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LANDSAT IMAGES AND MOSAICS OF ANTARCTICA FOR MAPPING AND GLACIOLOGICAL STUDIES

by

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ABSTRACT

The preparation of a US Geological Survey Professional Paper, "Satellite image atlas of glaciers", has produced a 1:5 000 000 scale "Landsat index map of Antarctica", in which each of the 2 470 Landsat nominal scene centers is represented by a symbol showing the suitability of available Landsat images for the preparation of planimetric image maps and for glaciological studies. Landsat has the potential for imaging about 79% of the area of Antarctica, and 70% of the Landsat imaging area, or about 55% of the continent, was found to have excellent or good (less than 10% cloud cover) coverage.

Australia, Japan, New Zealand, the United Kingdom, and the United States of America have published Landsat image maps, either as single Landsat scenes or as mosaics of two or more images. The Federal Republic of Germany and the Republic of South Africa also plan to publish Landsat image maps in the near future.

Available Landsat images could be used, in combination with Doppler satellite technology for geodetic control, to triple the area of Antarctica presently mapped at scales of 1:250 000 or larger. Landsat-3 RBV images can also be used to prepare 1:100 000 scale image maps. In addition to eventually using Landsat images to compile an accurate coastline of Antarctica, Landsat images have been successfully used for glaciological studies. Recent measurements of successive images of Pine Island Glacier, Walgreen Coast, West Antarctica, showed an average speed of flow of the terminus of 6 m d^{-1} over 750 d.

EVALUATION OF LANDSAT IMAGES OF ANTARCTICA

Specialized Landsat index maps of the glacierized areas of the world are being compiled as one aspect of the preparation of a US Geological Survey Professional Paper, "Satellite image atlas of glaciers" (Ferrigno and Williams 1980, Williams and Ferrigno 1981). Approximately 2 470 nominal scene centers exist from the coastline of Antarctica to about 82°S latitude. This area is covered by all 251 Landsat orbits (paths) and all or parts of 17 rows from row 103 (about 61°S latitude) to row 119 (about 81°S latitude). Because Landsat orbits converge at high latitudes, sidelap of adjacent Landsat scenes increases. Complete coverage of the terrain can therefore be accomplished with only 519 Landsat images by using every other Landsat scene at row 103, with a gradual reduction to every ninth scene at row 118. At row 119, however, because of the east to west (rather than the usual north-east to south-west) travel of the satellite, every sixth scene is required.

For the majority of 2 470 nominal Landsat scene centers in Antarctica, one or more images is available. One problem in evaluating the imagery is that the cloud cover assessment appearing on either the computer or the microfiche summaries of each image archived at the EROS Data Center is quite often unreliable; snow, for example, is often mistaken for clouds. In addition, the 1972 to 1980 16 mm microfilm cassettes, which contain only Landsat MSS (multispectral scanner) band-5 images and are often overexposed required that Landsat MSS band-7 images on the 70 mm archival film rolls stored at the Goddard Space Flight Center, Greenbelt, Maryland, of the National Aeronautics and Space Administration (NASA), should be used to make a definitive determination of cloud cover.

Over 10 000 individual Landsat images were evaluated in the search for the best available image for each nominal scene center; this image was classified in one of the following five classes: excellent (<5% cloud cover), good (5 to 10% cloud cover), fair to poor (>10 to 95% cloud cover), unusable, and no image ever acquired. Of these optimum images, 41% were rated excellent; 12% were good, 30% were fair to poor, and 5% were unusable; for 12% of the nominal scene centers, no images were ever acquired. The first two classes, comprising over one-half of the nominal scene centers, have little or no cloud cover, minimum snow cover in areas of exposed rock, or were acquired during times of low sun elevation angle to maximize morphologic details on the ice-sheet surface. Taking into account both sidelap and image suitability, 70% of the Antarctic continent, from the coast to about 82°S latitude, now has high quality Landsat MSS images available for glaciological studies and/or the preparation of planimetric image maps or image mosaics.

In order to make Landsat images more usable by the Antarctic scientific community, the US Geological Survey is planning to publish the results of the above evaluations as a "Landsat index map of Antarctica" at a scale of 1:5 000 000 with each of the 2 470 nominal scene centers plotted as one of the five classes discussed. The reverse side of the index map will contain a tabular presentation of the following information for each nominal scene center: path/row numbers, graphical symbol (same as map side), Landsat image identification numbers, percentage of cloud cover, and date of image acquisition. The

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completion of the index map will also permit identification of those areas for which Landsat images are still needed from NASA and will identify which images should be permanently archived in computer compatible tape (CCT) format.

AVAILABILITY OF LANDSAT IMAGE MAPS OF ANTARCTICA

In 1970, a National Academy of Sciences report ([USA] National Research Council. Committee on Polar Research 1970) discussed the potential value of using satellite imagery (e.g. the ERTS-1 (Landsat-1) spacecraft) for mapping in Antarctica. It has been 11 years since the report was released and nine years since the launch of the first of three Landsat spacecraft, so it was of considerable interest to determine what use various Scientific Committee on Antarctic Research (SCAR) nations had made of Landsat images of Antarctica.

In mid-January 1981, all organizations known to be involved in the mapping of Antarctica, whether it be topographic, geologic, or geophysical mapping by surface, aerial, or satellite instruments, were canvassed by letter "to determine their past, present, or planned use of Landsat (or other satellite) images of Antarctica for glaciological (or other scientific) studies and/or image or image mosaic map preparation". Letters were sent to 63 individuals in the following fourteen countries: Argentina, Australia, Belgium, Chile, the Federal Republic of Germany, France, Japan, New Zealand, Norway, Poland, the Republic of South Africa, the United Kingdom, the USSR, and the United States. Replies were received from all countries except Belgium, Chile, Poland, and the USSR.

1. Argentina

P Skvarca (written communication 23 April 1981) reported that the Glaciology Division of the Instituto Antártico Argentino has been using 1:250 000 scale enlargements of two Landsat images (2 740-11 454 and 2 740-11 461, 31 January 1977) to inventory the glaciers in the James Ross and Vega islands area of the Antarctic Peninsula, and a 1:250 000 scale image mosaic is published in this volume (Rabassa and others 1982). The Glaciology Division also has plans to use Landsat images of the Larsen and Filchner ice shelves in order to conduct various glaciological studies and to monitor dynamic changes of selected glaciers.

2. Australia

A G Bomford (written communication 2 February 1981) provided a complete review of the extensive Landsat image map program in Antarctica by the Division of National Mapping. Ninety Landsat image maps (derived from fifth generation data) are available at scales of 1:250 000 (58 sheets) and 1:500 000 (32 sheets) as dyeline copies from half-tone positives of original Landsat image mosaics (paper prints) (Australia. Division of National Mapping 1980). The images have not been enhanced, and only geographic place names and latitude-longitude reference have been added. Bomford states that "Natmap is not undertaking any series mapping in Antarctica at present, for lack of resources. I think it unlikely we shall ever do any photogrammetric compilations again, except of limited areas adjacent to the stations. I believe all future series mapping will be made from enhanced Landsat imagery".

R J Tingey (written communication 20 February 1981) reported on the two types of Landsat-related activities of the Bureau of Mineral Resources, Geology and Geophysics, especially with regard to geological mapping (Tingey unpublished). In the first type, Landsat images were used to produce a base map (line-drawn) to support 1:250 000 scale geological maps of the southern Prince Charles Mountains. The second type involves the preparation of two 1:500 000 scale geological maps of the Prince Charles Mountains area, Mac. Robertson Land, in which the geological data will be superimposed on a Landsat image mosaic base map. Tingey noted that "the Landsat background does give an excellent synoptic overview of the terrain in a way no line map ever can". Future plans call for the preparation of fourteen 1:250 000 scale geological maps of the Enderby Land area using Landsat image mosaics as the map base.

3. Federal Republic of Germany

Correspondence received from H Schmidt-Falkenberg (written communication 6 March 1981), Institut für Angewandte Geodäsie (IFAG), indicates that IFAG plans to apply their expertise in digitally processed Landsat image mosaics to prepare Landsat image maps of the Atka Bay and the Ronne and Filchner ice shelves areas of Antarctica.

4. France

J Nougier (written communication 27 January 1981), Laboratoire de Géologie of the Centre Universitaire d'Avignon reported that J-C Rivereau (1978) was editor of a series ("Geomorphic outline of the Antarctic") of fourteen 1:1 000 000 scale Landsat image mosaics (accompanied by 14 interpretation overlays showing morphological and structural elements, including lineaments and outcrops, over a combined area of 3.5×10^6 km^2) of various areas along the coast of Antarctica. The 14 mosaics were prepared by the Bureau d'Etudes Industrielles et de Coopération de l'Institut Français du Pétrole (BEICIP) as a source of data for the "Carte Géologique de l'Antarctique" project (scale of 1:2 500 000), a cooperative endeavor between BEICIP and the Centre National pour l'Exploitation des Océans.

5. Japan

Kou Kusunoki, National Institute of Polar Research, provided information (written communication 28 January 1981) on a 1:200 000 scale (working) map of the meteorite ice field, Yamato Mountains, Antarctica, which was published in 1976 (Japan. National Institute of Polar Research 1976). The map was compiled directly on a Landsat image mosaic and combined with available geodetic survey data and is available in two color versions.

6. New Zealand

The Remote Sensing Section of the Physics and Engineering Laboratory (PEL), Department of Scientific and Industrial Research (DSIR), has been working with the Department of Lands and Survey (DLS) to support various mapping and charting needs (including surface and aeronautical navigation) in Antarctica (I L Thomas, written communication 6 March 1981). One of the Landsat images of the McMurdo Sound area (1174-19433) has been digitally enhanced by PEL (destriped, haze-corrected, and texturally enhanced) and combined with latitude and longitude tick marks and geographic place names by DLS (I F Stirling, written communication 16 March 1981). It is available as a false color composite print at scales of 1:500 000 or 1:250 000 from DLS.

I F Stirling, Surveyor General DLS, also stated that five Landsat scenes of the northern Victoria Land area will be produced as reconnaissance maps at a scale of 1:250 000 as a collaborative effort with PEL (DSIR).

7. Norway

According to H Ødegaard (written communication 13 February 1981), IBM Norway is working closely with Norsk Polarinstitutt (O Orheim) "to produce one or more Landsat maps by the end of 1981 for parts of Antarctica". Because of Olav Orheim's previous research with Landsat images of Antarctica (1978), it is probable that the Norsk Polarinstitutt-IBM Norway Landsat maps of Antarctica will be of the Dronning Maud Land area.

8. Republic of South Africa

According to P R Condy, Scientific Coordinator, Antarctic Programme, Council for Scientific and Industrial Research (CSIR), there are four well-defined projects in the Republic of South Africa which are using Landsat images in some aspect of the

National Antarctic Programme (written communication 16 February 1981). E Fitschen, Director of Surveys, Department of Community Development and State Auxiliary Services, stated that "the geodesy and cartography component of the South African Antarctic programme is planning to establish ground control stations by satellite Doppler methods in the mountains east and west of the giant Jutulstraumen glacier and to produce controlled Landsat maps at a scale of 1:250 000 extending in longitude from 6°W to 2°E" (written communication 10 February 1981).

O G Malan, Optical Sciences Division of the National Physical Research Laboratory, CSIR, has been working with L G Wolmarans and A S van Zyl in the production of digitally enhanced Landsat image mosaics of Antarctica (Malan and van Zyl in press). Their first mosaic, a 6-scene compilation, covers in excess of 100 000 km^2 in the area between 70° to 75°S latitude and 6°W to 3°E longitude. Wolmarans, Geological Survey of South Africa, is using the Landsat images of Antarctica for glaciological studies and, in association with D R Hunter, for geological research.

D R Hunter, Department of Geology, University of Natal, is collaborating with Wolmarans and Malan on "a Geological Memoir which summarizes the work done by South African geologists in Antarctica in recent years and will have appended to it a geological map based on Landsat images" (E Fitschen, written communication 10 February 1981).

Although no satellite image maps have yet been published by the Republic of South Africa, according to P R Condy (written communication 16 February 1981), the National Antarctic Programme is "preparing for publication (in 1981 or 1982) a set of three computer-integrated Landsat mosaic maps (each 1:250 000 scale), showing the geology of the region 6°W to 0° (longitude) and 70° to 75°S (latitude). In due course we may publish geological maps of the area from 0° to about 9°E, also based on Landsat imagery, as our Antarctic programme (earth sciences) expands further eastward".

9. United Kingdom

According to M B McHugo (written communication 22 January 1981) of the Directorate of Overseas Surveys (DOS), Overseas Development Administration, "the Directorate has produced 15 (Landsat) imagery maps in the BAS 250P series, all at a scale of 1:250 000 and printed in either 1 or 2 colours; and we are currently working on the first 1:500 000 sheet". She also noted that Landsat and NOAA (weather satellite) imagery has been used to revise and update maps of Antarctica at scales smaller than 1:250 000.

Table I was sent to us by C W M Swithinbank, Head, Earth Sciences Division, British Antarctic Survey (BAS) (written communication 22 January 1981). The table provides specific information on Landsat image maps published, in production, or planned by BAS and DOS. W R MacDonald, of the US Geological Survey, and Swithinbank were pioneers in using Landsat images as the basis for a satellite image map series of Antarctica (Swithinbank and Land 1977) and as a source of data for improving existing maps (Swithinbank and others 1976).

10. USSR

No reply was received from the USSR; therefore, their use of Landsat or other satellite images in Antarctica is unknown. It is known, however, that the Soviet Union has an active program of using manned and unmanned satellites, from classified and unclassified sensors, to study and to map the Earth's surface, including glacierized areas (Desinov and others 1980).

11. USA

The late W R MacDonald, a cartographer with the Topographic Division (now the National Mapping Division), US Geological Survey, and Chief, Branch of International Activities, pioneered the use of Landsat images to produce Landsat nominal scene (single frame) maps and Landsat image mosaic maps of Antarctica, and the use of Landsat images to revise small-scale maps (1:1 000 000 scale IMW Series ST 57-60, McMurdo Sound, 1974) of Antarctica (see Table II of the present paper, Southard and MacDonald 1974,

TABLE 1. LANDSAT IMAGE MAPS OF ANTARCTICA PUBLISHED, IN PRODUCTION, OR PLANNED BY BAS/DOS

Name	Map sheet	Publication date	no.of images
Satellite image maps (1:250 000 scale) published in the United Kingdom			
Alexander Island	SR 17-18/15, 16	1974	2
George VI Sound	SR19-20/10	1974	1
Alexander Island	SR19-20/13	1974	3
George VI Sound	SR19-20/14	1974	2
Ronne Entrance	SS16-18/4	1974	3
Eklund Islands	Parts of SS16-18/8 & SS19-21/5	1974	1
Alexander Island	SS19-21/1	1974	3
Arrowsmith Peninsula	SQ19-20/14(Ext)	1978	4
Marguerite Bay	SR19-20/2	1978	3
Rouen Mountains	SR19/20/5(Ext)	1978	3
Cape Jeremy	SR19-20/6	1978	3
Colbert Mountains	SR19-20/9	1978	5
Shackleton Range	SU26-30/1(Ext)	1978	3
Anvers Island	SQ19-20/3	1979	4
Crystal Sound	SQ19-20/10	1979	2
Satellite image maps (1:500 000 scale) in production in the United Kingdom			
Orville Coast	SS17-20/SE	1981	15
Satellite image maps planned in the United Kingdom			
No decisions taken. This will depend on the acquisition of cloud-free imagery of areas of interest defined by path/row numbers supplied to NASA.			

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MacDonald 1976[a] and 1976[c], Colvocoresses and MacDonald unpublished).

In addition to the five Landsat image maps of Antarctica published by the US Geological Survey (1977), another eight 1:1 000 000-scale uncontrolled Landsat image mosaics have been prepared in preliminary form as another product of MacDonald's ERTS-1 (Landsat-1) experiment (Table II). The Ellsworth Land, Ronne Ice Shelf, and Filchner Ice Shelf mosaics have recently been combined and then redivided into three sheets. The three sheets of the Ronne-Filchner ice shelves area are presently undergoing a technical evaluation but have no firm publication date assigned to them. No publication plans have been developed with respect to the other five preliminary sheets. There are also tentative plans to eventually combine all the 1:1 000 000 scale Landsat image mosaics (including five more 1:1 000 000 scale mosaics not yet assembled) into a 1:10 000 000 scale Landsat image mosaic of Antarctica.

IMPORTANCE OF LANDSAT IMAGES AND IMAGE MAPS OF ANTARCTICA

Landsat has the potential for imaging about 1.1×10^7 km^2, or 79% of Antarctica. It cannot image the area around the geographic South Pole as it is beyond the Landsat orbit. About 70% of the Landsat imaging area (about 7.7×10^6 km^2) or about 55% of the continent now has excellent or good coverage. According to Swithinbank (1980), less than 20% of Antarctica, including about 50% of the coastal areas,

TABLE II. SATELLITE IMAGE MAPS OF ANTARCTICA PUBLISHED, IN PRODUCTION, IN PREPARATION, OR PLANNED BY THE US GEOLOGICAL SURVEY

Landsat image maps published by the US Geological Survey

Name	Scale	Publication date
Ellsworth Mountains	1:500 000	1976
Victoria Land coast	1:1 000 000	1976
McMurdo Sound	1:250 000	1975
McMurdo Sound	1:500 000	1975
McMurdo Sound, Antarctica (companion map to IMW ST57-60)	1:1 000 000	1976

Landsat image maps in production by the US Geological Survey

Area	Scale
Ronne Ice Shelf	1:1 000 000
Berkner Island	1:1 000 000
Filchner Ice Shelf	1:1 000 000

Landsat image maps in preparation by the US Geological Survey

Name	Scale	Remarks
Thurston Island-Thwaites area	1:1 000 000	Mosaic compiled w/grid
Prince Olav Coast	1:1 000 000	Mosaic compiled
Alexander Island-Palmer Land	1:1 000 000	Mosaic compiled
Adélie Coast	1.1 000 000	Mosaic compiled
Marie Byrd Land	1:1 000 000	Mosaic compiled

Satellite image maps planned by the US Geological Survey

Name	Scale	Remarks
Kemp-Mawson coast	1:1 000 000	Mosaic not compiled
Queen Mary coast	1:1 000 000	Mosaics needs to be recompiled
Banzare-Sabrina coast	1:1 000 000	Mosaic needs to be recompiled
Queen Maud coast	1:1 000 000	Mosaic not compiled
Lambert Glacier -Amery Ice Shelf	1:1 000 000	Mosaic not compiled
Antarctica (from ~ 60°S to ~ 82°S latitude)	1:10 000 000	To be compiled from 1:1 000 000 scale Landsat image mosaics.
Antarctica*	1:5 000 000	To be compiled from NOAA (weather satellite) AVHRR images acquired primarily by the HRPT receiving station at McMurdo station, Antarctica

* A cooperative project with the National Earth Satellite Service (NESS) of the National Oceanic and Atmospheric Administration (NOAA) and the National Science Foundation (NSF) (Berg and others 1982).

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has been mapped at scales of 1:250 000 or larger. Consequently, the area of Antarctica planimetrically mapped at a 1:250 000 scale could be tripled if available Landsat images were effectively used.

Nearly all the Landsat coverage of Antarctica was acquired during the austral summers of 1972-73 and 1973-74, the direct result of W R MacDonald's ERTS-1 (Landsat-1) experiment (SR-194) requirements. Subsequent to 1974, the available Landsat spacecraft had tape recorders which were either inoperative or were assigned to higher priority needs for Landsat data. There have been few additional Landsat images of Antarctica acquired between 1974 and 1981. Since March 1978, the Landsat-3 spacecraft has had the capability to acquire higher resolution return beam vidicom (RBV) images, but most Landsat-3 RBV images of Antarctica are overexposed and not generally useful. Some recently processed Landsat-3 RBV images acquired at low solar elevation angle, are superb, however (see Fig. 2).

Figure 1 is a typical Landsat MSS image of a part of the coast of Antarctica. The image (1460-21103,

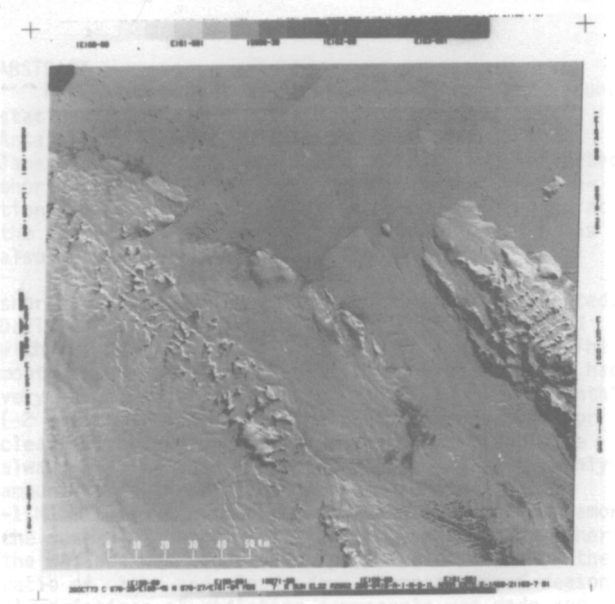

Fig.1. Landsat-3 MSS image of Rennick Glacier and environs, Oates Coast, northern Victoria Land, Antarctica (path 72-row 110; 1460-21103, band 7; 26 October 1973).

band 7) was acquired on 26 October 1973 at 2110 UT and has a pixel resolution of 80 m. It encompasses an area of about 33 000 km^2 (186 by 180 km trapezoidal format) in the Rennick Glacier area, Oates Coast, northern Victoria Land.

Figure 2 is a Landsat-3 RBV image of part of the same area shown on Figure 1. The image (30927-20382, subscene C) was acquired on 17 September 1980 at 2038 UT and has a pixel resolution of 30 m. It encompasses an area of about 8 100 km^2 (90 by 90 km square format) in the Rennick Glacier area, Oates Coast, northern Victoria Land. The image falls within the south-west quadrant of path 70-row 110.

In addition to using Landsat images of Antarctica to triple the area planimetrically mapped at present, Landsat image maps can be used to satisfy the need for adequate 1:250 000 scale base maps for already acquired geological and geophysical data (either from ground traverses or from airborne instrumentation (Swithinbank and Land 1977, Williams and Schoonmaker 1979). If sufficient Landsat-3 RBV images exist of an area, then 1:100 000 scale image maps could be prepared. Figure 2, the Landsat-3 RBV image

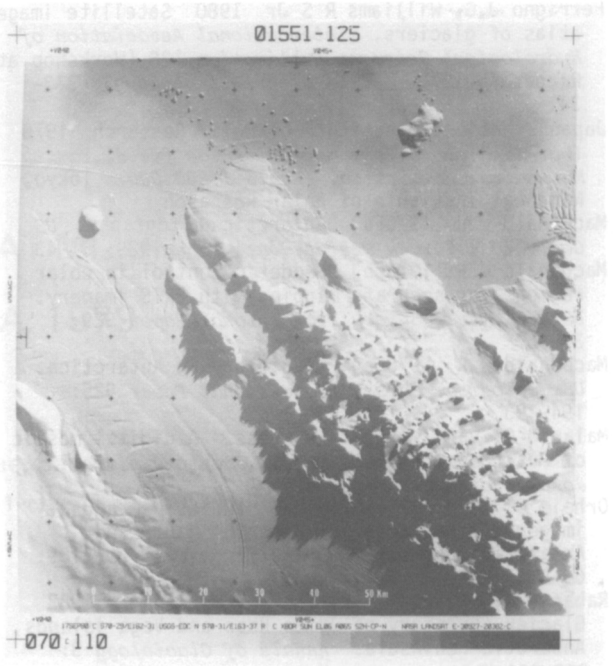

Fig.2. Landsat-3 RBV image of Rennick Glacier and environs, Oates Coast, northern Victoria Land, Antarctica (path 70-row 110; 30927-20382, subscene C; 17 September 1980).

of Rennick Glacier, shows considerable detail, especially in the distribution of crevasses at ice falls and at other subglacial topographic irregularities. Landsat image maps can also serve as the base for aeronautical charts of Antarctica over which the standard aeronautical information can be printed. If a sufficient number of image-identifiable ground-control points surveyed by either conventional or Doppler satellite methods (MacDonald 1976[b]) are present on a particular image, then a fitted grid can be generated which will convert the Landsat image to a Landsat image map.

One significant attribute of the Landsat image is that one knows the precise date (and time) of acquisition. The dynamic nature of the coast of Antarctica becomes readily apparent when "time-lapse" measurements are made of outlet glaciers. Twelve Landsat images were evaluated in a computation of the speed of flow of the terminus of Pine Island Glacier, Walgreen Coast, West Antarctica. Only two Landsat images (1185-13530, 24 January 1973, path 246-row 114, and 2022-13582, 13 February 1975, path 249-row 113) were sufficiently cloud-free and far enough separated in time to determine that the terminus of Pine Island Glacier had moved about 4.5 km during a period of 750 d, or an average speed of flow of 6 m d^{-1}.

REFERENCES

Australia. Division of National Mapping 1980 *Antarctica; maps and air photographs.* Canberra, Division of National Mapping (Leaflet No 7)

Berg C P, Wiesnet D R, Legeckis R 1982 The NOAA-6 satellite mosaic of Antarctica: a progress report. *Annals of Glaciology* 3: 23-26

Colvocoresses A P, MacDonald W R Unpublished. Landsat mapping of the polar regions. US Geological Survey Memorandum (EC-38-Landsat 22 June)

Denisov L V, Nosenko G A, Grechko G M, Ivanchenkov A S, Kotlyakov V M 1980 Glyatsiologicheskiye issledovaniya i eksperimenty na orbital'noy stantsii "Salyut-6" [Glaciological research and experiments on board the orbital station "Salyut-6"]. *Issledovaniye Zemli iz Kosmosa* 1980 (1): 25-34

https://doi.org/10.3189/S0260305500003001 Published online by Cambridge University Press

Ferrigno J G, Williams R S Jr 1980 Satellite image atlas of glaciers. *International Association of Hydrological Sciences Publication* 126 (Workshop at Riederalp 1978 — *World Glacier Inventory*): 333-341

Japan. National Institute of Polar Research 1976 *(Working) map of the meteorite ice field, Yamato Mountains, Antarctica. Scale 1:200 000.* Tokyo, National Institute of Polar Research

MacDonald W R 1976[a] Antarctic cartography. *US Geological Survey Professional Paper* 929: 37-43

MacDonald W R 1976[b] Geodetic control in polar regions for accurate mapping with ERTS imagery. *US Geological Survey Professional Paper* 929: 34-36

MacDonald W R 1976[c] Glaciology in Antarctica. *US Geological Survey Professional Paper* 929: 194-195

Malan O G, van Zyl A S In press. A digital mosaic of Antarctic Landsat images. *South African Journal of Antarctic Research*

Orheim O 1978 Glaciological studies by Landsat imagery of perimeter of Dronning Maud Land, Antarctica. *Norsk Polarinstitutt.Skrifter* 169: 69-80

Rabassa J, Skvarca P, Bertani L, Mazzoni E 1982 Glacier inventory of James Ross and Vega islands, Antarctic Peninsula. *Annals of Glaciology* 3: 260-264

Rivereau J-C 1978 *Morphostructural outline of the Antarctic: inventory of lineaments and outcropping areas from Landsat 1 and 2 imagery.* Rueil-Malmaison, Bureau d'Etudes Industrielles et de Coopération de l'Institut Français du Pétrole [BEICIP]

Southard R B, MacDonald W R 1974 The cartographic and scientific application of ERTS-1 imagery in polar regions. *US Geological Survey Journal of Research* 2(4): 385-394

Swithinbank C 1980 The problem of a glacier inventory of Antarctica. *International Association of Hydrological Sciences Publication* 126 (Workshop at Riederalp 1978 — *World Glacier Inventory*): 229-236

Swithinbank C, Land C 1977 Antarctic mapping from satellite imagery. *In* Peel R F, Curtis L F, Barrett E C (*eds*) *Remote sensing of the terrestrial environment. Proceedings of the 28th Symposium of the Colston Research Society, Bristol, 1976.* London, etc., Butterworths: 212-221

Swithinbank C, Doake C, Wager A, Crabtree R 1976 Major change in the map of Antarctica. *Polar Record* 18(114): 295-299

Tingey R J Unpublished. Application of ERTS imagery in geological mapping and other field operations in Antarctica. Canberra, Department of Mineral Resources, Geology and Geophysics (Internal report 1974/131)

[USA] National Research Council. Committee on Polar Research 1970 *Polar research; a survey.* Washington, DC, National Academy of Sciences

US Geological Survey 1977 *Maps published of Antarctica by the US Geological Survey. September 1977.* Washington, DC, US Government Printing Office

Williams R S Jr, Ferrigno J G 1981 Satellite image atlas of the Earth's glaciers. *In* Deutsch M, Wiesnet D R, Rango A *eds Satellite hydrology. Proceedings of the fifth Annual William T Pecora Memorial Symposium on Remote Sensing, Sioux Falls, South Dakota, 1979.* Minneapolis, American Water Resources Association: 173-182

Williams R S Jr, Schoonmaker J W Jr 1979 Surveying Antarctica from dogsled to satellite. *Air and Space* (Washington DC, Smithsonian Institution, National Air and Space Museum) 3(1): 2-4