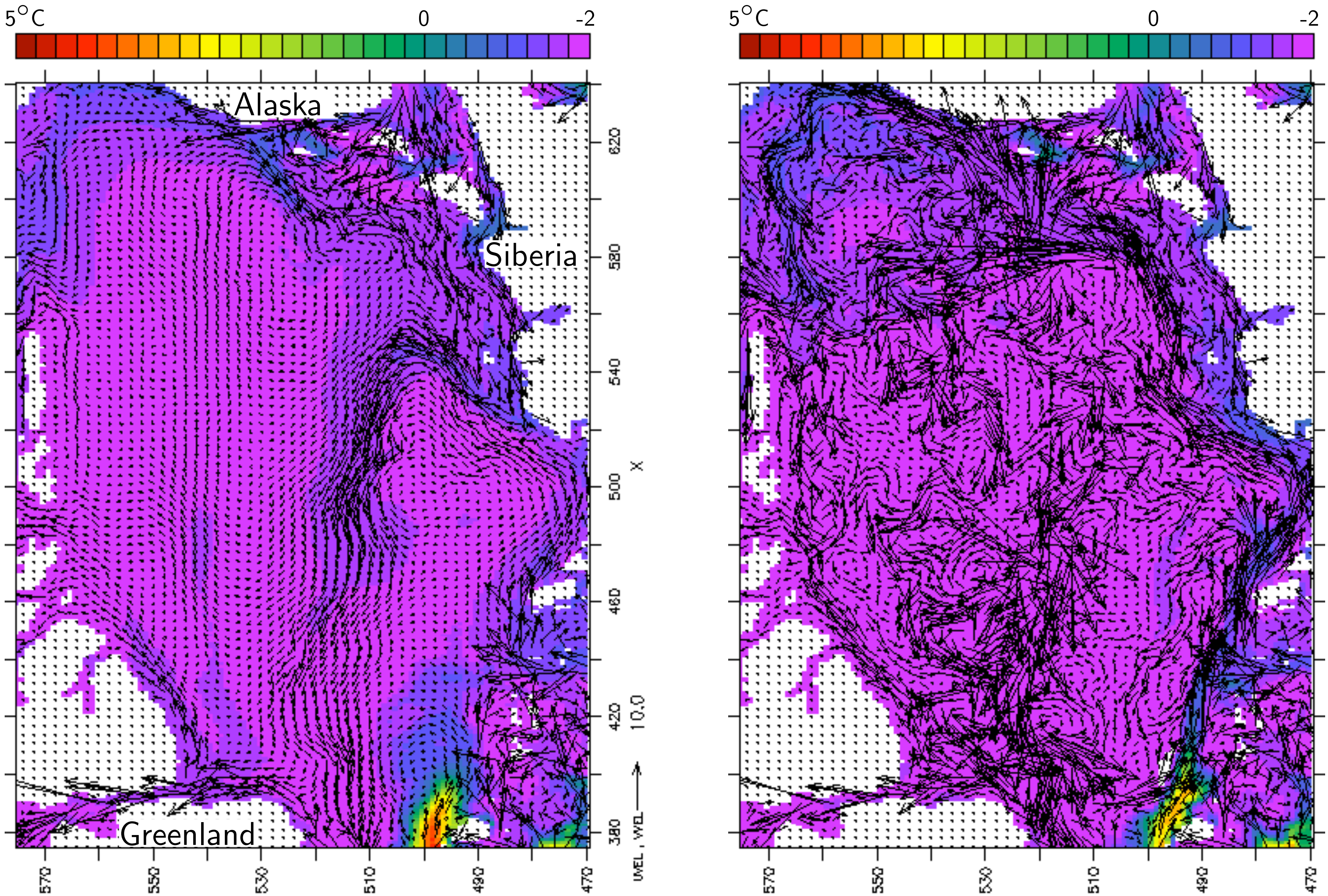
Los Alamos National Laboratory
Climate, Ocean and Sea Ice Modeling Program

High-latitude-friendly lateral mixing parameterizations for global ocean simulations

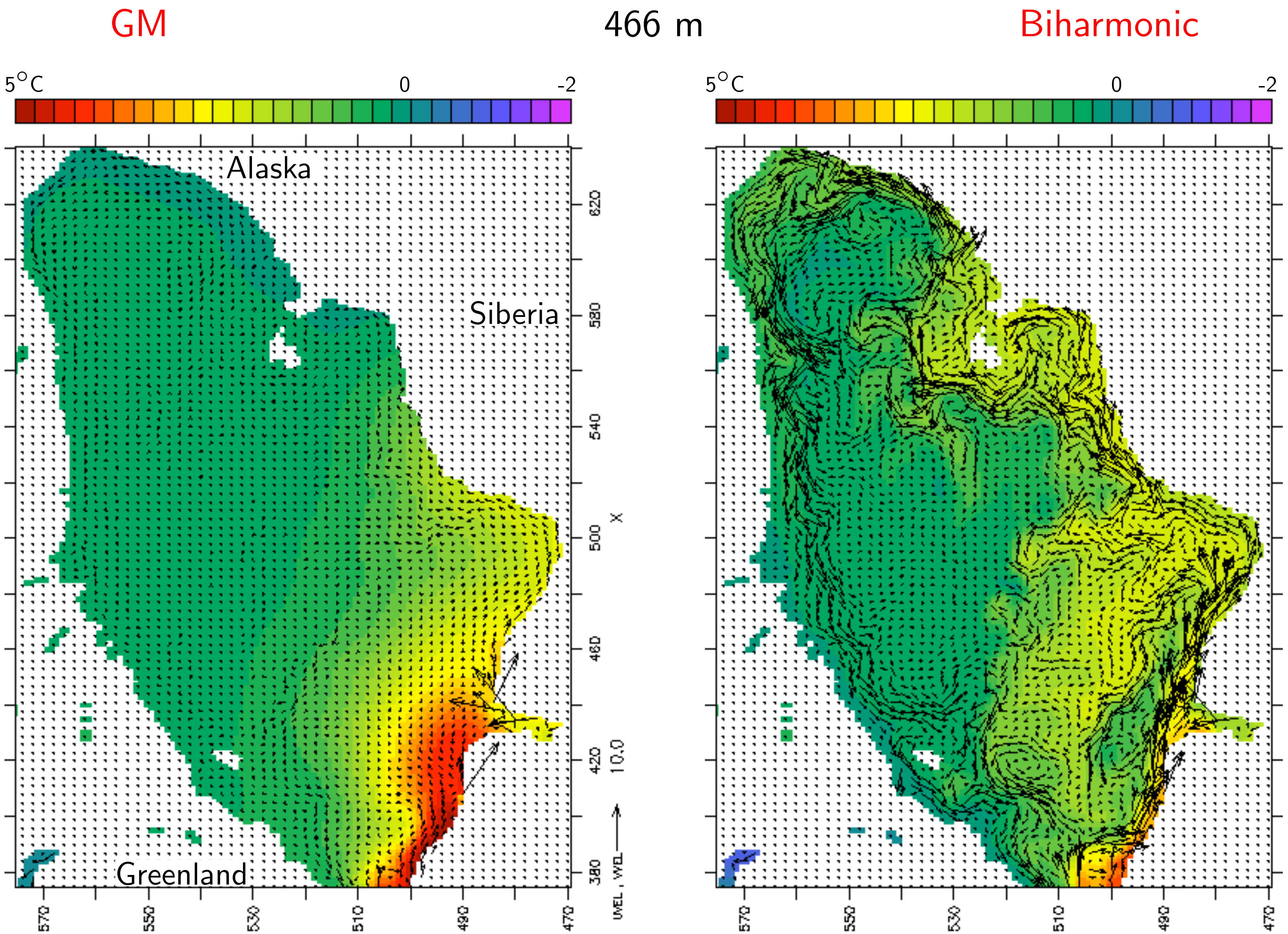
Elizabeth Hunke, Mat Maltrud, Matthew Hecht

1990 Potential Temperature and Velocity

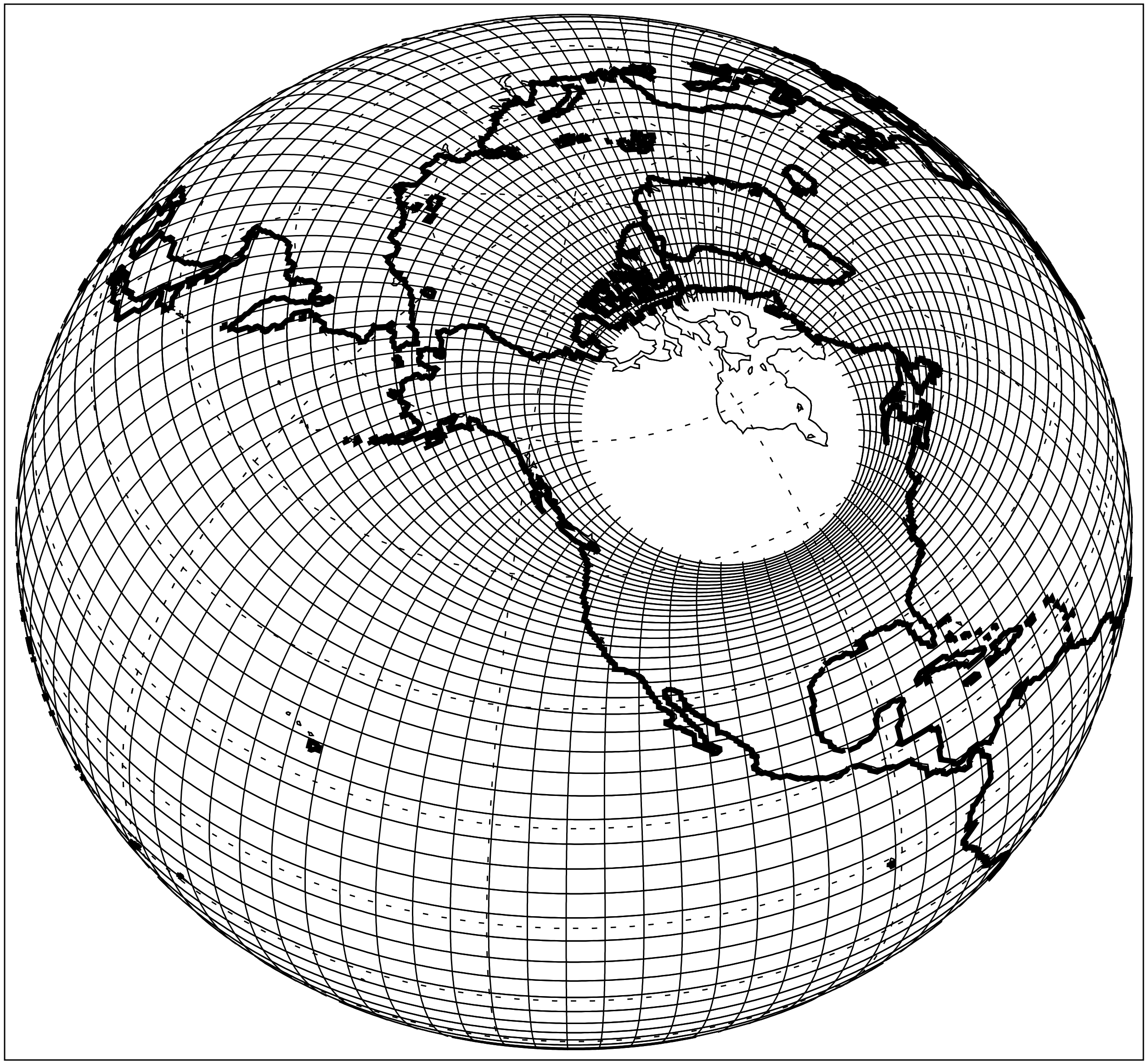
GM | 36 m | Biharmonic



1990 Potential Temperature and Velocity



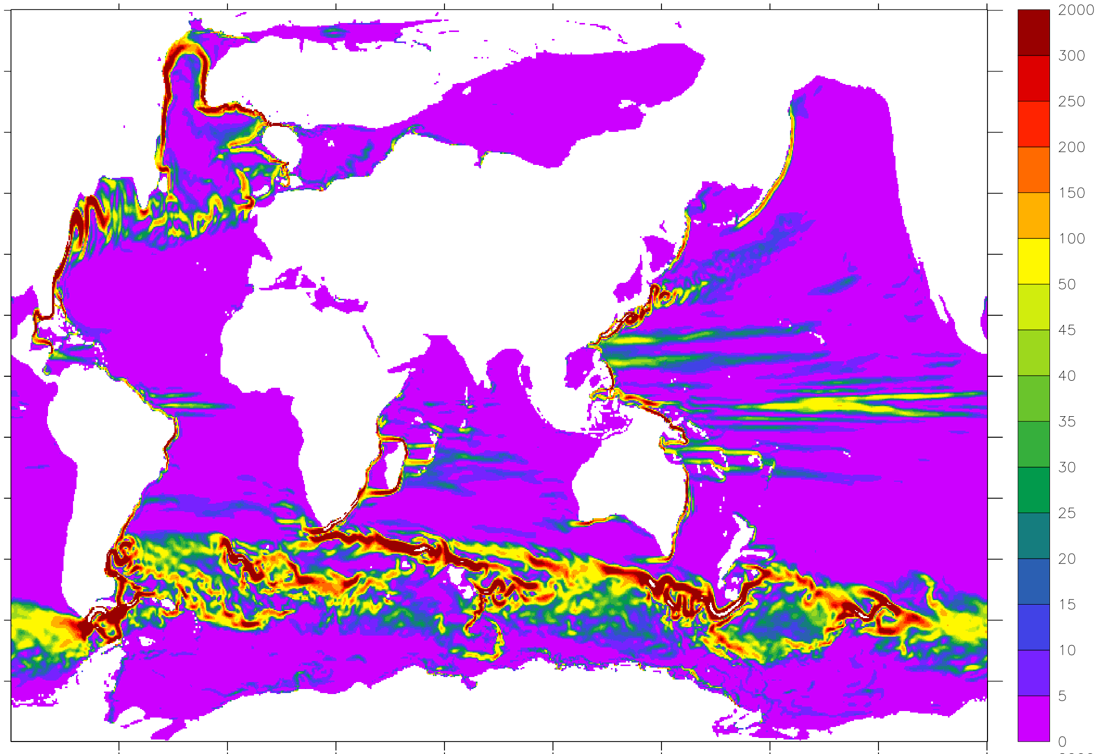
0.4°: 900x600x40



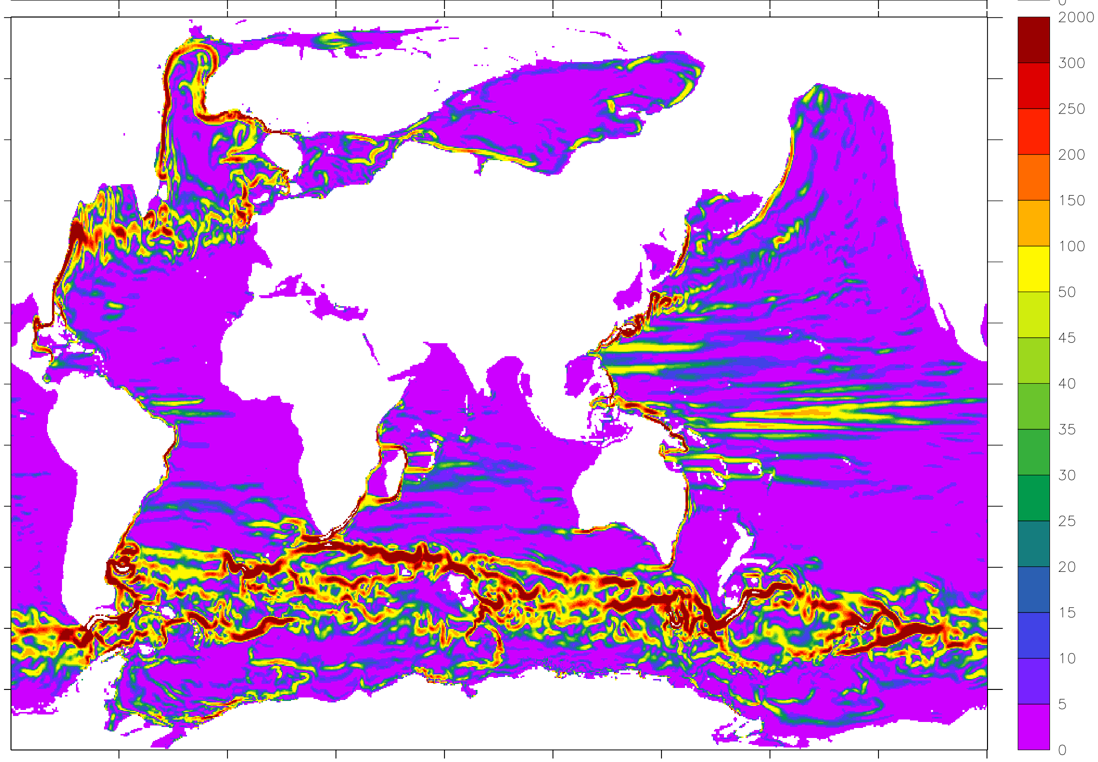
1 of every 100 mesh nodes shown

Kinetic Energy
1990, 466 m

GM



Biharmonic



Tracer transport

$$\frac{\partial T}{\partial t} + \mathbf{u} \cdot \nabla_2 T + w\frac{\partial T}{\partial z} = D_H(T) + D_V(T)$$

biharmonic mixing

$$D_H = \nabla_2^2(\kappa_\circ A^{\frac{3}{2}} \nabla_2^2 T)$$

Gent-McWilliams mixing

$$D_H = \nabla_3 \cdot \mathbf{K} \cdot \nabla_3 T$$

I. Damping time scales

for simple systems

following Griffies and Hallberg, MWR 2000

Suppose $T = \gamma(t) e^{ikx_n}$, where $x_n = n\Delta$. Then

(1) for the Laplacian case, $T_t = C\, T_{xx}$,

$$\gamma(t) = \exp\left[-C \left(\frac{2}{\Delta} \sin \frac{k\Delta}{2} \right)^2 t \right]$$

$$\text{Damping time scale} = \tau_C = \frac{1}{C \left(\frac{2}{\Delta} \sin \frac{k\Delta}{2} \right)^2}$$

(2) for the biharmonic case, $T_t = B\, T_{xxxx}$,

$$\text{Damping time scale} = \tau_B = \frac{1}{B \left(\frac{2}{\Delta} \sin \frac{k\Delta}{2} \right)^4}$$

$\Rightarrow \dfrac{\tau_B}{\tau_C} = \dfrac{C}{B} \left(\dfrac{2}{\Delta} \sin \dfrac{k\Delta}{2} \right)^{-2} \sim \dfrac{C}{Bk^2}$ if $\frac{k\Delta}{2}$ is small.

Tracer transport

$$\frac{\partial T}{\partial t} + \mathbf{u} \cdot \nabla_2 T + w\frac{\partial T}{\partial z} = D_H(T) + D_V(T)$$

biharmonic mixing

$$D_H = \nabla_2^2(\kappa_\circ A^{\frac{3}{2}} \nabla_2^2 T)$$

Gent-McWilliams mixing

$$D_H = \nabla_3 \cdot \mathbf{K} \cdot \nabla_3 T$$

II. Scaling argument for grid dependence

for simple systems

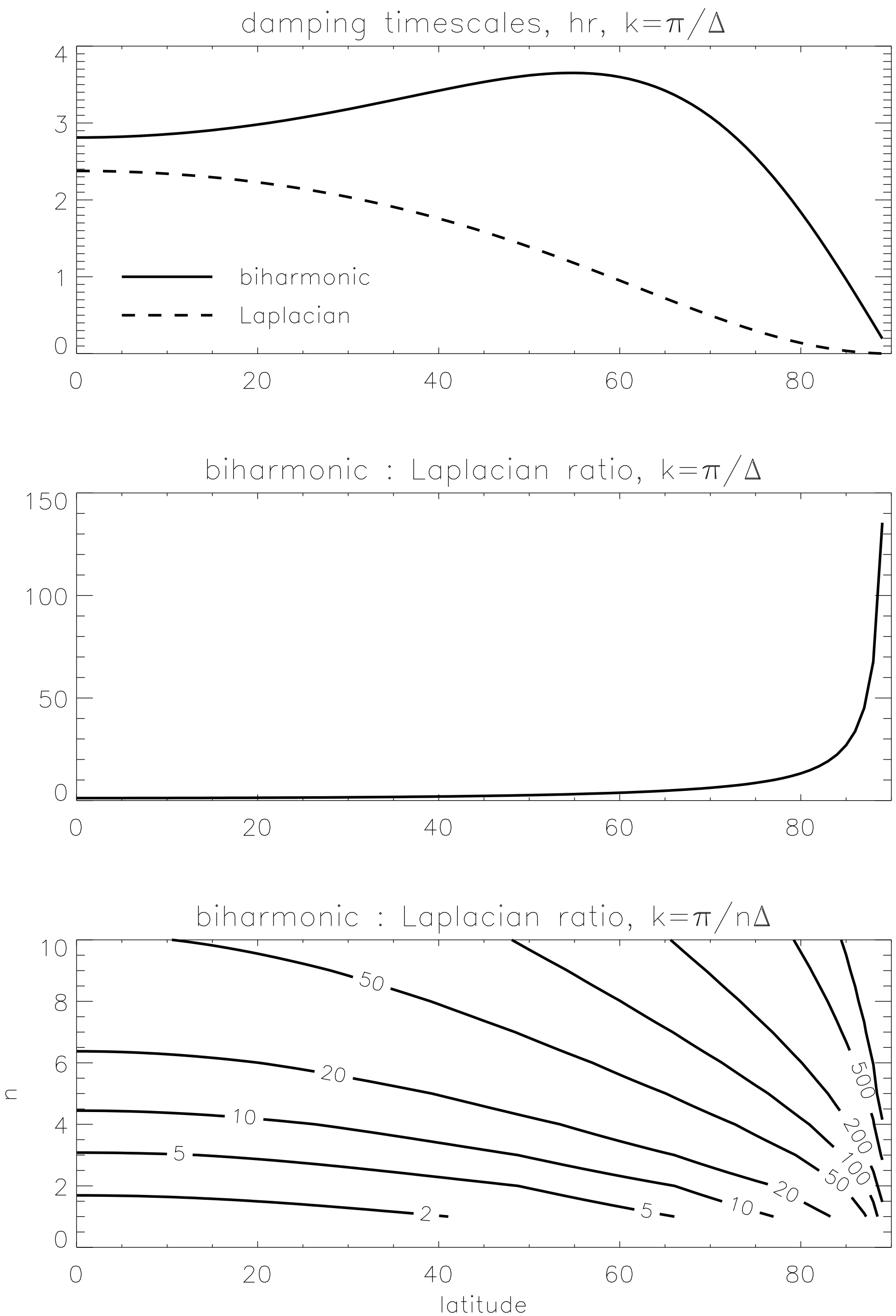
following Maltrud et al., JGR 1998

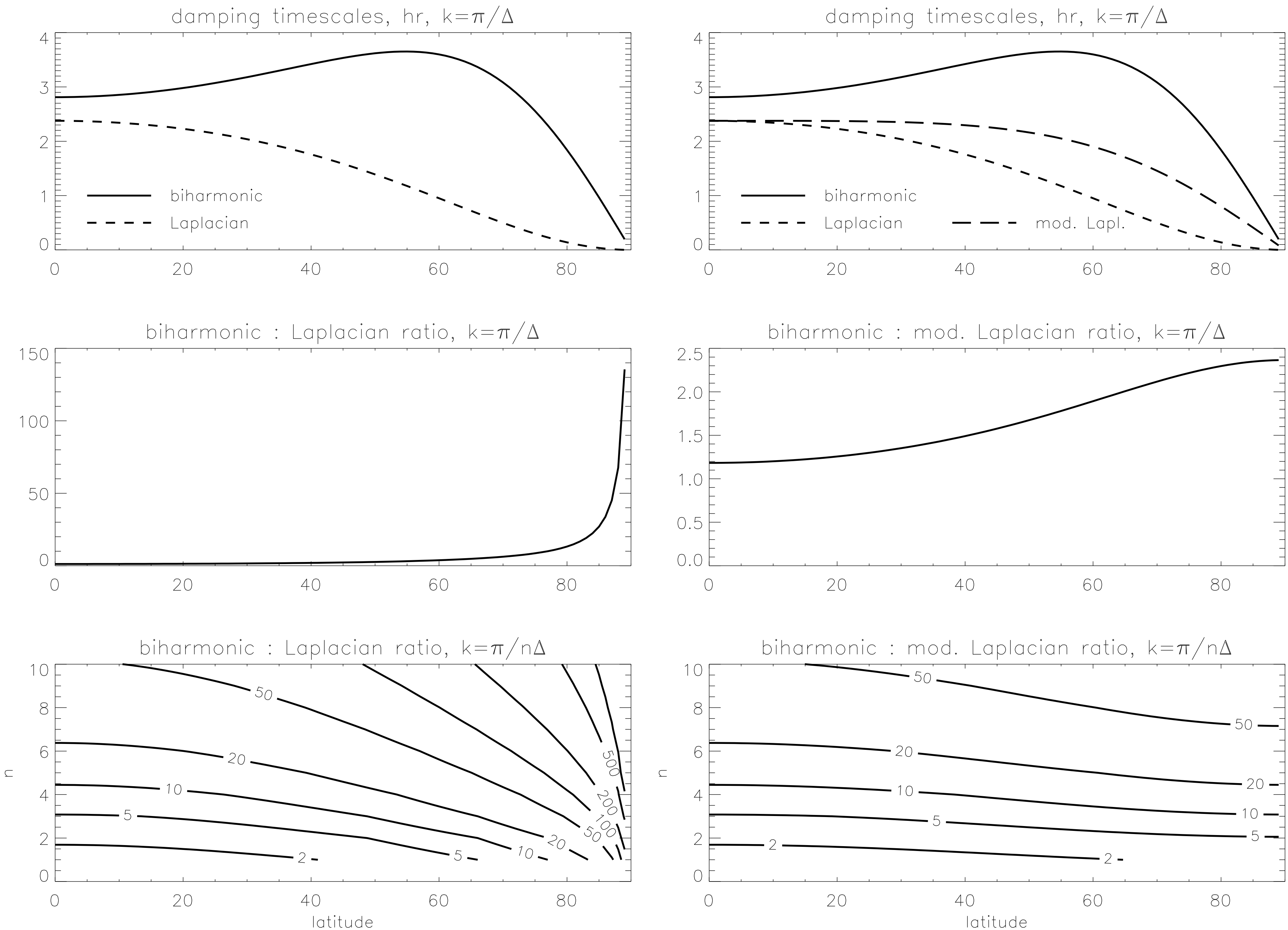
Balance advective and diffusive terms. Then

(1) for the Laplacian case, $U\frac{\partial T}{\partial x} = C\frac{\partial^2 T}{\partial x^2}$, and C scales with $\Delta \sim dx$,

(2) for the biharmonic case, $U\frac{\partial T}{\partial x} = B\frac{\partial^4 T}{\partial x^4}$, and B scales with Δ^3.

In 2D, grid cell area $A \sim \Delta^2$, so $C \propto A^{1/2}$ and $B \propto A^{3/2}$.


damping timescales, hr, k=π/Δ
biharmonic
Laplacian
biharmonic : Laplacian ratio, k=π/Δ
biharmonic : Laplacian ratio, k=π/nΔ
n
latitude
2
5
10
20
50
100
200
500



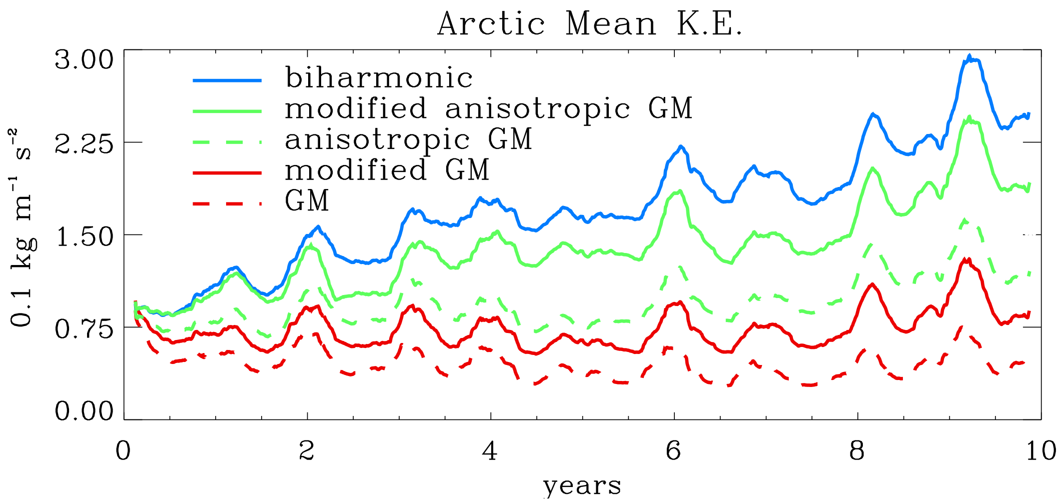
damping timescales, hr, k=π/Δ
biharmonic
Laplacian
damping timescales, hr, k=π/Δ
biharmonic
Laplacian
mod. Lapl.
biharmonic : Laplacian ratio, k=π/Δ
biharmonic : mod. Laplacian ratio, k=π/Δ
biharmonic : Laplacian ratio, k=π/nΔ
n
latitude
biharmonic : mod. Laplacian ratio, k=π/nΔ
n
latitude

Simulations

POP-CICE coupled model
0.4° grid, modified Large-Yeager atmospheric forcing

10-year "spin-up" runs
- biharmonic (includes area scaling)
- GM
- GM with area scaling ("modified GM")
- anisotropic GM
- anisotropic GM with area scaling ("modified anisotropic GM")

1-year "spin-down" runs
- from beginning of year 10, biharmonic run
- 5 runs above, plus Laplacian with and without area scaling



Mean kinetic energy

averaged over the ocean volume
north of 80°N

10-year "spin-up" (1981–1990)

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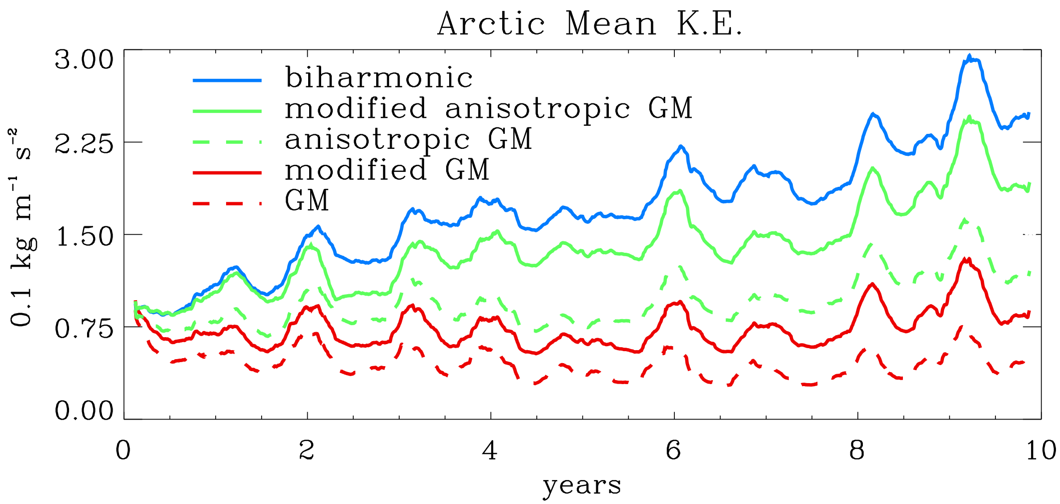
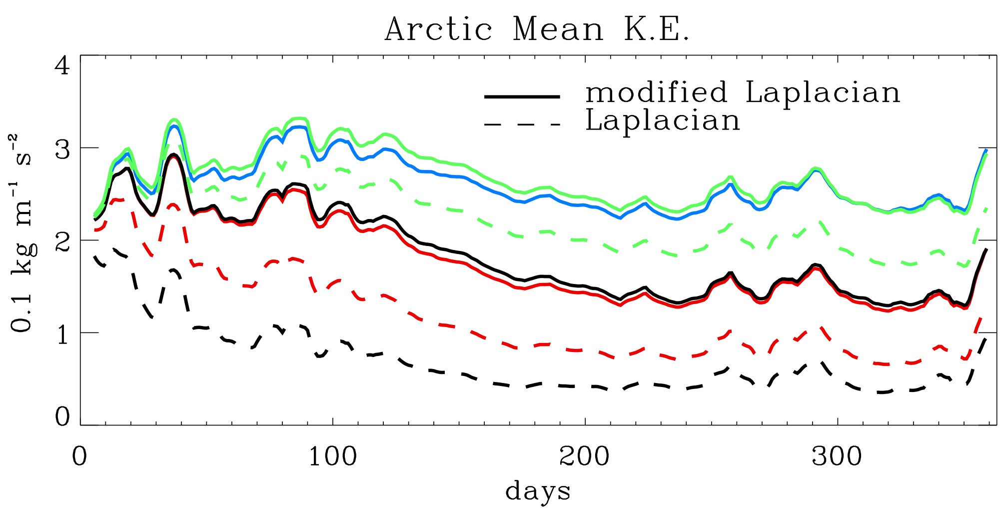
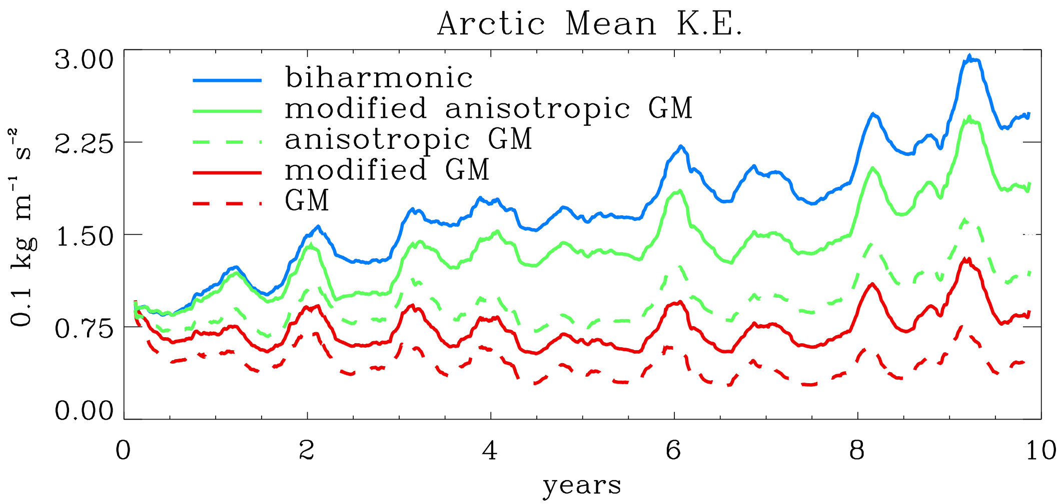


1-year "spin-down" (1990)

initialized from biharmonic



Mean kinetic energy



averaged over the ocean volume
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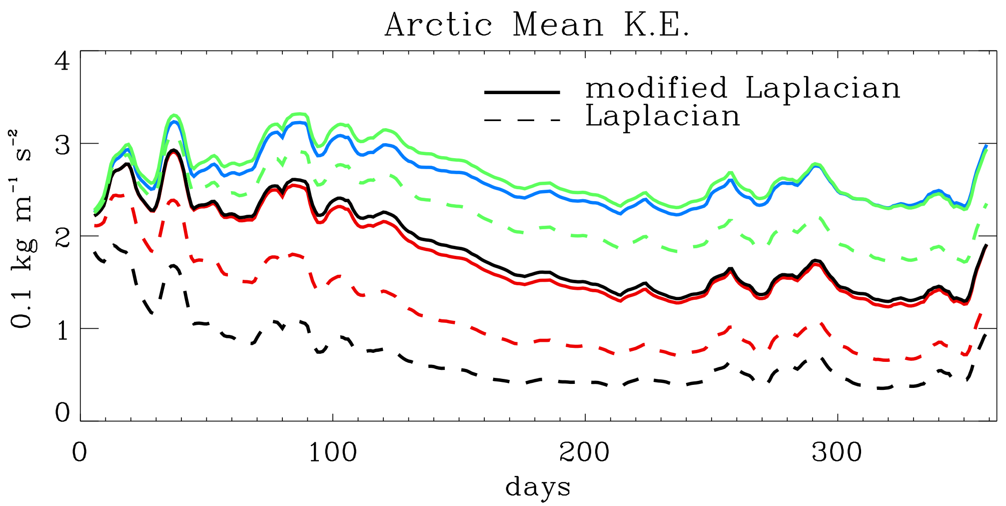

1-year “spin-down” (1990)

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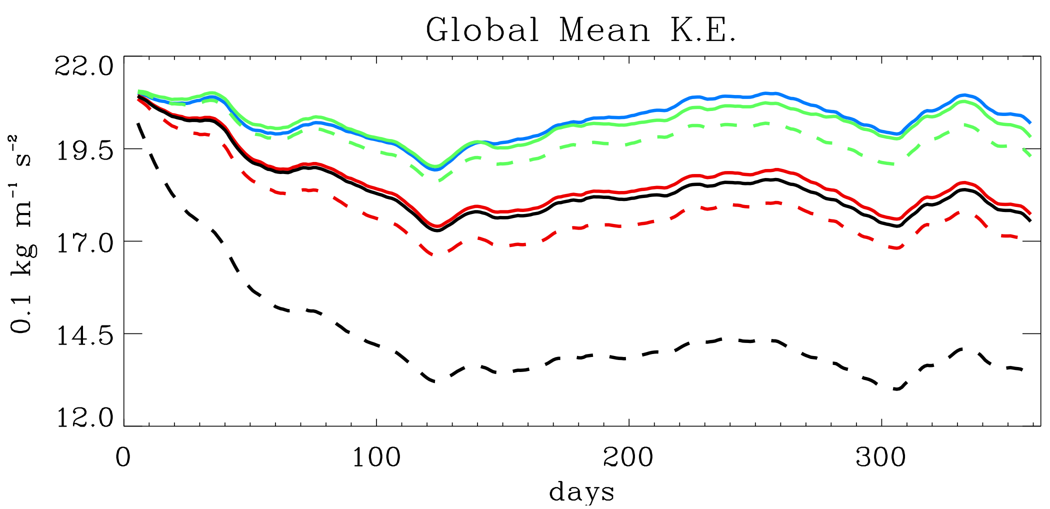
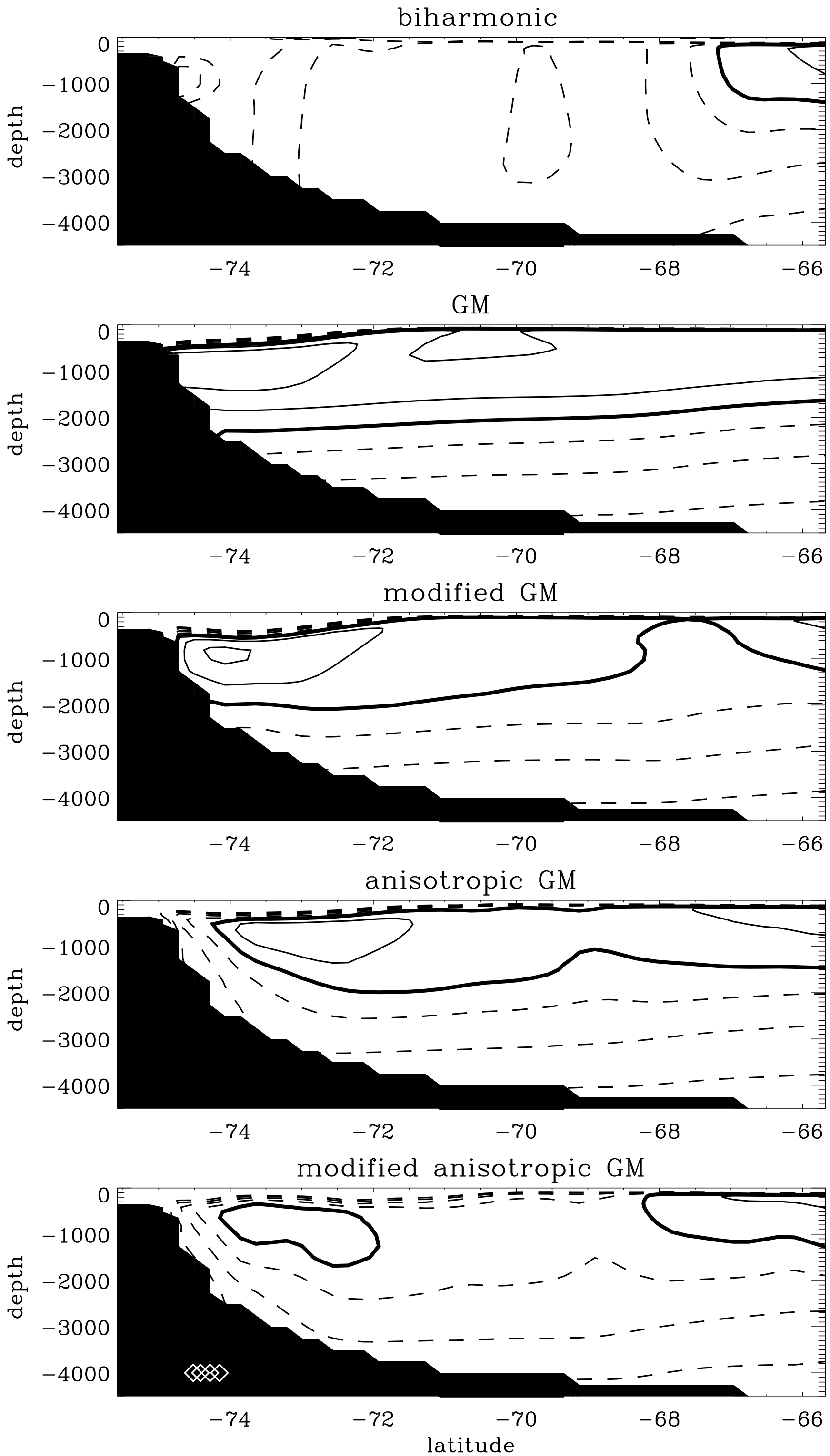


Global

1-year “spin-down” (1990)

Potential Temperature



Weddell Sea, 36.4 W

contour interval 0.2°

Foldvik et al., JGR 2004

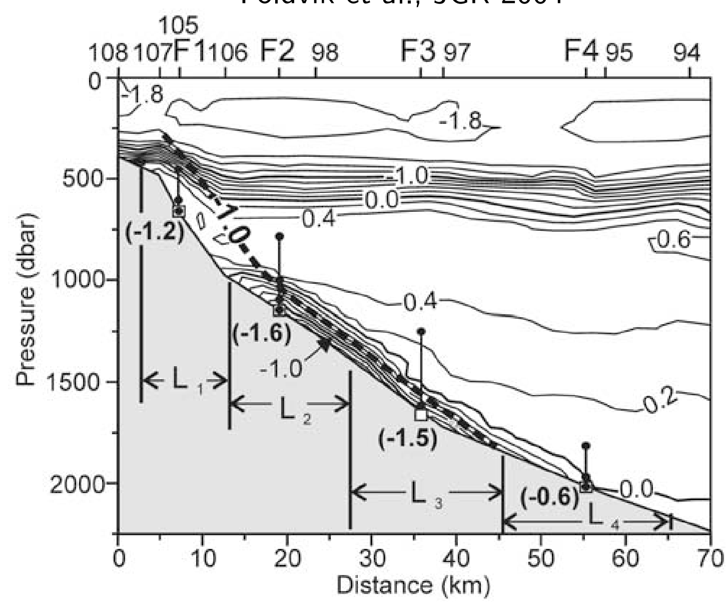


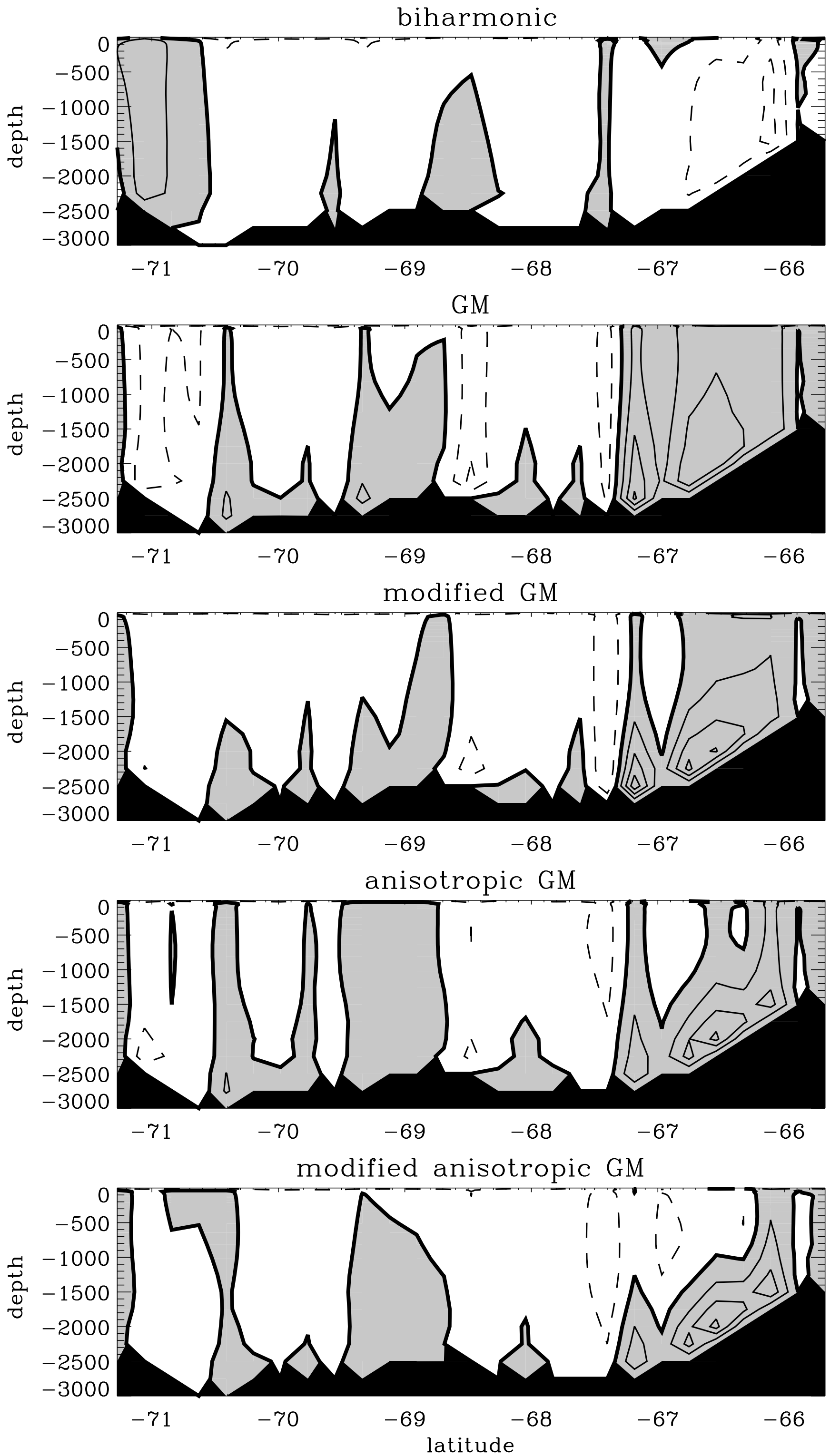
Figure 6. Potential temperature distribution at the F-section obtained during the recovery of the moorings (ANT XVI/2). The positions of the current meters (circles) and the MicroCATs (squares) are indicated. The one-year average of the −1°C isotherm obtained from the current-meters is shown by the thick, dashed curve. The average potential temperatures (°C) from the MicroCATs are indicated in parentheses. The horizontal distances L_i used for transport calculations are indicated. Tick-marks on the top axis mark the location of the CTD casts.

Current Speed

normal to 54 W (ISW transect)

contour interval 1 cm/s

shaded ⇒ eastward



MUENCH AND GORDON: WESTERN WEDDELL CIRCULATION AND TRANSPORT

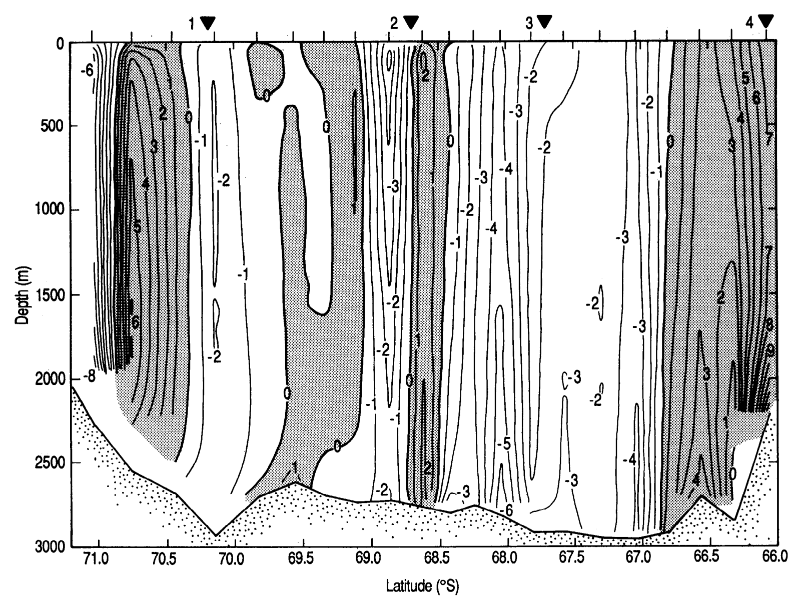
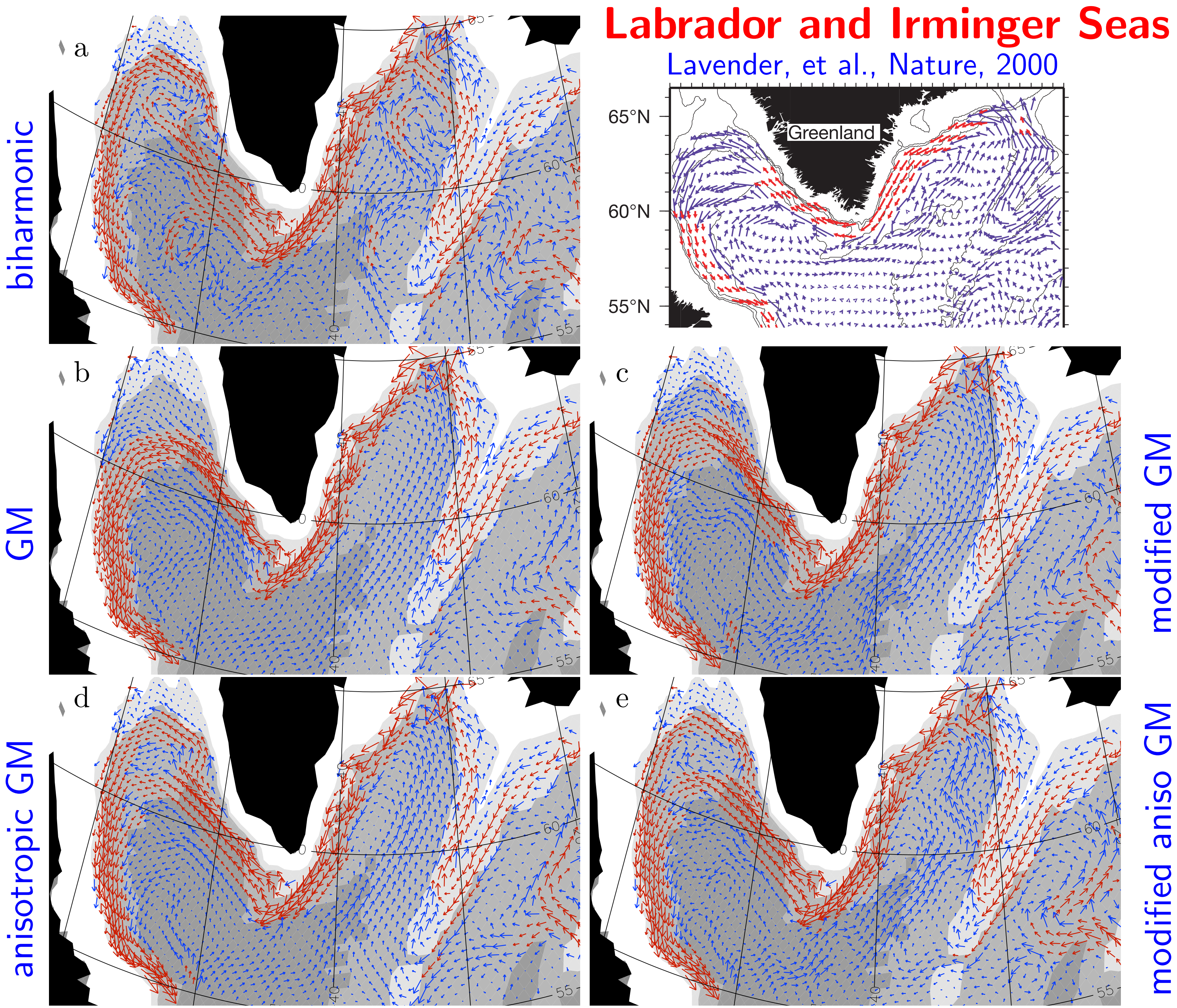
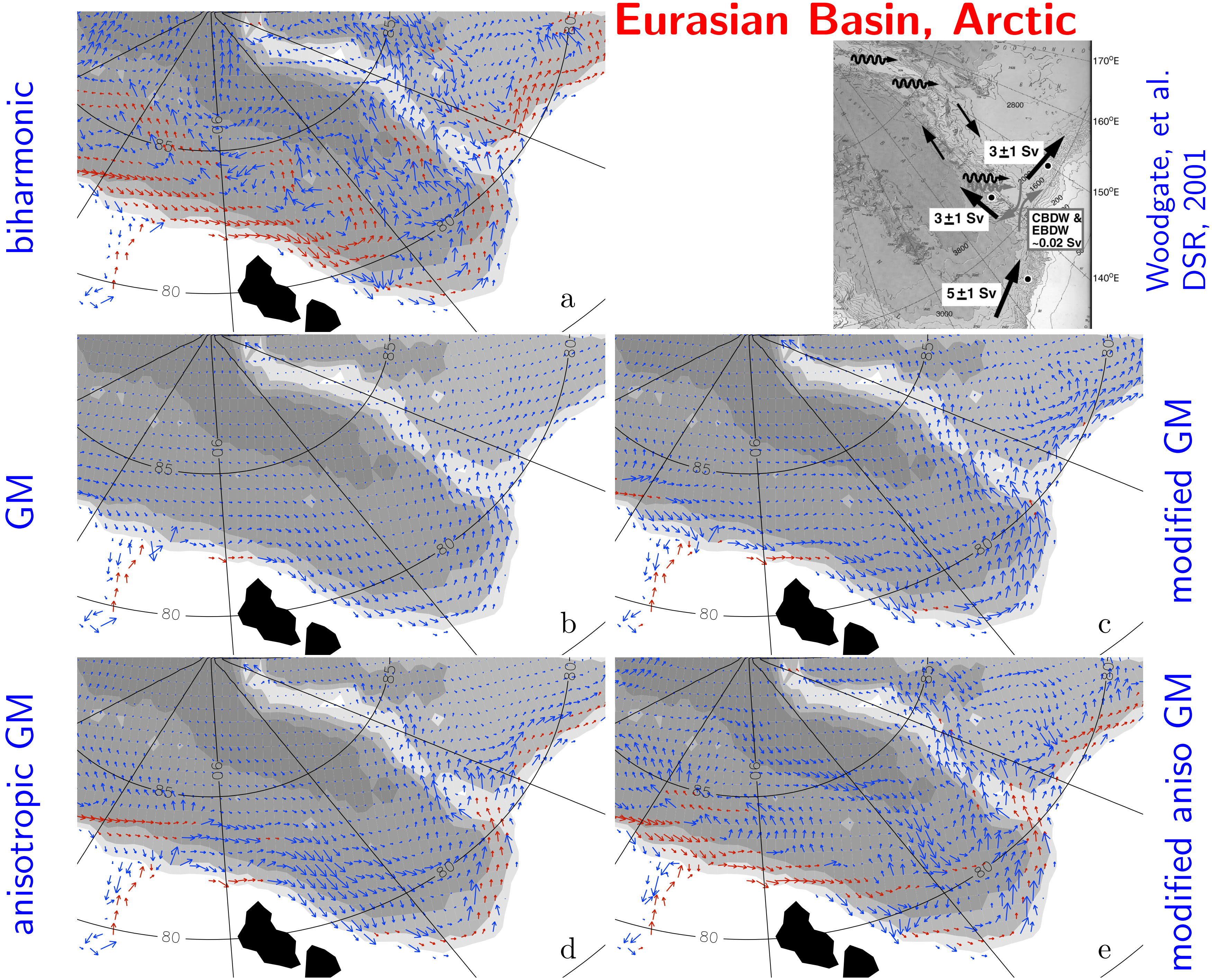


Figure 7. Distribution of current speed in centimeters per second normal to the meridional transect described by the northward drift of manned ice camp ISW-1. Positive values (shaded) indicate eastward flow. Numbered arrowheads along the top axis indicate locations where the transect intersected zonal CTD transects 1–4. Currents are referenced to measurements obtained from 50 and 200 m depths at the drifting current meter sites, as discussed in the text.



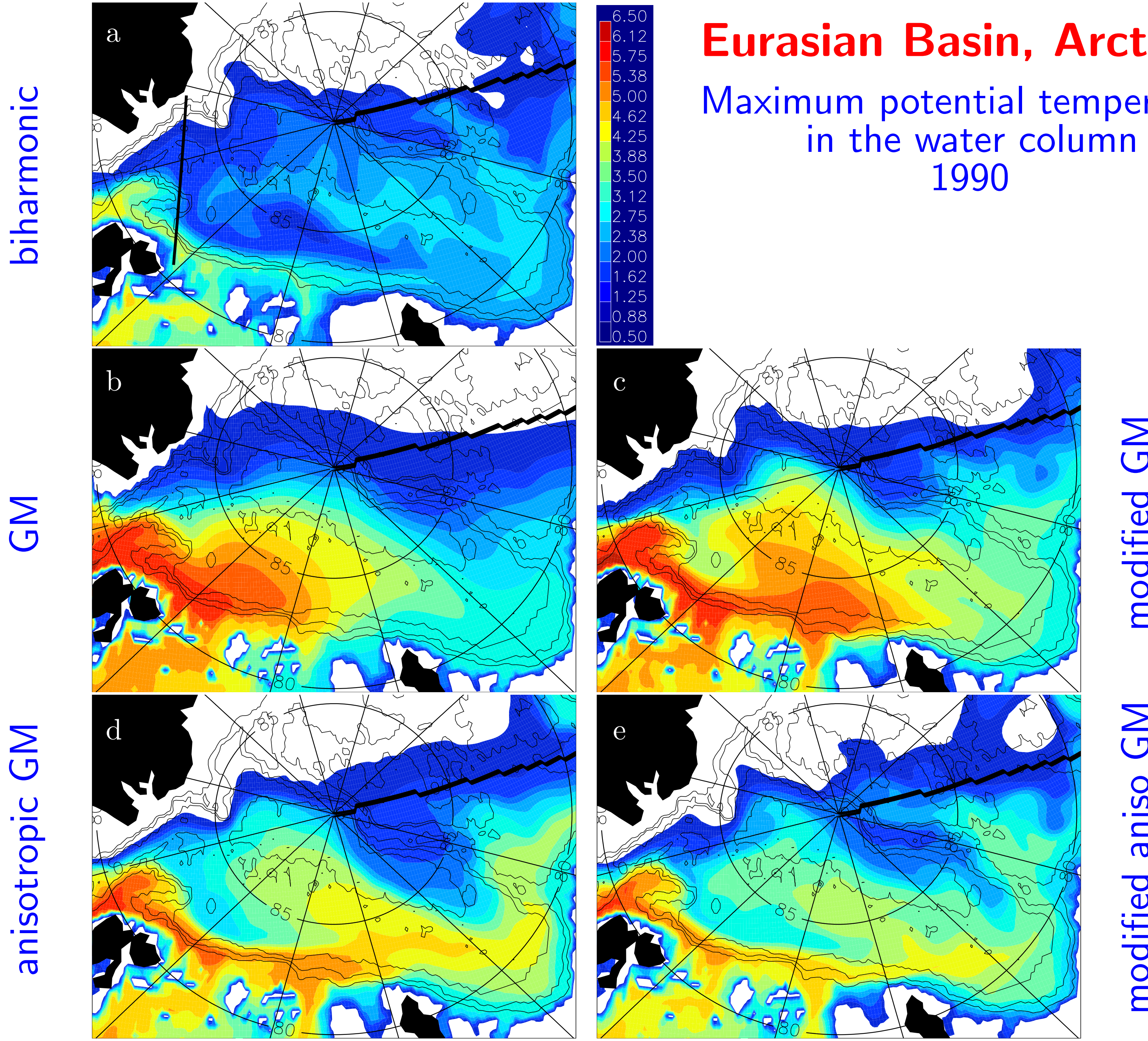
Labrador and Irminger Seas
Lavender, et al., Nature, 2000
Greenland
65°N
60°N
55°N
a
b
c
d
e
biharmonic
GM
modified GM
anisotropic GM
modified aniso GM

Eurasian Basin, Arctic



Eurasian Basin, Arctic

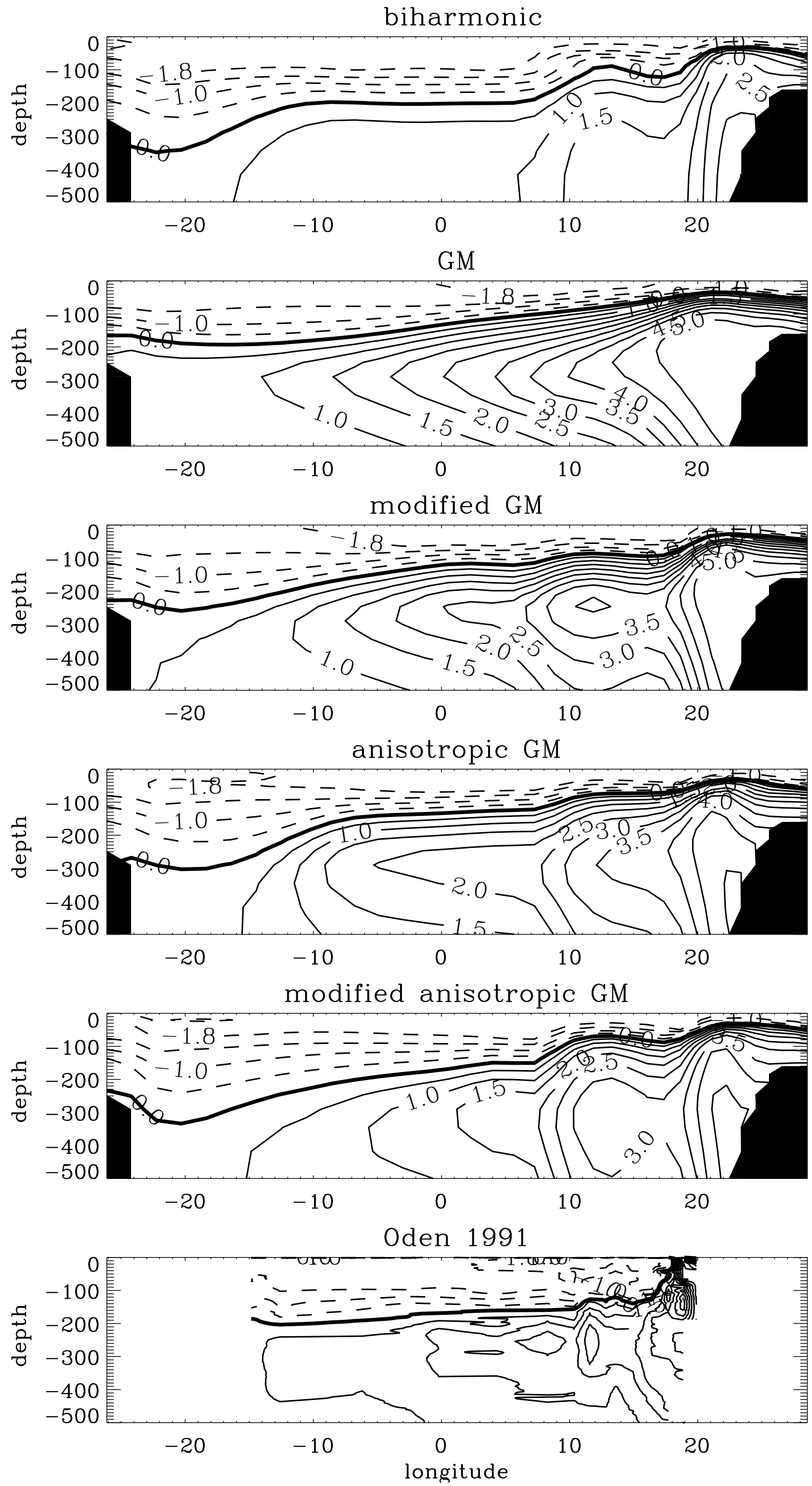
Maximum potential temperature
in the water column
1990



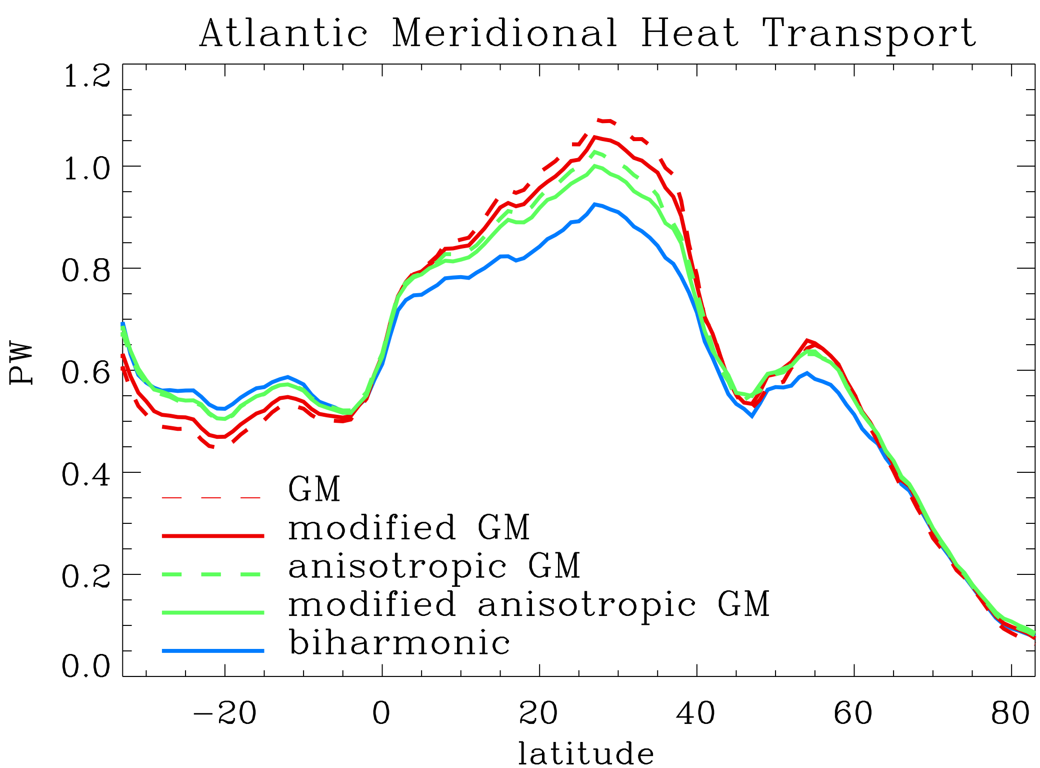
Potential Temperature

north of Fram Strait, 1990

(Oden 1991 section)

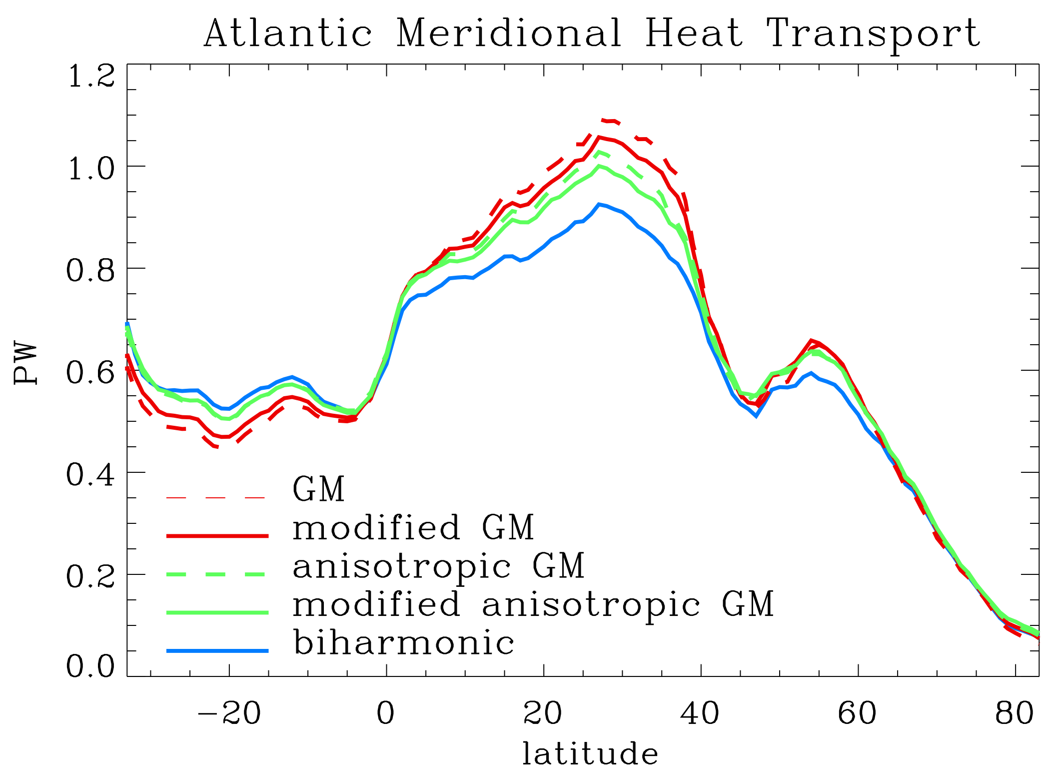


Global Considerations



(spin-down runs)

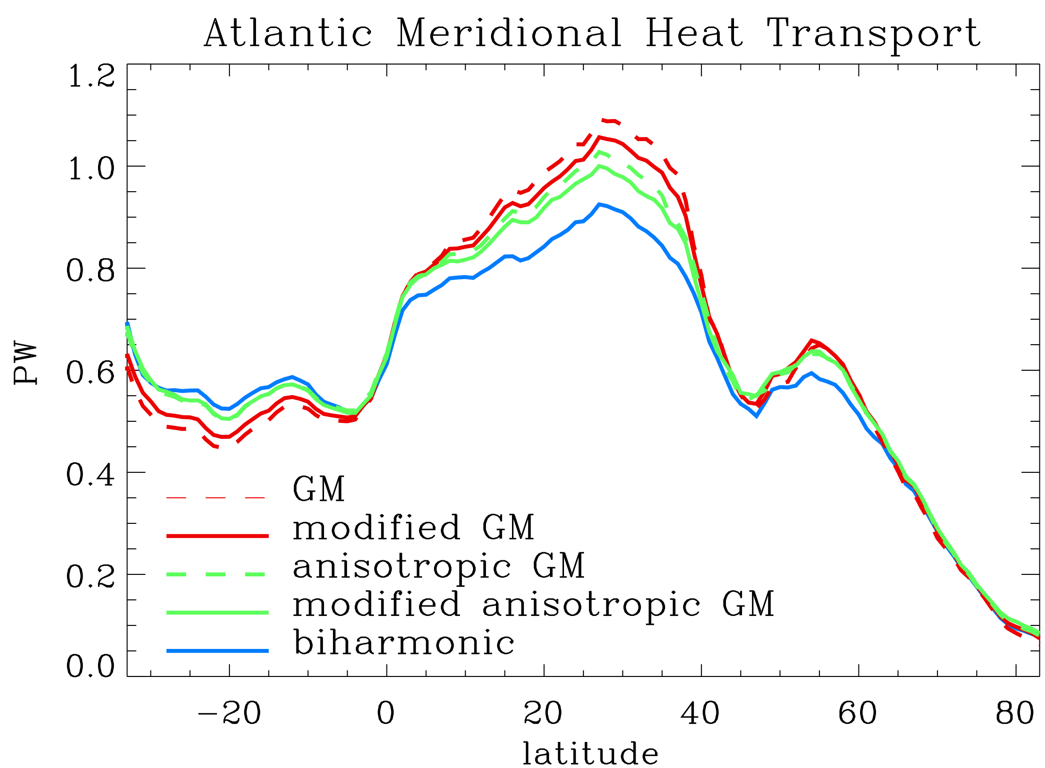
Global Considerations



(spin-down runs)

Mass Transport (Sv)	max MOC
GM	16.36
modified GM	15.53
anisotropic GM	14.94
modified anisotropic GM	14.72
biharmonic	14.39

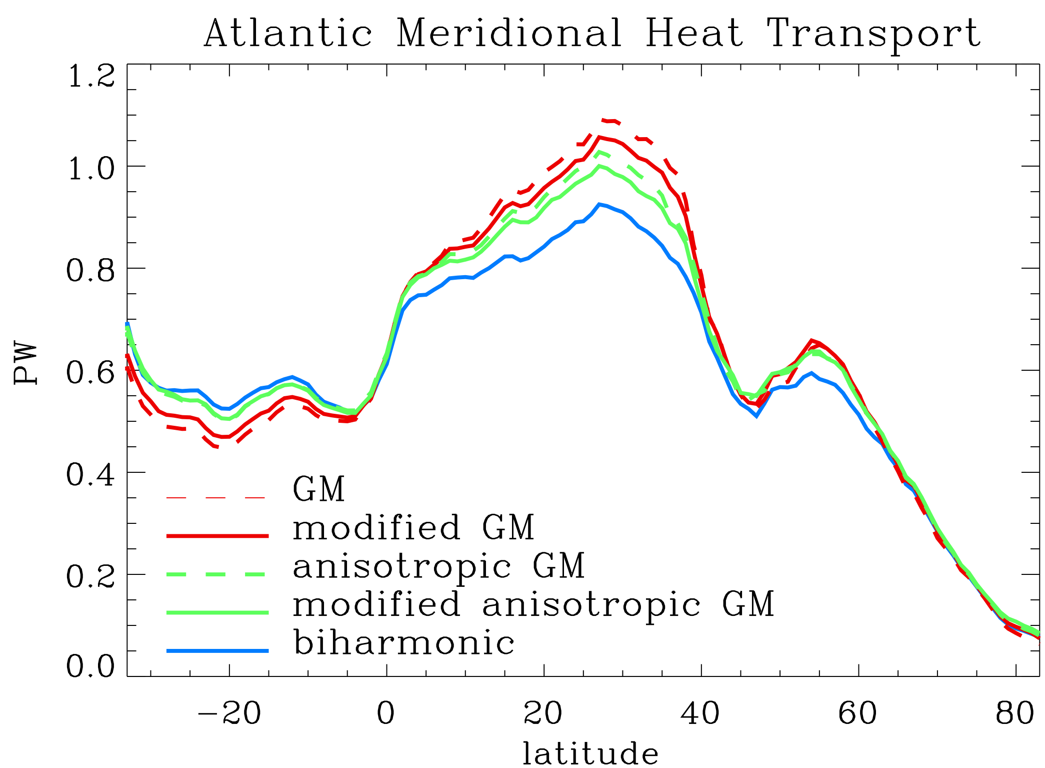
Global Considerations



(spin-down runs)

Mass Transport (Sv)	max MOC	Drake
GM	16.36	162.0 ± 8.0
modified GM	15.53	160.7 ± 7.5
anisotropic GM	14.94	160.6 ± 7.7
modified anisotropic GM	14.72	159.6 ± 7.2
biharmonic	14.39	158.0 ± 6.8
		$\Delta \sim 2.5\%$

Global Considerations



(spin-down runs)

Mass Transport (Sv)	max MOC	Drake	Fram
GM	16.36	162.0 ± 8.0	1.04 ± 2.31
modified GM	15.53	160.7 ± 7.5	0.91 ± 2.34
anisotropic GM	14.94	160.6 ± 7.7	0.70 ± 2.37
modified anisotropic GM	14.72	159.6 ± 7.2	0.73 ± 2.36
biharmonic	14.39	158.0 ± 6.8	0.71 ± 2.36
		$\Delta \sim 2.5\%$	$\Delta \sim 40\%$

Summary

1. Small eddies are not resolved on this 0.4° grid—we need to parameterize their effects yet still admit those that can be resolved. Scaling diffusivity by grid cell area is beneficial for relieving excessive high-latitude damping by constant-diffusivity GM.

2. Tuning GM parameters via Drake Passage transport (55–60 S) may miss important higher-latitude effects.

3. Anisotropic GM forms look quite promising, allowing eddy variability similar to biharmonic diffusion without excessive diapycnal mixing.

Thanks

Mat Maltrud
Matthew Hecht
JoAnn Lysne