SOLAR HEATING AND MELTING OF SNOWPACKS AND ICE SHEETS IN POLAR REGIONS

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Polar regions of our planet are undergoing rapid changes, including the decrease of ice/snow extent with corresponding impacts on polar environments (Barry and Hall-McKim 2018). The behavior of massive ice and snowpack under regular summer heating by solar radiation is one of the problems which are not well understood because of interaction of a variety of physical processes.

There are many research papers concerning the spectral properties of pure and polluted snow and also light-scattering ice sheets containing gas bubbles and some particulate inclusions. However, only few publications are focused on modeling the combined radiative and conductive heat transfer in a snowpack or ice sheet. One should recall the interesting findings of the early study by Brandt and Warren (1993) on a relatively deep penetration of shortwave solar radiation in a snowpack and night radiative cooling by emission of thermal infrared radiation to space occurring at the very top surface of the snow. The term “solid-state greenhouse” was suggested for the first of these interesting phenomena. Deep penetration of heat into the snowpack was discussed also by Liston and Winther (2005). In particular, they reported that about seven times more meltwater is produced subsurface compared to the surface for snow-covered areas in near coastal Antarctica.

It was the main objective of recent papers by Dombrovsky et al. (2019) and Dombrovsky and Kokhanovsky (2019, 2020a,b,c) to present an approximate but complete and reliable computational model for both the transfer of solar radiation and the related transient heat transfer in a snowpack and also in a light-scattering ice sheet. The physical models, analytical solutions, and computational procedures developed in these papers are quite general and can be employed in solving a wide range of problems associated with solar heating of snow or ice. The main results reported in these journal papers are discussed in subsequent articles of *Thermopedia* on solar heating of snow and ice in polar regions.

It should be noted that solar radiation not only heats snow or ice, but is also responsible for other important physical processes. In other words, not only the power of the absorbed radiation is important, but also the spectral composition of the radiation, which penetrates to some depth in snow or ice. In particular, the life cycle of microalgae, as well as the formation of gas bubbles in a surface layer of snowpack or ice sheet, are naturally associated with the spectrum of penetrating solar radiation (Hill et al. 2018). Moreover, generally speaking, there is a physical feedback between the spectral composition of the absorbed radiation and the formation of one or another morphology of snow or light-scattering ice (Williamson et al. 2020). One should not forget also about the ultraviolet (UV) solar radiation which is partially reflected by snow. The UV radiation may lead to a dangerous decease such as a malignant melanoma (Elwood and Jopson 1997, Reichard 2020, Amaro-Ortiz 2014). The eye is also sensitive to damage by the UV which may result in cataract (Balasubramanian 2000, Ayala et al. 2000). The foregoing means that the spectral radiative transfer is the main problem which should be solved first of all. After this, one can focus, for example, on the transient heat transfer problem or, for example, on the study of photosynthesis or, say, the process of formation and growth of gas bubbles in ice layer.

The approach chosen to solve the radiative transfer equation (RTE) is based on two assumptions. First of all, it is assumed that the so-called transport approximation can be used for the single-scattering phase function (Dombrovsky and Baillis 2010, Dombrovsky 2012). The transport approximation is sufficiently accurate in the case of multiple scattering which is typical for the radiative transfer in snow and scattering ice.

Note that in more complex problems concerning the angular dependence of radiation intensity, the two-step model is used to solve the RTE. At the first step of this solution, the two-flux method (in the case of a non-refracting host medium) or the modified two-flux approximation (in the case of a refractive host medium) suggested by Dombrovsky et al. (2006) is employed to determine the right-hand side of transport RTE. After that, the RTE is solved using the ray-tracing procedure. This combined method is usually sufficiently accurate. It was successfully used to solve diverse radiative transfer problems (Dombrovsky 2019). Fortunately, there is no need in the second step of the combined solution to calculate solar heating and melting of snowpacks and ice sheets.

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