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Radio-wave reflectivity from cold glaciers

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Radio echo-sounding is a powerful technique for investigating the subsurface of the glaciers. However, physics underlying the formation of the reflected signal is sometimes oversimplified in the geophysical glacier studies, leading to wrong results. Various remote sensing techniques use different wavelengths (e.g., 13.575 GHz for CryoSat and 20-25/200-600 MHz for ground-penetrating radar), but it is still not clear which particular wavelengths are the best to detect different characteristics of the ice. Possibly, the results gained using different wavelengths may not coincide but rather complement each other due to frequency dependence of the dielectric permittivity and conductivity of snow, ice and especially water.

Here we attempt to construct an electrophysical model of a cold glacier. This mathematical model considers the variability of the depth profile of the complex dielectric permittivity depending on the frequency of the probing radio signal and the surface temperature. A series of calculations of the reflection coefficients of radio waves from the modelled glacier show that at low temperatures for frequencies above 1 MHz the real part of the dielectric constant of the glacier does not change with frequency and surface temperature, but depends on the glacier structure, while the depth profile of the loss tangent is constant throughout the glacier. As wavelength decreases, the absorption of radio-waves by the glacier decreases and the frequency dependence of the reflection coefficient becomes a periodic function, its period and amplitude depend on the glacier thickness, the dielectric constant of the bedrock and ice on the surface.

The range of radio-waves from 0.1 to 1 MHz is not optimal for sounding cold glaciers: the absorption of radio-waves by ice is large for studying thick layers of the glacier, and the wavelength does not allow studying thin layers. Hence, reflection from the glacier surface prevails upon reflection of the signal. The small absorption of short radio waves by ice leads to the fact that the frequency dependence of the reflection coefficient of short radio-waves is practically the sum of the partial reflections of radio-waves from the surface and internal snow/firn and firn/ice boundaries. Period and amplitude of oscillations of the function depend on the depth of the internal boundaries and the gradient of dielectric characteristics of ice, snow, firn and bedrock.

Changes in surface temperature, leading to a change in the loss tangent of the upper glacier layers, are manifested in the phase magnitude of the reflection coefficient of radio-waves:it grows with the temperature. Theoretically, the high-frequency signal reflected from the glacier contains information about the structure of the cold glacier and the depth distribution of the dielectric constant, but to restore the electrophysical parameters of the glaciers, it is necessary to use a broadband signal with smooth spectrum and high digitization speed.

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