THE GLACIER AND ICE SURFACE TOPOGRAPHY INTERFEROMETER: FIRST RESULTS FROM GREENLAND

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1. INTRODUCTION

As part of the NASA International Polar Year activities, a Ka-band cross-track interferometric synthetic aperture radar recently demonstrated high precision elevation swath mapping capability. This proof-of-concept instrument was achieved by interfacing antennae and Ka-band electronics with the Jet Propulsion Laboratory's L-band UAVSAR. Deployed on the NASA Gulfstream III, initial successful engineering flights in March and April 2009 marked the first airborne demonstration of single-pass cross-track interferometry at Ka-band.

The estimation of the mass balance of ice sheets and glaciers on Earth is a problem of considerable scientific and societal importance. A key measurement to understanding, monitoring and forecasting these changes is ice-surface topography, both for ice-sheet and glacial regions Measurements over the major ice sheets have been achieved with satellite radar altimeters [1], airborne laser altimetry [2] and with satellite laser altimetry [3]. Satellite radar altimetry is most accurate over flat areas, but performs poorly over the steep coastal regions where most of the changes are localized. Airborne laser altimetry is more useful in these steep regions but is limited in spatial coverage and swath width (500m), rendering it impractical for use at the continental scale over Antarctica. Satellite laser altimetry, while limited in swath coverage has provided a time record over the lifetime of IceSat and the record is to be extended with the IceSat II mission expected for launch in 2015. In the interim, airborne activities underway will provide some measurement continuity between IceSat and IceSat II.

The various altimeter observations have shown that changes in the polar regions are rapid (occurring over years instead of centuries or millennia) and significant (*e.g.* meter scale lowering of ice surfaces instead of millimeters), with the coastal regions having more than half of the signal from the ice sheets. However, it is in the topographically rugged and temporally dynamic coastal regions where the spatial coverage limitations of a profiling sensor is most profound.

To adequately assess the dynamics and volume changes in glacial/coastal margins of the ice-sheet one requires a mapping capability that fills the gaps between altimeter tracks at sufficient resolution. Toward that end, Moller *et. al.* [4] introduced the Glacier and Ice Surface Topography Interferometer (GLISTIN) concept: a Ka-band single-pass cross-track radar interferometer that could provide elevation maps and imagery between nadir tracks. For a satellite implementation, GLISTIN would be capable of providing significant swath-widths, cover the poles sub-monthly, and provide inherently variable spatial resolution: high spatial resolution for meter-scale vertical precision on glaciers and coastal regions and coarse spatial resolution for decimeter accuracy on ice sheet interiors. The choice of Ka-band is key for minimizing penetration into snow cover, providing high precision for a compact baseline separation, yet remains relatively impervious to atmospheric attenuation.

2. SYSTEM IMPLEMENTATION

In order to realize a cost-effective and timely demonstration of the GLISTIN concept, an adaptation to the NASA/JPL UAVSAR was proposed under the NASA International Polar Year program. UAVSAR is an airborne interferometric synthetic aperture radar (SAR) that is carried in an external pod on the NASA C-20 (Gulfstream III) aircraft [5]. UAVSAR is operationally configured to support repeat-pass L-band (1.26 GHz) interferometric SAR images with a bandwidth of 80 MHz. This is accomplished with a single, electronically-steered phased array antenna. Data from multiple passes over the same target area are used to form interferometric radar images.

Table 1 : Key radar parameters and performance requirements.

Parameter	Unit	Value
Center frequency	GHz	35.66
Transmit Power (at antenna)	W	35
E-plane beamwidth	deg	35
H-plane beamwidth	deg	0.9
Baseline	cm	25
Baseline angle	deg	45
Bandwidth	MHz	80
Polarization		Horizontal
Minimum Swath	km	5
Height accuracy for 30m x 30m posting	m	0.5

For our demonstration, we replaced the L-band phased array with a pair of Ka-band (35.6 GHz) slotted-waveguide antennas (detailed subsequently) that are configured as a single-pass cross-track interferometer. Both antennas were mounted to a single structure with the same mechanical interface as the UAVSAR L-band antenna. Fig. 1 shows the two slotted waveguide antennae mounted in a pod on the GIII. Table 1 summarizes key radar parameters and performance requirements levied on the design.

3. INITIAL RESULTS

The Ka-band system was deployed to Greenland from May 1-13, 2009 and mapped more than 35000 km^2 (9 hours of data collection time) over coastal glaciers and at higher elevation over dry firn including Greenland's Summit. Fig. 2a shows a Ka-band backscatter image taken over a relatively rugged area along the West coast of Greenland at 69.1°N latitude 49.7°W longitude (just South of Jakobshavn glacier) from an altitude 8 km. Backscatter from the surface is relatively bright, except for a few dark regions, where interferometric correlation is correspondingly low. Low correlation prevented successful phase unwrapping resulting in some pixels not being mapped (indicated by black pixels). Fig. 2b is the corresponding height map with the image brightness indicating radar backscatter and elevation shown by color contours with a height wrap of 800 m (i.e. red to red corresponds to an 800 m elevation change). Figure 2c and 2d show the correlation map and height precisions respectively. The results shown are for posting of 3m x 3m and report height precisions that vary from 30 cm in the near range to about 3 m in the far range extending up to a 7.5km swath. Although systematic biases (including penetration) and calibration have not yet been assessed, we are clearly well within the requirements of Table 1 for a 30x30m posting if one scale the precisions by a factor of 1/10.

4. CONCLUSIONS

In this paper we detailed the implementation and the initial performance of the first Ka-band single-pass InSAR. This proof-of-concept demonstration was achieved by adapting the L-band UAVSAR system for operation at the higher frequency and housing two cross-track antennas with a stable baseline within the UAVSAR pod. The initial performance results for the Ka-band GLISTIN instrument over rugged-ice and topography exceeds engineering predictions and meets requirements for the height precision. Systematic and penetration biases have yet to be assessed with precision calibration.

5. ACKNOWLEDGMENT

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6. REFERENCES

[1] C. H. Davis, L. Yonghong, J. R. McConnell, M. M. Frey, and E. Hanna, "Snowfall-Driven Growth in East Antarctic Ice Sheet Mitigates Recent Sea-Level Rise," Science, 308(5730), pp.1898--1901, 2005

[2] R. Thomas, E. Frederick, W. Krabill, S. Manizade, and C. Martin, "Progressive increase in ice loss from Greenland," *Geophys. Res. Lett*., 33, L10503, doi:10.1029/2006GL026075., 2006

[3] H. D. Pritchard, R. J. Arthern, D. G. Vaughn, and L. A. Edwards, (2009, September 23). Extensive dynamic thinning on the margins of the Greenland and Antarctic ice sheets. *Nature* [Online], Advance on-line publication. Available: http://dx.doi.org/10.1038/nature08471

[4] D. Moller, B. Heavey, R. Hodges, S. Rengarajan, E. Rignot, F. Rogez, G. Sadowy, M. Simard, and M. Zawadzki, "The Glacier and Land Ice Surface Topography Interferometer (GLISTIN): A novel Ka-band digitally beamformed interferometer," *Proc. 2006 ESTC Conference*, Maryland, 2006.

[5] P. A. Rosen, S. Hensley, K. Wheeler, G. Sadowy, T. Miller, S. Shaffer, R. Muellerschoen, C. Jones, H. Zebker, S. Madsen, "UAVSAR: A New NASA Airborne SAR System for Science and Technology Research," *Proc. IEEE Conference on Radar*, 24-27 April 2006, pp8.

Figure 1: Picture of NASA Gulfstream III with pod configured for Ka-band interferometry. Lower insert shows close-up with details of the two antennas.

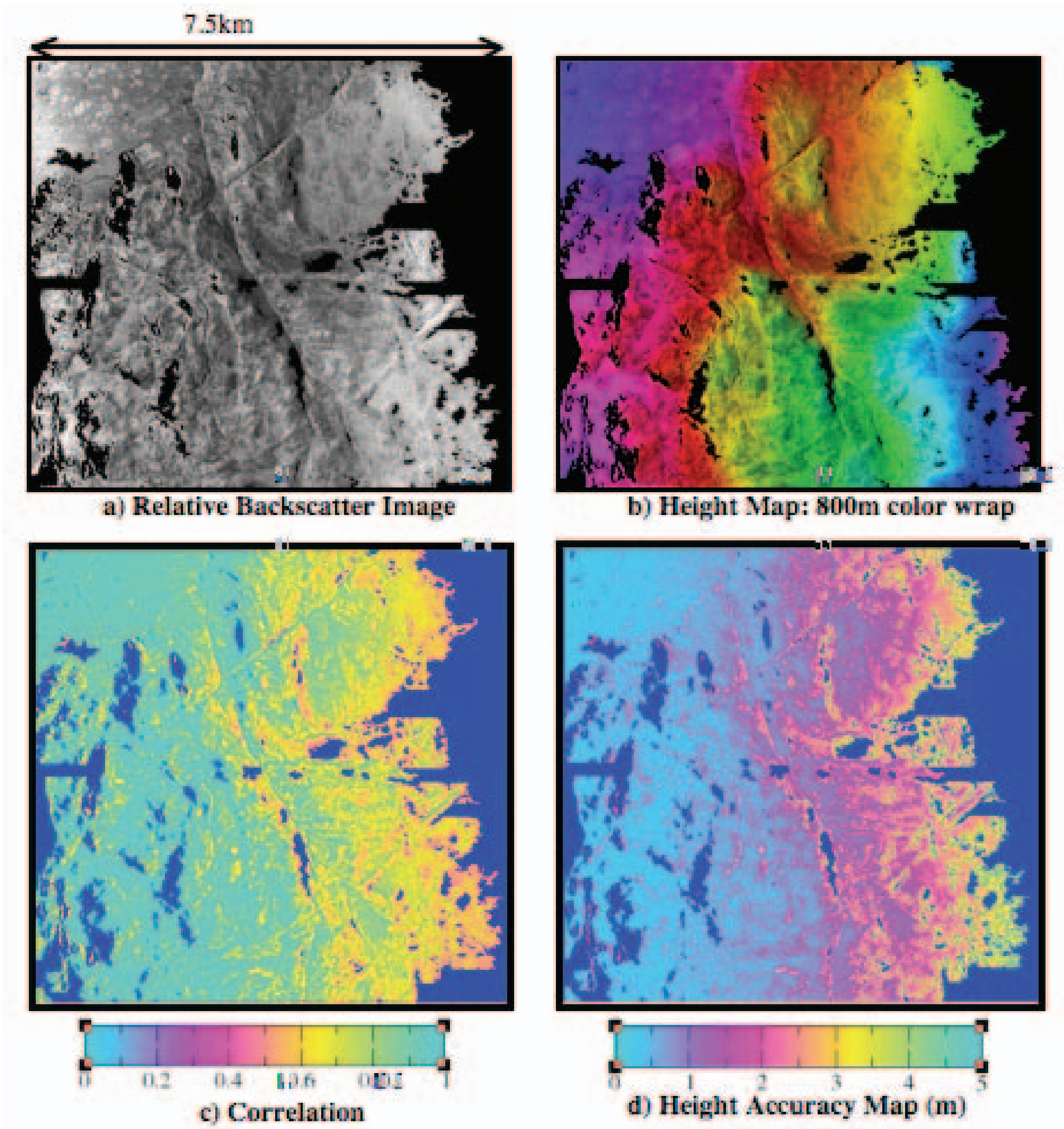

Figure 2: Ka-band maps at 3m x 3m posting generated from data collected on May 1, 2009 near the Greenland coast. a) relative backscatter image and b) Ka-band radar elevation map. Elevation contours are color coded with a wrap of 800 m, i.e. from red to red represents an elevation change of 800 m.c) Interferometric correlation and d) height error map (right) generated from the correlation data. Note the height accuracy varies from 30 cm in the near range to about 3 m in the far range. The data if averaged to the 30 m posting as needed for glacial science application will meet the 50 cm height accuracy requirements almost everywhere in the swath.