# DETERMINATION OF VARIATIONS IN GLACIER SURFACE MOVEMENTS THROUGH HIGH RESOLUTION INTERFEROMETRY; BYLOT ISLAND, CANADA

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## 1. INTRODUCTION

SAR interferometry (InSAR) has been used to measure ice displacement and to determine the velocities of large ice sheets since the early 1990s. A number of studies have made use of ice displacement measurements derived from satellites such as ERS-1, ERS-2, ENVISAT, and RADARSAT-1 to estimate flow rates and mass loss over the Greenland and Antarctic ice sheets, e.g. [1-3]. Although InSAR has also been used to investigate the dynamics of valley glaciers, the studies which have been carried out tend to be confined to larger glaciers, e.g. [4-6], mainly as a result of decorrelation and resolution issues. The combination of high strain rates between the centre of the glacier and the valley walls, along with repeat periods of several weeks, can result in glaciers being subject to significant decorrelation between acquisitions. Additionally, radar satellites such as ERS-1, ERS-2 and RADARSAT-1 have spatial resolutions in the tens of metres, which after multi-looking may be degraded to the point where there are insufficient pixels to derive accurate motion estimates.

High resolution radar satellites such as TerraSAR-X have the potential to overcome many of these limitations. Spatial resolutions of up to 1 m allow detailed interferograms to be generated for even the smallest glaciers, while the repeat period of 11 days considerably reduces the effects of temporal decorrelation, when compared with other radar satellites.

This study uses TerraSAR-X interferometry to measure flow rates and flow patterns for a slow moving polythermal arctic valley glacier located on Bylot Island, Canada. The combination of cold, stable climatic conditions with slow surface velocities allows coherence to be maintained over longer periods than would be the case for faster moving temperate glaciers. The high spatial resolution makes it possible to identify local motion anomalies occurring across the glacier surface. Many of these are believed to be related to subglacial hydrological conditions. Patterns of subsidence and surface lifting, occurring at different times of year, have been inferred to relate to variations in subglacial water pressure. The presence of stored water, especially at the glacier terminus is believed to play a significant part in the processes which are causing the glacier to retreat. Using high resolution interferometry it is hoped to shed new light on the complex interaction between surface dynamics and subglacial hydrology.

## 2. BACKGROUND AND STUDY AREA

This paper focuses on Fountain Glacier, a relatively small polythermal valley glacier located on Bylot Island in the Canadian Arctic. The seasonal dynamics of this glacier are thought to be strongly influenced by subglacial hydrological processes. It is believed that thermal constriction by the glacier's frozen margins results in considerable subglacial water storage under the terminus region. The hydrology of Fountain Glacier and its associated proglacial icing were investigated by Wainstein et al. [7], who concluded that the presence and annual regeneration of the icing provided evidence that liquid water is present at the base of the glacier, even in the winter.

Fountain glacier has started to retreat rapidly in the last 15 years, after having remained relatively stable since its Neoglacial maximum. Since the retreat commenced, the glacier snout has developed a vertical calving face, up to 30 m high in places, which now extends across the whole terminus. Consequently the main source of mass loss is now mass-wasting and avalanching, rather than surface melting, which was formerly the dominant process. It is believed that the collapse of subglacial caverns, which were formerly filled with water, has contributed significantly to the current retreat. This process is believed to be continuing and several areas of the terminus are thought to be subsiding at present. It is thought that this subsidence may precede further collapse, thus increasing retreat rates still further.

## 3. METHODOLOGY

Interferograms were generated from ascending and descending-pass TerraSAR-X image pairs obtained in May and October 2008, and February 2009. These interferograms were then unwrapped in order to derive surface flow magnitudes and directions for each of the three periods, using both ascending-pass and descending-pass measurements. The motion information derived from each of these three periods was used to provide a measure of baseline winter flow. Further interferograms will be generated as imagery becomes available, in order to optimally characterise the year-round flow regime.

Once baseline flow patterns have been established, the main focus will be to identify motion anomalies, especially in the terminus region. Interferograms will be compared with baseline flows in order to identify areas where motion patterns have changed. Where subsidence or surface lifting is occurring changes in the interferometric fringe pattern will reflect vertical, rather than down-glacier motion. The degree of vertical motion will be determined by comparing measured displacements with modeled theoretical surface flow. To rule out other potential sources of motion variation, such as glacier bed topographic variations, areas where motion anomalies are present will be investigated in the field using a variety of techniques, including photogrammetric measurements from time-lapse photography, repeat GPS surveys, and ground-penetrating radar.

## 4. EXPECTED RESULTS

It is expected that this study will show that there are significant seasonal variations in glacial dynamics across the surface of Fountain glacier. Winter measurements are expected to show relatively even motion across the glacier surface, since freezing temperatures will inhibit sliding. Measurements obtained during the melt season are expected to show more variations, since local hydrological processes are expected to influence surface flow.

While SAR interferometry has previously allowed general measurements to be made of glacial velocity, it is anticipated that the greatly improved spatial resolution of TerraSAR X will allow the detection of subtle motion anomalies resulting from variations in basal hydrological conditions.

The detection of localised patterns of ice motion on small valley glaciers is a new application for interferometry, made possible by the advent of high-resolution radar imagery. Care must be taken with the interpretation of the results, since these localised motion patterns will often reflect vertical, rather than horizontal motion. This means that the widely used assumption of surface parallel flow, often made in InSAR studies of glaciers, e.g.[4, 6], may not be valid in many cases. Additional inputs in the form of field measurements may be required to resolve the X, Y, and Z components of displacement.

## 5. REFERENCES


1. Rignot, E., *Mass Balance of East Antarctic Glaciers and Ice Shelves from Satellite Data.* Annals of Glaciology, 2002(34): p. 217 - 227.
2. Rignot, E., *Changes in ice dynamics and mass balance of the Antarctic ice sheet.* Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences, 2006. **364**(1844): p. 1637-1655.
3. Joughin, I., W. Abdalati, and M. Fahnestock, *Large fluctuations in speed on Greenland's Jakobshavn Isbræ glacier.* Nature, 2004. **432**: p. 608-610.
4. Cumming, I. and J. Zhang, *Measuring the 3-D Flow of the Lowell Glacier with InSAR.* FRINGE'99: Advancing ERS SAR Interferometry from Applications towards Operations, 2000.
5. Strozzi, T., Gudmundsson, G.H., Wegmüller, U. . *Estimation of the Surface Displacement of Swiss Alpine Glaciers Using Satellite Radar Interferometry*. in *EARSeL-LISSIG-Workshop Observing our Cryosphere from Space*. 2002. Bern, Switzerland.
6. Vachon, P.W., D. Geudtner, K. Mattar, A.L. Gray, M. Brugman, and I. Cumming, *Differential SAR Interferometry Measurements of Athabasca and Saskatchewan Glacier Flow Rate.* Canadian Journal of Remote Sensing, 1996. **Vol 22**(3): p. pp.287-296.
7. Wainstein, P., B. Moorman, and K. Whitehead, *Importance of Glacier - Permafrost Interactions in the Preservation of a Proglacial Icing: Fountain Glacier, Bylot Island, Canada.* Ninth International Conference on Permafrost. 2008: Fairbanks, Alaska.