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Half a Century of Measurements of Glaciers on Axel Heiberg Island, Nunavut, Canada

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ABSTRACT. We illustrate the value of longevity in high-latitude glaciological measurement series with results from a programme of research in the Expedition Fiord area of western Axel Heiberg Island that began in 1959. Diverse investigations in the decades that followed have focused on subjects such as glacier zonation, the thermal regime of the polythermal White Glacier, and the contrast in evolution of White Glacier (retreating) and the adjacent Thompson Glacier (advancing until recently). Mass-balance monitoring, initiated in 1959, continues to 2011. Measurement series such as these provide invaluable context for understanding climatic change at high northern latitudes, where in-situ information is sparse and lacks historical depth, and where warming is projected to be most pronounced.

Key words: glacier mass balance, glacier changes, Axel Heiberg Island

RÉSUMÉ. Nous illustrons la valeur de la longévité en ce qui a trait à une série de mesures glaciologiques en haute latitude au moyen des résultats découlant d'un programme de recherche effectué dans la région du fjord Expédition du côté ouest de l'île Axel Heiberg, programme qui a été entrepris en 1959. Diverses enquêtes réalisées au cours des décennies qui ont suivi ont porté sur des sujets tels que la zonation des glaciers, le régime thermique du glacier White et le contraste entourant l'évolution du glacier White (en retrait) et du glacier Thompson adjacent (qui s'avançait jusqu'à tout récemment). La surveillance du bilan massique, qui a été amorcée en 1959, se poursuit jusqu'en 2011. Les séries de mesure de ce genre fournissent un précieux contexte permettant de comprendre le changement climatique qui se produit dans les hautes latitudes du Nord, là où il y a peu d'information sur place, où la profondeur historique est mince et où le réchauffement devrait être le plus prononcé.

Mots clés : bilan massique du glacier, changements entourant le glacier, île Axel Heiberg

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INTRODUCTION

Long-term glacier records at high northern latitudes, where 21st-century warming is projected to be most pronounced, are of special value today (e.g., Fritzsche, 2010). The aim of this short note is to summarize a set of such records from close to 80˚ N and to emphasize the value of longevity in the glaciological context with illustrative examples.

GLACIOLOGICAL MEASUREMENTS AT EXPEDITION FIORD, AXEL HEIBERG ISLAND

Measurements of glaciers around Expedition Fiord, western Axel Heiberg Island, Nunavut (Fig. 1), began in 1959. Some of those measurement series, including mass-balance measurements on Baby and White glaciers, now extend over 50 years. Both glaciers have experienced negative mass balances since the 1970s. Changes in the terminuses of White Glacier and Thompson Glacier have been studied over the same period, with an extension back to 1948 based on an early aerial photograph. A special feature of this record is the persistent retreat of White Glacier and (until some time during the 2000s) the advance of Thompson Glacier.

The International Geophysical Year of 1957–58 triggered a surge of research activity in Canada's High Arctic islands, including the initiation of measurements on glaciers. Boon et al. (2010) report on series of measurements and research programmes on the Devon Ice Cap that now extend over more than 47 years. The work includes studies of mass balance, deep ice-cores, various aspects of ice-cap dynamics, and changes in the area and volume of the ice cap. Long series of measurements and studies like this, at very high latitudes, are the result of years of thoughtful persistence.

The series on Devon Island was begun by the Arctic Institute of North America's Devon Island Expedition in 1961 (e.g., Apollonio, 1962). In 1959, McGill University (Müller, 1961; Müller and Members of the Expedition, 1963) had begun mass-balance and other glaciological measurements in the Expedition Fiord area of western Axel Heiberg Island, northwest of Devon Island. Studies were initiated on a number of glaciers: Baby, Crusoe, Iceberg, Thompson, and White glaciers, as well as the Akaoia Ice Cap (often referred to as McGill Ice Cap, but now formally

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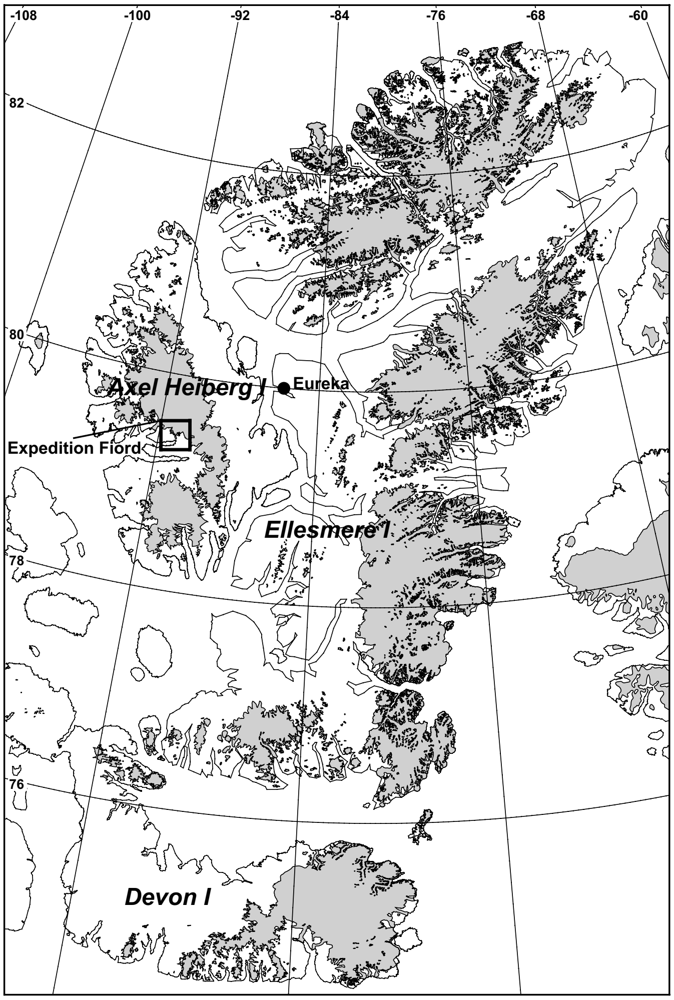

FIG. 1. Expedition Fiord, Axel Heiberg Island, in the setting of the Canadian High Arctic. Glaciers are shaded. UTM projection, zone 17.

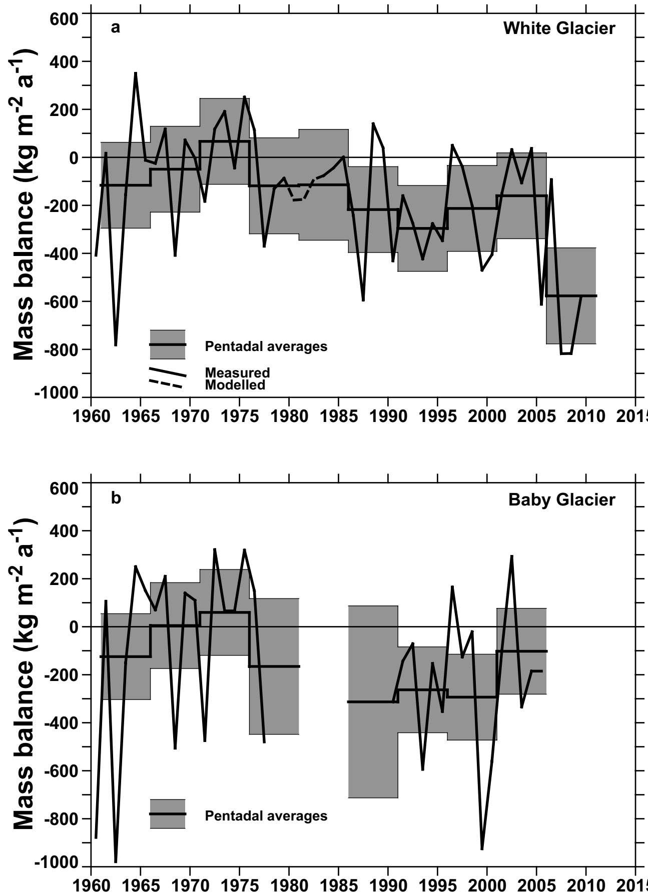

FIG. 2. Annual mass balance of a) White Glacier and b) Baby Glacier, Expedition Fiord, Axel Heiberg Island, 1959–60 to 2008–09. Horizontal lines, bounded by shading representing ± 2 standard errors, are statistically independent means for pentads (beginning with the mass-balance year 1960–61). Measurements have been made successively by groups from McGill University, Montréal; Eidgenössische Technische Hochschule (ETH), Zürich; and Trent University, Peterborough, Ontario. The unmeasured balance years on White Glacier, 1979–80 to 1981–82, were filled with a regression against meteorological data from Eureka, 160 km to the northeast.

named Müller Ice Cap). Mass-balance measurements continued only on Baby Glacier and White Glacier. The early observations contributed to the understanding of equilibrium-zone and accumulation-zone melt and accumulation processes (Müller, 1962, and see Paterson, 1994: Fig. 2.1). Work on Thompson Glacier focused on its push moraine (Kälin, 1971; Moisan and Pollard, 1992, 1995).

White Glacier became the principal glacier studied by Fritz Müller, who led the early expeditions, and by others after Müller's death in 1980 (Adams, 2007). One of the notable studies was a deep drilling programme (Blatter, 1987; Blatter and Hutter, 1991) that demonstrated the polythermal nature of the glacier, a condition suspected from earlier measurements (Iken, 1974) of variations in glacier velocity. Ommanney (1987) compiled an exhaustive bibliography of glaciological research on Axel Heiberg Island, which was updated by Cogley (1999a).

Figure 2 updates the annual mass-balance series from Baby Glacier (area 0.61 km^2) and White Glacier (area 39.4 km^2), and Figure 3 updates the terminus fluctuations of White Glacier and Thompson Glacier (area 384 km^2).

Both Baby Glacier and White Glacier have had consistently negative mass balances since the 1970s (Fig. 2). The average rate of loss of White Glacier since 1959–60 has been -175 mm w.e. a^{-1} (mm of water equivalent per year). Its average rate of loss for the most recent four years, 2005–06 to 2008–09, is -580 mm w.e. a^{-1}. The mass-balance record of Baby Glacier is less complete, but the average annual balance for the 34 years between 1959–60 and 2004–05 is -150 mm w.e. a^{-1}. The two time series are strongly correlated (r = 0.90 for 30 years with measurements on both glaciers), although the mass balance of Baby Glacier is more variable than that of White Glacier, the standard deviations of the series being respectively 377 and 250 mm w.e. a^{-1}.

Figure 3 shows the terminuses of White Glacier and its much larger neighbour, Thompson Glacier. Mapping and remote sensing have shown the markedly different behaviour of the two terminuses. Figure 3a shows the terminuses of White Glacier and Thompson Glacier as of 1960

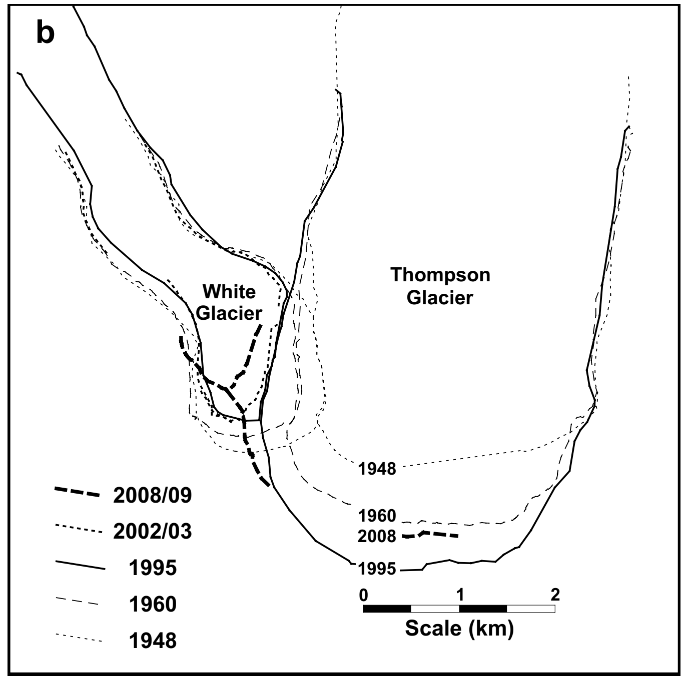

FIG. 3. Changes in the terminuses of White and Thompson glaciers, Axel Heiberg Island, 1948 to 2008. a) Topographic map at 1:50 000 scale based on air photography and topographic surveys undertaken in 1960. Note the distinctive moraines. b) Comparison of the 1960 glacier outlines to earlier and later outlines; outlines of 2002–03 are available only for White Glacier. Note the advance of White Glacier and the retreat of Thompson Glacier, discussed in the text.

(National Research Council, 1962). They were mapped as part of a comprehensive glacier-mapping programme (Ommanney, 1987), which has proved to be one of the lasting contributions of the McGill expeditions. In 1960, White Glacier had a steep but easily accessible tongue, fronted by a recessional moraine. Thompson Glacier, on the other hand, ended in a steep cliff, fronted by a distinctive push moraine, a characteristic feature of advancing Arctic glaciers (Evans and England, 1991).

The 1948 outline in Figure 3b was obtained by rectifying an early United States Army Air Force oblique air photo (Cogley and Adams, 2000). Glacier outlines later than those on the 1960 map (including some from intervening years, not shown here) were obtained in various ways, which include the use of airborne synthetic aperture radar (1995), ground traverses, and GPS (2002–03, 2008). For details of methods, see Cogley et al. (1996), Cogley (1999b), and Hember et al. (2003).

A striking feature of Figure 3b is the consistent retreat of White Glacier throughout the period of record and the consistent advance (until recently) of Thompson Glacier. White Glacier thinned, narrowed and retreated by about 250 m from 1948 to 1995 (Cogley et al., 1996). During the same period, Thompson Glacier advanced by about 950 m, occupying territory formerly occupied by White Glacier. One interpretation of these contrasting behaviours is that Thompson Glacier, an order of magnitude larger than White Glacier, has a much longer response time, so that its continued advance is a response to Little Ice Age cooling. White Glacier, with a shorter response time, would have advanced to a maximum forward position at some unknown date before 1948, and it has been retreating ever since (Cogley and Adams, 2000). Alternatively—and perhaps more probably, in view of related studies elsewhere (Müller, 1969; Copland et al., 2003)—Thompson Glacier may until recently have been in a state of "slow surge." Its sinuous medial moraines offer some support for this interpretation. However, the phenomenon is not well understood, although Copland et al. (2003) showed that it is not uncommon in surging glaciers of the region. Unfortunately there are no in-situ measurements, either at the base or on the surface of Thompson Glacier, to guide further investigation.

However, the 2008 measurements in Figure 3b show that Thompson Glacier appears now to have begun to retreat. Already the distinctive cliff of its terminus is much less pronounced and in places has disappeared. This probably means that its push moraine will cease to be active.

CONCLUDING REMARKS

At the local scale, the differing responses of White Glacier and Thompson Glacier to forcing are still not understood, but we would be aware of the paradox only sketchily in the absence of photographic coverage and ground control obtained in situ. In the global context, mass-balance measurements are heavily concentrated in accessible regions that contribute little to global total glacier extent. Table 1 shows that the Canadian Arctic compares favourably for density of measurements with some other remote and extensively glacierized regions, especially considering that in Antarctica, Greenland, and the Russian Arctic there are no long time series to provide continuity and statistical confidence (Cogley and Adams, 1998). Mass-balance records such as those from White Glacier, Baby Glacier, and the Devon Ice Cap therefore play a vital role in correcting spatial bias in the global data set (Cogley, 2009).

TABLE 1. Density of annual mass-balance measurements in selected glacierized regions.

Region	First measurement[1]	N_y[2]	S (km^2)[3]	1000 × N_y/S[4]
Alaska and Yukon	1945–46	270	85068	3.2
Canadian Arctic	1956–57	292	146690	2.0
Greenland[5]	1948–49	28	53414	0.5
Svalbard	1951–52	237	36506	6.5
European Alps	1884–85	861	3045	282.8
Scandinavia	1941–42	775	3057	235.5
Russian Arctic	1957–58	63	57770	1.1
Antarctica[5]	1959–60	59	127000	0.5

[1] Mass-balance year of first annual measurement.
[2] Number of annual mass-balance measurements, 1940–41 to 2008–09.
[3] Regional glacierized area.
[4] Number of annual-balance measurements per thousand km^2.
[5] Excluding the ice sheet.

We concur with Boon et al. (2010) that long-term measurements are essential for assessing the health of Arctic glaciers. Indeed, their assertion holds for glaciers in general. We urge that the maintenance of such valuable long-term series be given all possible support by the academic community, governments, and funders.

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