Flow Variations of the Antarctic Ice Sheet from Comparison of Modern and Historical Satellite Data

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INTRODUCTION

Since 1962, high quality satellite images of the Antarctic have been acquired which cover much of the Southern Continent. The earliest images, from the Corona Program, have only recently become available to the science community [1]. They reveal a rich variety of details about the ice sheet, ice shelves, grounding lines, and rocky areas [2,3,4]. The most recent high-resolution images covering all of Antarctica were collected by the Canadian Radarsat-1 in September and October of 1997 [5,6]. That activity, a collaboration between NASA and the Canadian Space Agency, has resulted in the first, complete, high resolution SAR mapping of the Antarctic. The Radarsat images are also spectacular and graphically portray Antarctic ice streams, outlet glaciers, calving margins, and mountains.

This paper examines how different Antarctic flow regimes have changed over the 35-year interval between Corona and Radarsat. Study areas focus on the Ross Ice Shelf and Crary Ice Rise. The comparison reveals dramatic variations in ice flow, particularly around Crary Ice Rise - an area of long standing glaciological interest because of its potential for retarding upstream flow (fig. 1).

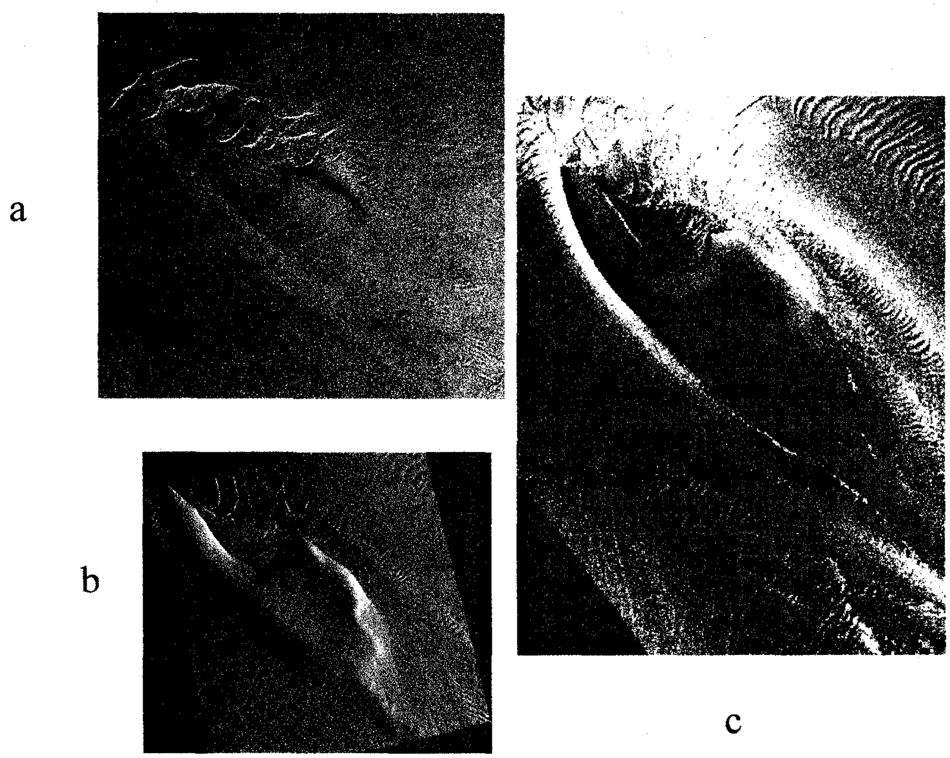

Fig. 1. Crary Ice Rise imaged by three spaceborne sensors: a) Optical Corona satellite imagery from 1963 (DISP); b) SPOT optical imagery from 1995; c) Radarsat synthetic aperture radar microwave imagery from 1997. North is approximately up. In each image, the ice rise is about 24 km wide at its mid-point.

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ANALYSIS

Crary Ice Rise (83S, 174W) is situated in the southeastern corner of the Ross Ice Shelf, Antarctica. Surrounded by ~ 400 m thick ice floating on the Ross Sea, Crary Ice Rise is an ice capped island that rises nearly 50 m above the adjacent shelf ice. The rise rests in the downstream ice flow from two West Antarctic Ice Streams. As such, some investigators conjecture that the ice rise presents an obstruction to ice flow, effectively damming the upstream ice and contributing to the stability of the inland ice sheet.

More recent studies of the ice rise suggest that Crary Ice Rise is changing - and consequently the effect the ice rise has on local ice flow [7]. Based on ice thickness and ice surface velocity data, the shelf immediately downstream of the ice rise is estimated to be thinning by about 1 m/y. Southwest of the ice stream, the ice shelf is believed to be thickening by a similar amount. These calculations lead to speculation that the location of the ice rise may be shifting. Photographs taken by the Corona Satellite in 1963 and then, 32 years later, by the SPOT Satellite, and most recently by Radarsat-1, support this idea (fig 1).

Declassified Intelligence Satellite Program (DISP) data were obtained in the form of a 4 by 5-inch positive transparency. The film product was digitized at 7-micron resolution that is commensurate with the 150-m spatial resolution of the original product. Both the DISP and Radarsat-1 data were warped to the geolocated SPOT image using a first degree polynomial and tie points selected at locations judged to be stable.

There are numbers of striking differences between the images. The most obvious differences are the seemingly fresh, sinusoidal cracks present in 1963 along the northeastern 'hook' of the ice rise. By 1995 the cracks have evolved into segmented blocks that are being rotated by the shearing flow past the ice rise.

There are also more subtle variations in flow over time and variability from location to location around the ice rise. The DISP image suggests a number of small ice rumples south southwest of the main ice rise (location a in fig. 2). The region downstream of the ice rumples seems to be largely crevasse free. By the mid 1990s, crevasses are clearly evident and surround several of the rumpled areas. Crevasses on the eastern flank of the southern part of the ice rise are nearly unchanged over the same period (b fig. 2). The interior of the ice rise northern embayment, or 'hook', seems relatively undeformed in the 1963 image. The radar image suggests it is cut by long arcuate crevasses formed in response to the shearing flow past the embayment. However, the appearance of the crevasses in the SAR imagery may well be a consequence of the penetration of microwave energy into snow bridges – revealing crevasses undetectable in either the DISP or SPOT data.

Remarkably, a number of objects east of the ice rise are

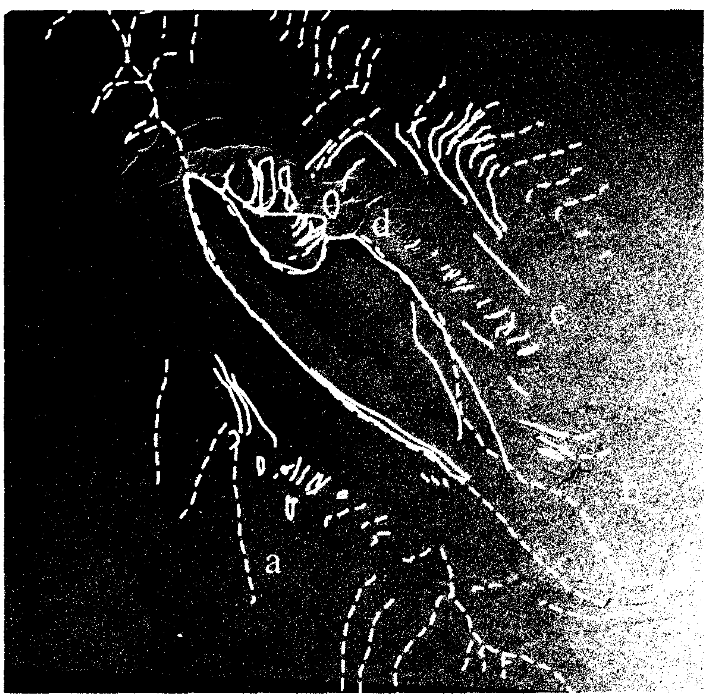

Fig 2. 1963 DISP image portion (120 km across). Solid lines are lineaments based on 1995 SPOT image. Dashed lines are lineaments based on 1997 Radarsat image

evident between the imagery. These reveal a counterclockwise rotational component to ice flow that becomes more pronounced to the north. Speeds off the southern flank of the ice rise are about 130 m per year (c). Near the right hand portion of the hook speeds drop to about 35-m per year (d) and there is little evidence for motion with the embayment itself. Speeds are about 350 m per year 10 km downstream of the northern nose of the ice stream. Speeds increase 25 % after about 25 km of downstream flow based on the position of the large rifts that form episodically at the northern tip of the ice stream.

Finally, the grounding line on the southwestern flank of the ice rise has advanced outward and upglacier by about 1500 m between 1963 and 1997. This is consistent with ice thickening along this flank of the ice rise and with little ice thickness change along the southeastern flank. Ice thickening may also explain the onset of extensive crevassing along the southwestern flank. There will be more extensive coupling between the ice and the bed as the ice thickens in the ice rumple region. The coupling will lead to increased basal shear stresses which will be manifest as surface crevasses.

SUMMARY

Large portions of this sector of Antarctica are susceptible to dramatic changes in ice flow. Ice streams, large rivers of ice that drain the West Antarctic Ice Sheet into the Ross Ice Shelf, are known to turn 'on and off' on time periods of many 100's of years. This in turn leads to local changes in the grounding line, the location where the terrestrial ice sheet goes afloat. It is believed that rapid changes in ice sheet behavior are in fact due to changes in the internal dynamics of the ice sheet. Rather than external climate forces, changes in glacier physical properties, such as subglacial water flow patterns, are presumed to be the important feedback mechanisms controlling rapid changes in the ice sheet. The structure of Crary Ice Rise eventually responds to inland ice sheet changes by growing or retreating as the upstream ice flux shifts.

The present pattern of thinning along the northeastern margin of the ice shelf and thickening along the southwestern margin may have been repeated in the past [8]. Evidence for this comes from ice thickness patterns far downstream of the ice rise. Here, the ice shelf acts as a 'tape-recorder' preserving remnants of ice thickness patterns of an earlier time. Paired ice thickness hollows and domes similar to the pattern seen today are located about 200 km downstream of the ice rise. Using present day ice velocities, these observations suggest a similar process occurred around the ice rise some 400 years ago. The Corona and SPOT data suggest researchers may now have an opportunity to study a repeat of that same, and perhaps episodic, process.

ACKNOWLEDGMENTS

This work was supported by NASA and under a cooperative agreement with the Canadian Space Agency. G. Hamilton contributed to the data analysis.

REFERENCES

[1] Macdonald, R.A, 1995. Corona: Success for space reconnaissance. A look into the cold war and a revolution in intelligence. Photogramm. Eng. Remote Sens., LXI, p 321-325.

[2] Committee on Environmental and Natural Resources Research, 1997. Our Changing Planet: The FY 1997 U.S. Global Change Research Program.

[3] Bindschadler, R. and P. Vornberger, 1998. Changes in the West Antarctic Ice Sheet since 1963 from Declassified Satellite Photography. Science, vol. 279, p. 689-692.

[4] Paulsen, T. and T. Wilson, 1998. Declassified Intelligence Satellite Photographs (DISP) provide first high-resolution space-borne views of the Transantarctic Mountains in the Antarctic interior. EOS, vol. 79, no. 8,

[5] Jezek, K.C., H.G. Sohn, and K.F. Noltimier, in press. The Radarsat Antarctic Mapping Project. Proceedings IGARSS'98, Seattle, WA.

[6] Jezek, K.C. and 11 others, in press. Snapshots of Antarctica from Radarsat-1. Proceedings IGARSS'98, Seattle, WA.

[7] Bindschadler, R., 1993. Siple Coast Project research of Crary Ice Rise and the mouths of Ice Streams Band C, West Antarctica: review and new perspectives. J. of Glac., vol. 39, no. 133, p. 538-552.

[8] Jezek, K.C., 1984. Recent changes in the dynamical condition of the Ross Ice Shelf, Antarctica. J. Geophys. Res., vol. 89, no. B1, p. 409-416.