SNOW WATER STUDIES AND COMPARATIVE ELECTROMAGNETIC MEASUREMENTS IN THE AUSTRIAN ALPS: A 15 YEAR FIELD STUDY

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ABSTRACT: Various methods for measuring the liquid water content of a natural snow cover have been tested extensively under field conditions: hot- and freezing calorimetry, dielectric methods operating in the low- and mid frequency regime, resonator/antenna methods and free-wave-methods operating in the VHF up to the microwave frequency regime; both thermo-gravimetry and resonator methods have been used for soil water measurements near the snow-soil interface. Comparative measurements of the vertical distribution of water in a natural snow cover, long-term water flow recordings with the detection of melt water shock-waves, and comparative measurements of the water saturation gradient near the snow-soil interface, and its variation with time, have been carried out.

From a 15 year field research program relations between snow geometric structure parameters derived from electromagnetic studies and characteristic snow hydraulic parameters derived from drainage and percolation studies are presented.

Keywords: Snow physics, electromagnetic properties, hydraulic properties, snow texture

1. INTRODUCTION

Snow texture parameters like mean grain diameter, grain size distribution, grain shape factors as a marker for the deviation of a spherical shape, and porosity are of particular importance for modelling water drainage and water storage capacity and in modelling of the electromagnetic response. It was the scope of a 15 year field research program to study the effect of these geometric structure parameters on water drainage and percolation and on the electromagnetic response of a natural snow cover with different stages of metamorphism and water content. The measurements have been carried out in the Stubai Alps, Tyrol, Austria, at a mean height of 3000 m a.s.l. And throughout a 15 year measurement period all types of snow from fresh, newly fallen snow, multi-year firm with large well rounded grains up to snow which has undergone multiple melt-freeze cycles have been encountered. The snow samples have been characterized by grain size, grain shape, porosity and liquid water content. Liquid water measurement techniques are given by Denoth and Foglar (1986), derivation of snow grain geometric parameters are described by Denoth (1982)

2. INSTRUMENTATION

Electromagnetic response is characterized by the dielectric function, dielectric and ionic loss-function and the magnetic permeability. These quantities have been measured in the field by network analyzers and appropriate sensors (plate condensor, resonator, monopol-antenna or free-space technique), according to the actual measuring frequency. Electromagnetic response has been measured over a large frequency regime from 10 Hz up to 16 GHz using a ZPV-unit from Rhode&Schwarz, and a HP8510-unit. Water drainage and percolation experiments have been done with more or less homogeneous snow, repacked in aluminium columns of 1,40m and 2m height, respectively. These columns have been thermally insulated in order to minimize snow texture changes during long-term experiments. Details of the experimental setup and data evaluation are given by Denoth and Seidenbusch (1978) and by Wilhelm et al. (1992). The snow water sampling unit for the measurement of water flux is shown in Fig.1., and Fig.2 shows the variation with time of water saturation within the snow column due to drainage for 3 different initial water saturations of S=11,6% (open circles),
S=9.8% (solid circles), and S=15% (open triangles).

Fig.1. Automatic snow water sampling unit for water flux measurements

Fig.2. Long-term variation of water saturation S due to drainage for 3 different initial saturations of S=11.6% (open circles), S=9.8% (solid circles), and S=15% (open triangles).

3. EXPERIMENTAL RESULTS

The large sets of snow electromagnetic response data and snow water drainage and percolation measurement data have been analyzed with respect to the effect of snow texture properties, especially snow grain shape, and with respect to the geometry of water inclusions within the ice-matrix in the case of wet snow. The shape of ice grains or water inclusions is characterized by the mean axial ratio, whereby, for practical reasons, the ice grains or water inclusions are approximated by spheroids (cf. Denoth, 1982). The axial ratio of spheroidal snow grains determines the electromagnetic depolarization factors $g_i$ for the ice component (with $g_1=g_2=g$, $g_3=1-2g$) and the axial ratio of the spheroidal water inclusions determines the electromagnetic depolarization factors $g_w$ for the water component (with $g_1=g_2=g_w$, $g_3=1-2g_w$). A graphical representation of experimental results is given in the Figs 3 to 5. Fig.3 shows the effect of grain shape on the static dielectric constant of dry snow with different porosities $\Phi$. Data points are only shown for old, coarse grained snow with shape factors $g$ in the range $g=0.23-0.30$ (represented by solid circles) and for newly fallen snow which has not undergone significant metamorphic changes with shape factors in the range $g=0.03-0.1$ (represented by open circles). For comparison, calculations according to the 3-phase dielectric mixing-model of Polder and van Santen (1946) are shown as solid lines for $g=1/3$ (a), $g=0.2$ (b), $g=0.1$ (c) and $g=0$ (d). It results a strong dependence of the static permittivity on porosity $\Phi$ and grain shape $g$.

Fig. 3. Dependence of the static dielectric constant of dry snow on porosity $\Phi$ and grain shape. Solid circles represent old snow with well rounded grains, open symbols represent new snow. The solid lines represent theoretical calculations for different shape factors $g$, $g=1/3$ (a), $g=0.2$ (b), $g=0.1$ (c), and $g=0$ (d).
Fig. 4 shows the dependence of the shape factor of the liquid water inclusions, $g_w$, on water saturation $S$, represented by solid circles, and the dependence of the magnetic loss factor $\mu''$ (at 14 GHz, and normalized to 1 mm grain size) on water saturation $S$, represented by open circles. $S$ is the water content $W$ normalized to the snow pore volume, $S = W/\Phi$. Three main saturation regimes with different values of $g_w$ can be observed, and are marked in the figure by arrows: a pendular zone characterized by isolated water bodies, with $g_w < -0.5$, a transitional zone and a funicular zone characterized by merged, coalescing water bodies, with $g_w > 0.8$. Within the pendular zone, a sub-zone may be formed which is characterized by ring-shaped water bodies. This zone is marked by increasing magnetic losses $\mu''$ with saturation, $S$, due to ring-shaped, electrically conducting water structures. In addition, within the pendular zone a second sub-zone is formed at saturations $S$ less than a critical saturation $S_c \approx 3\%$. This sub zone is characterized by a strongly decreasing shape factor $g_w$, $g_w \to 0$. In this zone $0 < S < S_c$ surface tension and capillary forces may control the shape of the water inclusions.

Although there is a large scatter in the experimental data, $S_c$ clearly is affected by grain shape, it increases with decreasing shape factor, and shows an upper and a lower limit: $\sim 2.5\% < S_c < 8.5\%$. So, the irreducible saturation or the water storage capacity for snow which has not undergone significant metamorphic changes is in the range of $\sim 8.5\%$ and is much higher than the value of $\sim 2.5\%$ for old snow with well rounded grains.

Fig. 5 shows the effect of grain shape $g$ on the limiting water saturation $S_l$ (irreducible saturation) derived from long-term drainage and water percolation experiments. Data points are shown together with a polynomial data fit (solid line).

It is noticeable, that $S_c$, the irreducible water saturation derived from drainage experiments excellently compares to the critical saturation $S_c$ derived from electromagnetic measurements; and $S_c$ and $S_l$ may be identical.

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5. REFERENCES:

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