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Diurnal variability of tracer transit speeds simulated by a two component model of the glacial drainage system

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Unteraargletscher results

Field experiments

Conducted by Schuler et al. (JGR 2004)

Methods:

- **injection moulin** fed by a supraglacial meltwater stream
- → large diurnal fluctuations (0.05–0.3 $m^3 s^{-1}$, Fig. 1a, green)
- 12 injections over a diurnal discharge cycle

Resulting tracer transit speed

- large diurnal fluctuations (0.3–0.75 ms^{-1}, Fig. 1b, diamonds)
- correlate with discharge into moulin

Model results

- very good agreement measurements–model (Fig. 1b)
- large fluctuations of moulin transit time (Fig. 1f)
- transit time in subglacial channel is fairly constant (Fig. 1f)
- variation of total transit time dominated by moulin (Fig. 1g)
- some features of transit speed are due to channel: small minima at 1400 h
- errors are small, few outliers (Fig. 1b)
- moulin cross-sectional area $A \approx 1.3 \pm 0.3 m^2$
- channel resistance $R \approx 2.1 \pm 0.05\, s^2 m^{-5}$
- → Manning roughness 0.26–0.076 $m^{-1/2} s^{-1}$ for a channel sinuosity 1–2

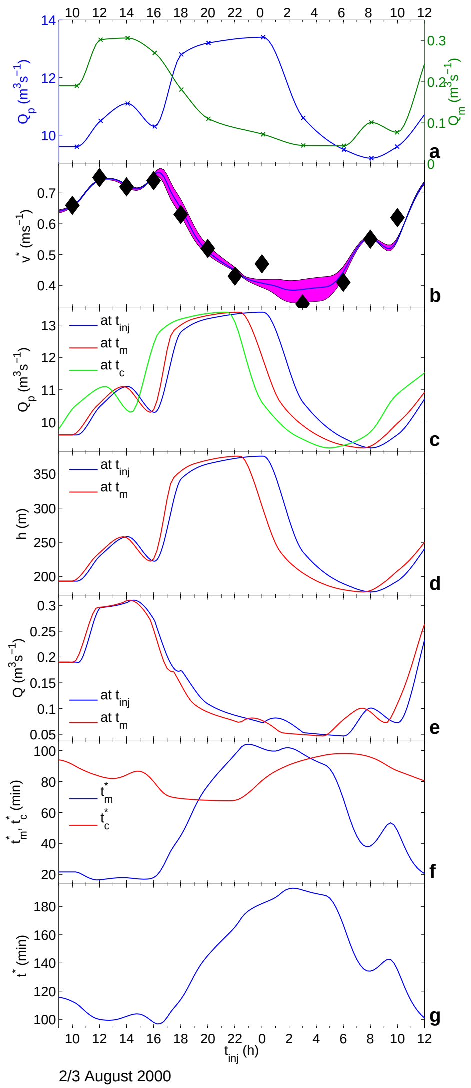

Fig.1: Field measurements (a–b) and model results (b–g) from Unteraargletscher.

Equations

Subglacial water pressure head

$$h = RQ_p^2.$$

The transit times can then be calculated for an injection at t_{inj} by solving for moulin exit time t_m and channel exit time t_c:

$$\text{Moulin:} \quad \int_{t_{inj}}^{t_m} Q_m(t)dt = A\, h(t_m)$$

$$\text{Channel:} \quad \int_{t_m}^{t_c} Q_p(t)\, dt = S\, l$$

$$\to \text{Total transit time:} \quad t^* = t_c - t_{inj}$$

Abstract

A two component model of the glacial drainage system is used to simulate diurnal variations of tracer transit speeds. The model consists of a moulin element, conducting the discharge of the supraglacial stream entering it, and a subglacial channel element, conducting the proglacial discharge. The model is driven by these two discharges and calculates transit speeds. It is fitted to the measured transit speeds by adjusting the moulin cross-sectional area and the channel resistance. We apply it to measurements using two moulins, one fed by a supraglacial meltstream on Unteraargletscher (left panel) and the other one by a draining ice marginal lake on Gornergletscher (right panel). The model fits the measured tracer transit speeds in both presented situations even though they are qualitatively quite different. Furthermore, it shows that to deduce subglacial flow speeds from tracer experiments, one needs to take the englacial water flow into account as well.

Model description

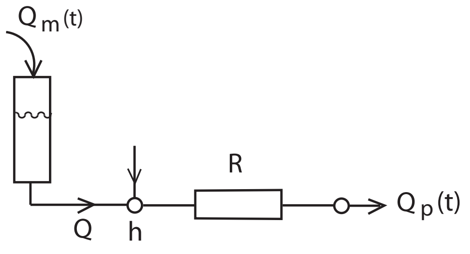

Fig.2: Schema of the two component model. Left: moulin element ; middle: main subglacial channel.

Input

Q_m: discharge into moulin

Q_p: proglacial discharge

Output

t^*: total transit time

Fitting parameters

A: moulin cross-sectional area

R: channel resistance

Moulin element

Vertical moulin with cross-sectional area A, filling height corresponding to subglacial water pressure head h and fed by Q_m.

Channel element

Static channel with cross-sectional area S, resistance R and length l. Carries the proglacial discharge Q_p.

Conclusions

- Simple model captures both qualitatively different cases
- Moulin and proglacial discharge measurements are indispensable for a coherent interpretation of the experiments
- Several injections during a diurnal discharge cycle are needed to distinguish between influence of en- and subglacial part.
- Transit time in the moulin is proportional to h, whereas in the channel inversely proportional to $\sqrt{h}$.

Gornergletscher results

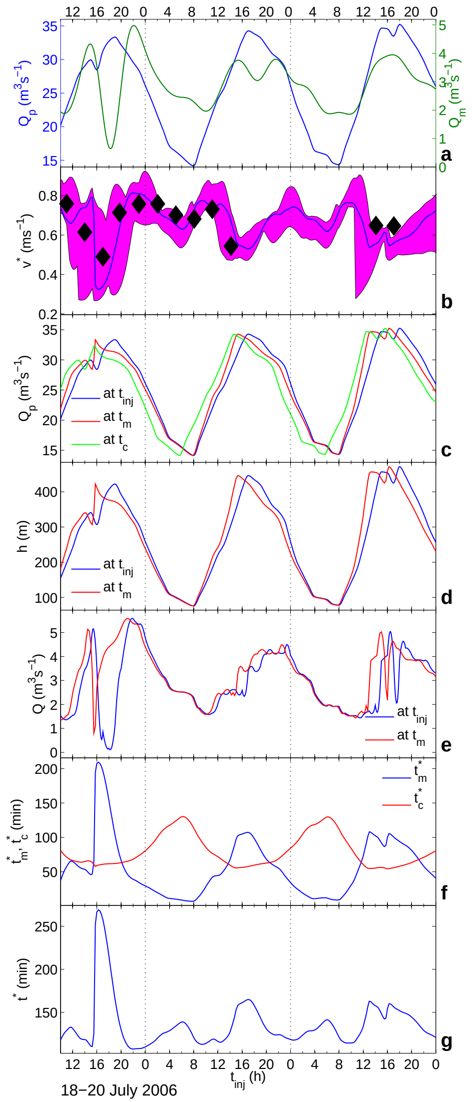

Fig.3: Field measurements (a–b) and model results (b–g) from Gronergletscher.

Field experiments

Methods:

- **injection moulin** fed by a draining ice marginal lake
- → exceptionally little diurnal fluctuations in discharge (2–4 $m^3 s^{-1}$, Fig. 3a, green)
- blockage of lake spillway by iceberg on first day (Fig. 3a)
- 12 injections over two diurnal discharge cycles

Resulting tracer transit speed

- shows small diurnal fluctuations (0.55–0.8 ms^{-1}, Fig. 3b, diamonds)
- two daily minima and maxima

Model results

- reasonable agreement measurements–model (Fig. 3b)
- reproduces two diurnal maxima/minima in transit speed (Fig. 3b)
- transit time in moulin and channel have similar amplitude but are in antiphase (Fig. 3f)
- large error in Q_m (Fig. 3a) leads to:
- → large error in modelled transit time and speed (Fig. 3b)
- iceberg blockage event reproduced
- moulin cross-sectional area $A \approx 60 \pm 40\, m^2$
- channel resistance $R \approx 0.37 \pm 0.05\, s^2 m^{-5}$
- → Manning roughness 0.22–0.062 $m^{-1/2} s^{-1}$ for a channel sinuosity 1–2

Symbols

Q_m, Q_p	moulin, proglacial discharge	t_{inj}	injection time
v^*	tracer transit speed	t^*	(total) transit time
h	subglacial water pressure head	R, S, l	channel resistance, cross section, length
Q	discharge at moulin exit	A	moulin cross section
t_m^*, t_c^*	moulin, channel transit time		