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Radio Echo Sounding Investigations on the Filchner/Ronne Ice Shelf 1979/80

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Summary: Intensive radio echo sounding was carried out during the site survey expedition 1979/80 to the Filchner Ice Shelf. The method was applied both for crevasse survey as well as for ice thickness determinations.
The ice shelf is crevasse-free in the station area except for some small crevasses close to the ice front. The ice shelf is about 100 m thick near the front. The thickness increases rapidly to about 150 m and reaches 220 m at the station. A further increase to 320 m is observed at 54 km south of the front. Astonishingly, the thickness decreases again further south.
The wedge-like profile of the ice shelf is due to bottom melting which is strongest near the ice front. From ice thicknesses, accumulation rate, ice movement and strain rates, a melt rate of 3,2 m/a is obtained at the station. The calving rate at the front is estimated to about 100 m/a. The advance of the ice front of 1100 m/a (MÖLLER & GERDAU, 1981) is consequently not balanced by calving and basal melt.

Zusammenfassung: Während der Standorterkundungsexpedition zum Filchner-Ronne-Schelfeis 1979/80 wurden im Bereich der Filchner-Station intensive Radarvermessungen vom Helikopter aus durchgeführt. Die Radarsondierungen dienten einmal der Spaltensuche, und zum anderen sollten die Mächtigkeiten des Schelfeises im Frontbereich bestimmt werden. Bis auf einige sehr schmale Spalten in der Nähe der Barriere ist das Ronne-Schelfeis im weiten Umkreis der Station spaltenfrei. Eismächtigkeiten wurden entlang der Schelfeiskante sowie bis zu 140 km Inland gemessen. Das Schelfeis ist an seiner Front ca. 100 m dick. Die Mächtigkeit wächst sehr schnell auf 150 m und erreicht an der Station 220 m. Eine weitere Zunahme bis auf 320 m ist bis 54 km südlich der Front zu beobachten. Danach nimmt die Mächtigkeit interessanterweise nach Süden hin wieder ab. Das keilförmige Profil des Schelfeises bis 54 km ist eine Folgeerscheinung starken Abschmelzens an der Eisunterseite, verursacht durch den Transport relativ warmer Wassermassen unter das Eis. Aus dem Dickenprofil, der Akkumulation, der Eisbewegung und Deformationsrate wird ein Schmelzbetrag von 3,2 m/Jahr an der Filchner-Station abgeleitet. Die Kalbungsrate an der Barriere bei 50 °W ist auf 100 m/Jahr geschätzt. Dem Vorschub des Schelfeises von 1100 m/Jahr (MÖLLER & GERDAU 1981) steht ein wesentlich kleinerer Massenverlust aus Schmelzen und Kalben entgegen, so daß sich das Ronne-Schelfeis an der Front keineswegs im Gleichgewicht befindet.

INTRODUCTION

As part of the site-survey investigations for the German wintering base, air-borne radio echo soundings have been carried out during the 1979/80 field season. The radar technique was applied firstly for a detailed crevasse survey in the station area around 77° S / 50° W but also for ice thickness measurements on profiles parallel and perpendicular to the ice front. The ice thickness soundings were designated for the forthcoming mass balance studies on the Filchner/Ronne Ice Shelf.

FIELD PROCEDURES

The SPRI (Scott Polar Research Institute) Mark IV system operating at 60 MHz was used together with antennae of Norsk Polarinstitutt especially designed by Gudmandsen (Lyngby, Denmark) for helicopter operations. The signals were recorded on UV sensitive paper (Honeywell fibre optic recorder, 1856 A). The system was mounted in a helicopter (Bell Jet Ranger). The flight lines are shown in Fig. 1. The maximum length was 140 km limited by the range of the helicopter. The flying altitude was chosen between 500 and 1.000 m above sea level cruising at a speed of 50 to 90 knots. The navigation was achieved by dead reckoning from flight direction, ground speed and flying time. Since no inertial navigation system was available, the error in the positioning amounted to ± 5 km at the end points of the 140 km flight line.

RESULTS

Fig. 2 shows a section of a record from a flight line between the station and Berkner Island. Surface crevasses were found on the western slope of Berkner Island and Hemmen Ice Rise and could, even when co-

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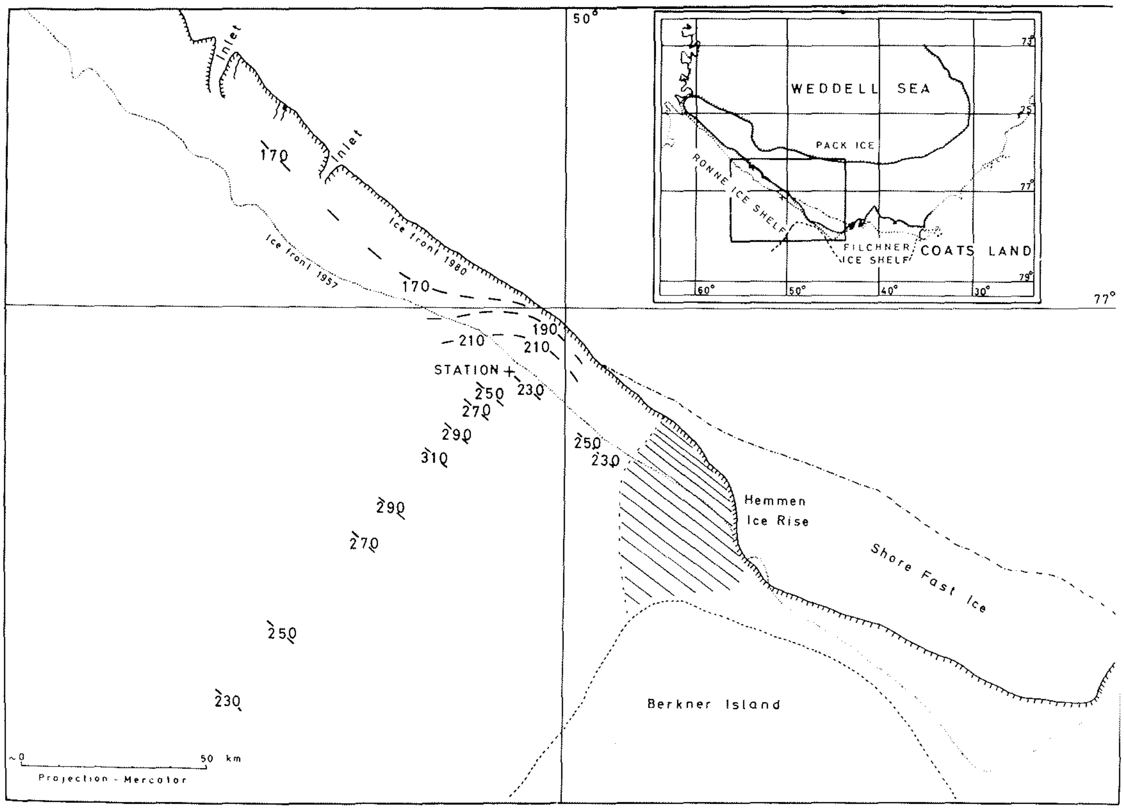

Fig. 1: Flight lines of the radio echo sounding flights.

Abb. 1: Routen der Radarsondierungsflüge.

vered by snow bridges, be clearly detected due to the typical diffraction pattern. Fig. 5 shows the area where surface crevasses were met. The region around the station location up to 80 km to the west, 50 km to the east as well as 140 km to the south is virtually crevasse free. Only small crevasses about 30 to 50 cm wide were found close (5 to 10 m) and parallel to the ice front. These crevasses do not present any serious hinderance or danger because they can be artificially bridged. If necessary, the part between the ice front and the crevasses can be blasted off using some hundred kilogramms of explosives as sucessfully demonstrated at the end of the field season.

The radio echo soundings were simultaneously used for ice thickness determinations. The ice thicknesses were calculated from the travel times and the wave velocities:

$$z = v \frac{t}{2},$$

where z is the ice thickness, t is the two-way travel time of the impulse signal from the ice surface to the ice bottom and back to the surface; v is the wave velocity in the ice which is related to the dielectric constant of the ice (ϵ) and the velocity in vacuum (c) by

$$v = \frac{c}{\sqrt{\epsilon}},$$

and t is obtained from the difference between the surface and the bottom echo. A wave velocity of 168

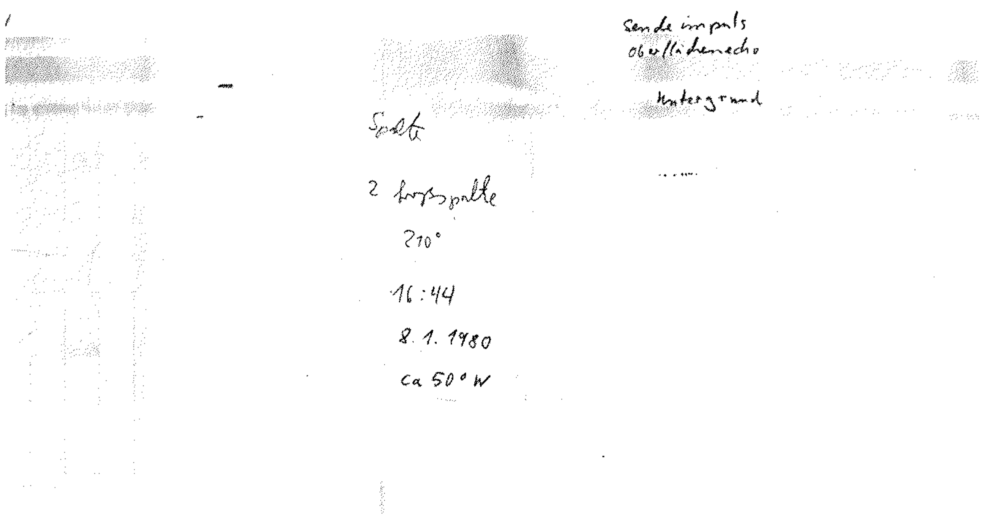

Fig. 2: Crevasse pattern on a radio echo sounding record.

Abb. 2: Diffraktionserscheinungen einer Spalte in einer Radaraufzeichnung.

m/μsec is used for the calculation, adding a constant value of 9 m to account for the density increase in the upper firn layer. From various experiments these values have proven to be appropriate for depth calculations. A broad spectrum of velocities has been determined from measurements on the ice sheet and on ice shelves ranging between 160 m/μsec and 180 m/μsec. However, no systematic trend or simple relation to physical parameters like temperature, density or ice thickness could be found (JEZEK et al., 1978). Thus, many researchers use average velocities like the above value or 170 m/μsec at all locations (CLOUGH, pers. communication).

Ice thickness obtained on profiles perpendicular to the ice front (flight lines 2 and 7), are plotted in Fig. 3 and Fig. 4. Fig. 3 represents the enlarged first 20 km section of the same profile. The surface topography was determined by geodetic methods (MÖLLER & GERDAU, 1981) and estimated from buoyancy considerations for the section beyond the station.

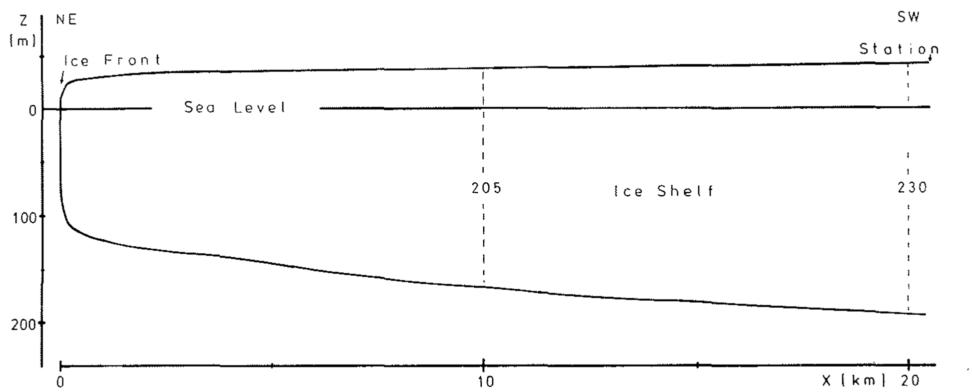

Fig. 3: Cross section of the frontal part of the Filchner Ice Shelf at 77° S / 50° W.

Abb. 3: Eisdickenprofil zwischen Barriere und Filchner-Station (77° S / 50° W).

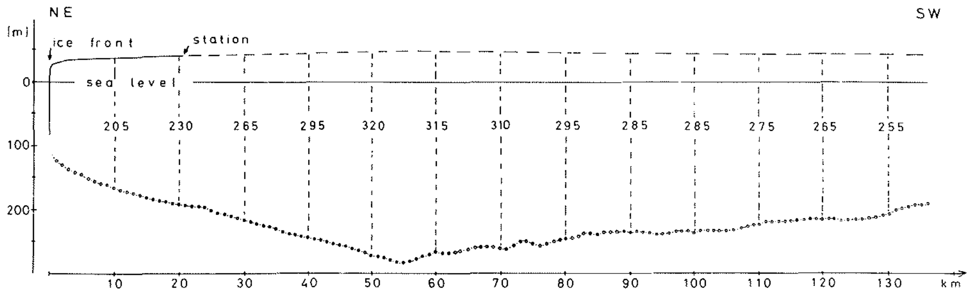

Fig. 4: Cross section through the ice front and the station area at 77° S / 50° W.

Abb. 4: Ein 140 km langes Eisdickenprofil von der Eisfront durch die Filchner-Station nach Süden.

The surface and bottom slope is very steep on the first 500 m with an ice thickness increasing from about 90 to 150 m. The increase in ice thickness persists southwards reaching 230 m at the station and a maximum of 320 m at 54 km southwest of the ice front (Fig. 4). The wedge-like shape is most likely due to strong bottom melting in the frontal zone of the ice shelf. GAMMELSRØD & SLOTSVIK (1981) have recorded tidal currents with velocities up to 30—40 cm/sec at the ice front flowing under the ice shelf. The water flowing under the ice shelf was 0,2 °C to 0,25 °C warmer than the outflux. Furthermore, both researchers conclude from their investigations that there is a general influx of water masses under the ice shelf in the area west of Berkner Island and Filchner Station superimposed on the tidal currents. Considerable melting is consequently expected near the ice front due to strong current components along the front enhanced by heat advection from warmer, downwelling waters as qualitatively discussed by ROBIN (1979). Melting may continue under the ice shelf to about 54 km southwest. There are different factors supporting this assumption. Firstly, strong radar bottom echoes were recorded on this section being attributed to bottom melting (NEAL, 1979). Secondly, there is a flow of water masses under the ice from the surface to a depth of nearly 300 m thereby decreasing the pressure melting point by 0,2 °C which leads to melting. Finally there is the influx of warm water masses during the summer (up to -1,6 °C!, GAMMELSRØD & SLOTSVIK, 1981) as observed at the front. The freezing point of this water is -1,9 °C.

A most striking feature is the rapid decrease in ice thickness between 54 km and 140 km southwest from 320 to 255 m. The decrease is accompanied by a successive weakening of the bottom echo which can be explained by a saline layer (NEAL, 1979) which might freeze to the bottom in this area. The freezing may be due to ascending water which raises the pressure melting point.

It can only be speculated how the ice thinning is caused. One explanation is that the thinning is stress induced, i. e. due to strain spreading. Thinning due to bottom melting as a consequence of a particular water circulation is hardly plausible. However, a mechanism causing thinning and consecutive thickening implies a highly complex strain field which to be understood requires much more field investigations. Fig. 5 shows the isolines of ice thickness. Besides the general increase in ice thicknesses towards the hinterland, a slight thinning along the ice front towards west can be deduced from the radio echo data.

Estimating the bottom melt rate $\dot{m}$ from ice thickness H, ice thickness gradient dH/dx, horizontal velocity V_X (1050 m/a; MÖLLER & GERDAU, 1981), accumulation rate $\dot{a}$ (0,2 m; REINWARTH, 1981) and vertical strain rate $\dot{\epsilon}$ using the equation

$$\dot{m} = \dot{a} - V_X \cdot dH/dx - H\dot{\epsilon} \text{ (CRARY et al, 1962)}$$

yields $\dot{m}$ = 3,2 m at the Filchner Station. $\dot{\epsilon}$ can only be estimated from the horizontal strain rates to be of the order of 10^{-4} a^{-1} or less because all deformations measured during the observation period in the strain pentagon were beyond the limits of the geodetic accuracy (MÖLLER, pers. communication). Even if the assumed strain value is erroneous by 100% and more, the basal melt rate will only be affected in the second decimal. The term, which governs the melt rate at this place, is the ice thickness gradient times the horizontal velocity.

The wedge-like cross section of the ice front is an equilibrium figure keeping the basal melting in buoyancy by downward bending of the ice shelf front. According to Fig. 3, surface and bottom slopes are greatest over the first 500 m which implies that bottom melting is strongest in this area. Neglecting the strain term and assuming steady state conditions lead to a rough guess of the basal melt rate of up to 10 m near the front. The particular shape of the ice edge gives rise to a calving mechanism similar to the type described by REEH (1968). Swell and ocean waves induce additional bending forces in the ice front which finally lead to crevassing and break-off. Parallel crevasses 30 to 50 cm wide, at distances of 5 to 10 m from the front, as well as ice pieces and bergy bits of corresponding size, which could be observed along the ice front, witness this calving mechanism. It is interesting to note that no larger ice bergs, originating from this area, were met.

The relative retreat of the ice front due to calving was estimated to be about 10 to 15 m during the observation period with the aid of markers. A brief reinspection of the site in 1981 yielded an annual break-off of not more than 100 m. There is consequently a considerable imbalance between advance and mass loss. Future remeasurements have to substantiate that the ice shelf at about 50° W is advancing by more than 1000 m per year cut back only by 10% due to calving and bottom melting at the ice front.

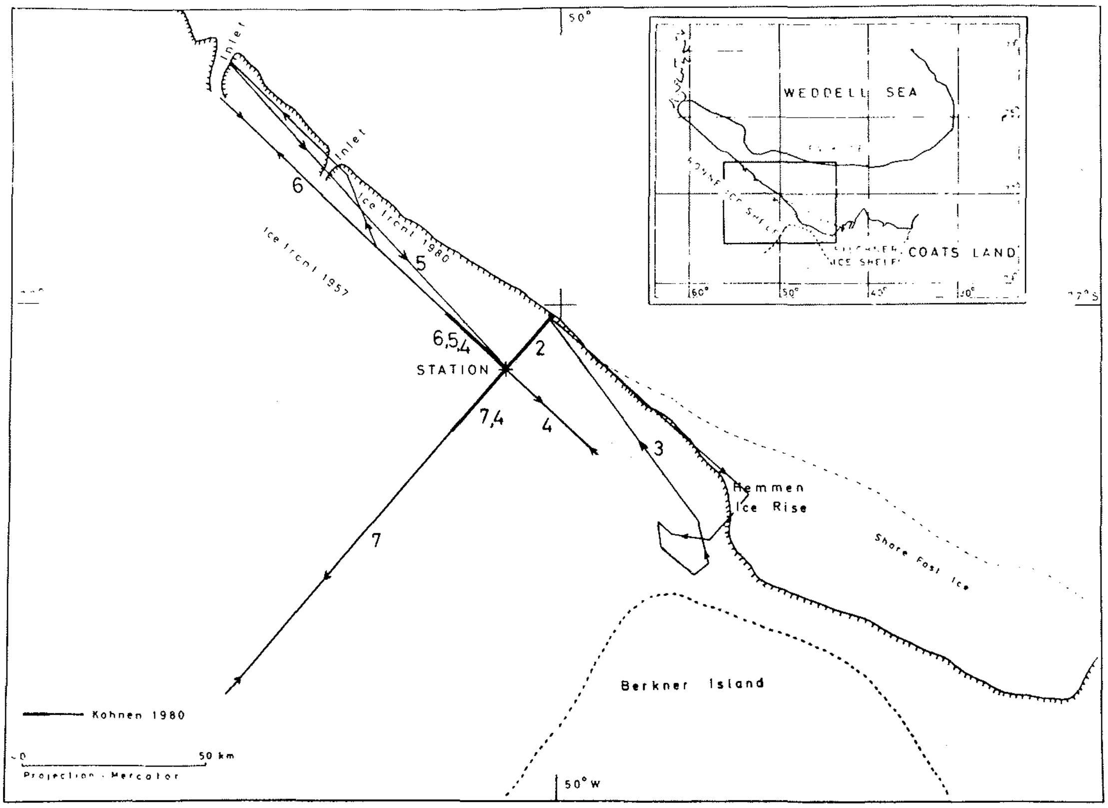

Fig. 5: Isolines of ice thicknesses of the Filchner Ice Shelf at the station area. Parallel lines denote crevasse fields.

Abb. 5: Eisdickenkarte des Schelfeises im Bereich der Filchner-Station. Gestrichelte Flächen bedeuten Spaltengebiete.

CONCLUSIONS

A preliminary and yet oversimplified model of the glaciological regime of the frontal zone of the Ronne Ice Shelf can be decuced from the investigations of the expedition which may serve as a working hypothesis. As under the Filchner Ice Shelf (CARMACK & FOSTER, 1975), currents may circulate in the southern Weddell Sea and underneath the Ronne Ice Shelf in a clockwise pattern. Water masses flow under the eastern Ronne Ice Shelf causing strong bottom melting due to heat advection and decreasing pressure melting point. The outflow from the ice shelf is expected in the western part (west of 56° W) where cold water masses with -2° C in its core (between 150 and 350 m depth; freezing point at the surface: -1,9° C) were observed along the ice front (GAMMELSRØD & SLOTSVIK, 1981). The out-flowing water may be cooled down by heat transfer during its circulation underneath the ice shelf. Strong bottom melting is, therefore, not expected near the ice front which is manifested by a much higher and consequently much thicker barrier west of 56° W (FUCHS et al., 1981).

The front of the eastern Ronne Ice Shelf is moving forward at a rate of approximately 1100 m/a (MÖLLER & GERDAU, 1981) counteracted by a mass loss of roughly 100 m/a yielding a drastical imbalance between forward movement and mass loss. This imbalance, i. e. advance of the ice front, may have persisted for at least two decades as implied by the two different ice front positions (FUCHS et al., 1981). The accurate rate of the long term advance has yet to be substantiated by future remeasurements. Nevertheless, an unsteady behaviour of the ice front, for instance a periodic pulsation as suggested earlier by ZAKHAROV & KOTLYAKOV (1980), may be a more realistic assumption than steady state or equilibrium conditions.

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