Performance and application of different image matching algorithms for investigating glacier and ice-shelf flow, permafrost creep and landslides.

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Correlation of repeat image data and radar interferometry are key technologies for investigating surface velocity fields of glaciers, ice shelves, permafrost creep and landslides, and their changes over time. Due to loss of phase coherence, radar interferometry over snow and ice usually requires tandem missions or short temporal baselines with a few days time base (Kääb, 2005). No such mission is currently or in the near future available, so that image correlation, both of optical and SAR images, is the only present way to measure terrain movements under snow and ice conditions. Further development and evaluation of image correlation techniques are therefore needed to select the optimal techniques for individual movement processes and image types, and to ensure optimal exploitation of the vast archives of repeat earth observation images. In this contribution we focus on the comparison of different spatial domain and frequency domain image matching algorithms, on displacement determination by subpixel accuracy, and on adaptive matching methods that take account of the spatial variability of image content. As a representative set of image types within our assessment studies we select airphotos, Landsat and ASTER type medium resolution optical satellite data, low resolution optical data such as MODIS, and medium and high resolution spaceborne SAR data. Application areas of our assessments are ice shelves, glaciers, rockglaciers and landslides.

Ice shelf velocity is an important indicator of the stability of Antarctic ice shelves. Several of the ice shelves that have disintegrated so far have shown a speed up prior to the collapse (Bindschadler et al., 1994; Skvarca et al., 1999; Skvarca et al., 2004). The size of the ice shelves and the amount of clouds in Antarctica make the ice shelves difficult to monitor, and up until now there has been only few studies focusing on velocity of these ice shelves. However, low resolution images have short repeat times, a fact that increases the likelihood of obtaining cloud free images. One image covers an entire ice shelf, which makes it easy to perform large-scale monitoring. Due to the spatial resolution, subpixel-accuracy measurements are needed in order to obtain the accuracy necessary to find velocity changes. Here, we use the Larsen C ice shelf, Antarctic Peninsula, as a test area. The velocity field is derived using MODIS images (250 m spatial resolution) over the periods 2002-2006 and

2006-2009. The measurements are validated for two ice shelf sections against repeat medium-resolution Landsat 7 ETM+ pan data (15 m spatial resolution). Horizontal surface velocities are obtained through image matching in both frequency and spatial domain, and the two methods are compared to each other. The uncertainty in the velocities turns out to be less than 70 m for the MODIS derived data, and less than 15 m for the Landsat-derived ones. The difference between MODIS and Landsat-based speeds is -15.4 m/a and 13.0 m/a for the first period for the two different validation sections on the ice shelf, and -26.7 m/a and 27.9 m/a for the second period for the same sections. This is within the uncertainty level, and leads us to conclude that repeat MODIS images are well suited to measure ice shelf velocity fields and monitor their changes over time. The frequency domain image correlation method seems better suited for this purpose because it is faster, produces fewer mismatches, and is able to match images with regular noise and data voids. The latter makes it possible to match Landsat 7 ETM+ images even after the 2003 failure of the Scan Line Corrector (SLC off) that leaves significant image sections with no data. We also applied our method successfully to other ice shelves around Antarctica.

In a second study, subpixel-accuracy measurements, influence of spatial sensor resolution on the matching results, and adaptive methods for optimizing the matching template sizes are tested using repeat airphotos of a glacier, a rockglacier and a landslide in the European Alps. Thereby, we focus on the use of the normalized cross-correlation, one of the most widely used spatial-domain image matching techniques. Our results reveal that image intensity interpolation beforehand the matching outperforms methods of defining the correlation peak at subpixel accuracy after the matching process. Bi-cubic intensity interpolation turns out to be the preferable intensity interpolation technique. By interpolating the original image by up to a ten times increased resolution, matching accuracies can be improved by up to 40 % of the original pixel size. For the three test sites studied we also assess through computation and comparison within an image resolution pyramid with which resolution or sensor type, respectively, the three mass movements could be successfully measured. As a third step in this study we demonstrate a number of methods for adaptively varying the size of matching template sizes in order to create the most reliable and accurate matches.

Finally, we assess a subset of the above matching techniques for a number of additional application studies, mainly measuring glacier flow based on repeat optical satellite data (ASTER, Landsat) and SAR data (ERS SAR, ASAR, Radarsat-1, Radarsat-2 and TerraSAR-X).

References:

Bindschadler, R. A., Fahnestock, M. A., Skvarca, P. and Scambos, T. A., 1994: Surface-velocity field of the northern Larsen Ice Shelf, Antarctica, Annals of Glaciology, 20, 319–326.

Kääb, A. 2005. Remote Sensing of Mountain Glaciers and Permafrost Creep. Schriftenreihe Physische Geographie. 48, 266 pp, ISBN 3 85543 244 9.

Skvarca, P., Rack, W. and Rott, H., 1999: 34 year satellite time series to monitor characteristics, extent and dynamics of Larsen B Ice Shelf, Antarctic Peninsula, Annals of Glaciology, 29, 255–260.

Skvarca, P., De Angelis, H. and Zakrajsek, A., 2004: Climatic conditions, mass balance and dynamics of Larsen B ice shelf, Antarctic Peninsula, prior to collapse, Annals of Glaciology, 39, 557–562.