Structural phase changes of the liquid water component in alpine snow

A. Denoth *
Institute of Experimental Physics, University of Innsbruck, Austria

ABSTRACT: The way free water is arranged in the complex texture of Alpine snow is measured by a series of different methods: Broadband electro-magnetic measurements ranging from radio-frequencies up to the microwave K-Band regime directly allow the detection of the geometrical structure of the water bodies; hydraulic measurements - measurements of water percolation through or water drainage off an Alpine snow cover - show a significant change of water movement characteristics which are caused by changes in the water geometrical configuration (structural phase changes) due to the natural variation in the free water saturation. Structural characteristics of water bodies included in snow are reflected by the dielectric depolarization factors, the special case of ring-shaped water inclusions is reflected by the magnetic permeability.
Field measurements have been carried out in the Alpine regions of the Stubai Alps, Austria, whereby metamorphism of these Alpine snow covers is characterized by several melt-freeze cycles. It results the existence of 4 main regimes of water saturation characterized by different structural properties of the free water bodies: the pendular zone with closed isolated water bodies, a funicular zone with confluent water bodies, a transitional zone where isolated water bodies begin to merge, and a sub-regime included in the pendular zone characterized by the existence of ring-shaped water bodies. Experimental results of a twelf-year field study are presented.

KEYWORDS: Snow physics, electromagnetic properties, hydraulic properties

1. INTRODUCTION

Independent of the stage of metamorphism, liquid water in snow exists generally in different geometric arrangements: the pendular regime with two different sub-zones, the funicular regime, a pendular-funicular transition zone and the regime of complete saturation. The pendular regime is characterized by isolated closed water bodies and ranges from the adsorbed-liquid limit to saturations at which some of the water bodies coalesce. Recently, the existence of closed ring-shaped water bodies within the pendular regime of Alpine snow which has experienced several freeze-thaw cycles has been proved (Denoth, 1999). The funicular regime at higher saturations shows continuous liquid paths throughout the pore space with an isolated and trapped gaseous phase. The actual arrangement and geometry of the individual components of wet snow - ice, water and air - influences both the electromagnetic and hydraulic response, and this offers a way to experimentally determine water geometry in the different saturation regimes.

* Institute of Experimental Physics, University of Innsbruck, Technikerstrasse 25 / 4, A-6020 Innsbruck, Austria. E-mail: armin.denoth@uibk.ac.at

2. EXPERIMENTAL RESULTS

Electric and magnetic permeability has been measured in the frequency range of 6 to 16 GHz, whereby water saturation S of the natural snow samples varied from 0% to 40%. Based on the effective medium model of Polder and van Santen (Sihvola, 1999) the characteristic shape factors, G_i, have been calculated using least-square fitting routines. Fig.1 shows the dependence on water saturation of G_2. Regions, where significant changes in the shape factors can be observed are marked by arrows. Both shape factors, G_1 and G_2, vary significantely with water saturation: funicular and pendular saturation regimes are clearly separated by a transitional zone ranging from S ~8% to ~13% of the pore volume. Within the pendular regime at liquid saturations S lower than a critical saturation, S_c, [$S_c \approx 4\%$], a subzone is formed characterized by a strongly decreasing shape factor G_1: $G_1 \rightarrow 0$. In the subzone $0 < S < S_c$ capillary forces and surface tension may be dominant and control the geometric shape of the water inclusions, for $S > S_c$, gravity forces may play the dominant role.
The dependence of magnetic loss μ'' on water saturation is shown in Fig.2 for a selected frequency of f = 14 GHz. Regions, where significant changes in the 'induced' diamagnetic losses can be observed, are

marked by arrows. The effect of changing geometry of water bodies on water flow caracteristics is shown in Fig.3: A more or less sudden change of flow type in the transitional regime of water saturation is clearly observed.

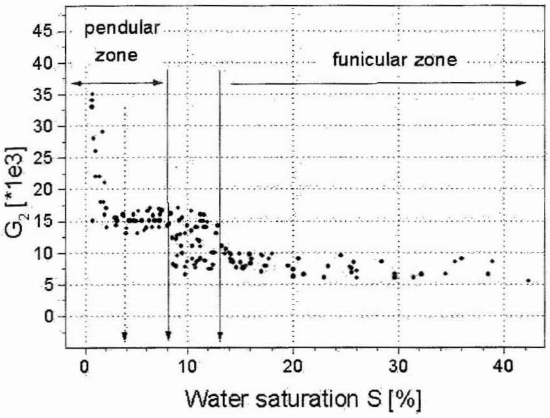

Fig.1. Dependence of shape factor G_2 on liquid water saturation

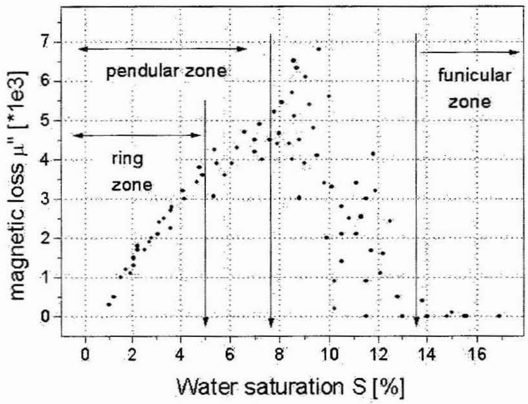

Fig.2. Dependence of magnetic loss on water saturation.

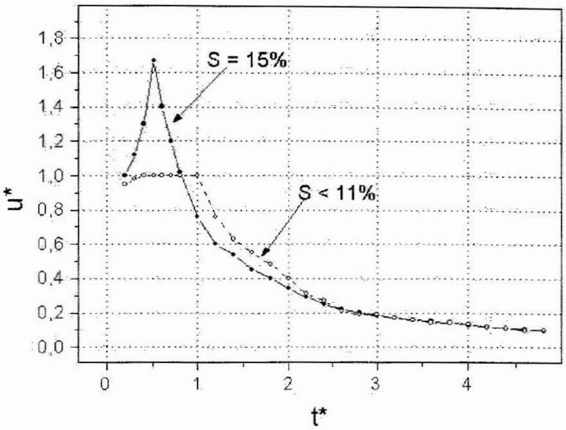

Fig.3. Variation of relative water flux u* with time for initial saturations of S=15% and S<11%.

It may be of interest, that S_i, the irreducible water saturation, compares excellent to the crititcal saturation, S_c, derived by electromagnetic measurements, and S_c and S_i may be identical. Consequentely, the saturation zone $0 < S \leq S_c \equiv S_i$ within the pendular regime is characterized by the domination of capillary / surface forces over gravitational forces.

3. REFERENCES

Denoth, A., 1999. Wet snow pendular regime: The amount of water in ring-shaped configurations. CRST 30, 13-18

Sihvola, A., 1999. Electromagnetic mixing formulas and applications. IEE Electromagnetic Waves Series, No 47. IEE, London, UK