MEaSUREs Greenland Monthly Ice Sheet Velocity Mosaics from SAR and Landsat, Version 1

Document Creation Date: 24 January 2018
Document Revision Date: 16 October 2019

Table of Contents

Detailed Data Description

This data set includes monthly surface velocity estimates for the Greenland Ice Sheet and periphery. To access similarly derived annual or quarterly velocity mosaics, see related GIMP datasets: *MEaSUREs Greenland Annual Ice Sheet Velocity Mosaics from SAR and Landsat* and *MEaSUREs Greenland Quarterly Ice Sheet Velocity Mosaics from SAR and Landsat*.

Format

GeoTIFF (.tif) Files

Data are provided at 200 m posting in GeoTIFF (.tif) format with 32-bit floating-point values. Six data files are available for each month: a velocity magnitude map (vv); separate x- and y-component velocities (vx, vy); separate x- and y-component error estimates (ex, ey), and temporal offsets (dT).

GDAL Virtual Raster Files

Image pyramids are included for each band in separate OVR files (.ovr). GDAL virtual raster (.vrt) files are included that join the image pyramids with their respective GeoTIFF files. All three files (.tif, .vrt, and .ovr) for a particular parameter (e.g., vx) must be in the same directory in order to open the complete pyramided data set by opening the .vrt file only. The advantage of using the overview files is that they greatly increase the performance for zooming and panning when navigating the image in a GIS application.

Browse Images / Quick-Look files

Two browse products are included for each monthly mosaic: a low-resolution browse JPG of the log-scaled velocity and a full resolution GeoTIFF map of the log-scaled velocity (i.e., a color-scale map, not data values). The GeoTIFF browse files contain pyramided overview images.

Shapefiles

Shapefiles are provided for each month to indicate the source image pairs that were processed to produce the mosaics. These are provided as two separate shapefiles (.shp): US Geologic Survey (USGS)-provided Landsat 8 (L8) and the German Aerospace Center (DLR) and European Space Agency (ESA)-provided Synthetic Aperture Radar (SAR) data. For some months, Landsat data may not have been used to produce the mosaics; therefore, only a SAR shapefile is included.

File and Directory Structure

Data are available via HTTPS:

https://daacdata.apps.nsidc.org/pub/DATASETS/nsidc0731_MEASURES_monthly_vel_mosaics_v01/

Within this directory, there are 36 folders, one for each month from 01 December 2014 through 30 November 2018.

File Naming Convention

This section explains the file naming convention used for this product with examples for the different file types. Refer to Table 1 for the valid values for the file name variables.

Naming Convention:
```
greenland_vel_mosaic_[date1]_[date2]_[vv OR vx OR vy]_v[xx.x].ext
greenland_vel_mosaic_[date1]_[date2]_[ex OR ey]_v[xx.x].ext
greenland_vel_mosaic_[date1]_[date2]_dT_v[xx.x].ext
greenland_vel_mosaic_[date1]_[date2]_[SS]_v[xx.x].ext
greenland_vel_mosaic_[date1]_[date2]_browse.ext
```

Example File Names:

GeoTIFF and GDAL Virtual Raster Files:
```
greenland_vel_mosaic_2015-01-01_2015-01-31_dT_v01.1.tif
greenland_vel_mosaic_2015-01-01_2015-01-31_dT_v01.1.vrt
greenland_vel_mosaic_2015-01-01_2015-01-31_dT_v01.1.vrt.ovr
greenland_vel_mosaic_2015-01-01_2015-01-31_ex_v01.1.tif
greenland_vel_mosaic_2015-01-01_2015-01-31_ex_v01.1.vrt
greenland_vel_mosaic_2015-01-01_2015-01-31_ex_v01.1.vrt.ovr
greenland_vel_mosaic_2015-01-01_2015-01-31_ey_v01.1.tif
greenland_vel_mosaic_2015-01-01_2015-01-31_ey_v01.1.vrt
greenland_vel_mosaic_2015-01-01_2015-01-31_ey_v01.1.vrt.ovr
greenland_vel_mosaic_2015-01-01_2015-01-31_vv_v01.1.tif
greenland_vel_mosaic_2015-01-01_2015-01-31_vv_v01.1.vrt
greenland_vel_mosaic_2015-01-01_2015-01-31_vv_v01.1.vrt.ovr
greenland_vel_mosaic_2015-01-01_2015-01-31_vx_v01.1.tif
greenland_vel_mosaic_2015-01-01_2015-01-31_vx_v01.1.vrt
greenland_vel_mosaic_2015-01-01_2015-01-31_vx_v01.1.vrt.ovr
greenland_vel_mosaic_2015-01-01_2015-01-31_vy_v01.1.tif
greenland_vel_mosaic_2015-01-01_2015-01-31_vy_v01.1.vrt
greenland_vel_mosaic_2015-01-01_2015-01-31_vy_v01.1.vrt.ovr
```

Shapefiles:
```
greenland_vel_mosaic_2015-01-01_2015-01-31_L8_v01.1.dbf
greenland_vel_mosaic_2015-01-01_2015-01-31_L8_v01.1.prj
greenland_vel_mosaic_2015-01-01_2015-01-31_L8_v01.1.shp
greenland_vel_mosaic_2015-01-01_2015-01-31_L8_v01.1.shx
greenland_vel_mosaic_2015-01-01_2015-01-31_SAR_v01.1.dbf
greenland_vel_mosaic_2015-01-01_2015-01-31_SAR_v01.1.prj
greenland_vel_mosaic_2015-01-01_2015-01-31_SAR_v01.1.shp
greenland_vel_mosaic_2015-01-01_2015-01-31_SAR_v01.1.shx
```

Browse images / Quick-Look files:
```
greenland_vel_mosaic_2015-01-01_2015-01-31_browse_v01.1.jpg
greenland_vel_mosaic_2015-01-01_2015-01-31_browse_v01.1.tif
```

Table 1. File Naming Conventions

Variable	Description
`greenland_vel_mosaic`	Greenland velocity mosaic
`date1`	Time period start YYYY-MM-DD
`date2`	Time period end YYYY-MM-DD
`vv OR vx OR vy`	Velocity magnitude OR velocity x-direction OR velocity y-direction
`ex OR ey`	Error x-direction OR error y-direction
`dT`	Temporal offset (see the Parameter Description section for more information)
`SS`	Source sensor and satellite information: SAR (TerraSAR-X/TanDEM-X, Sentinel-1A and -1B) OR L8 (Landsat-8)
`browse`	Browse image (provided in .jpg and .tif formats)
`vxx.x`	Version number
`.ext`	File extension: GeoTIFF (.tif) OR Shapefile (.shp, .dbf, .shx, .prj) OR GDAL virtual format (.vrt, .vrt.ovr) OR Browse image (.jpg)

Spatial Coverage

This data set spans the entire Greenland Ice Sheet.

Southernmost Latitude: 60° N
Northernmost Latitude: 83° N
Westernmost Longitude: 75° W
Easternmost Longitude: 14° W

Spatial Resolution

The data are posted at a 200 m spacing, which should not be confused with the actual resolution. These products are derived as spatially varying averages from source data with resolutions ranging from 500 m to 1.5 km, making it difficult to specify the resolution at any point. For example, some estimates are derived as the average of 30 or more individual measurements. Although this enhances the final resolution beyond that of the individual source products, the amount is not well quantified.

For work requiring finer resolution, it may be preferable to use the individual DLR TerraSAR-X (TSX)/TanDEM-X (TDX) and USGS Landsat data, when available (*MEaSUREs Greenland Ice Velocity: Selected Glacier Site Velocity Maps from InSAR, Version 1*; *MEaSUREs Greenland Ice Velocity: Selected Glacier Site Velocity Maps from Optical Images, Version 1*).

Projection and Grid Description

Data 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).

Temporal Coverage

This data set provides monthly velocity mosaics for months spanning 01 December 2014 through 30 November 2018.

Temporal Resolution

The temporal resolution is one month. Monthly periods are defined as the first day in the month to the last day in the month.

Parameter or Variable

The parameter for this data set is ice velocity.

Parameter Description

Data files

Velocities are reported in meters per year. The vx and vy files contain component velocities in the x- and y-directions defined by the polar stereographic grid. These velocities are true values and not subject to the distance distortions present in a polar stereographic grid. Small holes have been filled via interpolation in some areas. Interpolated values are identifiable as locations that have velocity data but no error estimates. Radar-derived velocities are determined using a combination of conventional Interferometric SAR (InSAR) and speckle-tracking techniques (Joughin et. al., 2002).

For positive-valued quantities (vv, ex, ey), the "no data" value is -1. For signed quantities (vx, vy, dT), the "no data" value is -2.0e+9.

Temporal offset data

The temporal offset dT is a parameter included with the monthly mosaics. The nominal time stamp for each mosaic is the midpoint date over the sampling period (e.g., 16 May 2015 for the 01 May 2015 to 31 May 2015 product). Because of the way the data are combined, this date is nominal rather than an exact time stamp. The dT metric is the difference between the date for each velocity estimate and the midpoint date. This metric can be used to measure temporal skew in the data. For more information regarding dT and its usage, refer to the Processing Steps section. The dT values are reported in days.

Sensor Metadata

The Landsat 8 (L8) shapefiles contain the following attribute fields for each image pair:

Table 2. L8 Attributes

Attribute	Definition
Path	P
Row	R
Date1	YYYY-MM-DD
Date2	YYYY-MM-DD
LSImage1	LANDSATSCENEID_B8ps.tif (NOTE: this contains the standard Landsat 8 scene ID, but the filename is appended with "ps" to indicate the image was reprojected prior to matching.)
LSImage2	LANDSATSCENEID_B8ps.tif
PercentGood	XX.X % (this is the percent area for the scene where a valid match was obtained that contributed to the mosaic).

The SAR shapefiles contain the following attribute fields:

Table 3. SAR Attributes

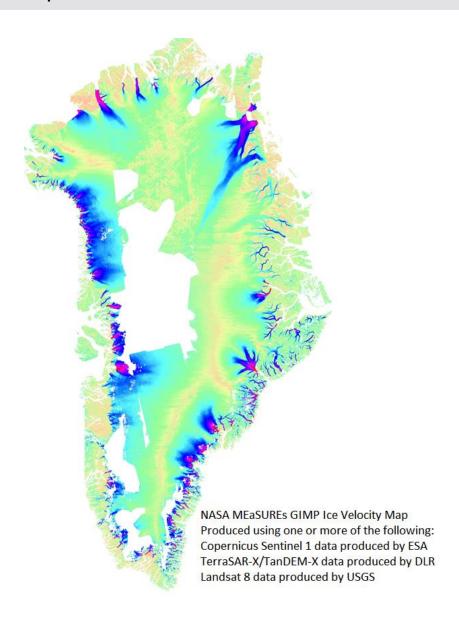| Attribute	Definition
Track	Sentinel reference track X of 175 tracks in 12-day repeat cycle
Date1	YYYY-MM-DD
Date2	YYYY-MM-DD
Orbit1	NNNNN
Orbit2	NNNNN
SAT1	S1A=Sentinel 1A, S1B=Sentinel 1B , TSX=TerraSAR-X, or TDX=TanDEM-X
SAT2	S1A=Sentinel 1A, S1B=Sentinel 1B , TSX=TerraSAR-X, or TDX=TanDEM-X

Figure 1. Greenland Monthly Velocity Mosaic Browse Image for period covering 01 May 2016 to 31 May 2016 produced by the MEaSUREs GIMP project. Refer to the Acknowledgements section for information on the instruments and data used.

Data Acquisition and Processing

Derivation Techniques and Algorithms

The data are posted to a 200 m grid, but the true resolution varies between 500 m to 1.5 km. Many small glaciers are resolved outside the main ice sheet, but for narrow (<1 km) glaciers, the velocity represents an average of both moving ice and stationary rock. As a result, while the glacier may be visible in the map, the actual speed may be underestimated. For smaller glaciers, interpolation produces artifacts where the interpolated value is derived from nearby rock, causing apparent stationary regions in the middle of otherwise active flow. The data have been screened to remove most of these artifacts, but should be used with caution.

Areas with no data correspond either to regions where no data were acquired or where the interferometric or optical correlation was insufficient to produce an estimate. This occurs most often in areas with high snow accumulation.

Processing Steps

These mosaics were produced mostly from Copernicus Sentinel-1A and Sentinel-1B data from ESA and supplemented with TSX/TDX data from DLR for coastal outlets. The data were acquired in either 12-day (through Sept 2016) or 6-day repeat cycles (October 2016 forward). In cases of missing acquisitions, the repeat periods may be longer (integer multiples of 6 or 12 days) for some of the image pairs. In addition, USGS's Landsat 8 velocities were merged with SAR data during periods when there was sufficient daylight.

Although the mosaics represent one-month periods, they are computed as averages of all available data at each point and weighted by their respective errors (Joughin, 2002); as such, they do not represent true monthly averages. For example, in some places the first half of a monthly period may be weighted more heavily than the latter half due to the availability of the data. In some regions, clouds or large snow accumulation events may also affect the distribution of the data. As a result, comparing adjacent years at any location might reveal differences that represent some degree of variation. Such differences should be small, particularly when examining trends over multiple years.

Unlike earlier SAR acquisitions, Sentinel-1A and -1B provide crossing ascending and descending orbit data over much of the ice sheet. In areas where crossing-orbit data were available, an error-weighted range-offset-only solution was included in the velocity product, which eliminated azimuth offsets and reduced the error from ionospheric streaking in the azimuth offsets.

For each one-month period, all available data are aggregated and combined in an error-weighted method to achieve an optimal estimate with respect to error reduction. Due to limited coverage or lack of unsuccessful matches, there are data gaps such that the full monthly period may not be sampled uniformly. In order to maximize coverage, data were included where the sampling interval of the input data did not fully lie within the output interval. In these cases, these data are weighted by the amount they overlap the output interval (e.g., if the first 6-days of a 12-day image pair lies within the output interval, a weight of 0.5 would be applied). If uniformly sampled data (e.g., every 12-days) and uniformly weighted data were combined, this procedure would be equivalent to a linear interpolation of the time series.

Finally, to reduce errors and improve coverage, data were also included where the input estimate spanned a window longer than the output window (e.g., up to a 48-day pair for the one-month output). This inclusion slightly degrades the temporal resolution, but improves coverage and helps reduce errors. For these data, we apply weights to de-emphasize the contribution of data spanning more than one month (i.e., they are only a factor where coverage from other data is poor). As a result, the nominal one-month resolution is applicable to most of the data set, but could be less in some regions.

Because of this data aggregation process, the true date represented by the data may differ from the nominal center-interval date. As a measure of temporal skew, the mean deviation, dT, was calculated from the center interval date in days for each point. This metric is calculated by applying the same weighting to the difference between the date for each velocity estimate and the center interval date, and then weighted using the same methods as the velocity data. In estimating velocity, different weights are used for the vx and vy components, so an intermediate weight is used for the individual dTs. In the final mosaicking step, any data with dT greater than one-half the output interval was discarded. As a result, for the one-month product, the time stamp error is less than or equal to approximately 16 days.

Although the averaged dT value provides some idea of the deviation from nominal date, **users should be cautious when using dT to correct dates.** As an example, if the mosaic covers the interval from May 1 to May 31 (nominal center date of May 16), then a value dT=5 would indicate that May 21 better represents the interval. Note, however, that a value of dT=0 representing May 16 could have resulted from data acquired May 1 to May 12 and May 19 to May 31, even though no measurement occurred on May 16. Because such convoluted cases can occur, the use of dT to flag potential time-skew issues is recommended, rather than for date correction. If a large temporal skew is identified, the use of other GIMP products with finer temporal sampling is recommended to analyze the temporally varying behavior.

Monthly mosaics for 2015 (Dec 1, 2014 - Nov 30, 2015)

Sentinel-1A data acquisitions began in 2015, but the acquisition rates were not as regular as in later years. As a result, these data tend to be somewhat noisier than the 2016 data, particularly in the middle of the ice sheet. In addition, the sampling of coastal regions is more irregular (there are gaps in the temporal coverage where TSX/TDX data were not acquired by the satellite for a month or more), which reduces the averaging of seasonal variation.

Monthly mosaics for 2016 (Dec 1, 2015 - Nov 30, 2016)

For this year, the six Sentinel-1A tracks that image the majority of the Greenland coast were collected for almost every 12-day satellite repeat cycle. Beginning in October 2016, Sentinel-1B started acquiring data over Greenland in an orbit that lags Sentinel-1A by six days, providing better coverage and thus more correlations in the data. As a result, the accuracy for these mosaics is considerably better than the mosaics for 2015 for most regions.

Monthly mosaics for 2017 (Dec 1, 2016 - Nov 30, 2017)

These products are similar to the earlier 2015 and 2016 products. The major difference is that this is the first year that regular 6-day coverage occurred throughout the year, which should improve performance on fast moving glaciers. In addition, the Copernicus Sentinel mission improved coverage for the southern part of Greenland in mid-2017, so the results should be improved for areas south of 67.5 degrees. **Note:** some of the Landsat8 shape files for the middle of

winter months, may have only a single file (36 bytes in size), with none of the other files that usually make up a shape file. This is an indicator that there were no Landsat 8 data for that month.

Monthly mosaics for 2018 (Dec 1, 2017 - Nov 30, 2018)

These products follow the same specifications as the previous year's release, with the following minor differences: some data using a few scenes from the COnstellation of small Satellites for the Mediterranean basin Observation (COSMOS-SkyMed) were included; some of the glaciers which were monitored by TSX in past years are covered by other instruments during this year.

Baseline Fits

Each image pair used in the mosaic requires a four- to six-parameter fit for the baseline parameters. The data are fit to a common set of ground control points as described by Joughin et al. (2010). For years where data is not well controlled (sparse ground control points), control points from other years with adequate controls are used. This greatly improves consistency of the data from month to month. While this could mask some true change, the errors without this procedure are far larger than any change likely to occur.

These data should not be used to determine inter-annual change for interior regions of the ice sheet (roughly defined as areas above 2,000 m). In outlet glaciers close to the coast where the baselines are well constrained by bedrock, the velocity mosaics are well suited to this task. However, care should be exercised in interpreting any change observed in intermediate regions (roughly 1,000 m to 2,000 m); in other words, areas where the observed changes seem to follow a satellite swath boundary should be avoided. Refer to Figure 5 in Phillips et al. (2013) for an example.

Interpolated Points

Small holes in the final maps have been filled via interpolation. These points can be identified as those that have valid velocity data but no corresponding error estimates.

See Joughin et al. (2002) for more detail on errors and how they were computed.

Error Sources and Limitations

Due to the large volume of averaged source data, the overall quality of the data set is good. While the spatial coverage is generally improved in the southeast relative to earlier Greenland Ice Mapping Project (GIMP) MEaSUREs products, the results are considerably noisy relative to other regions of the ice sheet. High snow accumulation in the southeast greatly reduces image-to-image correlation, resulting in higher noise. Additionally, in these regions there may be coherent displacement signals (e.g., vertical displacement associated with compacting snow) that are not associated with horizontal ice motion. If such displacement occurs with characteristics other than that assumed in the solution (e.g., predominantly vertical instead of horizontal displacement), then the results will be incorrectly mapped to horizontal motion, thereby contributing to the overall level of noise.

Error Estimates

Error estimates are provided for all non-interpolated, radar-derived velocity vectors in separate GeoTIFF files appended with `ex.tif` and `ey.tif`. Formal errors agree reasonably well with errors determined by comparison with GPS data (Joughin et al., 2002; Joughin et al., 2017). The values, however, underestimate true uncertainty in several ways, and as such, should be used more as an indication of relative quality rather than absolute error.

In general, the error estimates represent the average behavior of the data. This means that errors may be much lower than reported in some areas and much greater in others; care should be taken when assigning statistical significance based on the errors, especially given that the errors have been correlated over large areas. For example, even if the errors are correct in a global sense, one might compare two mosaics and find a large difference over 5% of the ice sheet. However, because errors can be spatially correlated over broad areas, one should not assume significance at the 95% confidence level; this might be precisely the 5% that statistically should exceed the errors because the errors are not uniformly distributed. By contrast, if the errors were completely uncorrelated, one could average over neighborhoods to reduce the error.

Sensor or Instrument Description

Descriptions of the instruments used to construct the mosaics from which this data set is derived are at the mission sites:

- European Space Agency (ESA): Copernicus Sentinel-1

- German Aerospace Center (DLR): TerraSAR-X (TSX) and TanDEM-X (TDX)

- US Geologic Survey (USGS): Landsat 8

Software and Tools

GeoTIFF files, virtual raster files, and shapefiles can be viewed with a variety of Geographical Information System (GIS) software packages including QGIS and ArcGIS.

Version History

Version	Description	Effective Date
V1.1	Updated the `.tif` file names within the `.vrt` files to match the actual `.tif` file names	October 2019
V1	Initial release	February 2018

References and Related Publications

Joughin, I. 1995. Estimation of ice-sheet topography and motion using interferometric synthetic aperture radar. PhD Dissertation, University of Washington.

Joughin, I. 2002. Ice-sheet velocity mapping: a combined interferometric and speckle-tracking approach. *Annals of Glaciology,* 34: 195-201.

Joughin, I., S. Tulaczyk, R. Bindschadler, and S. F. Price. 2002. Changes in West Antarctic ice stream velocities: observation and analysis. *Journal of Geophysical Research-Solid Earth,* 107(B11): EPM 3-1–EPM 3-22. DOI: 10.1029/2001JB001029.

Joughin, I., W. Abdalati, and M. Fahnestock. 2004. Large fluctuations in speed on Greenland's Jakobshavn Isbrae Glacier. *Nature,* 432(7017): 608-610. DOI: 10.1038/nature03130.

Joughin, I., B. Smith, I. M. Howat, T. Scambos, and T. Moon. 2010. Greenland flow variability from ice-sheet-wide velocity mapping. *Journal of Glaciology,* 56(197): 415-430. DOI: 10.3189/002214310792447734.

Joughin, I., B. E. Smith, and I. M. Howat. 2017. A complete map of Greenland ice velocity derived from satellite data collected over 20 years. *Journal of Glaciology*, 64(243): 1–11. DOI: 10.1017/jog.2017.73.

Joughin, I., B. E. Smith, and I. Howat. 2018. Greenland Ice Mapping Project: ice flow velocity variation at sub-monthly to decadal timescales. *The Cryosphere*, 12(7): 2211–2227. DOI: 10.5194/tc-12-2211-2018.

Moon, T. and I. Joughin 2008. Retreat and advance of Greenland tidewater glaciers from 1992 to 2007. *Journal of Geophysical Research - Earth Surface,* 113: Art. #F02022. DOI: 10.1029/2007JF000927.

Phillips, T., H. Rajaram, W. Colgan, K. Steffen, and W. Abdalati. 2013. Evaluation of cryo-hydrologic warming as an explanation for increased ice velocities in the wet snow zone, Sermeq Avannarleq, West Greenland. *Journal of Geophysical Research - Earth Surface,* 118(3): 1241-1256. DOI: 10.1002/jgrf.20079.

Rignot, E. and P. Kanagaratnam. 2006. Changes in the velocity structure of the Greenland ice sheet. *Science,* 311(5763): 986-990. DOI: 10.1126/science.1121381.

Related Data Collections

- MEaSUREs Greenland Annual Ice Sheet Velocity Mosaics from SAR and Landsat

- MEaSUREs Greenland Quarterly Ice Sheet Velocity Mosaics from SAR and Landsat

- MEaSUREs Greenland Ice Velocity: Selected Glacier Site Velocity Maps from InSAR

- MEaSUREs Greenland Ice Sheet Velocity Map from InSAR Data

Related Web Sites

- MEaSUREs Data | Overview

- Alaska Satellite Facility

- Greenland Ice Mapping Project (GIMP)

Contacts and Acknowledgments

Ian Joughin
University of Washington
Applied Physics Laboratory
1013 NE 40th Street
Box 355640
Seattle, WA 98105