The tide that shapes the tongue, or how tidally-induced processes impact on the spreading of the Mediterranean Outflow

Alfredo Izquierdo[1,2] & Uwe Mikolajewicz[1]

(1)Max Planck Institute for Meteorology, Hamburg, Germany; (2) Faculty of Marine and Environmental Sciences,University of Cádiz, Cádiz, Spain

1. INTRODUCTION AND MODEL SETUP

Considering that tidally-driven processes might be relevant at the Strait of Gibraltar and the Gulf of Cadiz, where the width of the Mediterranean Outflow (MO) plume is few tenths km wide, our goal is to investigate the effect of tidally-induced local-scale processes on the MO properties and spreading using the global MPI-OM. The grid configuration used (Fig. 1) places one pole in the Iberian Peninsula, allowing there 5 km resolution and a realistically open Strait of Gibraltar (mean global resolution 1.0˚). OMIP climatology (Röske, 2006) was used for the surface forcings. The only difference in the control experiments CTRL_NOTIDE and CTRL_TIDE is the inclusion in the latter of a full ephimeridic luni-solar tidal potential.

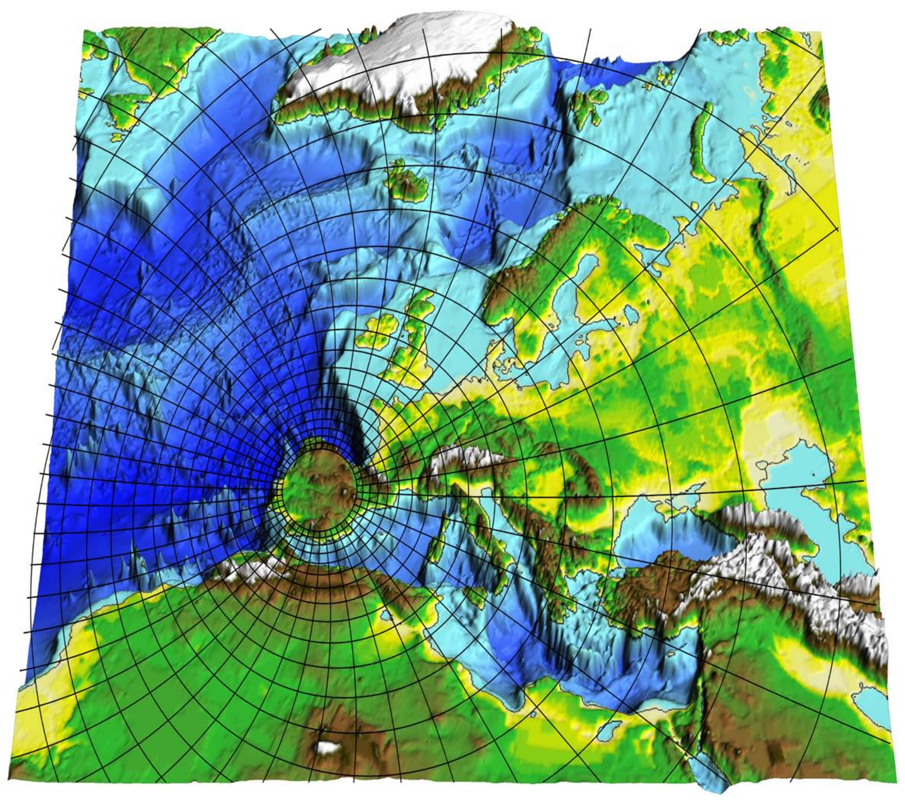

FIG.1. Detail of the global grid SPAN10. Only each eigth grid line is shown

Starting from the same initial conditions, after 10 years both experiments reproduce adequately the depth of the MO core. However, while the CTRL_TIDE run resembles the GDEM climatology, the CTRL_NOTIDE run presents a non realistic southward salt flux (Fig. 2), which does not resemble the MO pathways established from observations (Fig. 3).

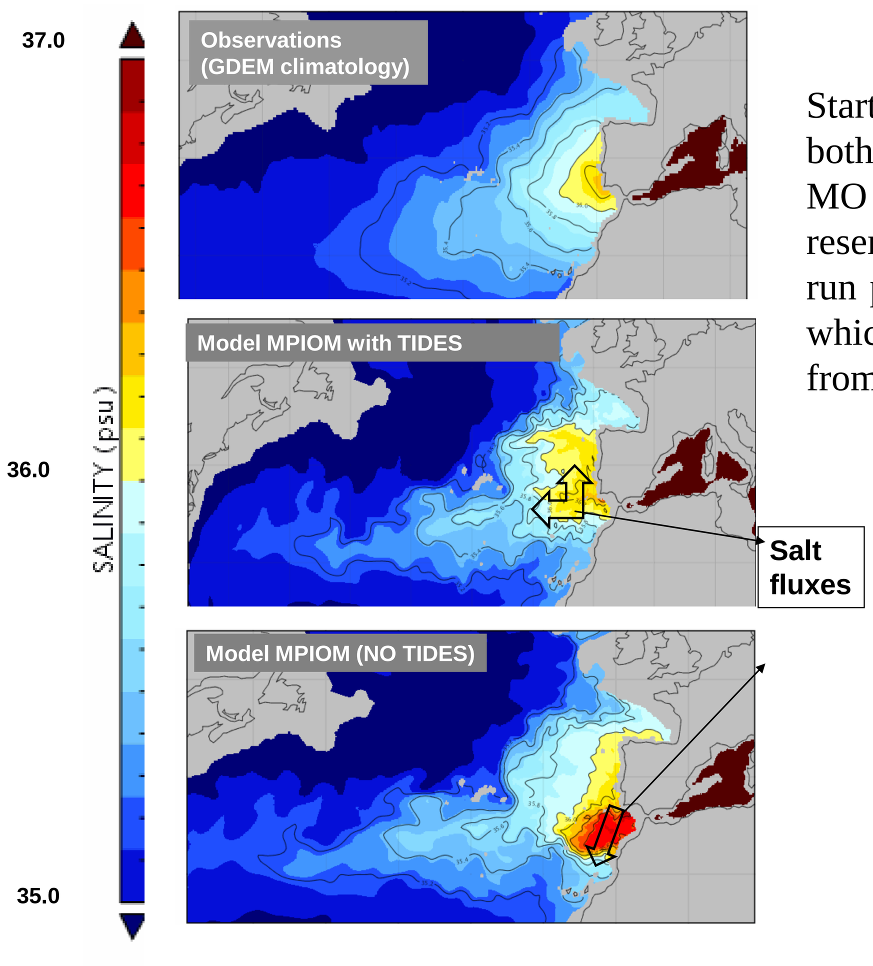

FIG.2.Salinity fields of GDEM climatology and CTRL runs at 1200 m depth

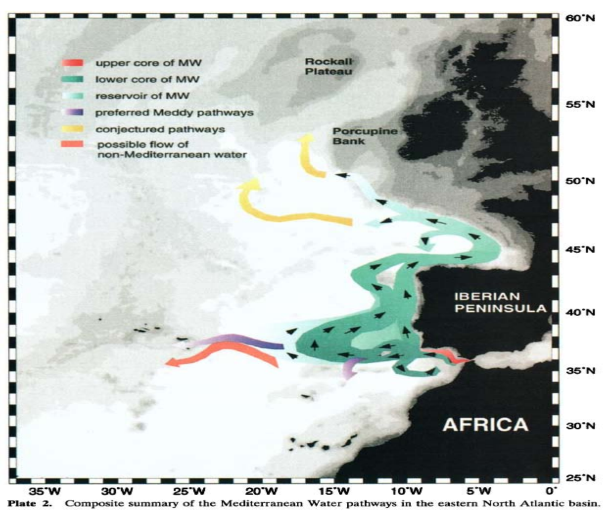

FIG.3.Scheme of the preferred MO pathways after Iorga & Lozier (1999)

2. FIXED WATER SOURCE EXPERIMENTS

In order to minimize the role that tidal mixing (very strong in the Strait of Gibraltar) plays in the differences between TIDE and NOTIDE setups, new experiments were carried out with a closed Strait of Gibraltar and a fixed water source (FWS): A continuous water source (0.8 Sv, 38.5 psu, 13˚ C, [Tracer]=1.0) was added at the bottom of the first cell (354 m depth) in the Atlantic side, guarantying the same salt, water and tracer fluxes for the FWS_TIDE and FWS_NOTIDE setups.

The FWS experiments show the same MO spreading pattern as those with an open Strait of Gibraltar (CTRL): while the FWS_TIDE run (Fig. 4a) reproduces the accepted MO spreading pathways (Fig. 3), the FWS_NOTIDE run (Fig. 4b) presents a clear unrealistic southward salt flux, the Gulf of Cadiz gets gradually saltier at mid-depths, and the salinity excess propagates to the southwest. This behaviour seems to be common to that of other global OGCMs not including tides (Fig. 5). The results remain at large unchanged with lighter or denser source water and with varying diffusivity, diffusion and bottom friction coefficients. All this points out to tidally-induced advective processes as responsible for such differences. Remarkably, in the FWS_TIDE run (Fig. 4a) the MO water is found as north as Porcupine Bank (black star in Fig. 4), leading to the question of a possible influence of MO on the North Atlantic deep water formation processes.

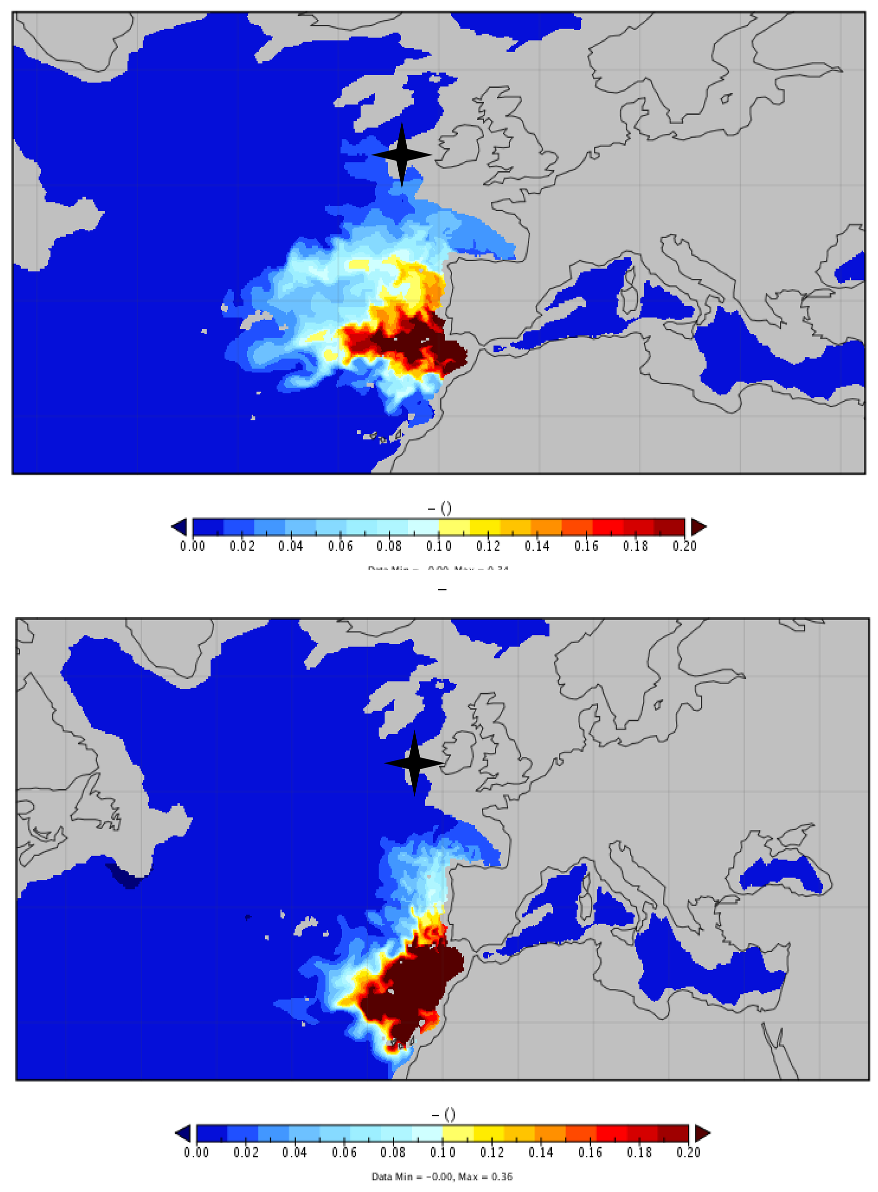

FIG.4.Tracer concentration at 1143 m depth for the a) FWS_TIDE and b) FWS_NOTIDE runs. Black star locates the Porcupine Bank

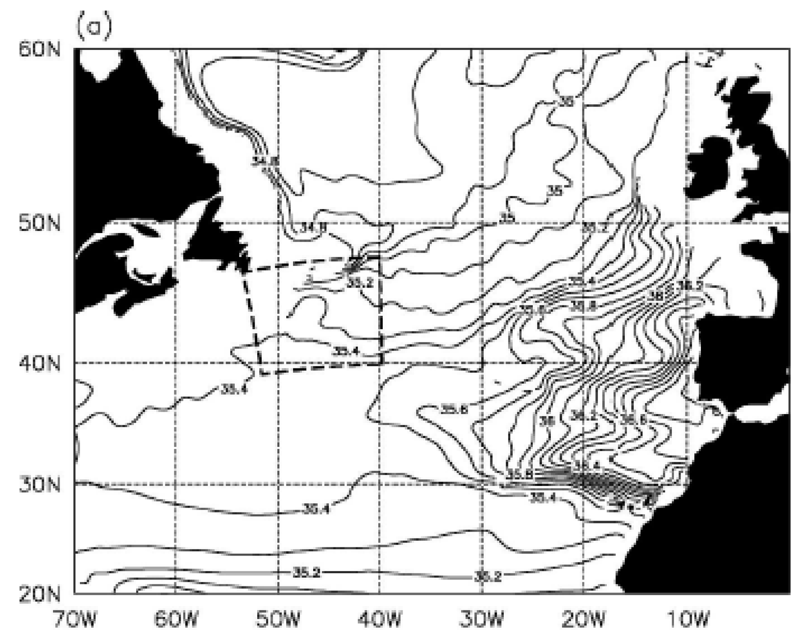

FIG.5. Salinity at 845 m depth from an OCCAM simulation from Jia et al.(2007)

3. TIDAL DYNAMICS: MODELED & OBSERVED

The CTRL_TIDE run gives an adequate representation of the surface tides in the North Atlantic (Fig. 6). The interaction of the barotropic tide with the bottom topography generates internal tides, which in the Gulf of Cadiz propagate eastward as a Poincare-like internal wave (Fig. 7). The comparison of the modeled M2-tide velocities with those obtained from a current-meter mooring in the Gulf of Cadiz (black star in Fig. 9) shows a good agreement (Fig. 8). Observations from SAR imaging (Fig. 9, Magalahes et al., 2010) also show internal wave trains propagating eastwards. The location of the maximum forcing spots made by these Authors coincides as well with one of the internal tide generation locations in the model (San Vicente Spur).

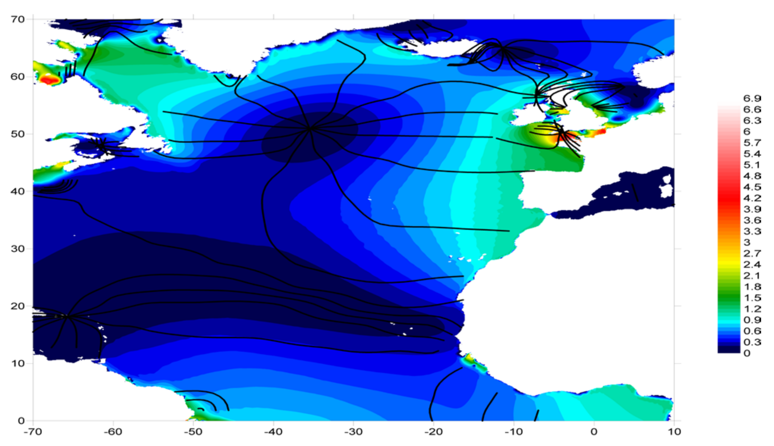

FIG.6. Calculated M_2 cotidal chart amplitudes (color shading) in meters

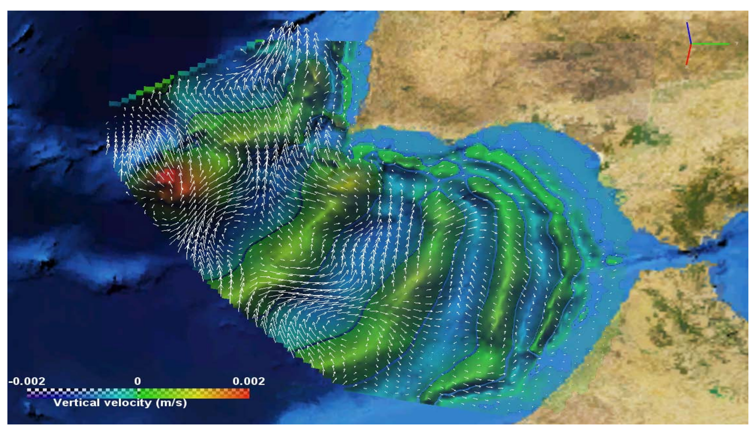

FIG.7. Snapshot of the M_2 vertical velocity at 1143 m. The horizontal tidal residual velocity is overlaid

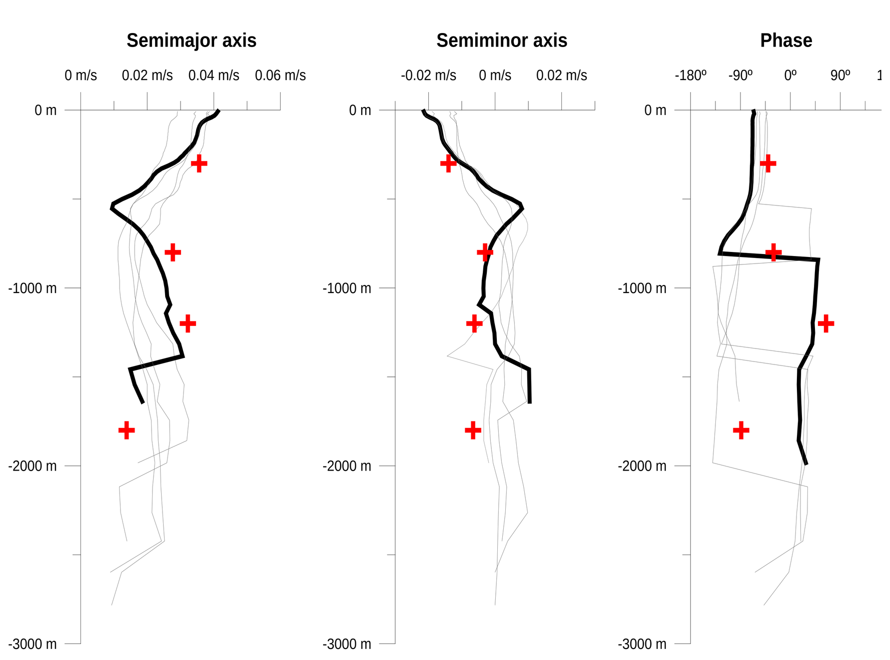

FIG.8. Comparison of modelled and measured (red crosses) M_2 tidal current ellipse parameters. Thick line is the model closest node to mooring location, thin lines the surrounding nodes. Black star in Fig. 9 shows the mooring location. Mooring data from the Instituto Español de Oceanografía (indamar.ieo.es).

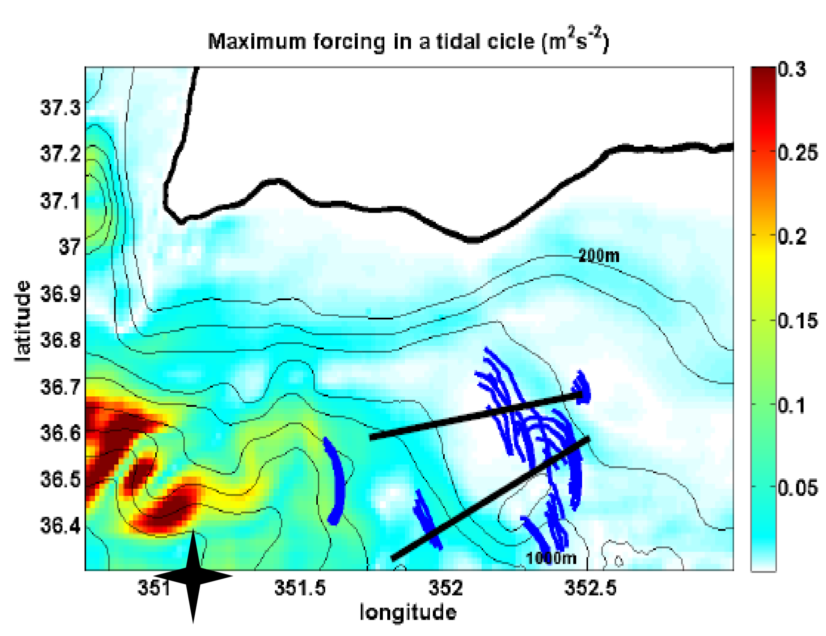

FIG.9. Internal tide generation areas (maximum barotropic forcing) at the SW Iberian coast. Also shown SAR signatures of internal waves (Magalhaes et al., 2010). Black star shows the mooring location of data referred to in Fig. 8.

4. TIDAL RESIDUAL CURRENTS AND FLUXES

Modeled tidal residual velocity (v_{TR}) follows closely the contours of tidal residual elevation (η_{TR}), which in turn are linked to bottom topography. The η_{TR} field is characterized by two consecutive depressions (D1 and D2) each with a corresponding cyclonic residual circulation. The maximum intensity of v_{TR} (3 cm/s) occurs in the gateway between Gorringe Bank (GB) and Saint Vincent Spur (SVS) (Fig. 10b). The "zonal" (across the solid line, i.e. between GB and SVS) and "meridional" (dotted line) integrated advective tracer fluxes (Fig. 10a) show clear differences between the CTRL_TIDE (black line) and CTRL_NOTIDE (red line) runs, with the CTRL_TIDE fluxes exiting mainly through the GB-SVS line as reported from observations. We have also recalculated the CTRL_NOTIDE fluxes with the addition of the constant 3D v_{TR} field to the time-varying CTRL_NOTIDE velocity (green line). The result approaches to the CTRL_TIDE fluxes, with a preferred pathway between GB and SVS. This confirms the leading role of the tidal residual currents in setting up the differences in MO water spreading.

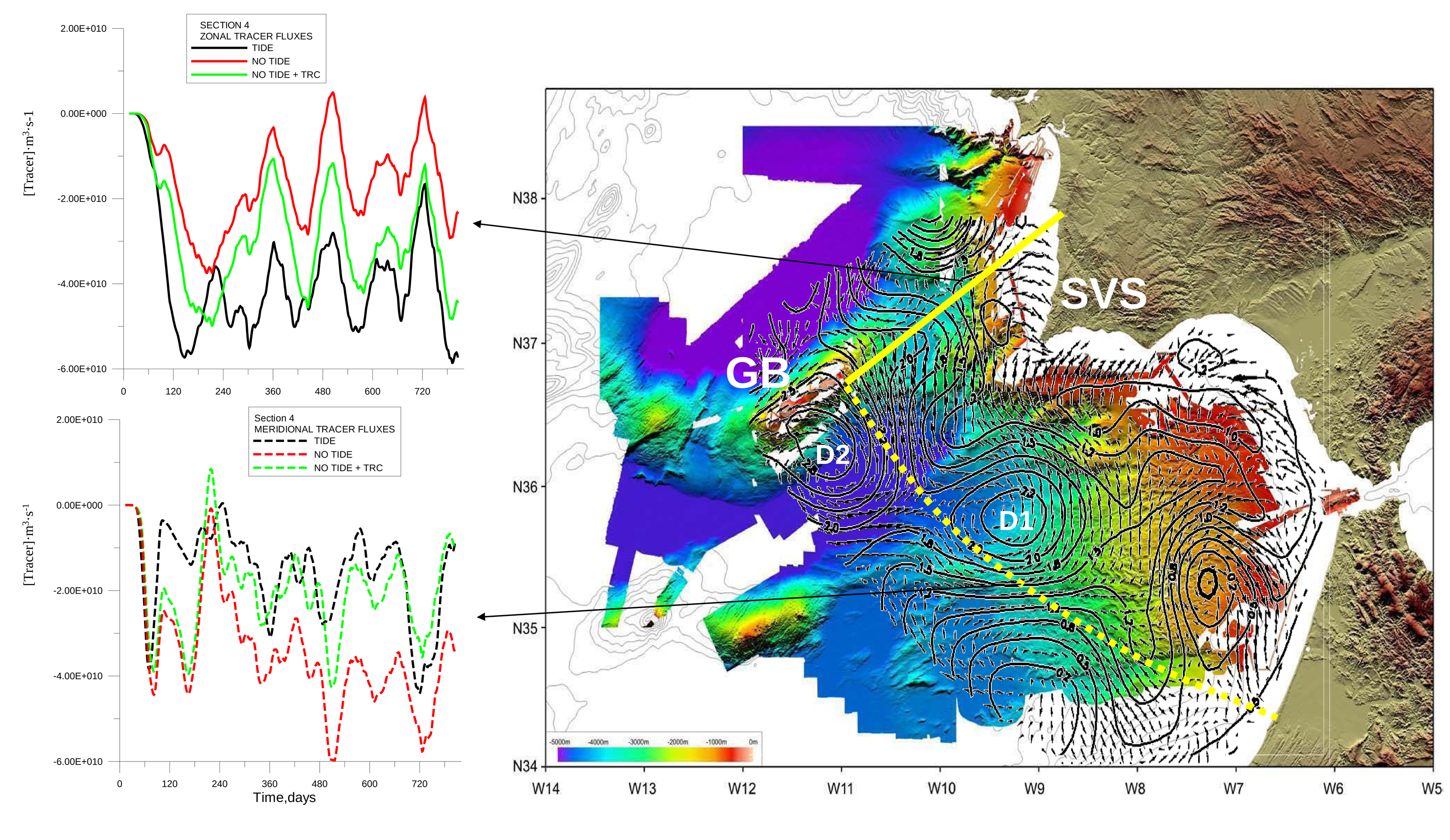

FIG.10. a) Time evolution of integrated "zonal" (solid) and "meridional" (dotted) advective tracer fluxes. b) Bathymetry of the Gulf of Cadiz (Zitellini et al., 2009). Isolines show the tidal residual elevation (η_{TR}) (all values negative) and vectors the depth-averaged tidal residual velocity (v_{TR}). D1 and D2 show the cyclonic circulation cells. Yellow lines were used for the calculation of the integrated tracer fluxes.

5. CONCLUSIONS

Our results reveal the impact that tides may have on the MO spreading in the North Atlantic, with the residual currents generated by the interaction of tides with local-scale topography in the Gulf of Cadiz playing a major role.

Therefore, the results of global OGCMs simulating the MO spreading without tidal forcing should be carefully considered, especially when used to estimate the contribution of MO to the Nordic Seas salinity.

Max-Planck-Institut für Meteorologie

References

Iorga M. & Lozier S., J. Geophys. Res., 104, 25985-26009, 1999

Jia Y., Coward A., Cuevas B., Webb D. Drijfhout S., J. Phys. Ocean., 37, 764-785, 2007

Magalhaes J., da Silva J.C., Grimshaw R., Griffiths S. and New A., 3rd International Workshop SEASAR 2010

Röske F., Ocean Modelling,11, 235-297,2006

Zitellini et al., Earth and Planetary Sciences, 280, 13-50, 2009

Acknowledgment

All computations have been performed at DKRZ under project bm0548.

This work was funded by the EC Marie Curie IEF Project PIEF-GA-2009-237426, "INMEDIATO"

MAX-PLANCK-GESELLSCHAFT