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A Brief Review of the Thermal Properties and Radation Characteristics of Snow

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Abstract: After considering heat transfer processes in snow and applications of heat conduction theory, the paper gives data on effective thermal conductivity (as a function of density), heat flux due to vapor diffusion and forced interstitial convection, apparent specific heat, latent heat (of fusion and sublimation), extinction coefficient (as a function of wavelength and snow density), spectral reflectance, and long wave emissivity.

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For studies of energy balance and metamorphism on snowfields, as well as for engineering purposes, it is necessary to know the material properties controlling heat transfer processes.

In dry snow, with no forced convection, heat transfer can be analyzed by standard heat conduction theory, utilizing a wide range of available solutions to the basic differential equation. Solutions for cyclic temperature changes at the surface of deep snow yield convenient expressions relating conductivity (diffusivity), wave attenuation, phase shift, depth, and temperature penetration rate. Absorption of solar radiation adds a source term to the conduction equation, the solution giving insight into near-surface metamorphism. Absorption of nuclear radiation can be dealt with by making the source strength a suitable function of distance. Temperature changes in snow subject to seasonal melting are less amenable to analysis.

Thermal conductivity k, presumably including the effect of vapor diffusion, has been reported for limited ranges as a function of density γ, an index which describes the snow incompletely. Ranges of values are: $\gamma = 0.1$ g cm^{-3}, k = 1.0—2.5 x 10^{-4} cal cm^{-1} sec^{-1}C^{-1}; $\gamma = 0.3$, k = 3.5—7.5 x 10^{-4}; $\gamma = 0.5$, k = 1.20—2.15 x 10^{-3}.

The diffusion coefficient for vapor diffusion in snow is 0.7—1.0 cm^{2}sec^{-1}, and is apparently independent of snow density. The heat flux due to vapor diffusion is of the order of $10^{-4} \frac{d\theta}{dz}$ cal cm^{-2}sec^{-1}. With forced convection through snow, an equivalent conductivity k_v can be expressed as a function of air flow rate. With zero forced flow (natural vapor diffusion), k_v represents 7.5 % of the "effective thermal conductivity" k_e for medium-density snow. With air flow of 10^{-3} g cm^{-2}sec^{-1}, k_v represents 19 % of k_e.

Apparent specific heat C_a decreases as temperature decreases, and when measured at temperatures close to the melting point increases with impurity concentration, since latent heat effects are involved. The commonly adopted value of 0.5 cal g^{-1}C^{-1} is too high where temperatures are below —10 C; closer approximations are 0.49 at —10 C, 0.47 at —20 C, 0.45 at —30 C, and 0.43 at —40 C.

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For most practical purposes latent heat of fusion can be takens as 79.7 cal g^{-1}. Latent heat of sublimation can probably be taken as the sum of the latent heat of fusion and the latent heat of vaporization from water at 0 ° C (677 cal g^{-1}).

No values for coefficients of thermal expansion are available, but they may be expected to be always less than the solid ice value ($5 \times 10^{-5} C^{-1}$), and to vary with snow density and grain structure.

The spectral extinction coefficient for homogeneous snow increases with wavelength in the visible spectrum, and the absorption coefficient rises sharply with wavelength in the near infrared. Extinction coefficient z decreases with increasing snow density; at $\gamma = 0.3$ g cm^{-3}, $z \sim 0.25$ cm^{-1}, while at $\gamma = 0.65$, $z \sim 0.1$. For high density snow, absorption coefficient is about 10^{-3} cm^{-1} in the SHF microwave band and about 10^{-4} in the MF/HF band.

Reflectance depends on surface characteristics and on sub-surface scattering and absorption. Reflectance varies appreciably with snow depth for thin snow covers. When deep snow is illuminated by diffuse light, spectral reflectance seems to decrease with increasing wavelength, as required by existing theory. In non-integrated direct sunlight the converse seems to hold for some incidence angles. No correlation of reflectance with density has been found; the density-dependence of extinction coefficient may be countered by the optical influence of grain size, since grain size generally incrases with density.

The emissivity of snow has long been regarded as being close to unity, although more recent experiments have given lower values in the range 0.82 — 0.95. Low values are apparently associated with fine grain size. Emittance has also been found to increase with temperature in the range —5 to 0 ° C.

Schneefegen im Massenhaushalte der Antarktis

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Messungen des Massenzuwachses und -abtrages in der Antarktis machen es normalerweise unnötig, den Beitrag des Schneefegens separat zu bestimmen. Der vom Winde transportierte Schnee spielt jedoch eine wesentliche indirekte Rolle, die große lokale Unterschiede in Zuwachs und Abtrag durch die Topographie erklärt. Nur so lassen sich Schwankungen der Ordnung von 50 Prozent an Punkten nicht mehr als 2 oder 3 km voneinander auf der scheinbar glatten, aber leicht gewellten Oberfläche des Inlandeises verstehen (Black und Budd 1964) [1] [2]

Um solche Unterschiede zu begründen, ist eine genaue Kenntnis der physikalischen Vorgänge im Schneefegen erforderlich. Erhebliche Fortschritte in dieser Richtung kommen von einer Schneefegeuntersuchung an der amerikanischen Byrdstation (80 ° S; 120 ° W) während des Jahres 1962. Diese Untersuchung wurde mit der Unterstützung des U.S. Weather Bureaus von dem meteorologischen Institut der Universität Melbourne (Australien) ausgeführt; die eigentlichen Messungen lagen in den Händen von R. Dingle. Bei 129 Gelegenheiten wurden gleichzeitige Schneeproben auf 8 Höhen gesammelt, die eine geometrische Reihe zwischen 3 cm und 400 cm bildeten. Auf der Mehrzahl dieser Höhen wurden gleichzeitig die Windgeschwindigkeiten gemessen. Andere Windmessungen ergaben die Einzelheiten des Windprofiles in den untersten tausend Metern über dem Inlandeise. Für diesen Zweck wurden die Positionen von Radiosondeballonen alle 6 Sekunden mit dem Radiotheodoliten vermessen. Außerdem wurden 12 Spezialraketen abgeschossen, deren Rauchfahnen von zwei Punkten aus in regelmäßigen Abständen fotografiert wurden.

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