Mass flux on the snow-soil interface

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INTRODUCTION

In the present time, when more and more global climatic models at last do not omit cold regions, study of physical processes occurring in snow slowly moves from almost purely engineering field in the direction to environmental science. Under such circumstances presently known data on heat and mass transfer in snow receives wider audience among geophysicists, which forces snow scientists to generalize known data and to find out what is missed and what has to be in near future. As examples of such generalization (Maeno and Kuroda 1986; Sturm, Holmgren et al. 1997) are addressed to the heat conduction in snow, and (Giddings and LaChapelle 1962; Colbeck 1993) represent understanding of the mass transfer process.

However if one will carefully analyze the numerous snow physics publications, surprisingly small amount of them will be addressed to the mass and heat fluxes on the upper and bottom interfaces of snow cover. Though these processes, often named in glaciology "snow-soil heat and mass exchange" and "evaporation/condensation balance of the snow surface" are probably the most important for geophysical models. The known works on snow–soil interaction are mostly related to water balance in the underlying grounds (Pavlov 1965; Gray, Granger et al. 1985). Study of evaporation/condensation often had the only aim to understand which part of snow cover had been lost or added as a result of these processes (Dyunin 1961; Bengtsson 1980; Kaser 1982).

Finally it can be said that for present time there is very weak link between data on snow metamorphism as a result of heat and mass transport inside snow, and data on fluxes around snow interfaces.

In attempt to change such situation seria of experiments, in which the present author took part, both on snow-soil heat and mass exchange and evaporation/condensation balance of the snow surface was done in Moscow State University[2]. Some of the obtained results were presented in (Golubev and Sokratov 1991; Golubev and Ermakov 1993; Golubev and Sokratov 1995; Golubev, Seliverstov et al. 1997), but most of data often formed new questions instead of answering those, which had been tried to be answered by setting the experimental work.

The purpose of this report is to share with other scientists some of the findings in snow-soil heat and mass transfer in a hope to find new ways to learn this process.

EXPERIMENTAL WORK

Two kinds of experiments were done on snow–soil mass transfer—isothermal and temperature gradient conditions were studied.

Several pairs of glass Petri dishes (one with snow and one with ice or frozen soil in each pair) were situated under isothermal conditions for prolonged period of time. Mass change of each dish was related to the water vapor flux (F) on the snow interface.

The experimental set–up for temperature gradient conditions was exactly the same, described in (Voitkovskii, Golubev et al. 1988). Pairs of plastic tubes (one with snow and one with frozen soil or ice in each pair) were situated in thermoinsulated box. One face of connected tubes was in contact with temperature–regulated can with kerosene, while the opposite face had temperature of the outside cold room. Temperature was measured on the snow–soil (or ice) interface and on the 5 mm distance from the interface in snow. It was so that snow was always cooler than ground or ice. The water vapor flux was calculated from the mass change of each tube,

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and the water vapor concentration gradient ($\partial C/\partial y$) could be obtained from the data on temperature (T) and temperature gradient ($\partial T/\partial y$) around the snow–ground interface.

Some results of both isothermal and temperature gradient measurements are shown in Table 1.

Table 1. Results of measurements.

Snow (grain size)	Ground/Ice content, %	T, °C	$\partial T/\partial y$, °C m^{-1}	F, $\times 10^{-8}$ kg m^{-2} s^{-1}	$\partial C/\partial y$, $\times 10^{-4}$ kg m^{-4}
Small	Ice	-13	0	-0.516	3.92
Large	Ice	-13	0	-1.031	7.83
Small	Sand/34	-13	0	-1.078	8.18
Large	Sand/34	-13	0	-2.587	19.6
Small	Sand/100	-13	0	-0.522	3.98
Large	Sand/100	-13	0	-1.020	7.70
Middle	Sand/9	-4	0	-1.199	8.65
Middle	Kaolin/15	-4	0	-1.279	9.23
Small	Ice	-5.7	-44	10.2	-50.7
Large	Ice	-7.9	-54	21.3	-107
Small	Sand/21	-5.0	-86	39.3	-195
Large	Sand/21	-7.0	-91	28.1	-141
Small	Loam/35	-8.3	-24	18.7	-94.3
Large	Loam/35	-5.3	-47	32.8	-163

One of the problems in study of not only snow–soil or snow–atmosphere mass transfer but also simultaneous heat and mass transfer in snow is impossibility of direct measurements of water vapor concentration (C) in porous space. It is accepted that the water vapor concentration in porous space of snow is close to saturation (C_s), however evidence of evaporation and condensation forces to conclude that water vapor is not always exactly saturated.

Specific experiments were done to measure water vapor concentration inside ground and inside snow. The set–up was very simple—a hair hygrograph was situated inside massive snow (or ground) sample (1×1×1 m) and humidity was measured in a "macropore" around measuring head. The hygrograph was drawing change of water vapor pressure in the "macropore" while temperature was changed around the sample. The obtained graphs could be recalculated to the actual water vapor pressure or concentration for each present temperature, as temperature of hygrograph calibration was known. The results are shown on Figures 1 and 2.

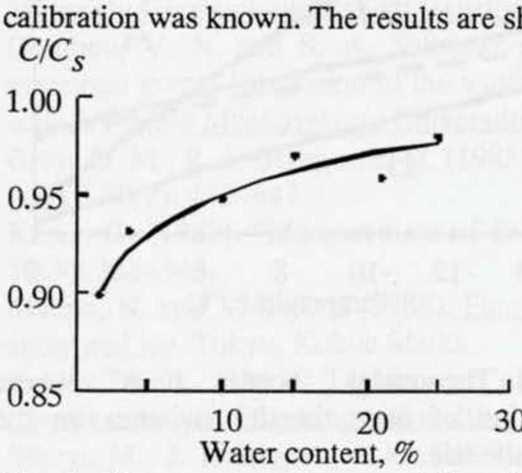

Fig. 1. Measurements in ground (loam), rate of non-saturation.

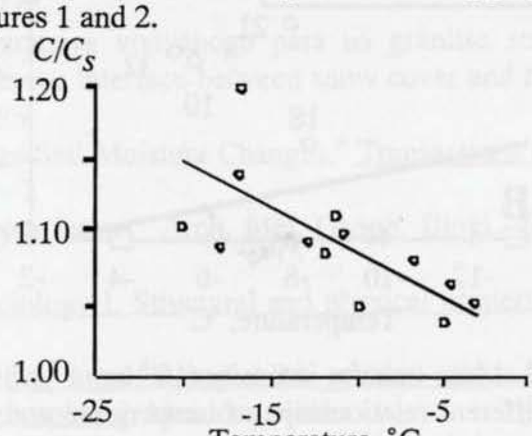

Fig. 2. Measurements in snow, rate of supersaturation.

Water vapor concentration in snow was also calculated from the measured snow samples mass decrease as a result of snow evaporation. The data was very close to results of the "macropore" measurements and also in good agreement with the water vapor content determination by absorption of infrared emission over snow surface.

DATA ANALYSIS

It can be seen in Table 1 that water vapor was always transferred from snow to ground under isothermal conditions. The process was more active in case of more porous space in ground, but even with 100% ice content or in case of pure ice the water vapor concentration in porous space had to be higher than concentration near the ice surface. This is in agreement with results of measurements, showing that the water vapor concentration in snow can be considered as supersaturated, and supersaturation increases with temperature decrease in the range of present measurements. The reason for such supersaturation can be curvature of snow crystals coupled with process of recrystallization. Snow metamorphism has to form micro fluxes of water vapor from smaller grains to larger grains even in isothermal conditions, and probably these fluxes influenced the conditions in macropores.

Figure 3 shows the content of the Table 1 in terms of temperature/temperature gradient relationships. Isothermal data is on the temperature axis, because temperature gradient was equal to 0. There are very few data yet to make any serious recalculations of temperature gradient into water vapor concentration gradient as a driving force of mass transfer. However it can be noted that the calculated on base of Figures 1 and 2 water vapor concentration gradients were close to those, calculated on base of measured water vapor flux (Table 1).

As the directions of water vapor flux under isothermal and temperature gradient conditions were different, there must be some "border line" (thick solid line on Figure 3) dividing the temperature/temperature gradient field on two parts with different sign of water vapor transfer. Such "border lines" for different soils were calculated on base of Figures 1 and 2 and shown on Figure 4. Of course these borders are the result of simplification, but in presence of more data it can be possible to make relationships more accurate and even use them for natural conditions. The calculations show that direction of mass transfer can be switched snow-to-ground (isothermal conditions) to ground-to-snow only with temperature gradient higher than some, specific for each temperature value.

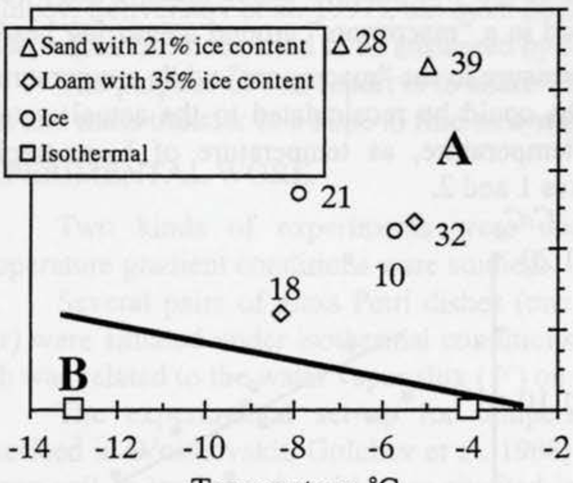

Fig. 3. Mass transfer intensity (10^{-8} kg m^{-2} s^{-1}) for different relationships of temperature and temperature gradient.

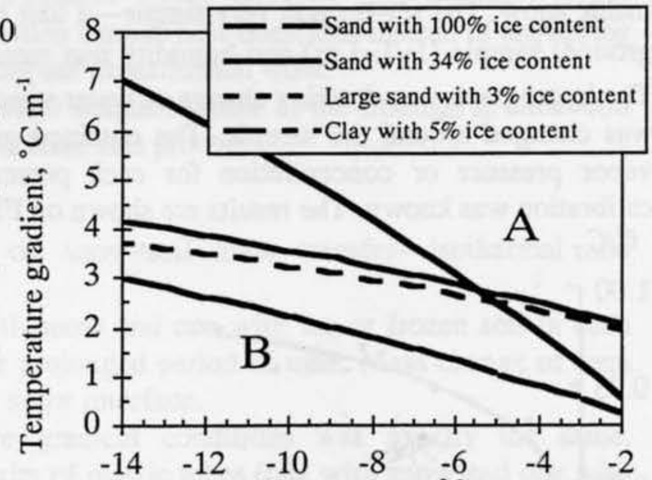

Fig. 4. Theoretical "border lines" where direction of mass transfer switches on the opposite one.

CONCLUSIONS

The water vapor transfer on the snow–soil interface can change its value and direction when temperature or temperature gradient is changed.

The value of the mass flux depends on ground ice content and ground dispersity. When all the pores are filled with ice—the mass flux value is regulated by snow grains morphology.

It is measured in natural conditions that the soil ice content change by water vapor migration on the soil–snow interface is relatively small, and that is why it can not be considered as a main mechanism of soil water content regulation. However direction on the transfer has to have important meaning for soil–atmosphere heat and mass balance modeling as represent the sign of heat exchange process. The mass transfer can be also important for snow recrystallization and depth hoar formation near the ground surface.

It is important to note that under small temperature gradients in snow near soil (usually observed in natural conditions) the direction of the heat transfer can be opposite to the direction of the mass transfer.

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