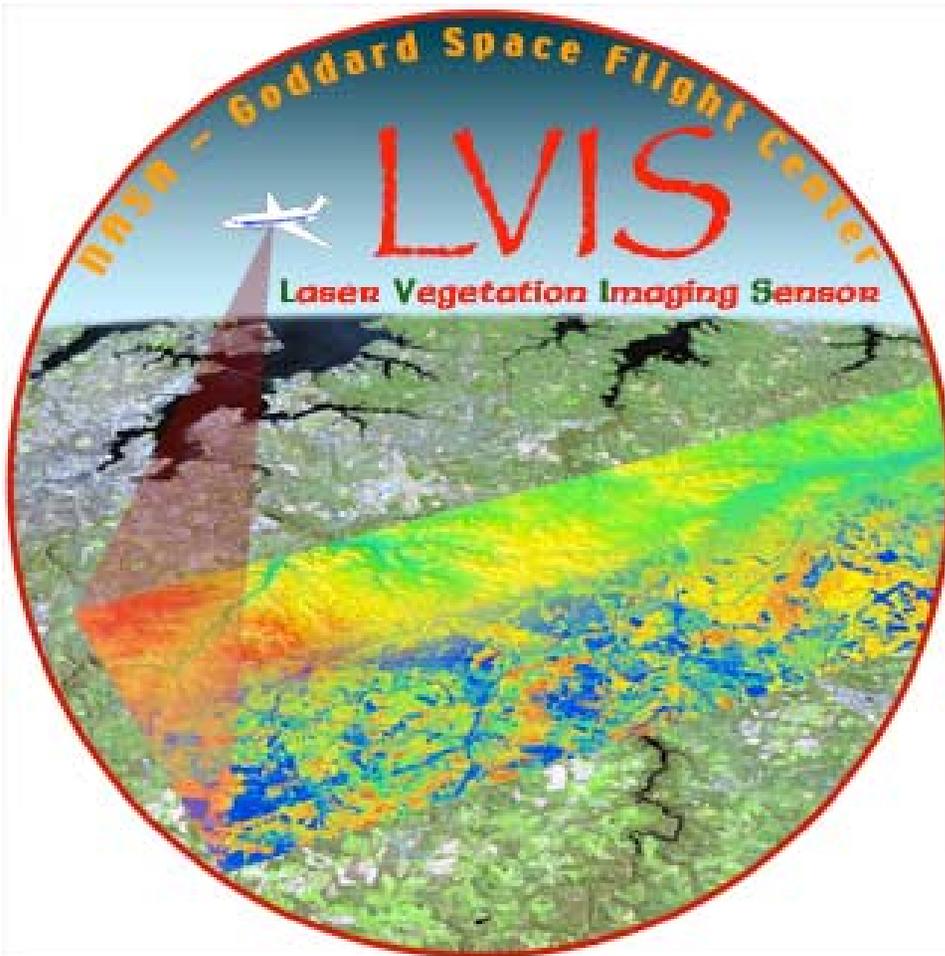


The Laser Vegetation Imaging Sensor (LVIS)



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David Rabine and Phillip Padden

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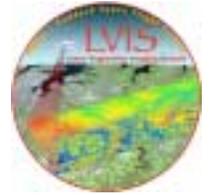
NASA Goddard Space Flight Center, Greenbelt MD

Wayne Welch

Welch Mechanical Designs LLC, Glen Burnie MD



Laser Vegetation Imaging Sensor

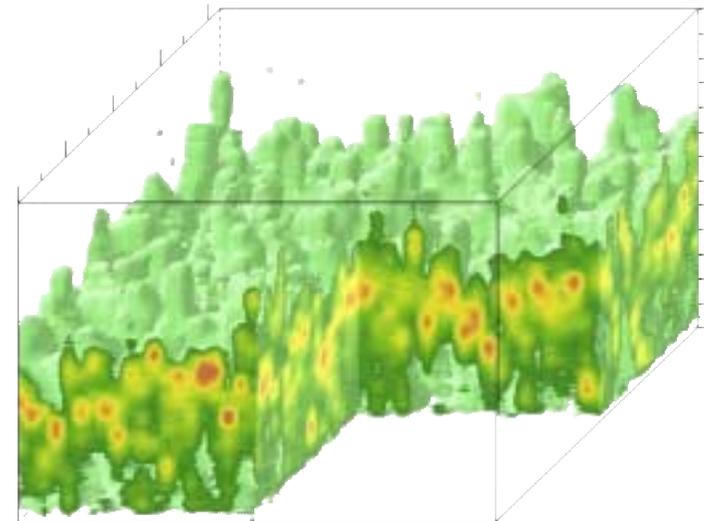
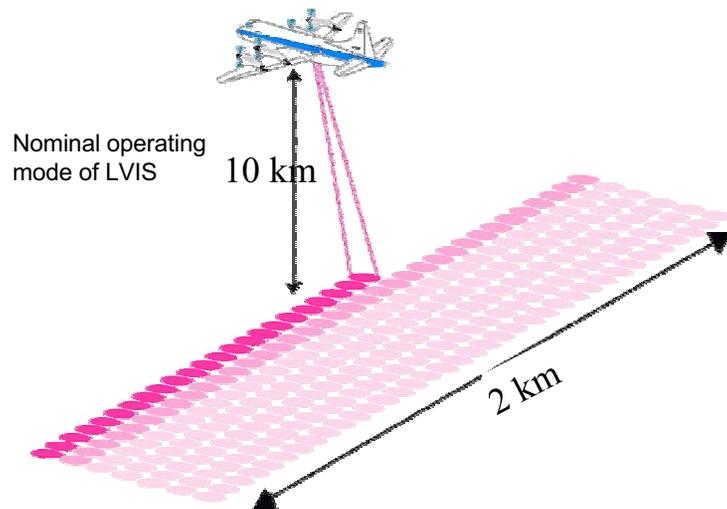


The Laser Vegetation Imaging Sensor (LVIS) was developed to support:

- Ranging and imaging techniques for future spaceborne implementation of wide-swath laser altimetry capable of global mapping of topography and vegetation
- Science applications of full-waveform altimetry, e.g., carbon cycle studies, solid earth science, natural hazards, hydrology, surface roughness, fire modeling, etc.
- Return-waveform processing algorithms and measurement approach development



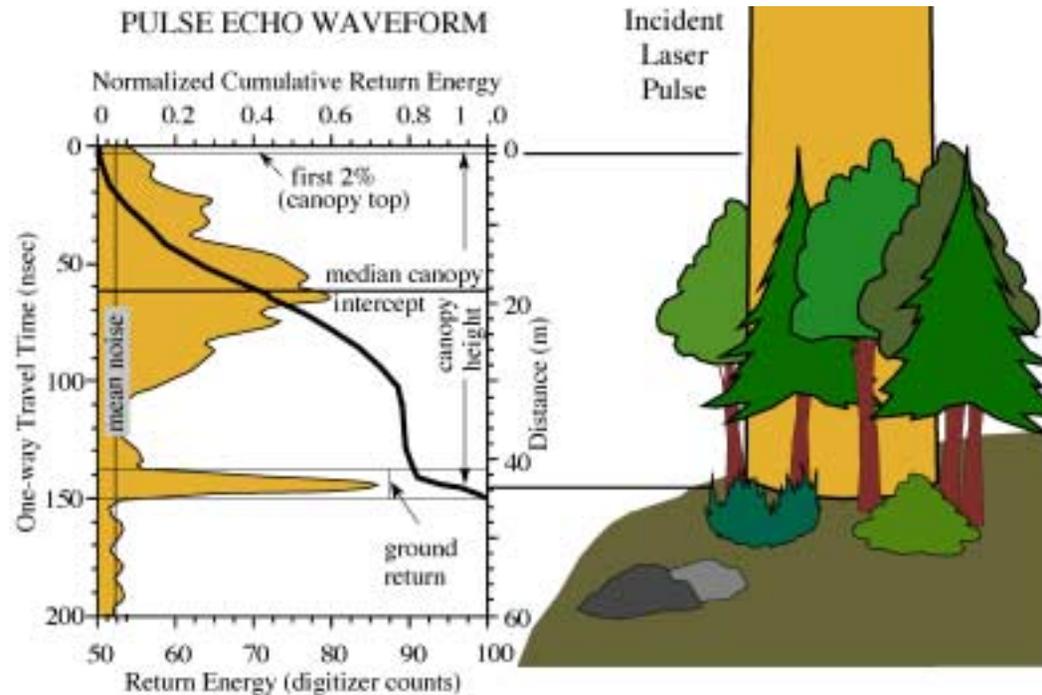
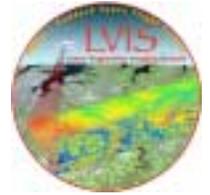
Sensor installed in NOAA Cessna Citation II



3-D surface structure of a 1 km² area of Costa Rica, mapped using LVIS



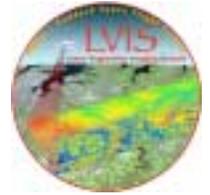
LVIS Primary Data Products



- ❖ Standard (publicly-released) data products from the LVIS system include images of
 - Ground elevation (mean elevation of lowest reflection within footprint),
 - Vertical extent/Canopy height (relative to ground reflection),
 - Height of median energy return (relative to ground reflection),
 - Ground vs. canopy energy ratios (e.g., canopy cover)
 - Quadrant heights (percentiles), complexity, pulse spreading for ground and canopy returns
- ❖ Parameter Images are a thousand times smaller than raw data => more accessible
- ❖ Individual proposal collaborations possible for unique application or reprocessing of waveforms



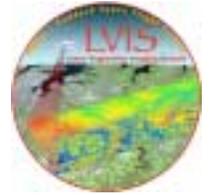
LVIS Instrument Status



- ❖ Instrument completely redesigned in 2001/2002.
- ❖ Smaller, lighter, more accurate, and more reliable.
- ❖ Added Applanix unit - coupled GPS/INS - greatly improved position and attitude knowledge resulting in better geolocation.
- ❖ Eliminated beam shifting issue from original LVIS instrument that resulted in processing difficulties.
- ❖ Significantly lowered power use - allows LVIS to operate on small aircraft.
- ❖ Working with NOAA on their Cessna Citation II jet aircraft.
 - Excellent platform
 - 5+ hour flight duration
 - Experienced remote sensing pilots



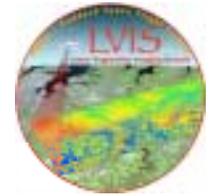
LVIS on the NOAA Citation II



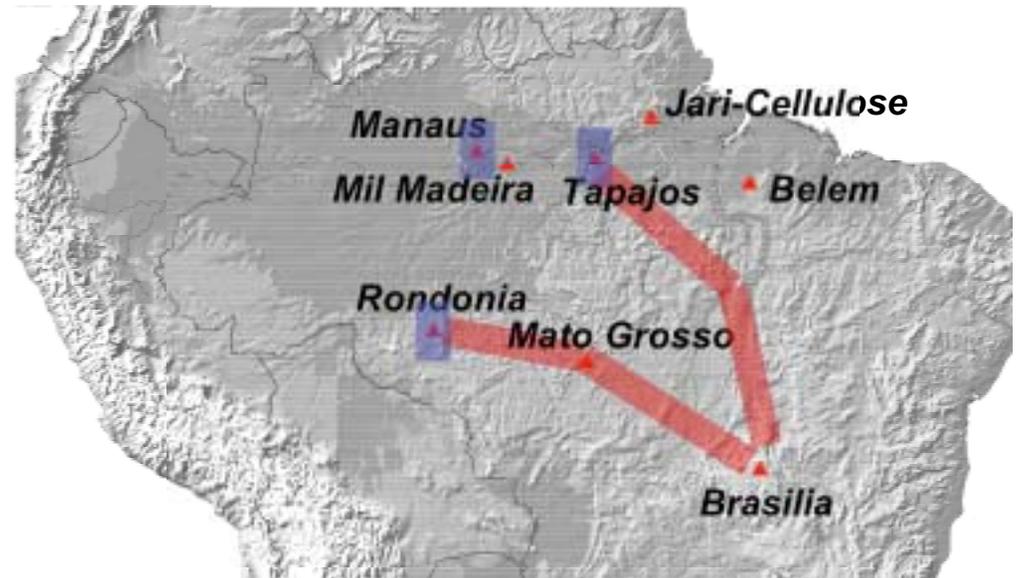
Bryan Blair
James.B.Blair@nasa.gov



LVIS Flight Missions: Brazil 2003 for NASA LBA-Program



- ❖ LVIS originally selected to fly in Brazil in 2003 as part of LBA Airborne Program
- ❖ Sites to be overflown included LBA study areas in Belem, Santarem, Manaus, and Rondonia, as well as two, 2000km-long transects from Rondonia to Brasilia, and Brasilia to Santarem
- ❖ Flights cancelled in June 2003
- ❖ Possible Brazil Campaign in 2005?

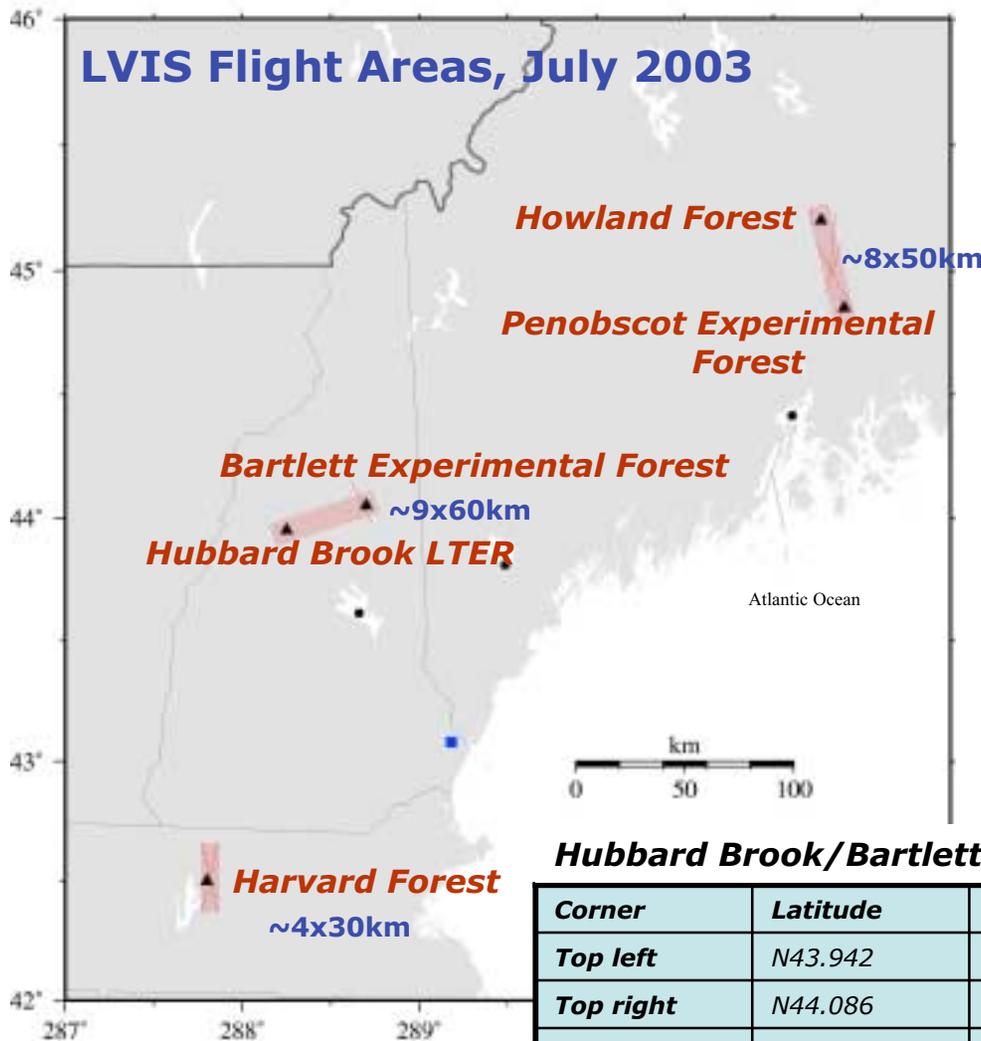
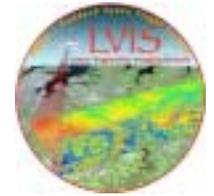


Overview of Brazil Mapping Plans

- ❖ Belem: 2km-wide transects
 - 2km-wide science transects over São Francisco do Pará, Capitão Poço and other selective logging sites
- ❖ Jari: 2km-wide transects (during transit to Santarem)
 - 2km-wide transects across plantation plots (various ages)
- ❖ Tapajos mapping: 32 x 75 km area
- ❖ Madeireira Mil: 2km-wide transect (during transit to Manaus)
- ❖ Manaus mapping: 45 x 50 km area
- ❖ Ji-Parana mapping: 20 x 90 km area
- ❖ 2km-wide Transect 1 : Porto Velho to Brasilia via Mato Grosso
- ❖ 2km-wide Transect 2: Brasilia to Santarem.
 - Repeats AVIRIS line



2003 Backup Plan: Northeastern US for Pre-NACP Activities



- ❖ In July, 2003 LVIS was used to map a total of ~2,000 km² in Maine, New Hampshire, and Massachusetts.
- ❖ Data have 20 m footprints, contiguous along/across track
- ❖ Standard data product images will be available by July 2004

Howland/Penobscot Coverage

Corner	Latitude	Longitude
Top left	N45.25	E291.205
Top right	N45.36	E291.265
Bottom right	N44.84	E291.435
Bottom left	N44.73	E291.375

Harvard Forest Coverage

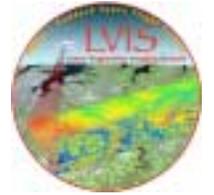
Corner	Latitude	Longitude
Top left	N42.67	E287.765
Top right	N42.67	E287.876
Bottom right	N42.35	E287.876
Bottom left	N42.35	E287.765

Hubbard Brook/Bartlett Coverage

Corner	Latitude	Longitude
Top left	N43.942	E288.12
Top right	N44.086	E288.715
Bottom right	N44.038	E288.800
Bottom left	N43.896	E288.21



Pre-NACP Mission Information



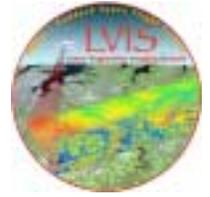
❖ Quick look images are available at: <http://www.lbaeco.org/NACS/lvis.htm>

Area	Dates	Approx. Area Covered	Approx Amount of Data	Footprint Diameter
Harvard Forest	20th July 2003	30km by 4km	4GB	20m
Hubbard Brook and Bartlett	18th, 20th, 26th July 2003	60km by 9 km	7.5GB	20m
Howland and Penobscott	26th July 2003	50km by 8 km	5.5GB	20m
Maryland*	July 13th, August 14th, 15th, 16th 2003	60km x 18km (~1,000 km ²)	25GB	12m

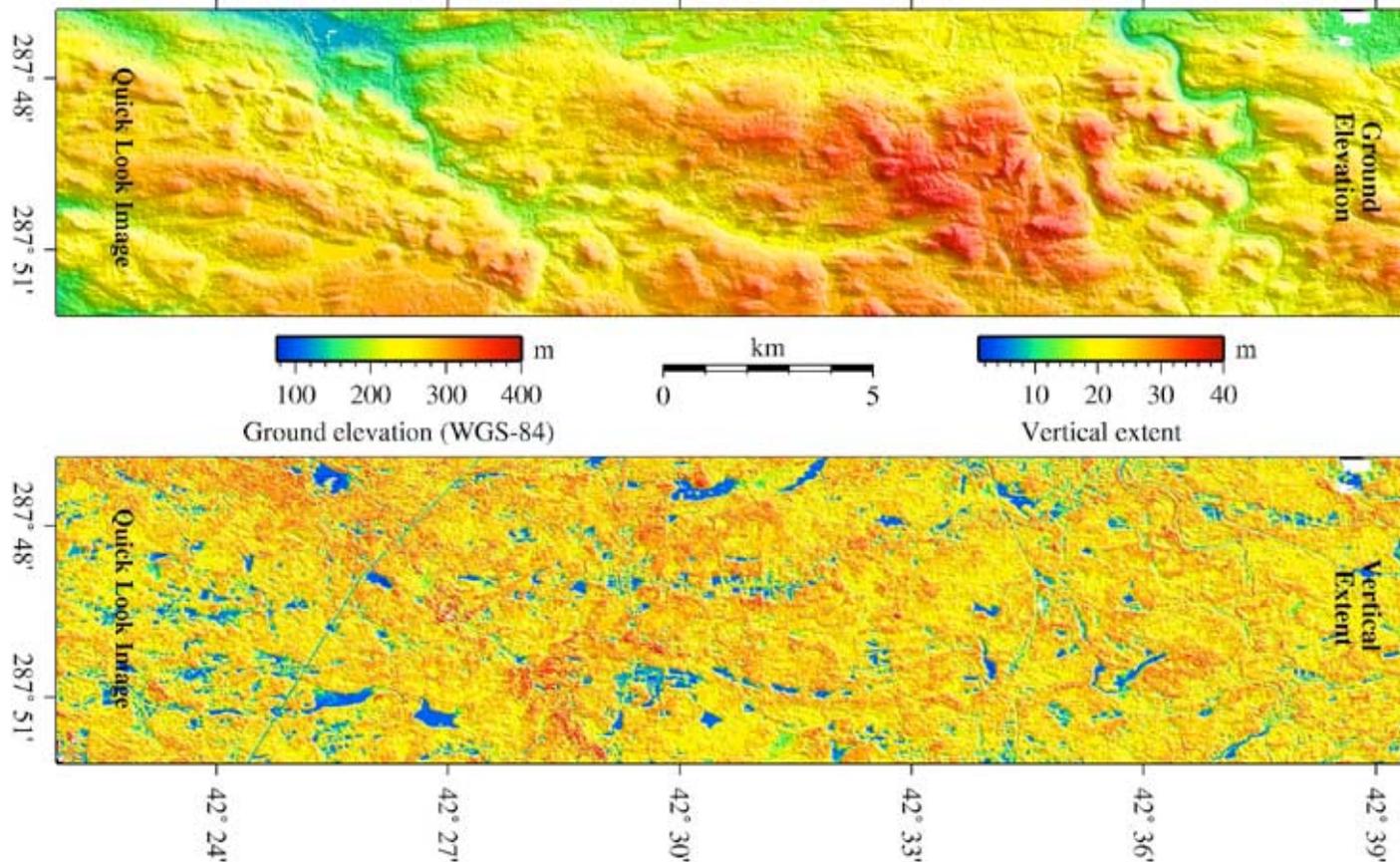
- ❖ Chibougamau-Howland Transect attempted 3 times, but cancelled due to weather conditions
- ❖ Oakridge, TN, flight also cancelled due to weather
- ❖ MD data collected in collaboration with RESAC at UMD & GMU/VAcess, funded by NASA.



Pre-NACP LVIS Flights: Harvard Forest

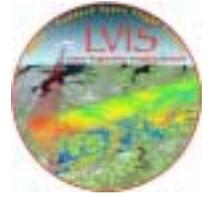


- ❖ Harvard Forest flight, 20th July 2003
- ❖ 20m footprint spacing, contiguous data along, across-track
- ❖ Coverage of approx. 30 by 4 km
- ❖ LVIS coverage coincident with AVIRIS

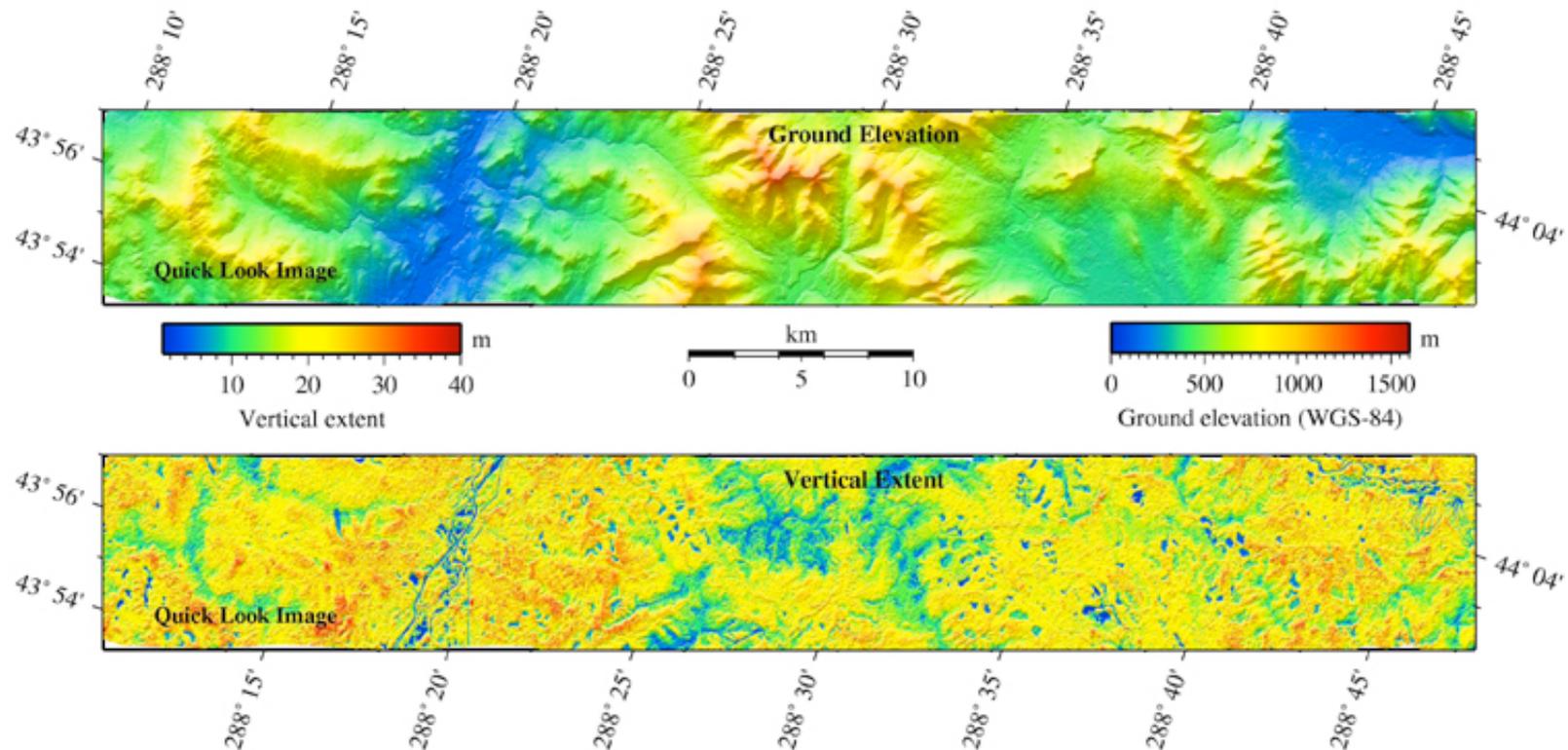




Pre-NACP LVIS Flights: Hubbard Brook and Bartlett

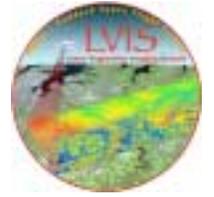


- ❖ Hubbard Brook and Bartlett flight, 18th July 2003, with fill-in for clouds on 20th and 26th July 2003
- ❖ 20m footprint spacing, contiguous data along, across-track
- ❖ Coverage of approx. 60 by 9 km
- ❖ LVIS coverage coincident with AVIRIS

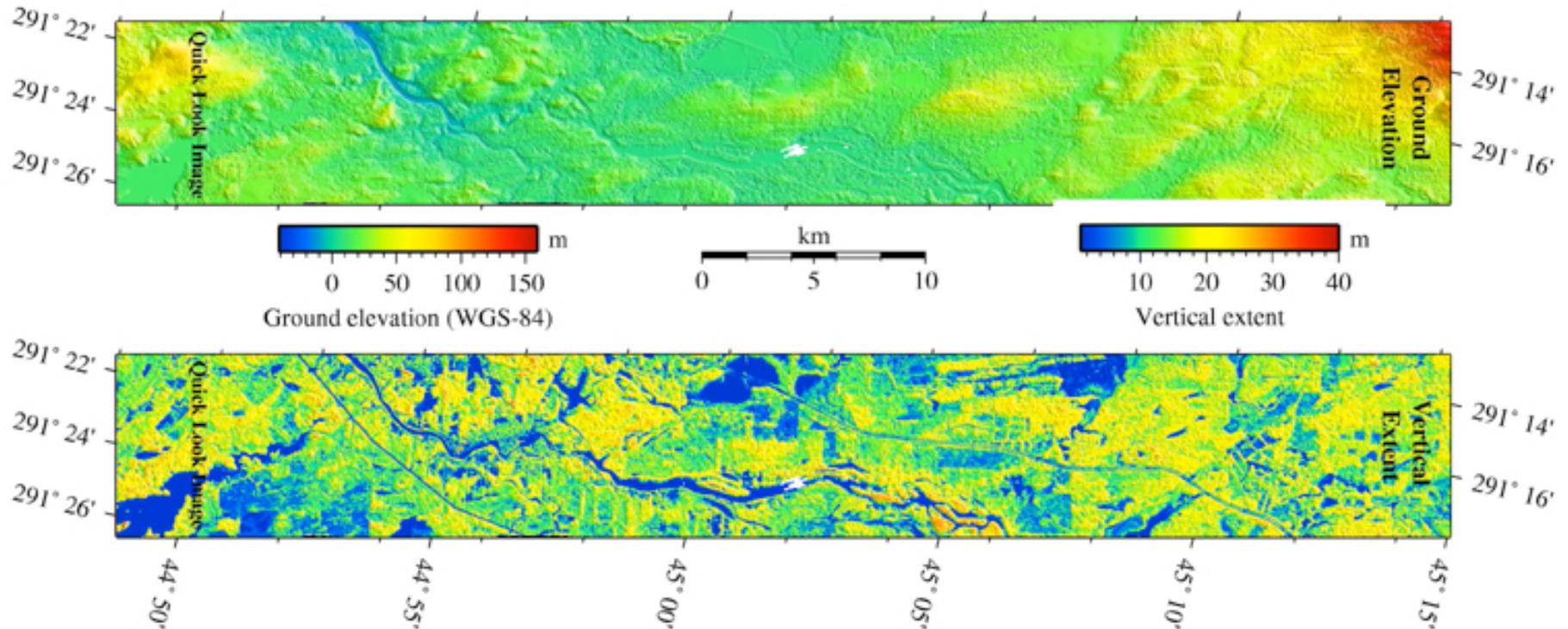




Pre-NACP LVIS Flights: Howland and Penobscot

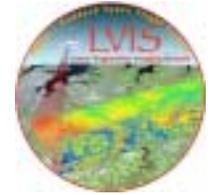


- ❖ Howland and Penobscot flight, 18th July 2003, with cloud fill-in flights on 20th, 26th July 2003
- ❖ 20m footprint spacing, contiguous data along, across-track
- ❖ Coverage of approx. 60 by 9 km
- ❖ LVIS coverage coincident with AVIRIS

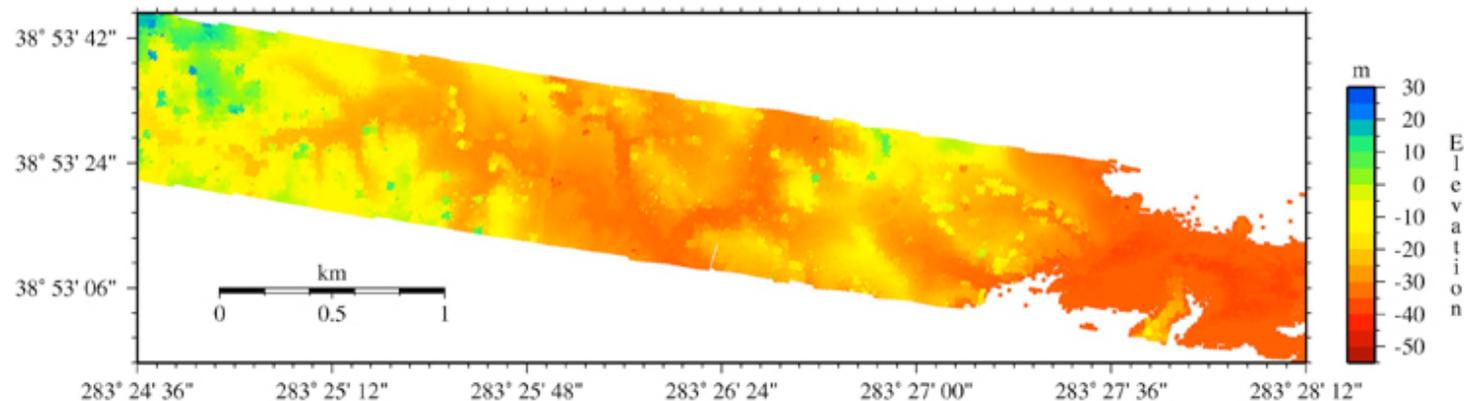
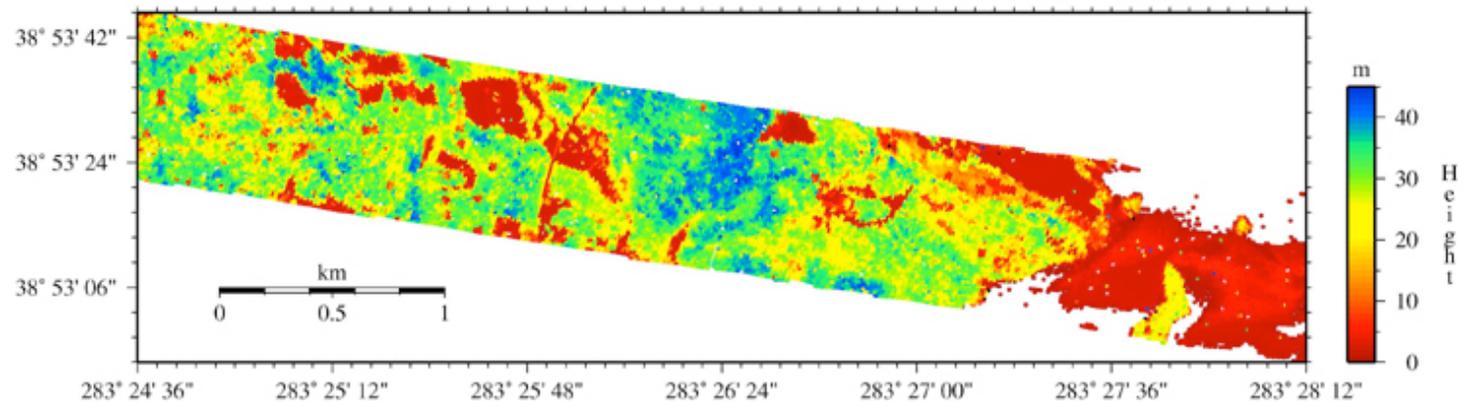




Pre-NACP LVIS Flights: SERC

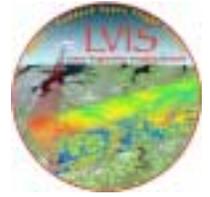


- ❖ SERC flight, 16th August 2003
- ❖ 12m footprint spacing, contiguous data along, across-track
- ❖ Coverage of approx. 0.6km by 4 km





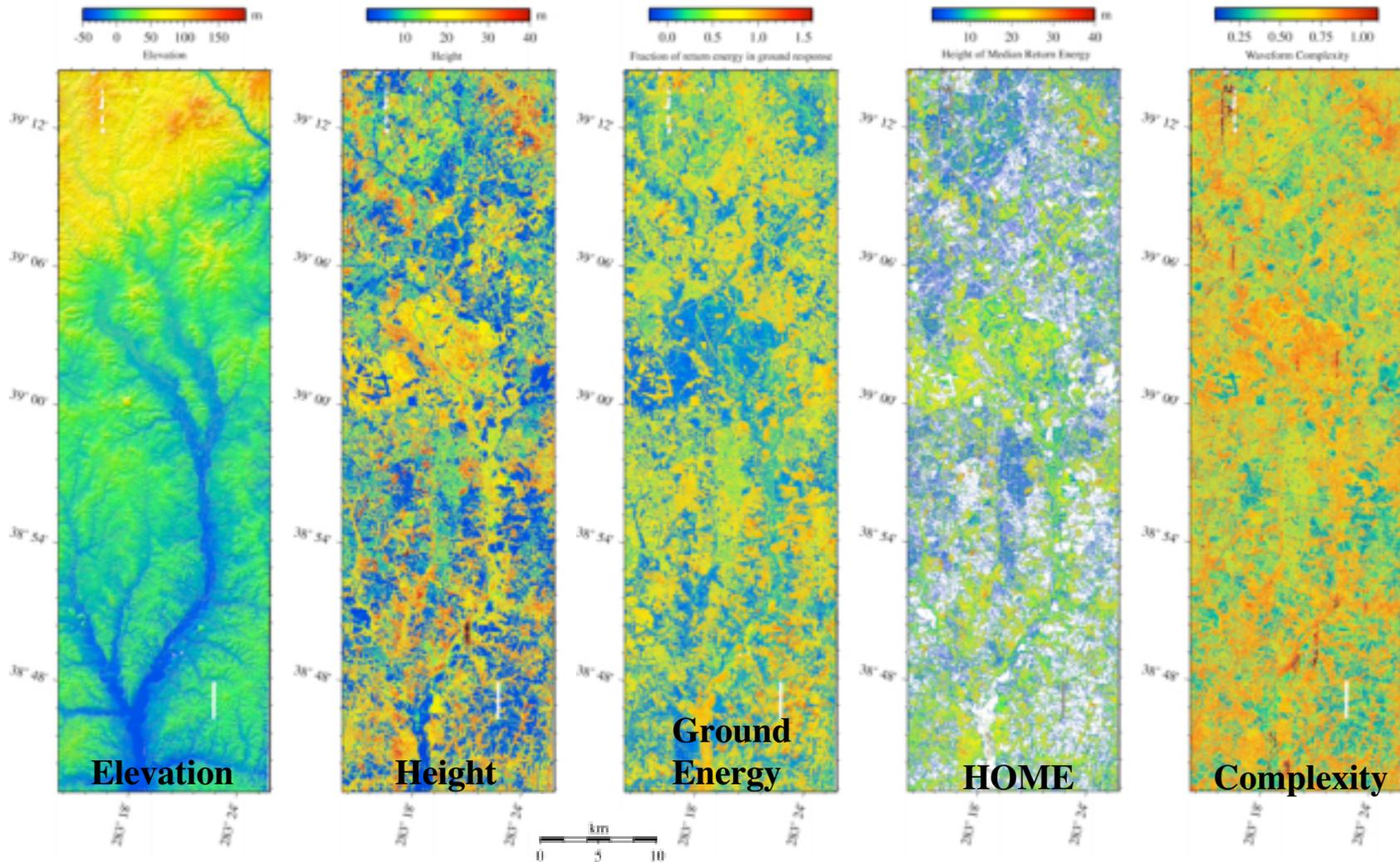
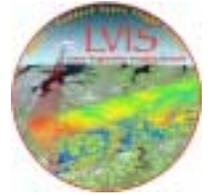
Overview of Processing System



- ❖ Original geolocation approach developed in-house for ATLAS/SLICER in IDL programming language with some C pre-processing. Manual, iterative parameter estimation.
- ❖ LVIS wide-swath scanning system overtaxed old parameter calibration software.
 - Too many parameters needed to be included, some time-varying.
- ❖ Processing software has now been rewritten (Blair, McCarthy, Hofton, Rabine, and Luthcke). Software is based on the advanced laser altimeter parameter estimation system, developed for SLA and VCL by Scott Luthcke/926.
- ❖ Parameter estimation is mostly automated now and works great.
- ❖ Processing system is dual processor, linux-based, capable of handling large (>100GB) data sets.



Multiple Data Products Extracted from Return Waveforms

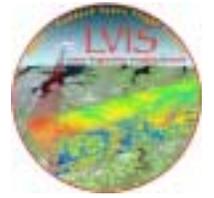


- ❖ Patuxent Watershed in Maryland, August 2003, collected in leaf-on conditions
- ❖ Data collected in collaboration with UMD/RESAC and GMU/VAccess, funded by NASA.

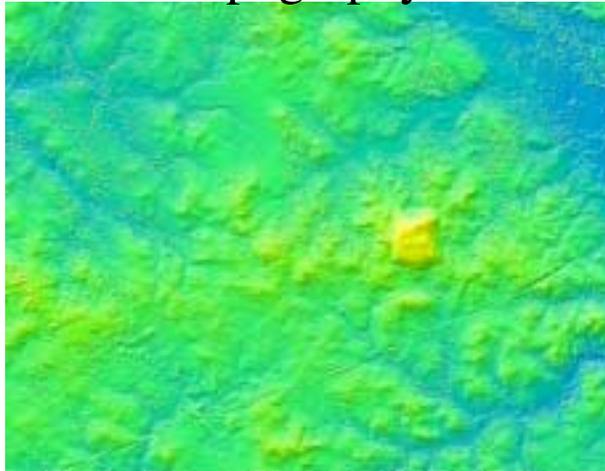
Bryan Blair
James.B.Blair@nasa.gov



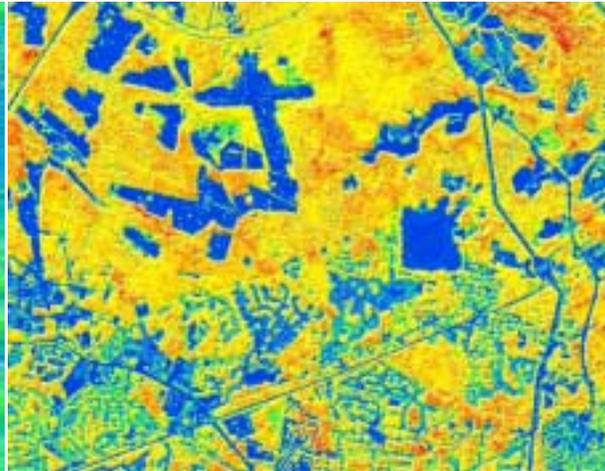
Multiple Data Products Extracted from Return Waveforms cont.



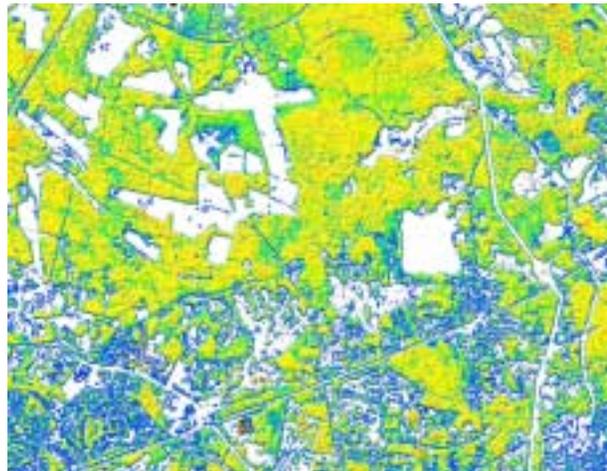
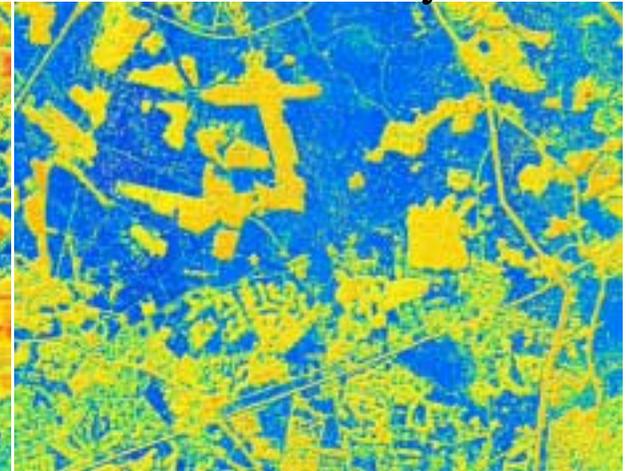
Sub-canopy
Topography



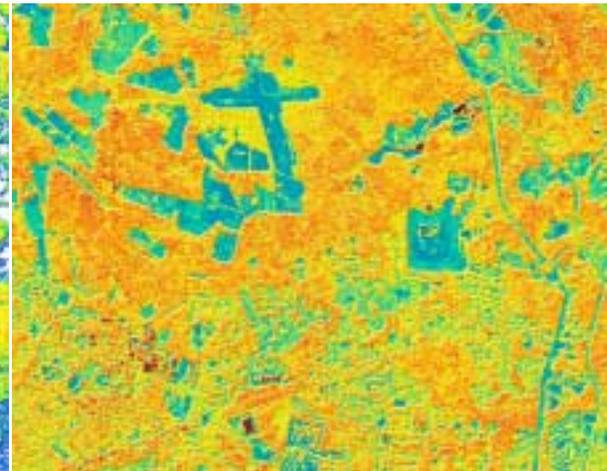
Vertical
Extent



Ground
Availability



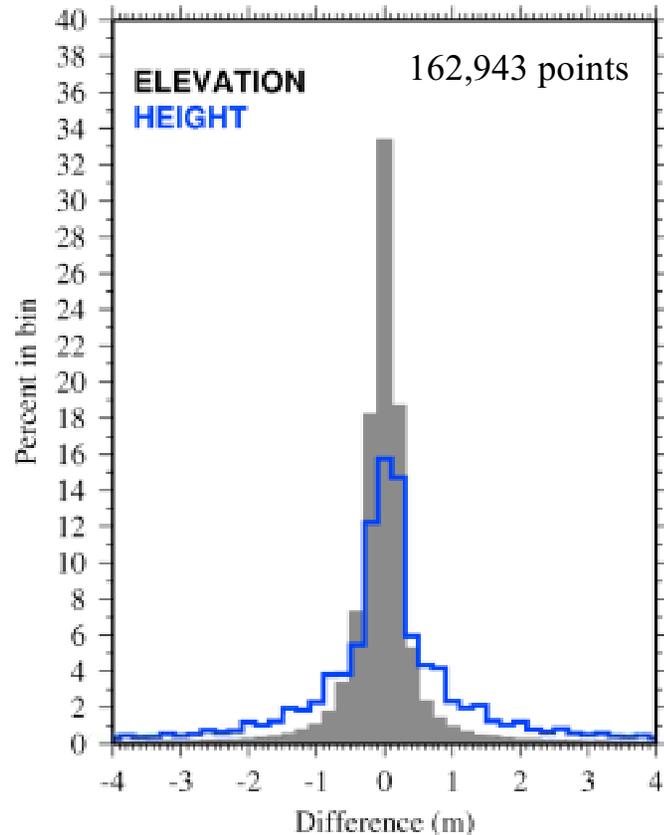
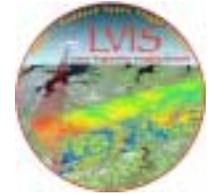
Height of Median Energy



Return Complexity



Preliminary Assessment of 2003 Data Precision: Crossover Comparisons



- ❖ We assess data precision by comparing elevation and height products of coincident footprints

Using data from Maryland 2003:

- 12.5m-wide footprints
- 6.2km above-ground-level flight altitude
- Comparing all footprints whose centers lie within 1m of each other, 162,943 points (regardless of land cover, slope etc.)

All data

	Topography	Height
μ	0.10 m	-0.10 m
σ	3.79 m	5.83 m

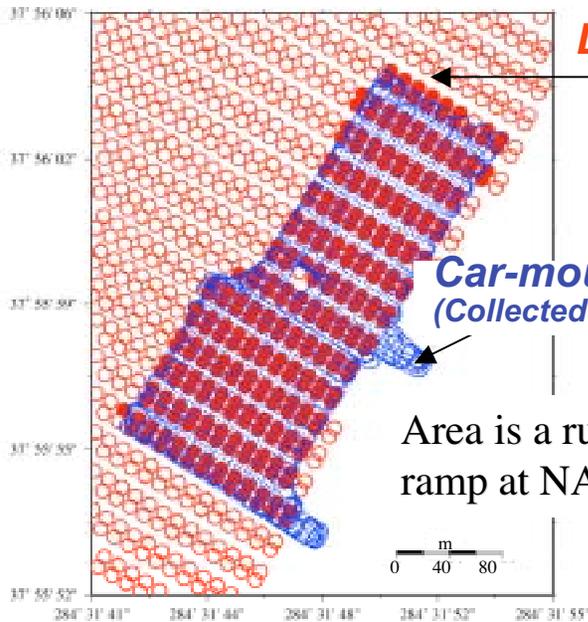
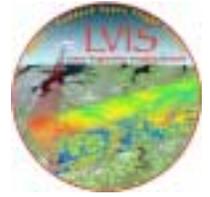
5% of outliers removed

	Topography	Height
μ	0.02 m	-0.05 m
σ	0.23 m	1.00 m

- ❖ Preliminary results are consistent with each other under a variety of landcover conditions
- ❖ Outliers caused by:
 - Quicklook processing method (applied day after the flight) occasionally misses the ground (uses a conservative thresholding approach).
 - Saturated pulses from a flooded area (flat smooth water below vegetation)
 - Noise in the detector that will be filtered out



Preliminary Assessment of 2003 Data Accuracy: Comparison with Ground GPS

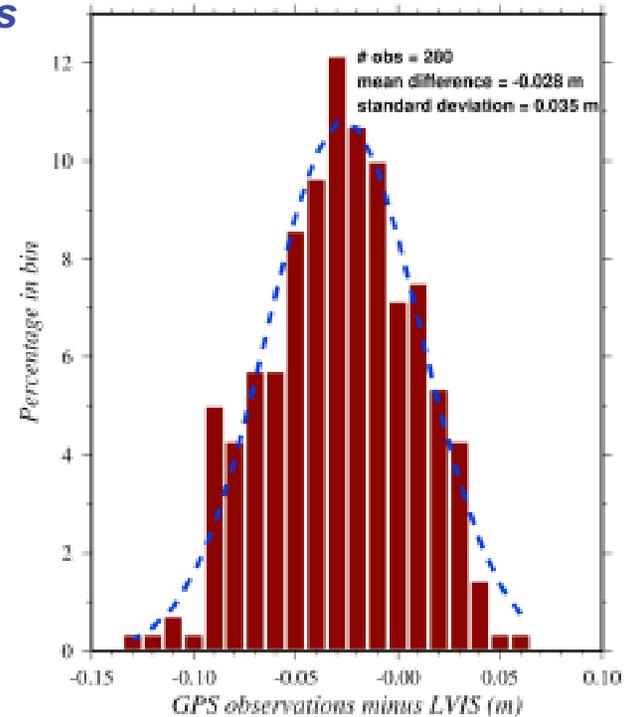


LVIS footprint locations
Collected in August 2003
6.2 km above ground level
12.5m-wide footprint

Car-mounted GPS survey points
(Collected in 1996 by E. Frederick/ATM)

Area is a runway access ramp at NASA Wallops FF

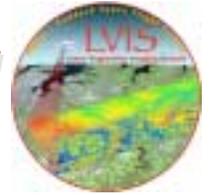
*Histogram of Elevation Differences
GPS minus LVIS*



- ❖ Comparison of LVIS elevations to GPS surveyed-elevations of access ramp/runway at NASA Wallops Flight Facility (WFF), VA
 - Differences are normally distributed.
 - Mean difference = -2.8 cm.
 - Standard Deviation = 3.5 cm.
- ❖ Preliminary results have few cm-level accuracy over flat, simple terrain

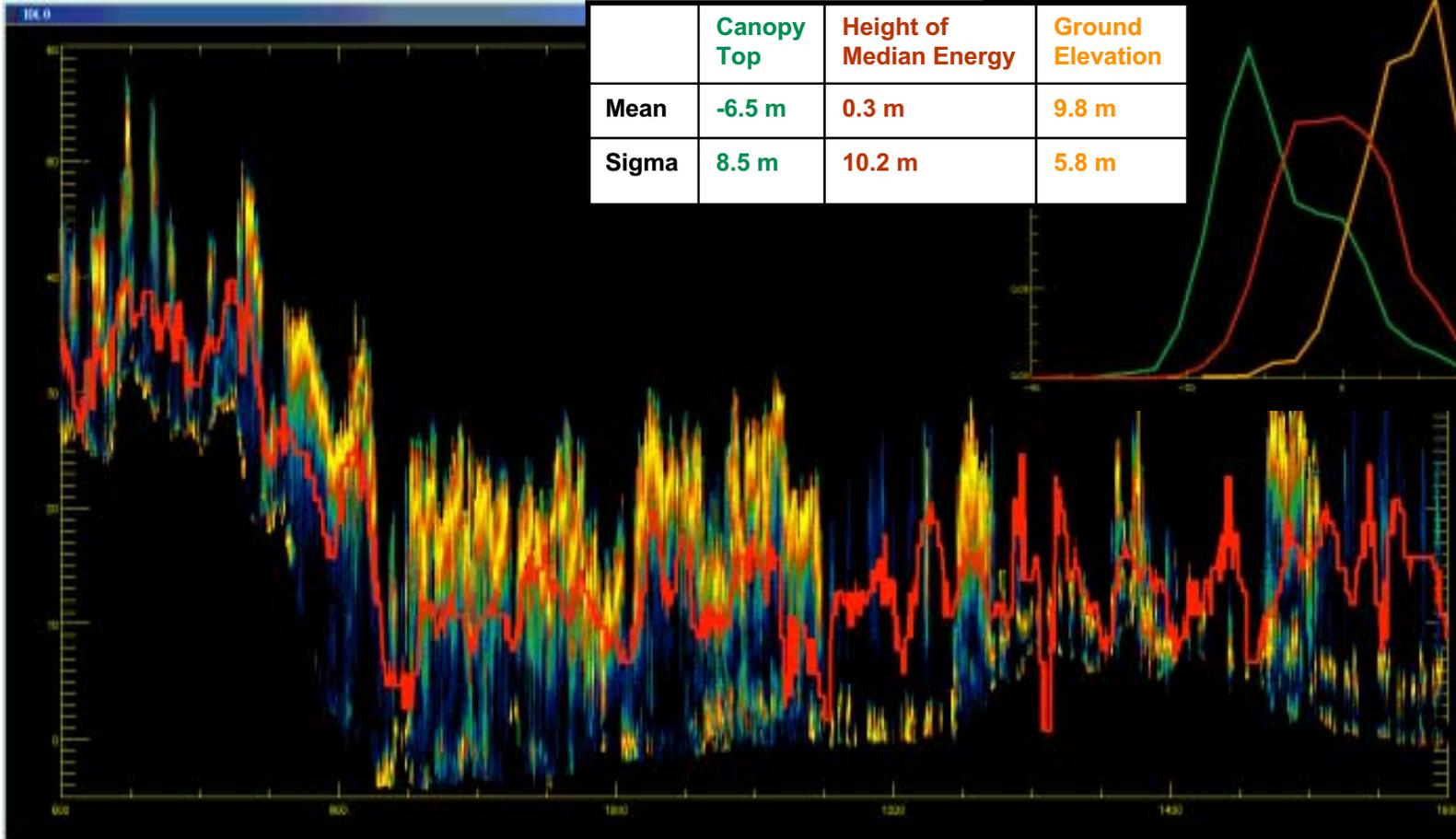


Comparison of 2003 Data with SRTM



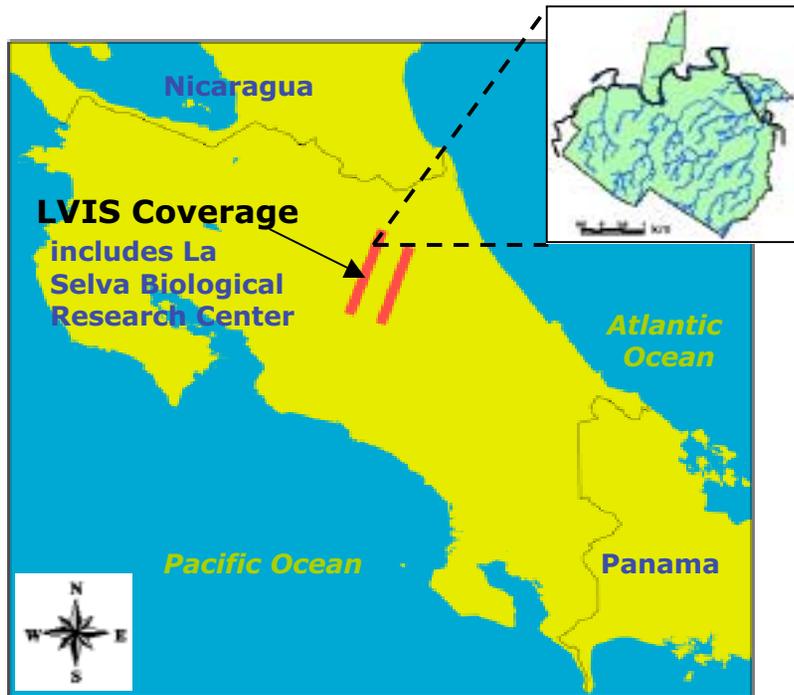
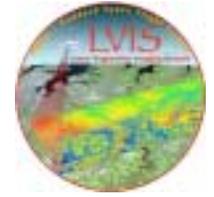
Below: *Side-looking view through the canopy.*
Color denotes intensity of LVIS return waveform at each elevation. Red line is SRTM elevation

Histogram of differences
(SRTM elevations *minus* LVIS metrics)





Processing of Older LVIS Data: Costa Rica, March 1998



- ❖ Processing and distribution of older LVIS data recently funded by NASA IDS program
- ❖ Older LVIS datasets include those collected in Costa Rica, Panama, and US in 1998, 1999
- ❖ Costa Rica mission (1998) mapped the La Selva Biological Research Station and environs, to determine ability of lidar to penetrate dense canopy.
- ❖ Mission supported VCL cal/val.
- ❖ Two mapped areas, each ~ 6 km by 60 km
- ❖ Estimated data release date: ~April 2005. Quicklook/best effort earlier

Instrument parameters:

- ❖ 3 flights over 6 days period
- ❖ ~25 m- diameter footprints
- ❖ ~8 m footprint spacing along and across-track
- ❖ Coverage not 100% due to clouds

Area 1 Coverage (approximate)

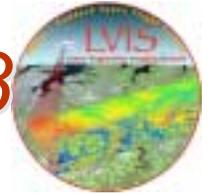
Corner	Latitude	Longitude
Top left	N10.5	E275.98
Top right	N10.5	E276.05
Bottom right	N10.05	E275.868
Bottom left	N10.05	E275.8

Area 2 Coverage (approximate)

Corner	Latitude	Longitude
Top left	N10.41	E276.125
Top right	N10.41	E276.18
Bottom right	N10.0	E276.03
Bottom left	N10.0	E275.97



Barro Colorado, Panama, March 1998



- ❖ Data collected as part of the LVIS Costa Rica mission to support VCL
- ❖ Close to 100% coverage over Barro Colorado island
- ❖ Core mapped area ~ 6 km by 6 km
- ❖ Standard data products will be made available
- ❖ Estimated data release date: ~April 2005
Quicklook/best effort earlier

Barro Colorado Coverage (approximate)

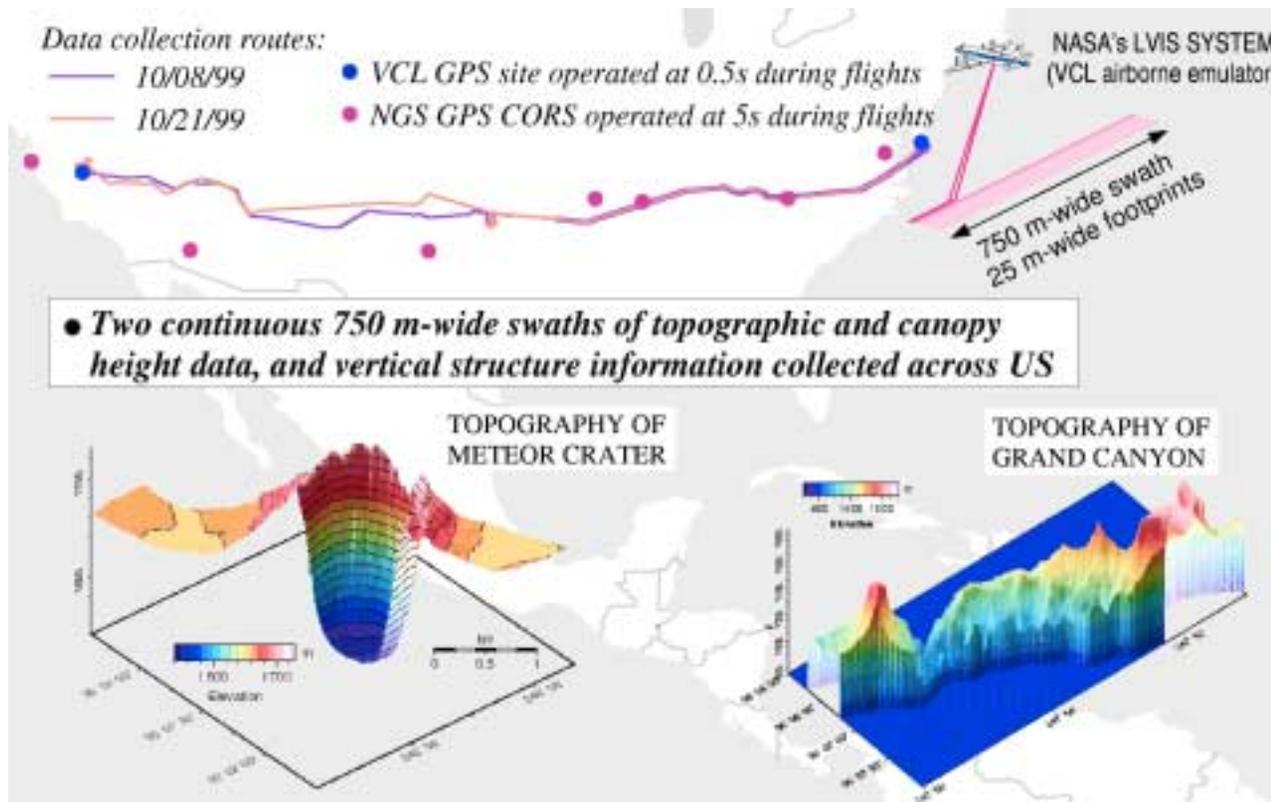
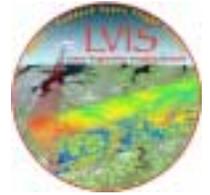
Corner	Latitude	Longitude
Top left	N9.183	E280.116
Top right	N9.183	E280.183
Bottom right	N9.116	E280.116
Bottom left	N9.116	E280.183

Instrument parameters:

- ❖ 1 flight only
- ❖ ~25 m- diameter footprints
- ❖ ~8 m footprint spacing along and across-track



Cross-Country Transit, October 1999



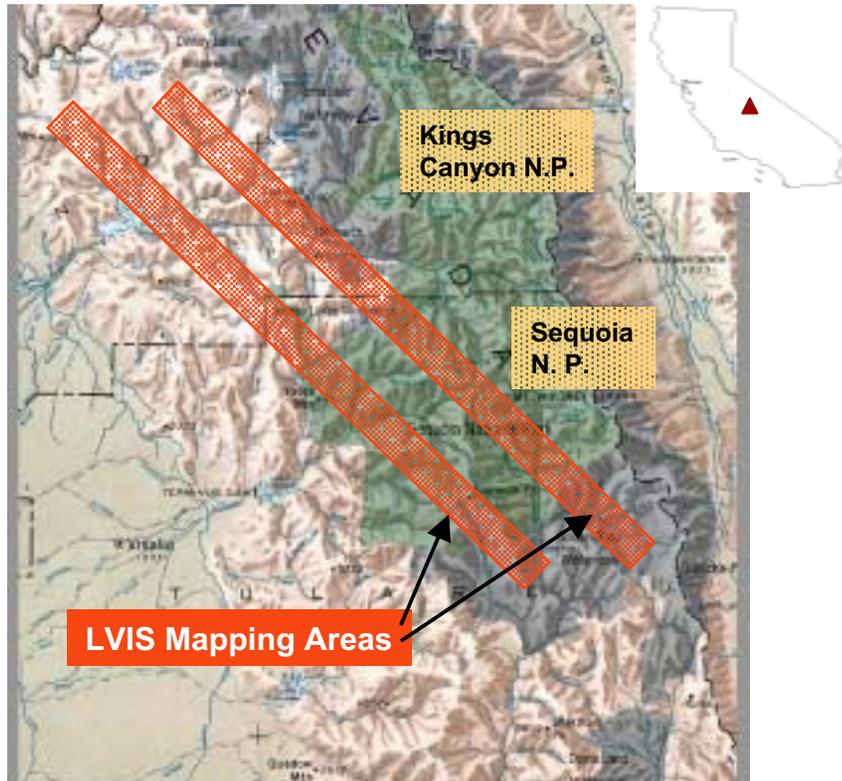
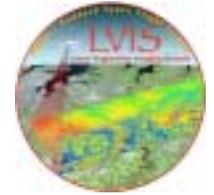
Sites overflow include:

- Virginia Coast Reserve
- Duke Forest
- Walker Branch, TN
- Sevilleta LTER
- Death Valley
- Meteor Crater
- Grand Canyon

- ❖ Data collected during transits to and from NASA/WFF to Fresno, CA,
- ❖ Estimated data release date, late 2005 - Quicklook/best effort earlier
- ❖ Geolocation is questionable due to long GPS baselines.



California, October 1999



- ❖ 1999 LVIS mission in support of VCL
- ❖ Mission mapped portions of the Kings Canyon, and Sequoia National Parks
- ❖ Two mapped areas, ~ 7 km by 100 km
- ❖ Estimated data release date: ~December 2005. Quicklook/best effort earlier
- ❖ Coverage is close to 100% - some holes due to clouds

Instrument parameters:

- ❖ 5 flights over 2 week period
- ❖ ~25 m- diameter footprints
- ❖ ~8 m footprint spacing along and across-track

Area 1 Coverage (approximate)

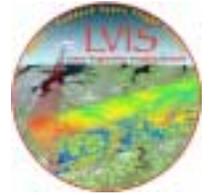
Corner	Latitude	Longitude
Top left	N37.0	E240.54
Top right	N37.0	E240.65
Bottom right	N36.40	E241.55
Bottom left	N36.37	E240.50

Area 2 Coverage (approximate)

Corner	Latitude	Longitude
Top left	N37.05	E240.77
Top right	N37.1	E240.83
Bottom right	N36.5	E241.74
Bottom left	N36.44	E241.7



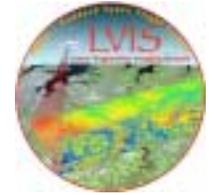
East Coast USA, 1999



- ❖ 1999 LVIS Mission in support of VCL
- ❖ Areas mapped include
 - Hubbard Brook (NH) and Coweeta (NC) LTERs,
 - areas of Duke Forest (VA), Harvard Forest (MA) and Bartlett Experimental Forest (NH),
 - parts of Patuxent and Patapsco watersheds (MD)
- ❖ Estimated data release date: ~December 2005
Quicklook/best effort earlier
- ❖ Instrument parameters:
 - 3 flights over a 2 week period
 - ~25 m diameter footprints
 - Oversampled along and across track - ~ 8 m spacing

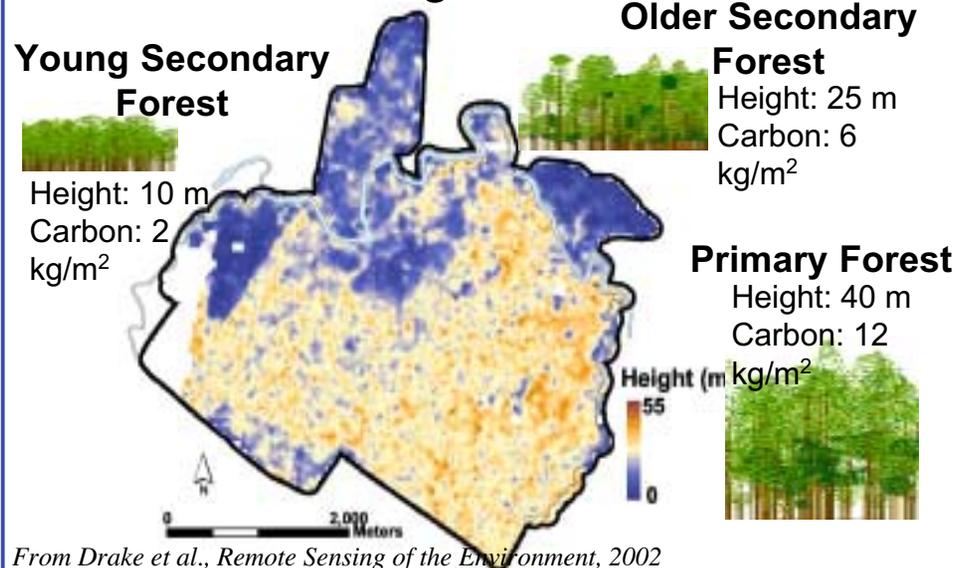


Example Applications of Waveform Data



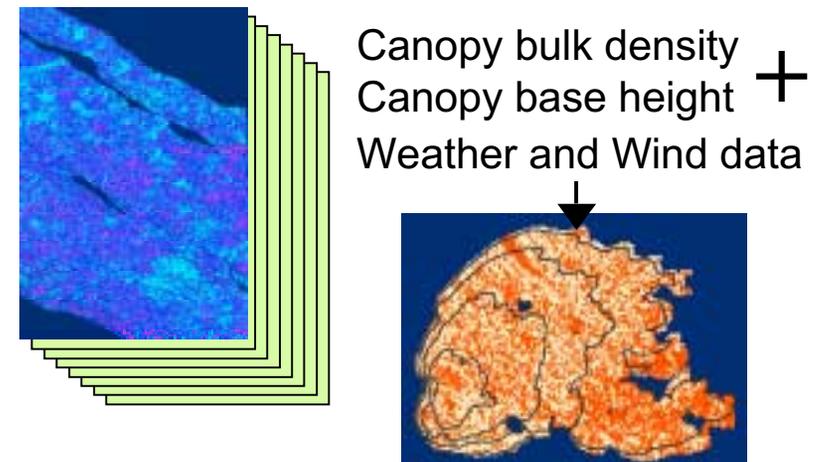
Estimating Biomass/Carbon

- Canopy metrics can be used to estimate above-ground C



Forest Fire Modeling

- Canopy structure can be used for predicting wildfire behavior



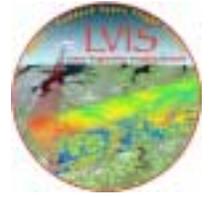
Outputs: Area burned, canopy fire frequency, spotting rate, etc.

Land cover classification

- Vertical height and return complexity can be used to determine cover type.
- Fusion with Hyperspectral and/or SAR



Summary



- ❖ Several high quality waveform-based lidar datasets were collected in leaf-on conditions in 2003.
 - Geolocated images of sub-canopy topography, canopy height, canopy cover, potentially land cover type, structure parameters
 - Preliminary assessment of sub-canopy topography looks good
- ❖ Data will be available publicly no later than July 2004
- ❖ Older LVIS data sets (Costa Rica, Panama, California, Eastern US sites) will be processed and made available starting in 2005.
- ❖ Currently exploring several new waveform products that could contribute to vegetation, hydrology, natural hazards, and solid earth sciences.
- ❖ Working toward Spaceborne Imaging Lidar.