Using CReSIS airborne RADAR to constrain ice-volume influx across the lateral shear margins of the Northeast Greenland Ice Sheet

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I. Introduction

The Northeast Greenland Ice Stream (NEGIS) initiates farther inland than any other glacier or ice stream on the Greenland Ice Sheet (GIS) and its catchment covers a large region. We suggest that, because of its extent, NEGIS acts as a major control on the surrounding ice sheet's total ice volume.

NEGIS exhibits unusual flow dynamics that have not been observed in other ice streams. Glaciers in Greenland typically form within a topographic low. NEGIS, however, does not conform to its basal topography. This lack of basal constraint is likely the cause of NEGIS' unusual widening-downstream geometry [1]. Though presently a relatively stable stream, the future stability of NEGIS remains unclear. Understanding the behavior of flow in NEGIS is therefore important in determining the fate of the GIS.

II. RADAR Data

RADAR Echo-Strength profiles collected by the Center for Remote Sensing of Ice Sheets (CReSIS) show laterally continuous, harmonic layering. These layers represent horizons of equal age (isochrones) because low-frequency RADAR reflections in ice are due primarily to electrical conductivity contrasts inherited from snow deposition or volcanic events [2]. Layers with a larger difference in electrical conductivity are thus easier to identify in radar images. A distinct intensity signature, coupled with its relative depth, allows for consistent identification of a layer in RADAR data collected at multiple geographic locations.

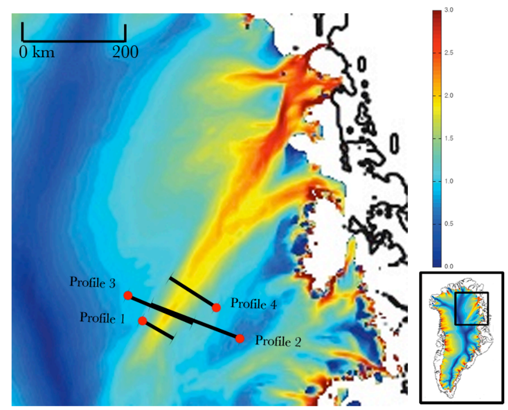

Fig. 1. Four Profiles were chosen. These Profiles cross approximately perpendicular to the direction of stream flow. The GPS coordinates of the endpoints are 75.70°N 36.70°W, 75.46°N 34.42°W (1); 75.43°N 30.59°W, 76.11°N 35.60°W (2); 76.42°N 38.38°W, 75.80°N 33.19°W (3); 76.18°N 30.76°W, 76.72°N 34.10°W (4). The red dot seen on each Profile signifies the first listed GPS coordinate and corresponds to the leftmost edge of each RADAR image. This map shows ice velocity, with faster flow appearing in red. Inset shows the location of NEGIS on GIS.

In this study, we examined RADAR images from the upstream region of NEGIS. We identified a set of isochrones in RADAR images for four sections across NEGIS (Fig. 1). These isochrones act as a reference for measuring cross-sectional area which, when compared to known stream velocities, will give an estimate of ice-volume influx in the upstream region.

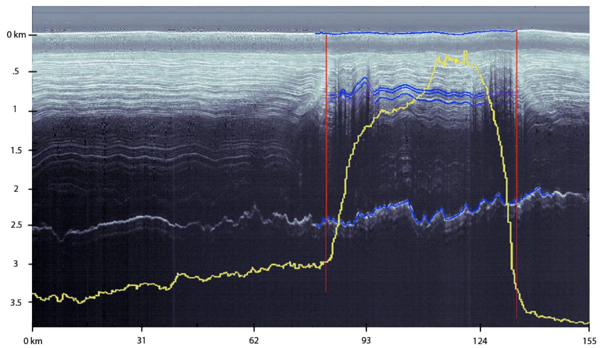

Fig. 2. The shear margins, in red, were defined at the point where the ice velocity, in yellow, levels off to that of the surrounding ice. The blue lines are the isochrone picks used to mask the flow belts (Fig. 3). Deformed regions believed to be relict margins can be seen just inside the present shear margins appearing in red.

III. METHODOLOGY

Isochrones were chosen if they were continuous across more than 80 percent of the stream's lateral extent and could be easily identified in all four Profiles. The stream's edges, or shear margins, were defined at the points where the change in ice flow velocity begins to approach zero on either side of the stream (Fig. 2).

Using this criterion, we picked three layers, the surface and the bed (five layers in all), which we then traced using a software package developed at St. Olaf College in Northfield, Minnesota. The four areas constrained by these layers and the shear margins, or flow belts, were masked and calculated using Adobe Photoshop and the ADINative software [3] (Fig. 3).

We looked at the ice-volume flux (km^3/yr) through these flow belts. The volume flux through a cross-sectional area is calculated by $\boldsymbol{u} \cdot \boldsymbol{A}$, where $\boldsymbol{u}$ is the average velocity vector and $\boldsymbol{A}$ is the area vector of the cross section.

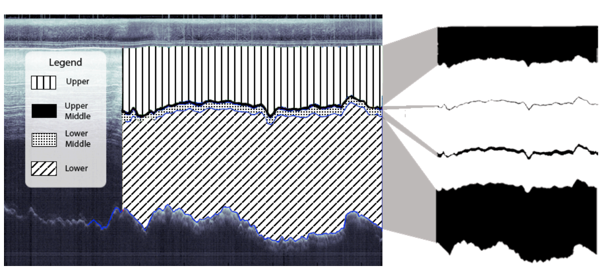

Fig. 3. Four flow belts were defined laterally by the present shear margins and confined vertically by isochrone picks. The flow belts expanded to the right show the masking process used to calculate area. In this process, we converted the percent masked area found by ADINative software to actual cross sectional area.

IV. ANALYSIS AND DISCUSSION

Our analysis shows a clear increase in ice-volume flux downstream in the inland part of NEGIS. Between Profiles 1 and 4, we found that ice-volume flux rose from 1.17 km^3 /yr to 4.16 km^3 /yr, a 257% increase (Fig. 4). A constant-volume flux is usually assumed for ice streams. The significant ice-volume increase observed in NEGIS can thus be attributed to ice entering across the shear margins.

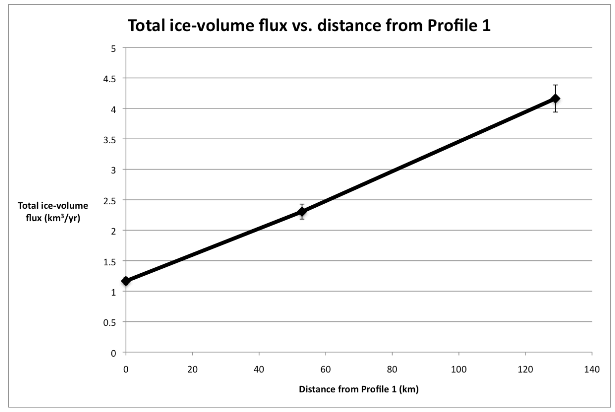

Fig. 4. This graph displays the total ice-volume flux through Profile 1, the Profile2/3 average, and Profile 4 against distance from Profile 1. The total ice-volume flux is the sum of the flux through the four flow belts at each Profile.

To ensure the validity of our calculated flux, we account for measurement error inherent in our method. We compare the cross sectional areas of Profiles 2 and 3. These Profiles cover the same geographic extent across the stream and should have the same volume flux (Fig. 1).

We compared the ice-volume flux through the four flow belts defined in both Profiles. The errors we found ranged from 2.7% to 5.4%. The 5.4% error was assumed to be characteristic and was applied to all data points.

There is a consistent, increasing trend in the ice-volume flux through each flow band with the Lower Middle band being slightly anomalous. Since we expect the volume flux increase to be distributed evenly throughout the layers, we can tell that our picking method was able to reliably select isochrones. Future radar-based ice stream research could use this approach to determine volume flux through radar cross-sections.

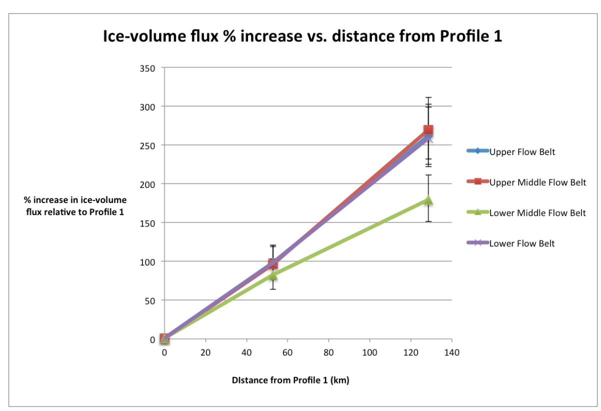

Fig. 5. A percent increase in ice-volume flux from Profile 1 is shown for four flow belts, at Profile 1, Profile 2/3 average, and Profile 4. The consistent trend seen in all four flow belts confirms the reliability of our flow band selection method.

Shear margins are heavily deformed bands of ice at the edges of an ice stream, and are marked by a sharp change in ice velocity. RADAR images reflect this deformation as chaotic columns of distorted internal layering (Fig. 2). Within our velocity-defined stream edges, we observed columns of significant deformation. We believe these deformation regions to be relict shear margins. This, coupled with the lack of deformation at present-day margins, indicates that these margins are relatively young and have widened over time.

V. Future Work

These results can be used as a baseline for future research interested in monitoring NEGIS' margins and determining its stability. Future work should examine other RADAR images across NEGIS to observe features of its shear margins, bed topography, surface elevation, overall thickness and isochrone deformation. Trends observed with RADAR data should be complemented with GPS measures of lateral ice flow, ultimately striving to create a model of NEGIS that can predict its future behavior in warming global conditions.

VI. Sources/Reference

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