TESTING of the PRESSURE GRADIENT ERROR in a TERRAIN-FOLLOWING HYCOM

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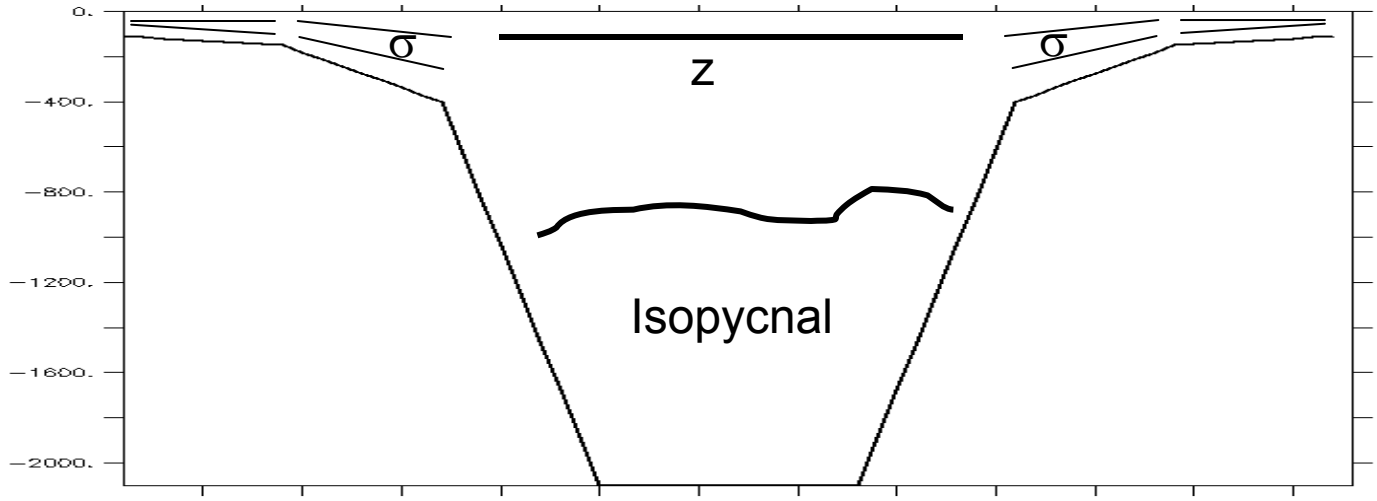
Hybrid coordinates: isopycnal, z, sigma

- Z : upper layers, unstratified seas
- Isopycnal : stratified deep ocean (conserve water mass property)
- σ (terrain-following) : coastal areas, shelves and top of continental slopes



Parametrization of coordinates

Choice of coordinates	nhybrid	Number of hybrid layer (z+σ)
	nsigma	Number of σ layer
Z-layers spacing parameter	Δp00	Thickness of the surface layer
	Δp00f	Stretching factor
	Δp00x	Maximum thickness
	$\Delta p(k)=\Delta p00 * \Delta p00f^{k-1}$	
σ-layers spacing parameter	Δs00	Thickness of the surface layer
	Δs00f	Stretching factor
	Δs00x	Maximum thickness
	$\Delta s(k)=\Delta s00 * \Delta s00f^{k-1}$	

Target densities

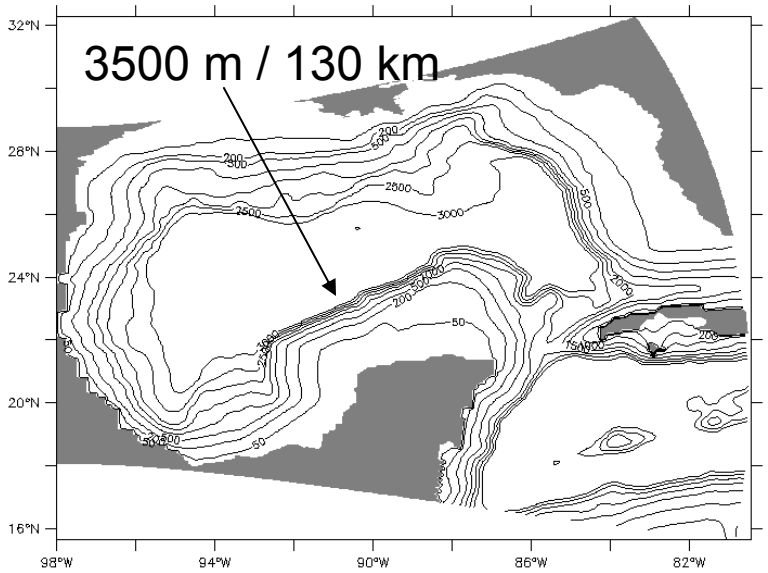
Condition : Δs00, Δs00f, Δs00x <= Δp00, Δp00f, Δp00x

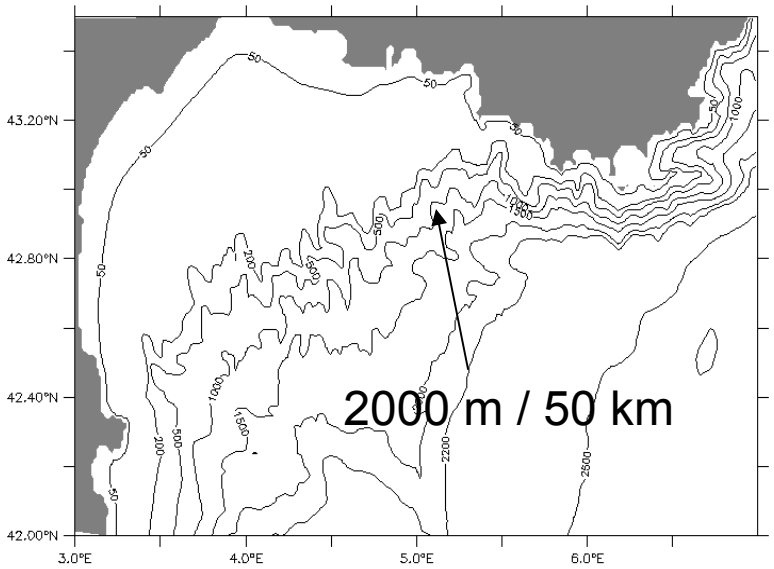
$\Delta h = \min (\Delta h_z , \max (\Delta h_s, depth/nsigma))$

Deep ocean
Very shallow water

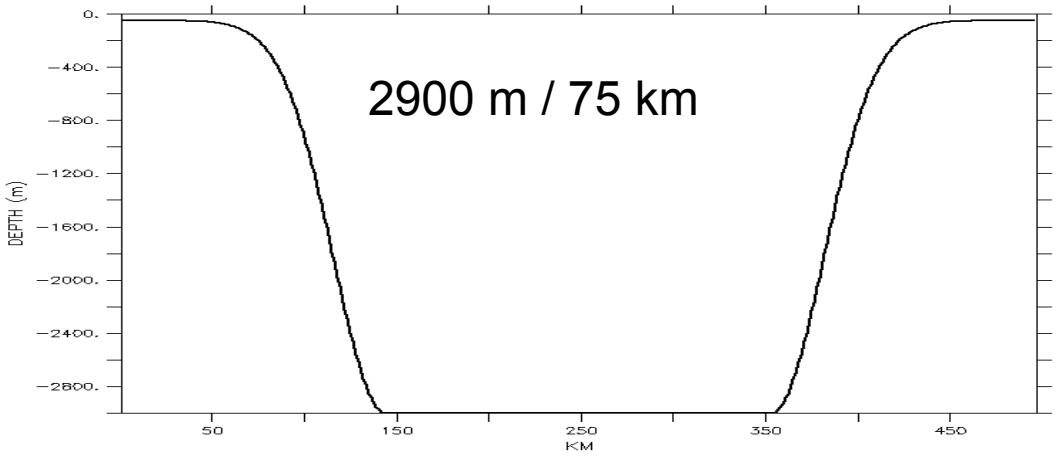
Coastal area

How does HYCOM perform over steep continental rises ?

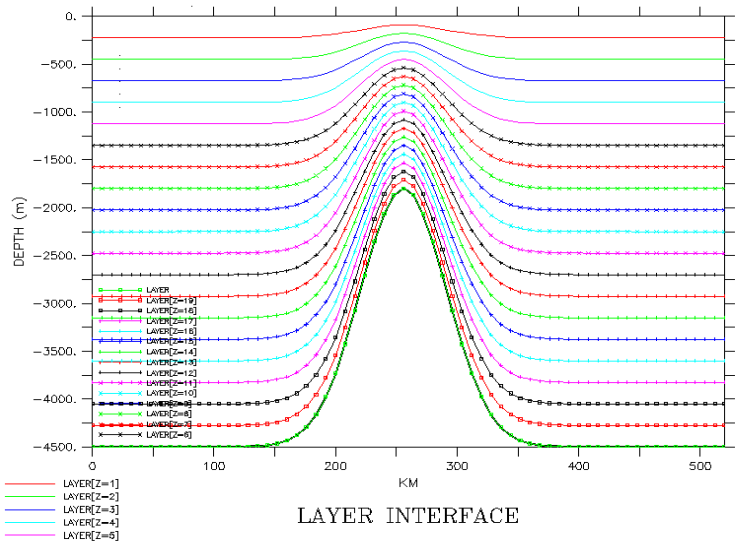




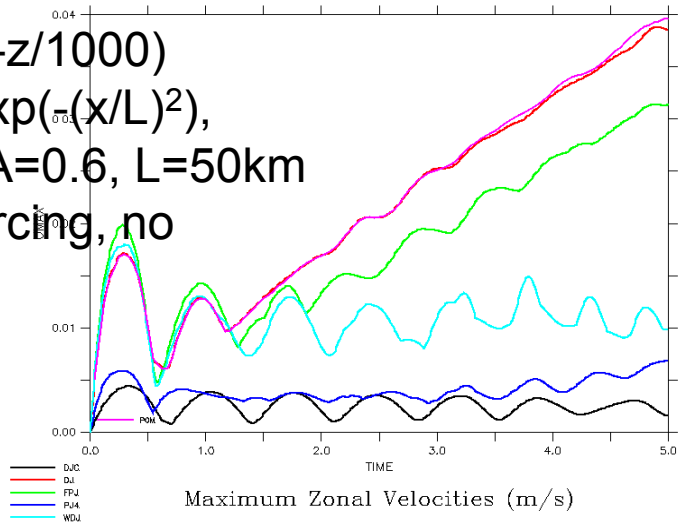
Realistic but extremely steep continental slope : $H=50+2950*\exp(-(x/L)^2)$, L=40 km



σ-models and the seamount problem



T=5+15 exp(-z/1000)
H=H0 (1-A exp(-(x/L)^2),
H0=4500m, A=0.6, L=50km
At rest, no forcing, no viscosity…



Irrelevant case for HYCOM

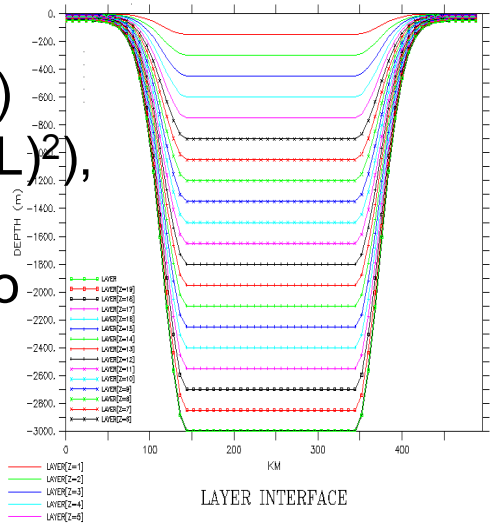
- never pure σ-layer mode,
- σ-layers over shelf,
- isopycnal layer in deep layers

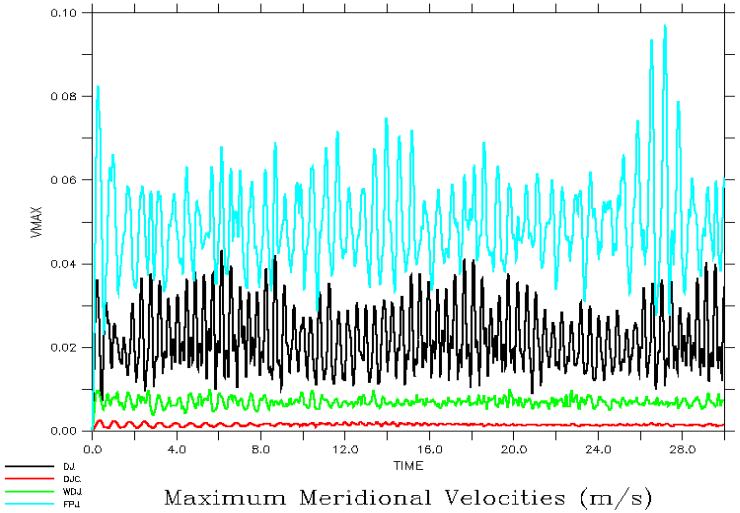
HYCOM
V_{max}=2.62 m/s !

No Pressure Gradient Error (PGE) with z and isopycnal layers

PGE with σ-layers over shelf ? ROMS

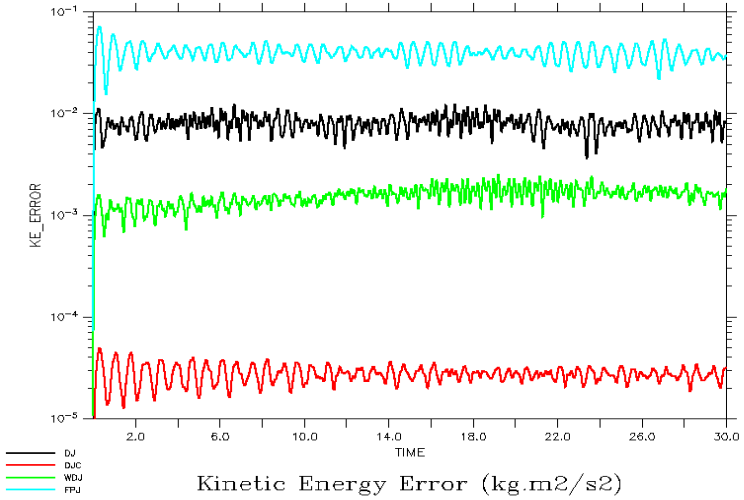
T=5+15 exp(-z/1000)
H=50+2950*exp(-(x/L)^2),
L=40 km
At rest, no forcing, no viscosity…





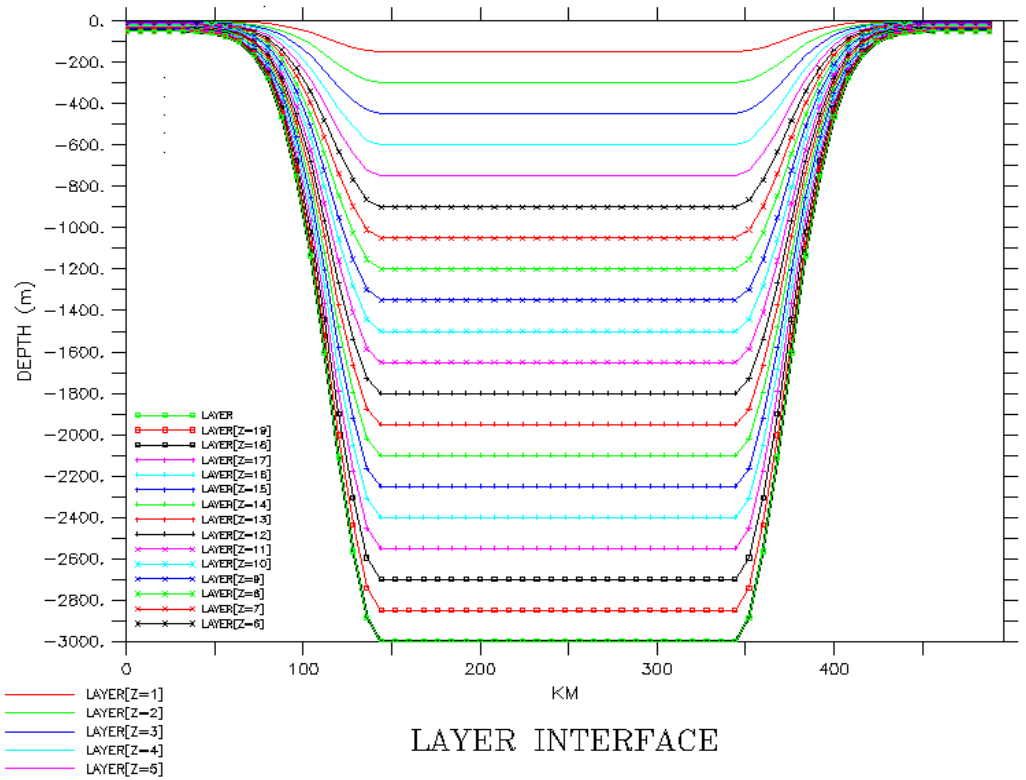
Accuracy of Pressure gradient schemes

1. DJC density Jacobian using monotized cubic polynomial fits
2. WDJ Weighted density Jacobian
3. DJ standard Density Jacobian
4. FPJ Finite-Volume Pressure Jacobian



PGE with σ-layers over shelf ? HYCOM

T=5+15 exp(-z/1000)
H=50+2950*exp(-(x/L)^2),
L=40 km
At rest, no forcing, no viscosity, no diffusivity, no bottom friction…

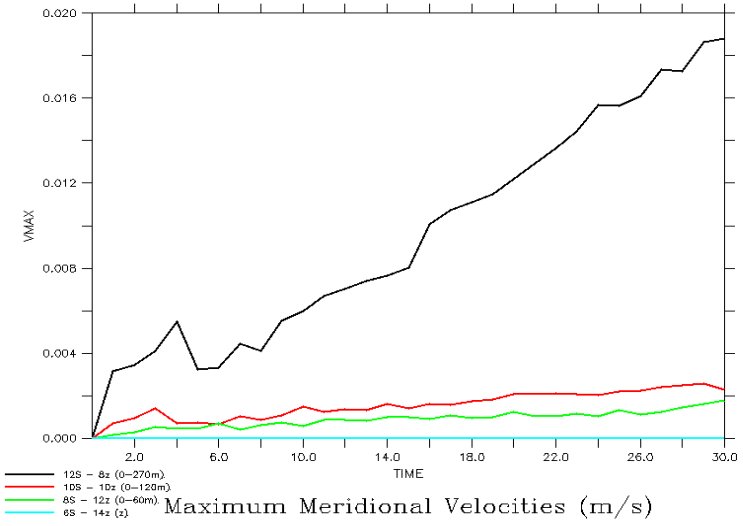


Blows up, but irrelevant case…

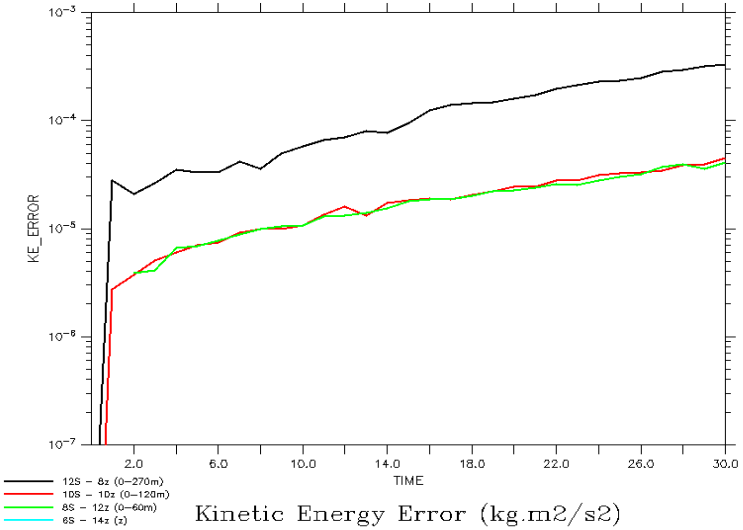
How deep can we use σ-layers ?

Δp00=Δs00=2
Δp00f=Δs00f=1.37

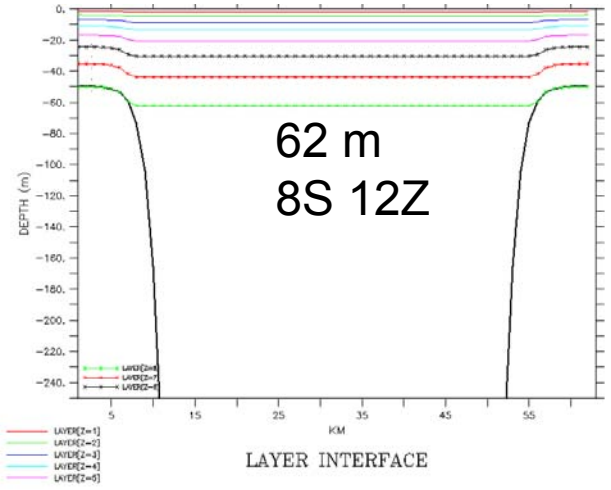
HYCOM



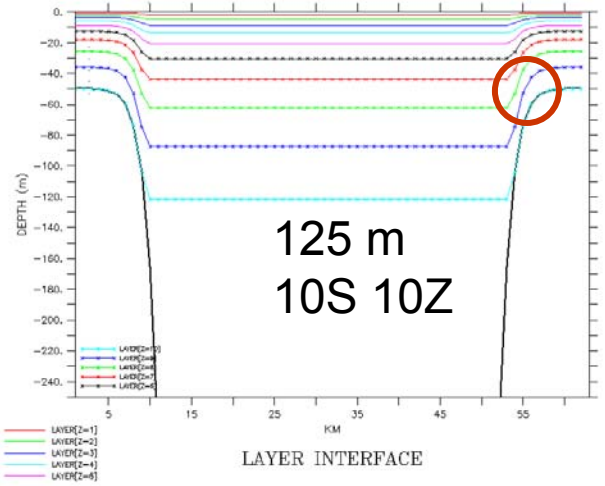
Maximum Meridional Velocities (m/s)



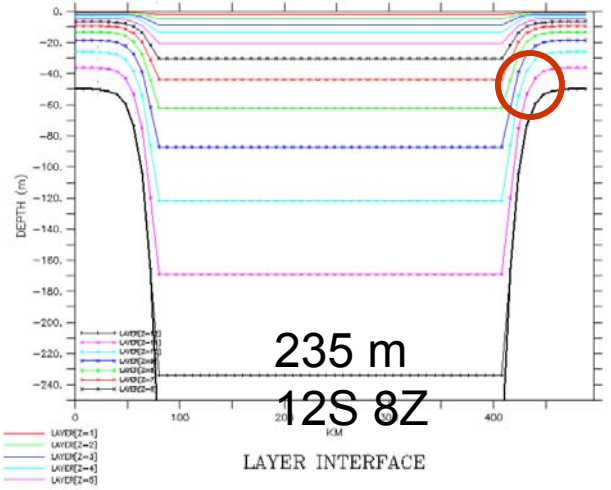
Kinetic Energy Error (kg.m2/s2)



LAYER INTERFACE



LAYER INTERFACE



LAYER INTERFACE

Conclusion

- Numerical experiments explore the limitation of the use of σ-layers in HYCOM. In case of an extremely steep slope, limitations come from computational errors in both terms of the horizontal pressure gradient formulation:

$$\alpha\delta_z p=\delta_s M-p\delta_s\alpha$$

- Pressure gradient errors are estimated as motion induced in an ocean initially at rest, uniformly stratified and unforced
- Pressure gradient errors can occur with the use of σ-layers, only
- Pressure gradient scheme is clearly less efficient in HYCOM than in pure σ-models (ROMS-POM)

Conclusion

- However the use of a combination of hybrid coordinates mitigate inaccuracy in horizontal pressure gradient term
- Careful choice of σ-layer parametrization should not induce any perturbation of the circulation due to PGE:
  - HYCOM performs accurately over shelves where slopes are gentle. In such conditions, PGE are comparable with σ-models (a few mm/s)
- Careful choice : do not use σ-layers above steep slopes

Perspectives

- In HYCOM, the use of σ-layers over shelf breaks requires improvements in the pressure gradient scheme
- Two approaches:
  - Density Jacobian formulation ?
  - More accurate Pressure Jacobian : cubic formulation (Shcheptkin & Mc Williams, 2003) instead of the current linear scheme ?