MEaSUREs ITS_LIVE Landsat Image-Pair Glacier and Ice Sheet Surface Velocities: Version 1 (Beta)

1. Data Description

The Inter-Mission Time Series of Land Ice Velocity and Elevation (ITS_LIVE) project, part of NASA's Making Earth System Data Records for Use in Research Environments (MEaSUREs) 2017 program, provides global low-latency measurements of glacier and ice sheet surface velocity and elevation change at a high temporal resolution.

The ITS_LIVE data set presented here features image-pair velocities at 240 m resolution generated from satellite optical imagery. This data set covers all land ice areas larger than 5 km^2 in area, and spans the time period from 1985 to 2018 (record will be extended with release of Version 2.0), subject to image availability and quality. The velocities are derived from Landsat 4, 5, 7, and 8 imagery using the autoRIFT feature tacking processing chain described in Gardner et al. (2018) and Lie et al. (2021). Data scarcity and/or low radiometric quality (e.g., band saturation) are significant limiting factors for many regions in the earlier product years. Annual coverage is nearly complete, globally, for the years following the launch of Landsat 8 in 2013. Version 1.0 is a beta version and low-latency version 2.0 data are expected to be available beginning in Fall, 2021.

This data set is used to create the regional velocity mosaics featured in the ITS_LIVE Regional Glacier and Ice Sheet Surface Velocities product.

1.1 Parameters

The parameters provided in this data set are listed in Table 1.

Table 1. List of Parameters

Parameter name	Description	Units	Class
x	Map-projected x-coordinate	m	double
y	Map-projected y-coordinate	m	double
vx	Velocity component in x-direction	m yr^{-1}	short
vy	Velocity component in y-direction	m yr^{-1}	short
v	Velocity magnitude	m yr^{-1}	short
UTM_Projection or Polar_Stereographic	Projected Coordinate System. UTM_Projection for non-Antarctic images Polar_Stereographic for images south of 70°S	-	char
interp_mask	Interpolated value mask (1 = interpolated velocity)	-	binary
img_pair_info	Information on each image pair	-	char
chip_size_width	Chip size width (in the sample or x-direction)	m	ushort
chip_size_height	Chip size height (in the line or y-direction)	m	ushort

1.2 File Information

1.2.1 File Format

The data are provided as netCDF-4 HDF5 (.nc) files with embedded metadata.

1.2.2 File Contents

Each netCDF file contains all of the parameters listed in Table 1, gridded at 240 m over the regional map areas. Figure 1 shows an example of an image-pair velocity field from the Petermann glacier in north-west Greenland.

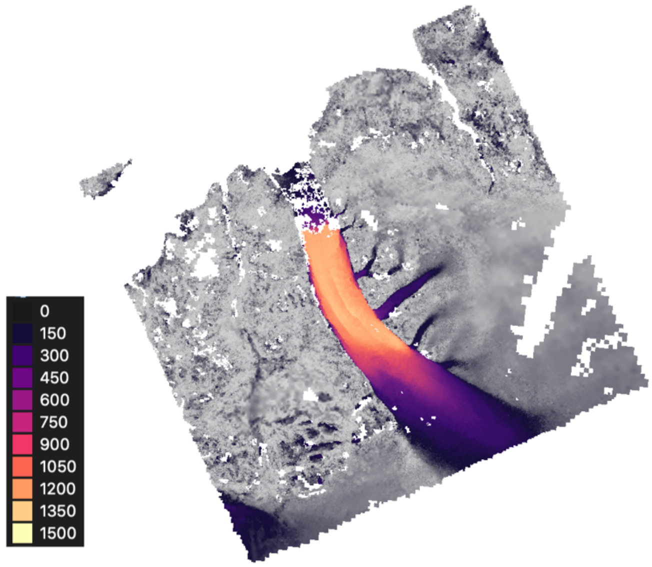

Figure 1. Example of image-pair velocity magnitude (v) field, in units of meters per year, for the Petermann Glacier in north Greenland – granule LC08_L1TP_042001_20180705_20180717_01_T1_X_LC08_L1TP_042001_20180416_20180501_01_T1_G0240V01_P091.nc

1.2.3 Data Access

To access the image-pair velocities, visit the ITS_LIVE application online. In the application, select "Toggle Data" and choose "Data Access: Image Pair Velocity Selection" (Figure 2). Use the pen icon on the right-hand side of the application to draw a polygon around the geographical area of interest (Figure 3). Once an area has been selected, click inside the polygon to open a window which will allow you to select the temporal range, the time separation between granules, and the percentage of possible glacier pixels that have reported velocities. Once you have completed your selection, click on "Get Granule URLs" to download an ASCII text file containing the granule URLs within the selected polygon (Figure 4). The NetCDF files for the selected polygon can be download using these URLs.

Please note that directories are organized by EPSG code (see the Geolocation section for more details on the EPSG codes used for these data).

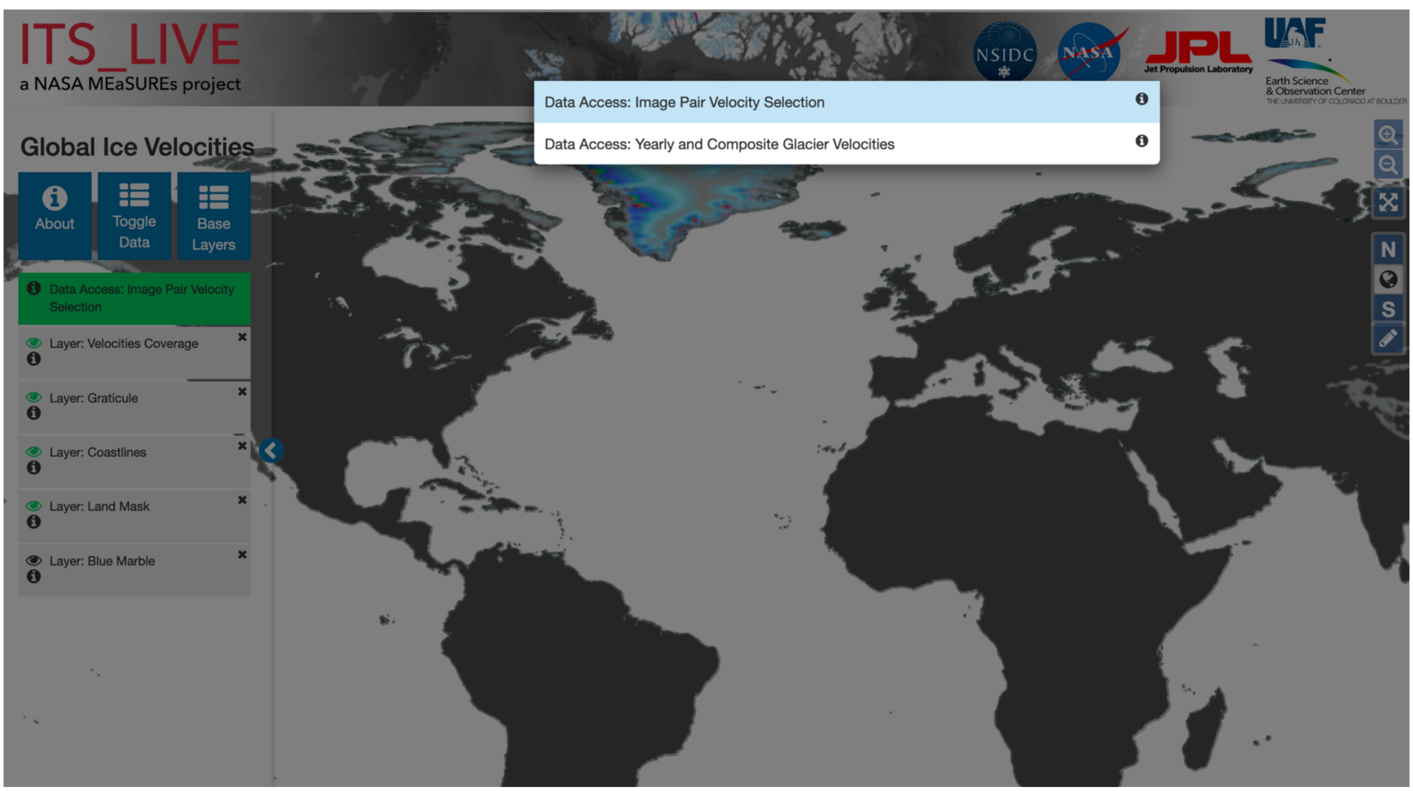

Figure 2. Screenshot of the ITS_LIVE Application, illustrating how to select the Image Pair Velocity Selection option. First select the 'Toggle Data' button in the top left. Then select the 'Data Access: Image Pair Velocity Selection'.

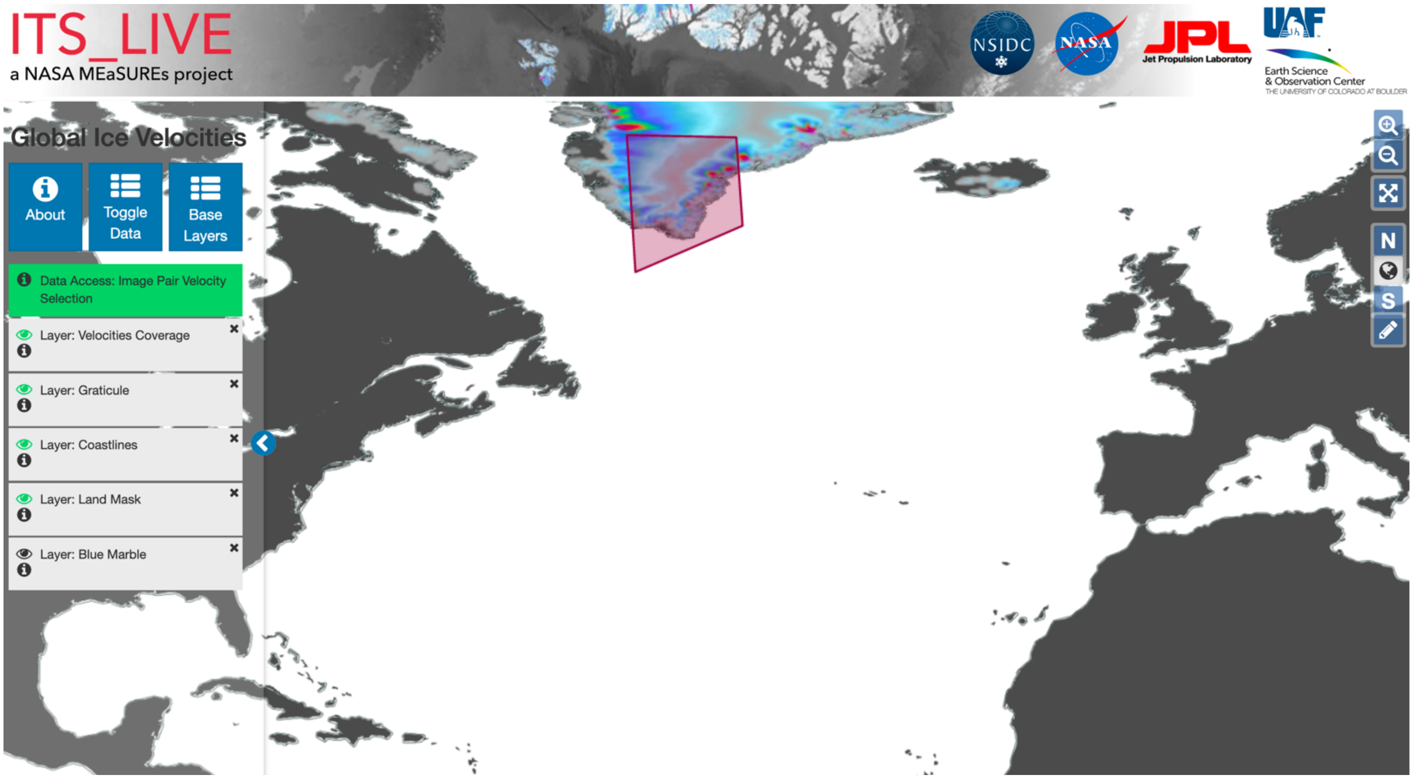

Figure 3: Screenshot of the ITS_LIVE Application, with an example polygon (shape in red) for selecting a geographical area of interest.

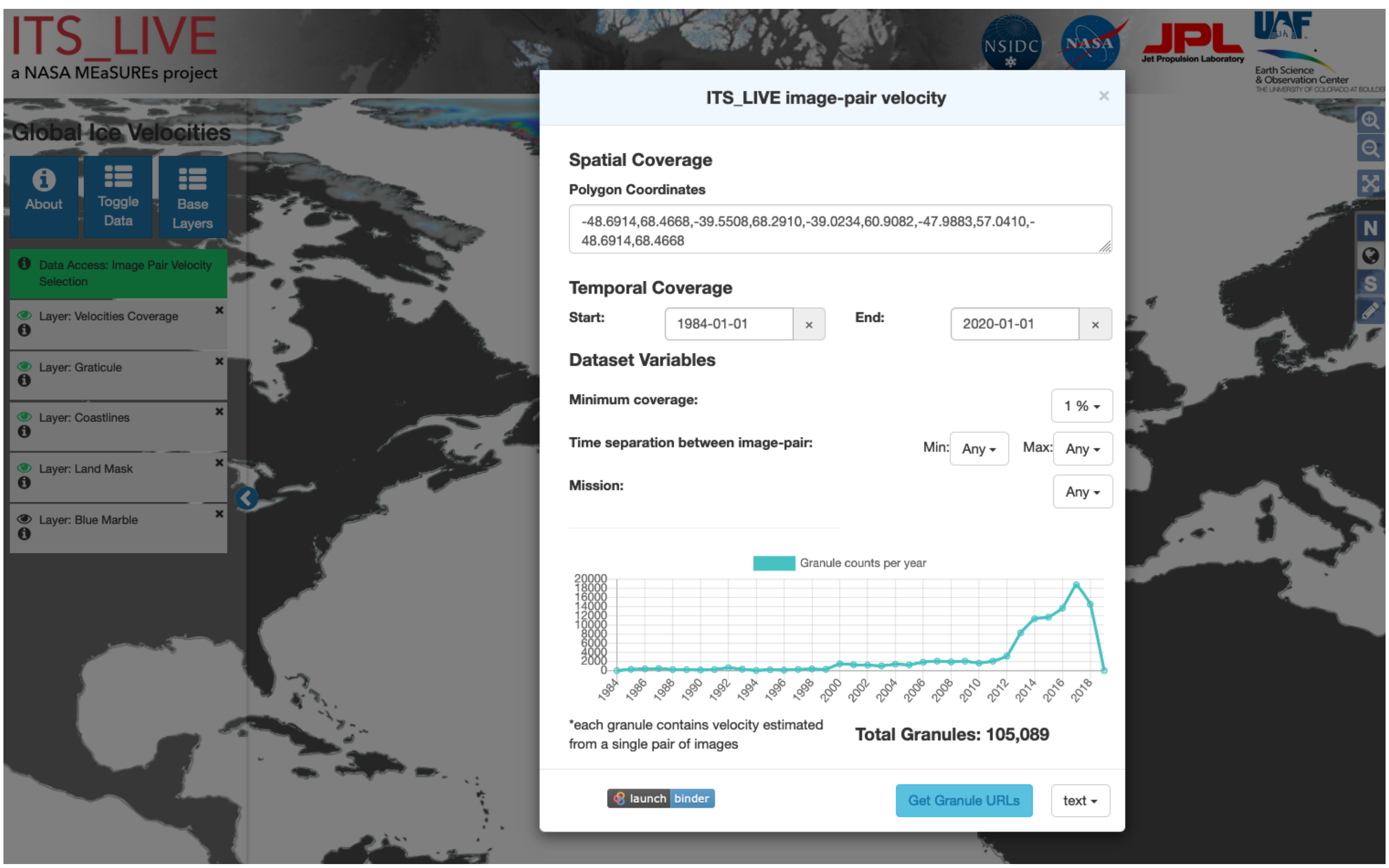

Figure 4: Screenshot of the ITS_LIVE Application, illustrating the search output after clicking on the user-defined polygon. You can filter the granules further by time, percentage coverage, time separation between image-pair, and the mission.

1.2.4 File Naming Convention

The file names include information for both images that make up the image pair. Example file name:

LC08_L1TP_152034_20160124_20170330_01_T1_X_LC08_L1TP_152034_20150817_20170406_01_T1_G0240V01_P090.nc ,

where the red (blue) portion provides information for the later (earlier) image. The conventions, outlined below, are described in Table 2:

LXSS_LLLL_PPPRRR_YYYYMMDD_yyyymmdd_CC_TX_X_LXSS_LLLL_PPPRRR_YYYYMMDD_yyyymmdd_CC_TX_**G0240V01_PXYZ.**nc

Table 2. File Naming Convention

Variable	Description
LXSS	L = Landsat X = Sensor (C = OLI/TIRS Combined, O = OLI-only, T = TIRS-only, E = ETM+, T = TM, M = MSS) [(1)] SS = Satellite (07 = Landsat 7, 08 = Landsat 8)
LLLL	LLLL = Processing correction level (L1TP=Precision Terrain, L1GT=Systematic Terrain, L1GS=Systematic)
PPPRRR	PPP = WRS path RRR = WRS row
YYYYMMDD	Acquisition year (YYYY), month (MM), and day (DD)
yyyymmdd	Processing year (yyyy), month (mm), and day (dd)
CC	CC = Collection number (01 = Collection 1, 02 = Collection 2)
TX	TX = Collection category (T1 = Tier 1: known tie points were used to refine the image geolocation; T2 = Tier 2: no tie points; geolocation based on satellite ephemeris)
_X_	Marker to distinguish between the two images in the file name. The later image appears first in the granule name, followed by the earlier image. The variables above are repeated for the second file after this marker.
G0240	Spacing of the velocity determinations (the output product has 240-meter pixels)
V01	Product Version 1
PXYZ	Percentage of possible glacier pixels that have reported velocities, where XYZ is the percentage. For example, P090 means that 90% of the possible glacier pixels have reported velocities.
.nc	NetCDF file extension

[(1)]NOTE: For more detailed information on Landsat product identifiers, visit this page: https://www.usgs.gov/faqs/how-can-i-tell-difference-between-landsat-collections-data-and-landsat-data-i-have-downloaded?qt-news_science_products=0#qt-news_science_products

1.3 Spatial Information

1.3.1 Coverage

Spatial coverage is global and includes all land ice areas with ice bodies larger than 5 km^2, dependent on data availability, quality, and for any given image-pair, offset tracking success.

The extent of the image-pair encompasses the successful offset determinations for that pair. This means that two granules for pairs from images with the same Landsat path, row designations may have different extents depending on offset tracking success – if one of the input images was largely cloud covered, then the extent to the output grid can be significantly reduced from the original image extents.

1.3.2 Resolution

ITS_LIVE image-pair granules provide one ice flow vector for every 240 m x 240 m area that is tracked by autoRIFT.

1.3.3 Geolocation

Each image-pair granule in the Version 1.0 release use the original USGS selected projections of the Landsat input images (with the exception of some images that are reprojected near UTM zone boundaries). For non-Antarctic images, this is the local UTM, EPSG:326xx (northern) and EPSG:327xx (southern), where xx is the UTM zone number. For images south of 70°S, it is the SCAR Antarctic Polar Stereographic projection (EPSG:3031).

1.4 Temporal Information

1.4.1 Coverage

1985 to 2018 for Version 1.0 release; to be extended to near-real-time, low latency when Version 2.0 is released.

1.4.2 Resolution

The separation times for the image pairs vary from 6 to 546 days.

2. Data Acquisition and Processing

2.1 Acquisition and Instrumentation

The imagery used to create the image-pair velocities in this data set comes from the following sources:

- USGS/NASA's Landsat 4 (1982 to 1993) Thematic Mapper - Band 2 (30 m)
- USGS/NASA's Landsat 5 (1984 to 2013) Thematic Mapper - Band 2 (30 m)
- USGS/NASA's Landsat 7 (1999 to present) Enhanced Thematic Mapper Plus - Band 8 (15 m)
- USGS/NASA's Landsat 8 (2013 to present) Operational Land Imager - Band 8 (15 m)

All images with 60% cloud cover or less, as indicated in the image metadata, were processed. Landsat imagery was provided courtesy of the USGS and downloaded from Google Cloud (https://cloud.google.com/storage/docs/public-datasets/landsat).

2.2 Processing Steps

2.2.1 Image Preprocessing

All images are preprocessed using a 5x5 Wallis operator to normalize for local variability in image radiance caused by shadows, topography, and sun angle, all of which can generate spurious artifacts when applying feature tracking to derive surface flow from optical imagery. For Landsat 4 and 5 Band 2 images, along-track artifacts that are introduced from the Thematic Mapper whisk broom sensor are removed using Fourier filtering. Missing data in Landsat 7 images, introduced after the Scan Line Corrector failure (SLC-off) in May of 2003, are filled with random noise so that they do not contribute to the amplitude of the correlation peak used in the feature tracking.

2.2.2 Image-pair velocities (autoRIFT v1)

All image pairs are processed using the JPL autonomous Repeat Image Feature Tracking algorithms (autoRIFT), first presented in Gardner et al., (2018). Release V01 of the ITS_LIVE image-pair velocities use autoRIFT Version 1.

This ITS_LIVE data set uses surface displacements generated by image pairs in repeat orbits, and image pairs generated by overlap areas of adjacent or near-adjacent orbits. Image pairs collected from the same satellite position ("same-path-row") are searched if they have a time separation of fewer than 546 days. This approach was used for all satellites in the Landsat series (L4 to L8). To increase data density prior to the launch of Landsat 8, images acquired from differing satellite positions, generally in adjacent or near-adjacent orbit swaths ("cross-path-row"), are also processed if they have a time separation between 10 and 96 days and an acquisition date prior to 14 June 2013 (beginning of regular Landsat 8 data). Feature tracking of cross-path-row image pairs produces velocity fields with a lower signal-to-noise ratio due to residual parallax from imperfect terrain correction. Same-path-row and cross-path-row preprocessed pairs of images are searched for matching features by finding local normalized cross-correlation (NCC) maxima at sub-pixel resolution by oversampling the correlation surface by a factor of 16 using a Gaussian kernel. A sparse grid pixel-integer NCC search (1/16 of the density of full search grid) is used to determine areas of coherent correlation between image pairs. For more information, see the Normalized Displacement Coherence (NDC) filter described in Gardner et al., (2018). Results from the sparse search guide a dense search with search centers spaced such that there is no overlap between adjacent template windows. Areas of unsuccessful retrievals, as determined using the NDC filter, are searched with progressively increasing template chip sizes. Minimum and maximum acceptable template chip sizes for each search center are defined geographically and depend on land surface type (ice or rock), spatial gradient of a reference velocity mapping, distance from ocean, and distance from ice edge. The data are then filtered one last time using the NDC filter, and a light interpolation is applied to fill in small data gaps. Interpolated values are indicated by interp_mask = 1.

To reduce computational demand, autoRIFT employs a downstream search that centers the NCC search template window in the search image at the downstream location of the expected displacement between the two image pairs as determined from the reference velocity. The NCC search radius is unique in both x- and y-directions and varies spatially. The NCC search radius is defined according to the surface type (ice or rock), magnitude of the component reference velocity (vx, vy), and the distance from the ocean. Ocean area is identified according to the Global Self-consistent, Hierarchical, High- resolution Geography Database (GSHHG). In Greenland, land ice area is identified according to a data set provided by F. Paul (Bolch et al., 2013); in Antarctica land ice is identified according to Depoorter et al. (2013); everywhere else land ice is determined using the Randolf Glacier Index release 3.2 (see https://www.glims.org/RGI/). Rock is defined as neither ocean nor land ice.

For more information on the processing steps that were taken to create the regional velocity mosaics derived from this data set, see the ITS_LIVE Regional Glacier and Ice Sheet Surface Velocities product.

2.3 Quality, Errors, and Limitations

Image geometry between same-path-row image pairs is highly stable, but images suffer from x- and y-coordinate geolocation errors of up to 15 m. If uncorrected, a geolocation error of ~21 m, i.e. $(15^2 + 15^2)^{1/2}$, between two images separated in time by 16 days would introduce a bias in velocity of as much as ~480 m yr^{-1}. To correct for these errors, the component velocities vx and vy are tied to a "stable" surface wherein the median of each velocity component is set to zero over rock surfaces and set to the median reference velocity over slow-moving areas of Greenland and Antarctica (ice movement of less than 15 m yr^{-1}). For Greenland, the MEaSUREs Greenland Annual Ice Sheet Velocity Mosaics from SAR and Landsat, Version 1 data are used as the reference velocity; for Antarctica, the MEaSUREs InSAR-Based Antarctica Ice Velocity Map, Version 2 data are used.

The uncertainty of each image-pair velocity field is set equal to the standard deviation in component velocities measured over a stable surface after applying the geolocation offset correction, if available. If an image-pair velocity field does not intersect a stable surface, the errors in vx and vy (parameters vx_err and vy_err in Table 1) are set to the RSS of the pointing uncertainty of both images. This error is updated to the standard deviation of the difference between the image-pair component velocities and the annual mean component velocities if the image-pair velocity is successfully co-registered during the creation of the annual mosaic that is described in the next section.

Velocities are calculated from imagery that has been map projected. This can introduce scale errors of up to a few percent that are dependent on the projection used and the location of the imagery. This distortion is corrected for in this data set, such that the velocities represent horizontal velocities that would be measured by an observer on the ground, This has several implications for Version 1.0 data:

1. When using ITS_LIVE image-pair velocities to calculate glacier flux, the flux gate cross-section needs to be corrected for projection scale distortion; however, the ITS_LIVE image-pair velocities do not need to be corrected.
2. When calculating Lagrangian paths in map coordinates, the ITS_LIVE image-pair velocities should be scaled from velocities in ground units to velocities in
3. map units to produce the appropriate speed in map coordinates.

Note: the next version (Version 2.0) the distortion due to calculating velocities from map projected imagery will not be corrected for. The implications of this will be detailed further in the documentation once Version 2.0 is released.

3. Software and Tools

The netCDF files can be opened using a wide range of software, for a further details please see Software for Manipulating or Displaying NetCDF Data. The metadata fields can be extracted using the gdalinfo command line utility available from the Geospatial Data Abstraction Library (GDAL) website.

4. Related Data Sets

Note: The data sets listed below are examples of the many already published products related to the ITS_LIVE project.

ITS_LIVE Regional Glacier and Ice Sheet Surface Velocities

Global Land Ice Velocity Extraction from Landsat 8 (GoLIVE), Version 1

Landsat 8 Ice Speed of Antarctica (LISA), Version 1

MEaSUREs Greenland Ice Velocity: Selected Glacier Site Velocity Maps from InSAR, Version 1

MEaSUREs Annual Antarctic Ice Velocity Maps 2005-2017, Version 1

5. Related Websites

GoLIVE data at NSIDC | Overview

MEaSUREs data at NSIDC | Overview

6. Contacts and Acknowledgments

The data can only be provided if user statistics support continued funding. To this end, please use both of the following citations:

Gardner, A. S., M. A. Fahnestock, and T. A. Scambos, 2019 [update to time of data download]: MEaSUREs ITS_LIVE Landsat Image-Pair Glacier and Ice Sheet Surface Velocities: Version 1, https://doi.org/10.5067/IMR9D3PEI28U

Gardner, A. S., G. Moholdt, T. Scambos, M. Fahnstock, S. Ligtenberg, M. van den Broeke, and J. Nilsson, 2018: Increased West Antarctic and unchanged East Antarctic ice discharge over the last 7 years, *Cryosphere*, 12(2): 521–547, https://doi:10.5194/tc-12-521-2018.

7. References

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Depoorter, M. A., Bamber, J. L., Griggs, J. A., Lenaerts, J. T. M., Ligtenberg, S. R. M., van den Broeke, M. R., & Moholdt, G. (2013). Calving fluxes and basal melt rates of Antarctic ice shelves. Nature, 502(7469), 89–92. https://doi.org/10.1038/nature12567

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Joughin, I., Smith, B. E., Howat, I. M., Scambos, T., & Moon, T. (2010). Greenland flow variability from ice-sheet-wide velocity mapping. Journal of Glaciology, 56(197), 415–430. https://doi.org/10.3189/002214310792447734

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Mouginot, J., Scheuchl, B., & Rignot, E. (2012). Mapping of Ice Motion in Antarctica Using Synthetic-Aperture Radar Data. Remote Sensing, 4(9), 2753– 2767. https://doi.org/10.3390/rs4092753

Rignot, E., Mouginot, J., & Scheuchl, B. (2011). Ice Flow of the Antarctic Ice Sheet. Science, 333(6048), 1427–1430. https://doi.org/10.1126/science. 1208336

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