MONITORING A GLACIER IN SOUTHEASTERN ICELAND WITH THE PORTABLE TERRESTRIAL RADAR INTERFEROMETER

Denis Voytenko[1], Timothy H. Dixon[1], Charles Werner[2], Noel Gourmelen[3], Ian M. Howat[4], Phaedra C. Tinder[4], Andrew Hooper[5]

[1]Department of Geology, University of South Florida, Tampa, FL, United States
[2]GAMMA Remote Sensing, Gumligen, Switzerland
[3]Institut de Physique du Globe de Strasbourg, University of Strasbourg, Strasbourg, France
[4]School of Earth Sciences, Ohio State University, Columbus, OH, United States
[5]Delft University of Technology, Delft, Netherlands

ABSTRACT

Terrestrial Radar Interferometry (TRI) has several advantages for measuring glacier velocity. These ground-based systems alleviate problems associated with the long revisit times of satellites, and provide higher spatial sampling compared to GPS-based approaches. TRI is the technique of choice for rapidly moving glaciers, especially their terminal zones, which tend to exhibit high spatial and temporal variability. In this study, we use the Gamma Portable Radar Interferometer (GPRI) to measure the velocity of Breidamerkurjokull, a marine-terminating outlet glacier on the southeastern coast of Iceland, and compare it to TerraSAR-X data taken shortly after. We document significant temporal and spatial variability of ice velocity within 800 meters of the calving front.

***Index Terms*—** geodesy, ice, radar interferometry

1. INTRODUCTION

The time-varying velocity field of glaciers is a useful tool for investigating glacial dynamics. Although satellite radar interferometry provides precise and spatially-dense measurements, satellite passes are not frequent enough to observe short-timescale processes in rapidly-moving glaciers. Terrestrial Radar Interferometry (TRI) resolves the issue of infrequent measurement by using a portable, ground-based radar located close to the observation site. In this study, we use the Gamma Portable Radar Interferometer (GPRI) to observe the terminal region of Breidamerkurjokull, a rapidly-moving outlet glacier in Southeastern Iceland (Figure 1).

Recently, the GPRI has been used to monitor geologically-rapid features like alpine glaciers and landslides [1]. The GPRI is a real-aperture radar that operates at a frequency of 17.2GHz (Ku-band) with a precision of <1 mm and an operating range of 20m to 10km [1]. The radar consists of one transmitting antenna and two receiving antennas, attached to a frame that rotates while the image is scanned.

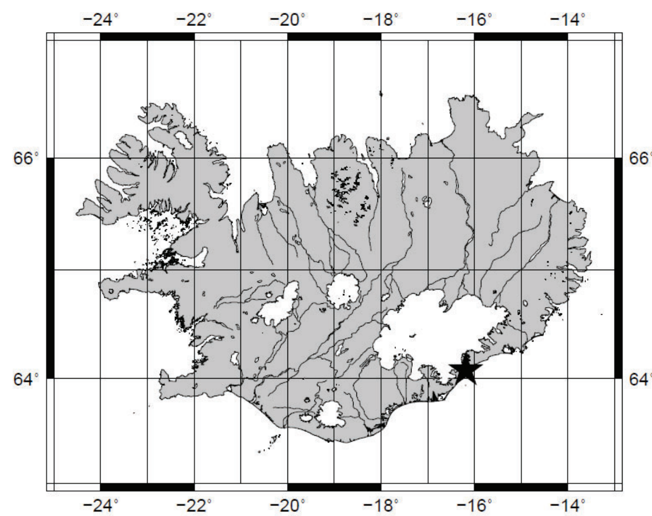

Figure 1. Map of Iceland showing the major glaciers obtained from the GLIMS database [2][3] (white) and the location of the study site at Breidamerkurjokull, (star).

Breidamerkurjokull is a marine-terminating outlet glacier of the Vatnajokull ice cap that is of interest for ice studies because of its spatially variable geometry and flow [4]. Its terminus is a mostly grounded ice front which regularly calves icebergs into a proglacial lagoon with an outlet to the Atlantic Ocean.

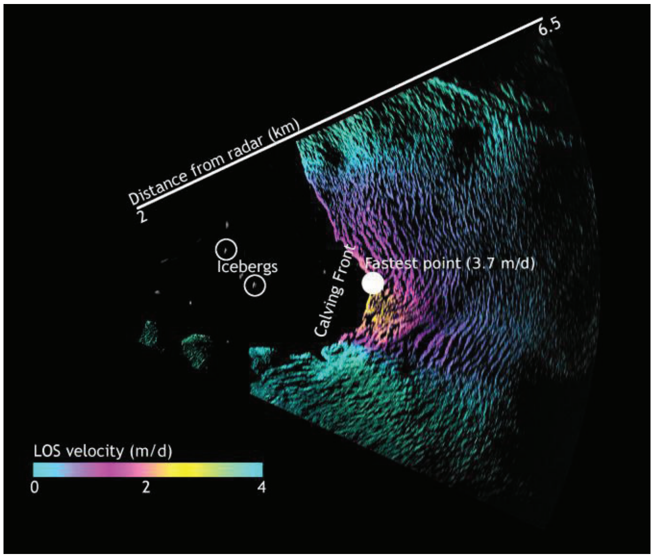

Figure 2. LOS velocity map for the first acquisition period, 2011-09-14 11:11-15:23

2. METHODS

We set up the GPRI on topographically-high moraine deposits with an unobstructed view of the glacier approximately 3km away from the calving front. We imaged the glacier by scanning a 50-degree arc every minute. The data presented are lower-antenna images from four continuous acquisition periods between 9/14/11-9/15/11 at the following times: 11:11-15:23, 15:40-00:24, 03:02-08:59 and 11:07-12:22. We processed the GPRI images with the GAMMA software to obtain three-minute interferograms. After unwrapping the phase, we stacked the interferograms to produce a map of average spatial velocity. We also extracted displacement values for any coherent pixel in a set of interferograms, forming a displacement and velocity time series with a sampling interval of 3 minutes.

We selected three pixels from the first and second acquisition periods, at distances of 3, 4, and 5km from the radar (0, 1, and 2km from the calving front) for time series analysis. The pixels are in radar coordinates, so their footprint increases with distance. The azimuth resolution of the GPRI at 1km is 7-8m, which scales linearly with distance due to the constant beamwidth of the antennas.

The time series were compared to tide gauge data filtered into two sets; one showing calving events (high-pass filter) and the other showing the full tidal signal (low-pass filter). We also selected transects through the middle of the radar image at each acquisition period to show spatial changes in velocity. Then, we compared them to a transect from a single TerraSAR-X interferogram acquired between 2011-09-22 and 2011-10-03.

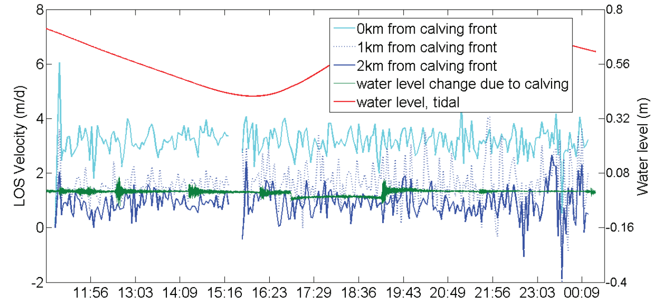

Figure 3. Velocity time series and water level data for the study period.

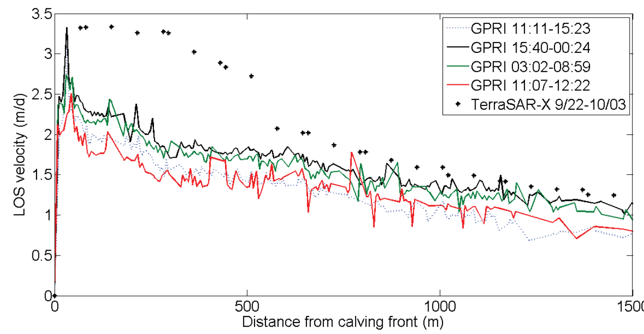

Figure 4. GPRI transect and TerraSAR-X velocity plot.

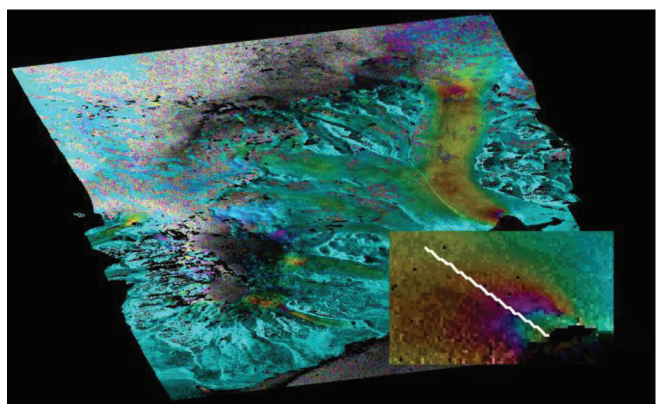

Figure 5. TerraSAR-X interferogram of Breidamerkurjokull between September 22, 2011 and October 3, 2011. The colormaps indicate the azimuth velocity. The enlarged square shows the TerraSAR-X transect (white) used in Figure 4.

3. RESULTS

The velocity map from the first GPRI acquisition period had a maximum LOS velocity of 3.7m/d at the calving front (Figure 2). The same map shows the approximate spatial velocity distribution for the glacier during the short study period.

Figure 3 shows the time series for pixels at and away from the calving front, along with the tide gauge data showing the tidal cycles and calving events. By inspection, there is no correlation between the velocity time series and the tide gauge data, perhaps reflecting the short time series.

The velocity range of each of the three pixels is in line with the velocities in Figure 2.

Figure 4 shows the spatial velocity distributions through the middle of the GPRI images along with the azimuth velocities from the TerraSAR-X data. There is good agreement between the two data sets at a distance greater than about 800 m from the calving front, with significant differences closer to the calving front.

Additionally, the displacement vs. time series can be used to estimate the total system noise (mainly due to the atmosphere) for the range measurements by focusing on a stationary pixel and examining its variability with time.

4. DISCUSSION

The one day study period was not long enough to investigate the impact of external forcing parameters (e.g., tides, calving events, and temperature variations) on the velocity of the glacier. A longer observation period is planned for future studies.

High velocities are observed near the calving front in both the GPRI and TerraSAR-X data (Figure 4). The higher velocities in the TerraSAR-X data compared with the GPRI near the calving front in the TerraSAR-X data may indicate time-variable motion, since the TerraSAR-X data were acquired after the GPRI data. The GPRI study lasted until 2011-09-15, while the first TerraSAR-X acquisition did not occur until 2011-09-22, with a subsequent image 11 days later. Also, the GPRI data suggest greater spatial variation in velocity compared with the “smoother” (longer time-average) TerraSAR-X data. This suggests that ice within the first ~800 meters of the calving front exhibits significant spatial and temporal variability. This dynamic region has not been studied in detail with existing methods, suggesting a promising role for future TRI studies.

5. REFERENCES

[1] Werner C., Strozzi T., Wesmann A., Wegmuller U. (2008), Gamma’s portable radar interferometer. 13th FIG Symposium on Deformation Measurements ad analysis, LNEC, Lisbon May 12-16 2008.

[2] Sigurdsson, O. 2005. GLIMS Glacier Database. Boulder, CO: National Snow and Ice Data Center/World Data Center for Glaciology. Digital Media.

[3] Raup, B.H.; A. Racoviteanu; S.J.S. Khalsa; C. Helm; R. Armstrong; Y. Arnaud (2007). "The GLIMS Geospatial Glacier Database: a New Tool for Studying Glacier Change". Global and Planetary Change 56:101—110. doi:10.1016/j.gloplacha.2006.07.018

[4] Howat, I. M., S. Tulaczyk, E. Waddington, and H. Björnsson (2008), Dynamic controls on glacier basal motion inferred from surface ice motion, J. Geophys. Res., 113, F03015, doi:10.1029/2007JF000925.