MEaSUREs Greenland Image Mosaics from Sentinel-1A and -1B, Version 4

USER GUIDE

How to Cite These Data

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

Joughin, I. 2021. *MEaSUREs Greenland Image Mosaics from Sentinel-1A and -1B, Version 4*. [Indicate subset used]. Boulder, Colorado USA. NASA National Snow and Ice Data Center Distributed Active Archive Center. https://doi.org/10.5067/WXQ366CP8YDE [Date Accessed].

We also request that you acknowledge the author(s) of this data set by referencing the following peer-reviewed publication:

Joughin, I., B. Smith, I. Howat, T. Moon, and T. Scambos. 2016. A SAR record of early 21st century change in Greenland. *Journal of Glaciology*, 62(231), 62-71. https://doi.org/10.1017/jog.2016.10

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

FOR CURRENT INFORMATION, VISIT https://nsidc.org/data/NSIDC-0723

TABLE OF CONTENTS

1 DATA DESCRIPTION

1.1 Parameters

The mosaics provided in this data set consist of calibrated and uncalibrated HH-polarized C-band Synthetic Aperture Radar (C-SAR) backscatter coefficients produced from data collected by the Copernicus Sentinel-1 satellites. HH-polarization means the radar both transmits and receives the data with horizontal polarization. In SAR applications, backscatter is the portion of the outgoing radar signal that the target redirects back towards the radar antenna. The scattering cross section in the direction of the radar is called the backscattering cross section, usually notated as σ (sigma), and is a measure of the reflective strength of a radar target. σ is represented in this data set by the uncalibrated, contrast-enhanced product `image`.

The normalized measure of the radar return from a distributed target is called the backscatter coefficient, or σ_0 (sigma nought), and is defined as per unit area on the ground. This data set also includes a radiometrically terrain-corrected backscatter coefficient, or γ_0 (gamma naught), which can be used to assess changes in backscatter independently of incident angle and topography. The σ_0 and γ_0 products are stored in this data set as `sigma0` and `gamma0`. Table 1 summarizes each parameter; refer to “Section 2 | Data Acquisition and Processing” for details on how they were derived.

Table 1. Parameter Descriptions

Parameter	Description / Purpose	Units	Valid range	NoData Value
`image`	Uncalibrated backscatter, designed largely for interpreting geographical and glaciological features (e.g., glacier terminus positions)	n/a	1 – 255	0
`sigma0`	Normalized backscatter, useful for looking at features due to hillshade effect	Decibels	-29.99 to 29.99	-30
`gamma0`	Radiometrically terrain-corrected backscatter, useful for looking at backscatter changes independent of the incident angle and topography	Decibels	-29.99 to N/A (i.e., no upper limit)	-30

1.2 File Information

1.2.1 Format and File Contents

Each mosaic product spans either a 12-day period (prior to 28 September 2016) or a 6-day period (starting on 28 September 2016). Each mosaic (`image`, `gamma0`, and `sigma0`) is available in Cloud-Optimized Geographic Tagged Image File Format (GeoTIFF) as a single file with embedded overviews posted at either 25 m (the uncalibrated `image` product) or 50 m (calibrated `sigma0` and `gamma0`), which is approximately equivalent to the image resolution after multi-look averaging. In addition, the following ancillary files are available:

- Each GeoTIFF file is accompanied by a 500-m Quicklook JPEG image, which in turn has an auxiliary Extensible Markup Language file (`.jpg.aux.xml`) that provides GDAL-generated geolocation information.
- Each set of mosaics is accompanied by a shapefile that provides the dates for the individual images used in each mosaic. In addition to the date, the shapefile specifies the track (relative orbit), orbit (absolute orbit), and particular satellite (S1A/B).
- Two video files in `.mov` format, that give an overview of the time series for the entire ice sheet (`greenland_v04.0.mov`), as well as a detailed view of a representative glacier, Upernavik (`upernavik_v04.0.mov`).

1.2.2 Sample Data Record

Figures 1 and 2 illustrate some of the products included in this data set.

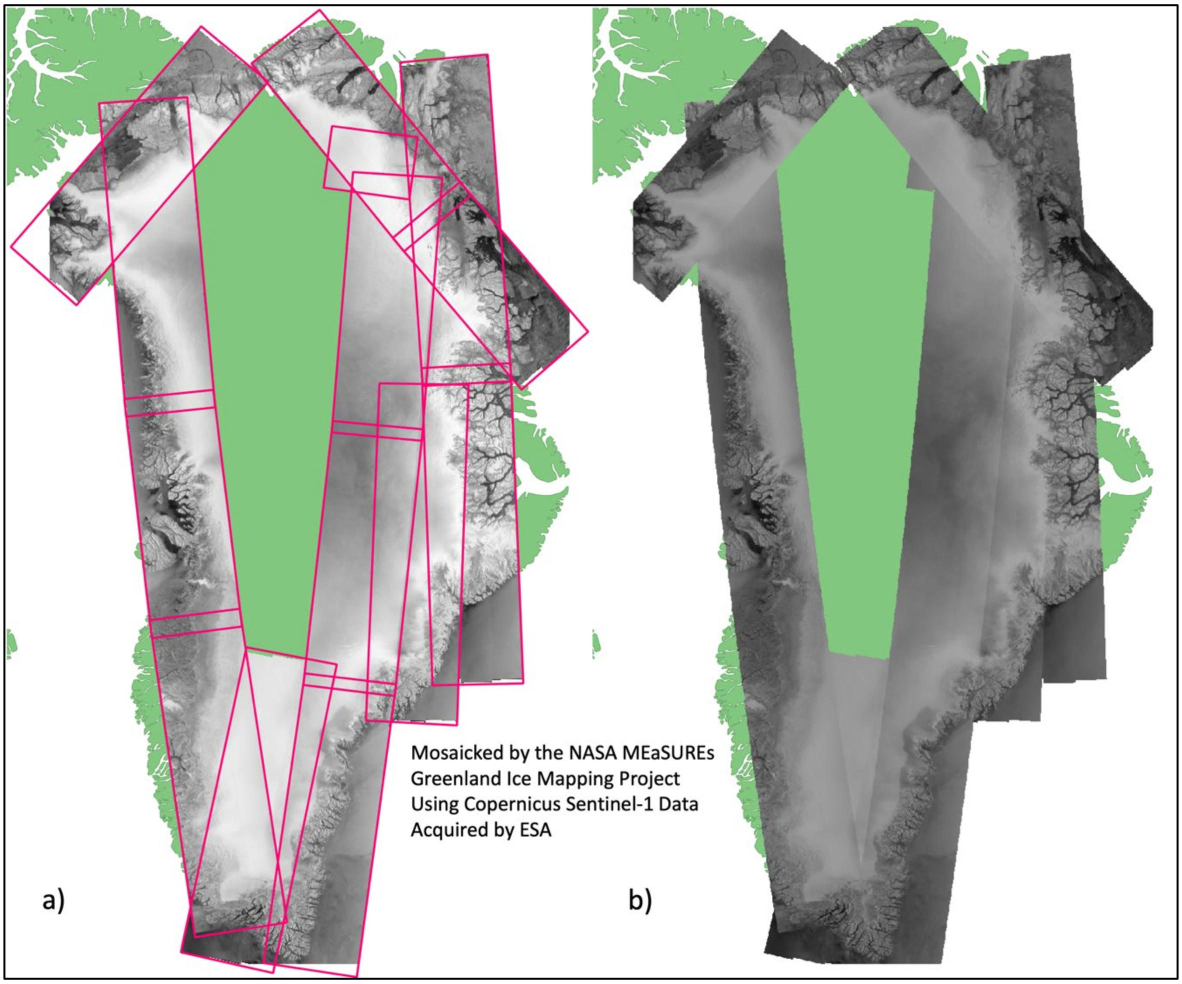

Figure 1**.** Sample mosaics of data collected from 06 November 2019 to 11 November 2019 (file names beginning with GL_S1bks_mosaic_06Nov19_11Nov19_), displayed here over Greenland's continental outline (not included in the data). In **a)**, the pink polygons are contained in the shapefile and denote the individual images used in the mosaic; attributes for each polygon indicate their date, track, orbit, and particular satellite (S1 A/B). The background image is the sigma0 JPEG Quicklook mosaic for the same dates. In **b)**, the sigma0 GeoTIFF mosaic for the same dates is displayed. All products contain modified Copernicus Sentinel data, acquired and processed by the European Space Agency, distributed through the Alaska Satellite Facility, and mosaicked by I. Joughin.

Figure 2. Individual frame from late October 2019 from the sample animation upernavik_v03.0.mov, focusing on the glacier termini near Upernavik in eastern Greenland. Product contains modified Copernicus Sentinel data, acquired and processed by the European Space Agency, distributed through the Alaska Satellite Facility, and mosaicked by I. Joughin.

1.2.3 Naming Convention

The following represents a generic file name for files in this data set:

```
GL_S1bks_mosaic_[start_date]_[end_date]_[product]_v0#.#.[ext]
```

Table 2 summarizes the naming conventions for each file type:

Table 2. File Naming Convention

Variable	GeoTIFF	JPEG	Shapefile
GL_S1bks_mosaic	Greenland Sentinel-1 satellites A and B multi-image backscatter mosaic		
start_date	Date of first image used in the mosaic period (DDMonYY)		
end_date	Date of last image used in the mosaic period (DDMonYY)		
product	[Product type]_[Spatial resolution]: image_25m: uncalibrated backscatter sigma0_50m: calibrated sigma naught gamma0_50m: calibrated gamma naught	[Product type]_[Spatial resolution]: image_500m sigma0_500m gamma0_500m	shape
V0#.#	Version number		
.ext	File extension. The cloud-optimized GeoTIFF file includes: .tif: the raster file where image statistics (min, max, mean and standard deviation) are included in the file header	File extension. The Quicklook JPEG includes: .jpg: the browse file .jpg.aux.xml: auxiliary file containing GDAL-generated geolocation information	The shapefile format consists of four files with the following extensions: .dbf (database file) .prj (projection information) .shp (shapes) .shx (shape indices)

1.2.4 Example File Names

1.2.4.1 GeoTIFFs and statistics files:

- GL_S1bks_mosaic_06Nov19_11Nov19_image_25m_v04.0.tif
- GL_S1bks_mosaic_06Nov19_11Nov19_sigma0_50m_v04.0.tif
- GL_S1bks_mosaic_06Nov19_11Nov19_gamma0_50m_v04.0.tif

1.2.4.2 Quicklook JPEGs and geolocation files:

- GL_S1bks_mosaic_06Nov19_11Nov19_image_500m_v04.0.jpg
- GL_S1bks_mosaic_06Nov19_11Nov19_image_500m_v04.0.jpg.aux.xml
- GL_S1bks_mosaic_06Nov19_11Nov19_sigma0_500m_v04.0.jpg
- GL_S1bks_mosaic_06Nov19_11Nov19_sigma0_500m_v04.0.jpg.aux.xml
- GL_S1bks_mosaic_06Nov19_11Nov19_gamma0_500m_v04.0.jpg
- GL_S1bks_mosaic_06Nov19_11Nov19_gamma0_500m_v04.0.jpg.aux.xml

1.2.4.3 Shapefiles:

- `GL_S1bks_mosaic_06Nov19_11Nov19_shape_v04.0.shp`
- `GL_S1bks_mosaic_06Nov19_11Nov19_shape_v04.0.dbf`
- `GL_S1bks_mosaic_06Nov19_11Nov19_shape_v04.0.prj`
- `GL_S1bks_mosaic_06Nov19_11Nov19_shape_v04.0.shx`

1.3 Spatial Information

1.3.1 Coverage

The data cover the entire Greenland periphery within the following bounding box:

- Northernmost Latitude: 81.4° N
- Southernmost Latitude: 58.8° N
- Easternmost Longitude: 5.8° E
- Westernmost Longitude: 87.1° W

1.3.2 Resolution

The nominal spatial resolution is 25 m x 25 m for the uncalibrated images and 50 m x 50 m for the calibrated `sigma0` and `gamma0` products.

1.3.3 Projection and Grid Description

GeoTIFFs and JPEGs are provided in a WGS 84 polar stereographic grid with a standard latitude of 70° N and rotation angle of -45° (sometimes specified as a longitude of 45° W). With this convention, the y-axis extends south from the North Pole along the 45° W meridian (EPSG:3413). The shapefiles do not contain a specified projection and all coordinates are expressed in latitude and longitude (EPSG: 4326).

Table 3. Northern Hemisphere Projection Based on WGS 1984 (EPSG: 3413)

Geographic Coordinate System	WGS 84
Projected Coordinate System	WGS 84 / NSIDC Sea Ice Polar Stereographic North
Longitude of True Origin	-45
Latitude of True Origin	70
Scale factor at longitude of true origin	1
Datum	WGS 1984
Ellipsoid/spheroid	WGS 84
Units	meter

False Easting	0
False Northing	0
PROJ4 String	+proj=stere +lat_0=90 +lat_ts=70 +lon_0=-45 +k=1 +x_0=0 +y_0=0 +datum=WGS84 +units=m +no_defs
Reference	http://epsg.io/3413

Table 4. Geographic Coordinate System

Geographic Coordinate System	**WGS 84**
EPSG code	4326
PROJ4 string	+proj=longlat +datum=WGS84 +no_defs
Reference	http://epsg.io/4326

1.4 Temporal Information

1.4.1 Coverage

01 January 2015 – 20 December 2024[1]

1.4.2 Resolution

The temporal resolution for data acquired prior to 28 September 2016 is 12 days. The temporal resolution for data acquired between 28 September 2016 and 24 December 2021 is 6 days. Due to the failure of the Sentinel-1B satellite, data acquired beginning 25 December 2021 has a temporal resolution of 12 days.

2 DATA ACQUISITION AND PROCESSING

2.1 Background

Interactions between radar signals and the ground depend upon many factors, such as the density and dielectric properties of surface materials, vegetation cover, surface roughness at the scale of the signal's wavelength, topographic variations, and the instrument's look angle and signal polarization. The image resolution is particularly affected by chirp pulse length and bandwidth, return signal integration time, and the time between pulse transmissions.

For a detailed discussion of SAR theory, see SAR Theory/Interpreting Images. For general information about the mathematical derivations and theories behind SAR processing algorithms,

[1]This data set undergoes periodic temporal coverage updates as new Sentinel-1 data are collected and processed.

see Scientific SAR User's Guide. This User Guide covers a few backscatter conventions, summarized from Small (2011), to help the user understand how the parameters included here were derived.

Radar backscatter is expressed as a ratio between the scattered power and incident power. For distributed targets, the backscatter coefficient provides a backscatter ratio estimate per given reference area. Three conventional reference areas are illustrated in Figure 3:

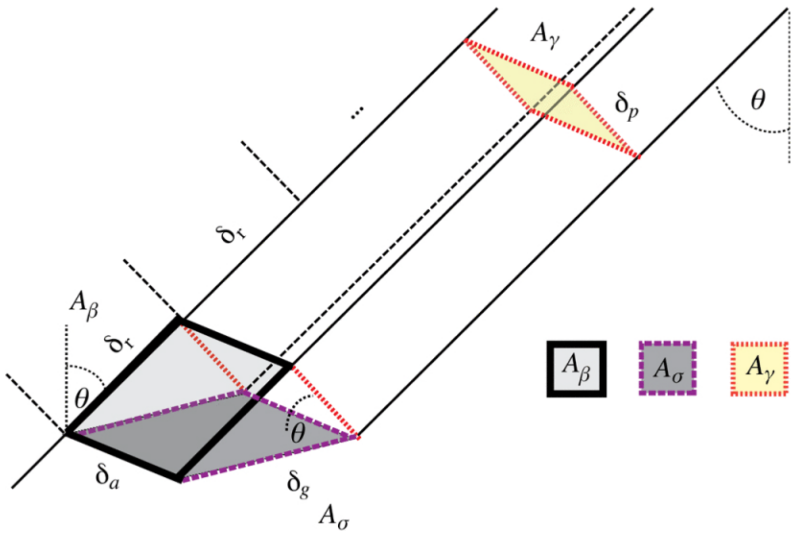

Figure 3. Normalization areas for SAR backscatter (from Small, 2011)

A common native radar brightness estimate, β^0, uses a reference area on the slant range plane (A_β). If the reference is defined as the ground area, i.e., locally tangent to an ellipsoidal model of the ground surface A_σ, the result is σ^0. If it is instead defined as the plane perpendicular to the line of sight from the sensor to an ellipsoidal model of the ground surface A_γ, the result γ^0.

2.2 Acquisition

Copernicus Sentinel-1A and -1B satellite imagery was acquired and processed to Level 1 by the European Space Agency and archived and distributed through the Alaska Satellite Facility.

From 01 January 2015 to 15 September 2016, data were acquired from the Sentinel-1A platform only. Beginning 28 September 2016 through 24 December 2021, data were acquired from both Sentinel-1A and Sentinel-1B platforms. Due to the failure of the Sentinel-1B satellite, data are only collected from Sentinel-1A beginning on 25 December 2021.

2.3 Processing

2.3.1 Processing Steps

The Alaska Satellite Facility provided all source data as Level-1 burst Single-Look Complex (SLC) data, including digitized voltage values, instrument calibration constants, satellite timing, attitude, and position information. The data were pre-processed by the European Space Agency (ESA) and provided courtesy of the Copernicus program. The SLC burst data were processed from full multi-burst SLC scenes using the GAMMA Modular SAR Processor (MSP) package to single-look complex images in native radar coordinates. These products were subsequently geocoded, terrain- and radiometrically corrected, and mosaicked using software developed within the Greenland Ice Mapping project (GrIMP).

The mosaics are produced from five descending (Tracks 26, 83, 112, 141, and 170) and two ascending (Tracks 74 and 90) tracks. In some cases, the image tracks overlapped, but at any given pixel, only one image was used. If the overlapping images were ascending and descending, the descending image was used (see the shapefile attribute field to determine track direction). If two parallel images overlapped, the top polygon in the shapefile should correspond to the image that was included in the mosaic. In some locations, it is possible that a mosaic for one time interval will have ascending geometry and for another time interval descending geometry because of missed acquisitions (i.e., a consistent geometry is used whenever sufficient data are acquired). In such areas, mountains and other topography features will appear to be illuminated from opposite sides. If the images are flickered back and forth, the different viewing geometries can give the impression of large shifts, even though the data are generally well registered. This effect should be reduced, albeit not perfectly, for the `gamma0` product. For regions with like-viewing geometry, the co-registration is far better than the 25- and 50-m postings, except in cases where the topography is extreme.

All products were derived from the β^0 values from the Sentinel-1 product. For the uncalibrated `image` product, the data have been mapped to grey scale values in the range of 0 - 255 (bytes) using a nonlinear stretch to allow visual discrimination of topographical features within the images. Although they are not calibrated and the values are not directly interpretable as dimensioned values, changes in relative brightness should indicate real change. This product is designed largely for interpreting geographical and glaciological features (e.g., glacier terminus positions). For looking at melt and some other phenomena, calibrated mosaics are preferred.

The calibrated `sigma0` mosaic shows spatial patterns in both the surface slope and the surface reflectance for C-band (5.3 GHz) radiation. Sigma naught refers to a calibration technique whereby the ratio between power incident on the surface and reflected power (backscatter) is normalized by a standard area on the ground (see Figure 3). Specifically, the σ^0 value is derived as

$$\sigma^0 = \beta^0 \cdot \sin\theta_E \ , \qquad \text{(Equation 1)}$$

where θ_E is the incidence angle relative to the surface normal for an ellipsoidal Earth (Figure 3). The imagery is thus calibrated with respect to instrument parameters and the range between the satellite and the target, while preserving information that gives visual clues to the shape of the surface topography. The σ^0 values are stored as floating-point decibels (dB; $10 * \log(\sigma^0)$) rounded to the nearest 0.01 dB.

Since the true incidence angle varies with slope and ellipsoidal earth, it can be difficult to compare σ^0 values across a range of incidence angles. Thus, images with radiometrically terrain-corrected γ^0 values are also provided (the `gamma0` product). These represent the area illuminated on the ground, projected on to the plane normal to radar line-of-sight (Small, 2011). The illuminated area, however, is slope-dependent, giving rise to shadow, layover, and foreshortening effects. These effects can be partially corrected using a digital elevation model (DEM); although slope errors leave some residual topographic effects and there are other angle and target-dependent scattering properties not accounted for. To produce radiometrically-corrected γ^0 values, an algorithm similar to that described by Small (2011) is used. In the process, each pixel in the output grid is divided into 3D triangular facets that are projected onto the plane perpendicular to the slant range to determine A_γ (see Fig. 6 in Small, 2011). A minor variant on the Small (2011) approach is that the triangular facets are projected onto the plane parallel to the look direction (i.e., the β plane), as opposed to producing an intermediate simulated slant-range image, to determine A_β. Using these values, γ^0 is computed as

$$\gamma^0 = \beta^0 \cdot \frac{A_\beta}{A_\gamma} \ , \qquad \text{(Equation 2)}$$

where multiple pixels in the output grid map in the same range pixel, A_β and A_γ are appropriately accumulated before applied to compute γ^0. As with σ^0 values, γ^0 values are stored as floating-point decibels (dB) rounded to the nearest 0.01 dB.

2.3.2 Geometric Terrain Correction

The mosaics in this data set were geometrically terrain-corrected with a modified version of *MEaSUREs Greenland Ice Mapping Project (GrIMP) Digital Elevation Model from GeoEye and WorldView Imagery, Version 1*. The modified version of the DEM differed from the published one in that it used geoidal heights for the ocean. As a result, some near-terminus locations could be shifted by a few 10s of meters relative to earlier data set versions. Also due to this correction, some slight differences in registration relative to *MEaSUREs Greenland Ice Sheet Mosaics from SAR Data, Version 1* mosaics exist.

Note to Users: For version 4 of this product, an additional correction was made to the DEM to address a horizontal shift of 15 m identified in the DEM used in Version 3, resulting in some changes to the data between version 3 and version 4 The horizontal shift in the DEM of 15 meters effectively created height errors that mapped into geolocation errors. For regions with small slopes (e.g., the ice sheet) this error should be negligible (< 1 m). For regions with high slopes, the geolocation error in the image could be several meters (roughly equal to 1.25 * slope * 15 m)

2.3.3 GDAL-Generated Cloud Optimized GeoTIFFs

Cloud optimized GeoTIFFs with images statistics written directly into the header were generated using Geospatial Data Abstraction Library (GDAL). GDAL generates previews for Cloud Optimized GeoTIFFs and the default is to use cubic interpolation but, this results in minor artifacts around the lower resolution previews. Therefore, averaging is used instead to avoid this issue and aliasing.

2.4 Quality, Errors, and Limitations

2.4.1 Error Sources

With the exception of extreme terrain regions, geometric accuracy is generally better than a single 25 m or 50 m pixel (Joughin et al., 2016). In flat areas (most of the ice sheet), radiometric accuracy should largely be consistent with that provided by the Sentinel instruments. In regions of high topography, the calibrated products can have much larger errors. A consistent algorithm is used, however, so that precision at a point should be as expected from the instrument.

2.5 Instrumentation

For more information on the SAR satellites Sentinel-1A and -1B, please see the European Space Agency's Copernicus Sentinel-1 web page.

3 SOFTWARE AND TOOLS

The files in this data set can be visualized and processed with a variety of Geographic Information System (GIS) software packages such as QGIS, GDAL, and ArcGIS.

4 VERSION HISTORY

Table 5. Version History

Version	Release Date	Description of Changes
V4.0	Mar 2025	• Temporal coverage extended through 20 Dec 2024
V4.0	Nov 2024	• Temporal coverage extended through 22 Aug 2024
V4.0	Aug 2024	• Temporal coverage extended through 30 May 2024
V4.0	May 2024	• Temporal coverage extended through 31 Mar 2024
V4.0	Apr 2024	• Temporal coverage extended through 31 Jan 2024
V4.0	Feb 2024	• Temporal coverage extended through 26 Dec 2023
V4.0	Jan 2024	• Temporal coverage extended through 27 Oct 2023
V4.0	Oct 2023	• Temporal coverage extended through 28 Aug 2023
V4.0	25 Sep 2023	• Temporal coverage extended through 23 Jul 2023
V4.0	18 Sep 2023	• Temporal coverage extended through 29 Jun 2023
V4.0	Jul 2023	• Temporal coverage extended through 24 May 2023
V4.0	Jun 2023	• Temporal coverage extended through 25 Mar 2023
V4.0	May 2023	• Temporal coverage extended through 17 Feb 2023

Version	Release Date	Description of Changes
V4.0	Apr 2023	• Temporal coverage extended through 24 Jan 2023
V4.0	15 Dec 2022	• Temporal coverage extended
V4.0	6 Dec 2022	• Temporal coverage extended
V4.0	June 2021	• Temporal coverage extended • Data reprocessed utilizing a corrected DEM.
V3.1	January 2021	• Data temporal coverage extended to 11 December 2020. • The GeoTIFFs were generated using GDAL 3.1.4 to make them compatible with the latest cloud optimized GeoTIFF format. • The GeoTIFF image statistics are now included in the header, so the ancillary, .tif.aux.xml, files are no longer produced.
V3	August 2020	• Data were reprocessed with upgraded software and a revised DEM • The spatial resolution of the uncalibrated product was improved from 50 to 25 meters • Two new parameters: (1) a calibrated sigma0 radar backscatter product with a 50 m spatial resolution; and (2) a calibrated and radiometrically terrain-corrected gamma0 radar backscatter product, also at 50 m resolution • The products have been simplified, with the mosaics merged into a single cloud-optimized GeoTIFF and thus replacing the multiple .tif, .vrt, and .ovr files included in V2 • The temporal coverage was expanded
V2.2	September 2019	• Updated the .tif file names within the .vrt files to match the actual .tif files. • The .gif files changed were replaced with .mov files.
V2.1	September 2017	• An additional track (Sentinel-1, track 83) added to improve coverage in the southern part of the ice sheet. This changes the geometry for a small region in the southwest from ascending to predominantly descending from May 2017 forward when track 83 is available. • May 2017 V2.0 and June 2017 V2.0 files replaced. July 2017 data added.

Version	Release Date	Description of Changes
V2	July 2017	• Data reprocessed with a small radiometric correction to improve consistency across seam boundaries. • Temporal coverage extended through 31 May 2017. • Dates added to the .gif files
V1	June 2017	Initial release

5 RELATED DATA SETS

- MEaSUREs Greenland Ice Mapping Project (GrIMP) Digital Elevation Model from GeoEye and WorldView Imagery, Version 1
- MEaSUREs Greenland Ice Sheet Mosaics from SAR Data
- Greenland Ice Sheet Mapping Project (GrIMP)

6 RELATED WEBSITES

- MEaSUREs at NSIDC | Overview
- European Space Agency (ESA)
- Alaska Satellite Facility (ASF)

7 CONTACTS AND ACKNOWLEDGMENTS

Ian Joughin
University of Washington
Applied Physics Laboratory

Acknowledgments

These mosaics were generated through a grant from the NASA MEaSUREs program. All products contain modified Copernicus Sentinel data (2015-2018), acquired by the European Space Agency, distributed through the Alaska Satellite Facility, and processed by I. Joughin.

The WMO Polar Space Task Group is acknowledged for its role in coordinating the routine Copernicus Sentinel-1 Greenland acquisition plans.

8 REFERENCES

Joughin, I., Smith, B. E., Howat, I. M., Moon, T., & Scambos, T. A. (2016). A SAR record of early 21st century change in Greenland. Journal of Glaciology, 62(231), 62–71. https://doi.org/10.1017/jog.2016.10

Small, D. (2011). Flattening Gamma: Radiometric Terrain Correction for SAR Imagery. IEEE Transactions on Geoscience and Remote Sensing, 49(8), 3081–3093. https://doi.org/10.1109/tgrs.2011.2120616

9 DOCUMENT INFORMATION

9.1 Publication Date

July 2021

9.2 Date Last Updated

April 2025