

## Use of Pleiades satellite imagery to characterize terrain properties and features on the surface of debris-covered glaciers

*Goal: The main goal of the visit was to jointly establish remote sensing methods for quantifying characteristics of debris covered glacier surfaces (supra-glacier lakes and ice cliffs) using the Khumbu region as a test site to take advantage of Nicholson's extensive field experience in this area.*

### Achievements for this visit:

1. **Pleiades digital elevation model (DEM) evaluation:** The first part of the Innsbruck visit was devoted to carefully evaluating the existing DEMs for the Khumbu area previously generated from Pleiades imagery using semi-global-matching algorithms in ERDAS Imagine and Saga software. These DEMs are needed for i) orthorectifying Pleiades panchromatic and multi-spectral scenes and subsequently ii) extracting surface features based on topography (lakes and ice cliffs). We identified issues to be addressed for post-processing of the DEMs (smoothing, blunder removal) and eventually re-generating some DEMs to be more suitable for surface analysis at a later stage in our collaboration.
2. **Orthorectification of multispectral bands of Pleiades imagery:** We chose two sets of triplets for Pleiades (Autumn 2015 and Spring 2016), since these scenes were mostly snow- and cloud-free. We used the Pleiades DEMs from each date to orthorectify the multi-spectral Pleiades scene. The scenes for each season were then stitched using ERDAS Imagine MosaicPro and the Rational Polynomial Coefficients (RPCs) provided with each image. For each triplet, we identified the most nadir-looking scene to be used as validation for step 3 below.
3. **Sub-pixel mapping of debris covered surfaces:** We ordered a Landsat 8 scene from Sept 30<sup>th</sup> which was the closest in time to the Pleiades imagery (Oct 10<sup>th</sup>, 2015). We defined 5 regions of interest (ROIs) in the area (vegetation, ponds, snow, ice, and moraine); these were digitized on the Landsat scene and cross-checked with high resolution Pleiades, then extracted spectral signatures and ran the Spectral hourglass algorithm to sub-pixel classification. Due to time constraints, we only tested the ENVI algorithm, as digitizing the classes and constraining the algorithm was time-consuming. We were able to constrain the algorithm and compute the % ice, water and moraine on debris covered glacier tongues.
4. **Preliminary results were presented** at a seminar in ACINN on Jan 25<sup>th</sup> with invitations sent to all Innsbruck institutions with interest in remote sensing and/or glaciers.

### Further steps and potential for continued collaboration:

The proposed project formalized the research collaboration between Racoviteanu (specializing in satellite remote sensing of debris covered glaciers) and Nicholson (expert in modelling debris covered glaciers). It allowed us to establish a workflow protocol, exchange large amounts of data, pre-process it and successfully test sub-pixel algorithms for debris cover mapping. The visit allowed collaborative use of Pleiades high-resolution satellite imagery, available at the host institution through an FFG project. This was an important step towards further collaborations involving fieldwork on glacier debris cover, as Racoviteanu plans to return to the Himalayas to get more validation data to test the algorithm in various areas. Preliminary results are promising, and we are drafting a paper to be published in a remote sensing peer-reviewed journal.

Further research steps to be taken include: i) testing ERDAS Imagine software sub-pixel routines to compare with the ENVI results; ii) applying atmospheric/topographic corrections to Landsat imagery, as this will remove illumination effects and might improve algorithm performance; iii) jointly plan field campaigns to acquire more validation data in other areas, such as Sikkim where Racoviteanu plans to develop her research as part of the DISCOVER GLACIERS project; iv) evaluate and use the Pleiades DEMs to extract surface characteristics for mapping supra-glacial features. This latter point was one of our goals for this visit, but given the time constraints and the issues found with the DEMs (blunders, noise) we could not target this goal. We plan to generate a single DEM for the autumn 2015 Pleiades data using the improved ERDAS Leica Photogrammetric Suite (LPS) available at University of Innsbruck, and plan to follow up with a second project-funded visit to further strengthen our existing collaboration, and finalise the research outcomes.