ArcticDEM Documentation and User Guidance

Version 1.3 – February 13, 2017

Contents

Overview

Background

ArcticDEM is a National Geospatial-Intelligence Agency (NGA) and National Science Foundation (NSF) public-private initiative to automatically produce a high-resolution, high-quality digital surface model (DSM) of the Arctic using optical stereo imagery, high-performance computing, and open source photogrammetry software. The product is a collection of time-dependent DEM strips and a seamless terrain mosaic that can be distributed without restriction.

The Polar Geospatial Center and collaborating institutions are using a three-pronged strategy to produce over 20 trillion 2-by-2 meter elevation cells over an area of 20 million square kilometers.

1. DigitalGlobe's Worldview-1, Worldview-2, and Worldview-3 satellites collect stereo imagery of the Arctic.
2. The imagery is processed into 2 meter posting elevation models using the Ohio State University's software package *Surface Extraction with TIN-based Search-space Minimization (SETSM)*.
3. The computation is performed on the NSF-supported Blue Waters petascale supercomputer at the National Center for Supercomputing Applications.

ArcticDEM offers a different way of producing and providing terrain data. It is a response to the need for high-quality data in remote locations, the availability of technology to cope with big data, and the need to measure topographic change. The producers did not intend the final product to be a single "eyes on" or edited product, but rather a collection of time-dependent elevation models and the infrastructure to process the flow of imagery from an ever-expanding constellation of satellites producing an ever-increasing volume of high-quality data.

Scope

ArcticDEM data encompasses all land area north of 60° north latitude. In addition, coverage will include all territory of Greenland, the entire state of Alaska, and the Kamchatka Peninsula of the Russian Federation. The project commenced with Alaska and is expected to create a comprehensive elevation model of the Arctic within the two-year term of the U.S. chairmanship of the Arctic Council, which began in April 2015.

Methodology

ArcticDEM data is generated by applying stereo auto-correlation techniques to overlapping pairs of high-resolution optical satellite images. Using the SETSM software developed by M.J. Noh and Ian Howat at the Ohio State University, stereopair images are processed to digital elevation models (DEMs) using the Blue Waters supercomputer located at the National Center for Supercomputing Applications at the University of Illinois at Urbana-Champaign.

For additional information on SETSM software, see: Noh, M.J., I.M. Howat, Automated stereo-photogrammetric DEM generation at high latitudes: Surface Extraction from TIN-Based Search Minimization (SETSM) validation and demonstration over glaciated regions, GIScience and Remote Sensing, doi:10.1080/15481603.2015.1008621

Output DEM raster files are available as 1) "strip" files output directly from SETSM that preserve the original source material temporal resolution and 2) mosaic files compiled from multiple strips that have been co-registered, blended, and feathered to reduce edge-matching artifacts.

Strip DEM files correspond to the overlap area of the input stereopair image swaths as they are collected by DigitalGlobe's polar-orbiting satellites. Strip DEM dimensions will vary according to the satellite sensor that acquired the images and the off-nadir angle of collection. Most strips are between 16 km and 18 km in width, and 110 km and 120 km in length. Mosaic DEM files adhere to a regular 100 km x 100 km tiling grid covering the ArcticDEM production domain. Each mosaic tile has been further sub-tiled into four, 50 km x 50 km sub-tiles for file size and distribution considerations

Filtered IceSAT altimetry data has been employed to improve the accuracy of both the strip and mosaic DEM files. ArcticDEM strip files are distributed with metadata describing the xyz offsets as determined by the altimetry data, but

have not had this translation applied to the rasters. Mosaicked ArcticDEM files have been registered to IceSAT altimetry information.

The methodology and scale of this data production initiative has a number of inherent strengths and weaknesses:

Strengths

- *The use of three polar orbiting satellites allows ArcticDEM to cover a large area in polar regions.* Satellites frequently revisit high-latitude areas and data generally can be collected quickly.
- *Areas can be recollected.* This allows for holes/gaps in ArcticDEM to be filled and also enables the potential for change detection.
- *Automation and high performance computing can generate a large amount of terrain in a short period of time.* Blue Waters has produced a 2 meter resolution DSM equivalent to the area of Argentina in 48 hours using one-third of the computer.
- *Elevation data can be regenerated as the photogrammetry software improves.*
- *Aircraft are not required.* High-latitude and remote areas are actually easier to collect than lower latitude areas near population centers.
- *Many different mosaics can be assembled as a time-dependent mix of elevation models to meet various requirements.* Users can construct mosaics from a specific year or season.

Weaknesses

- *There is no "bare earth" product.* The source imagery cannot penetrate vegetation or man-made surface features. Such features will exist in the elevation values of the product.
- *This is not an "eyes on" or manually edited product.* The volume of data is such that manually editing to remove artifacts or improve data would be time and cost prohibitive. Pits, spikes, false landforms, and other DEM anomalies may exist in this dataset. Polygonal hydrographic features have not been flattened and the data has not been hydrologically enforced.
- *It is optically derived.* Clouds, fog, shadows, and other atmospheric obstructions can obscure the ground and make it impossible to extract terrain.
- *ArcticDEM strip files have not been edge-matched.* Visible seams and deviations between adjacent DEMs may be observed.
- *Data management can be a problem*. A single 17 km by 120 km strip of 2 meter resolution terrain data can be over six gigabytes.
- *Versioning of products presents a challenge.* As more DEMs become available, holes can be filled in mosaics and specialty products can be made.
- *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. Laser altimetry data from the NASA IceSAT spacecraft has been applied to the ArcticDEM mosaic files. Users may wish to use other sources for smaller areas, particularly on ArcticDEM strip files. Strip DEM files contain IceSAT altimetry offsets within the metadata, but have not had these values applied to the DEM files.
- *The imagery spans multiple years and seasons*. A single season/year mosaic is not possible for large areas.

Source Material

ArcticDEM data is constructed from in-track, high-resolution (~0.5 meter) imagery acquired by the DigitalGlobe constellation of optical imaging satellites and licensed through the NGA NextView contact. Most ArcticDEM data was generated from the panchromatic bands of the Worldview-1, Worldview-2, and Worldview-3 satellites. A small percentage of data was generated from the GeoEye-1 satellite sensor.

Release Notes

Release 1 (August 31, 2016) – Alaska v1.0

The production of the DEM strips and mosaic of Alaska happened simultaneously with the development of the ArcticDEM workflow and the effort to fill holes in the stereo imagery archive from September 2015 to August 2016. Many of the holes in the 1.0 release of the mosaic will be filled in future releases by the imagery collected in June 2016. Specific attention was paid in the collection of stereo imagery in two of the cloudiest regions of Alaska: the Aleutian Islands and Southeast Alaska. We were pleased to see that many of the Aleutian Islands collected with minimal clouds and we were able to successfully extract elevation data. Southeast was another matter. The nature of the clouds in southeast was such that we were only able to extract elevation for small parts of valleys and even for just specific ranges of elevation in valleys. For this reason, we have excluded many of the mosaic tiles of Southeast Alaska from the v1.0 release.

The individual strips that have usable elevation data were included and we encourage users to examine them. In addition, we manually clipped out some bad data or areas with excessive voids to make a cleaner product. We expect to only do this in this version of Alaska. Future versions of Alaska will not have this manual attention, and other areas of the Arctic are expected to have sufficient coverage so manual clipping will not be required.

Release 2 (September 29, 2016) – Franz Josef Land v1.0 and Novaya Zemlya v1.0

ArcticDEM Release 2 includes data encompassing the two Russian archipelagos of Franz Josef Land and Novaya Zemlya. An additional 1124 strip DEM components at 2 meter resolution have been added to the ArcticDEM inventory, with an additional 96 mosaic DEM tiles at 5 meter resolution.

Release 3 (December 27, 2016)

ArcticDEM Release 3 contains versions 2.0 of Alaska (United States), Novaya Zemlya (Russia), Franz Josef Land (Russia), Baffin Island (Canada), Svalbard (Norway), and Iceland. Release 3 adds 4,977 strip DEM components at 2 meter resolution to the ArcticDEM inventory, with an additional 544 mosaic DEM tiles at 5 meter resolution.

Release 4 (February 13, 2017)

ArcticDEM Release 4 contains Kamchatka Peninsula (Russia), Faroe Islands, Canadian archipelago islands within Nunavut and the Northwest Territories (Canada), and northern and western regions of Greenland. Release 4 adds 9,884 strip DEM components at 2 meter resolution to the ArcticDEM inventory, with an additional 979 mosaic DEM tiles at 5 meter resolution.

Data Description

Format

Data is stored and distributed in 32 bit GeoTIFF file format with floating point elevation values.

Resolution

ArcticDEM strip files are distributed at a ground sample distance (GSD) of 2 meters. Mosaic files are distributed at 5 meter resolution.

Coordinate System

All strip and tiled mosaic ArcticDEM deliverables are projected to National Snow and Ice Data Center (NSIDC) Sea Ice Polar Stereographic North and referenced to WGS84 horizontal datum (EPSG 3413).

Vertical Reference

Vertical reference is height above the WGS84 ellipsoid.

Elevation Units

Elevation unit of measure is meters.

Null Values

Data may contain void pixels or regions over lakes, rivers, and other hydrographic features. Data voids may also be present where the source imagery contains cloud cover or shadowed areas. The void areas will contain null values (-9999) in lieu of the terrain elevations.

File Naming

Strip ArcticDEM files

File naming of strip ArcticDEM files incorporate several elements related to the source material used to create the data. The example below describes the naming convention:

- Example: WV02_20150615_10300100443C2D00_1030010043373000_seg1_2m_v1.0_dem
- Key: SENSOR_DATE_STEREOIMAGE1_STEREOIMAGE2_SEGMENT_RESOLUTION_VERSION_FILETYPE

SENSOR – DigitalGlobe satellite that collected the stereopair image
DATE – Date of source stereopair image acquisition as YYYMMDD
STEREOIMAGE1 – DigitalGlobe catalog ID number of the first stereopair image strip
STEREOIMAGE2 – DigitalGlobe catalog ID number of the second stereopair image strip
SEGMENT – Segment of DEM strip
RESOLUTION – Ground sample distance pixel size of the DEM file in meters
VERSION – Release version of DEM strip
FILETYPE – Category of file included within the distributed tape archive (TAR) file

Mosaic ArcticDEM files

File naming of ArcticDEM mosaic files corresponds to tiling grid established where each tile is 100 km x 100 km (approximately 2,400 tiles cover the ArcticDEM production domain). A shapefile index of the ArcticDEM mosaic tiling grid can be found at www.pgc.umn.edu/arcticdem.

File naming components of the example ArcticDEM mosaic file **48_20_1_1_5m_v1.0_reg_dem.tif**

- **48_20** – 100km x 100km Tile
- **1_1 –** 50km x 50km Sub-Tile
- **5m –** Pixel Resolution
- **v1.0 –** Mosaic File Version
- **reg** – IceSAT GCP registration tag
- **dem.tif** – File Type

Files Included

Strip ArcticDEM files

Each ArcticDEM strip TAR archive contains the following files:

- **_index.shp** – Esri Shapefile polygon depicting the geographic extent of the DEM file including basic metadata information within the attribute table
- **_dem.tif** - 32-bit DEM file
- **_matchtag.tif** - Bitmask raster indicating DEM pixels derived from a stereo match (1) or those that have been interpolated (0)
- **_mdf.txt** - Text file metadata document
- **_readme.txt** - Text file indicating development phase of the associated ArcticDEM file, terms of use, warranty, and contact information
- **_isreg.txt** – Text file indicating xyz offset of strip DEM to IceSAT altimetry control points (if available)
- **_ngareg.txt** – Text file indicating xyz offset of strip DEM to NGA-provided control points (if available)

Mosaic ArcticDEM files

Each ArcticDEM mosaic TAR archive contains the following files:

- **_index.shp** – Esri Shapefile polygon depicting the geographic extent of the 50 km x 50 km mosaic sub-tile
- **_dem.tif** - 32-bit DEM file
- **_matchtag.tif** - Bitmask raster indicating DEM pixels derived from a stereo match (1) or those that have been interpolated *or* filtered (0)
- **_meta.txt** - Text file metadata document describing the mosaicking alignment statistics for the parent 100 km x 100 km mosaic tile
- **_reg.txt** – Text file metadata document describing the IceSAT translation applied to the parent 100 km x 100 km mosaic tile

Metadata

Basic source material and production metadata is contained within the Esri shapefile and associated text files provided for each ArcticDEM strip and mosaic file.

Accuracy

Absolute horizontal and vertical accuracy specifications of ArcticDEM data have not been verified. Future work may include accuracy validation.

Characteristics

Digital Surface Model

ArcticDEM is a DSM that portrays first-return elevation values that include vegetation, tree canopy, buildings, and other man-made surface features. Exercise caution when using ArcticDEM data for applications that are better served using a bare-earth Digital Terrain Model (DTM) because results may be inaccurate or otherwise misleading.

Interpolation and Filtering

All DEM products derived from SETSM software come from a TIN-based model and pixels are given data values as the TIN is written to a raster. A default filter is applied using the matchtag raster that excludes pixels where >70% of the neighboring pixels in a local search window (21 x 21 or 5 x 5, depending on resolution) were interpolated. Further filtering can be accomplished using the matchtag raster.

Limitations

As with any optical imagery-derived elevation product, void areas or artifacts may appear where cloud cover, shadows, and unfrozen water bodies exist in the source imagery, or in regions of low radiometric contrast where pixel correlation cannot be resolved by the software.

Considerations

ArcticDEM has been assembled from source imagery collected over a period of several years and includes data collected throughout all seasons. Users should not assume that DEM data represent snow-free, leaf-off, or other temporally variable conditions. Every effort has been made to introduce the best-available source images into the final product, notwithstanding the challenges of producing a pan-Arctic dataset where source material from a single season or year is unavailable.

Distribution

Search, Discovery and Download

Polar Geospatial Center

The Polar Geospatial Center makes ArcticDEM data available for discovery and download through both HTTP and FTP protocols. The following links provide access to bulk downloads for ArcticDEM 2 meter strip and 5 meter mosaic files:

- ArcticDEM bulk strip FTP Download (2 meter resolution):
    - HTTP URL: http://data.pgc.umn.edu/elev/dem/setsm/ArcticDEM/geocell/v2.0/
    - FTP Client or Browser: ftp://ftp.data.pgc.umn.edu/elev/dem/setsm/ArcticDEM/geocell/v2.0/
- ArcticDEM bulk mosaic FTP Download (5 meter resolution):
    - HTTP URL: http://data.pgc.umn.edu/elev/dem/setsm/ArcticDEM/mosaic/v2.0/
    - FTP Client or Browser: ftp://ftp.data.pgc.umn.edu/elev/dem/setsm/ArcticDEM/mosaic/v2.0/

Esri

Esri has developed web applications and web services in support of the ArcticDEM initiative data that, in addition to providing raw download capability, can be used to view, explore and perform basic analysis and geoprocessing tasks:

ArcticDEM Service - Provides 2 meter and 5 meter DEM data. Currently includes v1.0 release of Alaska, Franz Josef Land and Novaya Zemlya, but will be updated to cover the arctic with subsequent releases

- Service Endpoint : http://elevation2.arcgis.com/arcgis/rest/services/Polar/ArcticDEM/ImageServer
- WebMap Item URL : http://www.arcgis.com/home/item.html?id=e34dc5a706d04901b3ba8d0085435a3d
- Imagery Layer Item URL : http://www.arcgis.com/home/item.html?id=db38a951a2b643478a942ab22cd78fc6

ArcticDEM Explorer - Application with range of rendering and analysis features

- ArcGIS ITEM URL : http://www.arcgis.com/home/item.html?id=d4c0bbb847584dcd9768738a3c913935
- App URL : http://arcticdemapp.s3-website-us-west-2.amazonaws.com/explorer

ArcticDEM Change Viewer - Simplified application that enables query and review of changes

- ArcGIS ITEM URL: http://www.arcgis.com/home/item.html?id=f5fe81fac2044d028547bd729edd39ad
- App URL: http://arcticdemapp.s3-website-us-west-2.amazonaws.com/change

OGC Service – Endpoints for applications that require OGC WMS and WCS connections

- Service Rest Endpoint: http://elevation2.arcgis.com/arcgis/rest/services/Polar/ArcticDEM_map/MapServer
- WMS: http://elevation2.arcgis.com/arcgis/services/Polar/ArcticDEM_map/MapServer/WMSServer?request=GetCapabilities&service=WMS
- WCS: http://elevation2.arcgis.com/arcgis/services/Polar/ArcticDEM_map/MapServer/WCSServer?request=GetCapabilities&service=WCS

Tiled Service - Tile cache of the 5 meter Alaska mosaic for faster overviews and use in story maps that require only simple visualization. Note that this may not be updated as versions of the services change.

- ArcGIS Item: http://www.arcgis.com/home/item.html?id=1e3ca671bfa74b8398bea01fd808cb2f
- Tile Service: http://tiles.arcgis.com/tiles/P3ePLMYs2RVChkJx/arcgis/rest/services/Arctic_DEM_Hillshade/MapServer

Base Reference - A base map in the Alaska Stereographic projection. If creating web applications from scratch then use this as the basemap. It has the required projection and enables one to zoom to level 17 (1.8m)

- ArcGIS Item: http://www.arcgis.com/home/item.html?id=3b178458337c4d6caacf9c1f096bbc56
- Tile Service: http://tiles.arcgis.com/tiles/P3ePLMYs2RVChkJx/arcgis/rest/services/ArcticBasemap_Alaska_Projection/MapServer

National Geospatial-Intelligence Agency

ArcticDEM and other publically available geospatial data of the Arctic is made available through the NGA's Open Data Application:

- nga.maps.arcgis.com/apps/MapSeries/index.html?appid=cf2fba21df7540fb981f8836f2a97e25

Organizational Structure

Strips

Strip ArcticDEM files are distributed in folders according to the 1° x 1° geocell in which the geometric center resides. Geocell folder naming refers to the southwest degree corner coordinate (e.g., folder *N72E129* will contain all ArcticDEM strip files with centroids within 72° to 73° north latitude, and 129° to 130° east longitude).

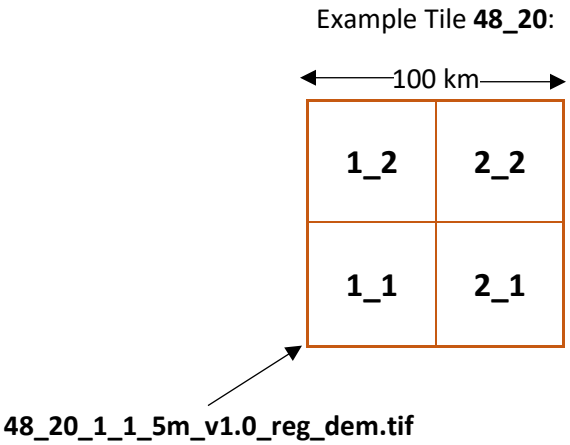
A shapefile index of all 2 meter resolution strip DEM data available to-date can be downloaded at the following link:

- http://pgc.umn.edu/system/files/ArcticDEM_Strip_Index_Rel4.zip

Mosaic Tiles

ArcticDEM mosaic files have been clipped to 100 km x 100 km tiles and organized into HTTP/FTP directory folders for distribution.

Each 100 km x 100 km mosaic folder contains four sub-tiled 50 km x 50 km DEM mosaics with appended naming according to the row/column position as illustrated in the example below:



A shapefile index of all 5 meter resolution mosaic DEM tiles available to-date can be downloaded at the following link:

- http://pgc.umn.edu/system/files/ArcticDEM_Tile_Index_Rel4.zip

Additional Information

Frequently Asked Questions

Why is the data in a Polar Stereographic map projection?

The state of Alaska will be the first region of ArcticDEM data released, although data for the entire Arctic will be released incrementally through 2017. National Snow and Ice Data Center Polar Stereographic North was selected by the ArcticDEM production team because it represents the most suitable metric projection that can be applied to the northern hemisphere north of 60°N latitude without the need for zones. Reprojections and datum transformations can be performed in nearly all contemporary GIS software programs.

Does ArcticDEM have copyright restrictions?

There is no license for the ArcticDEM data and it can be used and distributed freely.

What acknowledgements do I need to include in derived products and products that use ArcticDEM?

Please include "DEM(s) were created from DigitalGlobe, Inc., imagery and funded under National Science Foundation awards 1043681, 1559691, and 1542736."

Is SETSM software open source and available for download?

SETSM is being prepared for release to the public. Please check back for more information.

What is the difference between the ArcticDEM mosaic and strip files?

The DEM strips are extracted from DigitalGlobe, Inc., Worldview-1, Worldview-2 and Worldview-3 imagery. Each pair was acquired in a single orbit with a specific date and time.

The mosaic files are compiled from the statistically-determined, best-quality DEM strips. The largest, most complete (least void) strips are put on top. Additional DEM strips are added below until the mosaic tile is complete or data availability is exhausted. The mosaic files are at 5 meter post spacing subsampled from the 2 meter strip DEMs. Note that this is just one way to assemble a mosaic; we expect that users will assemble mosaics that fit their specialized requirements.

One important difference between the strips and the mosaic is that strips with excessive voiding or quality issues were excluded from the mosaic. The DEM strips that were excluded are still available for download as they can still be valuable for change detection or to fill holes in an end-user assembled product.

How are ground control points used to improve the data?

IceSAT altimetry data points are used to improve the vertical accuracy of both the DEM strips and mosaic files. IceSAT data points are filtered to exclude points in areas of high relief and over hydrographic features. Additional filtering is applied to remove altimetry points collected outside the temporal window of the source imagery acquisition date.

An xyz translation is calculated for each strip and the offset is added to the metadata file. The individual DEM strips are not translated before distribution. Users can apply their own corrections to the strip if they do not agree with the one originally provided.

Where available, additional control information such as LiDAR or surveyed GPS points have been applied.

Why are there holes/voids in the data?

The DEMs are extracted from optical imagery collected from orbit. Atmospheric obstructions and environmental conditions such as clouds, fog, shadows, and dust can prevent high quality elevation data from being obtained. Open water, swaying trees, and homogeneous terrain can also cause voids or unpredictable results.

If you are removing bad data then why are there still blunders and artifacts?

The filtering of blunders and omission of data due to quality considerations is a balancing act. If too little is data is filtered, poor data will remain in the DEM. If data filtering and removal is too aggressive, quality data is lost.

When will the entire Arctic dataset be available?

Data will be released on a rolling basis through 2017. In general, data will become available in the high latitudes first, then incrementally toward lower latitudes beginning with regions of good data coverage. The schedule is flexible because of availability of computer time on the Blue Waters supercomputer, and the computer cluster required to post process the data.

Why isn't the data clipped to the coastline?

Each one of the 2 meter posting DEM strips was collected over a number of years and has a date and time stamp. At this resolution coastlines, rivers, lakes, and many other types of features can change. If the data is clipped to a low-resolution coastline or a coastline from a particular year, usable, relevant data may be lost.

Why are lakes, rivers, and oceans portrayed inconsistently within ArcticDEM data (some as data voids, some flattened)?

Due to the seasonal variation in source imagery acquisition, some waterbodies were frozen while others were open. Stereo auto-correlation becomes problematic over open water due to the changing surface conditions, so data voids in

areas of open water can be expected. Water bodies that are frozen will often exist as data within the DEM files, depicted as relatively flat surfaces with varied degree of texture.

What factors must I be aware of if the imagery was collected over multiple years and all seasons?

Any factor you would consider when looking at high-resolution satellite imagery or air photography should be considered in ArcticDEM data. These include snow cover, sea ice in coastal areas, and vegetation leaf-on/off condition.

Is the source satellite imagery used to create the DEMs included?

Source imagery is not provided due to licensing restrictions. Users interested in licensing the commercial imagery should contact DigitalGlobe, Inc.

License and Usage

Disclaimer

Citation

Please include “DEM(s) were created from DigitalGlobe, Inc., imagery and funded under National Science Foundation awards 1043681, 1559691, and 1542736.”

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