Significant Ice Retreat in the Region Patagonia - Antarctic Peninsula Observed by ERS SAR

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Abstract

Areal changes and flow dynamics of glaciers of the Southern Patagonian Icefield (SPI) and of northern Larsen Ice Shelf (LIS) on the Antarctic Peninsula have been investigated based on ERS-1 and ERS-2 SAR data and on field work. After a period of steady retreat, coinciding with regional atmospheric warming during the last five decades, the two northernmost sections of the LIS (north of 65°S) disintegrated within a few days in early 1995. At the same time a large calving event occurred also in the section of the LIS south of 65°S. Recent observations of the ice front and of rifting zones indicate that the retreat of this section might accelerate in the near future. Studies of major outlet glaciers on the east side of the SPI, which extends from 48.3°S to 51.5°S, revealed significant retreat for the majority of glaciers. As an example, areal changes of Upsala Glacier, calving into Lago Argentino, are shown. The retreat accelerated considerably after 1993 resulting in unusually large calving events. The region Patagonia - Antarctic Peninsula, located in the west wind zone, reveals steep climatic gradients and therefore is particularly sensitive to climate change as indicated by the retreat of glaciers and ice shelves.
Keywords: ERS, SAR, Antarctica, Patagonia, glaciers

Introduction

The paper reports on glaciological research carried out in Patagonia (southern Argentina) and on the northern part of the Antarctic Peninsula, based on ERS-1 and ERS-2 SAR data and on field work. The SAR data were provided by ESA for the experiment Nr. AO2.A101 on "Comparative Investigations of Climate Sensitivity and Dynamics of Glaciers in Antarctica, Patagonia, and the Alps" (Principal Investigator H. Rott).

The investigation sites are located in a region orientated north-south, bounded longitudinally by 60°W and 74°W, and latitudinally by 49°S and 66°S (Fig. 1). The investigations were carried out on outlet glaciers of the Southern Patagonian Icefield (SPI) and on the northern Larsen Ice Shelf (LIS). Both regions are located in the west wind zone. The Andes mountain chain of Patagonia and the mountain range of the Antarctic Peninsula are the only barrier for the strong westerly winds at these latitude zones. Consequently, there are strong orographic effects resulting in high precipitation on the western and central parts of the mountains, and significant decrease of precipitation towards the east. The glaciers and ice shelves studied were on the east side of the mountain ranges which are nourished by ice streaming down from accumulation basins originating at the main divide between Pacific and Atlantic. Both the SPI and northern LIS have been subject to major ice retreat for about five decades, with considerable acceleration during the last few years. ERS SAR images are providing the opportunity to monitor these changes. SAR time sequences enabled not only the keeping track of the retreat during several years, but also the studying of the collapse of the two northernmost sections of the LIS with remarkable detail.

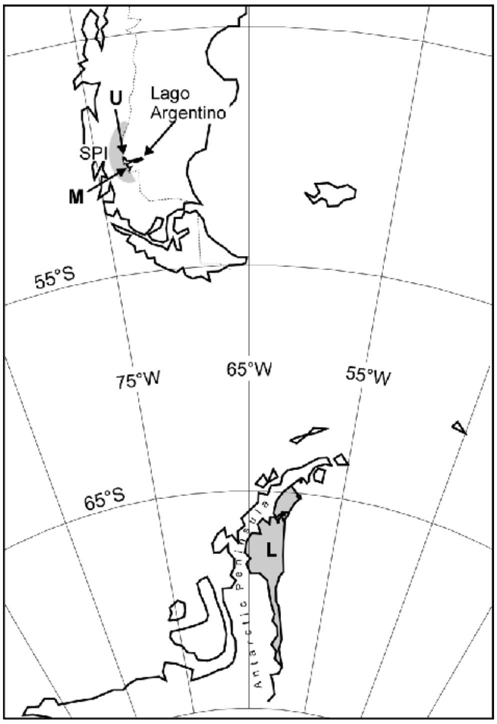

Figure 1. Map of the investigation area Patagonia - Antarctic Peninsula. U - Upsala Glacier and M - Moreno Glacier on the Southern Patagonian Icefield, L - Larsen Ice Shelf.

2. The retreat of the northern Larsen Ice Shelf

The LIS extends along the eastern side of the Antarctic Peninsula from latitude 64°S to 74°S. We studied the dynamics of the LIS north of Jason Peninsula (66°S) where drastic changes have occurred over the last few years. For the analysis we divided the ice shelf into 4 sections (Fig. 2):

(1) Jason Peninsula to Seal Nunataks. In this region the area of the grounded catchment basin draining towards the ice shelf is presently about 10% smaller than the floating section, though the mass inflow from the grounded part is significantly larger than the in situ accumulation (Rott *et. al.*, 1996). The ice velocities in the centre, about 15 km from the ice edge, were 420 m per year in 1996. Ice thicknesses range from 200 m in the north to 280 m in the south.

(2) The ice shelf around Seal Nunataks. This part of the LIS shows very little motion. Several nunatak peaks stand proud of the ice shelf, which is cut off from the ocean by the ice-covered Robertson Island.

(3) Seal Nunataks to Sobral Peninsula. This part was nourished by two large and several small glaciers descending from the mountains. Before the collapse the velocities in the central part of the ice shelf were about 200 m per year.

(4) The section between James Ross Island and the Antarctic Peninsula. This section was fed partly by ice drainage from the Antarctic Peninsula, partly by ice input from James Ross Island, and partly by long-term snow accumulation on fast sea ice. It was separated from the main part of the LIS in 1957 or 1958 (Doake, 1982).

Table 1. Ice shelf areas (km2) derived from ERS SAR images.

	2-Jul-92	26-Aug-93	30-Jan-95	8-Mar-95	28-Oct-95	29-Feb-96	1-Nov-96
Section 1	11775	11770	9496	9496	9501	9483	9391
Section 3	2244	2027	1101	368	268	251	253
Section 4	762	528	224	211	204	175	165

The parts of the LIS north of Robertson Island have retreated slowly but constantly since the 1940's (Doake, 1982,). This retreat coincides with a period of atmospheric warming at the Antarctic Peninsula (Vaughan *et. al.*, 1996). The retreat accelerated considerably during the last few years before the final collapse, as observed by means of ERS-1 SAR images (Rott *et. al.*, 1995). Sections 3 and 4 disintegrated almost completely early in 1995. In Table 1 the ice shelf areas of sections 1, 3, and 4 are listed for the period July 1992 to November 1996, as derived from ERS SAR images. The section 2 remained stationary because the nunataks and Robertson Island are acting as pinning points.

The total decrease in area between 2 July 1992 and 1 November 1996 amounts to 4972 km2. Whereas section 1 decreased by 20%, only small parts of sections 3 and 4 remain. The main changes took place during a period of a few days in early 1995 when a total of 4200 km2 broke away in the 3 sections (Rott *et. al.*, 1996).

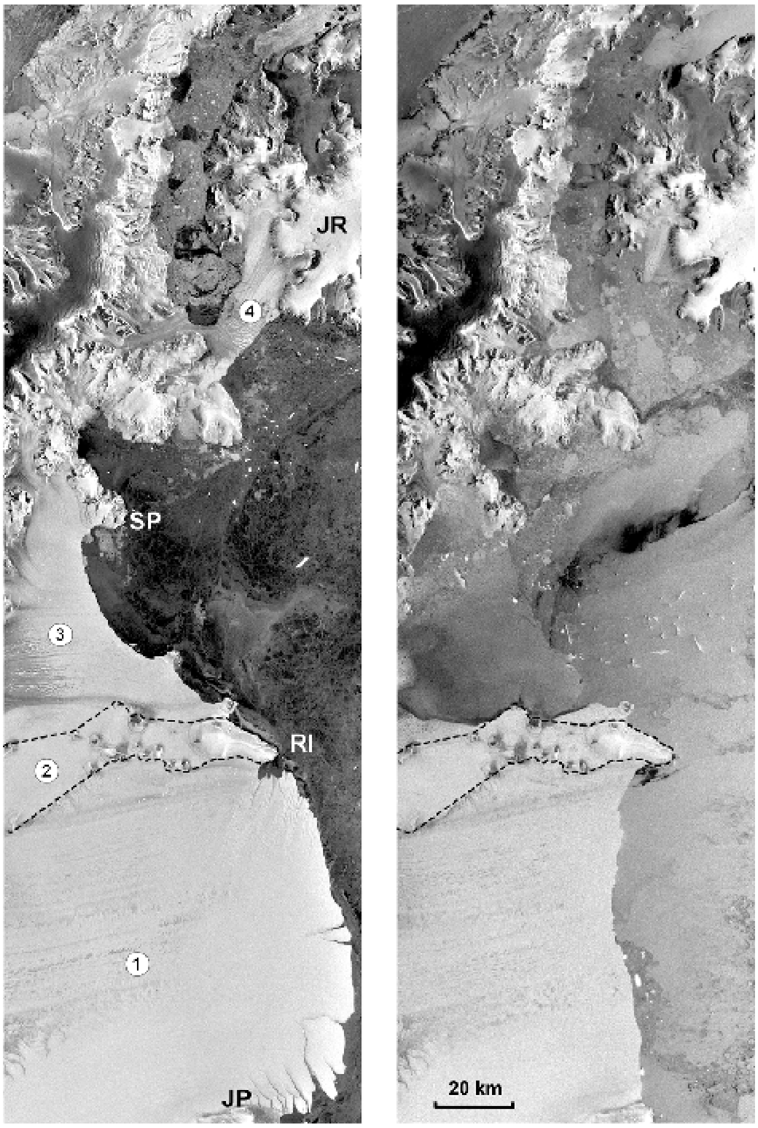

Figure 2. Mosaic of ERS SAR images of the northern Larsen Ice Shelf (LIS) from 26 August 1993 (left, ERS-1) and 17 November 1996 (right, ERS-2). The numbers 1 to 4 refer to the 4 sections of LIS which were studied. JR - James Ross Island, SP - Sobral Peninsula, RI Robertson Island, JP - Jason Peninsula.

Figure 3 shows an ERS-2 SAR image of section 1, acquired on 1 November 1996. The grounding line and the boundary versus ice shelf section 2 (in the upper part of the image) are enhanced, as well as the ice front towards the ocean which was mapped from SAR images of 26 August 1993 and 8 March 1995. The ice front had advanced seawards by a total of 5 to 6 km between 1975 and January 1995, with some minor calving losses south of Robertson Island after 1992. The large calving event, with a total calving loss of 2270 km2, took place between 25 and 30 January 1995 (Rott *et. al.*, 1996). A large iceberg with an area of 1700 km2 and many small pieces, covering a total of 550 km2, broke away. After this event the northern part of the ice front retreated further by distances between 1 km and 3.5 km until November 1996. The southern part advanced between 400 m and 800m. Since 1994 the number and size of rifts increased. In Fig. 3 the main rifts are visible; they are located in a zone up to 25 km inland from the ice front and are extending over several tens of kilometers along convex lines. Though field measurements revealed no significant changes of ice velocity between 1994 and 1996, further retreat of the ice front should be expected in the near future because of the irregular shape of the ice/ocean boundary and the rising number of rifts.

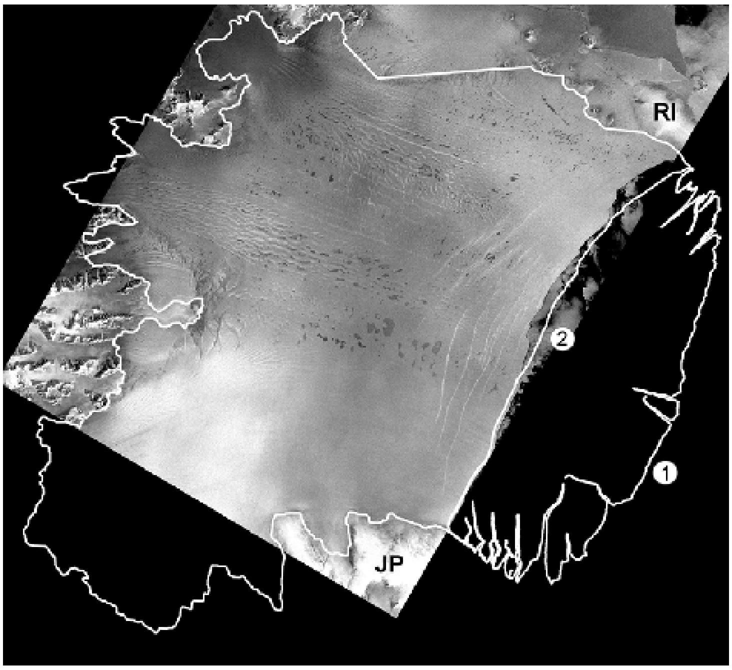

Figure 3. ERS-2 SAR image of Larsen Ice Shelf (section 1) between Jason Peninsula (JP) and Robertson Island (RI) from 1 November 1996. The grounding line and the ice boundaries on 26 August 1993 (1) and 8 March 1995 (2) are plotted.

3. The collapse of two sections of the Larsen Ice Shelf

During the calving event in January 1995 sections 3 and 4 of the ice shelf disintegrated almost completely leaving only small separated fragments in protected inlets. In the early 1990's, section 4, having a size of about 30 km x 25 km, connected James Ross Island and the Antarctic Peninsula and bridged the Prince Gustav Channel. The northern part of this small ice shelf broke away between July 1992 and August 1993, reducing the width of the "bridge" to 10 km (Rott *et. al.*, 1996). With the final disintegration event in January 1995 Prince Gustav Channel became open for navigation the first time, and only small parts of the ice shelf remained along the coast of the Peninsula and in Rhöss Bay at James Ross Island. Since January 1995 the areas of these remnant parts further decreased, retreating partly even beyond the grounding line of the glaciers which previously had nourished the ice shelf.

The most rapid retreat was observed for section 3, documented by a sequence of ERS SAR images in January 1995 (Rott *et. al.*, 1996). Fig. 4 shows an ERS-2 SAR image from 1 November 1996 where the bay between Seal Nunataks and Sobral Peninsula, which previously had been occupied by the ice shelf, is covered with sea ice. The position of the ice front has been mapped from ERS SAR images for several dates between July 1992 and November 1996, and parts of the analyzed ice front positions are shown in Fig. 4. Between 1975 and 1989 the ice front between Lindenberg Island and Sobral Peninsula retreated at an average rate of about 1 km per year. The retreat accelerated during summer 1992/93 when about 200 km2 of the ice shelf were lost by calving (Rott *et. al.*, 1995). Though the retreat was slower during the following year, the formation of rifts and crevasses intensified considerably, as known from a field campaign in October/November 1994.

The final disintegration took place during a period of intense north-westerly winds and high temperatures and coincided with the big calving event of the adjoining southern section (section 1). Between November 1994 and 28 January 1995, the ice front between Lindenberg Island and Sobral Peninsula retreated by about 5 km. Lindenberg Island acted as a pinning point that maintained the ice front south of the island, but due to the retreat north of it, the stress vector at the ice front rotated until it was finally aligned parallel to the flow lines. This triggered longitudinal rifting in addition to transverse rifting and lead over to the rapid collapse between 28 January and 2 February 1995. The changes between 25, 28 and 30 January have been analyzed from ERS SAR images. Ground based observations indicate that the ice shelf had retreated until 2 February to a position close to that derived from the ERS-1 SAR image of 8 March 1995 (Fig. 4). The ice fractured into many comparatively small icebergs of longitudinal form with typical lengths of several kilometers. The rapidity of the collapse and the small size of the icebergs indicate a dominant role of fracture dynamics which was enhanced by infiltration of meltwater.

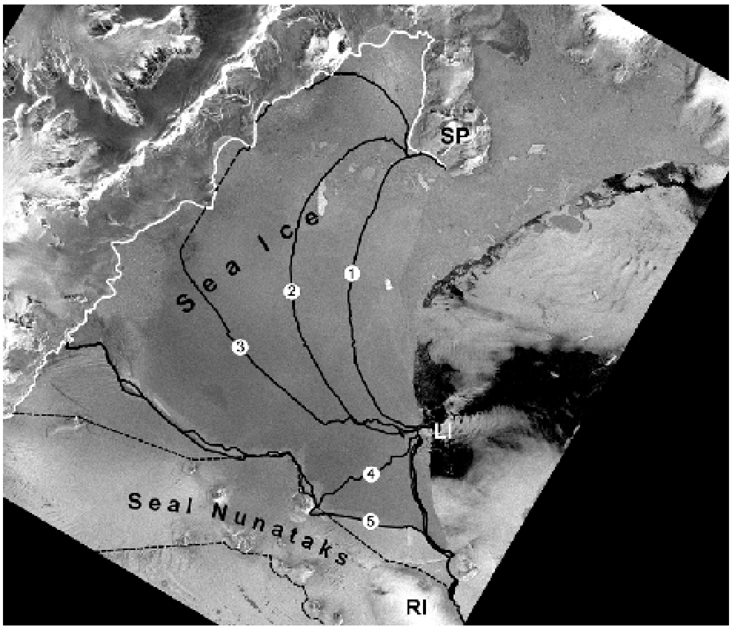

Figure 4. ERS-2 SAR image of Larsen Ice Shelf (section 3) between Seal Nunataks and Sobral Peninsula (SP) from 1 November 1996. The bay between Seal Nunataks and Sobral Peninsula is filled with sea ice. The position of the ice front is shown for the following dates: 1 - 16 February 1993, 2 - 28 January 1995, 3 - 30 January 1995, 4 - 8 March 1995, 5 - 1 November 1996. LI - Lindenberg Island, RI - Robertson Island.

4. The retreat of the Upsala Glacier, Patagonia

The SPI covers approximately 13.000 km2 and stretches for 350 km from 48.3° S to 51.5° S. The main accumulation zones are located on extended plateaus at elevations between 1200 m and 2500 m a.s.l. The large western outlet glaciers are calving into the Pacific fjords and the major eastern outlet glaciers into the big Patagonian lakes. Positions of frontal moraines, aerial photographs from the mid-1940s and the late 1970s, and sparsely available optical satellite imagery from the 1980's indicate a general trend of glacier retreat for the SPI. However, some of the glaciers behave differently because the terminus response depends not only on climatic factors but also on topographic characteristics and calving dynamics. One of the exceptions is Moreno Glacier which calves into Lago Argentino and the extent of which has been comparatively stable during the last fifty years. On Moreno Glacier an extended field program is presently conducted by the authors, involving measurements of ice motion, ice thickness, ablation, and calving rates. However, the knowledge about other glaciers is quite limited because of the adverse weather conditions and difficult access. Therefore SAR offers unique opportunities for obtaining synoptic information on extent and dynamics of the Patagonian glaciers.

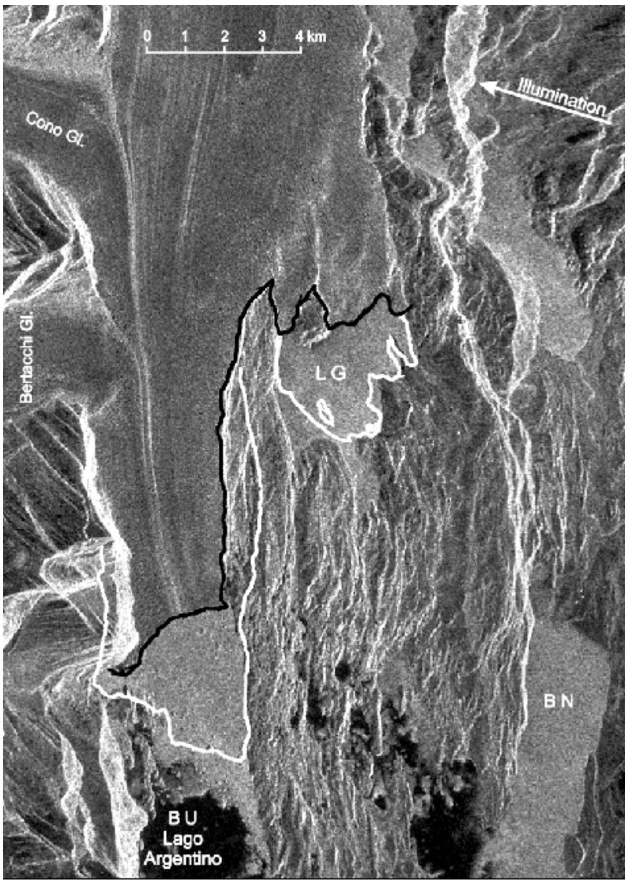

Figure 5. ERS-1 SAR image from 12 January 1993 showing the terminus of Upsala Glacier. BU - Brazo Upsala, LG - Lago Giullermo. The black line enhances the glacier boundary in the SAR image, the white line shows the glacier boundary on 24 February 1981 derived form aerial photography.

As an example, we present the analysis of terminus changes of Upsala Glacier using ERS SAR data. Upsala Glacier, covering 870 km2 in area, is one of the three main glaciers of the SPI. The main glacier stream is calving into Brazo Upsala of Lago Argentino and a side arm into Lago Guillermo (Fig. 5). After an almost stationary period in the 1970's pronounced retreat was observed after 1981, accelerating since 1993. In Figure 5 the glacier boundaries of 24 February 1981 and 12 January 1993 can be compared. At Brazo Upsala the frontal area decreased by 9.4 km2 between the two dates, and the area along the orographically left margin by 5 km2. The decrease at Lago Guillermo amounted to 8.5 km2. The most recent frontal changes at Brazo Upsala are shown in Figure 6, derived from ERS-1 and ERS-2 SAR images. Between 26 August 1993 and 11 December 1994 the front retreated between 0.6 km in the western part and 1.5 km in the eastern part, with an areal loss of 3.4 km2. Most of this retreat can be attributed to a big calving event in mid 1994 blocking the entrance to Brazo Upsala with icebergs for several months (Skvarca *et. al.*, 1995). Between January 1995 and October 1996 only minor changes occurred. Geodetic measurements at 7 points about 1 km from the front in 1993 showed an average surface lowering of 33 m for the period 1990-93 (Skvarca *et. al.*, 1995). These recent observations indicate significant changes of mass balance and dynamics of Upsala Glacier which is in accordance with the observed retreat of the majority of glaciers in Patagonia.

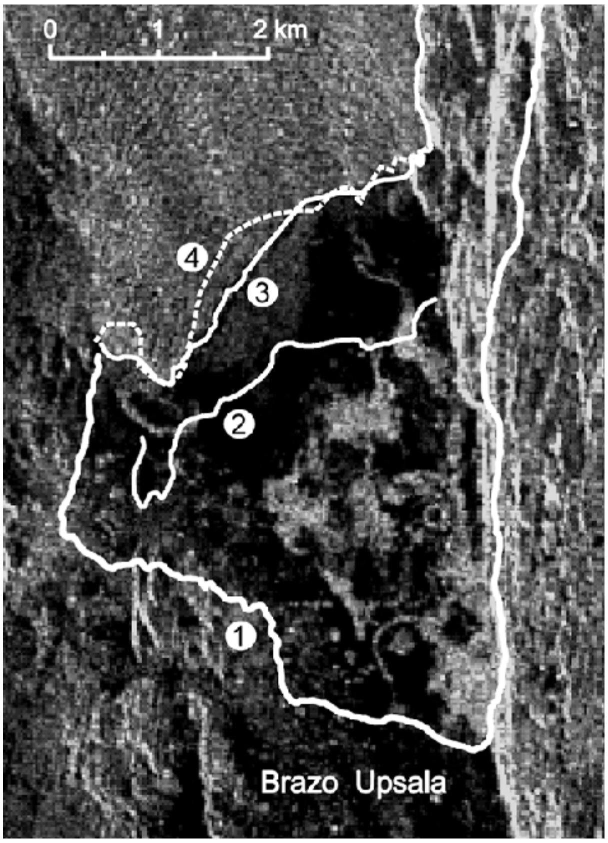

Figure 6. Calving front of the main stream of Upsala Glacier on ERS-1 SAR image from 22 January 1995. The dates for the frontal positions are: 1 - 24 February 1981 (from air photo), 2 - 26 August 1993 (ERS-1), 3 - 22 January 1995 (ERS-1), 4 - 20 October 1996 (ERS-2).

5. Conclusions

Floating ice shelves as well as calving glaciers are sensitive to climate change. The observed retreats of ice shelves on the Antarctic Peninsula and of outlet glaciers of the Patagonian Icefield provide clear hints on changing climatic conditions in this part of the southern west wind zone. The northern LIS is close to the climatic limit for the existence of ice shelves, and therefore changes in atmospheric and oceanic patterns have dramatic effects as indicated by the collapse of the two northernmost sections. Concluding from the magnitudes of mass fluxes, it would need a few centuries under favourable climatic conditions before the ice shelf could re-form. On the other hand, an ice shelf which has retreated beyond a critical limit due to disturbed mass balance may collapse within a very short period, as revealed by analysis of the time sequences of ERS SAR data.

It cannot yet be assessed if the ice retreat in Patagonia and on the LIS indicates just regional changes of the atmospheric circulation patterns or can be assigned to global climatic change. In any case, this region of steep climatic gradients is of significant interest for studying ice/climate interactions and for learning about the dynamic response of ice shelves and glaciers. Repeated observations of the ice extent and dynamics, as provided by spaceborne SAR, are needed to advance the knowledge of these processes.

6. Acknowledgements

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