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

National Snow and Ice Data Center

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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 by the symbol σ (sigma), and is a measure of the reflective strength of a radar target. This parameter is represented by the uncalibrated and contrast-enhanced product, `image`. The normalized measure of the radar return from a distributed target is called the backscatter coefficient, or sigma naught, and is defined as per unit area on the ground. This data set also includes a radiometrically terrain-corrected backscatter coefficient, gamma naught, which can be used to assess changes in backscatter independent of incident angle and topography. The calibrated products of this data set are `sigma0` and `gamma0`. Table 1 summarizes each parameter; refer to 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 – 29.99	-30
`gamma0`	Radiometrically terrain-corrected backscatter, useful for looking at backscatter changes independent of the incident angle and topography	Decibels	-29.99 – 29.99	-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.

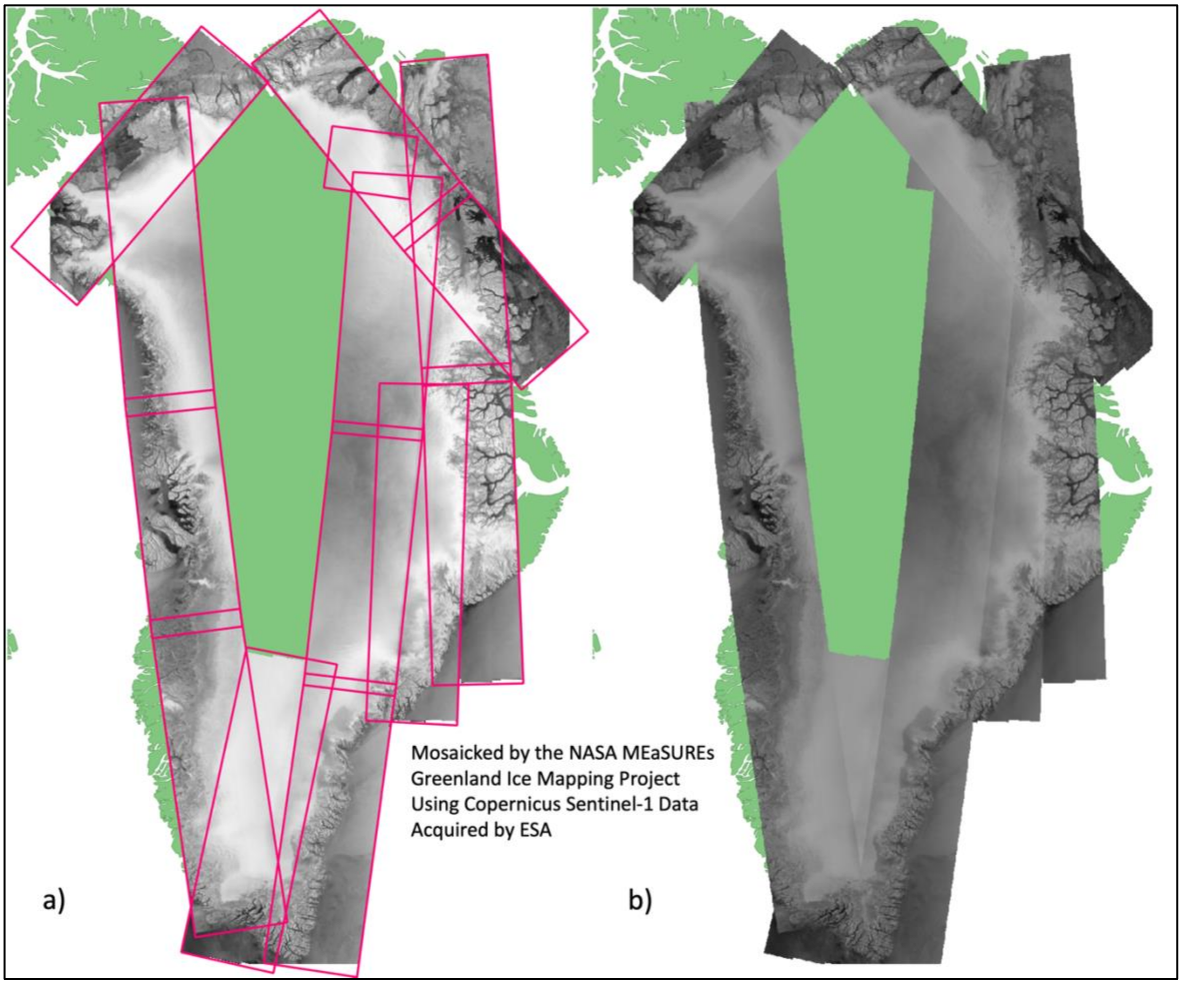

Figure 1**.** Sample mosaics of data collected from 06 November 2019 to 11 November 2019 (file names beginning with GL_S1bks_mosaic_06Nov19_11Nov19_), displayed here over Greenland's continental outline (not included in the data). In **a)**, the pink polygons are contained in the shapefile and denote 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 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		

Variable	GeoTIFF	JPEG	Shapefile
`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_mosiac_06Nov19_11Nov19_shape_v04.0.shp`
- `GL_S1bks_mosiac_06Nov19_11Nov19_shape_v04.0.dbf`
- `GL_S1bks_mosiac_06Nov19_11Nov19_shape_v04.0.prj`
- `GL_S1bks_mosiac_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:

- Southernmost Latitude: 60° N
- Northernmost Latitude: 82° N
- Easternmost Longitude: 20° W
- Westernmost Longitude: 70° 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

Data are currently available from 01 January 2015 through 27 February 2020. This data set undergoes periodic updates as new Sentinel-1 data are collected and processed.

1.4.2 Resolution

The temporal resolution for data acquired prior to 28 September 2016 is 12 days. The temporal resolution for data acquired after 28 September 2016 is 6 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, 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:

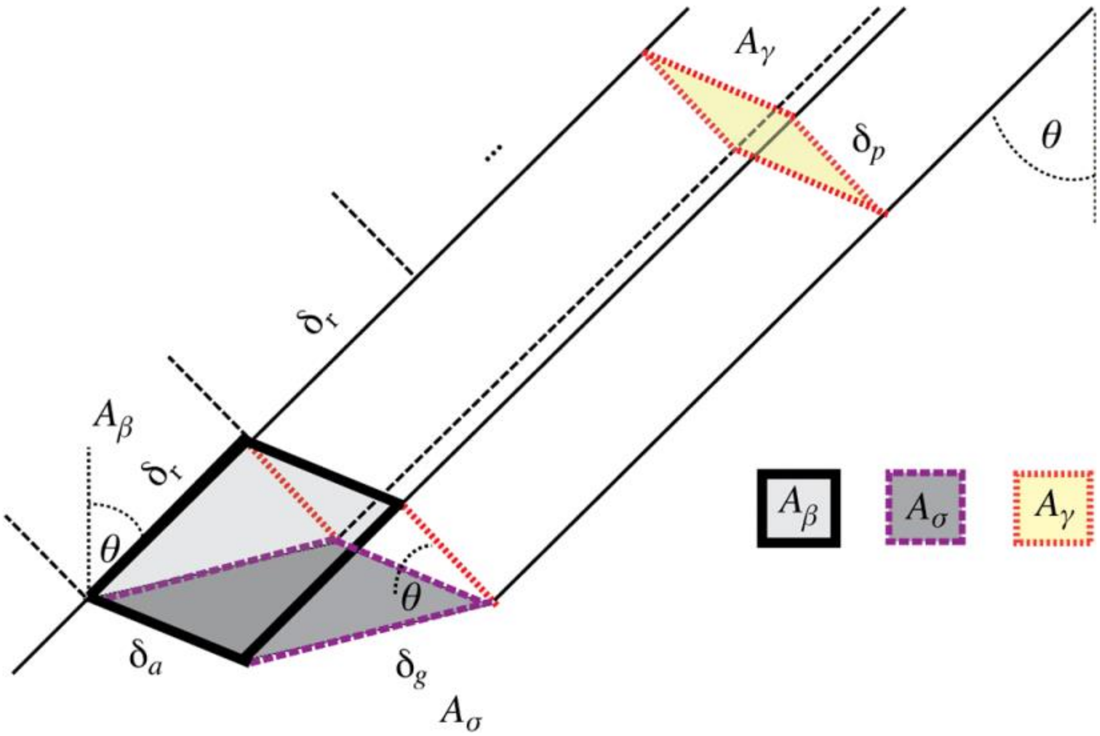

Figure 3. Normalization areas for SAR backscatter (from Small, 2011)

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

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, data were acquired from both Sentinel-1A and Sentinel-1B platforms.

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 (GIMP).

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 (GIMP) 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
V1	June 2017	Initial release
V2	July 2017	Data were reprocessed with a small radiometric correction to improve consistency across seam boundaries. Temporal coverage was expanded through 31 May 2017. Dates were added to the .gif files
V2.1	September 2017	An additional track (Sentinel-1, track 83) is included 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 were replaced. July 2017 data were added.
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.
V3	August 2020	Changes to this version include: 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
V3.1	January 2021	Changes to this version include: • 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.
V4.0	June 2021	This version update includes: • Update of temporal coverage • Data reprocessed utilizing a corrected DEM.

5 RELATED DATA SETS

- MEaSUREs Greenland Ice Mapping Project (GIMP) Digital Elevation Model from GeoEye and WorldView Imagery, Version 1

- MEaSUREs Greenland Ice Sheet Mosaics from SAR Data
- Greenland Ice Sheet Mapping Project (GIMP)

6 RELATED WEBSITES

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

7 CONTACTS AND ACKNOWLEDGMENTS

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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

06 July 2021