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Textile protection of snow and ice: Measured and simulated effects on the energy and mass balance

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ABSTRACT

Measurements and simulations of the energy fluxes and mass changes of an artificially covered snow and ice surface (geotextile material) and an unaltered control plot in an Austrian glacier ski resort are presented and compared. A modified version of the snow cover model SNOWPACK is used to successfully reproduce the artificially compacted and the additionally covered snow cover in a physically based way. Supplementary measurements of crucial material properties of the 4.5 mm thin geotextile serve as model input as well. Results indicate that the shortwave reflectivity of the covers is responsible for 46% of the performance. Thermal insulation of the material (14%) and a negative latent heat flux due to evaporation of precipitation from the cover surface (10%) have almost the same contribution. A layer of air between the cover and the snow and ice surface (thickness 7.5 cm to 12 cm) adds the rest, which is at the upper limit of observations and may therefore also compensate for model errors. This generally explains the high performance of the method in glacier ski resorts and, most importantly, an altitude dependent application limit of the method: the method becomes less effective at lower altitudes, where sensible heat fluxes become more important compared to shortwave radiation.

1. Introduction

Recent climatic warming has strongly affected the operation of Alpine glacier ski resorts, reducing their firn coverage, exposing bare ice and reducing ice coverage (Olefs and Obleitner, 2007; Olefs and Fischer, 2008). Glaciers are generally considered suitable for skiing when the ice is covered by at least 0.3 m of snow with a density of 400 kg m^{-3}. Skiing conditions are maintained on glaciers in a number of ways, which can be broadly classified into two categories. Methods that encourage snow to accumulate include installation of snow fences to artificially trigger preferential deposition of snow (Lehning et al., 2008), redistribution of snow by snowcats, densification of snow by snowcats or by injection of water, and artificial snow production. The prime method of reducing snow and ice ablation is to cover snow with various types of geotextiles (Olefs and Obleitner, 2007; Olefs and Fischer, 2008; Olefs, 2009).

The field experiments were begun in Austria in 2004 (Olefs, 2005; Olefs and Obleitner, 2007) and were completed with an intensive field measurement campaign between 2004 and 2006. Manually measured data (ablation stakes time-series, shortwave reflectivity, vertical profiles of snow density, water equivalent and temperature) from 2004 and 2005 have already been published in a comparative study (Olefs and Fischer, 2008). Prior results indicate that 4.5 mm thin special blankets (geotextiles) are the most efficient way to reduce snow and ice ablation and can decrease total ablation by 60% (two year mean value on a flat area relative to undisturbed ablation). After the success of these experiments, geotextiles are now used in critical areas of all five Tyrolean glacier ski resorts during the melt period, covering a total surface of around 0.3 km^2, corresponding on average to 2%–3% of the glacier area used for skiing. Geotextiles are only applied at neuralgic zones (rock outcrops, ski-lift tracks, ski-lift pylons, and glacier margin) because of the high cost associated with the application. Since the conditions in those critical zones often determine whether a ski resort can be opened, the method is effective despite the small total area of application. Additionally, seasonal snow from ice free areas is stored in piles below the glacier margins using snowcats in spring and is covered with geotextiles to minimize ablation. In autumn this snow is then used for the preparation of ski slopes together with natural and artificial snow.

Recently, the efficacy of the piling method was tested in relation to seasonal snow conservation measures at much lower altitudes. In the Swiss ski resort of Davos, the efficacy and physical mechanisms of two different conservation measures (geotextile and sawdust) were compared in 2008 using field and laboratory measurements as well as numerical simulation with an adapted version of the physically based snow cover model SNOWPACK (Rinderer, 2009). Modeling results indicate that the performance of the geotextile material is very sensitive to air temperature and wind speed and less sensitive to

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radiation. Several model runs with data from different elevations indicate that geotextiles do not effectively reduce snow ablation below an altitude of about 2200 m a.s.l. or a mean air temperature during the ablation period (May–Oct 2008) of more than 6 °C.

In spite of the practical success on glaciers, there is still a lack of understanding for the detailed physical processes involved in covering snow and ice with geotextiles. This paper presents energy fluxes and mass changes of control and covered conditions measured by automatic weather stations (AWS) from a northerly slope of Schaufelferner glacier, Stubai Alps, between 13 January 2005 and 8 August 2006 at an altitude of 2870 m a.s.l. Measurements of some crucial material properties of the covers are also presented. These data serve as input for a process-oriented adaptation of the physically based snow cover model SNOWPACK (Lehning and Fierz, 2008), making it feasible to conduct sensitivity studies by modification of important material characteristics, following the approach of Rinderer (2009).

Results of hand measurements of the shortwave reflectivity of different cover materials and the influence of cover thickness on melt reduction were shown in Olefs and Fischer (2008). In this paper, measurements of thermal conductivity, heat capacity, longwave emissivity and evaporation rates are added. Additionally, comparison of the continuously measured data at both AWS provides direct information on the effect of the cover on shortwave reflected and longwave emitted radiation.

1.1. Test site, characteristics of the ablation periods 2005 and 2006

The investigation area is located on Schaufelferner glacier (46°59′N, 11°07′E) in the Stubai Alps, Austria. The site is situated at an altitude of 2870 m a.s.l. in the glacier ski resort of Stubai and is considered typical for the neuralgic zones of Austrian glacier ski resorts. Olefs and Fischer (2008) present details about the topographical setting for this test site and on specific problems related to ice melt. The test site is a gentle, northerly exposed slope near the lower margin of the glacier, partly shaded by the ridges of Schaufelspitze. Two plots, one covered by geotextiles and one left unaltered as a control, were delineated, each with an area of 320 m^2. Each plot was monitored by an AWS and a webcam, installed in January 2005. Data was collected from 13 January 2005 to 8 August 2006. For technical reasons, the weather stations had to be dismantled at the beginning of August but manual ablation measurements using ablation stakes (Hoinkes, 1970) continued until the end of the ablation period, at the beginning of October 2006.

Natural ablation occurred at the control plot from 24 May, when the snow was at its maximum height of 2.68 m, to 16 September 2005 (121 days). Ice melt began on 1 August. Total snow ablation amounted to 1132 kg m^{-2}, ice ablation to 900 kg m^{-2} or 1 m in height.

In 2006, the ablation period began on 19 May and ended on 6 October (141 days). During that period, snow ablation amounted to 1272 kg m^{-2} (2.80 m in height), ice ablation, beginning on 23 July 2006, to 2160 kg m^{-2} (2.4 m in height). See Fig. 1 for a time-series of snow

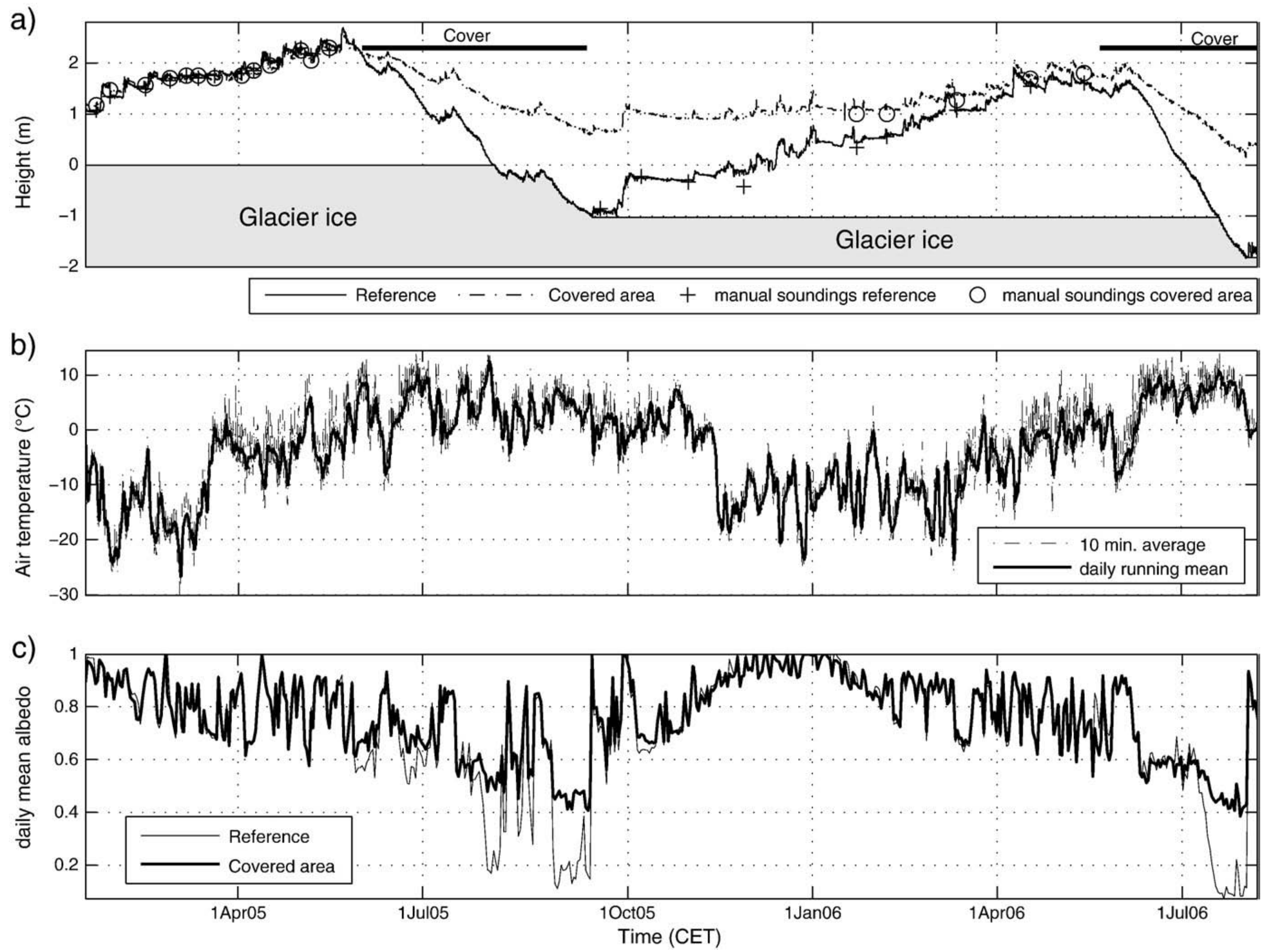

Fig. 1. a) Time-series of measured snow height and manual soundings, b) air temperature, and c) daily mean albedo for both the reference and the covered plot over the period 13 January 2005 to 8 August 2006 at test site Schaufelferner (Stubai Alps). Duration of glacier ice ablation is illustrated for the reference plot in the panel a). The time of covering is symbolized by horizontal bars. Total ablation in 2005 equals 3.8 m in height or 2032 kg m^{-2}, comprising 1 m of ice thickness loss (height). Until 8 August 2006 (time of station dismounting), the height loss of 2006 at the reference plot equals 3.7 m (2082 kg m^{-2}), comprising 0.9 m of ice thickness loss. Total ablation until 6 of October 2006 equals 4.8 m (3432 kg m^{-2}).