



Supplement of

Decadal predictions of wind, solar and compound power indicators to support the European renewable energy sector

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Table S1. Forecast systems contributing to the DCP-P-A component and historical simulations of CMIP6 used in this study and their specifications. Spatial resolution is given for the atmospheric grid as degrees latitude $\times$ degrees longitude.

Model	Institution	Members	Resolution (lon $\times$ lat)	Init. month	Reference
DCPP-A					
EC-Earth3-i1	BSC	8	$0.7^{\circ} \times 0.7^{\circ}$	November	Bilbao et al. (2020)
EC-Earth3-i2	SMHI-DMI	5	$0.7^{\circ} \times 0.7^{\circ}$	November	Tian et al. (2021)
EC-Earth3-i4	BSC	10	$0.7^{\circ} \times 0.7^{\circ}$	November	Bilbao et al. (2020)
IPSL-CM6A-LR	IPSL	10	$2.5^{\circ} \times 1.25^{\circ}$	January	Boucher et al. (2020)
MPI-ESM1.2-HR	DWD	10	$0.9^{\circ} \times 0.9^{\circ}$	November	Müller et al. (2018)
Historical simulations					
EC-Earth3	SMHI	7	$0.7^{\circ} \times 0.7^{\circ}$	–	Döscher et al. (2021)
IPSL-CM6A-LR	IPSL	11	$2.5^{\circ} \times 1.25^{\circ}$	–	Boucher et al. (2020)
MPI-ESM1.2-HR	DWD	2	$0.9^{\circ} \times 0.9^{\circ}$	–	Giorgetta et al. (2013)

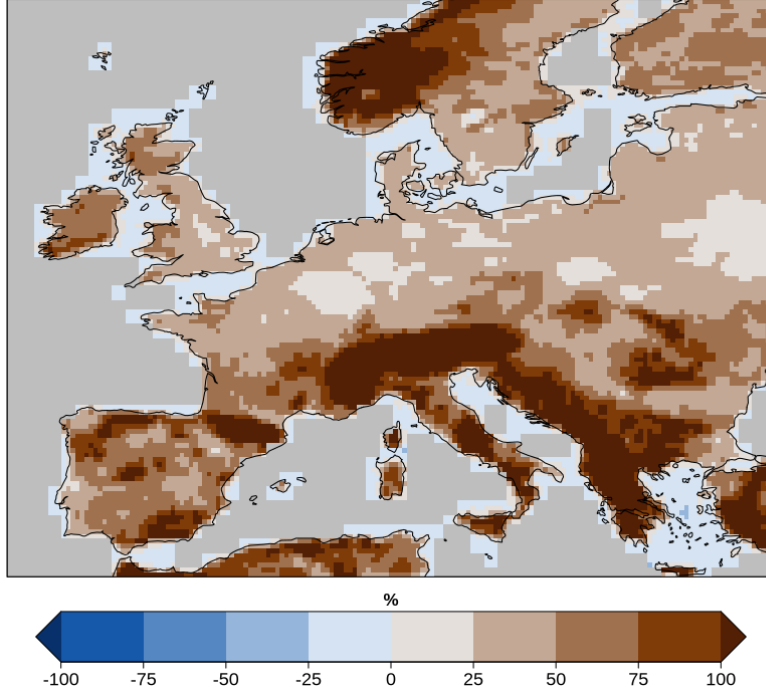


Figure S1. Percentage difference between 100m mean wind speeds from GWA and ERA5 over the period 1961 - 2017. ERA5 winds at 100m were extrapolated from 10m using a power law.

$$PV_{pot} = \alpha_1 RSDS + \alpha_2 RSDS^2 + \alpha_3 RSDS \cdot TAS + \alpha_4 RSDS \cdot SFCWIND \quad (S1)$$

with $\alpha_1 = 1.1035 \times 10^{-3}$, $\alpha_2 = -1.4 \times 10^{-7}$, $\alpha_3 = -4.715 \times 10^{-6}$, and $\alpha_4 = -7.64 \times 10^{-6}$.

$$\eta_{cell} = \eta_{rated} [1 + \beta (T_{cell} - T_{ref})] \quad (S2)$$

Here, β denotes the temperature coefficient of the photovoltaic cell material ($-0.45\% ^\circ C^{-1}$ for multi-crystalline silicon cells). T_{cell} represents the cell temperature, while T_{ref} corresponds to the reference temperature ($25^\circ C$). η_{cell} is the resulting cell efficiency and η_{rated} is the nominal efficiency under reference conditions. When $T_{cell} = T_{ref}$, the efficiency equals the rated value ($\eta_{cell} = \eta_{rated}$). When limiting the PV modules to operate down to 90% of their rated efficiency, a threshold of $T_{cell} = 45^\circ C$ is defined.

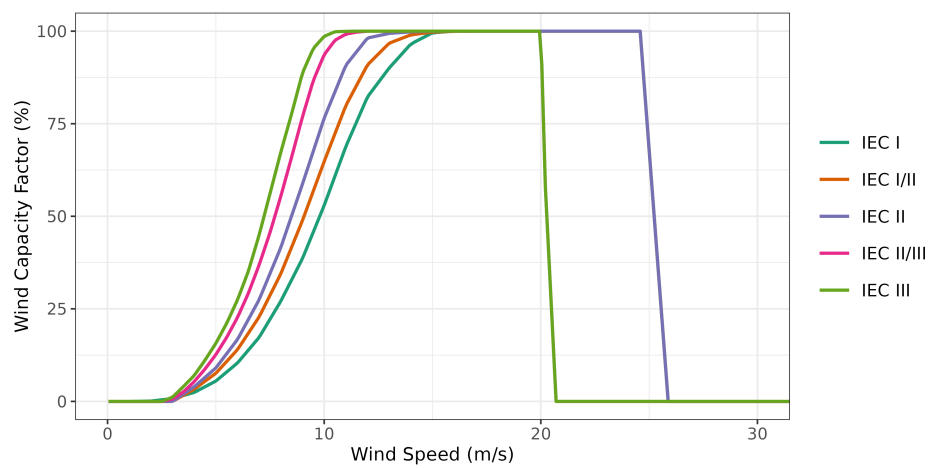


Figure S2. Power curves of WCF for different types of turbines (colored lines).

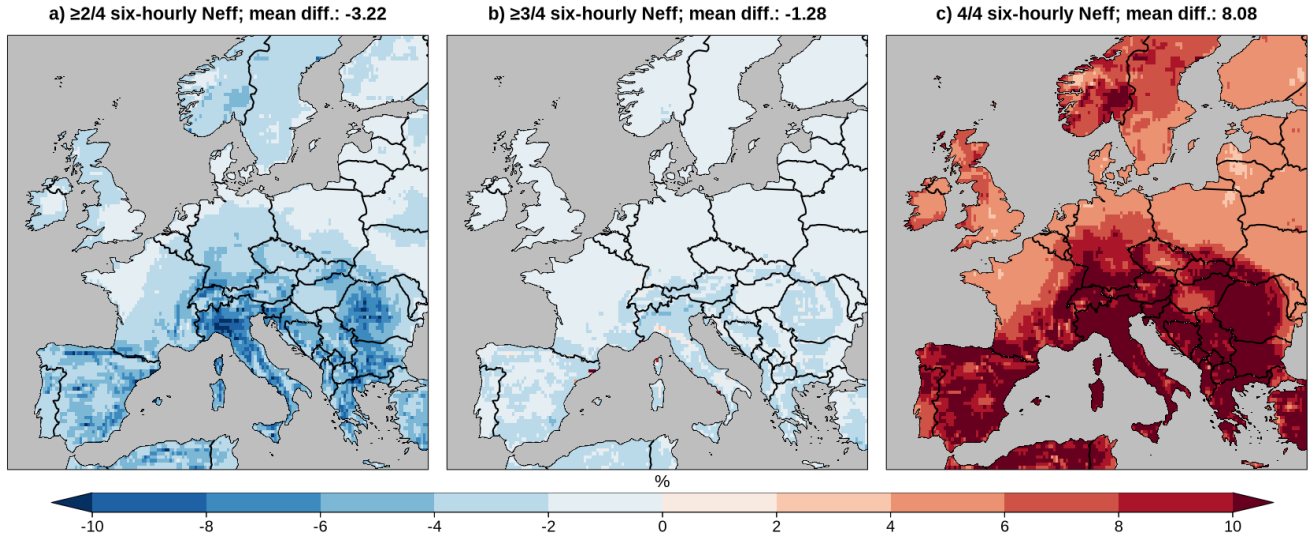


Figure S3. Sensitivity of daily wind Neff to the aggregation criterion from 6-hourly data for annual means. Differences (in percentage points) between daily Neff computed using three aggregation criteria-(a) at least 2 out of 4, (b) at least 3 out of 4, and (c) all 4 six-hourly values meeting the efficiency thresholds-and the original 6-hourly Neff. Panel titles indicate the mean difference over the study region.

Wind Neff is initially computed from 6-hourly wind data, while solar indicators are defined on a daily basis. To allow a consistent comparison between both energy sources, wind Neff is aggregated to daily values.

A sensitivity analysis is conducted to assess how different aggregation criteria affect the resulting number of effective days (Figure S3). Three criteria have been tested: a day is considered effective if at least 2 out of 4, 3 out of 4, or all 4 six-hourly values meet the efficiency thresholds. As a reference, results are compared with the original 6-hourly Neff.

Figure S3 shows the spatial differences between daily and 6-hourly Neff for each aggregation criterion, with the mean difference over the study region indicated in the panel titles. Defining a day as effective when at least 3 out of 4 six-hourly values meet the thresholds provides the closest agreement with the 6-hourly reference and is therefore adopted in this study.

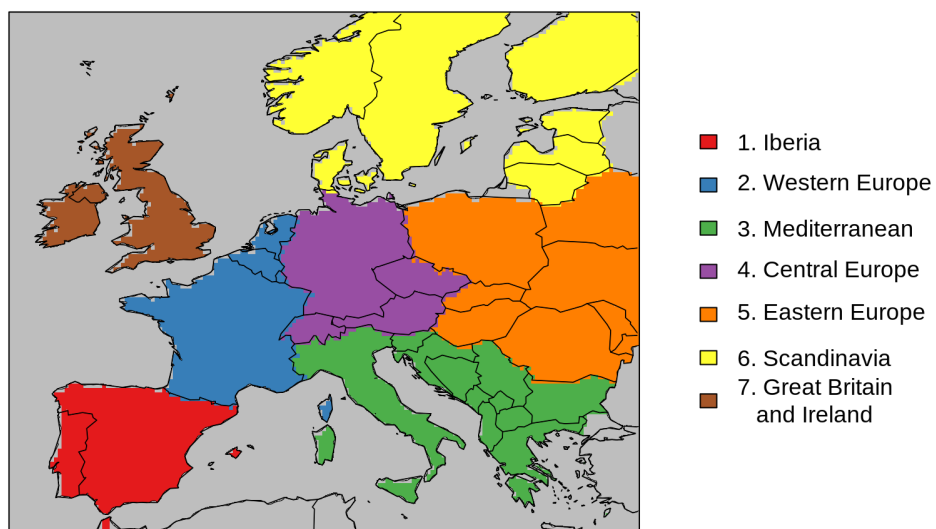


Figure S4. European sub-regions based on the regionalization of Priestley et al. (2024).

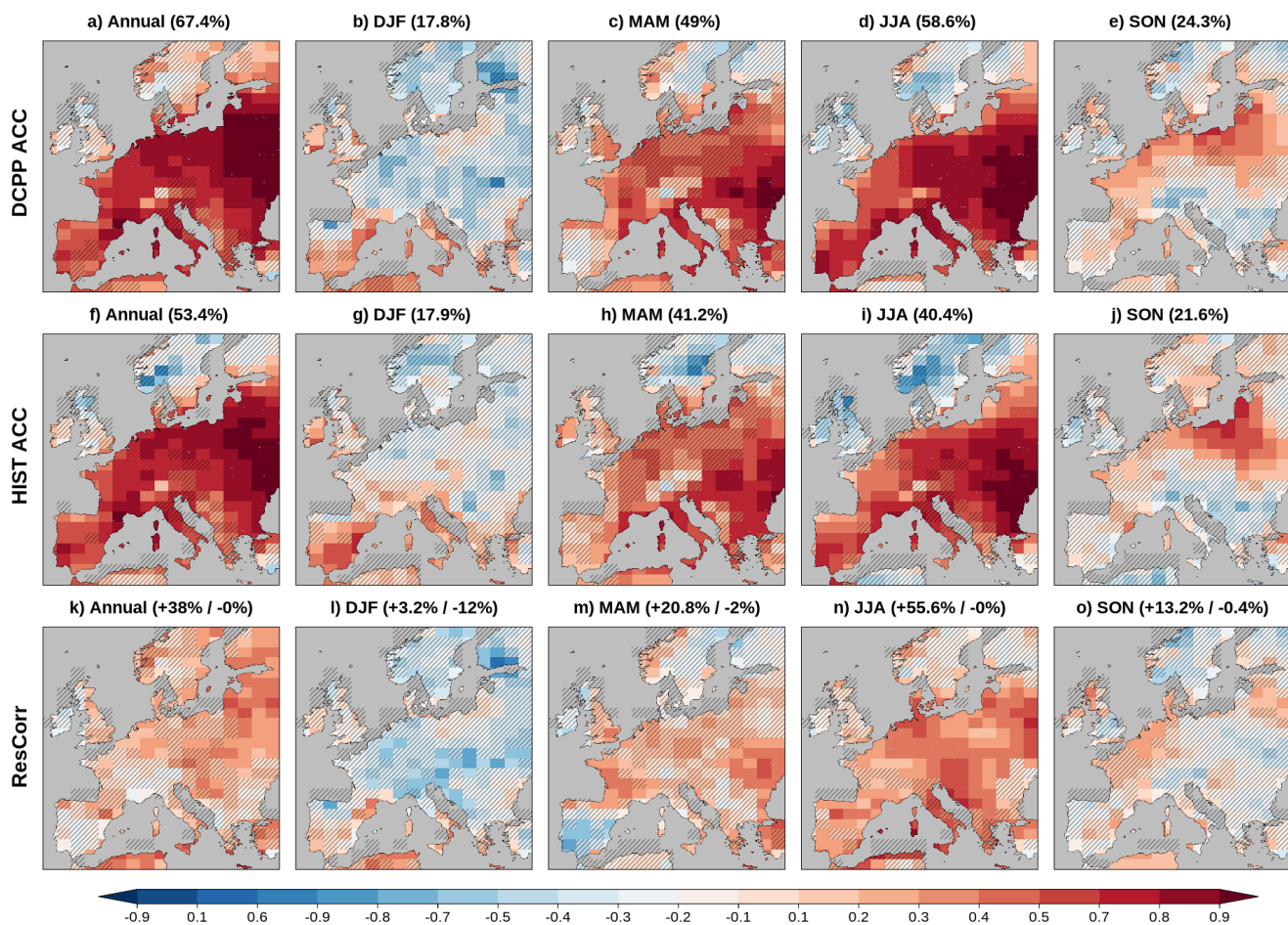


Figure S5. First row: ACC between DCPPEACC and ERA5 for PVpot for the annual mean (a) and seasonal means (b–e) for forecast years 1–3. Second row: ACC between HISTACC and ERA5 for the annual mean (f) and seasonal means (g–j). The percentages of significant grid points are indicated in brackets, and hatched regions denote non-significant correlations. Third row: ResCorr between DCPPEACC and ERA5 relative to HISTACC for the annual mean (k) and seasonal means (l–o). Percentages indicate the fractions of significantly positive (red) and significantly negative (blue) values. Positive (negative) ResCorr indicates higher (lower) skill for DCPPEACC compared to HISTACC. Results are computed on the native resolution of the coarsest prediction system considered (IPSL-CM6A-LR; $2.5^\circ \times 1.25^\circ$). Correlations are computed against ERA5 during the 1961–2019 period. ACC significance is assessed using a one-sided t-test at the 95% confidence level, accounting for time-series autocorrelation, while ResCorr significance is assessed using a two-sided t-test with effective degrees of freedom to account for temporal autocorrelation.

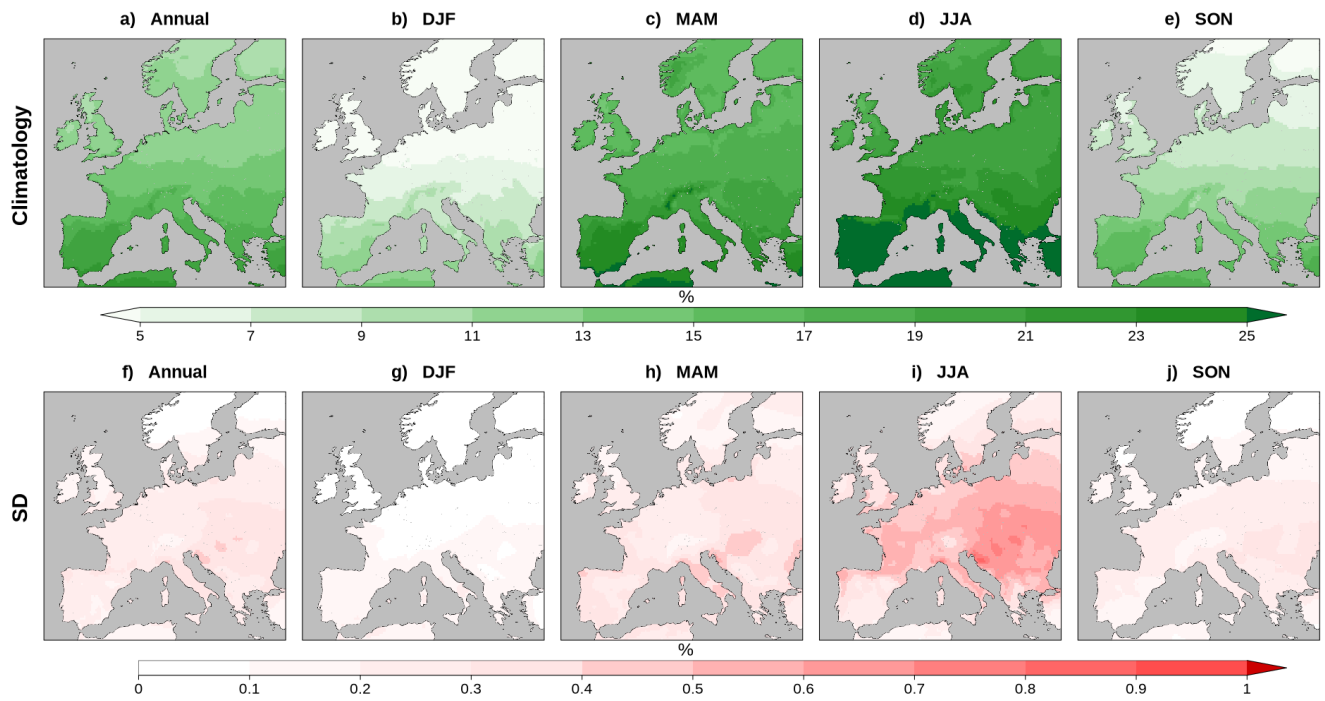


Figure S6. Climatological mean (a–e) and multiannual standard deviation (f–j) of PVpot for the annual mean and for each season over Europe.

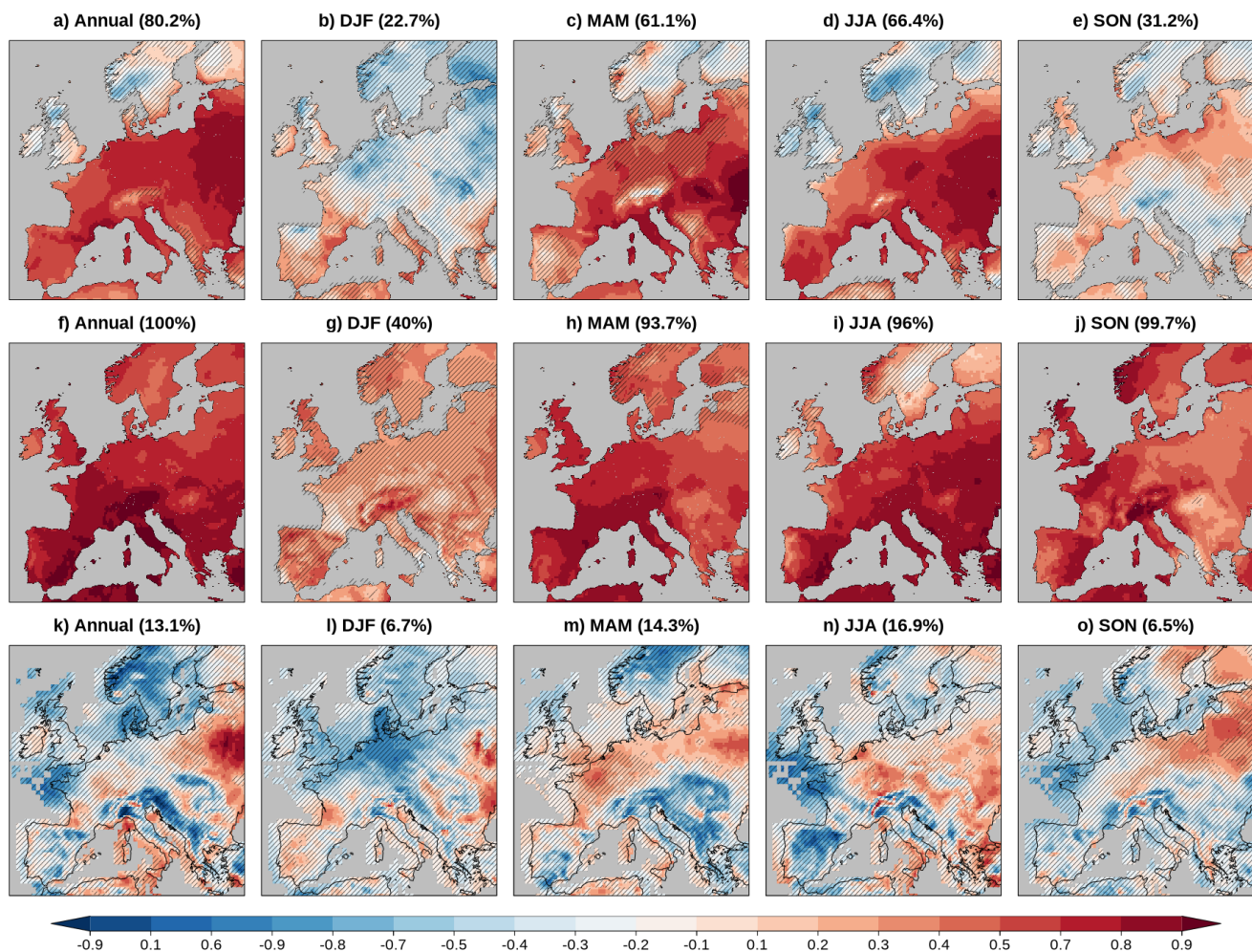


Figure S7. ACC between DCP and ERA5 for RSDS (a-e), TAS (f-j) and SFCWIND (k-o) for the annual mean (first column) and seasonal means (second to fifth columns) over forecast years 1–3. The percentages of significant grid points are indicated in brackets, and hatched regions denote non-significant correlations. Correlations are computed against ERA5 during the 1961–2019 period, and statistical significance is assessed using a one-sided t-test at the 95% confidence level, accounting for time-series autocorrelation.

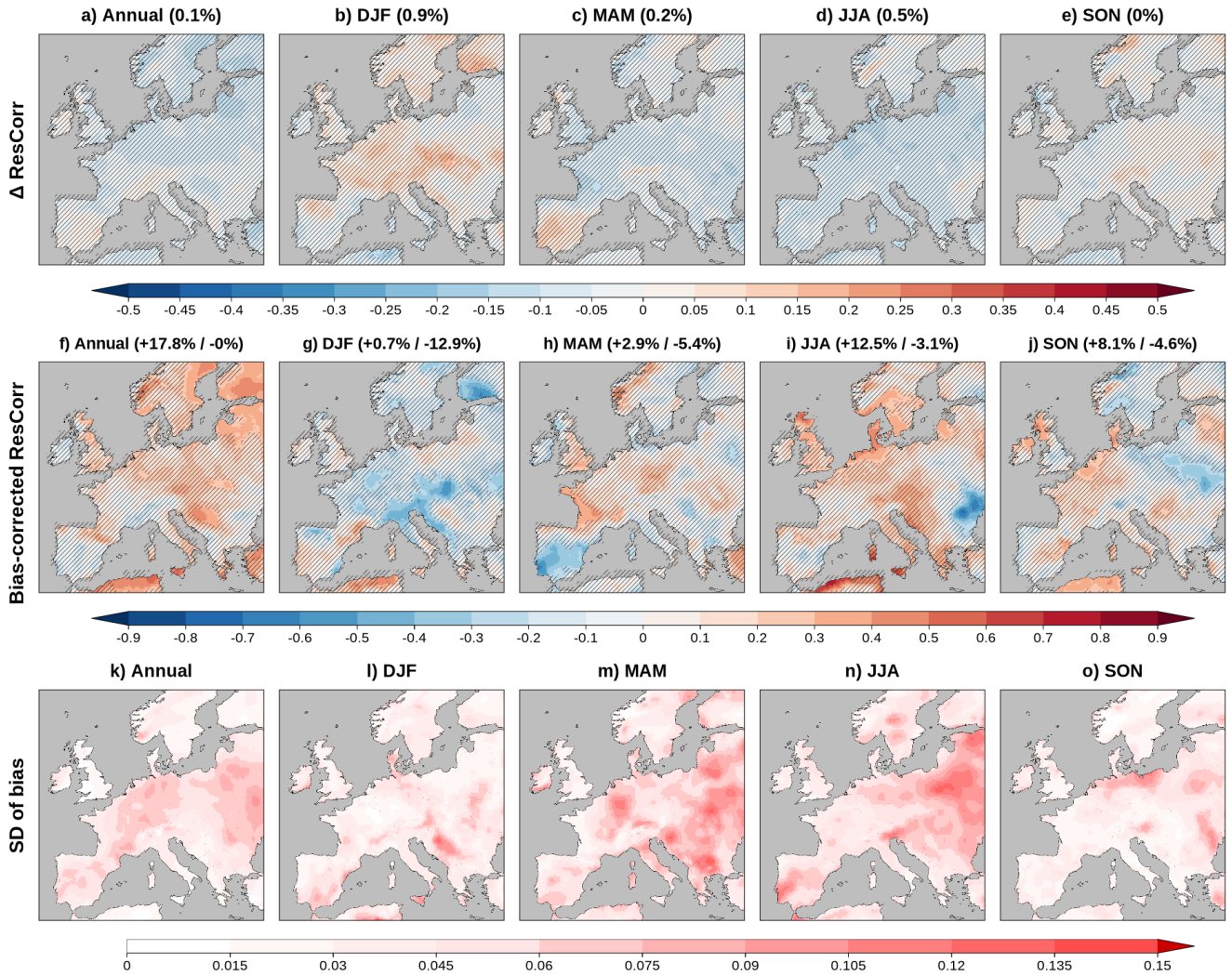


Figure S8. Sensitivity of PVpot ResCorr to ensemble size and finite HIST ensemble size. Top row (a–e): median difference in ResCorr ($\Delta\text{ResCorr}$) between the full and equal-member ensembles across 5000 resamples. Positive (negative) values indicate higher (lower) ResCorr for the full ensemble. Hatched regions indicate locations where the 95% confidence interval of $\Delta\text{ResCorr}$ includes zero, and percentages indicate the fraction of grid points with significant differences. Middle row (f–j): bias-corrected ResCorr accounting for the finite size of the HIST ensembles. Hatched regions indicate non-significant ResCorr values, and percentages indicate the fractions of significantly positive and negative grid points, respectively. Bottom row (k–o): standard deviation of the estimated finite-ensemble bias across the 5000 ensemble partitions, representing the uncertainty associated with the bias correction.

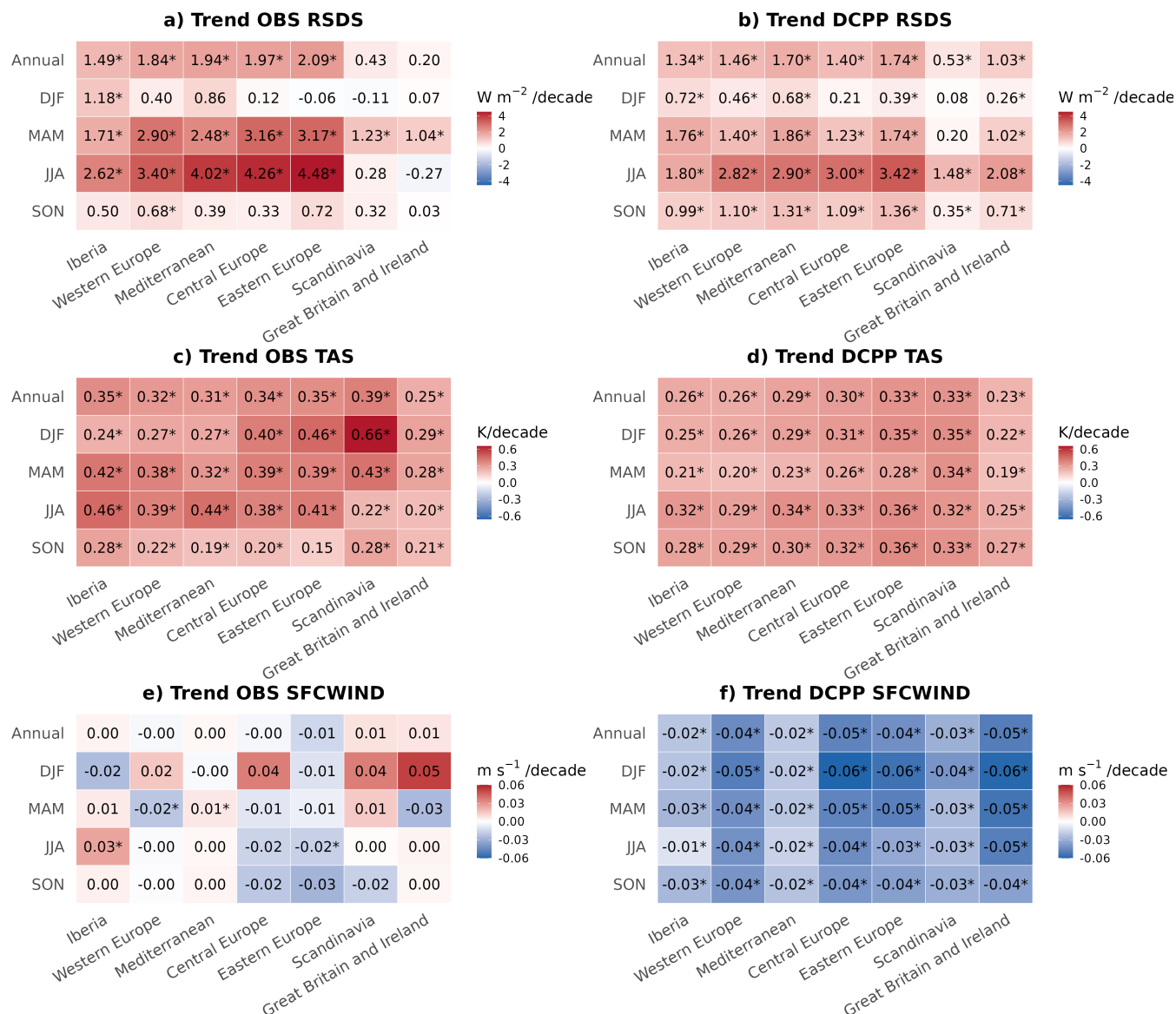


Figure S9. Regional trends for ERA5 (first column) and DCPD (second column) for RSDS (a-b), TAS (c-d) and SFCWIND (e-f).

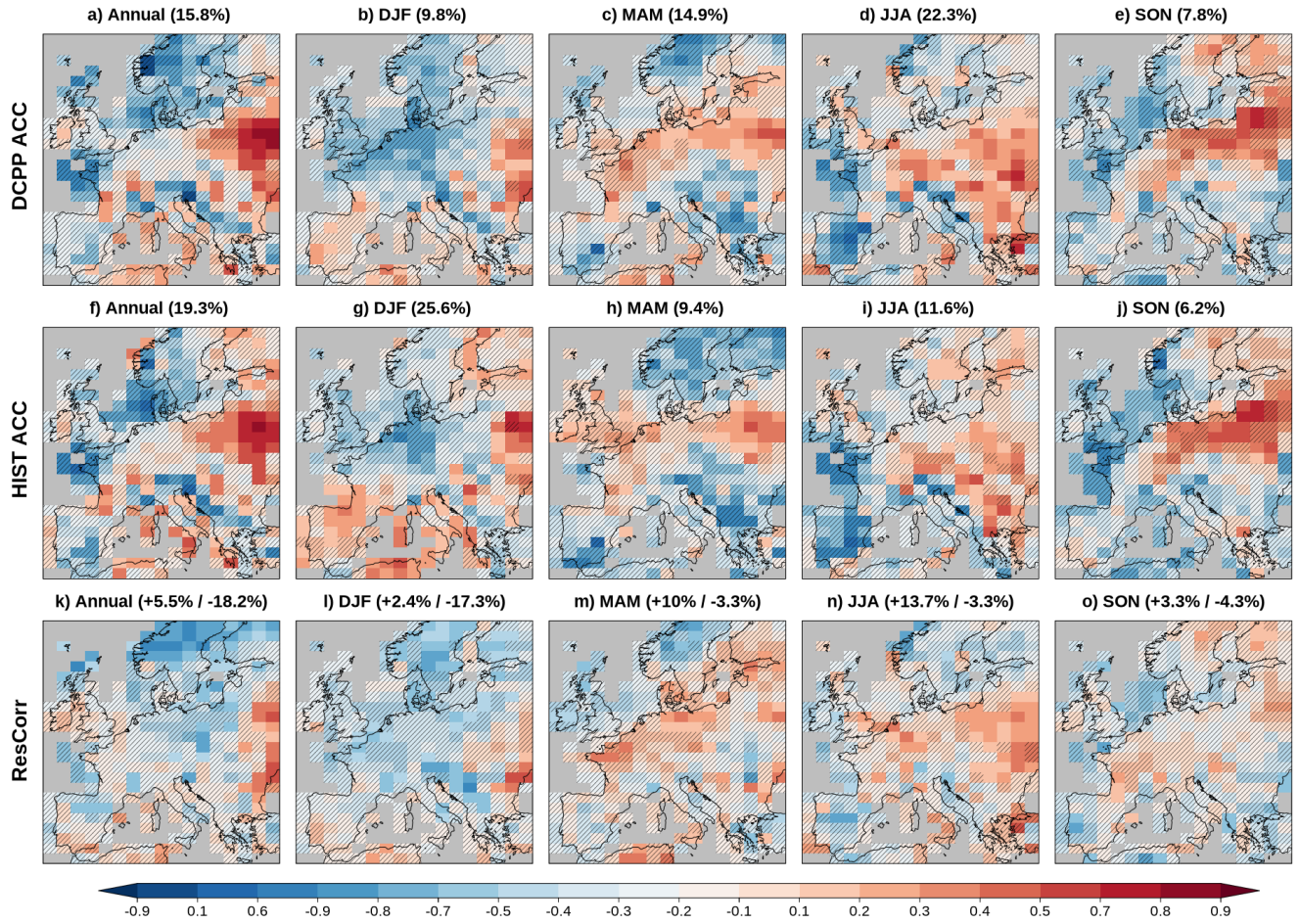


Figure S10. First row: ACC between DCP and ERA5 for WCF for the annual mean (a) and seasonal means (b–e) for forecast years 1–3. Second row: ACC between HIST and ERA5 for the annual mean (f) and seasonal means (g–j). The percentages of significant grid points are indicated in brackets, and hatched regions denote non-significant correlations. Third row: ResCorr between DCP and ERA5 relative to HIST for the annual mean (k) and seasonal means (l–o). Percentages indicate the fractions of significantly positive (red) and significantly negative (blue) values. Positive (negative) ResCorr indicates higher (lower) skill for DCP compared to HIST. Results are computed on the native resolution of the coarsest prediction system considered (IPSL-CM6A-LR; $2.5^\circ \times 1.25^\circ$). Correlations are computed against ERA5 during the 1961–2019 period. ACC significance is assessed using a one-sided t-test at the 95% confidence level, accounting for time-series autocorrelation, while ResCorr significance is assessed using a two-sided t-test with effective degrees of freedom to account for temporal autocorrelation.

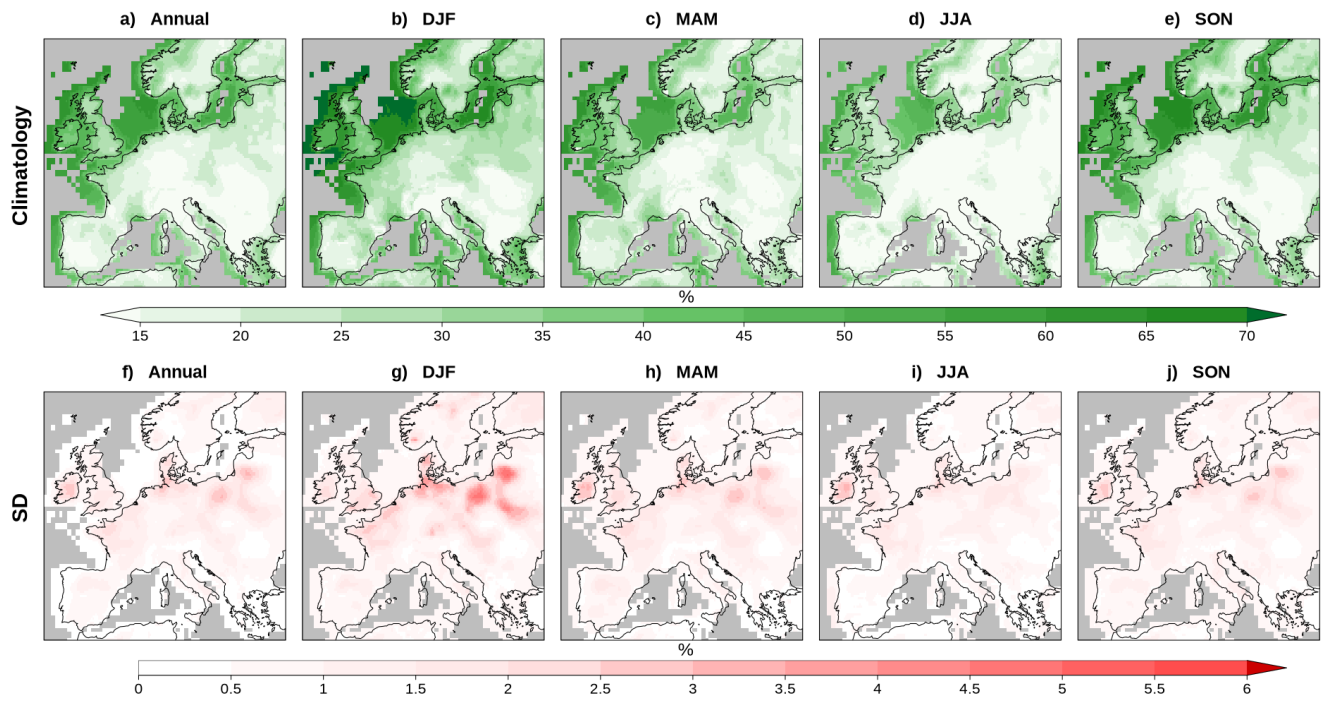


Figure S11. Climatological mean (a–e) and multiannual standard deviation (f–j) of WCF for the annual mean and for each season over Europe.

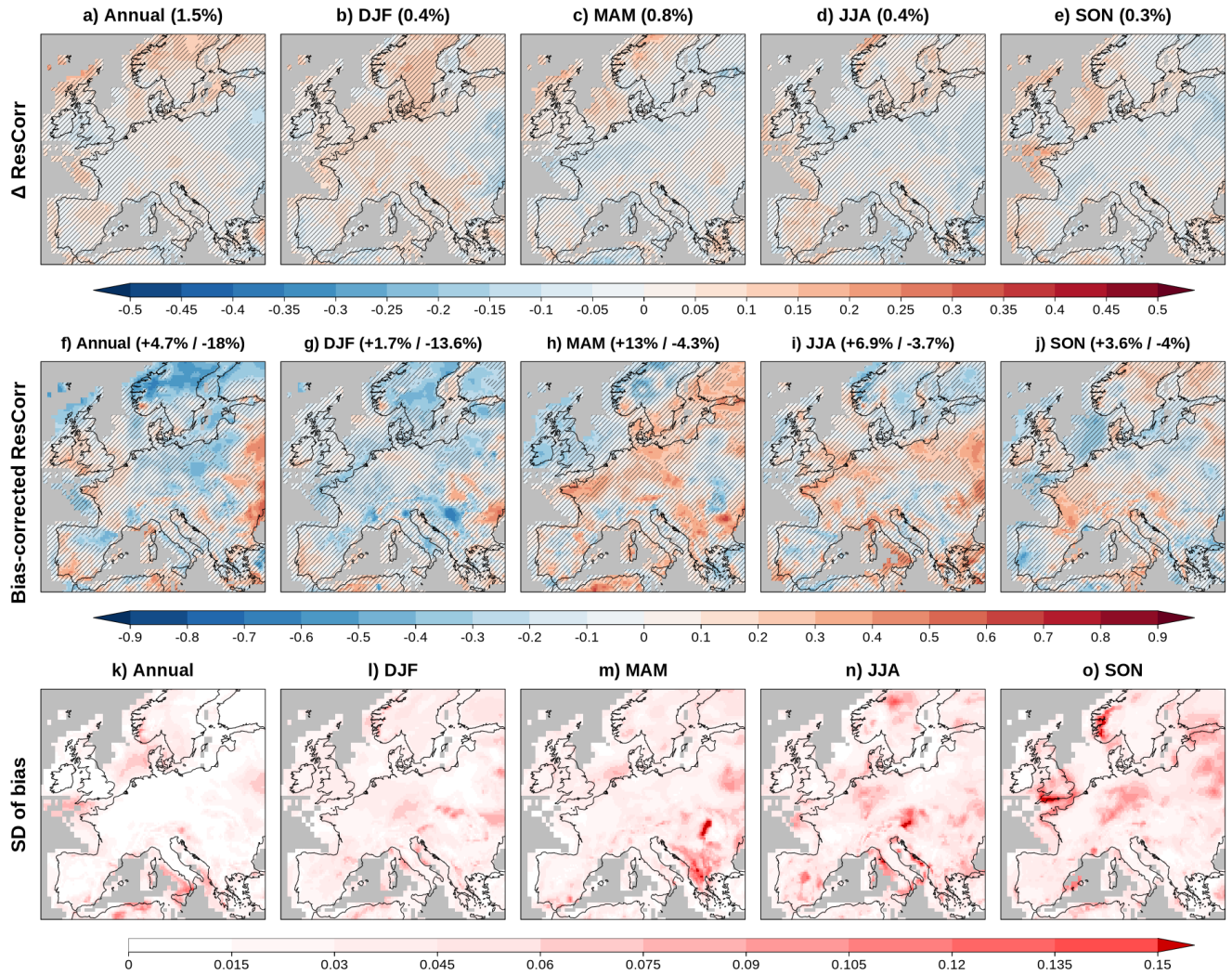


Figure S12. Sensitivity of WCF ResCorr to ensemble size and finite HIST ensemble size. Top row (a–e): median difference in ResCorr ($\Delta\text{ResCorr}$) between the full and equal-member ensembles across 5000 resamples. Positive (negative) values indicate higher (lower) ResCorr for the full ensemble. Hatched regions indicate locations where the 95% confidence interval of $\Delta\text{ResCorr}$ includes zero, and percentages indicate the fraction of grid points with significant differences. Middle row (f–j): bias-corrected ResCorr accounting for the finite size of the HIST ensembles. Hatched regions indicate non-significant ResCorr values, and percentages indicate the fractions of significantly positive and negative grid points, respectively. Bottom row (k–o): standard deviation of the estimated finite-ensemble bias across the 5000 ensemble partitions, representing the uncertainty associated with the bias correction.

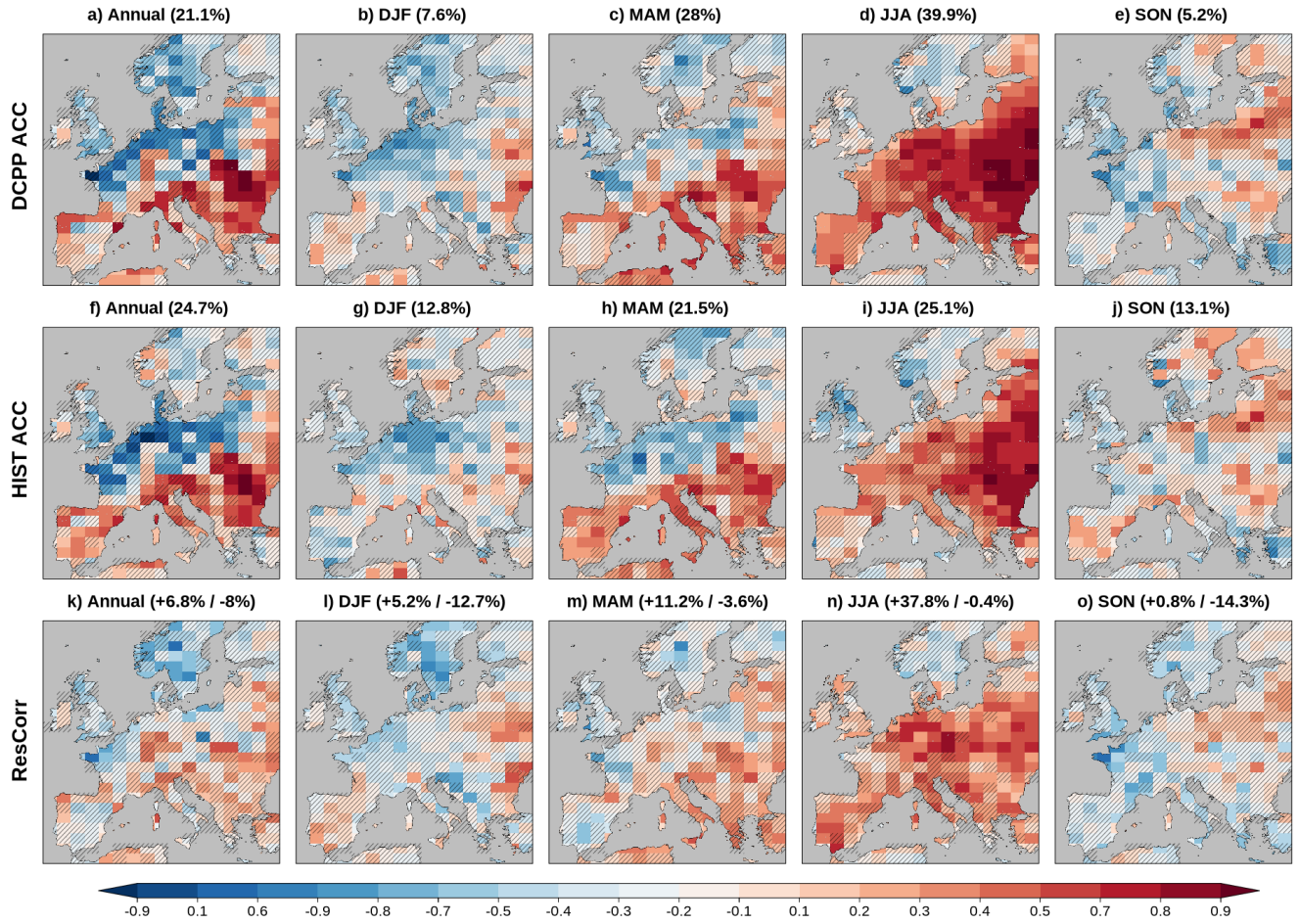
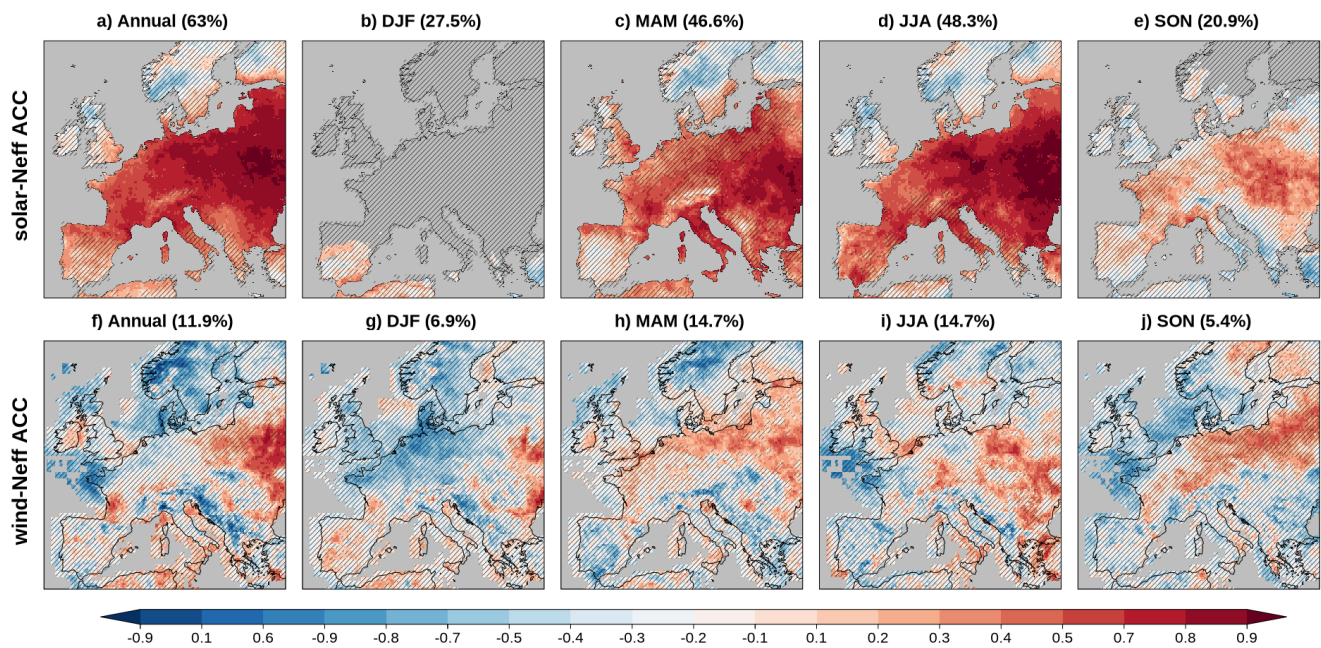


Figure S13. First row: ACC between DCPD and ERA5 for NED for the annual mean (a) and seasonal means (b–e) for forecast years 1–3. Second row: ACC between HIST and ERA5 for the annual mean (f) and seasonal means (g–j). The percentages of significant grid points are indicated in brackets, and hatched regions denote non-significant correlations. Third row: ResCorr between DCPD and ERA5 relative to HIST for the annual mean (k) and seasonal means (l–o). Percentages indicate the fractions of significantly positive (red) and significantly negative (blue) values. Positive (negative) ResCorr indicates higher (lower) skill for DCPD compared to HIST. Results are computed on the native resolution of the coarsest prediction system considered (IPSL-CM6A-LR; $2.5^\circ \times 1.25^\circ$). Correlations are computed against ERA5 during the 1961–2019 period. ACC significance is assessed using a one-sided t-test at the 95% confidence level, accounting for time-series autocorrelation, while ResCorr significance is assessed using a two-sided t-test with effective degrees of freedom to account for temporal autocorrelation.



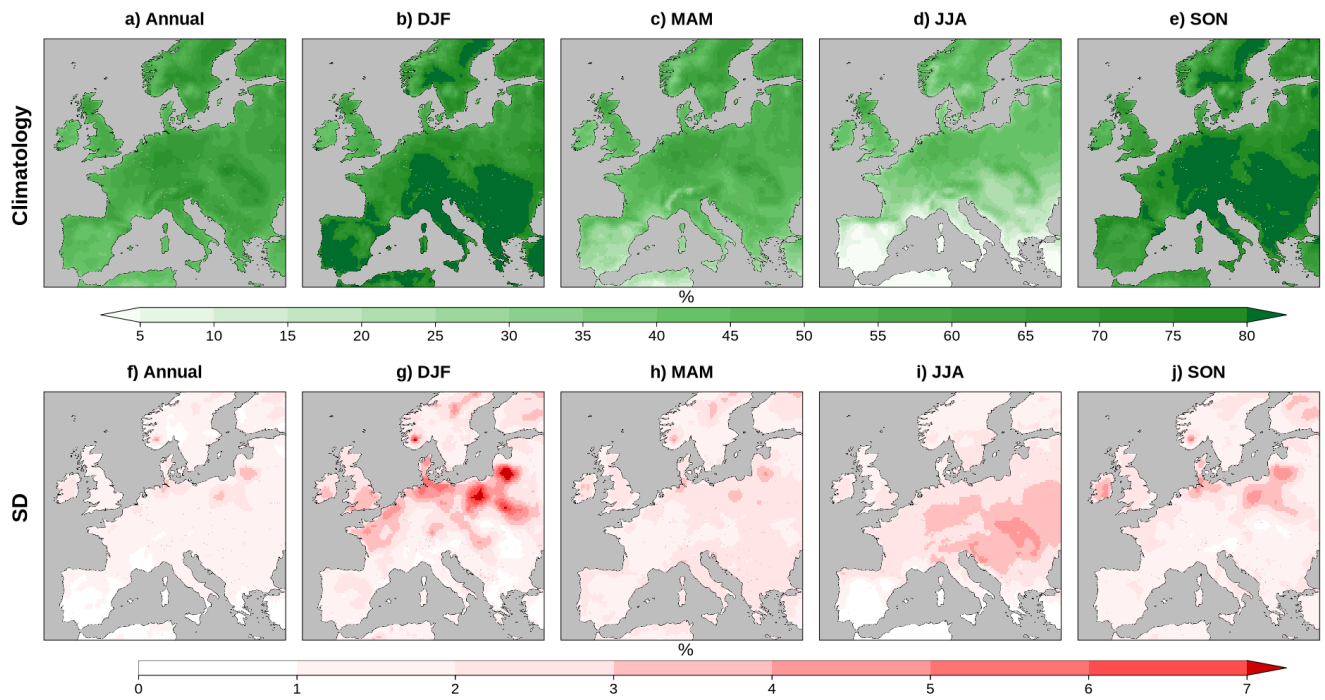


Figure S15. Climatological mean (a–e) and multiannual standard deviation (f–j) of NED for the annual mean and for each season over Europe.

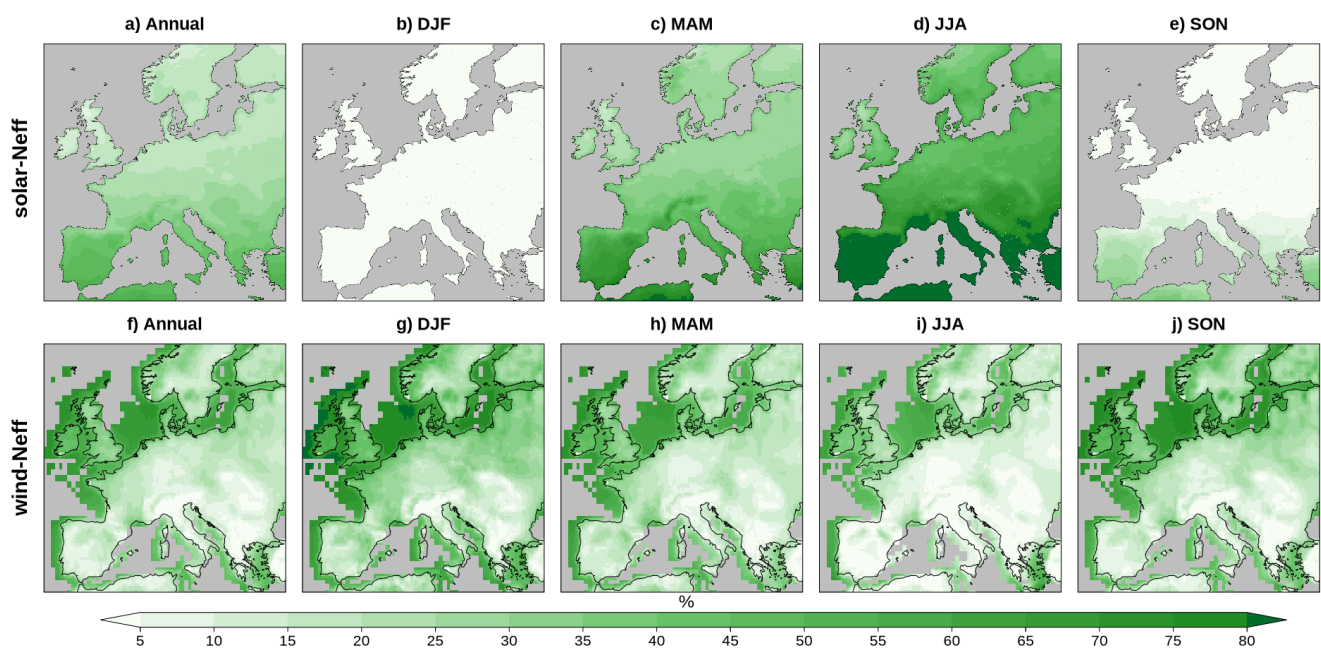


Figure S16. Climatological mean for solar-Neff (a–e) and wind-Neff (f–j).

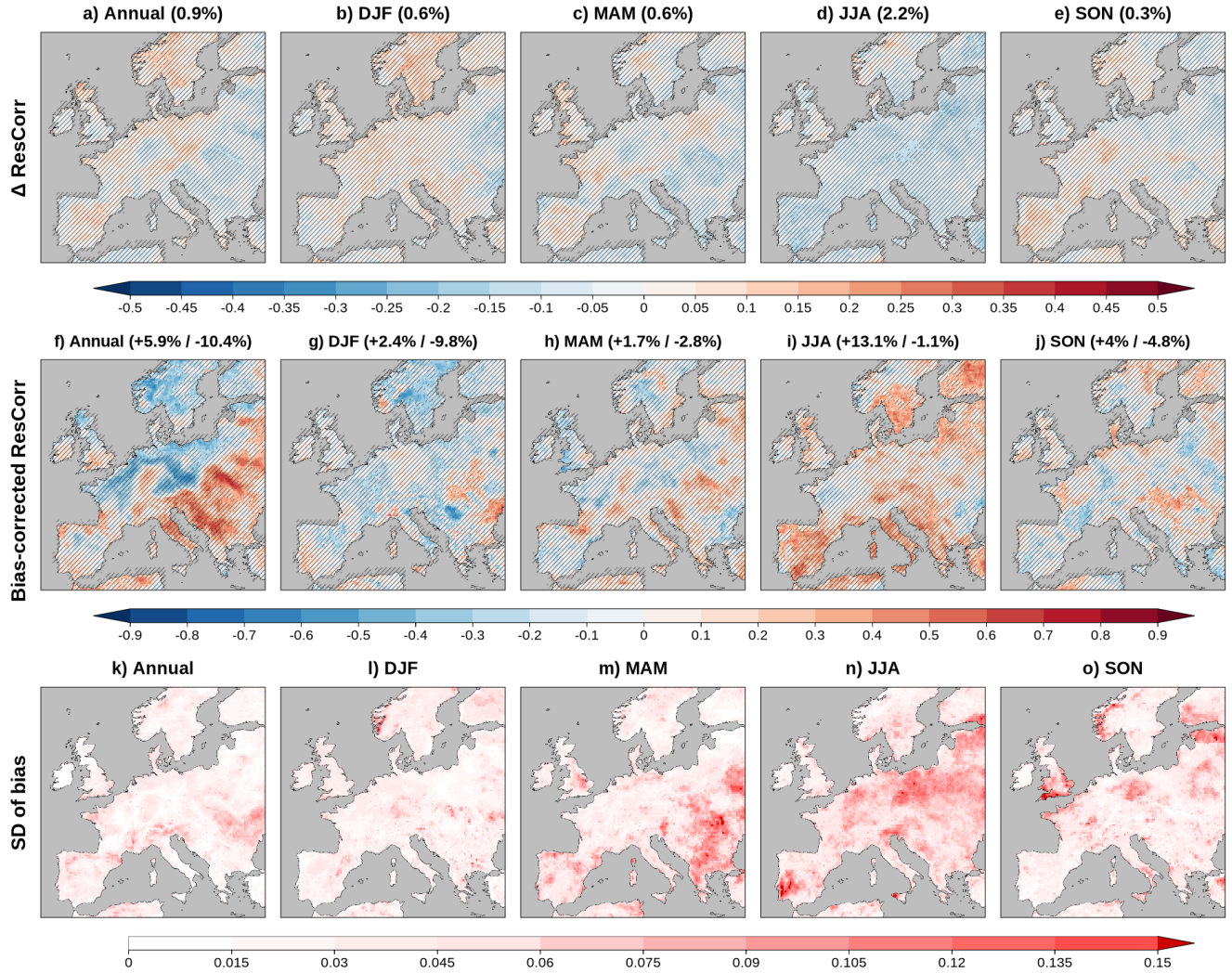


Figure S17. Sensitivity of NED ResCorr to ensemble size and finite HIST ensemble size. Top row (a–e): median difference in ResCorr ($\Delta\text{ResCorr}$) between the full and equal-member ensembles across 5000 resamples. Positive (negative) values indicate higher (lower) ResCorr for the full ensemble. Hatched regions indicate locations where the 95% confidence interval of $\Delta\text{ResCorr}$ includes zero, and percentages indicate the fraction of grid points with significant differences. Middle row (f–j): bias-corrected ResCorr accounting for the finite size of the HIST ensembles. Hatched regions indicate non-significant ResCorr values, and percentages indicate the fractions of significantly positive and negative grid points, respectively. Bottom row (k–o): standard deviation of the estimated finite-ensemble bias across the 5000 ensemble partitions, representing the uncertainty associated with the bias correction.

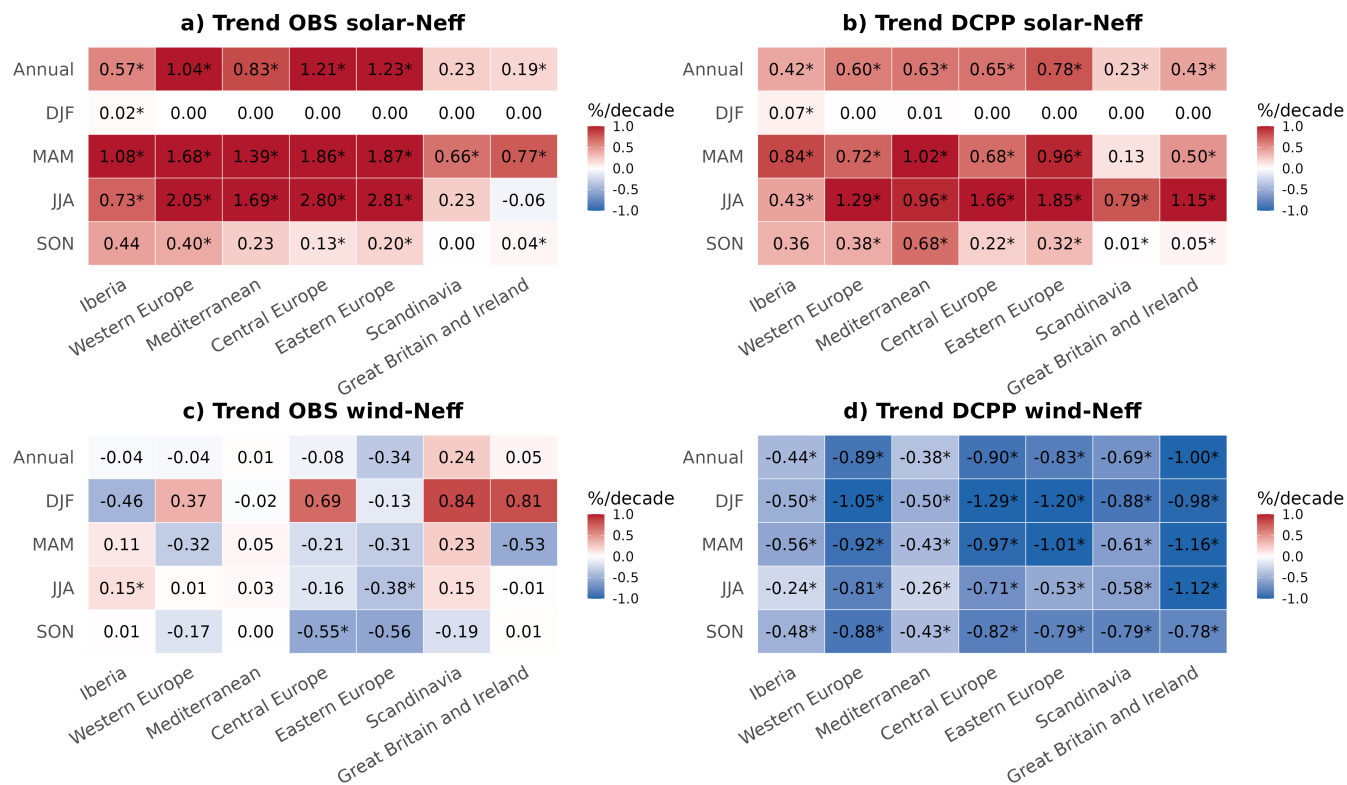


Figure S18. Regional trends for ERA5 (first column) and DCPD (second column) for solar-Neff (a-b) and wind-Neff (c-d).

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