Sensitivity of North Atlantic Circulation to Topography and Sub-Gridscale Parameterization

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Abstract

The eddy-resolving North Atlantic simulation of Smith et al. (2000) demonstrated the possibility of achieving a closer, more satisfactory comparison with the observed Gulf Stream/North Atlantic Current system with sufficient grid resolution. Subsequent studies (Eden and Boening, 2002; Maltrud and McClean, 2005) have underlined the fact that similarly well resolved models are likely to produce less satisfactory results under different but justifiable configurations.

A number of studies have been pursued in order to resolve the sensitivity of circulation and state to model configuration (Smith and Gent, 2004; Penduff et al., 2002; Bryan et al., 2006). Here we explore the sensitivity of North Atlantic circulation and state to topography and sub-gridscale parameterization. In particular we examine Gulf Stream separation and subsequent penetration of the Current into the region of the Northwest Corner, deep convection in the Labrador Sea, the depth and extent of the mixed layer in the Labrador and Irminger Seas and characteristics of the deep western boundary current.

0.1º North Atlantic Simulations

mixing →

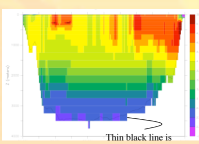
topography ↓

	Biharmonic, Richardson	Biharmonic, KPP	Anisotropic, KPP
40 Level full (5500 m)	BR_40L_full	BK_40L_full	AK_40L_full
42 Level full (6000 m)	BR_42L_full		
42 Level pbc	BR_42L_pbc		AK_42L_pbc
42 Level 3dxSmoothed pbc			AK_42L_S3

Six runs have been completed with daily ECMWF winds cycling through the period 1986--2001 and climatological buoyancy forcing. A seventh case, AK_42L_S3 with Cressman-style quadratic smoothing (Cressman, 1959) which falls to zero at a distance of 3dx (rather than 1.5dx in other cases), is underway. The anisotropic viscosity and Gent-McWilliams-style mixing follow Smith and McWilliams (2003) and Smith and Gent (2004). Full and pbc refer to the vertical grid discretization, as illustrated below. The three cases presented here are indicated in highlighted text.

Partial Bottom Cells

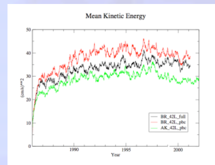
Pressure and tracer points in the x-z plane above partially-filled bottom cells.



Thin black line is PBC bottom, white is FULL

Interpolating tracer points to the same level before taking horizontal derivatives. From the Reference Manual for the Parallel Ocean Program (POP), available from http://climate.lanl.gov.

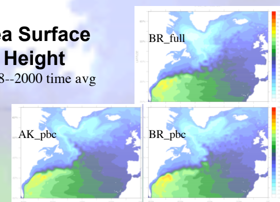
Mean KE



KE increases with pbc's, decreases with anisotropic mixing (at least with our chosen values of dissipative coefficients).

Sea Surface Height

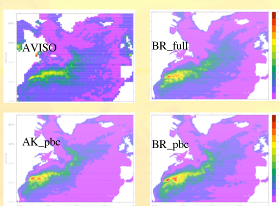
1998--2000 time avg



- NW Corner improves steadily.
- Less tendency to pre-separate, or depart too zonally from the continental slope, in cases with Anisotropic dissipation.
- Note qualitatively different shape of subrotopical gyre in SSH with Anisotropic dissipation and partial bottom cells (lower left panel), reflecting a more Northeastward orientation of flow through the western portion of the gyre.

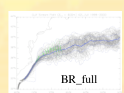
SSH Variability

1998-2000

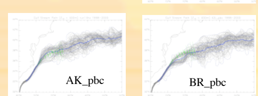


- Again, improvement in NW Corner with pbc's (lower panels) and with Anisotropic dissipation (lower left).
- Variability too high between Hatteras and the New England Sea Mount Chain: pbc's alone further accentuate variability, Anisotropic brings the variability more in line with the observations AVISO obs.
- Thanks to McClean and Ivanova for providing the obs

Gulf Stream Paths

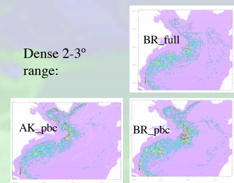


Model tracks at 10 day intervals, 1998-2000, with Obs from Watts (1995, shown in green). The tendency towards overly zonal separation is reduced with pbc's and Anisotropic dissipation.



Vertically integrated PT-class transports

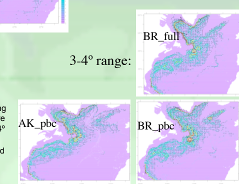
Dense 2-3º range:



Transport past Cape Farewell (Greenland) and around the Labrador Basin picks up, in 2-3º class, with partial bottom cells (lower right), and again with addition of Anisotropic dissipation (lower left).

Units: Sverdrups per 100km of cross-stream distance (10's of m^3/m/s)

3-4º range:

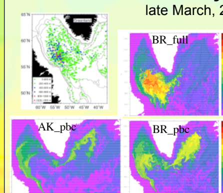


- In the base case with Biharmonic mixing & full cell topography (upper right) more of the transport is in this lighter 3-4º potential temperature class.
  - Not much makes it past the Grand Banks

Deep western boundary current can more clearly be seen, upstream of Cape Hatteras, in Anisotropic case (lower left).

Mixed layer depths

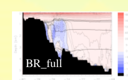
late March, 2000 (model)



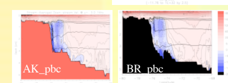
- Mixed layer depths in full cell case are somewhat deep (upper right, reaching 2500 m).
- Depth compares better with obs with partial bottom cells (lower right), but extent of deep mixed layer in the Irminger Basin is probably unrealistic.
- Deep mixed layers more topographically constrained with Anisotropic mixing (lower left).
- Obs from winter of 1996/7, Lavender et al. (2002, upper left).

Stream-averaged along-stream velocities

1998-2000



The component of the deep western boundary current (DWBC) which happens to be parallel to the stream is captured here, at the crossover point.



Notice deep, intense core of the DWBC with partial bottom cells, and increased coherence with the addition of anisotropic viscosity (we have seen that the Stream itself has reduced variability with anisotropic viscosity, and so the stream coordinate system is less variable in the lower left panel).

Summary

- Sensitivity to mixing parameterization is strong, as seen in path and variability of Gulf Stream/North Atlantic Current system
  - as discussed in Chassignet and Garraffo (2001), Dietrich et al. (2004), Bryan et al. (2006) and other papers.
  - We also see sensitivity in late winter-time mixed layer depths and other features associated with deep water characteristics
- Sensitivity to topography also significant
  - Use of piecewise constant but more vertically continuous "partial bottom cells", as presented by Adcroft (1997), advantageous.
- We are currently investigating the question of how much to smooth
  - Following up on the assertion of Penduff et al. (2002) that topography in z-coordinate ocean models should be smoothed

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