C31D MCC: 3010 Wednesday 1020h

NASA's Ice, Cloud, and Land Elevation Satellite (ICESat) Mission: Scientific and Technological Achievements II *(joint with A, B, G, H, OS)*

***Presiding:* H J Zwally,** NASA Goddard Space Flight Center**; B E Schutz,** Center for Space Research, University of Texas at Austin**; C A Shuman,** NASA Goddard Space Flight Center

C31D-01 1020h INVITED

Geoscience Laser Altimeter System (GLAS) on the ICESat Mission: Initial Science Measurement Performance

James B Abshire[1] (301 614-6081; James.B.Abshire@nasa.gov); Xiaoli Sun[1] (Xiaoli.Sun@gsfc.nasa.gov); Haris Riris[2] (Haris.Riris@gsfc.nasa.gov); Marcos Sirota[2] (Marcos.Sirota@gsfc.nasa.gov); Jan McGarry[1] (Jan.McGarry@gsfc.nasa.gov); Steve Palm[3] (Steve.Palm@gsfc.nasa.gov)

[1]NASA- Goddard Space Flight center, Laboratory for Terrestrial Physics, Mail Code 920, Greenbelt, MD 20771, United States

[2]Sigma Research and Engineering, c/o NASA Goddard Space Flight Center Mail Code 924, Greenbelt, MD 20771, United States

[3]Science Systems And Applications Inc., c/o NASA Goddard Space Flight Center Mail Code 912, Greenbelt, MD 20771, United States

The Geoscience Laser Altimeter System is the space lidar on the NASA ICESat mision. Its design combines an altimeter with 5 cm precision with a laser pointing angle determination system and a dual wavelength cloud and aerosol lidar. GLAS measures the range to the Earth's surface with 1064 nm laser pulses. Each laser pulse produces a precision pointing measurement from the stellar reference system (SRS) and an echo pulse waveform, which permits range determination and waveform spreading analysis. The single shot ranging accuracy is < 10 cm for ice surfaces with slopes < 2 degrees. GLAS also measures atmospheric backscatter profiles at both 1064 and 532 nm. The 1064 nm measurements use an analog Si APD detector and measure the height and profile the backscatter signal from thicker clouds. The measurements at 532 nm use photon counting detectors, and will measure the vertical height distributions of optically thin clouds and aerosol layers Before launch, the measurement performance of GLAS was evaluated using a lidar test instrument called the Bench Check Equipment (BCE). The BCE was developed in parallel with GLAS and served as an inverse altimeter, inverse lidar and a stellar source simulator. It was used to simulate the range of expected optical inputs to the GLAS receiver by illuminating its telescope with simulated background light as well as laser echoes with known powers, energy levels, widths and delay times. The BCE also allowed monitoring of the transmitted laser energy, the angle measurements of the SRS, the co-alignment of the transmitted laser beam to the receiver line of sight, and performance of the flight science algorithms. Performance was evaluated during the GLAS development, before and after environmental tests, and after delivery to the spacecraft. The ICESat observatory was launched into a 94 degree inclination, 590 km altitude circular polar orbit on January 12, 2003. Beginning in early February, GLAS was powered on tested in stages. Its 1064 nm optical receiver was evaluated in a several tests using both solar background light and an internal test source. Laser 1 was activated on February 20, 2003. GLAS operated with Laser 1 for 38 continuous days on orbit using its 1064 nm receiver channel, producing over 130 million individual laser measurements of the Earth's surface and atmosphere. These nadir-pointed measurements fell along the ICESat's ground track, and spanned more than 4 cycles of the initial 8-day ICESat repeat orbit. The initial GLAS measurement set shows strong echo pulses from ranging to the surface topography, oceans, ice sheets and cloud tops, as well as profiles of clouds and aerosols. The GLAS measurements have unprecedented vertical and angular resolution, and show nearly continuous height profiles of ice, land and ocean surfaces or cloud tops, as well profiles of backscatter from thin clouds and aerosol layers. Examples of these GLAS measurements and an initial assessment of its science measurement performance will be presented.

C31D-02 1035h

ICESAT Laser Altimeter Pointing, Ranging and Timing Calibration from Integrated Residual Analysis

Scott B Luthcke[1] (301 614-6112; Scott.B.Luthcke@nasa.gov); David D. Rowlands[1]; Claudia C. Carabajal[2]; David Harding[1]; Jack Bufton[3]; Teresa Williams[4]

[1]NASA / GSFC, Space Geodesy Branch, Code 926, Greenbelt, MD 20771, United States

[2]NVI Inc., @ NASA / GSFC, Greenbelt, MD 20771, United States

[3]NASA / GSFC (ret.), Laboratory for Terrestrial Physics, Greenbelt, MD 20771, United States

[4]Raytheon ITSS, 1616 McCormick Dr., Upper Marlboro, MD 20744, United States

On January 12, 2003 the Ice, Cloud and land Elevation Satellite (ICESat) was successfully placed into orbit. The ICESat mission carries the Geoscience Laser Altimeter System (GLAS), which has a primary measurement of short-pulse laser-ranging to the Earth's surface at 1064nm wavelength at a rate of 40 pulses per second. The instrument has collected precise elevation measurements of the ice sheets, sea ice roughness and thickness, ocean and land surface elevations and surface reflectivity. The accurate geolocation of GLAS's surface returns, the spots from which the laser energy reflects on the Earth's surface, is a critical issue in the scientific application of these data. Pointing, ranging, timing and orbit errors must be compensated to accurately geolocate the laser altimeter surface returns. Towards this end, the laser range observations can be fully exploited in an integrated residual analysis to accurately calibrate these geolocation/instrument parameters. ICESat laser altimeter data have been simultaneously processed as direct altimetry from ocean sweeps along with dynamic crossovers in order to calibrate pointing, ranging and timing. The calibration methodology and current calibration results are discussed along with future efforts.

C31D-03 1050h

Precision of ICESat/GLAS Elevation Measurements Over the Continental ice Sheets.

Anita C Brenner[1] (301-614-5914; anita.brenner@gsfc.nasa.gov)

H. Jay Zwally[2] (301-614-5643; jay.zwally@gsfc.nasa.gov)

[1]Raytheon ITSS, code 971 Goddard Space Flight Center, Greenbelt, MD 20771, United States

[2]Oceans and Ice Branch Goddard Space Flight Center, code 971 Goddard Space Flight Center, Greenbelt, MD 20771, United States

The precision of the Geoscience Laser Altimeter System (GLAS) elevations is investigated using crossing arc residuals formed when ascending and descending passes cross over the same location on the ground. This study uses the 5 contiguous 8-day repeat cycles from February 20th, through March 28th, 2003 of laser number one data and the laser number two data available from Fall 2003. The errors in the GLAS elevations consist of - 1) residual orbit errors, 2) unmodeled attitude error which cause erroneous geolocation of the return, 3) distortion of the received return relative to the return processing model, and 4) errors in the tide and atmospheric delay models. The ICESat mission precision orbit and GLAS attitude supplied by UTCSR are used for this study. Evaluation of crossover residuals within each 8-day repeat cycle for both continental ice sheets shows consistency in the precision of laser 1 throughout all 5 repeats. The distortion of the received return is investigated and crossover residuals are calculated with and without editing the distorted returns showing how well the return processing algorithm accounts for the distortion. Crossover statistics for laser 2 are calculated within each 8-day period and compared with those from laser 1 to show if there are any differences in precision in the measurements between the lasers. The precision as a function of surface slope is presented showing that precision degrades with slope. Higher slopes cause more distortion of the return and increase the effect of the attitude error. Cross-laser crossovers are calculated giving a measure of laser biases over the ice sheets in areas where little surface elevation changes are expected. A comparison is also made with radar altimetry crossovers from ERS-2 showing the expected large improvement in GLAS precision in the higher sloping regions compared with the radar.

C31D-04 1105h

Calibration and Validation of the ICESat Laser Altimeter

Lori Magruder[1] (512-232-1987; magruder@csr.utexas.edu); Eric Silverberg[1] (ecsilverberg@att.net); Randall Ricklefs[1] (ricklefs@csr.utexas.edu); Charles Webb[1] (webb@csr.utexas.edu); Sungkoo Bae[1] (bae@csr.utexas.edu); Matthew Horstman[1] (rumalo@csr.utexas.edu); Tim Urban[1] (urban@csr.utexas.edu); Bob Schutz[1] (schutz@csr.utexas.edu)

[1]Center for Space Research, University of Texas at Austin, 3925 West Braker Lane Suite 200, Austin, TX 78759, United States

ICESat, the altimetry mission devoted to determination of temporal variations in the Polar Regions, launched in January of 2003. The satellite is in a nearly circular orbit with an inclination of 94 deg and a mean altitude of 600 km. The science goals of ICESat are to perform repeat elevation measurements over time with an accuracy of 1.5 cm/yr for a 100 km by 100 km area. Achievement of the science goals partly depends on the accurate determination of the laser direction as well as identifying any biases in the timing and/or range measurements. The pointing or directional information of the laser in the celestial reference frame is provided by an innovative CCD camera onboard ICESat. The laser pointing accuracy requirement is 1.5 arc seconds. The pointing information and the range data product combine to produce a measured altitude vector. The Earth illuminated spot location is the vector sum of the altitude vector and the precision orbit position vector in the terrestrial reference frame. In order to verify that the laser directional information is appropriately accurate, several experiments have been implemented during the initial 35+ days of laser operation. These experiments, performed at White Sands (New Mexico) and Bonneville (Utah), contribute to the validation of the scalar altitude measurement, the time of measurement and the position of the laser footprint to within 4.5 meters (1.5 arc second). The two methodologies that will be conducted at one or both of the aforementioned locations are an airborne camera system that will photograph at least one ICESat laser spot on the ground, and a ground detection array that will capture' multiple spots on the surface. Both techniques will provide independent measurements for comparison to the onboard laser directional data and the measurement timing. During the initial laser operations period (Feb 20th - Mar 29th), photographs were acquired and analyzed for position determination. Although the ground array did not capture and time tag an ICESat footprint, the calibration activities assisted in tuning the implementation of off-nadir pointing commands and contributed to analysis of laser offset biases. An integral part of the verification of the scalar altitude measurement is the comparison to an independent airborne LIDAR survey over the White Sands area. Existing data has been crucial to ongoing analysis of the altimetry data products and the accuracies. Further refinement is expected when laser operations and the calibration activities resume.

C

C31D-05 1120h

Calibration of the Geoscience Laser Altimeter System (GLAS) 1064 nm Atmospheric Channel

Stephen P Palm[1] (301-614-6276; spp@virl.gsfc.nasa.gov); Dennis L Hlavka[1] (301-614-6278; sgdlh@virl.gsfc.nasa.gov); William D Hart[1] (301-614-6272; billhart@virl.gsfc.nasa.gov); James D Spinhirne[2] (301-614-6274; James.D.Spinhirne@nasa.gov); Ashwin Mahesh[3] (301-614-6338; mahesh@agnes.gsfc.nasa.gov); Matthew J McGill[2] (301-614-6281; Matthew.J.McGill@nasa.gov); Ellsworth J Welton[2] (301-614-6279; Ellsworth.J.Welton@nasa.gov)

[1]Science Systems and Applications Inc, 10210 Greenbelt Rd., Lanham, MD 20706, United States

[2]Code 912, Goddard Space Flight Center, Greenbelt, MD 20771, United States

[3]Goddard Earth Sciences and Technology Center, Goddard Space Flight Center, Greenbelt, MD 20771, United States

In order to obtain quantitative information on clouds and aerosols from earth orbiting backscatter lidars, accurate calibration is of fundamental importance. For lidar wavelengths in the visible and UV portion of the spectrum, molecular scattering from the atmosphere in regions devoid of cloud or aerosol can be used as a calibration target'. However, at 1064 nm, the signal from molecular scattering is too small to be detected from space. In this case alternate calibrated backscatter targets such as clouds, aerosols or

the earth's surface must be used. This paper uses colocated measurements of cloud and aerosol backscatter obtained from a well calibrated airborne lidar system to obtain the lidar calibration constant for the 1064 nm channel of the Geophysics Laser Altimeter System (GLAS). In January, 2003 GLAS was launched into a near polar orbit aboard the Ice, Cloud and land Elevation Satellite (ICESat). In addition to a high resolution altimetry channel, GLAS contains both 1064 and 532 nm backscatter lidar channels. After a month long engineering checkout phase, the first laser (GLAS has 3 lasers) was turned on and GLAS began obtaining atmospheric and surface returns at 1064 nm. The 532 nm channel was not activated at this time due to engineering concerns. In this paper we describe the methodology used to calibrate the GLAS 1064 lidar channel using validation measurements acquired by the Cloud Physics Lidar (CPL) during the THORpex (THe Observing-system Research and predictability experiment) campaign in February-March 2003. The CPL is a compact and versatile 3 wavelength (1064, 532 and 355 nm) lidar system that flies on the NASA ER-2 aircraft and serves as the primary validation instrument for the GLAS atmospheric measurements. On three days during THORpex, the ER-2 was flown directly underneath the GLAS track for 20 to 30 minutes as GLAS flew overhead at roughly the mid point of the ER-2 flight leg. The GLAS under flights were performed in regions that contained varying cloud types with one day obtaining mainly marine boundary layer aerosol. The talk will present a short overview of the GLAS instrument, the derivation of the GLAS theoretical calibration based on the system parameters, and the use of the CPL data to obtain the GLAS 1064 nm calibration.

URL: http://glo.gsfc.nasa.gov

C31D-06 1135h

Surface Topography and Ice-Sheet Dynamics Over the Vostok Subglacial Lake, Antarctica

Weili Wang[1] (1-301-614-5729; weili@icesat2.gsfc.nasa.gov)

Frank Pattyn[2] (fpattyn@vub.ac.be)

Jay Zwally[3] (zwally@icesat2.gsfc.nasa.gov)

Matthew Beckley[1] (matt@icesat2.gsfc.nasa.gov)

[1]Raytheon,ITSS, NASA/Goddard Space Flight Center, Code 971, Greenbelt, MD 20771, United States

[2]Department of Geography, Vrije Universiteit Brussel, Pleinlaan 2, B-1050 Brussel, Belgium

[3]Ocean and Ice Branch, NASA/Goddard Space Flight Center, Code 971, Greenbelt, MD 20771, United States

Surface topography in the region of the Vostok subglacial lake, Antarctica, from the previous analysis of radio-echo sounding and satellite radar-altimeter data indicated a trough (2-8 m) along the western margins and a rise (5-7 m) along the eastern margins. The elevation data obtained from Ice, Cloud, and Land Elevation Satellite (ICESat) show the troughs and rises in more detail, such as a deeper trough (18 m) in the western margin. These troughs and rises have been assumed to be caused by ice dynamics as the ice flows from grounded to floating and to re-grounded status, and associated buoyancy effect. We use a newly developed time-dependent 3-D thermo-mechanical higher-order numerical model to simulate the ice flow across Vostok subglacial lake. By comparing the surface topography generated from the model with the ICESat measurements, the ice-sheet behavior is investigated to explain in more detail the cause of the troughs and rises.

C31D-07 1150h

ICESat Observations of Southern Alaska Glaciers

Jeanne Sauber[1] (301-614-6465; jeanne@steller.gsfc.nasa.gov)

Bruce F. Molnia[2] (703-648-4120; bmolnia@usgs.gov)

Darius Mitchell[3]

[1]Geodynamics Branch, NASA's Goddard Space Flight Center, Greenbelt, MD 20771, United States

[2]U.S. Geological Survey, 926A National Center, Reston, VA 20192, United States

[3]Dept of Geological Sciences, Case Western Reserve University, Cleveland, OH 44106, United States

In late February and March, 2003, the Ice, Cloud, and land Elevation Satellite (ICESat) measured ice and land elevations along profiles across southern Alaska. During this initial data acquisition stage ICESat observations were made on 8-day repeat tracks to enable calibration and validation of the ICESat data products. Each profile consists of a series of single point values derived from centroid elevations of an ≈70 m diameter laser footprint. The points are separated by ≈172 m along track. Data sets of 8-day observations (an ascending and descending ground track) crossed the Bering and Malaspina Glacier. Following its 1993–1995 surge, the Bering Glacier has undergone major terminus retreat as well as ice thinning in the ablation zone. During the later part of the 20th century, parts of the Bering Glacier's piedmont lobe thinned ≥ 5 m/yr, while that of the Malaspina thinned by about 1 m/yr. The multiple observation profiles across the Bering and Malaspina piedmont lobes obtained in February/March are being geolocated on Landsat-7 images and the elevation profiles will be used for a number of scientific objectives. Based on our simulations of ICESat performance over the varied ice surface of the Jakobshavn Glacier of Greenland [*Mitchell et al.*, 2003], we expect to measure annual, and possibly seasonal, ice elevations changes on the large southern Alaskan glaciers. Using elevation data obtained from a second laser, we plan to estimate ice elevation changes on the Bering Glacier between March and October 2003.

C31D-08 1205h

A Test of Ocean Mesoscale Monitoring With ICESat Altimetry

Robert R Leben[1] (3034924113; leben@colorado.edu)

George H Born[1] (georgeb@colorado.edu)

Timothy J Urban[2] (urban@csr.texas.edu)

Bob E Schutz[1] (schutz@csr.texas.edu)

[1]Colorado Center for Astrodynamics Research, University of Colorado 431 UCB, Boulder, CO 80309-0431, United States

[2]The University of Texas at Austin/Center for Space Research, 3925 West Braker Lane #200, Austin, TX 78759, United States

The ocean mesoscale is under sampled even with the four operational microwave altimeters currently on orbit. Laser altimetry from ICESat could potentially provide a substantial amount of ocean topography measurements that would improve ocean mesoscale sampling if we understand the performance of the laser measurement system over the ocean and process the data in a manner consistent with microwave altimeter mesoscale mapping products. To test this capability, we compare along track ICESat sea level anomaly in the Gulf of Mexico to mesoscale sea surface height anomaly maps derived from Jason-1, TOPEX/POSEIDON, Geosat Follow-on and Envisat microwave altimetry. The anomalous topographic signals associated with Loop Current fronts and eddies are clearly seen in the 40 Hz ICESat data, which are verified by coincident microwave altimetry and radiometric images of sea surface temperature and ocean color. The remaining high frequency, fine spatial scale differences between the laser and microwave measurements can be mitigated by a variety of filtering techniques to reduce the noise in the laser measurements; however, systematic and non-random errors need further investigation before more accurate mesoscale altimetry maps can be produced by blending laser and microwave altimetry.

C32A MCC: Level 1 Wednesday 1330h

NASA's Ice, Cloud, and Land Elevation Satellite (ICESat) Mission: Scientific and Technological Achievements III Posters *(joint with A, B, G, H, OS)*

Presiding: **H J Zwally,** NASA Goddard Space Flight Center; **B E Schutz,** Center for Space Research, University of Texas at Austin; **C A Shuman,** NASA Goddard Space Flight Center

C32A-0417 1330h POSTER

Glaciology From ICESat - West Antarctic Divide

Vijay P. Suchdeo[1] (301-614-5918; vsuchdeo@icesat2.gsfc.nasa.gov)

Chris A. Shuman[2] (301-614-5706; Christopher.A.Shuman@nasa.gov)

[1]NVI, Inc., Oceans and Ice Branch, Laboratory for Hydrospheric Processes, NASA Goddard Space Flight, Code 971, Building 33, Room B209B, Greenbelt, MD 20771, United States

[2]Oceans and Ice Branch, Laboratory for Hydrospheric Processes, NASA Goddard Space Flight Center, Code 971, Building 33, Room A210, Greenbelt, MD 20771, United States

On January 12, 2003, NASA launched the Ice, Cloud, and land Elevation Satellite (ICESat) which is carrying the Geoscience Laser Altimeter System (GLAS). Orbiting at nearly 17,000 miles per hour (6 km/sec), ICESat/GLAS is providing data with unprecedented accuracy on the globe's third dimension, elevation. ICESat is the latest in a series of NASA's robotic Earth-orbiting spacecraft designed to study the environment of our home planet and how it may be changing. The main mission of ICESat is to measure the surface elevation of the large ice sheets covering Antarctica and Greenland. While several years of measurements are needed to determine mass balance changes, ICESat is already revealing details of ice sheet surface features from deep in the interior out to the surrounding sea ice. This presentation is based on 14 descending tracks from cycles 1-6 from ICESat's first mission phase (GLAS Laser 1 of 3) that occurred February 20 to March 29, 2003. Although the data are not yet fully calibrated, the Release 11 product utilized here is quite mature. Data from ICESat's second mission phase (Laser 2 of 3) is not included here. Using a technique that matches elevation data to gain and energy values enables rapid initial quality assessments. These assessments show that a substantial number of these West Antarctic elevation profiles are partially or substantially impacted by meteorological phenomena (clouds or blowing snow). This presentation will: 1) define the West Antarctic ice sheet's divide location and elevation; 2) illustrate the overall topography of a portion of West Antarctica; 3) demonstrate repeat track elevation analysis and composite track development; 4) discuss factors influencing selection of profiles for analysis; and 5) show other specific features of interest observed within the area.

C32A-0418 1330h POSTER

Accumulation-Driven and Long-Term Elevation Change on the Southern Greenland Ice Sheet

Joseph R. McConnell[1] (775-673-7348; jmcconn@dri.edu)

Robert J. Arthern[2] (1223 221400; rart@bas.ac.uk)

[1]Division of Hydrologic Sciences, Desert Research Institute, 2215 Raggio Parkway, Reno, NV 89509, United States

[2]Physical Sciences Division, British Antarctic Survey, Madingley Road, Cambridge CB30ET, United Kingdom

Understanding the past and current mass balance of the Greenland Ice Sheet (GIS) is critical to predicting changes in sea level. Repeat altimetry surveys of ice sheet elevation change (dH/dt) from 1978 to 1988 and 1993/94 to 1998/99 suggest that the higher elevation parts (above 2000 m) of the southern ice sheet are in overall mass balance, with some regions observed to be thickening (gaining) and others thinning (losing). While there was general agreement in the observed spatial patterns between the two time periods, with thickening to the west of the ice sheet divide and thinning to the east in southern Greenland, significant differences in dH/dt were found. Ice sheet elevation change includes both long-term and short-term components and the short-term components likely mask repeat altimetry measurements primarily intended to monitor the long-term behavior of the ice sheet. Long-term changes in ice sheet elevation are caused by isostatic rebound and ice sheet dynamics. Short-term changes are driven by spatia

C32A-0419 1330h POSTER

Glaciological Field Measurements in West Antarctica in Support of ICESat Laser Altimetry

Gordon S Hamilton[1] (207-581-3446; gordon.hamilton@maine.edu)

V. Blue Spikes[1]

H. Jay Zwally[2]

[1]Climate Change Institute, University of Maine, 303 Bryand Global Sciences Center, Orono, ME 04469, United States

[2]Code 971, NASA/Goddard Space Flight Center, Greenbelt, MD 20771, United States

We have been conducting several ground-based glaciological activities on the West Antarctic Ice Sheet to assist in the calibration/validation of ICESat laser altimeter data and to interpret elevation change results. In December 2002, just prior to the launch of ICESat, we conducted detailed geodetic mapping at two sites (100 km^2 and 25 km^2) to characterize the shape of the ice sheet surface. The ground measurements will be compared with 8-day repeat satellite data to assist in the evaluation of laser ranging accuracy. We