Models of the ocean: which ocean?

Anne Marie Treguier, CNRS,

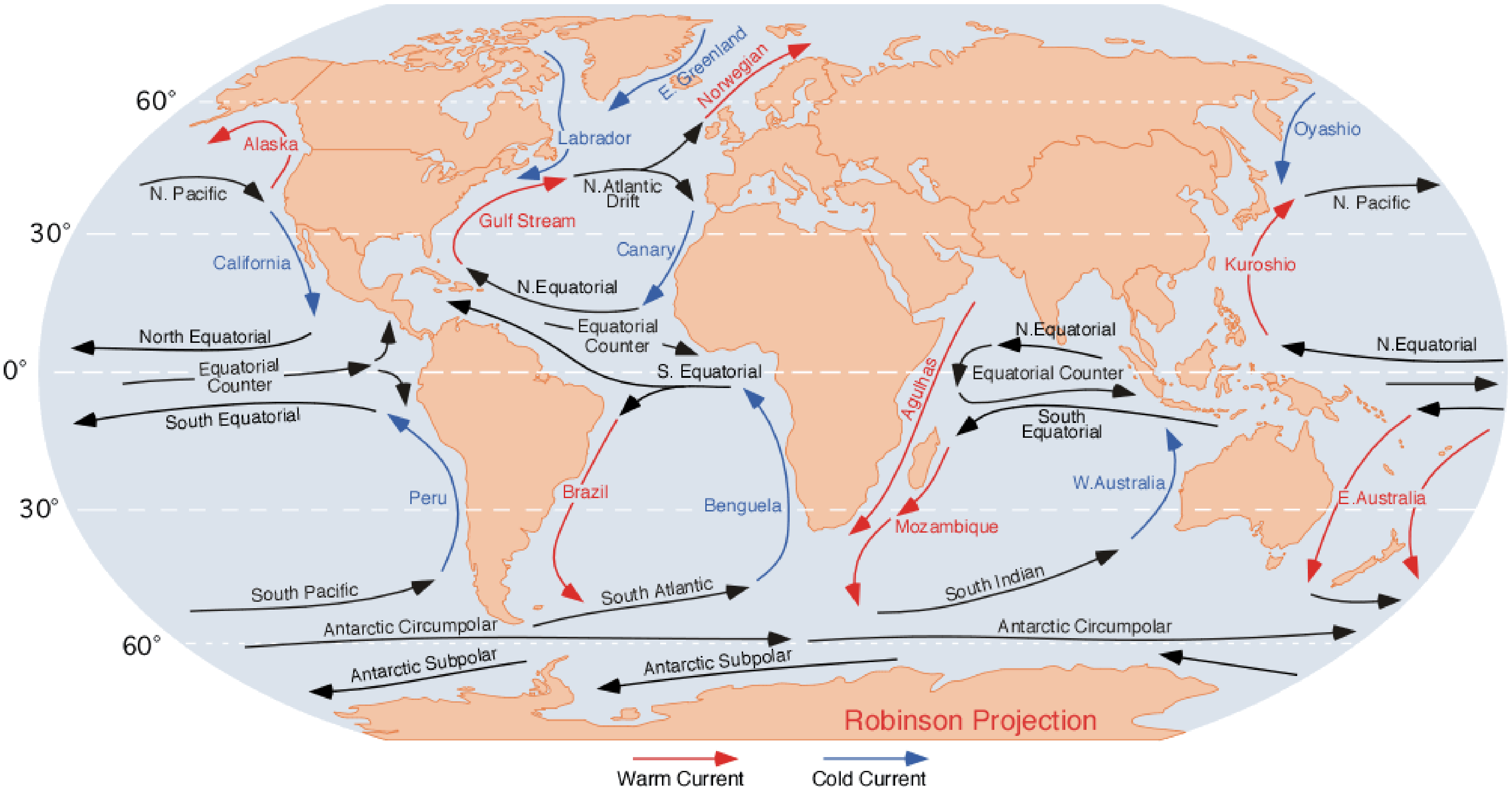
Laboratoire de Physique des Océans, Brest, France

Part 1: Some general statements

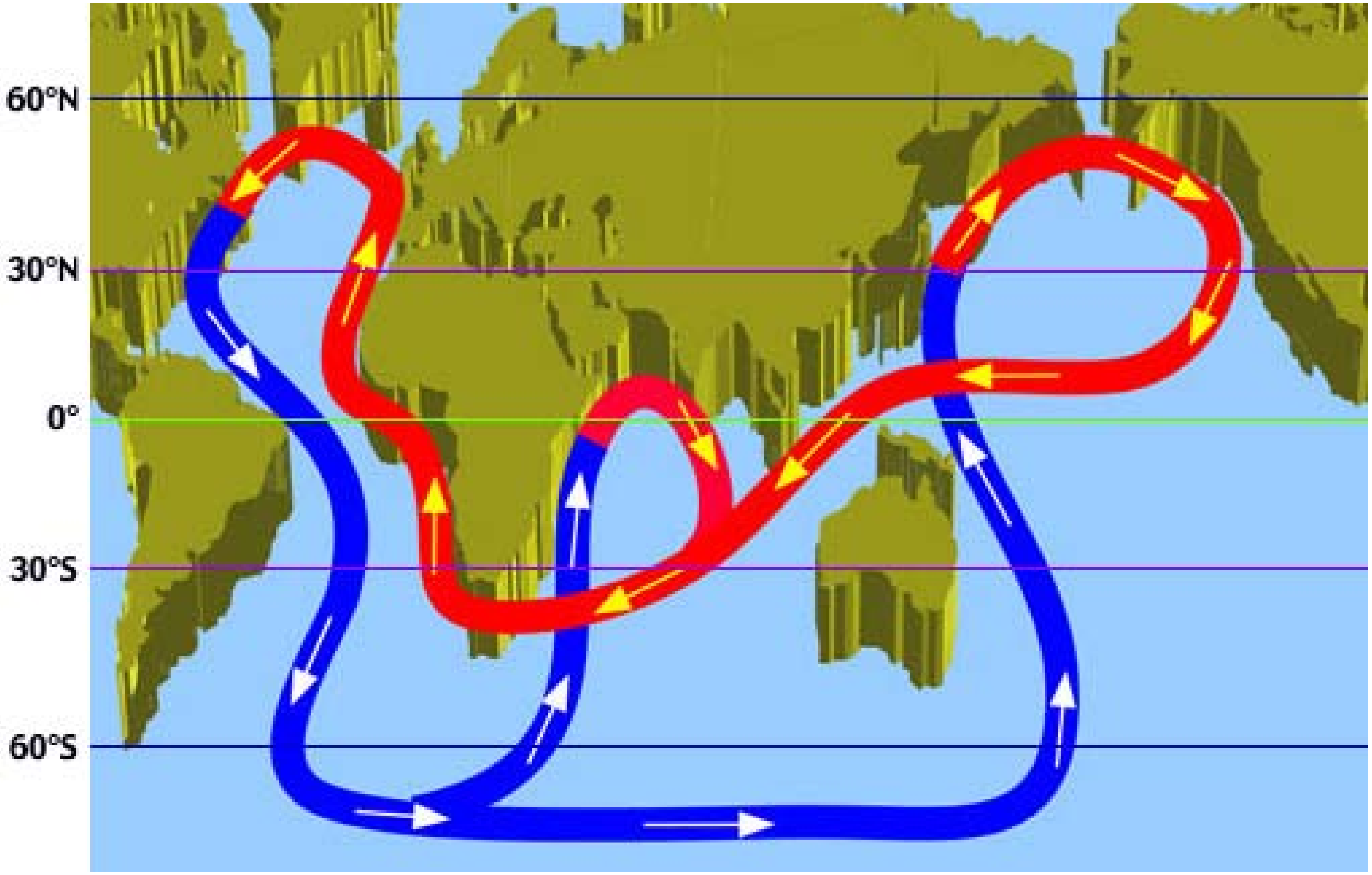
- ocean models
- convergence of solution
- diffusion equation
- internal/external processes

Part 2: Quick survey of parameterizations

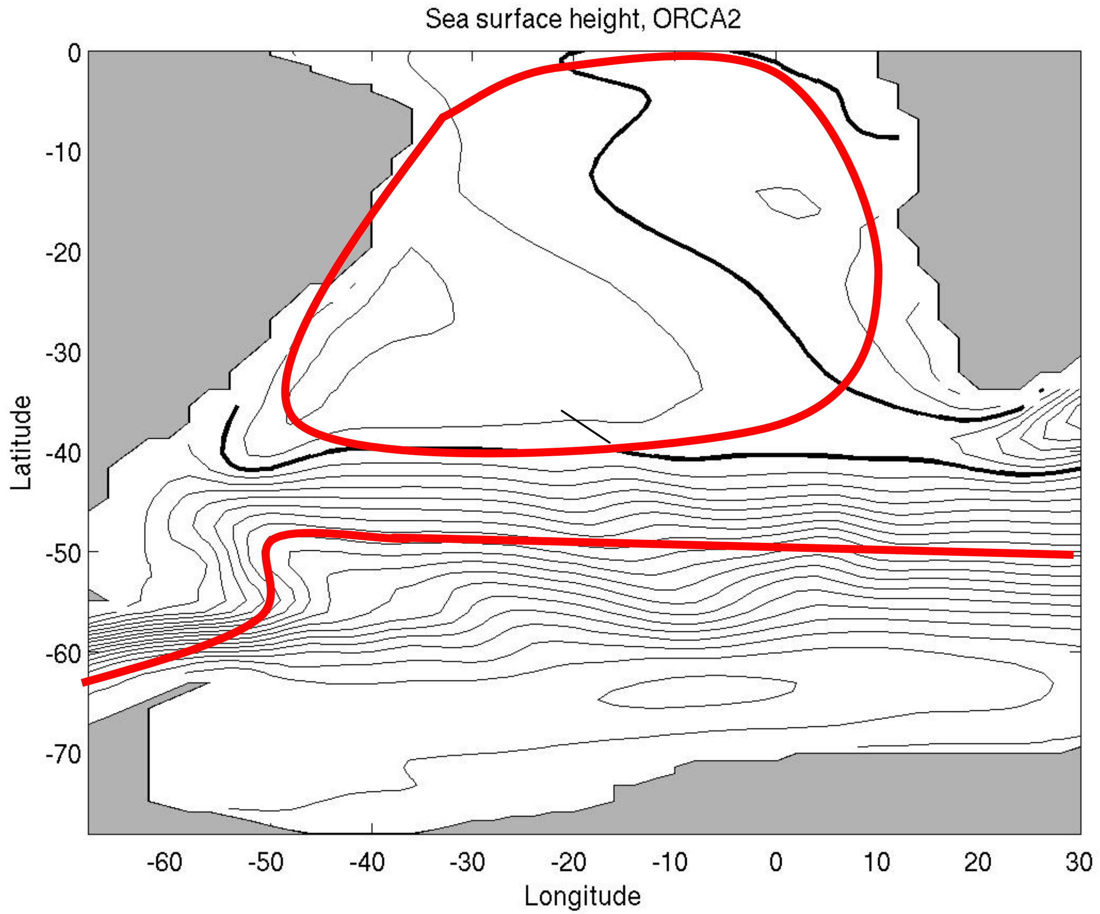
Ocean currents (1)



Conveyor belt

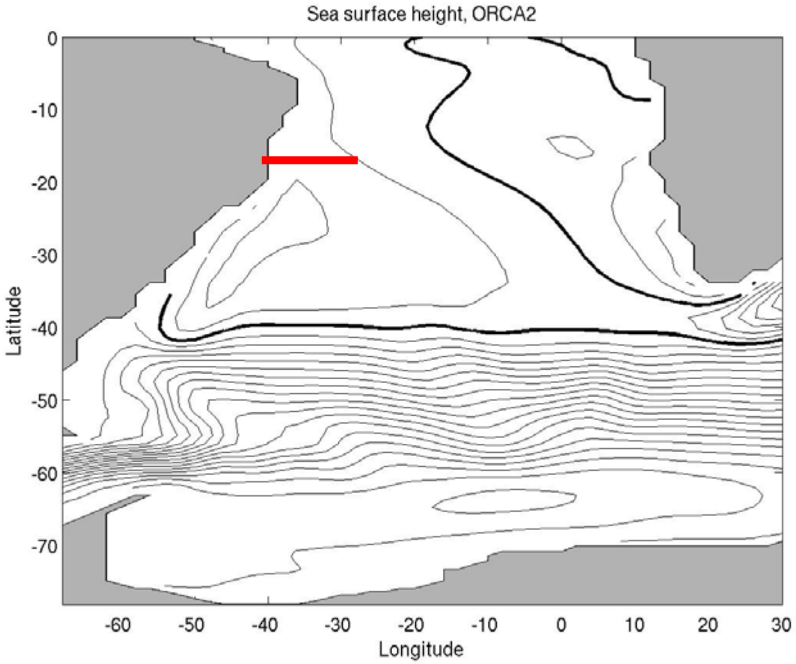


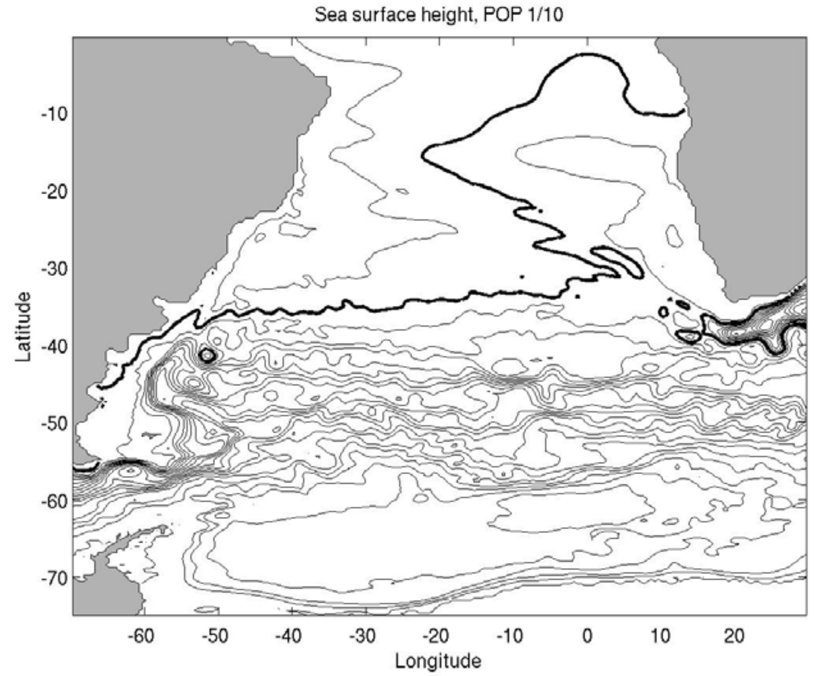
Ocean currents in models



ORCA2 global ocean model (Madec et al)

Ocean currents in models(2)

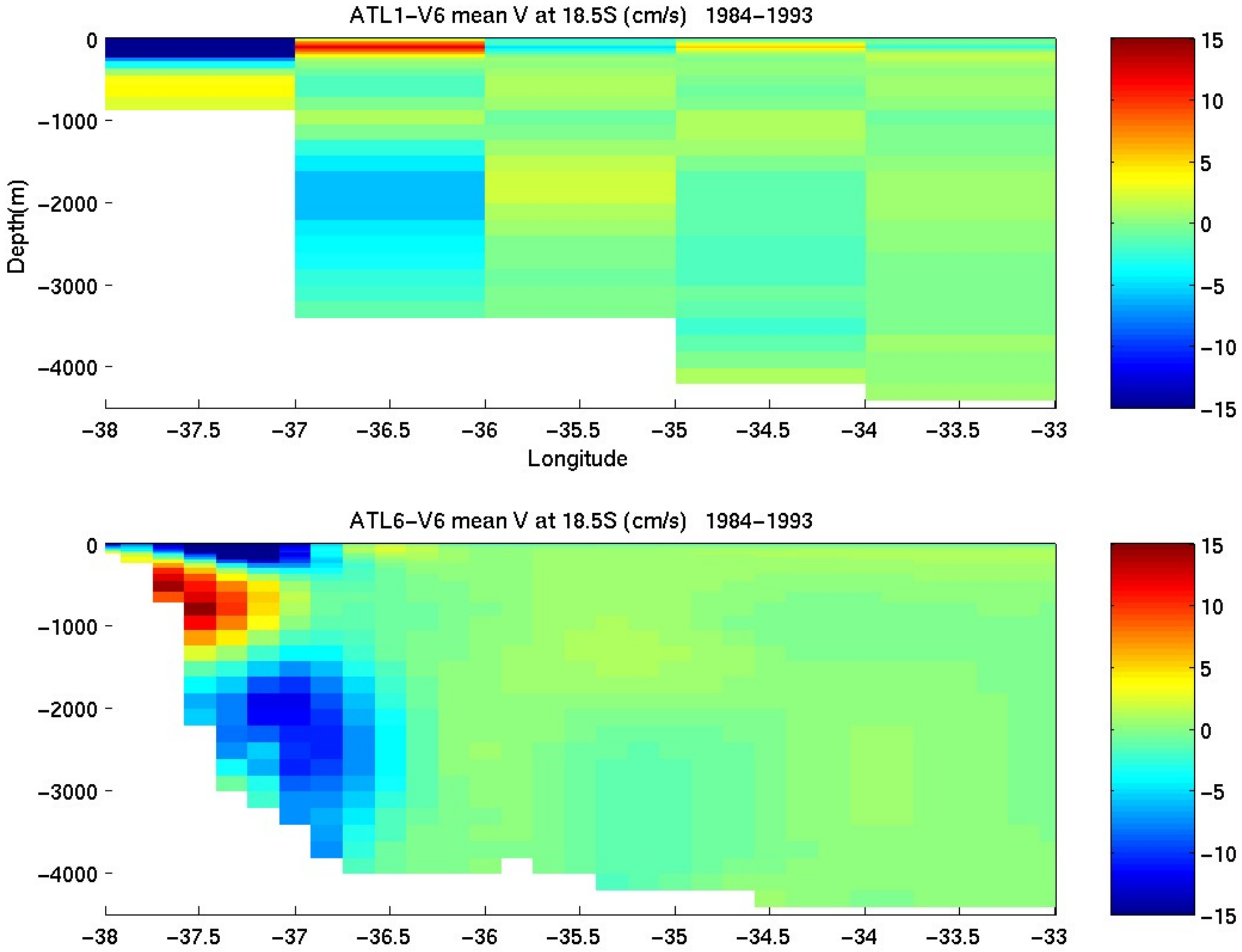




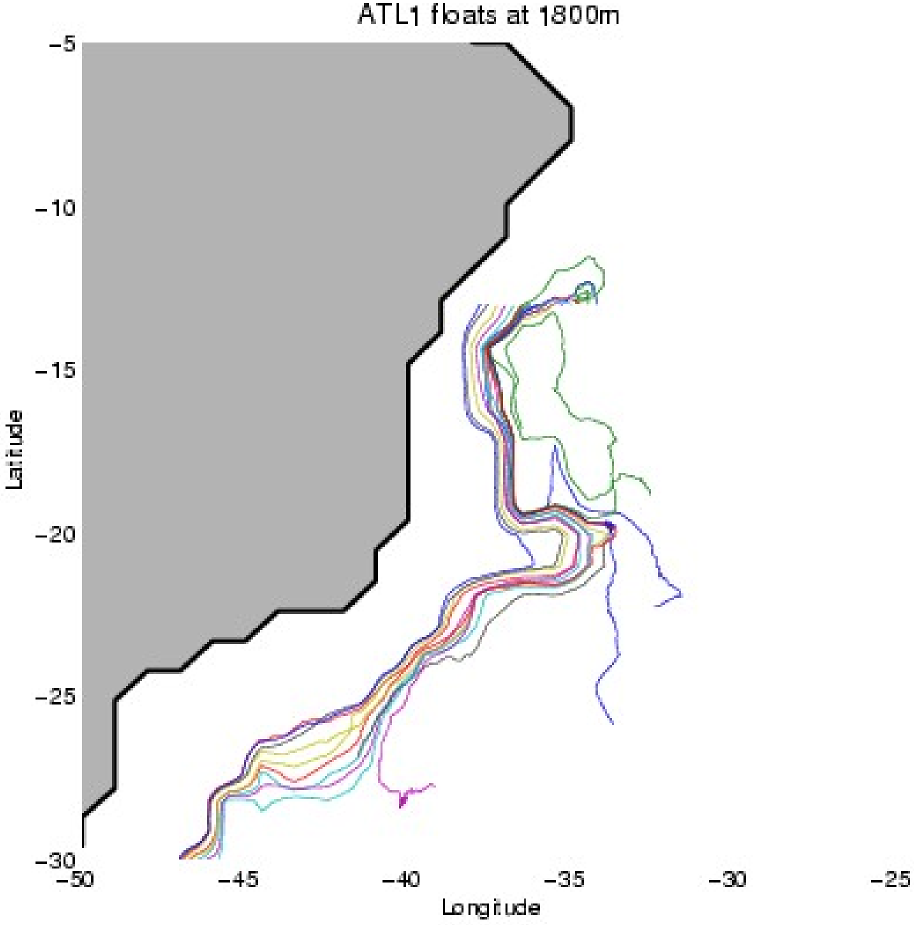
ORCA2

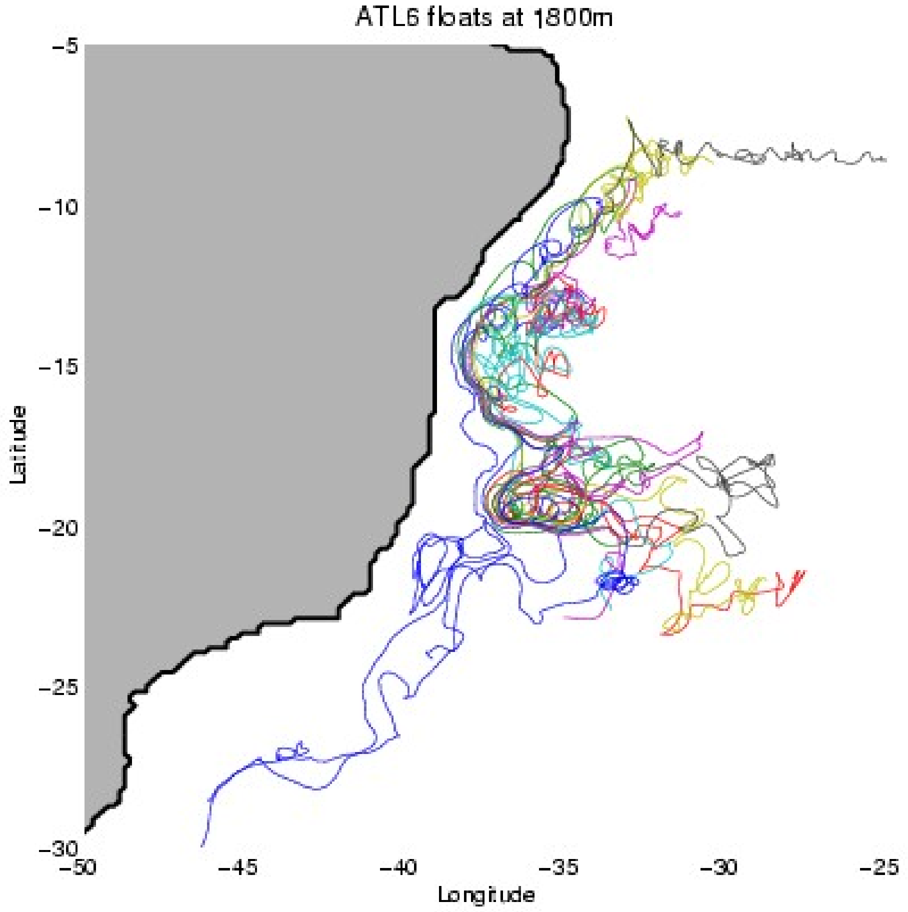
POP 1/10° global ocean model (Maltrud et al, 2004)

Deep western boundary current (1)



DWBC: Lagrangian view





Choice of ocean

- Choice of resolved scales
- Choice of parameterizations for the unresolved scales

PARAMETERIZATIONS MATTER

- Convergence of ocean model solutions
- Diffusion equation

Convergence of solutions

$\partial T / \partial t + V.\nabla T + S(T) = 0$

Resolved scales:

$$\partial T_R / \partial t + V_R.\nabla T_R + S_R (T_R) =$$

$$- ((V.\nabla T)_R - V_R.\nabla T_R) - (S(T)_R - S_R (T_R))$$

Numerical convergence / numerical error = lhs

RHS = parameterisations = choice of ocean

Numerical convergence

$\partial T_R / \partial t + V_R . \nabla T_R + S_R (T_R) = \ldots$

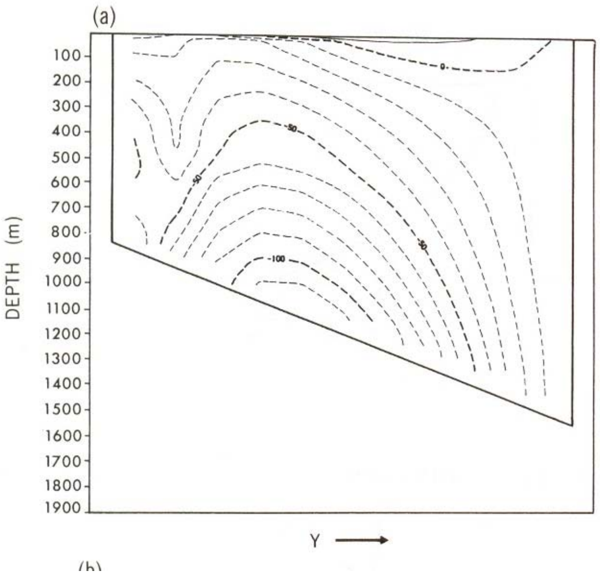
Solve the equations for the resolved variables using a finite difference scheme, with time step δt and grid spacing δx.

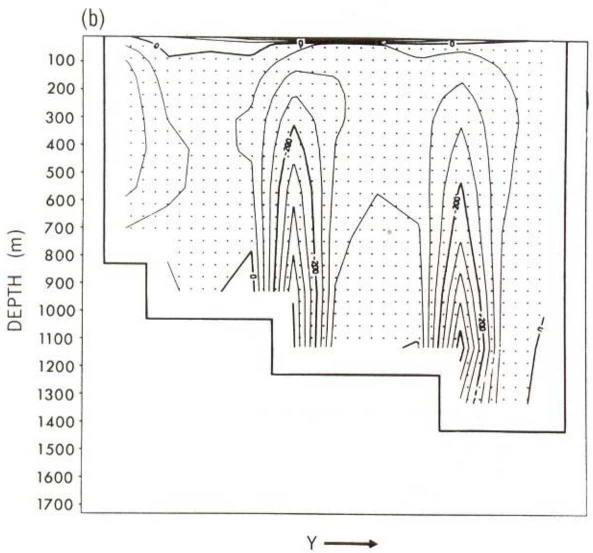
The solution converges as δt, δx tend to zero.

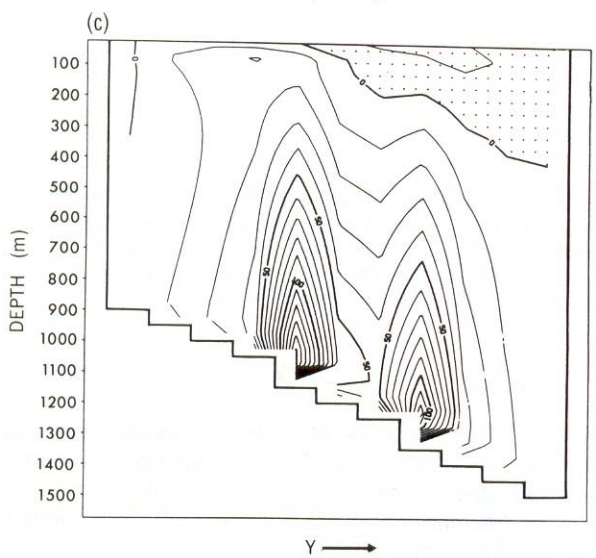
Do our present ocean model converge numerically?

Numerical convergence

Z-coordinate model with staircase topography. Representation of a topographic wave (Gerdes, 1993)







Convergence of solutions

$$\partial T / \partial t + V.\nabla T + S(T) = 0$$

Resolved scales:

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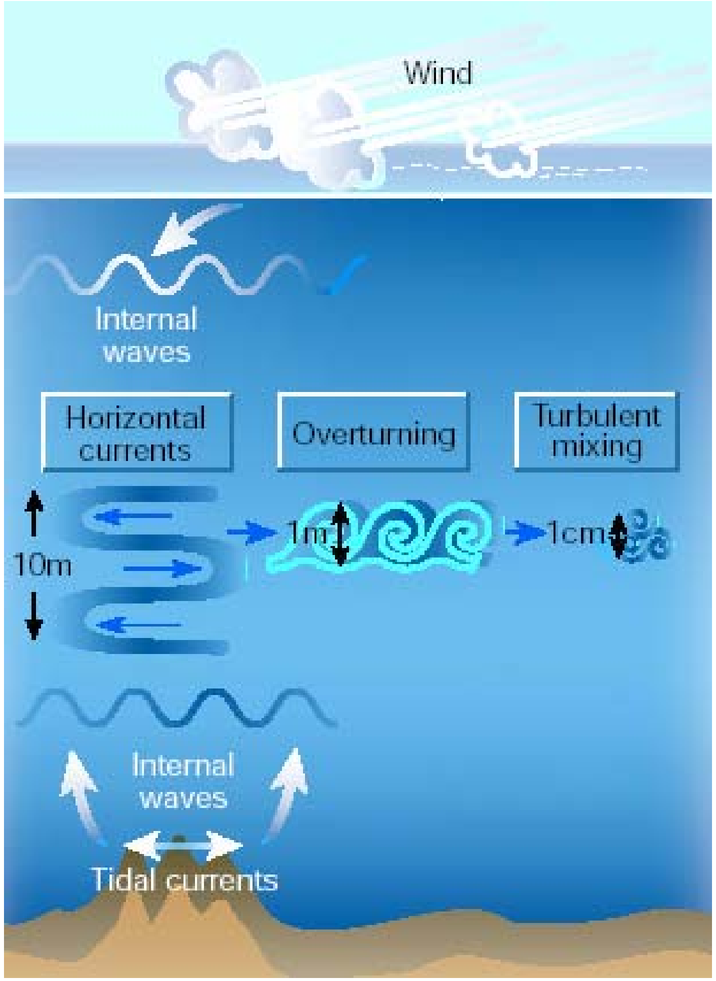
$$- ((V.\nabla T)_R - V_R.\nabla T_R) - (S(T)_R - S_R (T_R))$$

Numerical convergence / numerical error = lhs

Physical convergence / parameterization error = rhs

Subgrid scale effects: physical processes



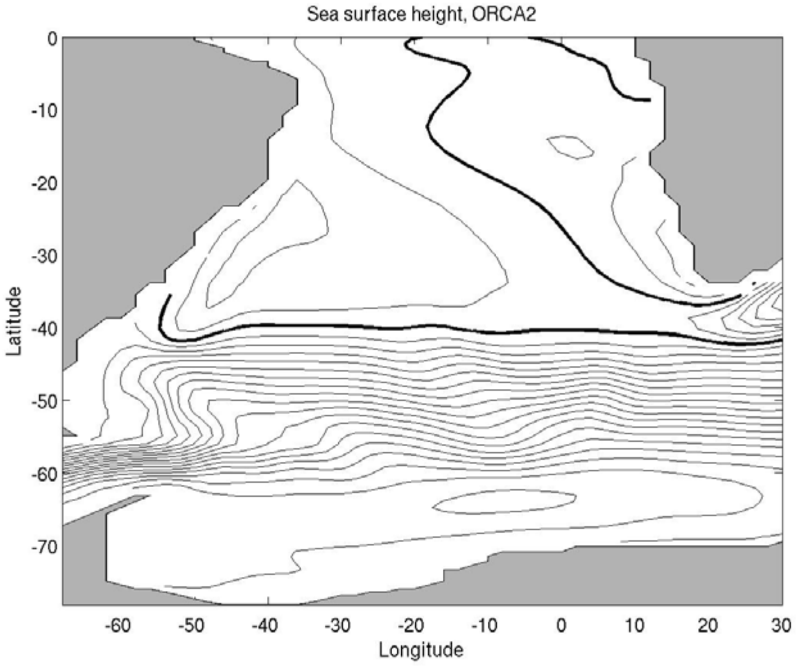
Isotropic turbulence: cm scale

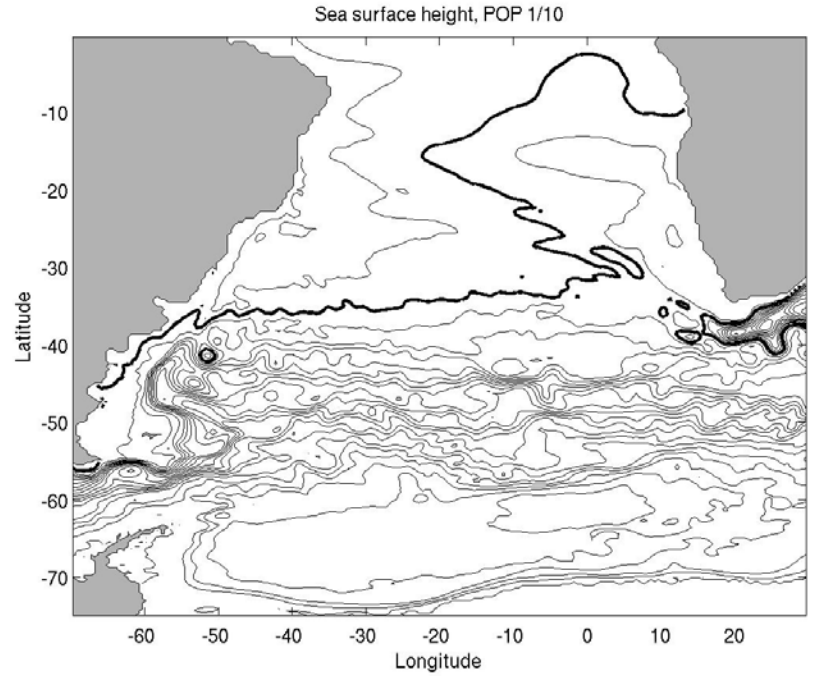
Internal wave breaking (gravity+ stratification)

Double diffusion

Convection

Mesocale eddies/topography





ORCA2

POP 1/10° global ocean model (Maltrud et al, 2004)

Convergence of solutions

$\partial T/ \partial t + V.\nabla T + S(T) = 0$

Resolved scales:

$\partial T_R/ \partial t + V_R.\nabla T_R + S_R (T_R) =$

$- ((V.\nabla T)_R - V_R.\nabla T_R) - (S(T)_R - S_R (T_R))$

Numerical convergence / numerical error = lhs

Physical convergence / parameterization error = rhs

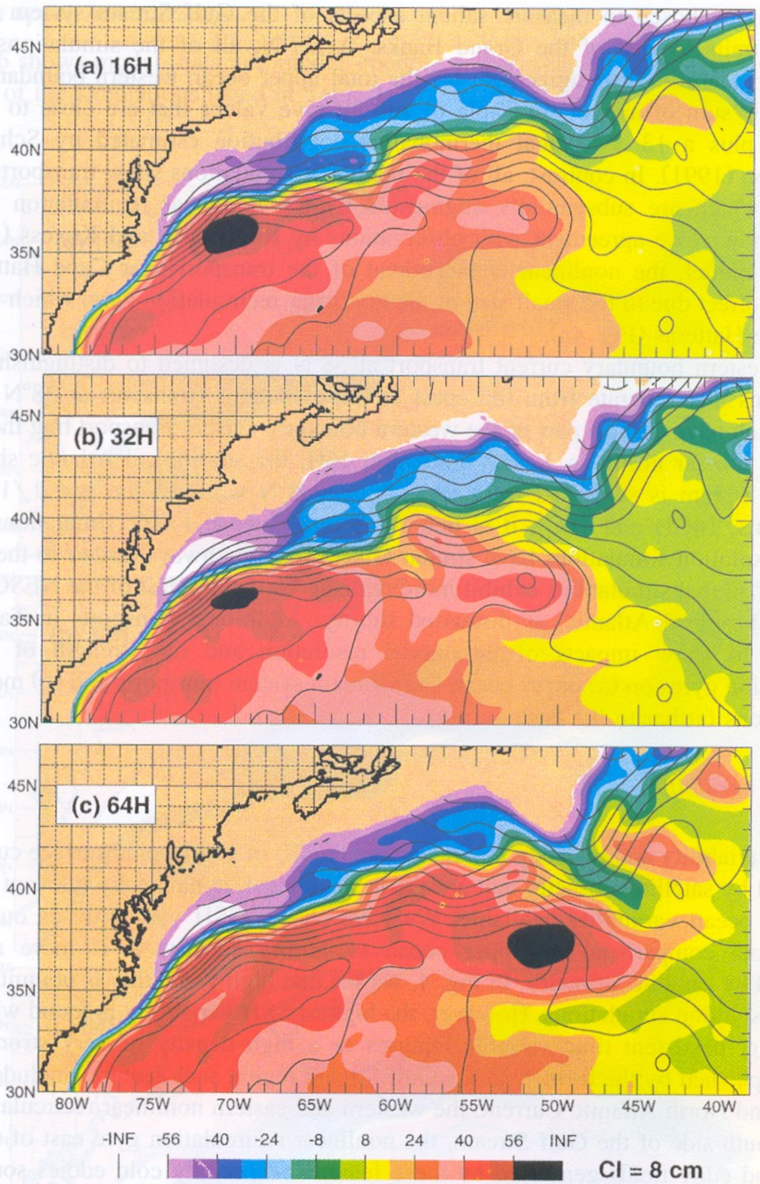
Convergence of solutions

Physical convergence: in a range of scales where physical processes remain the same

Example from the atmosphere: convergence of the dynamical core of an atmospheric model, simple setting (aquaplanet, no humidity, simple forcing….)

Atmospheric dynamical model converges at T63 ? (Boer and Denis, 1997)

Layered ocean model (1)



8. Mean SSH (color) in the Gulf Stream region from (a) 1/16° simulation 16H, (b) 1/32° simulation

Hurlburt and Hogan, 2000

From 7 km to 3.5 to 1.7km : still changes

Model ssh (color) and observed dynamic height

Layered ocean model (2)

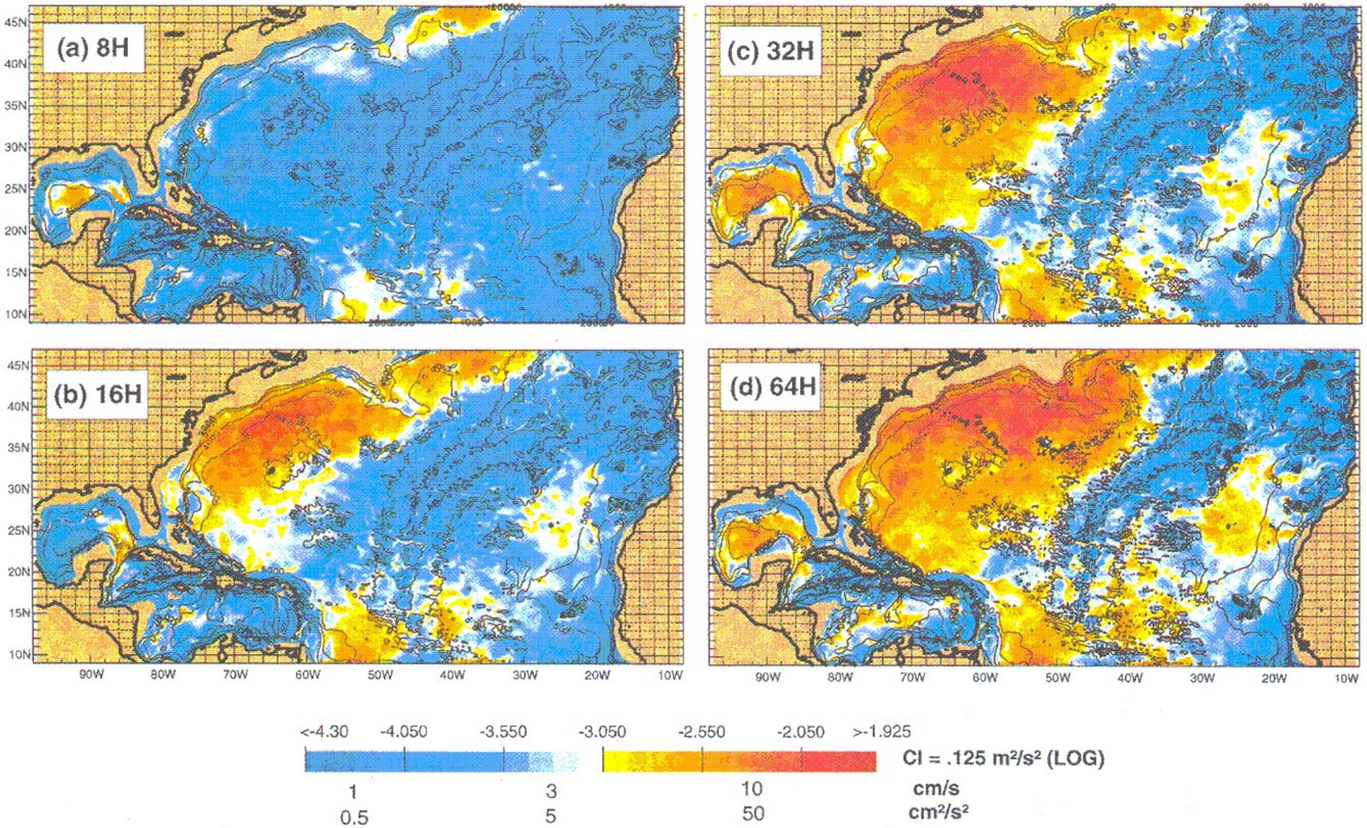
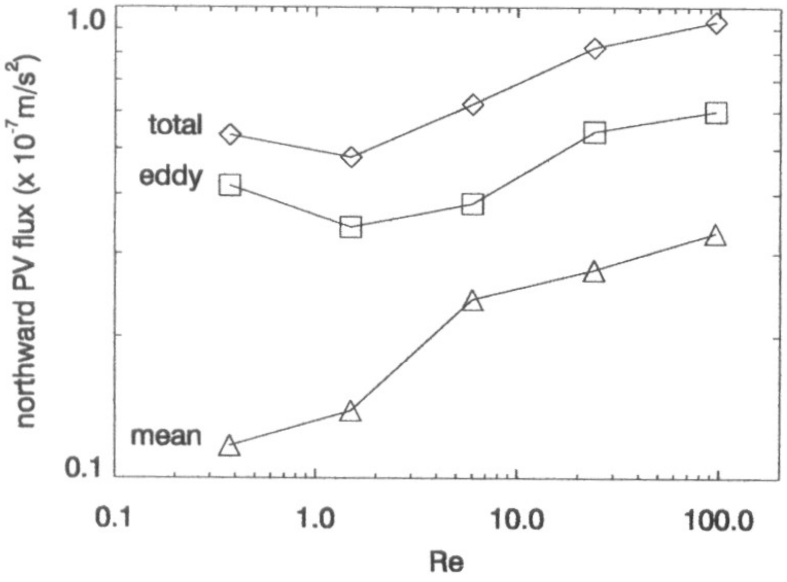


Fig. 12. Whole domain abyssal EKE from Atlantic subtropical gyre simulations with horizontal grid resolution of (a) 1/8° (simulation 8H), (b) 1/16° (simulation 16H), (c) 1/32° (simulation 32H), and (d) 1/64° (simulation 64H). The contour interval for EKE is 0.125 Log_{10} (m^{-2} s^{-2}).

PV flux convergence



Siegel et al, 2001,

Basin QG model

From 3 km to 1.5 km the PV flux still increases but more slowly.

Convergence of solutions

Atmospheric dynamical model converges at T63

= 1.87° = 150 km = 18% of Rossby radius (800 km).

The equivalent resolution for an ocean model is

7 km in the subtropics (Rossby radius 40 km)

2 km in subpolar gyre (Rossby radius 12 km)

Simplest parameterization: local flux-gradient relationship

Reynolds decomposition:

$(V.\nabla T)_R - V_R.\nabla T_R = (V' \nabla T')_R = \nabla(V'T')_R$

With $T' = T - T_R$

Fickian diffusion:

$(w'T')_R = - \kappa \partial T_R / \partial z$

Vertical mixing: the diffusion equation

Exemple: temperature in the surface mixed layer.

Local and nonlocal parameterizations

For local parameterizations,

$$(w'T')_R = -\kappa \partial T_R / \partial z$$

$$\partial T / \partial t = \partial (\kappa \, \partial T / \partial z) / \partial z$$

The trick is to specify $\kappa(x,y,z,t)$

Vertical mixing: constant κ

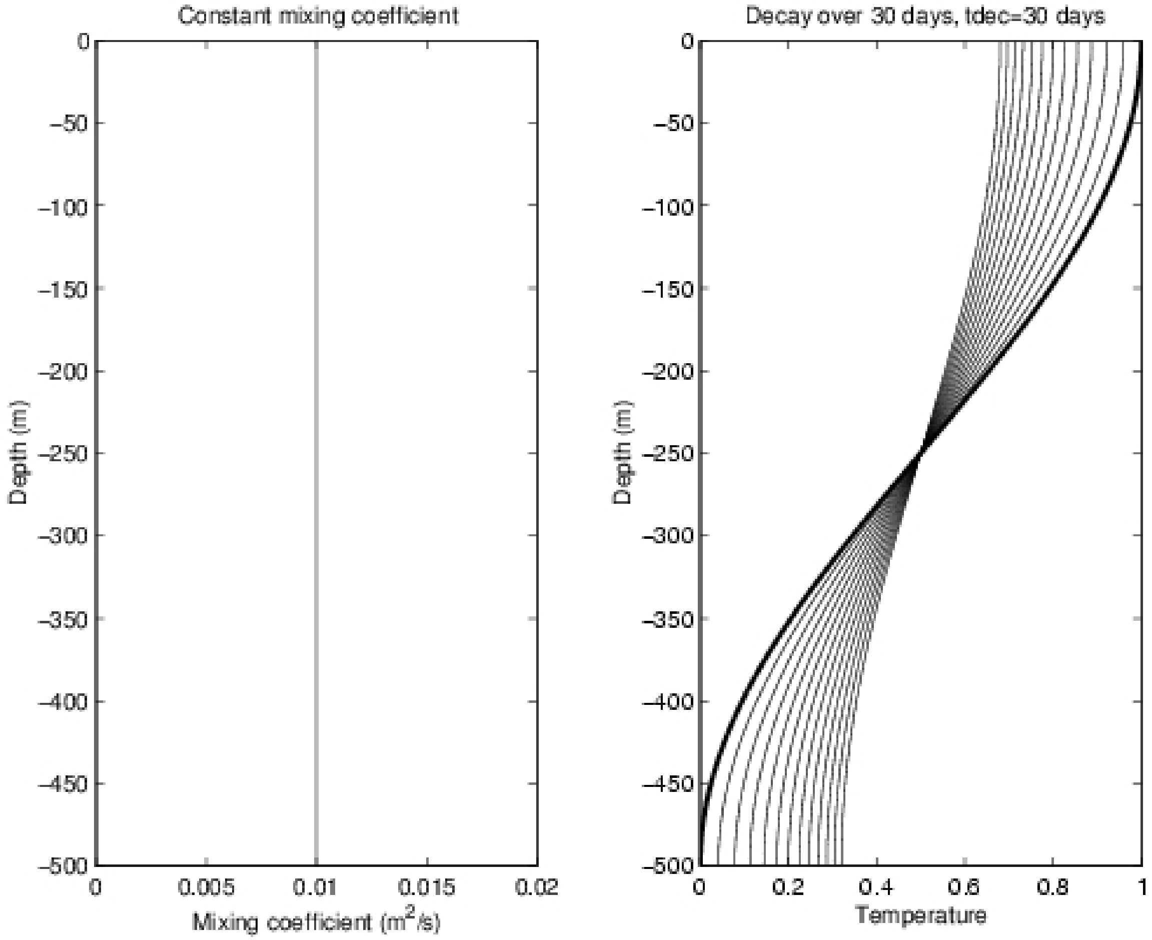
$\partial T/\partial t = \partial (\kappa\, \partial T/ \partial z) / \partial z$

$T_0 = 0.5*(1+\cos(\pi z/H)$;

$H = 500$m; $\kappa = 0.01$ m²/s;

$T_{decay} =$

$H^2/ (\pi^2 \kappa)=29.3$ day

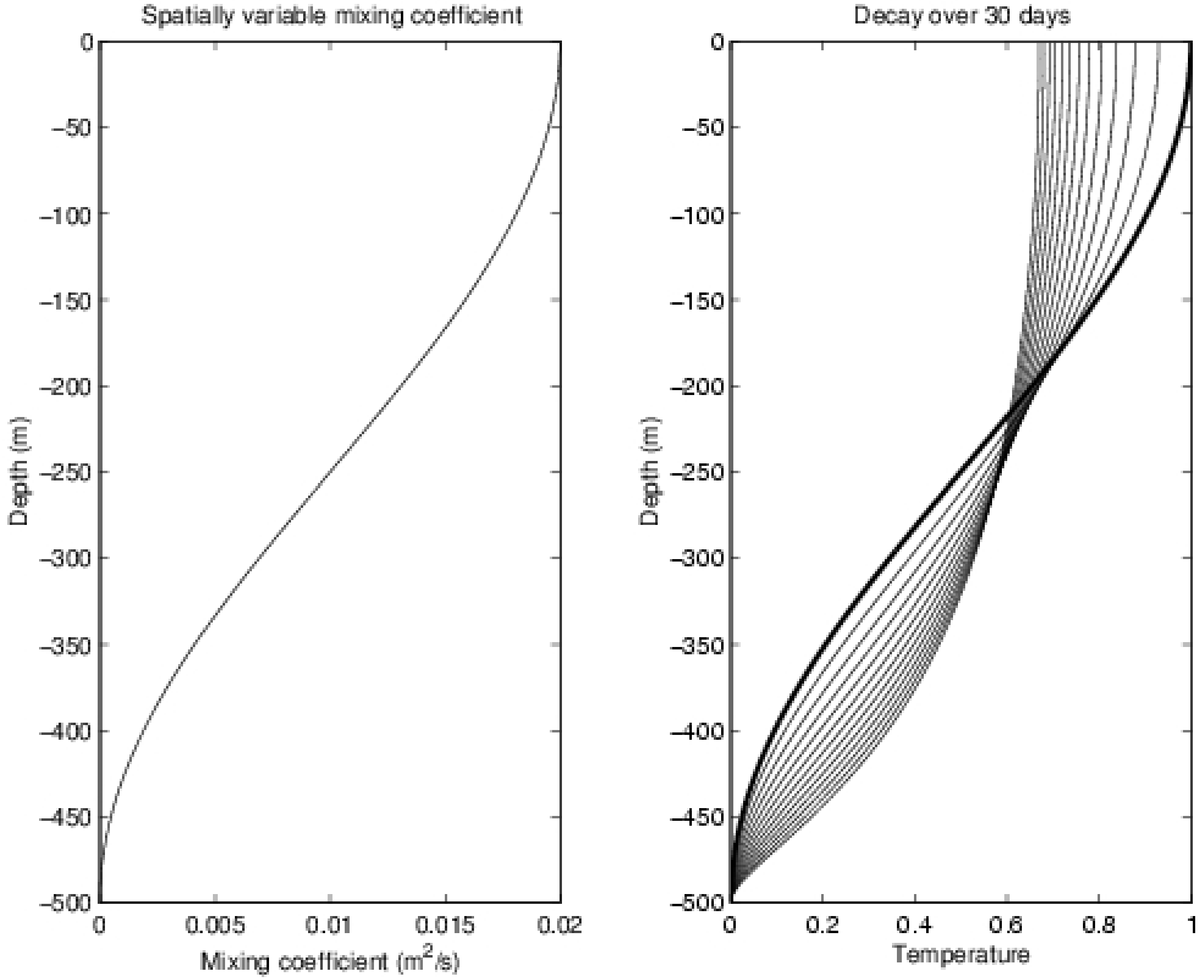


Vertical mixing: spatially variable κ

$$\partial T/\partial t = \partial\,(\kappa(z)\,\partial T/\,\partial z\,)\,/\,\partial z$$

$$= \kappa_z \partial T/\,\partial z \;+ \kappa\,\partial^2 T/\,\partial z^2$$

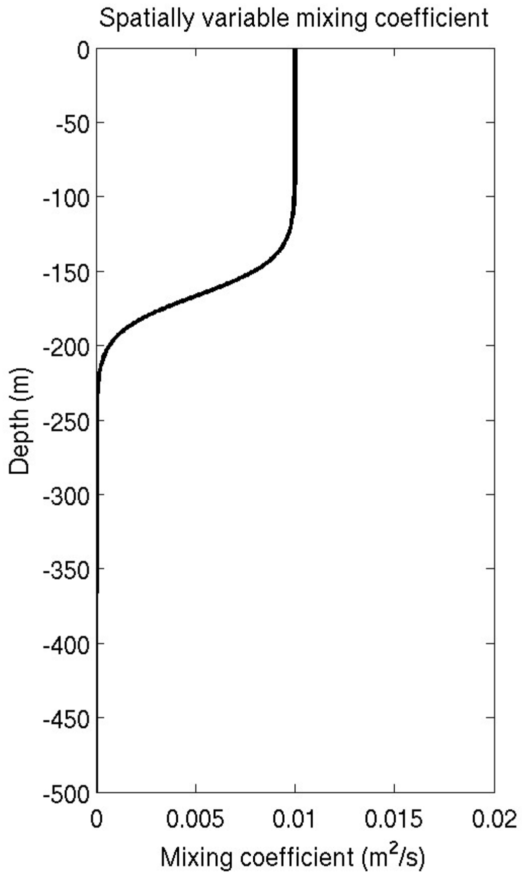
$$\kappa = 0.01*(1+\cos(\pi z/H)\;\;(m^2/s);$$

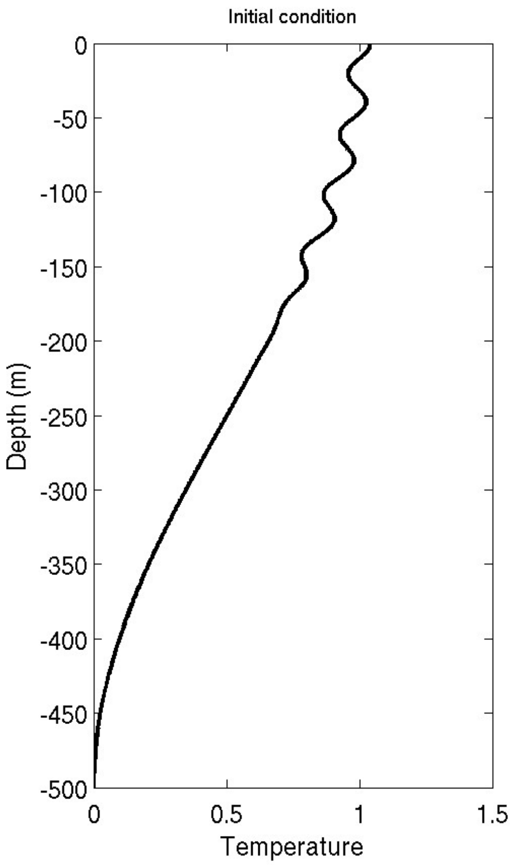


More spatially variable κ

$\kappa = 0.005*(\tanh(\alpha(z-H/3)+1)$ (m^2/s);

$\alpha = 1/(0.05H)$





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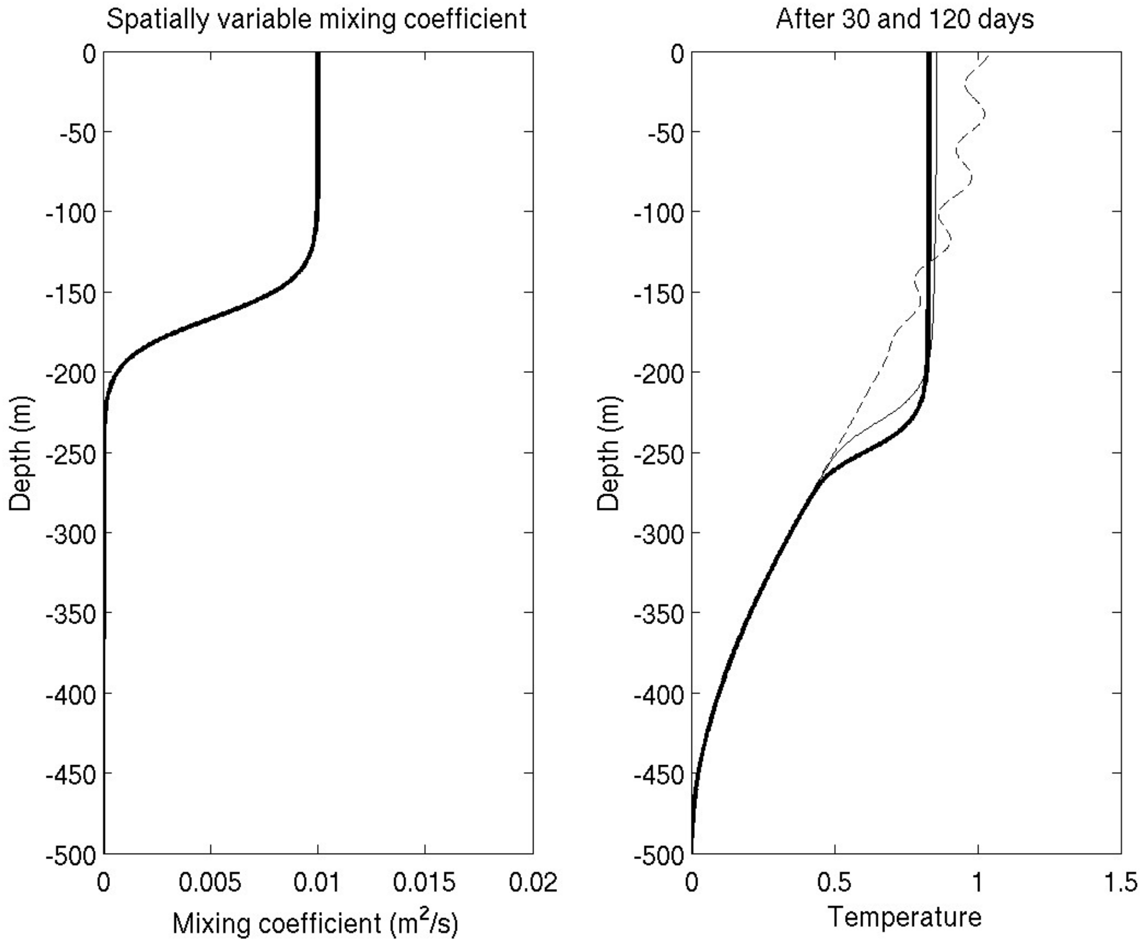


Growth of gradients with a spatially variable diffusion coefficient

Equation for the evolution of the gradient (P. Klein)

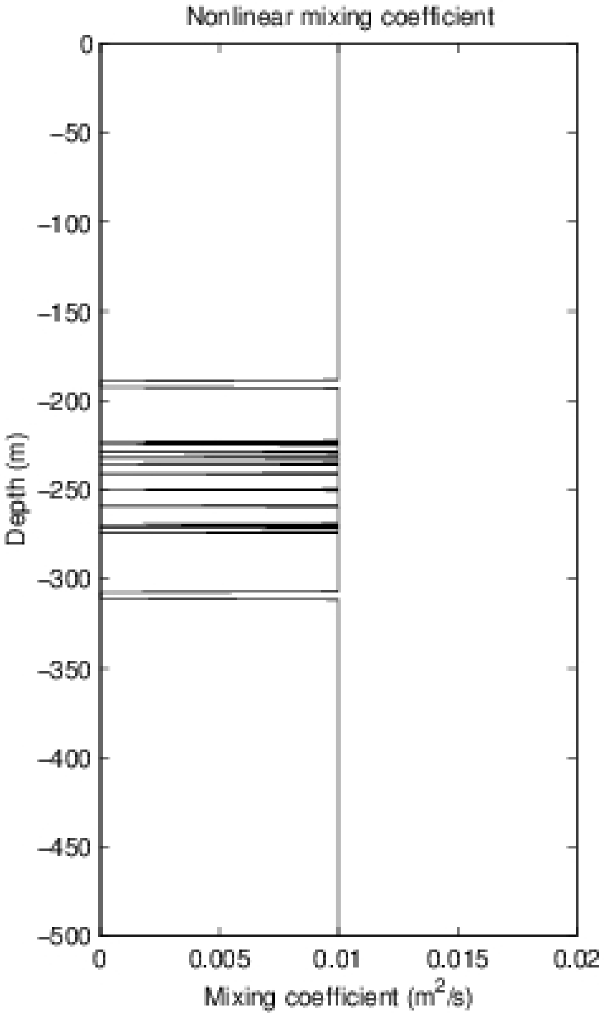
$$\partial T_z/\partial t = \kappa\, \partial^2 T_z/ \partial z^2 + 2\, \kappa_z \partial T_z/ \partial z + \partial^2\kappa / \partial z^2\, T_z$$

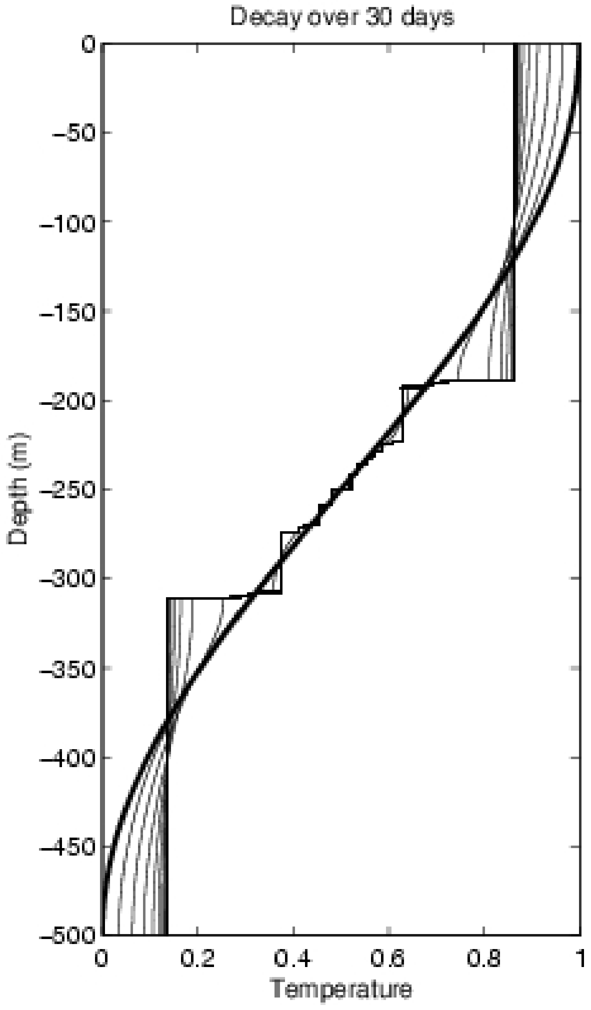
diffusion advection ?

Vertical mixing: nonlinear κ

$\gamma = \max(\partial T_0 / \partial z) = 0.5 * \pi / H$

$\kappa = 0.01 * \exp(-(\partial T / \partial z / \gamma)^2)$ (m²/s);

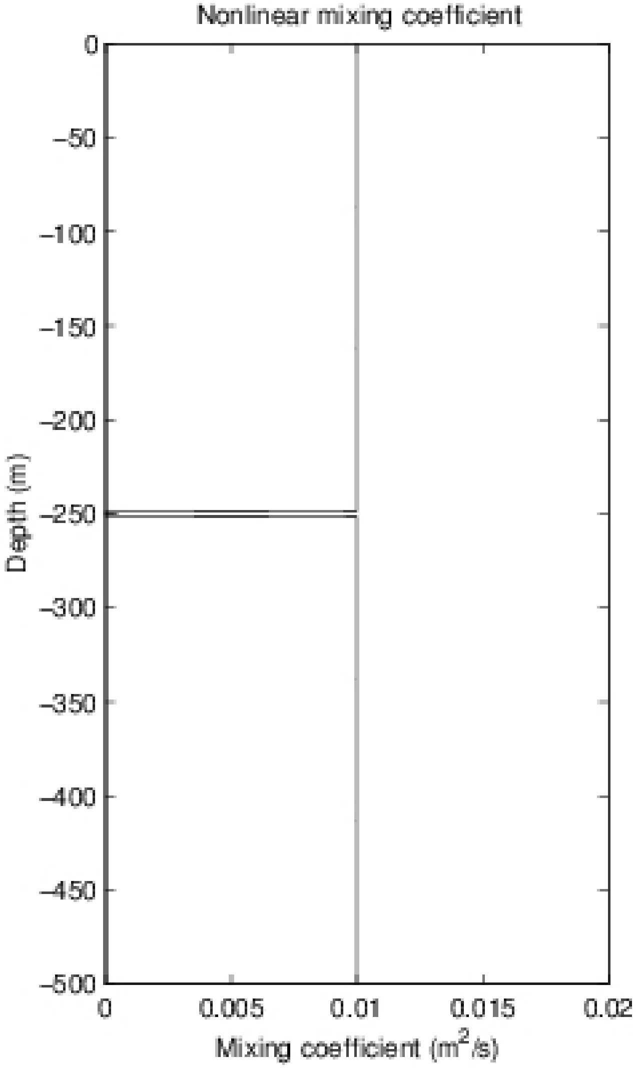


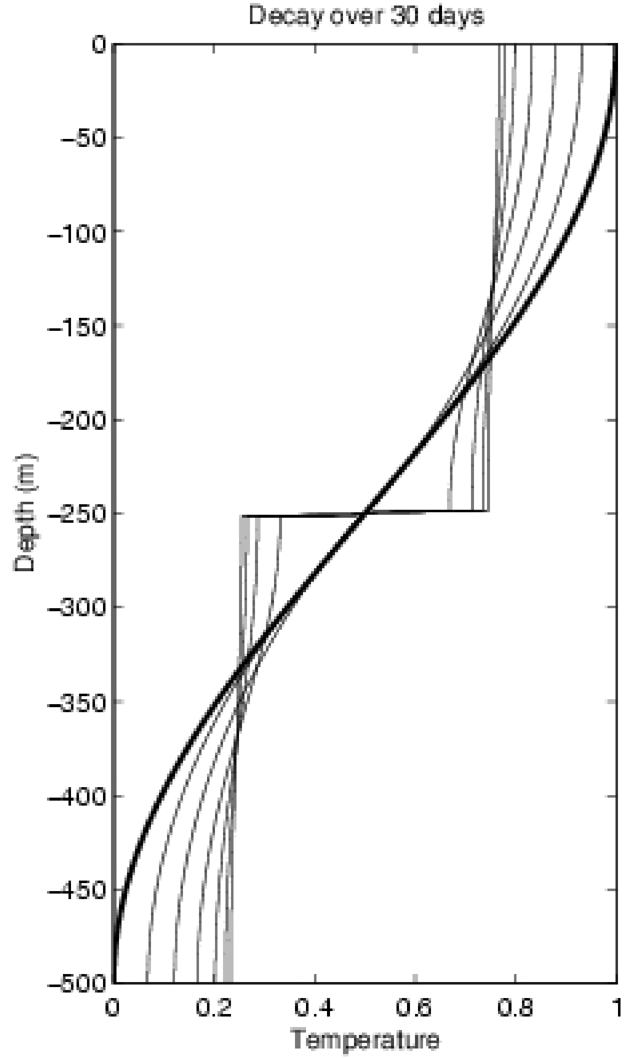


Vertical mixing: nonlinear κ

$\gamma = \max(\partial T_0 / \partial z) = 0.5 * \pi / H$

$\kappa = 0.01 * \exp(-(0.75 * \partial T / \partial z / \gamma)^2)$ (m²/s);





Vertical mixing: nonlinear κ

In the ocean, vertical mixing decreases when the vertical stratification increases (consequenses pointed out by Phillips 1972).

The dependency is strongly nonlinear.

(MY model, TKE model …)

Warning:

-The diffusion equation is not what it seems to be;

-Ocean model tend to develop discontinuities both in the vertical and the horizontal: numerics come into play.

Subgrid scale processes : internal/ external

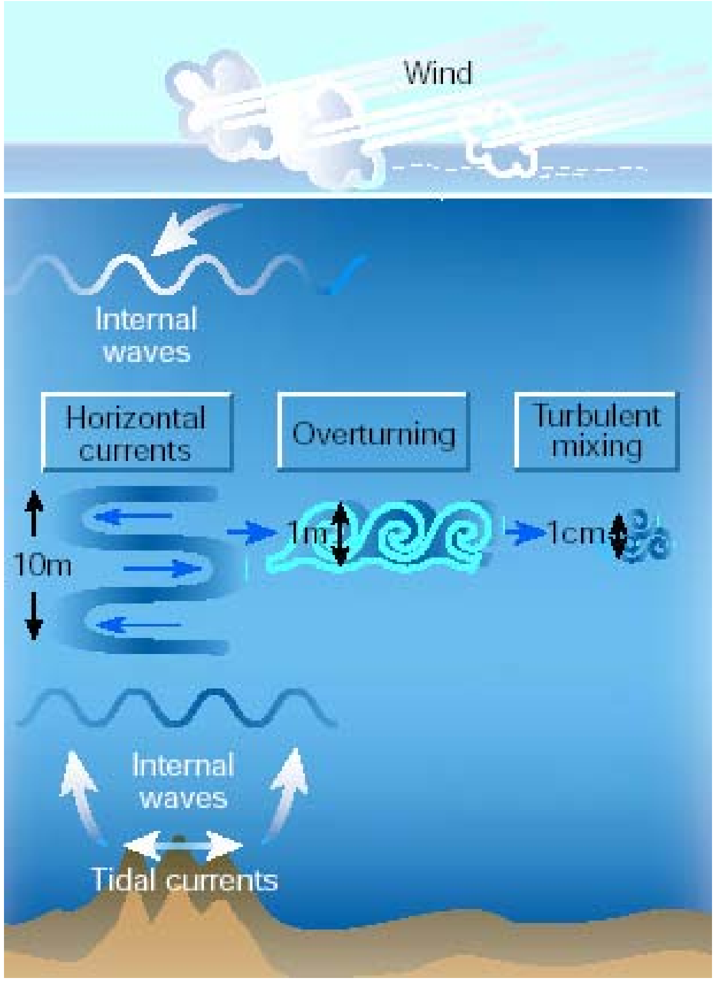
Internal : processes resulting from the nonlinearity of the equations (turbulence, instabilities)

Processes not represented due to approximations in the equations (convection)

External: Topographic effects, coastline

Air-sea fluxes…

Subgrid scale effects: physical processes



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Internal wave breaking (gravity+ stratification)

Double diffusion

Convection

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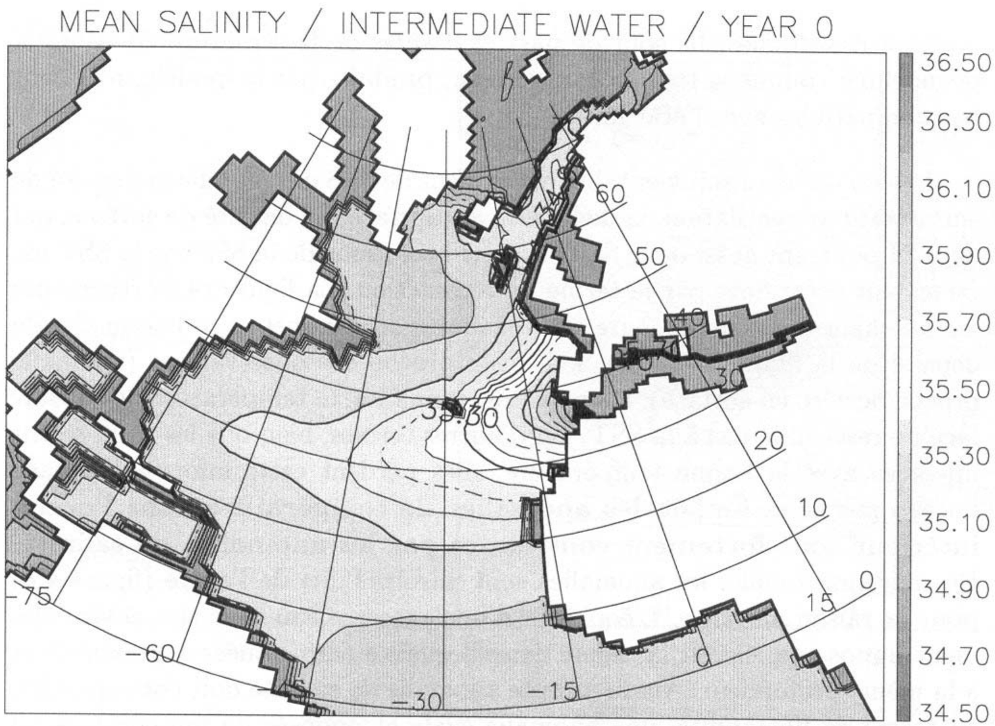
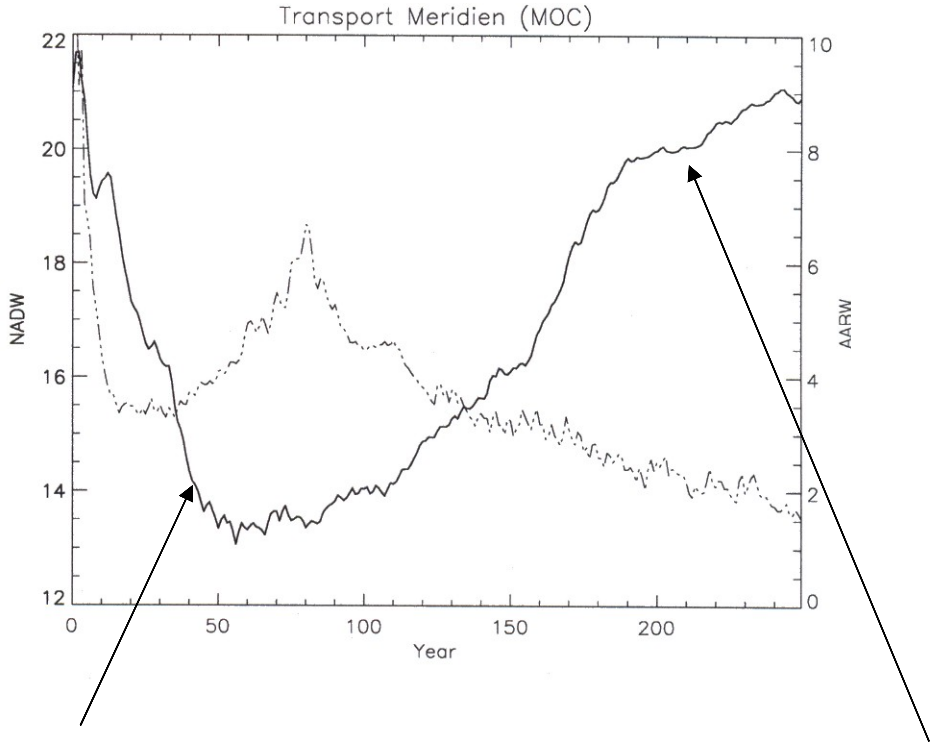
Subgrid scale effects: topography



Should Gibraltar Strait be a subgrid scale effect in ORCA2?

Simulations: G. Roullet's PhD thesis, 2000.

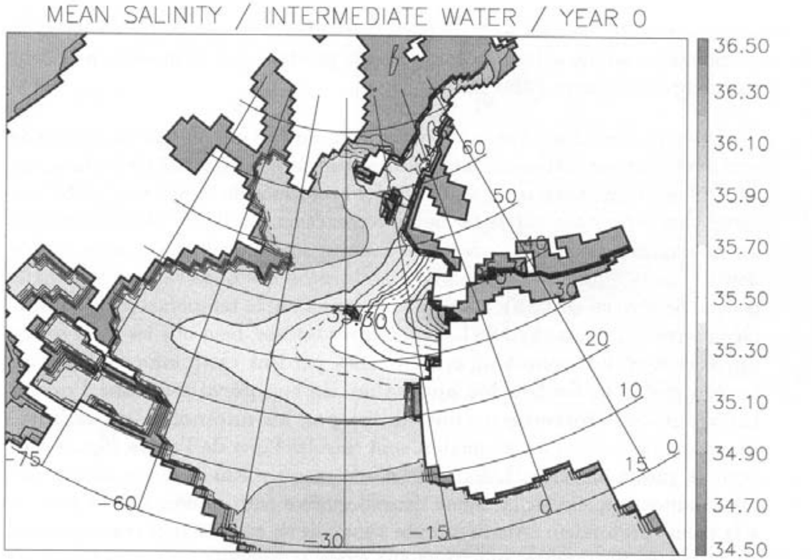
Subgrid scale topography (2)



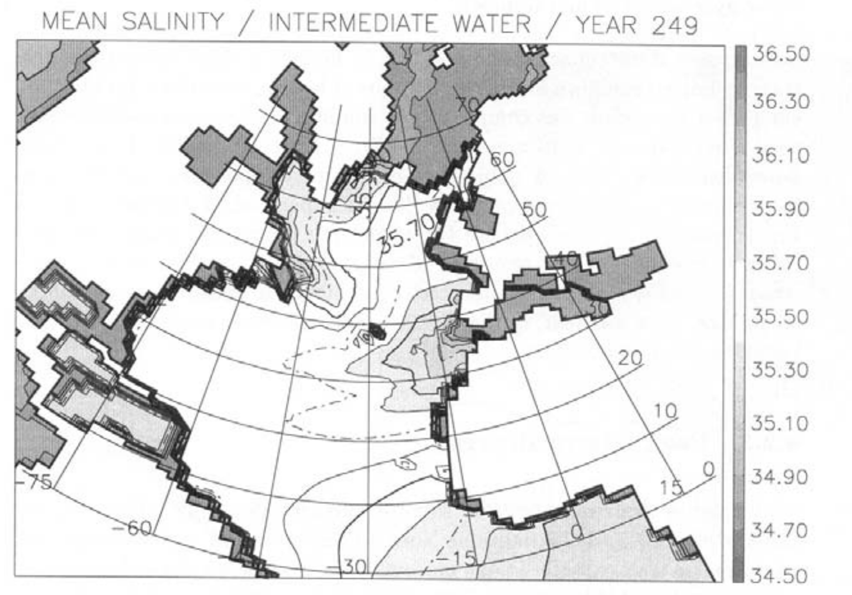
Rapid decrease of the overturning (50 years)

Slow increase up to 200 years

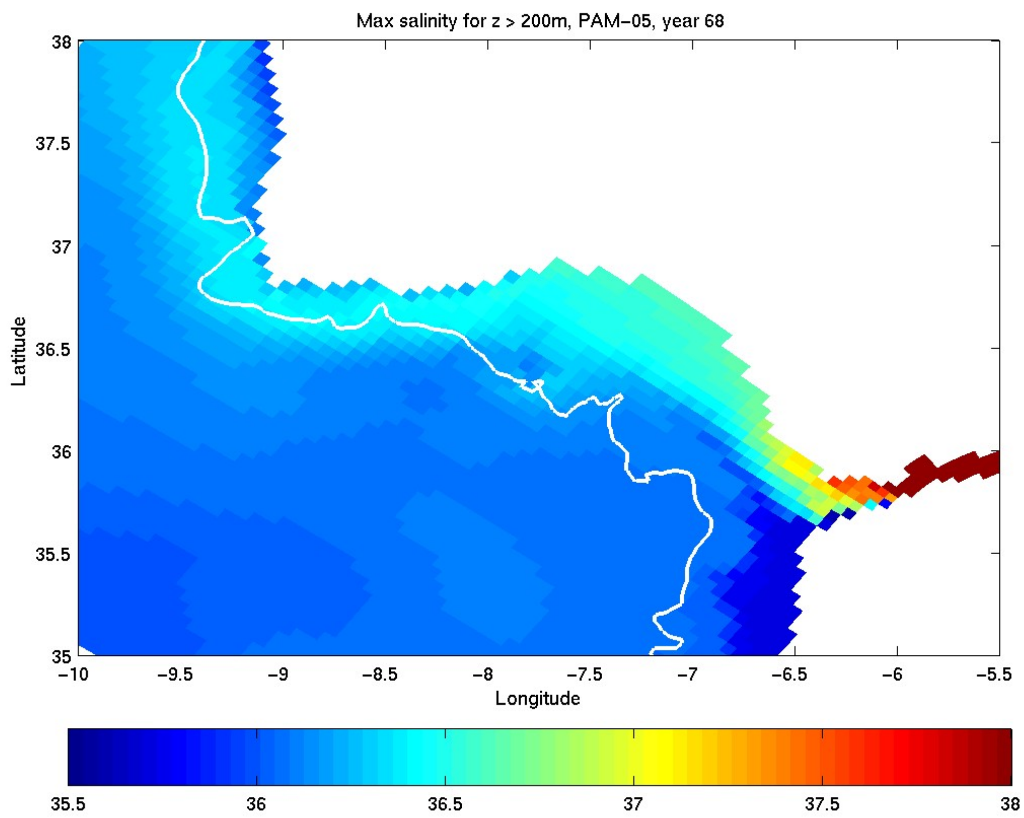
Subgrid scale topography (3)



Roullet, 2000.



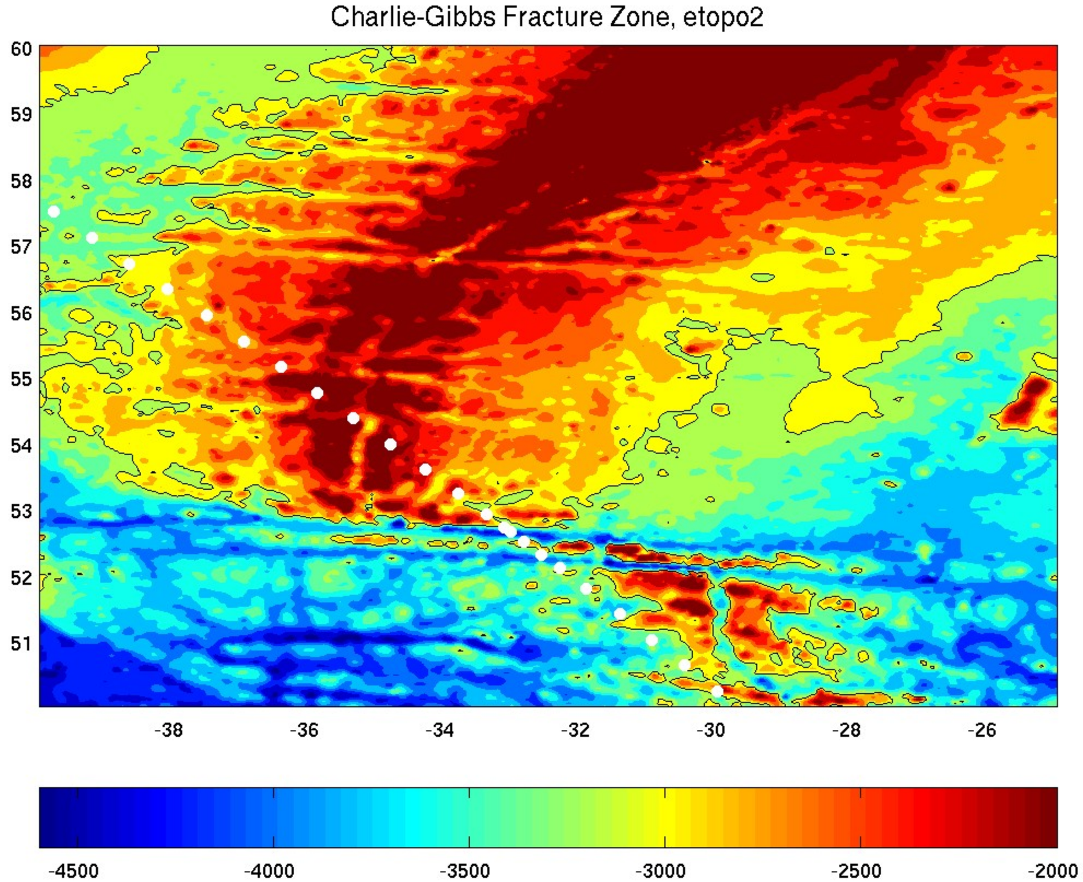
Subgrid scale topography



Is « resolved » resolved enough?

The overflow problem…

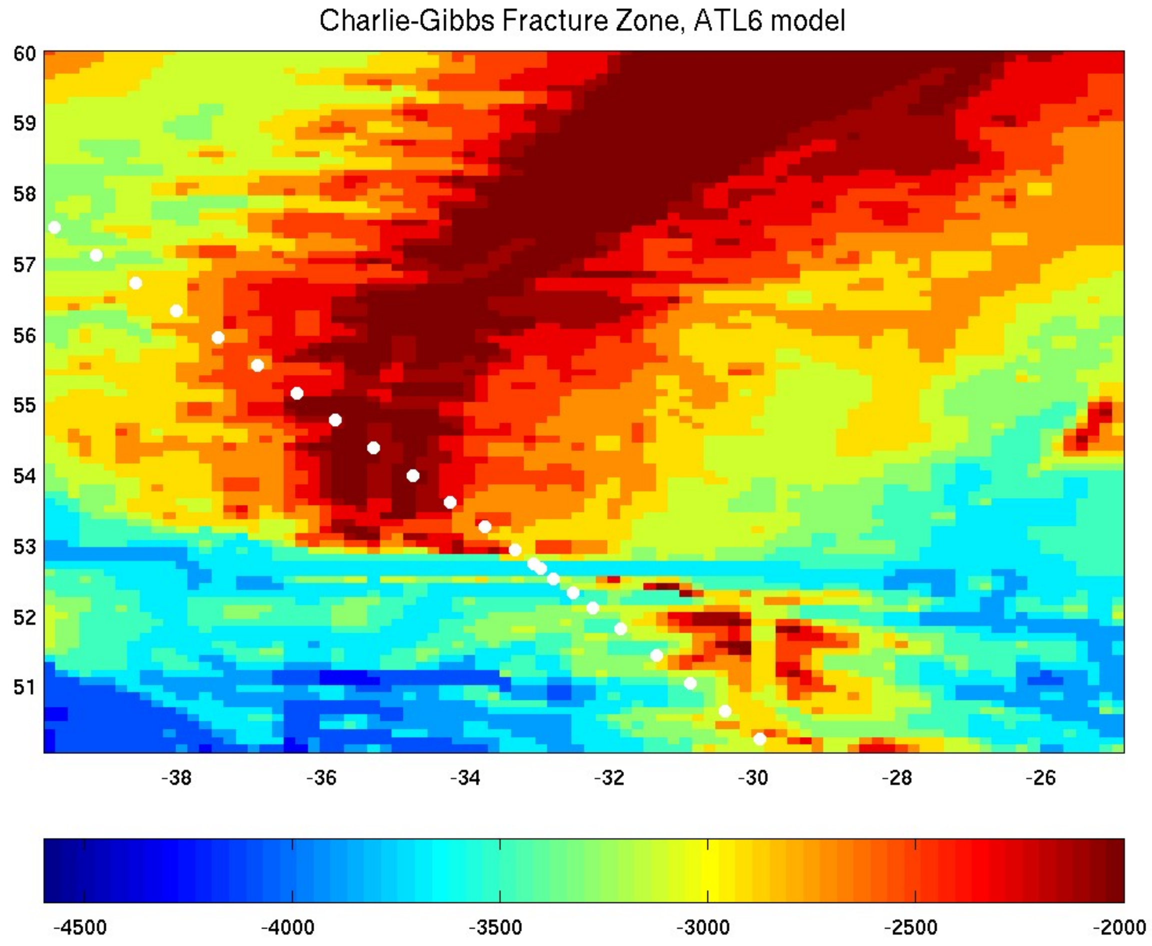
Subgridscale topography: CGFZ



4x cruise,

Alvarez et al.

Subgridscale topography: CGFZ

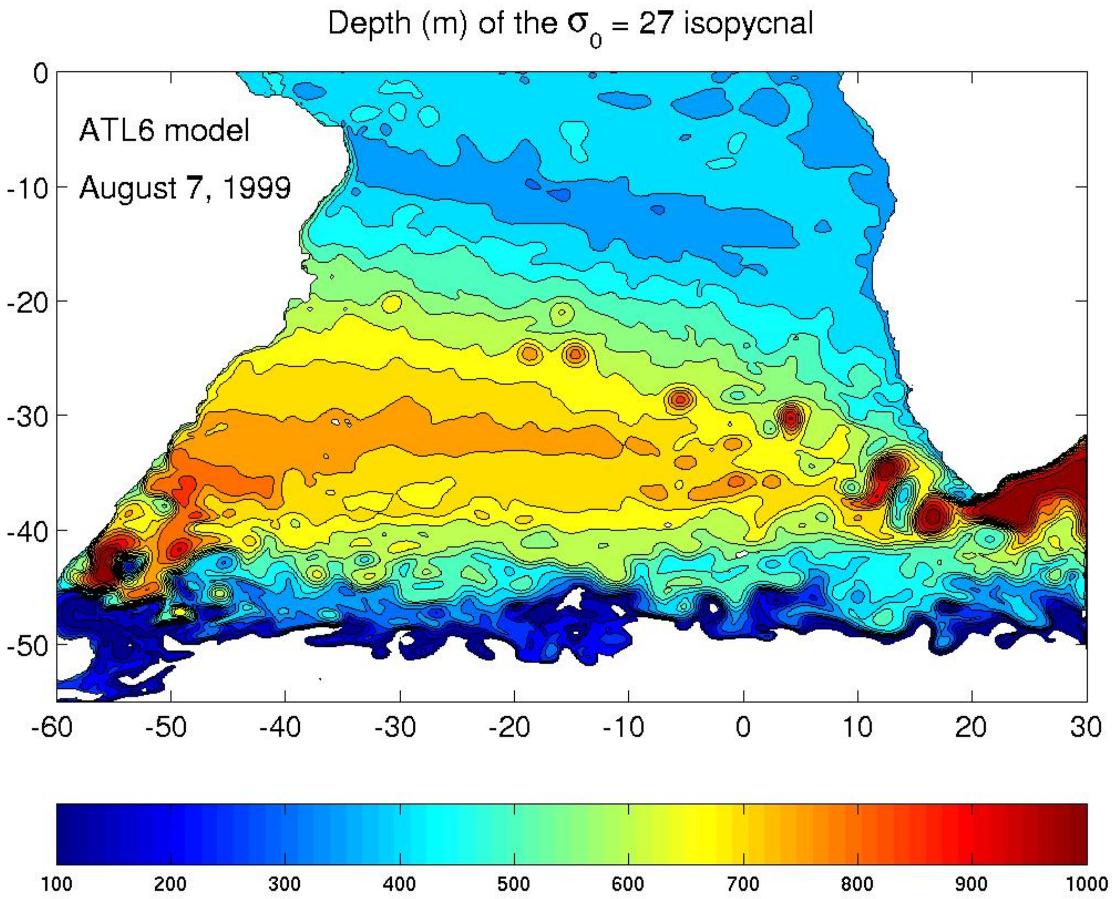


Choice to dig a channel,

No deep water component,

Mean flow is the wrong way.

Subgrid scale effects: forcings



Heat fluxes over Agulhas rings

Part 1: generalities

- Choosing an ocean to model
- Convergence of solutions
- Diffusion does not necessarily diffuse
- Parameterizations of « external » effects: subgrid scale forcing and topography.