

SUPPLEMENTARY MATERIALS TO:

## Multi-temporal glacier inventory revealing four decades of glacier changes in the Ladakh region

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Table S1. Details of the imagery used in this study

Satellite Sensor (date of acquisition)	Scene ID	Imagery date	Path/ Row	Purpose	Source
Landsat MSS (22 Sept. 1972 – 22 Oct. 1980)	LM01_L1GS_157037_19721027_20180429_01_T2	27 Oct. 1972	157/37	Glacier Boundary Delineation and Snow Line Mapping ( <a href="https://earthexplorer.usgs.gov/">https://earthexplorer.usgs.gov/</a> )	
	LM01_L1TP_158037_19720922_20180429_01_T2	22 Sept. 1972	158/37		
	LM02_L1TP_156037_19761014_20180424_01_T2	14 Oct. 1976	156/37		
	LM02_L1TP_156038_19761014_20180424_01_T2	14 Oct. 1976	156/38		
	LM02_L1TP_159035_19760911_20180424_01_T2	11 Sept. 1976	159/35		
	LM02_L1TP_159037_19760911_20180424_01_T2	11 Sept. 1976	159/37		
	LM02_L1TP_157036_19770922_20180423_01_T2	22 Sept. 1977	157/36		
	LM02_L1TP_157037_19770922_20180423_01_T2	22 Sept. 1977	157/37		
	LM02_L1TP_159036_19770801_20180422_01_T2	01 Aug. 1977	159/36		
	LM02_L1GS_158036_19770818_20180422_01_T2	18 Aug. 1977	158/36		
	LM02_L1TP_158036_19770713_20180422_01_T2	13 Jul. 1977	158/36		
	LM02_L1TP_159035_19770714_20180422_01_T2	14 Jul. 1977	159/35		
	LM02_L1TP_155038_19770920_20180423_01_T2	20 Sept. 1977	155/38		
	LM02_L1TP_160036_19770907_20180423_01_T2	07 Sept. 1977	160/36		
	LM03_L1TP_160036_19790906_20180419_01_T2	06 Sept. 1979	160/36		
	LM03_L1TP_158037_19801022_20180418_01_T2	22 Oct. 1980	158/37		
LM03_L1TP_157038_19800915_20180417_01_T2	15 Sept. 1980	157/38			
Landsat TM (07 Jul. 1993 – 21 Oct. 1994)	LT05_L1TP_147035_19930902_20170117_01_T1	02 Sept. 1993	147/35		
	LT05_L1TP_148035_19930707_20170118_01_T1	07 Jul. 1993	148/35		
	LT05_L1TP_144038_19941018_20170112_01_T1	18 Oct. 1994	144/38		
	LT05_L1TP_145036_19940923_20170112_01_T1	23 Sept. 1994	145/36		
	LT05_L1TP_145037_19940923_20170112_01_T1	23 Sept. 1994	145/37		
	LT05_L1TP_145038_19941009_20170112_01_T1	09 Oct. 1994	145/38		
	LT05_L1TP_146036_19940930_20170112_01_T1	30 Sept. 1994	146/36		
	LT05_L1TP_146037_19940930_20170112_01_T1	30 Sept. 1994	146/37		
	LT05_L1TP_146038_19940930_20170112_01_T1	30 Sept. 1994	146/38		
	LT05_L1TP_147036_19940921_20170112_01_T1	21 Sept. 1994	147/36		
	LT05_L1TP_147037_19940921_20170112_01_T1	21 Sept. 1994	147/37		
	LT05_L1TP_148036_19940726_20170113_01_T1	26 Jul. 1994	148/36		
	LT05_L1TP_148037_19940726_20170113_01_T2	26 Jul. 1994	148/37		
	LT05_L1TP_149036_19941021_20170111_01_T1	21 Oct. 1994	149/36		

<p style="text-align: center;">Landsat TM (04 Aug. 2009 – 30 Sep. 2009)</p>	<p>LT05_L1TP_145036_20090815_20161022_01_T1            LT05_L1TP_145037_20090916_20161020_01_T1            LT05_L1TP_146036_20090923_20161020_01_T1            LT05_L1TP_146037_20090923_20161020_01_T1            LT05_L1TP_146038_20090923_20161020_01_T1            LT05_L1TP_147035_20090930_20161019_01_T1            LT05_L1TP_147036_20090930_20161019_01_T1            LT05_L1TP_147037_20090930_20161019_01_T1            LT05_L1TP_148035_20090804_20161026_01_T1            LT05_L1TP_148036_20090921_20161020_01_T1            LT05_L1TP_148037_20090921_20161020_01_T1            LT05_L1TP_149035_20090827_20161021_01_T1            LT05_L1TP_149036_20090827_20161022_01_T1            LT05_L1TP_147037_20090813_20161022_01_T1            LT05_L1TP_146038_20090907_20161021_01_T1            LT05_L1TP_146037_20090907_20161021_01_T1            LT05_L1TP_144038_20090824_20161022_01_T1            LT05_L1TP_144038_20090824_20161022_01_T1            LT051450382009073001T1-SC20200810160011</p>	<p>15 Aug. 2009            16 Sept. 2009            23 Sept. 2009            23 Sept. 2009            23 Sept. 2009            30 Sept. 2009            30 Sept. 2009            30 Sept. 2009            30 Sept. 2009            04 Aug. 2009            21 Sept. 2009            21 Sept. 2009            27 Aug. 2009            27 Aug. 2009            13 Aug. 2009            07 Sept. 2009            07 Sept. 2009            24 Aug. 2009            30 Jul. 2009</p>	<p>145/36            145/37            145/38            146/36            146/37            146/38            147/35            147/36            147/37            148/35            148/36            148/37            149/36            147/37            146/38            146/37            144/38            145/38</p>	<p style="text-align: center;">Glacier Boundary Delineation and Snow Line Mapping (<a href="https://earthexplorer.usgs.gov/">https://earthexplorer.usgs.gov/</a>)</p>	
<p style="text-align: center;">Landsat OLI (29 Aug. 2018 – 23 Oct. 2019)</p>	<p>LC08_L1TP_144038_20191023_20191030_01_T1            LC08_L1TP_145036_20190912_20190917_01_T1            LC08_L1TP_145037_20190912_20190917_01_T1            LC08_L1TP_145038_20190912_20190917_01_T1            LC08_L1TP_146036_20190903_20190916_01_T1            LC08_L1TP_146037_20190919_20190926_01_T1            LC08_L1TP_146038_20190919_20190926_01_T1            LC08_L1TP_147035_20190910_20190917_01_T1            LC08_L1TP_147036_20190910_20190917_01_T1            LC08_L1TP_147037_20190910_20190917_01_T1            LC08_L1TP_148035_20190816_20190821_01_T1            LC08_L1TP_148036_20190816_20190821_01_T1            LC08_L1TP_148037_20180829_20180911_01_T1            LC08_L1TP_149036_20190924_20191017_01_T1</p>	<p>23 Oct. 2019            12 Sept. 2019            12 Sept. 2019            12 Sept. 2019            03 Sept. 2019            19 Sept. 2019            19 Sept. 2019            10 Sept. 2019            10 Sept. 2019            10 Sept. 2019            10 Sept. 2019            16 Aug. 2019            16 Aug. 2019            29 Aug. 2018            24 Sept. 2019</p>	<p>144/38            145/36            145/37            145/38            146/36            146/37            146/38            147/35            147/36            147/37            148/35            148/36            148/37            149/36</p>		
<p style="text-align: center;">ASTER GDEM (1 Jan. 2000 – 30 Nov. 2013)</p>	<p>ASTGTMV003_N32E080            ASTGTMV003_N33E080            ASTGTMV003_N34E075            ASTGTMV003_N34E079            ASTGTMV003_N32E078            ASTGTMV003_N33E076            ASTGTMV003_N32E077            ASTGTMV003_N35E077            ASTGTMV003_N35E076            ASTGTMV003_N33E078            ASTGTMV003_N34E078            ASTGTMV003_N34E077            ASTGTMV003_N34E076            ASTGTMV003_N32E079            ASTGTMV003_N35E078            ASTGTMV003_N33E079            ASTGTMV003_N33E077</p>	<p style="text-align: center;">01 March 2000 – 30 November 2013</p>	<p>N32E080            N33E080            N34E075            N34E079            N32E078            N33E076            N32E077            N35E077            N35E076            N33E078            N34E078            N34E077            N34E076            N32E079            N35E078            N33E079            N33E077</p>	<p style="text-align: center;">Catchment Delineation</p>	<p style="text-align: center;"><a href="https://search.earthdata.nasa.gov/">https://search.earthdata.nasa.gov/</a></p>

Table S2: Estimated uncertainty for different sensors and area classes through buffer based assesment.

<b>Sensor Uncertainty</b>				
<b>Sensor</b>	<b>Year</b>	<b>Area (Km<sup>2</sup>)</b>	<b>Uncertainty (Km<sup>2</sup>)</b>	<b>Uncertainty (%)</b>
<b>Landsat (MSS)</b>	1977	8511	±861	±10.1
<b>Landsat (TM)</b>	1994	8173	±431	±5.3
<b>Landsat (TM)</b>	2009	8096	±428	±5.3
<b>Landsat (OLI)</b>	2019	7923	±212	±2.7
<b>Overall mean</b>	1977-2019	8175	±483	±5.9
<b>Area Class Uncertainty</b>				
<b>Area Class</b>	<b>Year</b>	<b>Area (Km<sup>2</sup>)</b>	<b>Uncertainty (Km<sup>2</sup>)</b>	<b>Uncertainty (%)</b>
<b>0.5 – 1 km<sup>2</sup></b>	1977-2019	788	±85	±10.3
<b>1 – 5 km<sup>2</sup></b>	1977-2019	2327	±175	±7.4
<b>5 – 10 km<sup>2</sup></b>	1977-2019	867	±50	±5.7
<b>10 – 50 km<sup>2</sup></b>	1977-2019	1631	±78	±4.8
<b>50 – 100 km<sup>2</sup></b>	1977-2019	678	±29	±4.3
<b>&gt; 100 km<sup>2</sup></b>	1977-2019	1885	±66	±3.5

Table S3: Trend analysis using Mann-Kendall test and Sen's slope estimator of temperature, precipitation and positive degree days in the seven grids of the study area.

ERA5 Grid points	ANNUAL				JJAS				WINTER			
	Mann-Kendall Significance (p)	Sens Slope ( $\beta$ )	Long-term Mean ( $^{\circ}\text{C}$ or mm)	Change ( $^{\circ}\text{C}$ or mm)	Mann-Kendall Significance (p)	Sens Slope ( $\beta$ )	Long-term Mean ( $^{\circ}\text{C}$ or mm)	Change $^{\circ}\text{C}$ or mm	Mann-Kendall Significance (p)	Sens Slope ( $\beta$ )	Long-term Mean ( $^{\circ}\text{C}$ or mm)	Change $^{\circ}\text{C}$ or mm
<b><u>TEMPERATURE</u></b>												
	<u>ANNUAL</u>				<u>JJAS</u>				<u>WINTER</u>			
Shiquanhe	0.01	0.03	1.59	0.77	0.05	0.02	12	0.07	0.01	0.03	-6	-0.21
Tsomoriri	0.01	0.03	4.75	0.26	0.01	0.04	6.43	0.26	0.1	0.03	-12.28	-0.10
Leh	0.01	0.04	7.65	0.21	0.01	0.05	18.67	0.11	0.05	0.03	-0.45	-2.73
Rutog	0.01	0.03	-2.02	-0.61	0.01	0.02	9.63	0.09	0.05	0.03	-10.9	-0.11
Kargil	0.05	0.02	7.19	0.11	0.05	0.02	17.54	0.05	0.05	0.03	-0.59	-2.08
Padum	0.01	0.02	2.48	0.33	0.05	0.02	11.56	0.07	0.05	0.02	-4.77	-0.17
Turtuk	0.01	0.02	2.73	0.30	0.05	0.03	13.16	0.09	0.05	0.02	-5.24	-0.16
<b><u>PRECIPITATION</u></b>												
	<u>ANNUAL</u>				<u>JJAS</u>				<u>WINTER</u>			
	(p)	( $\beta$ )	Mean	Change	(p)	( $\beta$ )	Mean	Change	(p)	( $\beta$ )	Mean	Change
Shiquanhe	0.05	0.74	81	0.37	0.05	0.84	64	0.54	0.3	-0.05	12	-0.17
Tsomoriri	0.8	0.07	106.32	0.03	0.4	0.33	69.14	0.20	0.1	-0.13	29.85	-0.18
Leh	0.4	-0.33	58.12	-0.23	0.6	-0.1	27.65	-0.15	0.9	0.001	19.27	0.00
Rutog	0.05	0.93	116.93	0.33	0.05	1.05	95.22	0.45	0.3	-0.05	15.96	-0.13
Kargil	0.5	-0.12	122.67	-0.04	0.8	0.02	40.8	0.02	0.6	-0.13	72.22	-0.07
Padum	0.6	-0.19	124.64	-0.06	0.3	0.06	26.78	0.09	0.8	-0.07	87.73	-0.03
Turtuk	0.5	-0.1	85.65	-0.05	0.4	0.08	34.72	0.09	0.5	-0.06	44.11	-0.06
<b><u>POSITIVE DEGREE DAYS AND SOLID PRECIPITATION</u></b>												
	(p)	( $\beta$ )	Mean	Change	(p)	( $\beta$ )	Mean	Change				
	<u>PDD (Annual)</u>				<u>Psnow (Annual)</u>							
Shiquanhe	0.01	6.6	1807	0.15	0.1	-0.21	22	-0.37				
Tsomoriri	0.01	6.1	888	0.27	0.02	-0.49	62	-0.31				
Leh	0.01	12.1	3431	0.14	0.5	-0.02	11	-0.07				
Rutog	0.01	8.2	1668	0.20	0.12	-0.2	29	-0.28				
Kargil	0.01	8.0	3518	0.09	0.2	-0.08	16	-0.19				
Padum	0.01	7.5	2652	0.11	0.9	-0.09	35	-0.10				
Turtuk	0.1	5.9	2033	0.12	0.4	-0.07	31	-0.09				



a. Pensila Glacier, Kargil, Ladakh    b. Parkachik Glacier, Kargil, Ladakh    c. Khardung Glacier, Leh, Ladakh  
d. Changla Glacier, Leh, Ladakh    e. Lato Glacier, Leh, Ladakh    f. Stok Glacier, Leh, Ladakh

Figure S1: Some of the field investigated glaciers of the Ladakh region between 2016 and 2019. Glaciers of Suru Basin (a, b), Leh Basin (d, e, f) and Shayok Basin (c). The location of these glaciers is mentioned in Figure 1 with a star symbol.

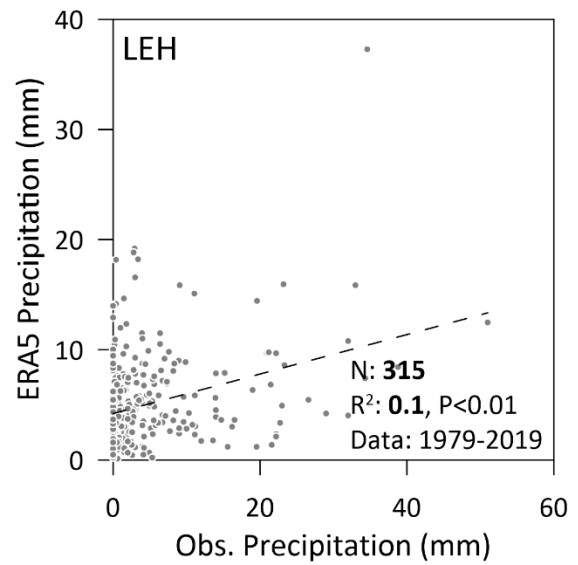
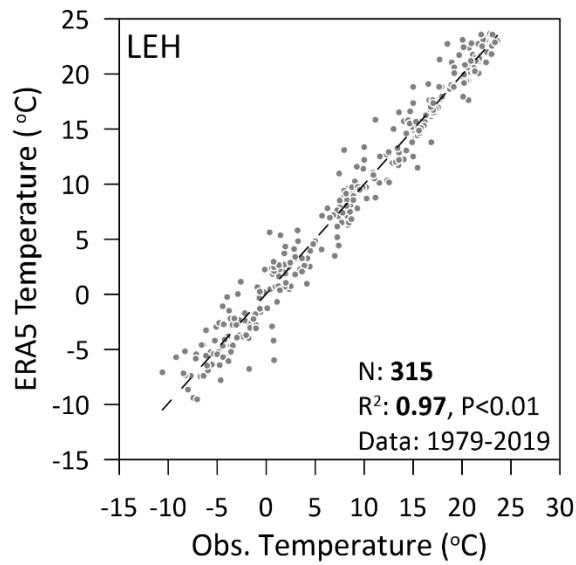
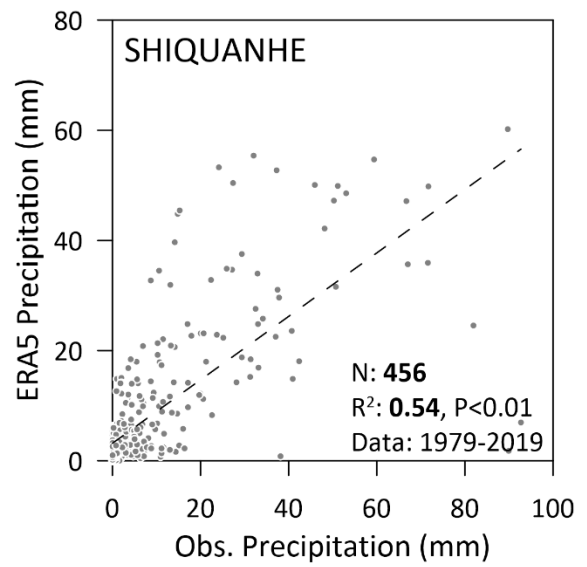
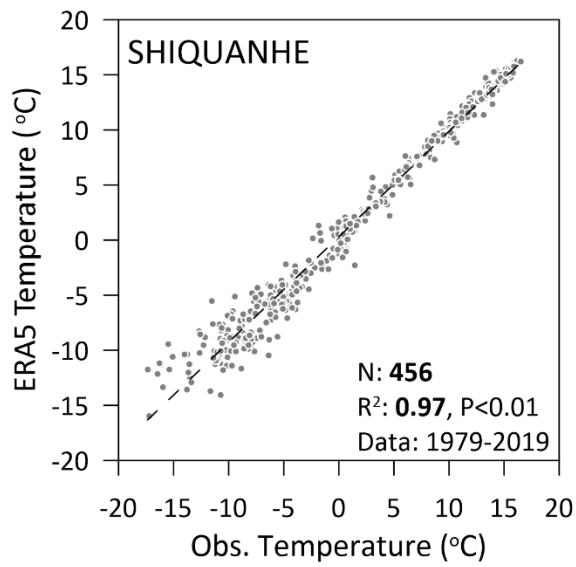


Figure S2: Observed vs bias-corrected ERA5 temperature and precipitation of Leh and Shiquanhe.

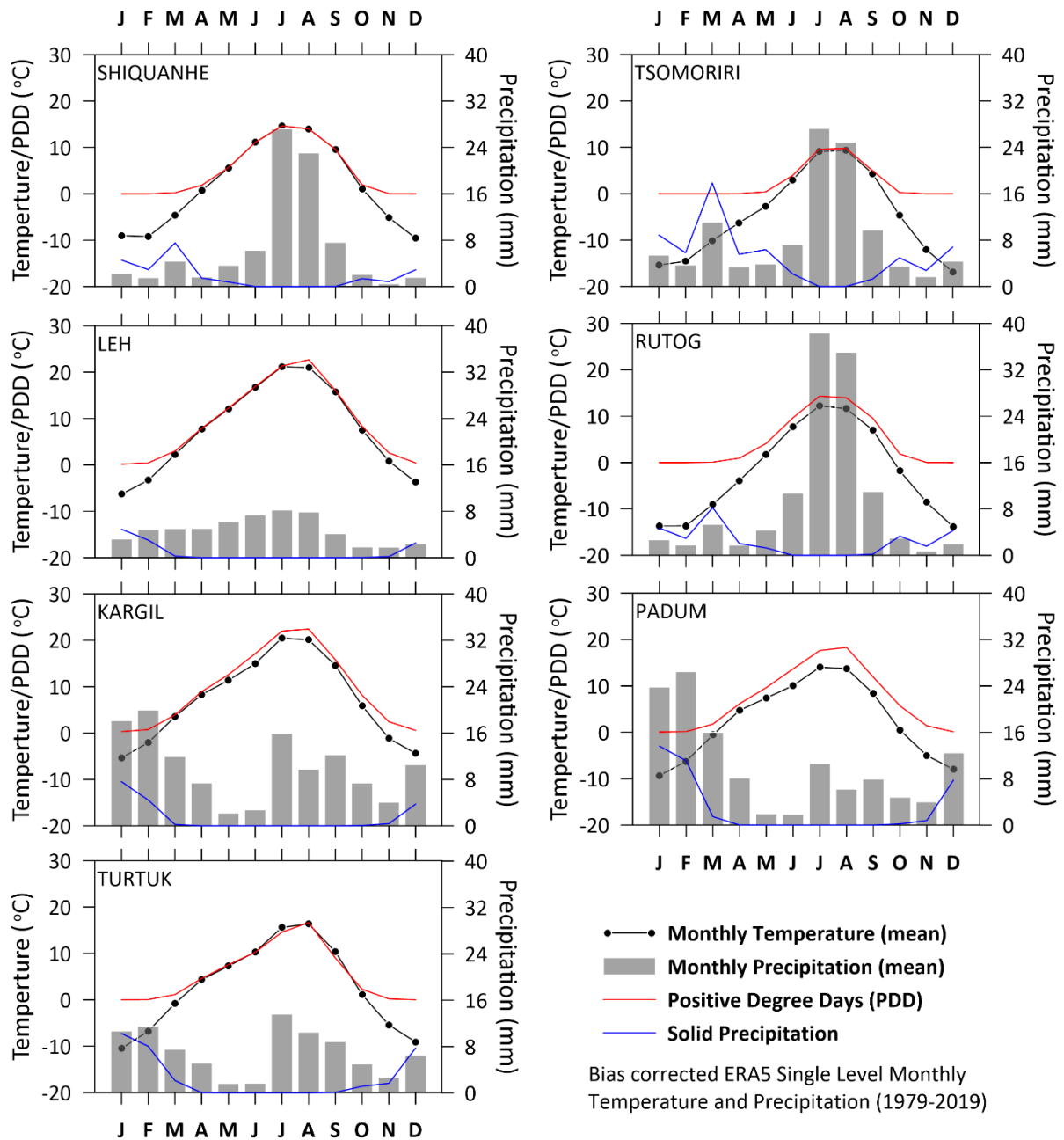


Figure S3: ERA5 bias-corrected mean monthly temperature and precipitation of the seven grids of the study area.