COASTAL-CHANGE AND GLACIOLOGICAL MAP OF THE EIGHTS COAST AREA, ANTARCTICA: 1972–2001

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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), on the basis of 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 part of the Antarctic ice sheet 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 during 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 (I–2600) 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; Ferrigno and others, 2002).

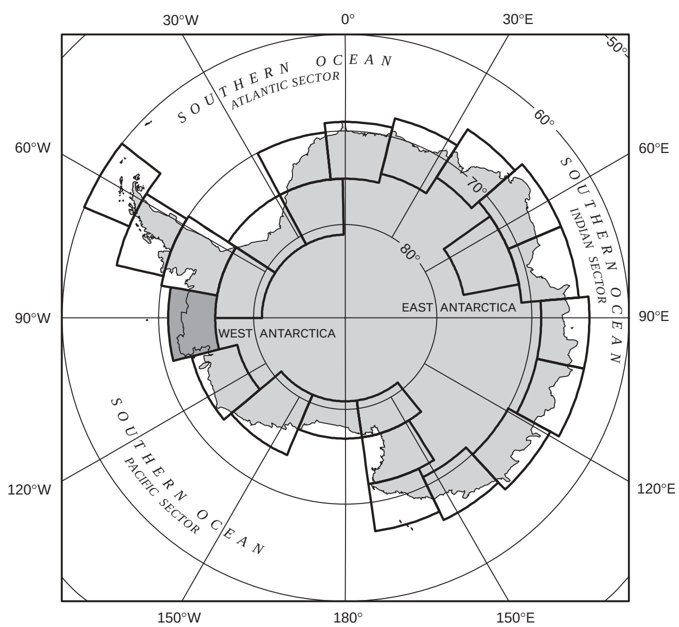

Figure 1.—Index map of the planned 24 coastal-change and glaciological maps of Antarctica at 1:1,000,000 scale. Eights Coast area map is shaded.

Objectives

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

(1) to determine coastline changes that have occurred during the past three decades, or longer where additional 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 Eights 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 1975; the later Landsat images are from 1984 to 1991.

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). A more recent position of the ice front of the Pine Island Glacier was determined from a 12 November 2001 Multi-angle Imaging SpectroRadiometer (MISR) image from the National Aeronautics and Space Administration's (NASA) Terra spacecraft.

Methodology

The primary steps in the compilation of the Eights 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. Because our goal is to produce the most accurate, high-resolution printed maps and digital databases of the coastal regions of Antarctica, we expended considerable thought and research 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 image 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. Features from corrected image data were digitized to ARC/INFO vector coverages using the digital overlay images as guides. The November 2001 Pine Island Glacier MISR image was digitally transferred from the NASA World Wide Web site and registered to the RADARSAT image mosaic;

(5) Addition of velocity vectors, geographic place-names, and codes for 21 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 the 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[6]

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 Eights Coast area map covers the part of Ellsworth Land that extends from just east of the tip of Rydberg Peninsula (long 80° W.) to the western part of Pine Island Bay (long 104° W.). The Eights Coast spans the central part of the map area and is named for James Eights, geologist, who in 1830 was the first American scientist to visit Antarctica. The map includes part of the Walgreen Coast in the west and all of the Bryan Coast in the east. The Eights Coast area map is dominated by two glaciological features: the 440-km-long, east-west-trending Abbot Ice Shelf, which lies between Thurston Island and the mainland and has an area (as of 1997) of 30,560 km^2, including ice rises; and the fast-flowing Pine Island Glacier (see following section on out-

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

let-glacier, ice-stream, and ice-shelf velocities). Pine Island Glacier flows into Pine Island Bay and the Amundsen Sea and drains a significant part of the ice sheet in West Antarctica; the drainage area was calculated by Vaughn and others (2001) to be about 165,000 km^2, and by Rignot and Thomas (2002) to be 162,300 km^2. In addition, there are two small ice shelves in the map area. Cosgrove Ice Shelf, approximately 65 km wide, drains westward into Ferrero Bay and the Amundsen Sea, and has an area (as of 1997) of 2,250 km^2. Venable Ice Shelf, 40 km wide, drains northward into the Bellingshausen Sea and has an area (as of 1997) of 3,016 km^2. Thurston Island, with its numerous outlet glaciers, is a significant coastal feature in the northwestern part of the map area. Along the coast of the map area, the floating ice of the glaciers, ice streams, and ice shelves is separated by the grounded ice of the semi-stable ice walls of numerous peninsulas, islands, and ice rises. The longest section of ice wall is at the eastern edge of the map area. It is about 250 km long and is interrupted by a number of small glaciers, most of which are classified as ice streams. The entire coastline was digitally measured to be 1,630 km long, of which 1,008 km, or 62 percent, is ice wall.

A total of 52 named glaciers and ice streams and 21 unnamed glaciers and ice streams (table 2) occur in the map area. Thirty-two named glaciers flow from Thurston Island to Abbot Ice Shelf or the Bellingshausen Sea. Four named glaciers flow from King Peninsula into Abbot Ice Shelf, and four named glaciers (including Pine Island Glacier) are located along the Walgreen Coast. Eight named glaciers and ice streams are along the Bryan Coast, and four named glaciers are located in the interior Jones Mountains.

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.

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 or ice shelf (table 1).

On the Eights Coast area map the fastest flowing glacier is Pine Island Glacier. The average surface velocity of the floating section of Pine Island Glacier was measured on 1973–75 Landsat imagery to be between 2.1 and 2.4 km a^{-1} (Crabtree and Doake, 1982; Williams and others, 1982; Lindstrom and Hughes, 1984). Later measurements using 1992–2000 imagery from Landsat and from the European Space Agency Remote-Sensing Satellite (ERS) have shown that the glacier appears to have sped up considerably in the grounding line area and that the velocity is as much as 2.9 km a^{-1} at the terminus (Lucchitta and others, 1995; Rosanova and others, 2000; Rignot and others, 2002).

Average surface velocities were also calculated by the authors for areas of ice flow across Cosgrove Ice Shelf, Abbot Ice Shelf, Venable Ice Shelf, and Morgan Inlet, ranging from 100 m a^{-1} in most areas to 200 m a^{-1} on Abbot Ice Shelf just east of Thurston Island, and 400 and 700 m a^{-1} on the eastern and western parts of Venable Ice Shelf, respectively (Ferrigno and others, 1998).

Coastal Change

The changes discussed below are based on an analysis of Landsat images, the RADARSAT image mosaic, and the MISR image of the coast between the Rydberg Peninsula and the western part of Pine Island Bay (long 80°–104° W.). The overall trend of coastal change in the map area during the 29-year survey period is retreat, although advance has been observed locally.

Pine Island Glacier

The most noticeable coastal change in the map area is the calving of an approximately 700-km^2 tabular iceberg from Pine Island Glacier in November 2001. The calving was predicted by R.A. Bindschadler (NASA) in early 2001 based on recognition of a large crevasse on the floating terminus of the glacier on Landsat 7 imagery. However, the iceberg calved earlier than expected and quite rapidly, within the time span of about a week (4–12 November 2001) (Bindschadler and Rignot, 2001; Bindschadler and others, 2002). The dynamic, fast-moving Pine Island Glacier, having the second most active drainage basin in Antarctica (Vaughan and Bamber, 1998) of approximately 165,000 km^2 (Vaughan and others, 2001), has been the focus of intense scientific interest because of its potential effect on a large segment of the West Antarctic part of the Antarctic ice sheet. Recent studies have shown that (1) the glacier velocity has increased considerably in the grounding line region (Rignot and others, 2002) and at the ice front, to 2.9 km a^{-1} at the terminus (Rosanova and others, 2000), (2) the grounding line has retreated 5 km inland (Rignot, 1998), (3) the glacier is thinning (Rignot, 1998; Shepherd and others, 2001; Rignot and Thomas, 2002), and (4) 31 km^3 of ice has been lost from the interior between 1992 and 2001 (Shepherd and others, 2001). Rignot and Thomas (2002), in their tabulation of the mass budget of 33 outlet glaciers and ice streams in Antarctica, show a net loss of about 8 km^3 a^{-1} for Pine Island Glacier in recent years.

It is also noteworthy that comparison of aerial photographs taken in 1947 (during the U.S. Navy's Operation Highjump) with Landsat imagery from the 1980s shows that there has been a significant reduction in the amount of iceberg discharge into Pine Island Bay and in the amount of sea ice in the bay (Rignot, 2002). These changes, and the large amount of basal melting from the underside of Pine Island Glacier, are probably due to warm Circumpolar Deep Water affecting this part of the coastline (Jacobs and others, 1996; Jenkins and others, 1997). Rignot and Jacobs (2002) reported high bottom-melting rates of outlet glaciers directly seaward of their grounding lines. A comprehensive review of Pine Island Glacier and its role in the mass balance of the West Antarctic part of the Antarctic ice sheet is presented in Vaughan and others (2001). Compared to Pine Island Glacier, the glaciers, ice streams, and ice shelves on the remainder of the Walgreen Coast and on the Eights and Bryan Coasts show much less change.

Walgreen Coast north of Pine Island Glacier

The ice front of Chavez Glacier in Cranton Bay remained fairly constant during the time span of this map. The front of Cosgrove Ice Shelf retreated during this period. From January 1973 to December 1989, it retreated an average of about 400 m, and from December 1989 to 1997, it retreated another 1,200 m. Considering that the measured velocity is about 100 m a^{-1}, this represents an ice loss of about 4 km across the approximately 40-km-long ice front, or 160 km^2, in 24 years.

Eights Coast

The tip of the Demas Ice Tongue retreated an average of about 3 km from January 1973 to December 1989, and a smaller amount from December 1989 to 1997, while the northern edge advanced slightly and the southern edge remained nearly constant. In spite of the retreat, the general shape has remained the same, implying that the ice tongue may be pinned on a submarine topographic high.

The ice fronts of the outlet glaciers of Thurston Island showed advance in some areas and retreat in other areas, but overall the trend is retreat. Foley Glacier, just west of Dyer Point, retreated slightly from January 1973 to 1997. Acosta Glacier, just west of Hughes Peninsula, advanced slightly from January 1973 to 1997.

The Wagoner Inlet ice front advanced about 1 km between January 1973 and December 1984, and further advanced about 1.2 km before 1997. The ice front of Peale Inlet advanced about 1.4 km from January 1973 to December 1984 and then retreated twice that amount, or 2.9 km, by 1997. Sikorski Glacier retreated about 1.5 km from January 1973 to 1997. Frankenfield Glacier advanced about 1 km from January 1973 to December 1984 and then retreated the same amount before 1997. At Murphy Inlet, the ice front experienced a small retreat from 1973 to 1984 and then advanced about 2.5 km before 1997. The ice front of Koether Inlet remained fairly constant from the 1970s to the 1980s, and then retreated about 3 km before 1997. Payne Glacier, at the north end of Evans Peninsula, retreated about 1 km from December 1972 to 1997. Payne Glacier is a good example of the benefit of time-lapse imagery from different sensors. This part of the coastline had originally been mapped as grounded ice wall, but is now recognized as floating ice front.

While it is significant that the Thurston Island glaciers as a whole are retreating rather than advancing, nevertheless the recession does not represent a large ice loss when compared to that from Pine Island Glacier. Although this part of the coastline receives considerable precipitation (Bromwich, 1990), the glaciers move slowly, probably 100 m a^{-1} or less, and their respective accumulation and drainage areas are small.

The front of Abbot Ice Shelf from Thurston Island to Dustin Island, where the ice-surface velocity is about 200 m a^{-1}, remained fairly constant from February 1991 to 1997, although there was some retreat in the eastern part. Considering the measured velocity, there would have been an ice-front advance of more than 1 km in those 6.5 years if there had been no calving. However, at least some, if not all, of the calved ice—from this interval as well as from earlier time periods—can be seen in front of the ice shelf. This is the only location on the map where there is an accumulation of fast ice, probably protected from dispersal by Dustin Island and the nearby peninsulas of Thurston Island.

The Abbot Ice Shelf front between Dustin Island and McNamara Island showed an average advance of 1.4 km in the western part from January 1973 to February 1991, and 0.9 km from February 1991 to 1997; the eastern part remained fairly constant. From McNamara Island to Farwell Island, the ice front advanced and retreated as much as 4 km, but with little overall change during the time period of the map. Between Farwell Island and Fletcher Peninsula, the easternmost section of the Eights Coast, the ice front advanced and retreated as much as 3 km, with somewhat more retreat than advance.

Bryan Coast

The Bryan Coast section of this map is composed of Venable Ice Shelf and a long extent of ice wall (about 250 km) interspersed with several small glaciers, most of which are classified as ice streams. The front of Venable Ice Shelf advanced between January 1974 and February 1988 a maximum of 2.8 km, with an average of about 2 km. Between 1988 and 1997, the ice front retreated a maximum of 5.6 km and an average of about 2 km. Averaged across the entire length of the ice shelf, the overall retreat is about 1 km. Considering the velocity of the ice shelf, the ice front would have advanced a minimum of 16 km on the western part and 9 km on the eastern part.

The ice front on the northeast side of Allison Peninsula advanced an average of 0.5 km from January 1974 to February 1988, and retreated an average of 1.8 km from 1988 to 1997, experiencing a net retreat. The front of the iceberg tongue of Fox Ice Stream, east of Allison Peninsula, showed a net retreat between 1974 and 1997. The iceberg tongue of Ferrigno Ice Stream, farther to the east, advanced about 5 km between January 1974 and January 1988, but lost half its width between January 1988 and 1997. The next ice streams to the east, AN77346S08243W and Alison Ice Stream, both receded between 1988 and 1997, the former 2.6 km and the latter almost 1 km.

Between Alison Ice Stream and Wirth Peninsula, the entire ice front was originally mapped as ice wall. However, a small section calved between 1988 and 1997, suggesting the existence of an unnamed ice stream. Between Wirth and Rydberg Peninsulas, Thomson Glacier showed a slight advance between 1973 and 1997.

Map Revisions

As discussed in the Sources and Methodology sections, the Eights Coast area map was compiled from annotations of geographic and glaciological 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 (Bryan Coast–Ellsworth Land and Thurston Island–Jones Mountains, both published in 1968), having shaded relief but generally without contours; and on one Antarctica 1:250,000-scale Topographic Reconnaissance Series map of the region (Jones Mountains, 1999), compiled from aerial photography and Landsat 1 MSS imagery, and having contours. Comparison of those earlier maps with this map reveals the following differences in cartographic representation of the geographic and glaciological features.

The two sketch maps cover the entire coastal area shown by this map with a very good representation of the geographic and glaciological features, owing to the skill of the early cartographers in photo-interpretation and airbrushing techniques. However, the sketch maps do not delineate features very far inland and cannot have the geodetic accuracy of this map because of the limitations of the surveyed geodetic ground control. In addition, this map is better at defining many of the glaciological features, such as grounding lines. Comparing this map with the 1:250,000-scale Jones Mountains map, it is clear that the Jones Mountains map is better at portraying bedrock outcrops and other small features in a limited area because of its scale and because of the 79-m pixel resolution of the Landsat image base compared to the 125-m resolution and the reduced contrast of this printed version of the RADARSAT image mosaic.

The analysis of Landsat imagery has also shown that in some cases geographic place-names do not accurately describe geographic and glaciological features. Table 2 lists geographic place-names shown on the Eights Coast area map with the corresponding glaciological term or geographic feature that more accurately describes them. Islands, peninsulas, and inlets in Antarctica were often incorrectly identified on earlier maps because of the lack of sufficient information.

GLACIER INVENTORY

Producing a sophisticated glacier inventory of Antarctica according to the requirements of the World Glacier Monitoring Service (WGMS), as part of its ongoing "World Glacier Inventory" program, is not possible with the present state of glaciological knowledge about Antarctica (Swithinbank, 1980). Rignot and Thomas (2002) showed catchment-basin boundaries for 33 outlet glaciers and ice streams on their map of calculated ice-sheet-balance velocity. Their published map (approximate scale of 1:46,700,000) provides a continent-wide delineation of major ice-discharge basins, but is not sufficiently detailed in areas of steep slopes to delineate smaller basins accurately. Future remotely sensed data may permit higher precision in geographic position of divides and much greater detail (for example, subdivisions) of ice-discharge basins, thereby permitting application of WGMS guidelines to glacier inventories. Landsat images and available maps were used to produce a reasonably complete preliminary inventory of named and unnamed (given a latitude/longitude identifier) glaciers and ice streams and also to identify related glaciological features more accurately, such as 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 1975), Landsat 4 and 5 MSS and TM images (1984 to 1991), the RADARSAT image mosaic (1997), and the MISR image (2001), all used in the preparation of this map of the Eights Coast area, made it possible to identify and describe glaciological features, document coastal change, and look for trends in the changing coastline. The Eights Coast area map has two dominant features: the 440-km-long, east-west-trending Abbot Ice Shelf between Thurston Island and the mainland; and the fast-flowing Pine Island Glacier, which has a velocity as great as 2.9 km a^{-1} at the ice front. The digitally measured length of the coastline is 1,630 km, of which 1,008 km, or 62 percent, is ice wall. A total of 52 named glaciers and ice streams and 21 unnamed glaciers and ice streams occur in the map area. Thirty-two named glaciers flow from Thurston Island to Abbot Ice Shelf or the Bellingshausen Sea, four named glaciers flow from King Peninsula into Abbot Ice Shelf, four named glaciers (including Pine Island Glacier) are located along the Walgreen Coast, eight named glaciers and ice streams are along the Bryan Coast, and four named glaciers are located in the interior Jones Mountains.

Pine Island Glacier is the most dynamic and significant glaciologic feature in the map area. The ice-surface velocity is as much as 2.9 km a^{-1} at the ice front. In addition, the glacier is thinning and the grounding line has retreated. Because of these recent changes and because of the large size of its drainage basin, (approximately 165,000 km^2), Pine Island Glacier clearly has a major role in influencing the mass balance of the West Antarctic part of the Antarctic ice sheet.

Abbot Ice Shelf, with a length of 440 km and an area of 30,560 km^2 including ice rises, is the largest ice shelf in the Eights Coast map area. This part of the coastline receives considerable precipitation, but the drainage areas of its glaciers are small; the glaciers move slowly, generally about 100 m a^{-1}, and changes in their ice volume do not strongly affect the ice mass balance in the overall region.

In addition to Abbot Ice Shelf, there are two smaller ice shelves in the Eights Coast map area. Cosgrove Ice Shelf, in the western part of the map area, is 65 km wide, has an area of 2,250 km^2, and has an ice-front velocity of 100 m a^{-1}. Venable Ice Shelf, in the eastern part of the map area, is 40 km wide, has an area of 3,016 km^2, and has ice-front velocities of 400 m a^{-1} in the east and 700 m a^{-1} in the west.

Observing the changes in the Eights Coast map area during the three time periods represented on this map reveals that although there have been a few areas of coastline advance, the general trend has been toward recession, especially in the later time interval from the 1980s to 1997. Considering this and the recently recognized changes in the Pine Island Glacier drainage basin, it is clear that the Eights Coast map area is an important segment of the Antarctic coastline to monitor for future changes.

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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
Abbot Ice Shelf (Thurston Island to Farwell Island)	Base image (TM)	232/111	52547-13593	20 Feb 91
	Coregistered images (MSS)	247/111	1168-13572	07 Jan 73
		247/112	1168-13575	07 Jan 73
Cosgrove Ice Shelf	Base image (TM)	001/112	42347-14232	18 Dec 88
	Coregistered image (MSS)	001/112	1191-14264	30 Jan 73
Morgan Inlet	Base image (TM)	232/111	52547-13593	20 Feb 91
	Coregistered image (MSS)	247/111	1168-13572	07 Jan 73
Venable Ice Shelf	Base image (MSS)	226/112	42035-13263	10 Feb 88
	Coregistered image (MSS)	240/112	1557-13132	31 Jan 74

Table 2.—Glacier inventory

Geographic place-name[1]	Glaciological term or geographic feature[2]
Named	
Acosta Glacier	outlet glacier
Alison Ice Stream	ice stream
Bearman Glacier	outlet glacier
Bellisime Glacier	outlet glacier
Bulbur Glacier	outlet glacier
Chavez Glacier	outlet glacier
Cooke Glacier	outlet glacier
Cox Glacier	outlet glacier
Craft Glacier	outlet glacier
Deadmond Glacier	outlet glacier
Exum Glacier	valley glacier
Ferrigno Ice Stream	ice stream
Foley Glacier	outlet glacier
Fox Ice Stream	ice stream
Frankenfield Glacier	outlet glacier
Goff Glacier	outlet glacier
Goodell Glacier	outlet glacier
Gopher Glacier	valley glacier
Hale Glacier	outlet glacier
Haskell Glacier	valley glacier
Hlubeck Glacier	outlet glacier
Isbrecht Glacier	outlet glacier
Kannheiser Glacier	outlet glacier
Levko Glacier	outlet glacier
Litz Glacier	outlet glacier
Long Glacier	outlet glacier
Lucchitta Glacier	outlet glacier/ice stream
Mahaffey Glacier	outlet glacier
Marck Glacier	outlet glacier
McCarty Glacier	outlet glacier
Mincer Glacier	outlet glacier
Morelli Glacier	outlet glacier
Myers Glacier	outlet glacier
Payne Glacier	outlet glacier
Pelter Glacier	outlet glacier
Pine Island Glacier	ice stream
Rexford Glacier	outlet glacier
Rignot Glacier	outlet glacier
Robbins Glacier	outlet glacier
Rochray Glacier	outlet glacier
Rosanova Glacier	outlet glacier
Savage Glacier	outlet glacier
Sessums Glacier	outlet glacier
Sikorski Glacier	outlet glacier
Stapleton Glacier	outlet glacier
Thomson Glacier	outlet glacier
Velasco Glacier	outlet glacier
Walk Glacier	valley glacier
Warr Glacier	outlet glacier
Wiesnet Ice Stream	ice stream
Williams Ice Stream	ice stream
Zinberg Glacier	outlet glacier

Table 2.—Glacier inventory—Continued.

Geographic place-name[1]	Glaciological term or geographic feature[2]
Unnamed[3]	
Thurston Island	
AN77157S10039W	outlet glacier
AN77156S10030W	outlet glacier
AN77152S10004W	outlet glacier
AN77205S09947W	outlet glacier
AN77203S09941W	outlet glacier
AN77230S09600W	outlet glacier
AN77233S09617W	outlet glacier
AN77221S09929W	outlet glacier
AN77212S10129W	outlet glacier
AN77209S10210W	outlet glacier
Abbot Ice Shelf/Eights Coast	
AN77315S09154W	ice stream
AN77318S09121W	ice stream
AN77310S08949W	ice stream
AN77308S08919W	ice stream
Bryan Coast	
AN77308S08834W	ice stream
AN77314S08753W	ice stream
AN77315S08719W	ice stream
AN77332S08506W	ice stream
AN77346S08243W	ice stream
Walgreen Coast	
AN77342S10140W	outlet glacier
AN77443S09944W	outlet glacier
Other features	
Abbot Ice Shelf	ice shelf
Allison Peninsula	peninsula
Cadwalader Inlet	ice shelf
Canisteo Peninsula	peninsula
Carpenter Island	ice rise
Cosgrove Ice Shelf	ice shelf
Demas Ice Tongue	ice shelf
Dendtler Island	ice rise
Dustin Island	island
Edwards Peninsula	peninsula
Evans Peninsula	peninsula
Farwell Island	ice rise
Fletcher Peninsula	peninsula
Henry Inlet	ice shelf
Hughes Peninsula	peninsula
Johnson Island	ice rise
King Peninsula	peninsula
Koether Inlet	ice shelf
Langhofer Island	ice rise
Lepley Nunatak	ice rise
Lofgren Peninsula	peninsula
McNamara Island	ice rise
Morgan Inlet	ice shelf
Murphy Inlet	ice shelf

Table 2.—Glacier inventory—Continued.

Geographic place-name[1]	Glaciological term or geographic feature[2]
Other features—Continued.	
Noville Peninsula	peninsula
Peale Inlet	glacier tongue/ice shelf
Potaka Inlet	glacier tongue/ice shelf
Rydberg Peninsula	peninsula
Sherman Island	ice rise
Starr Peninsula	peninsula
Thurston Island	island
Tierney Peninsula	peninsula
Tinglof Peninsula	peninsula
Trice Islands	ice rumples
Venable Ice Shelf	ice shelf
Wagoner Inlet	glacier tongue/ice shelf
Wirth Peninsula	peninsula

[1]The comprehensive listing of 89 named glaciers and selected other named glaciological and physical features was derived from published maps and gazetteers of the area encompassed by the Eights Coast area map. The geographic place-names are included in Alberts (1981, 1995), in National Science Foundation (1989), and on the USGS Geographic Names Information System (GNIS) web page. The 21 unnamed outlet glaciers and ice streams 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 (WGMS). 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.