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Comparing the impacts of mature spruce forests and grasslands on snow melt, water resource recharge, and run-off in the northern boreal environment

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Abstract

Snow-melt runoff is an important factor in control of flooding and soil erosion in higher and cold regions of the world. In 1992–2008–2008, processes of snow accumulation and melting were monitored at two adjacent sites of the Paljakka environmental research centre (Finland). The forest stand of mature spruce (*Picea abies*) has been compared with adjacent, local, and open grassland. In the forest, snowpack duration fluctuated for 180–245 days, with a maximum depth of 78–152 cm and snow–water content of 167–406 mm, while in the open grassland this occurred for some 20 days less, with maximum depth 65–122 cm, and snow–water content 143–288 mm. The snow–water captured in the canopy reached a maximum 27% of that registered on the ground; the loss of intercepted snow by sublimation was approximately 26% of the annual snowfall. During the high melt period (April–May), the degree-day factor in the forest stand achieved 60% of values observed in the grassland (2.3–3.5 against 3.8–6.0 mm $^{\circ}C^{-1}$ day^{-1}). The hydrological model BROOK 90 was employed to analyse potential water resources recharge, and flood risk at Paljakka. Considering the normal climate season, snow-melt runoff from the forest exceeded the grassland by 22% (225 against 185 mm). In extreme situations, the maximum daily runoff from snow-melt in the grasslands (57 mm day^{-1}) exceeded 2.6 times the values in spruce forest (22 mm day^{-1}).

Keywords: Spruce boreal forest; Snow-depth; Snow–water content; Canopy interception; Snowmelt; Degree-day factor; BROOK 90; Runoff distribution

1. Introduction

The biome of boreal forest is characterized by coniferous stands consisting mostly of Norway spruce (*Picea abies*) and Scots pine (*Pinus sylvestris*). The relationship between forest and snow cover has been extensively discussed (WMO, 1994). Brooks, Folliott, Gregersen, and DeBano (2003), Ishii and Fukushima (1993) emphasized differences

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in forest stand structures upon the snowmelt runoff; the most significant reduce in snowmelt intensity was found in the dense mature spruce plantation.

In Nordic countries of Europe, snow melt processes significantly affect the water resources recharge but also the occurrence of nature hazard (overland flow, flooding and soil erosion). In Finland, where forests cover now 74% of the land area, processes of snow accumulation and snow melting are controlled mainly by boreal forests. However, in the last years, the harvest of boreal forests in Finland has been rapidly increasing mainly because of the local energy demand (Parviainen & Västilä, 2011). In the future, with expected changes of the global climate IPCC, 2013, extensive changes in the vegetation cover should be still considered. In the north of Finland, forest growth may increase with the climate change but the special features of boreal forest may be diminished (Kellomäki, Peltola, Nuutinen, Korhonen, & Strandman, 2008).

The recent investigations in the boreal forest focused namely on the snow evidence; snow cover mapping was accomplished there by several methods including remote sensing (Metsämäki, Anttila, Huttunen, & Vepsäläinen, 2005). The general distribution of snow characteristics across the Taiga snow-zone of Finland is reported by the Finnish national overview (Rasmus, 2005). But, the detailed genesis of snowmelt, and, particularly, differences within forest stands and open fields are still not well understood, related to groundwater recharge (Kubin & Křeček, 2009), or water resources protection. The objective of this study is to evaluate the effects of mature spruce forests on the accumulation and melt of snow, in comparison with that in open grassland on moderate slopes and high altitudes in central Finland. The standard observation there was supported with continuous monitoring of snowpack in the forest canopy to identify the interception loss and the genesis of snow melt runoff.

2. Material and methods

In 1992–2008, snow observations were carried out at the Paljakka research area (65°26′N, 26°26′E, elevation 350 m) in mature spruce (*Picea abies*) forests and in open grassland fields. The research area is in the middle-boreal coniferous zone (Hämet-Ahti, 1981). The climate is continental/micro-thermal (Dfc type, Köppen classification), the long-term mean annual temperature is 1 °C, and annual precipitation is 672 mm/year (with 50% snowfall). The even-aged (120 year) spruce stand was closed (basal area 25 m^2/ha, timber volume 160 m^3/ha), with a mean height of 15 m. The soils are sandy, developed on granite, and thr profiles normally less than one metre in depth. The saturated hydraulic conductivity, K, ranges from 1.8 to 2.0 m s^{-1} to the depth of 60–70 cm, at which depth a relatively impermeable podzolic layer normally occurs.

The field observation of snow characteristics were performed twice weekly between 9:00 and 10:00 am, except after the 25th April when they were performed three times a week because intensive changes in the snow cover begin to occur at this time. Ten sampling points at a distance of 10 m were used. The snow–water equivalent was measured by weighing vertical cores of the snow-pack (weighing cylinder with 100 cm^2 cross-section, Doesken & Judein, 1997). The standard daily meteorological data were provided by the climate station Suomussalmi Pesiö (25 km distance from the Paljakka research site).

In the last season, the canopy snowpack was monitored continuously by estimating snow weight on two full-size spruce trees by pressure sensors. The trees selected were typical of level, mature spruce stands, and approximated the surrounding canopy height of 15 m with crown projection of 3.5 and 3.0 m^2. Subtracting the tare from the force transducer measurement provided the mass of intercepted snow.

Snow–water characteristics are reviewed by Dewale and Rango (2008). The snow–water equivalent SWE [m] is expressed as

$$SWE = \frac{V_m}{A} \tag{1}$$

$$SWE = \frac{\rho_s}{\rho_w} \cdot h_s \tag{2}$$

where, V_m [m^3] is the volume of melted water from the snowpack of depth h_s [m], and the basal area A [m^2], ρ_s is the snow density (the mass per unit volume of snow) and ρ_w water density [kg m^{-3}].

A relatively simple, accepted empirical degree-day method was used for calculating the snowmelt in temperature dependent melting conditions (Martinec, Rango, & Roberts, 1998). The degree-day factor a [m $°C^{-1}$ day^{-1}]