IceBridge DMS L3 Photogrammetric DEM, Version 1

USER GUIDE

How to Cite These Data

As a condition of using these data, you must include a citation:

Dotson, R. and J. Arvesen. 2012, updated 2014. *IceBridge DMS L3 Photogrammetric DEM, Version 1*. [Indicate subset used]. Boulder, Colorado USA. NASA National Snow and Ice Data Center Distributed Active Archive Center. https://doi.org/10.5067/39YO5T544XCC [Date Accessed].

FOR QUESTIONS ABOUT THESE DATA, CONTACT NSIDC@NSIDC.ORG

FOR CURRENT INFORMATION, VISIT https://nsidc.org/data/IODMS3

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1 DETAILED DATA DESCRIPTION

1.1 Format

The DEMs are provided as 40 cm resolution gridded, uncompressed 32-bit floating point GeoTIFF files. For a few 23 March 2011 lines, a 20 cm grid was used because of a lower flight altitude.

NOTE: Currently, the TIFF Sample Format tag is not embedded in the images. This results in client programs either auto-detecting the pixel format, or assuming a default. It has been discovered that some programs appear to assume a 32 bit unsigned integer format, while other programs auto-detect the correct 32 bit floating point. In the near future, TIFF headers will be updated to include the TIFF Sample Format tag indicating 32 bit floating point.

Orthorectified color images are provided as 10 to 20 cm gridded compressed 8-bit RGB GeoJPEG files.

XML files contain file level metadata and location, platform, and campaign information.

1.2 File Naming Convention

The files are named using the conventions shown below. File name variables are described in Table 1:

Example for a single DMS frame:

```
IODMS3_20130402_11531664_00110_DEM.tif
IODMS3_20130402_11531664_00110_DEM.tfw
IODMS3_20130402_11531664_00110_RGB.jpg
IODMS3_20130402_11531664_00110_RGB.jgw
```

```
IODMS3_YYYYMMDD_HHMMSSXX_NNNNN_TYP.EXT
```

Where:

Table 1. DEM and Orthorectified Image Data File Naming Convention

Variable	Description
IODMS3	Short name for IceBridge DMS L3 Photogrammetric DEM
YYYY	Four-digit year of survey
MM	Two-digit month of survey
DD	Two-digit day of survey
HH	Hour (00 - 23)
MM	Minute
SS	Second
XX	Hundredths of Second
NNNNN	Sequence number from DMS camera
TYP	File content type. DEM: gridded elevation data RGB: orthorectified visible imagery
.EXT	File extension. .tif = GeoTIFF file .tfw = TIFF world file .jpg = JPEG image file .jgw = JPEG world file

1.3 File Size

GeoTIFF DEM files range from approximately 4 MB to 8 MB each.

JPEG image files range from approximately 2 MB to 10 MB each.

1.4 Volume

The entire data set is approximately 9.2 GB.

1.5 Spatial Coverage

Spatial coverage for the IceBridge DMS L3 Photogrammetric DEM campaigns include the Arctic and Antarctica from the 2011 to 2013 campaigns.

Arctic / Greenland:
Southernmost Latitude: 60° N

Northernmost Latitude: 90° N

Westernmost Longitude: 180° W

Easternmost Longitude: 180° E

Antarctica:

Southernmost Latitude: 90°S

Northernmost Latitude: 60°S

Westernmost Longitude: 180° W

Easternmost Longitude: 180° E

1.5.1 Spatial Resolution

Resolution and coverage of DEMs and orthorectified images depends on the flight elevation and source raw image resolution.

The DEMs are 40 cm resolution grids. For a few 23 March 2011 lines, a 20 cm grid was used because of a lower flight altitude.

Orthorectified images are 10 to 20 cm. For a few lines, the resolution is 5 cm, but in general it is 10 cm for Sea Ice flights.

1.5.2 Projection and Grid Description

Polar Stereographic North Pole, WGS-84

Polar Stereographic South Pole, WGS-84

The projection for all files are in EPSG 3413 for the northern hemisphere and EPSG 3031 for Antarctica.

1.6 Temporal Information

These data were collected from 18 March 2011 to 26 November 2013 as part of NASA Operation IceBridge funded campaigns.

1.6.1 Temporal Resolution

IceBridge campaigns are conducted on an annual repeating basis. Arctic and Greenland campaigns are conducted during March, April, and May, and Antarctic campaigns are conducted during October and November.

1.7 Parameter or Variable

1.7.1 Parameter Description

The IceBridge DMS L3 Photogrammetric DEMs are GeoTIFF imagery, in meters and above the WGS-84 ellipsoid.

1.7.2 Sample Data Record

The figures below display the IODMS3_20130410_14474149_06610_DEM.tif GeoTIFF DEM file, and the IODMS3_20130410_14474149_06610_RGB.jpg JPEG RGB file.

Figure 1. GeoTIFF DEM File.

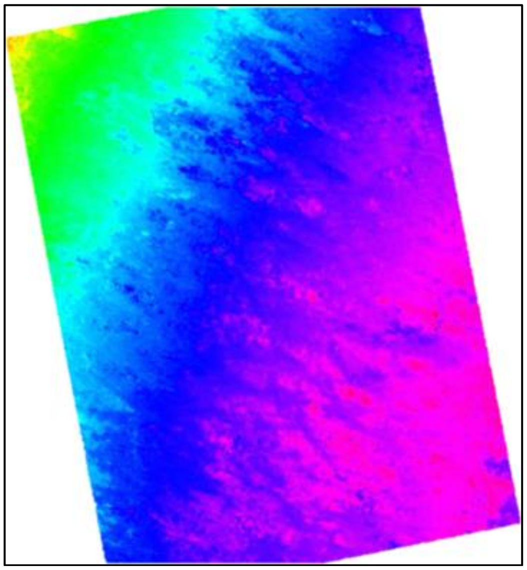

Figure 2. Orthorectified JPEG RGB image.

The listing below shows the information embedded in the GeoTIFF DEM image file in Figure 1. GeoTIFF file information can be displayed using tools such as gdalinfo from the Geospatial Data Abstraction Library (GDAL). Visit the GDAL Web site for more information.

gdalinfo output:

Driver: GTiff/GeoTIFF
Files: IODMS3_20130410_14474149_06610_DEM.tif
IODMS3_20130410_14474149_06610_DEM.tfw
Size is 1070, 1338
Coordinate System is:
Origin = (-114047.830829568890000,-2143173.486468893000000)
Pixel Size = (0.429558153786877,-0.429558153786877)
Image Structure Metadata:
INTERLEAVE=BAND
Corner Coordinates:
Upper Left (-114047.831,-2143173.486)
Lower Left (-114047.831,-2143748.235)
Upper Right (-113588.204,-2143173.486)
Lower Right (-113588.204,-2143748.235)
Center (-113818.017,-2143460.861)
Band 1 Block=1070x1 Type=UInt32, ColorInterp=Gray

The IODMS3_20130410_14474149_06610_DEM.tfw TIFF World file contains the following:

0.429558153786877

0

0

-0.429558153786877

-114047.616050492

-2143173.70124797

The IODMS3_20130410_14474149_06610_RGB.jgw JPEG World file contains the following:

0.2

0

0

-0.2

-114047.616050492

-2143173.70124797

2 SOFTWARE AND TOOLS

Software that recognizes the GeoTIFF file format is recommended for these images.
See libGeoTIFF.

Along with coordinate and projection information, additional metadata is embedded in the GeoTIFF files. NSIDC provides a MATLAB GeoTIFF reader that reads time and position from the GeoTIFF data files. The additional fields can be extracted using the gdalinfo command line utility available from the Geospatial Data Abstraction Library (GDAL). Visit the GDAL Web site for more information.

3 DATA ACQUISITION AND PROCESSING

The DMS DEM production process consists of several steps and uses a combination of commercial and custom developed software. Due to limitations of the DMS camera and limitations of the IceBridge flight plans, the photogrammetric DEMs were adjusted to an external control data set. We used IceBridge ATM L1B Elevation and Return Strength QFIT and HDF5 data for this purpose.

The DEMs are first generated by purely photogrammetric techniques using key point matching, bundle adjustment, and dense stereo depth map generation. Agisoft Photoscan™ is used to do this processing. The result of the Agisoft Photoscan™ processing is a depth map at a 1:4 resolution ratio from the original imagery.

A rigid Helmert transformation (7 parameters: 1 scale, 3 rotational, 3 translational) is then computed for each depth map to match the ATM point cloud. After alignment, the depth map is projected to a polar stereographic projection and the final DEM and orthorectified images are produced.

A quality review is performed on the final frames to identify processing failures.

3.1 Theory of Measurements

The altimetry measurements are computed by standard photogrammetric processing techniques with some necessary changes based on the DMS sensor and flight profiles used. The internal algorithmic details used by the Photoscan software package are considered proprietary and are not published by Agisoft. At a high level, the Photoscan processing steps consist of:

- Determine an approximate location for each image
- Match feature points between images (key feature points)
- Compute refined locations and orientations for each image
- Dense stereo matching and filtering
- Generation of triangulated mesh based on dense matches
- Projection of mesh to a depth map for each frame

Two fundamental challenges with the DMS raw imagery required modifications to this typical DEM generation workflow:

1. Pre-deployment calibration reports available for the DMS camera were not usable for this processing workflow. The investigators determined that several factors resulted in variation in the actual camera characteristics from the calibration report. Specifically:
    - Many data sets had changes to the camera aperture to account for scene brightness variations. Changes in aperture will affect the geometric lens distortion model as the portion of the lens used varies.
    - Temperature and vibration variation throughout the flight impacted the effective focal length of the camera, which is a key photogrammetric parameter determining scale and 3D location.
    - Focus changes to the camera impact effective focal length and lens distortion. Focus adjustments are required for the DMS camera to acquire high quality imagery, but can result in changes to the effective focal length.
2. Lack of control data and crossings.
    - IceBridge flights do not normally contain adjacent flight line grids or crossings, which are important for photogrammetric workflows because they lend numerical stability to the bundle adjustment processing. Single, long flight lines processed in Photoscan and other available photogrammetric packages result in slowly varying tilts and vertical shifts of the DEMs along the flight line. The shifts can range from several decimeters to several meters.

As a result of these limitations, raw output DEMs from the Photoscan software package have vertical and horizontal errors on the order of tens to hundreds of centimeters. In most cases, there are significant "tilts" in the output DEM surfaces which cannot be calibrated out due to the lack of adjacent flight lines.

Thus, a correction/calibration process is used to compute and apply a rigid 3D transformation to correct the depth maps prior to generating the final DEMs. The process is based on minimizing the difference between the DEM and the ATM LIDAR point cloud measurements on a per-frame basis.

The resulting singe-frame DEMs have a zero- or near-zero mean difference in absolute altitude from the corresponding LIDAR point cloud. The DEMs contain substantially more elevation detail (resolution) than the LIDAR data. In the event that LIDAR data is not available for a given frame, the frame is not processed.

3.2 Data Acquisition Methods

The input data were acquired from two locations:

- Images and LIDAR measurements were acquired from NSIDC as published data sets: IceBridge DMS L0 Raw Imagery and IceBridge ATM L1B Qfit Elevation and Return Strength data.
- Additional DMS image metadata (timestamps and trajectory info) were acquired from the DMS instrument group at NASA Ames.

3.3 Derivation Techniques and Algorithms

LIDAR Alignment Algorithm

In order to reduce the tilting and scaling issues that sometimes occur in the raw depth maps generated by Photoscan, a rigid transform is used to map these to existing ATM LIDAR data. This is done as a 4-step process:

1. Identify LIDAR points contained in the image. This is done by estimating an image footprint based on the nominal lens and camera characteristics and time-synchronized location and orientation data from the DMS sensor. This typically results in a set of several thousand LIDAR points. The points are converted to an Earth-Centered, Earth-Fixed (ECEF) coordinate system.
2. A scale is determined for the depth map. This is done by computing the average 3D distance from the relevant LIDAR points to the exposure location. For each LIDR point, the point is projected onto the image, determining an X-Y pixel coordinate for that point. The depth (range) for that pixel in the depth map is recorded. A single image-wide scale factor is then computed to convert the Photoscan depth map scale to the LIDAR physical scale based on the parings of LIDAR distances and depth map distances to the exposure location.
3. The re-scaled points from Step 2 define a second 3D point cloud from the depth map. This depth map point cloud is used to compute a Helmert transformation for the entire image based on the corresponding LIDAR points. The Helmert transform is computed by a Singular Value Decomposition (SVD) method on the sparse point pairs (Sjöbert 2013).

4. The transform and scale factor are applied to the entire depth map, resulting in a "dense" 3D point cloud in ECEF coordinates. The point cloud is converted to Polar Stereographic coordinates, and a Delaunay triangulation of the point cloud is computed. The point cloud is then rasterized based on the triangulation to the final gridded DEM.

3.3.1 Trajectory and Attitude Data

The trajectory and attitude data used in processing were acquired by the DMS Applanix POS/AV 510 system and provided by the DMS instrument group.

3.3.2 Processing Steps

An outline of the processing steps follows:

1. Correlation of raw imagery with DMS navigation data (Lat/Lon/Alt/Roll/Pitch/Heading/Time)
2. Import raw frames and metadata into Photoscan software package on a per-flight basis
3. Photoscan processing workflow:
    a. Group images into blocks of 25 frames
    b. Match features across image block
    c. Adjust image alignment (bundle adjustment)
    d. Dense Point Matching
    e. Depth Map Generation
    f. Export Depth Maps
4. Correction processing
    a. Import depth maps and determine ATM data for each frame extent
    b. Compute rigid transformation for each frame
    c. Rectify and output final DEM and RGB files
5. Quality review
    a. Automated comparison of output DEMs with LIDAR cloud including elevation offsets and Standard deviation of error.
    b. Manual inspection of suspect frames, rejecting those with clear problems

3.3.3 Version History

The underlying accuracy of the measurements can depend on a number of factors, including:

- **Camera calibration and stability**. This typically manifests in two forms:
    - Focal length errors, which result in scale factor error in the Z-dimension of the raw frame. The LIDAR correction algorithm is designed to correct this.
    - Distortion errors. In some cases, the distortion estimation routines in the Photoscan software package result in a poor lens distortion model. This can result in DEMs which are slightly concave or convex on the edges.
- **GPS trajectory accuracy for DMS exposure locations**. This is generally not a concern due to the correction against LIDAR data.
- **Ability to match points between frames**, both for sparse and dense matching steps. In some cases, especially with low-contrast images with fog or clouds, the Photoscan software may be not able to match points. This can result in a failure to produce any depth map, or can

occasionally produce depth maps with some artificial features. In some cases, low contrast sea ice or sheet ice can exhibit spikes in the final DEM. JPEG compression artifacts can amplify this effect.

- **Accuracy of ATM data set.** Given the LIDAR correction process in use, any systematic errors in the ATM Level-1B data set will impact the photogrammetric DEMs.
- **Accuracy of the alignment process for depth map correction.** The correction process depends on having a reasonable estimate for initial alignment between the LIDAR point cloud and the raw image footprint. Large initial displacements could cause incorrect correction processes. In this case, the mean vertical error is typically still near zero.
  Errors and Limitations

3.4 Sensor or Instrument Description

DMS provides natural color or panchromatic tracking imagery from low and medium altitude research aircraft. The system configuration includes a 21 megapixel Canon EOS 5D Mark II digital camera, computer-controlled intervalometer, and an Applanix POS/AV precision orientation system. In-flight operators maximize image quality with adjustments to exposure and intervalometer settings.

4 REFERENCES AND RELATED PUBLICATIONS

Sjöbert, L. E. 2013. Closed-form and Iterative Weighted Least Squares Solutions of Helmert Transformation Parameters, Journal of Geodetic Science. 3(1): 7–11, ISSN (Print) 2081-9943, DOI: 10.2478/jogs-2013-0002.

4.1 Related Data Collections

- GLAS/ICESat 1km Laser Altimetry Digital Elevation Model of Greenland
- IceBridge ATM L1B Elevation and Return Strength
- IceBridge DMS L0 Raw Imagery
- IceBridge DMS L1B Geolocated and Orthorectified Images
- IceBridge CAMBOT L1B Geolocated Images

4.2 Related Websites

- NASA Digital Mapping System Web page
- IceBridge Data Web site at NSIDC
- IceBridge Web site at NASA
- ICESat/GLAS Web site at NASA Wallops Flight Facility
- ICESat/GLAS Web site at NSIDC

5 CONTACTS AND ACKNOWLEDGMENTS

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6 DOCUMENT INFORMATION

6.1 Publication Date

03 December 2014

6.2 Date Last Updated

26 January 2015