Atmospheric blocking and biases of the large-scale flow in climate models

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Background: Accurate representation of the synoptic systems in Earth system models is required to estimate their societal and economic impacts under climate warming. Despite the development of the climate models (from CMIP2 to CMIP6), strong biases in these synoptic processes persist, such as underestimating atmospheric blocking in the North Atlantic region [5,10]. Furthermore, few studies have analyzed the contribution of moist processes to biases in blocking frequency, even when the relevance of latent heat release in the blocking intensity has been shown [6,7]; Here we consider both dry and moist processes.

Data: We analyze winter (DJF) blocks in the CMIP6 [2,4] and the storm-resolving models.

CMIP6 Model	Original resolution	Period
CESM2	100 km	1979-2014
MIROC6	250 km	1979-2014
MPI-ESM1-2-HR	100 km	1979-2014
MPI-ESM1-2-LR	250 km	1979-2014
MRI-ESM2-0	100 km	1979-2014

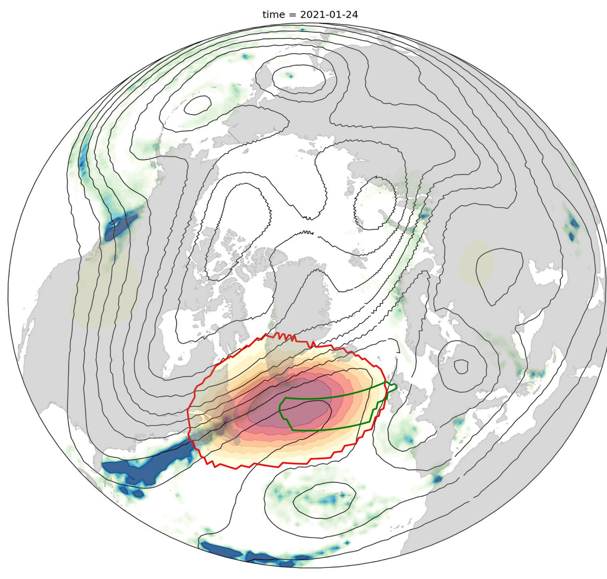
NextGEMS Model	Original resolution	Period
IFS	4.4 km	2020-2024
IFS	28 km	2020-2024
ICON	5 km	2020-2025

Reference: Reanalysis ERA5 (1990-2020) [1].

Atmospheric blocking indices:

1. Persistent and quasi-stationary mid-level (500 hPa) GH anomaly of the flow following the Schwierz index [3].

2. Reversal of the flow at 500 hPa, following the modified TMD2 algorithm [8].



Block frequency biases in CMIP6

Western Europe, Greenland, and the North Pacific are regions with high biases. They are associated with different processes:

Background flow (mode of the |dGH/dy|).
An equatorward shift of the strongest gradient of GH at 500 hPa favors a strong background flow that prevails in the central Atlantic.

Dry processes (transient activity computed using a band pass filter of 2-6 days).
An associated too zonal storm tracks results from background flow biases. Transient eddies activity accelerates the flow at the left exit of the jet, resulting in fewer Rossby wave breaking and less block formation.

Moist processes (ELIAS2.0 [2]).
Underestimation of WCB inflow/outflow frequency is identified. The WCB trajectories do not travel poleward (Figs. e,f), which can be linked to low latent heat release and slow vertical ascent.

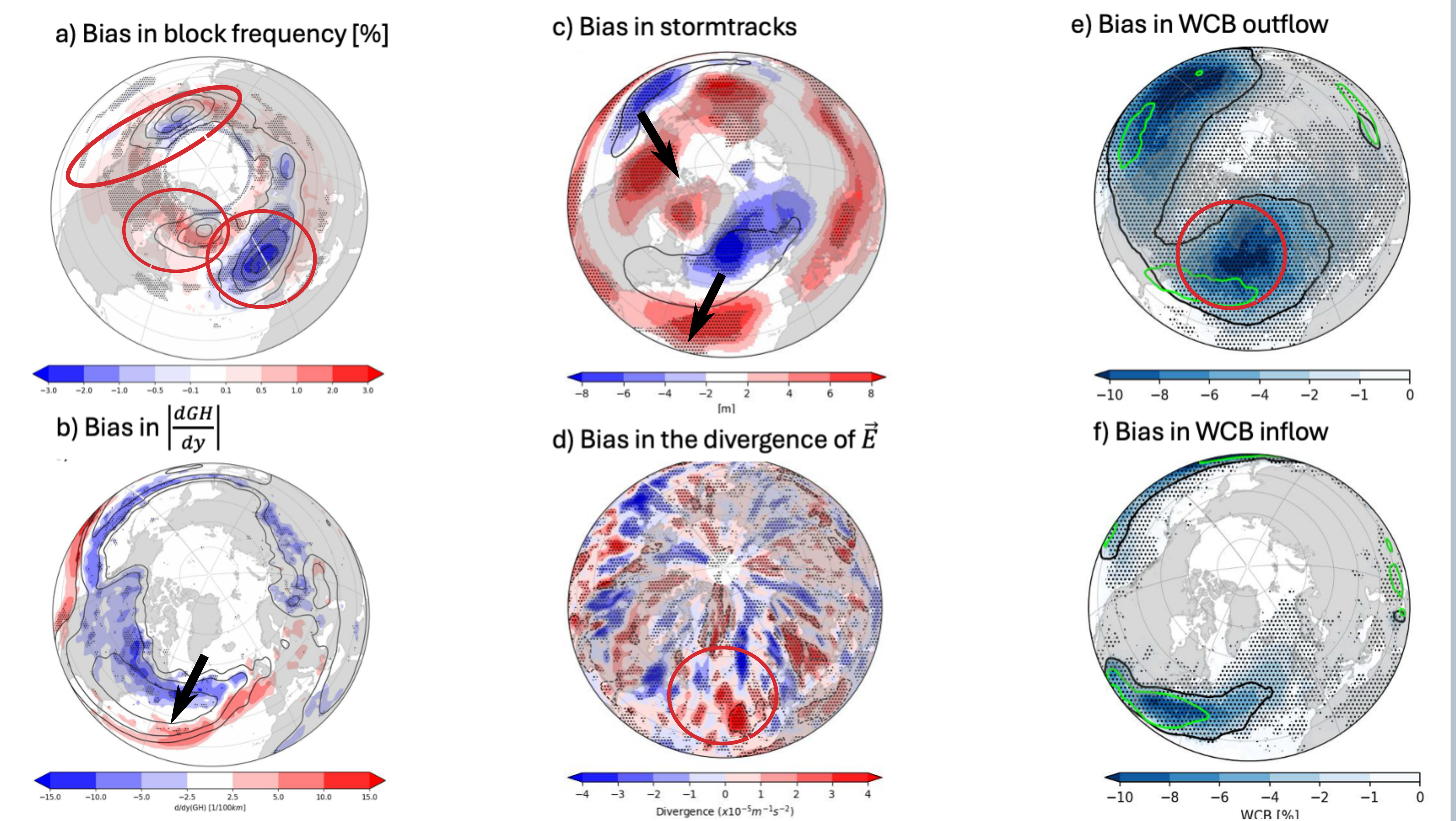


Figure 1. Bias in the a) block frequency, b) mode of |dGH/dy|, c) stormtracks, d) divergence of E vector, e) WCB outflow and f) WCB inflow frequency (colours). Relevant ERA5 values are prensented in contours. Stippling denotes regions of ensemble agreement on the sign of bias; i.e., more than 80% of the ensemble members indicate a bias of the same sign.

Block properties in storm-resolving climate models

Individual blocks identified in ERA5(1990-2020) **39092**, ICON **5648**, IFS-4.4 km **5934**, IFS-28 km **5472**, MPI (1979-2014): **43975**

Density distribution functions show **nextGEMS** improvements in representing the atmospheric blocking intensity (Figs. 2). The median and the goodness of the fit test confirm quantitatively the higher skill, where the IFS seems to produce blockings more similar to ERA5 than the ICON model.

	Median (m)	Goodness of fit
ERA5	205.9	
ICON	200.8	30.1
IFS 4.4 KM	204.9	18.8
IFS 28 KM	203.7	25.0
CMIP6 (MPI)	207.8	36.9

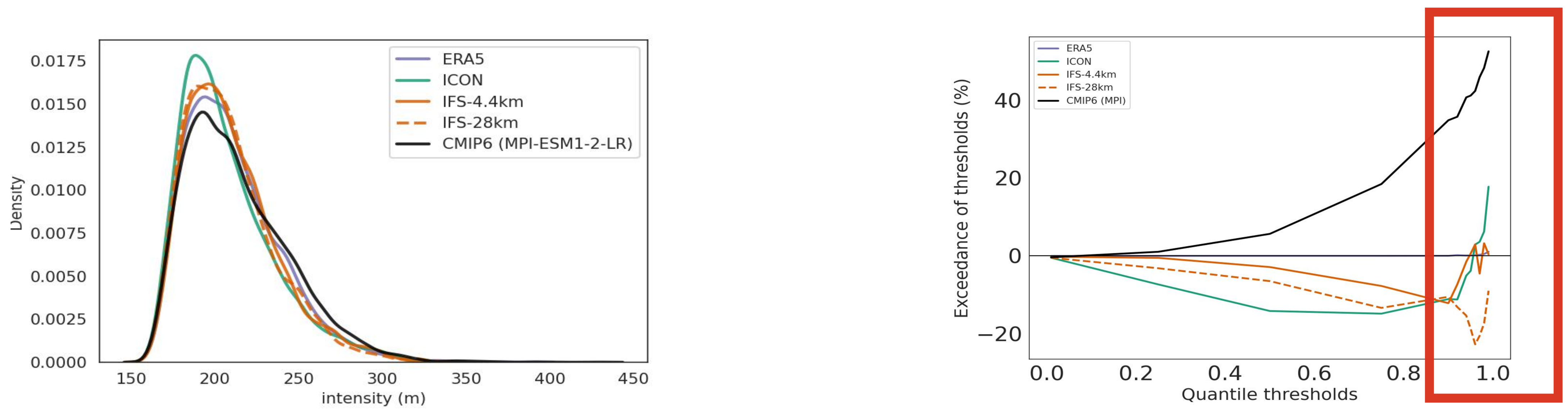


Figure 2. Density distribution function of blocking intensity in the nextGems models (left). Events exceeding the ERA5 percentiles in the atmospheric blocking intensity of the nextGEMS and CMIP6 models (right).

Take away

-The background flow creates the conditions to reduce European block and favors an eddies positive feedback.
-A reduction in the frequency of the warm conveyor belt outflow is impacting the evolution of downstream blocks and diabatic processes may play a role.
-**nextGEMS** captures the intensity of atmospheric blocking better than the chosen CMIP6 model, and improvements are also observed in the high percentiles.
-The final production runs are coming soon; stay tuned!

Reference:
[1] Hersbach, et al., 2020
[2] Eyring,et al., 2016
[3] Schwierz et al., 2004
[4] Palmer et al., 2023
[5] Davini and D'Andrea, 2020
[6] Pfahl et al., 2016
[7] Steinfeld et al., 2020
[8] Brunner and Steiner, 2017
[9] Quinting et al., 2022
[10] Woollings et al., 2018