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Supplement of

On the linkage between future Arctic sea ice retreat, Euro-Atlantic circulation regimes and temperature extremes over Europe

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Supporting information for the paper "On the linkage between future Arctic sea ice retreat, Euro-Atlantic circulation regimes and temperature extremes over Europe"

Table S1: List of PAMIP models that were used for the analysis in Figs. 2, S4 and S5. Listed is also the available ensemble size for each experimental setup (in number of years)

Institute	Model	pdSIC	futArcSIC	futBKSIC
Max Planck Institute for Meteorology, Hamburg	ECHAM6	100	100	100
National Center for Atmospheric Research Canadian	CESM2	200	200	-
Norwegian Meteorological Institute	NorESM2-LM	200	200	-
University of Tokyo/National Institute for Environmental Studies/Japan Agency for Marine-Earth	MIROC6	100	100	100
Canadian Centre for Climate Modelling and Analysis	CanESM5	300	300	-
US Department of Energy/University of California Irvine	E3SMv1	185	190	100
Met Office UK	HadGEM3-GC31-MM	300	300	200
National Center of Atmospheric Research/ University of California Irvine	CESM1-WACCM-SC	300	100	100
Institute of Atmospheric Physics, Beijing	FGOALS-f3-L	100	100	-
Centre Européen de Recherche et de Formation Avancée en Calcul Scientifique US	CNRM-CM6-1	300	300	-
Institute Pierre Simon Laplace University	IPSL-CM6A-LR	200	200	100

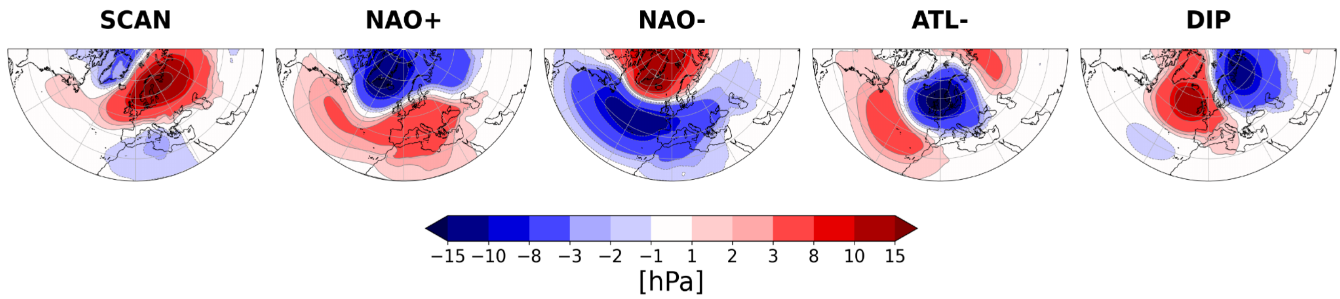

Figure S1: Five circulation regimes over the Euro-Atlantic domain computed from daily ERA5 sea level pressure anomaly data (1979--2018) for extended winter season (December, January, February, March).

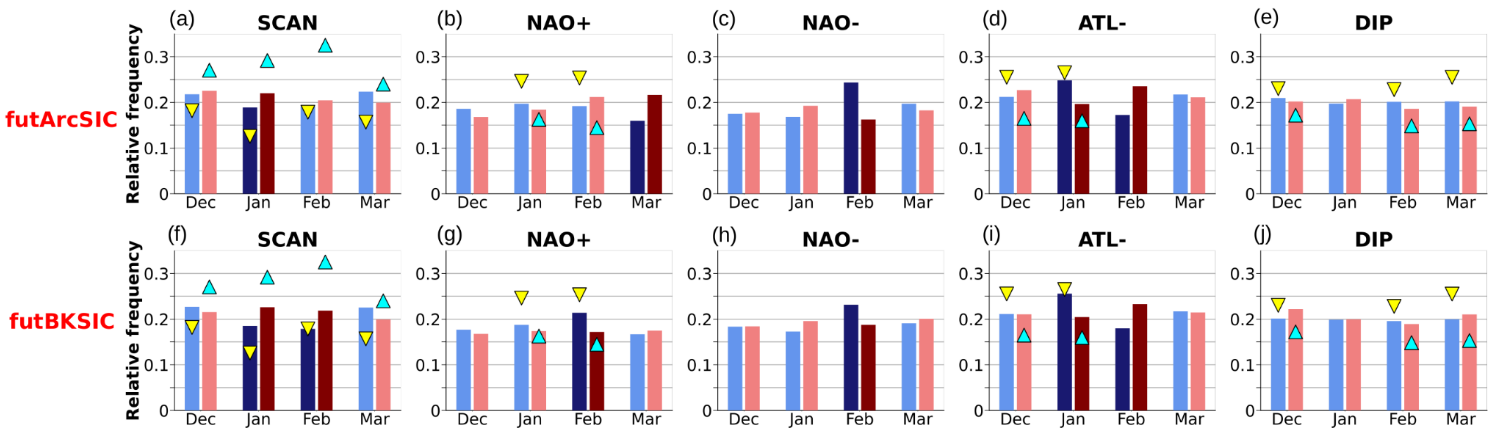

Figure S2: Relative regime occurrence frequencies in ECHAM6 for different winter months compared between the pdSIC reference simulation (blueish bars) and the futArcSIC (upper row, redish bars), as well as the futBKSIC sensitivity simulation (lower row, redish bars). Light redish and blueish bars indicate non-significant frequency differences between reference and sensitivity simulations, whereas the paired dark blueish/redish bars indicate significant differences in occurrence frequencies. Note that by definition the sum over all clusters for a specific month in a given simulation is one. The triangles indicate the respective ERA5 regime occurrence frequencies for recent low (upright bright-blueish triangles) and high (inverted yellow triangles) detrended Arctic sea ice conditions. Only ERA5 occurrence frequencies for months where significant differences between low and high ice conditions were found are shown here. Significant differences are derived from a moving block bootstrap. The absolute numbers of regime day counts in ECHAM6 and ERA5 that were used for the computation are shown in Tabs. S2–S4.

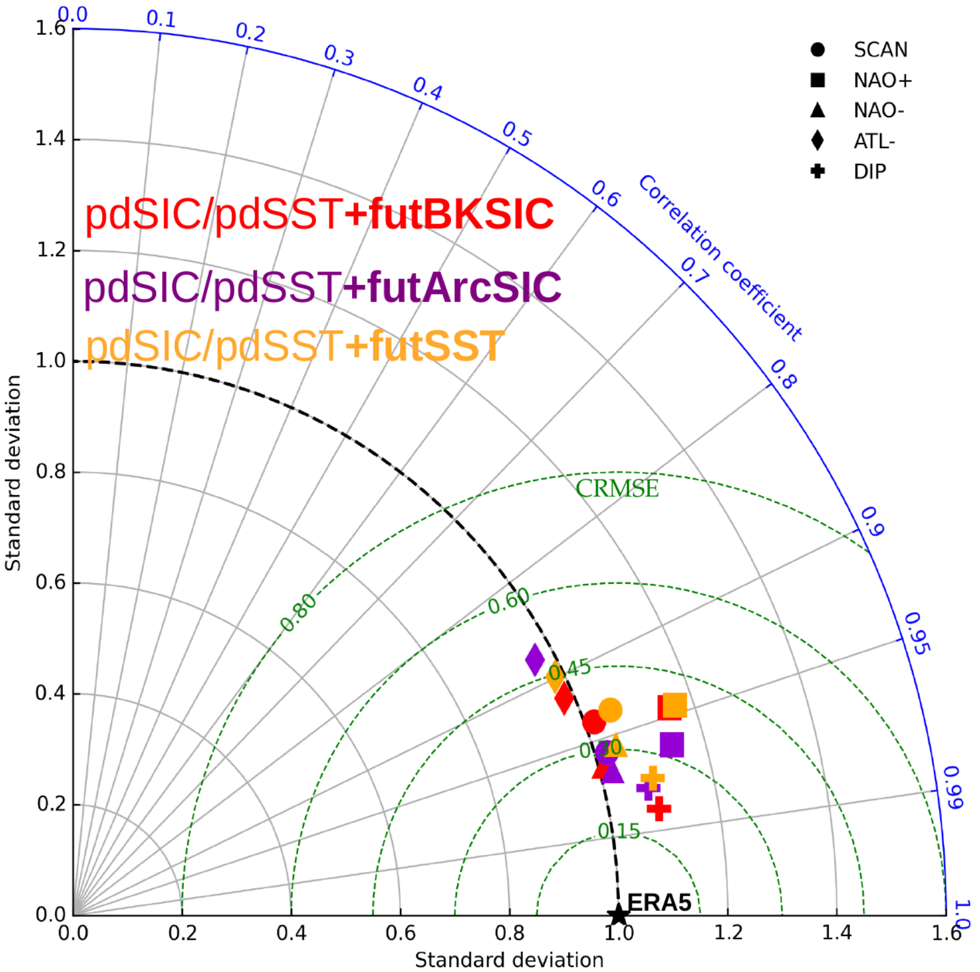

Figure S3: Taylor diagram (Taylor 2001) that summarizes different statistics in order to compare computed ECHAM6 model patterns with regime patterns obtained from ERA5. Different symbols indicate different regimes and different colors stand for different combinations of model simulations for which regimes are computed in this study. The black star symbolically indicates the ERA5 reference pattern. The concentric quadrants centered around the origin show the pattern standard deviation of the different model patterns relative to the standard deviation of the ERA5 reference patterns. The blue polar axis depicts the pattern correlation coefficient between the respective model patterns and the reanalysis pattern. The green concentric semicircles centered around the black reference point indicate the centered root mean square error (CRMSE) when comparing model and reanalysis patterns. Thus, model symbols close to the reference star mean high resemblance between model and reanalysis pattern.

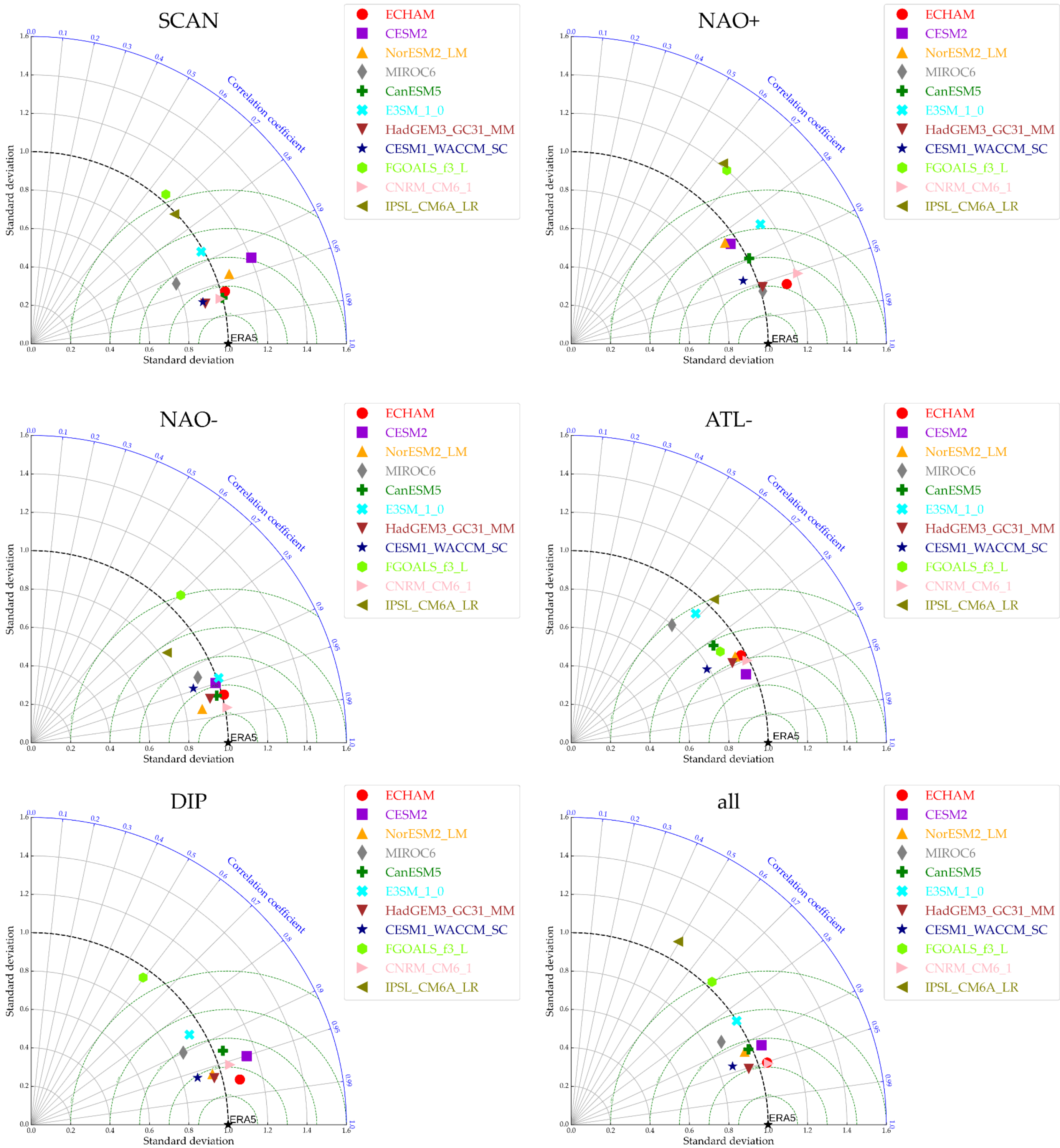

Figure S4: Taylor diagrams that summarize different statistics in order to compare computed model patterns from different PAMIP models with regime patterns obtained from ERA5 (see e.g. Fig. S1). Different symbols/colors indicate different models. Regimes were computed by merging the pdSIC with the futArcSIC data set. Individual Taylor diagrams compare individual model regimes with the respective ERA5 regimes. The Taylor diagram in the lower right ("all") compares the statistics averaged over all regimes.

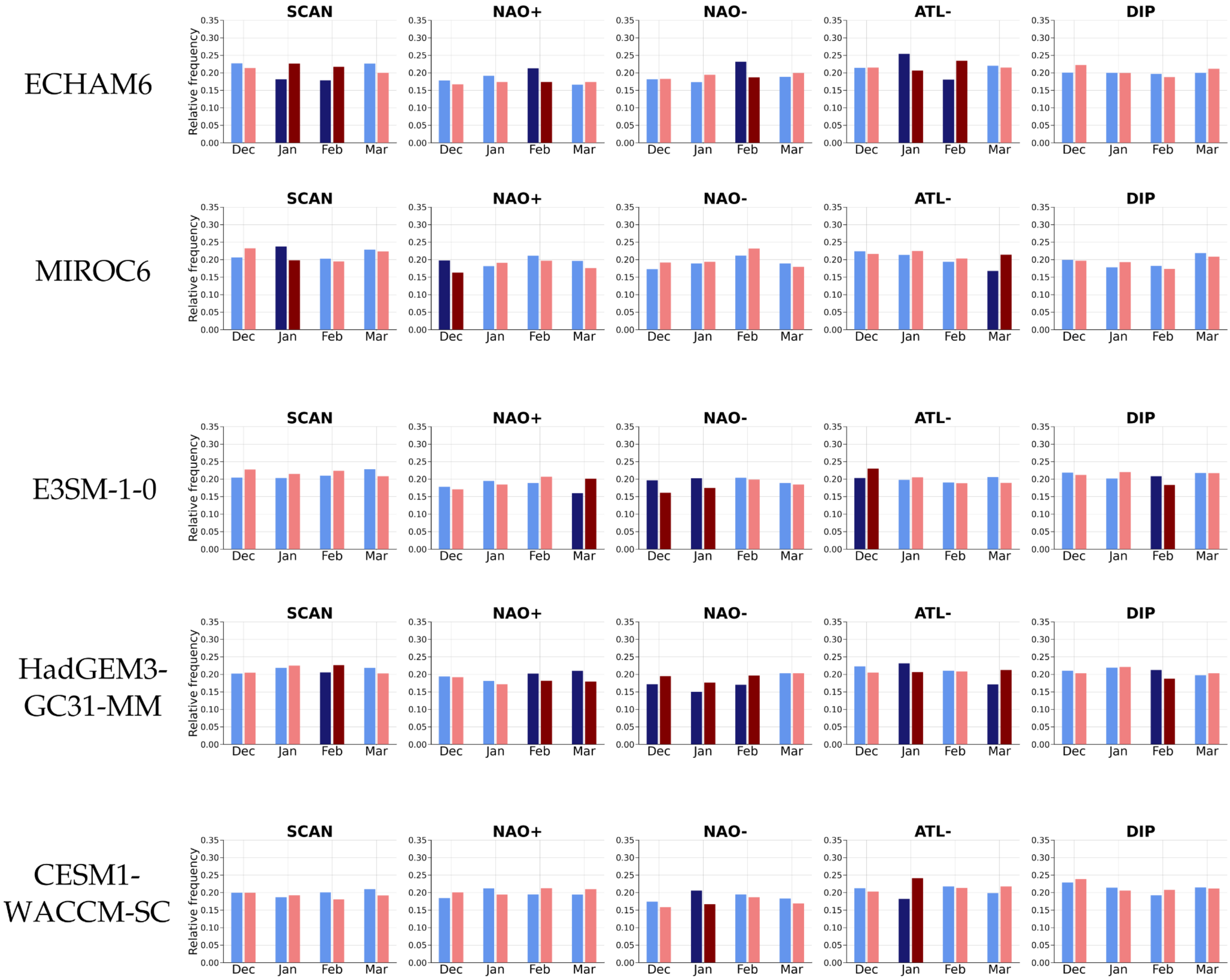

Figure S5: Relative regime occurrence frequencies for different winter months as in Fig. 2. Compared are the pdSIC reference simulation (blueish bars) and the futBKSIC experiment (redish bars). Only the five available models that according to Fig. S4 are able to realistically reproduce the regime pattern structure were considered here. Dark-colored bars indicate significant differences.

Table S2: Absolute number of regime days for each winter month that were used for the computation of the ERA5 regime frequencies in Fig. S2. Blue numbers indicate the number of regime days for high Arctic sea ice conditions, red numbers for low sea ice conditions.

	SCAN	NAO+	NAO-	ATL-	DIP
December	112/168	115/124	94/119	156/102	143/107
January	81/181	151/100	94/110	163/100	131/129
February	100/183	142/82	94/94	96/119	128/82
March	98/147	142/137	114/127	107/116	159/93.

Table S3: Absolute number of regime days for each winter month that were used for the computation of the relative frequencies in Figs. S2a–e. Blue numbers indicate the day count for the (100 year-long) ECHAM6 pdSIC experiment, red numbers for the (100 year-long) ECHAM6 futArcSIC experiment. Note, that the sum over all regimes for a specific month and an experiment sums up to 100 times the number of days within the respective month (e.g. 100*31 days =3100 days for December).

	SCAN	NAO+	NAO-	ATL-	DIP
December	676/699	576/521	540/552	657/702	651/626
January	585/682	610/569	522/596	770/611	613/642
February	534/572	536/594	682/455	484/660	564/519
March	693/619	494/671	612/566	674/654	627/590

Table S4: Same as Table S3 but for pdSIC and futBKSIC. Blue numbers indicate the day count for the (100 year-long) ECHAM6 pdSIC experiment, red numbers indicate the counts for the (100 year-long) ECHAM6 futBKSIC experiment that were used for the computation of the relative frequencies in Figs. S2f–j .

	SCAN	NAO+	NAO-	ATL-	DIP
December	706/ 666	546/ 521	564/ 567	662/ 654	622/ 692
January	567/ 703	585/ 537	534/ 605	792/ 634	622/ 621
February	498/ 612	598/ 482	646/ 524	505/ 652	553/ 530
March	700/ 618	518/ 542	585/ 619	679/ 666	618/ 655

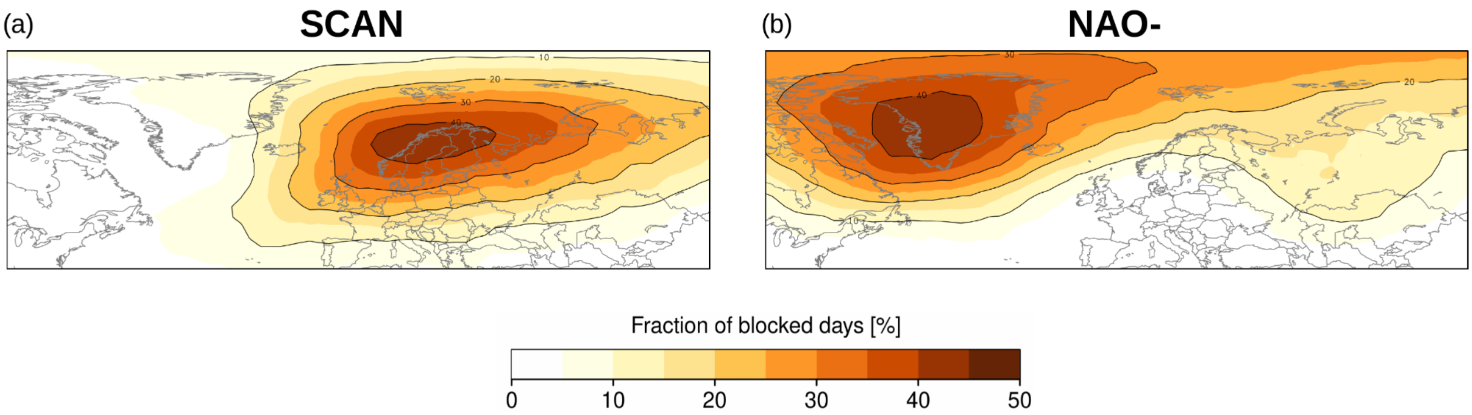

Figure S6: Mean DJFM relative blocking frequency (fraction of blocked days) at the same time a SCAN or negative NAO regime is present in ECHAM6 PAMIP pdSIC simulation. Blocking frequency is calculated at a grid point level based on a hybrid, two-dimensional blocking index. Daily blocked grid points were identified based on the inversion of meridional gradients in the 500 hPa geopotential height (gph) field according to a modified version of the index from Scherrer et al. (2006), and on areas of strong positive gph anomalies associated with the blocking detection. Finally, blocking events of a duration of at least 4 days and an area of 1.5 × 10^6 km^2 were selected by a subsequent tracking algorithm described in Schuster et al. (2019).

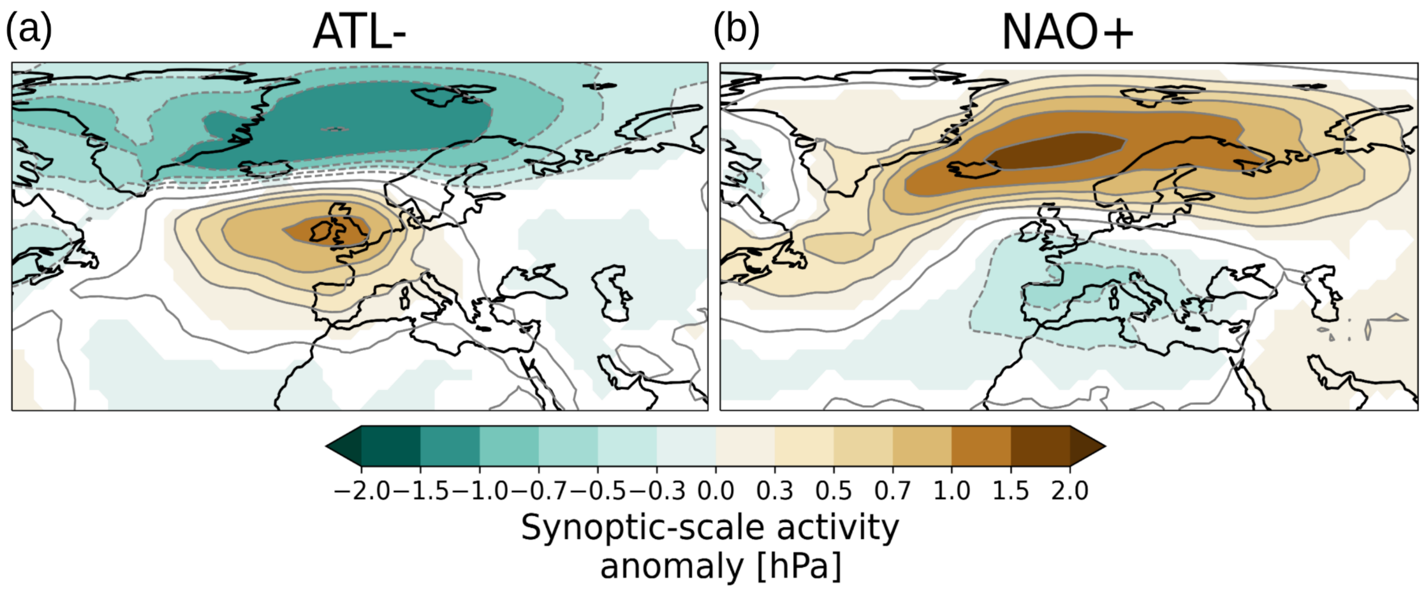

Figure S7: Synoptic-scale activity anomalies (DJFM) for the ATL- and NAO+ regimes computed from ECHAM6 pdSIC model data. Synoptic-scale activity is computed here as the 2–6 day bandpass filtered standard deviation of slp data (Blackmon, 1976). It provides a measure for baroclinic activity and characterizes stormtrack locations. Only anomalies that significantly differ from zero are shown in colors.

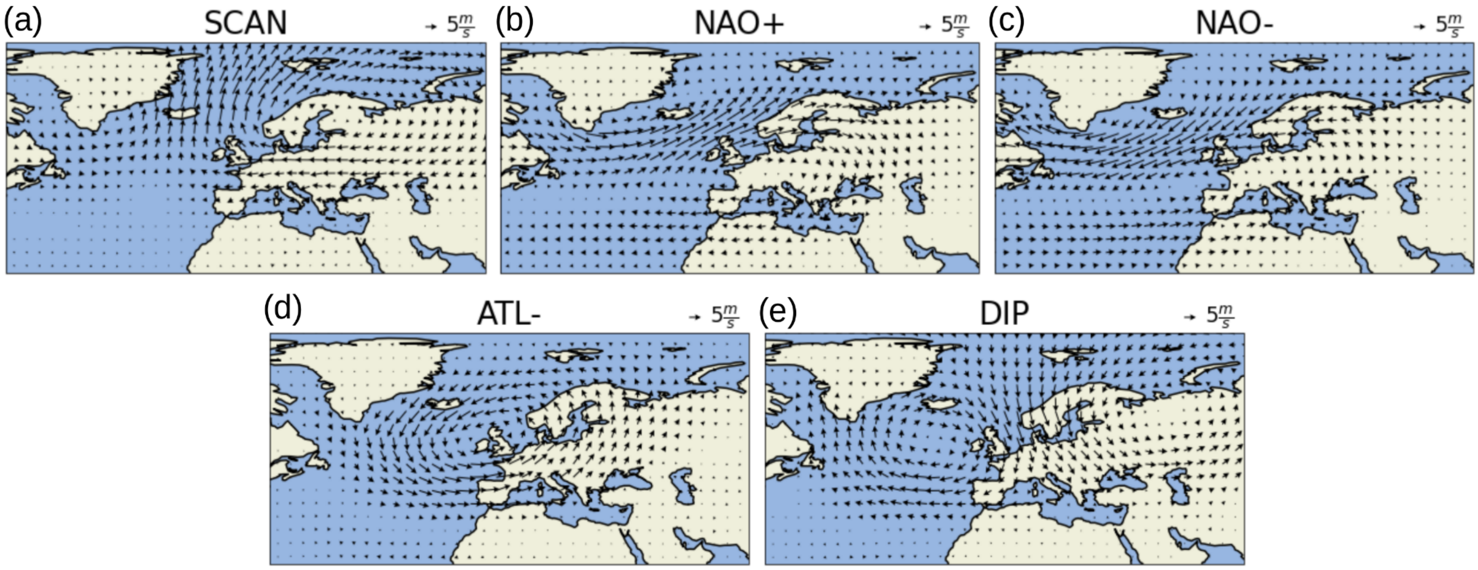

Figure S8: Wind anomalies at 700 hPa (DJFM) for the circulation regimes computed from ECHAM6 pdSIC model data.

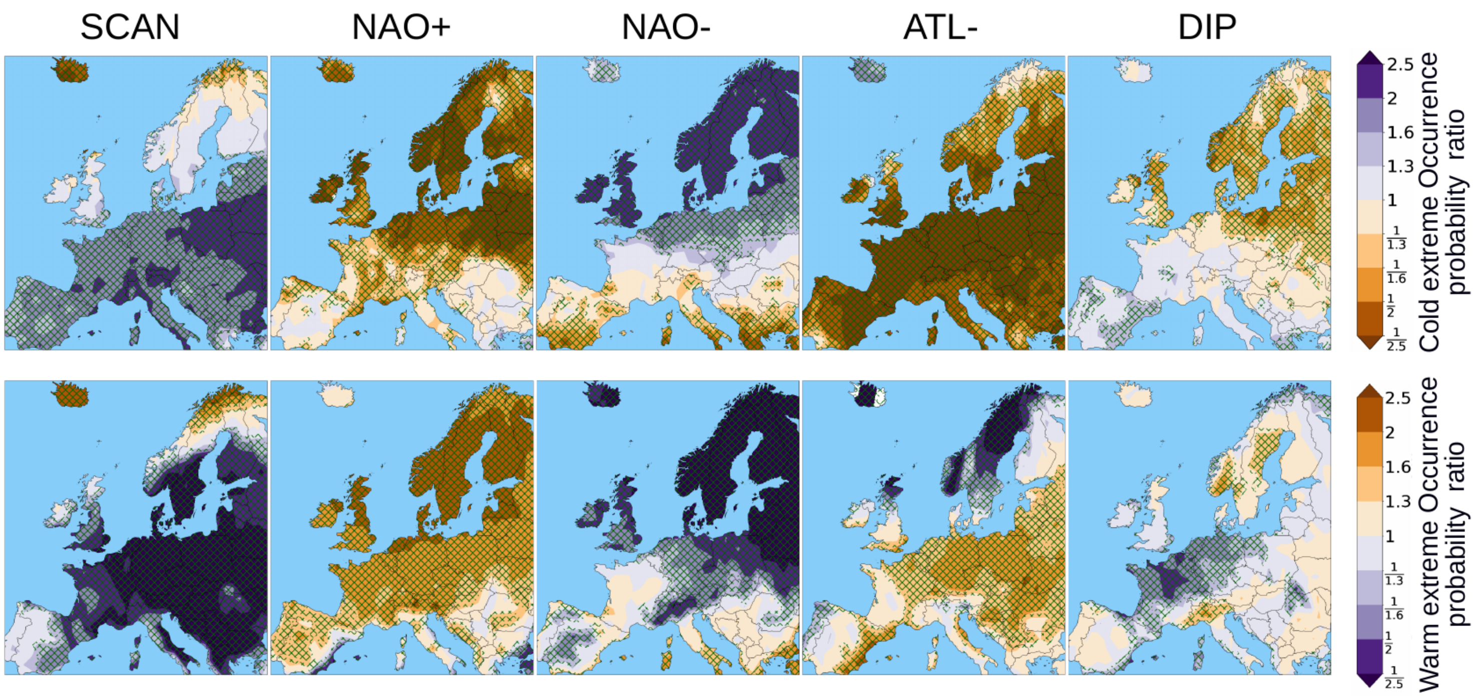

Figure S9: Same analysis as in Fig. 3, but for ERA5 over the period 1979–2018. Thus, regime patterns computed from ERA5 were used for computing these plots. ERA5 T2max/T2min times series at each grid point were linearly detrended beforehand.

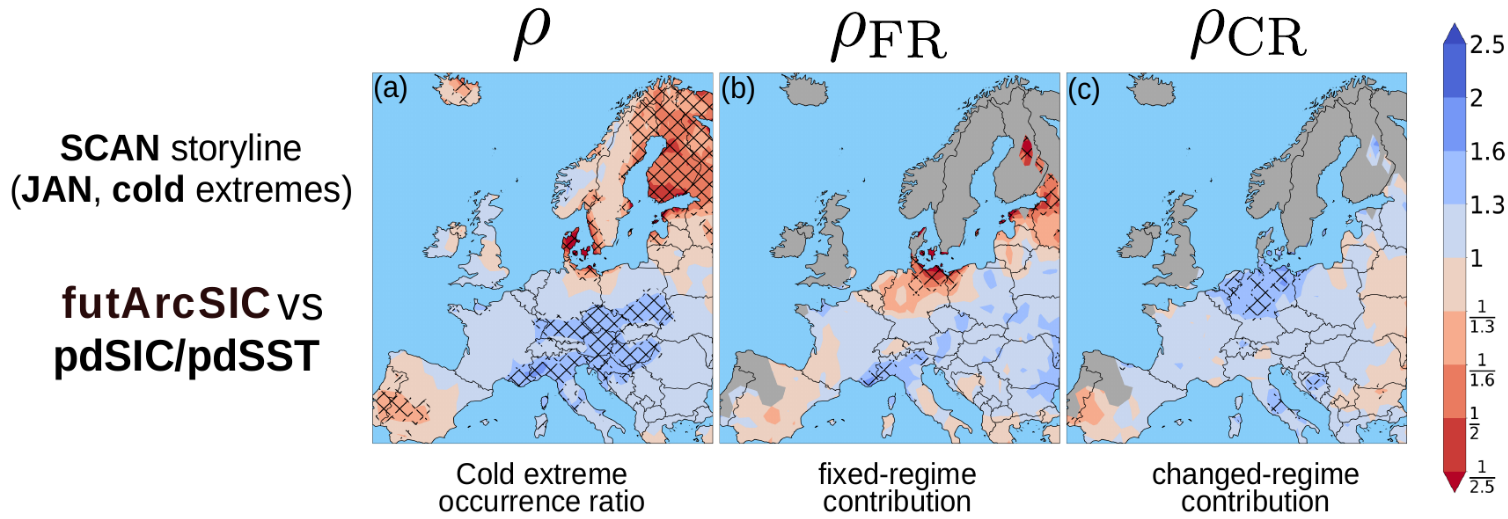

Figure S10: Same as in Fig. 6 but comparing the ECHAM6 futArcSIC and pdSIC simulations, and only for January cold extremes along a SCAN regime storyline. Occurrence ratio of SCAN regime occurrence in January is given as ρ_circ = 1.17. Thus, the SCAN occurs more frequently in the ECHAM6 futArcSIC simulation.

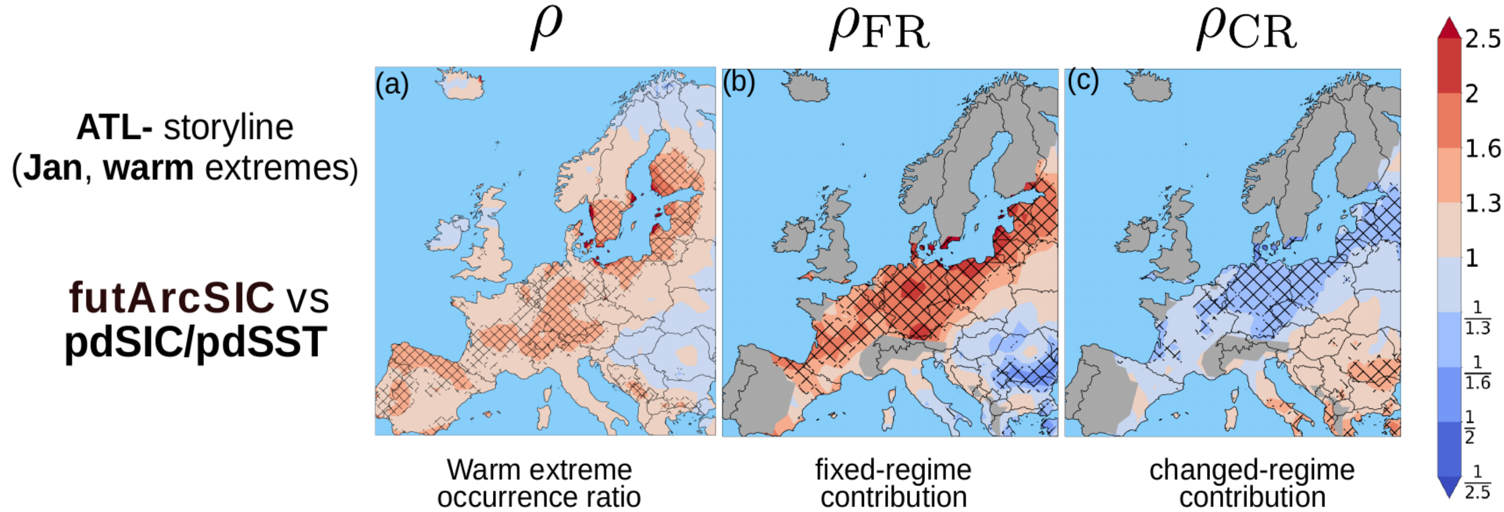

Figure S11: Same as in Fig. 7 but comparing the ECHAM6 futArcSIC and pdSIC simulations, and for January warm extremes along a ATL- regime storyline. Occurrence ratio of ATL- regime occurrence in January is given as ρ_circ = 0.79. Thus, the ATL- regime occurs less frequently in the ECHAM6 futArcSIC simulation.

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