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Chemical fluxes through a boreal forest snowpack during the snowmelt season

Keisuke SUZUKI[1], Yoshiyuki ISHII[2], Yuji KODAMA[2], Daiji KOBAYASHI[2] and H. G. JONES[3]
1 Department of Geography, Tokyo Metropolitan University, Hachioji, Tokyo 192−03 Japan
2 Institute of Low Temperature Science, Hokkaido University, Sapporo 060 Japan
3 INRS-Eau, University of Quebec, C. P. 7500 Sainte-Foy, Quebec, G1V 4C7 Canada

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Abstract

Chemistry of precipitation, snow cover and snow meltwaters was studied at an open site and a forested site in a boreal forest location, eastern Canada. The results allowed chemical fluxes through a snowpack to be estimated. Precipitation was collected by means of bulk collectors at both sites. Concentrations of major ions in precipitation are higher at the forested site than at the open site except for NH_4^+ and NO_3^-. Snow meltwater was collected by lysimeters. Snowmelt runoff and concentrations of NO_3^- and SO_4^{2-} in snow meltwater at the open site show diurnal variation. Concentration of NO_3^- in the meltwater at the open site is higher during the early period of snowmelt than at the end of the melt season. The total amount of NO_3^- in runoff of snow meltwater is smaller than the cumulative loss of NO_3^- from snow cover plus NO_3^- load in precipitation at both sites. The loss of NO_3^- in the snowpack is due to assimilation of the ion by microbiological processes. This loss of NO_3^- in the snowpack is larger at the forested site than at the open site.

1. Introduction

In snow-covered regions, snowmelt has a considerable influence on the chemical quality of surface waters. The chemical constituents accumulated from snowfall and dry deposition are retained in the snow cover during cold periods and are subsequently released during the short snowmelt period (Johannessen and Henriksen, 1978 ; Suzuki, 1982).

There are many studies on the effects of snow and snow meltwaters on the biogeochemistry of ecosystems. However, there is very little information on the effects of ecosystems on the chemistry of snow and meltwaters. Chemical dynamics of acid ionic species in a boreal forest snow cover were studied by Jones and Deblois (1987) and Jones (1988, 1991). The authors reported that depletion of N-containing ionic species takes place in boreal forest snowpacks when liquid water content is high. The uptake of these ions is due to microbiological processes.

In order to estimate biological effects on chemical fluxes during snowmelt we have studied the chemical dynamics of NO_3^- and SO_4^{2-} in snow meltwaters, snow cover and precipitation at an open site and a forested site in a boreal forest location.

2. Methods

2.1. *Study area*

The study area is situated at latitude 47°17'N and longitude 71°10'W in the Monmorency Forest 60 km north of Quebec City, Canada (Fig. 1). The forest cover consists of the balsam fir and the white birch. The mean annual temperature is 0.2°C, and the mean monthly temperature of January is −15.2°C. The mean annual precipitation is 1400 mm of which 34 per cent is snow (Plamondon, 1982). This site is usually covered with snow from mid-December to mid-May (Jones and Sochanska, 1985).

2.2. *Sampling procedure*

Precipitation, snow and snow meltwaters were collected at an open site and a forested site respectively during snowmelt season, 1991.

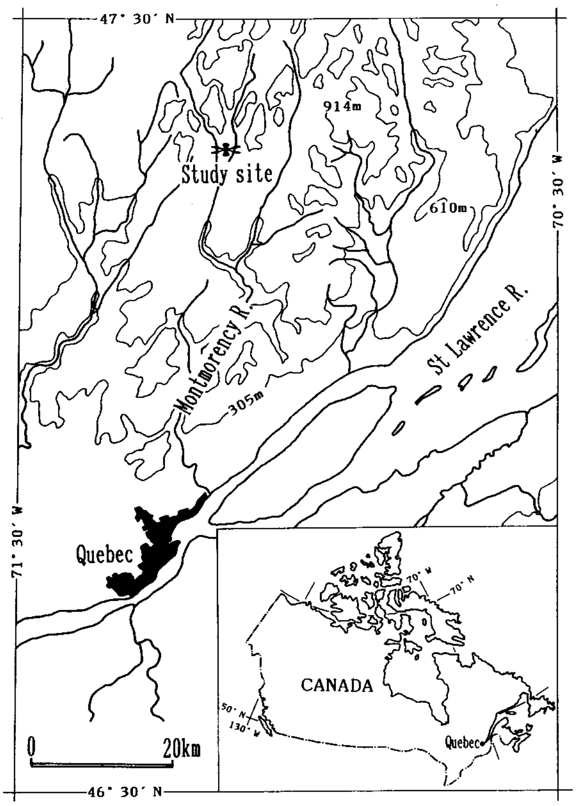

Fig. 1. Study site for the spring snowmelt period of 1991.

Precipitation was collected by means of bulk collectors. Two collectors were installed at an open site. Precipitation samples taken by two collectors were combined to give one integrated sample of precipitation at an open site. Three collectors were installed under tree canopies (balsam fir). Three samples were combined to give one integrated samples same as open site. The amount of precipitation was calculated by dividing the weight of the collected precipitation by the cross-sectional area of the collectors.

Total snow cover was taken by the use of a Adirondack-type corer. Snow cores were taken every 2−3 days. At the open site, 3−5 cores were collected and each snow core samples were analysed chemically. At the forested site, 5−10 cores were collected and each snow core samples were analysed chemically. The water equivalent of snow cover (HSW) was calculated by dividing the weight of the collected snow by the cross-sectional area of the corer.

Snow meltwaters were collected by lysimeters (fiberglass tanks, 1 m×4 m) which were installed before the first snowfall of the winter season. One lysimeter was installed in the open site, one was installed under tree canopies (balsam fir). Discharge of snow meltwaters was measured by the bucket type flow meter. Snow meltwater was sampled by the automatic water sampler periodically.

2.3. Analytical procedure

Solid samples were placed in plastic bags (polyethylene) and melted before filtering. All liquid samples were kept in plastic bottles under cool and dark environment for up to a maximum conservation time of 48 h. The samples were filtered by means of polycarbonate filters (47 mm in diameter, pore size 0.4 μm). Conductivity and pH were measured with a conducti-vity meter and pH meter, respectively. Anions and cations were determined by an ion chromatography (Dionex S12 and Dionex 2020i/SP).

3. Results and discussion

3.1. Chemical characteristics of precipitation

The total amount of precipitation and chemical characteristics of precipitation at both the open site and the forested site are shown in Table 1. The total amount of precipitation at the open site is greater than that at the forested site every events. This result shows the intercept effect of tree canopies on the total amount of precipitation. Conductivity of the open site precipitation is smaller and pH is higher than those of the forested site precipitation. Concentrations of major ions in precipitation are higher at the forested site than at the open site except for NH_4^+ and NO_3^-. Tree canopy components (branches and leaves) are effective scavengers of atmospheric aerosols due to higher surface areas (Höfken *et al.*, 1983). These chemical materials trapped by tree canopy components are dissolved in throughfall, so concentrations of chemical constituents of throughfall is considered to show the higher value. Differences of concentrations of NH_4^+ and NO_3^- between the open site precipitation and the forested site precipitation are in contrast to the other ions. Balsam fir canopy components remove NH_4^+ from the precipitation while epiphytic lichens also remove NO_3^- (Reiners and Olson, 1984). The losses of NH_4^+ and NO_3^- in throughfall are considered to be the result of microbiological activity in the forest canopy.

Table 1. Chemical characteristics of precipitation at both the open site and the forested site.

	Sampling Period	Prec. mm	pH	λ_{25} μS/cm	Na^+ μeq/1	NH_4^+ μeq/1	K^+ μeq/1	Mg^{2+} μeq/1	Ca^{2+} μeq/1	Cl^- μeq/1	NO_3^- μeq/1	SO_4^{2-} μeq/1
Open	4/23 900~4/24 900	5.0	4.80	13.1	2.98	0.70	1.73	3.84	38.32	3.78	23.30	47.28
	4/30 900~5/01 900	3.8	4.35	28.2	7.63	29.08	4.49	6.66	29.87	4.85	40.93	59.55
	5/01 900~5/02 1500	14.5	4.70	13.5	1.09	15.12	0.13	5.81	12.02	1.83	23.21	29.27
	5/02 1500~5/03 900	2.7	4.73	11.6	0.52	0.99	0.15	2.47	4.74	1.27	14.31	25.34
	5/06 1800~5/07 1600	12.1	4.56	14.5	0.35	13.41	0.16	3.29	3.88	1.07	20.76	29.94
	5/07 1600~5/08 900	3.4	4.59	10.3	0.70	5.84	0.15	1.65	2.99	1.52	11.52	24.28
Forest	4/23 900~4/24 900	2.8	4.66	19.2	7.91	0.00	19.67	14.24	55.33	8.24	17.13	60.23
	4/30 900~5/01 900	1.9	4.26	39.1	11.12	0.00	27.06	23.28	66.50	13.76	23.09	107.35
	5/01 900~5/02 1500	7.1	4.40	28.7	5.28	0.00	18.78	19.75	45.32	5.70	10.39	81.64
	5/02 1500~5/03 900	1.2	4.72	13.5	1.75	0.20	9.02	10.58	20.18	3.24	7.90	38.33
	5/06 1800~5/07 1600	10.6	4.49	18.0	1.41	0.44	11.62	10.64	20.69	4.15	4.08	39.06
	5/07 1600~5/08 900	2.3	4.40	21.3	1.40	0.00	12.78	8.67	13.98	3.38	5.06	44.43

3.2. *Snow cover chemistry*

Water equivalent of snow cover (HSW), NO_3^- and SO_4^{2-} concentrations of snow cover are shown in Fig. 2. Figure 2 shows the range of spatial variations of samples of both sites. Spatial variations of HSW, NO_3^- and SO_4^{2-} concentrations of snow cover are larger at the forested site than at the open site. Decreasing tendency of HSW at the open site is more rapid than that at the forested site. Concentrations of NO_3^- and SO_4^{2-} in snow cover are higher at the forested site than at the open site.

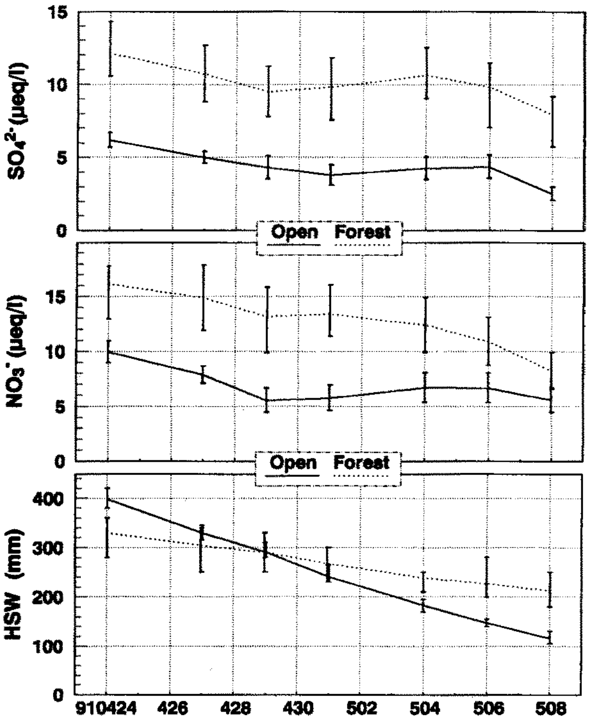

Fig. 2. Water equivalent of snow cover (HSW), NO_3^- and SO_4^{2-} concentrations of snow cover at both the open site and the forested site.

3.3. *Chemistry of snow meltwater*

Snowmelt runoff, NO_3^- and SO_4^{2-} concentrations in snow meltwater are shown in Fig. 3. Snowmelt runoff shows clear diurnal variation. The amount of snowmelt at the open site is more than twice as large as that at the forested site. Peak runoff of early in the morning on the 2nd and 7th of May is caused by heavy rainfall. At these time, there is not so much difference between the amount of snowmelt at the open site and at the forested site.

Concentrations of NO_3^- and SO_4^{2-} in meltwater at the open site show diurnal variation except the snowmelt day caused by rain, but there is a half-day time lag between a variation phase of NO_3^- and SO_4^{2-}. Concentration of NO_3^- fluctuates same phase as H^+, on the other hand concentration of SO_4^{2-} fluctuates same phase as Ca^{2+}. These variations are considered to be caused by the chemical strata structure of snow cover (Suzuki *et al.*, 1992) ; *i.e.* NO_3^- and H^+ concentrations in the upper layer are lower than that in the under layer. SO_4^{2-} and Ca^{2+} concentrations in the upper

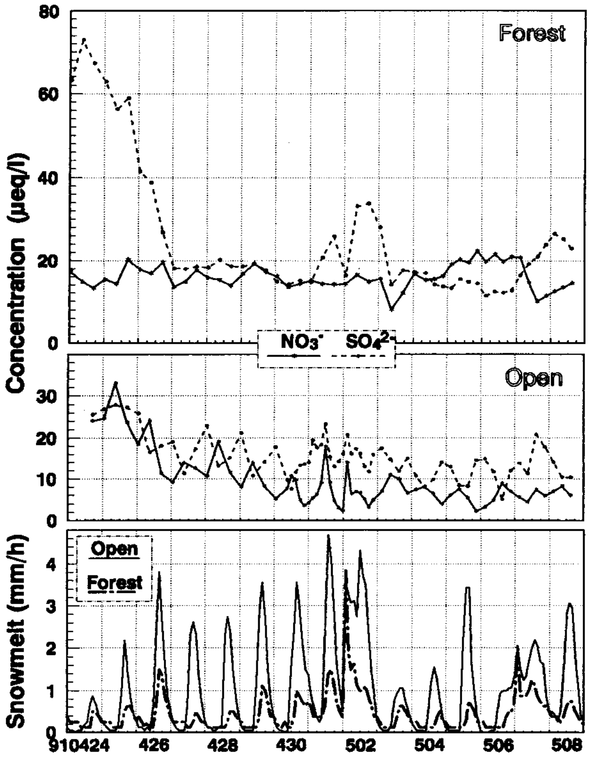

Fig. 3. Snowmelt runoff, NO_3^- and SO_4^{2-} concentrations of snow meltwater at both the open site and the forested site.

layer are higher than that in the under layer due to high dry deposition rate (Suzuki, 1983). Concentration of NO_3^- in meltwater at the open site is higher at the early period of snowmelt than at the end of melt season.

Concentrations of NO_3^- and SO_4^{2-} in meltwater at the forested site dose not show clear diurnal variation. Concentration of SO_4^{2-} in meltwater at the forested site is higher at the early period of snowmelt and after rainfall. Fluctuation range of NO_3^- concentration in meltwater at the forested site is smaller than that of SO_4^{2-}.

3.4. Hydrochemical budgets of snow cover

Hydrochemical budgets of snow cover are calculated by using of observational data mentioned above.

Snow cover was measured hydrochemically seven times every 2–3 days (Fig. 2). Loss of water equivalent of snow cover (LHSW, mm) and loss of any ion from snow cover (LIL_x, mg/m^2) are calculated from expressions (1) and (2).

$$\mathrm{LHSW}_n=\mathrm{HSW}_n-\mathrm{HSW}_{n-1} \qquad (1)$$

$$(\mathrm{LIL}_x)_n=(\mathrm{SC}_x)_n\times\mathrm{HSW}_n-(\mathrm{SC}_x)_{n-1}\times\mathrm{HSW}_{n-1} \qquad (2)$$

where :

HSW_n =mean water equivalent of snow cover at the measuring time n (mm) ;

$(\mathrm{SC}_x)_n$ =mean concentration of ion x in snow cover at the measuring time n (mg/l) ;

$n=2\sim7$.

Snowmelt runoff was measured sequentially. Concentration of ion x in meltwater was measured several times a day (3–8). The total amount of runoff of ion x from snow cover (RI_x, mg/m^2) is calculated from expression (3).

$$(\mathrm{RI}_x)_m=\mathrm{DR}_m\times(\mathrm{RC}_x)_m \qquad (3)$$

where :

DR_m =amount of daily snowmelt runoff on the day m (mm) ;

$(\mathrm{RC}_x)_m$=mean concentration of ion x in meltwater on the day m (mg/l) ;

$m=1$ (910424)$\sim$15 (910508).

Losses of water equivalent of snow cover, loss of NO_3^- and SO_4^{2-} from snow cover, the total amounts of snowmelt runoff and runoff of NO_3^- and SO_4^{2-} by snow meltwater at the both sites are shown in Figs. 4 and 5 cumulatively. The total amount of precipitation and the ionic load in precipitation are added respectively. The total amount of snowmelt runoff is nearly equal to cumulative loss of water equivalent plus precipitation both at the open site and at the forested site. The total amount of runoff of SO_4^{2-} by snow meltwater is nearly equal to cumulative loss of SO_4^{2-} from snow cover plus SO_4^{2-} load in precipitation at the forested site, but is larger at the open site. This difference is considered to be due to dry deposition at the open site. Dry deposited materials at the forested site are dissolved in throughfall. The total amount of dry deposited materials at open site was not estimated.

The total amount of runoff of NO_3^- by snow meltwater is smaller than the cumulative loss of NO_3^- from snow cover plus NO_3^- load in precipitation at both the open site and the forested site. Ratios of the cumulative loss of NO_3^- from snow cover plus NO_3^- load in precipitation and the total amount of runoff of NO_3^- by snow meltwater are 0.77 and 0.65 at the open site and the forested site respectively. The loss of

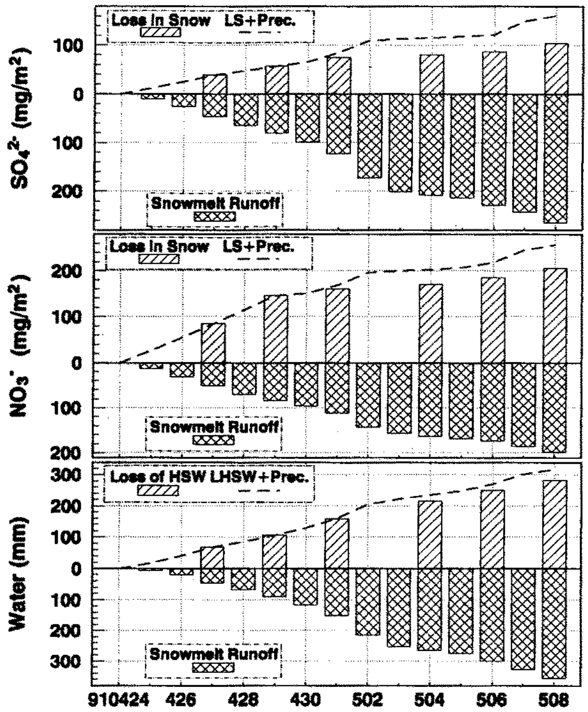

Fig. 4. Budgets of water, NO_3^- and SO_4^{2-} at the open site.

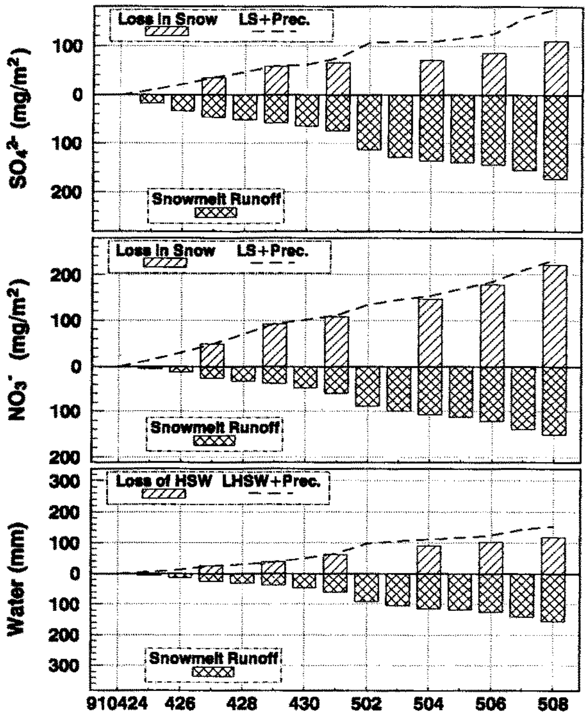

Fig. 5. Budgets of water, NO_3^- and SO_4^{2-} at the forested site.

NO_3^- in the snowpack is believed to be due to microbiological processes. The ratio of $((LIL_x)_7+\text{Prec.})/(RI_x)_{15}$ at the forested site is smaller than the ratio at the open site. The loss of NO_3^- in the snowpack is larger at the forested site than at the open site. Microbiological processes in the forested snowpack are more active than those in the snowpack at the open site.

4. Conclusion

The chemistry of precipitation, snow cover and snow meltwaters was characterized at both an open site and a forested site in a boreal forest location in Canada during snowmelt season, 1991.

Concentrations of major ions in precipitation are higher at the forested site than at the open site, except for NH_4^+ and NO_3^-. The losses of NH_4^+ and NO_3^- in throughfall are considered to be the result of microbiological activity in the forest canopy. Snowmelt runoff and concentrations of NO_3^- and SO_4^{2-} in meltwater at the open site show diurnal variation. Concentration of NO_3^- in meltwater at the open site is higher during the early period of snowmelt than the end of the melt season.

The total amount of SO_4^{2-} in the runoff of snow meltwaters is larger than the cumulative loss of SO_4^{2-} from snow cover plus the SO_4^{2-} load in precipitation at the open site. This difference is considered to be due to dry deposition. On the other hand, the total amount of NO_3^- in the runoff of snow meltwaters is smaller than the cumulative loss of NO_3^- in the snowpack plus the NO_3^- load in precipitation at both the open site and the forested site. The loss of NO_3^- is believed to be due to microbiological processes. The consumption of NO_3^- in the snowpack is larger at the forested site than at the open site. This suggests that microbiological processes in the forested snowpack are more active than those in the snowpack at the open site.

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