Digital SAR Mosaic and Elevation Map of the Greenland Ice Sheet, Version 1

USER GUIDE

How to Cite These Data

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

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National Snow and Ice Data Center

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1 DETAILED DATA DESCRIPTION

The European Space Agency's ERS-1 Satellite, carrying a C-band Synthetic Aperture Radar (SAR), has made it possible for the first time to rapidly map and document the hydrologic zones of a large ice sheet, providing a snapshot of surface features and conditions. The imaging radar produces high resolution views of the ice sheet independent of cloud cover and solar illumination, and because of the unique interaction of the radar signal with the ice sheet surface, can reveal the presence of snowpack variations resulting from spatially variable amounts of melting.

The Digital SAR Mosaic and Elevation Map of the Greenland Ice Sheet CD-ROM combines the most detailed synthetic aperture radar (SAR) image mosaic available with the best current digital elevation model. The mosaic image shows both the location of the ice edge and the distribution of melt-related "scatterers" on the surface. These scatterers include ice lenses and complex layered structure in the percolation zone and bare ice of the ablation zone. Other melt-related features that can be seen include lake and surface meltwater stream channels at lower elevations, as well as ice-marginal lakes.

This characterization of the ice sheet provides a reference against which future change can be measured. Changing conditions resulting from climatic variation should show up as changes in the ice margin and shifts in the hydrologic zones. It is hoped that the standard reference provided by this data set can facilitate activities aimed at change detection and promote other work aimed at understanding the processes operating on the ice sheet.

The image data are derived from SAR image swaths acquired by the ERS-1 satellite during August of 1992. The mosaic was assembled at Jet Propulsion Laboratory (JPL) and Goddard Space Flight Center. Its component images are a copyrighted product of the European Space Agency.

The mosaic, a value-added derived product, is available for non-profit, research-oriented purposes only. The Danish geodetic and cadastral agency Kort-og Matrikelsyrelsen (KMS) compiled the elevation data provided with the product from a number of sources, including field surveys, aerial photographs, and the ERS-1 radar altimeter. The elevation data are also provided only for non-profit, research-oriented purposes.

Included with the data is NSIDC's limb (large image map browser) software, which was developed in-house and allows Unix users to easily select and view portions of the mosaic image with elevation contours derived from the elevation data overlain. Limb is provided as "freeware" for general use.

NSIDC distributes the Digital SAR Mosaic and Elevation Map of the Greenland Ice Sheet CD-ROM. The product is available at no charge. To order the CD-ROM, or for more information, please contact NSIDC User Services.

The Digital SAR Mosaic and Elevation Map of the Greenland Ice Sheet CD-ROM contains two data sets: a synthetic aperture radar image mosaic and a digital elevation model (DEM), which was derived from a number of traditional sources as well as satellite radar altimetry.

The composite SAR image is compiled from a number of ERS-1 SAR image swaths digitally mosaicked, geolocated, and resampled to a 100 meter pixel size. The map projection is polar stereographic from the WGS84 ellipsoid. During the processing, the ellipsoidal version of the KMS DEM included here was used to partially terrain-correct the mosaic prior to projecting it. Geolocation accuracy of the SAR mosaic data is estimated to be roughly 400 meters. The overall size of the mosaic is 26266 lines by 15646 samples (410 MB).

The elevation data set was created by combining data from a large number of sources, including ground-based surveys, aerial photography, and coastal maps. Two versions of the DEM are included: one relative to the WGS84 ellipsoid and one relative to the OSU91A geoid. The majority of the data over the ice sheet interior come from satellite radar altimetry, and in particular, the ERS-1 altimetry from the 35-day repeat cycle portion of its data acquisition series. The DEM reports a modeled elevation every 0.02 degrees latitude and every 0.05 degrees longitude, roughly equal to a 2 km by 2 km grid spacing. The vertical accuracy of the elevation data is estimated to be a few meters over most areas, but elevation discrepancies as great as a few 10s of meters are observed in more steeply sloping parts of the ice surface because of slope-correction problems in the radar altimetry data. Note also that the DEM represents a smoothed surface with the smoothing scale being roughly 5 km. This smoothing eliminates many small undulations of the surface.

1.1 Format

The SAR data are stored on the CD-ROM as a simple, "flat" byte file with no header. The file contains 410957836 bytes. To view the data outside of the provided limb software, this file would need to be read as an array of bytes with 15646 lines and 26266 samples.

The DEM data are presented in tenths of meters as 2-byte integers in two (PC-byte order) flat files: one for the WGS84 ellipsoid and another for the OSU91A geoid.

- The WGS84 version consists of 1084 columns and 1226 rows, starts at 59.5°N 75°W, and has a data point every .02 degrees latitude and every .06° longitude.
- The OSU91A version consists of 1301 columns and 1251 rows, starts at 59°N 75°W, and has a data point every .02 degrees latitude and every .05° longitude.

1.2 File and Directory Structure

Table 1. File Names and Descriptions

File Name	Description
README.1st	"getting started" instructions
README.limb	instructions for installing limb
grnlnd_browse.392x657.img	browse image for SAR mosaic
grnlnd_browse.imd	image map descriptor for browse image
grnlnd_browse_overlay.dat	graphical overlay for the browse image
grnlnd_dem_osu91a.dat	DEM data based on OSU geoid
grnlnd_dem_osu91a.gpd	grid parameters definition for OSU DEM
grnlnd_dem_osu91a.imd	image map descriptor for OSU DEM
grnlnd_dem_osu91a.kms	ASCII version of OSU DEM
grnlnd_dem_osu91a.mpp	map projection parameters for OSU DEM
grnlnd_dem_wgs84.dat	DEM data based on WGS ellipsoid
grnlnd_dem_wgs84.gpd	grid parameters definition for WGS DEM
grnlnd_dem_wgs84.imd	image map descriptor for WGS DEM
grnlnd_dem_wgs84.kms	ASCII version of OSU DEM
grnlnd_dem_wgs84.mpp	map projection parameters for OSU DEM
grnlnd_sarmosaic.15646x26266.img	full resolution SAR mosaic image
grnlnd_sarmosaic.gpd	grid parameters definition for SAR mosaic
grnlnd_sarmosaic.imd	image map descriptor for SAR mosaic
grnlnd_sarmosaic.mpp	map projection parameters for SAR mosaic
info.html	documentation
info.txt	ASCII version of documentation
Limb.ad	application defaults file for limb
limb-alpha_DU3.2d	Dec Alpha version of limb executable
limb-irix_5.3	SGI version of limb executable
limb-linux_1.2.8	linux version of limb executable
limb-solaris_2.5	Sun version of limb executable
limb.1	preformatted man page for limb
Source Code	
limb.tar.Z	compressed tar file of limb source code
maps.tar.Z	compressed tar file of map library code
models.tar.Z	compressed tar file of model library code

Either the WGS84 ellipsoid or the OSU91A geoid can be accessed from the Unix command line using limb.

1.3 Spatial Coverage

The SAR mosaic covers approximately 80 percent of the Greenland Ice Sheet.

The DEMs cover all surfaces higher than sea level for the island of Greenland. Although Iceland is also enclosed within the corner points of the image map, no data for Iceland is included.

Spatial extent of SAR Mosaic:

	Lat	Lon
Upper left	81.691048	-92.013504
Upper right	79.925346	-10.813929
Lower left	60.133526	-56.501526
Lower right	59.636745	-29.399199

1.3.1 Spatial Coverage Map

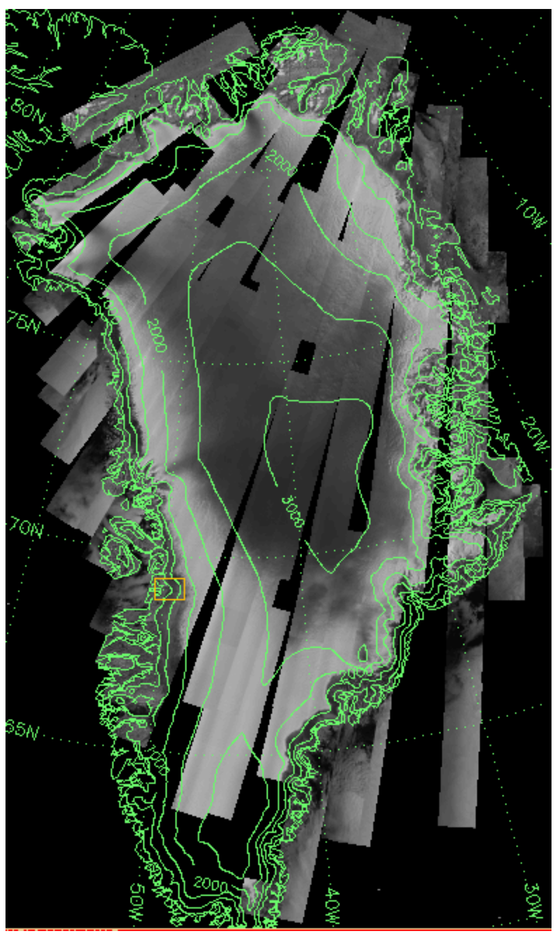

Figure 1. Spatial Coverage Map

1.3.2 Spatial Resolution

The WGS84 version of the DEM starts at 59.5°N 75°W and has a data point every .02 degrees latitude and every .06° longitude. The OSU91A version starts at 59°N 75°W and has a data point every .02 degrees latitude and every .05° longitude. Thus, the spatial distance between points varies across the grid. In the middle portion of the DEMs, the approximate spacing is 2 km by 2 km.

1.3.3 Projection and Grid Description

1.3.4 Projection

The SAR image data are in a polar stereographic projection using the WGS84 ellipsoid as a datum. The projection plane transects the ellipsoid at 70 degrees latitude. The Y-axis of the projected image data is parallel to 45 degrees west longitude. This projection is identical to the projection of the "SSM/I Grid" used for some SSM/I brightness temperature data distributed by NSIDC but not the same as the newer equal-area "EASE-Grid".

SAR data in the mosaic are reprojected at a scale of 100 meters per pixel (square). True resolution (i.e., the minimum size of a feature that would be unambiguously shown by the data), is approximately 1.5 to 2 times that value.

The DEM data are reported as a grid of elevations, and can therefore be projected into any grid. For the limb software, which is included with the CD-ROM, the DEM data are projected into the same polar stereographic view as the image data.

1.3.5 Grid

The DEM elevation data are gridded in a geographic system in which each cell represents 0.06 degrees of longitude and 0.02 degrees latitude.

1.4 Temporal Coverage

The data in the SAR mosaic are for 2 August 1992 through 9 September 1992.

The DEM data, compiled from a variety of sources, represent observations made over a much longer period. The satellite altimetry component of the data was collected roughly between 1991 and 1995. The Greenland Aerogeophysics Project (GAP) covered the southern part of Greenland in 1991 and the northern part in 1992. The Arctic Ice Mapping (AIM) project was in existence from 1991 through 1995. The ground-based survey data used in the DEM were taken much earlier (Ekholm, 1996).

1.4.1 Temporal Resolution

The individual SAR images in the digital SAR mosaic were taken during a single 35-day repeat mission of the ERS-1 satellite.

1.5 Parameter or Variable

For the SAR mosaic, the measured variable is a relative radar returned signal strength, that is, the reflected radiance for each pixel.

For the DEM data, the variable is height above the WGS84 ellipsoid or the OSU91A geoid in meters. With the browse tool, users can select the contour interval, which defaults to 100 m.

2 SOFTWARE AND TOOLS

2.1 Software

Ken Knowles of NSIDC wrote the limb software for use with the digital ERS-1 SAR mosaic and elevation map data sets on Unix workstations. Limb is a browse tool for large image maps (image files that have been rectified to a gridded map projection). It allows users to move around and inspect different parts of the larger image, select subsets of the larger image for magnified viewing, and retrieve information about specific points within a selected image (for example, selecting coordinates for later use in specifying a region of interest).

With limb, users are able to integrate the co-registered digital elevation model with the SAR image map.

Limb uses scroll bars to control window positions within images, a Control Panel to control window visibility and an image color map, and an Information Box to display data value and position information.

Via the limb Control Panel, users can select colors and adjust brightness, contrast, tone (saturation), and tint (hue). The limb Control Panel also allows users to toggle displays of graphics overlays, draw temporary elevation contour lines over the browse window, and magnify selected images.

For a given pixel selected with the mouse pointer, the limb Information Box displays the elevation, latitude, longitude, and column coordinates from the edges of the full image. The limb Information Box also displays the scaled data value from the image file in calibrated engineering units. By locating two points with the mouse, users can also determine the distance and the bearing between the points.

2.2 Software Access

NSIDC distributes limb with the data sets on the Digital SAR Mosaic and Elevation Map of the Greenland Ice Sheet CD-ROM. Instructions for accessing the software are included on the CD-ROM in help ("man") files describing limb resources and environment variables.

2.3 Data Center Status/Plans

A more complete SAR mosaic was acquired by the ERS-1 satellite in March of 1993 and is currently being processed. When available, this mosaic will be included with the best available DEM for a revised version of the CD-ROM.

A similar product is planned for Antarctica using data from the Radarsat Antarctic Mapping Project and ERS-1 radar altimeter.

2.4 Output Products and Availability

The Digital SAR Mosaic and Elevation Map of the Greenland Ice Sheet CD-ROM is available from NSIDC free of charge for non-profit, research-oriented purposes only.

2.5 Quality Assessment

2.5.1 Confidence Level/Accuracy Judgement

The accuracy and precision of the DEM is not adequate for the detection of real ice surface elevation changes over time, and thus the DEM should not be used for such purposes. Additional processing would be necessary before the DEM could be used as part of a scheme for elevation change detection. For more information about the DEM accuracy, see Ekholm (1996).

SAR data were found to have an uncertainty in the absolute calibration of up to 3 dB (in sigma_0). SAR also has an intrinsic "speckle" quality that is due to the interaction of the radar wave front with the array of scatterers on the surface. This speckle pattern changes over a period of days to weeks on polar ice surfaces.

2.5.2 Data Verification by Data Center

Although SAR responds to different surface characteristics than the Advanced Very High Resolution Radiometer, AVHRR images corroborate the general details of the SAR mosaic. Also, GPS measurements of several points in the interior were compared with the DEM-derived values and found to agree within a few meters.

2.5.3 Limitations of the Data

The accuracy and precision of the DEM is not adequate for the detection of ice surface elevation changes over time, and thus the DEM should not be used for such purposes. Additional processing would be necessary before the DEM could be used for change detection.

2.5.4 Known Problems with the Data

For the SAR data set, the UK path data are known to have problems with absolute calibration. The uncertainty could be as high as 3 dB. Further, there is a range dependence of scattering properties of the surface, which are not well represented in the data. This was not fully corrected in the processed data.

2.5.5 Usage Guidance

For a discussion of the limitations of the scientific applications of this product, see the Limitations of the Data section above.

Because the SAR mosaic is large (approximately 410 megabytes), display speed will be a consideration when using the data with slower CD-ROM readers.

Fahnestock et al. (1993) used the SAR mosaic to map hydrologic zones in Greenland. Fahnestock et al. also compared the August SAR mosaic, which represents the end of the melt season, with winter images, and concluded, "This data set, which is an accurate map of the ice sheet, provides a baseline against which future variations in surface characteristics can be detected."

The investigators also note that tracking ice features such as crevasses and lake shorelines is possible using sequential SAR images. In the SAR imagery, Fahnestock et al. observed a large flow feature in northeast Greenland that may play a significant role in the mass balance of the Greenland ice sheet.

The DEM is suitable for use as a map in future field work in Greenland and could be also used in the geolocation of ice core sites and in-situ data.

A more complete SAR mosaic was acquired by the ERS-1 satellite in March of 1993 and is currently being processed. When available, this mosaic will be included with the best available DEM for a revised version of the CD-ROM.

3 DATA ACQUISITION AND PROCESSING

3.1 Theory of Measurements

Synthetic aperture radar (SAR) is an active microwave sensor that transmits a focused pulse of radar energy and receives reflected energy from the target (in this case, the Earth) in a form that can be converted into a high-resolution image. A synthetic aperture radar basically uses the sweep of a relatively small antenna through space to mimic the resolution attainable by a much larger stationary antenna. SAR images of a polar surface give a different view than visible/near infrared imagery because of the differences in interactions with surface materials in the microwave band. In particular, SAR images show the great variability in radar backscattering properties of snow and ice surfaces. Dry snow is a very good radar absorber, while coarser snow with ice lenses and other melt structures within it is one of the brightest radar reflectors on the Earth's surface. Ablation regions, where the ice is exposed or thinly covered by snow also show as dark areas because of specular reflection of the radar signal off the smooth surface and away from the satellite.

Radar altimeters also actively transmit electromagnetic pulses to the surface of the Earth. In the case of altimetry, the radar beam is used as a sounder, measuring the perpendicular distance between the source (the satellite in this case) and the reflector (the surface). By measuring the time it takes the electromagnetic signal to travel from the altimeter antenna to the ice sheet surface and back to the altimeter's receiver as backscatter, investigators are able to determine the satellite's height above the ice sheet. This determination involves many factors including the properties of the snow or ice, as well as topographic variations of the ice sheet surface. However, the beam is only roughly focused, and illuminates a rather broad region of the surface. Thus, the measured height of the surface is a mean value over an area.

There are data reduction problems for both sensors over sloping terrain. In the case of radar imaging, the problem occurs when the radar beam, which intersects the Earth at an angle, contacts the top of a hill or mountain before its base. The return reflection from the top is received by the satellite earlier than the base, causing the mountain to appear tipped over in the final processed image. This problem is referred to as layover. A similar problem occurs in radar altimetry when the broad beam-front intersects a sloping surface. In the case of radar altimetry, the beam intersects the surface nearly perpendicularly. With a sloping surface, the first return is from a point not directly below the satellite, but to the uphill side. Thus, the elevation indicated by the return time is higher than that directly below the satellite. For both problems, processing can mitigate the errors.

Knowledge of the approximate surface shape and elevation is used in an iterative processing scheme to adjust the raw signal.

For an overview of SAR measurement theory, see Simonett, et al. (1983).

3.2 Data Acquisition Methods

Mark Fahnestock and Ron Kwok created the SAR mosaic using ERS-1 SAR imagery from the UK Processing and Archive Facility, a part of ESA's ground receiving and processing network. A series of acquisitions were requested for August of 1992 in a pattern designed to nearly cover Greenland. The data were received in 16-bit format as ungeoreferenced, processed image frames (SAR.PR1 products).

Simon Ekholm constructed the DEM from:

- GEOSAT and ERS-1 satellite altimetry
- Airborne radar altimetry from the U.S. Naval Research Laboratory's Greenland Aerogeophysics Project (GAP)
- Airborne laser altimetry from NASA's Arctic Ice Mapping (AIM) project
- A local survey on the summit of the ice sheet
- Stereo photogrammetry "scannings"
- Coastal information manually extracted from maps

3.2.1 Observations

3.2.1.1 Data Notes

For a detailed discussion of source data for the DEM, see Ekholm (1996).

3.2.1.2 Field Notes

No field work was required for the assembly of the SAR mosaic, although the geolocation accuracy was verified by comparing the mapped location of certain ground features with global positioning system (GPS) positions acquired by field groups at the sites. For the DEM, supplemental ground surveys were conducted across northern Greenland, again using GPS surveying equipment.

3.3 Derivation Techniques and Algorithms

3.3.1 Data Source

NSIDC received the source data sets from the investigators who created them. Mark Fahnestock and Ron Kwok created the SAR mosaic using ERS-1 SAR imagery from the UK Processing and

Archive Facility. Simon Ekholm constructed the DEM from GEOSAT and ERS-1 satellite altimetry, GAP airborne radar altimetry, AIM airborne laser altimetry, a local survey on the summit of the ice sheet, stereo photogrammetry scannings, and information manually extracted from maps.

For a detailed discussion of source data for the DEM, see Ekholm (1996).

3.3.2 Data Range

Elevations in the DEM range from 0 meters at sea level to 3251.4 meters. For the SAR mosaic, the brightness ranges from 0 to 255.

3.3.3 Processing Steps

For the DEM portion of the product, long wavelength errors in the satellite altimetry along the sloping sides of the ice sheet were reduced by comparison with the airborne altimetry, by "draping" the satellite altimetry on the airborne altimetry. All elevations are relative to sea level (converted from ellipsoidal heights using the latest geoid model, which is OSU91A improved with local gravity, including airborne GAP gravimetry). The model refers to the WGS84 datum. Least squares collocation was used in the modeling process, with prediction parameters adjusted according to the type of terrain (coastal bedrock or ice sheet) modeled. For more information about the DEM data processing, see Ekholm (1996).

For the SAR portion of this product, the geometric rectification and mosaicking were performed at JPL.

1. Geocoding and terrain-correcting: Each image was geocoded and terrain-corrected. Geocoding is the transformation of the sensor-specific geometry of an image into a cartographic representation with well-defined scale and angular distortions. In this case, the geocoded format is defined by the SSM/I polar stereographic projection.
2. Since radar is a range measuring instrument, the location of a point on a radar image is dependent on its elevation as well as its horizontal spatial location. Points above the ellipsoid are moved to nearer range with increasing elevation, which would cause large location errors if not removed. The terrain distortions introduced by the radar imaging geometry were removed with the ellipsoidal version of the DEM contained on the CD-ROM.
3. Location accuracy of points on the ice sheet: The JPL investigators compared the location of a point at the Greenland Ice Core Project (GRIP) drilling site with the geolocation of a pixel covering the same point they observed to get a location difference of approximately 400 m. This gives users an idea of the absolute location accuracy of the rest of the mosaic where the elevations from the DEM are considered to be reasonable, that is, away from regions with high surface slopes.
4. Radiometric Properties: The 16-bit raw DN representation was compressed to 8-bit representation for the mosaic. No attempt was made to create smooth seams between the image swaths. DN values may be converted to sigma-0 (the normalized backscatter coefficient) using the relationship:

$$sigma\_0 = 10 * \log10 (DN\_16^2 / K)$$

where:

DN_16 = 16-bit DN value = (1100 / 255) × DN_8 …. (original 16-bit values scaled to 8 bits)

DN_8 = 8-bit DN value from mosaic

K = calibration constant for UK-PAF = 890107.2

sigma_0 is unitless (dB/dB for perfect scatterer)

5. Mosaicking: After the geometric and radiometric compensations, the images were assembled onto the planimetric format. No attempt was made to adjust adjacent swaths to improve relative registration between swaths.

3.3.4 Error Sources

The ERS-1 radar altimeter was designed and intended primarily to measure open ocean topography. Ice sheet slope and surface irregularities cause more complex signal returns than are received from the ocean surface. The higher slopes of ice sheets and mountainous areas require a correction for off-nadir returns, as described above in the Theory of Measurements section.

For the SAR image data, the main error is a result of "layover," a situation in which the side-looking radar receiver sees a signal from the top of a mountain before the base. This error was not corrected, and users must be aware that the coastal mountain morphology shown in the mosaic appears tipped towards the satellite.

For a discussion of elevation errors associated with ice sheet radar altimetry data, see Ekholm et al. (1995) and Zwally et al. (1983).

3.3.4.1 Field Notes

No field work was required for the assembly of the SAR mosaic, although the geolocation accuracy was verified by comparing the mapped location of certain ground features with global positioning system (GPS) positions acquired by field groups at the sites. For the DEM, supplemental ground surveys were conducted across northern Greenland, again using GPS surveying equipment.

3.4 Platform/Sensor

The European Remote Sensing Satellite (ERS-1) is a European Space Agency (ESA) satellite in a sun-synchronous, near-circular polar orbit. For more information about the ERS-1 spacecraft, its mission, its environment, and the ground data system, please refer to the Alaska Satellite Facility's ERS-1 platform description document.

The Synthetic Aperture Radar (SAR) is an active microwave sensor that enables fine resolution, high contrast observation and accurate determinations of topographical features. For information about the SAR principles of operation, sensor specifications, or calibration information, please refer to the Alaska Satellite Facility's sensor description document for JERS-1.

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6 DOCUMENT INFORMATION

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