Dye-tracing on Khumbu Glacier

Field Campaign to Khumbu Glacier, April-May 2018

Final Report to the Mount Everest Foundation

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Introduction, aims and objectives

Khumbu Glacier (27° 56' 53" N, 86° 48' 36" E) is a debris-covered glacier at a particularly high elevation, as its ice is sourced on the flanks of Mount Everest. It flows down the infamous Khumbu Ice Fall, and forms a tongue around 10 km long which is covered in rocks avalanched onto the glacier surface from the surrounding mountain slopes. The debris cover influences the amount of melt occurring on the glacier, and produces surface features not commonly found on clean-ice glaciers, such as supraglacial (surface) ponds and bare-ice ice cliffs. While these features have been studied in relative detail (see previous MEF funded expedition to Khumbu Glacier in 2016), nothing is known about how meltwater is transported from such ponds, beneath the ice and through the glacier. Supraglacial streams exist in the upper glacier (beneath the ice fall), but none exist towards the terminus, suggesting that some form of subsurface meltwater transport must be present. Better understanding of this system will inform how much meltwater is being stored within the glacier, transferred to groundwater stores, or transported through the glacier and thus contributing to downstream water resources, which are being affected by ongoing glacier retreat in the Himalaya.

The aim of this scientific research was to determine the subsurface (englacial and subglacial) drainage structure of Khumbu Glacier, Nepal Himalaya, using fluorescent dye-tracing. The specific objectives were to determine:

1. Whether an englacial and/or subglacial system exists;
2. The efficiency of either/both of these systems;
3. Any potential links to the groundwater system that might act as a sink for water.

Expedition Dates: 15th April to 24th May 2018

Travel to Kathmandu, trek to glacier and acclimatisation – 11 days

Fieldwork on glacier (camping at various sites) – 23 days

Trek down to Kathmandu and travel home – 6 days

Field Team

The scientific project was led by the expedition leader and supported by a larger field team who had separate funding to carry out different scientific research, also on Khumbu Glacier. Logistics were arranged by Himalayan Research Expeditions, who also acquired all permits and provided porters, camp staff and a guide who were instrumental in carrying out this research.

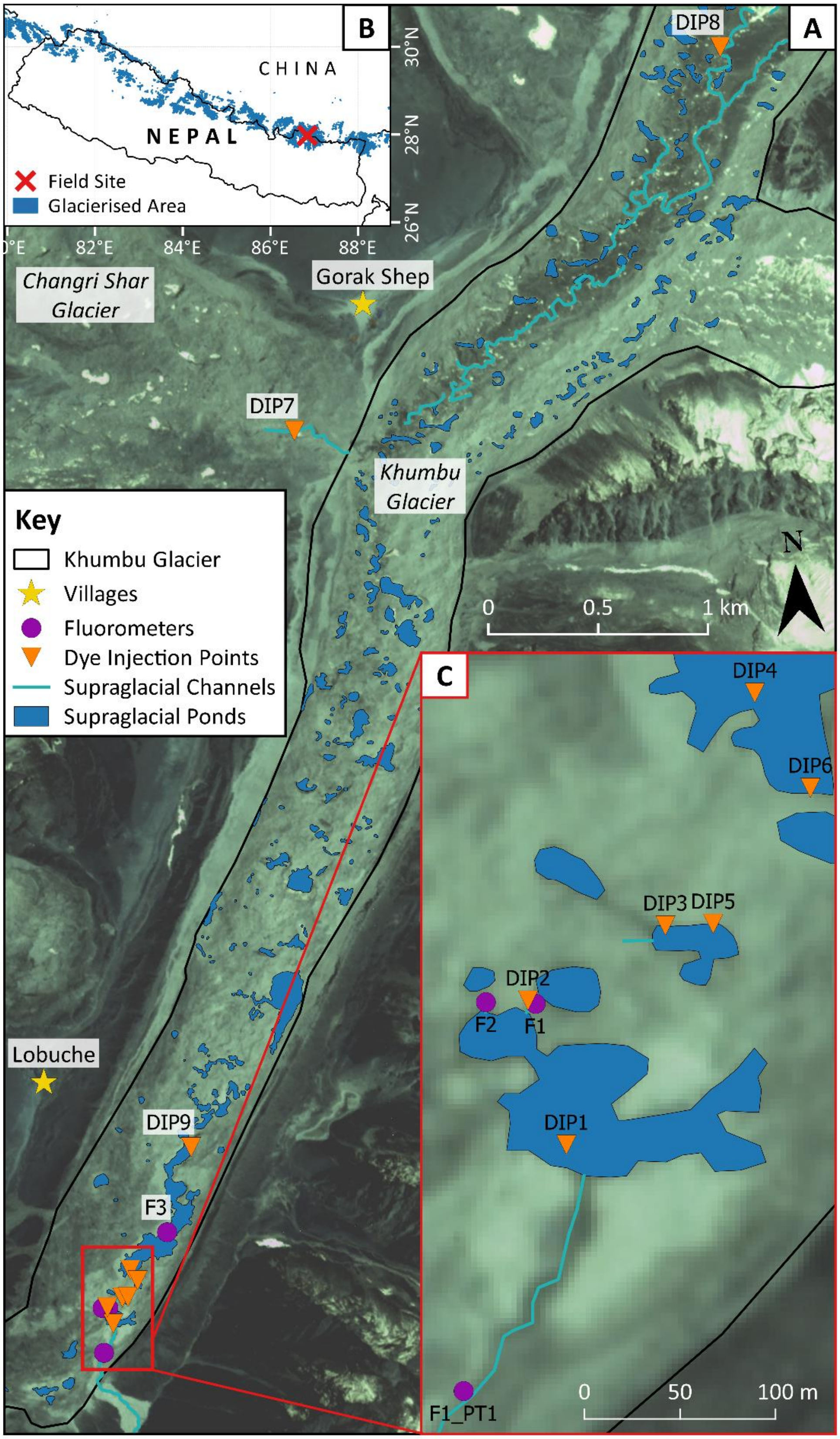

Figure 1: Location of field site, including dye injection points (DIP#) and fluorometer locations (F#, panel A & inset B) on Khumbu Glacier, and the location of the site within Nepal (inset C).

Field Report

Three weeks of fieldwork were carried out on Khumbu Glacier, Nepal, in which the primary aim was to carry out fluorescent dye-tracing to characterise the subsurface drainage of the glacier. Fifteen dye-tests were carried out from nine different locations on the glacier (see dye injection points (DIP#) in Figure 1) and dye was detected by fluorometers in four different locations (F# in Figure 1). Images of dye injections can be seen on the cover page and Figure 2 below. Environmental impacts were minimal, as very small (1-150 ml) amounts of dye were injected, with the intention that the dye was fully mixed, and therefore invisible to the human eye, by the time it reached the fluorometers. This was possible because the fluorometers used can detect miniscule dye concentrations (parts per billion). Longer-term environmental impacts were also not a concern, as the dye used (fluorescein) has a very short half-life (~7 hours), and was expected to have fluoresced out of the water before reaching the next villages downstream.

Figure 2: Example dye injection during a dye-test from DIP1, at the terminus of Khumbu Glacier

Of the fifteen traces, eleven were successful and have revealed previously unknown information about the subsurface drainage of this high-elevation, debris-covered glacier. The remaining four tests were carried out in supraglacial (surface) ponds, where very slow water flow resulted in small and dispersed dye returns. However, they still returned enough data to infer some information about how meltwater is transported through such ponds. An example successful dye-return (the same as that carried out in Figure 2) is shown in Figure 3.

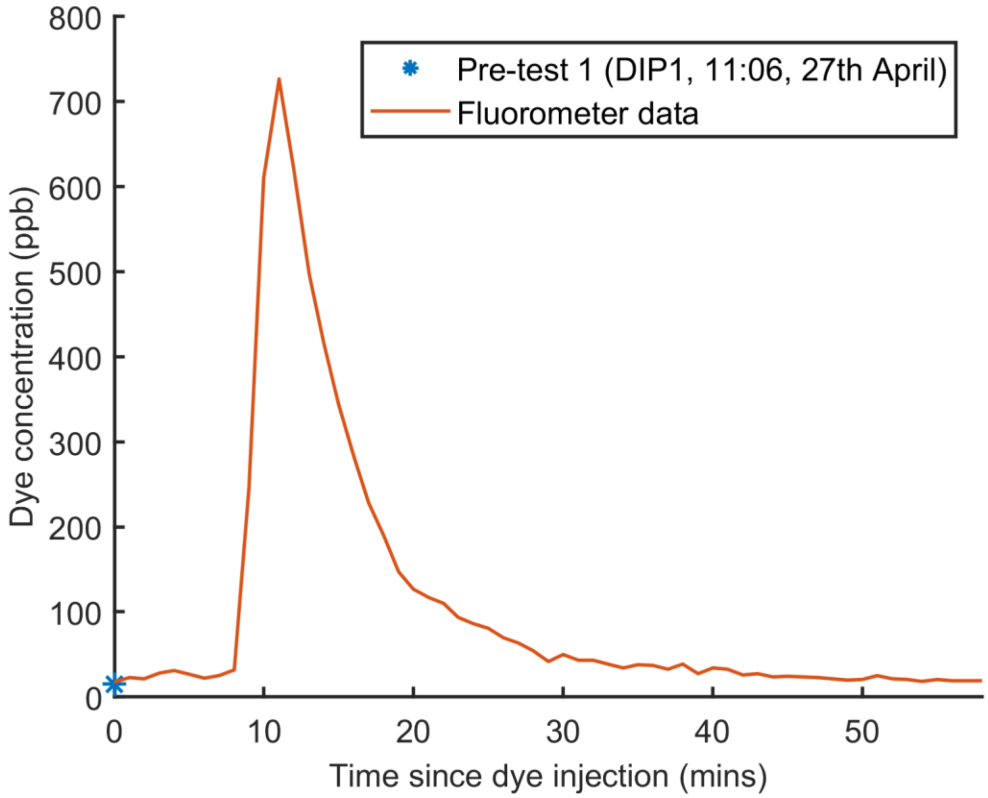

Figure 3: Example dye-return from a fluorometer during the very first dye-test into DIP1 (Fig. 1). The blue star indicates the dye injection. An image of this injection can be seen in Fig. 2.

Preliminary Data Analysis

The dye-tests have been classified into three categories: short-range tests, pond-based tests, and long-range tests. Preliminary analysis shows that subsurface drainage through Khumbu Glacier does exist, and is relatively slow and inefficient at transporting meltwater. Dye took a number of hours to travel to from DIPs 1-6 to the fluorometers (distances less than 200 m), but up to three days to travel from DIPs 7 & 8 to the terminus (5-7 km). The short-range tests show a possible increase in efficiency over the three weeks of measurements, whereas all of the pond-based tests show extremely inefficient water transport. This may be a result of the field season being carried out early in the melt season; many pond surfaces were frozen until late in the trip. The long-range tests were carried out 5-7 km from the glacier terminus (DIPs 7 & 8, Figure 1A), and yet show similar transit velocities to the short-range tests. This is significant, as it implies that there is not a substantial amount of water storage within the glacier or transfer to groundwater. There may also have been a long-range increase in efficiency during the field season, but a week or so after that recorded by the shorter-range tests.

Full data analysis is currently in progress, and the results will be presented at two UK-based conferences next month (September 2018): the International Glaciological Society British Branch Meeting (Exeter), and the British Society of Geomorphology meeting (Aberystwyth). I hope to obtain feedback and discuss my results with colleagues at these conferences, and subsequently prepare a paper for publication in an open-access academic journal. The paper will then be presented at the European Geosciences Union in Vienna in 2019. This is the first time that dye-tracing has been successfully carried out on a high-elevation debris-covered glacier, and I am very grateful for the support of the Mount Everest Foundation which allowed it to happen.

Photographs of Glaciers: for comparison with past and future pictures

Images of Khumbu Glacier taken from between Gorak Shep and Everest Base Camp are provided below, looking both upvalley towards Everest Base Camp and downvalley towards Lobuche (Figures 4 & 5). I have many photos of localised areas of Khumbu Glacier, particularly near dye injection and detection sites, which I am very happy to provide if specific images/regions are requested.

Figure 4: An image of Khumbu Glacier, taken from between Gorak Shep and Everest Base Camp. The image looks upglacier (upvalley), towards Everest Base Camp (far left of image) and the Khumbu Ice Fall (far centre of image).

Figure 5: An image of Khumbu Glacier, taken from between Gorak Shep and Everest Base Camp. The image looks downglacier (downvalley), towards Lobuche village and the glacier terminus.

Suggestions for new subjects for study in the area

Due to the remoteness of many Himalayan glaciers, very little is known about them. In the Everest region, the larger, debris-covered glaciers have been subject of some research in recent years. However, a lot remains to be discovered about these glaciers: the ice temperature, ice thickness and mass balance trend is unknown for almost all Himalayan glaciers. This study aimed to help determine how water flows through such a glacier, and thus how meltwater is delivered to rivers downstream. This could be done on a longer timescale on the same glacier (e.g. after the monsoon as well as before the monsoon) and across many other glaciers, along with determining more accurate estimates of glacier melt rates and thus future contributions to water resources which are glacially-fed. These should all be investigated in detail for both large and smaller valley glaciers in the Himalaya, which together provide a large proportion of water resources for huge populations across southeast Asia.

Observations on the accuracy, or otherwise, of Google Earth images

The quality and image resolution of scenes over Khumbu Glacier are high, however the most recent image for the lower glacier is 30th October 2017, and for the upper glacier (including

Everest Base Camp and the Khumbu Ice Fall) is 3rd December 2016. There have been a number of changes to trekking routes since these dates, and large changes to the glacier surface.

Notes on access, porters, or other issues of interest to future visitors

Our logistics were arranged by Himalayan Research Expeditions (HRE), who provided an excellent service from shipping our equipment, sorting permits and on the trek up to the glacier and while we were carrying out fieldwork. They are particularly careful to manage waste, leaving nothing on the mountain, and take good care of their staff (guides, porters and others), providing them with good wages and additional clothes and equipment for the expedition.

Details of any injury or illness to expedition members and/or porters

None who were funded by this grant or helped carry out the dye-tracing fieldwork were taken seriously ill or injured.

Details of waste disposal

All waste disposal was organised by our logistics and trekking company, HRE, who arranged for all waste to be carried down to and disposed of appropriately in Kathmandu. As we were a small expedition, human waste was discretely buried away from water sources, in accordance with the National Park regulations. Plastic waste was avoided by using water purification systems.

Summary of expedition accounts, including income and expenditure

Item	Income	Expenditure
MEF Research Grant	£2,000	
BSG Postgraduate Research Grant	£1,000	
RGS Postgraduate Research Award	£2,000	
Aberystwyth University DGES Postgraduate Discretionary Research Fund	£250	
Primary costs whilst in the field (incl. accommodation on trek up, camping costs, subsistence, staff and logistic company costs, permits and internal flights)		£4,443.02
Travel (international flights and travel to airport in UK)		£566.61
Visa		£75
Equipment costs		£84.99
Costs whilst in Kathmandu (incl. subsistence and travel)		£80.38
TOTAL	**£5,250**	**£5,250**