Projected 21st Century changes in extreme wind-wave events

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Background

Design Sea State:

Typically defined as the maximum significant wave height which can be expected over an N year period.

Collaroy (NSW) 2016 storm

(Hinkel et al., 2014)

In 2010, **290 million** people worldwide lived **below the 100-year flood level** and *US$9600 billion* of assets were exposed to inundation

1 in **100 years** significant wave height

Extreme Value Analysis (EVA)

The missing piece

Extreme wind-waves

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Past uncertainties:

- Wave model
- Atmospheric model
- Observations
- Statistical

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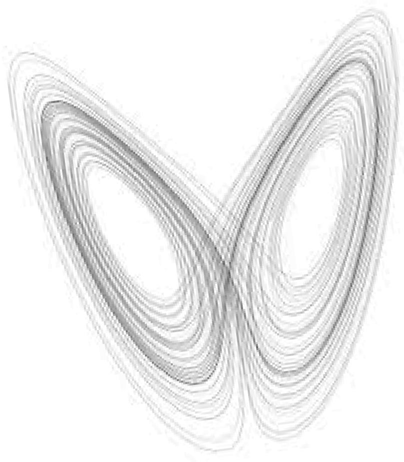
Future uncertainties:

- Emissions scenarios
- GCMs

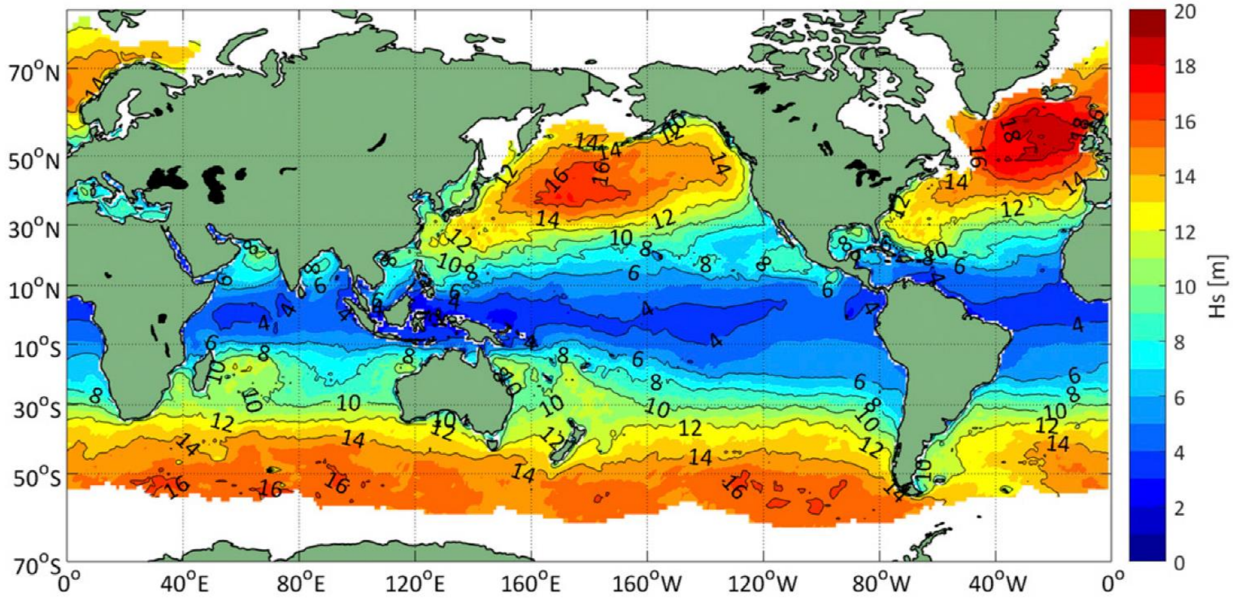
Ensemble approach to EVA

(Breivik et al., 2013, 2014; Meucci et al., 2018)

Equivalent of 750 years dataset



(Lorenz, 1965; Molteni et al., 1996)



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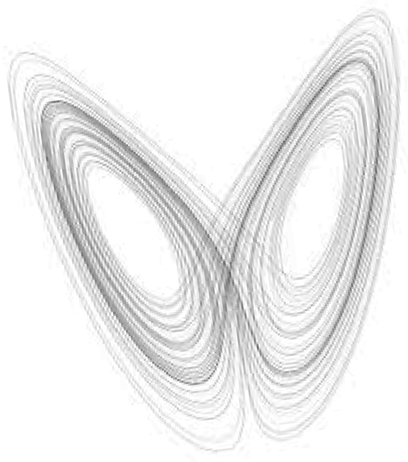

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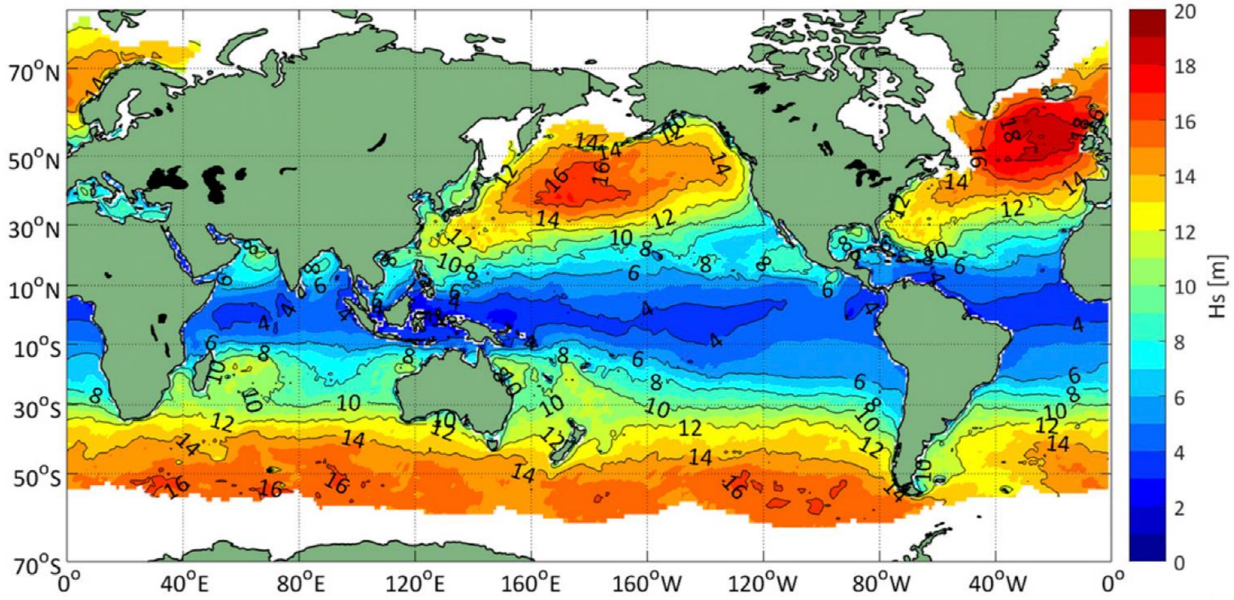
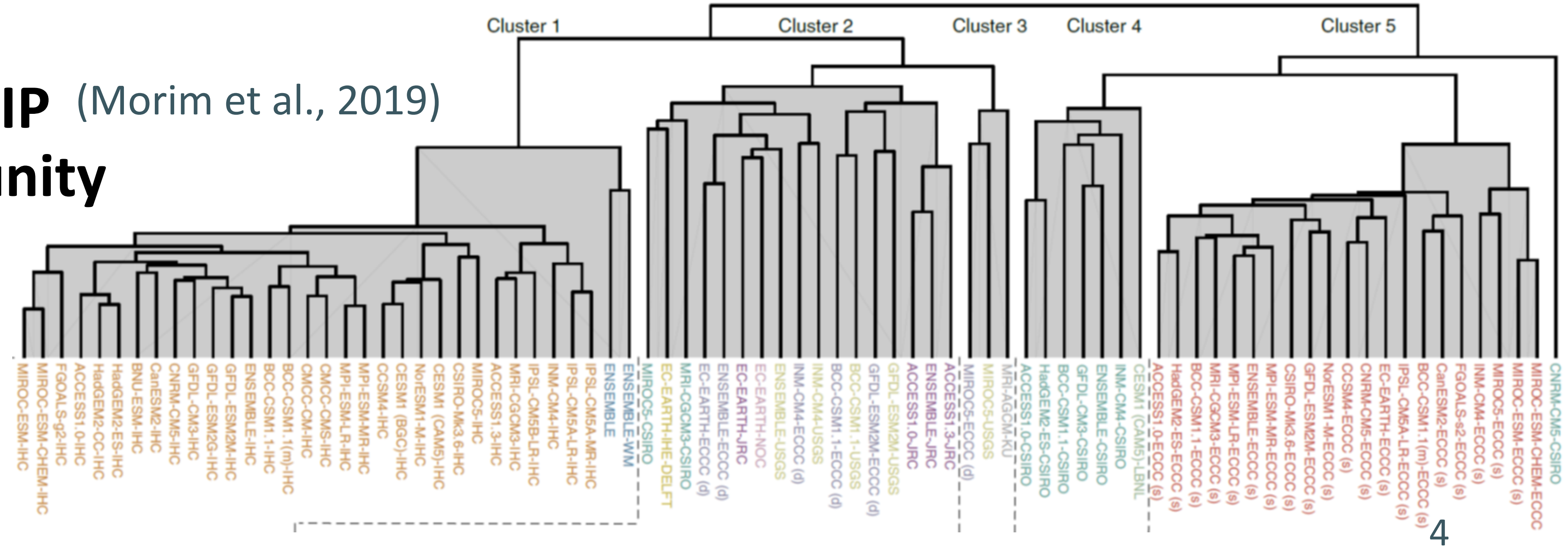


COWCLIP community (Morim et al., 2019)



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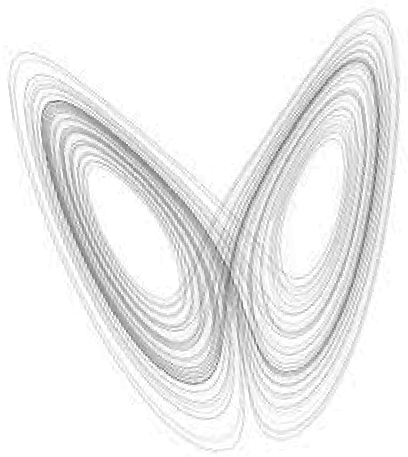

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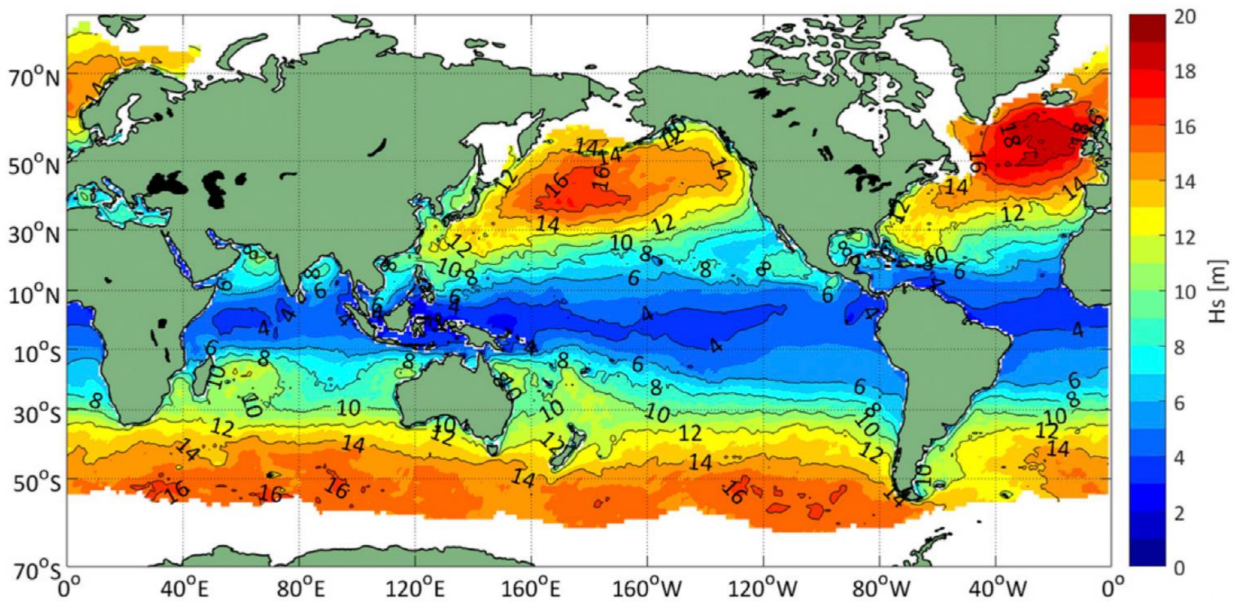

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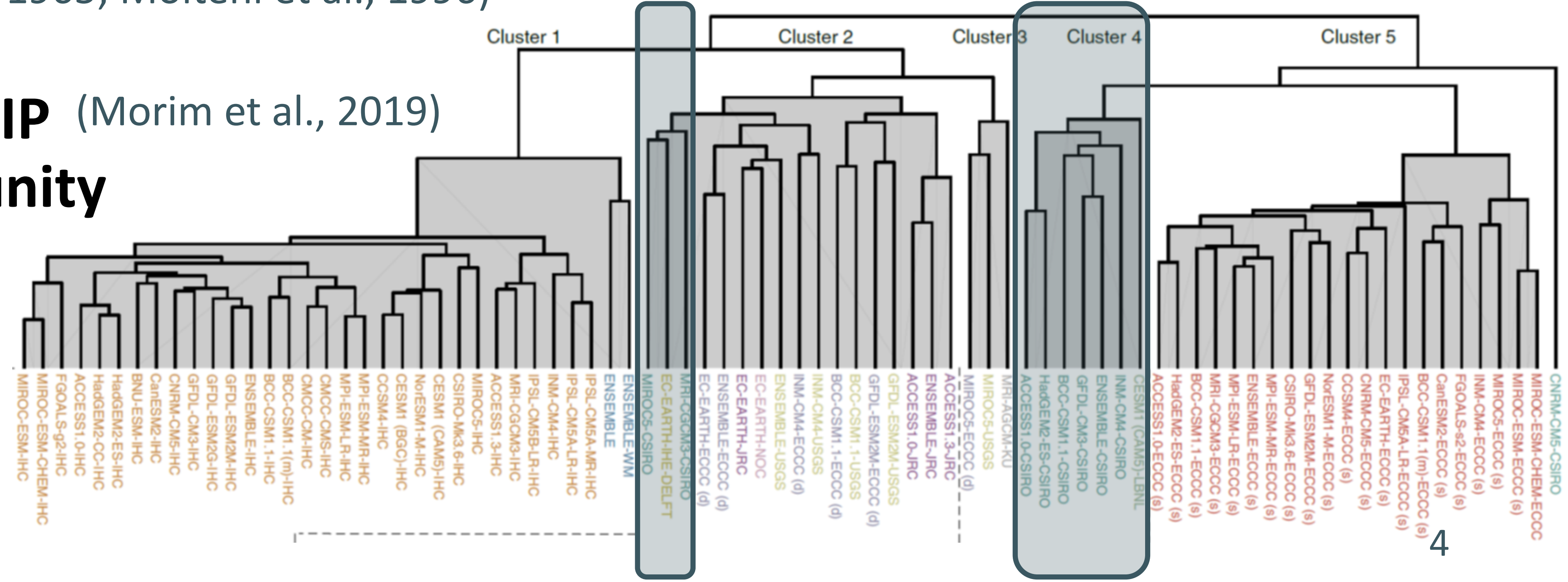

WWIII (v3.14) 6-hourly datasets forced using CMIP5 GCM surface winds

(Hemer et al., 2016)

Selection of extremes

1979-2005 | 2081-2100 RCP4.5 | 2081-2100 RCP8.5

- ACCESS1.0
- BCC-CSM1.1
- GFDL-CM3
- HadGEM2-ES
- INMCM4
- MIROC5
- MRI-CGCM3

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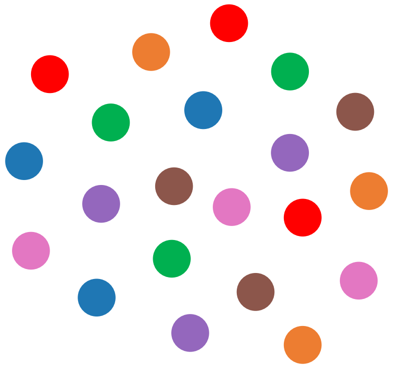
$$Z_m = \frac{H_{s,m} - \mu_m^{hist}}{\sigma_m^{hist}}$$

(Aarnes et al., 2017)

peaks over 90th percentile threshold for each model -- 48h storm independence



1000 highest peaks

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1000 highest peaks

Representative time interval

(Breivik et al., 2013, 2014)

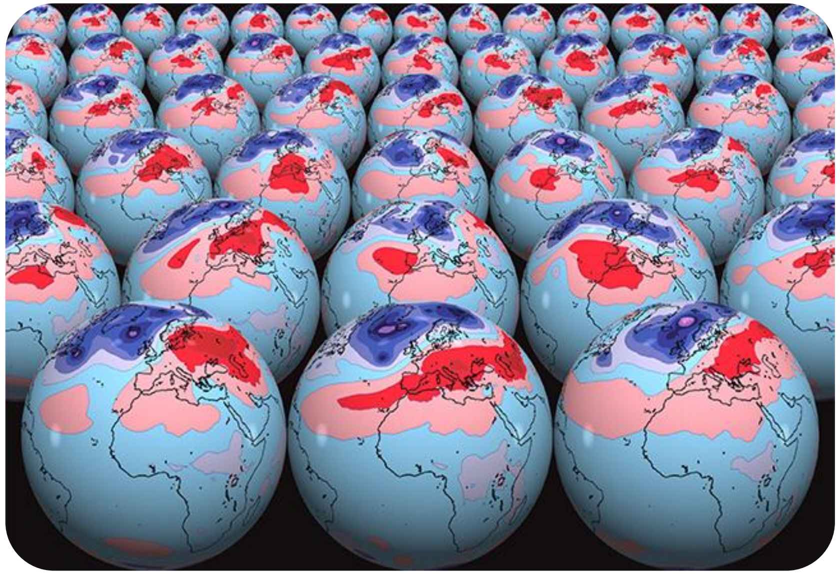
Historical dataset 1979-2005:

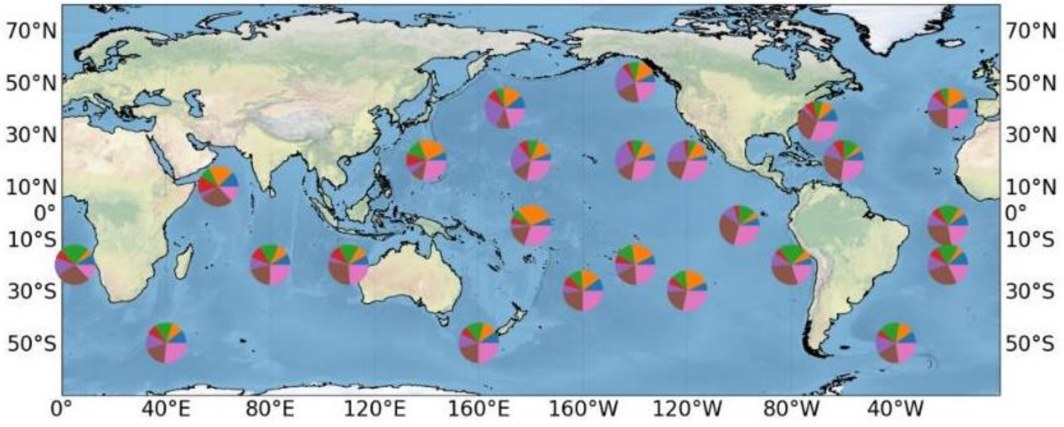
$\mathbf{T_{eq}}$ = 27 years · 365 · 4 hindcasts a day · **6h** · 7 GCMs = **189 years**

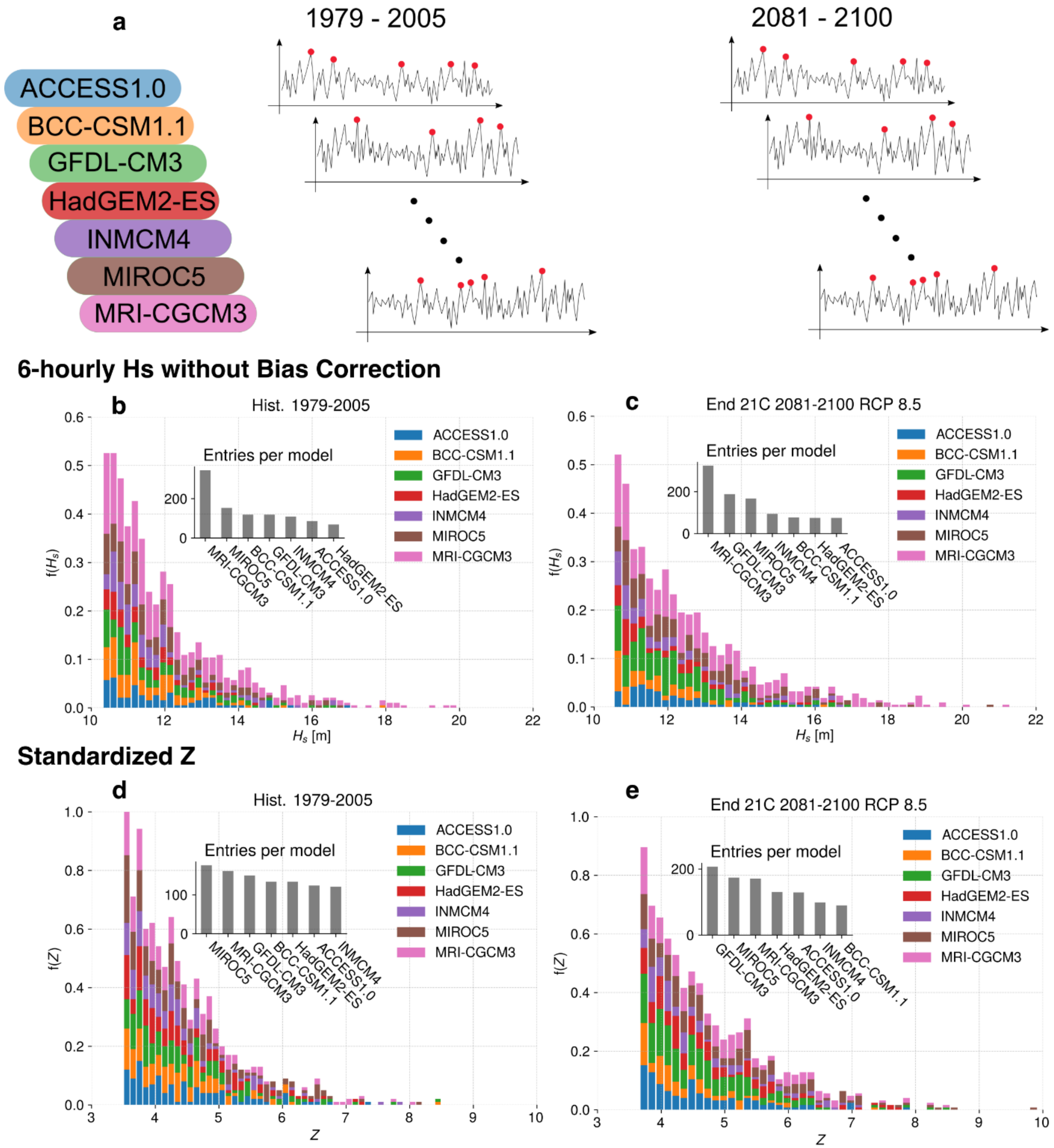
Future projection dataset 2081-2100:

$\mathbf{T_{eq}}$ = 20 years · 365 · 4 hindcasts a day · **6h** · 7 GCMs = **140 years**

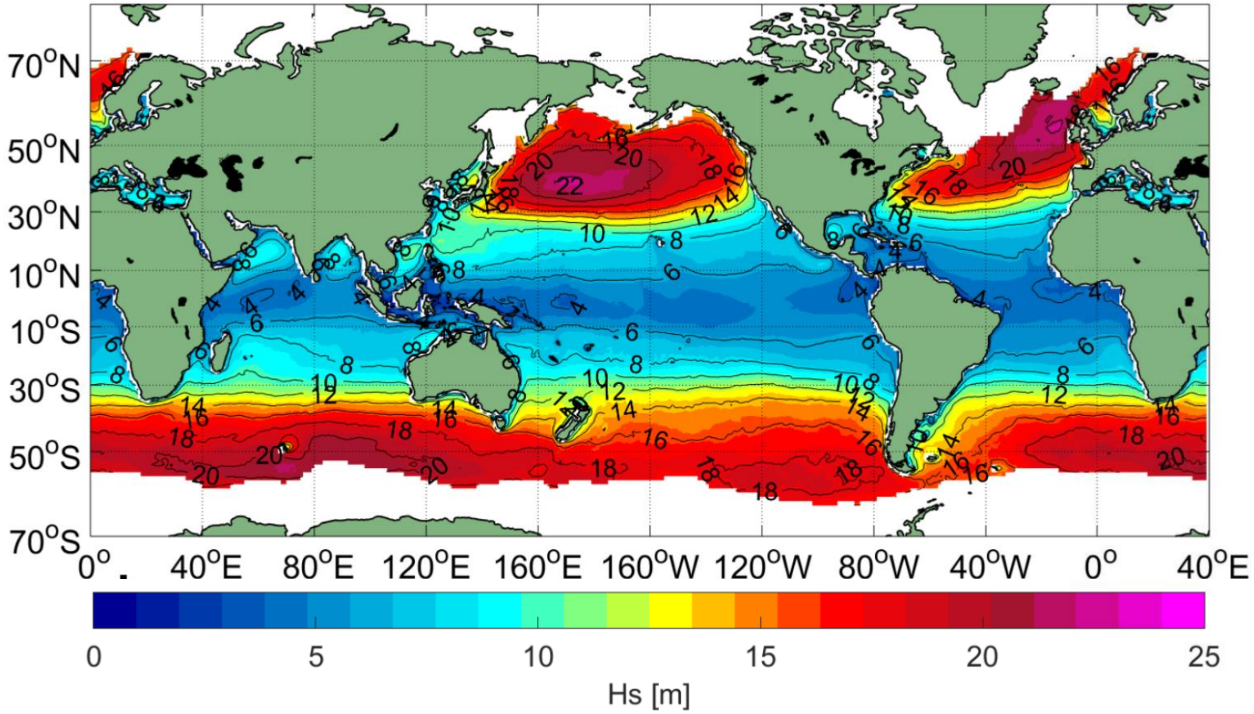
Models contribution

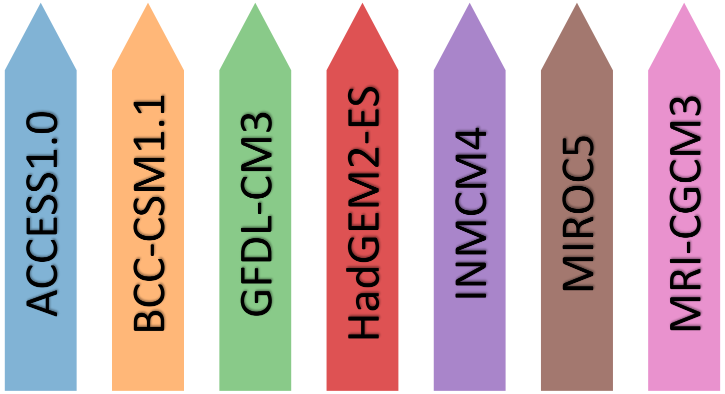






Historical dataset extreme estimates





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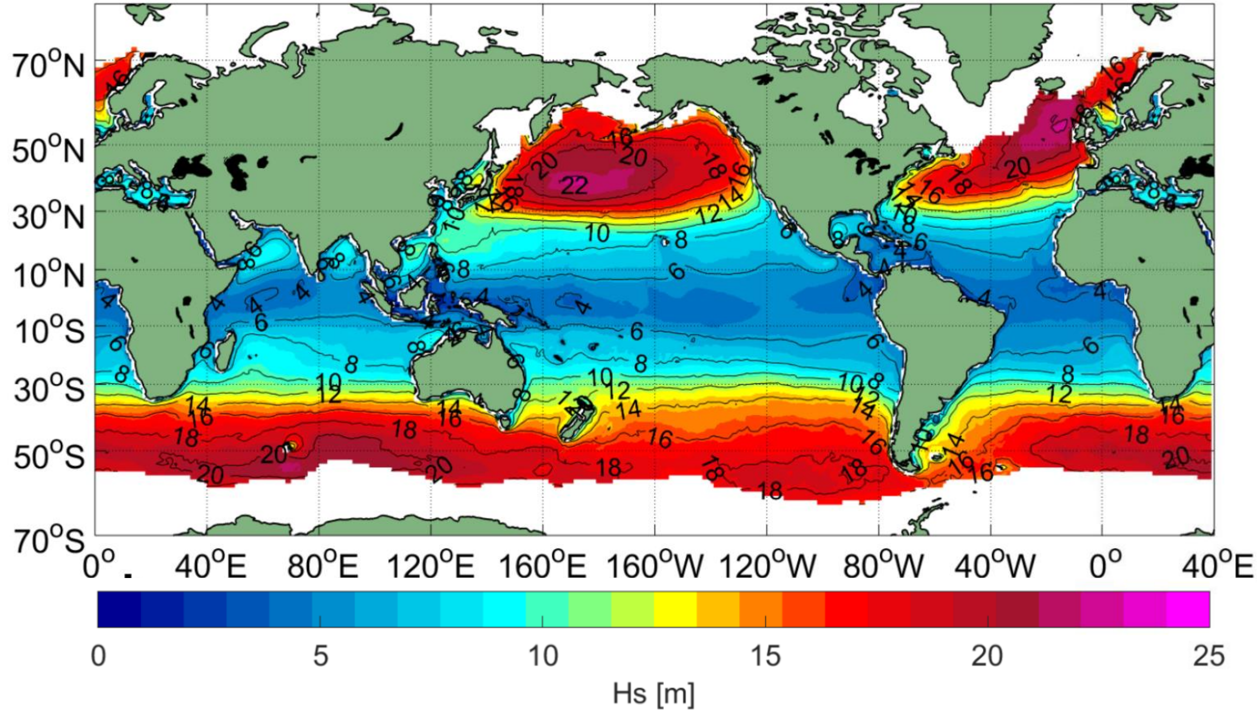

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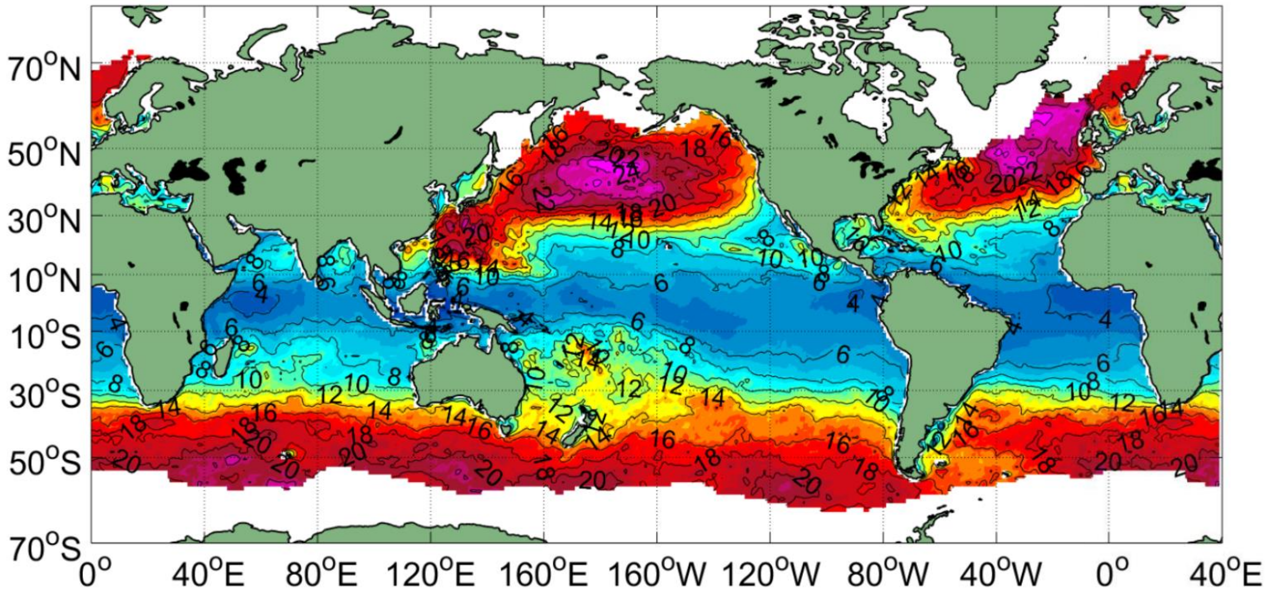
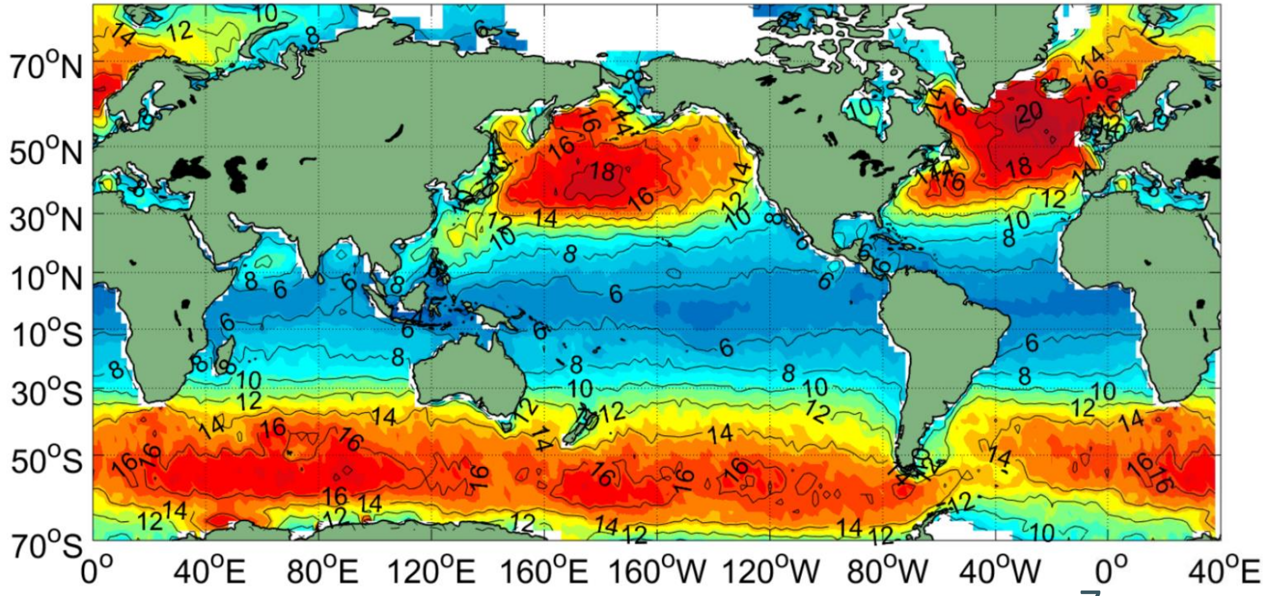
WWIII forced with CFSR winds



(Young and Ribal, 2019)

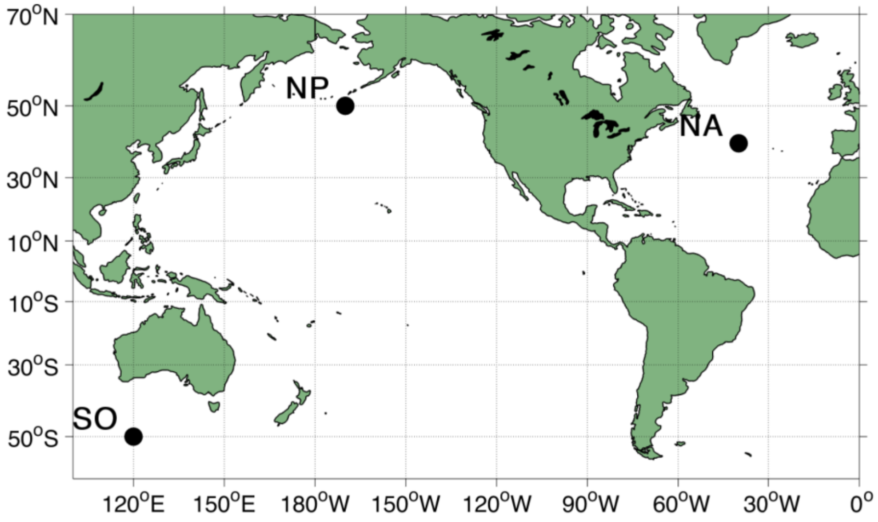
Satellite Altimeter

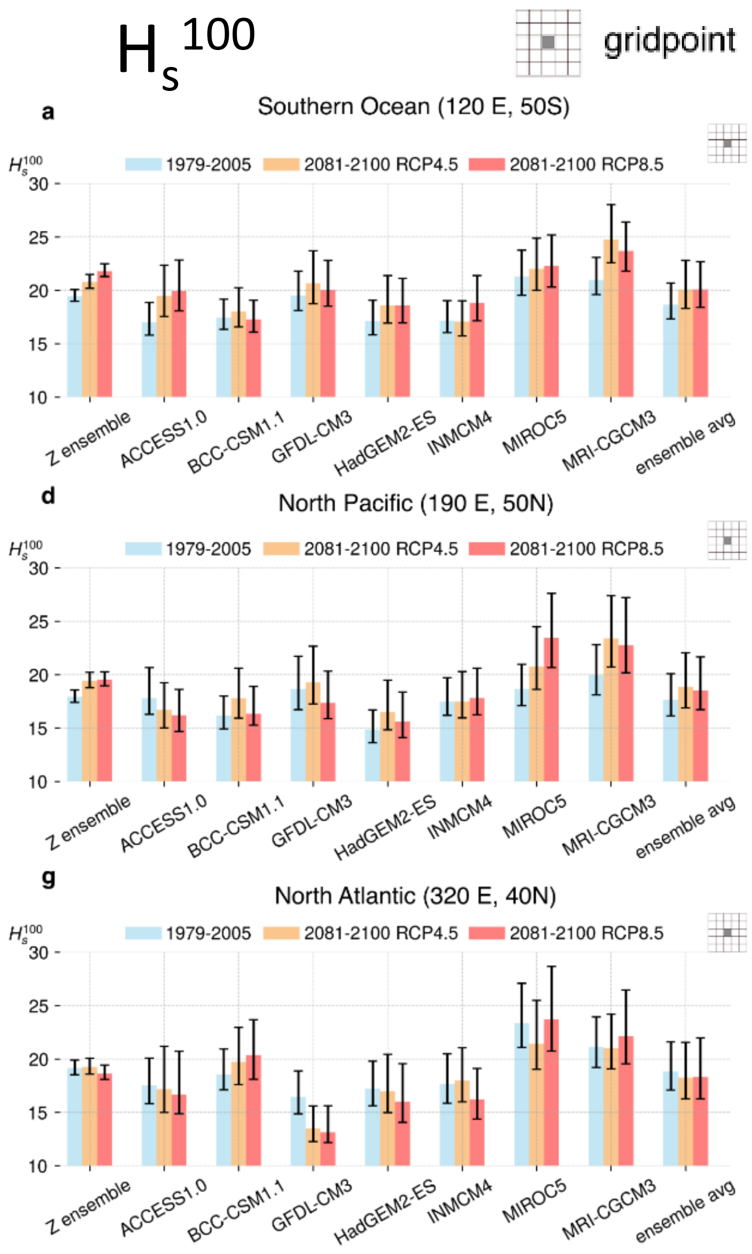


Confidence levels

<u>Bootstrap estimates</u>

on the 1000 peaks obtained from the ensemble pooling technique





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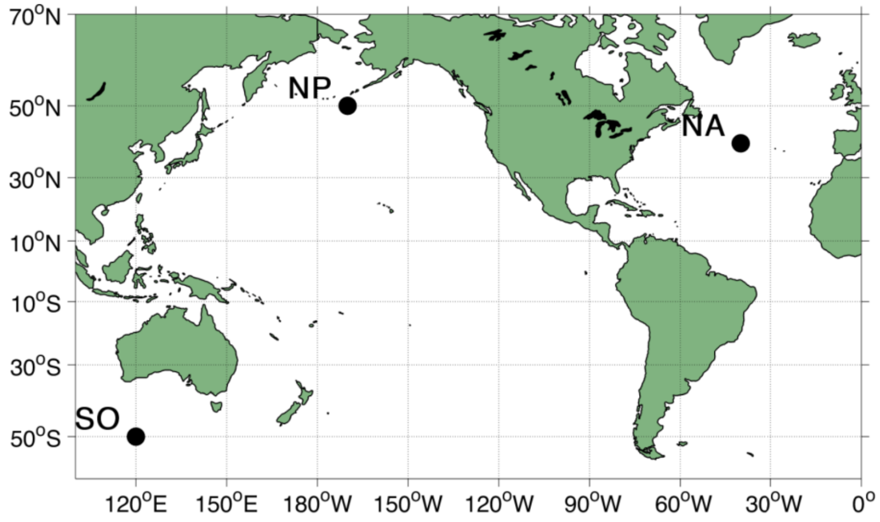
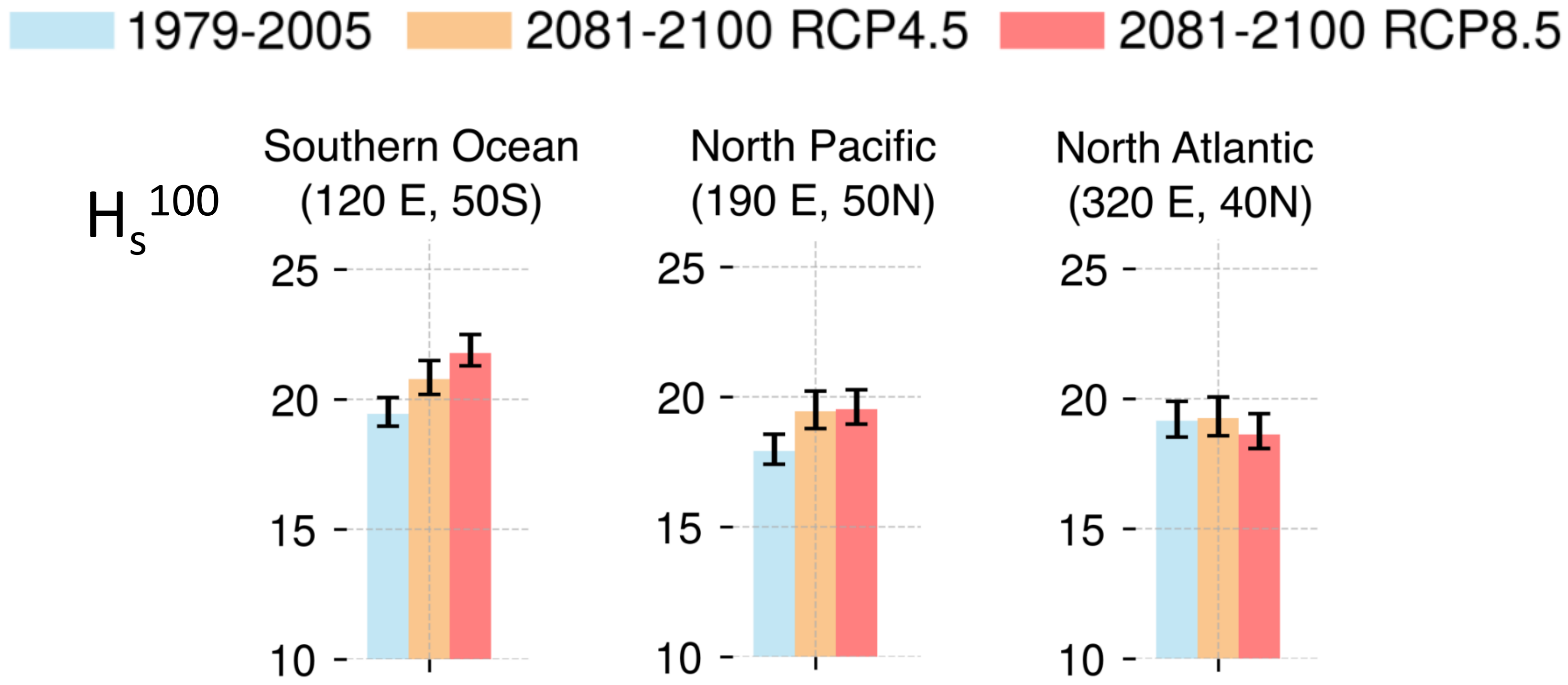
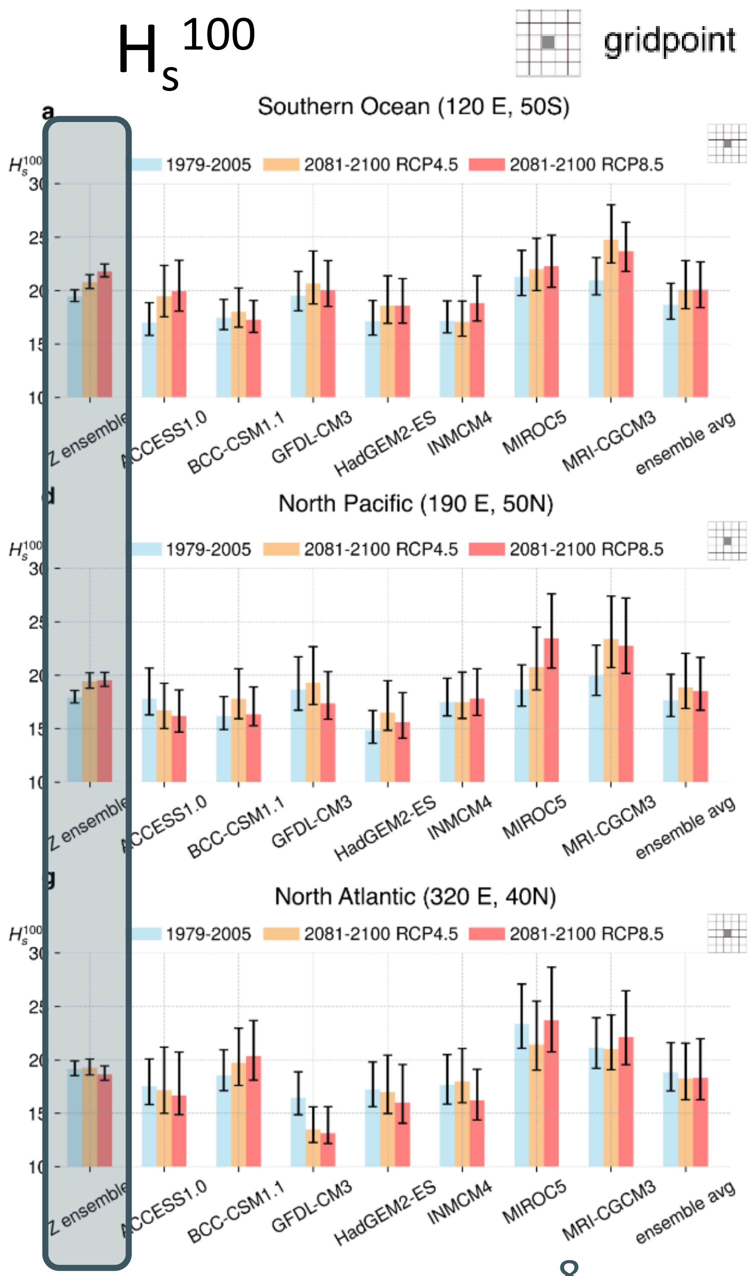


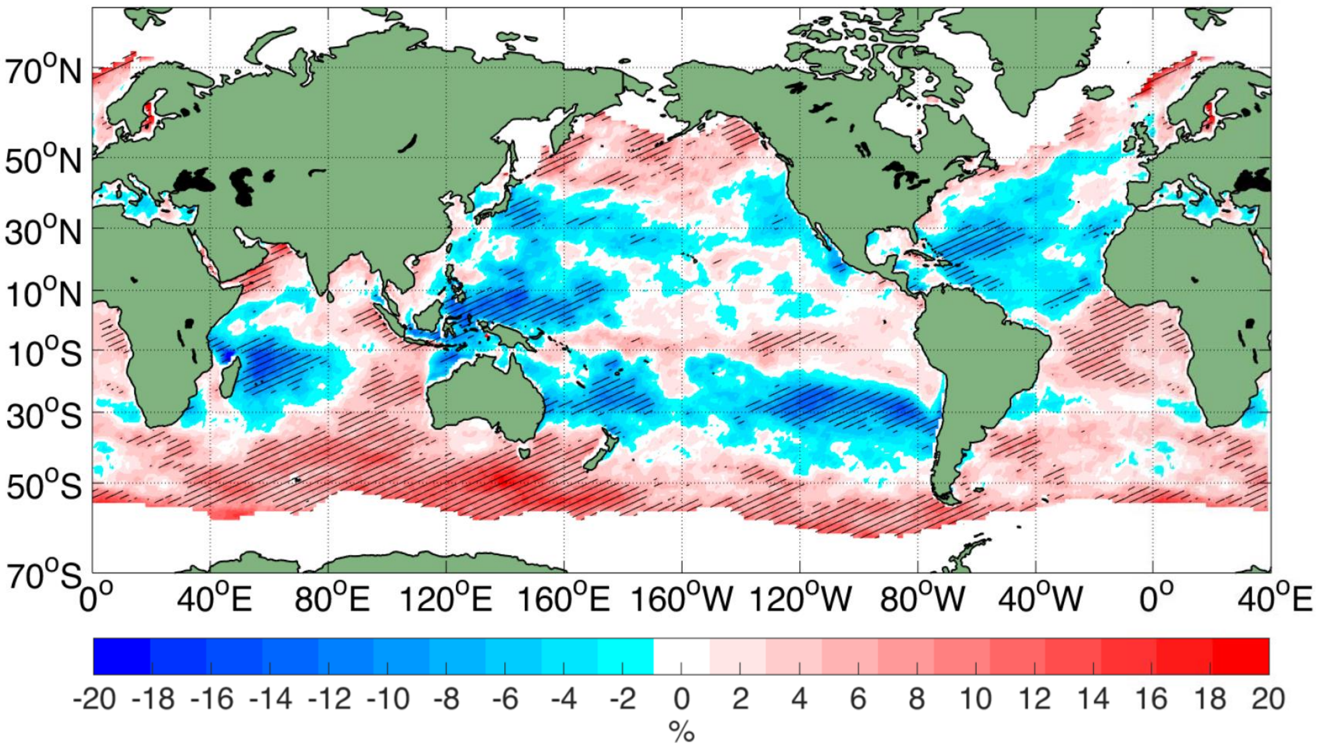




Projected changes in extreme wind-waves (H_s^{100})

2081–2100 - 1979–2005

RCP8.5



Projected changes in extreme wind-waves (H_s^{100})

2081–2100 - 1979–2005

90th perc.

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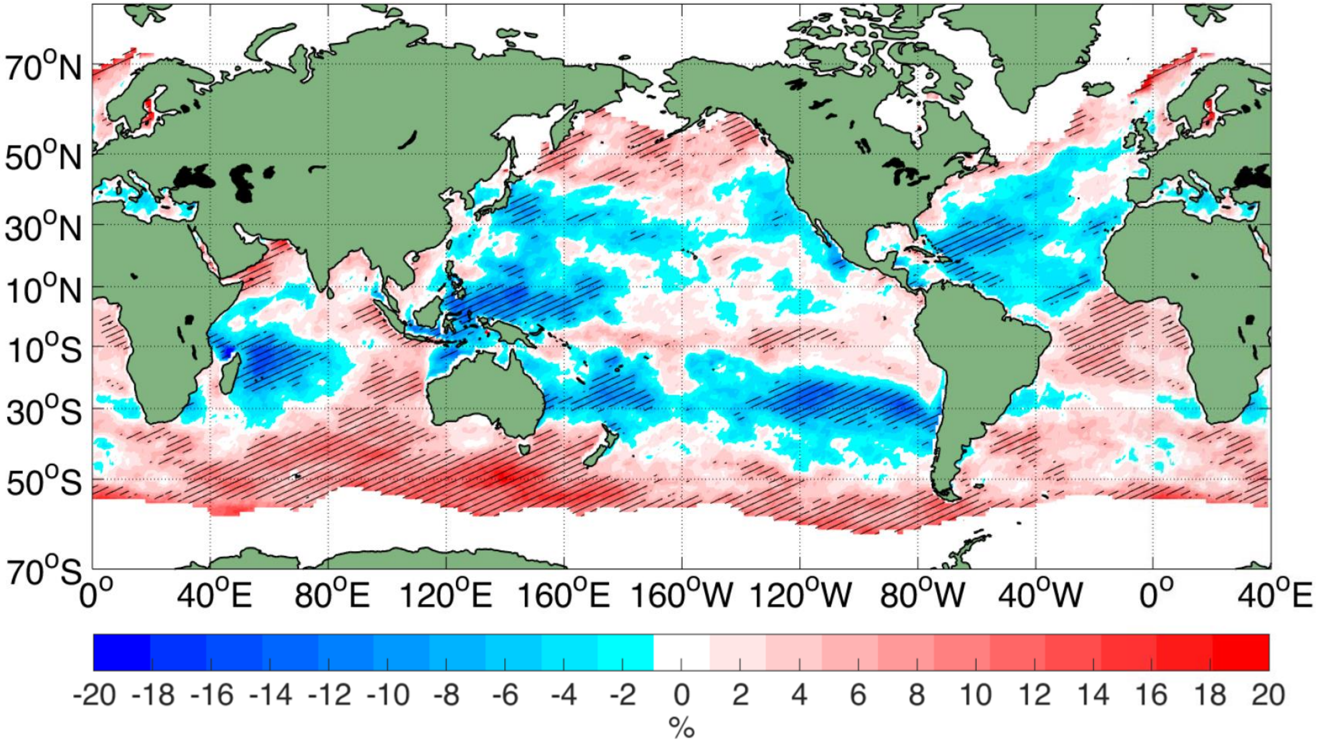
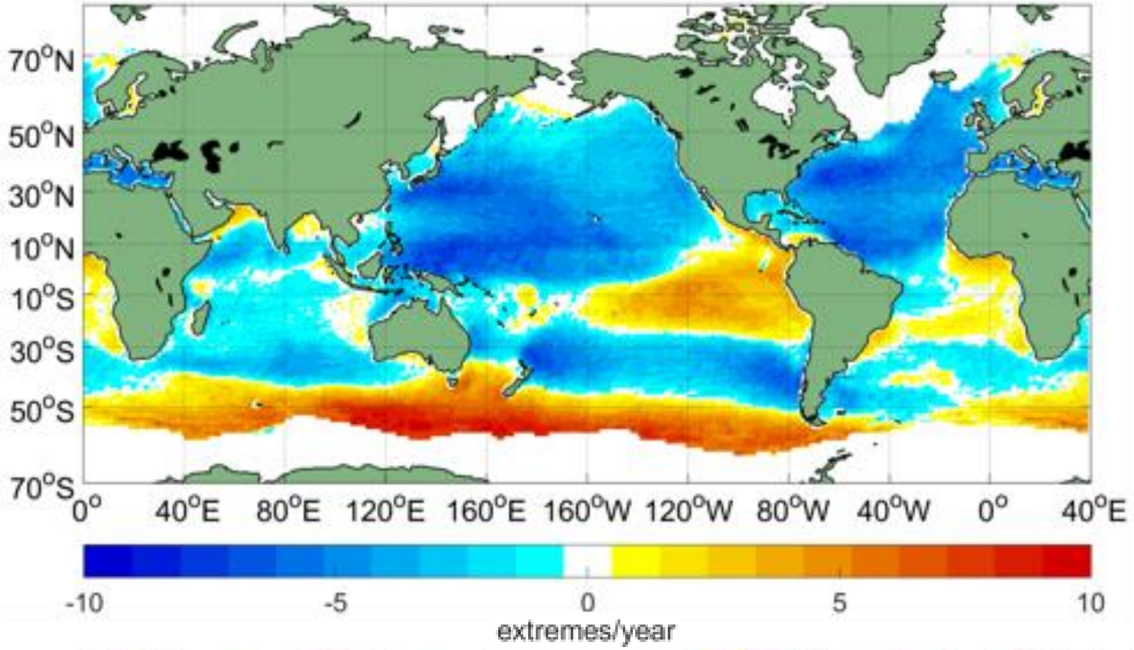
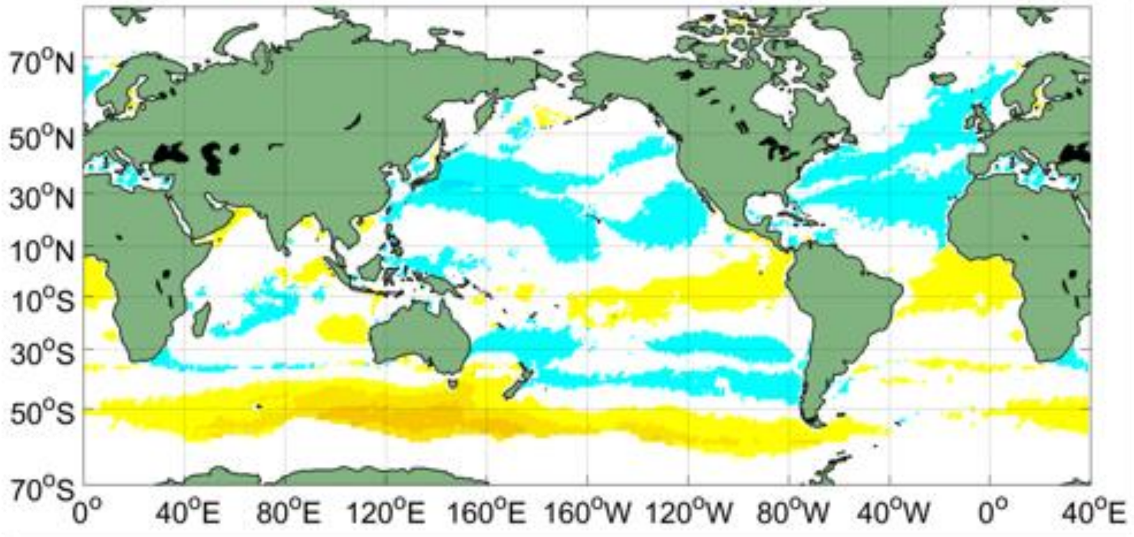


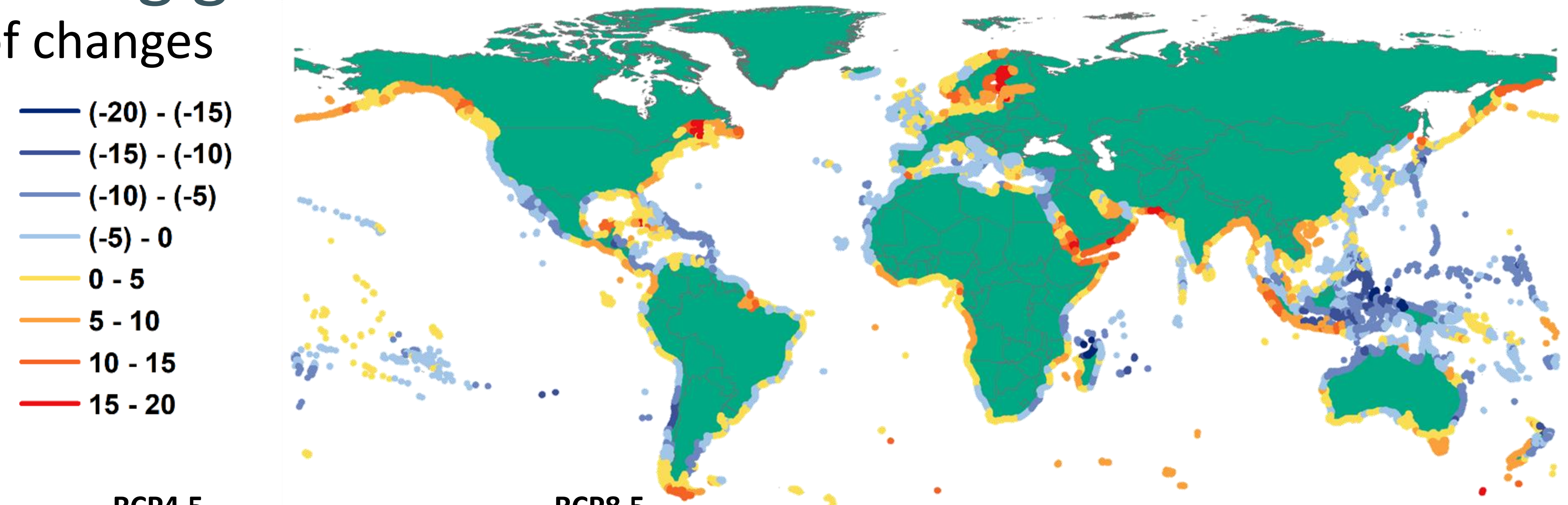




99.7th perc.

Changes along global coastlines

Percentage of changes in H_s^{100}



	RCP4.5		RCP8.5	
(% change)	Coastline length (km)	Coastline length (%)	Coastline length (km)	Coastline length (%)
-20% to -15%	9,643	0.89	7,399	0.69
-15% to -10%	13,130	1.22	25,281	2.34
-10% to -5%	69,208	6.42	120,625	11.18
-5% to 0%	277,810	25.76	285,227	26.45
0% to 5%	499,537	46.32	365,741	33.91
5% to 10%	168,420	15.62	182,163	16.89
10% to 15%	33,053	3.06	68,087	6.31
15% to 20%	7,737	0.72	24,015	2.23

DIVA dataset locations

ΔH_s^{100} at the closest offshore grid point

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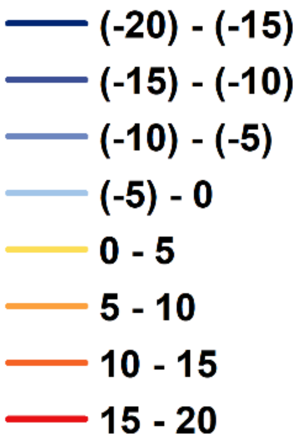

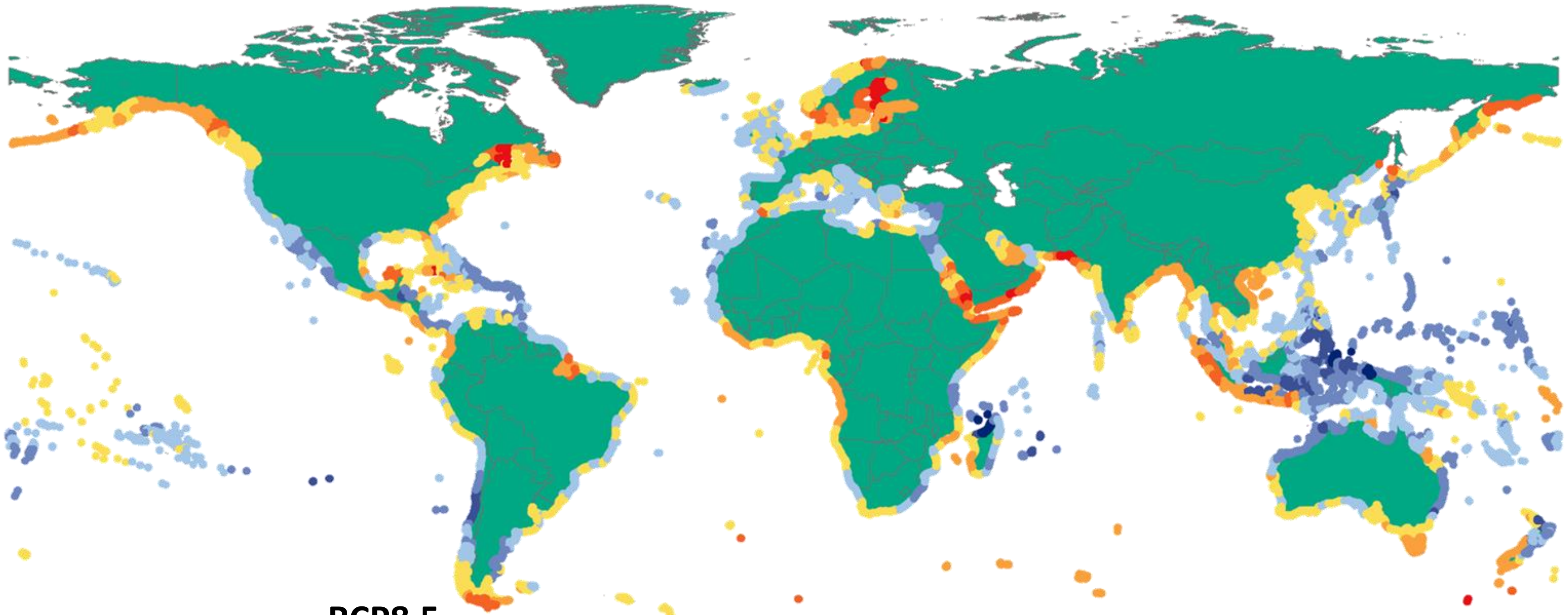

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- Results are consistent with previous studies
- Inter models low correlation guarantees independence
- Possibility to synthesize an equivalent time series of duration longer than the simulation period
- Increased dataset reduces confidence intervals

At what point are we?

- Higher resolutions are needed

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- Higher resolutions are needed
- Ensemble approach to TC areas with increasing model resolution
- Still many uncertainties are characterizing observations of extremes
- Improved GCMs and additional models may allow use of Direct Return level Estimates

References

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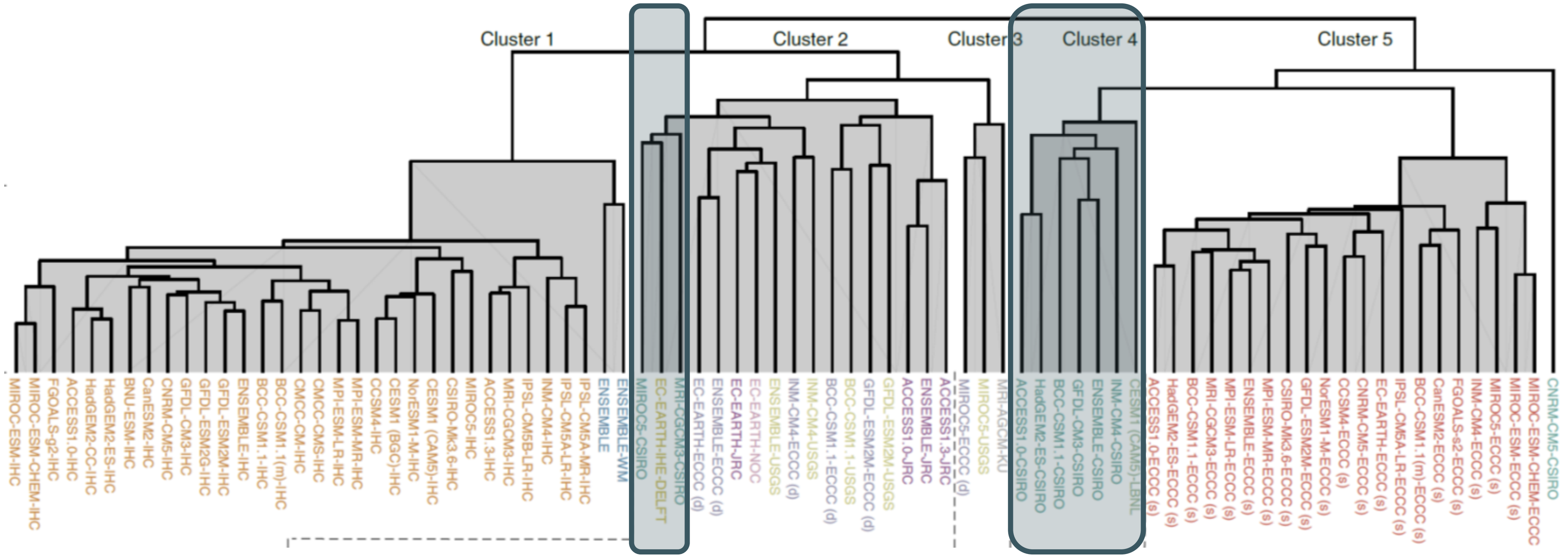
Supplementary material

Dataset

WWIII (v3.14) 6-hourly datasets forced using CMIP5 GCM surface winds

(Hemer et al., 2016)

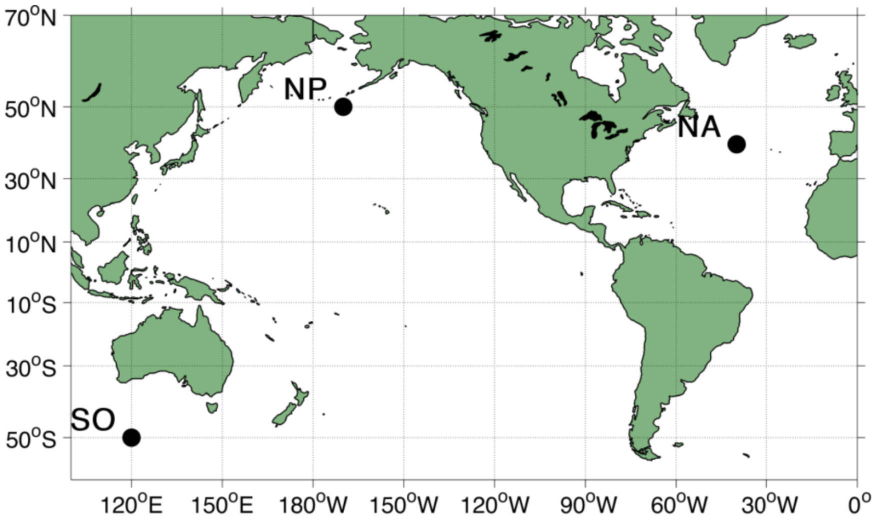


	CMIP	ATM	WAVE		Period	
	phase	lon x lat [˚]	lon x lat [˚]	Δt		
ACCESS1.0	5	1.88 x 1.25	1.0 x 1.0	6h	1979-2005	2081-2100
BCC-CSM1.1	5	2.8 x 2.8	1.0 x 1.0	6h	1979-2005	2081-2100
GFDL-CM3	5	2.5 x 2.0	1.0 x 1.0	6h	1979-2005	2081-2100
HadGEM2-ES	5	1.88 x 1.25	1.0 x 1.0	6h	1979-2005	2081-2100
INMCM4	5	2.0 x 1.25	1.0 x 1.0	6h	1979-2005	2081-2100
MIROC5	5	1.4 x 1.4	1.0 x 1.0	6h	1979-2005	2081-2100
MRI-CGCM3	5	1.1 x 1.1	1.0 x 1.0	6h	1979-2005	2081-2100

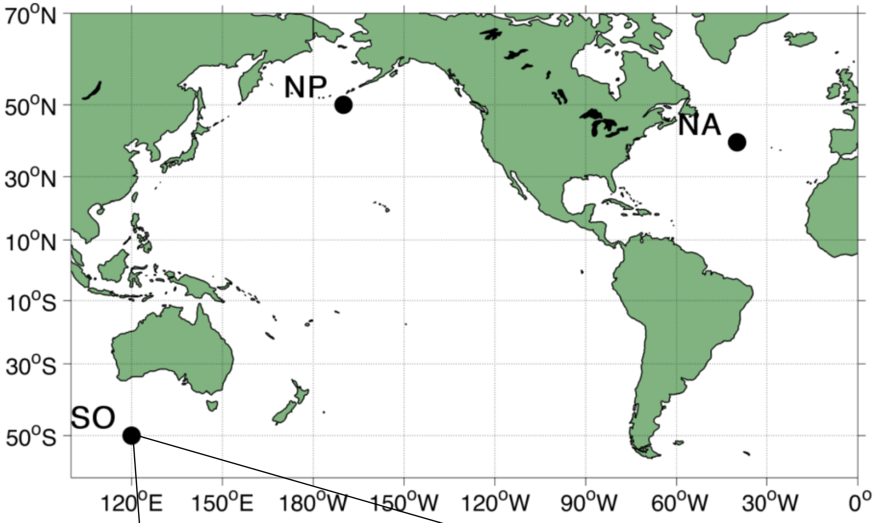
RCP4.5

RCP8.5

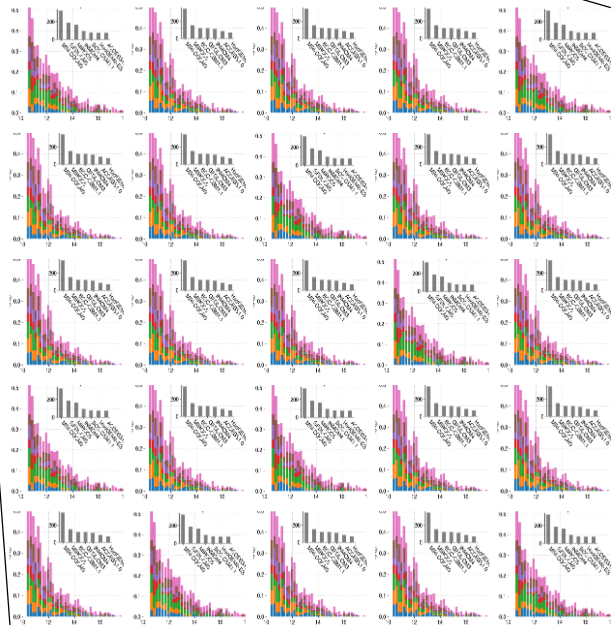
Extreme Value Analysis



Extreme Value Analysis

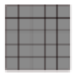


5x5 region



Extreme Value Analysis

Z-score



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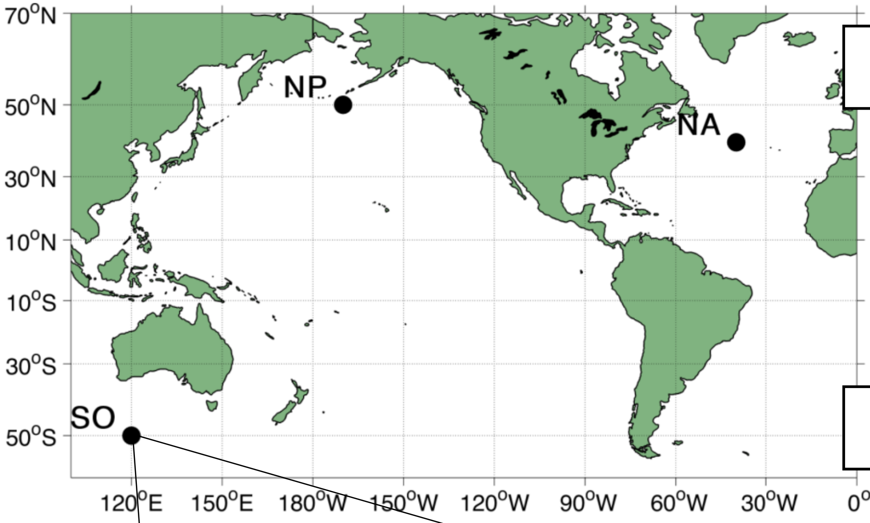

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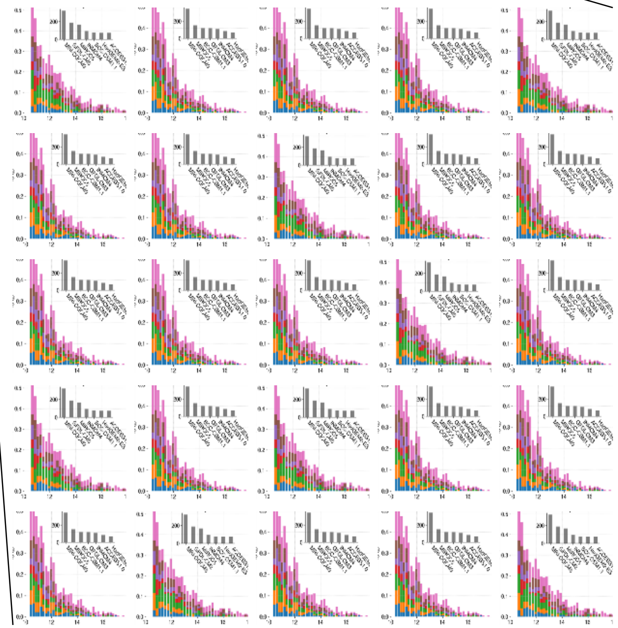

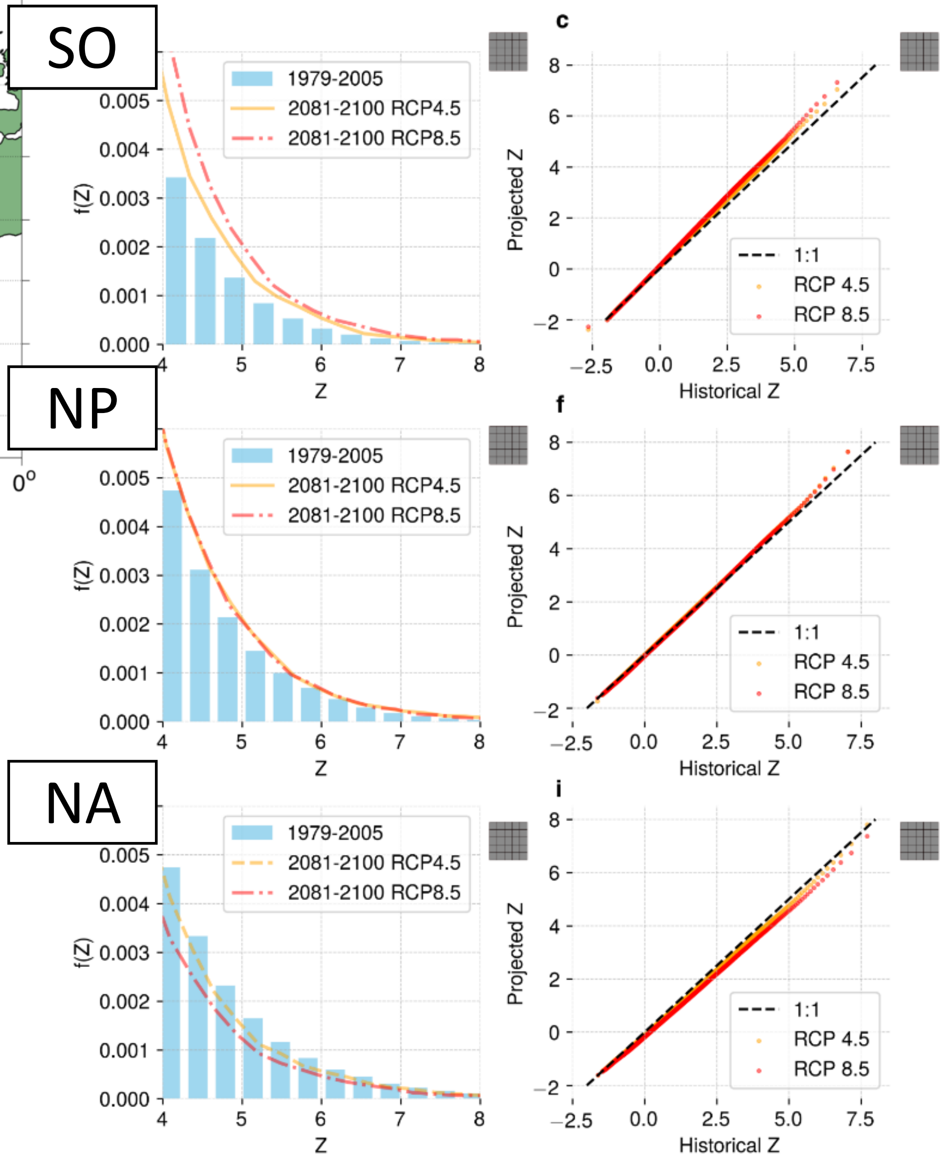

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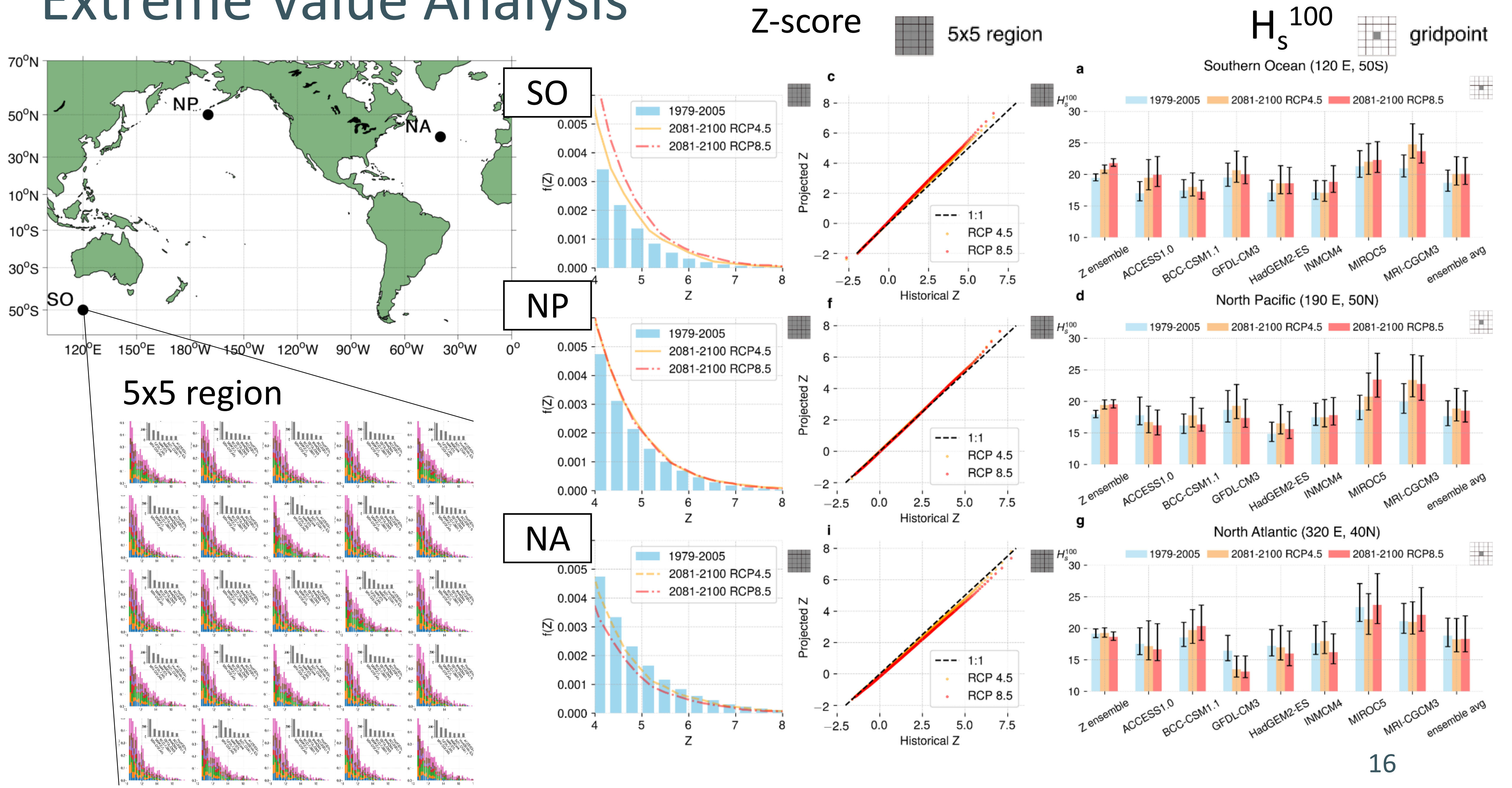
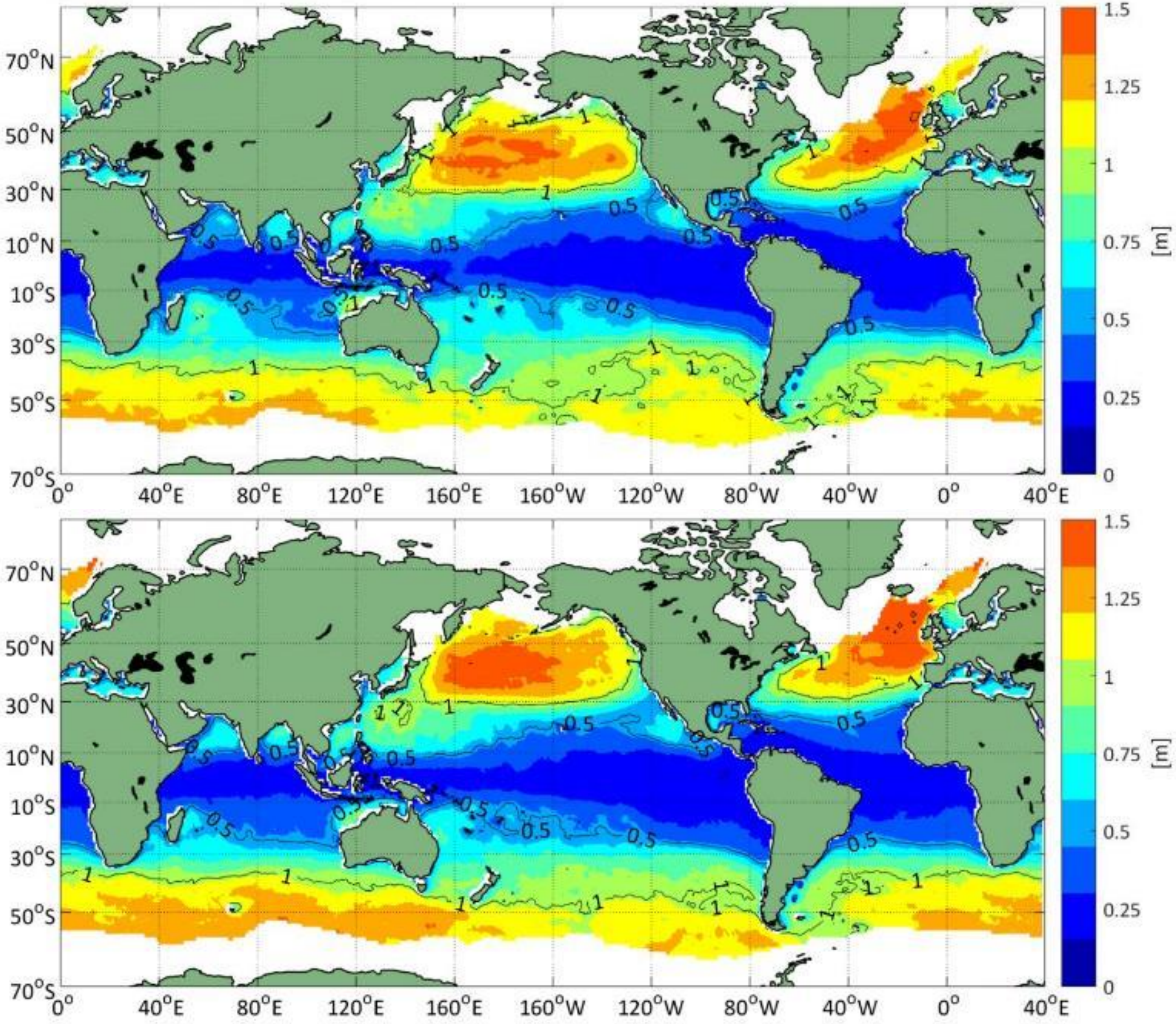


Confidence levels

1979-2005

2081-2100
RCP8.5



Bootstrap estimates on the 1000 peaks obtained from the ensemble pooling technique

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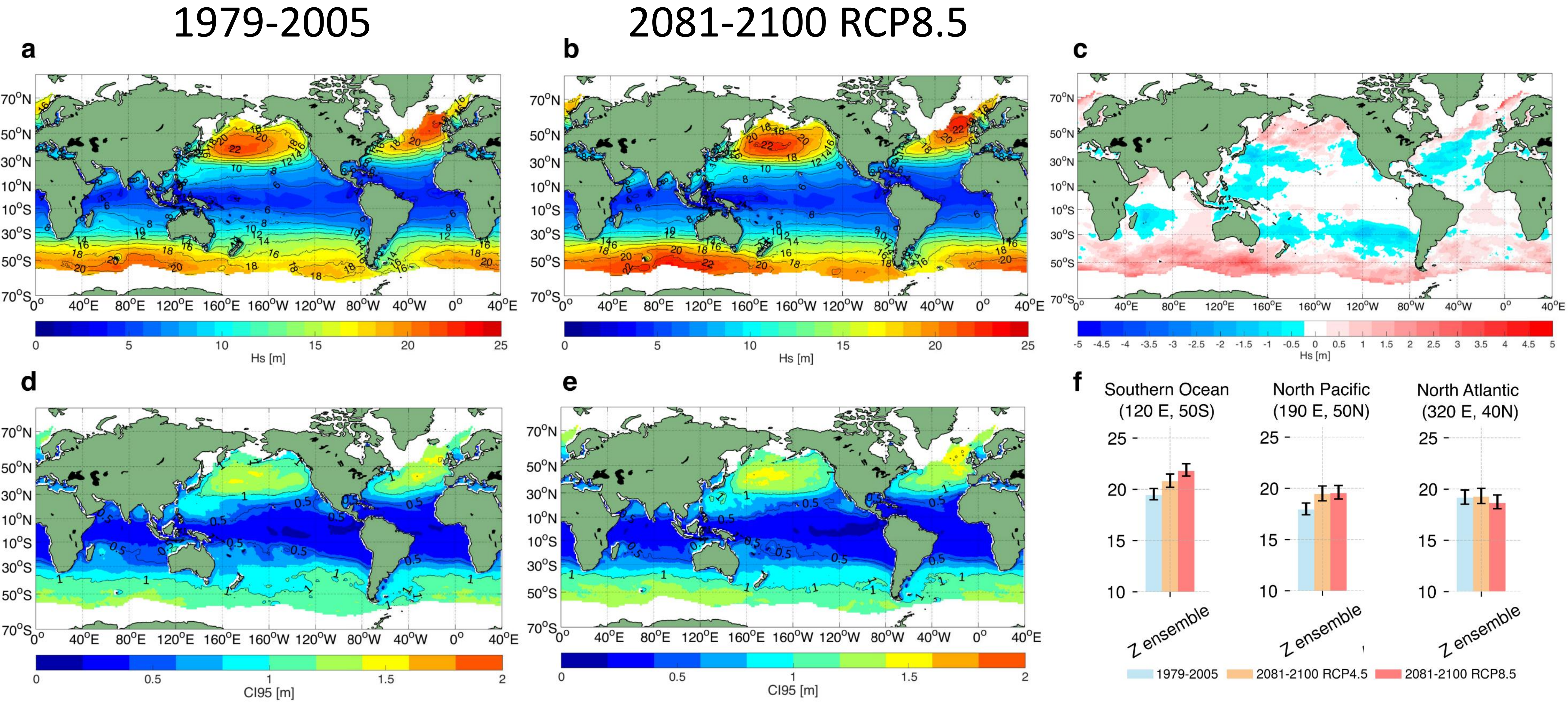
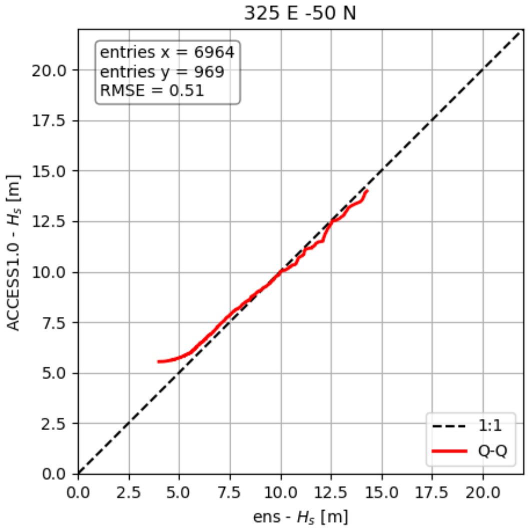
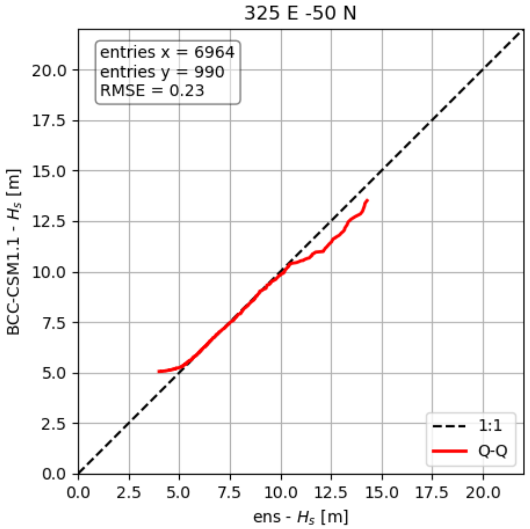
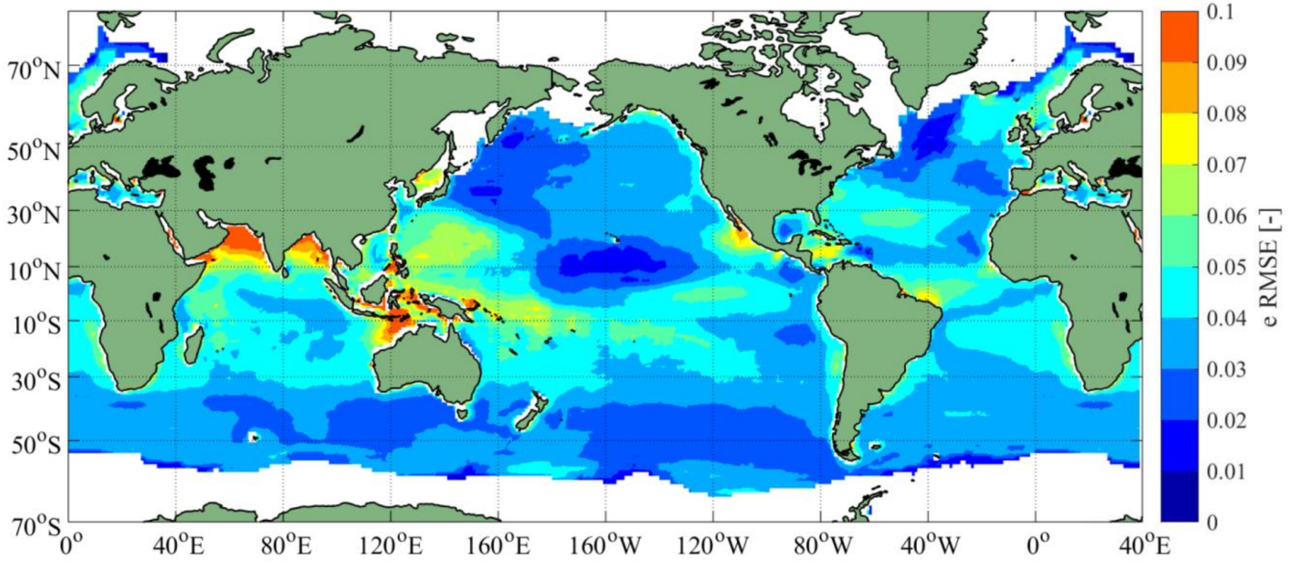
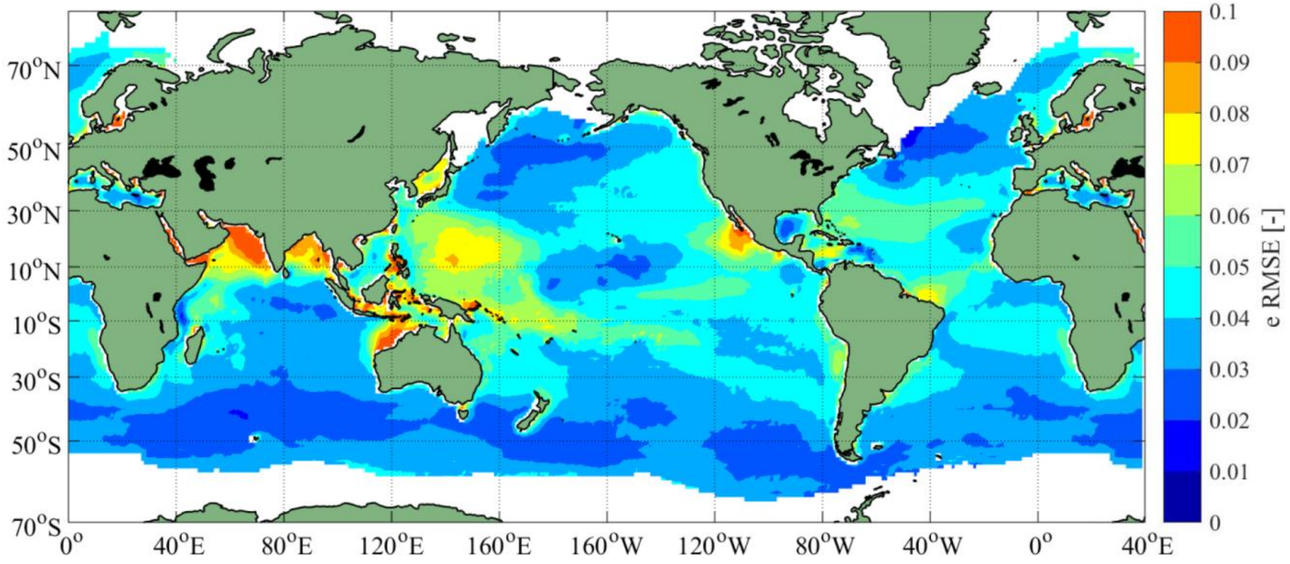


Similarity test between distribution of extremes



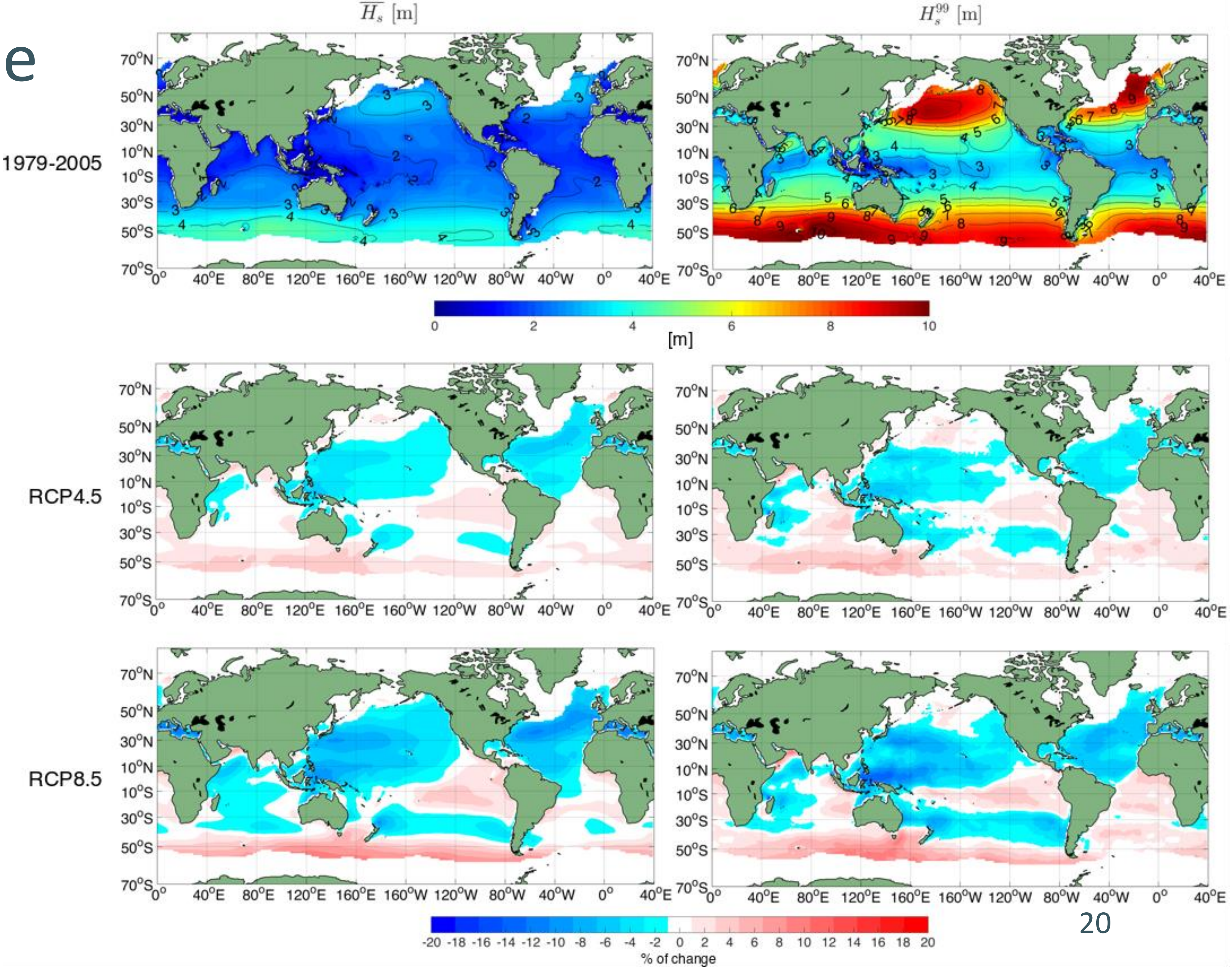






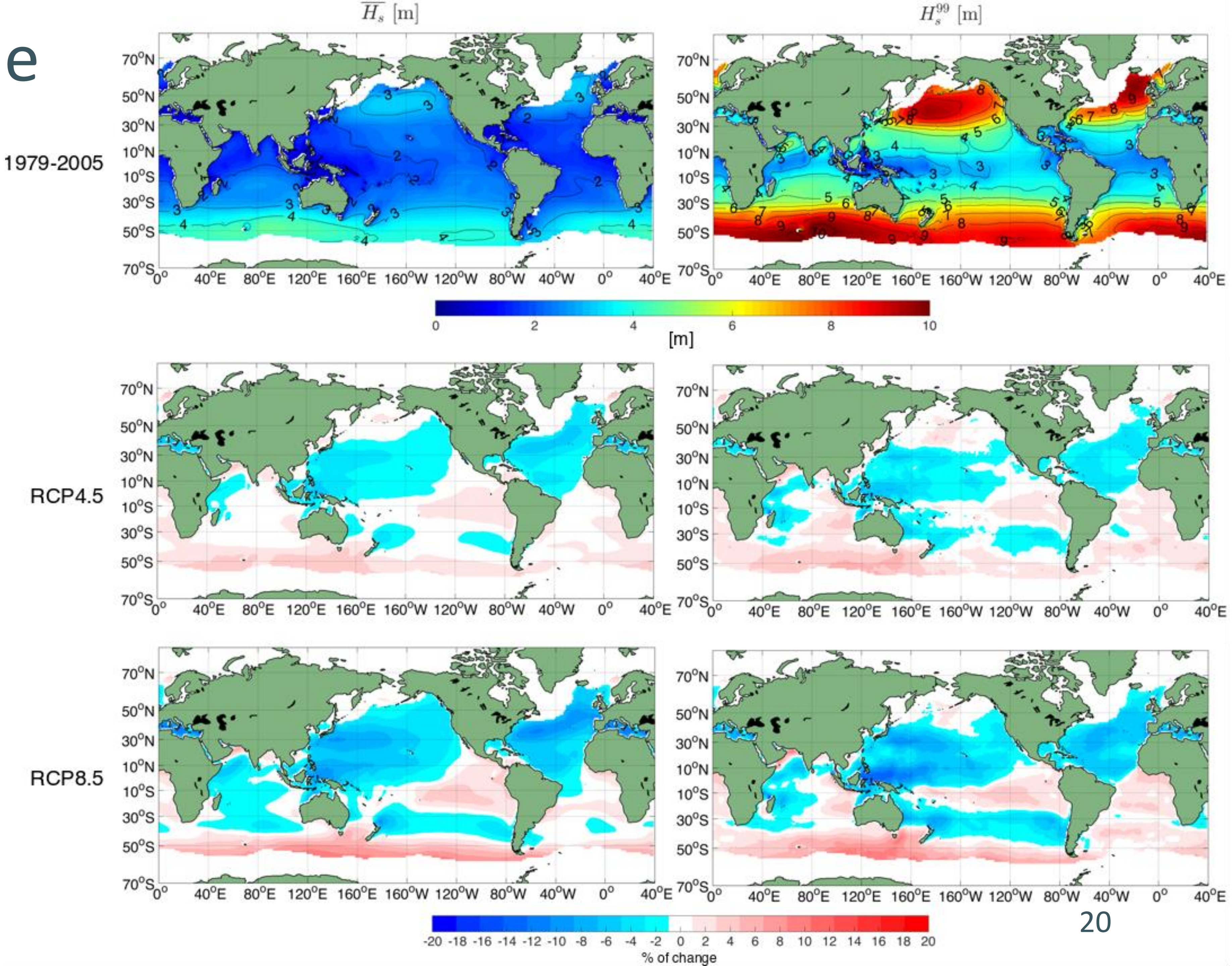
$$e_{RMSE} = 1 - \frac{\left| \frac{\sum RMSE_m}{n} - H_s^{100} \right|}{H_s^{100}}$$

Model ensemble performance



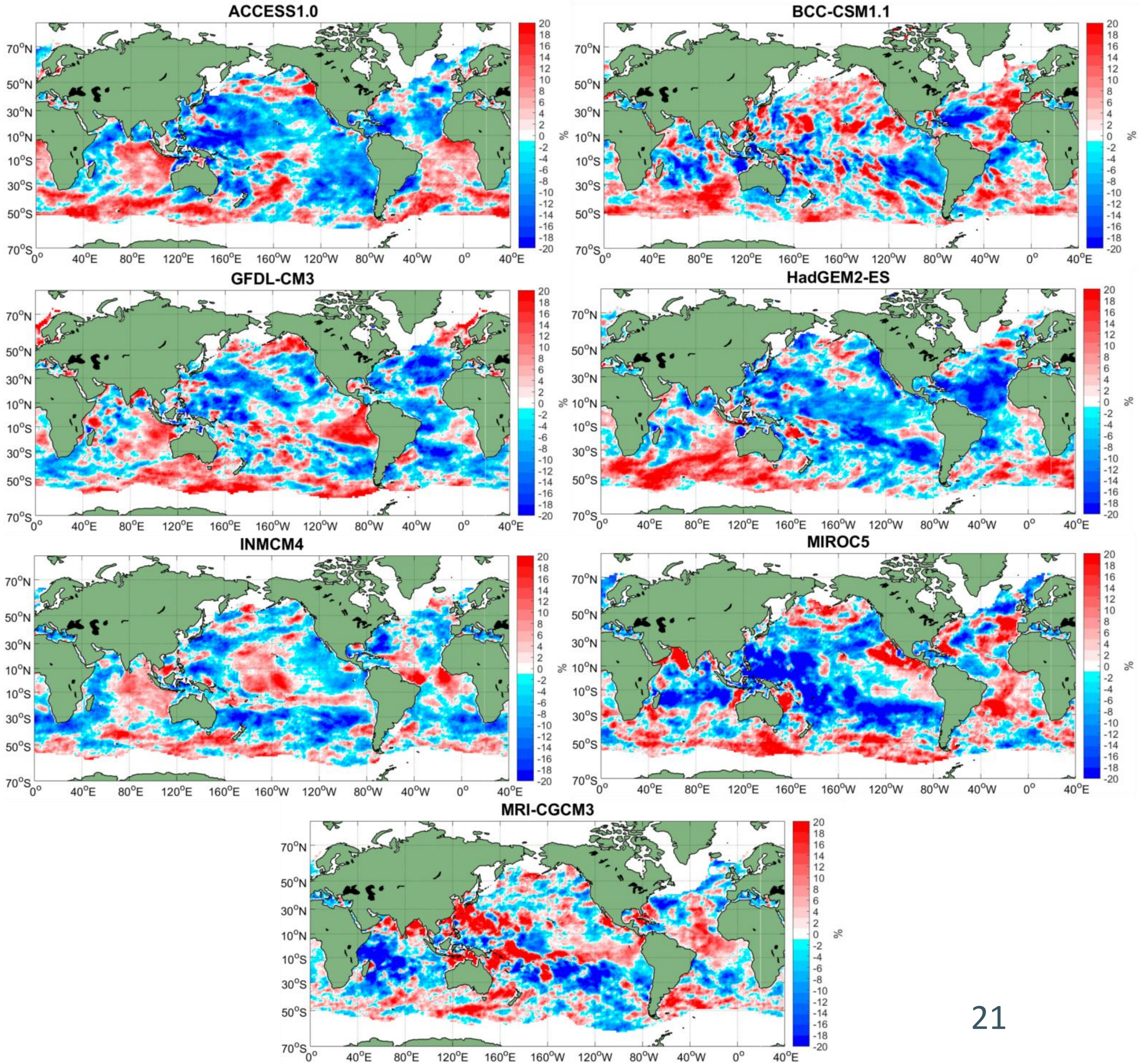
Model ensemble performance

Comparable to total multi-model ensemble in Morim et al., (2019)



Instability of single model projected extreme changes

$$\Delta = 1979\text{-}2005 - \frac{2081\text{-}2100}{RCP8.5}$$



Independent and Identically Distributed (i.i.d) data