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Photogrammetric Techniques for Spatio-temporal Analyses of Glacier Motion Patterns

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ABSTRACT

The paper gives a brief overview of activities of the Institute of Photogrammetry and Remote Sensing (TU Dresden) concerning the development of photogrammetric image sequence processing techniques for spatio-temporal analyses of glacier motion. The methods have been applied to measure and analyse surface velocity fields of several glaciers in Greenland and in the Patagonian Icefield.

1. INTRODUCTION

Jacobshavn Isbræ (Sermeq Kujalleq) is one of the fastest and most productive glaciers in the world. It drains 7% of Greenlands annual precipitation. At an observed speed of about 20 m/day, measured in 1890 … 1965 … 1995 (Hammer 1893, Carbonell/Bauer 1968), it used to produce an annual iceberg discharge of 30-40 km³, contributing 4% of the 20th century annual sea level increase (0.06 mm/year, Joughin et al., 2004). Jacobshavn Isbræ and the Kangia Fjord have been declared UNESCO world natural heritage in 2004 (Bennicke et al., 2004). In recent years, a rapid change of the glacier movement pattern has been observed, which is characterized by a dramatic retreat of the glacier front, a strong thinning of the glacier and a fast acceleration of glacier movement to now about 40 m/day.

In 2004-2010, we conducted four expeditions to the glacier. The goal of the project was an analysis of the situation at the front of the glacier, which has become instable in the past few years. This work includes the interpretation of satellite images as well as the determination of glacier movement velocities from terrestrial image sequences.

2. JACOBSHAVN ISBRÆ GLACIER FRONT RETREAT

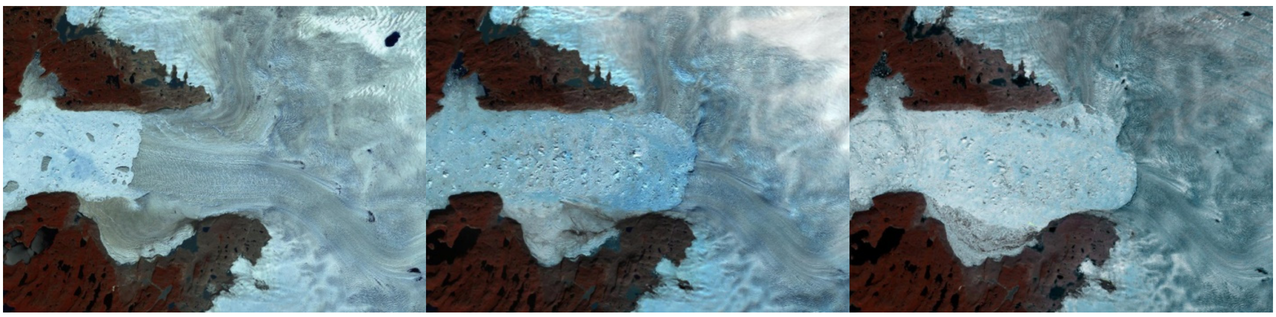

Figure 1: False color Landsat images of Jacobshavn Isbræ (7.7.2001, 8.9.2004, 8.7.2007).

Figure 1 shows three false color Landsat satellite images of the glacier front of Jacobshavn Isbræ calving into the Kangia Fjord, which is about 9.5 km wide (Maas et al., 2008). The glacier front has retreated by about 12 km between 2001 and 2004, 11 km thereof in spring 2003 (Podlech and Weidick, 2004). A further retreat of 1-2 km can be observed between 2004 and 2007.

3. MONOCULAR TERRESTRIAL IMAGE SEQUENCE ANALYSIS

Figure 2 shows a helicopter image of the Jacobshavn Isbræ glacier front. We used terrestrial high resolution digital camera image sequences to determine spatio-temporal glacier surface velocity fields (Maas et al., 2005/2006). Due to the prevailing motion behavior, monocular image sequences are sufficient here. Stereo partners are only acquired at the beginning of each sequence in order to determine scale factors for each trajectory.

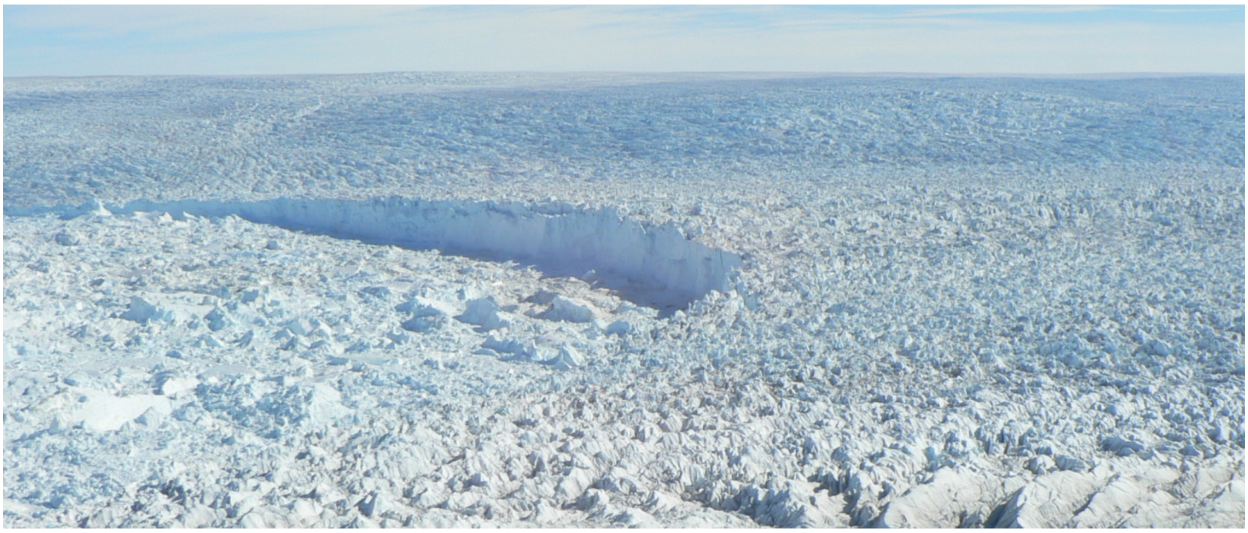

Figure 2: Terrestrial image of the Jacobshavn Isbræ glacier front (2007).

Glacier motion vector and trajectory fields were determined by a modified least-squares image matching approach (Schwalbe, 2013). Wind-induced camera motions were corrected on the basis of tracking some fiducials in the image foreground.

Figure 3 shows a color-coded glacier movement velocity field, obtained from 4400 tracked surface points over 24 hours (Dietrich et al., 2007). The velocities reach values beyond 40 m/day. The precision of velocity vector determination was estimated in the order of 10cm at 4 km distance to the camera.

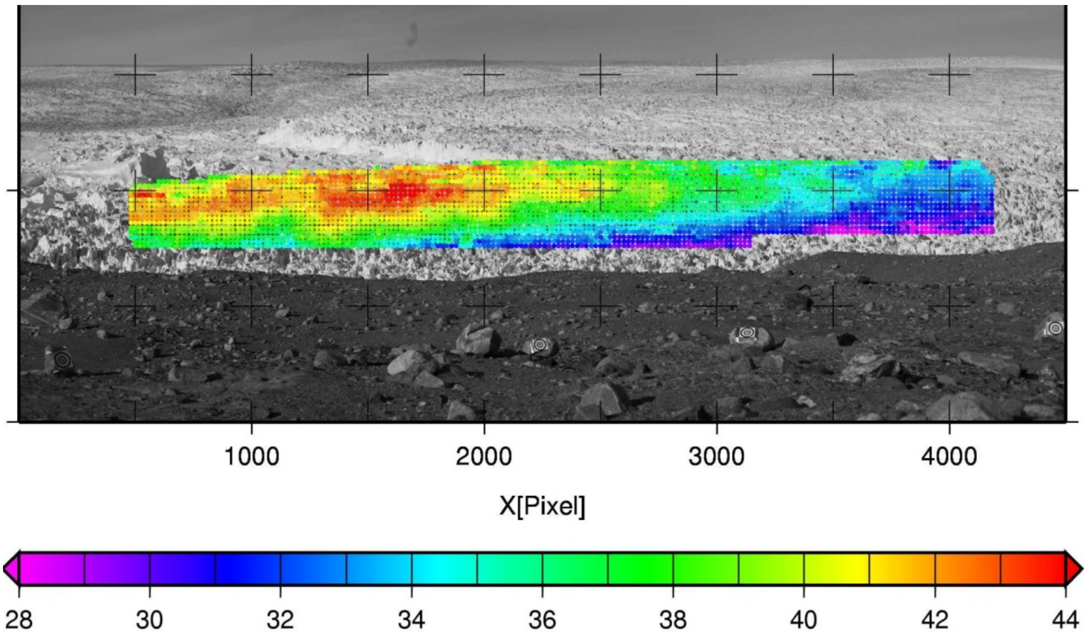

Figure 3: Velocity field [m/day] at Jacobshavn Isbræ glacier front (2004 data).

Figure 4 shows the vertical movement of one single point close to the glacier calving front. An analysis of the vertical movement pattern showed a perfect correlation with the local tide pattern, proving the fact that the glacier tongue is floating on the fjord and is not grounded – a fact which has severe consequences for the calving bahaviour of a glacier.

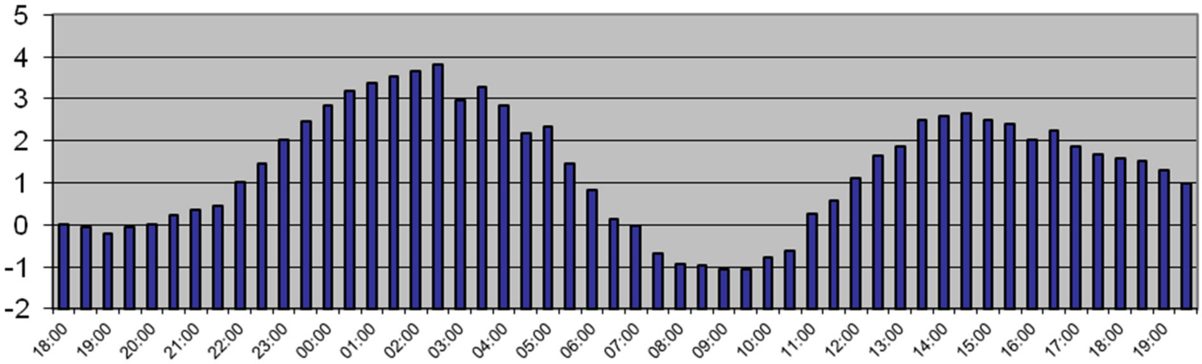

Figure 4: Vertical movement [m] of one single point (2004 data).

Beyond the application of terrestrial image sequence analysis techniques, we also did a study on the applicability of a long range terrestrial laser scanner. A laser scanner provides obvious advantages for instance in the ability of measuring the glacier front height and monitoring of glacier thinning, but comes with a much larger instrumental effort. We used a Riegl LPM-321 to be able to determine spatio-temporal velocity fields from feature tracking in multi-temporal scans on a section of the glacier, which was some 1.5 – 4.0 km away from the safe morain (Schwalbe et al., 2008, Maas/Schwalbe, 2013).

4. RESULTS FOR GLACIERS IN THE PATAGONIAN ICEFIELD

The photogrammetric image sequence analysis techniques as described above were also used for the determination of spatio-temporal velocity fields at Glaciar San Rafael in the Northern Patagonian Icefield. Again, monocular high resolution image sequences formed the basis for feature tracking,

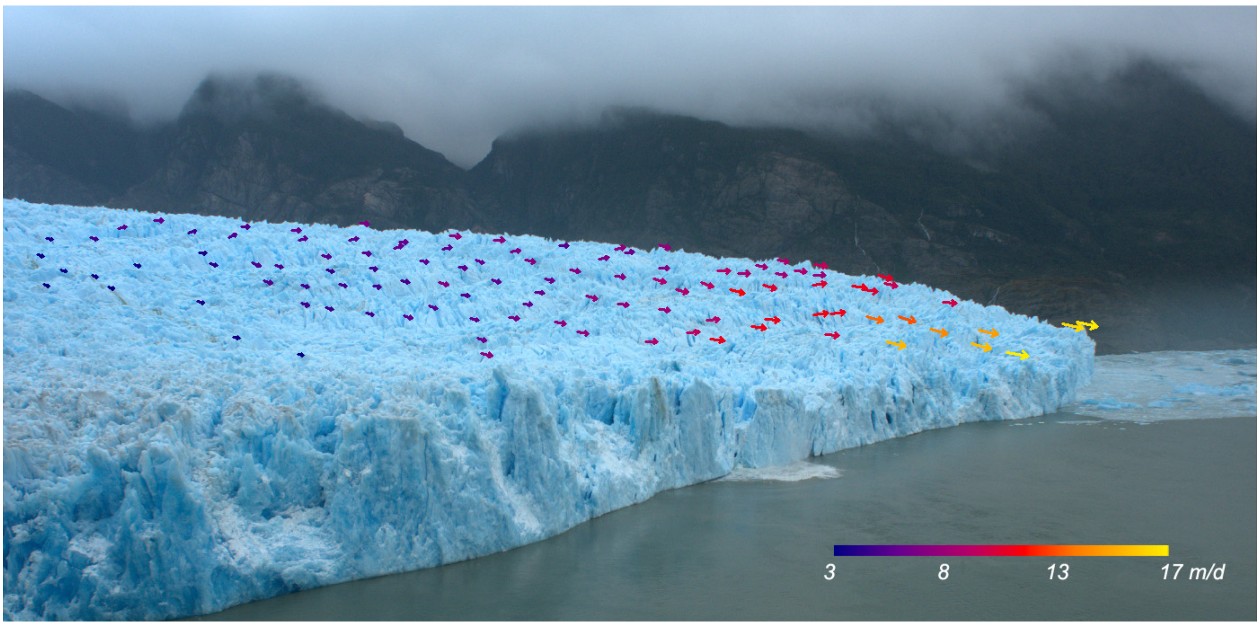

Figure 5: Velocity field at Glaciar San Rafael (2009).

with georeferencing solved in a combined geodetic-photogrammetric network based on GPS measurements and stereo images taken only at the beginning of a sequence.

The results are shown in Figure 5, with measured velocities of up to 17 m/day (Maas et al. 2010/2013).

5. CONCLUSIONS

The experience with the development and application of monoscopic terrestrial image sequence processing techniques, combined with proper techniques for trajectory scaling and georeferencing, has shown that these techniques may be a rather interesting tool for glaciologists. Compared to satellite imagery, they offer the obvious disadvantage of rather limited regional coverage, but the advantages of a much higher spatial resolution and precision and – most importantly – an almost arbitrary temporal resolution. This makes them complementary to conventional remote sensing techniques in glaciology. The instrumental effort can be limited to a (pre-calibrated) high resolution camera in a weather-proof housing with suitable (solar) power supply. Georeferencing may be performed at sufficient accuracy by a hand-held GPS device and stereo images taken at the beginning of a sequence, possibly supported by hand-held distometer measurements.

6. ACKNOWLEDGEMENTS

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