Microwave Interaction with Snowpack Observed at the Cold Land Processes Field Experiment

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EXTENDED ABSTRACT

The NASA Cold Land Processes Field Experiment (CLPX) was designed to advance our understanding of the terrestrial cryosphere (www.nohrsc.nws.gov/~cline/clp.html). One objective of the CLPX is to evaluate and improve radar retrieval algorithms for snow depth, density, and wetness. During February and March 2002 and in support of the CLPX, we measured the microwave interaction with snow pack at Fraser Experimental Forest, Colorado. We used broadband frequency modulated continuous wave (FMCW) radars to locate and measure the electromagnetic discontinuities in a snow pack. These discontinuities obstruct the passive microwave energy emitted by the ground, thus reducing the brightness temperature of a snow pack. Active microwave signals are also reflected and scattered by these discontinuities, which affect radar backscatter signatures. The location and magnitude of these discontinuities in a snow pack as a function of microwave frequency must be identified in order to accurately invert snow cover properties from active and passive microwave remote sensing systems.

Microwave FMCW radars operating at 2–6, 8–12, and 14–18 GHz bandwidths measured the electromagnetic discontinuities in a snow pack for the CLPX. The measurements were made with the radars mounted at the end of a 2-m long boom. The boom was attached to a motorized tripod and the radar scanned a 5-m section of an undisturbed snow pack. At the start of each radar scan, a calibrated target was placed at the snow surface. This reference determined the reflectivity of the discontinuities in the snow pack. In conjunction with the radar measurements, we obtained detailed snow pit measurements at a nearby site in order to correlate the radar profile with the snow pit records. The FCMW radar setup at CLPX is illustrated in Figure 1. Representative radar profiles obtained in a dry and a wet snow pack are presented in Figures 2 and 3.

Figure 1. Ground-based FMCW radar.

Microwave radar interaction with a dry snow pack is illustrated in Figure 2. The snow depth recorded at a nearby snow pit was 78 cm. The

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three contour plots represent the magnitude and the locations of the electromagnetic discontinuities in the snow pack recorded at three radar bandwidths. The vertical axis of the radar profile represents the travel time (the snow and ground reflections correspond to travel times of 0 and 2.5 ns, respectively), and the horizontal axis represents the radar position along a 5 m path. The shading represents the relative magnitude of the radar reflection. The average reflectivity (dB) measured at the various discontinuities is shown next to the travel time.

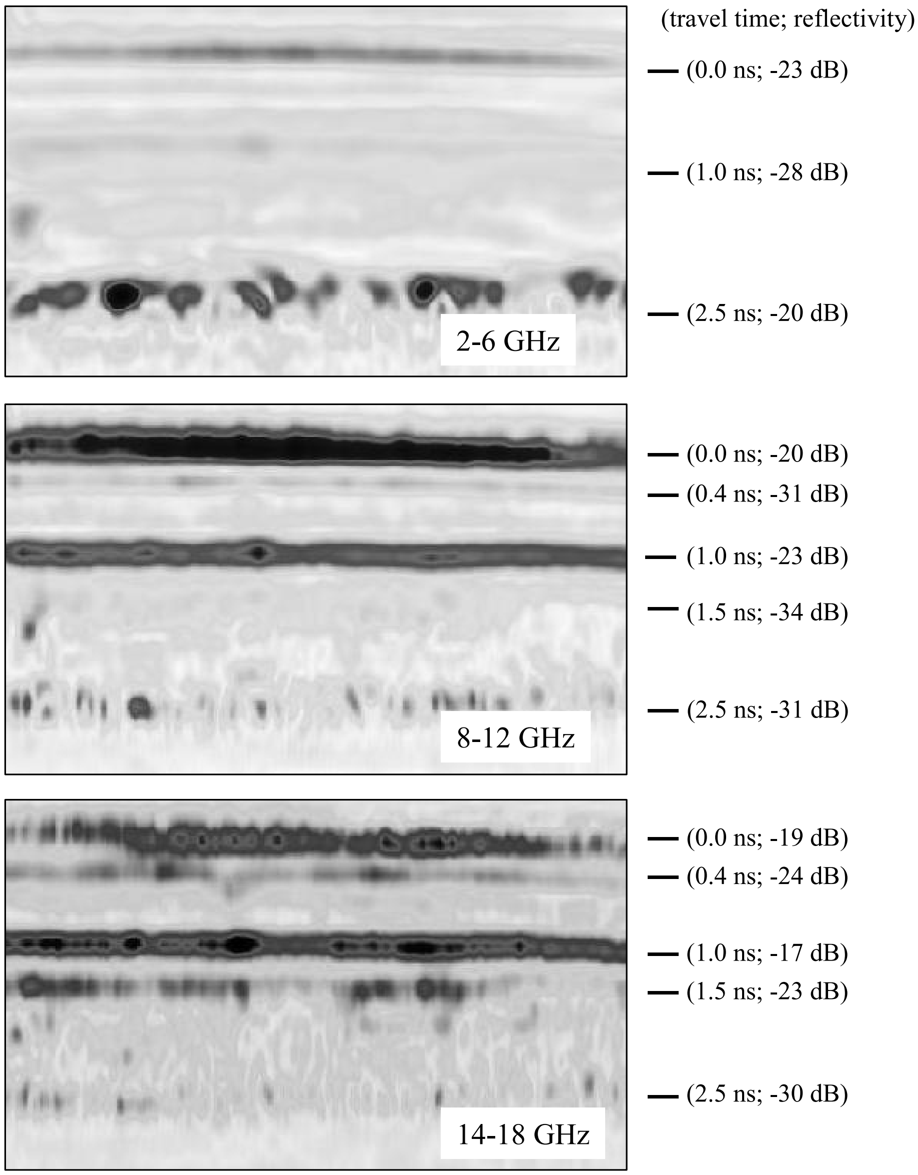

Figure 2. Multiband radar profile of a dry snowpack.

The 2–6 GHz radar profile shows that the internal properties of snow pack have a minimal affect on the low frequency radar. The radar return was characterized by a moderate reflection from snow surface (0 ns; –23 dB) and a much stronger return from the snow/ground interface (2.5 ns; –20 dB). A very weak return from an internal snow layer was observed (1.0 ns; –28 dB). However, as the radar frequency increased, the influence of snow layers becomes more evident. For example, the 14–18 GHz radar profile shows multiple discontinuities (0.4 ns, 1.0 ns and 1.5 ns) in the snow pack. The most significant discontinuity occurred at 1.0 ns. Snow pit records indicated that this layer corresponded to the start of a depth hoar layer. The large grain size discontinuity associated with the depth hoar layer was responsible for the observed reflectivity. In other words, as the radar frequency increased (shorter wavelength), the effect of snow grain size became more important. The multiband radar profile also illustrated the effect of scattering and reflection losses at the higher frequencies. The losses resulted in decreased penetration so that ground effects became less significant.

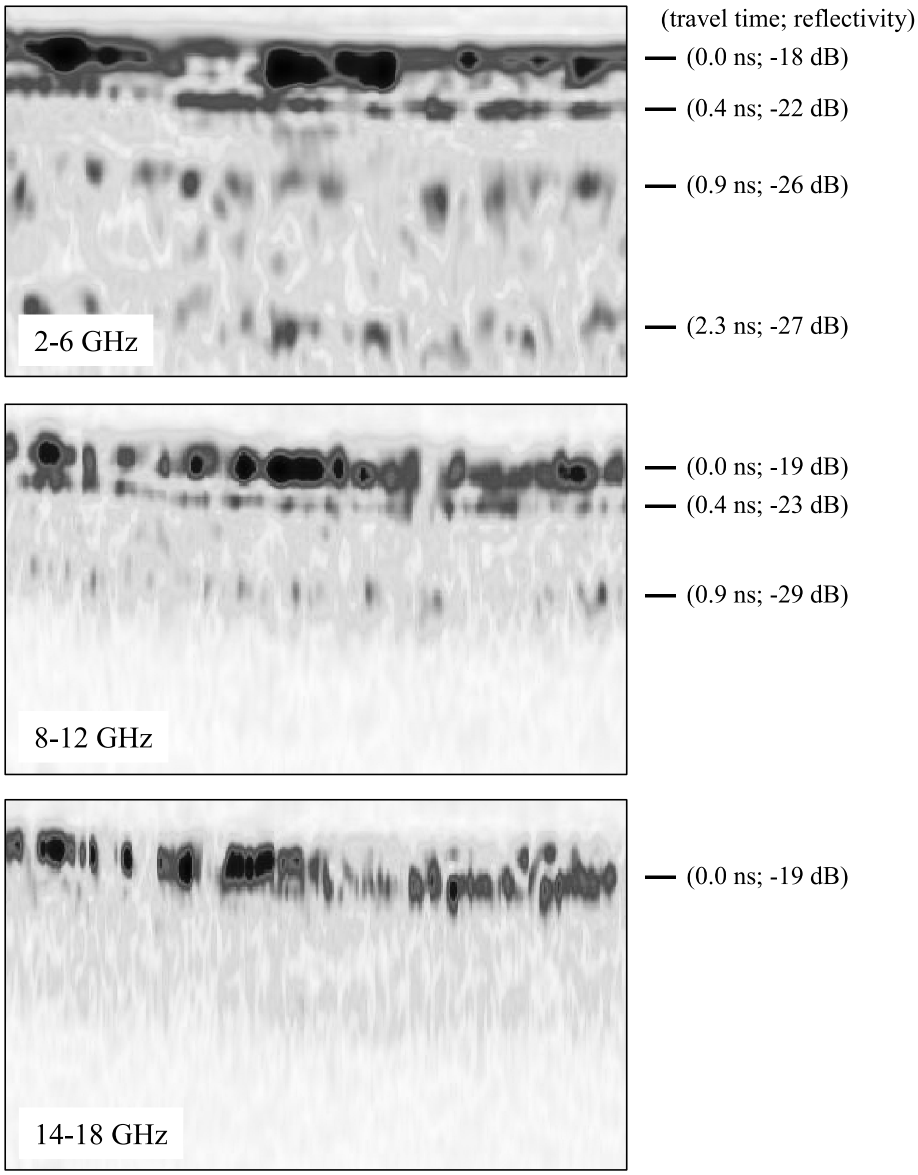

Figure 3. Multiband radar profile of a wet snowpack.

A multiband radar profile of a wet snow observed at the CLPX is illustrated in Figure 3. The snow depth recorded at a nearby snow pit was 57 cm. The snow moisture content was less than 2% throughout the snow pack. Due to the large difference in the complex dielectric constants of ice and water in the microwave regions, the presence of even a small amount of water affects radar interaction with a snow pack. The presence of water greatly reduced the ability of microwave signal to penetrate the snow pack. The radar signal was attenuated so that the ground return was insignificant. This was particularly true at the higher frequencies. The 8–12 GHz and 14–18 GHz radar profiles showed that the surface reflection was the dominant effect in wet snow.

The results from the CLPX indicate that radar operating at 14–18 GHz contains the most information about the internal features of a dry snow pack. However, the high frequency radar is of limited use in wet snow due to the high absorption loss in water. For a wet snow pack, radar operating at lower frequencies (2–6 GHz) was preferable to achieve the necessary penetration. These findings suggest that a dual-frequency approach for radar remote sensing may be necessary to retrieve snow pack parameters such as density, depth, and wetness.