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Possible albedo reduction due to light absorbing impurities in snowpack observed at various sites

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Possible albedo reduction due to light absorbing impurities (LAI) in snowpack observed at various sites in the world are investigated. Reviewing previously measured black carbon (BC) concentrations, their values distribute in a range of 0.07-0.25 ppbw (ng of BC in g of snow) in Antarctica, 0.55-20 ppbw in Greenland Ice Sheet (GrIS), 4.4-87.6 ppbw for the other Arctic except GrIS, and 4-1221 ppbw for mid-latitudes. As albedo reduction rate by LAI depends on snow grain size, it is more enhanced by larger grain snow such as melt form (melting snow) than smaller grain snow such as precipitation particles (new snow). By assuming two typical snow grain radii r_s = 1000 and 50 μm, respectively for those snow grain shapes, the albedo reduction as a function of BC concentration can be calculated with physically based snow albedo model. The result indicates that albedo in Antarctic snow is not affected by BC in any case of snow grain radius. In GrIS albedo reduction due to BC is small around 0.006 for r_s = 50 μm (new snow) but it rises to 0.026 for r_s = 1000 μm (melting snow), suggesting a few percent of albedo reduction could occur under warmer climate condition due to enhanced snow metamorphism. In the other Arctic except GrIS, the maximum albedo reductions for r_s = 50 μm (1000 μm) are 0.015 (0.064) at the maximum BC concentration (87.6 ppbw). For. mid-latitudes, it is 0.070 (0.24) for r_s = 50 μm (1000 μm) at the maximum BC concentration (1221 ppbw). These results mean albedo reduction in highly polluted area of mid-latitudes cannot be ignored even in case of new snow and is more serious for melting snow.

We have conducted energy budget and snow pit observations at Sapporo (43°N, 141°E, 15 m a.s.l), Japan since 2005. In addition, elemental carbon (EC~BC) and mineral dust concentrations in snowpack were also monitored for snow samples collected twice a week from 2007 by the thermal optical reflectance (TOT) method and gravimetric measurement of a filter. During 10 years from 2007 to 2017, the medians of EC and dust concentrations are 196 ppbw and 2700 ppbw, respectively. Using those data, contribution of LAI to albedo reduction and the radiative forcing (RF) were estimated. The 10-year-mean albedo reduction and RF due to BC+dust are 0.053 and

+6.7 Wm^{-2}, respectively, in which BC effect on albedo reduction is 5.6 times larger than dust. The albedo reduction by BC+dust for only melting period is 0.151, that is 4.8 times larger than that for accumulation period. The effect of LAI on albedo reduction is enhanced by snow grain growth as well as an increase of LAI in melting period compared to that for accumulation season.