LS4P-II Regional Climate Model Intercomparison for Tibetan Plateau Protocol - Experimental Designs and Work Plan

The regional climate model intercomparison for LS4P Phase-I has assessed the performance of eight regional climate models (RCMs) in simulating Tibetan Plateau (TP) Climate at subseasonal-seasonal-interannual scales. It is found that RCMs can generally produce the spatial patterns and inter-annual variations of seasonal precipitation over the TP, and multi-RCM ensemble means can improve the simulation of precipitation and surface temperature. However, biases and RMSE are still relatively large, and it is necessary to further study the sensitivity of RCMs' simulation to the land surface conditions over the TP to improve the RCM downscaling ability.

The LS4P-II RCM Intercomparison-East Asia aims to study the impact of the land surface conditions over the TP on the regional climate. The objectives of this project are 1) to assess the sensitivity of the TP precipitation to the initialization/surface boundary condition of land surface temperature/subsurface temperature (LST/SUBT), snow cover, and soil moisture over the TP; 2) to understand the impact of the TP land surface conditions on the precipitation anomaly over eastern Asia.

To date, six to nine RCMs from China, Japan, Korea, and USA show the interest in participating the LS4P-II RCM-EA. The technical specifications for the RCMs inter-comparisons are discussed in the following sections.

1. Experiment specification

The RCM domain should cover at least 25-40°N, 75-105°E excluding the simulation buffer zone with spatial resolution at 18 km. The LS4P-II RCM will consist of four experiments using regional climate models (See Table 1).

The LS4P-II RCM Intercomparison will select the years 2010-2015, 1998 and 2022 for the case study. The LS4P-II RCM-EA task 1 will consist of the control run from late April through August for 2010-2015, 1998 and 2022 with each RCM group's normal setting. The ICBC and lateral boundary data can be obtained from the ERA-5 reanalysis.

The land surface temperature dataset for the Chinese landmass and its surrounding areas (TRIMS LST; 2000-2021) will be used to validate the performance of RCM simulations. The TRIMS LST dataset can download from https://data.tpdc.ac.cn/zh-hans/data/05d6e569-6d4b-43c0-96aa-5584484259f0.

In the LST/SUBT sensitivity experiments (Task 2), the impact of land surface temperature/subsurface temperature (LST/SUBT) at TP will be tested. Two sensitivity experiments with +5 ℃ and -5 ℃ will be performed. And the sensitivity of cumulus parameterization schemes will also be tested with the setting of LST/SUBT experiments (Task 2.1).

In the third and fourth set of experiments (Task 3 and Task 4), different initialization of soil moisture and snow cover over TP will be conducted, respectively. The sensitivity experiments could be performed using initialization of snow cover and soil moisture at different percent of the following observations datasets (Table 2). The modeling groups are encouraged to combine various LST/SUBT, snow cover, and soil moisture based on their interest and publish their papers accordingly.

Table 1. LS4P-II RCM Experimental Design

Experiment	Description
Task 1 CTL	RCM ERA5 reanalysis forcing control run: Atmospheric initial and lateral boundary conditions are from ERA5 reanalysis. Land surface initial conditions are from the observations (Table 1). The control experiments run from late April through August for 2010-2015, 1998 and 2022.
Task 2 LST	Same as Task 1, except for an initial LST/SUBT mask will be imposed over the TP. At least two sensitivity experiments with +5 ℃ (Task 2 LST+5) and -5 ℃ (Task 2 LST-5) LST/SUBT anomaly will be performed. Each group needs to process the LST/SUBT setting according to its own land model to deal with change in water phase when the T change from above or below freezing
Task 2.1 LST-CS	Same as Task 2, except different cumulus parameterization schemes from Task 2 are used.
Task 3 SMI	Same as Task 1, except for different initialization of soil moisture with extremely wet anomaly and extreme dry anomaly of soil conditions based on soil moisture data 3. Two sensitivity experiments (Tsk3 SMI-wet and SMI-dry) will be conducted.
Task 4 SWI	Same as Task 1, except for the different initialization of snow depth. Different initialization of snow depth based on the snow depth data7 and 8 will be conducted. Two sensitivity experiments with snow depth at -20% (Task 4 SWI-20) and +20% (Task 4 SWI-20) anomaly of observation will be conducted.

Table 2. Observations of soil moisture and snow cover

Data set	Variable Name	Frequency/ Period	Source	Reference
1.	soil moisture	Daily/2009 -2019	A dataset of 10-year regional-scale soil moisture and soil temperature measurements at multiple depths over the Tibetan Plateau https://data.tpdc.ac.cn/zh-hans/data/805a6b93-201c-48ea-a131-27dd639d477a	Zhang, P., Zheng, D., van der Velde, R., Wen, J., Ma, Y., Zeng, Y., Wang, X., Wang, Z., Chen, J., & Su, Z. (2022). A dataset of 10-year regional-scale soil moisture and soil temperature measurements at multiple depths on the Tibetan Plateau, Earth Syst. Sci. Data, 14, 5513–5542, https://doi.org/10.5194/essd-14-5513-2022.
2.	soil moisture	Daily/2010 -2021	The multiscale observation of network of soil temperature and moisture over central Tibetan Platea (2010-2021) https://data.tpdc.ac.cn/zh-hans/data/b6269aeb-8b44-4d03-b514-2c804c2cfc26	Yang, K., Qin, J., Zhao, L., Chen, Y.Y., Tang, W.J., Han, M.L., Lazhu., Chen, Z.Q., Lv, N., Ding, B.H., Wu, H., &Lin, C.G. (2013). A Multi-Scale Soil Moisture and Freeze-Thaw Monitoring Network on the Third Pole. Bulletin of the American Meteorological Society, 94(12), 1907-1916.
3.	soil moisture	Daily/2001 -2020	A 1 km daily soil moisture dataset over the Qinghai-Tibet Plateau (2001-2020) https://data.tpdc.ac.cn/zh-hans/data/b611fb43-c18c-4966-a85c-949ce1ca60f2	Shangguan, Y., Min, X., & Shi, Z. (2023). Inter-comparison and integration of different soil moisture downscaling methods over the Qinghai-Tibet Plateau. Journal of Hydrology, 617, 129014, https://doi.org/10.1016/j.jhydrol.2022.129014

4.	snow cover fraction	Daily/2002-2016	Daily fractional snow cover dataset over High Asia based on MODIS (2002-2016) https://data.tpdc.ac.cn/zh-hans/data/a0f26718-e057-4da3-84cd-45787d7be49b	Qiu, Y. (2018). Daily fractional snow cover dataset over High Asia (2002-2016). National Tibetan Plateau/Third Pole Environment Data Center, https://doi.org/10.11888/GlaciolGeocryol.tpe.0000016.file.
5.	land surface temperature	Daily/2000-2021	Daily 1-km all-weather land surface temperature datasets for the Chinese landmass and its surrounding areas https://data.tpdc.ac.cn/zh-hans/data/05d6e569-6d4b-43c0-96aa-5584484259f0	Zhang, X., Zhou, J., Liang, S., Wang, D. (2021). A practical reanalysis data and thermal infrared remote sensing data merging (RTM) method for reconstruction of a 1-km all-weather land surface temperature. Remote Sensing of Environment, 260, 112437. https://doi.org/10.1016/j.rse.2021.112437
6.	snow depth	Daily/2013-2020	Physical snow process model supported global snow depth product retrieved from the passive microwave AMSR2 sensor https://data.tpdc.ac.cn/zh-hans/data/c3b7d80c-a43b-4b0b-a09e-a38f837fb921	Pan, J., Yang, J., Jiang, L., Xiong, C., Pan, F., Shi, J., Gao, X. (2022). Physical snow process model supported global snow depth product retrieved from the passive microwave AMSR2 sensor (2013-2020). National Tibetan Plateau/Third Pole Environment Data Center, https://doi.org/10.11888/Cryos.tpdc.272937. https://cstr.cn/18406.11.Cryos.tpdc.272937
7	snow depth	Daily/2000-2018	A daily, 0.05° Snow depth dataset for Tibetan Plateau https://data.tpdc.ac.cn/zh-hans/data/0515ce19-5a69-4f86-822b-	Yan, D., Ma N., Zhang Y. (2022). Development of a fine-resolution snow depth product based on the snow cover probability in the Tibetan Plateau: Validations and spatial-temporal analyses. Journal of Hydrology, 604,127027. https://doi.org/10.1016/j.jhydrol.2021.127027

			330aa11e2a28	
8	snow depth	Daily/1980-2019	Long-term series of daily snow depth dataset over the Northern Hemisphere based on machine learning https://data.tpdc.ac.cn/zh-hans/data/5576dba9-1b15-4ab0-a387-bac9bad80daf	Hu,Y.X., Che, T., Dai, L.Y., & Xiao, L. (2021). Snow depth fusion based on machine learning methods for the Northern Hemisphere. Remote Sensing, 13,1250

Variables data with hourly, 6-hourly, daily and monthly output are suggested in the following table.

2. Output list (NetCDF format)

2.1 Invariant variables

No.	Variable Name	Abbreviation	Unit
1	Orography (elevation)	orog	m
2	Land fraction	landfrac	%

2.2 Monthly mean 3D profile variables (Levels: 500, 400, 300, 200, 100 hPa)

No.	Variable Name	Abbreviation	Unit
3	Geopotential height	gh	gpm
4	Temperature	ta	K
5	Zonal wind	ua	m/s
6	Meridional wind	va	m/s
7	Vertical velocity (Omega)	wa	m/s
8	Specific humidity	hus	g/kg
9	Potential velocity*	pv	Pa/s
10	Relative humidity*	hur	%
11	Total diabatic heating*	tdh	K/day

***These variables are optional.**

2.3 Monthly mean 2D variables

No.	Variable Name	Abbreviation	Unit
12	Albedo	alb	%
13	2-meter temperature	t2m	K
14	2-meter dew point temperature	dp2	K
15	2-meter specific humidity	hus2m	g/kg
16	Surface (skin) temperature	skt	K

17	Maximum 2-m air temperature	t2max	K
18	Minimum 2-m air temperature	t2min	K
19	Total Precipitation	pr	kg/m^2
20	Convective precipitation	conpre	kg/m^2
21	Convective available potential energy	cape	J/kg
22	Total column water	tliq	kg/m^2
23	Snow water equivalent	snowliq	kg/m^2
24	Snow area fraction	fsno	%
25	Snow depth	h2osnw	mm
26	Land ice fraction	lif	%
27	Boundary layer thickness	blh	m
28	Surface pressure	sp	hPa
29	Sea level pressure	slp	hPa
30	Eastward 10-m wind speed	u10m	m/s
31	Westward 10-m wind speed	v10m	m/s
32	Maximum 10-m wind speed	uvmax	m/s
33	Total cloud cover fraction	tcc	%
34	Surface downwelling shortwave radiation	rsds	W/m^2
35	Surface downwelling longwave radiation	rlds	W/m^2
36	Surface upwelling shortwave radiation	rsus	W/m^2
37	Surface upwelling longwave radiation	rlus	W/m^2
38	TOA outgoing longwave radiation	rlut	W/m^2
39	TOA incident shortwave radiation	tsdt	W/m^2
40	TOA outgoing shortwave radiation	rsut	W/m^2
41	Surface Latent heat flux	hlfs	W/m^2
42	Surface sensible heat flux	hfss	W/m^2
43	Surface ground heat flux	hfgs	W/m^2
44	Canopy evaporation	fcev	W/m^2
45	Ground evaporation	fgev	W/m^2

46	Canopy transpiration	fctr	W/m^2
47	Volumetric soil water for top 5 lays (number of soil layer depends on the scheme)	h2osoi	m^3/m^3
48	Soil temperature for top 5 lays (number of soil layer depends on the scheme)	tsoi	K
49	Soil ice content for top 5 lays	fsw	m
50	Total soil water content	tsw	m
51	Surface runoff	qover	mm/s
52	Total runoff	qrunoff	mm/s
53	Aerosol optical depth	aod	1
54	Mass of black carbon in snow column	snoblmcl	kg/m^2
55	Mass of black carbon in top snow layer	snobcmsl	kg/m^2
56	Mass of dust in snow column	snodstmcl	kg/m^2
57	Mass of dust in top snow layer	snodstnsl	kg/m^2

2.4 Daily mean pressure level field (provided at 500, 400, 300, 200, 100 hPa)

No.	Variable Name	Abbreviation	Unit
58	Geopotential height	gh	gpm
59	Temperature	ta	K
60	Zonal wind	ua	m/s
61	Meridional wind	va	m/s
62	Vertical velocity (Omega)	wa	m/s
63	Specific humidity	hus	g/kg

2.5 Daily mean 2D variables

No.	Variable Name	Abbreviation	Unit
64	Albedo	alb	%
65	2-meter temperature	t2m	K
66	2-meter dew point temperature	dp2	K

67	2-meter specific humidity	hus	g/kg
68	Surface (skin) temperature	skt	K
69	Maximum 2-m air temperature	t2max	K
70	Minimum 2-m air temperature	t2min	K
71	Total Precipitation	pr	kg/m^2
72	Convective precipitation	conpre	kg/m^2
73	Convective available potential energy	cape	J/kg
74	Snow water equivalent	snowliq	kg/m^2
75	Snow area fraction	fsno	%
76	Snow depth	h2osnw	mm
77	Boundary layer thickness	blh	m
78	Surface pressure	sp	hPa
79	Sea level pressure	slp	hPa
80	Eastward 10-m wind speed	u10m	m/s
81	Westward 10-m wind speed	v10m	m/s
82	Maximum 10-m wind speed	uvmax	m/s
83	Total cloud cover fraction	tcc	%
84	Surface downwelling shortwave radiation	rsds	W/m^2
85	Surface downwelling longwave radiation	rlds	W/m^2
86	Surface upwelling shortwave radiation	rsus	W/m^2
87	Surface upwelling longwave radiation	rlus	W/m^2
88	Surface Latent heat flux	hlfs	W/m^2
89	Surface sensible heat flux	hfss	W/m^2
90	Surface ground heat flux	hfgs	W/m^2
91	Aerosol optical depth	aod	1
92	Volumetric soil water for top 5 lays	h2osoi	m^3/m^3
93	Soil temperature for top 5 lays	tsoi	K

2.6 6 hourly output

No.	Variable Name	Abbreviation	Unit
94	2-meter temperature	t2m	K
95	Geopotential height at 500 and 200 hPa	gh	gpm
96	Temperature at 500 and 200 hPa	ta	K
97	Zonal wind at 500 and 200 hPa	ua	m/s
98	Meridional wind at 500 and 200 hPa	va	m/s
99	Vertical velocity at 500 and 200 hPa	wa	m/s
100	Specific humidity 500 and 200 hPa	hus	g/kg
101	Boundary layer thickness	blh	m
102	Surface pressure	sp	hPa
103	Surface downwelling shortwave radiation	rsds	W/m^2
104	Surface downwelling longwave radiation	rlds	W/m^2
105	Surface upwelling shortwave radiation	rsus	W/m^2
106	Surface upwelling longwave radiation	rlus	W/m^2
107	Surface Latent heat flux	hlfs	W/m^2
108	Surface sensible heat flux	hfss	W/m^2
109	Surface ground heat flux	hfgs	W/m^2
110	Canopy evaporation	fcev	kg/m^2
111	Ground evaporation	fgev	kg/m^2
112	Canopy transpiration	fctr	kg/m^2
113	Volumetric soil water for top 5 lays	h2osoi	m^3/m^3
114	Soil temperature for top 5 lays	tsoi	K

2.7 Hourly output

No.	Variable Name	Abbreviation	Unit
115	2-meter temperature	t2m	K
116	Boundary layer thickness	blh	m
117	Surface pressure	sp	hPa
118	Surface downwelling shortwave radiation	rsds	W/m^2

119	Surface downwelling longwave radiation	rlds	W/m^2
120	Surface upwelling shortwave radiation	rsus	W/m^2
121	Surface upwelling longwave radiation	rlus	W/m^2
122	Surface Latent heat flux	hlfs	W/m^2
123	Surface sensible heat flux	hfss	W/m^2
124	Surface ground heat flux	hfgs	W/m^2
125	Volumetric soil water for top 5 lays	h2osoi	m^3/m^3
126	Soil temperature for top 5 lays	tsoi	K

3. Validation Data

Datasets from different sources including the site measurements, remote sensing, reanalysis and assimilations will be available for RCM research groups for validating their models. The following table lists some datasets specially for the Tibetan Plateau.

No.	Variable Name (Unit)	Frequency/Period	Resolution	Source	Website or References
1	Snow depth (cm)	Daily/1978-2005			Che T, Li X, Jin R, Armstrong RL, Zhang TJ. Snow depth derived from passive microwave-remote sensing data in China. Annals of Glaciology, 2008, 49: 145-154
2	Snow cover (%); Snow depth (cm)	Daily/ 1997.11-2017.2	24 km	Interactive Multi-Sensor Snow and Ice Mapping System (IMS)	Helfrich, S. R., McNamara, D., Ramsay, B. H., Baldwin, T. & Kasheta, T. Enhancements to, and forthcoming developments in the Interactive Multisensor Snow and Ice Mapping System (IMS). Hydrol. Process., 2007, 21: 1576–1586
3	Snow cover fraction (%)	Daily/ 1982-2016 exluding 1994			Chen, X., Long, D., Liang, S., He, L., Zeng, C., Hao, X., & Hong, Y. Developing a composite daily snow cover extent record over the Tibetan Plateau from 1981 to 2016 using multisource data. Remote Sensing of Environment, 2018, 215: 284-299
4	Soil moisture reanalysis (0-5cm, 0-10cm, 10-40cm, 40-100cm, 100-200cm) (mm^3/mm^3)	Hourly/2008-2016	1/16°	CLDAS	http://123.56.215.19/tipex/expeditionData1/id/1.html
5	Near surface atmospheric forcing including 2m temperature, surface pressure, 2m humidity, 10m wind, precipitation, downward shortwave radiation	Hourly/2008-2016	1/16°	CLDAS	http://123.56.215.19/tipex/expeditionData1/id/1.html

6	11 sites measured temperature, humidity, wind in different height of planetary boundary layer; soil temperature and moisture, and heat fluxes in different depth; surface shortwave and longwave radiation; photosynthetically active radiation (PAR)	10 or 30 minutes/ Summer in 2014	Site data	TIPEX-III	http://123.56.215.19/tipex/expeditionData/id/3.html
7	12 sites measured temperature, humidity, wind in different height of planetary boundary layer; soil temperature and moisture, and heat fluxes in different depth;	10 or 30 minutes/ 1-2 year all through 2015	Site data	TIPEX-III	http://123.56.215.19/tipex/expeditionData/id/3.html
8	33 meteorological stations observed soil water content	Hourly/ 20150101-2016123	Site data	TIPEX-III	http://123.56.215.19/tipex/expeditionData/id/7.html
9	2 meter air temperature (K)				Liang, shunlin
10	Maximum and minimum surface air temperature (K)	Monthly/ 2003-2011			Lu, N., Liang, S., Huang, G., Qin, J., Yao, L., Wang, D., & Yang, K. Hierarchical Bayesian space-time estimation of monthly maximum and minimum surface air temperature. Remote Sensing of Environment, 2018, 211: 48-58
11	Site measured black carbon and dust concentration	?/2014-2016	Site data		Zhang Y. et al., 2017, JGR; Kang S. & Zhang Q. et al., NSR, In revision
12	Net radiation flux, soil heat flux, and sensible and latent heat flux	Daily/2001-2016	1×1 km		Ma Yaoming, Y.Wang, C.Han, 2018, Regionalization of land surface heat fluxes over the heterogeneous landscape: from the Tibetan Plateau to the Third Pole region, International Journal of Remote Sensing, 39 : 5872-5890 ,

			doi:10.1080/01431161.2018.1508923.
13	Geopotential height, air temperature, wind, humidity from 500 to 100 hPa derived from NCEP-DOE AMIP-II Reanalysis (R-2), ERA-Interim reanalysis or Japanese Reanalysis (JAR-55) for references.		

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