INTERFEROMETRIC STUDY OF THE ICE STREAM IN INTERIOR NORTHEAST GREENLAND

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Abstract

Our initial work in Greenland with ERS-1 SAR imagery led to the discovery of a large ice stream which carries much of the ice discharge from the northeast quadrant of the ice sheet. The ice stream was identified based on the morphology of the surface, which indicated the influence of localized rapid ice flow. Continued investigations using repeat-pass interferometry from ERS-1 and ERS-2 have allowed us to determine the character of the rapid motion, mapping the onset region in the deep interior of the ice sheet as well as more rapid motion downstream. Markers have been placed on the ice sheet and are being tracked with GPS surveys to provide tie-points for the interferometry, which will allow us to determine absolute velocities in this very remote area.

This work will help us understand the history of the ice in this region, which includes the core site for a new European deep coring effort. Ice streams are the main conduit for rapid ice discharge from ice sheets and are one possible mechanism by which ice sheets could quickly affect global sea level.

Introduction

Initial SAR studies of the Greenland Ice Sheet revealed the presence of a large ice stream that appeared to drain a significant area in the northeast quadrant of the ice sheet.[Fahnestock et al. 1993] The ice stream is also visible in elevation models of the ice sheet constructed from ERS-1 radar altimetry.[Ekholm 1996] These two data sets, combined with visible imagery from weather satellites, have allowed us to map this ice stream. Our interest at present is to understand the mechanics of the ice motion responsible for this feature. We are using a combination of SAR interferometry and field work to measure its speed and flow pattern. In this paper we will show some early INSAR results as well as the distribution of surface survey markers that will allow us to produce absolute motion measurements from the interferometry, even in the ice sheet interior.

When we are able to complete our field measurements and INSAR mapping, we should have a very well documented picture of the ice motion in this area, and an improved understanding of the reasons for the rapid ice motion.

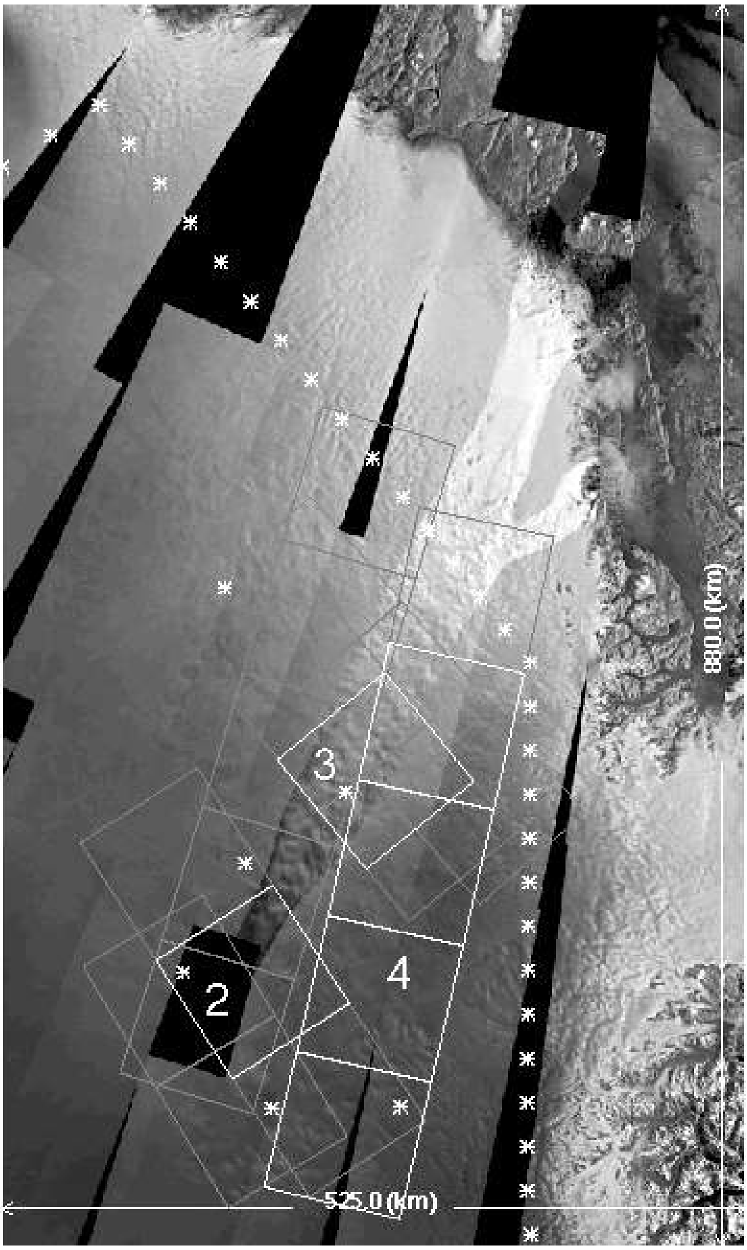

Figure 1. Interferometric frames (grey and white), and surface survey points (asterisks) plotted on an ERS-1 SAR mosaic of the northeast quadrant of the Greenland Ice Sheet. The numbers and white frames indicate the areas covered by the corresponding figures. The image contrast over the ice stream has been enhanced. SAR imagery ©ESA 1992.

Ice Stream Description

The ice stream starts in the interior near the ice divide. Its appearance in ERS-1 SAR imagery can be seen in Figure 1. The stream has several unique aspects, including its linear nature and a symmetric widening above the middle reach. The surface of the stream shows a more undulating character than the relatively flat, slow moving areas on either side. No other outlet glacier in Greenland reaches half as far inland; however there are a number of streams in Antarctica that are of a similar scale.

We have used a search of the INSAR baselines database to plan a series of interferometric pairs that can give us the proper set of baselines for double differencing [Kwok and Fahnestock, 1995, Joughin et al. 1996a, Joughin et al. 1996b] to produce both a high resolution elevation model of the area and a detailed velocity map with as fully determined a flow pattern as possible.[Joughin et al, submitted 1996] The locations of several strips that we have chosen are shown as white boxes in Figure 1. The numbered boxes correspond to Figures where the interferograms from these pairs are shown.

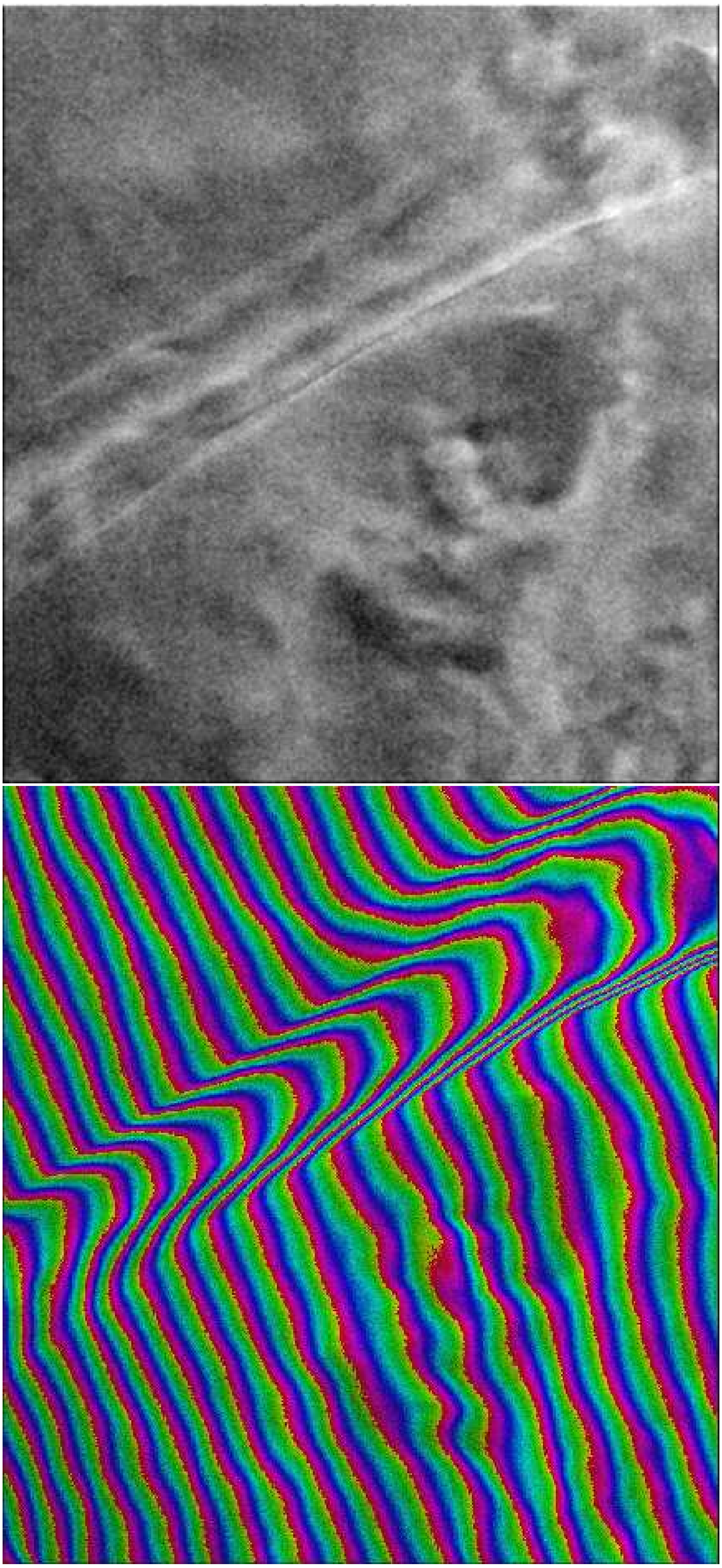

Figure 2. SAR amplitude image and interferogram from just below the onset region in the ice stream. Note the ice stream margins in the amplitude image and the ice motion fringes in the interferogram. The regular fringes running from the upper left to lower right in the interferogram are due to the regional topography, which slopes off to the upper right.

Examples of the interferograms and velocity results are shown in Figures 2, 3, and 4. The interferogram in Figure 2 shows the motion in the look direction (in large part in range) over a 3-day interval in the onset region. It is clear that the channeled nature of the flow is present even here. Figure 3 shows a velocity map from the mid point of the stream, and clearly demonstrates that there is substantial shear in the stream margins, and that the flow speed is clearly enhanced over that in the surrounding ice. [Fahnestock et al., submitted to Science 1997] Figure 4 shows a more complicated look at the ice motion over a 4 image swath across the southeastern margin of the stream. This figure is an interferogram from a 35-day repeat pass, so small gradients in motion in the look direction (dominantly vertical) are accentuated.

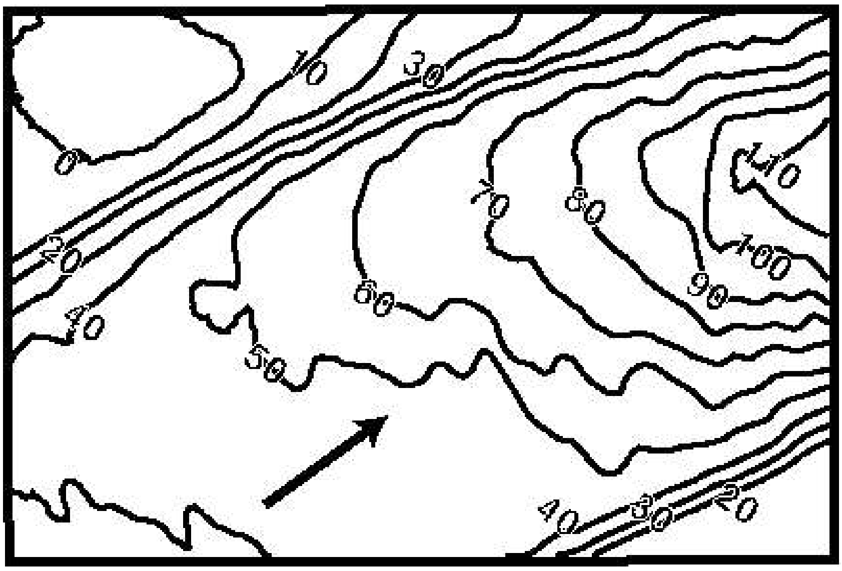

Figure 3. Velocity map near the midpoint of the ice stream. Velocity is in meters per year relative to an arbitrary zero point to the upper left. Note the shear in the margins (grouping of contours). Arrow indicated the downstream direction, which had to be assumed to derive flow velocity from this single interferogram.

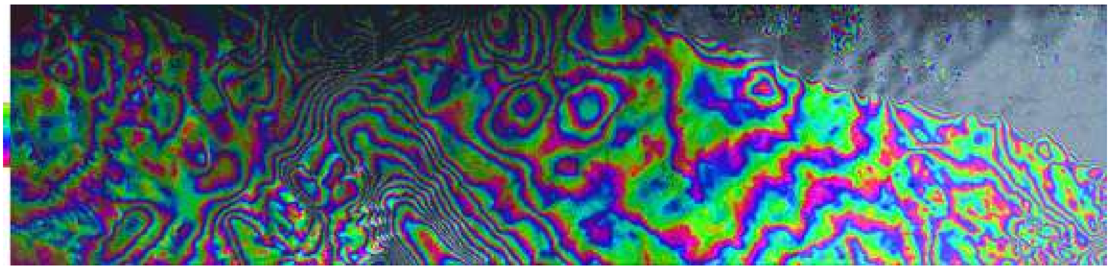

Figure 4. 35-day interferogram of the swath on the southeast of the ice stream. Lower part shows two regions of organized flow and a predominance of the effect of vertical motion. Upper part shows the edge of the ice stream and the very high fringe rates associated with the rapid flow.

Field Program

The interferometric measurements provide a relative map of ice motion which must be tied to points of known motion and elevation in order to properly scale the baselines (and hence topography) and to provide an absolute reference for ice motion. On the Greenland Ice Sheet, this requires a field program using ski-equipped aircraft and precision GPS (Global Positioning System) surveys. We have conducted the first year of a two year study to make the measurements required. (see Figure 5) The sites visited in this part of the ice sheet are shown in Figure 1 as white asterisks. At each site, a metal survey marker was planted and surveyed with a P-code GPS receiver for 0.5 to 8 hours, depending on logistical constraints. The surveys, which locate the markers to better than 5 cm in a global reference frame, will be repeated this spring, allowing the ice motion vectors to be determined.

Figure 5. Twin Otter aircraft on the ice sheet, with GPS surveying antenna indicated.

This type of measurement is logistically expensive, so steps were taken to limit the number of remote points required. The most important of these steps was to carefully analyze the baselines of already acquired interferometric pairs, to pick the distribution of frames that could be controlled with the fewest field measurements possible. The insar baseline database proved invaluable for this planning activity. The next step was to pick points in what appeared to be slow moving areas, so that small mislocations in referencing the surveyed points to the interferograms would not introduce error, and so that single point measurements of motion could be extrapolated over fair distances.

Conclusions

While we have been discussing a work in progress, our study of the northeast Greenland Ice Stream has already shown us a fair amount about the character of this feature. Building upon techniques developed over the last few years, we have been able to minimize the field work required to map ice motion and detailed topography over a wide area of the ice sheet interior. We hope that the emerging picture of ice motion will tell us more about the mechanics and origin of the rapid flow in this stream. As the map of ice flow is put together, additional work will be required to understand the role of the ice stream in the glaciological history of Greenland.

References

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