



ICESat Geolocation and Land Products Validation: Laser Altimetry Profile Matching

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ICESat Calibration & Validation: Integrated Residual Analysis (IRA)



PGSLA: Precision Geolocation System for Laser Altimetry

INPUTS

Direct Altimetry

- Ocean Scans
- Land Cal Sites

Dyn. Crossovers

- Ocean and Land
- Inter- / Intra-mission

Tracking Data

- GPS
- SLR

Orientation Data

- PAD

Combine data over mission life time – track changes in parameters

Integrated Residual Analysis (IRA)

Simultaneous estimation of orbit and instrument parameters from a combined reduction of altimeter and navigation tracking data

Use Profile and Waveform matching to DEMs to further discriminate and characterize solution performance and geolocation accuracy

1. Inst. Param. Calibration

- Pointing, Range and time.
- Not just simple bias – recover complex time varying corrections (environmental, thermal)

2. Orbit Cal. / Val.

- Independent POD from: GPS, SLR, Dynamic Crossovers, Direct Altimetry
- Validate Mission POD: internal performance tests, comparisons to mission POD

3. Mission Geolocation Val.

- Use 1 and 2 above and compute independent geolocation
- Internal geolocation performance tests
- Comparisons to Mission Geolocation



PROFILE MATCHING



- Technique matches elevation profiles to moderate resolution (10-90 m) Digital Elevation Models (DEMs) for areas with rugged topographic relief.
- Proven useful in assessing systematic errors in geolocation solutions for data from previous preliminary laser altimeter missions.
 - (Rowlands et al., 2000; Luthcke et al., 2002; Carabajal et al., 2003)
- Elevations are differenced for every ICESat footprint with the corresponding DEM value, and the standard deviation of the differences establishes a residual for the profile as a whole.
- As profiles are systematically shifted over the DEMs, the proper geolocation of the profile as a whole is established by the location of the residual minima.



PROFILE MATCHING



- Compared Mission Geolocation Solutions for selected ICESat profiles.
- Divided ICESat Track 87 in the Western United States into three consecutive segments, each approximately 275 km in length.
- Used USGS National Elevation Data (NED) DEMs, spatial resolution of 1 arc second (~30m) to match profiles.
- NED's vertical accuracy varies according to source; it was assessed at ~2.7m RMSE based on NGS control points (D. Gesch, personal communication).
- The ICESat and NED horizontal reference frames are essentially equivalent. However, NED's vertical datum is NAVD 88.

Horizontal Datum: NAD83-Cont. U.S., HI, PR & VI
NAD27-AK

Vertical Datum: NAVD88-Cont. U.S., HI, PR & VI
NAVD29-AK

- We convert ICESat elevations (referenced to the ITRF2000 ellipsoid) to orthometric heights by subtracting EGM96 Geoid heights (interpolated from first and last shot values for a 40 shot packet)

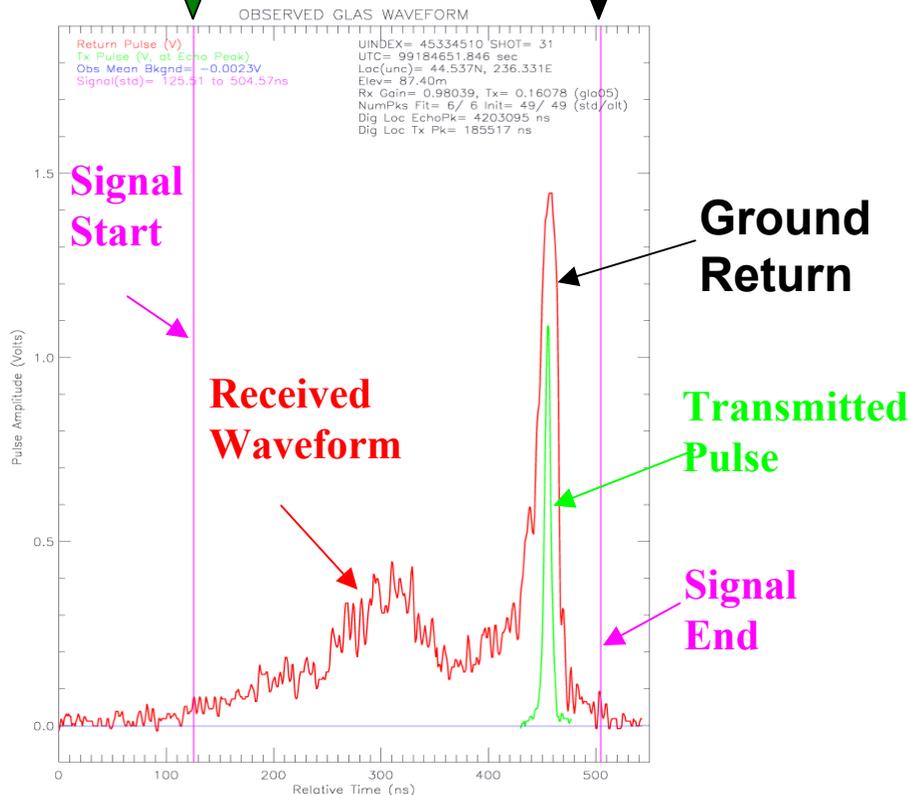


ICESat Elevations from Waveforms



Canopy returns (Signal Start)

Ground Returns (Signal End)



Derived elevations representing the lowest detected surface (i.e., ground) and highest detected surface (i.e., canopy top where vegetated) for matching.

Does not account for the transmit pulse impulse response (pulse width plus receiver bandwidth) → several meter distance between start and end of signal for flat, unvegetated surfaces



Revised ICESat Geolocation vs. NED



- Early in the ICESat cal/val phase, post-launch pointing and range biases were established.
- Close correspondence (within 1 DEM pixel) between the IRA geolocation result and NED.
 - ➔ pointing biases had been successfully recovered.
- Pointing recovery from IRA solutions showed that there was a discrepancy associated with solar illumination conditions.
 - difference between pointing biases
 - for day-time and night-time passes
 - (larger during day-time passes, descending tracks)
- ICESat mission geolocation solution was revised to include the pointing bias recovered for the night-time passes.



Revised ICESat Geolocation vs. NED



Tested ICESat data Release 11 with the purpose of:

- Assessing the reduction in geolocation error achieved.
- Testing if we could observe differences in geolocation error between day-time and night-time passes.

Data used:

- Two cloud-free segments of Track 87, cycle 003, one cloud-free segment of Track 87, cycle 004, day-time descending passes across the Western US (*).
- Two segments of Track 19, cycle 003 and cycle 004, night-time ascending passes across White Sands, New Mexico.

*The Track 87 data used follow the same ground track as the data that were analyzed before, but were acquired 8 days later on the subsequent orbit repeat cycles.



Release 11- ICESat Geolocation Track 87 – Cycle 003 vs. NED



Segment 1 - Ground returns

Elevation profile across Western US.

(descending, day-time)

Mission Pointing.

Optimal shift: 61.67m North;
22.55m West

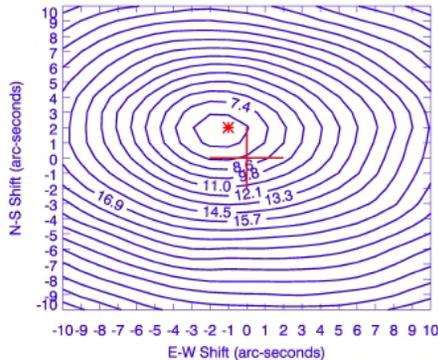
Mean=-0.18m; STD=5.58m.

NP=877.

GLA06 Track ICESat 87 vs. NED in US

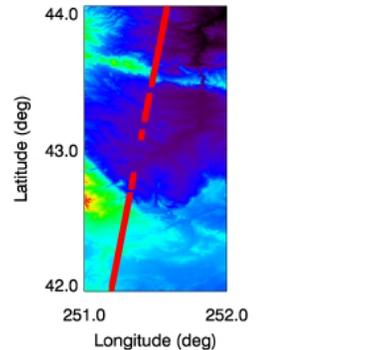
Initial shifts: E-W Shift: 0.00", N-S Shift: 0.00"

RMS Contours for Shifted Sub-orbital Track



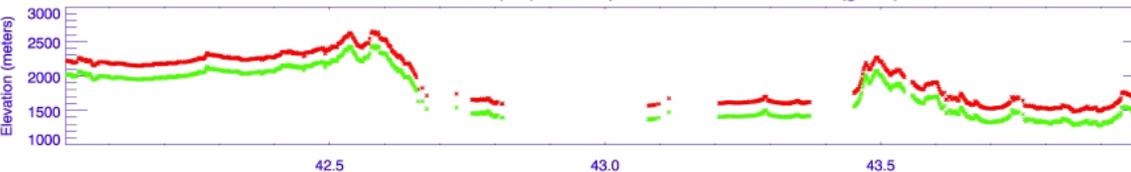
Ground Return: E-W Shift: -22.55 m, N-S Shift: 61.67 m

NED and ICESat 87 Track

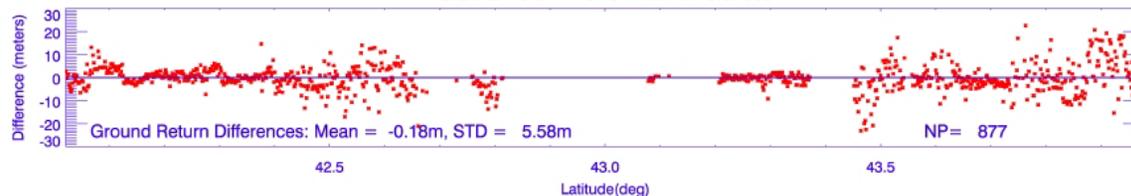


Elevation(m)
1243.71 1666.41 2089.10 2511.80 2934.50 3357.19 3779.89

Ground Return Profile (red) for accepted shots and NED-200.m (green)



Ground Return Profile - NED Differences



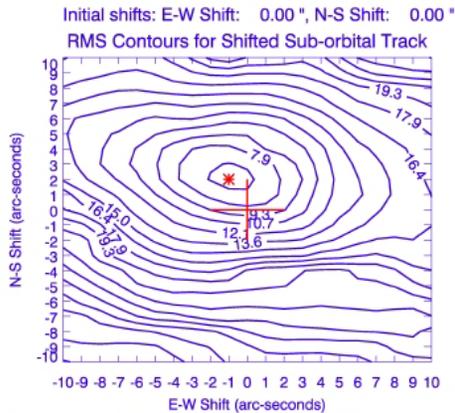


Release 11- ICESat Geolocation Track 87 – Cycle 003 vs. NED

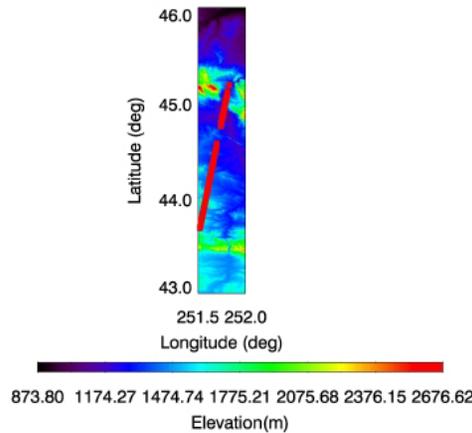


Segment 2 - Ground returns

GLA06 Track ICESat 87 vs. NED in US



NED and ICESat 87 Track



Elevation profile across Western US.

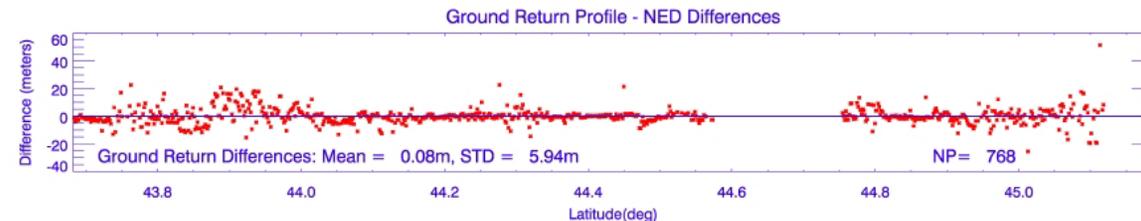
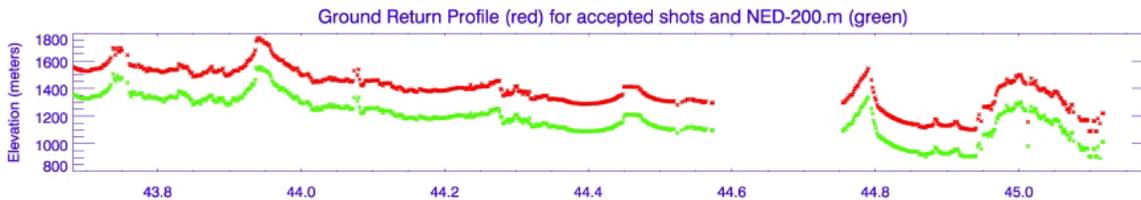
(descending, day-time)

Mission Pointing.

Optimal shift: 61.67m North;
22.02m West

Mean=0.08m; STD=5.94m.

NP=768.



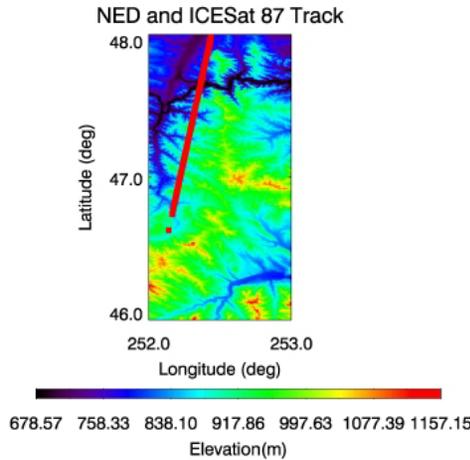
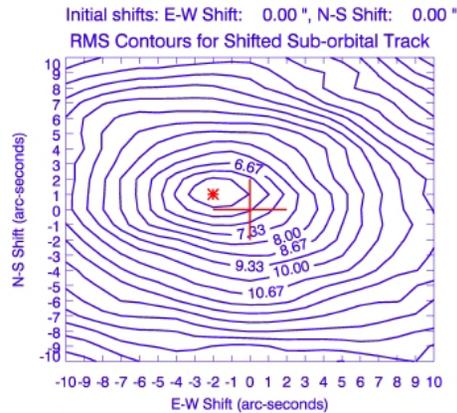


Release 11- ICESat Geolocation Track 87 – Cycle 004 vs. NED



Segment 3 - Ground returns

GLA06 Track ICESat 87 vs. NED in US



Elevation profile across Western US (descending, day-time).

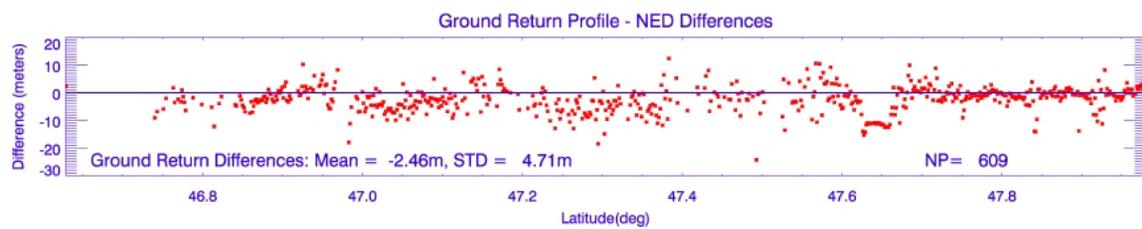
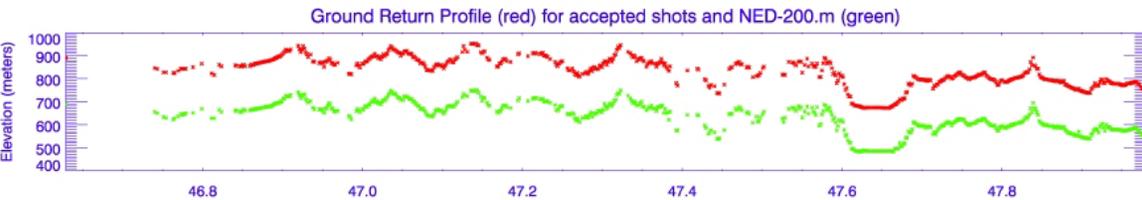
Mission Pointing.

Optimal shift: 30.83m North;
41.82m West

Mean=-2.46m; STD=4.71m.

NP=609.

Ground Return: E-W Shift: -41.82 m, N-S Shift: 30.83 m





PROFILE MATCHING Summary



Day-time Pass

Release 11 - ICESat Track 87 - Cycle 003 - Profile Matching to 1" NED

Segment	Mean (m)	STD (m)	NP	Shift N-S (m)	Shift E-W(m)	RSS(m)
1 (G)	-0.18	5.58	877	61.67	-22.55	65.66
1 (CT)	6.27	7.21	877	61.67	-22.55	65.66
1 (G) *	-0.43	5.25	877	51.39	-37.58	63.66
2 (G)	0.08	5.94	768	61.67	-22.02	65.48
2 (CT)	6.55	8.19	768	61.67	0.00	61.67
2 (G) *	0.06	5.53	768	71.94	-22.02	75.23

Release 11 - ICESat Track 87 - Cycle 004 - Profile Matching to 1" NED

3 (G)	-2.46	4.71	609	30.83	-41.82	51.96
3 (CT)	2.69	5.98	609	30.83	-41.82	51.96
3 (G) *	-2.24	4.74	609	20.56	-34.85	40.46

(G) Ground (End of Waveform)

(CT) Canopy Top (Start of Waveform)

* Sub-Sampling The DEM at 1/3" Increments

- Release 11 represents nearly a factor of 2.5 improvement in geolocation accuracy when matched to the 30 m NED.
- Mean NED elevation is in close agreement with the ground profile.
(But, did not account for the transmit pulse impulse response, pulse width plus receiver bandwidth, which introduces a several meter distance between start and end of signal for flat, unvegetated surfaces)

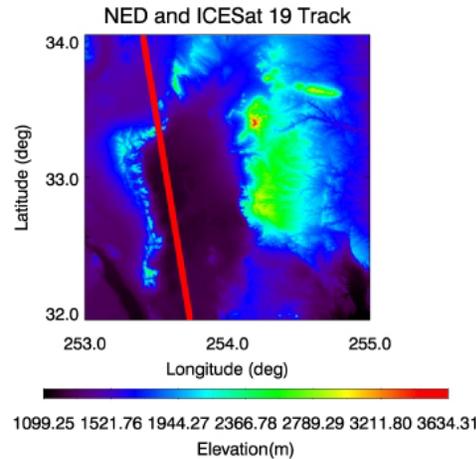
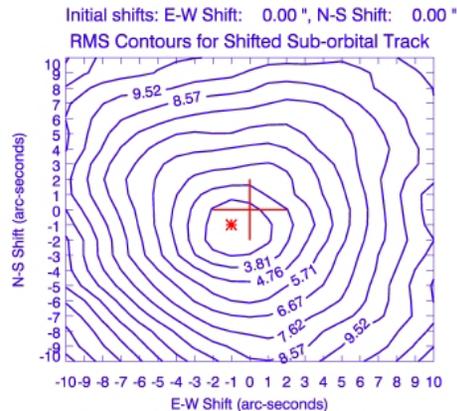


Release 11- ICESat Geolocation Track 19 – Cycle 003 vs. NED



Segment 1 - Ground returns

GLA06 Track ICESat 19 vs. NED in US



Elevation profile across White Sands (ascending, night-time).

Mission Pointing.

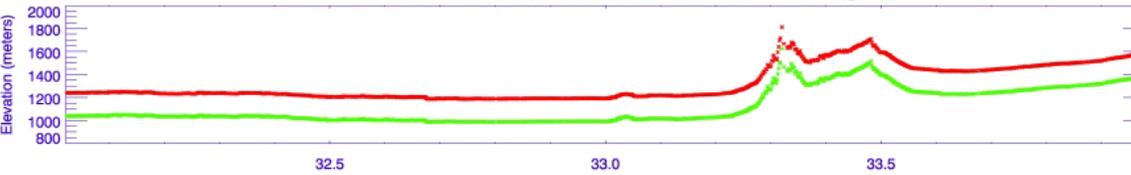
Optimal shift: 30.83 South;
25.86m West

Mean=0.13m; STD=1.87m.

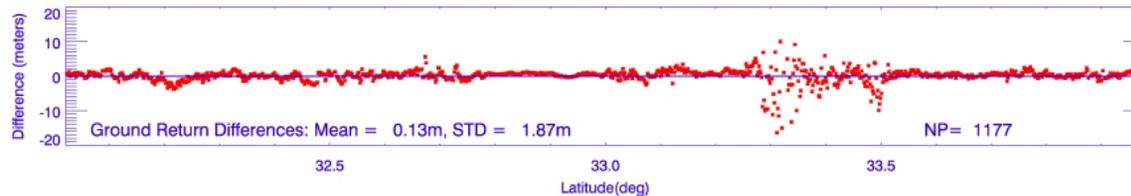
NP=1177.

Ground Return: E-W Shift: -25.86 m, N-S Shift: -30.83 m

Ground Return Profile (red) for accepted shots and NED-200.m (green)



Ground Return Profile - NED Differences



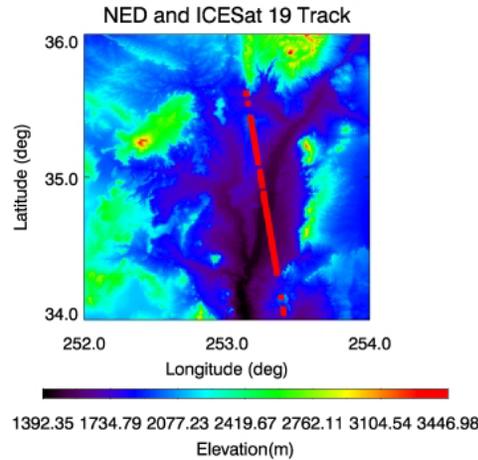
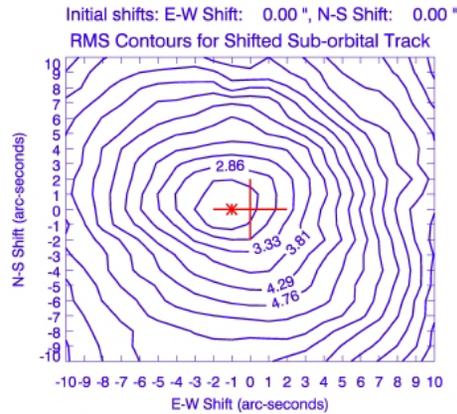


Release 11- ICESat Geolocation Track 19 – Cycle 003 vs. NED



Segment 2 - Ground returns

GLA06 Track ICESat 19 vs. NED in US



Elevation profile across White Sands (ascending, night-time).

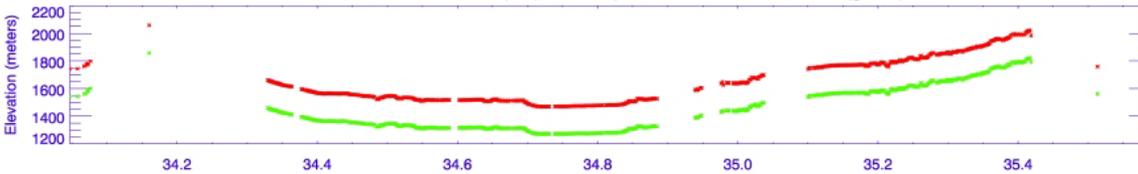
Mission Pointing.

Optimal shift: 0.0 South; 25.31m West.

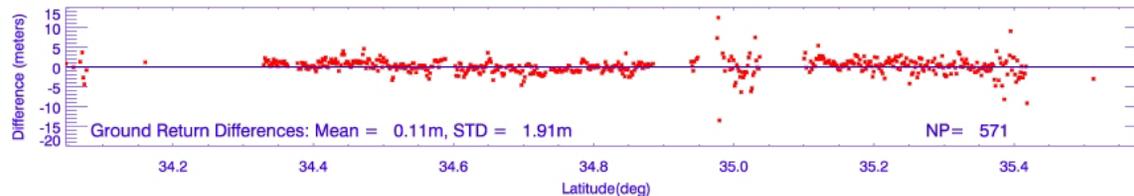
Mean=0.11m; STD=1.91m.

NP=571.

Ground Return Profile (red) for accepted shots and NED-200.m (green)



Ground Return Profile - NED Differences



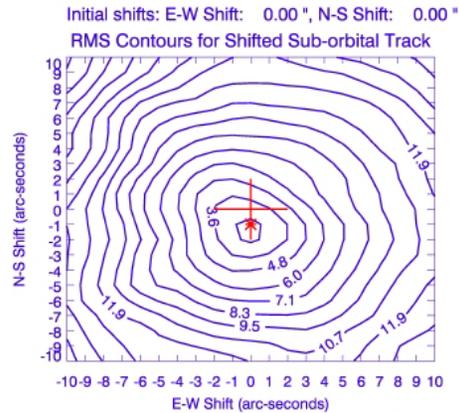


Release 11- ICESat Geolocation Track 19 – Cycle 004 vs. NED

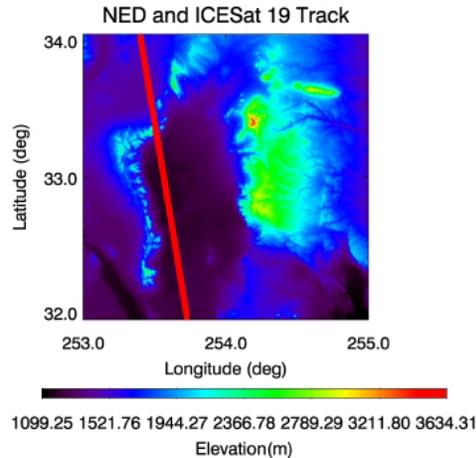


Segment 1 - Ground returns

GLA06 Track ICESat 19 vs. NED in US



Ground Return: E-W Shift: 0.00 m, N-S Shift: -30.83 m



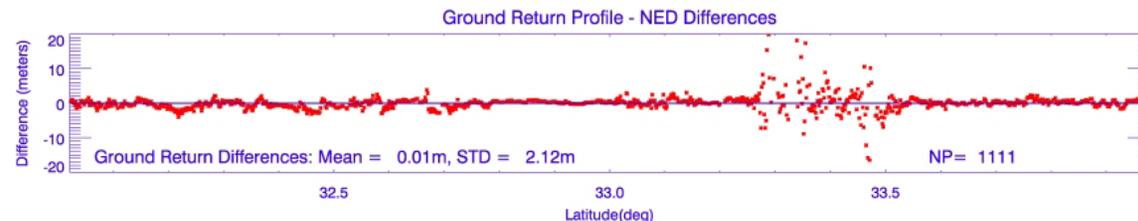
Elevation profile across White Sands (ascending, night-time).

Mission Pointing.

Optimal shift: 30.83 South;
0.0m West

Mean=0.01m; STD=2.12m.

NP=1111.





Release 11- ICESat Geolocation Track 19 – Cycle 004 vs. NED

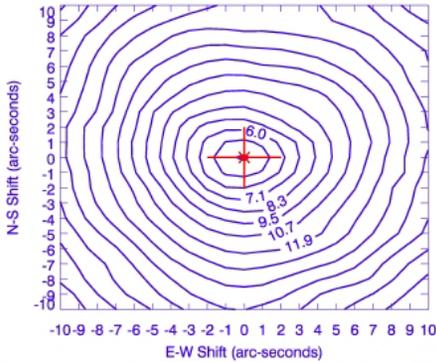


Segment 2 - Ground returns

GLA06 Track ICESat 19 vs. NED in US

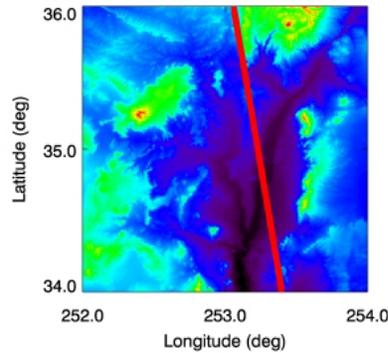
Initial shifts: E-W Shift: 0.00", N-S Shift: 0.00"

RMS Contours for Shifted Sub-orbital Track



Ground Return: E-W Shift: 0.00 m, N-S Shift: 0.00 m

NED and ICESat 19 Track



1392.35 1734.79 2077.23 2419.67 2762.11 3104.54 3446.98
Elevation(m)

Elevation profile across White Sands (ascending, night-time).

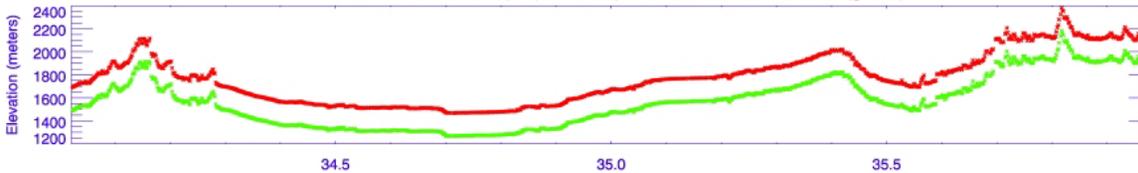
Mission Pointing.

Optimal shift: 0.0 South; 0.0m West.

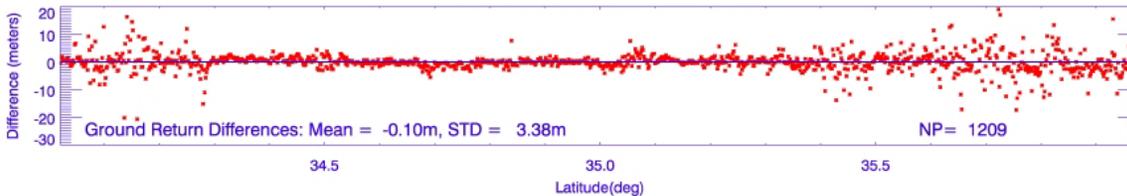
Mean=-0.10m; STD=3.38m.

NP=1209.

Ground Return Profile (red) for accepted shots and NED-200.m (green)



Ground Return Profile - NED Differences





PROFILE MATCHING Summary



Night-time Pass

Release 11 - ICESat Track 19 - Cycle 003 - Profile Matching to 1" NED

Segment	Mean (m)	STD (m)	NP	Shift N-S (m)	Shift E-W(m)	RSS(m)
1 (G)	0.13	1.87	1177	-30.83	-25.86	40.24
1 (CT)	3.79	3.58	1177	-30.83	-51.72	60.21
1 (G) *	0.21	1.80	1177	-41.11	-17.24	44.58
2 (G)	0.11	1.91	571	0.00	-25.31	25.31
2 (CT)	4.09	2.74	571	0.00	-75.94	75.94
2 (G) *	0.11	1.91	571	0.00	-25.31	25.31

Release 11 - ICESat Track 19 - Cycle 004 - Profile Matching to 1" NED

1 (G)	0.01	2.12	1111	-30.83	0.00	30.83
1 (CT)	3.54	4.29	1111	-30.83	-25.86	40.24
1 (G) *	-0.04	1.76	1111	-51.39	8.62	52.11
2 (G)	-0.10	3.38	1209	0.00	0.00	0.00
2 (CT)	6.16	6.49	1209	0.00	-25.26	25.26
2 (G) *	-0.10	3.38	1209	0.00	0.00	0.00

(G) Ground (End of Waveform)

(CT) Canopy Top (Start of Waveform)

* Sub-Sampling The DEM at 1/3" Increments

- Improvement in geolocation accuracy when matched to the 30 m NED.
- Geolocation errors for the night-time Track 19 are less than those observed for the day-time Track 87 (as expected).



PROFILE MATCHING Conclusions



- Further IRA analysis is being conducted to establish the temporal variability of **instrument pointing, timing and range biases**, and test its relationship to instrument thermal conditions, to provide a time-varying pointing bias correction for ICESat geolocation.

(new IRA solutions will be tested)

- Pixel-scale differences between the segment optimal shifts remain, indicating that the shift increment size is not the sole source of between-segment differences.
- Better agreement of 1/3" sub-sampling with 1" sampling results.
 - ➔ Higher resolution DEMs will provide more definitive and accurate assessments of geolocation errors.
 - **Use 10 m NED where available**
 - **Use high-resolution (1.8 m) airborne laser mapping "bald Earth" and canopy top DEMs of the Puget Lowland, Washington (PSLC)**
 - **Waveform Matching**