Soil–Vegetation–Atmosphere Transfer Schemes and Large-Scale Hydrological Models (Proceedings of a symposium held during the Sixth IAHS Scientific Assembly at Maastricht, The Netherlands, July 2001). IAHS Publ. no. 270, 2001.

Snow vegetation interactions: issues for a new initiative

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Abstract The Working Group on Snow–Vegetation Interactions of the IAHS International Commission on Snow and Ice has proposed enhanced study of the impact of stressors on snow–vegetation ecosystems such as deforestation, land-use change, climate change, long-range pollutants and land management and of the role of the snow–vegetation ecosystem in transmitting or moderating impacts from these stressors. These studies will include those that examine snow–vegetation interactive processes in various biomes, the relationship between these interactions and global atmospheric change, and the role of vegetation cover form, dynamics and management on snow and hydrology. Examples are shown here of case studies of snow–vegetation dynamics and implications for the environment, drawn from field studies in the Colorado Rocky Mountains, the Austrian Alps and the Canadian Sub-arctic. The examples are chosen to illustrate the utility of the principles outlined above when applied in the study of snow–vegetation ecosystems.

Key words snow; vegetation; nutrients; terrestrial ecology; climate; hydrology; arctic; alpine; boreal forest; snow drifts

INTRODUCTION

New definitions for the study of *snow ecology* (Jones, 1999) and recent field observations, suggest that high altitude and latitude vegetation communities are strongly linked to patterns of snow accumulation, avalanche and melt by their influence on mass, chemical and energy exchanges with the snow cover, and by their sensitivity to snow thermal insulation and spring time inputs of meltwater, nutrients, net radiation and turbulent heat exchange (Höller, 2001; Jones, 1991; Marsh & Pomeroy, 1996; Pomeroy & Brun, 2000; Walker *et al.*, 1993; Walker *et al.*, 2000). However, many parameterizations used in ecological, atmospheric and hydrological models presume stationary plant communities as part of their regional calibrations and include limited, or overly-simplified, interactions between vegetation communities and snow (e.g. Essery & Pomeroy, 2001).

The complex dynamics of a changing environment have increased the demand for focused studies of snow–vegetation interactions at small and large scales: plant, plant community, landscape, biome and global. The IAHS International Commission on Snow and Ice, Snow–Vegetation Interactions Working Group, SVIWG (Pomeroy & Walker, 1999), has proposed enhanced studies of the impact of stressors on snow–vegetation ecosystems such as deforestation, land-use change, climate change, long-range pollutants and land management and of the role of the snow–vegetation ecosystem in transmitting or moderating impacts from these stressors. These studies will include those that examine snow–vegetation interactive processes in various biomes, the relationship between these interactions and global atmospheric change, and the role of vegetation cover form, dynamics and management on snow and hydrology. Examples are shown in this paper of case studies of snow–vegetation dynamics and implications for the broader terrestrial, aquatic and atmospheric environment, drawn from field studies in the Colorado Rocky Mountains, the Austrian Alps and the Canadian Sub-arctic. The examples are chosen to illustrate the utility of the principles outlined above when applied in the study of snow–vegetation ecosystems.

CANADIAN SUB-ARCTIC–ARCTIC TRANSITION

The geochemistry of sub-arctic and arctic catchments is strongly influenced by the chemistry of snow cover. This is due to the long winter over which chemical species accumulate in snow and the rapid release of the chemical load from the pack upon melt (Marsh & Pomeroy, 1996). The delivery of major ions to these catchments is not uniform, as several atmospheric and land surface processes enhance or deplete concentrations in snow and the accumulation of snow (Barrie, 1991; Jones *et al.*, 1993; Woo & Marsh, 1978). Pomeroy *et al.* (1993) showed that wind redistribution of snow from smooth to rough surfaces and preferential dry deposition to forested terrain were the primary processes controlling the distribution of major ions in the late winter snow of the sub-arctic–arctic transition zone.

Relationships between snow water equivalent, snow ion load and leaf area index (*LAI*) in open spruce woodland and tundra environments were developed for the Trail Valley Creek research basin north of Inuvik, Northwest Territories (NWT), Canada (Pomeroy *et al.*, 1995). The sites with low *LAI* accumulated the least snow and the least ions (Fig. 1). Interestingly, though higher *LAI* developed greater ion and snow loads than did the lowest *LAI* sites, a linear increase in ion or snow loads with *LAI* was not apparent. The highest *LAI* did not correspond to the highest water equivalent or ion load. The nonlinear relationship between snow accumulation and *LAI* may explain why Timoney *et al.* (1992) found no significant correlation to a proposed linear relationship between snow depth and tree density in the sub-arctic near Great Slave Lake, NWT. A

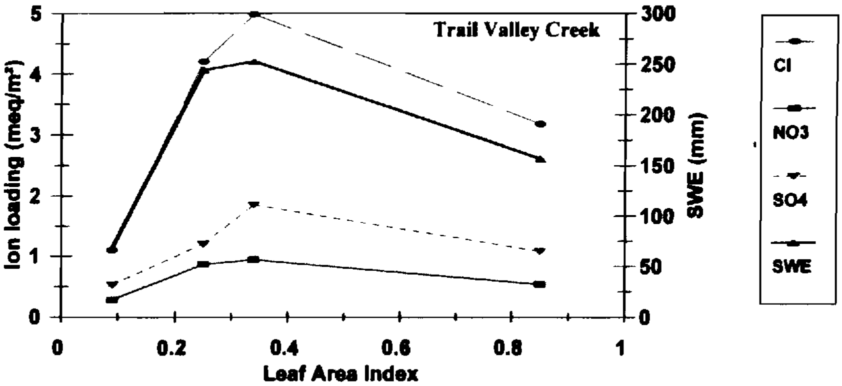

Fig. 1 Ion load and snow water equivalent as functions of leaf area index in transitional spruce forest, shrub tundra and sparse tundra for Trail Valley Creek, near Inuvik, Northwest Territories, Canada.

peak in snow and ion load occurs at *LAI* values between 0.25 and 0.35, corresponding to transitional vegetation between forest and tundra, usually deciduous, and at the leading edge of high roughness areas where wind-blown snow is deposited. Vegetation along the leading edge receives wind-blown snow and its chemical constituents from adjacent low *LAI* areas. Snow in the low *LAI* areas undergoes scouring, relocation and sublimation, resulting in low snow retention. The highest *LAI* areas are coniferous forests, which do not receive blowing snow inputs because they are normally fringed by taiga and shrub-tundra. The coniferous forests may lose snow over the winter due to sublimation of intercepted snow; however, snow surveys suggest that this loss is low for the sub-arctic and much lower than the southern boreal forest (Pomeroy *et al.*, 1998, 1999).

The load of snow and ions to a vegetation cover is therefore not due entirely to the vegetation aerodynamic characteristics, but to the spatial configuration of landscapes. *It is therefore extremely difficult to calculate the snow water equivalent and ion load to a vegetation stand in a windswept region using only point knowledge of the atmospheric deposition rate and the specific aerodynamic characteristics of the vegetation cover.* This effect becomes most pronounced in higher wind speed environments that undergo wind relocation of snow and is most pronounced for ions such as Cl^- and SO_4^{2-} that are conservative during sublimation, or scavenged by blowing snow processes (Pomeroy & Jones, 1996).

COLORADO ROCKY MOUNTAINS

Snow–vegetation interactions have been studied continuously since 1951 at Niwot Ridge in Colorado. Niwot Ridge is an alpine/sub-alpine ecosystem, located in the Colorado Front Range of the Rocky Mountains about 5 km east of the Continental Divide. Several examples of snow–vegetation interactions from research conducted at Niwot Ridge are presented here. A long-term snow fence experiment has been designed to assess the effects of changes in snow accumulation and duration on alpine ecology and biogeochemical cycles (Walker *et al.*, 1999). The responses of carbon (C) and nitrogen (N) dynamics in high-elevation mountains to changes in climate have been investigated by manipulating the length and duration of snow cover with the 2.6 × 60 m snow fence, providing a proxy for climate change. Results from the first year of operation in 1994 showed that, with this treatment, the period of continuous snow cover was increased by 90 days (Williams *et al.*, 1998). The deeper and earlier snowpack behind the fence insulated soils from winter air temperatures, resulting in a 9°C increase in annual minimum temperature at the soil surface (Fig. 2). The extended period of snow cover resulted in subnival microbial activity playing a major role in annual C and N cycling. The amount of C mineralized under the snow as measured by CO_2 production was 22 g m^{-2} in 1993 and 35 g m^{-2} in 1994, accounting for 20% of annual net primary aboveground production before construction of the snow fence in 1993 and 31% after the snow fence was constructed in 1994. In a similar fashion, maximum subnival N_2O flux increased threefold behind the snow fence, from 75 µg N m^{-2} day^{-1} in 1993 to 250 µg N m^{-2} day^{-1} in 1994. The amount of N lost from

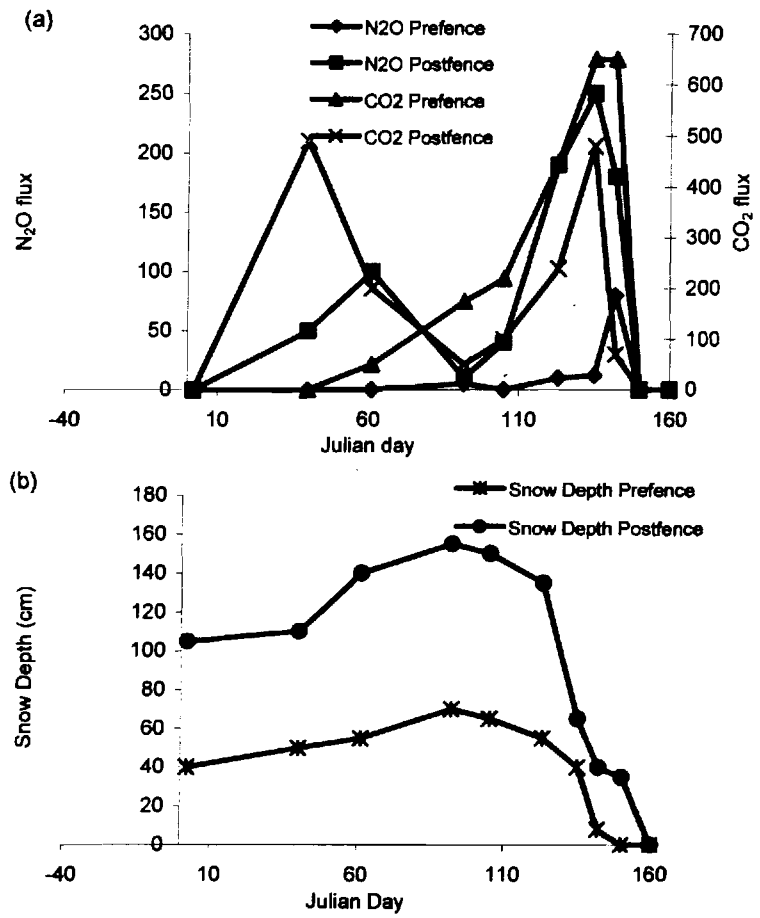

Fig. 2 Subnival CO_2 and N_2O fluxes as a function of snow depth before (1993, $n = 6$) and after (1994, $n = 9$) installation of a snow fence, Rocky Mountains, Colorado, USA.

denitrification was greater than the annual atmospheric input of N in snowfall. Changes in snowfall thus have the capability of causing large changes in biogeochemical cycling of seasonally snow-covered ecosystems and trace gas emissions to the atmosphere from those ecosystems. Incorporation of these trace gas emissions during the non-growing season have greatly improved the modelling of the carbon balance of ecosystems in northern high and temperate latitudes (McGuire *et al.*, 2000).

An interesting alpine example of snow–vegetation interactions is the tree island or krummholz. Seastedt & Adams (in press) have shown that tree islands strongly influence microclimate (temperature and moisture) by increasing snow cover amount and duration. Tree islands or krummholz found above the treeline in the Colorado Front Range are of interest because of their ability to migrate across the tundra landscape. This unique characteristic is caused by die-back of exposed, windward plant tissues, growth of the plant to the leeward, and the ability of these plants to produce new roots from branches buried in organic debris. This mobility also allows for the study of tree-induced changes on properties of soils initially formed by tundra vegetation. For example, Seastedt & Adams (in press) found significant reductions in amounts of soil organic matter (SOM) and KCl-extractable NH_4^- in soils influenced by tree islands. No recovery in soil SOM or NH_4^- was observed at locations that correspond to 250–500 years since the passage of a tree island. Cation exchange capacity was correlated with % SOM, but was not reduced by tree island passage.

AUSTRIAN ALPS

Snow gliding is an important transport phenomenon in many mountain environments (Höller, 2001). The influence of a change in agricultural use and hence vegetation on

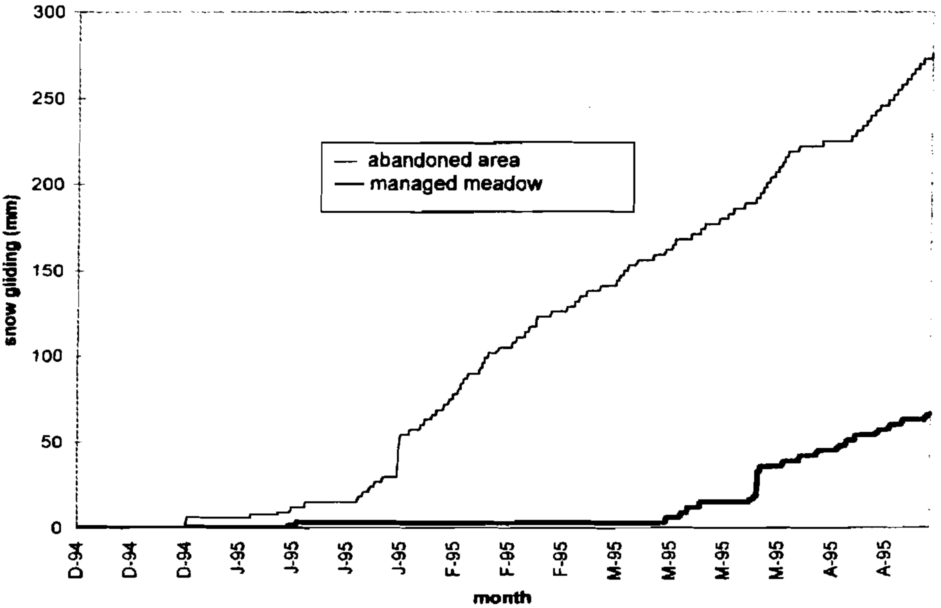

Fig. 3 Snow gliding in an abandoned area and a managed meadow, Austrian Alps.

the amount of snow movement, via snow gliding, is shown in an example from the Austrian Alps in Fig. 3. Snow gliding is a downhill motion of snow on the ground. It is mainly influenced by the ground surface (the smoother the ground surface the higher the glide rates) and the lowermost boundary layer of the snow cover. The two different measuring sites were located on an abandoned area (mainly *Nardetum strictae*) and a meadow (mainly *Trisetetum flavescentis*). While the glide rates on the meadow were only 50 mm, snow gliding on the abandoned area was increasing to more than 250 mm. These results confirm the effects of ground surface (vegetation) on snow gliding. Long-bladed grass mats on abandoned areas lead to a lower dry friction between snow cover and ground surface and this results in increased glide velocities. On the other hand, the surface roughness of the meadow is much higher, which leads to significantly lower glide rates and snow movements.

CONCLUSIONS

These examples show not only that vegetation has an extremely important influence on snow physical and chemical properties and processes, but that snow deposition, transport and the chemical load can have profound effects on the vegetation development. The examples shown here emphasize transitional vegetation areas where the effects of spatially variable snow accumulation and transport are very apparent; however, the effects are still important, but sometimes less apparent in environments near the centre of the major snowy biomes.

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