CROCO

Coastal and Regional Ocean COmmunity model

JONSMOD, Firenze 2018

Advances in CROCO
fine-scale non-hydrostatic dynamics

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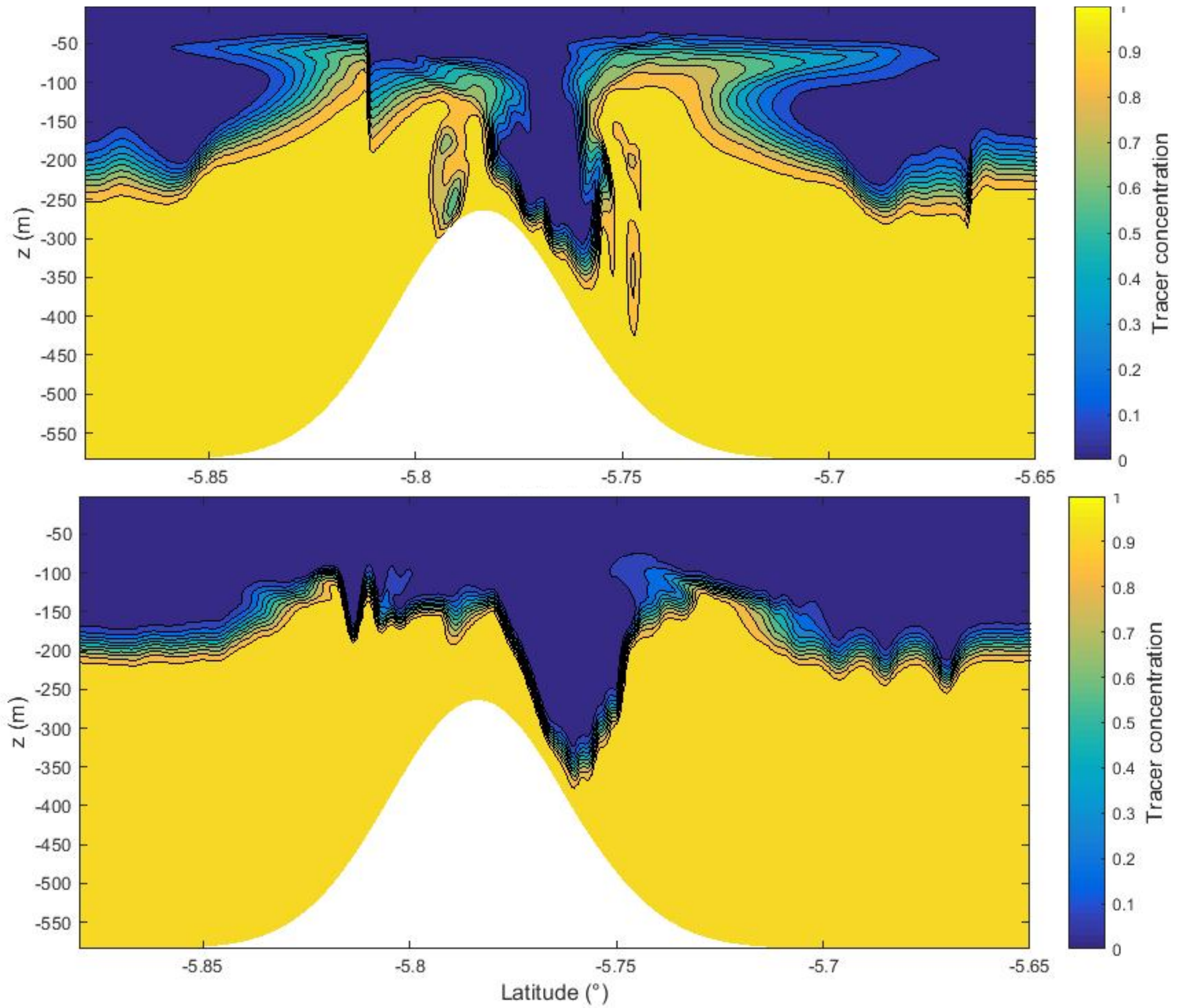
The Gibraltar bottleneck

The Gibraltar bottleneck

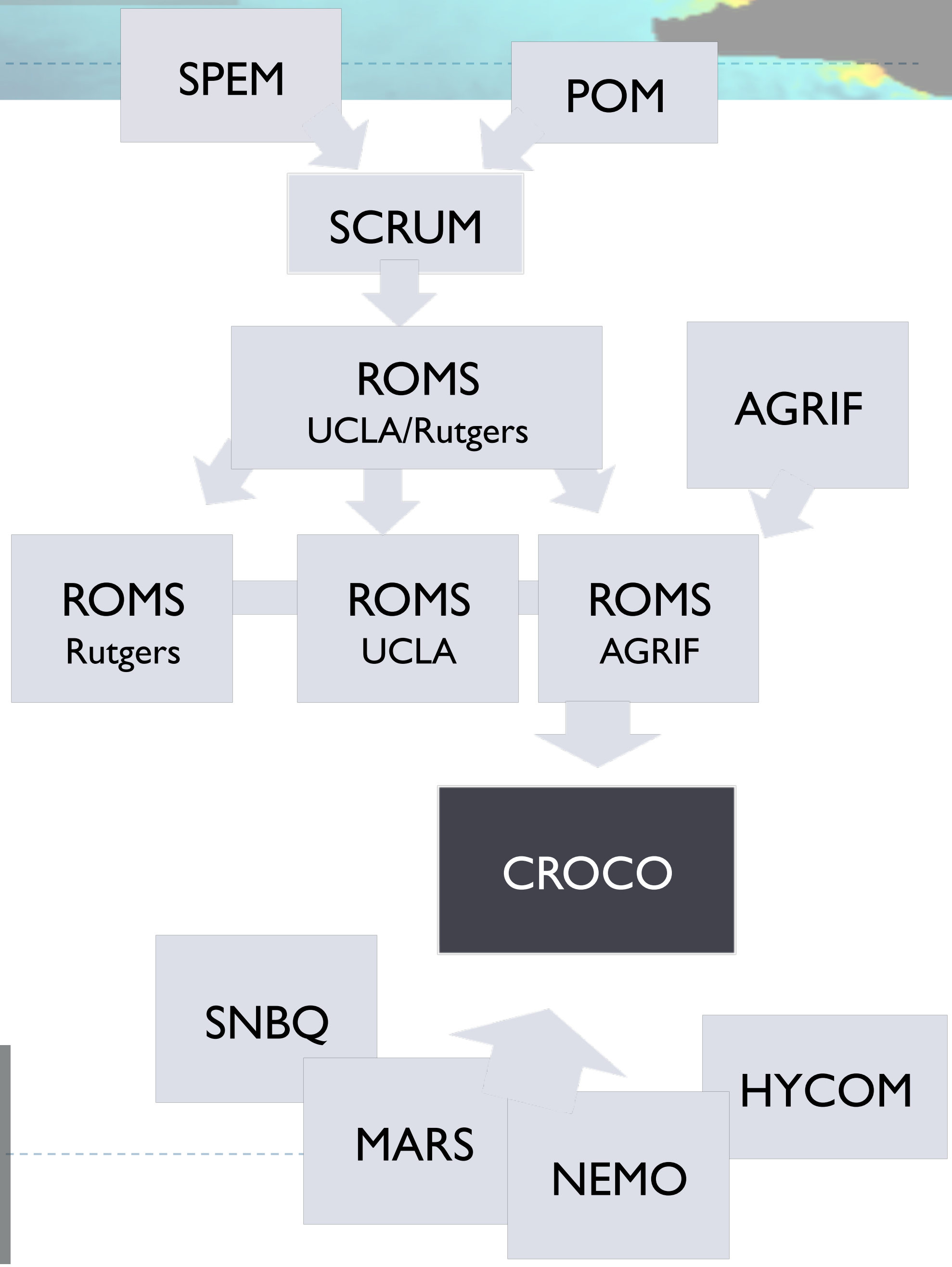
HYDROSTATIC

NON-HYDROSTATIC



CROCO project

- ✓ High-order accuracy
- ✓ Code efficiency
- ✓ Mesh refinement
- ✓ Realistic applications
- ✓ Large community



CONSORTIUM

From submesoscale to micro-turbulence: the non-hydrostatic approach

Non-hydrostatic approach

- Pressure correction method

Non-hydrostatic approach

- **Pressure correction method**

$$p = p_a + p_H + q,$$

Homogeneous linearized equations

$$\begin{aligned} \partial_x u &+ \partial_z w = 0 \\ \partial_t u &= -g\partial_x \eta - \partial_x q/\rho_0 \\ \partial_t w &= -\partial_z q/\rho_0 \\ \\ \partial_t \eta &= w(0) = -H\partial_x \overline{u} \end{aligned}$$

Solve $\Delta q = \frac{\rho_0}{\Delta t}\left(\partial_x \widetilde{u}^{n+1} + \partial_z \widetilde{w}^{n+1}\right)$

Correct velocity field to remove divergent part

$$u^{n+1} = \widetilde{u}^{n+1} - \Delta t \partial_x q, \quad w^{n+1} = \widetilde{w}^{n+1} - \Delta t \partial_z q$$

+ Problem with 2D/3D consistency
+ Complexity of Poisson solver in sigma coordinates
+ Scalability issues

Non-hydrostatic approach

- Pressure correction method
- Compressible approach (Auclair et al., 2017)

Non-hydrostatic approach

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$$p = p_a + p_H + c_s^2 \delta\rho$$

Homogeneous linearized equations

$$
\begin{aligned}
\partial_t u &= -g\partial_x \eta - c_s^2 \partial_x \delta\rho \\
\partial_t w &= -c_s^2 \partial_z \delta\rho \\
\partial_t \delta\rho &= -\rho_0 (\partial_x u + \partial_z w) \\
\\
\partial_t \eta &= w|_{z=0} \\
w|_{z=-H} &= 0 \\
\delta\rho|_{z=0} &= 0
\end{aligned}
$$

Acoustic mode integrated in a split-explicit free surface approach at the same fast step as the barotropic mode

Semi-implicit forward-backward

$$
\begin{aligned}
u^{m+1} &= u^m - \delta t \left(g\partial_x \eta^m + c_s^2 \partial_x \delta\rho^m \right) \\
w^{m+1} &= w^m - \delta t c_s^2 \partial_z \left(\delta\rho^{m+\theta} \right) \\
\delta\rho^{m+1} &= \delta\rho^m - \rho_0 \delta t \left(\partial_x u^{m+1} + \partial_z w^{m+\theta} \right) \\
\eta^{m+1} &= \eta^m + \delta t (w|_{z=0})^{m+\theta}
\end{aligned}
$$

Non-hydrostatic approach

- Pressure correction method
- Compressible approach (Auclair et al., 2017)

ADVANTAGES

Physics

- Solves short surface waves
- Solves mixed acoustic-gravity waves (tsunami precursor)
- High-order pressure gradient → accuracy for internal waves

Performances

- Same fast step as hydrostatic code because of :
  - ✓ possible reduction of c_S (> $\sqrt{gh}$)
  - ✓ semi-implicit treatment
- Scalability: scales well with resolution

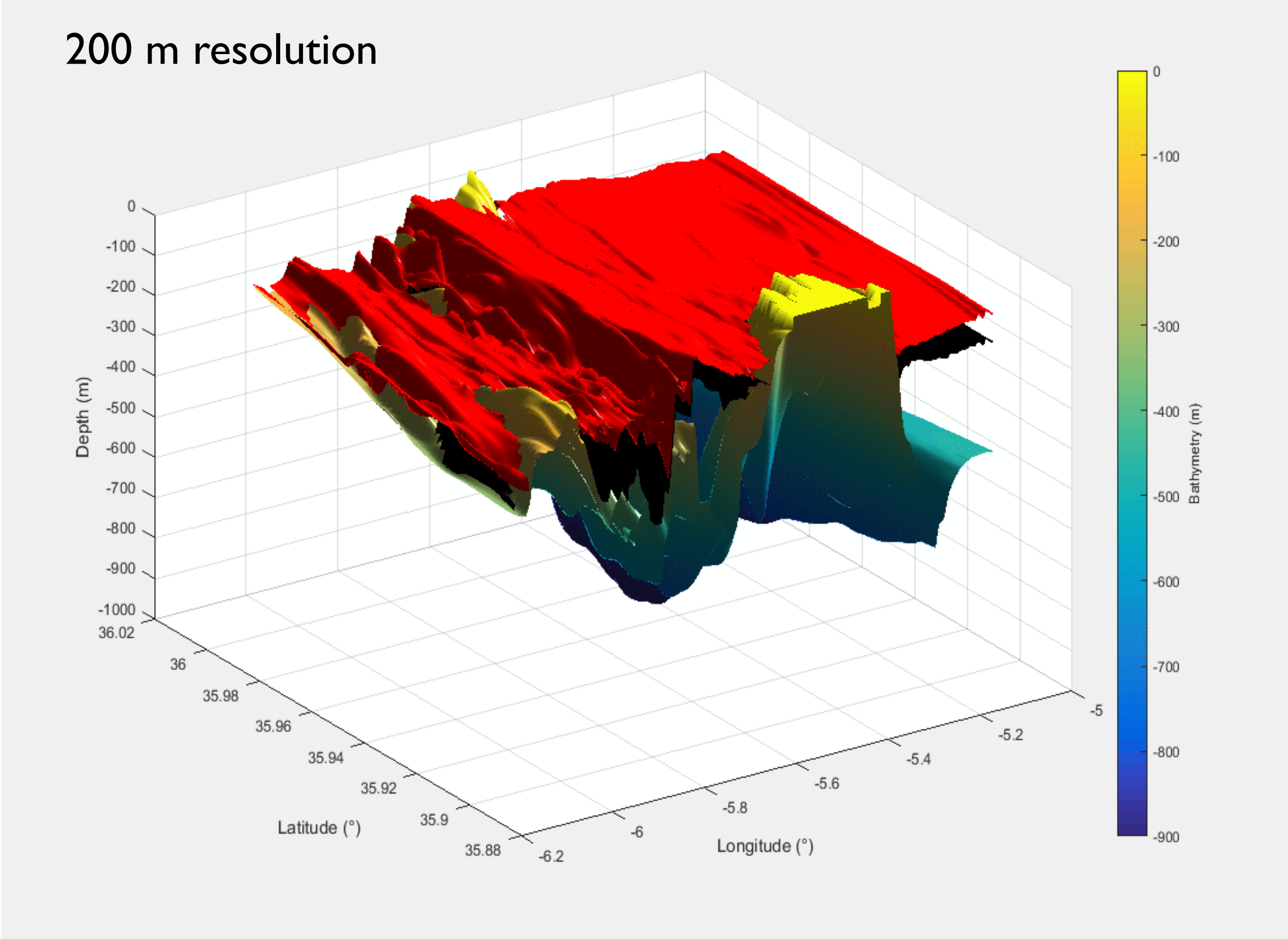
COST: NH ~ 3 x H

Applications

Submesoscale dynamics
Internal bores
Breaking internal tides
Turbulence mixing
Surface wave dynamics
River plumes

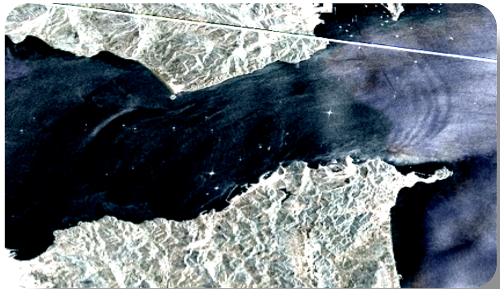
Nonlinear internal waves: Gibraltar

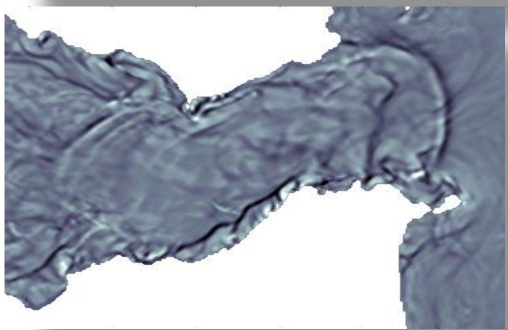
Bordois et al., 2018

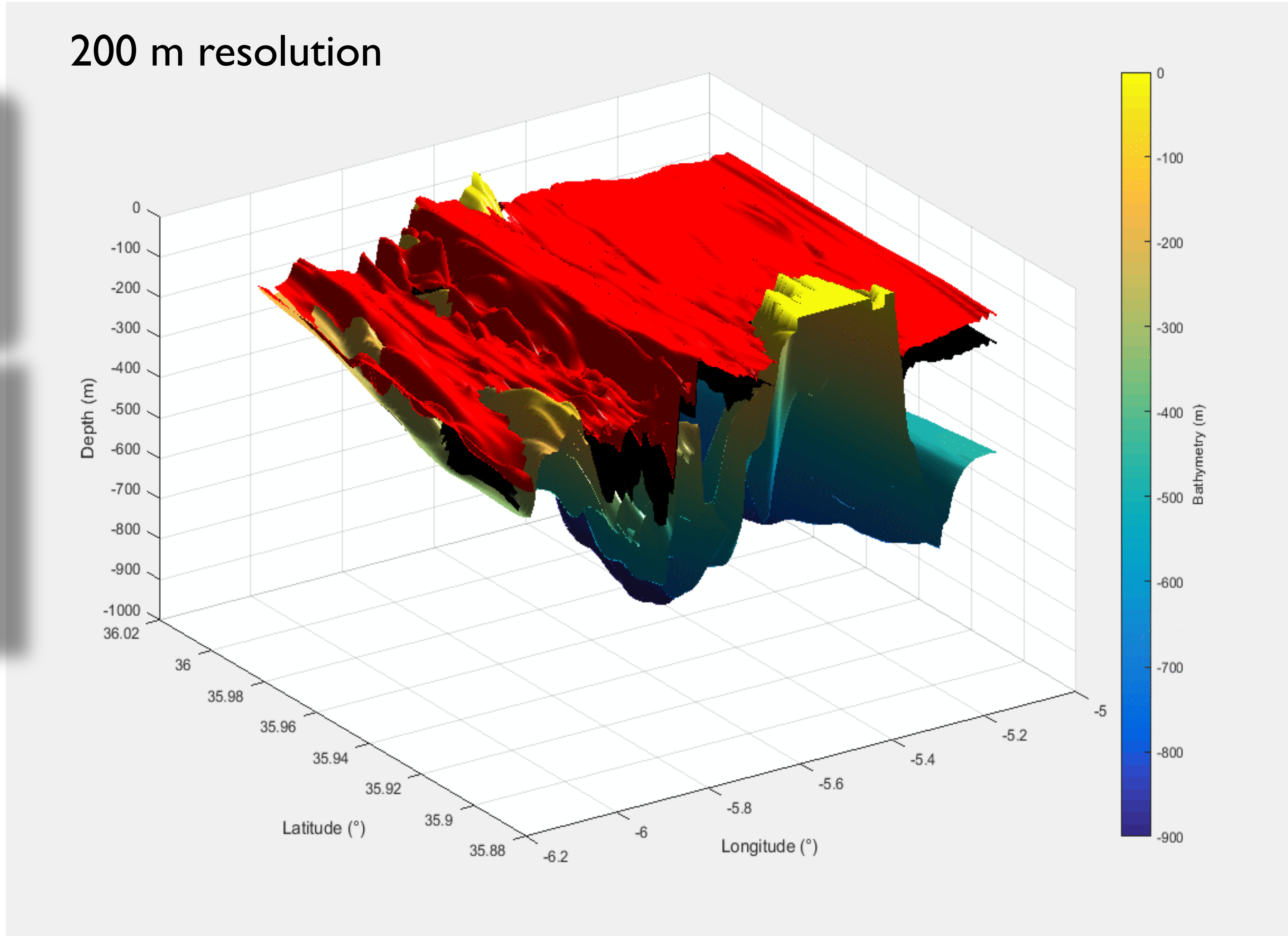


Nonlinear internal waves: Gibraltar

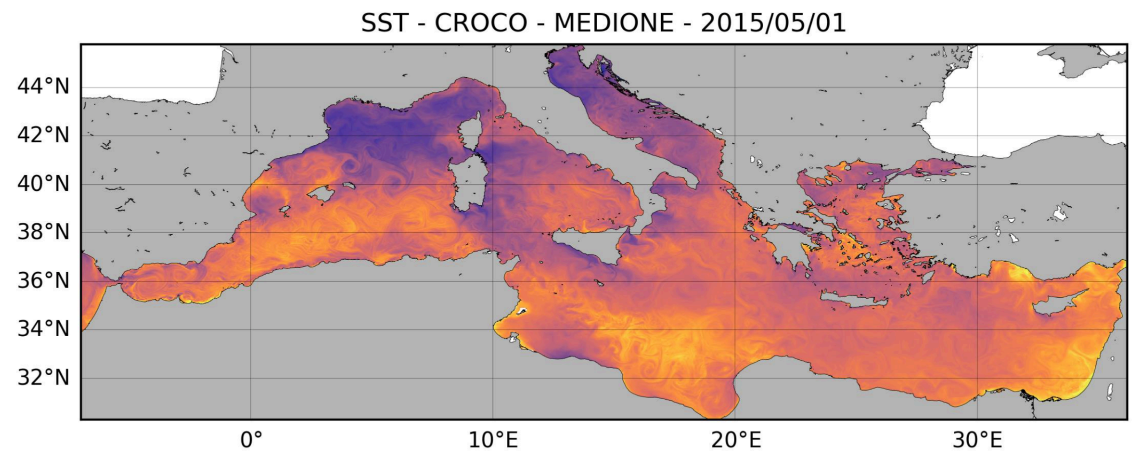
Bordois et al., 2018

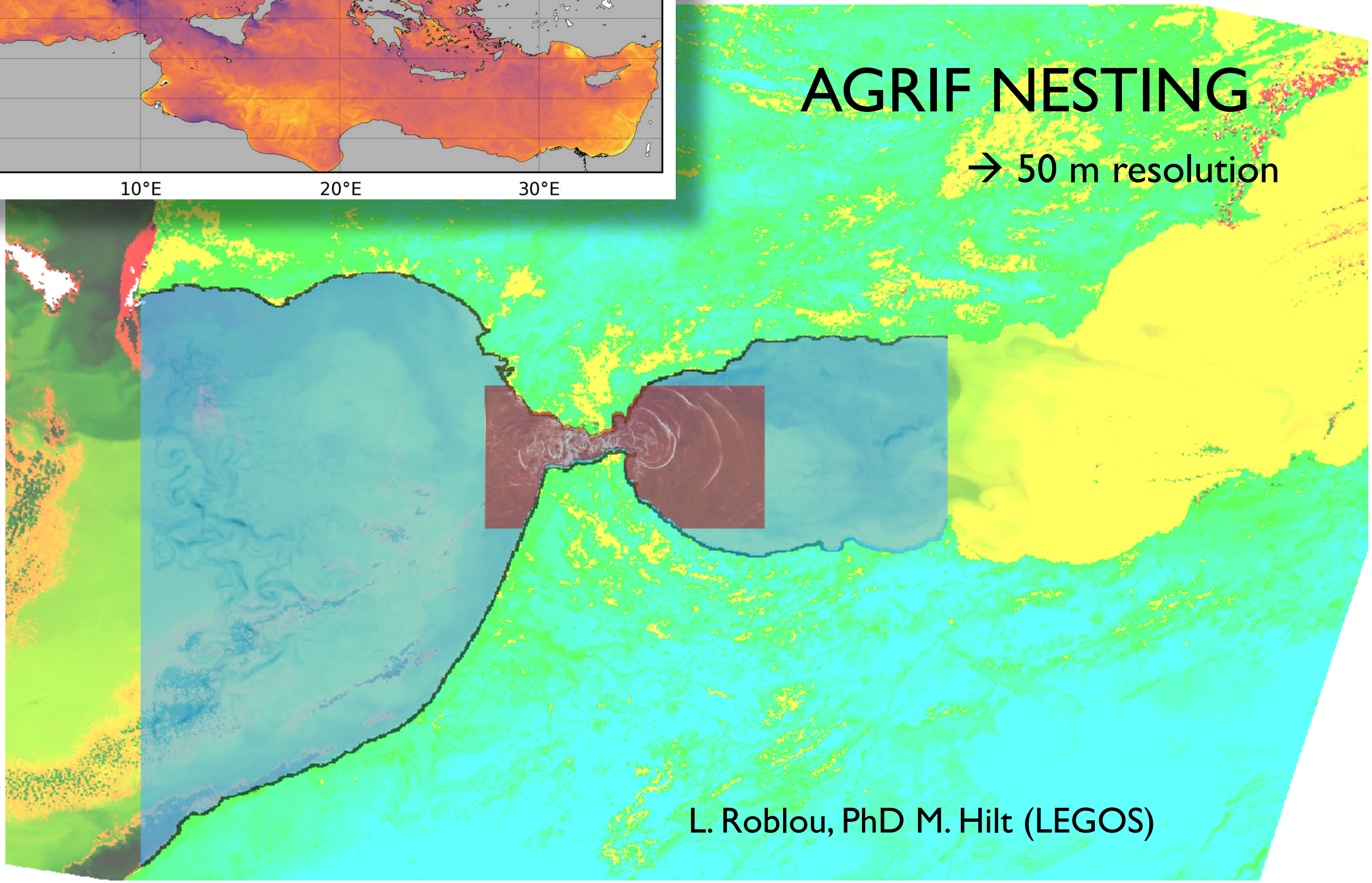






Nonlinear internal waves: Gibraltar





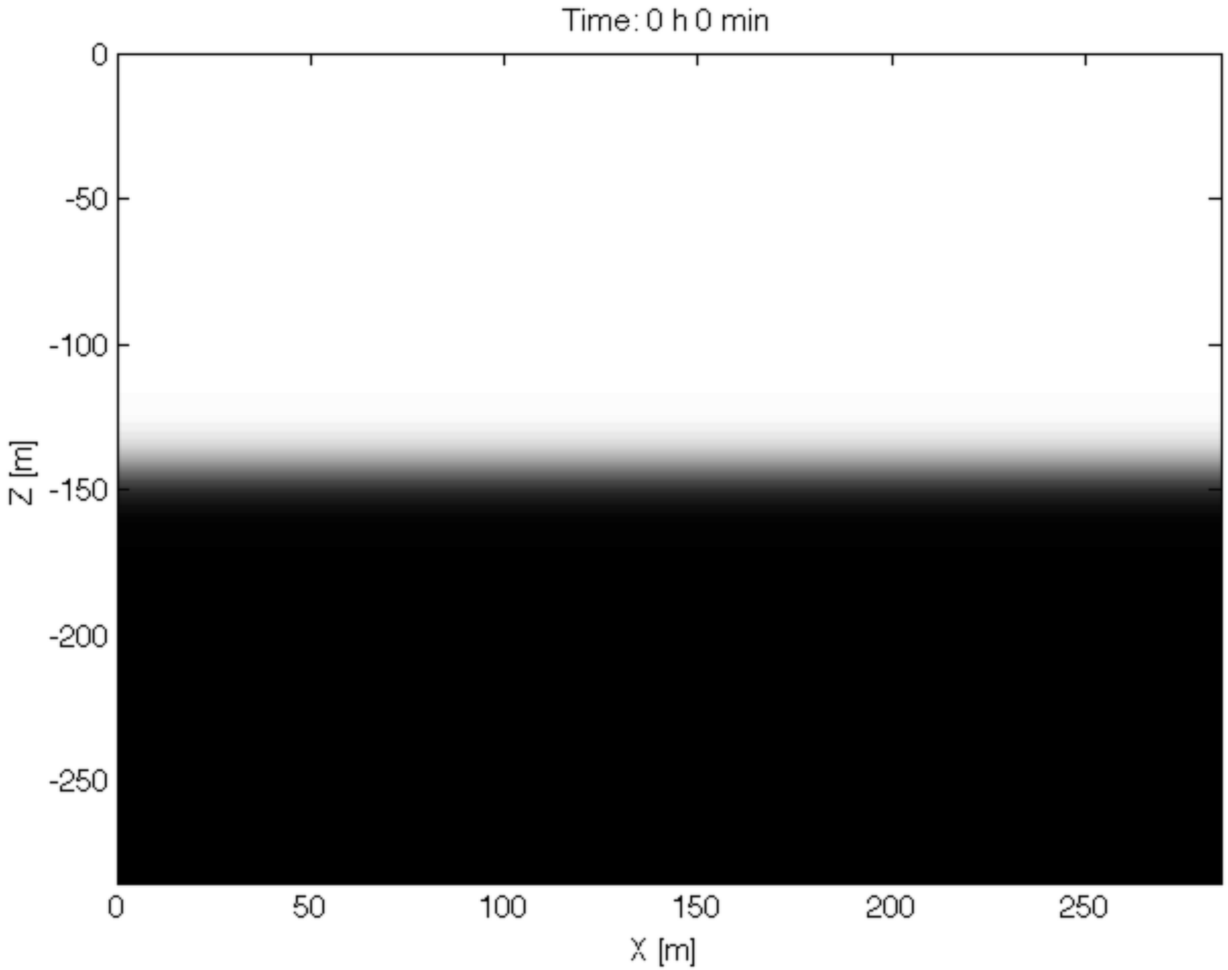
AGRIF NESTING

→ 50 m resolution

L. Roblou, PhD M. Hilt (LEGOS)

Turbulent mixing

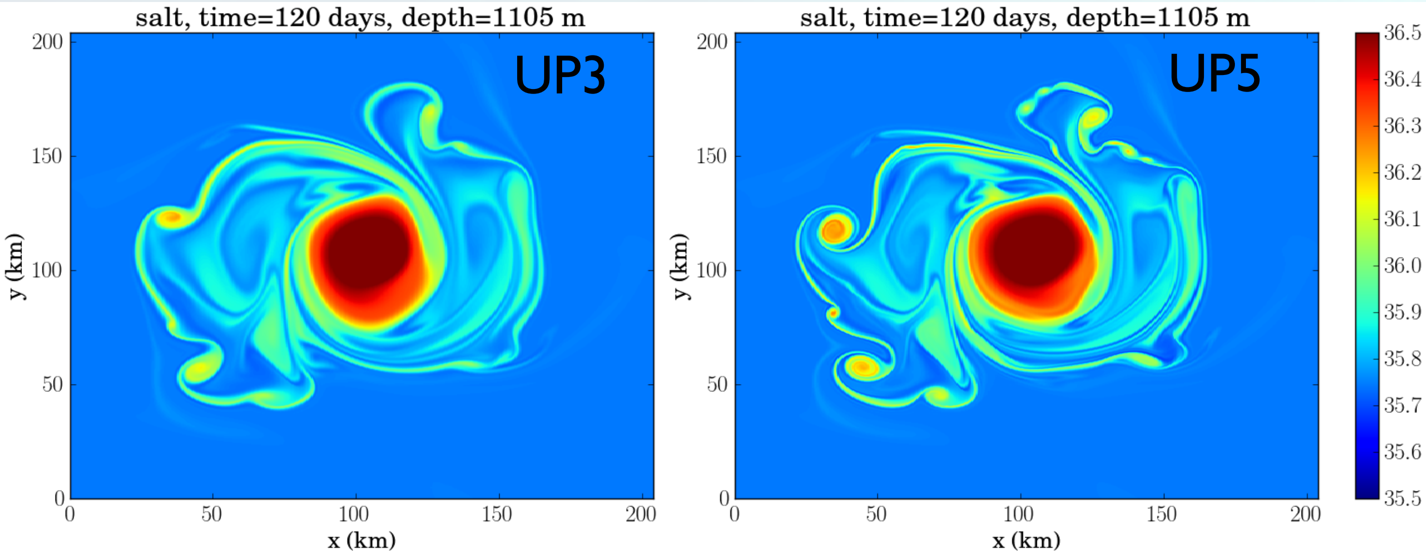
Penney et al., 2018

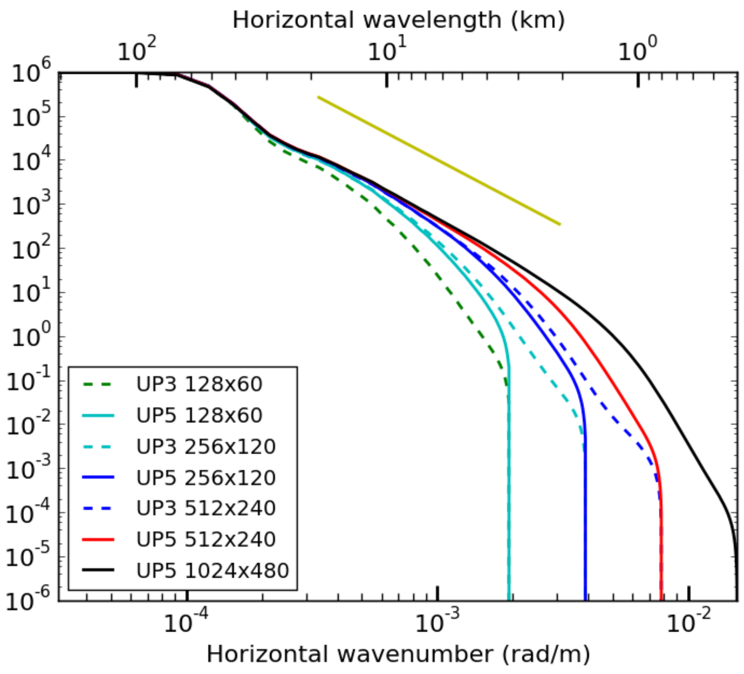


KH instability - 1 m resolution

Numerical methods

2- High-order benefit





Effective resolution: x 2

Cost: + 5%

2- High-order benefit: Gibraltar

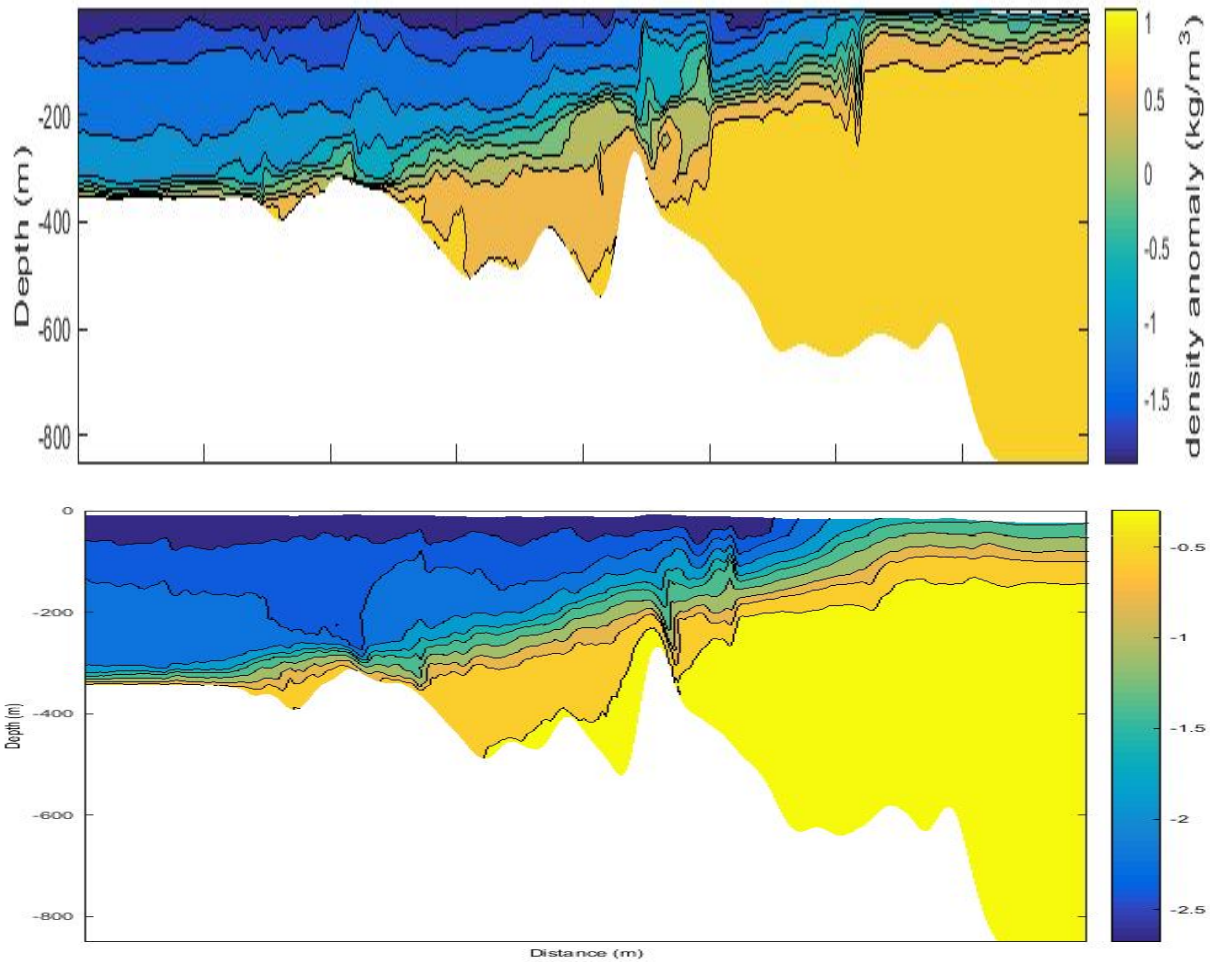
Gibraltar IGW

CROCO-NBQ

High-order accuracy

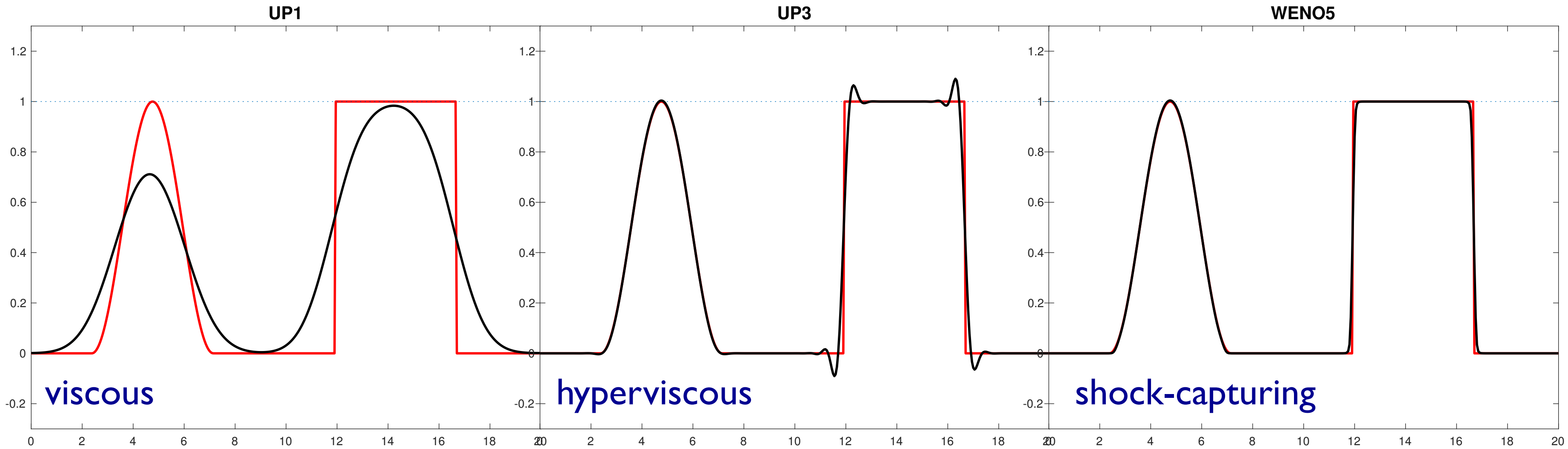
S-NBQ

Low-order accuracy



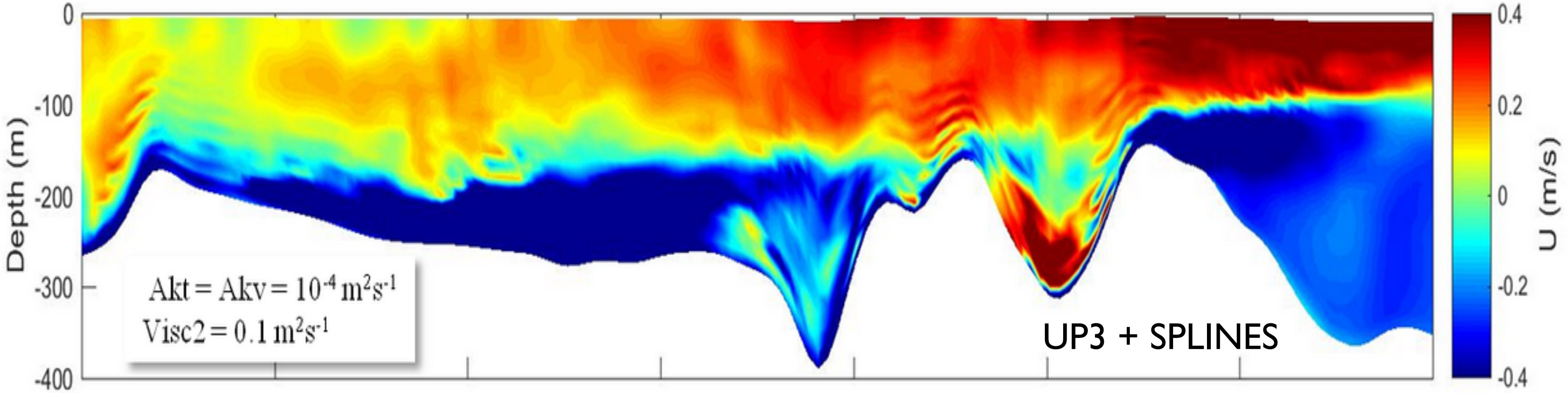
3- Hyperviscous shocks

Hyperviscosity in linear advection schemes does not preserve monotonicity
→ oscillations near shocks (Boyd, 1994)

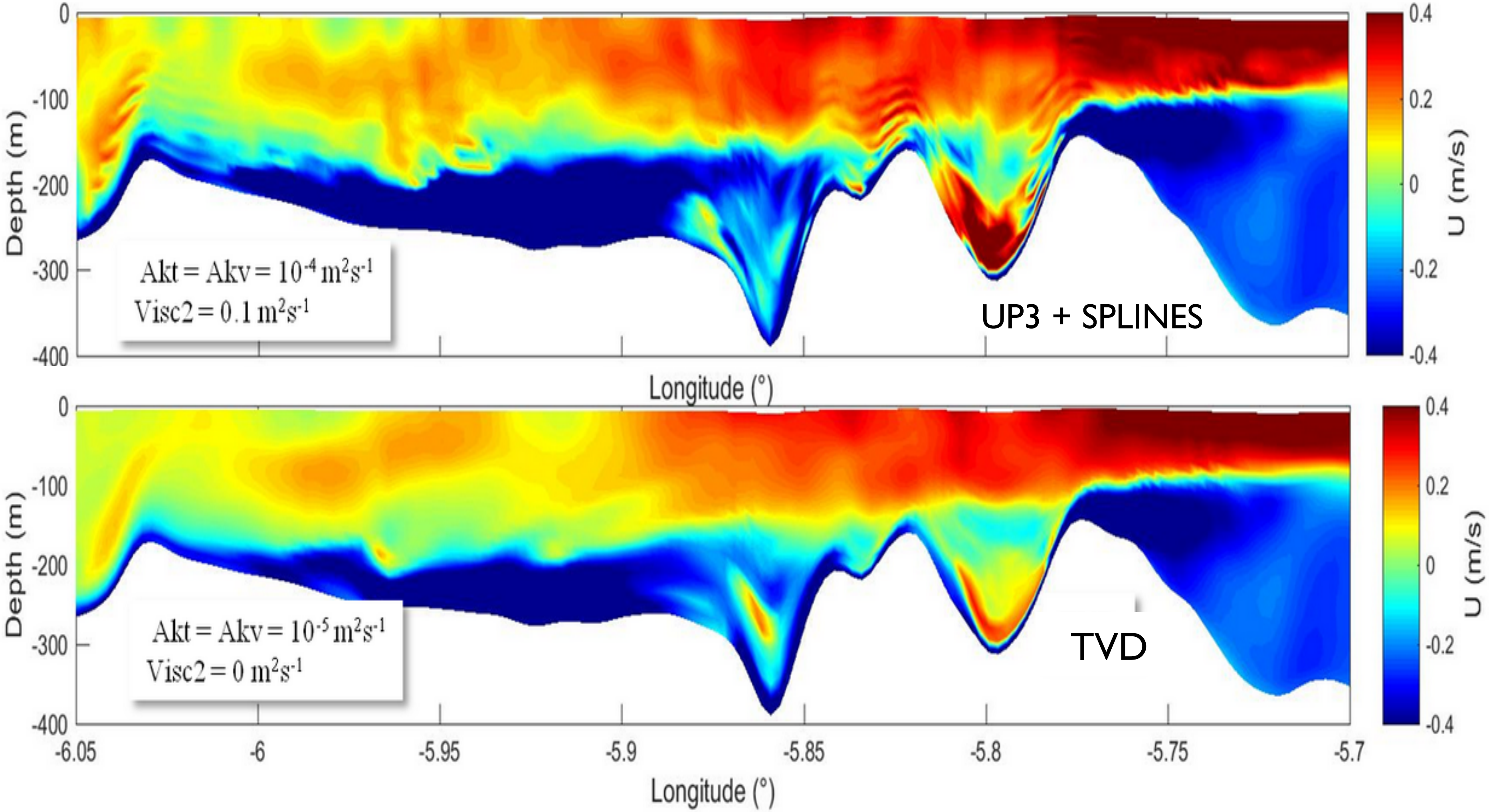


Viscous shock ~ Gibb's shock

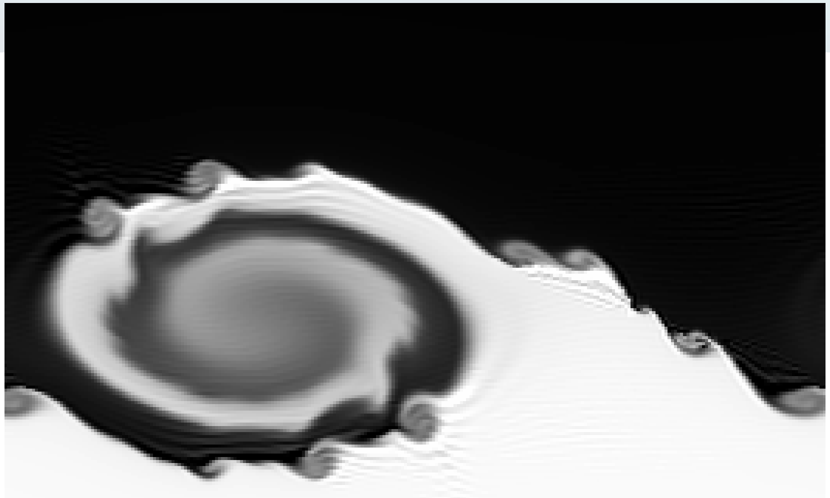
3- Hyperviscous shocks: Gibraltar



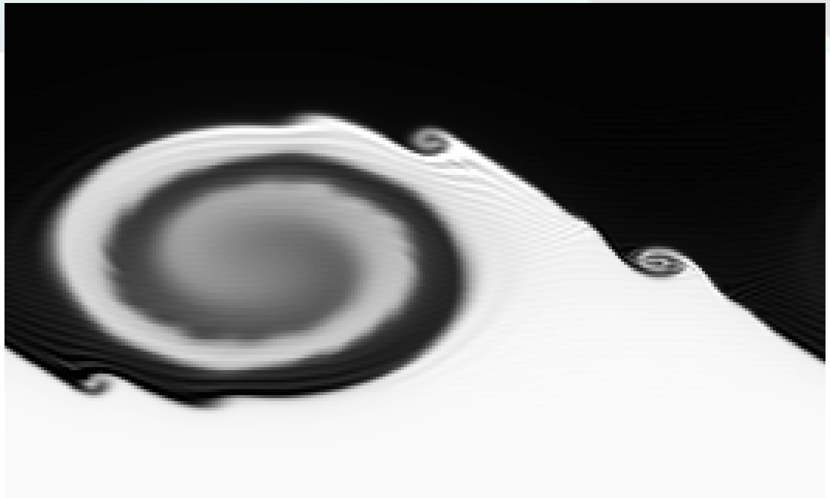
3- Hyperviscous shocks: Gibraltar



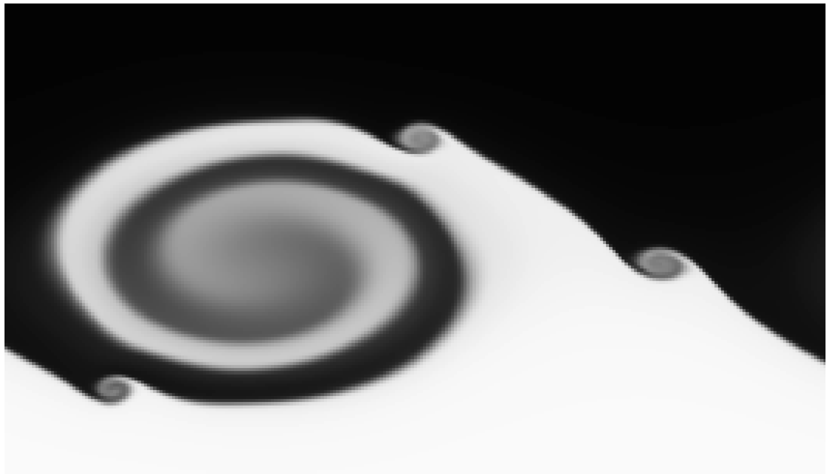
3- Hyperviscous shocks: KHI



Dispersive (ρ Vert Adv)



Non monotonic (ρ Vert Adv)



All monotonic (WENO5)

➡ MILES

CONCLUSIONS

- CROCO is designed for bridging a few gaps:
  - From geostrophic eddies to micro-turbulence
  - From the ocean to nearshore zone
- CROCO-NBQ is an original approach that shows many advantages (accuracy, performances)
- There is still room for improving numerical methods
  - heading for robust, high-order, monotonic advection schemes