Radarsat Antarctic Mapping Project Digital Elevation Model, Version 2

USER GUIDE

How to Cite These Data

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

Liu, H., K. C. Jezek, B. Li, and Z. Zhao. 2015. *Radarsat Antarctic Mapping Project Digital Elevation Model, Version 2*. [Indicate subset used]. Boulder, Colorado USA. NASA National Snow and Ice Data Center Distributed Active Archive Center. https://doi.org/10.5067/8JKNEW6BFRVD. [Date Accessed].

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National Snow and Ice Data Center

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The high-resolution Radarsat Antarctic Mapping Project (RAMP) digital elevation model (DEM) combines topographic data from a variety of sources to provide consistent coverage of all of Antarctica. Version 2 improves upon the original version by incorporating new topographic data, error corrections, extended coverage, and other modifications.

This DEM incorporates topographic data from satellite radar altimetry, airborne radar surveys, the recently-updated Antarctic Digital Database (Version 2), and large-scale topographic maps from the U.S. Geological Survey (USGS) and the Australian Antarctic Division. Data were collected between the 1940s and present, with most collected during the 1980s and 1990s. Although the RAMP DEM was created to aid in processing RAMP radar data, it does not utilize any RAMP radar data.

The 1 km, 400 m, and 200 m DEM data are provided in ARC/INFO and binary grid formats, and the 1 km and 400 m DEMs are also available in ASCII format. Data access is unrestricted, but users should register to receive e-mail notification of product updates and changes in processing.

1 APPLICATIONS

The RAMP DEM was created for use in processing images for the *RAMP AMM-1 SAR Image Mosaic of Antarctica*. The DEM has potentially broad applicability to studies of ice sheet morphology and ice dynamics. Current and planned applications include flow line mapping, catchment area determination, balance velocity mapping, and atmospheric modeling. The DEM is not appropriate for direct detection of elevation change by comparison with other DEMs, unless those changes are very significant (> ± 15 m).

2 DETAILED DATA DESCRIPTION

The RAMP DEM was developed by integrating a broad variety of available topographic source data in a GIS environment. By combining the comparative advantages of all available sources, the developers were able to fully exploit the most detailed and accurate topographic information in each data set. Error checking procedures included global statistical analysis, cross-validation methods, and creation of a synthetic stereo image for visualizing and detecting gross errors in the elevation data (Liu 1999). A new data integration technique allowed the developers to produce a DEM that is both seamless and geomorphologically consistent with ice-covered and ice-free terrain. The DEM captures details of geomorphology, ranging from small-scale mountain valleys to extensive ice sheet drainage basins.

Version 2 of the RAMP DEM incorporates diverse improvements over the original version, with effects in numerous application areas of Antarctica.

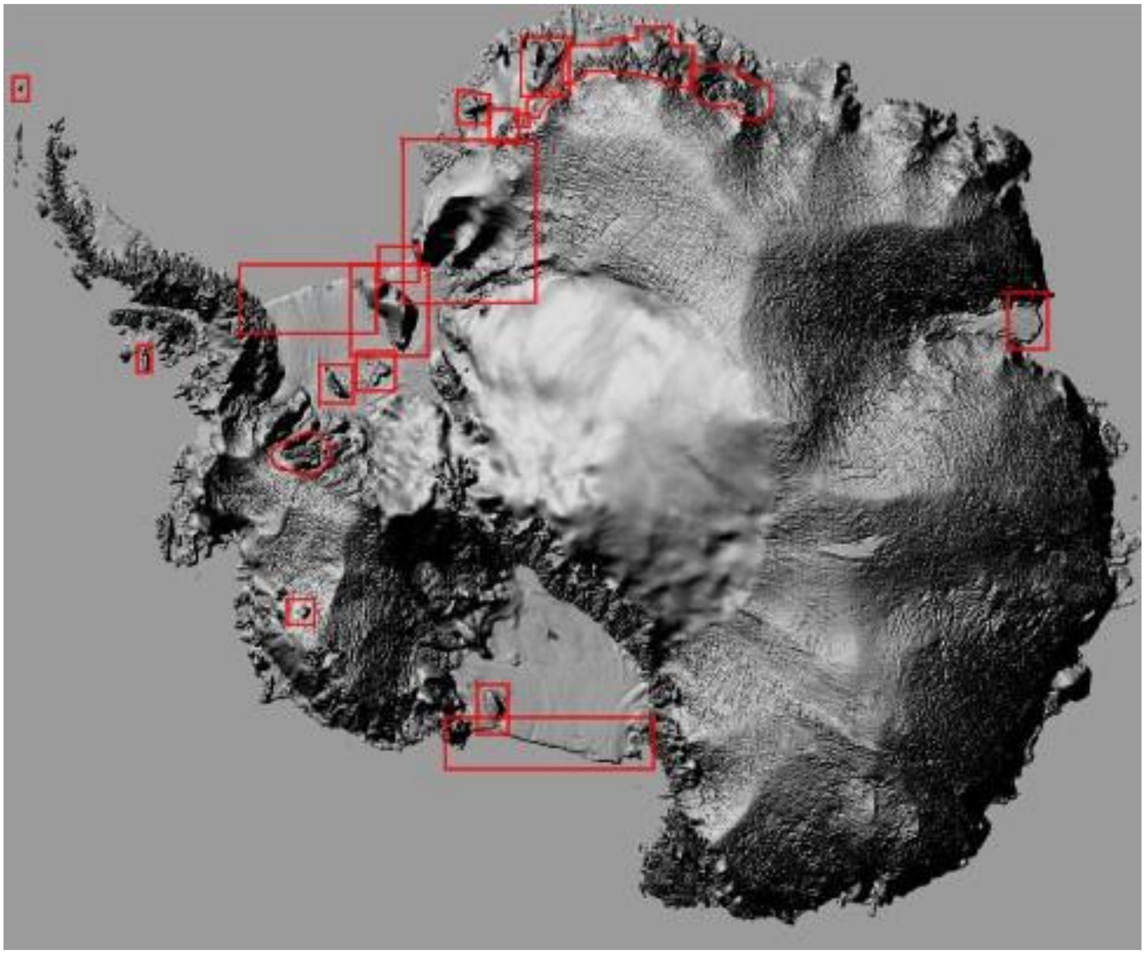

Figure 1. Application areas in Antarctica

The application areas in Antarctica are summarized below (table adapted from Jezek et al. 1999):

Table 1. Summary of Method and Application Areas

Method	Application areas
Increased accuracy and resolution using newly available data	Coats Land, Theron Mountains, Berkner Island, Henry Ice Rise, and Korff Ice Rise
Extended DEM over islands and surrounding ocean surface in support of sea ice and oceanography studies	South Shetland Islands, Latady Island, Weddell Sea, Amundsen Sea, Davis Sea, ocean around Queen Maud Land, and Shackleton Ice Shelf
Achieved better data selection and surface constraints using updated coastlines and grounding lines derived from the SAR mosaic	coastline for the entire continent, particularly the ice margins of Ross Ice Shelf, Amery Ice Shelf, and Filchner-Ronne Ice Shelf; Filchner Ice Shelf and Roosevelt Island grounding lines
Removed artifacts in the DEM by adjusting interpolation parameters and densifying contours	Crary Mountains, Sør Rondane Mountains
Corrected planimetric errors using SAR simulation and warping techniques	Ellsworth Mountains

2.1 Format

2.1.1 Data Source

The data originate from various sources. The developers and data contributors compiled a comprehensive collection of digital topographic source data. The data used can be grouped into the following three categories:

- cartographic data
- remotely sensed data
- survey data

Cartographic data include contours, spot height points, and surface structure lines digitized from paper topographic map sheets. Remotely sensed data consist of the European Remote Sensing Satellite-1 (ERS-1) satellite radar altimeter and airborne radar echo-sounding data. Survey data include ground-based survey data and satellite-based GPS measurements.

The following investigators contributed data:

- Jay Zwally of the NASA Goddard Space Flight Center, USA
- Anita Brenner and John DiMarzio of Raytheon Corporation, USA
- Jonathan Bamber of the Center of Remote Sensing, University of Bristol, UK
- Paul Cooper, David Vaughan, and Phil Homes of the British Antarctic Survey, UK
- Ted Scambos of the National Snow and Ice Data Center, USA
- Craig Lingle of the University of Alaska, USA
- Lee Belbin, Ursula Ryan, and Mike Craven of the Australian Antarctic Division, Australia
- Cheryl Hallam and Jerry Mullins of the USGS, USA
- Johannes Ihde of the Institut fur Angewandte Geodasie, Germany
- Ian Whillans, Paul Berkman, and Terry Wilson of the Ohio State University, USA

2.1.2 Data Format

All DEM data are provided in ARC/INFO and binary grid formats, and the 1 km and 400 m DEMs are also available in ASCII format. Following is a chart that summarizes characteristics of the binary grid.

Table 2. Binary Grid

	1 km	**400 m**	**200 m**
Rows	4916	12290	24580
Columns	5736	14340	28680
Byte Order	Big Endian	Big Endian	Big Endian
Bytes per Cell	2	2	2
Cell Size	1000 m	400 m	200 m
Bands	1	1	1
Row Bytes	11472	28680	57360

ASCII grids contain fields for latitude, longitude, elevation relative to the WGS84 ellipsoid, and elevation relative to the OSU91A geoid. Data are represented in decimal degrees, from -180 degrees (west) to 180 degrees (east) longitude; and -90 to -60 (south) degrees latitude.

ARC/INFO coverages of RAMP DEMs are organized into individual directories for each resolution (1 km, 400 m, and 200 m) and geoid/ellipsoid.

2.1.3 Unit of Measurement

Elevations for points in this data set are measured in meters [m] above both the WGS84 ellipsoid and the OSU91A geoid. (See Section 2.3.1 for a list of files referencing these two models.)

While the WGS84 ellipsoid is based on an approximation of the Earth's shape using only an equatorial radius and a polar radius (or a radius and an eccentricity), the OSU91A geoid is a more complex surface representing mean sea level. The OSU91A geoid is reported as a height above or below the WGS84 ellipsoid. The relationship between the two for the RAMP DEM can be described algebraically as follows:

$S = W - G$

Where:

W are the WGS84 elevations
G are the OSU91A elevations
S are mean sea level elevations of the OSU91A geoid, relative to the WGS84 ellipsoid

2.1.4 Data Range

Values are in meters for each grid.

Table 3. Grid Values in Meters

	Minimum	Maximum
OSU91A 200 m	0	5022
WGS84 200 m	-67	5008
OSU91A 400 m	0	5012
WGS84 400 m	-67	4997
OSU91A 1 km	0	4982
WGS84 1 km	-67	4968

Note: Maximum values decrease with increasing grid spacing because a larger region is averaged for each grid cell. Maximum elevation values are found in the Ellsworth Mountains near Vinson Massif. Zero values are at the coast; there are no points in the interior of Antarctica that are at or below sea level (i.e. with a geoid elevation of zero or less).

2.2 Sample Data Records

The following is sample output from a 1 km ASCII DEM file:

```
(       Lat      Lon      WGS  OSU  )

   -78.99166  -23.45572 1124 1134
   -78.99529  -23.41189 1122 1132
   -78.99891  -23.36804 1119 1129
   -79.00253  -23.32415 1116 1126
   -79.00613  -23.28023 1113 1123
   -79.00974  -23.23629 1109 1119
   -79.01333  -23.19231 1105 1115
   -79.01692  -23.14831 1102 1112
```

2.3 Data Organization

2.3.1 Data Granularity

A granule of RAMP DEM data (i.e. the smallest aggregation of data that is independently retrievable) includes coverage of the entire continent at a given resolution and geoid/ellipsoid model. Compressed and uncompressed file sizes are summarized below.

Table 4. Data Granules

Format	Granule File Name	Compressed	Uncompressed
ARC/INFO	demosu1km_v2.tar.gz	11 MB	25 MB
ARC/INFO	demwgs1km_v2.tar.gz	11 MB	25 MB
ARC/INFO	demosu200_v2.tar.gz	136 MB	324 MB
ARC/INFO	demwgs200_v2.tar.gz	141 MB	330 MB
ARC/INFO	demosu400_v2.tar.gz	39 MB	112 MB
ARC/INFO	demwgs400_v2.tar.gz	40 MB	114 MB
ASCII	ramp1kmdem_wgsosu_v2.txt.gz	151 MB	424 MB
ASCII	ramp400dem_wgsosu_v2.txt.gz	860 MB	2649 MB
Binary	ramp1kmdem_osu_v2.bin.gz	15 MB	56 MB
Binary	ramp1kmdem_osu_v2.hdr		
Binary	ramp1kmdem_wgs_v2.bin.gz	15 MB	56 MB
Binary	ramp1kmdem_wgs_v2.hdr		
Binary	ramp200dem_osu_v2.bin.gz	270 MB	1410 MB
Binary	ramp200dem_osu_v2.hdr		
Binary	ramp200dem_wgs_v2.bin.gz	274 MB	1410 MB
Binary	ramp200dem_wgs_v2.hd		
Binary	ramp400dem_osu_v2.bin.gz	61 MB	352 MB
Binary	ramp400dem_osu_v2.hdrr		
Binary	ramp400dem_wgs_v2.bin.gz	64 MB	352 MB
Binary	ramp400dem_wgs_v2.hdr		

2.4 Data Manipulation

2.4.1 Derivation Techniques and Algorithms

Interpolation of Satellite Radar Altimeter Data

The radar altimetry data sets for the RAMP Antarctic DEM had already been corrected for tracking and slope errors and preprocessed into evenly distributed points with a spacing of about 5 km, prior to being combined with the many additional data sets. Refer to NSIDC's Radar Altimeter page for more information (Davis and Zwally 1993, Zwally et al. 1983, and Brenner et al. 1983). The RAMP DEM development team used the Triangulated Irregular Network (TIN) Quintic interpolation method to further interpolate the satellite radar altimeter data (Liu, Jezek, and Li 1999).

Interpolation of Traverse Airborne Radar Data

Airborne radar data are densely sampled along flight lines but widely separated between flight transects. Most interpolation algorithms have difficulty resolving such a pattern. The development team for the RAMP Antarctic DEM used a procedure that combines the quadrant neighborhood-based Inverse Distance Weight (IDW) method to stabilize the interpolation result, with the TIN method to retain the topographic details present in the source data (Liu, Jezek, and Li 1999).

Interpolation of Contour-based Cartographic Data

Contour data are characterized by oversampling of information along contour lines and undersampling between contour lines, especially in low relief areas with widely spaced contours. It is the most difficult data type to interpolate with general-purpose interpolation techniques. The development team chose to use the TOPOGRID-based method (Hutchinson 1988; Hutchinson 1989; ESRI 1991; Gesch and Larson 1996) to interpolate the cartographic data in the RAMP Antarctic DEM. The team modified the TOPOGRID method slightly (Liu, Jezek, and Li 1999) to compensate for spurious sinks that occur in contour sparse areas corresponding to low slope areas like glacial valley floors (Bliss and Olsen 1996).

Determination of DEM Grid Spacing

The horizontal grid spacing of DEMs is an important parameter that needs to be specified during interpolation. In general, a small grid spacing is required to obtain an accurate representation of the surface details for a rugged and mountainous terrain, while a large grid spacing is sufficient for a low-relief terrain. For the satellite radar altimeter data and the airborne radar data, a post spacing of 1 km was used. For the contour data, 200 m grid spacing was used for rugged mountainous areas where the contour density is very high, while 400 m grid spacing was used for the sloped coastal area where the contours are relatively smooth and regularly, broadly spaced (Liu, Jezek, and Li 1999).

Data Integration

For mountainous and sloped coastal margins, the development team integrated the contour data, the spot elevation points, coastlines, grounding lines, and limited GPS data during the interpolation process. To avoid the edge effects, all the source data layers are merged into a number of overlapping blocks, and the interpolation extent at each time is set much smaller than that of input data. Individual DEM data sets are merged by using GIS logical "clipping" and "inserting" operations along coastlines and grounding lines, and by using a cubic Hermite blending function (S-shaped) along irregular buffer zones (Liu, Jezek, and Li 1999).

2.4.2 Accuracy

Horizontal (Spatial) Resolution

The real horizontal resolution of the DEM varies from place to place according to the density and scale of the original source data. The developers of the data set estimate that the horizontal resolution of the DEM is about 200 m in the Transantarctic Mountains and Antarctic Peninsula, and about 400 m in the sloped coastal regions. For ice shelves and the inland ice sheet covered by satellite radar altimeter data, the horizontal resolution is about 5 km, but where the airborne radar sounding data were used, the horizontal resolution is about 1 km. For the plateau inside 81.5 degrees south latitude, horizontal resolution is estimated at about 10 km (Liu, Jezek, and Li 1999).

Geolocation Accuracy

The accuracy of geolocation (i.e., the accuracy of the position of a given feature on the DEM) is governed by the accuracy of topographic data sources, and is generally better than the horizontal resolution of the DEM.

Vertical Accuracy

Vertical accuracy of the RAMP Antarctic DEM is ± 100 m over rugged mountainous areas, ± 15 m for steeply sloped coastal regions, ± 1 m on the ice shelves, ± 7.5 m for the gently sloping interior ice sheet, and ± 17.5 m for the relatively rough and steeply sloped portions of the ice sheet perimeter. For latitudes south of 81.5 degrees south, within the interior East Antarctic ice sheet and away from the mountain ranges, vertical accuracy is estimated to be ± 50 m (Liu, Jezek, and Li 1999).

2.4.3 Error Handling

Potential errors in the RAMP DEM include imperfections in the measuring instrument, faulty readings or recordings, calculation and execution faults, and digitizing errors. Errors were noted in the ARC/INFO contour coverages, with mislabeled contours and intersections of contours. In some cases, digitized contour lines deviated from their original position on the source map and often intersected one other, resulting in some positions having two or more conflicting values. Also, poor ground control and inaccurate navigation techniques used to acquire the original topographic data were noted. Some ground control points were assigned erroneously large values, due to data entry errors. The RAMP DEM development team employed a variety of techniques to detect and correct these errors (Liu 1999).

Global Statistical Analysis

Summary statistics were calculated from the ARC/INFO attribute tables where elevation data reside. These global statistics were used to identify extreme erroneous values, namely the elevation range, from prior knowledge about a specific region or from the frequency distribution of elevation measurements. Data points with elevation values outside the reasonable range were flagged, and erroneously large values and negative values for elevation were removed. Contour lines with irregular elevation values were detected and corrected according to the values of neighboring contours.

Cross-Validation

Cross-validation methods were used for multiple data sets that overlap in the same area. Spot height points were checked against corresponding contour coverages by first predicting the elevation values at the positions of spot points by interpolating between contours, then computing the differences between the interpolated values and spot height values. Points that had an absolute difference greater than one contour interval in the flat area and two times greater than the contour interval in highly variable areas were removed. Cross-checking was similarly conducted between contour data and satellite radar altimeter data.

Visual Inspection

Errors in elevation data were detected with a variety of interactive methods including perspective views, color sequence in contour lines, hill shading, and synthetic stereo display. In areas of question, contour lines were overlain with the source data to reveal errors in elevation values. When the DEM grid was rendered as a hill shaded image or synthetic stereo image, errors would appear as anomalous valleys or scars, especially when vertical exaggeration was increased or the illumination angle was adjusted.

Image Simulation

This method integrated a digital synthesis of a satellite image according to a DEM grid, with information about the satellite illumination angle and image geometry. In an area with homogenous land cover like that of Antarctica, a comparison and correlation analysis between the simulated image and real image can often reveal errors in the DEM.

Spatial Autocorrelation

Subtle errors in elevation values were detected using rigorous statistical methods, and by tracing errors back to the original source data after locating areas of spatial discontinuity. In checking the consistency and continuity of each data point relative to nearby points, erroneous data points are flagged as local outliers if they are inconsistent with neighboring points.

2.5 Spatial Coverage

This data set covers all of Antarctica from 60 degrees south to 90 degrees south latitude, including the grounded ice, exposed land surface, and ice shelves. Version 2 features expanded coverage of the surrounding ocean and islands.

2.5.1 Spatial Resolution and Projection

Resolution of elevation data is in units of meters. Please refer to Section 2.3.3 for more details.

Table 5. Binary Grid

	1 km	**400 m**	**200 m**
Rows	4916	12290	24580

	1 km	400 m	200 m
Columns	5736	14340	28680
Cell Size	1000 m	400 m	200 m
Corner Point x	-2868000 m1	-2868000 m1	-2868000 m1
Corner Point y	-2458000 m1	-2458000 m1	-2458000 m1

[1]These values represent the outer edges of the upper left corner point, with the origin at the South Pole, *x* increasing to the right, and *y* increasing downward in the Scientific Committee on Antarctic Research (SCAR) projection. The SCAR projection is a polar stereographic projection from a WGS84 ellipsoid surface with the reference plane defined by -71 degrees (south) latitude.

ASCII grids contain fields for latitude, longitude, elevation relative to the WGS84 ellipsoid, and elevation relative to the OSU91A geoid. Coordinates are given in decimal degrees, from -180 degrees (west) to 180 degrees (east) longitude; and -90 to -60 (south) degrees latitude.

The RAMP DEM covers the entire Antarctic continent and its surrounding offshore ocean area in a polar stereographic projection with reference to the WGS84 ellipsoid. The projection latitude is 71 degrees south, with 0 degrees longitude oriented vertically at the top of the projection. The South Pole is the origin of the projection.

2.6 Temporal Coverage

Topographic source data were collected by various instruments, teams, and projects between the 1940s and 1990s.

3 REFERENCES AND RELATED PUBLICATIONS

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3.1 Related Data Sets

RAMP AMM-1 SAR Image Mosaic of Antarctica

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5 DOCUMENT INFORMATION

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