Journal of Glaciology, Vol. 56, No. 199, 2010

Instruments and Methods

Using a draw-wire sensor to continuously monitor glacier melt

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ABSTRACT. A draw-wire sensor has successfully been used to measure surface lowering due to net ablation of a glacier. A thin steel wire attached to a weight is inserted and frozen into a borehole in the ice. The draw-wire sensor, installed on a tetrahedron on the surface, retracts the wire as the snow or ice melts. Relative surface lowering of the melting surface is recorded in a data logger and may be converted to mass loss. The instrument continuously logs net ablation over several melt seasons and has the potential to be used extensively in future studies of glacier melt, whenever high temporal resolution and precision are required.

INTRODUCTION

Glacier mass-balance data with high temporal resolution are required for calibration and validation of melt models and to study individual melt events on short timescales. In situ measurements are time-consuming and field trips to remote glaciers are expensive. Therefore, automated methods to continuously measure mass changes have great value in glacier monitoring.

Traditional approaches with ultrasonic rangers and older versions of ablatometers are dependent on stakes drilled into the ice, with a practical measurement range of 3–4 m before the stakes bend or tilt over. Bøggild and others (2004) presented a custom-built instrument for automatic ablation measurements. Their instrument (hereafter referred to as the 'Bøggild ablatometer') was mounted on a floating weather station, independent from stakes drilled into the ice, and can therefore survive several ablation seasons without revisit. The instrument records changes in the hydrostatic pressure at the bottom of an antifreeze-filled hose installed in a borehole drilled into the ice. The surface end of the hose is connected to a bladder to hold the excess volume of fluid, generated by thermal expansion of the antifreeze due to changes in ice temperatures. The hydrostatic pressure changes as the surface is lowered by melt.

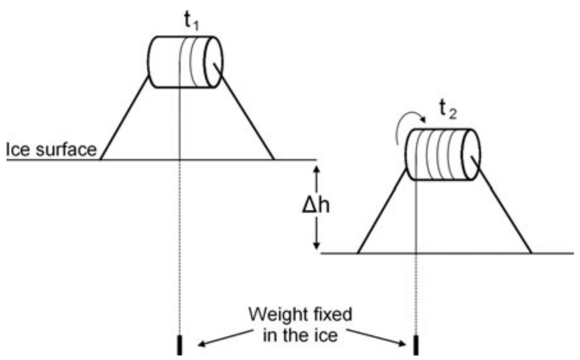

Fig. 1. Schematic diagram of ablation measurements with a draw-wire sensor. A weight is attached to the end of the wire and fixed in the ice. The draw-wire sensor is mounted on a tetrahedron freely standing on the melting surface and retracts the wire as the surface lowers. The instrument registers relative surface elevation change, Δh, in time, t_n, due to net ablation.

Here we present a method using a standard draw-wire sensor, commonly used to record linear displacement, to measure surface lowering due to net ablation of a glacier. This approach provides high precision and temporal-resolution ablation measurements and eliminates the problem of stakes melting out or bending. It can therefore operate for several ablation seasons, minimizing the need for revisit and maintenance of the instrument.

INSTRUMENT AND SET-UP

A draw-wire sensor measures linear displacement by means of a steel wire. The instrument consists of a spring-loaded spool with a thin steel wire wound around it. In this application, the spool is mounted on a freely standing tetrahedron on the melting surface. The free end of the wire is attached to a weight and inserted into a 25 mm diameter borehole in the glacier, where it is allowed to freeze. The wire retracts as the surface lowers due to melt. Signal output corresponds to the change in wire length and is recorded in a data logger (Fig. 1). The relative elevation change may then be converted to glacier mass loss, assuming a suitable density. This single set-up can record net ablation over several seasons depending on the melt rate, the length of the wire and the depth of the borehole.

The instrument (Kübler D135; Table 1) was installed on 1 April 2009 in the ablation area (330 m a.s.l.; 5–8° surface slope) on Sørbreen, a polythermal glacier on Jan Mayen, North Atlantic Ocean (71°00′ N, 8°30′ W; Orheim 1993; Hulth and others, 2010). We used a sensor with a 15 m measurement range, corresponding to an estimated surface lowering due to melt over three ablation seasons at that site. The instrument was mounted ~1.5 m above the ice surface on a tetrahedron constructed of 2 m long 40 × 3.5 mm aluminum pipes (Fig. 2).

A Bøggild ablatometer was installed on the same tetrahedron as the draw-wire sensor in 2009 (Fig. 2). It stopped working at the beginning of August 2009, due to an instrument failure. In March 2010, a Campbell Scientific

https://doi.org/10.3189/002214310794457290 Published online by Cambridge University Press

Table 1. Instrument specifications for the Kübler D135 draw-wire sensor used on Jan Mayen in 2009 and 2010

Variable	Value	Unit
Measuring range	15	m
Wire diameter	0.5	mm
Supply voltage	12–36	V d.c.
Output signal	0–10	V
Current consumption	22.5	mA
Size	180 × 135 × 135	mm
Instrument weight	2	kg
Operating temperature	–20	°C
Storage temperature	–40	°C
Environmental protection	IP67	

SR50A sonic ranger was installed to replace the Bøggild ablatometer. This instrument was mounted on a weather station ~50 m away from the draw-wire sensor. Measurements were sampled every hour and stored locally on a data logger as well as transmitted for download over the Internet via an Iridium satellite system.

Manual ablation measurements were made on 1 April 2009, 18 July 2009 and 21 July 2010, as an independent control of the automatic measurements. A metal tape measure was used as an ablation wire and installed in a borehole within 2 m of the tetrahedron.

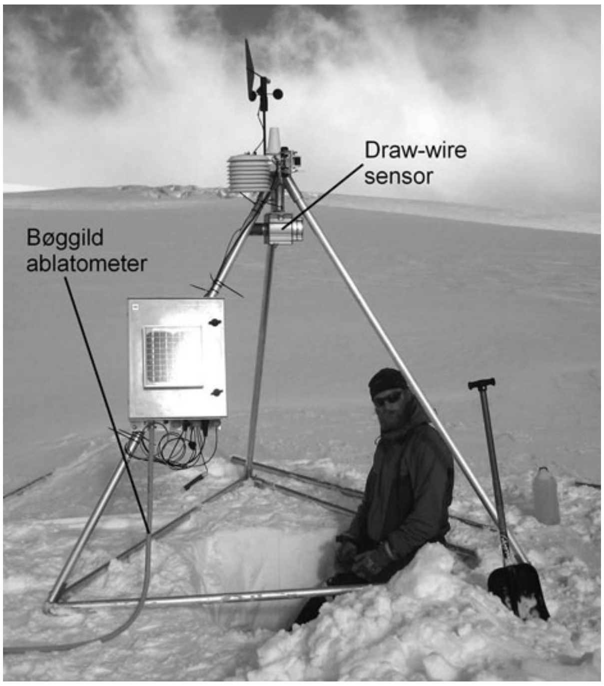

Fig. 2. Installation of the mass-balance station with a draw-wire sensor and a Bøggild ablatometer for ablation measurements on Sørbreen, Jan Mayen, 1 April 2009. The bladder to the Bøggild ablatometer is installed in the ventilated instrument box.

RESULTS AND ERROR ANALYSIS

The surface lowering measured with the draw-wire sensor was 6.09 m between 1 April 2009 and 21 July 2010. Total ice melt until 18 July 2009 and 21 July 2010 was 0.98 and 5.00 m respectively for the draw-wire sensor and 0.91 and 5.17 m respectively for the manual ablation measurement (Fig. 3a). Results show good agreement between the draw-wire sensor, the Bøggild ablatometer and the sonic ranger. The different methods measure very similar melt rates over the ablation season (Fig. 3a) and also on shorter (daily) timescales (Fig. 3b). However, there are biases between the methods (Fig. 3c and d). Even though the measurements were conducted relatively close to the draw-wire sensor, variations between the measurements can be attributed to uneven melt due to surface irregularities. Resulting tilt of the tetrahedron may have introduced a bias in the measured melt rates of the Bøggild ablatometer since the two instruments were installed at different locations on the tetrahedron.

The main sources for errors from the draw-wire method are errors related to (1) the instrument and (2) unwanted movements of the tetrahedron. Instrument errors are primarily from nonlinearity of the signal output and thermal expansion of the steel wire. These errors are stated by the manufacturer and confirmed by calibration of the draw-wire sensor to ±1.5 and ±0.5 cm respectively for magnitude of the measurement range of the instrument used in this study. Errors due to unwanted movements of the tetrahedron were assessed from five visits between 1 April 2009 and 21 July 2010, and may be decomposed into vertical and horizontal components. After the station is installed and melt begins, the tetrahedron will 'sink' into the melting surface and settle after some days. This results in an overestimation of the melt rate associated with the time of installation of the instrument, observed to be <5 cm at our test location. The amount of settling depends on the magnitude of solar radiation and the design of the tetrahedron. If the station is installed on a sloping surface, which is commonly the case on glaciers, the tetrahedron can potentially move horizontally when the ice surface melts. This will extract the wire and cause melt rates to be underestimated. The maximum horizontal movement observed during field visits was 57 cm, causing an underestimation of the melt rate by 10.5 cm. This explains some of the biases with the manual measurement on 21 July 2010 (Fig. 3d). Our observations do not indicate whether the movement is systematic in one direction or random. Further investigations are needed in different locations and climates to establish whether horizontal movement of the tetrahedron may be a larger source of error in applications at other sites. However, installing the sensor higher above the surface, preferably at 2 m, will reduce the impact of this uncertainty.

Change in the position of the 'fixed' weight within the ice is difficult to observe. The weight balances the tension in the wire, and the small diameter of the wire reduces the conduction of heat to the weight. These two factors minimize the risk of the weight moving due to pressure melting. The borehole at our test site was quickly frozen, and it is assumed that this movement is negligible. Additional uncertainty might arise if the instrument is installed on a temperate glacier and the borehole does not freeze quickly. Freeze-in of the weight is promoted by installation of the instrument during winter. We also assume that ice deformation and resultant borehole lengthening is insignificant at the shallow depths involved in these draw-wire measurements.

The propagation of errors gives an absolute error of about ±10 cm for the measurement range of the draw-wire sensor. Errors on short timescales (days) are assumed to be at least one magnitude smaller. Furthermore, our measurements offer a more representative sense of ice-surface lowering

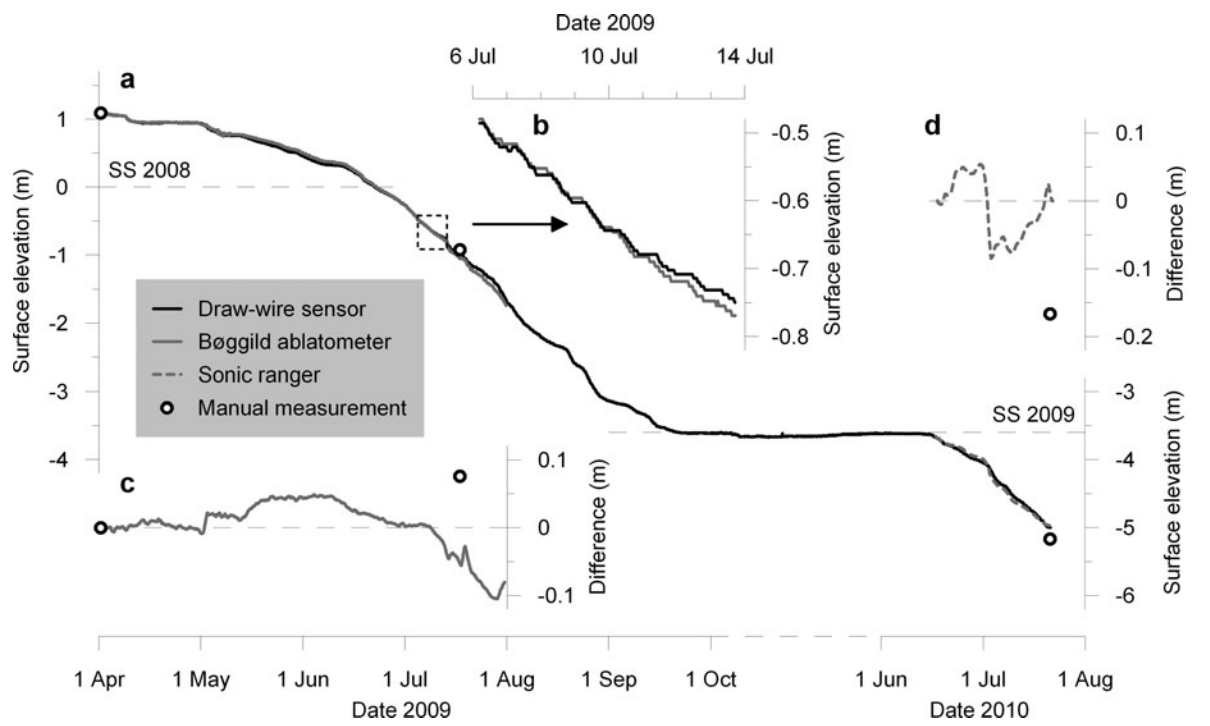

Fig. 3. (a) Surface elevation relative to the summer surface (SS) of 2008 measured continuously with a draw-wire sensor. Snow depth at 1 April 2009 was 1.09 m, and ice loss at 21 July 2010 was 5.00 m_{ice}. (b) A period of 8 days in July 2009 exaggerated to demonstrate the resolution of the measurements. (c, d) Differences in surface elevation compared with (c) a Bøggild ablatometer in 2009 and (d) a sonic ranger in 2010. In addition, manual measurements were conducted during field visits to evaluate the performance of the instrument.

than stake measurements or sonic rangers due to the spatial averaging intrinsic in the large surface area of our mount tetrahedron.

CONCLUSIONS

A draw-wire sensor can be used to measure glacier net ablation rate continuously with high accuracy, precision and temporal resolution. Results compare well with manual and continuous methods commonly used to measure ablation.

The draw-wire sensor is mounted on a tetrahedron freely standing on the melting surface, averaging the melt over a larger area compared to stake measurements. The proposed method eliminates the need for stakes limiting the possible measuring range. We therefore suggest that draw-wire sensors are an effective alternative or complement to sonic rangers which are difficult to maintain in remote areas and on glaciers with high melt rates. A draw-wire sensor should preferably be used to register net ablation, while a sonic ranger may be installed on the tetrahedron to record changes in snow depth.

Instrument costs for the draw-wire sensor and the Bøggild ablatometer are similar. The advantage of a draw-wire sensor is that it is available ‘off the shelf’ and easy to install, whereas a Bøggild ablatometer needs to be assembled from several parts and filled with antifreeze, with the risk of leakage.

The draw-wire sensor is a robust instrument with a high environmental protection (IP67) which has proven to be very useful to measure net ablation on Jan Mayen. It provides excellent data for calibration and validation of melt models. Therefore, we recommend it for extensive use in future glacier mass-balance studies.

ACKNOWLEDGEMENTS

I thank J. Snygg of Berserk Engineering for helping to install the mass-balance station on Jan Mayen, the staff at the Department of Mathematical Sciences and Technology workshop for assistance constructing the tetrahedron and data-logger system, and the staff on Jan Mayen for logistical support. This project was funded by a stipend to the author from the YMER-80 foundation and grants from the Norwegian Research Council through C. Rolstad. Comments by R. Hock, T. Bartholomaus and two anonymous reviewers greatly improved the manuscript.

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MS received 13 May 2010 and accepted in revised form 13 September 2010