I. Overview

The Sigma Space Micro Pulse Lidar (MPL), a 100 channel photon counting instrument, collected very dense swaths of data (~1 photon/m^2) over the Jacobshavn glacier and fjord and adjacent ice sheet regions in July 2009. This presentation explains the procedure we used to produce simulated ICESat-2 Advanced Topographic Laser Altimeter System (ATLAS) returns from this data and analyze the projected ATLAS instrument performance over these Greenland regions.

II. Source Data

The Sigma Space MPL collected data over the Jacobshavn glacier and fjord and adjacent ice sheet regions in July 2009. (Figs 1-3) (ref 1, 2)

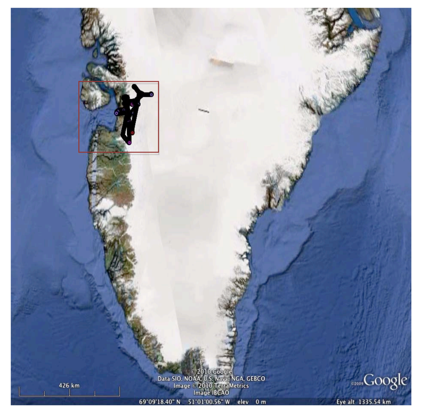


Fig 1a Region Flown

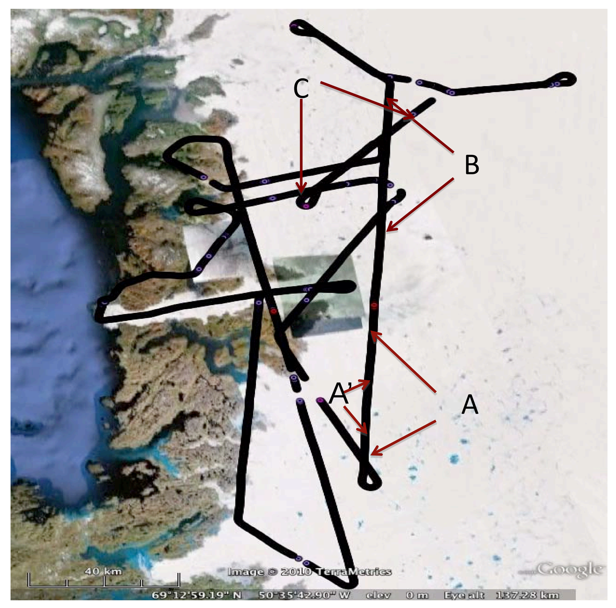


Fig 1b Flight 7 flight lines investigated for this study

Sigma Space preprocessed the data to geolocate it and remove instrument-induced anomalies and the majority of the atmospheric noise, delivering a "signal only" data set containing the x, y, z locations of photons received from the surface (ref 1).

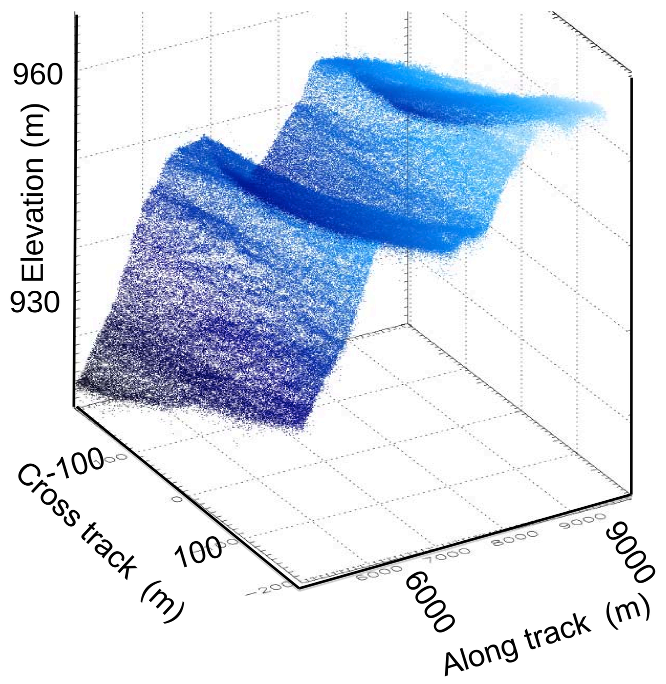


Fig 2 – 3-D plot of all signal photons within 200m of the nadir line – seg A'

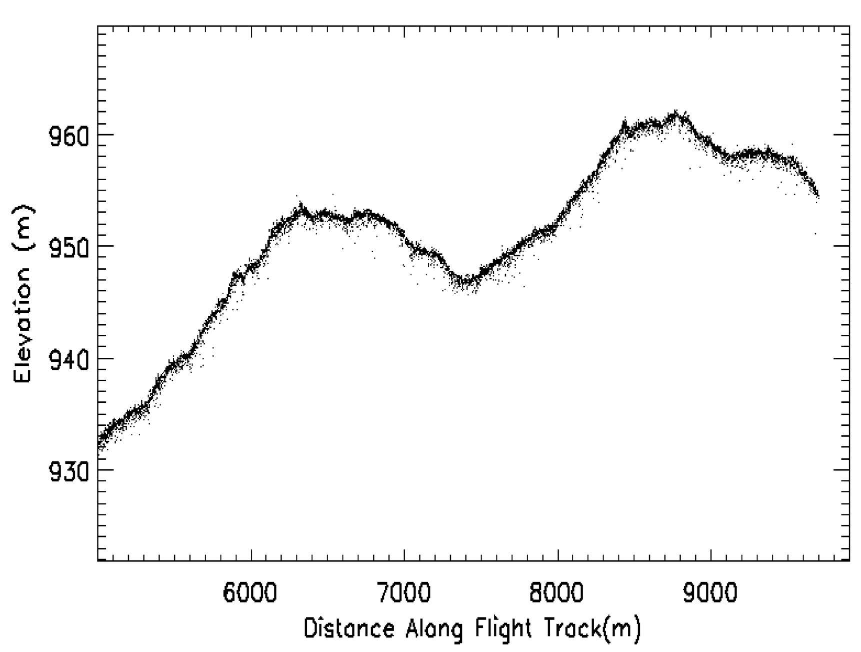


Fig 3 – 2-D profile of all signal photons within 5 meters of the nadir line - seg A'

III. ICESat-2 Simulated Data Creation

The current ATLAS instrument design includes 6-beams, grouped in three sets of two beams spanning 6.6 km in total width (Fig-4). The beams are rotated slightly from the flight path to allow for a cross track distance of ~100m between each weak and strong beam pair on the ground.

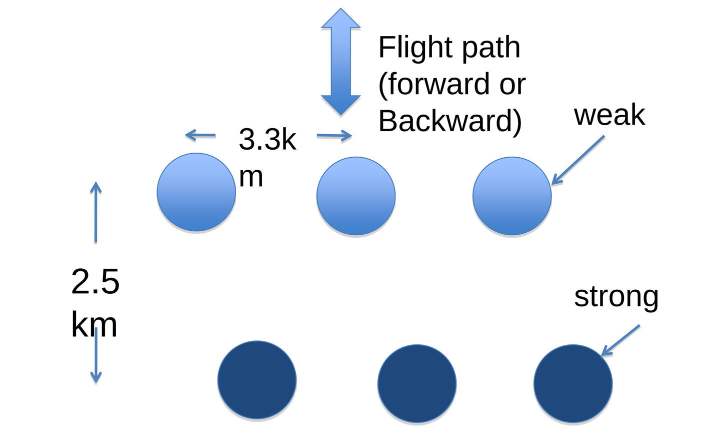


Fig 4 - ATLAS current configuration - laser spots on surface from 3 sets of weak and strong laser beams (Not drawn to scale)

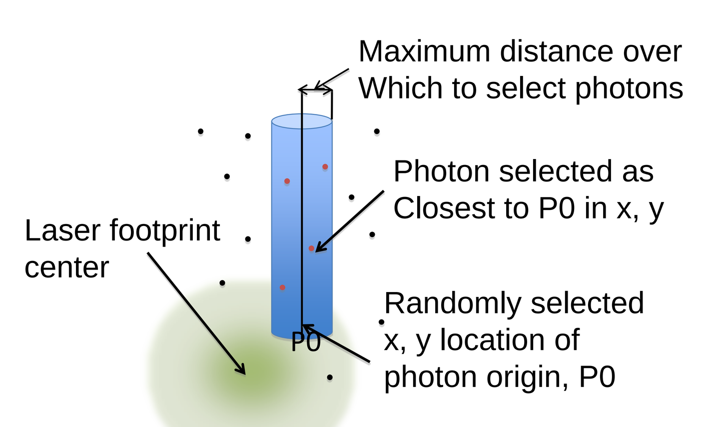


Fig 5 – Subsetting the MPL data to create ICESat-2 simulated data (Not drawn to scale)

ICESat-2 ATLAS returns were simulated by sub-sampling (Fig 5) the MPL photons and then adding realistic background noise (Fig 6), (ref 4)

Calculation of ICESat-2 simulated signal photons:

For each footprint location – every 70 cm along the flight path

1. The desired number of signal photons returned per footprint, NP_f was determined using a Poisson-distributed random number with a mean equal to the mean signal photons/shot (MSP) from the ATLAS design cases (ref 3) for summer ice sheet:

MSP, strong beam = 8.18 photons; MSP, weak beam =2.04 photons

2. For N=1 to NP_f a radial distance from the footprint center was calculated using a Gaussian-weighted random distribution (2-σ diameter = 10m) and an angle calculated from a uniform random distribution. The closest MPL photon to that location was selected or none if there were no photons within 3m (Fig 5)

Calculation of realistic ICESat-2 noise:

1. The mean number of noise photons per second of time the detector is open, Nns, is 6.83E06 was defined by the ATLAS design case for ice sheet summer conditions. Every 150m of range ≅ 1 µsec

2. The number of noise photons over the 150m of range surrounding the signal for each shot was calculated by using a Poisson distribution with a mean of Nns. These photons were distributed throughout the 150m in range using a uniform random distribution.

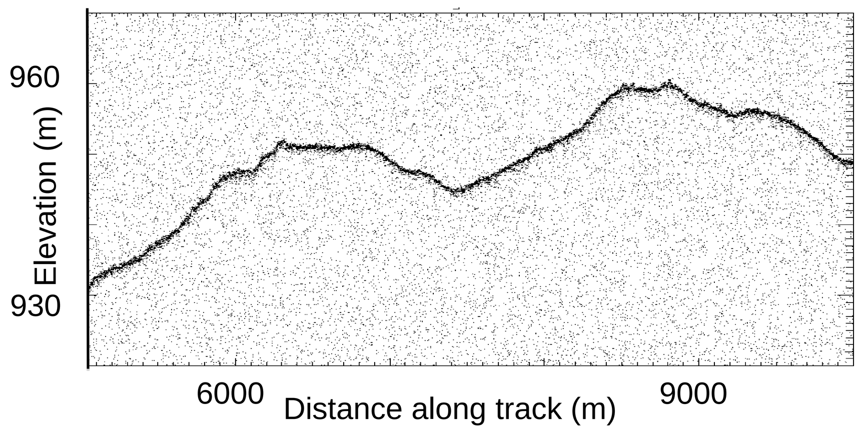


Fig-6a ICESat-2 simulated strong beam response with noise – Seg A'

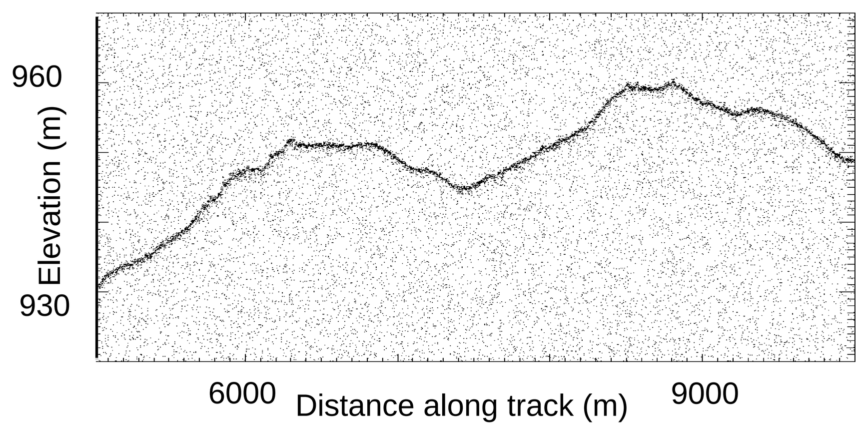


Fig-6b ICESat-2 simulated weak beam response with noise – Seg A'

IV. Ground Elevation Calculation

1.0 Aggregate all data within a given along track distance (20m-90m in increments of 10m used for testing)
2.0 Histogram aggregated data in elevation using 2m bin sizes
3.0 Select 3 bins – the one with the highest number of photons and two surrounding bins. Histogram this 6m of elevation using a bin size of 10cm. (Fig 7) Require that the # of photons in the most populated bin be >= min signal (12 used for 20m and scaled accordingly)
4.0 Calculate the "true" ground elevation as the average of the photon elevations in all bins in the 6m histogram that had at least half the number of photons as the most populated bin

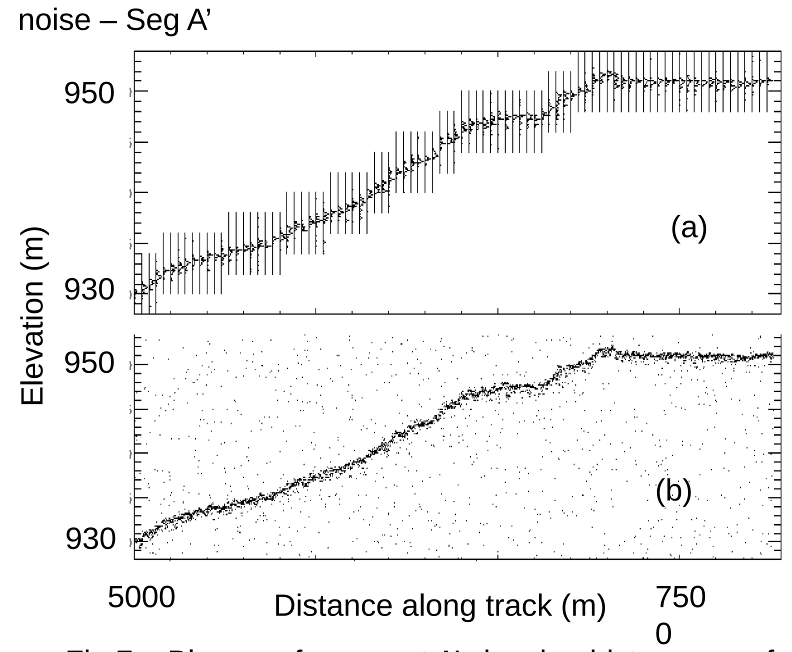


Fig 7 – Blowup of segment A' showing histograms of 3 bins surrounding that with the most photons (a) and all photons (b) using a 20m aggregation distance

V. Ground Elevation Evaluation

To evaluate how precisely the ground can be calculated from the ICESat-2 simulated data, we apply the ground elevation algorithm to the full rate MPL data (~ 1 photon/m^2) and designate this as "ground-truth". We then compare this to the ground calculated from the simulated data. Fig 8 shows these elevation profiles for Segments A and B.

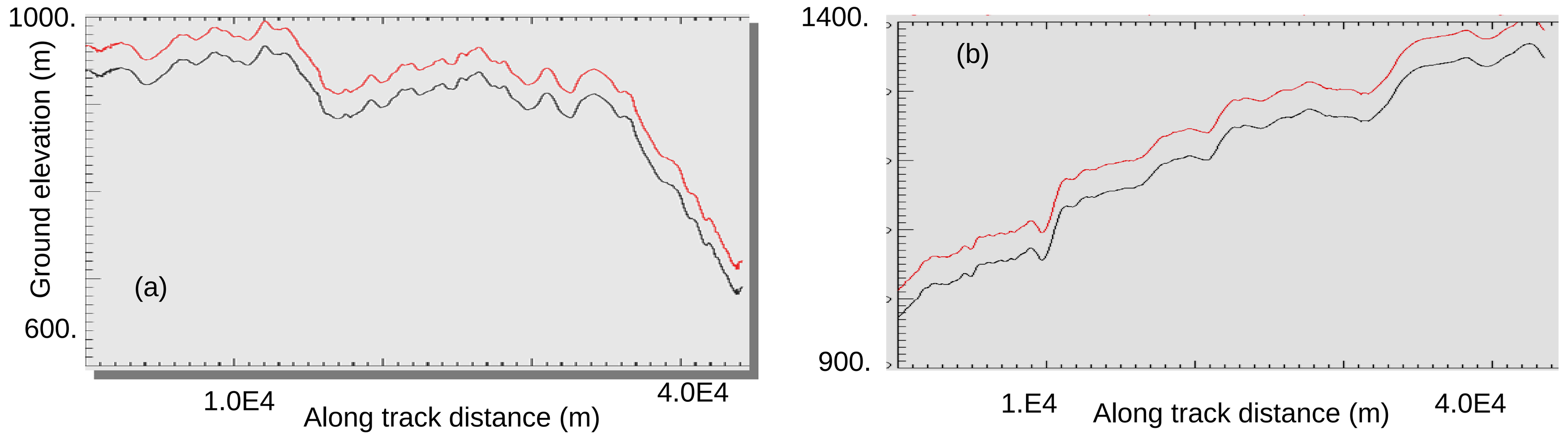


Fig 8 – Elevations calculated using both full rate MPL Data and ICESat-2 simulated data from the strong beam – 40m aggregation (a) segment A, (b) segment B _____Used all MPL data within 5m of nadir track _____Used Simulated ICESat-2 Data – Strong Beam (offset to show differences)

Comparing the derived elevations over Segment A (Fig 9) from both the strong and weak ICESat-2 beam simulations to the "ground-truth" for different along track aggregation distances shows that the standard deviation of the differences varies from 15 to 21 cm with the strong beam giving slightly better results. Over the smoother ice sheet surface of Segment B (Fig 10) we get even better comparisons with the standard deviation of the differences varying from 6 to 10cm. Over the smoother surface both the strong and weak beam show similar performance.

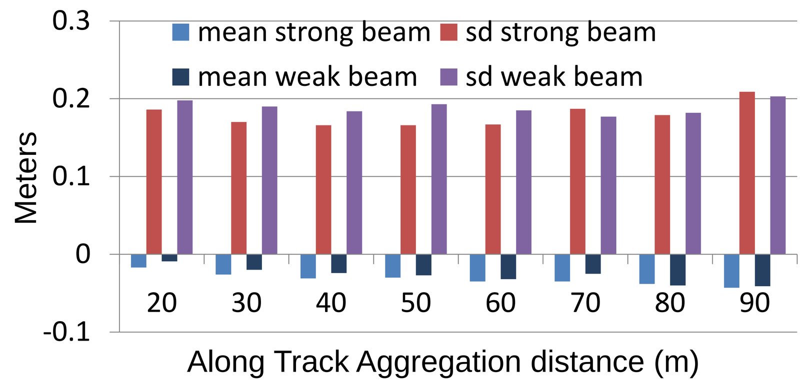


Fig 9- Segment A statistics of derived ground elevation from ICESat-2 simulated data compared with MPL "ground truth"

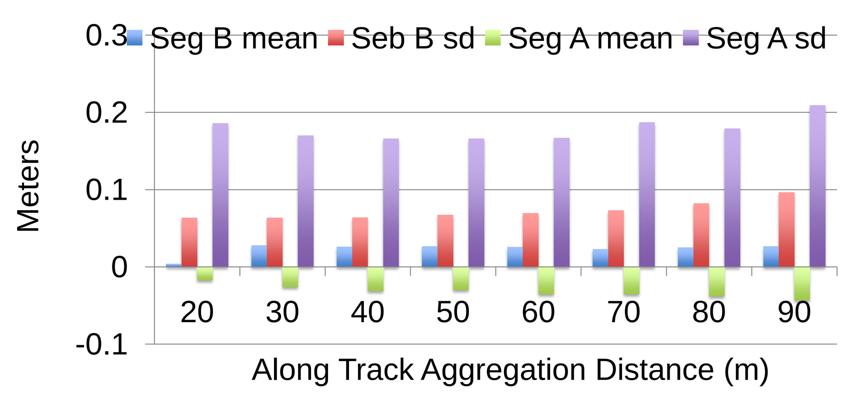


Fig 10 - comparison of derived ground elevations from the ICESat-2 simulated strong beam to the MPL "ground truth" for Segments A and B

VI. ICESat-2 Performance Evaluation

Each dual beam of the ICESat-2 configuration gives us a measure of the instantaneous cross track surface slope over distance scales on the same level as the variation in the ground track spacing among the different repeats (35m 2σ). This allows us to separate the real ground elevation changes from apparent changes due to each repeat measuring at slightly different locations by using the cross track slope to project the elevation to the reference track. The Sigma Space MPL data coverage gives detailed surface elevations for a swath of several hundred meters surrounding the flight line so it can be used to evaluate how accurately we can correct for cross track variation between repeats which is required to perform elevation change calculations using repeat track ICESat-2 data. Procedure used:

1.0 Create simulated ICESat-2 data along flight tracks parallel to the Aircraft track every 5m covering +/- 50m cross track for the strong beam and +/-100m cross track for the weak beam
2.0 Calculate ground elevations for each of the above using aggregation distances of 20, 60, and 90m (Fig 11)
3.0 Combine the tracks into dual beam pairs (one strong, one weak) to investigate dual beam cross track spacing from 50m to 100m and strong beam cross track variation from -50m to +50m from the reference track (flight line nadir)
4.0 For each pair calculate the cross track slope at every location (20m, 60m, or 90m) from the derived elevations
5.0 Project the elevations from the strong beam to the reference track using the above cross track slope
6.0 Calculate the statistics of the difference from the projected elevation to the derived elevation along the ref. track (Fig 12-14)

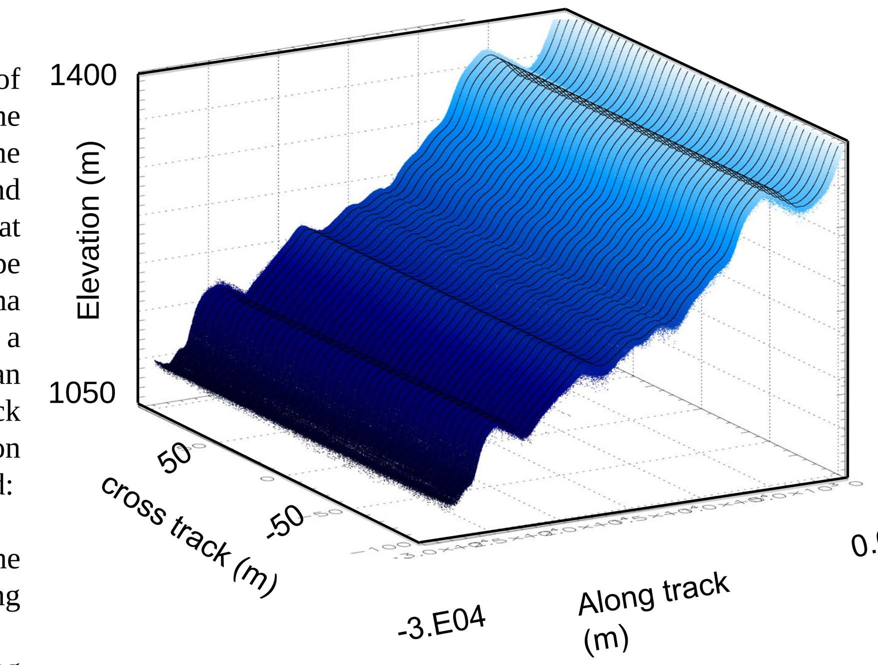


Fig 11 – MPL photons with ICESat-2 simulated ground returns for "tracks" every 5 m in cross track distance from nadir.

If the ice sheet were a perfect planar surface then the projected elevation would agree exactly with that of the reference track. The differences Fig 10-12 show the error we can expect over ice sheets surfaces similar to Seg A, B, and C from ICESat-2 as a function of the dual beam cross track spacing and the distance of the beam from the reference track

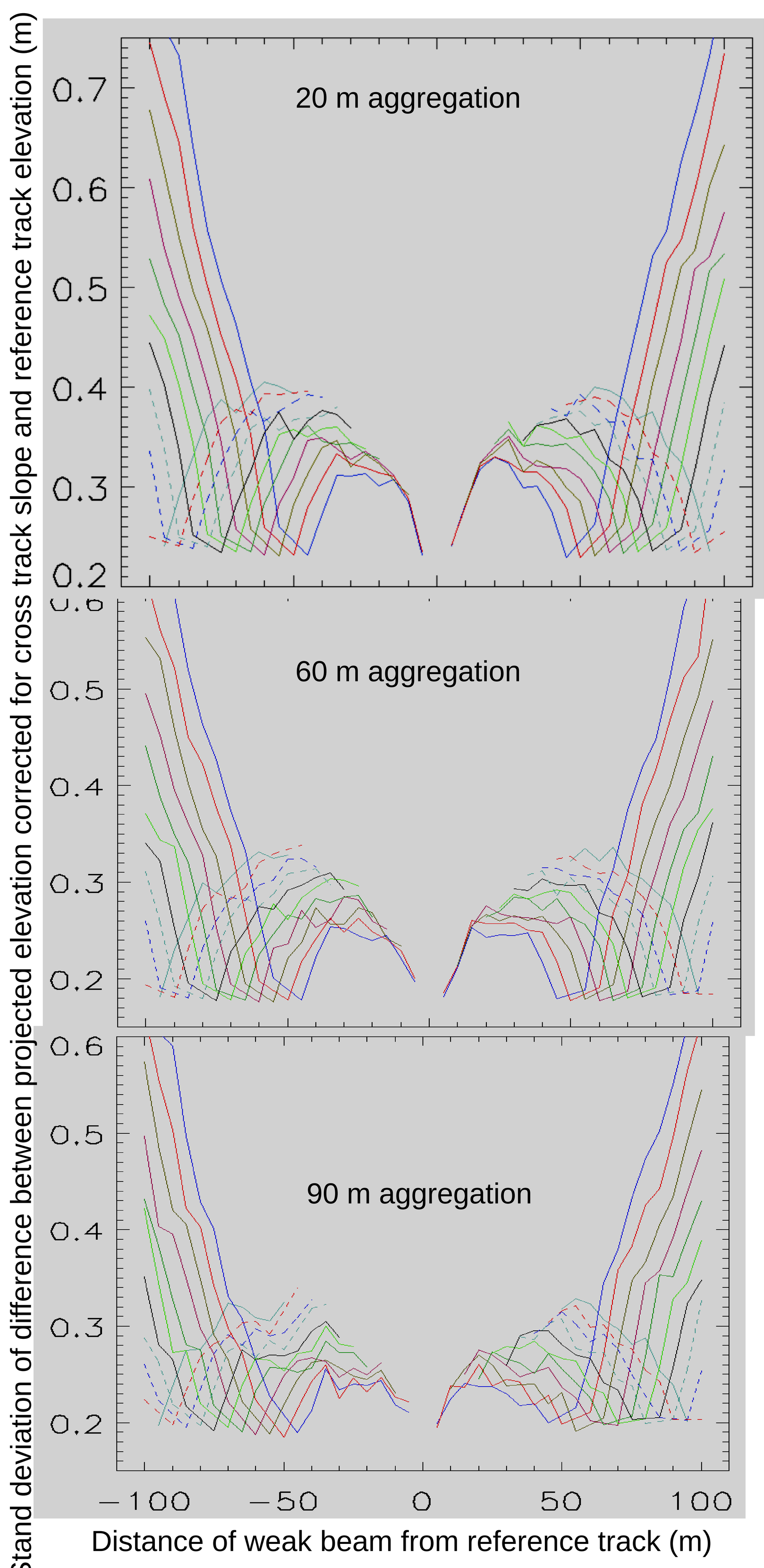
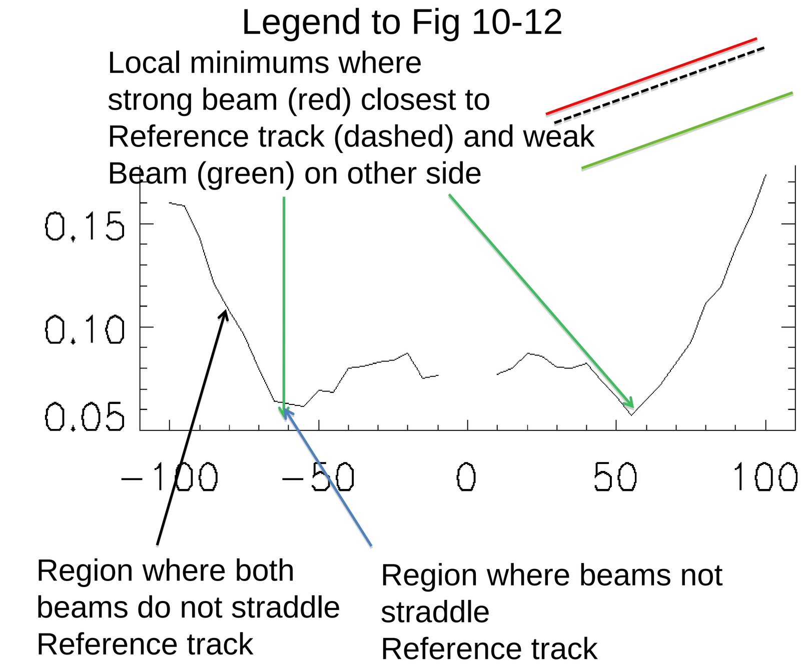


Figure 12 – Quantitative measure of how well we can correct for cross track differences between repeat cycles for different beam spacings for Segment A

Legend to Fig 10-12



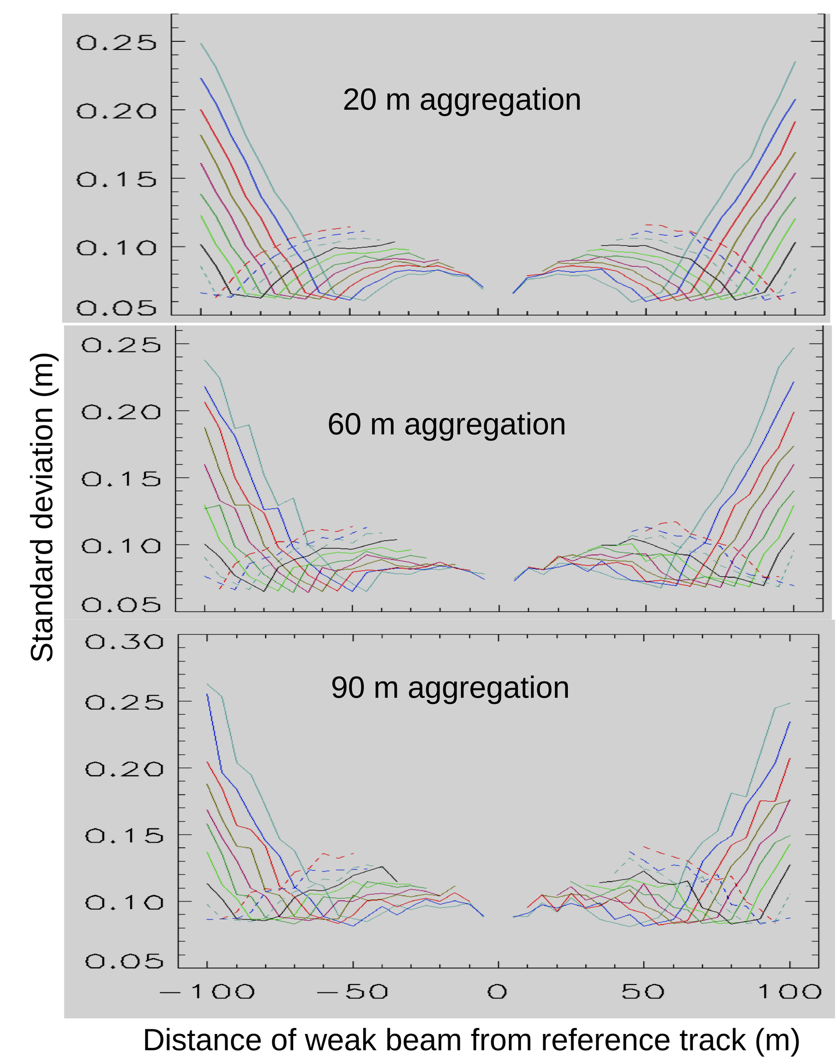


Figure 13 – Quantitative measure of how well we can correct for cross track differences between repeat cycles for different beam spacings for Segment B

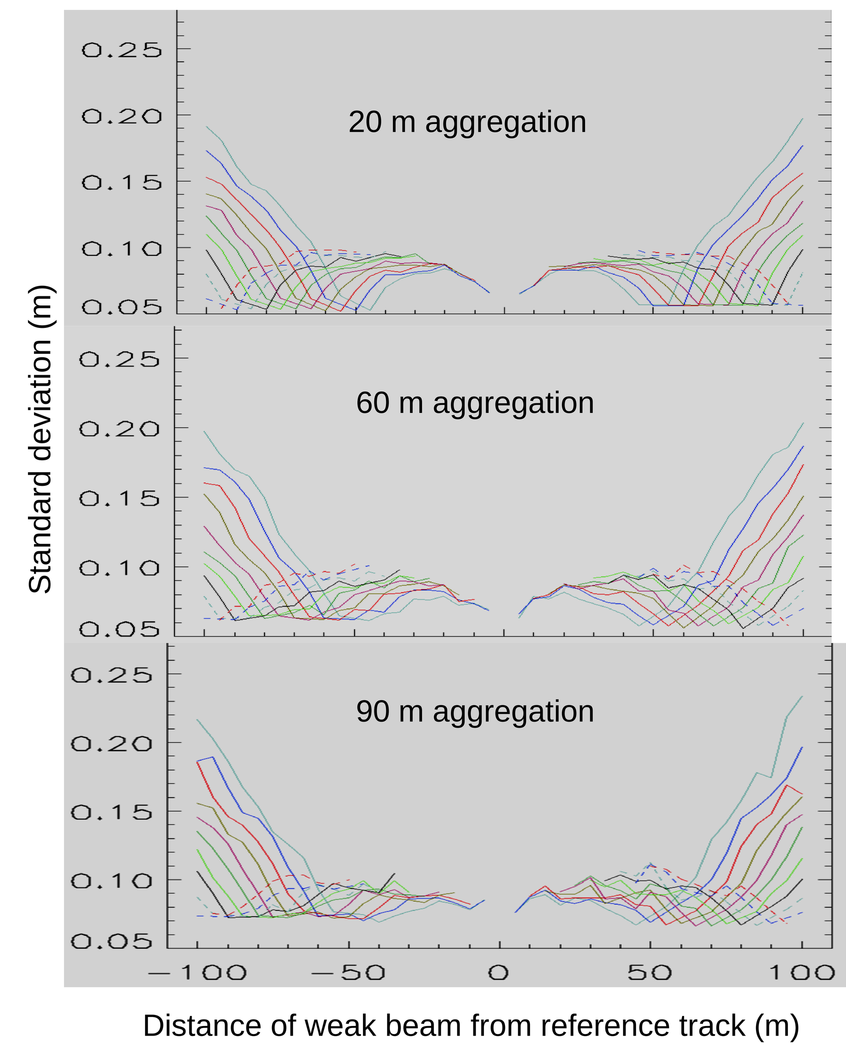


Figure 14 – Quantitative measure of how well we can correct for cross track differences between repeat cycles for different beam spacings for Segment C

VII. Performance Evaluation Summary

1.0 The precision with which we can project the elevation onto the reference track varies from 5-10cm for regions A and B and from 20-30cm for rougher region C using the methods in this study.
2.0 Best performance is achieved when the two beams straddle the reference track.
3.0 A larger cross track distance on the ground between the two beams improves the ability to project the elevation to the reference track over a wider range of repeat track variations.
4.0 For rougher regions (A vs B or C) an increased aggregation distance can increase the precision of the projected elevation onto the reference track.

VIII. ICESat-2 simulated data and documentation

The documentation listed below are available at URL:http://icesat.gsfc.nasa.gov/icesat2/data.php

1.0 J. Marcos Sirota & Christopher T. Field, Initial Report on Greenland Data.

2.0 C. Field, Description of Greenland Sigma Space MPLdata.

3.0 A. Martino, ATLAS Performance Spreadsheet

4.0 K. Barbieri, A. Brenner, T. Markus, T. Neumann, J. Saba, D. Yi, K. Brunt, Description of ICESat-II simulated data created from Sigma Space MPL laser data 23 August, 2010