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Small-Scale dynamics of the Strait of Gibraltar

The Strait of Gibraltar connects the North Atlantic and the Mediterranean Sea. It is a narrow and shallow area where **intense mixing** changes the characteristics of Mediterranean and Atlantic waters¹. Several small-scale (< 1 km) phenomena contribute to this mixing :

- Small amplitude internal gravity waves at the interface of Atlantic and Mediterranean waters.
- Hydraulic control at Camarinal Sill (and other locations) caused by tidal currents : an **hydraulic jump** is formed².
- Shear instabilities in the Mediterranean vein³.
- The hydraulic jump is released during inflowing conditions and propagates eastward as a train of **Internal Solitary Waves (ISWs)**².

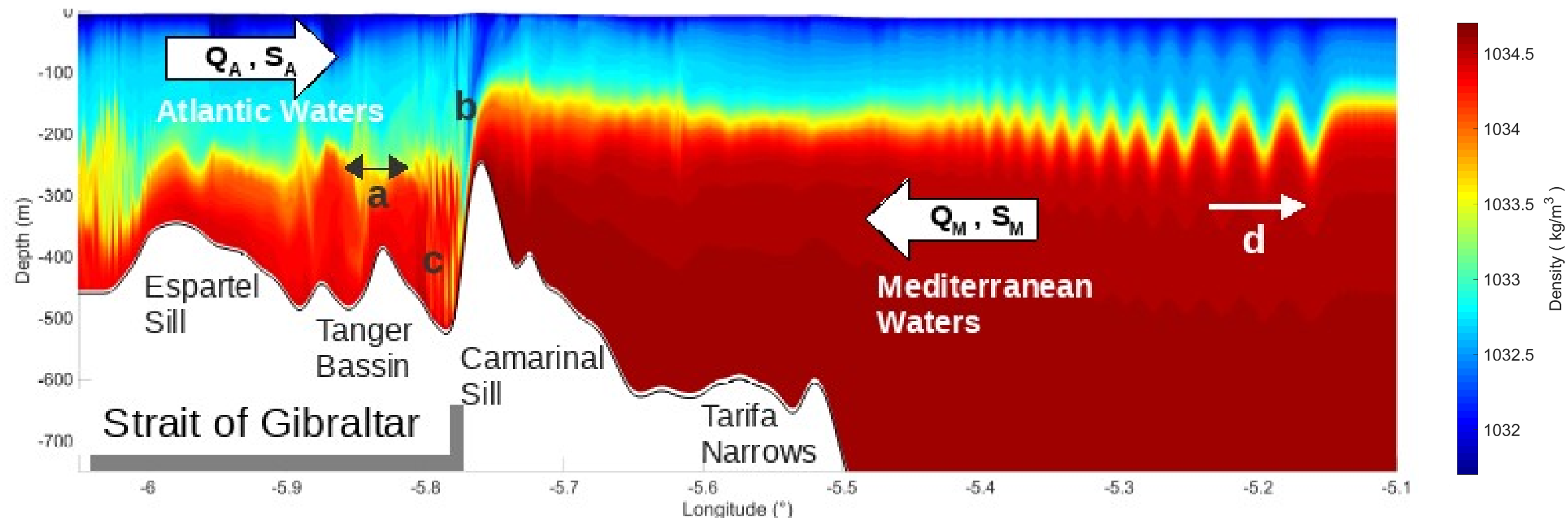


Fig. 1 : Vertical section of density in the longitudinal direction along the Strait of Gibraltar.

Numerical Model : CROCO-NBQ

- CROCO is a free-surface, compressible, NH ocean model based on ROMS-AGRIF.
- NH pressure computed in "Fast Mode"^{4,5}.
- Configuration based on a SHOM HR bathymetry.
- Initialization and lateral forcing from the ENEA Mediterranean and black Sea forecasting system⁶.

Domain	6°4.8'W 5°3.4'W ; 35°23.8'N 36°27.4'N	
Number of horizontal grid points ($\Delta t_s, N_t, C_s$)	2049 x 2621 (1 s, 11, 400 m/s)	
Number of vertical sigma levels	40	
Horizontal resolution dx	45 m	
Depth	Minimum	Maximum
	26 m	960 m
Vertical resolution	0.7 m	
Advection scheme	WENO-5	
Tidal components	M ₂ , S ₂ , H ₁ , O ₁	
Turbulent closure scheme	Smagorinski or k-ε or no-closure scheme ($K_p = \nu = 10^{-6} \text{ m}^2/\text{s}$)	
Simulation period	September 2017 (2 days)	

Table 1 : Main parameters of simulations.

Detection of coherent turbulent structures

Billows of primary shear instabilities are detected for positive values of **Q-parameter**, second invariant of velocity gradient⁷ :

$$Q = -\frac{1}{2} \frac{\partial u_i \partial u_j}{\partial x_j \partial x_i} = \frac{1}{2} (\Omega_{ij} \Omega_{ij} - S_{ij} S_{ij})$$

In outflowing conditions, patches of $Q > Q_{\min}$ appear west of Camarinal Sill at the shear interface and are characterised by a roll-up of salinity. They are advected westward by the Mediterranean outflow.

Detection of Hydraulic Jump

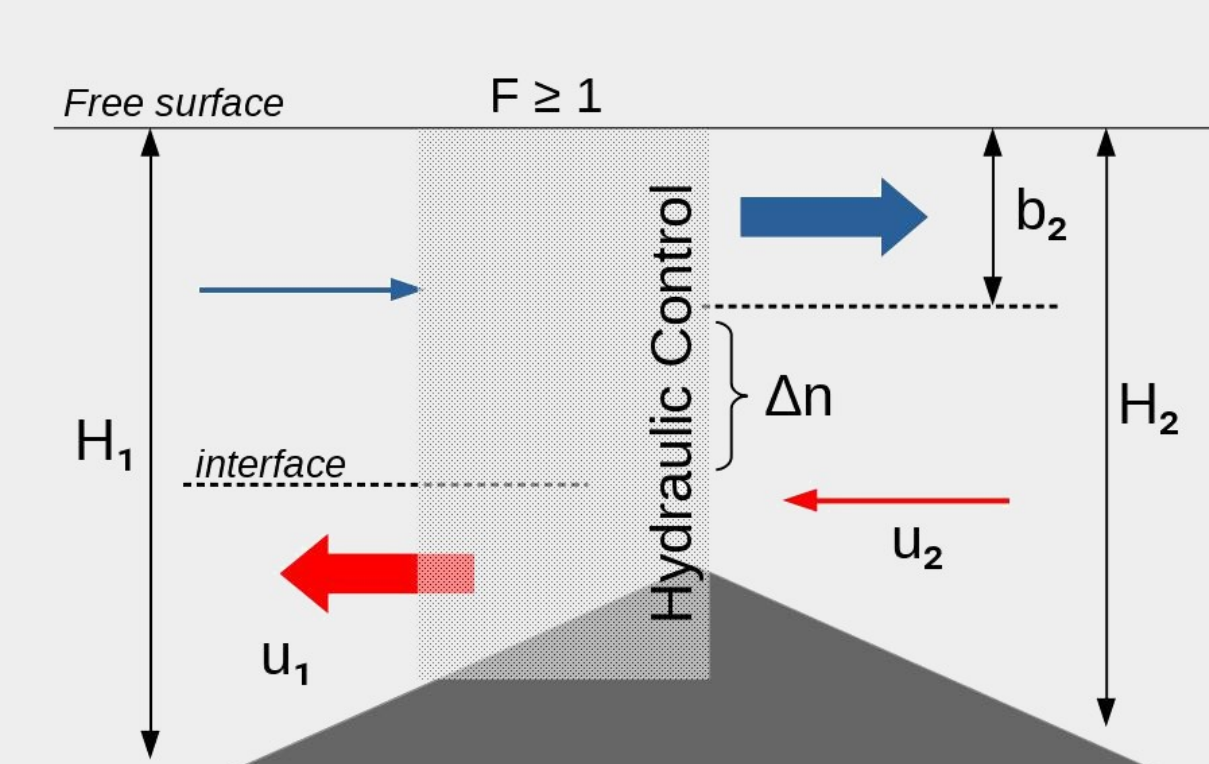


Fig. 2 : Schematic of hydraulic control over Camarinal Sill.

Flow criticality : $F = \frac{u_1^2}{c^2} \geq 1$

Interface discontinuity : Acceleration of surface and bottom layers: detection if $\Delta u_{\text{croco}} \geq \Delta u_{\text{theo}}$

$$\Delta u_s = -u_1 \frac{\Delta n}{b_2}, \quad \Delta u_b = -u_1 \frac{\Delta H + \Delta n}{H_2 - b_2}$$

$$|u_1| = c = \sqrt{g' \frac{(H_1 - \Delta n - b_2)(\Delta n + b_2)}{H_1}}$$

$b_2 \sim 50 \text{ m}, \Delta n \sim 20 \text{ m}, g' \approx 0.02 \text{ m/s}^2$

Hydraulic Jump variability

LES of hydraulic control of large-scale circulation at Camarinal Sill.

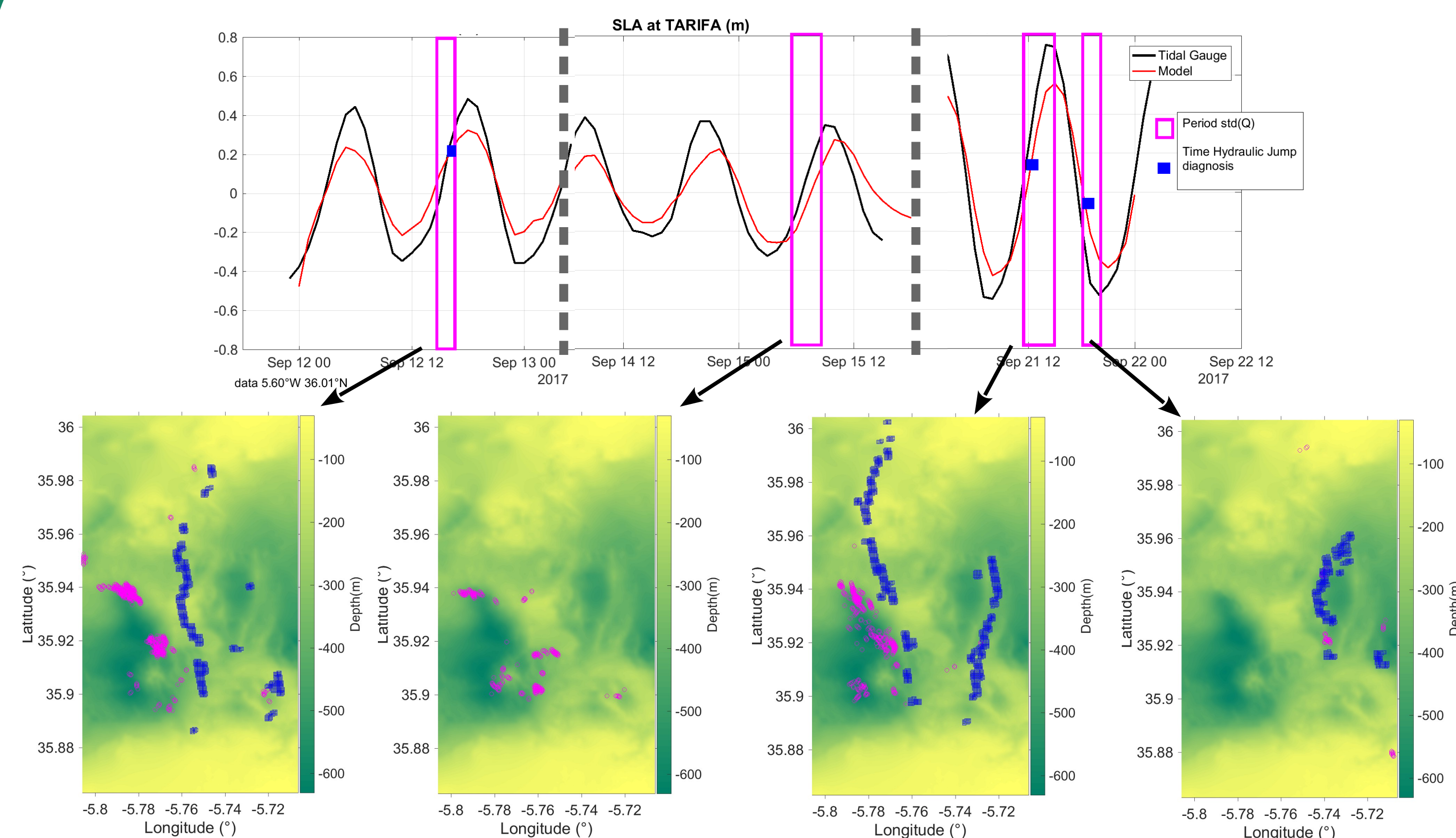


Fig. 4 : Tracking of hydraulic jumps and shear instabilities for several tidal regimes.

Upper panel : Sea level anomaly (cm) at Tarifa tidal gauge (black) and in the simulations (red). Pink rectangles : standard deviation of parameter Q. Blue squares : hydraulic jump.
Lower panels : Bathymetry, (○) location of large values of standard deviation of Q in the water column, indicating where coherent structures propagate, and (□) position of hydraulic jumps indicated by $\Delta u_{\text{croco}} \geq \Delta u_{\text{theo}}$ in both first and last vertical levels.

Dynamics of coherent turbulent structures

LES of Kelvin-Helmholtz instabilities inducing mixing of water masses.

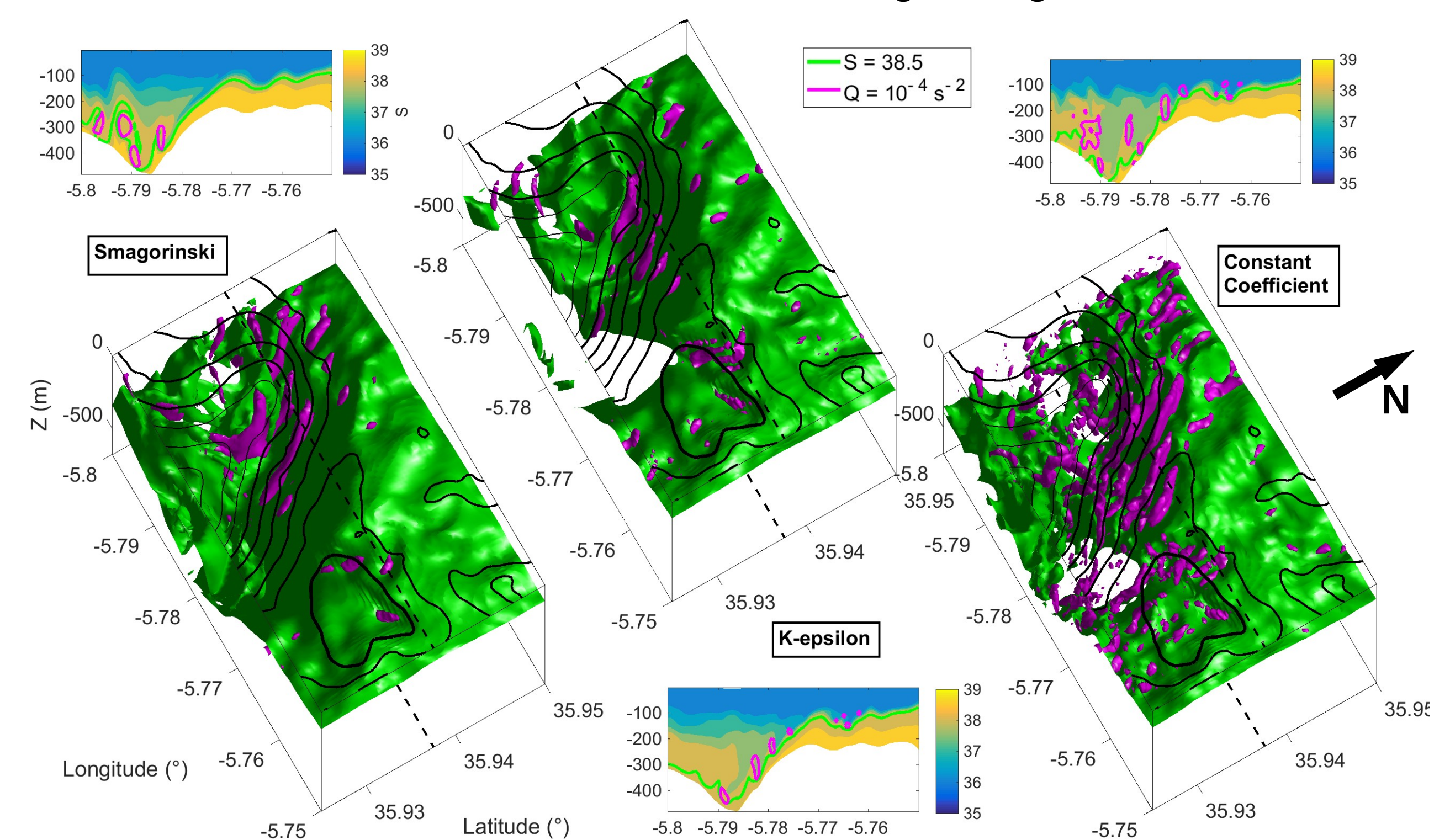


Fig. 3 : Sensitivity to turbulent closure schemes.

Isobathes (black), surface of constant salinity (green) & Q-parameter (pink) and vertical section of salinity for simulations (12/09/2017 - 3h40am) with different turbulent closure schemes (from left to right : Smagorinski, K-ε, and constant dissipation coefficients).

Dynamics of Internal Solitary Waves

LES of the generation, propagation and reflection of ISWs.

Sentinel 1 – SAR

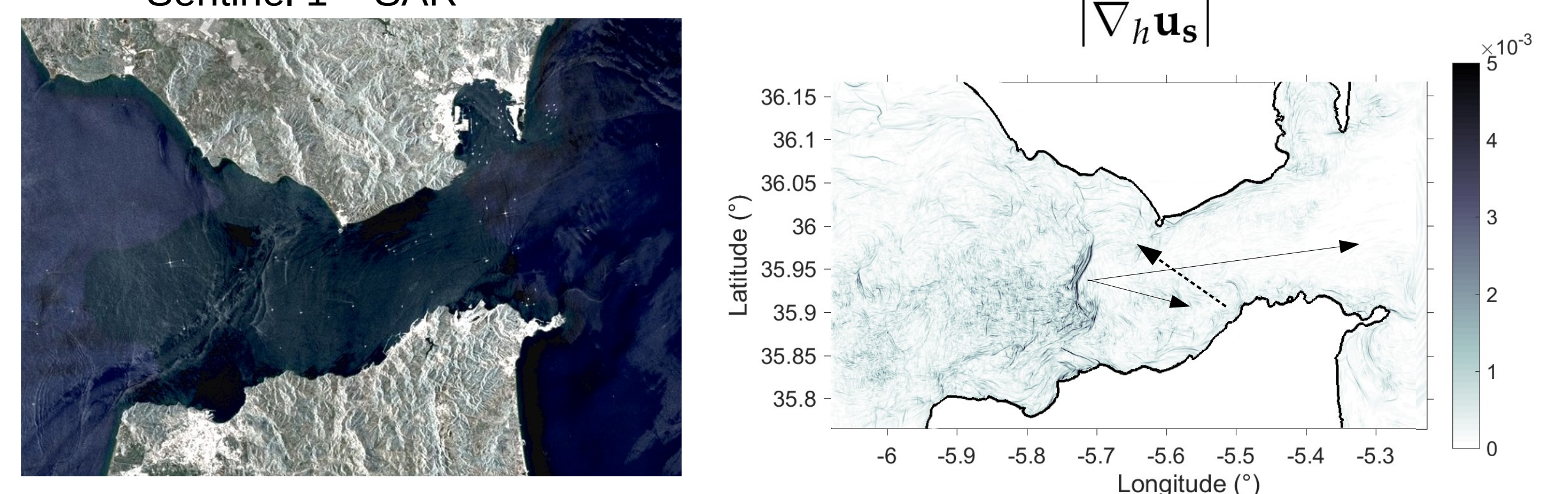


Fig. 5 : Comparison SAR / Simulation.

Left : Sentinel-1 Synthetic Aperture Radar (SAR) image (12/09/2017 - 6h18pm UTC).
Right : Norm of the gradient of surface horizontal velocity (s^{-1}) in the simulation (12/09/2017 - 6h30pm) and path of the ISW (reflection in dashed arrow).

Perspectives : Gibraltar 2020 Campaign

- Observing the small-scale physics in the Strait of Gibraltar
- Assessing the effect of different numerical schemes on mixing in the Strait

In September-October 2020, the field campaign GEPETO aims at making direct observations of hydraulic jumps, coherent mixing structures and ISWs.

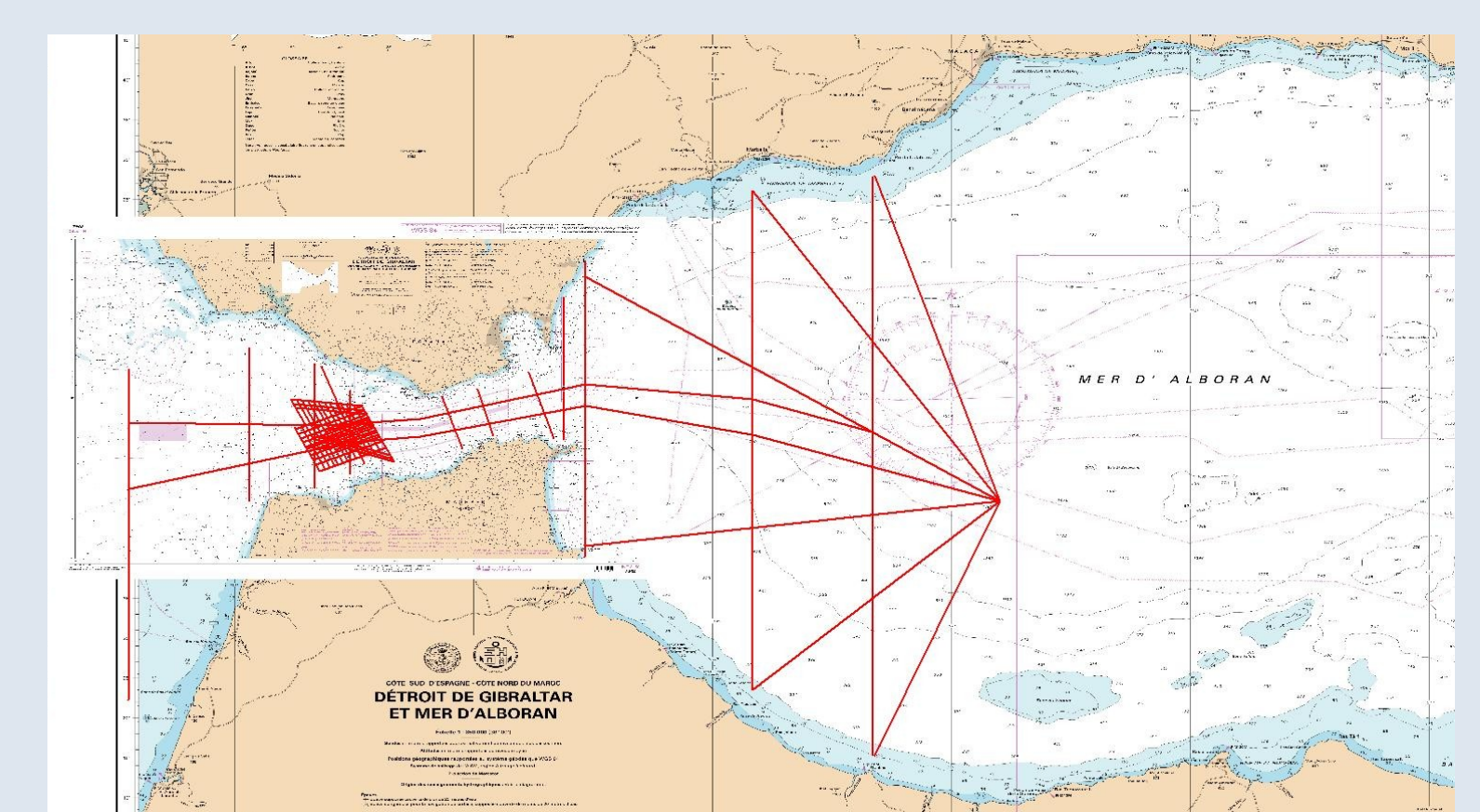


Fig. 6 : Potential radials for campaign GEPETO

References :

- Millot, C. Heterogeneities of in- and out-flows in the mediterranean sea. Progress in Oceanography 120, 254 – 278. (2014)
- Farmer, D., Armi, L. The flow of atlantic water through the strait of gibraltar. Progress in Oceanography 21, 1–103. (1988)
- Wesson, J., Gregg, M. Mixing at Camarinal Sill in the Strait of Gibraltar. Journal of Geophysical Research: Oceans 99, 9847–9878. (1994)
- Auclair, F., et al. A non-hydrostatic non-Boussinesq algorithm for free-surface ocean modelling. Ocean Modelling 132, 12 – 29. (2018)

- Hilt, M., et al. 2019. Numerical Modelling of Hydraulic Control, Solitary Waves and Primary Instabilities in the Strait of Gibraltar. Ocean Modelling. (In revision)
- http://www.enea.it/it/seguici/publicazioni/pdf-volumi/cresco-report-2016.pdf
- Lesieur, M., Métais, O., & Comte, P. Vortex dynamics. In Large-Eddy Simulations of Turbulence (pp. 21-38). Cambridge: Cambridge University Press.(2005)