**Spatiotemporal supraglacial pond and ice cliff changes in the Bhutan-Tibet border region from 2016-2018.**

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**Supplementary Information**

A picture containing scatter chart

Description automatically generated

*Figure S1*: Comparison of PlanetScope and RapidEye imagery for automatic identification of ponds using the same NDWI threshold (0.35).

A picture containing smoke, dark, line, distance

Description automatically generated

*Figure S2:* (a) Operator repeatability assessment from the repeat digitisation of 50 cliffs over the study period and (b) Comparison of NDWI ponded area and manually digitised ponded area.



*Figure S3:* A 30 m directional buffer used to analyse supraglacial pond and ice cliff coincidence, accounting for an unknown cliff geometry. Any pond within the buffer zone is classed as coincident.

***Chart, box and whisker chart

Description automatically generatedFigure S4:*** Percentage change in pond area per day for each glacier; G1 (black), G2 (blue) and G3 (yellow) for the period January 2016 to December 2018. Seasonal boundaries are indicated by the vertical dashed lines where W= Winter, M= Monsoon; PO= Post-monsoon and PR=Pre-monsoon. Periods with no data are indicated in grey.

Map

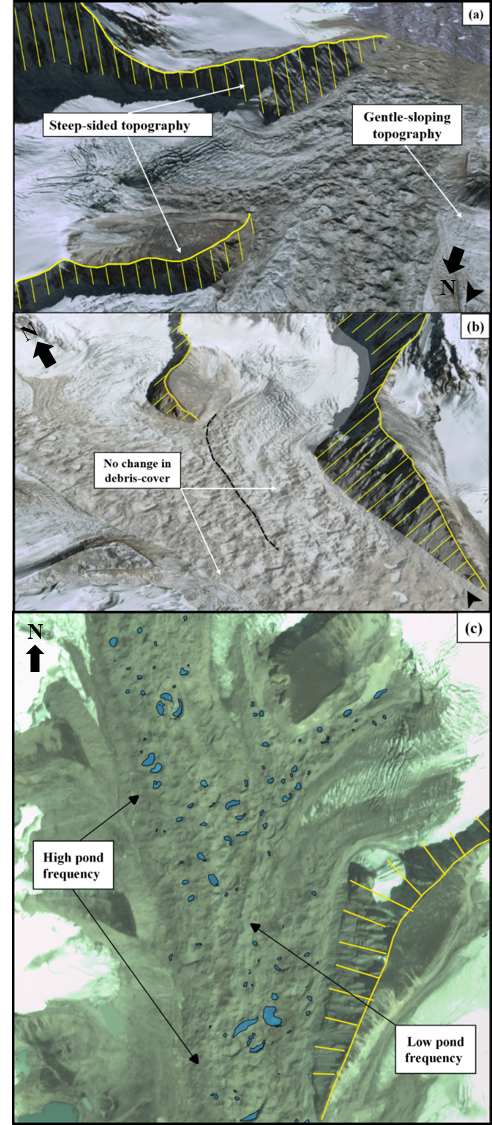
Description automatically generated

***Figure S5:*** Debris thickness estimates for the three study glaciers. Debris is generally thicker near the terminus and at the glacier margins, and thinner as you move up-glacier towards the headwall. Note ponding generally occurs where there is thinner debris cover (e.g. < 0.4 m) and in areas with thicker debris fewer ponds are found.

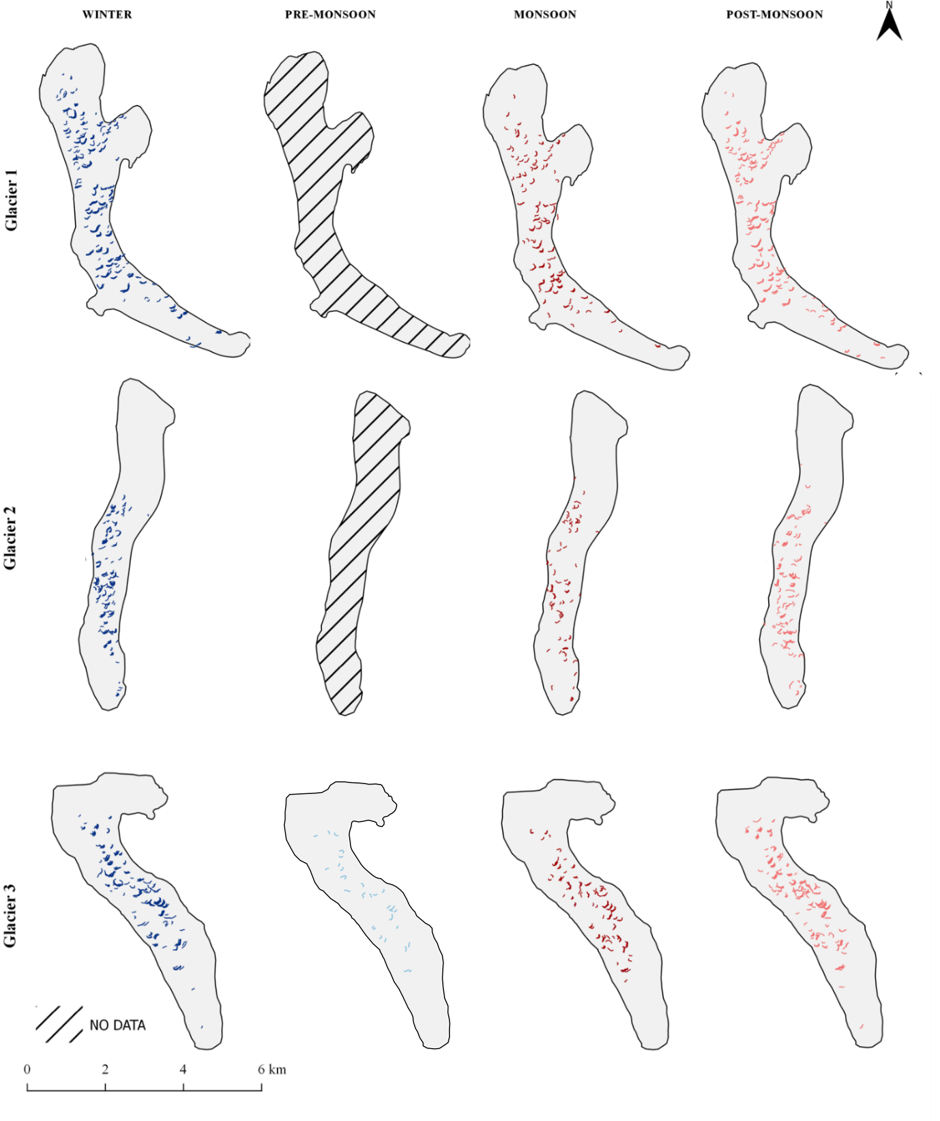
Map

Description automatically generated

***Figure S6::*** Surface slope estimates for the three study glaciers. Generally, slope is heterogenous across the glacier surface, which is to be expected given the presence of debris cover, supraglacial ponds and ice cliffs.



*Figure S7:* Topography of G1 (a) and (b) shows where the two source tributaries join; the steeper slopes on the eastern margins provide a large shadowing effect onto the glacier surface and (c) shows spatial pattern of ponding on the glacier surface. Background imagery is (a) and (b) GoogleEarth (2018) and (c) PlanetLabs (2018).



*Figure S8:* Spatial distribution of ice cliffs across all three study glaciers during the period 2016-2018 for all available seasons.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Image ID/description and spatial resolution | Image date | Image season | Number of scenes in mosaic |  | Glacier |  |
| G1 | G2 | G3 |
| **RapidEye Ortho-tile. 5 m**  **RapidEye Ortho-tile. 5 m** | **07/01/2016**  **07/02/2016**  **27/08/2016** | **W**  **W**  **M** | **2**  **4**  **1** | **\***  **\*** | **\***  **\*** | **\***  **\***  **\*** |
| **PlanetScope OS. 3 m**  **PlanetScope OS. 3 m**  **PlanetScope OS. 3 m**  **RapidEye Ortho-tile. 5 m** | **23/10/2016**  **23/11/2016**  **22/12/2016**  **07/01/2017** | **PO**  **PO**  **W**  **W** | **4**  **3**  **2**  **1** | **\***  **\***  **\*** | **\***  **\***  **\***  **\*** | **\***  **\***  **\***  **\*** |
| **PlanetScope OS. 3 m** | **16/02/2017** | **W** | **3** | **\*** | **\*** | **\*** |
| **PlanetScope OS. 3 m** | **16/06/2017** | **M** | **1** | **\*** | **\*** |  |
| **PlanetScope OS. 3 m** | **17/06/2017** | **M** | **2** |  |  | **\*** |
| **PlanetScope OS. 3 m** | **05/09/2017** | **M** | **2** |  |  | **\*** |
| **PlanetScope OS. 3 m**  **PlanetScope OS. 3m**  **PlanetScope OS. 3m**  **PlanetScope OS. 3m**  **PlanetScope OS. 3m**  **PlanetScope OS. 3m** | **19/10/2017**  **10/11/2017**  **04/12/2017**  **24/01/2018**  **02/02/2018**  **22/05/2018** | **PO**  **PO**  **W**  **W**  **W**  **PR** | **7**  **2**  **2**  **2**  **3**  **2** | **\***  **\***  **\***  **\***  **\*** | **\***  **\***  **\***  **\***  **\*** | **\***  **\***  **\***  **\***  **\*** |
| **PlanetScope OS. 3 m**  **PlanetScope OS. 3 m**  **PlanetScope OS. 3 m** | **19/06/2018**  **06/07/2018**  **08/09/2018** | **M**  **M**  **M** | **1**  **1**  **5** | **\***  **\*** | **\***  **\*** | **\*** |
| **PlanetScope OS. 3 m**  **PlanetScope OS. 3 m**  **PlanetScope OS. 3 m** | **16/10/2018**  **25/11/2018**  **06/12/2018** | **PO**  **PO**  **W** | **5**  **2**  **2** | **\***  **\***  **\*** | **\***  **\***  **\*** | **\***  **\***  **\*** |
| **High Mountain Asia DEM 8 m** | **16/07/2015** | **M** | **6** | **\*** | **\*** | **\*** |
| OS **= Orthoscene,** DEM **= Digital Elevation Model,** W**= Winter,** PR**= Pre-monsoon,** M**= Monsoon,** PO**= Post-monsoon.** Image Date: **dd/mm/yyyy.** | | | | | | |

***Table S1:*** Spatial and temporal coverage of imagery used in this study. Image ID (e.g. sensor type) and spatial resolution are given, along with the image date and the number of scenes within each monthly mosaic. The stars (\*) indicate glacier coverage. Data in red was discarded from the study.