Antarctic 5-km Digital Elevation Model from ERS-1 Altimetry, Version 1

USER GUIDE

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National Snow and Ice Data Center

TABLE OF CONTENTS

1 DATA DESCRIPTION

This data set provides a Digital Elevation Model (DEM) for Antarctica to 81.5 degrees south latitude, at a resolution of 5 km. Approximately twenty million data points were used to generate this data set. Data points were derived from ERS-1 radar altimetry during the geodetic phase from March 1994 to May 1995.

This Digital Elevation Model (DEM) provides coverage of the Antarctic ice sheet to 81.5°S at 5 km resolution. Approximately 20,000,000 data points were used to generate this data set. Data points were derived from ERS-1 radar altimetry during the geodetic phase from March 1994 to May 1995. DEM data are in a polar stereographic projection with the origin at the South Pole, and are referenced to the OSU91A geoid.

The improved density in coverage and resolution, compared with past satellite altimetry missions, provides better detection of topographic detail such as surface undulations, ice streams, grounding zones, and interstream ridges. Prior to the ERS-1 radar altimeter, researchers had very limited knowledge of the topography of Antarctica south of 72°S. The geodetic phase of ERS-1 provided coverage of the ice sheet to 81.5°S, with a higher density of data collection than previous satellite altimetry missions. When the DEM was gridded to 5 km resolution, it provided researchers with a more detailed observation of ice sheet flow characteristics and topography.

Radar altimetry data is generally used for studies of ice sheet mass balance and ice dynamics (direction and magnitude of ice flow). The 5 km resolution DEM for the Antarctic ice sheet provides detection of subtle topographic features including: surface undulations, flow lines, ice streams, interstream ridges, and grounding zones.

1.1 File Information

1.1.1 Format

Data are provided in space-delimited ASCII text format.

1.1.2 File Contents

Data are available on the HTTPS site in the https://daacdata/apps.nsidc.org/pub/DATASETS/BAMBER_DEM/ directory.

Within this directory, there is one file: bamber.5km97.dat

File size: 38720 KB

Sample ASCII output from bamber.5km97.dat:

Table 1. Sample Data Record

Lat	Lon	Elev	Difference
-81.3404	138.867	2375.68	-44.24
-81.3102	138.639	2387.87	-44.17
-81.2799	138.412	2396.72	-44.07
-81.2495	138.187	2403.71	-43.96

Columns represent latitude, longitude, and elevation with reference to the OSU91A geoid. The last column is the difference between the OSU91A geoid and the WGS84 ellipsoid. A value of 999.999 represents a grid cell where interpolation was not possible.

Latitude and longitude are expressed in decimal degrees to two decimal places. Negative longitude values represent the Western Hemisphere, and negative latitude values represent the Southern Hemisphere.

1.2 Spatial Information

1.2.1 Coverage

This data set contains surface elevations of the Antarctic ice sheet derived from ERS-1 from 65°S to 81.5°S. Antarctic Digital Database data filled the gap between 81.5°S to 90°S. Elevations in this region, along with areas of open ocean, are set to a fill value of 999.999

The dark circle in Figure 1 represents non-altimetric data from the Antarctic Digital Database used to fill in the area between 81.5- and 90-degrees South latitude.

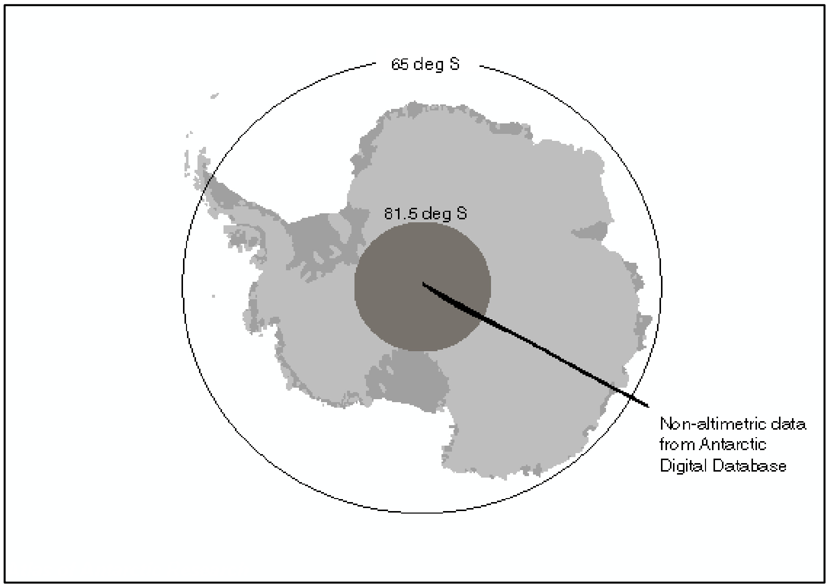

Figure 1. Spatial Coverage Map of Bamber DEM.

1.2.2 Resolution

The data are gridded with a cell size of 5 km.

1.2.3 Geolocation

Data are in a polar stereographic projection with geodetic latitude and longitude coordinates. The origin is at the South Pole. The projection is referenced to the WGS84 ellipsoid with an equatorial radius of 6378.137 km and an eccentricity of 0.081819190843. The standard parallel is 71°S.

A Cartesian grid is centered on the South Pole, with grid dimensions of 1121 by 1121 pixels and a range of -2800 km to + 2800 km. The following table summarizes the locations of the centers of selected grid cells in the DEM:

Table 2. Centers of selected grid cells in the DEM

Cell	Column	Row	Line	Latitude	Longitude
Upper left	0	0	1255521	-54.6732	-44.999
Upper right	1120	0	1256641	-54.6726	45.000
Lower left	0	1120	1	-54.6738	-135.000
Lower right	1120	1120	1121	-54.6732	134.999
Center	560	560	628321	-89.9993	45.000

1.3 Temporal Information

1.3.1 Coverage

Data were derived from ERS-1 radar altimetry during the geodetic phase from March 1994 to May 1995.

1.3.2 Resolution

Data were collected daily from the ERS-1 satellite for 336 days.

2 DATA ACQUISITION AND PROCESSING

2.1 Background

Satellite radar altimeters measure the time it takes an electromagnetic signal to travel from the altimeter antenna to the ice sheet surface and back to the altimeter's receiver. This range measurement allows investigators to determine the satellite's height above the ice sheet. See the Sensor or Instrument Description section of this document for more information.

Corrections are applied to the range measurements to account for the fact that returns are different over ice than over the ocean. The correction for interpreting the data over ice is called "retracking," and is described in papers by Davis and Zwally (1993), and Zwally, et al. (1983).

Over sloping terrain, the radar altimeter measurement needs to be corrected because the return comes from a point not directly below the satellite, but to the uphill side. The elevation indicated by the return time in this case is higher than that directly below the satellite. The data are slope-corrected to reduce the errors, using the slope correction algorithm from Brenner et al. (1983).

2.2 Acquisition

In March 1995, ERS-1 was operating along two repeat cycles of 168 days, which were offset so that they were equivalent to a single 336-day cycle. This provided 8.3 km across-track spacing at the equator, 4 km spacing at 60°S, and 2 km spacing at 70°S. The along-track spacing of each altimeter height measurement is 335 m (Bamber and Bindschadler 1997).

Detailed coverage of the Antarctic ice sheet by the ERS-1 radar altimeter, compared with past satellite altimetry missions, has improved the accuracy of the corresponding DEM by ensuring coverage of marginal regions, reducing spacing between adjacent sub-satellite tracks (thus reducing slope-induced error), and reducing random errors in individual altimeter height measurements.

A quantitative assessment of DEM accuracy is difficult to determine due to the lack of in situ validation data from the Antarctic ice sheet. However, vertical and horizontal accuracy are known to have improved from earlier Antarctic DEMs. To improve the accuracy of elevation estimates, various corrections were applied to the data including: a range-estimate refinement procedure (waveform tracking), slope correction, data filtering, and removal of anomalous orbits (Bamber and Bindschadler 1997).

2.3 Processing

The following discussion applies to the interior Antarctic ice sheet to 81.5°S.

2.3.1 Waveform Retracking

The purpose of a waveform retracking algorithm is to calculate the difference between a tracking point derived by the onboard software and a known, fixed position on the leading edge of a waveform signal. The point on a waveform that corresponds to the point on the surface closest to the satellite typically does not provide a useful representation of the surface height. However, determining elevation at any other location presents a problem because facets (faces of topographic features) with different elevations result in the interpretation of complex leading edges. Waveform analysis over variable terrain is a complicated procedure which requires prior knowledge of surface properties. Threshold and beta (ß) parameter retracking algorithms were used because they were considered the best methods for estimating the elevation at specific points (Bamber 1994).

2.3.2 Slope Induced Error Correction

A relocation algorithm was used to locate the closest point to the satellite and calculate the correction necessary to determine the surface elevation at that point, using an estimate of the surface slope magnitude and direction. For each data point, the algorithm first extracts the appropriate slope correction values from a look-up table, and calculates the magnitude and direction of the slope based on the range to the satellite. The latitude and longitude of this point is then estimated. The algorithm also calculates an elevation correction to account for the measurement not being taken at the satellite's nadir. The revised surface elevation is calculated using the relocation method (Bamber 1994).

2.3.3 Processing Steps

To make these data more useful in comparative studies, or as a control for ice sheet data and to avoid the need for other Level 2 products, Bamber attempted to improve the accuracy of elevation estimates of variable topographic surfaces with minimal biases by using the following steps (Bamber 1994).

1. A range-estimate refinement procedure (waveform tracking) was implemented using the offset center of gravity method for calculating the waveform amplitude, with a power threshold of 25 percent.
2. Slope correction was applied using a variation of the relocation method (Bamber 1994).
3. Data filtering techniques were implemented, including tests applied to the return-echo waveform shape, backscatter coefficient, and retracking correction value for each altimeter height estimate. Approximately 27 percent of the data were removed during this procedure.
4. Anomalous orbits were removed, by comparing one track with another where they cross (cross-over analysis).
5. Data were interpolated onto a 5 km grid, and a two-stage gridding procedure was employed with the following steps:
    a. Production of a local distance-weighted means of x, y and z in the region of a grid point, producing a quasi-regular array of average height estimates.
    b. A triangulation procedure to interpolate to the exact grid point locations and to extrapolate to grid points where no altimeter data were present (Bamber, Ekholm, and Krabill 1998).

2.4 Quality, Errors, and Limitations

2.4.1 Data Validation by Source

Data were validated by a validation procedure that uses surface elevation and backscatter coefficient data collected from an area larger than the antenna footprint. A surface is fitted to these data and used as input into an altimeter waveform simulator program. The output is a range estimate, which is compared with the actual altimeter range measurement. Slope-induced error is not considered at this point because it could potentially mask all other variables. The program also calculates surface elevation, an estimate of the relocated latitude and longitude coordinates, and a slope magnitude and direction. These data can be used to assess how well the processing sequence, including the slope correction algorithm, is performing. The magnitude of the difference between the two data sets depends primarily on how large the slope values are, and how accurately they are known. Limited in situ data sets were available for validating the surface DEM (Bamber, Ekholm, and Krabill 1998).

2.4.2 Measurement Error for Parameters

A lack of in situ data precludes an exact quantitative assessment of the improvement in accuracy of the 5 km DEM based on ground truth data, as compared with lower resolution DEMs (Bamber 1997). However, results were similar to those from the 10 km grid. For this particular grid surface, slopes less than 0.4° were estimated to have an accuracy better than 1.5 m. For surface slopes greater than 0.65°, height estimates from the altimeter become unreliable. This affects 10% of Antarctica, primarily near the ice margins. The precision for a single data point is ± 0.81 m. This value represents an average over all the different surface types. Accuracy ranges from 10.7 m at 65°S and a slope of 0.65°, to 1.4 m at 75°S and a slope of 0.1°. These errors are dominated by the height variability within each grid cell, rather than errors in the individual altimetric elevation estimates. In summary, the accuracy and noise level of the altimeter data is best over the ice shelves as they are the flattest regions in Antarctica (Bamber, Ekholm, and Krabill 1998, Bamber 1994).

2.4.3 Error Sources

The following discussion applies to the interior Antarctic ice sheet to 81.5°S.

2.4.4 Sources of Error

Errors in altimeter data can be introduced from several sources including geographically correlated orbit errors, errors in slope correction procedures, and non-uniform spatial sampling (Bamber, Ekholm, and Krabill 1998).

2.4.5 Limitations of the Data

Problems still remain with lack of high-density surface elevation estimates south of 81.5°S.

2.5 Instrumentation

2.5.1 Description

A radar altimeter collects elevation signals from land and ocean surfaces. These data are used to determine topographical features. This data set uses a radar altimeter instrument on the ERS-1 Satellite that measures the distance from the satellite to the Earth's surface using a radar signal. The instrument transmits an electronic pulse in the microwave frequency to the Earth's surface. The microwave pulse reflects off the surface and returns to the sensor. Altitude is determined from the pulse travel time (from transmit to receive) and from the waveform of the returned pulse.

2.5.2 Sensor/Instrument Mission Objectives

The radar altimeter measures the altitude of the Earth's surface to determine ice sheet topography and small-scale ocean roughness.

2.5.3 Key Variables

Satellite orbit, tropospheric/ionospheric signals, and geoid model.

2.5.4 Scanning or Data Collection Concept/Principles of Operation

The radar altimeter sends electromagnetic pulses at a microwave frequency to a land or ocean surface, then detects the reflected signals. The waveform data are then transmitted to a ground receiving station.

2.5.5 Sensor Description

The two major subsystems of the radar altimeter are: A peak power (RF) section and a signal processor.

2.5.6 *GEOSAT Radar Altimeter

Transmitter

- Type -- traveling wave tube
- Peak power (RF) -- 20 Watts (minimum)
- Power consumption -- 70 Watts

Receiver

- Type -- Dual conversion (500Mhz, 0h)
- Automatic gain control -- 0 to 63 decibels (1-dec steps)

Antenna

- Type -- 1-m parabolic
- Gain -- >37.6 decibels
- Beamwidth -- 2.0 degrees

Weight

- Signal processor -- 47 pounds
- RF Section -- 144 pounds

Envelope (in)

- RF section -- 41.25 (diameter) X 11.5 (height) = 15,369 cubic inches (-antenna)
- Antenna -- 41.25 (diameter) X 19.125 (height) = 25,559 cubic inches (incl. feed)
- Signal processor -- 20 (length) X 13.5 (width) X 10 (height) = 2700 cubic inches

*The GEOSAT and SEASAT radar altimeters share mechanical, thermal, and electrical interface characteristics.

Table 3. Radar Altimeter Characteristics for Various Satellites

Satellite	**Frequency (Ghz)**	**Bandwidth**	**Wavelength (m)**	**Range Resolution (m)**	**Pulse Compression**	**Wave Height**
ERS-1	13.50	400.00	0.02	0.10	8000.00	
ERS-2	13.50		0.02	0.1	58000.00	.13 m
Geos-3	13.90	80.00	0.02	0.50	30.00	±25% (4-10 m)
GEOSAT	13.50	320.00	0.02	0.10	30000.00	±10% (1-20 m)
GEOSAT Follow-On	13.50		0.02	0.018	58000.00	.035 m
SEASAT	13.50	320.00	0.02	0.10	1000.00	± 10% (1-20 m)
Skylab	13.90	100.00	0.02	1.00	13.00	1-2 m
TOPEX/Poseidon	5.3&13.6	320.00	.0566*amp;.02205	0.03	58000.00	.13 m

2.6 Calibration

Specifications

The GEOSAT radar altimeter contained an on-board calibration mode that was invoked twice daily to track waveform sample gain and attitude, wave height, automatic gain control, and height.

For waveform sample gain correction, the onboard tracker operated on a set of 60 waveform samples in the power spectrum outputs of a digital filter bank. Effects, such as in-band ripple and band-edge rolloff of anti-aliasing low-pass filters in the altimeter receiver were removed by individual waveform sample gain correction factors.

The correction processes of the attitude determination (and related corrections) started with computation of a voltage proportional to attitude (VATT) based on the amplitude of the last eight waveform samples.

3 CONTACTS AND ACKNOWLEDGMENTS

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5 DOCUMENT INFORMATION

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