Influence of water content on velocity of snowmelt due to pyroclastic material

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INTRODUCTION

Mudflows can be caused by snow melting due to the deposition of hot air-fall pyroclastic material, and have the potential to cause terrible disasters. When possible mudflows forecast, we should be able to predict quickly and precisely where and how the damage will occur and when the mudflow will reach residential areas. Recently, Tsutsumi et al. (2011) and Miyata et al. (2012) conducted experiments and proposed equations for predicting the hydrograph as a boundary condition when attempting to simulate potential mudflow. These equations were based on the assumption that the velocity of snowmelt may be expected to be less than that of infiltration, but this is not always the case. In this study, therefore, we investigated the threshold temperature of pyroclastic material at which the velocity of snowmelt could exceed that of infiltration. We focused on snow density and water content because these factors are important. Next, we conducted field observations to determine when the influence of water content should be considered in Japan.

THEORETICAL ANALYSIS

Using the equation for the velocity of snowmelt proposed by Miyata et al. (2012) and Darcy's law, we can calculate the threshold temperature T at which the velocity of snow melt exceeds that of infiltration. When the pyroclastic material and snow make contact, the following equation holds:

$$T_* = Tk_s / \left(E\left(1-r_{sl}\right)+Gr_{sl}\right)\rho_{sn}k\left(-\psi_{sn}\right) > 1,$$

in which, T_* is nondimensional temperature, k is the unsaturated permeability coefficient, ψ_{sn} is the pressure head of water in snow, k_s is the heat conductivity, E is the melting heat of snow (333.5 kJ/kg), G is the sublimation heat of snow (3,008.9 kJ/kg), r_{sl} is the rate of heat loss of snow, and ρ_{sn} is the density of snow. We expressed k and using the equation proposed by Sugie and Naruse (2000). Assuming k_s = 3.3 W / m / K, r_{sl} = 0.39 and the snow is new and dry (ρ_{sn} = 30 kg / m³, S = 0.071), then T is 115 °C. Conversely, if the dry density and saturation ratio increase slightly (ρ_{sn} = 100 kg / m³, S = 0.1), then T becomes 420 °C. Hence, we can see that the dry density of the snow and the water content are important factors. If the water content in the snow is low, a large amount of runoff will abruptly occur. In contrast, if the water content is high, the duration time of runoff will increase, and the prediction model for obtaining the hydrograph becomes that proposed by Miyata et al. (2012).

FIELD OBSERVATIONS

The theoretical results suggested that it is important to know the time-series variation of the water content in the snow. Therefore, we conducted field observations. The observation site was located in Takayama, Japan (36°15' 28.24" N, 137°34' 26.55" E). Takayama is near an active volcano, Mt. Yake (Figure 1). First, we dug into the deposited snow using a shovel and made a vertical wall section. Second, we inserted a thermocouple and time domain reflectometry (TDR) probe (CS616 equipped by Campbell Scientific, Inc.) at 5, 30, 55 and 75 cm above the ground. We calculated the volumetric water content in the snow using the equation proposed by Tiuri et al. (1984). Figure 2 shows the time series variation of the saturation ratio. During the observation period, the saturation ratio was relatively low at each depth. However, the saturation ratio at 5 cm above the ground increased gradually, although the value was still smaller than the residual saturation ratio of 0.07 (Colbeck, 1974). We estimated that if a volcanic eruption occurred during this period in this area, a large amount of runoff would abruptly occur.

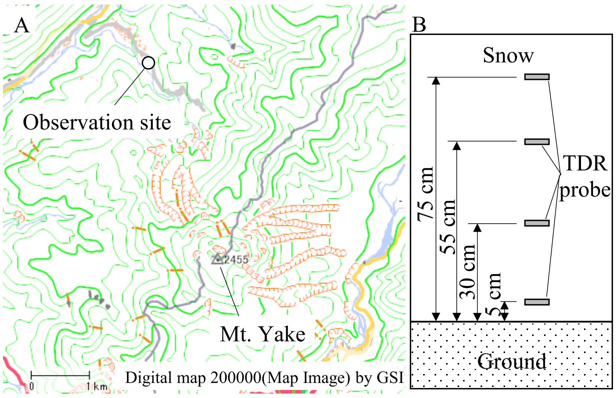

Figure 1. (A) Location of observation site and (B) schematic observation setup

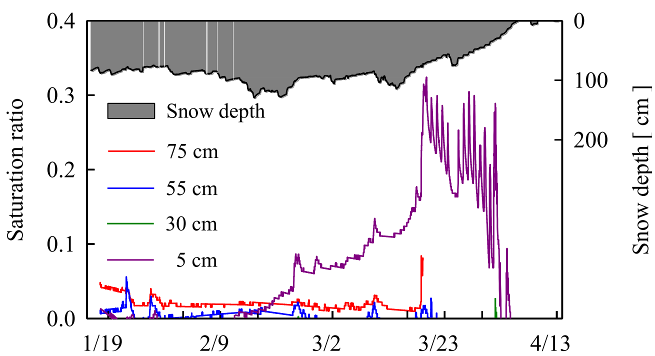

Figure 2. Time-series variation of saturation ratio in the snow and snow depth at the observation site

CONCLUSIONS

In this study, we investigated the threshold temperature at which the velocity of snowmelt becomes greater than that of infiltration. Although we discussed a limited condition, our findings suggest that at least two distinct models should be prepared to predict the hydrograph. We also observed the volumetric water content in deposited snow. In future research we will continue to assess the validity of our findings by comparing modeled and experimental results, and we will continue our field observations.

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KEYWORDS

mudflow; snowmelt; heat conduction; water content; snow density

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