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Coastal-Change and Glaciological Map of the Palmer Land Area, Antarctica: 1947–2009

By Jane G. Ferrigno, Alison J. Cook, Amy M. Mathie, Richard S. Williams, Jr., Charles Swithinbank, Kevin M. Foley, Adrian J. Fox, Janet W. Thomson, and Jörn Sievers

Pamphlet to accompany

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Conversion Factors

Multiply	By	To obtain
	Length	
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
	Area	
square kilometer (km^2)	0.3861	square mile (mi^2)
	Volume	
cubic kilometer (km^3)	0.2399	cubic mile (mi^3)

Coastal-Change and Glaciological Map of the Palmer Land Area, Antarctica: 1947–2009

By Jane G. Ferrigno,[1] Alison J. Cook,[2] Amy M. Mathie,[3] Richard S. Williams, Jr.,[4] Charles Swithinbank,[5] Kevin M. Foley,[1] Adrian J. Fox,[2] Janet W. Thomson,[6] and Jörn Sievers[7]

Introduction

Background

Reduction in the area and volume of the two polar ice sheets is intricately linked to changes in global climate, and the resulting rise in sea level could severely impact the densely populated coastal regions on Earth. Antarctica is Earth's largest reservoir of glacial ice. Melting of the West Antarctic part alone of the Antarctic ice sheet would cause a sea-level rise of approximately 6 meters (m), and 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). Shepherd and Wingham (2007) discussed change in the Antarctic ice sheet as part of the global picture, and Jenkins and Holland (2007) discussed the real potential of sea-level rise from the melting of floating ice such as ice shelves and icebergs. The mass balance (the net volumetric gain or loss) of the Antarctic ice sheet is highly complex, responding differently to different climatic and other conditions in each region (Vaughan, 2005). In a review paper, Rignot and Thomas (2002) concluded that the West Antarctic ice sheet is probably becoming thinner overall; although it is known to be thickening in the west, it is thinning in the north. Thomas and others (2004), on the basis of aircraft and satellite laser altimetry surveys, believe that the thinning may be accelerating. Joughin and Tulaczyk (2002), on the basis of ice-flow velocities derived from analysis of synthetic-aperture radar data, concluded that most of the Ross ice streams (ice streams flowing into the east side of the Ross Ice Shelf) have a positive mass balance, whereas Rignot and others (2004b) infer a larger negative mass balance for glaciers flowing northward into the Amundsen Sea, a trend indicated by Swithinbank and others (2003a,b, 2004). The mass balance of the East Antarctic ice sheet is thought by Davis and others (2005) to be positive on the basis of the change in satellite-altimetry measurements made between 1992 and 2003. On the basis of Gravity Recovery and Climate Experiment (GRACE) satellite measurements of Earth's gravity from 2002 to 2005, Velicogna and Wahr (2006) concluded that the mass of the Antarctic ice sheet decreased during the period of measurement, and that the West Antarctic ice sheet accounted for most of the loss of ice.

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 cryospheric coastline of Antarctica (Ferrigno and Gould, 1987). Although changes in the extent of the Antarctic ice sheet are not directly related to changes in mass balance, the two are related, and the analysis of the changing coastline can yield important information. 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) images (and in some areas Landsat 7 Enhanced Thematic Mapper Plus (ETM+) images), RADARSAT images, aerial photography, and other data where available, to compare changes that occurred during a 20- to 25- or 30-year

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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) (Williams and others, 1995; Swithinbank and others, 2003a,b, 2004; Ferrigno and others, 2002, 2005, 2006, 2007, 2008, and in press; and Williams and Ferrigno, 2005) (available online at http://www.glaciers.er.usgs.gov). Table 1 lists the USGS Geologic Investigations Series coastal-change and glaciological maps of Antarctica that have been published to date.

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 other satellite images, the glaciological characteristics (for example, floating ice, grounded ice, and so forth) of the coastline of Antarctica during three main time intervals: (1) early 1970s (Landsat 1, 2, or 3), (2) middle 1980s to early 1990s (Landsat 4 or 5), and (3) late 1990s to early 2000s (RADARSAT or Landsat 7 ETM+);
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 and other satellite images or from ancillary sources (for example, maps, gazetteers, digital databases, and so forth) (Swithinbank, 1980, 1985; Alberts, 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 1:1,000,000-scale maps. Each 1:1,000,000-scale map, apart from the three sheets covering the Antarctic Peninsula, extends to the southernmost nunatak within each map area or to the southernmost extent of Landsat

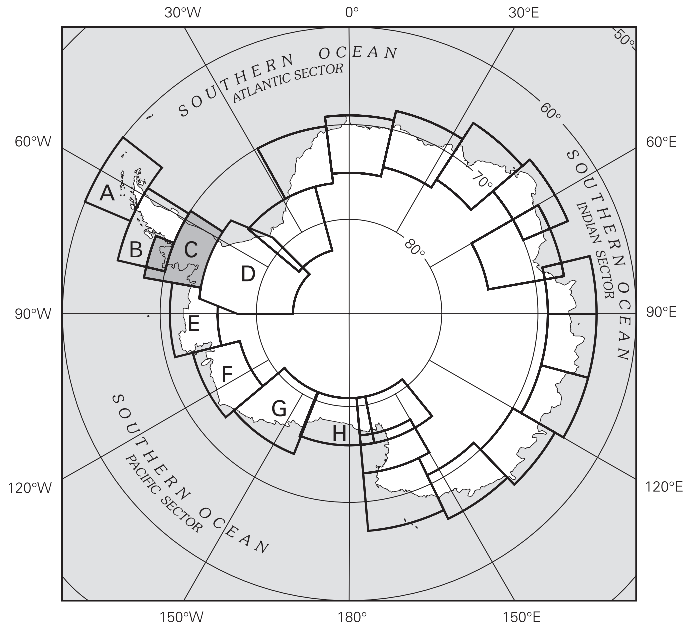

Figure 1. Index map of the planned and published coastal-change and glaciological maps of Antarctica at 1:1,000,000 scale. Palmer Land area map is shaded. Maps published to date are indicated by letter and described in table 1. They are available printed and online; see table 1 for more information.

Table 1. Coastal-change and glaciological maps of Antarctica at 1:1,000,000 scale, published to date.

[Information on ordering published maps can be obtained by calling the U.S. Geological Survey at 1-888-ASK-USGS or by visiting the USGS online at http://www.usgs.gov/pubprod]

As shown on index map	Map number	Map name	References (see References Cited)	URL for online access
A	I–2600–A	Trinity Peninsula and South Shetland Islands	Ferrigno and others (2006)	http://pubs.usgs.gov/imap/2600/A/
B	I–2600–B	Larsen Ice Shelf	Ferrigno and others (2008)	http://pubs.usgs.gov/imap/2600/B/
C	I–2600–C	Palmer Land	This report	http://pubs.usgs.gov/imap/2600/C/
D	I–2600–D	Ronne Ice Shelf	Ferrigno and others (2005)	http://pubs.usgs.gov/imap/2600/D/
E	I–2600–E	Eights Coast	Swithinbank and others (2004)	http://pubs.usgs.gov/imap/2600/E/
F	I–2600–F (2d ed.)	Bakutis Coast	Swithinbank and others (2003b)	http://pubs.usgs.gov/imap/2600/F/
G	I–2600–G	Saunders Coast	Swithinbank and others (2003a)	http://pubs.usgs.gov/imap/2600/G/
H	I–2600–H	Northern Ross Ice Shelf	Ferrigno and others (2007)	http://pubs.usgs.gov/imap/i-2600-h/

images (about lat 81.5º S.). The coverage area of some maps (for example, those covering the Ronne and Filchner Ice Shelves) was extended farther south to encompass the entire ice shelf.

Sources

Most of the earlier maps in the Coastal-Change and Glaciological Maps of Antarctica series relied almost exclusively on Landsat and other satellite data as the source of information. In addition to incorporating Landsat and other satellite imagery, this map, as well as the other two Antarctic Peninsula maps (Trinity Peninsula area and South Shetland Islands (map I–2600–A) and Larsen Ice Shelf area (map I–2600–B)), was compiled using the abundance of current and historical source material archived by the British Antarctic Survey (BAS). This source material included vertical and (or) oblique aerial photographs acquired during various years between 1947 and 1992 (table 2), maps from 1948 to 2000 (table 3 and map collar), and various publications (References Cited). (Table 3 is in appendix following the References Cited.)

The Landsat 4 and 5 TM image base used for the Palmer Land area map is derived from images of the Antarctic Peninsula that were digitally mosaicked and georeferenced by the former German Institut für Angewandte Geodäsie (IfAG), now known as the Bundesamt für Kartographie und Geodäsie (BKG), and made available by Jörn Sievers. The resulting image mosaic was augmented by the addition of one Landsat 7 ETM+ scene to complete the coverage of Charcot Island and two Landsat 4 TM scenes to complete the coverage of the Smyley Island area. The coverage areas of the Landsat 1, 2, and 3 MSS images, Landsat 4 and 5 TM images, and Landsat 7 ETM+ images used in the compilation of the printed map are shown on the index maps on the accompanying map. Below the index maps, information about each image is listed.

Other Landsat images in photographic or digital form were used for the analysis of geographic and glaciological features. Photographic prints at 1:500,000 scale dating from 1973 to 1991 were used in the initial analytical phase of the project by Charles Swithinbank.

The early Landsat scenes were acquired during the period 1973 to 1979. The Landsat 4 and 5 TM images date from 1986 to 1991. The Landsat 7 ETM+ images used in the completion of the mosaic and in the analysis of coastline change were digital and date from 2000, 2001, and 2002. Other satellite images used for analysis of coastal change were RADARSAT images (1997) from the Canadian Space Agency radar satellite.

Analytical and Other Methodologies Used for Each Data Source

The large number of data sources, each having different characteristics, spatial resolutions, and geodetic accuracies, necessitated the application of different methodologies to use each source most effectively; these methodologies are discussed in the following section. Relative accuracy assigned to each data source is shown in the table below and described more fully in the Coastline Accuracies section. The large amount of information produced as a result of the abundance of data sources and the extensive analysis is generally too complex to portray properly on the printed map at 1:1,000,000 scale. As a result, much of the data used and analysis employed is found on the SCAR ADD (Antarctic Digital Database) Web site hosted by BAS at http://www.add.scar.org:8080/add/

IfAG Mosaic

The IfAG Landsat TM image mosaic (30-m pixel resolution) was used as the image base onto which the coastlines were mapped for each of the three USGS-BAS maps of the Antarctic Peninsula (I–2600–A, –B, and –C). This mosaic was

Relative accuracy assigned to each data source.

Source material	Relative accuracy (reliability) compared to IfAG mosaic (1, most accurate)
IfAG mosaic	1
Landsat 1–5 images	1, 2, or 3
Landsat 7 ETM+ images	1 or 2
Vertical aerial photographs	1, 2, or 3
Oblique aerial photographs	2 or 3
Maps and publications	3
RADARSAT images	2 or 3

Table 2. Vertical and (or) oblique aerial photographs used in analysis of ice-front change for the coastal-change and glaciological map of the Palmer Land area.

[Abbreviations used: BAS, British Antarctic Survey; RARE, Ronne Antarctic Research Expedition; TMA, Trimetrogon Antarctica (USA)]

Date	Source	Scale
1966–68	TMA vertical and oblique	1:38,000 and 1:40,000 (vertical); oblique has various scales
1947	RARE vertical and oblique	1:14,000 and 1:18,000 (vertical); oblique has various scales
1992	BAS vertical	1:20,000

determined to be the most geodetically accurate image base available of the peninsula. It was compiled using 62 control points from the BAS geodetic-control network of the area adjusted in 1985. Conventional block-adjustment techniques were used (Sievers and others, 1989). The accuracy was calculated by A.P.R. Cooper, BAS, to be ±150 m (Cooper, oral commun., 2001).

The coastline on the Landsat 4 and 5 image mosaic was digitized and assigned a reliability of 1. Because the IfAG mosaic was used as the image base, the accuracy of all other data sources was assigned relative to the accuracy of the IfAG mosaic. For those parts of the rock coastline that were hidden in shadow, or in areas obscured by cloud, the IfAG mosaic was used in conjunction with vertical and oblique aerial photography (see table 2) and with the Antarctic Digital Database (ADD) coastline (British Antarctic Survey and others, 1993; ADD Consortium, 2007).

Landsat Images and Overlays

The initial analysis of glaciological features and coastal change began with annotation of glaciological features by Charles Swithinbank using the SCAR Code (Scientific Committee on Antarctic Research, 1980) for symbols on maps or the SCAR ADD geocode (British Antarctic Survey and others, 1993) on transparent overlays of the enlarged 1:500,000-scale Landsat images. The resulting images and overlays were later transferred to BAS to be combined digitally with the other sources of information.

In the BAS Mapping and Geographic Information Centre (MAGIC), each satellite image was incorporated into the digital database using a series of nine artificial control points that could be identified on the IfAG image mosaic. The arcs (line segments) were digitized following, for the most part, the glaciological annotations made by Charles Swithinbank. Because they were digitized at scale 1:500,000, they were given a reliability of 2 or 3.

Landsat 7 ETM+ Images

The Landsat 7 ETM+ images (30-m pixel resolution) were imported digitally and reprojected. Where necessary, an image was registered and rectified. Once correctly positioned, the ice-coast areas (grounded or floating) were digitized and assigned a reliability of 1 or 2.

Vertical Aerial Photographs

Vertical aerial photographs were by far the most common data source used and their reliability generally was high. When it was possible to digitize the ice front or ice wall accurately from the photographs, the ice front or wall was assigned a reliability of 1. In other cases, for example where features were obscured to a greater or lesser degree by cloud, the information was given a reliability of 2. Frequently, there were no permanent features visible or present on the background image or the photograph, so that positioning of the ice front or ice wall was difficult or impossible. In such cases, the ice front or ice wall either was not drawn at all, or was assigned a reliability of 3 if it could be placed with reasonable confidence. In cases of reliability 2 or 3, the reliability rating chosen is explained in the comment field of the Excel file on the SCAR ADD Web site.

Oblique Aerial Photographs

Oblique aerial photographs were always given a reliability of 2 or 3. Although it was difficult to accurately define scale or distance from oblique aerial photographs, it was still possible to position the coastline relative to other features. If the ice front or ice wall could be clearly seen, was in the foreground, and could be positioned relative to fixed features, it was drawn with a reliability of 2. If it was obscured by cloud, or if the photograph was grainy, or if the coast was in the background of the photograph, it was assigned a reliability of 3. Often a coastline was positioned by using a combination of oblique aerial photographs from different directions or in conjunction with vertical aerial photographs, and in these cases it was possible to give a reliability of 1 or 2.

Maps and Publications

Many paper maps and publications dating back to 1948 show or describe the icebound coast (see table 3 and References Cited). Although some of the early sources of data are too inaccurate to meet the scientific objectives of this project, the coastlines revealed on these historical maps and charts give a qualitative idea of the approximate position of the ice front. We were able to determine the position of the ice front on some maps when they were used in conjunction with aerial photographs. Other maps were published at a large enough scale (for example, 1:100,000) to make them usable, and they were assigned a reliability of 3.

RADARSAT Images

Individual RADARSAT images having a pixel resolution of 25 m were used for the project. Because of geodetic position errors and layover problems associated with the high-relief terrain of the Antarctic Peninsula, the coastline digitized from these images had an offset of features ranging from 500 m to 3 kilometers (km) when compared to the IfAG mosaic. Where possible, the RADARSAT coastline was corrected using the more reliable areas of rock coastline, allowing some areas of ice shelf and outlet-glacier fronts to be included in the dataset with a reliability of 2 or 3.

Coastline Accuracies

Reliability 1 (within 60 m, or 2 pixels on IfAG image mosaic)

Accurately digitized from:

- Vertical aerial photographs that have adequate rock-outcrop features for positioning.
- Landsat TM and Landsat 7 ETM+ digital satellite images (good-quality georeferenced imagery).

Reliability 2 (within 150 m, or 5 pixels on IfAG image mosaic)

Interpreted from:

- Vertical aerial photographs that are grainy or in which the coastline is slightly obscured by cloud.
- Near-oblique aerial photographs in which the ice coastline is clearly visible and is in the foreground, and adequate fixed features are visible.
- Photographs (enlarged to 1:500,000 scale) of Landsat MSS and TM images interpreted on a digitizing table.
- Digital RADARSAT images registered to the IfAG mosaic.

Reliability 3 (within 300 m, or 10 pixels on IfAG image mosaic)

Interpreted from:

- Vertical or oblique aerial photographs in which few or no reference features are visible.
- Oblique aerial photographs in which the coastline is in the distance or is poorly visible.
- Satellite images in which some features are poorly georeferenced but still show useful coastline data.
- Non-georeferenced large-scale maps, and sketch maps.

Geographic Description and Glaciological Features

The Palmer Land area map covers most of the Palmer Land part of the Antarctic Peninsula, except for small sections just to the north (see map I–2600–B, Larsen Ice Shelf area, Ferrigno and others, 2008) and south (see map I–2600–D, Ronne Ice Shelf area, Ferrigno and others, 2005). The map also includes a small part of Ellsworth Land as well as adjacent islands, including Alexander Island. The map covers the area between lat 70° and 74° S., and between long 57° and 80° W., but also extends northward on the western side to 68°S., an area already delineated and described on the Larsen Ice Shelf area map (I–2600–B), in order to include Rothschild Island and the northern ends of Charcot and Alexander Islands, and to include the retreat of the northern part of George VI and Wilkins Ice Shelves. Palmer Land is named for Capt. Nathaniel B. Palmer, American sealer and native of Stonington, Conn., who was the first American to visit the Antarctic Peninsula. He sailed southward from Deception Island in November 1820 in his 14-m sloop, the *Hero*.

The map includes Wilkins, Black, and Lassiter Coasts on the east, and Fallières, Rymill, and English Coasts on the west. All land except for small areas of exposed rock is covered by glacier ice and permanent snow. The most noticeable glaciological features in the map area are the numerous large and small ice shelves. Some of the ice shelves have experienced substantial retreat during the time period represented by the map. The large ice shelves are on the western side of the Antarctic Peninsula and include George VI, Wilkins, Stange, and Bach Ice Shelves. The coastline of the eastern side of the Antarctic Peninsula is composed mainly of narrow ice shelf, mostly part of the southern Larsen Ice Shelf that is informally called Larsen “C” (Vaughan and Doake, 1996). This ice shelf is formed by the ice from many glaciers flowing out through numerous inlets. It is pinned on the seaward side to Dolleman, Steele, and Butler Islands and to Tharp Ice Rise. In addition to the floating ice shelf, the coastline is made up of a few grounded ice walls such as the eastern edge of Kemp Peninsula.

Glacier Inventory

Producing a sophisticated glacier inventory of the entire continent of Antarctica according to the requirements of the World Glacier Monitoring Service (Müller and others, 1977, 1978), as part of its ongoing “World Glacier Inventory” program, has been impossible with the present state of glaciological knowledge about Antarctica (Swithinbank, 1980). As recently as 2008, the World Glacier Inventory Web site hosted by the National Snow and Ice Data Center (NSIDC) did not include Antarctic data. However, as more remotely sensed data become available and as more scientific interest is focused on Antarctica, more glacier inventories will be developed, especially for localized areas. The first glacier inventory carried out in Antarctica using the methodology of the World Glacier Inventory was done on the northern end of the Antarctic Peninsula on James Ross Island by Rabassa and others (1982). Braun and others (2001) proposed a geographic information system (GIS)-based glacier inventory for the Antarctic Peninsula as part of the Global Land Ice Measurements from Space (GLIMS) Project (Kieffer and others, 2000), and Rau and others (2004) carried out a thorough GIS inventory of 900 individual glaciers and glaciological features in the northern part of the Antarctic Peninsula.

Because of the glaciological complexity and the large number of unnamed and unidentified glaciers on the islands and mainland of the Antarctic Peninsula, we have not attempted to compile a comprehensive glacier inventory of the entire peninsula. Instead, we have used satellite images, aerial photographs, available maps, and historical records to focus on and document coastal change. From published maps, the Geographic Names of the Antarctic (Alberts, 1995), the USGS Geographic Names Information System (GNIS) database for Antarctica (http://geonames.usgs.gov/antarctic/index.html), and the SCAR Composite Gazetteer of Antarctica (http://data.aad.gov.au/aadc/gaz/scar/), we compiled a list of named glaciers and related glaciological features within the Palmer Land area map.

There are 153 named glaciers and related glaciological features on the map as defined in various scientific glossaries (Armstrong and others, 1973, 1977; Neuendorf and others, 2005) (table 4). The named features include ice streams, outlet, valley, and cirque glaciers, ice shelves, ice piedmonts, ice rises, and snowfields. They are distributed as follows: 82 on Alexander and Rothschild Islands, 25 on Black Coast, 6 on English Coast, 2 on Fallières Coast, 10 on Lassiter Coast, 18 on Rymill Coast, and 8 on Wilkins Coast, and two ice shelves that extend along more than one coast. George VI Ice Shelf, east and south of Alexander Island, is part of both English and Rymill Coasts; and Larsen Ice Shelf, extending along the eastern part of the Antarctic Peninsula as far south as Cape Mackintosh, is part of both Black and Wilkins Coasts on this map (table 4). Of the 153 named glaciological features, 38 are on the western part of the map between lat 68º and 70º S. and are shown and discussed on the Larsen Ice Shelf area map (I–2600–B), and one, Waverly Glacier, is better shown on the Ronne Ice Shelf area map (I–2600–D) to the south. Changes in some of the remaining 114 glaciological features located on the part of the Palmer Land area map between lat 70º and 74º S. are discussed below.

Analysis

Methodology for Coastal-Change Analysis

As would be expected, the ice fronts, iceberg tongues, and glacier tongues are the most dynamic and changeable features in the coastal regions of Antarctica. On this particular map, most of the changing ice fronts are the floating seaward margins of ice shelves. The positions of the dynamic ice fronts as observed on the three sets of Landsat imagery, on the aerial photographs, on other satellite imagery, and on historical data sources, were mapped and annotated with the date for each position. This made it possible to accurately date and analyze changes that have occurred. The drawback of this methodology, regardless of the number of data sources used, is that the observations are "snapshots" in time, providing variable time-lapse intervals to document change. We are able to determine trends of coastal change, but we have not necessarily seen the maximum advance or retreat, and changes that occur between observations may be missed.

Excluding measurements made north of lat 70º S. that are discussed in the pamphlet accompanying the Larsen Ice Shelf area map (I–2600–B), coastal-change measurements were made at 29 locations on the changing ice fronts of this map. Eight of these locations are named features and are identified in table 4; the remaining 21 of these locations are unnamed ice fronts or parts of larger features that are described by nearby geographic features and given a latitude/longitude identifier, and they are listed in table 5. The measurements along the larger ice shelves—George VI, Wilkins, Stange, and especially Larsen "C"—have been divided into separate sections because of the shelves' length and coastal geometry. The separate sections are identified on the map and in this pamphlet. A total of 1,811 individual measurements of ice-front location using all source data were made at the 29 locations. Sample lines—imaginary lines extending from the ice front to an established base line—were drawn normal to the trend of the ice fronts at each of the 29 ice-front locations to measure advance and retreat. The number of sample lines drawn through each ice front varied according to the nature of the front. For wide areas of glacier-ice coast or large ice shelves, the sample lines were typically spaced at 1-km or larger intervals, whereas for small, narrow ice fronts the sample-line spacing was much closer. The lines were drawn to reflect a true sample of the way in which the terminus of each ice front changed between observations (fig. 2).

The final results show all of the attributes of the coastlines for each sample line within each glacier. The distance from each ice front to land was calculated, as was the maximum, minimum, and average advance or retreat between each observation. The number of months for each time period was determined and the change per year in meters was calculated.

Discussion of Observed Coastal Changes

After the coastal changes were digitally mapped, it became evident that the magnitude of the change on an annual to decadal basis is often not discernible at 1:1,000,000 scale, the scale of the printed map. We selected coastal-change information to show on the printed map that is of high interest and that is visible at the map scale. The entire set of mapped changes is included in a digital dataset available at the SCAR ADD Web site hosted by BAS at http://www.add.scar.org:8080/add/

The most noticeable and dramatic changes that can be seen on the Palmer Land area map are the retreat of the George VI, Wilkins, Bach, and northern Stange Ice Shelves. A discussion of changes on each of these four ice shelves follows.

George VI Ice Shelf

George VI Ice Shelf is located between Alexander Island and the English and Rymill Coasts of the Antarctic Peninsula. The ice shelf was first sighted and photographed by Lincoln Ellsworth in 1935. It was named for George VI, King of

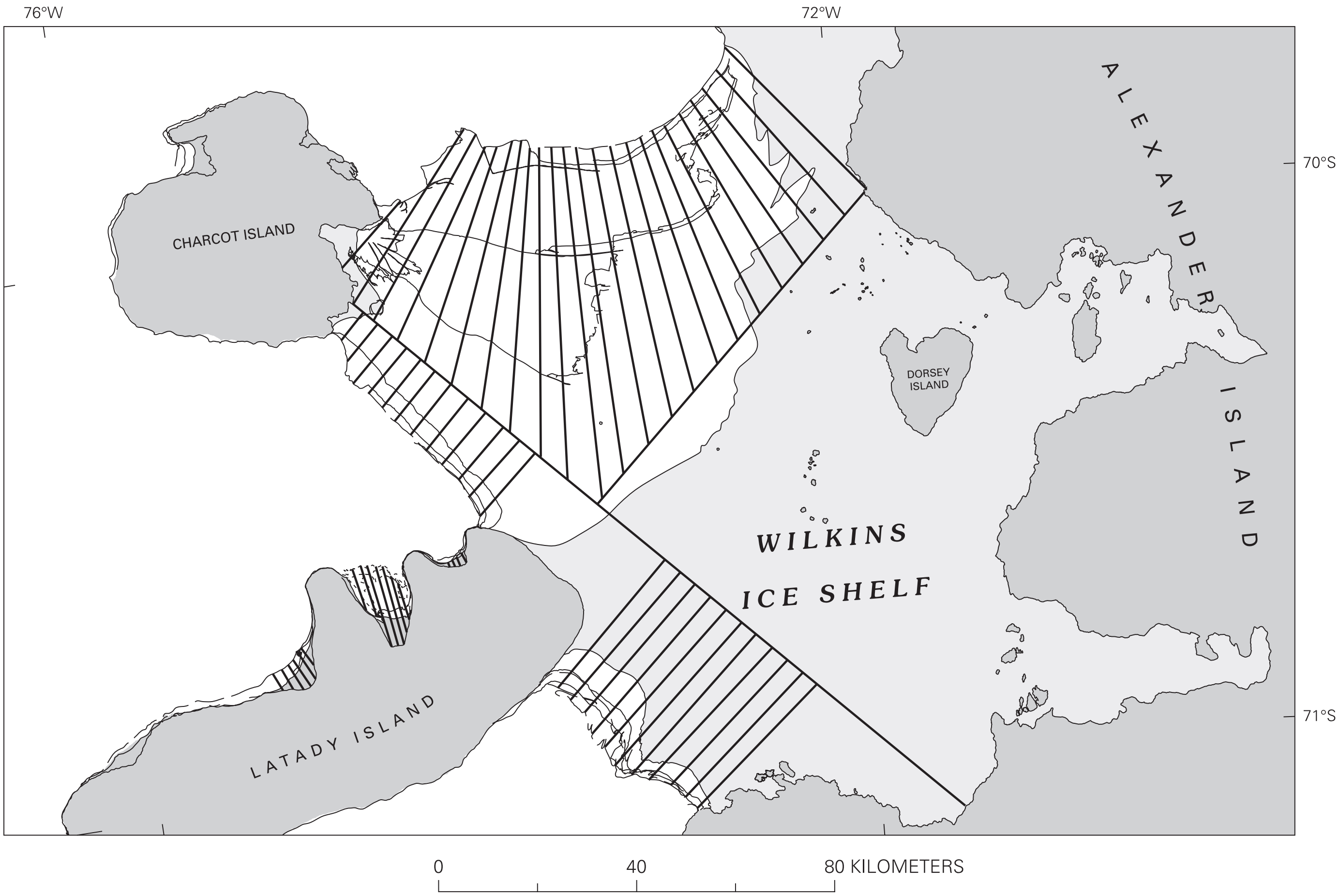

Figure 2. Sketch map of sample lines drawn for analysis of ice-front change in the Wilkins Ice Shelf region of the Antarctic Peninsula.

England from 1936 to 1952. It is more than 400 km long, and the width ranges from 20 to about 75 km. Its area is about 25,000 km^2. The ice shelf has two ice fronts, which can be seen on the map. The northern ice front is almost 25 km long, and the southern ice front, interrupted by DeAtley Island, is more than 90 km long. We used data from 1947 to 2001 to map changes in the ice fronts (tables 6*A*, *B*). The northern ice front of George VI Ice Shelf is sometimes difficult to discern because the narrow George VI Sound is often choked with fragmented shelf, glacier, and fast ice. The northern ice front was at its farthest extent during our period of observation between 1966 and 1974. It retreated 20 to 30 km, losing 906 km^2 between 1974 and 1992, according to Lucchitta and Rosanova (1998). From our data (table 6), most of the retreat occurred between 1974 and 1979, with some additional retreat between 1979 and 1989, and a small amount of further retreat between 1989 and 1992. The ice front retreated 6 km more on the eastern side, losing 87 km^2 between 1992 and 1995 (Lucchitta and Rosanova, 1998). After 1995, it retreated an additional 1 to more than 6 km to its most recent position on this map by 2001.

The southern George VI ice front retreated considerably from 1947 to the late 1960s on the main ice front (southern front “a”, located between Monteverdi Peninsula and DeAtley Island; see map and table 6*A*). From the late 1960s to 1973, there was additional substantial retreat, the greatest during the period of measurements, on both the main ice front and the smaller ice front (southern front “b”, located between DeAtley Island and Spaatz Island; see map and table 6*A*). From 1973 to 2001, the southern ice front “a” fluctuated with overall noticeable retreat of the southern part. Southern front “b” retreated from 1973 to 1986, advanced from 1986 to 1989, then consistently retreated to 2001.

Wilkins Ice Shelf

Wilkins Ice Shelf is located between the western coast of Alexander Island and the coastlines of Rothschild, Charcot, and Latady Islands, and the Eroica Peninsula. It was named for Sir Hubert Wilkins, Australian polar explorer and pioneer air photographer who observed the area from an airplane in 1929. The ice shelf has several visible named and unnamed ice rises; digital processing of satellite imagery makes it possible to see and analyze surface features. According to Vaughan and others (1993), who did a synthesis of remote sensing data of the ice shelf, the shelf covered an area of 16,000 km^2 in the early 1990s and had a grounded catchment area of about

16,900 km^2. The main ice source is Lewis Snowfield. However, because of the small proportion of catchment area to ice shelf area, Vaughan and others (1993) concluded that the ice shelf is sustained mainly by accumulation of snow on the ice shelf itself.

Limited field work has been done on Wilkins Ice Shelf. One field measurement of surface velocity made in the central part of the ice shelf in the early 1970s yielded 59 m/yr (m a^{-1}), with flow in a northerly direction (Vaughan and others, 1993). Vaughan and others (1993) attempted to determine surface velocity by measuring displacement of surface features, but had limited success. Their velocities were in the range of 30 to 90 m a^{-1}. They concluded that the low surface velocities and lack of dynamic glaciers feeding the ice shelf may cause it to respond to climate change differently than do some of the other ice shelves on the Antarctic Peninsula.

Until recently, Wilkins Ice Shelf had four ice fronts. They consisted of one short ice front between Alexander Island and Rothschild Island and three longer ice fronts, (1) between Rothschild Island and Charcot Island (~ 80 km) (here called Wilkins “a” for easier description), (2) between Charcot Island and Latady Island (~50 km) (Wilkins “b”), and (3) between Latady Island and the Eroica Peninsula (more than 40 km) (Wilkins “c”). All ice fronts experienced overall retreat during the time period of our study, but Wilkins “a” and “b” have had the most dramatic retreat.

Our data sources for mapping the retreat of Wilkins “a” ice front include aerial photography from 1947, 1966, and 1968, satellite imagery from 1975, 1990, 1997, 2001, and 2002 (tables 7*A*, *B*), and 2008 and 2009 Envisat Advanced Synthetic Aperture Radar (ASAR) images. They show an essentially stable ice front from 1947 to the later 1960s, at least on the eastern part of the ice shelf where data from the 1960s are available. From the 1960s to 1975, the change appears to be on average a slight advance in the eastern quarter and some retreat ranging from 350 m to 2.5 km in the next quarter of the ice shelf. From 1975 to 1997, the entire ice front retreated. The retreat is particularly noticeable on the western two-thirds of the ice front, averaging from 2 to 3 km a^{-1}. From 1997 to the early 2000s, there was some slight advance on some parts of the eastern half of the ice front, but the western half continued to retreat rapidly, as much as 6 km a^{-1}. Comparison of these measurements of change with the studies by Vaughan and others (1993) and Lucchitta and Rosanova (1998) and with the 1998 Advanced Very High Resolution Radiometer (AVHRR) images from NSIDC (1999), makes it possible to determine more closely the time period when change occurred. According to Vaughan and others (1993), the ice front remained stable during the 1970s and 1980s on the basis of satellite data from 1973, 1986, and 1990. Lucchitta and Rosanova (1998) compared Landsat MSS data from 1974 with European Remote Sensing (ERS) satellite data from July 1992 and October 1995. They noticed retreat of the eastern part of Wilkins “a” ice front of about 10 km from 1974 to 1992 and another 8 to 10 km from 1992 to 1995. Combining their measurements with those from our study reveals that Wilkins “a” ice front retreated 0.7 to 1.7 km from 1975 to 1990, 8 to 9 km from 1990 to 1992, 8 to 10 km from 1992 to 1995, and as much as 15 km from 1995 to 1997. In 1998, AVHRR images showed a large breakup of the western Wilkins Sound part of the ice shelf estimated to be 1,100 km^2 (NSIDC, 1999). It was the largest single retreat event up to that time. Inspection of a 2007 Moderate Resolution Imaging Spectroradiometer (MODIS) image (http://nsidc.org/data/iceshelves_images/wilkins.html) showed there was minor calving from Wilkins “a” between 1998 and 2007, but no major events. In 2008 several large breakoffs occurred totaling about 2,000 km^2, and in early April 2009 the ice bridge collapsed that had stabilized the ice shelf, connecting it to Charcot Island on the northwest and to Latady Island on the southwest. As a result about 330 km^2 of ice was lost. Following that, large pieces of the ice shelf fractured from the north and west sides, causing the loss of an additional area of about 700 km^2. These dramatic events cast doubt on the future of Wilkins Ice Shelf.

Prior to 2009, Wilkins “b” ice front showed a consistent trend toward retreat (see map and tables 7*A*, *B*). Our data sources for the northernmost part of Wilkins “b” ice front include only satellite data from 1990, 1997, 2000, and 2002. Farther south, Wilkins “b” has these sources as well as aerial photography from 1947 and satellite data from 1986. Both northern and southern Wilkins “b” show the same trend where there is coverage of both areas, so it is possible that northernmost Wilkins “b” responded similarly to southern Wilkins “b” in 1947 and 1986. From 1947 to 1986, southern Wilkins “b” was fairly stable, with only a slight amount of retreat. By 1990, southern Wilkins “b” exhibited an increased rate of retreat (table 7*A*). Retreat continued until 1997, then the rate of retreat increased from 1997 to 2000 and increased considerably more from 2000 to 2002 (the period of fastest retreat), with some measurements showing a retreat of more than 1.5 km a^{-1}. The retreat of both Wilkins “a” and Wilkins “b” ice fronts from 2002 to 2009 left only a narrow strip of ice pinning the shelf to Charcot Island. When the ice bridge fractured in 2009, Wilkins “b” ice front disappeared. Considering that the flow of the ice shelf is in a northerly direction (Vaughan and others, 1993), there is little recharge of ice to this area, leaving it very unlikely that the ice shelf will recover.

One of the side effects of the retreat of Wilkins Ice Shelf is the loss of Burgess Ice Rise, which was in the part of the ice shelf that was lost between 2002 and 2009.

Wilkins “c” ice front has had a slightly more complex history. Although the overall trend has been retreat, there have been periods of advance (table 7*A*). The data sources for Wilkins “c” ice front are aerial photography from 1947 and 1968, and satellite data from 1973, 1986, 1989, 1990, 1997, and 2000 (table 7*B*). From 1947 to 1968, there was advance along most of the ice front. From 1968 to 1973, there was retreat of the northern part of Wilkins “c” and advance of the southern part. From 1973 to 1986, the ice front retreated, and from 1986 to 1989 nearly the entire ice front advanced. It is noteworthy that during the periods of advance, the average advance (table 7*A*) was greater than the measured velocity of Wilkins Ice Shelf (Vaughan and Doake, 1996); the measurements showed "surge" characteristics. From 1989 to 1990, the ice front showed substantial retreat of as much as 3.6 km a^{-1}. That time interval was the time interval of greatest average retreat for Wilkins "c". From 1990 to 1997, and from 1997 to 2000, retreat continued, averaging 200 to 800 m a^{-1}.

Bach Ice Shelf

Bach Ice Shelf, located between Beethoven and Monteverdi Peninsulas, is smaller than Wilkins Ice Shelf and located farther south. It has one approximately 40-km-long ice front that trends northwest-southeast. The data sources we used to map coastal change of the ice front are December 1947 RARE (Ronne Antarctic Research Expedition) and December 1968 TMA (Trimetrogon Antarctica (USA)) aerial photography, and the following satellite imagery: January 1973 Landsat 1 MSS, February 1986 Landsat 5 TM, January 1989 Landsat 4 TM, October 1997 RADARSAT, and December 2001 Landsat 7 ETM+. During the period of observation, the ice front maintained a fairly consistent profile; it advanced or retreated at the same time along the entire ice front. From 1947 to 1968, the ice front retreated a maximum of 7 km, with an annual average ranging from 13 to 335 m a^{-1}. From 1968 to 1973, there was considerable advance, with a maximum of more than 5 km and annual average ranging from 395 to almost 1600 m a^{-1}. From 1973 to 1986, the ice front retreated about 5 km, with an annual average ranging between 161 and 400 m a^{-1}. The period from 1986 to 1989 was one of moderate advance, of 54 to 128 m a^{-1}. From 1989 to 1997 and from 1997 to 2001 the trend returned to retreat, with a maximum of 4 km, but typically averaging from 100 to almost 500 m a^{-1}. The overall trend of Bach Ice Shelf, shown on the map, is retreat.

Stange Ice Shelf

Stange Ice Shelf, in the southwest corner of the map area, is an irregularly shaped ice shelf bounded on the east by Spaatz Island and on the west by Smyley and Case Islands. The data sources covering Stange Ice Shelf include December 1947 RARE aerial photography, a 1968 USGS Bryan Coast–Ellsworth Land 1:500,000-scale Antarctica Sketch Map based on 1965–66 TMA photography, and December 1968 TMA aerial photography. Also used were January 1973 Landsat 1 MSS, February 1986 Landsat 5 TM, January and December 1989 Landsat 4 TM, October 1997 RADARSAT, and January 2001 Landsat 7 ETM+ satellite imagery. Because of the irregular shape of the ice shelf, coastal change was measured in four sections: "a", the northern ice front, between Smyley and Spaatz Islands; and "b", "c", and "d", the sections of the southern ice front, between Smyley Island and Case Island, measured in a clockwise direction. The ice front between Case Island and the Rydberg Peninsula is associated with Berg Ice Stream.

During the period of observation, it is apparent from the map that the 1947, 1965–66, 1973, and 1986 ice fronts were more advanced, and the 1997 and 2001 ice fronts were more in retreat. The earlier data are geographically less accurate, and it is difficult to analyze them quantitatively. However, the 1986, 1989, 1997, and 2001 satellite images are more accurate, and it is possible to measure change during that time period. On the northern Stange ice front ("a"), there was overall advance from 1986 to 1989, then retreat from 1989 to 1997 and from 1997 to 2001; the net result was retreat. On the Stange "b" ice front, there was overall advance from 1986 to 1989, retreat from 1989 to 1997, and mixed advance and retreat from 1997 to 2001, with the 2001 ice front in much the same place as the 1986 ice front. On the Stange "c" ice front, there was overall advance from 1986 to 1989, overall retreat from 1989 to 1997, and advance from 1997 to 2001, but the final result was overall retreat. The Stange "d" ice front retreated from 1986 to 1989, and advanced from 1989 to 1997 and from 1997 to 2001, with little net change. In summary, while Stange Ice Shelf fluctuated during the period of observation and showed retreat on the northern front, the southern fronts changed little, and none of the changes was dramatic.

Larsen Ice Shelf

An approximately 325-km length of Larsen "C" Ice Shelf is shown on the eastern part of this map from the northern boundary of the map to Cape Mackintosh, the southern limit of Larsen Ice Shelf. We mapped the changes of this ice front using November and December 1947 RARE aerial photography and January and December 1966 TMA aerial photography, and the following satellite imagery: November 1975 Landsat 1 MSS and December 1978 Landsat 3 MSS; February 1986, January 1988, March 1988, January 1989, and March 1989 Landsat 4 TM; February 1988 and March 1997 Landsat 5 TM; October 1997 RADARSAT; and February 2000, March 2000, and February 2001 Landsat 7 ETM+. The individual data sources cover different parts of the ice front.

Because of the length of the ice front, it has been separated into sections to simplify measurement. The segment from the northern boundary of the map to Dolleman Island is informally called Larsen "C1"; from Dolleman Island to Steele Island, "C2"; from Steele Island to Butler Island, "C3"; and from Butler Island to Cape Mackintosh, "C4". Although Cape Mackintosh is actually the southern end of Larsen "C" Ice Shelf, the area east of New Bedford Inlet is referred to as "C5", and the area between Lamb Point and Cape Wheeler as "C6". The digital measurements are identified by these informal names in the digital database at http://www.add.scar.org:8080/add/. Contrary to the history of Larsen Ice Shelf farther north on the Antarctic Peninsula as portrayed on the coastal-change maps of the Trinity Peninsula area (I–2600–A) and Larsen Ice Shelf area (I–2600–B), the component of the Larsen Ice Shelf shown on this map has changed very little. There have been some small fluctuations of the ice front, and it has advanced somewhat in the southern part of the map area, but there have been no dramatic changes, probably due both to the ice shelf's southern latitude and to the fact that it is well pinned.

Other Ice Fronts

All other named and unnamed ice fronts on the map have retreated overall during the period of observation except for the front of Berg Ice Stream, located on the western English Coast. The front of Berg Ice Stream fluctuated moderately from 1966 to 1997. From 1997 to 2001, the tongue of the ice stream partially separated and rotated, possibly due to a minor surge.

Coastal Change in the Palmer Land Area Compared to the Entire Antarctic Peninsula

The overall trend of the changing ice fronts in the Palmer Land area has been retreat, as has been the trend on the entire Antarctic Peninsula. This may be seen on the Trinity Peninsula area map (I–2600–A), the Larsen Ice Shelf area map (I–2600–B), and this map. The more dramatic ice-shelf breakups were noticed first in the northern part of the Antarctic Peninsula, with the breakup of Larsen "A" and "B" Ice Shelves, but substantial retreat also has been ongoing in the more southerly parts of the Antarctic Peninsula for several decades.

The retreat of ice shelves, a possible precursor to the deglaciation of West Antarctica predicted by Mercer (1978), has been tied to the significant and consistent warming trend of the peninsula area, documented by King (1994) and others. According to a review by Vaughan and others (2003), the Antarctic Peninsula warming rate of 3.7±1.6°C per century is an order of magnitude larger than the global mean warming rate of 0.6±0.2°C. Many researchers have observed, described, monitored, and analyzed the ongoing changes in the Antarctic Peninsula using field work, a large variety of remotely sensed data, and mathematical modeling, and have discussed the probable mechanics of the retreat. Most research has focused on the dramatic changes of the larger ice shelves and their tributary glaciers, but substantial change has been occurring in many smaller ice fronts of the Antarctic Peninsula. Although the changes occurring on the eastern side of the peninsula are more dramatic and more noticeable, the changes occurring on the western side are equally important and also have the potential of affecting the mass balance of the entire Antarctic Peninsula. Beginning with Doake and Vaughan's (1991) study of the retreat of Wordie Ice Shelf, the overall peninsula area has been well studied by Hindmarsh (1996), Vaughan and Doake (1996), Hulbe (1997), Rott and others (1998), Skvarca and others (1998, 1999), Scambos and others (2000, 2003, 2004), Domack and others (2001, 2005), Vaughan and others (2001, 2003), Fahnestock and others (2002), Morris and Vaughan (2003), Skvarca and De Angelis (2003), Rignot and others (2004a), Cook and others (2005), Ferrigno and others (2006), and Smith and others (2007), among others. Other regional studies can be found cited on the other Antarctic Peninsula maps (I–2600–A, –B).

Retreat During the Holocene

There has been considerable discussion of the stability of the ice shelves of the Antarctic Peninsula in the past as well as in the present. While it has been shown that Larsen "B" Ice Shelf was stable throughout the Holocene (Domack and others, 2001, 2005) prior to its collapse in 2002, it seems that other ice shelves, including George VI Ice Shelf, have responded to changing climatic conditions by retreating. Pudsey and Evans (2001) described a mid-Holocene retreat of Prince Gustav Ice Shelf. Bentley and others (2005), dating sediments in Moutonnée Lake on George VI Ice Shelf, showed the ice shelf was absent about 9,500 years ago but re-formed about 1,500 years later. Work by many scientists since the 1980s on the effect of basal melting on ice-shelf stability has indicated that, in addition to atmospheric warming, basal melting from warm waters intruding on the continental shelf has likely influenced the retreat of George VI, Larsen "A", and Prince Gustav Ice Shelves (Hodgson and others, 2006; Jenkins and Jacobs, 2008; and Smith and others, 2007) and will likely affect their future stability. Change on the Antarctic ice shelves and ice fronts may be due to incursions of warm water, changes in atmospheric temperature, differences in the accumulation rate, or combinations of these factors, and must be interpreted with caution.

Summary

The analysis of aerial photography (1947–92), Landsat 1, 2, and 3 MSS images (1972–79), Landsat 4 and 5 MSS and TM images (1984–91), Landsat 7 ETM+ images (2000–2002), and other satellite imagery and historical data of the Palmer Land area made it possible to identify and describe glaciological features, document coastal change, and look for trends in the changing cryospheric coastline. The analysis resulted in this map and a digital database and was a cooperative endeavor between the USGS and BAS.

The Palmer Land area map covers the part of the Antarctic Peninsula that extends from lat 70° to 74° S., and from long 57° to 80° W.; the western part of the map extends north to 68° S., to include northern Alexander Island and northern Charcot Island. All land except for small areas of exposed rock is covered by glacier ice and permanent snow. The main glaciological features in the map area are the large and small ice shelves. On the eastern side of the Antarctic Peninsula is the southern part of Larsen Ice Shelf. The western side of the Antarctic Peninsula has the large George VI, Wilkins, Bach, and Stange Ice Shelves as well as several smaller shelves. There are 153 named glaciological features: 71 on the mainland, and 82 on Alexander and Rothschild Islands. In addition, there are 40 unnamed glaciers and ice fronts where coastal change was measured; 19 of these are shown and discussed on the Larsen Ice Shelf area map (I–2600–B).

The most noticeable and dramatic changes that can be seen on the Palmer Land area map are the retreat of George VI, Wilkins, Bach, and northern Stange Ice Shelves. The northern ice front of George VI Ice Shelf was at its farthest extent during our period of observation between 1966 and 1974. It retreated, losing 906 km^2 between 1974 and 1992 and 87 km^2 between 1992 and 1995. After 1995, it retreated an additional 1 km to more than 6 km by 2001. The southern George VI ice front retreated considerably from 1947 to the late 1960s. From the late 1960s to 1973, there was additional substantial retreat, the greatest during the period of measurements. From 1973 to 2001, there was overall noticeable retreat.

Wilkins Ice Shelf had four ice fronts up till 2009; all retreated during the time period of our study, but Wilkins "a" and "b" have had the most dramatic change, including extensive calving in 2009 that eliminated ice front "b" and threatened the future of the ice shelf. During the period of observation, the Bach Ice Shelf front maintained a fairly consistent profile, and advanced or retreated at the same time along the entire ice front. The overall trend of Bach Ice Shelf is retreat. On the northern Stange Ice Shelf during the period of observation, the 1947, 1965–66, 1973, and 1986 ice fronts were more advanced, and the 1997 and 2001 ice fronts were more in retreat. However, the earlier data are less accurate geographically, and it is difficult to quantitatively analyze them. The later satellite images are more accurate, and it is possible to measure overall advance from 1986 to 1989, then retreat from 1989 to 1997 and from1997 to 2001; the net result was retreat.

The three coastal-change and glaciological maps of the Antarctic Peninsula (I–2600–A, –B, and –C) portray one of the most rapidly changing areas on Earth. The changes exhibited in the region are widely regarded as among the most profound and unambiguous examples of the effects of global warming yet seen on the planet.

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Appendix—Tables 3, 4, 5, 6*A*, 6*B*, 7*A*, and 7*B*

Table 3. Maps used as source materials for the coastal-change and glaciological map of the Palmer Land area.

[Abbreviations of areas covered: Black, Black Coast; Detroit, Detroit Plateau; Larsen_C, Larsen "C" Ice Shelf; Lassiter, Lassiter Coast; Marg_Bay, Marguerite Bay; SW_Alex, SW Alexander Island; Wilkins, Wilkins Coast. Other abbreviations: BAT, British Antarctic Territory; BGLE, British Graham Land Expedition 1934–37; DCS, Great Britain Directorate of Colonial Surveys; DOS, Great Britain Directorate of Overseas Surveys; FID, Great Britain Colonial Office, Falkland Islands (and) Dependencies; FIDS, Falkland Islands Dependencies Survey; RARE, Ronne Antarctic Research Expedition 1947–48; TMA, Trimetrogon Antarctica (USA); USAAF, United States Army Air Force; USGS, U.S. Geological Survey; Provis., provisional; Pub., published; Unpub., unpublished]

Areas covered	Pub./ unpub.	Publisher	Map date	Map series	Edition	Scale	BAS reference number	Map name and sheet	Comments
Larsen_C, Black	Pub.	DCS	1948	DCS 701	1st (Provis.)	1:500,000	PM/GB/02/C/01/D	FID – South Shetlands and Graham Land; Sheet D	Compiled from unpub. 1:200,000 FIDS surveys (1947); BGLE map (1938); Admiralty Chart no. 3175 (1940).
Detroit	Pub.	DCS	1949	DCS 701	1st (Provis.)	1:500,000	PM/GB/02/C/01/E	FID – South Shetlands and Graham Land; Sheet E	Compiled from Admiralty Chart no. 3175 (1940) and unpub. surveys by FIDS (1947).
Wilkins, SW_Alex, Marg_Bay	Pub.	DCS	1949	DCS 9	1st (Provis.)	1:500,000	PM/GB/02/C/01/F	FID – South Shetlands and Graham Land; Sheet F	Compiled from Admiralty Chart no. 3175 (1940) and BGLE unpub. maps (1934–37).
Wilkins, SW_Alex, Marg_Bay	Pub.	DCS	1950	DCS 701	1st (Provis.)	1:500,000	PM/GB/02/C/01/G	FID – South Shetlands and Graham Land; Sheet G	Compiled from Admiralty Chart no. 3175 (1940) and BGLE unpub. maps (1934–37).
Larsen_C	Pub.	DCS	1949	DCS 701	1st (Provis.)	1:500,000	PM/GB/02/C/01/H	FID – South Shetlands and Graham Land; Sheet H	Compiled from unpub. 1:200,000 surveys by FIDS (1947–48).
Wilkins, SW_Alex, Marg_Bay	Pub.	DCS	1948	DCS 9	1st (Provis.)	1:500,000	PM/GB/02/C/01/J	FID – South Shetlands and Graham Land; Sheet J	Compiled from U.S. Hydrographic Office Chart (1946); USAAF Chart (1943).
Wilkins, SW_Alex, Marg_Bay	Pub.	DCS	1948	DCS 9	1st (Provis.)	1:500,000	PM/GB/02/C/01/K	FID – South Shetlands and Graham Land; Sheet K	Compiled from U.S. Hydrographic Office Chart (1946); USAAF Chart (1943).
Lassiter	Pub.	DCS	1949	DCS 701	1st (Provis.)	1:500,000	PM/GB/02/C/01/L	FID – South Shetlands and Graham Land; Sheet L	Larsen ice front in Dec. 1947 – compiled from unpub. 1:200,000 surveys by FIDS.
Black	Pub.	DCS	1955	DCS 601	1st	1:200,000	PM/GB/02/D/01/7060	FID – Sheet 70 60; Dolleman Island	Joint FIDS and RARE party 1947–48.
Black	Pub.	DCS	1955	DCS 601	1st	1:200,000	PM/GB/02/D/01/7160	FID – Sheet 71 60; Steele Island	Joint FIDS and RARE party 1947–48.

Table 3. Maps used as source materials for the coastal-change and glaciological map of the Palmer Land area.—Continued

[Abbreviations of areas covered: Black, Black Coast; Detroit, Detroit Plateau; Larsen_C, Larsen "C" Ice Shelf; Lassiter, Lassiter Coast; Marg_Bay, Marguerite Bay; SW_Alex, SW Alexander Island; Wilkins, Wilkins Coast. Other abbreviations: BAT, British Antarctic Territory; BGLE, British Graham Land Expedition 1934–37; DCS, Great Britain Directorate of Colonial Surveys; DOS, Great Britain Directorate of Overseas Surveys; FID, Great Britain Colonial Office, Falkland Islands (and) Dependencies; FIDS, Falkland Islands Dependencies Survey; RARE, Ronne Antarctic Research Expedition 1947–48; TMA, Trimetrogon Antarctica (USA); USAAF, United States Army Air Force; USGS, U.S. Geological Survey; Provis., provisional; Pub., published; Unpub., unpublished]

Areas covered	Pub./ unpub.	Publisher	Map date	Map series	Edition	Scale	BAS reference number	Map name and sheet	Comments
Black	Pub.	DCS	1956	DCS 601	1st	1:200,000	PM/GB/02/ D/01/7260	FID – Sheet 72 60; Kemp Peninsula	Joint FIDS and RARE party 1947–48.
Lassiter	Pub.	DOS	1957	DOS 601	1st	1:200,000	PM/GB/02/ D/01/7360	FID – Sheet W 73 60; Kemp Peninsula – Cape Wheeler	Joint FIDS and RARE party 1947–48.
Lassiter	Pub.	DOS	1957	DOS 601	1st	1:200,000	PM/GB/02/ D/01/7460	FID – Sheet W 74 60; Smith Peninsula	Joint FIDS and RARE party 1947–48.
SW_Alex	Pub.	DOS	1957	DOS 601	1st	1:200,000	PM/GB/02/ D/01/7372	FID – Sheet W 73 72; Ronne Entrance	Compiled from surveys in 1948–50 and 1955.
SW_Alex, Marg_Bay	Pub.	DOS	1957	DOS 601	1st	1:200,000	PM/GB/02/ D/01/7370	FID – Sheet W 73 70; King George VI Sound	Compiled from surveys in 1948–50.
Wilkins	Pub.	DOS	1960	DOS 610 Series D501	2d	1:200,000	PM/GB/02/ D/01/7274 (2)	FID – Sheet W 72 74	Compiled from RARE aerial photography (1947–48).
SW_Alex	Pub.	DOS	1960	DOS 610 Series D501	2d	1:200,000	PM/GB/02/ D/01/7272 (2)	FID – Sheet W 72 72; Alexander Island	Compiled from RARE aerial photography (1947–48).
SW_Alex	Pub.	DOS	1960	DOS 610 Series D501	1st	1:200,000	PM/GB/02/ D/01/7172	FID – Sheet W 71 72; Alexander Island	Compiled from RARE aerial photography (1947–48).
SW_Alex	Pub.	DOS	1960	DOS 610 Series D501	1st	1:200,000	PM/GB/02/ D/01/7174	FID – Sheet W 71 74; Alexander Island	Compiled from RARE aerial photography (1947–48).

Table 3. Maps used as source materials for the coastal-change and glaciological map of the Palmer Land area.—Continued

[Abbreviations of areas covered: Black, Black Coast; Detroit, Detroit Plateau; Larsen_C, Larsen “C” Ice Shelf; Lassiter, Lassiter Coast; Marg_Bay, Marguerite Bay; SW_Alex, SW Alexander Island; Wilkins, Wilkins Coast. Other abbreviations: BAT, British Antarctic Territory; BGLE, British Graham Land Expedition 1934–37; DCS, Great Britain Directorate of Colonial Surveys; DOS, Great Britain Directorate of Overseas Surveys; FID, Great Britain Colonial Office, Falkland Islands (and) Dependencies; FIDS, Falkland Islands Dependencies Survey; RARE, Ronne Antarctic Research Expedition 1947–48; TMA, Trimetrogon Antarctica (USA); USAAF, United States Army Air Force; USGS, U.S. Geological Survey; Provis., provisional; Pub., published; Unpub., unpublished]

Areas covered	Pub./ unpub.	Publisher	Map date	Map series	Edition	Scale	BAS reference number	Map name and sheet	Comments
Wilkins, SW_Alex	Pub.	DOS	1960	DOS 610 Series D501	1st	1:200,000	PM/GB/02/ D/01/7272 (2)	FID – Sheet W 72 72; Alexander Island	Compiled from RARE aerial photography (1947–48).
Marg_Bay	Pub.	DOS	1963	DOS 610 Series D501	1st	1:200,000	PM/GB/02/ D/01/6968	BAT – Sheet W 69 68; Marg. Bay and George VI ice front	Compiled from RARE aerial photography (1947–48).
Larsen_C	Pub.	DOS	1976	BAS 250	1st	1:250,000	PM/GB/02/ D/06/ SR19-20/12	BAT – Sheet SR19-20/12; Palmer Land	Compiled using TMA aerial photography (1966).
Larsen_C	Pub.	DOS	1976	BAS 250	1st	1:250,000	PM/GB/02/ D/06/ SR19-20/16	BAT – Sheet SR19-20/16; Palmer Land	Compiled using TMA aerial photography (1966).
Wilkins, SW_Alex	Pub.	USGS – Dept. of Interior	1968	Antarctica Sketch Map		1:500,000	PM/US/02/ C/02	Bryan Coast – Ellsworth Land	Compiled from U.S. Navy Tricamera aerial photography (1965–66).
Lassiter	Pub.	USGS – Dept. of Interior	1969	Antarctica Sketch Map		1:500,000	PM/US/02/ C/02	Ellsworth Land (East Part) – Palmer Land (South Part)	Compiled from U.S. Navy Tricamera aerial photography (1966–69).
Larsen_C	Pub.	USGS – Dept. of Interior	1979	Antarctica Sketch Map		1:500,000	PM/US/02/ C/02	Palmer Land (North Part)	Compiled from U.S. Navy Tricamera aerial photography (1966–69).
SW_Alex	Unpub.		1985			1:236,000	K9603/1/ Pu25	Ronne Entrance East Part	U.K. Hydrographic chart (shows ice front of George VI Sound and Stange Sound in 1985).

Table 4. Inventory of named glaciers and glaciological features on the coastal-change and glaciological map of the Palmer Land area.

[Reference to Larsen map is to USGS Map I–2600–B (Ferrigno and others, 2008), and reference to Ronne map is to USGS Map I–2600–D (Ferrigno and others, 2005). All geographical names in this report have been approved by the U.S. Advisory Committee on Antarctic Names; this does not necessarily imply their acceptance by all Antarctic Treaty Contracting Parties.]

Geographic Place-name	Glaciological Description
Alexander and Rothschild Islands	
Alyabiev Glacier	outlet glacier
Arensky Glacier	outlet glacier
Asafiev Glacier	outlet glacier
Bach Ice Shelf	ice shelf
Balakirev Glacier	outlet glacier
Bartók Glacier (also on Larsen map)	valley glacier
Bishop Glacier (also on Larsen map)	outlet glacier
Bongrain Ice Piedmont (also on Larsen map)	ice piedmont
Brahms Ice Shelf	ice shelf
Britten Ice Shelf	ice shelf
Burgess Ice Rise	ice rise
Clarsach Glacier (also on Larsen map)	valley glacier
Coulter Glacier (also on Larsen map)	outlet glacier
Dargomyzhsky Glacier	outlet glacier
Delius Glacier (also on Larsen map)	valley glacier
Dvořák Ice Rise	ice rise
Eros Glacier	outlet glacier
Foreman Glacier (also on Larsen map)	valley glacier
Frachat Glacier (also on Larsen map)	outlet glacier
Geelan Ice Piedmont (also on Larsen map)	ice piedmont
Gerontius Glacier (also on Larsen map)	valley glacier
Gilbert Glacier (also on Larsen map)	glacier
Glazunov Glacier	ice stream
Grotto Glacier	outlet glacier
Hampton Glacier (also on Larsen map)	outlet glacier
Handel Ice Piedmont	ice piedmont
Holoviak Glacier	outlet glacier
Hushen Glacier	outlet glacier
Ives Ice Rise	ice rise
Jupiter Glacier	outlet glacier
Landy Ice Rises	ice rise
Lennon Glacier (also on Larsen map)	outlet glacier
Lewis Snowfield	snowfield
Liadov Glacier	outlet glacier
Mars Glacier	outlet glacier
Martin Ice Rise	ice rise
McManus Glacier (also on Larsen map)	valley glacier
Alexander and Rothschild Islands—Continued	
Mendelssohn Ice Shelf	ice shelf
Mercury Glacier	outlet glacier
Mikado Glacier (also on Larsen map)	valley glacier
Milky Way	ice valley
Moran Glacier (also on Larsen map)	outlet glacier
Mozart Ice Piedmont (also on Larsen map)	ice piedmont
Neptune Glacier	outlet glacier
Nichols Snowfield (also on Larsen map)	snowfield
Palestrina Glacier (also on Larsen map)	outlet glacier
Paulus Glacier (also on Larsen map)	valley glacier
Petrie Ice Rises	ice rise
Pluto Glacier	outlet glacier
Purcell Snowfield	snowfield
The Quadrangle	cirque glacier
Rachmaninoff Glacier	ice stream
Rameau Ice Shelf	ice shelf
Reuning Glacier	outlet glacier
Roberts Ice Piedmont (also on Larsen map)	ice piedmont
Rosselin Glacier (also on Larsen map)	valley glacier
Rubble Glacier	outlet glacier
Satellite Snowfield	snowfield
Saturn Glacier	outlet glacier
Schaus Ice Rises	ice rise
Sedgwick Glacier (also on Larsen map)	outlet glacier
Sibelius Glacier (also on Larsen map)	glacier
Siegfried Glacier (also on Larsen map)	outlet glacier
Spartan Glacier	outlet glacier
Sullivan Glacier (also on Larsen map)	valley glacier
Toynbee Glacier (also on Larsen map)	outlet glacier
Transition Glacier	outlet glacier
Trench Glacier	outlet glacier
Trio Glacier	outlet glacier
Tumble Glacier (also on Larsen map)	outlet glacier
Uranus Glacier	outlet glacier
Utopia Glacier	outlet glacier
Varlamov Glacier	outlet glacier
Venus Glacier	outlet glacier

Table 4. Inventory of named glaciers and glaciological features on the coastal-change and glaciological map of the Palmer Land area.—Continued

[Reference to Larsen map is to USGS Map I–2600–B (Ferrigno and others, 2008), and reference to Ronne map is to USGS Map I–2600–D (Ferrigno and others, 2005). All geographical names in this report have been approved by the U.S. Advisory Committee on Antarctic Names; this does not necessarily imply their acceptance by all Antarctic Treaty Contracting Parties.]

Geographic Place-name	Glaciological Description
Alexander and Rothschild Islands—Continued	
Verdi Ice Shelf	ice shelf
Vere Ice Rise	ice rise
Vivaldi Glacier	outlet glacier
Wager Glacier (also on Larsen map)	outlet glacier
Wagner Ice Piedmont (also on Larsen map)	ice piedmont
Walter Glacier (also on Larsen map)	outlet glacier
Wilkins Ice Shelf	ice shelf
Wubbold Glacier (also on Larsen map)	outlet glacier
Black Coast	
Ashton Glacier	outlet glacier
Beaumont Glacier	outlet glacier
Böhnecke Glacier	outlet glacier
Cline Glacier	outlet glacier
Clowes Glacier	outlet glacier
Dana Glacier	outlet glacier
Defant Glacier	outlet glacier
Gain Glacier	outlet glacier
Gruening Glacier	outlet glacier
Guard Glacier	valley glacier
Haley Glacier	outlet glacier
Heezen Glacier	outlet glacier
Heirtzler Ice Piedmont	ice piedmont
Kauffman Glacier	outlet glacier
Kellogg Glacier	outlet glacier
Larsen Ice Shelf (also on Wilkins Coast)	ice shelf
Matheson Glacier	outlet glacier
Maury Glacier	outlet glacier
Murrish Glacier	outlet glacier
Muus Glacier	outlet glacier
Rankin Glacier	outlet glacier
Runcorn Glacier	outlet glacier
Soto Glacier	outlet glacier
Spiess Glacier	outlet glacier
Tharp Ice Rise	ice rise
Yates Glacier	outlet glacier

Geographic Place-name	Glaciological Description
English Coast	
Berg Ice Stream	ice stream
George VI Ice Shelf (also on Rymill Coast)	ice shelf
Hall Glacier	ice stream
Hill Glacier	outlet glacier
Lidke Ice Stream	ice stream
Nikitin Glacier	ice stream
Stange Ice Shelf	ice shelf
Fallières Coast	
Sirocco Glacier (also on Larsen map)	outlet glacier
Carlson Glacier (also on Larsen map)	outlet glacier
Lassiter Coast	
Bryan Glacier	outlet glacier
Douglas Glacier	outlet glacier
Fenton Glacier	outlet glacier
Haines Glacier	valley glacier
Meinardus Glacier	outlet glacier
Mosby Glacier	outlet glacier
Squires Glacier	valley glacier
Swann Glacier	valley glacier
Waverly Glacier (also on Ronne map)	outlet glacier
Wells Glacier	outlet glacier
George VI Sound (Rymill Coast)	
Armstrong Glacier	outlet glacier
Bertram Glacier	outlet glacier
Chapman Glacier	outlet glacier
Conchie Glacier	outlet glacier
Eureka Glacier (also on Larsen map)	ice stream
George VI Ice Shelf (also on English Coast)	ice shelf
Goodenough Glacier	ice stream
McArthur Glacier	outlet glacier
Meiklejohn Glacier	outlet glacier
Millett Glacier	outlet glacier
Naess Glacier	outlet glacier
Norman Glacier	outlet glacier
Riley Glacier	outlet glacier

Table 4. Inventory of named glaciers and glaciological features on the coastal-change and glaciological map of the Palmer Land area.—Continued

[Reference to Larsen map is to USGS Map I–2600–B (Ferrigno and others, 2008), and reference to Ronne map is to USGS Map I–2600–D (Ferrigno and others, 2005). All geographical names in this report have been approved by the U.S. Advisory Committee on Antarctic Names; this does not necessarily imply their acceptance by all Antarctic Treaty Contracting Parties.]

Geographic Place-name	Glaciological Description
George VI Sound (Rymill Coast)—Continued	
Ryder Glacier	outlet glacier
Skinner Glacier	outlet glacier
Warren Ice Piedmont (also on Larsen map)	ice piedmont
Willey Glacier	outlet glacier
Zephyr Glacier (also on Larsen map)	outlet glacier
Zonda Glacier (also on Larsen map)	outlet glacier
Wilkins Coast	
Clifford Glacier	outlet glacier
Wilkins Coast—Continued	
Croom Glacier	outlet glacier
Gurling Glacier	outlet glacier
Houston Glacier	outlet glacier
Hughes Ice Piedmont	ice piedmont
Kubitza Glacier	outlet glacier
Larsen Ice Shelf (also on Black Coast)	ice shelf
Richardson Glacier	outlet glacier
Shabica Glacier	outlet glacier

Table 5. Inventory of unnamed glaciers and ice fronts for which measurements of advance and retreat were made on the coastal-change and glaciological map of the Palmer Land area.

[Bold type for 21 unnamed ice fronts indicates that the ice front is located between lat 70° and 74° S. and is portrayed only on this map. The remaining unnamed locations are included on the Larsen Ice Shelf area map (USGS Map I–2600–B (Ferrigno and others, 2008) and are discussed there. Geographic descriptions are as given in the Excel table on the SCAR ADD Web site (http://www.add.scar.org:8080/add/)

(N.B. The glaciers and ice fronts listed in this table are not formally named. They are described by an adjacent geographic feature, and this description should not be considered an official geographic place-name.)

	Location and Geographic Location Code[1]	Geographic Description
	Alexander Island	
1.	AN76953S6917W	E. Mount King glacier
2.	AN76945S6920W	N. Marr Bluff glacier
3.	AN76942S6920W	S. Damocles Point glacier
4.	AN76936S6924W	N. Damocles Point glacier
5.	AN76928S6933W	E. Mount Spivey ice front
6.	AN76924S6938W	E. Mount Nicholas glacier
7.	AN76912S7005W	E. Mount Calais glacier
8.	AN76915S7204W	W. Havre Mountains “a” glacier
9.	AN76920S7158W	W. Havre Mountains “b” glacier
	Alexander Island – Beethoven Peninsula	
1.	***AN77202S7428W***	***Couperin Bay ice shelf***
2.	***AN77142S7515W***	***Pesce Peninsula ice shelf***
	George VI Sound (Rymill Coast)	
1.	AN76939S6826W	Rhyolite Islands ice shelf
2.	AN76947S6826W	Niznik Island ice shelf
	George VI Ice Shelf South	
1.	***AN77257S7218W***	***Ice front “a”***
2.	***AN77307S7406W***	***Ice front “b”***
	Latady Island	
1.	***AN77046S7505W***	***Latady ice shelf “a”***
2.	***AN77042S7436W***	***Latady ice shelf “b”***
3.	***AN77036S7411W***	***Latady ice shelf “c”***
	Stange Ice Shelf	
1.	***AN77243S7615W***	***Ice front “a”***
2.	***AN77258S7752W***	***Ice front “b”***
3.	***AN77310S7718W***	***Ice front “c”***
4	***AN77320S7725W***	***Ice front “d”***
	Fallières Coast	
1.	AN76919S6810W	E. Mount Guernsey “a” ice front
2.	AN76920S6804W	E. Mount Guernsey “b” ice front
3.	AN76924S6817W	West Bay “a” glacier
4.	AN76922S6816W	West Bay “b” glacier
5.	AN76923S6838W	W. Brindle Cliffs ice front
	Wilkins Sound	
1.	AN76949S7442W	E. Charcot Island “a” ice shelf
2.	AN76952S7432W	E. Charcot Island “b” ice shelf
3.	AN76949S7517W	W. Charcot Island ice shelf

Table 5. Inventory of unnamed glaciers and ice fronts for which measurements of advance and retreat were made on the coastal-change and glaciological map of the Palmer Land area.—Continued

[Bold type for 21 unnamed ice fronts indicates that the ice front is located between lat 70° and 74° S. and is portrayed only on this map. The remaining unnamed locations are included on the Larsen Ice Shelf area map (USGS Map I–2600–B (Ferrigno and others, 2008) and are discussed there. Geographic descriptions are as given in the Excel table on the SCAR ADD Web site (http://www.add.scar.org:8080/add/)

(N.B. The glaciers and ice fronts listed in this table are not formally named. They are described by an adjacent geographic feature, and this description should not be considered an official geographic place-name.)

	Location and Geographic Location Code[1]	Geographic Description
	Wilkins Ice Shelf	
1.	***AN77004S7305W***	***Ice front "a"***
2.	***AN77020S7412W***	***Ice front "b"***
3.	***AN77059S7314W***	***Ice front "c"***
	Larsen "C" Ice Shelf	
1.	***AN77015S6058W***	***Ice front "C1"***
2.	***AN77049S6047W***	***Ice front "C2"***
	Larsen "C" Ice Shelf—Continued	
3.	***AN77136S6031W***	***Ice front "C3"***
4.	***AN77230S5947W***	***Ice front "C4"***
5.	***AN77329S6046W***	***Ice front "C5"***
6.	***AN77348S6038W***	***Ice front "C6"***
7.	***AN77340S6049W***	***Howkins Inlet***

[1]The 40 unnamed glaciers and ice fronts that have been identified on source data were each given a geographic location code. For example, the code AN77427S11344W represents Antarctica (AN7), location at lat 74º27´ S. (7427S), long 113º44´ W. (11344W). AN7 is the continent code assigned by the World Glacier Monitoring Service for Antarctica. A latitude and longitude designator (degrees and minutes) is used in place of a drainage basin/glacier number code, because the latter has not been defined for Antarctica.

Table 6*A*. Average annual change of the ice fronts of George VI Ice Shelf calculated for the time intervals between years when measurements were made.

[In meters per year, rounded to the nearest meter. Negative values are retreat; positive values are advance. #, time of first measurement at each location; –, no measurement. Location numbers refer to site of sample lines drawn in George VI Ice Shelf area, similar to lines shown in figure 2. The numbering sequence for the northern front and southern front "b" is from east to west, and for southern front "a" is from north to south. For more detailed information, see complete digital file at http://www.add.scar.org:8080/add/]

Northern front							
Location	3 Dec 1947	27 Dec 1966	1974	1979	20 Feb 1989	1997	4 Jan 2001
1.	#	311	-34	-3,671	-343	708	-860
2.	#	293	94	-4,137	-314	-506	-2,042
3.	#	200	494	-4,219	-420	-458	-1,445
4.	#	427	676	-4,294	-462	-537	-1,181
5.	#	352	53	-3,143	-377	-515	-1,192
6.	#	383	390	–	-1,366	-348	-1,253
7.	#	627	89	–	-1,435	-322	-573
8.	#	867	-341	–	-1,500	-374	42
9.	#	1,059	-700	–	-1,483	-291	-239
10.	#	1,115	-567	–	-1,548	-198	-188
11.	#	1,035	-339	–	-1,464	-233	-479

Table 6*A*. Average annual change of the ice fronts of George VI Ice Shelf calculated for the time intervals between years when measurements were made.—Continued

[In meters per year, rounded to the nearest meter. Negative values are retreat; positive values are advance. #, time of first measurement at each location; –, no measurement. Location numbers refer to site of sample lines drawn in George VI Ice Shelf area, similar to lines shown in figure 2. The numbering sequence for the northern front and southern front "b" is from east to west, and for southern front "a" is from north to south. For more detailed information, see complete digital file at http://www.add.scar.org:8080/add/]

Southern front "a"								
Location	**23 Dec 1947**	**1967/68**	**1973**	**1986**	**26 Nov, 12 Dec 1989**	**1991**	**1997**	**20 Dec 2001**
1.	#	/118	-973	-280			-63	-28
2.	#	/-159	-2,505	151		145	38	
3.	#	/-271	-2,247	147		214	300	
4.	#	/-318	-2,312	112		-54	209	
5.	#	/-434	-2,972	209		-43	-20	
6.	#	/-548	-2,825		-12	627	-217	
7.	#	/-708	-2,033		-167	-322	-297	
8.	#	/-636	-1,565		-339	-74	-470	
9.	#	-401/-174	-1,452	-555		-589	-867	
10.	#	3/-54	156	-572	-1,579	-1,793	-1,495	
11.	#	-115/	309	140	-1,832	-79	-236	204
12.	#	4/	-324	-336	141	-350	-573	404
13.		#	-890	407	-30	-4,345	-179	60

Southern front "b"							
Location	**23 Dec 1947**	**21 Dec 1966**	**1973**	**1986**	**12 Dec 1989**	**1997**	**20 Dec 2001**
1.	#	-34	-109	-36	65	-56	47
2.	#	-84	-351	-54	59	5	-117
3.	#	-61	-756	-34	92	-3	-244
4.	#	-66	-821	-83	22	-59	-26
5.	#	-54	-747	-196	85	-75	-108
6.	#	-23	-793	-207	71	-103	-22
7.	#	95	-1,043	-241	73	-113	-20
8.	#	163	-1,172	-212	81	-169	-4

Table 6*B*. Source materials for coastal-change measurements of George VI Ice Shelf.

[Reliability ranking is explained in the Coastline Accuracies section of this pamphlet. Abbreviations used: RARE, Ronne Antarctic Research Expedition; TMA, Trimetrogon Antarctica (USA); MSS, Multispectral Scanner; TM, Thematic Mapper; ETM+, Enhanced Thematic Mapper Plus]

Date	Type	Reliability	Identification
03 Dec 1947	Aerial photography	2	RARE
23 Dec 1947	Aerial photography	2, 3	RARE
21 Dec 1966	Aerial photography	2	TMA
27 Dec 1966	Aerial photography	1, 3	TMA
01 Feb 1967	Aerial photography	1, 2	TMA
20 Dec 1968	Aerial photography	1, 3	TMA
29 Jan 1973	Satellite image	2	Landsat 1 MSS (1190–12374; Path 233, Row 112)
06 Jan 1974	Satellite image	3	Landsat 1 MSS (1532–12325; Path 233, Row 109)
03 Feb 1979	Satellite image	3	Landsat 3 MSS (30335–12253; Path 233, Row 109)
18 Feb 1986	Satellite image	1	Landsat 5 TM (50719–12510; Path 220, Row 109)
20 Feb 1989	Satellite image	1, 3	Landsat 4 TM (42411–12441; Path 218, Row 109)
26 Nov 1989	Satellite image	3	Landsat 4 TM (42690–12512; Path 219, Row 111)
12 Dec 1989	Satellite image	2, 3	Landsat 4 TM (42706–12514; Path 219, Row 112)
04 Feb 1991	Satellite image	2	Landsat 5 TM (52531–12204; Path 216, Row 112)
01 Oct 1997	Satellite image	2	RADARSAT
04 Jan 2001	Satellite image	1	Landsat 7 ETM+ (LE7218109000100450)
20 Dec 2001	Satellite image	1	Landsat 7 ETM+ (LE7220111000135450)

Table 7*A*. Average annual change of ice fronts “a”, “b”, and “c” of Wilkins Ice Shelf calculated for the time intervals between years when measurements were made.

[In meters per year, rounded to the nearest meter. Negative values are retreat; positive values are advance. #, time of first measurement at each location; –, no measurement. Location numbers refer to site of sample lines drawn in Wilkins Ice Shelf area, similar to lines shown in figure 2. The numbering sequence for Wilkins “a” is from east to west, and for Wilkins “b” and “c” is from north to south. For more detailed information, see complete digital file at http://www.add.scar.org:8080/add/]

Wilkins “a”						
Location	**1947**	**1966, (1968)**	**1975**	**1990**	**1997**	**2001, *2002***
1.	#	6	179	-107	-46	143
2.	#	9	149	-89	-561	173
3.	#	4	134	-94	-502	-378
4.	#	29	85	-116	-310	-914
5.	#	33	-46	-80	-729	212
6.	#	39	-151	-80	-524	-3,878
7.	#	38	-248	-88	-2,287	287
8.	#	60	-350	-66	-2,201	220
9.	#	–	-86	-75	-2,046	173
10.	#	–	-113	-50	-1,996	306
11.	#	–	-90	-62	-2,071	*-410*
12.	#	–	–	-84	-2,142	*-1,175*
13.	#	–	–	-84	-2,165	*-5,172*
14.	#	–	–	-76	-2,192	*-6,155*
15.	–	–	–	#	-2,399	*-5,813*

Table 7*A*. Average annual change of ice fronts "a", "b", and "c" of Wilkins Ice Shelf calculated for the time intervals between years when measurements were made.—Continued

[In meters per year, rounded to the nearest meter. Negative values are retreat; positive values are advance. #, time of first measurement at each location; –, no measurement. Location numbers refer to site of sample lines drawn in Wilkins Ice Shelf area, similar to lines shown in figure 2. The numbering sequence for Wilkins "a" is from east to west, and for Wilkins "b" and "c" is from north to south. For more detailed information, see complete digital file at http://www.add.scar.org:8080/add/]

Wilkins "a"—Continued

Location	1947	1966, (1968)	1975	1990	1997	2001, *2002*
16.	–	–	–	#	-2,693	*-5,070*
17.	–	–	–	#	-2,860	*-4,510*
18.	–	–	–	#	-2,760	*-4,484*
19.	–	–	–	#	-2,522	*-4,064*
20.	–	–	–	#	-2,513	*-3,110*
21.	–	–	–	#	-2,987	*-1,349*
22.	–	–	–	#	-3,196	*-204*
23.	–	(#)	–	-35	-657	*-231*

Wilkins "b"

Location	1947	1986	1990	1997	2000	2002
1.	–	–	#	-97	-506	50
2.	–	–	#	-51	-1,020	-683
3.	–	–	#	40	-1,091	-1,643
4.	–	–	#	-137	-402	-1,297
5.	#	–	-2	-139	-359	-1,274
6.	#	–	-3	-206	-331	-1,203
7.	#	–	-5	-107	-151	-1,502
8.	#	-7	-132	-71	-141	-1,472
9.	#	-2	-125	-118	-103	-1,036
10.	#	5	-147	-76	-118	-652
11.	#	-9	-124	-112	-133	-1,185
12.	#	-12	-224	-94	-195	-1,400

Wilkins "c"

Location	1947	1968	1973	1986	1989	1990	1997	2000
1.	#	182	-278	-248	158	716	-486	-610
2.	#	203	-522	-185	195	-1,055	-497	-637
3.	#	195	-532	-207	191	-1,228	-603	-405
4.	#	266	-930	-252	129	-1,845	-460	-775
5.	#	162	-1,041	-218	42	-1,000	-332	-828
6.	#	158	-109	-133	148	-3,630	-241	-121
7.	#	22	251	-142	141	-260	-215	-470
8.	#	-40	350	-178	85	-95	-214	-433
9.	#	-26	202	-79	91	-553	-296	-506
10.	#	--	-9	-50	-46	-472	-187	-517
11.	#	--	-4	-95	62	-575	-49	-396

Table 7*B*. Source materials for coastal-change measurements of Wilkins Ice Shelf.

[Reliability ranking is explained in the Coastline Accuracies section of this pamphlet. Abbreviations used: RARE, Ronne Antarctic Research Expedition; TMA, Trimetrogon Antarctica (USA); MSS, Multispectral Scanner; TM, Thematic Mapper; ETM+, Enhanced Thematic Mapper Plus]

Date	Type	Reliability	Identification[1]
23 Dec 1947	Aerial photography	2, 3	RARE
28 Nov 1966	Aerial photography	3	TMA
20 Dec 1968	Aerial photography	2, 3	TMA
29 Jan 1973	Satellite image	2	Landsat 1 MSS (1190–12371; Path 233, Row 111)
18 Feb 1975	Satellite image	2	Landsat 2 MSS (2027–12420; Path 236, Row 109)
18 Feb 1986	Satellite image	2	Landsat 5 TM (50719–12504; Path 220, Row 110)
10 Jan 1989	Satellite image	2	Landsat 4 TM (42370–12502; Path 219, Row 110)
27 Jan 1990	Satellite image	1	Landsat 4 TM (42752–13022; Path 221, Row 109)
27 Jan 1990	Satellite image	1	Landsat 4 TM (42752–13024; Path 221, Row 110)
01 Oct 1997	Satellite image	2	RADARSAT
15 Feb 2000	Satellite image	1	Landsat 7 ETM+ (LE7222110000004650)
19 Feb 2001	Satellite image	1	Landsat 7 ETM+ (LE7220109000105050)
26 Jan 2002	Satellite image	2, 1	Landsat 7 ETM+ (LE7223109000202650)