A comparison of the drainage systems of two High Asian debris-covered glaciers

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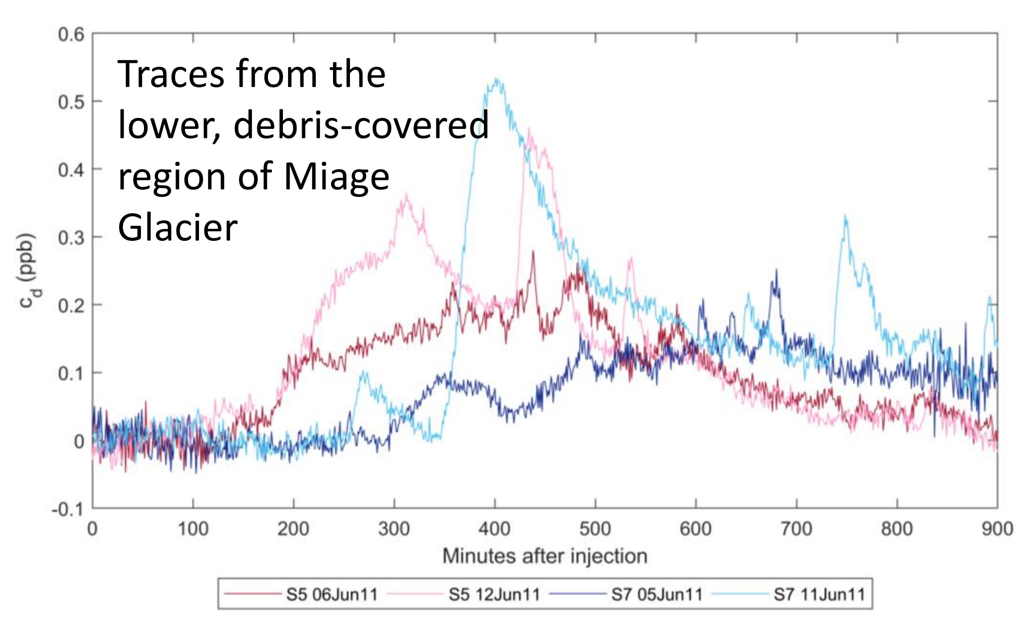
Introduction

- Previous work suggests that debris-covered glaciers have an inefficient hydrological system beneath their debris-covered area (Fyffe *et al.,* 2019a; Miles *et al.,* 2019)
- This results in a more subdued proglacial runoff hydrograph (smaller diurnal amplitude, longer lag from Ta to Q peak) (Fyffe *et al.,* 2019b)
- However, there have been few glacier hydrology studies of glaciers in High Mountain Asia, especially those able to study all parts of the hydrological system and to identify seasonal changes



Our objectives are:

1. To determine the structure and efficiency of each part of the drainage system and how this changes over the season

2. Compare the characteristics of the hydrological system and proglacial runoff signal of Langtang and 24K Glaciers

Methods

Two study sites:

Langtang Glacier, Nepal

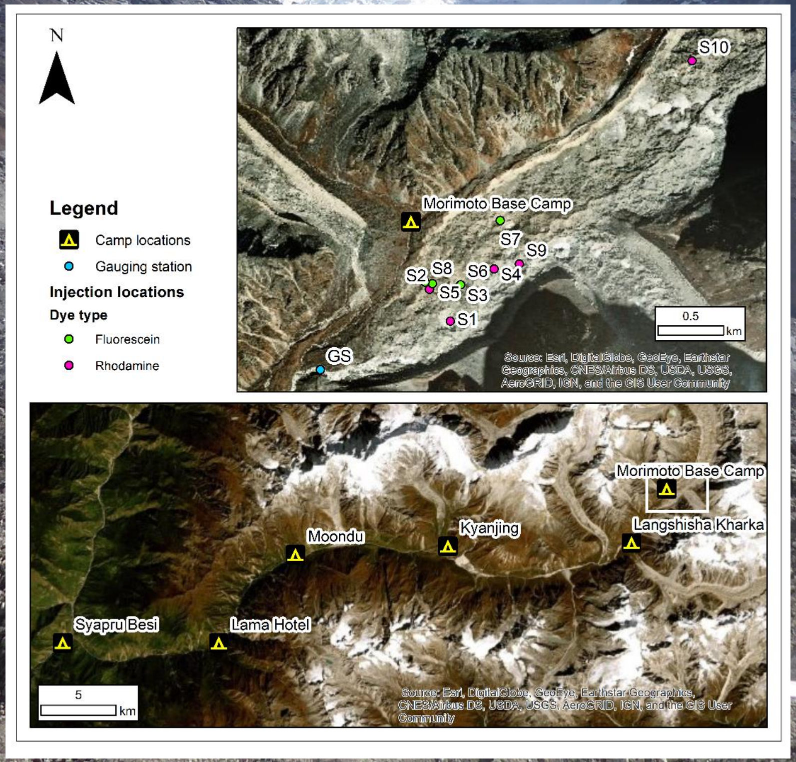
- metre thick debris, very hummocky topography
- Visited May and Nov 2019

24K Glacier, SE Tibetan Plateau

- Thinner debris, very wet climate
- Visited June and Oct 2019

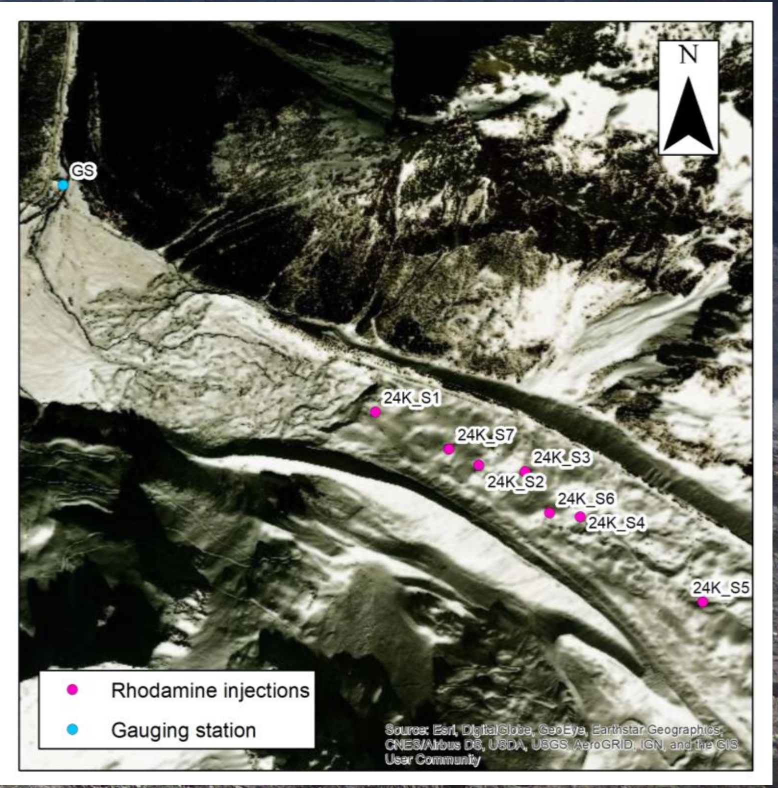
Langtang Glacier

- Surface and Englacial/subglacial dye tracing
- 6 rhodamine and 6 fluorescein dye traces conducted
- Gauging station installed, 14 dilution gaugings conducted, time series of 15 min discharge created from May to November 2019

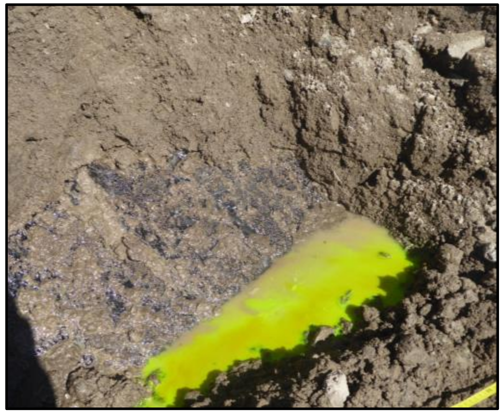


24K Glacier

- Surface and Englacial/subglacial dye tracing
- 14 rhodamine dye traces conducted
- Gauging station maintained by ITP, 24 velocity-area and dilution gaugings used to create rating, two hourly time series of discharge created from April 2016 to Oct 2019



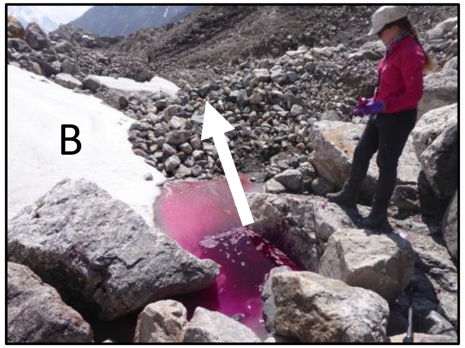
Langtang supraglacial hydrology

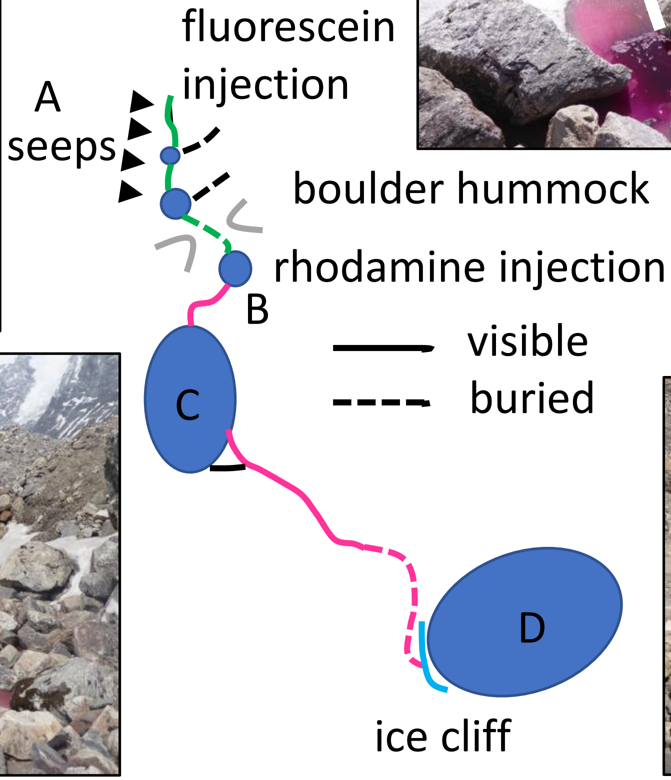


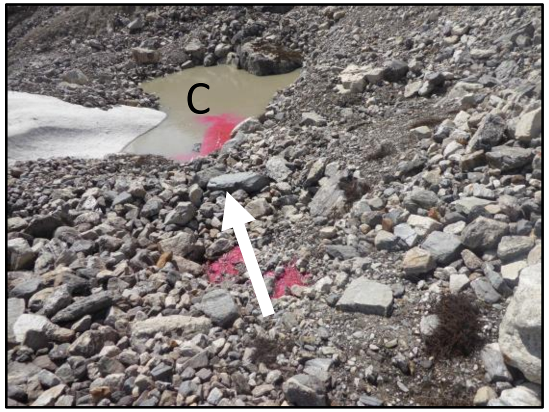
In two experiments fluorescein was poured in a trough dug to the ice-debris interface. After several hours the dye had not reached the ponds below. Debris can act to store water for long periods.

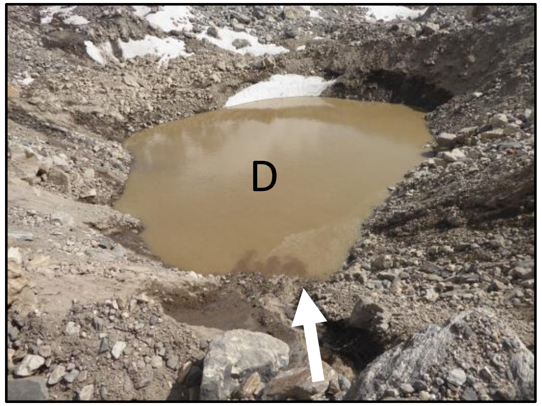
Supraglacial investigations revealed:

- Water could be seen emerging from the debris in the form of small seeps (May only)
- Clear hydrological links existed between ponds via steams that were partially visible, but often travelled within or beneath the debris matrix
- Sub-debris streams could pass through boulder hummocks, disregarding the surface topography
- In November most ponds had drained, reducing connectivity









24K Glacier supraglacial hydrology

- The supraglacial hydrology of 24K Glacier is dominated by a main pond-stream system
- This system was traced with rhodamine dye on the 9th of June and 17th of October
- In June the system was composed of three distinct ponds joined by sub-surface (englacial or sub-debris) drainage, with the final pond leading to a supraglacial stream and the 24K_S2 moulin (velocity through system = 0.029 ms^{-1})
- In October (shown below) the pond system had evolved into a more coherent, faster stream network, with ponds 1 and 3 now just depressions (velocity from injection to 1st pond = 0.15 ms^{-1}).

However the dye reached only pond 2, showing disconnection with the rest of the system.

Langtang Glacier englacial/subglacial hydrology

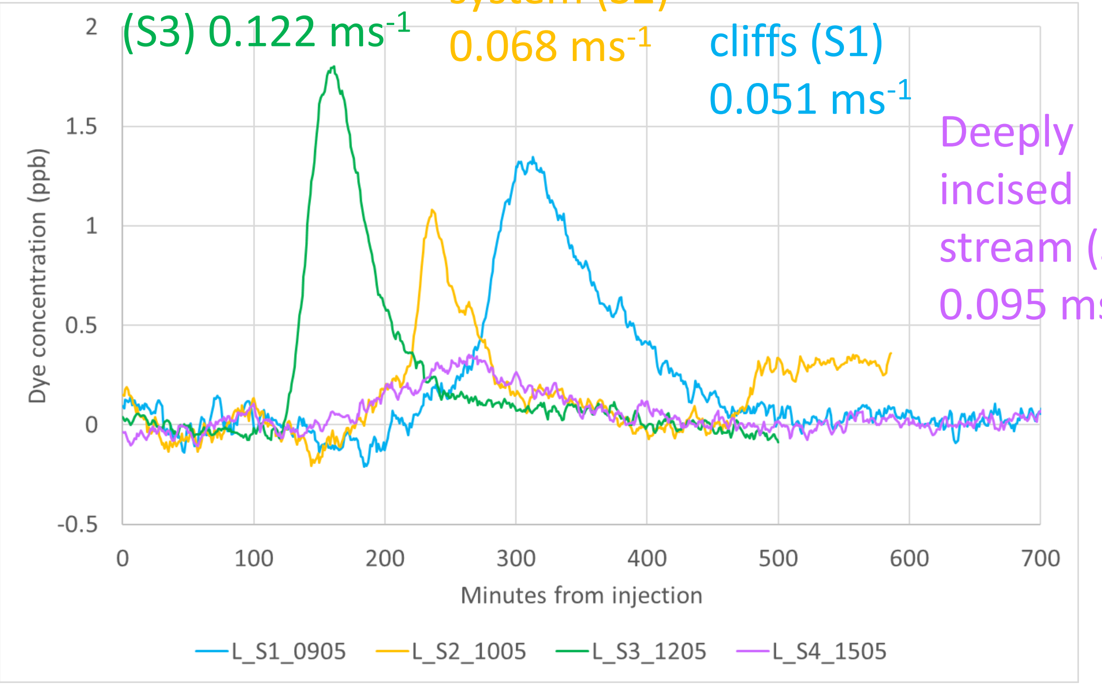
May

Stream near drained pond (S3) 0.122 ms^{-1}

Pond system (S2) 0.068 ms^{-1}

Stream in area of ice cliffs (S1) 0.051 ms^{-1}

Deeply incised stream (S4) 0.095 ms^{-1}



- Returns are slow and dispersed compared to efficient conduits traced on alpine glaciers
- The fastest return was that into the stream close to a draining pond, which was also the largest stream we found

In November surface water was very scarce and limited to small streams at the base of ice cliffs, and a few isolated ponds.

Lack of post-monsoon water suggests melt is limited to ice cliffs and/or can be accommodated within the debris.

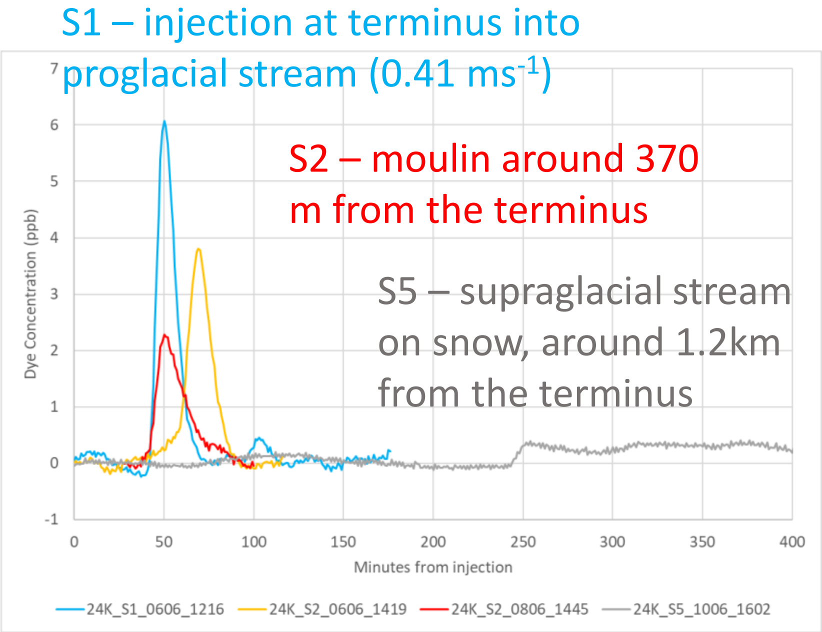
Repeat tracing was not successful.

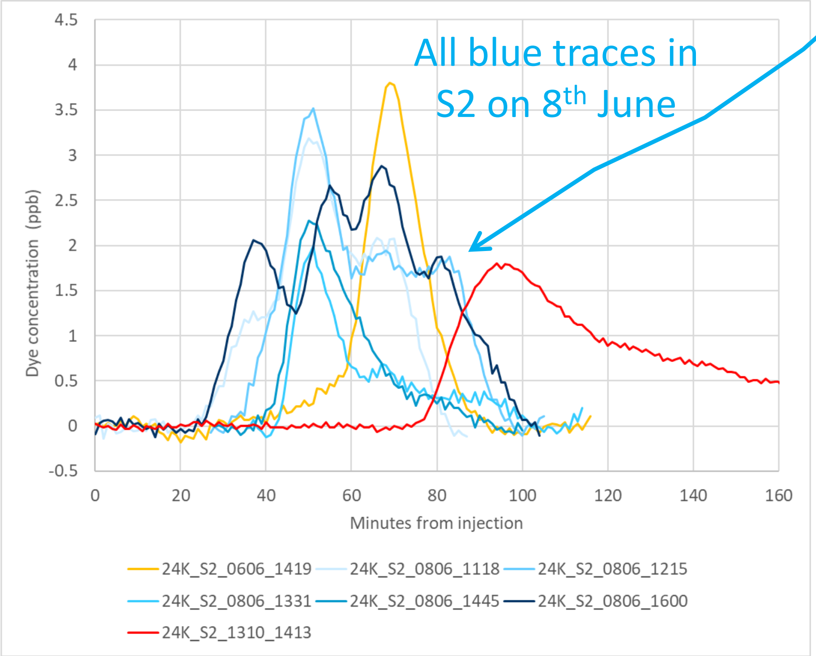
The only stream found not directly beneath ice cliffs

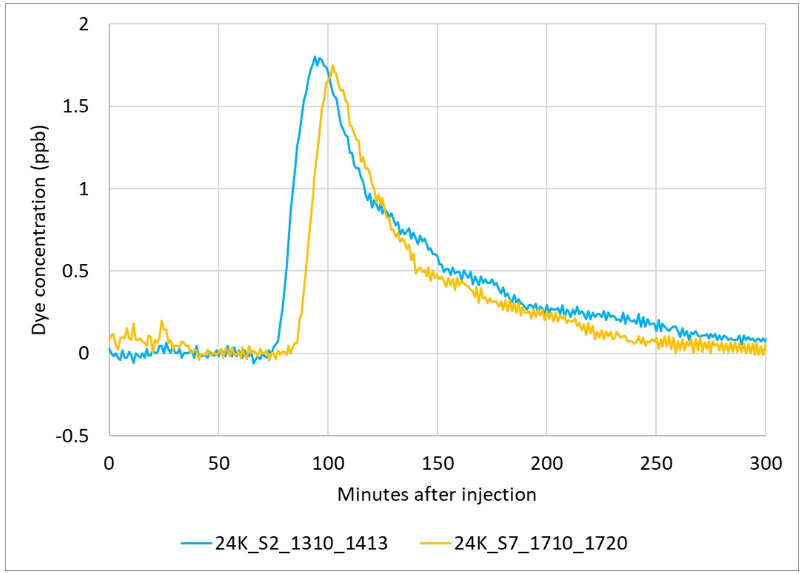
24K Glacier englacial/subglacial hydrology

- In June, traces into S2 had a similar velocity (mean 0.49 ms^{-1}) to the traces into S1 (0.41 ms^{-1}, the proglacial stream at the terminus)
- The S2 drainage system was therefore relatively efficient
- Multiple traces were conducted into S2 on the 8th of June. The traces in the morning (11:18 and 12:15) and late afternoon (16:00) were broader and showed multiple peaks – suggesting use of multiple flow paths, despite the relatively fast velocities
- However, the hydrological system higher on the glacier (which was mainly still snow-covered) was not yet well-connected to the S2 network, as a trace into S4 gave no return and the S5 breakthrough curve was slow and dispersed (0.16 ms^{-1}).

- In October water velocities were slower in S2 (0.28 ms^{-1})
- The breakthrough curves into S2 and S7 were very similar (see figure below) so water likely follows the same route

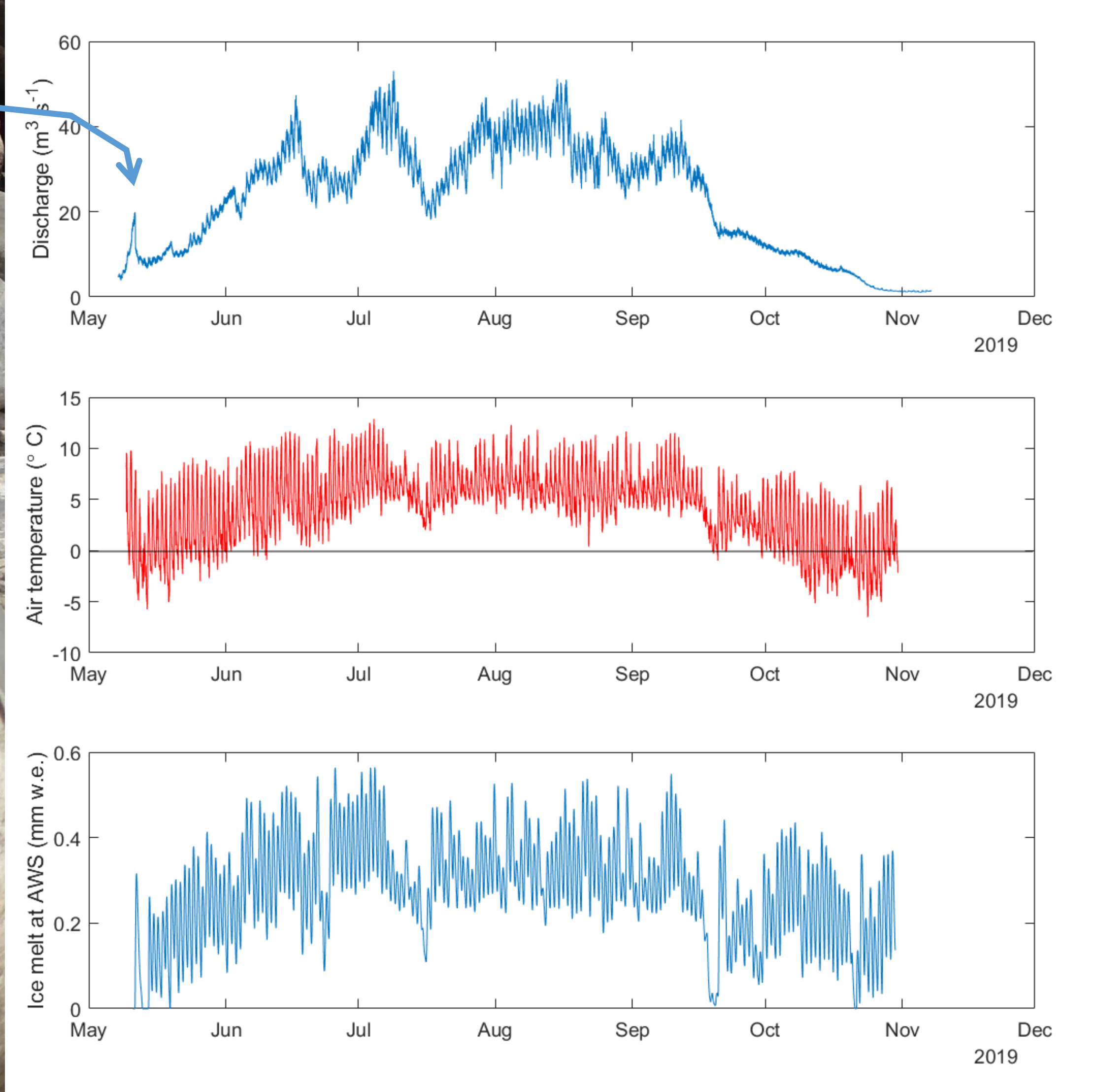


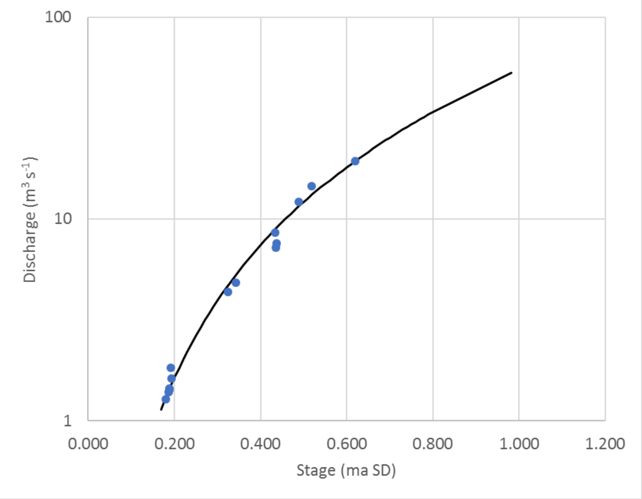




Langtang glacier proglacial hydrology

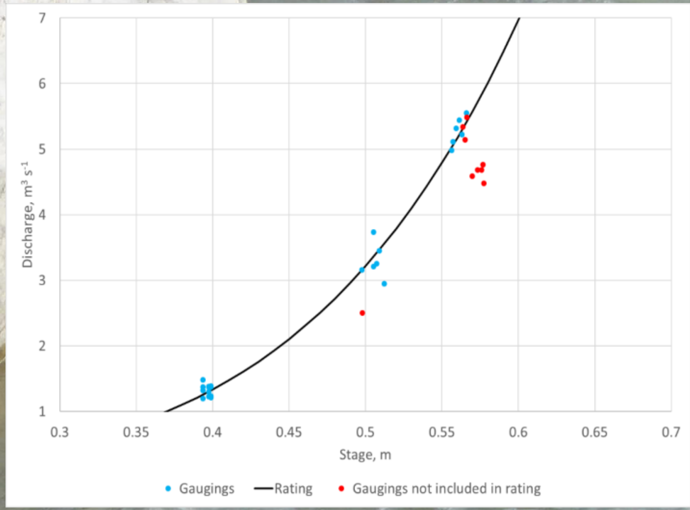
- Large discharge peak in May due to (documented) supraglacial lake drainage event
- Further work will assess the record for other lake drainage episodes and assess the seasonal variation in diurnal amplitude and lag time



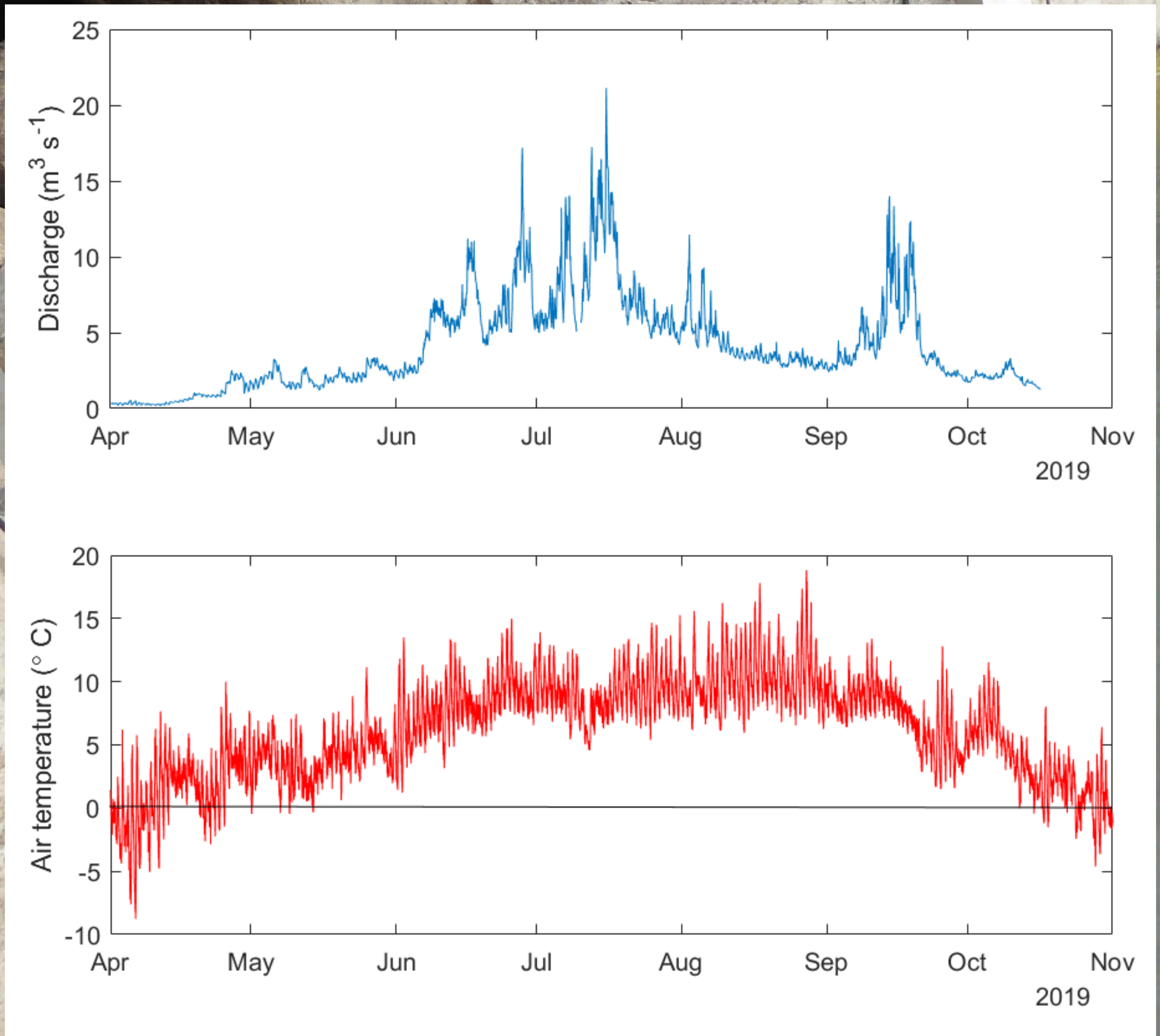


- Diurnal amplitude small in the pre-monsoon (May) and post-monsoon (mid Sep onwards).
- This corresponds with air temperature < 0°C
- Post-monsoon recession very clear despite air temperatures during the day above zero
- Diurnal amplitude clear but small compared to total discharge even during the monsoon

24K glacier proglacial hydrology



- Peaks in 24K Glacier discharge not related to air temperature, so likely driven by rainfall events
- Largest discharges don't correspond with highest air temperatures



- Discharges increase above the winter baseflow once air temperatures are consistently > 0°C
- Diurnal fluctuations in discharge are apparent, but are small in magnitude, even in the middle of the monsoon
- The diurnal hydrograph is also less smooth than for Langtang Glacier

Comparison of Langtang and 24K Glaciers

- Supraglacial hydrology
  - On both glaciers linked pond-stream systems existed on the surface
  - However, on 24K Glacier there was a clear main supraglacial network along the glacier centreline, whereas this was not the case on the larger and more hummocky Langtang Glacier
- Englacial/Subglacial hydrology
  - All the dye traces on Langtang Glacier indicated slower water velocities than on 24K Glacier, suggesting a less efficient englacial/subglacial network beneath Langtang
  - In the post-monsoon trace velocities were slower on 24K Glacier than in June, but on Langtang Glacier any surface water was only due to ice cliff melt
- Proglacial hydrology
  - Air temperature is seen to be a key driver of the Langtang Glacier stream discharge, with peaks due to lake drainage, whereas on 24K Glacier, precipitation results in the highest peaks and diurnal fluctuations are less apparent

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