Supplementary Material

Global warming makes weather in boreal summer more persistent

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Supplementary Figures
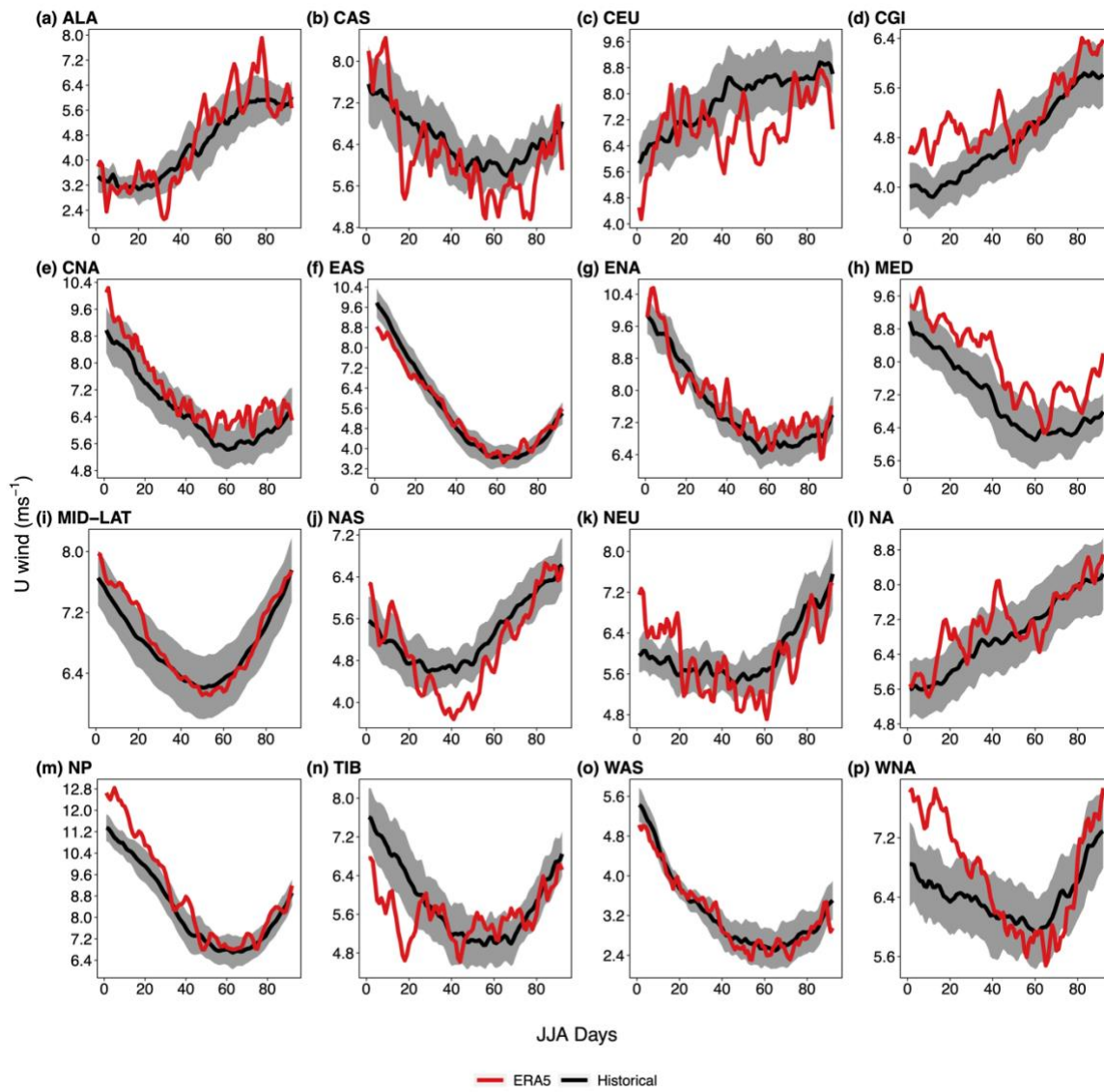
Figure S1. As Figure 2(b)-(q) but for U wind (ms-1).
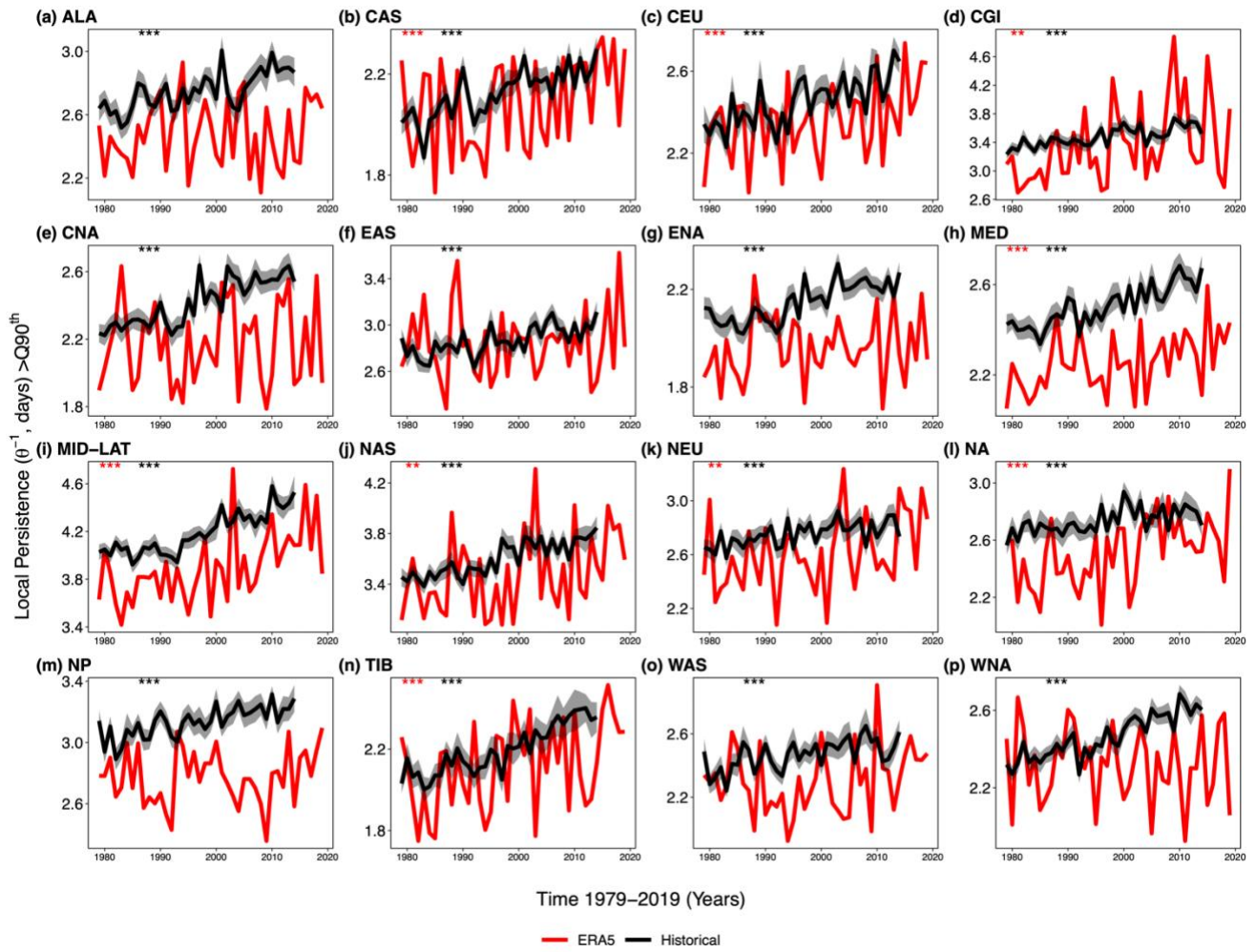
Figure S2. As Figure 3 but for trends in extreme persistence (exceeding the 90th percentile). See also Table S3.
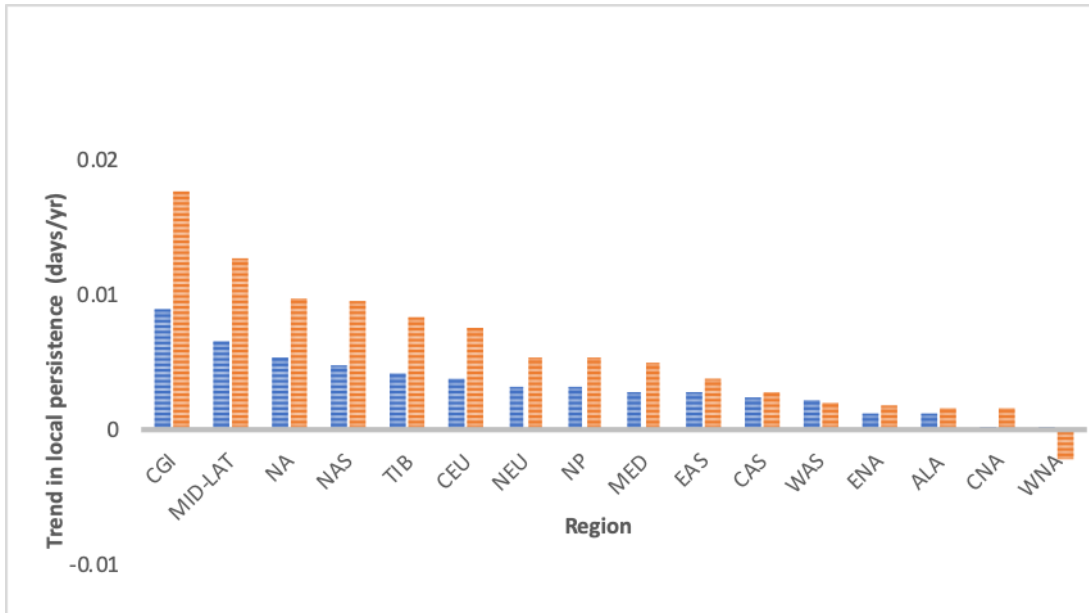
Figure S3. Comparison between trends in mean (blue) and 90th percentile (orange) persistence in ERA5 over 1979-2019. Regions are ordered according to the magnitude of the mean trend.
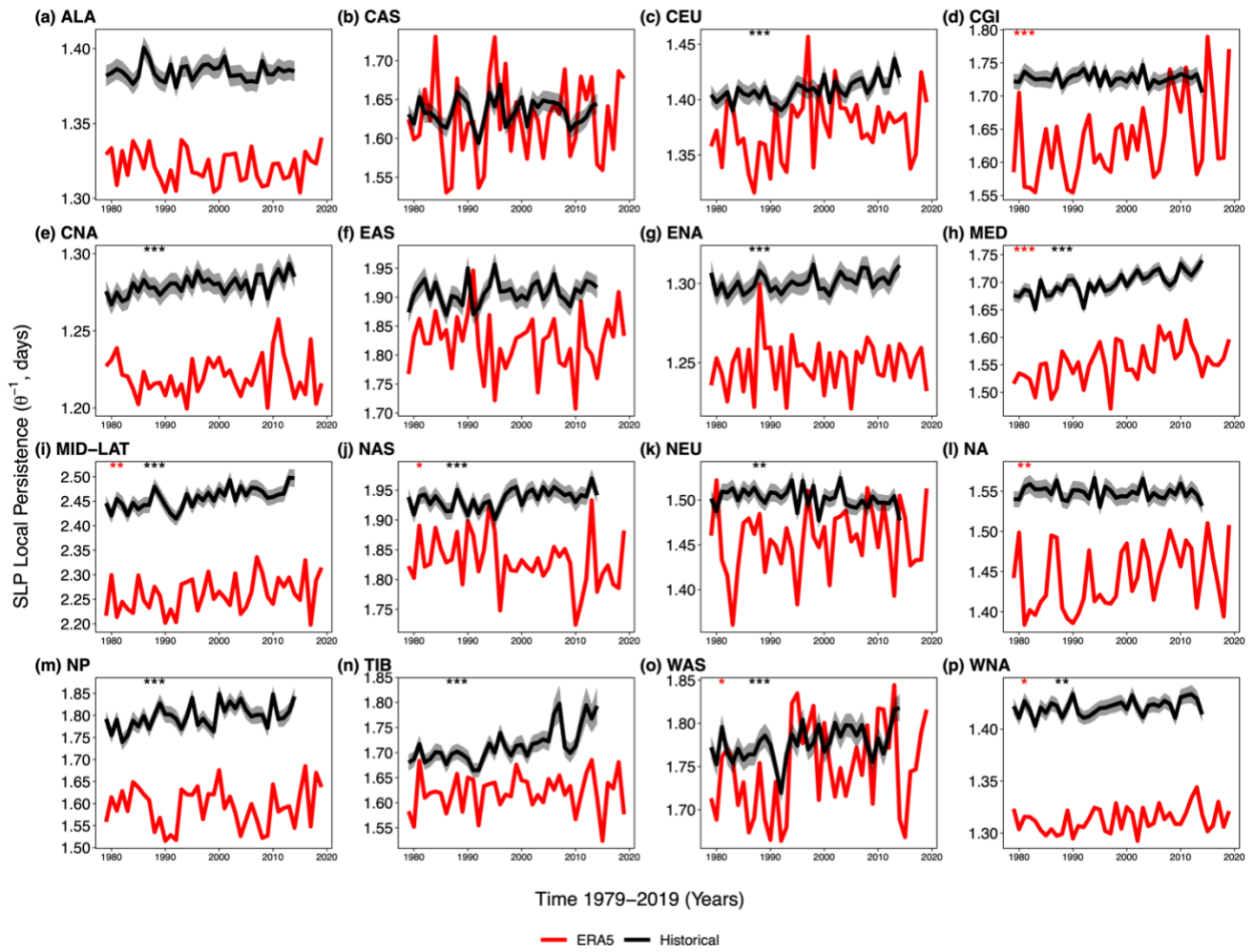
Figure S4. As Figure 3 bur for daily sea-level pressure (SLP) persistence. See also Table S4.
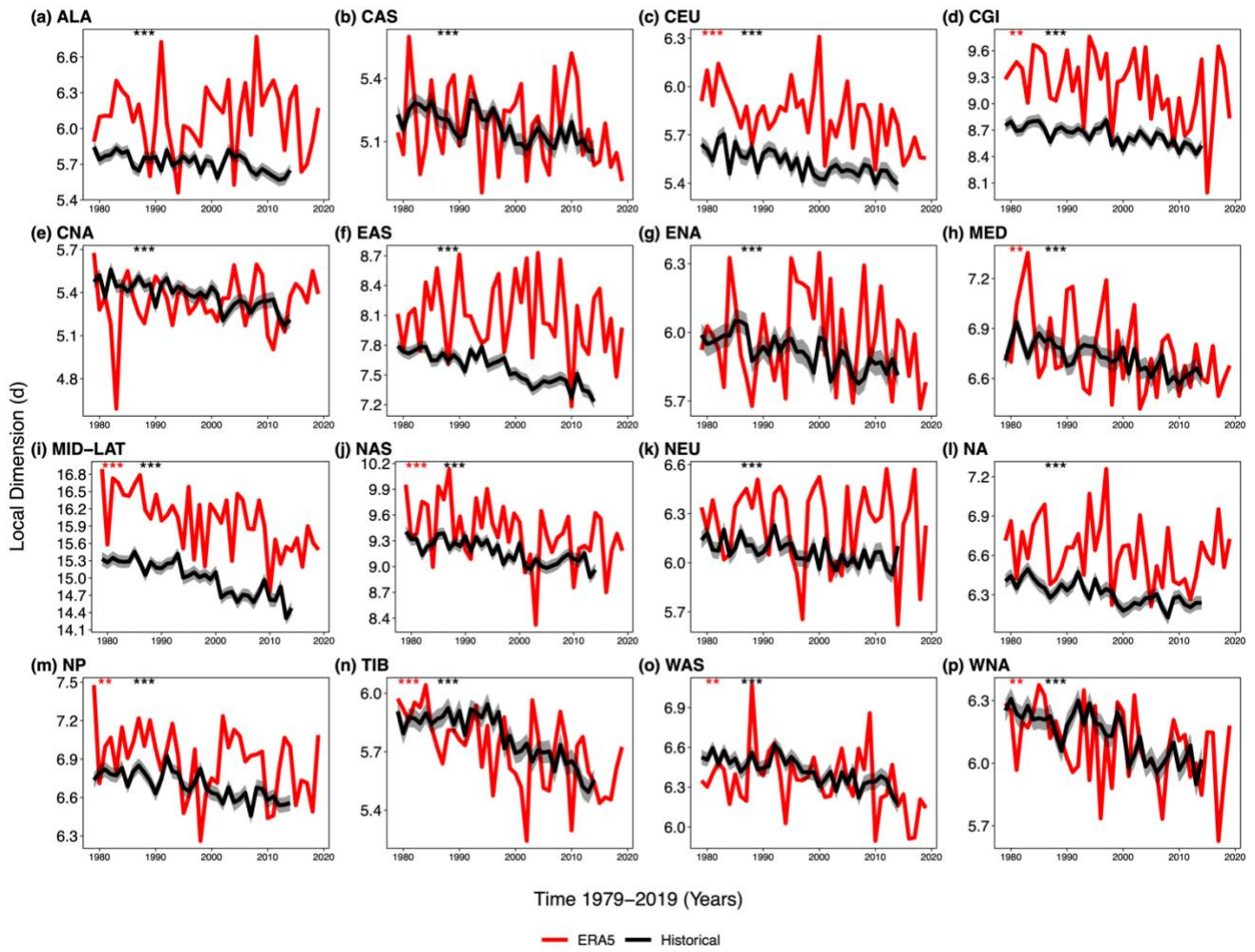
Figure S5. As Figure 3 but for the other dynamical systems metric local dimension (d).
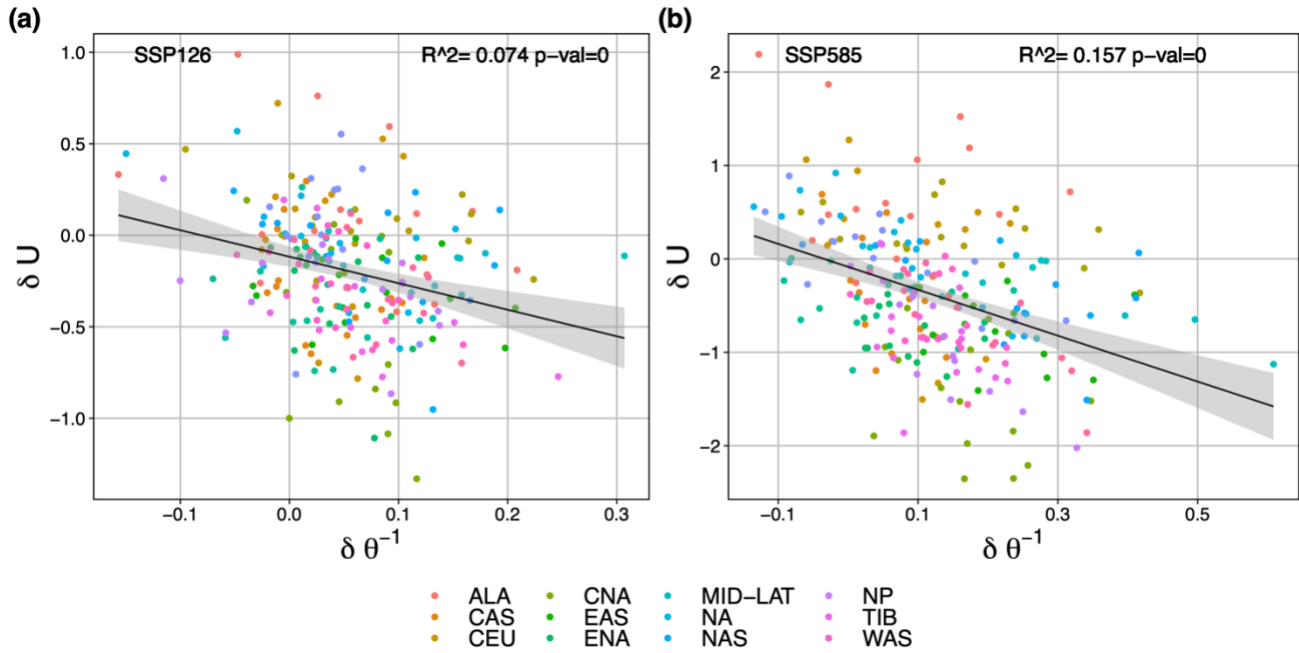
Figure S6: Regression analyses between future changes in the July-August zonal wind (δU) and persistence ($\delta\theta_{-1}$) for SSP126 (left) and SSP585 (right) for mid-latitude regions (coloring). δU and $\delta\theta_{-1}$ are computed by subtracting historical values (mean over 1981-200) from the two SSPs (mean over 2081-2100). Grey shaded areas represent the 95% confidence intervals of the linear regressions.

Supplementary Tables

CMIP6 model	Nominal resolution	Variable	Time-period	Ensemble member
ACCESS-CM2	250Km	slp	hist	r1i1p1f1
		ua	hist, ssp126, ssp585	r1i1p1f1, r1i1p1f1, r1i1p1f1
		zg	hist, ssp126, ssp585	r1i1p1f1, r1i1p1f1, r1i1p1f1
ACCESS-ESM1-5	250Km	ua	hist, ssp126, ssp585	r1i1p1f1, r1i1p1f1, r1i1p1f1
		zg	ssp126, ssp585	r1i1p1f1, r1i1p1f1
AWI-CM-1-1-MR	100Km	ua	ssp126, ssp585	r1i1p1f1, r1i1p1f1
		zg	ssp126, ssp585	r1i1p1f1, r1i1p1f1
BCC-CSM2-MR	100Km	slp	hist	r1i1p1f1
		ua	hist, ssp126, ssp585	r1i1p1f1, r1i1p1f1, r1i1p1f1
		zg	hist, ssp126, ssp585	r1i1p1f1, r1i1p1f1, r1i1p1f1
CanESM5	500Km	slp	hist	r1i1p1f1
		ua	hist, ssp126, ssp585	r1i1p1f1, r1i1p1f1, r1i1p1f1
		zg	hist, ssp126, ssp585	r1i1p1f1, r1i1p1f1, r1i1p1f1
CESM2-WACCM	100Km	slp	hist	r1i1p1f1
		ua	hist, ssp126, ssp585	r1i1p1f1, r1i1p1f1, r1i1p1f1
		zg	hist, ssp126, ssp585	r1i1p1f1, r1i1p1f1, r1i1p1f1
CNRM-CM6-1-HR	50Km	ua	ssp585	r1i1p1f2
		zg	ssp126, ssp585	r1i1p1f2, r1i1p1f2
CNRM-CM6-1	250Km	slp	hist	r1i1p1f2
		ua	hist, ssp126, ssp585	r1i1p1f2, r1i1p1f2, r1i1p1f2
		zg	hist, ssp126, ssp585	r1i1p1f2, r1i1p1f2, r1i1p1f2
CNRM-ESM2-1	250Km	slp	hist	r1i1p1f2
		ua	hist, ssp126, ssp585	r1i1p1f2, r1i1p1f2, r1i1p1f2
		zg	hist, ssp126, ssp585	r1i1p1f2, r1i1p1f2, r1i1p1f2
EC-Earth3	100Km	slp	hist	r1i1p1f1
		ua	hist, ssp126, ssp585	r1i1p1f1, r4i1p1f1, r4i1p1f1

		zg	hist, ssp126, ssp585	r1i1p1f1, r4i1p1f1, r4i1p1f1
EC-Earth3-Veg	100Km	ua	hist, ssp126, ssp585	r1i1p1f1, r1i1p1f1, r1i1p1f1
		zg	ssp126, ssp585	r1i1p1f1, r1i1p1f1
GFDL-CM4	250Km	zg	ssp585	r1i1p1f1
HadGEM3-GC31-LL	250Km	ua	ssp126, ssp585	r1i1p1f3, r1i1p1f3
		zg	ssp126, ssp585	r1i1p1f3, r1i1p1f3
INM-CM4-8	100Km	slp	hist	r1i1p1f1
		ua	hist, ssp126, ssp585	r1i1p1f1, r1i1p1f1, r1i1p1f1
		zg	hist, ssp126, ssp585	r1i1p1f1, r1i1p1f1, r1i1p1f1
INM-CM5-0	100Km	slp	hist	r1i1p1f1
		ua	hist, ssp126, ssp585	r1i1p1f1, r1i1p1f1, r1i1p1f1
		zg	hist, ssp126, ssp585	r1i1p1f1, r1i1p1f1, r1i1p1f1
IPSL-CM6A-LR	250Km	slp	hist	r1i1p1f1
		ua	hist, ssp126, ssp585	r1i1p1f1, r1i1p1f1, r1i1p1f1
		zg	hist, ssp126, ssp585	r1i1p1f1, r1i1p1f1, r1i1p1f1
MIROC6	250Km	slp	hist	r1i1p1f1
		ua	hist, ssp126, ssp585	r1i1p1f1, r1i1p1f1, r1i1p1f1
		zg	hist, ssp126, ssp585	r1i1p1f1, r1i1p1f1, r1i1p1f1
MPI-ESM1-2-HR	100Km	slp	hist	r1i1p1f1
		ua	hist, ssp126, ssp585	r1i1p1f1, r1i1p1f1, r1i1p1f1
		zg	hist, ssp126, ssp585	r1i1p1f1, r1i1p1f1, r1i1p1f1
MPI-ESM1-2-LR	250Km	slp	hist	r1i1p1f1
		ua	hist, ssp126, ssp585	r1i1p1f1, r1i1p1f1, r1i1p1f1
		zg	hist, ssp126, ssp585	r1i1p1f1, r1i1p1f1, r1i1p1f1
MRI-ESM2-0	100Km	slp	hist	r1i1p1f1
		ua	hist, ssp126, ssp585	r1i1p1f1, r1i1p1f1, r1i1p1f1
		zg	hist, ssp126, ssp585	r1i1p1f1, r1i1p1f1, r1i1p1f1
NorESM2-LM	250Km	slp	hist	r1i1p1f1
		ua	hist, ssp126, ssp585	r1i1p1f1, r1i1p1f1, r1i1p1f1

		zg	hist, ssp126, ssp585	r1i1p1f1, r1i1p1f1, r1i1p1f1
NorESM2-MM	100Km	ua	ssp126	r1i1p1f1
		zg	ssp126, ssp585	r1i1p1f1, r1i1p1f1
UKESM1-0-LL	250Km	ua	ssp126, ssp585	r1i1p1f2, r1i1p1f2
		zg	ssp126, ssp585	r1i1p1f2, r1i1p1f2

Table S1. List of CMIP6 models, variables, runs and ensemble members used in the analyses. Data have been downloaded from World Climate Research Programme (WCRP, https://www.wcrp-climate.org/).

CMIP6 Model	Variable	Region	Time-period
ACCESS-CM2	zg	MID-LAT	Historical
ACCESS-CM2	zg	TIB	Historical
ACCESS-CM2	zg	MID-LAT	SSP126
CNRM-CM6-1-HR	zg	MID-LAT	SSP126
HadGEM3-GC31-LL	zg	MID-LAT	SSP126
UKESM1-0-LL	zg	MID-LAT	SSP126
ACCESS-CM2	zg	TIB	SSP126
CNRM-CM6-1-HR	zg	TIB	SSP126
HadGEM3-GC31-LL	zg	TIB	SSP126
UKESM1-0-LL	zg	TIB	SSP126
CNRM-CM6-1-HR	zg	MID-LAT	SSP585
CNRM-CM6-1-HR	zg	TIB	SSP585

Table S2. Datasets excluded from the analyses because missing values (NAs) present in the original CMIP6 data.

Region	Data	Sen's slope	p-value
ALA	ERA5	0.00117	0.45173
	Historical	0.00388	0
CAS	ERA5	0.00237	0.05767
	Historical	0.00336	0
CEU	ERA5	0.00373	0.00044
	Historical	0.0039	0
CGI	ERA5	0.00899	0.00127
	Historical	0.00524	0
CNA	ERA5	0.00027	0.77886
	Historical	0.00577	0
EAS	ERA5	0.00278	0.09422
	Historical	0.00629	0
ENA	ERA5	0.00125	0.11326
	Historical	0.00398	0
MED	ERA5	0.0028	0.00363
	Historical	0.00405	0
MID-LAT	ERA5	0.00653	2,00E-05
	Historical	0.0089	0
NA	ERA5	0.0054	0.00014
	Historical	0.00339	0
NAS	ERA5	0.00482	0.00389
	Historical	0.00684	0
NEU	ERA5	0.00319	0.04205
	Historical	0.00284	0.00001
NP	ERA5	0.00311	0.06384
	Historical	0.0056	0
TIB	ERA5	0.00425	0.00018
	Historical	0.00501	0
WAS	ERA5	0.0021	0.02007
	Historical	0.00331	0
WNA	ERA5	0.00018	0.83101
	Historical	0.00533	0

Table S3. Sen's slopes and p-values of local persistence Mann-Kendall trend tests for ERA5 (1979-2019) and CMIP6 multi-model mean (MMM) Historical runs (1979-2014). The Table refers to Figure 3.

Region	Data	Sen's slope	p-value
ALA	ERA5	0.00286	0.41226
	Historical	0.00821	0.00001
CAS	ERA5	0.0049	0.00679
	Historical	0.00716	0
CEU	ERA5	0.00535	0.00887
	Historical	0.00867	0
CGI	ERA5	0.01767	0.01078
	Historical	0.00941	0
CNA	ERA5	0.00158	0.56676
	Historical	0.01092	0
EAS	ERA5	0.00158	0.64515
	Historical	0.00834	0.00003
ENA	ERA5	0.00174	0.29622
	Historical	0.00589	0
MED	ERA5	0.00532	0.00148
	Historical	0.00733	0
MID-LAT	ERA5	0.01265	0.00007
	Historical	0.0142	0
NA	ERA5	0.00966	0.00314
	Historical	0.00472	0.00077
NAS	ERA5	0.00944	0.03018
	Historical	0.01109	0
NEU	ERA5	0.00838	0.02397
	Historical	0.0055	0.00016
NP	ERA5	0.00203	0.45173
	Historical	0.0065	0
TIB	ERA5	0.00752	0.00777
	Historical	0.01054	0
WAS	ERA5	0.00375	0.26615
	Historical	0.00578	0.00013
WNA	ERA5	-0.00224	0.50753
	Historical	0.00939	0

Table S4. As Table S2 but it refers to Figure S2.

Region	Data	Sen's slope	p-value
ALA	ERA5	-0.00012	0.45173
	Historical	0.00003	0.75407
CAS	ERA5	0.00077	0.3749
	Historical	0.00008	0.81688
CEU	ERA5	0.00058	0.14736
	Historical	0.00055	0.00016
CGI	ERA5	0.00226	0.00217
	Historical	0.00002	0.9457
CNA	ERA5	0.00001	0.93733
	Historical	0.00034	0.00034
EAS	ERA5	-0.00012	0.83101
	Historical	0.00047	0.16063
ENA	ERA5	0.00011	0.53674
	Historical	0.00028	0.00523
MED	ERA5	0.00141	0.00217
	Historical	0.00144	0
MID-LAT	ERA5	0.00115	0.0213
	Historical	0.00131	0.00007
NA	ERA5	0.00159	0.01011
	Historical	-0.00016	0.39083
NAS	ERA5	-0.00097	0.07412
	Historical	0.00063	0.00928
NEU	ERA5	0.00052	0.29622
	Historical	-0.00036	0.03971
NP	ERA5	0.00007	0.90167
	Historical	0.00108	0.00523
TIB	ERA5	0.00052	0.45173
	Historical	0.00194	0.00001
WAS	ERA5	0.00147	0.08169
	Historical	0.00097	0.00312
WNA	ERA5	0.00028	0.07412
	Historical	0.00032	0.01985

Table S5. As Table S2 but it refers to Figure S4.

Data	Sen's slope	p-value	Region
ERA5	0.00083	0.86621	ALA
Historical	-0.00493	0.00022	ALA
ERA5	-0.00351	0.16712	CAS
Historical	-0.00529	0	CAS
ERA5	-0.00806	0.00056	CEU
Historical	-0.00609	1,00E-05	CEU
ERA5	-0.0124	0.03018	CGI
Historical	-0.00744	0	CGI
ERA5	2,00E-04	0.91948	CNA
Historical	-0.0067	0	CNA
ERA5	-0.00375	0.24732	EAS
Historical	-0.01339	0	EAS
ERA5	-0.00204	0.42518	ENA
Historical	-0.005	1,00E-05	ENA
ERA5	-0.00788	0.01225	MED
Historical	-0.0069	0	MED
ERA5	-0.02798	2,00E-05	MID-LAT
Historical	-0.02501	0	MID-LAT
ERA5	-0.00475	0.18135	NA
Historical	-0.00625	0	NA
ERA5	-0.01308	0.00727	NAS
Historical	-0.01034	1,00E-05	NAS
ERA5	-0.00142	0.58207	NEU
Historical	-0.00401	0.00063	NEU
ERA5	-0.00722	0.04681	NP
Historical	-0.00793	0	NP
ERA5	-0.00929	4,00E-05	TIB
Historical	-0.00996	0	TIB
ERA5	-0.00557	0.04438	WAS
Historical	-0.00754	0	WAS
ERA5	-0.00612	0.01306	WNA
Historical	-0.00814	0	WNA

Table S6. As Table S2 but it refers to Figure S5.

Region	SSP	p-value	MMM $\delta\theta_{-1}$
ALA	SSP126	0.19462	0.0564
ALA	SSP585	0.08034	0.074
CAS	SSP126	0.21814	0.0283
CAS	SSP585	0.07424	0.0643
CEU	SSP126	0.34134	0.0336
CEU	SSP585	0.14272	0.0833
CGI	SSP126	0.14272	0.0711
CGI	SSP585	0.01045	0.1614
CNA	SSP126	0.07424	0.0556
CNA	SSP585	0.0002	0.1705
EAS	SSP126	0.12478	0.0794
EAS	SSP585	0.0064	0.2111
ENA	SSP126	0.08034	0.0423
ENA	SSP585	0.00285	0.0871
MED	SSP126	0.38742	0.0162
MED	SSP585	0.19462	0.0314
MID-LAT	SSP126	0.03102	0.1182
MID-LAT	SSP585	0.00288	0.2399
NA	SSP126	0.32644	0.0309
NA	SSP585	0.4351	0.0587
NAS	SSP126	0.11641	0.079
NAS	SSP585	0.00158	0.2163
NEU	SSP126	0.21814	0.0314
NEU	SSP585	0.16227	0.0675
NP	SSP126	0.26965	0.0404
NP	SSP585	0.03064	0.1298
TIB	SSP126	0.15321	0.0639
TIB	SSP585	0.03833	0.1231
WAS	SSP126	0.21814	0.0448
WAS	SSP585	0.01836	0.1235
WNA	SSP126	0.08034	0.0725
WNA	SSP585	0.00158	0.1706

Table S7. Local persistence change ($\delta\theta_{-1}$) and p-values of CMIP6 MMM SSP126 and SSP585 (2081-2100) compared with Historical (1981-2000). Statistical significance was assessed with a Mann-Whitney test (one-tailed) under the null hypothesis that the SSPs persistence values are greater than the Historical's. The Table refers to Figure 4.