Correspondence

Another surge of Variegated Glacier, Alaska, USA, 2003/04

Variegated Glacier (60°00′ N, 139°11′ W), located in the coastal St Elias Mountains, Alaska, USA, is one of the few thoroughly studied surge-type glaciers in the world. Our knowledge comes from extensive field studies carried out between 1973 and 1986 (e.g. Kamb and others, 1985; Raymond, 1987; Raymond and others, 1987; Raymond and Harrison, 1988; Humphrey and Raymond, 1994), and other studies which produced a history of seven surges during the 20th century (e.g. Eisen and others, 2005; Fig. 1). Here we report on the most recent surge, which terminated in 2004. There is no ongoing study of Variegated Glacier, but information from satellite imagery and other sources has been pieced together to constrain the date, seasonal timing and morphology of this surge. We also compare it with earlier surges, and consider some of the implications.

We first consider the date and seasonal timing of surge termination. The low-resolution catalogue version of a DigitalGlobe QuickBird satellite image acquired on 18 March 2004 (http://archivetool1.digitalglobe.com) shows no significant disruption of the surface of the lower part of the glacier by crevassing. It is possible that crevassing there could be hidden by thick snow cover, but another image at the same time of year (3 March) in 2006 does show major surface disruption, implying that 2004 snow was not likely to have hidden major crevassing on the lower glacier. Thus the surge affected the lower glacier significantly only after 18 March 2004. However, because of the time needed to propagate the surge down the lower glacier (Raymond and others, 1987), it is likely that the surge did not terminate until well after this 18 March limit.

A high-resolution Ikonos satellite image (http://doi.pangaea.de/10.1594/PANGAEA.655702) and a lower-resolution version of it (Fig. 2) acquired on 16 July 2004 show major crevassing on the lower glacier. There is also a high-resolution image on Google Earth (http://download.earth.googlepages.com/home) (dated 4 August 2004 by comparison of snow and cloud cover with that of a dated image from the DigitalGlobe catalogue) which indicates major crevassing of the entire surface, and surface debris patterns identical to those on the Ikonos image. Taken together, these images indicate that the surge was complete by 16 July 2004. Little if any change occurred between then and 13 September 2004 when we obtained a set of oblique aerial photos.

In summary, we are confident that the surge terminated well after 18 March, but before 16 July 2004. This interpretation is consistent with several casual observations on the ground and from the air between 2002 and 2006. The previous two surges terminated on 5 July 1983 and 11 June (or shortly after) 1995 (Kamb and others, 1985; Eisen and others, 2005).

Information is also available on the evolution of the surge. Although it had not affected the lower glacier significantly by 18 March 2004, it was already in progress by 8 June 2003 on the upper glacier, where another Ikonos image (http://doi.pangaea.de/10.1594/PANGAEA.655702) covering most of the upper 9 km of the glacier shows moderately heavy crevassing everywhere, including the single tributary. A similar image (same reference) 13 months later (13 July 2004) shows more intense crevassing. Thus the surge began sometime before 18 June 2003, and, as already noted, ended shortly before 16 July 2004.

This information is limited, but reminiscent of what occurred in the well-studied 1982/83 surge. This had two phases, the first of which began in January 1982 and terminated in mid-July 1982 after affecting mainly the upper glacier. The second began in autumn 1982 and terminated in early July 1983. It affected the lower glacier and increased the intensity of crevassing in the upper glacier. What we know about the 2003/04 surge is at least consistent with this pattern. There is some evidence that the 1964/65 surge also followed this two-phase pattern (Eisen and others, 2005, p. 400), although we have no information about the earlier surges. Two-phase surges may be common on this glacier.

In Figure 2 we compare the extent of the 2004 surge with those of earlier surges. The 2003/04 surge terminated about 17.3 km from the head of the glacier, which is about 1 km less than the well-studied 1982/83 surge. There are differences in extent and detail, but the general intensity and pattern of surface crevassing is similar for these two surges. Although we have no information about surface topography in 2004 to compare with that of previous surges, the similarity in surface morphology of the 1982/83 and 2003/04 surges suggests that they were not much different from each other, in contrast to the surge in 1995 as described below.

The 2003/04 occurrence of the surge is of special interest in the light of the finding of Eisen and others (2001) that the onset of most if not all of the seven surges occurring in the 20th century can be correlated with the cumulative mass balance at a point in the accumulation area, which on the basis of field observations was connected to temperature and precipitation at the nearest weather station, in Yakutat (55 km to the south-southwest near the coast).

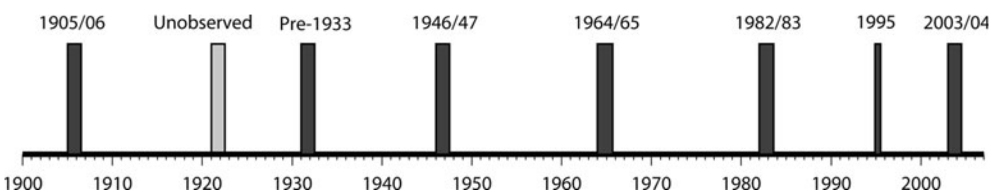

Fig. 1. Surge history, updated from Eisen and others (2005). The width of the bars indicates the estimated duration of the surges (see text).

https://doi.org/10.3189/002214308784409134 Published online by Cambridge University Press

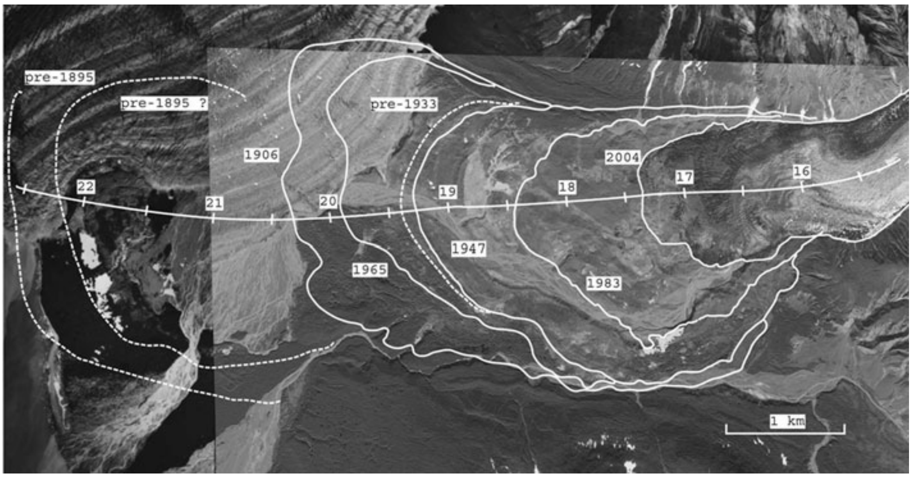

Fig. 2. Extents of surges superimposed on an Ikonos satellite image (16 July 2004, center and right) and a vertical composite aerial photo (28 August 1983, top and left). See Eisen and others (2005). The 1995 extent is poorly defined; its boundary is off the figure to the right. The tick marks are distances in kilometers from the head of the glacier. To the upper left is ice from Hubbard Glacier. The Ikonos image has been slightly distorted to match the composite aerial photo. It was provided by GeoEye.

Although the onset of the previous surge in 1995 followed this pattern, the 1995 surge was unusual in that it terminated before having a major impact on the lower glacier, even though the effect on the upper glacier was intense. This early termination in 1995 was probably caused by the massive input of surface meltwater occasioned by the two hottest days ever recorded at the Yakutat weather station, as noted by Eisen and others (2005). They speculated that this premature termination, together with the lack of a significant second phase of this surge, would interrupt the correlation between mass balance and surge occurrence which had held in the 20th century. Their idea was that the unusual post-surge topography after the 1995 surge made it more probable that the next surge would occur earlier.

This has been borne out by the 2003/04 surge. It is shown in Figure 3 that the estimated cumulative mass balance by 2003/04 was only half of that required for previous surges. Now, however, after the occurrence of the relatively 'normal' 2003/04 surge, which likely reset the topography to a more typical post-surge configuration, it will be interesting to see whether the old correlation will hold for the next surge.

In addition to their implications for the correlation between mass balance and the year of surge initiation, these observations reinforce the conclusion of Eisen and others (2001) and Harrison and Post (2003), for example, that surges of this glacier and of other glaciers in Alaska tend to terminate in the melt season; Variegated Glacier surges have terminated in the earlier part of it. This adds credibility to their inference that surge characteristics usually do depend upon both climate and weather. Evidence for water-filled crevasses in the 2004 Google Earth image, seen on many surging glaciers, is further indication for the importance of stored water and a disrupted hydraulic system. However, little new light is shed upon key issues addressed by these and other authors, such as the critical role of the evolving basal shear stress (Eisen and others, 2005), or the probably soft morphology of the beds of surge-type glaciers and its effect on the hydraulic system.

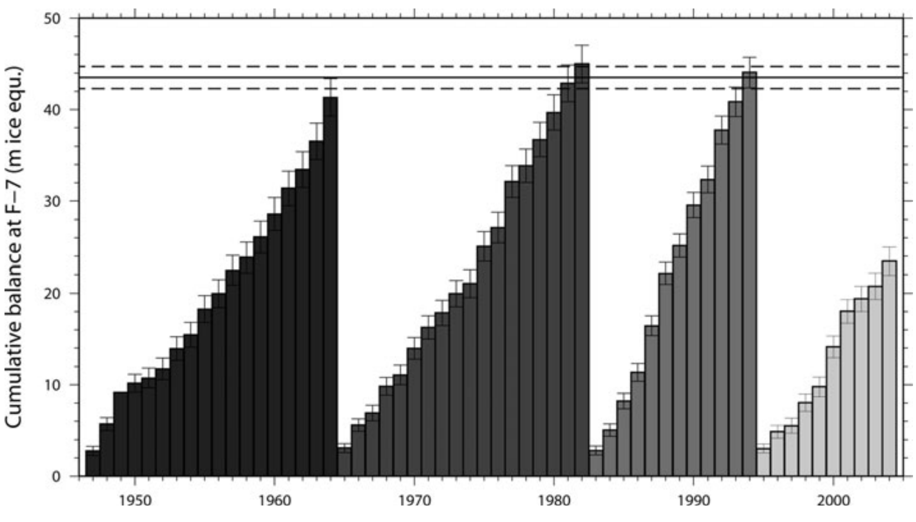

Fig. 3. Estimated cumulative balance series at a point in the accumulation area (Eisen and others, 2001) prior to each surge with 1σ errors.

https://doi.org/10.3189/002214308784409134 Published online by Cambridge University Press

ACKNOWLEDGEMENTS

Support from the US National Science Foundation grant OPP032067 and from the University of Alaska Geophysical Institute are recognized. We are grateful to the GeoEye Foundation, which donated the high-resolution Ikonos images.

Geophysical Institute,
University of Alaska,
903 Koyukuk Drive,
Fairbanks, Alaska 99775-7320,
USA
E-mail: harrison@gi.alaska.edu

W.D. HARRISON
R.J. MOTYKA
M. TRUFFER

Alfred Wegener Institute for
Polar and Marine Research,
PO Box 120161,
D-27515 Bremerhaven,
Germany

O. EISEN

USDA Forest Service – Yakutat RD,
712 Ocean Cape Road,
Yakutat, Alaska 99689,
USA

M.T. MORAN

Department of Earth and
Space Sciences, Box 351310,
University of Washington,
Seattle,
Washington 98195-1310,
USA

C.F. RAYMOND

Institute for the Study of Earth,
Oceans, and Space,
University of New Hampshire,
Durham, New Hampshire 03824,
USA

M.A. FAHNESTOCK

Water and Environmental
Research Center,
Northern Engineering,
306 Tanana Drive,
University of Alaska Fairbanks,
Fairbanks, Alaska 99775-5860,
USA

M. NOLAN

12 November 2007

REFERENCES

Eisen, O., W.D. Harrison and C.F. Raymond. 2001. The surges of Variegated Glacier, Alaska, U.S.A., and their connection to climate and mass balance. *J. Glaciol.,* **47**(158), 351–358.

Eisen, O., W.D. Harrison, C.F. Raymond, K.A. Echelmeyer, G.A. Bender and L.D. Gorda. 2005. Variegated Glacier, Alaska, USA: a century of surges. *J. Glaciol.,* **51**(174), 399–406.

Harrison, W.D. and A.S. Post. 2003. How much do we really know about glacier surging? *Ann. Glaciol.,* **36**, 1–6.

Humphrey, N.F. and C.F. Raymond. 1994. Hydrology, erosion and sediment production in a surging glacier: Variegated Glacier, Alaska, 1982–83. *J. Glaciol.,* **40**(136), 539–552.

Kamb, B. *and 7 others*. 1985. Glacier surge mechanism: 1982–1983 surge of Variegated Glacier, Alaska. *Science,* **227**(4686), 469–479.

Raymond, C.F. 1987. How do glaciers surge? A review. *J. Geophys. Res.,* **92**(B9), 9121–9134.

Raymond, C.F. and W.D. Harrison. 1988. Evolution of Variegated Glacier, Alaska, USA, prior to its surge. *J. Glaciol.,* **34**(117), 154–169.

Raymond, C., T. Jóhannesson, T. Pfeffer and M. Sharp. 1987. Propagation of a glacier surge into stagnant ice. *J. Geophys. Res.,* **92**(B9), 9037–9049.