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Effect of reindeer grazing on snowmelt, albedo and energy balance based on satellite data analyses

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ABSTRACT

Surface albedo has a major influence on the energy balance of the Earth. The albedo difference between snow-covered and snow-free tundra is high. Earlier studies have shown that taller and denser vegetation causes earlier snowmelt, and that shrub height and abundance, as well as the total biomass in summer reindeer pastures are lower than in winter pastures. Therefore, reindeer summer grazing could eventually delay the snowmelt and decrease the absorbed solar energy on the ground. The effect of reindeer summer grazing on the vegetation, snowmelt timing, surface albedo and ground heating is investigated in this study by comparing summer and non-summer pastures in the northern tundra areas of Fennoscandia. A comparison of vegetation types, NDVI, fractional snow cover and albedo between the Finnish year-round (including summer) pastures and the Norwegian non-summer (winter or spring/autumn) pastures is performed. Other factors influencing the snowmelt, such as surface air temperature, ground elevation and incoming solar radiation are taken into account. Information about the vegetation on the ground is based on a vegetation map compiled from Landsat TM/ETM + satellite data and ancillary map information. The NDVI, snowmelt and albedo analyses are performed using multi-temporal remote sensing data such as GlobSnow SE and MODIS based NDVI, snow and albedo products. The results here support previous studies and indicate that vegetation in the summer pastures is shorter and sparser and that snowmelt there occurs later than in the more densely vegetated, non-summer pastures. More shrubs protruding above the snowpack and earlier snowmelt on the Norwegian side lower the albedo during the snowmelt season. This causes higher solar energy absorption of up to 6 W/m^2 in the snowmelt season and contributes up to 0.5 W/m^2 to the yearly energy balance. Therefore this study suggests that summer reindeer herding can be used to delay snowmelt, increase surface albedo and to decrease the ground heating in the snowmelt season.

1. Introduction

The energy balance between the land surface and the atmosphere controls the climate system of the earth locally, regionally and on a global scale. The high latitude zone has several features that increase its impact on the climate system such as shortness of the growing season, long summer days, permafrost large extent of land ice and cold soils, extensive wetlands and shallow lakes, boreal woodlands and forests and low-vegetation tundra and forests (Eugster et al., 2000). The importance of snow-cover on the energy balance of the earth is well documented. The most critical feature of the snow in the climate system is its high albedo i.e. its ability to reflect back most of the solar radiation coming to the earth surface. The impact of snow-cover on the surface energy balance and its feedback on air temperature is the highest during the snowmelt season (Groisman et al., 1994), especially in low vegetated areas. According to Euskirchen et al. (2007), ground heating from snow-covered to snow-free ground increases by 80–90 W/m^2 in tundra and by 65–75 W/m^2 in shrubs and grasslands.

Previous studies have shown that in high latitude tundra areas, earlier or faster snowmelt occurs where the vegetation is more abundant or protrudes above the snowpack (Grippa et al., 2005; Loranty et al., 2011; Lundberg & Beringer, 2005; Marsh et al., 2010; Pomeroy et al., 2006), because vegetation above the snow decreases the total surface albedo, which increases the absorption of solar radiation (Bewley et al., 2010; Ménard et al., 2012; Sturm et al., 2005a). Therefore, for a better understanding of the climate system, it is necessary to observe the changes in vegetation and snow-cover in high latitude ecosystems and to study the possible influence of vegetation abundance on snow-cover and snowmelt processes (Euskirchen et al., 2007).

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Vegetation growth in the tundra is highly dependent upon air temperature, such that heading southward, vegetation becomes taller and denser (Chernov, 1985; Warhol, 2007). Previous studies have shown that shrub cover in arctic and subarctic tundra regions have been increasing (Chapin et al., 2005; Forbes et al., 2010; Tape et al., 2006) and that the greening trend of the tundra has happened mostly due to warming climate (Bunn et al., 2005; Goetz et al., 2005; Raynolds et al., 2008; Sturm et al., 2001). Similar shrub encroachment has been observed in Northern Fennoscandia by Tømmervik et al. (2004) and Olofsson et al. (2009). Shrub expansion triggers regional atmospheric warming in the spring and the summer, and especially tall shrubs increase the sub-surface soil temperature, deepen the active layer and shorten the length of the sub-freezing season (Bonfils et al., 2012; Sturm et al., 2005b). In the Alaskan tundra, an increase in atmospheric heating of 3.47 W/m^2 per decade has been observed for the last 60 years, and in complete tundra to shrub conversion, the ground heating is expected to increase up to 6.37 W/m^2 (Chapin et al., 2005). There is also a positive feedback loop between surface albedo and air temperature such that rising temperatures increase snowmelt, which decreases the average surface albedo and increases the yearly absorbed solar radiation, which furthermore raises the temperatures (Ahrens, 2007).

In recent years there has been a growing recognition that also herbivore population and grazing affect shrub cover (den Herder et al., 2008; Myers-Smith et al., 2011). Numerous studies have shown that herbivores in general, such as sheep, wild caribou, semi-domestical reindeer or rodents have decreased the shrub abundance (den Herder et al., 2008; Kitti et al., 2009; Olofsson et al., 2009; Post & Pedersen, 2008; Ravolainen et al., 2011). Reindeer grazing in particular causes a decrease in the overall biomass (Yu et al., 2009) and especially in the amount of lichen and deciduous shrubs (Ravolainen et al., 2011; Yu et al., 2011). Reindeer also reduce the vegetation height (den Herder et al., 2004, 2008; Kitti et al., 2009; Pajunen et al., 2008), which increases the albedo over snow-covered ground and decreases the ground heating.

Reindeer herding practices in Northern Fennoscandia vary from seasonal migrational to sedentary regimes [Fig. 1]. In Norway, reindeer herding regime is migratory such that, the inland areas are grazed from December until April, and in late April or early May reindeer migrate rapidly to coastal summer pastures, which they are allowed to leave after late August. During September and November, reindeer stay in the migration zone (spring and autumn pastures) and entrance to winter ranges is normally allowed after 1st of December (Riseth & Oksanen, 2007). On the Finnish side the herding system is more sedentary i.e. reindeer graze throughout the year. However, treeless tundra is preferred in summer because it is windier, which reduces the mosquito plague. The boundary between winter grazed and primarily summer grazed tundra areas is sharp, because migration across the border was prohibited in 1852. Continuous reindeer fence following the border has prevented Finnish Sámi from illegally utilizing Norwegian ranges and also stopped accidental border crossings by reindeer.

The impact of reindeer grazing on the vegetation is stronger in the summer than in the winter. In summer, reindeer browse leaves and shoots of trees and shrubs, whereas in winter they eat lichens and winter-green graminoids, but do not consume woody plants (Den Herder et al., 2004; Olofsson et al., 2009; Skjenneberg & Slagsvold,

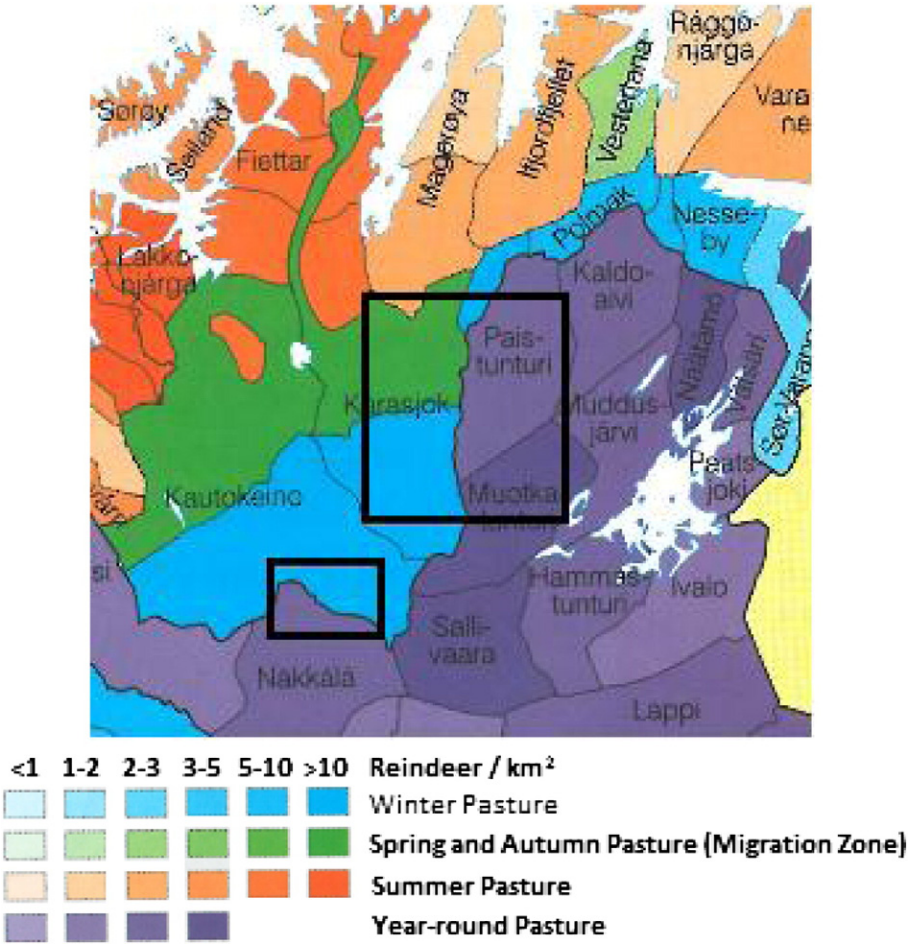

Fig. 1. Reindeer herding districts and number of reindeer in Northern Fennoscandia. (Bernes, 1996). The reindeer herding regime in Norway is migratory such that reindeer migrate between coastal summer pastures and inland winter ranges. On the Finnish side the herding system is more sedentary i.e. reindeer grazing occurs all year-round.