The Northwest Corner of the Atlantic and Rapid Climate Change

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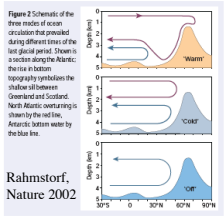
Abstract

The Northwest region of the Atlantic plays a lead role in the reorganization of ocean circulation associated with rapid climate change. This same region of the ocean remains one of the most problematic in ocean general circulation models. A more realistic mean circulation with development of the North Atlantic Current emerges from eddy-resolving models, though not without some difficulty. We review modes of North Atlantic circulation, consider the relevance of eddy-resolving ocean modeling to more accurate characterization of the thermohaline circulation and its response to anthropogenic forcing, and present findings on the sensitivity of the Gulf Stream/North Atlantic Current system to ocean model configuration.

Modes of Atlantic Circulation (review)



Rahmstorf, Nature 2002

Vert. View

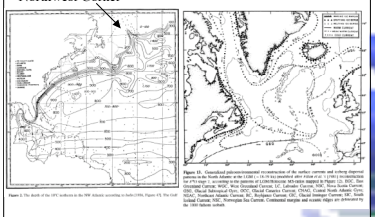
Modern

Glacial

Shutdown

Horizontal View

Northwest Corner



Modern circulation (10°C isotherm), from Iselin (1936, as shown in Rossby (1996), left); note penetration of North Atlantic Current into **Northwest Corner**. Surface currents and iceberg dispersal at **Last Glacial Max**, from Robinson et al. (1995), showing Gulf Stream feeding into broad North Atlantic Drift with no high latitude penetration of subtropical gyre.

Conceptual mechanism for rapid switching between two modes shown above, with onset of northern deep water formation: through **T**opographic and **P**lanetary waves, from Rossby and Nilsson (2005).

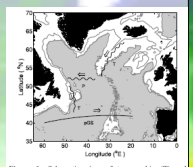


Figure 1. Schematic view of topographic (T) and planetary (P) wave propagation from Iceland to the Grand Banks south of Newfoundland. The path of the paleo-Gulf Stream (pGS) is also indicated. Depths greater than 2.5 km corresponding to the spread of Southern Ocean Waters are shaded.

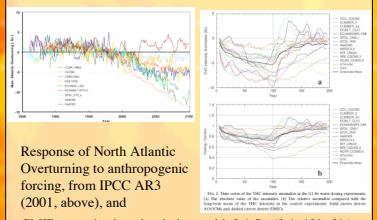
Given preconditioning of Atlantic and then resumption of deep water formation:

- topographic and planetary waves communicate this shift to Grand Banks region, and
- North Atlantic Current forms, turning north at Grand Banks and into NW Corner

Importance of transport of saline subtropical gyre water for

- onset of deep water formation
- maintenance of deep water formation

Modeling of THC Stability (more review)

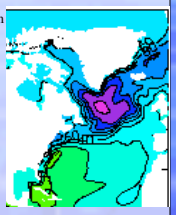


Response of North Atlantic Overturning to anthropogenic forcing, from IPCC AR3 (2001, above), and

CMIP water hosing simulations with 0.1 Sv ($0.1 \times 10^6 m^3/s$) applied for 100 years (Stouffer (2006), right).

The Northwest Atlantic in Ocean Climate Models

Ocean climate models don't form a Northwest Corner, in contrast with observations (compare plot of 10°C isotherm in left-most column). Sea surface height, at right, from Community Climate System Model Version 3 control integration. SST errors of order 5°C found here; transport of saline subtrop gyre waters may be greater issue for modeling of THC response.

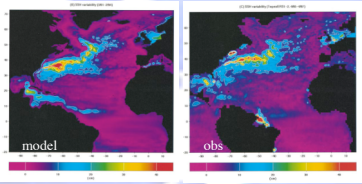


Eddy-Resolving Ocean Models for Climate Science?

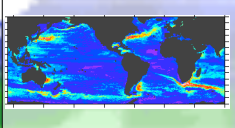
- Eddies essential to mean circulation of Northwest Atlantic
- THC stability would be climate science application where high resolution has role
  - opportunity to support "IPCC-class" climate simulation

Gulf Stream/North Atlantic Current System in Eddy-Resolving Models

Possible to get good Gulf Stream/North Atlantic Current in eddy-resolving model:



Sea surface height variability from 0.1° regional model of Smith et al. (2000), and from TOPEX/Poseidon obs of Le Traon et al. (1998).



But 0.1° resolution does not guarantee emergence of NAC, as seen in the closely related global model of Maltrud and McClean (2005).

How to Get GS separation, North Atlantic Current in Global Model?

Factors we address here in regional modeling context:

- Horizontal dissipation (parameterization, coefficient)
- Preparation of topography (smoothness, detail)

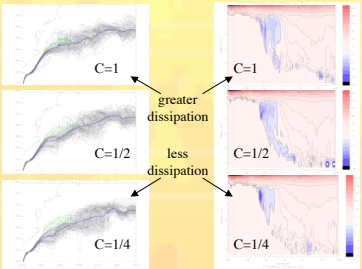
Other factors we've examined:

- Vertical mixing
- Forcing
- Advection (simple centered vs. quasi-monotonic)

Factors particular to global configuration:

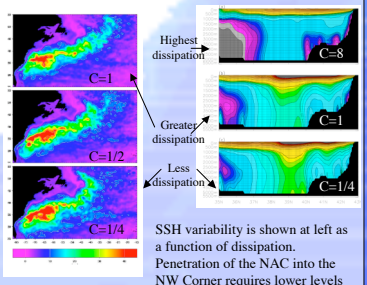
- Horizontal grid discretization
- Lateral boundary conditions (lack thereof)

Sensitivity to Horizontal Dissipation



Gulf Stream path (model in black, from 3 years at 10 day intervals; obs in green) as intersection of 12°C isotherm and 400m, on left; crossover point showing velocity normal to Stream on right (DWBC in blue). Results support the hypothesis of Thompson and Schmitz (1989) of control of DWBC on separation of the Gulf Stream.

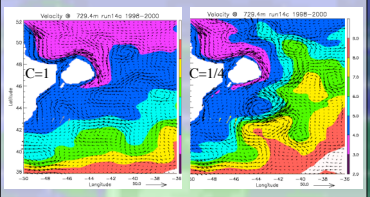
Whereas Gulf Stream separation calls for higher levels of dissipation (using biharmonic form), North Atlantic Current more satisfactory at lower level of dissipation. Together they determine acceptable bounds:



SSH variability is shown at left as a function of dissipation. Penetration of the NAC into the NW Corner requires lower levels of dissipation (bottom panels).

Eddy kinetic energy is shown, above right, as a function of dissipation. Section shows Gulf Stream just before encountering topography of Grand Banks region. Deep eddy kinetic energy appears to be required for reattachment to topography, supporting mechanism of Ozgokmen et al. (1997, proposed for Gulf Stream separation but appearing to apply to Stream reattachment).

The very different frontal structures in cases with and without strong NAC formation are shown below:

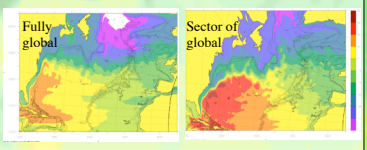


Additionally, use of Gent-McWilliams parameterization, even in eddy-resolving regime, as suggested by Roberts and Marshall (1998), has since been demonstrated by Smith and Gent (2004) using an anisotropic form.

Sensitivity to Preparation of Topography (still in regional context)

Both use of partial bottom cells and additional smoothing of topography ("partial bottom cells" more smoothly represent shallow slope regions) allow for more active SSH variability in Northwest Corner (results not shown here).

Influence of Lateral BC's



North Atlantic SSH from fully global 0.1° dipole grid (3600x2400 points), left, and from sector version of same grid (1130x1500 points with **restoring boundaries** at N/S, no throughflow), right.

- North Atlantic Current emerges with imposed lateral boundary conditions on temperature and salinity.
- Highlights importance of source waters (another poster…)

Findings Applied to Global Modeling

- Ocean-only study with "transit time distributions" and Lagrangian tracers
  - Using tripole grid, partial bottom cells, aniso. GM and viscosity, nearly monotonic advection
- Fully-coupled climate simulation
  - Within the Community Climate System Model
  - (Short) control and CO_2 increase runs

Both efforts involve many people, various institutions.

Finally, Questions to Contemplate in particularly optimistic moments

- Smarter ways to bring in effects of mesoscale eddies?
- Impact of vertical representation (beyond smoothness)
  - Pressure vs. density as vertical coordinate
  - Parameterization of mixing in overflows

And: How can we effectively combine findings from short temporal duration eddy-resolving simulation with ability of faster models (IPCC-class, paleo, or fully implicit) to study preconditioning and triggering of paleoclimate transitions?

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