Australasian Wind Wave Extremes Projections
Using CORDEX Australasia CMIP6 Winds

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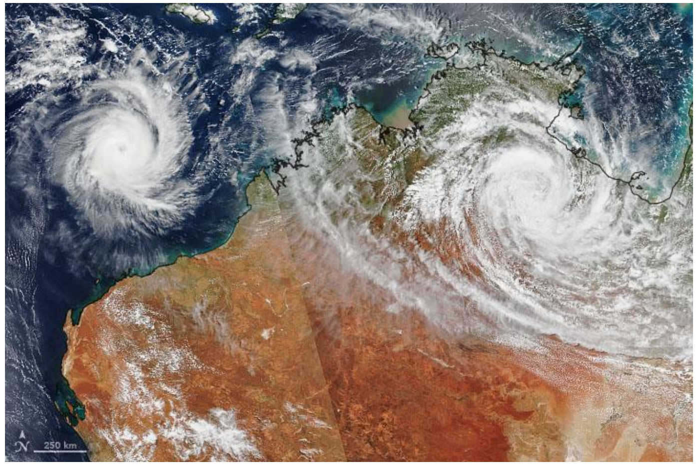
Australasian wind wave climate

<u>Exposed to three different climatic regions:</u>

Extra-tropical climate with powerful ETC-generated swells

Sub-Tropical climate region of particular interest for Offshore Renewables

Tropical Regions affected by on average, **9–11 tropical cyclones annually**, with about 4-5 making landfall

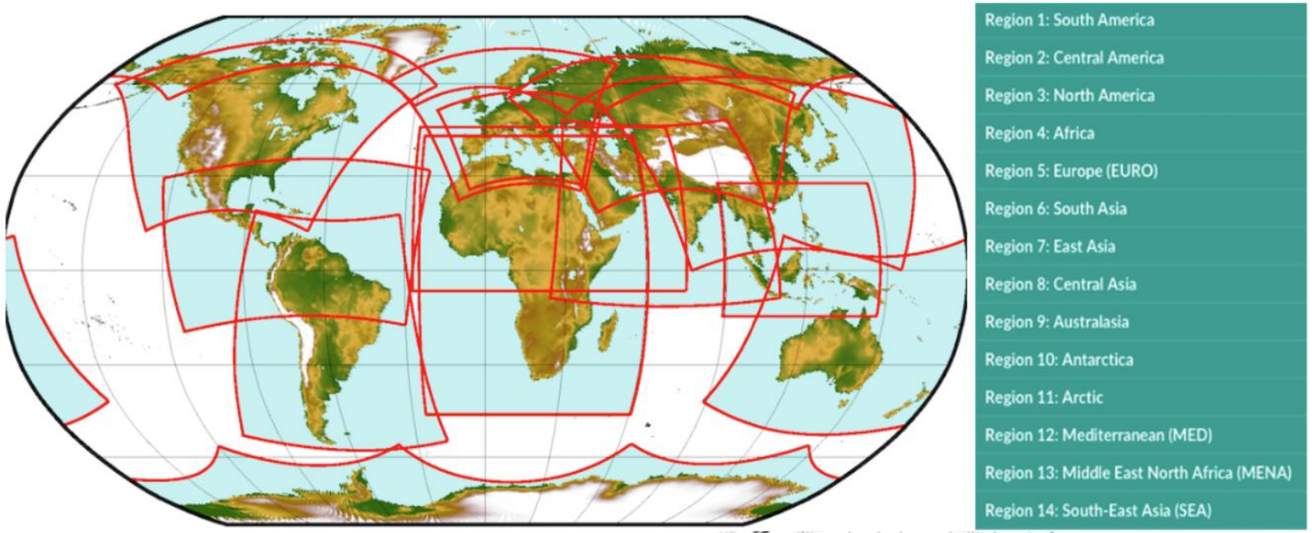


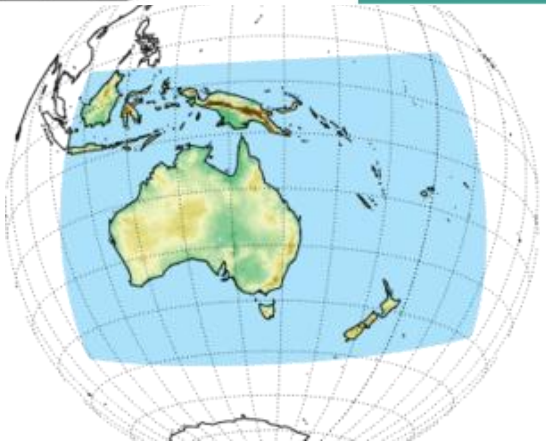
Deciphering extremes climate for hazard-relevant scales

- Coarse GCM winds challenge wave-extreme estimates, especially for TCs.
- How do we predict and explain uncertainty?
- Do higher-resolution winds "improve" wave climate extremes?

COordinated Regional climate Downscaling Experiment (CORDEX)

Continental-scale downscaling on 14 standard domains





4 RCMs

	CCAM-Qld	NARCLIM2.0 (2x WRF configurations)	CCAM	BARPA
ACCESS-CM2	r2i1p1f1oc		r4i1p1f1	r4i1p1f1
ACCESS-ESM1.5	r6i1p1f1 r20i1p1f1oc r40i1p1f1oc	r6i1p1f1	r6i1p1f1	r6i1p1f1
CESM2			r11i1p1f1	r11i1p1f1
CMCC-ESM2	r1i1p1f1		r1i1p1f1	r1i1p1f1
CNRM-CM6.1-HR	r1i1p1f2 r1i1p1f2oc			
CNRM-ESM2-1			r1i1p1f2	
EC-Earth3	r1i1p1f1		r1i1p1f1	r1i1p1f1
EC-Earth3-Veg		r1i1p1f1		
FGOALS-g3	r4i1p1f1			
GFDL-ESM4	r1i1p1f1			
GISS-E2-1-G	r2i1p1f2			
MPI-ESM1-2-HR		r1i1p1f1		
MPI-ESM1-2-LR	r9i1p1f1			
MRI-ESM2-0	r1i1p1f1			
NorESM2-MM	r1i1p1f1 r1i1p1f1oc	r1i1p1f1	r1i1p1f1	r1i1p1f1
UKESM1-0-LL		r1i1p1f1		

16 GCMs

Modelling Experiment: Wind forcing

(Meucci et al., 2023, 2024)

GCMs

(Bi et al., 2020)
(Döscher et al., 2021)

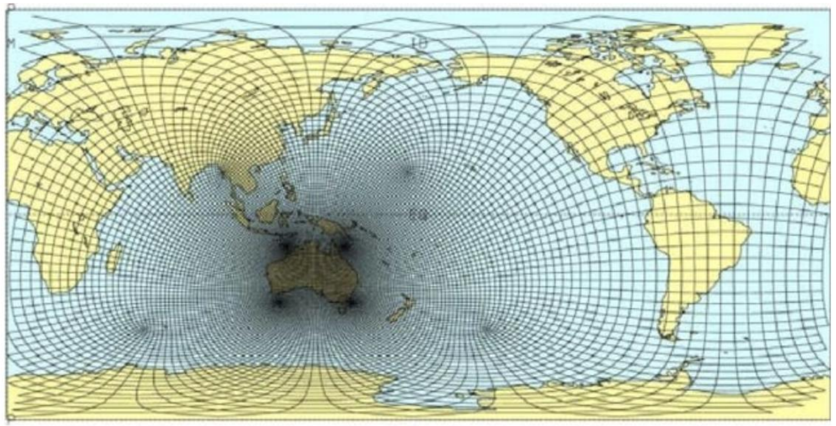
Different grid resolution and model setups.
We hereby focus on ACCESS-CM2 and EC-Earth3 models

- ACCESS-CM2 runs the MetUM-HadGEM3-GA7.1 with a nom. Res. Of **~250km**
- EC-Earth3 runs the IFS CY36R4 with a nominal resolution of **~100km**

CCAM-ACS

(Chapman et al., 2023)

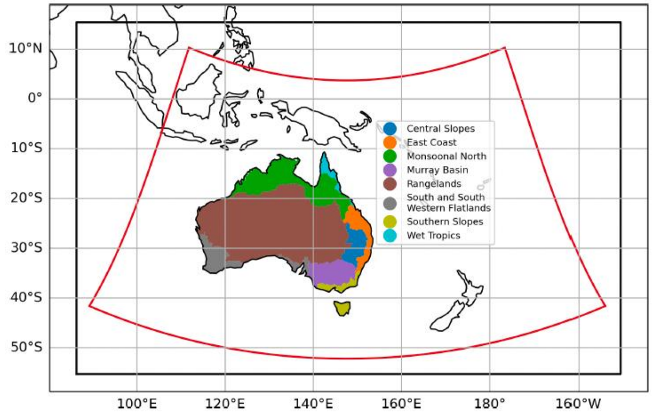
Conformal **C**ubic grid **A**tmosphere **M**odel.
This is a variable resolution C384 "stretched grid" (Schmidt = 2.1) with a focus on the Australasia region at the expense of reducing resolution in the other areas of the world (Highest res. **12.5km**, lowest res. ~150km)



BARPA-R

(Howard et al., 2024)

Bureau **A**tmospheric **R**egional **P**rojections for **A**ustralia Land-Atmosphere limited-area RCM
17km horizontal resolution



Modelling Experiment: Wind forcing

CCAM-ACS

(McGregor et al., 2003)
(Thatcher et al., 2009)

Rather than providing lateral boundaries CCAM follows the host GCM large-scale features for temperatures, winds, and pressures, through a spectral nudging technique at:

- large spatial scales of 3000km
- 1.5 km a.s.l.

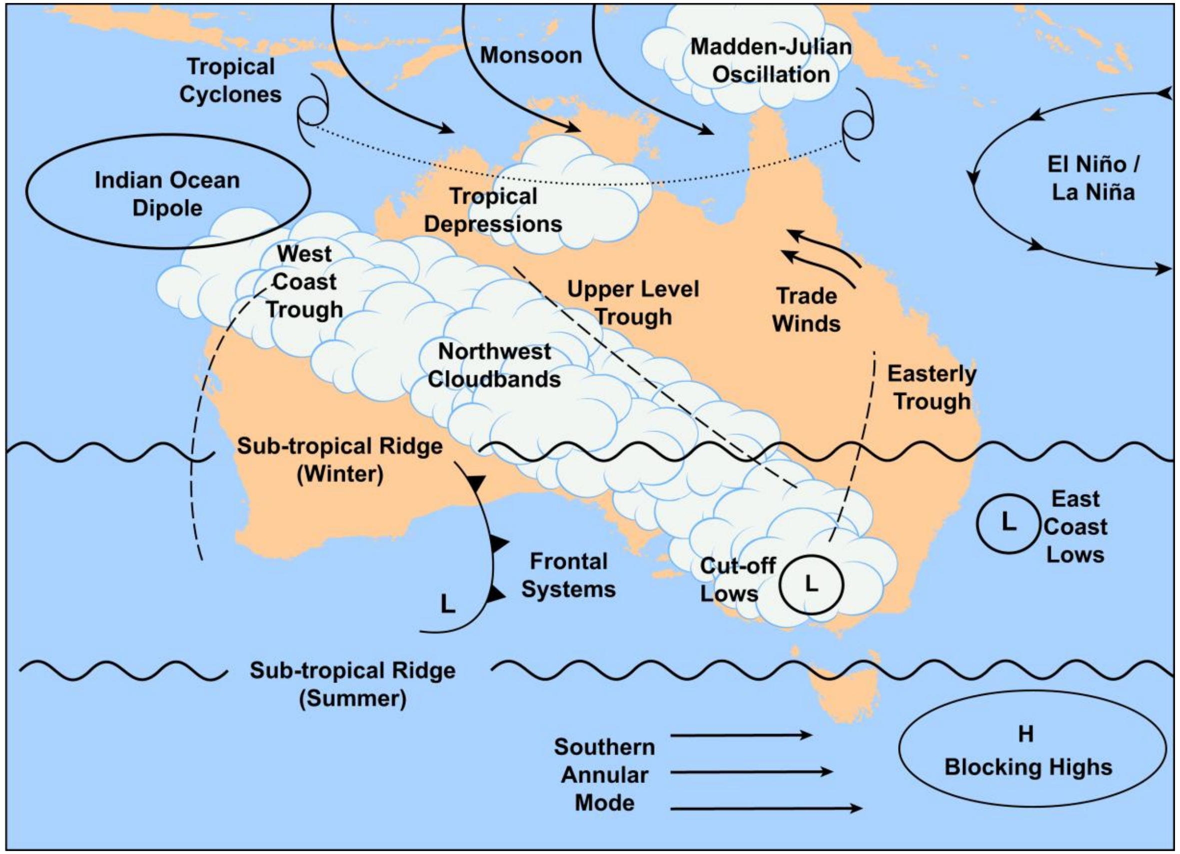
Allows small-scale features to evolve naturally within the regional model. Avoids direct interference with local-scale processes.

Convection-related features such as **TCs**, **the South Pacific Convergence Zone**, the **northwest Cloudband** and the **monsoon westerlies** show more divergence from obs. than mid-latitude phenomena such as the **westerly jets** and **ETCs**.

BARPA-R

(Su et al., 2022b)
(Howard et al., 2023)

Land-Atmosphere limited-area RCM with lateral boundaries provided by the GCM.



Modelling Experiment: wave climate model

WAVEWATCH III v6.07

Physics

- **ST6** parametrization
- **DIA** scheme non-linear int.
- **No currents**

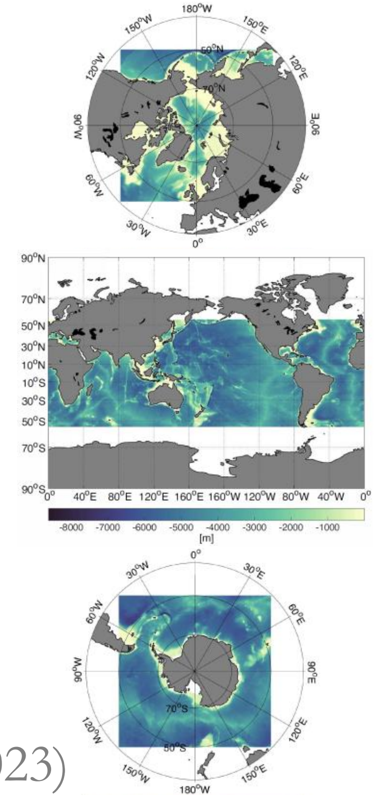
Sea-ice

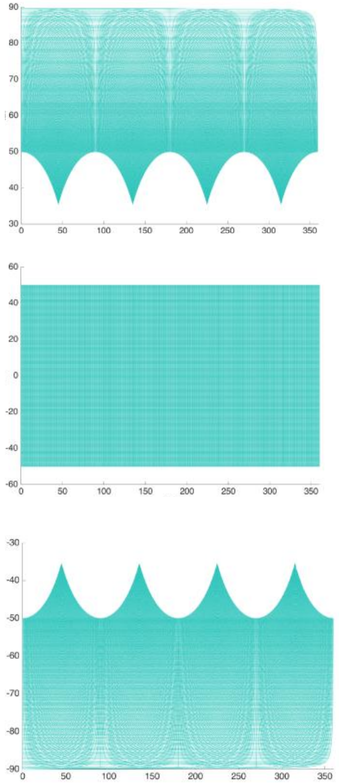
- <25% open ocean
- 25% < SI < 75% ln decay
- >75% land

Irregular
Regular
Irregular
grid

(Rogers et al., 2018)
(Liu et al., 2021)

(Meucci et al., 2023)





Curv. grid 34 Km res. @ 70°N

Regular 0.5° rect. grid ~ 55Km res.

Curv. grid 34 Km res. @ 70°S

Outputs 3-hourly outputs re-gridded over a global **0.5° reg. grid**

Spectral res.:

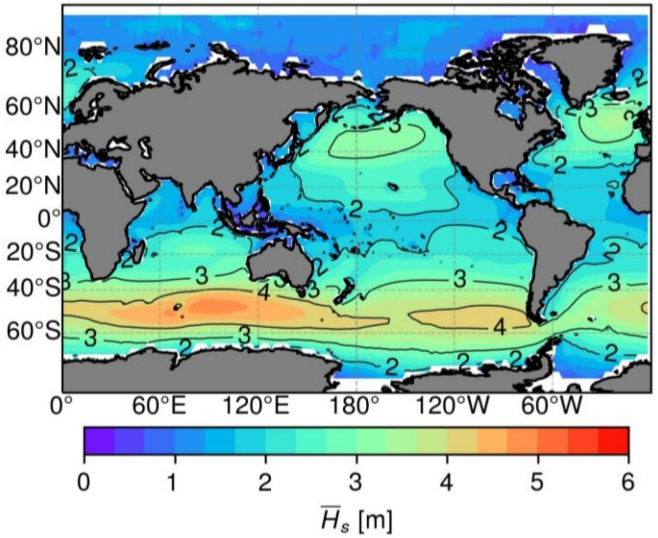
- 50 freq. (0.035 - 0.96 Hz)
- 36 dir. ($\Delta\theta = 10°$)

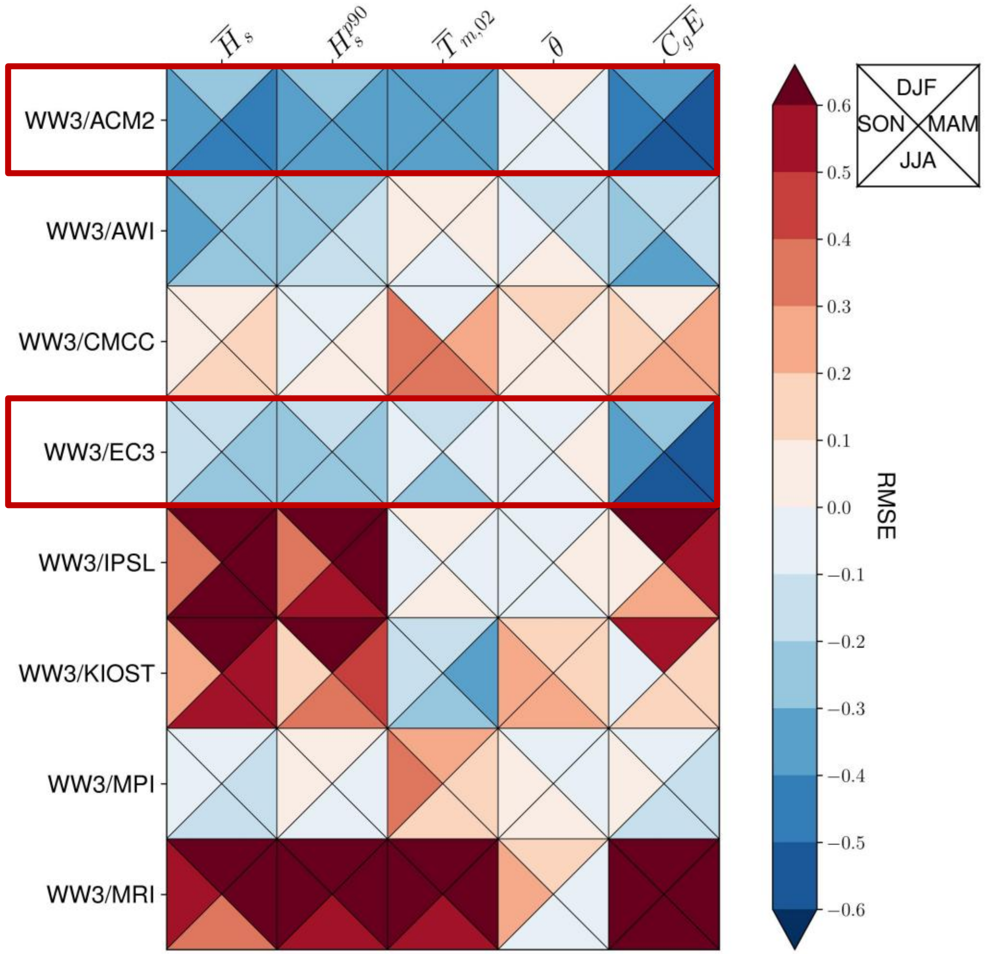
Wave climate simulations

ACCESS-CM2 (r1i1p1f1 GCM, r4i1p1f1 RCM) & **EC-Earth3** (r1i1p1f1)

Parent GCMs

(Meucci et al., 2023; 2024)



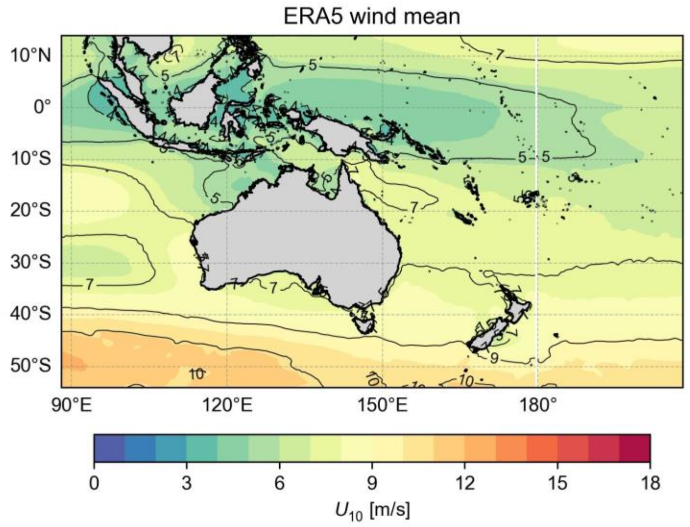


Comparison with ERA5 Hindcast

RCM downscaling

1. **CCAM-ACS**
2. **BARPA-R**

- Historical (1985-2014)
- SSP1-2.6 (2071-2100)
- SSP3-7.0
- SSP5-8.5

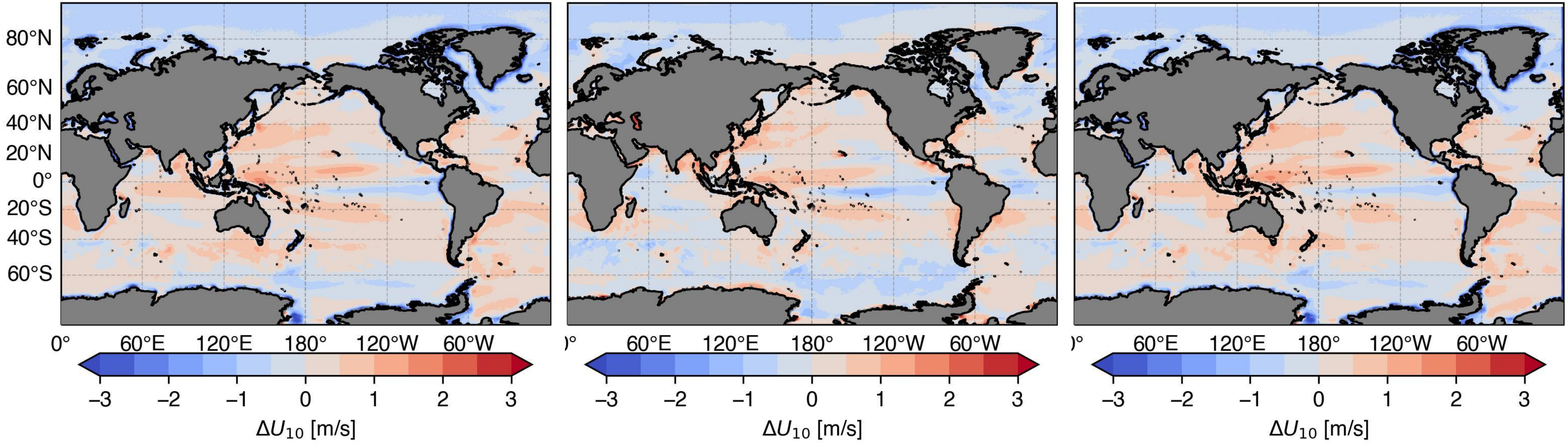


Global Wind Climate performance

10-m surface wind speed 1985-2014 avg. climatology

Downscaled ACCESS-CM2 r4i1p1f1 evaluated against ERA5

GCM **CCAM-ACS** **BARPA-R/GCM**



Added Value of downscaling

Reference Wave Hindcast (WHACS)

$$\mathcal{P}(X;u) = \{\, x_t \in X \mid x_t > u \,\}$$

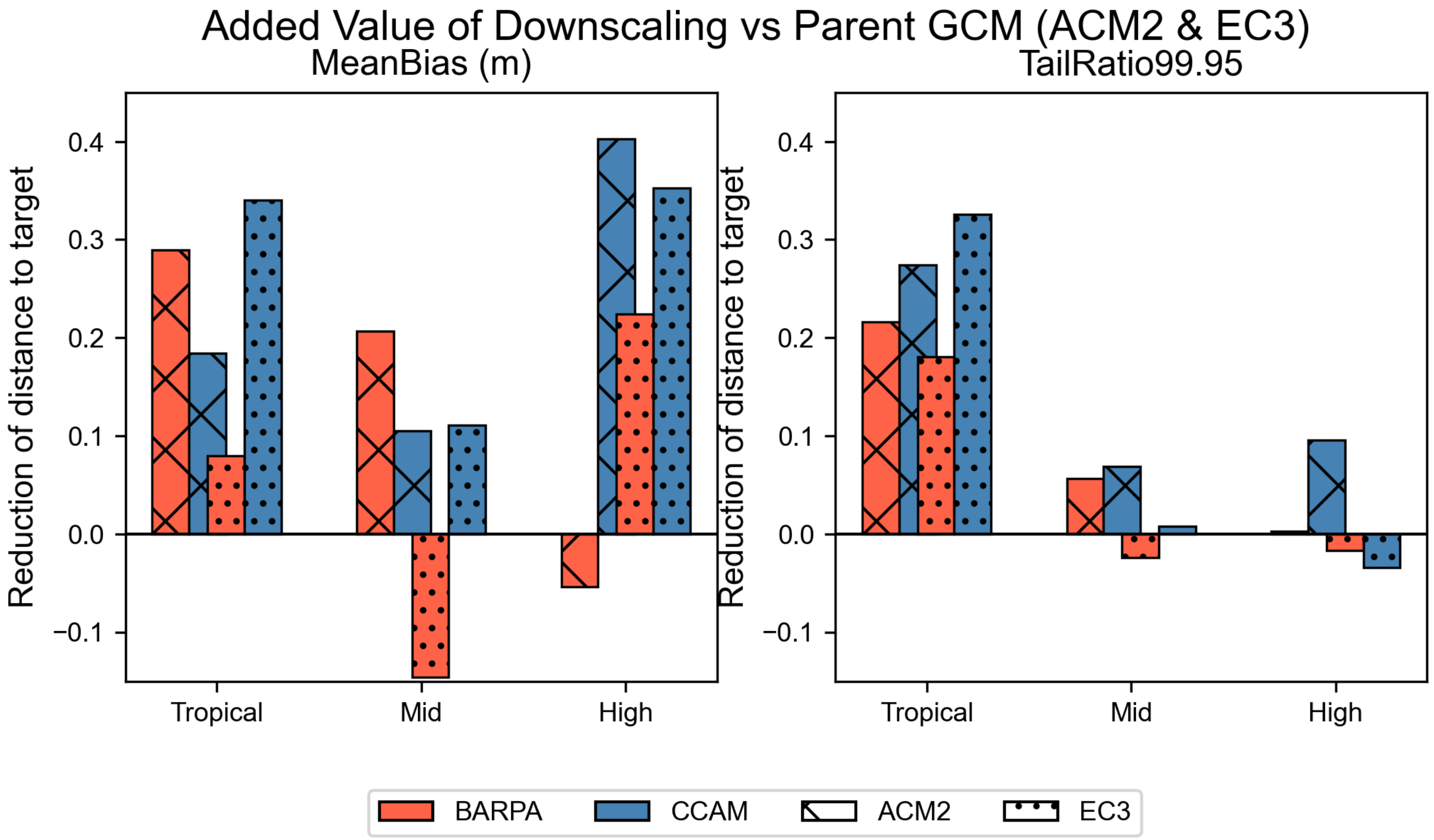
For each model we consider two POT samples:

$$R = \mathcal{P}(X^{\text{ref}};u)$$

$$S = \mathcal{P}(X^{\text{sim}};u)$$

All stats computed for pair elements:

(r_i, s_i) with $r_i \in R$ and $s_i \in S$



$$\text{MeanBias} = \frac{1}{N}\sum_{i=1}^{N}(s_i - r_i) \qquad \text{TailRatio}_{99.95} = \frac{Q_S(0.9995)}{Q_R(0.9995)}$$

Non-Stationary Generalised Extreme Value (GEV)

Extract Data:
<u>Annual maxima</u> of Significant Wave Height (Hs) and 10-meter surface wind speed (U10)

Fit Models:
Stationary: $\mu(t) = \mu 0, \sigma, \xi$
Non-Stationary: $\boldsymbol{\mu(t) = \mu 0 + \mu 1 \times t}$, σ, ξ

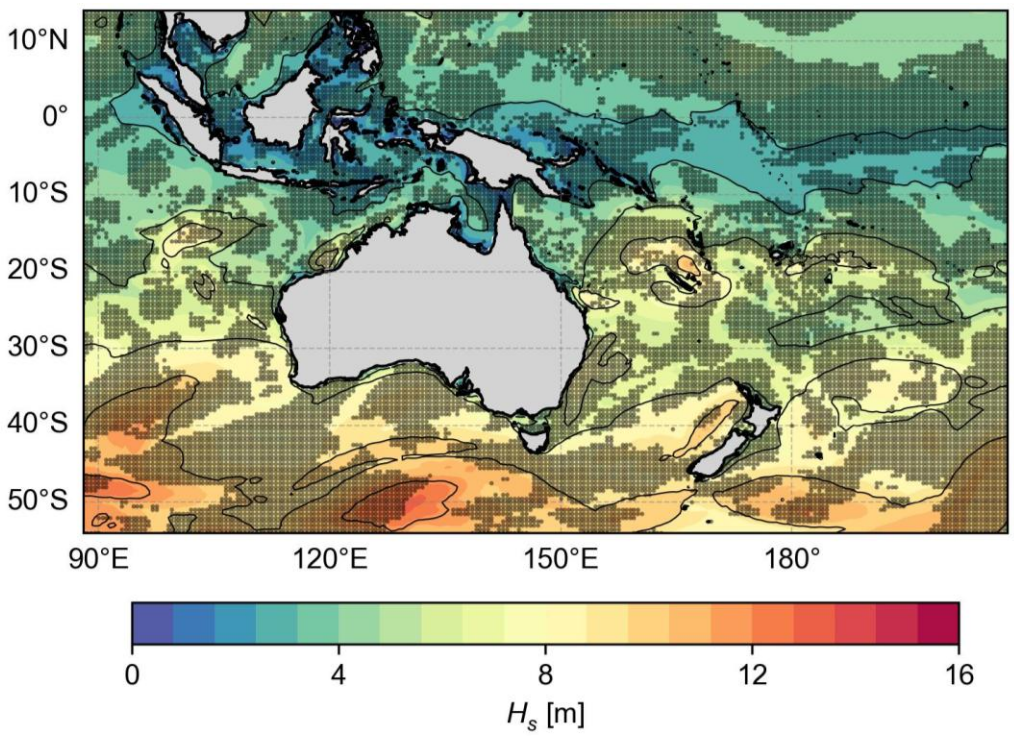
Compute Negative Log-Likelihood (NLL):
Minimise the negative log-likelihood for both models.

Model Selection:
Compute Deviance Statistic: $D = 2*(NLL_{stationary} - NLL_{non\text{-}stationary})$

Compare the Deviance statistic with the chi-squared critical values for significance (in this case for one degree of freedom).

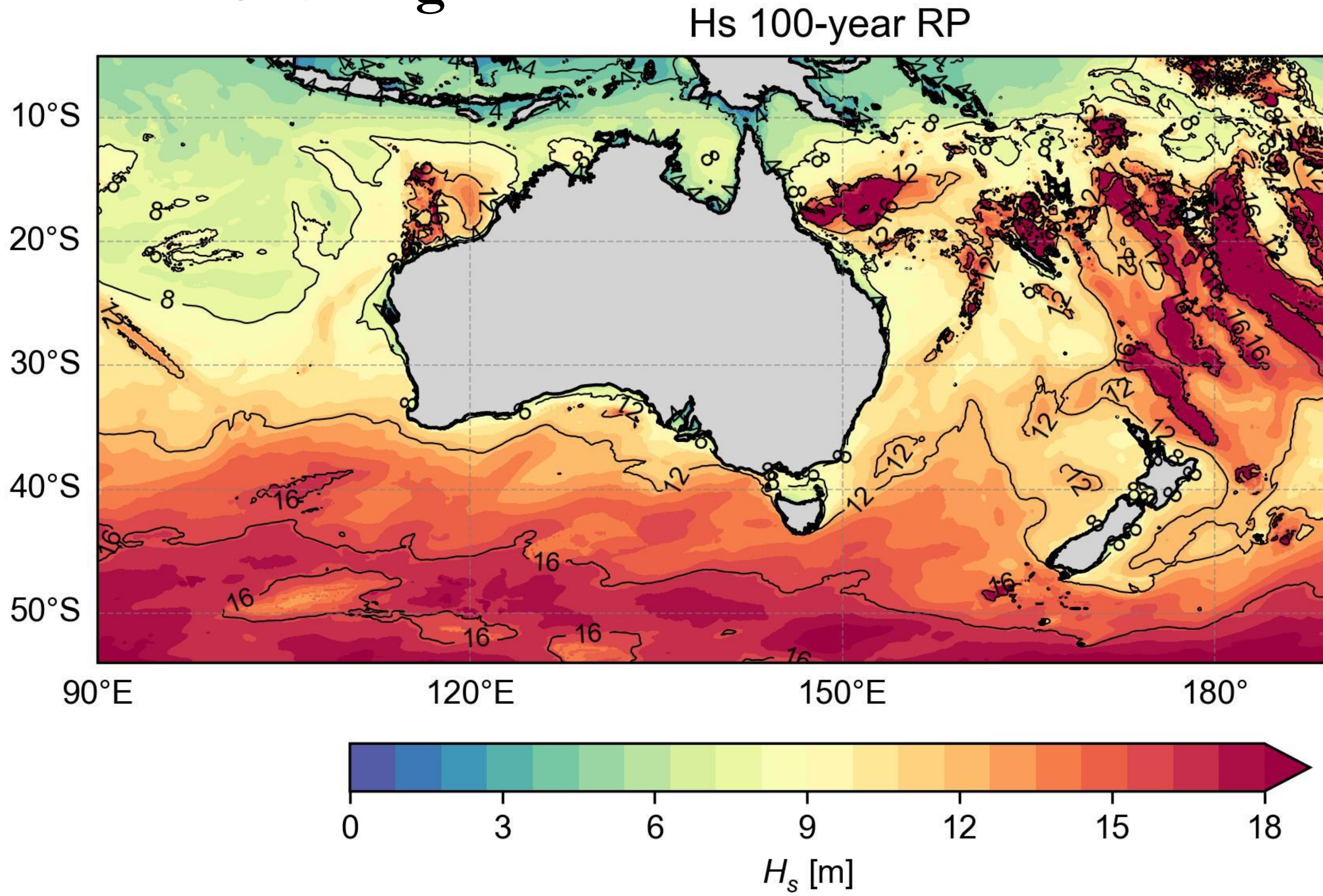
Return value estimate:

$$H_s = \mu(t) - \frac{\sigma}{\xi}\left[1 - \left(-\ln\left(1 - \frac{1}{T}\right)\right)^{-\xi}\right], \quad \text{for } \xi \neq 0,$$



100-year Hs Non-Stat GEV AM 1985-2014

WHACS ERA5 forcing

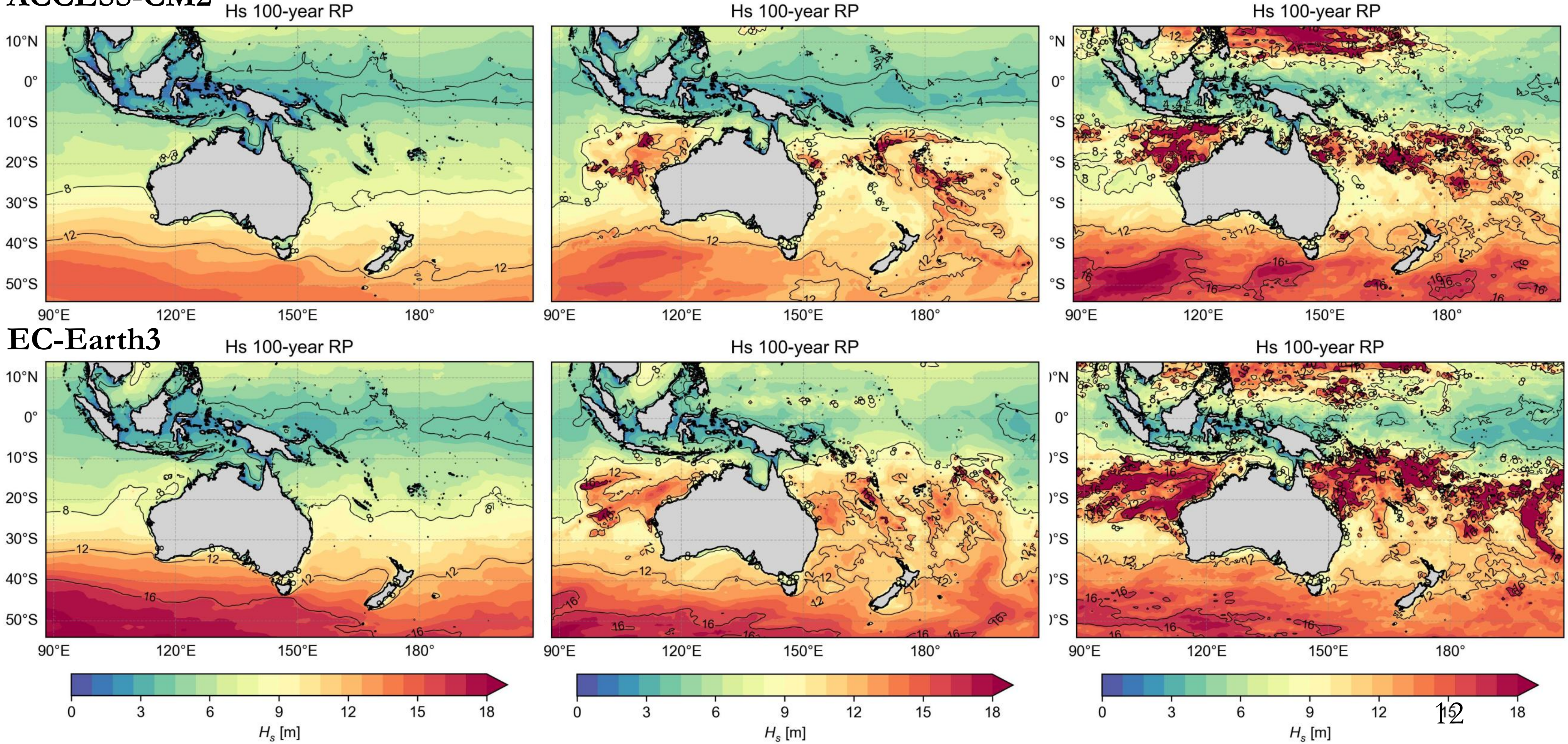


100-year Hs Non-Stat GEV AM 1985-2014

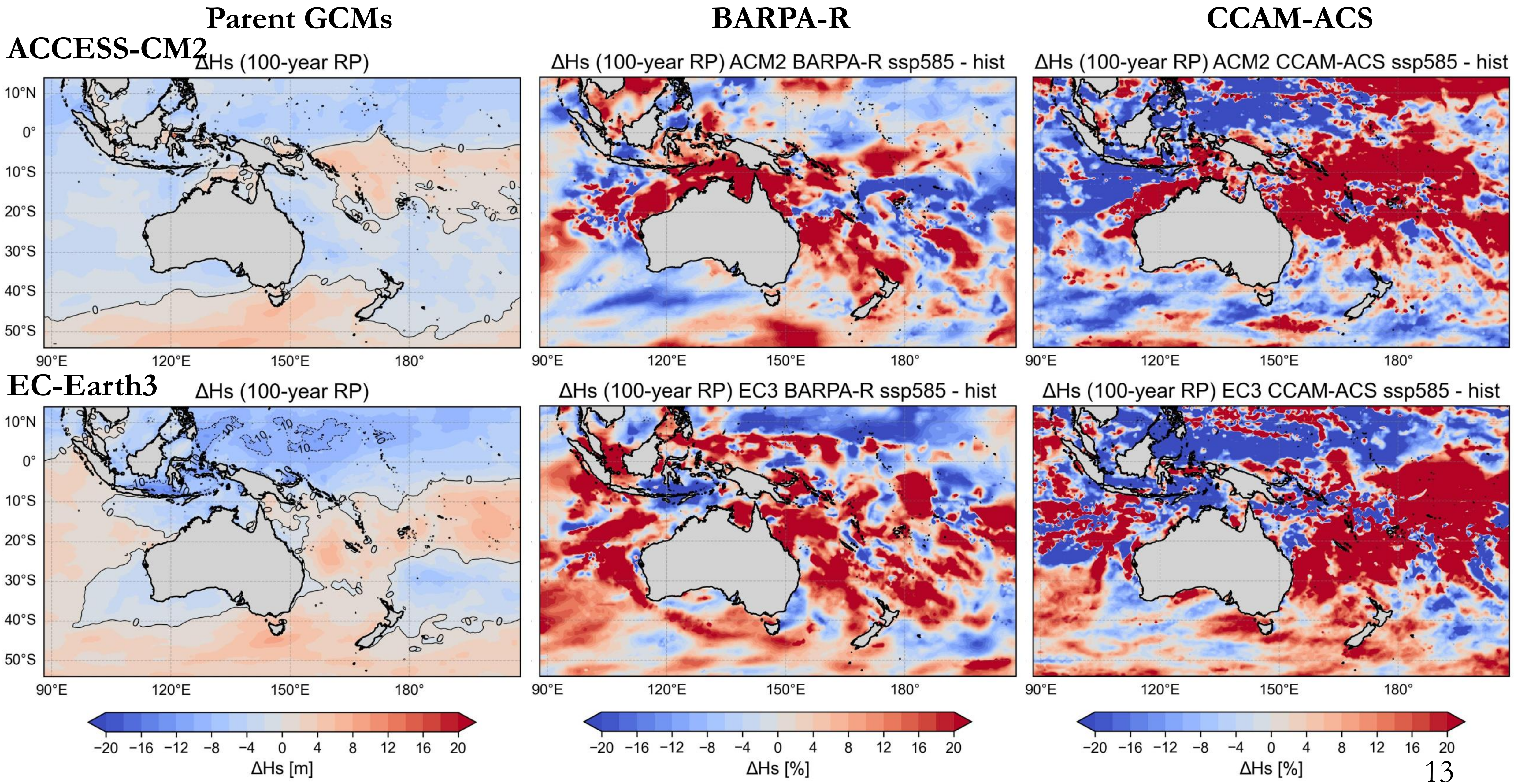
Parent GCMs | **BARPA-R** | **CCAM-ACS**

ACCESS-CM2

EC-Earth3



100-year Hs delta Non-Stat GEV AM SSP5-8.5 2071-2100



An overall picture…

			Tropical Region					Sub-Tropical Region					Southern Ocean				
ACCESS-CM2		%	mean	median	std	Area inc	Area dec	mean	median	std	Area inc	Area dec	mean	median	std	Area inc	Area dec
	BARPA-R	ssp126	1.58	-1.41	41.04	46.22	53.78	1.8	0.81	12.9	53.14	46.86	-0.7	-0.66	8.43	46.85	53.15
		ssp370	4.85	3.1	29.02	55.73	44.27	2.45	1.23	12.28	54.64	45.36	2.42	2.16	12.13	56.74	43.26
		ssp585	6.39	1.81	32.85	53.84	46.16	2.46	0.9	11.03	53.62	46.38	0.84	0.21	9.33	51.16	48.84
	CCAM-ACS	ssp126	6.97	0.72	51.81	51.35	48.65	0.98	0.39	10.79	51.28	48.72	-5.47	-5.81	9.33	25.67	74.33
		ssp370	9.32	4.54	49.55	56.45	43.55	2.29	0.83	11.42	54.11	45.89	0.47	-1	9.98	46.34	53.66
EC-Earth3		ssp585	25.02	8.8	97.74	59.38	40.62	-0.83	-1.99	11.83	42.03	57.97	-3.6	-5.02	11.66	32.85	67.15
	BARPA	ssp126	1.98	0.58	27.36	51.72	48.28	4.65	4.22	9.42	70.49	29.51	-0.34	-0.86	9.96	45.97	54.03
		ssp370	6.04	4.29	21.04	61.51	38.49	3.47	2.93	11.1	62.02	37.98	2.48	2.44	8.05	61.27	38.73
		ssp585	10.59	8.67	23.21	70.18	29.82	8.1	9	11.54	74.5	25.5	4.22	3.79	8.93	69.25	30.75
	CCAM-ACS	ssp126	12.29	-1.02	94.5	48.54	51.46	1.51	0.93	11.91	53.91	46.09	0.77	0.71	8.47	53.92	46.08
		ssp370	21.49	-0.26	180.48	49.67	50.33	-3.77	-5.25	16.59	29.78	70.22	-0.93	-0.6	8.59	46.93	53.07
		ssp585	62.88	8.75	486.12	59.3	40.7	4.62	4.06	14.81	62.14	37.86	5	5.07	8.56	72.35	27.65

Tropical Region: Consistent increases with higher emissions scenarios but high uncertainty.

Sub-Tropical Region: Mixed changes with some decreases, especially under lower emissions scenarios.

Southern Ocean: Modest increases with relatively low variability and more consistent projections across scenarios.

Conclusions

Clear added value of downscaling extremes

The CCAM stretched grid approach seems like the better downscaling approach.

Non-stationary GEV fit

Limitations in the goodness of fit to the data.

Consistency in the projected changes across different downscaling methods.

This is also evident in Tropical Cyclone regions, highlighting the importance of large-scale climate patterns in driving changes in Tropical Cyclone winds during downscaling.

Higher emission scenarios do show a higher differential in the Tropical regions

However, the variability increases with it, and as such, the uncertainty.

Downscaling, as expected, increases complexity

Then, adding challenges to the interpretation of deltas.