
Supplementary information

Observation-constrained projections reveal longer-than-expected dry spells

In the format provided by the
authors and unedited

Supplementary Table

Supplementary Data Table 1 | Observational precipitation data sets. Seven precipitation data sets selected for the analysis from FROGS database ⁵⁶ after the validation procedure and their main characteristics. The data sets are sorted from “*wetter*” (top) to “*drier*” (bottom) based on the magnitude of their climatological global (50°S–50°N) mean LAD value. All FROGS datasets are available at 1x1 degree resolution. For native resolution and details a reader is referred to the original datasets’ references ^{59,60,76–82}.

Supplementary Data Table 2 | CMIP5 climate models. CMIP5 models ⁶³ participating in this study and their attributes. The models are distinguished as “*wet*” and “*dry*” based on the magnitude of their climatological global (50°S–50°N) mean LAD value (see Methods). Horizontal resolution at the equator is estimated based on the longitude resolution of the corresponding atmospheric model.

Supplementary Data Table 3 | CMIP6 climate models. CMIP6 models ⁶² participating in this study and their attributes. The models are distinguished as “*wet*” and “*dry*” based on the magnitude of their climatological global (50°S–50°N) mean LAD value (see Methods). Horizontal resolution at the equator is estimated based on the longitude resolution of the corresponding atmospheric model.

Supplementary Data Table 4 | CMIP6 hydroclimatic variables. Sixteen CMIP6 climate model variables downloaded from Google cloud storage ⁷⁰ and Pangeo platform ⁷¹, and used for the analysis at monthly scale.

Supplementary Data Table 5 | Significance of the differences in future changes in hydroclimatic variables. Significance is defined by p-value of AD test and is assessed between locally defined “*dry*” and “*wet*” models. P-values ≤ 0.01 are underlined. Invalid or missing data point is indicated as ‘*nan*’.

Supplementary Information References

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Supplementary Data Table 1.

Name	Source reference	Time-period	Resolution (lat x lon)	type
GPCP 1DD CDR v1.3	Huffman et al. 2001 ⁷⁶	1997–2017	1x1 degree	satellite, gauge
Merged TRMM3B42– CMORPH v1.0	Huffman et al. 2007 ⁵⁹ ; Xie et al. 2017 ⁶⁰	1998–2018		satellite, gauge
PERSIANN CDR v1r1	Ashouri et al.2015 ⁷⁷ Sorooshian et al.2014 ⁷⁸	1983–2017		satellite, gauge
CPC	Xie et al. 2010 ⁷⁹	1979–2017		gauge
REGEN-AllStation	Contractor et al. 2019 ⁸⁰	1950–2016		gauge
GPCC	Ziese et al. 2018 ⁸¹	1982–2016		gauge
GSMaP-NRT-gauges v6.0	Kubota et al. 2007 ⁸²	2001–2017		satellite, gauge

Supplementary Data Table 2.

No	Model name	Modeling center/ group	Horizontal resolution at the equator (km)	Model type based on global mean LAD
1	ACCESS1-0	Commonwealth Scientific and Industrial Research Organisation, and Bureau of Meteorology, Australia	208 km	–
2	BNU-ESM	College of Global Change and Earth System Science (GCESS), Beijing Normal University (BNU), China	312 km	–
3	CCSM4	National Center for Atmospheric Research (NCAR), USA	138 km	“wet”
4	CMCC-CESM	Centro Euro-Mediterraneo per i Cambiamenti Climatici, Italy	416 km	“dry”
5	CMCC-CMS	Centro Euro-Mediterraneo per i Cambiamenti Climatici, Italy	208 km	“dry”
6	CMCC-CM	Centro Euro-Mediterraneo per i Cambiamenti Climatici, Italy	83 km	–
7	CNRM-CM5	National Center for Meteorological Research (CNRM)/CERFACS, France	156 km	–
8	CSIRO-Mk3-6-0	Australian Commonwealth Scientific and Industrial Research Organisation (CSIRO)	208 km	“dry”

		Marine and Atmospheric Research in collaboration with the Queensland Climate Change Centre of Excellence (QCCCE), Australia		
9	CanESM2	Canadian Centre for Climate Modelling and Analysis (CCCma), Canada	312 km	–
10	FGOALS-g2	Institute of Atmospheric Physics, Chinese Academy of Sciences and Tsinghua University, China	312 km	“wet”
11	FGOALS-s2	Institute of Atmospheric Physics, Chinese Academy of Sciences and Tsinghua University, China	312 km	–
12	GFDL-CM3	NOAA Geophysical Fluid Dynamics Laboratory, USA	278 km	–
13	GFDL-ESM2G	NOAA Geophysical Fluid Dynamics Laboratory, USA	278 km	–
14	GFDL-ESM2M	NOAA Geophysical Fluid Dynamics Laboratory, USA	278 km	–
15	HadGEM2-CC	Met Office Hadley Centre, UK	208 km	–
16	HadGEM2-ES	Met Office Hadley Centre, UK	208 km	
17	IPSL-CM5A-LR	Institut Pierre Simon Laplace, France	416 km	“dry”

18	IPSL-CM5A-MR	Institut Pierre Simon Laplace, France	278 km	<i>“dry”</i>
19	IPSL-CM5B-LR	Institut Pierre Simon Laplace, France	416 km	
20	MIROC-ESM-CHEM	Japan Agency for Marine-Earth Science and Technology, Atmosphere and Ocean Research Institute, The University of Tokyo, National Institute for Environmental Studies, RIKEN Center for Computational Science, Japan	312 km	<i>“wet”</i>
21	MIROC-ESM	Japan Agency for Marine-Earth Science and Technology, Atmosphere and Ocean Research Institute, The University of Tokyo, National Institute for Environmental Studies, RIKEN Center for Computational Science, Japan	312 km	<i>“wet”</i>
22	MIROC5	Japan Agency for Marine-Earth Science and Technology, Atmosphere and Ocean Research Institute, The University of Tokyo, National Institute for Environmental Studies, RIKEN Center for Computational Science, Japan	156 km	<i>“wet”</i>
23	MPI-ESM-LR	Max Planck Institute for Meteorology, Germany	208 km	<i>“dry”</i>
24	MPI-ESM-MR	Max Planck Institute for Meteorology,	208 km	<i>“dry”</i>

		Germany		
25	MRI-CGCM3	Meteorological Research Institute, Japan	125 km	–
26	NorESM1-M	Norwegian Climate Centre, Norway	278 km	–
27	bcc-csm1-1-m	Beijing Climate Center (BCC), China Meteorological Administration, China	125 km	“wet”
28	bcc-csm1-1	Beijing Climate Center (BCC), China Meteorological Administration, China	312 km	–
29	inmcm4	Institute for Numerical Mathematics (INM), Russia	222 km	“wet”

Supplementary Data Table 3.

No	Model name	Modeling center/ group	Horizontal resolution at the equator (km)	Model type based on global mean LAD
1	ACCESS-CM2	Commonwealth Scientific and Industrial Research Organisation, and Bureau of Meteorology, Australia	208 km	–
2	ACCESS-ESM1-5	Commonwealth Scientific and Industrial Research Organisation, and Bureau of Meteorology, Australia	208 km	–
3	BCC-CSM2-MR	Beijing Climate Center (BCC), China Meteorological Administration, China	125 km	“wet”
4	CNRM-CM6-1-HR	National Center for Meteorological Research (CNRM)-CERFACS, France	56 km	–
5	CNRM-CM6-1	National Center for Meteorological Research (CNRM)-CERFACS, France	156 km	“dry”
6	CNRM-ESM2-1	National Center for Meteorological Research (CNRM)-CERFACS, France	156 km	“dry”
7	CanESM5	Canadian Centre for Climate Modelling and Analysis (CCCma), Canada	312 km	–

8	EC-Earth3-Veg	EC-Earth-Consortium	124 km	<i>“dry”</i>
9	EC-Earth3	EC-Earth-Consortium	78 km	–
10	FGOALS-g3	NOAA Geophysical Fluid Dynamics Laboratory, USA	222 km	<i>“wet”</i>
11	GFDL-CM4	NOAA Geophysical Fluid Dynamics Laboratory, USA	139 km	–
12	GFDL-ESM4	NOAA Geophysical Fluid Dynamics Laboratory, USA	139 km	–
13	HadGEM3- GC31-LL	Met Office Hadley Centre, UK	208 km	–
14	INM-CM4-8	Institute for Numerical Mathematics, Russian Academy of Science, Russia	222 km	<i>“wet”</i>
15	INM-CM5-0	Institute for Numerical Mathematics, Russian Academy of Science, Russia	222 km	<i>“wet”</i>
16	IPSL-CM6A-LR	Institut Pierre Simon Laplace, France	278 km	–
17	KACE-1-0-G	National Institute of Meteorological Sciences/Korea Meteorological Administration, Climate Research Division, Republic of Korea	208 km	–
18	MIROC-ES2L	Japan Agency for Marine-Earth Science and Technology, Atmosphere and Ocean Research Institute, The University of	312 km	<i>“wet”</i>

		Tokyo, National Institute for Environmental Studies, RIKEN Center for Computational Science, Japan		
19	MIROC6	Japan Agency for Marine-Earth Science and Technology, Atmosphere and Ocean Research Institute, The University of Tokyo, National Institute for Environmental Studies, RIKEN Center for Computational Science, Japan	156 km	<i>“wet”</i>
20	MPI-ESM1-2-HR	Max Planck Institute for Meteorology, Germany	104 km	<i>“dry”</i>
21	MPI-ESM1-2-LR	Max Planck Institute for Meteorology, Germany	208 km	<i>“dry”</i>
22	MRI-ESM2-0	Meteorological Research Institute, Japan	124 km	–
23	NESM3'	Nanjing University of Information Science and Technology, China	208 km	<i>“dry”</i>
24	NorESM2-LM	Norwegian Climate Centre, Norway	277 km	–
25	NorESM2-MM	Norwegian Climate Centre, Norway	138 km	–
26	UKESM1-0-LL	Met Office Hadley Centre, UK	208 km	–

Supplementary Data Table 4.

Variable ID	Full name	Units	Realm
<i>mrsos</i>	Moisture in upper portion of soil column	Kg m-2	Lmon
<i>mrso</i>	Total soil moisture content	Kg m-2	Lmon
<i>hfls</i>	Surface upward latent heat flux	W m-2	Amon
<i>hfss</i>	Surface upward sensible heat flux	W m-2	Amon
<i>evspsbl</i>	Net evaporation	kg m-2 s-1	Lmon
<i>lai</i>	Leaf area index	1	Lmon
<i>rsds</i>	Surface downwelling shortwave radiation	W m-2	Amon
<i>hur</i>	Relative humidity	%	Amon
<i>hus</i>	Specific humidity	1	Amon
<i>prw</i>	Water vapour path	Kg m-2	Amon
<i>clt</i>	Total cloud cover percentage	%	Amon
<i>clwvi</i>	Condensed water path	Kg m-2	Amon
<i>pr</i>	Precipitation	Kg m-2 s-1	Amon
<i>prc</i>	Convective precipitation	Kg m-2 s-1	Amon
<i>zg</i>	Geopotential height	m	Amon
<i>tas</i>	Near-surface air temperature	K	Amon

Supplementary Data Table 5.

Variable	NA	AMZ	S-AF	CE-AS	EUR	SAH	IND	Globe
<i>LAD</i>	0.123	0.021	0.219	<u>0.002</u>	0.011	0.25	0.181	0.011
<i>mrsos</i>	0.25	<u>0.001</u>	<u>0.003</u>	nan	0.073	0.027	nan	0.016
<i>mrso</i>	0.25	<u>0.004</u>	<u>0.001</u>	<u>0.007</u>	<u>0.008</u>	<u>0.001</u>	nan	nan
<i>hfls</i>	0.25	<u>0.005</u>	0.036	<u>0.005</u>	<u>0.001</u>	0.25	<u>0.009</u>	<u>0.001</u>
<i>hfss</i>	<u>0.001</u>	0.24	<u>0.002</u>	<u>0.002</u>	<u>0.001</u>	<u>0.009</u>	0.028	<u>0.001</u>
<i>evspsbl</i>	0.25	<u>0.005</u>	0.022	<u>0.005</u>	<u>0.001</u>	0.193	<u>0.009</u>	<u>0.001</u>
<i>lai</i>	0.124	<u>0.001</u>	<u>0.004</u>	0.25	0.014	<u>0.001</u>	nan	<u>0.008</u>
<i>rsds</i>	<u>0.001</u>	<u>0.001</u>	<u>0.001</u>	0.25	0.022	<u>0.001</u>	<u>0.001</u>	0.017
<i>hur</i>	0.159	<u>0.001</u>	<u>0.001</u>	<u>0.001</u>	<u>0.001</u>	<u>0.004</u>	nan	nan
<i>hus</i>	0.063	0.06	<u>0.001</u>	<u>0.008</u>	0.244	0.123	0.144	0.177
<i>prw</i>	0.095	0.133	<u>0.001</u>	0.018	<u>0.004</u>	0.25	0.25	0.105
<i>clt</i>	0.064	0.130	<u>0.003</u>	0.235	0.011	<u>0.001</u>	0.180	0.060
<i>clwvi</i>	<u>0.005</u>	0.154	<u>0.001</u>	<u>0.001</u>	0.066	0.044	<u>0.002</u>	<u>0.007</u>
<i>pr</i>	0.146	<u>0.007</u>	<u>0.066</u>	0.25	0.017	0.087	<u>0.001</u>	0.25
<i>prc</i>	<u>0.01</u>	0.123	<u>0.002</u>	<u>0.001</u>	<u>0.001</u>	<u>0.001</u>	0.075	<u>0.0014</u>
<i>zg</i>	0.043	0.014	<u>0.003</u>	<u>0.009</u>	0.078	0.051	0.1	0.06
<i>tas</i>	<u>0.008</u>	0.16	<u>0.007</u>	0.02	0.03	<u>0.003</u>	0.02	<u>0.003</u>