Increasing Greenland blocking trend not present in climate models

US CLIVAR Blocking and Extreme Weather in a Changing Climate Workshop

Jacob Maddison. 19 March 2024.

University of Exeter

Outline

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1. Introduction and motivation.
2. An apparent increasing trend in summertime Greenland blocking.
3. Greenland blocking in climate models.
4. Climate model assessment of Greenland blocking trend.
5. Identification of possible drivers of Greenland blocking.
6. Conclusions and future work.

Greenland climate change

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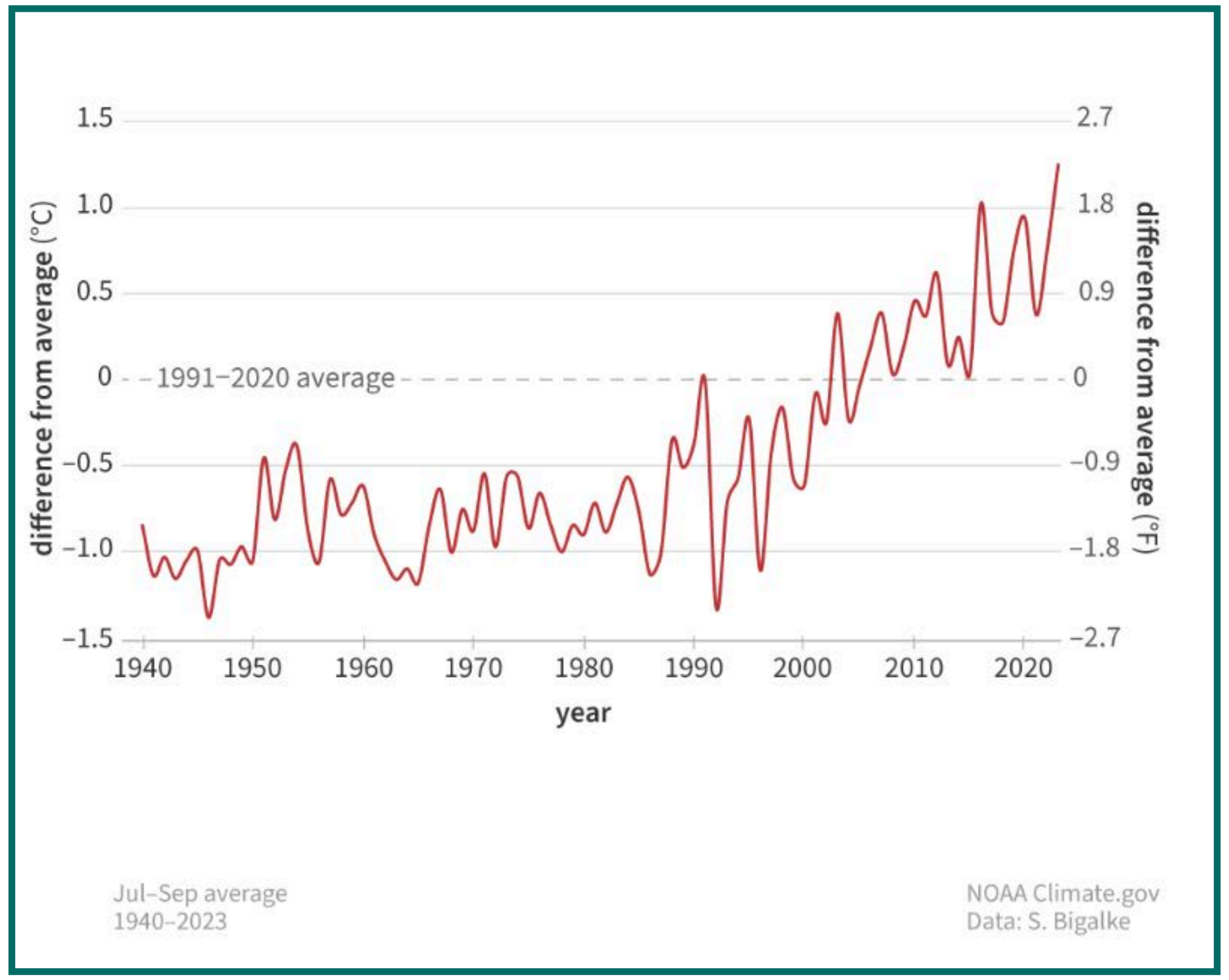
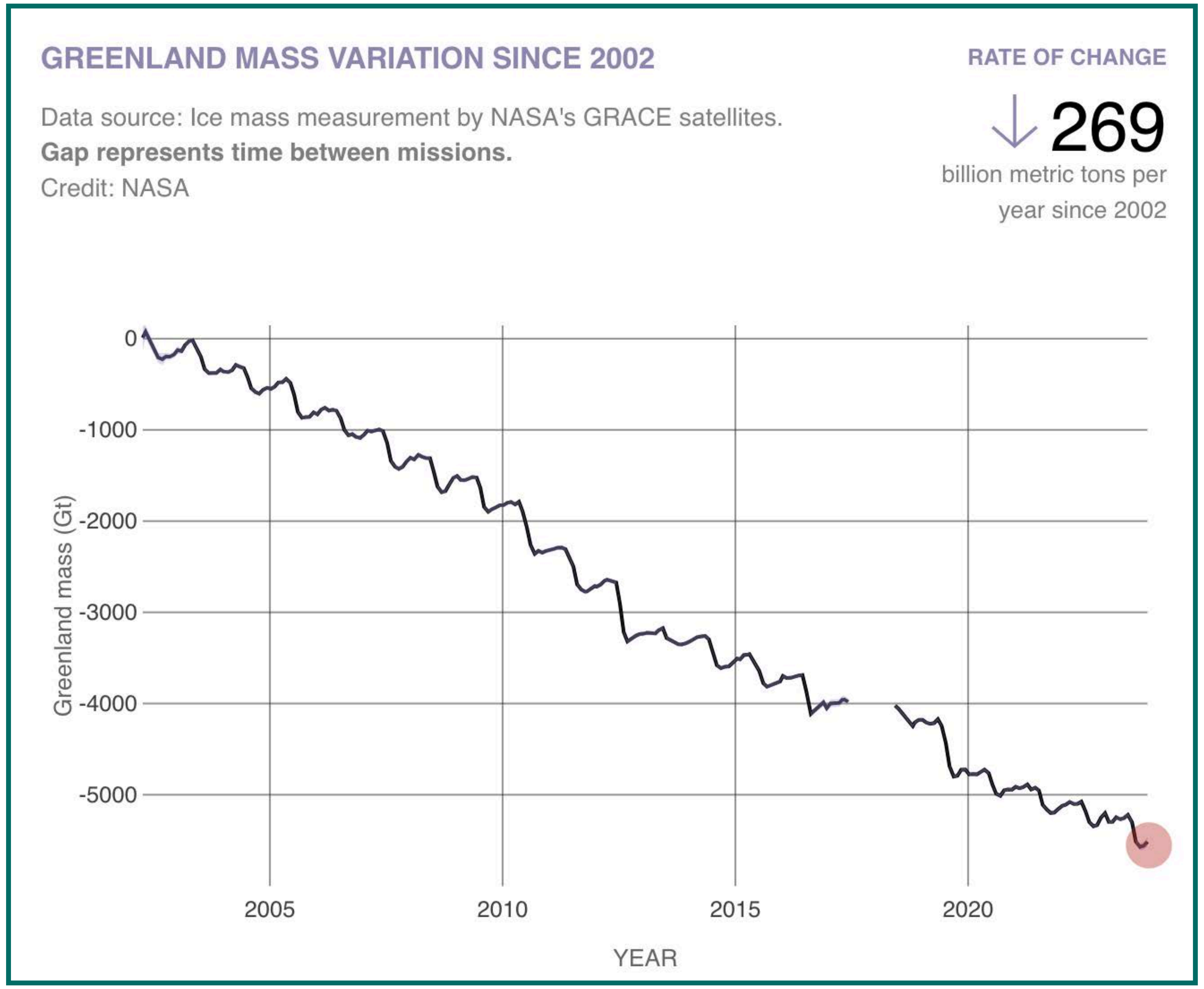
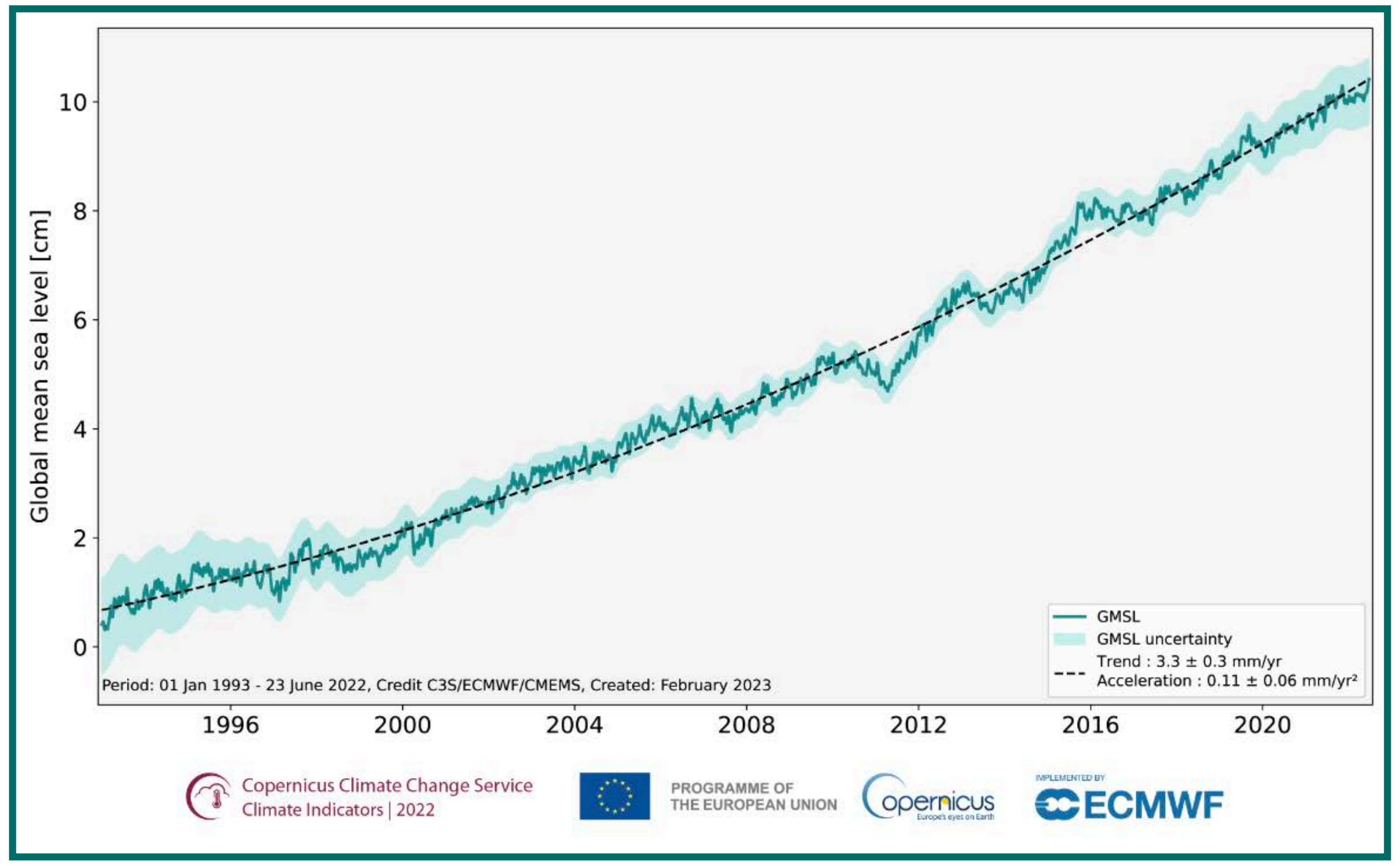
Arctic temperatures in summer are rising fast.



Greenland ice sheet is melting.



Melting ice sheet contributes to global sea level rise. Contributing around 15% to the total.



Summer Greenland blocking trend

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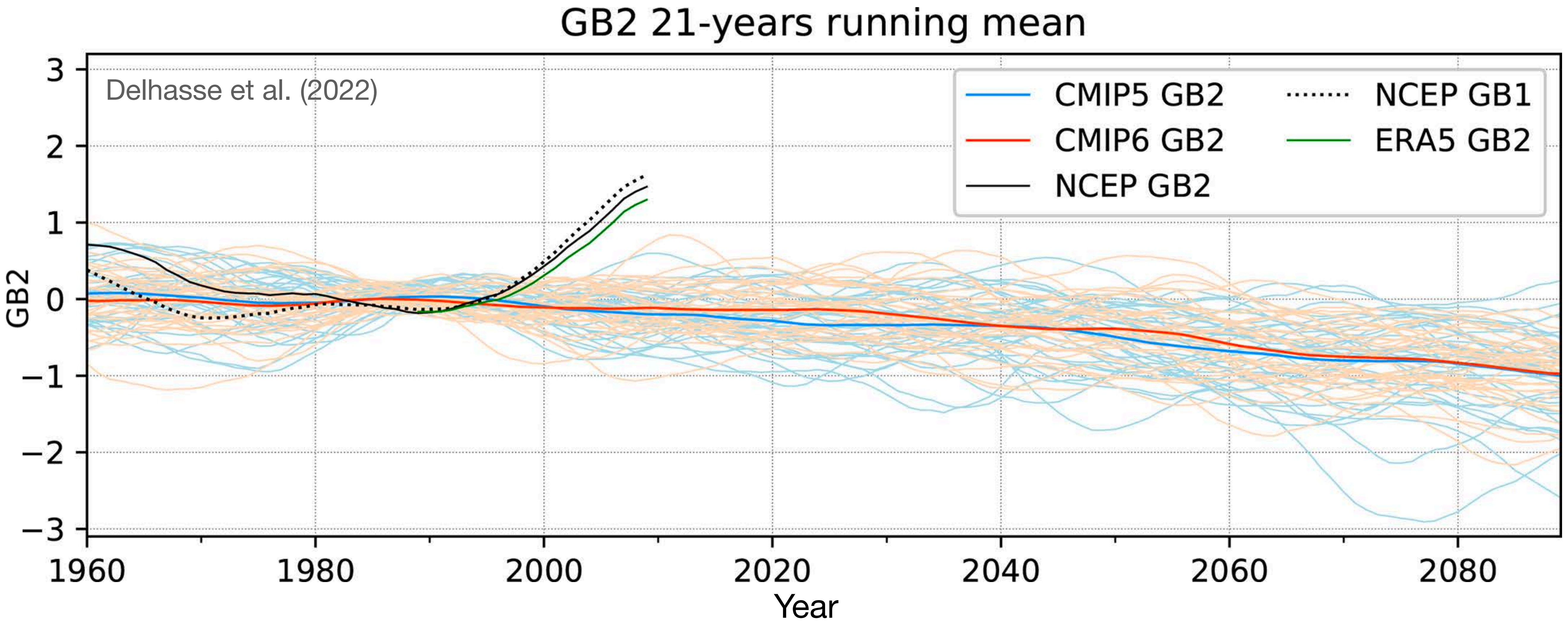
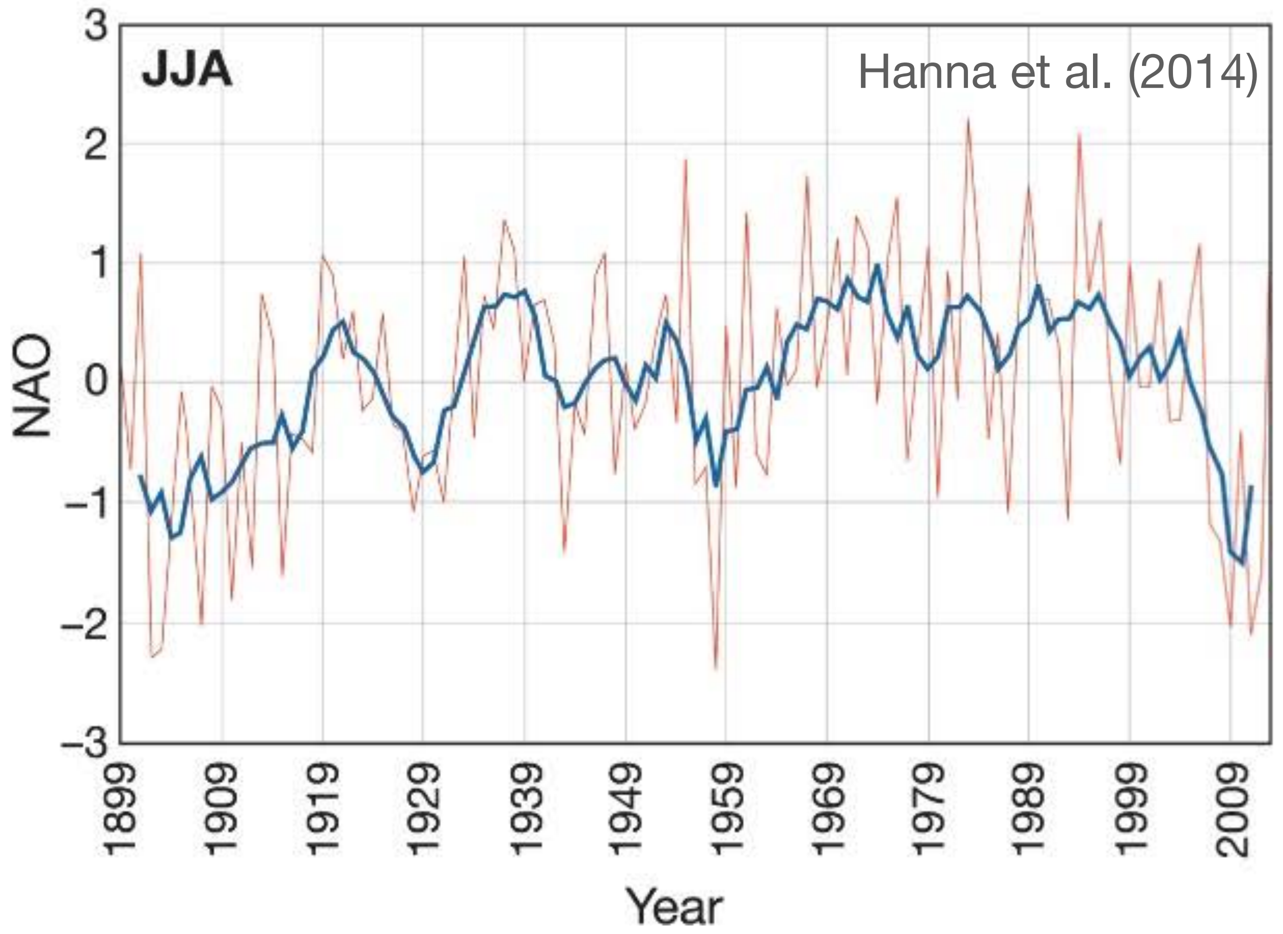
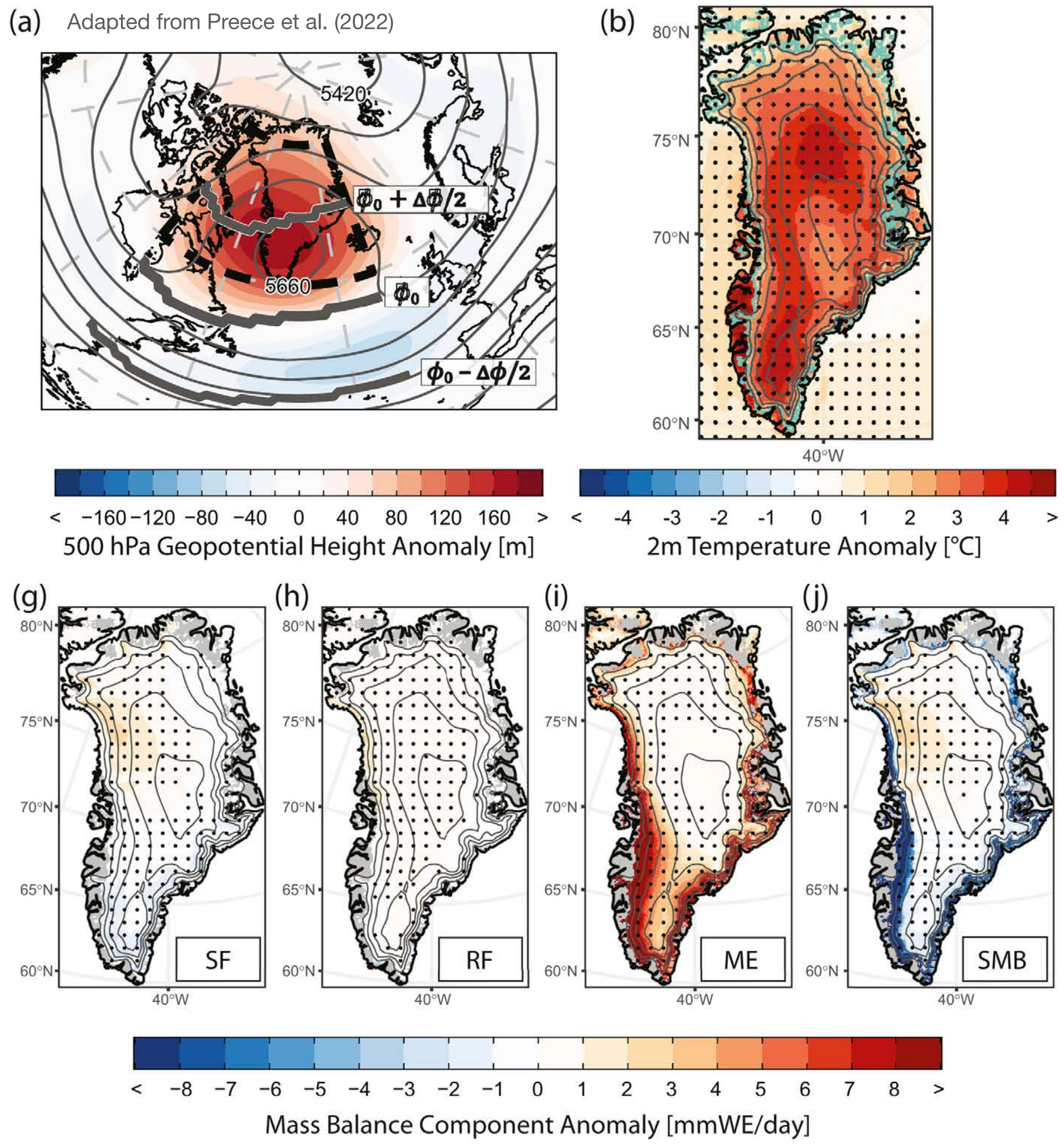


A positive trend in Greenland blocking identified in reanalyses was not identified in members from CMIP6 and CMIP5.

This Greenland blocking trend also evident in observations.





More blocking = higher temperatures + more melting

Greenland blocking in climate models

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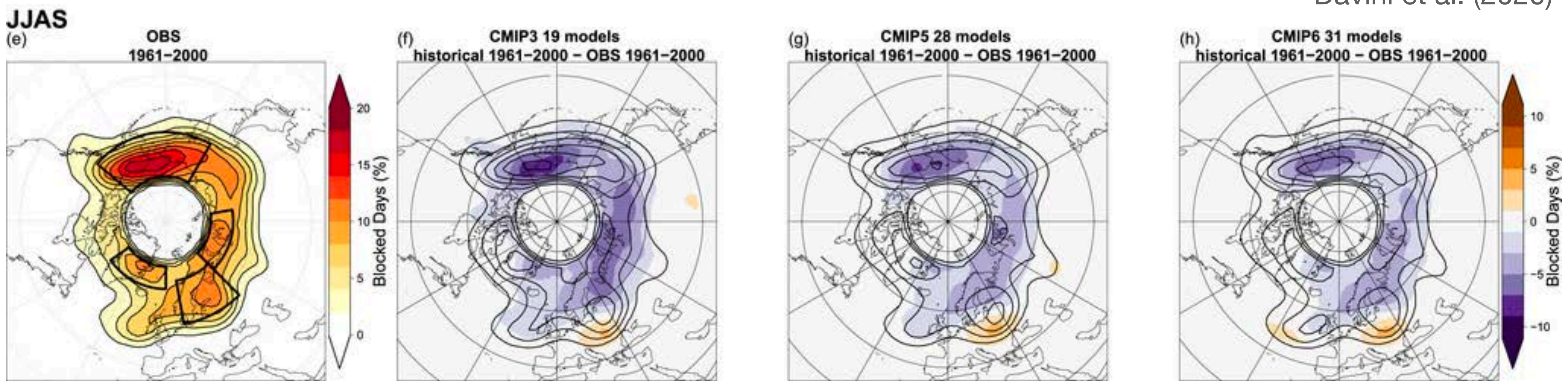
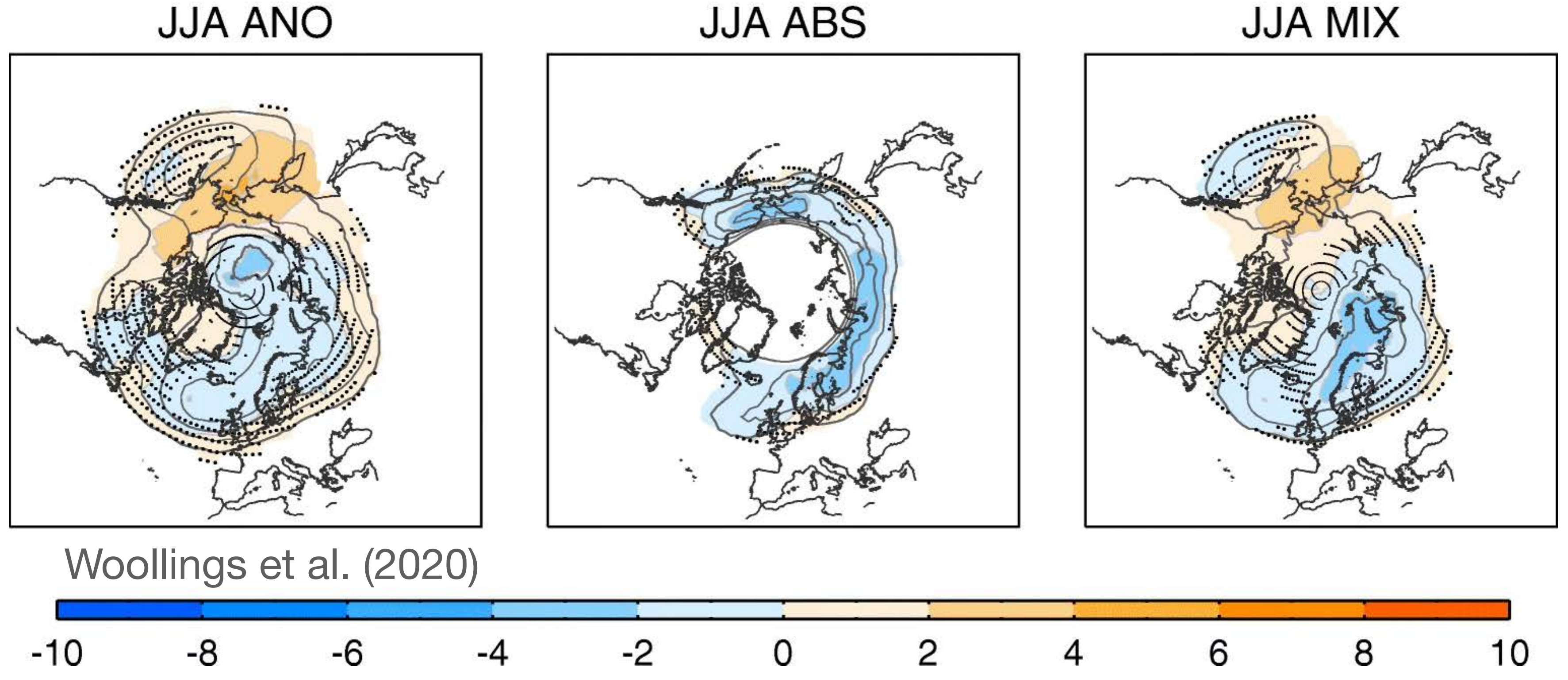
Climate model biases

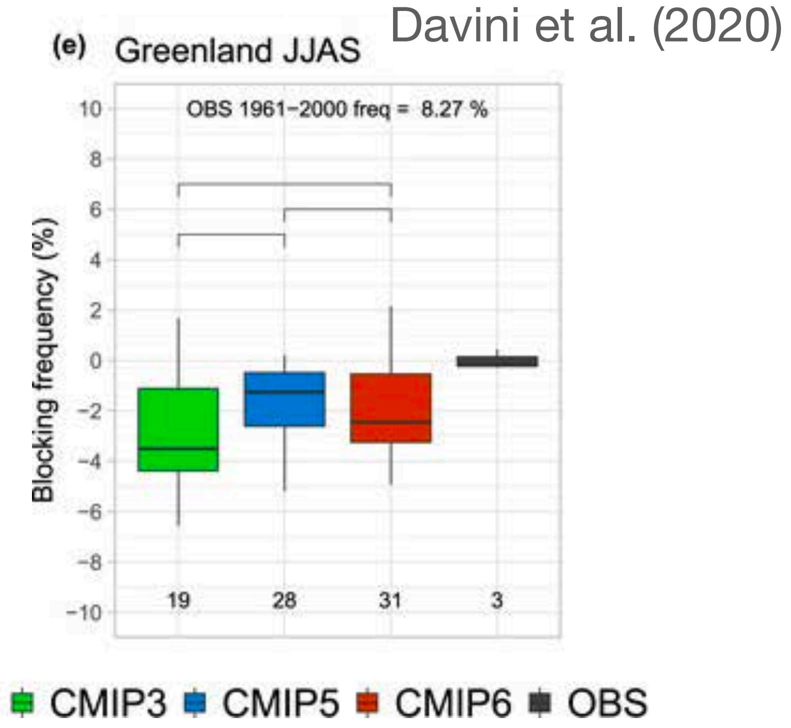
Davini et al. (2020)





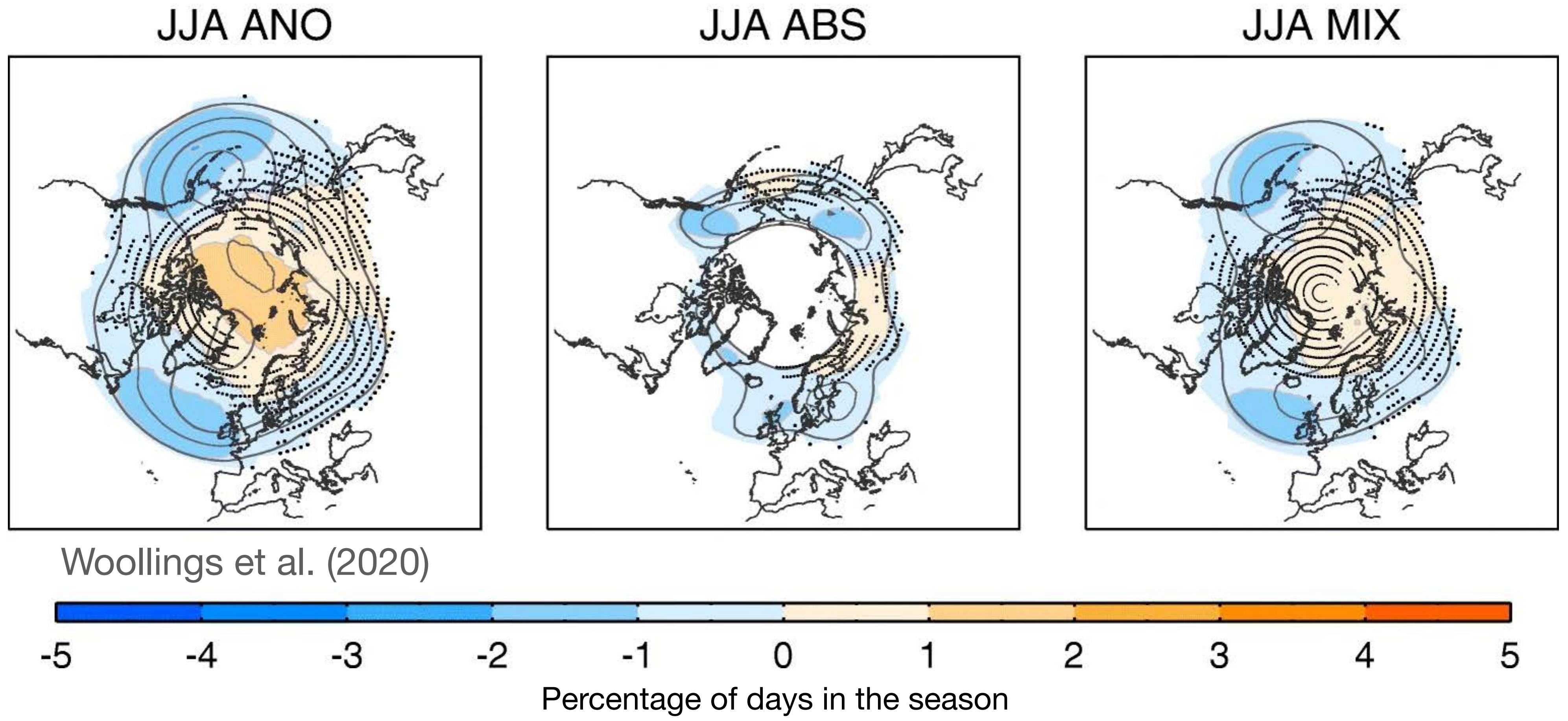
Woollings et al. (2020)

Davini et al. (2020)



1. Block frequency is underestimated in climate models (and has been for decades).
2. Are there processes key for blocking missing in models?

Future trends



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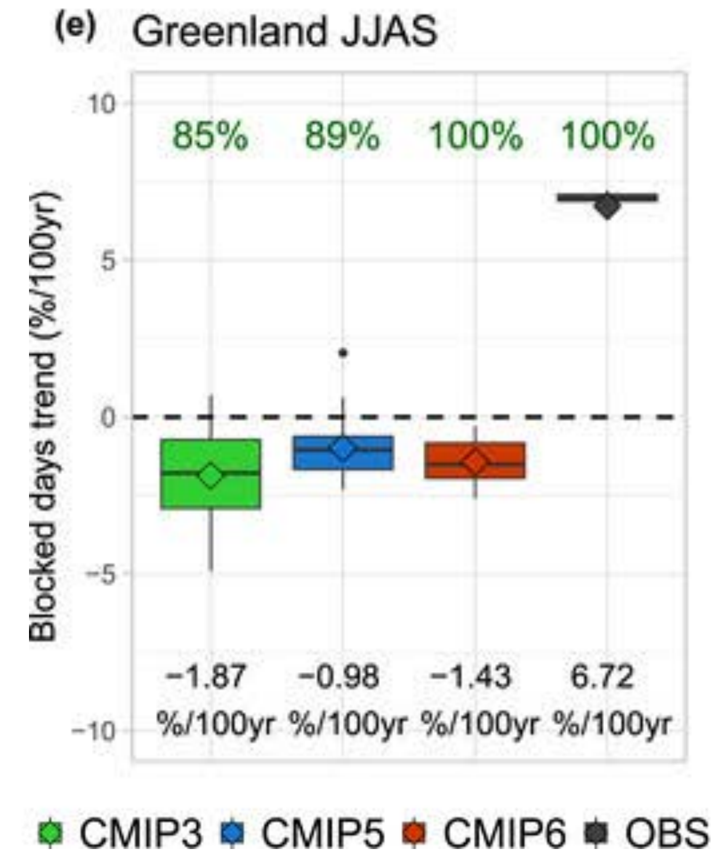

1. Climate model simulations suggest a decrease in GB is expected with global warming.
2. This is opposite to what has been observed in recent years.

Results

Missing decadal variability of summer Greenland blocking in climate models

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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.

Data and methods

Focus on temporal characteristics of GB in a large ensemble (488 members) of CMIP6 models:

- ~170 historical simulations.
- ~140 AMIP simulations.
- ~70 hist-aer DAMIP simulations.
- ~70 hist-GHG DAMIP simulations.
- ~70 hist-nat DAMIP simulations.
- ~20 hist-1950 HighResMIP simulations.

Identify blocking using four blocking indices:

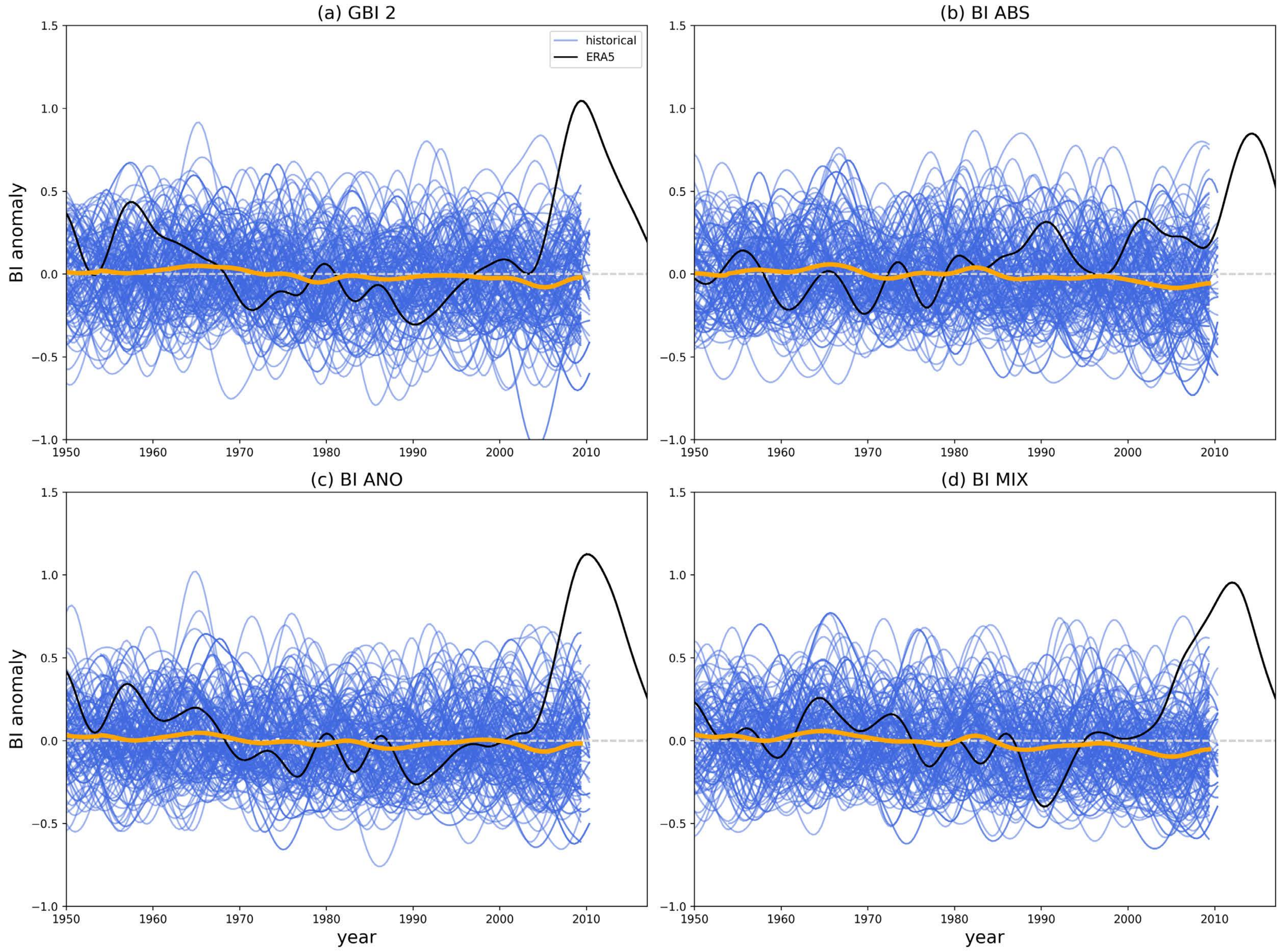
1. **GBI2**: area-averaged geopotential height at 500 hPa (Z500) in region covering Greenland. Normalised with a hemispheric mean to eliminate role of background warming.
2. **BI ABS**: flow reversal index based on Z500, calculated for region between 35—75N and summed for grid points within Greenland region.
3. **BI ANO**: geopotential height anomaly index. Blocked grid points defined as those that have a Z500 anomaly exceeding the climatological 90th percentile in the region 50—80N.
4. **BI MIX**: a combination of the BI ABS and BI ANO indices. At least one grid point identified in a block by BI ANO must also meet the flow reversal criteria of BI ABS.

Greenland blocking time series

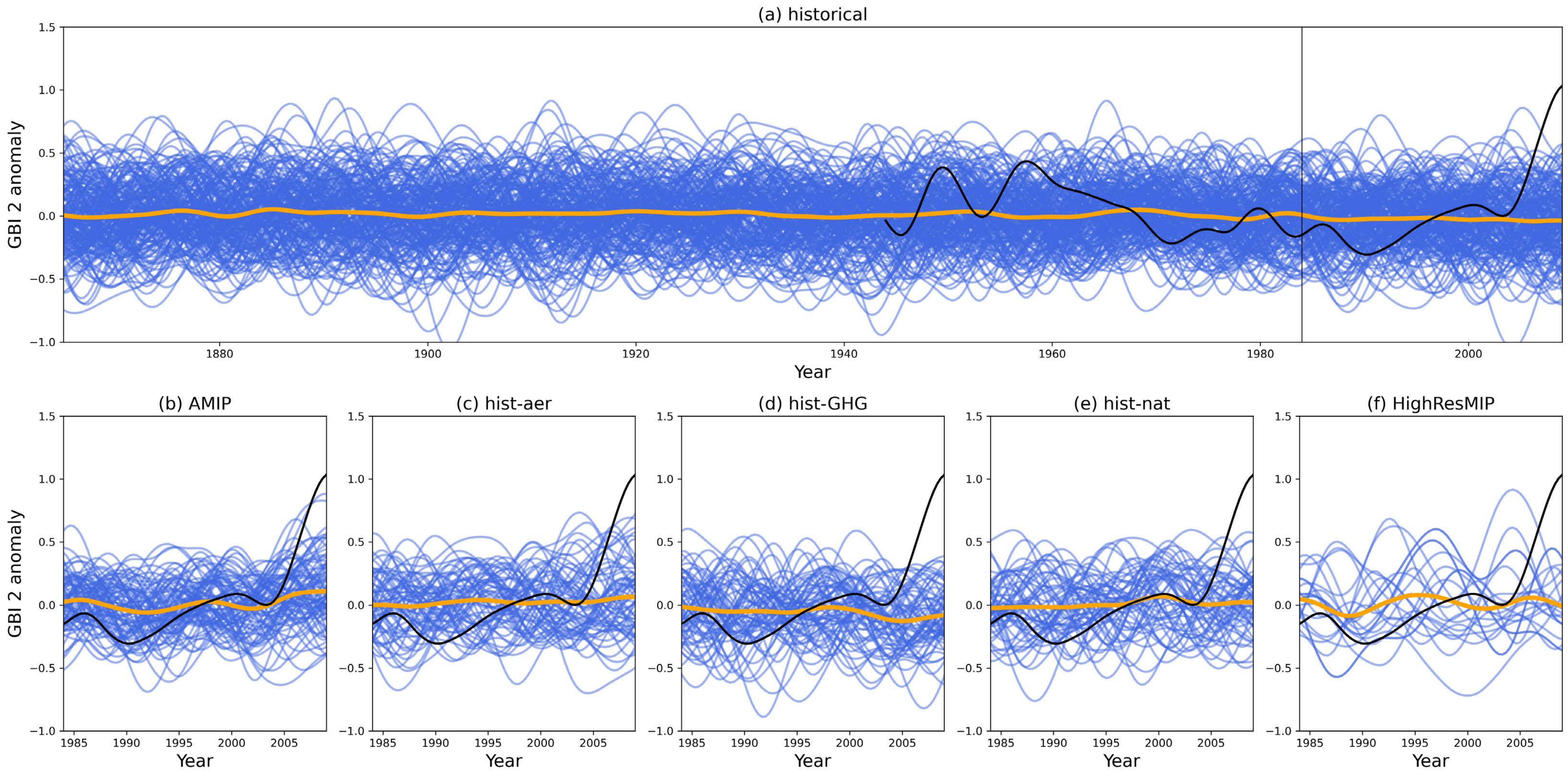
1. The GB trend does not appear to be a continued increase.

2. The four blocking indices agree well on the timing and magnitude of increased GB period.

3. The ERA5 time series lies outside the spread in the large ensemble of historical coupled simulations.

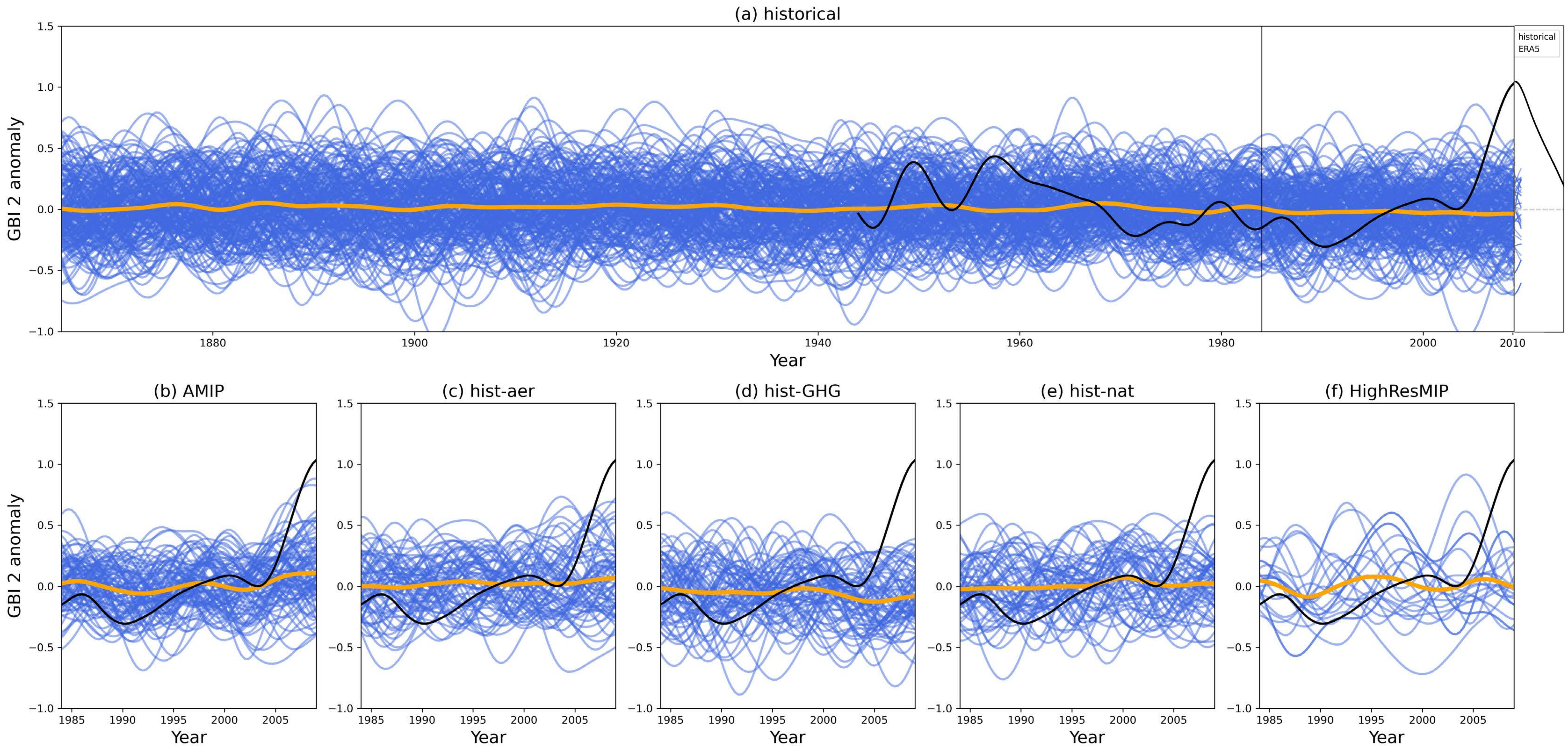


CMIP experiment comparison



1. The ERA5 GB time series remains an outlier in all of the experiments considered. The multi-model ensemble mean shows little variation.
2. Can the models simulate a period of increased GB like that seen in ERA5?

CMIP experiment comparison



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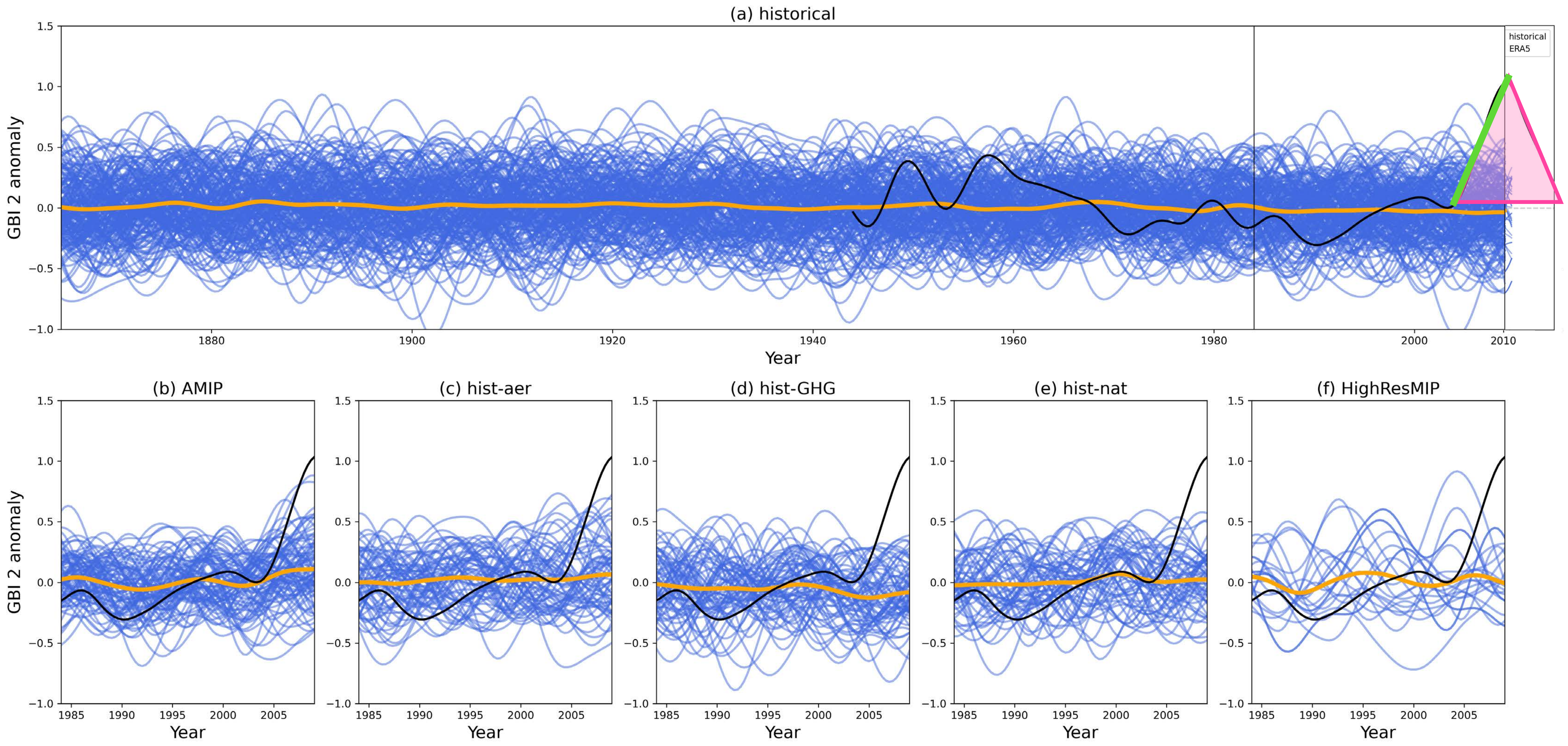

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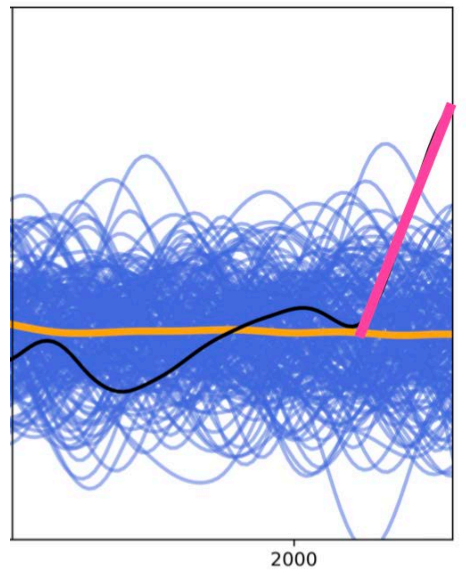
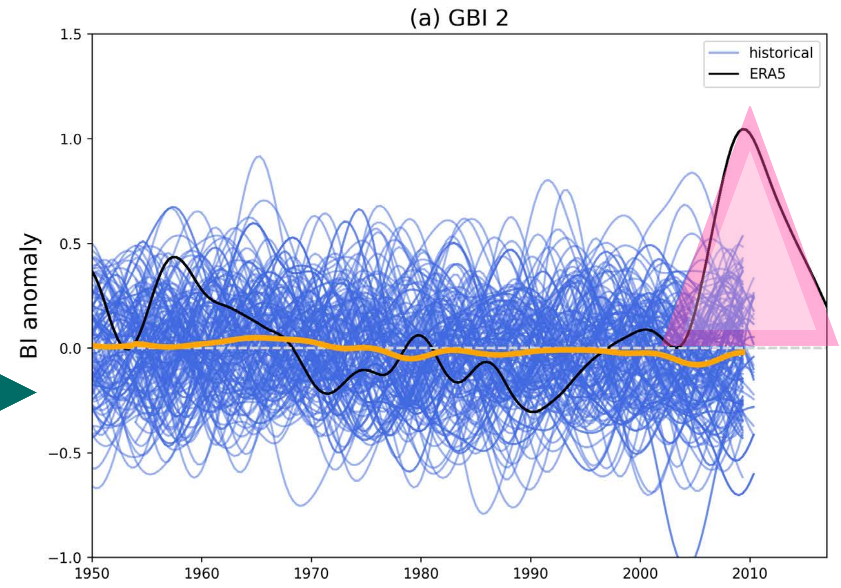
How extreme is the observed trend?



The ERA5 GB trend is quantified in two ways:

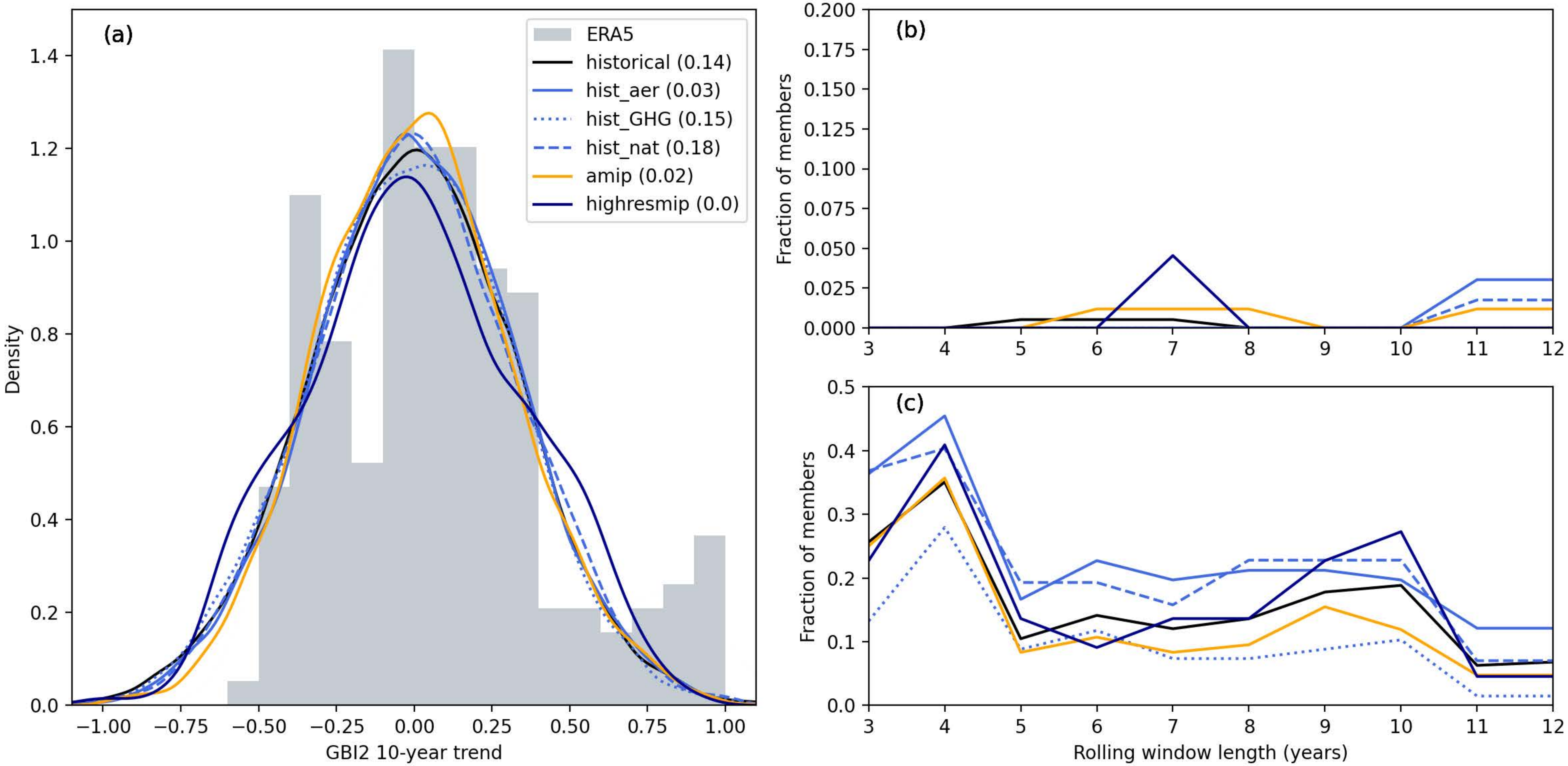
1. The 10-year change in GBI
2. The duration and mean of the positive GBI anomaly



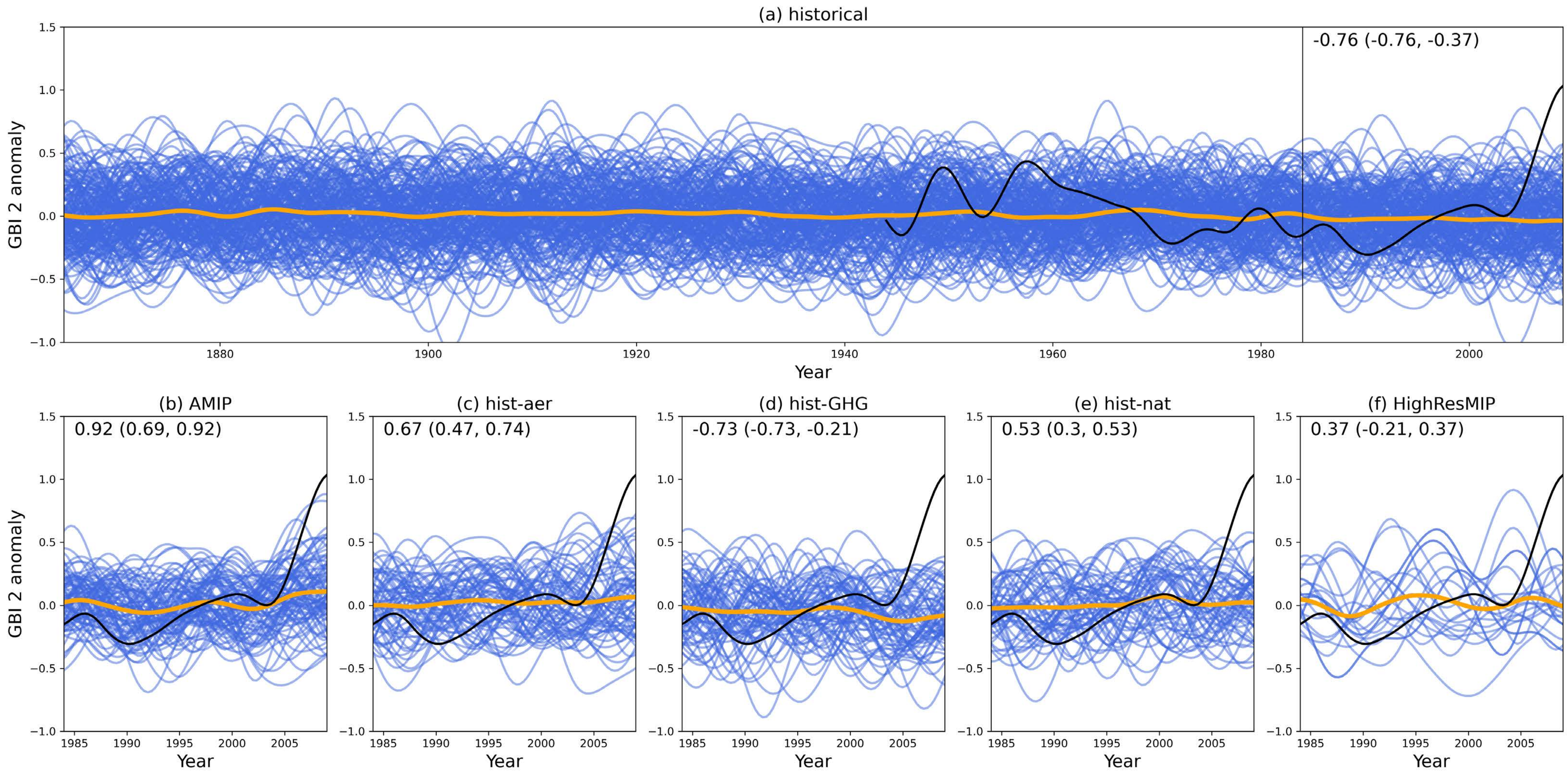
1. The ERA5 10-year GB trend lies at the very tail of the GCM distributions of GB trends.

2. A small fraction of ensemble members have a period of GB with an average anomaly as that in ERA5.

3. A period of positive GB anomaly of the same length as that in ERA5 is less rare, with around a quarter of members simulations such.



Possible forced response



1. The ensemble mean time series in the AMIP and hist-aer experiments correlate strongly with ERA5.
2. This suggests a forced response in GB from SST/SICs and/or anthropogenic aerosols which may be too weak in the models.

RPC correction

Individual ensemble members of weather or climate models often contain some predictable signal but this may be too weak (Eade et al., 2014; Smith et al., 2020). We can correct the ensemble mean using

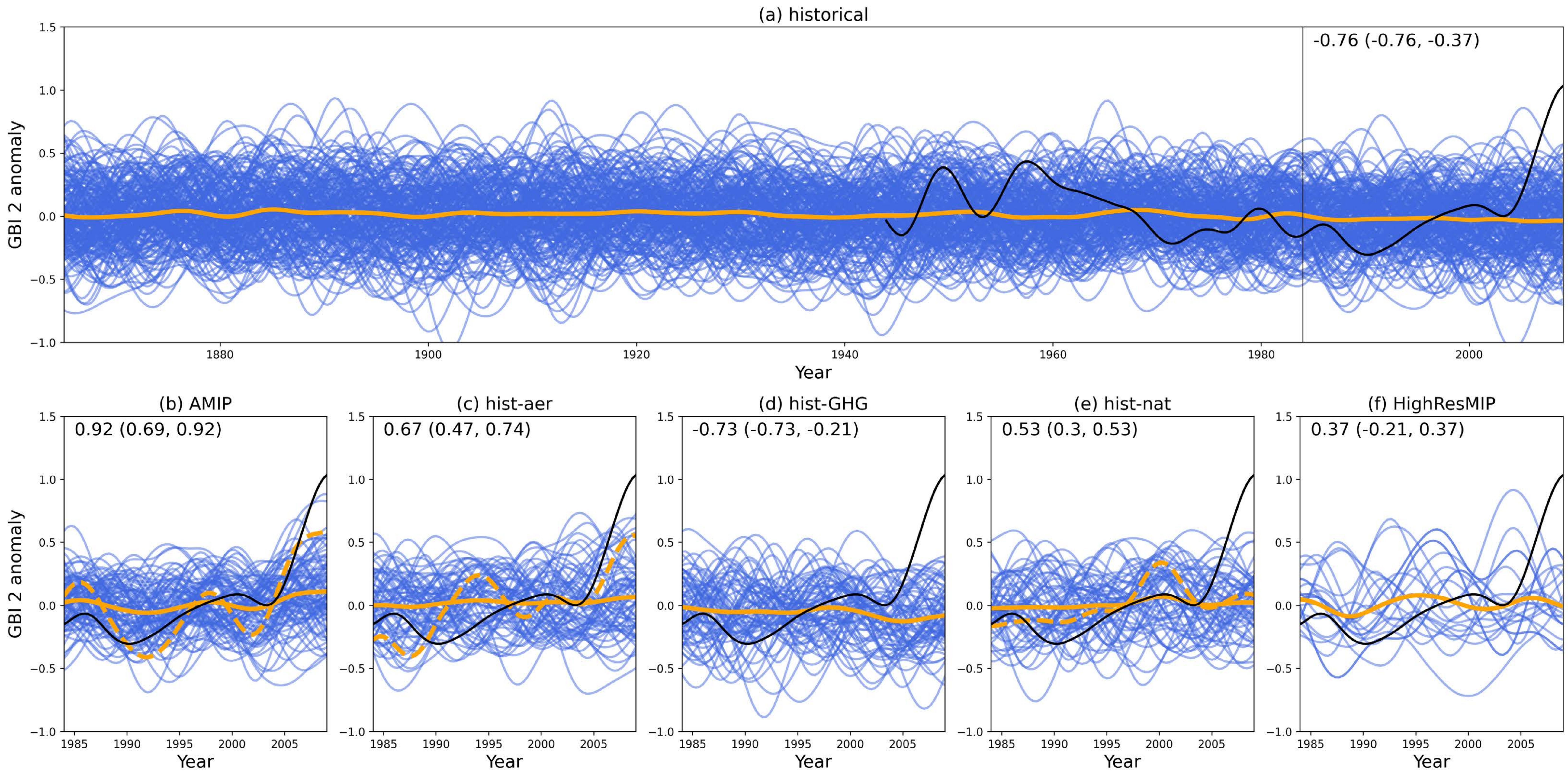
$$G\bar{B}_t^* = (G\bar{B}_t - G\hat{B})\frac{\sigma_{obs} r}{\sigma_{sig}} + G\hat{B}$$

where GB_t is the time series of the GBI, $G\bar{B}_t^*$ is the corrected ensemble mean, the overbar 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_{sig} are the standard deviations of the observations and ensemble mean, respectively.

$$RPC = \frac{PC_{obs}}{PC_{mod}} \geq \frac{r}{\sqrt{\frac{\sigma_{sig}^2}{\sigma_{tot}^2}}}$$

where σ_{sig}^2 and σ_{tot}^2 are the variances of the observations and mean of the ensemble members, respectively.

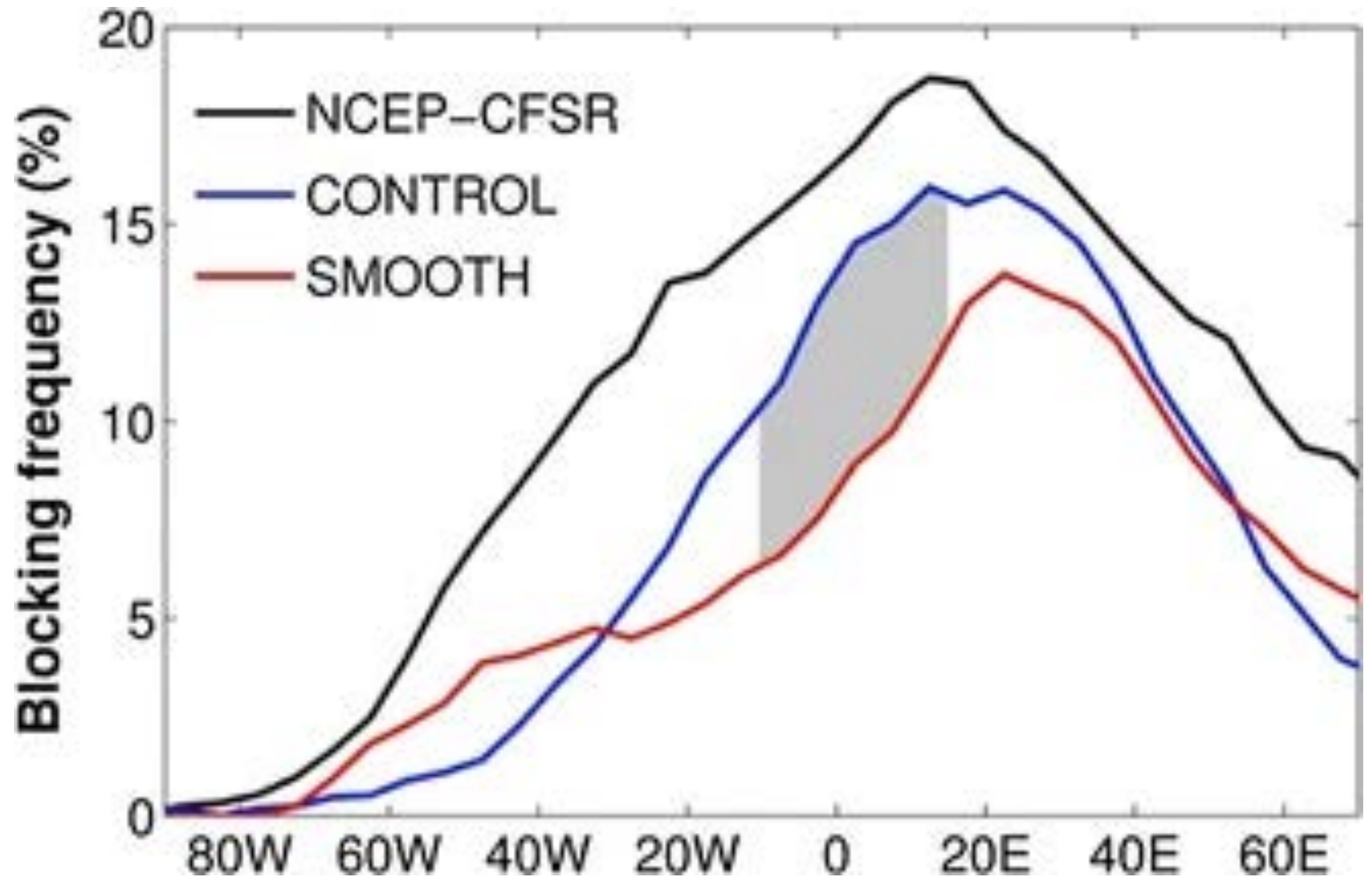
Corrected GBI time series



1. The corrected ensemble mean of the AMIP and hist-aer experiments more closely follow the ERA5 GB time series.

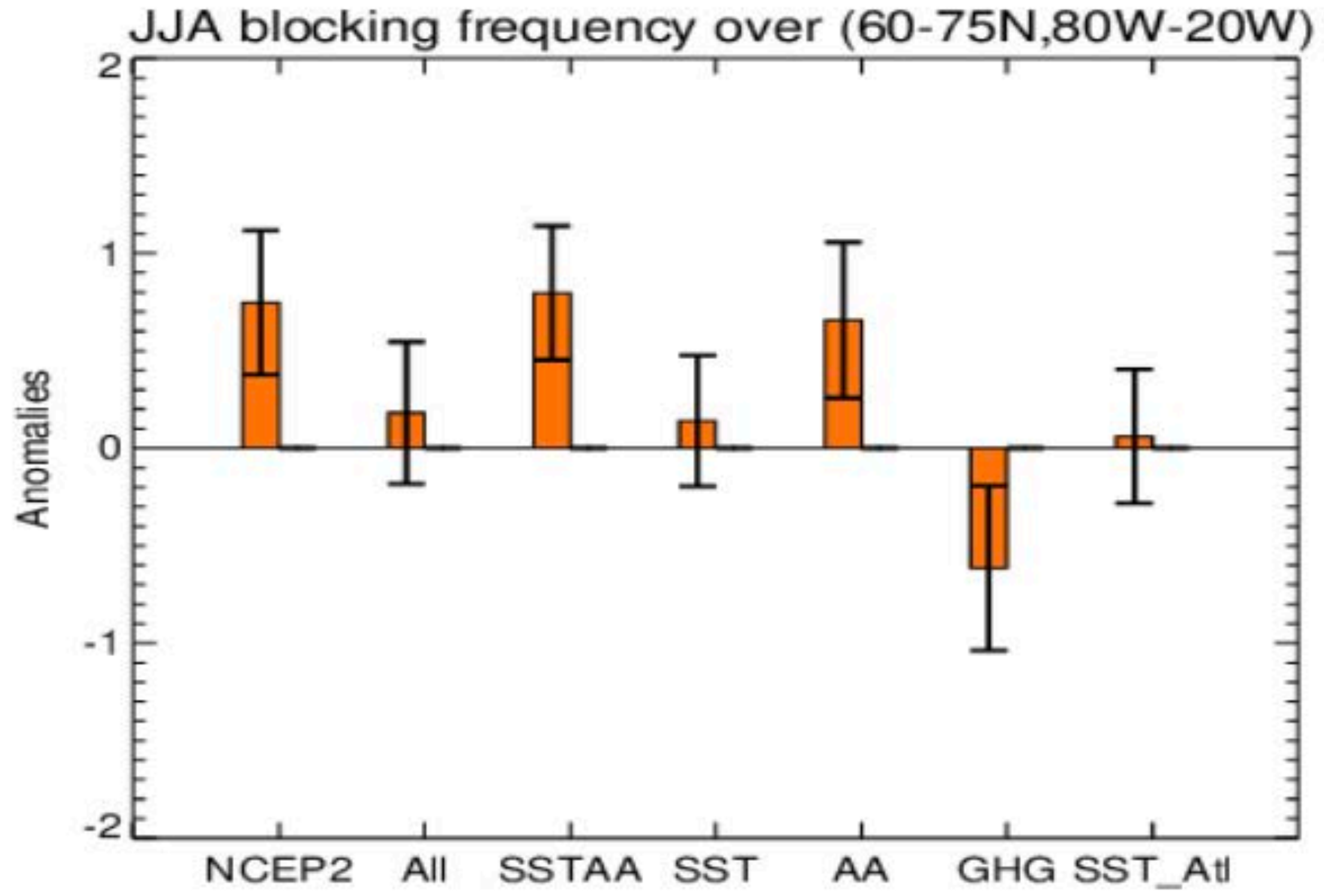
SST and aerosol forcing of GB

SST influence.



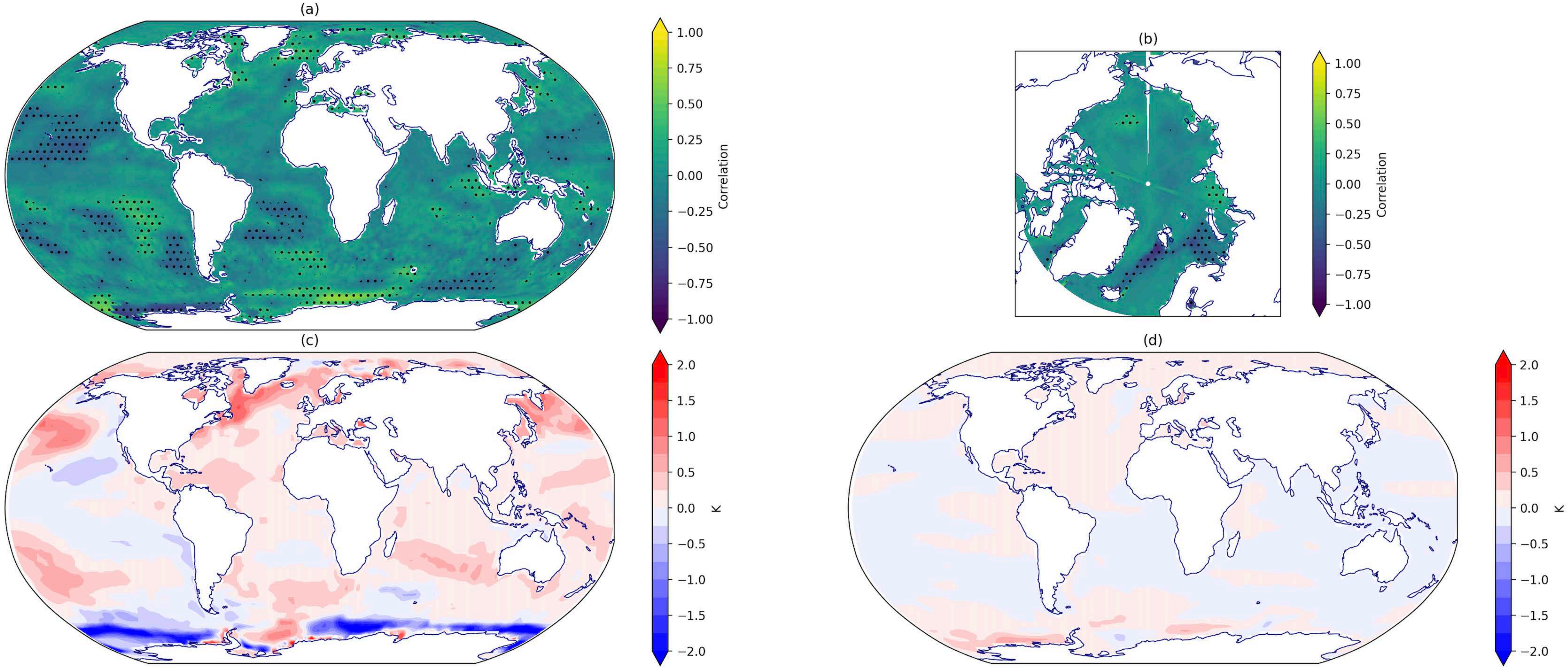
The wintertime (DJF) blocking frequencies in the NCEP-CFSR (black), CONTROL (blue) and SMOOTH (red). The grey shaded region indicates where the difference is significant at the 10 % significance level. O'Reilly et al. (2016).

Aerosol impact.



GB summer (JJA) changes in NCEP2 and Met Office MetUM-GA6 atmosphere simulations to different forcings between the periods 1964-1981 and 1994-2011. Bars show modelled blocking responses to changes in all forcings (All), sea-surface temperature/sea-ice extent and anthropogenic aerosols (SSTAA), sea-surface temperature/sea-ice extent (SST), anthropogenic aerosols (AA), greenhouse gases (GHG), and Atlantic sector sea-surf. temperature/sea-ice extent (SST_Atl). From Dong and Sutton (2021).

SST and aerosol forcing of GB



1. Temporal correlations between the hist-aer experiment and ERA5 are low (top row). (AMIP correlates strongly with ERA5 as they are based on obs).

2. SST anomalies during the GB period are different in the AMIP and hist-aer experiments (bottom row).

3. SSTs/SICs and anthropogenic aerosol forcing appear to be acting through different pathways.

Conclusions and outlook

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- Recent period of increased Greenland blocking was not a sustained trend but an anomalous period of frequent summertime blocking.
- Such an anomalous period of blocking is extremely rare in ~500 members from the CMIP6 archive, including members from historical, atmosphere-only, single forcing and high resolution experiments.
- The multimodel means of the atmosphere-only and anthropogenic aerosol experiments correlate with the observed trend in Greenland blocking, suggesting a forced response that may be too weak in the models.
- The anthropogenic aerosol experiments do not seem to be influencing Greenland blocking via the SSTs.
- Running experiments with the Met Office climate model (HadGEM3) trying to better understand SST/sea ice forcing and the influence of aerosols.

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