Further Retreat of the Northern Larsen Ice Shelf and Collapse of Larsen B

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Introduction

The northern Larsen Ice Shelf (NLIS), Antarctic Peninsula, was subject to substantial retreat during the past decades (*Skvarca et al., 1999*). For the analysis of the retreat the ice shelf can be separated into several sections, which behave dynamically different (*Rack et al., 1999*) (Fig. 1). These are from north to south: Prince Gustav Channel (P-G), Larsen Inlet (L-I), the section between Sobral Peninsula and Seal Nunataks (Larsen A), the stagnant part around the Seal Nunataks (S-N), and the section between Seal Nunataks and Robertson Island (Larsen B). The ice shelf in P-G became separated from the southern sections during the late 1940s (*Cooper, 1997*). The total area of NLIS decreased from 15765 km^2 in 1986 to 4400 km^2 in March 2002. The first section which disintegrated was the ice shelf in Larsen Inlet; this happened between 1989 and 1992 (*Skvarca, 1993*). The retreat of the ice shelf sections north of Seal Nunataks culminated in the collapse of the sections P-G and Larsen A in early 1995, when the remaining parts of these ice shelves broke into hundreds of small icebergs within few days (*Rott et al., 1996*). At the same time, a large single iceberg and several small ones calved from Larsen B (2320 km^2 in total), which had advanced steadily for several decades before.

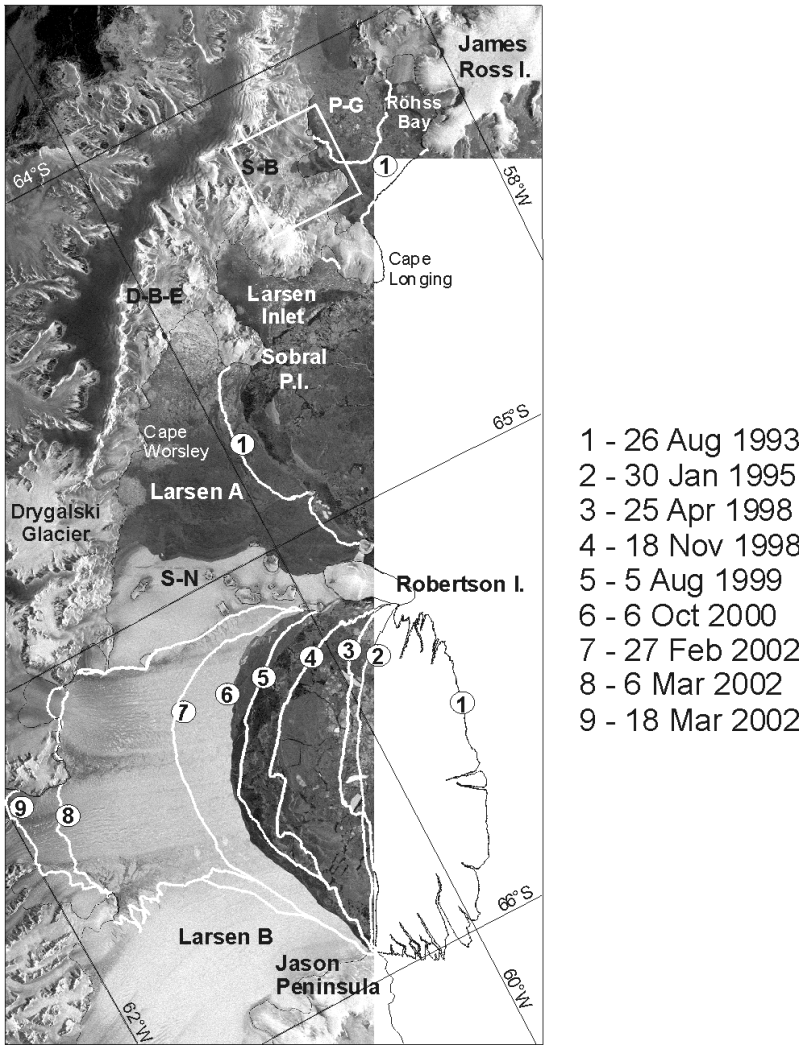

Fig. 1: ERS SAR image composite of the northern Larsen Ice Shelf (October 2000) with ice edge positions on several dates. The white rectangle indicates the position of Figure 2.

The retreat of NLIS coincided with a period of significant climate warming in the Antarctic Peninsula region (*Skvarca et al., 1998*). For example, the mean summer air temperature at Marambio station (64°14'S, 56°37'W), 180 km northeast of Seal Nunataks, was –1.9 °C with a linear increase of 0.074°C/a in the period 1971-97. Major retreat was observed during summers with air temperatures significantly above average, eg. in 1992/93 (+0.2°C) and 1994/95 (+0.6°C). According to measurements of several weather stations also summer 2001/02 figures among the warmest throughout the whole region. Long melt seasons and the existence of melt water are argued to be one main factors to cause the disintegration of ice shelves (*Scambos et al., 2000*).
The analysis of the areal changes presented here is primarily based on ERS SAR images and a ScanSAR image of the ESA's ENVISAT satellite, which was launched on 1 March 2002.

Retreat of grounded and floating ice north of Seal Nunataks after 1995

Shortly after the break up of ice shelves in 1995, also grounded ice of previous contributing glaciers started to retreat and accelerate (*Rott et al., 2002*). As an example, the terminus position of Sjögren and Boydell Glacier is plotted in Fig. 2 for several dates. S-B glaciers drain a 700 km^2 catchment basin and represented the main inflow to the P-G ice shelf (*Rack, 2000*). Due to the retreat after the ice shelf break-up in 1995 the glaciers were separated from each other in summer 2002. The ice edge retreated up to 6.3 km between October 1995 and March 2002 corresponding to a loss of grounded ice of about 40 km^2. According to an interferometric SAR analysis the ice retreat coincided with a strong acceleration (by about a factor of 2) of the ice flow between 1995 and 1999. Similar observations were made at contributing glaciers of Larsen A: The loss of grounded ice at Dinsmoor-Bombardier-Edgeworth glaciers (D-B-E), the glaciers at Cape Worsley, and Drygalski glacier amounts to 47, 24, and 28 km^2, respectively. The total overall loss of grounded ice sums up to about 145 km^2 since January 1995. A detailed motion analysis for the period 1995-99 was possible for Drygalski glacier, where the increase of velocity is up to three-fold at the terminus, but is also clearly pronounced further upstream (*Rott et al., 2002*).

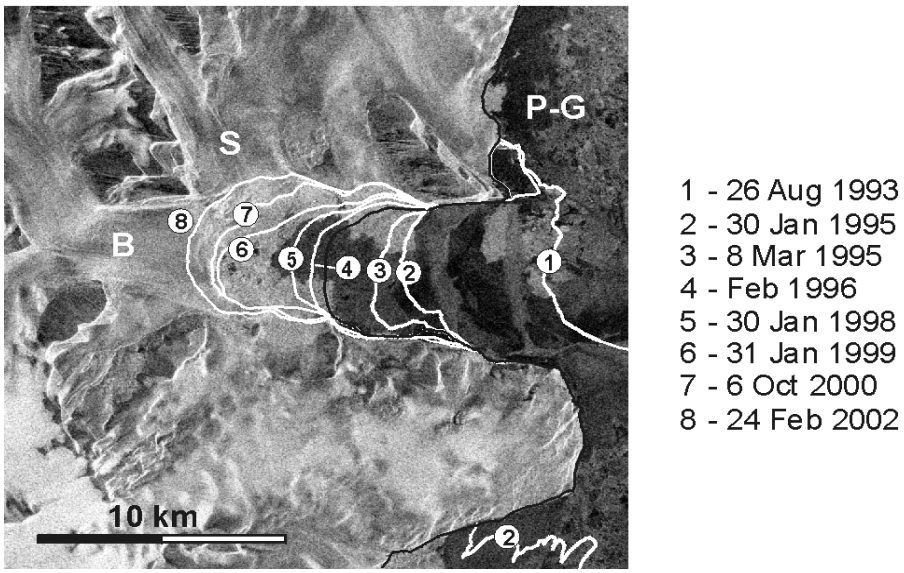

Fig. 2: Retreat of floating and grounded ice at Sjögren (S) and Boydell (B) Glaciers between 1993 and 2002. The black line is the former grounding line.

In February 2002, also the small remnant parts of ice shelves in Prince Gustav Channel disappeared. In Röhss Bay and the inlet north of Cape Longing, 47 km^2 and 21 km^2 of ice shelf broke away. The NLIS north of Seal Nunataks has now completely disintegrated.

The retreat of Larsen B and the collapse in March 2002

After the iceberg calving in January 1995 at Larsen B, the southern half of the ice edge advanced again, but the northern half of the ice front continued to retreat. This indicated a change in the dynamics in comparison to the previous multiyear advance. Although the areal loss was small (170 km^2 until April 1998), field and satellite observations showed enhanced rifting in the northern and central parts. Model calculations from *Doake et al. (1998)* indicate that the ice shelf reached at this time a state of irreversible retreat. This was confirmed by field measurements of ice velocity, which showed a strong acceleration shortly before the break up (*Rack et al.,*

1999). First major calving along the whole ice edge was observed in November 1998, when 1193km^2 of ice broke off.
The collapse of the northern parts of Larsen B happened in February/March 2002. As known from interferometric analysis, the northern and southern boundaries of the disintegrating zones were already heavily rifted before the break up. According to meteorological observations at the automatic weather station Larsen Ice (66.97° S, 60.55° W) and satellite observations it is likely, that the final collapse started at the beginning of March during days with strong westerly winds and ended around 6th March. Fig. 3 shows the situation on 18th March and the ice edge position for three dates. About 3200 km^2 of Larsen B have fractured into thousands of small icebergs and ice fragments, and form a plume which is sharply delineated towards the east. During the disintegration, icebergs moved fast towards southeast, whereas large icebergs outside the embayment (e.g. A-38B, which calved from Ronne Ice Shelf in 1998) moved with the Weddell gyre slowly towards north.
The ENVISAT image shows that icebergs which calved at the beginning and from the central and southern parts are in general larger. From the southern part of the ice shelf, where the ice is thicker, only one single large iceberg calved off.

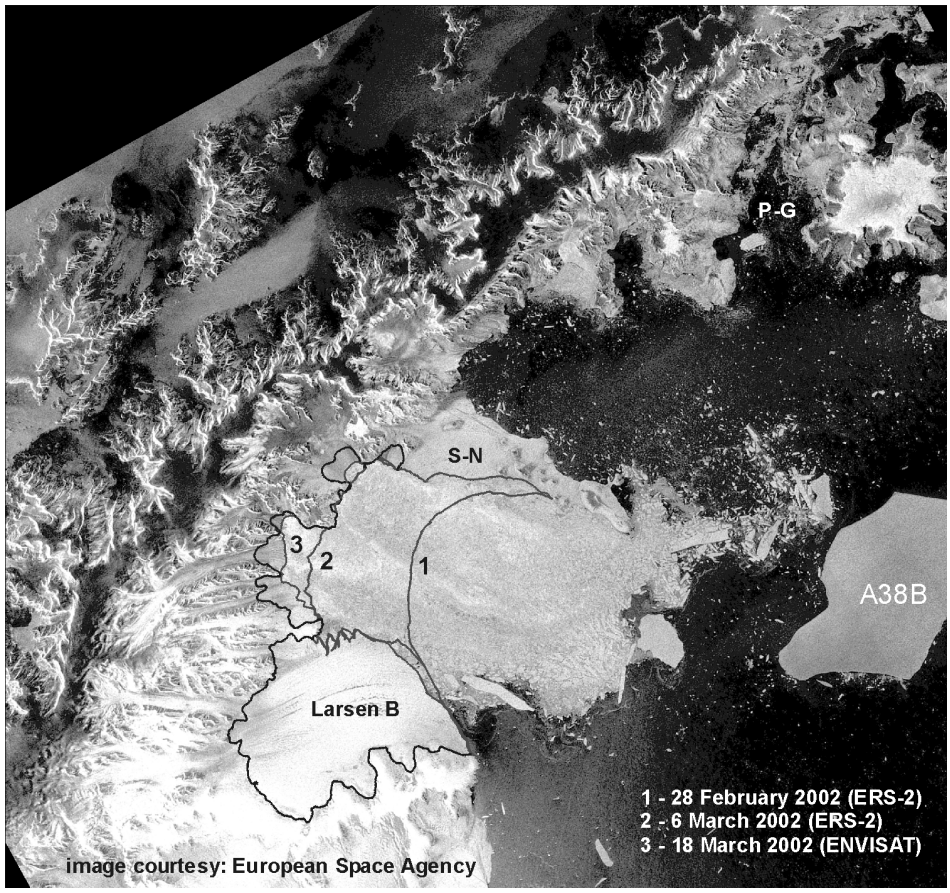

Fig. 3: Disintegration of Larsen B as seen on a ENVISAT ScanSAR image on 18 March 2002.

Remarks

The disintegration event at Larsen B in March 2002, which resembles that of Larsen A seven years before, has still to be analysed in detail. The dynamics of retreating ice shelves is still poorly understood, as the comparison of real and synthetic interferograms shows (*Rack et al., 2000*).
North of Seal Nunataks a significant change in the flow behaviour at various outlet glaciers was observed soon after the ice shelf break up. This suggests a sensitivity of glacier flow to ice shelf backpressure. So far, no change in the dynamics of contributing glaciers at Larsen B was observed.
The ice shelf around the Seal Nunataks, about 950 km^2 large, is now bordered by the open sea towards the north and the south, and the disintegration of this section has to be expected for the near future.
Investigations of sea sediments (*Pudsey and Evans, 2001*) below the former P-G ice shelf show, that this section was not existing in the Holocene warm period about 5000 to 2000 years ago. This is probably not the case for Larsen B, which is possibly disintegrating for the first time in the Holocene (*Domack et al., 2002*).

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References

Cooper, A.P.R., Historical observations of Prince Gustav Ice Shelf, *Polar Rec*., **33** (133), 538-552, 1997.

Doake, C.S.M., H.F.J. Corr, H. Rott, P. Skvarca, and N.W. Young, Breakup and conditions for stability of the northern Larsen Ice Shelf, Antarctica, *Nature*, **391**, 778-780, 1998.

Domack, E. and 10 others: a historical and paleoenvironmental perspective. Abstract, workshop on Antarctic Peninsula climate variability, Hamilton College, Clinton, NY. April 3-5, 2002.

Pudsey, C.J. and J. Evans, First survey of Antarctic sub-ice shelf sediments reveals mid-Holocene ice shelf retreat, *Geology*, **29** (9), 787-790, 2001.

Rack, W., H. Rott, A. Siegel, and P. Skvarca, The Motion Field of Northern Larsen Ice Shelf, Antarctic Peninsula, Derived from Satellite Imagery, *Ann. Glaciol.*, 29, 261-266, 1999.

Rack, W., C.S.M. Doake, H. Rott, A. Siegel, and P. Skvarca, Interferometric analysis of the deformation pattern of the northern Larsen Ice Shelf, Antarctic Peninsula, compared to field measurements and numerical modeling, *Ann. Glaciol.*, 31, 205-210, 2000.

Rack, W., Dynamic Behavior and Disintegration of the Northern Larsen Ice Shelf, Antarctic Peninsula, Doctoral Thesis, Science Faculty, Univ. of Innsbruck, Austria, p. 166, 2000.

Rott, H., P. Skvarca, and T. Nagler, Rapid collapse of northern Larsen Ice Shelf, Antarctica, *Science*, **271** (5250), 788-792, 1996.

Rott, H., W. Rack, T. Nagler, and P. Skvarca, Climatically Induced Retreat and Collapse of Northern Larsen Ice Shelf, Antarctic Peninsula, *Ann. Glaciol*., 27, 86-92, 1998.

Rott, H., W. Rack, P. Skvarca, and H. de Angelis, Northern Larsen Ice Shelf – Further Retreat after the Collapse, *Ann. Glaciol*., 34, 277-282, 2002.

Scambos, T.A., C. Hulbe, M. Fahnestock, and J. Bohlander, The link between climate warming and break-up of ice shelves in the Antarctic Peninsula, *J. Glaciol*., **46** (154), 2000.

Skvarca, P., Fast recession of the northern Larsen Ice Shelf, monitored by space images, *Ann. Glaciol.*, 17, 317-321, 1993.

Skvarca, P., W. Rack, H. Rott, and T. Ibarzábal-Donángelo, Evidence of Recent Climatic Warming on the Eastern Antarctic Peninsula, *Ann. Glaciol.*, 27, 628-632, 1998.

Skvarca, P., W. Rack, and H. Rott, 34 year satellite time series to monitor characteristics, extent and dynamics of Larsen B, Antarctic Peninsula, *Ann. Glaciol*., 29, 255-260, 1999.