Microwave emission of snow in Alpine regions and the detection of surface hoar

Giovanni Macelloni, Simonetta Paloscia, Paolo Pampaloni, Roberto Ruisi, Marco Tedesco
CNR-IROE
Via Panciatichi 64, I-50127 Florence, Italy, Ph: +390554235205, Fax: +390554235290
Email: paloscia @iroe.fi.cnr.it

A. Cagnati M. Valt
Centro Sperimentale Valanghe e Difesa Idrogeologica, Arabba, Italy

ABSTRACT

Microwave radiometric measurements of snow packs were carried out in various test sites, to study different snow cover conditions, from dry snow at high and low density, to wet snow, and lastly, to a typical surface layer composed of big hoar crystals. It has been shown that dual-frequency (10 and 37 GHz), dual polarized microwave data appear efficient in separating wet from dry snow and in identifting the presence of surface hoar, which is is of significant interest for the research on avalanche forecast.

INTRODUCTION

The capability of passive microwave sensors to monitor seasonal variation of snow cover has been the subject of several experimental activities carried out with ground based and satellite systems [1-4]. Moreover, the dielectric characteristics of several snow types have been investigated by means of experiments and theoretical models and data are available at frequencies up to 90 GHz [5]. Measurements carried out between 3 GHz and 90 GHz have pointed out the sensitivity of microwave emission to snow type and water equivalent. At the lower frequencies of the microwave band emission from a layer of dry snow is mostly influenced by the soil conditions below the snow pack and by snow layering, while at the higher frequencies the role played by volume scattering increases and emissivity appears sensitive to snow water equivalent [1, 4]. If snow melts, the presence of liquid water in the surface layer determines an increase emissivity, especially at the higher frequency[5]. The average spectra of brightness temperature *Tb* obtained by Schanda et al.[6] show that *Tb* of dry and refrozen snow decreases with frequency whereas *Tb* of wet spring snow increases. In some cases the spectral behavior of wet snow shows a slight increase with frequency due to the increasing effect of surface roughness [6].

In this paper we discuss experimental results obtained in various test sites on Alpine regions with particular regard to the detection of surface hoar, which is of significant interest for the research on avalanche forecast. Indeed, if the hoar crystals are buried by a subsequent snowfall, they may form a sliding layer for a slab avalanche release. Surface hoar is typically formed by the deposition of water vapor on the snow surface during a clear night.

THE EXPERIMENT

Microwave radiometric measurements of snow packs were carried out on the Italian Alps and Apennines at various dates in 1996, 1997 and 1999, and on various test sites with different snow covers. Several snow types were investigated, including dry snow at high and low density, a typical spring situation with rounded particles and wet snow, showing at the surface high density and a very low consistence, and lastly, a typical surface layer composed of big surface hoar crystals. In each test site the composition of the snow pack was analysed according to conventional methods. Remote sensing data were simultaneously collected, by means of a ground based Radiometer set (IROE) operating at three different microwave frequencies (37, 10 and 6.8 GHz) and in the thermal infrared (8-14 μm) band, at incidence angles between 30 and 70 degrees. In situ contact measurements of snow wetness were carried out with an electromagnetic probe.

THE EXPERIMENTAL RESULTS

Dry/ wet snow discrimination

Fig. 1 shows spectra of the normalized temperature (i.e. the ratio between microwave and infrared brightness temperatures), of snow with different values of wetness. We can see that a dual-frequency microwave radiometer at X and Ka bands would be efficient in separating wet from dry now. However, for low wetness (< 2 %) the spectrum is very close to that of dry snow. In this case discrimination can be better accomplished using the 37GHz polarization index PI = (Tbv - Tbh) / (Tbv + Tbh), which is much higher for dry snow (Fig. 2).

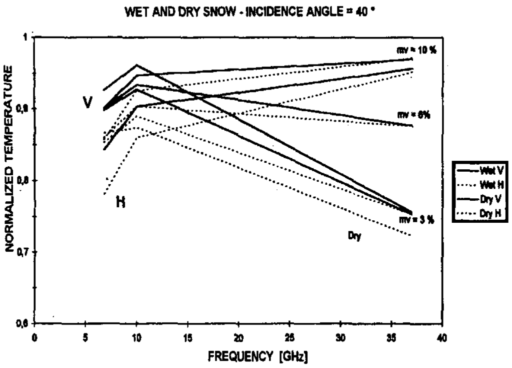

Fig. 1- Microwave spectra of snow with different wetness

The snow melting cycle

As expected, microwave emission showed a high sensitivity to daily melting cycle of snow. As an example Fig. 3 shows the brightness temperature at 37 GHz as a function of time compared with the temperature of snow and the snow wetness measured with the e.m. probe. We see that, in the morning, the generation of liquid water in the snow layer caused an increaseof the absorption in the upper layer of snow-pack and a consequent strong increase of the 37 GHz emission that reached a maximum at around 1:00 pm. L.T. when the snow wetness was about 3%. The increase was much smaller at lower frequencies where penetration is higher and volumetric effects are dominant. After 1:00 pm the snow wetness continued to increase up to 7% , whereas the brightness temperature remained almost constant. Indeed, when snow wetness exceeds 3%, the increase of the imaginary part of snow permittivity is much smaller and the albedo becomes practically constant.

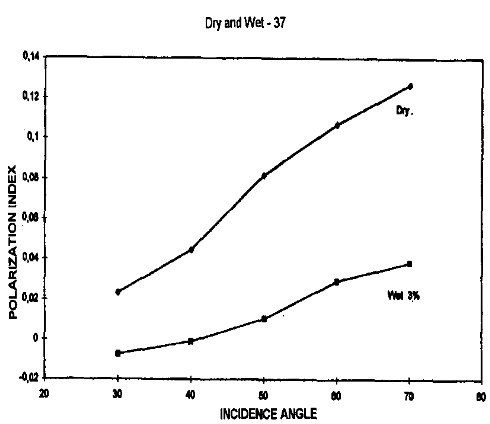

Fig. 2 - The polarization Index PI at 37 GHz as a function of incidence angle for dry snow (top) and snow with low wetness

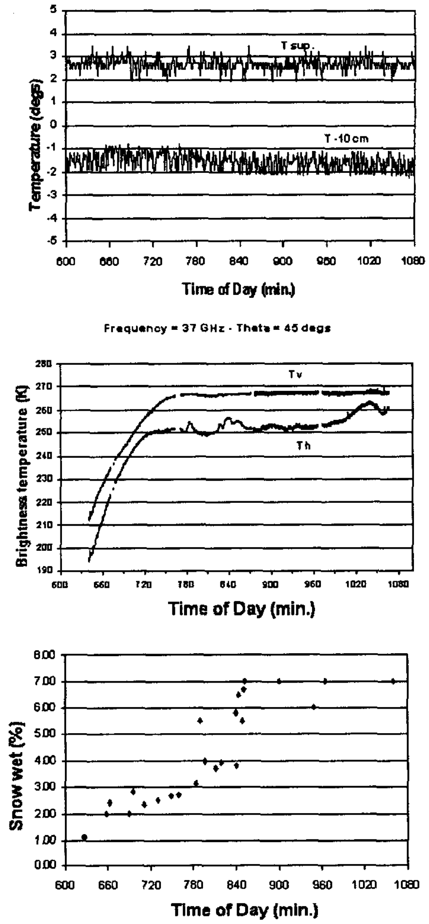

Fig.3 - The snow melting cycle observed at Corno alle Scale: a) the physical temperature of snow measured at the surface and 10 cm below the surface, b) the vertical and horizontal components of brightness temperature, c) the snow wetness measured 5 cm below the surface with the e.m. probe. Local time is in minutes.

The surface hoar

The effect of surface hoar was studied on a site (Falcade, Italy) whose surface layer was composed of big crystals of hoar. Microwave emission was first measured on the undisturbed natural snow cover and then after removing the first layer containing the hoar crystals. The spectrum of surface hoar was found well separated by that of wet snow but rather similar to

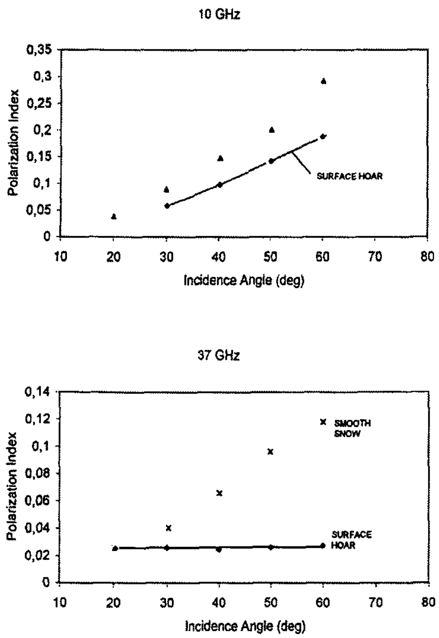

Fig.4 - The Polarization Index PI as a function of incidence angle on snow with surface hoar (continuous line) compared with PI measured on smooth dry (wetness < 2%) snow (a- 10 GHz, b- 37 GHz).

that of dry smooth snow, as we can see from Table I, which reproduces the differences between the brightness temperature at 10 and 37 GHz. However, the separation between surface hoar and dry snow is well pointed out by using the polarization index at 37 GHz (Fig. 4).

Table I - Brightness temperature difference $\Delta Tb = Tb(10GHz) - Tb(37GHz)$ measured at $\theta = 40°$

Snow type	ΔTb (Vpol)	ΔTb (HPol)
Surface Hoar	89.2 K	70 K
Dry snow (smooth)	77.5 K	60.7 K
Wet snow (10%)	-15.6 K	-26 K

On the basis of the previous considerations, surface hoar con be separated by smooth dry and wet snow according to the following Table II

Table II- Separability of snow types

Snow type	Tb(10) - Tb (37)	PI (50°)
Smooth dry	high	high
Wet	low (or < 0)	low
Hoar	high	low

CONCLUSIONS

Experimental data of microwave emission from snow pack in different conditions have been collected on the Italian Alps and Apennines. The measured brightness temperature has been compared with nivological measurements carried out with standard methods and by using an electromagnetic contact probe. The obtained results have shown the capability of a dual frequency microwave radiometer in separating snow cover type and have pointed out the sensitivity of the polarization index to surface hoar.

ACKNOWLEDGMENTS

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