Algorithm Theoretical Basis Document (ATBD)
for
GEDI L3 Gridded Land Surface Metrics

Scott B Luthcke[1], Terence J. Sabaka[1], Joseph Nicholas[2], Sandra Preaux[3], Michelle Hofton[4]

1. NASA Goddard Space Flight Center, Code 61A, Greenbelt, MD
2. Emergent Space Technologies, Laurel, MD
3. KBR Greenbelt, MD
4. UMD Department of Geographical Sciences, College Park, MD

Release 1.0
Release date: March 4, 2021
Goddard Space Flight Center, Greenbelt, MD

Authors:		Principal Investigator:
Scott B. Luthcke		Ralph Dubayah
Terence J. Sabaka	____________________	____________________
Joseph Nicholas	____________________	
Sandra Preaux	____________________	
Michelle Hofton	____________________	

Abstract

The GEDI instrument consists of 3 lasers producing a total of 8 beam ground transects that are spaced approximately 600 m apart on the Earth's surface in the cross-track direction. Each beam transect consists of ~30 m footprint samples approximately spaced every 60 m along track. The fundamental footprint surface return observations made by the GEDI instrument are geolocated received waveforms of energy (number of photons) as a function of receive time. GEDI Level 3 products are grids with a cell size of 1 km x 1 km produced from the Level 2 geolocated footprint data. Level 2 products include laser footprint measurements of canopy height and structure, and ground elevation from the 8 GEDI laser beam transects. This document provides the description of the Level 3 algorithms and resultant initial Release 01 of the Level 3 products.

Foreword

This document is the Algorithm Theoretical Basis Document for the GEDI gridded Level 3 Products. The GEDI Science Team and Science Operations Center team assumes responsibility for this document and updates it, as required, as algorithms are refined. Reviews of this document are performed when appropriate, and as needed updates to this document are made.

This document is a GEDI ATBD controlled document. Changes to this document require prior approval of the project. Proposed changes shall be noted in the change log, as well as incrementing the document version number.

Questions or comments concerning this document should be addressed to:
Scott B. Luthcke
NASA Goddard Space Flight Center, Code 61A
Scott.B.Luthcke@nasa.gov
301-614-6112

Change History Log

Revision Level	Description of Change	Date Approved

Table of Contents

LIST OF FIGURES

LIST OF TABLES

1.0 INTRODUCTION

1.1 GEDI Data Products Overview

The GEDI Level 1 data products are developed in two separate products, a Level 1A (L1A) and a Level 1B (L1B) product. The GEDI L1A data product contains fundamental instrument engineering and housekeeping data as well as the raw waveform and geolocation information to compute higher level data products. The GEDI L1B geolocated waveform data product, while very similar to the L1A data product, contains specific data to support the computation of the higher level 2A and 2B data products. These L1B data include the corrected receive waveform, as well as the receive waveform geolocation information. Level 2 (L2) products contain ground and vegetation metrics derived from the L1 data. Level 3 (L3) products are grids of some of those L2 metrics. Level 4 (L4) are derived ecosystem parameters. The GEDI data products are listed below in Table 1-1.

Table 1-1 GEDI Data Products

Product	Description
Level 1	Geolocated Waveforms
Level 2	Canopy Height/Profile Metrics • RH metrics • Canopy top height • Ground elevation • Canopy cover and cover profile • Plant area index (PAI) and vertical PAI profile
Level 3	Gridded Metrics
Level 4	Biomass
Level 4	Demonstrative Products • Ecosystem model outputs • Enhanced height/biomass using fusion with Landsat • Habitat model outputs

1.2 Document Overview and Objective

This document is designed to provide: a general theoretical overview of the algorithms, processing steps and procedures required to provide Level 3 (L3) gridded metrics, and a gridding algorithm implementation and processing flow for the GEDI mission L3 products.

All figures are located at the end of the document. Tables and equations are imbedded in the text. References are cited in the text by author's last name and year of publication in italics. A full bibliographic reference list is presented at the end of the text before the figures.

1.3 GEDI Configuration

The GEDI instrument consists of three lasers producing a total of eight beam ground transects that are spaced approximately 600 m apart on the Earth's surface in the cross-track direction relative to the flight direction, and approximately 735 m of zonal (parallel to lines of latitude) spacing. Each beam transect consists of ~30 m footprint (surface return) samples approximately spaced every 60 m along track. The "coverage" laser is split into two transects that are then each dithered producing four ground transects. The other two lasers are dithered only, producing two ground transects each. The configuration of the ground tracks is shown in Figure 1. The ranging points from each footprint's waveform are geolocated to produce geolocation data groups ("geolocation" and "geophys_corr") provided in the L1 and L2 data products.

1.4 L3 Product Overview

GEDI L3 products are grids with a cell size of 1 km x 1 km produced from the L2 geolocated footprint data. The first release (Rel 01) of L3 products are simple averages and standard deviations of the valid footprints within each 1 km^2 cell. Later releases will account for the distribution of footprint measurements in both along- and across-track directions leading to uneven sampling of only a small percentage of each 1km^2 cell. The techniques used for the later releases will account for variability and sampling effects in order to create grids that more accurately represent the topography and canopy structure throughout each cell. Footprint data from both inside a cell and from neighboring cells will be used to ensure the value assigned to each cell will be representative of the totality of the cell. Figure 2 illustrates some of the variation in sampling that can occur in 1 km^2 grid cells (shown in cyan). Tracks are in red. The black dashed line represents the center of the beam pattern.

1.5 Related Documentation

Related documents include parent documents, applicable documents, and information documents.

1.5.1 Parent Documents

- GEDI Science Data Management Plan

1.5.2 Applicable Documents

- GEDI ATBD for GEDI Transmit and Receive Waveform Processing for L1 and L2 Products.
- GEDI ATBD for GEDI Waveform Geolocation for L1 and L2 Products
- GEDI L2A Product Data Dictionary (gedi_l2a_product_data_dictionary.html)
- GEDI L2B Product Data Dictionary (gedi_l2b_product_data_dictionary.html)

2.0 GRIDDING ALGORITHM

2.1 Overview

The GEDI L3 Gridded Land Surface Metrics are derived from edited L2 footprint quantities by computing the average and standard deviation for the elevation of the lowest mode and RH100 values. Grids of the number of shots per cell are also included. Section 2.2 includes a description of the approach used for Rel 01, and Section 3 contains the details of the multi-step L2 data editing, and grid cell verification used in the creation of the Rel 01 grids.

Future releases will be made by optimally interpolating to produce a representative value for each cell of a 1 km x 1 km grid. Techniques for this optimal interpolation are still being investigated but include Ordinary Kriging, see *Cressie 2015*, and Tensioned Thin Plate Splines, see *Smith & Wessel 1990*. These techniques are briefly described in Section 2.3.

2.2 Mathematical Description

2.2.1 Counts

The counts grid provides the number of valid footprints in each 1 km^2 grid cell, *n*.

2.2.2 Mean

The mean grids provide the average of the specified variable, $\bar{x}$, for all valid footprints in each 1 km^2 grid cell, as shown in Equation 1, where x_i represents the value from the i^{th} footprint and *n* is the total number of valid footprints. The mean and standard deviation computations are efficiently implemented using Welford's Method, *Welford 1962*.

$$(1)\ \bar{x} = \frac{1}{n}\sum x_i$$

2.2.3 Standard Deviation

The standard deviation grids provide the standard deviation of the specified variable for all valid footprints in each 1 km^2 grid cell, as shown in Equation 2.

$$(2)\ \sigma = \sqrt{\frac{\sum(x_i-\bar{x})^2}{n}}$$

2.3 Future Methods for Release 02

As previously discussed, the current L3 Rel 01 products are based on block mean and standard deviation, supplying the number of shots within a block enables the computation of the standard error of the mean and other weighting, smoothing and filtering by the user. Future releases of L3 will employ advanced gridding algorithms which are briefly described here.

2.3.1 Statistical Methods – Kriging

Of the gridding algorithms that make predictions based upon weighted-averages of in-situ raw data, *Smith & Wessel 1990*, divide these into two classes: 1) statistical methods; and 2) integral methods. The statistical methods, like Kriging, determine data weights that minimize prediction error given noise and signal covariances of the data and underlying geophysical process, respectively. The advantage of these statistical methods is that they yield direct estimates of errors in the predictions, but the disadvantage is they cannot guarantee global properties of the prediction surface and they often require the inversion of large, dense matrices. Kriging considers both a deterministic and a stochastic part of the underlying process. The deterministic part can be a known mean ("Simple Kriging"), an unknown mean that must be estimated ("Ordinary Kriging"), or some unknown surface that is more complex than just a mean that must be estimated ("Universal Kriging"). The stochastic part requires the estimation of parameters from the data of a positive-definite functional form that describes either a signal/noise covariance or variogram, *Cressie 1985*. This stochastic parameter estimation can be done simultaneously with the deterministic parameters or before. If the error in the stochastic parameters is taken into account, then the method is sometimes called "Empirical Bayesian Kriging", *Cui et.al 1995*, *Lindstrom & Bates 1988*, and *More & Halvorson 1989*. After investigation of an LVIS proxy for GEDI data using Universal Kriging with deterministic polynomial surfaces, it was found that a simple mean would suffice, i.e., Ordinary Kriging. This reveals that the choice of both deterministic and stochastic parameters is something that must be decided after experience with each data set. This can sometimes be an onerous task, especially for large data sets in different settings.

2.3.2 Integral Methods – Tension Thin Plate Splines

The integral methods construct prediction surfaces that minimize certain norms, often smoothing properties, over the domain of interest. The advantage of these methods is that the surface indeed satisfies the smoothing constraints, but the disadvantage is that error estimates of predictions are not straightforward. Another advantage is that integral methods only require a small set of free parameters to be specified to produce reasonable predictions. A popular norm is the curvature norm, which consists of the integral of the square of all second-order derivatives over the domain. This is related to the energy integral of a thin, flexing plate. This norm, along with the requirement that observations be interpolated exactly, leads to an exact closed-form solution known as a Thin Plate Spline (TPS) solution, which consists of radial basis functions centered on each position. Additional linear trends may be added in order to control boundary conditions. While the TPS performs very well in dense measurement regions, it does display spurious fluctuations in areas of sparse data coverage. In order to avoid this, *Smith & Wessel 1990* included an isotropic tensile stress term in the analysis which leads to solutions of splines under tension. This leads to damped fluctuations away from data concentrations, but does not lead to a close-form solution. The solution is obtained from a numerical approach where a single parameter determines the degree of tradeoff between a minimum curvature solution and a purely harmonic solution with no extrema between measurement locations. While the radial basis function approach often requires the inversion of large, dense matrices, the *Smith & Wessel 1990* approach leads to large, but sparse matrices that are amenable to spare direct solvers or efficient iterative methods, thus accommodating larger solutions.

3.0 IMPLEMENTATION

3.1 Input footprint level quantities to be gridded

For each L3 gridded product the corresponding L2 footprint product, error estimates and flags are used as input along with various metadata for each location including cell and pass identification, leaf-on, day/night, full-power or cover laser flags. Table 3-1 lists the L2 footprint products to be gridded. The output of the algorithm is 1km x1km grids of the mean and standard deviation for the L2 footprint products. Text files containing a list of edited orbits and edited cells, and a binary file recording the shot number of edited returns are also created. In future releases, other statistics including the model parameters may be available for output from the algorithm and additional L2 products may be gridded.

Table 3-1 Level 2 footprint products to be gridded.

Name	Units	Description	Variable	Data Type	Source
Shot Count	counts	Number of footprints in each grid cell after editing	counts	INT32	GEDI02_A
Ground elevation	m	Elevation of lowest mode	Zg	FLOAT32	GEDI02_A
Relative height (p=1.00)	m	100^{th} percentile of waveform energy relative to ground elevation	RH100	FLOAT32	GEDI02_A

3.2 The Grid

The 1 km^2 resolution global EASE-Grid 2.0, see Figure 3, is used for GEDI L3 grids. This grid features equal area cells and compatibility with many existing biosphere data sets. More information on this grid can be found either in *Brodzic, et. al. 2012* or online from NSIDC at https://nsidc.org/data/ease. L2 footprint positions in latitude, and longitude are converted to x and y coordinates in the grid. The L2 footprints are assigned to 1 km^2 grid cells based on the projected ground position at the footprint center.

3.3 Procedure

For each product type the L2 footprint data for each 1 km^2 block is identified and edited according to the criteria in Section 3.3.1. Next, footprints from previously identified poor performing orbits are excluded. Orbits where ground elevation significantly deviates from TanDEM-X (TDX) are identified according to the criteria in Section 3.3.2. Individual footprints are then edited based on the criteria explained in Section 3.3.3. Finally, 1 km^2 cells are compared to surrounding cells and excluded based on the procedure in Section 3.3.4. In future releases, these editing procedures will be optimized, and the editing will be based on characterization of the individual returns as well as comparison to other data sources (e.g. TDX).

3.3.1 Initial Footprint Editing

The returns are selected for inclusion based on the criteria in Table 3-2. Then cells are excluded that are determined to be ocean using the land mask file, GEDI_MASK_LAND_NOMINAL_r1000m_EASE2.0_UMD_v3.tif. Finally, the return elevation_lowestmode is compared to TDX or MSS and only included if it is within 150 m.

Table 3-2 Initial Editing Criteria

L2A Variable Name	Criteria for Return Inclusion
rx_assess_quality_flag	≠ 0
surface_flag	≠ 0
stale_return_flag	= 0
rx_maxamp	> 8*sd_corrected
sensitivity	<=1 and > sensitivity_threshold
rx_algrunflag	≠ 0
Zcross	> 0
Toploc	> 0
degrade_flag	= 0

3.3.2 Orbit Editing

First, previously identified suspect orbits are excluded. Then, TDX and SRTM are re-gridded to the EASE 2.0 1 km^2 grid and the difference is computed (Equation 3, Figure 4).

$$(3)\ \Delta h_{SRTM-TDX} = h_{SRTM1km} - h_{TDX1km}$$

In regions where TDX and SRTM surface elevation agree within 1.5 m, the individual footprint-level residuals (Equation 4) are computed in 1 km^2 cells.

$$(4)\ \Delta h_i = h_{GEDIfootprint} - h_{90mTDX}$$

The average residual is considered to be large if it is greater than 5 times the difference between SRTM and TDX for that cell (Equation 5).

$$(5)\ \left|\frac{\sum_i \Delta h_i}{n}\right| > 5 * |\Delta h_{SRTM-TDX}|$$

Orbits that have more than 26% of 1 km^2 cells with large average residuals (see Figure 5) are excluded. Finally orbits where the RMS of the residuals minus the differences between SRTM and TDX is greater than 12.9 m are excluded (Equation 6, Figure 6).

$$(6)\ RMS\left(\left|\frac{\sum_i \Delta h_i}{n}\right| - |\Delta h_{SRTM-TDX}|\right) > 12.9\ m$$

The threshold values in equation 5 and 6 were empirically derived from the data distribution and range. These combined criteria result in 12.2% of orbits being excluded.

3.3.3 Second Round of Shot Editing

A second round of shot editing is performed on the remaining data. The GEDI highest return and lowest mode are compared to TDX. Two sets of criteria are used, one for footprints in cells where SRTM and TDX are within 1.5 m and another for footprints in cells where SRTM and TDX differ by more than 1.5 m. Shots are excluded if their difference with TDX exceeds the relevant bound. The lower and upper bounds for each case are in Table 3-3 below. The limits in use were empirically chosen and result in 0.1% of the data being excluded.

Table 3-3 Second Shot Editing Criteria

GEDI Variable	SRTM, TDX Difference	(GEDI – TDX) Lower Bound	(GEDI – TDX) Upper Bound
Highest Return	<1.5 m	-23.3 m	57.8 m
Highest Return	>1.5 m	-38.3 m	78.7 m
Lowest Mode	<1.5 m	-41.3 m	32.8 m
Lowest Mode	>1.5 m	-56.3 m	59.5 m

3.3.4 Cell Quality Control

Some suspect data makes it through the previous editing steps, so a final quality control step is performed on the cells by comparing them to the cells within 125 km. A cell is excluded if its mean is greater than 3 times the standard deviation of the means from cells in a 125 km box centered on that cell. This quality control is performed using both the elevation of the lowest mode and the RH100. If a cell is eliminated in either variable, it is removed for all variables. Currently this quality control results in 0.21% of cells excluded due to the elevation of the lowest mode and 0.94% due to RH100. 12.2% of the lowest mode exclusions are also RH100 exclusions.

3.4 Release 01 Grid Files

3.4.1 File Names

The GEDI L3 grid files use the following file name convention

[product_shortname]_[variable_name]_[start_date]_[end_date]_[release_number]_[production_version].tif

e.g., GEDI03_counts_2019108_2020106_001_01.tif

where, start_date and end_dates are in Julian day of year format YYYYDDD, release_number is the SOC SDS (software) release number, production_version is the granule production version.

Additionally, a PNG image of each grid is included with the same base name and ‘.png’ file extension.

3.4.2 File Descriptions and Sizes

Figure 7 to Figure 8 show the Release 01 image files for the lowestmode_mean and RH100_mean grids respectively. The file names and sizes for all of the grid and image files are given in Table 3-4.

Table 3-4 L3 File Names and Sizes

GEDI L03 V08	File Size (Bytes)
GEDI03_rh100_stddev_2019108_2020106_001_08.png	29052673
GEDI03_rh100_mean_2019108_2020106_001_08.png	26770209
GEDI03_elev_lowestmode_stddev_2019108_2020106_001_08.png	28766500
GEDI03_elev_lowestmode_mean_2019108_2020106_001_08.png	21613651
GEDI03_counts_2019108_2020106_001_08.png	25195587
GEDI03_rh100_stddev_2019108_2020106_001_08.tif	709955398
GEDI03_rh100_mean_2019108_2020106_001_08.tif	632929738
GEDI03_elev_lowestmode_stddev_2019108_2020106_001_08.tif	720344335
GEDI03_elev_lowestmode_mean_2019108_2020106_001_08.tif	684381792
GEDI03_counts_2019108_2020106_001_08.tif	208065505

4.0 TEST DATA FOR EVALUATION, DEVELOPMENT, AND CAL/VAL

4.1 Test Data for Algorithm Evaluation and Improvement

TDX and SRTM provide global surface elevation grids which can be re-gridded to the EASE 2.0 1 km^2 global grid and directly compared to GEDI L3 grids. Care must be taken with both TDX and SRTM used for comparison due to details of each data set. SRTM for example shows banding and swath errors compared to TDX and GEDI (see Figure 9).

TDX does not penetrate to the ground as effectively as SRTM or GEDI in heavily vegetated regions. The effects of this are evident when comparing the differences for ground elevation of GEDI-TDX to GEDI-SRTM and SRTM-TDX, see Section 5.

4.2 Data for Future Testing

4.2.1 LVIS Data Overview

Data from the LVIS sensor flown over specific regions of interest is being used for algorithm development and in the future will be used for calibration/validation of the L3 GEDI gridded data products. For regions LVIS data provides near continuous mapping with ~20 m footprints, and therefore provides an excellent "truth" data set. Figure 10 shows a sample of the 2 km wide scan swath of LVIS. GEDI simulated data can be generated by down sampling to develop the gridding algorithms and for performance assessment.

The footprint data produced by LVIS is nearly identical to that which produced by GEDI except that the footprint diameter varies slightly, with the average footprint diameter between 10 and 25 meters.

In March of 2016 the LVIS instrument was used to collect data congruent with GEDI over two regions in Gabon designated Lope & RABI. These data are interpolated, using nearest neighbor interpolation, to simulated points that GEDI would collect over its two-year mission. That simulated footprint data along with GEDI data is the input for testing the advanced algorithms presented in this document and the original LVIS data can be used to validate the results. Figure 11 shows a 10 x 9 km area from the Lope Region and the synthetic GEDI data generated from it.

4.2.2 LVIS Surveys Available for Comparison

Each existing LVIS survey within the coverage area for GEDI can be used for GEDI process testing and for limited calibration and validation. The cal/val use of LVIS data is limited due to the specific time each LVIS survey was collected and the short period over which they happen. Limitations include real changes in vegetation cover due to the time between the LVIS survey and the GEDI data collection and also real variation in factors that are seasonal if the LVIS survey and the GEDI data are not collected in the same season. Below is a table containing the LVIS data to be used in future algorithm development.

Table 4-1 LVIS Surveys

Location/Description	Year(s)
La Selva Biological Research station (Costa Rica)	1998, 2005
Sierra National Forest (CA, USA)	1999, 2006, 2008
Long Valley (CA, USA)	1999, 2006
White River wildlife Refuge (AR, USA)	2006
Duke Forest (NC, USA)	1999
Penobscot forest (ME, USA)	2003, 2009
Howland (ME, USA)	2003, 2009
Harvard Forest (MA, USA)	2003, 2009
Ithaca (NY, USA)	2009
Quebec, CA	2009
Bartlett Experimental Forest (NH, USA)	1999, 2003, 2009
Hubbard Brook LTER (NH, USA)	1999, 2003, 2009
Gulf of Mexico Coast in support of NOAA/NRL gravity	2005, 2006
Patuxent water shed (MD, USA)	2003, 2004
Antarctica in support of Operation IceBridge	2009-2011
Gabon, Africa, part of AfriSAR project	2016
Northern US/southern Canada (as part of ABoVE)	2017
GEDI under-flights in US, Central America and Costa Rica	2019

The LVIS instrument will continue to collect data in the coming years. Each new survey presents a new opportunity for CAL/VAL of GEDI data in that region.

5.0 TESTING PROCEDURE AND RESULTS

5.1 Procedure

Finer grids of surface elevation from SRTM and TDX are re-gridded onto the EASE 2.0 1 km^2 grid. These new grids can then be compared directly with GEDI L3 products and each other. Some consideration must be given to the specifics of each data set for these comparisons. Banding and swath errors in SRTM and TDX's minimal penetration in heavily vegetated areas will show up in comparison to GEDI L3 products. In most cases the source of the error becomes apparent when comparing GEDI L3 to both SRTM and TDX grids allowing regions where valid comparisons can be made to be identified.

5.2 Results

Figure 12 and 13 show the surface elevation GEDI minus TDX and GEDI minus SRTM respectively. While there is good agreement between all three products, it is apparent that GEDI shows larger differences with TDX over the most heavily vegetated regions, for example the Amazon Rainforest and eastern North America. Those larger differences do not appear in the GEDI-SRTM comparison, supporting the discrepancy is due to TDX not penetrating vegetation as effectively as SRTM and correctly as GEDI. Visible are banding errors that exist in the GEDI-SRTM comparison, but do not exist in the GEDI-TDX comparison, indicating these errors are in the SRTM product.

Figures 14 & 15 present all three comparisons and demonstrates the separation of suspect orbits in the GEDI data from other issues in the SRTM or TDX products: areas where TDX did not penetrate vegetation, where SRTM shows banding or swath errors, and suspect GEDI orbits are indicated in the figures.

6.0 REFERENCES

Brodzik, M. J., Billingsley, B., Haran, T., Raup, B., & Savoie, M. H. (2012). EASE-Grid 2.0: Incremental but Significant Improvements for Earth-Gridded Data Sets. ISPRS International Journal of Geo-Information, 1(3), 32–45. http://doi.org/10.3390/ijgi1010032

Cressie, N., Fitting variogram models by weighted least-squares. *Math. Geol*., 17:653-702, 1985.

Cressie, N., Statistics for Spatial Data, Revised Edition 2015.

Cui, H., A. Stein, and D.E. Myers. Extension of spatial information, Bayesian kriging and updating of prior variogram parameters. *Environmetrics*, 6:373-384, 1995.

Lindstrom, M.J., and D.M. Bates. Newton-Raphson and EM algorithms for linear mixed-effects models for repeated-measures data. *J. Am. Stat. Assoc*., 83:1014-1022, 1988.

More, H. and K.B. Halvorsen. The Bayesian bridge between simple and universal kriging. *Math. Geol*., 21:767-786, 1989.

Smith, W.H.F., and P.Wessel. Gridding with continuous curvature splines in tension. *Geophysics*, 55:293-305, 1990.

Welford, B. P. Note on a Method for Calculating Corrected Sums of Squares and Products. *Technometrics*, Vol. 4, No. 3 (Aug., 1962), pp. 419-420. http://www.jstor.org/stable/1266577

GLOSSARY/ACRONYMS

ATBD	Algorithm Theoretical Basis Document
BM	Block Mean
CF	Cloud Fraction
DEM	Digital Elevation Model
GEDI	Global Ecosystem Dynamics Investigation
GPS	Global Positioning System
JD	Julian Date
MSS	Mean Sea Surface
OK	Ordinary Kriging
PAI	Plant Area Index
SK	Simple Kriging
SRTM	Shuttle Radar Topography Mission, specifically the NASADEM-SRTM product
SSP	Spatial-Scale Parameter
TBD	To Be Determined
TDX	TerraSAR-X add-on for Digital Elevation Measurement or the DEM grid from this mission
VCF	Vegetation Cover Fraction
UK	Universal Kriging

FIGURES

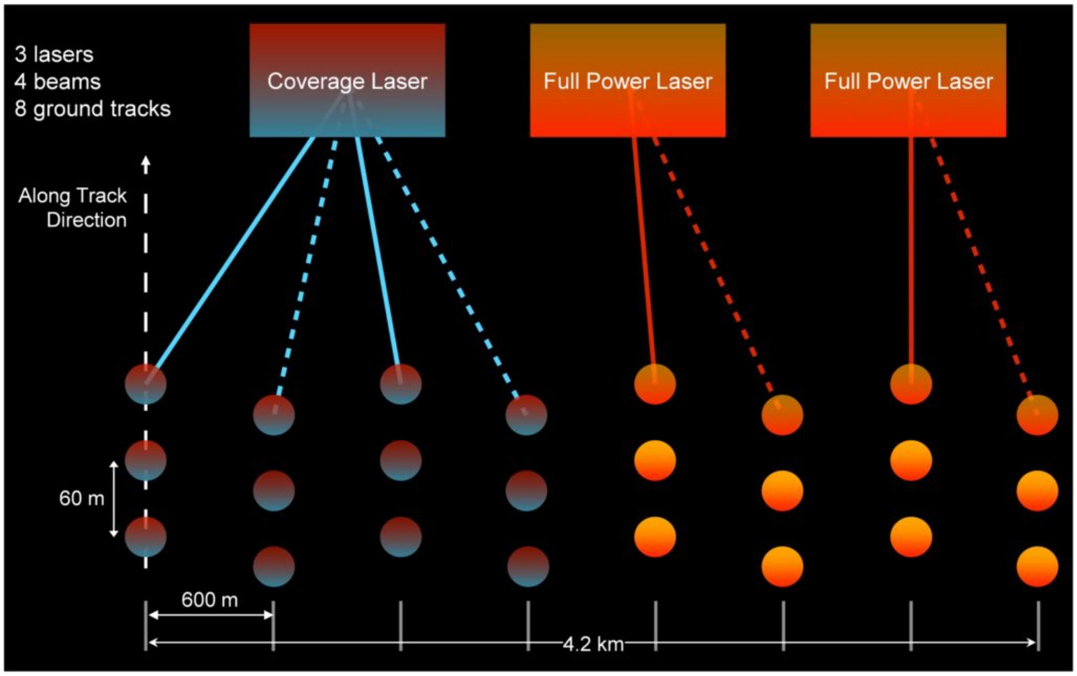

Figure 1 GEDI Beam Ground-track Configuration

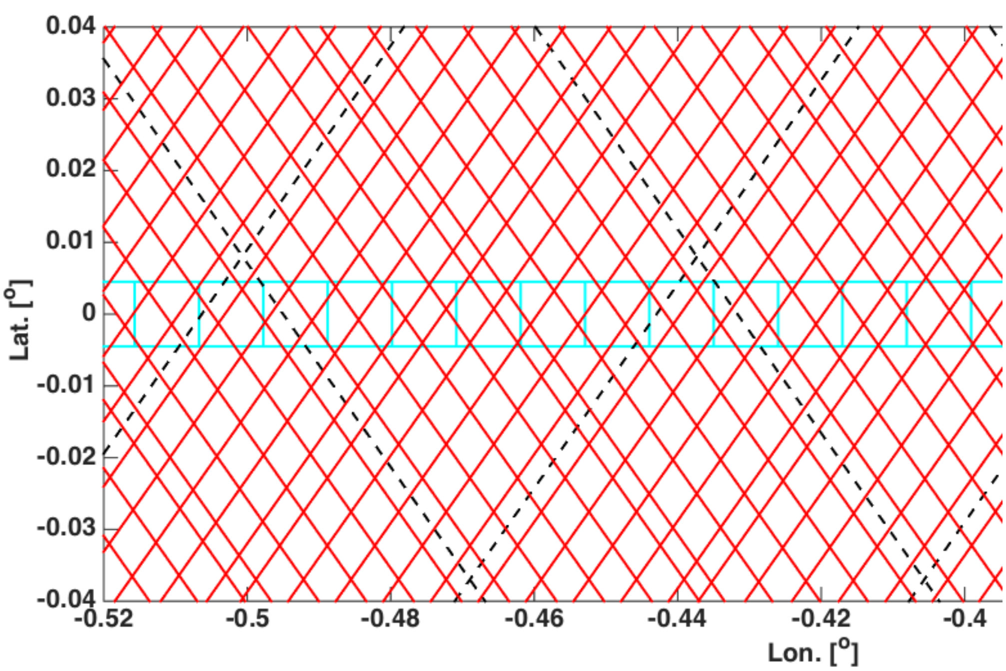

Figure 2 Sample GEDI Track (red) Distribution Through 1Km Grid Cells(cyan). The center of the beam pattern is designated by the dashed black line

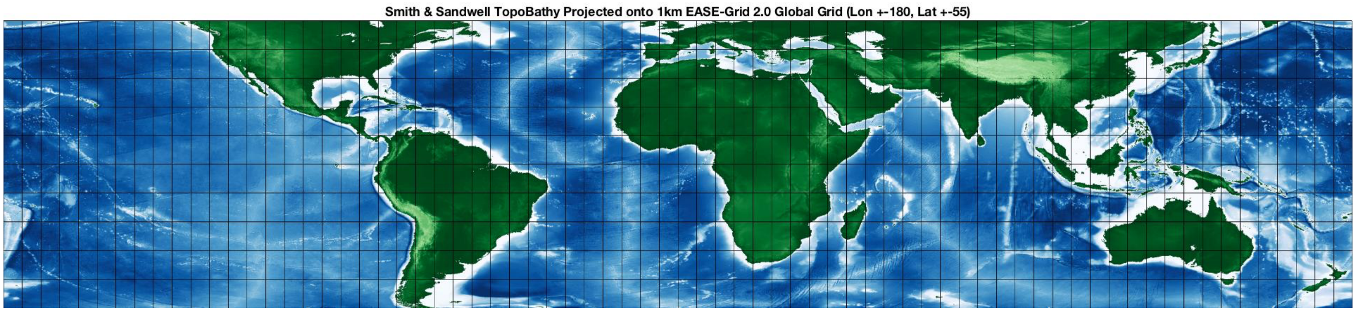

Figure 3 Surface Map shown in the global EASE-Grid 2.0

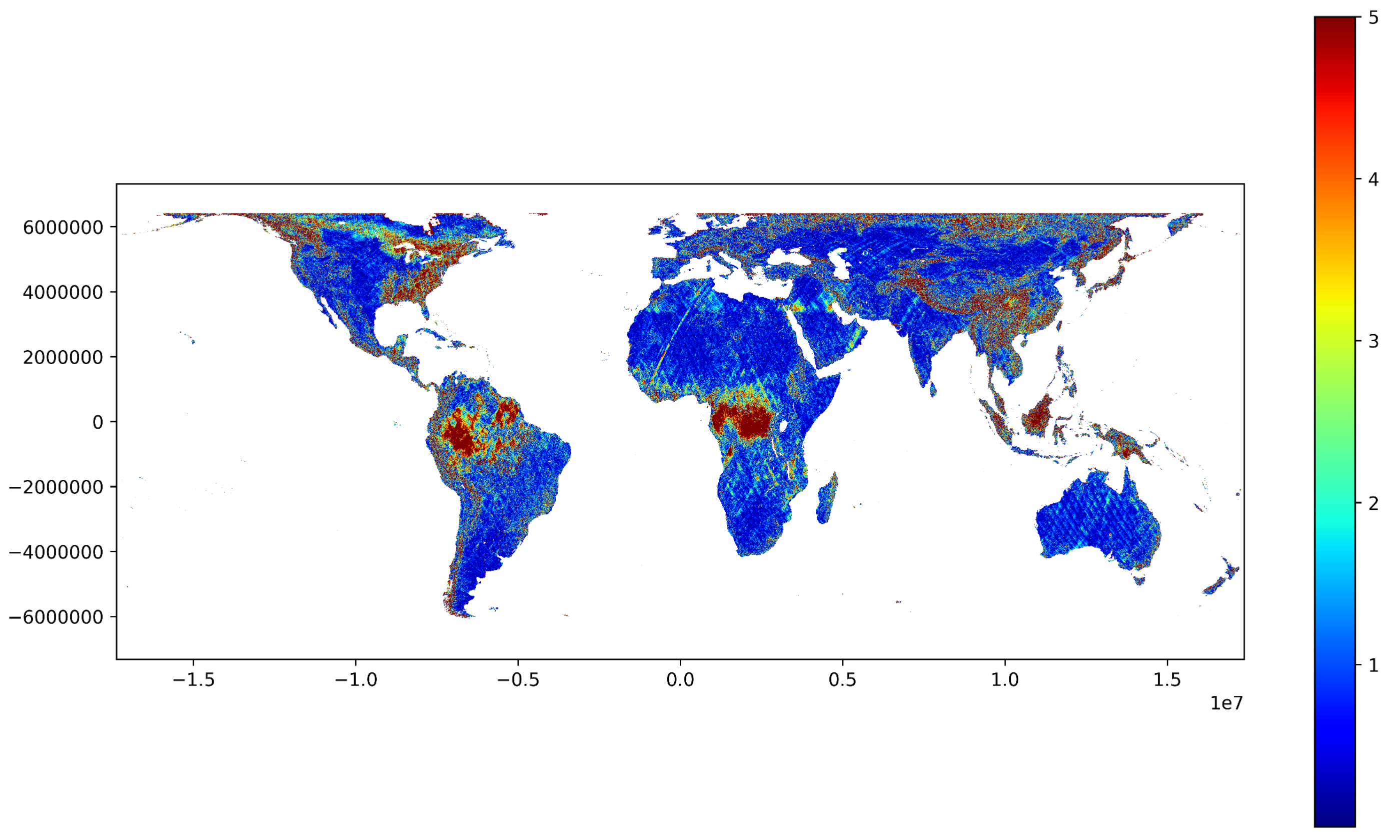

Figure 4 . |STRM-TanDEM-X| on 1km2 EASE 2.0 global grid, areas <1.5m used for orbit editing

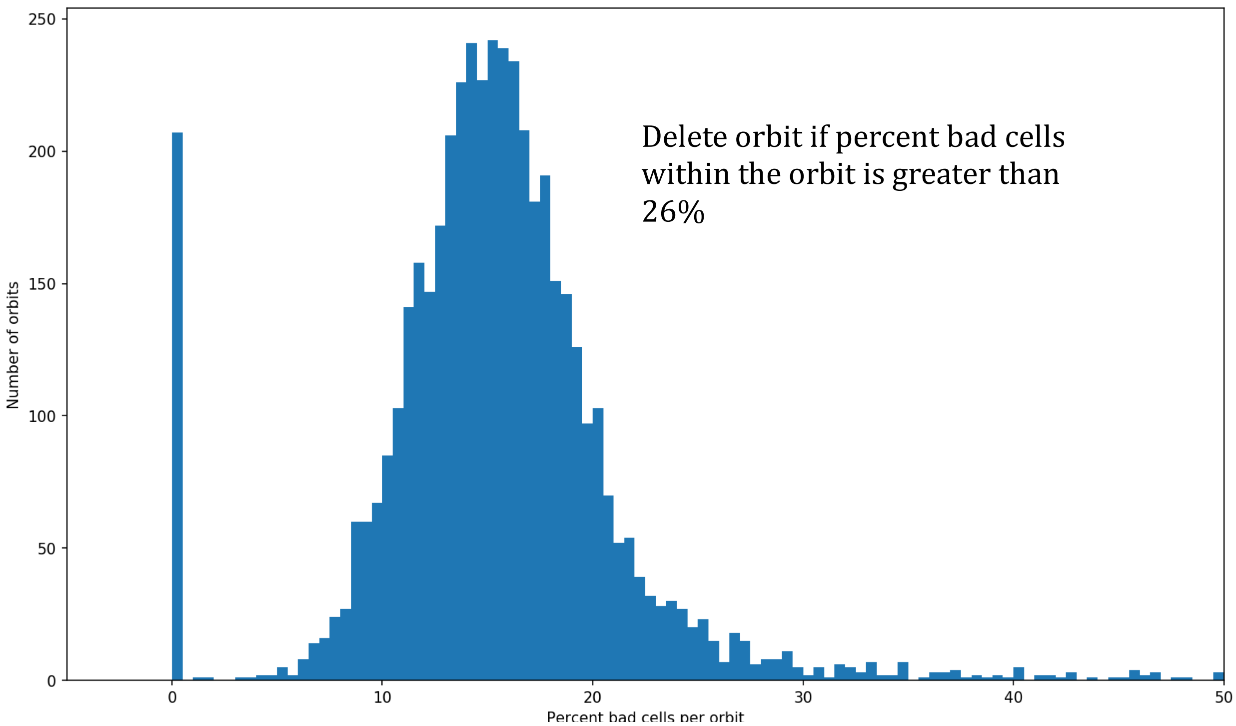

Figure 5. Distribution of orbits with various percentage of bad cells

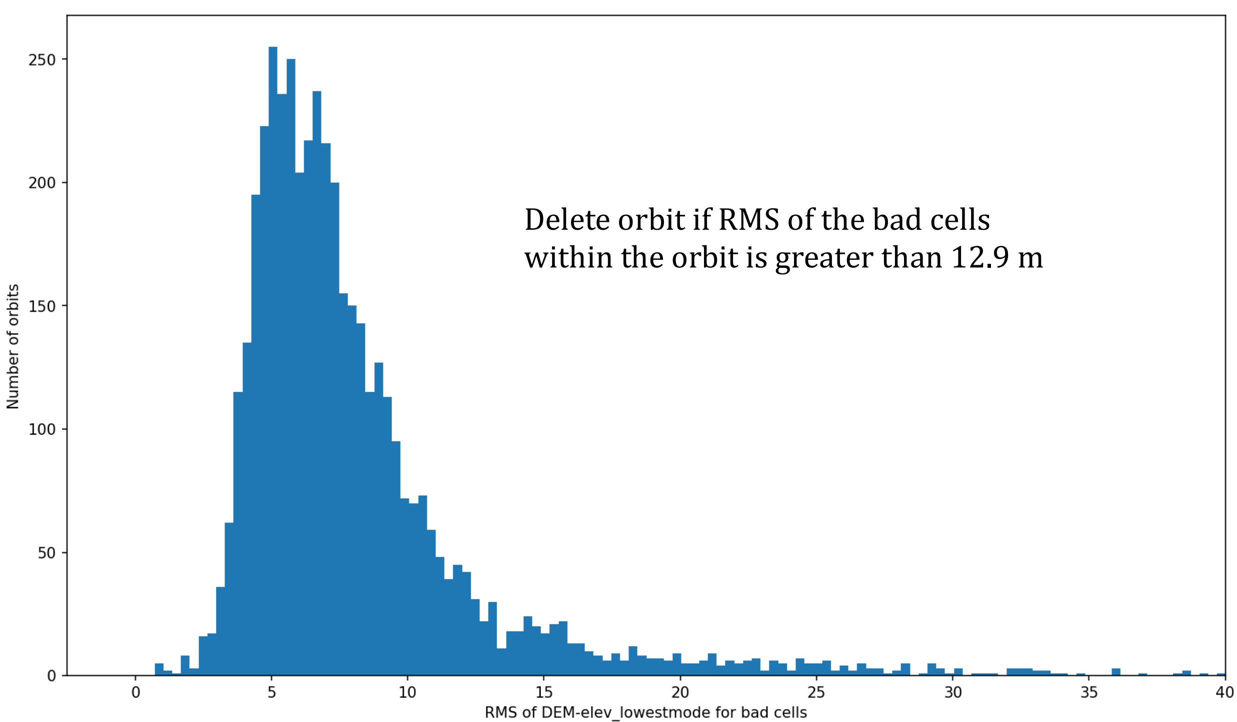

Figure 6. Distribution of RMS for bad cells

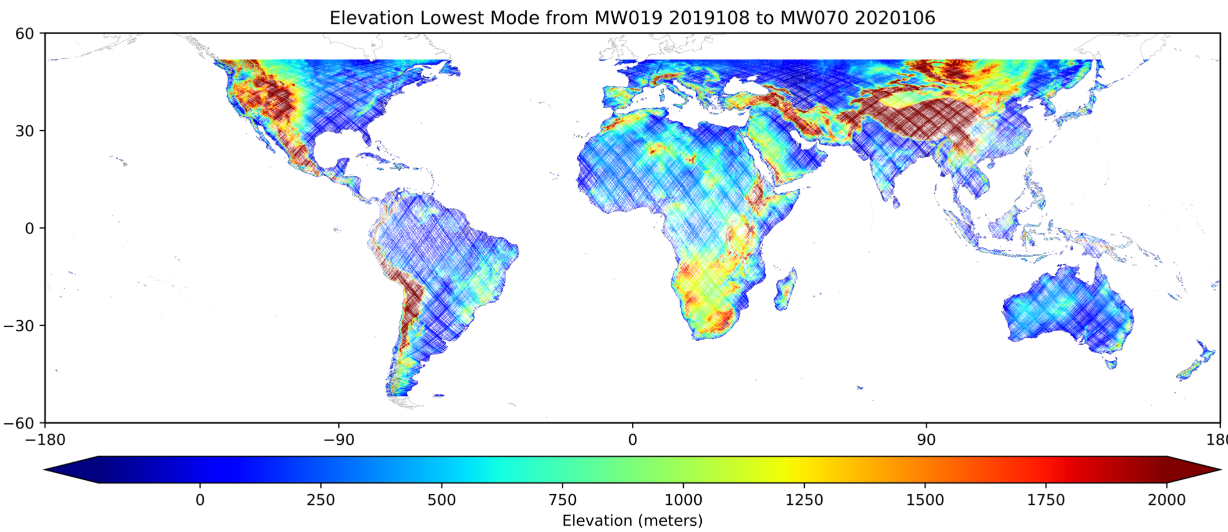

Figure 7. GEDI Mean Elevation Lowest Mode Rel 01

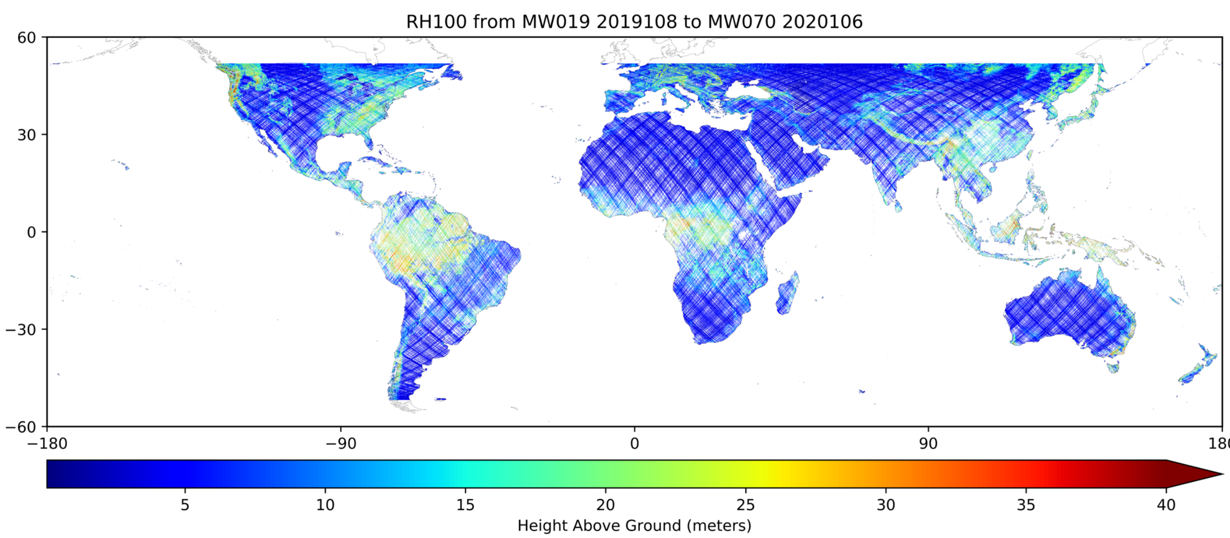

Figure 8. GEDI Mean RH100 Rel 01

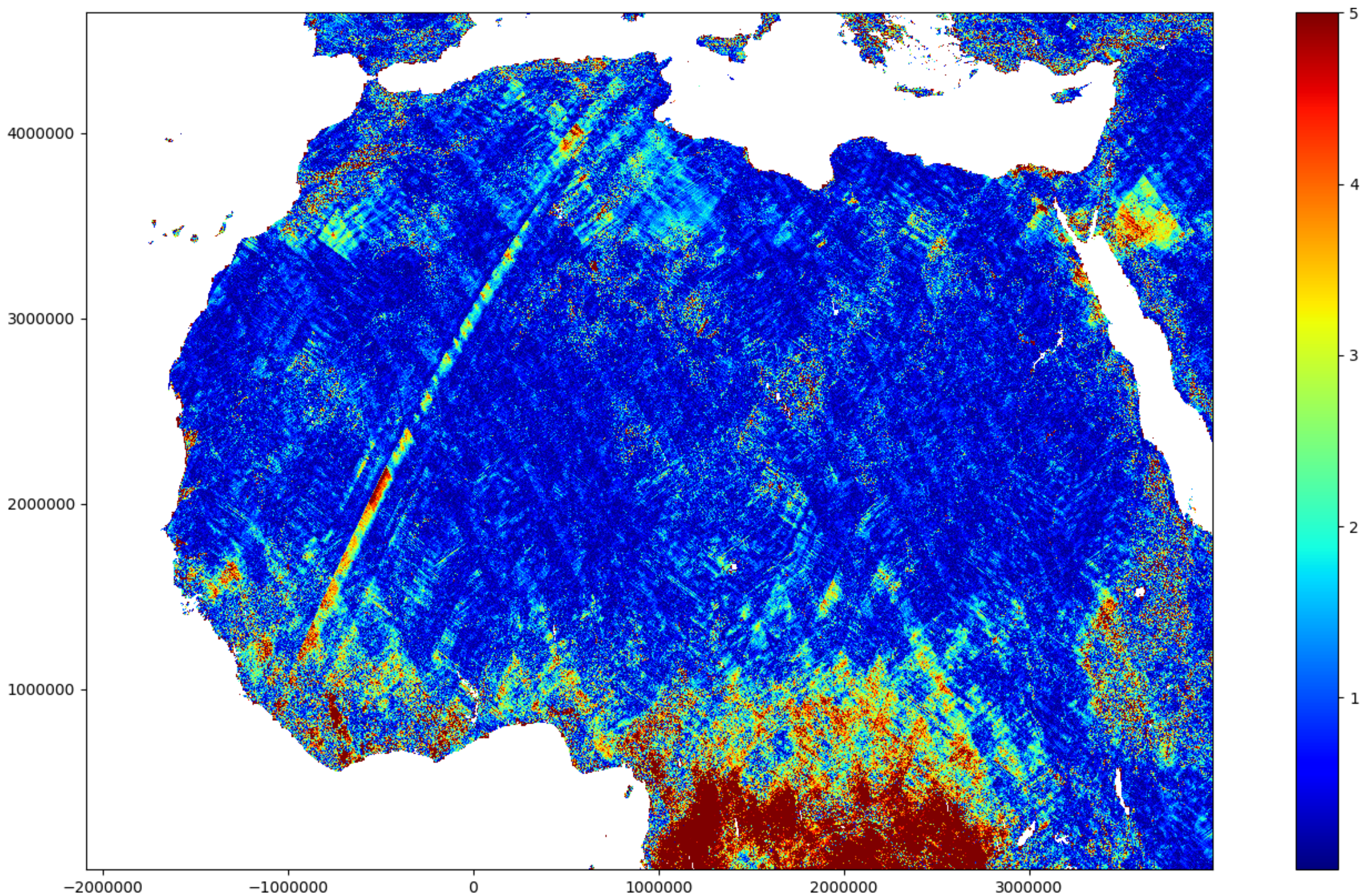

Figure 9. SRTM-TDX at 1km2 showing SRTM banding and swath error

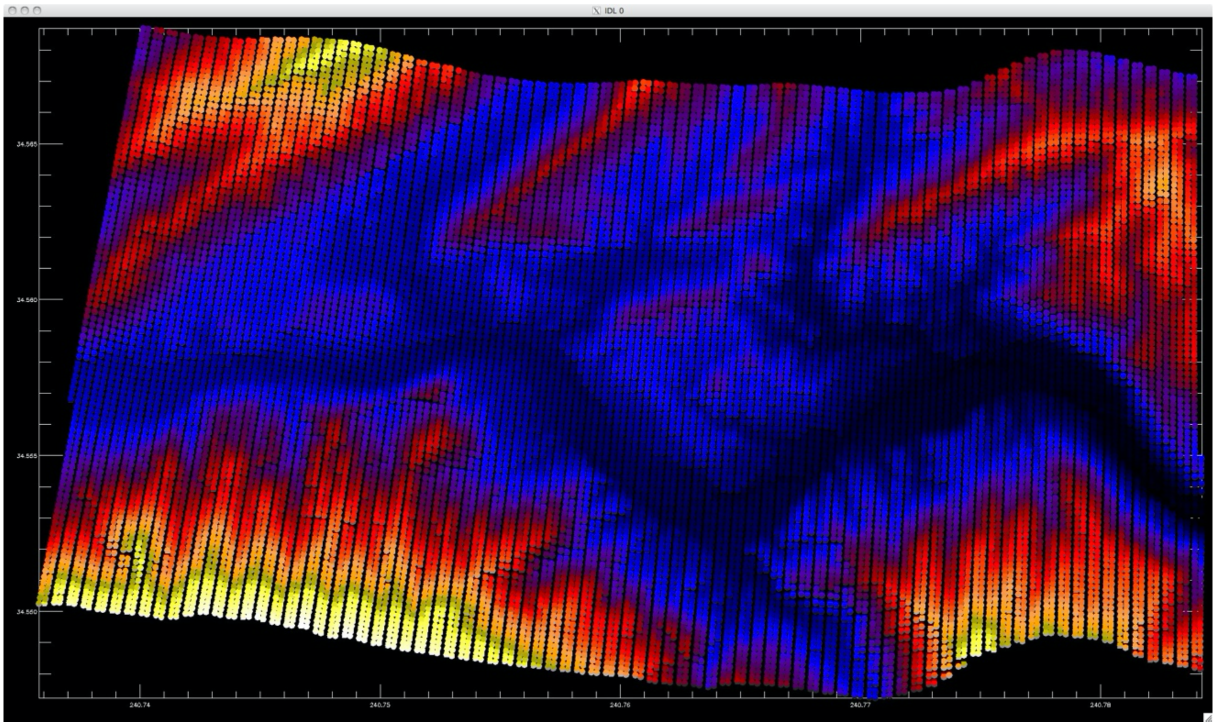

Figure 10. The LVIS scan and beam pattern. The unique LVIS scanning system generates this pattern that evenly and completely samples the surface below. There are approximately 100 beams across the 2 km wide swath. The colors represent the surface elevation.

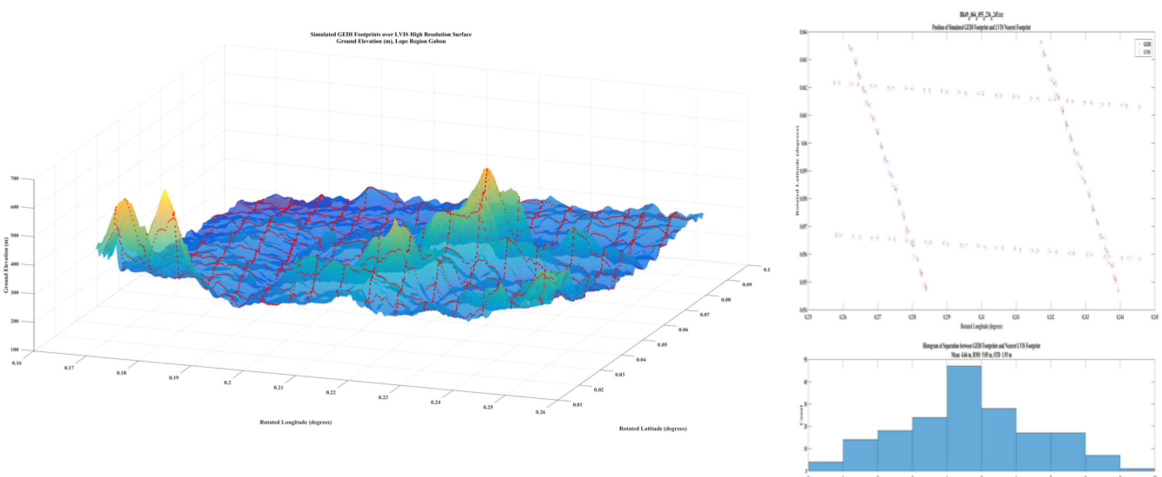

Figure 11. 10 x 9 km test region. Left: Ground topography with GEDI footprints in red. Right: GEDI footprint location with Nearest LVIS footprint (top) Histogram of separation between GEDI and nearest LVIS footprint (bottom) for one 1kmx 1km block

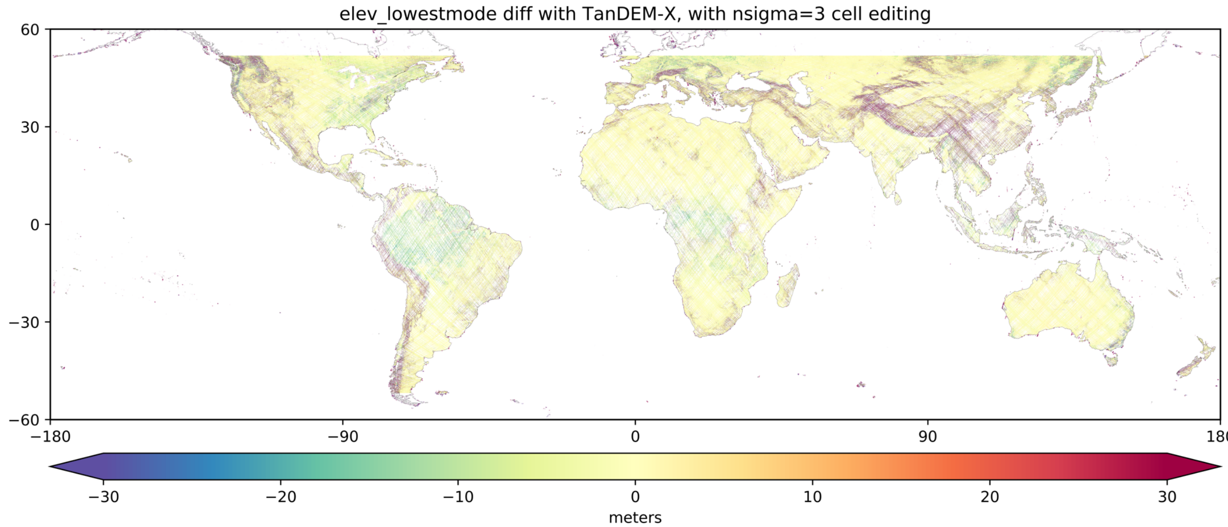

Figure 12 Surface Elevation GEDI minus TDX

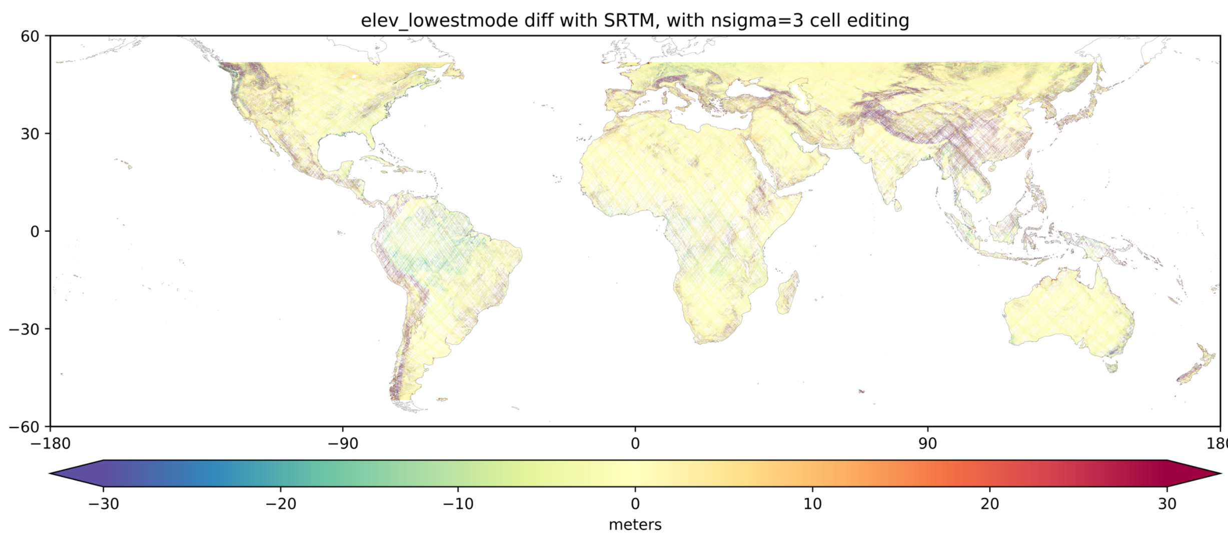

Figure 13. Surface Elevation GEDI minus SRTM

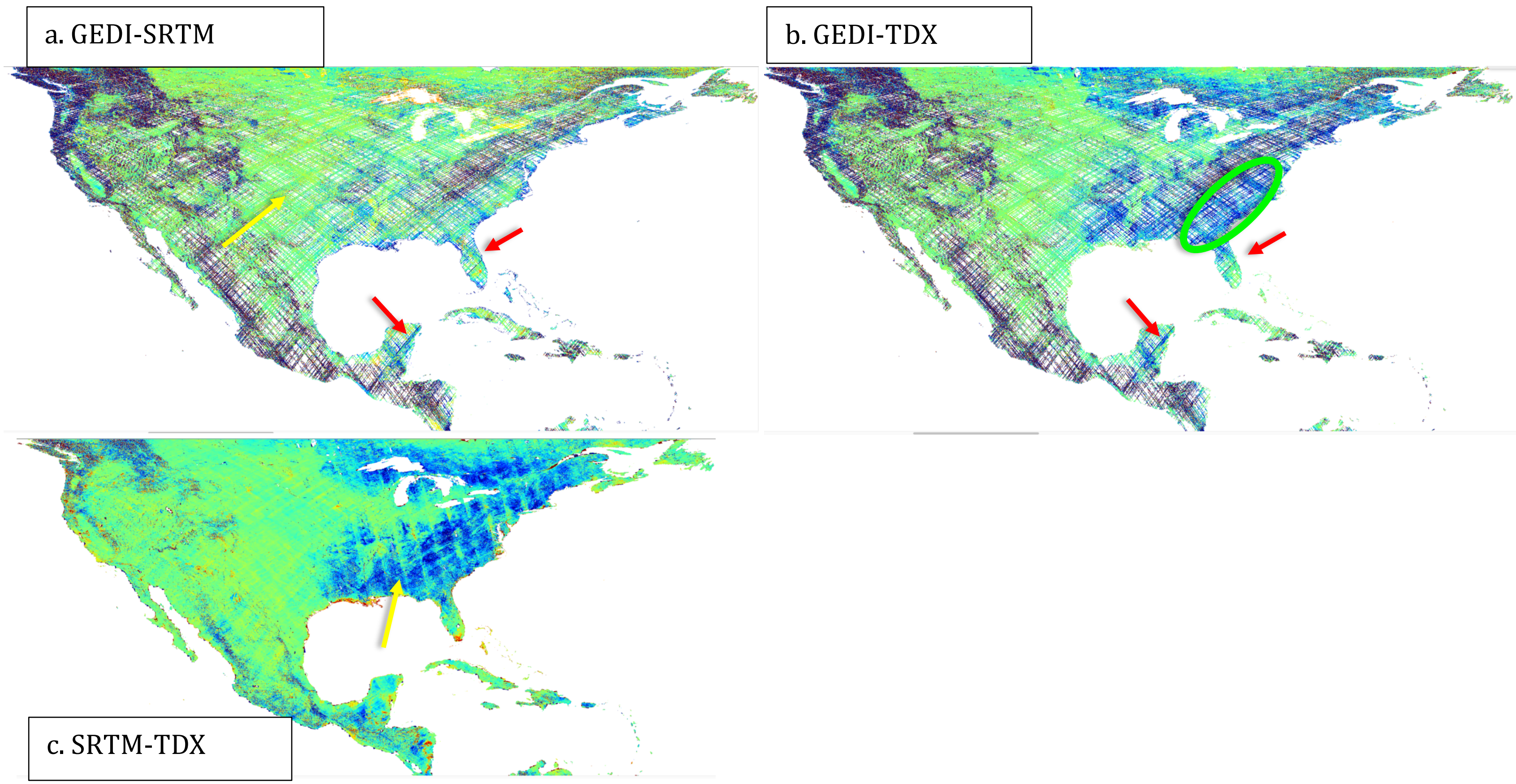

Figure 14 a. GEDI-SRTM, b. GEDI-TDX, c. SRTM-TDX, North America. Green Oval: TDX is not penetrating vegetation, Yellow Arrows: SRTM Banding and Red Arrow: GEDI suspect orbits

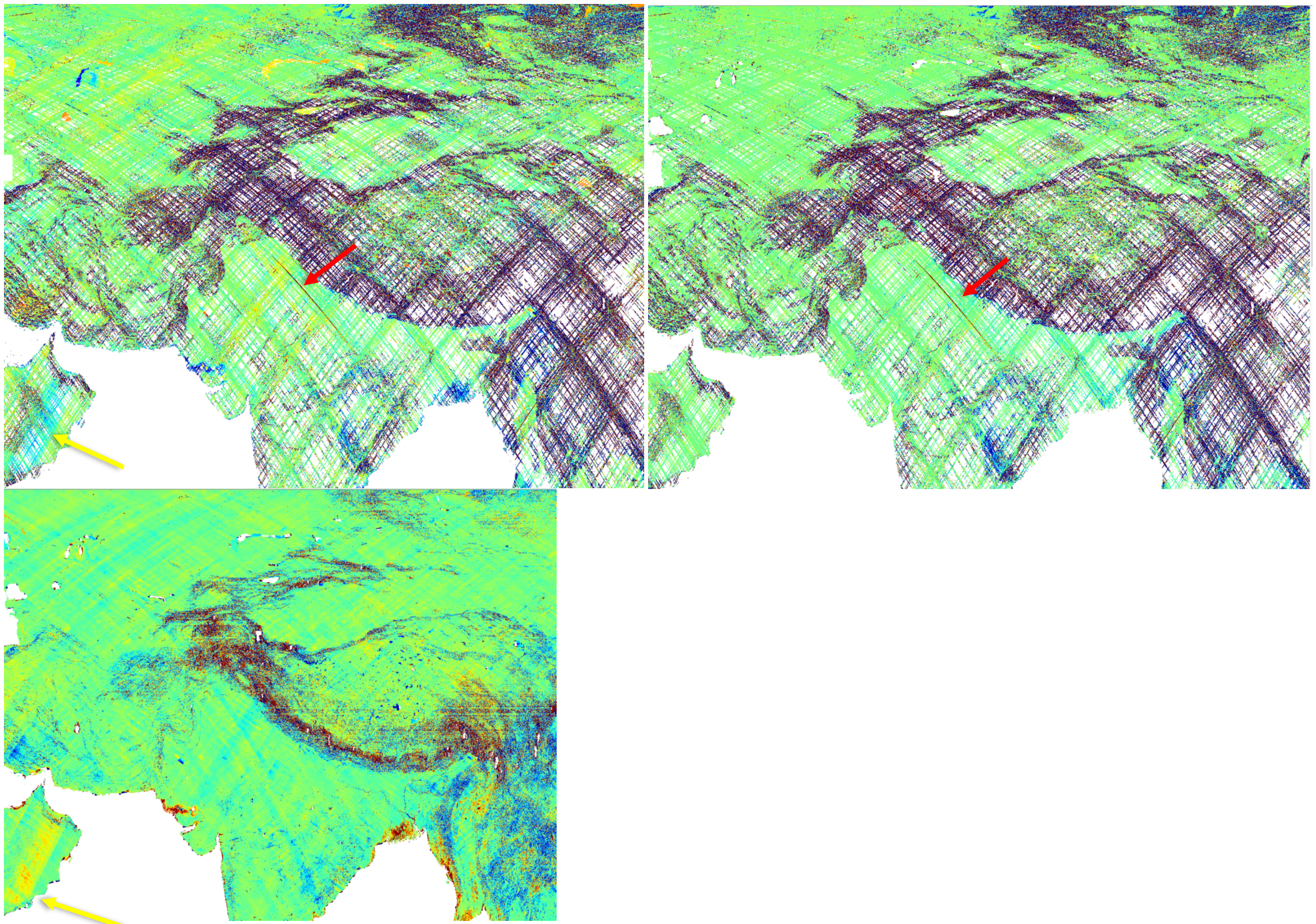

Figure 15 a. GEDI-SRTM, b. GEDI-TDX, c. SRTM-TDX, Asia. Yellow Arrows: SRTM Banding and Red Arrow: GEDI suspect orbits