# AIRBORNE HIGH-ALTITUDE, 25M FOOTPRINT, WAVEFORM LIDAR MAPPING OF GREENLAND AND ANTARCTICA

*M. Hofton[1], S. Luthcke[2], J. B. Blair[3], D. Rabine[3], C. McIntosh[4]*

[1]Dept. Of Geography, University of Maryland, College Park, Maryland
[2]Code 698, NASA GSFC, Greenbelt, Maryland
[3]Code 694, NASA GSFC, Greenbelt, Maryland
[4]Sigma Space Corporation, Lanham, Maryland

## 1. INTRODUCTION

NASAs Operation IceBridge [1] is an airborne, multi-sensor program designed to survey the Greenland and Antarctic ice sheets during the data gap between the current orbital ICESat [2] and future lidar missions. To date, extensive survey missions have been carried out of areas of Greenland (March-April, 2009) and Antarctica (October-November 2009) utilizing NASA's P3-B and DC8 aircraft. One of the sensors involved in Operation IceBridge is NASA's Land, Vegetation and Ice Sensor (LVIS [3]). The LVIS is an airborne, medium-footprint (25m diameter), full waveform-recording, airborne, scanning lidar system that has been used extensively for mapping surface structure for various scientific investigations including of the Greenland ice sheet in 2007 [4]. During the missions, the LVIS was flown at high altitude (27,000'-36,000'), utilizing a 25m-wide footprint and 2km-wide swath over areas of Greenland and Antarctica. Data collected included ground elevation and vertical extent measurements for each laser footprint, as well as the vertical distribution of intercepted surfaces (the return waveform) from which surface slope, roughness and other metrics can be extracted. In this paper, we focus on the precision and accuracy of the LVIS data, as well as their comparison to coincident ICESat data in order to establish the accuracy of the sensor-to-sensor comparison under various surface conditions. These data, along with data collected by the other sensors involved in Operation IceBridge, form the basis for future repeat surveys of the ice sheet and its margins from the air. In particular, the data set collected using the LVIS sensor provides a consistent datum to enable ICESat inter-mission calibration and validation, and assist in the separation of inter-mission observational system biases and errors from true decadal and seasonal surface elevation change.

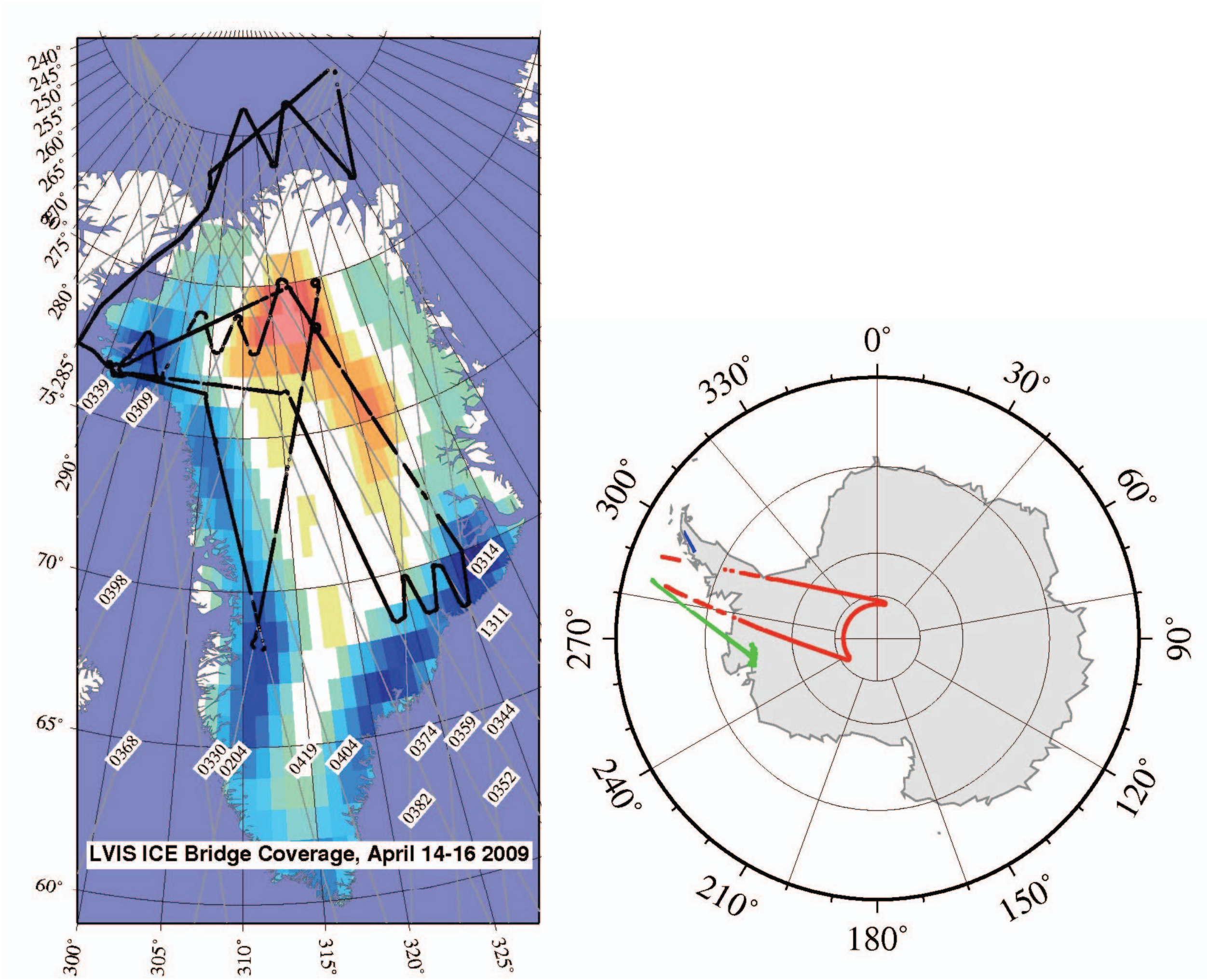


Figure 1: Areas of Greenland and Antarctica overflown using LVIS in 2009.

## 2. NASA'S LAND, VEGETATION AND ICE (LVIS) SENSOR

NASA's LVIS is an airborne, medium-footprint (25m diameter), full waveform-recording, airborne, scanning lidar system that has been used extensively for mapping surface structure for various scientific investigations (e.g., [5], [6], [4]). The system digitally records the shape of the returning laser echo, or waveform, after its interaction with the various reflecting surfaces of the earth, providing a true 3-dimensional record of the surface structure within each footprint in the data swath. In April 2009, the system was flown over regions of the Greenland ice sheet and Arctic Ocean on board NASA's P3-B aircraft as part of NASA's Operation IceBridge (Figure 1). Flying at ~8 km altitude, using ~20-25 m-wide laser footprints that were contiguous along and across-track within the ~1.5 km-wide laser swath, a total of ~9,500 lineal km of ICESat repeat ground-track "corridors" were imaged during three flights, including ~1,500 lineal km that were imaged previously using LVIS in

September 2007. In October 2009, the system was flown over regions of the Antarctica ice sheet and sea ice on board NASA's DC8 aircraft (Figure 1). Flying at 10km altitude using a 25m-wide laser footprint and 2km wide laser swath, data were collected over Pine Island glacier, the ICESat "pole hole" edge (86S) and a complete mapping of a 250km by 30km area centered on Crane glacier. Data collected included ground elevation and vertical extent measurements for each laser footprint, as well as the vertical distribution of intercepted surfaces (the return waveform) from which surface slope, roughness and other metrics can be extracted.

## 2. RESULTS

In order to assess the precision of the LVIS lidar elevations, the differences between elevations of coincident footprints are compared. In Greenland, results showed the differences were normally distributed with a zero, or close to zero, mean indicating no significant systematic errors remain in the measurement process. The 1sigma standard deviation of the differences were <7cm, improved slightly over 2007 data [4]. Results are still being assessed for the Antarctica data. To assess the efficacy of LVIS data for ICESat inter-mission calibration and validation we compared elevations of coincident LVIS and ICESat footprints (using ICESat GLA12 product). ICESat, launched in January 2003 used a single beam waveform recording laser altimeter (~65m footprint, ~170m spacing along track) to make elevation measurements [2}. Note that the LVIS wide-swath coverage allows us to utilize all ICESat footprints (without interpolation) in the comparison. In Greenland, over regions of smooth, interior ice coincident LVIS and ICESat elevations agreed to better than 9cm (except for L2A, L2c and L2E). Results are still being assessed for the Antarctica data, however preliminary comparisons of data from the "pole hole" flight, i.e., an arc along the 86S latitude line from -120W to 20E indicate in the region of 500,000 ICESat footprints were imaged and are available for comparison to LVIS. Comparisons of LVIS and ICESat data over also indicate surface elevation  changes that have occured in the regions.

## 3. SUMMARY

Precise and accurate LVIS data collected in Greenland and Antarctica offer unprecedented surface topographic coverage images for investigators. These data, along with data collected by the other sensors involved in Operation IceBridge, form the basis for future repeat surveys of the ice sheet and its margins from the air during the data gap between the current orbital ICESat and future lidar missions. In particular, the data set collected using the LVIS sensor provides a consistent datum to enable inter-mission calibration and validation, and enable the separation of inter-mission observational system biases and errors from true decadal and seasonal surface elevation change.

## 4. REFERENCES


[1] NASA Operation IceBridge Home page, http://www.espo.nasa.gov/oib/, 2009.

[2] Zwally, J., et al., ICESat's laser measurements of polar ice, atmosphere, ocean and land, J. Geodyn., 34, 405 – 445, 2002.

[3] Blair, J. B., D. L. Rabine, and M. A. Hofton, The Laser Vegetation Imaging Sensor (LVIS): A medium-altitude, digitization-only, airborne laser altimeter for mapping vegetation and topography, ISPRS J. Photo. Rem. Sens., 54, 115–122, 1999.

[4] Hofton, M. A., J. B. Blair, S. B. Luthcke, and D. L. Rabine, Assessing the performance of 20–25 m footprint waveform lidar data collected in ICESat data corridors in Greenland, *Geophys. Res. Lett.*, 35, L24501, doi:10.1029/2008GL035774, 2008.

[5] Drake, J.B., Dubayah, R.O., Clark, D.B., Knox, R.G., Blair, J.B., Hofton, M.A., Chazdon, R.L., Weishampel, J.F. and Prince, S., Estimation of tropical forest structural characteristics using large-footprint lidar. *Remote Sensing of Environment*, 79, 305–319, 2002.

[6] M. A. Hofton, E. Malavassi, and J. B. Blair, Quantifying recent pyroclastic and lava flows at Arenal Volcano, Costa Rica, using medium-footprint lidar, *Geophy. Res. Lett.,* 33, L21306, doi:10.1029/2006GL027822, 2006.