Internal tide propagation sensitivity to model vertical coordinate and resolution

Arnaud Le Boyer, Cyril Lathuilière, Annick Pichon, Flavien Gouillon

Outline

- Context and motivation: COMODO Project
- Experiments Set up and Diagnostics
- High resolution = Convergence ?
- Accuracy of the vertical grid
- Conclusion

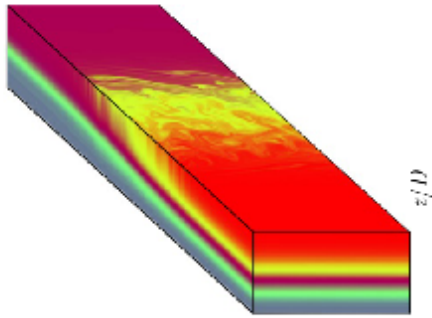
Context and motivation

COMODO Project

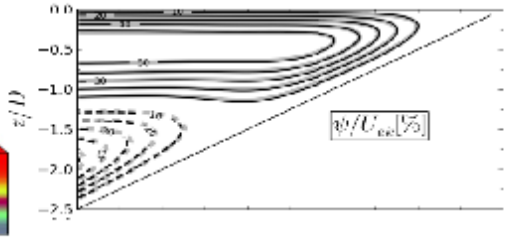
- ✓ 8 research labs
- ✓ 6 numerical ocean circulation models
- ✓ 10 test cases
- ✓ Guide the modelling community toward the next model generation

Series of test cases

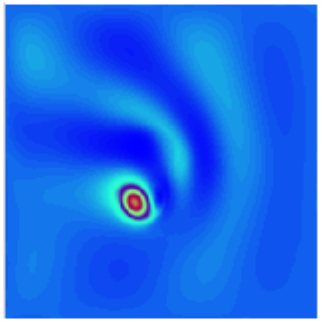
Idealized baroclinic jet



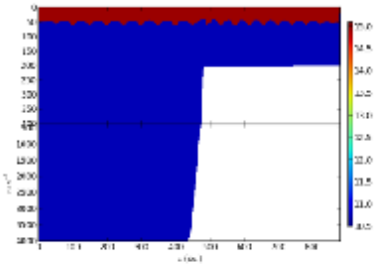
Idealized coastal upwelling



Idealized baroclinic vortex



Idealized shelf break



Context and motivation: Modeling Internal Tides

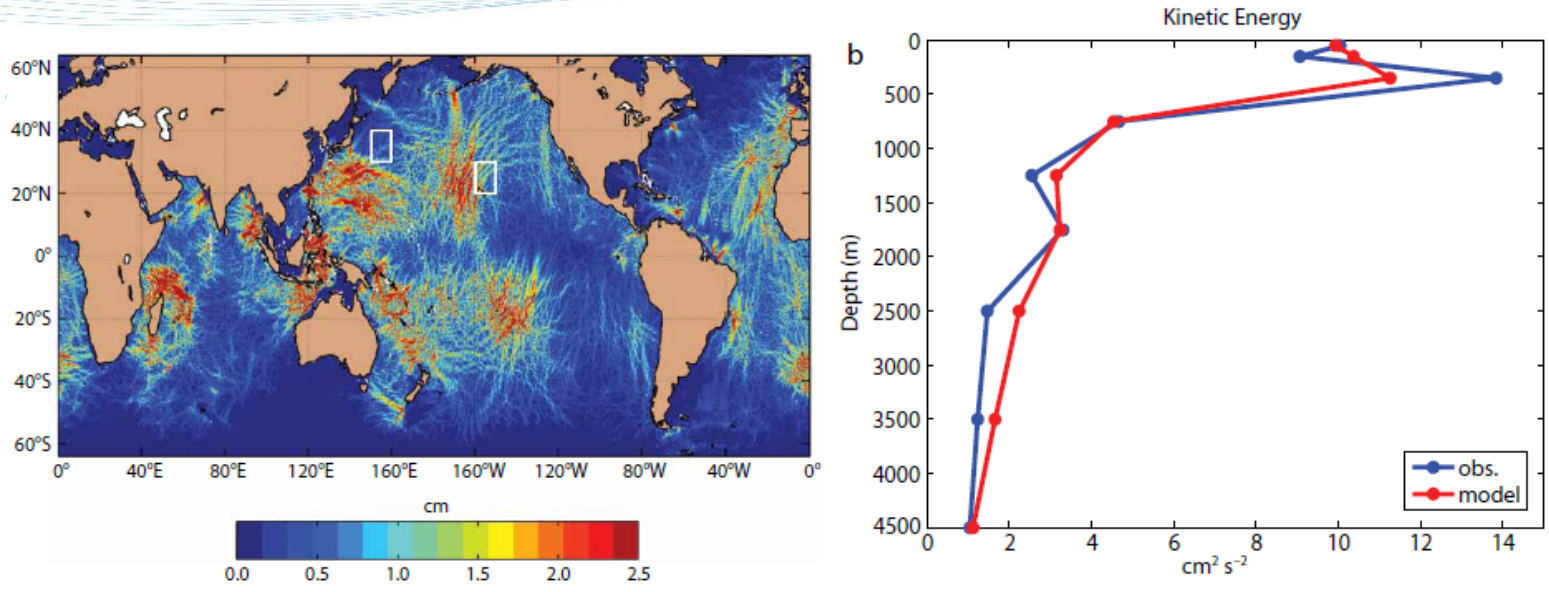


Figure : *Arbic et al. Oceanography. 2012*: (Left) Amplitude (cm) of the M2 internal tide signature in steric sea surface height. (Right) Vertical Distribution of M2 tidal Kinetic Energy for current meters observation (obs) and HYCOM simulation (model)

The COMODO project is the occasion to accurately compare models output on important physical processes. The models differences highlight potential error sources for a realistic representation of these processes.

Experiments Set up

- Width: 880 km
- Δx=1km
- Depth: 4000 m to 200 m
- at least 30 days
- 30 min output
- Forcing :
  Barotropic S2 tide (12h)
- biharmonic viscosity
- No explicit vertical mixing

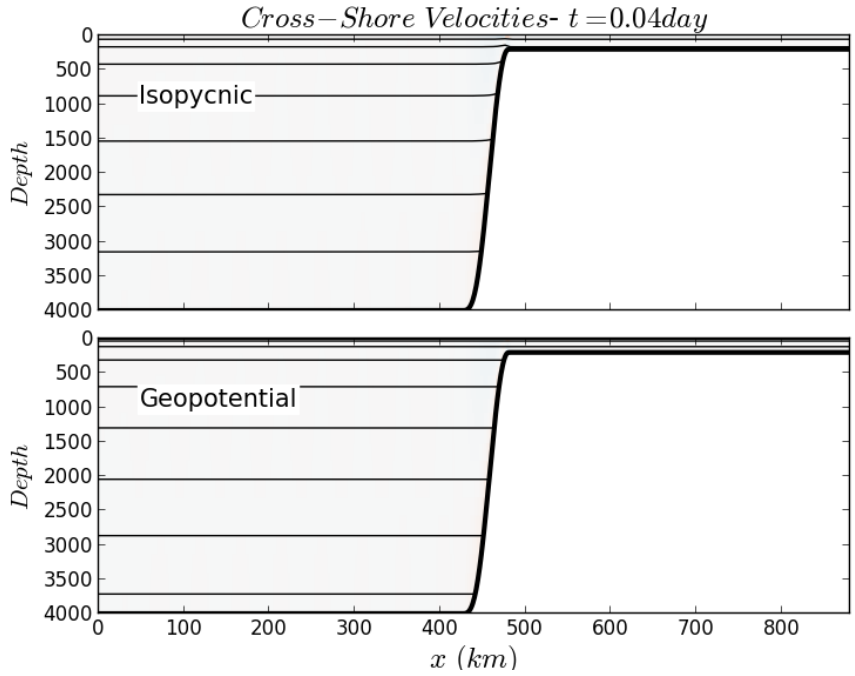


Figure : HYCOM allows to run experiments with the same initial conditions in fully isopycnic or Z vertical coordinate

Vertical Grid

Algorithm from the Primitive Equation (PE) model NEMO, *Madec.2012*):

$$z_i = h_{sur} + h_0 i - h_1 \quad ln\left[cosh(\frac{i - h_{th}}{h_{cr}})\right] \quad (1)$$

Surface resolution:
mean thickness of the surface layers above 100 m

Bottom resolution :
mean thickness of the bottom layers from 3000m to 4000m.

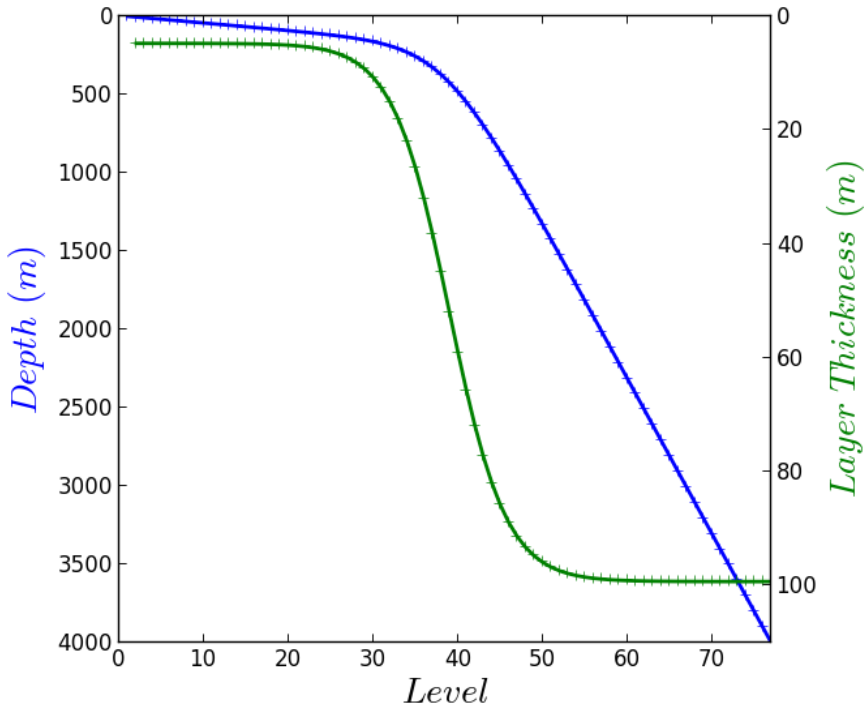
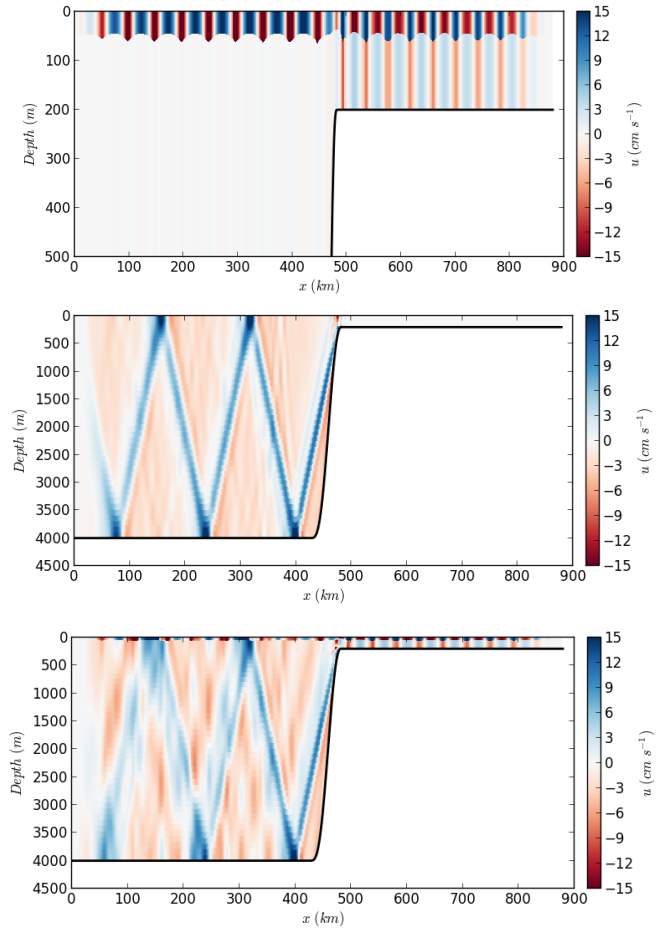


Figure : Example of vertical grid. The averaged surface and bottom layer thickness are 5m and 100m, respectively

Stratification

- Step Stratification: 2 layers with surface layer of 50 meters thickness
- Uniform Stratification: Buoyancy Frequency N=0.002
- 50 meters thick Surface layer and Buoyancy Frequency N=0.002 below

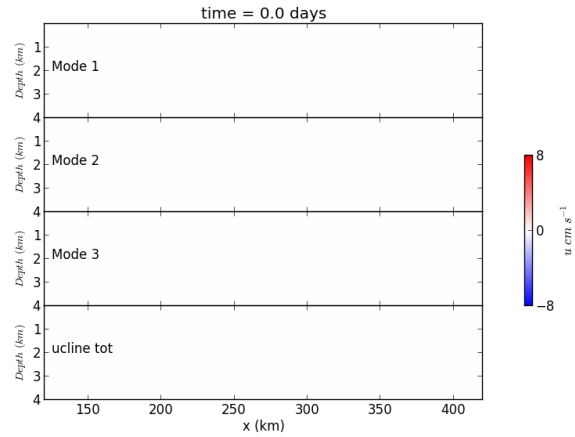


Diagnostics: Baroclinic Mode

For a flat bottom area, the velocity field u can be projected on vertical mode $\psi(z)$ defined by the stratification

$$\frac{d}{dz}\left(\frac{1}{N^2(z)}\frac{d}{dz}\psi(z)\right)+\frac{1}{C_\phi^2}\psi(z)=0 \quad (2)$$

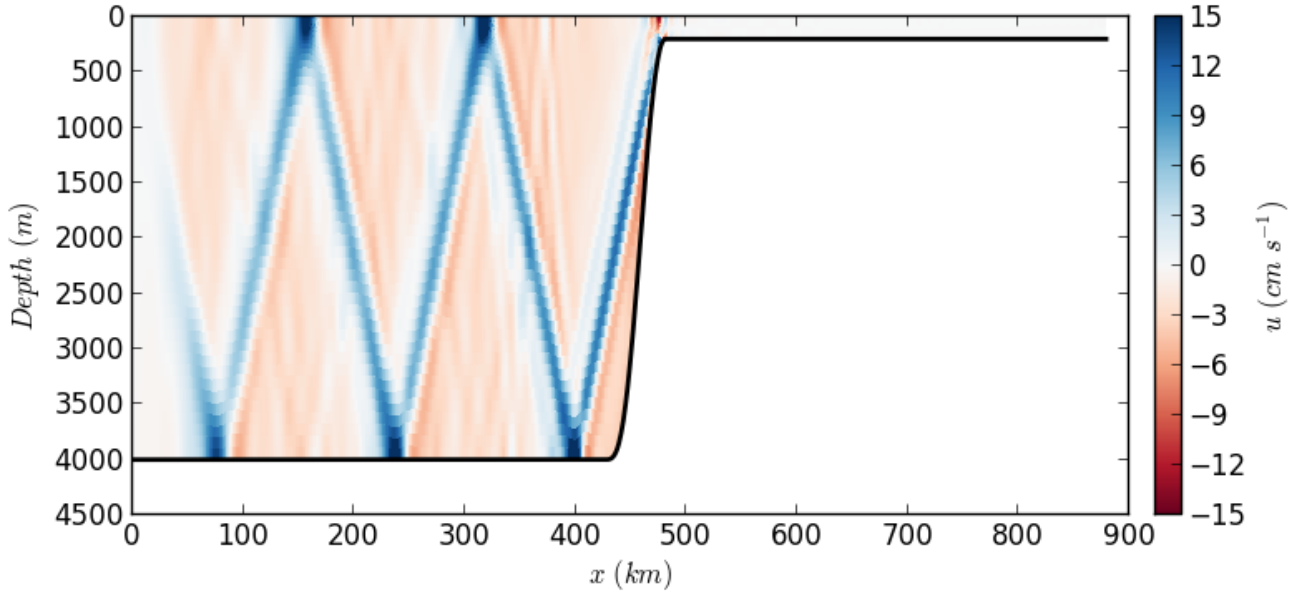
- C_ϕ: eigen values - Phase Speed
- $\psi(z)$: Eigen vectors - Vertical Profil



$\sum$ Modal velocities = model velocity\

For a n level vertical grid = n-1 baroclinic modes

High resolution = Convergence ? - Uniformly Stratified Ocean



High resolution = Convergence ? - Uniformly Stratified Ocean

- Coarse resolution, the z coordinate IT beam is narrower and steeper

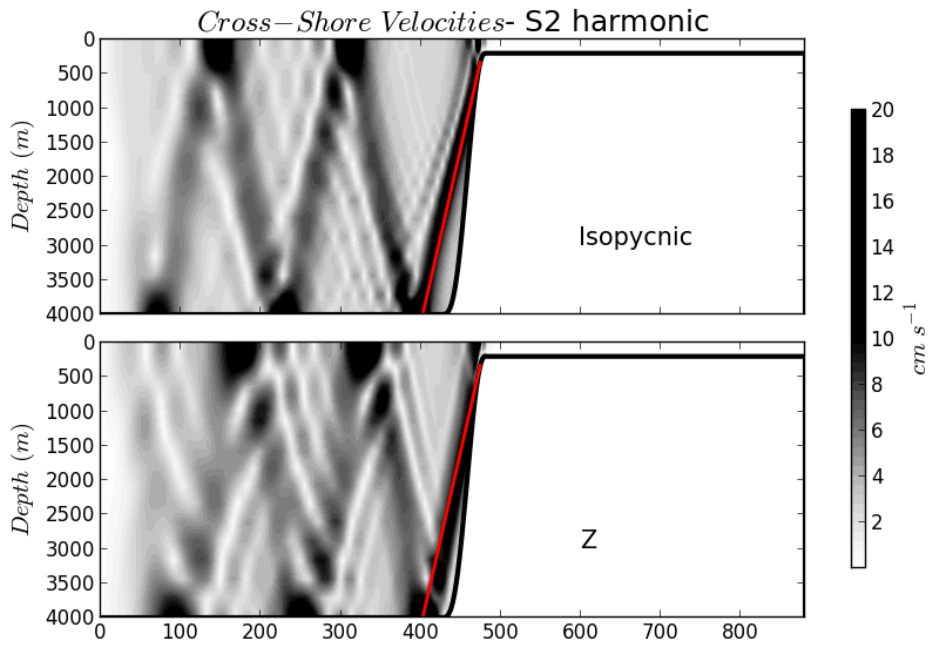


Figure : Amplitude of the S2 harmonic of the baroclinic cross shore velocities. Bottom resolution: 300 meters.Redline: Theoretical IT beam

High resolution = Convergence ? - Uniformly Stratified Ocean

- Coarse resolution, the z coordinate IT beam is narrower and steeper
- differences decrease with the resolution.

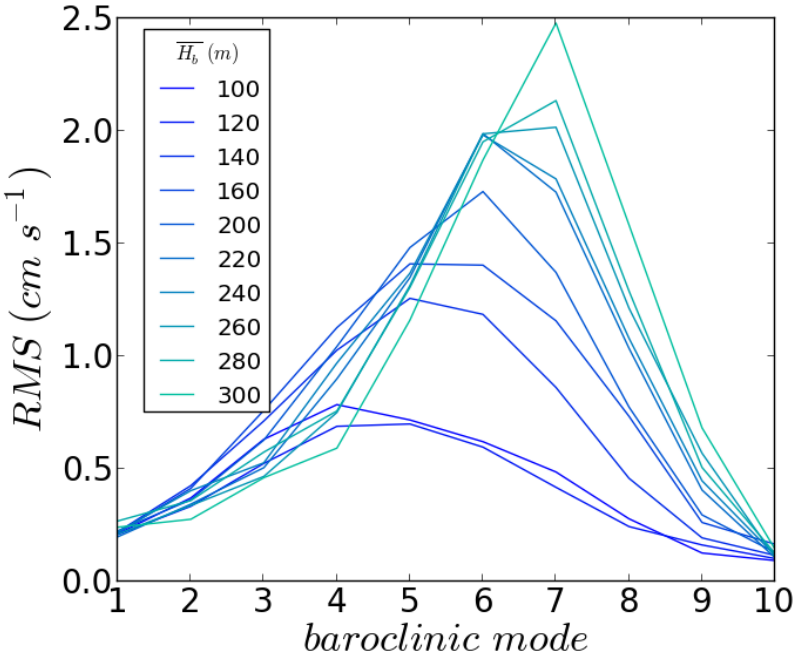


Figure : Modal velocities RMS differences between the isopycnic and the Z solutions

High resolution = Convergence ? - Uniformly Stratified Ocean

- Coarse resolution, the z coordinate IT beam is narrower and steeper
- differences decrease with the resolution.
- phase delay with Z coordinate and coarse resolution

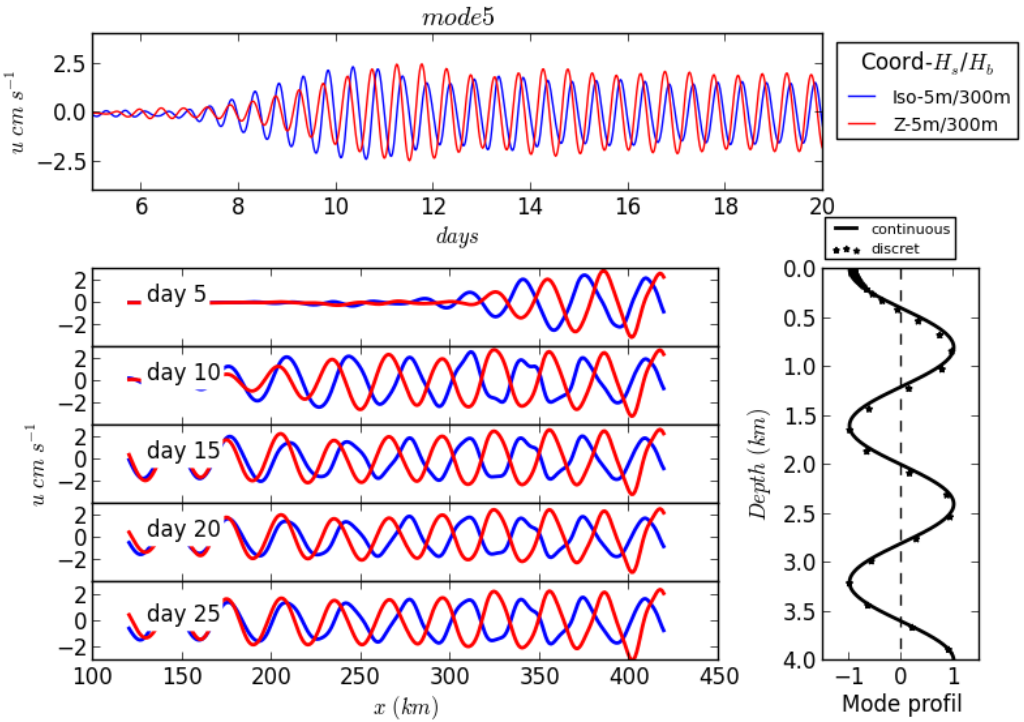


Figure : Temporal and spatial evolution of the mode 5 velocities. Bottom layer thickness: 300 meters. Z and isopycnic coordinate

High resolution = Convergence ? - Uniformly Stratified Ocean

- Coarse resolution, the z coordinate IT beam is narrower and steeper
- differences decrease with the resolution.
- phase delay with Z coordinate and coarse resolution
- Finer resolutions improve the generation of the IT

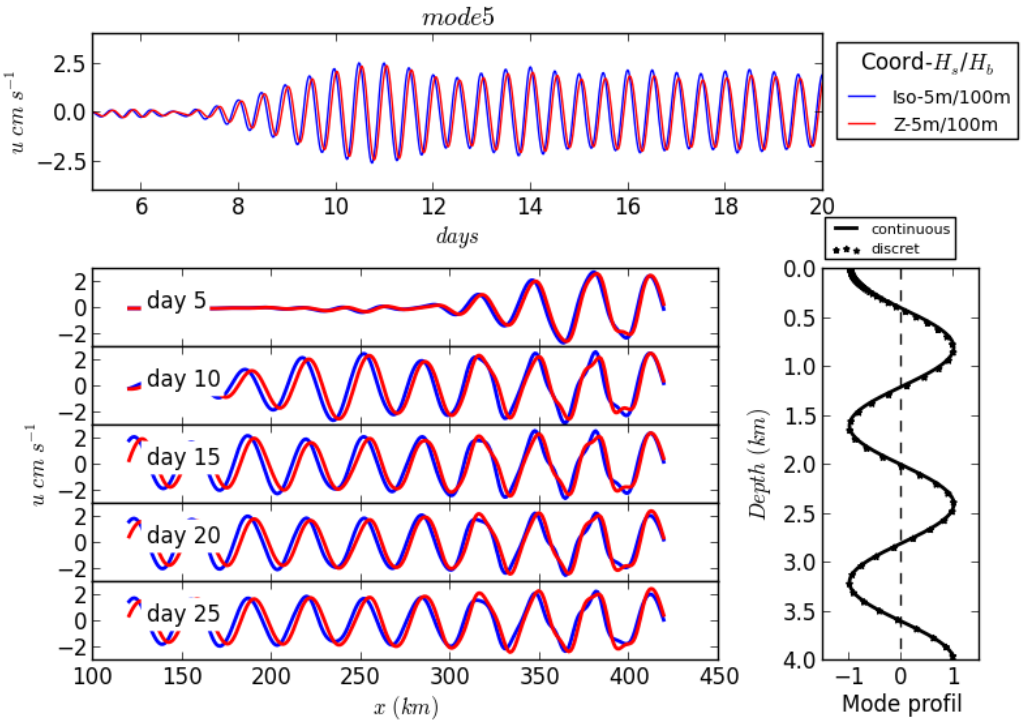
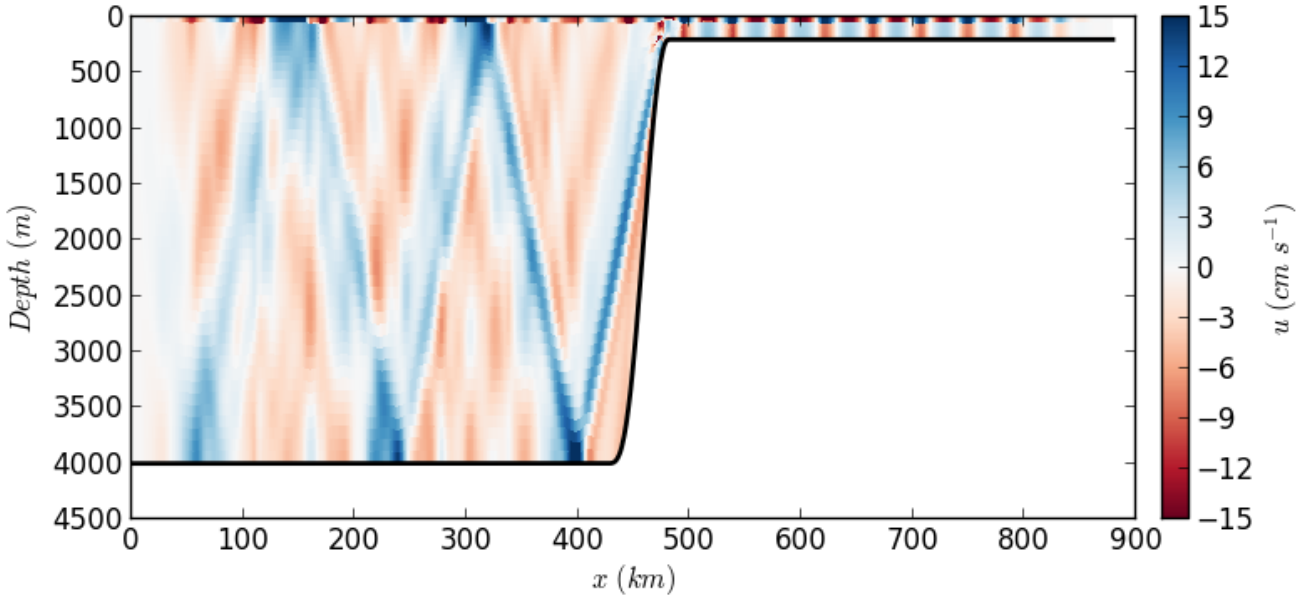


Figure : Temporal and spatial evolution of the mode 5 velocities. Bottom layer thickness: 100 meters. Z and isopycnic coordinate

High resolution = Convergence ? - Uniformly Stratified Ocean and Mixed layer



High resolution = Convergence ? Uniformly Stratified Ocean and Mixed layer

- With surface mixed layer, Z coordinate solution are more energetic

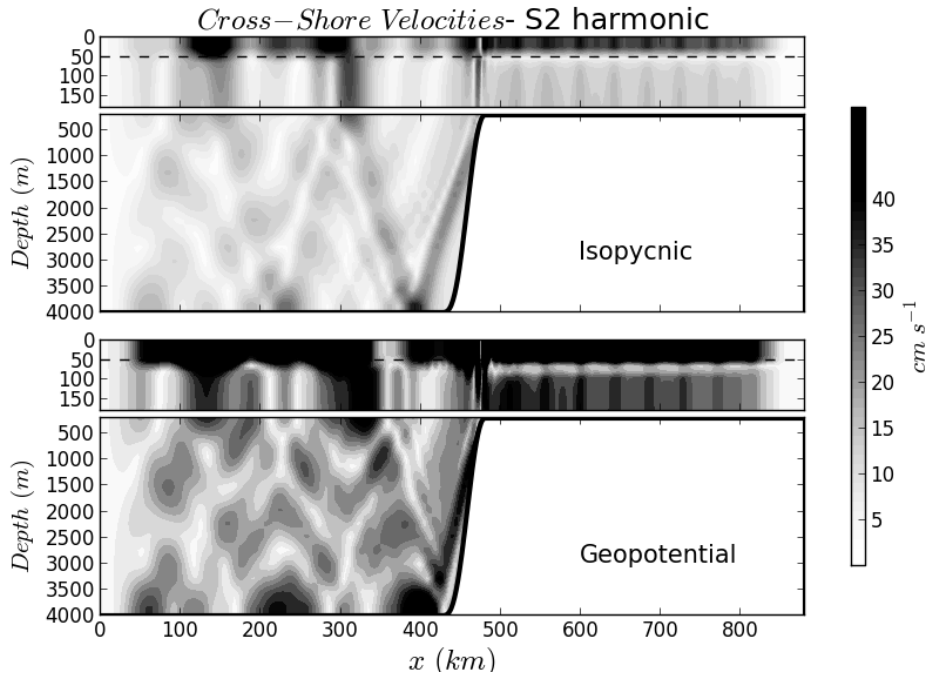


Figure : Amplitude of the S2 harmonic of the baroclinic cross shore velocities

High resolution = Convergence ? Uniformly Stratified Ocean and Mixed layer

- With surface mixed layer, Z coordinate solution are more energetic
- The energy is projected on the interfacial mode (higher than the 2 first modes)

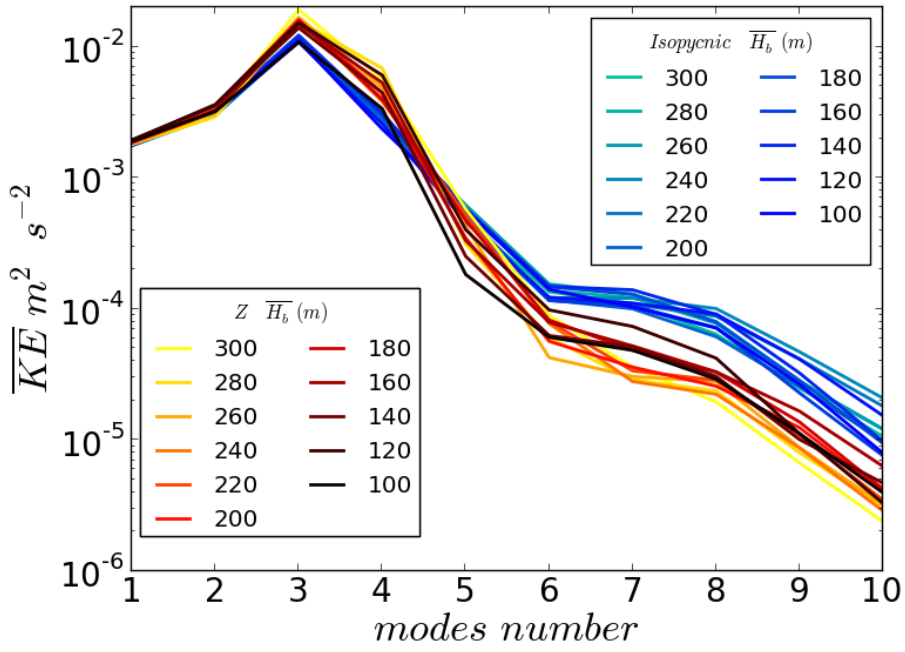


Figure : Kinetic energy per mode for Isopycnic and Z coordinates.

High resolution = Convergence ? Uniformly Stratified Ocean and Mixed layer

- With surface mixed layer, Z coordinate solution are more energetic
- The energy is projected on the interfacial mode (higher than the 2 first modes)
- Solutions converge toward the higher resolution.
- The interface discretization produce variability too

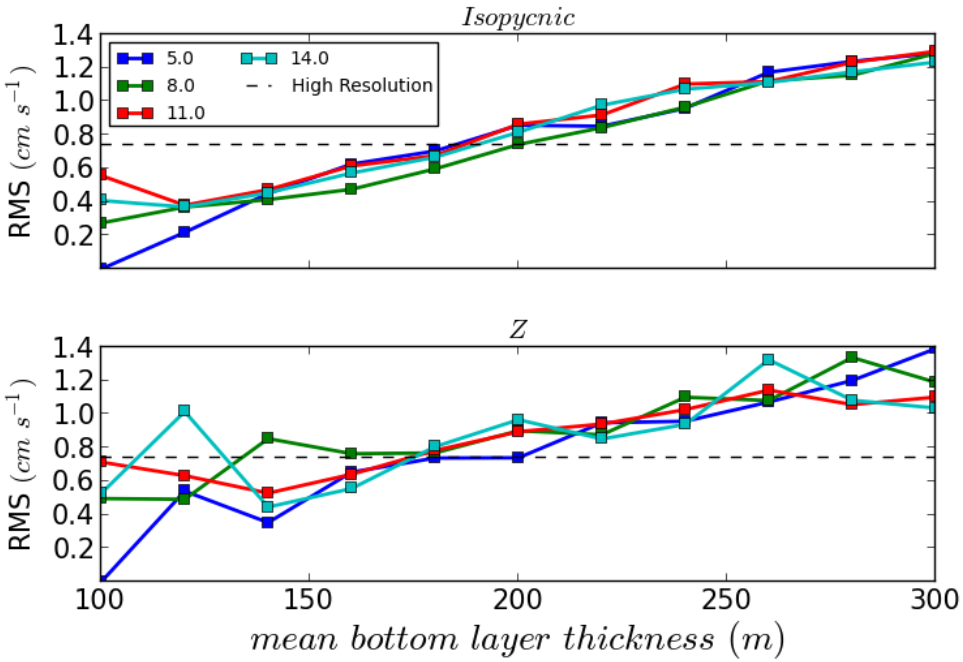
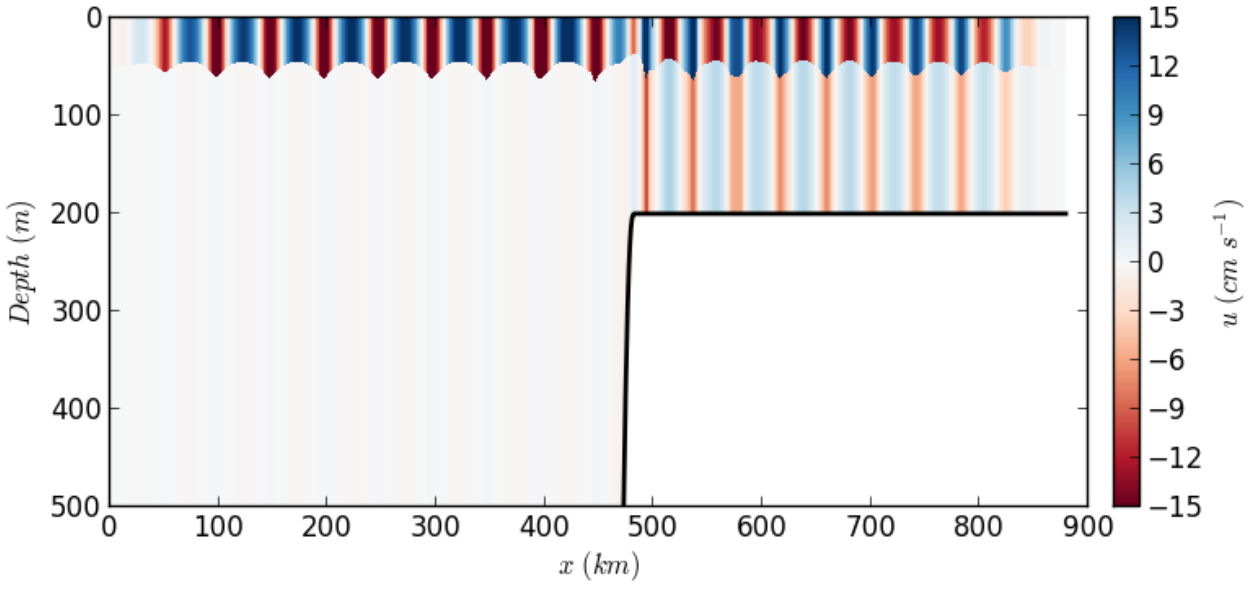


Figure : RMS differences with the highest resolution. Colored lines: surface resolutions (5,8,11,14 m)

Accuracy of the vertical grid: 50 m surface layer



Accuracy of the vertical grid: 50 m surface layer

- Need of accurate vertical grid or an adapted stratification

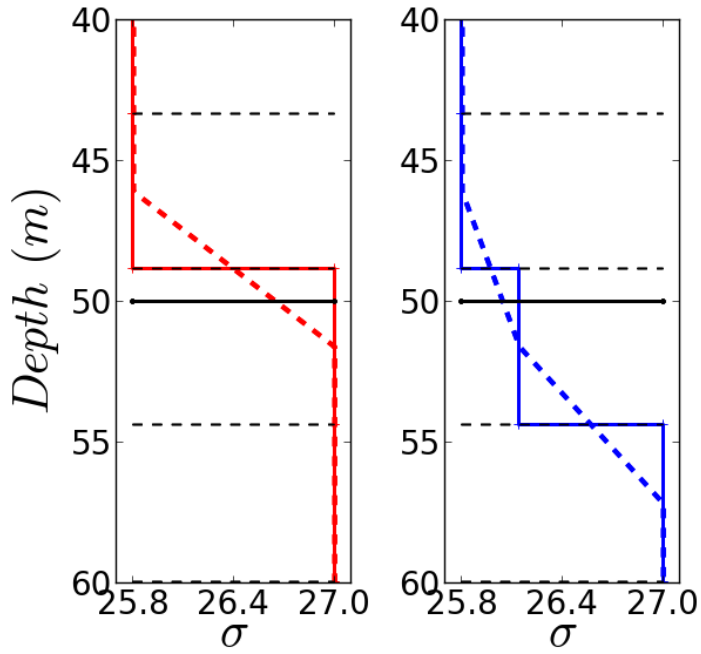


Figure : Density Profiles for a non accurate vertical grid. Step and interpolated stratification

Accuracy of the vertical grid: 50 m surface layer

- Need of accurate vertical grid or an adapted stratification
- adapted stratification produce same IT as isopycnic coordinate
- Differences on the shelf

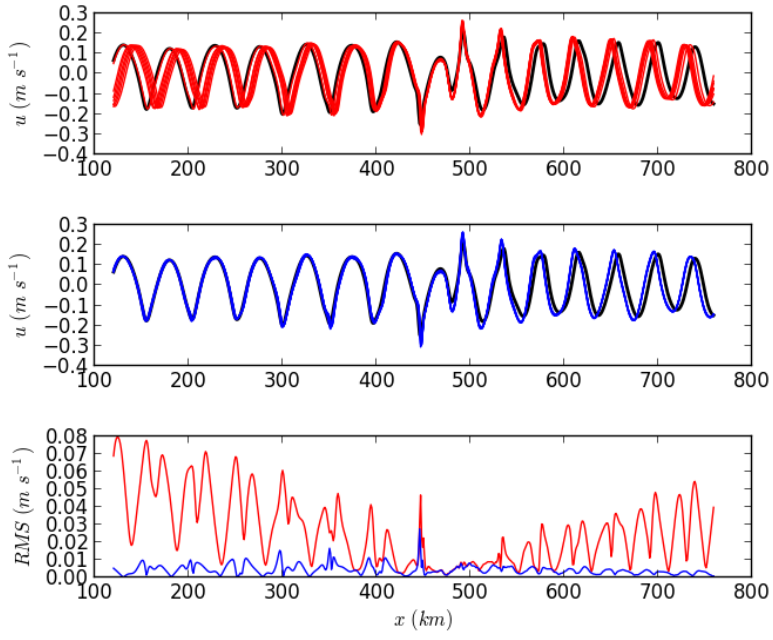


Figure : Surface velocities for a step and interpolated stratifications and few vertical grids. Black line: isopycnic solution. Bottom: RMS differences between solutions

Accuracy of the vertical grid: 50 m surface layer

- Need of accurate vertical grid or an adapted stratification
- adapted stratification produce same IT as isopycnic coordinate
- Differences on the shelf
- On the shelf, the fixed vertical coordinate change the wavelength

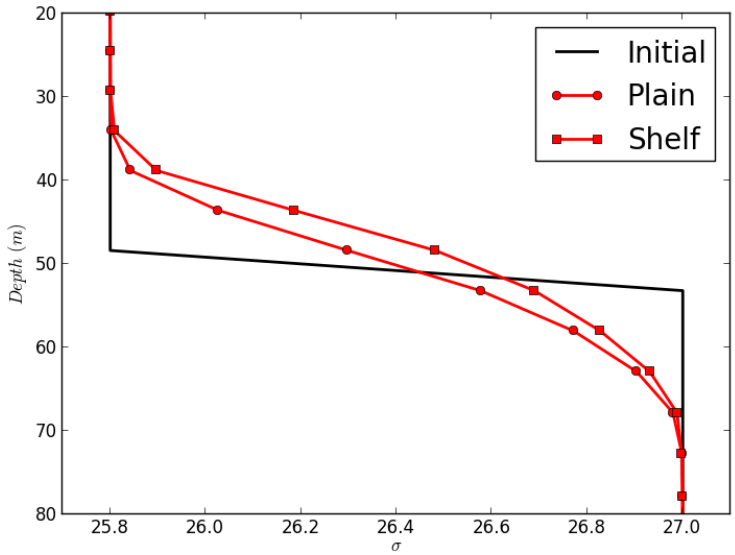


Figure : Density Profiles on the shelf and on the plain for the last tidal cycle

Conclusion

- Isopycnic coordinate solutions are less resolution dependent than the geopotential coordinate.
- Increasing the resolution tend to generate solutions that converge for both vertical coordinate systems
- For fine resolution, the increase of the resolution is not enough to generate similar solutions
- Fine resolution need a extremely accurate vertical grid to represent either step stratification or generation area.
- Stratification evolution due to spurious mixing lead to an IT characteristics variation with the time

adding plot

- Weak forcing-linear motion-obvious resolution sensitivity

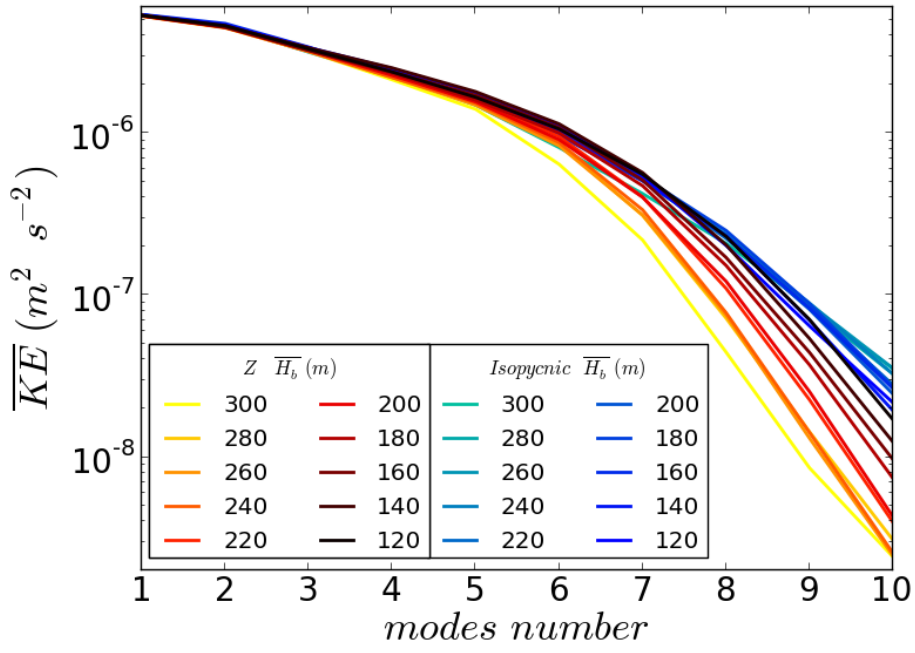


Figure : Weak forcing, N constant, KE per mode for Z and isopycnic solutions

adding plot

- Weak forcing-linear motion-obvious resolution sensitivity
- Wavelength

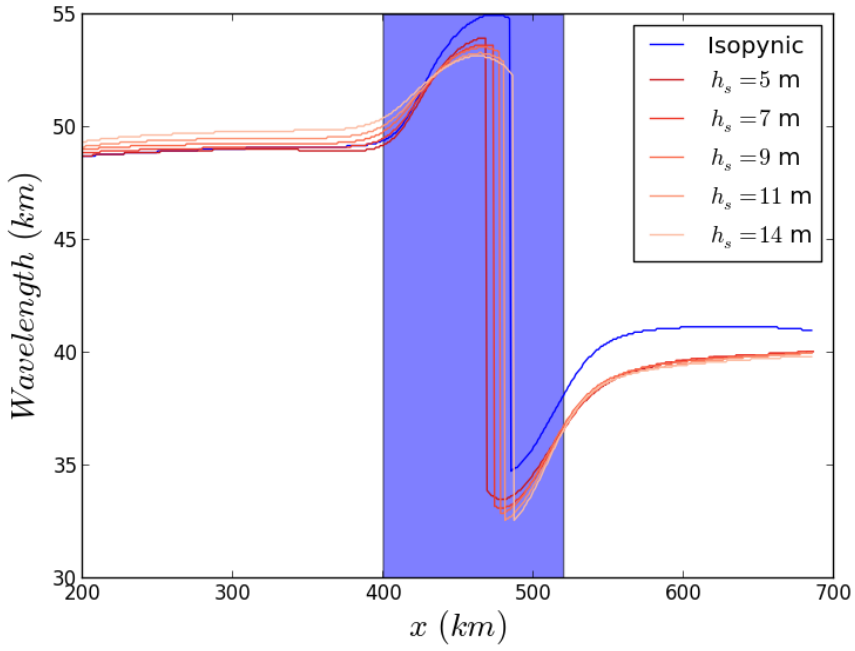


Figure : Wavelength by wavelet

adding plot

- Weak forcing-linear motion-obvious resolution sensitivity
- Wavelength
- Phase speed similar to analytical solution

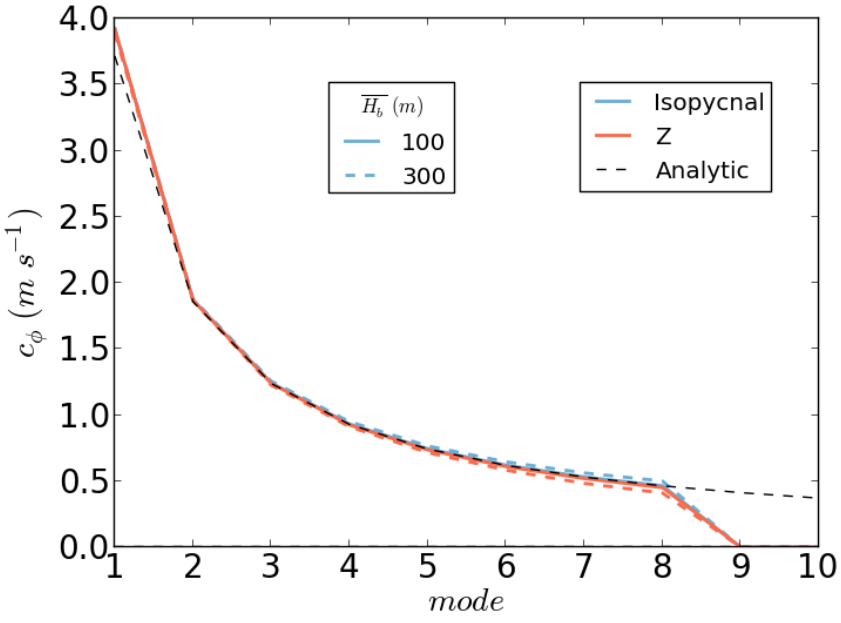


Figure : N=0.002. Modeled phase speed

adding plot

- Weak forcing-linear motion-obvious resolution sensitivity
- Wavelength
- Phase speed similar to analytical solution
- Sigma-isopycnic-geopotential

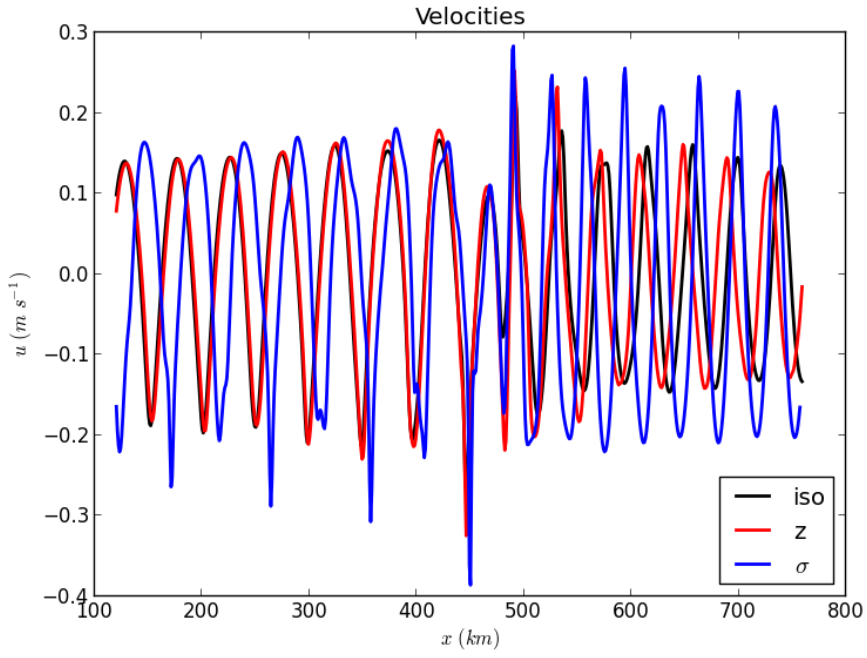


Figure : Comparaison ROMS HYCOM