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Physical Geography

Object-based analysis of unmanned aerial vehicle imagery to map and characterise surface features on a debris-covered glacier

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Spatially heterogeneous melt patterns caused by ice cliffs and supraglacial pond systems on debris-covered glaciers result in substantial mass losses over time. The exact mechanisms controlling the formation and survival of cliffs and ponds remain largely unknown. To study their distribution and characteristics we deploy an unmanned aerial vehicle (UAV) over Langtang Glacier, Nepal. The acquired images are processed into orthomosaics and elevation models using Structure from Motion (SfM). Ice cliffs and ponds are classified using object-based image analysis (OBIA) and their morphology and spatial distribution are analysed and evaluated using object, pixel and point cloud approaches. Results show that most ice cliffs are north facing, indicating that the shortwave radiation regime is important in the survival, and the highest cliff and lake density is found in regions where compressive forces are largest, e.g. at a confluence with a tributary.

Study area

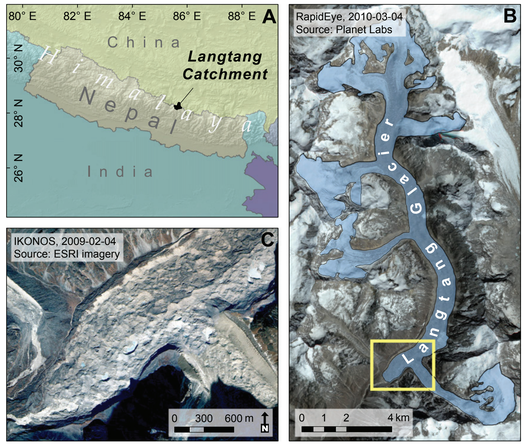


Figure: The location of the study area, the snout (C) of the Langtang Glacier (B) located in the Langtang Catchment in the Nepalese Himalaya (A).

UAV survey

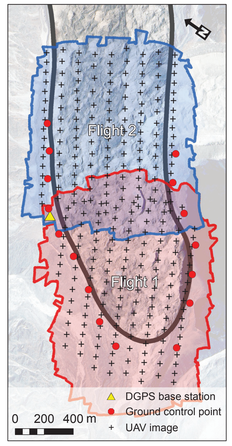


Figure: The coverage of the two UAV flights that were performed on the 7th of May ground control markers and the DGPS base station.

Mapping and characterization

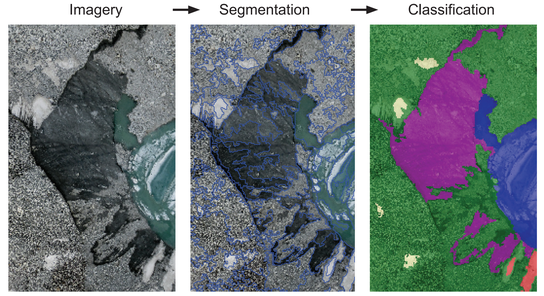


Figure: Basic object-based image classification procedure.

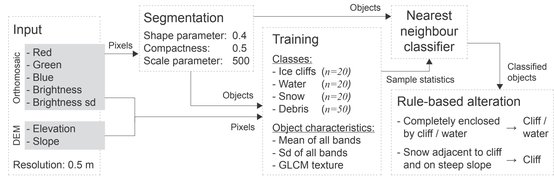


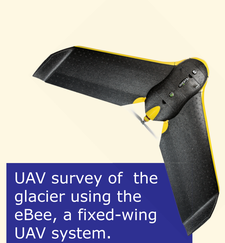
Figure: Flowchart of the steps and settings used in OBIA procedure that was performed to classify the cliffs and ponds from UAV imagery.

Ice cliff and ponds were classified using an object-based image analysis approach:

1. Image segmentation
   Pixels were grouped into polygonal objects using the software eCognition Developer. This segmentation was performed on a single scale and using only the optical information captured by the UAV.
2. Training
   Training data were acquired for random objects. Evaluated training statistics comprised averages and standard deviations of the optical data as well as of elevation and slope. Additionally, texture measures were used that were determined from the imagery.
3. Object classification
   Using the training objects, the object set was classified using a fuzzy nearest neighbor classification strategy. The classification was subsequently improved in a rule-based final step.

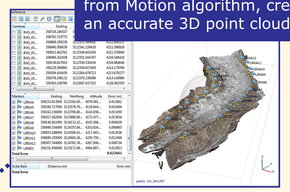
Analysis of ice cliffs and ponds:

- DEM subsets were extracted using the object delineations of the classifiction
- Slope and aspect of each ice cliff were quantitatively analysed
- Distribution of ice cliffs and ponds over the survey area was evaluated



Many overlapping 6 cm resolution images of the glacier surface

Imagery processing in Agisoft Photoscan using the Structure from Motion algorithm, creating an accurate 3D point cloud

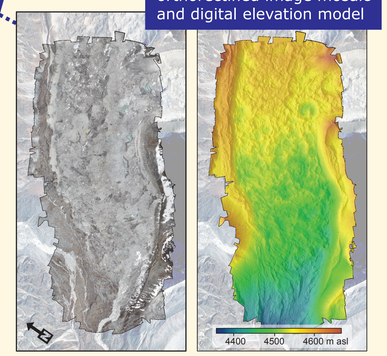


UAV survey of the glacier using the eBee, a fixed-wing UAV system. Images are captured by the mounted RGB compact camera

UAV Methodology

Ground control point survey. Markers are distributed on the lateral moraines and glacier surface and measured using a dGPS system

Derive 10 cm resolution orthorectified image mosaic and digital elevation model



Results

Classification:

- Training using only the averages and standard deviations of the optical and the slope data provided the best classification. Inclusion of slope greatly increased classification accuracy for ice cliffs.
- Classification accuracies are 87% for ice cliffs and 97% for ponds. normalized for object area ther are 93% and 98%, respectively.

Cliff and pond analysis:

- Uneven distribution of ice cliffs and supraglacial ponds over the survey area. There is a higher density near the tributary.
- The aspect of ice cliffs is mostly north- or east-facing. There is barely any cliff facing towards sun. Large cliffs that do not face north are part of large cliff-pond systems.
- Most cliffs have a slope of around 40°. Cliff face with a slope of less than 20° is rare.

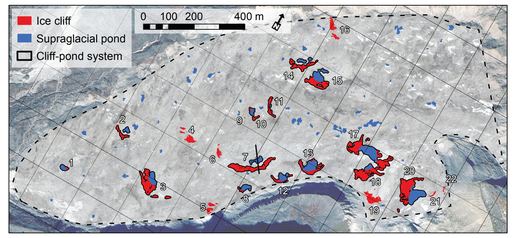


Figure: Ice cliffs and supraglacial ponds on Langtang Glacier as classified automatically on UAV imagery by object-based classification.

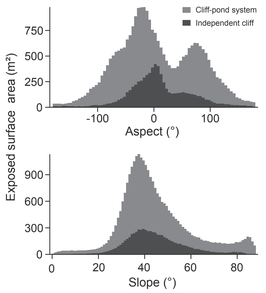


Figure: Histograms of aspect and slope (B) for all classified ice cliffs that either belong to a cliff-pond system or are independent.

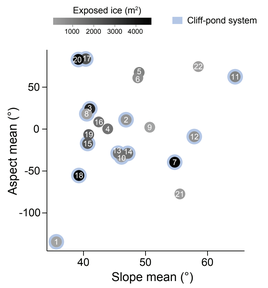


Figure: Scatter plot that shows the means of both aspect and slope for all classified ice cliffs.

3D reconstruction of cliff morphology

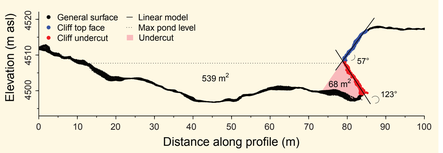


Figure: Cross-section of the UAV-derived point cloud of a cliff. The UAV is capable of capturing undercut morphology because of the low flight altitude and oblique images. Systematic volumetric 3D analyses of multi-temporal point cloud data may provide valuable information about the changes in cliff morphology and their causes.

Conclusions

- OBIA of UAV data is capable of automatic delineation of cliffs and ponds
- Slope data is key for acccurate classification
- Potential for large scale, objective analysis
- Ice cliffs are predominantly north-facing
- Confluences appear to affect cliff and pond formation
- UAV-derived dense point clouds are promising for systematic ice cliff morphology analyses

Link to article

AGU FALL MEETING