ICESat Laser Altimetry and SRTM

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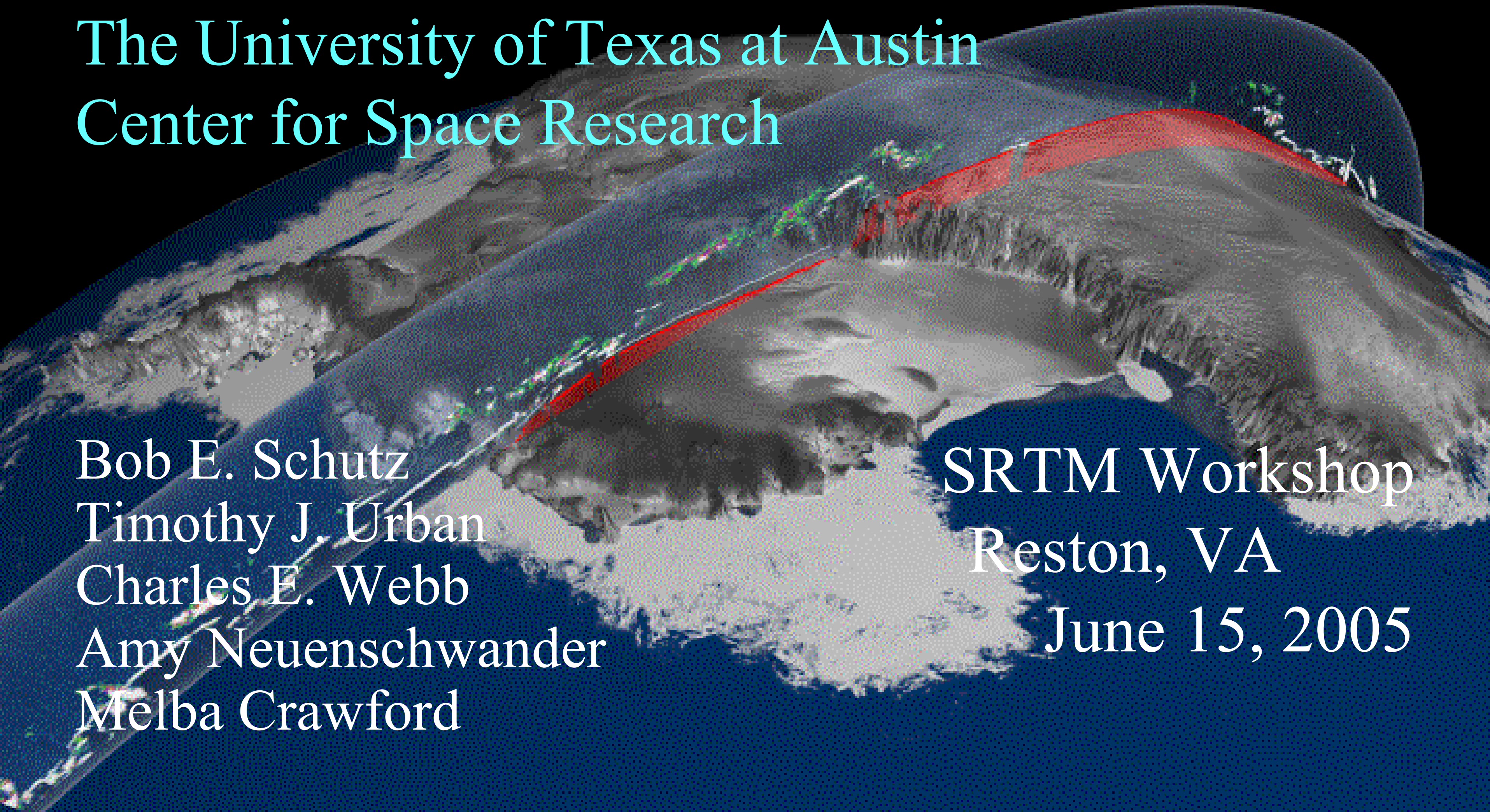

SRTM Workshop
Reston, VA
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Overview

- ICESat overview
- ICESat data summary and calibration/validation
- Examples:
  - White Sands Space Harbor (NM)
  - Okavango Delta, Botswana, Africa

The NASA ICESat/GLAS Mission

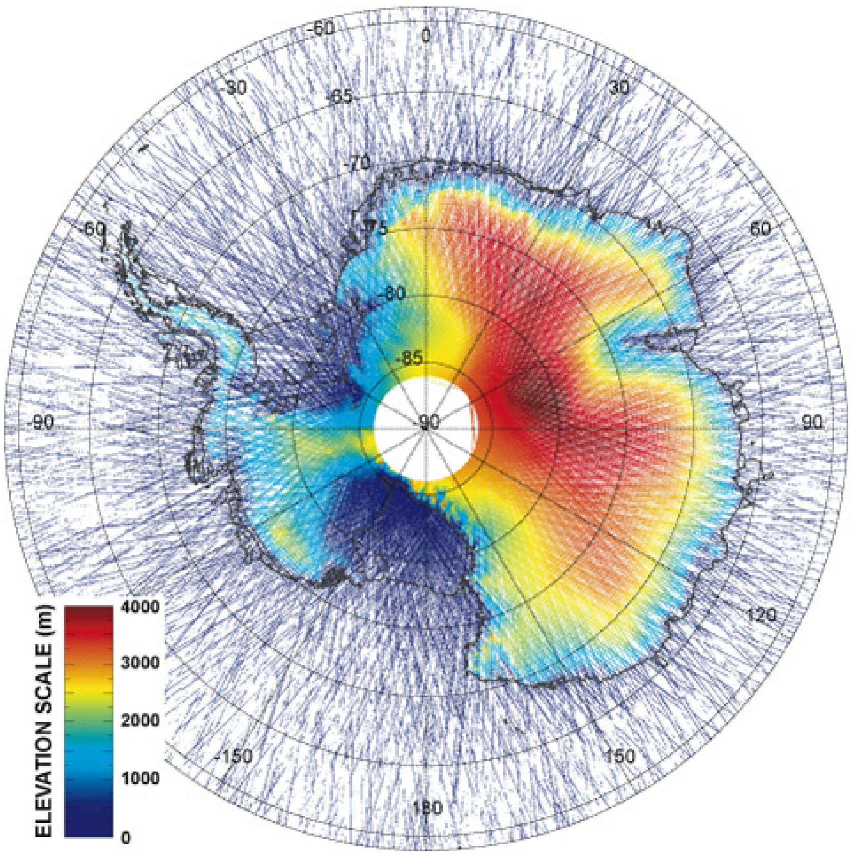
Ice, Cloud and land Elevation Satellite

- 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 (infrared) pulses at 40 Hz for altimetry
- 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)
- Two orbit repeat cycles: 8-day, 91-day (33-day subcycle)

ICESat



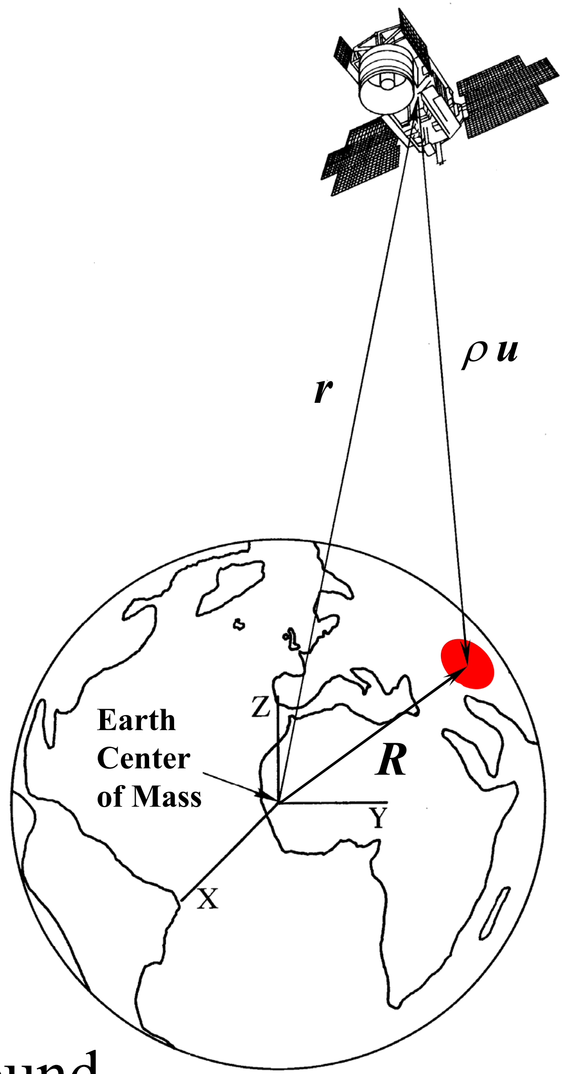
- Primary science objective is detection of change in the polar ice sheets
- ICESat generates an accurate profile of surface topography along the tracks
- DEM created from profiles
- Change detection from crossovers and repeat tracks

Shuman, et al. (GSFC)

Laser Altimetry Concept

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

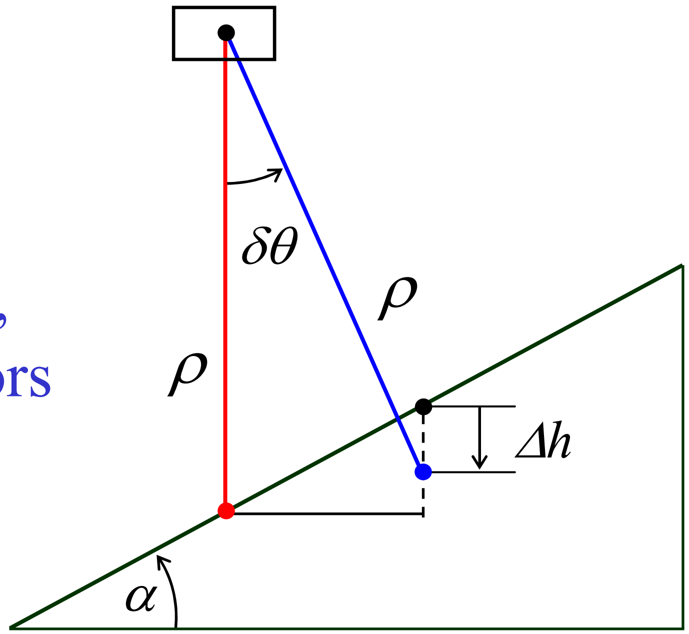
$$\boldsymbol{R} = \boldsymbol{r} + \rho \boldsymbol{u}$$



- Echo pulse digitized on board, sent to ground

Elevation Error Sources

- Like radar altimetry, elevation accuracy depends on orbit, timing, and range errors
- In ICESat altimetry, elevation accuracy also depends on saturation, surface roughness, and pointing errors
- Pointing-related elevation errors increase for sloped surfaces and during off-nadir targeting



- For ICESat, effective range error (translates to elevation):

$$\Delta h = 5 \text{ cm} * \alpha\,(\text{deg}) * \delta\theta\,(\text{arcsec})$$

Example, near-nadir, 1" $\Delta h = 5 \text{ cm} * 0.3 * 1 = 1.5 \text{ cm}$

Example,near-nadir, 10" → $= 15.0 \text{ cm}$

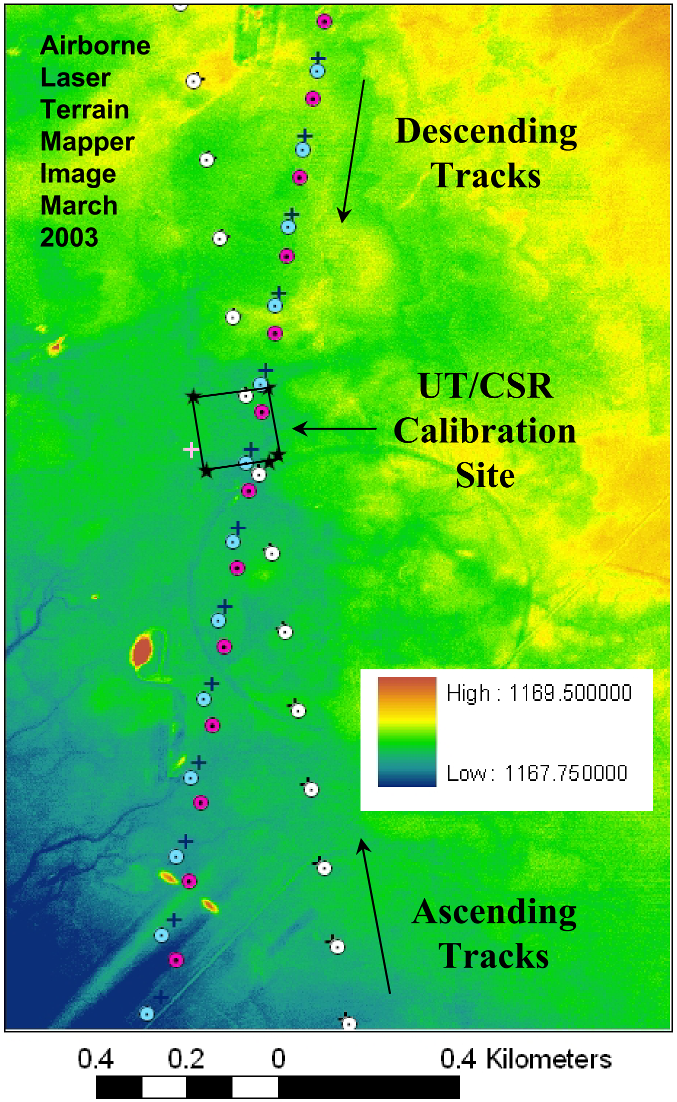
Calibration & Validation

- GPS-based POD yields 2-3 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 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)
  - pointing determined using star tracker (IST) & gyros mounted on laser optical bench
  - special spacecraft calibration maneuvers (Luthcke, 2005)
  - not all data sets calibrated to same level (ongoing)
  - may have ~ 10 cm range bias from prelaunch calibration

Estimated ICESat Accuracy

- Laser 2a (September-November, 2003), publicly released:
  - Nominal performance of instrumentation used in pointing determination
    - Release 21: ~1.5 arcsec (1-σ) after ocean scan calibrations
- Laser 3a (October-November, 2004)
  - Incomplete calibrations: estimated pointing accuracy ~3-5 arcsec
  - Remaining calibrations thermally driven by day/night orbital cycle
  - Fully calibrated set available by end July
- Other operation periods
  - Incomplete calibrations: estimated pointing accuracy ~10-15 arcsec
- ICESat elevations products with respect to same ellipsoid used by TOPEX/Poseidon; for SRTM comparisons, adjusted to give height with respect to EGM96 geoid

White Sands Space Harbor (WSSH)

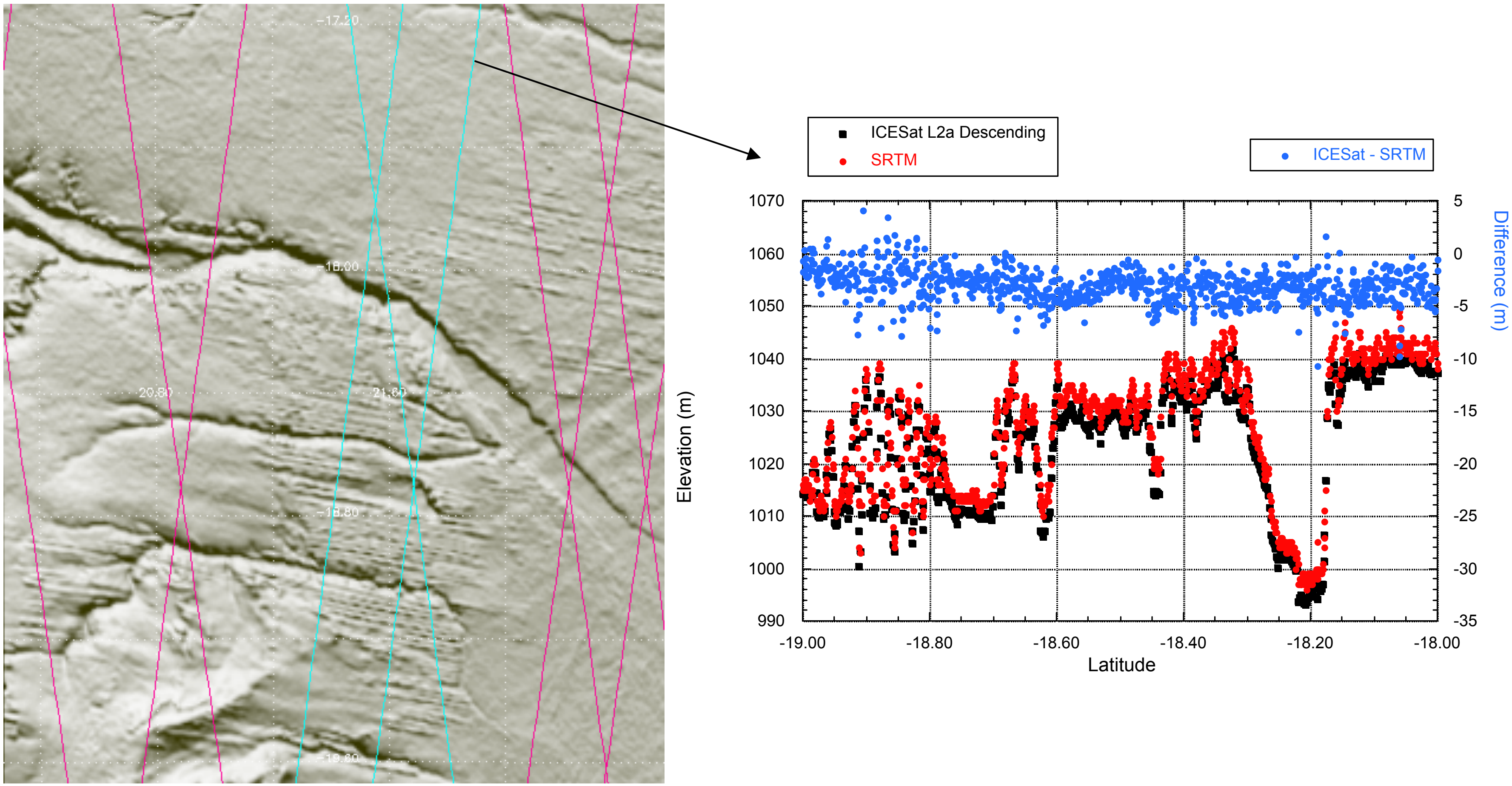


- WSSH area used for ICESat Cal/Val
- University of Texas Optech Airborne Laser Terrain Mapper used in March 2003 to create “lidar” refererence surface
- Area shown is 1.5 km x 2.5 km
- Elevation varies from 1169.5 m (red) to 1167.75 m (blue)
- No vegetation

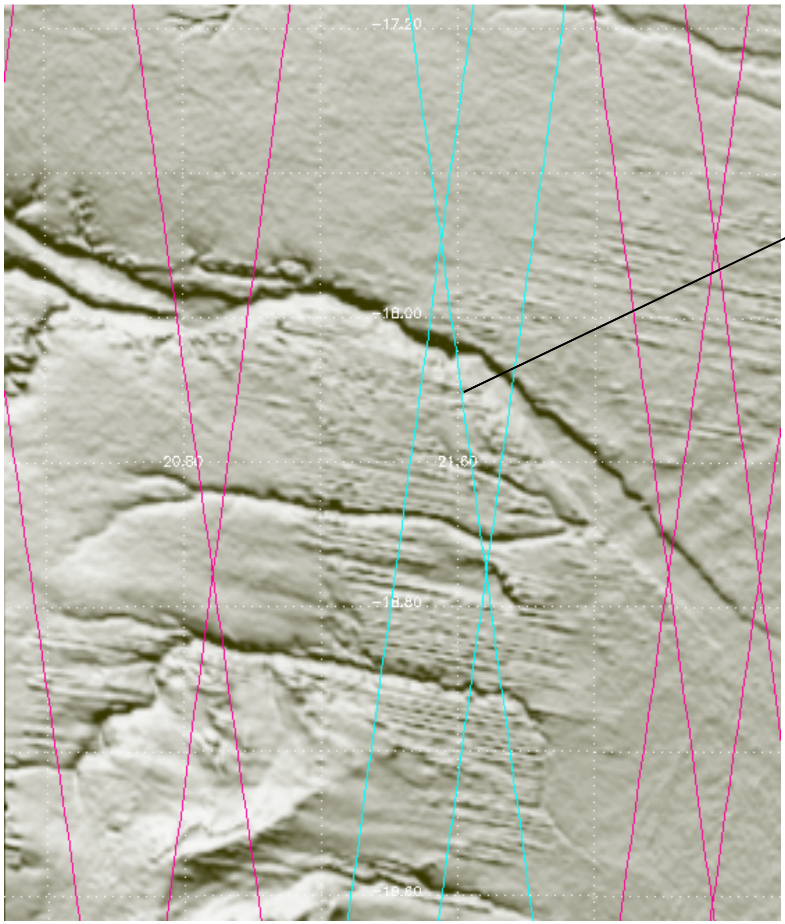
WSSH Elevation Comparisons

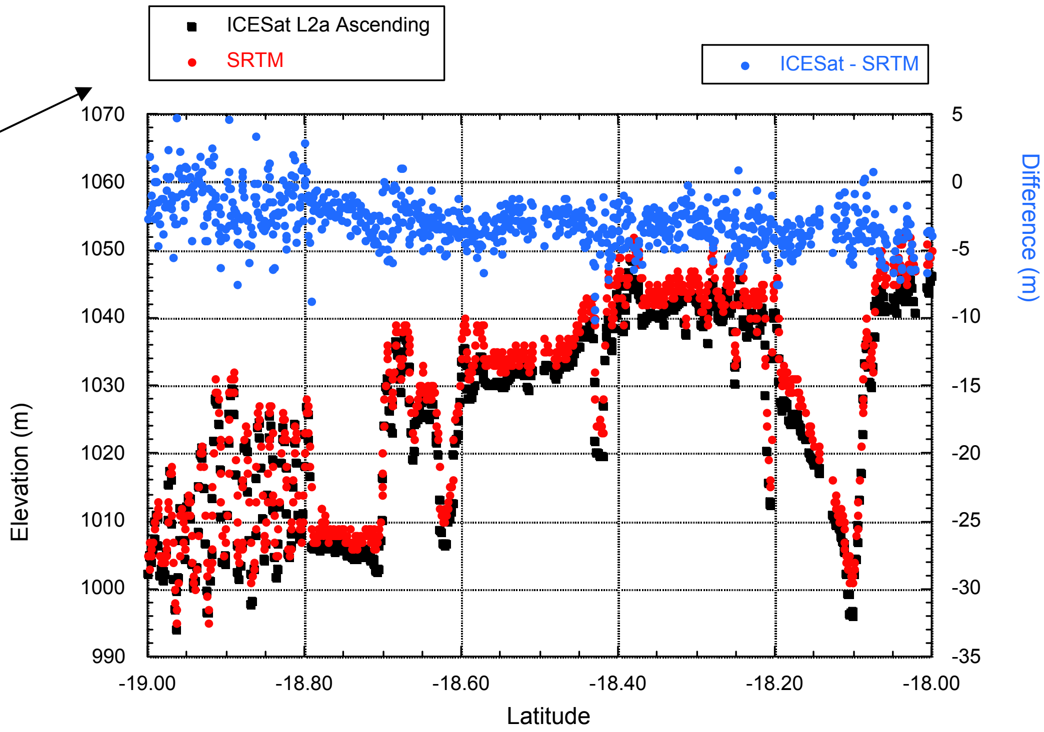
- Lidar - SRTM
  - Mean = - 37.8 cm, RMS = 182.1 cm (67,517 points)
- ICESat – Lidar (near nadir points, ~ 0.3° from nadir)
  - 2a: mean = - 4.3 cm, RMS = 12.2 cm
  - 3a: mean = -6.6 cm, RMS = 10.5 cm
- ICESat – SRTM
  - 2a: mean = - 25.1 cm, RMS = 171.9 cm
- Are SRTM differences caused by elevation change between the 2000 flight of SRTM and 2003-2004 measurements of ICESat?

Okavango Delta, Botswana: I

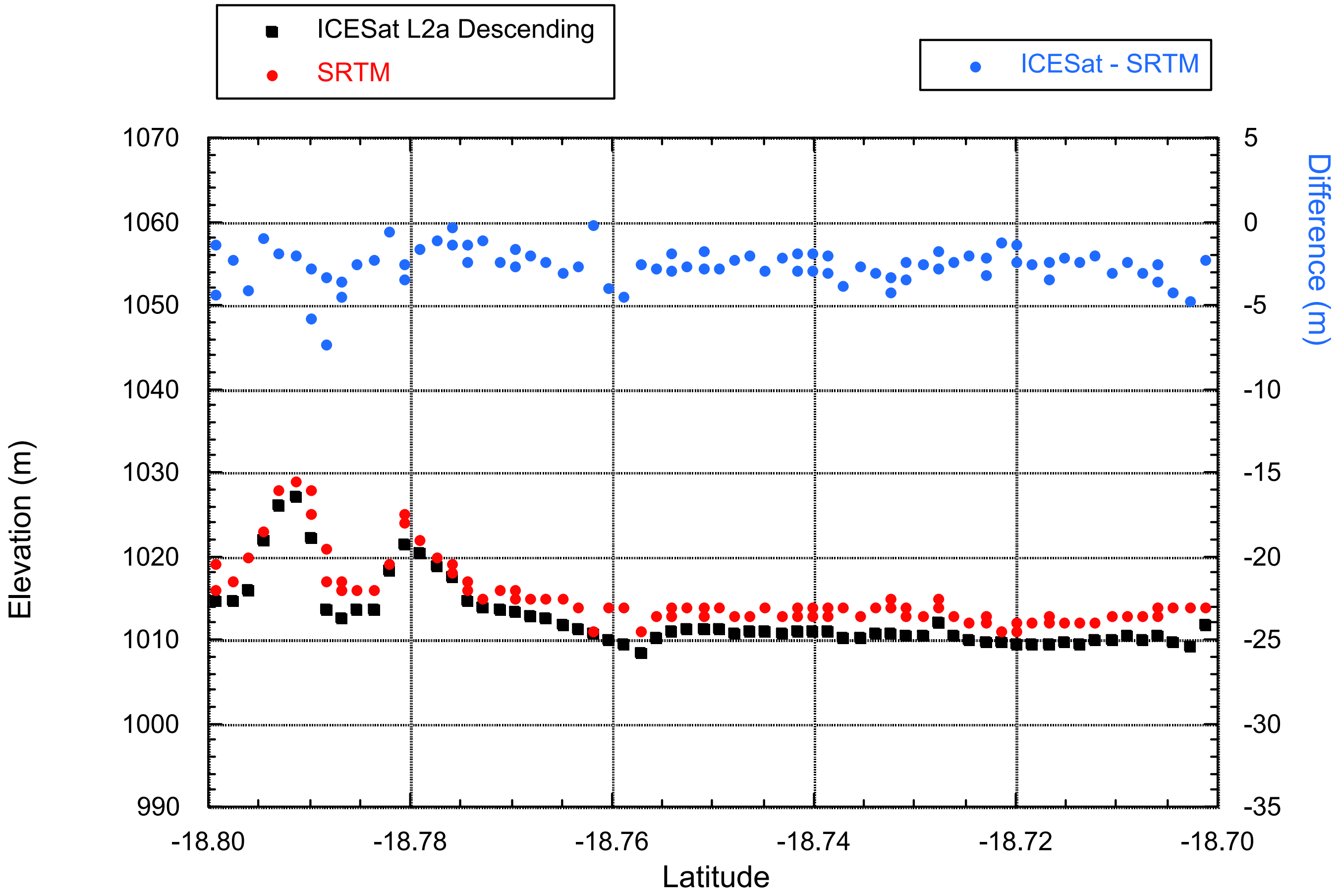


Okavango Delta, Botswana: II

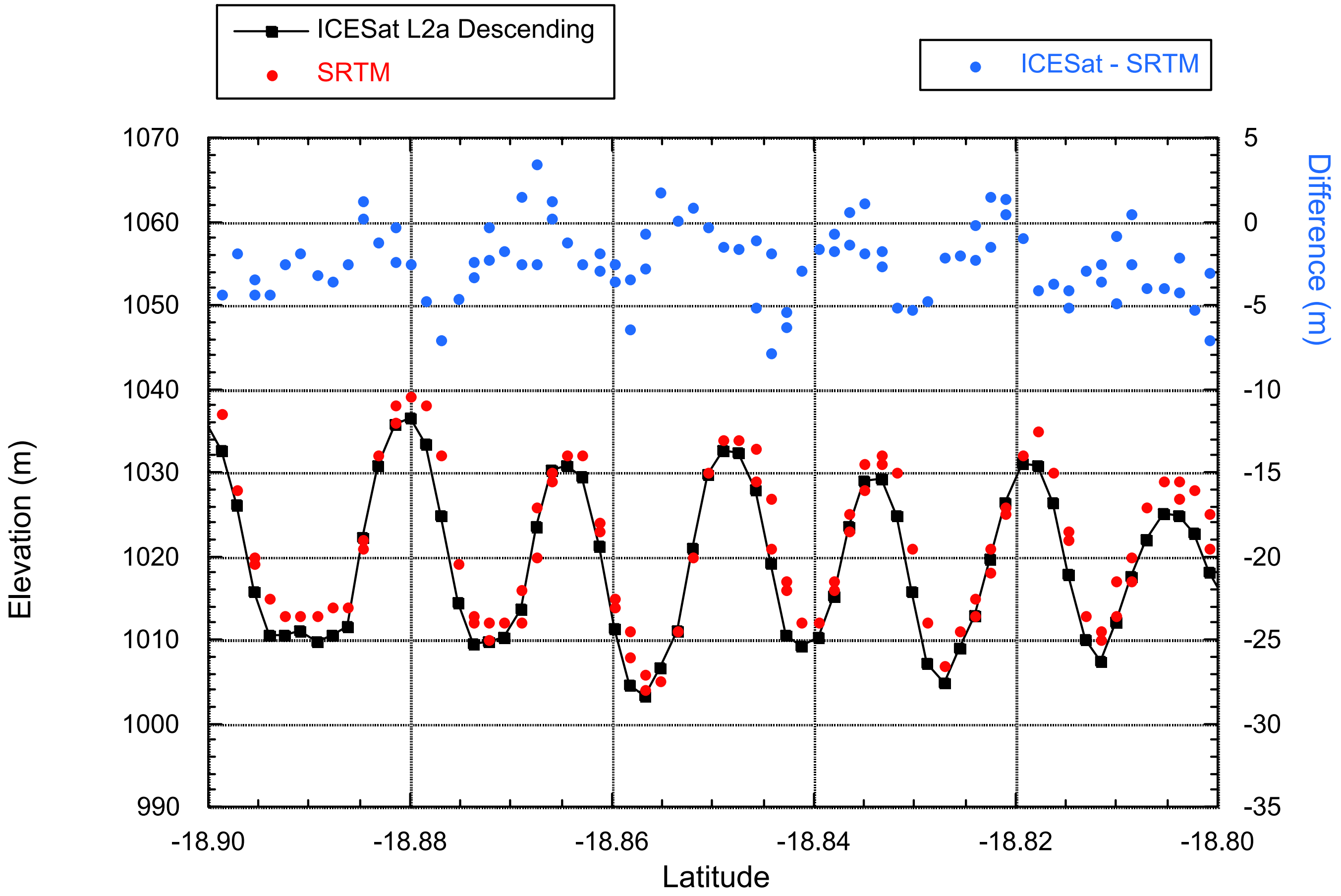




Okavango “Flats”

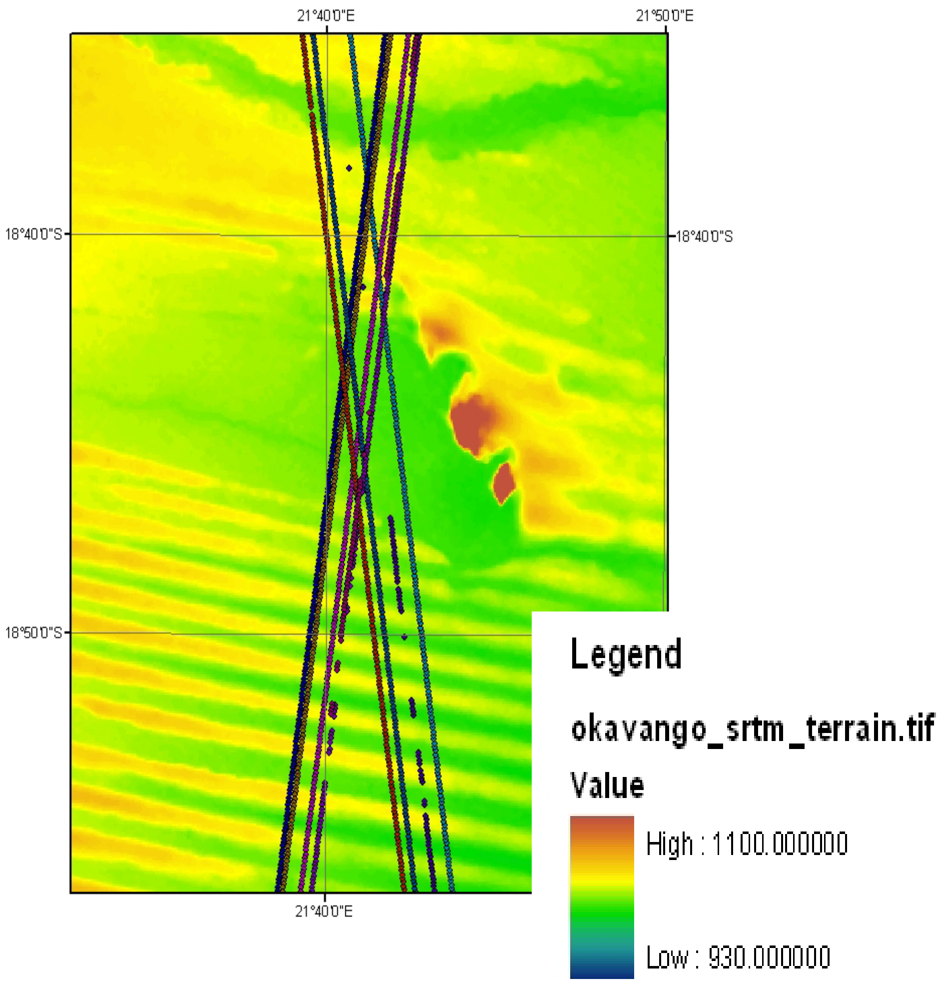


Paleodunes



ICESat L2a Descending
SRTM
ICESat - SRTM
1070
1060
1050
1040
1030
1020
1010
1000
990
5
0
-5
-10
-15
-20
-25
-30
-35
Elevation (m)
Difference (m)
-18.90
-18.88
-18.86
-18.84
-18.82
-18.80
Latitude

ICESat Repeat Tracks



- In mid-latitudes, ICESat orbit is controlled to repeat within 1 km of a reference track
- Figure shows 4-5 repeats from 2003 to 2004; some cloudy tracks
- Are SRTM/ICESat differences caused by surface change between 2000 flight and 2003/2004?

ICESat – SRTM

Mean (standard deviation) in meters

Ops period	Dunes	Flats	Entire track
2a/descending	-2.1 (1.8)	-2.5 (1.1)	-3.0 (1.5)
3a/descending	-1.8 (1.7)	-2.9 (1.4)	-3.0 (1.5)
2a/ascending	-1.5 (2.0)	-2.6 (1.4)	-2.9 (1.8)
3a/ascending	-2.0 (2.1)	-2.7(1.2)	-3.1 (1.7)

Conclusions

- Two regional comparisons made between ICESat elevations and SRTM
  - Both regions are mostly flat, surface slope < 0.5°
  - White Sands Space Harbor (no vegetation)
    - ICESat – SRTM: mean ~ -0.25 m, RMS ~ 1.70 m
    - Similar results comparing airborne lidar with SRTM
  - Okavango Delta, Botswana
    - ICESat – SRTM: mean ~ - 3 m, RMS ~ 1.5 to 1.8 m
    - Slight long wavelength difference in both ascending and descending ICESat tracks
    - Some vegetation contribution
    - Tracks over paleodunes (oriented east/west) suggest better agreement between ICESat and SRTM on south side than north side
  - Contributions from temporal surface change between February 2000 and September/October 2003 deemed small