National Aeronautics and Space Administration

Commercial Satellite Data Acquisition Program

Polar Geospatial Center EarthDEM Quality Assessment Report

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Signature/Approval Page

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Preface

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Abstract

The evaluation summarized in this report was conducted by subject matter experts (SMEs) funded by NASA's CSDA Program. The SMEs evaluated the quality of the Polar Geospatial Center's EarthDEM products for the NASA Earth science research and applications community. The results of the evaluation help to inform NASA program management on the quality of the data for NASA science.

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Acronyms & Abbreviations

3DEP	3-Dimensional Elevation Program, USGS
API	Application Programming Interface
ATBD	Algorithm Theoretical Basis Document
CONUS	Conterminous United States
CE90	Circular Error 90%
CEOS	Committee on Earth Observation Satellites
CSDA	Commercial Satellite Data Acquisition Program
DEM	Digital Elevation Model
DMS	Degrees, Minutes, Seconds
DSM	Digital Surface Model
EDAP	Earthnet Data Assessment Pilot, ESA
ESA	European Space Agency
ESRI	Environmental Systems Research Institute, Inc.
EULA	End User License Agreement
FAIR	Findable, Accessible, Interoperable and Reusable
FRIDGE	Federal Research Imagery and DEM Geospatial Explorer
GeoTIFF	Geographic Tag Image File Format
GSFC	Goddard Space Flight Center
JSON	JavaScript Object Notation
LE90	Linear Error 90%
Lidar	Light Detection and Ranging
NASA	National Aeronautics and Space Administration
NLCD	National Land Cover Database
PDAL	Point Data Abstraction Library
PGC	Polar Geospatial Center
QGIS	Quantum Geographic Information System, open-source software package
RMSE	Root Mean Square Error
$RMSE_H$	Root Mean Square Error Horizontal
$RMSE_V$	Root Mean Square Error Vertical
RPC	Rational Polynomial Coefficients
SDX	Satellite Data Explorer
TIN	Triangulated Irregular Network
UAS	Uncrewed Aircraft System
USGS	United States Geological Survey
WGS84	World Geodetic System 1984

Executive Summary

The Commercial Satellite Data Acquisition (CSDA) Program was established to identify, evaluate, and acquire data from commercial sources that support the National Aeronautics and Space Administration (NASA) Earth science research and application goals. NASA's Earth Science Division (ESD) recognizes the potential impact commercial satellite constellations may have in encouraging/enabling efficient approaches to advancing Earth system science and applications development for societal benefit. Commercially acquired data may also provide a cost-effective means to augment and/or complement the suite of Earth observations acquired by NASA and other U.S. government agencies and those by international partners and agencies.

In this report, the CSDA program provides an evaluation of the quality of the University of Minnesota Polar Geospatial Center (PGC) EarthDEM elevation products. It should be noted that the PGC EarthDEM product is not technically a commercial product, we are assessing this research product that was created from commercial imagery. EarthDEM is a digital elevation dataset derived from imagery collected from the Vantor (formerly Maxar) fleet of optical satellites. The PGC provides two EarthDEM products, referred to as the Strip DSM and the Mosaic Tile. Both of the EarthDEM products are Digital Surface Models (DSMs). Here, we provide an evaluation of both the Strip DSM and Mosaic Tile product quality for their ability to advance NASA’s Earth system science research and applications. This evaluation of the horizontal and vertical accuracy of PGC’s EarthDEM Strip DSM and Mosaic Tile products was carried out by NASA Digital Elevation Model (DEM) subject matter experts (SMEs) enlisted to evaluate the quality of these products. The Strip DSMs evaluated were produced by the assessment team using code provided by the PGC. The Mosaic Tiles were provided by the PGC. The guidance used for this assessment followed the joint European Space Agency (ESA)/NASA assessment guidelines for Digital Elevation Models (ESA-NASA, 2026), currently in draft form.

For the Data Provider Documentation Review of these data, both the PGC website information, as well as a series of peer-reviewed publications by Dr. Myoung-Jong Noh and Dr. Ian Howat, of the Byrd Polar and Climate Research Center (The Ohio State University), were considered. Only documents listed in this report were considered in the evaluation. Product Information documentation was graded from Good to Excellent. The EarthDEM Product Generation documentation was graded from Basic to Excellent. The Post-Processing was graded as Basic due to the existence of ‘No Data’ gaps within the Mosaic Tile product. Overall, the EarthDEM product is well documented, with most information present within the product User Guide, a series of peer-reviewed papers, or the PGC GitHub repository.

An independent assessment of the vertical and horizontal accuracy of the EarthDEM Strip DSM and Mosaic Tile products was performed by the CSDA team through comparisons to airborne lidar data collections. Various reference lidar sample sites across the United States (US) and Senegal were used, which allowed for the evaluation of Strip DSM and Mosaic Tile product performance over a variety of surface characteristics. The horizontal accuracy results of the EarthDEM products (Strip DSM: 0.5 m $RMSE_H$; Mosaic Tile: 0.3 m $RMSE_H$) were in agreement with the specifications provided by the PGC and were graded as Excellent. The vertical accuracy results of the EarthDEM Strip DSM (5.6 m $RMSE_V$) and the Mosaic Tile (4.9 m $RMSE_V$) products varied by land cover type, with all land cover types exceeding the specification provided by the PGC (0.5 m $RMSE_V$). Strip DSM vertical accuracy was found to vary from 4.6-6.8 m $RMSE_V$ depending on the cloud

cover metadata field generated by the PGC. The vertical accuracy compliance for the EarthDEM products was graded as Basic.

It is critical that users of the PGC DEM products utilize the metadata fields provided with the Strip DSM products to filter out the Strip DSMs that are likely to be less accurate, as differing imaging conditions can result in inconsistent vertical accuracy. A pixel-level mask is derived and provided with the product, but it is not applied to the data. It is up to the user to consider this pixel-level mask and whether it is appropriate for their application. Those working in challenging imaging environments, such as persistently cloudy regions or over steep terrain, should be aware that ideal conditions for stereoscopic image data collection may be limited and that the vertical accuracy of the Strip DSMs collected in suboptimal conditionals may not be suitable for all applications.

Overall, the evaluation supports the use of EarthDEM data for NASA Earth science research and applications, where the data characteristics (e.g., vertical accuracy, poor cloud masking, missing surface features, data voids, etc.) are compatible with the specific science objectives and use cases.

1. Background

The CSDA Program was established by NASA's ESD in 2020 following the successful completion of the Private-Sector Small Constellation Satellite Data Product Pilot. The program's primary objective is to identify, evaluate, and acquire commercial remote sensing data that enhances NASA's Earth science research and applications. CSDA provides structured on-ramping opportunities for emerging commercial satellite data vendors, enabling NASA to continuously integrate innovative data sources as the private sector evolves. By leveraging these partnerships, NASA's ESD aims to accelerate scientific discovery and expand applications of Earth observation data for societal benefit.

Since the initial pilot, the Program has conducted three on-ramp activities, resulting in the addition of several vendors into sustainment. In 2024, CSDA streamlined its evaluation process by introducing high-quality, SME-led data assessments, accelerating reviews and strengthening NASA's engagement with the rapidly growing commercial data ecosystem. This evaluation framework not only ensures NASA gains timely access to high-quality, mission-relevant commercial data, but also provides valuable feedback to private-sector providers, fostering innovation, improved data products, and alignment of industry capabilities with NASA's evolving scientific needs.

1.1 Polar Geospatial Center DEM Products

The Polar Geospatial Center is a polar science and logistics support organization founded in 2007 at the University of Minnesota with core funding provided by the National Science Foundation's Office of Polar Programs. Support to these polar programs included using commercial satellite data to create imagery mosaics with sub-meter resolution. In 2015, the PGC began producing DEMs using satellite stereoscopic (stereo) image pairs from the Vantor fleet of high-resolution imagery. They have subsequently produced 2 m DEMs of the polar regions, ArcticDEM and the Reference Elevation Model of Antarctica (REMA), as well as EarthDEM in the mid-latitudes.

DEM production by the PGC relies on the Surface Extraction for TIN-based Search-space Minimization (SETSM) algorithm developed by The Ohio State University (Noh and Howat, 2017). SETSM uses Vantor stereo imagery as input to produce a DEM of the image strips (Strip DSM product). These Strip DSMs are then combined using the Co-registration, Adjustment, and Median of Stacks approach (Howat, 2023) to create a wall-to-wall mosaic DEM product, referred to as the Mosaic Tile product. This Mosaic Tile is created from all available Strip DSMs over a fixed grid area (100 x 100 km), regardless of date/season, and is distributed as 50 x 50 km tiles. Both the Strip DSMs and Mosaic Tiles are digital surface model products.

After SETSM processing, PGC produces a bitmask to identify potential erroneous elevation retrievals, providing users a layer to identify (clouds, water, edge) components that may contribute to poor elevation quality. This evaluation applied all components of this bitmask layer to the Strip DSMs produced. The PGC also generates their own strip-level cloud_area_percent metadata field for each Strip DSM product using the cloud component of the bitmask, in place of the cloud cover metadata field provided by Vantor.

The PGC EarthDEM Strip DSM processing uses in-track stereoscopic image pairs with less than 50% cloud cover, screened using the Vantor metadata field. In this assessment, the Strip DSMs evaluated were generated in-house by the GSFC SME evaluation team using the CSDA archive of Vantor stereo imagery. The CSDA program Vantor archive consists primarily of imagery with less than 20% cloud cover. Because CSDA discovered this difference in the images used to create the Strip DSM products after completing this evaluation, CSDA plans to add Strip DSMs produced from stereo image pairs with 20-50% cloud cover over the evaluation sites to account for this difference. The findings from this further analysis will be added as an addendum to this report when completed.

It should also be noted that the SETSM algorithm contains a Local Surface Fitting (LSF) module that can be applied to the Strip DSMs. The module was designed to reduce noise in the DEM products and is routinely applied by PGC to Strip DSMs for their ArcticDEM and REMA products. Application of the LSF module removes small surface features and may be appropriate in polar regions, but we have chosen not to apply it in our assessment. The PGC has used the LSF module for EarthDEM in the past but later decided that its application is a decision that should be left up to the user. Thus, the EarthDEM dataset currently hosted by CSDA contains a mixture of Strip DSMs with and without the LSF module applied. The use of the LSF module is indicated within the metadata. The Strip DSMs hosted by CSDA, processed with the LSF module, will be replaced in 2026 by PGC with non-LSF versions. The SETSM LSF module is open-source and can be accessed via the SETSM GitHub repository (https://github.com/setsmdeveloper/SETSM).

2. Cal/Val Maturity Matrices

2.1. Summary Cal/Val Maturity Matrix

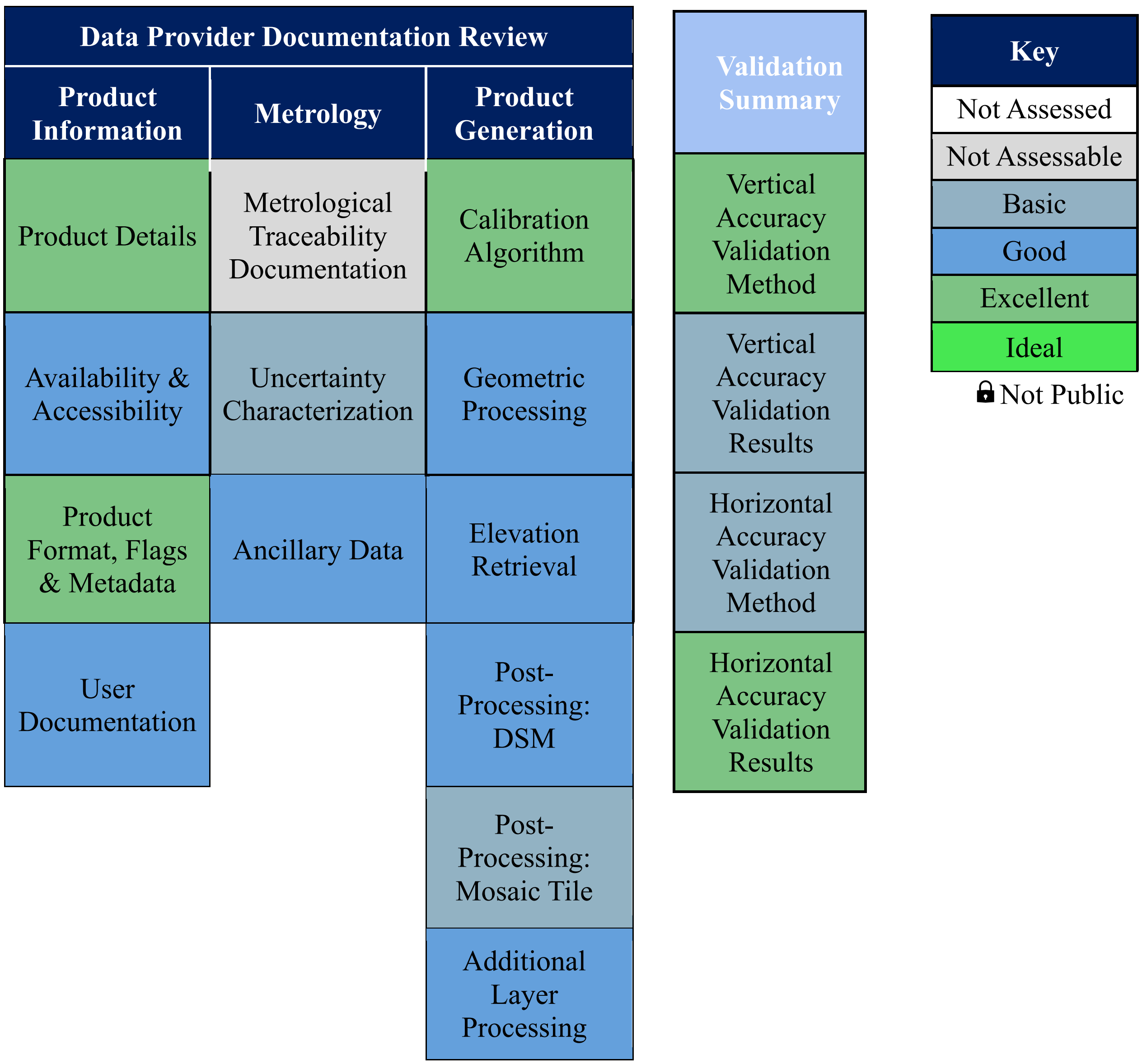

Figure 1. Summary Maturity Matrix for the Polar Geospatial Center's EarthDEM products.

2.2. Detailed Validation Maturity Matrix

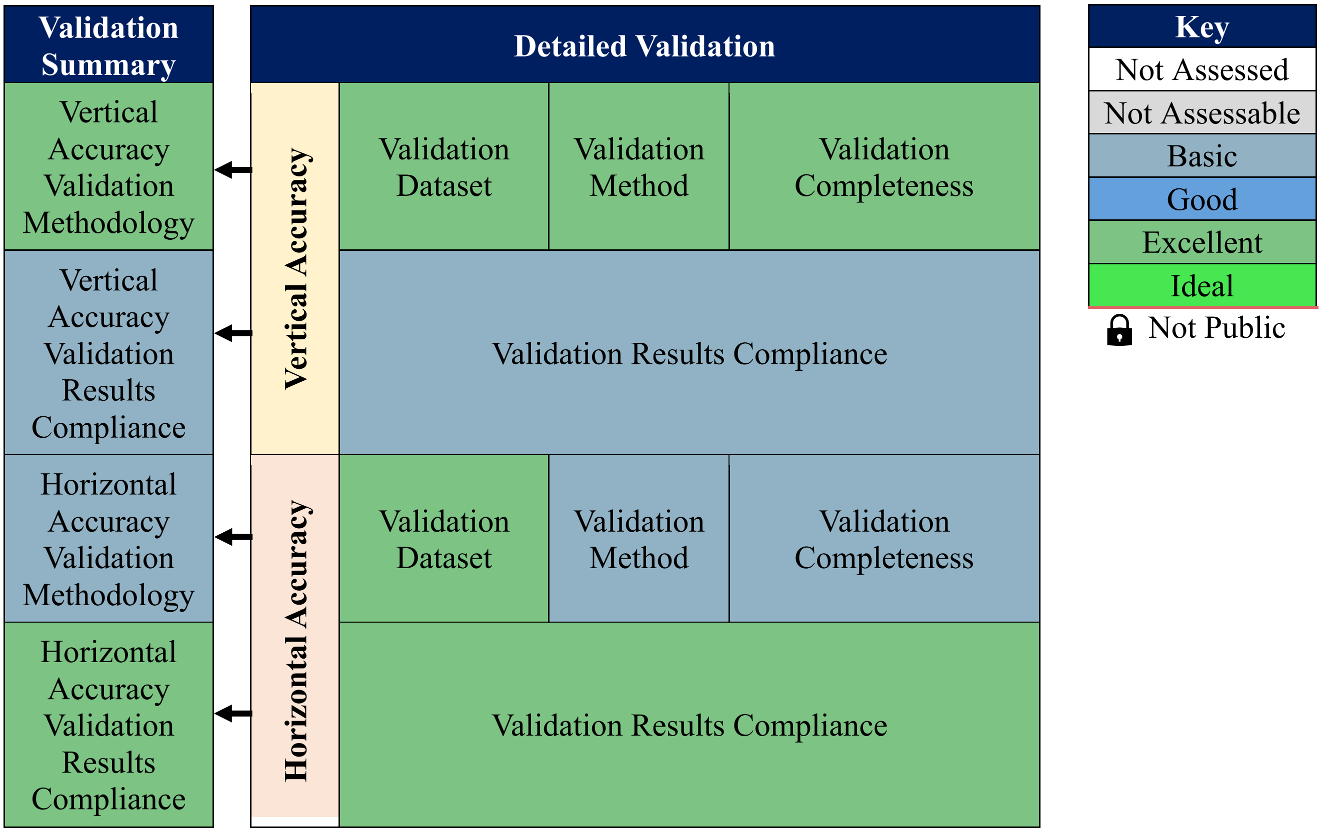

Figure 2. Detailed Validation Maturity Matrix for EarthDEM, showing the Validation Summary column from the Summary Validation Maturity Matrix.

3. Data Provider Documentation Review

3.1. Product Information

Product Details	
Grade: Excellent	
Justification	All DEM product details except the WGS84 realization are available in the PGC documentation. Publicly available mission details for the Vantor satellites are provided on the PGC web page with links to Vantor satellite data sheets.
Product Name	EarthDEM Strip DSM EarthDEM Mosaic Tile
Product Type	Digital Elevation Model
Data Type	Float32
Sensor Name	Multiple contributing satellites: GeoEye-1, WorldView-1, WorldView-2, and WorldView-3
Sensor Type	Panchromatic and Multispectral imagery
DEM Type	Photogrammetric Digital Surface Model
Version	Mosaic Tile: Version 1.1 Strip DSM: s2s041
Software	Surface Extraction with TIN-based Search-space Minimization (SETSM) Algorithm (Noh and Howat, 2017)
Measured Quantity Name	Elevation
Measured Quantity Units	meters (referencing the WGS84 ellipsoid)
Temporal Coverage	Strip DSM: 2009-2024 Mosaic Tile: The date range of Strip DSMs used to compute each Mosaic Tile pixel is provided as a separate data layer.
Temporal Resolution	Strip DSMs: There is no specified repeat frequency. Temporal frequency is dependent on the stereo imagery available. Mosaic Tile: There is no repeat time.
Coordinate Reference System	UTM
Horizontal Datum	WGS84
Vertical Datum	WGS84 Ellipsoid
DEM Data Format	GeoTIFF
Stated Horizontal Accuracy	4 m

Stated Vertical Accuracy	Without ground control points, absolute accuracy is approximately 4 meters in horizontal and vertical planes. Uniform ground control must be applied to achieve higher accuracy. DEMs can be co-registered to local ground control points or other reference elevation data to reduce this error to below 50 cm. Accuracy is reported as RMSE.
Spatial Coverage	60° S to 60° N
Ground Sampling Distance	2 m
Product Locator	The PGC provides vector files to query available Mosaic Tiles and Strip DSMs on CSDA's SDX API. Data is available on the PGC FRIDGE API and the CSDA SDX for federally funded and approved users.
Conditions for Access	All data used in this evaluation were produced using data acquired through a U.S. Government-wide license.
Copyright	None
Limitations on Public Access	Not for public access, free for federally funded researchers.

Availability & Accessibility	
Grade: Good	
Justification	EarthDEM metadata meets all FAIR principles. Product metadata are publicly accessible through the PGC website and accompany the data distributed via the CSDA SDX data portal.
Compliant with FAIR principles	Yes
Data Management Plan	The PGC does not have a data management plan.
Availability Status	Data are available to approved users through the NASA CSDA SDX data portal.

Product Format, Flags & Metadata	
Grade: Excellent	
Justification	Products are provided with sufficient metadata. DEMs contain all crucial geometry metadata. Additional raster layers are provided with Mosaic Tile DEMs (DEM count, minimum DEM date, maximum DEM date, median absolute deviation of used DEMs, and a bitmask) and Strip DSMs (pixels with interpolated elevation values and a data mask). Metadata text files containing processing information are provided. Additional metadata is provided within the footprint vector layers hosted on the PGC website and when selecting files within the CSDA SDX API.
Product File Format	GeoTIFF, JSON, ESRI Shapefile, Text file
Metadata Conventions	
Analysis Ready Data?	No. Strip DSMs frequently require the masking of potentially erroneous elevation estimates. Mosaic Tiles could be considered analysis-ready depending on the application and the presence of data voids.

User Documentation	
Grade: Good	
Justification	The PGC provides all required information in a product user guide except for the WGS84 realization. An ATBD is not provided. The SETSM algorithm information is provided in a series of peer-reviewed publications. Documentation is up to date.
Document	***Reference***
Product User Guide	https://www.pgc.umn.edu/guides/stereo-derived-elevation-models/pgc-dem-products-arcticdem-rema-and-earthdem
ATBD	None.

3.2. Metrology

Metrological Traceability Documentation	
Not Assessable	
Justification	No traceability chain provided.
References	None

Uncertainty Characterisation	
Grade: Basic	
Justification	An uncertainty analysis was performed on a limited subset of the ArcticDEM data by Noh and Howat (2015) and Howat (2023). However, the assessments were small samples limited to polar regions and thus are not directly extensible to EarthDEM due to the varied surface characteristics in the mid-latitudes. The Strip DSM metadata include an expected vertical accuracy related to the base to height ratio of the stereo images (Hasegawa et al. 2000).
References	• Noh and Howat (2015) • Howat (2023) • Hasegawa et al. (2000)

Ancillary Data	
Grade: Good	
Justification	The PGC employs the water cover class from the ESA WorldCover 2021 product during Mosaic Tile generation. The water mask is considered to be fit for purpose.
References	• Zanaga et al. (2022)

3.3. Product Generation

Calibration Algorithm	
Grade: Excellent	
Justification	Calibration activities aim to correct potential altimetric biases and/or planimetric misregistration in the generated elevations. Positional differences between stereo image pairs caused by bias in the Rational Polynomial Coefficients (RPCs) are corrected before generating surface elevations. The horizontal and vertical translations used to align DEMs within a strip are reported within the Strip DSM metadata file. Strip DSMs used to generate a Mosaic Tile are intercalibrated by co-registering each pair of overlapping Strip DSM to calculate the pairwise offsets required for horizontal and vertical alignment. EarthDEM does not use existing elevation datasets for calibration. The calibration methods are well described in the reference documents below.
References	• Noh and Howat (2018) • Noh and Howat (2014) • Howat (2023)

Geometric Processing	
Grade: Good	
Justification	Geometric processing involves the steps required to retrieve DEM elevations at the correct locations. SETSM relies on sensor RPCs to retrieve elevations at the correct locations. The SETSM algorithm corrects for biases between RPCs of stereo image pairs caused by orbital navigation errors, satellite drift errors, and interior orientation errors. Noh and Howat (2018) document how their methods increase the matching ratio between two stereo images and the relationship between their bias correction and object space translations, showing how the algorithm converges on biases with each iteration. Uncertainty is provided overall but is not provided per processing step. The DEM products are projected into the corresponding UTM zone or a polar stereographic projection.
References	• Noh and Howat (2018)

Elevation Retrieval	
Grade: Good	
Justification	The retrieval algorithm covers all processing used to generate the final DEM elevation layer. SETSM is an advanced elevation retrieval algorithm designed for satellite stereo imagery. The algorithm is well-documented, published in peer-reviewed literature, and is open source. SETSM implements corrections for RPC bias and satellite jitter, uses methods for increasing the likelihood of detecting matched features on low-contrast surfaces, and implements methods for identifying and removing outliers. Elevations in the final DEM are interpolated from a TIN. The stated vertical accuracies are not achieved in some scenarios (Section 4.4). DEMs produced by SETSM commonly have a thin strip of erroneous elevations at the edges of the DEM extent. Mosaic Tile elevations are computed from a stack of Strip DSMs using the Co-registration, Adjustment, and Median of Stacks method outlined in Howat (2023).
References	• Noh and Howat (2015) • Noh and Howat (2017) • Howat (2023) • https://github.com/setsmdeveloper/SETSM

Post-Processing: Strip DSM	
Grade: Good	
Justification	Image strips collected by Vantor are delivered to users as overlapping tiles, referred to as scenes. SETSM produces DSMs for each scene within an image strip. The scene DSMs are then co-registered and mosaicked together to form Strip DSMs using the scenes2strips Python script. The PGC creates a bitmask layer within the scenes2strips workflow using the underlying optical data and the elevation retrievals to create a mask for removal of potentially erroneous elevation retrievals. The bitmask and the SETSM LSF module are applied to the Strip DSM data prior to Mosaic Tile generation. Additionally, the ESA WorldCover water class is used in combination with outliers among contributing Strip DEMs to mask elevation retrievals over waterbodies. The Strip DSM post-processing was graded as Good.
References	• https://www.pgc.umn.edu/guides/stereo-derived-elevation-models/pgc-dem-products-arcticdem-rema-and-earthdem/ • https://github.com/PolarGeospatialCenter/setsm_postprocessing_python • Noh and Howat (2019)

Post-Processing: Mosaic Tile	
Grade: Basic	
Justification	The PGC provides the Mosaic Tile product with a consistent tiling scheme that is feathered along tile edges to remove abrupt changes in elevation. Mosaic Tile post-processing was graded as basic due to the presence of data voids within the Mosaic Tile products.
References	• https://www.pgc.umn.edu/guides/stereo-derived-elevation-models/pgc-dem-products-arcticdem-rema-and-earthdem/ • https://github.com/PolarGeospatialCenter/setsm_postprocessing_python • Noh and Howat (2019)

Additional Layer Processing	
Grade: Good	
Justification	The PGC utilizes the scenes2strips Python script to produce a bitmask layer that identifies potentially erroneous elevation retrievals within the Strip DSMs. Filters are used to identify erroneous elevations directly from the DSM and classify their source as either cloud, water, or edge. Generation of the mask layer is well documented within the PGC GitHub documentation. A brief description is included within the user guide and Strip DSM documentation. The accuracy of the bitmask layer was not quantitatively evaluated by the evaluation team.
References	• https://www.pgc.umn.edu/guides/stereo-derived-elevation-models/pgc-dem-products-arcticdem-rema-and-earthdem • https://www.pgc.umn.edu/files/2021/01/PGC-SETSM-v4-Strip-DEM-Documentation.pdf • https://github.com/PolarGeospatialCenter/setsm_postprocessing_python

4. Detailed Validation - Vertical

4.1. Validation Dataset

The CSDA DEM evaluation team selected 52 sites across the conterminous US (CONUS), totaling 15,821 km^2, and 24 sites across Senegal, totaling 2.2 km^2, as evaluation sites (Figures 3 and 5) for the EarthDEM datasets. Sites within Senegal with recent lidar collections that were available were also included for additional diversity in the assessment dataset. The CONUS evaluation site names and sizes are provided in Appendix Table A1.

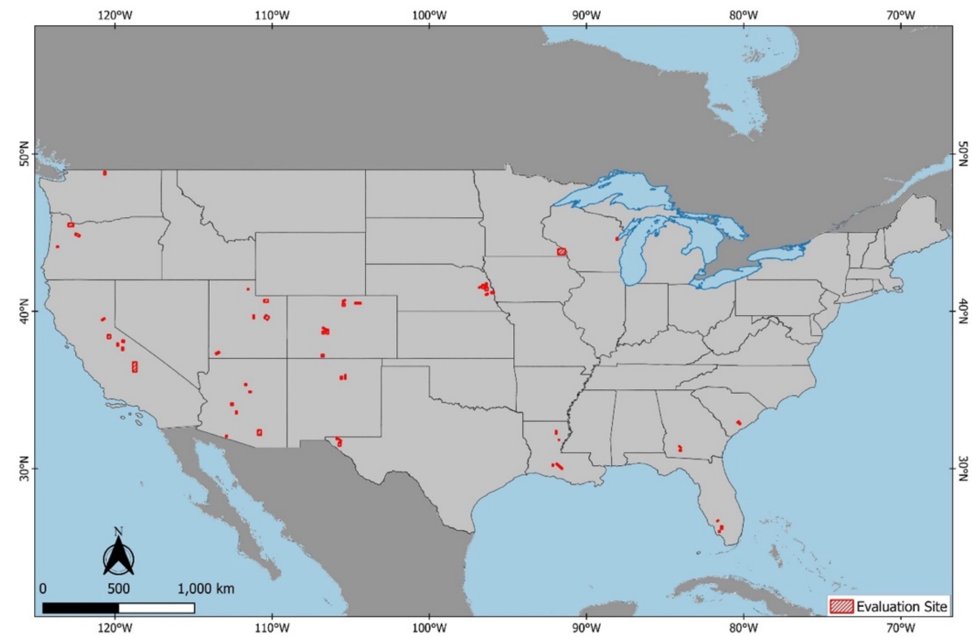

Figure 3. Location of US-based study sites for the EarthDEM evaluation indicated in red.

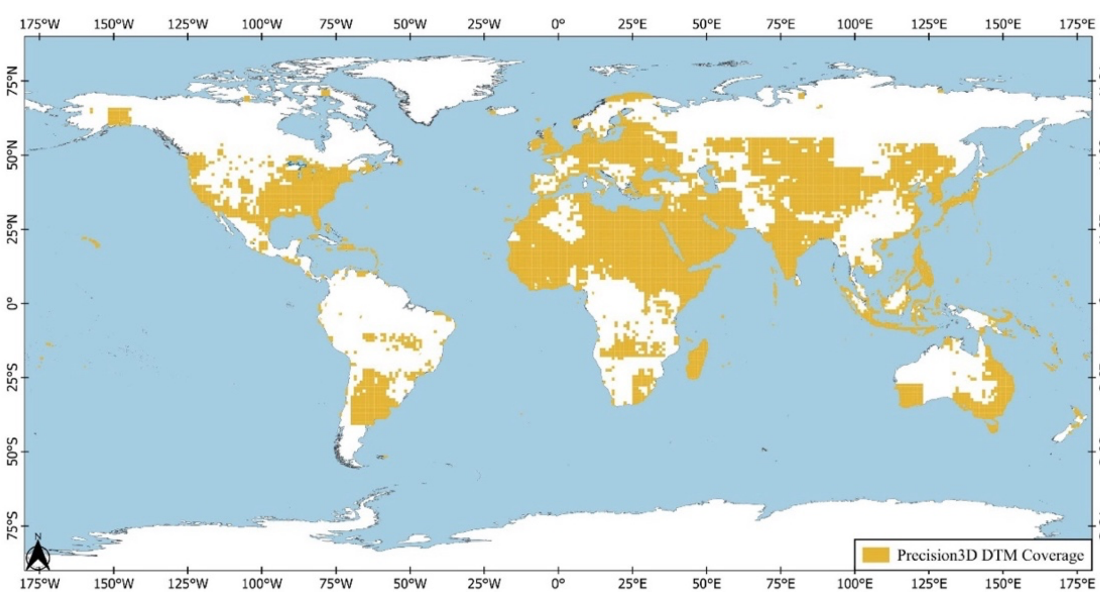

Figure 4. Precision3D DTM spatial coverage as of November 21, 2024, used to constrain evaluation site locations.

The evaluation sites that were used to evaluate the EarthDEM datasets were the same the CSDA Program used in the first CSDA DEM evaluation (available online: https://science.nasa.gov/wp-content/uploads/2026/05/vantor-precision3d-qa-report-final.pdf), which was the Vantor Precision3D product. The site selection process began by assembling potential evaluation site locations across the US that had both high quality lidar data collected during leaf-on conditions and availability of the Vantor Precision3D DTM product at the time (Figure 4). Additionally, the point density of the reference lidar needed to be sufficient to generate a 1 m DEM. The list of potential evaluation sites included sites used by the NASA Surface Topography and Vegetation Study, as these were valuable sites with additional coincident datasets. The site selection criteria excluded datasets in the northeast US, due to a lack of growing season lidar acquisitions, as well as much of the western US, due to lack of Precision3D DTM coverage. The final evaluation site locations were selected from the remaining sites based on surface topography, diversity of land cover, and vegetation density. This process ensured that the evaluation sites represented a sufficient variety and spatial extent with different surface characteristics. Twenty-four of the 52 CONUS evaluation sites overlapped with established Surface Topography and Vegetation evaluation sites.

Airborne lidar data were used as a reference dataset to validate the accuracy of the EarthDEM Strip DSM and Mosaic Tile products. These lidar measurements typically offer high horizontal and vertical accuracy and are the standard for validation of elevation data. The 3D Elevation Program (3DEP), managed by the United States Geological Survey (USGS) National Geospatial Program, was started in 2015 in response to a call to action for high-quality topographic data within the US. One action taken by 3DEP was the development of a set of lidar data standards and specifications for data collection (available online: https://www.usgs.gov/ngp-standards-and-specifications/lidar-base-specification-online). As of 2025, all of the conterminous US has, or is in the process of collecting, lidar data that meets the 3DEP standards (USGS, 2025). The USGS hosts topographic datasets online that meet the 3DEP standards that are freely available without use restrictions (https:/rockyweb.usgs.gov). This EarthDEM evaluation was performed almost exclusively within the US due to the large volume of high-quality publicly available lidar datasets.

Data from lidar collections overlapping our CONUS evaluation sites were downloaded from the USGS. The 3DEP lidar reference sites used in the evaluation are listed in Appendix Table A1. Each lidar dataset contained point clouds classified using the American Society of Photogrammetry and Remote Sensing (ASPRS) standard classification scheme (ASPRS, 2025). CSDA further processed the 3DEP point cloud data to further screen noise not covered by 3DEP standard requirements processing. The lidar returns, excluding those classified as noise, were processed into DSMs by taking the maximum elevation of all lidar returns within each grid cell. The lidar DSMs were resampled to 2 m resolution to match the spatial resolution of the EarthDEM dataset. In order to ensure that the EarthDEM Strip DSM and Mosaic Tile elevations were compared with actual lidar returns, no interpolation was used to fill raster cells with no lidar returns. Point clouds were reprojected to the same horizontal and vertical coordinate reference system (WGS84 Ellipsoid) as the EarthDEM dataset before generating the reference DEM. Lidar point cloud processing was performed using the open-source Point Data Abstraction Library (PDAL) (Howard Butler et al., 2024). The PDAL workflow (referred to as a pipeline) used to process the 3DEP lidar is provided in Appendix Table A2.1. Areas of temporal change (e.g., timber harvest, forest fires, excavation, building demolition or construction, etc.) between the reference lidar collection and the EarthDEM Mosaic Tiles were identified through manual interpretation of the DEMs. Vehicles were present within the reference lidar data collection. Vehicles within roadways and parking lots were identified using methods described in the CSDA Precision3D Quality Assessment Report. The areas of change and the vehicles isolated within the roads and parking lots were both removed from the evaluation of the Mosaic Tile and Strip DSM products.

Twenty-four additional evaluation sites, totaling 2.2 square kilometers, were selected in Senegal (Figure 5). These 24 sites are located across multiple dryland ecosystem sub-types and along precipitation and aridity gradients. Regional vegetation type and structure vary by latitude and precipitation, and cover types include mixed woodland/grassland, savanna/shrubland, and agropastoral. Airborne lidar data were collected at each site using an Uncrewed Aircraft System (UAS) through a collaborative effort with the University of Maryland, College Park, Department of Geographical Sciences and the Centre de Suivi Ecologique, Senegal. The UAS data were acquired between February 20th and 26th, 2023. Each site was flown with a DJI Matrice 600 Pro aircraft equipped with a Riegl MiniVUX-SYS laser scanner system at an altitude of 25 m above ground level and a ground speed of 4 m/s. The resulting point cloud data had densities ranging from 500-4500 points/m^2, depending on the height of the surface feature. Similar to the USGS 3DEP lidar, the lidar returns from these acquisitions were originally processed into DSMs with a horizontal resolution of 1 m and were resampled to 2 m resolution for this evaluation. Additional processing was required for the Senegal sites because the point clouds provided by these data were not classified. The additional processing needed to identify ground and non-ground returns was performed using the Simple Morphological Filter (Pingel et al., 2013) to identify ground and non-ground returns. Noise points were identified using the Extended Local Minimum Filter (Chen et al., 2012). The PDAL pipeline used to process the Senegal UAS lidar is provided in Appendix Table A2.2. Areas of temporal change were not removed for the Senegal sites due to the challenge of differentiating poor elevation retrievals in the EarthDEM data from change to surface features. However, visual image inspection of archived Vantor imagery showed minimal change for each site within the last fifteen years.

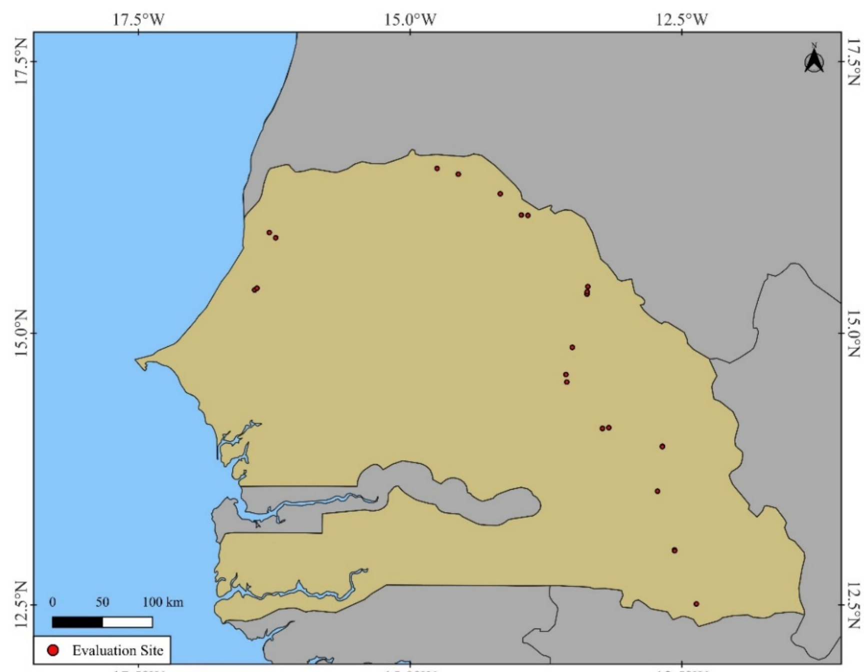

Figure 5. Location of Senegal-based study sites for the EarthDEM evaluation. The evaluation sites are located along a vegetation density gradient in the Sahel region of Africa.

An "Excellent" grade was assigned to the validation data sets, as they were of sufficient quality and resolution to assess the accuracy of the EarthDEM Strip DSMs and Mosaic Tiles. Temporal mismatches between the 3DEP reference lidar and the EarthDEM data were managed by manually excluding areas with visually apparent change. Additionally, Strip DSMs were only evaluated if they were acquired during leaf-on periods. It is possible that temporal mismatches of small spatial extents, such as removal of individual trees, were not completely masked due to the total spatial extent of the evaluation sites and the difficulty in determining whether a feature was missing due to a systematic error or a temporal mismatch.

4.2 Validation Methodology

EarthDEM Strip DSMs were produced locally by the evaluation team using code provided by the PGC. Strip DSM quality is dependent on the quality of the input stereoscopic imagery. Lower image quality, due to atmospheric conditions or sun-target-sensor geometries, will result in lower quality Strip DSMs irrespective of the elevation retrieval algorithm. All in-track stereoscopic image pairs with less than 20% cloud cover, as reported in the Vantor image metadata, intersecting the evaluation sites were assembled. No other metrics were used to optimize image quality prior to DSM generation. Stereoscopic image pairs were processed using SETSM v5.3.5 and merged into Strip DSMs using scenes2strips v4.1. Note that although the GSFC team used SETSM v5.3.5 in the Strip DSM workflow and PGC used v4.3 for the EarthDEM data CSDA distributes, v5.3.5 was updated to add functionality for other input image datasets, and Vantor DEM processing within the more recent version remains the same as v4.3. The Strip DSMs produced at GSFC were processed without the SETSM Local Surface Fitting module. The data masks generated during the scenes2strips processing were applied to each Strip DSM to remove potentially poor elevation retrievals due to clouds, water, or edge artifacts.

A total of 211 Strip DSMs were evaluated for the CONUS evaluation sites and 59 for the Senegal evaluation sites. Nine of the 52 CONUS evaluation sites lacked Vantor stereo pairs during leaf-on periods and were excluded from the Strip DSM assessment. Strip DSMs were then co-registered to their corresponding reference lidar DSM (Appendix 3). EarthDEM Mosaic Tiles were provided as a tiled dataset. Tiles were 50 x 50 km with a spatial resolution of 2 m. The tiles intersecting each evaluation site were mosaicked together and then co-registered to their respective reference lidar DSMs (Appendix 4). Co-registration was performed using the methods described in Nuth and Kääb (2011) to ensure that the DEMs were aligned both horizontally and vertically. Once co-registered, the per pixel difference between the Mosaic Tile or Strip DSM elevation and the lidar DSM elevation was calculated by subtracting the lidar elevation from the EarthDEM elevation. Vertical errors were grouped by National Land Cover Database (NLCD) cover type (USGS, 2025), slope, and terrain aspect. Flat terrain (defined here as slope less than or equal to 2°) was used to determine the errors by NLCD cover type to reduce the effect of slope on elevation errors. The NLCD Barren class was manually edited to remove areas incorrectly classified as Barren. For example, areas of sparse forest were commonly misidentified as Barren. Misidentified areas were removed to ensure that the performance of the EarthDEM products more accurately captured areas with direct line-of-sight to the surface. No other NLCD cover classes were edited. The Barren land class was used to determine error over varying slopes to reduce the effect that cover type may have on elevation errors. The resulting statistics (minimum, maximum, mean, median, standard deviation, root mean square error [RMSE], and linear error 90% [LE90]) were computed to quantify the overall vertical error as well as the vertical error within each of NLCD class.

Due to the 2 m EarthDEM resolution and the spatial extent of the evaluation sites, random points were sampled across all US evaluation sites. 750,000 points were randomly sampled by NLCD cover class on flat terrain for the EarthDEM Mosaic Tiles, and 300,000 points were randomly sampled for the EarthDEM Strip DSMs. Fewer sample points were available for the Strip DSM evaluation due to the high number of 'No Data' values in the individual images after applying the bitmask to remove poor quality retrievals.

Overall vertical error statistics were computed by selecting a random sample of points weighted by the land cover type proportion in the conterminous US (Table 1). A total of 3 million points were set to be randomly sampled to compute the overall vertical error statistics for the EarthDEM Mosaic Tiles and 1.25 million points were set to be sampled for the EarthDEM Strip DSMs. However, the final number of points randomly sampled to compute the overall statistics was slightly less due to rounding.

Table 1. The proportion of each National Land Cover Database (NLCD) cover classes within the conterminous US. The water class, perennial ice/snow, and the cover classes unique to Alaska were excluded.

NLCD Land Cover Class	Percent Coverage
Developed, Open Space	3.03%
Developed, Low Intensity	1.56%
Developed, Medium Intensity	0.74%
Developed, High Intensity	0.26%
Barren	1.08%
Deciduous Forest	9.89%
Evergreen Forest	12.07%
Mixed Forest	3.83%
Shrub/Scrub	22.99%
Grassland/Herbaceous	14.61%
Pasture/Hay	6.63%
Cultivated Crops	17.15%
Woody Wetland	4.61%
Emergent Herbaceous Wetlands	1.55%

The USGS 3DEP 1/3 arc-second (10 m) raster DEM data were downloaded for each CONUS evaluation site to calculate slope and aspect. These 10 m DEMs are produced by the USGS and represent bare earth elevations. Slope and aspect images were computed for each evaluation site using the Horn algorithm (Horn, 1981).

250,000 points were randomly sampled per slope class, which ranged from zero to 85°, with 5° increments, for both the Strip DSM and Mosaic Tile products. Only slopes classified as Barren were sampled. 52 of the Strip DSMs did not have any slopes classified as Barren and were excluded from sampling. Only a few areas within the evaluation sites had slopes ranging from 65-90° that intersected the Barren land cover class. This was further compounded by the number of void pixels within the Strip DSMs and Mosaic Tiles, and as a result, it was not always possible to sample 250,000 points for each of these slope classes. Thus, all Strip DSM pixels that intersected Barren land cover with slopes ranging from 75-85° were included, and all Mosaic Tile pixels that intersected Barren land cover with slopes ranging from 65-85° were included. It was possible to sample 250,000 Strip DSM elevations for the 65-75° slope classes due to the volume of Strip DSMs, and there were no samples with slopes between 85-90° that intersected the Barren land cover class. One million points were randomly sampled per aspect class for the Strip DSMs and the Mosaic Tiles. Aspect classes ranged from 0-360° with step sizes of 15°.

The vertical error of the EarthDEM products at the Senegal evaluation sites was computed separately from the US-based sites due to the two different reference lidar datasets used. Errors were not categorized by slope or aspect for the Senegal sites due to the small size of the evaluation sites and the relatively flat terrain.

An "Excellent" grade was assigned to the validation methodology, as it is reproducible and a state-of-the-art methodology was used.

4.3 Validation Completeness

Vertical accuracy validation completeness was given an "Excellent" grade. The validation completeness could not be graded higher because the evaluation of the EarthDEM Strip DSMs and Mosaic Tiles was not carried out globally. However, the validation was completed over large spatial extents, with varying land cover and topography using high-quality airborne lidar data as the reference data. The variety of surface characteristics in the evaluation sites permitted assessment of how they affected the two EarthDEM products. Temporal differences between the EarthDEM products and the reference data were minimized by masking out areas of change and removal of Strip DSMs produced from imagery acquired during leaf-off periods. It was not possible to account for differences caused by seasonal vegetation variation within the Mosaic Tiles as they are generated using all Strip DSMs regardless of date.

4.4 Validation Results Compliance

4.4.1 EarthDEM Strip DSMs

Differences in elevation were compared by NLCD cover type for areas with slopes less than or equal to 2° for the 211 EarthDEM Strip DSMs (Table 2). The most extreme errors for the EarthDEM Strip DSMs were frequently due to the bitmask layer failing to capture erroneous elevation retrievals on the periphery of clouds.

Table 2. EarthDEM Strip DSM vertical errors (m) by NLCD cover type over terrain with slopes less than or equal to 2°. 300,000 points were randomly sampled across all US evaluation sites per NLCD cover type to generate the overall statistics. The number of points sampled per cover type for the weighted average statistic was proportional to the percent area for each class across the CONUS (Table 1).

Cover Type	Minimum	Maximum	Median	Mean	StD	RMSE	LE90	Count
Developed, Open Space	-97.5	302.8	0.3	-0.4	4.8	4.8	6.8	300,000
Developed, Low Intensity	-103.3	348.2	0.3	-0.4	4.4	4.4	6.3	300,000
Developed, Medium Intensity	-111.9	74.2	0.5	-0.1	3.0	3.0	3.9	300,000
Developed, High Intensity	-108.0	49.2	0.5	0.6	2.8	2.9	3.9	300,000
Barren	-56.5	33.6	0.4	0.2	2.4	2.4	2.4	300,000
Deciduous Forest	-42.7	111.7	-0.3	-0.8	7.3	7.3	10.9	300,000
Evergreen Forest	-178.5	105.9	0.0	-2.0	8.3	8.5	14.6	300,000
Mixed Forest	-91.4	94.7	0.3	0.8	8.5	8.5	14.2	300,000
Shrub/Scrub	-366.8	126.1	0.3	-0.2	3.8	3.8	3.5	300,000
Grassland/Herbaceous	-114.2	144.2	0.2	-1.2	6.3	6.4	8.8	300,000
Pasture/Hay	-53.0	131.1	0.4	-0.1	2.8	2.8	3.0	300,000
Cultivated Crops	-71.1	162.7	0.3	0.2	2.6	2.6	2.8	300,000
Woody Wetlands	-394.1	392.1	0.5	-0.4	6.3	6.3	9.4	300,000
Emergent Herbaceous Wetlands	-406.9	93.2	0.6	-0.2	5.7	5.7	5.9	300,000
Weighted Average	**-403.5**	**177.3**	**0.3**	**-0.5**	**5.6**	**5.6**	**7.9**	**1,249,993**

Interpolation errors in stereo-photogrammetric DSMs are typically due to obscuration of the surface due to viewing geometries or shadowing. The largest of these errors were observed within the developed cover classes. Large positive errors were present where the ground surface adjacent to buildings or where gaps between buildings were obscured (Figure 6 and Figure 7). Large negative errors were caused by small positional differences between buildings in the EarthDEM Strip DSM and the reference lidar, incomplete representation of a building's shape, or the omission of a building.

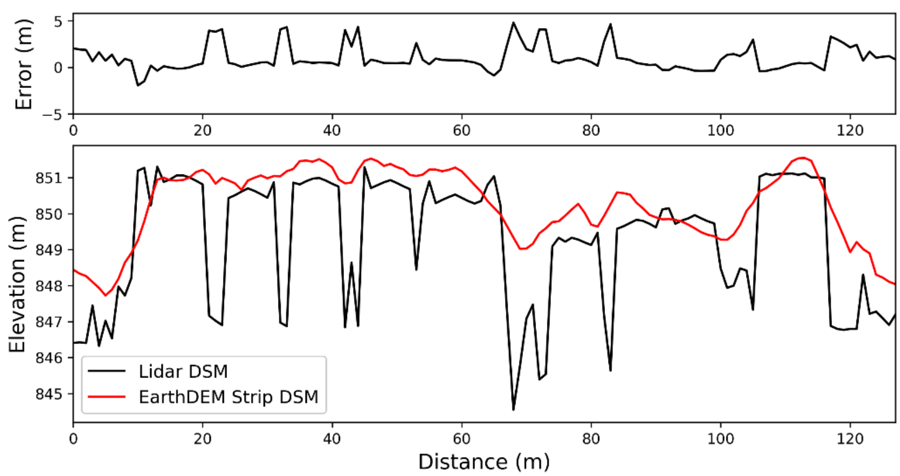

Figure 6. Elevation cross section for an EarthDEM Strip DSM (red) from October 10th, 2020, and the reference lidar DSM (black) at the evaluation site in Tucson, AZ. Vertical error (m) was calculated by subtracting the lidar DSM elevation from the EarthDEM Strip DSM elevation. The EarthDEM Strip DSM was co-registered to the reference lidar DSM using the methods described in Nuth and Kääb (2011) before computing the cross section.

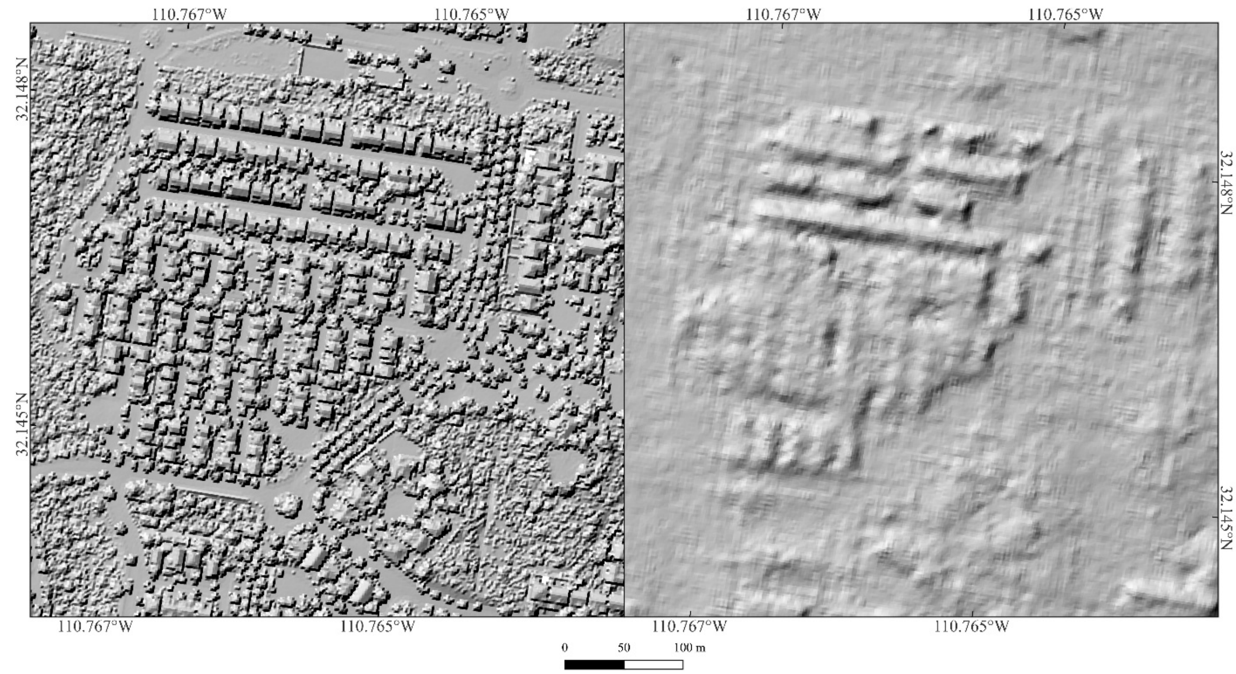

Figure 7. Shaded relief of the reference lidar DSM (left) and an EarthDEM Strip DSM (right) for Tucson, AZ. Interpolation around vertical features results in the omission of gaps between buildings. Note also the areas of trees not represented in the EarthDEM Strip DSM shaded relief. See Figure 11 for the corresponding area in the Mosaic Tile product.

Trees were a common source of error across all cover types, with evergreen (coniferous in the US) forests having the largest errors (14.6 m LE90) overall. The Strip DSMs were unable to consistently capture the elevation of coniferous tree canopies, resulting in significant omission of coniferous tree canopy across a range of stem densities (Figures 8 and 9). Vertical accuracy in deciduous forests was comparatively better (10.9 m LE90). Deciduous tree canopies were more accurately captured in locations with high canopy cover. Individual and small clusters of deciduous trees were commonly omitted. The SETSM algorithm identifies sparse and highly peaked points during the elevation retrieval workflow and removes them (Noh and Howat, 2025). This resulted in the frequent omission of individual and small clusters of trees within the Strip DSMs. Positive errors across all forest cover types were caused by the omission of tree canopy gaps. The EarthDEM Strip DSM vertical accuracy was highest for Barren land, with a RMSE and LE90 of 2.4 m. This cover class, devoid of surface features, offers a direct line of sight from the satellite to the Earth surface. The overall LE90 for all EarthDEM Strip DSM evaluation sites was 7.9 m (Table 2), when accounting for US land cover class distribution.

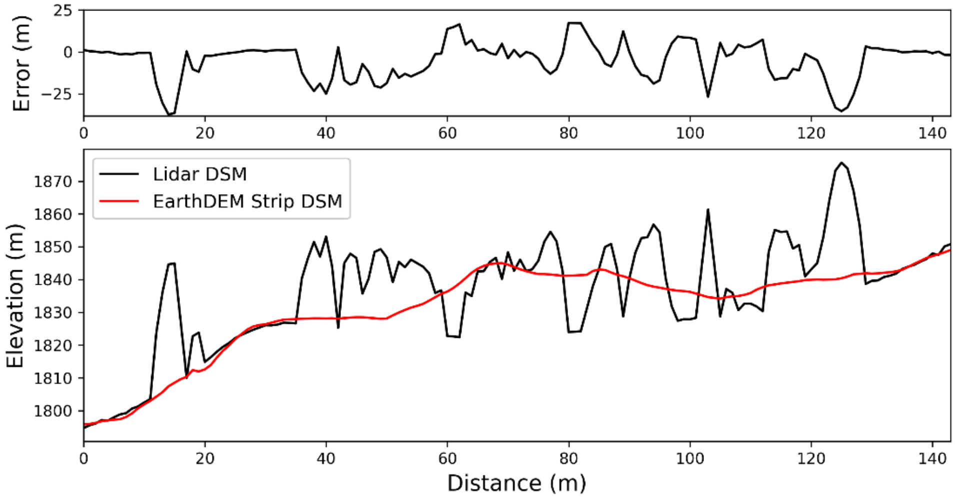

Figure 8. Elevation cross section for an EarthDEM Strip DSM (red) from September 14th, 2019, and the reference lidar DSM (black) at the evaluation site in Yosemite National Park, CA. Vertical error (m) was calculated by subtracting elevation of the lidar DSM from the Strip DSM. The cross section shows multiple, large trees that were not represented in the EarthDEM Strip DSM product. The EarthDEM Strip DSM was co-registered to the reference lidar DSM using the methods described in Nuth and Kääb (2011) before computing the cross section.

Figure 9. Shaded relief of the reference lidar DSM (left) and an EarthDEM Strip DSM (right) for a forested area in Yosemite National Park, California. Stem density varies throughout the displayed area. Note the lack of detail in the treed areas in the EarthDEM Strip DSM shaded relief.

It is possible that some vertical errors measured for the Strip DSMs were caused by small-scale surface changes due to temporal differences between the stereo image pair acquisition and the lidar acquisition. These small-scale changes were not removed from the evaluation as they were too difficult to visually distinguish from poor elevation estimates (e.g., an individual tree). Instead, we recomputed the errors by NLCD cover type using three time periods (Table 3): 1) All Strip DSMs acquired within one year of the mean lidar acquisition date; 2), All Strip DSMs acquired within two years of the mean lidar acquisition date; and 3) All Strip DSMs acquired more than two years from the mean lidar acquisition date. Mean lidar acquisition date is defined as: $(Begin\ Date + End\ Date)/2$. When categorizing errors by recency to the reference lidar acquisition date, the difference in vertical RMSE was minor for many cover types. The improvement in vertical accuracy for some cover types when using Strip DSMs acquired further from the date of lidar acquisition suggests that other factors, such as the stereoscopic image quality, are likely influencing the vertical accuracy. Full error statistics of all three time periods can be found in Appendices 5, 6 and 7.

Table 3. EarthDEM Strip DSM vertical RMSE (m) by NLCD cover type separated by recency to the corresponding lidar acquisition. The total number of points sampled varied based on Strip DSM count per time period. 120,000 points were randomly sampled per cover class across the 90 Strip DSMs within 1 year of the lidar acquisition, 200,000 points were randomly sampled per cover class across the 139 Strip DSMs within 2 years of the lidar acquisition, and 100,000 points were randomly sampled across the 75 Strip DSMs acquired more than 2 years from the lidar acquisition. 499,993 points were used to compute the weighted average based on NLCD cover class distribution (Table 1) for the 1 Year and 2 Year time frames. 399,993 points were used to compute the weighted average based on NLCD cover class distribution for the greater than 2 Year time frame. The RMSE values computed using all Strip DSMs (Table 2) is provided as a reference.

Cover Type	Vertical RMSE (m) 1 Year	Vertical RMSE (m) 2 Years	Vertical RMSE (m) > 2 Years	All Vertical RMSE (m)
Developed, Open Space	4.8	4.7	4.9	4.8
Developed, Low Intensity	4.3	4.1	4.7	4.4
Developed, Medium Intensity	3.2	3.0	3.1	3.0
Developed, High Intensity	3.0	2.9	2.8	2.9
Barren	1.4	1.3	2.3	2.4
Deciduous Forest	8.5	7.6	6.8	7.3
Evergreen Forest	8.2	8.0	9.4	8.5
Mixed Forest	9.5	8.5	8.5	8.5
Shrub/Scrub	4.0	3.4	4.2	3.8
Grassland/Herbaceous	4.5	5.3	7.4	6.4
Pasture/Hay	2.6	2.7	2.8	2.8
Cultivated Crops	2.4	2.4	3.0	2.6
Woody Wetlands	6.9	6.5	6.3	6.3
Emergent Herbaceous Wetlands	5.7	5.5	6.4	5.7
Weighted Average	**5.5**	**5.3**	**6.0**	**5.6**

Stereo-photogrammetric DEM quality is dependent on the quality of the underlying stereoscopic imagery. The PGC provides a series of metadata fields that can be used to filter Strip DSMs. Here we demonstrate the importance of using one of these metadata fields, cloud area percent, to filter individual Strip DSMs. The cloud area percent metadata field is generated by PGC for each Strip DSM and is independent of the cloud cover percent metadata field Vantor provides with their image metadata. The PGC uses the elevation retrievals together with the imagery to identify erroneous elevations and classifies their source as either cloud, water, or edge in a bitmask. The cloud component of this pixel level mask is used to calculate a cloud area percent metadata field for each Strip DSM. Below in Table 4, we use this calculated metadata field to separate vertical errors by NLCD cover class for Strip DSMs with a cloud area percent less than 20 from those with cloud area percent greater than 20. The Strip DSMs with cloud area percent less than 20 were generally more accurate than those above 20. Note also that the Strip DSMs produced for this assessment were only those with less than 20% clouds, according to the Vantor cloud cover metadata field, however, 42% of Strip DSMs assessed over the CONUS study sites had a greater than 20% cloud area according to the PGC cloud area percent metric. The differing cloud cover metadata fields between Vantor and the PGC were not explored by the assessment team but highlights inaccuracies in either the Vantor cloud cover metadata field or the PGC's cloud area percent metric. Full error statistics of the two sets of DSMs in the table below are provided in Appendices 8 and 9.

Table 4. EarthDEM Strip DSM vertical RMSE by NLCD cover type split by the PGC-generated cloud_area_percent metadata field. 100,000 points were randomly sampled for each NLCD cover class using the 122 Strip DSMs with cloud_area_percent less than 20 and the 89 Strip DSMs with greater than 20. 399,993 points were used to compute the weighted average based on NLCD cover class distribution (Table 1). RMSE values from Table 2, using all Strip DSMs, are included here as a reference. Splitting the Strip DSMs by cloud_area_percent resulted in an assessment over different evaluation sites, as shown below. It is possible that the different surface characteristics within each set of DSMs also contributed to the error computed for each group.

Cover Type	Vertical RMSE (m) using 122 Strip DSMs with < 20% Cloud Area (32 evaluation sites)	Vertical RMSE (m) using 89 Strip DSMs with > 20% Cloud Area (29 evaluation sites)	Vertical RMSE (m) All 211 Strip DSMs
Developed, Open Space	3.8	6.3	4.8
Developed, Low Intensity	3.5	5.4	4.4
Developed, Medium Intensity	2.6	3.6	3.0
Developed, High Intensity	2.7	3.1	2.9
Barren	1.4	2.3	2.4
Deciduous Forest	7.2	7.7	7.3
Evergreen Forest	7.6	9.5	8.5
Mixed Forest	7.0	10.1	8.5
Shrub/Scrub	2.9	5.2	3.8
Grassland/Herbaceous	3.9	8.4	6.4
Pasture/Hay	2.6	3.0	2.8
Cultivated Crops	1.4	3.7	2.6
Woody Wetlands	4.7	8.5	6.3
Emergent Herbaceous Wetlands	3.6	8.1	5.7
Weighted Average	**4.6**	**6.8**	**5.6**

Figure 10 below demonstrates some of the variability among individual Strip DSMs relative to the reference DSMs. Vertical accuracy will vary between individual Strip DSMs due to the variable imaging conditions within the source stereo imagery for each and users are strongly advised to investigate the provided product metadata fields to filter the criteria that is suitable for their application.

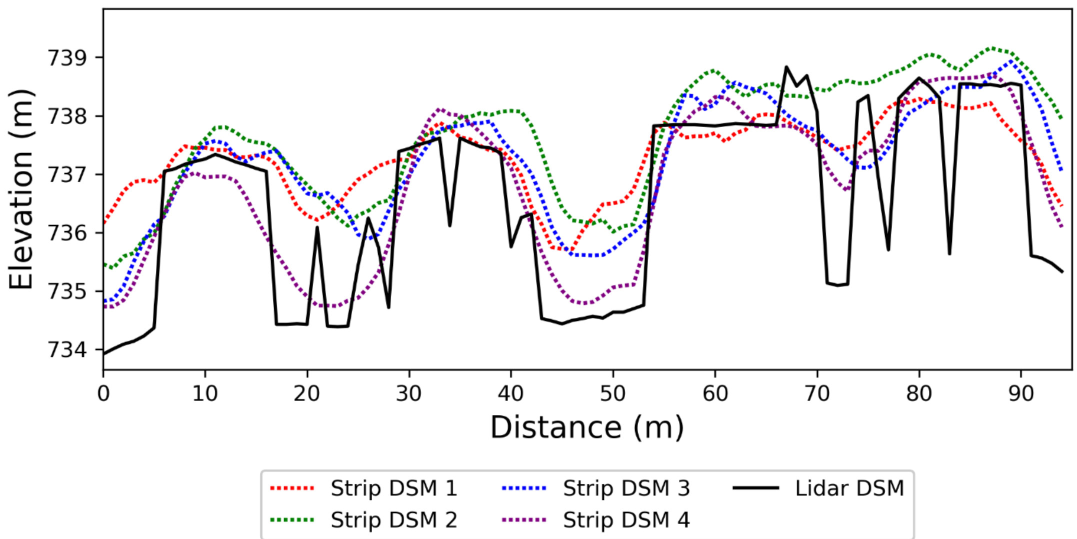

Figure 10. Elevation cross section from four EarthDEM Strip DSMs in Tucson, AZ compared to the reference lidar DSM (black). The cross sections show the variability in elevation retrievals between individual Strip DSMs. The following Strip DSM pair names were used within the figure:
1) WV02_20200908_10300100ABC9B600_10300100AD286800;
2) WV02_20201010_10300100AD917B00_10300100B0997F00;
3) WV02_20201123_10300100ACA53600_10300100AE8A9200; and
4) WV03_20200330_104001005A2A7500_104001005AB09800.

4.4.2 EarthDEM Mosaic Tile Product

Differences in elevation between the EarthDEM Mosaic Tiles and the reference lidar data were computed for areas with slopes less than or equal to 2° (Table 5). Large positive and negative vertical errors were less common in the Mosaic Tiles than the Strip DSMs.

Table 5. EarthDEM Mosaic Tile vertical errors (m) by NLCD cover type over terrain with slopes less than or equal to 2°. Points were randomly sampled from each cover type to generate the overall statistics. Number of points sampled per cover type for the weighted average statistic is proportional to the percent area for each cover class across the CONUS (Table 1).

Cover Type	Minimum	Maximum	Median	Mean	StD	RMSE	LE90	Count
Developed, Open Space	-56.2	42.6	0.3	-0.7	4.2	4.3	6.6	750,000
Developed, Low Intensity	-68.5	43.3	0.3	-0.9	3.8	3.9	5.7	750,000
Developed, Medium Intensity	-50.5	66.2	0.3	-0.5	3.0	3.1	4.1	750,000
Developed, High Intensity	-73.5	78.7	0.4	0.5	3.0	3.0	3.6	750,000
Barren	-20.5	15.4	0.2	0.1	1.1	1.1	1.3	750,000
Deciduous Forest	-82.3	55.7	-0.8	-1.7	8.8	8.9	15.6	750,000
Evergreen Forest	-86.2	70.1	-0.2	-0.7	8.1	8.1	14.3	750,000
Mixed Forest	-49.2	66.7	0.3	0.6	8.4	8.4	14.8	750,000
Shrub/Scrub	-63.2	55.5	0.1	0.0	1.4	1.4	0.8	750,000
Grassland/Herbaceous	-60.0	57.9	0.0	-0.1	2.8	2.8	0.8	750,000
Pasture/Hay	-76.2	50.4	0.5	-0.1	3.2	3.2	3.7	750,000
Cultivated Crops	-89.0	29.8	0.3	0.2	1.7	1.7	1.9	750,000
Woody Wetlands	-62.9	38.6	0.0	0.0	6.0	6.0	9.7	750,000
Emergent Herbaceous Wetlands	-39.3	30.1	0.6	0.1	3.7	3.7	4.8	750,000
Weighted Average	**-89.0**	**70.1**	**0.1**	**-0.3**	**4.9**	**4.9**	**7.4**	**2,999,993**

Large positive errors in the Developed cover classes were due to interpolation errors across gaps between buildings. Buildings and building gaps within the Mosaic Tiles were generally better resolved than within the Strip DSMs (Figure 11). However, clusters of buildings within the Mosaic Tiles were frequently represented as a single feature instead of multiple, smaller features. Large negative errors were due to the inaccurate capture of building shapes.

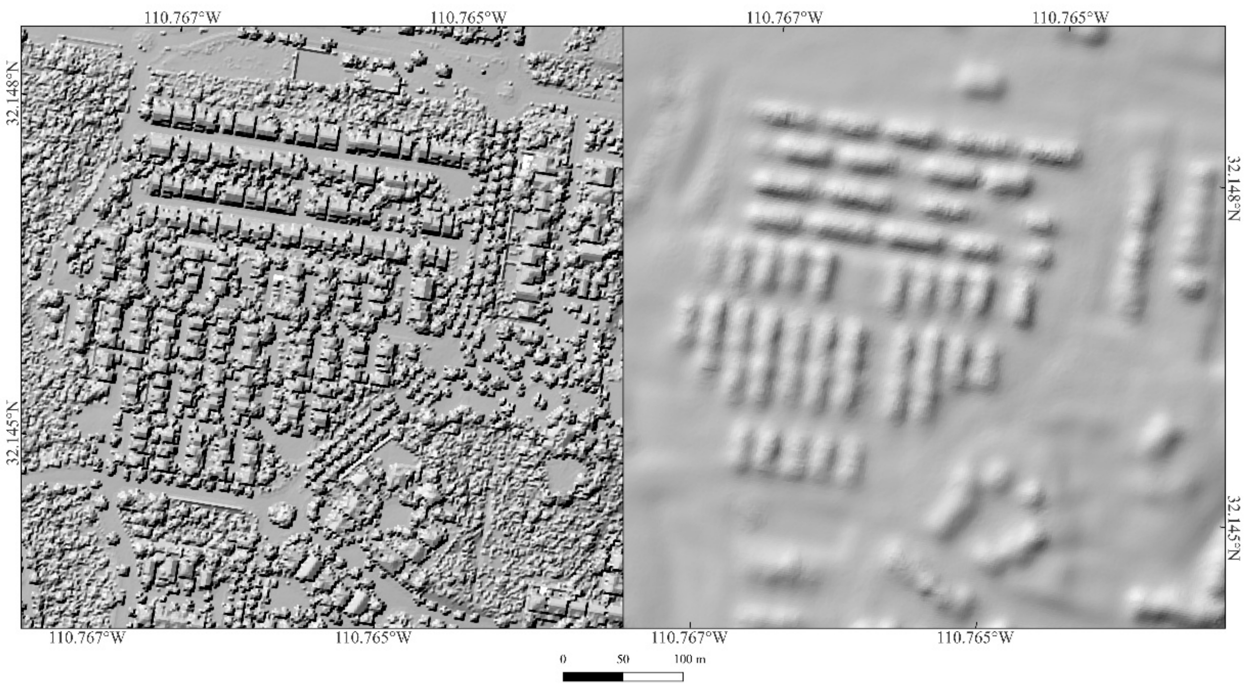

Figure 11. Shaded relief image of the reference lidar DSM (left) and the EarthDEM Mosaic Tile (right) for Tucson, Arizona. See Figure 7 for the corresponding area in a Strip DSM.

Trees continued to be a common source of error in the Mosaic Tiles across all cover types. Vertical accuracy improved slightly for the Evergreen Forest cover class (14.3 m LE90) compared to the Strip DSMs (14.6 m LE90). Vertical accuracy of the Deciduous Forest class declined significantly (15.6 m LE90) compared to the Strip DSMs (10.9 m). Since the EarthDEM Mosaic Tiles are created from all Strip DSMs regardless of seasonality, the resulting elevation estimates will thus be anywhere between the top of canopy and bare Earth (Figure 12). This can lead to large errors when compared to a reference DSM representing the top of canopy elevation. Vertical accuracy of the EarthDEM Mosaic Tiles improved for the Barren class on flat terrain (1.3 m LE90) compared to the Strip DSMs (2.4 m LE90). The overall LE90 value for the EarthDEM Mosaic Tiles at our evaluation sites was 7.4 m when accounting for US land cover distribution, slightly better than the overall LE90 for Strip DSMs (7.9 m).

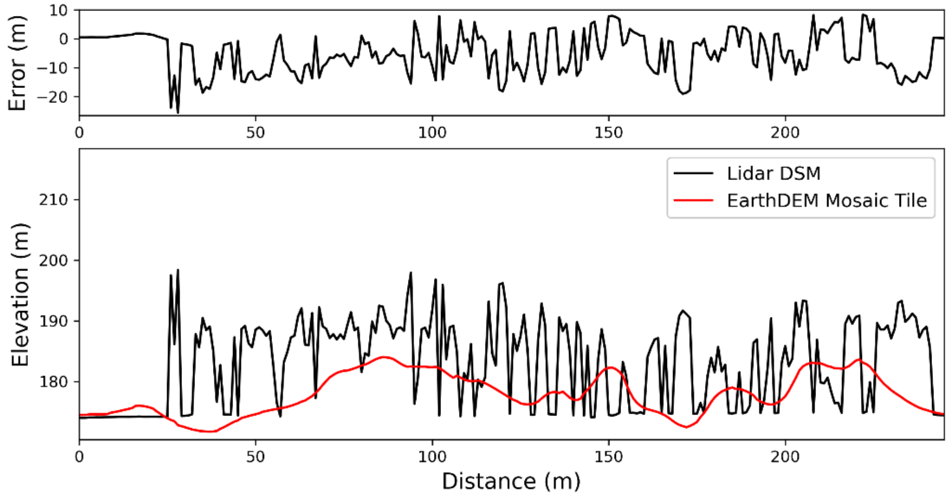

Figure 12. Elevation cross section for the EarthDEM Mosaic Tile (red) and the reference lidar DSM (black) for a deciduous forest in Minnesota, USA. Vertical error (m) was calculated by subtracting the lidar DSM elevation from the EarthDEM Mosaic Tile elevation. The cross section shows the incorrect capture of seasonal vegetative canopies due to the inclusion of DEMs acquired during leaf-off conditions. The EarthDEM Mosaic Tile was co-registered to the reference lidar DSM using the methods described in Nuth and Kääb (2011) before computing the cross section.

4.4.3 Vertical Error Analysis of EarthDEM Products Using Barren Class

The EarthDEM Strip DSM and Mosaic Tile vertical errors (Figure 13 and 14, respectively) were evaluated for the Barren class with slopes ranging from 0-85° in 5° increments. Both products showed a general trend of decreasing accuracy with increasing slope. Large positive and negative errors were more common on steeper slopes. Both the Strip DSMs and Mosaic tiles struggled to capture the shape of steeper terrain in some instances, which contributed to the large vertical errors. Details of the vertical error values within each slope category are provided in Appendix 10.

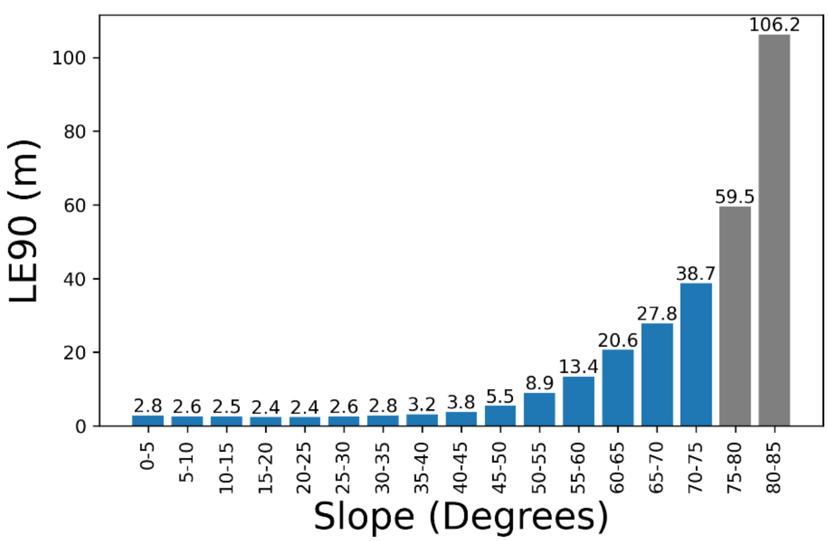

Figure 13. EarthDEM Strip DSM vertical errors (m) by slope for the Barren class. 250,000 points were randomly sampled by slope class for the NLCD Barren land cover class. Grey bars indicate the slope classes with fewer than 250,000 sample points.

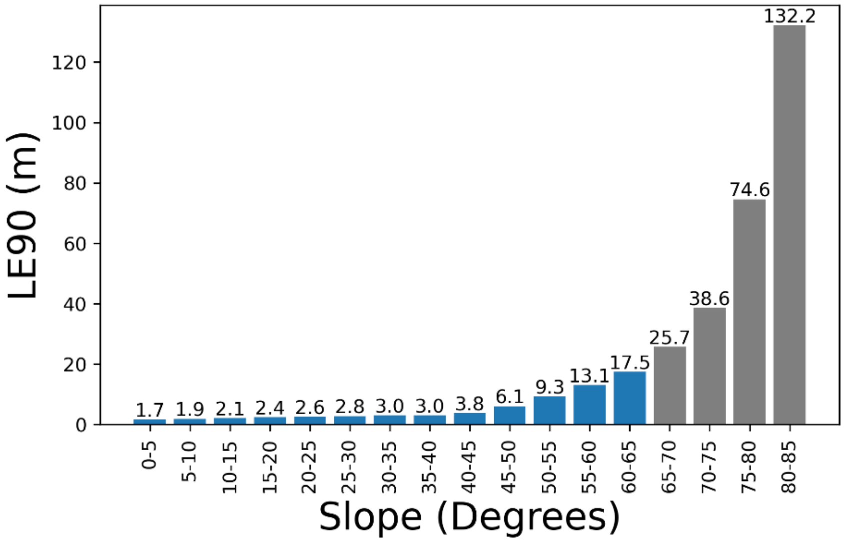

Figure 14. EarthDEM Mosaic Tile vertical errors (m) by slope for the Barren class. 250,000 points were randomly sampled by slope class for the NLCD Barren land cover class. Grey bars indicate the slope classes with fewer than 250,000 sample points.

The EarthDEM Strip DSM and Mosaic Tile vertical errors were grouped by aspect in step sizes of 15° (Appendix Tables A11.1 and A11.2, respectively). Inspection of the LE90 values for each aspect group indicates slightly larger errors for east-southeast aspects for both the Strip DSMs and Mosaic Tiles. However, this trend was reduced when considering land cover (Figure 15 and 16). 500,000 points were randomly sampled within the NLCD forested cover types (Deciduous Forest, Evergreen Forest, and Mixed Forest) and the Barren land cover class for each aspect category. In Figures 15 and 16, the LE90 for the forested cover classes grouped by aspect represent the upper limit of the error bars, and the LE90 for the Barren cover class grouped by aspect represent the lower limits for the error bars. Forested cover classes were used to establish the upper limits of the error bars as those classes overall had the highest vertical errors. The Barren cover class was used to establish the lower limit of the error bars as the sensor has direct line-of-sight to the surface for this class, corresponding to the maximum achievable accuracy by the EarthDEM products. Inspection of the vertical error over the Barren class by aspect (lower limit of the error bars) indicates minimal change in vertical error across all aspect categories for the Mosaic Tiles (Figure 16). This suggests that the larger errors associated with east-southeast aspects are the result of cover type. Large differences of vertical error over the Barren class by aspect for the Strip DSMs is likely caused by poor masking of bad data (Figure 15).

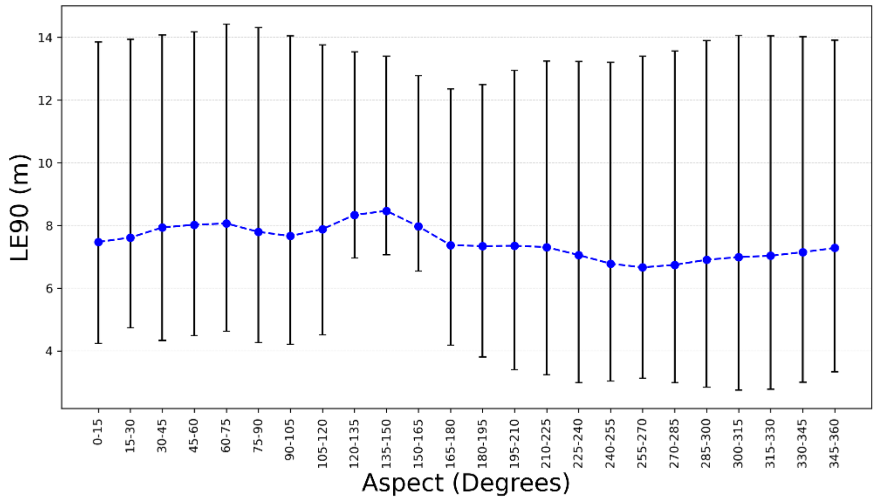

Figure 15. Vertical error (LE90) for the EarthDEM Strip DSM for each aspect group. The LE90 calculated without considering land cover type (blue). Error bars represent the LE90 values for each aspect group when only considering forest land cover types (upper limits) and the Barren land class (lower limits). Errors are provided in meters.

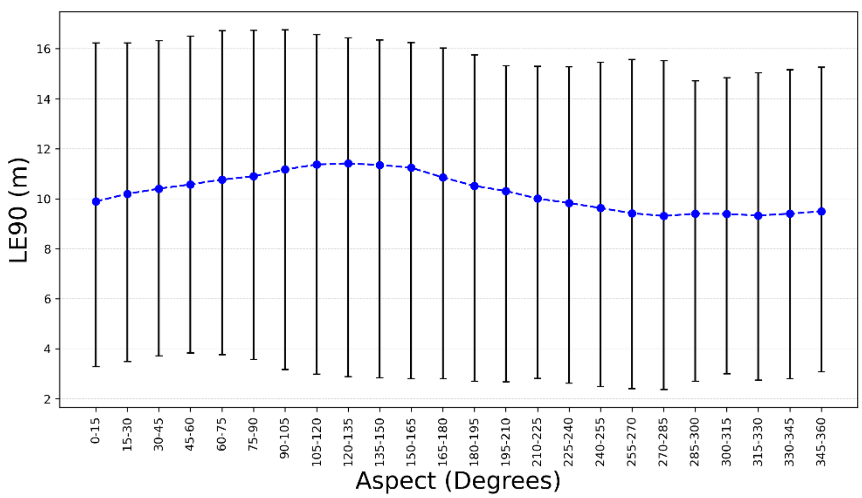

Figure 16. Vertical error (LE90) for the EarthDEM Mosaic Tile for each aspect group. The LE90 is calculated across land cover types is shown in blue. Error bars represent the LE90 values for each aspect group when only considering forest land cover (upper limits) and Barren land class (lower limits). Errors are provided in meters.

4.4.4. Senegal Evaluation Site Results

The vertical accuracy of the EarthDEM products was higher for the Senegal evaluation sites (Table 6). The EarthDEM Strip DSMs achieved a LE90 of 3.7 m, while the EarthDEM Mosaic Tile achieved a LE90 of 4.1 m. Both products struggled to capture vegetation across all sites (Figure 17). These errors resulted in a significant left tail to the Strip DSM (Figure 18) and Mosaic Tile (Figure 19) error distribution. Vegetation at these sites is dominated by trees less than 15 m tall with increasing stem density southward along a precipitation gradient. The higher accuracies compared to the CONUS evaluation sites is due to accurate elevation estimates of bare Earth in areas of low stem densities and small trees.

Table 6. EarthDEM Strip DSM and Mosaic Tile vertical errors across all Senegal evaluation sites. Errors are provided in meters.

Product	Minimum	Maximum	Median	Mean	StD	RMSE	LE90	Count
Strip DSM	-19.4	20.8	0.2	-0.2	2.3	2.3	3.7	1,408,142
Mosaic Tile	-18.6	15.3	0.15	-0.4	2.4	2.4	4.1	542,687

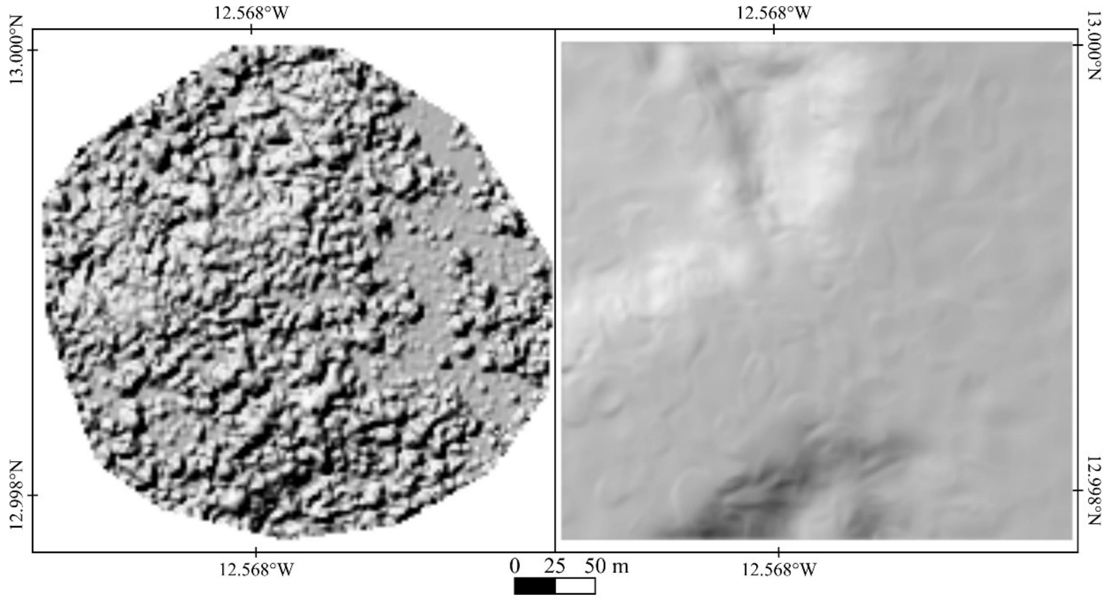

Figure 17. Shaded relief of the reference lidar DSM (left) and the EarthDEM Mosaic Tile (right) for a densely forested evaluation site in Senegal. The lidar DSM captures the variable tree heights and shapes, while the EarthDEM Mosaic Tile does not capture the same surface characteristics.

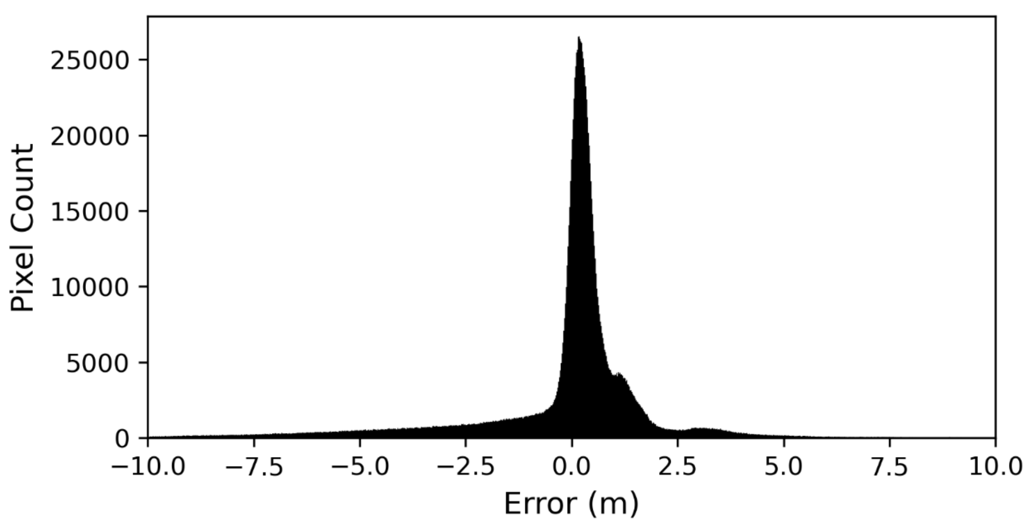

Figure 18. Histogram of the 59 EarthDEM Strip DSMs errors for all Senegal evaluation sites, showing a strong left tail in the error distribution. The left tail indicates the underestimation of surface elevations.

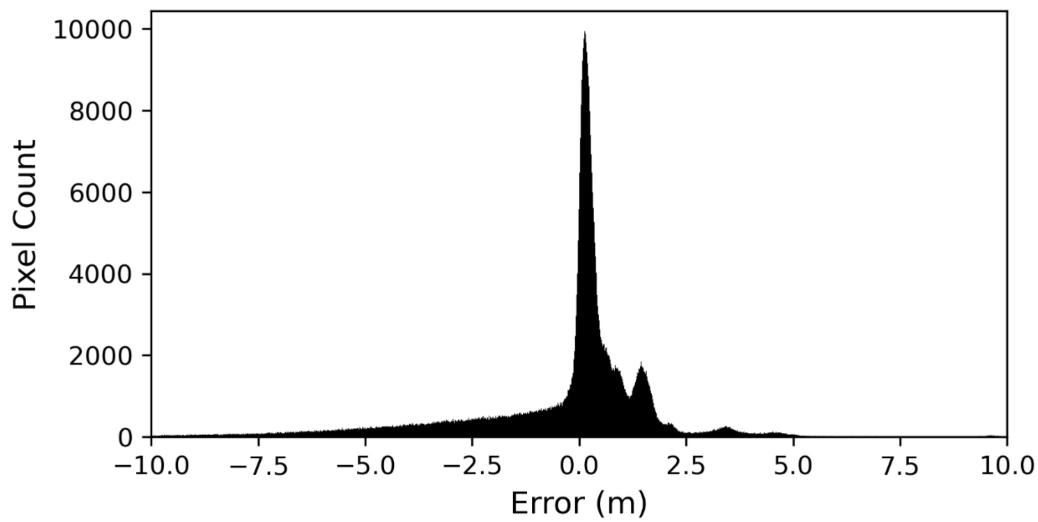

Figure 19. Histogram of the EarthDEM Mosaic Tile errors for all Senegal evaluation sites, showing a strong left tail in the error distribution. The left tail indicates the underestimation of surface elevations.

5. Detailed Validation - Horizontal

5.1 Validation Dataset

The evaluation dataset was graded as "Excellent" due to the high spatial resolution and high horizontal accuracy. The reference validation dataset used for the horizontal validation is the same dataset used for vertical accuracy, described in section 4.1.

5.2 Validation Methodology

Horizontal accuracy was assessed by calculating the horizontal offset between the EarthDEM products and the reference lidar DEM. Horizontal offsets were computed using the co-registration methods described in Nuth and Kääb (2011). Each EarthDEM Strip DSM and Mosaic Tile were co-registered to the corresponding reference lidar DEM (Appendices 3 and 4). Circular error at the 90^{th} percentile (CE90) and horizontal RMSE were computed using the calculated horizontal offsets. The horizontal offsets represent the relative error between the EarthDEM products and the more accurately geolocated lidar data. This approach was given a "Basic" grade. Horizontal differences were not calculated at the pixel-level, and it cannot be determined whether horizontal accuracy changes within individual EarthDEM Strip DSMs and Mosaic Tiles or across different surface characteristics.

5.3 Validation Completeness

The horizontal accuracy validation completeness was graded as "Basic". The methodology used to assess the horizontal accuracy of the EarthDEM products was limited to a single metric for each evaluation site. This methodology did not account for pixel-level horizontal errors or categorize horizontal errors using ancillary data (e.g., landcover type, slope, or aspect).

5.4 Validation Results Compliance

The geolocation of the EarthDEM Strip DSMs aligned well with the reference lidar DSM in the US and Senegal, with a horizontal RMSE of 0.5 m and a CE90 of 0.7 m (Figure 20, left). Co-registration results with the EarthDEM Mosaic Tiles indicate smaller shifts, with a horizontal RMSE of 0.3 m and a CE90 of 0.4 m (Figure 20, right). Overall, the horizontal accuracy of the EarthDEM products was assessed as "Excellent". The horizontal accuracy of the EarthDEM data relies on the geolocation accuracy of the imagery used to compute the DEMs, which varies by sensor (DigitalGlobe Inc., 2016), and the sensor RPC bias adjustment implemented during SETSM processing (Noh and Howat, 2018). Additional analysis would be needed to determine the pixel-level horizontal errors.

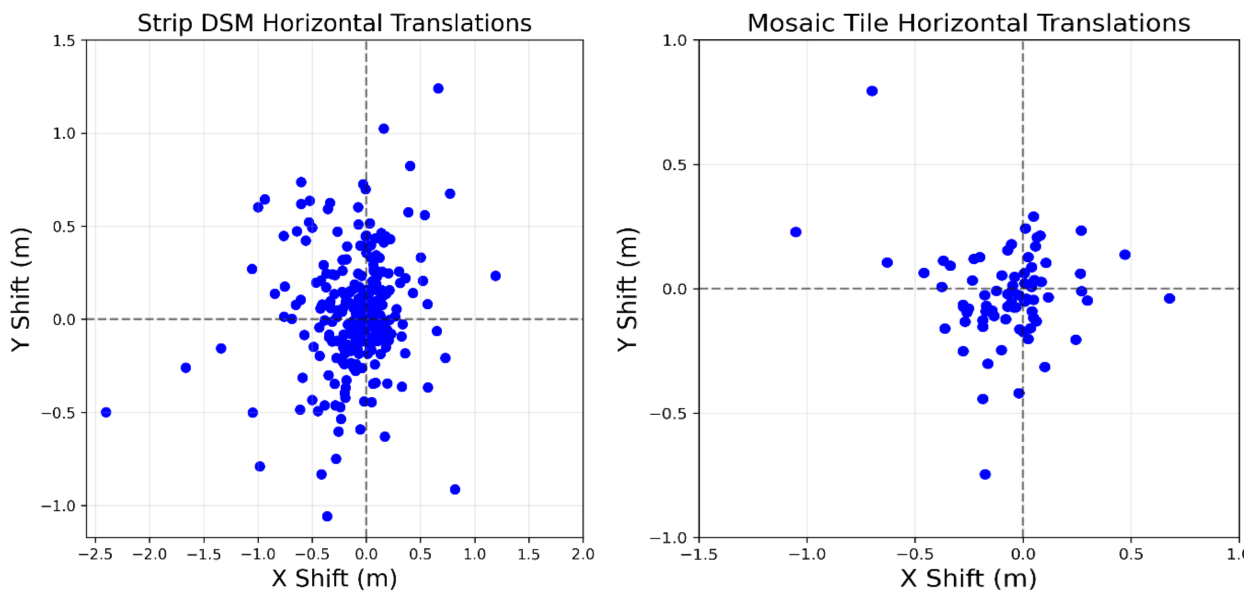

Figure 20. Horizontal translations (m) used to spatially align the EarthDEM Strip DSM (left) and Mosaic Tile (right) to the reference lidar DEM in the US and Senegal. Translation values were computed using the methods described in Nuth and Kääb (2011). A horizontal RMSE of 0.5 m and a CE90 of 0.7 m was calculated for the EarthDEM Strip DSM product. A horizontal RMSE of 0.3 m and a CE90 of 0.4 m was calculated for the EarthDEM Mosaic Tile product.

6. Summary

The vertical accuracy of the EarthDEM data was found to be variable by land cover type. The Polar Geospatial Center specifies vertical accuracies of 4 m RMSE before co-registration and 0.5 m RMSE after co-registration. RMSE values for the Strip DSMs at the US evaluation sites were higher than product specification for all NLCD land cover types. The overall RMSE value for the EarthDEM Strip DSM, when accounting for national land cover type proportions, was 5.6 m for US evaluation sites. This was reduced to 4.6 m RMSE when excluding Strip DSMs using the 'cloud_area_percent' metadata field. Additionally, the EarthDEM Strip DSM had an RMSE value of 2.3 m for the Senegal evaluation sites. The RMSE values for EarthDEM Mosaic Tile were higher than the product specification for all NLCD land cover types. The overall RMSE value for the EarthDEM Mosaic Tiles was 4.9 m for US evaluation sites and 2.4 m for the Senegal evaluation sites. Both EarthDEM products had poorer accuracy in forested cover types and trees outside of forests. Scattered trees, forests with low stem densities, and canopy gaps were frequently omitted across both products. Top of canopy elevations were less accurate for deciduous trees in the Mosaic Tiles due to the use of multi-season data.

The variable vertical accuracy by land cover type and the omission of trees in the EarthDEM Strip DSMs and Mosaic Tiles resulted in a "Basic" grade for the vertical accuracy. The horizontal accuracy of the EarthDEM data at the selected evaluation sites showed excellent agreement with the vendor specification of 4 m. This resulted in an "Excellent" grade for the horizontal accuracy.

Users should be cognizant that the vertical accuracy of the Strip DSMs is not consistent between Strip DSMs due to the variety of imaging and cloud cover conditions per acquisition. Although Strip DSMs are produced using Vantor stereoscopic image pairs with cloud cover less than 50%, not all Strip DSMs will be suitable for every application. It is strongly recommended that users filter the available Strip DSMs over their area of interest using the provided metadata fields to select the most appropriate data for their application. This includes filtering by acquisition date as the elevations of seasonal vegetation will be less accurate within Strip DSMs acquired during leaf-off periods. Users of these data should also be aware that the bitmask layer created by the PGC does not capture every erroneous elevation retrieval (see Table 2). It is recommended that users validate the accuracy of the bitmask for their desired Strip DSMs before using in their science application.

7. References

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Appendix 1. Evaluation Sites

Table A.1. Evaluation site name, area, and reference lidar information. Reference lidar were downloaded from the USGS 3D Elevation Program (3DEP) FTP site.

Evaluation Site Name	Area (km^2)	3DEP Reference Lidar Datasets	Survey Start Date	Survey End Date	Non-Vegetated Vertical Accuracy (95% CI) cm
AZ_Coconino_2019_B1_1	135	AZ_Coconino_B1_2019	7/16/2022	10/11/2022	11.3
AZ_Coconino_2019_B1_2	144	AZ_Coconino_B1_2019	7/16/2022	10/11/2022	11.3
AZ_MaricopaPinal_2020_B20_1	183	AZ_MaricopaPinal_1_2020	10/2/2020	12/18/2021	9.89
AZ_OrganPipeCactusNM_2020_B20_1	105	AZ_OrganPipeCactusNM_2020_B20	9/19/2020	9/26/2020	7.84
AZ_PimaCounty_2021_B21_1	822	AZ_PimaCo_2_2021	9/27/2021	11/17/2021	10.7
AZ_Yavapai_2021_B21_1	255	AZ_Yavapai_2_2021	9/13/2021	11/17/2021	8.3
CA_SierraNevada_B22_1	196	CA_SierraNevada_B22	6/4/2022	9/23/2022	9.74
CA_SierraNevada_B22_2	471	CA_SierraNevada_B22	6/4/2022	9/23/2022	9.74
CA_SierraNevada_B22_3	1692	CA_SierraNevada_B22	6/4/2022	9/23/2022	9.74
CA_YosemiteNP_2019_D19_1	241	CA_YosemiteNP_2019_D19	10/7/2019	10/23/2019	6.99
CA_YosemiteNP_2019_D19_2	240	CA_YosemiteNP_2019_D19	10/7/2019	10/23/2019	6.99
CA_YosemiteNP_2019_D19_3	209	CA_YosemiteNP_2019_D19	10/7/2019	10/23/2019	6.99
CO_CameronPeakWildfire_2021_D21_1	295	CO_CameronPeakWildfire_2021_D21	9/7/2021	9/22/2021	9.76
CO_CameronPeakWildfire_2021_D21_2	169	CO_CameronPeakWildfire_2021_D21	9/7/2021	9/22/2021	9.76
CO_EasternColorado_2018_A18_1	331	CO_EasternColorado_2018_A18	4/30/2018	7/25/2018	9.41
CO_Southwest_NRCS_2018_D18_1	281	CO_Southwest_NRCS_2018_D18	10/5/2018	11/3/2018	6.32
CO_WestCentral_2019_A19_1	256	CO_WestCentral_2019_A19	8/21/2019	9/19/2019	9.29
CO_WestCentral_2019_A19_2	375	CO_WestCentral_2019_A19	8/21/2019	9/19/2019	9.29
CO_WestCentral_2019_A19_3	229	CO_WestCentral_2019_A19	8/21/2019	9/19/2019	9.29
FL_Southwest_2018_D18_SUPPLEMENTAL_1	270	FL_Southwest_2018_D18_SUPPLEMENTAL	5/8/2018	10/29/2018	17.5
FL_Southwest_2018_D18_SUPPLEMENTAL_2	106	FL_Southwest_2018_D18_SUPPLEMENTAL	5/8/2018	10/29/2018	17.5
FL_Southwest_2018_D18_SUPPLEMENTAL_3	95	FL_Southwest_2018_D18_SUPPLEMENTAL	5/8/2018	10/29/2018	17.5
GA_Central_2019_B19_1	126	GA_Central_2019_B19	2/2/2020	3/28/2020	12.33
GA_Central_2019_B19_2	148	GA_Central_2019_B19	2/2/2020	3/28/2020	12.33
LA_Catahoula_Concordia_2017_D17_1	498	LA_Catahoula_Concordia_2017_D17	10/6/2019	11/21/2019	17.8
LA_Catahoula_Concordia_2017_D17_2	121	LA_Catahoula_Concordia_2017_D17	10/6/2019	11/21/2019	17.8
LA_Catahoula_Concordia_2017_D17_3	50	LA_Catahoula_Concordia_2017_D17	10/6/2019	11/21/2019	17.8
LA_NortheastDOTD_2017_C20_1	155	LA_NortheastDOTD_2017_C20	3/8/2018	9/3/2019	8.02
MN_SE_Driftless_2021_B21_1	1699	MN_SE_Driftless_2021_B21	4/25/2021	5/15/2022	6.94
NE_PostSpringFlood_OrthoLidar_2019_D19_1	113	NE_PostSpringFlood_OrthoLidar_2019_D19	6/1/2019	6/7/2019	10.4
NE_PostSpringFlood_OrthoLidar_2019_D19_2	160	NE_PostSpringFlood_OrthoLidar_2019_D19	6/1/2019	6/7/2019	10.4
NE_PostSpringFlood_OrthoLidar_2019_D19_3	388	NE_PostSpringFlood_OrthoLidar_2019_D19	6/1/2019	6/7/2019	10.4
NE_PostSpringFlood_OrthoLidar_2019_D19_4	175	NE_PostSpringFlood_OrthoLidar_2019_D19	6/1/2019	6/7/2019	10.4
NE_PostSpringFlood_OrthoLidar_2019_D19_5	355	NE_PostSpringFlood_OrthoLidar_2019_D19	6/1/2019	6/7/2019	10.4
NE_PostSpringFlood_OrthoLidar_2019_D19_6	315	NE_PostSpringFlood_OrthoLidar_2019_D19	6/1/2019	6/7/2019	10.4
NM_HermitsPeak_D23_1	199	NM_HermitsPeak_D23	9/17/2023	10/8/2023	15.6
NM_HermitsPeak_D23_2	209	NM_HermitsPeak_D23	9/17/2023	10/8/2023	15.6
OR_OLCMetro_2019_A19_1	699	OR_OLCMetro_2019_A19	5/8/2020	9/3/2020	7.31
OR_WesternWildfires_A22_1	101	OR_WesternWildfires_1_A22	6/2/2020	9/7/2022	7.3
OR_WesternWildfires_A22_2	398	OR_WesternWildfires_2_A22	5/7/2020	9/3/2020	9.8
SC_SavannahPeeDee_2019_B19_1	115	SC_SavannahPeeDee_2019_B19	1/20/2020	3/12/2020	8.7
SC_SavannahPeeDee_2019_B19_2	151	SC_SavannahPeeDee_2019_B19	1/20/2020	3/12/2020	8.7
TX_DesertMountains_2018_D19_1	435	TX_DesertMountains_2018_D19	9/11/2019	10/20/2019	11.99
TX_DesertMountains_2018_D19_2	152	TX_DesertMountains_2018_D19	9/11/2019	10/20/2019	11.99
TX_DesertMountains_2018_D19_3	130	TX_DesertMountains_2018_D19	9/11/2019	10/20/2019	11.99
UT_FEMA_FS_FlamingGorge_2020_B20_1	306	UT_FEMA_FS_FlamingGorge_2020_B20	8/8/2020	11/20/2020	14.31

UT_FEMA_FS_FlamingGorge_2020_B20_2	693	UT_FEMA_FS_FlamingGorge_2020_B20	8/8/2020	11/20/2020	14.31
UT_FEMA_FS_FlamingGorge_2020_B20_3	73	UT_FEMA_FS_FlamingGorge_2020_B20	8/8/2020	11/20/2020	14.31
UT_FEMA_FS_FlamingGorge_2020_B20_4	209	UT_FEMA_FS_FlamingGorge_2020_B20	8/8/2020	11/20/2020	14.31
UT_WestEast_B22_1	480	UT_WestEast_B22	7/23/2020	9/2/2020	9.18
WA_NorthCentral_2021_B21_1	241	WA_NorthCentral_2021_B21	8/25/2021	5/4/2022	7.23
WI_BrownRusk_2020_B20_1	136	WI_BrownRusk_2020_B20	5/7/2020	5/7/2020	6.66

Appendix 2. PDAL Lidar Processing Pipelines

Table A2.1. PDAL Pipeline for DSM Processing of USGS 3DEP Lidar.

```
{
  "pipeline":[
    {
      "type": "readers.las",
      "filename": "#"
    },
    {
      "type": "filters.reprojection",
      "in_srs": "#",
      "out_srs": "#"
    },
    {
      "type": "filters.assign",
      "value": ["Classification = 7 WHERE Classification == 18"]
    },
    {
      "type": "filters.hag_nn"
    },
    {
      "type": "filters.assign",
      "value": ["Classification = 7 WHERE HeightAboveGround > 125"]
    },
    {
      "type": "filters.outlier",
      "method": "radius",
      "radius": 0.5,
      "min_k": 4,
      "where": "((HeightAboveGround > 15) && (Classification == 1))"
    },
    {
      "type": "filters.range",
      "limits": "Classification[1:6],Classification[10:17]"
    },
    {
      "type": "writers.gdal",
      "filename": "#",
      "gdaldriver": "GTiff",
      "output_type": "max",
      "radius": 0.5,
      "resolution": "1.0",
      "dimension": "Z"
    }
]
}
```

Table A2.2. PDAL Pipeline code used for processing of Senegal UAS Lidar DSM.

```
{
  "pipeline":[
    {
      "type": "readers.las",
      "filename": "#"
    },
    {
      "type": "filters.reprojection",
      "in_srs": "#",
      "out_srs": "#"
    },
    {
      "type": "filters.smrf",
      "scalar": 1.25,
      "slope": 0.1,
      "threshold": 0.4,
      "window": 3.0
    },
    {
      "type": "filters.elm",
      "threshold": 2.0
    },
    {
      "type": "filters.hag_nn"
    },
    {
      "type": "filters.assign",
      "value": ["Classification = 7 WHERE HeightAboveGround > 30"]
    },
    {
      "type": "filters.outlier",
      "method": "radius",
      "radius": 1.0,
      "min_k": 4,
      "where": "((HeightAboveGround > 3) && (Classification != 7))"
    },
    {
      "type": "filters.range",
      "limits": "Classification[0:2]"
    },
    {
      "type": "writers.gdal",
      "filename": "#",
      "gdaldriver": "GTiff",
      "output_type": "max",
      "radius": 0.5,
      "resolution": "1",
      "dimension": "Z"
    }
]
}
```

Appendix 3. EarthDEM Strip DSM Co-Registration Results

Table A3. Horizontal (x, y) and vertical (z) translations required to align the EarthDEM Strip DSM to their respective reference lidar DSM. Translations were computed using the Nuth and Kaab (2011) co-registration methods.

DEM_ID	Reference Lidar Dataset ID	X Shift (m)	Y Shift (m)	Z Shift (m)
SETSM_s2s041_WV01_20200925_102001009B66C500_102001009D4C4D00_2m_seg1	AZ_Coconino_2019_B19	-0.11	-0.09	1.79
SETSM_s2s041_WV02_20201125_10300100B1425B00_10300100B2D47200_2m_seg1	AZ_Coconino_2019_B19	-0.11	0.19	2.75
SETSM_s2s041_WV02_20220425_10300100D206D200_10300100D24FB100_2m_seg1	AZ_Coconino_2019_B19	0.34	-0.03	2.54
SETSM_s2s041_WV01_20211229_10200100BD440400_10200100BDA71700_2m_seg1	AZ_Coconino_2019_B19	-0.10	-0.12	-0.79
SETSM_s2s041_WV03_20220720_1040010077389100_104001007AC4CD00_2m_seg1	AZ_Coconino_2019_B19	0.06	0.29	4.31
SETSM_s2s041_WV01_20200912_102001009C737B00_102001009E0BFD00_2m_seg1	AZ_Coconino_2019_B19	-0.09	-0.06	-3.27
SETSM_s2s041_WV01_20221209_10200100CE0F3700_10200100D0458900_2m_seg1	AZ_MaricopaPinal_2020_B20	-0.38	-0.01	-2.59
SETSM_s2s041_WV01_20221118_10200100CE047F00_10200100CE991800_2m_seg1	AZ_MaricopaPinal_2020_B20	-0.04	0.23	-0.36
SETSM_s2s041_WV03_20240229_104001008E874000_1040010090454400_2m_seg1	AZ_MaricopaPinal_2020_B20	0.19	-0.05	0.67
SETSM_s2s041_WV02_20201125_10300100B11E1000_10300100B1651C00_2m_seg1	AZ_OrganPipeCactusNM_2020_B20	0.50	0.33	1.75
SETSM_s2s041_WV02_20201114_10300100AF6D8600_10300100B1AEB800_2m_seg1	AZ_OrganPipeCactusNM_2020_B20	-0.34	0.63	0.53
SETSM_s2s041_WV02_20201103_10300100AD845700_10300100B004DF00_2m_seg1	AZ_OrganPipeCactusNM_2020_B20	-1.05	-0.50	-3.18
SETSM_s2s041_WV01_20211130_10200100BB0CAA00_10200100BB320500_2m_seg1	AZ_OrganPipeCactusNM_2020_B20	-0.76	0.02	0.53
SETSM_s2s041_WV02_20211215_10300100CA8ED000_10300100CABB1500_2m_seg1	AZ_OrganPipeCactusNM_2020_B20	0.26	0.02	-1.68
SETSM_s2s041_WV01_20210820_10200100B4075600_10200100B50D3900_2m_seg1	AZ_OrganPipeCactusNM_2020_B20	-0.04	-0.05	-0.41
SETSM_s2s041_WV01_20230224_10200100D435E400_10200100D58AFE00_2m_seg1	AZ_PimaCounty_2021_B21	-0.22	0.26	-0.64
SETSM_s2s041_WV01_20221127_10200100CE4C9700_10200100CFC4B700_2m_seg1	AZ_PimaCounty_2021_B21	-0.94	0.65	3.21
SETSM_s2s041_WV01_20220804_10200100C8DBD000_10200100C9049900_2m_seg1	AZ_PimaCounty_2021_B21	0.13	0.15	-1.10
SETSM_s2s041_WV01_20220907_10200100CB29DC00_10200100CB682800_2m_seg1	AZ_PimaCounty_2021_B21	0.13	0.02	1.40
SETSM_s2s041_WV01_20220605_10200100C58D1700_10200100C5D26500_2m_seg1	AZ_PimaCounty_2021_B21	-0.21	-0.15	1.25
SETSM_s2s041_GE01_20201117_105001002115AD00_105001002115AF00_2m_seg1	AZ_PimaCounty_2021_B21	0.16	0.41	-0.55
SETSM_s2s041_WV01_20200309_1020010094B52300_1020010094244600_2m_seg1	AZ_PimaCounty_2021_B21	0.01	0.16	0.28
SETSM_s2s041_GE01_20240204_1050010038BC7000_1050010038BC7200_2m_seg1	AZ_PimaCounty_2021_B21	0.21	0.16	0.40
SETSM_s2s041_GE01_20230209_105001003183D000_105001003183D200_2m_seg2	AZ_PimaCounty_2021_B21	-0.02	0.13	-1.68
SETSM_s2s041_GE01_20221208_10500100306BF600_10500100306BF800_2m_seg1	AZ_PimaCounty_2021_B21	0.03	0.52	-4.75
SETSM_s2s041_GE01_20210223_10500100229D1600_10500100229D1900_2m_seg2	AZ_PimaCounty_2021_B21	0.09	0.34	-4.93

SETSM_s2s041_GE01_20210105_1050010021BB5500_1050010021BB5700_2m_seg1	AZ_PimaCounty_2021_B21	0.66	1.24	-2.54
SETSM_s2s041_WV01_20211113_10200100BAB71800_10200100BABD1300_2m_seg1	AZ_PimaCounty_2021_B21	-0.43	-0.20	0.18
SETSM_s2s041_GE01_20231227_10500100382A1900_10500100382A1B00_2m_seg1	AZ_PimaCounty_2021_B21	0.39	0.57	-2.49
SETSM_s2s041_WV01_20241110_1020010106A36A00_1020010106DC1A00_2m_seg1	AZ_PimaCounty_2021_B21	-0.03	-0.02	-0.73
SETSM_s2s041_WV02_20200403_10300100A4823F00_10300100A5580500_2m_seg1	AZ_PimaCounty_2021_B21	-0.06	0.40	0.03
SETSM_s2s041_WV02_20190604_1030010092833500_1030010093B8C300_2m_seg1	AZ_PimaCounty_2021_B21	0.73	-0.21	-0.08
SETSM_s2s041_WV02_20221217_10300100DD95A900_10300100DE43DF00_2m_seg1	AZ_PimaCounty_2021_B21	-0.15	0.15	-1.90
SETSM_s2s041_WV02_20220916_10300100DA132900_10300100DA8CD900_2m_seg1	AZ_PimaCounty_2021_B21	-0.38	0.08	-0.83
SETSM_s2s041_WV02_20220916_10300100D962DF00_10300100DA2F0700_2m_seg1	AZ_PimaCounty_2021_B21	-0.22	0.15	-0.77
SETSM_s2s041_WV02_20201123_10300100ACA53600_10300100AE8A9200_2m_seg1	AZ_PimaCounty_2021_B21	-0.52	0.64	-1.10
SETSM_s2s041_WV03_20200330_104001005A2A7500_104001005AB09800_2m_seg1	AZ_PimaCounty_2021_B21	0.07	0.26	0.77
SETSM_s2s041_WV02_20201010_10300100AD917B00_10300100B0997F00_2m_seg1	AZ_PimaCounty_2021_B21	0.00	0.45	-2.99
SETSM_s2s041_WV02_20200908_10300100ABC9B600_10300100AD286800_2m_seg1	AZ_PimaCounty_2021_B21	-1.67	-0.26	3.12
SETSM_s2s041_GE01_20201217_10500100217D8200_10500100217D8500_2m_seg2	AZ_PimaCounty_2021_B21	0.52	0.21	0.49
SETSM_s2s041_WV02_20221219_10300100DE171600_10300100DF502100_2m_seg1	AZ_Yavapai_2021_B21	-0.19	0.09	-0.70
SETSM_s2s041_WV01_20221113_10200100CD122E00_10200100CDD40E00_2m_seg1	AZ_Yavapai_2021_B21	-0.10	-0.06	-2.28
SETSM_s2s041_WV02_20190504_103001009086AB00_103001008F167300_2m_seg1	CA_SierraNevada_B22	-0.07	0.51	2.03
SETSM_s2s041_WV02_20211013_10300100C71B8B00_10300100C734E000_2m_seg1	CA_SierraNevada_B22	-0.07	0.09	1.01
SETSM_s2s041_WV02_20200523_10300100A6AF6000_10300100A6B05D00_2m_seg1	CA_SierraNevada_B22	0.00	0.05	1.88
SETSM_s2s041_WV02_20191003_103001009B8E1400_103001009B30B000_2m_seg1	CA_SierraNevada_B22	-0.98	-0.79	2.70
SETSM_s2s041_WV02_20211010_10300100C64FF100_10300100C7948300_2m_seg1	CA_SierraNevada_B22	0.00	0.36	2.48
SETSM_s2s041_WV02_20190831_1030010098CFBA00_10300100979ABC00_2m_seg1	CA_SierraNevada_B22	-1.05	0.27	2.67
SETSM_s2s041_WV02_20190826_1030010099CAC500_1030010097C79100_2m_seg1	CA_SierraNevada_B22	-0.01	0.45	3.42
SETSM_s2s041_WV01_20220824_10200100C9828700_10200100CA9BCA00_2m_seg1	CA_SierraNevada_B22	0.57	0.08	0.23
SETSM_s2s041_WV03_20230711_1040010087445200_10400100881C0300_2m_seg1	CA_SierraNevada_B22	0.23	-0.08	2.46
SETSM_s2s041_WV03_20230603_10400100861AE700_1040010086C0CD00_2m_seg1	CA_SierraNevada_B22	0.17	-0.63	1.98
SETSM_s2s041_WV03_20191014_1040010053A9F300_10400100533E5F00_2m_seg1	CA_SierraNevada_B22	0.82	-0.91	-2.43
SETSM_s2s041_WV03_20190913_10400100525B9400_1040010052D56700_2m_seg1	CA_SierraNevada_B22	0.21	0.00	-1.99
SETSM_s2s041_WV03_20190913_10400100525B9400_1040010052D56700_2m_seg2	CA_SierraNevada_B22	0.15	-0.02	-0.90
SETSM_s2s041_WV03_20200421_1040010059C26100_104001005A49B400_2m_seg1	CA_SierraNevada_B22	0.09	0.05	0.71
SETSM_s2s041_WV03_20200510_104001005BB73700_104001005A2E2E00_2m_seg1	CA_SierraNevada_B22	0.08	-0.01	1.26
SETSM_s2s041_WV03_20220509_1040010075137700_1040010076B0EB00_2m_seg1	CA_SierraNevada_B22	0.07	-0.34	3.35

SETSM_s2s041_WV03_20200629_104001005B563900_104001005E35D600_2m_seg1	CA_SierraNevada_B22	0.10	0.15	2.01
SETSM_s2s041_WV03_20210620_104001006B284A00_104001006BC31900_2m_seg1	CA_SierraNevada_B22	0.16	1.02	2.12
SETSM_s2s041_WV03_20200629_104001005B563900_104001005E35D600_2m_seg2	CA_SierraNevada_B22	-0.07	-0.04	3.19
SETSM_s2s041_WV02_20190809_1030010099308F00_103001009614D300_2m_seg1	CA_SierraNevada_B22	-0.22	0.32	0.76
SETSM_s2s041_WV01_20180413_102001006FE8F700_1020010072950400_2m_seg1	CA_SierraNevada_B22	0.00	0.40	1.57
SETSM_s2s041_WV02_20210607_10300100C0D54600_10300100C0D5F100_2m_seg1	CA_SierraNevada_B22	-0.12	0.16	1.39
SETSM_s2s041_WV01_20210602_10200100B1C8C600_10200100B2478500_2m_seg1	CA_SierraNevada_B22	-0.18	0.32	2.03
SETSM_s2s041_WV01_20210602_10200100B1C8C600_10200100B2478500_2m_seg2	CA_SierraNevada_B22	0.17	-0.09	2.66
SETSM_s2s041_WV01_20210715_10200100B380F900_10200100B3876E00_2m_seg1	CA_SierraNevada_B22	-0.09	0.03	1.13
SETSM_s2s041_WV01_20210723_10200100B43D8700_10200100B4C3B800_2m_seg6	CA_SierraNevada_B22	-0.04	-0.26	-0.77
SETSM_s2s041_WV01_20210810_10200100B5010500_10200100B57C3400_2m_seg1	CA_SierraNevada_B22	-0.33	0.06	0.88
SETSM_s2s041_WV01_20210810_10200100B5A58900_10200100B5D5BA00_2m_seg1	CA_SierraNevada_B22	0.01	-0.01	1.03
SETSM_s2s041_WV01_20200609_10200100979CF300_10200100987B1E00_2m_seg1	CA_SierraNevada_B22	0.18	-0.15	2.44
SETSM_s2s041_WV01_20180422_10200100712A3500_102001006E5D3F00_2m_seg1	CA_SierraNevada_B22	0.00	0.04	0.30
SETSM_s2s041_WV01_20210827_10200100B5803A00_10200100B634DF00_2m_seg1	CA_SierraNevada_B22	0.05	0.21	-1.29
SETSM_s2s041_WV01_20180413_1020010070BBAA00_1020010072D6B900_2m_seg1	CA_SierraNevada_B22	0.06	-0.02	1.78
SETSM_s2s041_WV02_20190820_1030010096A2F100_1030010098B59100_2m_seg1	CA_YosemiteNP_2019_D19	-0.18	0.39	1.74
SETSM_s2s041_WV02_20191008_103001009B6A7600_103001009CA6FB00_2m_seg1	CA_YosemiteNP_2019_D19	0.01	0.05	-1.28
SETSM_s2s041_WV02_20190914_10300100994CDD00_1030010099AE6300_2m_seg1	CA_YosemiteNP_2019_D19	-0.04	-0.12	-0.22
SETSM_s2s041_WV02_20190922_103001009B2DDB00_103001009969B000_2m_seg1	CA_YosemiteNP_2019_D19	0.28	0.05	0.93
SETSM_s2s041_WV01_20190820_10200100890DBD00_102001008B055F00_2m_seg1	CA_YosemiteNP_2019_D19	-0.69	0.00	2.94
SETSM_s2s041_WV01_20191006_102001008E543300_102001008EE06B00_2m_seg1	CA_YosemiteNP_2019_D19	0.36	-0.18	2.76
SETSM_s2s041_WV01_20190927_102001008B4E1D00_102001008ECD8600_2m_seg1	CA_YosemiteNP_2019_D19	0.13	-0.19	-0.29
SETSM_s2s041_WV02_20191008_103001009D4A4600_103001009B0F1300_2m_seg1	CA_YosemiteNP_2019_D19	-0.09	-0.01	1.57
SETSM_s2s041_WV02_20240806_103001010292C300_1030010102AEE600_2m_seg1	CA_YosemiteNP_2019_D19	-0.15	0.15	-0.39
SETSM_s2s041_WV02_20191019_103001009C19F400_103001009B383D00_2m_seg1	CA_YosemiteNP_2019_D19	0.30	0.26	-0.52
SETSM_s2s041_WV02_20190730_10300100994D8300_10300100960FFB00_2m_seg1	CA_YosemiteNP_2019_D19	0.06	-0.35	-0.75
SETSM_s2s041_WV02_20200426_10300100A467D700_10300100A5334C00_2m_seg1	CA_YosemiteNP_2019_D19	-1.00	0.60	-0.87
SETSM_s2s041_WV02_20200722_10300100AB558400_10300100AB838D00_2m_seg1	CA_YosemiteNP_2019_D19	0.77	0.68	3.33
SETSM_s2s041_WV02_20200802_10300100AB402300_10300100AB527600_2m_seg1	CA_YosemiteNP_2019_D19	0.43	0.14	4.95
SETSM_s2s041_WV01_20180508_102001007549DC00_10200100742C0D00_2m_seg1	CA_YosemiteNP_2019_D19	0.09	0.02	0.78
SETSM_s2s041_WV01_20180508_1020010073974300_1020010073340700_2m_seg1	CA_YosemiteNP_2019_D19	0.12	0.33	-1.88

SETSM_s2s041_WV01_20180421_1020010071CB2800_1020010072C5B500_2m_seg1	CA_YosemiteNP_2019_D19	0.01	0.02	-0.89
SETSM_s2s041_WV02_20191014_103001009B2CDB00_103001009CC2B200_2m_seg1	CA_YosemiteNP_2019_D19	-0.39	-0.46	3.31
SETSM_s2s041_WV01_20211030_10200100B8212600_10200100BA4CA300_2m_seg1	CA_YosemiteNP_2019_D19	-0.16	0.09	3.73
SETSM_s2s041_WV01_20210925_10200100B8880F00_10200100B8B02F00_2m_seg2	CA_YosemiteNP_2019_D19	0.05	-0.16	-1.74
SETSM_s2s041_WV02_20190520_1030010091CED100_10300100933C3800_2m_seg1	CA_YosemiteNP_2019_D19	0.05	-0.44	1.65
SETSM_s2s041_WV01_20220417_10200100C3B0E200_10200100C3BFEB00_2m_seg1	CA_YosemiteNP_2019_D19	-0.31	0.24	-1.38
SETSM_s2s041_WV01_20210827_10200100B5DF9000_10200100B6D18100_2m_seg1	CA_YosemiteNP_2019_D19	0.03	0.06	-1.91
SETSM_s2s041_WV03_20220521_10400100757B9000_1040010077C26D00_2m_seg1	CA_YosemiteNP_2019_D19	0.31	0.20	4.42
SETSM_s2s041_WV01_20200506_1020010092605100_102001009707B400_2m_seg1	CA_YosemiteNP_2019_D19	-0.13	-0.15	0.43
SETSM_s2s041_WV03_20200618_104001005D21E500_104001005DAD5300_2m_seg1	CA_YosemiteNP_2019_D19	0.54	0.56	2.62
SETSM_s2s041_WV01_20240810_10200100F61FE700_10200100F6B90A00_2m_seg1	CA_YosemiteNP_2019_D19	0.03	0.01	0.22
SETSM_s2s041_WV03_20200617_104001005C0D4900_104001005CC03900_2m_seg1	CA_YosemiteNP_2019_D19	0.22	0.43	2.66
SETSM_s2s041_WV03_20200610_104001005C03FC00_104001005D0BBD00_2m_seg1	CA_YosemiteNP_2019_D19	-0.09	0.00	4.30
SETSM_s2s041_WV01_20201015_102001009E2B6D00_102001009F94D500_2m_seg1	CA_YosemiteNP_2019_D19	0.06	-0.04	3.44
SETSM_s2s041_WV01_20191031_102001008A825400_102001008FC90300_2m_seg1	CA_YosemiteNP_2019_D19	0.11	-0.04	-0.27
SETSM_s2s041_WV03_20191021_1040010053CBDD00_104001005248DF00_2m_seg2	CA_YosemiteNP_2019_D19	0.18	0.14	-0.51
SETSM_s2s041_WV02_20190504_1030010092766500_103001009144EA00_2m_seg1	CA_YosemiteNP_2019_D19	0.40	0.82	2.31
SETSM_s2s041_WV02_20190407_1030010091CA4000_103001008F8D8700_2m_seg1	CA_YosemiteNP_2019_D19	0.14	-0.03	1.07
SETSM_s2s041_WV03_20200428_10400100580DFF00_1040010059143F00_2m_seg1	CA_YosemiteNP_2019_D19	0.04	0.33	0.55
SETSM_s2s041_WV03_20200601_104001005B717200_104001005D787100_2m_seg1	CO_CameronPeakWildfire_2021_D21	-0.01	0.08	0.28
SETSM_s2s041_WV03_20190601_104001004CD2BB00_104001004DD54900_2m_seg1	CO_CameronPeakWildfire_2021_D21	0.18	0.45	4.10
SETSM_s2s041_WV01_20210825_10200100B5E00900_10200100B6EBAA00_2m_seg1	CO_CameronPeakWildfire_2021_D21	-0.42	0.21	-0.34
SETSM_s2s041_WV01_20210825_10200100B508B000_10200100B6B19100_2m_seg1	CO_CameronPeakWildfire_2021_D21	-0.37	0.25	1.19
SETSM_s2s041_WV01_20210816_10200100B5E94D00_10200100B63E0300_2m_seg1	CO_CameronPeakWildfire_2021_D21	-0.17	-0.03	-0.91
SETSM_s2s041_WV01_20190512_1020010086AFBC00_1020010085932B00_2m_seg2	CO_CameronPeakWildfire_2021_D21	0.09	0.19	1.41
SETSM_s2s041_WV01_20200521_102001009A768800_102001009937AF00_2m_seg1	CO_CameronPeakWildfire_2021_D21	-0.06	-0.08	1.57
SETSM_s2s041_WV01_20210804_10200100B4707D00_10200100B4A80000_2m_seg1	CO_CameronPeakWildfire_2021_D21	0.02	0.14	1.84
SETSM_s2s041_WV01_20180511_1020010073E4F100_10200100759C5C00_2m_seg1	CO_Southwest_NRCS_2018_D18	0.09	-0.03	1.64
SETSM_s2s041_WV02_20220511_10300100D2415D00_10300100D2544B00_2m_seg1	CO_Southwest_NRCS_2018_D18	-0.14	-0.17	3.09
SETSM_s2s041_WV01_20181020_102001007E0CBC00_102001007CC3F300_2m_seg1	CO_Southwest_NRCS_2018_D18	-0.29	-0.46	0.53
SETSM_s2s041_WV03_20210604_1040010068150000_104001006A8CC900_2m_seg1	CO_Southwest_NRCS_2018_D18	0.36	0.22	3.38
SETSM_s2s041_WV01_20180630_10200100752F0B00_10200100771D3C00_2m_seg1	CO_Southwest_NRCS_2018_D18	-0.07	0.60	2.99

SETSM_s2s041_WV03_20210604_10400100672E9700_1040010069247100_2m_seg2	CO_Southwest_NRCS_2018_D18	0.01	0.06	2.79
SETSM_s2s041_WV01_20190930_102001008EC5AC00_102001008BE9BB00_2m_seg1	CO_WestCentral_2019_A19	0.11	0.44	3.44
SETSM_s2s041_WV01_20190930_1020010088168700_102001008BD60800_2m_seg1	CO_WestCentral_2019_A19	0.02	0.04	1.38
SETSM_s2s041_WV02_20190628_103001009513D600_1030010094C68100_2m_seg1	CO_WestCentral_2019_A19	0.57	-0.36	-0.82
SETSM_s2s041_WV02_20230210_10300100E106FD00_10300100E2C20400_2m_seg7	FL_Southwest_2018_D18_SUPPLEMENTAL	-0.12	-0.02	1.61
SETSM_s2s041_WV02_20221030_10300100DD444B00_10300100DDB90D00_2m_seg1	FL_Southwest_2018_D18_SUPPLEMENTAL	0.10	-0.12	-0.72
SETSM_s2s041_WV02_20200223_10300100A2082F00_10300100A17FFE00_2m_seg1	FL_Southwest_2018_D18_SUPPLEMENTAL	-0.07	-0.11	-1.32
SETSM_s2s041_WV01_20230221_10200100D4604D00_10200100D5309700_2m_seg5	FL_Southwest_2018_D18_SUPPLEMENTAL	-0.08	-0.16	-1.03
SETSM_s2s041_WV02_20180326_1030010079C9A200_1030010079723E00_2m_seg4	FL_Southwest_2018_D18_SUPPLEMENTAL	-0.10	-0.07	-3.07
SETSM_s2s041_WV01_20200227_1020010091EB9600_10200100909A8A00_2m_seg2	FL_Southwest_2018_D18_SUPPLEMENTAL	-0.01	-0.05	2.79
SETSM_s2s041_WV02_20180326_1030010079C9A200_1030010079723E00_2m_seg2	FL_Southwest_2018_D18_SUPPLEMENTAL	-0.08	-0.03	-0.87
SETSM_s2s041_WV02_20180318_1030010079BA3900_1030010079A8AE00_2m_seg5	FL_Southwest_2018_D18_SUPPLEMENTAL	0.02	0.16	1.53
SETSM_s2s041_WV01_20210318_10200100A7291F00_10200100A7B2B600_2m_seg1	LA_Catahoula_Concordia_2017_D17	-0.17	-0.14	0.03
SETSM_s2s041_WV01_20241002_10200101030B9100_1020010104932C00_2m_seg1	LA_Catahoula_Concordia_2017_D17	0.09	0.05	1.08
SETSM_s2s041_WV03_20211123_104001006FC11D00_1040010071971E00_2m_seg1	LA_Catahoula_Concordia_2017_D17	0.00	-0.05	0.05
SETSM_s2s041_WV02_20200424_10300100A6957800_10300100A5B3A000_2m_seg1	LA_Catahoula_Concordia_2017_D17	-0.21	0.14	-0.70
SETSM_s2s041_WV02_20220915_10300100DA053B00_10300100DB77DE00_2m_seg1	LA_Catahoula_Concordia_2017_D17	0.09	-0.08	0.00
SETSM_s2s041_WV02_20200811_10300100A9D3FD00_10300100AB32C800_2m_seg1	LA_NortheastDOTD_2017_C20	0.01	-0.01	-0.25
SETSM_s2s041_WV02_20220508_10300100D2400800_10300100D2D59500_2m_seg1	LA_NortheastDOTD_2017_C20	0.12	-0.08	-0.84
SETSM_s2s041_WV03_20200611_104001005C885D00_104001005B457A00_2m_seg1	MN_SE_Driftless_2021_B21	-0.22	-0.12	-2.52
SETSM_s2s041_WV03_20210828_104001006D4DD900_104001006DBE4C00_2m_seg1	NE_PostSpringFlood_OrthoLidar_2019_D19	0.10	-0.10	3.37
SETSM_s2s041_WV02_20241031_1030010107513C00_1030010107D15600_2m_seg1	NE_PostSpringFlood_OrthoLidar_2019_D19	0.33	-0.36	-2.25
SETSM_s2s041_WV02_20241025_1030010107682700_103001010778DC00_2m_seg1	NE_PostSpringFlood_OrthoLidar_2019_D19	-0.29	-0.35	-3.35
SETSM_s2s041_WV02_20241014_1030010106CDB100_10300101072E3B00_2m_seg1	NE_PostSpringFlood_OrthoLidar_2019_D19	0.03	0.02	-0.76
SETSM_s2s041_WV03_20210828_104001006C682B00_104001006F550E00_2m_seg1	NE_PostSpringFlood_OrthoLidar_2019_D19	0.14	0.16	2.17
SETSM_s2s041_WV02_20231006_10300100EE3DF100_10300100EF135600_2m_seg1	NE_PostSpringFlood_OrthoLidar_2019_D19	-0.19	0.12	-1.30
SETSM_s2s041_WV02_20190602_10300100918ECA00_1030010092A3FC00_2m_seg1	NE_PostSpringFlood_OrthoLidar_2019_D19	0.65	-0.06	2.43
SETSM_s2s041_WV01_20200504_102001009223F300_1020010097B2E900_2m_seg1	NM_HermitsPeak_D23	-0.04	0.10	0.49
SETSM_s2s041_WV01_20200504_1020010095D46A00_10200100993CFD00_2m_seg1	NM_HermitsPeak_D23	-0.07	0.11	0.57
SETSM_s2s041_WV01_20210907_10200100B602E500_10200100B65F0600_2m_seg1	OR_OLCMetro_2019_A19	-0.35	-0.30	-3.69
SETSM_s2s041_WV01_20200509_1020010096B96B00_1020010097D6EB00_2m_seg2	OR_OLCMetro_2019_A19	0.09	0.10	-1.14
SETSM_s2s041_WV02_20190626_1030010093730800_1030010095840A00_2m_seg1	OR_OLCMetro_2019_A19	0.15	0.25	-1.69

SETSM_s2s041_WV03_20230727_10400100873C7F00_104001008A4D3900_2m_seg1	OR_WesternWildfires_A22	-0.08	0.25	2.74
SETSM_s2s041_WV01_20230715_10200100DCE4CA00_10200100DD6DA000_2m_seg1	OR_WesternWildfires_A22	-0.41	0.08	0.82
SETSM_s2s041_WV01_20230715_10200100DC02DA00_10200100DC5ABC00_2m_seg1	OR_WesternWildfires_A22	-0.32	-0.01	0.81
SETSM_s2s041_WV01_20210718_10200100B424F900_10200100B447D900_2m_seg8	OR_WesternWildfires_A22	-0.65	0.08	0.09
SETSM_s2s041_WV01_20201108_102001009D97D800_102001009E06F300_2m_seg1	OR_WesternWildfires_A22	-0.50	-0.43	1.71
SETSM_s2s041_WV02_20230922_10300100ED2E6900_10300100ED46D800_2m_seg1	OR_WesternWildfires_A22	0.00	0.03	-0.75
SETSM_s2s041_WV01_20201009_102001009BCAE200_102001009C478800_2m_seg1	OR_WesternWildfires_A22	-0.06	-0.59	-4.09
SETSM_s2s041_WV02_20210902_10300100C5079900_10300100C57B4B00_2m_seg1	OR_WesternWildfires_A22	-0.22	0.04	1.66
SETSM_s2s041_WV01_20200819_1020010098D41D00_102001009E487300_2m_seg1	OR_WesternWildfires_A22	-0.37	0.17	-0.45
SETSM_s2s041_WV01_20211020_10200100B940AC00_10200100B968F300_2m_seg1	SC_SavannahPeeDee_2019_B19	-0.49	-0.15	-4.26
SETSM_s2s041_WV01_20210929_10200100B80B2D00_10200100B823F500_2m_seg1	SC_SavannahPeeDee_2019_B19	0.14	0.46	-2.81
SETSM_s2s041_WV01_20220313_10200100BF161C00_10200100C0B99600_2m_seg1	SC_SavannahPeeDee_2019_B19	-0.20	-0.40	-3.06
SETSM_s2s041_WV01_20201014_102001009F6D0800_102001009FBD2D00_2m_seg1	SC_SavannahPeeDee_2019_B19	-0.04	0.16	-1.18
SETSM_s2s041_WV01_20200409_10200100997ADF00_1020010096152000_2m_seg4	SC_SavannahPeeDee_2019_B19	-0.04	-0.05	-0.44
SETSM_s2s041_WV01_20200222_102001009145CE00_10200100949FD800_2m_seg1	SC_SavannahPeeDee_2019_B19	0.08	-0.12	-2.60
SETSM_s2s041_WV01_20211127_10200100BB20B900_10200100BB3C9000_2m_seg1	SC_SavannahPeeDee_2019_B19	-0.32	-0.12	-5.30
SETSM_s2s041_WV02_20210516_10300100BE2A3200_10300100BE4ABA00_2m_seg7	SC_SavannahPeeDee_2019_B19	0.33	-0.09	-2.28
SETSM_s2s041_WV01_20230417_10200100D5CD2300_10200100D8C1EE00_2m_seg2	SC_SavannahPeeDee_2019_B19	-0.12	0.06	-1.80
SETSM_s2s041_WV01_20230908_10200100DE415A00_10200100DF954500_2m_seg1	SC_SavannahPeeDee_2019_B19	-0.10	-0.24	-0.86
SETSM_s2s041_WV02_20230610_10300100E7367C00_10300100E7D0EC00_2m_seg1	SC_SavannahPeeDee_2019_B19	-0.05	0.03	-2.33
SETSM_s2s041_WV01_20240412_10200100EC007500_10200100ED323A00_2m_seg4	SC_SavannahPeeDee_2019_B19	-0.14	-0.23	-1.80
SETSM_s2s041_WV02_20240405_10300100F842F400_10300100F9346200_2m_seg3	SC_SavannahPeeDee_2019_B19	0.05	-0.12	-4.30
SETSM_s2s041_WV02_20240405_10300100F87E2700_10300100F892F700_2m_seg2	SC_SavannahPeeDee_2019_B19	-0.10	-0.28	-3.92
SETSM_s2s041_WV02_20220629_10300100D57EFD00_10300100D5956000_2m_seg1	Senegal_230220_093037	-0.61	0.12	-0.89
SETSM_s2s041_WV02_20200621_10300100AA93EB00_10300100A99A9D00_2m_seg1	Senegal_230220_093037	-0.23	0.02	7.74
SETSM_s2s041_WV01_20201108_102001009E00A400_10200100A19BA600_2m_seg1	Senegal_230220_093037	-0.60	0.06	3.36
SETSM_s2s041_WV01_20191121_102001008EE64700_102001008F75C500_2m_seg1	Senegal_230220_093037	-0.55	-0.20	4.61
SETSM_s2s041_WV01_20170316_102001005E02ED00_102001005ADD0E00_2m_seg1	Senegal_230220_093037	0.28	-0.27	5.13
SETSM_s2s041_WV01_20170609_1020010063479100_1020010062DF7700_2m_seg1	Senegal_230220_160421	-0.76	0.33	3.56
SETSM_s2s041_WV01_20161125_102001005899C900_1020010055B64200_2m_seg1	Senegal_230220_160421	-0.32	0.04	0.51
SETSM_s2s041_WV01_20200409_10200100963AD600_10200100921C8E00_2m_seg1	Senegal_230220_160421	-0.18	0.37	6.73
SETSM_s2s041_WV02_20140322_103001002EB14200_103001002E895200_2m_seg1	Senegal_230220_160421	-0.14	0.37	9.04

SETSM_s2s041_WV01_20211206_10200100BA1E8900_10200100BC0B1C00_2m_seg1	Senegal_230220_160421	-0.77	0.02	2.62
SETSM_s2s041_WV01_20230417_10200100D507BC00_10200100D7DFA000_2m_seg1	Senegal_230221_131222	0.06	-0.07	9.44
SETSM_s2s041_WV02_20140410_103001003055EA00_103001002F58B000_2m_seg1	Senegal_230221_131222	-0.01	0.00	13.87
SETSM_s2s041_WV01_20170107_102001005B946300_102001005D003700_2m_seg1	Senegal_230221_131222	-0.43	-0.36	3.22
SETSM_s2s041_WV02_20140322_103001002EB14200_103001002E895200_2m_seg2	Senegal_230221_131222	-0.13	-0.04	12.85
SETSM_s2s041_WV02_20140322_103001002EB14200_103001002E895200_2m_seg3	Senegal_230222_161802	0.16	-0.11	6.18
SETSM_s2s041_WV01_20170107_102001005B946300_102001005D003700_2m_seg2	Senegal_230222_161802	0.07	-0.09	1.84
SETSM_s2s041_WV01_20170124_102001005B820000_102001005909C900_2m_seg1	Senegal_230223_092637	0.21	0.01	4.03
SETSM_s2s041_WV03_20170125_1040010027C91E00_1040010026BAFE00_2m_seg1	Senegal_230223_105654	-0.34	0.11	0.82
SETSM_s2s041_WV02_20221209_10300100DE20FF00_10300100DF3CA700_2m_seg1	Senegal_230224_114919	-0.16	-0.24	1.75
SETSM_s2s041_WV02_20221209_10300100DE20FF00_10300100DF3CA700_2m_seg2	Senegal_230224_145307	-0.46	0.04	1.22
SETSM_s2s041_WV03_20161031_1040010024B57300_1040010024CECF00_2m_seg1	Senegal_230224_145307	-0.95	0.08	2.94
SETSM_s2s041_WV02_20200511_10300100A322B000_10300100A6156800_2m_seg1	Senegal_230224_145307	-0.32	0.08	1.37
SETSM_s2s041_WV03_20150628_104001000D88ED00_104001000D335600_2m_seg1	Senegal_230225_085946	-0.26	0.00	3.09
SETSM_s2s041_WV01_20201221_10200100A3574700_10200100A36CCB00_2m_seg1	Senegal_230225_085946	-0.09	-0.04	1.05
SETSM_s2s041_WV01_20240520_10200100EE470D00_10200100F06B1600_2m_seg1	Senegal_230225_095401	-0.31	0.04	3.14
SETSM_s2s041_WV01_20220104_10200100BCC4E900_10200100BD0C0A00_2m_seg1	Senegal_230225_095401	-0.30	0.05	-0.62
SETSM_s2s041_WV01_20241107_1020010105729200_1020010105E02100_2m_seg1	Senegal_230225_153626	-0.35	0.28	1.58
SETSM_s2s041_WV01_20220412_10200100C24DCE00_10200100C3B5E500_2m_seg1	Senegal_230225_172547	-0.03	0.16	1.42
SETSM_s2s041_WV03_20220224_1040010073550000_1040010073A53300_2m_seg1	Senegal_230225_172547	-0.18	0.20	1.09
SETSM_s2s041_WV01_20240912_10200101031D9A00_102001010392B000_2m_seg1	Senegal_230225_172547	0.22	1.00	-2.34
SETSM_s2s041_WV01_20190318_1020010083435A00_1020010082EAFC00_2m_seg1	Senegal_230225_172547	-0.23	0.54	-1.47
SETSM_s2s041_WV02_20241029_10300101074AC300_1030010108BA7700_2m_seg1	Senegal_230225_172547	-0.27	0.26	-0.80
SETSM_s2s041_WV01_20190810_102001008B91C100_102001008D17CB00_2m_seg1	Senegal_230226_074329	-0.38	0.30	1.46
SETSM_s2s041_WV01_20170320_102001005FEB1B00_102001005B3D8800_2m_seg1	Senegal_230226_074329	-0.20	0.26	-0.58
SETSM_s2s041_WV01_20190930_102001008B3D3400_102001008CA93800_2m_seg1	Senegal_230226_074329	-0.69	0.40	-3.60
SETSM_s2s041_WV01_20210316_10200100A45DFA00_10200100A64CDD00_2m_seg1	Senegal_230226_074329	-0.76	0.52	-2.36
SETSM_s2s041_WV01_20210627_10200100B39D9E00_10200100B3C17E00_2m_seg1	Senegal_230226_074329	-0.01	0.16	1.24
SETSM_s2s041_WV01_20210718_10200100B3440C00_10200100B4A09500_2m_seg1	Senegal_230226_101124	-0.26	-0.43	-0.06
SETSM_s2s041_WV01_20191203_102001008E634700_1020010090E1D100_2m_seg1	Senegal_230226_101124	-0.22	-0.33	-0.75
SETSM_s2s041_WV01_20170324_102001005F615A00_102001005E1FDD00_2m_seg1	Senegal_230226_101124	-0.50	-0.72	-2.51
SETSM_s2s041_WV03_20150216_1040010007907900_10400100089F9200_2m_seg1	Senegal_230226_101124	-0.24	-0.16	1.54

SETSM_s2s041_WV01_20210705_10200100B2CA9A00_10200100B39CD200_2m_seg1	Senegal_230226_101124	-0.22	-0.46	-1.52
SETSM_s2s041_WV03_20241105_104001009D0D6200_104001009E5FD700_2m_seg1	Senegal_230226_101124	-0.29	-0.38	0.47
SETSM_s2s041_WV01_20170119_102001005C43ED00_102001005BA95800_2m_seg1	Senegal_230226_101124	-0.24	-0.19	0.38
SETSM_s2s041_WV01_20170307_102001005EB14F00_102001005DDFDC00_2m_seg1	Senegal_230226_113446	-0.19	-0.45	3.23
SETSM_s2s041_WV01_20240507_10200100ED0DFB00_10200100EFB53900_2m_seg1	Senegal_230226_113446	-0.09	-0.18	1.82
SETSM_s2s041_WV01_20241025_1020010105C92600_102001010618EF00_2m_seg1	Senegal_230226_113446	0.11	-0.59	3.80
SETSM_s2s041_WV03_20240912_104001009BB65800_104001009D4E5A00_2m_seg1	Senegal_230226_113446	-0.68	-0.04	4.56
SETSM_s2s041_WV01_20190917_102001008ECBBB00_102001008C80A800_2m_seg1	Senegal_230226_113446	-0.97	-0.52	5.12
SETSM_s2s041_WV01_20190913_102001008D295E00_102001008A3CE500_2m_seg1	Senegal_230226_113446	-0.17	-0.13	-0.35
SETSM_s2s041_WV01_20210226_10200100A3563C00_10200100A69EC700_2m_seg1	Senegal_230227_121455	-0.67	0.94	-5.15
SETSM_s2s041_WV02_20240305_10300100F7C73300_10300100F8C51300_2m_seg2	Senegal_230227_121455	-0.70	0.20	-0.06
SETSM_s2s041_WV01_20210701_10200100B3C32D00_10200100B462CA00_2m_seg1	Senegal_230227_121455	-0.27	-0.09	-3.16
SETSM_s2s041_WV01_20190508_1020010086A06D00_1020010084C03400_2m_seg1	Senegal_230227_121455	-0.91	0.41	-3.81
SETSM_s2s041_WV01_20170901_1020010066C90200_1020010067575500_2m_seg2	Senegal_230227_121455	-0.32	0.09	-1.05
SETSM_s2s041_WV03_20210204_10400100657E0400_1040010065BA6100_2m_seg1	Senegal_230227_121455	-1.07	0.75	-3.73
SETSM_s2s041_WV01_20240208_10200100E7E7C300_10200100E9E6D000_2m_seg1	Senegal_230227_131905	0.44	0.32	7.03
SETSM_s2s041_WV01_20201116_10200100A2998400_10200100A2B44F00_2m_seg1	Senegal_230227_131905	0.03	0.06	0.48
SETSM_s2s041_WV01_20150416_102001003E78BB00_102001003B651500_2m_seg1	Senegal_230227_131905	-0.17	0.61	-0.76
SETSM_s2s041_WV01_20170901_1020010066C90200_1020010067575500_2m_seg1	Senegal_230227_160049	0.13	-0.17	2.48
SETSM_s2s041_WV02_20240305_10300100F7C73300_10300100F8C51300_2m_seg1	Senegal_230227_170229	-2.01	0.35	4.46
SETSM_s2s041_WV03_20210327_1040010066BE4600_1040010067924900_2m_seg1	Senegal_230227_170229	-1.04	0.98	4.06
SETSM_s2s041_WV03_20220322_1040010073A8EB00_1040010074220200_2m_seg1	Senegal_230227_170229	-0.62	0.90	3.09
SETSM_s2s041_WV03_20201113_104001006235F500_1040010063297200_2m_seg1	Senegal_230227_170229	-0.73	0.72	3.61
SETSM_s2s041_WV01_20240317_10200100EAAEED00_10200100EB011600_2m_seg1	Senegal_230227_170229	-0.58	0.25	0.26
SETSM_s2s041_WV01_20170815_1020010065AEAE00_1020010063734500_2m_seg1	Senegal_230227_170229	-0.66	0.02	1.68
SETSM_s2s041_WV02_20231215_10300100F12C0700_10300100F3C67C00_2m_seg1	TX_DesertMountains_2018_D19	0.03	-0.15	-1.47
SETSM_s2s041_WV02_20220908_10300100D94BDC00_10300100DA912E00_2m_seg2	TX_DesertMountains_2018_D19	-0.10	-0.10	-1.45
SETSM_s2s041_WV02_20220908_10300100D94BDC00_10300100DA912E00_2m_seg3	TX_DesertMountains_2018_D19	0.02	0.10	-1.50
SETSM_s2s041_WV01_20210519_10200100B0187900_10200100B17B1200_2m_seg2	TX_DesertMountains_2018_D19	0.11	0.01	1.08
SETSM_s2s041_WV01_20210705_10200100B32E5D00_10200100B378F600_2m_seg1	TX_DesertMountains_2018_D19	-0.59	-0.31	1.14
SETSM_s2s041_WV01_20210817_10200100B4C59B00_10200100B5BA9600_2m_seg1	TX_DesertMountains_2018_D19	0.16	0.13	1.63
SETSM_s2s041_WV02_20221112_10300100DC655600_10300100DC858900_2m_seg1	TX_DesertMountains_2018_D19	-0.02	-0.44	-0.99

SETSM_s2s041_WV02_20200520_10300100A6557900_10300100A6739700_2m_seg1	TX_DesertMountains_2018_D19	-0.21	-0.08	0.64
SETSM_s2s041_WV02_20231226_10300100F35BE600_10300100F3D60700_2m_seg1	TX_DesertMountains_2018_D19	-0.20	-0.18	-1.75
SETSM_s2s041_WV02_20190828_1030010097D5CC00_10300100984A3A00_2m_seg1	TX_DesertMountains_2018_D19	-0.75	0.18	3.24
SETSM_s2s041_WV03_20190828_104001004F2AFC00_104001004F984300_2m_seg1	TX_DesertMountains_2018_D19	-0.10	-0.09	3.30
SETSM_s2s041_WV02_20220908_10300100D94BDC00_10300100DA912E00_2m_seg1	TX_DesertMountains_2018_D19	-0.44	-0.04	-1.51
SETSM_s2s041_WV02_20190731_1030010097D48500_103001009806AF00_2m_seg1	TX_DesertMountains_2018_D19	0.18	-0.08	-0.71
SETSM_s2s041_WV01_20211205_10200100BB261200_10200100BB65E200_2m_seg1	TX_DesertMountains_2018_D19	-2.40	-0.50	0.20
SETSM_s2s041_WV03_20241010_104001009C447F00_104001009CC80600_2m_seg1	TX_DesertMountains_2018_D19	-0.34	-0.08	-1.11
SETSM_s2s041_WV01_20221219_10200100CEE8DA00_10200100D10F2600_2m_seg1	TX_DesertMountains_2018_D19	0.20	0.25	0.96
SETSM_s2s041_WV02_20180329_103001007A929200_103001007C69C100_2m_seg1	TX_DesertMountains_2018_D19	0.15	0.08	1.19
SETSM_s2s041_WV02_20200531_10300100A5763500_10300100A6B0D900_2m_seg1	TX_DesertMountains_2018_D19	0.06	0.06	-0.15
SETSM_s2s041_WV01_20210505_10200100B0069300_10200100B0DAA000_2m_seg1	UT_FEMA_FS_FlamingGorge_2020_B20	-0.39	0.29	0.77
SETSM_s2s041_WV01_20240928_10200101041D7900_1020010104542300_2m_seg1	UT_FEMA_FS_FlamingGorge_2020_B20	-0.22	-0.23	0.16
SETSM_s2s041_WV01_20240812_10200100F2B62D00_10200100F5E64300_2m_seg1	UT_FEMA_FS_FlamingGorge_2020_B20	-0.57	-0.08	2.09
SETSM_s2s041_WV01_20220911_10200100CA66E600_10200100CCCCF000_2m_seg1	UT_FEMA_FS_FlamingGorge_2020_B20	0.01	-0.18	1.13
SETSM_s2s041_WV02_20200905_10300100AB297D00_10300100AD3B1E00_2m_seg1	UT_FEMA_FS_FlamingGorge_2020_B20	0.17	0.13	2.08
SETSM_s2s041_WV02_20200707_10300100A884F500_10300100AA49B200_2m_seg1	UT_WestEast_B22	1.19	0.23	3.97
SETSM_s2s041_WV01_20201029_102001009FB00E00_10200100A1DFAA00_2m_seg1	UT_WestEast_B22	-0.23	-0.53	-0.61
SETSM_s2s041_WV01_20200525_10200100968E1900_1020010096E38500_2m_seg1	UT_WestEast_B22	0.07	0.04	2.44
SETSM_s2s041_WV01_20221028_10200100CDA58D00_10200100CE00CC00_2m_seg1	UT_WestEast_B22	-0.06	-0.02	3.82
SETSM_s2s041_WV01_20220502_10200100C1CF1F00_10200100C303F400_2m_seg2	UT_WestEast_B22	0.00	0.10	1.92
SETSM_s2s041_WV01_20221118_10200100CEB93000_10200100CF9EA500_2m_seg1	UT_WestEast_B22	-0.27	0.01	3.34
SETSM_s2s041_WV01_20220924_10200100CCCCFD00_10200100CD0E2300_2m_seg1	UT_WestEast_B22	-0.27	0.47	2.32
SETSM_s2s041_WV01_20200925_102001009A58AE00_102001009DBB0900_2m_seg1	UT_WestEast_B22	-0.01	0.01	1.44
SETSM_s2s041_WV03_20200502_104001005ACC6E00_104001005B461800_2m_seg1	WI_BrownRusk_2020_B20	0.09	-0.06	0.81
SETSM_s2s041_WV03_20200621_104001005C2BD600_104001005C0A2F00_2m_seg1	WI_BrownRusk_2020_B20	0.02	-0.09	0.83
SETSM_s2s041_WV03_20200729_104001005D1C4200_104001005D9D3E00_2m_seg1	WI_BrownRusk_2020_B20	0.15	-0.01	0.68

Appendix 4. EarthDEM Mosaic Tile Co-Registration Results

Table A4. Horizontal (x, y) and vertical (z) translations required to align the EarthDEM Mosaic Tiles to their respective reference lidar DSM. Translations were computed using the Nuth and Kaab (2011) co-registration methods.

DEM ID	Reference Lidar Dataset ID	X Shift (m)	Y Shift (m)	Z Shift (m)
AZ_Coconino_2019_B19_1	AZ_Coconino_2019_B19	-0.05	-0.05	1.49
AZ_Coconino_2019_B19_2	AZ_Coconino_2019_B19	-0.14	-0.09	3.84
AZ_MaricopaPinal_2020_B20_1	AZ_MaricopaPinal_2020_B20	0.02	0.13	0.80
AZ_OrganPipeCactusNM_2020_B20_1	AZ_OrganPipeCactusNM_2020_B20	-0.70	0.79	0.16
AZ_PimaCounty_2021_B21_1	AZ_PimaCounty_2021_B21	0.10	-0.31	0.82
AZ_Yavapai_2021_B21_1	AZ_Yavapai_2021_B21	-0.34	0.09	0.41
CA_SierraNevada_B22_1	CA_SierraNevada_B22	-0.13	-0.11	1.87
CA_SierraNevada_B22_2	CA_SierraNevada_B22	-0.04	-0.01	1.22
CA_SierraNevada_B22_3	CA_SierraNevada_B22	-0.05	0.01	-0.08
CA_YosemiteNP_2019_D19_1	CA_YosemiteNP_2019_D19	0.06	-0.13	-1.58
CA_YosemiteNP_2019_D19_2	CA_YosemiteNP_2019_D19	0.08	0.21	0.63
CA_YosemiteNP_2019_D19_3	CA_YosemiteNP_2019_D19	0.00	-0.18	-0.11
CO_CameronPeakWildfire_2021_D21_1	CO_CameronPeakWildfire_2021_D21	0.02	-0.04	0.89
CO_CameronPeakWildfire_2021_D21_2	CO_CameronPeakWildfire_2021_D21	0.05	0.04	0.81
CO_EasternColorado_2018_A18_1	CO_EasternColorado_2018_A18	0.11	0.10	0.98
CO_Southwest_NRCS_2018_D18_1	CO_Southwest_NRCS_2018_D18	-0.07	0.15	0.43
CO_WestCentral_2019_A19_1	CO_WestCentral_2019_A19	-0.25	-0.08	1.22
CO_WestCentral_2019_A19_2	CO_WestCentral_2019_A19	-0.36	-0.16	0.19
CO_WestCentral_2019_A19_3	CO_WestCentral_2019_A19	-0.17	-0.07	0.46
FL_Southwest_2018_D18_SUPPLEMENTAL_1	FL_Southwest_2018_D18_SUPPLEMENTAL	-0.10	0.05	3.24
FL_Southwest_2018_D18_SUPPLEMENTAL_2	FL_Southwest_2018_D18_SUPPLEMENTAL	0.12	-0.04	2.54
FL_Southwest_2018_D18_SUPPLEMENTAL_3	FL_Southwest_2018_D18_SUPPLEMENTAL	-0.02	-0.16	2.10
GA_Central_2019_B19_1	GA_Central_2019_B19_1_dsm	-0.02	-0.03	1.87
GA_Central_2019_B19_2	GA_Central_2019_B19_2_dsm	0.01	0.02	1.80
LA_Catahoula_Concordia_2017_D17_1	LA_Catahoula_Concordia_2017_D17	-0.07	-0.07	3.61
LA_Catahoula_Concordia_2017_D17_2	LA_Catahoula_Concordia_2017_D17	-0.28	-0.06	1.48
LA_Catahoula_Concordia_2017_D17_3	LA_Catahoula_Concordia_2017_D17	-0.26	-0.09	3.24
LA_NortheastDOTD_2017_C20_1	LA_NortheastDOTD_2017_C20	-0.10	-0.25	2.95
MN_SE_Driftless_2021_B21_1	MN_SE_Driftless_2021_B21	0.02	-0.20	1.59
NE_PostSpringFlood_OrthoLidar_2019_D19_1	NE_PostSpringFlood_OrthoLidar_2019_D19	-0.05	0.18	0.83
NE_PostSpringFlood_OrthoLidar_2019_D19_2	NE_PostSpringFlood_OrthoLidar_2019_D19	-0.23	0.12	1.49
NE_PostSpringFlood_OrthoLidar_2019_D19_3	NE_PostSpringFlood_OrthoLidar_2019_D19	0.05	-0.12	1.33
NE_PostSpringFlood_OrthoLidar_2019_D19_4	NE_PostSpringFlood_OrthoLidar_2019_D19	-0.07	-0.02	1.28
NE_PostSpringFlood_OrthoLidar_2019_D19_5	NE_PostSpringFlood_OrthoLidar_2019_D19	-0.04	-0.07	1.44
NE_PostSpringFlood_OrthoLidar_2019_D19_6	NE_PostSpringFlood_OrthoLidar_2019_D19	0.05	-0.04	1.86
NM_HermitsPeak_D23_1	NM_HermitsPeak_D23	-0.38	0.01	-0.29
NM_HermitsPeak_D23_2	NM_HermitsPeak_D23	-0.06	-0.06	0.12
OR_OLCMetro_2019_A19_1	OR_OLCMetro_2019_A19	0.06	0.17	1.12
OR_WesternWildfires_A22_1	OR_WesternWildfires_A22	-0.19	-0.13	6.55
OR_WesternWildfires_A22_2	OR_WesternWildfires_A22	-0.27	-0.13	-0.05
SC_SavannahPeeDee_2019_B19_1	SC_SavannahPeeDee_2019_B19	-0.03	-0.08	2.81
SC_SavannahPeeDee_2019_B19_2	SC_SavannahPeeDee_2019_B19	-0.08	-0.12	4.05
TX_DesertMountains_2018_D19_1	TX_DesertMountains_2018_D19	-0.63	0.10	1.06
TX_DesertMountains_2018_D19_2	TX_DesertMountains_2018_D19	0.05	0.29	1.07
TX_DesertMountains_2018_D19_3	TX_DesertMountains_2018_D19	0.26	0.06	0.88
UT_FEMA_FS_FlamingGorge_2020_B20_1	UT_FEMA_FS_FlamingGorge_2020_B20	-0.20	0.13	0.82
UT_FEMA_FS_FlamingGorge_2020_B20_2	UT_FEMA_FS_FlamingGorge_2020_B20	-0.46	0.06	0.88
UT_FEMA_FS_FlamingGorge_2020_B20_3	UT_FEMA_FS_FlamingGorge_2020_B20	0.27	-0.01	0.83
UT_FEMA_FS_FlamingGorge_2020_B20_4	UT_FEMA_FS_FlamingGorge_2020_B20	-0.17	-0.09	1.14

UT_WestEast_B22_1	UT_WestEast_B22	-0.04	0.05	0.93
WA_NorthCentral_2021_B21_1	WA_NorthCentral_2021_B21	-0.18	-0.03	0.73
WI_BrownRusk_2020_B20_1	WI_BrownRusk_2020_B20	0.03	-0.16	0.80
230220_093037	Senegal_230220_093037	0.24	-0.20	2.41
230220_134217	Senegal_230220_134217	-1.05	0.23	2.43
230220_160421	Senegal_230220_160421	0.27	0.23	4.13
230221_131222	Senegal_230221_131222	-0.02	-0.42	8.21
230222_161802	Senegal_230222_161802	0.04	-0.09	1.29
230223_085011	Senegal_230223_085011	0.01	0.24	1.96
230223_092637	Senegal_230223_092637	0.01	-0.05	2.66
230223_105654	Senegal_230223_105654	0.01	0.06	1.47
230223_132903	Senegal_230223_132903	0.04	0.01	1.79
230224_103852	Senegal_230224_103852	0.04	0.09	0.72
230224_114919	Senegal_230224_114919	-0.16	-0.30	1.87
230224_145307	Senegal_230224_145307	-0.37	0.11	1.26
230225_085946	Senegal_230225_085946	-0.12	-0.01	1.43
230225_095401	Senegal_230225_095401	-0.24	0.03	1.76
230225_110217	Senegal_230225_110217	0.08	0.03	1.17
230225_153626	Senegal_230225_153626	-0.19	-0.15	2.36
230225_172547	Senegal_230225_172547	0.06	0.21	1.55
230226_074329	Senegal_230226_074329	-0.28	-0.25	0.86
230226_101124	Senegal_230226_101124	-0.19	-0.44	0.21
230226_113446	Senegal_230226_113446	-0.18	-0.75	3.65
230227_121455	Senegal_230227_121455	-0.28	-0.07	-2.04
230227_131905	Senegal_230227_131905	0.68	-0.04	2.08
230227_160049	Senegal_230227_160049	0.47	0.14	2.90
230227_170229	Senegal_230227_170229	0.30	-0.05	2.96

Appendix 5. EarthDEM Strip DSM Accuracy for Strip DSMs Acquired within One Year of the Lidar

Table A5. EarthDEM Strip DSM vertical errors (m) by NLCD cover type over terrain with slopes less than or equal to 2°. Only the 90 Strip DSMs acquired within one year of the mean lidar acquisition date for their respective evaluation site were used in the random sample. 300,000 points were randomly sampled across all US evaluation sites per NLCD cover type. Points were randomly sampled from each cover type to generate the overall statistics. The number of points sampled per cover type for the weighted average were proportional to the percent area for each class across the CONUS (Table 1).

Cover Type	Minimum	Maximum	Median	Mean	StD	RMSE	LE90	Count
Developed, Open Space	-71.6	207.7	0.3	-0.2	4.8	4.8	6.8	120,000
Developed, Low Intensity	-52.5	71.2	0.4	-0.3	4.3	4.3	6.8	120,000
Developed, Medium Intensity	-39.8	72.7	0.5	-0.1	3.2	3.2	4.1	120,000
Developed, High Intensity	-68.1	31.6	0.5	0.5	3.0	3.0	3.8	120,000
Barren	-19.6	22.3	0.5	0.5	1.3	1.4	1.8	120,000
Deciduous Forest	-35.2	111.7	-0.2	-0.3	8.5	8.5	11.9	120,000
Evergreen Forest	-119.4	158.5	0.0	-1.8	8.0	8.2	13.5	120,000
Mixed Forest	-94.3	94.7	-0.1	0.2	9.5	9.5	14.8	120,000
Shrub/Scrub	-403.9	73.7	0.4	-0.1	4.0	4.0	2.9	120,000
Grassland/Herbaceous	-49.2	144.2	0.4	0.0	4.5	4.5	4.6	120,000
Pasture/Hay	-50.6	31.7	0.5	0.1	2.6	2.6	2.6	120,000
Cultivated Crops	-33.0	22.6	0.3	0.3	2.4	2.4	2.3	120,000
Woody Wetlands	-394.2	123.6	0.5	-0.4	6.9	6.9	8.3	120,000
Emergent Herbaceous Wetlands	-408.4	90.1	0.6	0.4	5.7	5.7	3.1	120,000
Weighted Average	**-406.9**	**207.7**	**0.3**	**-0.2**	**5.5**	**5.5**	**7.2**	**499,993**

Appendix 6. EarthDEM Strip DSM Accuracy for Strip DSMs Acquired within Two Years of the Lidar

Table A6. EarthDEM Strip DSM vertical errors (m) by NLCD cover type over terrain with slopes less than or equal to 2°. Only the 139 Strip DSMs acquired within one year of the mean lidar acquisition date for their respective evaluation site were used in the random sample. 200,000 points were randomly sampled across all US evaluation sites per NLCD cover type. Points were randomly sampled from each cover type to generate the overall statistics. The number of points sampled per cover type for the weighted average were proportional to the percent area for each class across the CONUS (Table 1).

Cover Type	Minimum	Maximum	Median	Mean	StD	RMSE	LE90	Count
Developed, Open Space	-94.5	317.7	0.3	-0.2	4.7	4.7	6.4	200,000
Developed, Low Intensity	-95.5	321.8	0.4	-0.2	4.1	4.1	5.9	200,000
Developed, Medium Intensity	-96.6	59.4	0.5	0.0	3.0	3.0	3.9	200,000
Developed, High Intensity	-108.0	42.5	0.6	0.6	2.8	2.9	3.9	200,000
Barren	-21.9	23.0	0.4	0.4	1.3	1.3	1.7	200,000
Deciduous Forest	-35.2	111.7	-0.4	-0.7	7.5	7.6	10.6	200,000
Evergreen Forest	-121.8	134.7	-0.1	-1.6	7.8	8.0	13.0	200,000
Mixed Forest	-94.3	94.7	-0.1	0.2	8.5	8.5	13.5	200,000
Shrub/Scrub	-366.8	83.0	0.3	-0.2	3.4	3.4	2.9	200,000
Grassland/Herbaceous	-80.6	179.8	0.2	-0.5	5.3	5.3	5.0	200,000
Pasture/Hay	-49.8	75.3	0.4	0.0	2.7	2.7	3.0	200,000
Cultivated Crops	-71.1	162.7	0.3	0.2	2.4	2.4	2.5	200,000
Woody Wetlands	-404.8	392.1	0.5	-0.3	6.5	6.5	8.5	200,000
Emergent Herbaceous Wetlands	-408.4	413.8	0.6	0.3	5.5	5.5	4.1	200,000
Weighted Average	**-406.2**	**310.2**	**0.3**	**-0.3**	**5.3**	**5.3**	**7.1**	**499,993**

Appendix 7. EarthDEM Strip DSM Accuracy for Strip DSMs Acquired Greater than Two Years from the Lidar

Table A7. EarthDEM Strip DSM vertical errors (m) by NLCD cover type over terrain with slopes less than or equal to 2°. Only the 75 Strip DSMs acquired greater than two years from the mean lidar acquisition date for their respective evaluation site were used in the random sample. 100,000 points were randomly sampled across all US evaluation sites per NLCD cover type. Points were randomly sampled from each cover type to generate the overall statistics. The number of points sampled per cover type for the weighted average were proportional to the percent area for each class across the CONUS (Table 1).

Cover Type	Minimum	Maximum	Median	Mean	StD	RMSE	LE90	Count
Developed, Open Space	-44.0	51.9	0.3	-0.8	4.8	4.9	7.4	100,000
Developed, Low Intensity	-53.2	228.3	0.2	-0.9	4.6	4.7	6.9	100,000
Developed, Medium Intensity	-35.7	166.7	0.4	-0.2	3.1	3.1	3.9	100,000
Developed, High Intensity	-41.8	35.8	0.4	0.3	2.7	2.8	3.9	100,000
Barren	-56.5	33.6	0.5	0.6	2.3	2.3	3.1	100,000
Deciduous Forest	-44.9	35.2	0.0	-1.3	6.6	6.8	11.8	100,000
Evergreen Forest	-75.7	51.6	0.0	-2.8	8.9	9.4	17.0	100,000
Mixed Forest	-42.1	40.1	0.9	2.0	8.3	8.5	15.4	100,000
Shrub/Scrub	-79.2	84.3	0.4	-0.4	4.2	4.2	5.0	100,000
Grassland/Herbaceous	-113.9	50.2	0.1	-2.2	7.1	7.4	12.8	100,000
Pasture/Hay	-38.0	48.1	0.2	-0.3	2.8	2.8	2.6	100,000
Cultivated Crops	-33.3	22.7	0.3	0.3	3.0	3.0	3.8	100,000
Woody Wetlands	-70.3	104.0	0.7	-0.6	6.3	6.3	11.0	100,000
Emergent Herbaceous Wetlands	-38.7	21.2	0.7	-1.2	6.3	6.4	9.1	100,000
Weighted Average	**-113.9**	**166.7**	**0.3**	**-0.9**	**5.9**	**6.0**	**9.5**	**399,993**

Appendix 8. EarthDEM Strip DSM Accuracy for Strip DSMs with Less Than 20% Cloud Cover

Table A8. EarthDEM Strip DSM vertical errors (m) by NLCD cover type over terrain with slopes less than or equal to 2°. Only the 122 Strip DSMs with less than 20% cloud cover as estimated by the "cloud_area_percent" metadata field were used in the random sample. 100,000 points were randomly sampled per NLCD cover type across the 32 US evaluation sites intersected by the 122 Strip DSMs. Points were randomly sampled from each cover type to generate the overall statistics. The number of points sampled per cover type for the weighted average were proportional to the percent area for each class across the CONUS (Table 1).

Cover Type	Minimum	Maximum	Median	Mean	StD	RMSE	LE90	Count
Developed, Open Space	-94.1	92.0	0.3	0.0	3.8	3.8	4.8	100,000
Developed, Low Intensity	-58.4	54.1	0.4	-0.1	3.5	3.5	5.3	100,000
Developed, Medium Intensity	-111.9	20.4	0.7	0.3	2.5	2.6	3.4	100,000
Developed, High Intensity	-108.0	36.4	0.6	0.6	2.7	2.7	3.7	100,000
Barren	-18.3	33.6	0.4	0.5	1.3	1.4	1.9	100,000
Deciduous Forest	-33.5	109.7	-0.6	-1.1	7.1	7.2	9.8	100,000
Evergreen Forest	-75.5	60.5	-0.1	-1.8	7.4	7.6	12.6	100,000
Mixed Forest	-42.1	94.7	-0.2	-0.1	7.0	7.0	11.1	100,000
Shrub/Scrub	-68.4	61.1	0.3	0.0	2.9	2.9	2.8	100,000
Grassland/Herbaceous	-99.6	63.3	0.2	-0.1	3.9	3.9	3.6	100,000
Pasture/Hay	-38.5	34.4	0.5	0.2	2.6	2.6	3.1	100,000
Cultivated Crops	-71.1	25.1	0.3	0.3	1.4	1.4	1.7	100,000
Woody Wetlands	-47.9	91.2	0.5	-0.5	4.7	4.7	7.2	100,000
Emergent Herbaceous Wetlands	-42.2	64.7	0.7	0.4	3.6	3.6	3.9	100,000
Weighted Average	**-91.5**	**109.7**	**0.3**	**-0.3**	**4.6**	**4.6**	**6.2**	**399,993**

Appendix 9. EarthDEM Strip DSM Accuracy for Strip DSMs with Greater Than 20% Cloud Cover

Table A9. EarthDEM Strip DSM vertical errors (m) by NLCD cover type over terrain with slopes less than or equal to 2°. Only the 89 Strip DSMs with greater than 20% cloud cover as estimated by the "cloud_area_percent" metadata field were used in the random sample. 100,000 points were randomly sampled per NLCD cover type across the 29 US evaluation sites intersected by the 89 Strip DSMs. Points were randomly sampled from each cover type to generate the overall statistics. The number of points sampled per cover type for the weighted average were proportional to the percent area for each class across the CONUS (Table 1).

Cover Type	Minimum	Maximum	Median	Mean	StD	RMSE	LE90	Count
Developed, Open Space	-78.2	310.2	0.2	-1.0	6.2	6.3	10.3	100,000
Developed, Low Intensity	-42.3	228.3	0.1	-1.0	5.3	5.4	8.6	100,000
Developed, Medium Intensity	-35.2	77.5	0.1	-0.6	3.6	3.6	4.8	100,000
Developed, High Intensity	-68.4	27.4	0.4	0.4	3.1	3.1	4.4	100,000
Barren	-56.5	32.7	0.4	0.2	2.3	2.3	2.7	100,000
Deciduous Forest	-44.9	43.8	0.4	-0.1	7.7	7.7	13.4	100,000
Evergreen Forest	-92.2	191.9	0.0	-2.3	9.2	9.5	16.7	100,000
Mixed Forest	-91.1	40.1	1.2	1.8	9.9	10.1	17.0	100,000
Shrub/Scrub	-369.8	48.3	0.3	-0.7	5.2	5.2	4.7	100,000
Grassland/Herbaceous	-65.3	41.3	0.0	-2.6	8.0	8.4	16.6	100,000
Pasture/Hay	-52.5	131.1	0.1	-0.5	3.0	3.0	3.0	100,000
Cultivated Crops	-29.6	120.2	0.3	0.2	3.7	3.7	5.1	100,000
Woody Wetlands	-403.2	408.0	0.6	-0.3	8.5	8.5	12.1	100,000
Emergent Herbaceous Wetlands	-408.3	96.5	0.5	-0.8	8.1	8.1	8.8	100,000
Weighted Average	**-399.3**	**226.7**	**0.2**	**-0.8**	**6.7**	**6.8**	**10.8**	**399,993**

Appendix 10. EarthDEM Strip DSM and Mosaic Tile Vertical Error by Slope

Table A10.1. EarthDEM Strip DSM vertical errors by slope class. 250,000 points were randomly sampled per slope class, which contained only land classified as Barren in the NLCD. It was not possible to sample 250,000 points for slope classes 75-85° due to the small spatial extent of those classes within the evaluation sites and the masking of erroneous elevations. Errors are provided in meters.

Slope (degrees)	Minimum	Maximum	Median	Mean	StD	RMSE	LE90	Count
0-5	-89.51	134.50	0.05	0.16	5.18	5.18	2.84	250,000
5-10	-85.79	279.46	0.42	0.24	2.73	2.74	2.57	250,000
10-15	-143.19	42.32	0.56	0.58	2.43	2.49	2.46	250,000
15-20	-372.84	284.57	0.42	0.42	3.31	3.34	2.39	250,000
20-25	-414.81	336.28	0.28	0.18	5.56	5.56	2.41	250,000
25-30	-398.81	358.72	0.20	0.15	4.23	4.24	2.56	250,000
30-35	-224.21	331.53	0.14	0.12	3.81	3.81	2.76	250,000
35-40	-181.81	336.74	0.10	0.22	5.01	5.02	3.15	250,000
40-45	-167.04	339.40	0.01	0.12	5.23	5.23	3.79	250,000
45-50	-178.08	353.13	-0.04	0.24	7.12	7.13	5.54	250,000
50-55	-179.81	313.15	-0.12	0.30	9.10	9.11	8.93	250,000
55-60	-184.17	144.77	-0.14	0.50	11.54	11.55	13.39	250,000
60-65	-209.39	149.92	-0.21	0.71	14.78	14.79	20.61	250,000
65-70	-178.26	167.35	-0.33	0.74	18.48	18.50	27.79	250,000
70-75	-216.92	169.23	-0.12	2.18	24.74	24.84	38.72	250,000
75-80	-220.06	178.59	0.74	4.99	35.23	35.58	59.50	191,857
80-85	-213.20	171.81	9.92	11.22	60.54	61.57	106.16	49,990

Table A10.2. EarthDEM Mosaic Tile vertical errors by slope class. 250,000 points were randomly sampled per slope class, which contained only land classified as Barren in the NLCD. It was not possible to sample 250,000 points for slope classes 65-85° due to the small spatial extent of those classes within the evaluation sites and voids in the DEMs. Errors are provided in meters.

Slope (degrees)	Minimum	Maximum	Median	Mean	StD	RMSE	LE90	Count
0-5	-84.21	78.80	0.31	0.05	1.74	1.74	1.73	250,000
5-10	-64.80	79.26	0.48	0.30	1.53	1.56	1.94	250,000
10-15	-167.76	71.50	0.49	0.38	1.64	1.68	2.08	250,000
15-20	-109.53	68.06	0.49	0.48	1.72	1.78	2.38	250,000
20-25	-82.16	79.17	0.49	0.56	2.27	2.34	2.62	250,000
25-30	-151.52	83.11	0.48	0.65	2.77	2.84	2.82	250,000
30-35	-136.56	92.00	0.47	0.67	2.99	3.07	3.03	250,000
35-40	-148.74	109.50	0.38	0.55	3.02	3.07	3.02	250,000
40-45	-171.25	98.72	0.33	0.53	3.84	3.87	3.76	250,000
45-50	-177.31	100.32	0.37	0.69	5.63	5.67	6.10	250,000
50-55	-163.83	98.74	0.34	0.88	7.46	7.51	9.34	250,000
55-60	-173.97	114.87	0.34	1.07	9.70	9.76	13.11	250,000
60-65	-149.06	99.45	0.26	1.32	12.17	12.24	17.45	250,000
65-70	-177.47	116.76	0.50	2.18	16.67	16.81	25.69	149,844
70-75	-178.76	92.73	0.57	1.59	24.44	24.49	38.59	53,600
75-80	-176.00	96.58	4.01	0.92	47.53	47.54	74.65	10,594
80-85	-136.41	94.16	32.84	8.34	64.29	64.83	132.20	133

Appendix 11. EarthDEM Strip DSM and Mosaic Tile Vertical Error by Aspect

Table A11.1. EarthDEM Strip DSM vertical errors by aspect. 1,000,000 points were randomly sampled per aspect group, which contained all land cover types. Errors are provided in meters.

Aspect (degrees)	Minimum	Maximum	Median	Mean	StD	RMSE	LE90	Count
0-15	-167.8	410.3	0.1	-0.2	5.8	5.8	7.5	1,000,000
15-30	-177.0	433.7	0.0	-0.3	6.5	6.5	7.6	1,000,000
30-45	-736.9	444.9	0.0	-0.3	6.7	6.7	7.9	1,000,000
45-60	-762.0	397.2	0.0	-0.3	6.7	6.7	8.0	1,000,000
60-75	-780.2	436.6	0.1	-0.2	6.7	6.7	8.1	1,000,000
75-90	-791.1	315.4	0.1	-0.1	6.8	6.8	7.8	1,000,000
90-105	-837.0	919.5	0.1	-0.2	6.3	6.3	7.7	1,000,000
105-120	-848.7	1314.0	0.1	-0.4	7.1	7.1	7.9	1,000,000
120-135	-841.7	1122.6	0.0	-0.5	7.0	7.0	8.3	1,000,000
135-150	-724.9	1386.6	0.0	-0.7	6.8	6.8	8.5	1,000,000
150-165	-637.0	1400.1	0.1	-0.6	6.9	7.0	8.0	1,000,000
165-180	-401.9	1399.0	0.2	-0.5	6.2	6.3	7.4	1,000,000
180-195	-929.6	1332.6	0.2	-0.6	7.4	7.4	7.3	1,000,000
195-210	-829.4	1218.4	0.1	-0.7	6.6	6.6	7.3	1,000,000
210-225	-343.7	1161.7	0.1	-0.8	5.7	5.7	7.3	1,000,000
225-240	-353.5	439.7	0.2	-0.7	5.5	5.6	7.1	1,000,000
240-255	-377.4	449.4	0.2	-0.6	5.3	5.3	6.8	1,000,000
255-270	-434.7	409.8	0.2	-0.5	5.2	5.2	6.7	1,000,000
270-285	-162.1	411.6	0.2	-0.5	5.2	5.3	6.7	1,000,000
285-300	-185.0	414.8	0.1	-0.6	5.4	5.4	6.9	1,000,000
300-315	-266.8	421.1	0.0	-0.7	5.6	5.6	7.0	1,000,000
315-330	-478.7	441.3	0.0	-0.7	5.6	5.6	7.0	1,000,000
330-345	-646.2	436.1	0.0	-0.6	5.8	5.8	7.1	1,000,000
345-360	-733.8	419.6	0.1	-0.3	5.8	5.8	7.3	1,000,000

Table A11.2. EarthDEM Mosaic Tile vertical errors by aspect. One million points were randomly sampled per aspect group, which contained all land cover types. Errors are provided in meters.

Aspect (Degrees)	Minimum	Maximum	Median	Mean	StD	RMSE	LE90	Count
0-15	-98.4	119.3	0.2	-0.3	6.3	6.3	9.9	1,000,000
15-30	-144.8	108.3	0.2	-0.2	6.5	6.5	10.2	1,000,000
30-45	-120.1	118.8	0.2	-0.1	6.6	6.6	10.4	1,000,000
45-60	-144.1	121.1	0.2	0.0	6.7	6.7	10.6	1,000,000
60-75	-165.0	146.7	0.2	0.0	6.9	6.9	10.8	1,000,000
75-90	-103.1	134.6	0.2	-0.1	6.9	6.9	10.9	1,000,000
90-105	-114.8	183.4	0.1	-0.2	7.1	7.1	11.2	1,000,000
105-120	-91.6	173.8	0.1	-0.4	7.1	7.2	11.4	1,000,000
120-135	-93.6	142.7	0.1	-0.6	7.1	7.2	11.4	1,000,000
135-150	-134.4	122.8	0.1	-0.8	7.1	7.1	11.4	1,000,000
150-165	-84.4	77.4	0.0	-0.9	7.0	7.0	11.2	1,000,000
165-180	-133.0	97.1	0.0	-1.0	6.8	6.8	10.9	1,000,000
180-195	-128.7	101.6	0.1	-1.0	6.6	6.6	10.5	1,000,000
195-210	-147.5	88.9	0.1	-1.0	6.4	6.4	10.3	1,000,000
210-225	-120.9	95.6	0.1	-1.0	6.2	6.3	10.0	1,000,000
225-240	-91.4	78.5	0.1	-1.0	6.2	6.2	9.8	1,000,000
240-255	-85.0	82.8	0.1	-0.9	6.1	6.2	9.6	1,000,000
255-270	-135.9	74.5	0.1	-0.9	6.0	6.1	9.4	1,000,000
270-285	-112.8	84.0	0.1	-0.8	6.0	6.0	9.3	1,000,000
285-300	-85.9	85.1	0.1	-0.8	6.0	6.0	9.4	1,000,000
300-315	-81.7	74.2	0.1	-0.7	6.0	6.0	9.4	1,000,000
315-330	-88.8	87.8	0.1	-0.6	6.0	6.0	9.3	1,000,000
330-345	-148.5	87.1	0.1	-0.5	6.1	6.1	9.4	1,000,000
345-360	-91.5	84.4	0.2	-0.4	6.2	6.2	9.5	1,000,000