Greenland blocking in climate model simulations

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Introduction

Atmospheric blocks (quasi-stationary, synoptic-scale ridges of high pressure) have become more frequent over Greenland in summer. CMIP6 (and CMIP5) models do not capture this recent trend (Delhasse et al. 2020). The main aims of this work are to better understand the drivers of Greenland blocking and why the recent observed trend is missing in the CMIP6 ensemble.

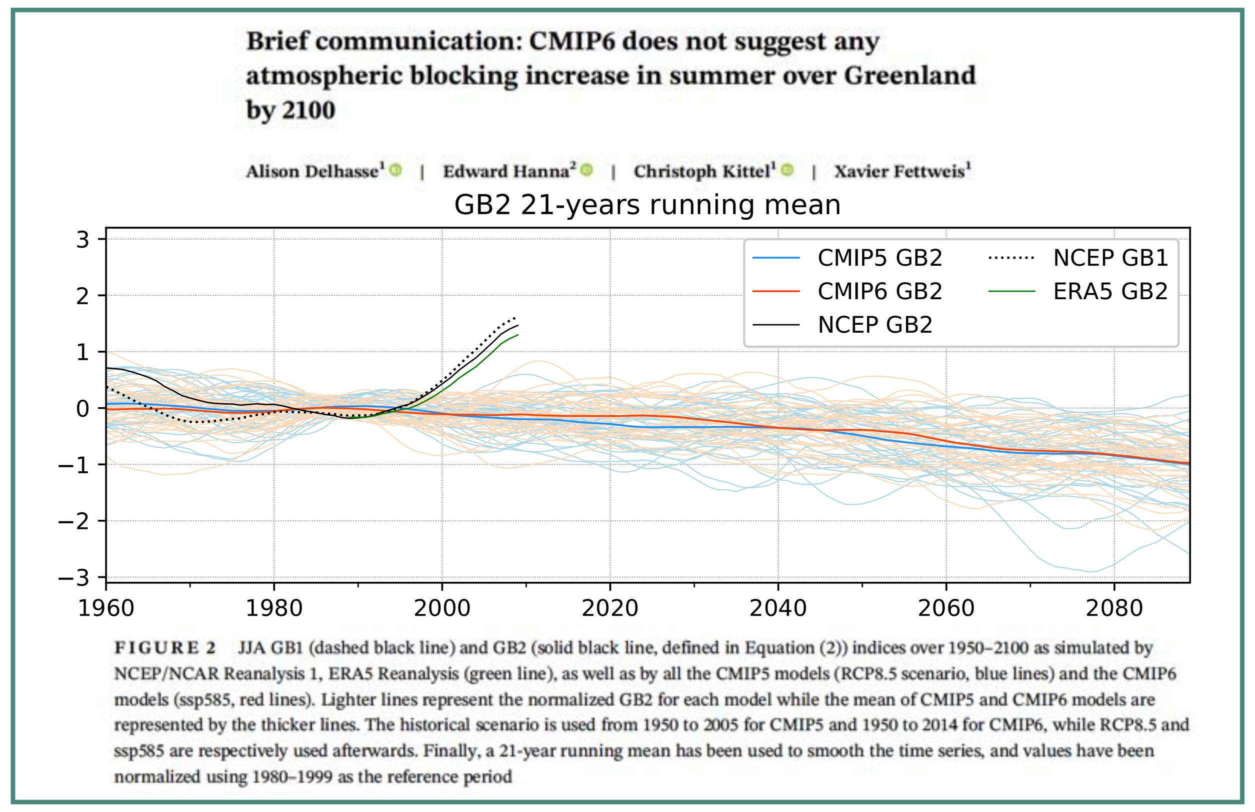
Brief communication: CMIP6 does not suggest any atmospheric blocking increase in summer over Greenland by 2100

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FIGURE 2 JJA GBI (dashed black line) and GB2 (solid black line, defined in Equation (2)) indices over 1950–2100 as simulated by NCEP/NCAR Reanalysis 1, ERA5 Reanalysis (green line), as well as by all the CMIP5 models (RCP8.5 scenario, blue lines) and the CMIP6 models (ssp585, red lines). Lighter lines represent the normalized GB2 for each model while the mean of CMIP5 and CMIP6 models are represented by the thicker lines. The historical scenario is used from 1950 to 2005 for CMIP5 and 1950 to 2014 for CMIP6, while RCP8.5 and ssp585 are respectively used afterwards. Finally, a 21-year running mean has been used to smooth the time series, and values have been normalized using 1980–1999 as the reference period

Data and methods

We extend the analysis of Delhasse et al. (2020) to a larger ensemble of CMIP6 model simulations. Nearly 500 members from different CMIP6 experiments are included here. The ERA5 reanalysis is used for verification. Blocking is identified using four different indices based on 500 hPa geopotential height (Z):

- **GBI 2:** area averaged Z over Greenland (60° —80° N, 20° —80° W) normalised by the hemispheric mean across the same latitudes.
- **BI ABS:** for each longitude λ meridional gradients are calculated for a given latitude ϕ and a block is identified when: $GHGN(\lambda,\phi) = \frac{(Z(\lambda,\phi+\Delta) - Z(\lambda,\phi)}{\Delta} < -10gpm/^{\circ}$ $GHGS(\lambda,\phi) = \frac{(Z(\lambda,\phi) - Z(\lambda,\phi-\Delta)}{\Delta} > 0gpm/^{\circ}$ $GHGS_2(\lambda,\phi) = \frac{(Z(\lambda,\phi-\Delta) - Z(\lambda,\phi-2\Delta)}{\Delta} < -5gpm/^{\circ}$ where 45°<ϕ<75° N and Δ=15° latitude.
- **BI ANO:** daily anomalies of Z are calculated for each grid point as the difference with respect to the climatological mean daily values. Blocks are identified as grid points with Z anomalies above the 90th percentile of the Z anomaly distribution over 50°—80°N.
- **BI MIX:** take blocks identified in BI ANO and also require meridional flow reversal (like in BI ABS) for at least one grid point.

Models from the historical and AMIP experiments from the CMIP6 deck, as well as the hist-aer, hist-GHG and hist-nat experiments from the detection and attribution MIP (DAMIP), and coupled experiments from the high resolution MIP (HighResMIP) are analysed.

- The increasing trend in Greenland blocking previously identified appears to have reversed.
- None of the coupled ensemble members have a blocked period with an anomaly as strong as that in ERA5.
- The four different blocking indices agree well on the temporal evolution of Greenland blocking.

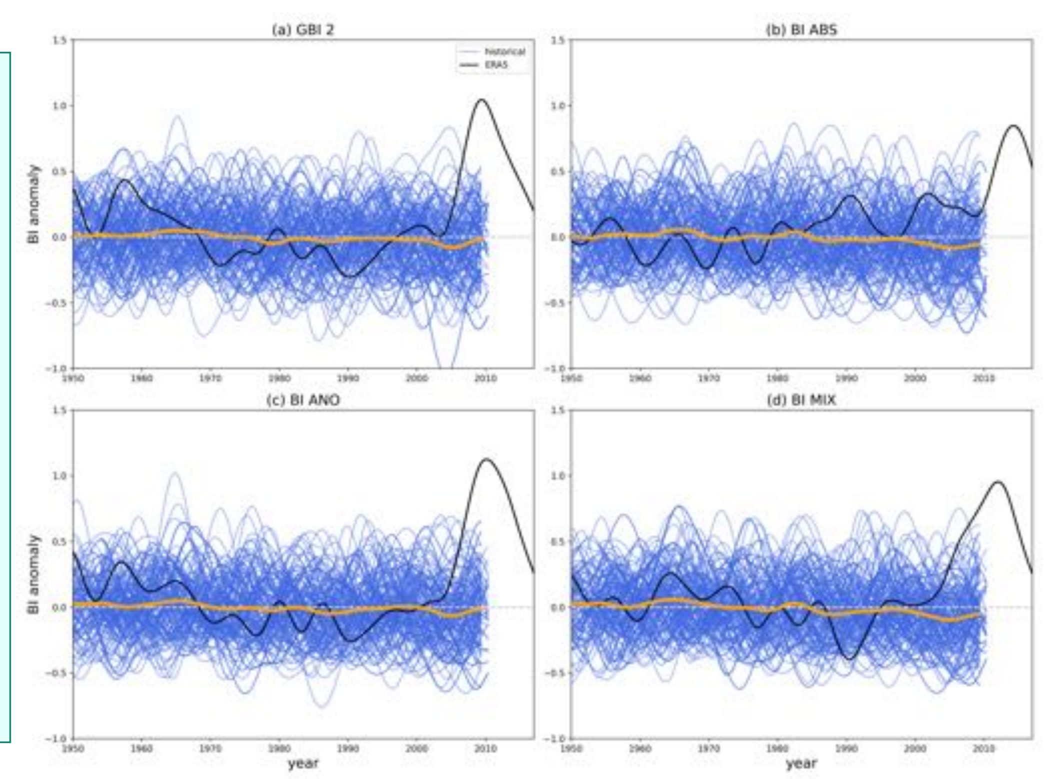

Figure 1: Time series of summertime Greenland blocking in four different blocking indices in the historical simulations from CMIP6. Blue lines represent the CMIP6 ensemble, the orange line the ensemble mean, and the black line the ERA5 time series. The time series are normalised to the period 1951–2000 and a 10-year rolling-mean applied.

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Blocking biases in CMIP6 coupled simulations

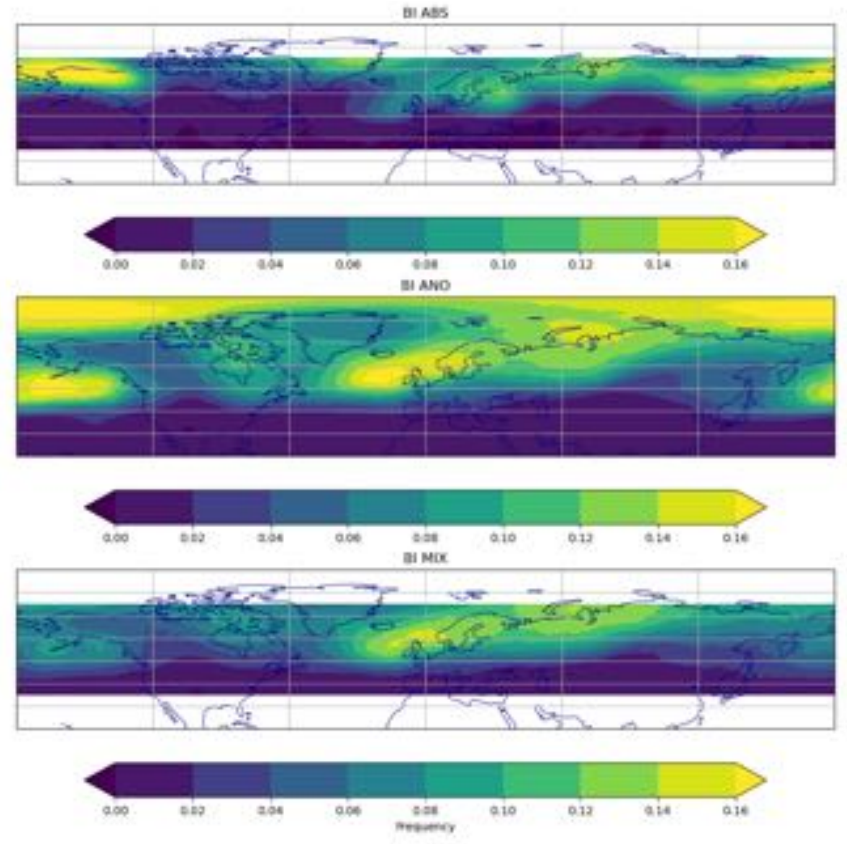


Figure 2: frequency of blocked days in summer in the ERA5 reanalysis in the BI ABS, BI ANO and BI MIX indices during the period 1950–2021.

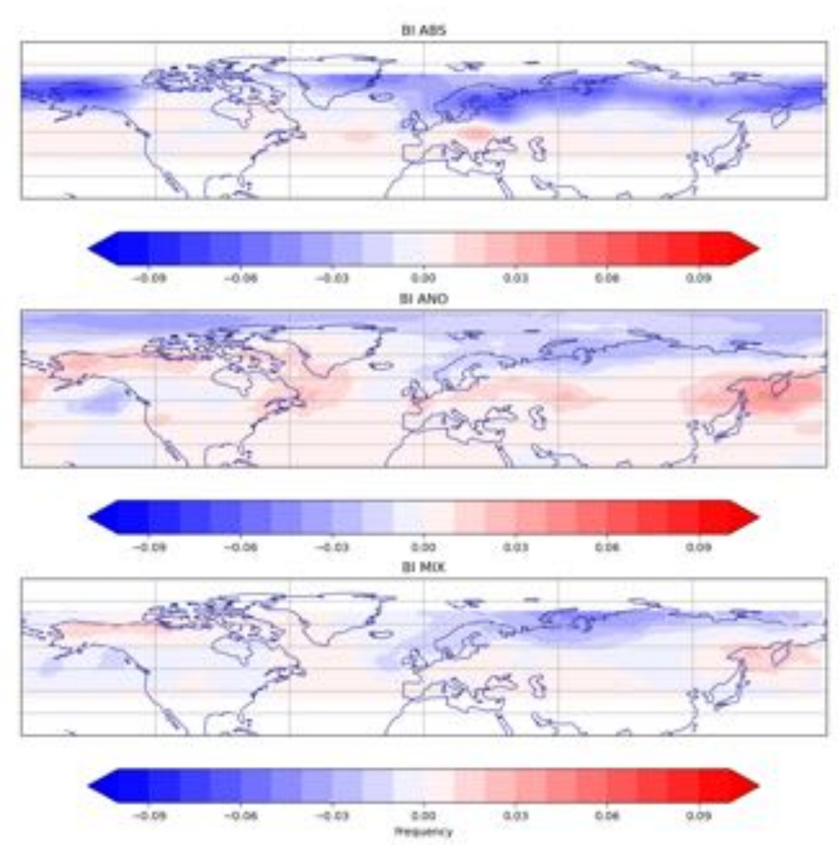


Figure 3: bias in the frequency of blocked days in summer in the CMIP6 multimodel mean (model minus reanalysis) in the BI ABS, BI ANO and BI MIX indices.

Greenland blocking (GB) biases and time series in CMIP6

- Blocking is most frequent over the North Atlantic/Europe and Pacific regions (Figure 2). The three different blocking indices generally agree quite well on locations with frequent blocking activity. CMIP6 models underestimate the frequency of blocking over much of the Northern Hemisphere (Figure 3), particularly for the BI ABS index. (This is a long standing bias in both weather and climate models.)
- The recent increase (that did not continue!) in Greenland blocking in ERA5 remains an outlier in the full historical period of CMIP6 models and across the different CMIP6 experiments (Figure 4).
- Multimodel mean blocking trends are close to zero. In the AMIP and hist-aer experiments the ensemble mean correlates with the ERA5 time series, suggesting a forced response in these experiments that may be too weak in the models.
- RPC-corrected ensemble means (see text below) for the AMIP and hist-aer experiments more closely match ERA5.

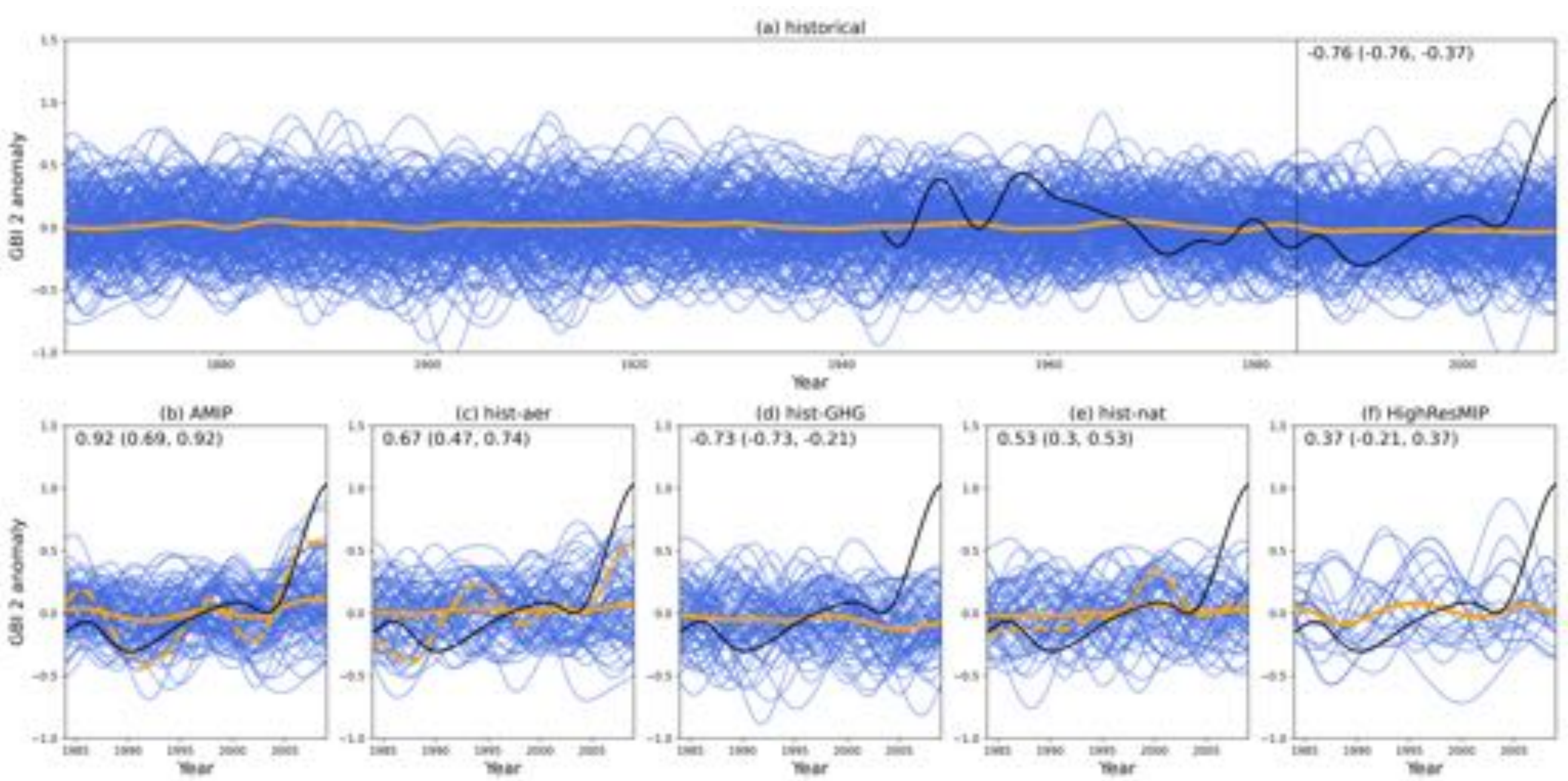


Figure 4: Time series of the summertime GBI2 in six different CMIP6 experiments smoothed with a 10-year rolling mean. The experiments included are (a) the historical coupled simulations, (b) the AMIP atmosphere-only experiments, (c) the hist-aer, (d) hist-GHG and (e) hist-nat single-forcing experiments as well as (f) the HighResMIP experiments. ERA5 is shown by the black line, the experiment ensemble members are shown in blue, and the ensemble mean of each experiment is shown in the orange line. The RPC-corrected (see text) ensemble mean is shown by the dashed orange line. Correlations between the ensemble mean of each experiment and ERA5 are shown by the values in each panel, as well as the maximum and minimum correlations for rolling window lengths between 4 and 14 years.

Ratio of predictable components

Individual members of weather or climate models often contain some predictable signal, but it is too weak (Eade et al. 2014; Smith et al. 2020). We can correct for this using the equation $\bar{GB}_t^* = (\bar{GB}_t - \hat{GB})\frac{\sigma_{obs} r}{\sigma_{mod}} + \hat{GB}$, where where GB_t is the time series of the GBI, the bar represents the ensemble mean, the hat the mean across all t, r is the correlation between the ensemble mean and observations, and σ_{obs} and σ_{mod} are the standard deviations of the observations and ensemble mean, respectively.

The ensemble mean is corrected for experiments with an RPC >= 1, where $RPC = \frac{r}{\sqrt{\sigma^2_{mod}/\sigma^2_{tot}}}$ and σ^2_{mod} and σ^2_{tot} are the variances of the ensemble mean and the average variance of the individual ensemble members, respectively.

Can CMIP6 models represent a strong an increase in Greenland blocking?

We look at all ten-year Greenland blocking trends in ERA5 and CMIP6 and compare to the recent strong increase seen in ERA5 (highlighted in pink in Fig. 5). The strongly increasing trend found in ERA5 is an outlier compared to the trend distributions from CMIP6 in all of the experiments considered (Fig. 6a).

We then compare the magnitude and persistence of the recent ERA5 Greenland blocking period (Fig. 6b,c). A period of positive GB anomaly as strong as that in ERA5 is found in less than 1 in 50 of the ensemble members in general. An event of the same length as in ERA5 is more commonly produced in the models.

An increase in GB as rapid and anomalous as that in ERA5 is therefore a very rare event in the model ensemble and there is potentially some process key for Greenland blocking missing in them.

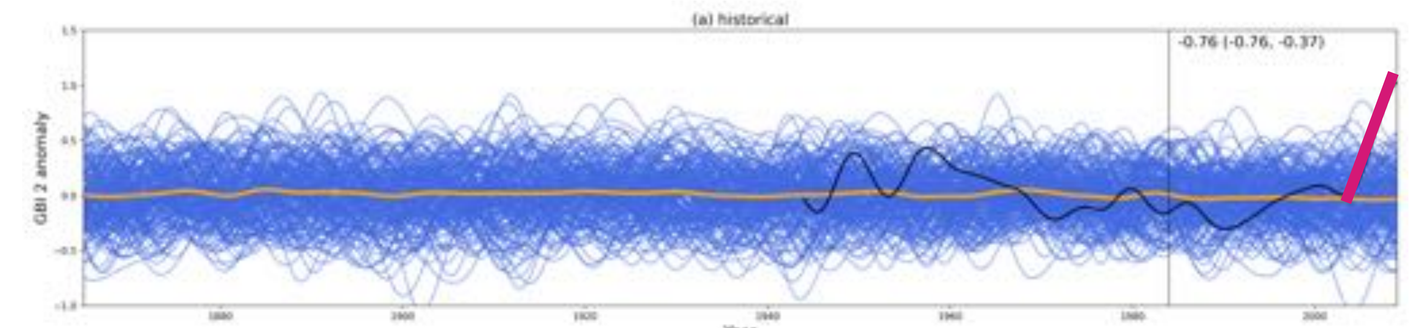
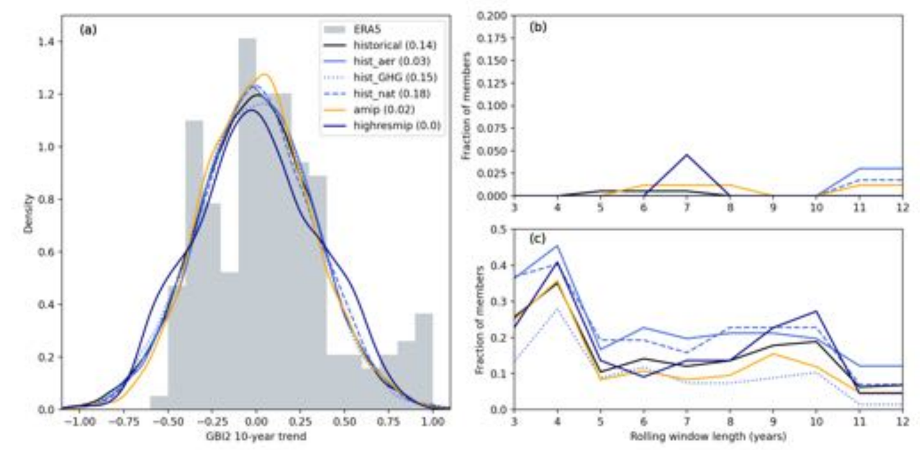


Figure 5 (above): Greenland blocking time series as in Figure 4, with the strong recent trend in ERA5 highlighted in pink.

Figure 6 (right) :(a) Distributions of all 10-year Greenland Blocking trends in ERA5 (grey bars) and all members of the historical, AMIP, DAMIP and HighResMIP experiments during their full integrations (coloured lines). Trends are calculated for the time series with a 10-year rolling mean. The numbers in parentheses in the legend show the fraction of ensemble members with a trend exceeding the maximum trend in ERA5. (b) The fraction of models that exhibit a period of anomalous positive Greenland blocking with mean anomaly equal to that in ERA5, shown as a function of rolling window length. (c) The fraction of models that exhibit a period of anomalous positive Greenland blocking as long as that in ERA5, again shown as a function of rolling window length.



Sea surface temperature, sea ice and aerosol forcing?

- The results shown in Figure 4 suggest part of the variability in Greenland blocking may be driven by variability in the SSTs/sea ice concentrations (SICs) and/or anthropogenic aerosol emissions.
- In Figure 7, we test if these forcings are acting through a common pathway by comparing the temporal correlations of SSTs/SICs in the hist-aer experiment and ERA5 as well as looking at the SST anomalies during the period 2005—2015.
- The correlations are low for both SST and SICs, and the SST anomalies are very different during the considered period, so we conclude that the forcing from SSTs/SICs and anthropogenic aerosols are acting through different pathways.

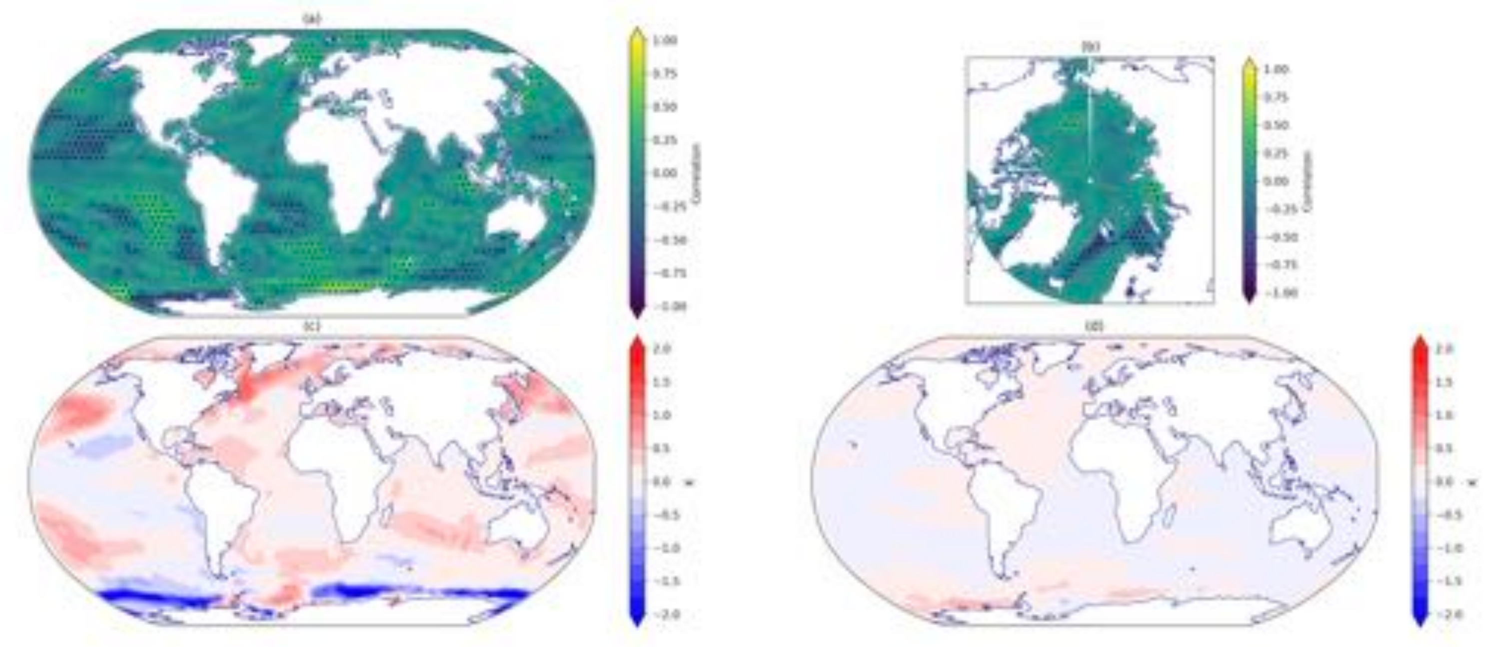


Figure 7: Temporal correlations between the ensemble mean of the hist-aer experiment with ERA5 for the (a) sea surface temperature and (b) sea ice fields during summer for the period 1980–2014. Significant correlations (p<0.05) are indicated by the stippling. The seasonal cycle and linear trend have been removed from both fields prior to the calculations. Also shown are SST anomalies during the period 2005–2014 (with respect to 1981–2010) for the (c) AMIP and (d) hist-aer experiments. The ensemble members have been regridded to a common grid prior to the calculation of the results presented in this figure.

Key points

- The observed rapid increase in summertime Greenland blocking during the first decade of the twenty-first century has not continued.
- A period of increased summertime Greenland blocking of similar magnitude to observed is rarely reproduced in a large ensemble of climate models.
- Decadal variability in Greenland blocking in climate models is partly driven by SST/sea ice and/or anthropogenic aerosols.