2C NOW webinar

Impacts of Climate Change on Structure Design

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WP 4 – Summary

OBJECTIVES

- Comparisons of numerical **wave** and **water level reanalyses** on French seafronts.
- **Statistical downscaling** of wave and water level climate datasets.
- Assessment of the impact of climate change on **waves** and **water levels**.
- Assessment of the impact of climate change on **design**:
  - **Extreme analyzes**
  - **Operations & Maintenance**
  - **Landing zone**
  - **Fatigue on OW turbine**

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Historical Data

Waves

In-situ data

- Data from **Copernicus In-Situ TAC**, with sufficient data
- **12 Buoys**: 3 in the English Channel, 5 on the Atlantic coast and 4 in the Mediterranean Sea

Reanalyses

- Atlantic and English Channel : **RESOURCECODE** (RSCD, Accensi et al., 2022) and **HYWAT** (Hydrodynamics and Waves hindcast, Jourdan et al., 2020)
- Mediterranean Coast: **MEDUG** reanalysis (Faidherbe et al., 2024) and the **MED-WAV** (Korres et al., 2021)

Water levels

In-situ data

- Data from **RONIM** network
- **23 tide gauge stations**: 7 in the English Channel, 11 along the Atlantic coast, and 7 in the Mediterranean Sea

Reanalyses

- Atlantic and English Channel: **GTSM-ERA5** (Copernicus Climate Change Service), **IBI-MFC** (Copernicus Marine Service)
- Mediterranean Coast: **GTSM-ERA5** (Copernicus Climate Change Service), **MED-MFC** (Copernicus Marine Service)

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Choice of Reanalyses

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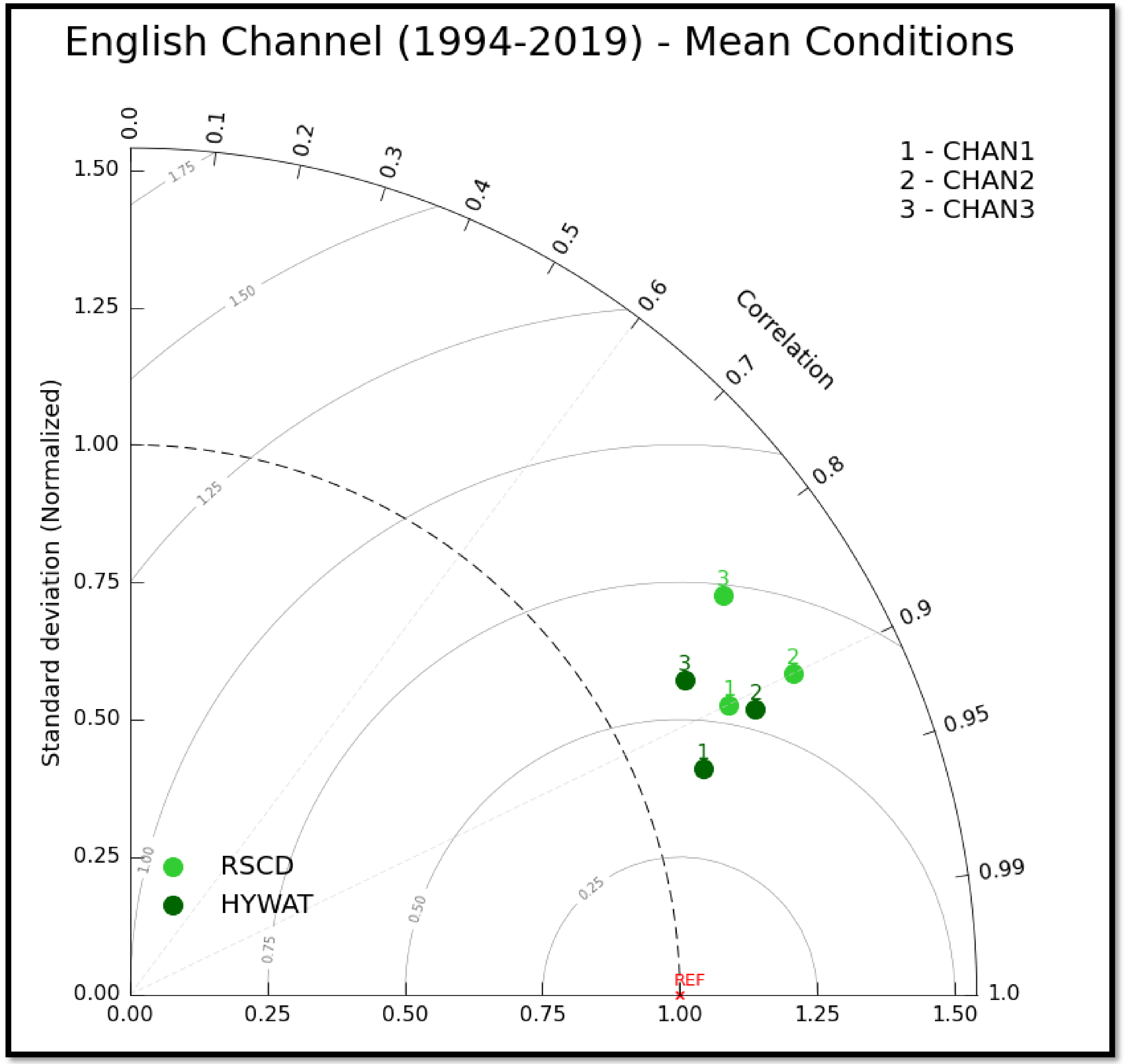
Table 10: best reanalyses for each French maritime seafront in terms of waves.

Maritime seafront	Best reanalysis
English Channel	**HYWAT**
Atlantic Ocean	**HYWAT**
Mediterranean Sea	**MED-WAV**

Table 18: Best reanalyses for each French maritime seafront in terms of water levels.

Maritime seafront	Best reanalysis
English Channel	**GTSM-ERA5**
Atlantic Ocean	**GTSM-ERA5**
Mediterranean Sea	**GTSM-ERA5**



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GCMs used in the project

Waves (Meucci et al., 2024)

Models	Provider
ACCESS-CM2	ACCESS (Australia)
AWI-CM-1-1-MR	AWI (Germany)
CMCC-CM2-SR5	CMCC (Italy)
EC-Earth3	EC-Earth-Consortium (Europe)
IPSL-CM6A-LR	IPSL (France)
KIOST-ESM	KIOST (Korea)
MPI-ESM1-2-LR	MPI (Germany)
MRI-ESM2-0	MRI (Japan)

Surges (Muis et al., 2022)

Models	Provider
CMCC-CM2-VHR4	Centro Euro-Mediterraneo sui Cambiamenti Climatici
EC-Earth3P-HR	Swedish Meteorological and Hydrological Institute
GFDL-CM4C192-SST	GFDL
HadGEM3-GC31-HM	Met Office Hadley Centre
HadGEM3-GC31-HM-SST	Met Office Hadley Centre

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GCMs used in the project

Waves (Meucci et al., 2024)

Models	Provider
ACCESS-CM2	ACCESS (Australia)
AWI-CM-1-1-MR	AWI (Germany)
MPI-ESM1-2-LR	MPI (Germany)
MRI-ESM2-0	MRI (Japan)

Historical: 1985–2014

SSP1-2.6, SSP5-8.5: 2071–2100

Surges (Muis et al., 2022)

Models	Provider
CMCC-CM2-VHR4	Centro Euro-Mediterraneo sui Cambiamenti Climatici
EC-E	and
GFD	
Had	
HadGEM3-GC31-HM-SST	Met Office Hadley Centre

Historical: 1950–2014

SSP5-8.5: 2015–2050

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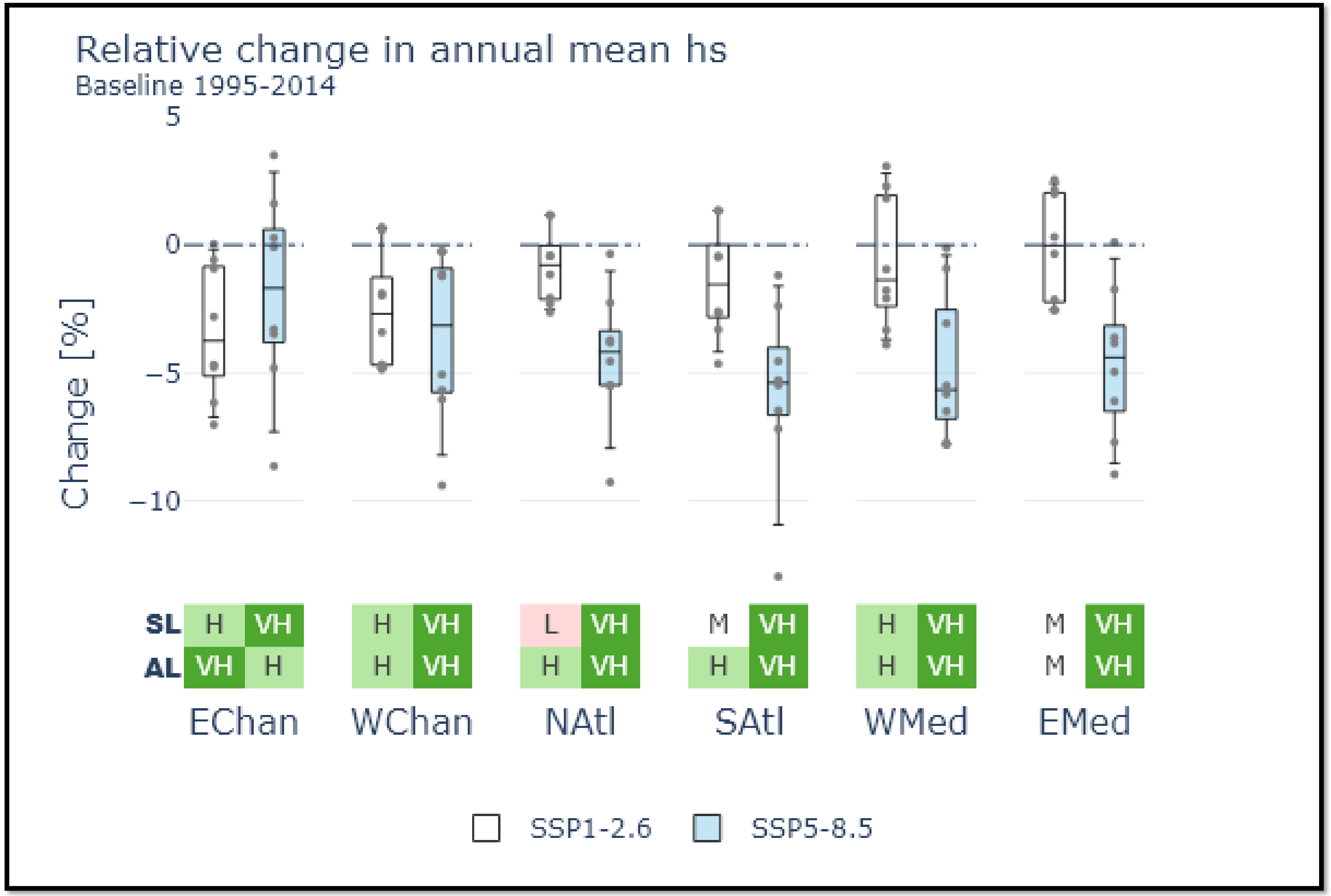
Change in annual Mean Significant Wave Height

- **Higher significance and agreement** levels under SSP5-8.5
- **Decrease in median** under SSP5-8.5 (and SSP1-2.6 for Chan)
- **Large model spread**;
- Not shown here:
  - no clear evolution of seasonal variations;
  - Small evolutions of Peak Period Tp


Relative change in annual mean hs
Baseline 1995-2014

SL = Significance Level				
AL = Agreement Level				
VL	L	M	H	VH
[0;20%[	[20%;40%[	[40%;60%[	[60%;80%[	[80%;100%[

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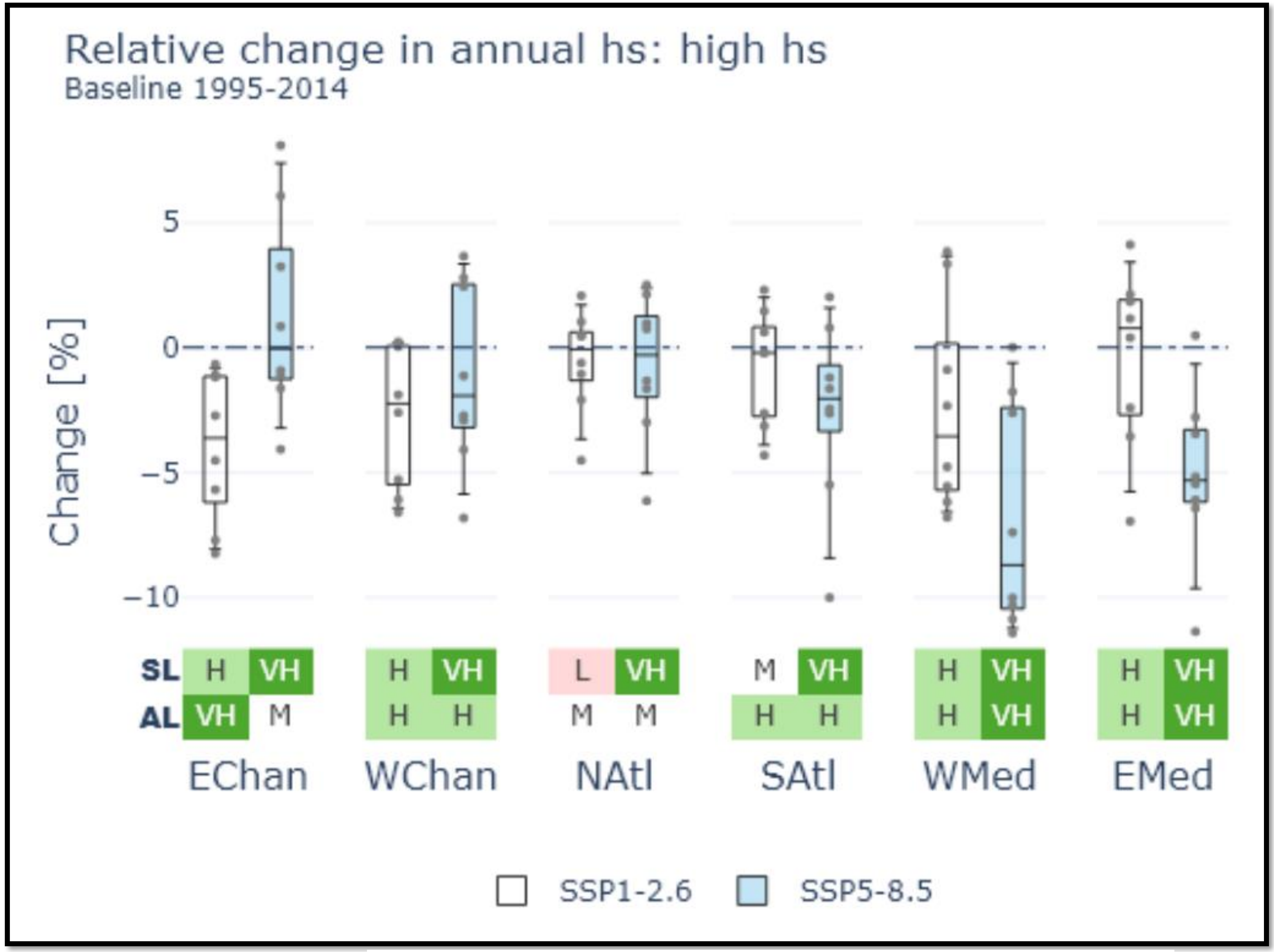
Relative change in Q95 Significant Wave Height

- **Negative trend** in Mediteranean Sea;
- **Positive trend** in the Chanel;
- No clear signal in the Atlantic
- SSP5-8.5 amplifies the trends
- **Large model spread**



SL = Significance Level

AL = Agreement Level

VL	L	M	H	VH
[0;20%[	[20%;40%[	[40%;60%[	[60%;80%[	[80%;100%[

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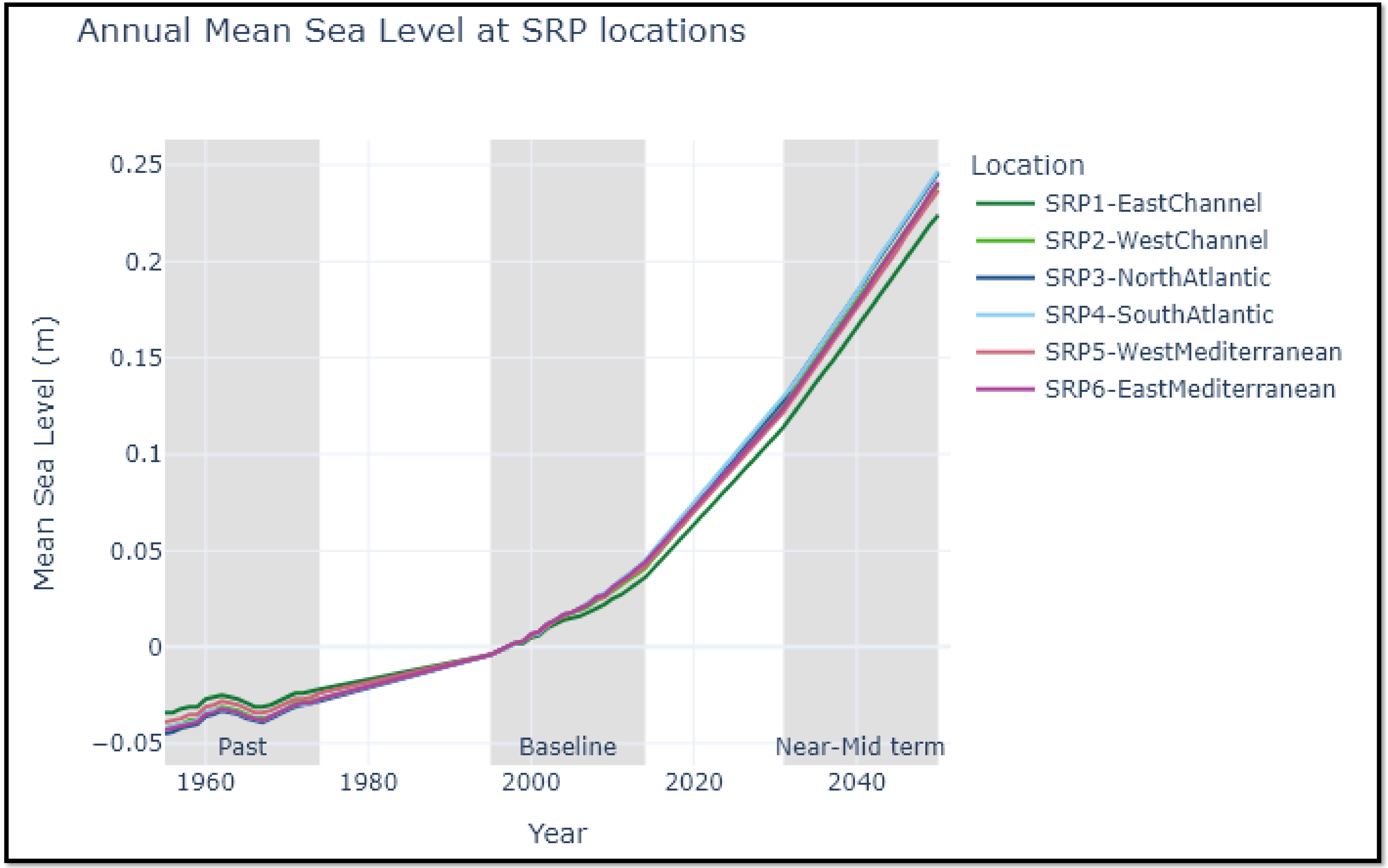
Mean Sea Level (MSL) rise

- One model (Le Bars, 2018), and one scenario (RCP8.5);
- 1° resolution;
- **Similar increase** over each coast
- Slightly lower increase for East Channel



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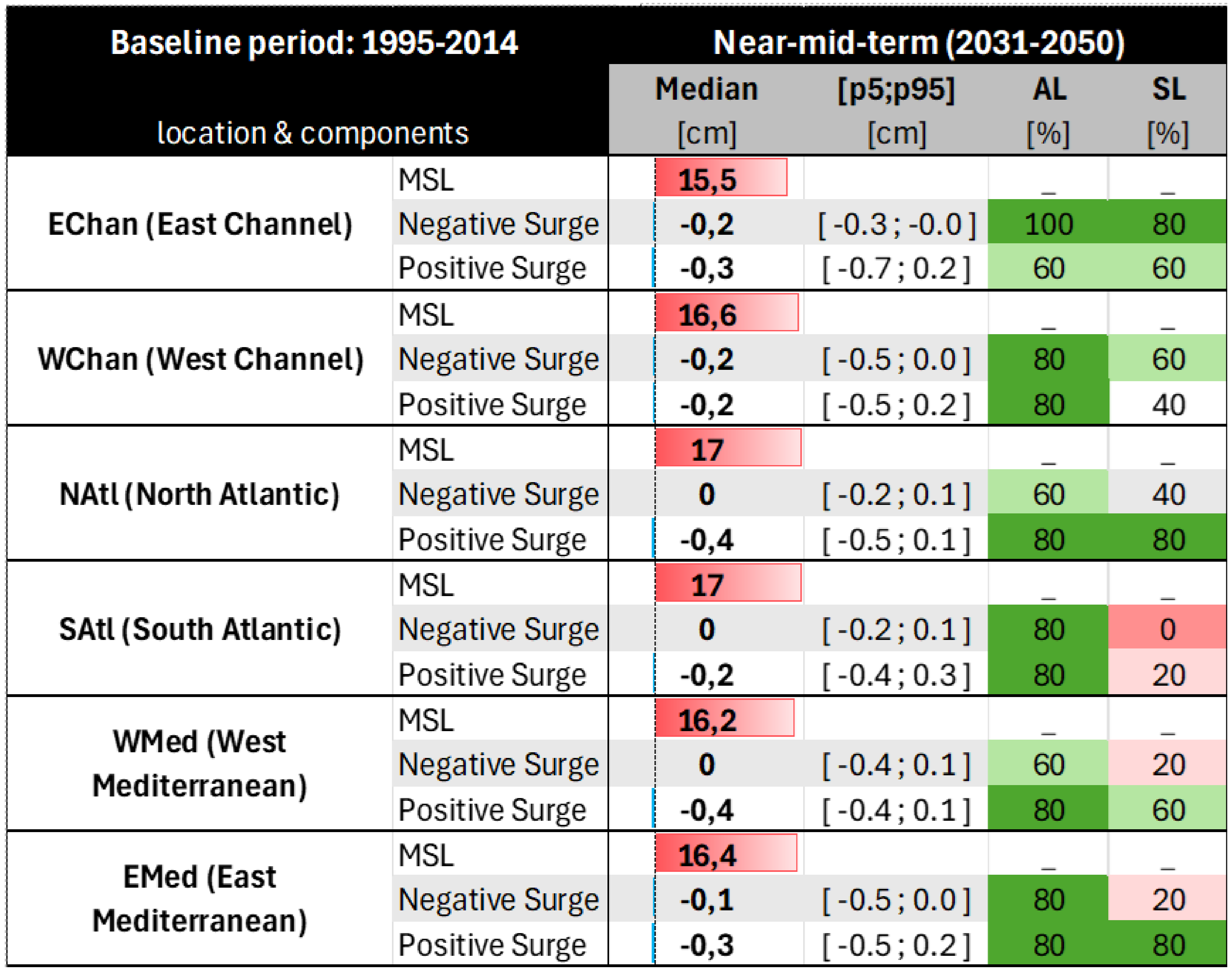
Absolute change in MSL and surges components

- **Surges :**
  - high **AL but variable SL;**
  - Only **negative absolute changes** between baseline and near-mid-term (positive and negative surges)
  - Less than 1 cm
- **MSL inscrease is more important** than past changes in surges



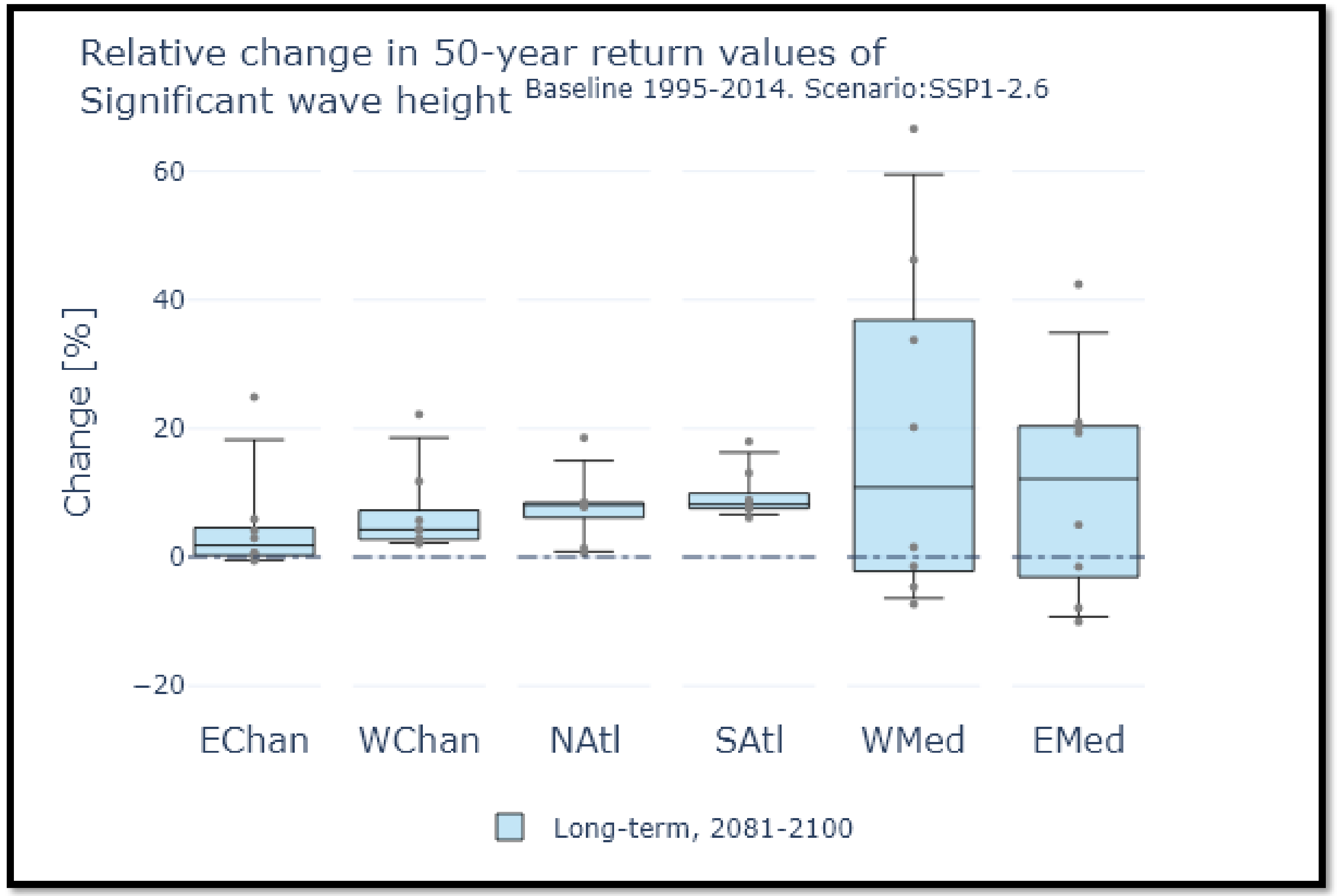
Baseline period: 1995-2014		Near-mid-term (2031-2050)			
location & components		Median [cm]	[p5;p95] [cm]	AL [%]	SL [%]
EChan (East Channel)	MSL	**15,5**		_	_
	Negative Surge	**-0,2**	[-0.3 ; -0.0]	100	80
	Positive Surge	**-0,3**	[-0.7 ; 0.2]	60	60
WChan (West Channel)	MSL	**16,6**		_	_
	Negative Surge	**-0,2**	[-0.5 ; 0.0]	80	60
	Positive Surge	**-0,2**	[-0.5 ; 0.2]	80	40
NAtl (North Atlantic)	MSL	**17**		_	_
	Negative Surge	**0**	[-0.2 ; 0.1]	60	40
	Positive Surge	**-0,4**	[-0.5 ; 0.1]	80	80
SAtl (South Atlantic)	MSL	**17**		_	_
	Negative Surge	**0**	[-0.2 ; 0.1]	80	0
	Positive Surge	**-0,2**	[-0.4 ; 0.3]	80	20
WMed (West Mediterranean)	MSL	**16,2**		_	_
	Negative Surge	**0**	[-0.4 ; 0.1]	60	20
	Positive Surge	**-0,4**	[-0.4 ; 0.1]	80	60
EMed (East Mediterranean)	MSL	**16,4**		_	_
	Negative Surge	**-0,1**	[-0.5 ; 0.0]	80	20
	Positive Surge	**-0,3**	[-0.5 ; 0.2]	80	80

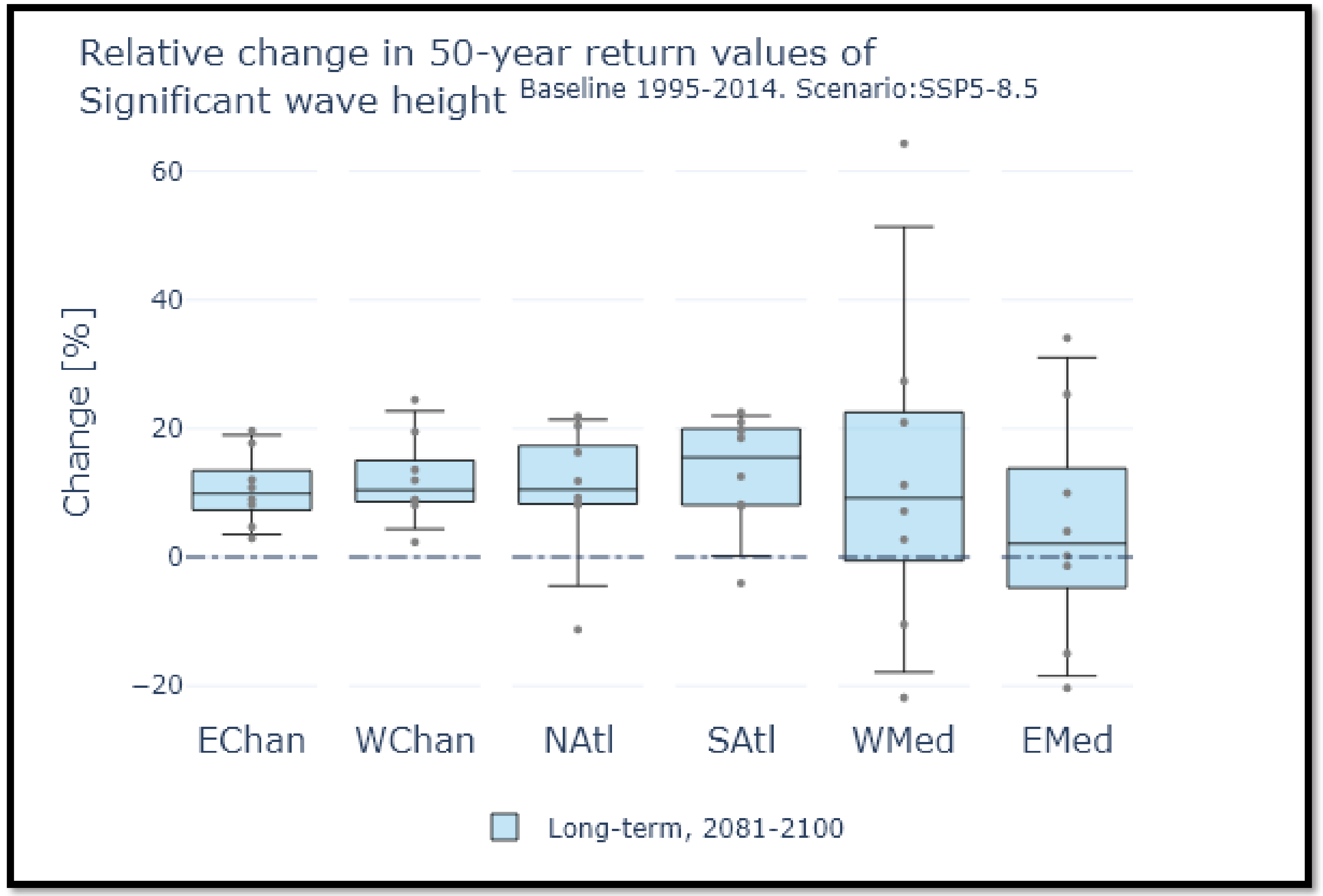
WP4 - Impact on Design

Extreme Analyses

WP4 – Impact of CC on design
Extreme Analyses

Results for Waves





- 50-year return value computed using **non-stationary GEV models** from monthly maxima;
- All regions show **increased extreme values** under future climate scenarios;
- West Mediterranean exhibits largest absolute increase (+2.34m under SSP1-2.6):
- The Atlantic has highest consistency in projections;
- Higher emission scenario (SSP5-8.5) generally shows larger extreme values than SSP1-2.6;
- **Large model spread**, especially in Mediterranean Sea

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Extreme Analyses

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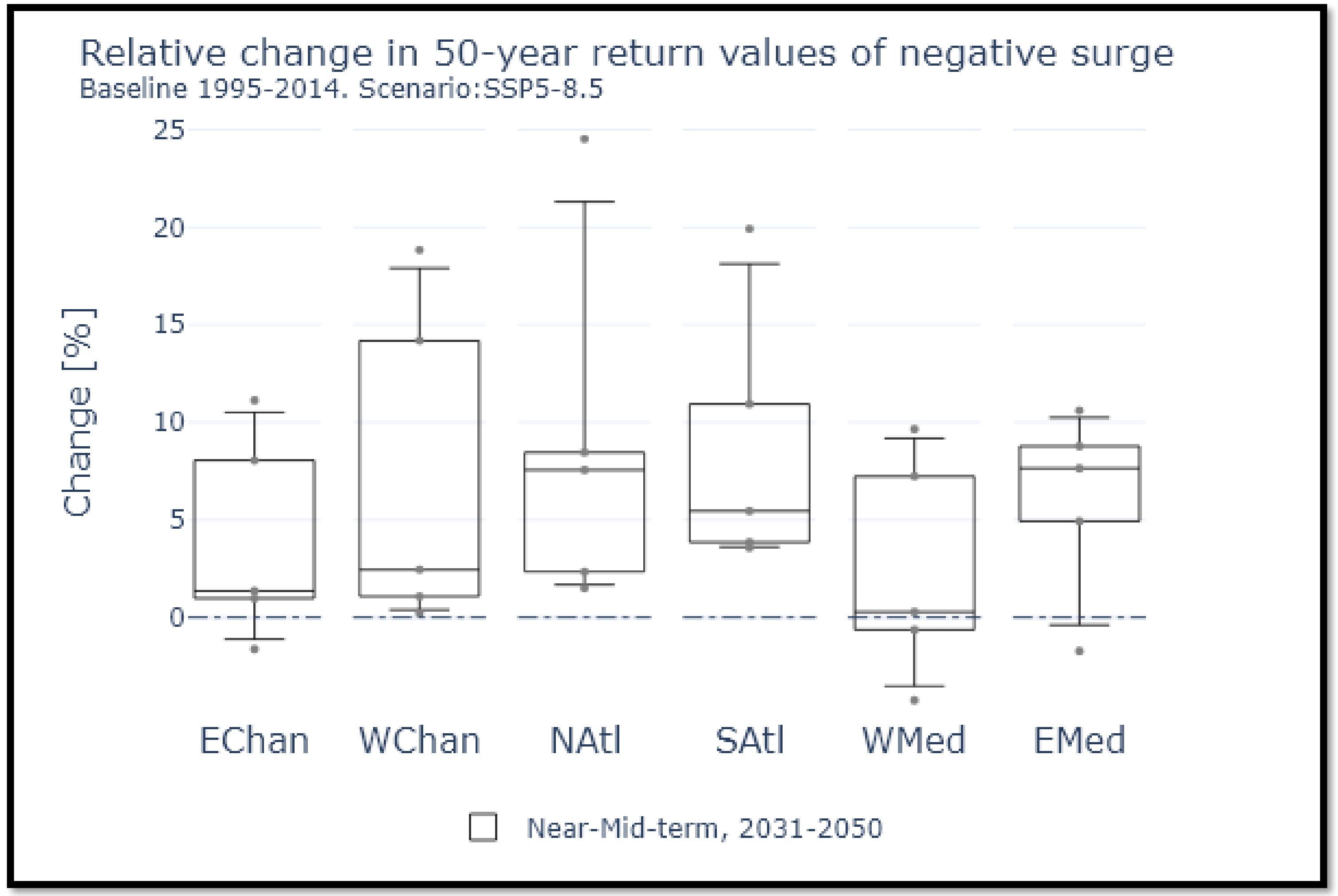
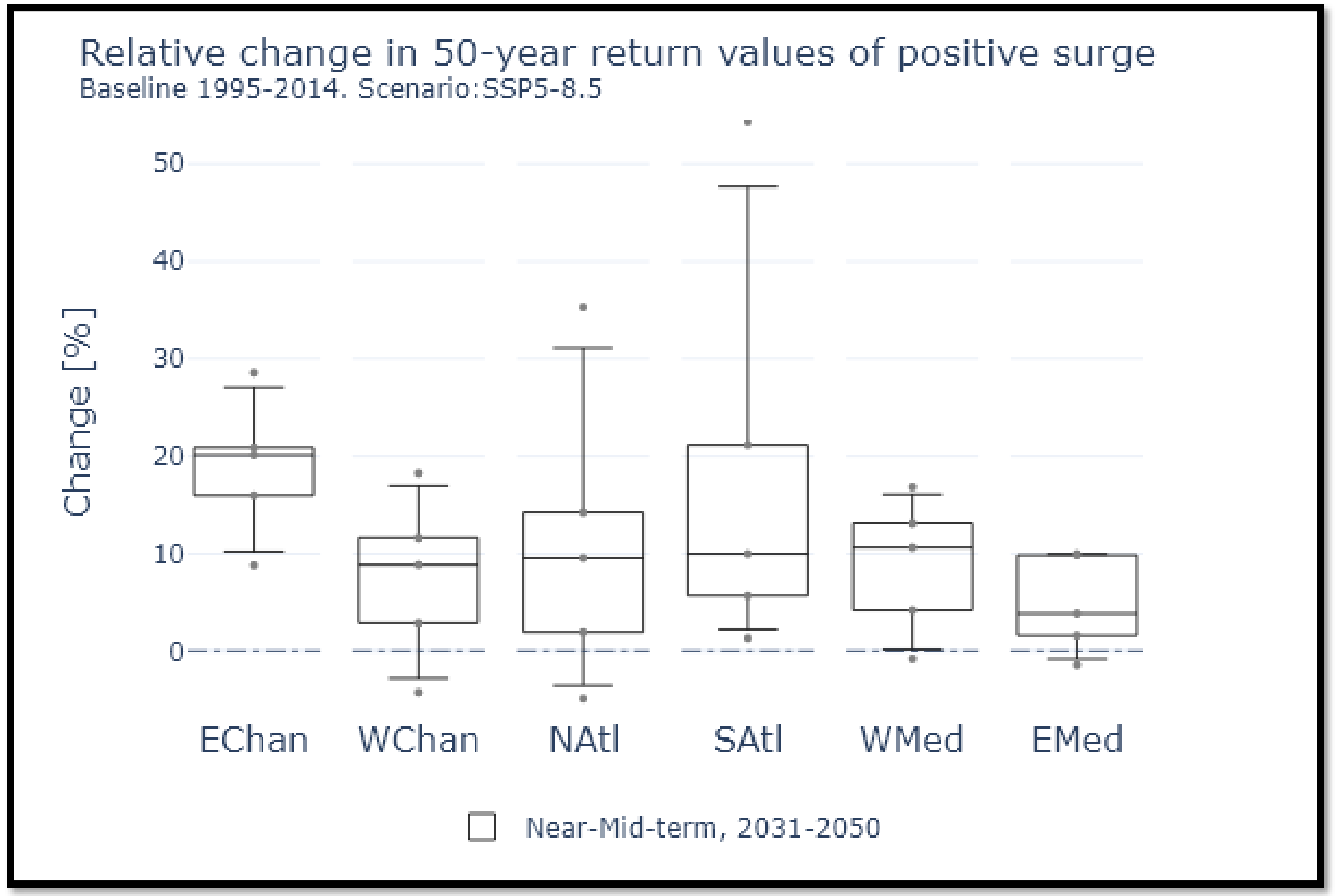
Results for Storm Surge (negative left, positive right)





- East Channel shows **largest projected** increase;
- Mediterranean regions show **modest increases**;
- **Large model spread**, but change of the **same magnitude as the MSL** rise (not shown);

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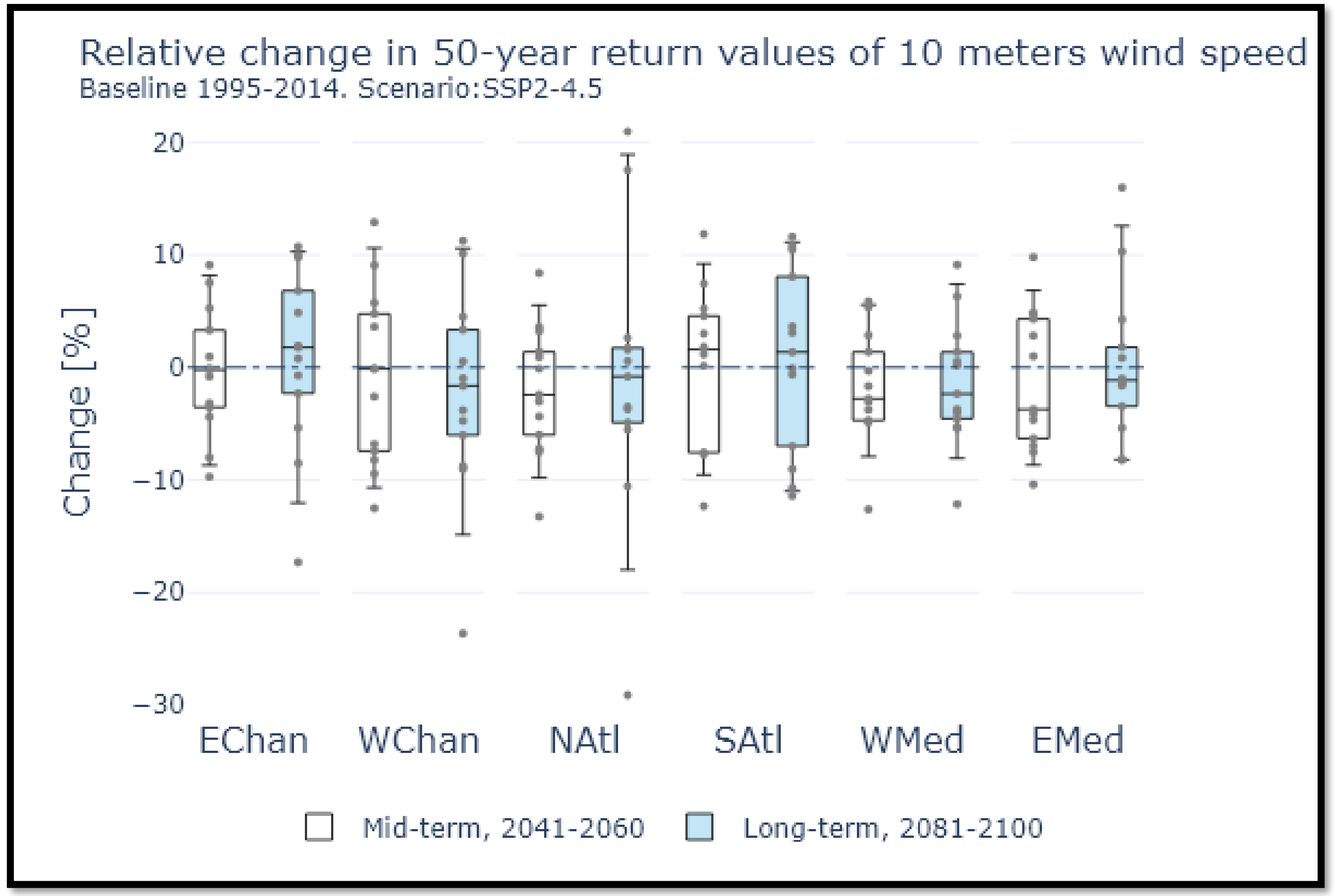
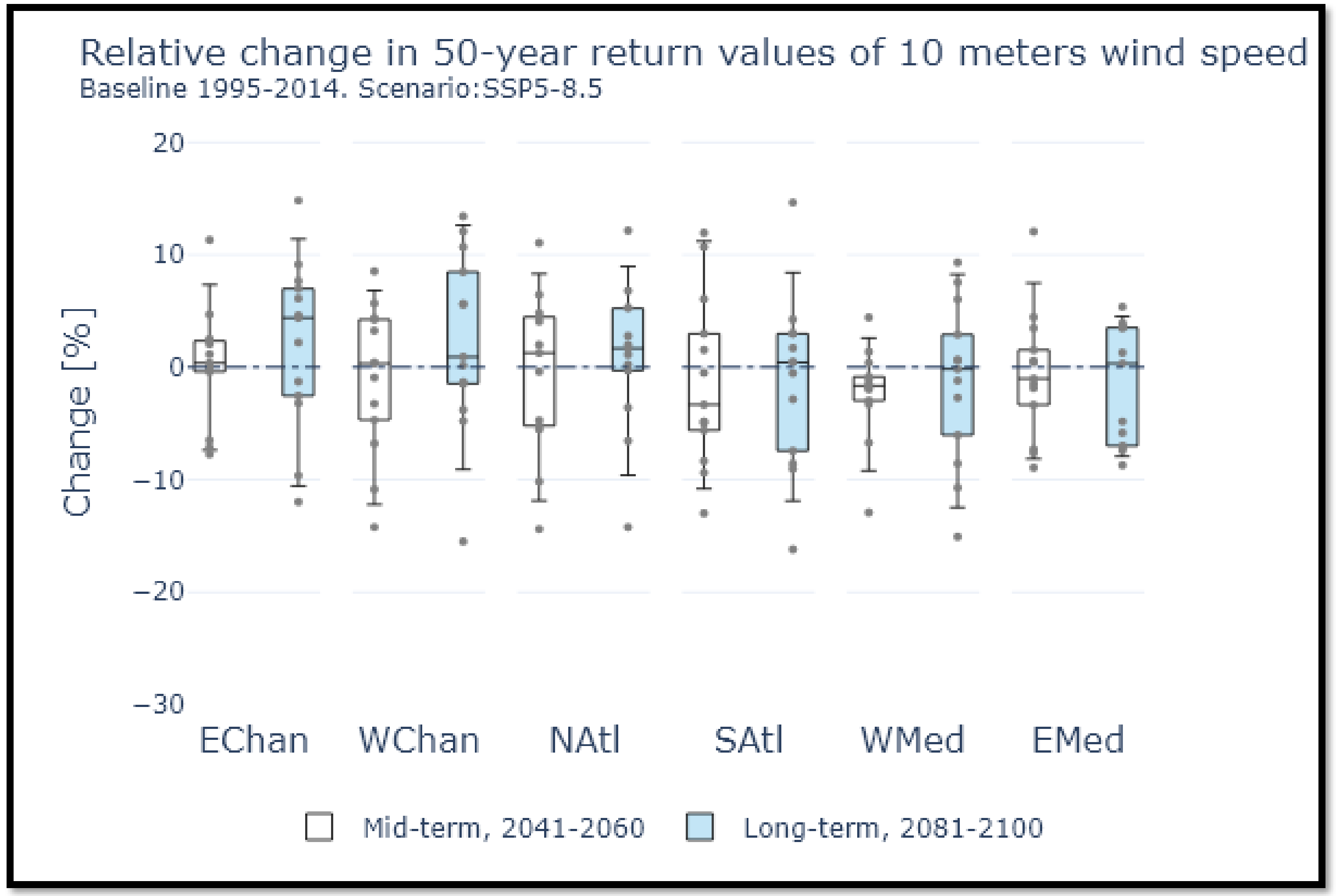
Extreme Analyses

Results for Wind speed at 10m





- Consistent **increase from baseline to mid-term to long-term** across all regions:
- **Progressive intensification across emission scenarios** (SSP1-2.6 → SSP5-8.5) (not seen here):
- **Uncertainty dominates** generally over climate signal.

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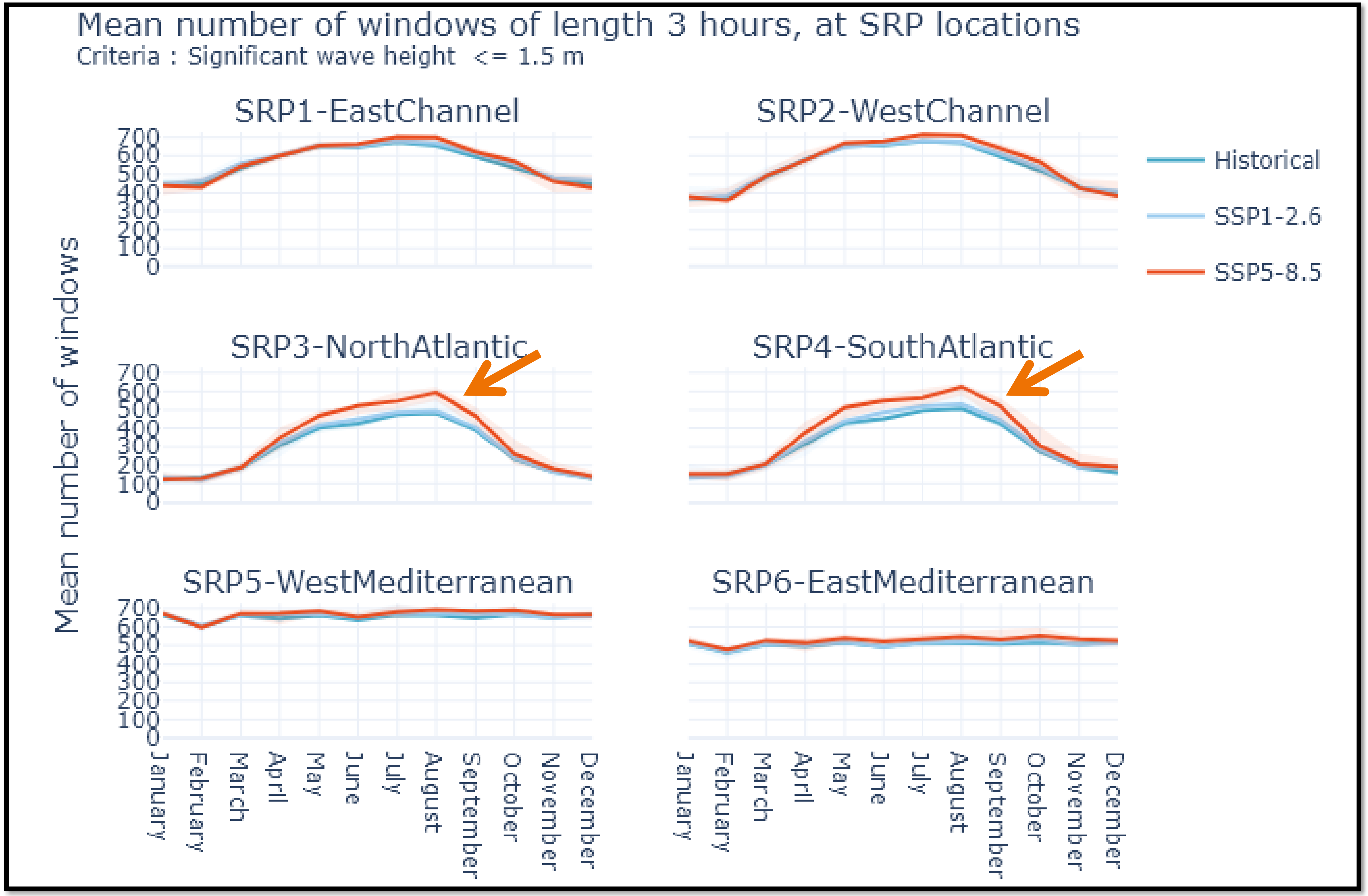
Operation and Maintenance

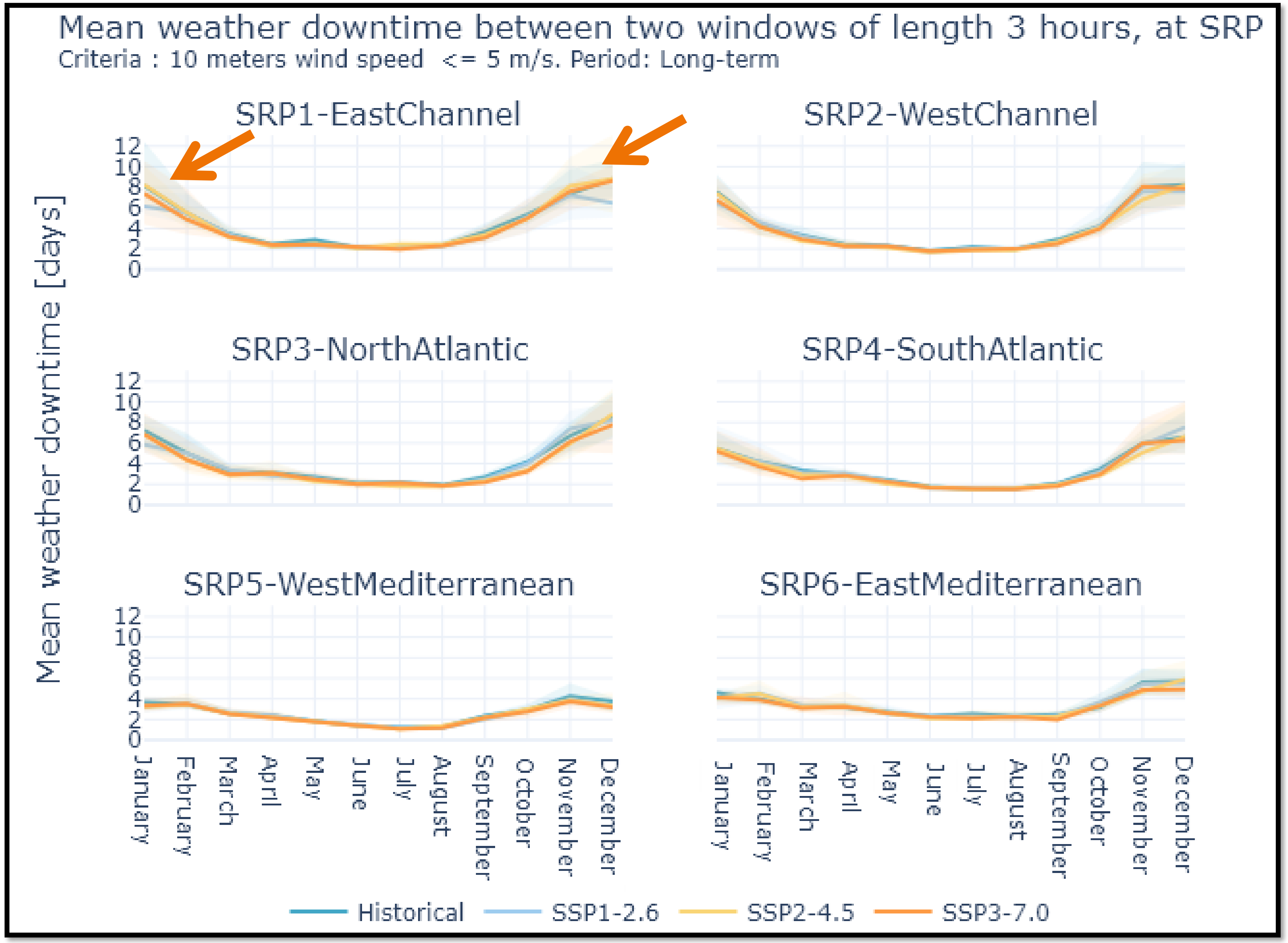
WP4 – Climate change impact on O&M number of 3-hours weather windows - Hs

- **Count** the number of weather windows with Hs ≤ 1.5m for each month;
- **Atlantic:** **more windows** late summer between SSP5-8.5 (long-term) and Historical;
- **Ranges** about 100 windows in summer;
- **Large model spread**.



WP4.3 – Climate change impact on O&M weather downtime – WS10, Long-term

- **Count** of the weather downtime for wind speed ≤ 5 m.s-1
- **East Channel**: **+ 2 days in weather downtime** in December and January between long-term scenarios and Historical (baseline)
- **Large model spread**.



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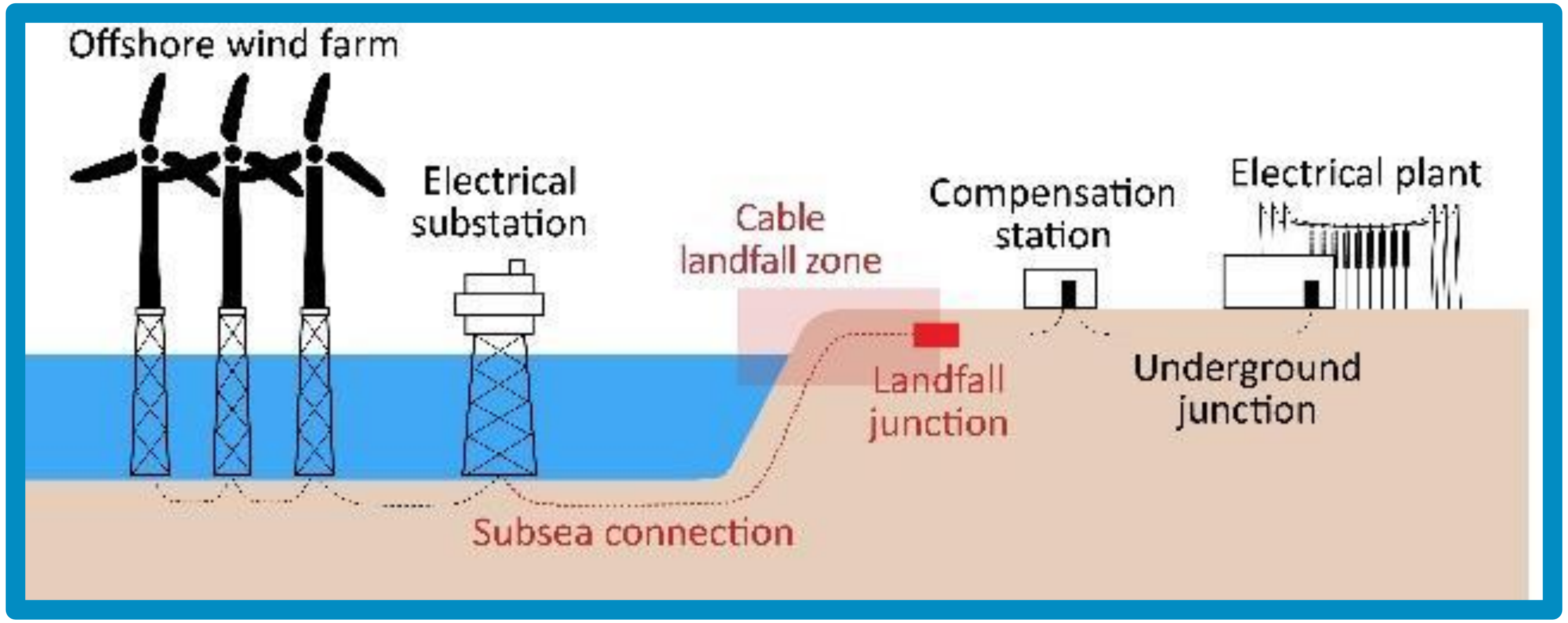
Landing Zone

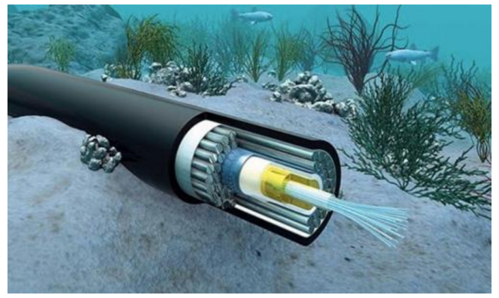
Marissa Yates (ENPC)
Olivia Cadiou (FEM)
Nicolas Michelet (FEM)

WP4 – Climate change impact on Landing Zone
Cable landfall site morphological evolution

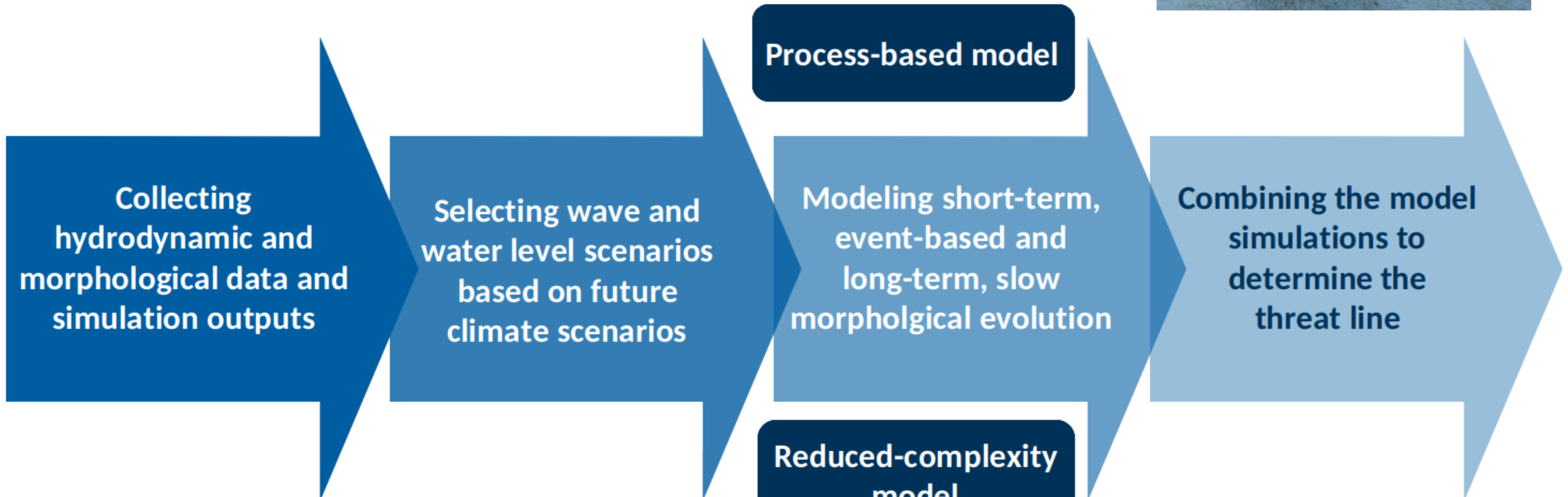


2C NOW objective:

Define the state-of-the-art and propose a method for evaluating nearshore morphological evolution considering climate change impacts



- Electricity carried to the coast via a submarine cable
- Cable buried in nearshore zone to protect it from hazards
- Optimal burial depth defined by risks
  - **erosion** : freespanning and mechanical failure
  - **accretion** : overheating and reduced functioning or failure



Collecting hydrodynamic and morphological data and simulation outputs

Selecting wave and water level scenarios based on future climate scenarios

Modeling short-term, event-based and long-term, slow morpholgical evolution

- Process-based model
- Reduced-complexity model

Combining the model simulations to determine the threat line

Proposed method

WP4 – Climate change impact on Landing Zone
Demonstration of the proposed approach

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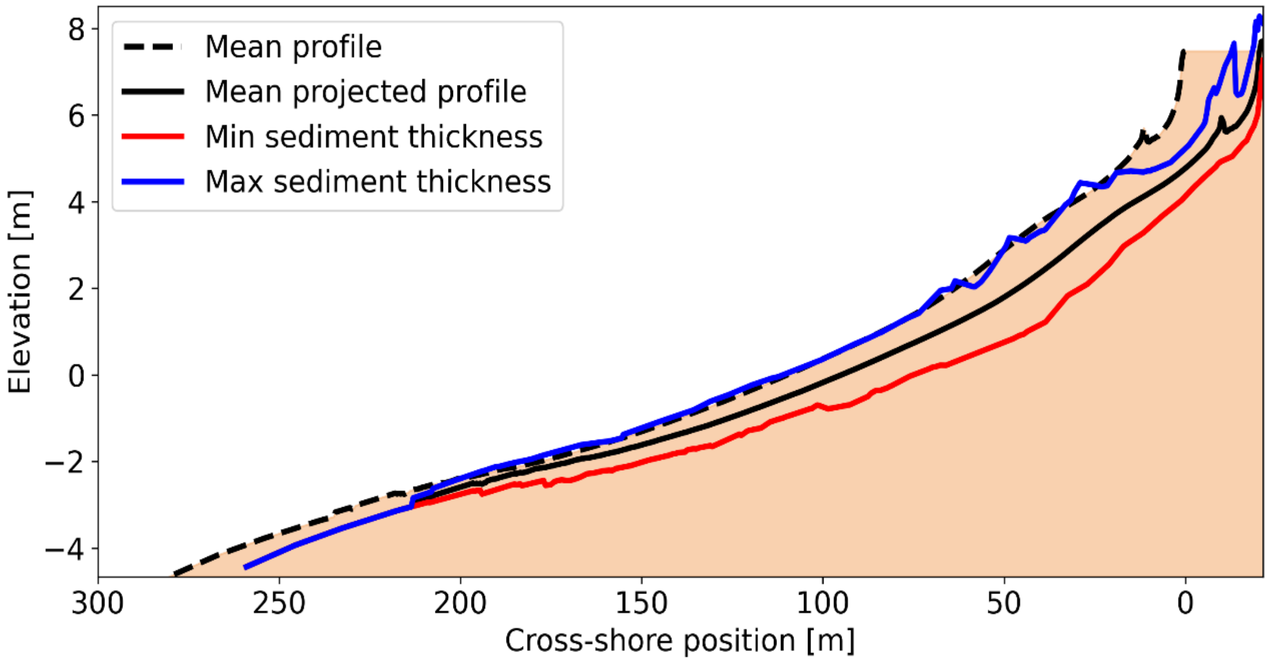
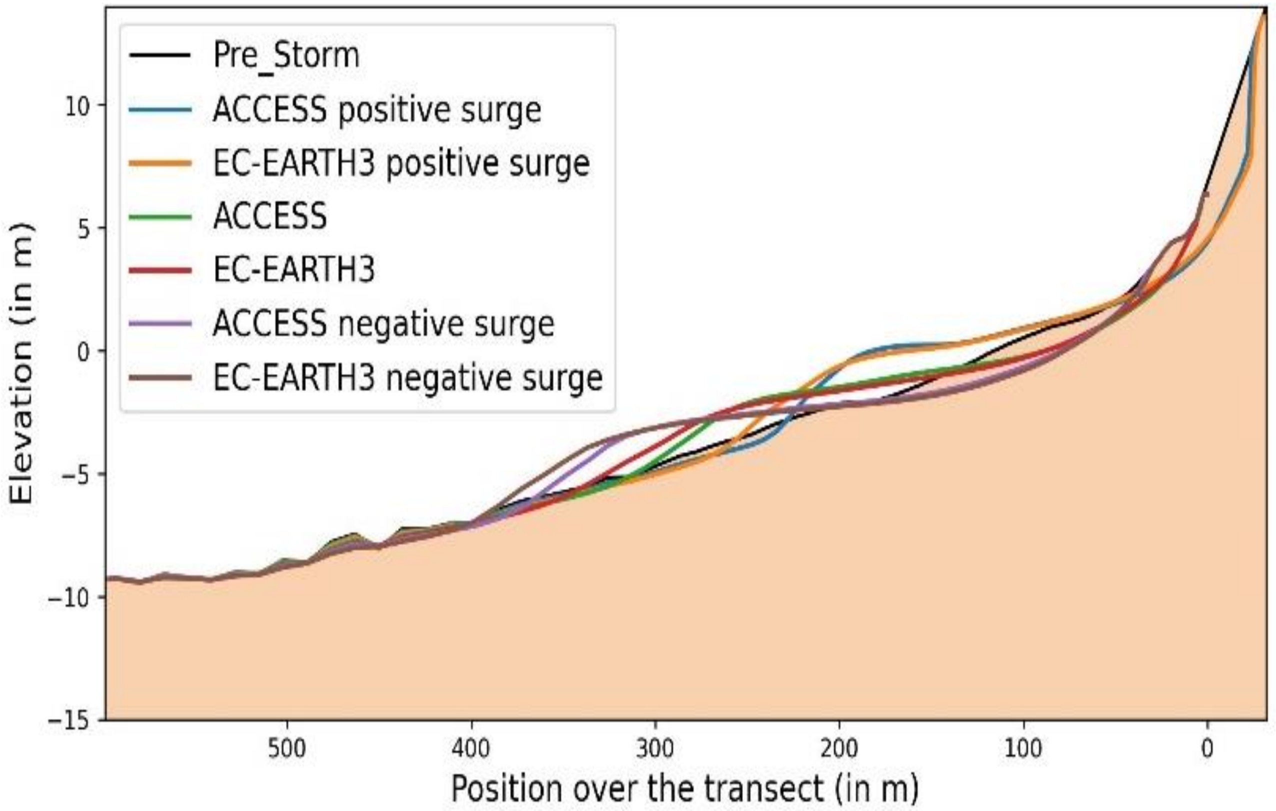
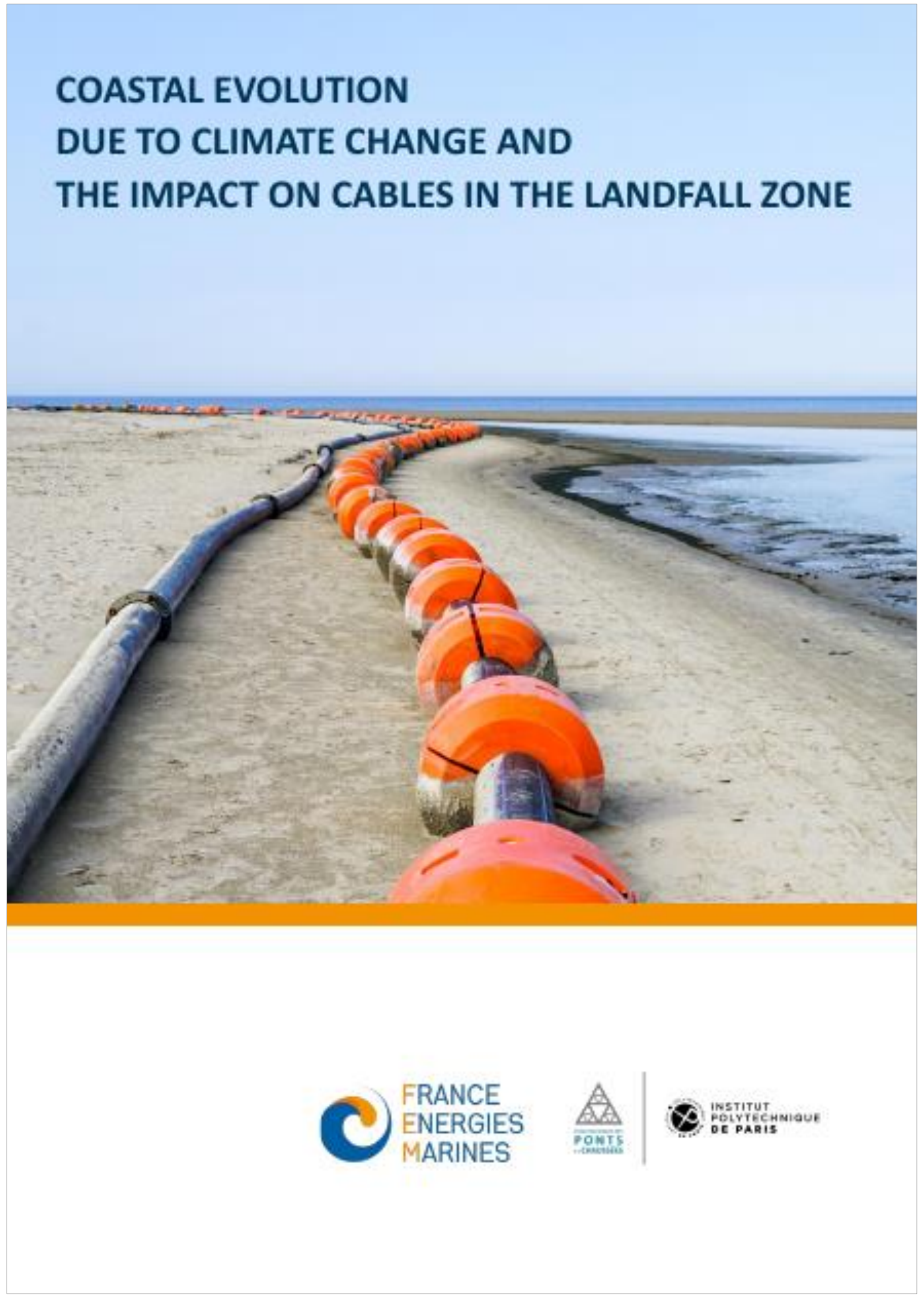
- Demonstration at Porsmilin Beach, with high quality and frequency data

Medium to long-term evolution



Short-term, storm-based evolution




COASTAL EVOLUTION
DUE TO CLIMATE CHANGE AND
THE IMPACT ON CABLES IN THE LANDFALL ZONE

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INSTITUT POLYTECHNIQUE DE PARIS

Perspectives:

- Evaluating uncertainties
- Need for long-term, continuous wave projections
- Sensitivity analyses to necessary data for model calibration
- Satellite observations improving access to morphological observations

WP4 - Impact on Design

Offshore Wind Turbine Fatigue

Clémentine Girandier (INNOSEA)
Matéo Pimoult (INNOSEA)
Thomas Potentier (INNOSEA)

WP4 – Climate change impact on Fatigue
Description of the method

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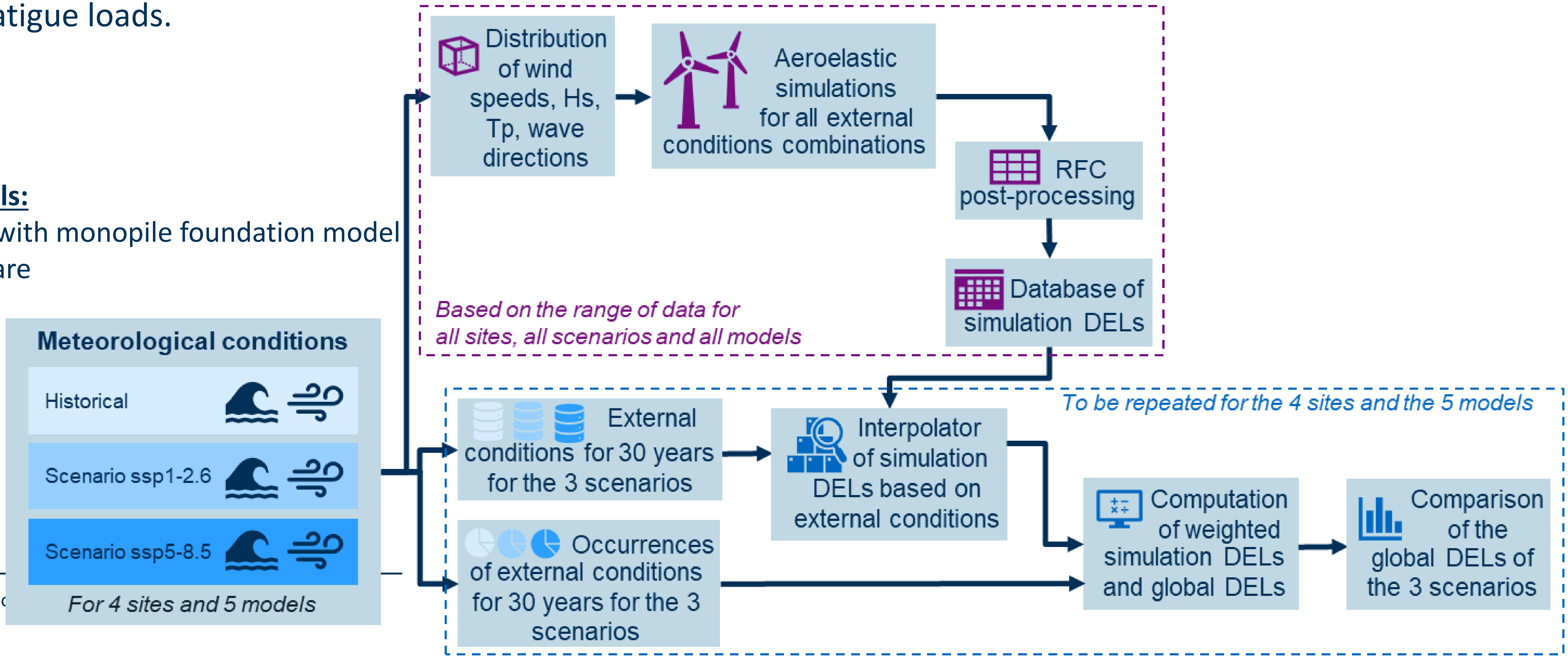
1. **Environmental data processing** of historical and future climate data (SSP1-2.6 and SSP5-8.5 scenarios) to define range of environmental conditions for aeroelastic simulations ;
2. **Aeroelastic simulation →**database of Damage Equivalent Loads (DEL) representative of the environmental conditions;
3. **Interpolation within the database and analysis** for all the sites, climate models and scenarios to potentially identify trends in fatigue loads.

Open Source tools:
IEA 10MW WTG with monopile foundation model
OpenFAST software



Meteorological conditions

Historical

Scenario ssp1-2.6

Scenario ssp5-8.5

For 4 sites and 5 models

Distribution of wind speeds, Hs, Tp, wave directions

Aeroelastic simulations for all external conditions combinations

RFC post-processing

Database of simulation DELs

Based on the range of data for all sites, all scenarios and all models

To be repeated for the 4 sites and the 5 models

External conditions for 30 years for the 3 scenarios

Occurrences of external conditions for 30 years for the 3 scenarios

Interpolator of simulation DELs based on external conditions

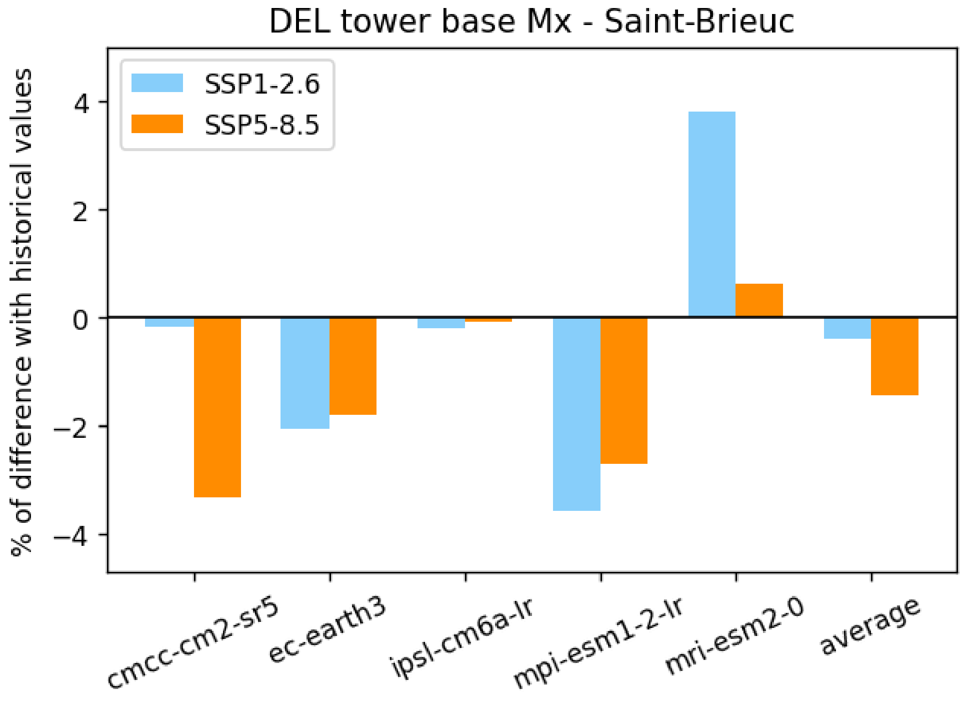
Computation of weighted simulation DELs and global DELs

Comparison of the global DELs of the 3 scenarios

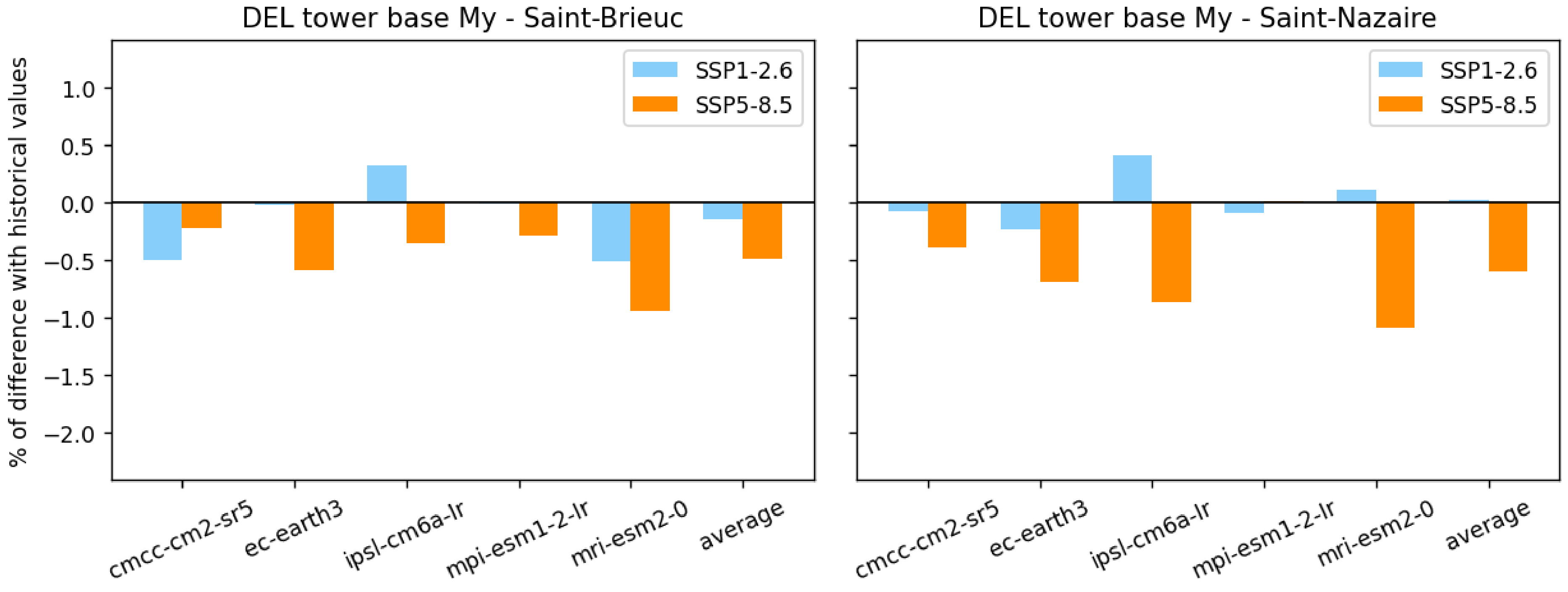
WP4 – Climate change impact on Fatigue

Results

Mx tower base DEL



My tower base DEL



- General trend of **decreasing DEL** across the climate scenarios;
- **High variability among models and sites** (not shown here);
- **Potential extension of the operational lifetime** of OWF or potential for compensation of other adverse effects of climate change (e.g. more frequent extreme weather events);
- Study **focuses only on wind speed, Hs and Tp** during turbine operation neglecting other potential driving factors of fatigue such as turbulence, wind shear, sea level rise or wind-wave direction.

WP4 - Impact on Design

Conclusions

Main results of WP4
Climate change impacts on design

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Take away messages:

- General **decrease in mean conditions** for Hs and storm surges;
- **Increase of extremes events** for Hs and storm surges, unclear results for winds;
- **Decrease in fatigue** on average;
- More important changes occurs for **extreme emission scenarios**;
- **Large model spread**.

Limitations and future work:

- Climate model spatial and temporal resolution;
- Number of models and representativeness of extremes after downscalling;
- Quantification of different uncertainty sources;
- Multivariate modeling of extremes.