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Projections of waves in the North Atlantic under high-end emissions scenarios

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OUTLINE

- Motivation – the RISES-am- project – storms and waves
- Questions to be addressed
- Summary
- Climate and Wave Model downscaling
- Implementation of WWIII on global and regional grids
- Liverpool tidal barrage/lagoon with multiple use to manage coastal flooding

MOTIVATION

RISES-AM Project (Funded by EU FP7)**:**
Responses to coastal climate change: Innovative Strategies for high End Scenarios -Adaptation and Mitigation

Aim:

- To examine the projections of coastal impacts and resilience under high-end climate change scenarios (where global average warming is projected to exceed 2°C with respect to pre-industrial temperatures)
- We are using RCP4.5 (medium emission) and RCP8.5 (high emission) projections from the Coupled Model Inter-comparison Project Phase 5 (CMIP5) climate model results to force global and regional models of storm surges and waves which will then feed into regional and local coastal impact case studies

Areas of interest: global, regional (Mediterranean, NW Europe), local

Questions to be addressed

- What are projected changes in storms under a warming climate?

- Can these be modelled accurately in the latest climate models (CMIP5)?

- Are there significant changes between CMIP3 and CMPI5?

- Will these be converted to significant changes in waves and surges on the Atlantic coast of Europe?

- Can we distinguish between natural variability and the climate signal?

- What novel adaptation/mitigation methodologies can be deployed?

SUMMARY (Ref: IPCC AR5)

- Tropical cyclone frequency will likely decrease or remain roughly constant, but it is more likely than not that the frequency of the most intense storms will increase in some ocean basins
- Changes in extra-tropical storms – less clear
- Change from CMIP3 to CMIP5 – still some biases in storm tracks
- Wave generation in the Southern Ocean is projected to undergo pronounced increase in the wind speed and significant wave height in the near future under a future scenario of climate change
- Ocean waves projected to increase in the ice-free future Arctic Ocean
- In the main part of North Atlantic, a decrease of wind speed and significant wave height is projected
- Low confidence in region-specific projections due to the low confidence in tropical and extratropical storm projections, and to the challenge of downscaling future wind fields from coarse-resolution climate models.

Assessment of Climate Models (AR5)

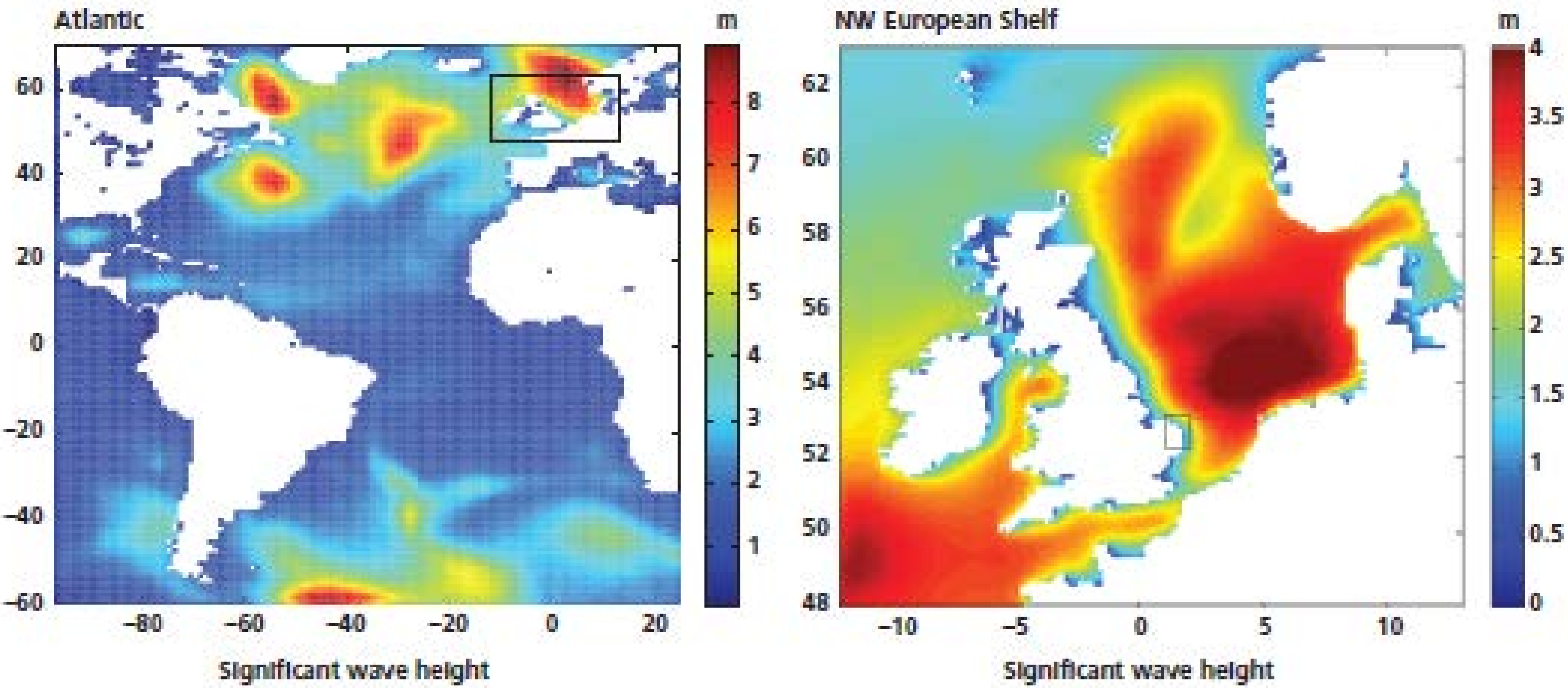
- **Models are able to capture the general characteristics of storm tracks and extra-tropical cyclones, and there is some evidence of improvement since the AR4.** Storm track biases in the North Atlantic have improved slightly, but models still produce a storm track that is too zonal and underestimate cyclone intensity

- Mediterranean storms are affected by Atlantic storm track/jet stream pattern, but modified by local cyclogenesis

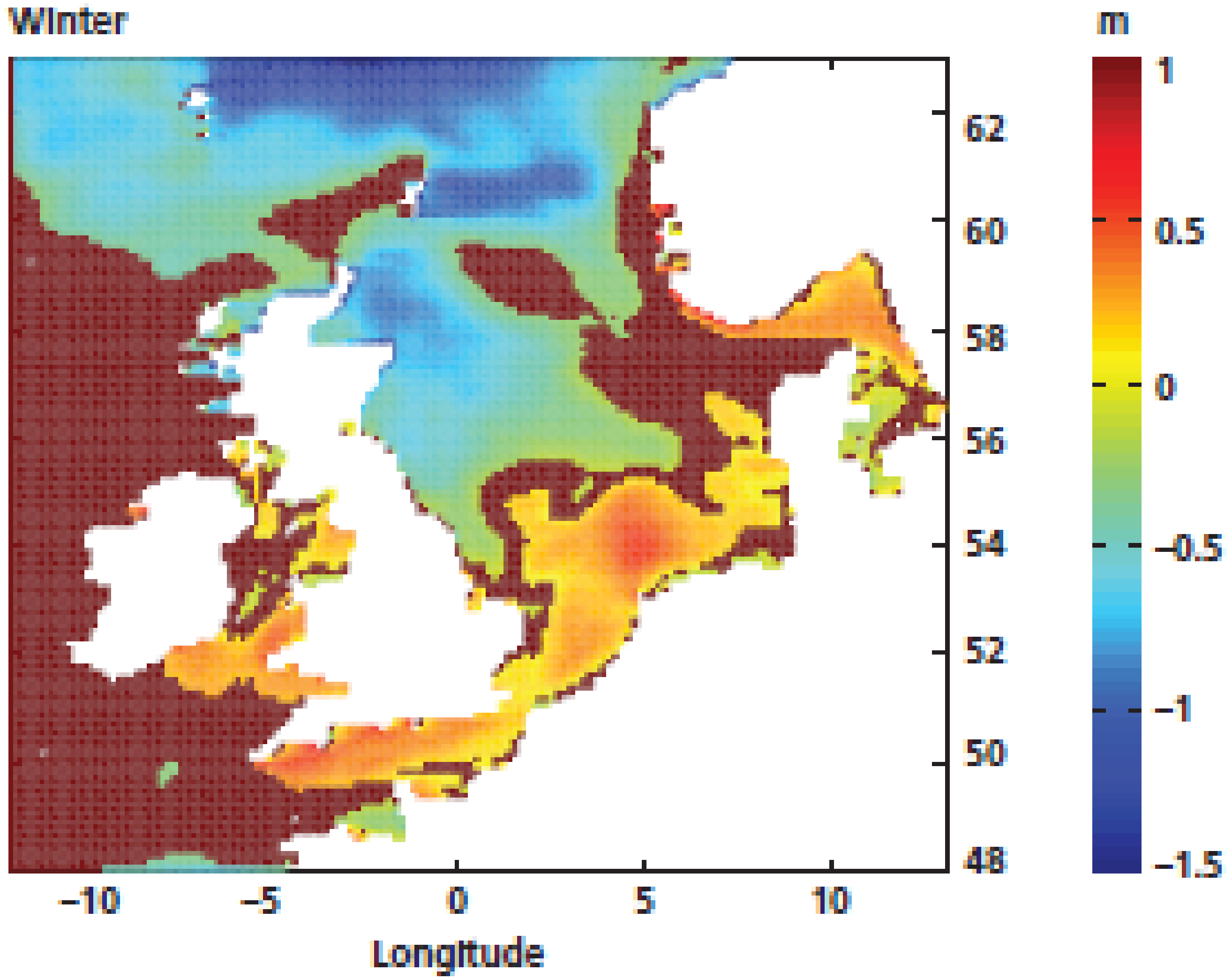
Downscaling global to regional winds and waves

- Climate change assessments almost always based on the outputs of general circulation models (GCMs)
- This typically includes an additional step of downscaling using higher resolution regional climate models or some form of statistical model (Wolf et al., 2015)
- Ways of incorporating climate change
  - Use GCM output directly – but **there may be bias** between statistics for ‘control runs’ of historic climate and actual climate
  - Adjust historic climate using ‘change factors’
  - Use ‘climate analogues’ - using past periods to represent future
  - Accept bias and use difference between present and future GCM outputs

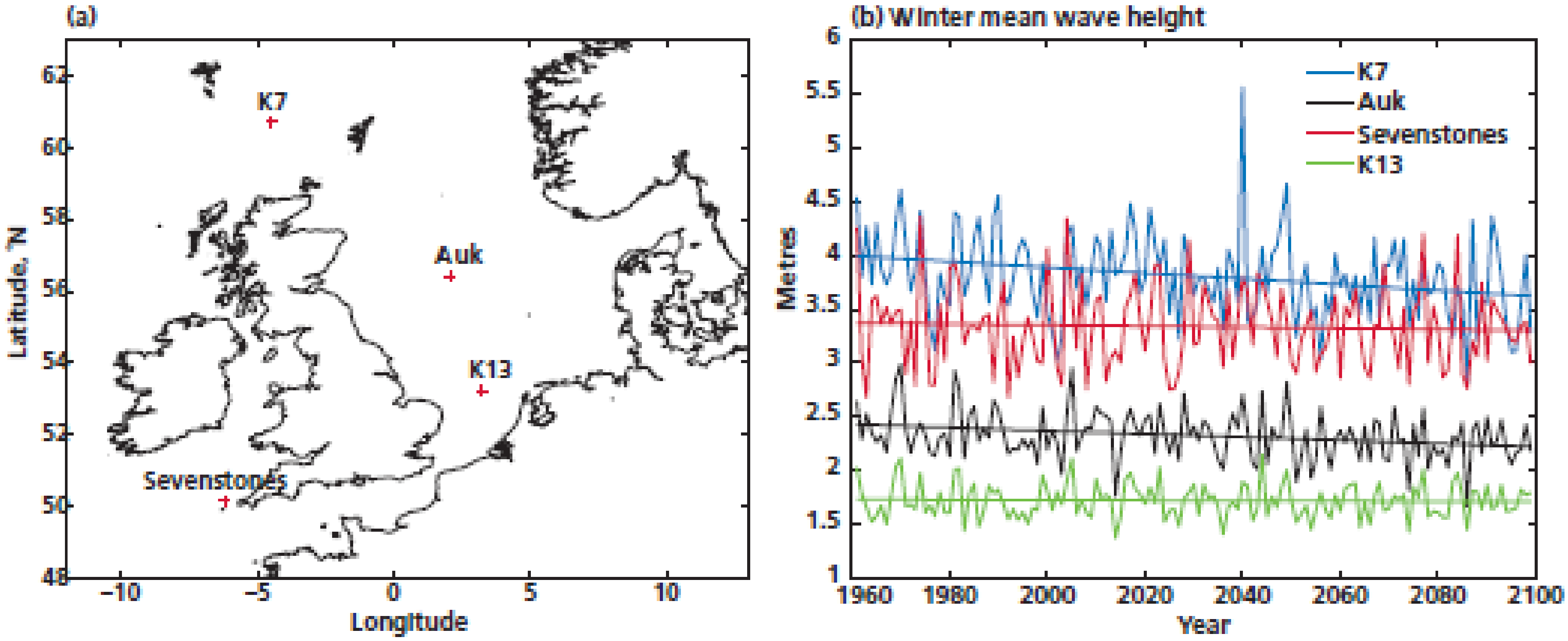
Wave projections (Wolf et al., 2015)



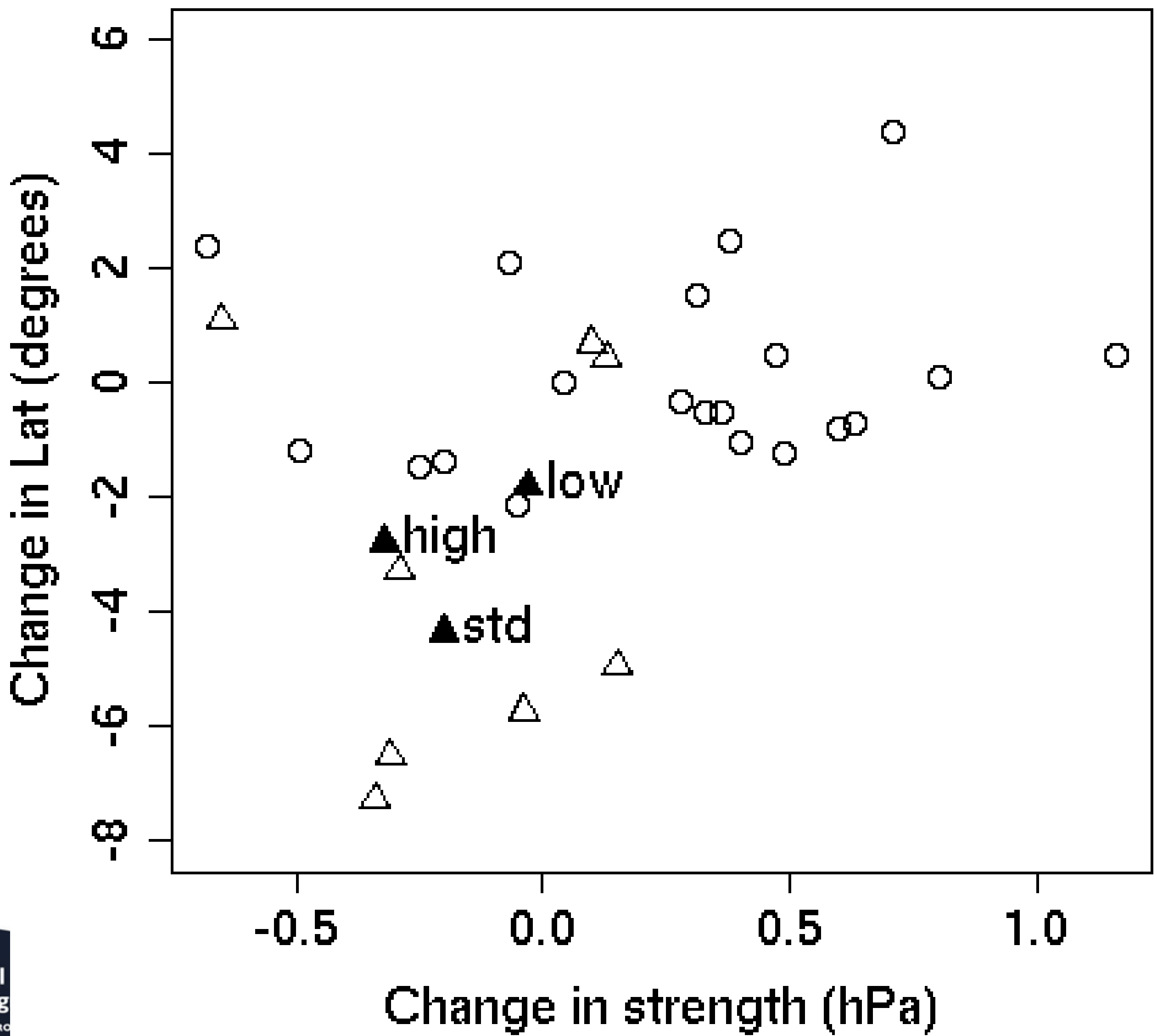
Projected changes in mean winter wave height



Decadal variability



Changes in Atlantic storm track intensity and location at 4 degrees west (CMIP3)



Open circles show the CMIP3 MME and triangles show the HadCM3 PPE, the filled triangles show the subset used for wave model forcing in UKCP09

North Atlantic storms in CMIP5 (Zappa et al., 2013)

- winter-time North Atlantic storm tracks (compared to CMIP3) are still either **too zonal or displaced southwards**
- there are improvements both in number and intensity of North Atlantic cyclones, in the higher resolution CMIP5 models. 3 groups of models:
  - small biases in winter-time position, median latitude consistent with reanalysis data: EC-Earth, GFDL-CM3, HadGEM2 and MRI-CGCM3
  - southern displacement of the winter-time storm track: BCC-CSM, CMCC-CM, CNRM-CM5, CSIRO, FGOALS-g2, IPSL-LR, and MIROC-ESM
  - Remainder of CMIP5 models too zonal
- winter-time southward displacement of the North Atlantic storm track leads to too few and weaker cyclones over the Norwegian Sea and too many cyclones in central Europe

Models generally perform better in summer!

Relationship between biases in Northern Hemisphere (NH) atmospheric blocking frequency and extratropical cyclone track density
Zappa et al. (GRL, 2014)

Looked at 12 CMIP5 climate models

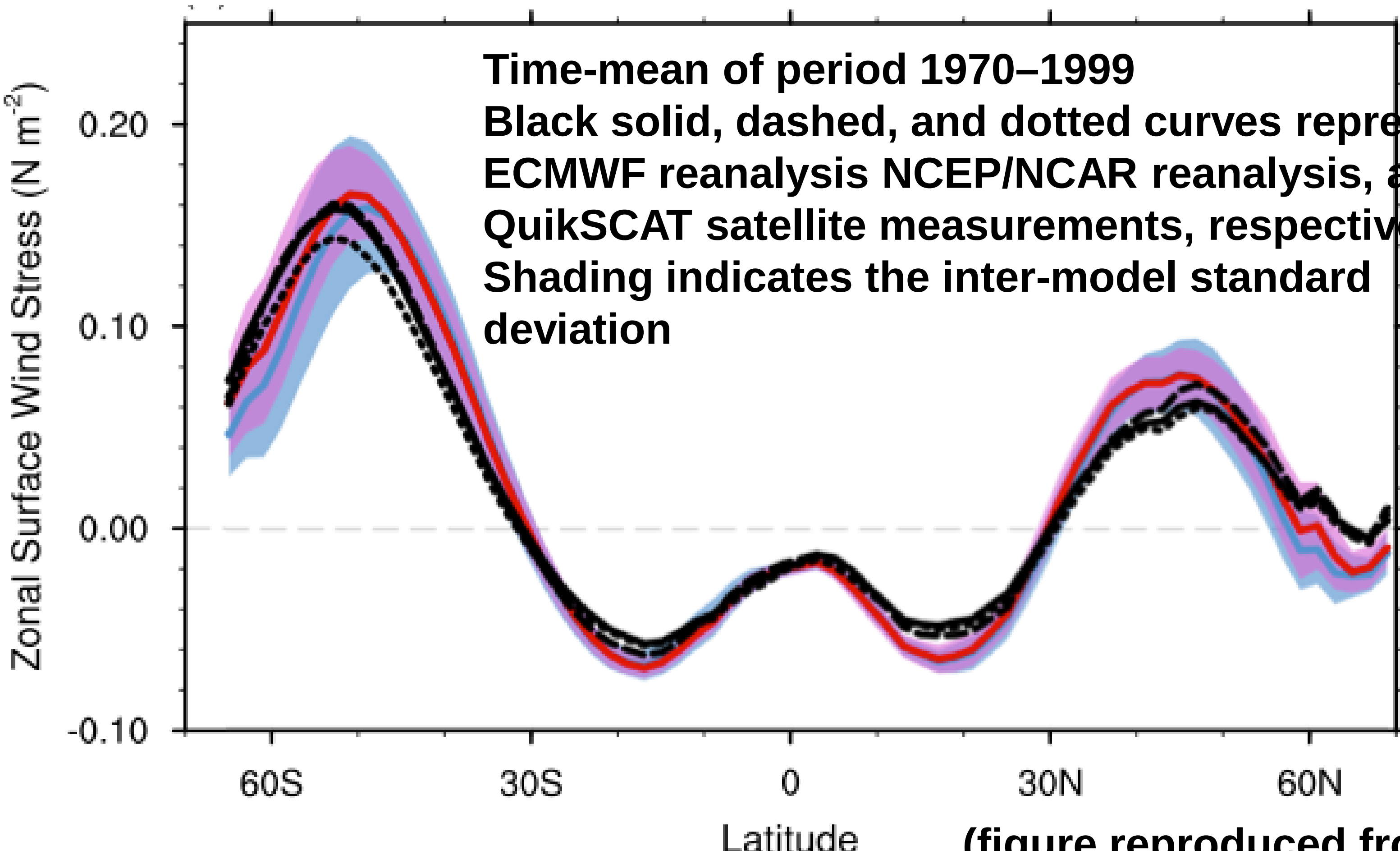
Biases in the Greenland blocking and summer Pacific blocking frequencies are associated with biases in the storm track latitudes, while biases in winter European blocking frequency are related to the North Atlantic storm track tilt and Mediterranean cyclone density.

Biases in summer European and winter Pacific blocking appear less related with cyclone track density.

Models with smaller biases in winter European blocking frequency have smaller biases in the cyclone density in Europe, which suggests that they are different aspects of the same bias.

Summer North Atlantic and the North Pacific mean CMIP5 track density and blocking biases might have different origins.

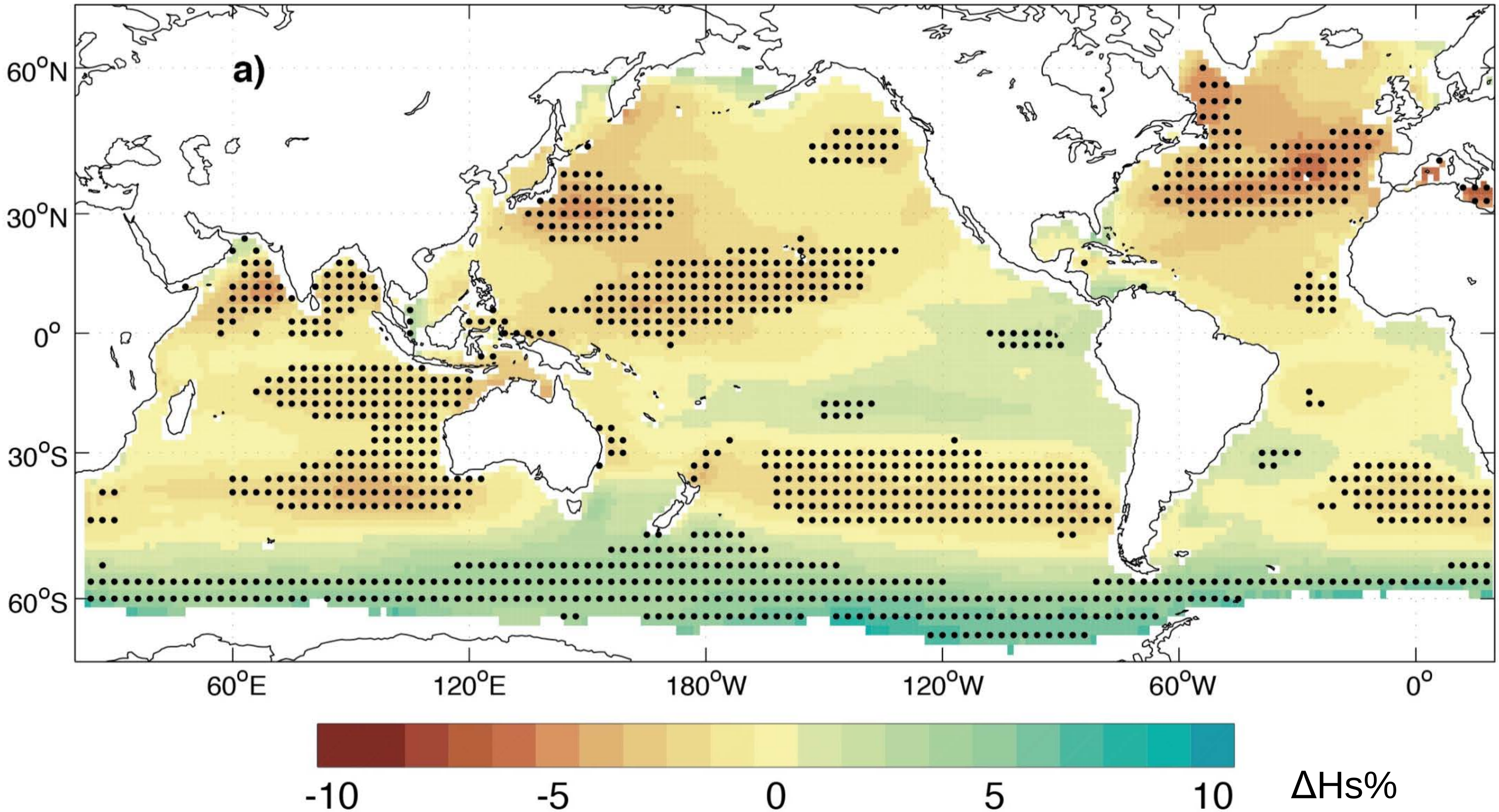
Zonal-mean zonal wind stress over the oceans in a multi-model mean from CMIP3 (blue) and CMIP5 (red) models simulations.



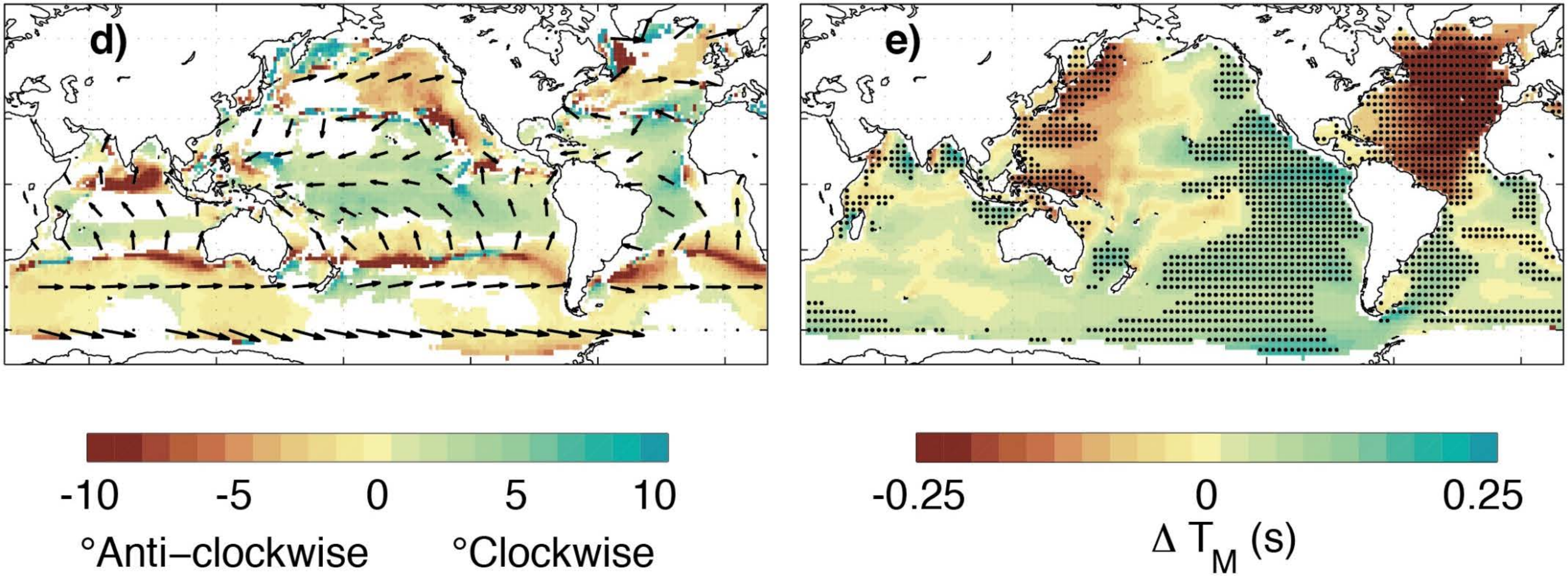
Time-mean of period 1970–1999
Black solid, dashed, and dotted curves represent ECMWF reanalysis NCEP/NCAR reanalysis, and QuikSCAT satellite measurements, respectively. Shading indicates the inter-model standard deviation

(figure reproduced from Fig. 9.19b in IPCC AR5)

Changes in waves, CMIP3: IPCC AR5 Figure 13:26

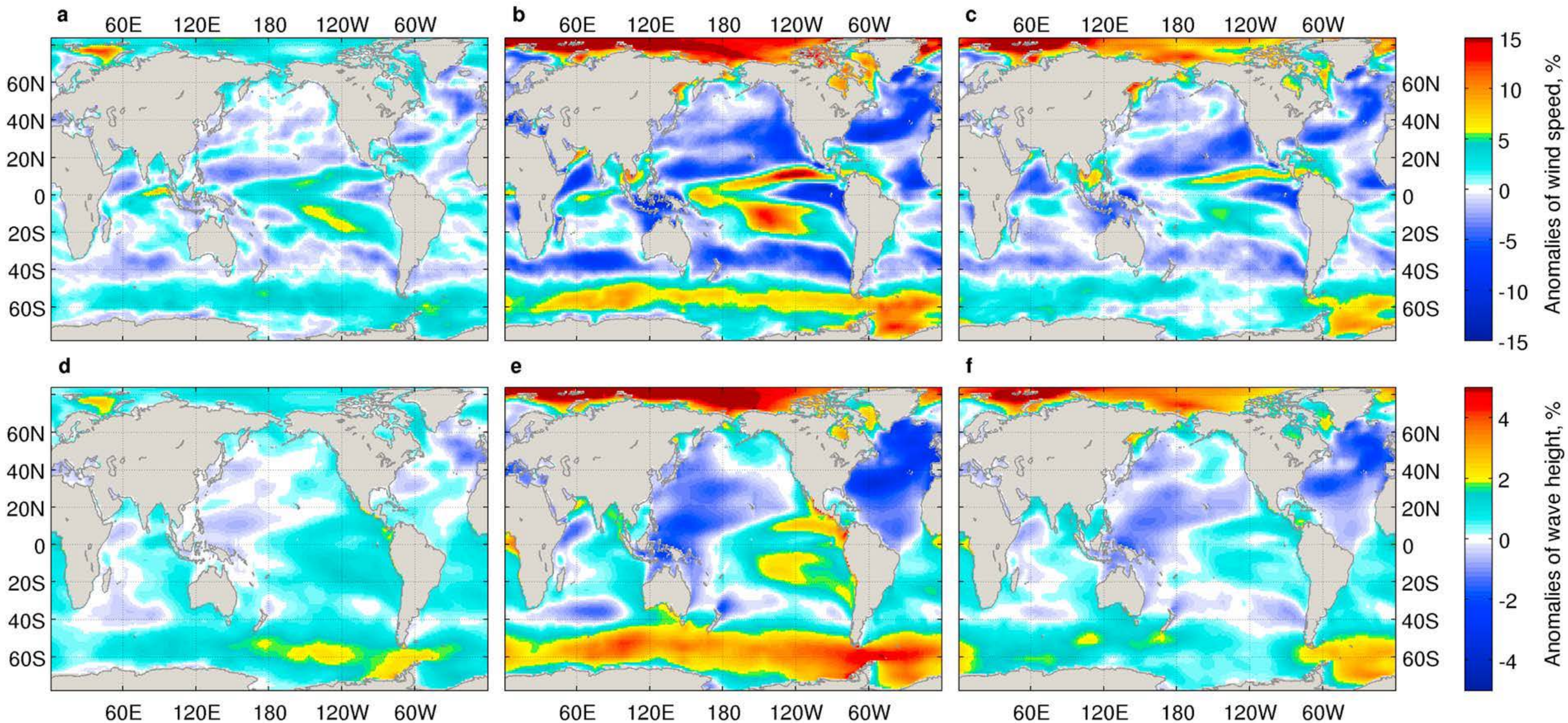


Projected changes in wind-wave conditions (~2075-2100 compared with 1980-2009) derived from the COWCLIP project (Hemer et al., 2013) (a) percentage difference in annual mean significant wave height. Hashed regions indicate the difference is greater than the 5-member ensemble standard deviation



(d) as (a) but displaying absolute changes in mean wave direction, with positive values representing projected clockwise rotation relative to displayed vectors, and colours shown only where ensemble members agree on sign of change (e) as for (a), but displaying absolute change in mean wave period.

Preliminary CMIP5 wave results: WAM forced by EC-Earth - Dobrynin et al. (GRL, 2012)



1989-1999 | 2090-2100 RCP8.5 | 2090-2100 RCP4.5

Top = wind speed anomaly (relative to period 1850 to 1870)

Bottom = Significant wave height (")

Wang et al (GRL, 2014) Statistical wave modelling from 20 CMIP5 models

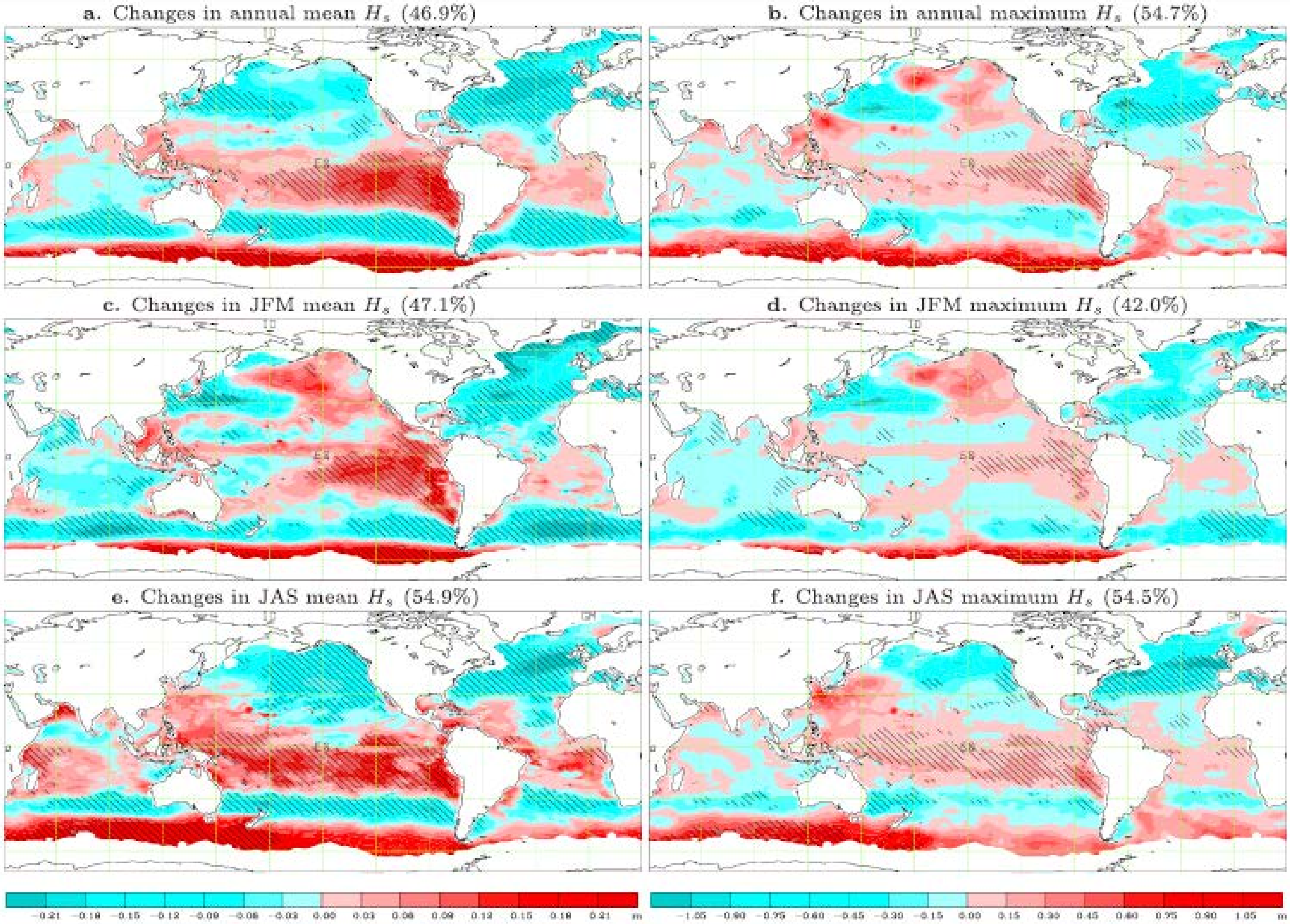
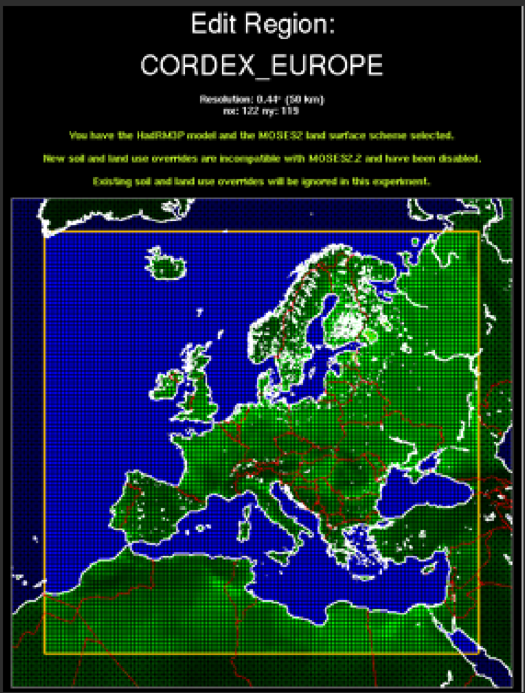


Figure 2. (a–f) The 20-model ensemble mean of projected changes in annual/seasonal mean and maximum significant wave heights (H_s, m) for the period 2080–2099 relative to the period 1980–1999 for the RCP8.5 scenario. Hatchings indicate areas where the multimodel ensemble mean exceeds the intermodel standard deviation. The percentage of area with projected H_s increases are shown in parentheses on top of each panel.

Euro-CORDEX dynamical downscaling

http://wcrp-cordex.ipsl.jussieu.fr/index.php/community/domain-euro-cordex

Region 4: EURO-CORDEX



Ref: Description of the CORDEX domains (02/04/2013 version)

A) For rotated polar RCMs (in rotated coordinates):

RotPole (198.0; 39.25)
TLC (331.79; 21.67)
Nx=106
Ny=103

B) For non-rotated polar I

TLC (315.86; 60.21)
CNB (1.92; 71.84)
TRC (64.4; 66.65)
CWB (338.23; 42.36)
CPD (9.75; 49.68)
CEB (44.77; 46.72)
BLC (350.01; 22.20)
CSB (12.48; 27.34)
BRC (36.30; 25.36)

Website:

- EURO-CORDEX

SAT responsible and poi

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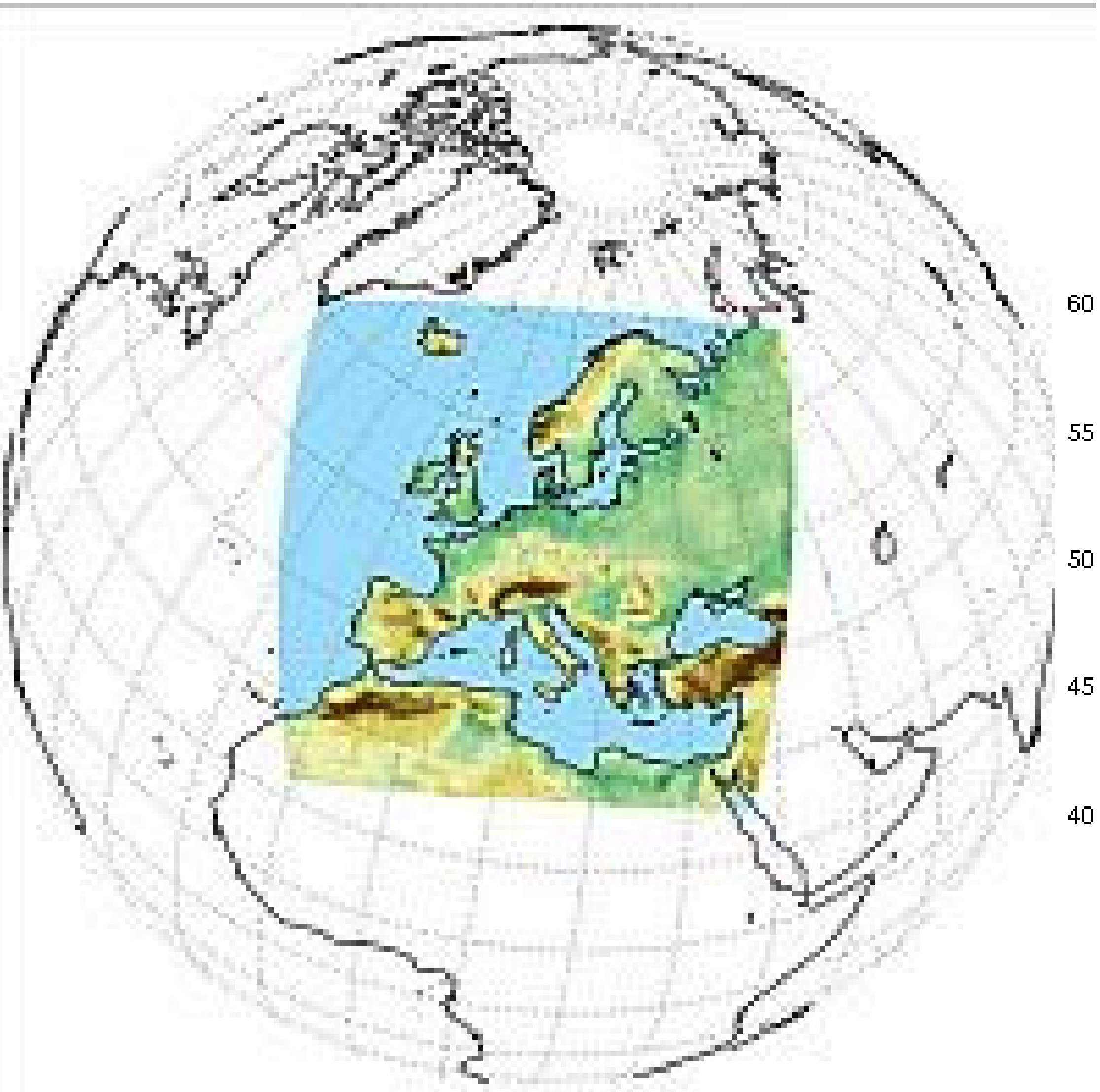
Objectives:

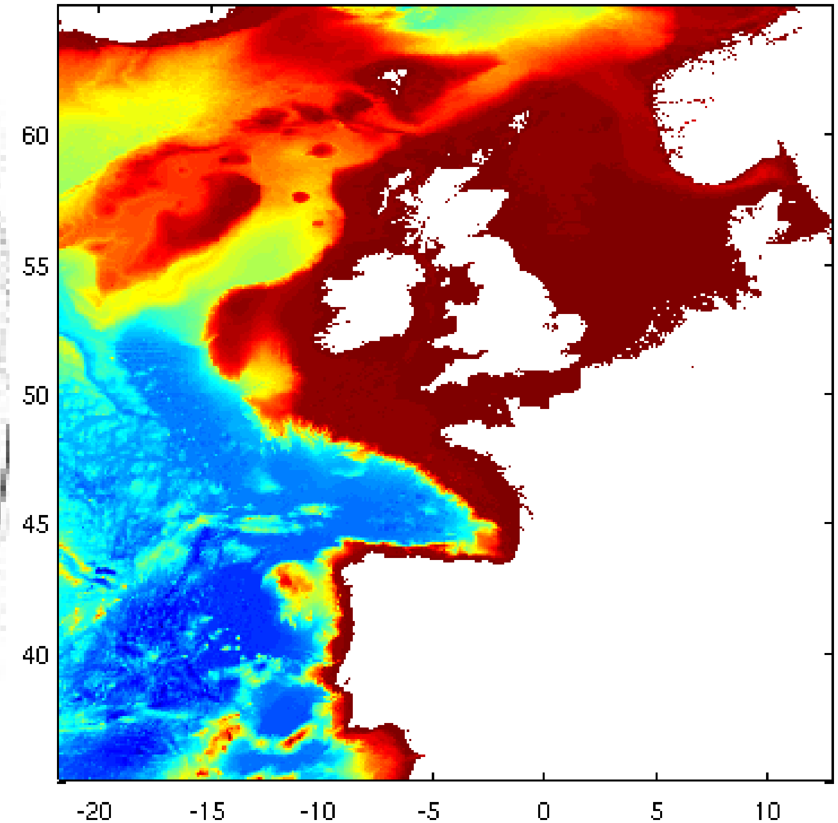
- GCMs with weak performances over Europe should be avoided
- spread of CMIP5 simulations should be adequately sampled
- RCM data are only available as daily means for the atmospheric surface variables - higher frequency output may be available through project partners

CORDEX Domains

- Definition
- RDEX
- ORDEX
- erica CORDEX
- merica
- erica CORDEX
- Antarctica
- RDEX
- RDEX
- RDEX
- a CORDEX
- sia CORDEX
- East Asia CORDEX

~12km WW3 model based on Euro-CORDEX area, nested in Atlantic wave model forced by GCM winds

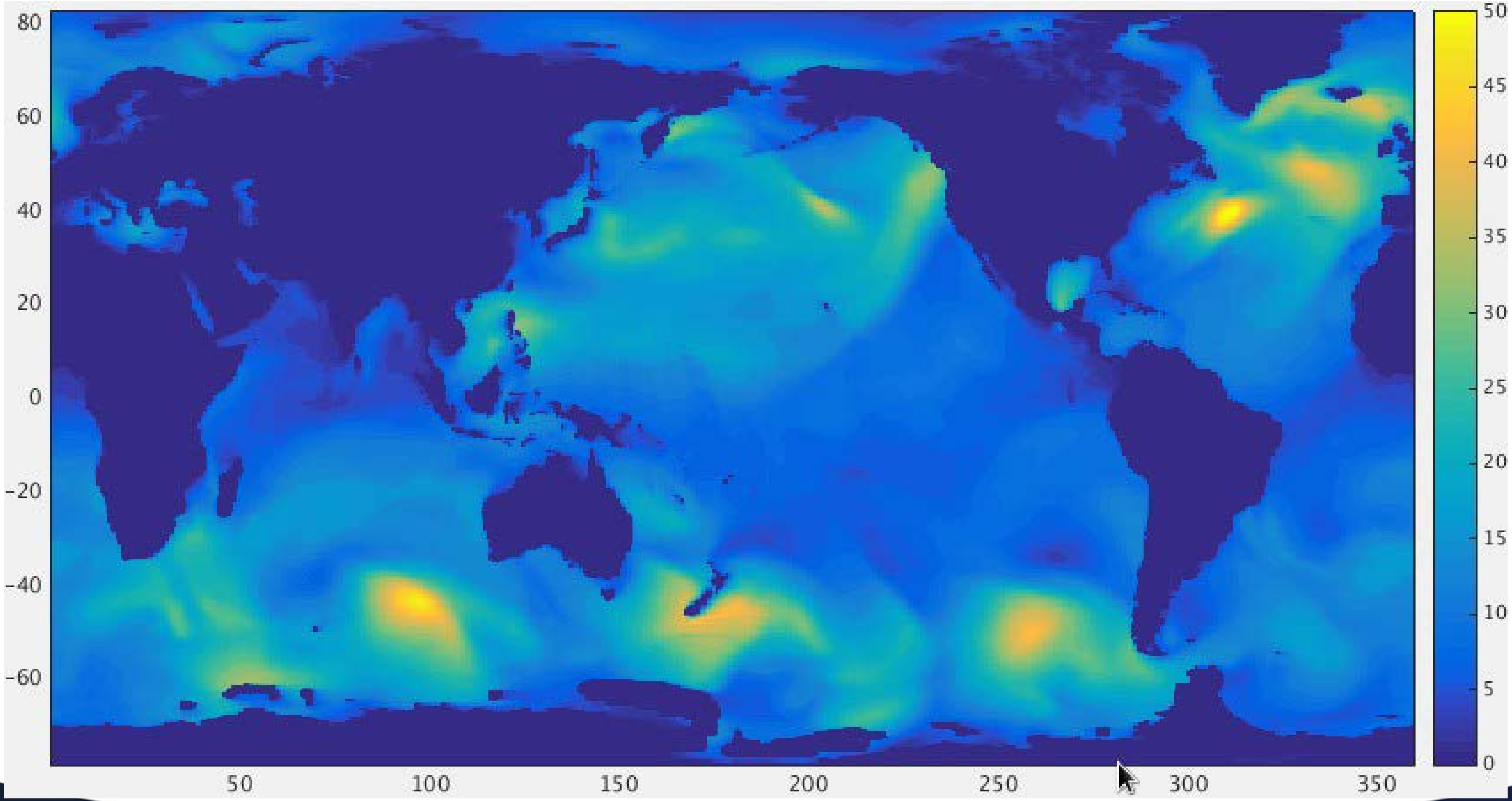




SMHI-RCA4 CORDEX Europe (EUR-11)

ID	Rean/GCMs	Exp.	Res.	Period
201117	ERA-INT	eval	0.11	1979-2010
201254	ERA-INT SN	eval	0.11	1979-2010
201143	CNRM-CM5	hist	0.11°	1969-2005
201144	CNRM-CM5	rcp45	0.11°	2006-2050
201145	CNRM-CM5	rcp85	0.11°	2006-2100
201131	HadGEM2-ES	hist	0.11°	1969-2005
201132	HadGEM2-ES	rcp45	0.11°	2006-2099
201133	HadGEM2-ES	rcp85	0.11°	2006-2099
201137	EC-Earth	hist	0.11°	1969-2005
201138	EC-Earth	rcp45	0.11°	2006-2100
201139	EC-Earth	rcp85	0.11°	2006-2100
201147	EC-Earth	rcp26	0.11°	2006-2100
201247	MPI-ESM-LR	hist	0.11°	1969-2005
201402	MPI-ESM-LR	rcp45	0.11°	2006-2100
201248	MPI-ESM-LR	rcp85	0.11°	2006-2100
201249	IPSL-CM5A-MR	hist	0.11°	1969-2005
201403	IPSL-CM5A-MR	rcp45	0.11°	2006-2100
201250	IPSL-CM5A-MR	rcp85	0.11°	2006-2100

Example of global model output



Estimated run time on UK National Supercomputer (ARCHER)

The total runtime required is: 1970-2005 2006-2100	Historic: 1970-2005	RCP 4.5: 2006-2100	RCP 8.5: 2006-2100
Global	35 hours	94 hours	94 hours
NEA	35 hours	94 hours	94 hours

References

Wolf, J., Lowe, J. and Howard, T. (2015) Climate Downscaling: Local Mean Sea-Level, Surge and Wave Modelling, Chapter 2 in ‘Broad Scale Coastal Simulation: New Techniques to Understand and Manage Shorelines in the Third Millennium’ (eds. R. J. Nicholls, R. J. Dawson and S. A. Day); Springer.

Chini, N., Stansby, P., Leake, J., Wolf, J., Roberts-Jones, J. and Lowe, J. 2010 The impact of sea level rise and climate change on extreme inshore wave climate: a case study for East Anglia (UK). Coastal Engineering, 57, 11-12, 973-984.

Lowe, J.A., Howard, T., Pardaens, A., Tinker, J., Holt, J., Wakelin, S., Milne, G., Leake, J., Wolf, J., Horsburgh, K., Reeder, T., Jenkins, G., Ridley, J., Dye, S. and Bradley, S. (2009) UK Climate Projections science report: Marine and coastal projections. Met Office Hadley Centre, Exeter, UK.

Questions?