High-Resolution Monitoring of Internal Layers at NGRIP

P. Kanagaratnam, S.P. Gogineni, J. Legarsky, T. Akins
The University of Kansas, Radar Systems and Remote Sensing Laboratory
2291 Irving Hill Road, Lawrence, KS 66045, USA
785/864-7735 (T) - 785/864-7789 (F) - pkanagar@rsl.ukans.edu

Neils Gundestrup, Lars Larsen
Department of Glaciology
University of Copenhagen, Denmark

Josef Kipfstuhl
Alfred Wegener Institute
Bremerhaven, Germany

Abstract - A key variable in assessing the mass balance of an ice sheet is accumulation rate. Currently, accumulation rate is determined from sparsely distributed ice cores and pits. There are uncertainties in existing accumulation rates derived from these cores and pits.

We developed an ultra wideband Frequency Modulated Continuous Wave (FMCW) radar for mapping internal layers, from known volcanic events, in the ice for estimating accumulation rate from high-resolution radar data. We tested the radar system during the 1998 surface experiment at the North GReenland Ice core Project (NGRIP) ice camp. Our results show that internal layers were mapped with high resolution down to 200 m. In this paper, we present the results of the 1998 NGRIP surface experiment.

INTRODUCTION

One of the major goals of NASA's Office of Earth Science Polar Program is to determine the mass balance of the Greenland and Antarctic ice sheets. A key variable in assessing the mass balance of an ice sheet is accumulation rate [1]. Currently, accumulation rate is determined from ice cores and pits. These data are sparse, and there are large uncertainties in existing accumulation rate maps [2] derived from sparely distributed ice cores and pits. There is an urgent need to develop remote sensing techniques for determining accumulation rate.

It has been reported that the real part of the acidic layer and background are the same, and that the main cause of internal reflections from ice is change in conductivity resulting in acidic impurities embedded in ice during volcanic eruptions [3]. The reflection coefficient resulting from a change in conductivity is purely imaginary, whereas the reflection coefficient caused by change in the real part of the permittivity is purely real. Therefore, by measuring both echo amplitude and phase, we can isolate the returns of known volcanic events from the returns of other events. This information combined with published density and thickness data can be used to estimate the accumulation rate.

We developed an ultra wideband Frequency Modulated-Continuous Wave (FMCW) radar system [4] to map the internal layers in the ice. The radar system operates over the frequency range from 170 to 2000 MHz for imaging the top 200 to 300 m of ice with high resolution.

Using electrical conductivity measurements, we designed and developed a radar system to operate over this frequency range. We performed shallow radar sounding experiments at the North Greenland Icecore Project (NGRIP) site during June and July of 1998. We collected data over a 2-km traverse with the radar mounted on a tracked vehicle.

SYSTEM DESCRIPTION

Fig. 1 shows a block diagram of the radar system that we developed. This system has been designed to operate either from 170 MHz to 600 MHz or from 500 MHz to 2 GHz.

SIGNAL PROCESSING

The IF signal of the return from a target for a FMCW radar is given by

$$v_r(t) = \Gamma[f(t)]\cos\{2\pi f_b t + 2\pi f_o \tau - \pi f_b \tau - \phi[f(t)]\}$$

where $f(t)$ is the sweep frequency as a function of time,
$\Gamma[f(t)]$ is the magnitude of the reflection coefficient of the target,
$\phi[f(t)]$ is the phase of the reflection coefficient,
f_b is the beat frequency,
f_o is the initial sweep frequency, and
τ is the two-way travel time of the transmitted signal.

The amplitude and phase of the target's reflection coefficient can be extracted by means of the Hilbert Transform (HT) of the IF signal. The HT of the IF signal will give us a complex signal. We can obtain the phase response of the target by computing the phase of the complex signal and calibrating it with a target of known phase. The amplitude can be similarly obtained by computing the magnitude of the complex signal and calibrating it with a target of known amplitude.

RESULTS

Fig. 2 shows the radar echogram of internal layers observed at NGRIP. We can see that some of the layers correspond to known volcanic events. The volcanic horizons were identified at the NGRIP site by scientists from the Alfred Wegner Institute (Germany) and the Department of Glaciology at the University of Copenhagen (Denmark). The layer depths measured with our radar are within +/- 2 m of the volcanic layers obtained from ice-core data.

CONCLUSIONS

We developed an ultra wideband FMCW radar for mapping the volcanic layers in the ice to help estimate the accumulation rate. Our radar system was tested during the 1998 surface experiment at the NGRIP ice camp. Our results show that volcanic layers were mapped with high resolution down to 200 m.

We are currently performing detailed analysis of these data. We will determine amplitude and phase information as a function of depth for the top 200 to 300 meters of ice. By determining echo amplitude and phase, we can isolate the returns from known volcanic events from the returns from other events. This will help us to estimate the accumulation rate. European investigators have drilled a deep core at this site and have performed conductivity measurements on it. We will compare radar and conductivity data and will develop an algorithm for estimating accumulation rate at this site.

REFERENCES

[1] Paterson, W.S.B., *The Physics of Glaciers*, Pergamon, England, 1994.

[2] Moore, J. C., "Dielectric variability of a 130m Antartic ice core: Implications for radar sounding," *Annals of Glaciology*, vol. 11, pp. 95-99, 1988.

[3] Ohmura, A., and N. Reeh, "New precipitation and accumulation maps for Greenland," *Journal of Glaciology*, vol. 37, no. 125, pp. 140-148, 1991.

[4] Stove, A. G., "Linear FMCW radar techniques," *IEE Proceedings-F*, vol. 139, no. 5, pp. 343-350, October 1992.

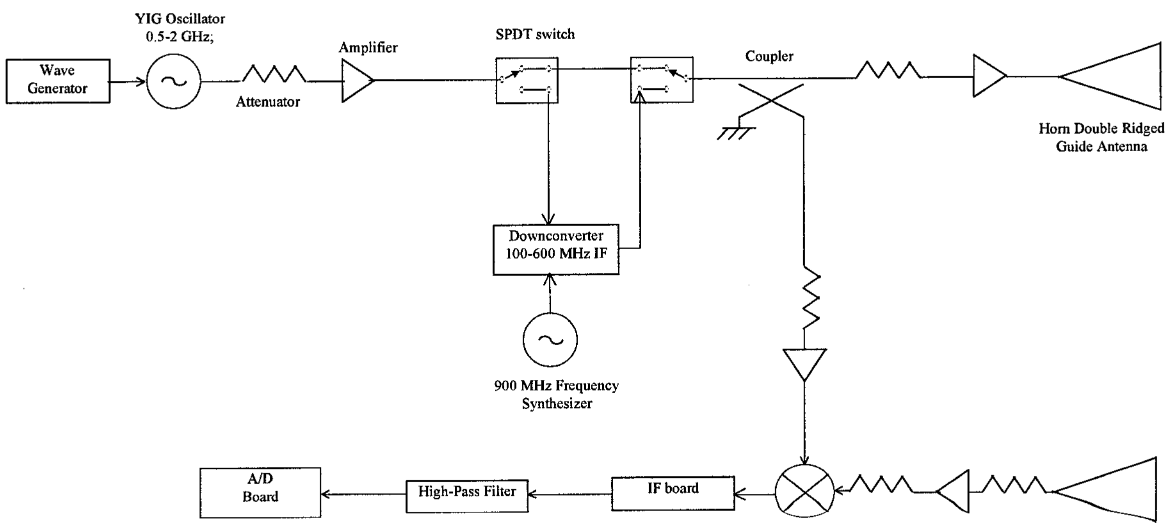

Figure 1. Block diagram of wideband radar for mapping internal layers.

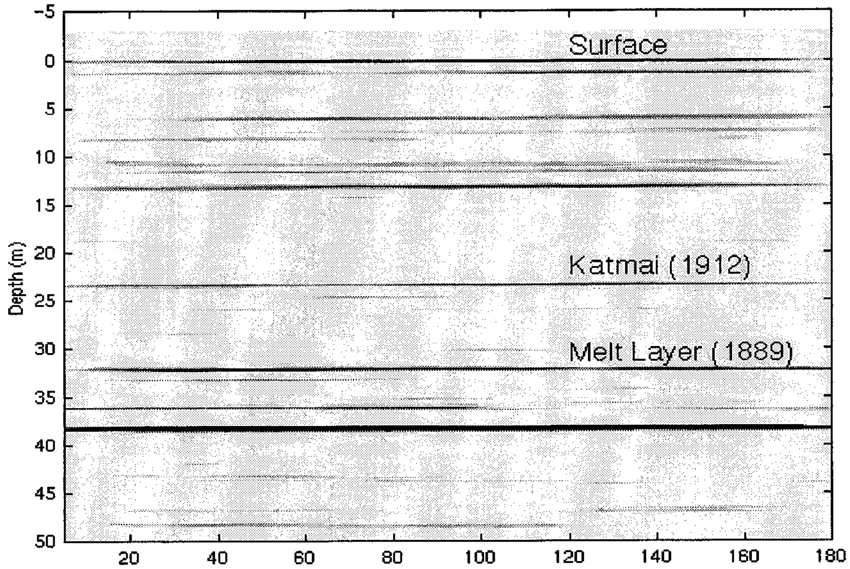

Figure 2(a). Radar echogram of internal layers observed along a 2-km transect at NGRIP (0-50m depth).

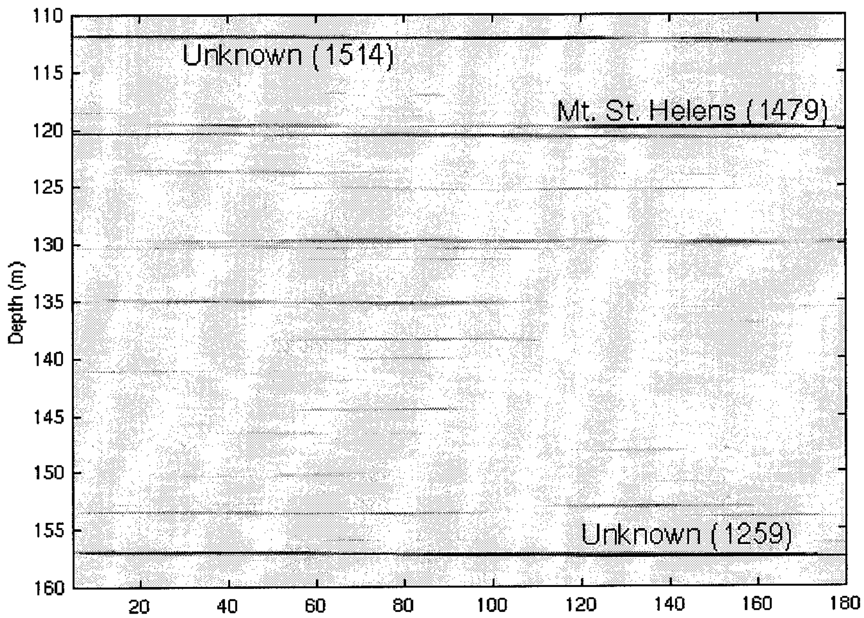

Figure 2(b). Radar echogram of internal layers observed along a 2-km transect at NGRIP (110-160m depth).