SUPPLIMENTARY MATERIALS TO:

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

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**Note**: Supplementary tables (S1, S2 and S3) are also available as csv format.

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  LM01\_L1TP\_158037\_19720922\_20180429\_01\_T2  LM02\_L1TP\_156037\_19761014\_20180424\_01\_T2  LM02\_L1TP\_156038\_19761014\_20180424\_01\_T2  LM02\_L1TP\_159035\_19760911\_20180424\_01\_T2  LM02\_L1TP\_159037\_19760911\_20180424\_01\_T2  LM02\_L1TP\_157036\_19770922\_20180423\_01\_T2  LM02\_L1TP\_157037\_19770922\_20180423\_01\_T2  LM02\_L1TP\_159036\_19770801\_20180422\_01\_T2  LM02\_L1GS\_158036\_19770818\_20180422\_01\_T2  LM02\_L1TP\_158036\_19770713\_20180422\_01\_T2  LM02\_L1TP\_159035\_19770714\_20180422\_01\_T2  LM02\_L1TP\_155038\_19770920\_20180423\_01\_T2  LM02\_L1TP\_160036\_19770907\_20180423\_01\_T2  LM03\_L1TP\_160036\_19790906\_20180419\_01\_T2  LM03\_L1TP\_158037\_19801022\_20180418\_01\_T2  LM03\_L1TP\_157038\_19800915\_20180417\_01\_T2 | 27 Oct. 1972  22 Sept. 1972  14 Oct. 1976  14 Oct. 1976  11 Sept. 1976  11 Sept. 1976  22 Sept. 1977  22 Sept. 1977  01 Aug. 1977  18 Aug. 1977  13 Jul. 1977  14 Jul. 1977  20 Sept. 1977  07 Sept. 1977  06 Sept. 1979  22 Oct. 1980  15 Sept. 1980 | 157/37  158/37  156/37  156/38  159/35  159/37  157/36  157/37  159/36  158/36  158/36  159/35  155/38  160/36  160/36  158/37  157/38 | Glacier Boundary Delineation and Snow Line Mapping | | (https://earthexplorer.usgs.gov/) |
| Landsat TM  (07 Jul. 1993 – 21 Oct. 1994) | LT05\_L1TP\_147035\_19930902\_20170117\_01\_T1  LT05\_L1TP\_148035\_19930707\_20170118\_01\_T1  LT05\_L1TP\_144038\_19941018\_20170112\_01\_T1  LT05\_L1TP\_145036\_19940923\_20170112\_01\_T1  LT05\_L1TP\_145037\_19940923\_20170112\_01\_T1  LT05\_L1TP\_145038\_19941009\_20170112\_01\_T1  LT05\_L1TP\_146036\_19940930\_20170112\_01\_T1  LT05\_L1TP\_146037\_19940930\_20170112\_01\_T1  LT05\_L1TP\_146038\_19940930\_20170112\_01\_T1  LT05\_L1TP\_147036\_19940921\_20170112\_01\_T1  LT05\_L1TP\_147037\_19940921\_20170112\_01\_T1  LT05\_L1TP\_148036\_19940726\_20170113\_01\_T1  LT05\_L1TP\_148037\_19940726\_20170113\_01\_T2  LT05\_L1TP\_149036\_19941021\_20170111\_01\_T1 | 02 Sept. 1993  07 Jul. 1993  18 Oct. 1994  23 Sept. 1994  23 Sept. 1994  09 Oct. 1994  30 Sept. 1994  30 Sept. 1994  30 Sept. 1994  21 Sept. 1994  21 Sept. 1994  26 Jul. 1994  26 Jul. 1994  21 Oct. 1994 | 147/35  148/35  144/38  145/36  145/37  145/38  146/36  146/37  146/38  147/36  147/37  148/36  148/37  149/36 |
| Landsat TM  (04 Aug. 2009 – 30 Sep. 2009) | 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  LT051450382009073001T1-SC20200810160011 | 15 Aug. 2009  16 Sept. 2009  23 Sept. 2009  23 Sept. 2009  23 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 | 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 | Glacier Boundary Delineation and Snow Line Mapping | | (https://earthexplorer.usgs.gov/) |
| Landsat OLI  (29 Aug. 2018 – 23 Oct. 2019) | 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 | 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  16 Aug. 2019  16 Aug. 2019  29 Aug. 2018  24 Sept. 2019 | 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 |
| ASTER GDEM  (1 Jan. 2000 – 30 Nov. 2013) | 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 | 01 March 2000 – 30 November 2013 | N32E080  N33E080  N34E075  N34E079  N32E078  N33E076  N32E077  N35E077  N35E076  N33E078  N34E078  N34E077  N34E076  N32E079  N35E078  N33E079  N33E077 | Catchment Delineation | <https://search.earthdata.nasa.gov/> | |

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

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Sensor** | **Year** | **Area uncertainty** | | | **Length uncertainty** | | |
| **Area (Km2)** | **Uncertainty (Km2)** | **Uncertainty (%)** | **Length range (Km)** | **Uncertainty (Km)** | **Uncertainty (%)** |
| Landsat (MSS) | 1977 | 8511 | ±430 | ±7.2 | 0.7-74 | ±0.08 | ±2.6 |
| Landsat (TM) | 1994 | 8173 | ±215 | ±3.9 | 0.5-73.7 | ±0.04 | ±1.5 |
| Landsat (TM) | 2009 | 8096 | ±214 | ±3.9 | 0.5-73.7 | ±0.04 | ±1.5 |
| Landsat (OLI) | 2019 | 7923 | ±106 | ±2.1 | 0.5-72.5 | ±0.04 | ±1.5 |
| Overall mean | 1977-2019 | 8175 | ±241 | ±4.2 | 0.5-73.5 | ±0.05 | ±1.8 |
|  |  |  |  |  |  |  |  |
| **Area Class** | **Year** | **Area (Km2)** | **Uncertainty (Km2)** | **Uncertainty (%)** | **Length range (Km)** | **Uncertainty (Km)** | **Uncertainty (%)** |
| 0.5 – 1 km2 | 1977-2019 | 788 | ±31 | ±5.3 | 0.5-3.2 | ±0.02 | ±1 |
| 1 – 5 km2 | 1977-2019 | 2327 | ±96 | ±4.0 | 0.6-6.3 | ±0.04 | ±0.6 |
| 5 – 10 km2 | 1977-2019 | 867 | ±27 | ±2.9 | 2.8-9.6 | ±0.08 | ±0.3 |
| 10 – 50 km2 | 1977-2019 | 1631 | ±40 | ±2.5 | 4.4-17.8 | ±0.14 | ±0.2 |
| 50 – 100 km2 | 1977-2019 | 678 | ±15 | ±2.2 | 13.4-23.7 | ±0.28 | ±0.1 |
| > 100 km2 | 1977-2019 | 1885 | ±33 | ±1.9 | 21.2-72.5 | ±0.54 | ±0.05 |

Table S3: Comparison of glacier change attributes between the present study and others recent studies.

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Source** | **Basin** | **Range/ Glacier/ Region** | **Code** | **Other recent studies** | | | | | **Present study** | | | | |
| **No. of glaciers** | **Size (km2)** | **Year** | **Total Retreat (%)** | **Retreat rate (%/year)** | **No. of glaciers** | **Size (km2)** | **Year** | **Total Retreat (%)** | **Retreat rate (%/year)** |
| Negi et al., 2021 | Shayok | Shayok sub-basin | SSB | 569 | >1 | 1991-2014 | -0.19 | -0.008 | 603 | >1 | 1994-2019 | -0.94 | -0.038 |
| Siachen Glacier | A | 1 | >100 | 1990-2014 | -0.08 | -0.003 | 1 | >100 | 1994-2019 | -0.28 | -0.007 |
| Central Rimo Glacier | B | 1 | >100 | 1990-2014 | -0.52 | -0.022 | 1 | >100 | 1994-2019 | 0.61 | 0.015 |
| Southern Rimo Glacier | C | 1 | >100 | 1990-2014 | -1.05 | -0.044 | 1 | >100 | 1994-2019 | -1.87 | -0.045 |
| Mamosto Glacier | F | 1 | 50-100 | 1990-2014 | -0.17 | -0.007 | 1 | 50-100 | 1994-2019 | -0.79 | -0.019 |
| Kumdan Glacier | D | 1 | 50-100 | 1990-2014 | -2.35 | -0.098 | 1 | 50-100 | 1994-2019 | -0.84 | -0.020 |
| Urdolep Glacier | J | 1 | 10-50 | 1990-2014 | -0.19 | -0.008 | 1 | 10-50 | 1994-2019 | -0.59 | -0.014 |
| Layongma Glacier | H | 1 | 10-50 | 1990-2014 | -1.71 | -0.071 | 1 | 10-50 | 1994-2019 | -2.39 | -0.057 |
| Lagongma Glacier | G | 1 | 10-50 | 1990-2014 | -0.27 | -0.011 | 1 | 10-50 | 1994-2019 | -1.47 | -0.035 |
| Aktash Glacier | E | 1 | 10-50 | 1990-2014 | 16.88 | 0.703 | 1 | 10-50 | 1994-2019 | 2.39 | 0.057 |
| Thusa Glacier | I | 1 | 10-50 | 1990-2014 | -7.47 | -0.311 | 1 | 10-50 | 1994-2019 | -1.81 | -0.043 |
| Bhambri et al. 2013 | Upper Shayok Basin | USB | 136 | >0.2 | 1974-2011 | 0.14 | 0.004 | 570 | >0.5 | 1977-2009 | -2.2 | -0.069 |
| Central Rimo Glacier | B | 1 | >100 | 1974-1998 | 0.04 | 0.002 | 1 | >100 | 1977-1994 | -1.88 | -0.111 |
| Central Rimo Glacier | B | 1 | >100 | 1998-2011 | -0.59 | -0.045 | 1 | >100 | 1994-2009 | 1.16 | 0.078 |
| Kumdan Glacier | D | 1 | 50-100 | 1974-1998 | -6.71 | -0.279 | 1 | 50-100 | 1977-1994 | -3.24 | -0.191 |
| Kumdan Glacier | D | 1 | 50-100 | 1998-2011 | 5.27 | 0.406 | 1 | 50-100 | 1994-2009 | 2.98 | 0.199 |
| Aktash Glacier | E | 1 | 10-50 | 1974-1998 | 0.37 | 0.016 | 1 | 10-50 | 1977-1994 | -0.78 | -0.048 |
| Aktash Glacier | E | 1 | 10-50 | 1998-2011 | 2.99 | 0.230 | 1 | 10-50 | 1994-2009 | 3.42 | 0.228 |
| Schmidt and Nüsser, 2017;  Schmidt and Nüsser, 2012 | Leh/ Zanskar/ Tsomoriri | Selected regions of central and eastern Ladakh | CEL | 1800 | >0.03 | 1969-2016 | -19 | -0.4 | 517 | >0.5 | 1977-2019 | -19.3 | -0.46 |
| Phuche Glacier | K | 1 | 0.5-1 | 1969-2016 | -18.0 | -0.50 | 1 | 0.5-1 | 1977-2019 | -21.0 | -0.50 |
| Hemis Shukpachen Glaciers | L | 5 | 0.2-1 | 1969-2016 | -38.0 | -0.80 | 2 | 0.5-1 | 1977-2019 | -33.0 | -0.78 |
| Stok Range | M | 7 | 0.2-1 | 1969-2016 | -22.4 | -0.40 | 3 | 0.5-1 | 1977-2019 | -10.5 | -0.30 |
| Kang Yatze | N | 35 | 0.5-1 | 1969-2010 | -18.8 | -0.40 | 26 | 0.5-1 | 1977-2010 | -24.0 | -0.50 |
| Kang Yatze | N | 25 | >1 | 1969-2010 | -12.2 | -0.20 | 17 | >1 | 1977-2010 | -11.0 | -0.25 |
| Lungser Range | O | 39 | 0.5-5 | 1969-2014 | -17.7 | -0.40 | 22 | 0.5-5 | 1977-2019 | -16.4 | -0.39 |
| Chudley et al, 2017 | Leh/ Shayok | Central Ladakh range | CLR | 76 | 1-5 | 1991-2014 | -6.6 | -0.29 | 82 | 1-5 | 1994-2019 | 7.1 | -0.39 |
| Shukla et al., 2020 | Suru | Suru Sub-basin | SUB1 | 130 | >0.5 | 1971-2017 | -9.08 | -0.20 | 136 | >0.5 | 1977-2019 | -14 | -0.28 |
| Suru Sub-basin | SUB2 | 22 | 0.5-1 | 1971-2017 | -24.04 | -0.52 | 22 | 0.5-1 | 1977-2019 | -25.18 | -0.60 |
| Suru Sub-basin | SUB3 | 47 | 1-5 | 1971-2017 | -12.10 | -0.26 | 47 | 1-5 | 1977-2019 | -16.03 | -0.38 |
| Suru Sub-basin | SUB4 | 15 | 5-10 | 1971-2017 | -4.15 | -0.09 | 15 | 5-10 | 1977-2019 | -7.91 | -0.19 |
| Suru Sub-basin | SUB5 | 6 | 10-50 | 1971-2017 | -11.11 | -0.24 | 6 | 10-50 | 1977-2010 | -4.33 | -0.10 |
| Suru Sub-basin | SUB6 | 1 | 50-100 | 1971-2017 | -0.28 | -0.01 | 1 | 50-100 | 1977-2010 | -1.24 | -0.03 |
| Tongul Glacier | P | 1 | 5-10 | 1971-2017 | -11.07 | -0.24 | 1 | 5-10 | 1977-2019 | -6.14 | -0.15 |
| Rantak Glacier | Q | 1 | 5-10 | 1971-2017 | -15.23 | -0.33 | 1 | 5-10 | 1977-2019 | -11.52 | -0.27 |
| Sentik Glacier | R | 1 | 1-5 | 1971-2017 | -14.06 | -0.31 | 1 | 1-5 | 1977-2019 | -10.48 | -0.25 |
| Parkachik Glacier | S | 1 | 10-50 | 1971-2017 | -0.27 | -0.01 | 1 | 10-50 | 1977-2019 | -1.24 | -0.03 |
| Shafat Glacier | T | 1 | 10-50 | 1971-2017 | -15.57 | -0.34 | 1 | 10-50 | 1977-2010 | -14.18 | -0.34 |
| Dulung Glacier | U | 1 | 10-50 | 1971-2017 | -10.81 | -0.24 | 1 | 10-50 | 1977-2010 | -9.05 | -0.22 |
| Chilung Glacier | V | 1 | 5-10 | 1971-2017 | -12.74 | -0.28 | 1 | 5-10 | 1977-2019 | -15.20 | -0.36 |
| Lalung Glacier | W | 1 | 10-50 | 1971-2017 | -6.57 | -0.14 | 1 | 10-50 | 1977-2019 | -3.35 | -0.08 |
| Pensilungpa Glacier | X | 1 | 10-50 | 1971-2017 | -6.14 | -0.13 | 1 | 10-50 | 1977-2019 | -3.39 | -0.08 |
| Garg et al., 2022 | Parkachik glacier | S | 1 | 10-50 | 1971-2018 | -3.30 | -0.07 | 1 | 10-50 | 1977-2019 | -1.24 | -0.03 |
| Garg et al., 2021 | Pensilungpa Glacier | X | 1 | 10-50 | 1993-2016 | -2.59 | -0.11 | 1 | 10-50 | 1994-2018 | -0.94 | -0.04 |

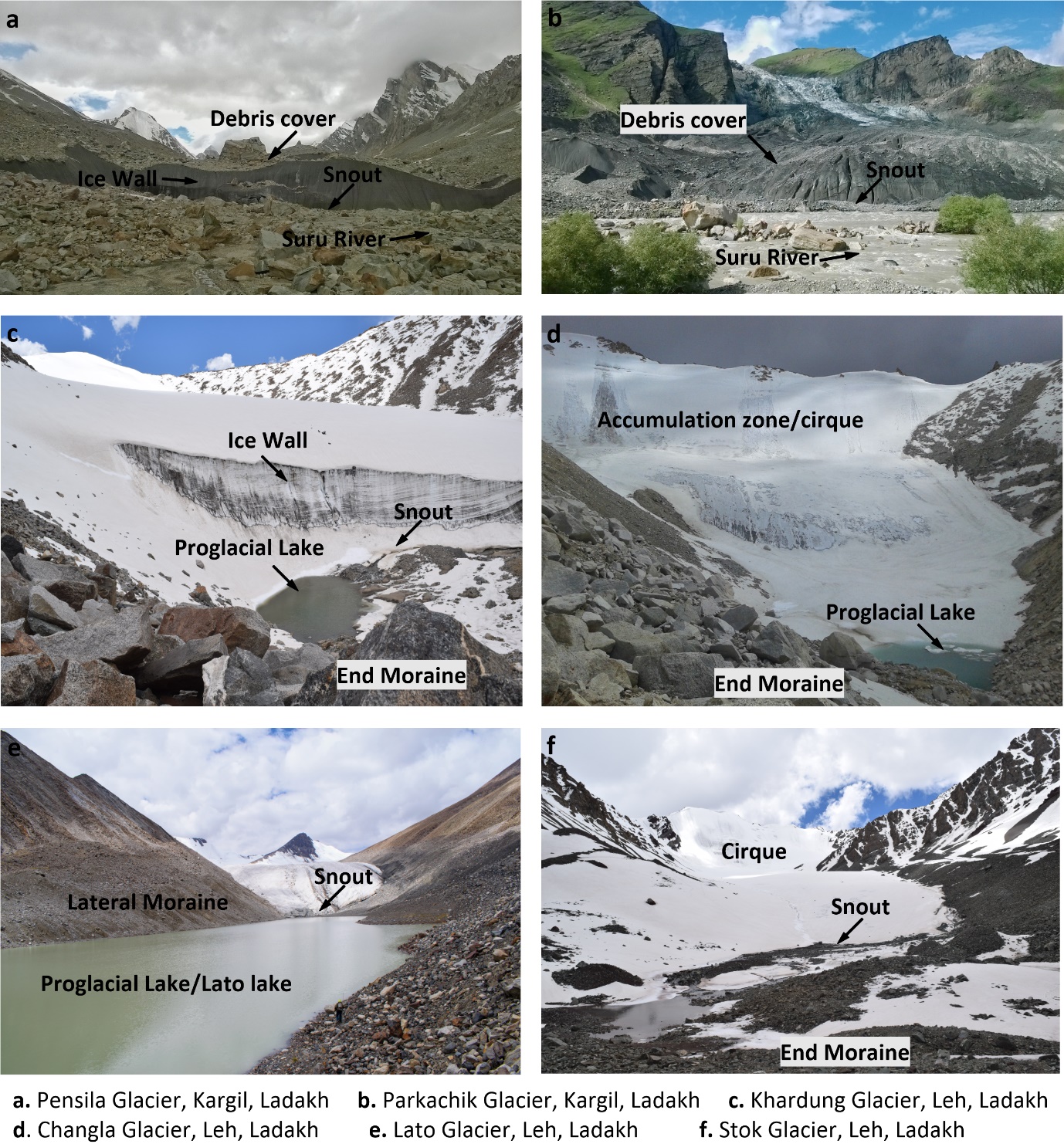


Figure S1: Some of the field investigated glaciers of the Ladakh region between 2016 and 2019. Glaciers of Suru Basin (a, b), Leh Basin (d, e, f) and Shayok Basin (c). The location of these glaciers is mentioned in Figure 1 with a star symbol.

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Figure S2: Presents the dynamics of Kumdan and Aktash glacier of Shayok basin as an example of a surge type glacier. Location of these glaciers are marked in Figure 5.