Analysis of Glacier Flow Dynamics from Preliminary RADARSAT InSAR Data of the Antarctic Mapping Mission

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INTRODUCTION

The entire continent of Antarctica was mapped at a 25-meter resolution with synthetic aperture radar (SAR) during the Radarsat Antarctic Mapping Project (RAMP) over a 30-day period in the fall of 1997 providing a static "snapshot" of the ice sheet [1]. Since Radarsat-1 has a 24-day orbit cycle, repeat-pass interferometric SAR (InSAR) data was also acquired. The extensive InSAR data [1,2] will provide a view of ice sheet kinematics, for use in studies of glacier dynamics over vast unexplored areas. This information is required to determine the response of the Antarctic Ice Sheet to present and future climate change. In this paper we present the results of analysis of an InSAR pair for the Recovery Glacier, East Antarctica.

RECOVERY GLACIER

The Recovery Glacier is a major outlet draining a portion of Queen Maud Land to the Filchner Ice Shelf. Feeding the glacier is a large ice stream and tributaries, the extent of which, are easily observable from the RAMP mosaic (Fig. 1) [3]. The shear margins are well delineated by the strong returns from the intense crevassing. The InSAR scene (Fig. 2) straddles both of Recovery Glacier's lateral shear margins. The main trunk of this part of the ice stream is contained in the lower third of the image. Radarsat-1 (λ = 5.66 cm) imaged the area on Sept 24 and Oct. 18, 1997 from ascending orbits with a 28 look angle.

INTERFEROMETRY

The single look complex pair was processed at CCRS with a range and azimuth spacing of 8.12 and 5.37 m respectively. The interferogram was produced using 3 range and 10 azimuth looks resulting in approximately 50 m pixels (Fig. 3).

The coherence (Fig. 4) is remarkably high for most of the area considering its dynamic nature coupled with the 24-day repeat. The lateral shear margins are clearly evident as the wide linear bands of very low coherence caused by large differential motion and/or rotation within the crevasse zones. The high coherence of the main ice stream was obtained by allowing for additional pixel offsets for this portion of the image. The bright bands orthogonal to the flow direction on

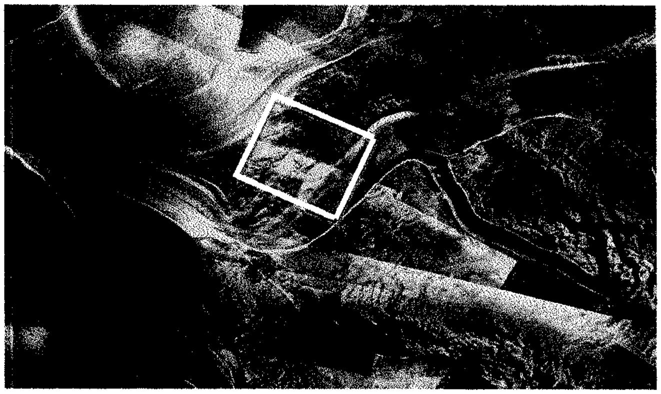

Figure1. RADARSAT mosaic of the East Antarctic Ice streams centered on Recovery Glacier. Box is InSAR scene

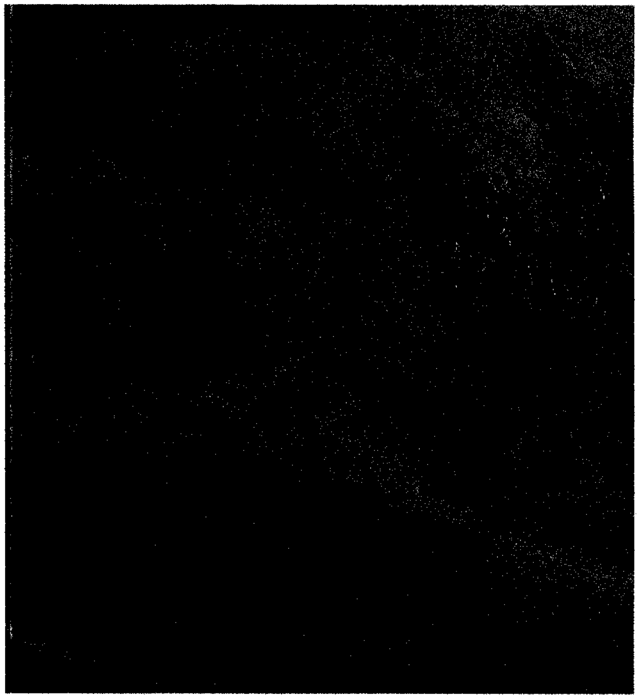

Figure 2. Amplitude image of Recovery Glacier Ice Stream. The width is 100 km and illumination is from the left

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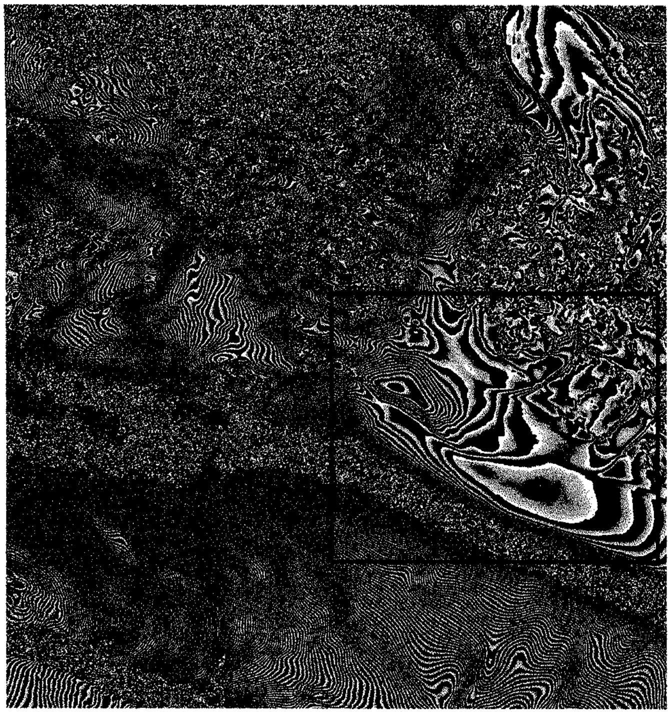

Figure 3. Flattened interferogram showing location of Fig. 5

the lower right of the main trunk have a wavelength of 5 km and are not evident on the amplitude image (Fig. 2). We suspect that subtle topographic undulations are causing these fluctuations in coherence possibly due to the vertical displacement variability. This is also suggested by the tightly curving phase lines (Fig. 3). If the pattern were caused by slight scattering differences associated with topography it is likely it would be observable on the amplitude image as well. The rumpled texture in the upper central portion of the image also appears in the amplitude image but with much less contrast. We interpret this as another example of subtle ice sheet topography detected with the phase coherence map.

The grounding line also appears to be detectable in both the amplitude (Fig. 2) and coherence images (Fig. 4). It is delineated by the abrupt change of intensity at the very top of the amplitude image and can be traced as a more subtle line back to the mountains. The coherence map shows this area as a more diffuse transition to low coherence. Interestingly there is an area of high coherence immediately on the floating side of the grounding line.

The flattened fringe image (Fig. 3) contains contributions from both displacement and topography. However, outside of the Shackleton Range (center right) the area is rather flat leaving the phase to be dominated by displacement. The slower moving ice on the flanks of the mountains is separated from the faster moving central core by the incoherent phase within the northern shear margin.

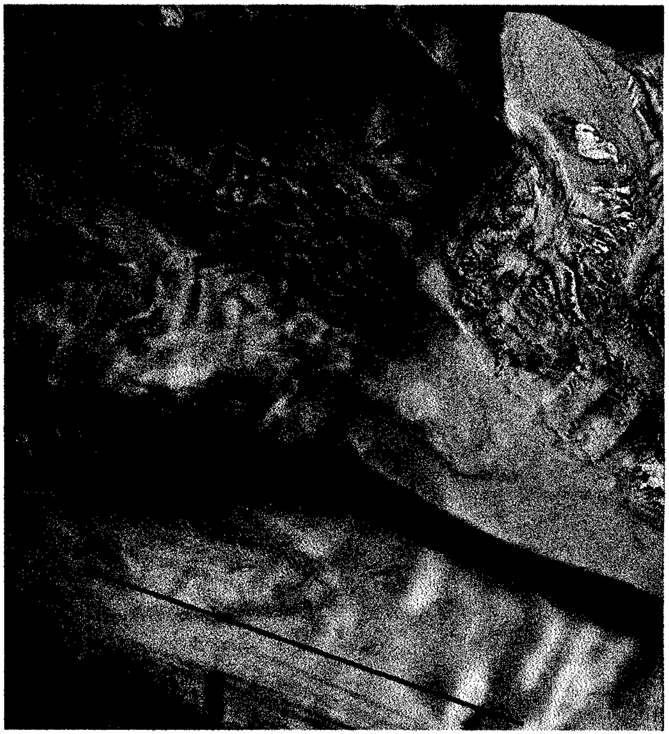

Figure 4. Coherence map with strain rate transect.

The phase was initially flattened by removing the dominant fringe rate in the range and azimuth directions. A more precise estimate of the baseline and removal of its effects will be done using ground control points acquired for generating the final RAMP mosaic. The topographic phase component will also be removed using a DEM that is being compiled for terrain correction of the RAMP data.

ICE VELOCITY AND STRAIN RATE

The phase was successfully unwrapped over most of the image using the branch-cut method. The unwrapped phase was scaled by the wavelength converting it to a relative displacement in the radar line-of-sight (LOS). Displacements at rock out-crops were set to zero by adding a constant resulting in an absolute LOS displacement map.

A portion of the LOS velocity map is shown in Fig. 5 over the amplitude image. The extent of the map shown was intentionally limited to areas of coherence > 0.5. The LOS velocities rapidly increase from 1.5 to 8 m/a at the shear margin. This portion of the glacier, along the flank of the Shackelton Range, separated from the main flow by the right lateral shear margin is moving very slowly and appears to be fed only by small mountain glaciers. This corridor of isolated flow extends up glacier for over 200 km along the range. Its ice does not enter the Filchner Ice Shelf through the constriction of the Recovery Glacier instead it widens and enters to the east of the main outlet (Fig. 1). The ice at this point must be very thin.

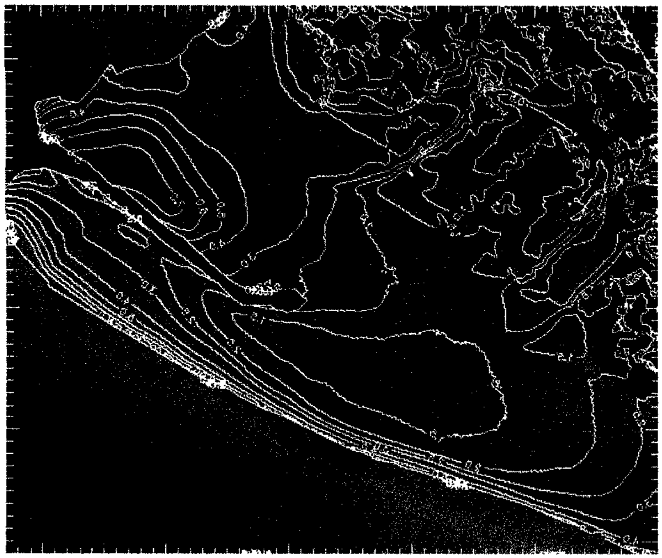

Figure 5. Radar line-of-sight velocity contours over the amplitude image. Contours range from 0.5 to 8.0 m/a.

This initial LOS velocity map is less reliable for the small mountain glaciers due to topographical influences that will be removed in later versions using our DEM. The LOS velocity can be converted to horizontal ice surface velocities with a DEM and an estimate of flow direction from either the DEM or flow lines that are visible on the amplitude image.

The highly decorrelated lateral shear margins of the ice stream prevent us from tying the relative displacement field to a point of no displacement. However, the relative displacements along with a flow direction can be used to calculate the strain rates. In fact, the phase need not be unwrapped to calculate strain rates.

The longitudinal strain rate for the main trunk along a flow line was calculated directly from the wrapped phase using

$$\dot{\varepsilon} = \frac{dV_f}{dx}$$

$$V = \frac{\phi\lambda}{4\pi}\frac{1}{T} + V_0$$

$$V_f = \frac{V}{\cos\alpha\sin\theta - \cos\theta}$$

$$\frac{dV_f}{dx} = \frac{\lambda}{4\pi}\frac{d\phi}{dx}\frac{1}{T}$$

where V_f is the ice surface velocity in the direction of flow, x is the distance along the transect, V is the radar line-of-sight velocity, ϕ is the wrapped phase, λ is the radar wavelength, T is the time between SAR acquisitions, V_0 translates the relative velocity to absolute, α is the angle between flow direction and cross-track heading, and Θ is the radar look angle.

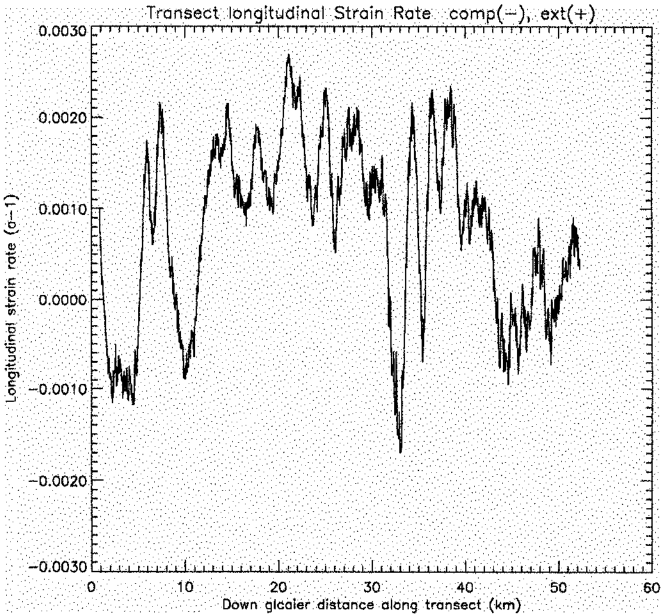

Figure 6. Longitudinal strain rate along a flow line calculated from the wrapped phase of the interferogram. The location of the transect is shown in Figs. 2 and 4.

The results are shown in Fig. 6. The strain rate is predominately compressive with fluctuations at approximately a 5 km wavelength. The locations of change to compressive flow are associated with the bright and dark patterns seen on the correlation map (Fig. 3). This is consistent with their interpretation as subtle topographic features.

SUMMARY

Analysis of the Recovery Glacier data set has demonstrated the excellent quality of InSAR data available from the Radarsat Antarctic Mapping Mission and its application to glacier dynamics. Phase coherence is high over most this highly dynamic area even though the temporal baseline is 24 days. The coherence image enhances subtle ice sheet topography and indicates the location of shear margins and the grounding line. A radar line-of sight ice velocity map identified a large region of slow moving ice that drains the Shackelton Range. Longitudinal stain rates along a flow line within the main ice stream were calculated directly from the wrapped phase.

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[3] Jezek, K. H. Sohn and K. Noltimier, 1998. "The Radarsat Antarctic Mapping Mission", IGARSS'98, Seattle WA.