Induced Flow Channels in a Natural Snowpack

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ABSTRACT

Preliminary results from the response of two snowmelt lysimeters are examined in order to investigate the outflow differences between a disturbed and undisturbed natural snow cover. The lysimeters are located 5 m apart on level ground and are identical, except that one has instrumentation that induces vertical flow channels, while the other does not. The number of vertical flow paths in shallow, layered snowpacks has a large influence on snowmelt discharge. In ripe, homogeneous snowpacks with high discharge rates, induced vertical flow paths have little influence on discharge. Layering in shallow snow can influence snowmelt discharge through a significant portion of the snowmelt season.

INTRODUCTION

Nonuniformities such as ice layers and vertical flow channels exist in natural snowpacks and can greatly affect the rate of water movement through snow (e.g., Marsh and Woo 1985, Wankiewicz 1979, Colbeck 1978). This channeling causes a spatial variability of snowpack outflow that tends to create large discrepancies between calculated and measured snow outflow (e.g., Price 1977, Jordan 1983).

Kattleman (1989) reported great variation in lysimeter outflow of a snowpack in the Sierra Nevadas, and deduced that structural discontinuities and microtopography served to redirect the percolating water. Because the lysimeters used had no mechanism to isolate the snow over the lysimeter from the rest of the pack, the total area of snow contributing to the lysimeter outflow is not known.

The spatial nonuniformities present difficulties in the analysis of snowpack outflow, because flow depends on snow stratigraphy and microstructure and on thermal boundary conditions. Marsh and Woo (1985) found that the flow variability in layered natural snow is primarily due to ice layers, and is not caused by the vertical flow fingers that are created by preferential crystal growth in the absence of ice layers. However, ice layers in natural snowpacks are rarely impermeable boundaries; discontinuities or openings through these layers may control vertical flow. To date, no studies have been done to investigate whether an increase in the number of vertical flow channels through ice layers in a natural snowpack would affect the snowpack outflow.

This paper reports preliminary findings from lysimeter data from a field experiment conducted this year (1992) at Sleepers River Research Watershed in northern Vermont. An experiment was set up to measure 3-D snow temperatures, and a 3-D array of temperature sensors was installed over a snowmelt lysimeter. The support structure for the temperature array, which consisted of vertical dowels extending from the lysimeter to above the snowpack, created vertical flow channels in the snowpack. The purpose of this paper is to present preliminary findings of some of the effects of induced vertical flow channels on lysimeter outflow, under three environmental conditions: (1) melt and rain on a layered snowpack, (2) diurnal melt/freeze without precipitation, and (3) continuous snow melt with and without precipitation in a ripe snowpack.

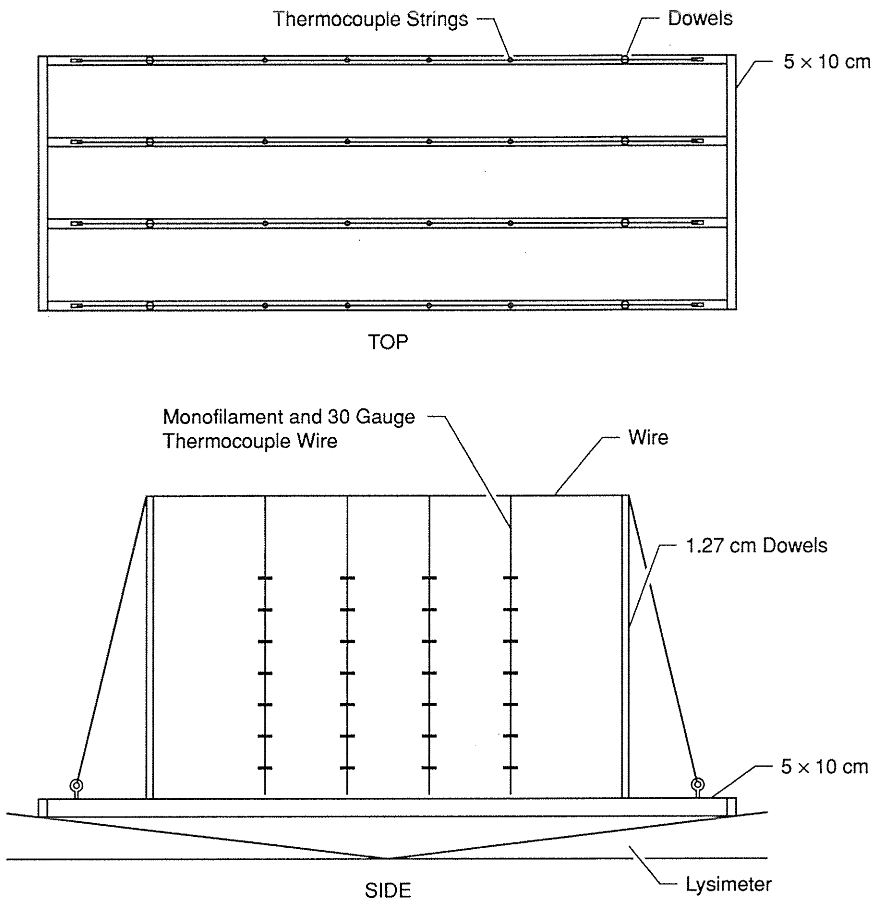

Figure 1. Schematic of the thermocouple array and lysimeter.

APPARATUS

The equipment consists of a 3-D array of thermocouples and a wooden support structure situated on top of a snowmelt lysimeter, as illustrated in Figure 1. The lysimeter is 3 m in diameter, and has a heat ring to separate the snow above the lysimeter from surrounding snow. An identical lysimeter, but without the thermocouple array and support structure, is situated approximately 5 m to the west. Construction and operation of the lysimeters are discussed in Greenan and Anderson (1984). The two lysimeters had yielded nearly identical results through many years of operation before the thermocouple array was installed. The only exceptions to this were due to mechanical problems in 1978 and 1979, and in several other years when the west lysimeter had greater outflow than the east because of natural variability in stratigraphy as determined from snow courses. The lysimeters were tested and calibrated before snowfall this year and found to be in good operating condition.

The support structure for the thermocouple array consists of six 5- × 10-cm members that serve as the base for the array, and eight 1.3-cm vertical wooden dowels. From this structure, 16 vertical thermocouple strands (each consisting of eight 30-gauge type T thermocouples) are hung. The thermocouple wires are strung along the bottom of the support system, and through a 1.9-cm hole drilled in the side wall of the lysimeter. The temperatures measured by the thermocouples are recorded by a Campbell CR7 datalogger. The array was installed in the lysimeter before the first snowfall.

OBSERVATIONS

Data from three outflow events will be discussed: two events are snowmelt on layered snow with and without rain, and the third is snowmelt in a ripe snowpack. The first outflow event involves snowmelt with some rain; the outflow event started on March

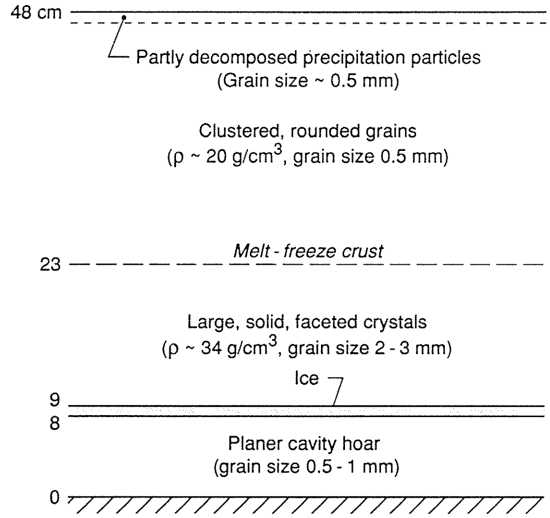

Figure 2. Snow on the ground on March 26.

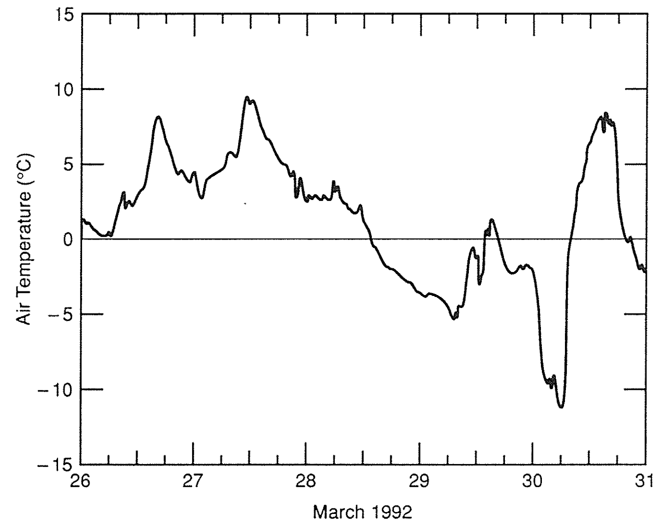

Figure 4a. Air temperature for the period beginning March 26.

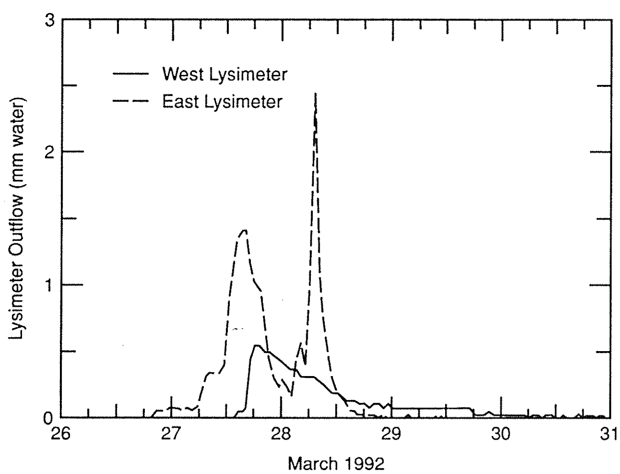

Figure 3. Lysimeter outflows for the period beginning March 26.

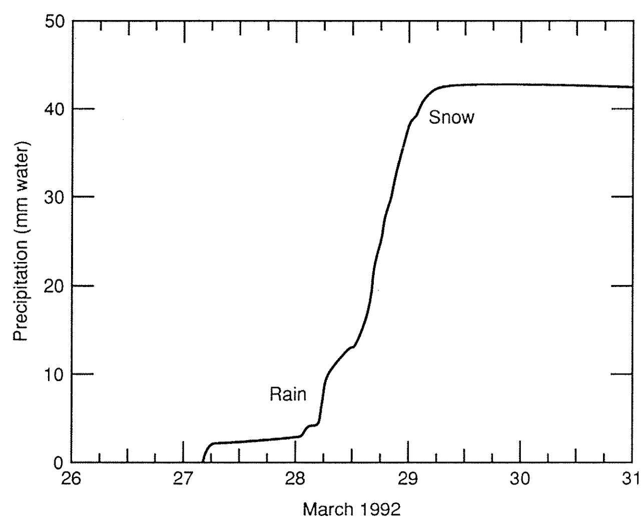

Figure 4b. Precipitation for the period beginning March 26.

26. The weather had previously been cool, with nightly temperatures near –10° to –25°C, and daytime highs near zero, but had recently become warmer. From snowpit data at 0830 on March 26, there was 48 cm of layered snow on the ground (Fig. 2). The snowpack was subfreezing before the rain, but became isothermal in later times. Figure 3 depicts both lysimeter outflows for 26–30 March. The 2-m air temperature and precipitation for that period are shown in Figures 4a and 4b, respectively. The east lysimeter (containing the thermocouple array and support structure) yields outflow much sooner and with more volume than the undisturbed west lysimeter (Fig. 3). The peaks in outflow from the east lysimeter are caused by daytime solar radiation snowmelt effects, while the outflow from the west lysimeter had no such peaks. Evidently the induced vertical channels allow the meltwater that would otherwise pond on an ice layer to drain out of the snow.

The second outflow event examined occurred between 6 and 13 April, a period without precipitation until 11 April (Fig. 5). As can be seen from the plot of the air temperature in Figure 6, it is a period when the daytime highs were between 5° and 10°C, and

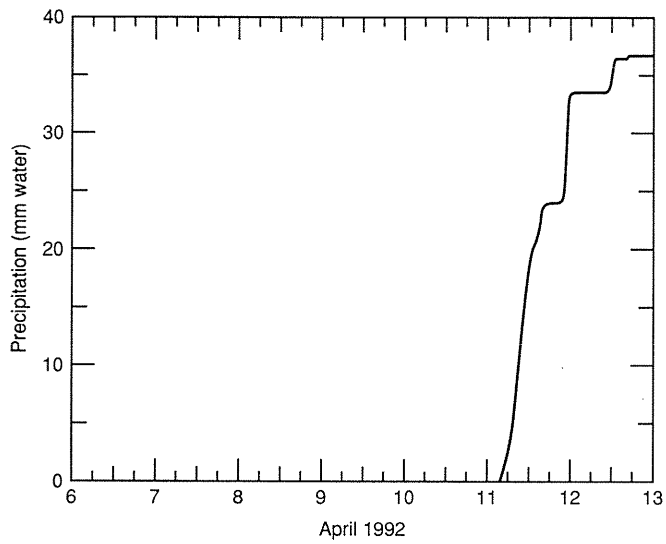

Figure 5. Air temperature for the period beginning April 6.

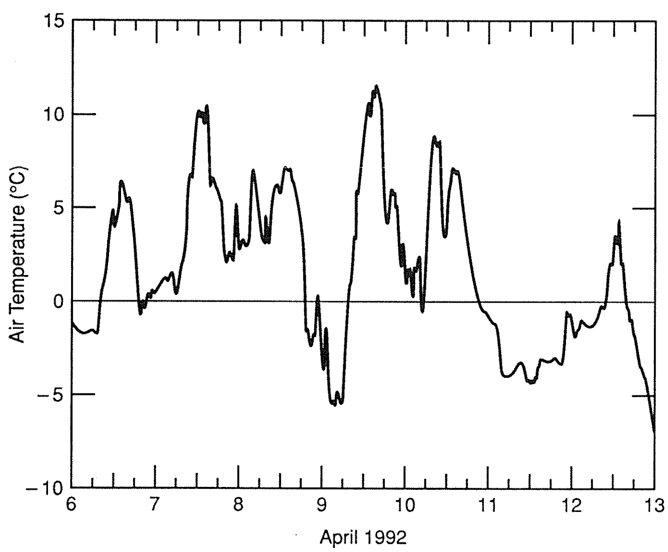

Figure 6. Precipitation for the period beginning April 6.

only a few nights were below freezing. At that time, the snowpack was 43 cm deep, composed mostly of rounded, melt-freeze polycrystals, and had a persistent centimeter-thick ice layer approximately 8 cm above the ground surface. The outflows of the two lysimeters are plotted in Figure 7, which shows that the responses were still very different. The outflow from the east lysimeter has a distinct diurnal variation due to solar-induced melt that started on the 6th, whereas the outflow from the undisturbed west lysimeter started on the afternoon of the 9th, when a flow approximately one-tenth that of the other lysimeter commenced.

The difference in the magnitude of the outflows is very large in this case, and there may be two reasons for this difference. First, since by this time more flow had passed through the east lysimeter than the west, it is likely that the stratigraphy of the snow within the two lysimeters was different, although they appeared the same from visual inspection of the surface. Snow course data from areas adjacent to the lysimeters indicates generally thicker ice layers near the west lysimeter than near the east. A mass balance on the two lysimeters indicates that in March several centimeters more outflow occurred from the east than from the west (while the difference between the two was very much less in other months), and a more persistent ice layer in the west lysimeter probably prevented outflow there or perhaps diverted outflow over the 5-cm high lysimeter lip. (As described in Greenan and Anderson [1984], the lysimeter drain is heated when necessary to ensure that it is not plugged with ice; the lysimeters were operated as in previous years, and it is believed that both lysimeters remained in proper operating condition for the entire season.)

A second effect may be from solar heating of the vertical members of the structure, which may cause more snow to melt than might melt in the undisturbed snow. Some sun-cupping effects were observed around the vertical dowels in the late season, although they were not noticeable during the cold-snow season. The solar heating effect alone, however, is insufficient to explain to magnitude of the difference in outflows. While a precise description of the cause of the difference is not possible, the lesser outflow of the west lysimeter during this period does give an indication that ice layers can remain intact for days of above-freezing temperatures before developing discontinuities that allow water to percolate through.

The third situation examined is that of a ripe snowpack during a dry period when temperatures were well above freezing, followed by rain. The air temperature and precipitation for 18–24 April are plotted in Figures 8a and 8b, respectively. By this time, the snowpack had diminished to a depth of 35 cm, and was fairly uniformly composed of clustered, rounded grains. The ice layer near the bottom of the pack was gone; slush existed between the snow and the ground where there were depressions in the ground. In Figure 9 the outflows of both lysimeters are plotted. In contrast to the two situations previously described, this time the outflows of the two

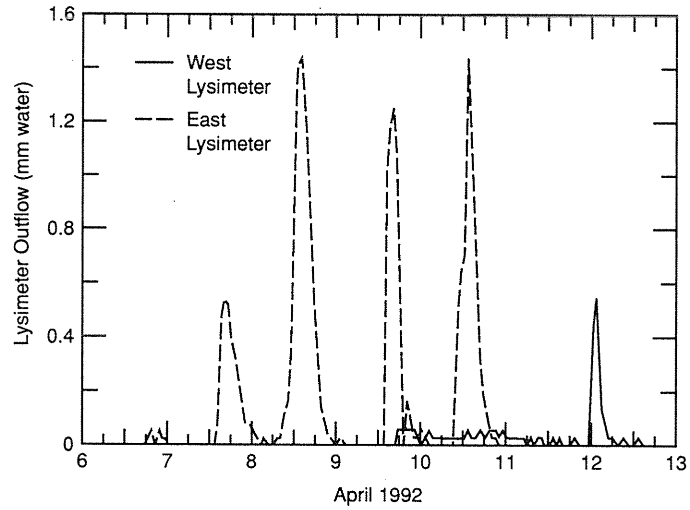

Figure 7. Lysimeter outflow for the period beginning April 6.

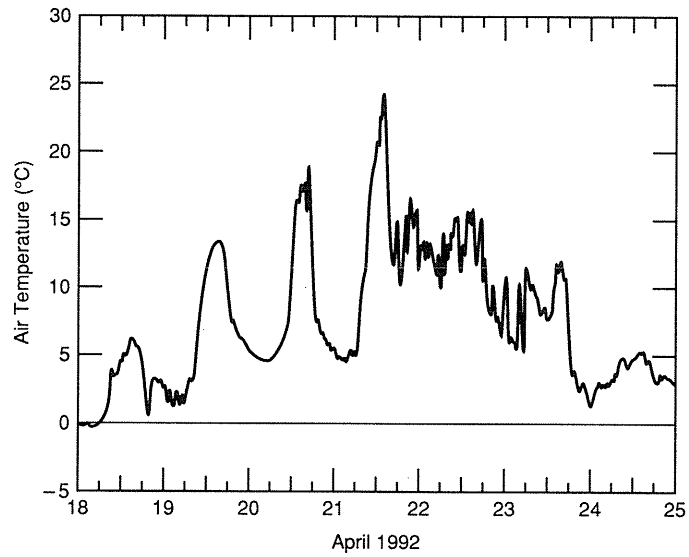

Figure 8a. Air temperature for the period beginning April 18.

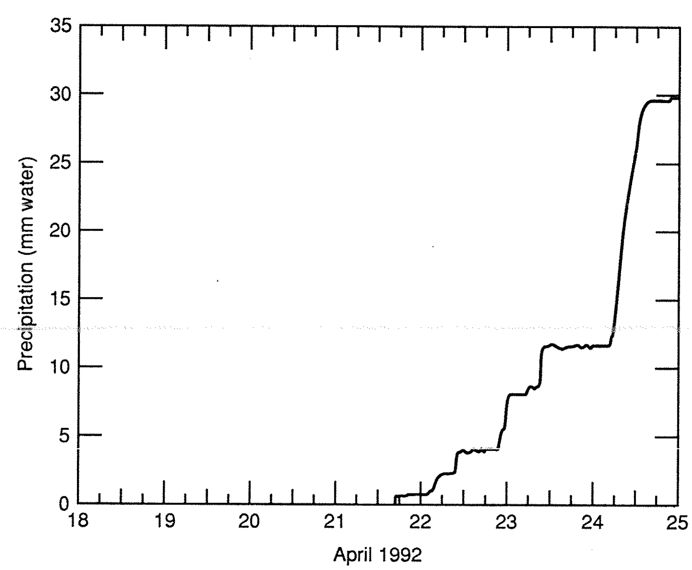

Figure 8b. Precipitation for the period beginning April 18.

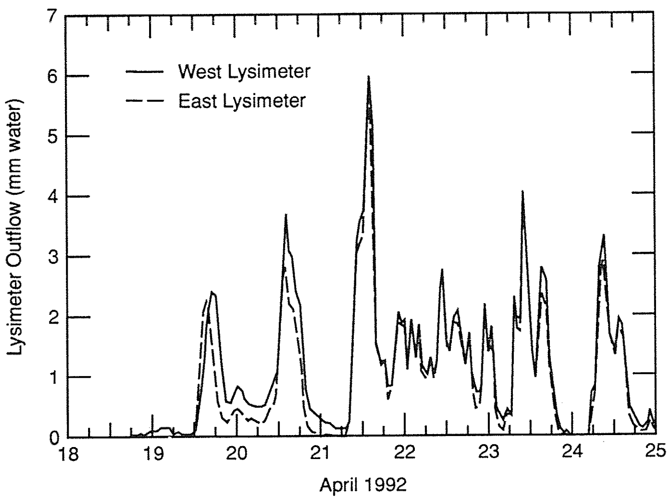

Figure 9. Lysimeter outflows for the period beginning April 18.

lysimeters are very similar, and during April 19–21 when the outflows are slightly different, the outflow of the west lysimeter is the greater. The outflow rates are also much higher than in the previous two situations. Evidently in this case the addition of induced flow channels has almost no effect on lysimeter outflow; the water flows just as easily through the ripe snow as through the induced pathways. This is in agreement with data presented by Kattleman (1989), who noted that the variation in the Sierra Nevada lysimeter flow decreased as the melt season progressed.

CONCLUSIONS

By examining the response of two side-by-side, identical lysimeters, one with a disturbed snow cover and one without, the number of vertical flow paths for shallow, layered snowpacks appears to have a large influence on snowmelt discharge. For ripe, homogeneous snowpacks with large discharge rates, induced vertical flow paths have little influence on discharge. Layering effects such as ice layers in shallow snow influence snowmelt discharge through a significant portion of the snowmelt season, and should not be neglected in snowmelt simulation models.

ACKNOWLEDGMENTS

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