Overflow representation using K-profile and Turner parameterization in HYCOM

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Thanks to: *Alan Wallcraft, George Halliwell, Zulema Garraffo*

- **Comparison of K-profile and Turner parameterization using idealized configurations**

- *Mediterranean outflow experiment*

- *My Future plan*

Diapycnal Mixing in HYCOM

MICOM mode/ TP

$$\frac{\partial h_k}{\partial t} = \frac{\partial}{\partial \rho}\left(k\frac{\partial \rho}{\partial z}\right)\Bigg|_{k+1/2} - \frac{\partial}{\partial \rho}\left(k\frac{\partial \rho}{\partial z}\right)\Bigg|_{k-1/2}$$

$$\frac{\partial h_k}{\partial t} = \left(\frac{1}{\Delta\rho_{k-1/2}} + \frac{1}{\Delta\rho_{k+1/2}}\right)F_k - G_k$$

$$with \qquad F_k = \frac{k_k \Delta\rho_k}{h_k}; G_k = \frac{F_{k-1}}{\Delta\rho_{k-1/2}} + \frac{F_{k+1}}{\Delta\rho_{k+1/2}}$$

$$k_{diffusive} = 0.1 cm^2/\sec$$

$$w_E = \begin{cases} \Delta U(0.08 - 0.1Ri)/(1+5Ri) & Ri < 0.8 \\ 0 & otherwise \end{cases}$$

Density of each layer is fixed, diapycnal mixing is expressed as layer thickness changes.

HYBRD mode/ KPP + hybgen

$$\frac{\partial \theta, S}{\partial t} = -\frac{\partial}{\partial z}\left(-\kappa_{\theta,S}\frac{\partial \theta, S}{\partial z}\right)$$

$$\frac{\partial V}{\partial t} = -\frac{\partial}{\partial z}\left(-\kappa_M\frac{\partial V}{\partial z}\right)$$

$$k_{background} = 0.1 cm^2/\sec$$

$$k_{shear} = k_{\max}[1-(Ri/Ri_0)^2]^3$$

$$k_{doublediffusion} = \ldots$$

Density of each layer is changed via vertical diffusivity, and ‘hybgen’ moves the layer interfaces to restore the layer density to its target.

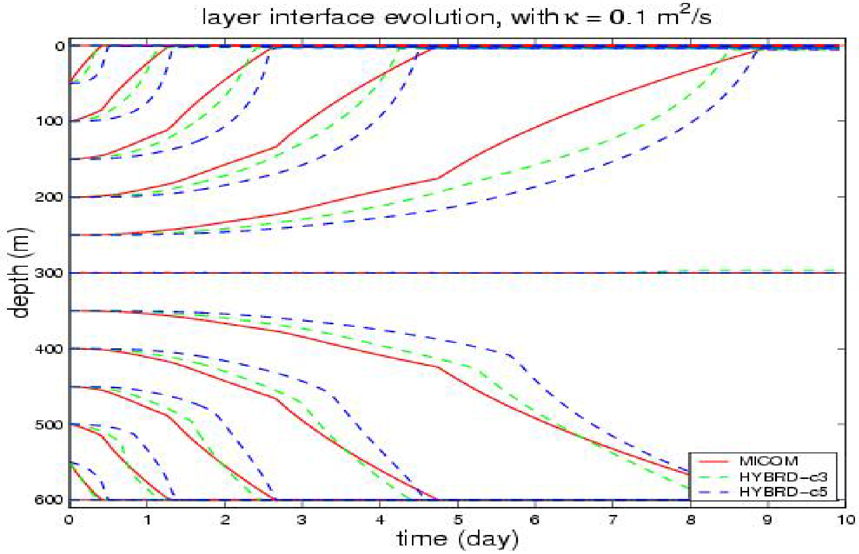
✓ **Comparison between HYBRD/ MICOM mode (1-D diffusion experiments with same parameterization)**

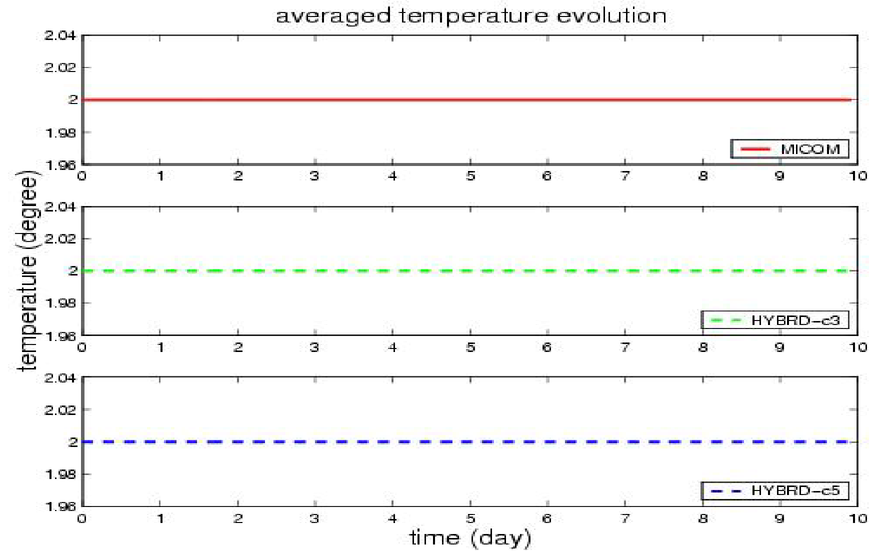
- Constant diffusivity: $k = 0.1 m^2 / \sec$
- Linear temperature profile: $\theta = 5.0 - 0.01 z; \quad 0 \le z \le 600 m$
- Linear equation of state: $\sigma = 28.0 - 0.08\theta$

> ➢ *Expt_A: constant layer thickness;*
>
> ➢ *Expt_B: thin layer inflation*

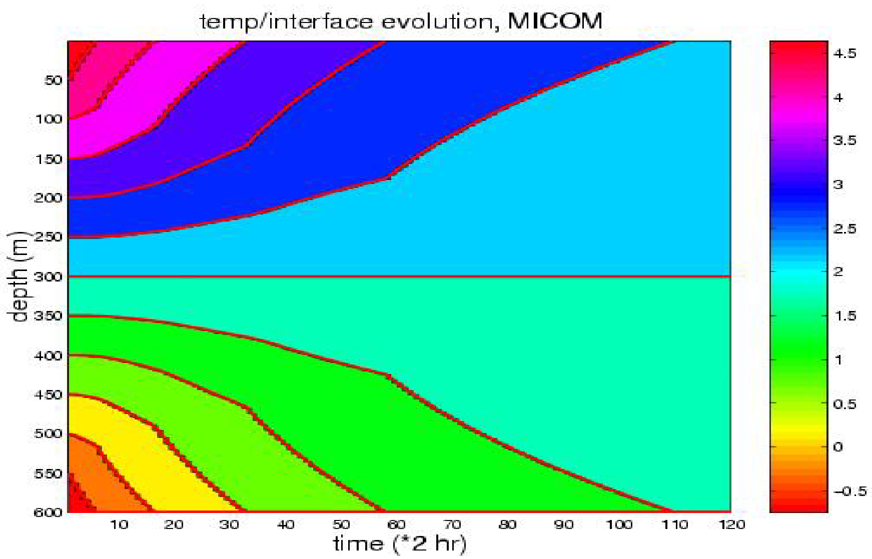
✓ **Comparison of KPP and TP (2-D ‘dam-break’ experiments)**

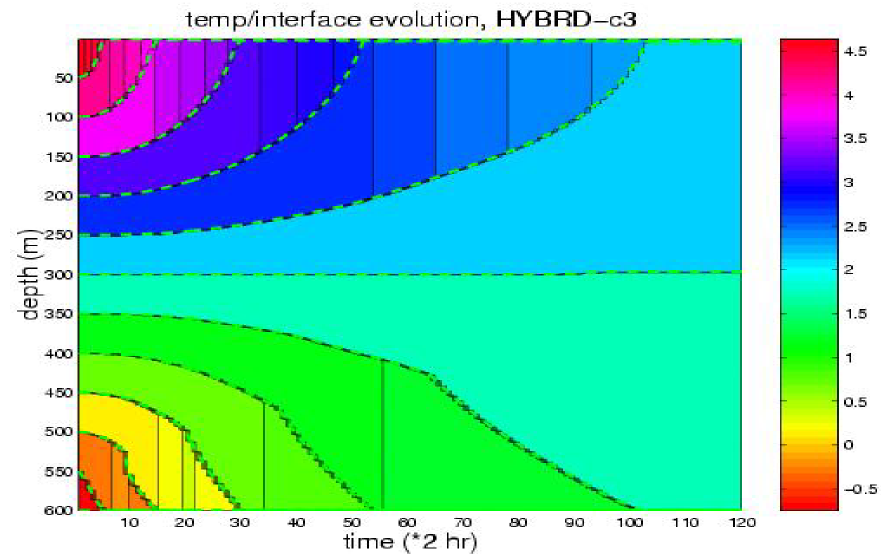
EXPT A: constant layer thickness





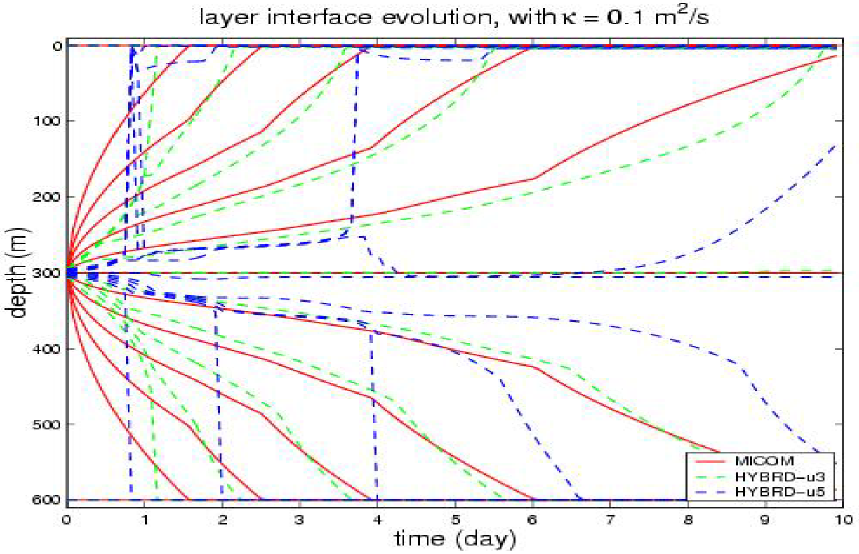
Time evolution of: layer interface (L), averaged temperature (R)

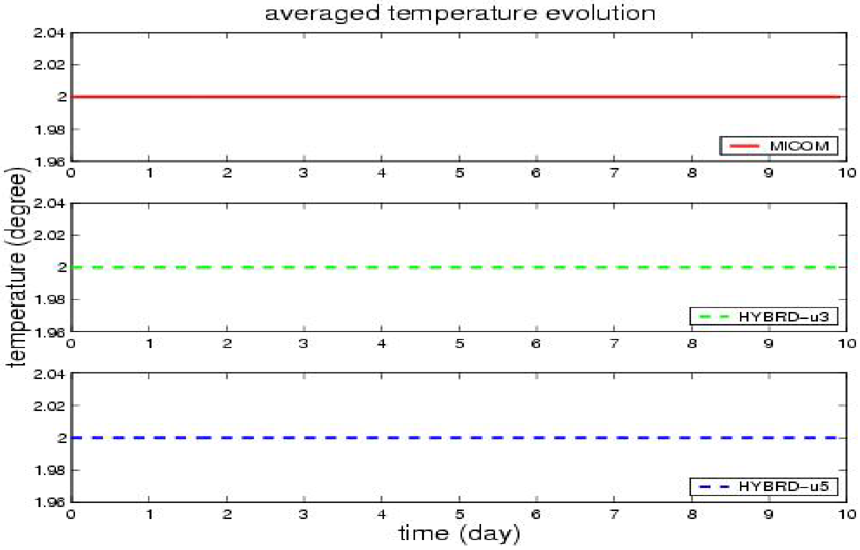




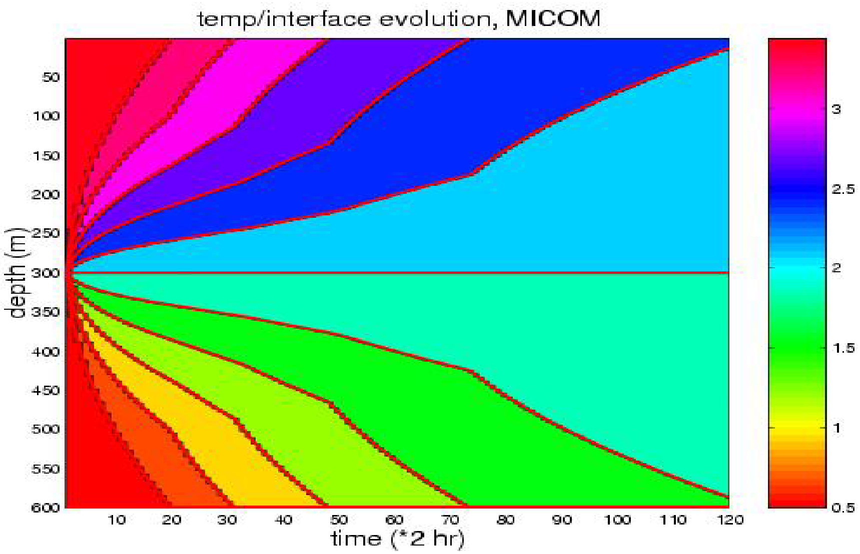
Time evolution of temperature profile in MICOM (L), HYBRD (R) mode

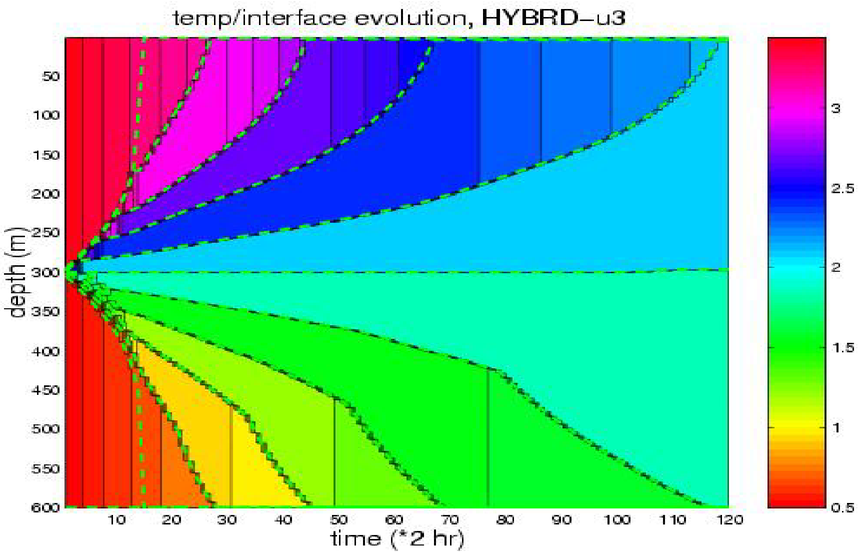
EXPT B: Inflation experiment





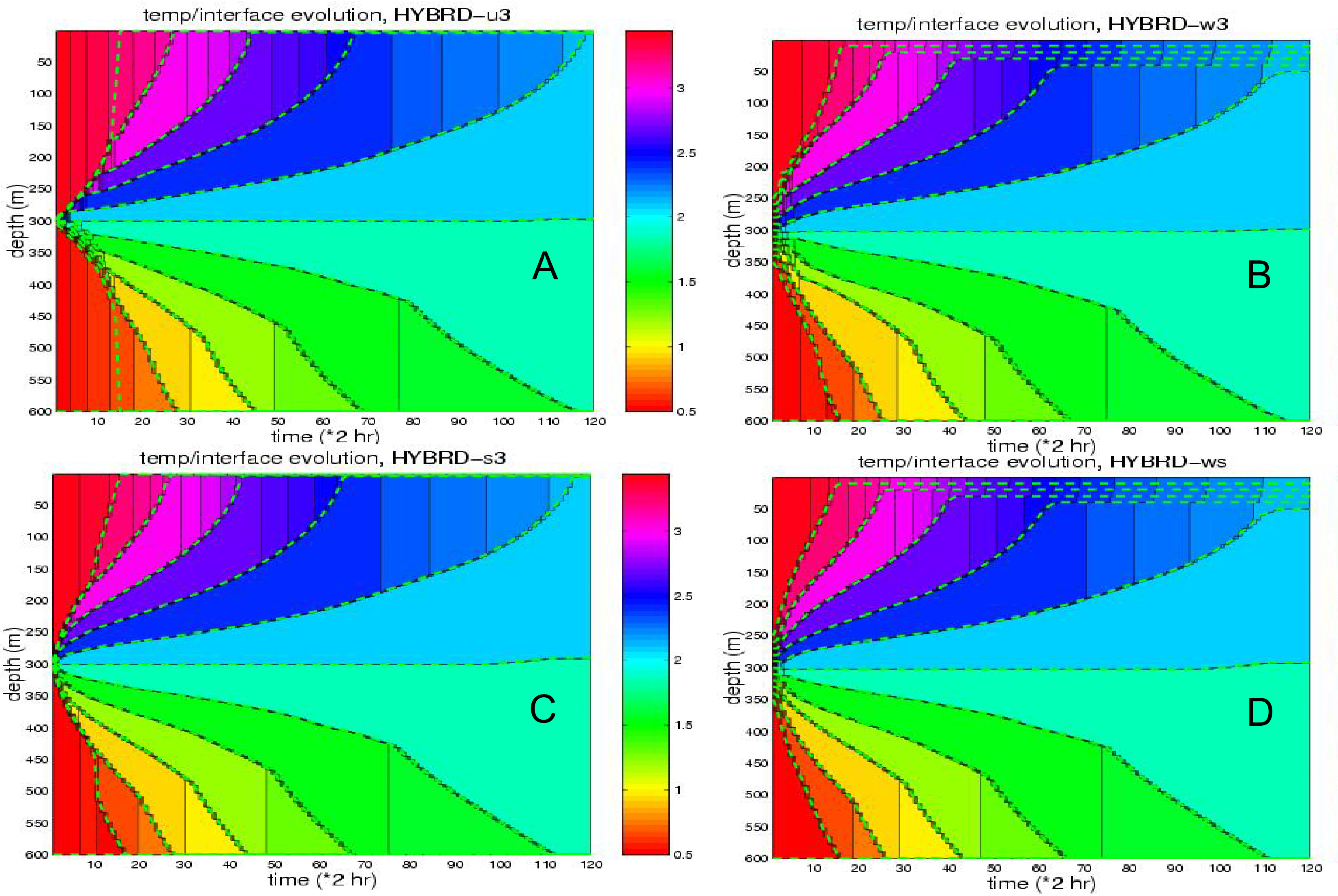
Time evolution of: layer interface (L), averaged temperature (R)





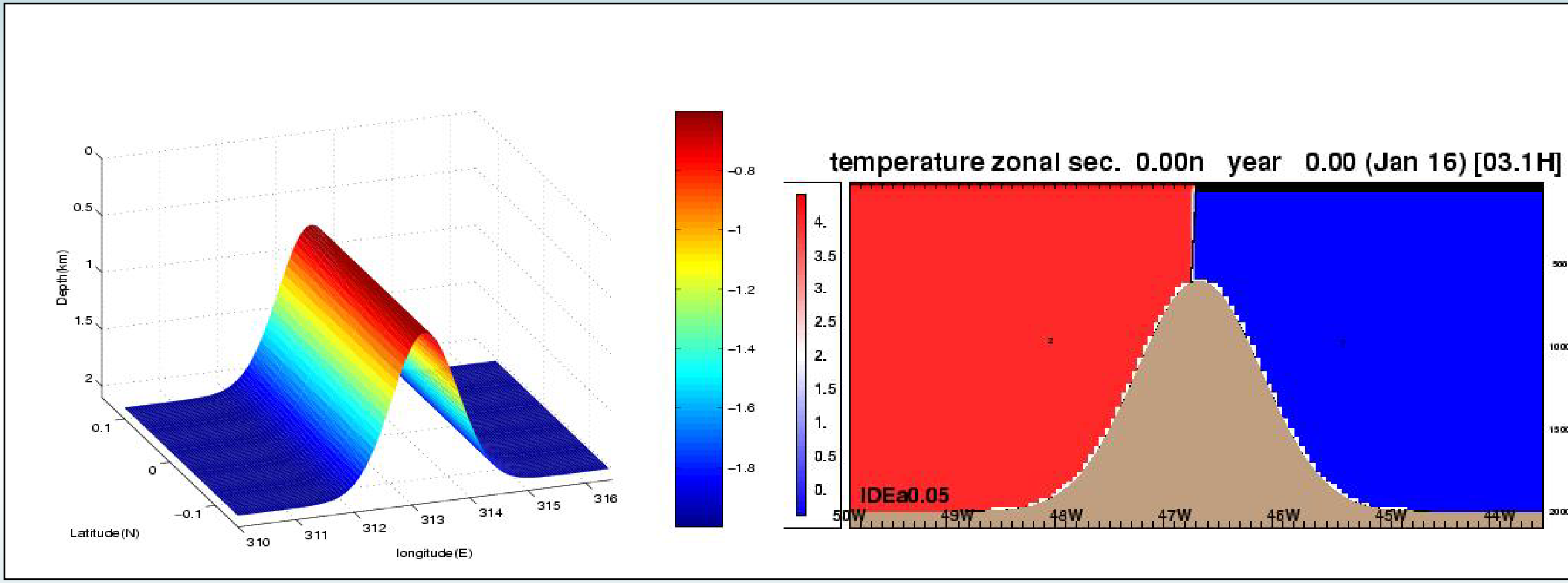
Time evolution of temperature profile in MICOM (L), HYBRD (R) mode

EXPT B: Inflation experiment (continue …)



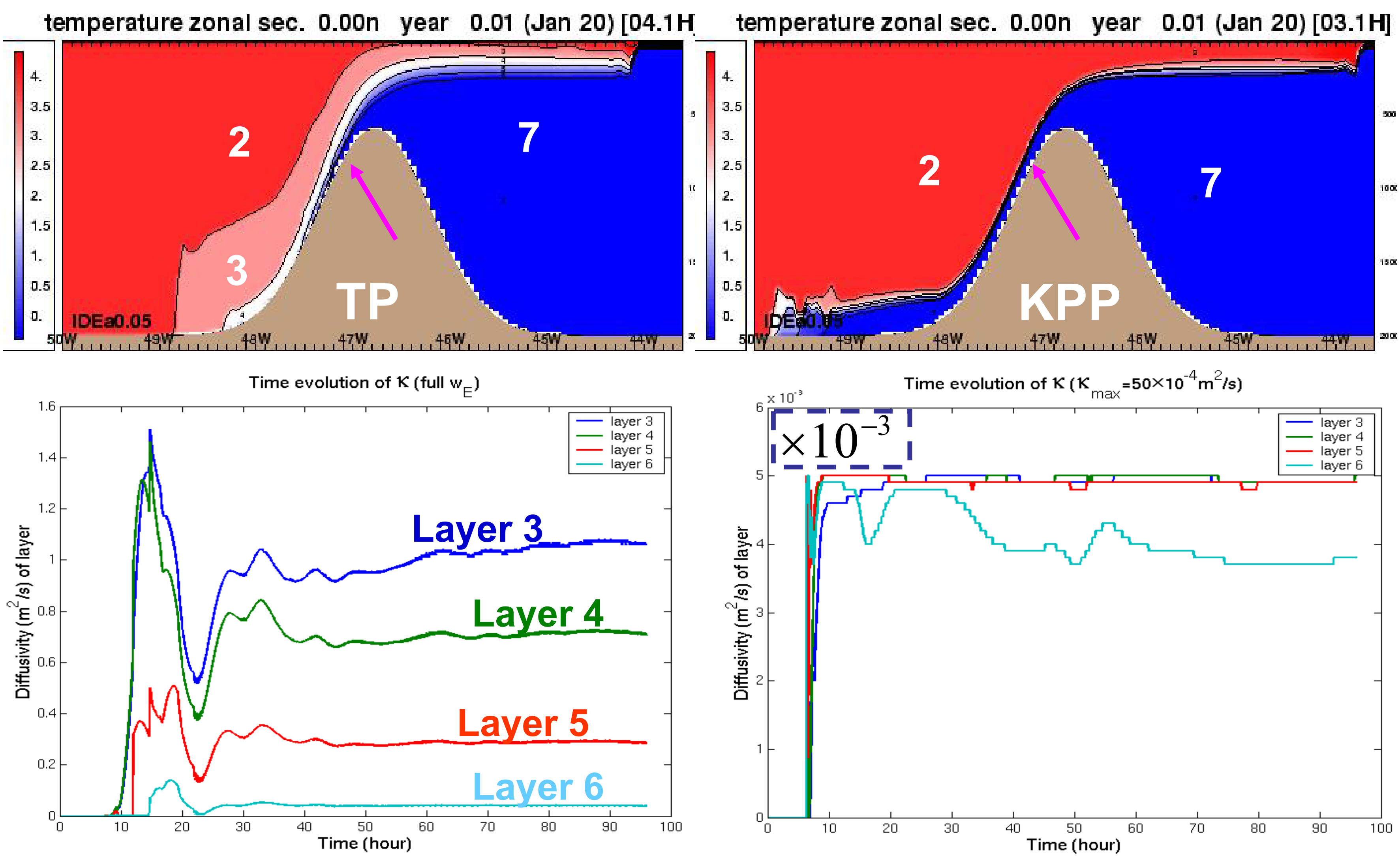
Time evolution of temperature profile in HYBRD mode: default (A), with larger minimum layer thickness (B), with shorter time step (C), with larger minimum layer thickness and shorter time step (D).

✓ *Two-dimensional configuration:*



- Smooth Gaussian topography: 600~2000m
- Two water masses (5 C vs. -1 C) divided by vertical front on top
- Linear equation of state

Original comparison



Temperature snapshot 4 days after dam-break (Above); diffusivity as function of time (below)

Modified TP and KPP experiments

MICOM mode/ TP

$$\frac{\partial h_k}{\partial t} = \left(\frac{1}{\Delta\rho_{k-1/2}} + \frac{1}{\Delta\rho_{k+1/2}} \right) F_k - G_k$$

with $$F_k = \frac{k_k \Delta\rho_k}{h_k} \le \frac{k_{\max} \Delta\rho_k}{h_k}$$

$$G_k = \frac{F_{k-1}}{\Delta\rho_{k-1/2}} + \frac{F_{k+1}}{\Delta\rho_{k+1/2}}$$

$$k_{diffusive} = 0.1 cm^2 / \sec$$

$$w_E = \begin{cases} \Delta U (0.08 - 0.1 Ri)/(1 + 5Ri) & Ri < 0.8 \\ 0 & otherwise \end{cases}$$

Expt_A: modify TP by applying constraint (K_max) similar to KPP

HYBRD mode/ KPP

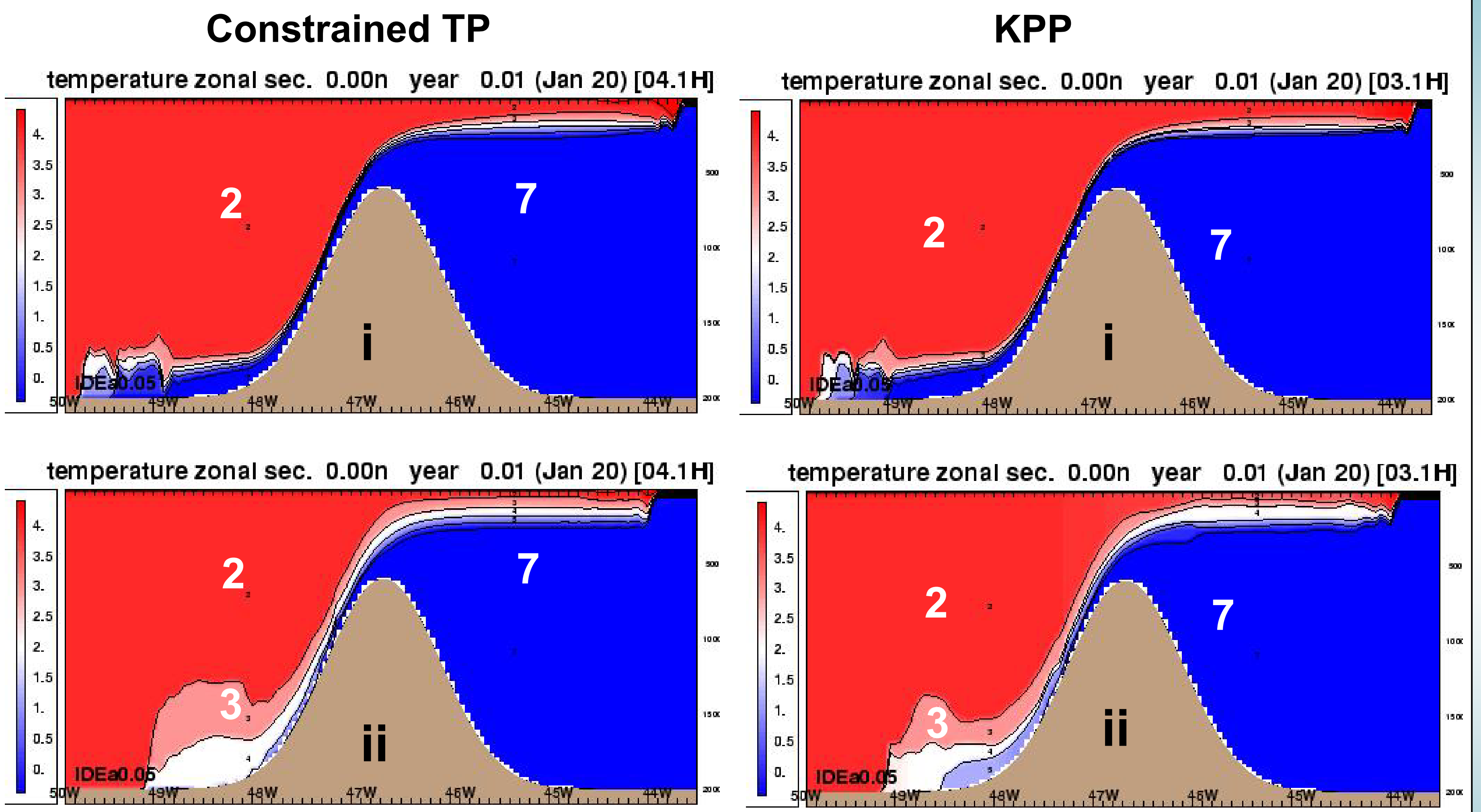
$$k_{doublediffusion} = \ldots$$

$$k_{background} = 0.1 cm^2 / \sec$$

$$k_{shear} = F_k \frac{h_k}{\Delta\rho_k} \ne K_{\max} [1 - (Ri / Ri_0)^2]^3$$

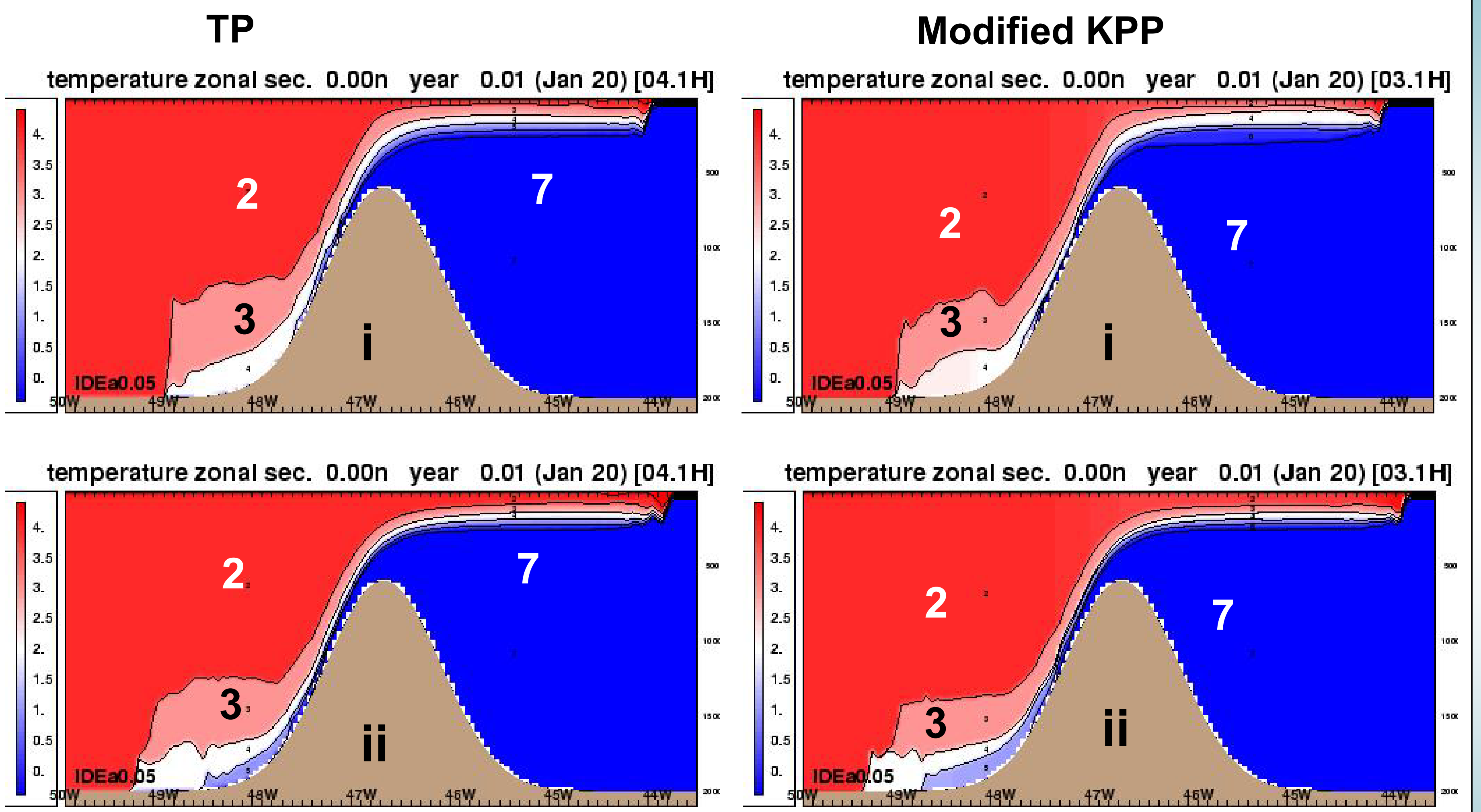
Expt_B: modify KPP by using formula from TP

Modified TP/KPP comparison: Expt_A



Expt_A results: $k_{\max} = 100cm^2/s$ (**i**); $k_{\max} = 2500cm^2/s$ (**ii**)

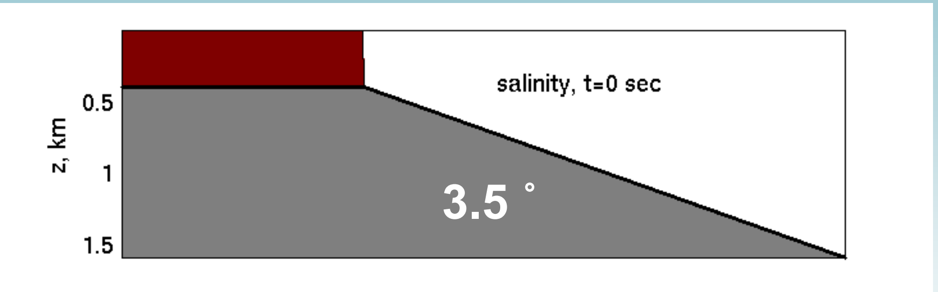
Modified TP/KPP comparison: Expt_B

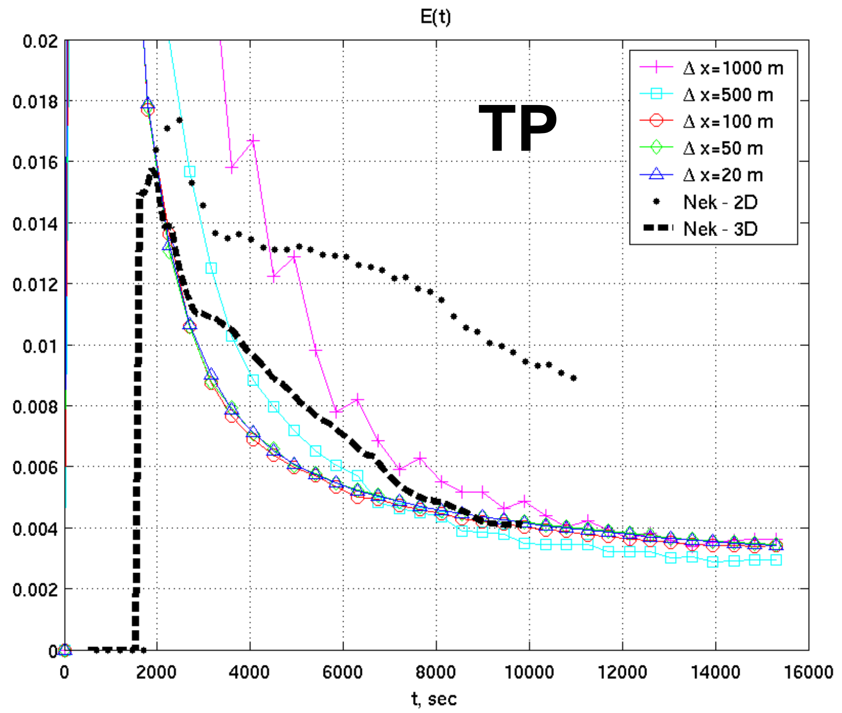


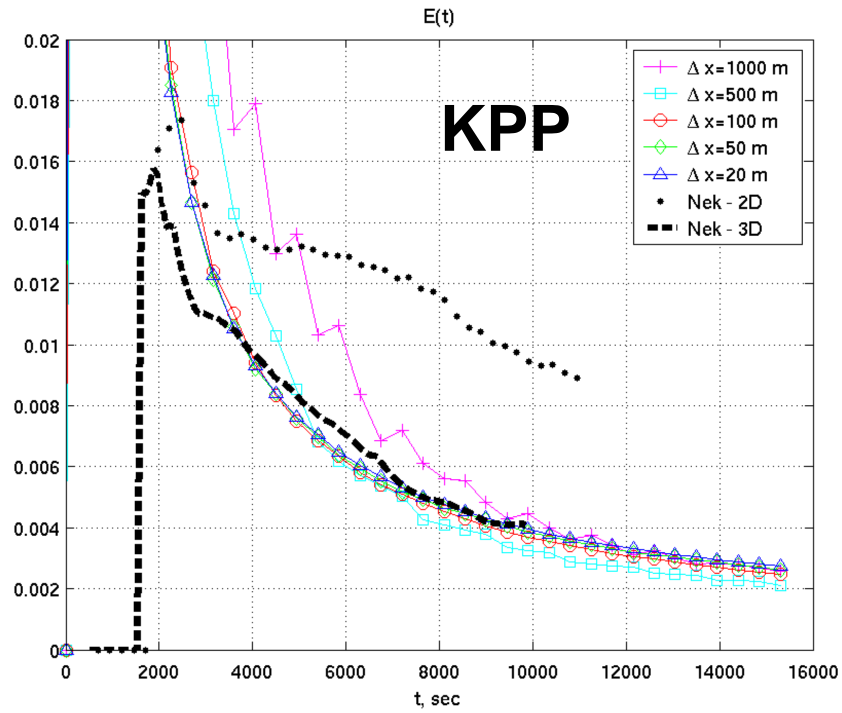
Expt_B results: $0.5 \times W_E$ (**i**); $0.1 \times W_E$ (**ii**)

Quantitative comparison between tuned TP, KPP and a non-hydrostatic model Nek-3D.

$$E(t) \equiv \frac{dh}{dX} = \frac{\bar{h}(t) - \bar{h}_0(t)}{\bar{l}(t)}$$







$$w_E = 0.15 \times \Delta U \ldots$$

$$k_{shear} = 50 \times k_{\max} \ldots$$

Why TP contains stronger mixing than KPP?

- TP is designed to represent the overflow mixing, the parameters are based on laboratory gravity current experiments in which the slope has to be bigger than the real ocean;

- KPP is not designed for overflow mixing, although it does concerned the mixing due to resolved shear instability. The parameters are based in LES in equatorial upper layer using z-model (slope is zero).

Why overflow mixing has anything to do with the slope? (*Price and Baringer, 1994*)

- **Consider a steady channel outflow that is subject to bottom stress and entrainment**

$$g'\alpha = C_d \frac{U^2}{H} + \frac{EU}{H}$$

$$\frac{E}{U} = \alpha R - C_d \qquad R \equiv g'H/U^2 \le 1$$

- **Assuming that *R is near 1*, defining an equivalent friction velocity *u** and an external Richardson number *R****

$$u^* = \sqrt{g'H(\alpha - C_d)} \qquad R^* = g'H/{u^*}^2$$

$$\frac{E}{u^*} = {R^*}^{-1/2} = \sqrt{\alpha - C_d}$$

- **I apply a slope-dependent factor before the K_{max} in KPP to enhance the mixing.**

$$k'_{\max} = f \times k_{\max} = [C \times \sqrt{\max(0, \alpha - \alpha_0)} + 1] \times k_{\max} \ldots$$

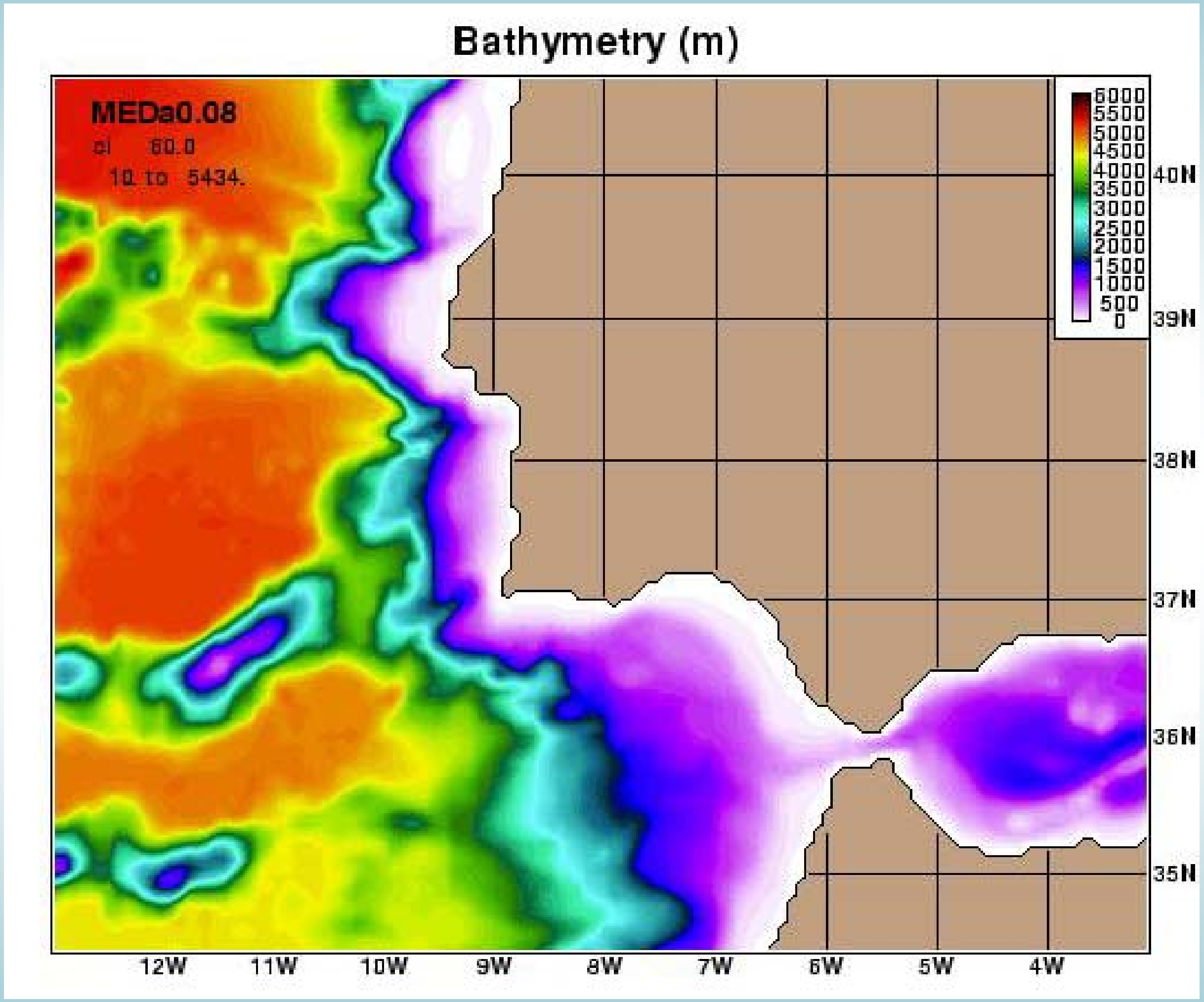
- *Comparison of K-profile and Turner parameterization using idealized configurations*

- **Mediterranean outflow experiment**

- *My Future plan*

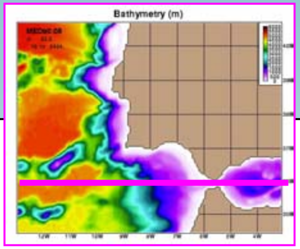
Configuration

- Topography (ATLd0.08)
- Initial condition (GDEM3)
- 28 Layer Sigma 2
- Forcing (ECMWF-Reana)
- Relaxation
- KPP vs. KPP modified

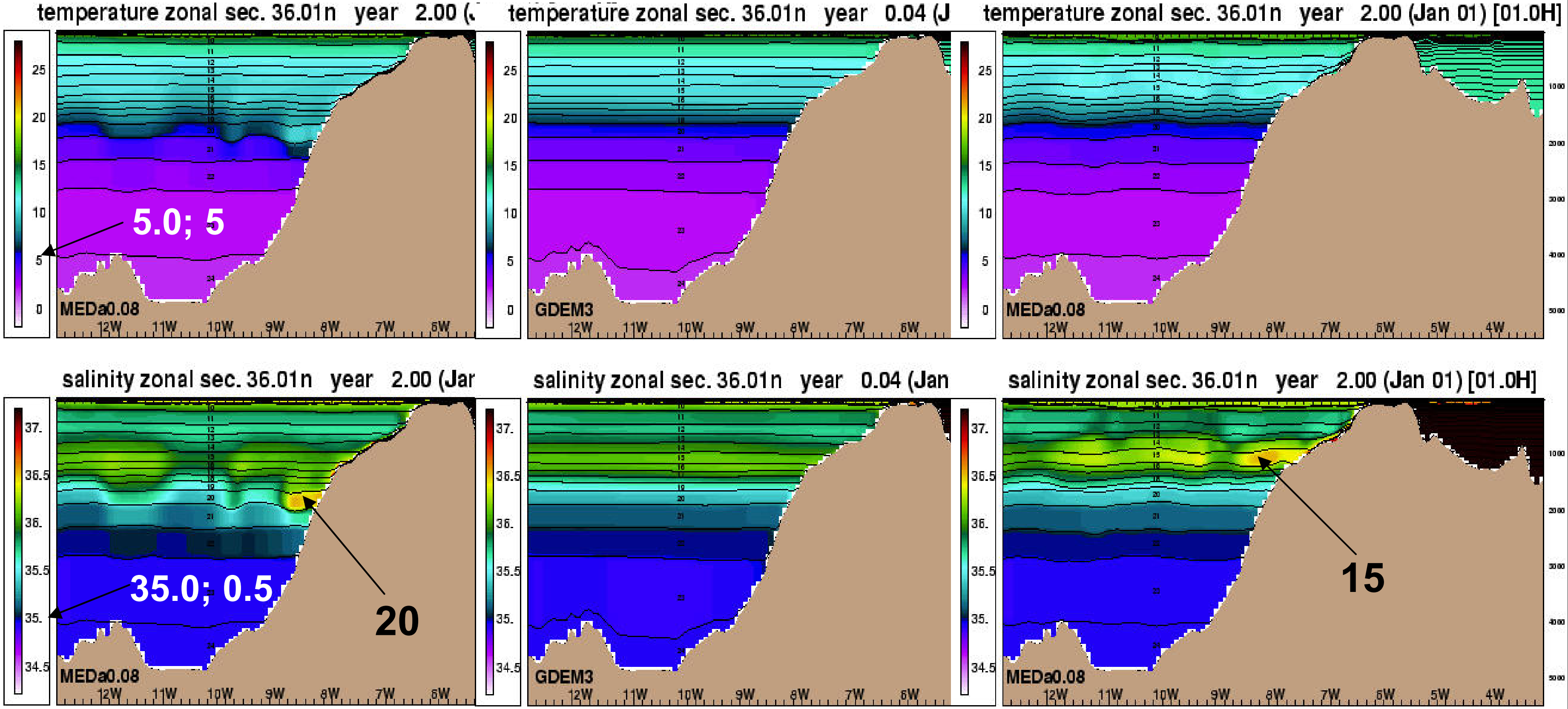


Domain and topography

• *Comparison between simulation and climatology values …*

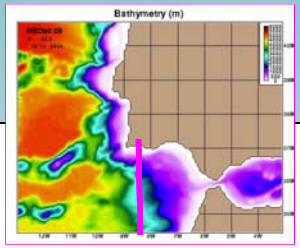


Original KPP **Climatology (GDEM3)** **Modified KPP**

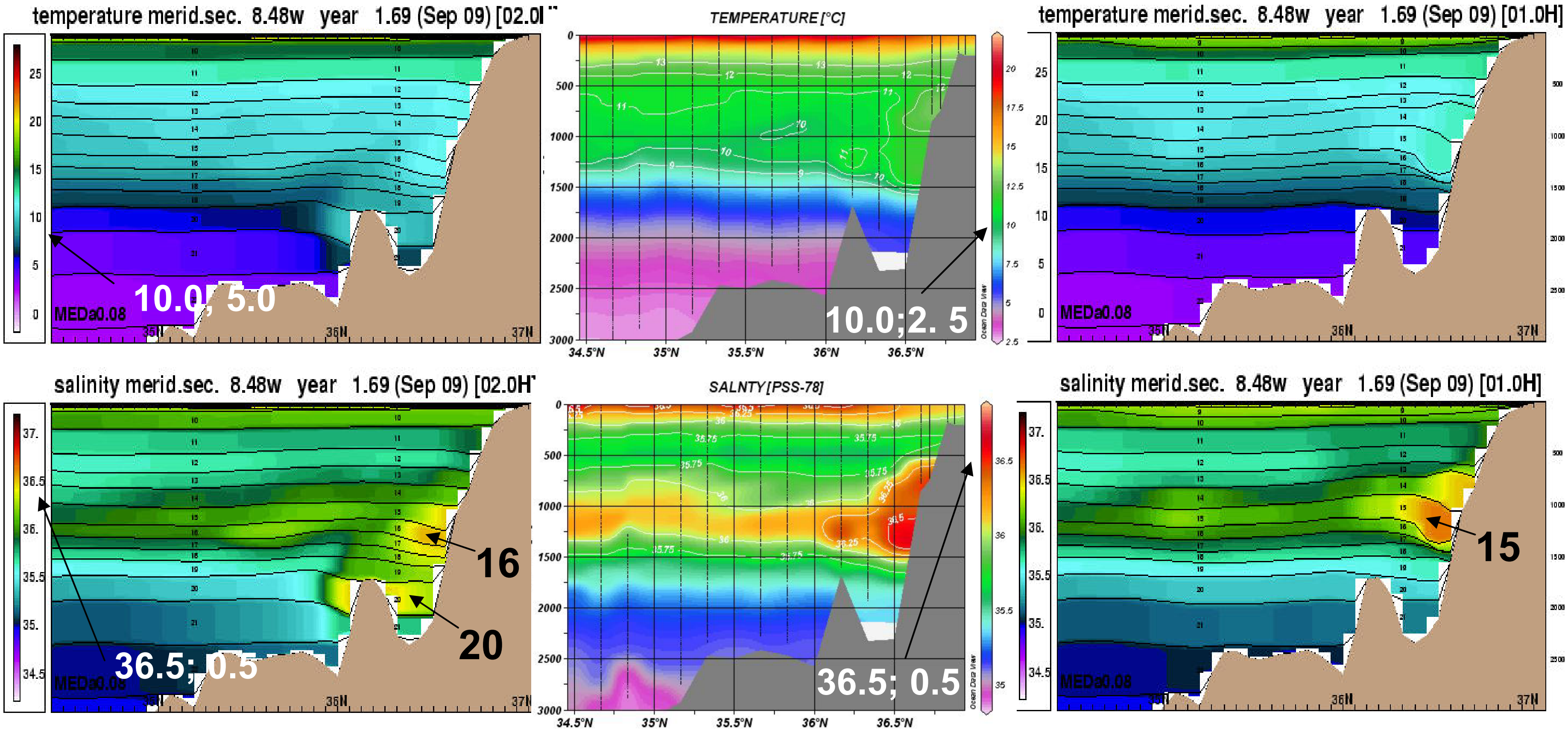


T/ S on zonal section (36 N): Original KPP results (left), Climatology (center) and Modified KPP results (right);

• *Comparison between simulation and real data …*

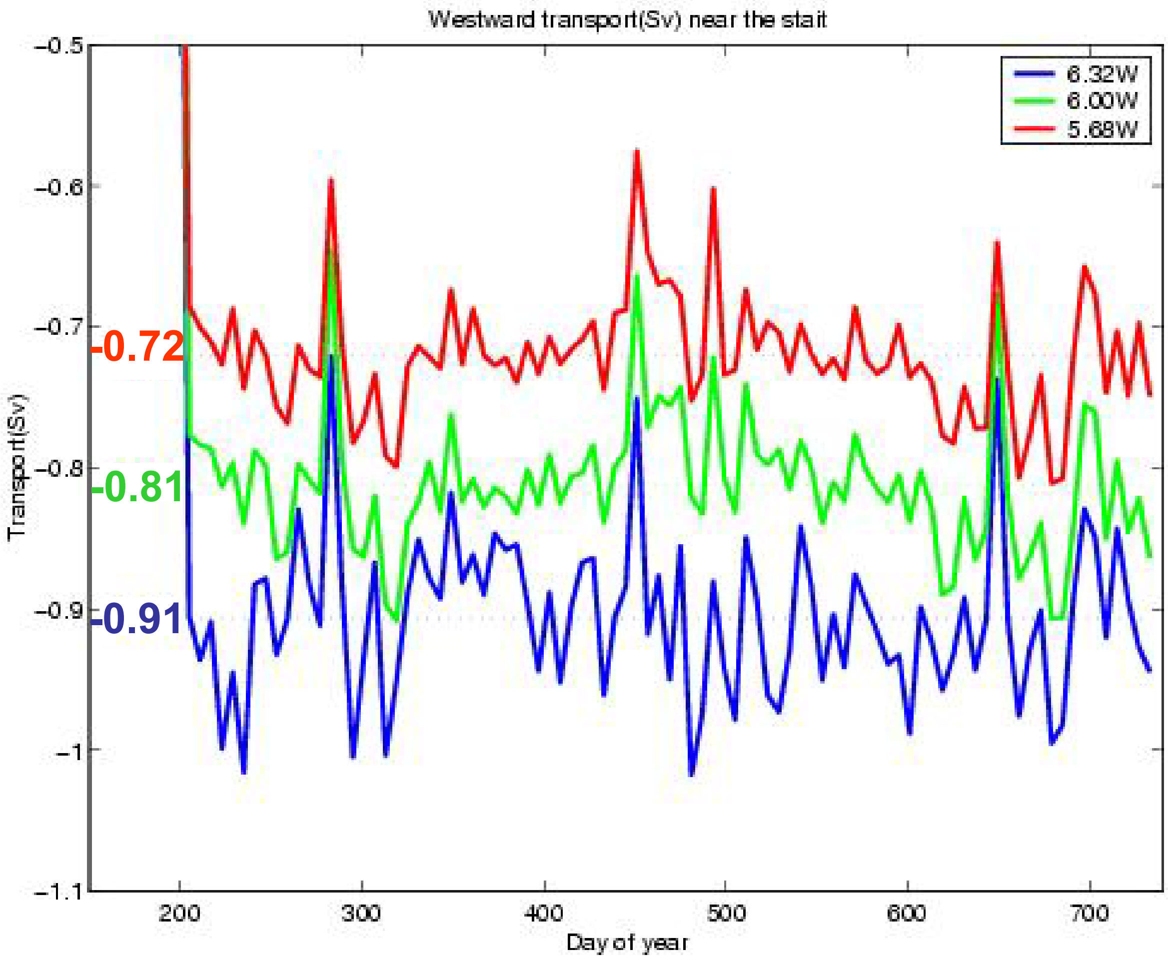


Original KPP | **WOCE AR16_07AL1991** | **Modified KPP**



T/ S on meridional section (8.5 W): Original KPP results (left), WOCE data (center) and Modified KPP results (right);

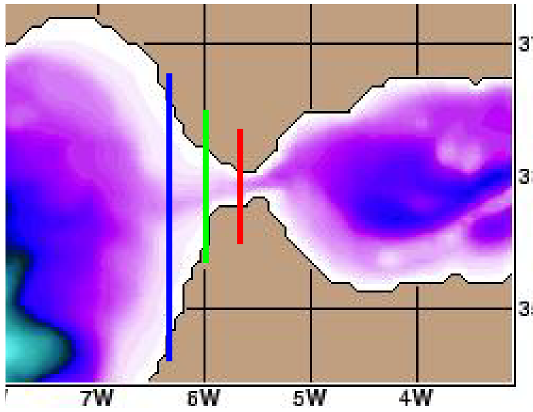
Outflow transport near the Gibraltar St.



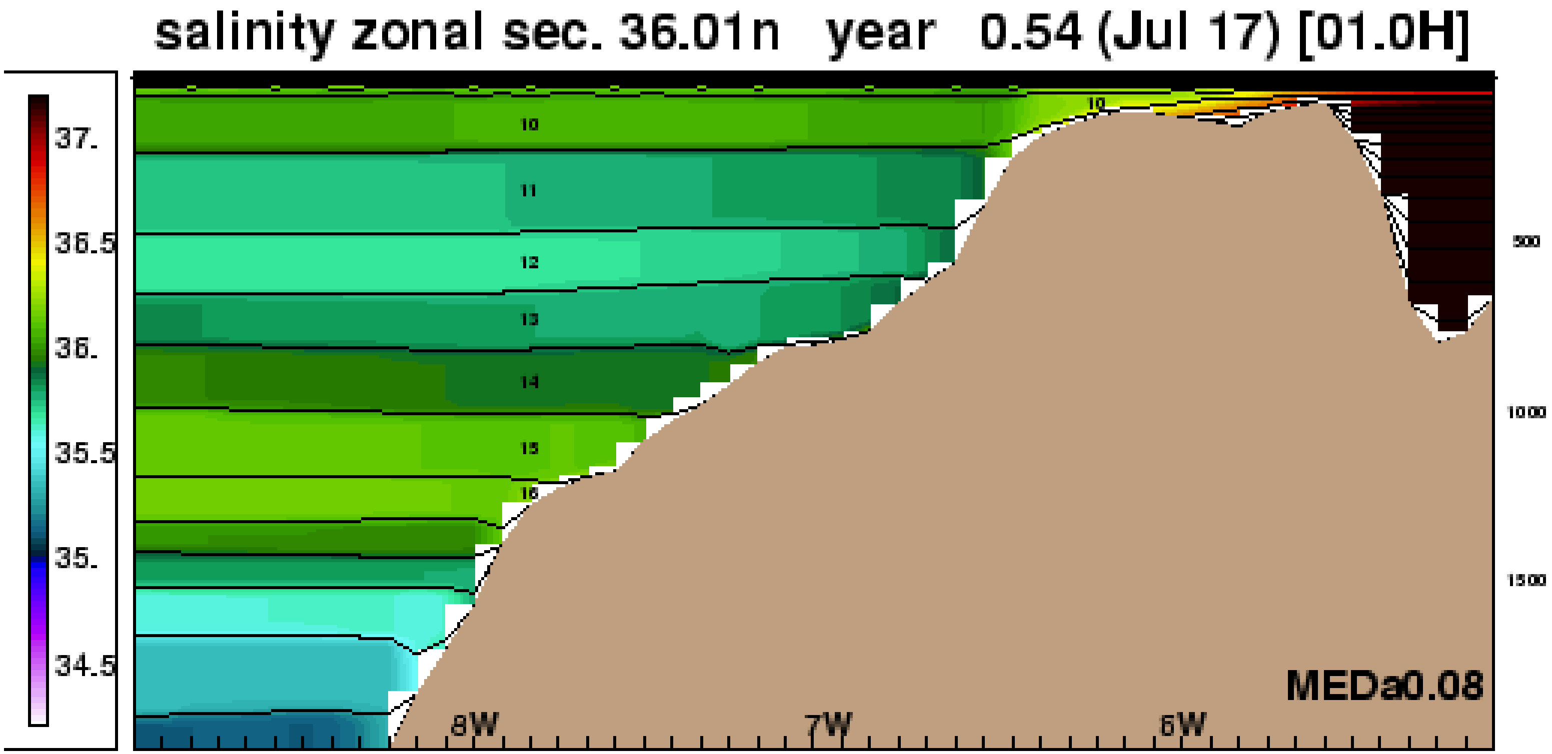
-0.68, *Bryden et al., 1994;*

-0.70, *Baringer and Price, 1997;*

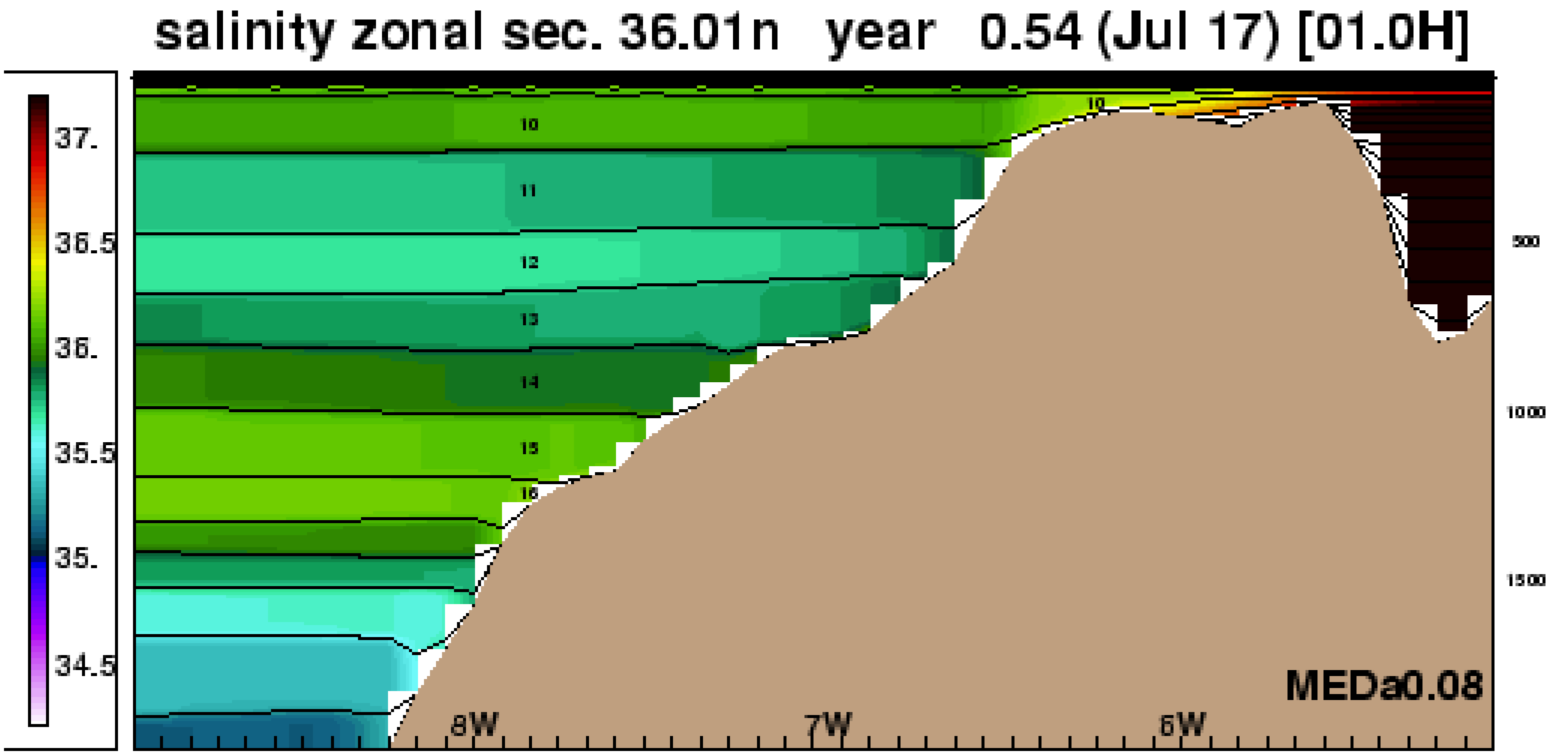
-0.97, *Candela, 2001*; seasonal variation with min at early summer and max at late winter



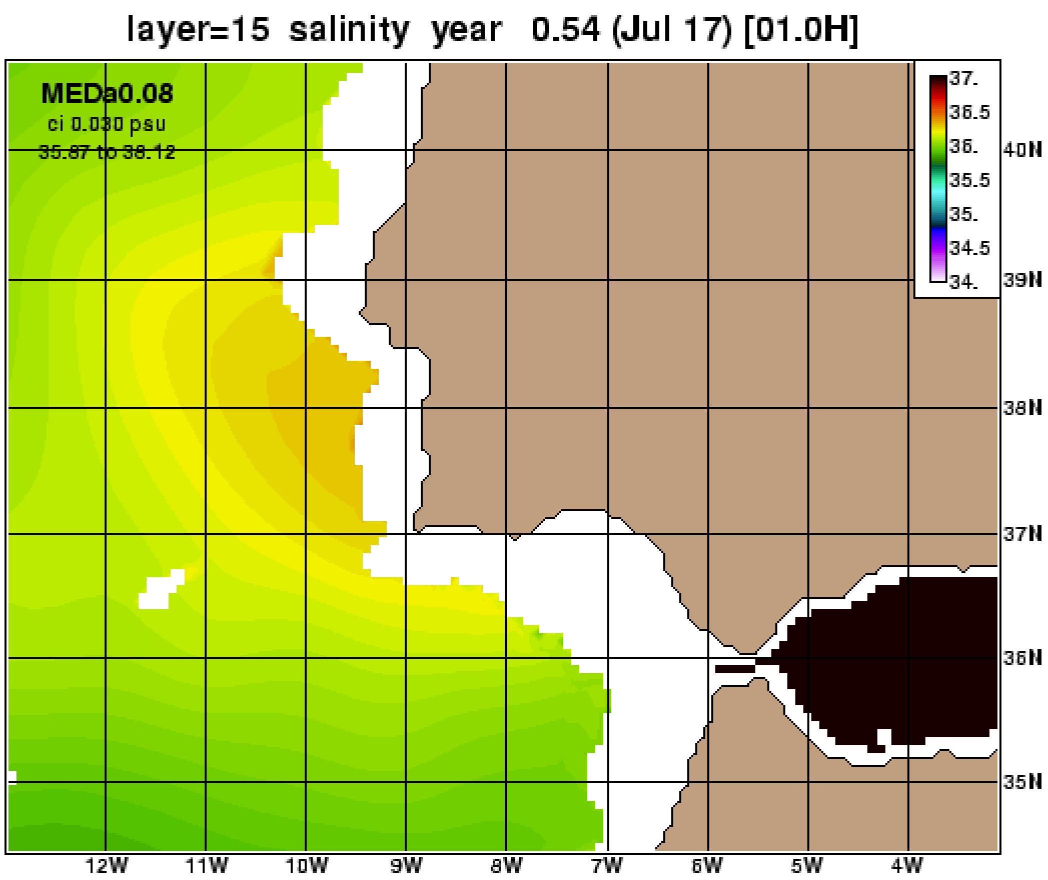
Westward transport near the Strait of Gibraltar as function of time (the number ahead of line are 1.5-year average)



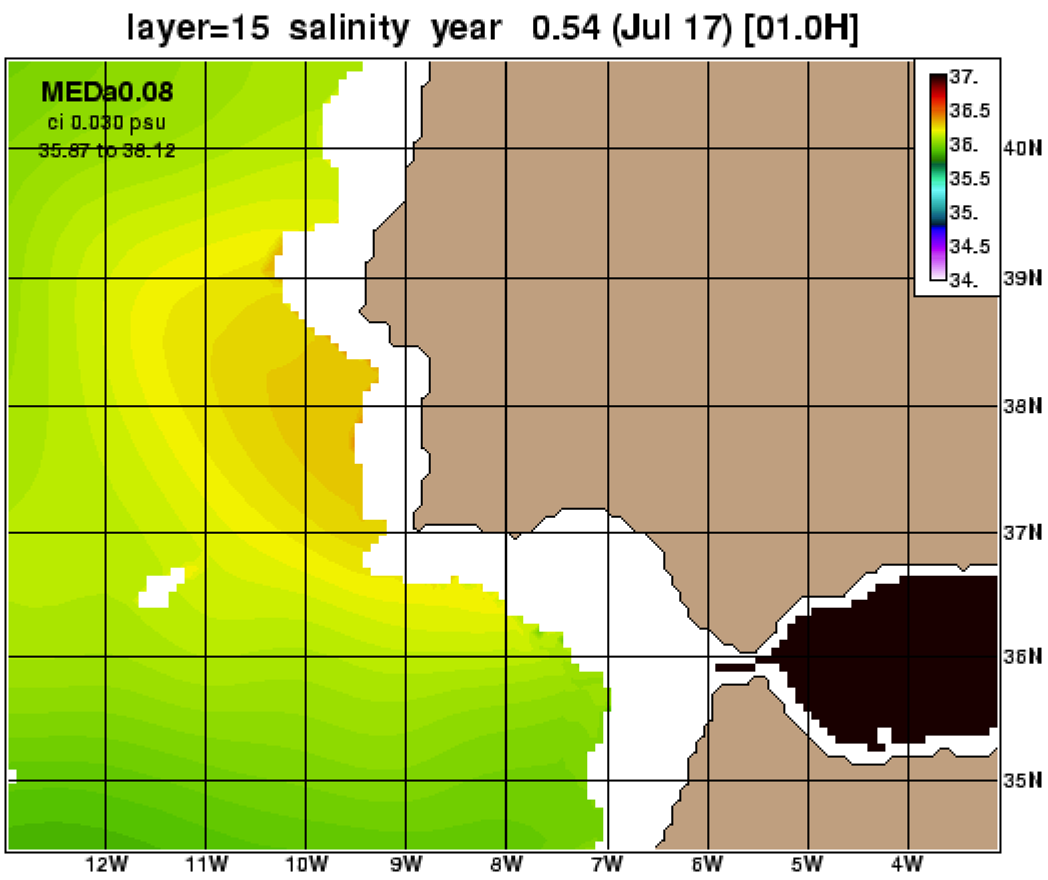
Vertical view of outflow descending down the slope of west of Gibraltar Strait at around 36 N …



Vertical view of outflow descending down the slope of west of Gibraltar Strait at around 36 N …



Plane view of outflow spreading into the Gulf of Cadiz and North Atlantic …



Plane view of outflow spreading into the Gulf of Cadiz and North Atlantic …

- *Comparison of K-profile and Turner parameterization using idealized configurations*
- *Mediterranean outflow experiment*
- **My future plan**

The challenge of representing overflow in 3-D primitive equation models

- High resolution is demanded to resolve the small topography feature like sills or straits;
- The descending property of overflow (especially for z-model);
- The difficulty to parameterize the diapycnal mixing.

Advantages of using isopycnic model

- ✓ Naturally migrate vertical resolution to high density gradient regions (atop the overflow layer)
- ✓ No ‘numerically induced mixing’
- ✓ Direct prescription of entrainment
- ✓ More flexibility (HYCOM)

Overflows in North Atlantic Ocean:

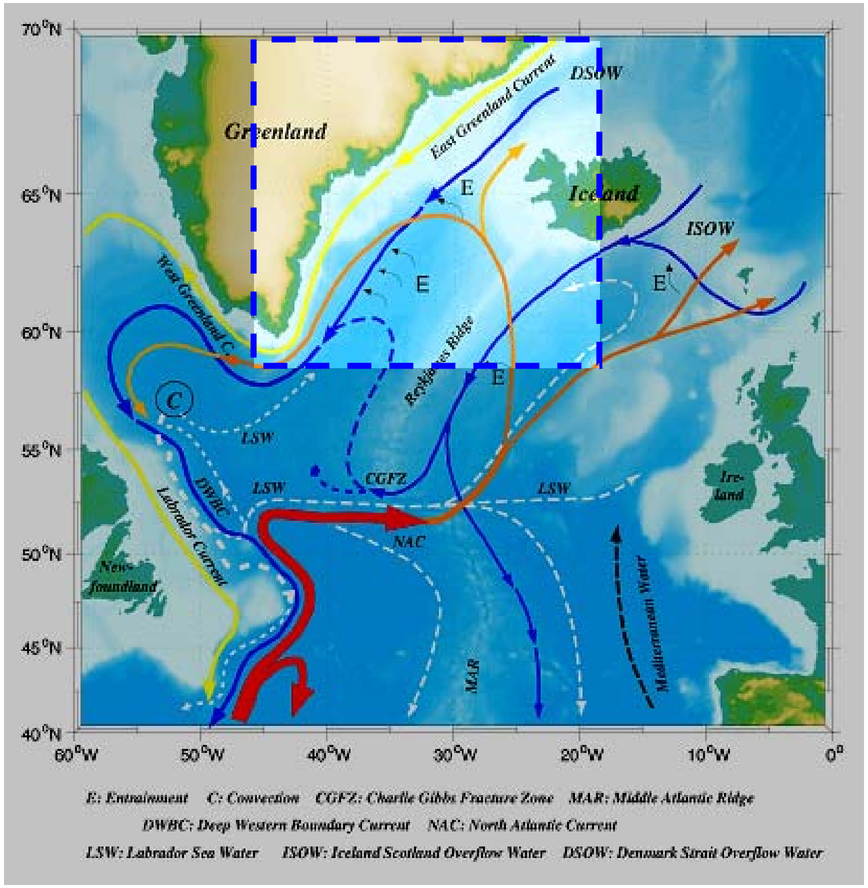
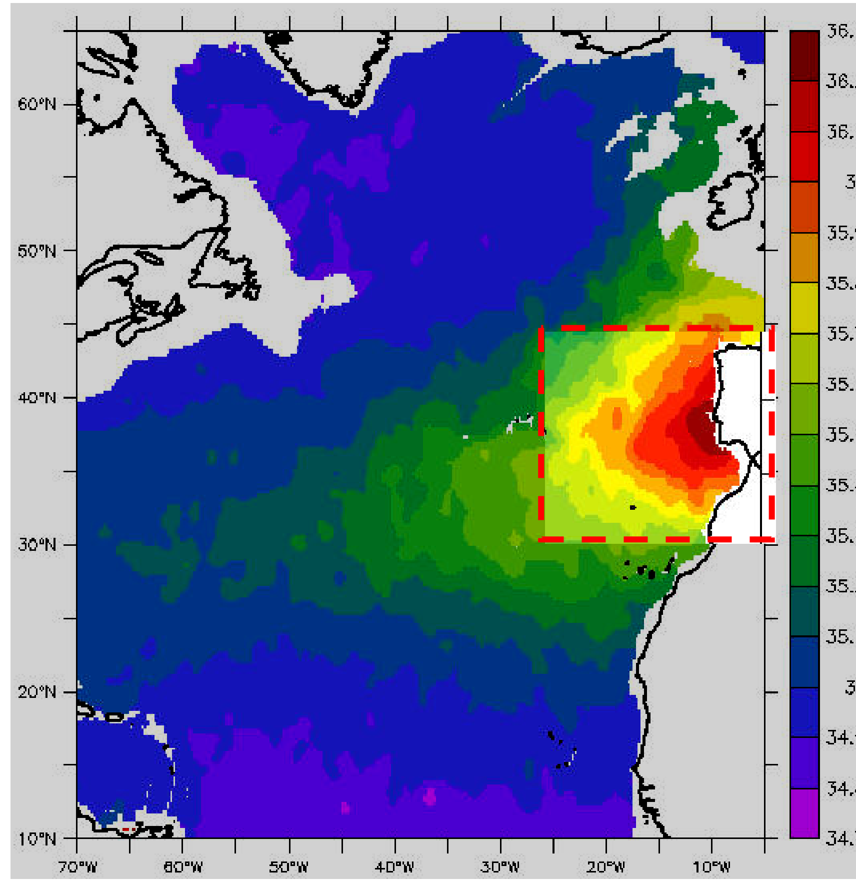


Diagram of the meridional overturning circulation in the subpolar North Atlantic (from *IFM, Kiel*)



Annual mean salinity field at 1100m (from *Levitus 1994*)

Next works

- **Overflow representation using different diapycnal mixing schemes, resolutions, and imposed conditions.** *Focus on the Denmark St. and MED overflows;*

- **Mediterranean outflow spreading in open North Atlantic.** *How/ how much MED outflow water is transport northward and westward using a regional high-resolution model, which resolves the outflow explicitly***.**

- **Overflow response to water property change in source and environment water.**

Summary

- **1-D diffusion experiments suggest that the HYBRD mode and MICOM mode works similarly; difference exist mainly due to in HYBRD mode, the density is allowed to be different from its reference.**
- **2-D 'dam-break' experiments illustrate very different mixing scenario between TP and KPP: these two schemes imply different strength of mixing.**
- **Med outflow experiment shows the eddy coefficients in original KPP are too small to represent Mediterranean outflow mixing. Applying a simple slope-dependent factor could considerably improve the simulation.**
- **A project aimed at more systematic investigation on overflow representation is proposed, one focus of this study is the diapycnal mixing.**

Thank you