The effects of nonhydrostaticity on the simulated exchange flow through the Strait of Gibraltar.

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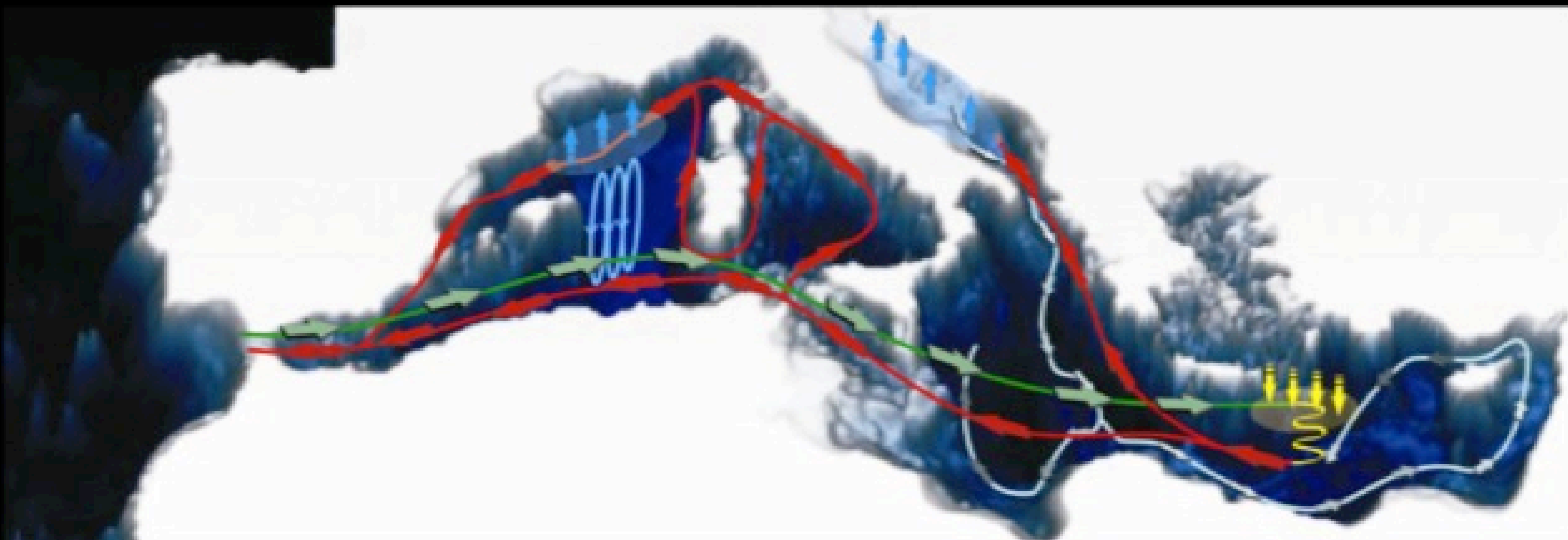
Background – Mediterranean Thermohaline Circulation

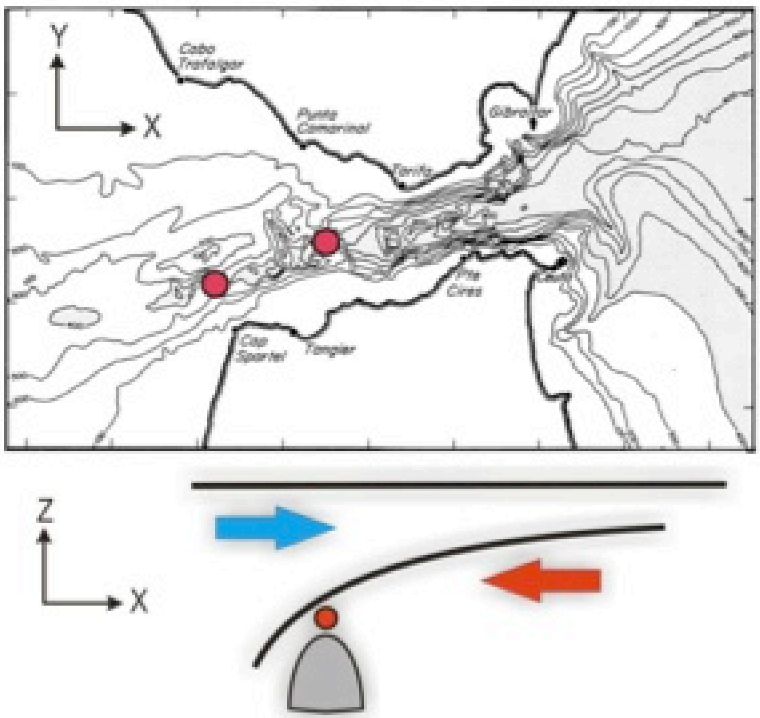
The Mediterranean Sea is a semi-enclosed basin displaying an active thermohaline circulation that is sustained by the atmospheric forcing and controlled by the narrow and shallow Strait of Gibraltar



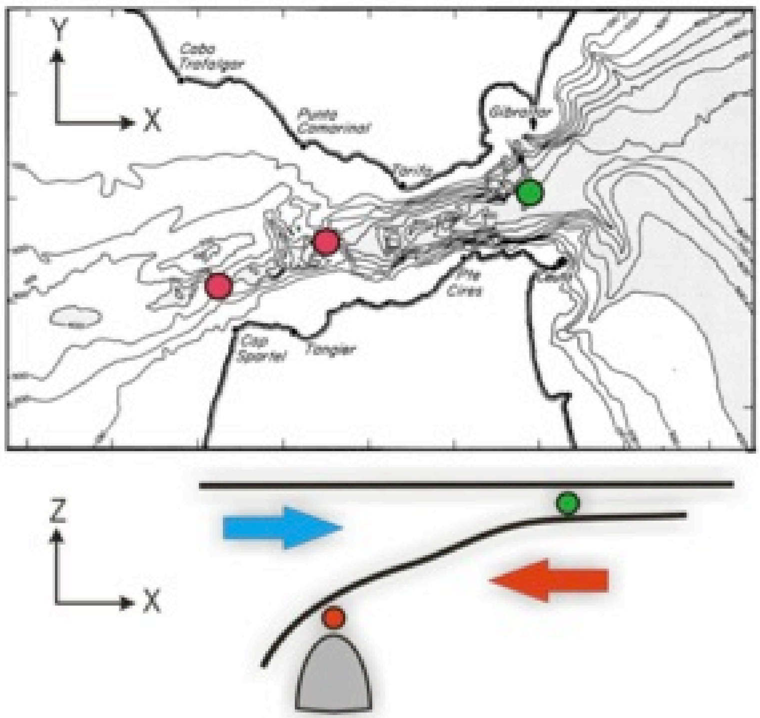
Mediterranean Atlantic Water (MAW)
Levantine Intermediate Water (LIW)
Eastern Mediterranean Deep water (EMDW)
Western Mediterranean Deep water (WMDW)
Cooling
Heating

Background – Strait of Gibraltar hydraulic

Submaximal Exchange

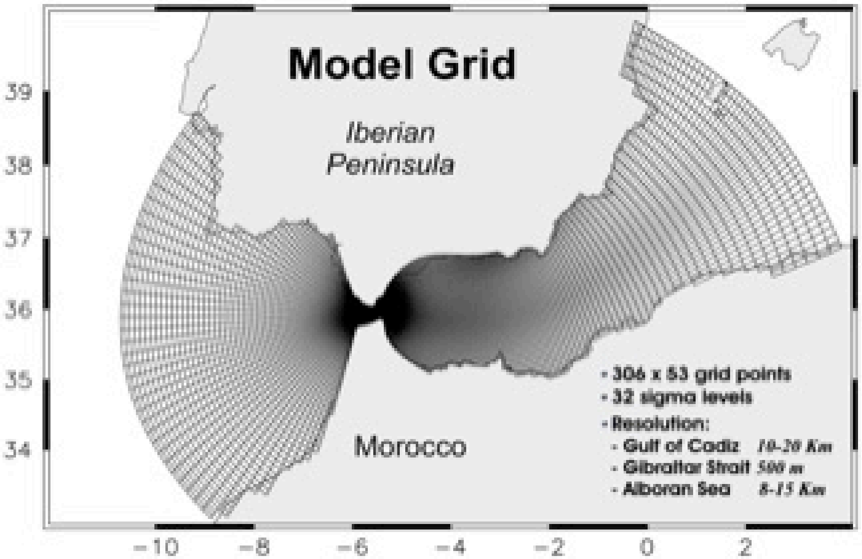


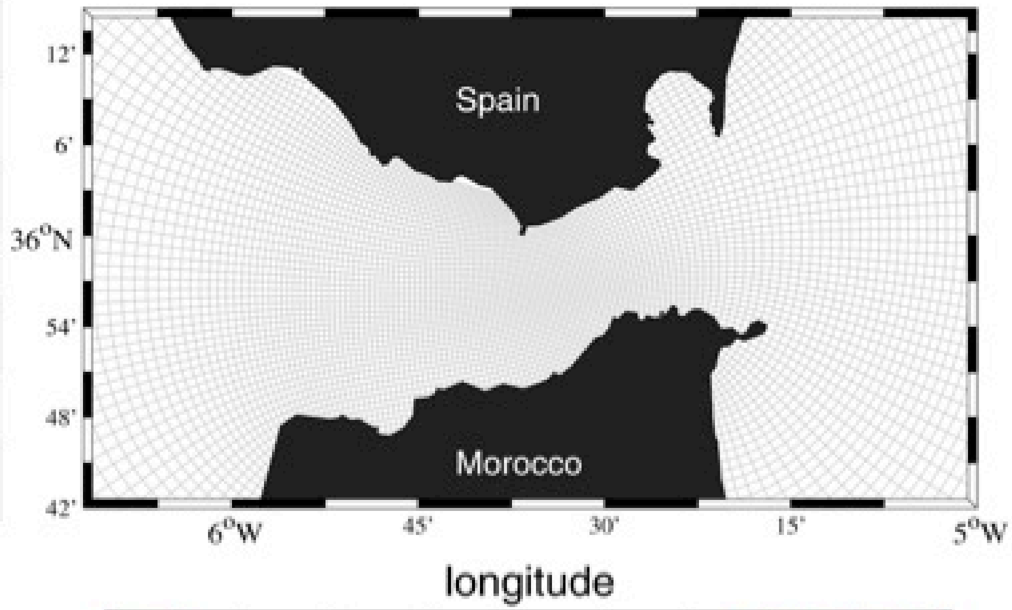
Maximal Exchange



If the exchange is subject to one hydraulic control in the western part of the Strait, the regime is called submaximal, while if the flow exchange is also controlled in the eastern part of the Strait along TN, the regime is called maximal.

Background – Strait of Gibraltar – POM model





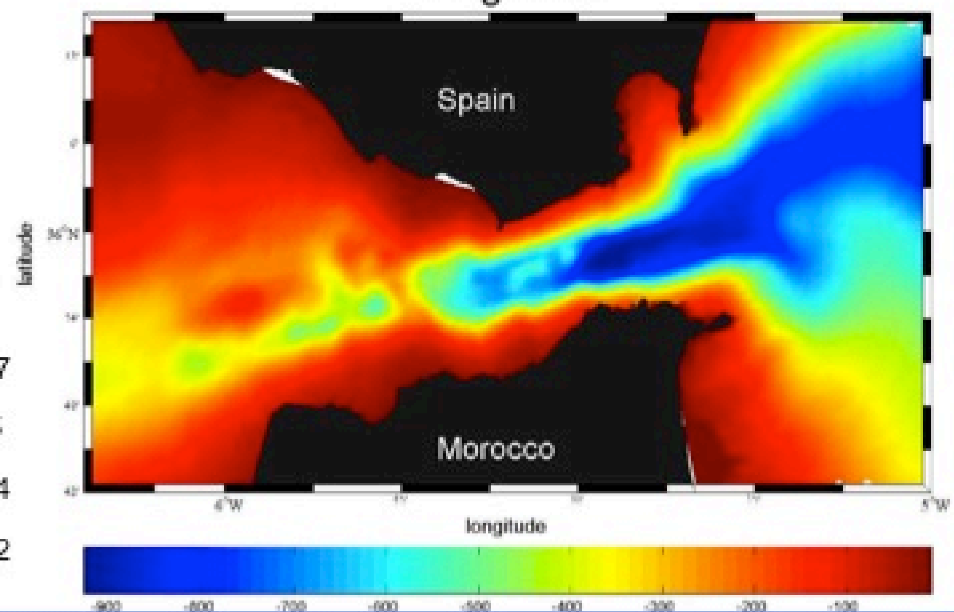
Modified POM

Max Hor. Resolution: 300 m

External Time-Step: 0.1 sec

O_1 K_1 diurnal tidal component

M_2 S_2 diurnal tidal component



•Sannino et al, JPO, 2009

•Sanchez et al, JGR, 2009

•Garrido et al, JGR, 2008

•Lafuente et al, JGR, 2007

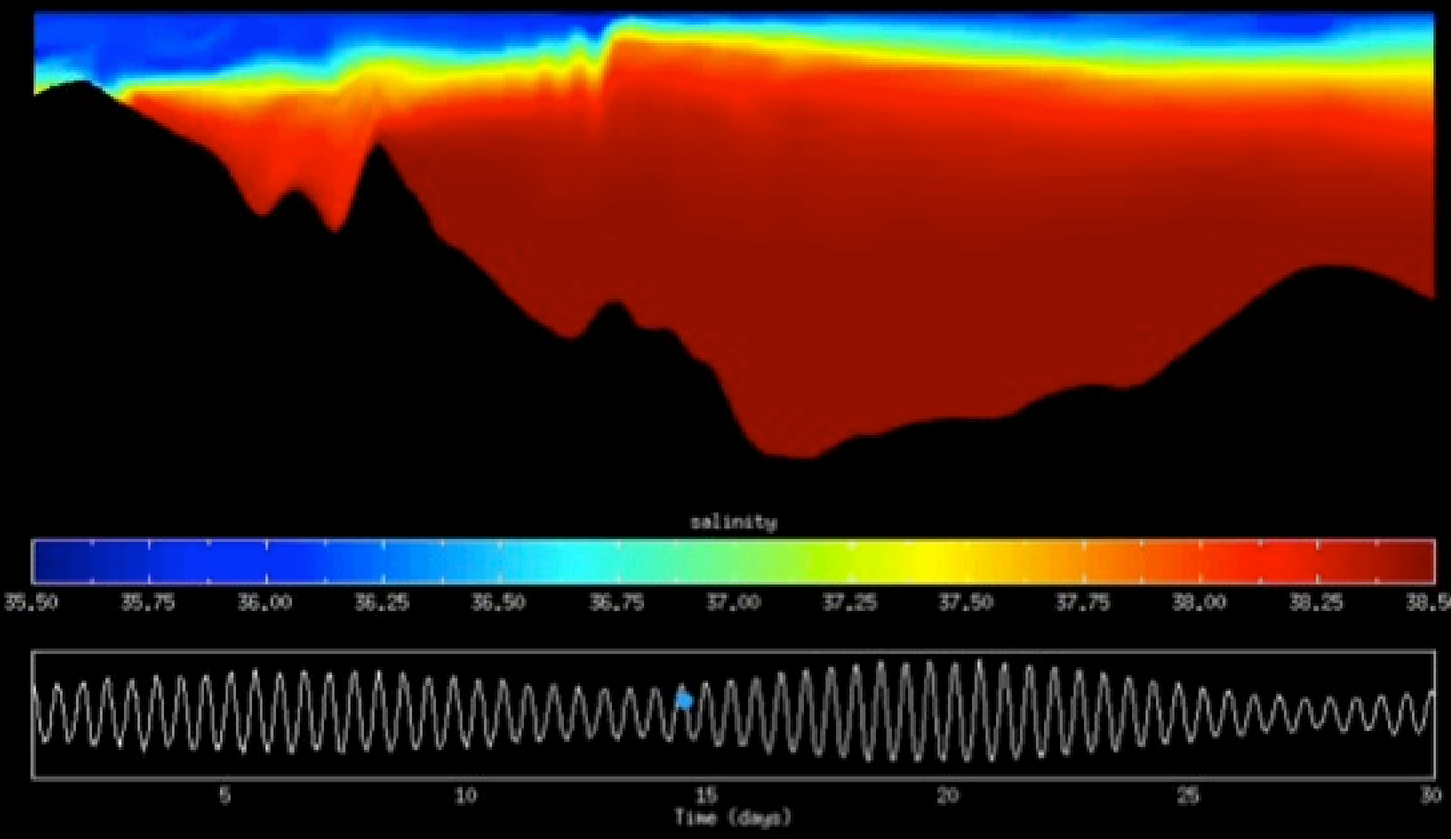
•Sannino et al, JGR, 2007

•Sannino et al , NC, 2005

•Sannino et al, JGR, 2004

•Sannino et al, JGR, 2002

Background – POM model simulation



salinity along-strait section

Background – POM model validation

Tidal Components comparison
Surface elevation

TABLE 1. Comparison between Observed and Predicted Amplitudes A and Phases P of M_2 tidal elevation.

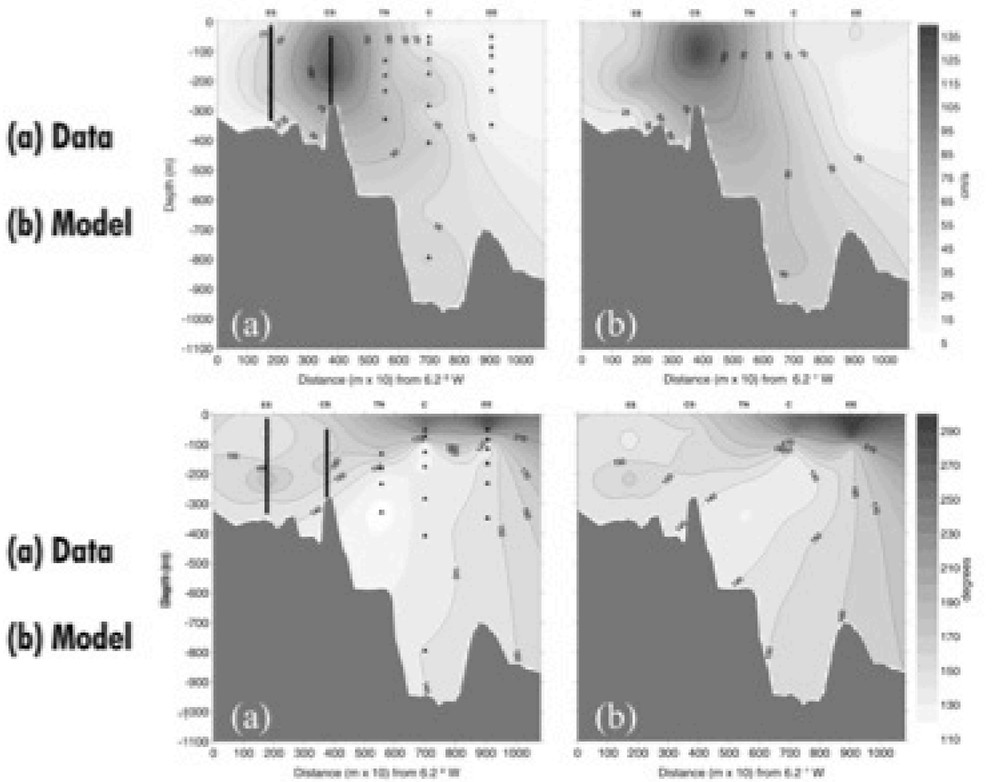
			Observed M_2		Predicted M_2		Predicted - Observed		
Location	Latitude	Longitude	A,cm	P,deg	A,cm	P,deg	A,cm	A,%	P,deg
			Tsimplis et al. (1995)						
Gibraltar	36°08'	05°21'	29.8	46.0	29.5	46.0	-0.3	1.0	+0.0*
			García-Lafuente (1986)						
Pta. Gracia	36°05.4'	05°48.6'	64.9 ± 0.2	49.0 ± 0.5	67.6	53.8	+2.7	4.1	+4.5
Tarifa	36°00.2'	05°36.4'	41.5 ± 0.2	57.0 ± 0.5	43.5	49.7	+2.0	4.8	-7.3
Pta. Cires	35°54.7'	05°28.8'	36.4 ± 0.2	46.5 ± 0.5	35.0	54.9	-1.4	3.8	+8.4
Pta. Carnero	36°04.3'	05°25.7'	31.1 ± 0.2	47.5 ± 0.5	30.8	47.4	-0.3	0.9	-0.1
			Candela et al. (1990)						
DN	35°58'	05°46'	60.1	51.8	58.2	57.8	-1.9	3.1	+6.0
DS	35°54'	05°44'	54.0	61.8	54.1	64.1	+0.1	0.2	+2.3
SN	36°03'	05°43'	52.3	47.6	52.3	52.9	0.0	0.0	+5.3
SS	35°59'	05°43'	57.1	66.8	56.8	67.4	-0.3	0.5	+0.6
DW	35°53'	05°58'	78.5	56.1	76.6	62.7	-1.9	2.4	+6.6
TA	36°01'	05°36'	41.2	41.2	43.5	49.7	+2.3	5.5	+8.5
AL	36°08'	05°26'	31.0	48.0	30.0	49.7	-1.0	3.2	+1.7
CE	35°53'	05°18'	29.7	50.3	29.5	51.5	-0.2	0.6	+1.2
DPS	36°00'	05°34'	44.4	47.6	42.1	47.6	-2.3	5.1	+0.0

*Calibration.

Max Differences:
Amp: 3.6 cm
Pha: 11°

Sannino et al.,JPO, 2009

Tidal Components comparison
Along-strait velocity



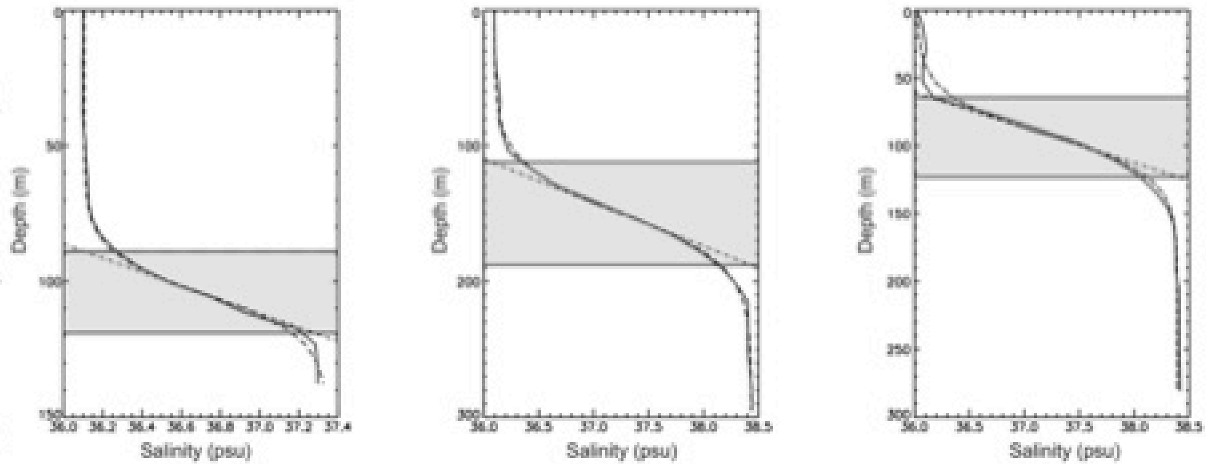
Max Differences:
Amp: 10 cm s^{-1}
Pha: 20°

Sánchez-Román et al., JGR, 2009

$$\tilde{F}_1^2 = \left(\frac{1}{w_2}\int_{y_{1L}}^{y_{1R}} \frac{g'_{21}H_1}{u_1^2}dy_1\right)^{-1}$$

$$\tilde{F}_2^2 = \left(\frac{1}{w_2}\int_{y_{2L}}^{y_{2R}} \frac{g'_{32}H_2}{u_2^2}dy_2\right)^{-1}$$

$$\tilde{F}_3^2 = \left(\frac{1}{w_3}\int_{y_{3L}}^{y_{3R}} \frac{g'_{32}H_3}{u_3^2}dy_3\right)^{-1}$$



$$g'_{21} = g(\rho_2 - \rho_1)/\bar{\rho}, \quad g'_{32} = g(\rho_3 - \rho_2)/\bar{\rho}, \quad r = \frac{\rho_2-\rho_1}{\rho_3-\rho_1}$$

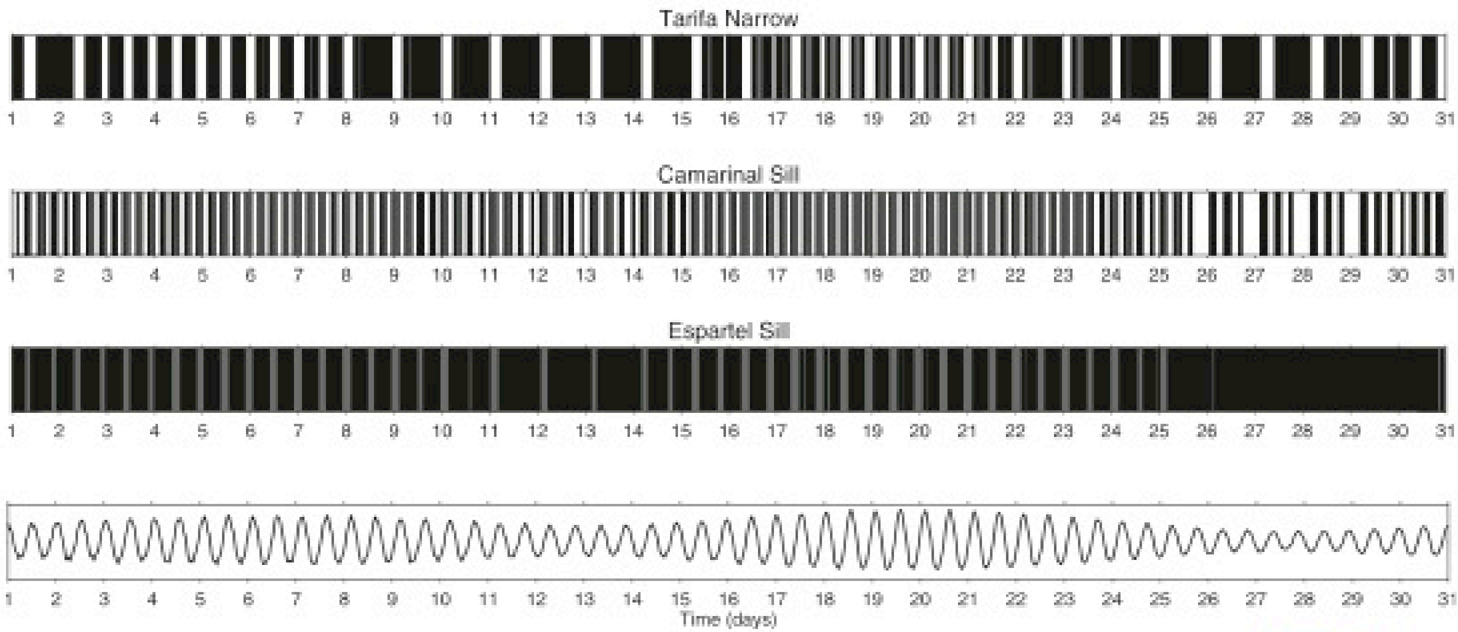
$$\tilde{F}_1^2 + \left(\frac{1-r}{r} + \frac{w_3}{w_2}\right)\tilde{F}_2^2 + \tilde{F}_3^2 - \frac{w_3}{w_2}\tilde{F}_1^2\tilde{F}_2^2 - \tilde{F}_1^2\tilde{F}_3^2 - \frac{1-r}{r}\tilde{F}_2^2\tilde{F}_3^2 = 1$$

$$\frac{w_3}{w_2}\tilde{F}_2^2 = -\frac{(\tilde{F}_1^2-1)(\tilde{F}_3^2-1)}{(\tilde{F}_1^2-1)+\beta(\tilde{F}_3^2-1)}$$

$$\beta = \frac{w_2(1-r)}{w_3 r}$$

Sannino et al, JPO, 2009

Background – POM model and hydraulics



Bars indicating the presence of provisional supercritical flow with respect to one mode (black) and with respect to both modes (grey) in the three main regions of the Strait: Espartel Sill, Camarinal Sill and Tarifa Narrow. Lower panel indicates tidal elevation at Tarifa.

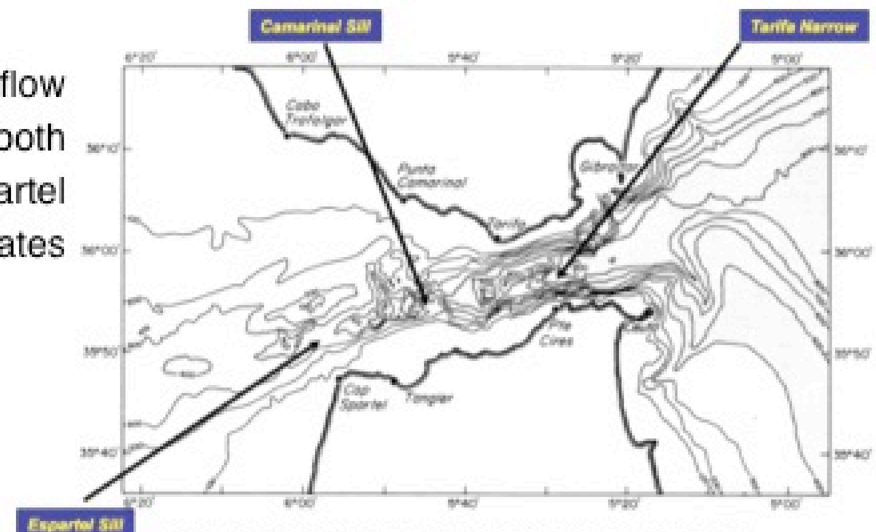
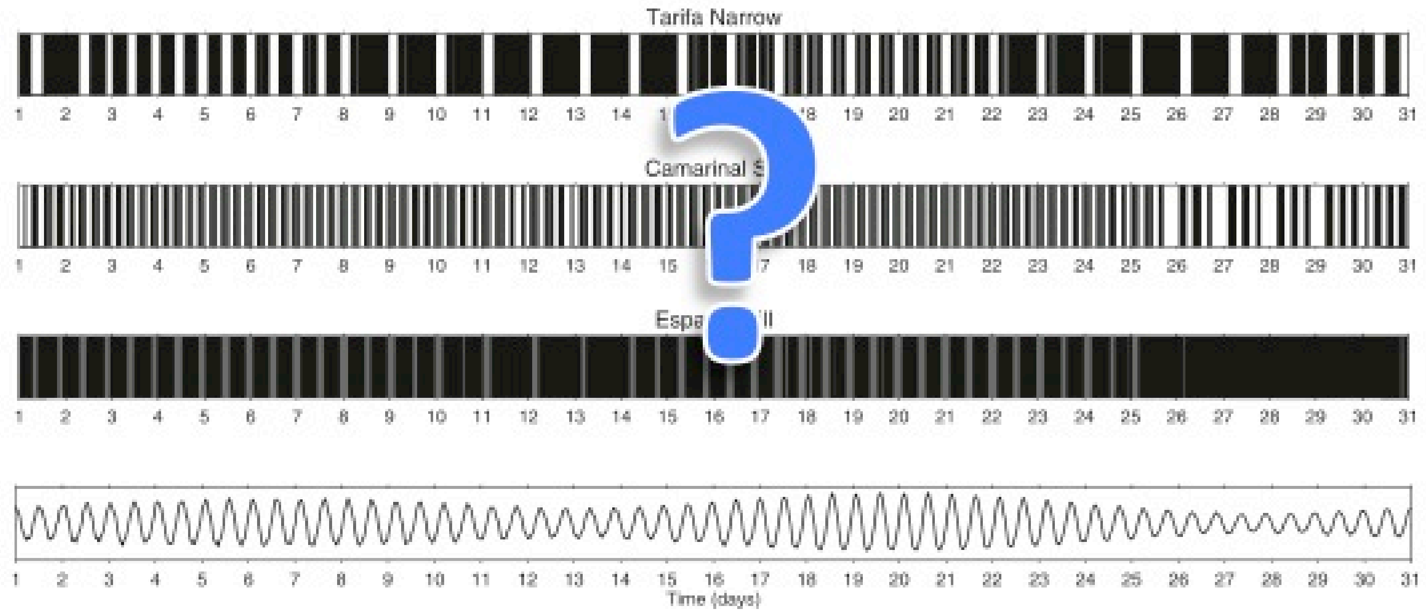


Chart of the Strait of Gibraltar showing the principal geographic features. Areas deeper than 400 m are shaded

Motivation of the work

Are the hydraulic results model depended?



To answer the question the exchange flow simulated by POM has been compared with the exchange flow simulated by a very high resolution non-hydrostatic model implemented for the Strait region.

The non-hydrostatic model used is the MITgcm.

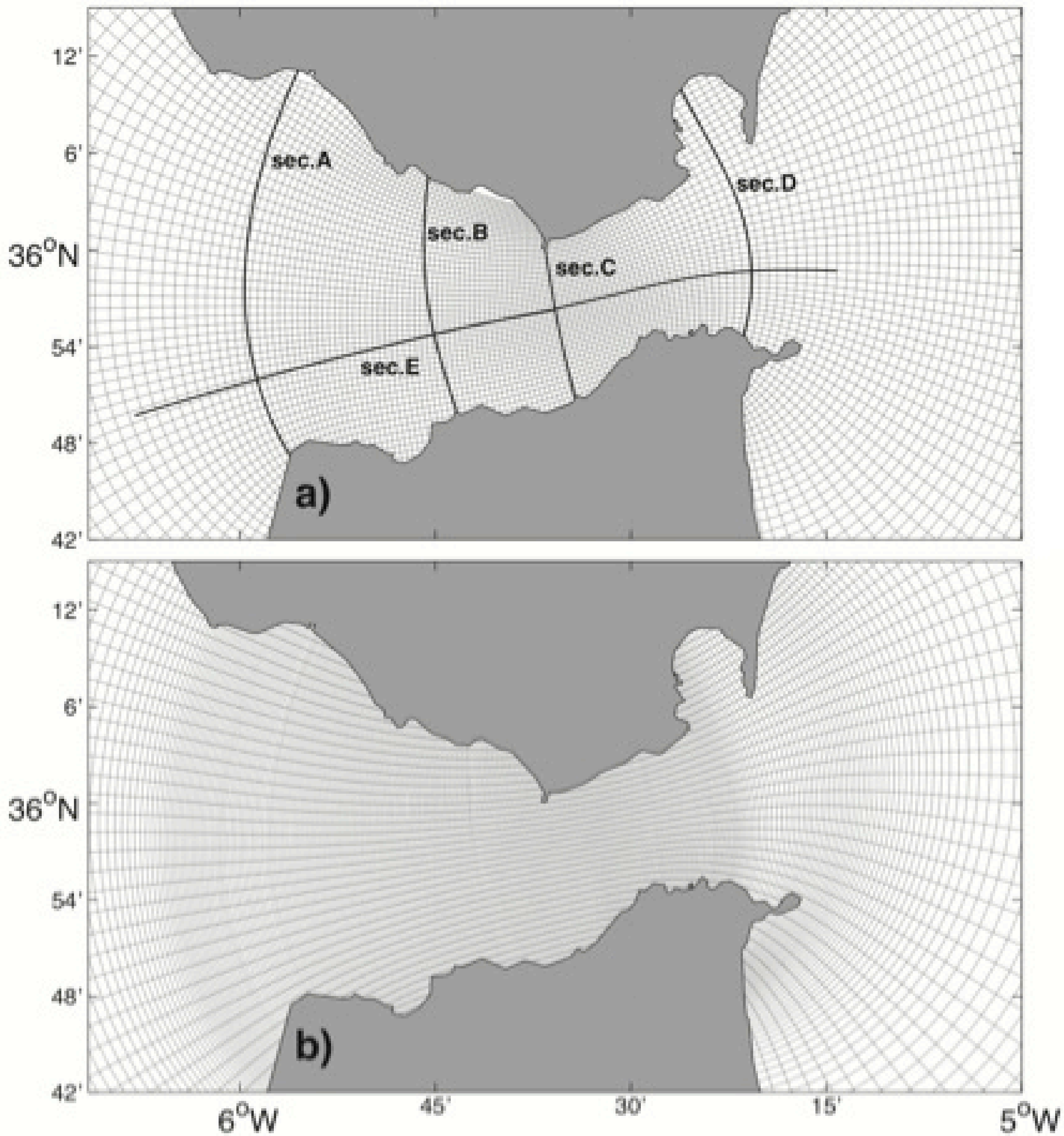
Why?

As recently demonstrated by Legg et all., OM 2006, the non-hydrostatic version of the MITgcm, when implemented at very high resolution, is able to explicitly capture the largest-scale mixing processes responsible for mixing and entrainment. This means that the model does not need a specific parameterizations for the entrainment and mixing and can be considered as a mixing permitting model.

MITgcm vs POM : model grids

POM grid
Max resolution
300 m

MITgcm grid
Max resolution
25 m
(only 25% of the actual grid is shown)

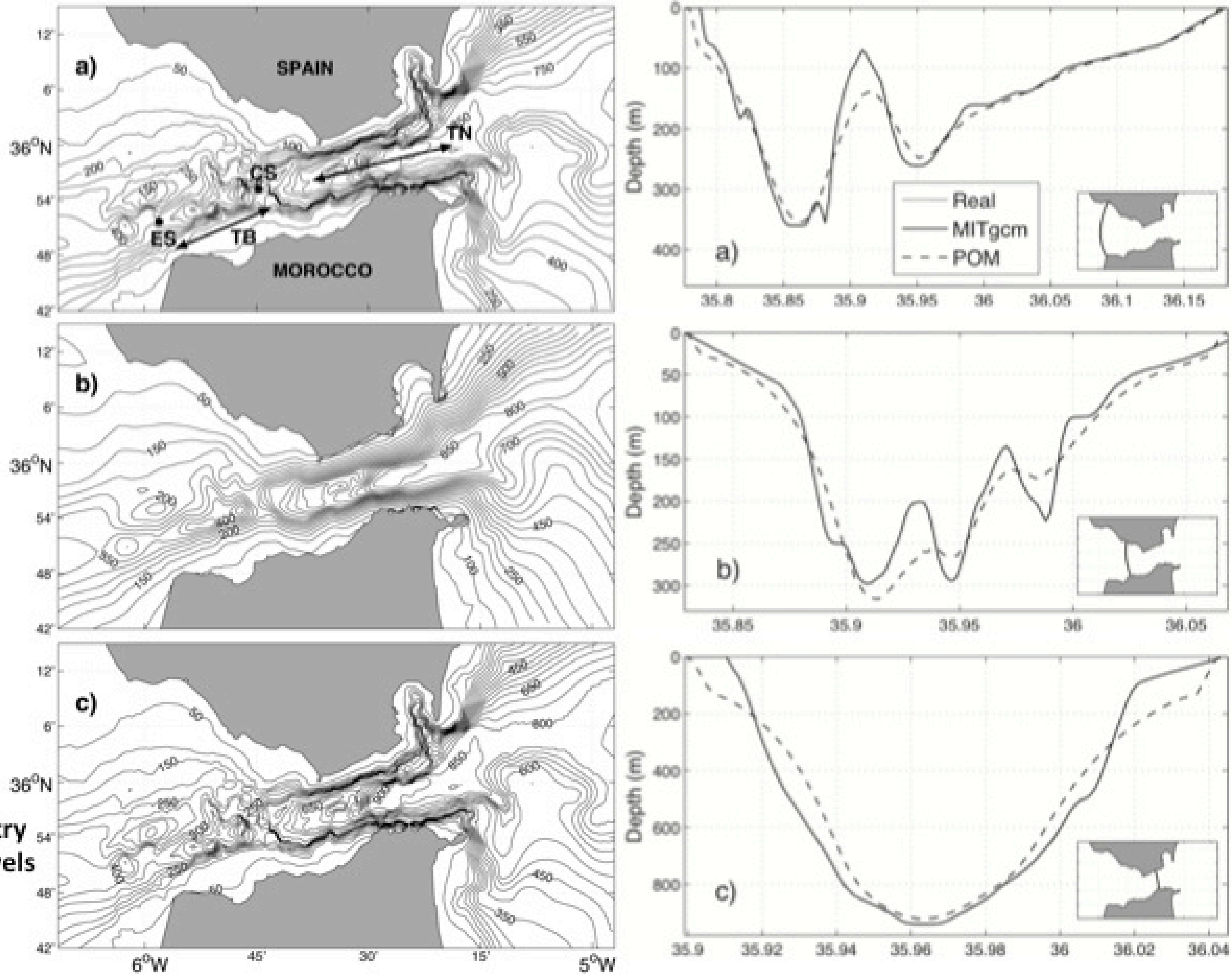


MITgcm vs POM : model bathymetry

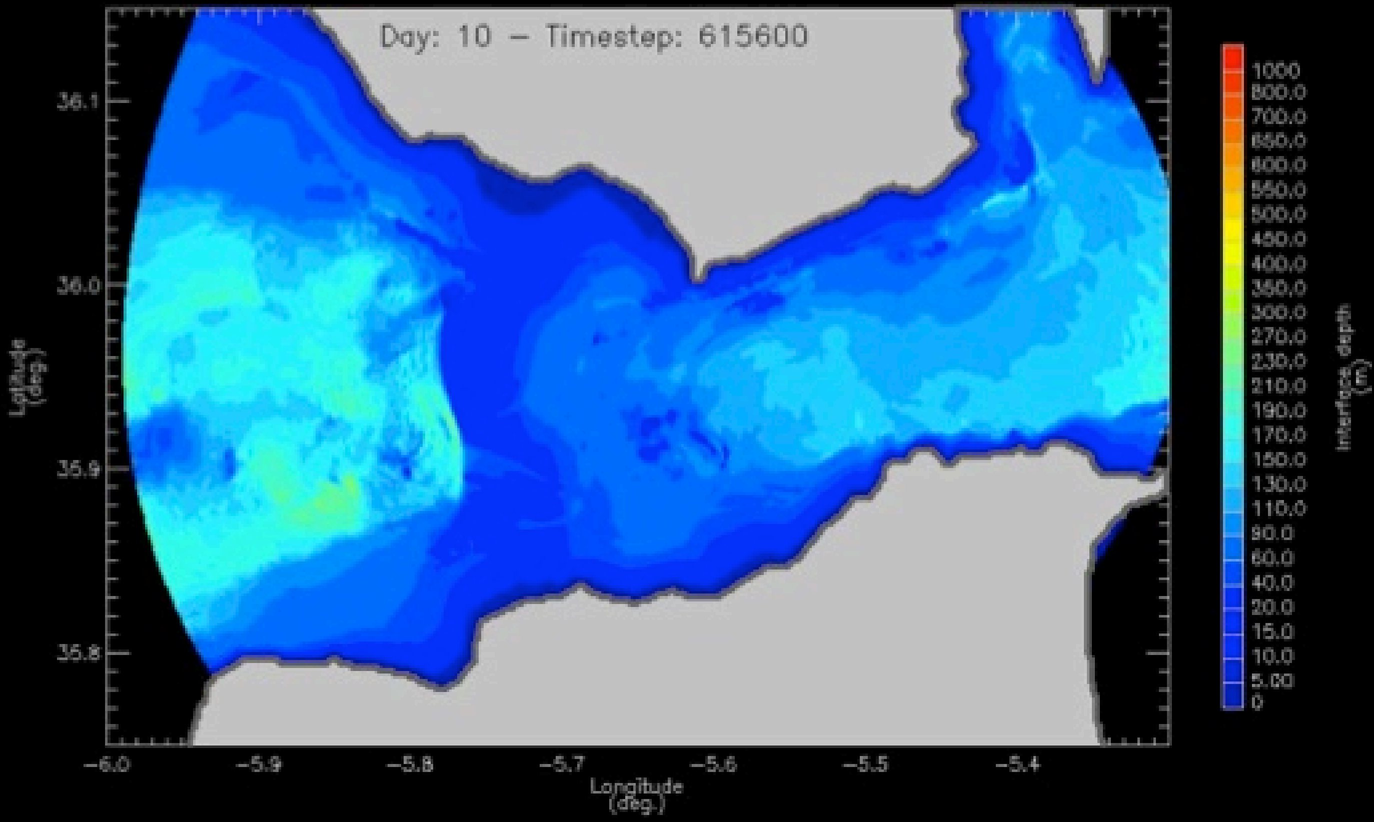
Real bathymetry

POM bathymetry
32 sigma-levels

MITgcm bathymetry
53 vertical zeta-levels
(partial cell)

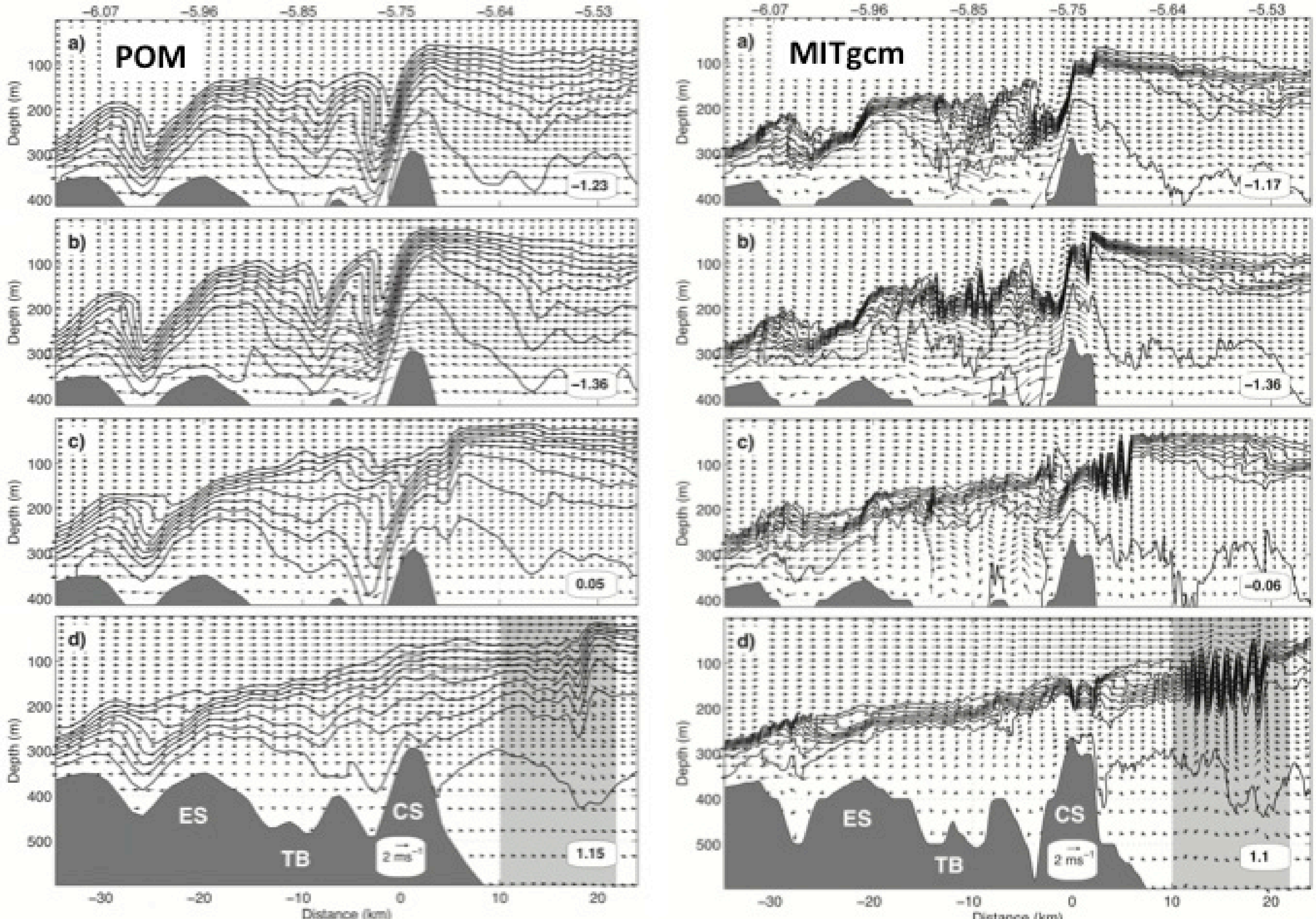


MITgcm model simulation



Interface depth evolution

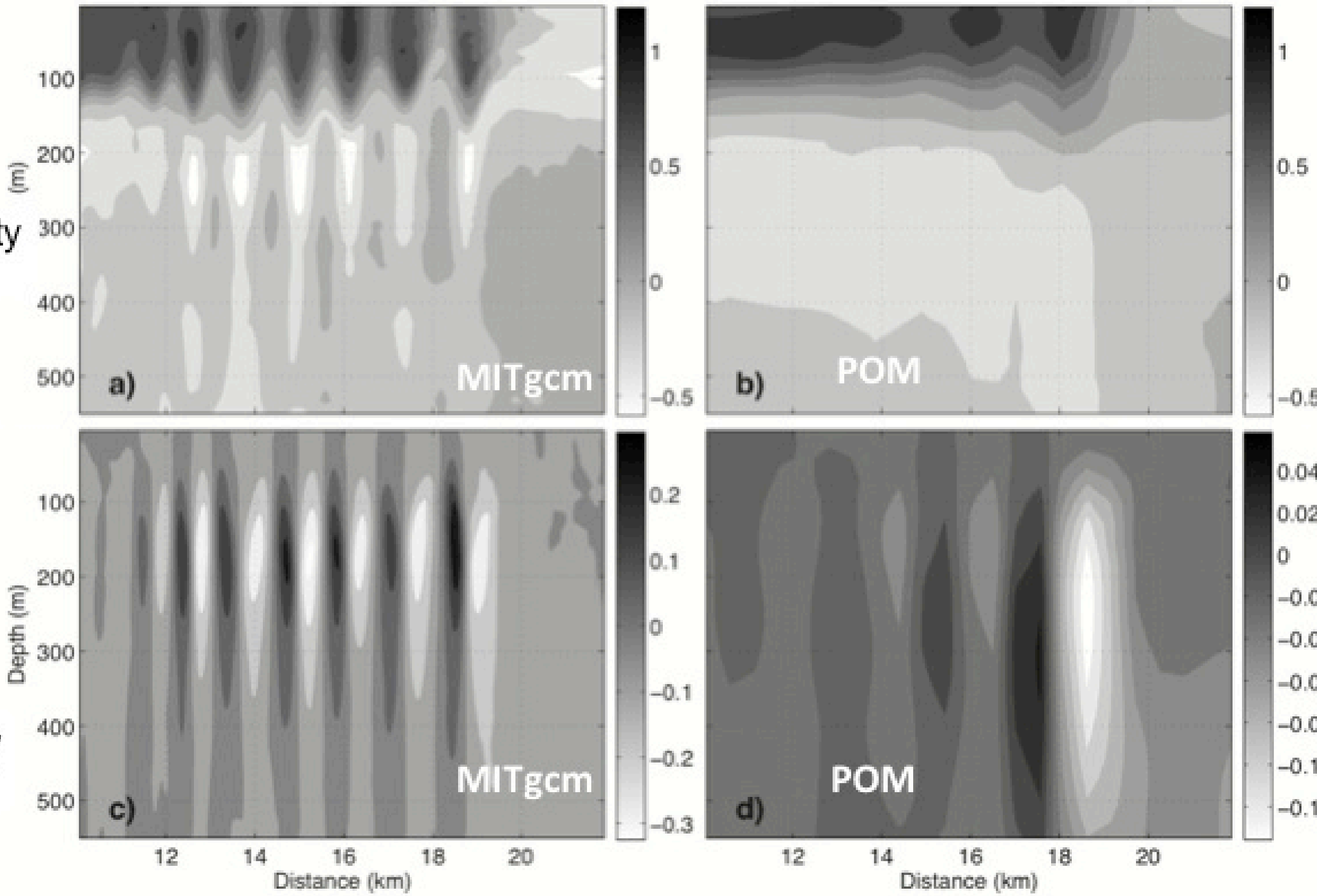
MITgcm vs POM – Internal bore evolution



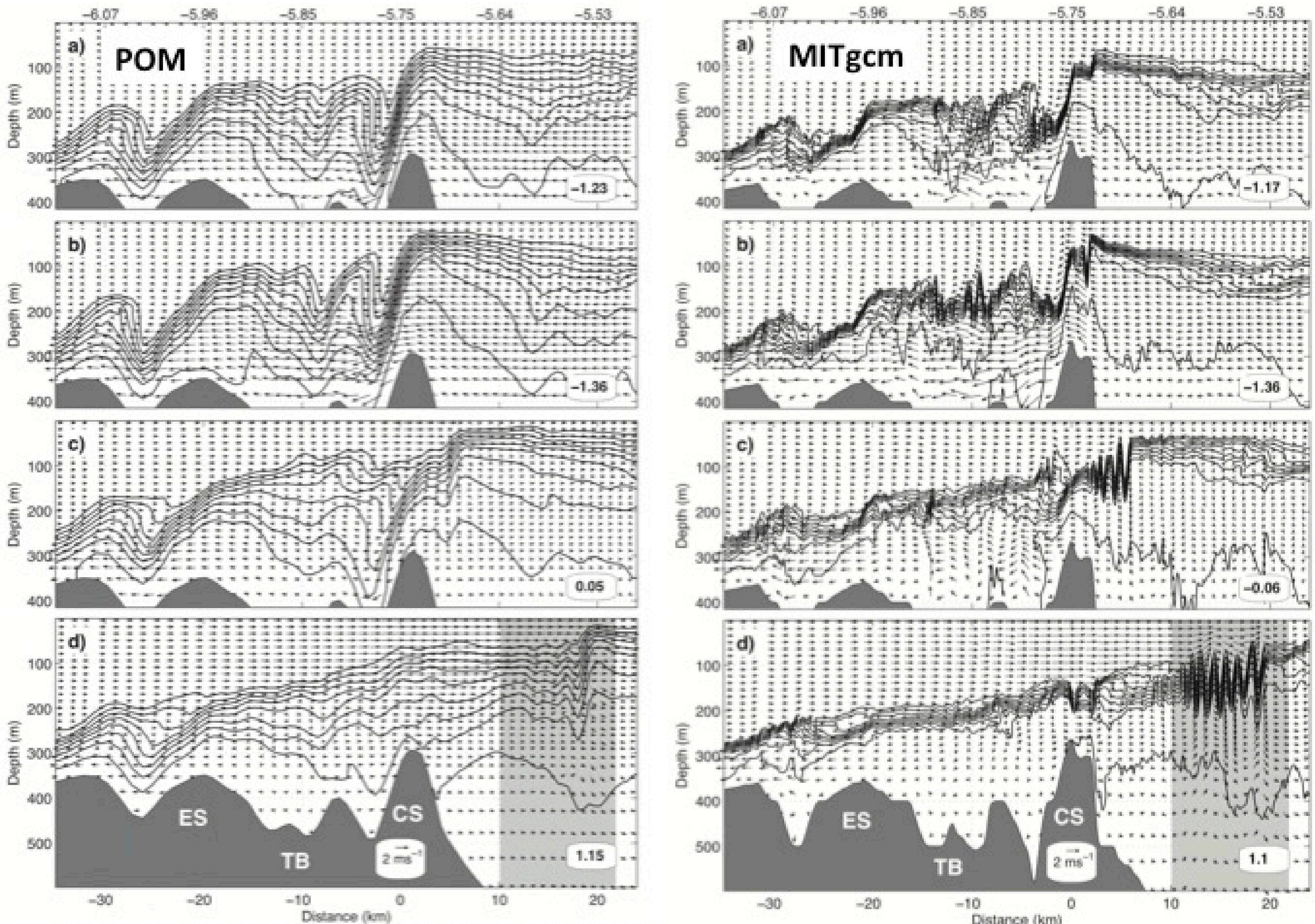
MITgcm vs POM – Internal bore evolution

Horizontal velocity (m/s)

Vertical velocity (m/s)

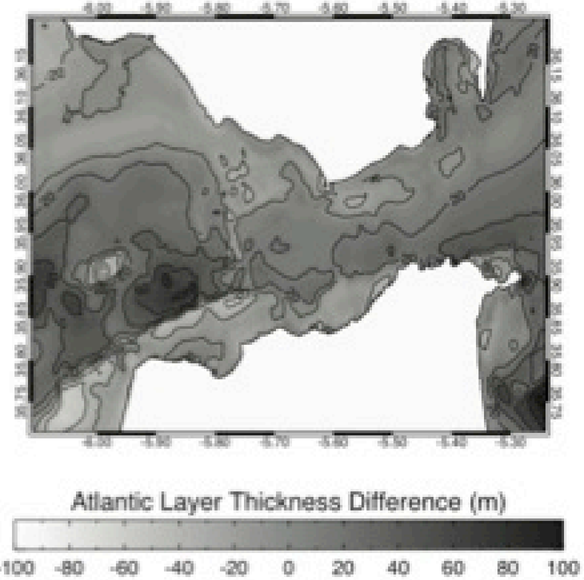


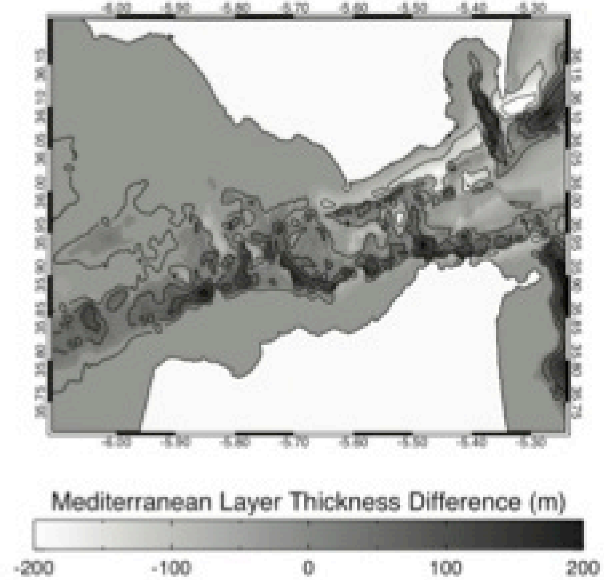
MITgcm vs POM – Internal bore evolution



Layer thickness difference: MITgcm – POM

POM underestimate west of CS





POM underestimate west of CS

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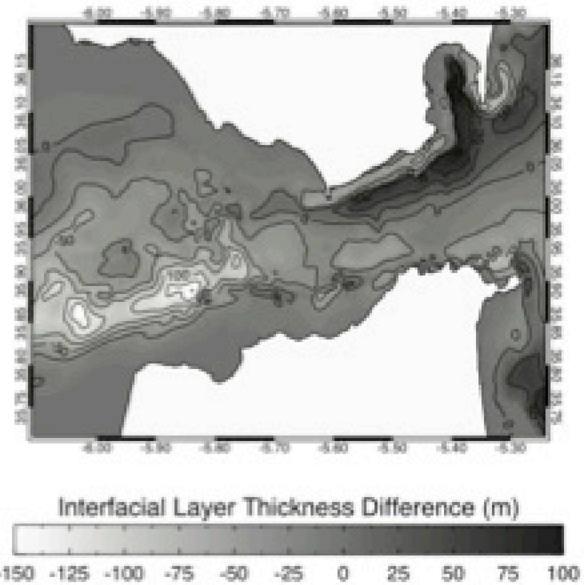
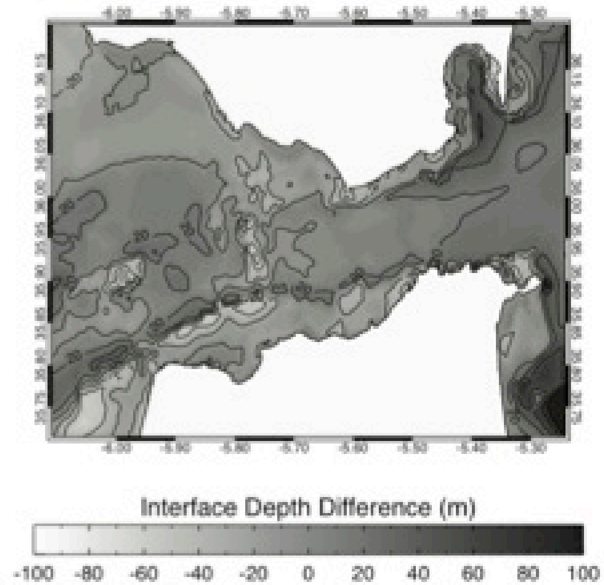




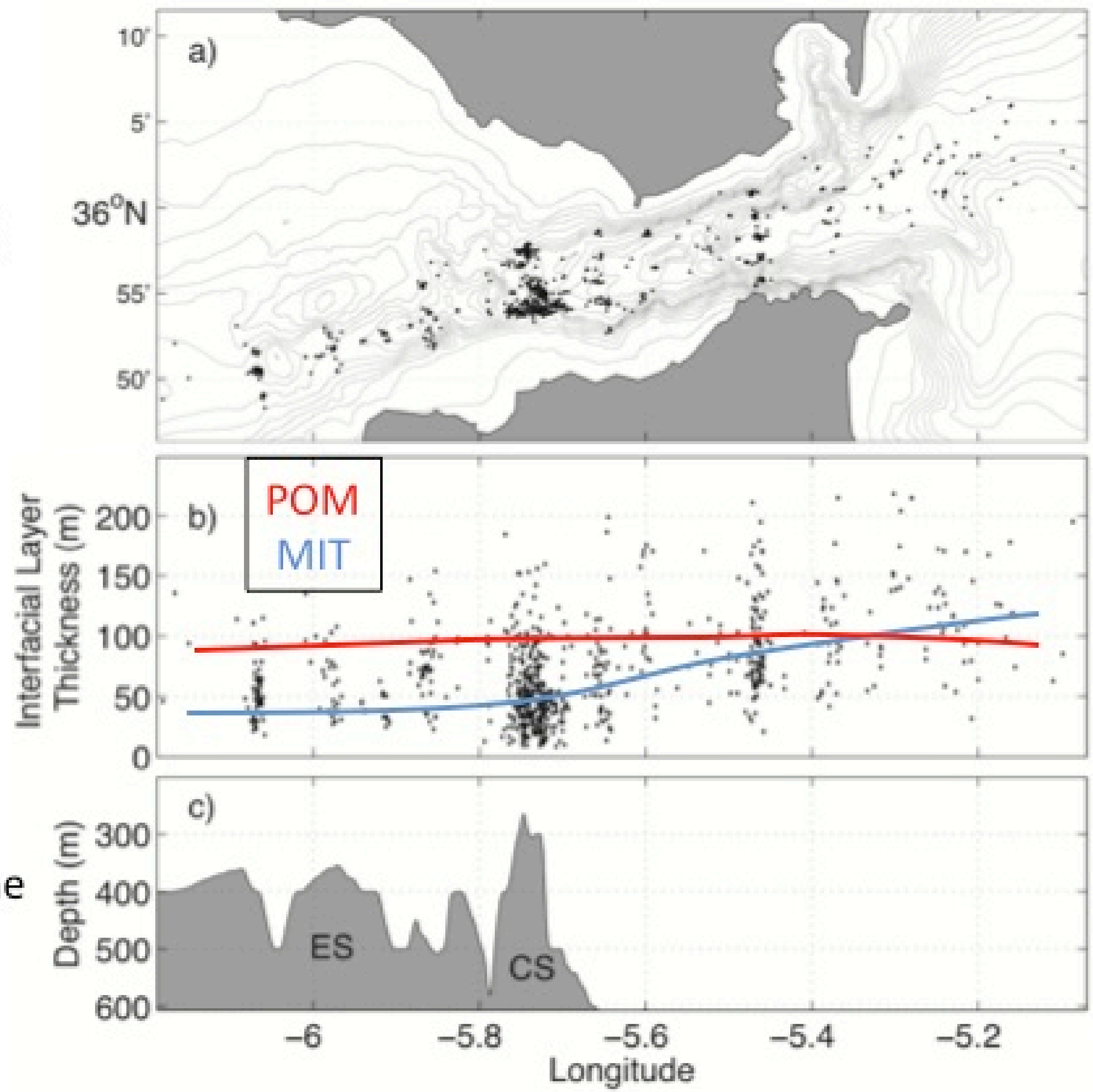
POM and MIT almost agree

Observed interface layer thickness

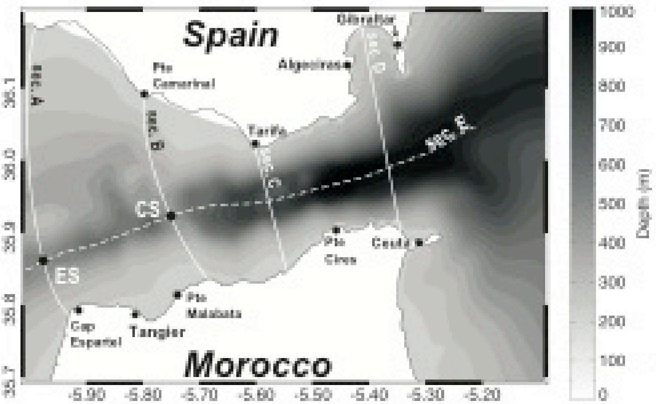
a) Locations of historical conductivity-temperature-depth data (CTD, black dots) collected in the Strait.

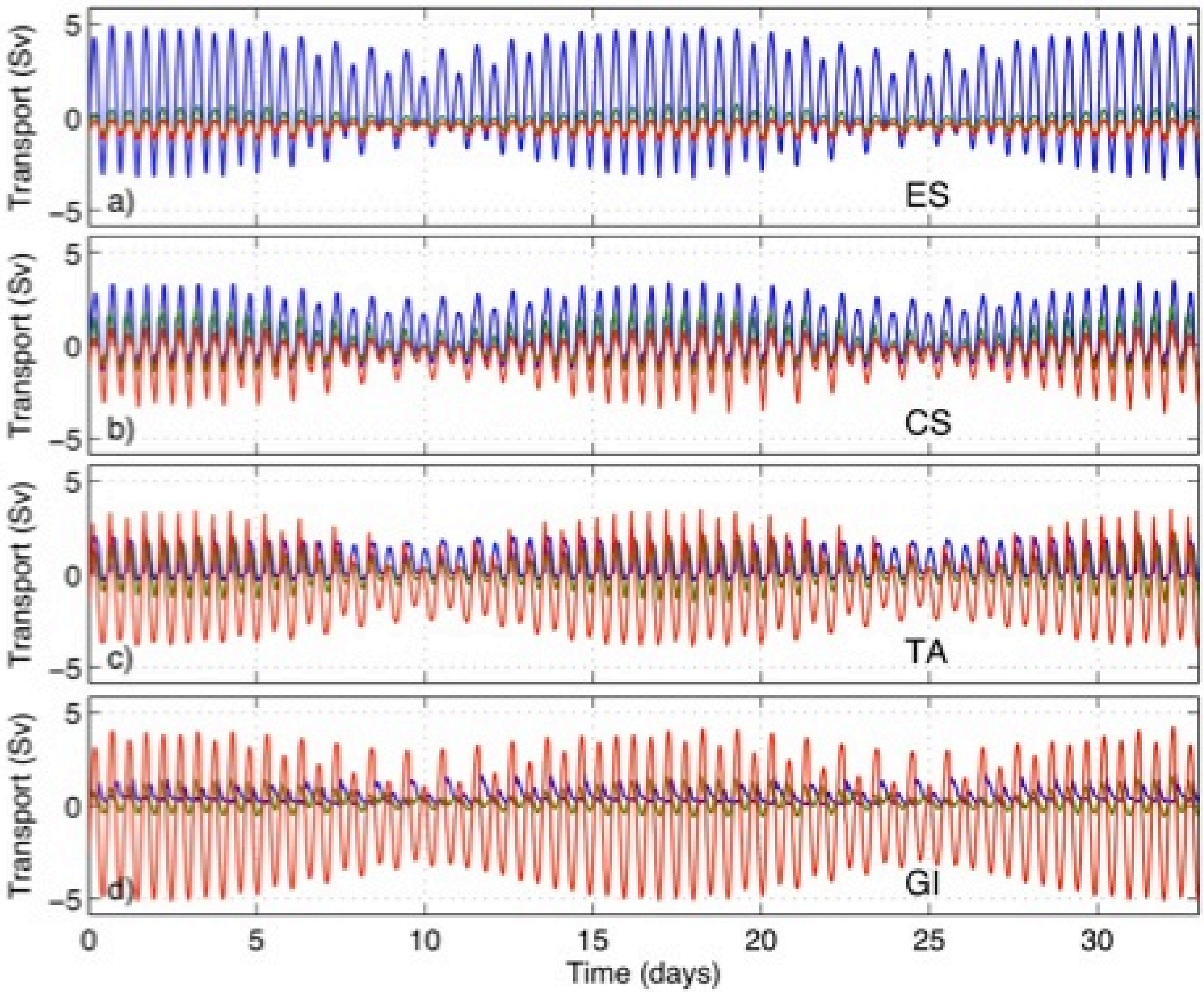
b) Interface layer thickness computed from CTD data.

c) Bottom topography along the central axis of the Strait.



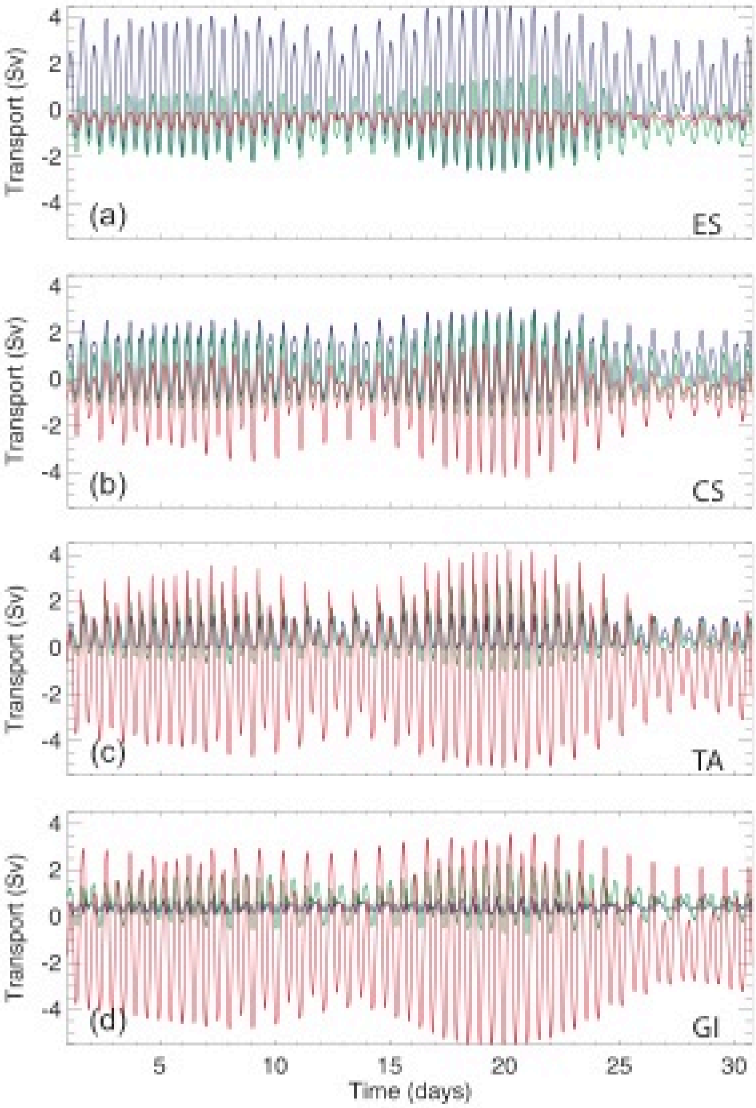
MITgcm 3-Layer transports

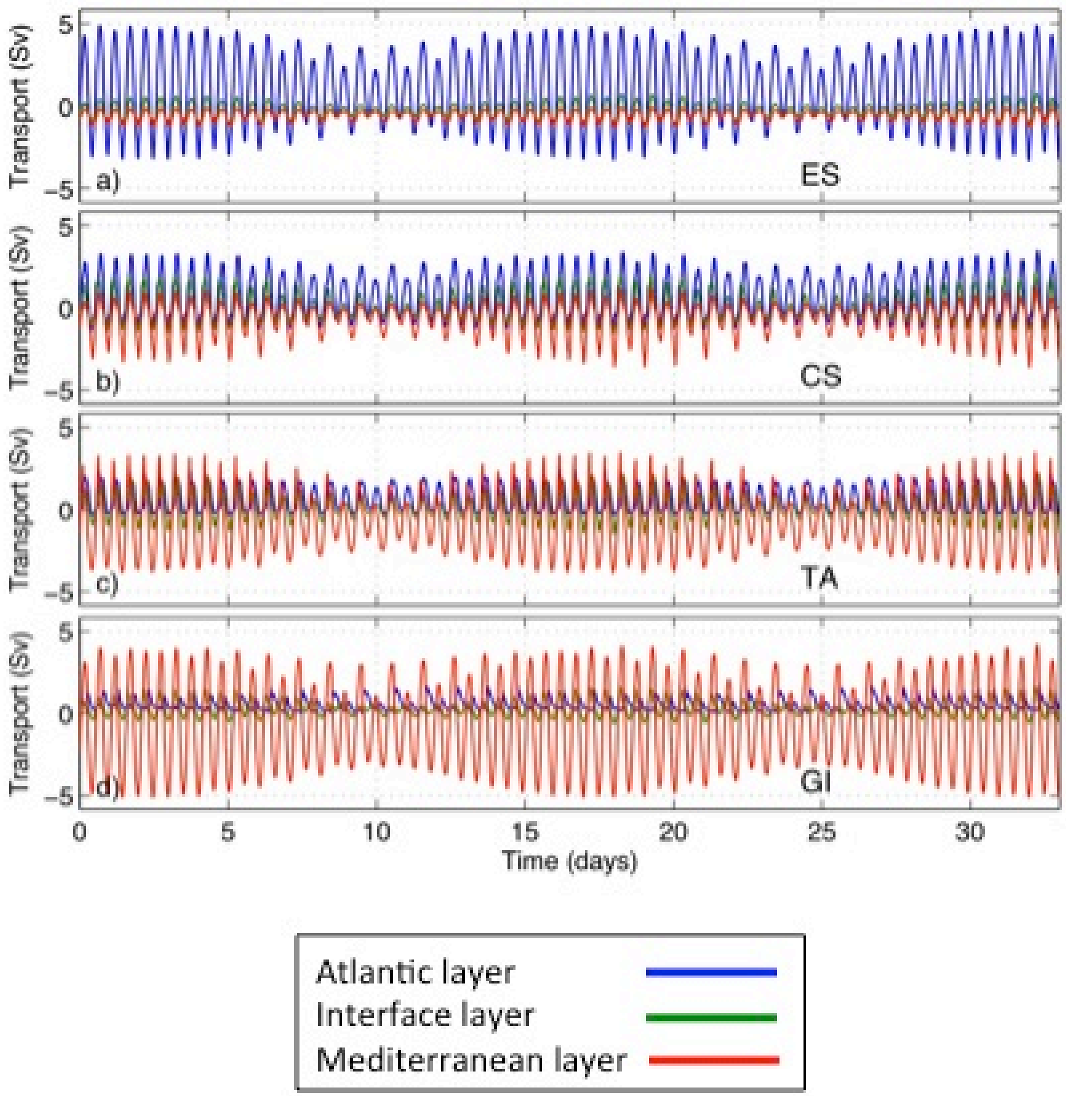




Time-dependent Atlantic layer (blue line), interfacial layer (green line), and Mediterranean layer (red line) volume transports at (a) Espartel Sill, (b) Camarinal Sill, (c) Tarifa (TA) and (d) Gibraltar (GI), respectively sec. A, sec. B, sec. C and sec. D.

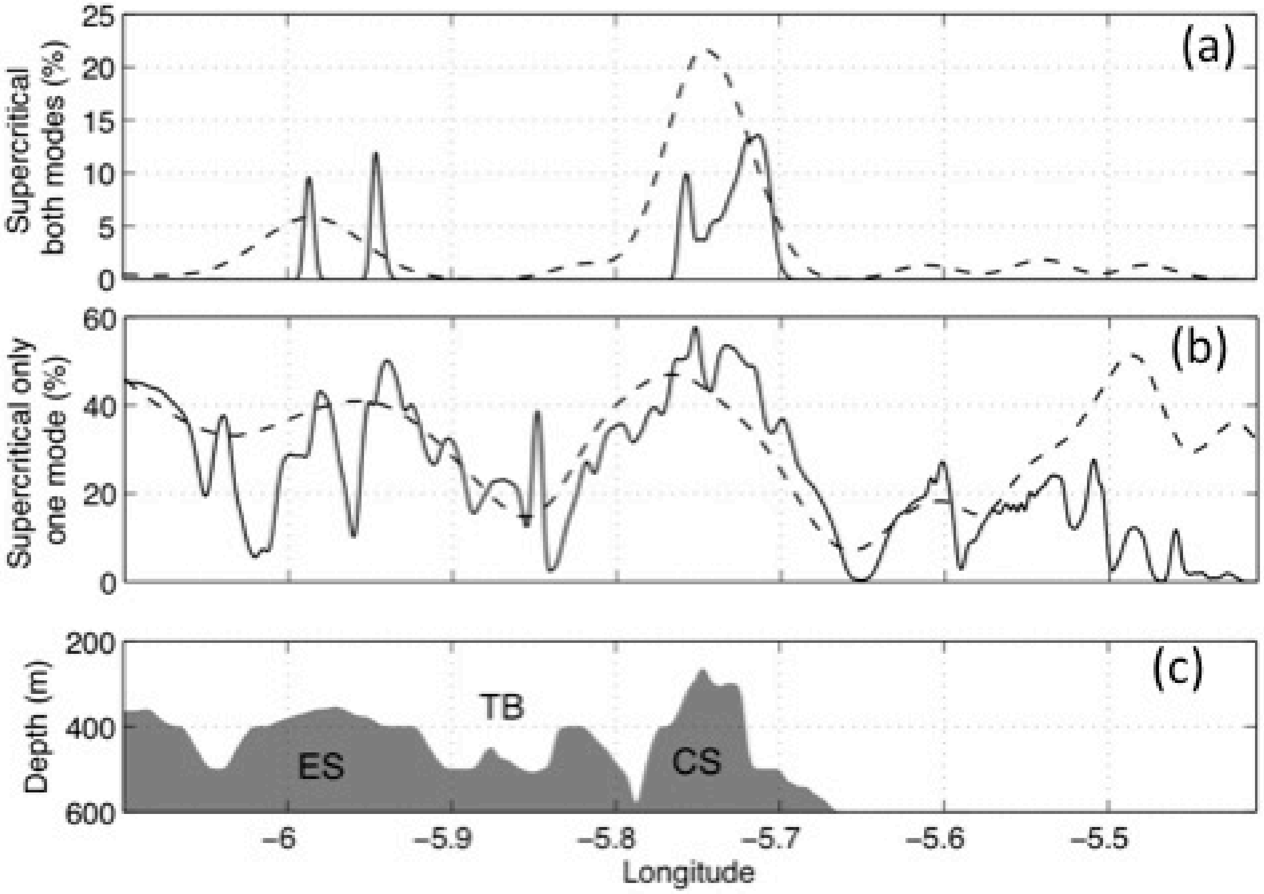
MITgcm 3-Layer transports





MITgcm vs POM alongstrait hydraulics

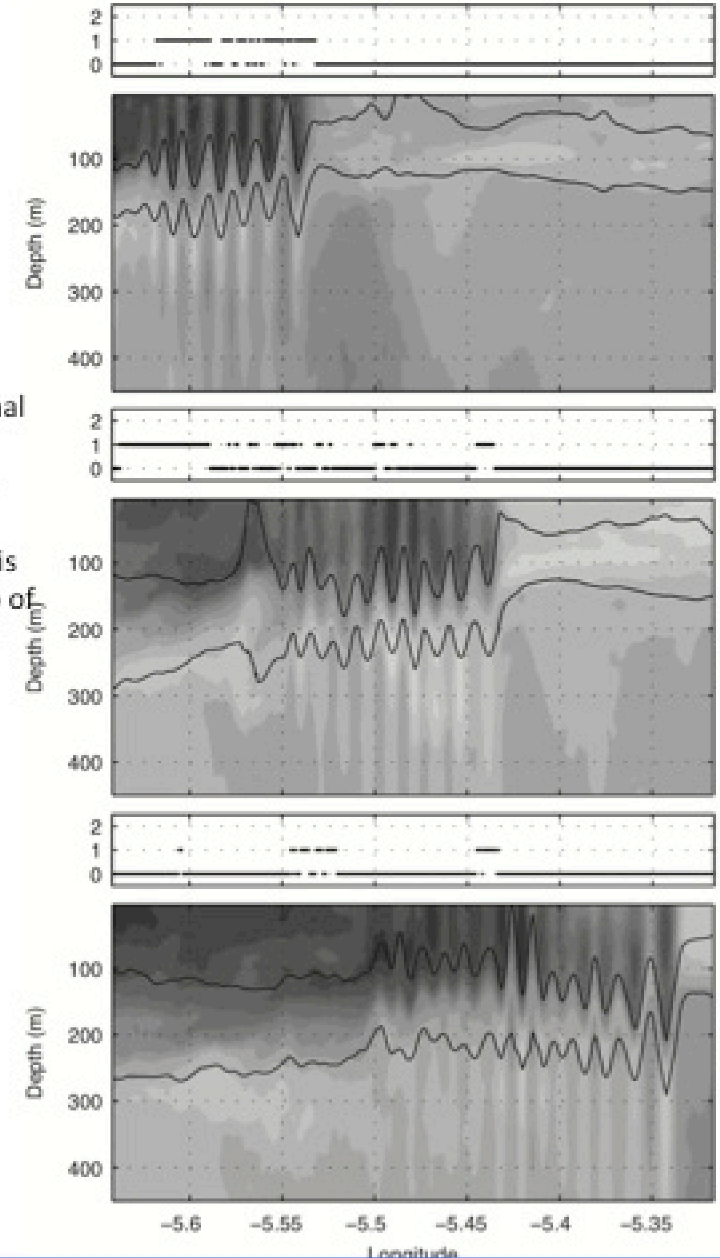
Frequency of occurrence, over the tropical month period, of supercritical flow with respect to one mode (a) and both modes (b) along the Strait as obtained by POM (dashed line) and MITgcm (solid line).

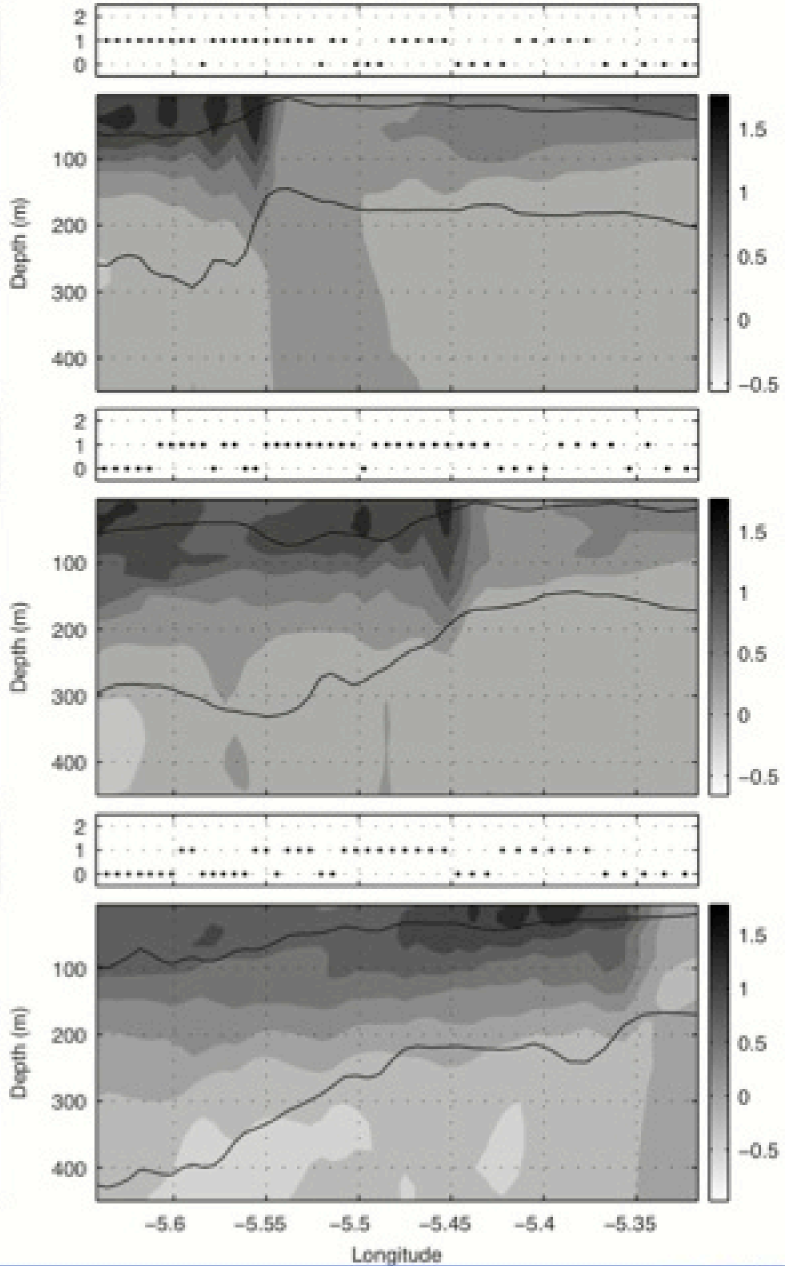


MITgcm displays a marked along-strait variability associated to the finer description of the bathymetry. Moreover when both modes are supercritical (a), MITgcm predicts lower values all along the Strait with respect to POM, except for ES where on the contrary MITgcm exceeds POM. When the flow is supercritical with respect to just one mode, the major differences are confined along TN. In particular POM predicts higher frequencies with respect to MITgcm.

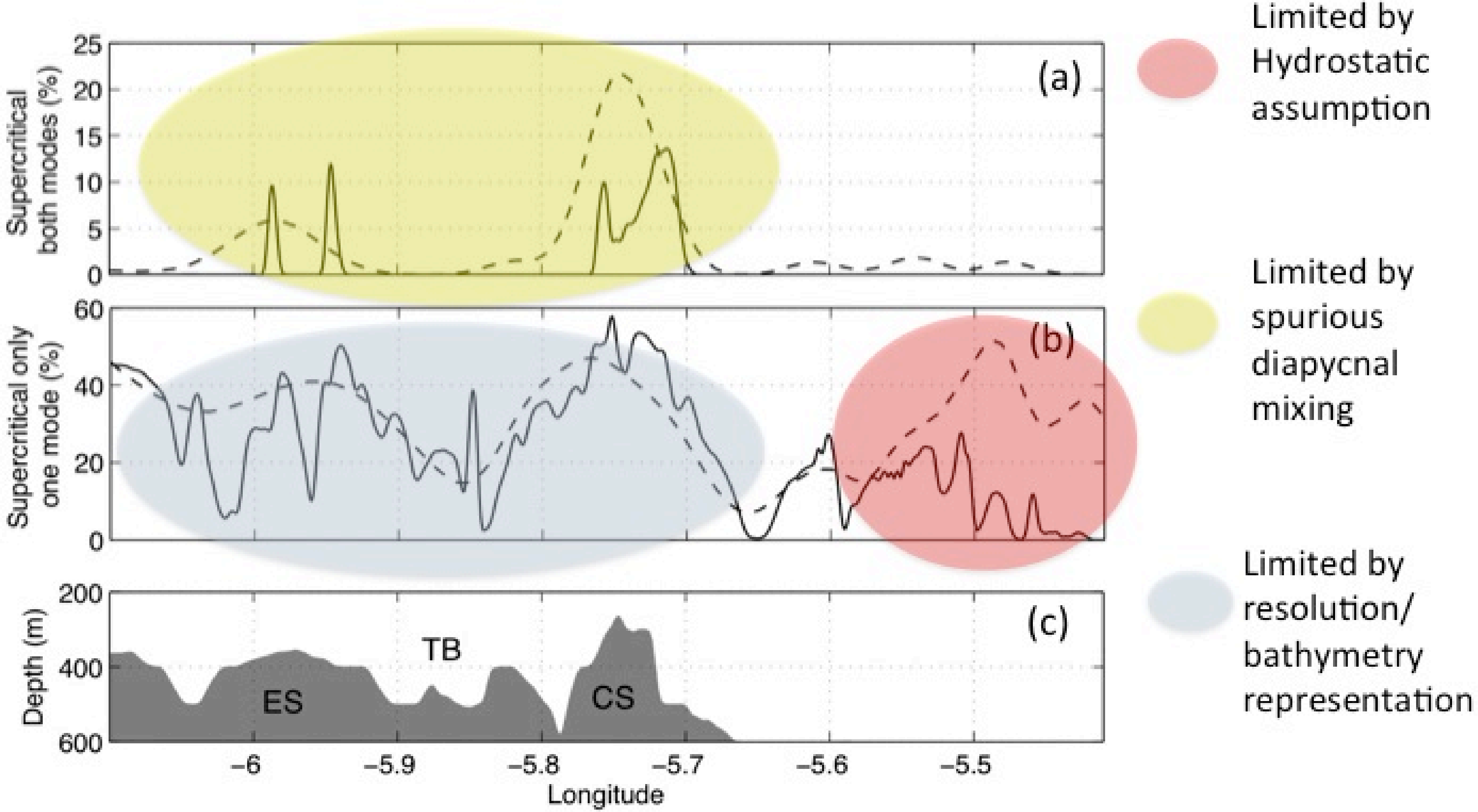
MITgcm vs POM alongstrait hydraulics & bore propagation

Evolution of the horizontal velocity field along longitudinal section in the middle of the Strait during the arrival of an interval wave train to TN. Elapse time between frames is 1.33 hours. Panels on the top of each frame indicate the flow criticality; zero: subcritical flow; one: only one internal mode controlled; two: both internal modes controlled.





MITgcm vs POM alongstrait hydraulics



Frequency of occurrence, over the tropical month period, of supercritical flow with respect to one mode (a) and both modes (b) along the Strait as obtained by POM (dashed line) and MITgcm (solid line).

Summary and Conclusions

- The exchange flow through the Strait of Gibraltar simulated by POM has been compared with the exchange flow simulated by a higher resolution nonhydrostatic model (MITgcm).
- Differences were found in:
  - Tracers stratification
  - Interface layer thickness and transport
  - Hydraulics
- Differences are due to:
  - Spurious diapycnal mixing
  - Bathymetry representation
  - Hydrostatic assumption
- Concluding, the MITgcm results provide a benchmark against which future models that includes the SoG may be compared. Moreover, the model and technique applied in this work could be used in future applications…may be for the Turkish straits.