HIGH-RESOLUTION PROJECTIONS OF EXTREME SEA LEVEL CHANGES ALONG THE COASTS OF WESTERN EUROPE

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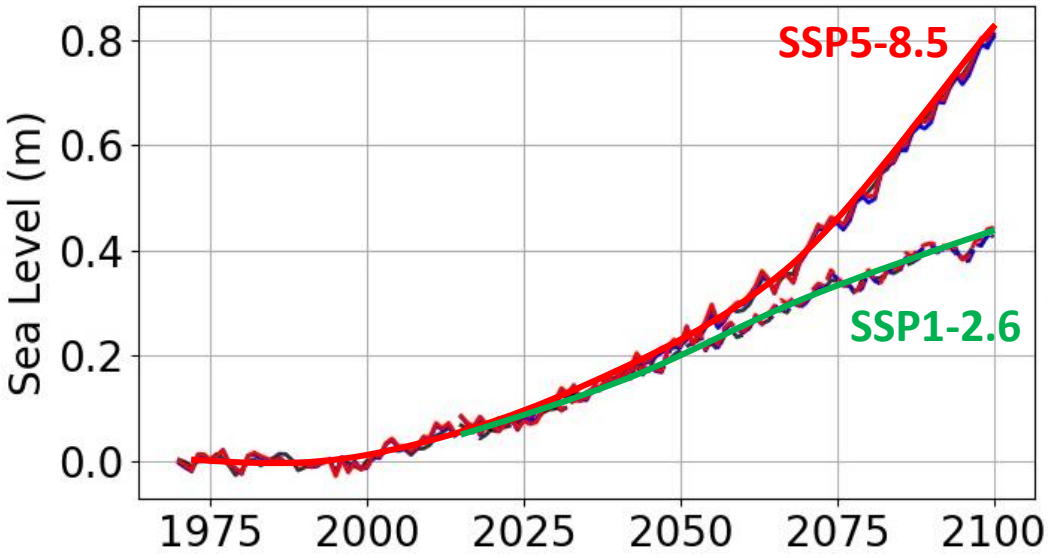
[2] Mercator Ocean International, Toulouse, France.
[3] Météo-France, Toulouse, France.

AMA - 07/06/2022

CONTEXT - INTRODUCTION

Sea level rise (SLR) = key indicator of climate change *(World Meteorological Organization)*



Projections of mean sea level over the north-eastern Atlantic domain
Adapted from Chaigneau et al., 2022a

- Hazards :
  - **Increased frequency of extreme sea levels**
  - Marine flooding
  - Salinization of lands
  - Erosion
  - Disappearance of coastal ecosystems

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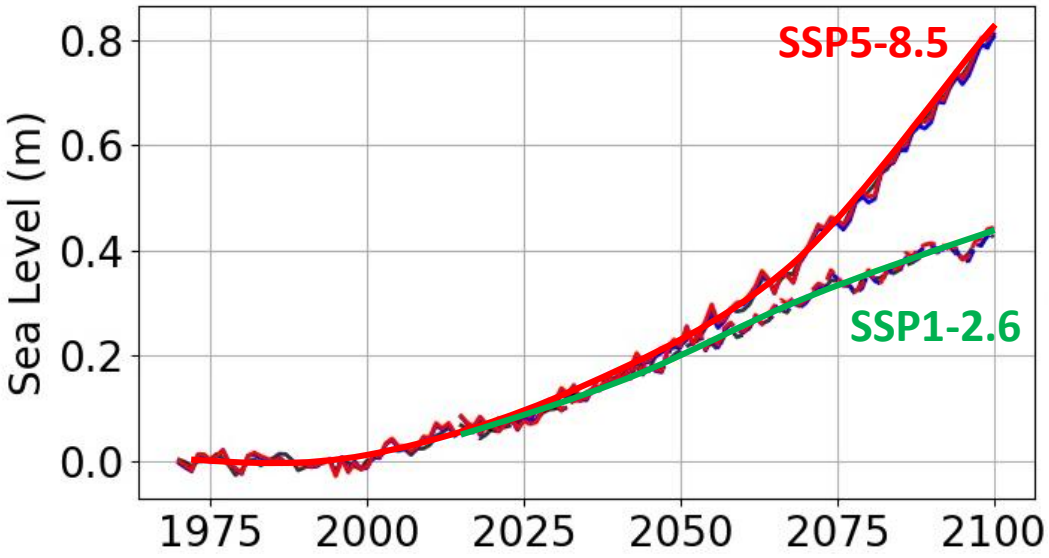

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- Hazards :
  - **Increased frequency of extreme sea levels**
  - Marine flooding
  - Salinization of lands
  - Erosion
  - Disappearance of coastal ecosystems

- Exposure :
  - 10% of the world's population living in low-lying coastal areas *(McMichael et al., 2020)*
  - In Europe : **200 million people involved** *(Vousdoukas et al., 2020)*

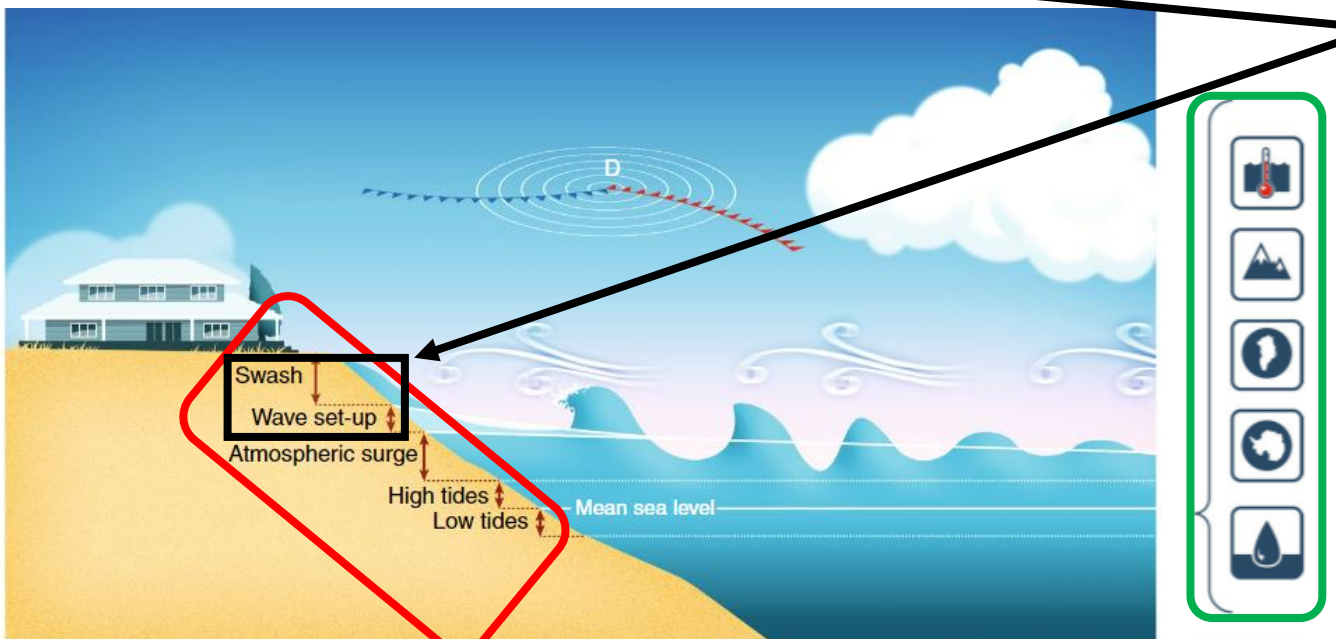
➢ **Projections of extreme sea levels (ESLs) needed**

SCIENTIFIC CONTEXT – STATE OF ART

Coastal water level changes =

Regional processes + **Coastal processes** *(Woodworth et al., 2019; Dodet et al., 2019; Lowe et al., 2021,…)*

+ ***interactions*** *(Idier et al., 2019; Arns et al., 2020; Arns et al., 2017; Staneva et al., 2016; Marcos et al., 2019; Lewis et al., 2019,…)*



Processes contributing to coastal water level changes
Melet et al., 2018

often not considered for projections of ESLs
(Muis et al., 2020; Colberg et al., 2019; Fox-Kemper et al., 2021; Kirezci et al., 2020; Vousdoukas et al., 2018;…)

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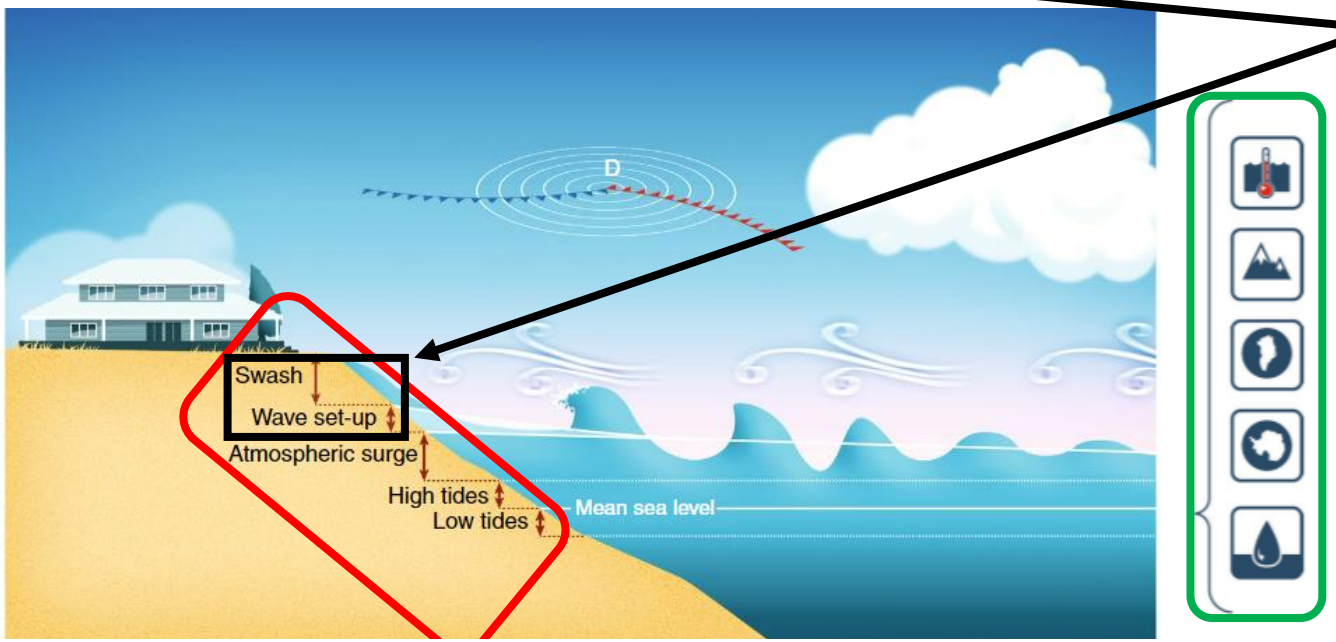

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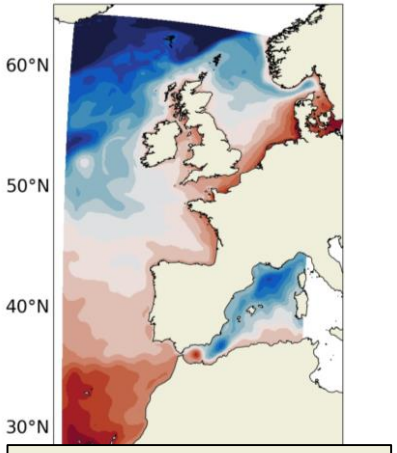
Aim : At **regional scale**, ESLs projections based on a model that includes :

- the **different contributions** at the coast: tides, atmospheric surge and **waves**
- the **interactions** between these processes

SEA LEVEL SIMULATIONS
1970-2100, SSP5-8.5 and SSP1-2.6



Chaigneau et al., 2022a

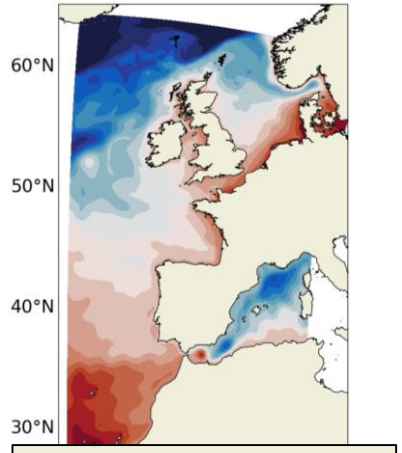
Regional ocean model ⟶ **Water Level (WL) :**

(1/12° - 75 lev)

IBI-CCS

- **Mean Sea Level**
- **Tides**
- **Storm surge**

SEA LEVEL SIMULATIONS
1970-2100, SSP5-8.5 and SSP1-2.6



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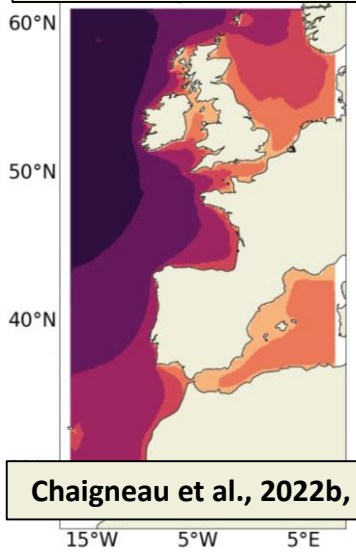


Chaigneau et al., 2022b, in prep

Regional ocean model → **Water Level (WL) :**

(1/12° - 75 lev)

IBI-CCS

- **Mean Sea Level**
- **Tides**
- **Storm surge**

Currents

Currents & Sea level

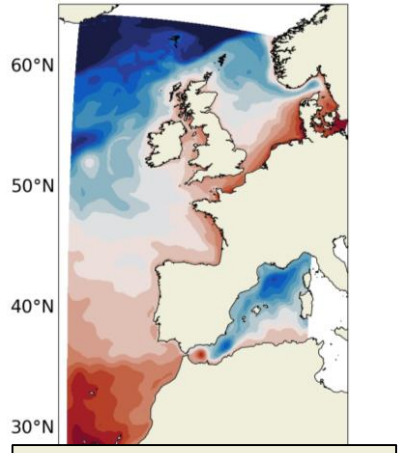
(1) Waves-sea level **non-linear interactions** ?

Regional wave model

(1/10°)

IBI-CCS-WAV / IBI-CCS-WAV_ssh

SEA LEVEL SIMULATIONS
1970-2100, SSP5-8.5 and SSP1-2.6



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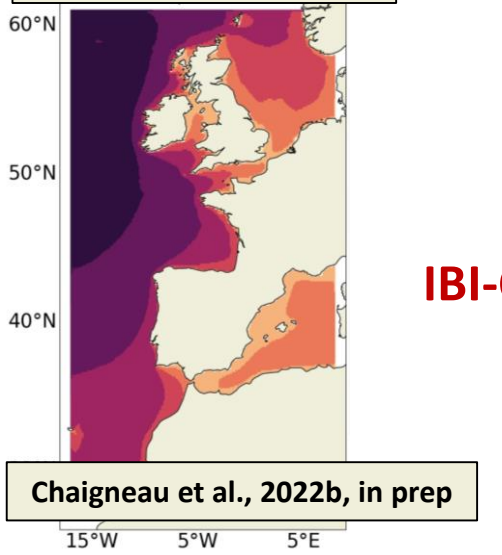


Chaigneau et al., 2022b, in prep

Regional ocean model *(1/12° - 75 lev)*

IBI-CCS

Currents

Currents & Sea level

Regional wave model *(1/10°)*

IBI-CCS-WAV / IBI-CCS-WAV_ssh

Water Level (WL) :

- **Mean Sea Level**
- **Tides**
- **Storm surge**

+

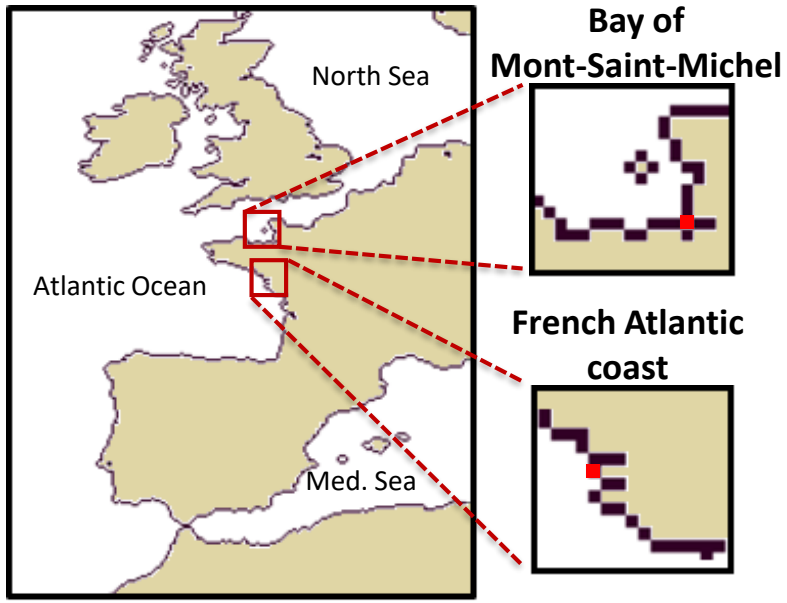
- **Wave setup**
  = $\mathbf{0.35\beta\sqrt{H_s L_p}}$ (Stockdon 2006)

(2) **Wave setup contribution** to ESLs ?

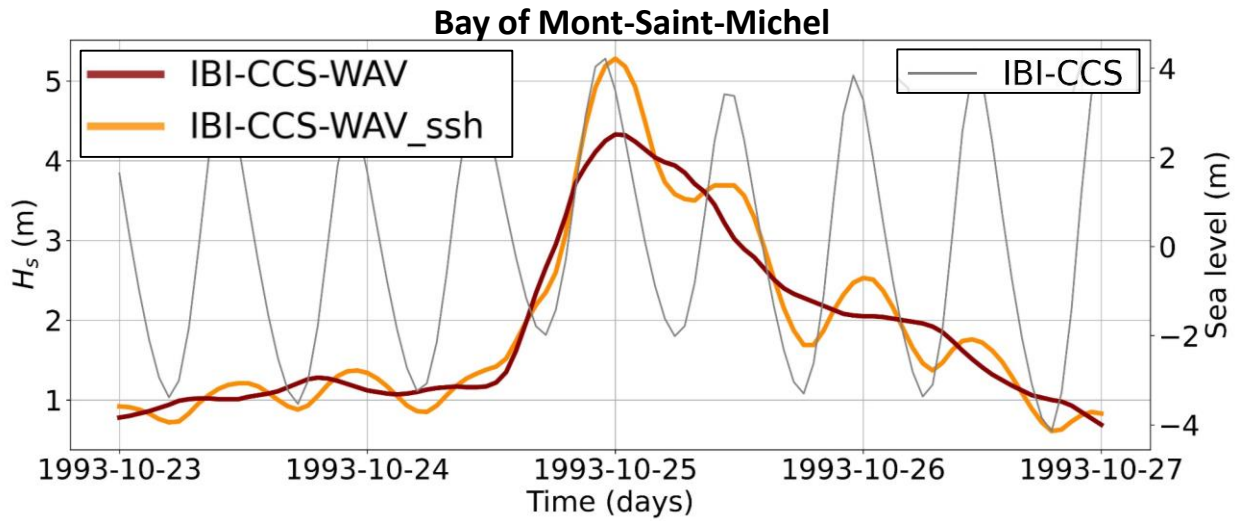
=

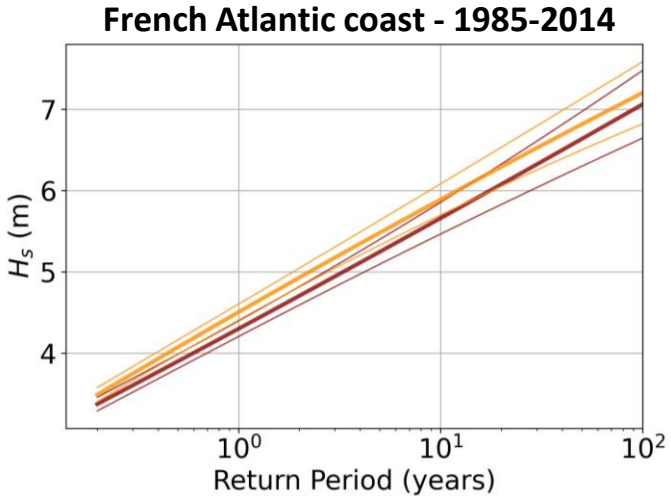
Total water level (TWL)

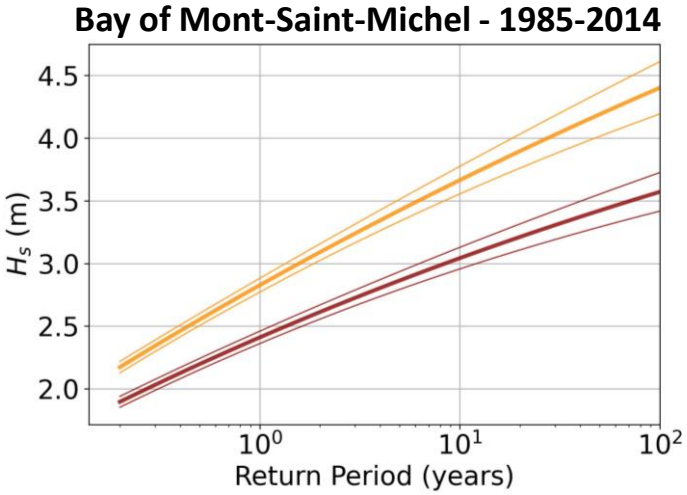
RESULTS :
WAVES-SEA LEVEL NON-LINEAR INTERACTIONS



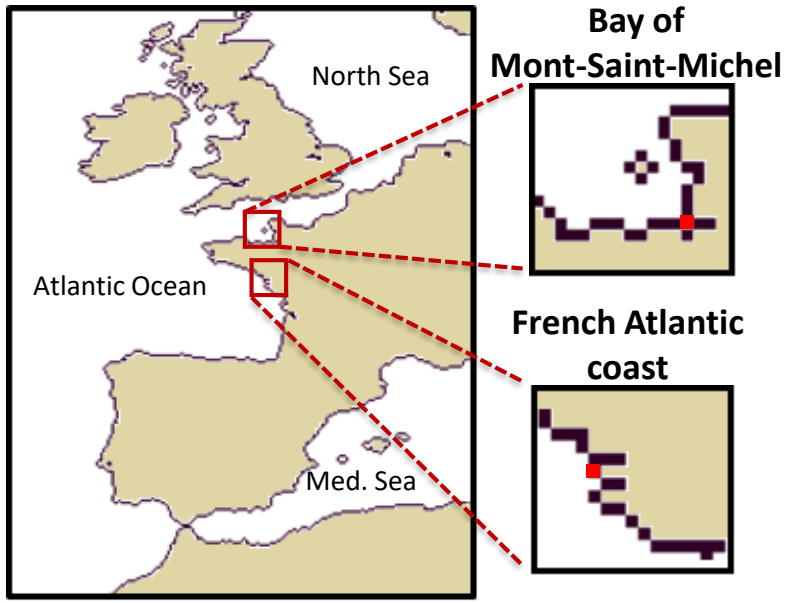
SIGNIFICANT WAVE HEIGHT : (Hs)





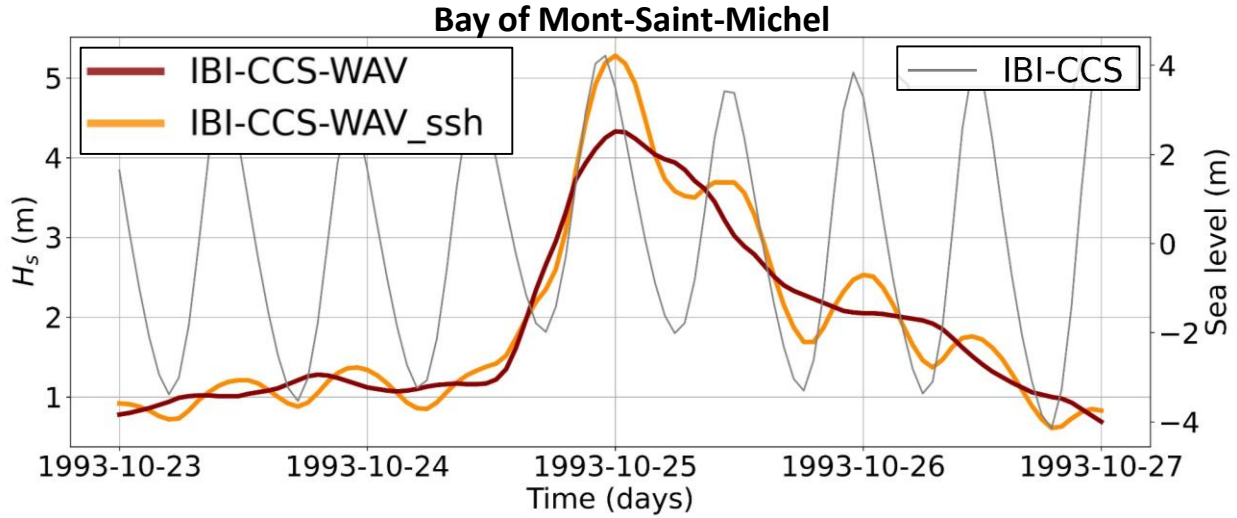


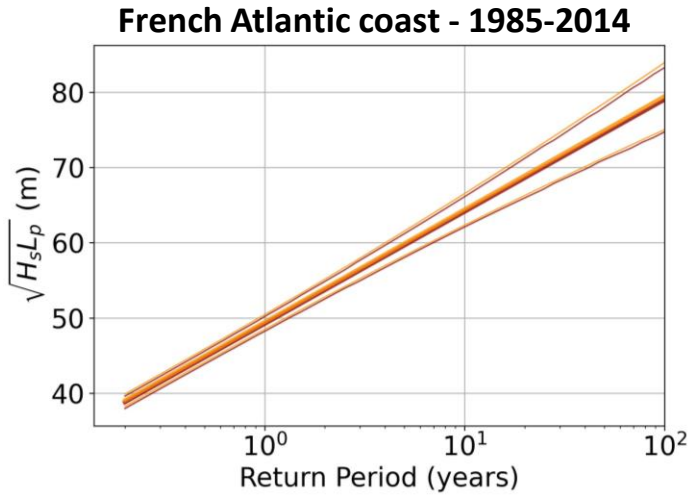
RESULTS :
WAVES-SEA LEVEL NON-LINEAR INTERACTIONS

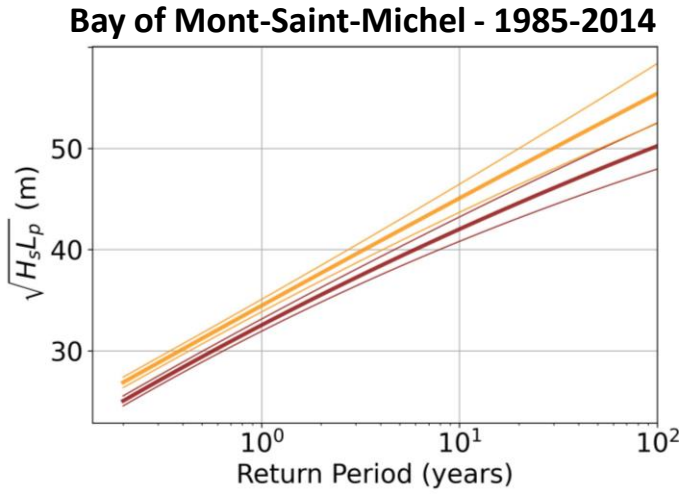


WAVE SETUP SCALING:

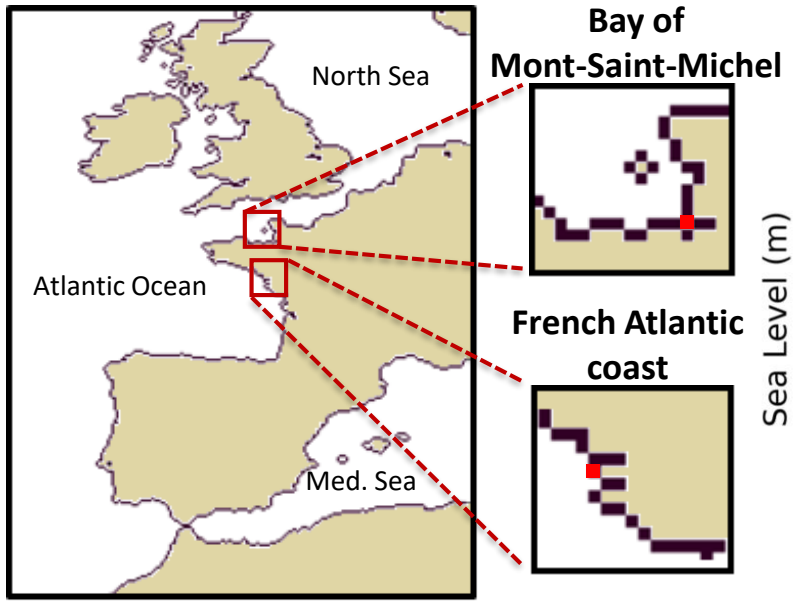
$(\sqrt{HsLp})$







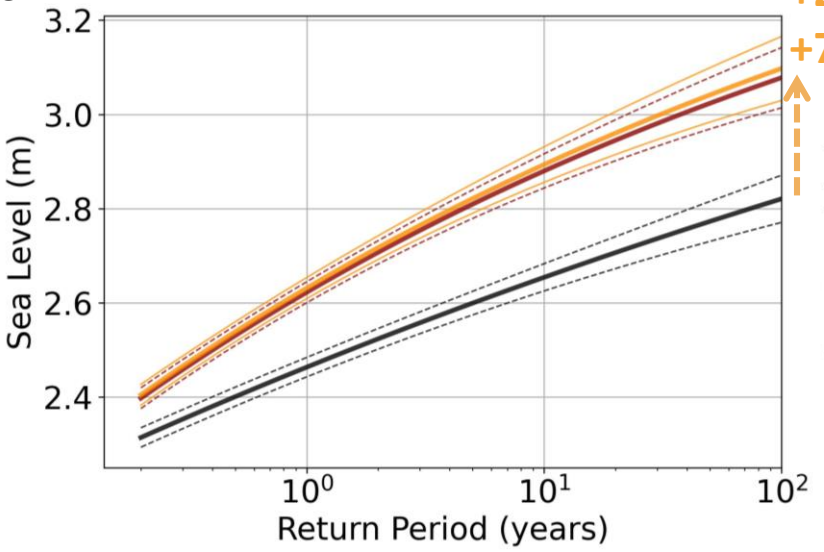
RESULTS : HISTORICAL ESLs RETURN LEVELS (1985-2014)



Bay of Mont-Saint-Michel

French Atlantic coast

French Atlantic coast



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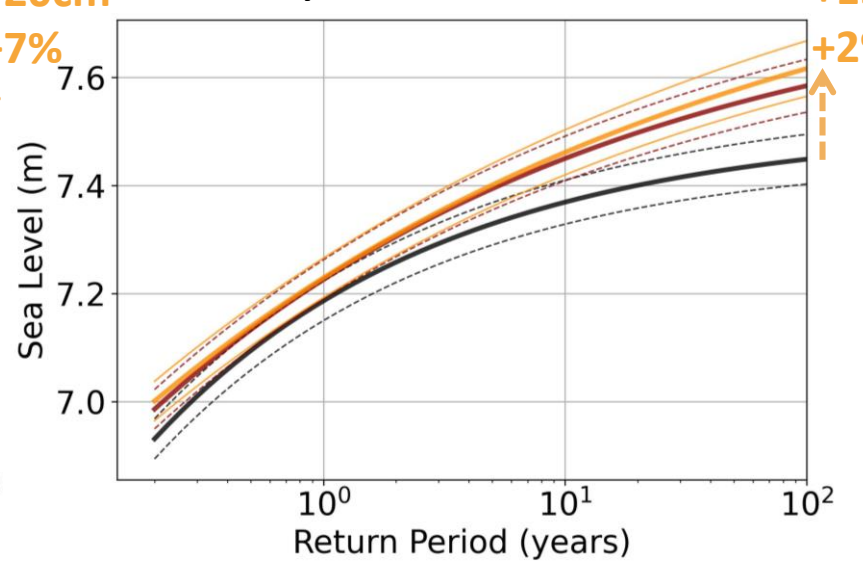

IBI-CCS (WL)
IBI-CCS+IBI-CCS-WAV(TWL)
IBI-CCS+IBI-CCS-WAV_ssh (TWL)

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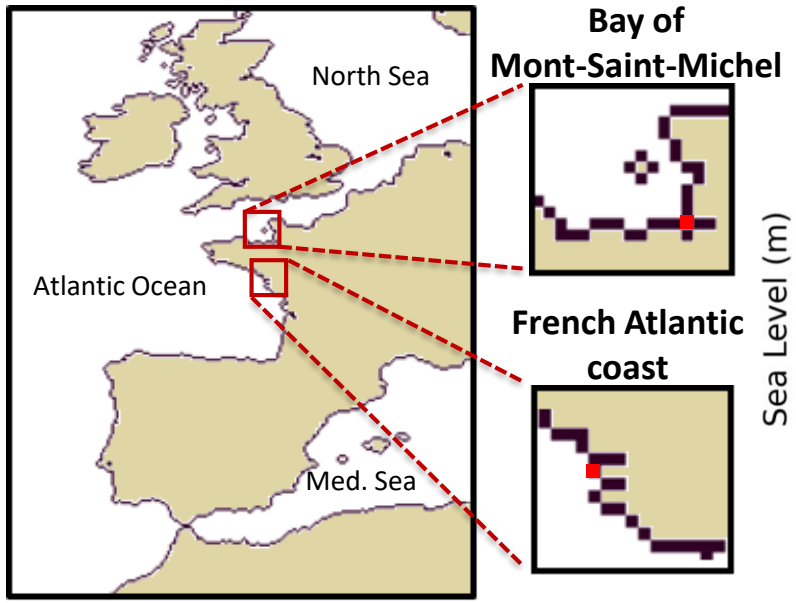

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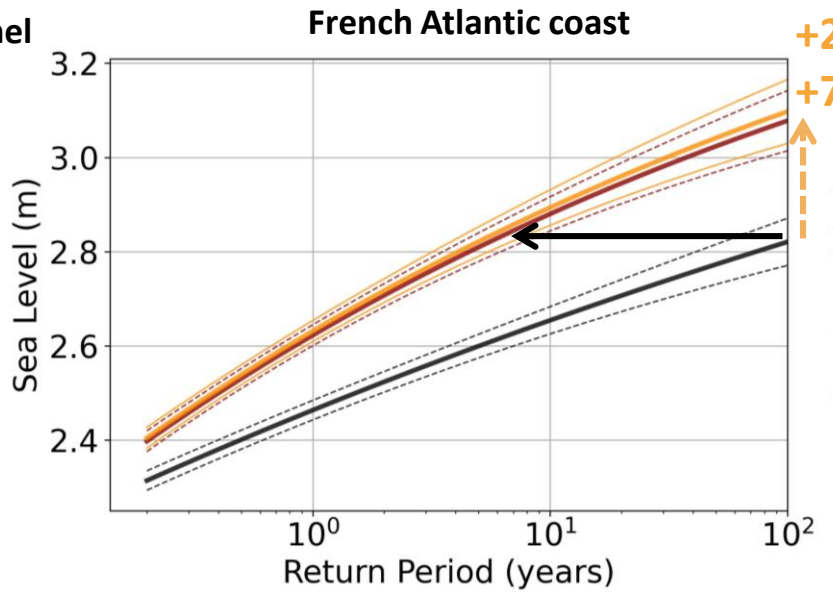

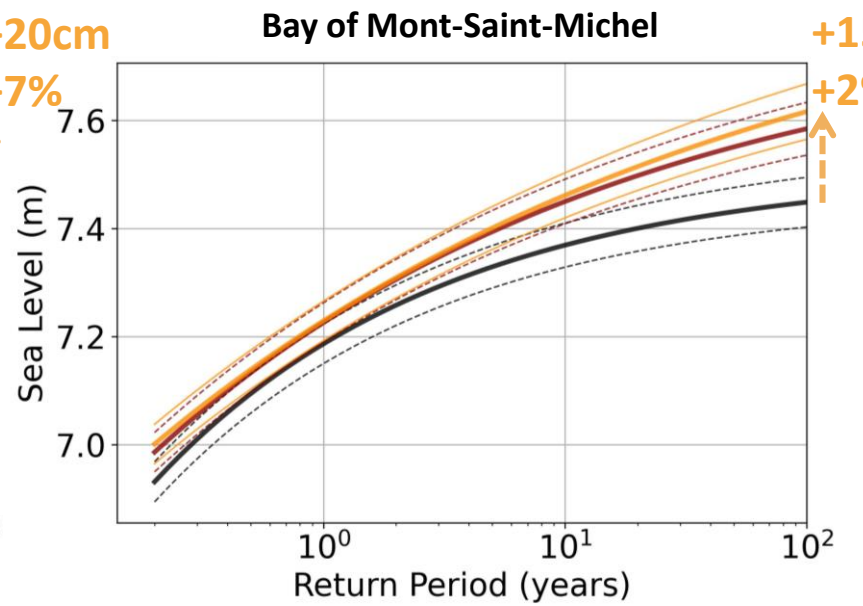

IBI-CCS (WL)
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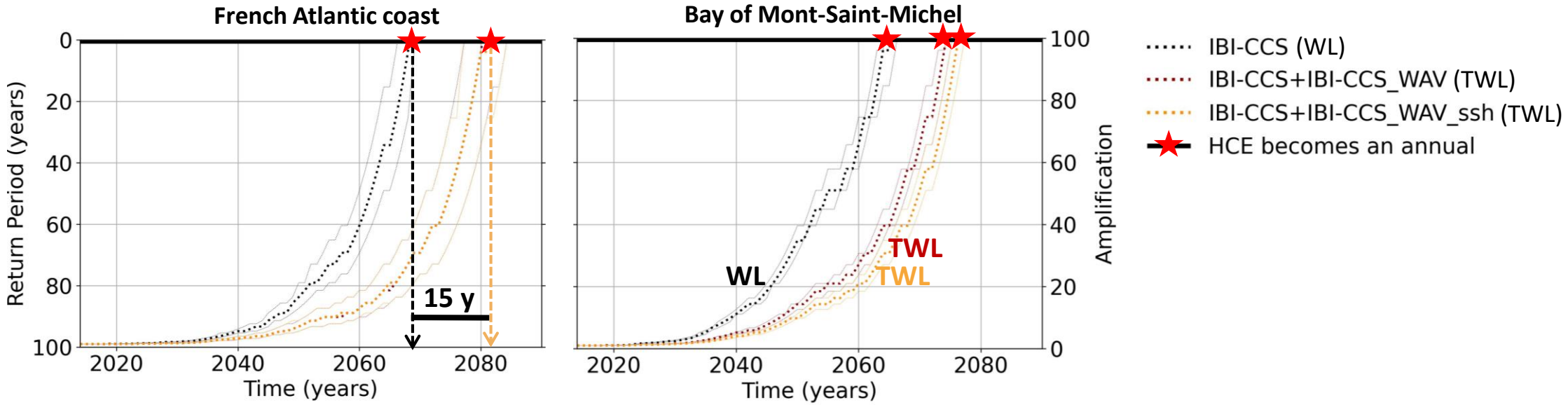
RESULTS : AMPLIFICATION OF THE HISTORICAL CENTENNIAL EVENT (HCE)

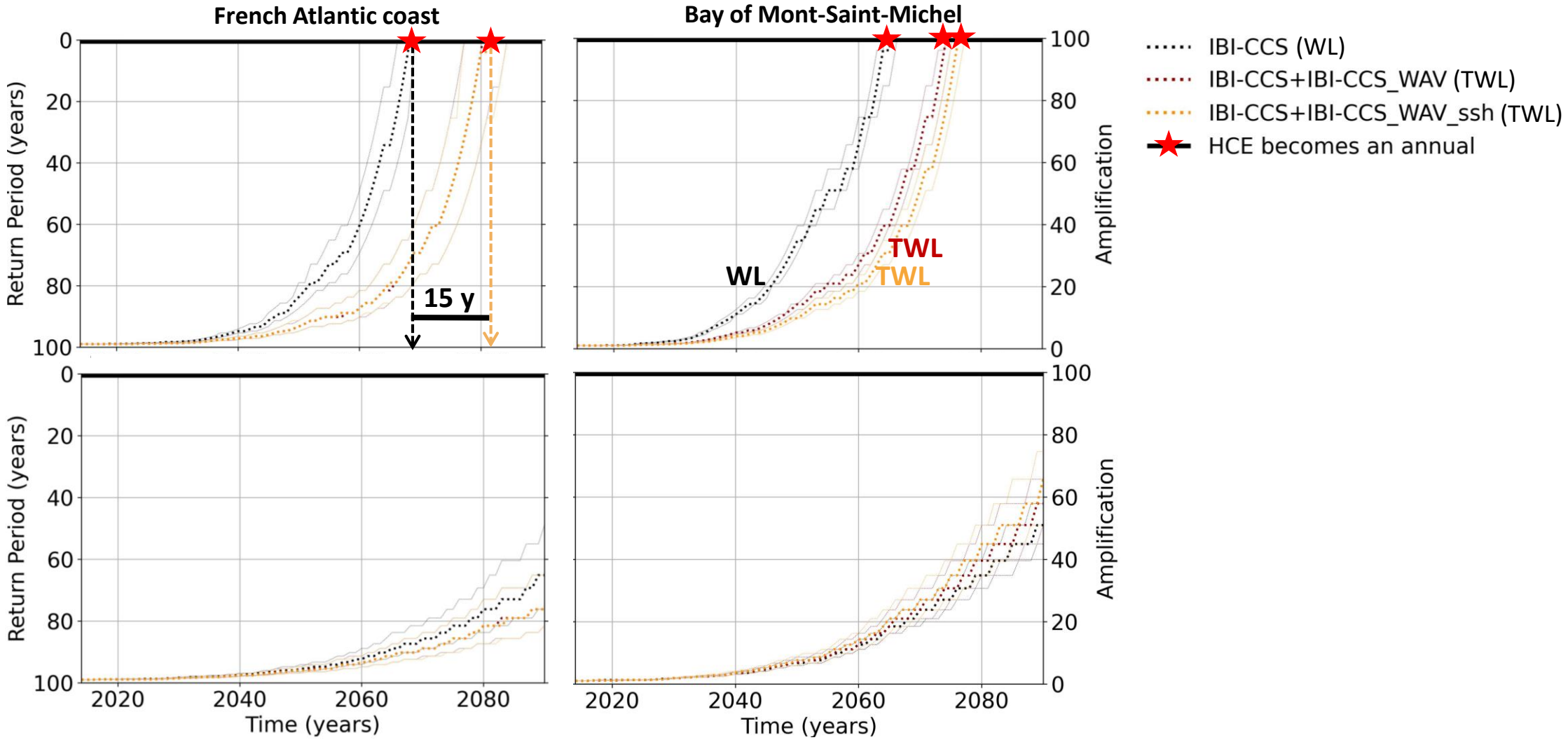
SSP5-8.5



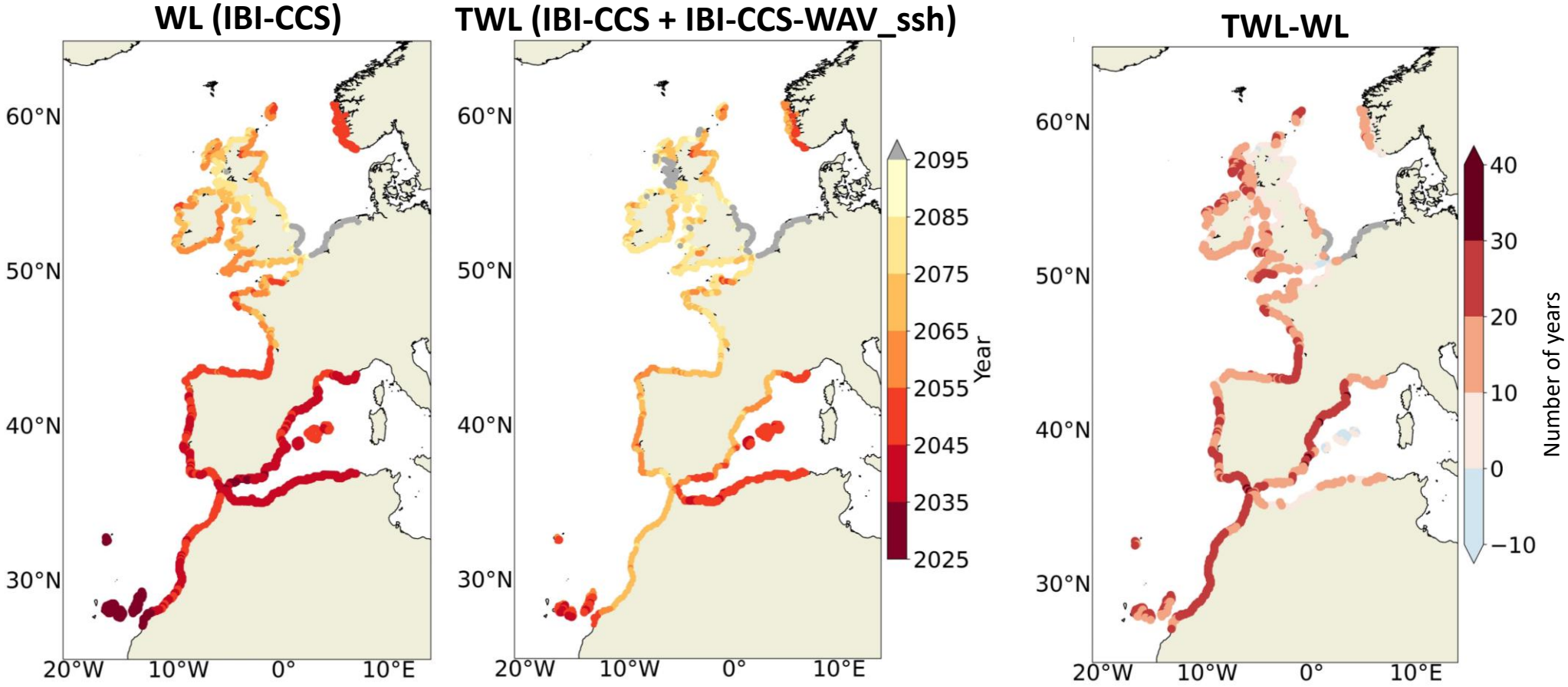
RESULTS : AMPLIFICATION OF THE HISTORICAL CENTENNIAL EVENT (HCE)

SSP5-8.5

SSP1-2.6



RESULTS : YEAR IN WHICH THE HISTORICAL CENTENNIAL EVENT (HCE) OCCURS ONCE A YEAR (SSP5-8.5)



● : Locations where HCEs recur annually after 2095

CONCLUSIONS & LIMITATIONS

Conclusions:

(1) Nonlinear waves-sea level interactions are **large for significant wave height** but are **small for wave setup**
(2) Wave setup contribution to ESLs is **large over the northeastern Atlantic region**

Limitations of the study :

- Ocean modeling *(Chaigneau et al., 2022a)*
  - dry areas not allowed
  - GRD (gravitation, rotation, and deformation) effects : regional fingerprint not included
  - Impact waves → sea level not considered

- Wave contribution *(Chaigneau et al., 2022b in prep)*
  - Swash (wave oscillations) not accounted for
  - Parameterization for wave setup (Stockdon 2006)
  - 1/10° horizontal resolution limits the nonlinear interactions

Thank you!

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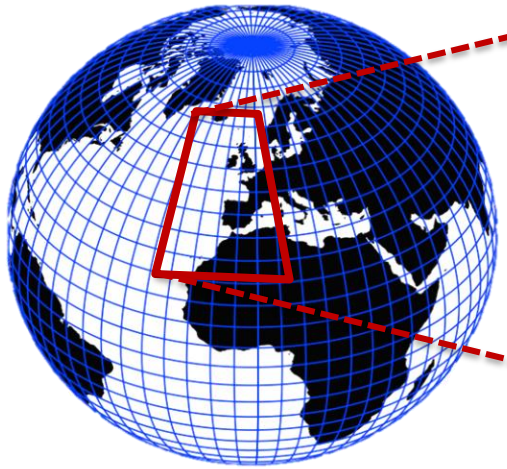
ADDITIONAL SLIDES

METHODOLOGY

DYNAMICAL DOWNSCALING :

Global climate model (GCM) :
CNRM-CM6-1-HR

Ocean component (1/4° - 75lev)
Atmospheric component (1/2°)

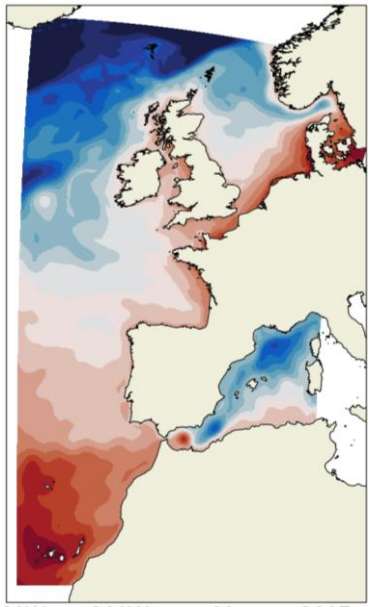


Forcing at lateral & air-sea boundaries

with bias corrections

Regional ocean model (RCM) :
IBI-CCS

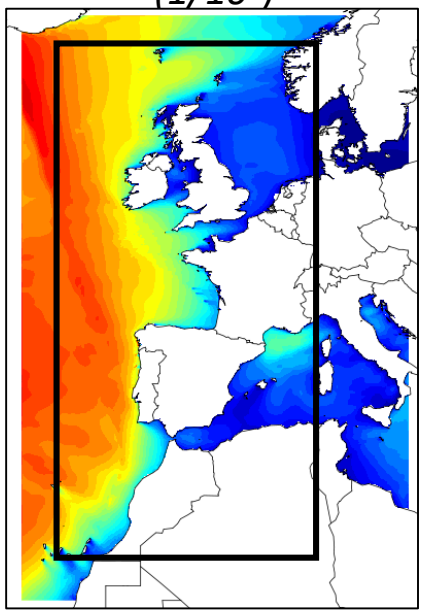
(1/12° - 75 lev)



Sea level & currents hourly forcing

Regional wave model :
IBI-CCS-WAV

(1/10°)



<u>Expertise</u> :
Aurore Voldoire (CNRM)

<u>Expertise</u> :
Guillaume Reffray (Mercator Ocean)

<u>Expertise :</u>
Stéphane Law Chune (Mercator Ocean)
Lotfi Aouf (Météo-France)

METHODOLOGY

DYNAMICAL DOWNSCALING :

Global climate model (GCM) :
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Ocean component (1/4° - 75lev)
Atmospheric component (1/2°)

Mean Sea Level

Forcing at lateral & air-sea boundaries
with bias corrections

Regional ocean model (RCM) :
IBI-CCS

(1/12° - 75 lev)

Water Level (WL) :

- ***Mean Sea Level***
- ***Tides***
- ***Atmospheric pressure forcing***
- ***Ocean circulation***

Sea level & currents hourly forcing

Regional wave model :
IBI-CCS-WAV

Wave setup

$= 0.35\beta\sqrt{H_s L_p}$

(Stockdon 2006)

+

= Total water level (TWL)

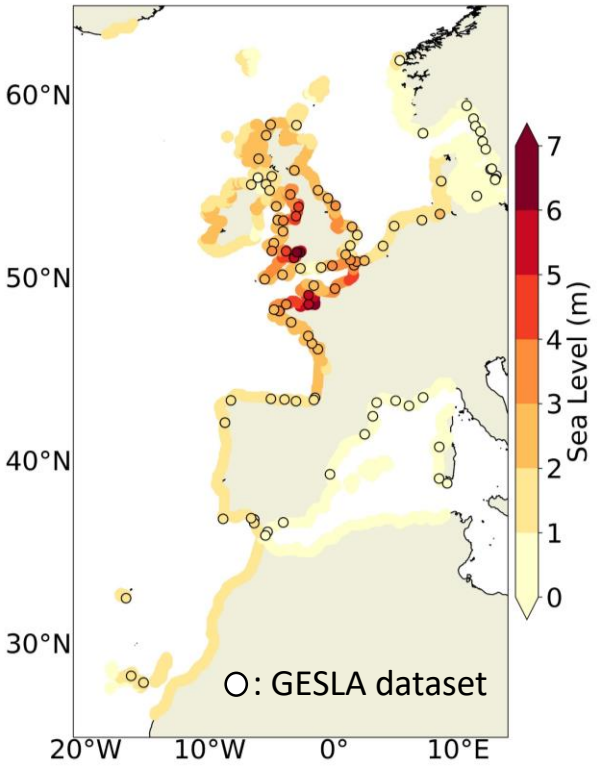
3 simulations : 1970-2100, SSP5-8.5 and SSP1-2.6 scenarios

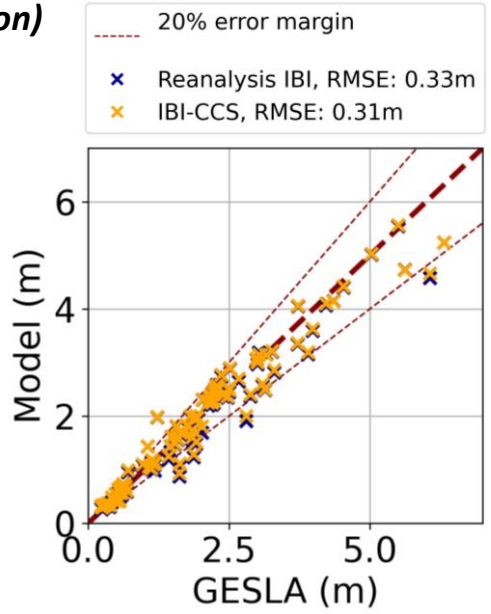
1) **WL: IBI-CCS**
2) **TWL1: IBI-CCS + IBI-CCS_WAV** (without sea level forcing)
3) **TWL2: IBI-CCS + IBI-CCS_WAV_ssh** (with hourly sea level forcing)

RESULTS : VALIDATION OF THE 99^{th} PERCENTILE (1993-2014)

IBI-CCS

Water Level (***Mean Sea Level, tides, atmospheric pressure forcing, ocean circulation***)

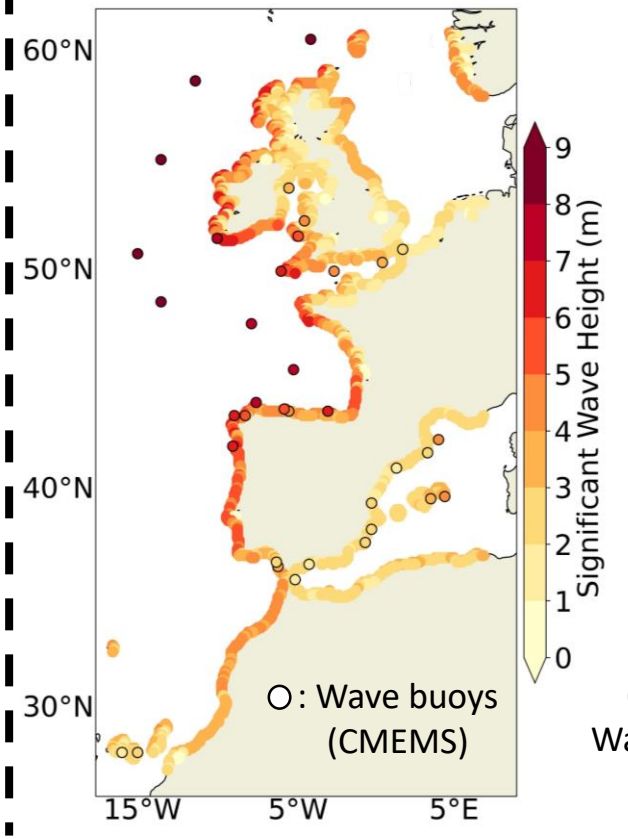


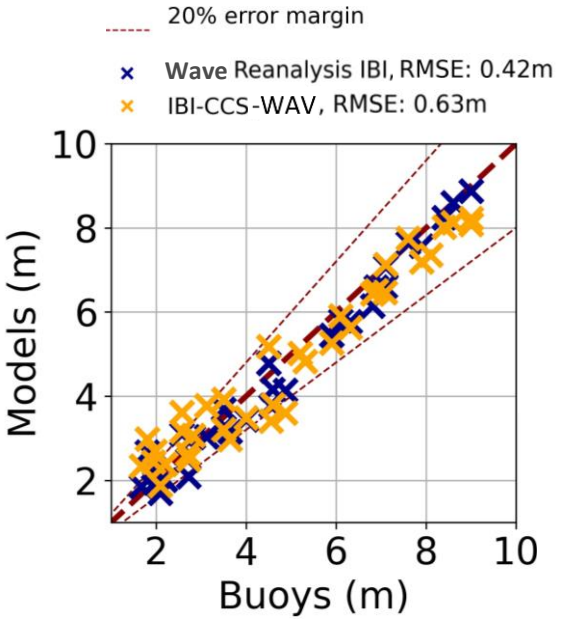


GESLA dataset : high-frequency tide gauge records *(Woodworth et al., 2017)*
Reanalysis IBI : model from CMEMS *(Levier et al., 2020)*

IBI-CCS-WAV

Significant wave height





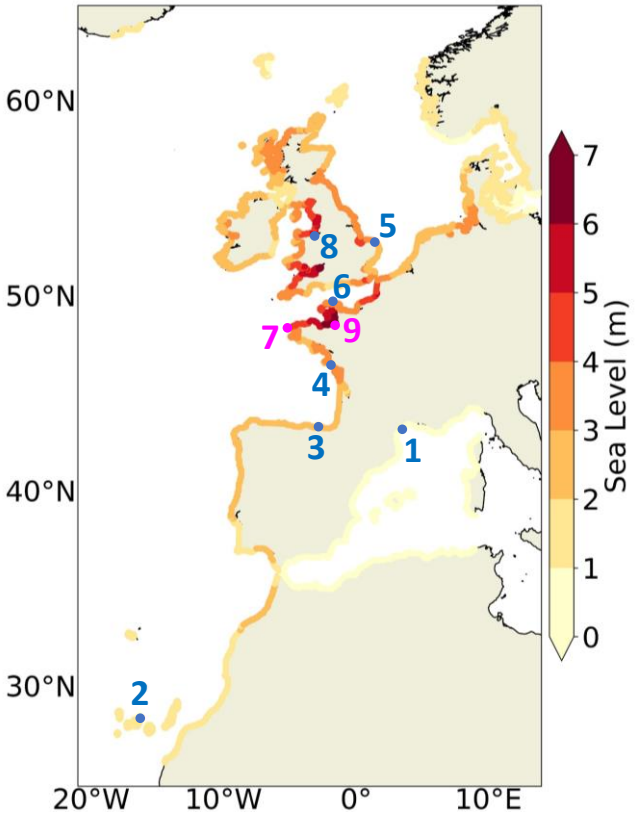
Wave buoys (https://marine.copernicus.eu/fr) and Wave Reanalysis IBI *(Toledano et al., 2021)* from CMEMS

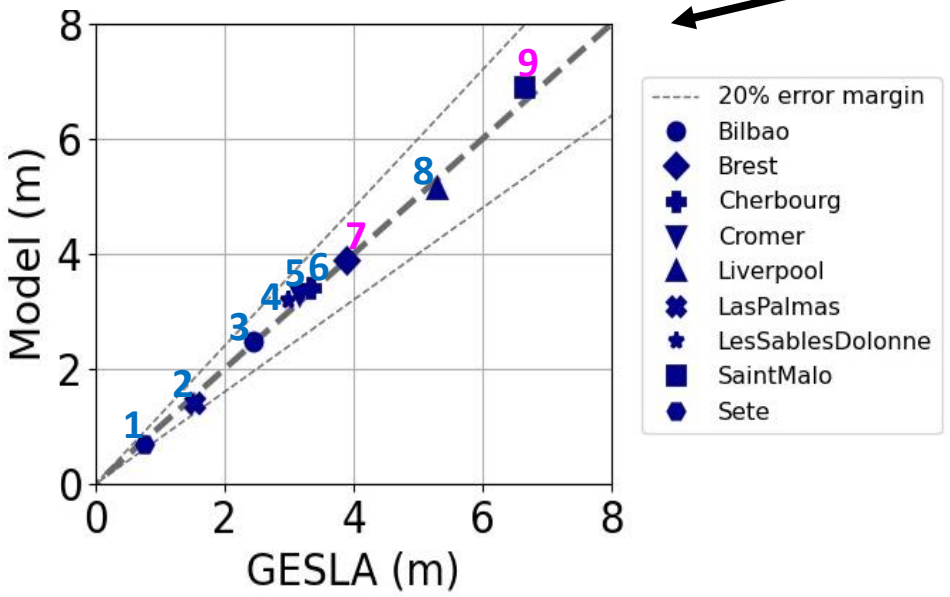
Validation of non-tidal residuals in *Chaigneau et al., 2022 (GMD)*

RESULTS : VALIDATION OF HISTORICAL 10-YEAR RETURN LEVEL (1985-2014)

IBI-CCS

Water Level (***Mean Sea Level, tides, atmospheric pressure forcing, ocean circulation***)





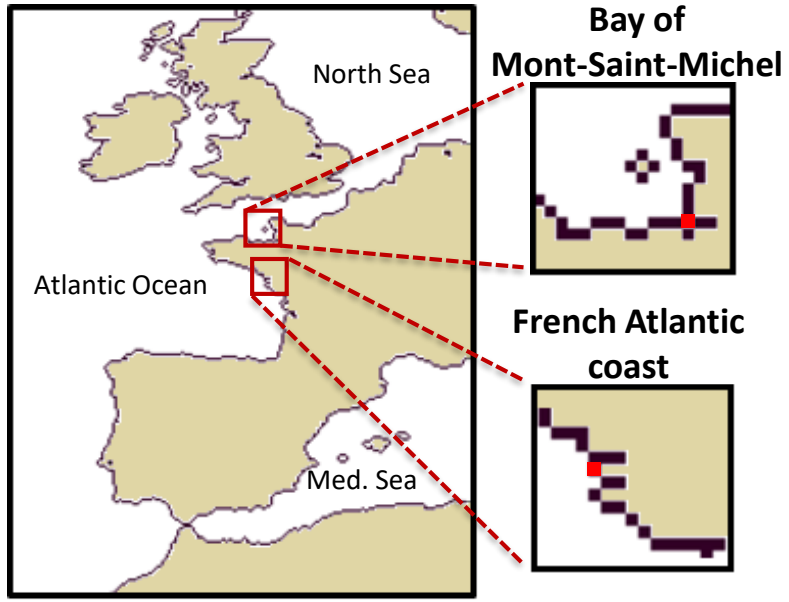
GESLA dataset : high-frequency tide gauge records *(Woodworth et al., 2017)*

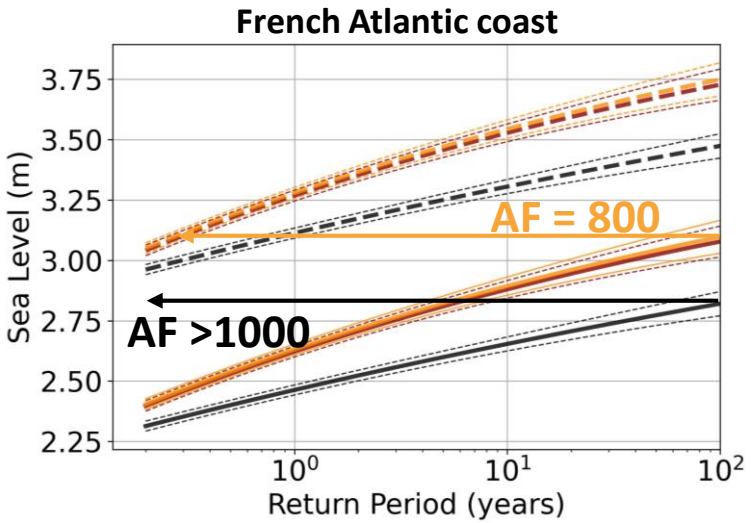
Extreme value analysis :

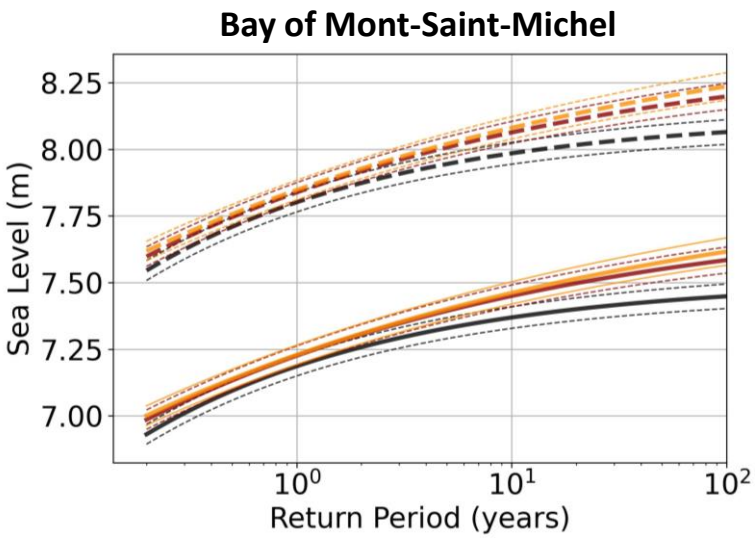
- **Univariate non-stationary approach**
- **131 year period**
- **Declustering time of 3 days between events**
- **Peak over threshold: 3 events/year**
- **GPD (Generalized Pareto Distribution)**

based on Mentaschi et al., 2016

RESULTS : PROJECTIONS OF ESLs (SSP5-8.5) RETURN LEVELS (1985-2014 & 2071-2100)





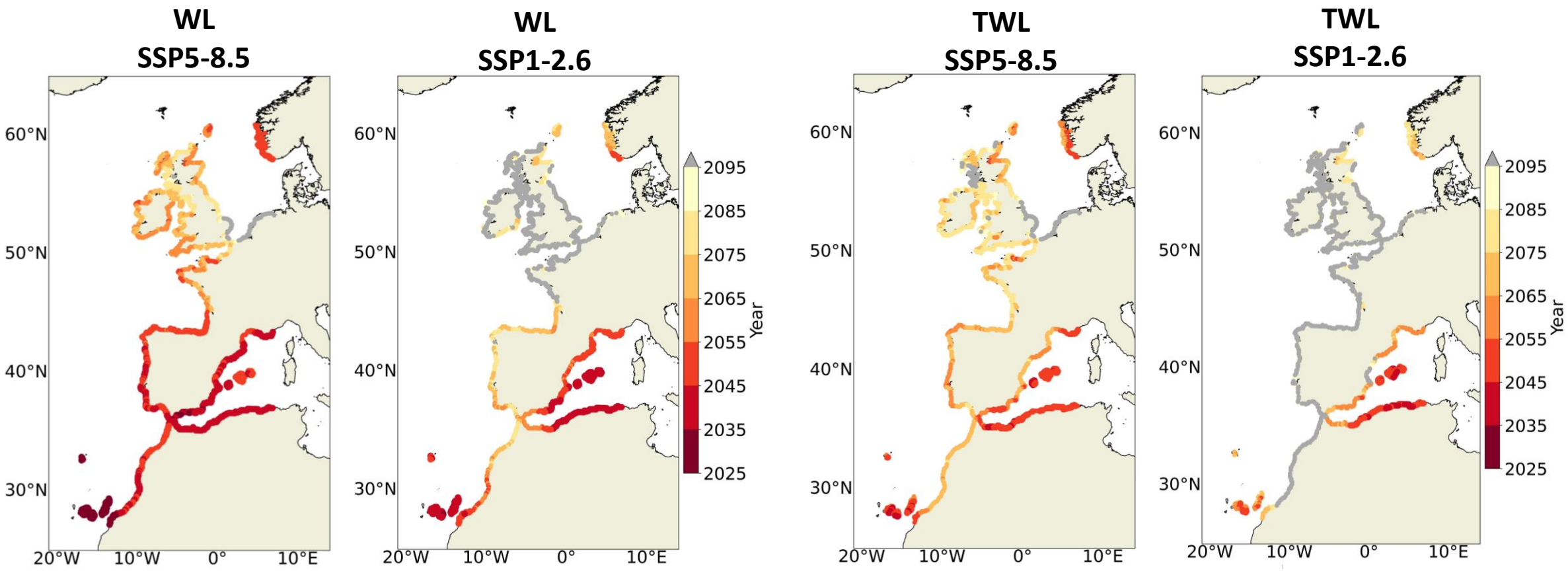


- IBI-CCS (WL)
- IBI-CCS+IBI-CCS-WAV (TWL)
- IBI-CCS+IBI-CCS-WAV_ssh (TWL)
- IBI-CCS, ssp585
- IBI-CCS+IBI-CCS-WAV, ssp585
- IBI-CCS+IBI-CCS_WAV_ssh, ssp585

Future frequency of the historical 100-year event (Amplification Factor = AF)

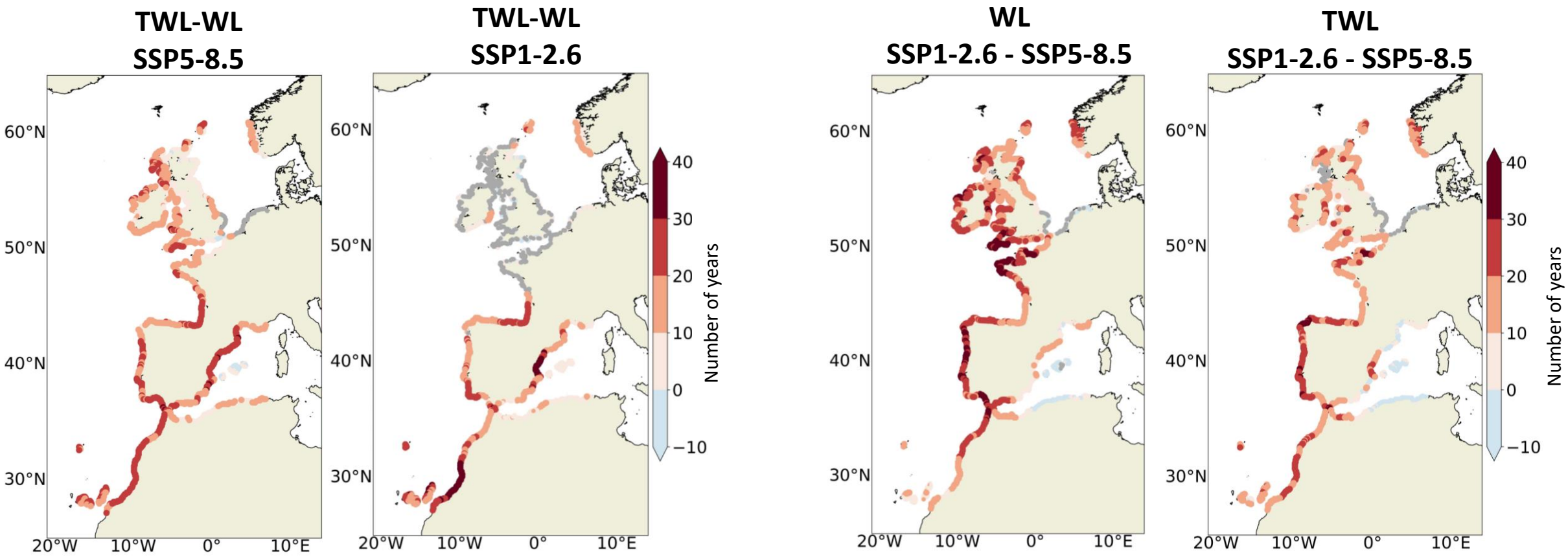
- AFs are reduced in wave dominated areas as the curves have a larger slope (as shown in Lambert et al., 2020)

RESULTS : YEAR IN WHICH THE HISTORICAL CENTENNIAL EVENT (HCE) OCCURS ONCE A YEAR



● : Locations where HCEs recur annually after 2095

RESULTS : YEAR IN WHICH THE HISTORICAL CENTENNIAL EVENT (HCE) OCCURS ONCE A YEAR



● : Locations where HCEs recur annually after 2095