Hydrochemical Responses of Snowmelt in Artificial Rain-on-Snow Experiments

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ABSTRACT

We conducted a set of rain-on-snow experiments in 2002–2003. We used conservative anion tracers, such as F^-, Br^-, and SO_4^{2-}, and mixed tracers in the water to be rained onto the snow surface. The solutes were introduced as a mobile phase and the initial pore water was largely clean. Unlike the results from Feng et al. (2001), tracer concentrations in our experiments are negatively related to input water flux. These two different experimental results may reflect the same transport mechanism which can be described using a mobile-immobile transport model.

Keywords: rain-on-snow experiment, transport mechanism

INTRODUCTION

Ionic concentrations in snowmelt depend on how effectively solutes in the pore water between snow grains are eluted. This implies that the snowmelt chemistry is affected by solute transport mechanisms. In the case of a piston flow, for example, all solutes in pore water are pushed out by the early melt water and the snowmelt show a brief and intense pulse of solute out flow. Under a preferential flow condition, on the other hand, only solutes along flow channels are eluted and solutes in the relatively immobile water can only enter the mobile water by some form of exchange (e.g., diffusion).

Previous studies have shown that preferential flow mechanism is consistent with the observed concentration discharge relationships. This flow mechanism is often conceptually approximated using a mobile-immobile model (MIM): the mobile water is described by advective-dispersive equations, and the immobile water exchanges with the mobile water at defined rates. This work compares two sets of experiments studying solute transport in snow under different flow conditions. The MIM model is used as the theoretical framework.

SOLUTE TRANSPORT IN SNOW

Feng et al. (2001) studied solute transport mechanism in snow using REE tracers and artificial rain-on-snow events. They sprayed tracer solutions to the snow surface such that the tracers are contained in the immobile phase near the surface before the onset of artificial rainstorms. They found that tracer concentrations in the discharge were positively associated with the input water flux. They modeled the data using a MIM, and they found that they could only explain the data

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using a MIM if the exchange rate constant between mobile and immobile fluids increases with the flow rate of water. This suggests that the solute in the immobile phase is eluted more efficiently during a high flow than during a low flow.

We conducted a different set of experiments in the winter of 2002. Instead of putting the tracers into the immobile water, we mixed the tracers into the water to be used for rain-on-snow events, i.e., the tracers were introduced into the mobile water. We also used conservative anions, such as F^-, Br^-, and SO_4^{2-} to overcome the absorption problem associated with the high positively charged REE ions. The results of our experiments are shown in Figure 1. This observation is different from those by Feng et al. (2001) in that after the end of tracer application, the solute concentration is negatively related to the water flux.

When clean input water flux increases, solutes may be diluted. However, in the experiments by Feng et al. (2001), the solute concentration is also affected by the rate at which immobile water exchanges with mobile water. They concluded that this exchange rate increases with flow rate. Since the immobile water is more concentrated at the surface, the increased mixing may out-compete the dilution effect at a high flow. As a result, concentration in the discharge may be positively correlated with the input water flux. In our experiment, however, the immobile water is relatively clean compared to the mobile water that contains tracers. Therefore, the exchange between mobile and immobile water does not significantly affect, or if so it decreases, the tracer concentration in the mobile fluid. Therefore, the dilution effect would be the dominant mechanism affecting the solute concentration in the outflow. We are in the process of testing this result qualitatively with a mobile-immobile transport model.

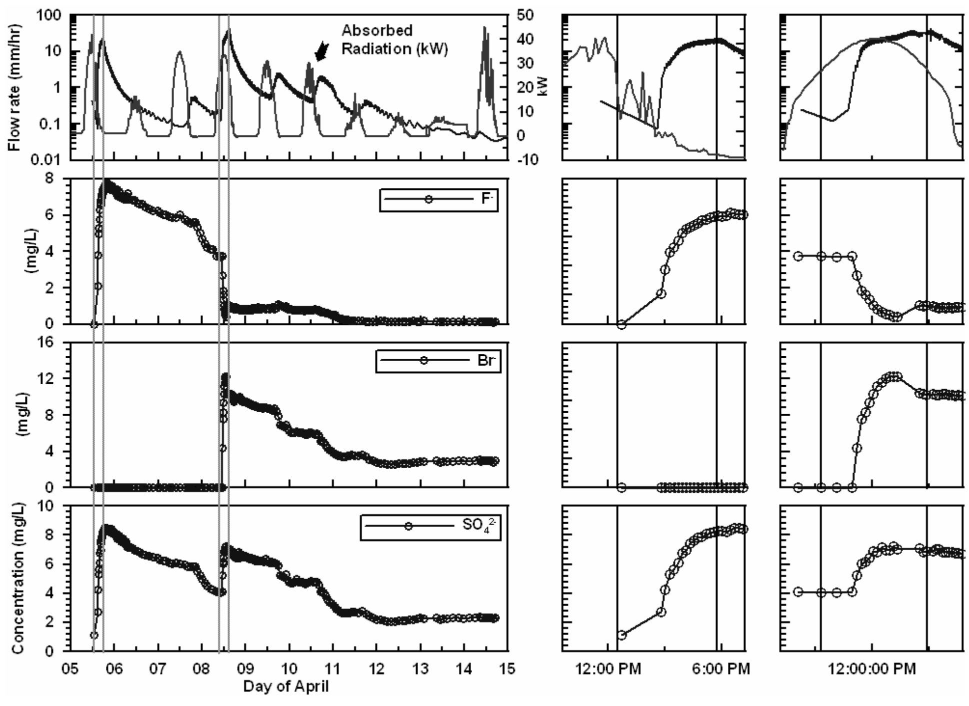

Figure 1. Experimental results from artificial rain-on-snow experiments. In each row, the left-hand side shows 10 days time series and the two right-hand side show details of the two artificial rain-on-snow events. The gray lines indicate the beginning and end of each experiment.

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