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CMIP5-based global wave climate projections including the entire Arctic Ocean

1ST International Workshop ON Waves, storm Surges and Coastal Hazards

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Outlines

- Wave modelling setup
- Evaluation of the historical simulations
  - Wave climate
  - Climate of wind & sea ice concentration
- Projected changes
  - globally
  - Arctic Ocean
- Summary

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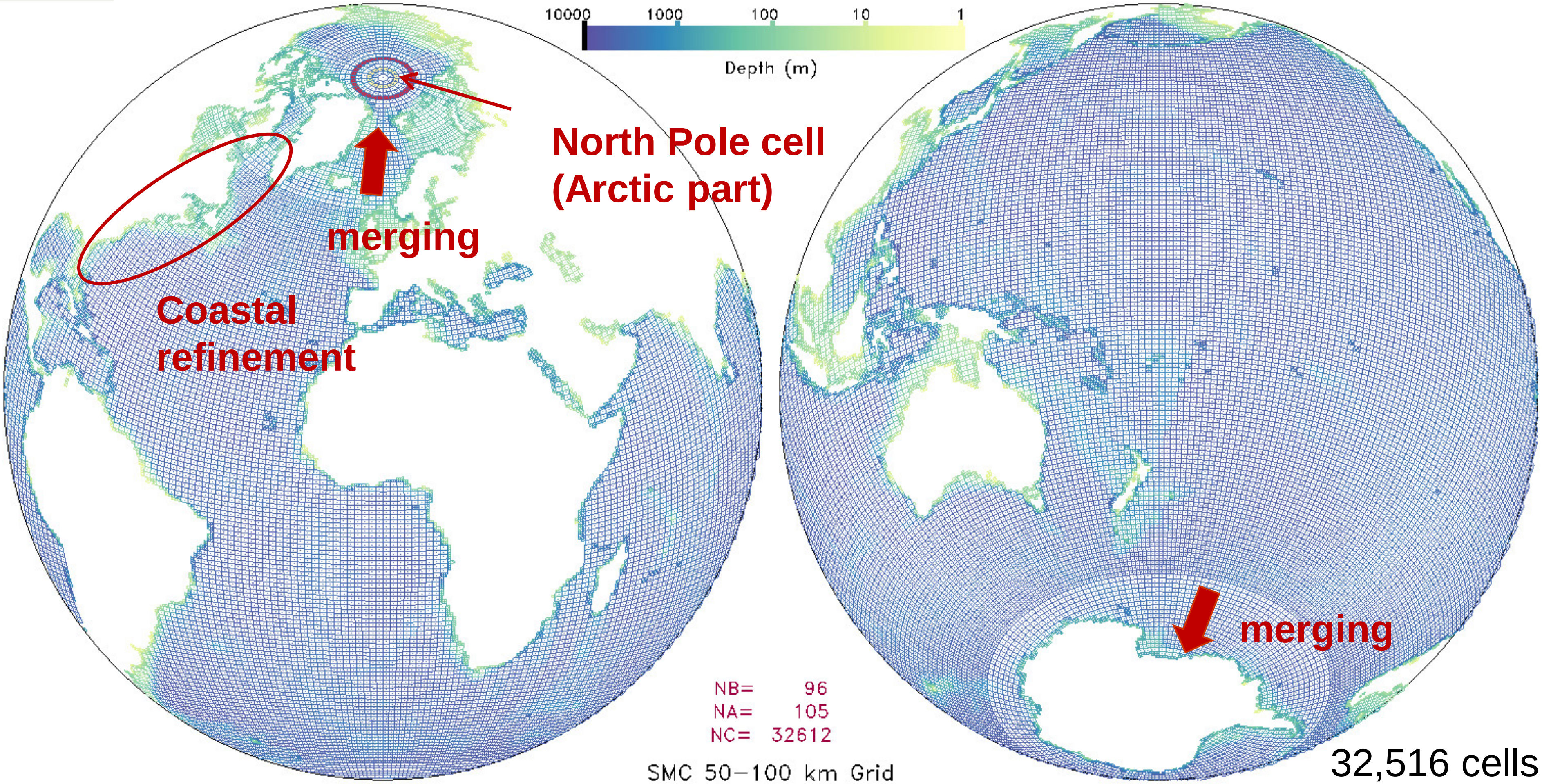
Wave modelling setup

- Used WaveWatch III v4.18
- Model physics: ST4, NL1, IC0 (25%, 75%)
- Spectrum resolution: 29 frequency and 24 direction bins
- Wave grid: Spherical Multiple-Cell (SMC) grid (Li 2010) – (next slide)
- Time resolution: 1 hour (computational and output)
- Input data:
  - 3-hourly 10-m surface winds (1° ~ 2.8° horizontal resolution)
  - daily sea ice concentration data (0.5° ~ 1.4°horizontal resolution)

  from five CMIP5 models: BCC-CSM1-1, EC-EARTH, GFDL-ESM2M, INMCM4, MIROC5
- Simulation periods: 1979-2005 (historical) and 2081-2010 (RCP8.5)
- Output data: H_s, T_p, θ_m → Inverse wave age A^{-1}

The SMC grid used: base ~100 km, coasts~50 km



32,516 cells
(reg. grid 1˚: 35,000)

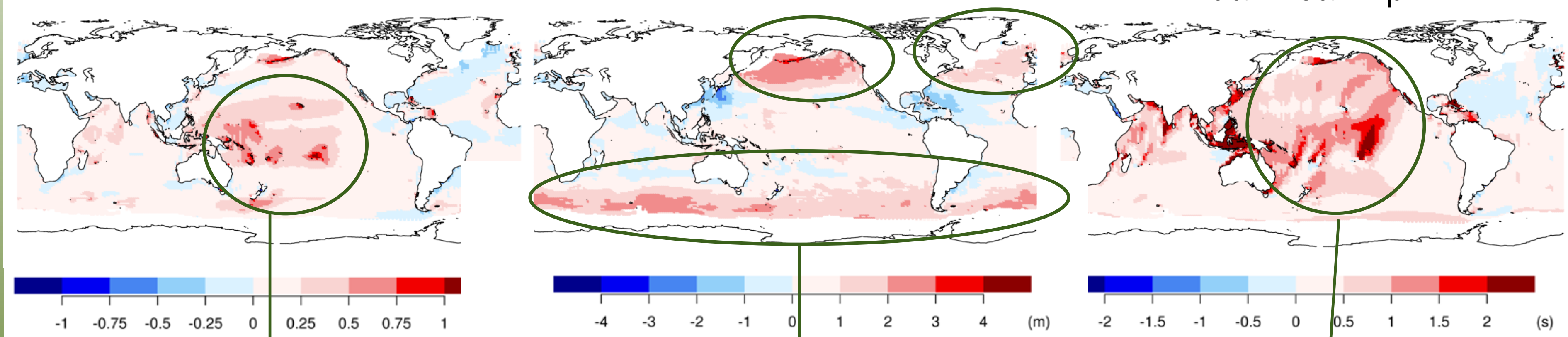
Evaluation -
Historical simulations (1979-2005) *vs.* CFSR[c]

CFSR[c]: wave hindcast forced by corrected CFSR winds
(http://polar.ncep.noaa.gov/waves/hindcasts/nopp-phase2.php)

Used the democracy approach (equal weights) for the multi-model average

CMIP5-based multi-model average *minus* CFSR[c]

Annual mean Hs | Annual max Hs | Annual mean Tp



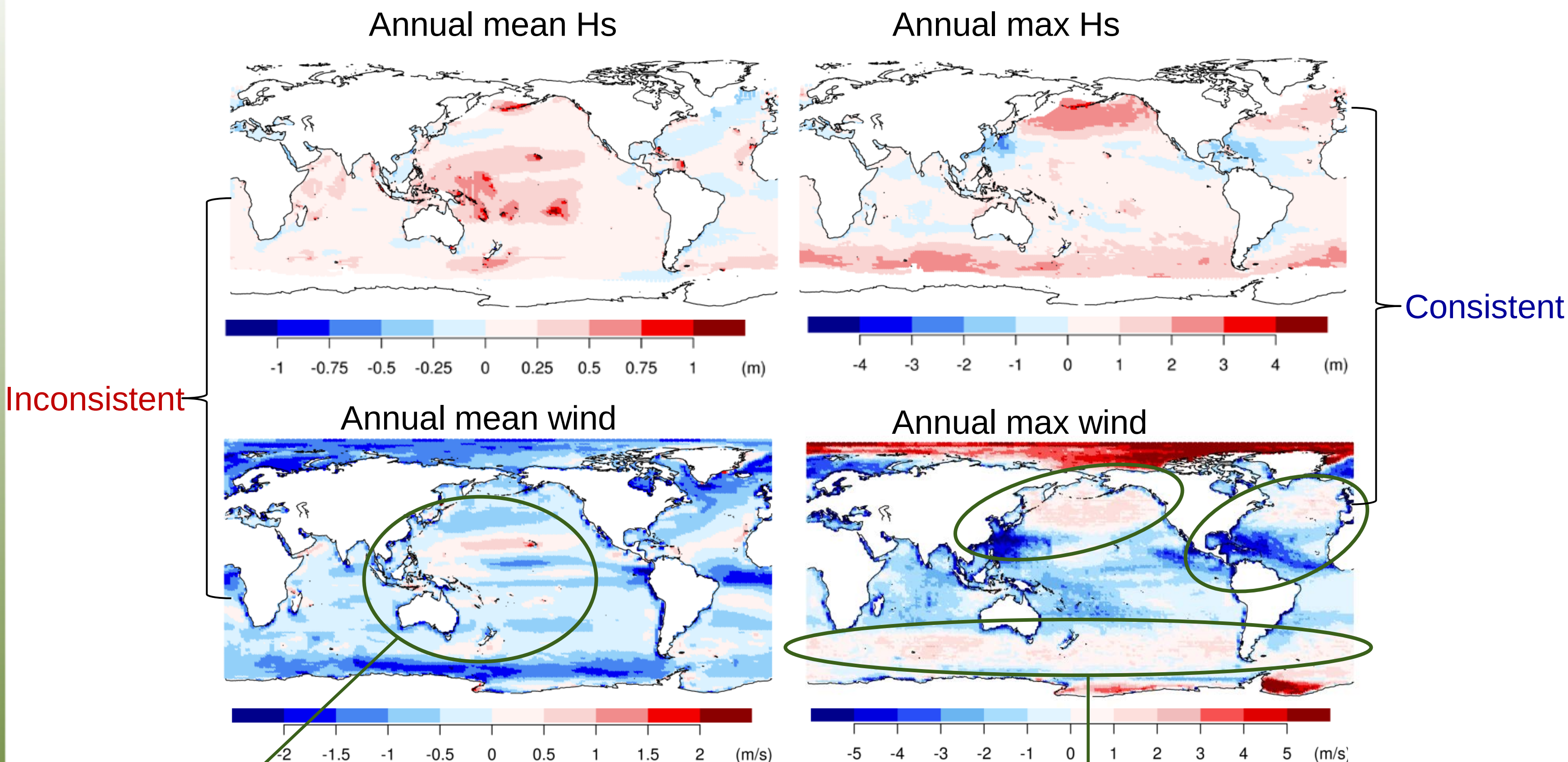
There are more extensive and greater positive biases than negative biases

Resolution issues around small islands

The simulations show more energetic conditions in already energetic areas

Positive Tp biases imply the influence of swells

Can the biases in wind explain the biases in wave?



Positive biases are not as extensive in the mean winds as in the mean Hs

But biases in max Hs are consistent with biases in the max. winds in these regions, but inconsistent in the tropics

(Biases= CMIP5-based multi-model average *minus* CFSR[c])

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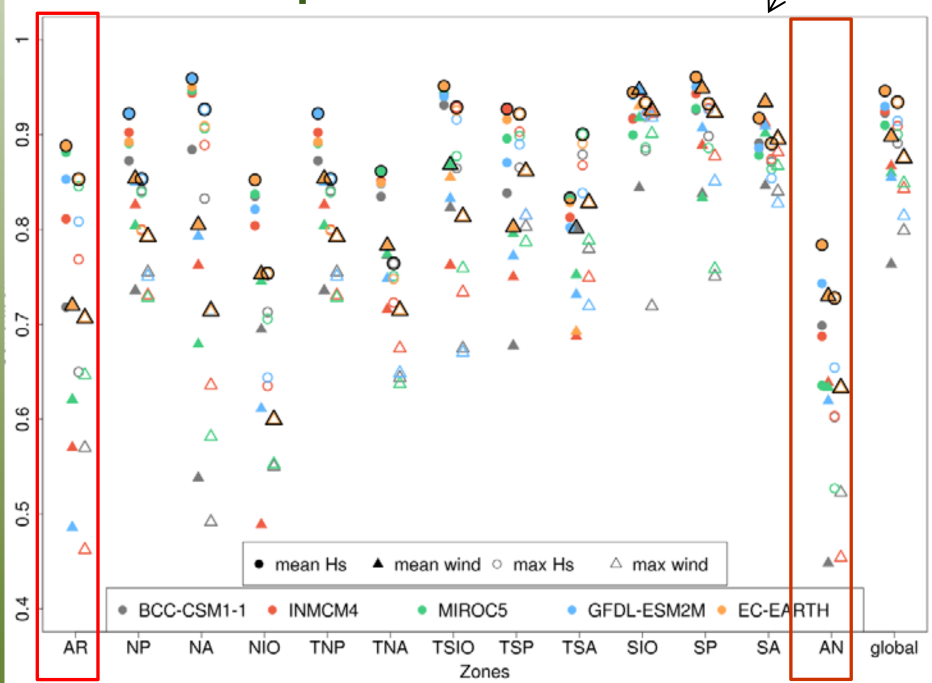
Skill for Hs *vs.* for wind

Q: Is the CMIP5 model skill for surface **wind** representative of its skill for ocean surface **wave**?

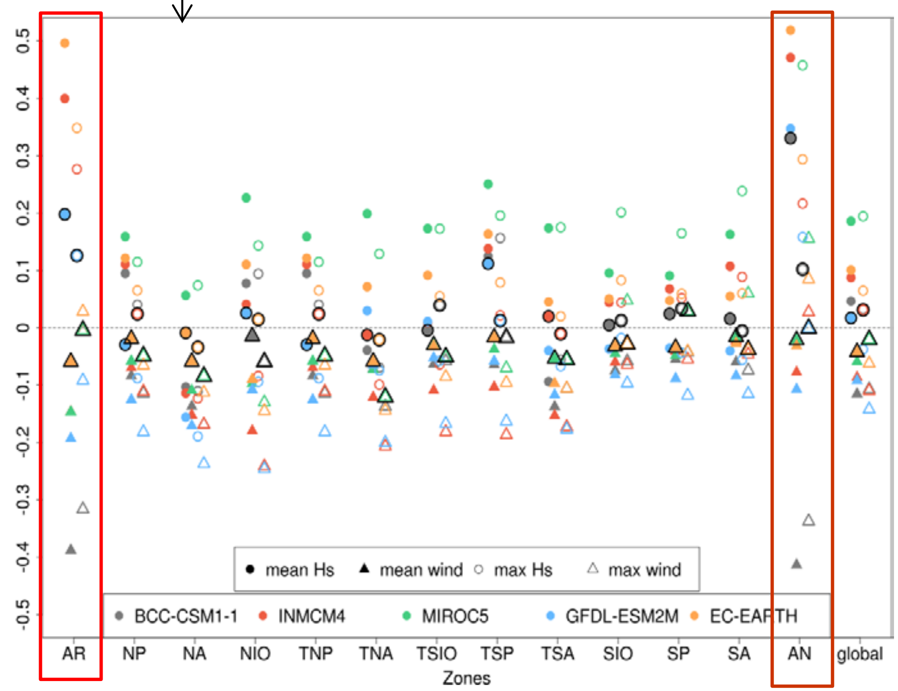
In terms of spatial correlation, we see higher correlations for Hs than for wind; but the model skill ranks similarly for Hs and wind: Best: EC-EARTH, GFDL-ESM2M

In terms of biases, we see more positive biases in Hs than in wind; the model skill ranks diff'tly:
Best for Hs: GFDL-ESM2M, BCC-CSM1-1
Best for wind: EC-EARTH

Spatial correlations

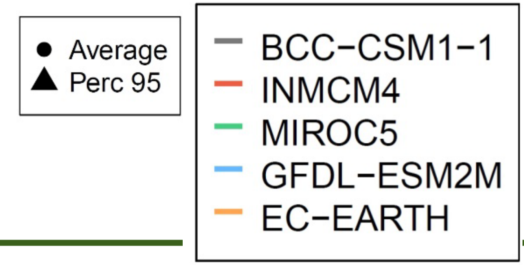


Relative biases



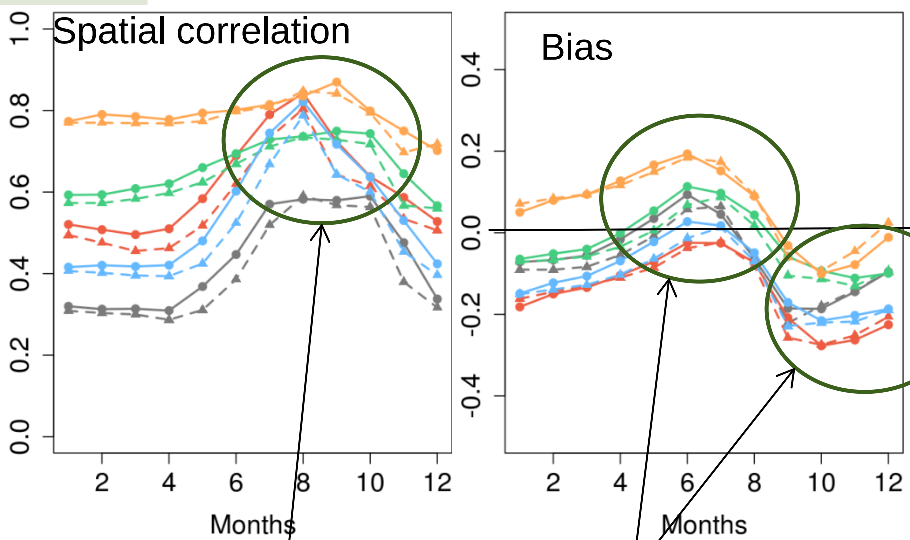
Worst performance seen for the Arctic & Antarctica: challenging regional climate to model

Skill for simulating sea ice concentration (*vs.* CFSR)



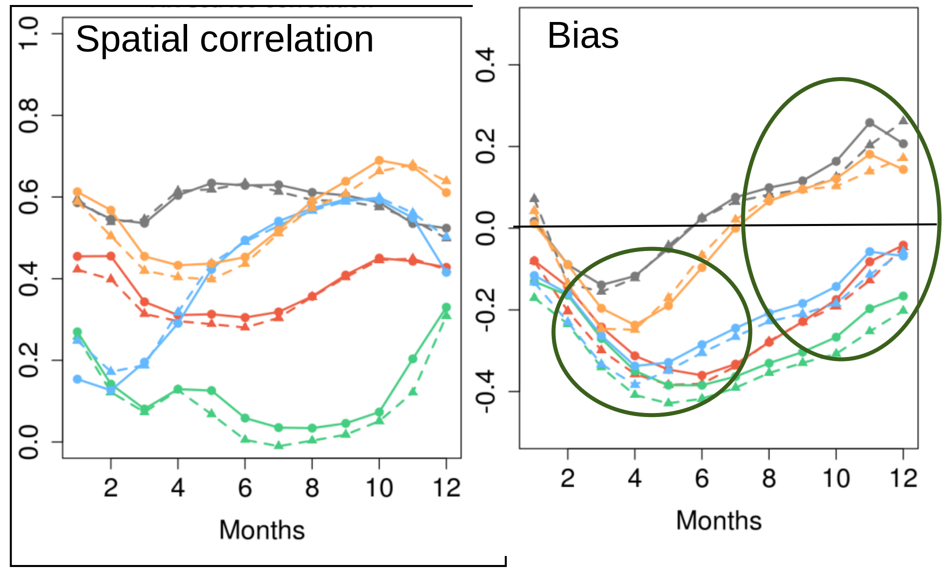
For Arctic (AR):

EC-EARTH is the best



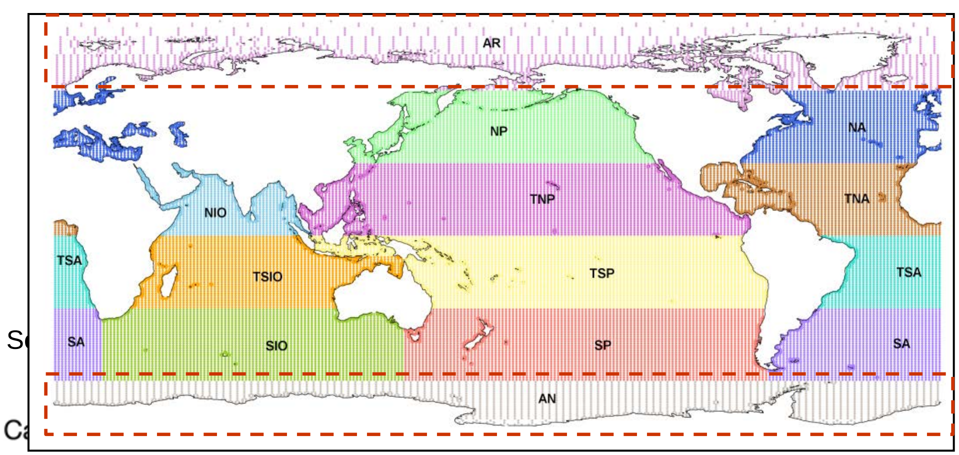
For Antarctica (AN):

The EC-EARTH and BCC-' are better



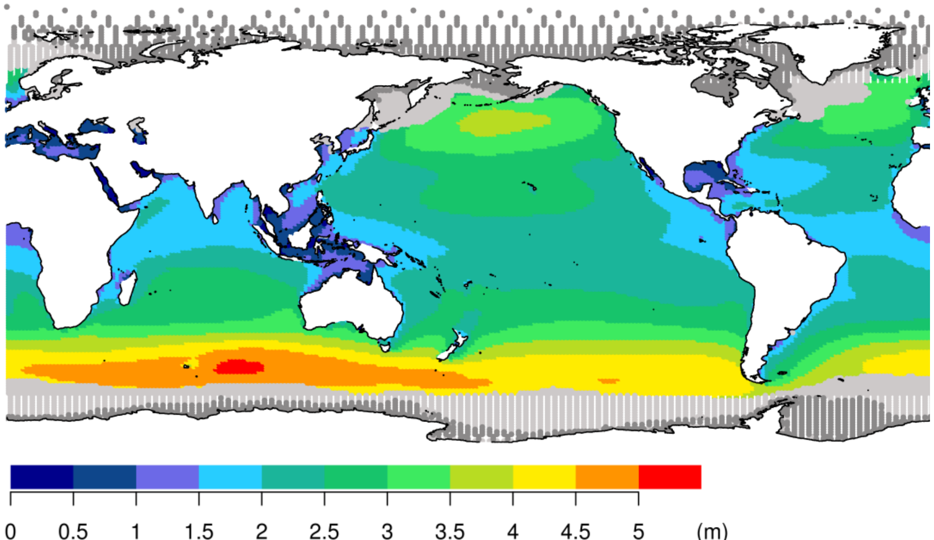
Better correlations in summer ←lowest ice coverage, so that the skill is less sensitive to the actual model performance

This fluctuation before/after summer indicates slower ice melting/freezing in CMIP5 simulations

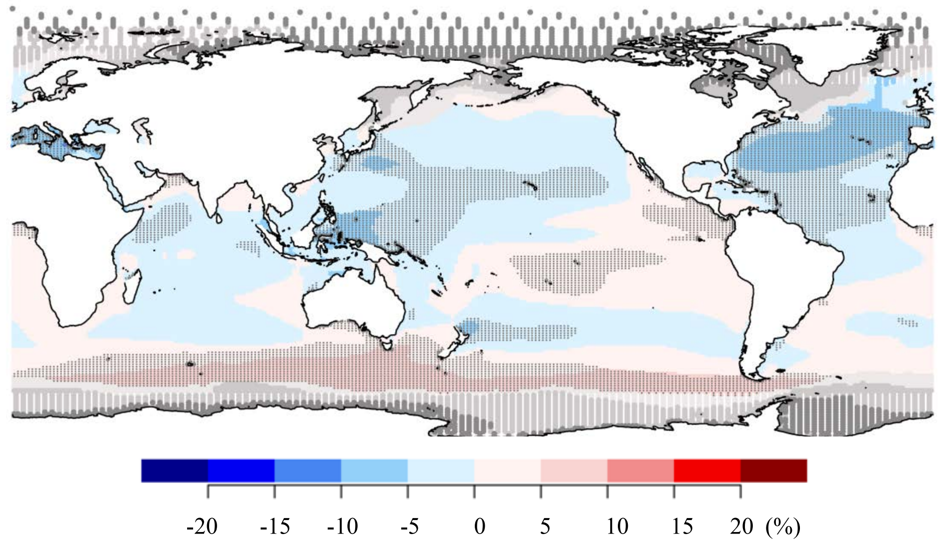


Projected changes by 2081-2100 in annual mean H_s

Multi-model average of annual mean Hs (1979-2005)

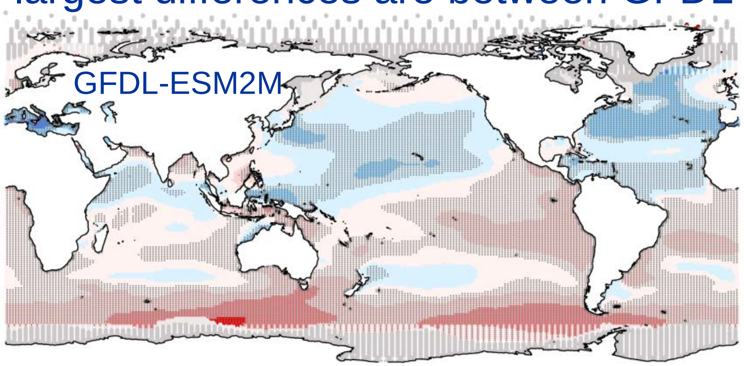


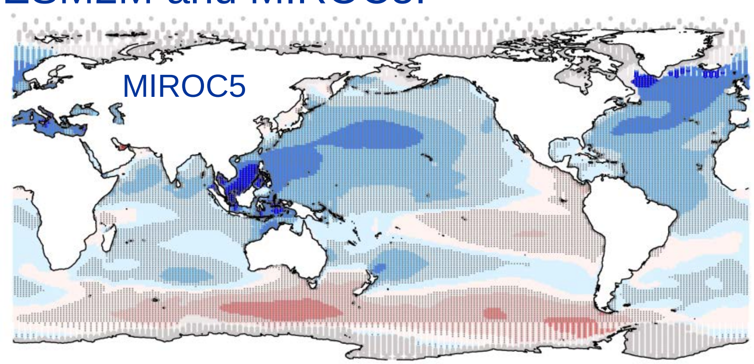
Multi-model average of projected relative changes



Similar patterns of projected changes associated with the five CMIP5 models, but with different intensities and extension of changes

The largest differences are between GFDL-ESM2M and MIROC5:

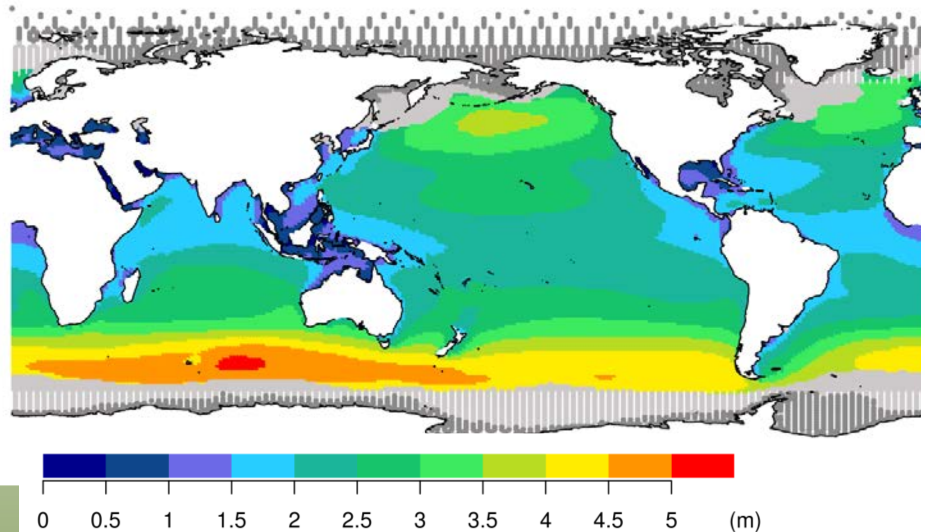




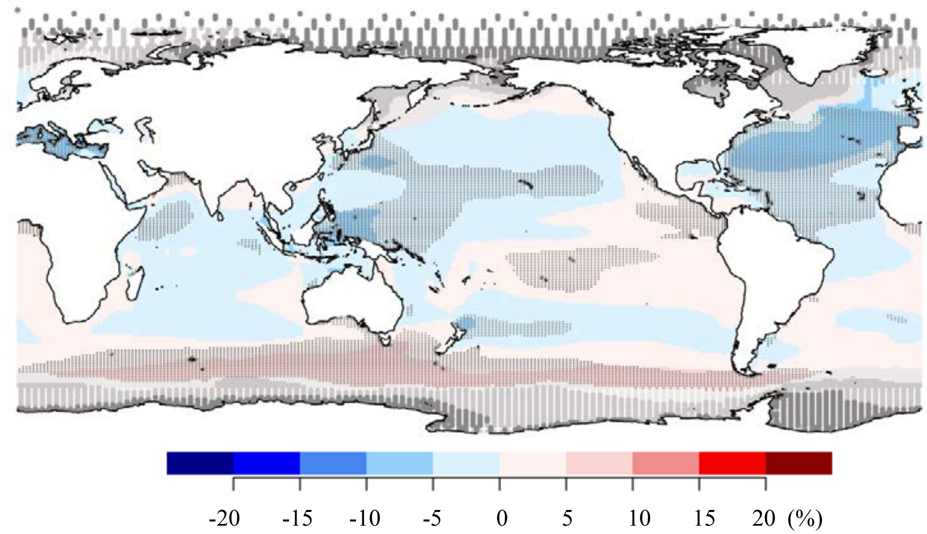
Changes in wind largely explain changes in Hs, except for the E side of the basins (swells)

But in the Arctic, large increases seen in wind but not in Hs (due to ice cover);
and there exists large inter-model variability

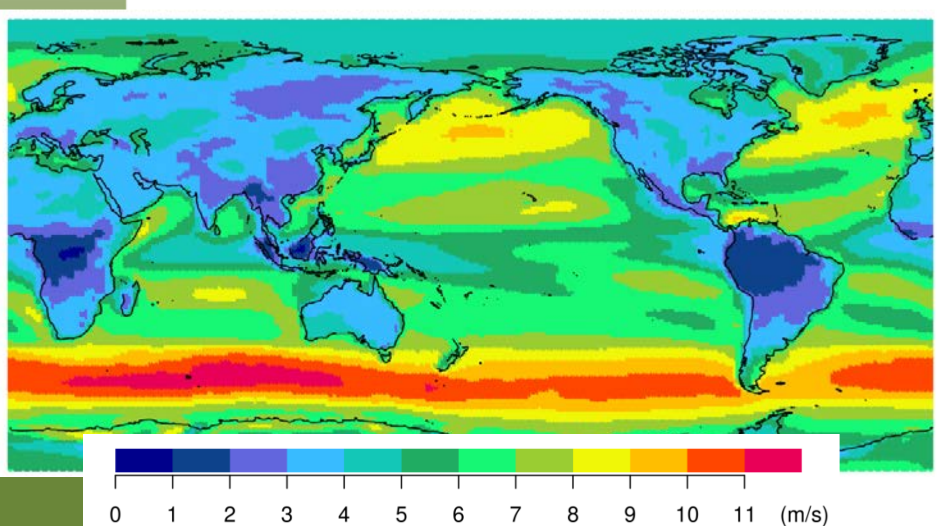
Multi-model average of annual mean Hs (1979-2005)

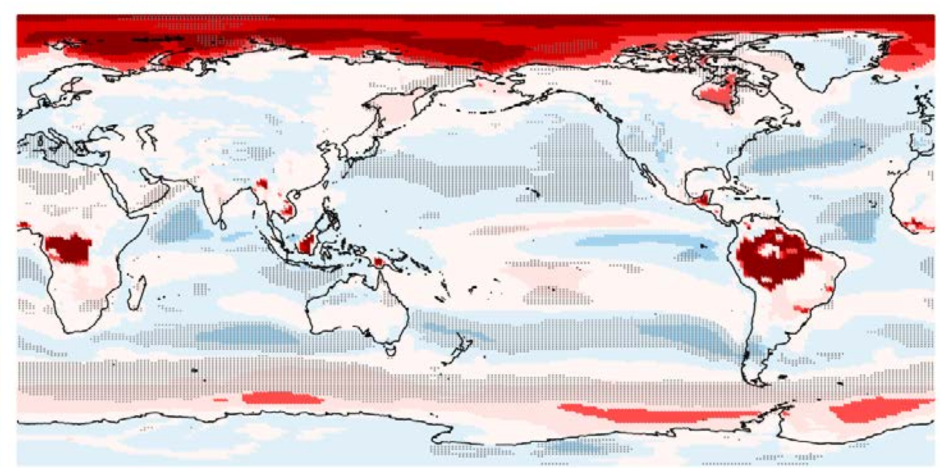


Multi-model average of proj. relative changes in mean Hs



Similar for the wind field:

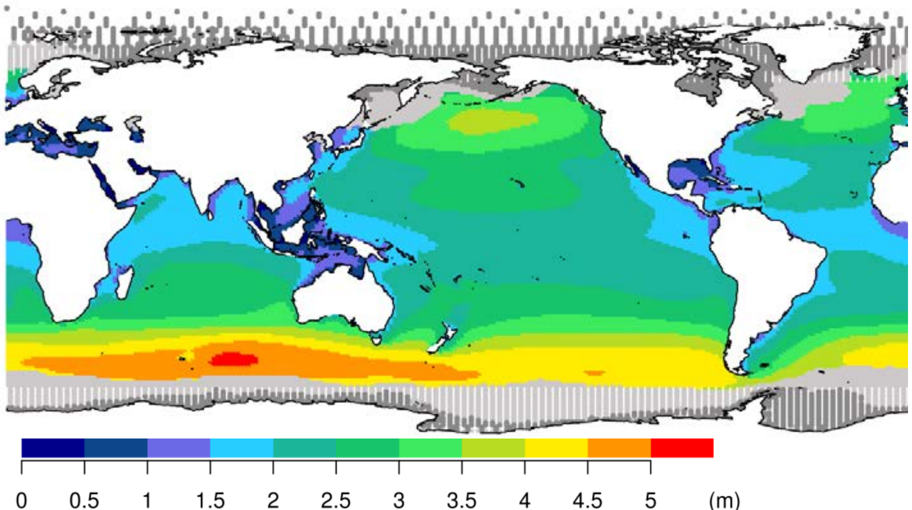




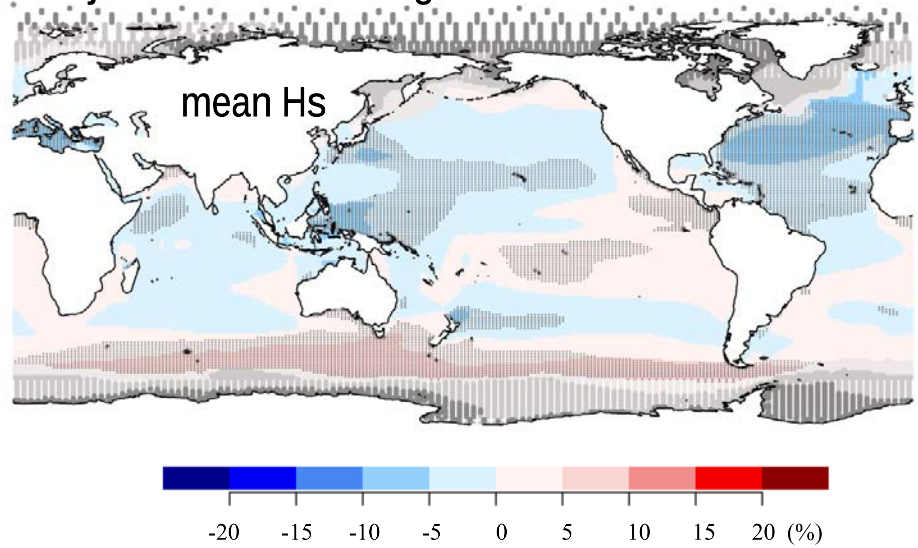
Projected changes by 2081-2100 in annual mean *vs.* max H_s

Similar large-scale patterns of projected change, but **larger inter-model variability** (i.e., uncertainty) for max Hs

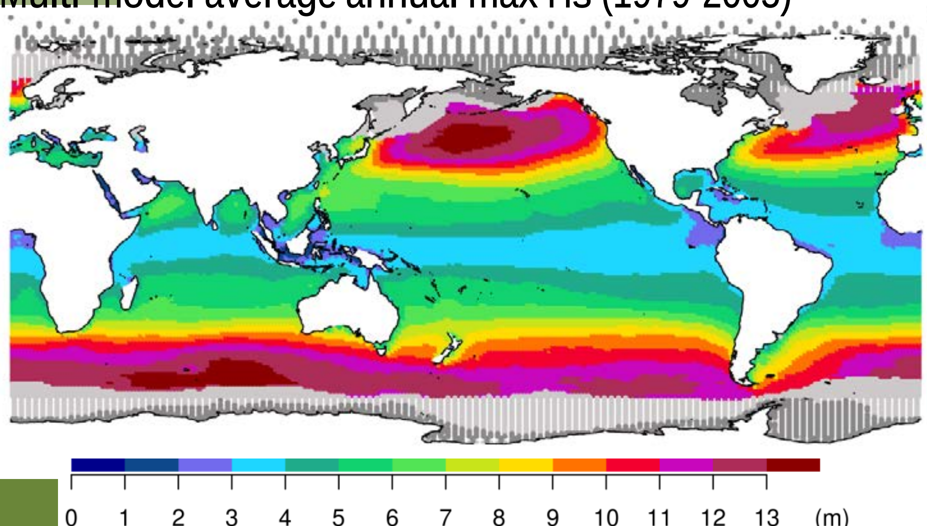
Multi-model average annual mean Hs (1979-2005)

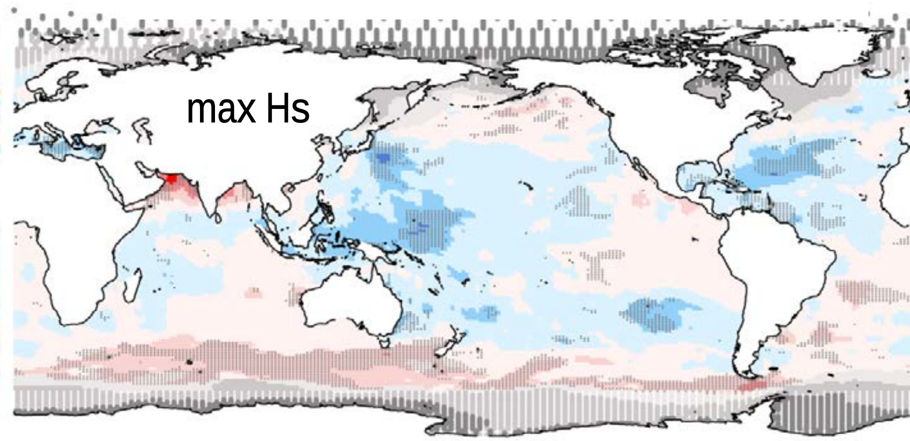


Projected relative changes



Multi-model average annual max Hs (1979-2005)

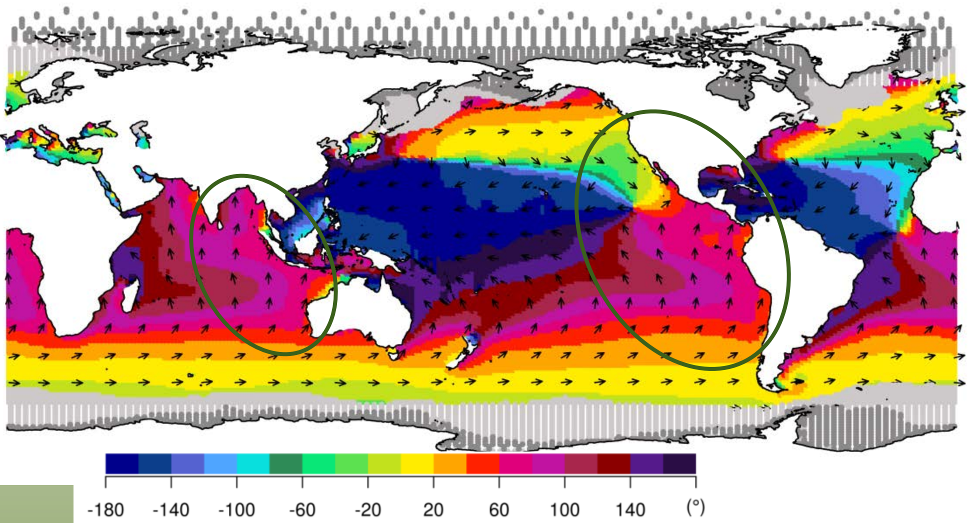




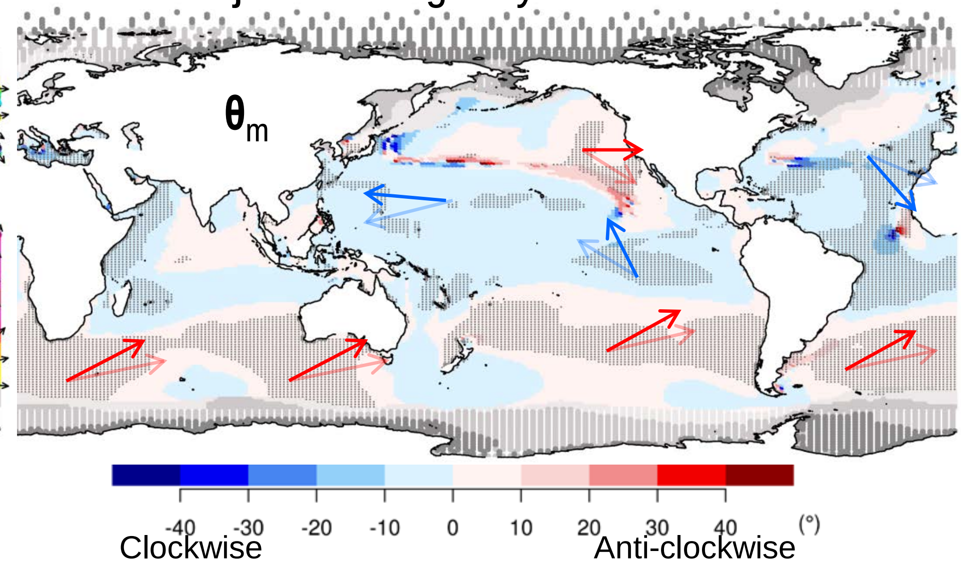
Projected changes in annual mean θ_m and T_p

- enhanced **westerly flow** at the mid-high latitudes and enhanced **swell motion;**
- extensively significant positive Tp changes in most basins (especially the east side) due to enhanced swells

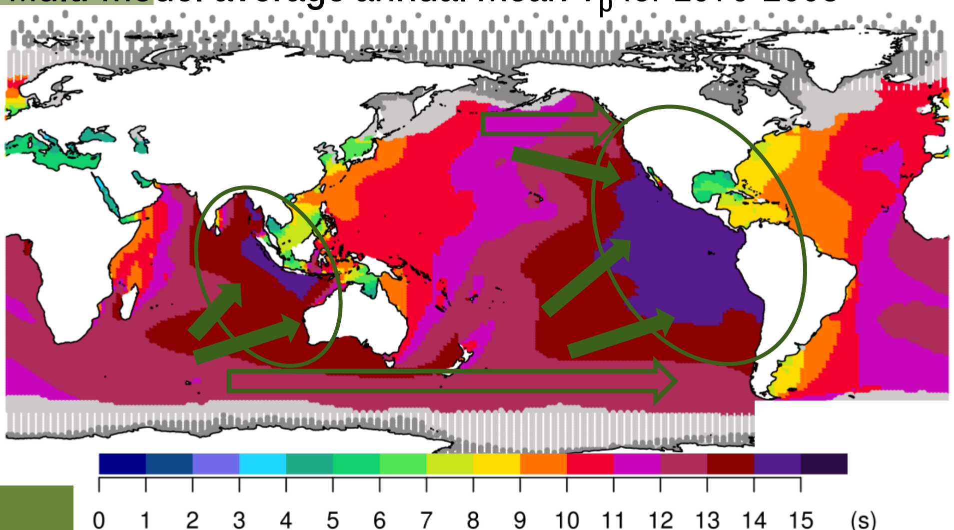
Multi-model average annual mean θ_m for 1979-2005

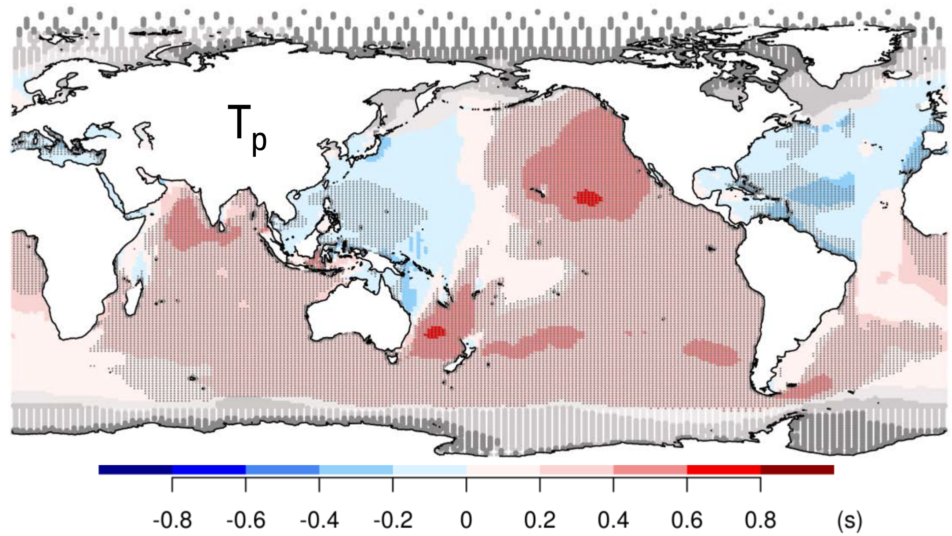


Projected changes by 2081-2100



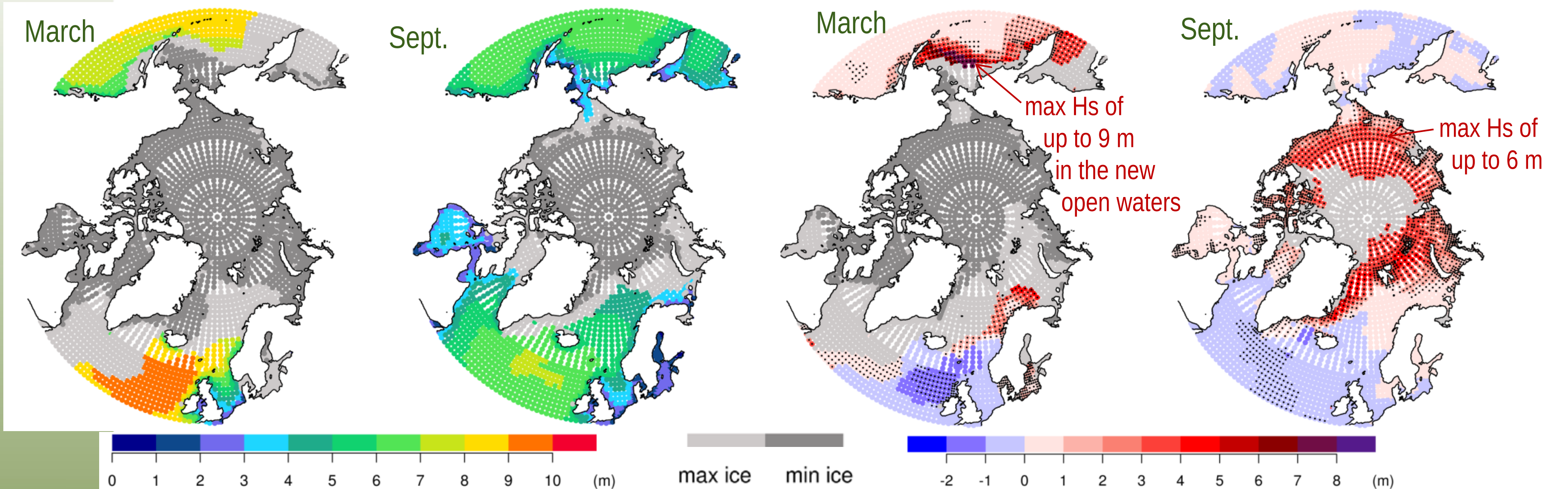
Multi-model average annual mean T_p for 1979-2005



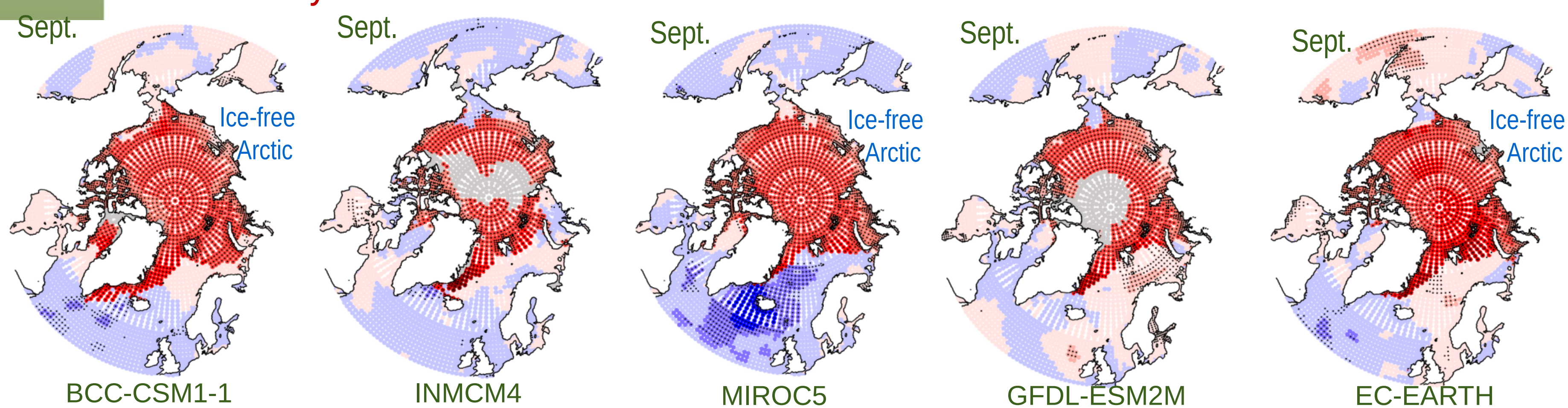


Projected changes in Arctic monthly max H_s

Multi-model average of monthly max Hs (1979-2005) | Multi-model average projected changes by 2081-2100



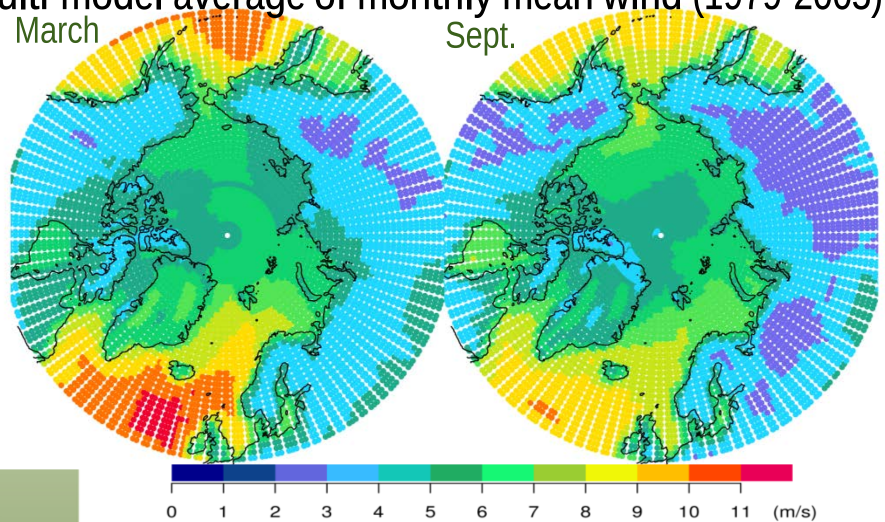
Inter-model variability:



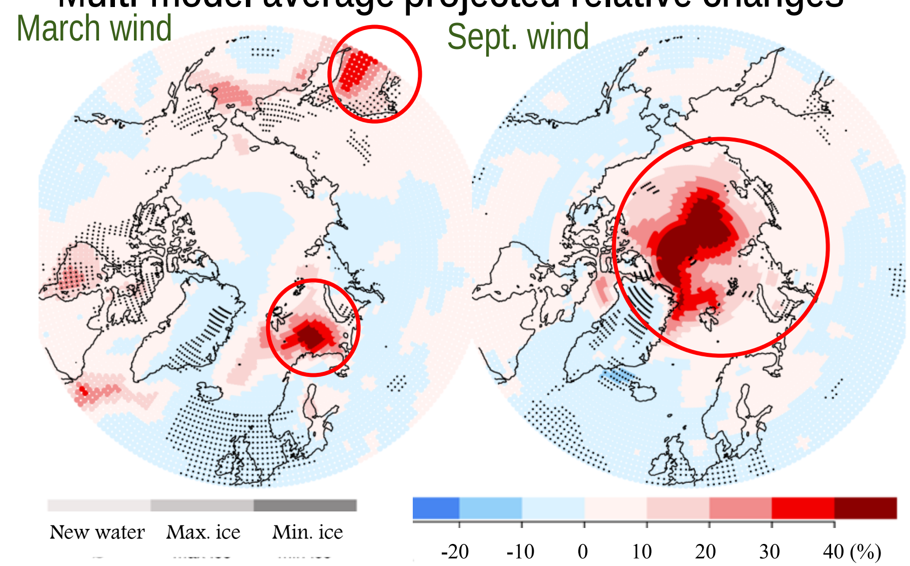
Projected changes in Arctic wind *vs.* H_s :

Notable but **stat'ly insignificant increases in wind speed** over the Barents and Okhotsk Seas in March (<50%), and over the inner Arctic in Sept. These are areas of notable **ice retreat.**

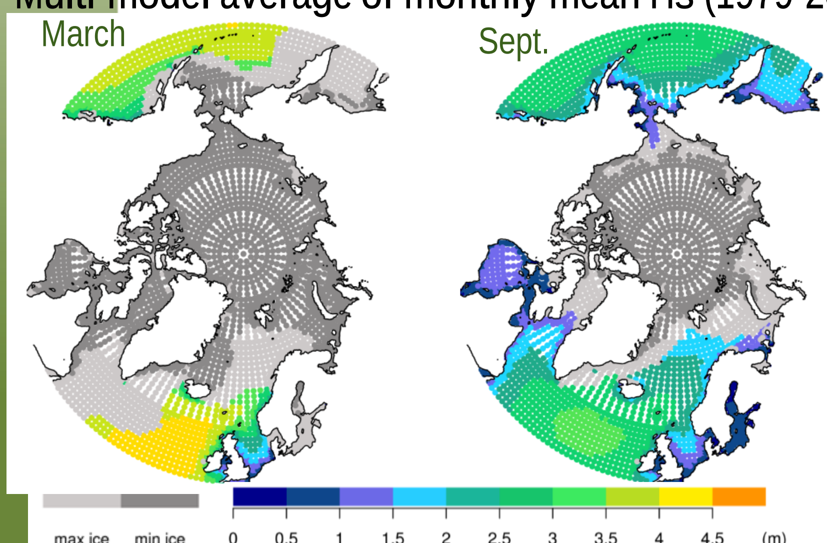
Multi-model average of monthly mean wind (1979-2005)

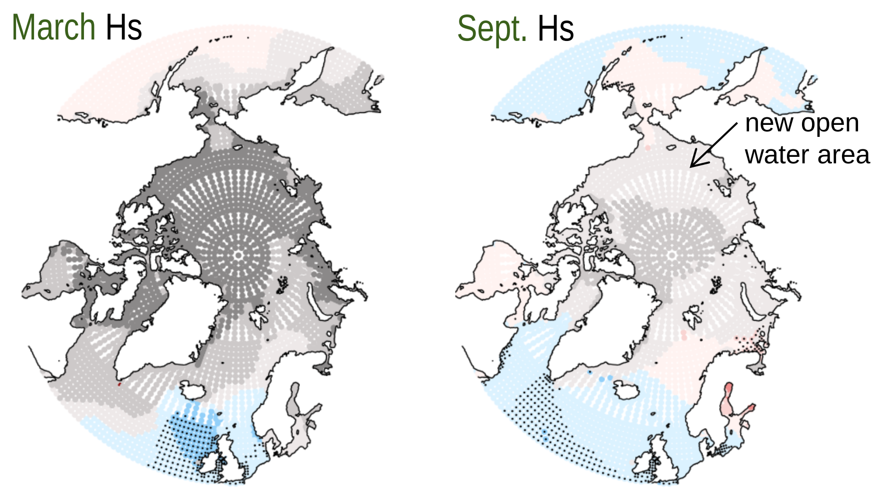


Multi-model average projected relative changes

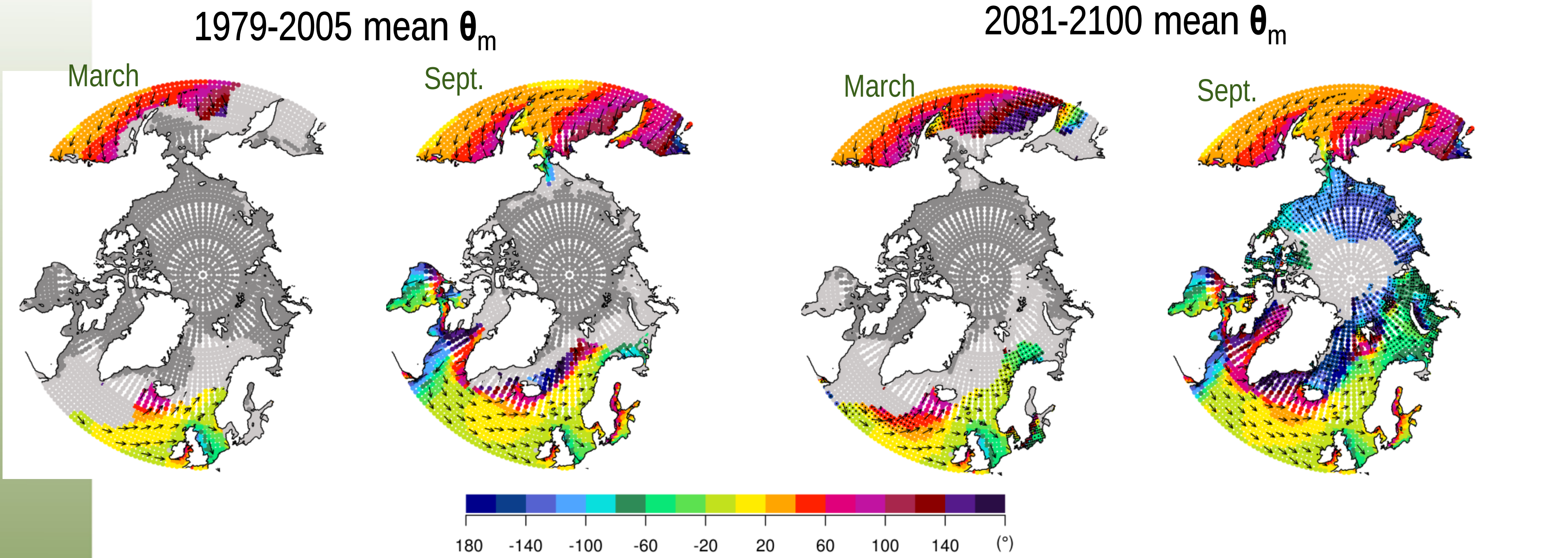


Multi-model average of monthly mean Hs (1979-2005)





Projected changes in Arctic monthly mean θ_m

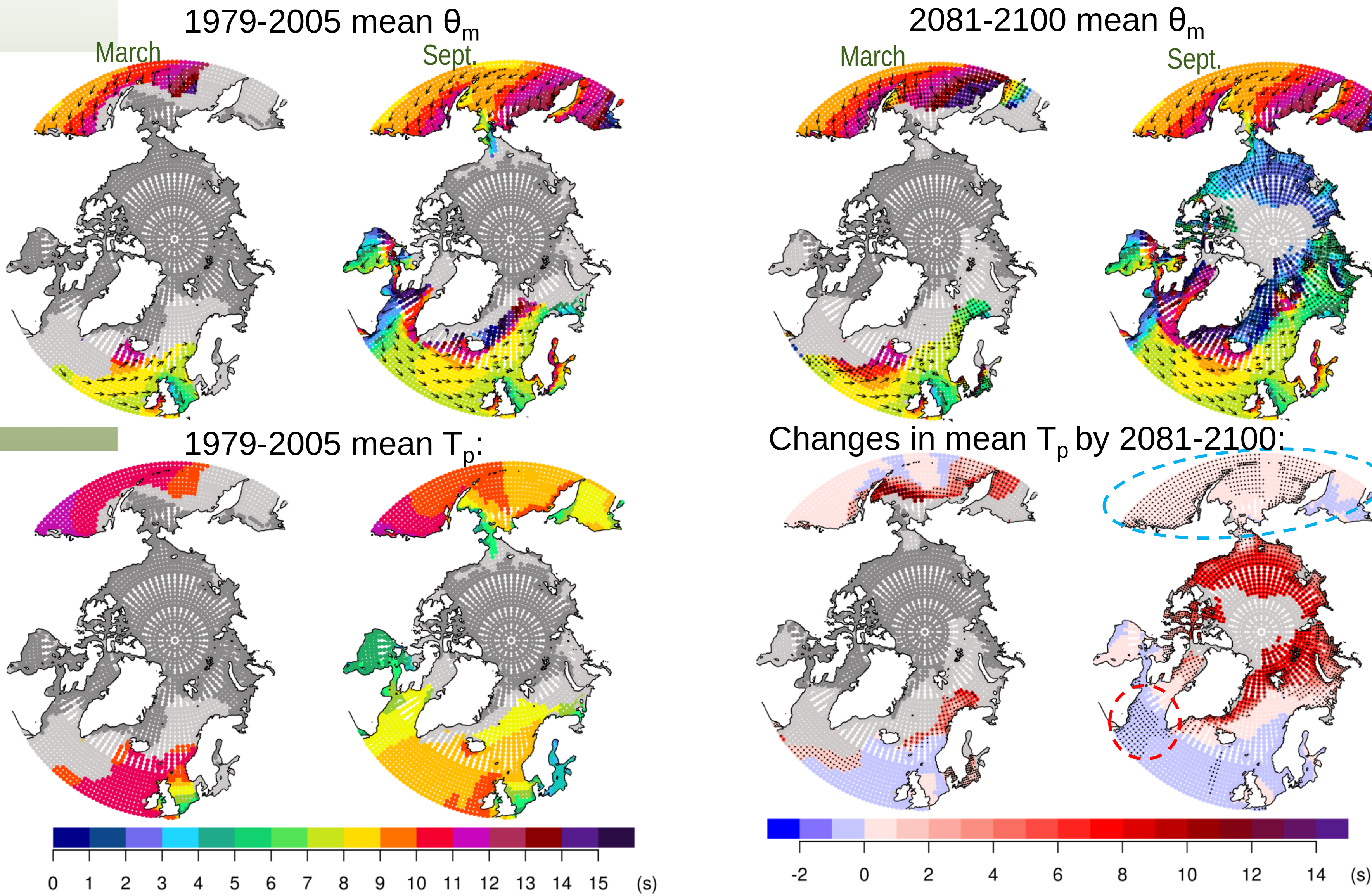


Statistically insignificant changes in the historically (1979-2005) open-water areas

In the new open water areas in inner Arctic in Sept.: the mean θ_m points **southwards** with a slight **clockwise** rotation near the North Pole → favours wave height increase due to fetch increase as ice retreats → coastal threats for Canada/Alaska/Siberia coasts.

Projected changes in Arctic mean T_p

In Sept.: significant **increases in T_p in the N. Pacific** (calmer conditions and therefore higher potential for swells); but **significant decreases in the NW Atlantic.**
Mean T_p of up to 14s in the new open water areas.



Summary

- Our CMIP5-based simulations show mostly **positive bias in H_s** in comparison with CFSR[c], which cannot be explained by biases in wind speed alone, and could result from overestimation of **zonal wind** and from **swells** spreading positive biases.
- The five CMIP5 models rank similarly for **wind** and **H_s** in terms of spatial correlation skill, but they differ in terms of climate biases. The worst performance is seen for the **Arctic** and **Antarctica**.
- The CMIP5 models simulated **slower melting/freezing** of sea ice in the Arctic Ocean than did the CFSR.
- For annual mean Hs, the multi-model average projected **statistically significant** increases in the **southern high latitudes** and the **Tropical Eastern Pacific**, and decreases in the **northern mid-latitudes**.
- Changes in mean and **max Hs** show similar patterns, but larger **inter-model uncertainty for max Hs**.
- T_p was projected to increase in most basins, which is in part due to enhanced swell influence, as reflected in the changes in θ_m.

Summary (cont'd)

For the Arctic Ocean:

- Three out of the five CMIP5 models projected **ice-free September** by the end of this century
- For the new open water areas, the multi-model average projected monthly max. Hs of up to **9 m** in the Bering Sea in March, and of up to **6 m** in the Barents and Okhotsk Seas in September.
- The multi-model average projected **notable** but stat'ly insignificant **increases in wind speed** over the areas of notable ice retreats.
- The projected changes in mean wave direction might contribute to **larger waves as fetch increase with ice retreat**, threatening Canada/Alaska/Siberia coasts.

Acknowledgements

- Dr. Jian-Guo Li for his kind help in the design and implementation of the SMC grid
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Thank you very much for listening!