Impact of a Two-Way Grid Refinement at the Strait of Gibraltar on the Thermohaline Circulation of the Mediterranean Sea

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Background: Global Thermohaline Circulation
The excess of evaporation over precipitation and river runoff in the Mediterranean basin represents, together with the conservation of mass and salt, the main forcing of the thermoaline circulation in the Mediterranean.

The magnitude and hydrological properties of the thermohaline circulation strongly depend on the physical configuration of the strait of Gibraltar via hydraulic controls.
Background: 3D Gibraltar Bathymetry
Background: Gibraltar Bathymetry

Bathymetry of the Strait of Gibraltar
Background: Gibraltar Bathymetry

Bathymetry of the Strait of Gibraltar

Espartel Sill 360 m
Camarinal Sill 284 m

Spain

Morocco

Depth (m)
While in case of maximal regime the strait will respond relatively slow to an internal change of the thermohaline circulation of the Mediterranean Sea due to air-sea interaction over the whole basin, a more rapid adaptation of the transports in the strait will be exhibited in case of submaximal regime.
Modeling the Strait of Gibraltar: “First Model”

- Modified POM
- Minimal Hor. Resolution: 500 m
- External Time-Step: 0.1 sec
- Diurnal and semidiurnal tidal components

Garrido et al, JGR, 2008
Sanchez et al, JGR, 2009
Garcia-Lafuente et al, JGR, 2007
Sannino et al, JPO, 2009
Sannino et al, JGR, 2007
Sannino et al, JGR, 2004
Sannino et al, NC, 2005
Sannino et al, JGR, 2002
Modeling the Strait of Gibraltar: “First model”

Longitudinal salinity section
Velocity AMP & PHA comparison for $M_2$ tidal component

Modeling the Strait of Gibraltar: “First Model”

Observed data vs Model simulation

- (a) Observation
- (b) Model
### Amp & Pha of surf. elev. for $M_2$

Table 3.2: Comparison between Observed and Predicted Amplitudes $A$ and Phases $P$ of $M_2$ tidal elevation.

<table>
<thead>
<tr>
<th>Location</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Observed $M_2$</th>
<th>Predicted $M_2$</th>
<th>Predicted - Observed</th>
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</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>$A_{,cm}$</td>
<td>$P_{,deg}$</td>
<td>$A_{,cm}$ $A_{,%}$ $P_{,deg}$</td>
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<tr>
<td><strong>Tsimplis et al. (1995)</strong></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Gibraltar</td>
<td>36° 08'</td>
<td>05° 21'</td>
<td>29.8</td>
<td>46.0</td>
<td></td>
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<tr>
<td><strong>García-Lafuente (1986)</strong></td>
<td></td>
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<tr>
<td>Pta. Gracia</td>
<td>36° 05.4'</td>
<td>05° 48.6'</td>
<td>64.9 ± 0.2</td>
<td>49.0 ± 0.5</td>
<td></td>
</tr>
<tr>
<td>Tarifa</td>
<td>36° 00.2'</td>
<td>05° 36.4'</td>
<td>41.5 ± 0.2</td>
<td>57.0 ± 0.5</td>
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</tr>
<tr>
<td>Pta. Cieres</td>
<td>35° 54.7'</td>
<td>05° 28.8'</td>
<td>36.4 ± 0.2</td>
<td>46.5 ± 0.5</td>
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<tr>
<td>Pta. Carnero</td>
<td>36° 04.3'</td>
<td>05° 25.7'</td>
<td>31.1 ± 0.2</td>
<td>47.5 ± 0.5</td>
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<td><strong>Candela et al. (1990)</strong></td>
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<td>05° 34'</td>
<td>44.4</td>
<td>47.6</td>
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</table>

*aCalibration.*
Monitored Channel

NO DATA for this Channel

Location: 35.86 ° N / 05.97 ° W
ADCP Depth: 345 m
Data: from october 2004 until now
Velocity: 48 – 328 m (each 8 meters)
T – S at 356 m
ΔT = 30 min
The longest outflow transport estimation at the western end of strait of Gibraltar

Mean outflow transport value = 0.74 Sv

Sanchez-Sannino J. Geophysical Research in press

ADCP DATA

Numerical Model
For a 3-layer system (Figure 2b) the generalized critical condition is

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

where

\[ \tilde{F}^2_1 = \left( \frac{1}{w_2} \int_{y_1}^{y_2} \frac{g_1 H_1}{u_1} dy_1 \right)^{-1}, \quad \tilde{F}^2_2 = \left( \frac{1}{w_2} \int_{y_2}^{y_3} \frac{g_2 H_2}{u_2} dy_2 \right)^{-1}, \quad \tilde{F}^2_3 = \left( \frac{1}{w_3} \int_{y_3}^{y_4} \frac{g_3 H_3}{u_3} dy_3 \right)^{-1}. \]

\[ g'_{21} = g(\rho_2 - \rho_1)/\bar{\rho}, \quad g'_{32} = g(\rho_3 - \rho_2)/\bar{\rho}, \quad r = \frac{\rho_3 - \rho_1}{\rho_2 - \rho_1} \] and \( w_n \) is the width of the interface overlying layer \( n \).
Hydraulic criticality of the exchange flow through the Strait of Gibraltar

G. Sannino, L. Pratt and A. Carillo
J. Physical Oceanography in press

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: Espartell Sill, Camarinal Sill and Tarifa Narrow. Lower panel indicates tidal elevation at Tarifa.
Recipe for a good model of the Strait of Gibraltar

1) Enough resolution (around 1 Km)

2) Entrainment and mixing must be taken into account

3) Tidal forcing
Recipe for a good model of the Strait of Gibraltar

1) Enough resolution (around 1 Km)

2) Entrainment and mixing must be taken into account

3) Tidal forcing

Motivation

How many Mediterranean regional model are able to represent correctly the strait dynamic?
Motivation

Recipe

1) Enough resolution (around 1 Km)

2) Entrainment and mixing must be taken into account

3) Tidal forcing
Motivation

We propose a direct simulation of the strait dynamic via a two-way grid-refinement

Recipe

1) Enough resolution (around 1 Km)

2) Entrainment and mixing must be taken into account

3) Tidal forcing
Two-way grid-refinement

1/8° x 1/8°
42 z-levels
Two-way grid-refinement

1/8° x 1/8°
42 z-levels

40 years of simulations
ERA40 period (1958-1998)
- ERA40 ECMWF Wind Stress
- ERA40 ECMWF Heat Fluxes (Corrected in the Gulf of Lion)
- SST relaxation to montly data (30 days)
- SSS relaxation to montly MedAtlas data (5 days)
- 3D relaxation to monthly Levitus data in the Atlantic box.

MITgcm (hydrostatic):
- BiHarmonic hor. visc: 1.0*10^{10} m^4/sec
- BiHarmonic hor. diff: 1.4*10^{10} m^4/sec
- Harmonic vert. visc: 1.0*10^3 m^2/sec
- Harmonic vert. diff: 3.0*10^{-5} m^2/sec
Two-way grid-refinement: model grids

Ratio = 3:1
Two-way grid-refinement: models bathymetry

Strait bathymetry

1/8° x 1/8°
42 z-levels

1/24° x 1/24°
42 z-levels
Two-way grid-refinement: procedure

For each prognostic variable:

(1) integrate the coarse model one time step ahead;

(2) interpolate the fine grid boundary conditions from the coarse grid model and impose the boundary conditions to the fine grid model in the so-called “dynamic interface”;

(3) integrate the fine grid model three time step ahead;

(4) average the values of the fine grid model lying on and inside the “feedback interface” and replace the corresponding values of the coarse grid model.

Similar to Spall & Holland, JPO, 1991
The coarse model and the nested fine model are both treated as independent models.

Both models run in the parallel (MPI).

Interpolations and exchange fields between the two models are done by an external driver.

To reduce the time for interpolation and exchange the driver has been parallelized via MPI.

Multiple nesting are allowed (telescopic nesting).
### Two-way grid-refinement: technical implementation

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<td>24</td>
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</table>
Two-way grid-refinement: Results

Salinity field at 40 m depth

XY sec: 3  |  Depth: 40m  |  Time: 2/8/1961
Two-way grid-refinement: models bathymetry

1/8° x 1/8°
42 z-levels
Two-way grid-refinement: models bathymetry

2 Experiments

- GridRef
- NO-GridRef + Tuning

1/8° x 1/8°
42 z-levels

1/24° x 1/24°
42 z-levels
Grid-Refinement vs No-Grid-Refinement

Velocity field at Gibraltar

Velocity at 60 m (m/s), GR

Max: 0.6 m s\(^{-1}\)

Velocity at 320 m (m/s), GR

Max: 0.5 m s\(^{-1}\)

Velocity at 60 m (m/s), NOGR

Velocity at 320 m (m/s), NOGR
Grid-Refinement vs No-Grid-Refinement 

RMS(KE) field at Gibraltar

RMS (KE) at 60 m (m²/s²), GR

RMS (KE) at 60 m (m²/s²), NOGR

RMS (KE) at 320 m (m²/s²), GR

RMS (KE) at 320 m (m²/s²), NOGR

Longitude vs Latitude
Grid-Refinement vs No-Grid-Refinement
Grid-Refinement vs No-Grid-Refinement

XY sec: 3  Depth: 40m  Time: 2/8/1981

salinity

36.20  36.28  36.36  36.44  36.52  36.60  36.68  36.76  36.84  36.92  37.00
Grid-Refinement vs No-Grid-Refinement
Grid-Refinement vs No-Grid-Refinement

Isosurface 36.5 psu in the Gulf of Cadiz
Grid-Refinement vs No-Grid-Refinement

Mixed layer depth averaged 1958-1997

NOGR

Golf of Lion

GR

Golf of Lion

MLD, GR

MLD, GR–NOGR
Grid-Refinement vs No-Grid-Refinement

Convection depth in the Gulf of Lion

[Graph showing convection depth variations from 1975 to 1995 for Grid-Refinement (GR) and No-Grid-Refinement (NO-GR)].
Black circles mark the experimentally observed convection depth (Mertens and Schott, 1998).
Overturning circulation

Stream function $\Psi(x, \rho)$ as function of longitude and density
winter mean values over the period 1958-1998

Exp. with Grid-refinement
Overturning circulation

Stream function $\Psi(x, \rho)$ as function of longitude and density
winter mean values over the period 1958-1998
Overturning circulation

Stream function $\Psi(x, \rho)$ as function of longitude and density
winter mean values over the period 1958-1998

Grid-Refinement vs No-Grid-Refinement

Difference
GR-NOGR
Grid-Refinement vs No-Grid-Refinement

Overturning circulation

Stream function \( \Psi(x, \rho) \) as function of longitude and density
winter mean values over the period 1958-1998

Grid-Refinement vs No-Grid-Refinement

Difference GR-NOGR
Grid-Refinement vs No-Grid-Refinement

Hydraulic control

1/8° x 1/8°
42 z-levels

1/24° x 1/24°
42 z-levels

Espanetel Sill

Camarinal Sill
Future Plans

Recipe

1) Enough resolution (around 1 Km)

2) Entrainment and mixing must be taken into account

3) Tidal forcing
Future Plans

Recipe

1) Enough resolution (around 1 Km)

2) Entrainment and mixing must be taken into account

3) Tidal forcing

Non-hydrostatic

- 1/8°
- 1/24°
- 1/72°
Modeling the Strait of Gibraltar: “Second Model”

*MITgcm model*
*non-hydrostatic*
*52 z-levels (pc)*

**Model bathymetry**

**Model Resolution**
Modeling the Strait of Gibraltar: "Second Model"
Modeling the Strait of Gibraltar: “Second Model”