Signal Processing and Thickness Calculation
For the Greenland Ice Sheet

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Abstract

The world's sea level has increased by 2mm/year over the past century, it is predicted to rise between 50 and 70 cm within the next hundred years. The threat of flooding from the thermal expansion of the ocean and melting of mountain glaciers can be devastating. With the premise that the main contributing factors of the sea level rise come from Greenland and Antarctica, a program to monitor the mass balance of the Greenland ice sheets was initiated by NASA in 1993 known as the PARCA (Program for Arctic Regional Climate Assessment) initiative.

The Radar Systems and Remote Sensing Laboratory (RSL) at the University of Kansas has played a significant role in PARCA by collecting and monitoring the mass and overall ice dynamics of the ice sheet in Greenland with the use of an ice penetrating radar. The University of Kansas developed the Coherent Antarctic Radar Depth Sounder (CARDS) in the 1980s for the use of data collecting in Antarctica. However, there were several shortcomings with this system which resulted in less than optimum performance. As a result, this system was redesigned and rebuilt in 1996. Although the Improved Coherent Antarctic Radar Depth Sounder (ICARDS) eliminated previous problems faced by CARDS, it was oversized. This led to the development of the Next-Generation Coherent Radar Depth Sounder (NG-CORDS) system, which is an airborne radar that uses complementary Surface-Acoustic-Wave (SAW) devices for both signal generation and matched filtering of a linear chirp wave form. NG-CORDS uses Radio Frequency Integrated Circuits (RFICs) and Microwave Monolithic Integrated Circuits (MMICs) with 12-bit A/D converters instead of the two 8-bit A/D converters previously used by CARDS. Recent field experiments have used the ACORDS (Advanced COherent Radar Depth Sounder) which is a more compact design. ACORDS is an enhanced version of the NG-CORDS that incorporated the latest digital technology in the radar system. It is unique because of its ability to generate the transmit waveform digitally and uses band pass sampling and digital pulse compression techniques. By having the improved Radar Depth Sounder, data has and continues to be collected from Greenland's ice sheet. These data acquisitions have to be obtained periodically to provide solid measurement of the ice and its behavior. Even though there are some challenges remaining with the ACORDS system, such as surface clutter due to heavy crevassing masking the bedrock return and signal loss due to increased melting in some outlet glaciers, over 90% of the collected data was of good quality.

Introduction

The Polar ice sheets account for 80% of the world's fresh water and play a major role in sea level rise. Greenland is a 90% ice covered land region. If this ice were to melt, the sea level would rise by 7m. Climate change and variability have a significant impact on humanity. With global warming having progressively increased the temperature of the earth's atmosphere, the eminent threat of flooding arises. The flooding would have severe consequences due to the fact that 60% of the world's population living in the coastal zones. About 37% live no more than 60km from the coast. More than 70% of the mega cities, each with a population of over eight million people, are situated in the coastal regions. Millions of people would have to migrate away from those areas. For example if the sea level rises by 1m, the 100 million people would be affected. Moreover, the effects of global warming could bring storm patterns and changes in precipitation. This is why PARCA was formed. The polar ice has to be monitored in order to understand and evaluate what is occurring. The ice sheet of Greenland is monitored by using SAR (Synthetic Aperture Radar).

Functionality of ACORDS

The development of ACORDS commenced in 2002 to address some of the problems faced by NG-CORDS. NG-CORDS had trouble sounding shallow ice due to the effects of blanking the strong surface reflection. The artifacts of blanking usually masked the weaker return from the bedrock in areas with shallow ice. ACORDS uses a dual channel receiver to enable the capture of strong returns in one channel and weak returns in another channel. ACORDS also uses digital pulse compression techniques. This enabled us to perform additional signal processing that improved the quality of the data.

ACORDS is a 150 MHz radar used to measure ice thickness. ACORDS is mounted on the NASA P-3 aircraft. The P-3 aircraft is equipped with precision laser altimeter systems and Global Positioning Systems (GPS) receivers. It is usually flown at and altitude of 500m at a speed of 70-130m/s. Below is a picture of the NASA P-3 aircraft.

fig. 1 NASA P-3 Aircraft

ACORDS generates the transmit waveform digitally and uses band-pass sampling and other digital pulse compression techniques. It consists of a synchronization circuit, transmitter, power amplifier, dual channel receivers, and antennas. Figure 3 shows a block diagram of ACORDS.

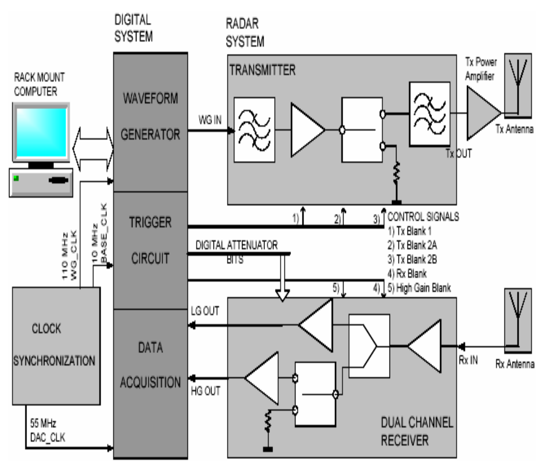


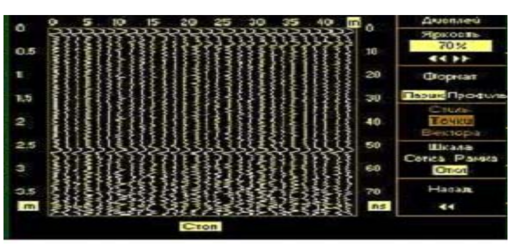
fig.2 Block Diagram of ACORDS

ACORDS uses two 4-element λ/2 dipole antennas. One antenna is for transmitting and the other is for receiving. There is a spacing of 1m between each dipole. The following diagram shows the radar system's parameters.

Description	Characteristic	Units
Radar Type	Pulse Compression	----
RF Carrier Frequency	150	MHz
RF Up-Chirp Bandwidth	17.00	MHz
Transmitted Pulse Width	Selectable (200nsec – 10usec)	µs
Range Sidelobes	< 36	dB
Peak Transmit Power	200	W
PRF	Selectable	KHz
Number of Coherent Integrations	32 – 1024	----
Number of Incoherent Integrations	0 – 64,000	----
A/D dynamic range	12-bit, 72	dB
Receiver Dynamic Range	>110	dB
Sampling Period	18.182 (55 MHz)	ns
Range Resolution	4.494	m
Antennas	4-element λ/2 dipole arrays	

fig3. Radar System Parameters of ACORDS

The transmitter sends a chirp pulse, generated by the waveform generator, to one of two amplifiers through a switch, which is blanked when the radar receives the signal. The chirp is then amplified to a 200 W peak power pulse and transmitted using an antenna. The received signals are amplified and split into two parts, high-gain (HG) and low-gain (LG), which are controlled by two channels. High peak power signals are passed through the LG channel and the low peak signals are passed through the HG channel to amplify the signal. The Radio Frequency (RF) signal is digitized at 55MHz using band-pass sampling and integrated coherently before storing. This is to reduce the volume of data making it easier to store the data. The received signal is in the form of an A-scope which is a plot between the amplitude of the returned signal and distance traveled by the pulse.



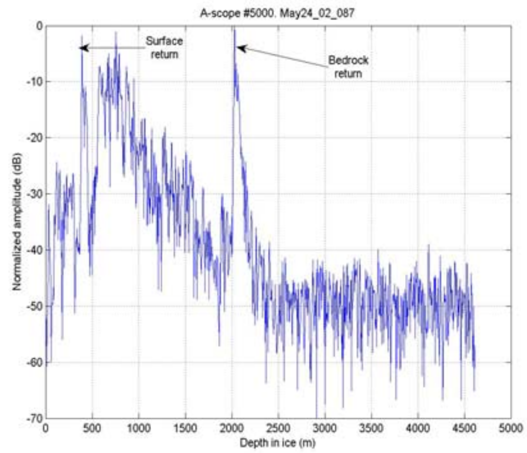


fig.4 Example of an A-scope

The A-scopes are combined as a matrix with each column representing an individual A-scope.

0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12
.									
.									
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.									
0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4

fig.5 matrix of A-scopes

Data Processing

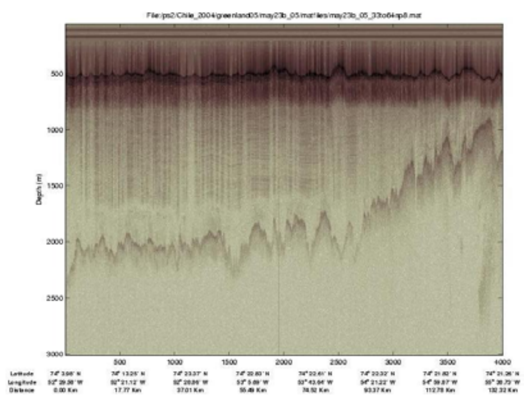
After the data is collected, it must be formatted before being processed. Each file usually consists up to 1000 records. Each record indicates one A-scope. Procedures to process the data acquired from Greenland include two stages. In the first stage, signal processing is done to enhance the quality of the data. The programs were written in MatLab and run on a Linux platform. Incoherent averaging is done to reduce fading. To find the number of Post Average, nPostAvg, the following formula is used.

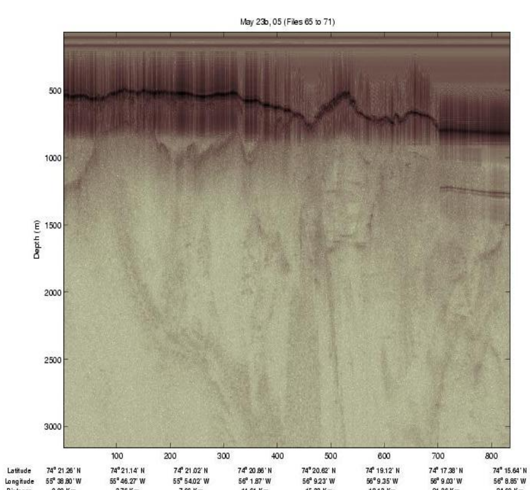
Navg= Tavg x fp
where fp(Hz) = nSamples/Presums
and Tavg(s) = distance(m)/Velocity(m/s)

The distance = [sqrt(R x λ)]/2
where R is the aircraft height in meters and λ is the wavelength.

The DC offset is removed and clutter that masks the weak signal returns from the ice and bedrock is minimized. In the second stage, an ice-feature tracking program is used to track the ice surface and bedrock for determining the ice thickness.

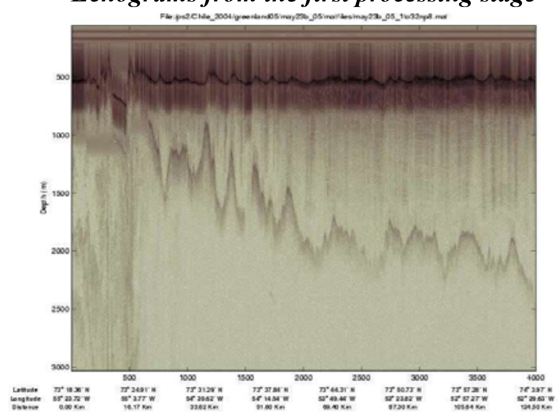
Results



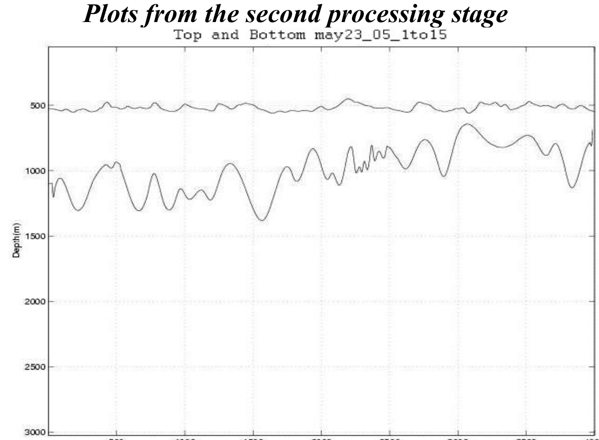


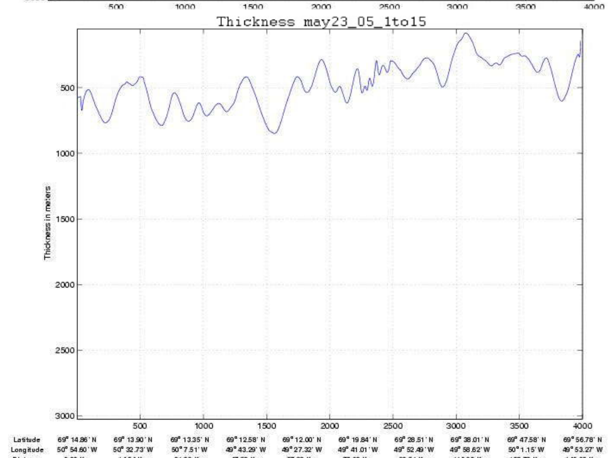
The following diagrams are echograms and plots obtained from both signal-processing procedures. The data used was acquired during the month of May 2005.

Echograms from the first processing stage



Plots from the second processing stage





Conclusion

With the threat of flooding from the thermal expansion of the ocean and melting of mountain glaciers, programs like PARCA are needed to monitor the mass balance of polar ice. By monitoring the polar ice sheets, plans can be made for adaptation to sea level rise. With quality data from depth sounder radars, ice measurement comparisons can be made in future experiments to determine the behavior of the ice throughout time intervals.

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6. Gogineni, S., T. Chuah, C. Allen, K. Jezek, and R. K. Moore, An Improved Coherent Radar Depth Sounder, Journal of Glaciology, Vol. 44, no. 148, 1998