

Supplementary information of:
Detection and attribution of trends of meteorological extremes in Central America
Climatic Change

By:

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Section 1. Tables of the models used in the study and on the definition of extreme indices of precipitation and temperature calculated from daily precipitation, maximum and minimum data.

Table S1. CMIP6 General Circulation Models (CGMs) used in this analysis.

ID	Model	Climate Center	Run	Native resolution
1	GFDL-ESM4	Geophysical Fluid Dynamics Laboratory (GFDL)	r1i1p1f1	lonlat (288x180)
2	IPSL-CM6A-LR	Institut Pierre-Simon Laplace (IPSL)	r1i1p1f1	lonlat (144x143)
3	MPI-ESM1-2-HR	Max Planck Institute for Meteorology (MPI-M)	r1i1p1f1	gaussian (384x192)
4	MRI-ESM2-0	Meteorological Research Institute (MRI)	r1i1p1f1	gaussian (320x160)
5	UKESM1-0-LL	UK Earth System Modelling	r1i1p1f2	lonlat (192x144)
6	CanESM5	Canadian Centre for Climate Modelling and Analysis (CCCMA)	r1i1p1f1	gaussian (128x64)
7	CNRM-CM6-1	Centre National de Recherches Meteorologiques / Centre 3 Europeen de Recherche et Formation Avancees en Calcul Scientifique (CNRM)	r1i1p1f2	gaussian (256x128)
8	CNRM-ESM2-1	CNRM	r1i1p1f2	gaussian (256x128)
9	EC-Earth3	EC-EARTH consortium	r1i1p1f1	gaussian (512x256)

10	MIROC6	Atmosphere and Ocean Research Institute (The University of 3 Tokyo), National Institute for Environmental Studies, and Japan Agency for Marine-Earth Science and Technology. (MIROC)	r1i1p1f1	gaussian (256x128)
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Table S2. List of precipitation indices from CLIMDEX. RR=rainfall rate.

ID	Name	Indicator name	Definition	Units
1	RX1day	max 1-day precipitation amount	annual maximum 1-day precipitation	mm
2	RX5day	max 5-day precipitation amount	annual maximum 5-day precipitation	mm
3	SDII	simple daily intensity index	annual total precipitation divided by the number of wet days in the year	mm/day
4	R10mm	number of heavy precipitation days	annual count of days when precipitation \geq 10mm	days
5	R20mm	number of very heavy precipitation days	annual count of days when precipitation \geq 20mm	days
6	CDD	consecutive dry days & maximum number of consecutive days with daily rainfall	maximum number of consecutive days with daily rainfall < 1mm	days
7	CWD	consecutive wet days	maximum number of consecutive days with daily rainfall \geq 1mm	days
8	R95p	very wet days	annual total PRCP when RR > 95th percentile	mm
9	R99p	extremely wet days	annual total PRCP when RR > 99th percentile	mm

10	PRCPTOT	annual total wet-day precipitation	annual total PRCP in wet days (RR \geq 1mm)	mm
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Table S3. List of temperature indices from CLIMDEX.

ID	Name	Indicator name	Definition	Units
1	TXx	max Tmax	annual maximum value of daily maximum temperature	°C
2	TNx	max Tmin	annual maximum value of daily minimum temp	°C
3	TXn	min Tmax	annual minimum value of daily maximum temperature	°C
4	TNn	min Tmin	annual minimum value of daily minimum temp	°C
5	TN10p	cool nights	percentage of days when TN < 10th percentile	% days
6	TN90p	warm nights	percentage of days when TN > 90th percentile	% days
7	TX10p	cool days	percentage of days when TX < 10th percentile	% days
8	TX90p	warm days	percentage of days when TX > 90th percentile	% days
9	WSDI	warm spell duration indicator	annual count of days with at least 6 consecutive days when TX > 90th percentile	% days
10	CSDI	cold spell duration indicator	annual count of days with at least 6 consecutive days when TN < 10th percentile	% days
11	DTR	diurnal temperature range	annual mean difference between TX and TN	°C

Section 2. Examples of the effect on the December-January-February (DJF) precipitation noise traces by fitting equation 3 with different types of Atlantic/Caribbean predictors.

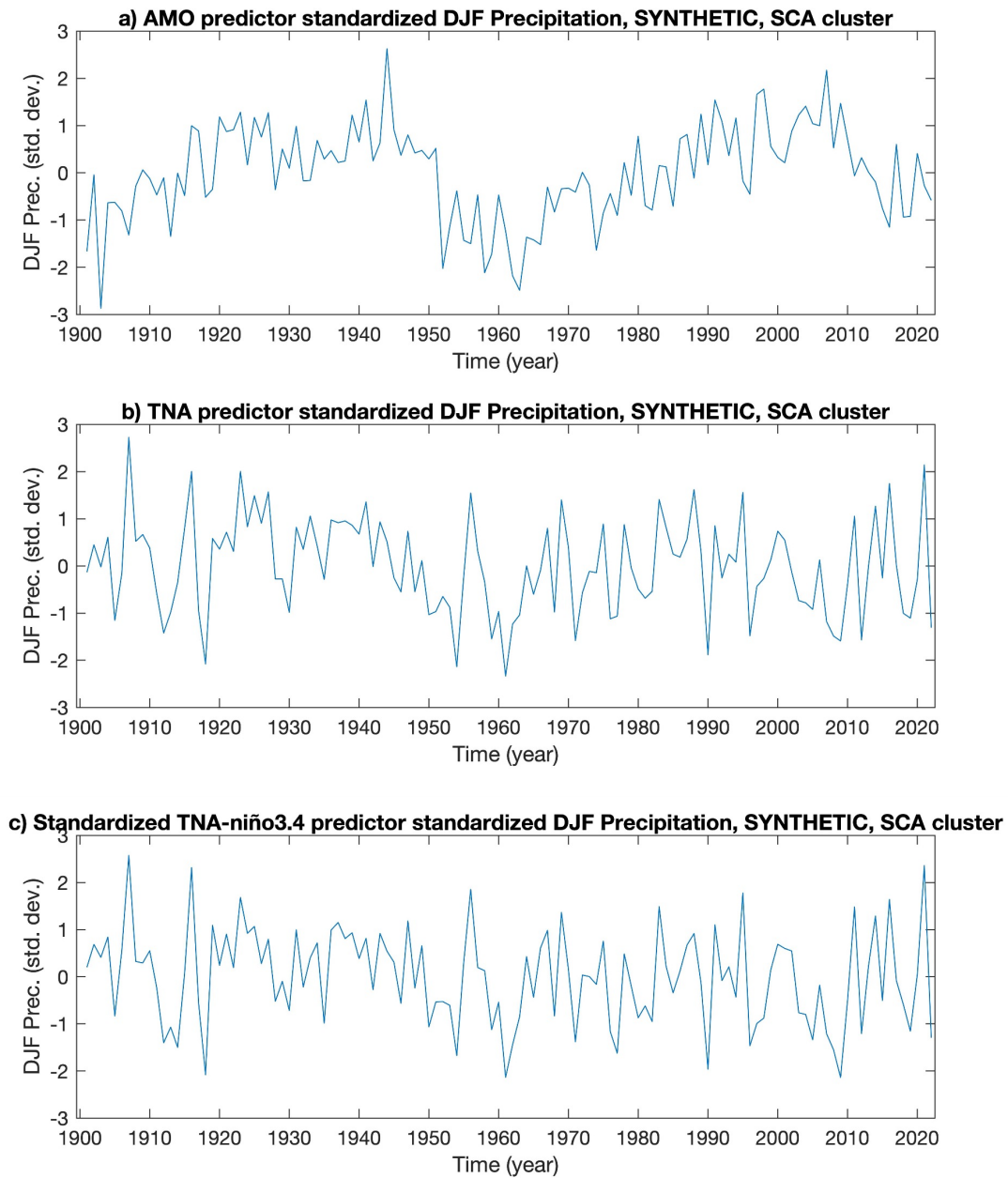


Figure S1. Standardized December-January-February precipitation (PDJF) example traces for three versions of fitting Eq. 3 using Atlantic Multidecadal Oscillation (AMO) (top), Tropical North Atlantic (TNA index) (middle) and a composite index of the difference between standardized versions of the TNA minus niño3.4 datasets. For each of these ways to fit the Eq. 3, 1000 traces of the noise were generated synthetically. Time series shown for the SCP cluster.

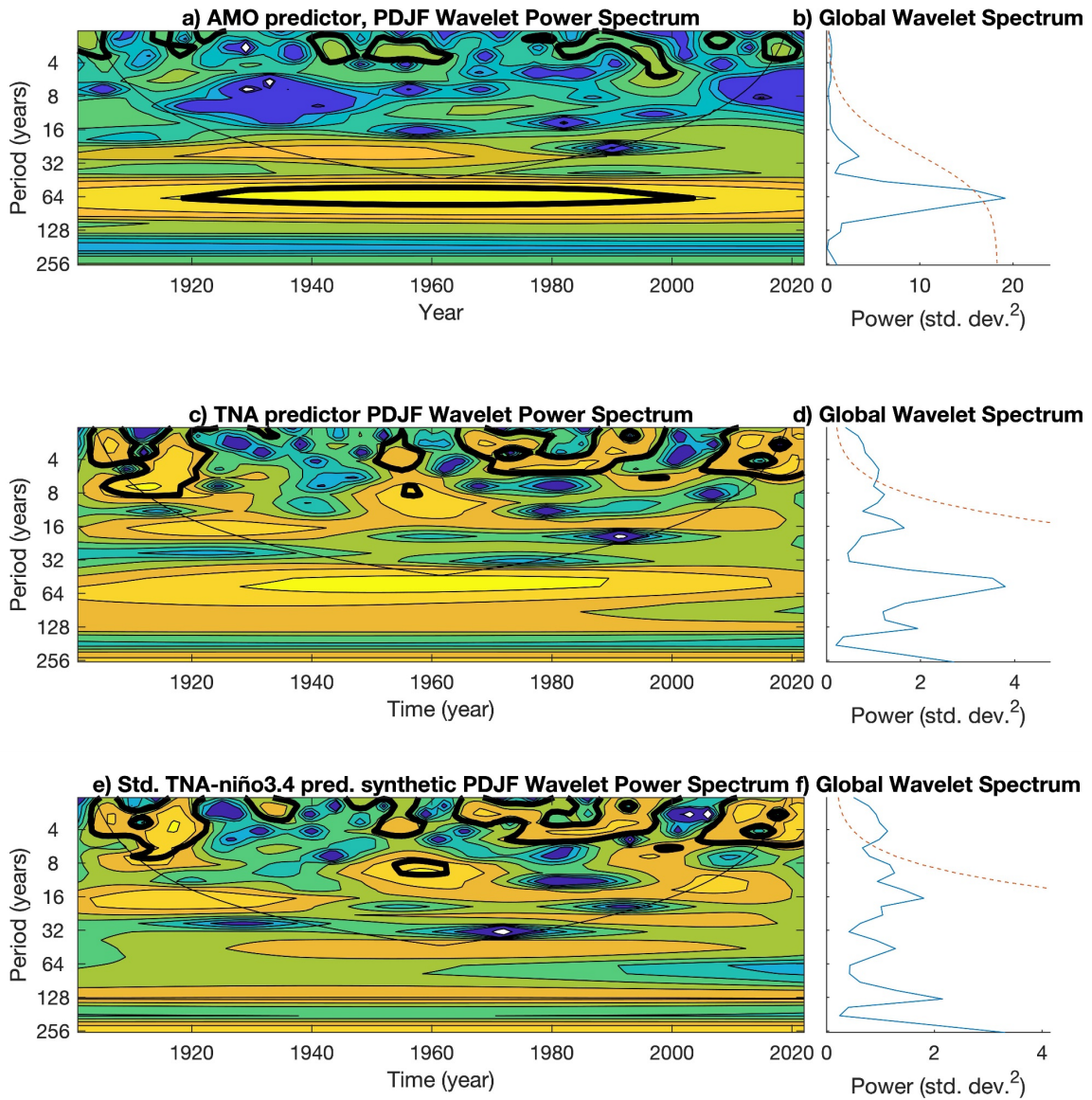


Figure S2. Same as Fig. S1, but for the wavelet power spectrum according to Torrence and Compo (1998). The mother wavelet is Morlet, $dt=1$, $pad=1$, $dj=0.25$, $s0=2*dt$, $j1=7/dj$, $lag1=0.72$. The dark thick lines represent places in the spectrum that are significantly above the red-noise background. The cone of influence below plots (a), (c), and (e) represents frequencies of signals that are by the boundaries of the plot and should be interpreted with caution. The plots on the right represent the global spectrum as an integration of the data for all the times.

Section 3. Precipitation and temperature climatologies of the clusters of Fig. 1.

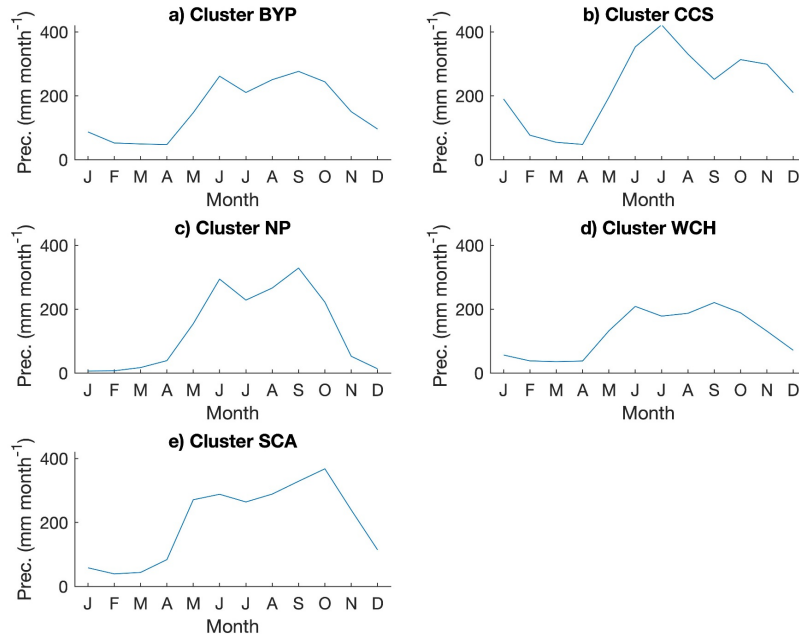


Figure S3. Seasonal cycles of precipitation for the clusters defined in Fig.1.

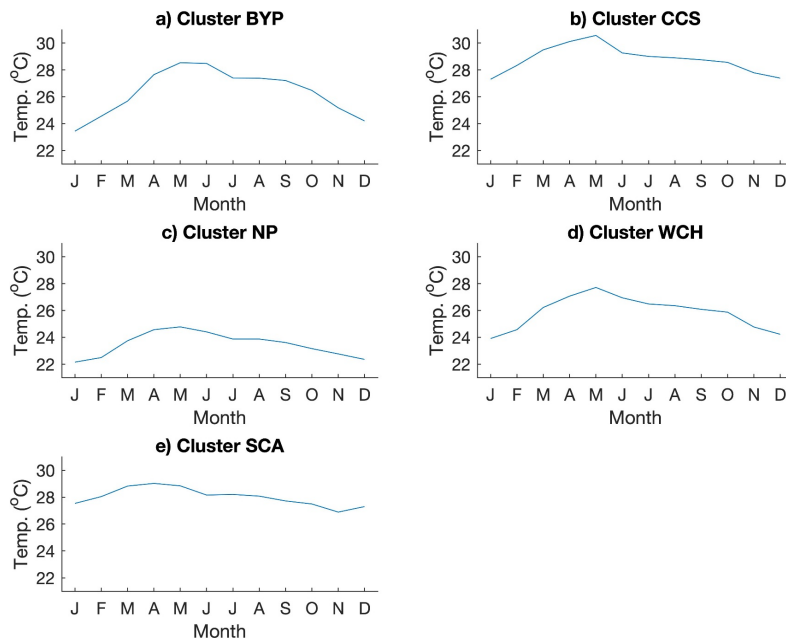


Figure S4. Seasonal cycles of temperature for the clusters defined in Fig.1.

Cluster BYP is similar to WCH in terms of the relative seasonal cycle of precipitation distribution throughout the year, but BYP has more absolute monthly accumulations during the wet season. BYP is a region where

multiple tropical cyclones from the Caribbean make landfall (more than in WCH) and that may explain a difference in the distribution of extreme precipitation that ultimately is reflected in monthly accumulations. CCS has the wettest month and a remarkable distribution that stands out from the rest (clearly a Caribbean slope type of distribution). NP is the only one with a clear dry season (although other regions may have dry seasons but are averaged with other regions that present significant rainfall from December to March). SCA has an earlier start of the rainy season of all distributions.

Temperature-wise, BYP, CCS and SCA showed the highest temperatures, WCH is moderate and NP is the coldest region. The combination of very hot-wet versus moderate temp-rain may also explain the difference between cluster BYP and WCH.

Section 4. Table of statistics related to the fit of equation 3.

Table S4. Fitting parameters for Eq. 3. See definitions of the variables in tables S2 and S3 and definition of the clusters in Fig. 1.

Variable	Cluster	β_0 (<i>inter.</i>)	β_1 (<i>Niño3.4</i>)	β_2 (<i>CLLJ</i>)	β_3 (<i>PDO_{perp}</i>)	β_4 (<i>F_y</i>)	r ²
RX1day	SCA	-1.36	0.69	-0.03	-0.03	2.75	0.51
	BYP	-1.11	0.55	-0.15	-0.15	2.52	0.38
	NP	-0.65	0.23	0.15	0.15	1.14	0.22
	WCH	-0.78	-0.07	0.31	0.31	1.49	0.17
	CCS	1.25	-0.32	-0.50	-0.50	-2.35	0.62
RX5day	SCA	-0.12	0.69	0.48	0.48	0.02	0.50
	BYP	0.80	-0.36	-0.19	-0.19	-1.44	0.32
	NP	-0.83	0.10	-0.07	-0.07	1.69	0.11
	WCH	0.85	-0.01	-0.74	-0.74	-1.55	0.47
	CCS	-1.86	0.52	0.29	0.29	3.78	0.81
SDII	SCA	-1.15	0.36	0.45	0.45	2.25	0.50
	BYP	-2.09	0.36	-0.14	-0.14	4.32	0.67
	NP	1.25	-0.76	0.18	0.18	-2.58	0.45
	WCH	-1.32	0.50	0.35	0.35	2.72	0.58
	CCS	1.29	-0.50	-0.18	-0.18	-2.53	0.48
R10mm	SCA	1.07	-0.79	-0.22	-0.22	-2.04	0.64
	BYP	-0.63	-0.08	-0.12	-0.12	1.29	0.07
	NP	-1.82	0.66	-0.41	-0.41	3.88	0.59
	WCH	0.59	-0.40	-0.47	-0.47	-0.95	0.43

	CCS	-1.73	0.70	-0.43	-0.43	3.75	0.56
R20mm	SCA	-1.36	0.66	0.27	0.27	2.76	0.65
	BYP	0.75	-0.37	-0.19	-0.19	-1.34	0.30
	NP	1.37	-0.62	-0.16	-0.16	-2.62	0.65
	WCH	-1.73	0.55	-0.17	-0.17	3.61	0.53
	CCS	-1.41	0.10	-0.17	-0.17	3.08	0.27
CDD	SCA	0.53	-0.75	-0.58	-0.58	-0.84	0.73
	BYP	-1.19	0.18	-0.36	-0.36	2.34	0.40
	NP	-2.11	0.59	-0.05	-0.05	4.33	0.81
	WCH	-0.73	0.03	-0.06	-0.06	1.47	0.09
	CCS	1.24	-0.51	-0.17	-0.17	-2.44	0.46
CWD	SCA	-1.05	0.90	0.26	0.26	2.10	0.73
	BYP	-0.64	0.65	-0.55	-0.55	1.60	0.29
	NP	-1.55	-0.04	-0.17	-0.17	3.31	0.30
	WCH	0.54	-0.41	-0.47	-0.47	-0.86	0.41
	CCS	0.95	0.10	-0.91	-0.91	-1.63	0.69
R95p	SCA	-1.56	-0.02	-0.03	-0.03	3.36	0.32
	BYP	-1.67	0.52	-0.19	-0.19	3.45	0.50
	NP	1.33	-0.63	-0.16	-0.16	-2.55	0.64
	WCH	0.21	0.53	-0.63	-0.63	-0.41	0.21
	CCS	-1.07	0.47	-0.49	-0.49	2.37	0.24
R99p	SCA	0.50	-0.75	-0.57	-0.57	-0.78	0.71

	BYP	-0.43	0.78	0.20	0.20	0.63	0.49
	NP	-0.71	0.01	0.28	0.28	1.24	0.25
	WCH	-1.18	0.20	0.00	0.00	2.54	0.22
	CCS	-0.99	0.67	-0.31	-0.31	2.16	0.29
PRCPTOT	SCA	1.21	0.45	0.53	0.53	-2.69	0.43
	BYP	-1.07	0.24	0.43	0.43	2.06	0.40
	NP	-0.79	0.86	-0.11	-0.11	1.67	0.40
	WCH	-1.07	0.68	-0.53	-0.53	2.38	0.32
	CCS	-0.51	0.43	0.05	0.05	0.82	0.29
TXx	SCA	-0.52	-0.30	-0.95	-0.95	1.34	0.62
	BYP	-0.82	0.05	0.51	0.51	1.40	0.42
	NP	-0.72	-0.73	-0.57	-0.57	1.68	0.58
	WCH	0.14	0.00	-0.22	-0.22	-0.19	0.04
	CCS	-0.52	-0.25	0.09	0.09	1.03	0.06
TNx	SCA	-0.46	-0.12	0.52	0.52	0.77	0.19
	BYP	-1.32	-0.33	0.05	0.05	2.66	0.29
	NP	-0.59	-0.66	-0.68	-0.68	1.42	0.62
	WCH	0.18	-0.23	-0.85	-0.85	-0.16	0.53
	CCS	-0.16	-0.21	-0.22	-0.22	0.45	0.07
TXn	SCA	0.69	-0.18	-0.16	-0.16	-1.33	0.13
	BYP	-0.96	-0.28	0.03	0.03	1.95	0.16
	NP	-0.15	0.02	0.02	0.02	0.26	0.01

	WCH	0.11	-0.10	-0.74	-0.74	-0.07	0.34
	CCS	1.16	-0.03	-0.53	-0.53	-2.19	0.44
TNn	SCA	-0.56	-0.17	-0.94	-0.94	1.40	0.54
	BYP	-0.14	-0.52	-0.26	-0.26	0.42	0.21
	NP	0.20	-0.62	-0.59	-0.59	-0.17	0.55
	WCH	-0.23	-0.12	0.61	0.61	0.23	0.22
	CCS	0.96	-0.01	-0.49	-0.49	-1.78	0.36
TN10p	SCA	-0.54	-0.10	-0.89	-0.89	1.33	0.46
	BYP	-0.44	-0.49	-0.28	-0.28	1.04	0.21
	NP	-0.64	-0.38	-0.76	-0.76	1.52	0.50
	WCH	-0.09	0.12	-0.72	-0.72	0.41	0.24
	CCS	-0.16	0.50	-0.36	-0.36	0.40	0.09
TN90p	SCA	-0.57	-0.23	-1.06	-1.06	1.48	0.70
	BYP	-0.27	0.11	-0.11	-0.11	0.41	0.11
	NP	-0.68	-0.21	-0.78	-0.78	1.63	0.42
	WCH	-0.21	-0.04	-0.67	-0.67	0.58	0.25
	CCS	1.38	0.59	-0.41	-0.41	-2.75	0.40
TX10p	SCA	-1.39	0.06	-0.44	-0.44	3.07	0.29
	BYP	0.16	-0.68	-0.25	-0.25	-0.10	0.37
	NP	-0.77	-0.64	-0.69	-0.69	1.82	0.62
	WCH	-0.25	-0.06	-0.41	-0.41	0.50	0.15
	CCS	0.17	-0.24	-0.13	-0.13	-0.28	0.06

TX90p	SCA	-0.56	0.36	-0.66	-0.66	1.44	0.23
	BYP	-0.64	-0.44	0.06	0.06	1.28	0.12
	NP	-0.96	-0.11	-0.82	-0.82	2.22	0.44
	WCH	-0.19	-0.25	-0.83	-0.83	0.58	0.48
	CCS	-0.25	-0.45	0.05	0.05	0.46	0.10
WSDI	SCA	-0.38	0.31	0.09	0.09	0.63	0.14
	BYP	-0.85	-0.20	0.14	0.14	1.61	0.19
	NP	-1.04	-0.12	-0.76	-0.76	2.32	0.42
	WCH	-0.54	-0.07	-0.68	-0.68	1.29	0.27
	CCS	0.61	-0.19	-0.41	-0.41	-1.11	0.24
CSDI	SCA	-0.54	-0.01	-0.18	-0.18	1.12	0.05
	BYP	-0.54	-0.59	-0.10	-0.10	1.17	0.19
	NP	-0.50	-0.30	-0.75	-0.75	1.24	0.43
	WCH	-0.78	0.01	-0.87	-0.87	1.87	0.41
	CCS	-0.90	0.09	-0.11	-0.11	1.82	0.14
DTR	SCA	0.00	0.11	-0.44	-0.44	-0.01	0.12
	BYP	-0.63	-0.34	0.14	0.14	1.17	0.15
	NP	-0.26	-0.28	-1.04	-1.04	0.88	0.73
	WCH	-0.38	-0.59	-0.65	-0.65	0.90	0.55
	CCS	-0.66	0.20	-0.42	-0.42	1.28	0.24
P	SCA	-0.05	0.04	-0.07	-0.07	-0.08	0.12
	BYP	-0.19	0.17	0.35	0.35	0.37	0.14

	NP	0.43	-0.14	0.15	0.15	-0.88	0.04
	WCH	-0.09	-0.11	0.17	0.17	0.06	0.04
	CCS	0.95	-0.22	0.08	0.08	-1.93	0.16
T	SCA	-1.21	0.75	0.38	0.38	2.34	0.76
	BYP	-1.39	0.56	0.20	0.20	2.75	0.57
	NP	-1.79	0.70	-0.01	-0.01	3.65	0.72
	WCH	-1.41	0.43	0.38	0.38	2.79	0.60
	CCS	-1.82	0.44	0.32	0.32	3.59	0.80
PET	SCA	-1.30	0.74	0.36	0.36	2.55	0.77
	BYP	-1.61	0.56	0.07	0.07	3.26	0.60
	NP	-1.86	0.69	-0.12	-0.12	3.85	0.69
	WCH	-1.51	0.48	0.18	0.18	3.07	0.53
	CCS	-1.95	0.44	0.21	0.21	3.91	0.79
ϕ	SCA	0.48	-0.32	-0.24	-0.24	-1.11	0.26
	BYP	0.27	0.00	0.34	0.34	-0.58	0.08
	NP	0.92	-0.27	0.24	0.24	-1.96	0.14
	WCH	0.34	-0.21	0.10	0.10	-0.82	0.06
	CCS	1.48	-0.34	-0.04	-0.04	-2.98	0.43
PDJF	SCA	-0.24	0.06	0.15	0.15	0.17	0.04
	BYP	0.39	0.10	-0.13	-0.13	-0.48	0.08
	NP	0.41	0.24	0.15	0.15	-1.05	0.11
	WCH	0.18	0.00	0.07	0.07	-0.49	0.01

	CCS	0.27	0.21	0.29	0.29	-1.05	0.08
PMAM	SCA	1.51	0.18	-0.18	-0.18	1.98	0.11
	BYP	-1.99	0.34	-0.16	-0.16	2.12	0.27
	NP	1.00	0.64	0.15	0.15	0.15	0.14
	WCH	-0.40	0.45	0.07	0.07	0.97	0.14
	CCS	1.76	0.56	0.07	0.07	0.01	0.07
PJJA	SCA	0.29	0.30	-0.17	-0.17	-1.21	0.16
	BYP	-0.89	0.03	0.13	0.13	-0.25	0.04
	NP	-0.57	-0.01	0.00	0.00	-1.96	0.13
	WCH	-0.44	-0.12	0.00	0.00	-0.91	0.09
	CCS	0.05	-0.08	-0.07	-0.07	-2.75	0.29
PSON	SCA	0.96	-0.32	0.16	0.16	0.49	0.15
	BYP	-0.20	0.10	-0.01	-0.01	0.97	0.04
	NP	0.18	-0.34	0.05	0.05	1.13	0.13
	WCH	0.78	-0.38	0.29	0.29	0.85	0.14
	CCS	0.36	-0.33	-0.02	-0.02	0.41	0.13

Section 5. Detection and attribution analysis for selected clusters in Central America.

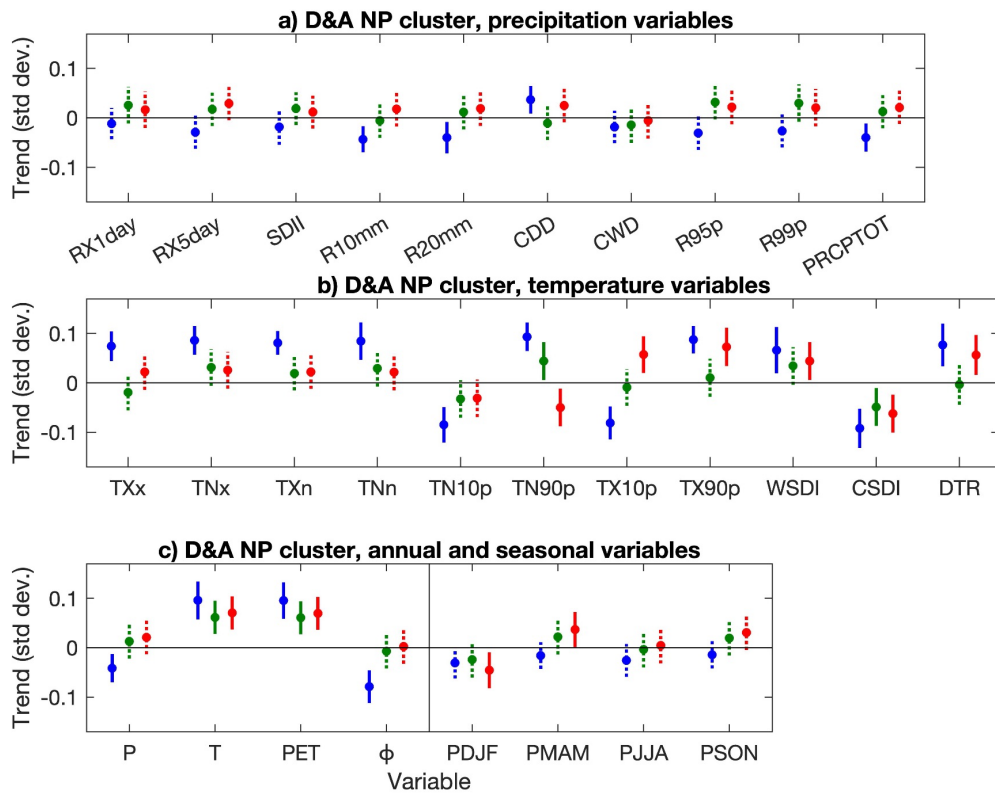


Fig S5 Results of detection and attribution analysis for the North Pacific cluster (NP; see Fig. 1). The analysis was performed for precipitation (top panel) and temperature (middle panel) CLIMDEX extreme indices (definitions in tables S2 and S3 in the Supplementary Information). Also shown in the bottom panel are the analysis for the annual averages of precipitation (P), 2-m temperature (T), potential evapotranspiration (PET) and the ϕ aridity index (defined as P/PET). The four rightmost variables in the bottom panel display the trends of the boreal seasonal precipitation averages. Blue dots represent trends in each standardized variables from a historical run involving an ensemble of 10 models, while the blue confidence intervals are constructed based on the ensemble noise derived from the respective preindustrial control runs. Green dots represent trends based on W5E5 data, with their confidence intervals computed using the synthetic generation described by McKinnon and Deser (2021). Red dots represent trends from the CHIRPs and CHIRTs “observations” (Funk et al. 2015), with the noise levels matching the green methodology. Trends that can (cannot) be detected from the natural variability noise are shown with solid (dotted) lines, according to the different methods applied. The trends correspond to the period 1983-2016 for the blue and red analysis, and from 1979 to 2019 for the green analysis

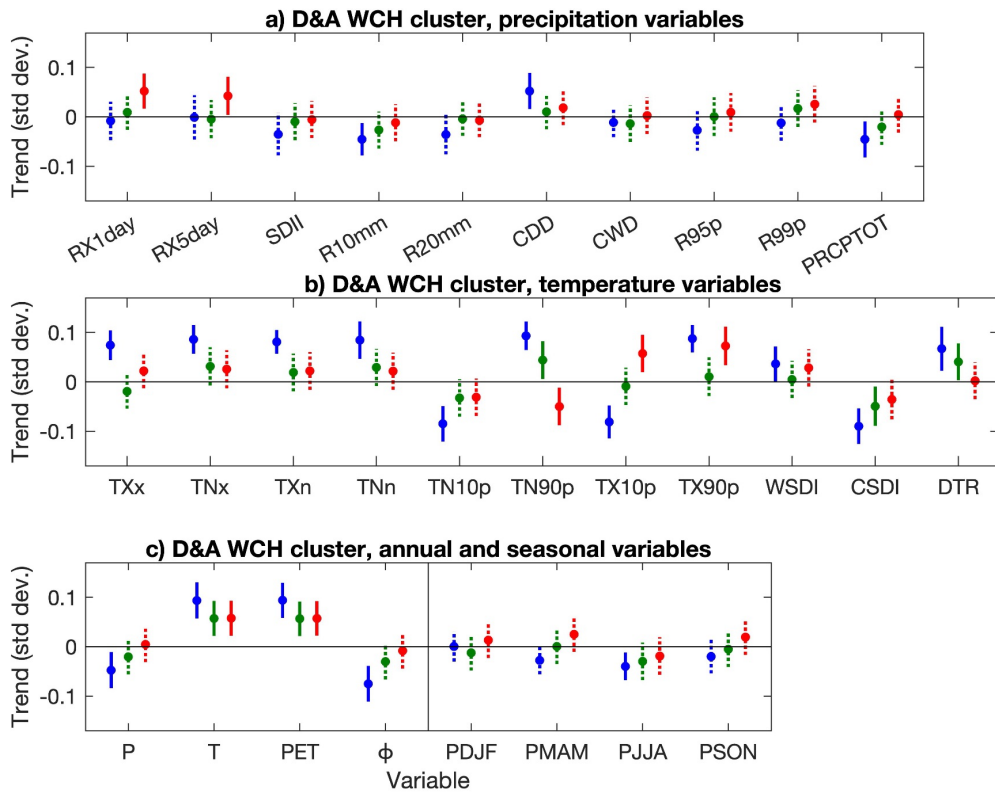


Fig. S6 Same as in Fig. S5 but for the WCH cluster.