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,
Global and Planetary Change , DOI: doi: 10.1016/j.gloplacha.2013.09.006
For waves … manuscript in preparation

MOTIVATIONS

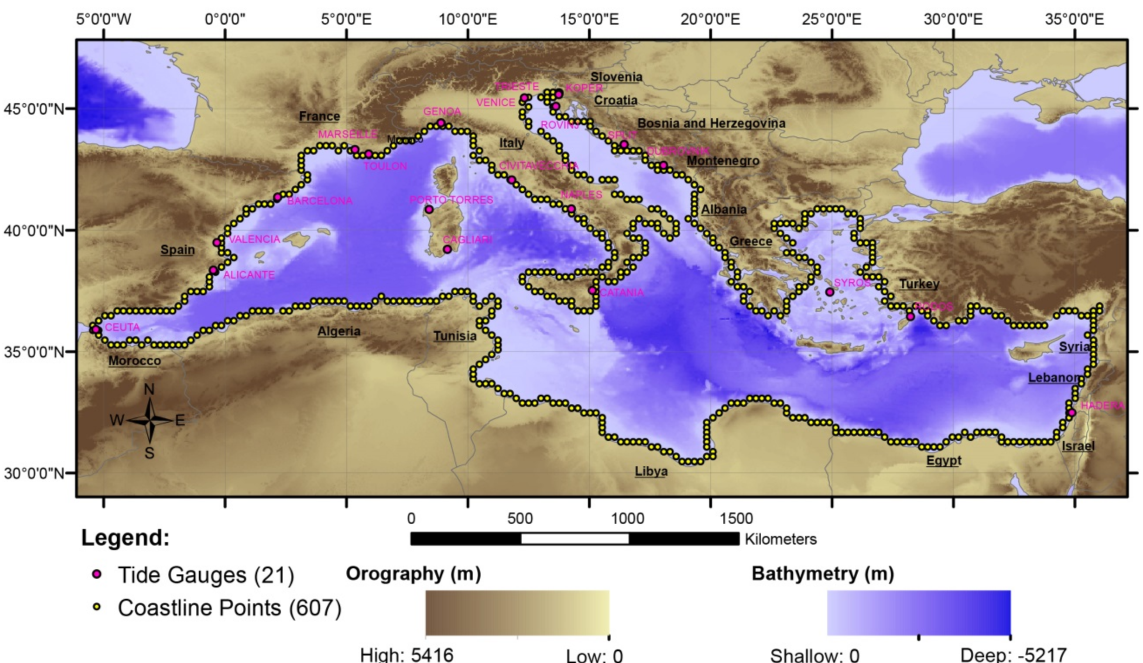
Case studies of coastal cities (Venice and Alexandria), deltas (Nile, Po, Rhone and Ebro), and islands (Cyprus) support the need to consider the effects of climate change (Nichols and Hoozemans, 1996). Future hazard level is related to a combination of factors: sea level rise, vertical land motion, marine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

MAIN OBJECTIVE

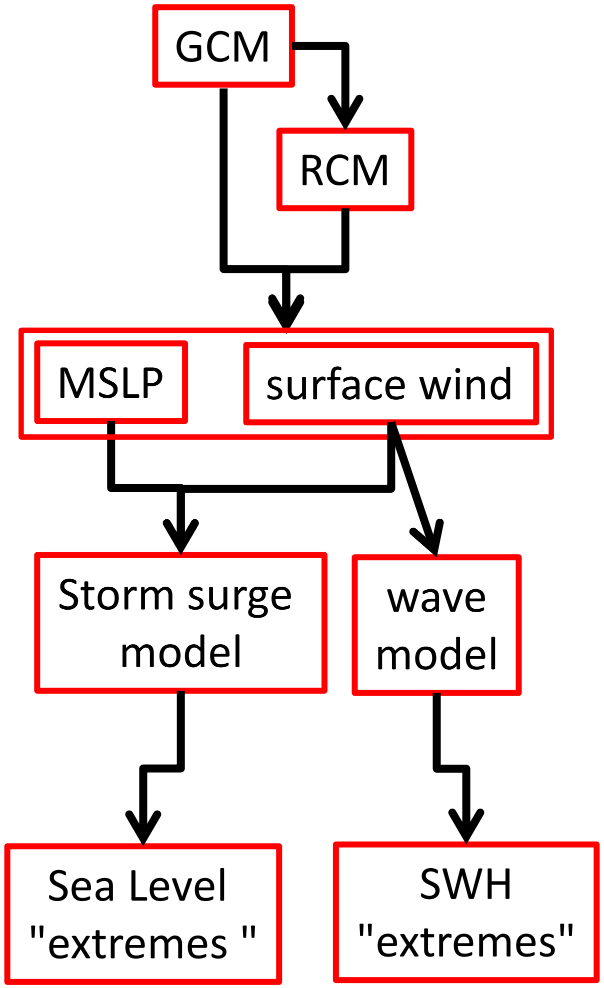
To assess climate change effect on **marine storminess** along the coast of the Mediterranean Sea in the next decades by a multi-model approach

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.



Data and methods

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.

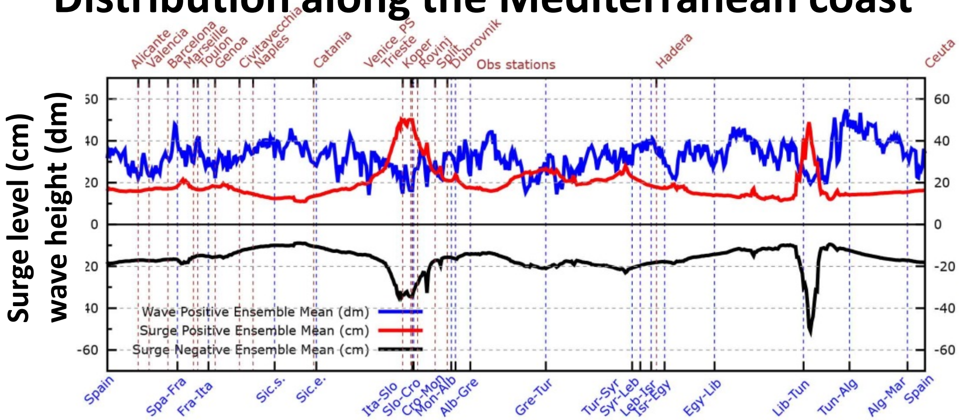
Climate signal is computed as the difference between the surge statistics in the 2021-2050 and 1971-2000 period.

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

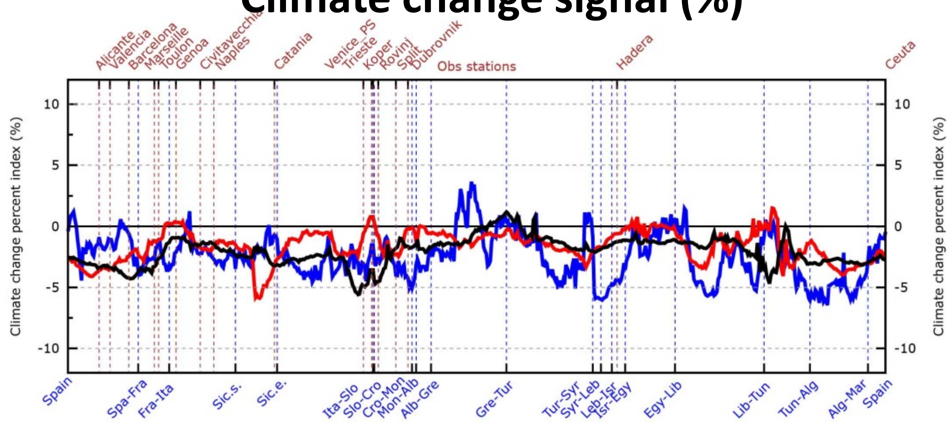
This presentation is focused on surges. Wave simulations have been completed, but only a preliminary analysis is available

CONCLUSIONS

Distribution along the Mediterranean coast



Climate change signal (%)



Positive surges negative surges waves

- 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 simulations

Label	Period	simulation	time step	Short description and grid resolution	weight
HIPOCAS	1958-2001	hindcast	1h	Based on HIPOCAS reanalysis (0.5degs)	
HIPOCAS	1958-2001	hindcast	6h a	Forcings are 6-hour average of HIPOCAS (1h) fields	
CMCC LR	1951-2050	Climate	6h	Forcing is from AOGCM coupled to a high resolution model of the Mediterranean Sea circulation (T159, ~150km)	1/10
CMCC HR	1970-2050	Climate	6h	Forcing is from ARCM (downscaling of CMCC-LR forcings at 0.12degs resolution)	1/40
CMCC HR-HR grid	1970-2050	Climate	6h	Same as CMCC-HR but HYPSE is implemented at high resolution grid (0.05degs)	1/40
MPI	1951-2050	Climate	6h a	Forcing is from an AORCM and represent 6 hour average values. (it is a downscaling of CMCC-LR at 0.22degs)	1/20
ENEA	1951-2050	Climate	6h	Forcing is from AORCM at a 30km resolution	1/5
ARPEGE	1951-2050	Climate	6h (24h mslp)	Forcing is from a stretched grid AOGCM (50km in the Mediterranean region) coupled to a high resolution model of the Mediterranean Sea circulation	1/5
IPSL3	1951-2050	Climate	2h	Forcing is from AORCM at 30km resolution	1/5
IPSL2	1951-2050	Climate	2h	Same as IPSL2 but with the feedback of the AORCM on the driving AOGCM	1/5

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

$$E_i(\%) = \frac{SSIobs_i - SSImod_i}{\frac{SSIobs_i + SSImod_i}{2}} * 100$$

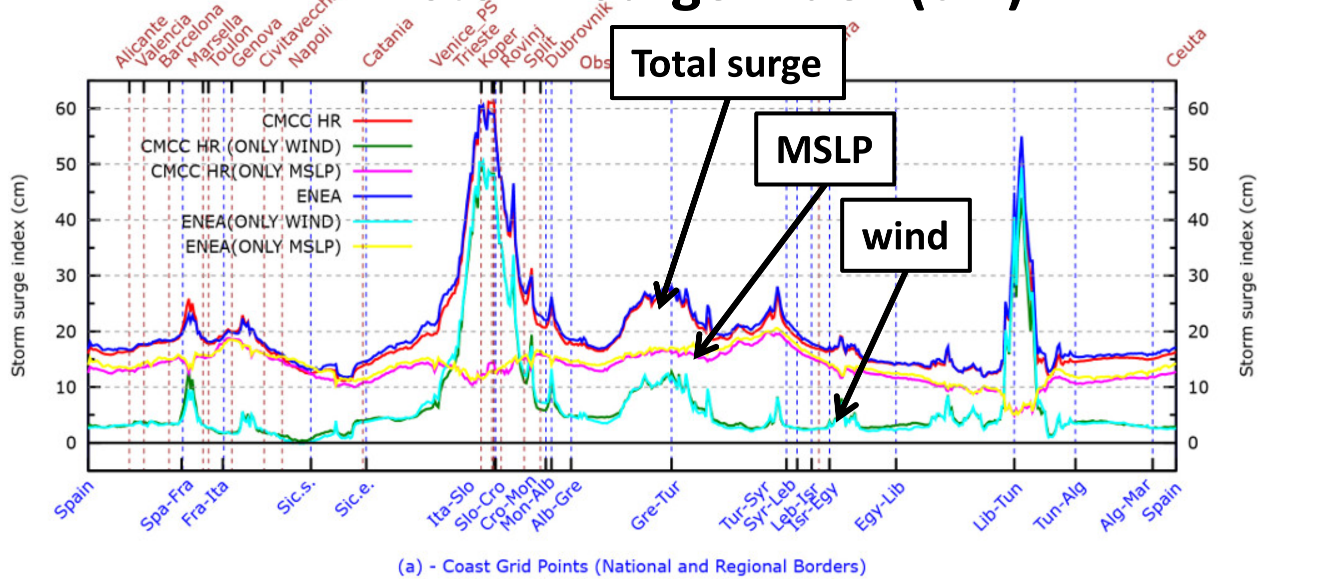
error index

(which compares errors with the variability of the anomalies)

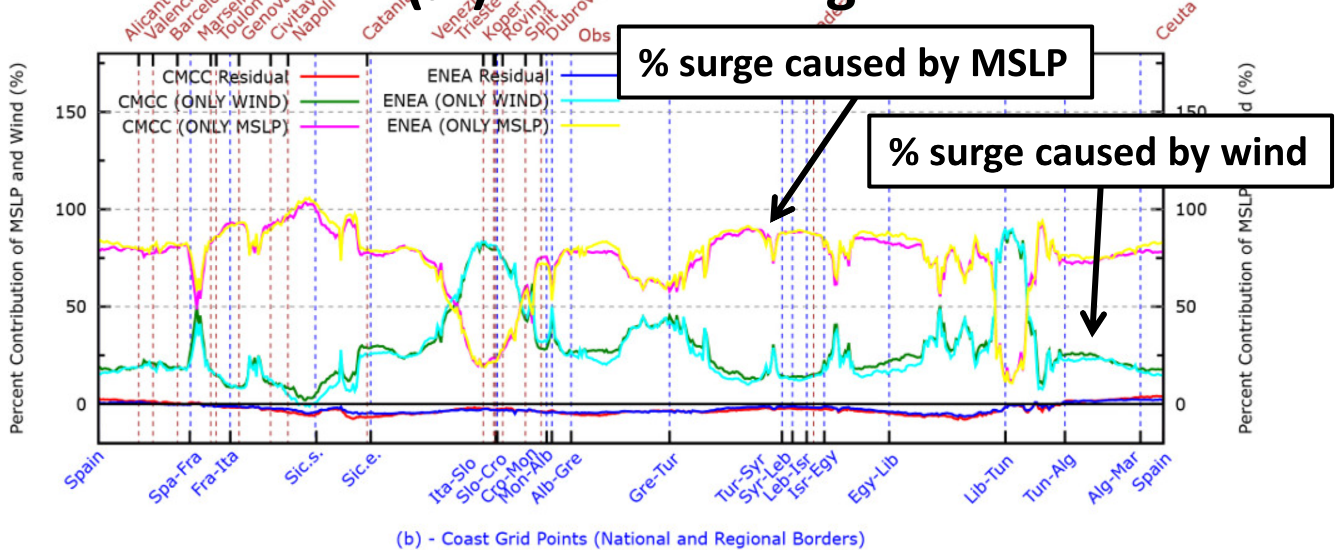
$$EI_i = \frac{SSIobs_i - SSI\,\mathrm{mod}_i}{\sqrt{\frac{\sigma^2_{SSIobs_i} + \sigma^2_{SSI\,\mathrm{mod}_i}}{2}}}$$

POSITIVE SURGES: RELATIVE IMPORTANCE OF MSLP AND WIND

storm surge index (cm)



fraction (%) of storm surge

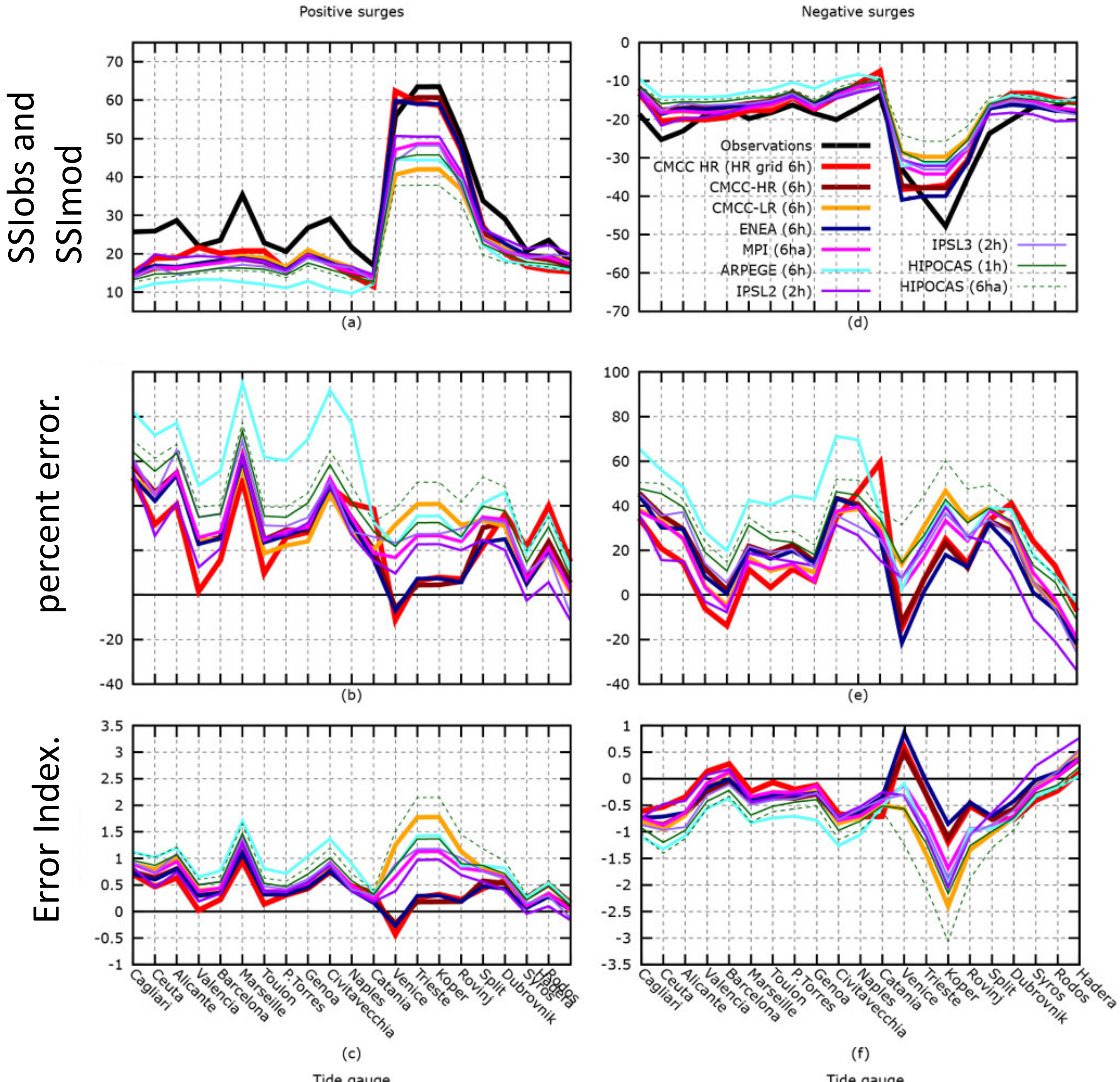


top panel: Values of the storm surge index (cm) in the wind driven (WIND), sea level pressure driven (MSLP) and complete forcing simulations.

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

$$\Delta E_i = \frac{SSI\,\mathrm{mod}_i^{(2021-2050)} - SSI\,\mathrm{mod}_i^{(1971-2000)}}{SSImod_i^{(1971-2000)}} * 100$$

extreme value climate change index

$$\Delta RV5_i(\%) = \frac{RV5_i^{(2026-2050)} - RV5_i^{(1976-2000)}}{RV5_i^{(1976-2000)}} * 100$$

distances between the climate change indices

Models and their weigth In the ensemble mean	ENEA	MPI	CMCC-LR	CMCC-HR	CMCC-HR (HR-grid)	CNRM	IPSL3	IPSL2
ENEA (1/5)	0	**1.72**	**1.57**	1.13	1.33	1.19	**1.93**	1.49
MPI (1/20)	1.72	0	**0.16**	**0.48**	0.80	1.19	0.80	0.68
CMCC-LR (1/10)	1.57	0.16	0	**0.35**	0.61	1.07	0.85	0.53
CMCC-HR (1/40)	1.13	0.48	0.35	0	**0.23**	1.06	1.24	0.87
CMCC-HR (HR grid) (1/40)	1.33	0.80	0.61	0.23	0	1.26	**1.73**	1.27
CNRM (1/5)	1.19	1.19	1.07	1.06	1.26	0	0.80	0.90
IPSL3 (1/5)	1.93	0.80	0.85	1.24	1.73	0.80	0	0.75
IPSL2 (1/5)	1.49	0.68	0.53	0.87	1.27	0.90	0.75	0

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).

Climate simulations

weights

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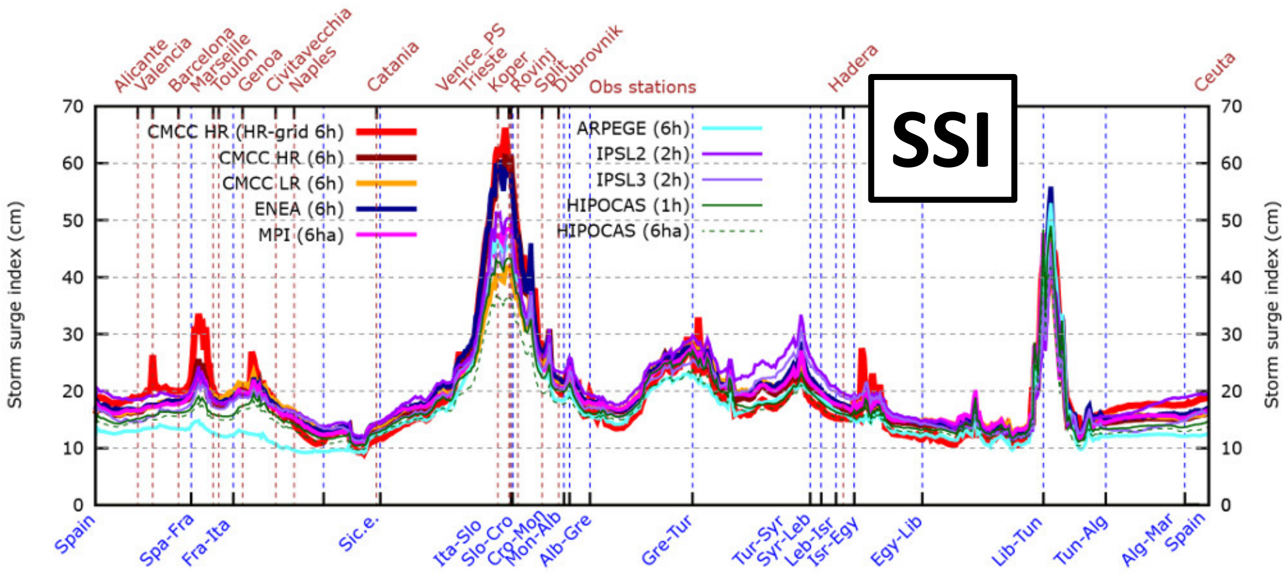
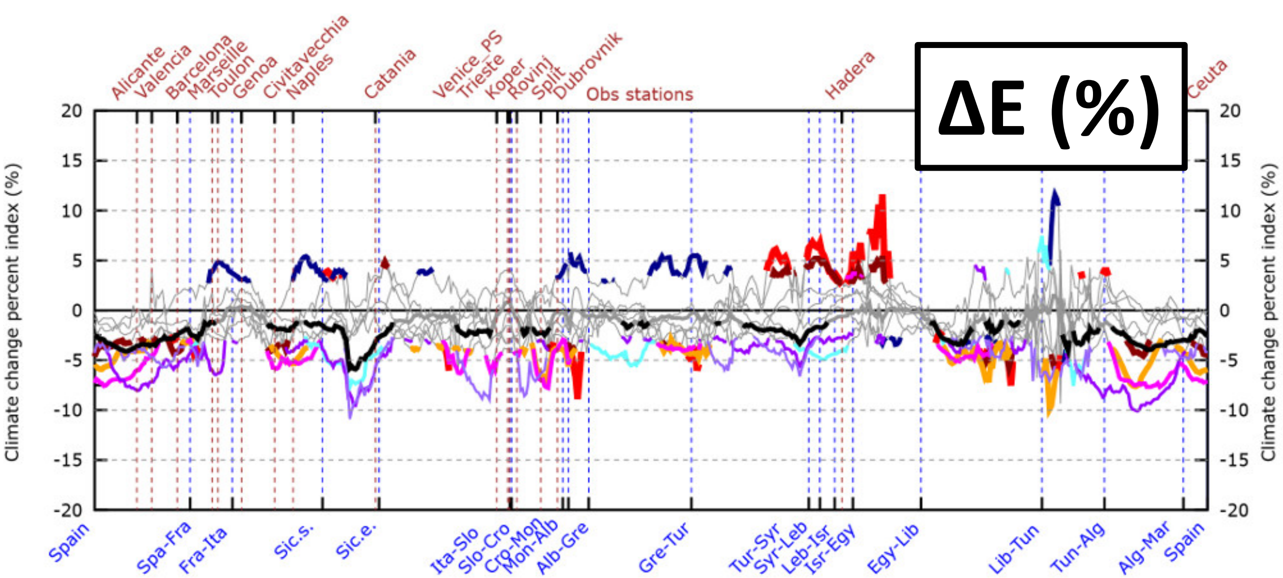
LARGE POSITIVE SURGES: SPATIAL DISTRIBUTION AND CLIMATE CHANGE



(a) - Coast Grid Points (National and Regional Borders)



(b) - Coast Grid Points (National and Regional Borders)

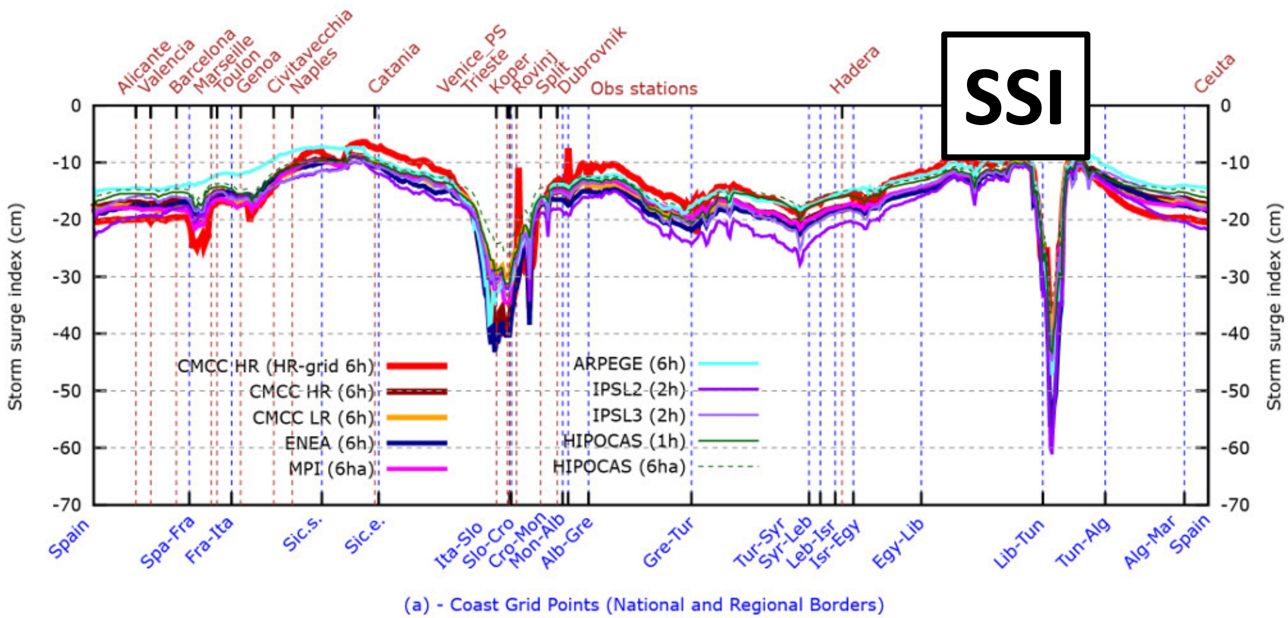
top panel: storm surge index for positive surges (cm) in the present climate in model simulations.

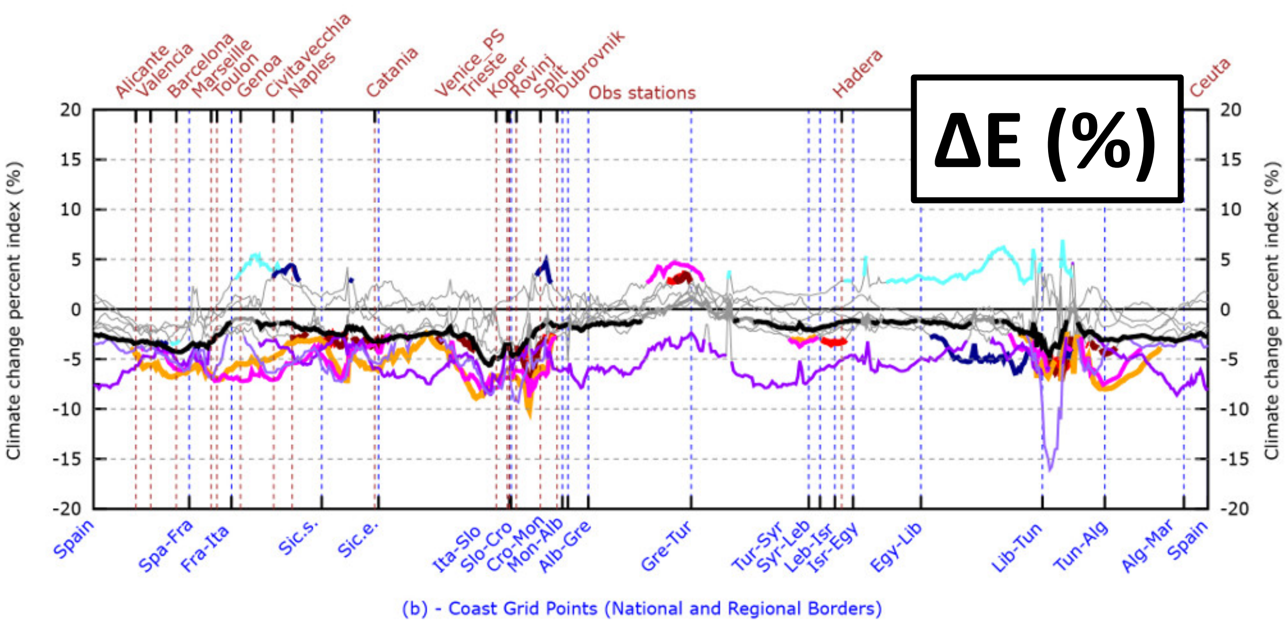
Bottom panel: its fractional (%) variation in the future (Climate change percent index)

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)

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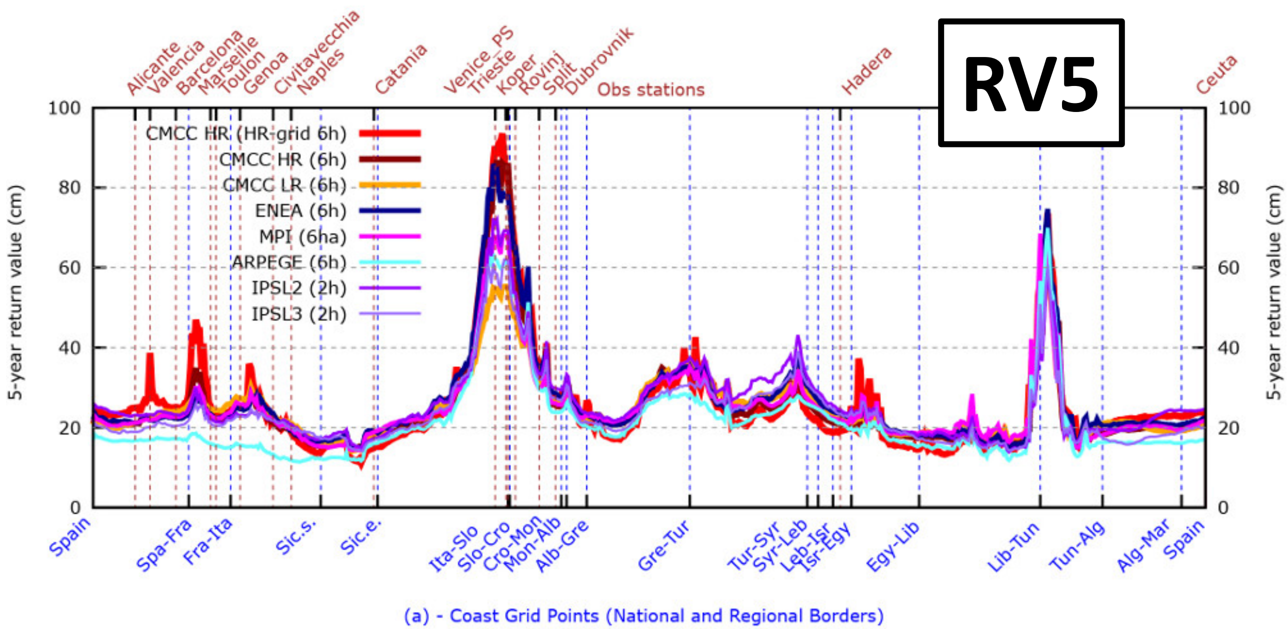
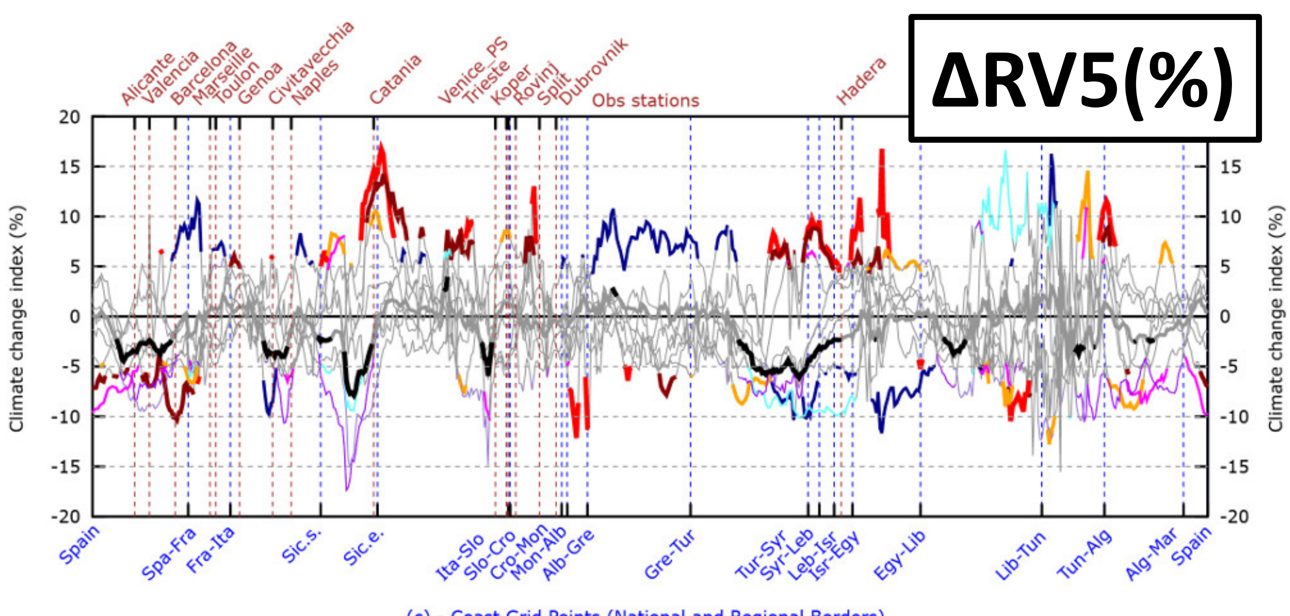
EXTREME **POSITIVE** SURGES (5-year RV): SPATIAL DISTRIBUTION AND CLIMATE CHANGE





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)

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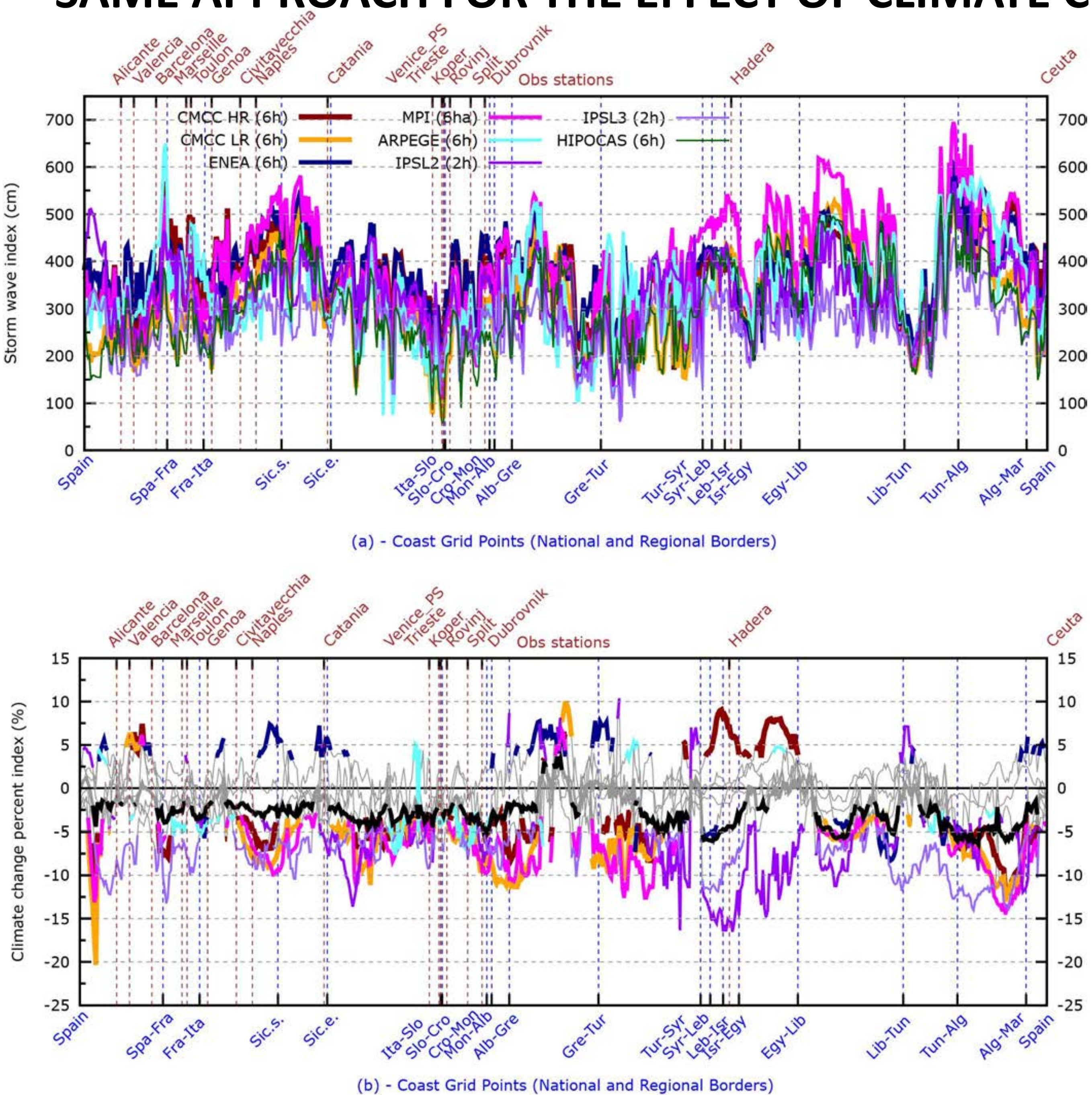
SAME APPROACH FOR THE EFFECT OF CLIMATE CHANGE ON WAVES



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

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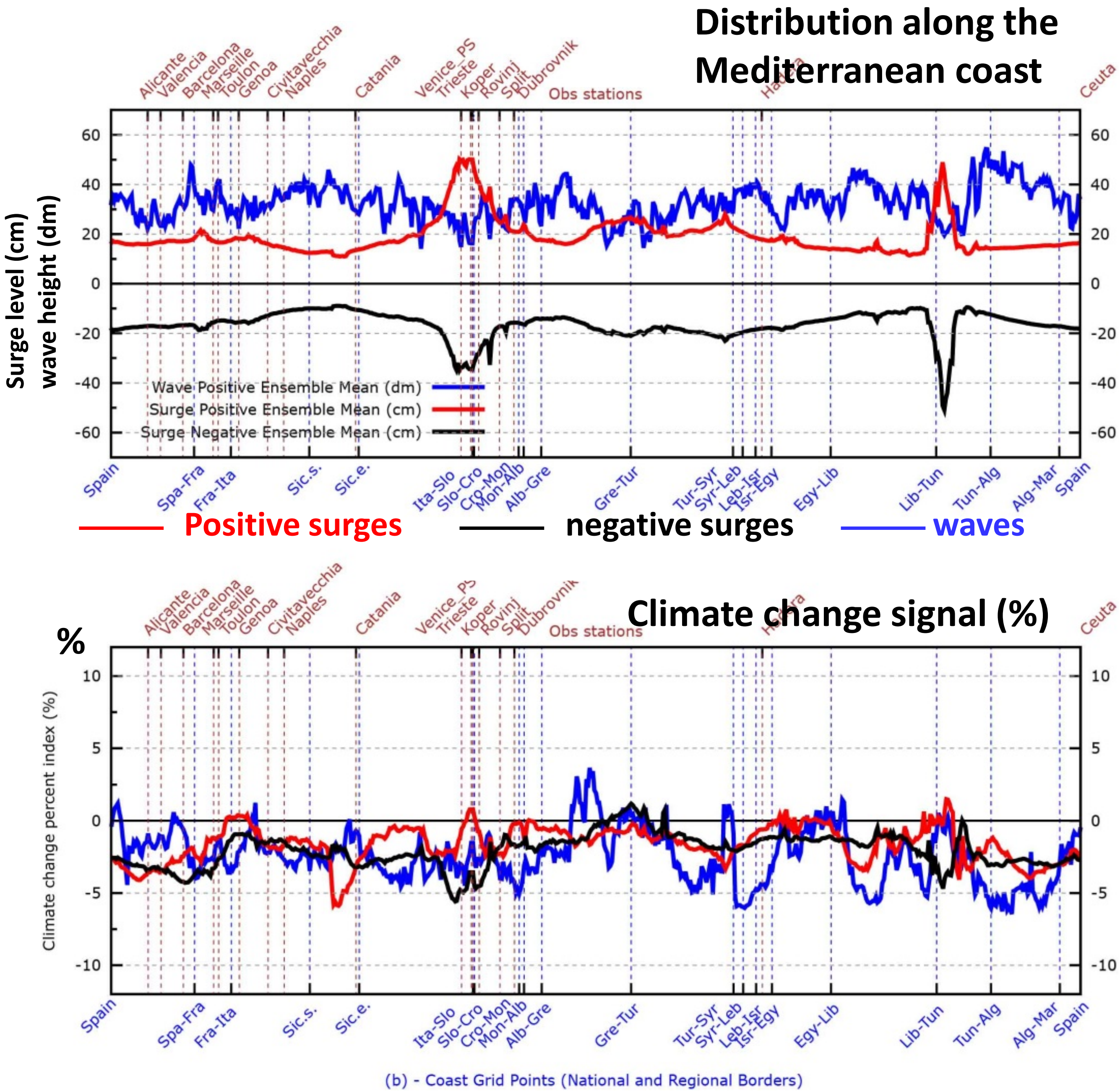
Black is the ensemble mean

Take-home message in one figure…..



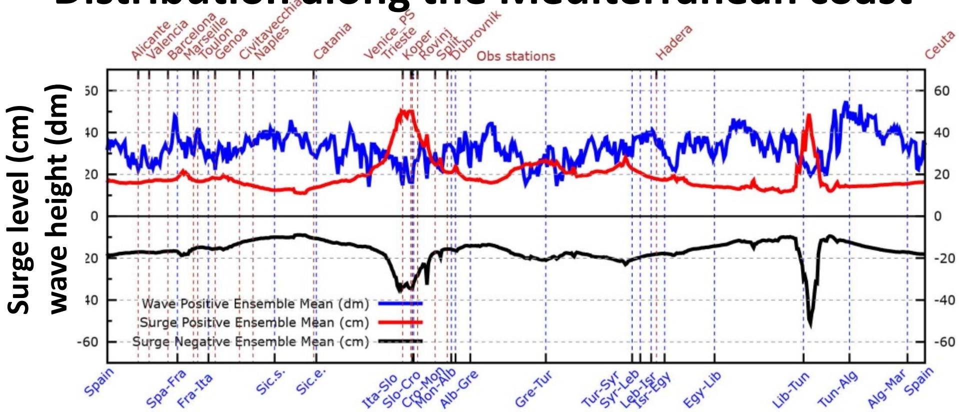
TOP panel: Ensemble mean storm surge index (cm) for positive (red line, cm) and negative (black line, cm) surges and waves (dm) in the present climate in model simulations

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

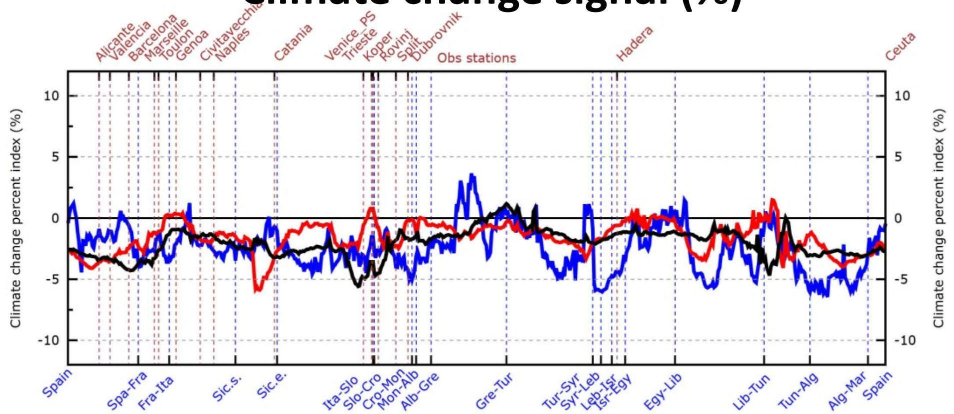
Coastal points are ordered clockwise starting from Gibraltar. Country national borders and some stations used are marked to help locating the different stretches of the Mediterranean coastline.

CONCLUSIONS

Distribution along the Mediterranean coast



Climate change signal (%)



Positive surges **negative surges** **waves**

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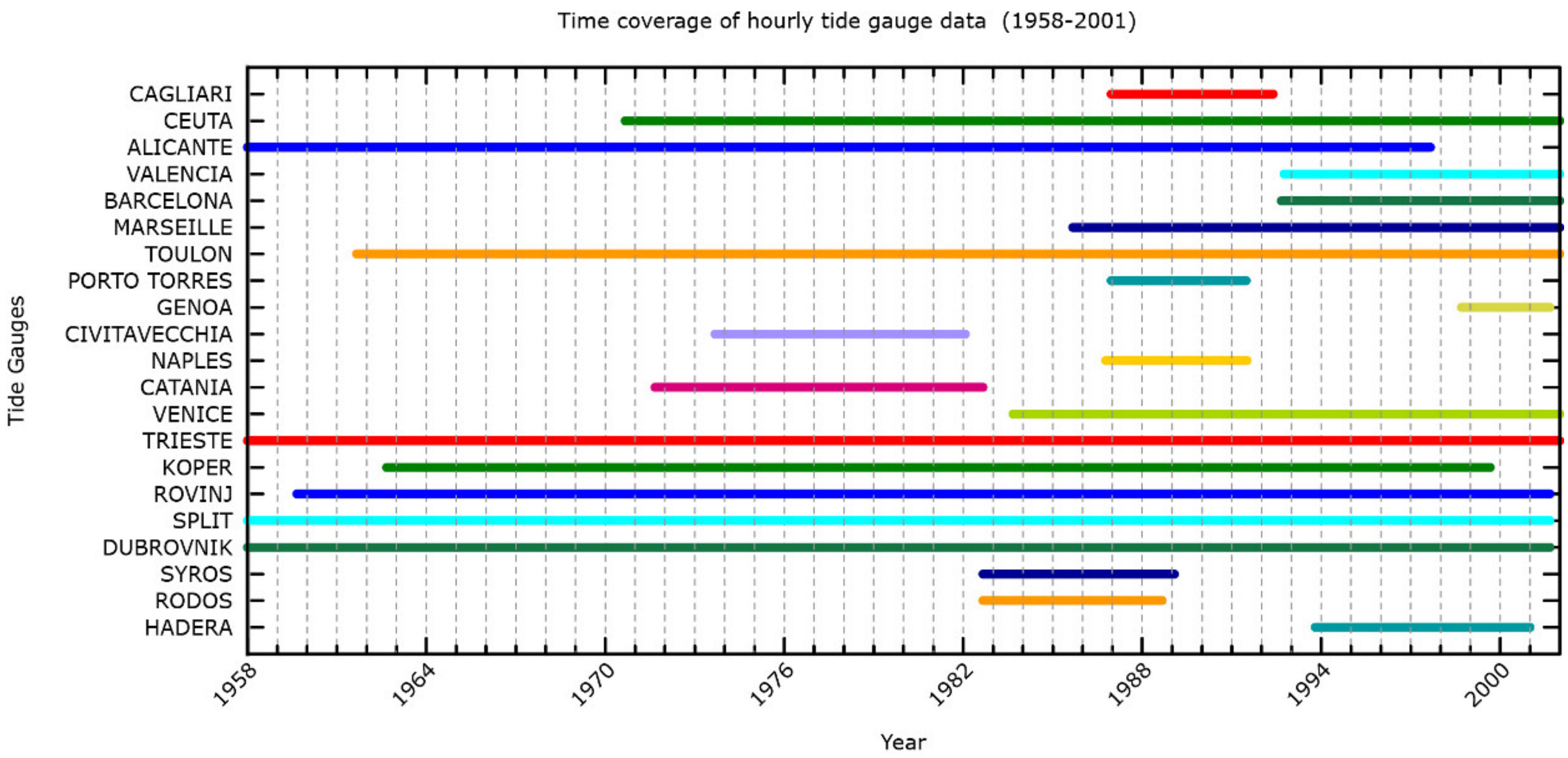
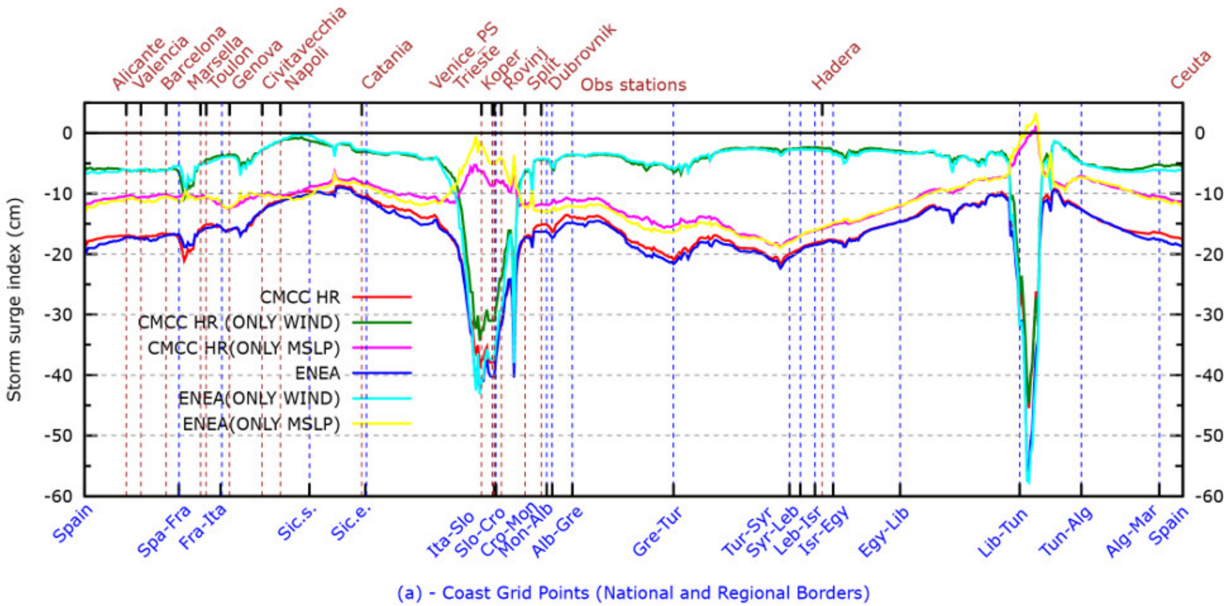


time coverage of the tide gauges used for model validations. Different colours are meant only as visual help to identifying the duration for each station.

NEGATIVE SURGES:
RELATIVE IMPORTANCE OF MSLP AND WIND



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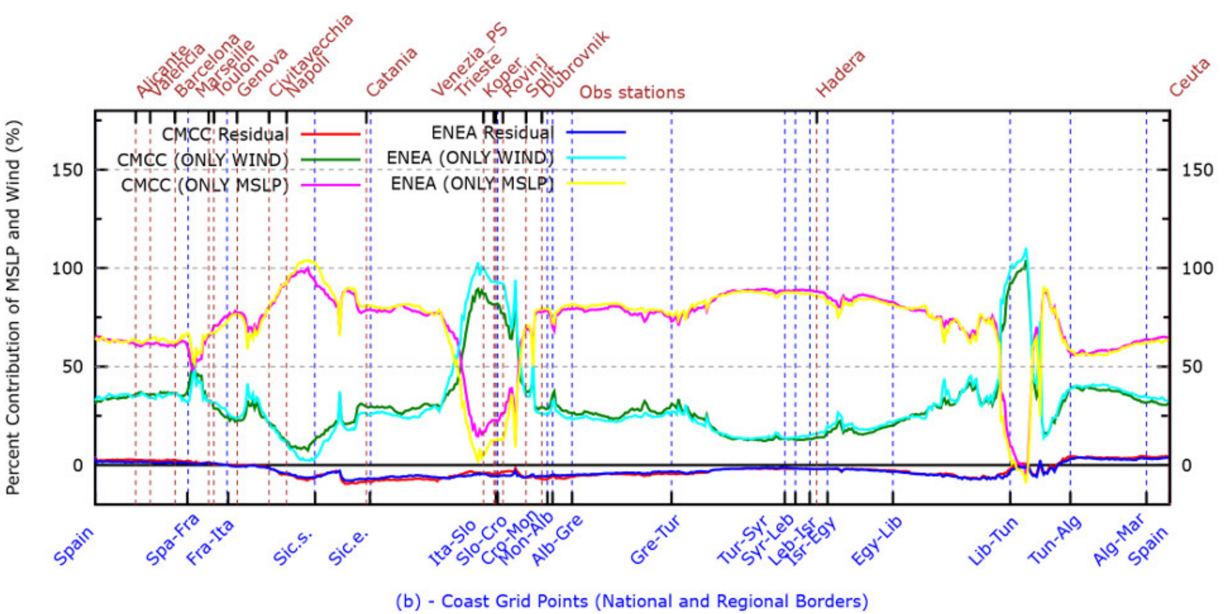

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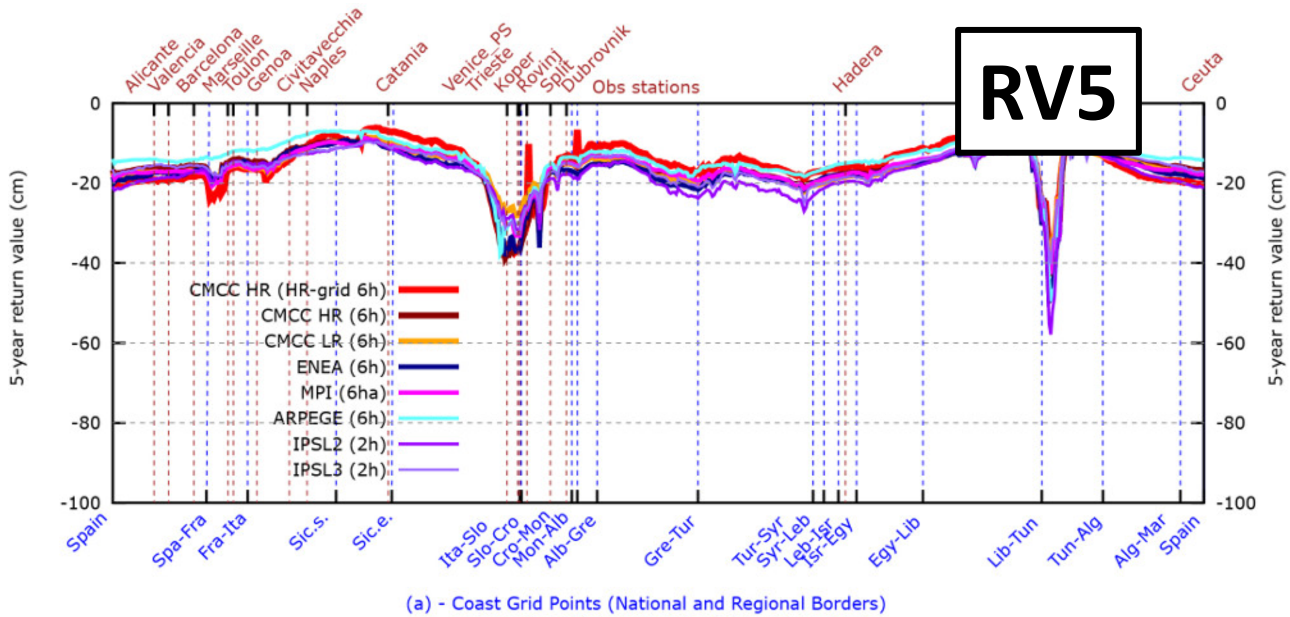

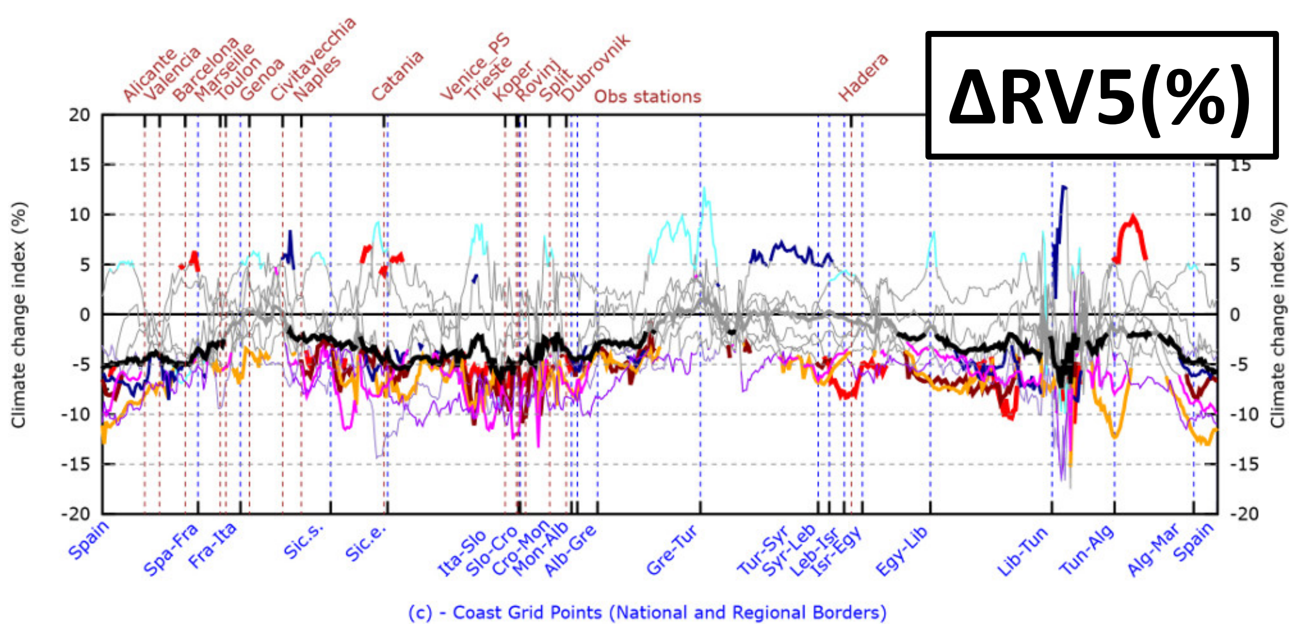

top panel: **5-year RV** for negative surges (cm) in the present climate in model simulations.

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

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