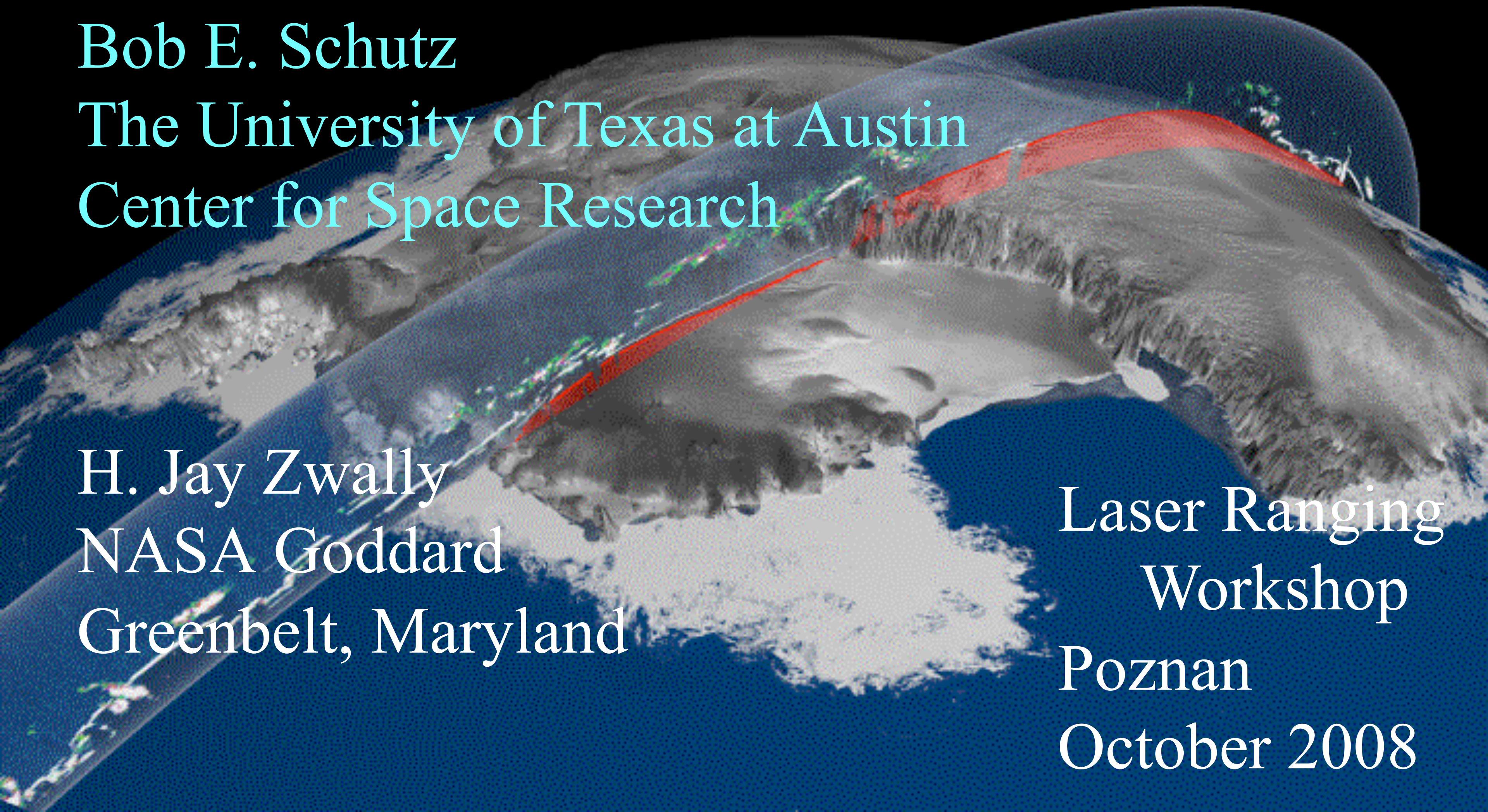
ICESat Overview



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Laser Ranging Workshop
Poznan
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Overview

- ICESat overview
- ICESat data summary and calibration/validation
- Science and cal/val examples
- Acknowledgements: ICESat/GLAS Science Team, Instrument Team, Operations Team, Science Data Processing Team

The NASA ICESat/GLAS Mission

Ice, Cloud and land Elevation Satellite

- Carries Geoscience Laser Altimeter System (GLAS)
- Launched January 2003
- 600-km altitude, 94-deg inclination

Geoscience Laser Altimeter System

- Built by NASA GSFC
- Three redundant Nd:YAG lasers generate 6-ns 1064-nm pulses at 40 Hz for altimetry; 532-nm for atmospheric backscatter
- Illuminated surface spot is elliptical, ~65 m mean diameter
- Surface spots separated by ~ 170 m
- Laser lifetime issues has led to three ~33 day laser operation periods per year (~ February, June, October); now two operation periods (~Feburary, October)
- With current operation scenario and estimated laser life, expect to conduct operational campaigns into 2011

ICESat

Shuman, et al. (GSFC)

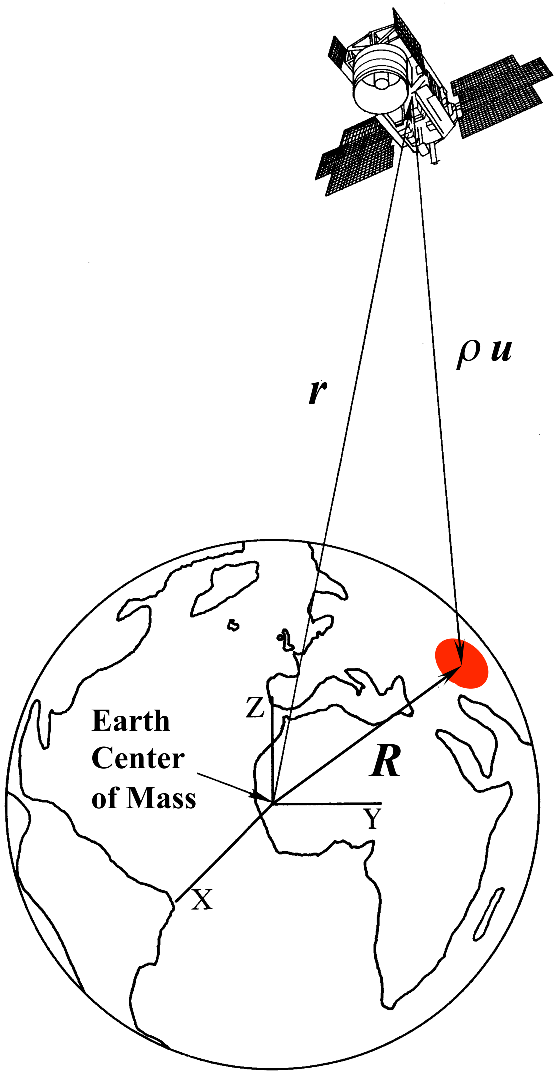
- ICESat spacecraft bus built by Ball Aerospace
- GLAS telescope is 1 meter diameter (shown attached to the spacecraft bus)
- ICESat measurements enable an accurate profile of surface topography along the tracks
- Change detection from “crossovers” and “repeat” tracks

Laser Altimetry Concept

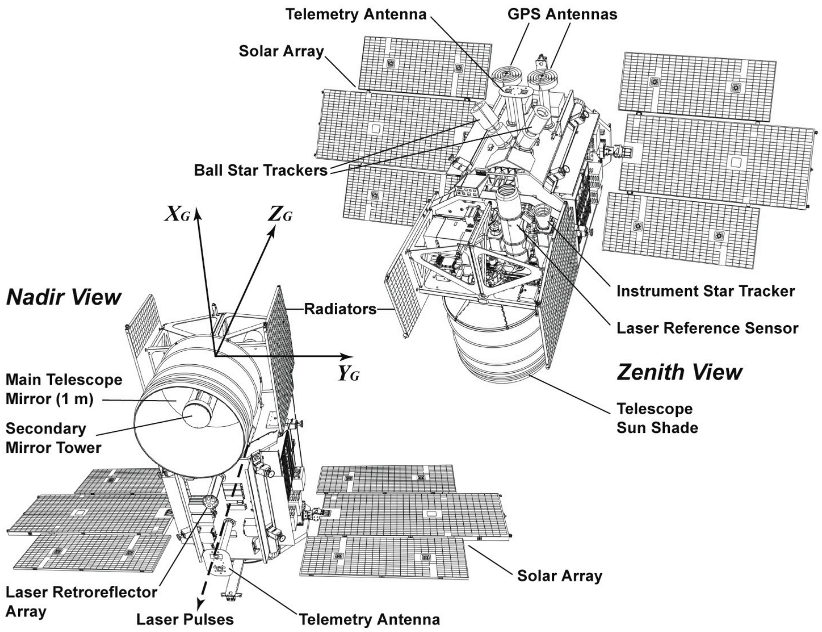
- Altimeter provides scalar range ρ from instrument to surface (based on "time of flight"
- Position of instrument $\boldsymbol{r}$ found through precision orbit determination (POD)
- Laser pointing $\boldsymbol{u}$ found through precision pointing determination, which includes precision attitude determination (PAD)
- Geolocation process combines these data to determine location and geodetic elevation of each laser spot centroid on the Earth

$$\boldsymbol{R} = \boldsymbol{r} + \rho\, \boldsymbol{u}$$

- Transmit and echo pulse digitized on board, sent to ground



Configuration



- POD based on GPS measurements (LRA used for validation)
- PAD based on Stellar Reference System (star trackers) and gyros

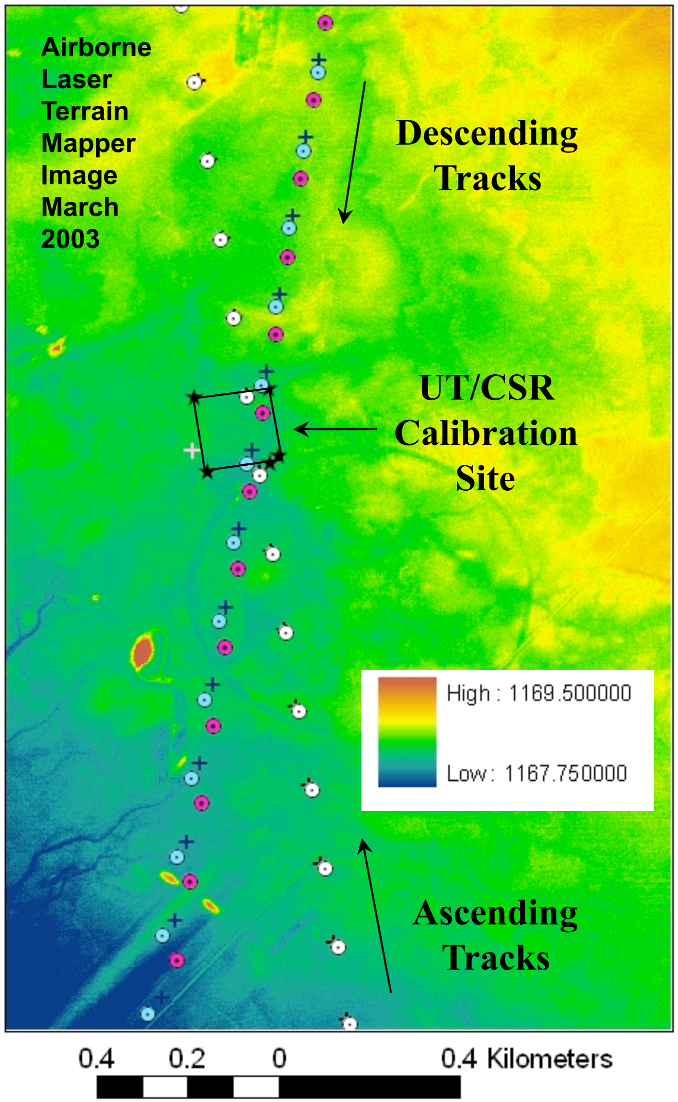
ICESat POD

- POD based on GPS measurements
- SLR is essential for validation of GPS derived POD
- SLR data is with held from POD, but examination of SLR residuals from GPS-determined orbit demonstrates POD accuracy at < 2 cm radial

Calibration & Validation

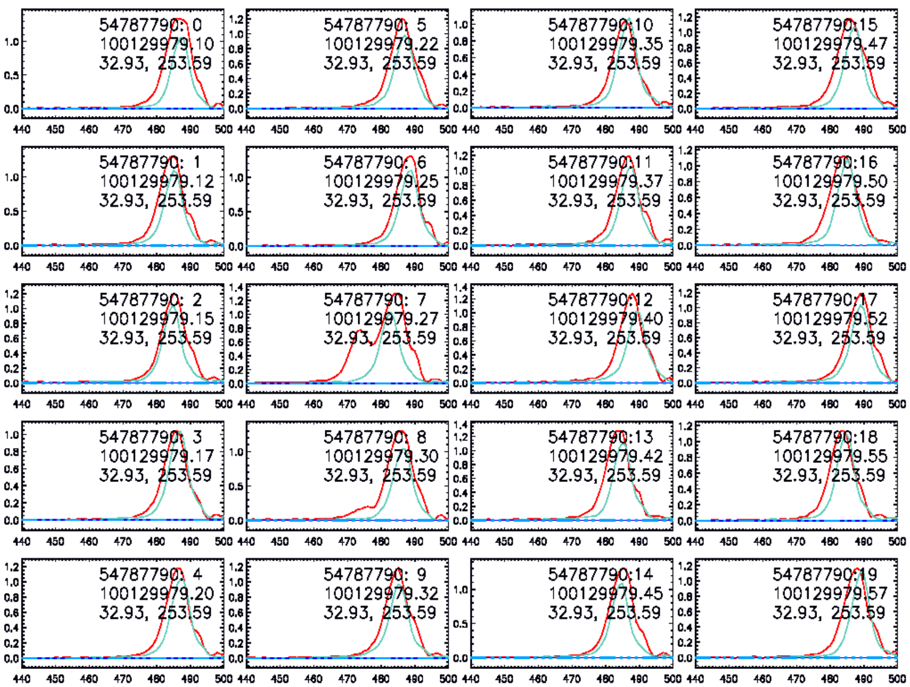
- POD yields <2 cm radial orbit accuracy, validated with satellite laser ranging (SLR) (5 cm requirement)
- Derived bounce time tags verified to 3 μsec accuracy using ground-based laser detectors at White Sands Space Harbor (100 μsec requirement)
- Extensive efforts (ongoing) by UT/CSR and NASA GSFC to identify instrument contributions to laser pointing errors (1.5 arcsec requirement = 4.5 meters horizontal, on surface from 600 km altitude)
  - various issues with PAD including systematic errors from Stellar Reference System
  - special spacecraft calibration maneuvers (Luthcke, 2005)

White Sands Space Harbor (WSSH)



- WSSH area used for ICESat Cal/Val
- University of Texas Optech Airborne Laser Terrain Mapper used in March 2003 to create “lidar” refererence surface
- Area shown is 1.5 km x 2.5 km
- Elevation varies from 1169.5 m (red) to 1167.75 m (blue)
- No vegetation
- Use off-nadir pointing capability (up to 5°)

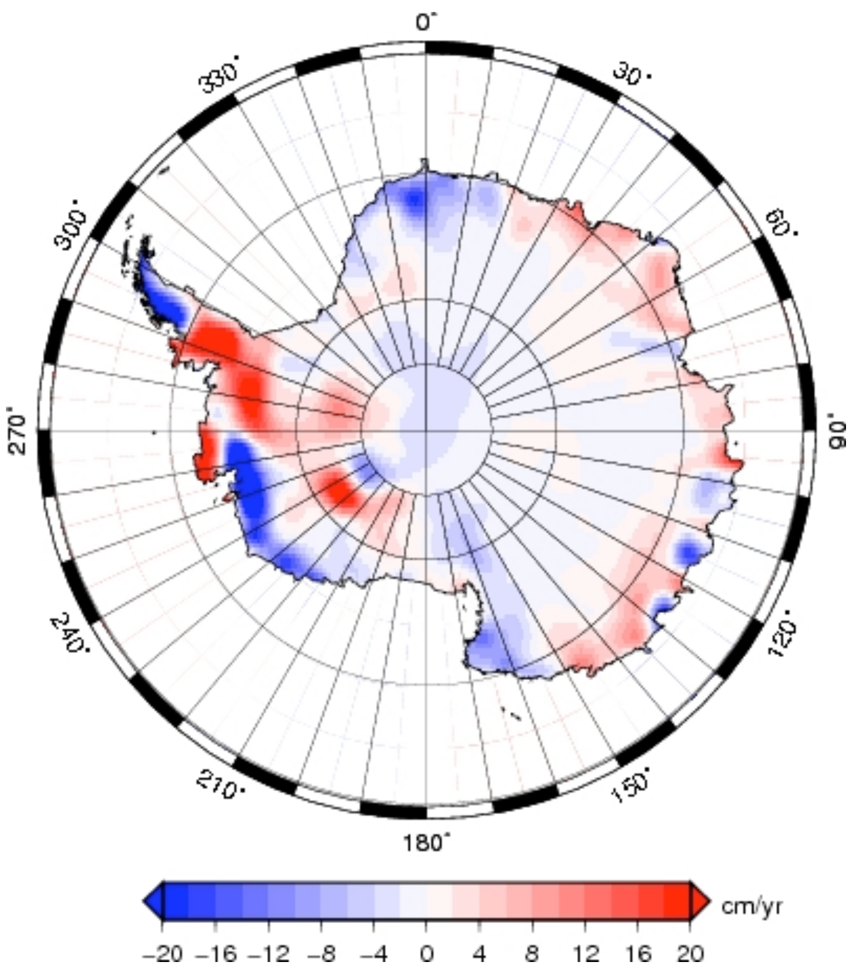
White Sands Experiments



- GLAS digitized waveforms during Laser 1 at White Sands
  - Near Gaussian
  - Double peak case resulted from Corner Cube Reflector used within target array (peaks match expected CCR height)

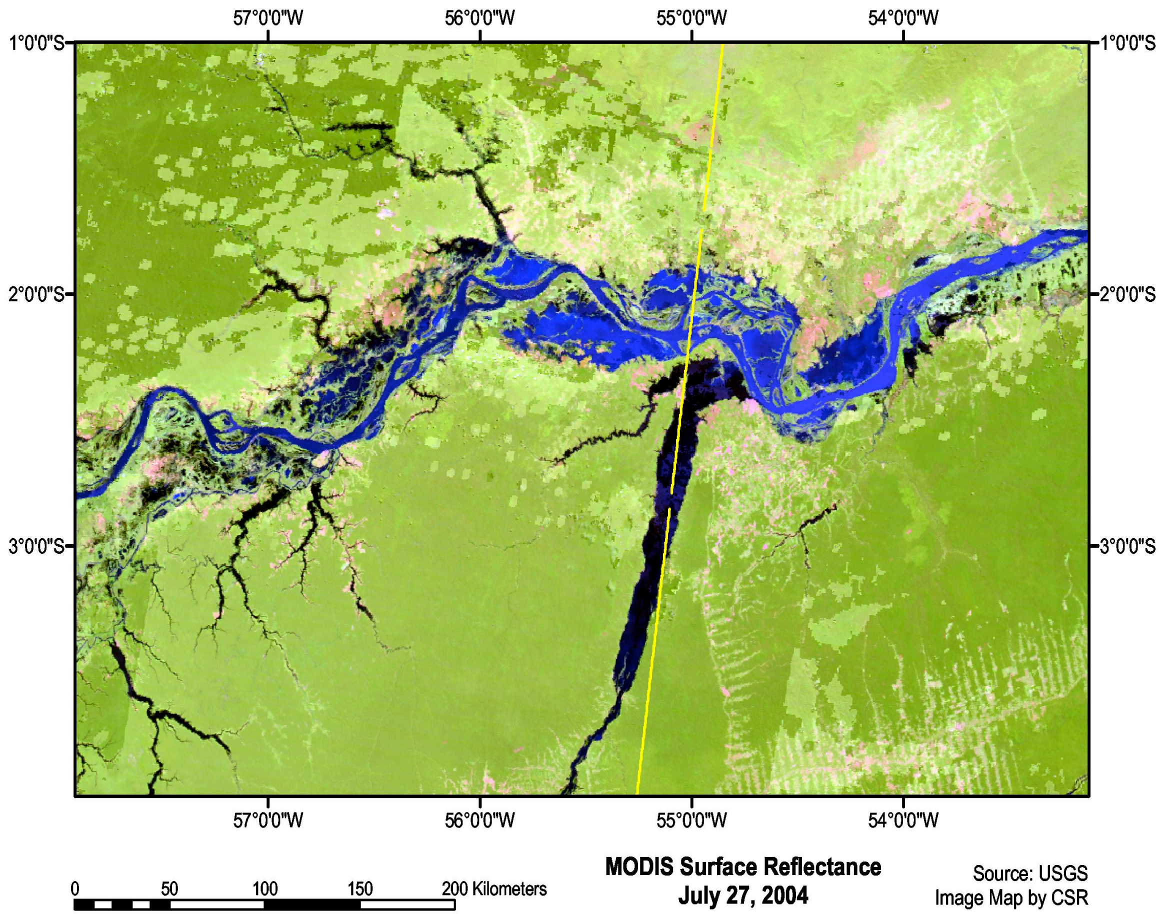
Antarctica

ICESat dh/dt



- ICESat derived dh/dt shown for 2003-2007
- GRACE derived mass change over same period is very similar;
  - GRACE measures mass change
  - ICESat measures volume change

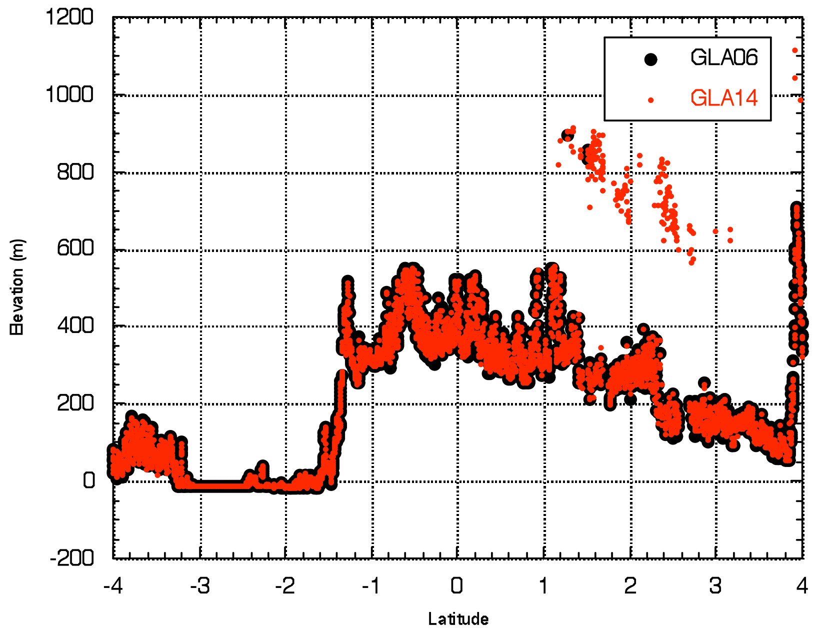
Rio Tapajos, Brazil

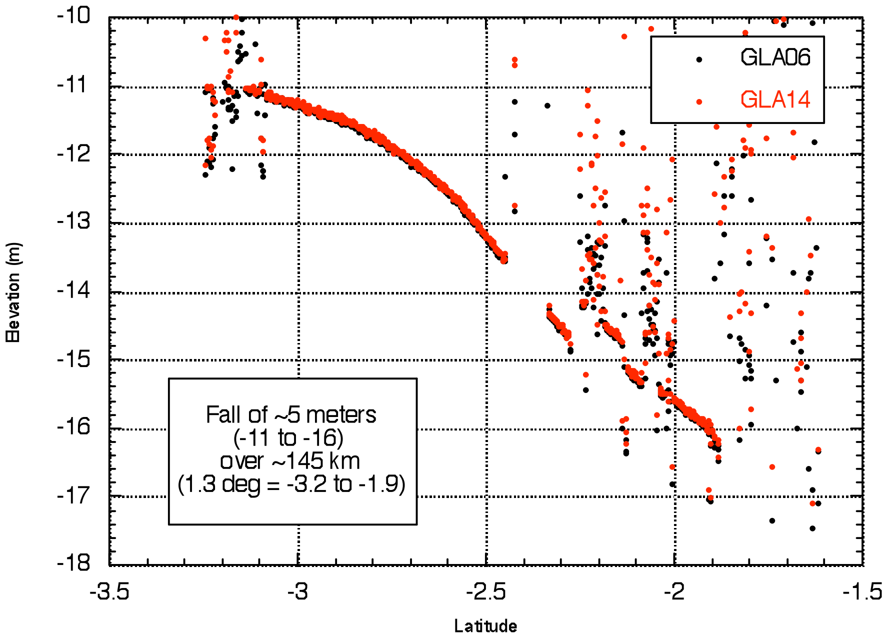


MODIS Surface Reflectance
July 27, 2004

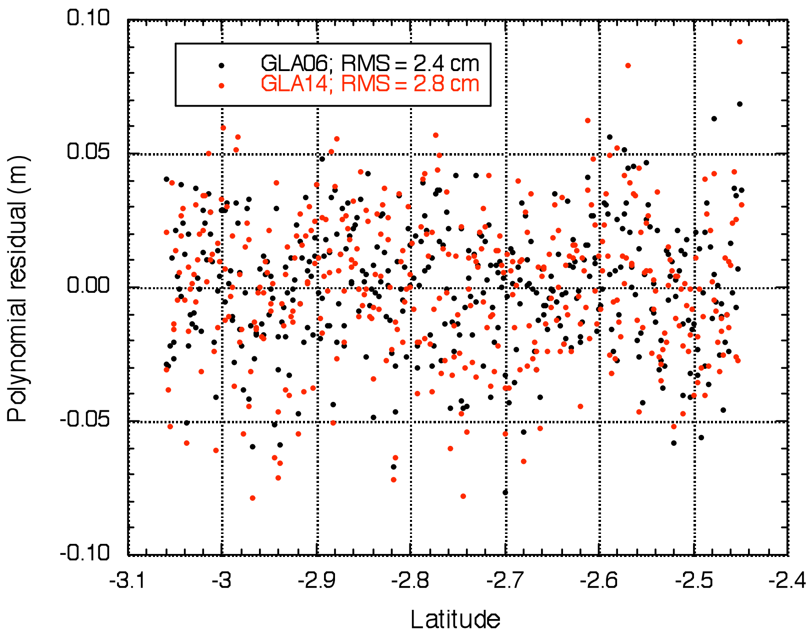
Source: USGS
Image Map by CSR

Rio Tapajos Track (Laser 2a)





GLAS Precision



- Residuals to degree two polynomial fit of elevation on Rio Tapajos represent GLAS precision
- Both GLAS data products give similar result (echo waveform is Gaussian)
- 40 Hz points shown (*no averaging*)
- Over this water surface, the precision is < 3 cm
- May be decimeter bias (accuracy), but other results (Fricker, et al., 2005) at Bolivia salt flat show bias is ~ zero

Conclusions

- SLR makes essential contribution to ICESat (verification that radial orbit accuracy is <2 cm)
  - *Many thanks for SLR contributions*
- Completed 5 years on-orbit; operational strategy expected to enable operation into 2011
- Science results in polar regions
  - High correlation with change observed by GRACE
  - Subglacial hydrology patterns delineated (Fricker, et al.)
  - Sea ice change (Kwok, et al.)

BACKUP

Data Release Schedule

- Released to NSIDC:
  - Laser 1 (Feb-Mar, 2003, 36 days): early release (10 arcsec pointing accuracy)
  - Laser 2a (Sep-Nov, 2003, 55 days): Release 21, (1.5 arcsec pointing accuracy)
- Release schedule (to NSIDC), expected accuracy: ~ 2 arcsec except for near real time products (~ 5 arcsec)
  - Laser 3a (Oct-Nov, 2004, ~33 days) Release 23: August 15
  - Laser 2b (Feb-Mar, 2004, ~33 days) Release ??: September 15
  - Laser 3b (Feb-Mar, 2005, ~33 days) Release ??: October 15
  - Laser 3d (Oct-Nov, 2005), ~33 days) Release ??: near real time (~ 7 day latency, accuracy 5 arcsec)
  - Laser 3d reprocessed with full calibrations: ~ 30 days after 3d period
  - Laser 2c (May-Jun, 2004, ~33 days) Release ??: November/December
  - Laser 3c (May-Jun, 2005, ~33 days) Release ??: November/December
  - Laser 1 (Feb-Mar, 2003, 36 days) Release ??: November/December

Estimated ICESat Elevation Accuracy

- Laser 2a (September-November, 2003), released via NSIDC:
  - Nominal performance of instrumentation used in pointing determination; but on-orbit performance showed need to additional corrections
    - Release 21: ~1.5 arcsec pointing accuracy (1-σ) after ocean scan calibrations (special maneuvers performed twice daily over Pacific, plus one per week around the world, Luthcke, et al., 2005, accommodates boresight and remaining temporal variations)
- Other operation periods
  - Incomplete calibrations in preliminary releases: estimated pointing accuracy, up to 20 arcsec or more (complication is temporal change in pointing accuracy)
  - Effective range error from pointing that is absorbed by geolocated spot coordinates: 5 cm per arcsecond pointing knowledge error per deg surface slope (or effective slope from off-nadir pointing)
    - 1° effective slope, 1 arcsec pointing error yields 1.5 cm effective range error
    - 1° effective slope, 20 arcsec pointing error yields 100 cm effective range error
  - Status: reprocessing underway to apply known pointing and other corrections

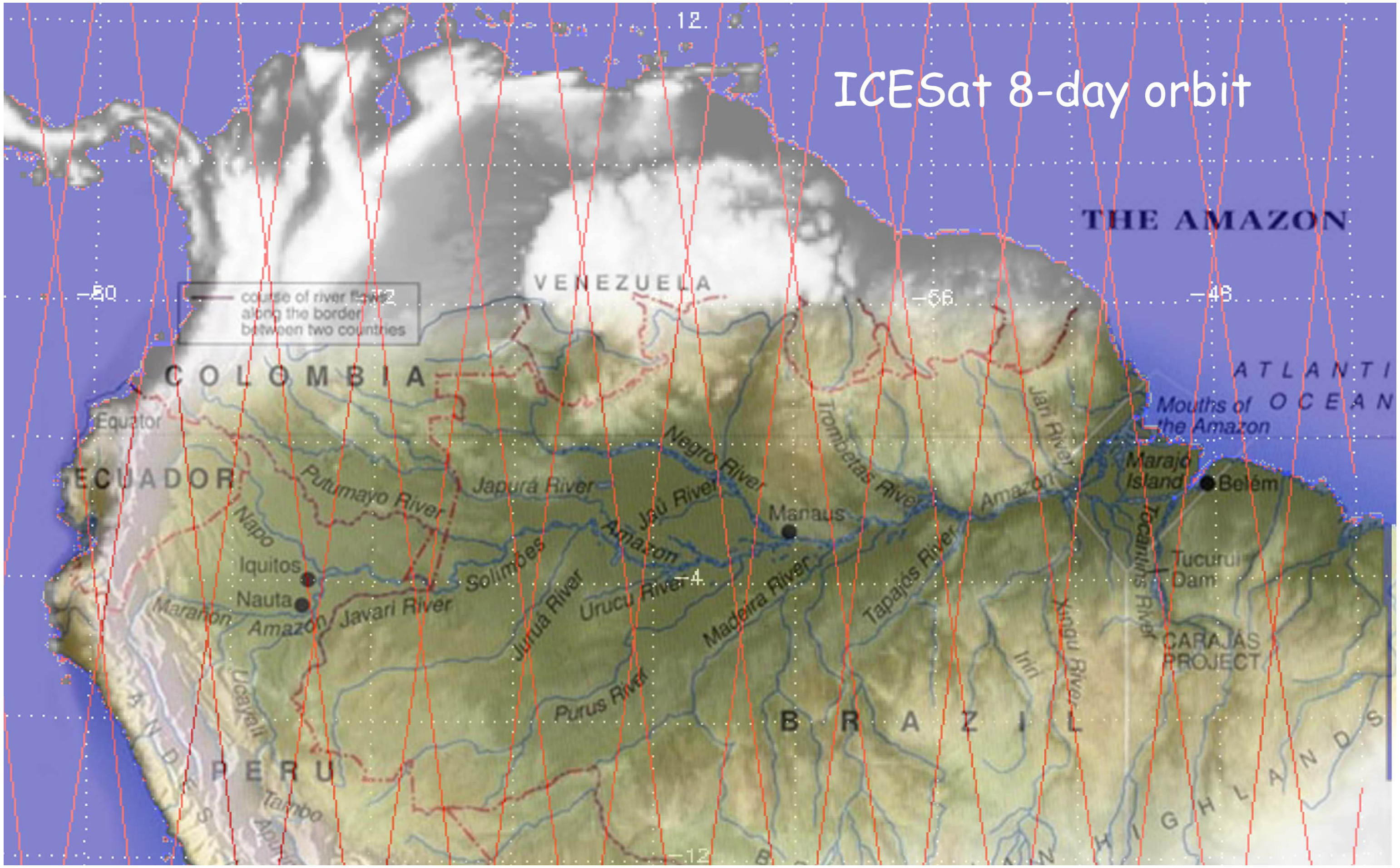
Elevation Error Sources

- Like radar altimetry, derived surface elevation accuracy in laser altimetry depends on orbit, timing, and range errors
- In ICESat laser altimetry, elevation accuracy also depends on saturation, surface roughness, atmospheric forward scattering, field of view shadowing (boresight) and pointing errors
- Pointing-related elevation errors increase for sloped surfaces and during off-nadir targeting
  - Effective range error: 5 cm per one effective slope per arcsec pointing knowledge error

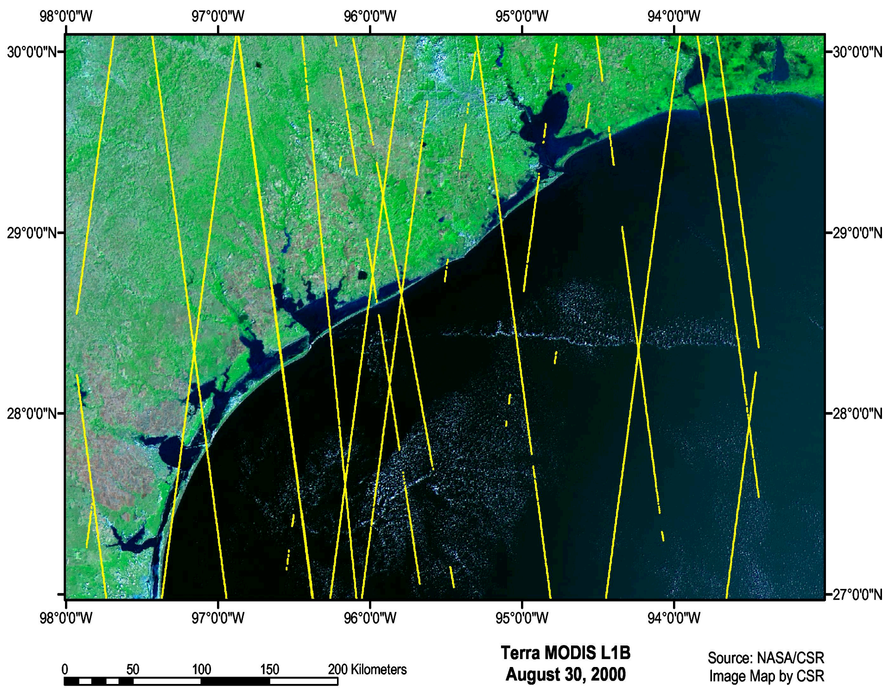
White Sands Pointing Results

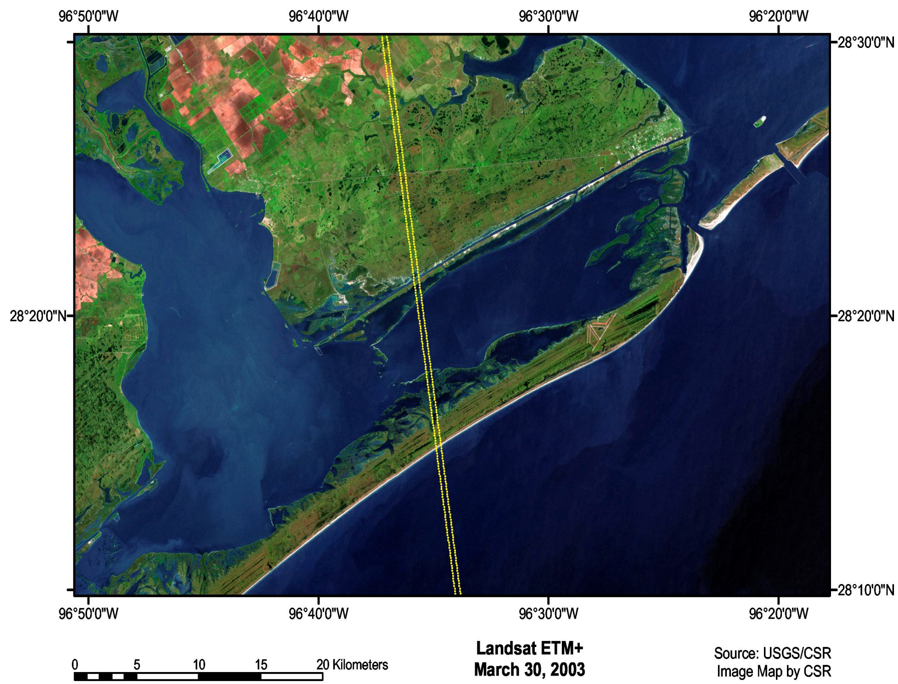
Laser	Orbit Track	Day of 2003	Range bias (cm)	Off-nadir angle (°)	Direction (Ascend, Descend)	Inferred pointing error (")
2a	1136	280	23.6 cm	2.6°	Asc	1.8"
2a	1188	283	35.2	3.5	Dsc	2.0
2a	1307	291	3.3	4.4	Dsc	0.2
2a	154	305	36.9	2.4	Asc	3.1
2a	273	313	-9.5	5.3	Asc	-0.4

Laser 2a Example

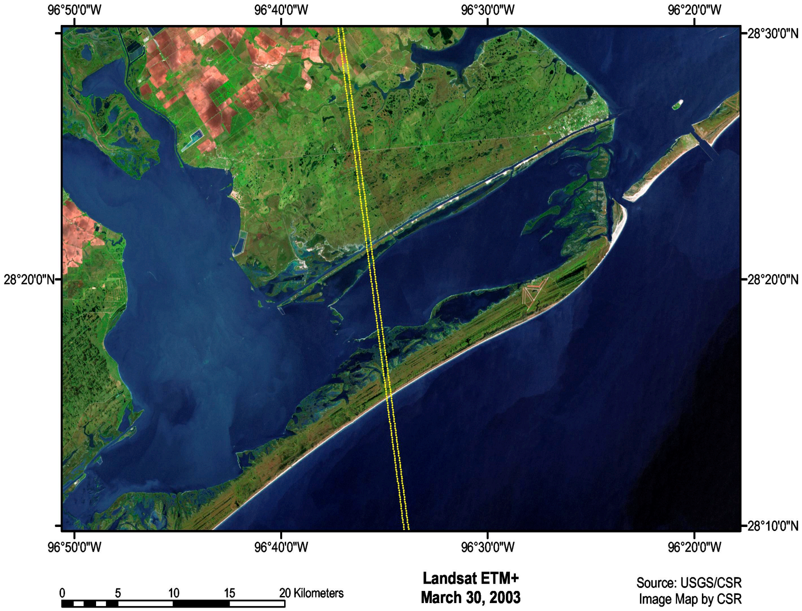


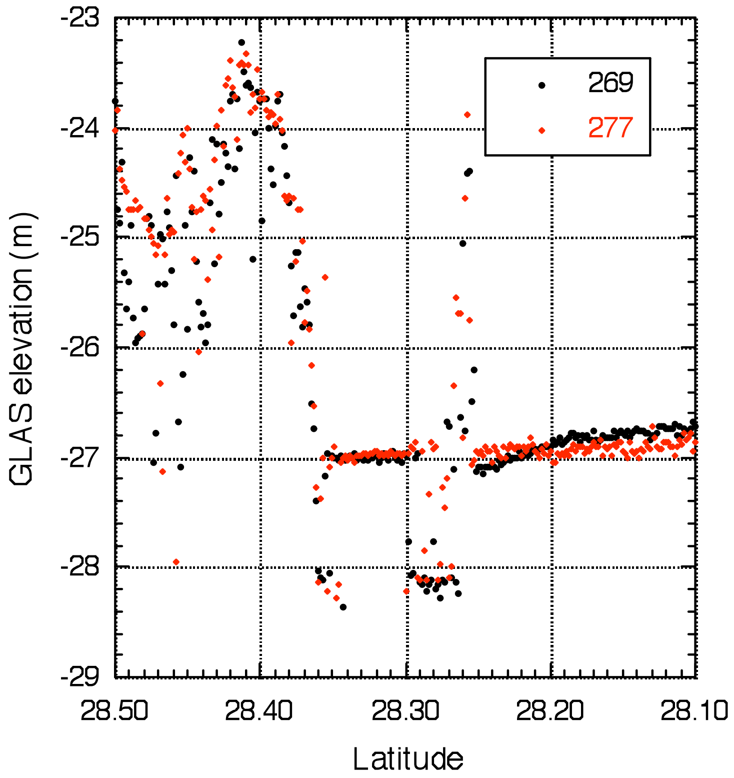
Texas Coast: Matagorda Island (Laser 2a)



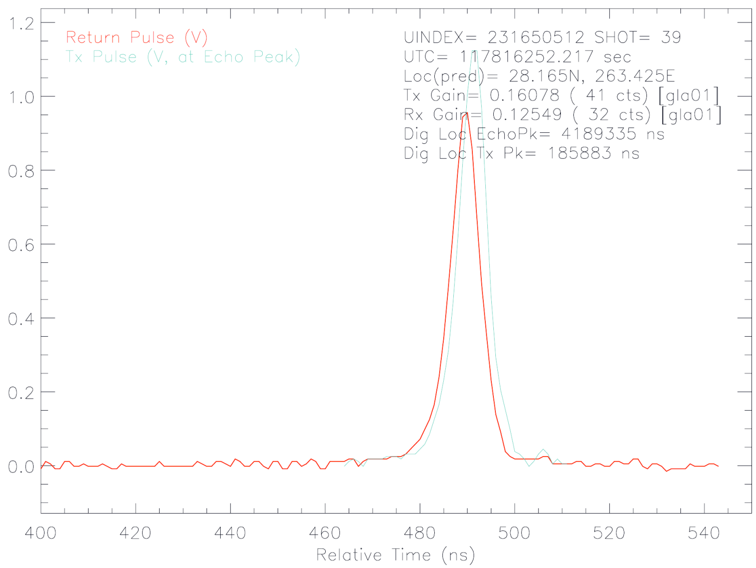


Matagorda Island (continued)

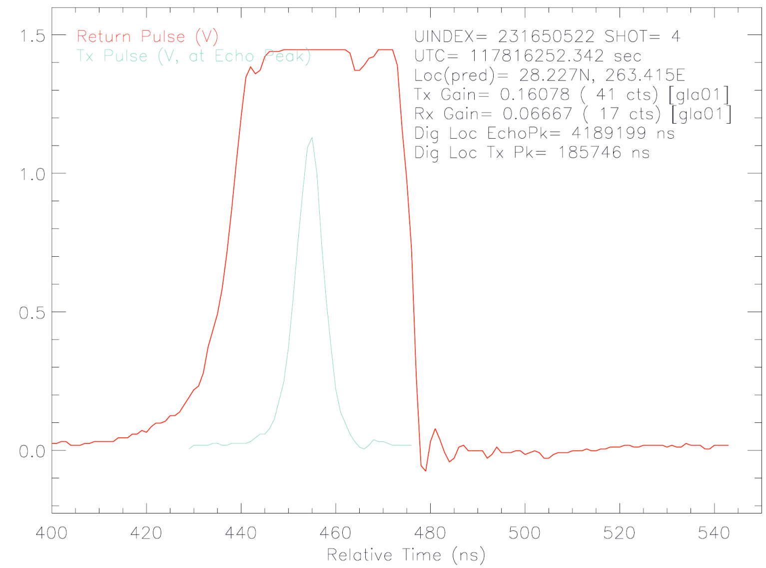




Matagorda Echo Pulse Examples



Typical Gaussian echo



Saturated echo