![frontiers]

Supplementary Material

1 Atmosphere-Ocean General Circulation Model data

This work makes use of a CMIP5-based multi-model ensemble consistent of seven atmosphere-ocean general circulation models (GCMs) (**Supplementary Table 1**; further information at https://esgf-node.llnl.gov/projects/cmip5/). The criterion to select the models is to choose GCMs that provide surface winds and sea ice coverage fields with the maximum time resolution as possible to produce hourly time series of integrated parameters and directional spectra. All the GCMs provide 3-hourly winds and daily ice coverage fields (except from HadGEM2-ES that provides monthly ice) for the historical and projected periods, for the RCP 8.5 greenhouse gas emission scenario (Cubasch et al., 2013).

2 Numerical model set-up

A series of global wave projections are dynamically simulated considering sea surface wind fields and ice coverage outputs from GCMs as inputs of the wave generation model. The third-generation wave model WaveWatchIII (WW3) version 4.18 (Hendrick L. Tolman, 2014) is used to run the simulations. The main features of the numerical scheme used in this work are summarized below:

- Parametrization TEST451(Ardhuin et al., 2010).
- Continuous ice concentration blocking from 0.25 (no blocking) to 0.75 (total blocking).
- Discrete Interaction Approximation (DIA, Hasselmann et al., 1985).
- Depth-inducing breaking following Battjes and Janssen approach (Battjes & Janssen, 1979).
- SHOWEX bottom friction formulation (Ardhuin et al., 2003).
- Coastal reflexion equal to 0.05.
- Energy flux reduction due to islands or any other coastal obstacles smaller than cell size (Hendrik L. Tolman, 2003).
- Third-order Ultimate Quickest propagation scheme (Leonard, 1979).

We define three regular domains to develop the wave climate projections. A global regular mesh with one-degree spatial resolution that covers the global ocean from 85ºS to 88ºN. Then, we define an artic domain with a spatial resolution of 1.0º, covering the northernmost region of the ocean from 75ºN to 88ºN. Finally, a domain with 0.5º spatial resolution covers the European North Atlantic Ocean. **Supplementary Table 2** summarizes the geographical limits and time steps defined for each of the described domains.

The simulations provide two kinds of outputs. First, we extract hourly-time series of the integrated wave parameters significant wave height (H_s), mean wave period (T_m), peak wave period (T_p) and mean wave direction (Dir_m) at each grid node of the domains. In addition, we store hourly time series of directional spectra in 14 locations distributed across the global ocean. The criteria to select the target locations is fully described in the manuscript.

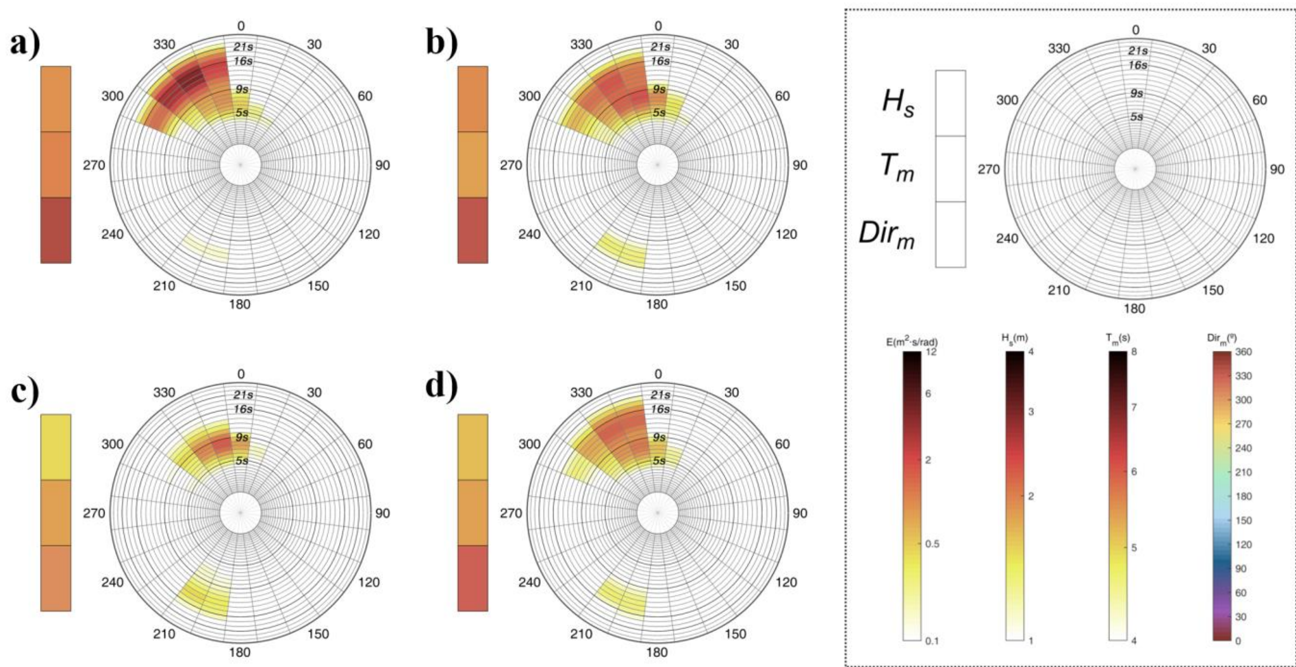
3 Wave climate projections bias

Prior to the assessment of the projected changes in wind-wave directional spectra, we analyze the biases in the developed wave climate projections (**Supplementary Figure 5 to 18**). First, bias increases with latitude, which is consistent with the higher wave energy in the extra-tropical region. In addition, a heterogenous pattern can be observed within the spectra, i.e. there coexist positive and negative biases. The reasons behind this behavior can be, first, biases with different sign associated to different wave systems (e.g. see ACCESS1.0 at P7). Second, biases in the location of the generation areas that induce a frequency-direction mismatch between wave systems from GCMs and reference hindcast.

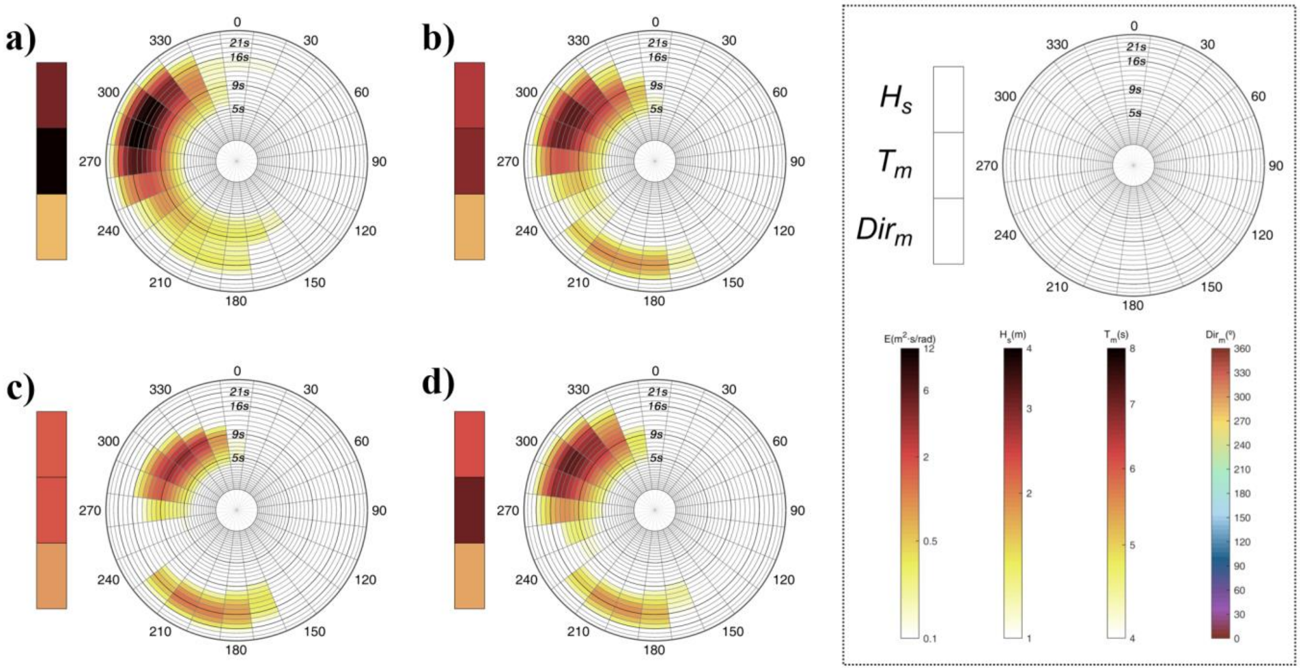
Results show sensitive differences among the seven ensemble members. CMCC-CM and MIROC5 are clearly the models that show the lowest biases. On the contrary, IPSL-CM5A-MR and CNRM-CM5 are the models that worst represent present-day climate (i.e. greatest biases).

4 Supplementary Figures and Tables

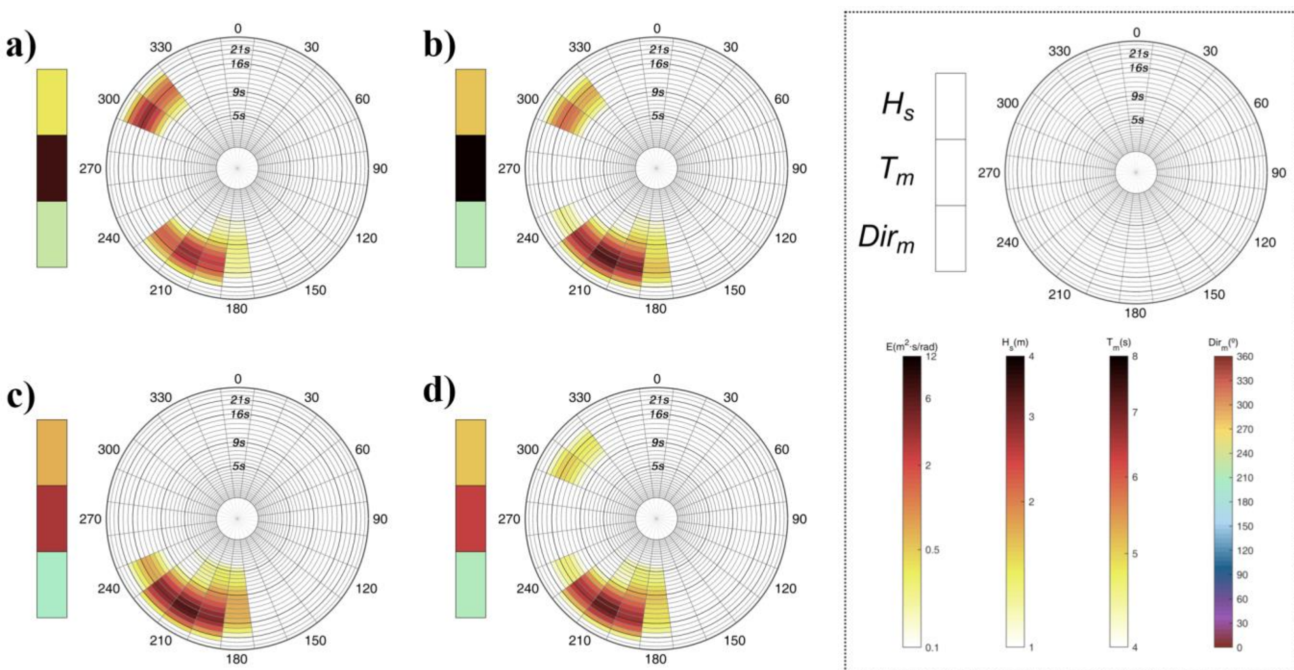
4.1 Supplementary Figures



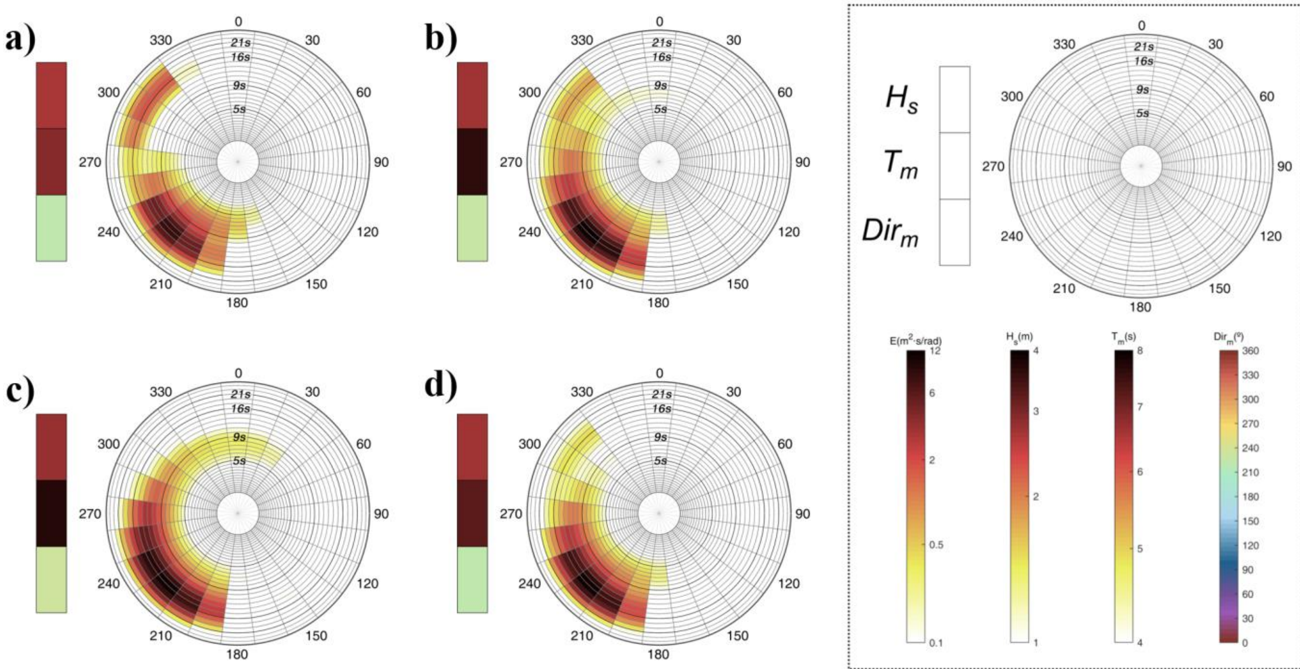
Supplementary Figure 1 Seasonal mean wave climatology at *P7*: a) Dec-Jan-Feb, b) Mar-Apr-May, c) Jun-Jul-Aug, c) Sep-Oct-Nov



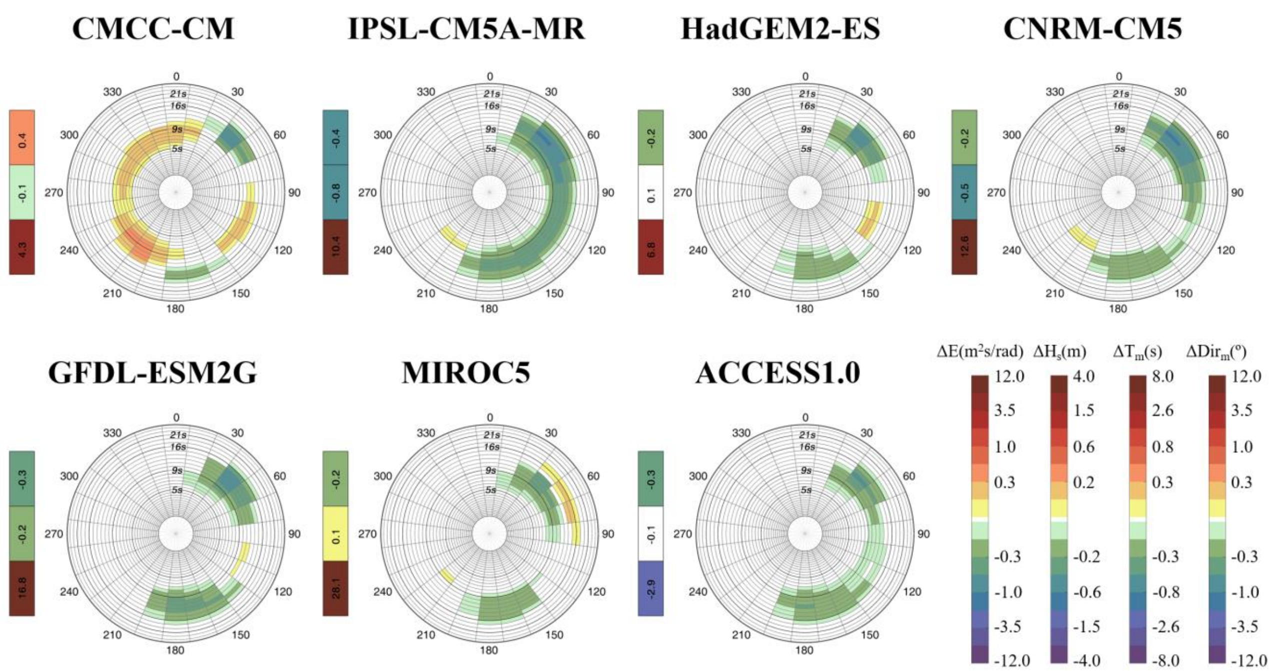
Supplementary Figure 2 Same as in Supplementary Figure 1 but at *P2*.



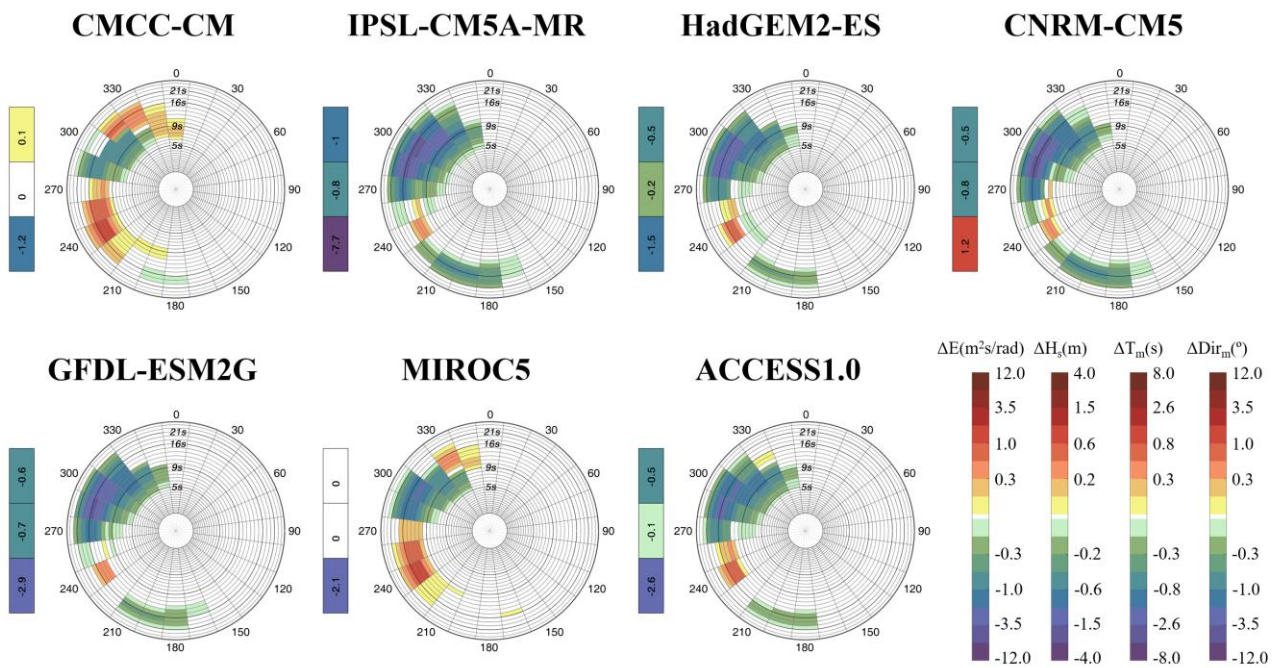
Supplementary Figure 3 Same as in Supplementary Figure 1 but at *P11*



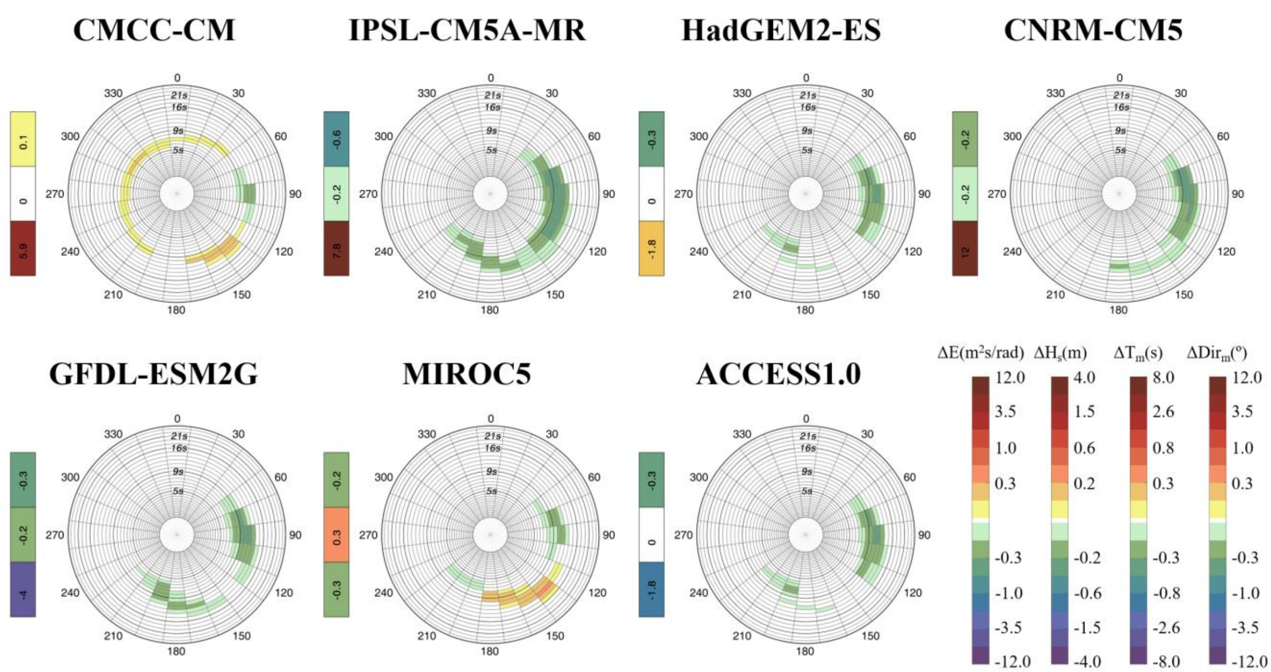
Supplementary Figure 4 Same as in Supplementary Figure 1 but at *P12*



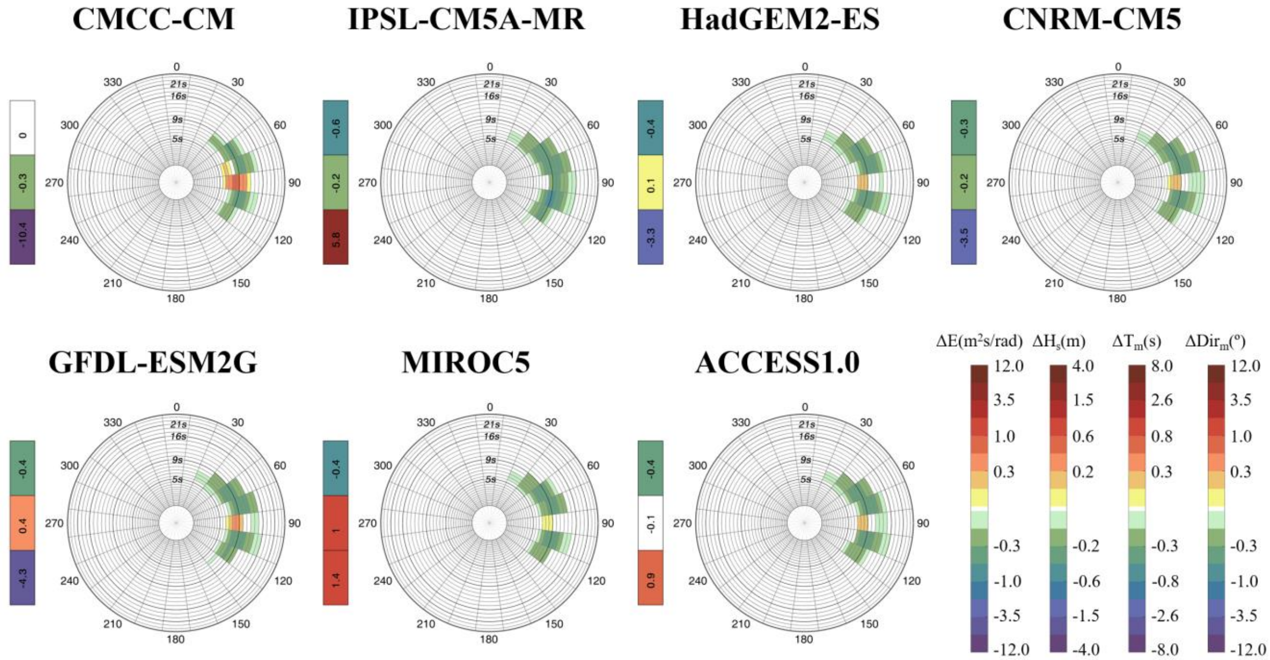
Supplementary Figure 5 Bias in annual mean directional spectra calculated as GCM-GOW2 at *P1*



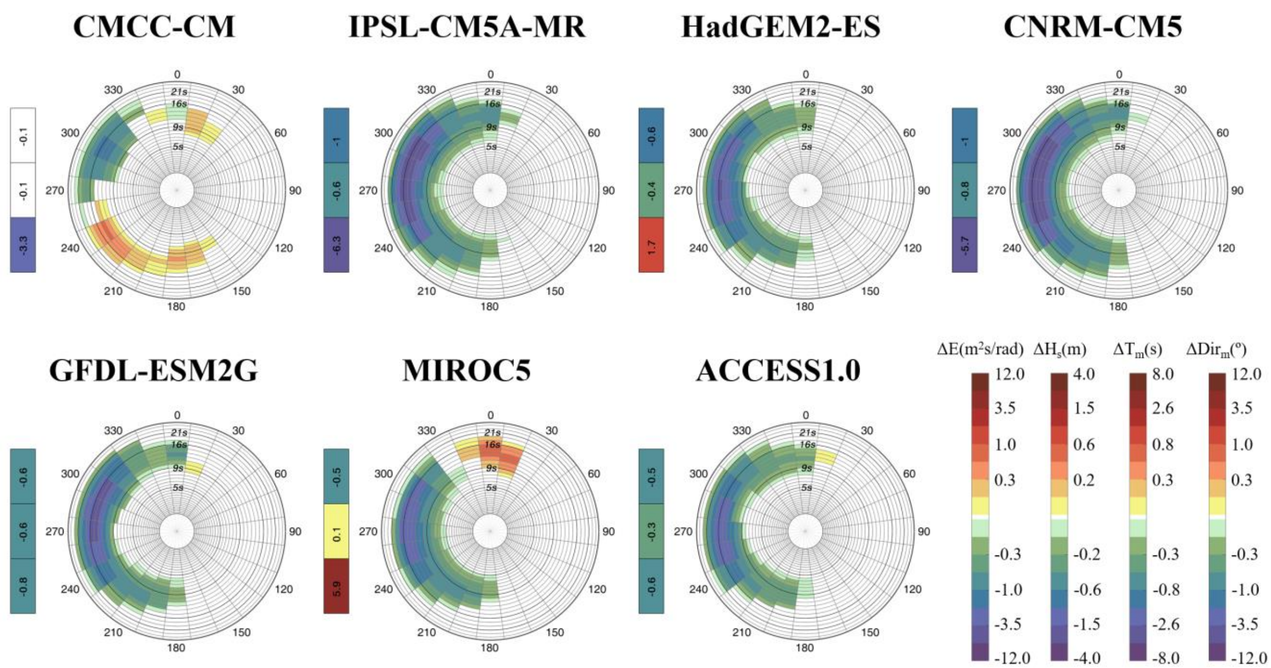
Supplementary Figure 6 Same as in Supplementary Figure 4 but at *P2*



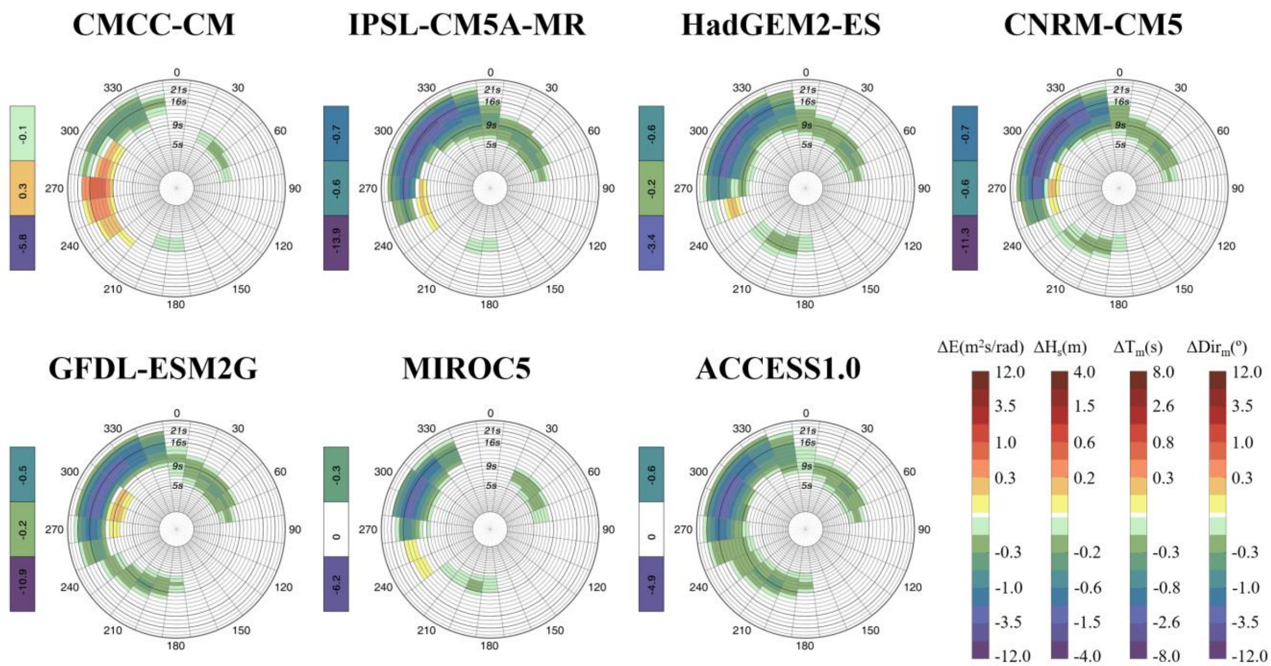
Supplementary Figure 7 Same as in Supplementary Figure 4 but at *P3*



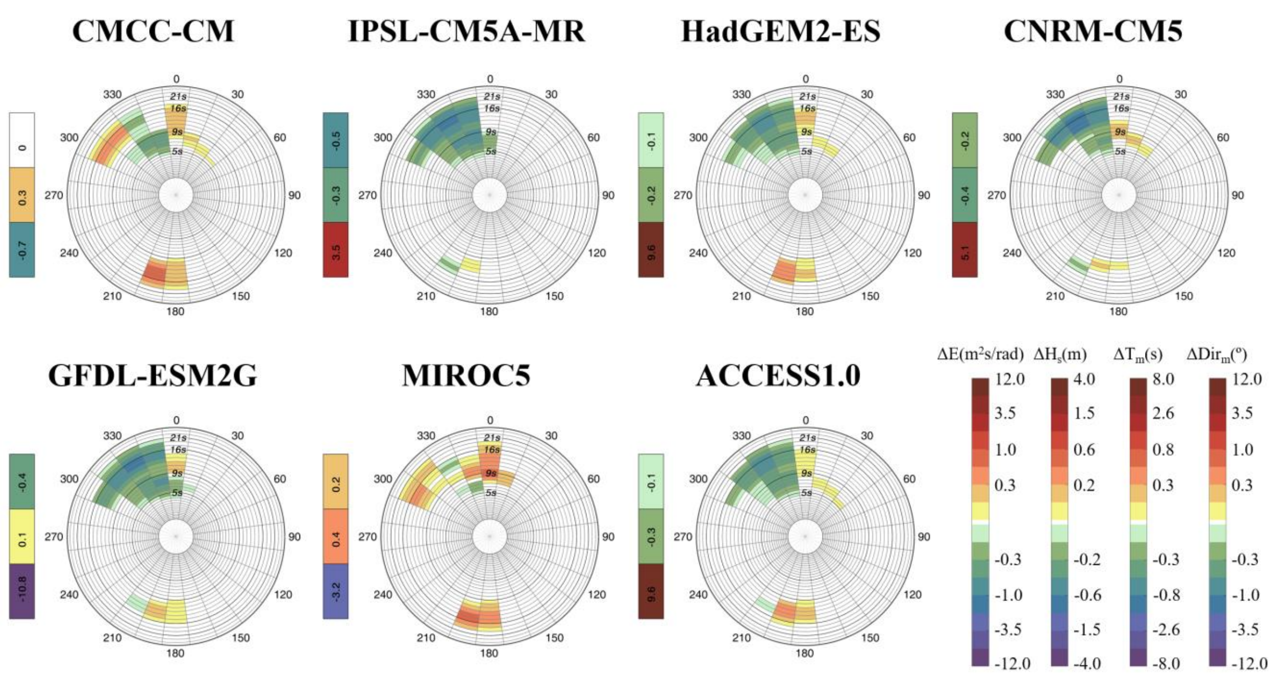
Supplementary Figure 8 Same as in Supplementary Figure 4 but at *P4*



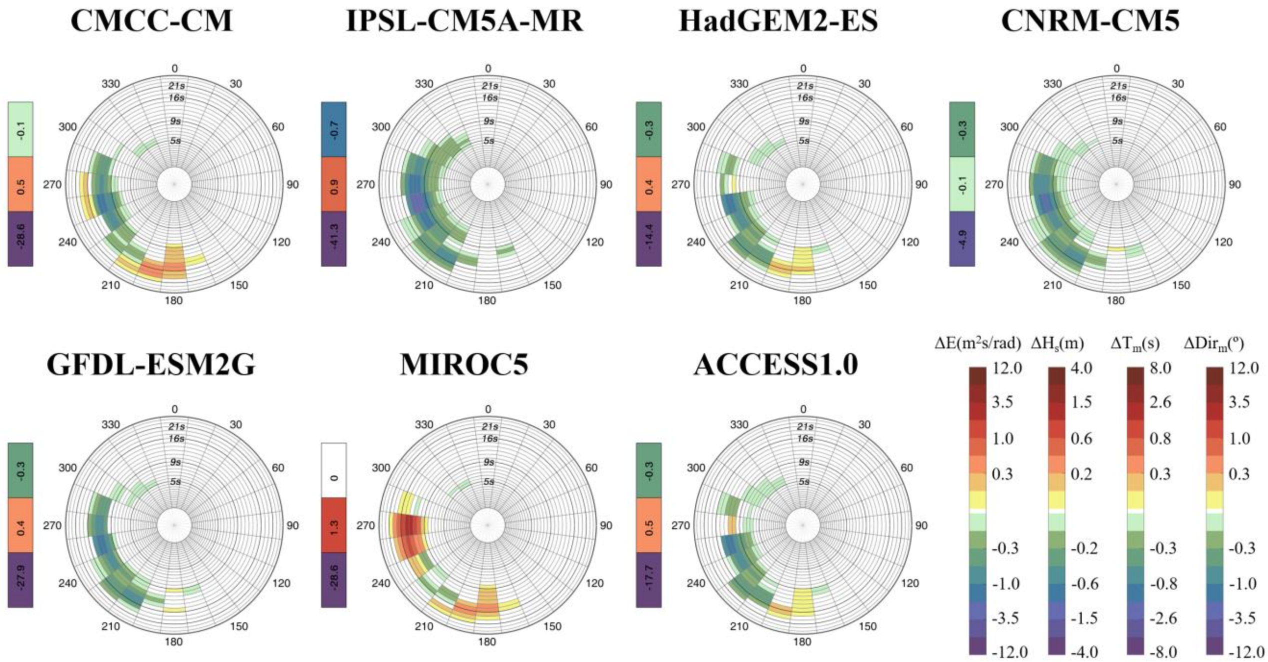
Supplementary Figure 9 Same as in Supplementary Figure 4 but at *P5*



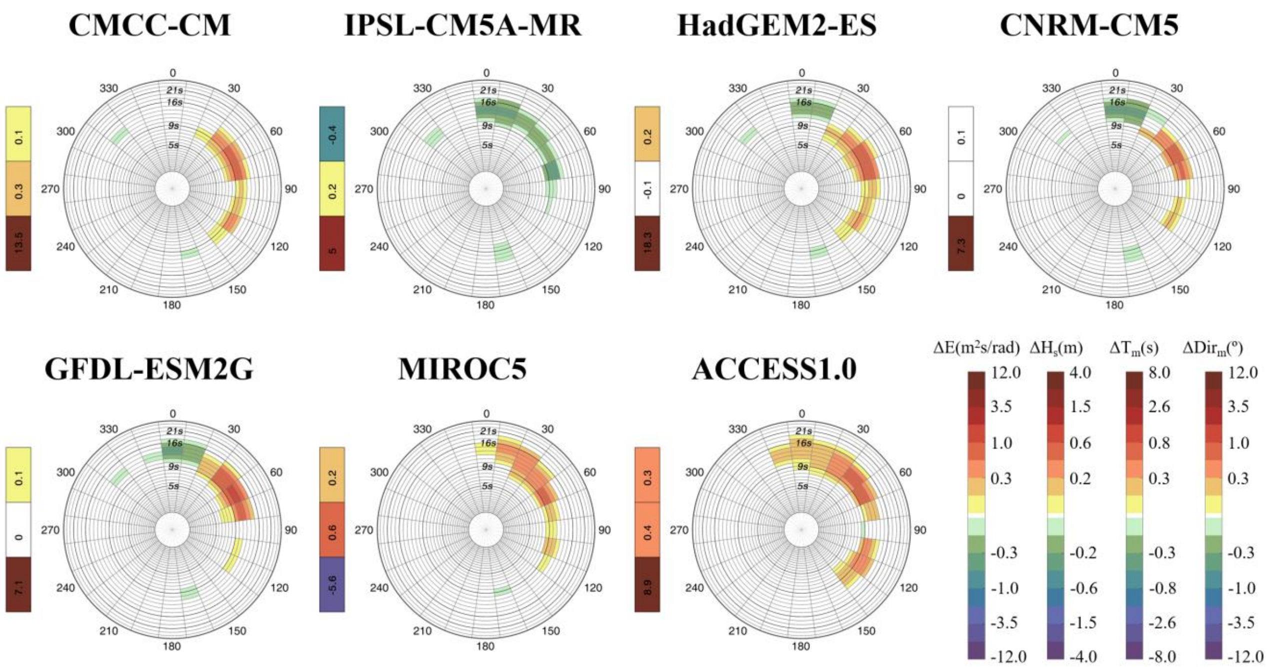
Supplementary Figure 10 Same as in Supplementary Figure 4 but at *P6*



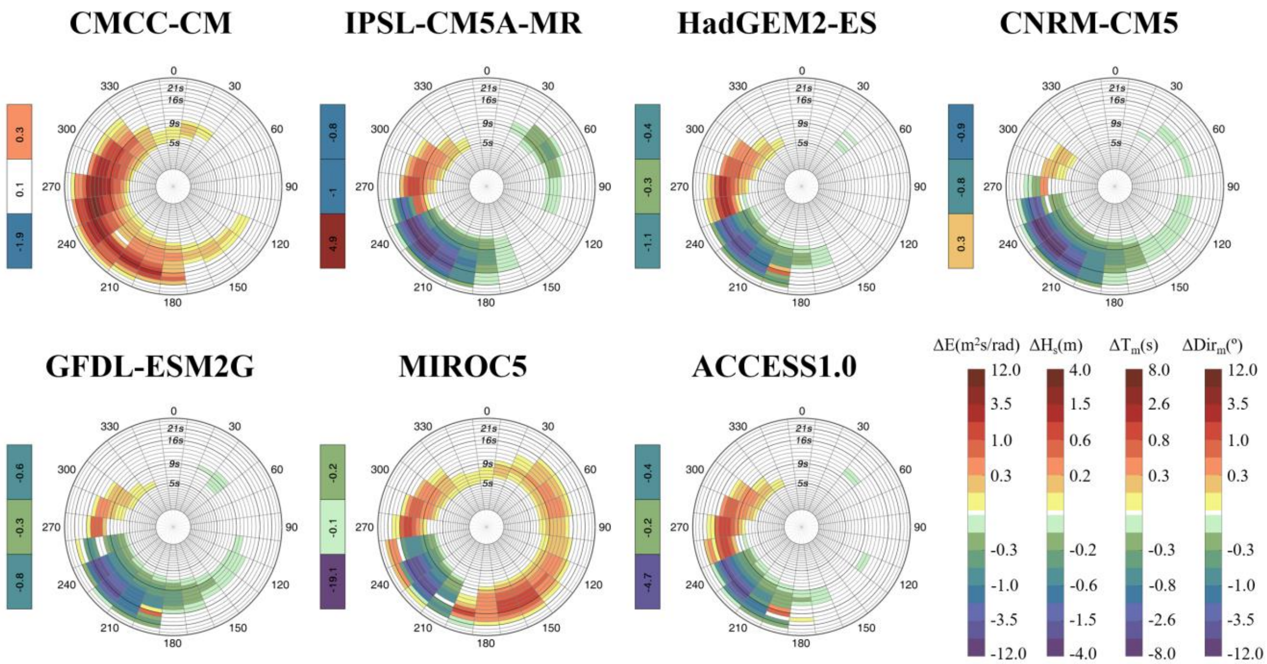
Supplementary Figure 11 Same as in Supplementary Figure 4 but at *P7*



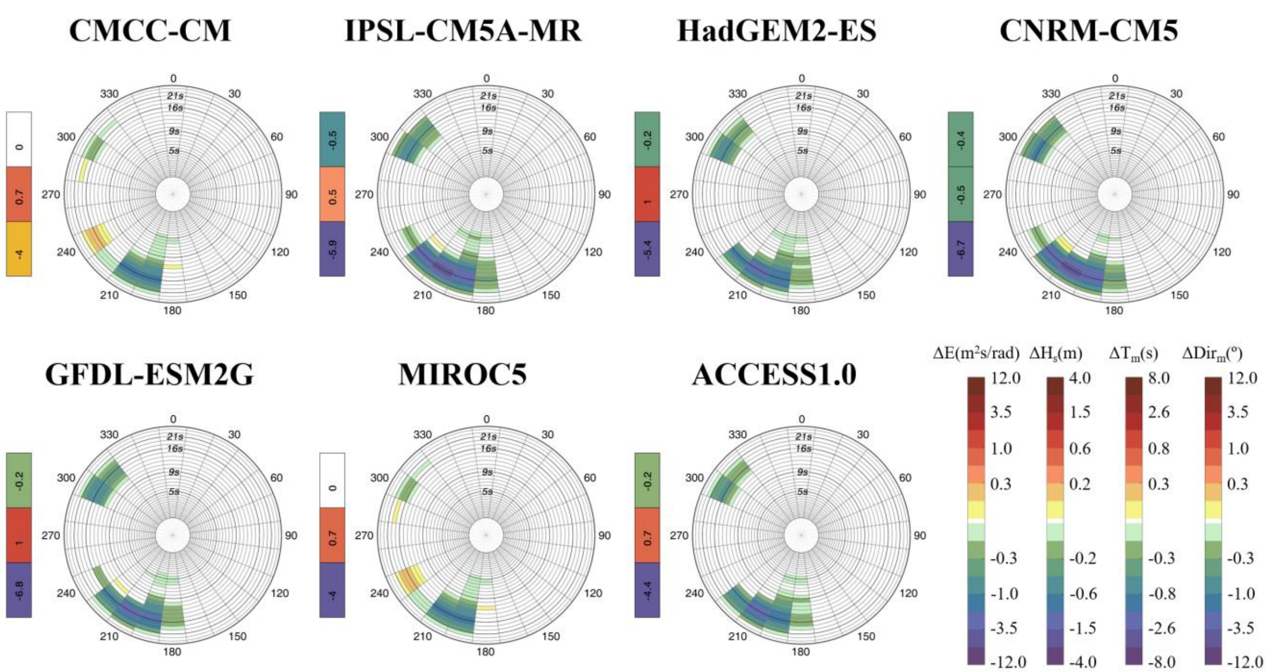
Supplementary Figure 12 Same as in Supplementary Figure 4 but at *P8*



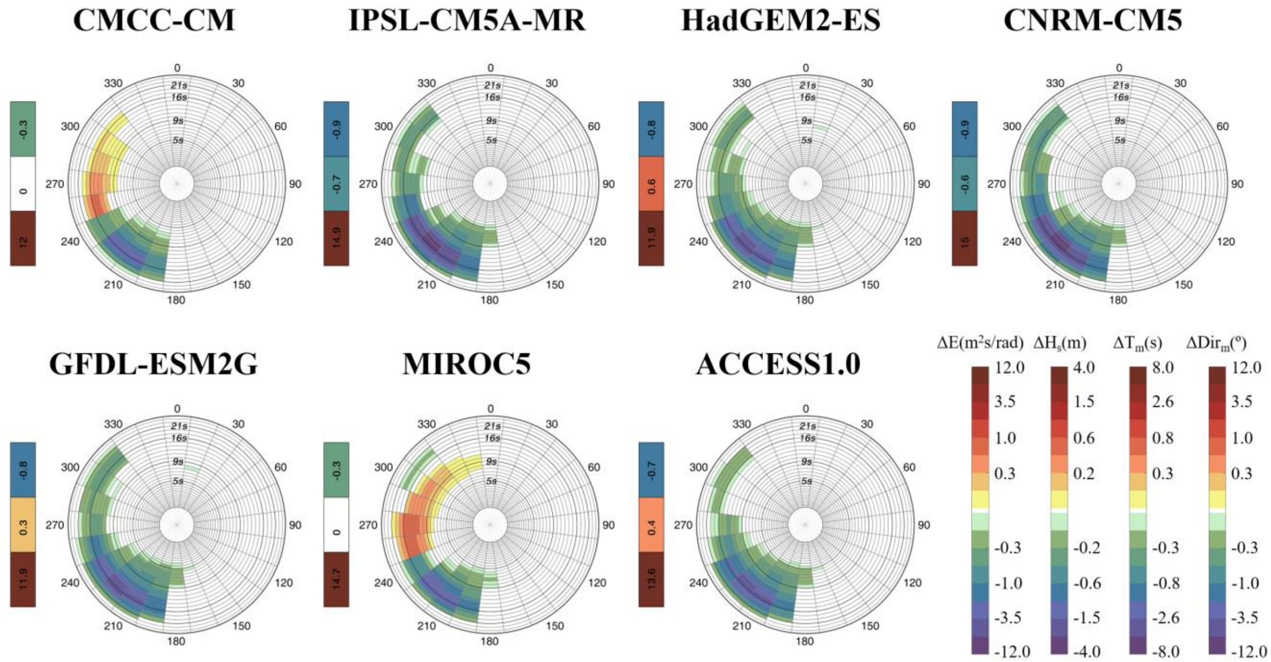
Supplementary Figure 13 Same as in Supplementary Figure 4 but at *P9*



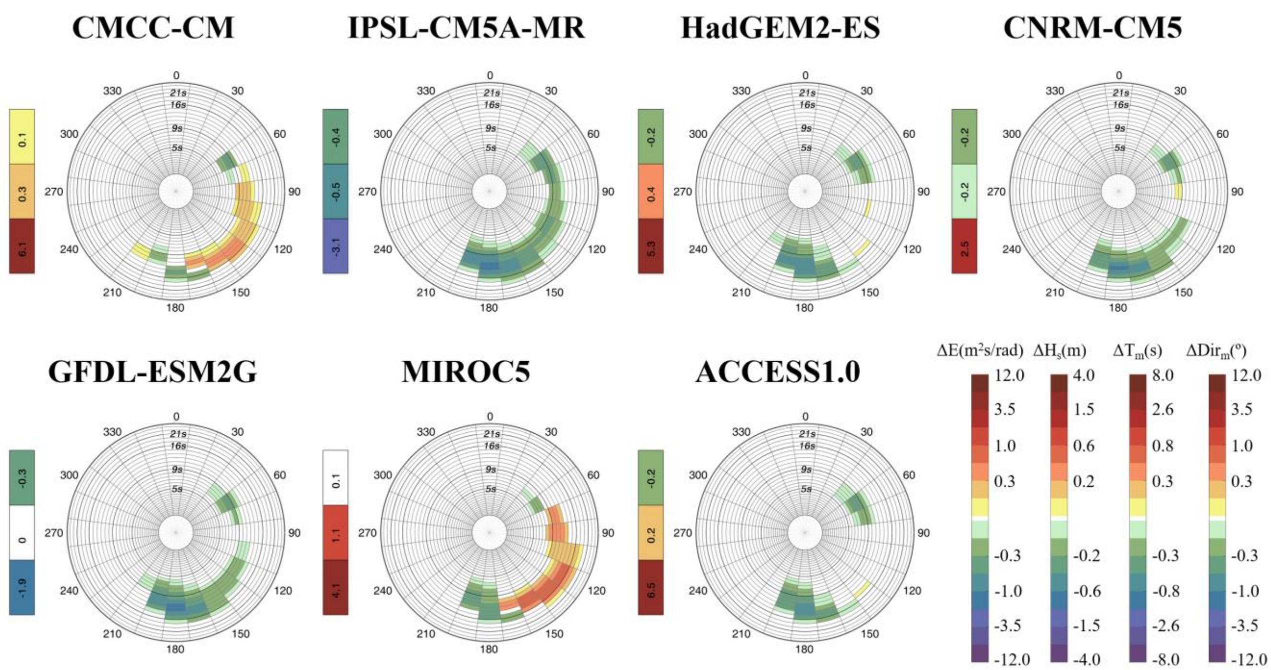
Supplementary Figure 14 Same as in Supplementary Figure 4 but at *P10*



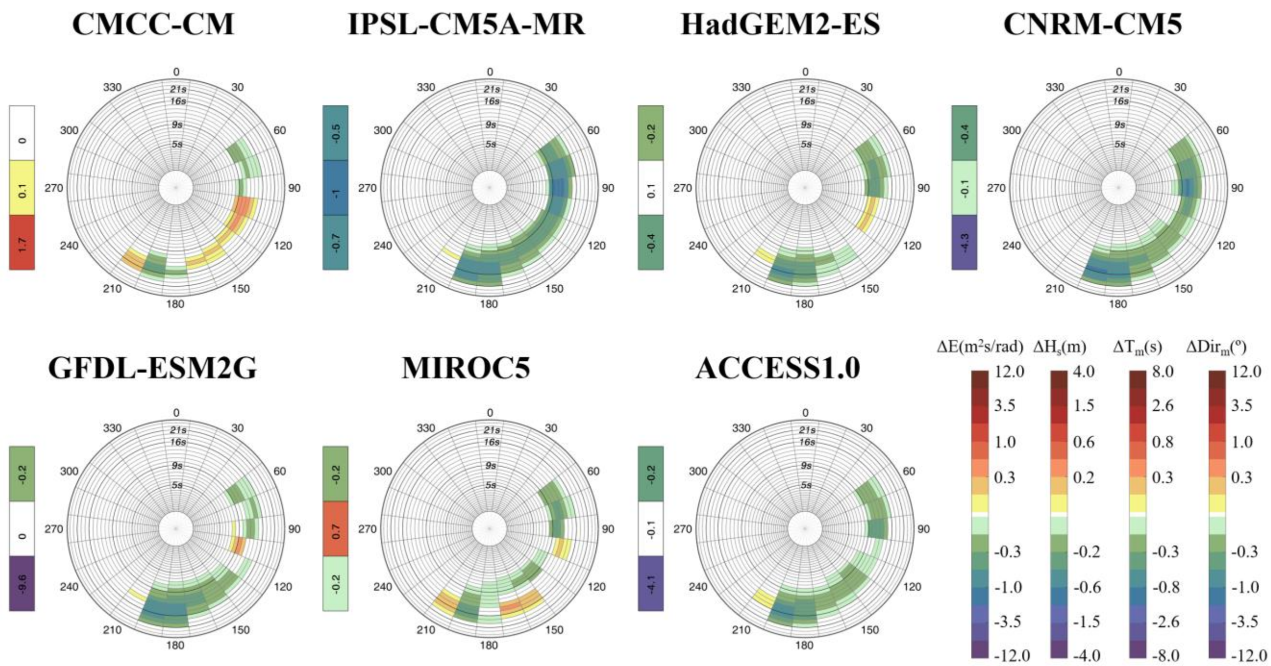
Supplementary Figure 15 Same as in Supplementary Figure 4 but at *P11*



Supplementary Figure 16 Same as in Supplementary Figure 4 but at *P12*



Supplementary Figure 17 Same as in Supplementary Figure 4 but at *P13*



Supplementary Figure 18 Same as in Supplementary Figure 4 but at *P14*

4.2 Supplementary Tables

GCM	Institution	Country	Atmospheric resolution (lat x lon)
MIROC5	MIROC	Japan	1.40º x 1.40º
IPSL-CM5A-MR	Institut Pierre-Simon Laplace	France	1.25º x 1.25º
GFDL-ESM2G	NOAA Geophysical Fluid Dynamics Laboratory	USA	2.00º x 2.50º
CNRM-CM5	Centre National de Recherches Météorologiques	France	1.40º x 1.40º
CMCC-CM	Centro Euro-Mediterraneo per I Cambiamenti Climatici	Italy	0.75º x 0.75º
ACCESS1.0	CSIRO-BOM	Australia	1.25º x 1.90º

HadGEM2-ES	Met Office Hadley Centre	UK	1.25º x 1.90º

Supplementary Table 1 Main characteristics of the selected Atmosphere-Ocean General Circulation Models.

Domain	Lat. Limits (°)	Long. Limits (°)	Spatial resolution (°)	Time steps (s)
				Overall/CFL/refraction/minimum
Global	-85 to 88	-180 to 180	1	2880/720/1440/20
North Atlantic	23 to 61	-35 to 9	0.5	1800/900/900/20
Arctic	75 to 88	-180 to 180	1	1800/900/900/20

Supplementary Table 2 Main characteristics of the numerical domains: latitudinal limits, longitudinal limits, spatial resolution and time steps.

5 References

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