A DESIGN CONCEPT FOR SPACEBORNE IMAGING OF THE BASE OF TERRESTRIAL ICE SHEETS AND ICY BODIES IN THE OUTER SOLAR

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Glaciers and ice sheets modulate global sea level by storing water deposited as snow on the surface and discharging water back into the ocean through melting and via icebergs. Only recently have we recognized, primarily from satellite observations, that the size of this frozen reservoir can change as demonstrated by the rapid thinning of Jacobshavn Glacier in Greenland [1], the Pine Island and Thwaites Glaciers in Antarctica [2] and the demise of the Larsen Ice Shelf followed by thinning of interior Antarctic Peninsula Glaciers. Yet none of these events are captured by current glaciological models suggesting that there are critical gaps in observations and theory about the dynamics of large ice sheets.

Missing from the constellation of satellites currently observing the polar regions, is a sensor capable of probing the volume of the ice sheet and measuring the topography and properties of the glacier bed. While much work has been done to measure ice thickness from aircraft, gaps in coverage remain especially over part of Antarctica [3]. Very little information is available about variations in properties of the subglacial bed where we believe critical changes in the control on ice sheet flow takes place. Here, we present a concept for a new sensor to probe, systematically and comprehensively, the base of the polar ice sheets. We ultimately seek to perform pole-to-pole measurements of glacier and ice sheet thickness, basal topography, and physical properties of the glacier bed that will help to answer two fundamental questions: What is the impact of changing ice sheets on global sea level rise?; Can we predict changes in ice sheet volume and hence changes in global sea level as global climate changes?

Our technology concept addresses an approach for obtaining spaceborne estimates of the mass of the polar ice sheets with an ultimate goal of providing essential information to modelers estimating the mass balance of the polar ice sheets and estimating the response of ice sheets to changing climate. The science goals driving our concept are: 1) determine total global ice sheet volume by mapping surface and basal topography; 2) determine basal boundary conditions from radar reflectivity; and 3) understand the phenomenology of radar sounding of ice for applications to planetary studies.

Our concept is built around a VHF and P-band, multi-phase-center radar for measuring the surface and bottom topographies of polar ice sheets. Our approach, which relies on a combination of radar interferometry and multi-phase center tomography, serves to eliminate signal contamination from surface clutter, measure the topography of the glacier bed, and paint a picture of variations in bed characteristics. We have recently shown that is possible to image a small portion of the base of the polar ice sheets using an in situ SAR approach. We envision this technology transitioning to a spaceborne platform configured to make measurements over both of the great ice sheets. The technology will also have applications for planetary exploration including studies of the Martian ice caps and the icy moons of the outer solar system.

Our proposed system consists of a synthetic aperture radar interferometer (IFSAR) operating at P-band and using a 45 m interferometric baseline. We restrict data collection to near nadir incidence angles leading to a 50-km swath that starts at a cross-track distance of 10 km from the nadir track. Simulations show that we can obtain satisfactory signal–to-noise ratios for ice depths up to 4 km. Clutter contributions are the primary noise sources to the signal over the swath.

As soon as an off-nadir swath is required, brightness returns from a surface are insufficient to estimate height and an interferometric radar is required. The height accuracy which can be achieved with an interferometer depends on the signal-to-noise (SNR) and signal-to-clutter (SCR) ratios, the number of radar looks, and the interferometric baseline [4, 5]. Modifying the equations in those references to include ray bending and the presence of a second surface which generates clutter contamination, we can derive the expected retrieved height accuracy as a function of SNR and SCR. Due to the large number of looks and the 1 km spatial resolution of the planned system, we find that an SNR between –5dB and 0 dB is sufficient for achieving the desired height accuracy out to 60 km cross track distance. We also find that the clutter reduction need not be perfect: achieving rejection ratios so that the final SCR is in the range between –10 dB and 0 dB is sufficient to meet the science requirements.

We have selected the system to operate at 430 MHz for several reasons: 1) antenna size reduction; 2) baseline reduction so that it is achievable in a single spacecraft; and, 3) field experiments have shown that the attenuation due to ice propagation is relatively constant over the frequency range from 100 to 500 MHz. The main disadvantage of P-band is higher surface clutter and so we retain an option for a lower frequency system.

We have selected a polarimetric system to allow for corrections due to ionospheric distortions and Faraday rotation. Freeman [6] and Freeman and Saatchi [7] have shown that using polarimetric returns, one can achieve an azimuth resolution commensurate with our 1 km spatial resolution requirement and not lose significant signal power due to Faraday rotation [8].

References:
[1] Thomas, R.H., W. Abadalati, E. Frederick, W. Krabill, S. Manizade, K. Steffen, (2003). J. of Glaciology, 49(165), 231-239.
[2] Rignot, E., 2001. J. Glaciology, 47(157), 213-222.
[3] ISMASS Committee, 2004. Global and Planetary Change, 42, 1-15.
[4] Rodriguez, E., and J. M. Martin, (1992). Proceedings of the IEE.
[5] Rosen, PA, Hensley, S, Joughin, IR, Li, FK, Madsen, SN, Rodriguez, E, Goldstein, RM, Proc. IEEE 88, 3, 333-382, 2000.
[6] Freeman, A, (2004) IEEE Trans. Geoscience and Remote Sensing, 42 (8), 1617 - 1624
[7] Freeman, A.; Saatchi, S.S,(2004), IEEE Trans. Geoscience and Remote Sensing, 42(8), 1607-1616
[8] Liu, J., Yasuo Kuga, Akira Ishimaru, Xiaoqing Pi, and Anthony Freeman, (2003), IEEE Trans. Geoscience and Remote Sensing,