User information for dataset: A 10-year (2009-2019) surface soil moisture dataset produced based on *in situ* measurements collected from the Tibet-Obs

1. Introduction

The Tibet-Obs consists of three regional-scale soil moisture (SM) monitoring networks, i.e. the Maqu, Naqu, and Ngari (including Ali and Shiquanhe) networks (Fig. 1). The summary of main Tibet-Obs applications and corresponding findings are listed in Table 1.

This surface SM dataset includes the original 15-min *in situ* measurements collected at a depth of 5 cm by multiple SM monitoring sites of the three networks, and the spatially upscaled SM records produced for the Maqu and Shiquanhe networks. The supplementary data includes the upscaled SM produced by the four methods in a single year, precipitation data, and three model-based products (i.e. ERA5-land. GLDAS Noah, and MERRA2) for the Maqu and Shiquanhe network areas.

This document describes the content of the dataset, the status of the Tibet-Obs, and existing dataset utilized in the study.

A publication based on the dataset is submitted to the journal Earth Systems Science Data in July 2020:

Pei Zhang, Donghai Zheng, Rogier van der Velde, Jun Wen, Yijian Zeng, Xin Wang, Zuoliang Wang, Jiali Chen, Zhongbo Su, *"Status of the Tibetan Plateau observatory (Tibet-Obs) and a 10-year (2009-2019) surface soil moisture dataset"*[1]

Please refer to [1] for details on the production of the upscaled SM dataset.

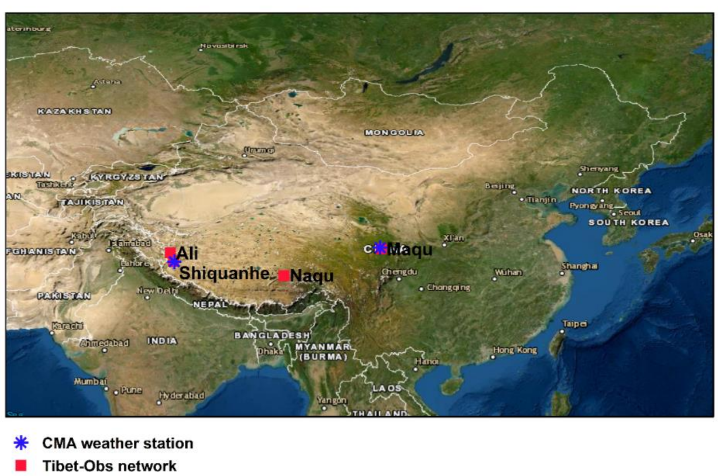

Fig. 1. Locations of the Tibet-Obs including Maqu, Naqu, and Ngari (including Ali and Shiquanhe) soil moisture monitoring networks. The weather stations of Maqu and Shiquanhe operated by the China Meteorological Administration (CMA) are also shown. (Base map is from Esri, Copyright: © Esri)

Table 1. Summary of the main Tibet-Obs applications and corresponding findings.

Literature	*In situ* data	Satellite- and/or model-based products	Key findings
Dente et al. (2012a)	Maqu network, period between 2008 and 2009	LPRM AMSR-E SM product, ASCAT SM product	i) The weighted average of SM depended on the percentage spatial coverage strata can be regarded as the ground reference. ii) The AMSR-E and ASCAT products are able to provide reasonable area SM during monsoon seasons.
Dente et al. (2012b)	Maqu network, period of 2010	Soil Moisture and Ocean Salinity (SMOS) Level 2 SM product	The SMOS product exhibits a systematic dry bias (0.13 m^3 m^{-3}) at the Maqu network.
Zeng et al. (2015)	Maqu network, period between 2008 and 2010	SMOS Level 3 SM product (version 2.45), Advanced Microwave Scanning Radiometer for Earth Observation System SM products (AMSR-E) SM products developed by National Aeronautics and Space Administration (NASA version 6), Land Parameter Retrieval Model (LPRM version 2), and Japan Aerospace Exploration Agency (JAXA version 700), AMSR2 Level 3 SM product (version 1.11), Advanced Scatterometer SM product (ASCAT version TU-Wien-WARP 5.5), ERA-Interim SM product (version 2.0), and Essential Climate Variable SM product (ECV version 02.0)	i) The ECV and ERA products give the best performance, and all products are able to capture the SM dynamic except for the NASA product. ii) The JAXA AMSR-E/AMSR2 products underestimate SM, while the ASCAT product overestimates it. iii) The SMOS product exhibits big noise and bias, and the LPRM AMSR-E product shows a significantly larger seasonal amplitude.
Zheng et al. (2015a)	Maqu network, period between 2009 and 2010	Noah LSM (land surface model) simulations	The modified hydraulic parameterization is able to resolve the SM underestimation in the upper soil layer under wet conditions, and it also leads to better capture for SM profile dynamics combined with the modified root distribution.
Bi & Ma (2015)	Maqu network, period between 2008 and 2011	GLDAS SM products produced by Noah, Mosaic CLM and Variable Infiltration Capacity (VIC) models	The SM simulated by the four LSMs can give reasonable SM dynamics but still show negative biases probably resulted from the high soil organic carbon content.
Li et al. (2018)	Maqu network, period between 2015 and 2016	Soil Moisture Active Passive (SMAP) Level 3 standard (36km) and enhanced (9km) passive SM products (version 3), Community Land Model (CLM4.5) simulations	i) The standard and enhanced SMAP products have similar performance for SM spatial distributions. ii) The SM of enhanced SMAP product exhibits good agreement with the CLM4.5 SM simulation.
Zhao et al. (2017)	Maqu network, period between 2008 and 2010	Downscaled SM from five typical triangle-based empirical SM relationship models	The model treating the surface SM as a second-order polynomial with LST, vegetation indices, and surface albedo outperforms other models.
Ju et al. (2019)	Maqu network, period of 2012	VIC LSM simulations	The IEPFM (immune evolution particle filter with Markov chain Monte Carlo simulation) is able to mitigate particle impoverishment and provide better assimilation results.
Zheng et al. (2018b)	Ngari network, period between 2015 and 2016	SMAP Level 2 radiometer SM product	Modifying surface roughness and employing soil temperature and texture information can improve the SMAP SM retrievals for the desert ecosystem of the TP.
Zhang et al. (2018)	Maqu and Ngari networks, period between 2010 and 2013	ERA-Interim SM product, MERRA SM product, GLDAS_Noah SM product (version2.0 and version2.1)	All these products exhibit overestimation at the Ngari network while underestimation at the Maqu network except for the ERA-Interim product.
Zheng et al. (2018a)	Maqu and Ngari networks, period	SMAP Level 1C radiometer brightness temperature products (version 3)	i) The SMAP algorithm underestimates the significance of surface roughness while overestimates the impact of vegetation.

	between 2015 and 2016		ii) The modified brightness temperature simulation can result in better SM retrievals.
Wei et al. (2019)	Maqu and Ngari networks, period between 2015 and 2016	SMAP Level 3 SM passive product	The downscaled SM still can keep accuracy compared to the SM of original SMAP product.
Liu et al. (2019)	Maqu and Ngari networks, period between 2012 and 2016	SMAP Level 3 SM products (version 4.00), SMOS-IC SM products (version 105), Fengyun-3B Microwave Radiation Image SM product (FY3B MWRI), JAXA AMSR2 Level 3 SM product, LPRM AMSR2 Level 3 SM product (version 3.00)	i) The JAXA AMSR2 product underestimates area SM while the LPRM AMSR2 product overestimates it. ii) The SMOS-IC product exhibits some noise of SM temporal variation. iii) The SMAP product has the highest accuracy among the five products while FY3B shows relatively lower accuracy.
Yang et al. (2020)	Maqu and Ngari network, period between 2008 and 2011	AMSR-E brightness temperature product	The assimilated SM products exhibit higher accuracy than the AMSR-E product and LSM simulations for wet areas, whereas their accuracy is similar for dry areas.
Su et al. (2013)	Maqu and Naqu networks, period between 2008 and 2009.	AMSR-E SM product, ASCAT Level 2 SM product, ECMWF SM analyses i.e. optimum interpolation and extended Kalman filter products	i) The Naqu area SM is overestimated by the ECMWF products in monsoon seasons, while the Maqu area SM produced by the ECMWF is comparable to previous studies. ii) The SM estimate cannot be considerably improved by assimilating ASCAT data due to the CDF matching approach and the data quality.
Zeng et al. (2016)	Maqu, Naqu and Ngari networks, period between 2010 and 2011	LPRM AMSR-E SM product, ERA-Interim SM product	The blended SM is able to capture temporal variations across different climatic zones over the TP.
Cheng et al. (2019)	Maqu, Naqu and Ngari networks, period of 2010	European Space Agency Climate Change Initiative Soil Moisture SM product (ESA CCISM version 4.4), ERA5 SM product	i) The seasonal variation and spatial distribution of SM can be captured by all four products i.e., ESA CCI_active, ESA CCI_passive, ESA CCI_combined, and ERA5. ii) The ESA CCI_active and ESA CCI_combined products exhibit narrower magnitude than the ESA CCI passive and ERA5 products. iii) The SM uptrend across the TP can be found from the ERA5 product.

2. Folder and file structure

Folder	File/subfolder	Sheet
In situ soil moisture\\	\\Maqu.xlsx	- Information: This sheet contains the information of all the monitoring sites including location, elevation, topography, land cover, soil texture and soil organic matter content. - 2009-2019: These 11 sheets contain the available original 15-min/30-min *in situ* measurements at 5 cm depth for each year.
	\\Shiquanhe.xlsx	- Information: This sheet contains the information of all the monitoring sites including location, elevation, topography, land cover, soil texture and soil organic matter content. - 2010-2019: These 10 sheets contain the available original 15-min *in situ* measurements at 5 cm depth for each year.
	\\Ali.xlsx	- Information: This sheet contains the information of monitoring sites including location, elevation, topography, land cover, soil texture and soil organic matter content. - 2010-2018: These 9 sheets contain the available original 15-min *in situ* measurements at 5 cm depth for each year.
	\\Naqu.xlsx	- Information: This sheet contains the information of monitoring sites including location, elevation, topography, land cover, soil texture and soil organic matter content. - 2010-2019: These 10 sheets contain the available original 15-min *in situ* measurements at 5/2.5 cm depth for each year.
\\Upscaled soil moisture\\	\\Maqu upscaled.xlsx	- 2009-2019: These 11 sheets contain spatial upscaled soil moisture with the input of original *in situ* measurement between 5/15/2009 and 5/15/2019.
	\\ Maqu upscaled-daily average.xlsx	- 2009-2019: These 11 sheets contain spatial upscaled soil moisture with the input of daily average measurement between 5/15/2009 and 5/15/2019.
	\\Shiquanhe upscaled. xlsx	- 2010-2019: These 10 sheets contain spatial upscaled soil moisture with the input of original *in situ* measurement between 8/1/2010 and 8/1/2019
	\\Shiquanhe upscaled-daily average.xlsx	- 2010-2019: These 10 sheets contain spatial upscaled soil moisture with the input of daily average measurement between 8/1/2010 and 8/1/2019
\\ Supplementary data \\	\\ Upscaled -daily average. xlsx	- Maqu: This sheet contains spatial upscaled soil moisture with the input of daily mean from 17 sites (3 sites) between 11/1/2009 and 10/31/2010 - Shiquanhe: This sheet contains spatial upscaled soil moisture with the input of daily mean from 12 sites (4 sites) between 8/1/2018 and 7/31/2019
	\\Model-based products.xlsx	- Maqu: This sheet contains daily regional mean soil moisture of Maqu network area (Fig. 2) from the ERA5-land, GLDAS Noah, and MERRA2 products between 5/15/2009 and 5/15/2019 - Shiquanhe: This sheet contains daily regional mean soil moisture of Shiquanhe network area (Fig. 3) from the ERA5-land, GLDAS Noah, and MERRA2 products between 8/1/2010 and 8/1/2019
	\\Precipitation.xlsx	- Maqu: This sheet contains daily precipitation of Maqu weather station (Fig. 1) between 5/15/2009 and 5/15/2019 - Shiquanhe: This sheet contains daily precipitation of Shiquanhe weather station (Fig. 1) between 8/1/2010 and 8/1/2019

3. Status of the Tibet-Obs

3.1 Maqu network

The Maqu network is located in the north-eastern edge of the TP (33°30’-34°15’N, 101°38’-102°45’E) at the first major bend of the Yellow River. The landscape is dominated by the short grass at elevations varying from 108 3400 to 3800 m. The climate type is characterized as cold-humid with cold dry winters and rainy summers. The mean annual air temperature is about 1.2 ℃, with -10 ℃ for the coldest month (January) and 11.7 ℃ for the warmest month (July). The Maqu network covers an area of approximately 40 by 80 km^2 and consists originally of 20 SMST monitoring sites installed in 2008. The basic information of each monitoring site is summarized in Table 2, and the typical characteristics of topography and land cover within the network are shown in Fig 2 as well. Table 3 provides the specific periods of data missing during each year and the total data lengths of surface SM for each site.

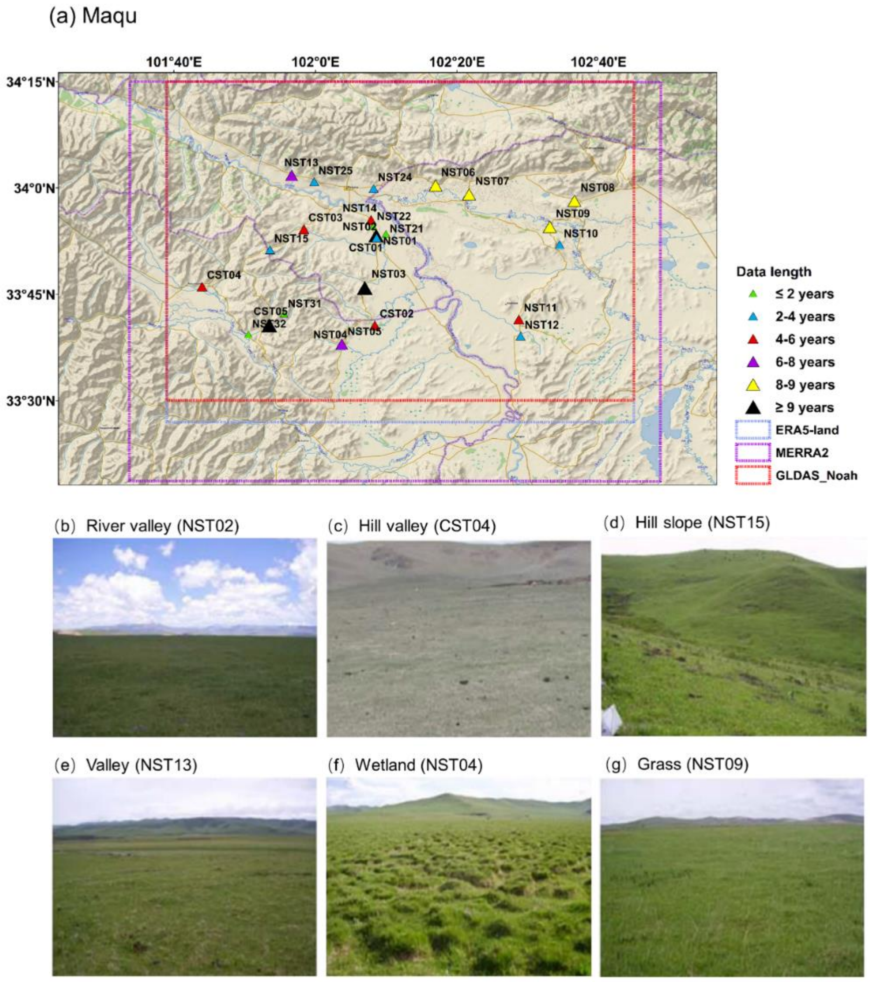

Fig. 2. (a) Overview of the Maqu monitoring network, and typical characteristics of topography and land cover within the network: (b) river valley, (c) hill valley, (d) hill slope, (e) valley, (f) wetland and (g) grass. The colored triangles in (a) represent different data lengths of surface SM measurements for each site, and the colored boxes represent the coverage of selected model-based products. The site name in the bracket in (b)-(g) indicates the site location for which the photograph is selected. (Base map copyright: ©2018 Garmin)

Table 2. Site information of the Maqu network (site name, elevation, topography (TPG), land cover (LC), soil texture at 5-15cm depth (STX), soil bulk density at 5cm depth (BD), soil organic matter content at 5-15cm depth (OMC), Not Available (NA), BD and OMC values are measured in the laboratory).

Site name	Elevation. (m)	TPG	LC	STX	BD (kg m^{-3})	OMC (g/kg)
CST01	3431	River valley	Grass	NA	NA	NA
CST02	3449	River valley	Grass	NA	NA	NA
CST03	3507	Hill valley	Grass	NA	NA	NA
CST04	3504	Hill valley	Grass	NA	NA	NA
CST05	3542	Hill valley	Grass	NA	NA	NA
NST01	3431	River valley	Grass	Silt loam	0.96	18
NST02	3434	River valley	Grass	Silt loam	0.81	18
NST03	3513	Hill slope	Grass	Silt loam	0.63	49
NST04	3448	River valley	Wetland	Silt loam	0.26	229
NST05	3476	Hill slope	Grass	Silt loam	0.75	22
NST06	3428	River valley	Grass	Silt loam	0.81	23
NST07	3430	River valley	Grass	Silt loam	0.58	23
NST08	3473	Valley	Grass	Silt loam	1.06	34
NST09	3434	River valley	Grass	Sandy loam	0.91	17
NST10	3512	Hill slope	Grass	Loam-silt loam	1.05	24
NST11	3442	River valley	Wetland	Organic soil	0.24	136
NST12	3441	River valley	Grass	Silt loam	1.02	39
NST13	3519	Valley	Grass	Silt loam	0.67	29
NST14	3432	River valley	Grass	Silt loam	0.68	30
NST15	3752	Hill slope	Grass	Silt loam	0.78	56
NST21	3428	River valley	Grass	Silt loam	NA	NA
NST22	3440	River valley	Grass	Silt loam	NA	NA
NST24	3446	River valley	Grass	Silt loam	NA	NA
NST25	3600	Hill slope	Grass	Silt loam	NA	NA
NST31	3490	NA	NA	NA	NA	NA
NST32	3490	Hill valley	Grass	NA	NA	NA

Table 3. Data records of all the SMST monitoring sites performed for the Maqu network. Green shaded cells represent that there is not data missing, blue and pink shaded cells represent that the lengths of data missing are less than and more than one month for each year, respectively. Blank cells represent that there is not measurement performed. The number represents the month(s) when the data is missing.

	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	Data length (months)
CST01			10~12	1~6 10~12								36
CST02			5~12	1~10	6	7~12						46

CST03					6~12	1~10	7~12			1~9	5~12	68
CST04	1~5		12	1~3 11~12	1~2 6	8~10	7~12		1~6	7~12		73
CST05					6			5~7		1~2	6~12	119
NST01	1~5				6			5~7			6~12	116
NST02	1~3			7~8 10~12								40
NST03			5~10		6			5~7			6~12	115
NST04			10~12									33
NST05	3~5				6~12	1~7		5~7	7~12	1~7	6~12	92
NST06		1~3 12	1~3		6			6~7	8~12	1~7	6~12	104
NST07			3		6, 12	1	12	1~2 7,12	1~2 12	1~3 9~12		101
NST08		2, 4 9~12	1~5		6~10	1~10		6~7			6~12	95
NST09	1, 12	1~4 12	1~3		1~2 6	7~10	12	1~3 7, 12	1~2 7		6~12	99
NST10		11~12	1~5 7~12	1~6	6~12					1~7	6~12	44
NST11				7~8	6	7~12						63
NST12	10~12	1~9			6~12	1~10	7~12					49
NST13					6		7~12					77
NST14	6~9				6	10~12						64
NST15		10~12	1~5	6~12								33
NST21						1~7	7~12					11
NST22						1~7	7~12					11
NST24						1~7	2~12	1~7			6~12	40
NST25						1~7		2~12	1~8		6~12	39
NST31									1~8	7~12		10
NST32										1~5	6~12	12

3.2 Ngari network

The Ngari network is located in the western part of the TP at the headwater of the Indus River. It consists of two SMST networks established around the cities of Ali and Shiquanhe, respectively. The landscape is dominated by a desert ecosystem at elevations varying from 4200 to 4700 m. The climate type is characterized as cold-arid with a mean annual air temperature of 7.0 ℃. The annual precipitation is less than 100 mm that falls mainly in the monsoon season (July-August). The Shiquanhe network consists originally of 16 SMST monitoring sites installed in 2010. and five new sites were installed in 2016. The Ali network comprise four SM monitoring sites. The basic information of each monitoring site is summarized in Table 4, and the typical characteristics of topography and land cover within the network are also shown in Fig. 3. Table 5 provides the specific periods of data missing during each year and the total data lengths of surface SM for each site.

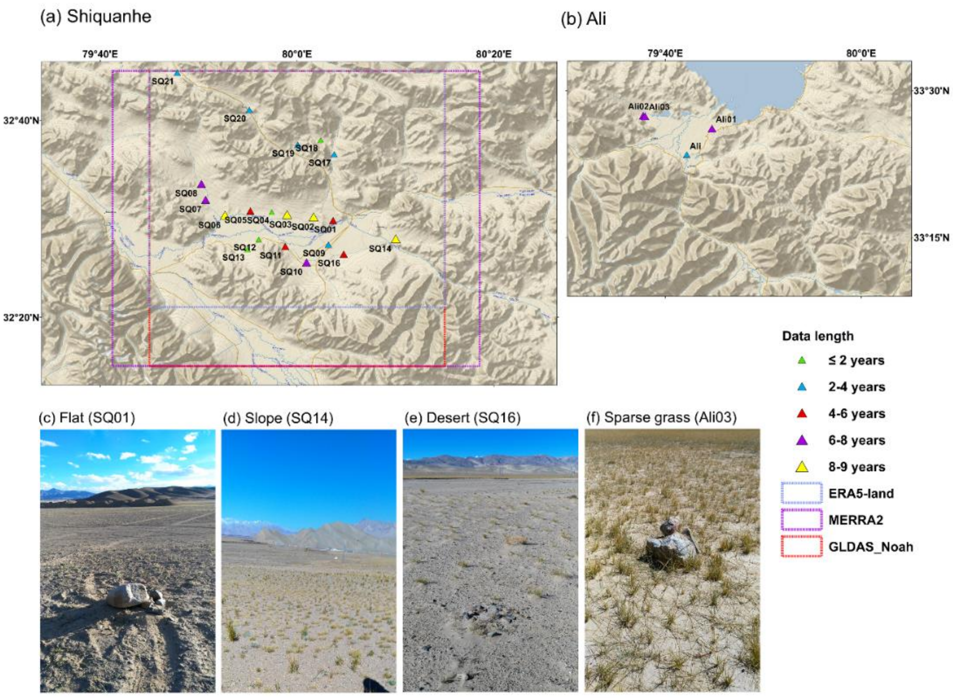

Fig. 3. Overview of the Ngari monitoring network including (a) Shiquanhe and (b) Ali networks, and typical characteristics of topography and land cover within the network: (c) flat, (d) slope (e) desert, and (f) sparse grass. The colored triangles in (a) and (b) represent different data lengths of surface SM measurements for each site, and the colored boxes represent the coverage of selected model-based products. The site name in the bracket in (c)-(f) indicates the site location for which the photograph is selected. (Base map copyright: ©2018 Garmin)

Table 4. Same as the Table 2 but for the Ngari network (BD and OMG data are not available).

Site name	Elevation (m)	TPG	LC	STX
		Shiquanhe network		
SQ01	4306	Flat	Desert	Loamy sand
SQ02	4304	Gentle slope	Desert	Sand
SQ03	4278	Gentle slope	Desert (with sparse bushes)	Sand
SQ04	4269	Edge of a wetland	Sparse grass	Loamy sand
SQ05	4261	Edge of a marsh	Sparse grass	Sand
SQ06	4257	Flat	Sparse grass	Loamy Sand
SQ07	4280	Flat	Desert (with sparse bushes)	Sand
SQ08	4306	Flat	Desert	Sand
SQ09	4275	Flat	Desert/river bed	Sand
SQ10	4275	Flat	Grassland	Fine sand with some thick roots
SQ11	4274	Flat	Grassland with bushes	Loamy sand
SQ12	4264	Flat	Edge of riverbed	Sandy loam
SQ13	4292	Flat	Valley bottom	Sand
SQ14	4368	Slope	Desert	Sandy loam
SQ16	4288	Flat	Desert/river bed	Loam

SQ17	4563	NA	NA	NA
SQ18	4634	NA	NA	NA
SQ19	4647	NA	NA	NA
SQ20	4695	NA	NA	NA
SQ21	4606	NA	NA	NA
Ali network				
Ali	4288	Flat	Grass	Loamy sand
Ali01	4262	Flat	Sparse grass	Sand
Ali02	4266	Flat	Sparse grass	Sand
Ali03	4261	Edge of a wetland	Grass	Sand

Table 5. Same as Table 3 but for the Ngari network.

	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	Data length (months)
Shiquanhe network											
SQ01	1~7				9~12	1~9					52
SQ02	1~7				5~9					9~12	104
SQ03	1~7				8~9					9~12	107
SQ04	1~7		9~12								25
SQ05	1~7				5~12						45
SQ06	1~7		9~12	1	2~9					9~12	96
SQ07	1~7			9~12	1~8		7~8	7~8		9~12	93
SQ08	1~7	8~12		1~8	8~9					9~12	82
SQ09	1~7		9~12	1~8	9~12						37
SQ10		1~8			7~12	1~9	7~12	1~8		9~12	67
SQ11	1~7			9~12					1~8	9~12	49
SQ12	1~7		9~12								25
SQ13	1~7	8~12									12
SQ14	1~7				6 8~9					9~12	106
SQ16	1~7	7~8			3~8	9~12					53
SQ17							1~8			9~12	36
SQ18							1~8	1	9~12		23
SQ19							1~8			9~12	36
SQ20							1~8			9~12	36
SQ21							1~8			9~12	36
Ali network											

Ail	**1~7**		**9~12**	**1~8**				**1~8**	**8~12**		**40**
Ali01	**1~7**	**8~12**	**1~8**		**8**				**8~12**		**82**
Ali02	**1~7 11~12**	**1~8**			**8**				**8~12**		**85**
Ali03	**1~7**			**3~12**	**1~8**				**8~12**		**78**

3.3 Naqu network

The Naqu network is located in the Naqu river basin with an average elevation of 4500 m. The climate type is characterized as cold-semiarid with cold dry winters and rainy summers. Over three-quarters of total annual precipitation (400 mm) falls between June and August. The landscape is dominated by the short grass. The network consists originally of five SMST monitoring sites installed in 2006, and six new sites were installed between 2010 and 2016. The basic information of each monitoring site is summarized in Table 6, and the typical characteristics of topography and land cover within the network are shown in Fig 4 as well. Table 7 provides the specific periods of data missing during each year and the total data lengths of surface SM for each site.

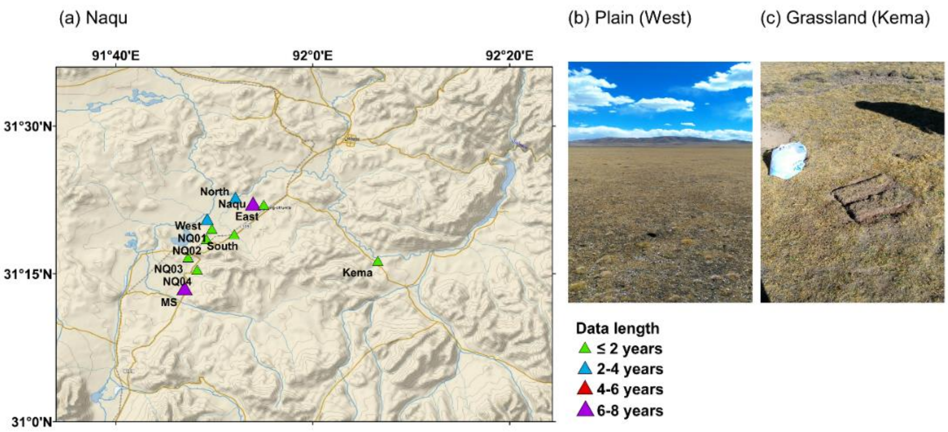

Fig. 4. (a) Overview of the Naqu monitoring network, and typical characteristics of topography and land cover within the network: (b) plain, and (c) grassland. The colored triangles in (a) represent different data lengths of surface SM measurements for each site. The site name in the bracket in (b) and (c) indicates the site location for which the photograph is selected. (Base map copyright: ©2018 Garmin)

Table 6. Same as the Table 2 but for the Naqu network (BD and OMG data are not available).

Site name	Elevation (m)	TPG	LC	STX
Naqu	4509	Plain	Grassland	Loamy sand
East	4527	Flat hill top	Grassland	Loamy sand
West	4506	Plain	Grassland	Loamy sand
North	4507	Slope on riverbank	Grassland	Loamy sand
South	4510	Wetland	Wetland	Loamy sand
Kema	4465	River valley	Grass	Silt loam
MS	4583	NA	NA	NA
NQ01	4517	NA	NA	NA

NQ02	4552	NA	NA	NA
NQ03	4638	NA	NA	NA
NQ04	4632	NA	NA	NA

Table 7. Same as Table 3 but for the Naqu network.

	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	Data length (months)
Naqu	1~7			8~9	6~8	6~9		9~12	1~8	9~12	88
East		1~8		9~12							24
West	1~7	1~8		1~9	7~12	1~7	8~12				42
North		1~8 11~12	1~3 9	9~12			1~8	9~12	1~8	9~12	42
South		1~8	9~12								12
Kema				1~9	3~9		8~12				26
MS	1~7		10~12	1~9	8~9 11~12	1~5		9~12	1~8	9~12	76
NQ01									1~8	9~12	12
NQ02									1~8	9~12	12
NQ03							1~8	9~12	1~8	9~12	24
NQ04									1~8	9~12	12

4. Existing dataset/script linkage

1. MODIS datasets
   - MODIS/Terra+Aqua BRDF/Albedo Albedo Daily L3 Global - 500m V006 (MCD43A3) https://search.earthdata.nasa.gov/search?q=C1000000426-LPDAAC_ECS
   - MODIS/Aqua Land Surface Temperature/Emissivity Daily L3 Global 1km SIN Grid V006 (MYD11A1) https://search.earthdata.nasa.gov/search?q=C203669661-LPDAAC_ECS
   - MODIS/Terra Land Surface Temperature/Emissivity Daily L3 Global 1km SIN Grid V006 (MOD11A1) https://search.earthdata.nasa.gov/search?q=C203669662-LPDAAC_ECS
2. ERA5-land dataset
   - ERA5-land hourly data: Volumetric soil water layer 1 (swvl1) https://cds.climate.copernicus.eu/cdsapp#!/dataset/reanalysis-era5-land?tab=form
3. MERRA2 dataset
   - MERRA-2 tavg1_2d_int_Nx: Soil Water surface layer (SFMC) https://search.earthdata.nasa.gov/search?q=M2T1NXINT
4. GLDAS Noah dataset
   - GLDAS_NOAH025_3H: SoilMoi0_10cm_inst https://search.earthdata.nasa.gov/search?q=GLDAS_NOAH025_3H_2.0
5. Precipitation data
   https://data.cma.cn/dataService/cdcindex/datacode/SURF_CLI_CHN_MUL_DAY.html.

5. Reference

Bi, H., & Ma, J. (2015). Evaluation of simulated soil moisture in GLDAS using in-situ measurements over the Tibetan Plateau. *International Geoscience and Remote Sensing Symposium (IGARSS)*, *2015-Novem*, 4825–4828. https://doi.org/10.1109/IGARSS.2015.7326910

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