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Impacts of light-absorbing impurities on snow and their quantification using bidirectional reflectance measurements

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In order to quantify the effects of absorbing material on snow and define its contribution to climate change, we have conducted a series of dedicated bidirectional reflectance measurements. Chimney soot, volcanic sand, and glaciogenic silt were deposited on snow in a controlled way [1, 2]. The bidirectional reflectance factors of these targets and untouched snow have been measured using the Finnish Geodetic Institute's field goniospectrometer FIGIFIGO, see, e.g., [3, 4] and references therein. It has been found that the contaminants darken the snow, and modify its appearance mostly as expected, with a clear directional signal and a modest spectral signal. A remarkable feature is the fact that any absorbing contaminant on snow enhances the metamorphosis under strong sunlight. Immediately after deposition, the contaminated snow surface appears darker than the pure snow in all viewing directions, but the heated soot particles sink down into the snow within minutes. The nadir measurement remains darkest, but at larger zenith angles the surface of the soot-contaminated snow changes back to almost as white as clean snow. Thus, for an observer on the ground, the darkening by impurities can be completely invisible, overestimating the albedo, but a nadir looking satellite sees the darkest points, now underestimating the albedo.
After more time, also the nadir view brightens, and the remaining impurities may be biased towards more shadowed locations or less absorbing orientations by natural selection. This suggests that at noon the albedo should be lower than in the morning or afternoon. When sunlight stimulates more sinking than melting, albedo should be higher in the afternoon than in the morning, and vice versa when melting is dominating. Thus to estimate the effect on climate change caused by black carbon (BC) deposited on snow, one may need to take into account possible rapid diffusion of the BC inside the snow from its surface. When the snow melt rate gets faster than the diffusion rate (under condition of warm outside temperatures), as was observed at the end of the experiment reported here, dark material starts accumulating into the surface. The BC deposited on snow at warm temperatures initiates rapid melting and may cause dramatic changes on the snow surface.

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