CASE STUDY

Using a swinglet CAM to analyse glacier dynamics in the Himalayas

Learn how an international team of glacial hydrologists used senseFly drone technology to overcome the limitations of traditional data collection methods

Himalayan glaciers are a crucial source of natural water, giving birth to more than ten of Asia's great rivers, on which a fifth of the world's population depend for water, agriculture, industry and sanitation.

Thanks to field studies and satellite data, scientists know that our warming planet is causing many of these giant ice flows to melt. However these same scientists have, up to now, been lacking the high-resolution data they need to understand exactly how glaciers melt and how this affects the rivers they serve.

Image: Google Earth

"The key analysis is to monitor the dynamic 'tongue' of the glacier over time," says Dr W. W. Immerzeel of Utrecht University's Department of Physical Geography. "This allows us to accurately measure glacier velocities, mass-loss rates and precipitation lapse rates, which in turn helps us improve glacio-hydrological models of the region." However these tongues have not been studied nearly as much as scientists would like.

There are two key reasons for this dearth of research. First and foremost is the extreme difficulty of the terrain. The traditional drilling of stakes into the ice, to measure XYZ movement and to determine ice melt by monitoring a stake's exposure over time, is highly problematic, due to the thick buildup of rock debris on and in front of glacial tongues. As a result it is almost impossible to drill stakes at a sufficiently high density to accurately capture the spatial variability and differing melt rates of a glacier.

Secondly, this struggle on the ground is compounded by the fact that hydrologists typically consider existing space-borne remote sensing data, such as satellite imaging, too low a resolution to be useful.

The upshot is that studies of debris-covered glaciers are few and far between.

"The mass loss of Himalayan glaciers can, for a large part, be determined by surface features such as debris, supra-glacial lakes and ice cliffs," Dr Immerzeel says. "However there was

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The project's team includes hydrologists from Utrecht University in the Netherlands, the International Centre for Integrated Mountain Development and ETH Zurich.

Bridging the data gap

It's for these reasons that, in 2013, an international team of hydrologists from Utrecht University in the Netherlands, the International Centre for Integrated Mountain Development and ETH Zurich, decided to try and overcome these data gathering challenges. Working with flying sensor specialists HiView, the team used a senseFly swinglet CAM drone – or Unmanned Aerial Vehicle (UAV) – to calculate the mass loss and surface velocity of the Lirung Glacier. This particular ice flow is located in the Langtang Valley region of the Nepalese Himalayas, approximately 100 km (62 miles) north of Kathmandu.

The project was to become the first to fly a mapping drone over a debris-covered Himalayan glacier.

"We decided to investigate the role and dynamics of ice cliffs and supra-glacial lakes by studying selected regions of the Lirung Glacier in Nepal," Dr Immerzeel explains. "For this we decided to use a professional low-cost UAV to collect two remotely sensed datasets, flying the drone during two field campaigns in May and October of 2013. With the UAV's imagery, alongside highly accurate differential GPS measurements, we would produce detailed orthomosaics and digital elevation models (DEMs). Then by recording the differences between these DEMs at different points in time, and manual feature tracking, we could calculate the glacier's mass loss and surface velocity, at a high spatial accuracy, over the entire monsoon season."

The methodology

The team's swinglet CAM drone, carrying an autopilot-triggered 16 megapixel IXUS still camera, was used to collect aerial

The snow covered slopes of the Langtang Lirung Peak (7,234 m / 23,733 feet) feed the Lirung Glacier, shown in the foreground, with ice and debris by means of avalanches and rock falls.

imagery in May and September. Flights were typically carried out in the mornings, when winds over the glacier tend to be lower, in order to maximise the system's flight stability and therefore the quality of its images.

After using the drone's supplied eMotion software to highlight on a base map the region they wanted to photograph, the team used the same program to set the image overlap required for each flight and to set an average ground resolution of 2 - 5 cm per pixel.

The team carried out seven flights in May 2013, five of which produced usable data (while the team got used to using their drone and configuring its flights), followed by three flights in October.

Each flight lasted, on average, 20 minutes, for a total coverage of 4.21 km^2 (1.62 mi^2) in May, based on 284 photos taken, and 3.75 km^2 (1.45 mi^2) in October via the capture of 307 images.

Lirung Glacier

The Lirung Glacier is characterised by concurrent accumulation and ablation – the simultaneous build-up and loss of snow, ice, and water – during the monsoon season from June to September, when 70% of the region's annual precipitation (~800 mm y−1) falls. The glacier's tongue is situated approximately 4,000 metres above sea level and its debris cover alone is thicker than 50 cm (1.6 ft) in many places, with the tongue itself often tens of metres thick. This tongue measures 3.5 km (2.2 mi) in length, with an average width of 500 m (1,640 ft).

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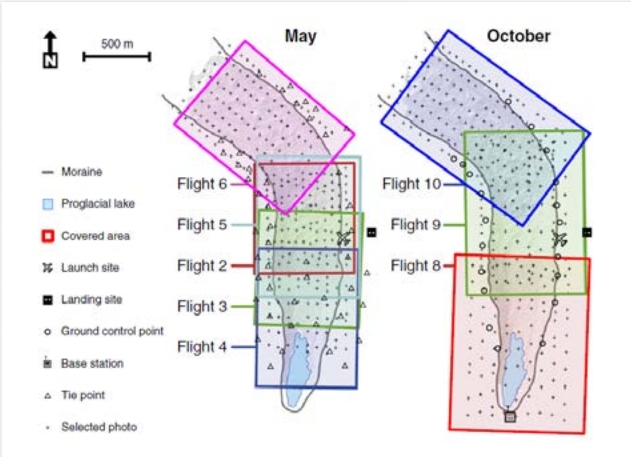


Overview of the study area, approximate coverages of the successful flights, positions of the selected images and locations of the ground control points (GCP) and tie points. (Reprinted from Remote Sensing of Environment, 150 (2014), W.W. Immerzeel, P.D.A. Kraaijenbrink, J.M. Shea, A.B. Shrestha, F. Pellicciotti, M.F.P. Bierkens, S.M. de Jong, High-resolution monitoring of Himalayan glacier dynamics using unmanned aerial vehicles, pgs 93 - 103, 0034-4257, © 2014, with permission from Elsevier.)

Placing and measuring ground control points using the dGPS. (Images: Steven de Jong)

To accurately geo-reference the outputs produced, ground control points were set in both May and October. During the May mission, however, the team experienced problems with its GCP methodology c in the form of visual identification issues – which meant a change of approach was required. “May’s data were therefore geo-referenced using 47 tie points, of which the x and y coordinates were sampled from the October orthomosaic and the z values from the October DEM at locations without changes in elevation or flow,” explains Philip Kraaijenbrink, a PhD student who is supervised by Dr Immerzeel and works on the project’s team.

October’s 19 ground control points posed no problems. “Two identical GPS devices were used simultaneously: a base station and a rover,” Kraaijenbrink continues. “A base station was installed near the outlet of the Lirung Glacier and occupied for two consecutive days, while the rover was used to measure the 19 GCPs. The base station and rover data were then post-processed using Topcon tools software.”

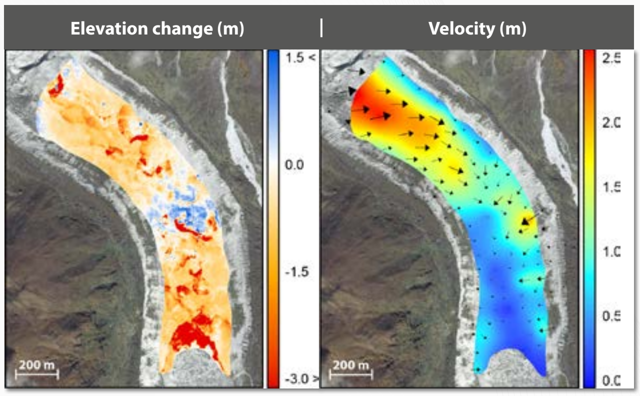
The photos collected by the team’s swinglet CAM were processed into orthophotos and grid-based digital elevation models (DEMs) of the glacier, its lateral moraines and its direct surroundings, using a Structure from Motion (SfM) workflow in Agisoft PhotoScan software. In order to make accurate comparisons of the May and October DEMs, the October DEM was then geometrically transformed to exactly match the May model using the direction and magnitude of the glacier’s surface velocity.

Ensuring accuracy

When assessing the accuracy of the resulting orthomosaics and DEMs, two types of error were taken into account: input and output. The input errors – given by the dGPS system’s post processing software of the dGPS system – related to the deviations of the dGPS base station, as well as the precision of each measurement performed by the dGPS rover.

Meanwhile the uncertainty introduced by the SfM processing technique, referred to as the output error, was assessed using two methods:

- The difference between the May and October DEMs was compared to unpublished ablation stake data gathered during the same time period – the melt observed at the stakes being compared with the DEM difference integrated over the flow path between May and October 2013.
- The vertical output uncertainty was assessed by calculating the difference between the GCP elevation data and the generated DEMs. The horizontal uncertainty was determined manually, by measuring the horizontal displacement between the original GCP (October) and tie



Changes in the glacier’s elevation between May and October 2013 (left) and the derived surface velocity and direction of flow (right).

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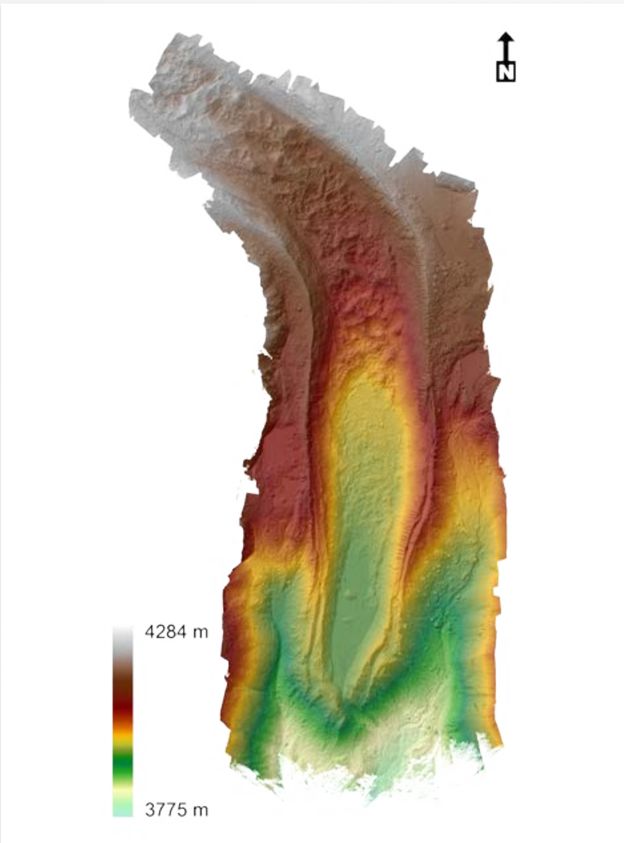

The team's final drone-sourced October 2013 orthomosaic (top) and digital elevation model (bottom).

point (May) coordinates and the apparent GCP locations on the orthomosaics.

The team's October DEM featured a geodetic accuracy of within 0.25 m (10 in) for both the horizontal and vertical. For the May DEM and orthomosaic the errors were within 0.70 m (27 in). However, the bulk of the measurements show deviations of less than 0.20 m (8 in).

"As the May data were geo-referenced using the October data, only the deviations from the May tie points with the May orthomosaic and DEM are related to the uncertainty in the DEM difference," Kraaijenbrink notes. "Because the locations of both the October GCPs and the reference GCPs were well distributed over the study area, we assumed that the errors at locations away from the GCPs were not considerably higher than those at the GCPs."

Drone learnings

The team's 2013 Lirung Glacier project provided significant new insights into the hydrology of the world's premier mountain range.

By studying the DEMs generated from its UAV-sourced photography, Dr Immerzeel's team deduced that the Lirung Glacier's melt rate and flow were both low, indicative of it being in its final stage. The glacier's accumulation zone had separated from the tongue, the tongue had slowed down almost completely, and the tongue continues to lose mass. "We think the fate of the Lirung Glacier could prove symptomatic for what is happening throughout this vast range," Kraaijenbrink states.

"Although the glacier is in its final stage and not very dynamic overall, some parts are still quite dynamic." says Kraaijenbrink. "We see highly variable melt patterns on the glacier and, especially near ice cliffs and ponds, higher melt rates are found. These surface features are possibly connected by a network of voids in the glacier, which may play an important role in controlling the melt of debris-covered glaciers. The high-resolution imagery enables us to study these smaller scale processes more easily, with more detail and on a larger scale than before."

With regards to drone technology's potential, Dr Immerzeel is convinced of the positive role UAVs can play. "The conclusion of our team is that drone deployment has great potential in the field of glaciology," he says. "While drilling stakes is a labour-intensive, time-consuming process, our data acquisition in May and October was carried out in just two half days. Our results show that high-resolution DEM differencing based on UAV imagery provides the equivalent of millions of stakes at a sufficiently high accuracy, while UAVs offer results, on-demand, at a resolution and accuracy that satellite-derived products cannot currently meet."

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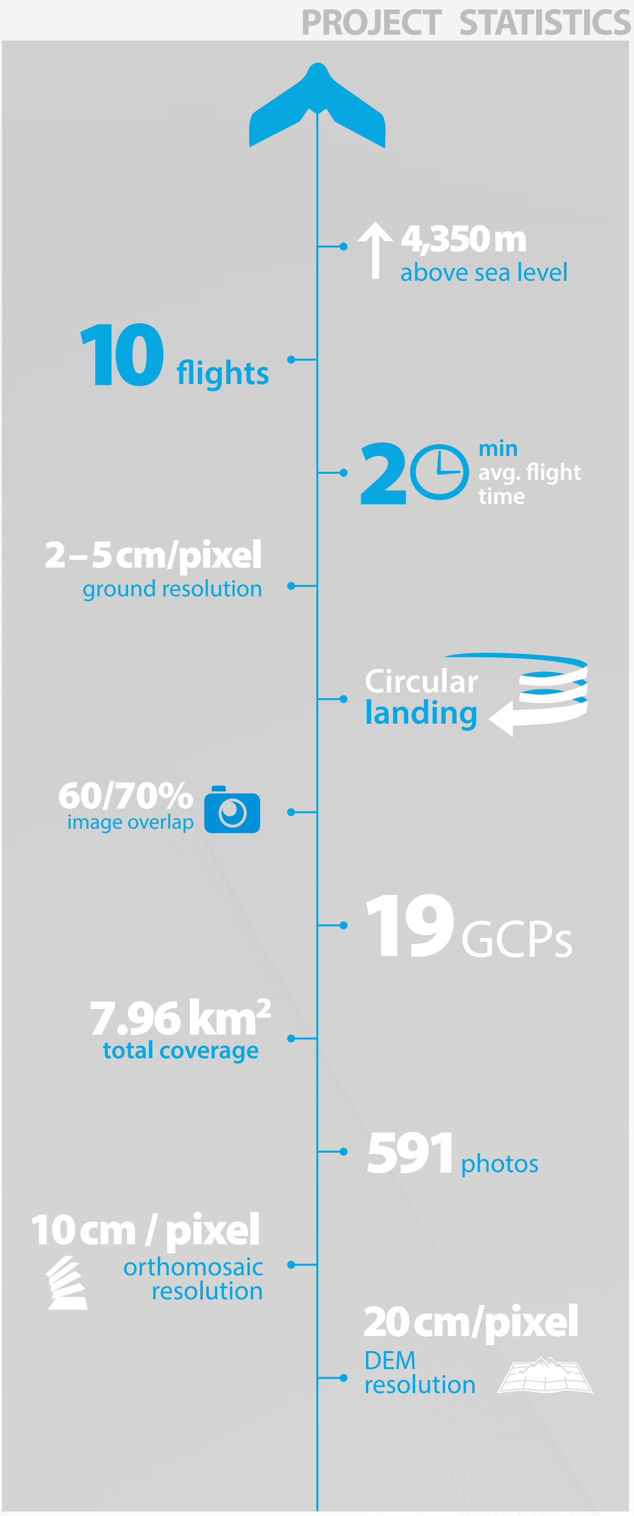
Looking ahead, Dr Immerzeel and his team believe that annual UAV campaigns on benchmark glaciers could make an important contribution to understanding the impacts of climate change, permitting scientists to fine-tune their simulation models in a much higher resolution than ever before, improving accuracy and leading to better predictions.

"We've shown that using a drone is possible in one catchment in Nepal, but the variation throughout the Himalayas is so large that we have to extend this technology throughout the entire region," he says.

Learn more

Watch the project video
Read/purchase the full Remote Sensing of Environment paper
Profile of Dr W. W. Immerzeel
Profile of Philip Kraaijenbrink



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