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Faculty of Geosciences
Physical Geography

Multi-temporal high-resolution monitoring of debris-covered glaciers using unmanned aerial vehicles

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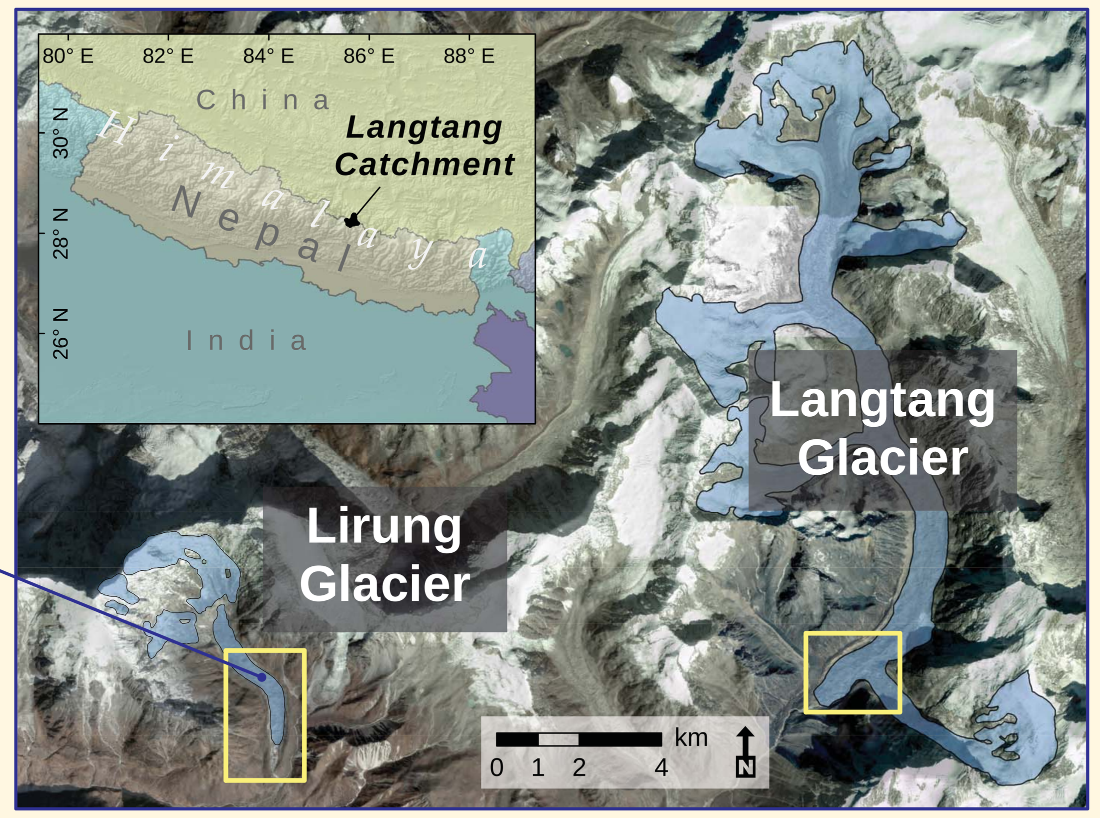
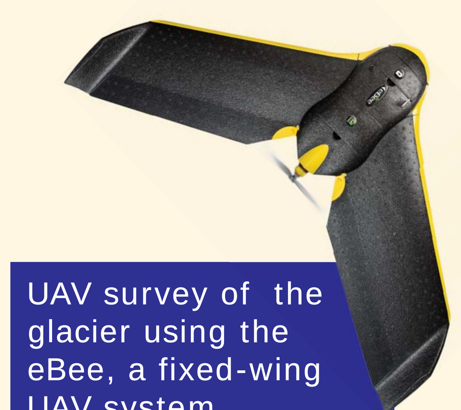
Debris-covered glaciers are common in the Himalaya and an important source of melt water. However, they remain relatively unstudied because of the inaccessibility of the terrain and the difficulties in fieldwork. Here, we utilize unmanned aerial vehicles (UAVs) for debris-covered glacier monitoring.
In three separate studies we have explored their potential by determination of elevation changes and surface velocities in great detail, and by automatic delineation of ice cliffs and supraglacial ponds using an object-based approach.

Study area

Figure: Focus of the studies are the debris-covered tongues of the Lirung and Langtang glaciers, located at above 4000 m elevation in the Nepalese Himalaya.

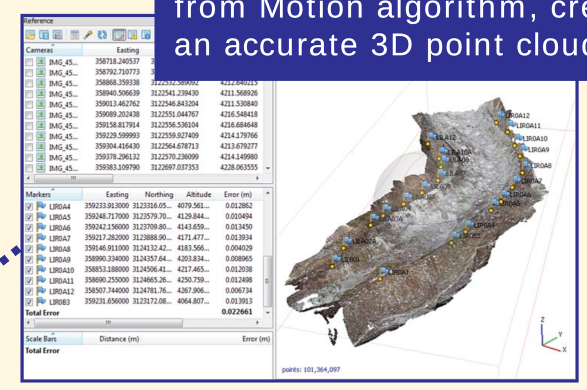


General UAV Methodology

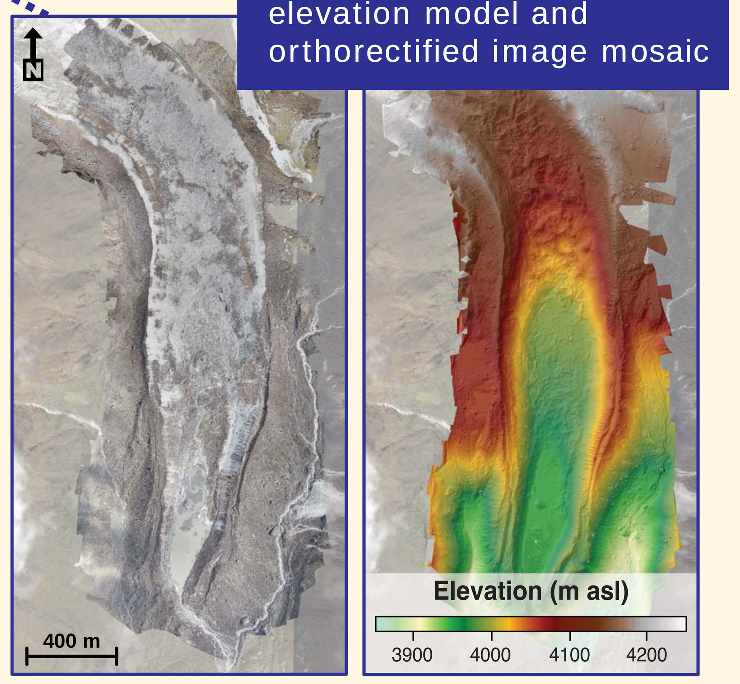


UAV survey of the glacier using the eBee, a fixed-wing UAV system. Images are captured by the mounted RGB compact camera

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



Derive 10 cm resolution elevation model and orthorectified image mosaic

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

1. Elevation change

- **Derive surface lowering using UAV data**
- **Evaluate melt patterns and dynamics**

- May and Oct 2013 surveys of Lirung Glacier

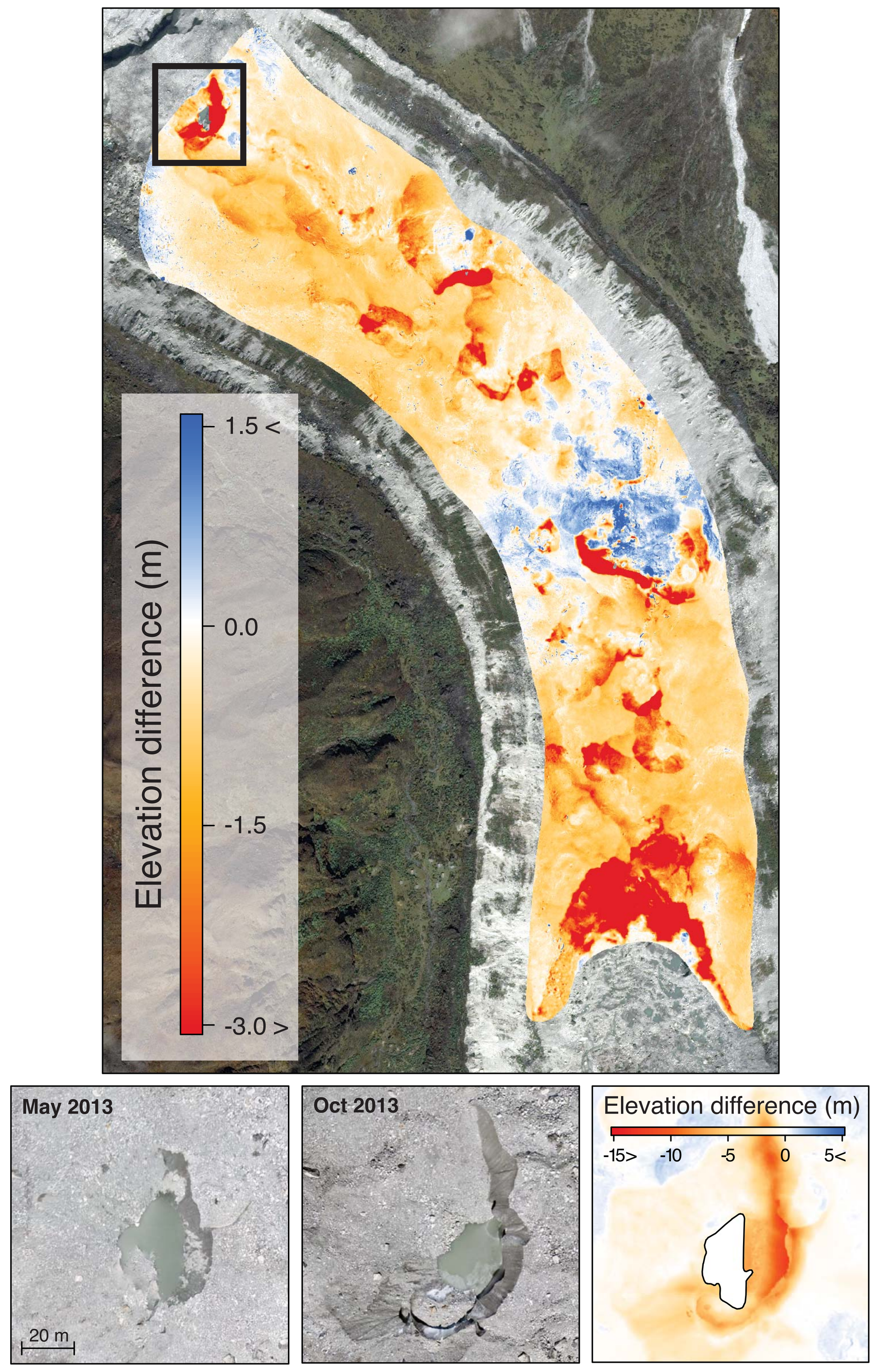


Figure: Heterogeneous patterns of elevation change observed over the 2013 monsoon season. Ice cliffs found on Lirung are highly dynamic and have considerable influence on total melt. Elevation gains in the bend because of emergence.

Conclusions

- UAVs have high potential and may revolutionize methods of glacier monitoring
- Average surface lowering is limited, i.e. -1.09 m
- Highly heterogeneous melt patterns
- Mass loss near ice cliffs 10 times higher than average

Immerzeel, W. W., Kraaijenbrink, P. D. A., Shea, J. M., Shrestha, A. B., Pellicciotti, F., Bierkens, M. F. P., & de Jong, S. M. (2014). *High-resolution monitoring of Himalayan glacier dynamics using unmanned aerial vehicles*. Remote Sensing of Environment, 150, 93–103.

2. Surface velocity

- **Assess automated feature tracking for high-resolution UAV imagery**
- **Evaluate seasonal differences in surface velocity**

- Additional May 2014 survey of Lirung

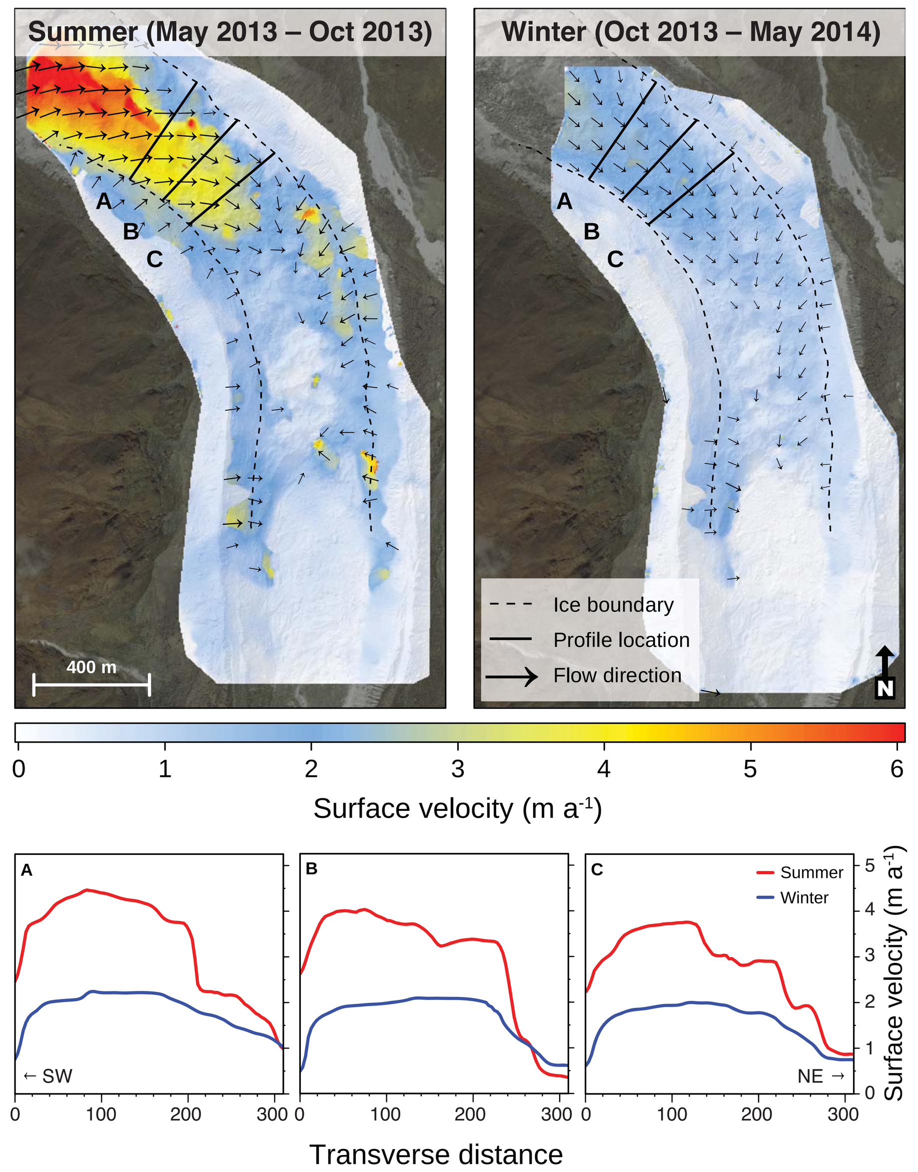


Figure: Surface velocity and flow direction as determined using frequency cross-correlation of UAV imagery for the summer and winter period. The plots show transverse surface velocity profiles at the indicated locations.

Conclusions

- Frequency cross correlation useful for UAV imagery
- Optical input data provides best results
- UAV useful to determine seasonal differences
- Large difference between summer and winter
- Basal sliding (summer) vs deformation (winter) could be the mechanism

Kraaijenbrink, P. D. A., Meijer, S. W., Shea, J. M., Pellicciotti, F., Jong, S. M. D. E., & Immerzeel, W. W. (2016). *Seasonal surface velocities of a Himalayan glacier derived by automated correlation of unmanned aerial vehicle imagery*. Annals of Glaciology, 57(71), 103–113.

3. Ice cliffs and ponds

- **Develop object-based method to automatically extract quantitative data on ice cliffs and supraglacial ponds.**
- **Evaluate the spatial distribution and characteristics of these surface features**

- Survey in May 2014 of Langtang Glacier

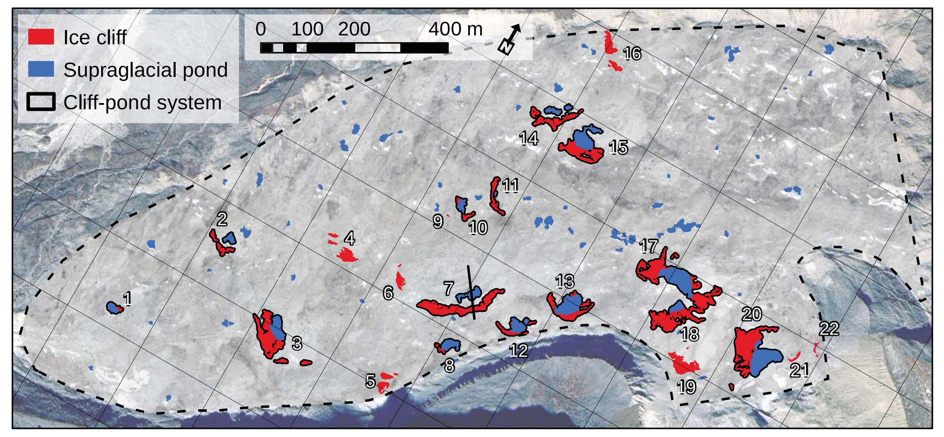


Figure: Ice cliffs and supraglacial ponds on Langtang Glacier as classified automatically on UAV imagery by object-based classification.

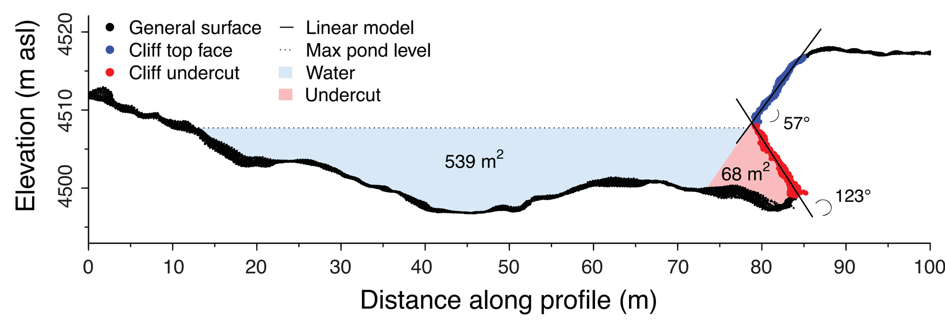


Figure: Cross-section of the UAV-derived point cloud of a cliff. The UAV is capable of capturing undercut morphology. Location of the cross-section is indicated in the map above.

Conclusions

- Object-based analysis of UAV data is capable of automatic delineation of cliffs and ponds
- Slope data is key for acccurate classifcation
- Potential for large scale, objective analysis
- UAV-derived dense point clouds promising for systematic ice cliff morphology analyses
- Ice cliffs are predominantly north-facing
- Glacier confluences are likely to affect supraglacial pond formation

Kraaijenbrink, P. D. A., Shea, J. M., Pellicciotti, F., de Jong, S. M., & Immerzeel, W. W. (2016). *Object-based analysis of unmanned aerial vehicle imagery to map and characterise surface features on a debris-covered glacier*. Remote Sensing of Environment (*under review*), 1–14.

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