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# LES Modelling of the Impact of the Topography on Large-scale Exchange Flow in the Strait of Gibraltar

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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 waters<sup>1</sup>. Several small-scale (< 1 km) phenomena contribute to this mixing :

- (a) **Small amplitude internal gravity waves** at the interface of Atlantic and Mediterranean waters.
- (b) **Hydraulic control** at Camarinal Sill (and other locations) caused by tidal currents : an **hydraulic jump** is formed<sup>2</sup>.
- (c) **Shear instabilities** in the Mediterranean vein<sup>3</sup>.
- (d) The hydraulic jump is released during inflowing conditions and propagates eastward as a train of **Internal Solitary Waves (ISWs)**<sup>2</sup>.

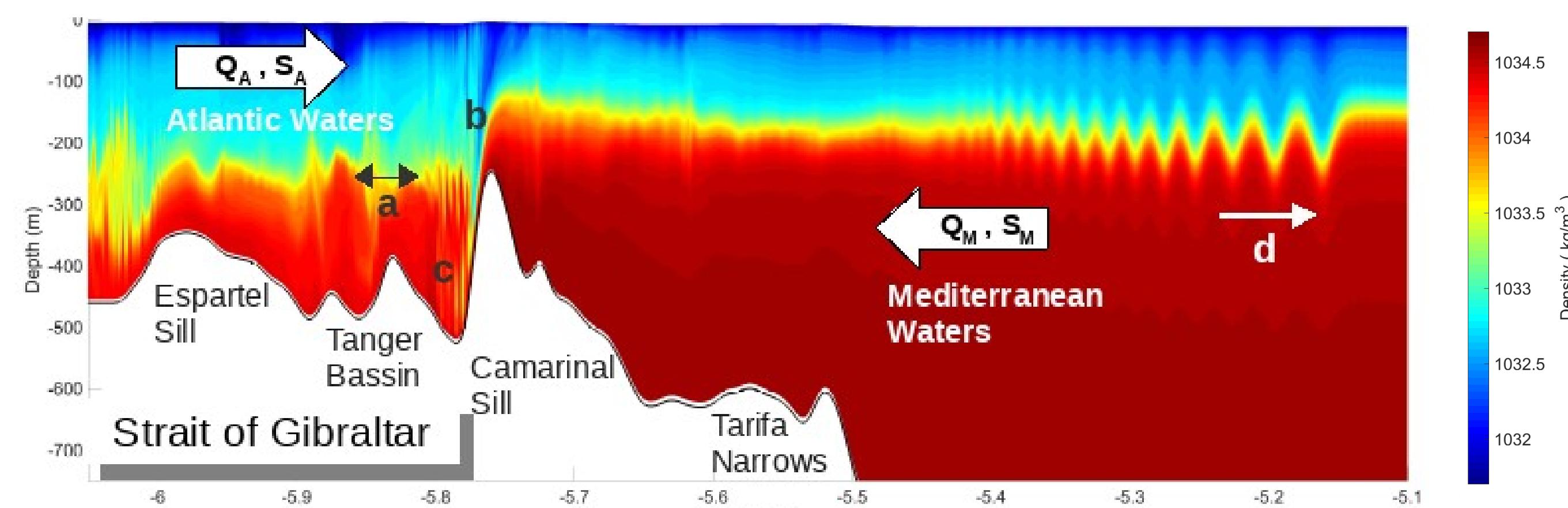


Fig. 1 : Vertical section of density in the longitudinal direction along the Strait of Gibraltar.

## Numerical Model : CROCO-NBQ

- CROCO is a free-surface, compressible, NH ocean model based on ROMS-AGRI.
- NH pressure computed in "Fast Mode" <sup>4,5</sup>.
- Configuration based on a SHOM HR bathymetry.
- Initialization and lateral forcing from the ENEA Mediterranean and black Sea forecasting system<sup>6</sup>.

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 (1s, 11, 400 m/s)
Number of vertical sigma levels	40
Horizontal resolution dx	45 m
Depth	Minimum 26 m Maximum 960 m
Vertical resolution	0.7 m
Advection scheme	WENO-5
Tidal components	$M_2, S_2, H_1, O_1$
Turbulent closure scheme	Smagorinsky or k-ε or no-closure scheme ( $K_p = v = 10^{-6} \text{ m}^2/\text{s}$ )
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 gradient<sup>7</sup> :

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

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

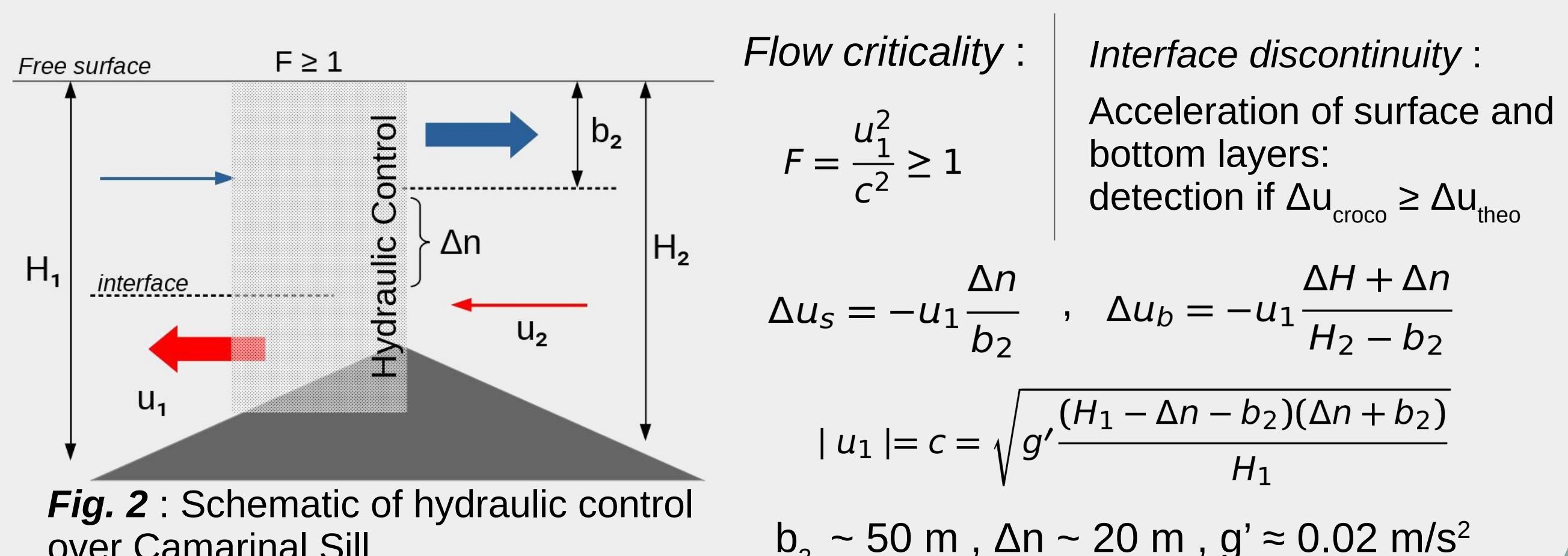


Fig. 2 : Schematic of hydraulic control over Camarinal Sill.

## Hydraulic Jump variability

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

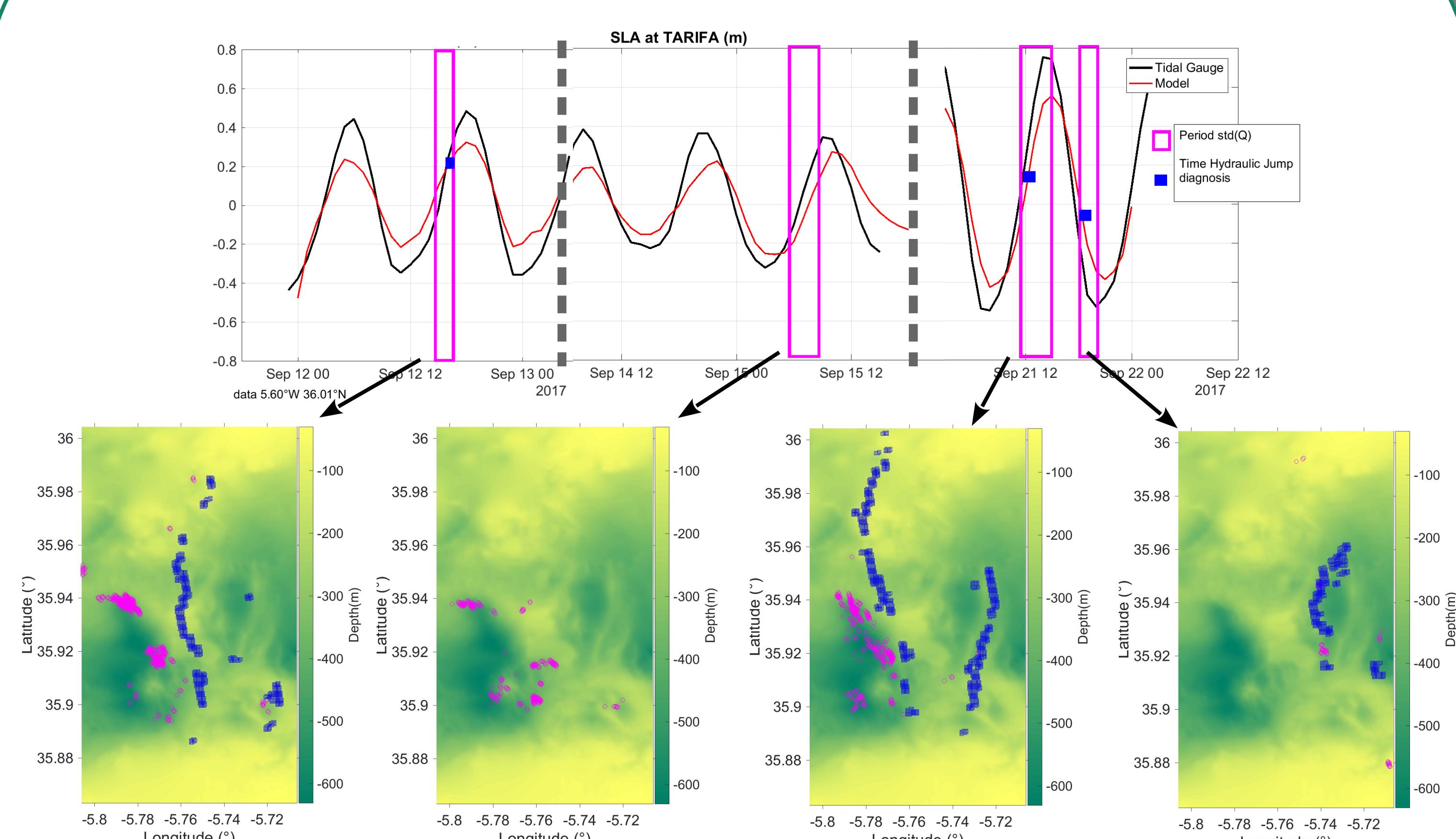


Fig. 4 : Tracking of hydraulic jumps and shear instabilities for several tidal regimes.

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.  
(○) 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.

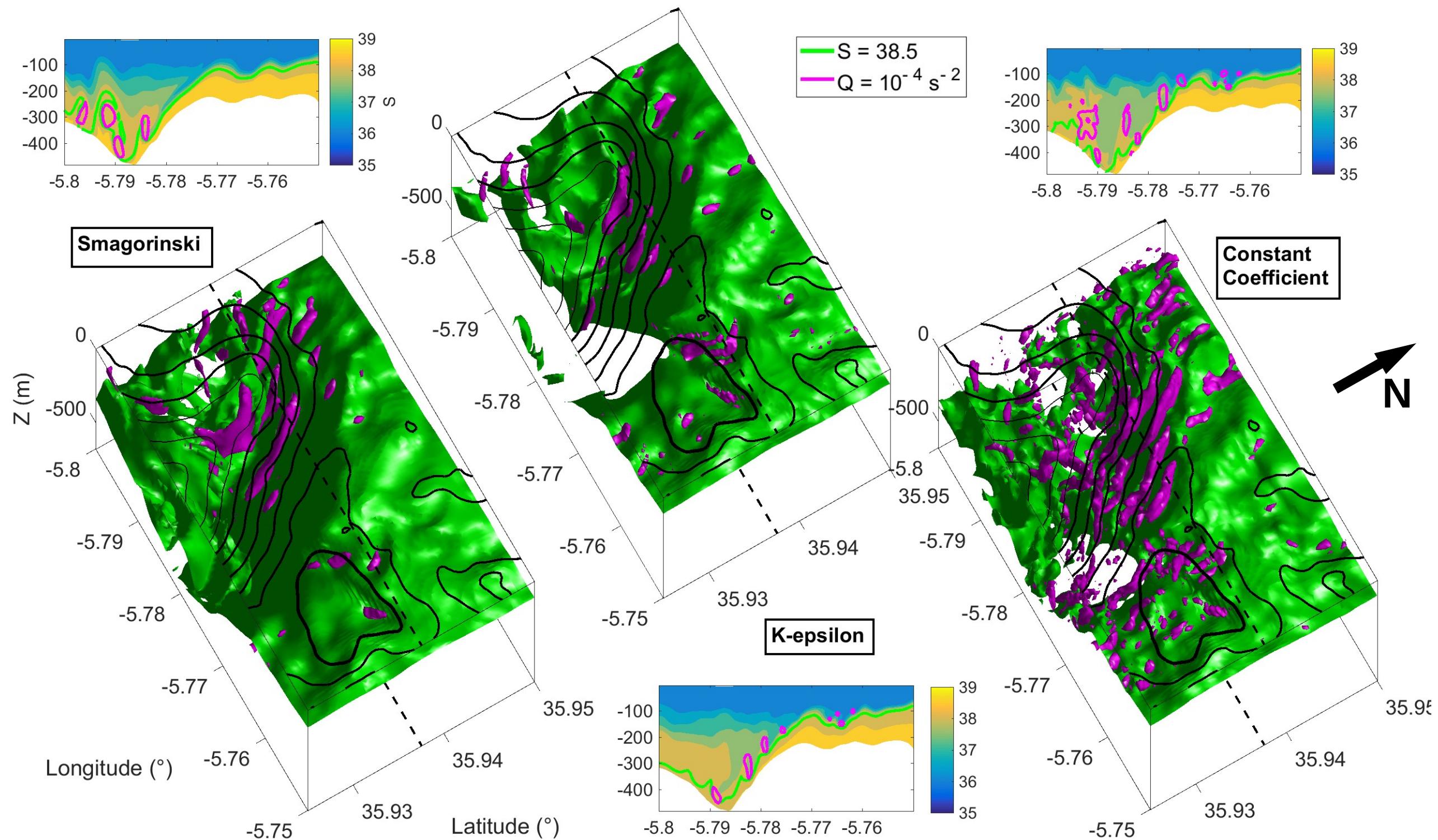


Fig. 3 : Sensitivity to turbulent closure schemes.

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.

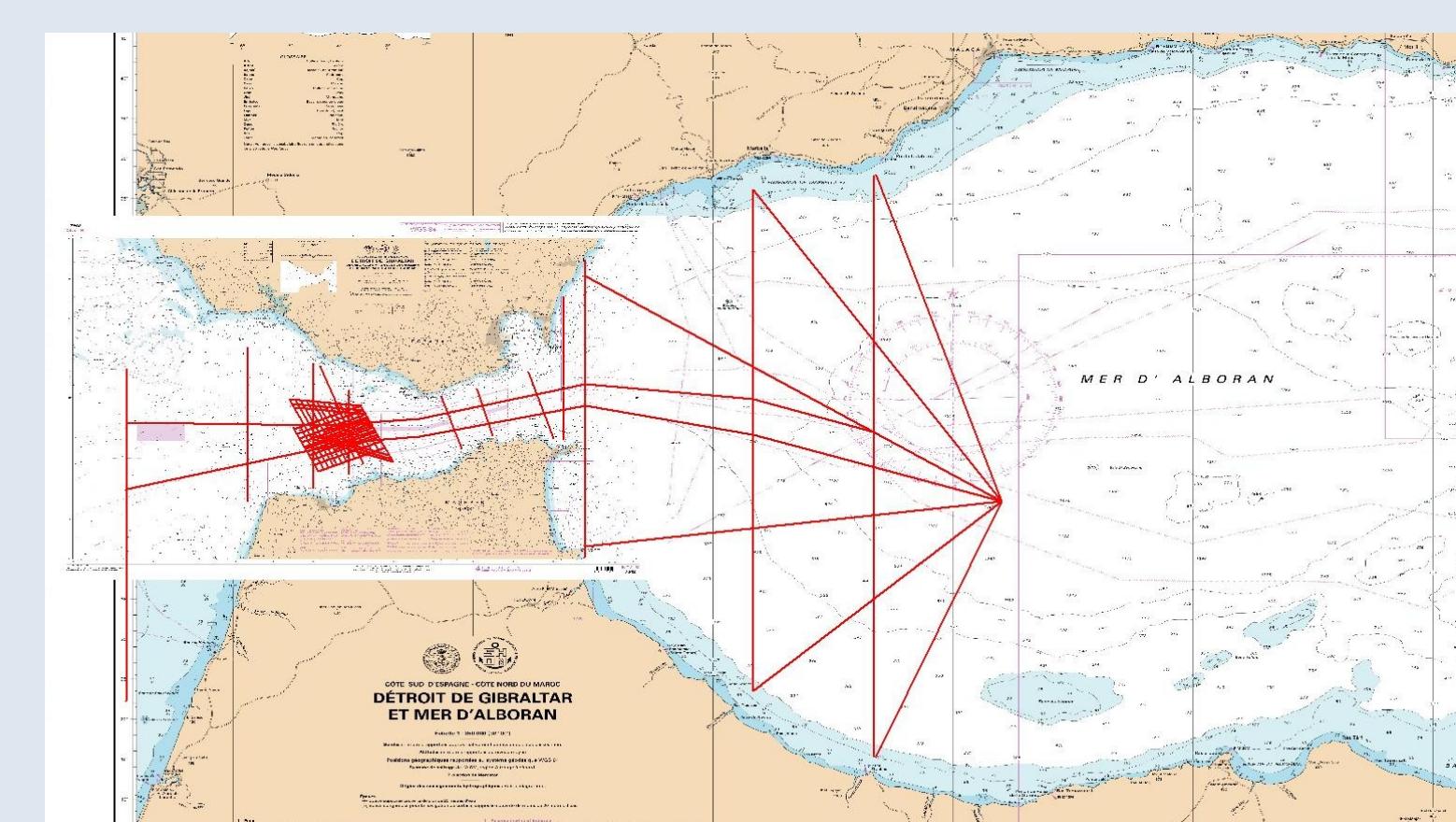


Fig. 6 : Potential radials for campaign GEPETO

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