ALPINE AND MARITIME SNOW COVERS:
SIMILARITIES AND DIFFERENCES IN WATER DISTRIBUTION

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ABSTRACT: The nature of a snow cover differs greatly from area to area and it is highly interesting to compare the various consistencies of snow covers in diverse countries. Two regions with different types of climate which generate typically high snow covers have been selected: Iceland with a maritime climate and Austria as a representative for the alpine climate. Both types of climate show different effects on the physical properties of the snow cover and metamorphism. To minimize the effect of topography measurements sites with well matching topographies have been selected: Field measurements have been carried out in the Alpine regions near Innsbruck, Austria, and in the northern part of Iceland near the city of Akureyri. Special attention in this comparative study was given to the vertical distribution of snow temperature, density, electric permittivity and liquid water content. Liquid water content of snow was determined by using both a calibrated electronic moisture meter and freezing calorimetry.
Experimental results of a four months field study from February to May 2002 are presented.

Keywords: snow physics, water content, maritime and alpine climates.

1. INTRODUCTION

The snow precipitation and the layering of the snow cover depend greatly on the climate. To compare two different climate types which generate high snow covers, the maritime climate and the alpine climate was chosen. Iceland was selected as a representative for the maritime climate and Austria as a representative for the alpine climate.

To minimize the effect of topographical differences onto the comparative study, similar areas in both countries were selected. In Austria Tirol was chosen to represent the alpine climate the best and in Iceland Eyjafjarðarsýsla to match the mountainous topography of Tirol.

The liquid water content (LWC) of a snow cover as the main measurement category of this study is a substantial parameter for many applications. The stability of a snowpack is of interest to avalanche prediction. Liquid water can change the stability of a snow layer by refreezing after infiltrating the relevant layer.
Water storage capabilities of snowpacks and percolation processes of liquid water through snow are of interest to hydrology. These characteristics of snow are vital for the computation of river peak flows and therefore worthwhile knowing for the operation of hydroelectric power stations. The calculation of river peak flows is also important for the prognosis of possible floods.

These are examples for applications of the knowledge extracted from research on liquid water in snow covers. The aim of this paper is to study different distributions of liquid water in snow covers from two different countries with different climates. A detailed account of the study is given by Jarosch (2003). The emphasis lies on the vertical distribution of the liquid water content in snowpacks. With one representative profile from each country the different features of the snow covers according to the climate types are presented.

2. STUDY SITES

In Iceland five profiles were measured in the county Eyjafjarðarsýsla. The area around Akureyri was chosen as a representative for the maritime climate because of the closeness to the sea and yet a mountainous topography. Typical maritime snow covers can be expected in this area. A map of the study sites in Iceland, SP01 up to SP04/05 is shown in Figure 1. Snow profile at site SP05 located in the valley of Fnjóskádalur

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was chosen as a representative for Iceland and results are shown in Figures 3a, 3b, and 3c.

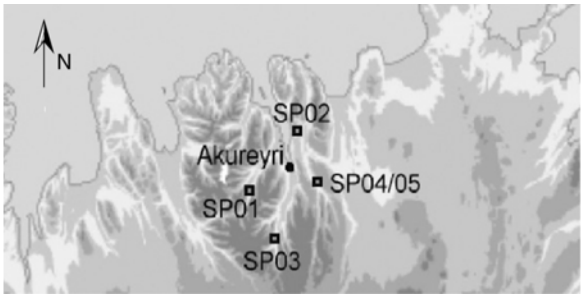

Fig. 1 Map of the Icelandic study sites (LMI 2004).

In Austria three snow profiles were measured in the federal state of Tirol. A map of the Austrian study sites, SP06 up to SP08, is shown in Figure 2. This mountainous region in the central Alps was chosen to represent typical alpine snow cover. All three profiles were measured in the region of the Hafelekar Spitze near Innsbruck. As a representative for Tirol, SP08 was chosen and results are shown in Figures 4a and 4b. GPS coordinates of all study sites in Iceland and Austria are given in Table 1.

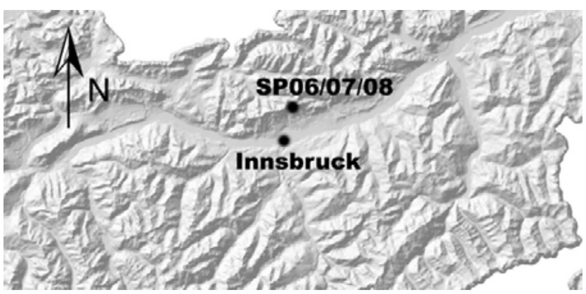

Fig. 2 Map of the Austrian study sites (tiris 2004).

Study site	Latitude	Longitude
SP01	N 65° 33' 15.3"	W 18° 32' 52.9"
SP02	N 65° 48' 36.0"	W 18° 00' 02.3"
SP03	N 65° 20' 56.0"	W 18° 15' 53.8"
SP04/05	N 65° 35' 30.1"	W 17° 46' 26.1"
SP06/07/08	N 47° 18' 45.7"	E 11° 23' 7.9"

Tab. 1 Geographical coordinates of the study sites with map datum WGS84.

The measurements in Iceland were performed in February 2002 and in Austria in the first half of May 2002. Those dates were selected for this comparative study in order to have comparable highs and lows in the values of liquid water content.

3. METHODS AND MATERIALS

All measurement categories were done at certain depth levels inside the snow pit, and the vertical coordinate, D, for depth, was introduced with the origin on the snow cover surface and positive values increasing with depth. D is measured in cm. In the figures 3 and 4, both the snow/ground interface and the snow/air interface are marked by dot-dashed lines.

As mentioned above the liquid water content, θ (given in % by volume), was the main measurement category of this study. It was measured with a capacitive snow wetness meter (Denoth, 1994). This method uses the snow permittivity and snow density to calculate the liquid water content. As an additional, independent measurement, freezing calorimetry was partly used for comparison. Details are given in Jarosch (2003). From both methods mean values of LWC are derived, averaged over a sensor-specific volume, the sphere of influence. This has to be considered when correlating values of LWC with snow temperature values, which are not volume-mean but local values.

To achieve a good vertical resolution in the snow cover LWC and to avoid the overlapping of the spheres of influence due to sensor geometry a vertical distance not less than 5 cm between the measuring points is suitable. As a standard distance 10 cm are used at all research sites. Only when small, interesting features in the snow cover are present, a narrow grid of 5 cm vertical distance is used.

The density, ρ (given in g/cm^3), of the snow was calculated from the mass and the volume measurement. To sample the same volume from the snow cover at each measurement depth a wedge shaped sampler with a known volume was used. With this procedure a constant sample volume is ensured and densification of the snow sample is minimized.

The densification effect during the sampling of snow causes the asymmetric errors in density and liquid water content because the density is assumed to be correct or overestimated according to this method.

To complete the data set for each measurement point the temperature of snow T is also taken. T is given in °C. To measure the snow temperature a digital thermometer is used with a spike shaped sensor.

Icelandic snow covers are classified as maritime with large thickness and frequent ice layers. Thickness between 90 cm and 180 cm were found during this research. Densities range from 0.2 g/cm³ to almost 0.6 g/cm³. Melt – freeze metamorphism was found in some layers inside the snowpacks, however large layers of wind compressed snow with small grain sizes around 1 mm are typical for Iceland. The ground was covered with grass or moss at the Icelandic study sites which made the snow cover – ground interface an accumulation zone for liquid water due to surface and interfacial tension.

The alpine snow covers in Austria are characterized by multiple layers of melt - freeze metamorphism with mean grain sizes of 2 mm and the overall layering of the snow packs was found to be highly variable. Less ice layers compared to Iceland were observed and the density of the snow was varying around a mean value of 0.4 g/cm³ and reaching maxima of nearly 0.6 g/cm³. Thickness between 90 and 110 cm were measured. The ground in Austria was either solid rock or a thin layer of grass. This caused the snow cover – ground interface to either enable water percolation or favoring surface runoff.

4. EXPERIMENTAL RESULTS

Out of a total of five measurement series carried out in Iceland, and out of a total of three measurements series made in the Austrian Alps, one representative and characteristic data set from each country is presented and discussed: The set of Figures 3a, 3b and 3c shows a characteristic vertical distribution of LWC (θ), snow density (ρ), and snow temperature (T) for Iceland at location SP04/05 (cf. Figure 1); the set of Figures 4a and 4b shows a characteristic vertical distribution of LWC and snow density for Austria at location SP08 (cf. Figure 2). Snow temperature at study site SP08 was at T = 0 °C throughout the snow cover. A typical horizontal distribution of LWC over a distance of 100 cm at location SP04/05 is shown in Figure 5.

In general, three different regions inside the snowpacks, marked in the figures 3 and 4 with grey shading, have to be considered separately:

1) The snow cover top layer, ranging from D = 0 cm to D = 15 cm, including the snow - air interface at the surface. This region is highly influenced by solar radiation and bi-directional heat exchange.

2) The bottom layer, which is roughly a 15 cm thick layer above the snow - ground interface, as a region highly influenced by interface properties such as surface tension and capillary forces.

3) The snow cover volume between the top layer and the bottom layer.

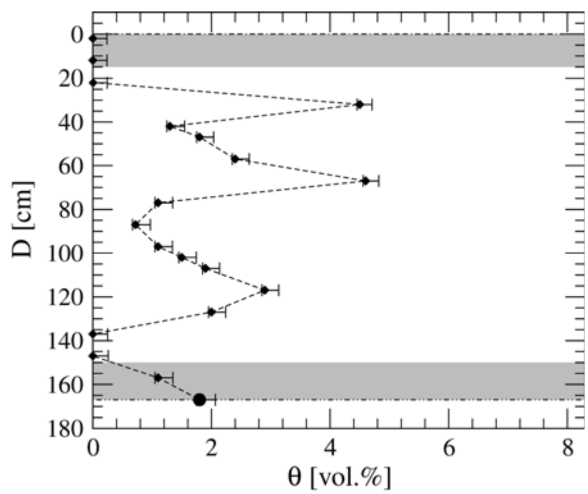

Fig.3a Vertical distribution of LWC θ [vol. %] at location SP04/05, Iceland.

The LWC-distribution is characterized by a relatively dry top layer, followed by marked variations in LWC within the snow volume ranging from very low values of θ between 0 and 1 % up to two maxima of θ ~ 4.6% at depth levels of D = 32 cm and D = 67 cm. The bottom layer is characterized by an increasing LWC with increasing depth, ending up at a value of θ = 1.8 % at the snow ground interface.

The density-distribution (Figure 3b) is characterized by a significant increase from ρ ~ 0.24 g/cm³ near the snow-air interface to a maximum of ρ = 0.56 in the bulk-region. In the bulk-region high variations in snow density are observed. Less variation in density around a mean of ρ = 0.5 g/cm³ was found in the bottom layer of the snowpack.

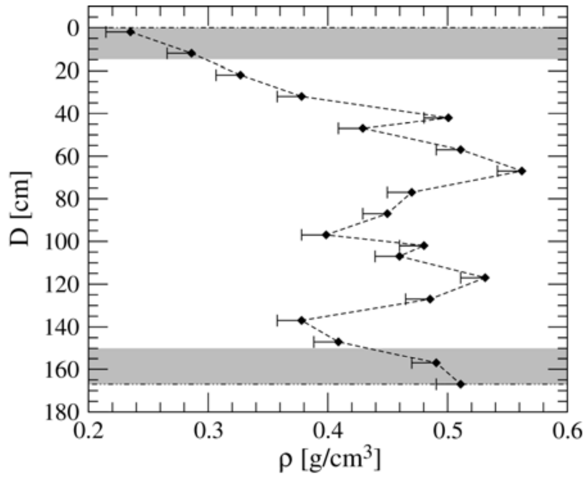

Fig.3b Vertical distribution of snow density ρ [g/cm³] at location SP04/05, Iceland.

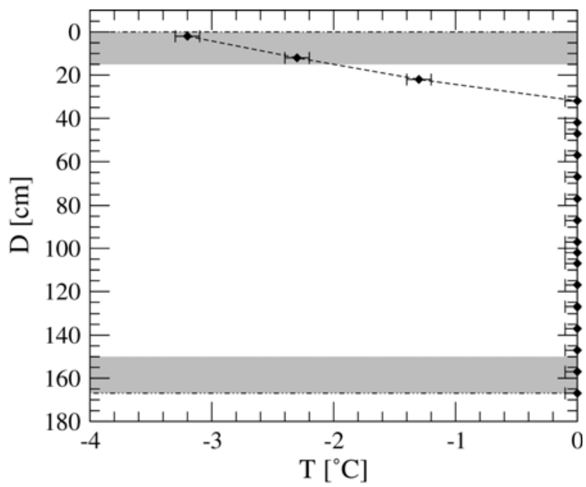

Fig.3c Vertical distribution of snow temperature T [°C] at location SP04/05, Iceland.

Snow temperature at location SP04/05 shows a marked increase from –3.2 °C at the snow-air interface to 0°C at a depth of D = 32 cm, and keeps constant throughout the remaining snow cover.

LWC-distribution at study site SP08, Figure 4a, is characterized by a relatively wet top layer showing a maximum of θ = 6.3%, followed by marked variations in LWC within the snow volume ranging from low values of θ ~ 2 % up to a maximum of θ = 4.8% at a depth of D ~ 60 cm. The lower bulk region and the bottom layer are characterized by a decreasing LWC with increasing depth, starting at a depth of 90 cm.

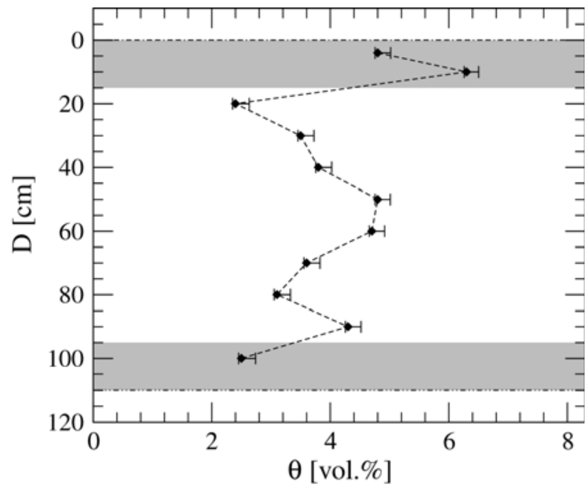

Fig.4a Vertical distribution of LWC θ [vol. %] at location SP08, Austria

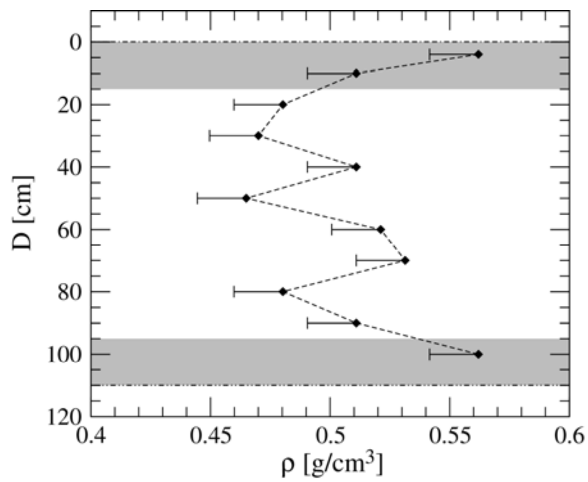

Fig.4b Vertical distribution of snow density ρ [g/cm³] at location SP08, Austria

Density-distribution is characterized by a significant decrease from ρ ~ 0.56 g/cm³ near the snow-air interface to a low of ρ ~ 0.46 g/cm³ in the bulk-region. In the bulk region high variations in snow density are observed, reaching again a high value of ρ ~ 0.56 g/cm³ in the bottom layer near the snow/soil interface. Snow temperature at location SP08 is at the melting point throughout the snow cover. Figure 5 demonstrates the horizontal variations in LWC inside a snow cover at study site SP04/05, Iceland. In the upper region of the snow cover volume distinct horizontal differences are observed, whereas towards the ground a more homogeneous layering with a smaller horizontal variability in LWC was found.

Different local values of LWC are represented on a grey-scale.

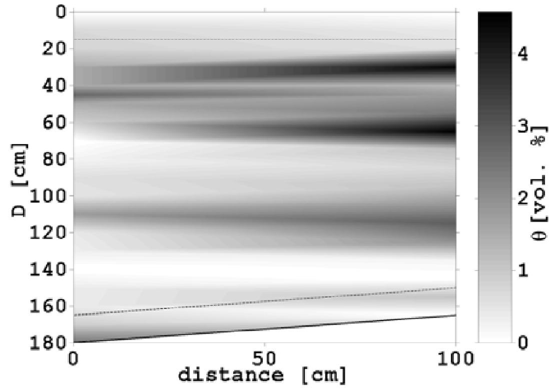

Fig.5 Horizontal distribution of LWC at location SP04/05, Iceland.

5. CONCLUSIONS

The comparison of maritime and alpine snow covers was fruitful in revealing differences in the bottom layers of the snowpacks as well as differences in the top layers. The snow cover volumes showed different but also comparable behaviors.

The snow cover top layer of maritime snow covers displayed small amounts of liquid water content and less variability compared to alpine snow covers. High variability in LWC in the snow cover volume of maritime snowpacks is presented in this paper and cases of no LWC in the snow cover volumes of maritime snowpacks are reported by Jarosch (2003). Alpine snow cover volumes were found to be less variable around a higher mean value of liquid water content compared to maritime snow covers.

The liquid water content in the snow cover bottom layer of maritime snow covers increased with depth compared to a decrease of the amount of liquid water in alpine snow covers at the lower bulk region and the bottom layer. The snow-ground interface in maritime snow covers was found to be a barrier for percolation of water whereas the snow-ground interface in alpine snow covers appeared to be no barrier for percolation processes (Colbeck, 1971).

As an outlook for further research a possible special case in Iceland should be mentioned. Due to the geothermal activity in Iceland a snow cover with two warm boundaries would be possible. A heat flow from warm air above the snow cover and a heat flow at the bottom of the snow cover caused by geothermal activity would form a special case of liquid water content distribution. Unfortunately an investigation of such a case was not possible during the measurement period in Iceland in February 2002 because of the mild winter climate in that year.

6. ACKNOWLEDGEMENTS

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