

## Effect of winter warming on the stream water acidification

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### Abstract

We studied the annual variation of the pH of stream water in a snowy temperate area, where rain or temporary warming can cause frequent melting at the surface of snow cover, even in mid-winter with its intermittent snowfall. On the other hand, in the snowy cold area, the air temperature seldom rises above freezing point during winter. We reported the seasonal variation of the pH of stream water in a snowy temperate area. The pH value of stream water in a snowy temperate area was always changeably, decreasing in cold seasons and increasing in warm seasons. The drop in pH during the snowmelt season was remarkable. Although the pH drop of stream water was also temporarily observed in flooding during warm seasons, relatively long pH drops were observed in cold seasons. The air temperature and the snow depth in winter determine the pH of stream water in the snowmelt season. We examine the relationship between the pH of stream water in the snowmelt season and the air temperature and the snow depth in winter. The monthly mean temperature in February is very closely correlated with the monthly average pH of stream water in March. Furthermore, the maximum snow depth is also closely correlated with the monthly average pH of stream water in March.

### 1. Introduction

Throughout the lakes of eastern Canada and Scandinavia, effects of acidic precipitation on the inland water ecosystem have been reported (Gorham, 1961; Beamish and Harvey, 1972; Johannessen and Henriksen, 1978; Jeffries *et al.*, 1979; Minns, 1981). Geologic and soil conditions in the catchment of those lakes provide only a weak buffer against acidic precipitation, and the alkalinity of the inland water is low. Furthermore, in those areas most precipitation occurs as solid precipitation, namely snowfall, which covers the ground for about half the year. During snowmelt season, the acidic substances which deposited from the atmosphere to snow by wet and dry processes, flow out from snow cover relatively all at once. Thus the pH of stream water and lakes drops rapidly during the snowmelt season. Acidic precipitation is also observed in Japan, where there is as much acidic deposition as in eastern Canada (Langner and Rodhe, 1997). Nevertheless, the large buffer capacity of the soil and the high alkalinity of the inland water inhibit acidic precipitation from directly influencing the inland water ecosystem in Japan.

The snowy temperate area is defined as the area where temporary warming or rain cause frequent melting at the surface of snow cover, even in mid-winter

with its intermittent snowfall. On the other hand, in the snowy cold area, the air temperature seldom rises above freezing point during winter. Suzuki (2003) reported the seasonal variation of the quality of stream water in a snowy temperate area. The pH value of stream water in a snowy temperate area was always changeably, decreasing in cold seasons and increasing in warm seasons. The drop in pH during the snowmelt season was remarkable. Although the pH drop of stream water was also temporarily observed in flooding during warm seasons, relatively long pH drops were observed in cold seasons.

We present a relationship between the stream water acidification and the winter warming, which, in this context, is important for at least two reasons. First, the winter warming affects the degree of stream water acidification in the snowmelt seasons. Second, the monthly mean air temperature in February can forecast the monthly mean pH value of stream water in March. We focus on the continuous pH observation of stream water and on its comparison with the air temperature and snow depth records.

### 2. Methods

The forested stream studied in this report is located in Fukushima Prefecture, northeastern Japan. The catchment area is 0.14 km<sup>2</sup> at an elevation of 745

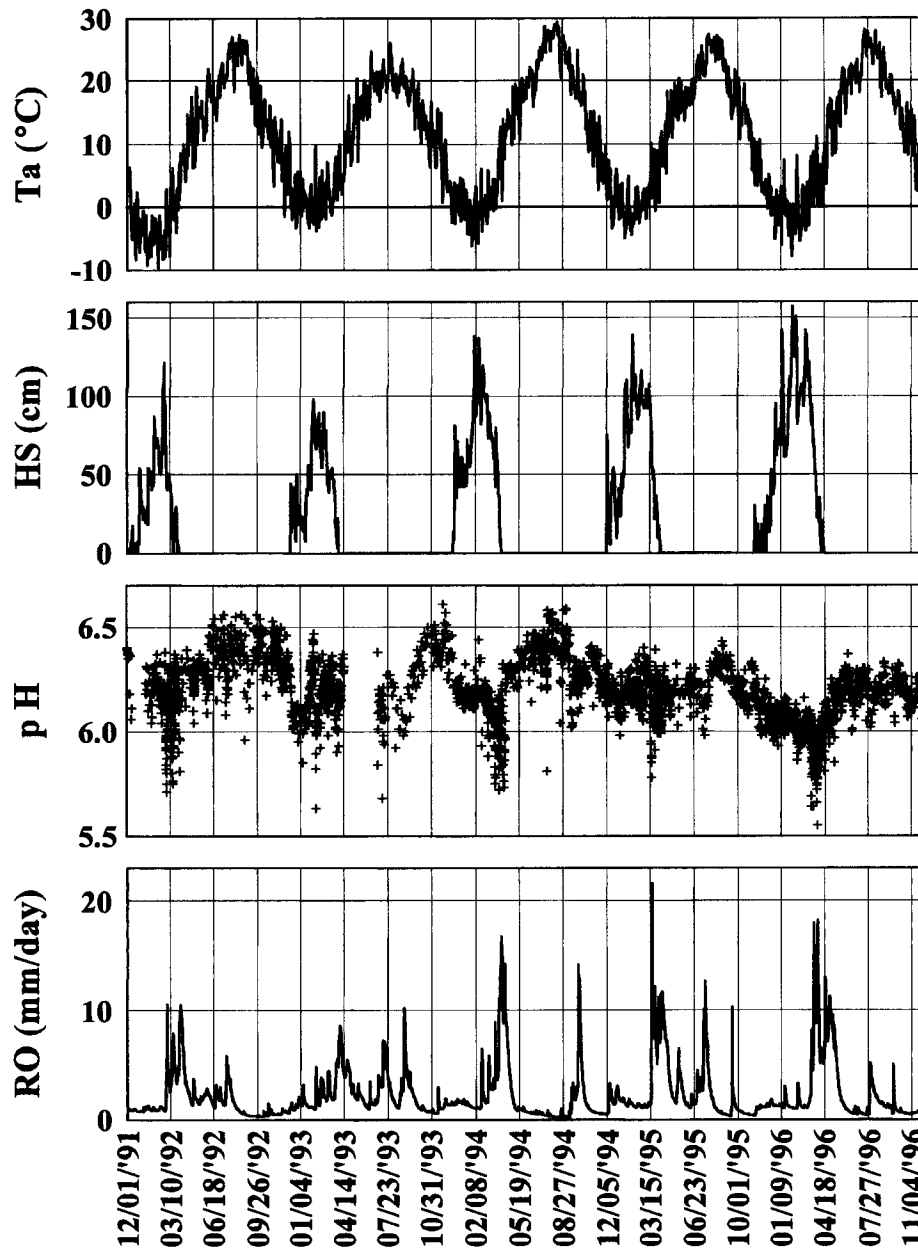


Fig. 1. The variations in daily mean air temperature ( $T_a$ ), snow depth (HS), pH of the stream water, and daily runoff (RO) in the five water years.

to 910 m a.s.l. The surface soil of the catchment is sedimentary rock consisting of tuff sandstone, conglomerate, tuff breccia and tuff neogene, and the bedrock is exposed on most stream beds except for downstream.

In order to measure the stream discharge, a 90° V-notch stainless steel weir was installed. A pressure sensor and data-logger (KONA system Co. Ltd., KDC-S 10 & KADEC-US) were employed for the automatic measurement of the water level at this weir; these measurements were used to calculate discharge. Stream water was periodically sampled with an automatic water sampler (ISCO Co. Ltd., 2900). The sampling interval was set short in cold seasons and long in warm seasons, and ranged between 1 and 60 hours. And the pH of stream water was measured by using

the pH meter (TOA Co. Ltd., HM-30V).

The weather observation field was set up at about 120 m east from the discharge measurement weir, on a ridge at 754 m a.s.l. In the observation field, air temperature was automatically measured by a ventilated-type temperature sensor (KONA System Co. Ltd., KDC-S02 & KADEC-US), and snow depth by a snow-depth gauge (KONA System Co. Ltd., KADEC-S6 & KADEC-UP).

### 3. Results and discussion

Observations are conducted for the five years from December 1, 1991, to November 30, 1996. In the catchment studied here, monthly precipitation is lowest in April, yet stream discharge peaks at this time of

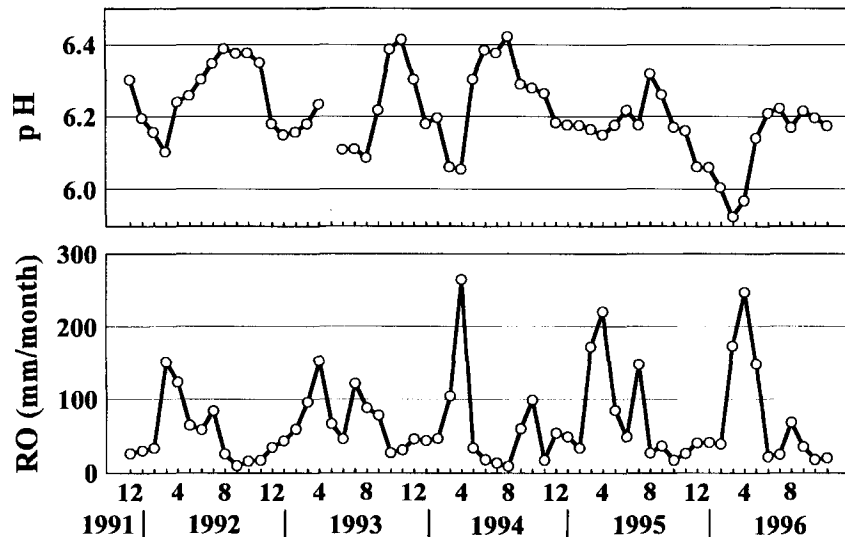


Fig. 2. The fluctuation of monthly averages of the stream water runoff (RO) and pH of the stream water for the five water years.

year, since it is the snowmelt season. November has the second-lowest amount of precipitation but, unlike April, its rate of stream discharge is low. Hence it seems reasonable to define a water year as beginning in December.

The variations in daily mean air temperature, daily maximum snow depth, pH of stream water, and daily runoff during the five water years are illustrated in Figure 1. The snow depth in winter 1993 is relatively low, with a maximum depth of snow cover of 98 cm. The daily mean temperature in winter 1993 is also higher than in other years. The peak value of daily runoff during the snowmelt season in 1993 is the lowest throughout the five years. The snow depth in winter 1996 is the highest, with a 157 cm maximum depth of snow cover. The total runoff of the snowmelt season in 1996 is the largest throughout the five years. The pH of stream water shows annual variations throughout five years, decreasing in the snowmelt seasons and increasing in warm seasons. The decreasing of pH value in the early stage of the snowmelt season is remarkable every year. Although the pH drop of stream water is temporarily observed also in flooding during warm seasons, relatively long pH drops are observed in cold seasons. However, pH dropped less frequently in the cold season in 1993 than in the cold seasons in 1992, 1994 or 1996. This is considered to be the influence of winter warming and of little snow during winter 1993. Unless melting takes place, chemical substances deposited by snowfall and dry deposition are preserved in the snow cover (Suzuki, 1982). However, if melting occurs frequently, chemical substances do not accumulate in the snow cover, so the snowmelt acidification mechanism hardly works. Therefore, it is assumed that only a slight pH drop in the stream water is observed in the snowmelt season in 1993.

In order to clarify the seasonal variation in stream water pH, the monthly mean of pH is examined below. Figure 2 illustrates the monthly averages of the stream runoff and the stream water pH for the five water years. In this stream, the runoff increases in the snow melting period of March and April every year, and the pH of stream water decreases in the same period. The runoff of stream water also increases in the warm season, namely Bai-u and typhoon periods, but the monthly average pH does not show noticeable change at these times. The monthly average pH of stream water is higher in the warm season, and the difference in monthly average pH between warm season and cold season is approximately 0.2 to 0.3. The lowest monthly average pH during the observation period is 5.92 in March 1996. In the winter of 1996, as mentioned before, the snow depth was the largest in the observation period and the winter air temperature was relatively low. On the other hand, the snowmelt season of 1993, when the snow depth was the lowest and the winter air temperature was high, the monthly average pH of stream water only decreased to 6.15. Likewise, in the snowmelt season of 1995, when the winter air temperature was high, the monthly average pH of stream water also decreased only to 6.15.

It is assumed that the air temperature and the snow depth in winter determine the pH of stream water in the snowmelt season. Therefore, we examine the relationship between the pH of stream water in the snowmelt season and the air temperature, and also between the snow depth in winter and the air temperature. The pH of stream water is represented by the monthly average of March, when snow melting is the most active (Suzuki, 2003), and the monthly mean temperature is represented by that of February, when the monthly mean temperature is the lowest. Figure 3 shows the relationship between the monthly mean

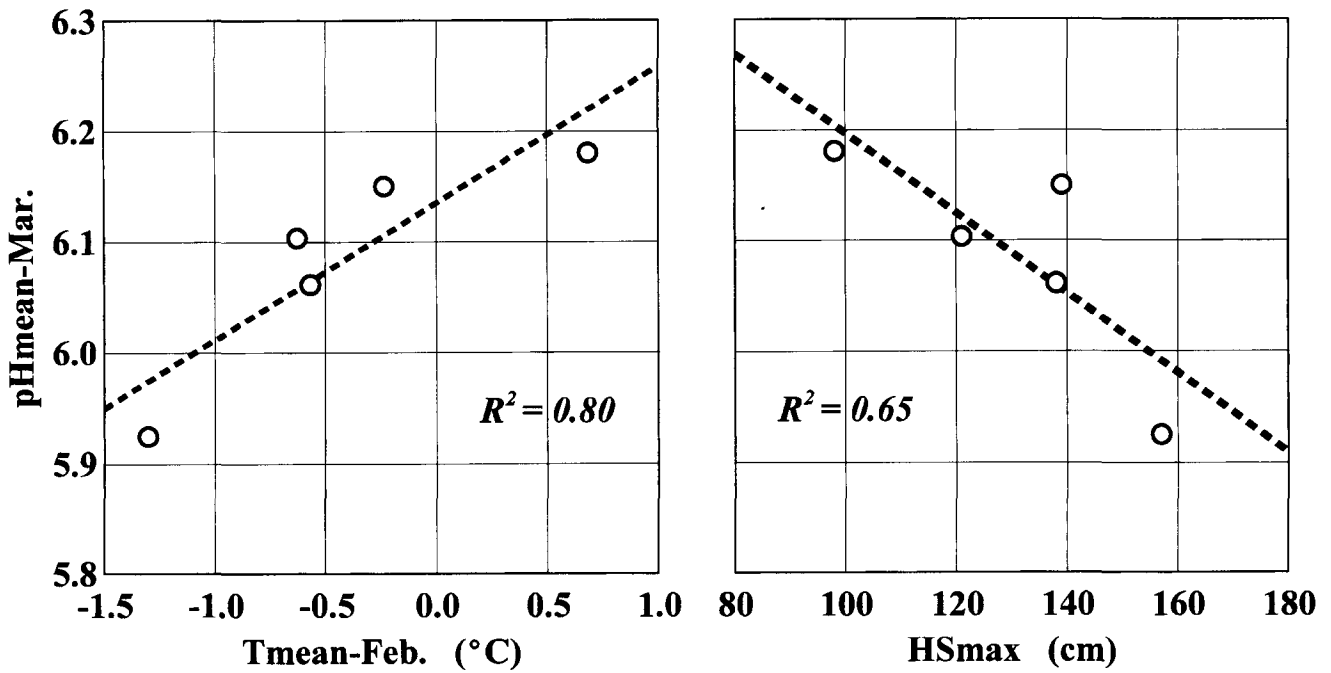


Fig. 3. The relationship between the monthly mean temperature in February and the monthly average pH in March, and between the maximum snow depth and the monthly average pH in March.

temperature in February and the monthly average pH in March, as well as the relationship between the maximum snow depth and the monthly average pH in March. The monthly mean temperature in February is very closely correlated with the monthly average pH in March. It is clear that when the monthly mean temperature of February is high, the monthly average pH of stream water of March is high, and when the monthly mean temperature of February is low, the monthly average pH of stream water of March is low. It clearly shows that the air temperature in February affects the pH of stream water in March, when snow melting is the most active. Furthermore, the maximum snow depth is also closely correlated with the monthly average pH in March. When the maximum snow depth is large, the monthly average pH of stream water in March is low, and when the maximum snow depth is small, the monthly average pH of stream water in March is high. It shows that snow depth in winter affects the pH of stream water in the snowmelt season.

In the snowy temperate areas, slight increase of air temperature in winter changes snowfall to rain. It means that even if the amount of precipitation in winter is the same, higher air temperature reduces the amount of snow cover. In other words, the air temperature in winter directly influences the amount of snow cover in the snowy temperate areas. It has been reported that global warming reduces the amount of snow cover in the snowy region. This paper examined the relationship between meteorological conditions during winter and the pH of stream water and found that global warming influences the pH of stream wa-

ter in the snowmelt season.

#### 4. Conclusion

The pH of stream water in a snowy temperate catchment was investigated throughout five water years. In the snowy temperate catchment, melting occurs frequently due to temporary warming or to rainfall occurring even in mid-winter. In such cases, the pH of stream water drops temporarily. The pH of stream water shows annual variations throughout five years, decreasing in the snowmelt seasons and increasing in warm seasons. The decreasing of pH value in the early stage of the snowmelt season is remarkable every year. The monthly mean temperature in February is very closely correlated with the monthly average pH in March. It clearly shows that the air temperature in February affects the pH of stream water in March, when snow melting is the most active. The maximum snow depth is also closely correlated with the monthly average pH in March. It shows that snow depth in winter affects the pH of stream water in the snowmelt season. In the snowy temperate areas, the air temperature in winter directly influences the snow depth. It has been reported that global warming reduces the amount of snow cover in the snowy region. We examined the relationship between meteorological conditions during winter and the pH of stream water and found that global warming influences the pH of stream water in the snowmelt season.

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