CLIMATE SIMULATIONS OF STORM SURGES AND WIND WAVES IN THE MEDITERRANEAN SEA

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Concerning surges more details in Conte D. and P. Lionello (2013)
Characteristics of large positive and negative surges in the Mediterranean Sea and their attenuation in future climate scenarios,
For waves ... manuscript in preparation
MOTIVATIONS

Case studies of coastal cities (Venice and Alexandria), deltas (Nile, Po, Rhone and Ebro), and islands (Cyprus) support the need to consider the effects of climate change (Nichols and Hoozemans, 1996). Future hazard level is related to a combination of factors: sea level rise, vertical land motion, marine storminess.

MAIN OBJECTIVE

To assess climate change effect on marine storminess along the coast of the Mediterranean Sea in the next decades by a multi-model approach

Minor objectives:
Relative importance on wind and SLP for large surges, analogies between positive and negative surges, analogies between surges and wind-waves, sources of uncertainty of climate change signal ...

Mediterranean region: dots denote the coastal grid points used for storm surge and wind-wave analysis.
a 7-member climate model ensemble [produced within the CIRCE fp6 project (Climate Change and Impact Research: the Mediterranean Environment)], covering the period 1951-2050 under the A1B emission scenario is used for driving:

- The hydro-dynamical shallow water model HYPSE (Hydrostatic Padua Sea Elevation model)
- The WAM model

Model validation is based on the comparison of a model hindcast (1958-2001) and climate simulations with observations at tide gauges and buoys.

The 5-year return value and an index of intense storm conditions (large surges or/and high waves) are used for analysing the results.

Climate signal is computed as the difference between the surge statistics in the 2021-2050 and 1971-2000 period.

A weighted ensemble mean is used for a robust estimate of climate change

This presentation is focused on surges. Wave simulations have been completed, but only a preliminary analysis is available.
CONCLUSIONS

Distribution along the Mediterranean coast

• Models reproduce the present spatial variability of surge extremes, although values are often underestimated.

• Future scenario shows large differences among individual simulations. Results are not coherent spatially (climate change has different signs and/or statistical significance in different parts of the coastline and for different models), mostly they are not statistically significant, inter-model spread is a relevant source of uncertainty.

• The largest fraction of uncertainty is attributed to the choice of the global simulation for the boundary conditions.

• A weighted ensemble mean, constructed with results from different simulations, suggests a wide spread reduction of amplitude of large (and extremes) surges and waves in future climate scenarios.

Climate change signal (%)

Positive surges

negative surges

waves
<table>
<thead>
<tr>
<th>Label</th>
<th>Period</th>
<th>simulation</th>
<th>time step</th>
<th>Short description and grid resolution</th>
<th>weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>HIPOCAS</td>
<td>1958-2001</td>
<td>hindcast</td>
<td>1h</td>
<td>Based on HIPOCAS reanalysis (0.5degs)</td>
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<td>Forcing is from ARCM (downscaling of CMCC-LR forcings at 0.12degs resolution)</td>
<td>1/40</td>
</tr>
<tr>
<td>CMCC HR-HR grid</td>
<td>1970-2050</td>
<td>Climate</td>
<td>6h</td>
<td>Same as CMCC-HR but HYPSE is implemented at high resolution grid (0.05degs)</td>
<td>1/40</td>
</tr>
<tr>
<td>MPI</td>
<td>1951-2050</td>
<td>Climate</td>
<td>6h</td>
<td>Forcing is from an AORCM and represent 6 hour average values. (it is a downscaling of CMCC-LR at 0.22degs)</td>
<td>1/20</td>
</tr>
<tr>
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</tr>
<tr>
<td>ARPEGE</td>
<td>1951-2050</td>
<td>Climate</td>
<td>6h (24h mslp)</td>
<td>Forcing is from a stretched grid AOGCM (50km in the Mediterranean region) coupled to a high resolution model of the Mediterranean Sea circulation</td>
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</table>
Indicators

Two main indicators have been used:
- the storm surge index ($SSI$): annual average of the 3 largest independent events
- the 5-year return value ($RV5$)

which for model validations are used to compute:

percent error

$$E_i(\%) = \frac{SSI_{obs_i} - SSI_{mod_i}}{SSI_{obs_i} + SSI_{mod_i}} \times 100$$

error index

(which compares errors with the variability of the anomalies)

$$EI_i = \frac{SSI_{obs_i} - SSI_{mod_i}}{\sqrt{\frac{\sigma^2_{SSI_{obs_i}}}{2} + \frac{\sigma^2_{SSI_{mod_i}}}{2}}}$$
top panel: Values of the storm surge index (cm) in the wind driven (WIND), sea level pressure driven (MSLP) and complete forcing simulations.

Bottom panel, fraction (%) of storm surge due to the WIND, to the MSLP forcing and residual.

The ENEA and the CMCC-HR simulations are used. Coastal points are ordered clockwise starting from Gibraltar. Country national borders and stations used for model validations are marked to help locating the different sections of the Mediterranean coastline.
Storm surge climate: VALIDATION

Values at the 21 tide gauges (names are reported along the bottom axis of the bottom panel).

The black line denotes observations at the tide gauges. Coloured lines denote model simulations.

The left/right column refers to positive/negative surges,
CLIMATE CHANGE

Evaluation of the climate change signal in climate projections is based on comparing the storm surge indexes of two 30 year-long periods: 1971-2000, representing the past (reference), and 2021-2050 representing the future. Two indicators are used:

- Climate change percent index
  \[ \Delta E_i = \frac{SSI_{\text{mod}}^{(2021-2050)} - SSI_{\text{mod}}^{(1971-2000)}}{SSI_{\text{mod}}^{(1971-2000)}} \times 100 \]

- Extreme value climate change index
  \[ \Delta RV5_i(\%) = \frac{RV5_i^{(2026-2050)} - RV5_i^{(1976-2000)}}{RV5_i^{(1976-2000)}} \times 100 \]
## distances between the climate change indices

<table>
<thead>
<tr>
<th>Models and their weight In the ensemble mean</th>
<th>ENEA</th>
<th>MPI</th>
<th>CMCC-LR</th>
<th>CMCC-HR</th>
<th>CMCC-HR (HR grid)</th>
<th>CNRM</th>
<th>IPSL3</th>
<th>IPSL2</th>
</tr>
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<tr>
<td>ENEA (1/5)</td>
<td>0</td>
<td><strong>1.72</strong></td>
<td><strong>1.57</strong></td>
<td>1.13</td>
<td>1.33</td>
<td>1.19</td>
<td><strong>1.93</strong></td>
<td>1.49</td>
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<tr>
<td>MPI (1/20)</td>
<td><strong>1.72</strong></td>
<td>0</td>
<td><strong>0.16</strong></td>
<td><strong>0.48</strong></td>
<td>0.80</td>
<td>1.19</td>
<td>0.80</td>
<td>0.68</td>
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<td>CMCC-LR (1/10)</td>
<td><strong>1.57</strong></td>
<td><strong>0.16</strong></td>
<td>0</td>
<td><strong>0.35</strong></td>
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<td><strong>1.26</strong></td>
<td><strong>1.73</strong></td>
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<td><strong>1.19</strong></td>
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<td>0.53</td>
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Table with the distances between the climate change indeces of the simulations described in this study. All values are normalized with the average distance. Obviously diagonal terms are all zero and the table reports a symmetric matrix. The smallest distances (below 0.5) are shown with large characters, the largest distances (above 1.5) are shown with large underlined characters. Values below the diagonal are in light grey (they duplicate values above the diagonal and are included only for facilitating the visualization of the whole matrix).
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LARGE POSITIVE SURGES:
SPATIAL DISTRIBUTION AND CLIMATE CHANGE

Top panel: storm surge index for positive surges (cm) in the present climate in model simulations.

Bottom panel: its fractional (%) variation in the future (Climate change percent index)

Thick parts of the lines denote where the climate change is significant.

Black is the ensemble mean
LARGE NEGATIVE SURGES:
SPATIAL DISTRIBUTION AND CLIMATE CHANGE

**top panel:** storm surge index for negative surges (cm) in the present climate in model simulations.

**Bottom panel:** its fractional (%) variation in the future (Climate change percent index)

Thick parts of the lines denote where the climate change is significant.

**Black is the ensemble mean**
EXTREME POSITIVE SURGES (5-year RV): SPATIAL DISTRIBUTION AND CLIMATE CHANGE

Top panel: 5-year RV for positive surges (cm) in the present climate in model simulations.

Bottom panel: its fractional (%) variation in the future (Extreme value climate change percent index)

Thick parts of the lines denote where the climate change is significant.

Black is the ensemble mean
SAME APPROACH FOR THE EFFECT OF CLIMATE CHANGE ON WAVES

Top panel: wave storm index for positive surges (cm) in the present climate in model simulations.

Bottom panel: its fractional (%) variation in the future (Climate change percent index)

Thick parts of the lines denote where the climate change is significant.

Black is the ensemble mean
Take-home message in one figure.....

Distribution along the Mediterranean coast

TOP panel: Ensemble mean storm surge index (cm) for positive (red line, cm) and negative (black line, cm) surges and waves (dm) in the present climate in model simulations.

Bottom panel: Climate change percent index (%) for positive (red line) and negative (black line) surges and waves (blue line).

Coastal points are ordered clockwise starting from Gibraltar. Country national borders and some stations used are marked to help locating the different stretches of the Mediterranean coastline.
CONCLUSIONS

Distribution along the Mediterranean coast

- Models reproduce the present spatial variability of surge extremes, although values are often underestimated.
- Future scenario shows large differences among individual simulations. Results are not coherent spatially (climate change has different signs and/or statistical significance in different parts of the coastline and for different models), mostly they are not statistically significant, inter-model spread is a relevant source of uncertainty.
- The largest fraction of uncertainty is attributed to the choice of the global simulation for the boundary conditions.
- A weighted ensemble mean, constructed with results from different simulations, suggests a wide spread reduction of amplitude of large (and extremes) surges and waves in future climate scenarios.

Climate change signal (%)

Positive surges  negative surges  waves
The time coverage of the tide gauges used for model validations. Different colours are meant only as visual help to identifying the duration for each station.
NEGATIVE SURGES:
RELATIVE IMPORTANCE OF MSLP AND WIND

Top panel: Values of the storm surge index (cm) in the wind driven (WIND), sea level pressure driven (MSLP) and complete forcing simulations.

Bottom panel, fraction (%) of storm surge due to the WIND, to the MSLP forcing and residual.

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SPATIAL DISTRIBUTION AND CLIMATE CHANGE

Top panel: 5-year RV for negative surges (cm) in the present climate in model simulations.

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