

## MASS BALANCE OF THE WARD HUNT ICE RISE AND ICE SHELF: A 10 YEAR RECORD

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**ABSTRACT.** The results of 10 years' (1958–68) record of accumulation and ablation from the Ward Hunt ice rise and of 3 years' (1965–68) record from the Ward Hunt Ice Shelf are presented. The net mass balances on the ice rise for the 3 years 1962–65 are positive, while the net mass balances measured in the other years on both ice rise and ice shelf are all negative.

**RÉSUMÉ.** *Bilan de masse du dôme de glace de Ward Hunt et de Ward Hunt Ice Shelf: 10 ans de résultats.* On présente les résultats de 10 ans (1958–68) d'observations de l'accumulation et de l'ablation sur le dôme de glace de Ward Hunt et de trois années (1965–68) sur la Ward Hunt Ice Shelf. Le bilan net du dôme de glace pour les trois années 1962–65 est positif, tandis que les bilans nets mesurés les autres années tant sur le dôme que sur la plate-forme de glace sont tous négatifs.

**ZUSAMMENFASSUNG.** *Massenbilanz der Ward-Hunt-Eisaufwölbung und des Ward Hunt Ice Shelf: eine 10-Jahre-Ubersicht.* Die Ergebnisse 10-jähriger Beobachtungen (1958–68) der Akkumulation und der Ablation an der Ward-Hunt-Eisaufwölbung und 3-jähriger Beobachtungen (1965–68) am Ward Hunt Ice Shelf werden vorgelegt. Die Netto-Massenbilanzen der Eisaufwölbung sind für die 3 Jahre 1962–65 positiv, während die Netto-Massenbilanzen aller anderen Jahre sowohl für die Eisaufwölbung wie für das Eisschelf negativ sind.

### INTRODUCTION

Since the recognition in 1950 that ice shelves occur off the north coast of Ellesmere Island (Koenig and others, 1952), there has been speculation on whether they should be considered as relict features or as essentially the product of present climatic conditions. Field work in 1953–54 showed that the Ward Hunt Ice Shelf in its most recent history has undergone a long period of net ablation (Hattersley-Smith and others, 1955). This was evident from the heavy concentration of wind-blown dust at the surface and from the discovery of debris resting on the ice from one of R. E. Peary's overnight camps of 1906, since when there had evidently been no net accumulation. Both the Ward Hunt Ice Shelf and the ice rise showed considerable net surface ablation for the budget year 1953–54; at one pole on the ice shelf this amounted to as much as 630 mm water. In the four summers from 1955 to 1958 the total net ablation on the ice shelf amounted to more than 1 350 mm water (Crary, 1959). Further work on the ice shelf and ice rise showed net surface ablation of from 70 to 200 mm water in both the 1958–59 and 1959–60 budget years (Lotz, 1961; Lister, 1962; Sagar, 1962). In the winter of 1961–62 massive calving reduced the area of the Ward Hunt Ice Shelf by about 600 km<sup>2</sup>; a strip of the ice shelf up to 8 km wide had moved to sea along a line back to the northern edge of the Ward Hunt ice rise (Hattersley-Smith, 1963). The part of the ice shelf where the 1959–60 observations had been made was removed, but the 1959–60 grid of poles on the Ward Hunt ice rise was unaffected (Fig. 1).

Since 1963 we have continued to make accumulation and ablation measurements each spring at the original poles on the ice rise, nearly all of which are still standing, and since 1966 we have made similar measurements at a 0.9 km square grid of 100 poles that were set in the ice shelf, 5 km east of Ward Hunt Island, in 1965–66 (Fig. 1). In this paper the results of 10 years' (1958–68) records on the ice rise and 3 years' (1965–68) records on the ice shelf are analysed.

### FIELD DATA

The results of the measurements at 42 poles on the ice rise and at 100 poles on the ice shelf between 1963 and 1969, together with data from 45 poles on the ice rise for 1959–60, are shown in Tables I and II. In each table the ranges and the means of total annual accumulation and of net annual accumulation or ablation at the various poles are shown. For the years

1960–62 there are figures only for the combined net ablation for the 2 years, and there are no figures for the 1965–66 accumulation. The ice shelf is characterized by a system of parallel surface ridges and troughs (Hattersley-Smith, 1957) and in Table II results from ridge poles are distinguished from those from trough poles in separate columns.

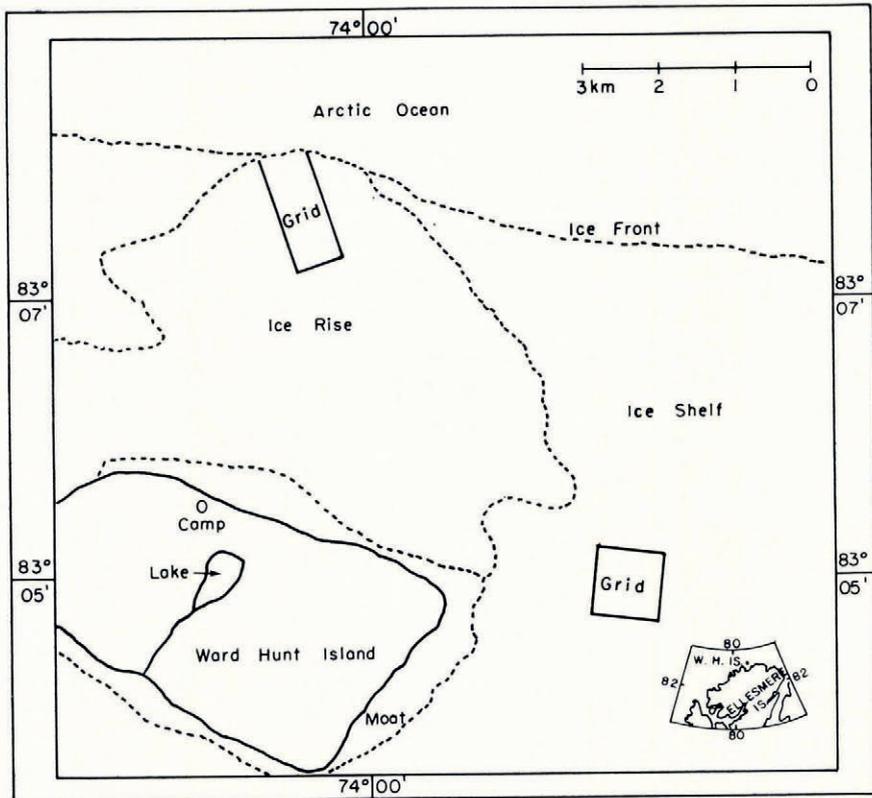


Fig. 1. Map of Ward Hunt Island and adjacent ice rise and ice shelf.

TABLE I. ACCUMULATION AND ABLATION ON THE WARD HUNT ICE RISE

Summer	Number of poles	Date	Accumulation			Net ablation/accumulation		
			Range mm	Mean mm	Mean mm water	Range mm	Mean mm	Mean mm water
1959	45	Late June		510	173		-122	-110
1960	45	Late June		780	255		-76	-68
1961 } 1962 }	42					-90 to -1 010	-640	-576
1963	42	20 June	410-1 260	810	251	-140 to +570	+180	+117
1964	41	25 June	250-1 420	550	171	-270 to +360	+160	+104
1965	42	12 June	230-900	570	177	+40 to +750	+310	+202
1966	42					-420 to +10	-210	-137
1967	42	17 June	330-660	490	152	-470 to +30	-140	-91
1968	40	5 May	240-1 120	560	174	-470 to +170	-10	-7
1969	38	15 May	260-720	470	146			

In computing water equivalents from these data certain assumptions have been made. First, a mean density of  $0.31 \text{ Mg m}^{-3}$  has been assumed for the spring snow cover, based on the results of pit studies in 1968 and 1969. It must be remembered, however, that the total accumulation in any year was not measured, since no record is available of snow that fell between May or June and the end of the ablation season. Hence, figures for snow accumulation must be regarded as minima. The limited data cause an obvious discrepancy in the 1965 summer when the net accumulation for the ice rise exceeds the apparent total accumulation by 25 mm (Table I). Evidently, in this very cool summer there was appreciable snowfall after the middle of June. Secondly, in computing net accumulation which in this area takes the form of superimposed ice or very icy firn, a mean density of  $0.65 \text{ Mg m}^{-3}$  has been assumed for the material. The same density has been used for computing the ablation of this material as formed after 1962, but a density of  $0.9 \text{ Mg m}^{-3}$  has been used for the density of the ice melted from the long-standing ablation surface that existed before 1963.

TABLE II. ACCUMULATION AND ABLATION ON THE WARD HUNT ICE SHELF

Date	Number of poles	Ridge poles			Number of poles	Trough poles			All poles	
		Range mm	Mean Accumulation mm	Mean mm water		Range mm	Mean Accumulation mm	Mean mm water	Mean Accumulation mm	Mean mm water
23 June 1967	18	420-740	537	166	3	480-690	560	174	540	167
13 May 1968	60	270-980	560	174	36	330-1240	620	192	580	170
18 May 1969	60	270-630	440	136	38	210-910	480	149	460	143
Summer		Net ablation/accumulation				Net ablation/accumulation			Net ablation	
		Range mm	Mean (-) mm	Mean (+) mm water		Range mm	Mean (-) mm	Mean (+) mm water	Mean mm	Mean mm water
1966	18	-550 to -180	-310	-279	3	-220 to -640	-390	-351	320	288
1967	60	-440 to -40	-250	-225	35	-750 to -110	-340	-306	280	252
1968	60	-360 to +150	-100	-90	34	-460 to +250	-130	-117	110	99

ANALYSIS

The data in Tables I and II have been plotted in Figure 2. Since there are no complete meteorological data for Ward Hunt Island for the summers in question, temperature data from Alert, the nearest weather station, have been used to provide an indication of the "warmth" or otherwise of the summers 1959-68. Mean temperatures at Alert for the months of June, July and August, and for the whole summers have been plotted below the mass-balance data.

Considering first the 10 years' data from the Ward Hunt ice rise, we note: (1) the great range of snow depths measured in the spring, varying by up to 50% or more about a mean, (2) the similarly great range in net ablation and accumulation, including both ablation and accumulation at different poles in the same season. Snow depths are dependent on wind action and on irregularities of the previous season's ablation surface, which are comparatively large in relation to snow depths of the order of 500 mm. At the same time, the topography of the ice rise, although subdued with an elevation nowhere exceeding 30 m, is such that poles are situated with aspects varying from more or less northerly to more or less southerly and leading to differences in amounts of ablation. The main point emerging from comparison of summer ablation values on the ice rise with the corresponding mean monthly temperatures at Alert is that there is no close correlation. Admittedly, Ward Hunt Island is about 200 km west-north-west of Alert, so that local variations in the general weather pattern of north-eastern Ellesmere Island may well account for the lack of correlation. But there are two other factors that should be mentioned. The method of calculating mean daily temperatures at Alert (from which the mean monthly temperatures are derived) as  $\frac{1}{2}$ (daily maximum plus daily minimum) may not provide the best assessment of an ablation season, as Arnold and MacKay (1964) have pointed

out. Nor in the present case does the use of mean daily maximum temperatures at Alert give any better correlation. Furthermore, any assessment of the ablation season based on temperatures alone ignores the drastic reduction in melting caused by a new cover of snow with its high albedo. In an area where mean summer temperature does not exceed  $+3^{\circ}\text{C}$ , the small temperature difference that determines whether precipitation falls as rain or snow is very much

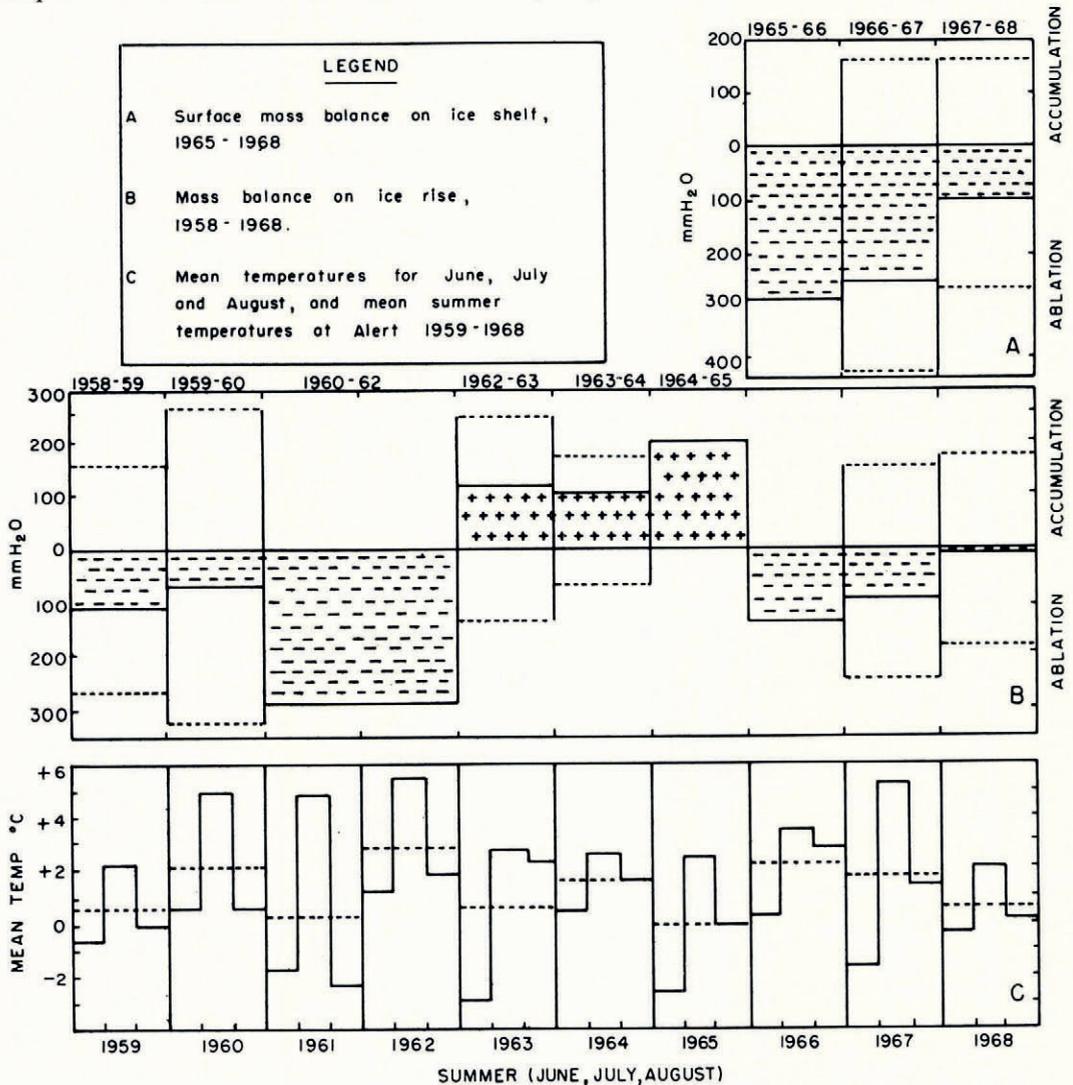


Fig. 2. Mass balance on the Ward Hunt Ice Shelf and ice rise, and mean summer temperatures at Alert.

out of proportion to the effect on ablation at an ice surface (Hattersley-Smith, 1960). The high incidence of low cloud and fog near Ward Hunt Island in summer (Sagar, 1962) is probably a further factor leading to low ablation, as has been suggested by Paterson (1969) in the case of the Meighen Ice Cap, and to distortion of any comparison with the weather at Alert. Since the main purpose in this paper is to present rather than explain the figures for mass balance of the ice near Ward Hunt Island, the comparison with data for Alert will not

be pressed, nor is it believed for the reasons indicated above that this would be very fruitful. It is sufficient to point out the correlation between more than average warm summers and more than average cold summers in the two areas. Thus the relatively high net ablation on the ice rise for the combined summers 1961–62 agrees with the unusually high temperatures at Alert in the summer of 1962; presumably most of the ablation occurred in 1962. Again, the relatively high net accumulation in 1965 agrees with the low summer temperatures at Alert. But it is anomalous to find that there was net ablation on the ice rise in the summer of 1959 but net accumulation in the summer of 1964, which was appreciably warmer at Alert.

For the ice-shelf grid in the 3 years 1965–68 for which records are available, there was a range of snow accumulation both for ridges and troughs similar to that measured on the ice rise (Table II). In 1967 only three trough poles were available for measurement, but in 1968 and 1969 the mean snow depths in the troughs were 60 and 40 mm greater, respectively, than on the ridges. At the same time net ablation in the troughs was 81 and 27 mm greater than on the ridges, with wide variations in both areas. The lakes that occupy the troughs during the ablation season do not drain completely, so that the net ablation measured on the ridges is less than the actual ablation. Nevertheless, the current regime, as shown from only 2 years' useful observations, is competent to preserve the ridge-and-trough topography and even to allow slight deepening of the troughs. It is interesting to find approximately twice as much net ablation on the ice shelf as on the ice rise in the two summers of 1966–67, although in 1968, when the ice rise was essentially in balance, there was a deficit of about  $100 \text{ kg m}^{-2}$  on the ice shelf. From the figures of net accumulation on the ice rise in 1962–65 (Table I), it seems very likely that there was also net surface gain on the ice shelf during these 3 years. It should be emphasized that the present data refer only to the surface mass balance of the ice shelf; there is no information on whether melting or accretion is taking place at the underside.

#### CONCLUSIONS

On the ice shelf the years 1906–62 were a period of net surface ablation of the order of metres of water; they were followed by 3 years (1962–65) of probable positive surface regime, and then by 3 years (1965–68) of net surface ablation totalling 640 mm water (Table II). On the ice rise the years 1958–68 were a period of negative mass balance totalling 570 mm water, but the years 1962–68 were a period of positive mass balance totalling 190 mm water (Table I). Quite small deviations from mean summer temperature appear to determine whether the mass balance is positive or negative, and for this reason neither ice rise nor ice shelf should be considered as a relict glacial feature.

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