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Supplement of

Bergen metrics: composite error metrics for assessing performance of climate models using EURO-CORDEX simulations

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Supplementary Figure

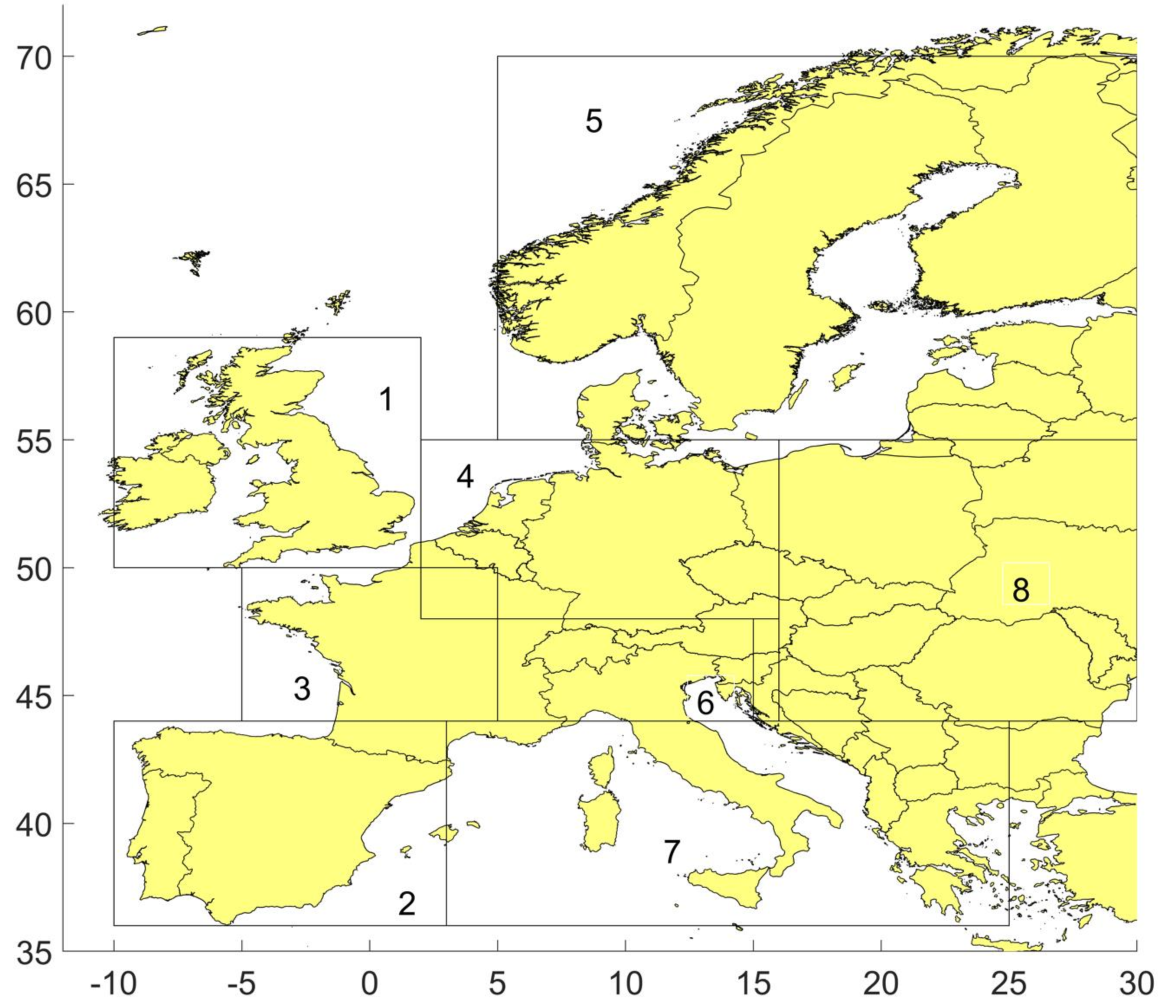

Figure S1: The European study region and it's subregions: 1) British Isles (BI) 2) Iberian Peninsula (IP) 3) France (FR) 4) Mid-Europe (ME) 5) Scandinavia (SC) 6) Alps (AL) 7) Mediterranean 8) Eastern Europe (EA)

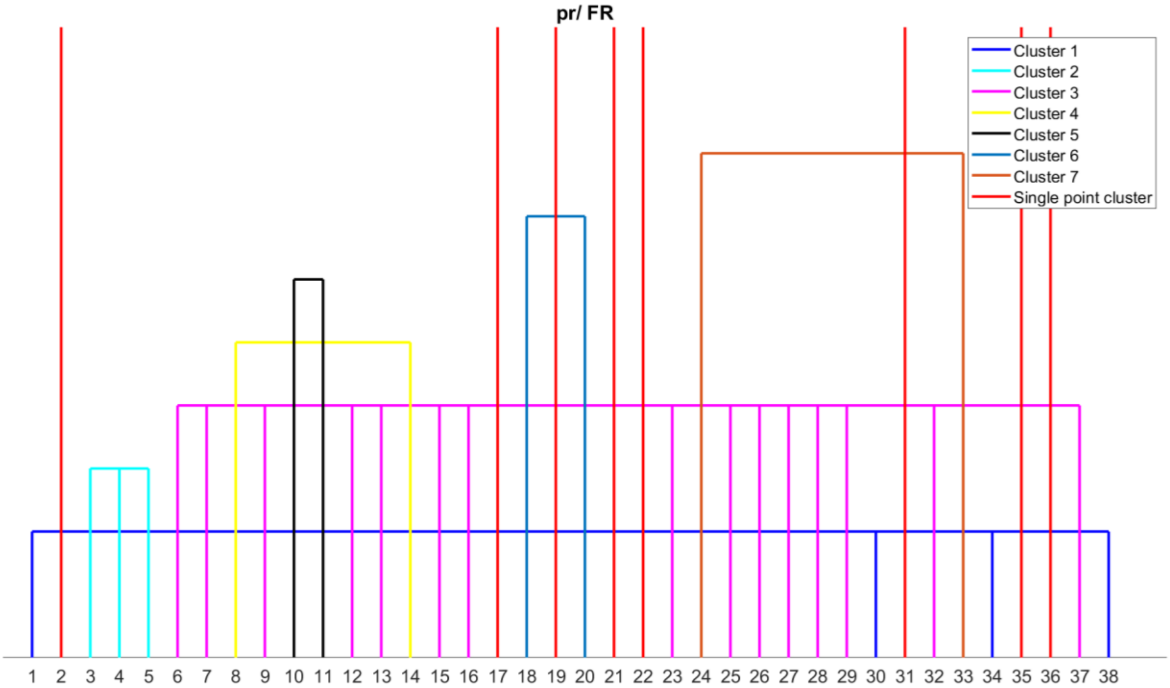

Figure S2: Clustering of error metrics using precipitation (pr) data for France (FR) region. Each error metric can be identified by the number using Table S3.

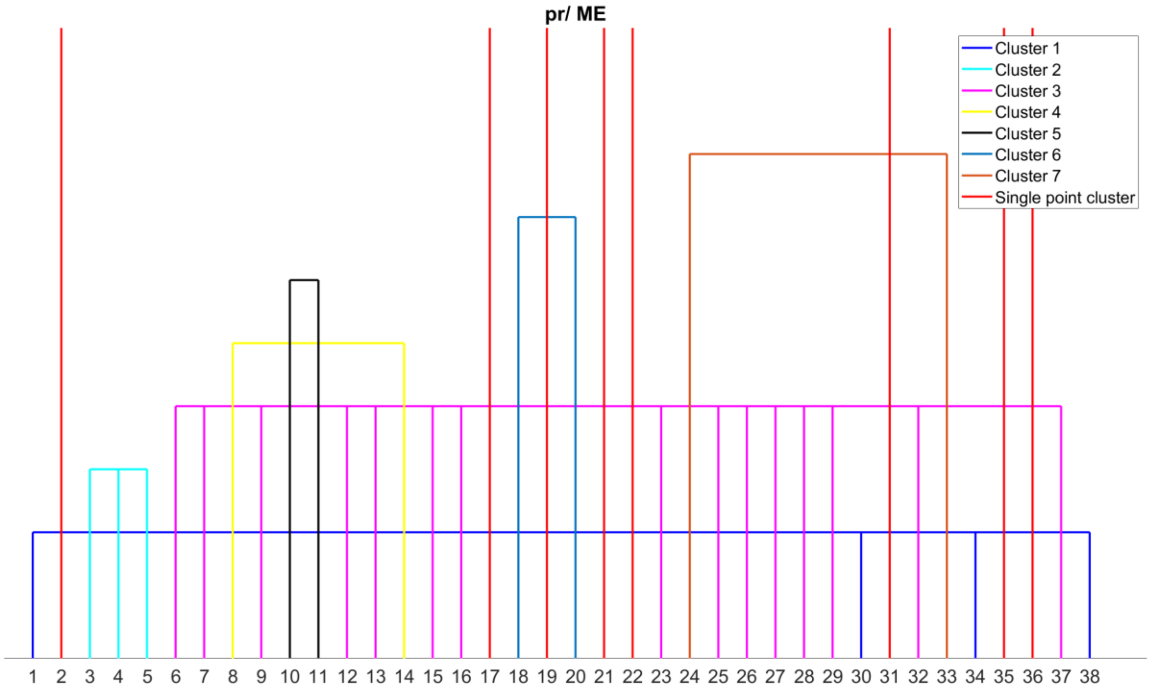

Figure S3: Clustering of error metrics using precipitation (pr) data for Mid-Europe (ME) region. Each error metric can be identified by the number using Table S3.

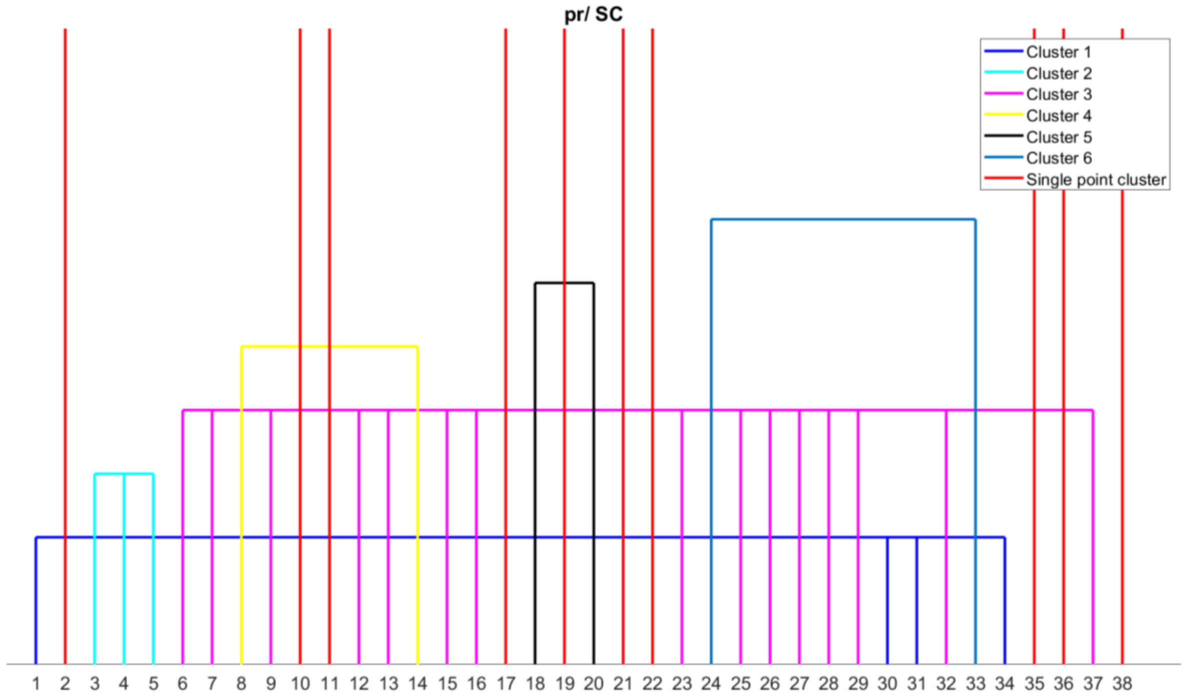

Figure S4: Clustering of error metrics using precipitation (pr) data for Scandinavia (SC) region. Each error metric can be identified by the number using Table S3.

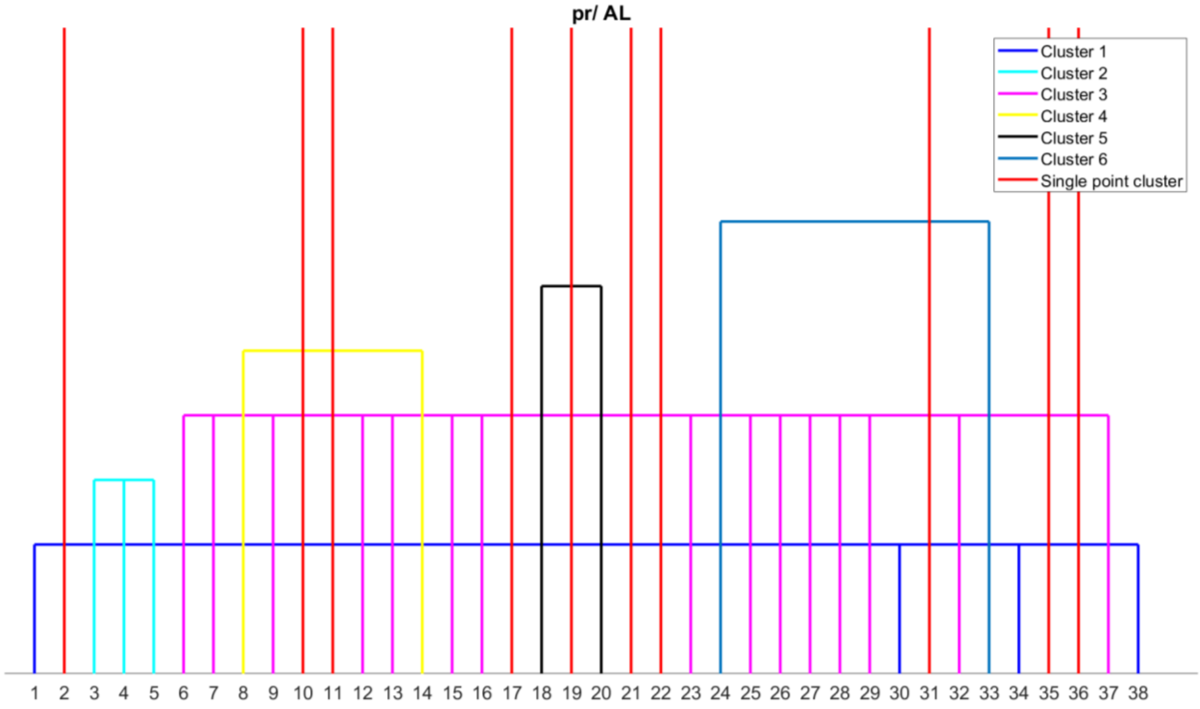

Figure S5: Clustering of error metrics using precipitation (pr) data for Alps (AL) region. Each error metric can be identified by the number using Table S3.

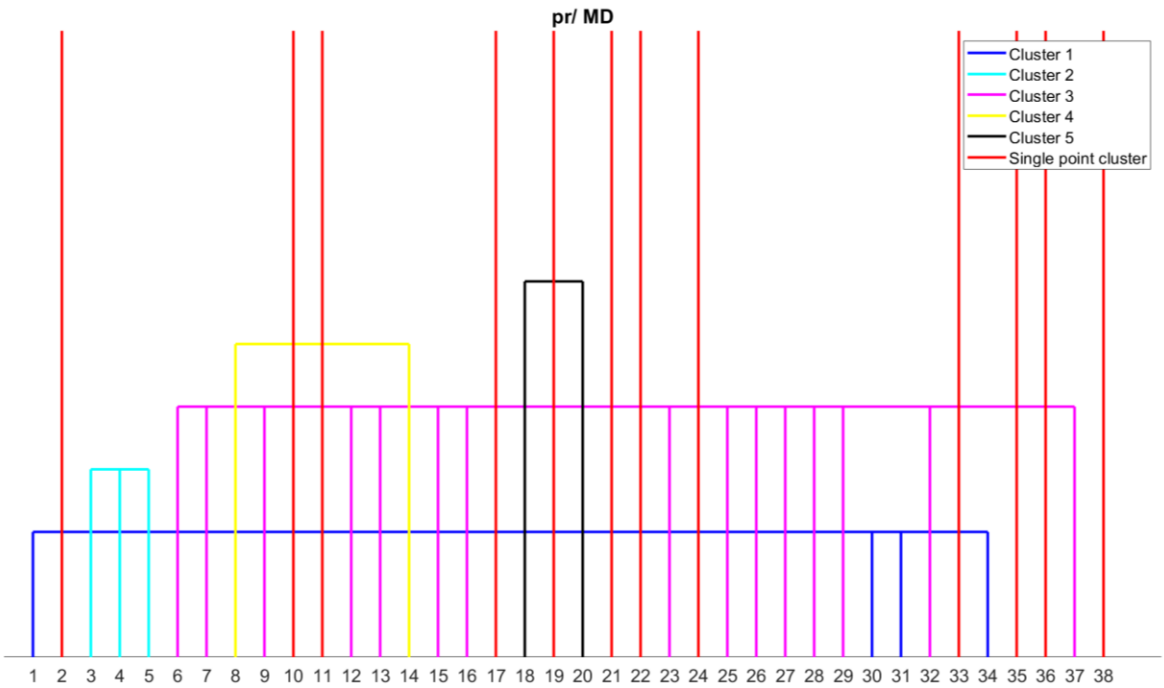

Figure S6: Clustering of error metrics using precipitation (pr) data for Mediterranean (MD) region. Each error metric can be identified by the number using Table S3.

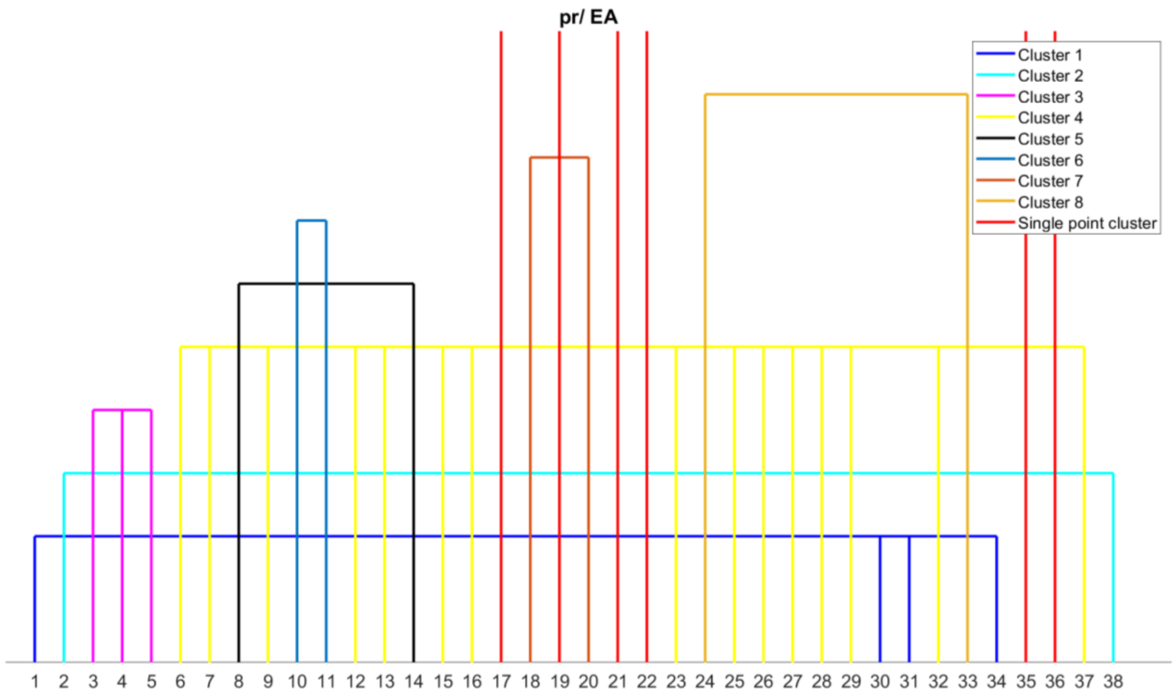

Figure S7: Clustering of error metrics using precipitation (pr) data for Eastern Europe (EA) region. Each error metric can be identified by the number using Table S3.

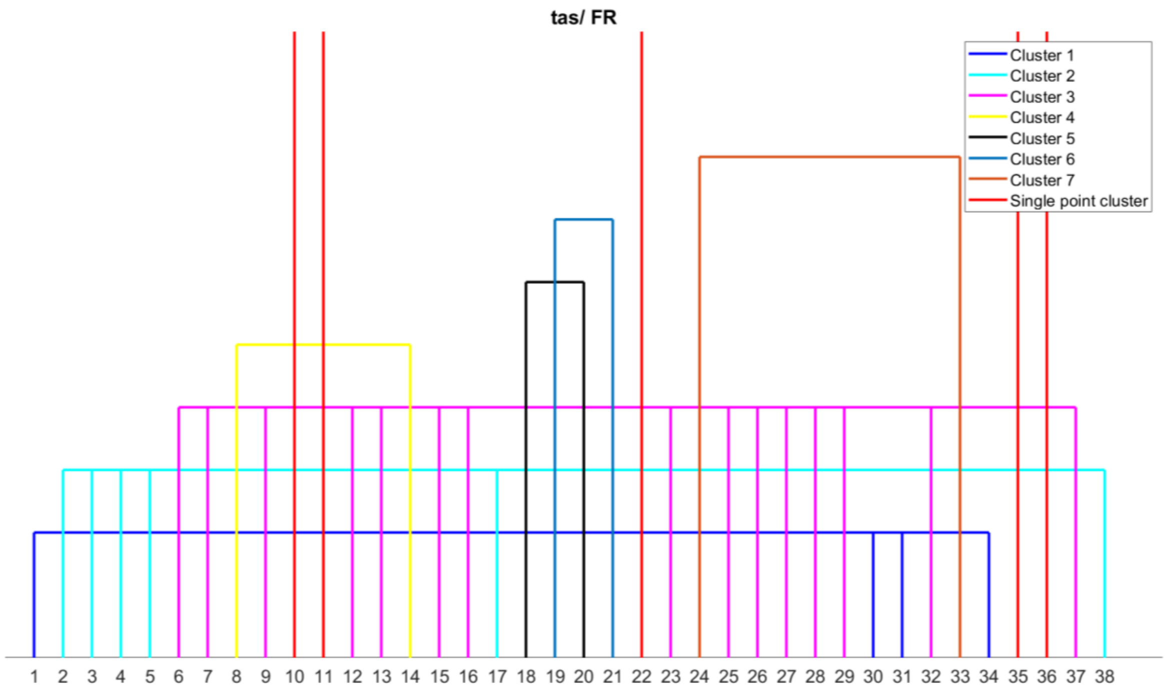

Figure S8: Clustering of error metrics using temperature (tas) data for France (FR) region. Each error metric can be identified by the number using Table S3.

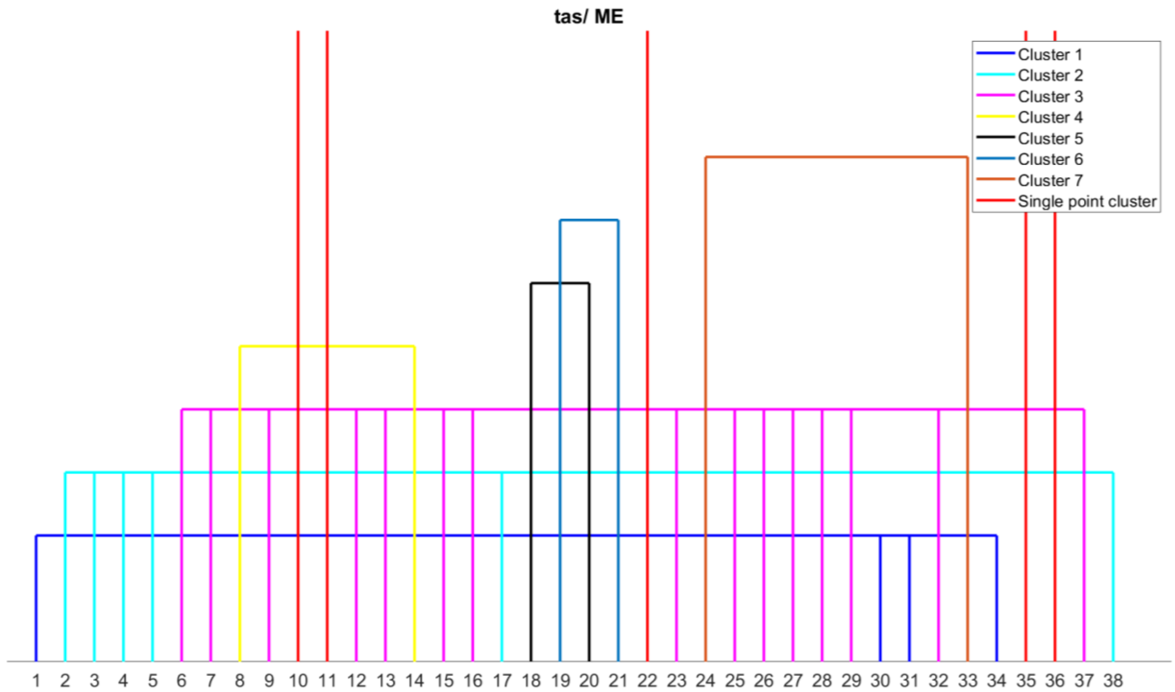

Figure S9: Clustering of error metrics using temperature (tas) data for Mid-Europe (ME) region. Each error metric can be identified by the number using Table S3.

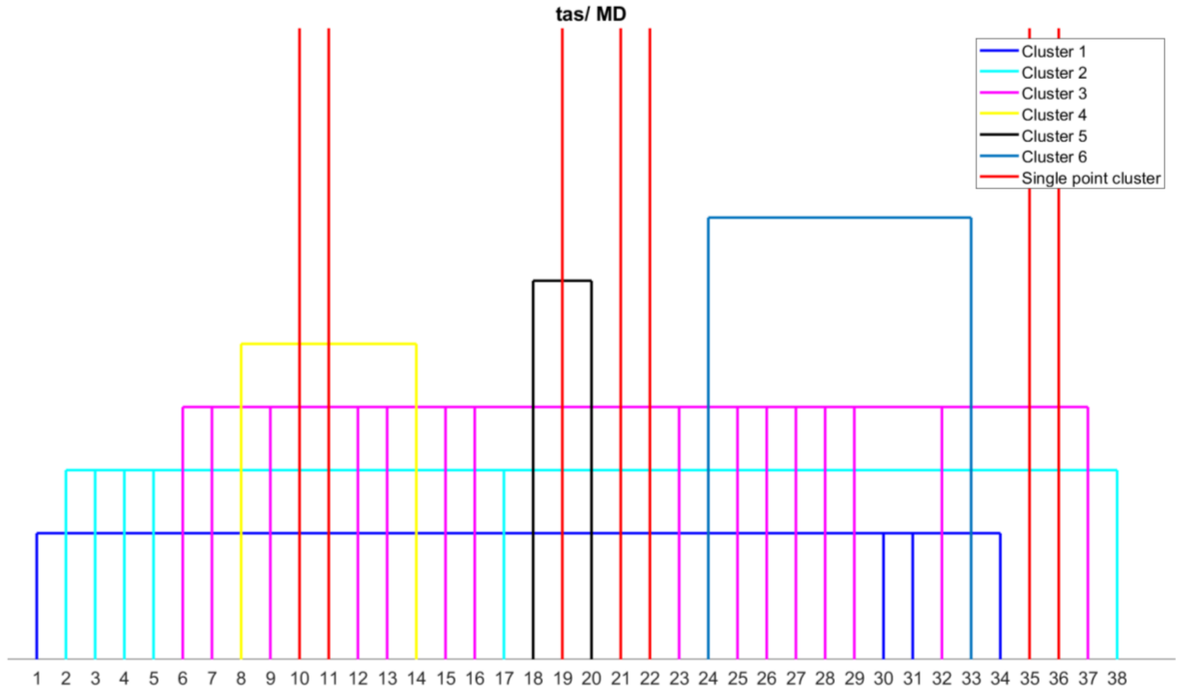

Figure S10: Clustering of error metrics using temperature (tas) data for Mediterranean (MD) region. Each error metric can be identified by the number using Table S3.

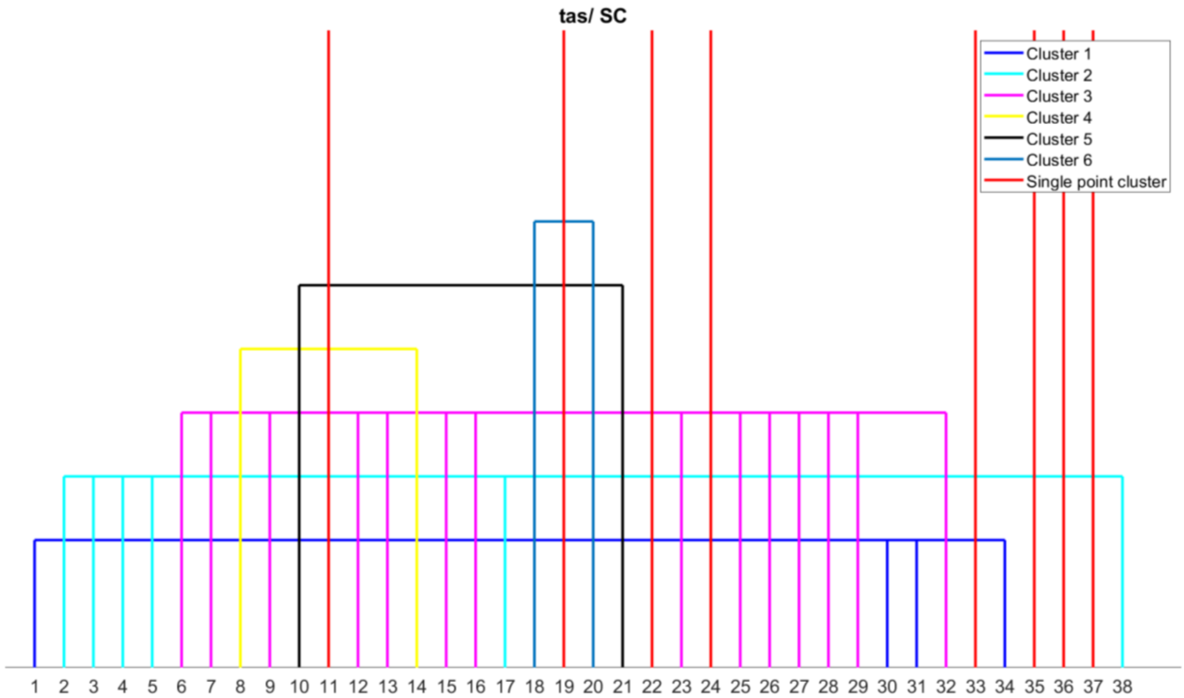

Figure S11: Clustering of error metrics using temperature (tas) data for Scandinavia (SC) region. Each error metric can be identified by the number using Table S3.

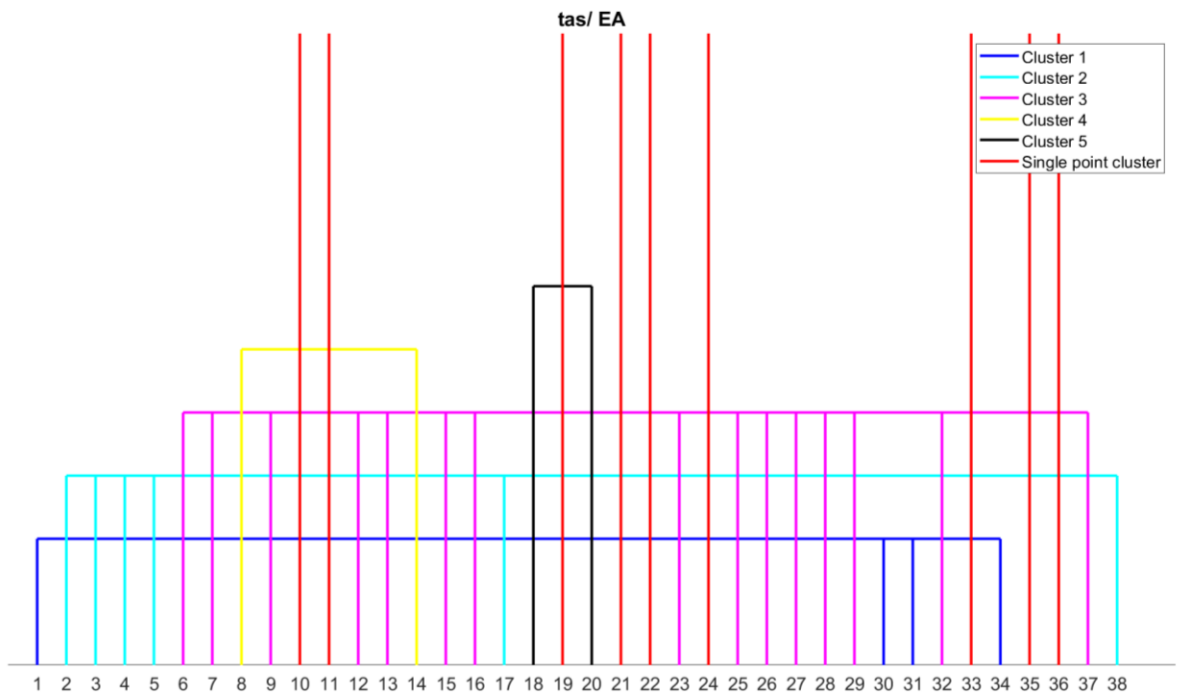

Figure S12: Clustering of error metrics using temperature (tas) data for Eastern Europe (EA) region. Each error metric can be identified by the number using Table S3.

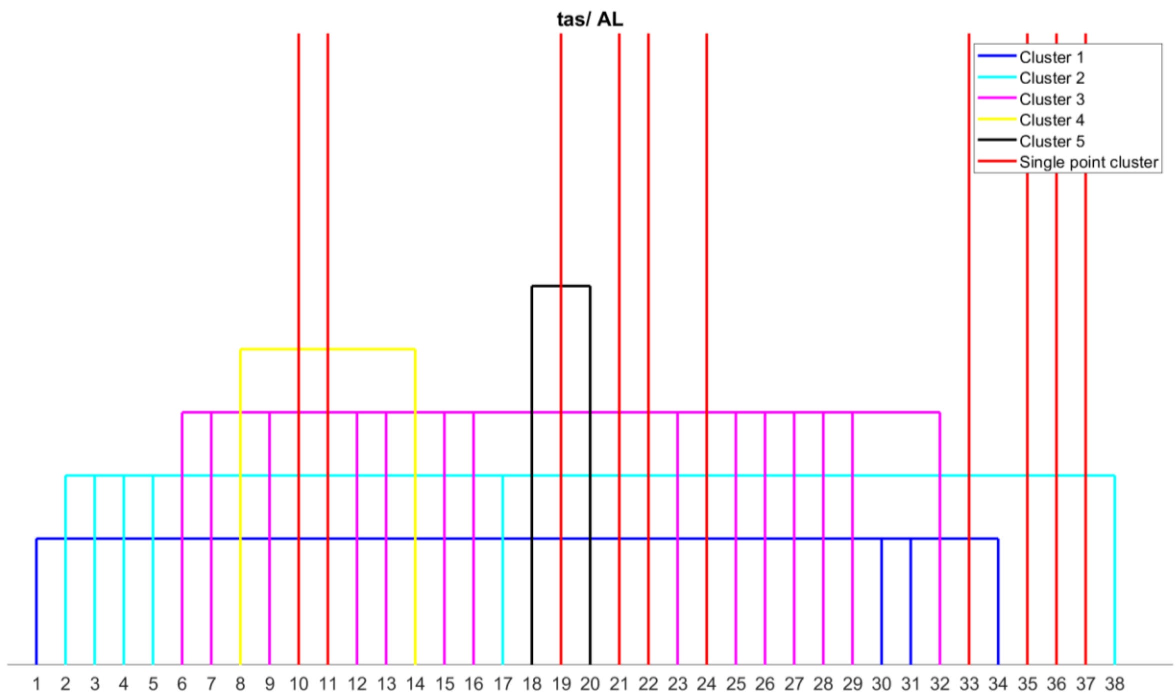

Figure S13: Clustering of error metrics using temperature (tas) data for Alps (AL) region. Each error metric can be identified by the number using Table S3.

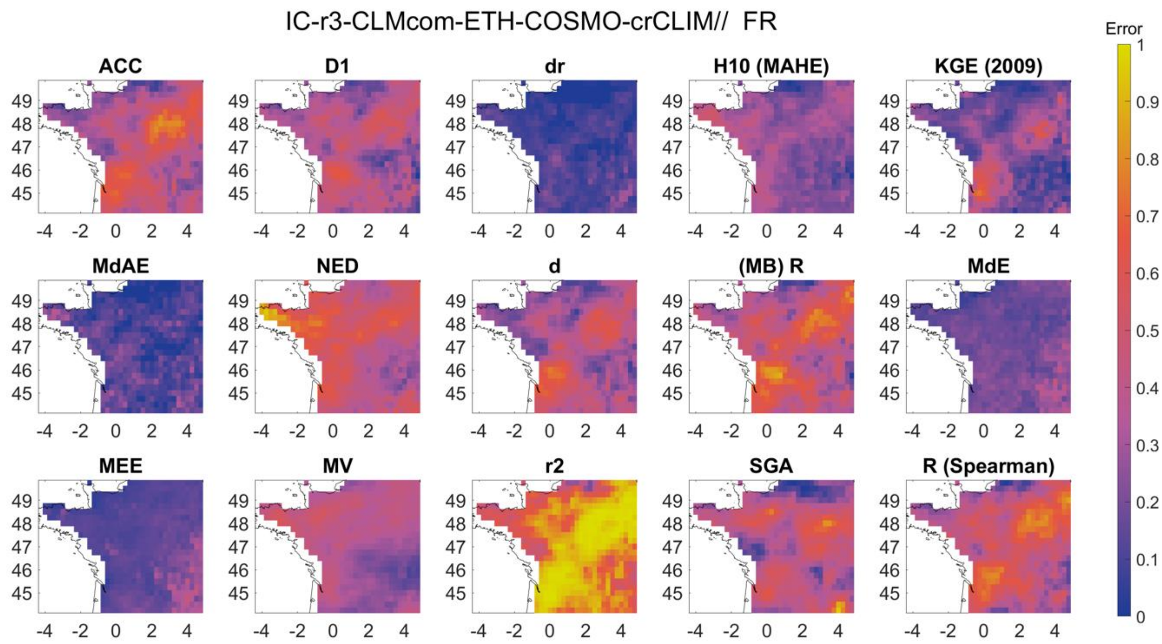

Figure S14: Spatial distribution of the error metrics used to compute the Bergen metric for precipitation and for France (FR) region. The error metrics have been labeled by the abbreviation and the corresponding error metrics can be identified from Table S3.

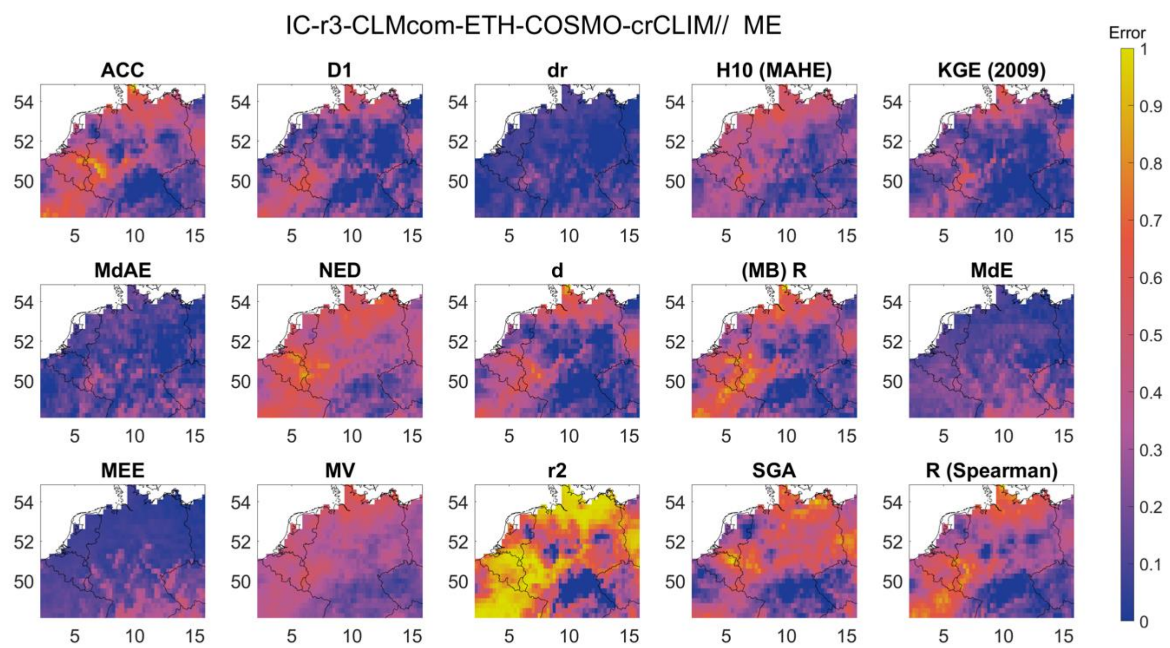

Figure S15: Spatial distribution of the error metrics used to compute the Bergen metric for precipitation and for Mid-Europe (ME) region. The error metrics have been labeled by the abbreviation and the corresponding error metrics can be identified from Table S3.

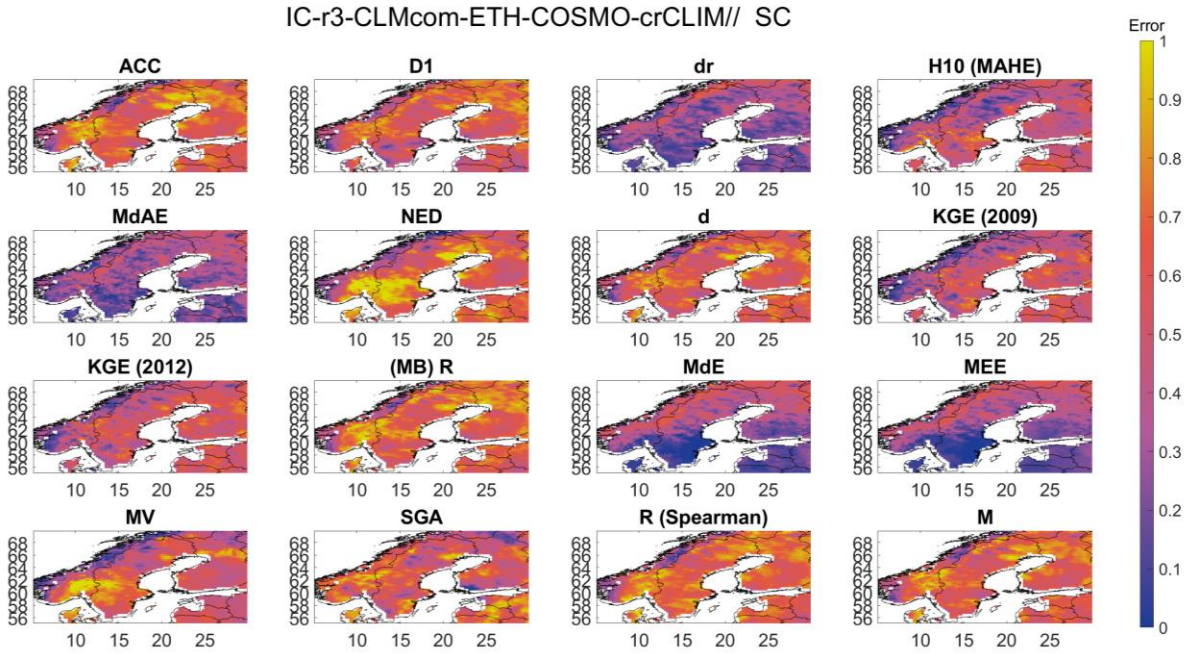

Figure S16: Spatial distribution of the error metrics used to compute the Bergen metric for precipitation and for Scandinavia (SC) region. The error metrics have been labeled by the abbreviation and the corresponding error metrics can be identified from Table S3.

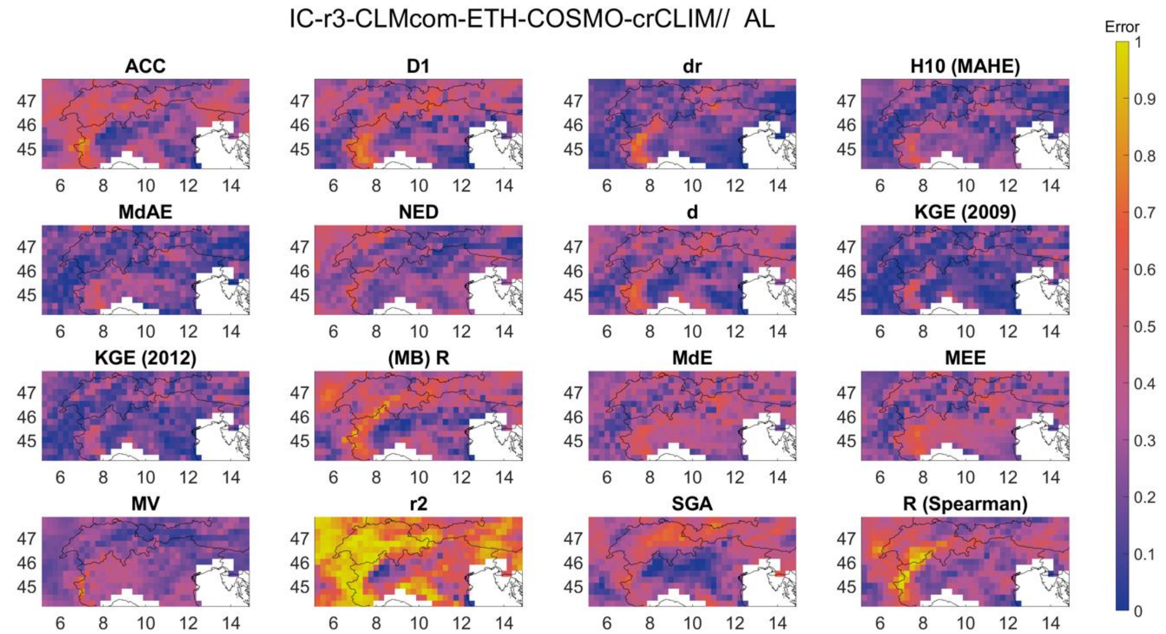

Figure S17: Spatial distribution of the error metrics used to compute the Bergen metric for precipitation and for Alps (AL) region. The error metrics have been labeled by the abbreviation and the corresponding error metrics can be identified from Table S3.

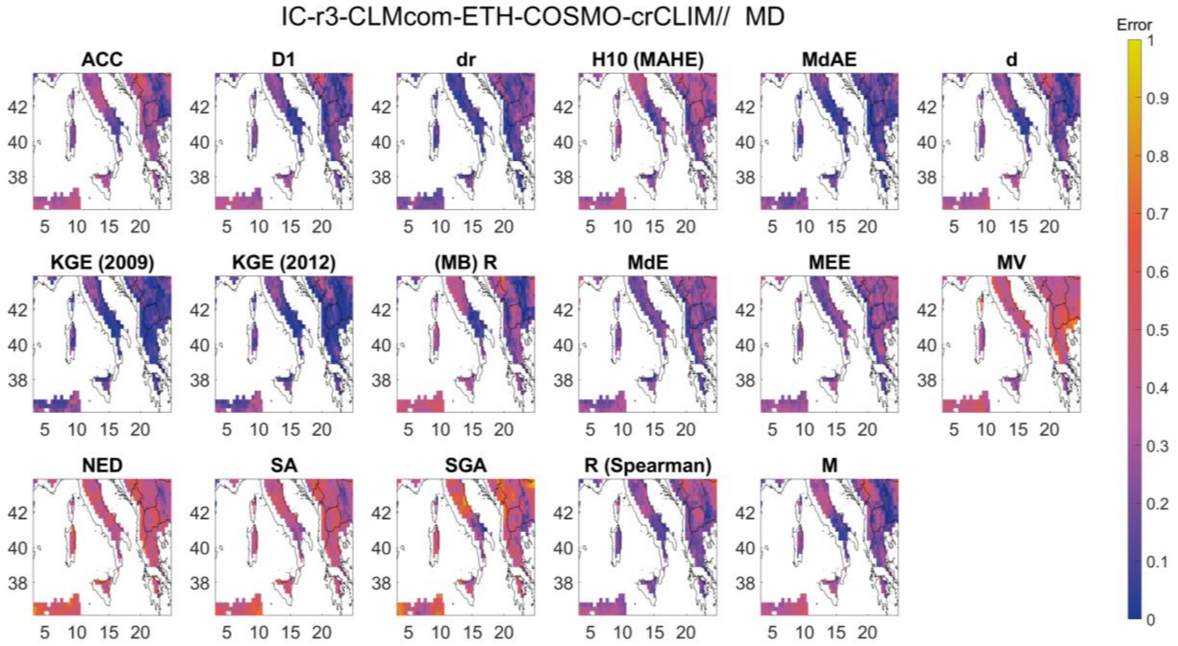

Figure S18: Spatial distribution of the error metrics used to compute the Bergen metric for precipitation and for Mediterranean (MD) region. The error metrics have been labeled by the abbreviation and the corresponding error metrics can be identified from Table S3.

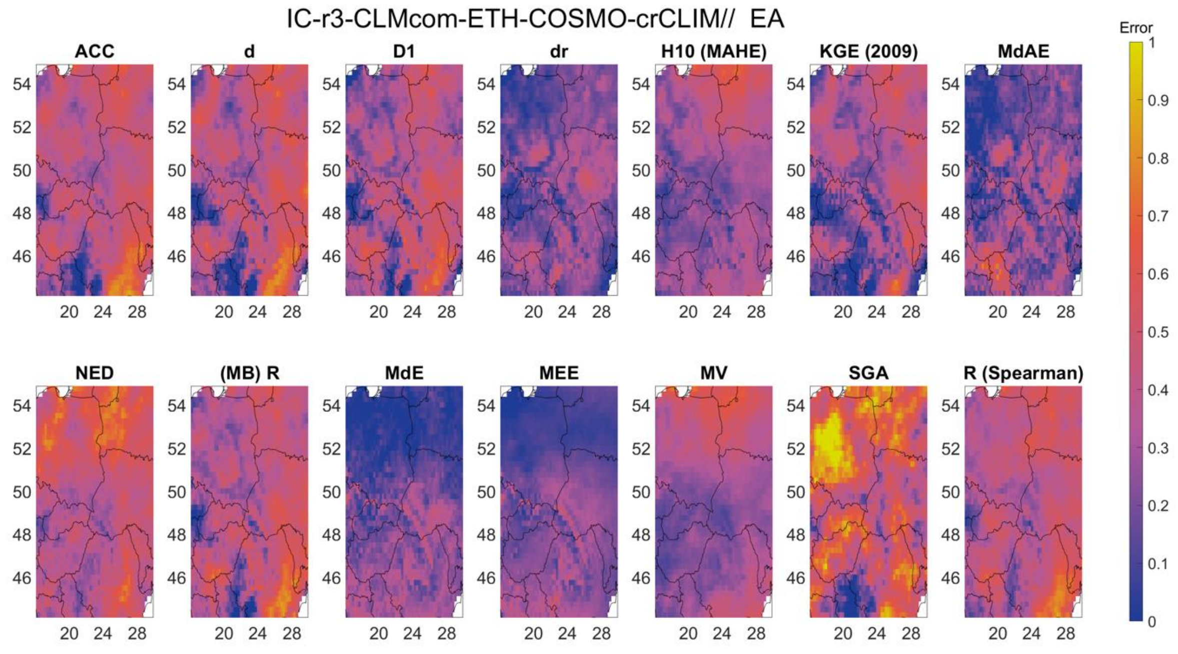

Figure S19: Spatial distribution of the error metrics used to compute the Bergen metric for precipitation and for Eastern Europe (EA) region. The error metrics have been labeled by the abbreviation and the corresponding error metrics can be identified from Table S3.

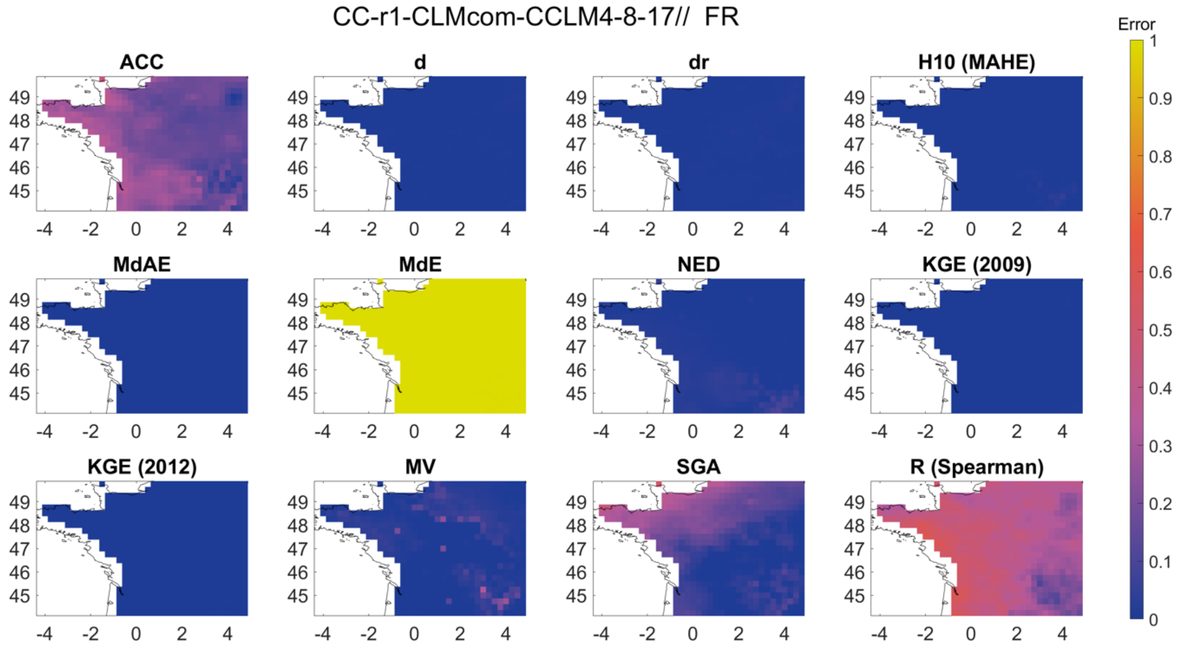

Figure S20: Spatial distribution of the error metrics used to compute the Bergen metric for temperature and for France (FR) region. The error metrics have been labeled by the abbreviation and the corresponding error metrics can be identified from Table S3.

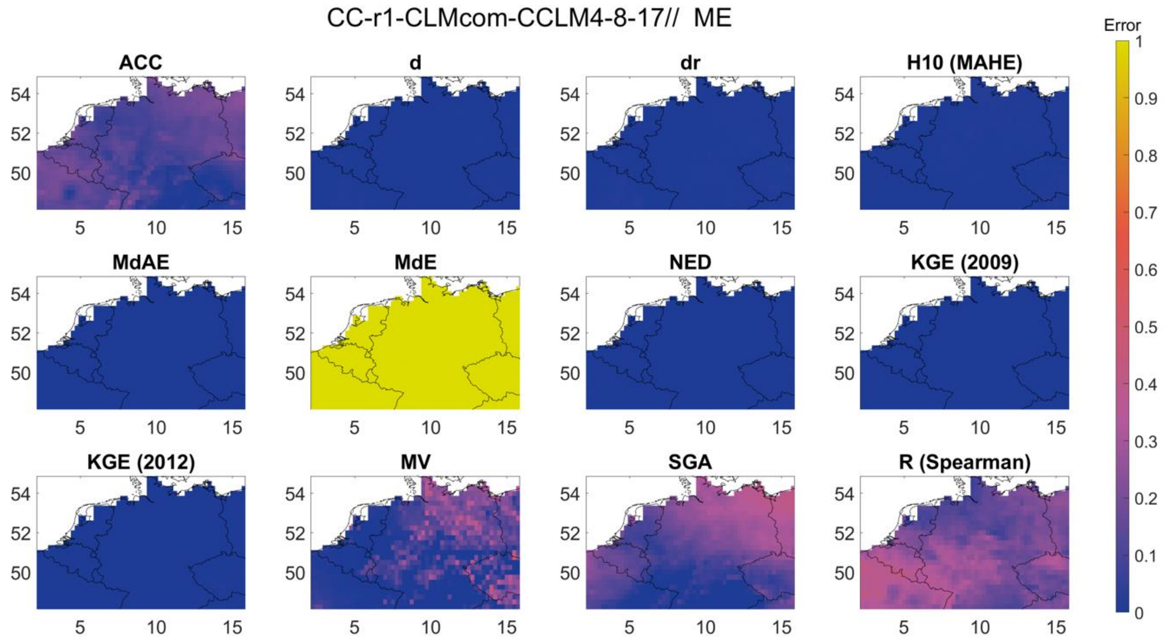

Figure S21: Spatial distribution of the error metrics used to compute the Bergen metric for temperature and for Mid-Europe (ME) region. The error metrics have been labeled by the abbreviation and the corresponding error metrics can be identified from Table S3.

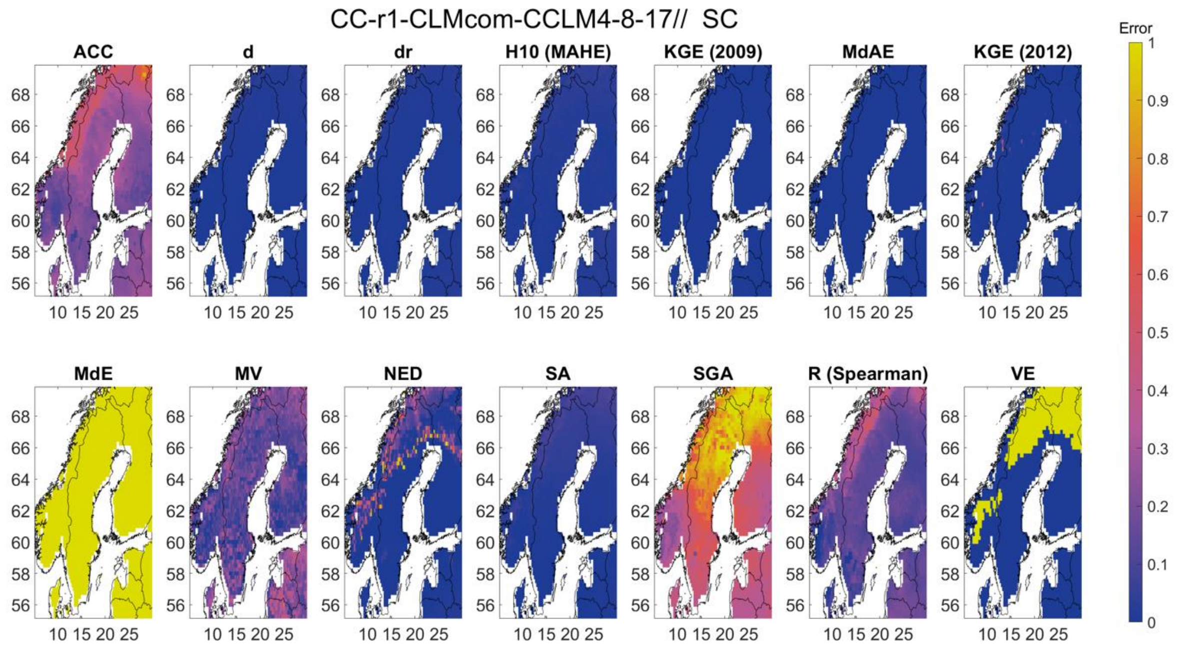

Figure S22: Spatial distribution of the error metrics used to compute the Bergen metric for temperature and for Scandinavia (SC) region. The error metrics have been labeled by the abbreviation and the corresponding error metrics can be identified from Table S3.

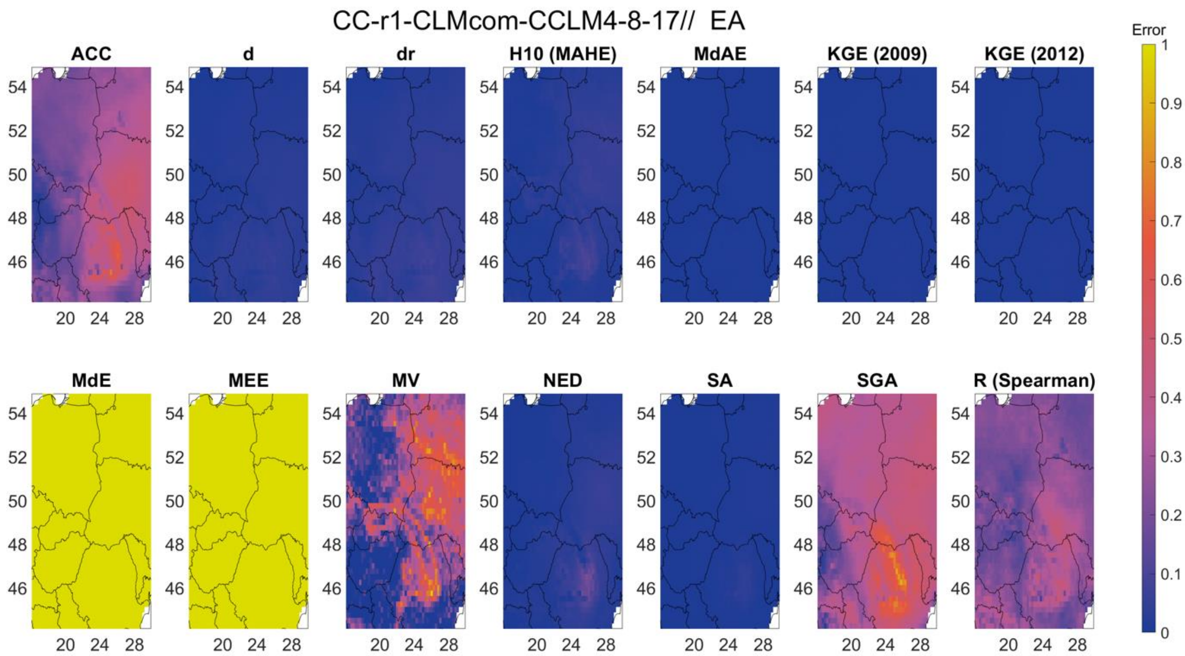

Figure S23: Spatial distribution of the error metrics used to compute the Bergen metric for temperature and for Eastern Europe (EA) region. The error metrics have been labeled by the abbreviation and the corresponding error metrics can be identified from Table S3.

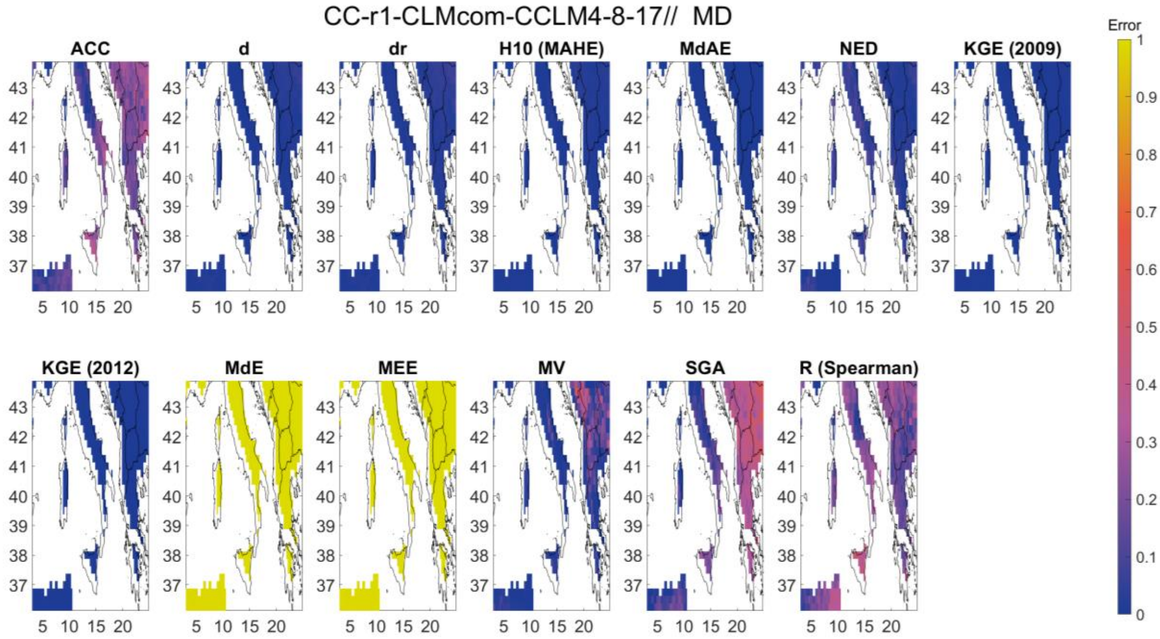

Figure S24: Spatial distribution of the error metrics used to compute the Bergen metric for temperature and for Mediterranean (MD) region. The error metrics have been labeled by the abbreviation and the corresponding error metrics can be identified from Table S3.

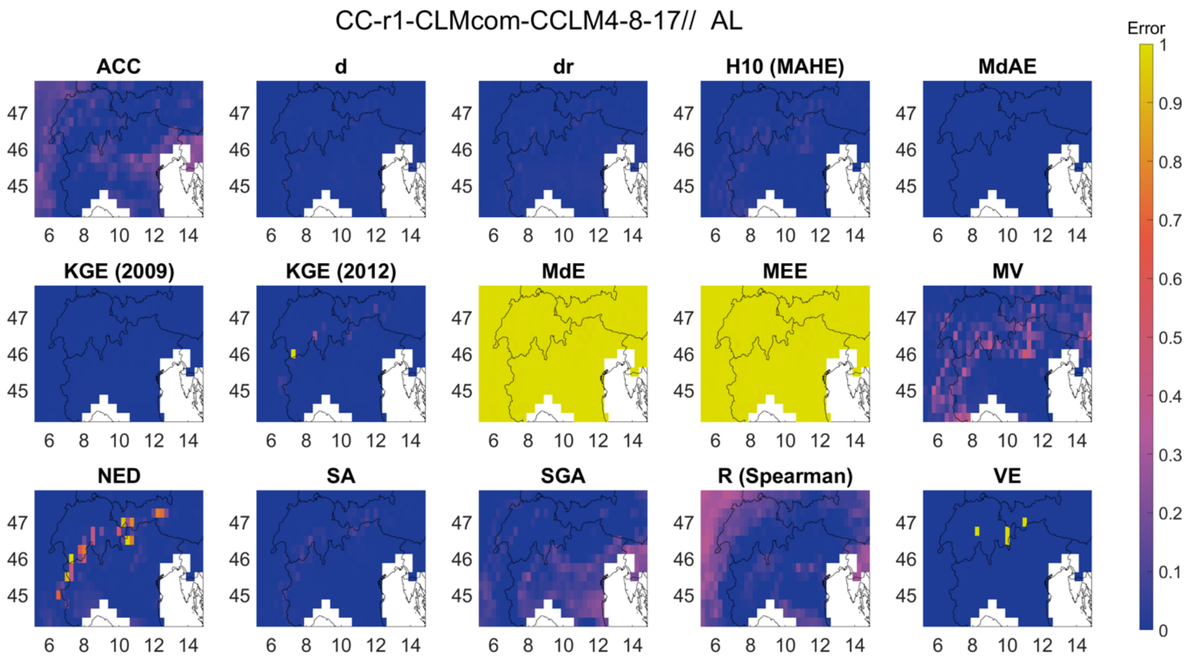

Figure S25: Spatial distribution of the error metrics used to compute the Bergen metric for temperature and for Alps (AL) region. The error metrics have been labeled by the abbreviation and the corresponding error metrics can be identified from Table S3.

Supplementary Table

Table S1: List of global climate models used in the study

id	GCM	Used Realization	Number of RCM (Precipitation and Mean Temperature)
1	CCCma-CanESM2	r1i1p1	4
2	CNRM-CERFACS-CNRM-CM5	r1i1p1	13
3	ICHEC-EC-EARTH	r1i1p1	6
		r3i1p1	5
		r12i1p1	11
4	IPSL-IPSL-CM5A-LR	r1i1p1	1
5	IPSL-IPSL-CM5A-MR	r1i1p1	6
6	MIROC-MIROC5	r1i1p1	4
7	MOHC-HadGEM2-ES	r1i1p1	13
8	MPI-M-MPI-ESM-LR	r1i1p1	12
		r2i1p1	4
		r3i1p1	3
9	NCC-NorESM1-M	r1i1p1	6
10	NOAA-GFDL-GFDL-ESM2G	r1i1p1	1

Table S2: List of climate models used in the study

Number	Model
1	EUR-11_CCCma-CanESM2_historical_r1i1p1_CLMcom-CCLM4-8-17_v1
2	EUR-11_CCCma-CanESM2_historical_r1i1p1_GERICS-REMO2015_v1
3	own_ReKliEs-DWD_CCCma-CanESM2_historical_r1i1p1_CLMcom-CCLM4-8-17_v1_EUR-11
4	own_ReKliEs-DWD_CCCma-CanESM2_historical_r1i1p1_GERICS-REMO2015_v1_EUR-11
5	EUR-11_CNRM-CERFACS-CNRM-CM5_historical_r1i1p1_CLMcom-CCLM4-8-17_v1
6	EUR-11_CNRM-CERFACS-CNRM-CM5_historical_r1i1p1_CLMcom-ETH-COSMO-crCLIM-v1-1_v1
7	EUR-11_CNRM-CERFACS-CNRM-CM5_historical_r1i1p1_CNRM-ALADIN53_v1
8	EUR-11_CNRM-CERFACS-CNRM-CM5_historical_r1i1p1_CNRM-ALADIN63_v2
9	EUR-11_CNRM-CERFACS-CNRM-CM5_historical_r1i1p1_DMI-HIRHAM5_v2
10	EUR-11_CNRM-CERFACS-CNRM-CM5_historical_r1i1p1_GERICS-REMO2015_v1
11	EUR-11_CNRM-CERFACS-CNRM-CM5_historical_r1i1p1_GERICS-REMO2015_v2
12	EUR-11_CNRM-CERFACS-CNRM-CM5_historical_r1i1p1_KNMI-RACMO22E_v2
13	EUR-11_CNRM-CERFACS-CNRM-CM5_historical_r1i1p1_RMIB-UGent-ALARO-0_v1
14	EUR-11_CNRM-CERFACS-CNRM-CM5_historical_r1i1p1_SMHI-RCA4_v1
15	own_ReKliEs-DWD_CNRM-CERFACS-CNRM-CM5_historical_r1i1p1_CLMcom-CCLM4-8-17_v1_EUR-11
16	own_ReKliEs-DWD_CNRM-CERFACS-CNRM-CM5_historical_r1i1p1_GERICS-REMO2015_v1_EUR-11
17	own_ReKliEs-DWD_CNRM-CERFACS-CNRM-CM5_historical_r1i1p1_SMHI-RCA4_v1_EUR-11
18	EUR-11_ICHEC-EC-EARTH_historical_r12i1p1_CLMcom-CCLM4-8-17_v1
19	EUR-11_ICHEC-EC-EARTH_historical_r12i1p1_CLMcom-ETH-COSMO-crCLIM-v1-1_v1
20	EUR-11_ICHEC-EC-EARTH_historical_r12i1p1_DMI-HIRHAM5_v1
21	EUR-11_ICHEC-EC-EARTH_historical_r12i1p1_GERICS-REMO2015_v1
22	EUR-11_ICHEC-EC-EARTH_historical_r12i1p1_KNMI-RACMO22E_v1
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86	EUR-11_NCC-NorESM1-M_historical_r1i1p1_GERICS-REMO2015_v1
87	EUR-11_NCC-NorESM1-M_historical_r1i1p1_KNMI-RACMO22E_v1
88	EUR-11_NCC-NorESM1-M_historical_r1i1p1_SMHI-RCA4_v1
89	EUR-11_NOAA-GFDL-GFDL-ESM2G_historical_r1i1p1_GERICS-REMO2015_v1

Table S3: List of error metrics used in the study

Number	Metrics	Abbreviation
1	Anomaly Correlation Coefficient	ACC
2	Index of Agreement	d
3	Legate-McCabe Index of Agreement	D1
4	Index of Agreement	d1
5	Modified Index of Agreement	d (Mod.)
6	Index of Agreement Refined	dr
7	Euclidean Distance	ED
8	Mean Absolute H10 Error	H10 (MAHE)
9	Inertial Root Mean Square Error	IRMSE
10	Kling-Gupta Efficiency (2009)	KGE (2009)
11	Kling-Gupta Efficiency (2012)	KGE (2012)
12	Legate-McCabe Efficiency Index	E1
13	Mean Absolute Error	MAE
14	Mean Absolute Log Error	MALE
15	Mean Absolute Percentage Deviation	MAPD
16	Mean Absolute Scaled Error	MASE
17	Mielke-Berry R	(MB) R
18	Median Absolute Error	MdAE
19	Median Error	MdE
20	Median Squared Error	MdSE
21	Mean Error	MEE
22	Mean Variance	MV
23	Mean Squared Error	MSE
24	Normalized Eclidean Distance	NED
25	Normalized Root Mean Square Error - IQR	NRMSE (IQR)
26	Normalized Root Mean Square Error - Mean	NRMSE (Mean)
27	Normalized Root Mean Square Error - Range	NRMSE (Range)
28	Nash-Sutcliffe Efficiency	NSE
29	Modified Nash-Sutcliffe Efficiency	NSE (Mod.)
30	Pearson Correlation Coefficient	R (Pearson))
31	Coefficient of Determination	r^2
32	Root Mean Square Error	RMSE
33	Spectral Angle	SA
34	Spectral Correlation	SCO
35	Spectral Gradient Angle	SGA
36	Spearman Rank Correlation Coefficient	R (Spearman)
37	Volumetric Efficiency	VE
38	Watterson s M	M

Supplementary Text

Text S1

To evaluate the effectiveness of the non-parametric clustering (Np) method used in this study, it is compared to K-means clustering (Hartigan & Wong, 1979) for both precipitation and temperature in all the eight regions. K-means is also a non-parametric clustering and it has been selected for comparison with the Np clustering because of its popularity and robust framework. For K-means clustering, the ranking order of each metric is pooled together for all grid points as a single column matrix and used as a feature vector for that region and error metric. The mean absolute error is then computed for all possible combinations of error metrics within a cluster and presented as a box plot in Figure S26. The results show that the MAE produced by the Np clustering method is lower than that produced by K-means clustering for all regions in both precipitation and temperature. Therefore, the Np clustering method is selected as the preferred approach for classifying the error metrics in the study.

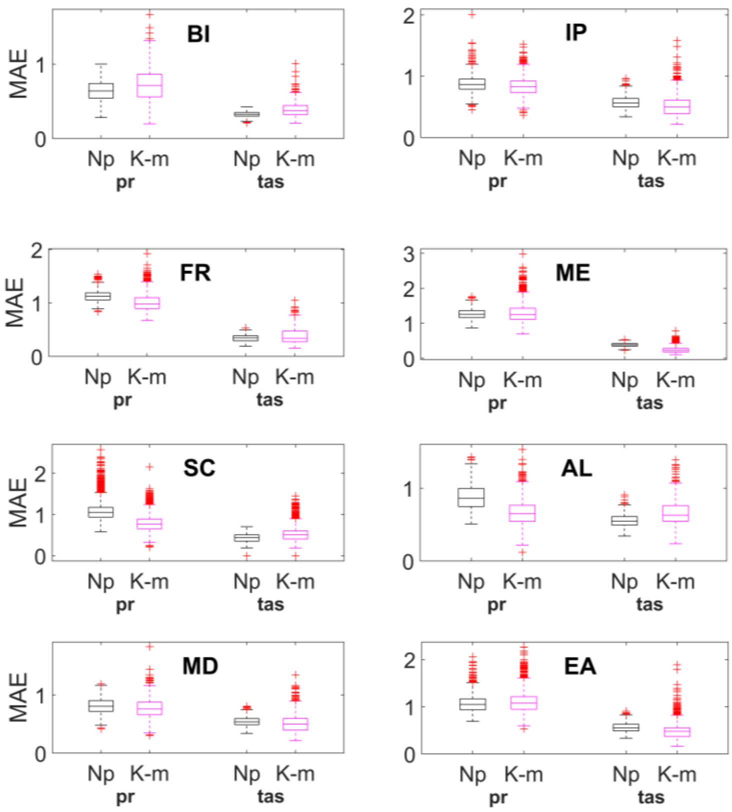

Figure S26: A comparison between the non-parametric clustering (Np) adopted in the study and K-means clustering (K-m) using MAE for both precipitation and temperature and for all the eight regions

Hartigan, J. A., & Wong, M. A.: Algorithm AS 136: A k-means clustering algorithm. *Journal of the royal statistical society. series c (applied statistics)*, *28*(1), 100-108, https://doi.org/10.2307/2346830, 1979.

Text S2

The clustering of error metrics using ranking order has led to a significant reduction in the number of error metrics. This enables the use of a single error metric from each cluster to calculate the Bergen metric, as explained in the methodology section. However, it is still a challenge to choose a metric from each cluster. The study assumes that random selection of a metric from the cluster will not have any effect on the ranking order produced by Bergen metric. To validate it, we conducted 10 experiments for both precipitation and temperature, whereby a metric is randomly drawn from each cluster, and the Bergen metric is computed for each experiment and for all the climate models across each grid points in Europe. The study then identifies the best model for each grid point using the Bergen metric and a histogram is generated to display the frequency of each model being identified as the best. Figure S27 shows no differences between the experiments conducted in both precipitation and temperature, indicating that randomly selecting a metric from each cluster do not affect the ranking order produced by the Bergen metric.

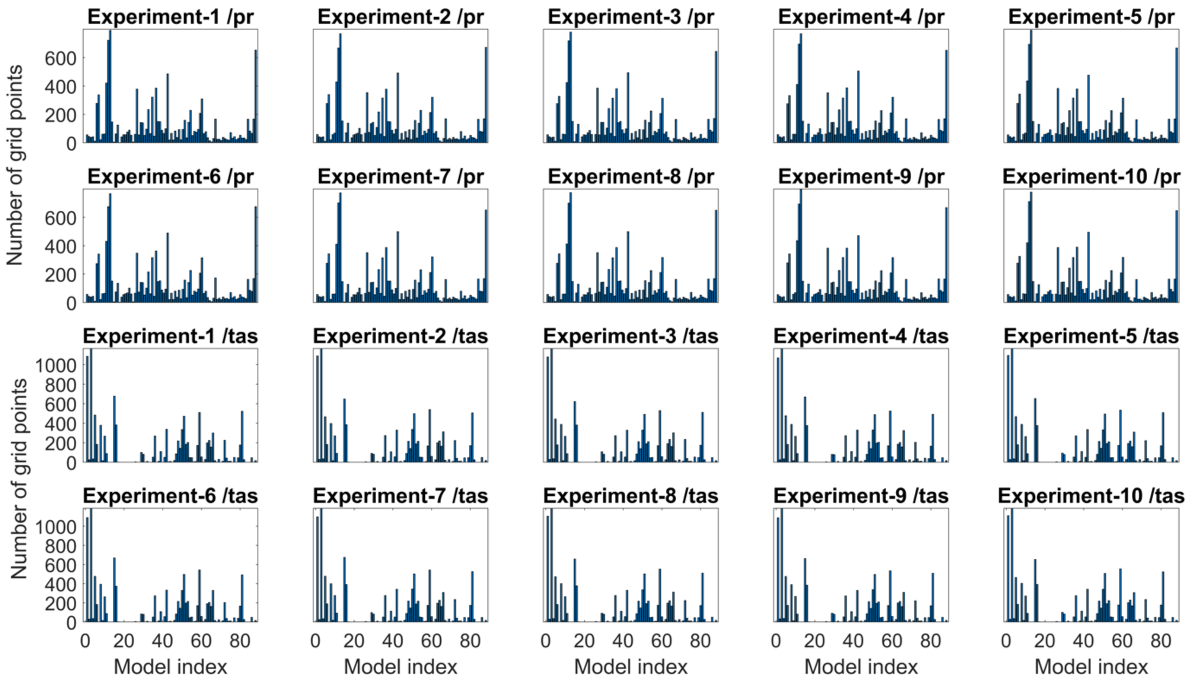

Figure S27: Influence on Bergen metric by the random selection of error metric