COASTAL-CHANGE AND GLACIOLOGICAL MAP OF THE SAUNDERS COAST AREA, ANTARCTICA: 1972–1997

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INTRODUCTION

Background

Changes in the area and volume of polar ice sheets are intricately linked to changes in global climate, and the resulting changes in sea level may severely impact the densely populated coastal regions on Earth. Melting of the West Antarctic part alone of the Antarctic ice sheet could cause a sea-level rise of approximately 6 meters (m). The potential sea-level rise after melting of the entire Antarctic ice sheet is estimated to be 65 m (Lythe and others, 2001) to 73 m (Williams and Hall, 1993). In spite of its importance, the mass balance (the net volumetric gain or loss) of the Antarctic ice sheet is poorly known; it is not known for certain whether the ice sheet is growing or shrinking. In a review paper, Rignot and Thomas (2002) concluded that the West Antarctic part of the Antarctic ice sheet is probably becoming thinner overall; although the western part is thickening, the northern part is thinning. Joughin and Tulaczyk (2002), based on analysis of ice-flow velocities derived from synthetic aperture radar, concluded that most of the Ross ice streams (ice streams on the east side of the Ross Ice Shelf) have a positive mass balance. The mass balance of the East Antarctic is unknown, but thought to be in near equilibrium.

Measurement of changes in area and mass balance of the Antarctic ice sheet was given a very high priority in recommendations by the Polar Research Board of the National Research Council (1986), in subsequent recommendations by the Scientific Committee on Antarctic Research (SCAR) (1989, 1993), and by the National Science Foundation's (1990) Division of Polar Programs. On the basis of these recommendations, the U.S. Geological Survey (USGS) decided that the archive of early 1970s Landsat 1, 2, and 3 Multispectral Scanner (MSS) images of Antarctica and the subsequent repeat coverage made possible with Landsat and other satellite images provided an excellent means of documenting changes in the coastline of Antarctica (Ferrigno and Gould, 1987). The availability of this information provided the impetus for carrying out a comprehensive analysis of the glaciological features of the coastal regions and changes in ice fronts of Antarctica (Swithinbank, 1988; Williams and Ferrigno, 1988). The project was later modified to include Landsat 4 and 5 MSS and Thematic Mapper (TM) (and in some areas Landsat 7 Enhanced Thematic Mapper Plus (ETM+)), RADARSAT images, and other data where available, to compare changes over a 20- to 25- or 30-year time interval (or longer where data were available, as in the Antarctic Peninsula). The results of the analysis are being used to produce a digital database and a series of USGS Geologic Investigations Series Maps consisting of 24 maps at 1:1,000,000 scale and 1 map at 1:5,000,000 scale, in both paper and digital format (Williams and others, 1995; Williams and Ferrigno, 1998; and Ferrigno and others, 2002).

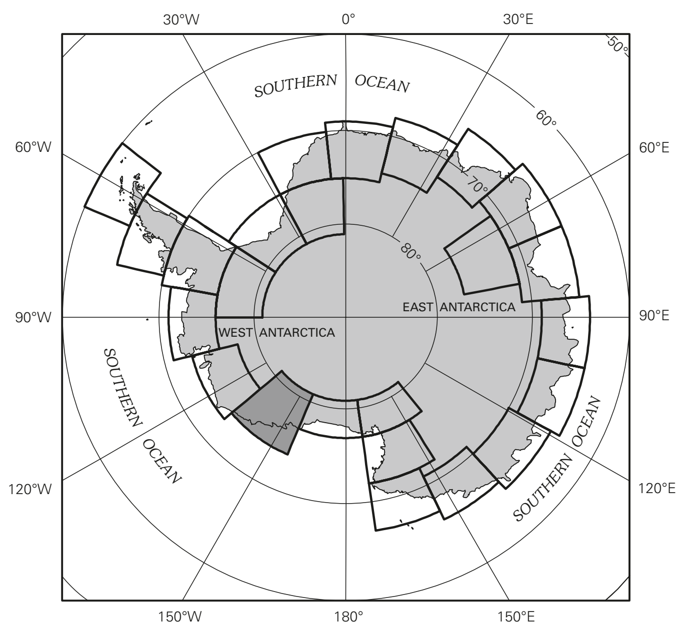

Figure 1.—Index map of the planned 24 coastal-change and glaciological maps of Antarctica at 1:1,000,000 scale. Saunders Coast area map is shaded.

Objectives

The coastal-change and glaciological mapping project has five objectives, listed as follows:

(1) to determine coastline changes that have occurred during the past three decades, or longer where information exists;

(2) to establish an accurate baseline series of 1:1,000,000-scale maps (fig. 1) that defines, from the analysis of Landsat and RADARSAT images, the glaciological characteristics (for example, floating ice, grounded ice, etc.) of the coastline of Antarctica during three time intervals: (1) early 1970s

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(Landsat), (2) middle 1980s to early 1990s) (Landsat), and (3) 1997 (RADARSAT);

(3) to determine velocities of outlet glaciers, ice streams, and ice shelves, and the position of the grounding line, from analysis of Landsat images and other sources;

(4) to compile a comprehensive inventory of named (from published maps) and unnamed (from analysis of Landsat images) outlet glaciers and ice streams in Antarctica that are mappable from Landsat images or from ancillary sources (for example, maps, gazetteers, digital databases, etc.) (Swithinbank, 1980, 1985; Alberts, 1981, 1995; National Science Foundation, 1989; British Antarctic Survey and others, 1993);

(5) to compile a 1:5,000,000-scale map of Antarctica derived from the 24 1:1,000,000-scale maps. Each 1:1,000,000-scale map extends to the southernmost nunatak within each map area or to the southernmost extent of Landsat images (about 81.5° S. lat).

Sources

Landsat images used in the compilation of the Saunders Coast area map were obtained from either the USGS EROS Data Center, Sioux Falls, SD 57198, or the former Earth Observation Satellite (EOSAT) Corporation, now Space Imaging LLC, 12076 Grant St., Thornton, CO 80241. The coverage areas of the Landsat 1 and 2 MSS and Landsat 4 and 5 MSS and TM images used in the compilation are shown in the index maps on the accompanying map. Below the index maps, information about each image is listed. The specific images that were used to measure ice velocities are listed in table 1 in this pamphlet. The 1:500,000-scale photographic prints of Landsat images used in the analytical phase were derived from three types of source material: (1) 1:1,000,000-scale film transparencies from the EROS Data Center, (2) 1:1,000,000-scale black-and-white or false-color-infrared prints from EOSAT, and (3) 1:500,000-scale black-and-white digitally enhanced prints from the USGS, Flagstaff, Ariz. The early Landsat scenes cover the years 1972 to 1976. The later Landsat images are from 1986 to 1990. One Landsat-7 image, dated 12 December 1999 and obtained in digital form from the EROS Data Center, was used to fill a hiatus in coverage of the coast at the western edge of the map area. A mosaic of Landsat TM scenes dated from December 1984 to February 1990, produced by the USGS to map the Siple Coast area and to study grounding lines (Ferrigno and others, 1994; Jacobel and others, 1994), is used for Bindschadler and MacAyeal Ice Streams. The Siple Coast is the next coast southward of the Shirase Coast, along the Ross Ice Shelf.

The 125-m picture-element (pixel)-resolution RADARSAT image mosaic of Antarctica was used both as a base for correct geographic position and geometric rectification of digitized Landsat imagery and as an additional source of coastal-change data. The RADARSAT image mosaic is composed of data recorded from 9 September to 20 October 1997 (Jezek, 1998). The 1997 RADARSAT image mosaic was obtained from The Ohio State University's Byrd Polar Research Center (BPRC).

Methodology

The primary steps in the compilation of the Saunders Coast area map are listed and discussed below:

(1) Identification of optimum Landsat MSS or TM images for two time intervals (early 1970s; middle 1980s to early 1990s) and enlargement to a nominal scale of 1:500,000;

(2) Manual annotation of glaciological features by SCAR Code (Scientific Committee on Antarctic Research, 1980) or Antarctic Digital Database (ADD) Geocode (British Antarctic Survey and others, 1993) on 1:500,000-scale transparent overlays of Landsat images for both time intervals and directly on the computer workstation monitor for the 1997 RADARSAT image mosaic;

(3) Positional control of mapped features. Having a goal of producing the most accurate, high-resolution printed maps and digital databases of the coastal regions of Antarctica, considerable thought and research was expended on choosing the optimum method of geolocating mapped features. The initial process of geolocating the Landsat scenes and annotations involved the use of geodetic ground-control points surveyed by the USGS in the 1960s. The control points came from a network of geodetic control that used a single well-fixed point as reference. The internal consistency of the network was known to be quite reliable, but the location of the ground reference point determined by astronomical measurement was subject to error in longitude that could be as large as 1 to 1.5 kilometers (km). Use of these geodetic ground-control points proved problematic in attempts to geolocate the images and annotated overlays for manually mapping the coast. Attempts to use these control points for digital processing in a world coordinate system again proved problematic and generated an unacceptably high positional error. The use of these geodetic ground-control points was rejected in favor of georegistering the imagery and annotations to the 1997 RADARSAT image mosaic of Antarctica produced by the BPRC to give the most geometrically accurate base. An added benefit was that the RADARSAT mosaic was compiled in polar stereographic projection having a standard parallel at lat 71° S.—the map projection selected for the 25 maps, with due consideration given to scale distortion on map coverage north and south of lat 71° S. (Sievers and Bennat, 1989). The primary benefit of the polar stereographic projection is cartographic continuity between adjacent maps in the coverage provided of the coastal regions of Antarctica.

The RADARSAT mosaic of Antarctica was generated from Synthetic Aperture Radar (SAR) data collected by the Canadian Space Agency's RADARSAT-1 satellite. Geodetic ground-control points (GCPs) supplied by the National Imagery and Mapping Agency (NIMA) and the Environmental Research Institute of Michigan (ERIM) were used in conjunction with a calibration transponder located at the South Pole in the processing of data to improve the accuracy of geolocation from what is possible from use of satellite ephemeris data alone (Jezek, 1998, p. 15). Most of the 231 GCPs chosen (clustered at 91 locations) were located on nunataks in coastal regions; others were distributed along the Transantarctic Mountains. The geodetic accuracy of the RADARSAT mosaic is cited as ±150 m (Noltimier and others, 1999). Orthorectification of the mosaic was done using a Digital Elevation Model (DEM) generated by the BPRC specifically for the production of the mosaic. Data used in construction of the DEM were obtained from multiple sources. Types of data include ground-leveling and Global Positioning System (GPS) surveys, radar and laser altimeter data, optical and SAR stereographic image pairs and spot-elevation points, and contours and form lines digitized from map sheets (Liu, 1999, p. 15);

(4) Scanning hard-copy images to produce 400-dots-per-inch (dpi), 256-shade, gray-scale digitized satellite images. The digitized satellite images were coregistered and geometrically corrected to the RADARSAT image mosaic using ERDAS Imagine software. Pass points were used to geometrically fit the scenes to the RADARSAT base. Because the RADARSAT mosaic was derived from data collected with an off-nadir, non-orthographic sidescan imaging device, horizontal displacement of local slopes and mountain peaks is evident. Therefore, peaks and features located on slopes were not selected as pass points. Low-elevation features were selected preferentially and used wherever possible. Selection of low-elevation points does not produce an even distribution of control across the image, but strongly clusters the geodetic ground control around image-identifiable features in the coastal regions of Antarctica. Application of second-degree or higher polynomial correction to an image with uneven distribution of control provides unsatisfactory results in image areas distant from the coast. For this reason, a first-degree polynomial function was used in coregistration and geometric correction. The single Landsat-7 scene and the Siple Coast mosaic were obtained in digital form and were included using the registration and projection information supplied with the image data. Features from corrected image data were digitized to ARC/INFO vector coverages using the digital overlay images as guides;

(5) Addition of velocity vectors, geographic place-names, and codes for unnamed outlet glaciers and ice streams identified on Landsat images (see tables 1 and 2); and addition of topographic contours at selected intervals, generated from BPRC DEM data and modified where necessary to be congruent with surface features;

(6) Analysis of coastal changes, glaciological features (including the position of the grounding line), and ice-surface velocities of selected outlet glaciers, ice streams, and ice shelves.

Geodetic Accuracy of the RADARSAT Image Mosaic of Antarctica[5]

Introduction

The RADARSAT image mosaic of Antarctica was selected as the most accurate base available for geolocating the Landsat imagery; therefore, it was considered essential to confirm the published geodetic accuracy of the mosaic (±150 m, Noltimier and others, 1999).

BPRC's Procedure

With the assistance of BPRC personnel, the procedure for constructing the RADARSAT image mosaic was comprehensively reviewed. BPRC used custom software from Vexcel, a contractor on the project (Norikane and others, 1998). Described simply, long radar data strips were mosaicked into 24 blocks. These blocks were then rectified using a generated digital terrain model to remove relief distortion and mosaicked together to form the RADARSAT mosaic. Of the original 164 proposed sites for GCPs, 91 sites containing 231 high-quality GCPs were supplied by NIMA and identified on the RADARSAT imagery by ERIM. These were used in the block construction and the mosaic construction in conjunction with a calibration transponder located at the South Pole (K.F. Noltimier, BPRC, written commun., 9 Oct. 2001). The GCPs used were not evenly distributed over the continent, however, but tended to be in the flat coastal areas, with few in the mountainous regions. Some GCPs were withheld as a check of the overall accuracy. Unfortunately, the BPRC overall-accuracy check of the mosaic construction was not available for analysis. Large amounts of intermediate data were reviewed, basically the residuals for each tie point and control point used in each of the 24 blocks, but the overall results of the final block adjustments were not available. Based on a study of the data, the following analysis was made and conclusions reached.

USGS Analysis

Each block had three sets of errors called Block Overall, GCPs Overall, and Tie Points Overall. Each error set had both an average and a root mean square (RMS). Both the average and the RMS had separate values for x, y, and z, but no vector sum. In the sense used, it appears that "average" is really a measure of bias (shift); the RMS is essentially the residual. The RMS of the GCPs for each block was analyzed by the USGS, and a composite residual (the vector sum of the residuals in x, y, and z) for each block was calculated. The largest residual calculated was 113.5 m for block 2; the smallest residual calculated was 28.0 m for block 14. The overall residual for the 24 blocks was determined to be 74.0 m. However, the lack of control in mountainous areas would adversely affect the accuracy of the digital terrain models used to rectify the mosaic blocks and therefore the accuracy of the blocks.

Conclusions

From what is presently known, the published figure of 150-m geolocation accuracy seems reasonable, at least in coastal areas where adequate control was utilized. This degree of accuracy assumes several considerations:

(1) that Vexcel's software was correctly written. No documentation has been made available that could be evaluated or peer-reviewed by non-Vexcel geodesists;

(2) that NIMA and ERIM technical personnel correctly identified the geodetic ground-control points in the radar data;

(3) that BPRC scientists and engineers made correct decisions in the selection of the 231 optimum GCPs and deletion of suspect GCPs.

Therefore, the only way to be absolutely certain of the geometric accuracy of the RADARSAT image mosaic would be to have the mosaic measured against well-distributed control, including mountainous areas not used in the mosaic construction. This could be done but would require using more GCPs and (or) evaluating the GCPs that BPRC used in the overall accuracy analysis.

Glaciological Features

The Saunders Coast area map covers the part of Marie Byrd Land that extends from the eastern end of the Ross Ice Shelf (long 158.5° W.) to the western part of the Getz Ice Shelf (long 130° W.), and it includes the Saunders Coast, the Ruppert Coast, and parts of the Shirase and Hobbs Coasts. The map area is composed of two glaciologically different regions. In one, in the southwest corner of the map area, Bindschadler, MacAyeal, and Echelmeyer Ice Streams and Kiel Glacier drain from the Shirase Coast into the massive, buttressing Ross Ice Shelf. The length of the grounding line along this part of the coastline is 800 km. In the other, northern region, the coastline is composed mainly of a constantly moving, floating ice front interspersed with a few small areas of fairly stable, grounded ice walls. The total coast-

[5]Geodetic accuracy was determined by J. William Schoonmaker, research geodesist, USGS (ret.).

line in the Saunders Coast area map was digitally measured to be 1,197 km long, of which only 458 km or 38 percent is ice wall. The dominant glaciological features on the map are Bindschadler (partly shown), MacAyeal, and Echelmeyer Ice Streams in the southwestern part of the map area, and, on the northern coast, Sulzberger, Nickerson, and Getz Ice Shelves, and Land, Hull, and DeVicq Glaciers. The Sulzberger Ice Shelf is the largest ice shelf in the map area, measuring about 160 km long (northeast to southwest) and more than 100 km wide (northwest to southeast). It is easily recognizable by more than two dozen large and small ice rises distributed over its areal expanse between the Edward VII and Guest Peninsulas. Its area, including ice rises, is 15,721 km^2. Nickerson Ice Shelf, the next ice shelf to the east, is separated from Sulzberger Ice Shelf by the Guest Peninsula. According to the Antarctic Gazetteer (Alberts, 1995), the Nickerson Ice Shelf is located north of Siemiatkowski Glacier and the western part of the Ruppert Coast and is about 60 km wide. There is no published measurement of the length. The placement of the ice-shelf name on the USGS Saunders Coast–Marie Byrd Land Antarctica Sketch Map also makes it difficult to determine the length of the ice shelf. However, on the satellite images, it is clear that the ice shelf extends about 170 km from the Guest Peninsula to east of Groves Island, making it the longest ice-shelf front on the map sheet. The area of the Nickerson Ice Shelf is 7,207 km^2, measured using the 1997 ice front. To the east, the Getz Ice Shelf extends 140 km to the eastern edge of the map area, and continues for another 450 km to the east within the adjacent Bakutis Coast area map. It is about 40 km wide on the average. The area of the Getz Ice Shelf on this map is 5,840 km^2 as of 1997. Of the three major glaciers, Land and Hull Glaciers flow directly into the Pacific sector of the Southern Ocean, and DeVicq Glacier flows through the Getz Ice Shelf. A total of 49 named and 3 unnamed glaciers and ice streams flow into the ice shelves or directly into the Southern Ocean; four other named glaciers are located in a mountain range in the interior (table 2).

ANALYSIS

Overview

As would be expected, ice fronts, iceberg tongues, and glacier tongues are the most dynamic and changeable features in the coastal regions of Antarctica. Seaward of the grounding line of outlet glaciers, ice streams, and ice shelves, the floating ice margin is subject to frequent calving and rapid flow. Both of these situations lead to annual and decadal changes in the position of ice fronts on the order of several kilometers, even tens of kilometers in extreme cases of major, infrequent calving. On this map, the positions of the dynamic ice fronts as observed on the two sets of Landsat imagery and the 1997 RADARSAT image mosaic have been mapped and annotated with the exact date for each position (the exact date is given for Landsat imagery, but only the year is given for the RADARSAT image mosaic because all the imagery was acquired between 9 September and 20 October 1997). This makes it possible to accurately analyze changes that have occurred. Where lines representing ice fronts on the map end abruptly, it is due to the absence or margin of a Landsat image or to cloud cover. Although calving does occur along ice walls, the magnitude of the change on an annual to decadal basis is generally not discernible on either the Landsat images or the RADARSAT image mosaic; therefore, ice walls can be used as relatively stable reference features against which to measure other changes along the coast. Only a single observation date is given for the position of ice walls.

Outlet Glacier, Ice Stream, and Ice Shelf Velocities

Larger glacier tongues and ice shelves have well-developed crevasse patterns. These patterns can be tracked over time and used for velocity calculations. Surface velocities of selected glaciers were determined by two methods: an interactive one in which crevasse patterns were tracked visually on images (Lucchitta and others, 1993) and an auto-correlation program developed by Bindschadler and Scambos (1991) and Scambos and others (1992). Under optimum conditions, errors can be as small as ±0.02 km a^{-1} (kilometers per year), but for most Landsat image pairs, where registration of features is accurate to one or two pixels, the accuracy of velocity vectors is ±0.1 km a^{-1}. The measurement errors improve when there are longer time intervals between the images and faster velocities, both increasing ice displacement. Ten to one hundred measurement points were made for each glacier tongue or ice shelf (table 1). Velocity measurements have been made on Land Glacier and on the Sulzberger Ice Shelf (Ferrigno and others, 1998; Rosanova and others, 1998). Three average ice-surface velocities were calculated on the Sulzberger Ice Shelf, which is one of the slowest moving ice-surface areas in Marie Byrd Land. Landsat images from 1972 and 1986 produced velocities of 200 m a^{-1} west of Kizer Island, and 100 m a^{-1} just east of Kizer Island. Calculation of ice-surface velocities made on the Nickerson Ice Shelf using Landsat images from 1976 and 1986 yielded a range of values from 0.6 to 0.14 km a^{-1}. Measurements on Land Glacier using Landsat images from 1975 and 1988 resulted in an average velocity of 1.8 km a^{-1}, comparable to the velocity of some other tidewater glaciers in Marie Byrd Land. Ice-surface velocity increases nearer a glacier terminus; the ice surface velocity of Land Glacier at the ice front is at least 2 km a^{-1}. DeVicq Glacier flows into the Getz Ice Shelf with velocities ranging from 0.9 to more than 1.1 km a^{-1}, calculated using Landsat images from 1973 to 1988. Other researchers have calculated average velocities near the mouths of Bindschadler and MacAyeal Ice Streams to be approximately 400 and 340 m a^{-1}, respectively (Bindschadler and others, 1996). According to the National Snow and Ice Data Center (NSIDC) Internet website (http://nsidc.org/data/velmap/index.html), the velocities of Echelmeyer Ice Stream range from 20 to 170 m a^{-1}, and of Kiel Glacier (Prestrud Inlet) from 20 to 180 m a^{-1}.

Coastal Change

The Landsat images and RADARSAT image mosaic used for this map provide the opportunity to analyze coastal changes from the eastern edge of the Ross Ice Shelf to the Getz Ice Shelf from 1972 to 1997. Starting with Withrow Glacier (lat 77°24′ S., long 156°25′ W.), just east of Cape Colbeck, and looking eastward along the coast to Land Glacier (lat 75°40′ S., long 141°45′ W.), we observed a pattern of slow continuous advance of the ice front—as much as 4.9 km—between the early 1970s and 1997. Just west of Land Glacier, the pattern changes. East and west of Groves Island, the fronts of two glaciers, Holcomb Glacier and an unnamed glacier (AN77532S14338W), have fluctuated. The iceberg-tongue front of the unnamed glacier on the west had a net advance of 4.5 km from December 1972 to December 1986 and another net advance of 4.7 km between December 1986 and October 1997. Holcomb Glacier, to the east of Groves Island, had a net recession of 3.8 km from December 1972 to December 1986 and then a net advance of 1.3 km from December 1986 to October 1997.

In the case of Land Glacier, the dominant glacier in the center of the map area, the ice front advanced 16.1 km from January 1973 to December 1988 and then receded 4.5 km before October 1997. The 1973 to 1988 advance created a 425-km^2 increase in the area of the glacier tongue. The 1988 to 1997 recession signified a 237-km^2 loss in area of the glacier tongue. However, because the velocity of Land Glacier averages 2 km a^{-1} at the ice front, the ice front would have advanced about 32 km during the almost 16-year interval between the January 1973 and December 1988 Landsat images if no calving had occurred. The 16.1-km advance actually represents only about 50 percent of the actual advance of the Land Glacier front before calving, and an actual net loss in area of about 400 km^2. Assuming a conservative average thickness of the glacier tongue of 200 m, this represents a net volume loss of at least 80 km^3. In the almost 9 years between December 1988 and October 1997, Land Glacier would have advanced almost 18 km if no calving had occurred. The 4.5-km recession of the ice front represents an actual loss of about 22.5 km in length, or almost 600 km^2 in area, and a net volume loss of almost 120 km^3. The total loss in area and volume of Land Glacier by calving between 1973 and 1997 was roughly 1,000 km^2 and 200 km^3, respectively.

Proceeding eastward from Land Glacier, the ice-front changes are much more complex. The terminus of the first small glacier east of Land Glacier, Anandakrishnan Glacier, receded 3 km from January 1973 to December 1988 and then advanced 2.2 km before October 1997. The front of the next glacier to the east, Strauss Glacier, receded in both time periods; the front of the next glacier to the east (AN77517S13952W) advanced, and the front of the next glacier, Shuman Glacier, receded continuously. First advance, then recession, is seen with the ice fronts of the next three glaciers to the east (Clarke, Lord, and Frostman Glaciers). In fact, the iceberg tongues of these three glaciers have almost completely disappeared. Much of the fast ice and iceberg tongues in this area broke up and moved seaward or melted during the time period between 1988 and 1997, a possible indication of changing environmental conditions. Hull Glacier also shows a pattern of continuous retreat. There was a net retreat of 12.4 km between January 1973 and December 1988 and 5.3 km before October 1997, for a total of more than 17 km. Unfortunately, we have no velocity measurements of Hull Glacier to further analyze this substantial retreat. East of Hull Glacier, between Cape Burks and the Getz Ice Shelf, there are two small ice fronts; the smaller ice front advanced on the average 1 km between January 1973 and December 1988 and receded almost the same amount by October 1997. The other, belonging to Jackson Glacier, retreated about 1.8 km between January 1973 and December 1988 and at least another 1.7 km by October 1997. The Getz Ice Shelf, west of Shepard Island, has advanced and then receded, but did not change very much on average during the period between January 1973 and December 1988. Between Shepard Island and Grant Island, the ice front receded slightly during the period from 1973 to 1997. The terminus of DeVicq Glacier receded 18.6 km between January 1973 and October 1997. Using ice-surface velocity measurements of more than 1 km a^{-1} for the Getz Ice Shelf north of DeVicq Glacier, we calculated that the ice front would have advanced more than 25 km during the almost 25-year period between the Landsat images, had there been no calving. The 18.6-km retreat actually represents a calving retreat of the ice front of more than 43 km during the 1973 to 1997 time period. The overall trend of ice-front recession from Land Glacier to the eastern edge of the map area is noteworthy, especially in light of (1) the recent thinning of the Getz Ice Shelf shown by radar data (H.J. Zwally, National Aeronautics and Space Administration, oral commun., 2001) and (2) the amount of warm bottom water along much of the Marie Byrd Land coast (Jacobs and others, 1996).

Map Revisions

As discussed in the Sources and Methodology sections, the Saunders Coast area map was compiled from annotations of geographic features on Landsat 1, 2, 4, and 5 images that were georegistered to the RADARSAT image mosaic. The area had been previously mapped by the USGS based on trimetrogon aerial photography and geodetic ground surveys on two 1:500,000-scale Antarctica Sketch Maps (Saunders Coast–Marie Byrd Land and Hobbs Coast–Marie Byrd Land, both published in 1968), with shaded relief but generally without contours; on 11 Antarctica 1:250,000-scale Topographic Reconnaissance Series maps (Alexandra Mountains, 1972; Boyd Glacier, 1973; Cape Burks, 1974; Dean Island, 1976; Grant Island, 1974; Guest Peninsula, 1972; Gutenko Nunataks, 1973; Hull Glacier, 1975; Mount Berlin, 1974; Mount Kosciusko, 1976; and Mount McCoy, 1973); and on 15 1:250,000-scale Satellite Image Maps of the Shirase and Siple Coasts compiled from georeferenced Landsat TM images (Ferrigno and others, 1994). Comparison of those earlier maps with this map reveals the following improvements in cartographic representation of the geographic features.

The two sketch maps cover the entire coastal area covered by this map but do not delineate the geographic features very far inland. The Saunders Coast–Marie Byrd Land Sketch Map extends to a maximum of about lat 78° S., and the Hobbs Coast-Marie Byrd Land Sketch Map extends to a maximum of about lat 76° S. in the eastern part and lat 77°30′ S. in the western part. Our map extends to lat 81° S. and includes MacAyeal and Echelmeyer Ice Streams and part of Bindschadler Ice Stream. Comparing the representation of the coastal features on the sketch maps with this map, it is striking how well the sketch maps have represented the major geographic features along most of the coastline. From the western edge of this map to the Nickerson Ice Shelf, and on the eastern edge of this map along the Getz Ice Shelf, the features correlate very well with the sketch maps. It is only in the central area, from the eastern Nickerson Ice Shelf to the western Getz Ice Shelf, that this map portrays the coastal features and the grounding line much more accurately than the two sketch maps. It is also clear from this map that the Nickerson Ice Shelf extends the entire distance from Guest Peninsula to Groves Island.

Comparing the Saunders Coast area map, which is based on analysis of Landsat and RADARSAT images, with the 1:250,000-scale Topographic Reconnaissance Series maps, it is clear that the Reconnaissance Series maps are better at portraying bedrock outcrops and some other small features. However, this map is better at defining many of the glaciological features, especially the grounding lines. It also shows features in the vicinity of Newman Island (Nickerson Ice Shelf) and around Cape Colbeck where there is no USGS 1:250,000-scale Topographic Reconnaissance Series coverage.

The analysis of Landsat imagery has also shown that in some cases geographic place-names do not accurately describe geographic features. Table 2 lists geographic place-names shown on this map with the corresponding glaciological term or geographic feature that accurately describes them. Islands, bays, and inlets in Antarctica were often incorrectly identified on earlier maps because of the lack of sufficient information. On this map, an inlet and a bay are, in actuality, ice shelves; in addition, 14 islands have been glaciologically reclassified as ice rises.

GLACIER INVENTORY

Producing a sophisticated glacier inventory of Antarctica according to the requirements of the World Glacier Monitoring Service, as part of its ongoing "World Glacier Inventory" program, is impossible with the present state of glaciological knowledge about Antarctica (Swithinbank, 1980). Landsat images and available maps were used to produce a reasonably complete preliminary inventory of named and unnamed outlet glaciers and ice streams (those that are unnamed were given a latitude/longitude identifier) and also to identify related glaciological features more accurately, such as ice domes, ice piedmonts, ice shelves, ice rises, ice rumples, glacier tongues, iceberg tongues, and so forth, as defined in various scientific glossaries (Armstrong and others, 1973, 1977; Jackson, 1997) (see table 2).

SUMMARY

The analysis of Landsat 1 and 2 MSS images (1972 to 1976), Landsat 4 and 5 MSS and TM images (1986 to 1990), and the RADARSAT image mosaic (1997), all used in the preparation of this map of the Saunders Coast area, made it possible to identify and describe glaciological features, document coastal changes, and look for trends in the changing coastline. The Saunders Coast area is composed of two glaciologically different regions. In one, in the southwest corner of the map area, Bindschadler, MacAyeal, and Echelmeyer Ice Streams and Kiel Glacier drain from the Shirase Coast into the massive, buttressing Ross Ice Shelf. Constrained by the ice shelf, the average velocities near the mouths of Bindschadler and MacAyeal Ice Streams are 400 and 340 m a^{-1}, respectively. The velocities of Echelmeyer Ice Stream range from 20 to 170 m a^{-1}, and those of Kiel Glacier range from 20 to 180 m a^{-1}. The length of the grounding line along this part of the coastline is 800 km.

In the other, northern region, the coastline is composed mainly of a constantly moving, floating ice front interspersed with a few small areas of fairly stable, grounded ice walls. The total coastline in the Saunders Coast area map was digitally measured to be 1,197 km long, of which only 458 km, or 38 percent, is ice wall. The measured ice-surface velocities of the floating ice front of the northern coast range from the slow-moving sections of the Sulzberger Ice Shelf (100–200 m a^{-1}) to the terminus of Land Glacier (at least 2 km a^{-1}). DeVicq Glacier, the other glacier in the area that has been measured, has velocities ranging from 0.7 to more than 1.1 km a^{-1}.

The northern coastline is dominated by three large, fringing ice shelves: Sulzberger Ice Shelf (15,721 km^2), Nickerson Ice Shelf (7,207 km^2), and the western part of Getz Ice Shelf (5,840 km^2 on this map). There are a total of 49 named glaciers and ice streams, including three major outlet glaciers—Land, Hull, and DeVicq Glaciers—and 3 unnamed glaciers that flow into the ice shelves or directly into the Pacific sector of the Southern Ocean; four other named glaciers are located in a mountain range in the interior.

Observing the changes in the ice-front location along the Saunders Coast area in the three time frames represented by the satellite imagery, the following general trends were evident:

(1) From the western edge of the map area to Land Glacier, which represents approximately two-thirds of the distance along the northern coastline, the ice front shows a slow continuous advance from 1972 to 1997, corresponding to the expected advance with measured velocities. There has apparently been very little to no calving.

(2) The front of the Land Glacier terminus advanced 16.1 km from 1973 to 1988 and receded 4.5 km before 1997. Taking the velocity of Land Glacier into consideration, this represents calving of about 38.6 km of the length of the glacier tongue, an estimated net loss of approximately 1,000 km^2 in area and 200 km^3 in volume.

(3) East of Land Glacier, the ice-front changes are more complex. The ice front has advanced and retreated, but with an overall trend toward retreat. Hull Glacier has shown continuous retreat. In addition, much of the fast ice and many of the iceberg tongues fractured, moved seaward, or melted during the 1972 to 1997 time period. This overall trend is noteworthy and a possible indication of changing environmental conditions, especially in light of reported recent thinning of the Getz Ice Shelf and the presence of warm bottom water along much of the Marie Byrd Land coast.

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Table 1.—Landsat MSS and TM images used in the measurement of velocities of outlet glaciers, ice streams, and ice shelves.

Glaciological feature	Landsat image	Path/Row	Image No.	Date
DeVicq Glacier	Base image (TM)	018/113	42050-16015	25 Feb 88
	Coregistered image (MSS)	018/113	1172-16042	11 Jan 73
Land Glacier	Base image (TM)	024/114	42348-16461	19 Dec 88
	Coregistered image (MSS)	023/114	2317-16195	5 Dec 75
Nickerson Ice Shelf	Base image (TM)	027/114	51015-16513	11 Dec 86
	Coregistered image (MSS)	025/115	2391-16304	17 Feb 76
Sulzberger Ice Shelf	Base image (TM)	027/115	51015-16515	11 Dec 86
	Coregistered image (MSS)	022/116	1158-16284	28 Dec 72

Table 2.—Glacier inventory.

Geographic place-name[1]	Glaciological term or geographic feature[2]
Named	
Anandakrishnan Glacier	outlet glacier
Arthur Glacier	valley glacier
Balchen Glacier	valley glacier
Berry Glacier	outlet glacier
Bindschadler Ice Stream	ice stream
Blades Glacier	valley glacier
Boyd Glacier	ice stream/outlet glacier
Butler Glacier	valley glacier
Clarke Glacier	outlet glacier
Coleman Glacier	valley glacier
Crevasse Valley Glacier	valley glacier
Cumbie Glacier	valley glacier
Dalton Glacier	ice stream
DeVicq Glacier	ice stream
Echelmeyer Ice Stream	ice stream
El-Sayed Glacier	valley glacier
Fahnestock Glacier	outlet glacier
Farbo Glacier	valley glacier
Frostman Glacier	outlet glacier
Garfield Glacier	valley glacier
Gerry Glacier	outlet glacier
Hamilton Glacier	outlet glacier
Hammond Glacier	ice stream/outlet glacier
Herbst Glacier	valley glacier
Holcomb Glacier	valley glacier
Hull Glacier	outlet glacier
Jackson Glacier	ice stream
Jacobel Glacier	outlet glacier
Jacoby Glacier	valley glacier
Johnson Glacier	outlet glacier
Kiel Glacier	ice stream
Kirkpatrick Glacier	outlet glacier
Land Glacier	outlet glacier
Larson Glacier	valley glacier
Lord Glacier	outlet glacier
MacAyeal Ice Stream	ice stream
Ochs Glacier	valley glacier
Paschal Glacier	outlet glacier
Perkins Glacier	valley glacier
Ragle Glacier	valley glacier
Reynolds Glacier	valley glacier
Richter Glacier	ice stream/outlet glacier
Rosenberg Glacier	valley glacier
Rubey Glacier	ice stream
Scambos Glacier	outlet glacier
Shuman Glacier	outlet glacier
Siemiatkowski Glacier	ice stream
Stewart Glacier	ice stream
Strauss Glacier	outlet glacier
Swope Glacier	outlet glacier
Venzke Glacier	outlet glacier
White Glacier	outlet glacier
Withrow Glacier	ice stream/outlet glacier
Unnamed[3]	
AN77517S13952W	ice stream/outlet glacier
AN77532S14338W	ice stream/outlet glacier
AN77708S15443W	outlet glacier
Other features	
Bartlett Inlet	ice shelf
Benton Island	ice rise
Block Bay	ice shelf
Bursey Icefalls	icefall
Cronenwett Island	ice rise
Dickson Icefalls	icefall
Driscoll Island	ice rise
Farmer Island	ice rise
Fisher Island	ice rise
Getz Ice Shelf	ice shelf
Hutchinson Island	ice rise
Kizer Island	ice rise
Moody Island	ice rise
Morris Island	ice rise
Moulton Icefalls	icefall
Newman Island	ice rise
Nickerson Ice Shelf	ice shelf
Prezbecheski Island	ice rise
Rhodes Icefall	icefall
Steventon Island	ice rise
Sulzberger Ice Shelf	ice shelf
Swinburne Ice Shelf	ice shelf
Vollmer Island	ice rise

[1]The comprehensive listing of named glaciers and selected other named glaciological and physical features was derived from published maps of the area encompassed by the Saunders Coast area map. The geographic place-names are included in Alberts (1981, 1995) and National Science Foundation (1989). The three unnamed glaciers were identified from analysis of the Landsat images.

[2]The descriptive terms used to characterize the glaciological or geographic features were derived from analysis of the Landsat images. For definitions of glaciological terms, see Armstrong and others (1973, 1977) [primary references] and Jackson (1997) [secondary reference].

[3]Unnamed outlet glaciers and ice streams that have been identified on Landsat images were each given a geographic location code. For example, the code AN77427S11344W represents Antarctica (AN7), location at lat 74°27′ S. (7427S), long 113°44′ W. (11344W). AN7 is the continent code assigned for Antarctica by the World Glacier Monitoring Service. A latitude and longitude designator (degrees and minutes) is used in place of a drainage basin/glacier number code, because the latter is yet to be defined for Antarctica.