DIGITAL MAPPING OF THE NORDAUSTLANDET ICE CAPS FROM AIRBORNE GEOPHYSICAL INVESTIGATIONS

by

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ABSTRACT

Airborne geophysical investigations of the previously little-studied Nordaustlandet ice caps (11 150 km²) took place in 1983, using SPRI 60 MHz radio echo-sounding (RES) equipment of 160 dB system performance. RES and navigational data were recorded digitally. Navigation used a ranging system (accurate to ±30 m) from aircraft to ground-based transponders, located by satellite geocivers, supplemented by the aircraft’s navigational instruments and timed crossings of known features. Ice surface and bedrock elevations were measured, using aircraft pressure altitude, terrain clearance, and ice thickness data. The mean error of 251 crossing points on Austfonna was 11 m. The reduced geophysical data are stored on a direct-access computer database. During 3400 km of flying, Austfonna (81 055 km²) was covered by traverses a nominal 5 km apart, whereas a 15 km-spaced grid was flown over Vestfonna (2510 km²). Maps of ice surface morphology and subglacial, bedrock topography were produced for Austfonna and Vestfonna, along with an ice thickness map of Austfonna. Austfonna reaches a maximum surface elevation of 791 m and ice thickness of 583 m. 28% of the bedrock area beneath Austfonna lies below sea level. RES yielded bedrock echoes for 91% of track over Austfonna, but only 52% over Vestfonna. This was probably due to warmer conditions on Vestfonna, resulting in greater absorption and scattering of electro-magnetic energy. Ice surface elevations are a principal data source in the revision of official Norwegian maps of Nordaustlandet.

METHODS OF DIGITAL MAPPING

SPRI Mk IV Radar and Digital Recording System

An SPRI Mk. IV pulse-modulated radar system, operating at a centre frequency of 60 MHz, was used during the 1983 field season. This equipment is a modified version of the 35 MHz SPRI Mk. II apparatus described by Evans and Smith (1969). A short pulse length of 300 ns and a logarithmic receiver with bandwidth of 15 MHz were used. System performance, the ratio of peak power output to receiver input noise, was 160 dB. Antenna gain and the effects of digital integration are not included in the value given for system performance. A de Havilland Twin Otter fixed-wing aircraft was used for RES in Svalbard. Simple dipole antennas were mounted under either wing, one for transmitting and the other for receiving. Antenna forward gain was 8.3 dB.
The digitization and recording of radio-echo pulses was controlled by a Z-80 based micro-computer, which also handled the recording of navigational data. Both radar and navigational information were logged onto magnetic tape. Data cartridges (conforming to International Standards Organization No. 4057), holding 3.2 M byte of data (c. 5 hr of airborne RES), were used to record data on tape in the aircraft. The data were then transferred to standard 1600 bp/s back-up, magnetic tape, prior to further reduction.

During airborne RES, data were recorded at two-second intervals. The mean of 8 'A' scopes (i.e. displays of log. returned power against time range), spaced uniformly over a one-second interval (c. 60 m along-track), was digitized and recorded on data cards. Reducing system noise through its integrating effect, increasing signal-to-noise ratio by 4.5 dB. The other second of each two-second cycle was spent writing this information, together with the navigational data, to tape. The micro-computer digitized each 'A' scope as 256 points, spaced at 100 ns intervals, giving a total time scale of 25.6 μs. This is equal to 2150 m in ice, using a velocity of 168 m μs⁻¹ for the velocity of radio waves in that medium. The nominal accuracy of the system was therefore 100 ns. Fractions of that interval could, however, be defined by interpolation to give improved time resolution. This interpolation procedure is valid because the wavelength of the SPIRI Mk. I radiation is 300 ns, and a digitization interval of 100 ns is therefore above the Nyquist frequency. The interpolation of the position of the leading edge of the surface return is accurate to approximately 2 m, in air. The received, analogue signal was also displayed continuously on an oscilloscope in the 'A' mode and the digitized signal was displayed in real time on a small cathode ray tube in either 'A' or 'Z' mode, to provide a check on the functioning of the radar system. A Honeywell oscillographic recorder also provided back-up analogue 'Z' scopes on heat-sensitive paper in near real time (a 3 minute lag).

Navigation on the Nordaustlandet Ice Caps

Aircraft navigation over the Nordaustlandet ice caps used three main data sources: (1) a Motorola ranging system from the aircraft to a network of ground-based transponders, which were located accurately on the surface by satellite geociever measurements; (2) the aircraft's own navigational instruments, which gave a calculated latitude and longitude after processing by the on-board Tactical Air Navigation System (TANS) computer; and (3) timed crossings of known features on the ground (e.g. the termini of outlet glaciers).

The Motorola microwave distance-measuring system used an on-board transmitter/receiver and micro-computer, to calculate the distance of the aircraft from four ground-based transponders (Fig.1b). The maximum operating range of the transponders was approximately 40 km. Some difficulties were experienced, however, in ensuring a clear line of sight between the transponders and the aircraft, owing to their narrow vertical beamwidth and obstructing ice-surface topography. In particular, transponder range northwards from stations 1 and 3 (Fig.1b) was limited by the proximity of the main ice divide on Austfonna. Even so, 35% of Austfonna (sensu Dowdeswell and Drewry, 1985) was within range of two or more transponders, while range from one or more transponders were received over 61% of the ice cap (Fig.1b).

To calculate the position of the aircraft, the absolute position of at least two transponders must be known accurately. The latter was determined from a line of position recorded by a second transponder 2, 3 and 4 was, therefore, measured by satellite geocievers, set up by a ground party (Fig.1b). The accuracy of each geociever position was ±2 m and the location of each transponder, relative to the geociever antenna, was measured by theodolite and electronic distance measurer. For logistical reasons, no geociever was located on Austfonna in 1984. The position of the second transponder 2 was found by calculating the location of the aircraft at a number of points, where transponders 1, 2 and 3 were giving signals. Transponders 2 and 3 were used to locate the aircraft, while the intersections of several distance measurements to transponder 1 were used to find the latter's latitude and longitude. Where the aircraft was within range of three or more transponders, range errors of less than ±30 m were measured. This value defines the operational accuracy of the Motorola system.

The aircraft's other navigational instruments were used to supplement the transponder-derived data. The on-board TANS computer took dead-reckoning and air data (air speed, altitude, and temperature) to calculate aircraft latitude and longitude. Due to failure of the Doppler navigation system, however, these data contained large errors in absolute location, resulting from the effect of wind. The dead-reckoning and air data were therefore controlled by absolute fixes from timed crossings of known points and transponder ranging data, where available. Navigational accuracy over Nordaustlandet was thus not uniform. Errors were calculated as ±100 m, where fixes from tw o or more Motorola transponders were available over parts of Austfonna (Fig.1b) and were estimated as ±250 m in other areas of that ice cap, together with the whole of Vestfonna.

Navigational data from the TANS computer and from each Motorola transponder were recorded on magnetic tape aboard the aircraft. The reduction of these data and the insertion of fixes, utilizing the position of known points on the ground, was carried out on an IBM 3081 computer.

Ice Cap Surface and Bedrock Elevations

To calculate ice cap surface and bedrock elevations above sea level, data from both the aircraft's instruments and the SPIRI Mk. IV RES equipment were used. Hence:

\[ S_p = P_A - T_C \]

(1)

\[ B_p = P_B - T_C - h \]

(2)

where \( S_p \) and \( B_p \) are surface and bedrock elevations (m a.s.l.), \( P_A \) is pressure altitude, \( T_C \) is aircraft terrain clearance, and \( h \) is ice thickness. Pressure altitude was measured by the aircraft pressure altimeter, to an accuracy of ±2 m. Aircraft terrain clearance and ice thickness data both came from the reduction of digital RES data. The aircraft was fitted with its own radar altimeter but, although information from this instrument was recorded, terrain clearance data from the SPIRI Mk. IV radar were preferred, because they were less noisy than those from the former instrument (Fig.2). The close correspondence between the pressure altimeter and SPIRI Mk. IV terrace elevation measurements of the sea surface in Figure 2 also implies that any aircraft oscillations were removed in the calculation of surface elevation (equation 1). Absolute aircraft altitude was obtained by fixing pressure altitude readings to sea level over 2-4 km sections of open water or floating fast ice. The longest interval between fixing the pressure altimeter over sea was approximately 45 minutes and was usually significantly less than this, thus reducing the effects of any variations in the pressure surface.

To calculate ice surface and bedrock elevations, aircraft terrain clearance and ice thickness were extracted from the raw, digital RES data. The time delay to the first return of ice surface and bedrock echoes during a two-second recording cycle was identified, using simple tracking routines. The raw data were differentiated (Fig.3a), to emphasize the surface and bed echoes, and the tracking routine searched downwards through the 256 data points, recording the first return of the positive echo. The value for differentiated, returned power was located (i.e. a change from decreasing power to increasing power). Interpolation, within the appropriate 100 ns interval, then took place to identify the precise position of the leading edge of the echo. The first rise in the gradient of returned signal represented the ice surface, while a second rise (where pressure signals indicated the position of bedrock. Internal layer echoes, similar to those reported by Dowdeswell and others (1984b), were not normally noted on differentiated records from the Nordaustlandet ice caps. Data from the next two-second cycle were then examined, but this time only the three (surface) or five (bedrock) 100 ns intervals, either side of the previous position, were searched for returns. If
Fig. 2. SPRI Mk. IV terrain clearance, aircraft radar altimeter and aircraft pressure altimeter elevation data, collected over sea off Nordaustlandet. Relative elevations are shown for ease of comparison.

![Graph showing SPRI Mk. IV terrain clearance, aircraft radar altimeter, and aircraft pressure altimeter elevation data.]

Fig. 3. (a) Differentiated, digital RES data in the 'Z' mode, collected over Austfonna. Increasing pixel density indicates an increase in the gradient of returned power. (b) Results of surface and bedrock tracking of the digital data.

Airborne RES of the ice caps of Nordaustlandet was carried out during five missions between 23 and 28 April, 1983 (Drewry and Liestøl, 1985). On-station flying over glacier ice in Nordaustlandet was carried out at a nominal velocity of 115 kts (210 km hr$^{-1}$). During airborne traverses across the ice caps, the aircraft normally flew between 750 and 1000 m a.s.l., at a constant altitude, in order to minimize rapid pressure fluctuations which might affect pressure altimeter readings. However, because the ice cap surface ranged between sea level and approximately 800 m a.s.l., aircraft terrain clearance varied between 100 and 750 m. During certain airborne traverses, which involved long intervals of flying over both low- and high-altitude parts of the ice caps, it was necessary to adjust the flying height of the aircraft. This was because, at large terrain clearances, the bottom echo was sometimes obscured by surface scattering, due to the relatively large (100$^\circ$) antenna beamwidth. The minimum terrain clearance was controlled by the recovery time of the RES receiver. During the 5 missions, approximately 3400 km of RES data were obtained in 20.4 hr of on-station flying over Nordaustlandet (Fig. 4). This amounted to over 30 000 geophysical data points. Most of Austfonna was covered by airborne traverses spaced a...
Fig. 4. Aircraft flight lines over the Nordaustlandet ice caps. Dashed lines show where RES bedrock returns were not received.

nominal 5 km apart, whereas a 15 km-spaced grid was flown over Vestfonna. Flight lines, diagonal to the main grid, were also inserted up flow lines in several drainage basins (Fig.4). The navigational methods, described above, were used to locate the flight lines shown in Figure 4. The gently-curving nature of many of the traverses was due to the failure of the on-board Doppler navigation system. The pilots were therefore navigating by compass headings and visual contacts with known points, and some drifting due to cross-winds was relatively common.

Ice Cap Surface Morphology
Maps of the surface morphology of Austfonna and Vestfonna were produced with a contour interval of 50 m, which is significantly in excess of the elevation errors, discussed above. Surface elevations on Austfonna are mapped in Figure 5. This map is based almost entirely on aircraft altimetric data from the flight lines in Figure 4. Landsat imagery and aerial photographs were used, however, to add detail in certain regions of relatively complex topography. Topographic features on Landsat imagery were digitized, fixed, and transformed to latitudes and longitudes, according to the procedure outlined in Dowdeswell and Cooper (1986). These accurately-located features were then used to shape the surface contours, defined from surface altimetric data, particularly in the areas between flight lines.

The 8105 km² Austfonna has two main domes, which make up the summit areas Austdomen and Sørdomen (Dowdeswell and Drewry, 1985). Austdomen reaches a maximum, measured elevation of 791 m a.s.l., while the summit of Sørdomen is 683 m in altitude. The two domes are separated by a col, some 50 m lower than Sørdomen summit. A pronounced ice divide continues west of Sørdomen, marking the boundary between ice flowing north towards Wahlenbergfjorden and that moving south to Svartknausflya (Fig.5).

Several large outlet glaciers (e.g. Bråsvellbreen, Etonbreen (E)) form pronounced basins, which remain well-defined right to the main ice divide (Fig.5). Ice surface slopes generally become steeper with distance from this divide, but the widely-spaced contours in the terminal 25 km of Bråsvellbreen indicate significant deviation from an equilibrium profile (Dowdeswell, 1984). A small, but pronounced, subsidiary ice dome (Isdomen) is also mapped as I in Figure 5. Several other clearly-defined basins can also be observed in association with outlet glaciers draining the north side of Austfonna. The drainage basins of the Nordaustlandet ice caps are discussed in more detail in Dowdeswell and Drewry (1985).

Fig.5. Ice surface elevations on Austfonna, Vegafonna, Glítefonna, and Storayjokulen. Contour interval 50 m. Dots indicate ice-free land.
The surface morphology of Austfonna is also presented as an isometric plot in Figure 6a. The small ice caps of Vegaflonna and Glitneflonna, together with Storeyjokulen, on Storoya, are also illustrated. The isometric views provide a three-dimensional picture of the ice caps which shows their major surface features, viewed from the east (Fig.6), because their simple form was confirmed through the study of Landsat imagery. Detail on the north side of Vegaflonna has also been added from this additional data source. Contouring on Glitneflonna was restricted, because information from only one airborne traverse was available.

The ice cap consists of a main ice divide of inverted 'T' shape, rising to a maximum elevation of approximately 620 m a.s.l. (Fig.7). Several minor ice domes are present on the ice cap and are related to high areas of the subglacial bedrock (Fig.9). Ice, draining south into Wahlenbergfjorden, some 20-25 km from the divide, consists of four well-defined outlet glaciers: Bodleybreen (B), Aldousbreen (A), Frazerbreen (Fr) and Idunbreen (I) (Fig.7). Additional detail, derived from the interpretation of Landsat imagery, has aided in shaping the contours associated with these outlet glaciers. Clearly-defined outlet glaciers also drain the north-east and western parts of Vestfonna (Fig.7). The two arms of Franklinbreen (F), in particular, form a major basin on the west side of the ice cap, which separates two parts of the main ice divide. Landsat and aerial photographic evidence has aided the contouring of the relatively complex ice surface terrain in the most northerly part of Vestfonna (Fig.7). A contour map of Ahlmannfonna is inset in Figure 7 and, because only two intersecting flight lines cross this small ice cap, the position of its surface contours was refined using Landsat imagery.

These new maps of the surface of the Nordaustlandet ice caps (Figs. 5 and 7) will provide a principal data source for the complete revision of the existing official Norwegian 1:500 000 and 1:1 000 000 scale maps of the island.

The Spatial Distribution of Bedrock Returns

While calibrated pressure altimetry and terrain clearance provide the main data source for the study of ice cap surface morphology, evidence on subglacial bedrock morphology and ice thickness comes from airborne RES data, collected in 1983. The spatial pattern of RES flight lines along which bedrock returns were absent is indicated in Figure 4. Bedrock echoes were not recorded for 48% of sounding over Vestfonna, but were absent over only some 9% of Austfonna. This indicates a qualitative difference between these two parts of Nordaustlandet, in terms of the ability of 60 MHz radar equipment to resolve the glacier bed. Throughout Nordaustlandet, bed echoes were more often absent in the accumulation area than in the ablation zone (Fig.4). Given the sub-polar thermal regime of these ice caps (Schytt, 1969; Dowdeswell, 1984) and the problems encountered in RES in the accumulation areas of Spitsbergen glaciers (Dowdeswell and others, 1984a, 1984b), the disproportionate lack of bed returns from Vestfonna suggests that this ice cap contains more ice that is at or close to the melting point. Such warm ice will lead to both greater absorption and more internal scattering. The latter is associated with the presence of more internal inhomogeneities, for example ice lenses and water pockets. Available 10 m temperature data from Nordaustlandet supports this interpretation (Dowdeswell, 1984).

But returns may remain undetected for two main reasons (Smith and Evans, 1972): (1) returned signal from that interface drops below the noise level of the receiver; and (2) scattering, which can be from discrete surface or internal inhomogeneities, masks bed echoes, even when they are relatively strong. An examination of 'Z' records from both digital and analogue sources showed that, in most areas of Austfonna, bedrock returns typically disappear gradually as they fall below the level of receiver noise, probably as
signal attenuation increases, due to the presence of warmer and/or thicker ice. The drainage basin of Leighbreen (Fig.4) is an exception to this generalization and is discussed below. On Vestfonna, the reasons for the absence of bottom echoes are more varied. In some areas of the accumulation zone, returned power appears to fall below receiver noise while, in others, the bed return becomes obscured by internal scatter echoes. These discrete reflectors may be associated with warmer temperatures and less homogeneous firn and ice on Vestfonna.

Strong surface scattering is responsible for some areas where bed echoes are masked, particularly nearer the margins of the Nordaustlandet ice caps and on actively surging glaciers. A large area of heavy surface scattering is found on Leighbreen, where the bed is obscured on two long stretches of track up the basin (Fig.4). However, bedrock returns are absent from only one of the flight lines which are orthogonal to and intersect these two legs (Fig.4). An investigation of the terrain clearances at which these legs were flown demonstrates the nature of the problem. The tracks up Leighbreen without bed echoes (Fig.4) were flown at 390–450 m above the surface, but a cross-cutting leg flown at a terrain clearance of 145–165 m recorded bedrock returns. Thus, the bottom is increasingly likely to be lost as terrain clearance and, therefore, the size of the radar footprint increases, because the number of scatterers illuminated rises as the square of terrain clearance and scatter echoes are received over a longer time delay. On Austfonna, heavy surface scattering is confined largely to Leighbreen, where very large sastrugi and some crevassing were observed during flight. On Vestfonna, part of the bed of Bodleybreen is also marked by surface scattering from crevasses associated with surge activity.

**Bedrock Morphology under Austfonna and Vestfonna**

Bottom returns were obtained from over 90% of track flown over Austfonna (Fig.4). The elevation of subglacial bedrock is therefore mapped for the whole ice cap in Figure 8. A contour interval of 100 m was selected, in order to show the major trends in bedrock morphology. This is much greater than estimated errors of less than ±20 m in absolute bedrock elevations. An isometric view of the bedrock beneath Austfonna is presented in Figure 6b.

Three features are particularly prominent in Figure 8. First, two bedrock ridges, rising to over 300 m a.s.l. and separated by a valley, reaching an elevation of approximately 150 m, run west to east across Austfonna. The valley is also a marked feature on the isometric view from the east of Nordaustlandet (Fig.6b). Secondly, much of the bedrock underlying the south and east sides of the ice cap is below sea level, by up to 157 m (Fig.8). The isometric plots provide visual images of these depressions (Fig.6b). A total of 28% (2270 km²) of the bedrock area beneath Austfonna is below sea level, including 57% of the Bråsvellbreen basin and 47% of Leighbreen. Thirdly, subglacial bedrock troughs are associated with several outlet glaciers and drainage basins of the ice cap.

Despite the observation that some 28% of the base of Austfonna lies below sea level, there is little evidence that glacier ice is floating. The following equation, describing the surface elevation above sea level (e) of an ice shelf, assumed to be in hydrostatic equilibrium (Crary and others, 1962), was applied to known ice thickness values (h) around the periphery of the Nordaustlandet ice caps:

\[
e = h \left[1 - \left(\rho_s/\rho_m\right)\right] - s \left[\rho_s - \rho_i\right]/\rho_m
\]

where \(s\) is the depth of low density firn and \(\rho_i\), \(\rho_s\) and \(\rho_m\) are the densities of ice, sea water and snow. Everywhere, ice surface elevations were an order of magnitude greater than those predicted for an ice shelf, using equation 3.

The morphology of the bedrock underlying Vestfonna is mapped in Figure 9. Bottom returns were received over only 52% of track flown and were seldom obtained from the central parts of the ice cap (Fig.4). The area is therefore contoured at 100 m intervals, with regions of uncertain bedrock elevation marked by dashed lines. Shading

![Fig.8. Subglacial bedrock elevations beneath Austfonna (contour interval 100 m).](image)
margins of Franklinbreen. A smaller proportion of the subglacial bedrock of Vestfonna, as compared with Austfonna, is below sea level. This is expected, because the latter ice cap has ice cliffs over 130 km in length on its eastern, seaward margin, whereas Vestfonna is drained by a number of outlet glaciers, which are constrained topographically.

Ice Thickness

The ice thickness of Austfonna is mapped in Figure 10. Note that the 100 m thickness contour is not usually present, because the ice is generally of greater thickness, even at the ice cap margin. An isometric view of ice thickness is found in Figure 6c. The general trend is, as expected, for ice thickness to decrease towards glacier termini. A comparable map of Vestfonna has not been constructed, due to the relative lack of bedrock returns from that ice cap (Fig.4).

A relatively large area of ice, over 500 m thick (maximum 583 m), coincides with the summit of Austfonna (Austdomen) and extends approximately 50 km to the north-east. Ice, 300-440 m thick, also parallels the ice surface divide west of Sordomen and the eastern flank of Brøsvelbreen (Fig.10). The only region of the ice caps less than 100 m thick is at the western terminus of Brøsvelbreen, although even here the surface elevation is considerably greater than that predicted by equation 3 for a floating ice shelf of similar thickness. The seaward 20 km of Brøsvelbreen is almost all less than 300 m in thickness and corresponds to the ice lobe resulting from the surge observed in 1938 (Schytt, 1969). A submarine ridge, subparallel to, and approximately 3 km offshore from, the present terminus of Brøsvelbreen, probably marks the maximum extent of the surge (Solheim and Pfirman, 1985). It is assumed, because this basin is now in the quiescent phase between surges, that ice in this area is relatively inactive and thinning (c.f. Liestøl, 1969). Another area of particularly thin ice (<200 m) is found beneath Isdomen (I), located 10 km west of Hartogbukta (Fig.10).

Comparison with seismic measurements of ice thickness...
on Austfonna (Ekman, 1971) shows differences that are usually less than 6% of ice depth. It is suggested that navigational inaccuracies of <900 m, for the IGY traverse (Schytt, 1964), and of <250 m, falling to <30 m over central Austfonna (Fig.1.b), for our own work, are largely responsible for these discrepancies. On Vestfonna, the lack of bottom echoes over the central area makes comparison with the IGY seismic work and a single Soviet RES flight line (Macheret, 1981; Macheret and Zhuravlev, 1982) difficult, although the few coincident measurements available indicate differences of less than 5% of ice depth.

CONCLUSIONS

Airborne geophysical investigations of the ice caps of Nordaustlandet, during spring 1983, yielded a comprehensive data set on ice surface elevation, bedrock morphology and ice thickness. SPRI Mk. IV 60 MHz RES equipment was used, in conjunction with a digital recording system, which made data reduction significantly more rapid than using traditional, analogue, recording methods. Where two or more ground transponders were received, navigation was also significantly more accurate (±30 m) than in previous airborne RES surveys of large ice masses. The reduced geophysical information is held as a direct access computer database.

The results of these airborne geophysical investigations are presented here as a series of maps of the morphology of the Nordaustlandet ice caps. This information is being used in a number of wider cartographical and geophysical applications. Ice surface elevations provide a principal data source in the complete revision of official Norwegian maps of Nordaustlandet. Glaciological applications of this ice cap morphological information include the calculation of basal shear stresses over the ice caps and the comparison of observed with theoretical ice surface profiles along flow lines (Dowdeswell, 1984). More detailed mathematical, modelling studies of the dynamics of the Nordaustlandet ice caps must, however, await further field observations on the thermal regime, mass balance and distribution of velocities over the ice caps to complement the data presented above.

ACKNOWLEDGEMENTS

We thank Store Norsk Spitsbergen Kullcompani for logistical assistance and the British Antarctic Survey for the loan of a Twin Otter aircraft. SPRI funding was through UK NERC Grant GR3/4463 to DJD and a Studentship to DJD. Collaborative meetings were funded through a NATO grant.

REFERENCES


Dowdeswell J A, Cooper A P R 1986 Digital mapping in polar regions from Landsat photographic products: a case study. Annals of Glaciology 8:


Macheret Yu Ya 1981 Forms of glacial relief of Spitsbergen glaciers. Annals of Glaciology 2: 45-51


