A RADAR SUITE FOR ICE SHEET ACCUMULATION MEASUREMENTS AND NEAR-SURFACE INTERNAL LAYER MAPPING

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Recent satellite observations are showing that the disintegration of the Arctic and Antarctic ice sheets is proceeding rapidly, exacerbated by multiple positive feedbacks. The summer melt area in Greenland has been increasing at a rate of ~40,000 km^2/year since 1992. QuickSCAT observations have also confirmed increasing summer melt areas and an increase in the length of the melt season in West Antarctica since 1999. Positive feedback mechanisms responsible for the recent acceleration in ice sheet melting can occur on and under the ice sheets as well as in adjacent oceans [4]. Key feedbacks such as decreased ice sheet albedo due to surface melting, increased ice stream and outlet glacier velocities due to basal lubrication, and increased iceberg discharge due to loss of buttressing ice shelves have led to an overall negative mass balance [1] [3].

The mass balance of both the Greenland and Antarctic ice sheets can be defined, in simple terms, as the difference between precipitation — addition of mass — and the combination of evaporation, runoff, and ice discharge — removal of mass [7]. These processes are directly affected by temperature increases in both the air and ocean surrounding the ice sheets. The ocean temperature near the ice sheet is vital to its stability. Recent trends show warming both the atmosphere and oceans. Higher ocean temperatures can be linked to higher precipitation rates and accelerated melting of ice shelves and free sea ice [4]. To fully understand the mechanisms and key processes requires a variety of observations — both from space and airborne platforms.

Many satellite, airborne, and in situ observations have been made to better understand the mass balance of the ice sheets. Satellite missions such as GRACE, ICESat, and Cryosat provide broad coverage, but are only capable of collecting data at relatively coarse temporal and spatial resolutions [7] [8]. Satellite observations alone are not sufficient to fully understand all mechanisms responsible for changes in the overall ice sheet mass balance. While these are sufficient over much of the interior of the ice sheet, to understand and model the dynamics of fast flowing glaciers, and the margins of the ice sheet, finer resolution is required. Airborne platforms, especially autonomous platforms, allow for key regions of the ice sheets to be measured with fine-resolution remote sensing instruments. These platforms provide more accurate ice thickness estimates, internal layer mapping, and ice-bedrock interface imaging [2].

To address this gap in the observations, we are designing and developing an instrumentation suite to be deployed on crewed and uncrewed aircraft. Here we will focus on two radars in the instrumentation suite: an accumulation radar and a radar altimeter. The altimeter will be capable of measuring surface elevation and near-surface internal layers to a depth of about 10 m. The accumulation radar will be capable of measuring internal layers to a depth of about 100 m. While part of this radar suite, but beyond the scope of this document, a previously developed 150 MHz radar depth sounder/imager will be used to map layers below 100 m, as well as the ice-bedrock interface. Field data collection using these systems will be performed simultaneously, providing a fine-resolution characterization of the ice sheet from surface to bedrock. The altimeter provides annual and short-term information on the accumulation (less than 5 years old), while the accumulation radar provides information on the decadal scale variability. The depth sounder provides information on the century scale variability. Initial data collection is expected during the early spring 2009 Greenland field season; additional data collection will continue during future campaigns both in Greenland and Antarctic. System refinements will allow for this suite to be deployed on uncrewed aerial vehicles (UAVs) being developed at the University of Kansas.

The altimeter is an ultra-wideband FM-CW radar that operates over the frequency range from 12 to 18 GHz. It is designed to optimize the generation and transmission of a highly linear chirp with digitally-controlled amplitude shaping to correct for distortion introduced by amplifiers and the antenna. This amplitude control network also allows for the application of temporal weighting functions on the transmit waveform to obtain range sidelobes of 60 dB or lower with vertical resolution of about 7.5 cm [5]. The basic system topology was modeled using a previously designed undergraduate senior design project radar [6]. The new system improves upon the previous design by incorporating a highly linear chirp using a fast-settling phase-locked loop driven by a Direct Digital Synthesizer (DDS) to produce a transmit signal over the frequency range from 12 to 18 GHz.

Similar design considerations are also used in the development of the accumulation radar. This is also a FM-CW radar, operating at lower frequencies between 600 and 900 MHz. Lower bandwidth requirements allow for the direct generation of a linear chirp using a DDS; this chirp is mixed to the band of interest. Design and development of a simple amplitude controlled network will allow for same transmit waveform shaping as used with the altimeter. This system will serve as a proof-of-concept for the equivalent system within the altimeter. Care in design, fabrication, and packaging will produce a system with about 60 cm vertical resolution. Future renditions of this radar will include weighted antenna arrays to allow for clutter suppression.

In the paper we will present detailed design, provide laboratory test results from simulated targets, and experimental results from March-April 2009 field campaign.

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