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Sea-Level Change in semi-enclosed basins. The case of the Mediterranean Sea.

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Outline

Can/will a semi-enclosed basin like the Mediterranean Sea evolve very differently from global mean sea level ?

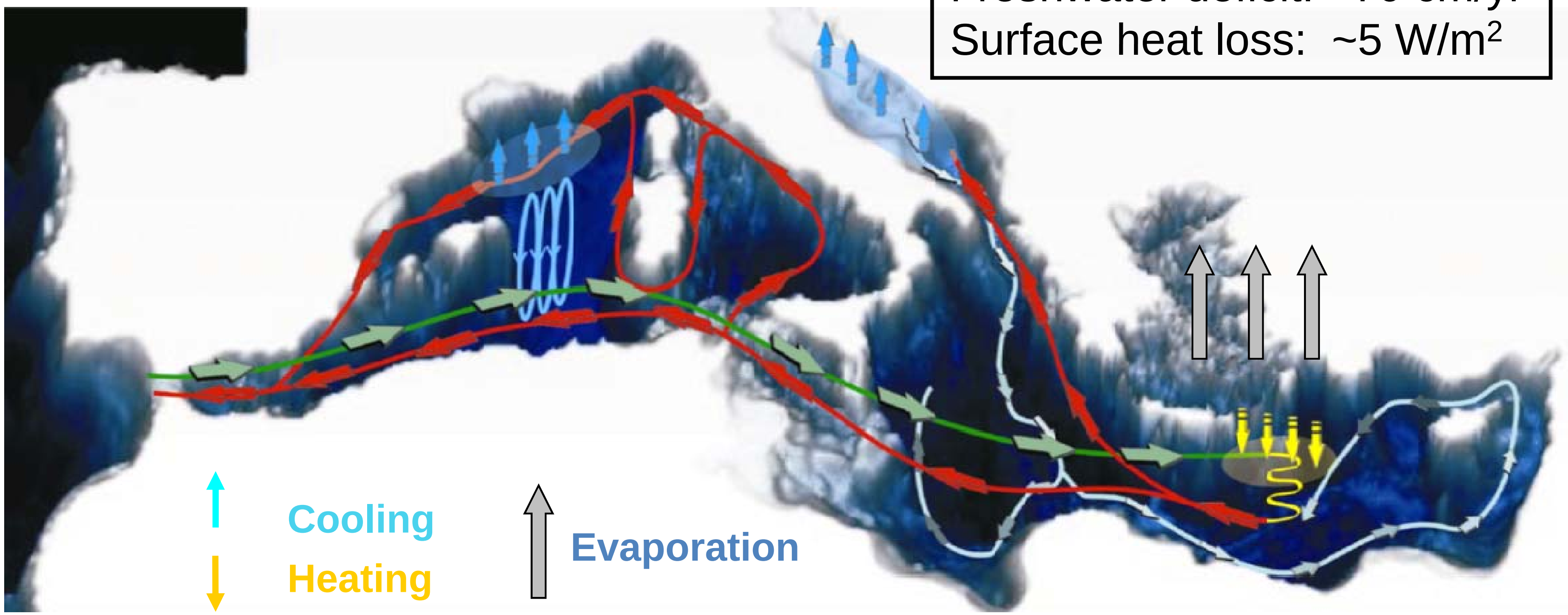
- **The evolution of the Mediterranean Sea during the last decades**
  - total sea level as observed by tide gauges
  - the role of atmospheric pressure; the role of salinity
- **The modelling of Mediterranean Sea level**
  - the issue of the boundary conditions in Regional Climate Models (RCMs)
  - the computation of sea level from RCMs
- **Mediterranean sea level projections**
  - NE Atlantic sea level vs. global sea level
  - the sea level slope along the Strait of Gibraltar
  - the atmospheric component, the ice melting and the fingerprint contributions
- **Summary**

The Mediterranean Sea

The Med Sea is a nearly isolated marginal sea, connected to the open ocean only through a narrow (~15 km) and relatively shallow (~ 300 m) Strait.

It is a **concentration basin**, which makes that the mean salinity of the basin will always be higher than the salinity of the nearby open ocean.

Freshwater deficit: ~70 cm/yr
Surface heat loss: ~5 W/m^2

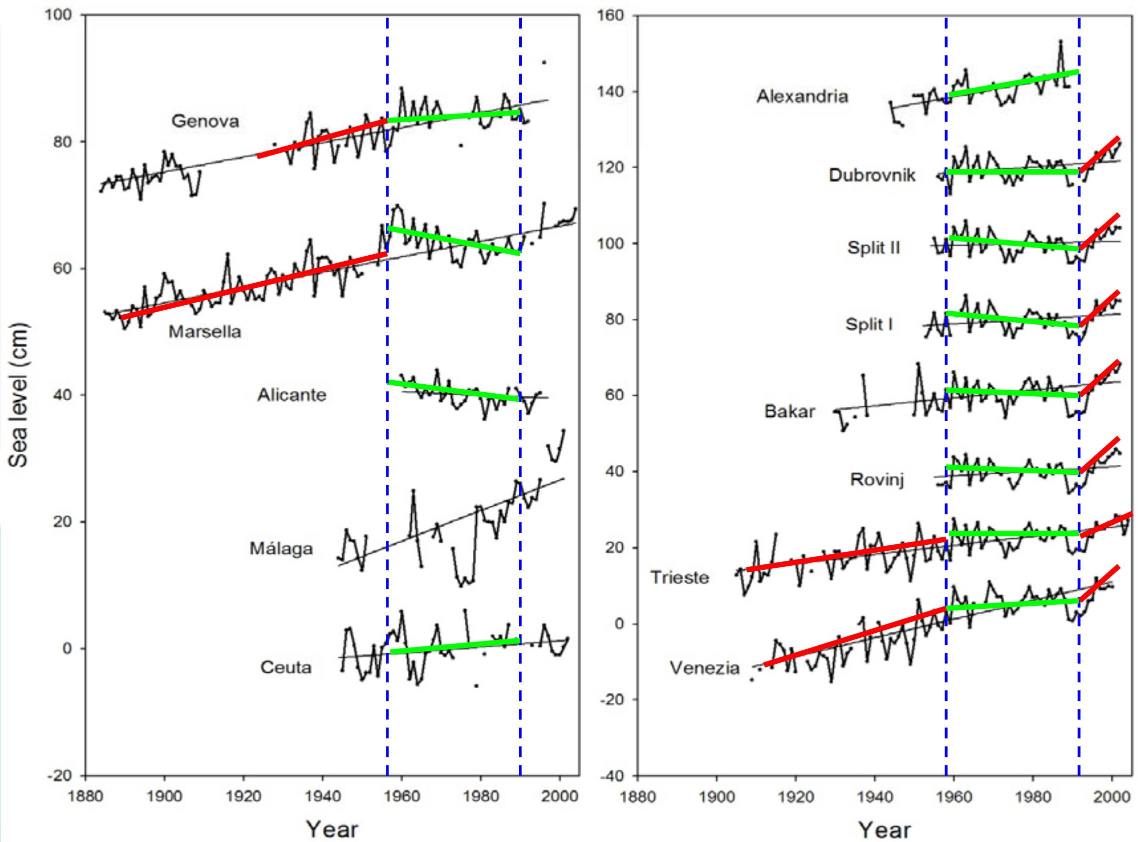


The evolution of the Mediterranean Sea during the last decades

During the period 1960-2000 the Mediterranean Sea level has been rising at a rate of about: **0.3 ± 0.4 mm/yr**

... while the NE Atlantic Ocean has been rising at a rate of **1.1 ± 0.6 mm/yr**

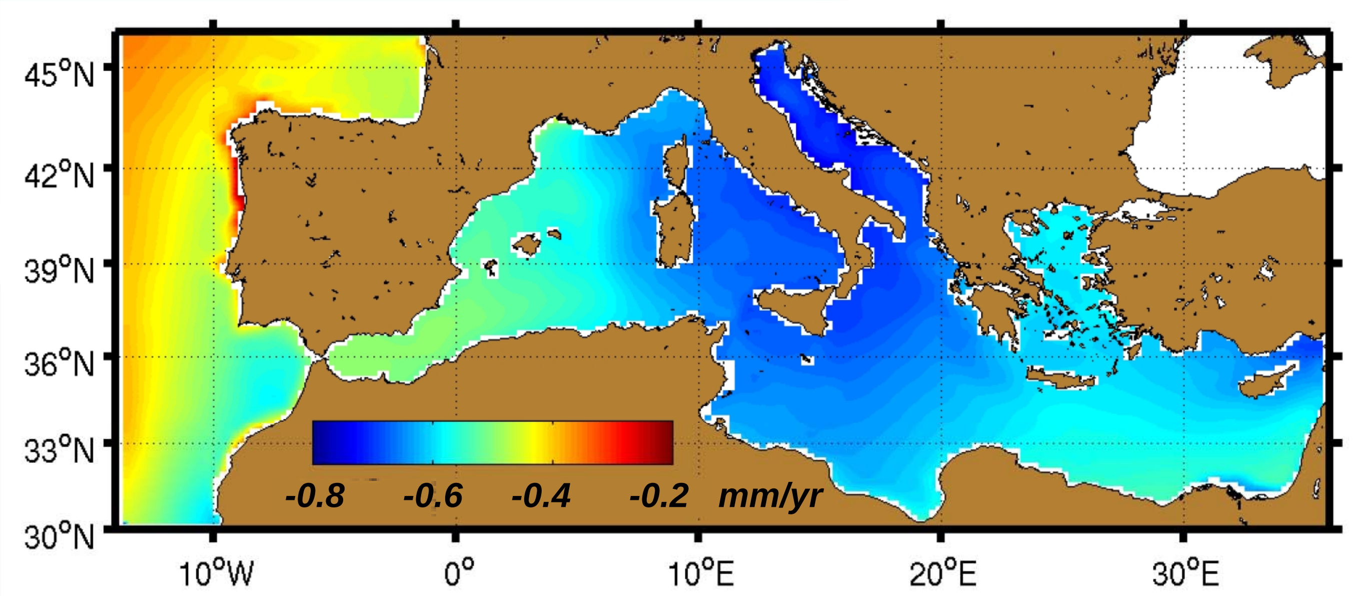
... and the global ocean at a rate of: **1.6 ± 0.2 mm/yr**



From Marcos and Tsimplis, GJI 2008

The evolution of the Mediterranean Sea during the last decades

A large part of the differences between the evolution of the Med Sea and the nearby Atlantic during the last decades are due to the atmospheric forcing (atmospheric pressure mainly).



Atmospheric forcing of sea level computed for the period 1958-2001 from the output of a barotropic model (HAMSOM).

From Gomis et al., GPC 2008

Subtracting the atmospheric component from total sea level: ~~0.3~~ **0.9 mm/yr**

... while in the NE Atlantic Ocean: ~~1.1~~ **1.3 mm/yr**
global mean sea level obviously remains unaltered: 1.6 mm/yr

The remaining differences have often been explained in terms of a **salinity increase**, which would partially compensate the temperature increase when computing the steric component of sea level.

Moreover, the fact that most projections show a continued salinity increase along the 21st century has made some authors to state that **Mediterranean sea level could remain significantly lower than global mean sea level.**

However, this statement bases on a **conceptual fault** related to the computation of sea level changes. This has often been estimated as:

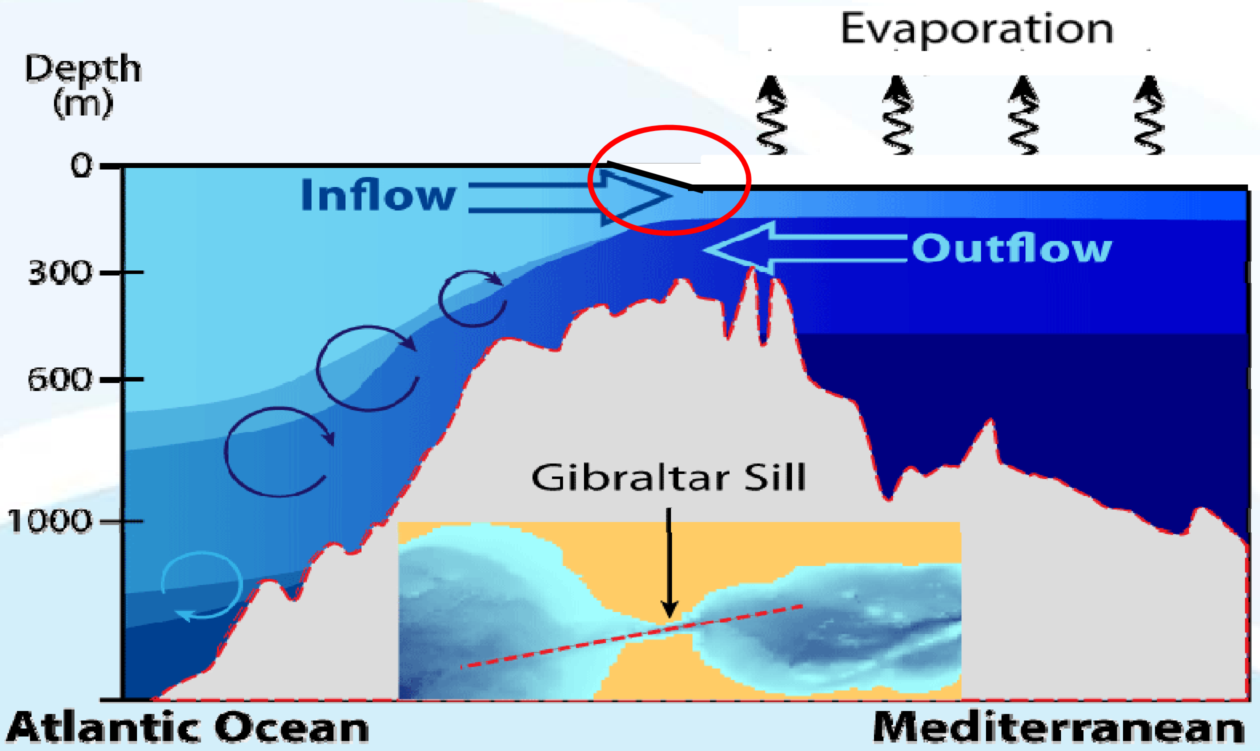
total sea level change = steric change + mass change

continental ice melting (+ atmospheric forcing)

This approach misses the (positive) contribution of a salinity increase to the mass component, which can be even larger than its (negative) contribution to the steric component (see *Jordà and Gomis, JGR 2013*).

The relation between high salinity – low sea level comes from open ocean dynamics, where geostrophy (i.e., the conservation of mass above a given reference level) is a reasonable assumption.

However, this does not hold for a semi-enclosed basin, where the salt (mass) content can increase without having a large effect on sea level.



The modelling of Mediterranean Sea level

Regional models:

- They have enough resolution (1/8º - 1/32º) to represent Gibraltar fluxes and key processes within the basin such as DW formation. However,...

- The conditions imposed on the Atlantic open boundary usually do not represent **actual mass exchanges with the open ocean** (the sponge layer works for T, S and currents, but not for sea level). This implies that there are barotropic and other remote internal processes associated with the global circulation that do not have an impact on Mediterranean sea level.

Global models:

- They account for the impact of remote process on the nearby NE Atlantic and therefore they have the potential to transfer that impact to the Mediterranean Sea. However...

- They can properly solve neither the Gibraltar fluxes nor crucial regional processes such as DW formation due to their low resolution (1º-2º).

The modelling of Mediterranean Sea level

Computation of sea level from RCM simulations:

$\eta(x,t) =$ **SSH(x,t)**	***Baroclinic/barotropic gradients within the model domain*** *(<SSH>=0).*
+ Ster(t)	***Mean steric contribution over the model domain****. Most RCMs conserve volume and therefore Ster(t) must be computed from the model output, integrating the density over the whole domain at each time step.*
+ Mass(t)	***Mass exchanges through the boundaries.*** *Not requested for global models, for RCMs it can only be computed if boundary conditions are properly set.*
+ Atmos(x,t)	*to be computed from barotropic models if RCMs do not include atmospheric pressure.*
+ Ice(t)	*to be computed from global Ice models.*

The modelling of Mediterranean Sea level

In absence of a significant number of RCM runs with proper sea level boundary conditions, we can think of an alternative approach based on the combination of existing global and regional simulations:

$\eta(x,t) =$	***GMSL(t)***	*from GCMs*
	+ SSH_NEAtl (t)	*from GCMs*
	+ SSH_Med-Atl (x,t)	*from RCMs*
	+ Atmos(x,t)	*from barotropic models*
	+ Ice(t)	*from global Ice models*
	+ Ice Fingerprint(x,t)	*from global Ice models*

or:

$$\eta - GMSL/Ice = SSH\_NEAtl + SSH\_Med\text{-}Atl + Atmos + Ice\ Fing.$$

Mediterranean sea level projections

η – GMSL/Ice = SSH_NEAtl + SSH_Med-Atl + Atmos + Ice fing.

From GCMs accounting for the large-scale ocean circulation and hence for the impact of remote signals on the Eastern Atlantic **CMIP3-5 (~ 60 runs)**

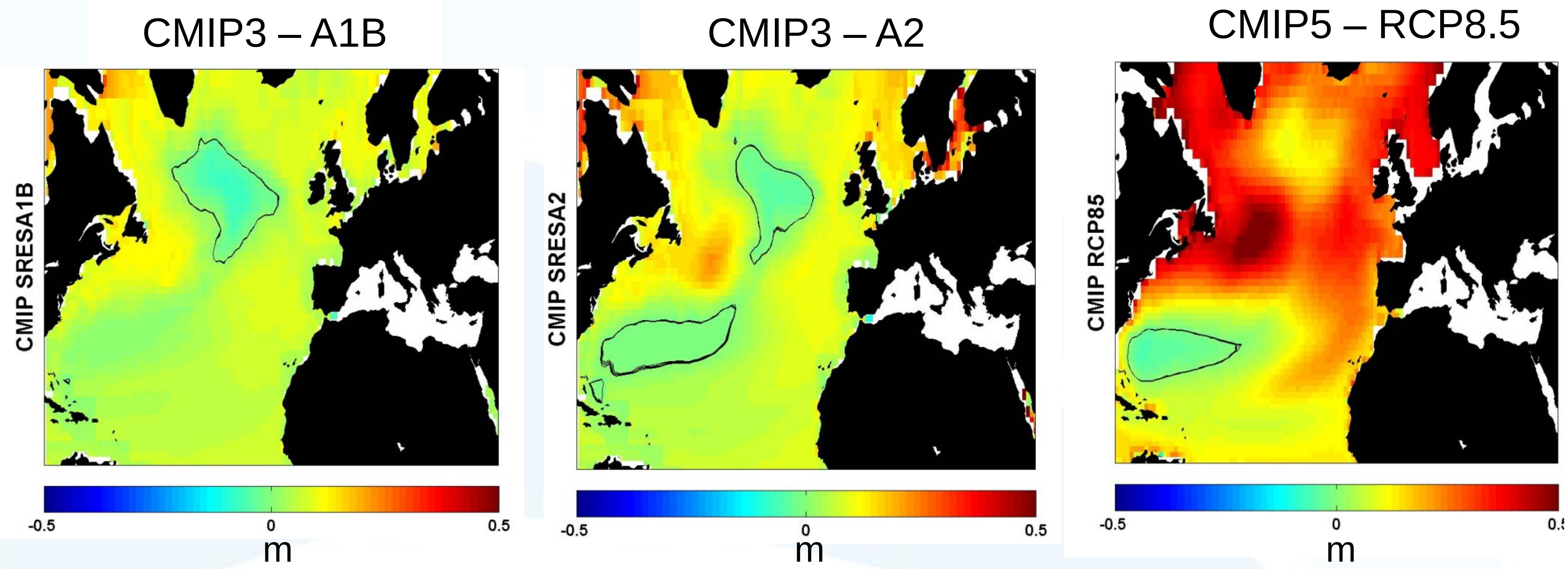
From RCMs accounting for the connection between the Med Sea and the nearby Atlantic through the Strait of Gibraltar **(~ 10 runs)**

From Regional Storm surge models (~15 runs) + GCMs

From Global Fingerprint Ice models (~1 run)

Mediterranean sea level projections

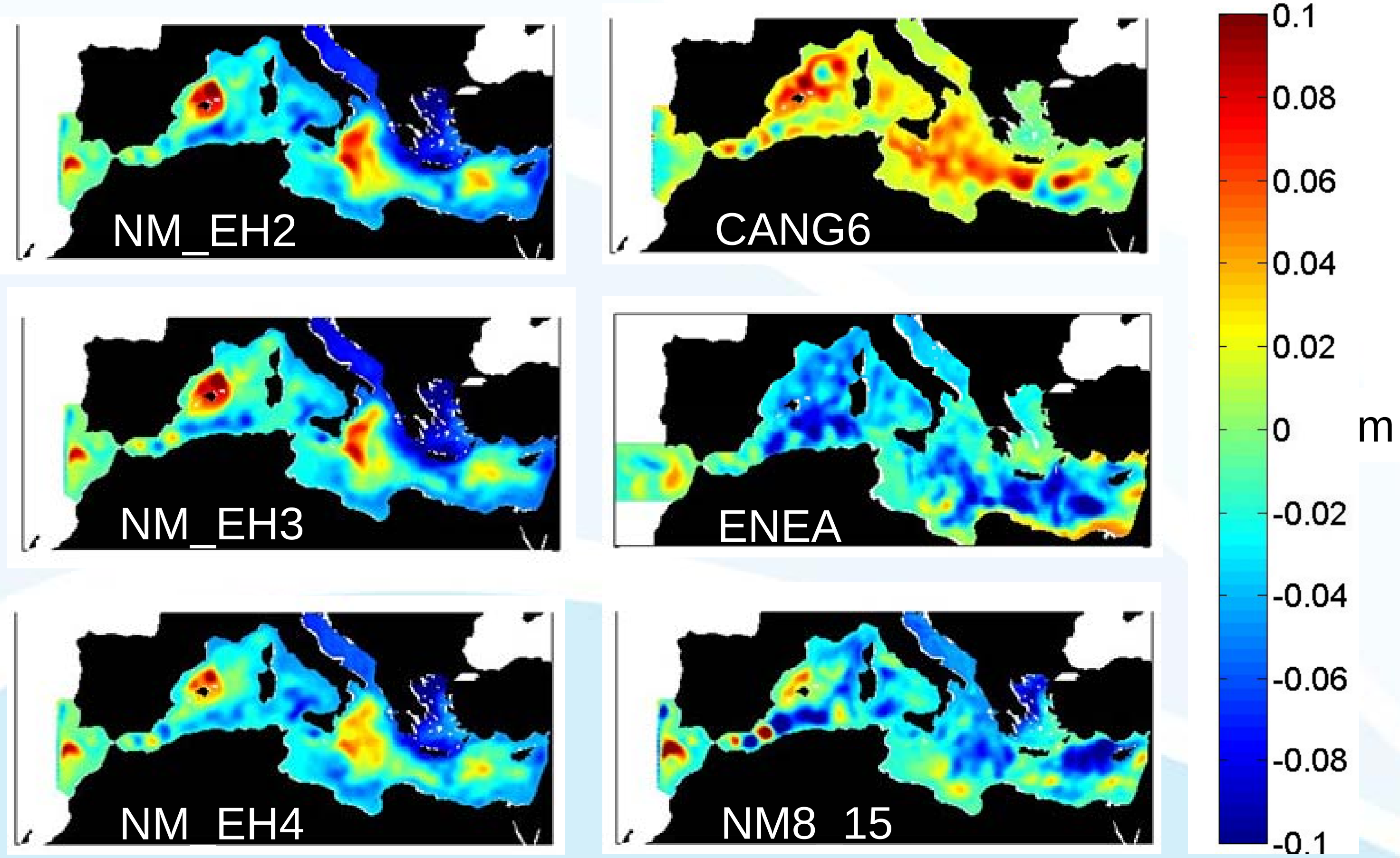
SSH_NEAtl: ensemble mean for the period 2080-2100 *vs* 1980-2000:



GCMs project for the NE Atlantic a **positive SL anomaly with respect to GMSL** of up to 35 cm, depending on the model and scenario. The mean value is ~15 cm and the spread is significantly larger for the CMIP5 ensemble than for the CMIP3 ensemble.

Mediterranean sea level projections

SSH_Med-Atl: change for the period 2080-2100 *vs* 1980-2000 as given by different models:



Mediterranean sea level projections

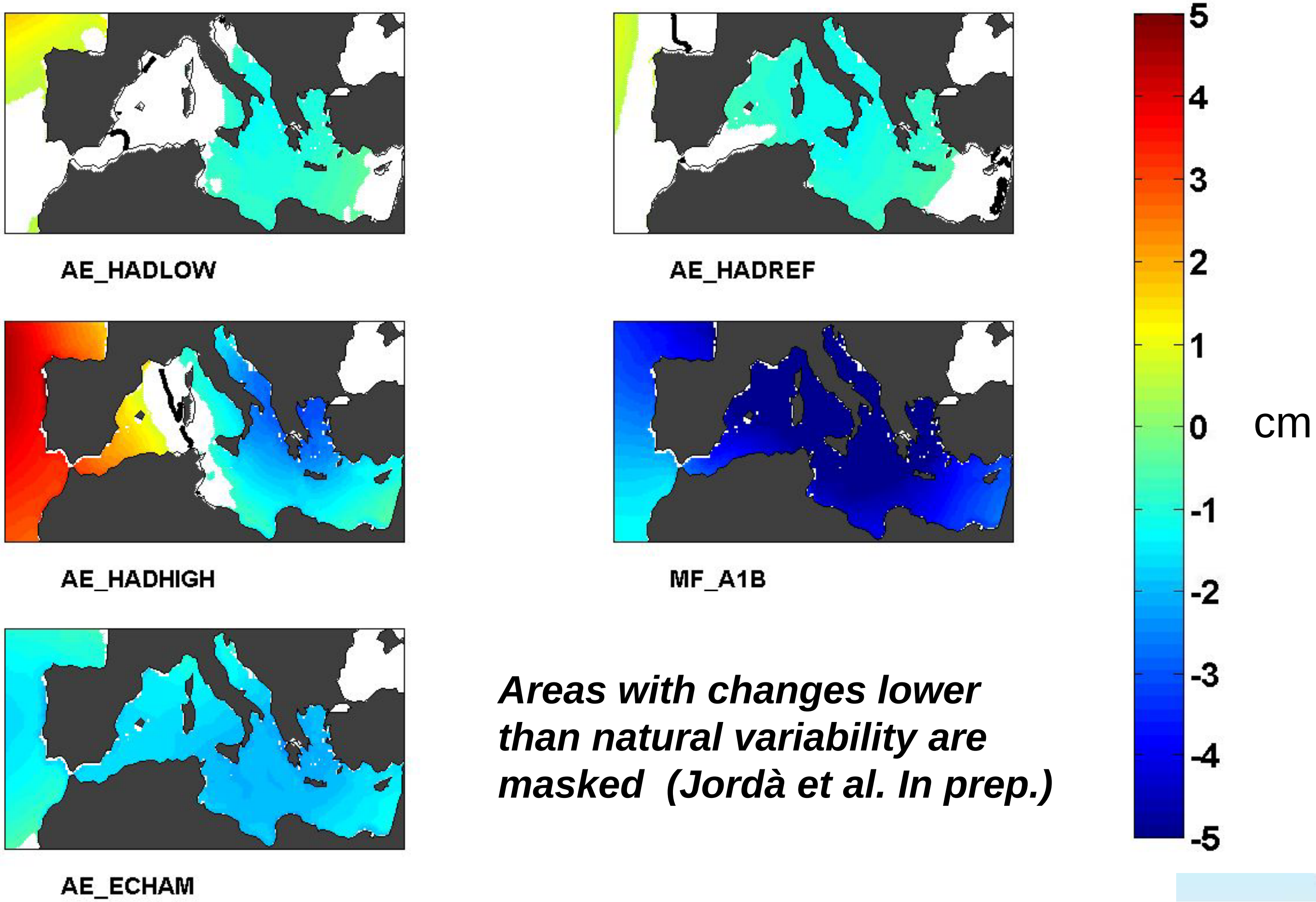
SSH_Med-Atl: change for the period 2080-2100 *vs* 1980-2000 as given by different models:

The basin mean value of **SSH_Med-Atl** is small (~ 5 cm) in all models.

The sea level slope along Gibraltar will increase due to the increase in the Atlantic-Mediterranean density differences, but only a few cm.

Mediterranean sea level projections

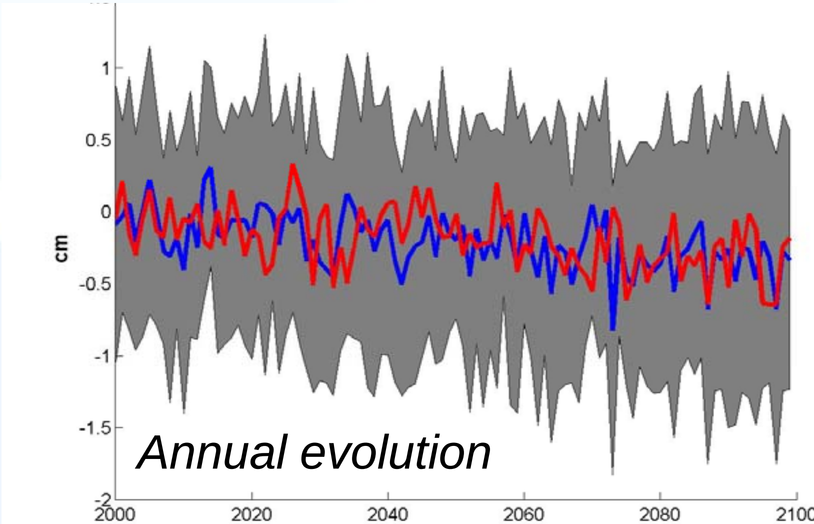
Atmos: change in the Winter Average (2080-2100 vs 1980-2000) from an ensemble of storm surge regional simulations (*only selected runs are shown)*



Areas with changes lower than natural variability are masked (Jordà et al. In prep.)

Mediterranean sea level projections

Atmos: Inverse Barometer from 30 GCMs (CMIP3)

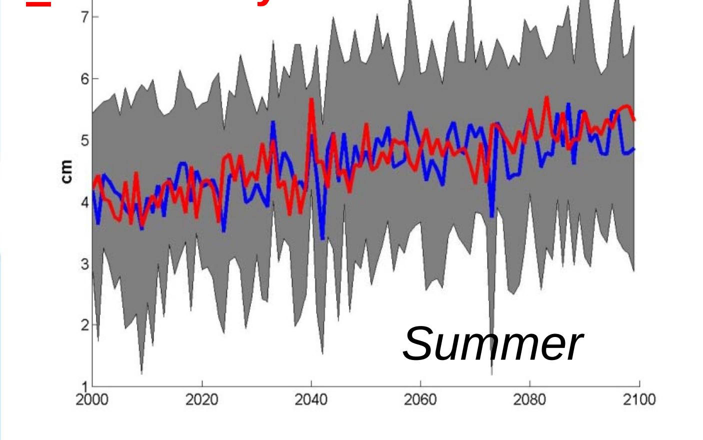


A1B > -0.05 ± 0.08 mm/yr

A2 > -0.06 ± 0.06 mm/yr

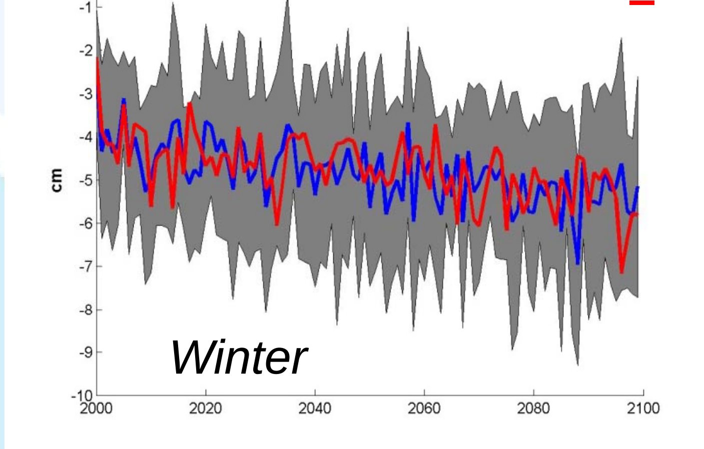
A1B > 0.12 ± 0.08 mm/yr

A2 > 0.14 ± 0.11 mm/yr



A1B > -0.14 ± 0.08 mm/yr

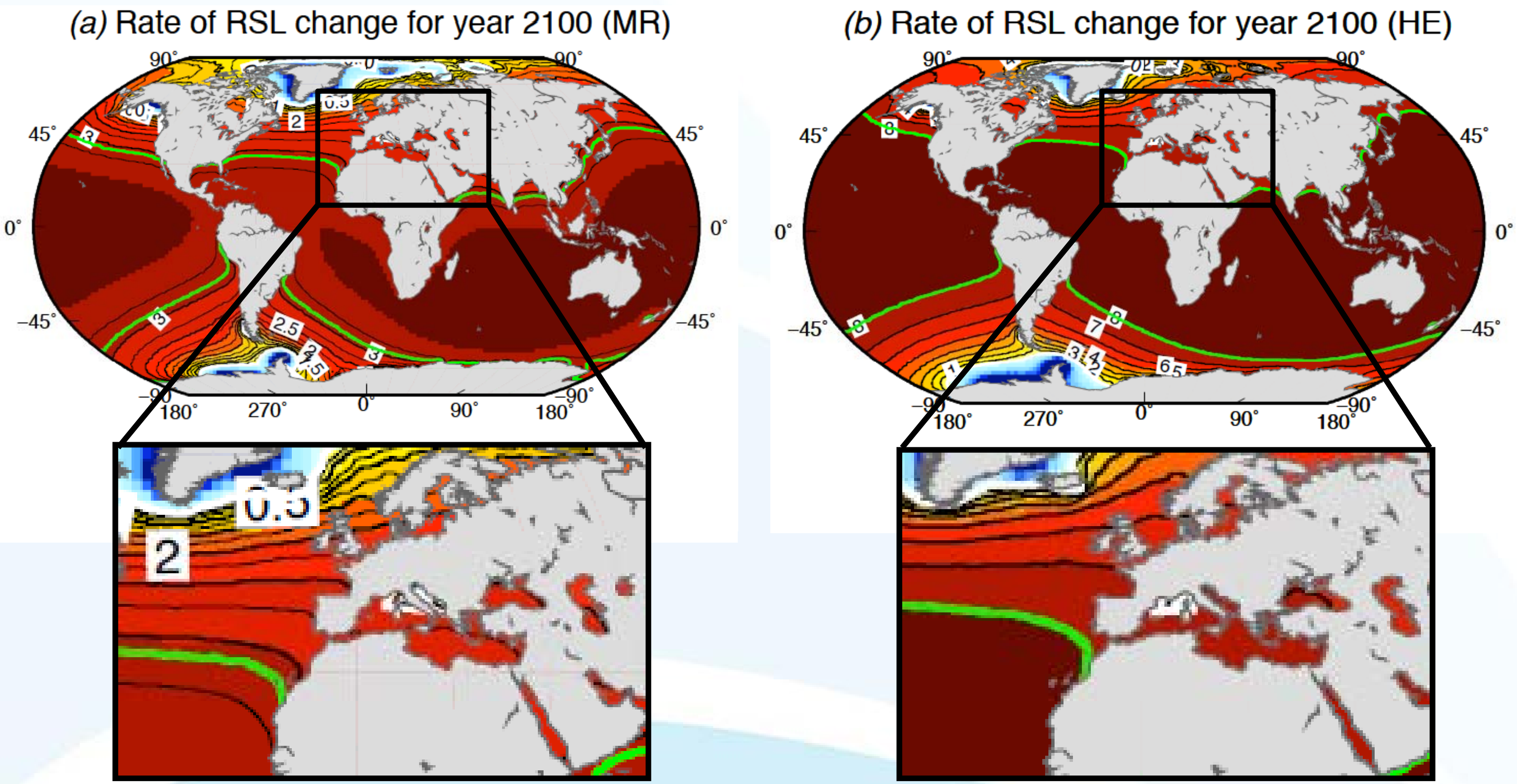
A2 > -0.16 ± 0.11 mm/yr



Mediterranean sea level projections

Ice melting Fingerprints:

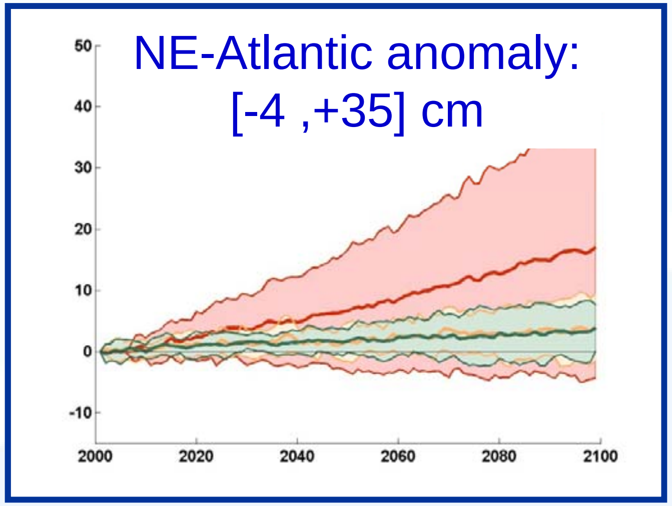
Spada et al., GRL 2013

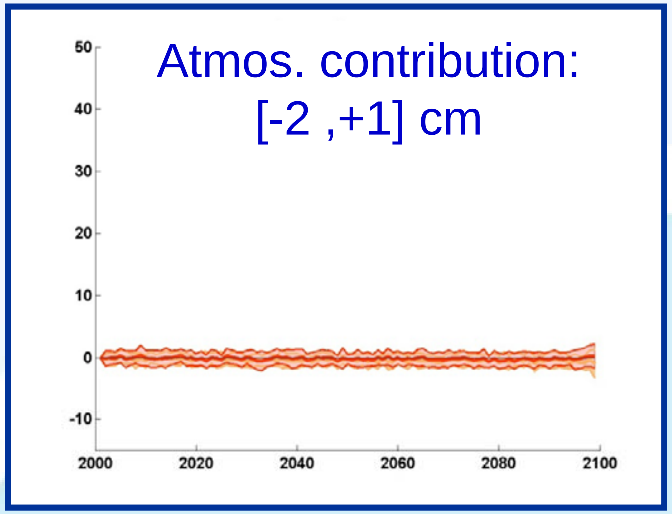


Ice Melting contribution to Mediterranean Sea Level: 2.7 mm/yr (MR)
7.5 mm/yr (HE)

It is equivalent to **~0.9 times the global value**

Summary of all terms contributing to Global-Mediterranean differences:

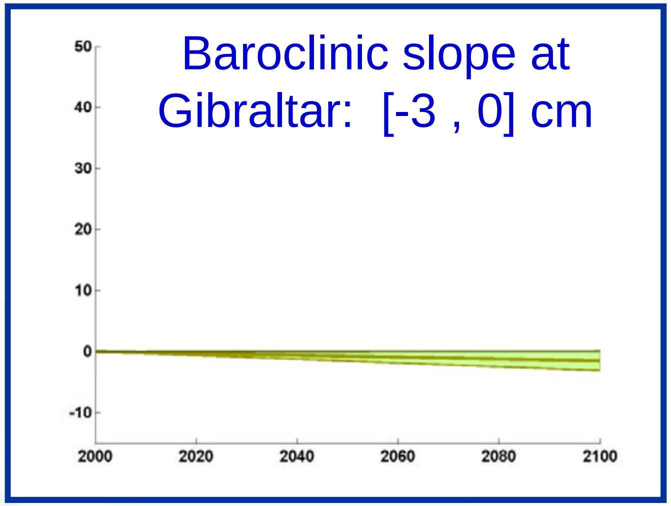


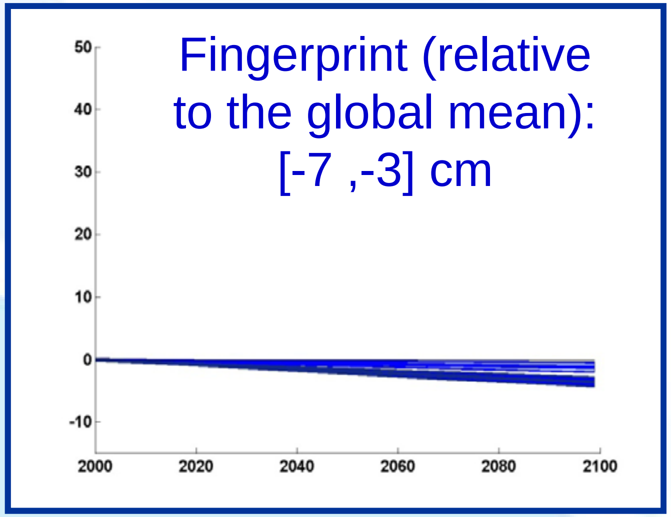


By 2100 the mean sea level of the Med Sea would be

10 ± 25 cm

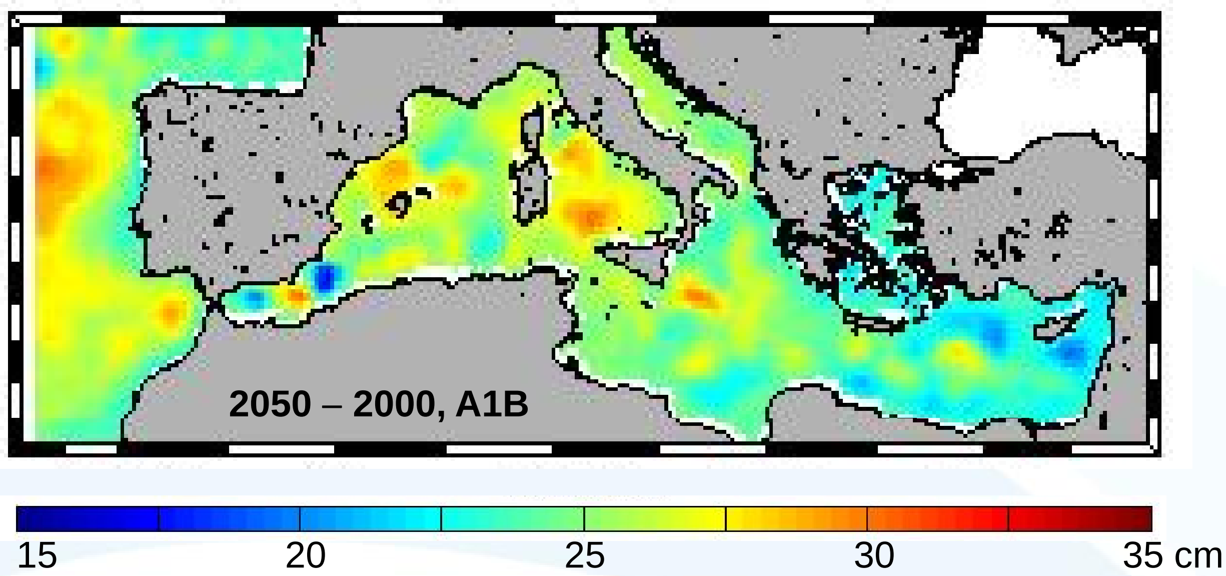
higher than global mean sea level <u>at that time</u>





Mediterranean sea level projections

Regional differences within the Mediterranean are nevertheless important !
as they are required for the study of coastal impacts.



Up to date the number of available RCM runs is increasing, but still far from the number of GCM runs → **the assessment of uncertainties is not very robust**.

→ **efforts such as MedCORDEX are really necessary**

Summary

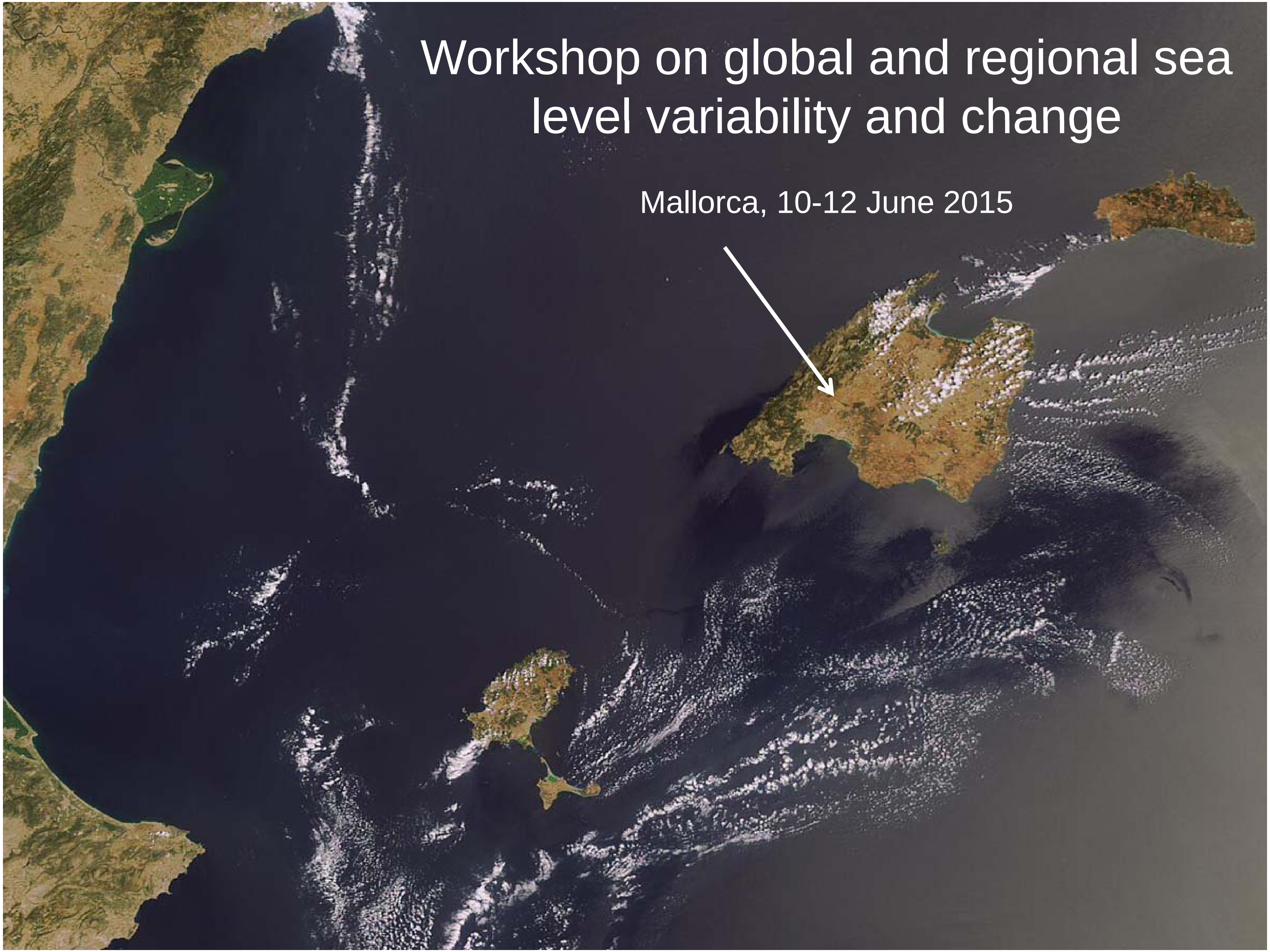
- RCMs need of **sea level boundary conditions** (in addition to hydrographic conditions) for a proper estimate of sea level. Alternatively, Mediterranean Sea level can also be inferred from the **combination of GCMs and RCMs** (assuming this is done in a proper way).
- Global projections suggest that **NE Atlantic sea level will rise faster than global mean sea level** (~15 cm difference by 2100). However, the spread of results is quite large (± 20 cm).
- Regional models show that Mediterranean hydrodynamics cannot support large sea level differences along the Strait of Gibraltar. **Mediterranean mean sea level is and will be only slightly lower** (by a few cm) than the NE Atlantic.
- **Atmospheric pressure can act as a distinctive forcing at regional level**. During the last decades of the 20th century Mediterranean sea level lowered several cm due to anomalously high pressures over the basin; however, this situation does not appear to maintain along the 21st century (projections show an atmospheric contribution of about -1 cm by 2100).
- The contribution of ice melting and its associated fingerprint would be about **10% lower in the Mediterranean than for global mean sea level**.

Summary

- We can therefore conclude that **Mediterranean sea level will not behave very differently from the nearby Atlantic**, which by the end of the 21st century might be **10 ± 25 cm higher than global mean sea level <u>at that time</u>**.

- The small diagnosed departures from global mean sea level do not mean that regional simulation are useless !. **Diagnosing regional-to-local sea level is essential for impact studies.**

- There is still a need for more RCM runs for a better **assessment of regional uncertainties.**


Workshop on global and regional sea level variability and change
Mallorca, 10-12 June 2015