# Equilibration of Mesoscale Eddies: Effects of Upper and Lower Boundary Conditions

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## The Problems

What is an appropriate surface boundary condition for a numerical ocean model?

How sensitive are mesoscale eddies to this, and to the friction/topography at the bottom?

## Various Upper Boundary Conditions

- Run a coupled atmospheric model.
  Expensive. Climate drift. No connection to observations.

- Specify fluxes from observations (e.g., an NCEP reanalysis).
  Does not allow the ‘atmosphere’ to respond to SST anomalies etc., which then feedback on the ocean. Thus, the lifetime of SST anomalies is likely incorrectly predicted.

- Relax to observations (e.g. Levitus).
  Fails to account for the scale selectivity of atmosphere-ocean interaction.

- Run an atmospheric anomaly model, with fluxes specified.

Does the ocean model care what we do?

## A Simple Atmosphere

(c.f. Budyko/Sellers/North, Fanning and Weaver, Marotzke and Pierce, Rahmstorf and Willebrand)

$$\frac{\partial T_a}{\partial t} = (\mathsf{S} + \mathsf{IR}) + \kappa\nabla^2 T_a + \gamma_T (T_o - T_a)$$

$T_a =$ temperature of the atmosphere.

### Anomaly Model:

Write $T_a = \widehat{T}_a + T'_a$ and $T_o = \widehat{T}_o + T'_o$. Becomes

$$\frac{\partial T'_a}{\partial t} \;=\; S - \mathsf{I\widehat{R}} + \gamma_T(\widehat{T}_o - \widehat{T}_a) + \kappa\nabla^2\widehat{T}_o + \mathsf{IR'} + \gamma_T(T'_o - T'_a) + \kappa\nabla^2$$

whence

$$\boxed{\frac{\partial T'_a}{\partial t} = \kappa\nabla^2 T'_a + \gamma_T(T'_o - T'_a)}.$$

or even,

$$\boxed{\kappa\nabla^2 T'_a - \gamma_T T'_a = -\gamma_T T'_o}.$$

### Fluxes to Ocean:

$$\boxed{F_Q = (\text{Specified Surface Heat Flux}) - \gamma_T(T'_o - T'_a)}$$

Small Scales: $(L^2 \ll \kappa/\gamma_T)$:
$T'_a \ll T'_o \Longrightarrow$ Relaxation boundary conditions

Very Large Scales: $(L^2 \gg \kappa/\gamma_T)$:
$T'_a \sim T'_o \Longrightarrow$ Flux boundary conditions

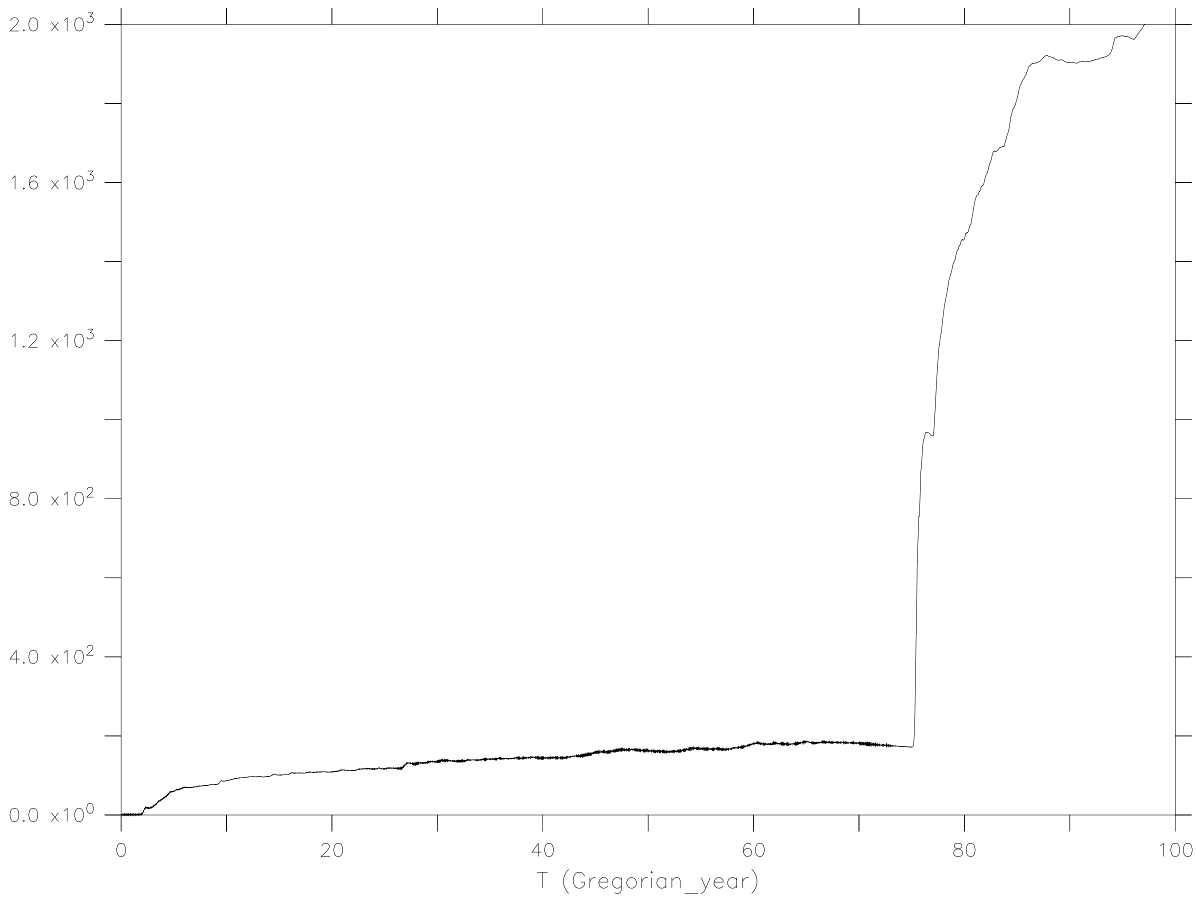
## Numerical Experiments

Eddying hydrostatic z-coordinate model in a channel (MOM 3)
Explicit free surface. Linear eqn. of motion, no salt. Partial cells.

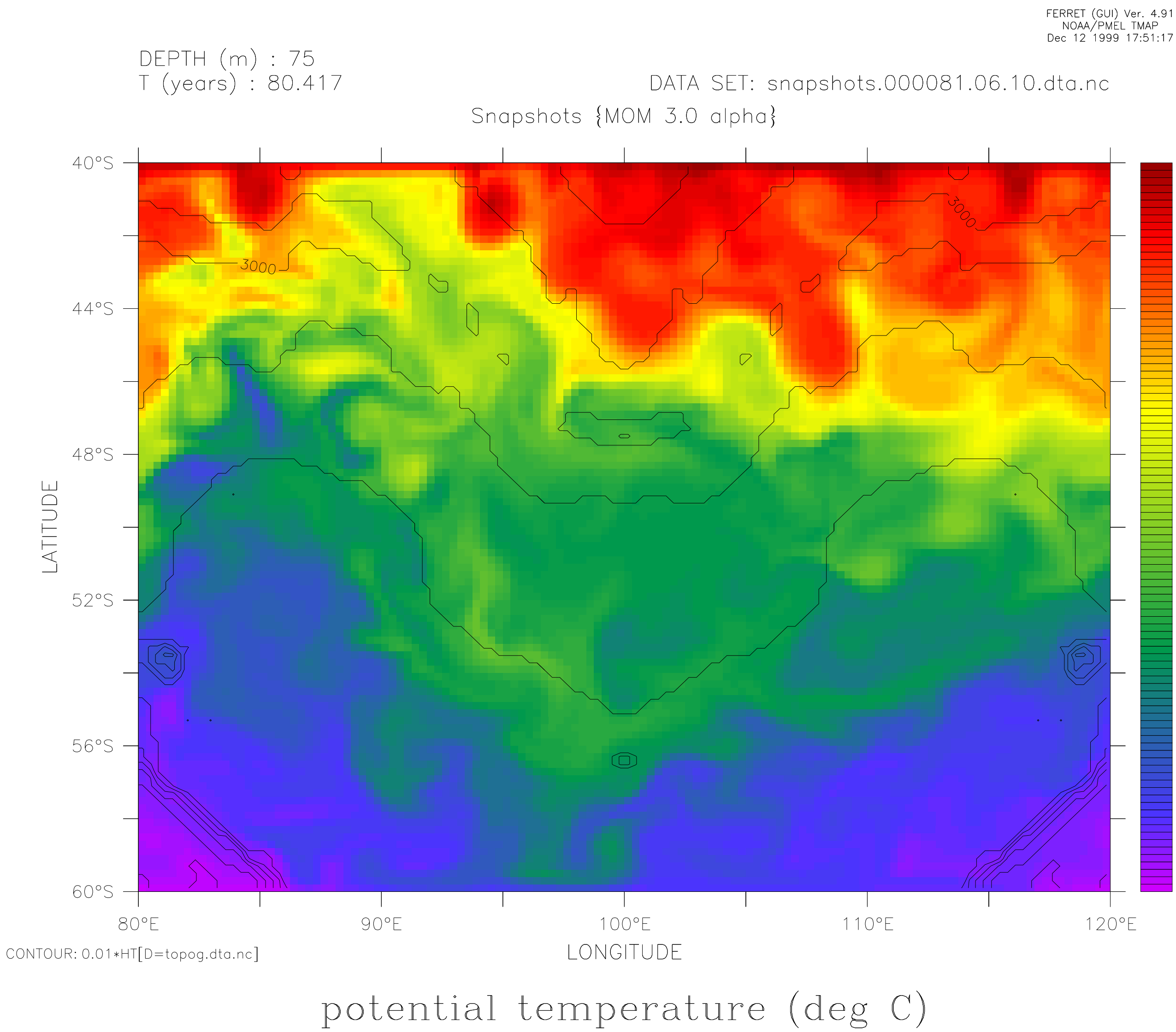
Periodic channel, 40S – 60S, 40° wide. Realisttic topography (80E – 100E). 1/5° horizontal res, 18 levels.

Biharmonic horizontal diffusion of tracer and momentum ('small', 2 $10^{10}\,\mathrm{m}^4\,\mathrm{s}^{-1}$). Vertical diffusion of tracer ($0.5\,\mathrm{cm}^2\,\mathrm{s}^{-1}$) and momentum ($5\,\mathrm{cm}^2\,\mathrm{s}^{-1}$).

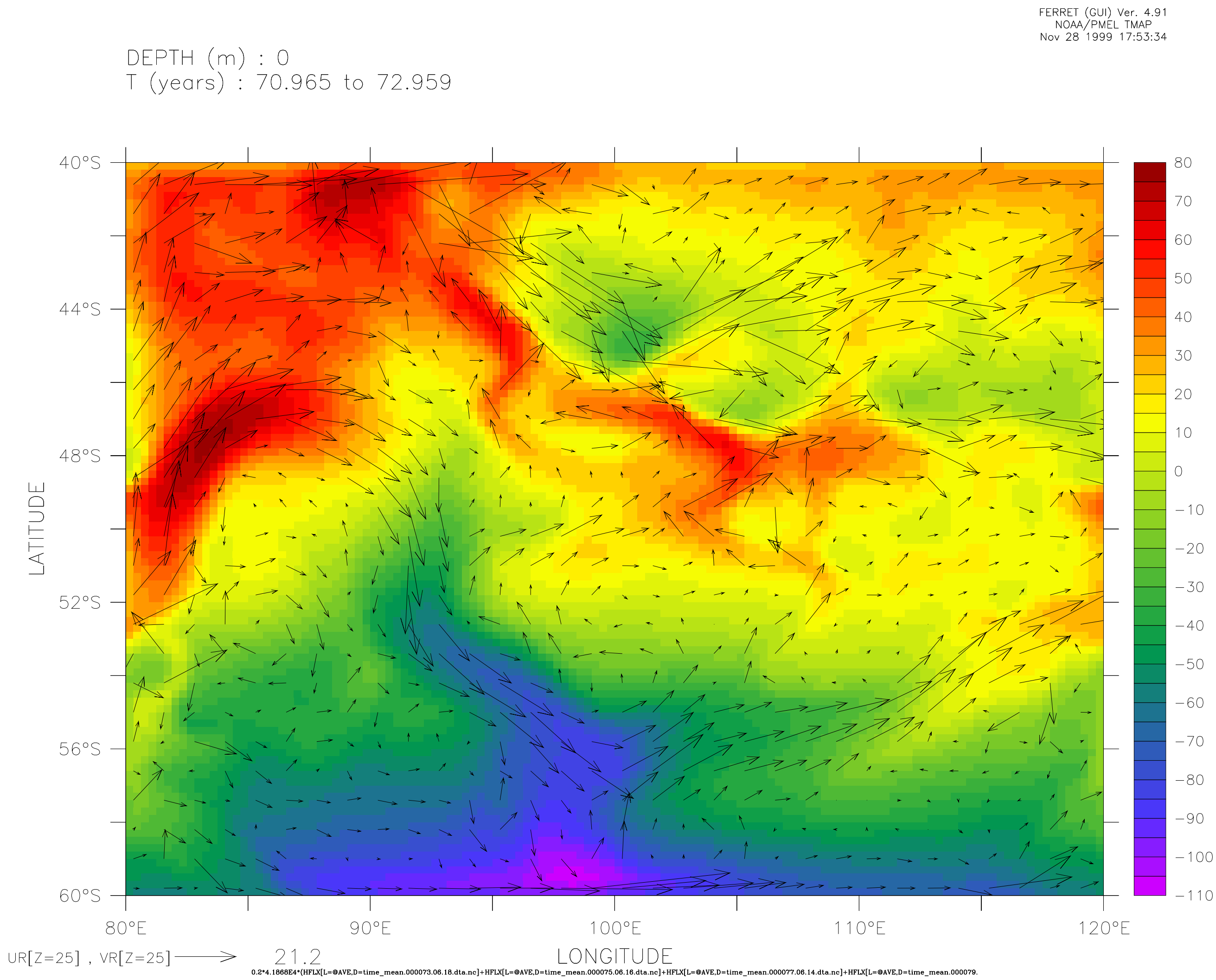
Surface fluxes:
(i) Restoring SST, with a $\Delta T = 12K$ across channel, $35\,\mathrm{W/m^2/K}$ (66 days restoring time scale for 50 m mixed layer).
(ii) Fix surface fluxes, diagnosed from (i)
(iii) use them in an atmospheric anomaly EBM.



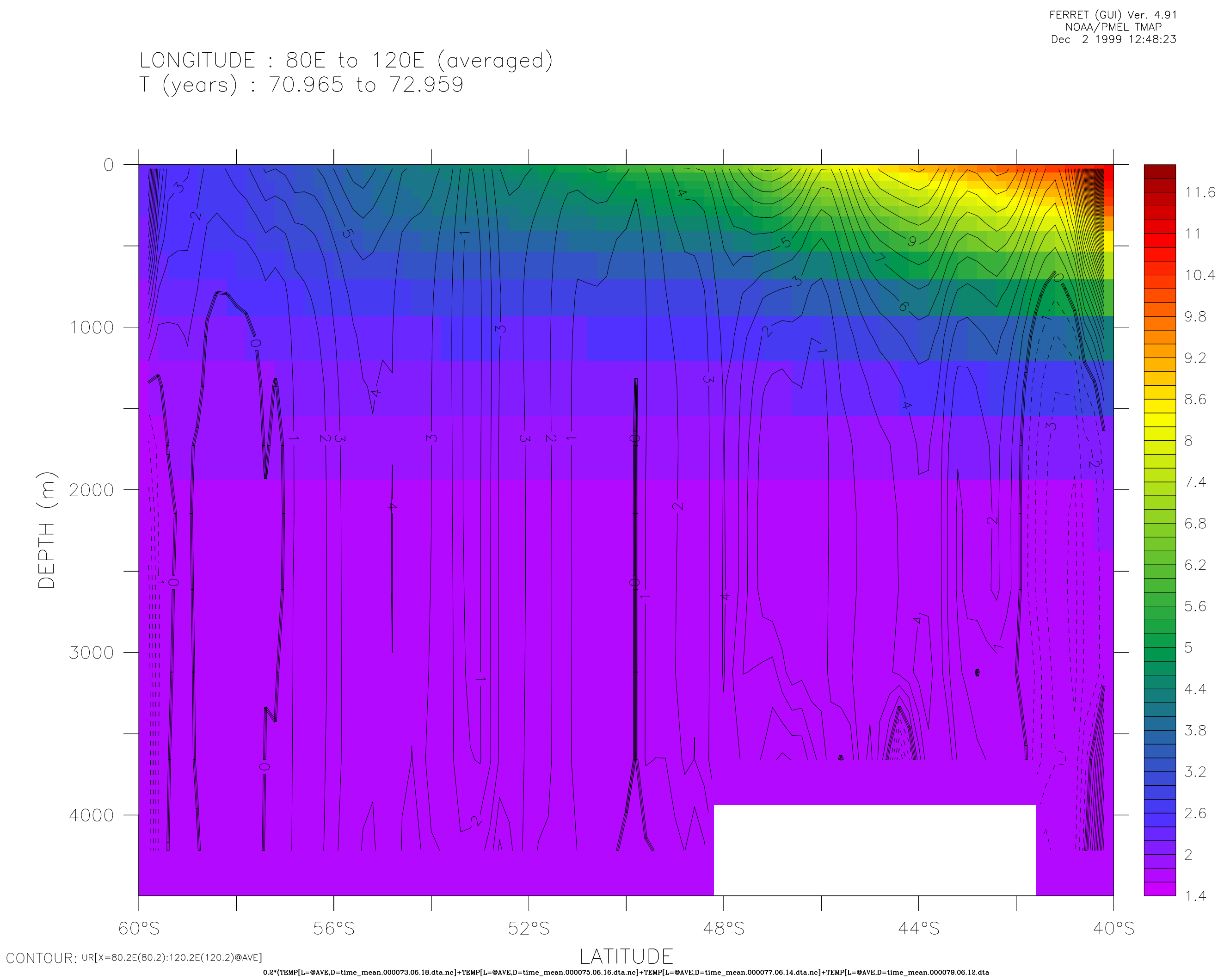

Time series of K.E. with no bottom friction or topography. Barotropic mode through the mean zonal velocity which keeps rising. Will stabilise with bottom friction.



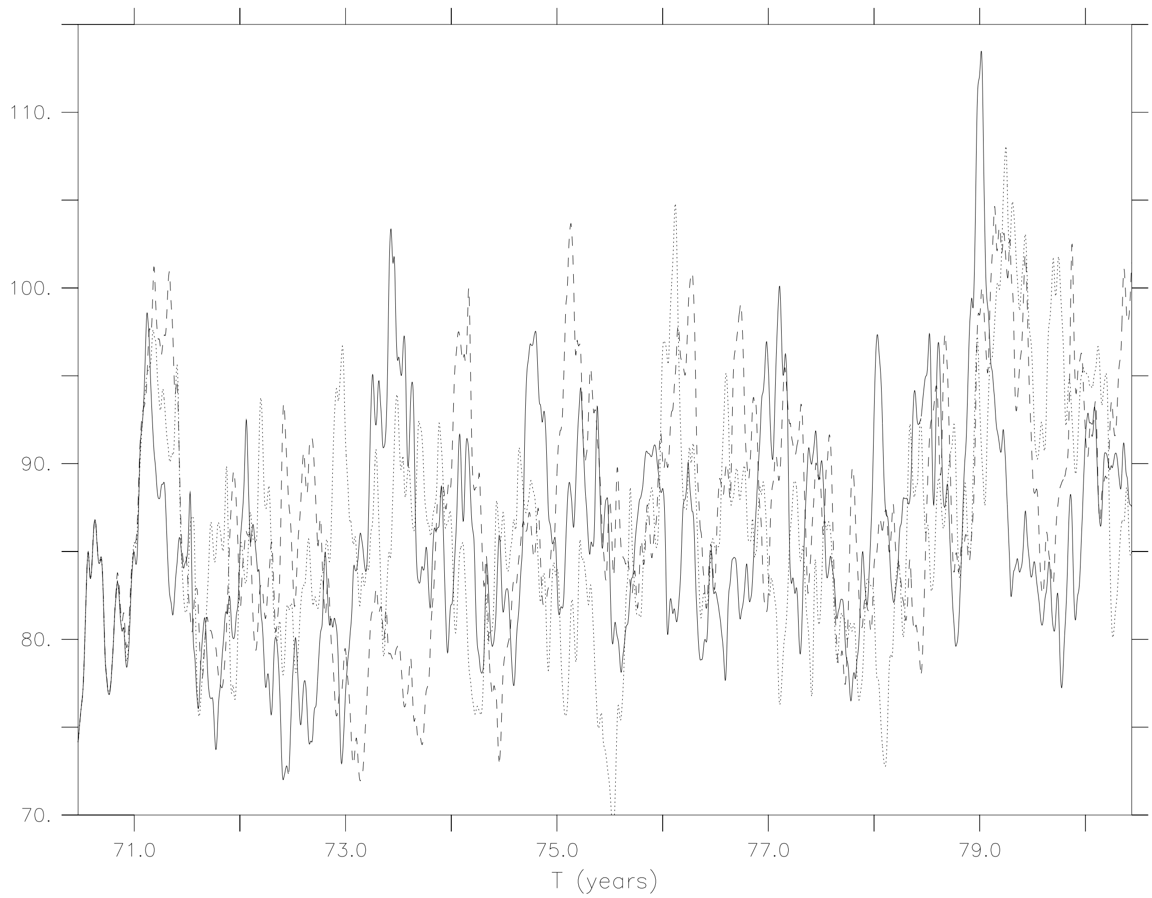

Snapshot of temperature at 75m, plus contours of bottom topography



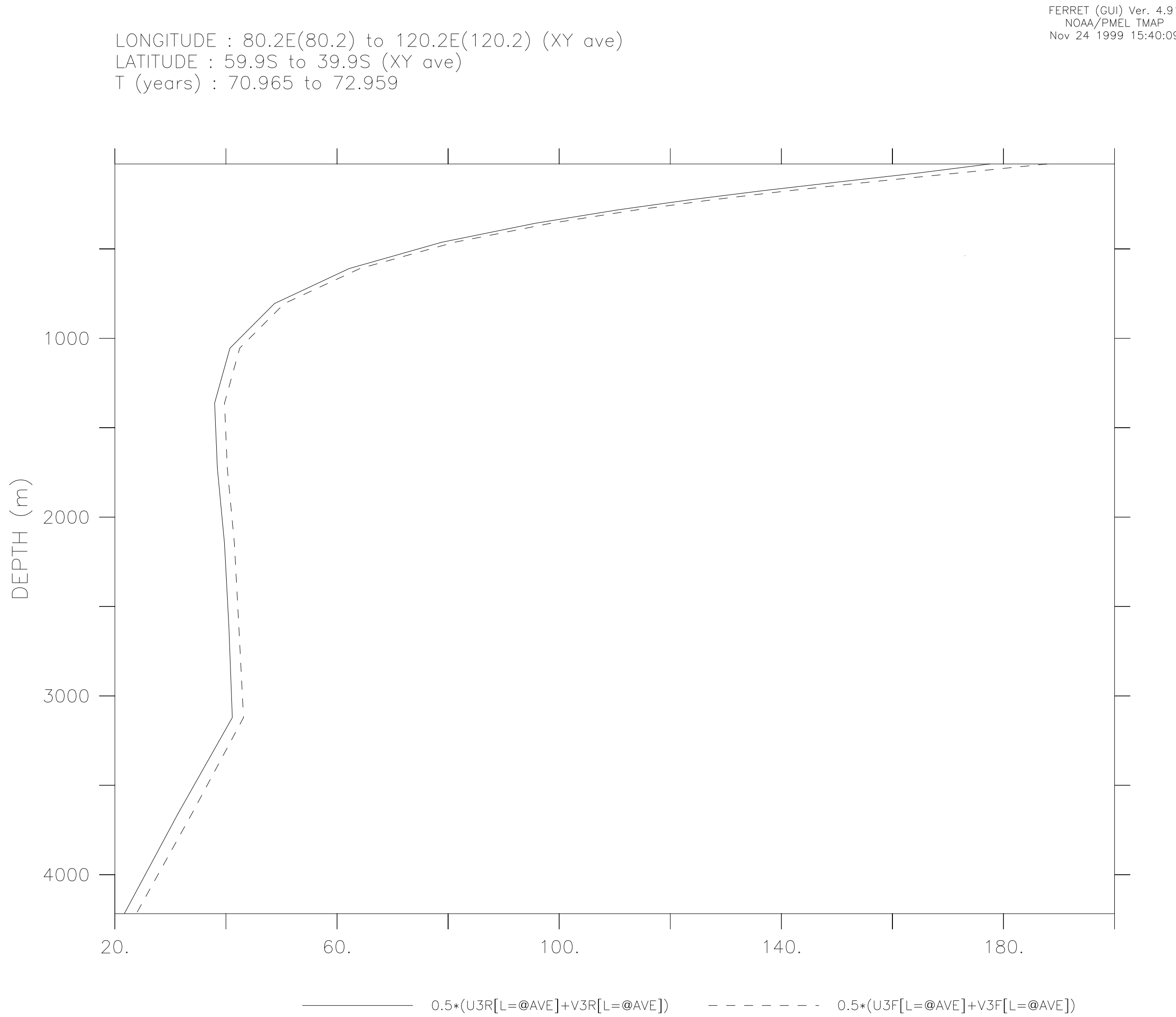

Time-averaged heat fluxes, diagnosed from 'restoring' experiment, plus 25m velocity.



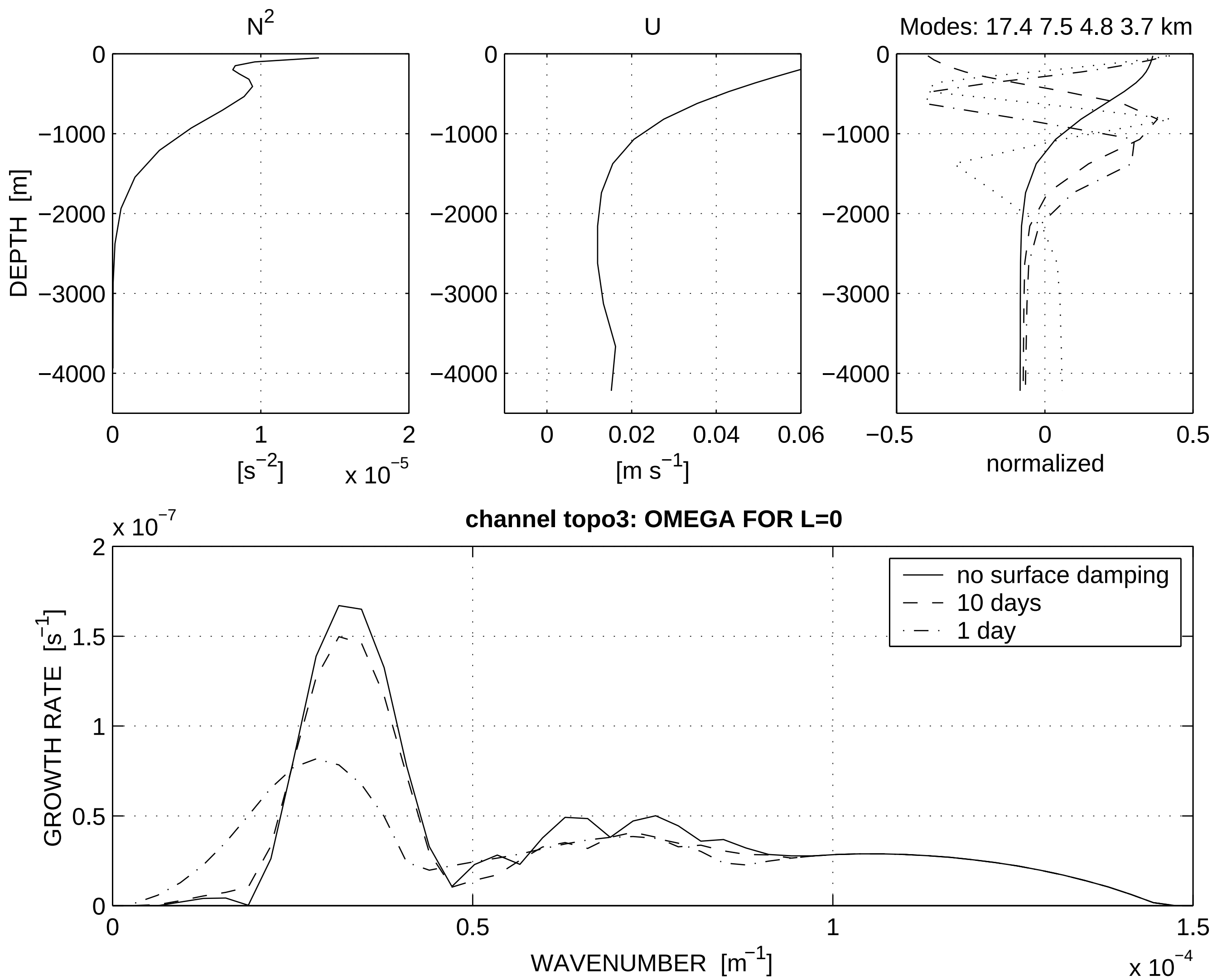

Vertical section of zonally-averaged temperature (colours) and zonal velocity (contours)




Total kinetic energy as a function of time for the 3 experiments R F A Note the large deviations on periods up to a year long.




Vertical distribution of eddy kinetic energy under restoring (solid) and fixed flux (dashed) surface boundary condition.




Linear QG stability analysis for the horizontally averaged zonal velocities and stratification in the channel experiments, for various value of the restoring time scale of the streamfunction in the upper layer.

## Conclusions

- Absent topography, mesoscale eddies do not equilibrate (or only equilibrate at very high energy levels) without finite amount of bottom drag.

  Mechanism: barotropisation $\Rightarrow$ non-negligible abyssal flow, energy removal at the bottom. Without drag there is no mechanism for such energy removel.

- With topography equilibration does occurs for small drag.

- The energy levels of mesoscale eddies are relatively insensitive to the surface boundary condition (specified fluxes, relaxation, EBM etc.)

- The use of an anomaly EBM affects life-time larger-scale SST anomalies.

- Statistics of mesoscale eddy field only stable for periods $> 10$ yrs.