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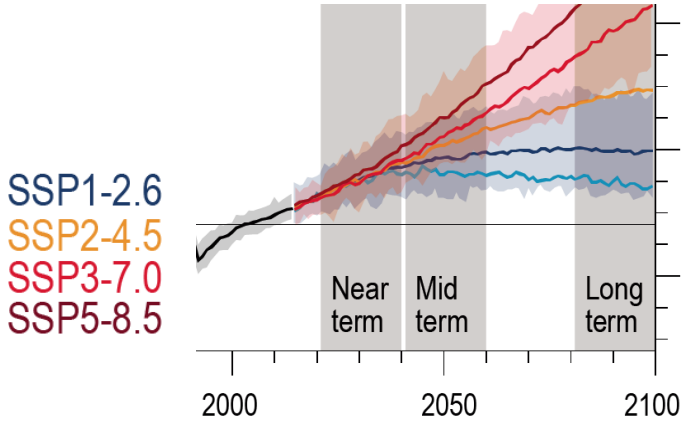
A Global High-Resolution Ensemble of Wave and Storm Surge Projections Forced by CMIP6 Models

Vitali Sharmar

Outline

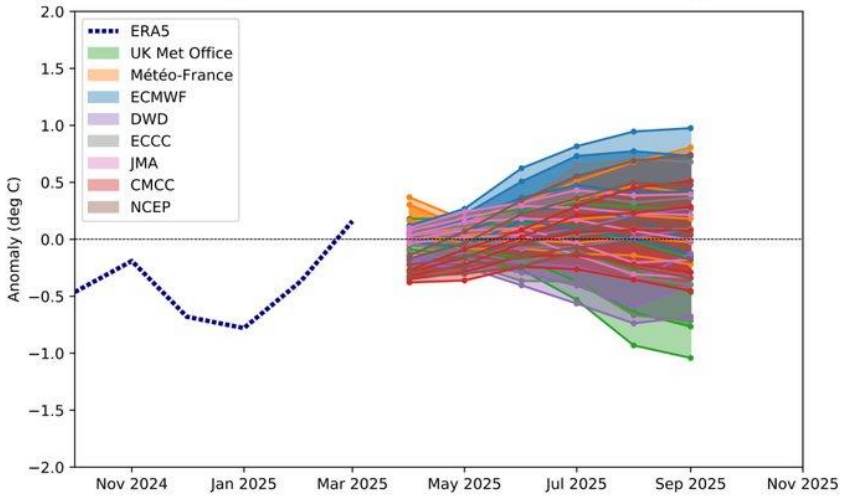
- The importance of waves and storm surges for climate simulations
- The coupled model and experimental setup
- A brief overview of the model's variability
- The results concerning the predictability of waves and storm surges
- How an analysis related to the whole globe is applicable to coast
- Ensemble mean projections in waves and storm surges
- Applications to physical processes through which wind-generated waves can affect coastal sea level



Motivation

C3S multi-system ENSO forecast

NINO3.4 SST anomaly percentiles 10, 25, 50, 75, 90 C3S:
Multi-system forecast from 1 April 2025 monthly mean anomalies
relative to 1981-2010 climatology

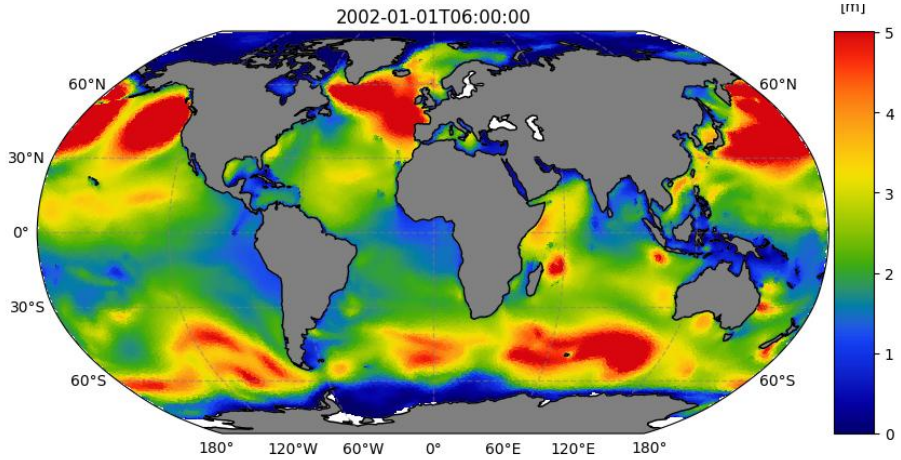


Interannual to decadal predictability is based on concept suggested by Hasselmann's (1976) stochastic climate modeling approach.
"Due to the memory of the system it is possible to derive useful forecasts of oceanic quantities (such as SST) much longer than the predictability limit of atmospheric weather that is about 2 weeks".

Waves and storm surges are not the direct output of Global Climate Models and are needed to be derived from offline simulations
Using high resolution coupled model configuration we produce wave and storm surge projections at global and coastal scale, highlighting areas of significant changes

Modeling framework

- Coupled model experiment
- Unstructured model
- Period of simulations
- Historical 1981-2014
- Picontrol 2015-2099



Significant wave height field, [m]

current velocities

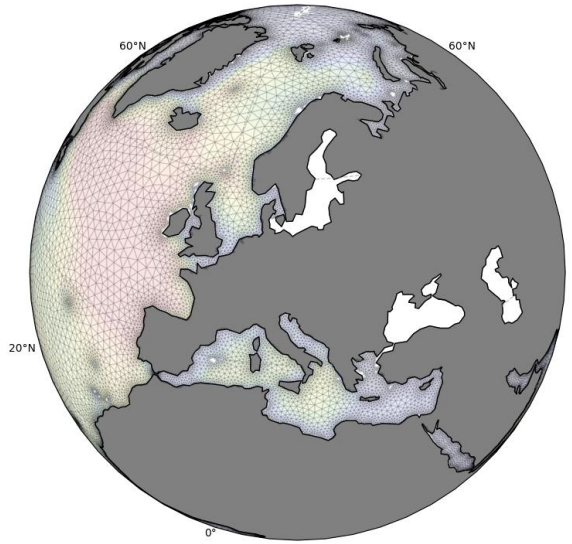
sea level

2d-dimensional barotropic ocean circulation

spectral wave model

surface roughness

- **10 models**
- 5 primary, 5 secondary
- 15 km resolution along shore
- 1° resolution in the open sea



Model domain

Coupled model accounts for the combined effects of wind, atmospheric pressure gradients, without tidal forcing. Bathymetric data-EMODnet

Inter-Sectoral Impact Model Intercomparison Project
(bias adjusted CMIP6)

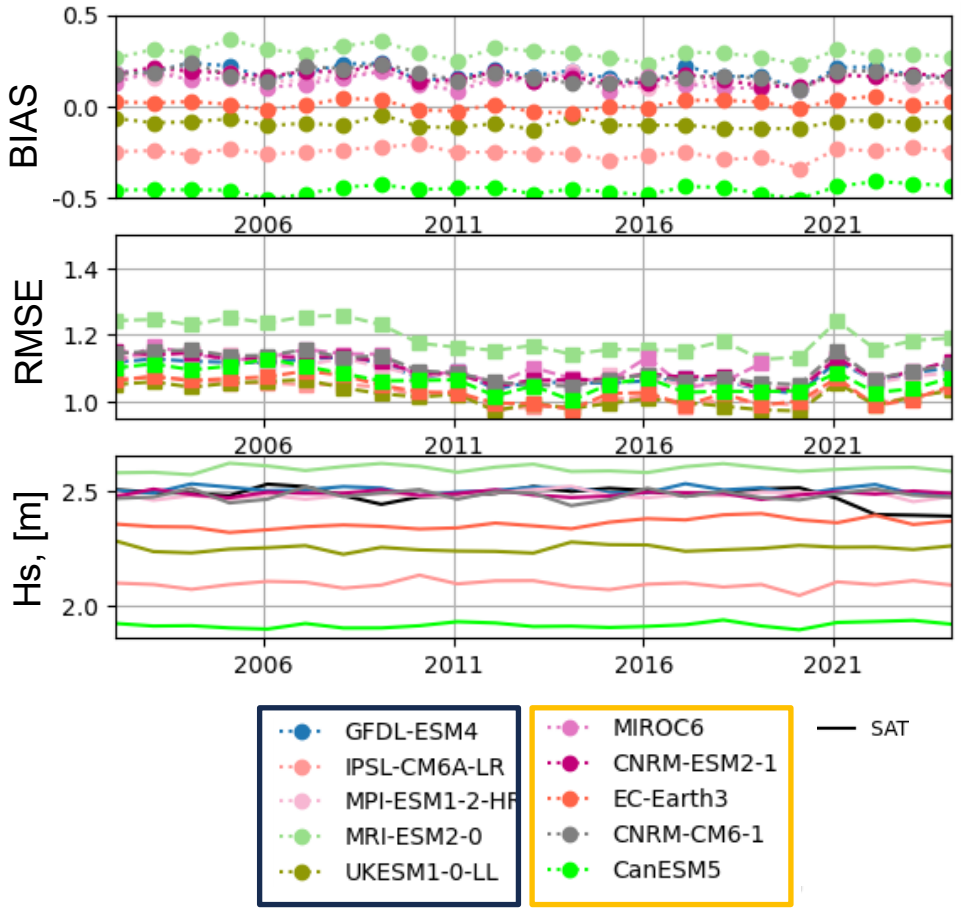
schism+WWM-V based projection
GFDL-ESM4
IPSL-CM6A-LR
MPI-ESM1-2-HR
MRI-ESM2-0
UKESM1-0-LL
MIROC6
CNRM-ESM2-1
EC-Earth3
CNRM-CM6-1
CanESM5

Validation: SWH

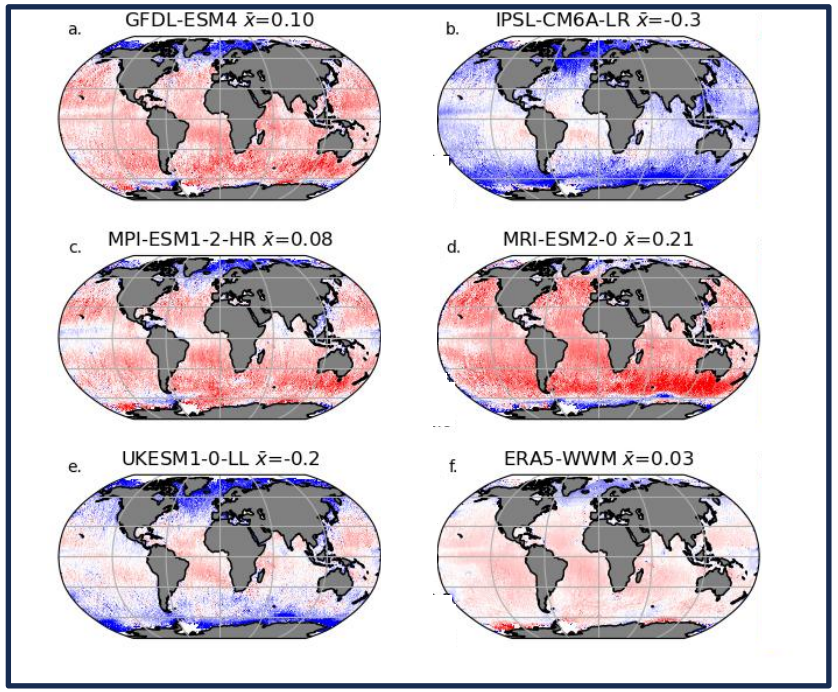
Validation of multimodel historical run (2002-2014) has been joined with pi-control run SSP5-8.5 (2015-2024) against multi satellite product

Validation is also supported by wave model forced with ERA5 winds generated for the corresponding period as for a baseline.

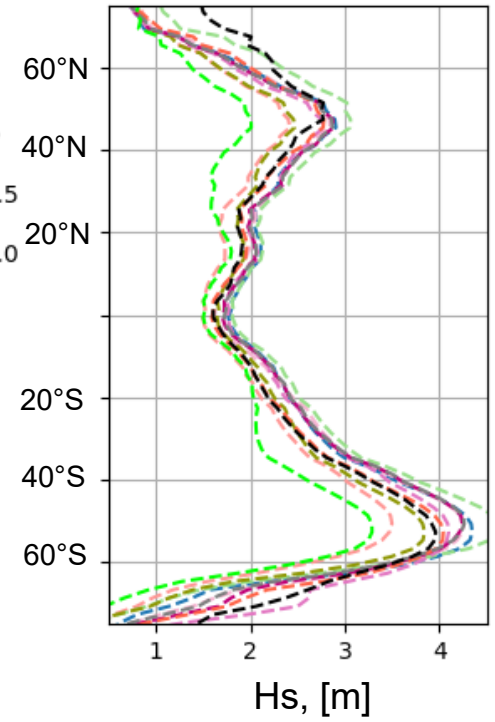
Descriptive statistics



Bias between models & satellites



Zonal average SWH

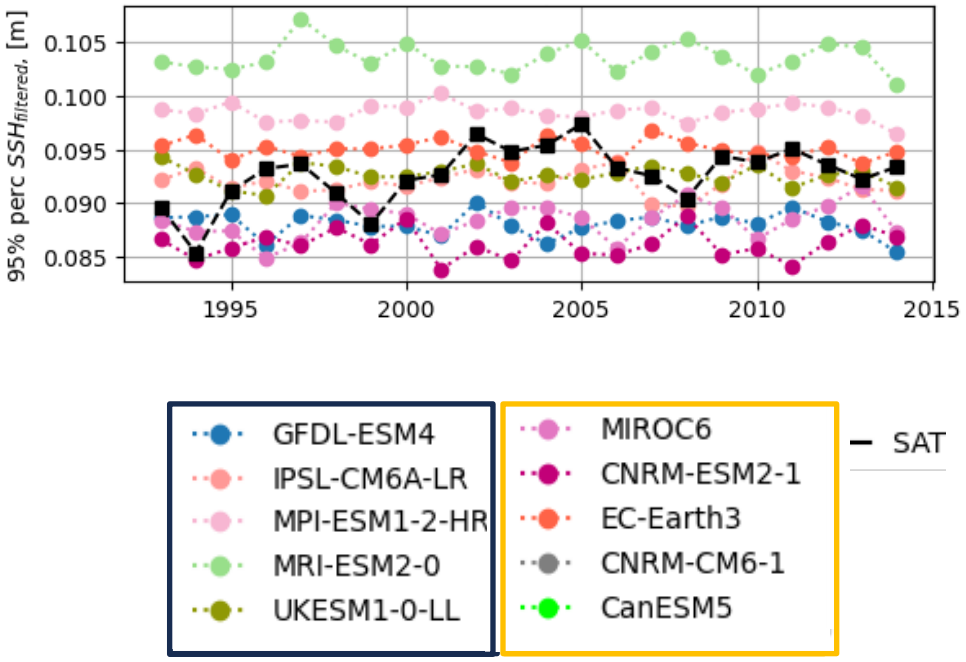


Validation: SSH

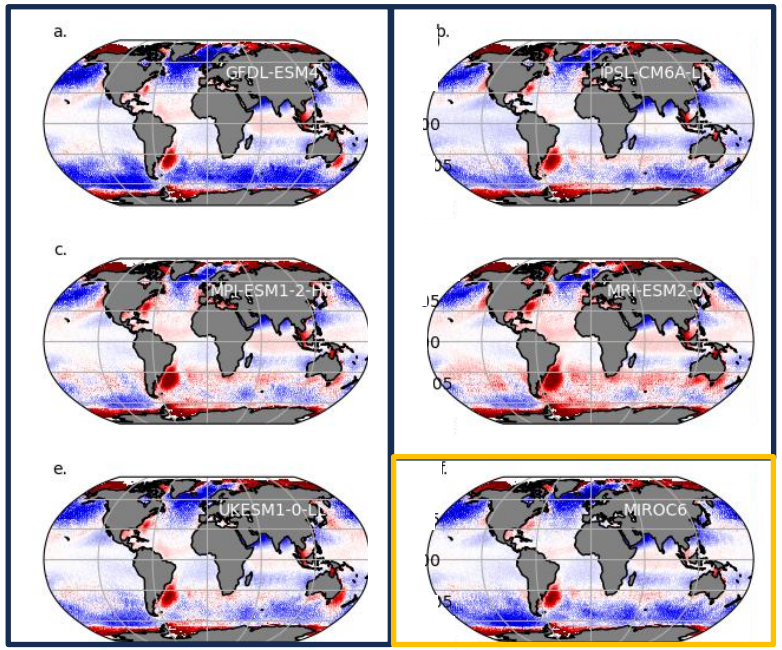
The sea surface height (SSH) validation against satellite altimetry dac (*dac* - a posterior correction of the altimeter SLA measurements for both the low and the high frequency oceanic signals) during the period of 1993-2014.

As our barotropic model is unable to reproduce low-frequency variability of sea levels and Sea Level Rise, both simulations and observations of SSH were detrended prior to comparison.

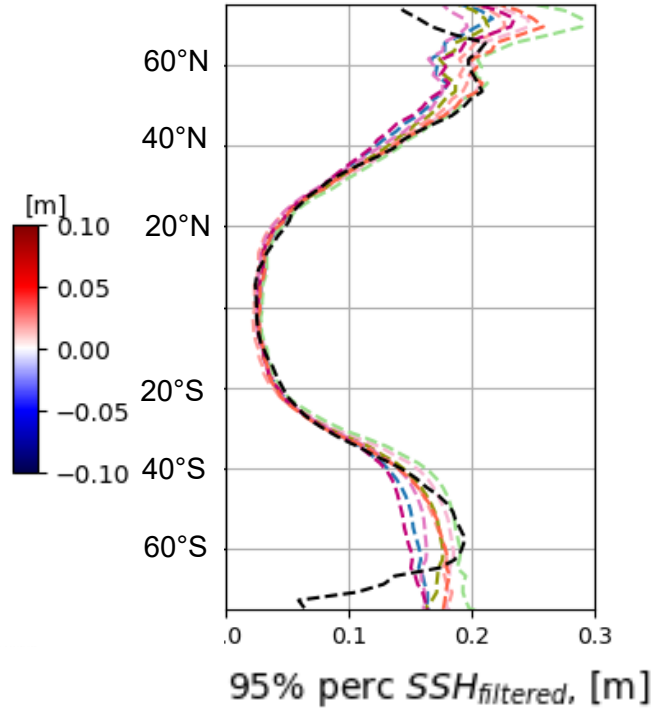
Descriptive statistics



Bias between models & satellites

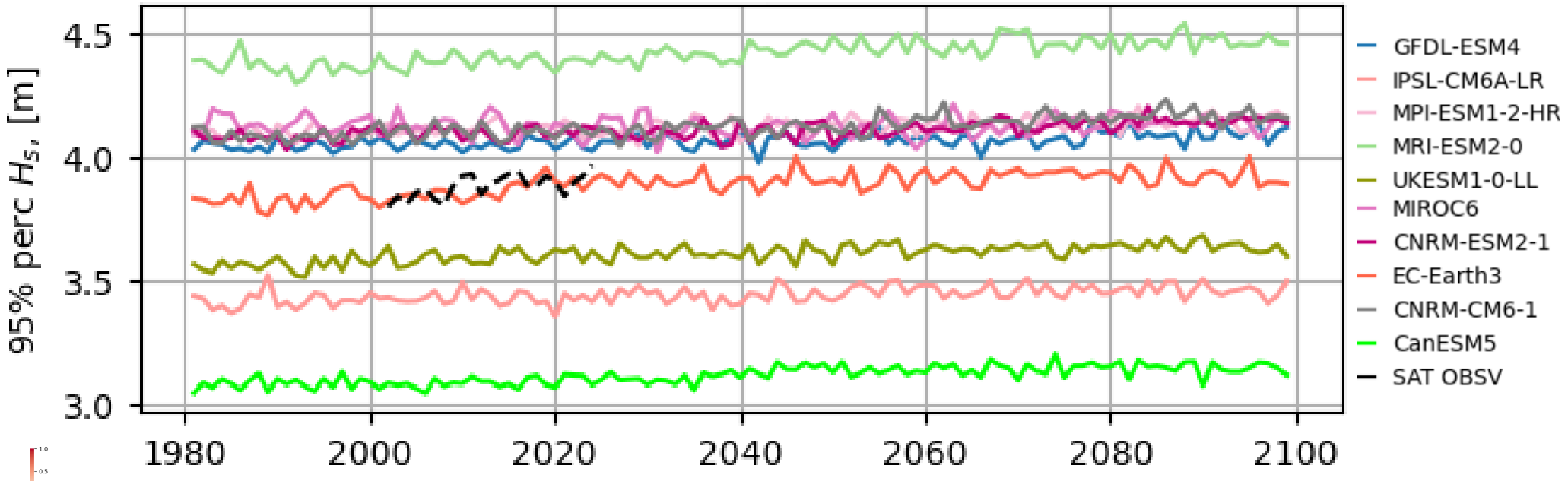


Zonal average SSH



Validation: Interannual variability

Time series of the global extreme H_s illustrates that CanESM5 and MRI-ESM2-0 stand out with respect to remaining datasets in terms of linear trends in annual extreme H_s. Black line color corresponds to satellites.



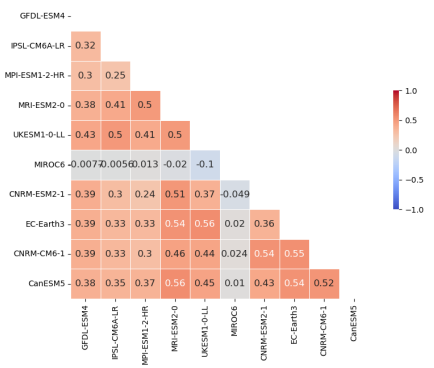
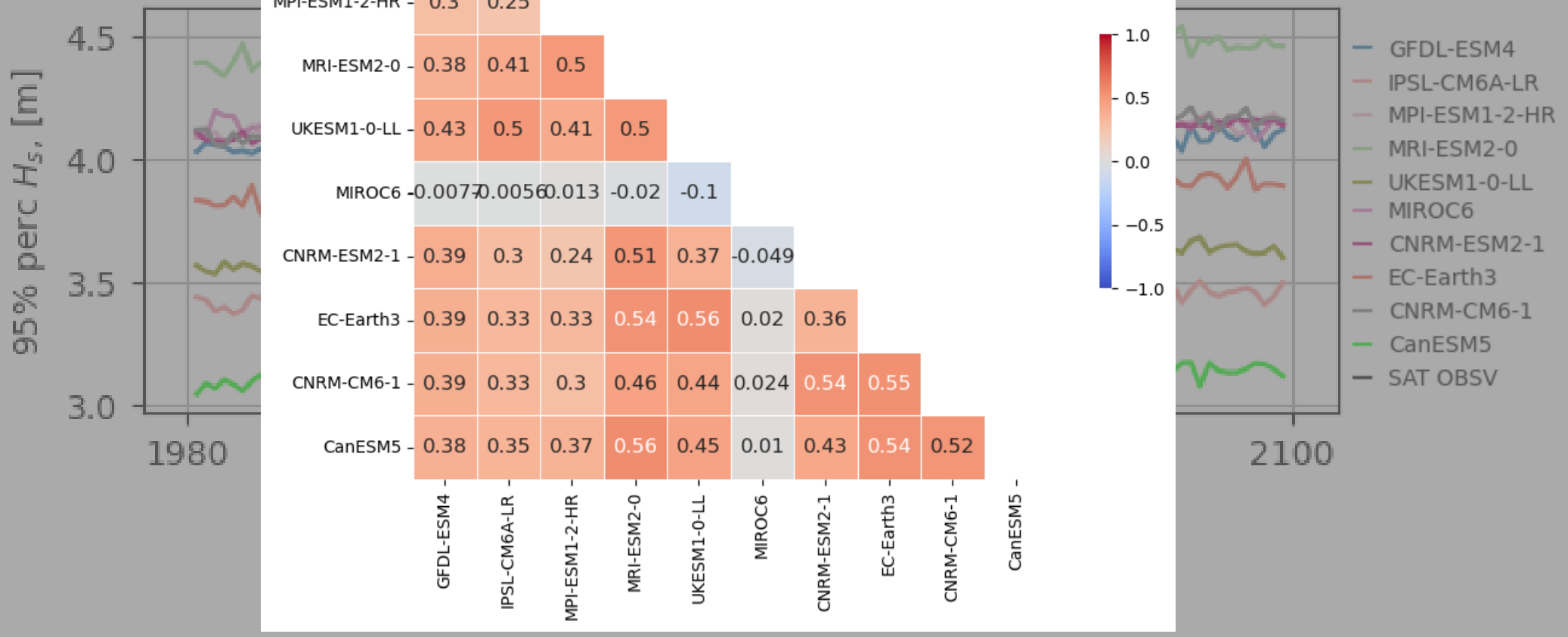


Table 1 Contributing climate models form ISIMIP3b

Model	Atmospheric resolution (lon x lat)
MRI-ESM2-0	1.125° x 1.125°, 80 levels to 0.01 hPa
CanESM5	2.81° x 2.81°, 49 levels to 1 hPa

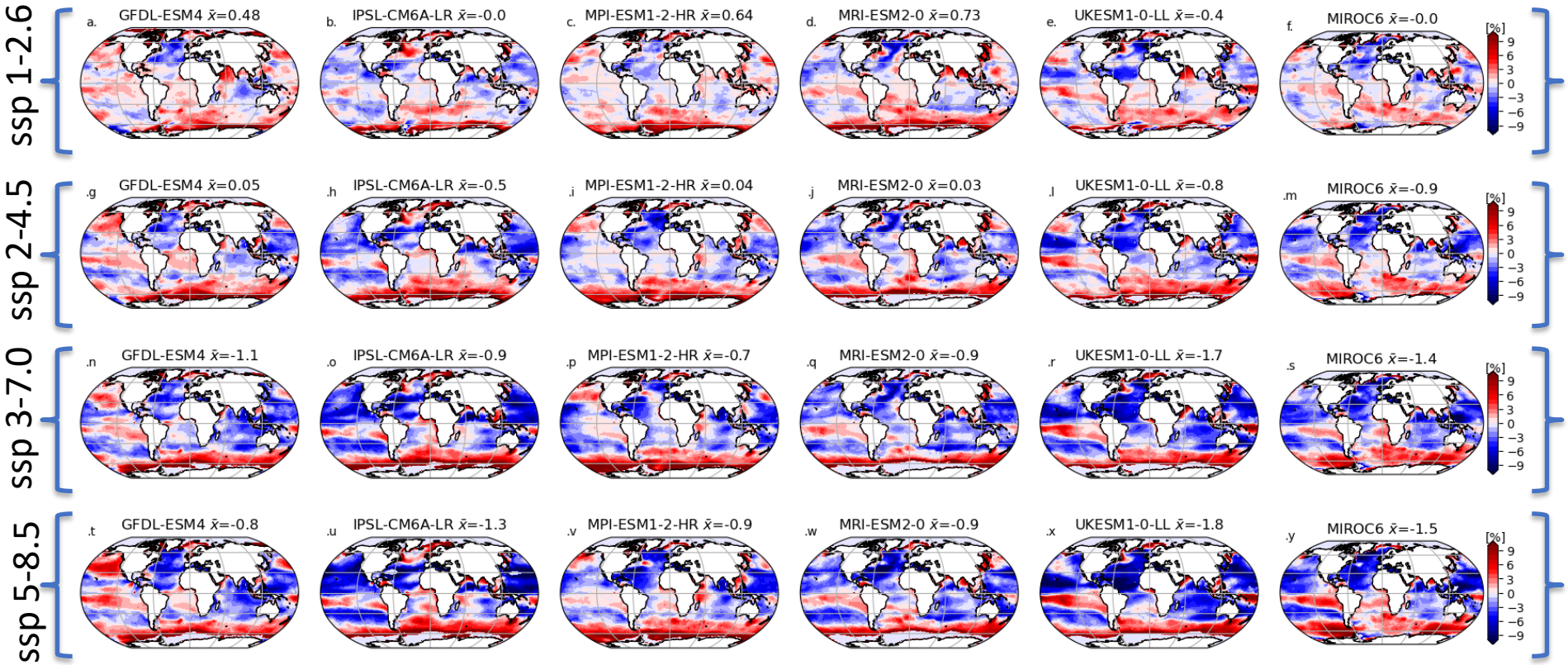
Validation: Interannual variability

Time series of the global extreme H_s illustrates that CanESM5 and MPI-ESM1-2-HR stand out with respect to remaining datasets in terms of li… …onds to satellites.

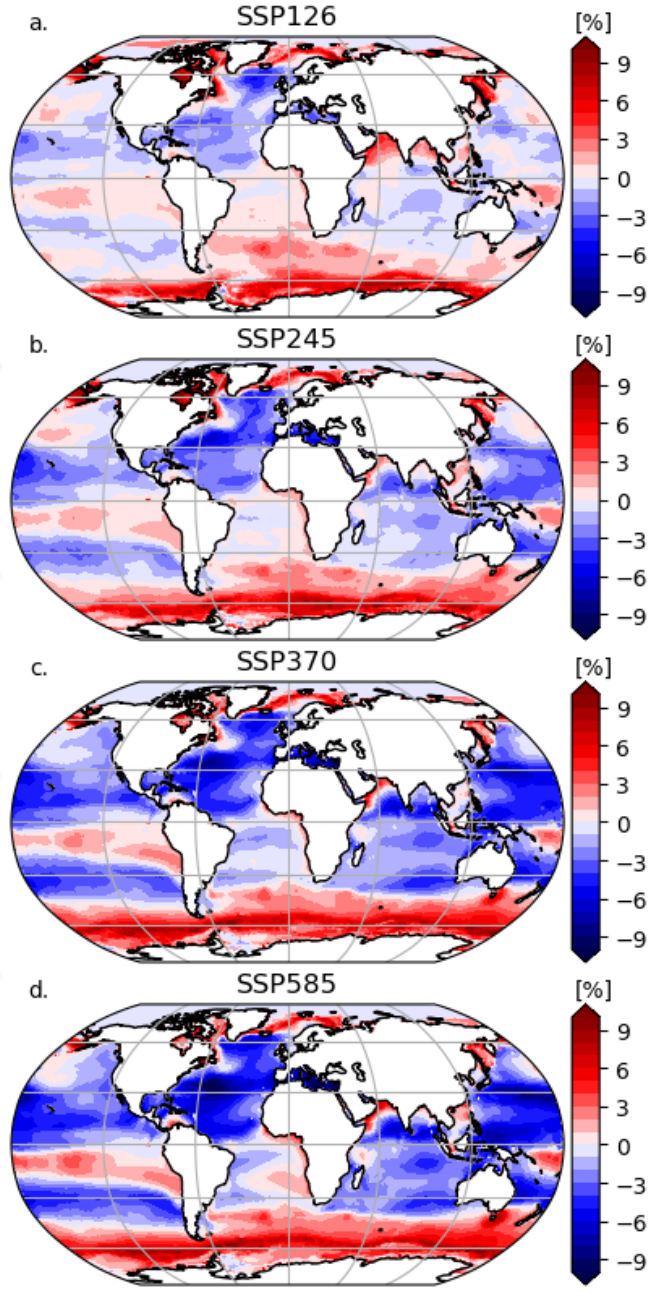


Future annual extreme wave statistics

Annual extreme wave height changes are calculated by subtracting present day climate under the historical run (baseline 1985-2014) from the pi-control runs under ssp 1-2.6, 2-4.5, 3-7.0, 5-8.5 (2070-2099).

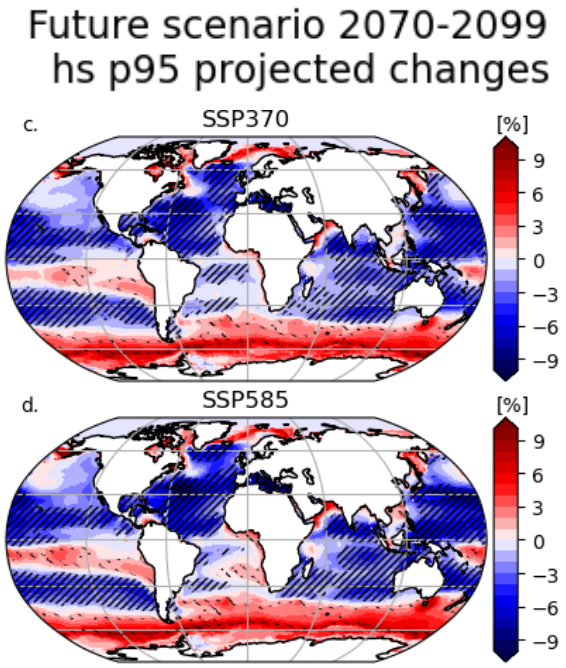


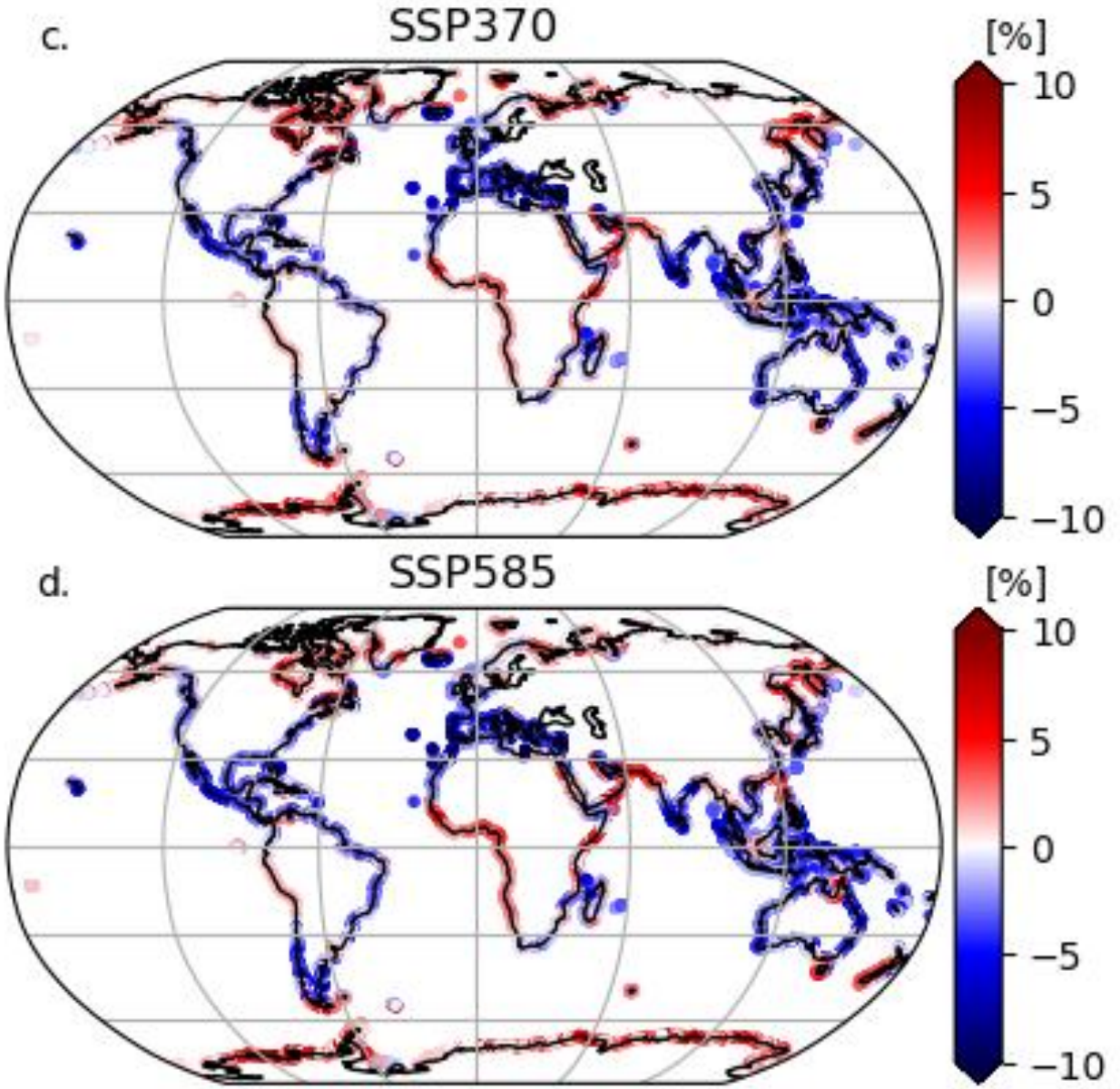
Future scenario 2070-2099
hs p95 projected changes



Ensemble mean projections: swh

For the spatial composite field statistically significant values are indicated with hatched lines for annual extreme wave height changes from the pi-control runs under, 3-7.0, 5-8.5 (2070-2099).





The contribution of wave to coastal sea level

Coastal points
Hs, Tp, Wave Length, Spectral peaks

- ssp 1-2.6
- ssp 2-4.5
- ssp 3-7.0
- ssp 5-8.5

Baseline
Near term
Mid term
Long term

Transect dataset includes:

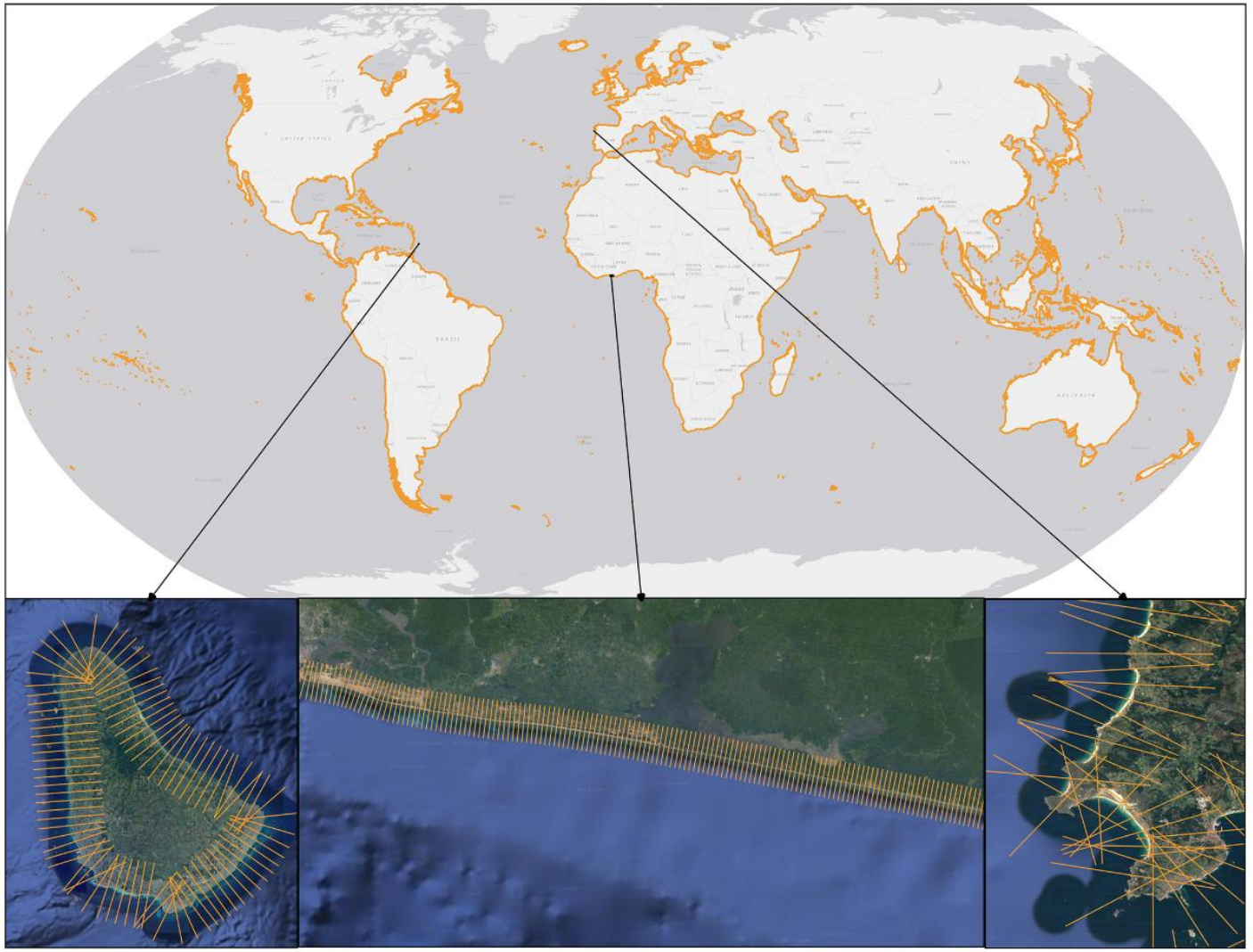
- Subaerial and submerged beach slope
- Shoreline orientation

Wave run-up height R2 based on the Stockdon empirical formulae

Following Athanasiou et al. 2023 transect dataset & using Snell's Law (US army corp engineering handbook, 2002)

Wave breaking Height

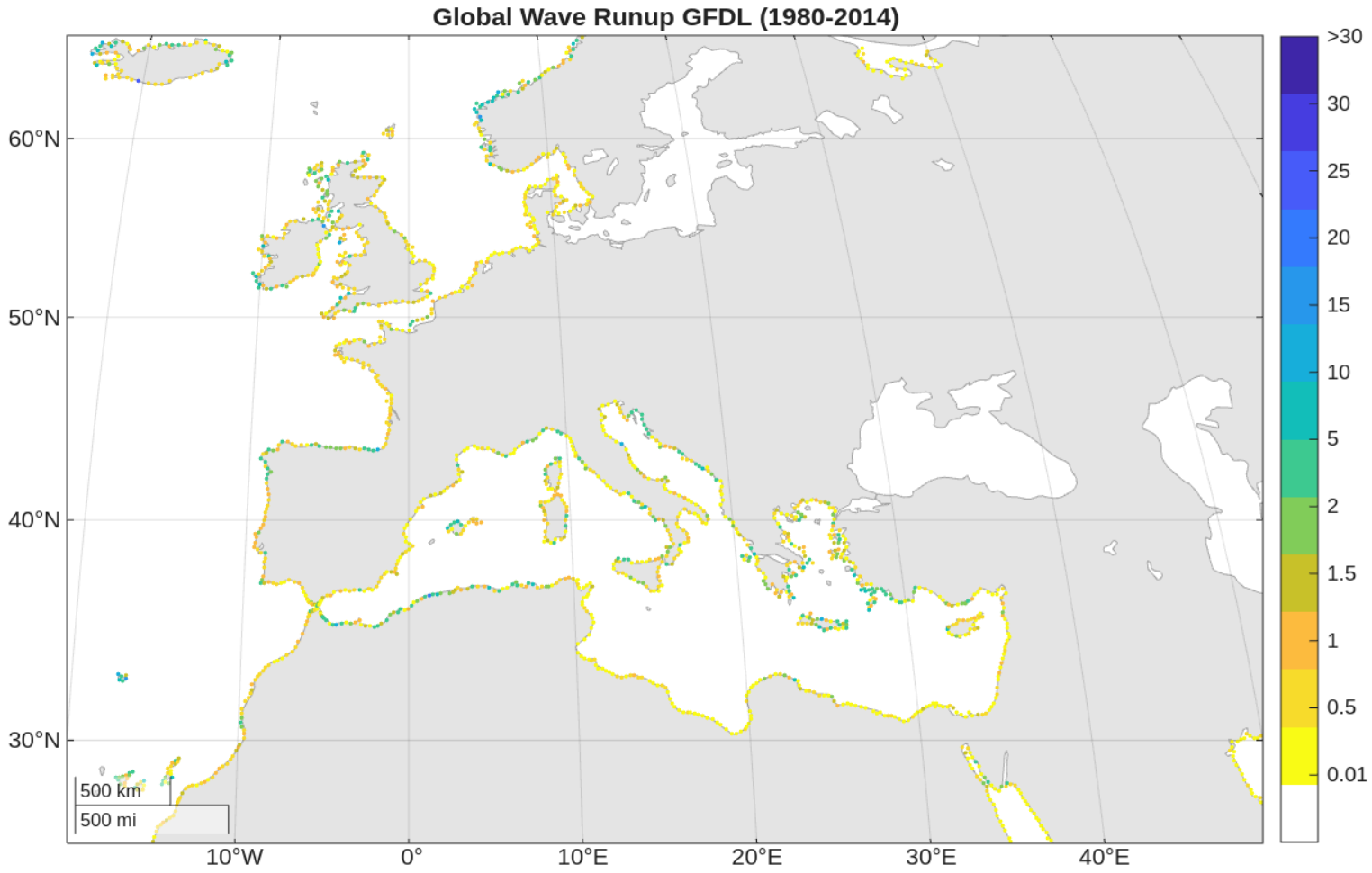
Combine the wave run-up with the storm surge to obtain the total water level.



P. Athanasiou et al 2023

The contribution of wave to coastal sea level

The above steps result in wave runup height estimates for each spectral peak and we consider the highest value as the characteristic for the specific time stamp.



Conclusions

- We have developed Global projections of waves under climate change scenarios to alert about potential socio-economic impact on the coastal population with three dangerous effects: wind waves, storm surges and wave run-ups.
- In this project we implemented all the ISIMIP3b models, same GCM and ensemble number.
- Global projections can be easily applied to coastal.
- This will allow us crossing our coastal data with other outputs from this intercomparison project.

Outlook

- Validation of ensemblemean projections, high percentiles, total water level

Thank you!

Any questions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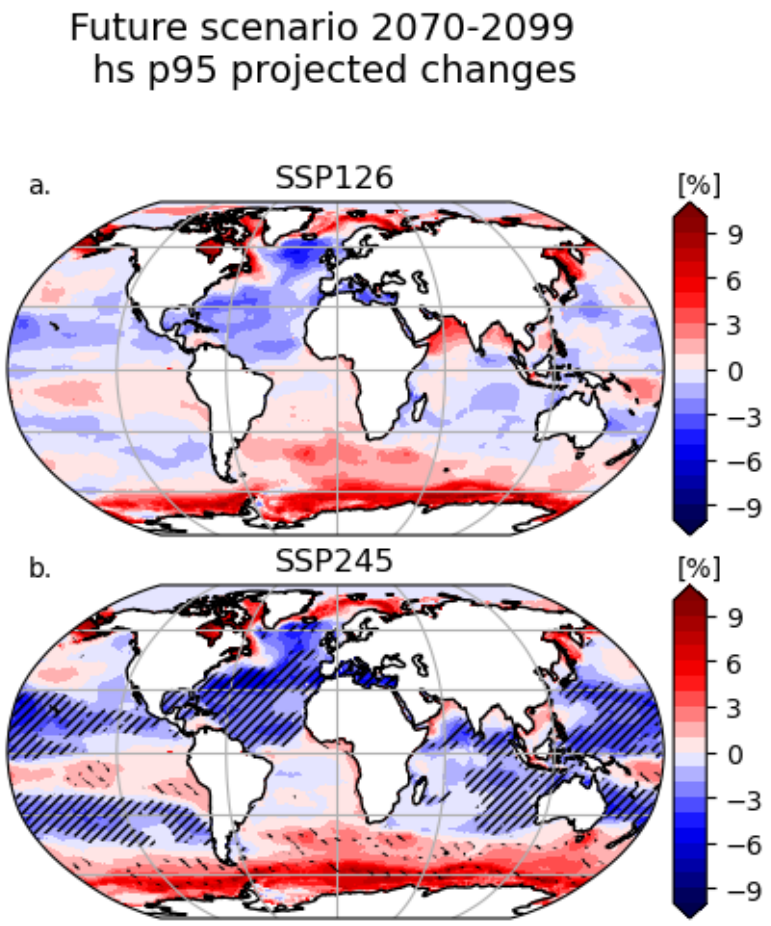
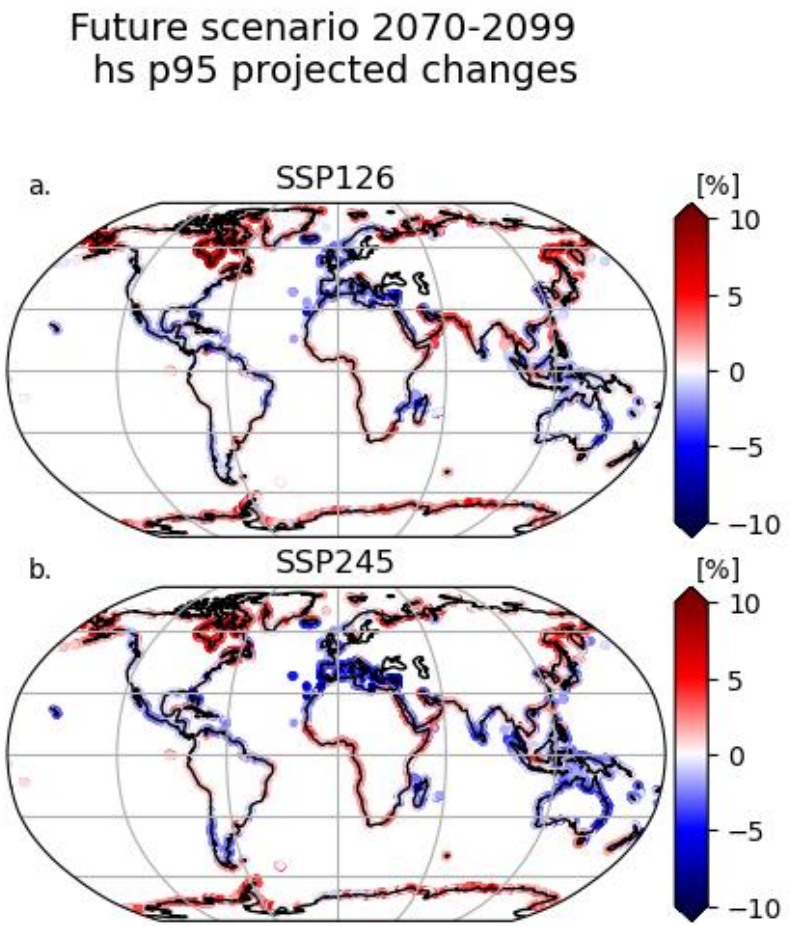
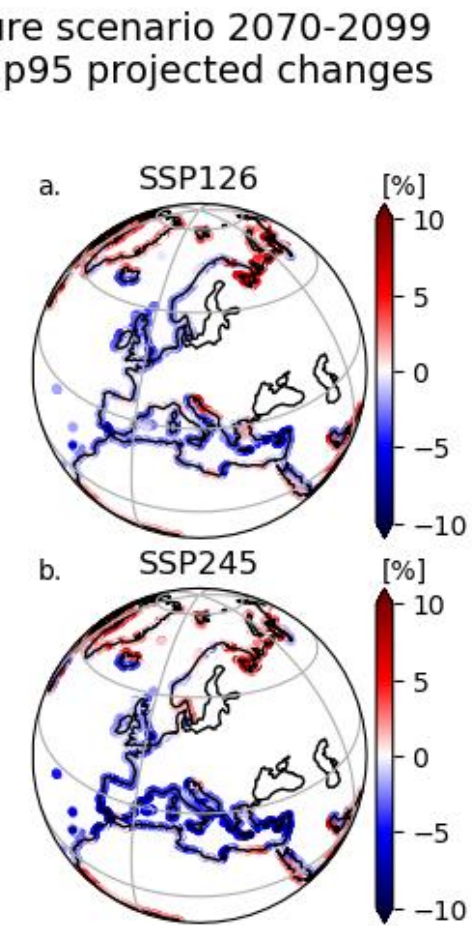
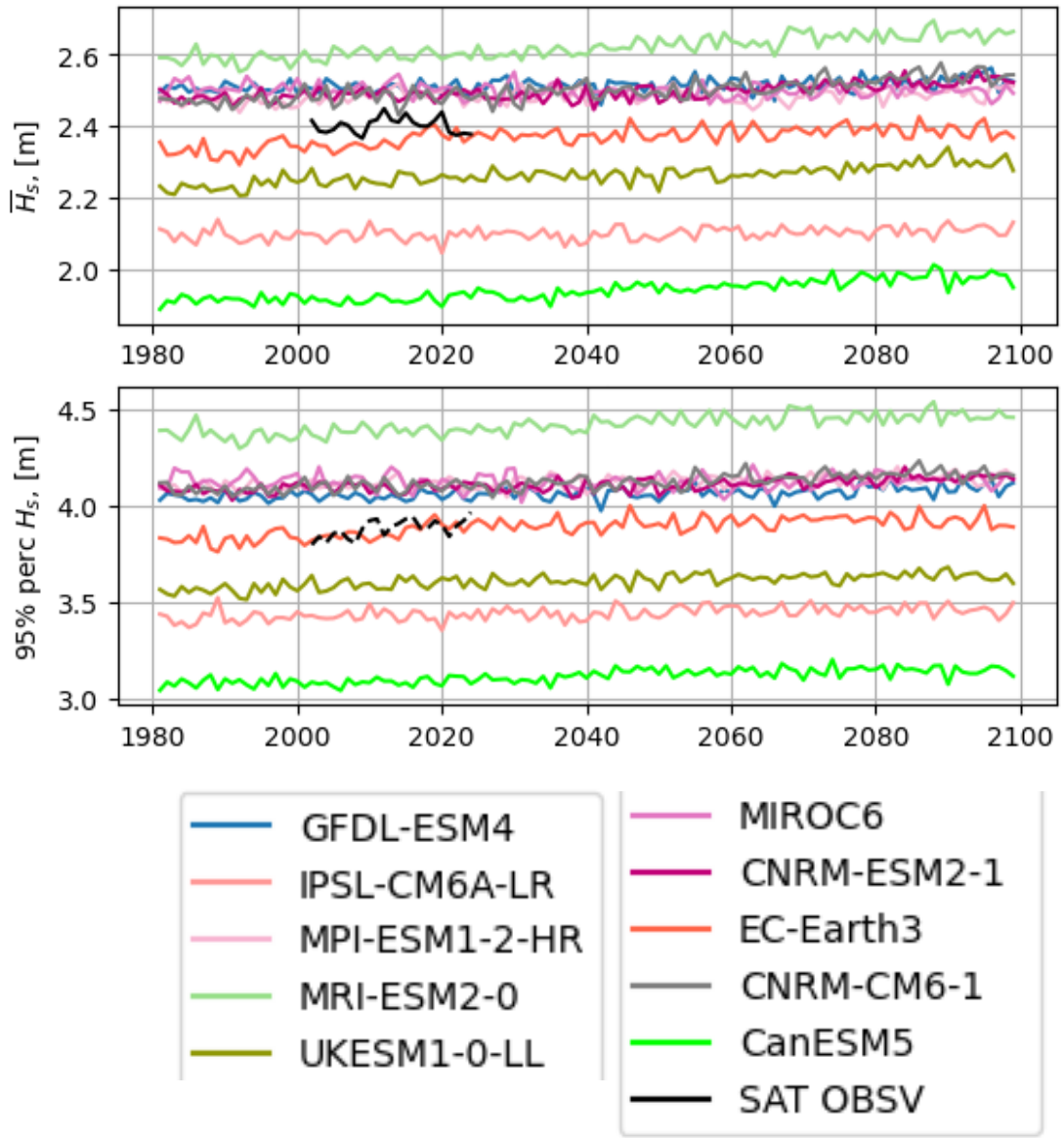
Thanks

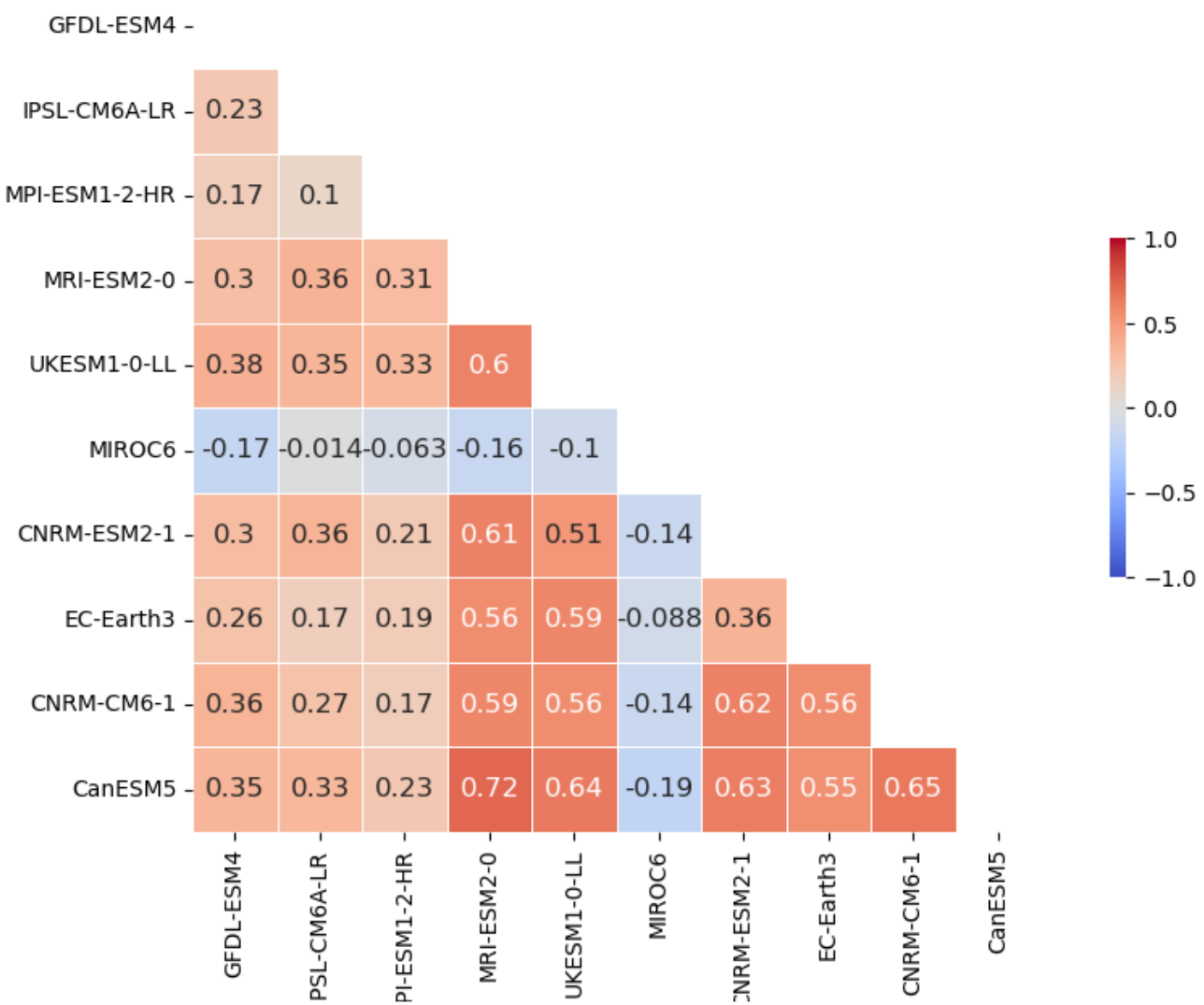
Ensemble mean projections: swh





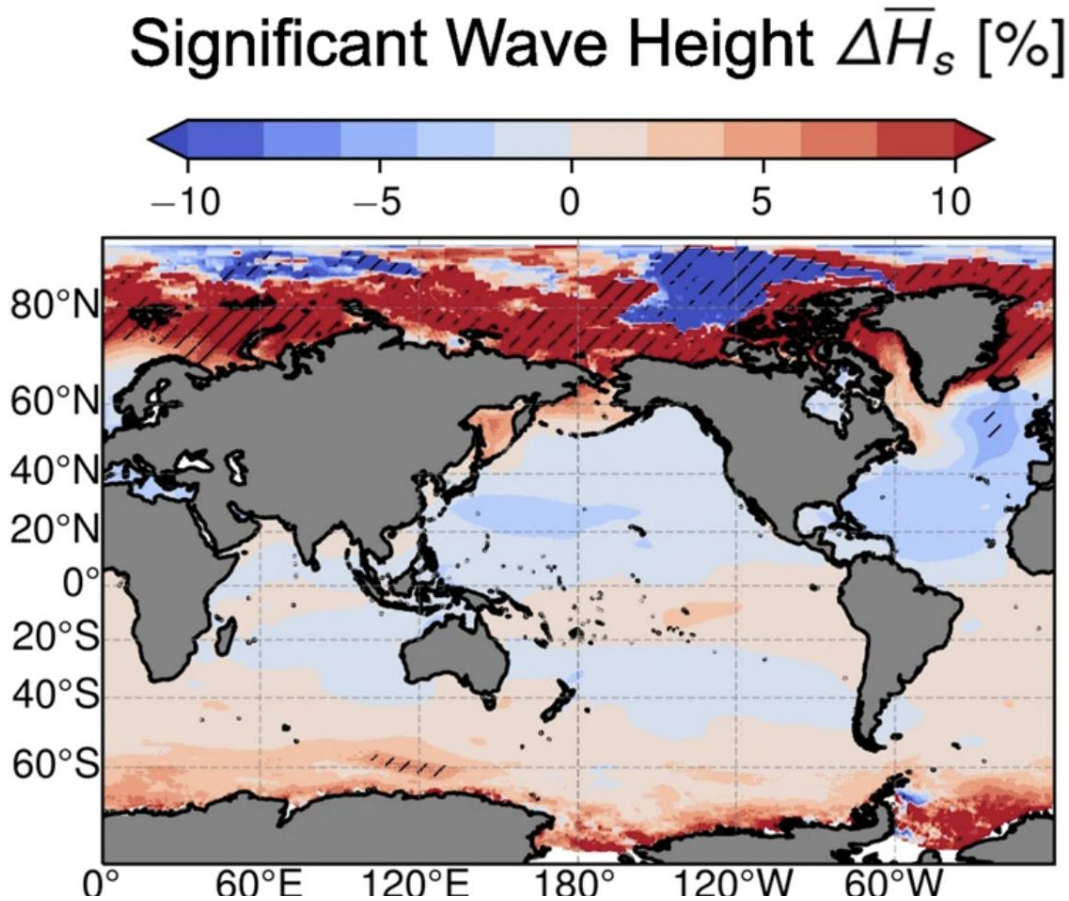


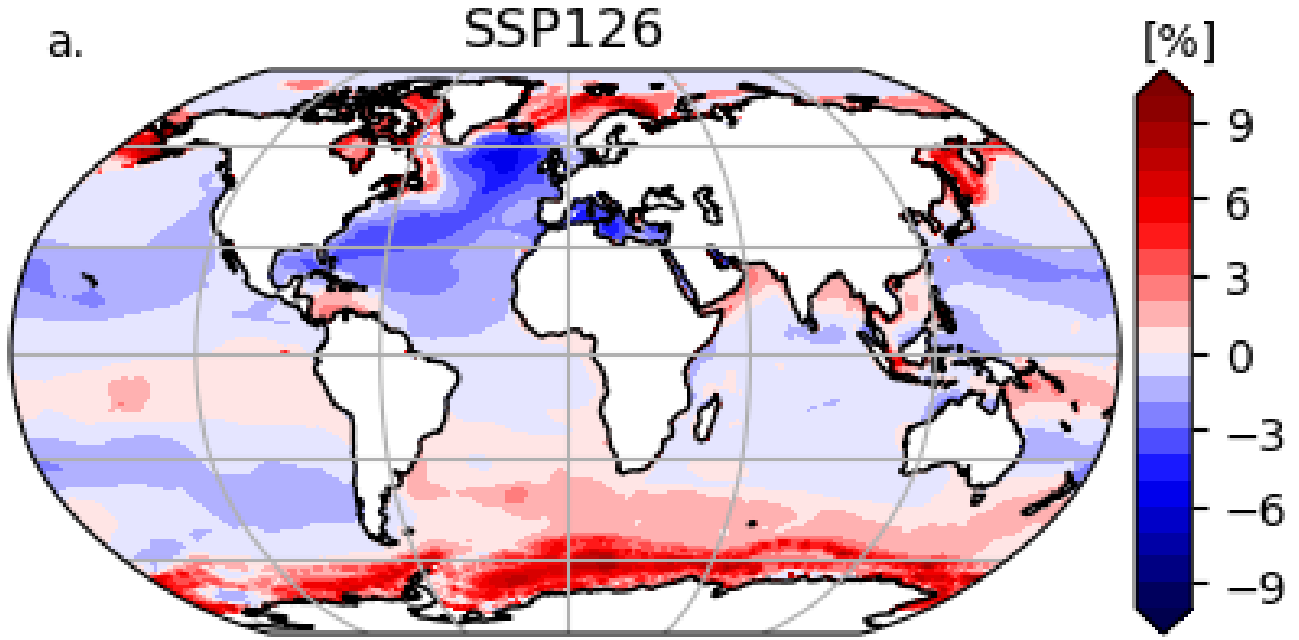

$\overline{H}_s$, [m]
2.6
2.4
2.2
2.0
1980
2000
2020
2040
2060
2080
2100
95% perc H_s, [m]
4.5
4.0
3.5
3.0
GFDL-ESM4
IPSL-CM6A-LR
MPI-ESM1-2-HR
MRI-ESM2-0
UKESM1-0-LL
MIROC6
CNRM-ESM2-1
EC-Earth3
CNRM-CM6-1
CanESM5
SAT OBSV


GFDL-ESM4
IPSL-CM6A-LR 0.23
MPI-ESM1-2-HR 0.17 0.1
MRI-ESM2-0 0.3 0.36 0.31
UKESM1-0-LL 0.38 0.35 0.33 0.6
MIROC6 -0.17 -0.014 -0.063 -0.16 -0.1
CNRM-ESM2-1 0.3 0.36 0.21 0.61 0.51 -0.14
EC-Earth3 0.26 0.17 0.19 0.56 0.59 -0.088 0.36
CNRM-CM6-1 0.36 0.27 0.17 0.59 0.56 -0.14 0.62 0.56
CanESM5 0.35 0.33 0.23 0.72 0.64 -0.19 0.63 0.55 0.65
GFDL-ESM4
PSL-CM6A-LR
PI-ESM1-2-HR
MRI-ESM2-0
UKESM1-0-LL
MIROC6
NRM-ESM2-1
EC-Earth3
CNRM-CM6-1
CanESM5
1.0
0.5
0.0
−0.5
−1.0

WW3-based projection	WW3-based projection on SMC grid	schism+WWM-V based projection
ACCESS-CM2 (ACM2)	ACCESS-CM2	GFDL-ESM4
AWI-CM-1-1-MR (AWI)	CMCC-CM2-SR5	IPSL-CM6A-LR
CMCC-CM2-SR5 (CMCC)	CNRM-CM6-1-HR	MPI-ESM1-2-HR
EC-Earth3 (EC3)	EC-Earth3	MRI-ESM2-0
IPSL-CM6A-LR (IPSL)	HadGEM3-GC31-MM	UKESM1-0-LL
KIOST-ESM (KIOST)	IPSL-CM6A-LR	MIROC6
MPI-ESM1-2-LR (MPI)	MIROC6	CNRM-ESM2-1
MRI-ESM2-0 (MRI)	MPI-ESM1-2-HR	EC-Earth3
		CNRM-CM6-1
		CanESM5

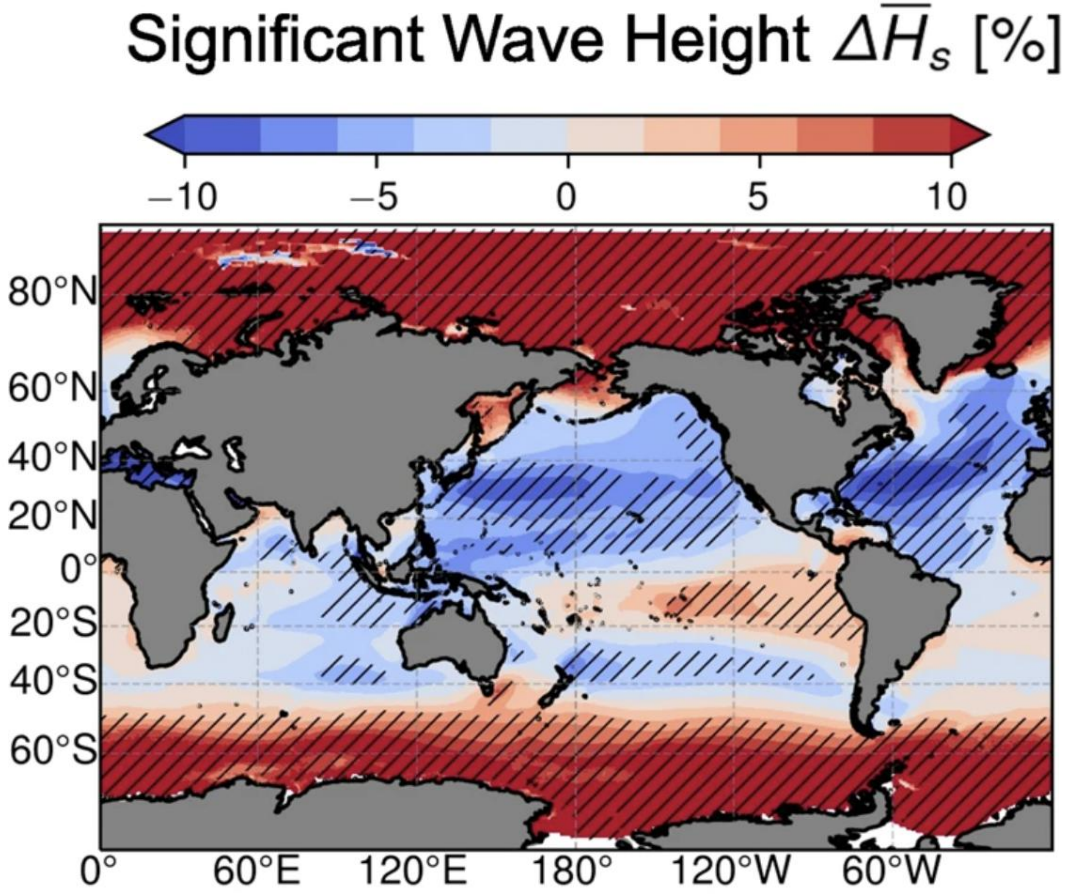
Comparison with Meucci of scenario ssp1-2.6

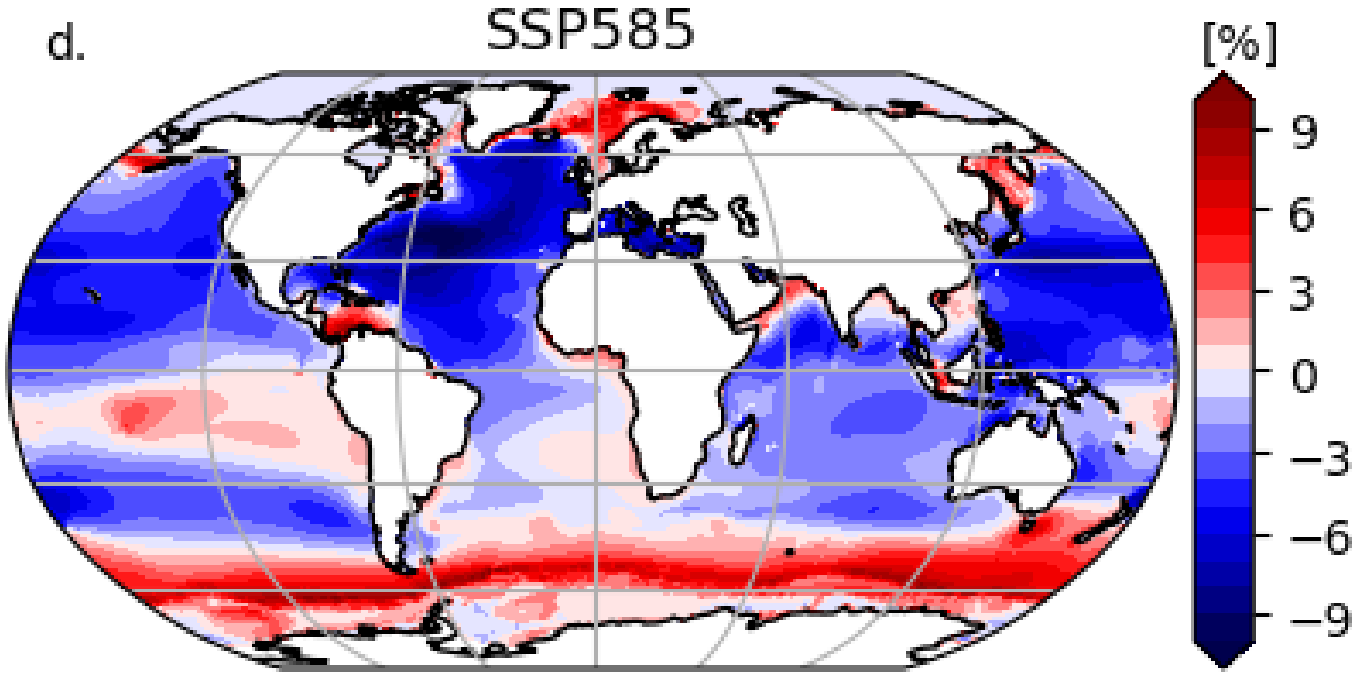




The Walker Circulation is a large-scale atmospheric circulation pattern over the equatorial Pacific Ocean
The Atlantic Multidecadal Oscillation (AMO) is a natural climate pattern in the North Atlantic, marked by alternating warm and cool phases over several decades.

Comparison with Meucci of scenario ssp5-8.5





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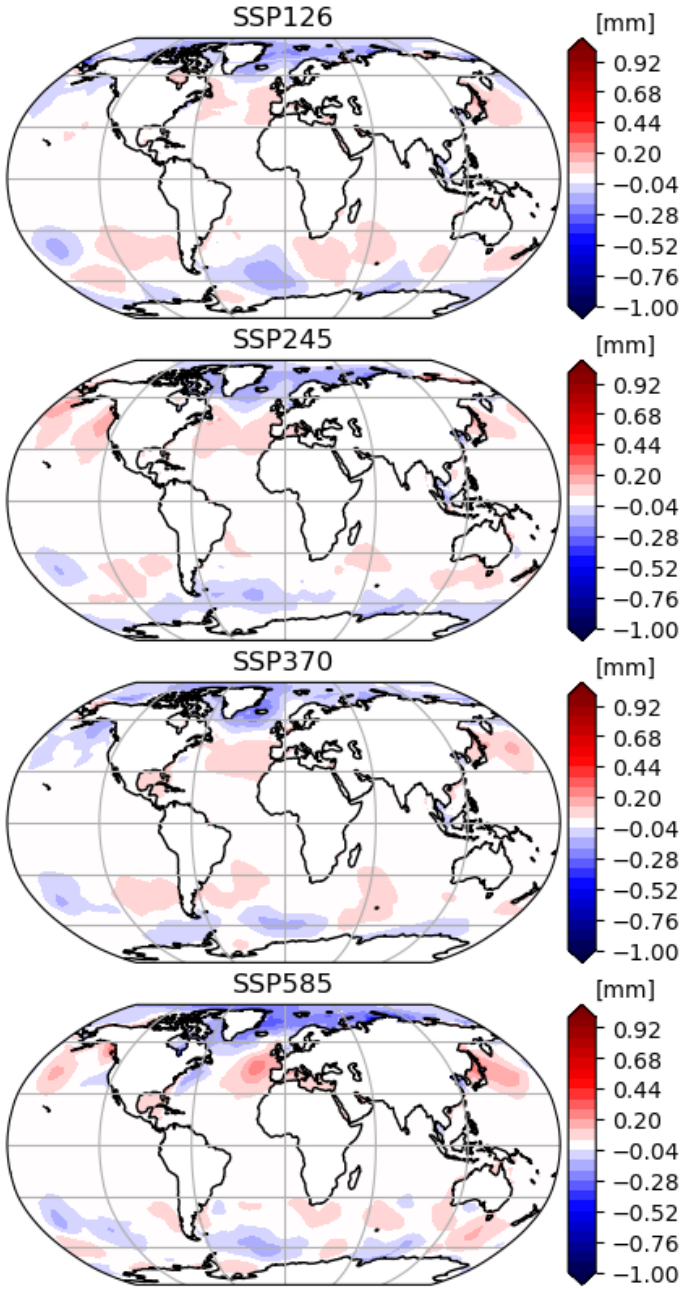
Future scenario 2070-2099
elev mean projected changes



Future scenario 2070-2099
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