Final Report: Variable Ice-Sheet Discharge and Coastal Change in West Antarctica

(results of a three-year Proposal To NASA in response to the Research Announcement issued December 1994: "Investigations using RADARSAT data and other archived data from the Alaska SAR Facility")

Ted A. Scambos, National Snow and Ice Data Center, University of Colorado
Boulder, CO 80309-0449 teds@icehouse.colorado.edu 303/492-1113

NASA Research Announcement 94-MTPE-05
NASA Award Number: NAG5-4179
University of Colorado Grant Number 153-2439

SUMMARY

The grant is a collaboration between this investigator and Dr. Mark Fahnestock of the University of Maryland, Dr. Ron Kwok of Jet Propulsion Laboratory, and Dr. Robert Bindschadler of NASA's Goddard Space Flight Center. The University of Colorado portion of the work included ice shelf monitoring of the Antarctic Peninsula and West Antarctic coast using AVHRR data from the Polar 1-km Data Set, archived at NISDC. These data were intended to extend the temporal coverage available from Radarsat ScanSAR of the ice shelves and outlet streams. The grant also funded studies of ice velocity in outlet glaciers of the West Antarctic Ice Sheet (WAIS), specifically, the Sulzberger Bay area, Ice Stream D, and the Thwaites/ Pine Island Glacier system.

RESULTS

Ice Shelf Patrol:

A review of the Polar AVHRR 1-km Level 1B Data Set at NSIDC has yielded several hundred scenes useful for the ice shelf monitoring collection. From the selected scenes, we created enhanced panchromatic (combined channel 1 and 2) and thermal (combined channel 4 and 5) scenes, yielding images with additional detail of the ice shelf surfaces in both summer and winter. We instituted regular monitoring of the Prince Gustav, Larsen, Wilkins, Bach, and George VI ice shelves in the first year, and in Year 2 expanded that to include the Venable, Abbott, Pine Island Bay, Dotson, and Getz ice shelves (essentially the whole north coast of the

West Antarctic). In the third year, we further extended the coverage to include the Ross, Ronne, Filchner, Riiser-Larsen, Fimbul, and Amery ice shelves. The Ice Shelf Patrol now monitors the majority of the ice shelves in the Antarctic, and has a detailed image record of front changes, calvings and melt activity over the period 1992 to the present. (The only area not regularly covered is the quadrant from 90E to 180E; the Australian program at University of Tasmania monitors this area). We have moved towards near-real-time coverage of most of these areas, using NOAA's Satellite Active Archive Data Center as a source for input AVHRR data.

The objective of monitoring the shelf fronts of the Antarctic is to determine the extent of shelf changes brought about by climate warming. A strong pattern of warming, with an increased number of melt days and increased melt ponding in the summer season was observed for several shelf areas near the Peninsula, but this pattern did not extend southward to the north coast of the West Antarctic in the period of observations. We identified indications of warming in the 1990s in all the northernmost Peninsula ice shelves, including the Prince Gustav, the Larsen 'A', Larsen 'B', Wilkins, and George VI ice shelves. Several of these shelves disintegrated in the period of observations, in some cases essentially disappearing. Surveys for melt ponding in the several ice shelves on the north WAIS coast showed no evidence of ponds.

Images of the Wilkins Ice shelf indicate that its northeastern corner underwent a rapid breakup sometime in late austral summer of 1993. In the January 13 1993 image of the area, extensive melt ponds are seen both in the northeastern Wilkins and the entirety of the George VI ice shelf. This confirmed an earlier report by Luccitta and Rosanova based on ERS-1 images, and refined the timing of the largest portion of the breakup (the earlier report only stated that the observed retreat occurred between July 1992 and October 1995). However, in their October 1995 image, the breakup appears to be continuing. Cracks are observed across the entire northern front of the shelf. Subsequent monitoring has shown only slight additional retreat up to July 1997, and in the recent summers, the tabular icebergs generated by the earlier breakup appear to be incorporated into fast ice that remained intact through the warm season. In March of 1998, a very large retreat occurred, comprising ~1000 km2 along much of the northwestern front. This retreat was identified first in AVHRR and later confirmed with SAR images.

Similarly, a pattern of breakup was identified in the northern Larsen ice shelf areas, specifically the Larsen 'A' and 'B'. A series of retreat events were recorded in AVHRR data, with events occurring in 1993, 1995, 1998, 1999, and (as this report is being written) 2000.

Retreat events are distinct from normal calving events. Normal calving events are comprised of one or a few relatively large icebergs, which calve along lines bounded by pinning points such as islands or peninsulas. These events may occur at almost any time of year. Retreat events are characterized by numerous calvings of hundreds of smaller icebergs, usually very elongate in shape (i.e., 5:1 or greater length to width) with the long axis parallel to the shelf front. The retreat calvings cause the front to embay well within the line between pinning points. In the case of the Larsen and Wilkins, we were able to show using historical data that a distinct change in shelf behavior occurred in the last two decades of the century.

The patrol images indicate that regions of breakup coincide closely with areas that express surface melt ponding during late summer. This link is established with the Larsen A, Wilkins, and George VI ice shelves. A careful survey of the southern Larsen, Bach, Venable, Abbot, and Getz using the patrol images shows no melt ponding and no evidence of breakup areas. The Larsen B has experience extensive melt ponding in its northern half during the 1990's, and its southern half has been relatively free of melt ponds. In the most recent major breakups of 1998, 1999, and the present, the northern portion of the shelf has disintegrated far more than the southern portion. We predict that the southern one-third of the Larsen 'B' will remain after the northern sections have disappeared, until melt ponding appears on the southern portion. (The southern section is the region between Cape Disappointment and the Jason Peninsula).

Both modelling and observation indicate that the presence of meltwater ponds at the surface, which implies a saturated firn and therefore a large reservoir of liquid water, leads to pervasive fracturing throughout the thickness of the shelf ice. With melt ponds at the surface, any crack that forms remains open and waterfilled, and cracks propagate through the entire thickness of the shelf (as first proposed by Weertman, 1973).

Outlet glacier velocity mapping

SPOT and Landsat ice flow mapping of the lower portion of Ice Stream D suggests a slowdown of approximately 0.8% per year between 1988 and 1995. However, these observations are very close to the limit of detection, and we await additional data from Landsat 7 images before we conclude that this large WAIS outlet glacier has slowed. Other studies have indicated that Ice Stream B has definitely slowed by about 1.5% per year since at least the 1960s, and initial reports are that Thwaites and Pine Island have increased in speed. In our study of Thwaites Glacier, funded by this grant and a related grant for work with Landsat 7 data, we reviewed the existing velocity data and acquired new data from additional Landsat image pairs. Our review concluded that much of the observed speedup in the Thwaites is downstream of the probable grounding line, and therefore possibly due to the removal of the Thwaites Iceberg Tongue in 1993. If subsequent image pairs or interferometric analysis indicates that this speedup is propagating upstream, it could signal an increase in ice discharge from the grounded ice of the WAIS into the ocean, and thus contribute a small but significant amount to the observed sea level rise.

Published results

Several talks and publications have directly resulted from this grant, and the funds have established a web-based ice shelf monitoring site using AVHRR data. The site is currently maintained by the NSIDC Data Center. See http://www-nsidc.colorado.edu/NSIDC/iceshelves.

Hulbe, C. L., Scambos, T. A., and Bohlander, J. A., 1997. Ice shelf breakup and retreat in the Antarctic Peninsula and factors affecting ice shelf stability. Eos, v. 78(46), p. F249.

Bohlander, J. A., and Scambos, T. A., 1997. Ice velocity mapping of Ice Streams D, F, and the Shirase Coast: flow dynamics and change. Eos, v. 78(46), p. F252.

Fahnestock, M. A., Scambos, T. A., and Payne, W., 1998. Summer snow melt patterns and disintegration of ice shelves on the Antarctic Peninsula. Eos v. 80, p. F327.

Bohlander, J. A., and Scambos, T. A., 1999. Velocity measurements for the Prestrud and Sulzberger Ice Shelves, West Antarctica. Submitted to Antarctic Journal of the U. S.

Scambos, T. A., Hulbe, C. , Fahnestock, M. A., and Bohlander, J.A., 2000. The link between climate warming and ice shelf breakups in the Antarctica Peninsula. Submitted to Journal of Glaciology.

Figures:

Please ignore numbers given on the printouts – they refer to the publication figures for the above papers.

Figure 1. Synopsis of ice shelf activity and melt ponding in the Antarctic Peninsula.

Figure 2. Shelf front history of the Larsen and Prince Gustav area, 1902 – 2000.

Figure 3. Shelf front history of the Wilkins area, 1928 – 1998.

Figure 4. Melt ponding variability over the Larsen B shelf in the period 1993 to 1995.

Figure 5. The relationship of melt season (determined from SSM/I) and ice shelf breakup events in the Antarctic Peninsula over the last twenty-two years.

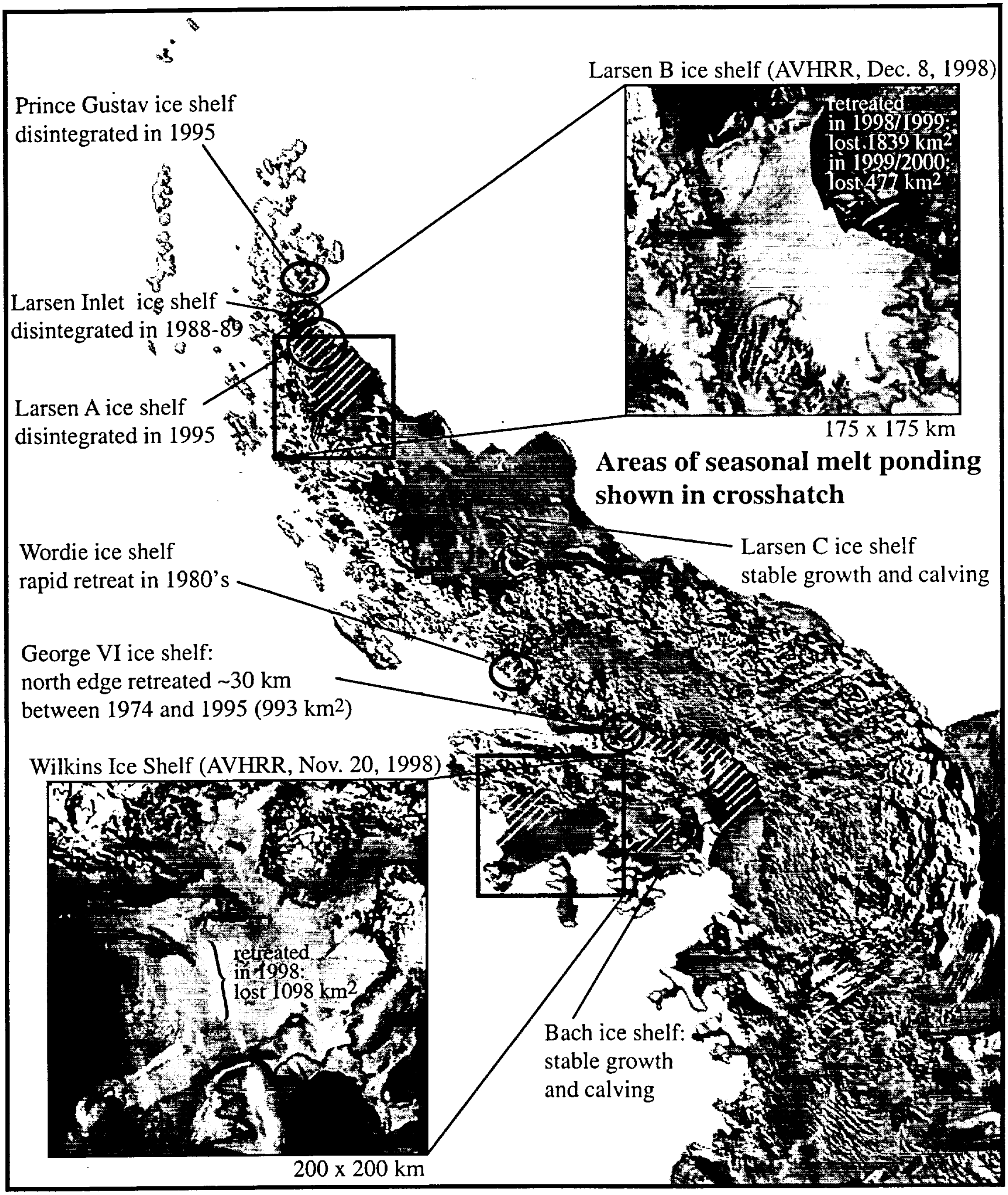

Figure 1 Scambos and others
please print at this size

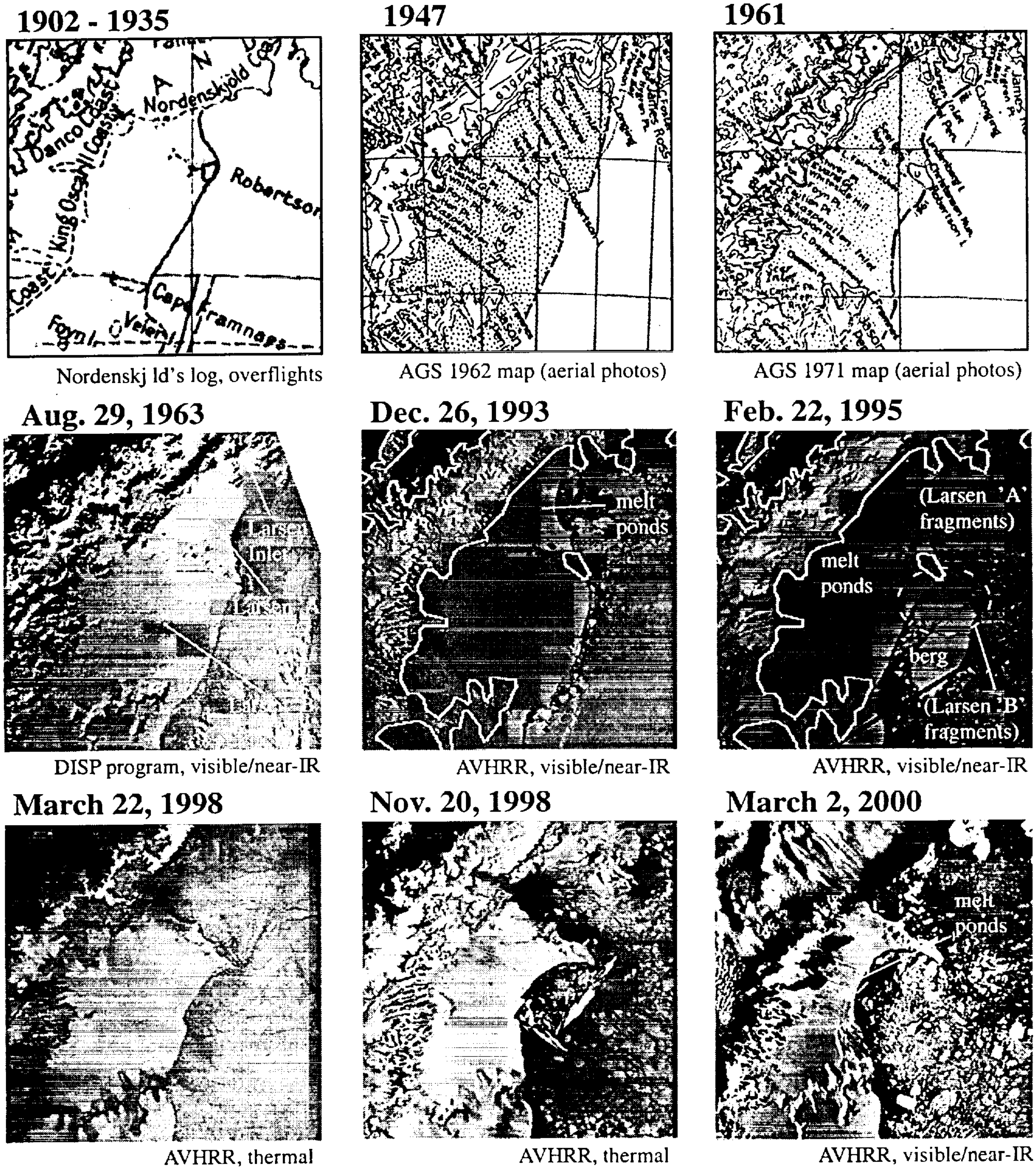

Figure 3 Scambos et al.
please print at this size

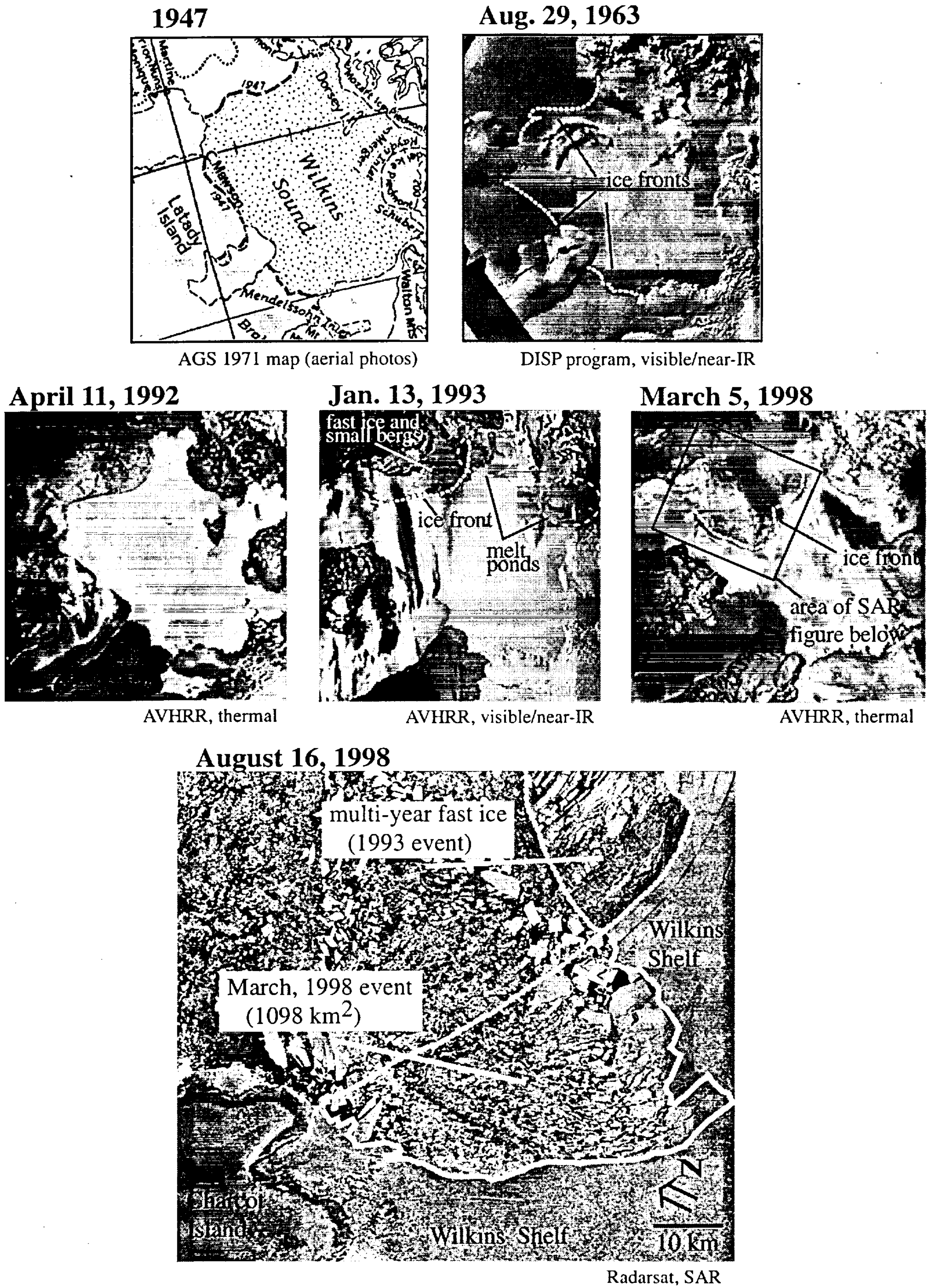

Figure 4 Scambos and others.
please print at this size

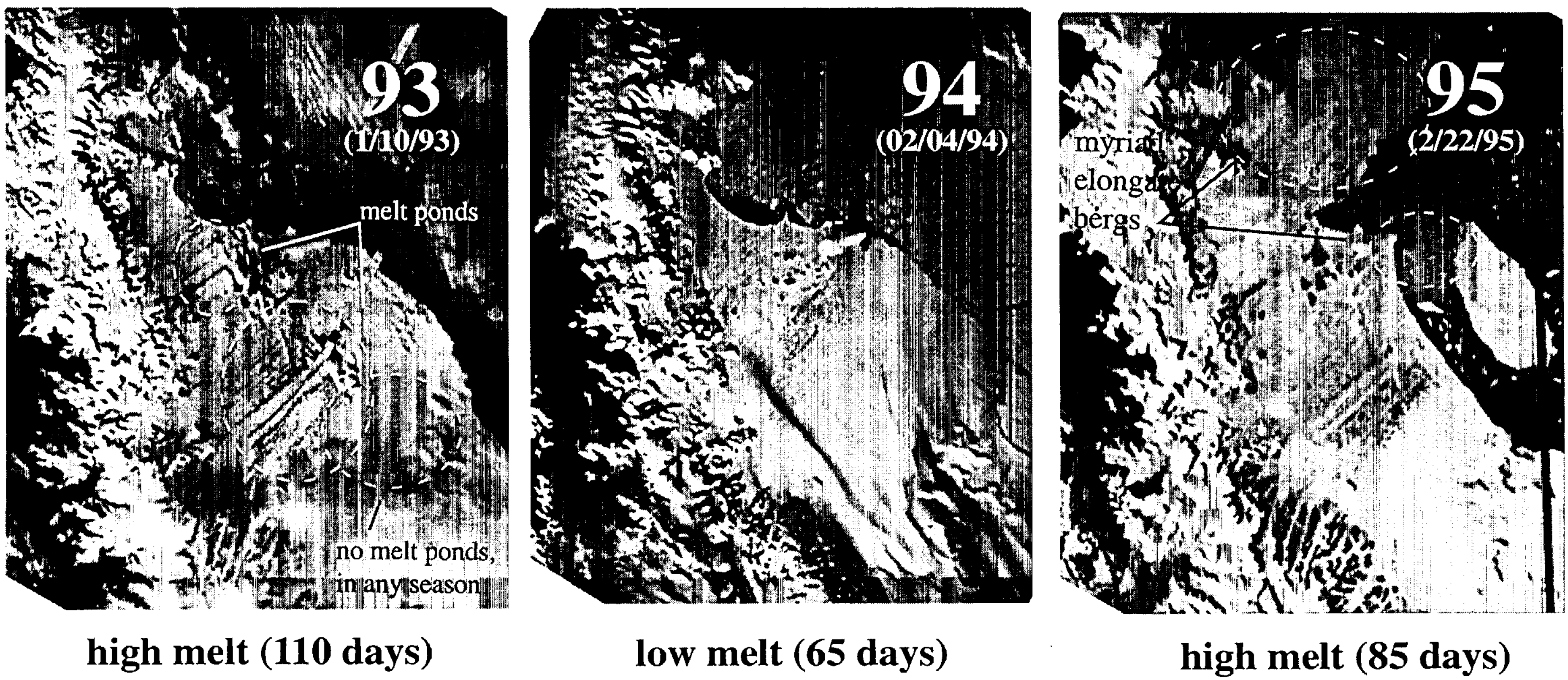

Figure 7 Scambos et al.

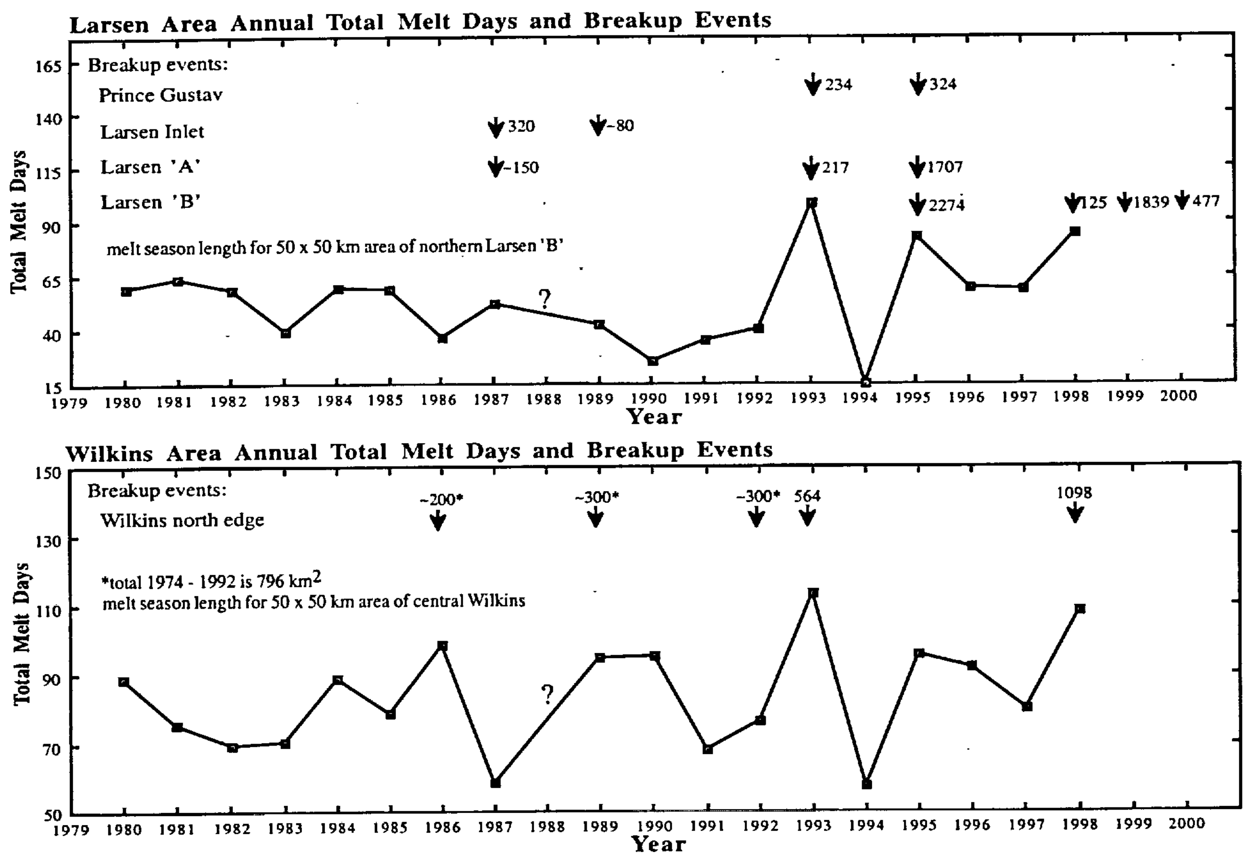

Figure 5 Scambos and others
please print at this size