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AN ISOTOPE AND ENERGY BALANCE STUDY OF THE SNOW-MELT PROCESS

(Abstract)

by

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Energy, mass and isotope balances in the snow-melt process have been studied during the spring of 1984 at a forested site on the property of Atomic Energy of Canada Limited at Chalk River, Ontario. For the whole of the period, continuous measurements were made of the variables controlling the energy balance over the surface of the snowpack. The volume flow rate of water out of the base of the snowpack was measured using a 25 m^2 lysimeter. A water sample was taken every two hours throughout the thaw for chemical and isotopic analysis.

The deuterium content of precipitation is directly related to air temperature at time of precipitation. As a result there is a strong seasonal fluctuation of deuterium in precipitation and spring rain has a significantly higher deuterium concentration than the melting snowpack accumulated from the winter's snowfall. Thus isotopic measurements afford a means of differentiating on a molecular basis between snow-melt and rain flow-through in the drainage water from a melting snowpack. It is of value to compare estimates of the proportions of snow-melt and rain flow-through in drainage water derived from isotope measurements with those obtained from energy balance considerations.

Analysis of energy, mass and isotope balances has been done for three example periods: (i) snow-melt only, (ii) snow-melt plus modest rainfall, (iii) snow-melt plus dominant rainfall. The first example period demonstrates the overall energy balance conditions during snow-melt in a deciduous forest. The dominant energy flux is Q^* (net all-wave radiation). Our data show that Q^* generates about 90% of snow-melt under most atmospheric conditions, and that the long-wave portion (L^*) of net all-wave may become very large in the forest during snow-melt. Because of the reduction of wind speed at the forest floor, and because of the conditions of extreme atmospheric stability which invariably occur over a melting snow-pack, the turbulent exchanges (H and LE; sensible and latent heat) are very small. The maximum hourly melt rate due to Q^* in the first example, is 3.6 mm h^{-1}, and the maximum due to H + LE is 0.12 mm h^{-1}. At a maximum, H + LE account for less than 13% of daily snow-melt.

For all three example periods, vertically integrated (cored) snow-pack samples had deuterium values close to $\delta D = -130^0/oo$†. Analysis of the deuterium data for the first example period shows that there is only small variability in the values for the runoff from the snowpack, with values essentially identical to that of the snow.

The second example period is a rain-on-snow event. Data from the lysimeter and rain gauge suggest that of a total runoff of 10.3 mm, 6.3 mm was rain and 4.0 mm was snow-melt. The energy balance data suggest that of the 10.3 mm of runoff, as much as 5.0 mm may have been snow-melt. Taking the latter case, with the snowpack δD being $-130^0/oo$ and that of the rain $-52^0/oo$, then the δD of the runoff ought to be $-89^0/oo$, compared with an observed value of $-95^0/oo$. After the rain stopped, snow-melt continued for several hours and over the next 24 h the δD values of the runoff returned slowly to the snowpack δD value of about $-130^0/oo$.

The third example period is another rain-on-snow event, in which 45.0 mm of rain fell onto the snowpack over 48 h. For this period, total melt due to Q^* was 3.1 mm, that due to H + LE was <0.1 mm, and melt due to heat held in the rain was 1.8 mm, so that snow-melt water was 10% of total water inputs. Before the rain started, runoff from the lysimeter was at snowpack δD levels of $-130^0/oo$. After the first 26 mm of rainfall at a δD value of $-96^0/oo$, the runoff had a δD of $-98^0/oo$, showing that almost all of the water reaching the base of the snowpack during this major rain-on-snow event was rain and not snow-melt. This confirms the energy balance estimate of the small amount of snow melted by the heat of the rain (1.8 mm), and should lay to rest the notion that large rainfalls are influential in the snowmelt process.

This work has demonstrated the usefulness of isotope measurements as an independent check on water and energy balance computations in studying the mechanisms of the snow-melt process.

† $\delta D = \frac{D/H\ (sample) - D/H\ (standard)}{D/H\ (standard)} \times 1000^0/oo$

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