vs. Time (yr)
Surface Heat Flux: E-Greenland

Surface Heat Flux Anomaly

- Lab $R_{0.1}$
- Nordic $R_{0.1}$
- Lab x1
- Nordic x1

% vs. Time (yr)
Overturning Response: Hosing

AMOC Strength Anomaly

![Graph showing AMOC strength anomaly over time.](image)

- $S_y$ vs Time (yr)
- Lines represent different conditions:
  - E–Greenland $R_{0.1}$
  - E–Hosing $R_{0.1}$
  - E–Greenland $x1$
  - E–Hosing $x1$
New Results: 0.5 Sv Perturbation
Den Toom et al. (in prep.)

\[ \psi(\varphi, b, t) = -r_0 \cos \varphi \int_{\lambda_w}^{\lambda_E} \int_{-H}^{\xi(\lambda, \varphi, b, t)} v(\lambda, \varphi, z, t) \, dz \, d\lambda \quad \text{Streamfunction} \]

\[ V(\varphi, b, t) = r_0 \cos \varphi \int_{\varphi}^{90N} \int_{\lambda_w}^{\lambda_E} \int_{-H}^{\xi(\lambda, \varphi, b, t)} dz \, d\lambda \, d\varphi \quad \text{Volume} \]

\[ G(\varphi, b, t) = \psi(\varphi, b, t) + \frac{\partial V(\varphi, b, t)}{\partial t} \quad \text{Transformation streamfunction} \]

e.g., Marsh et al. (2000); Wolfe & Cessi (2011)
New Results: 0.5 Sv Perturbation

Den Toom et al. (in prep.)

Yr 76

Yr 116-76
New Results: 0.5 Sv Perturbation

Den Toom et al. (in prep.)

Yr 76

Yr 116-76
Conclusions

- **Greenland freshwater flux perturbations**
  - No quantitative difference in MOC response
  - Qualitative differences
    - Rapid initial adjustment in \( x1 \)
    - Gradual, more persistent in \( R_{0.1} \)
      - Deep convection more resilient to freshwater perturbation
      - Increase of Nordic Seas ventilation in \( x1 \)

- **E-Greenland vs. E-Hosing**
  - No difference in \( x1 \)
  - \( R_{0.1} \) much more sensitive to *spatial distribution*

- **Adiabatic pole-to-pole: limited predictive value for transient response**
Dye Arrival Time (112 m)
Dye Arrival Time (112 m)

0.1°

R_{0.1} 112m

Year 2

1.0°

x1 112m

Year 5
Dye Arrival Time (112 m)

Year 4

Year 8
Dye Arrival Time (1626 m)

0.1°

1.0°

R_{0.1}
1626m

x1
1626m
Dye Arrival Time (1626 m)

0.1°

Year 5

1.0°

Year 14
Dye Arrival Time (1626 m)

- 0.1°: R_{0.1} 1626m
- 1.0°: x1 1626m

> 50 Years