INTERNAL STRUCTURE OF ARIEBREEN, SPITSBERGEN, FROM RADIO-ECHO SOUNDING DATA

F. NAVARRO[1], M. GRABIEC[2], D. PUCZKO[3], U. JONSELL[4] AND A. NAWROT[5]

[1] Dept. Matemática Aplicada, ETSI de Telecomunicación, Universidad Politécnica de Madrid, Spain.
[2] Dept. of Geomorphology, Faculty of Earth Sciences, University of Silesia, Poland
[3] Institute of Geophysics, Polish Academy of Sciences, Poland
[4] Dept. of Earth Sciences, Uppsala University, Sweden
[5] Institute of Paleogeography and Geoecology, Adam Mickiewicz University, Poland

Introduction

Ariebreen (77º 01' N, 15º 29' E) is a small valley glacier (ca. 0.36 km^2 in August 2007) located at Hornsund, Spitsbergen, Svalbard, ca. 2.5 km to the west of Hornsund Polish Polar Station. Ariebreen, like many other Svalbard glaciers, has experienced a significant recession at least since the 1930s, and most likely since the end of Little Ice Age (LIA) in the early part of the 20th century. Moreover, the thinning rate of western Svalbard glaciers has shown an acceleration during the most recent decades. Ariebreen follows this general retreat pattern, as is shown in another contribution to this workshop (Petlicki et al., 2008). Most investigated glaciers in Hornsund area, in the neighbourhood of Ariebreen, are known to be polythermal (e.g. Hansbreen and Werenskioldbreen, Pälli et al., 2003). It has been suggested (Macheret et al., 1992) that the thinning of polythermal glaciers may result in a switch to cold thermal structure under appropriate conditions. The strong thinning experienced by Ariebreen during the recent decades makes it an ideal candidate to undergo such change.

The main aims of this contribution are to understand the internal structure of Ariebreen, in particular, its hydrothermal regime, and to determine whether the glacier is undergoing or has already experienced a transition from polythermal to cold structure. The main tool to accomplish this will be the analysis of radio-echo sounding data.

Ground-penetrating radar measurements and data analysis

During summer 2006 and spring 2007 radar profiles were done providing a full coverage of Ariebreen (Figure 1). The total length of useful radar profiles was 2200 m in the summer campaign and 4000 m in the spring campaign, resulting a total length of profiles of 6200 m. The radar data were acquired using an ice-penetrating radar Ramac/GPR with unshielded antennae, of 200 MHz in summer 2006 and 25 MHz in spring 2007. The choice of the 200 MHz antennae was dictated by the interest in accurately determining the presence and extent, or the absence, of a firn layer. For this reason, the sampling frequency within each radar trace was set quite high, 2012 MHz, resulting a total time window of 509 ns and thus limiting the maximum depth sampled to about 42 m. Consequently, the bedrock was not reached in the areas of thickest ice. Using the 25 MHz antennae, sampling frequency was set to 250 MHz, resulting a time window of 2044 ns, so that bedrock was reached in all cases. In addition to the radar data, navigation information from a stand-alone GPS receiver was also recorded; in the summer campaign, the profile endpoints were also measured by differential GPS.

No common midpoint measurements were done on this glacier in order to determine the radio-wave velocity (RWV). However, they are available, both for spring and summer periods, for the neighbouring Hansbreen glacier (Jania et al. 2005). On the basis of such measurements, we took a value of 168 m/μs (typical of cold ice) for the RWV at Ariebreen. This gives us a vertical resolution of the radar data of ±1.68 m for the 25 MHz antennae, and ±0.42 m for the 200 MHz antennae, considering the vertical resolution as one quarter of the wavelength in ice.

The processing of radar data included DC correction, amplitude scaling, band-pass filtering, deconvolution, migration where required and conversion to depth.

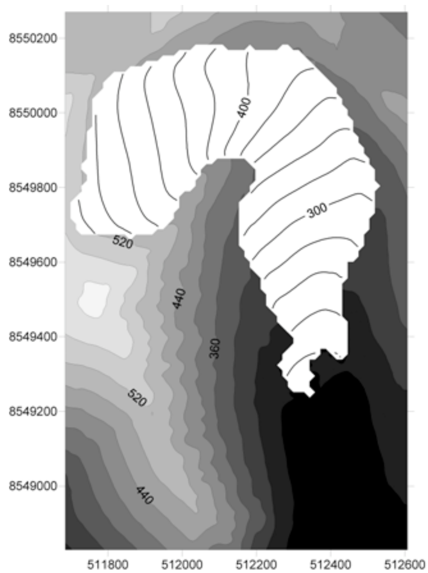

Figure 1. Left: Schematics of the radar profiles done in Ariebreen, drawn on an image showing the glacier extent in 1990. The straight blue lines correspond to profiles surveyed in summer 2006, and the remaining ones correspond to those surveyed in spring 2007. Right: Ariebreen surface topography based on geodetic measurements done by the authors in 2007.

Results, discussion and conclusions

The ice thickness map for 2006-2007, constructed from radar data, and the subglacial relief map, constructed by subtracting the ice thickness from the surface topography map, are shown in Figure 2. The average ice thickness in 2007 was only 22.29 ± 1.66 m. The thickest ice, with a maximum value of 81.24 ± 1.68 m, is found in the west-east orientated upper part of the glacier; thickness for the north-south orientated mid-lower part of the glacier only exceeds 50 m in its uppermost part. The lower part shows very thin ice. The subglacial relief map shows gentle slopes in the lower part of the glacier, steadily increasing as we approach the upper part.

The analysis of the radar sections shows three main features concerning the internal structure of Ariebreen:

1. Nearly absence of endoglacial diffractions. This is true for both high (200 MHz) and low (25 MHz) frequency radar data.
2. Absence of any internal reflector, which could be interpreted as an interface between cold and temperate ice layers. Again true for both high and low frequencies.
3. Absence of a firn layer or, if any, a very thin one (2-3 m). The vertical resolution of the radar data is 1.7 m for the 25 MHz radar and 0.4 m for the 200 MHz. Though the uppermost 2-3 m are obscured in the radar records, neither layering nor near-surface interface is visible below some 3 m depth.

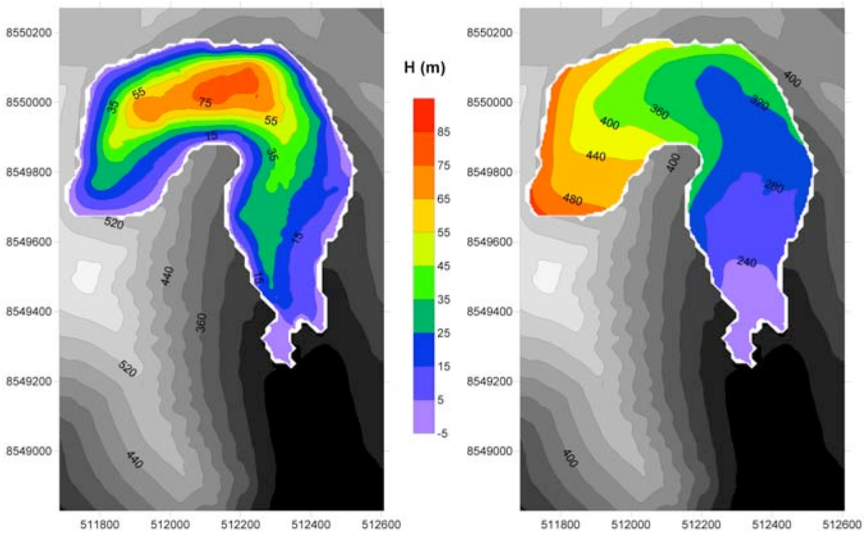

Figure 2. Left: Ice thickness map of Ariebreen in 2006-2007. Right: Subglacial relief map.

On the basis of the above assertions, we preliminarily conclude that Ariebreen is a cold glacier, in contrast with the polythermal structure of the neighbouring Hansbreen and Werenskioldbreen. This is, however, not surprising, because of the low ice thickness of Ariebreen, which allows for a relatively fast transmission through the ice column, and release through the glacier surface, of the geothermal heat flow warming the glacier bed. In the accumulation area, the extremely small thickness of the firn layer also implies that any possible heat generated by refreezing of percolating meltwater rapidly reaches the glacier surface and therefore does not substantially contribute to heating the glacier body. In the ablation area, if a polythermal structure were assumed the small ice thickness would also contribute to a fast transmission to the glacier surface of the latent heat generated by the freezing of liquid water in temperate ice at the cold-temperate interface, and therefore to the downward migration of the freezing front. This, combined with strong thinning, could justify a slow transition from polythermal to cold structure.

References

Jania J., Macheret Yu.Ya., Navarro F.J., Glazovskiy A.F., Vasilenko E.V., Lapazaran J., Glowacki P., Migala K., Balut A., Piwowar B.A. 2005. Temporal changes in the radiophysical properties of a polythermal glacier in Spitsbergen. Annals of Glaciology 42, 125-134.

Macheret Yu.Ya., Krass M.S., Glazovsky A.F. 1992: Structure, hydrothermal state and regime of subpolar glaciers. In V.M. Kotlyakov (ed.): Regime and evolution of polar ice sheets. Pp. 48-115. Saint-Petersburg: Gidrometizdat. (In Russian).

Pälli A., Moore J.C., Jania J., Kolondra L., Glowacki P. 2003. The drainage pattern of Hansbreen and Werenskioldbreen, two polythermal glaciers in Svalbard, Polar Research 22, 355-371.

Petlicki M., Lapazaran J., Navarro F., Glowacki P., Machío F. 2008. Ice volume changes of Ariebreen, Spitsbergen, during 1936-1990-2007. Workshop on the dynamics and mass budget of Arctic glaciers/ Glaciodyn (IPY) meeting, Obergurgl, Austria, January 2008.