Instruments and Methods

A peak-capturing measurement circuit for detecting and recording short-duration glacial signals

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ABSTRACT. A simple circuit has been developed to allow measurement of brief subglacial water-pressure pulses. This circuit continuously powers a pressure transducer and captures the peak output of the transducer during each measurement interval, thus allowing determination of the maximum pressure attained during the interval. This circuit provides an alternative to setting a data logger to perform rapid repeated measurements, and overcomes some key limitations imposed by rapid measurement. Benefits include significantly lower demands on the data-logger microprocessor, which allows additional instruments to be monitored simultaneously, reduced memory usage and moderately lower power consumption. The reduced microprocessor and memory loads allow older and slower logger models, many of which are still in common use, to be used to obtain data that compare favourably with high-frequency data obtained using newer data loggers.

INTRODUCTION

Although glacier motion is typically assumed to be relatively steady, several recent studies have shown that the motion of some soft-bedded ice masses is much more episodic in nature. Stick–slip motion has been demonstrated by in situ measurements at the glacier bed (Fischer and Clarke, 1997) and by surface observations of ice flow (Bindschadler and others, 2003), and seismic emissions consistent with abrupt basal motion have been documented at valley glaciers (e.g. Weaver and Malone, 1979), major outlet glaciers of the Greenland ice sheet (e.g. Ekström and others, 2006), and Whillans Ice Stream, West Antarctica (e.g. Wiens and others, 2008). Because these stick–slip behaviors occur over relatively brief time intervals, observations aimed at capturing these phenomena need to be able to resolve short-duration events.

One way to do this is to sample at a high rate. Although modern data loggers (e.g. the Campbell Scientific CR1000) can sample continuously at rates as high as 100 Hz, such elevated sampling rates introduce additional difficulties, including limitations on the number of additional instruments that can be monitored simultaneously and increased memory consumption. An alternative method is to use an interface circuit that captures and holds short-duration signals for subsequent recording by a data logger. Such an interface circuit was used by Kavanaugh (2009) to record short-duration subglacial water-pressure 'pulses' generated during basal motion events. Here we describe the circuit used in that study.

METHODS

In the following discussions, we refer to pressures recorded at regular intervals as 'discrete pressure' values P_{D} (here expressed in units of pressure head, which have SI units of meters). We further define P_{M} and P_{N} to be the maximum and minimum pressure values, respectively, recorded during the interval immediately preceding each discrete pressure measurement. If we consider pressure 'pulses' to be brief departures from a slowly varying ambient pressure, then positive-valued pulses can be defined as $\Delta P_{+} = P_{\mathrm{M}} - P_{\mathrm{D}}$ and negative-valued pulses as $\Delta P_{-} = P_{\mathrm{M}} - P_{\mathrm{D}}$.

Measurement of pressure pulses using high sampling rate

The circuit used to record pressure pulses at Trapridge Glacier, Yukon, Canada, had a response time of ~0.1 s (Kavanaugh, 2009). This indicates that pulses of similar duration should be readily detectable by measurements made at 10 Hz, and that the use of higher measurement rates should allow shorter-duration events to be recorded. Higher measurement rates should additionally increase the probability that the maximum (or, in the case of negative-valued pulses, minimum) pressure attained during a given pressure excursion is captured. To demonstrate the feasibility of recording pressure pulses using a high measurement rate, a pressure transducer was sampled at a rate of 50 Hz at Storglaciären, Sweden, a soft-bedded polythermal glacier with a long history of scientific investigation (e.g. Holmlund and Hooke, 1983; Holmlund and Eriksson, 1989; Iverson and others, 1995).

Field data: Storglaciären

Figure 1 shows water-pressure measurements made at Storglaciären between 14 August (day 227) and 7 November (day 335) 2008. These data were recorded using a pressure transducer (Omega Engineering, Inc., Model PX302, full-scale range 0–300 psi (0–20.69 bar)) that was installed near the bottom of a borehole drilled to within ~1 m of the glacier bed. This installation method was employed to ensure that the volume of water within the borehole remains constant over timescales relevant to the pulse-generating mechanisms (as required by the transient stress analysis of Kavanaugh

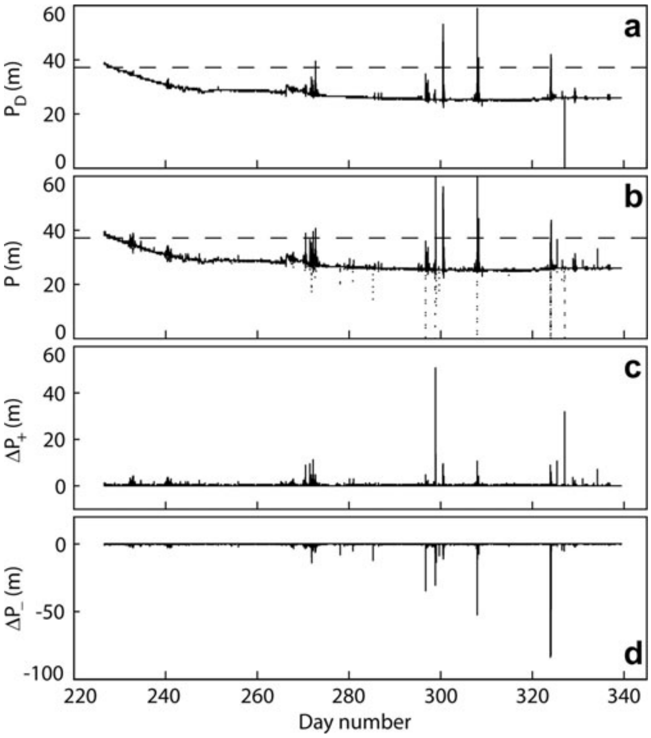

Fig. 1. Pressure values recorded at Storglaciären. (a) Discrete pressure values P_D (solid line) recorded between 14 August (day 227) and 30 November (day 335) 2008 with flotation pressure $P_F = 37$ m (dashed line) shown for reference. (b) Maximum (P_M; solid line) and minimum (P_N; dotted line) pressure values recorded between 14 August (day 227) and 30 November (day 335) 2008, with flotation pressure $P_F = 37.6$ m (dashed line) shown for reference. Pressures <0 m or >60 m plot off-scale. (c) Positive pressure pulse record $\Delta P_+ = P_M - P_D$ for the period 14 August (day 227) to 30 November (day 335) 2008. (d) Negative pressure pulse record $\Delta P_- = P_N - P_D$ for the period 14 August (day 227) to 30 November (day 335) 2008.

(2009)). The transducer was sampled at a rate of 50 Hz by a Campbell Scientific CR1000 data logger. The discrete water-pressure value was stored at 1.0 s intervals, as were the maximum and minimum pressures measured during the previous second. (The program used to record the data shown here is included in the Appendix.) Although the two-sigma uncertainty of the calibration for this transducer is 0.44 m, the accuracy of the values is limited to the ~0.6 m measurement resolution of the data logger.

Discrete pressure values P_D are plotted in Figure 1a (solid line), with the local flotation pressure $P_F = 37$ m represented by a horizontal dashed line. Recorded pressures were approximately equal to flotation immediately following installation, and show a gradual near-monotonic decrease to ~70% of this value. Because the borehole in which the transducer was installed did not reach the glacier bed, these values do not necessarily represent basal water-pressure conditions. Figure 1b shows the maximum (P_M; solid line) and minimum (P_N; dotted line) pressures detected during each 1 s interval. Comparison with the discrete record P_D reveals many brief (i.e. sub-1 s) pressure excursions of both positive and negative values. The maximum pressure captured during the 113 day record was 76 m, and the minimum recorded pressure value was –57 m; both values plot off-scale in Figure 1b. Two additional points of note are that: (1) at some times during the study (e.g. day 299), all three pressure records P_D, P_M and P_N simultaneously recorded intervals of elevated pressure excursion activity; and (2) negative-valued minimum pressures P_N were recorded in nine measurement intervals during the study period (thus plotting off-scale in Fig. 1b).

Figure 1c and d show positive and negative pressure pulse values $\Delta P_+ = P_M - P_D$ and $\Delta P_- = P_N - P_D$, respectively, calculated from measured values P_D, P_M and P_N. The largest positive-valued pulse measured 51 m; the largest negative-valued pulse had a magnitude of –84 m (see Kavanaugh and Clarke (2000) for a discussion of negative-valued water pressures). The minimum detectable pressure pulse magnitude is twice the discretization level employed by the data logger's analog-to-digital converter (as smaller pulses are indistinguishable from transitions between levels); here this is ~1.2 m. (The program presented in the Appendix has been modified to record four-byte, rather than two-byte, floating-point values; this significantly improves the measurement resolution.) During the 113 day study period, a total of 5347 pressure pulses were recorded, comprising $n_+ = 2693$ positive-valued pulses and $n_- = 2654$ negative-valued pulses.

Peak pressure interface circuit

The Storglaciären data presented above demonstrate that pressure pulses can be detected directly by setting a data logger to a sufficiently high sampling rate. This method does impose significant demands upon the data logger's microprocessor, however, and can preclude the data logger from simultaneously monitoring additional sensors. For these reasons, a peak-pressure capturing circuit was developed and installed at Trapridge Glacier, a soft-bedded polythermal surge-type glacier in the Saint Elias Range of southwestern Yukon, Canada, which has been the location of numerous hydrological and mechanical studies (e.g. Clarke and others, 1984; Blake and others, 1994; Flowers and Clarke, 2002; Kavanaugh and Clarke, 2006). An improved version of this circuit is shown in Figure 2; component values are given in Table 1. The most notable improvement from the original circuit is the elimination of a capacitor from the signal path, which markedly improves response time.

This circuit was designed to use the single-ended 5 V power supply incorporated into Campbell Scientific CR10X and CR1000 data loggers, which powers both the pressure transducer and the monitoring circuit. The differential output voltage of the pressure transducer is measured by a differential amplifier (Fig. 2a), which provides a high input impedance and (given that resistors R_1–R_4 are equal in value) yields an output $V_a = V_+ - V_-$. This voltage is fed into a non-inverting amplifier (Fig. 2b), for which the output is $V_1 = [(R_6 + R_7)/R_7]V_a$. For the Trapridge Glacier study, resistor values of $R_6 = 100\,\text{k}\Omega$ and $R_7 = 2.7\,\text{k}\Omega$ were used, which yielded $V_1 \approx 38V_a$. Given the maximum input voltage of ~2700 mV allowed by the Campbell CR10X, this allows peak pressure head values as large as ~185 m to be measured. Two points should be made about this gain. First, the fact that the maximum pressure head recorded during the observation period ($P_M = 183$ m) is very close to the voltage limit of the data logger suggests that the gain should be reduced, as doing so would allow larger pulses to be measured. Second, if the ice thickness differs significantly from that of Trapridge Glacier, or if different data loggers or pressure transducers are used, the gain value should be adjusted accordingly. Because of the signal amplification

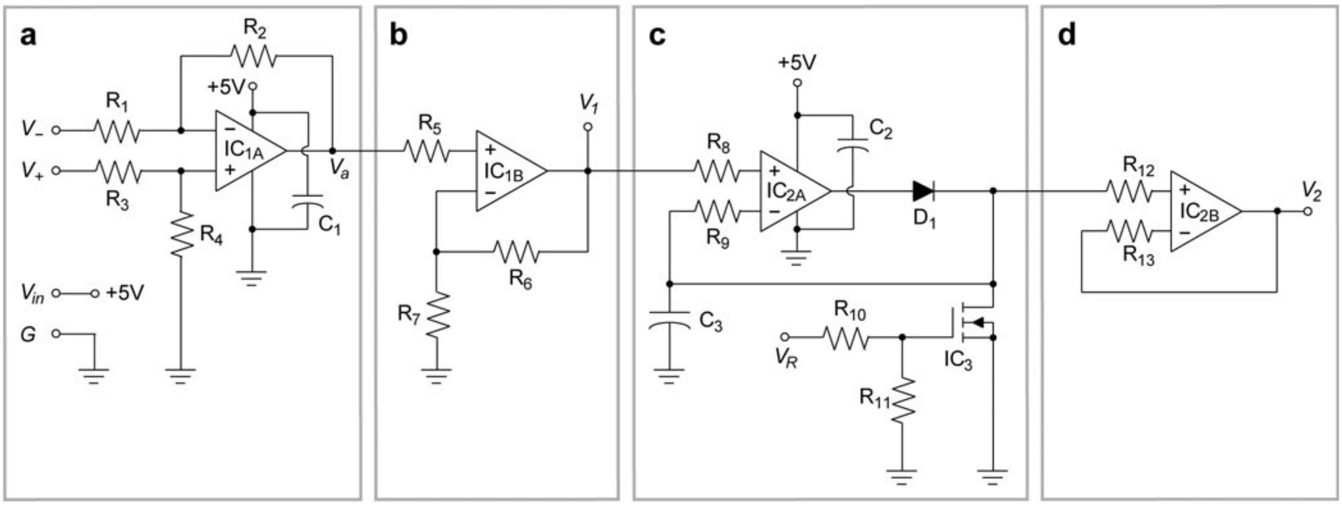

Fig. 2. Diagram of improved peak pressure circuit; see text for operational details. (a) Differential amplifier block; (b) non-inverting amplifier block; (c) peak detection/hold block; (d) voltage follower block.

provided by the circuit, the transducer and monitoring circuit must be calibrated as a unit.

Voltage V_1 is recorded by the data logger, which allows determination of the discrete pressure value P_D. Voltage V_1 is additionally fed into a peak detection circuit (Fig. 2c), which holds the maximum value of voltage V_1 attained during a measurement interval on capacitor C_1. After each measurement interval, this capacitor is discharged (thus resetting the peak detection circuit) by briefly applying a positive voltage to input V_R (provided by a data-logger 'control' port). The peak voltage is passed through a unity-gain voltage follower (which provides a low-impedance output; Fig. 2d), yielding a final output voltage V_2. This value is recorded by the data logger to determine the maximum pressure value P_M.

Table 1. Monitoring circuit component list. As noted in text, values for resistors R_5, R_6 and R_7 should be chosen to optimize the gain of the non-inverting amplifier section (Fig. 2b)

Component	Type	Value/specification
R_1	Resistor	100 kΩ
R_2		100 kΩ
R_3		100 kΩ
R_4		100 kΩ
R_5		$(R_6 R_7)/(R_6 + R_7)$
R_6		SOT
R_7		SOT
R_8		10 kΩ
R_9		10 kΩ
R_{10}		2.7 kΩ
R_{11}		10 kΩ
R_{12}		10 kΩ
R_{13}		10 kΩ
C_1	Capacitor	0.1 μF mica
D_1	Diode	1N4002
IC_1	Operational amplifier	LMC6482
IC_2		LMC6482
IC_3	D-MOS transistor	BS170

Notes: SOT: small-outline transistor; D-MOS: double-diffused metal-oxide semiconductor.

Figure 3 shows the response of the improved circuit to inputs of varying voltage value and duration. The voltage response curve (Fig. 3a) was generated using two Campbell Scientific data loggers. The first of these data loggers provided controlled input voltages; the second recorded the circuit output. The voltage response curve shows that the output voltage is linear for input voltages $V_a < 10\,\text{mV}$; the reduced

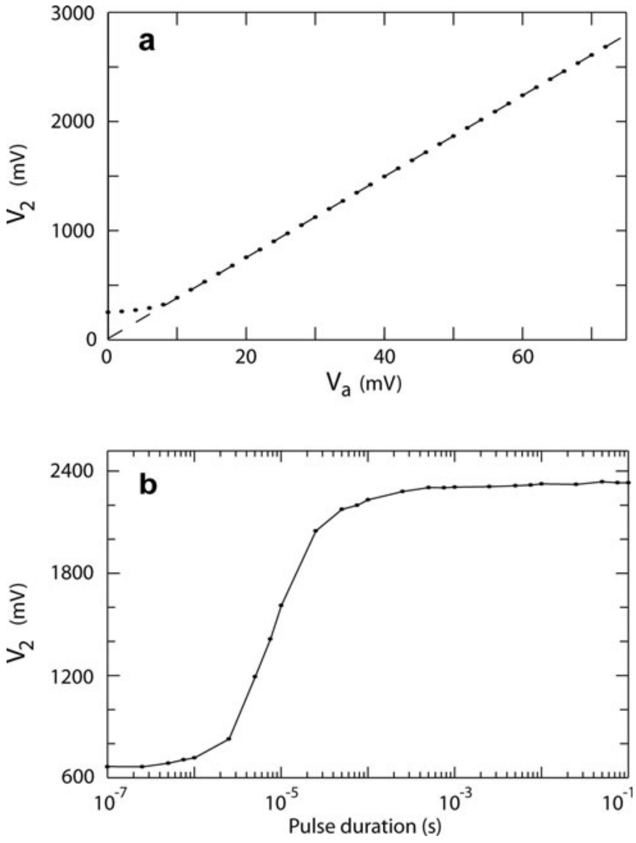

Fig. 3. Characteristics of the improved peak pressure circuit. Resistor values used for the non-inverting amplifier block (Fig. 2b) were $R_5 = 2.7\,\text{k}\Omega$, $R_6 = 100\,\text{k}\Omega$ and $R_7 = 2.8\,\text{k}\Omega$; these values yield a gain of $V_1 \approx 37 V_a$. (a) Voltage response curve for the peak pressure circuit. (b) Time response curve for the peak pressure circuit.

response at lower input voltages results from the use of a single-ended voltage supply. Because pressures at the ice–bed interface will generally result in output voltages exceeding 10 mV, the observed non-linearity poses no difficulty for field measurements. The time response curve (Fig. 3b) was compiled using a Tektronix, Inc. 2101 Pulse Generator to provide brief (100 ns–100 ms) +40 mV pulses; in order to mimic subglacial conditions (where pulses represent brief departures from ambient pressure conditions), these pulses were superimposed onto a +20 mV baseline voltage. Inspection of Figure 3b shows that the modified circuit responds much more rapidly than did that employed by Kavanaugh (2009), which had a response time of ~0.1 s. With the improved circuit, a pulse of 50 µs generates a response that is 90% of the full signal, and the full output is achieved with a pulse of 0.5 ms duration. (The small variations in V_2 observed for pulse durations $\geq$0.5 ms are due to inconsistencies in the output of the analog Tektronix pulse generator, rather than to variations in the circuit's response.)

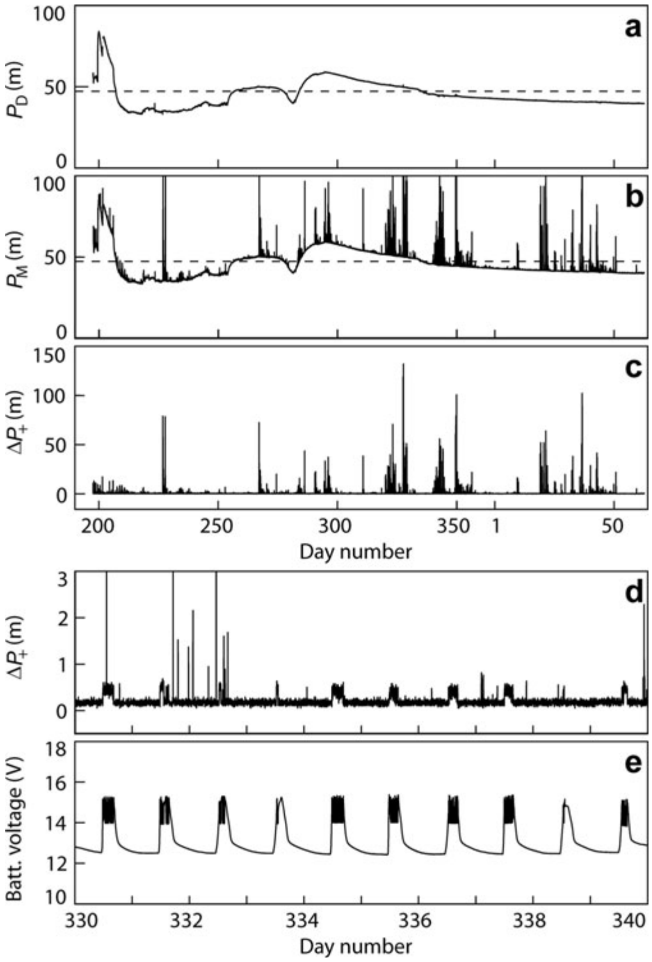

Fig. 4. Subglacial water-pressure (a–d) and data-logger voltage (e) values recorded at Trapridge Glacier. (a–c) are adapted from Kavanaugh (2009). (a) Discrete pressure values P_D (solid line) recorded between 16 July (day 197) 2005 and 4 March (day 63) 2006, with flotation pressure $P_F = 47$ m (dashed line) shown for reference. (b) Maximum pressure values P_M (solid line) recorded between 16 July (day 197) 2005 and 4 March (day 63) 2006, with flotation pressure P_F (dashed line) shown for reference. Note that pressure values >100 m plot off-scale. (c) Pressure pulse record $\Delta P_+ = P_M - P_D$ for the period 16 July (day 197) 2005 to 4 March (day 63) 2006. (d) Pressure pulse record ΔP_+ for the period 26 November (day 330) to 6 December (day 340) 2005. Pulses with magnitudes >3 m plot off-scale. (e) Data-logger battery voltage values for the period 26 November (day 330) to 6 December (day 340) 2005.

Field data: Trapridge Glacier

Figure 4 shows data collected at Trapridge Glacier between 16 July (day 197) 2005 and 4 March (day 63) 2006. Subglacial water pressures (Fig. 4a–d) were recorded by a pressure transducer (Barksdale Inc. Model 402; full-scale rating: 0–200 psi (0–13.79 bar), absolute) installed 0.44 m above the ice–bed interface in a 51.5 m deep borehole. This transducer was connected to a monitoring circuit similar to that described above (though with a slower response time) and controlled by a Campbell Scientific CR10X data logger. Discrete and maximum pressure values were recorded at 2 min intervals. Figure 4a shows the discrete pressure record P_D during the period. Following installation, pressure values rise for several days, reaching a peak value of 84 m on 19 July (day 200) 2005; this pressure is approximately 1.8 times the local ice-flotation pressure of $P_F = 47.2$ m. Pressures subsequently decrease to sub-flotation values, and slowly fluctuate over a range of 70–125% of flotation for the remainder of the record. Maximum subglacial water pressures P_M during this interval are plotted in Figure 4b. Visible in this record are a large number of short-duration pressure excursions that are absent in the discrete pressure record of Figure 4a. The largest of these excursions occurred on 23 November (day 327) 2005 and measured $P_M = 183$ m (or approximately 3.9 times the local flotation value; note that pulse magnitudes >100 m plot off-scale in Fig. 4c.)

Pressure pulse magnitudes $\Delta P_+ = P_M - P_D$ are shown in Figure 4c. Seventy pulses during this interval exceeded the local flotation value $P_F = 47$ m, and the largest-magnitude pulse measured, at $\Delta P = 132$ m, achieved 2.8 times P_F. While the maximum detected pressure pulse is easily determined from the recorded pressure values, determination of the minimum detectable pressure pulse value requires an examination of the noise characteristics of the monitoring circuit. Figure 4d and e plot pressure pulse magnitudes ΔP_+ and CR10X data-logger battery voltage values between 26 November (day 330) and 6 December (day 340) 2005. Comparison of these records shows strong correlation between (1) a small (~0.5–0.7 m) increase in pressure pulse minima and (2) times during which rapid variations are observed in the data-logger battery voltage. The common timing of these features suggests the presence of electrical interference between the solar regulator and the monitoring circuit (Kavanaugh, 2009), and indicates that pressure pulses with magnitudes less than ~0.8 m in this record are indistinguishable from noise. During the 231 day record shown in Figure 4, 7422 pulses with magnitudes exceeding this value were detected. For a more complete examination of these water-pressure data, including comparisons with contemporaneous records from other subglacial and englacial instruments and analyses of their magnitude and temporal distributions, see Kavanaugh (2009).

DISCUSSION AND CONCLUSIONS

Data presented in Figures 1 and 4 show that brief excursions in subglacial (or in-borehole) water pressure are readily recorded both by rapid repeated measurements and by the peak pressure circuit shown in Figure 2. Kavanaugh (2009) demonstrated that the magnitude of these pulses can be used to determine the size of longitudinal stress transients associated with episodic basal motion. Assuming that the volume of water contained within the borehole remains constant over timescales relevant to these events, the stress can be approximated as

$$\sigma_{xx} = \frac{E[\exp(-\beta \Delta p) - 1]}{1 - \nu - 2\nu^2}, \qquad (1)$$

where $E = 9.0 \times 10^9$ Pa and $\nu = 0.28$ are Young's modulus and Poisson's ratio for ice, respectively, $\beta = 5.10 \times 10^{-10}$ Pa^{-1} is the coefficient of compressibility for water and Δp is the positive or negative pressure pulse magnitude (in SI units of Pa). That study also demonstrated that the magnitude and return-time distributions of pressure pulses closely resemble those exhibited by earthquakes. These results suggest that pressure pulses can be useful indicators of stick–slip motion at the ice–bed interface.

Although pressure pulses can be recorded by setting a data logger to sample at a high rate, use of the peak pressure circuit presented here significantly reduces demands upon the data-logger microprocessor, and allows any additional instruments that might be connected to be sampled. In contrast, the 50 Hz sampling rate used in the Storglaciären study is high enough that the data logger would be unable to monitor additional instruments simultaneously. Therefore, use of the peak pressure circuit permits a data logger to be utilized more completely. This could be an important consideration when the number of available data loggers is limited.

Use of the peak pressure circuit can also significantly reduce demands on the data-logger memory. Values at Trapridge Glacier were recorded at 2 min intervals, resulting in the generation of ~13 KB d^{-1} of data. (In addition to discrete and maximum pressure values for one transducer, these records include the date and time of measurement and the data-logger battery voltage and wiring panel temperature; the latter two measurements are for data quality control.) Given a 16 MB storage module capacity, this would permit ~1300 days of data storage. In contrast, values at Storglaciären were recorded at 1.0 s intervals, generating data at the rate of 2.1 MB d^{-1} (for two pressure transducers). Use of a 2 GB Compact Flash card would allow continuous collection at this rate for ~950 days. As noted above, greater accuracy would have been obtained if the pressure values had been recorded as four-byte floating point numbers. Saved in this format, the rate of memory usage would increase to 3.2 MB d^{-1}, and the maximum record length would decrease to ~650 days. Although the faster measurement rate used at Storglaciären yields a time resolution that is more than two orders of magnitude greater than that provided by the 2 min sampling interval used at Trapridge Glacier, this greater resolution was achieved at the cost of a much larger data volume. Although this volume could be reduced by decreasing the rate at which values are recorded, the high sampling rate required for this method would continue to limit (or prohibit) the use of other instruments in the data logger. For this reason, the peak pressure circuit provides substantial benefits over rapid measurement for those studies in which a high time-resolution record of pressure pulses is not necessary. As demonstrated by Kavanaugh (2009), a 2 min sampling interval is sufficiently rapid to allow useful comparison of the pressure pulse record with responses detected by other instruments (including geophones and ploughmeters) installed in the glacier; that study also showed that use of the peak pulse circuit can increase the utility of the relatively slow and memory-limited Campbell CR10X data loggers.

The peak pressure circuit does have some limitations. The monitoring board used for the Trapridge Glacier study exhibited noise due to interference with the solar charging regulator; this noise might be reduced or eliminated with careful shielding of the monitoring circuit. Additionally, as designed, only positive-valued pressure pulses ΔP_+ can be detected by the circuit, whereas direct measurement allows negative-valued pressure pulses to be detected readily; however, the addition of negative peak-detecting capabilities would be relatively straightforward. Finally, because the circuit is insensitive during the 0.1 s portion of each measurement interval when the peak detection/hold block is reset (see Appendix), any pulses that occur during this time will escape detection. For this reason, the circuit is less well suited to high time-resolution studies than is direct measurement by high-frequency sampling; the two methods of pressure pulse measurement are thus complementary.

The pressure pulse records presented here and in Kavanaugh (2009) demonstrate the utility of this circuit for detecting short-duration phenomena. It is likely that such phenomena would be detectable by other commonly used glacial instruments, such as ploughmeters (Fischer and Clarke, 1994). With simple modifications, this circuit should be able to capture events of similar duration using these instruments.

ACKNOWLEDGEMENTS

We thank A. Schaeffer and G.K.C. Clarke for calibrating and installing the pressure pulse sensors at Trapridge Glacier, and Parks Canada for permitting fieldwork to be conducted in Kluane National Park. We also thank N. Iverson and P. Jansson for coordinating the fieldwork at Storglaciären, J. Byers and M. Mathison for assisting with the calibration and installation of transducers at Storglaciären, and R.K. Stefaniuk for his suggestions for improving the monitoring circuit. This work was supported by grants from the Canadian Natural Sciences and Engineering Research Council and the US National Science Foundation (EAR-0541918).

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APPENDIX

We include here additional practical information for recording pressure pulses. This information includes: (1) the Campbell Scientific CR10X data-logger program used to operate the pulse-monitoring circuit; (2) the Campbell Scientific CR1000 data-logger program used to detect pressure pulses directly at Storglaciären; and (3) information about the additional power consumption resulting from pressure pulse measurement.

CR10X data-logger program for operating the peak pressure circuit

Below is the program used to operate the peak pressure circuit at Trapridge Glacier. Two points should be noted. (1) Control Port 1 on the data logger is used to reset the monitoring circuit following each measurement interval. As written below, the pulse duration is 0.1 s, and is set in Program Table 1, command 04. This duration was chosen to eliminate dielectric absorption (or ‘soakage’) effects. (2) Current leakage through D_1 and IC_3 results in a slow discharge of capacitor C_1. To reduce the impact of this leakage on the maximum voltage measurement, the voltage V_2 is sampled every 0.5 s. This sampling (and storage of the maximum voltage value) is accomplished in Program Table 2. Data-logger battery voltage and wiring panel temperature values are recorded for data quality assessment.

```
Program Table 1

01: 120  Sampling interval, seconds

01:P10   Battery voltage
         01: 0001     Loc 1

02:P17   Logger temp
         01: 0002     Loc 2

03:P20   Port set
         01: 0000     Set ports 8765 low
         02: 0000     Set ports 4321 low

04:P30   X=F*10^n
         01: 1.0000   F
         02: 01       n
         03: 0006     Loc 6 (10 cs)

05:P01   SE voltage measurement
         01: 01       Reps
         02: 25       Range code (2500mV, 60Hz reject)
         03: 01       SE channel 1
         04: 0003     Loc 3
         05: 1.0000   Multiplier
         06: 0.0000   Offset

06:P86   Set flag
         01: 10       Set output flag high

07:P77   Time stamp
         01: 110      Day, hr, min

08:P78   Resolution
         01:00        Low resolution

09:P70   Sample
         01: 0002     Reps
         02: 01       Start loc

10:P78   Resolution
         01:01        High resolution

11:P70   Sample
         01: 0002     Reps
         02: 03       Start loc

12:P96   Output to Storage Module
         01: 71       Write to module 1

13:P30   Z=F*10^n
         01: 0.0000   F
         02: 00       n
         03: 0004     Loc 4 (reset stored max. value)

14:P21   Port excitation
         01: 01       Port
         02: 06       Loc 6 (pulse duration; units: cs)

Program Table 2

02: 0.5  Sampling interval, seconds

01:P01   SE Voltage
         01: 01       Reps
         02: 25       Range code (2500mV, 60Hz reject)
         03: 02       SE channel 2
         04: 0005     Loc 5

         05: 1.0000   Multiplier
         06: 0.0000   Offset

02:P88   IF X<=> Y
         01: 0005     X (loc)
         02: 03       >=
         03: 0004     Y (loc)

04: 30   THEN DO

03:P31   Z=X
         01: 0005     X (loc)
         02: 0004     Z (loc)

04:P95   END DO
```

CR1000 data-logger program for rapid pressure measurement

The program included below is similar to that used for taking pressure pulse measurements at Storglaciären. Two modifications have been made: (1) values stored in Table 1 are here recorded as four-byte ‘IEEE4’ values rather than two-byte ‘FP2’ values to obtain higher resolution; (2) the ‘BrFull’ measurement in the main program has been split into two lines to fit within the column width and these lines must be recombined prior to compilation.

In this program, the two pressure transducers are sampled at 20 ms intervals, with discrete maximum and minimum pressure values for each recorded every 1.0 s (in Output Table 1). Also recorded are hourly minimum battery voltages; these are stored in Output Table 2. Note that the wiring panel temperature is not monitored in this program (as its inclusion would preclude sampling at 50 Hz). If needed for data quality assessment, values recorded by nearby data loggers could be used.

```
' Program name: PRESSURE_PULSE_0.1.CR1
' Revision Number: 1.1
' Revision Date: 06 Jan. 2009
'
' Revised By: JLK
'
' Station Description:  Two-transducer pressure
'                        pulse monitoring station
'
' SENSOR AND PERIPHERAL WIRING
'
' Pressure Transducer P1:
' 1H          - V_out + (Green)
' 1L          - V_out - (Yellow)
' EX1         - V_in + (Red)
' AG          - V_in - (Black)
'
' Pressure Transducer P2:
' 2H          - V_out + (Green)
' 2L          - V_out - (Yellow)
' EX2         - V_in + (Red)
' AG          - V_in - (Black)
'
' DATA TABLE DEFINITIONS
'
' ***** Table 1 *****
'
' 01: Date (Year, Date, Time)
' 02: Record Number
' 03: Discrete Pressure, P1
' 04: Maximum Pressure, P1
' 05: Minimum Pressure, P1
' 06: Discrete Pressure, P2
' 07: Maximum Pressure, P2
' 08: Maximum Pressure, P2
'
' ***** Table 2 *****
'
' 01: Date (Year, Date, Time)
' 02: Record Number
' 03: Minimum Battery Voltage
'Declare Variables and Units
Public Batt_Volt
Public FullBR(2)
Units Batt_Volt=Volts
Units FullBR=mV
'Define Data Tables
DataTable(Table1,True,-1)
   DataInterval(0,1,Sec,10)
   CardOut(0,-1)
   Sample(1,FullBR(1),IEEE4)
   Maximum(1,FullBR(1),IEEE4,False,False)
   Minimum(1,FullBR(1),IEEE4,False,False)
   Sample(1,FullBR(2),IEEE4)
   Maximum(1,FullBR(2),IEEE4,False,False)
   Minimum(1,FullBR(2),IEEE4,False,False)
EndTable

DataTable(Table2,True,-1)
  DataInterval(0,60,Min,10)
  CardOut(0,-1)
  Minimum(1,Batt-_Volt,FP2,False,False)
End Table

'Main Program
BeginProg
  Scan(20,mSec,1,0)
     'Datalogger battery voltage measurement:
     Battery(Batt_Volt)
     'Generic full bridge measurements:
     BrFull(FullBR(1),2,mV250,1,1,1,2500, ...
            False,False,1000,250,1.0,0.0)
     'Call Data Tables and Store Data
     CallTable(Table 1)
     Call Table(Table 2)
  NextScan
EndProg
```

Power supply considerations

Because both the peak pressure circuit and pressure transducer are powered continuously, it is important to consider their additional demand on the power supply. The pair draw 2.2 mA of current at 5 V for a total additional usage of 11 mW. This results in an increased current draw of ~1 mA from a 12 V (nominal) power supply. An additional increase in current draw results from the 0.5 s sampling of V_2 (see CR10X data-logger program section above), which requires the data logger to spend more time in higher-power measurement and processing states (e.g. see Campbell Scientific, Inc. App. Note 5-F, Rev. 9). The average current draw of a CR10X, monitoring board and pressure transducer is ~5 mA. This additional power consumption is slightly lower than that resulting from directly measuring pressure pulses using a high sampling rate, as rapid measurements force the data logger to remain in higher-power states for much of the time. The mean current draw of a CR1000 data logger sampling two pressure transducers at 50 Hz (as used in the Storglaciären study) is ~6.5 mA. These methods thus require similar-sized power supplies of ~40–100 Ah capacity, depending on the latitude and expected temperature conditions (e.g. see Campbell Scientific, Inc. App. Note 5-F, Rev. 9).

MS received 4 February 2009 and accepted in revised form 5 November 2009