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Coastal-Change and Glaciological Maps of Antarctica

Changes in the area and volume of the two polar ice sheets in Antarctica (fig. 1) and Greenland are intricately linked to changes in global climate, and could result in sea-level changes that could severely affect the densely populated coastal regions on Earth. Melting of the West Antarctica part of the Antarctic ice sheet alone could cause a sea-level rise of approximately 6 m. The potential sea-level rise after melting of the entire Antarctic ice sheet is estimated to be 73 m. 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 whether the ice sheet is growing or shrinking. As a result, measurement of changes in the Antarctic ice sheet has been given a very high priority in recommendations by the Polar Research Board of the National Research Council, by the Scientific Committee on Antarctic Research (SCAR), and by the National Science Foundation's Office of Polar Programs.

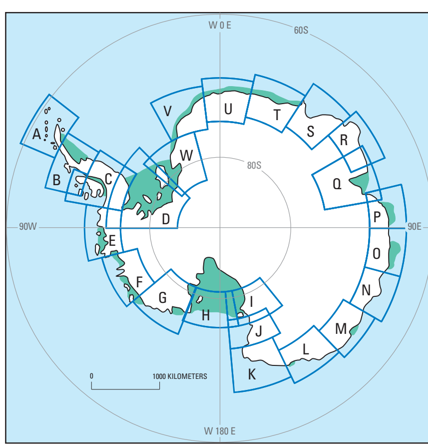
An extensive archive of early 1970s Landsat 1, 2, and 3 Multispectral Scanner (MSS) images of Antarctica was the impetus for the U.S. Geological Survey (USGS), in cooperation with Scott Polar Research Institute (Cambridge, U.K.), to carry out a comprehensive analysis of the glaciological features of the coastal regions of Antarctica. The project was later modified to include analysis of coastal change using Landsat 4 and 5 MSS and Thematic Mapper (TM) images from the late 1980s/early 1990s, declassified 1963 Argon (Corona Program) images, 1992 and 1995 European Space Agency) (ESA) Remote Sensing Satellite (ERS) radar images, 9 September–2 October 1997 RADARSAT images, Landsat 7 Enhanced Thematic Mapper (ETM+) images (April 1999–May 2003), and Moderate Resolution Imaging Spectroradiometer (MODIS) images (post-mid-December 1999). The different data sets allow determination of coastal change in Antarctica for >30 years where suitable images exist. Coastal change has been most pronounced on the Antarctic Peninsula in the last few decades, where the Wordie Ice Shelf has practically disappeared, the northern part of the Larsen Ice Shelf has disintegrated, and other ice shelves are also changing. Cooperation with other Antarctic mapping groups now includes scientists from Italy, Russia, Norway, Canada. Australia, Argentina, and Germany.

The coastal-change and glaciological mapping task, an element of the Glacier Studies Project, has several objectives:

- Determine coastline changes in Antarctica that have occurred at three or more time intervals between the mid-1970s and the latest available images.
- Establish an accurate base-line series of 1:1,000,000-scale maps (in printed and/or digital format) (fig. 2) that defines, from the analysis of remotely sensed data, the glaciological characteristics of the coastline of Antarctica, for example, floating ice (ice fronts) and grounded ice (ice walls), and the location of floating ice fronts during the time periods represented by the imagery.
- Determine glacier-ice velocities of selective outlet glaciers, ice streams, and ice shelves in some coastal regions.
- Compile an inventory of named (from published maps and gazetteers) and unnamed (from analysis of Landsat and other images) outlet glaciers and ice streams in Antarctica.
- Publish the results of the analyses in 23 maps as I–2600–A–W of the USGS Geologic Investigations Series (I–Maps) (fig. 2). Most 1:1,000,000-scale maps extend to the southernmost nunatak within each map area or to the southernmost extent of Landsat images (about 81.5°S. lat.), although for some ice shelves, RADARSAT or MODIS images were used to extend maps further south. The 1:1,000,000-scale maps will be combined to produce a 24th map, I-2600-X, a 1:5,000,000-scale map of Antarctica (in both printed and digital formats).

Ice fronts, iceberg tongues, and glacier tongues are the most dynamic and changeable features in the coastal regions of Antarctica. Floating ice margins are subject to frequent and large calving events or rapid flow. These situations lead to annual and decadal changes

Figure 1. Index map to the principal geographic features of Antarctica, including the ice shelves where large coastal-change events commonly occur.



Published (Date of Publication) and Planned USGS I–2600 Maps:

A-Trinity Peninsula (2006)
B-Larsen Ice Shelf (in press)
C-Palmer Land
D-Ronne Ice Shelf (2005)
E-Eights Coast (2004)
F-Bakutis Coast (2005)
G-Saunders Coast (2003)
H-Ross Ice Shelf (2007)
I-Ross Island

J-Drygalski Ice Tongue*
K-Oates Coast*
L-George V Coast*
M-Banzare Coast*
N-Budd Coast*
O-Queen Mary Coast*

P-West Ice Shelf*
Q-Amery Ice Shelf*
R-Mawson Coast*
S-Prince Olav Coast*
T-Princess Ragnhild Coast*
U-Fimbul Ice Shelf*
V-Cape Norvegia*
W-Filchner Ice Shelf-Coats Land*

X-Antarctica

*Maps I-2600-J–W will be published in digital format only, collective groupings in the USGS Open-File Report series.

Figure 2. Index map showing the locations and names of the 23 published and planned 1:1,000,000-scale coastal-change and glaciological maps of Antarctica. The dates (2004) of published maps are shown that are available in print and digital formats. Web access to digital data is as follows: *http://pubs.usgs.gov/imap/2600/G* for the Saunders Coast map (I–2600–G), for example.

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in the position of ice fronts on the order of several kilometers, even tens of kilometers in extreme cases of major calving events (fig. 3).

On the coastal-change and glaciological maps, the positions of the dynamic ice fronts as observed on remotely sensed data have been mapped and annotated with the exact date of each position. This record makes it possible to analyze changes that have occurred. Although calving does occur along ice walls, the magnitude of the change on an annual to decadal basis is generally not discernible on the images; therefore, ice walls can be used as relatively stable reference features against which to measure other changes along the coast. Only a single observation date is given for the position of ice walls.

Velocities of floating glaciers (such as glacier tongues, ice streams, ice shelves) are determined by three methods. (1) An interactive one in which crevasse patterns are traced visually on images. (2) An auto-correlation program developed by the U.S. National Aeronautics and Space Administration (NASA). The larger glacier tongues and ice shelves have well-developed rift patterns that can be used for velocity measurements. Under optimum conditions, errors can be as small as ±0.02 km per year (a^{-1}), but for most Landsat image pairs, where registration of features is not as accurate, the accuracy of velocity vectors is ±0.1 km a^{-1}. (3) Ice-surface velocities can be determined from satellite radar interferometry, a technique developed by scientists at the California Institute of Technology (Jet Propulsion Laboratory) and NASA.

Producing a sophisticated glacier inventory of Antarctica according to the requirements of the World Glacier Monitoring Service, as part of its ongoing "World Glacier Inventory" program, is difficult to accomplish with the present state of glaciological knowledge about Antarctica. Landsat and other images and available maps are used in the compilation of the coastal-change and glaciological maps to produce a reasonably complete preliminary inventory of named and unnamed outlet glaciers and ice streams and also to define, more accurately, related glaciological features such as ice domes, ice piedmonts, ice shelves, ice rises, ice rumples, glacier tongues, iceberg tongues, etc.

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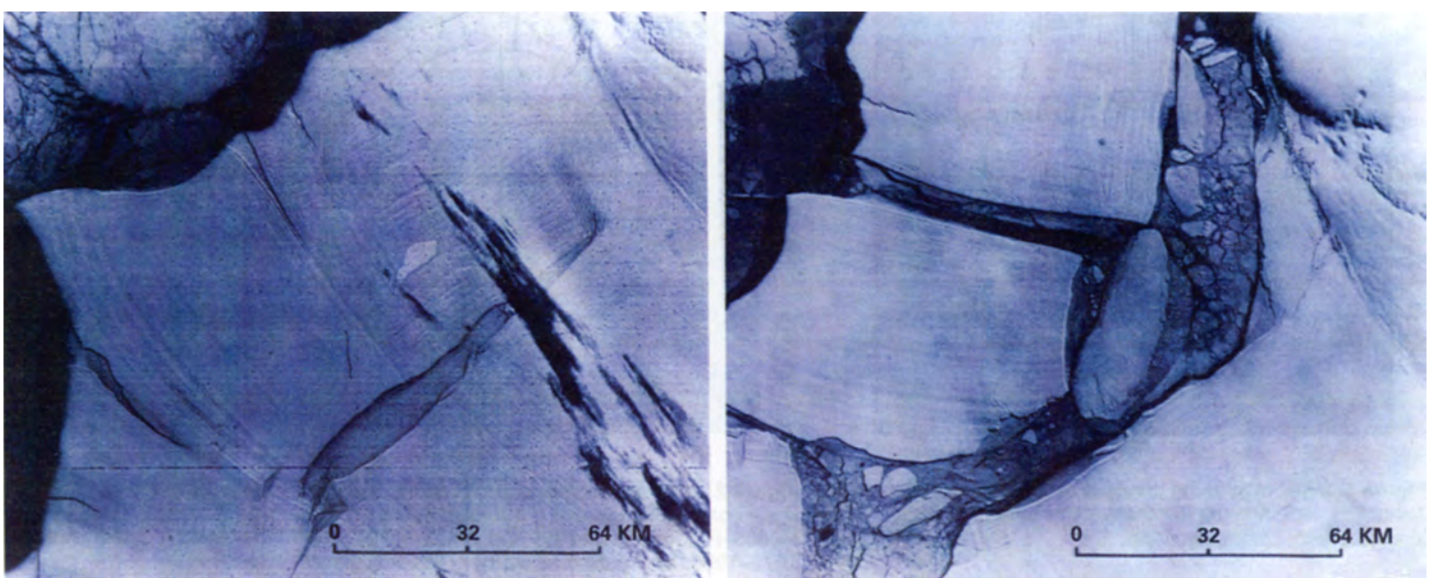

Figure 3. Left, Landsat MSS image of margin of the Filchner Ice Shelf, Weddell Sea, West Antaractica, on 11 November 1973. Right, Landsat image of the same area on 18 October 1986 after a major calving event.