

# Simulating decadal changes in atmospheric circulation using a bias-corrected atmospheric model

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## Key points

- ECHAM6 global climate model biases are corrected by applying reanalysis-based dynamical forcings on model experiments
- Bias correction insignificantly improved the December–February (DJF) North Atlantic Oscillation (NAO) response to sea surface temperature and sea ice forcings and the troposphere-stratosphere interaction in decadal time scale
- Observed change of the NAO index towards positive phase and shift of the polar vortex towards Eurasia are probably forced responses, but the effect of internal variability is large

## Two-step bias correction

We use ECHAM6 spectral atmospheric general circulation model with triangular truncation T63 and 95 vertical levels. The model Northern Hemisphere stratospheric polar vortex is on average too weak by 10–15 m/s in DJF (Tyrrell et al., 2020).

### Bias correction process:

Following Kharin and Scinocca (2012) and Tyrrell et al. (2020):

- 1) Nudging large-scale modes of divergence, vorticity, temperature and log of surface pressure towards ERA-Interim 1979–2009 climatology
  - Recording 6-hourly tendencies with wavenumbers below 21 (features larger than about 1000 km)
  - Mean annual cycle of tendencies smoothed with a Gaussian filter with 25-day window
- 2) Applying smoothed nudging tendencies of temperature and divergence to freely running model to compensate for inherent biases

### Model experiments with different sea surface conditions:

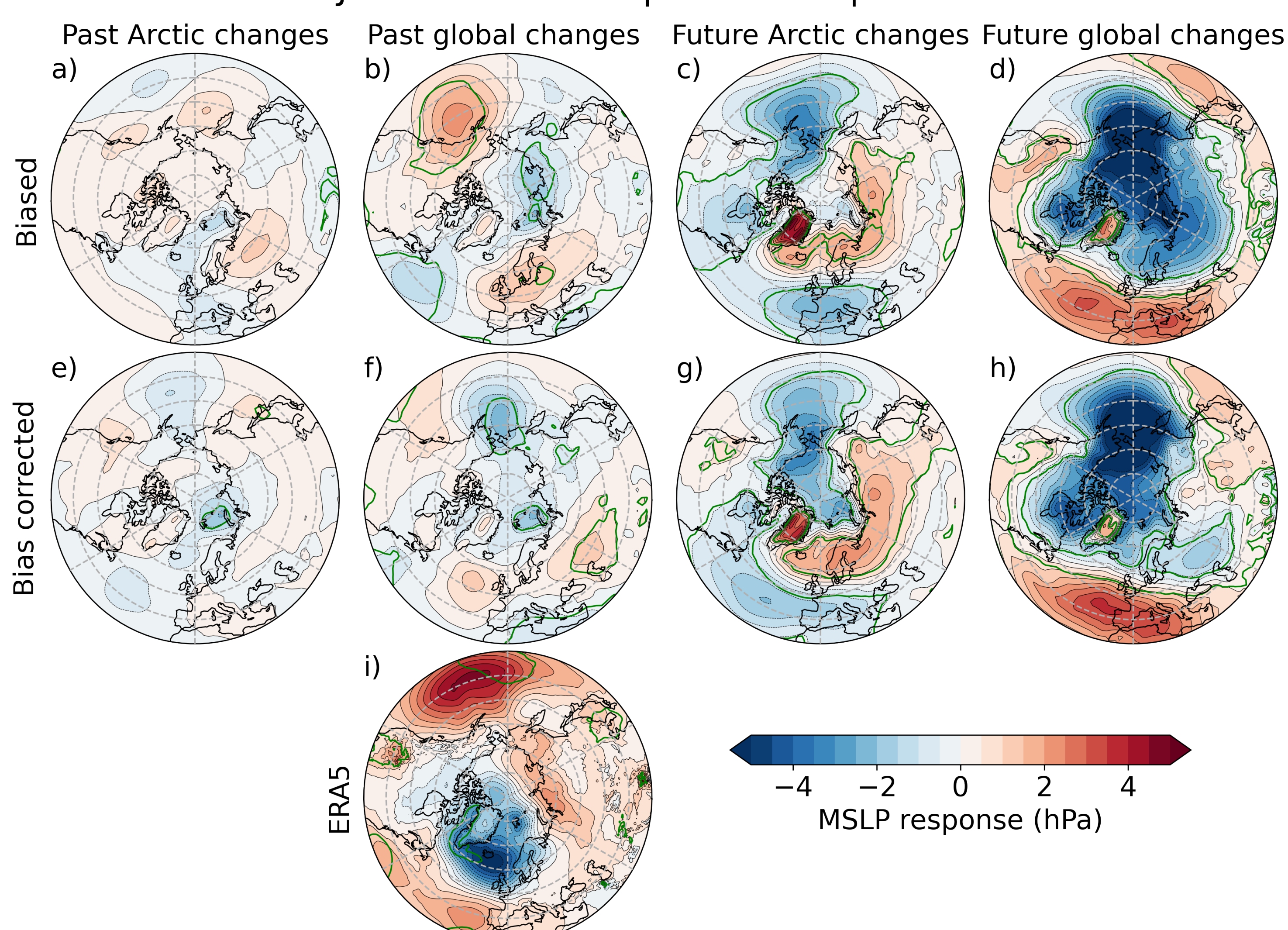
- Both uncorrected and bias corrected 100-year ECHAM6 runs are forced with monthly varying sea surface temperature (SST) and sea ice concentration (SIC) anomalies, and model responses are calculated as differences between runs:
- Past Arctic: difference in time-slice experiments of HadISST4 SST and SIC applied north of 65° N, 2011–2020 mean minus 1980–1989 mean
  - Past global: as Past Arctic, but with forcings applied globally
  - Future Arctic: difference in time-slice experiments of CMIP6 SSP5-8.5 SST and SIC applied north of 65° N, 2071–2100 mean minus 1979–2008 HadISST4 mean
  - Future global: as Future Arctic, but with forcings applied globally

ERA5 difference between 2011–2020 and 1980–1989 means is used for reference.

## Different MSLP response

- Past response slightly improved in the Atlantic and Europe, but not in the Pacific
- Negative NAO pattern with future Arctic changes
- Stronger positive NAO pattern and higher pressure in Eurasia by global warming with bias correction

### DJF mean sea level pressure response



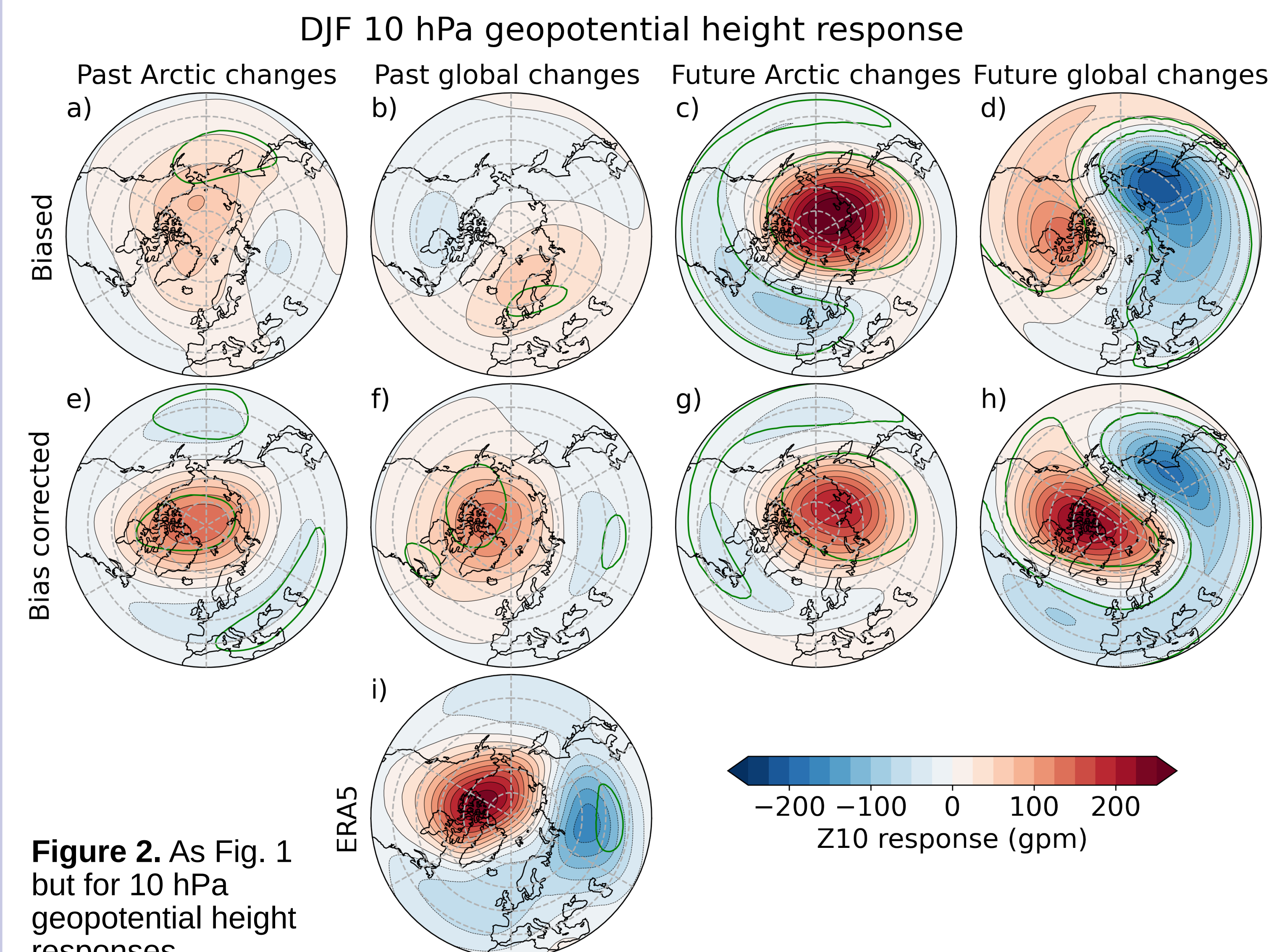
**Figure 1.** December–February mean sea level pressure response to past Arctic (first column), past global (second column), future Arctic (third column) and future global (fourth column) SST and SIC changes in 100-year uncorrected (top row) and bias corrected (middle row) model runs, and the corresponding past change in ERA5 (bottom). Values inside green contours are significant in the 95 % level.

## References

- Kharin, V. V. and Scinocca, J. F. 2012. The impact of model fidelity on seasonal predictive skill. *Geophys. Res. Lett.*, 39, L18803.
- Tyrrell, N. L. et al. 2020. Siberian Snow Forcing in a Dynamically Bias-Corrected Model. *J. Clim.*, 33, 24.

## Improved past stratospheric response

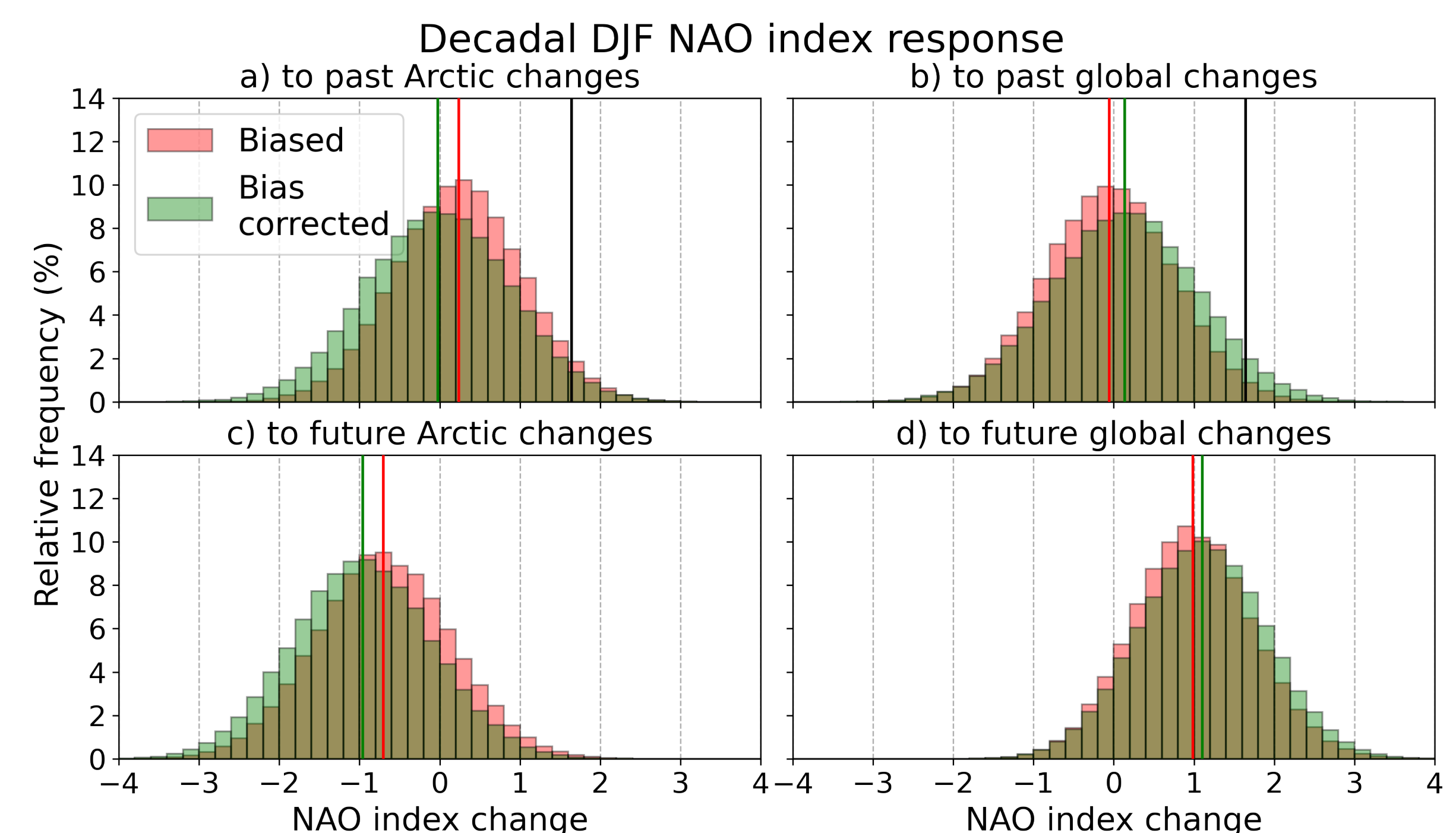
- Bias corrected model better captures the past shift of polar vortex towards Eurasia
- Future Arctic changes weaken the vortex, global changes shift it eastward



**Figure 2.** As Fig. 1 but for 10 hPa geopotential height responses.

## Modelled NAO responses weak

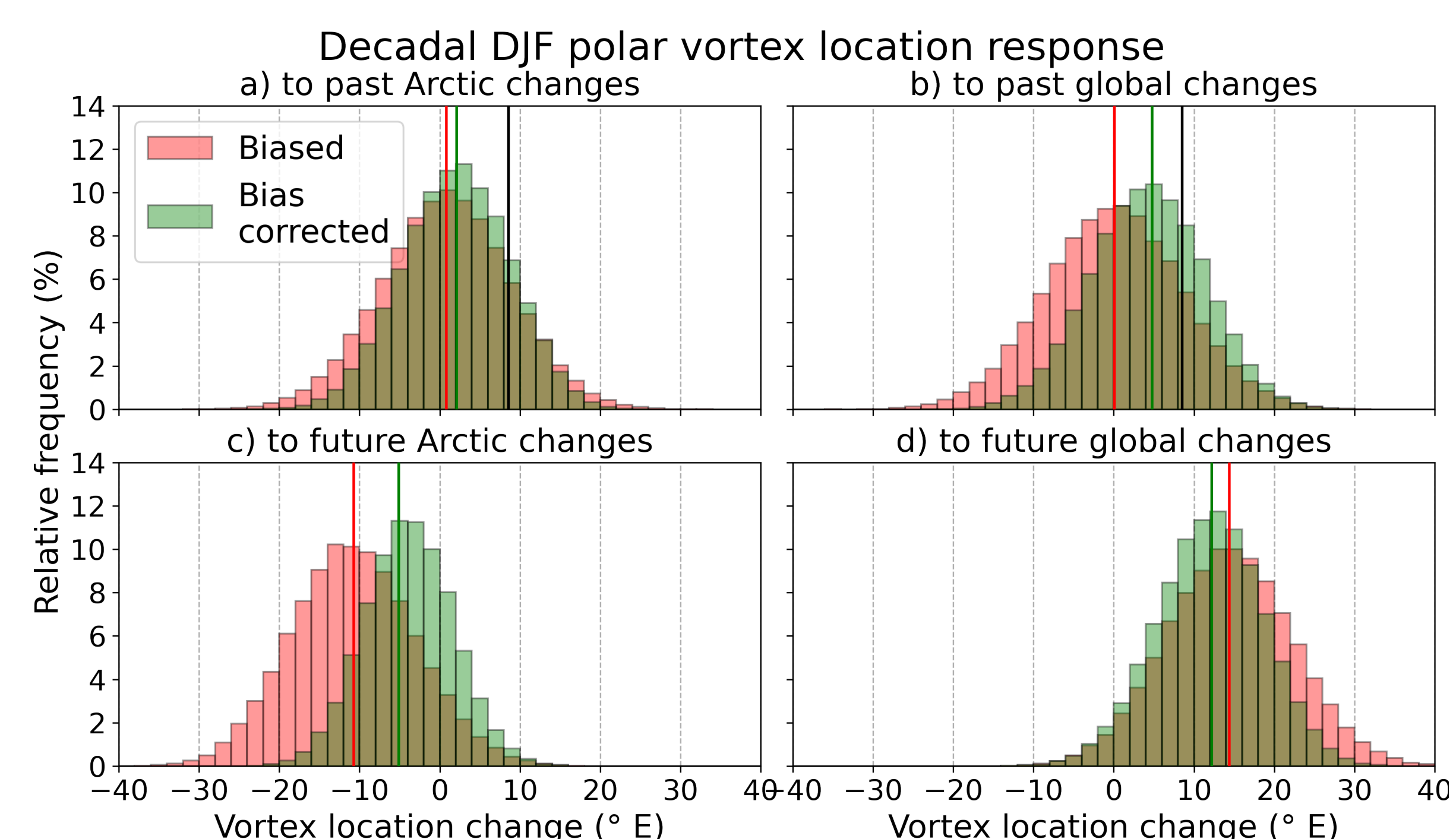
- Bias correction slightly improves the positive NAO response to global warming
- Response to Arctic warming shifted towards the negative phase



**Figure 3.** Probability density function of decadal mean December–February NAO index response of uncorrected (red bars) and bias corrected (green bars, overlaps with brown) model runs to past Arctic (a), past global (b), future Arctic (c) and future global (d) SST and SIC changes. Relative frequencies were obtained by calculating the difference between the NAO indices of random decadal December–February means with replacement 100 000 times. Mean values of ERA5, uncorrected model and bias corrected model are drawn with black, red and green vertical lines, respectively.

## Location of polar vortex sensitive to biases

- Observed shift towards Eurasia better simulated in bias corrected model
- Weaker responses to future changes with bias correction, but less variability



**Figure 4.** As Fig. 3 but for the response of polar vortex centroid longitude calculated from the wave-1 phase of 55°–65° N average of 10 hPa geopotential height.