Effect of snow impurities on the radiation budget and snow melting observed at Sapporo during 10 winter seasons

*Yoichiro Hirozawa[1], Teruo Aoki[1,2], Masashi Niwano[2], Sumito Matoba[3], Yuji Kodama[4], Tomonori Tanikawa[2]

1. Okayama University, Graduate School of Natural Science and Technology, 2. Meteorological Research Institute, 3. Institute of Low Temperature Science, Hokkaido University, 4. National Institute of Polar Research

Snow impurities originated from light-absorbing aerosols in the atmosphere have an effect to accelerate the cryospheric warming by reducing the albedo. According to IPCC AR5, black carbon (BC) on snow and ice was assessed to have a global and annual mean radiative forcing (RF) of +0.04 Wm^{-2}. However, the larger effect on the radiation budget and snow melting could be expected in urban area where the snow impurity concentrations are high. In this study, we investigated the effect of snow impurity (BC and mineral dust) concentration on albedo and snow melting from snow and meteorological data observed at Sapporo using physical based snow albedo model (PBSAM) (Aoki et al., 2011). The observation site is the meteorological observation field (43° 04' 56"N, 141° 20' 30"E, 15 m a.s.l) of the Institute of Low Temperature Science of Hokkaido University and the observation period analyzed is 10 winter seasons from 2007 to 2017. The observed broadband albedos were compared with the theoretical values calculated with the PBSAM to which the observed data of snow grain size, impurity concentrations, and downward radiation were input. In addition, we conducted numerical sensitivity experiments on the albedo change due to snow impurities and calculated their RFs. We also estimated a contribution of snow impurities to snow melting from the energy balance analysis.
Comparing the time series of the observed broadband albedos with the theoretically calculated values, the calculated albedo variations due to the change in snow grain size and impurity concentration agreed well with the observations in each year of the analysis period. The determination coefficient (R^2) and the root mean square error (RMSE) for the whole period obtained from the albedo comparison in the shortwave (SW) spectral region were 0.847 and 0.046, respectively, confirming the high accuracy of PBSAM. Next, sensitivity experiments were conducted on the albedo changes in the visible (VIS), near-infrared (NIR), and SW regions depending on the presence and absence of snow impurities. The albedo change and RF due to snow impurities (BC + mineral dust) in the whole period were -0.053 and +6.7 Wm^{-2}, respectively for the SW region. In addition, we estimated total snowmelt amount from the surface energy balance calculation and measured energy flux between the bottom of the snowpack and the underlying ground. The total estimated amount of snow melt for the whole period was 398 mm w. e..The contributions from surface melting and melting at the ground were 76% and 24%, respectively. The melting energy due to snow impurity-induced albedo reduction is equivalent to 28% of total amount of snow melting, which is larger than the melting at the ground and is not negligible. Furthermore, the contributions from BC and dust to this value are 21% and 7%, respectively.

References

Aoki, T., K. Kuchiki, M. Niwano, Y. Kodama, M. Hosaka and T. Tanaka (2011), Physically based snow albedo model for calculating broadband albedos and the solar heating profile in snowpack for general circulation models. *J. Geophys. Res.*, **116**, D11114, doi:10.1029/2010JD015507.

