MEaSUREs Greenland Ice Velocity: Selected Glacier Site Single-Pair Velocity Maps from Optical Images, Version 1

USER GUIDE

How to Cite These Data

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

Howatt, I., T.R. Chudley, and M.J. Noh. 2022. *MEaSUREs Greenland Ice Velocity: Selected Glacier Site Single-Pair Velocity Maps from Optical Images, Version 1*. [Indicate subset used]. Boulder, Colorado USA. NASA National Snow and Ice Data Center Distributed Active Archive Center. https://doi.org/10.5067/B28FM2QVVYWY. [Date Accessed].

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

FOR CURRENT INFORMATION, VISIT https://nsidc.org/data/NSIDC-0777

National Snow and Ice Data Center

TABLE OF CONTENTS

1 DATA DESCRIPTION

1.1 Parameters

This data set contains surface ice velocities and descriptive statistics for select Greenland Ice Sheet outlet glaciers. Velocities are generated using an automated photogrammetry software package that tracks visible features in optical image pairs. Input data were acquired by the U.S. Geological Survey (USGS) Landsat 8 Operational Land Imager (OLI) and the European Space Agency (ESA) Sentinel-2A and Sentinel-2B satellites.

1.2 File Information

1.2.1 Format

Velocity data are provided as NetCDF-4 (.nc) formatted files. Glacier/ROI (region of interest) IDs are available separately as either a GeoPackage (.gpkg) or a comma-separated values (.csv) file.

> ⓘ A GeoPackage file (.gpkg) is a SQLite database container formatted according to the open, portable, and platform-independent GeoPackage Encoding Standard. For details about working with a GeoPackage, see the GeoPackage Implementation Guidance website.

1.2.2 File Contents

1.2.2.1 Glacier/ROI

The glacier/ROI GeoPackage and CSV file contain ID numbers, official Greenlandic (Bjork) and foreign names, and spatial bounding boxes for each glacier/ROI. Internal processing IDs are also provided to help interpret the naming convention used for the velocity data files (See 1.2.3 | Naming Convention below.). The GeoPackage additionally contains all the geolocation information needed to view and work with the glaciers/ROIs in geographic information system (GIS) software (See Figure 1.).

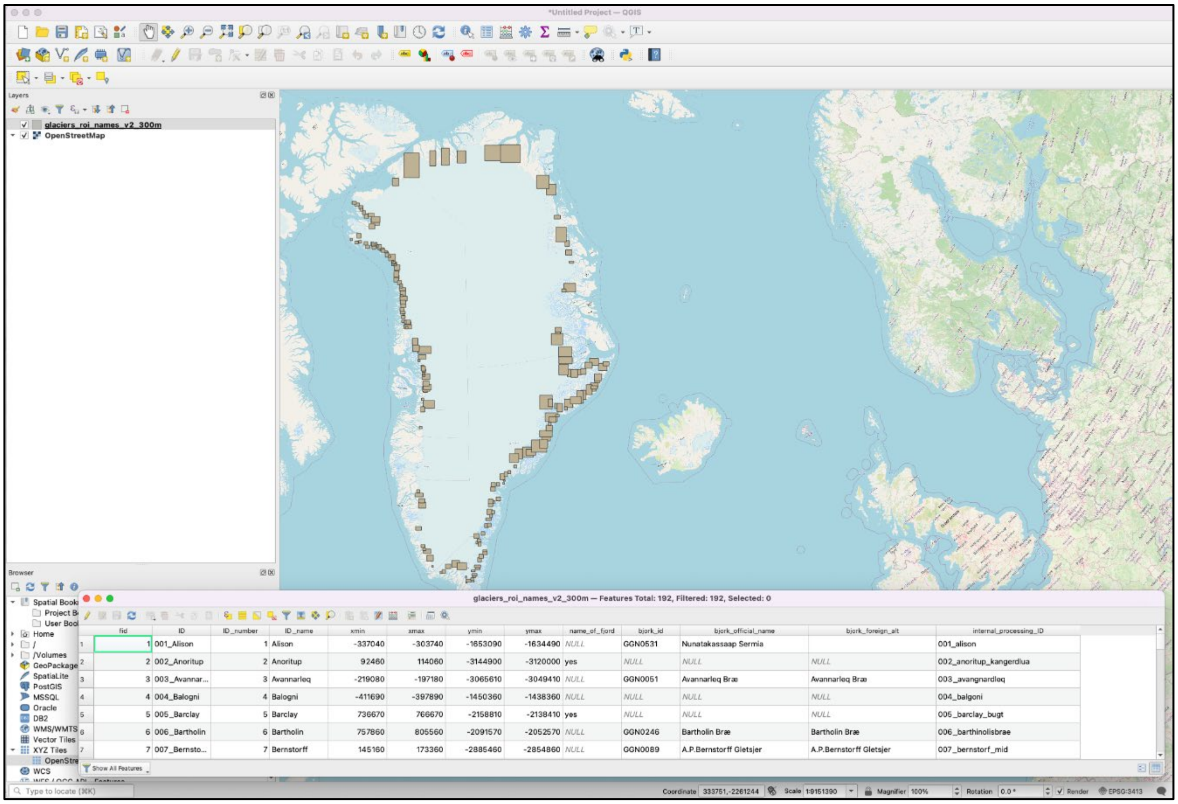

Figure 1. Glacier/ROI ID GeoPackage (QGIS)

1.2.2.2 Velocity

Velocity data for each glacier/ROI are broken out into separate files for each year in the data record. The data are stored as 3D arrays (x,y,t), where each layer represents the spatial grid (x,y) at a different date/time (t) during the specified year. Table 1 describes the variables in the NetCDF files.

ⓘ The velocity data arrays utilize zero-based indexing and have different dimensions depending on the glacier/ROI and year.

Table 1. Variable Names and Descriptions

Variable Name	Description	Dimensions	Units
id	Velocity field ID: [glacier ID]_[datetime1]_[datetime2]_ [satellite]	string	n/a
vx, vy	Velocity component in x, y direction	(t × y × x)	m/day
x	x coordinate at center of grid cell	(x × 1)	m (from origin)
y	y coordinate at center of grid cell	(y × 1)	m (from origin)

Variable Name	Description	Dimensions	Units
error_dx_mean error_dy_mean	Mean off-ice[1] velocity in x, y direction	(t × 1)	m/day
error_dx_sd error_dy_sd	Off-ice velocity standard deviation in x, y direction	(t × 1)	m/day
error_mag_rmse	Magnitude of off-ice velocity root mean square error	(t × 1)	m/day
percent_ice_area_notnull	Percentage of GrIMP ice mask region that contains valid data	(t × 1)	percent
scene_1_datetime scene_2_datetime	Scene 1, scene 2 acquisition date/time	(t × 1)	seconds since 1970-01-01
midpoint_datetime	Midpoint between scene 1 and scene 2 acquisition time	(t × 1)	seconds since 1970-01-01
baseline_days[2]	Temporal baseline between scene 1 and scene 2	(t × 1)	days
scene_1_satellite scene_2_satellite	Scene source satellite	string	n/a
scene_1_orbit scene_2_orbit	Sentinel-2 relative orbit number. E.g., 125 = Relative Orbit R125.	string	n/a
scene_1_processing_version scene_2_processing_version	Sentinel-2 processing baseline version. E.g., '301' = processing baseline 03.01.	string	n/a
NetCDF Dimensions			
index, string4, string6, string11, string49	NetCDF dimension, not a NetCDF variable	dimension scale	n/a

[1]The off-ice area is defined using the GrIMP land mask (Howat et al., 2014). As land is assumed to be stable (velocity = 0), any observed 'off-ice velocity' is assumed to be error and used as an error estimate for the velocity fields.

[2]As a rough rule of thumb, as the temporal baseline between the two scenes increases, the impact of error components (e.g., orthorectification error) decreases. As such, longer, velocity estimates with longer temporal baselines are expected to have lower relative error. Users may wish to filter small baselines from their analyses. However, at fast-moving, rapidly-changing locations, users may prefer shorter baselines to properly capture the change. For example, where a summer termination occurs within the span of a week, scenes separated by 30 days are unlikely to be helpful.

ⓘ Note for Panoply users: To plot the vx and vy variables in Panoply, on the "Create Plot" screen select "Color contour plot using" and change the drop-down menus to read "x for x axis" and "y for y axis," respectively.

1.2.3 Naming Convention

The GeoPackage (.gpkg) and CSV files are named:

glacier_roi_names_v01.0.gpkg
glacier_roi_names_v01.0.csv

NetCDF data files utilize the following naming convention:

[ID]_[name]_[year]_v[nn].[r].nc

Example:
001_Alison_2016_v01.0.nc

The "ID" and "name" variables, when combined (e.g., 001_Alison), correspond to the "ID" field and column in the GeoPackage and CSV file, respectively. Each file thus contains all the velocity data for the specified glacier/ROI ID and year. v[nn].[r] specifies the major [nn] and minor[3] [r] version number.

ⓘ For V01.1, data files for 2021 were reprocessed to accommodate a mid-year change in how ESA orthorectified L1C/L2A Sentinel-2 products (See "Section 2.2 | Processing".). These reprocessed files were renamed to v01.1. However, two data-sparse glaciers — Arsuk (ID 134) and LindenowC (ID 140) — were found to be unaffected by this change. As such, these glaciers' data files for 2021 — "134_Arsuk_2021_v01.0.nc" and "140_LindenowC_2021_v01.0.nc" — were not reprocessed, i.e., still contain "v1.0" in the file names.

[3] Occasionally, some or all of the files within a major version (e.g., v01.0) may need to be updated or replaced. When this happens, a minor version update is released. Any reprocessed data files, or new data files associated with the update, will have the minor version number incremented by 1 (e.g., v01.1) in their file names.

1.3 Spatial Information

1.3.1 Coverage

Northernmost Latitude: 82° N

Southernmost Latitude : 60° N

Easternmost Longitude: 20° W

Westernmost Longitude: 70° W

1.3.2 Resolution

Data are posted at 100 m.

1.3.3 Geolocation

Data are provided in the WGS 84 / NSIDC Sea Ice Polar Stereographic North projection. The following tables provide additional details about geolocating this data set.

Table 2. Geolocation Details

Geographic coordinate system	World Geodetic System 1984
Projected coordinate system	WGS 84 / NSIDC Sea Ice Polar Stereographic North
Longitude of true origin	45° W
Latitude of true origin	70° N
Scale factor at longitude of true origin	1
Datum	WGS 84
Ellipsoid/spheroid	WGS 84
Units	meter
False easting	0
False northing	0
EPSG code	3413
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

1.4 Temporal Information

1.4.1 Coverage

11 January 2016 – 02 November 2022

1.4.2 Resolution

Varies between 2 – 50 days

2 DATA ACQUISITION AND PROCESSING

2.1 Acquisition

Sentinel source data comprise orthorectified, Sentinel-2 L2A scene pairs (both repeat-track and cross-track pairs) with a temporal baseline of between 2 and 50 days.

Orthorectified Landsat 8 images (panchromatic band) were obtained from Landsat standard data products (Level L1T or L1G).

2.2 Processing

Subsets of tiles were constructed for each glacier and reprojected from UTM to NSIDC Sea Ice Polar Stereographic North (EPSG:3413). Adjacent, overlapping tiles were then mosaicked and the resulting rasters were clipped using bounding polygons corresponding to each glacier's region of interest.

Velocity fields were produced using "Surface Extraction through TIN Searchspace Minimization" (SETSM), an open-source photogrammetry software package that performs cross-correlations of sequential images (see Noh and Howat, 2019). Developed previously to produce high-resolution estimates of surface displacements across Antarctic Digital Elevation Models (DEMs), the original method compensated for relative sensor-model biases (i.e., minimized co-registration errors) and removed orthorectification errors due to height changes through time.

The algorithm was modified for this data set such that the relative sensor-model bias compensation module is applied directly to orthorectified images as co-registrations. Processing is fully automated with one exception: InSAR-derived velocity fields from 2016 to 2017 are used as an a priori, or seed velocity field, to specify maximum displacements when determining the initial resolution in the coarse-to-fine processing scheme (Joughin, 2021).

To correct the significant orthorectification error in Sentinel-2 cross-track pairs, empirical estimates of systematic error were computed for each individual cross-track pair.

As a function of satellite geometry, orthorectification error should result in consistent offsets (in units of absolute displacement rather than velocity) across all velocity fields generated from the same repeat-orbit pairs. In addition, the algorithm assumes that other errors in the velocity field (e.g., image matching errors and co-registration errors) are random and do not correlate with specific ROI pairings. As such, the orthorectification error for specific orbital pairs is inferred by measuring the average offset between: the ice displacement measured from Sentinel-2 scenes; and the expected displacement from a reference velocity field, calculated as the median value of repeat-track pairs across the study period.

Once orbit-pair offsets have been constructed, uncorrected velocity fields are converted to absolute displacement, corrected using the appropriate orbit-pair displacement offset field, and then converted back to velocity.

ⓘ Prior to 23 August 2021, ESA orthorectified L1C/L2A Sentinel-2 products using the commercial 90 m global digital elevation model from PlanetDEM. However, orthorectification was switched on the 23rd to an improved geometric refinement with two major changes: scenes were co-registered to a Global Reference Image (GRI); and the PlanetDEM used for topographic corrections was replaced with the Copernicus DEM at 90 m resolution (GLO-90).

Because GLO-90 is based on 2011 – 2015 satellite radar data acquired during the TanDEM-X mission, the switch introduced a height discontinuity between the pre- and post-2021 data. As such, starting with V01.1, two different correction fields are generated from/applied to Sentinel-2-derived velocities: one prior to 23 August 2021 and the other from the 23rd forward.

To mitigate the effect of erroneous velocity measurements, a filter is applied to remove areas within the GrIMP ice mask where flow directions deviate by >20° from the reference flow field. If no data remain after filtering (<1% of the ice area has valid velocity measurements) the field is discarded and no output data are generated.

Displacements are corrected only over ice as defined in the Greenland Ice Mapping Project ice mask (Howat et al. 2014). Vertical DEM error outside of this mask is assumed to come only from elevation measurement error and not from surface elevation change.

2.3 Quality, Errors, and Limitations

As a first-order estimate of error, the data set includes the root mean square error (RMSE) of the absolute velocity of the bedrock area (as defined by the GrIMP bedrock mask). RMSEs tend to be low, with the median RMSE consistently beneath <0.5 m/day. Additionally, the mean and standard deviation of the bedrock area vx and vy velocity fields are also provided, so users can assess systematic co-registration error within individual flow fields due to e.g., poor co-registration. Where the mean of the vy or vy velocity is greater than one standard deviation away from zero, the field likely has a systematic co-registration error and users may wish to correct or discard these fields.

Finally, due to changing ice boundaries at marine-terminating locations, areas within the GrIMP ocean mask have not been filtered or removed. However, ice velocities beyond the extent of the GrIMP ice mask should not be considered reliable.

2.4 Instrumentation

2.4.1 Description

The Multi-Spectral Instrument (MSI) on board the Sentinel-2 satellites is a push-broom, 13-band, multispectral scanning radiometer capable of providing high-resolution imaging information of the Earth's surface. Orbiting at an altitude of 786 km, the instrument detects spectrally-filtered radiation in the visible/near-infrared (VNIR) and short wave infrared spectral range (SWIR) with a field of view of 290 km.

Individual satellite revisit times are 10 days, with two identical satellites (Sentinel-2A and Sentinel-2B) phased 180 degrees from each other on the same orbit, allowing for a 5-day revisit cycle. Swath overlap at high latitudes enhances this revisit time further. The near-infrared (NIR) band 8 has a spatial resolution of 10 m, a central wavelength of 832.8 nm, a bandwidth of 106 nm, and a radiometric resolution of 12 bits. For more information, see the ESA's Sentinel Online | MultiSpectral Instrument (MSI) Overview web page.

The OLI aboard Landsat 8 observes Earth in the visible, near infrared, and shortwave infrared wavelengths and produces images with 15 m panchromatic and 30 m multi-spectral spatial resolutions. The satellite orbits Earth in a sun-synchronous, near-polar orbit at an altitude of 705 km. It completes one Earth orbit every 99 minutes and has a 16-day repeat cycle with a local equatorial crossing time of 10:00 a.m. (+/- 15 minutes). For more information, see the USGS Landsat 8 mission webpage.

3 SOFTWARE AND TOOLS

A GeoPackage can be accessed using Geographic Information System (GIS) software like QGIS (free, open source). For additional details about working with a GeoPackage, see the GeoPackage Implementation Guidance website.

4 VERSION HISTORY

Version	Release Date	Description of Changes
1.1	Oct, 2023	• New data added for 2022, extending the temporal coverage through 2 November 2022. • 2021 data reprocessed. To account for a change on 23 August 2021 in how ESA orthorectifies Sentinel-2 L1C/L2A products, V01.1 applies different empirical corrections to Sentinel-2-derived velocities, pre- and post-23 August 2021. As such, Sentinel-2 data that had been excluded from V01.0 are now included in V01.1. • Version number in file names incremented to v01.1 for new (2022) and reprocessed (2021) files.
1.0	Jul, 2022	Initial release

5 RELATED DATA SETS

MEaSUREs Data at NSIDC

6 CONTACTS AND ACKNOWLEDGMENTS

6.1 Investigators

Ian M. Howat, Tom R. Chudley, and Myoung-Jong Noh

Byrd Polar Research Center

Ohio State University

Columbus, OH 43210

7 REFERENCES

Howat, I., A. Negrete, and B. Smith. 2014. The Greenland Ice Mapping Project (GIMP) land classification and surface elevation data sets. *The Cryosphere*, 8. 1509-1518. https://doi.org/10.5194/tc-8-1509-2014

Joughin, I. (2021). *MEaSUREs Greenland Annual Ice Sheet Velocity Mosaics from SAR and Landsat, Version 3*. NASA National Snow and Ice Data Center Distributed Active Archive Center. https://doi.org/10.5067/C2GFA20CXUI4

Kääb, A., Winsvold, S. H., Altena, B., Nuth, C., Nagler, T., & Wuite, J. (2016). Glacier Remote Sensing Using Sentinel-2. Part I: Radiometric and Geometric Performance, and Application to Ice Velocity. *Remote Sensing*, 8(7), 598. https://doi.org/10.3390/rs8070598

Noh, M. J., & Howat, I. M. (2019). Applications of High-Resolution, Cross-Track, Pushbroom Satellite Images With the SETSM Algorithm. *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, 12(10), 3885-3899. https://doi.org/10.1109/JSTARS.2019.2938146

8 DOCUMENT INFORMATION

8.1 Publication Date

July 2022

8.2 Date Last Updated

October 2023