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European Space Agency

Input/Output data Definition (IODDv1)



glaciers
cci

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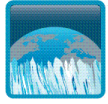
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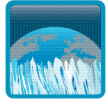
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1. Executive Summary

The input/output data definition (IODD) provides a description of the data required for and produced by the prototype system. For each of the five products it covers a description of the format, structure and data ranges of the following data types:

- satellite input datasets;
- auxiliary files;
- generated output products;
- test and validation datasets.

This document does not duplicate the information already provided for the input datasets in the Data Access Requirements Document (DARD) or available in separate documents from the data producers. Here we just refer to the related sections, tables or web pages. For the output datasets reference is made to the details provided in the Product Specification Document (PSD). The IODD summarizes this information and provides complementary information, e.g. on auxiliary and validation datasets. Issues to be solved by the analyst or the software used are also not detailed here (we just give typical examples) as they have no impact on the design of the system. As the format of the input and output datasets for the respective products is directly related to the interface or software used to read or write them, we include a description of the required interfaces in this document.



2. Introduction

2.1 Purpose and scope

This is deliverable 2.8 of the Glaciers_cci project describing the Input Output Data Definition version 1 (IODDv1). The document provides an overview of the input datasets required for the glacier area, elevation change and velocity algorithms to generate the respective output products. It also describes the required auxiliary, test and validation datasets as well as the interface descriptions required to import and export the data. It is organised in five sections:

- Glacier area
- Elevation change: DEM differencing
- Elevation change: Altimetry
- Velocity from optical sensors
- Velocity from microwave sensors

The document starts with an overview of the Glaciers_cci prototype system before the datasets and the interfaces are described.

2.2 Overview of the prototype system

The Glaciers_cci prototype system is a combination of software tools designed to generate three products: (1) glacier area, (2) elevation change, and (3) velocity.

Figure 1 shows the general architecture of the system. For glacier area only one macro-module is proposed while the elevation change block has two different macro-modules, one for DEM differencing and one for repeat altimetry. These are related to the two different techniques of data production as described in the [ATBDv1](#) (Glaciers_cci, 2012b). Similarly, the block for the velocity product has two different macro-modules, one for optical and one for microwave sensors. In this case the difference is made because of the different pre-processing requirements, while the main processing and the output products are very similar (Glaciers_cci, 2011a). Each macro-module implement a given functionality, using EO data and other input data to generate the three products mentioned above. More details on the architecture are given in the [DPMv1](#) (Glaciers_cci, 2012c). For the description of the input/output data we focus on the information relevant for the system engineer rather than on details to be solved by the analyst (e.g. selection of a specific dataset) or the software used for reading/writing the input/output (e.g. handling different input file formats).

Between the input and output data described here and the macro-modules described in the DPM, interfaces prepare the input data allowing the correct functioning of the processors or make the output data of the processing system available in the format described in the [PSD](#) (Glaciers_cci, 2011a). A schematical overview of the 'input interface' seen in Fig. 1 is shown in Fig. 2. The individual steps to be performed depend on the format of the input datasets and several analysts decisions. Technical details of the respective interfaces are described for each product in a separate section. Conversion of the macro-module output to the respective ECV product format (Geotiff, shape file) is handled by the modules described in the DPM. Creation of a netCDF product from the global glacier map will be handled by additional software and is not part of the macro-module.

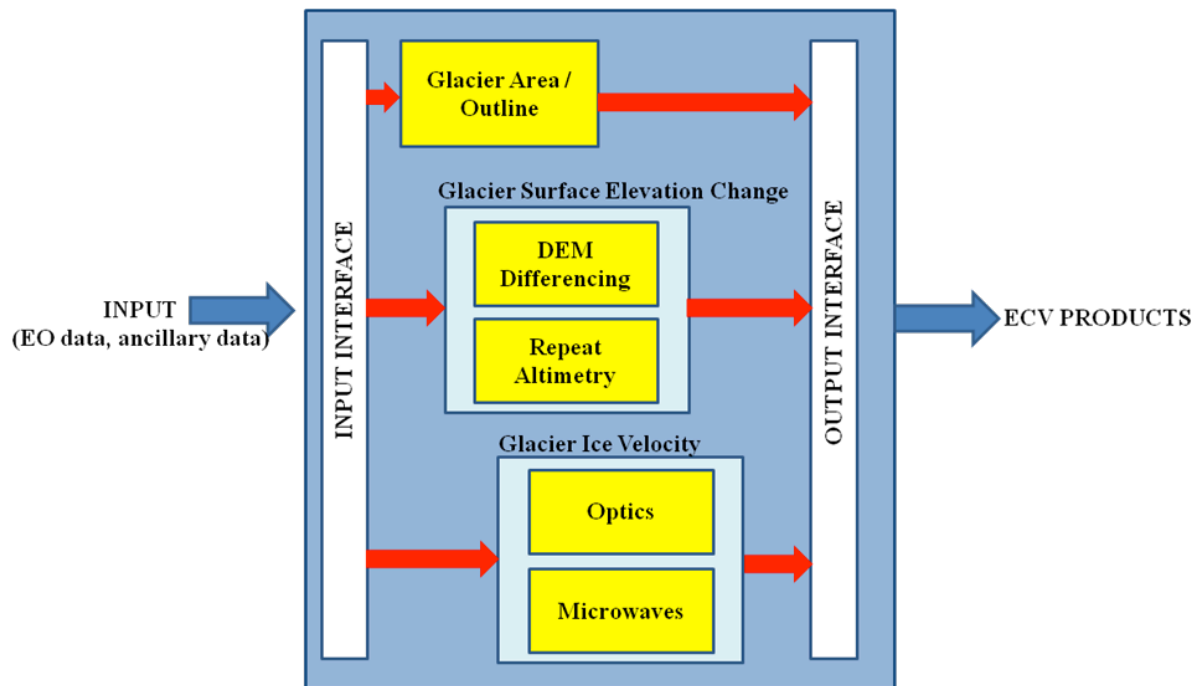


Fig. 1: Architecture of the Glaciers_cci prototype system including the input and output interfaces.

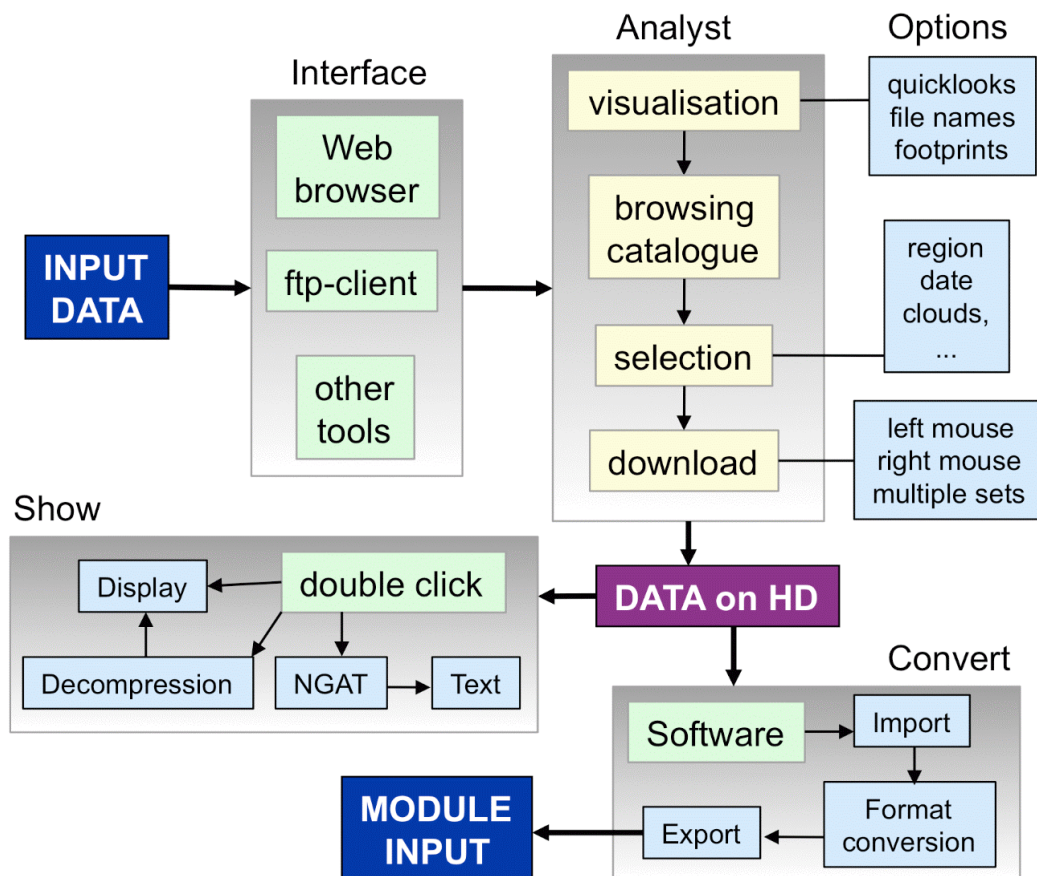


Fig. 2: Principle structure and workflow within the input interface



3. Glacier area

3.1 Input products

3.1.1 Overview

The key input data for the glacier area macro-module are the satellite data and the DEM (see 4.2). The required orthorectified data (level 1T product from USGS) are downloaded from the glovis.usgs.gov website in the form of a gzipped tar file with a *filename* such as LT50650162009210PAC02.tar.gz. The filename decodes in this case as follows: LT5 is Landsat 5 Thematic Mapper, 065 is the path, 016 is the row, 2009 is the year, 210 the day of the year, PAC the receiving station (Prince Albert, Canada), and 02 a further identifier. This file has first to be decompressed or unzipped (e.g. using '*gunzip filename*' in a Unix/Linux environment) and then the individual files have to be extracted from the tape archive (e.g. using '*tar xf filename*' in a Unix/Linux environment). On most platforms these two steps are performed automatically by just double clicking on the file name. This will create a folder with the filenames described in the next section.

Tools for reading and displaying the files are widely available from commercial and public domain software packages and are not described here. In general these work interactively, i.e. the software has to be started and the respective program has to be selected by choosing from a pull down menu. Two different purposes have to be distinguished in regard to the further data analysis: (1) read only functionality that only displays the data without the possibility to modify the files physically (e.g. a band 5, 4, 3 composite image shown in the background), and (2) a manipulation functionality that allows to directly work with the raw data (e.g. to calculate a band ratio to map the glaciers. In the latter case it is in most cases required to transform the data to the format of the software used beforehand (e.g. to a grid in the case of ESRI software). The important information for data processing (e.g. projection, datum, pixel size, coordinates) is stored internally in the TIF file header and read by the software. This information can also be exported and stored in a separate file (e.g. a projection file '.prj' in ESRI software) or in a more general way in a so-called world file (.tfw) that has the same name as the data file but the ending .tfw instead of .tif (or .jgw for a jpg file). The world file only stores information about coordinates and pixel size, so a projection and datum must be assigned additionally when it is imported in most of the software products.

3.1.2 Format and technical content

In Table 3.1 and 3.2 we list the individual files contained in a Landsat 5 and Landsat 7 ETM+ folder, respectively. The tar.gz file (typical size 150-250 MB for Landsat 5 TM and 250-350 MB for Landsat 7 ETM+) is not removed after decompression and file extraction. This can be done manually to reduce disk space if required. However, one original file should be kept. The auxiliary files 9.-13. in Table 3.1 and 7., 8. and 13 in Table 3.2 are not required by the data processing software. They are for information only and are thus not shown here. The GLS2000 DEM used for the orthorectification (entry 8) is not part of all downloaded files, but can be downloaded separately if required (source: <http://glcf.umd.edu/data/glsdem/>). The filenames contain the following information: L5 (Landsat 5), 065 (path), 016 (row start), _016 (row end), 2009 (year), 07 (month), 29 (day), B10/B20/... (band 1/2/...). This is equivalent to Landsat 7 ETM+ with some exceptions for the additional bands (see Table 3.2).

Nr.	Landsat 5 TM	Description
1.	L5065016_01620090729_B10.TIF	Geotiff of image band 1 (blue)
2.	L5065016_01620090729_B20.TIF	Geotiff of image band 2 (green)
3.	L5065016_01620090729_B30.TIF	Geotiff of image band 3 (red)
4.	L5065016_01620090729_B40.TIF	Geotiff of image band 4 (NIR)
5.	L5065016_01620090729_B50.TIF	Geotiff of image band 5 (SWIR)
6.	L5065016_01620090729_B60.TIF	Geotiff of image band 6 (TIR)
7.	L5065016_01620090729_B70.TIF	Geotiff of image band 7 (SWIR)
8.	L5065016_01620090729_DEM.TIF	Geotiff of the GLS2000 DEM used for orthorectification
9.	L5065016_01620090729_GCP.TXT	Report on the ground control point accuracy
10.	L5065016_01620090729_MTL.TXT	Metadata compilation
11.	L5065016_01620090729_VER.TXT	Geometric Verification report
12.	L5065016_01620090729_VER.JPG	Geometric Verification image
13.	README.GTF	File describing what has been downloaded in detail

Table 3.1: List of files contained in the file LT50650162009210PAC02.tar.gz as downloaded from glovis.usgs.gov (after decompression and extraction).

Nr.	Landsat 7 ETM+	Description
1.	L71229009_00920000810_B10.TIF	Geotiff of image band 1 (blue)
2.	L71229009_00920000810_B20.TIF	Geotiff of image band 2 (green)
3.	L71229009_00920000810_B30.TIF	Geotiff of image band 3 (red)
4.	L71229009_00920000810_B40.TIF	Geotiff of image band 4 (NIR)
5.	L71229009_00920000810_B50.TIF	Geotiff of image band 5 (SWIR)
6.	L71229009_00920000810_B61.TIF	Geotiff of image band 6 (TIR gain 1)
7.	L71229009_00920000810_GCP.TXT	Report on the ground control point accuracy
8.	L71229009_00920000810_MTL.TXT	Metadata compilation
9.	L72229009_00920000810_B62.TIF	Geotiff of image band 6 (TIR gain 2)
10.	L72229009_00920000810_B70.TIF	Geotiff of image band 7 (SWIR)
11.	L72229009_00920000810_B80.TIF	Geotiff of image band 8 (pan)
13.	README.GTF	File describing what has been downloaded in detail

Table 3.2: List of files contained in the file LE72290092000223SGS00.tar.gz as downloaded from glovis.usgs.gov (after decompression and extraction).

The geolocation information stored in the TIF file header might typically include the following information that is extracted by the software used for file import (here shown in the format of an ESRI projection file, these might look different in other software):

```
PROJCS["WGS_1984_UTM_Zone_22N",GEOGCS["GCS_WGS_1984",DATUM["D_WGS_1984",SPHEROID["WGS_1984",6378137.0,298.257223563]],PRIMEM["Greenwich",0.0],UNIT["Degree",0.0174532925199433]],PROJECTION["Transverse_Mercator"],PARAMETER["False_Easting",500000.0],PARAMETER["False_Northing",0.0],PARAMETER["Central_Meridian",51.0],PARAMETER["Scale_Factor",0.9996],PARAMETER["Latitude_Of_Origin",0.0],UNIT["Meter",1.0]]
```

3.1.3 Input Interface

Once satellite data have been selected and downloaded, they are either automatically or after a double click expanded / unpacked to the formats of the respective dataset (see Fig. 2 and examples in Tables 3.1 and 3.2). While visualization of these formats is in general available on a double click, the further processing requires to transform them to the software specific format before they can be used in the format required by the modules. For example, the geotiff images are converted to the internal ESRI raster format by applying the command



imagegrid. Calculations of the modules are then performed on these grids. For practical reasons, this command is part of the module doing the main processing, but as this is an analyst specific command line operation, it can also be seen as a part of the input data interface. The same command (*imagegrid*) is used to transform the SRTM DEM from the hgt (bil) format to the raster format of the GIS (see 3.2.2). Other software products might use other ways of data conversion, but from a system perspective the principle steps have to be performed as well. More schematically, the involved file names are:

Glacier area input

- filename.tar.gz = compressed tar file (double click gives a folder called 'filename')
- filename = folder containing the geotiff images and the metadata
- filename_b10.tif to filename_b70.tif = geotiff export and conversion for module GAM1
- dem_file.hgt = DEM in raw format (could also be geotif, depending on source)

Glacier area output

- b1.tif, b3.tif, b5.tif = tif images of the three input bands
- DEM = floating point DEM converted to grid format

3.2 Auxiliary data

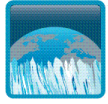
3.2.1 Overview

As described in the previous documents, a DEM is a most important file when a glacier inventory should be created (e.g. to derive drainage divides and topographic parameters for each glacier). The DEM for the satellite scene analyzed is not normally included in the image file (as in the example above) but has to be separately downloaded from one of the servers listed in the DARD (e.g. the SRTM DEM or the ASTER GDEM). The DEMs are normally arranged in tiles covering a specific longitude and latitude range (e.g. 1 by 1 or 5 by 5 degrees). The DEM tiles required for a specific scene have to be selected and downloaded manually, in most cases more than one tile is required to cover all glaciers within a scene. This differs for the case shown above (where the GLS2000 DEM is part of the scene) or when a DEM from a specific ASTER scene (e.g. the AST14DMO product) is ordered. Normally, some format conversion is required (e.g. from .bil to ASCII) and the 16 bit signed integer format requires some computational adjustment (see 3.2.2).

A most important part is that any required mosaicking of tiles is performed in the geographic coordinate space (longitude, latitude) to avoid artifacts at DEM boundaries from reprojection. Reprojection to the projection / datum of the satellite scene (e.g. UTM with WGS84 datum) should only be done after mosaicking. The final (metric) cell size should also be applied already at this stage to avoid resampling artefacts. It is advisable to use a multiple of the satellite pixel size to have an accurate match of the boundaries of all pixels with the DEM grid cells (e.g. 30, 60 or 90 m for SRTM when used for Landsat TM or ETM+ data). To avoid strong smoothing, the cell size should not be increased too much over the original resolution. For example, 30 m for SRTM C-band is already exaggerated, but 60 m would still work as a compromise in regions with many very small glaciers (Frey and Paul, 2012; Paul et al., 2011).

3.2.2 Format and technical content

A typical file name for an SRTM tile (with 3 arc seconds resolution) is N37E105.hgt.zip. The description of its format reads (taken from the online documentation at http://dds.cr.usgs.gov/srtm/version2_1/Documentation/Quickstart.pdf):



File names refer to the latitude and longitude of the lower left corner of the tile - e.g. N37W105 has its lower left corner at 37 degrees north latitude and 105 degrees west longitude. To be more exact, these coordinates refer to the geometric center of the lower left pixel, which in the case of SRTM3 data will be about 90 meters in extent.

Height files have the extension .HGT and are signed two byte integers. The bytes are in Motorola "big-endian" order with the most significant byte first, directly readable by systems such as Sun SPARC, Silicon Graphics and Macintosh computers using Power PC processors. DEC Alpha, most PCs and Macintosh computers built after 2006 use Intel ("little-endian") order so some byte-swapping may be necessary. Heights are in meters referenced to the WGS84/EGM96 geoid. Data voids are assigned the value -32768.

SRTM3 files contain 1201 lines and 1201 samples. The rows at the north and south edges as well as the columns at the east and west edges of each cell overlap and are identical to the edge rows and columns in the adjacent cell. SRTM1 files contain 3601 lines and 3601 samples, with similar overlap.

When these files are imported with ESRI's ArcInfo, some transformations have to be applied, including a renaming of the file, creation of a header file and conversion of the little-endian coding. A detailed description on how this can be performed is available from the website http://dds.cr.usgs.gov/srtm/version2_1/Documentation/Notes_for_ARCInfo_users.pdf:

Users of ARC/INFO or ArcView can display the DEM data directly after renaming the file extension from .HGT to .BIL. However, if a user needs access to the actual elevation values for analysis in ARC/INFO the DEM must be converted to an ARC/INFO grid with the command IMAGEGRID. For IMAGEGRID to work there must be a separate header file whose name (including case) is exactly the same as the image file name. The contents of a sample file that works with 3 arc-second SRTM file N37W105.hgt are below:

```
-----  
BYTEORDERM  
LAYOUT BIL  
NROWS 1201  
NCOLS 1201  
NBANDS 1  
NBITS 16  
BANDROWBYTES 2402  
TOTALROWBYTES 2402  
BANDGAPBYTES 0  
NODATA 32768  
ULXMAP -105.0  
ULYMAP 38.0  
XDIM 0.0008333333333333  
YDIM 0.0008333333333333  
-----
```

IMAGEGRID does not support conversion of signed image data, therefore the negative 16-bit DEM values will not be interpreted correctly. After running IMAGEGRID, an easy fix can be accomplished using the following formula in Grid:

```
out_grid = con(in_grid >= 32768, in_grid - 65536, in_grid)
```

The conversion shown above might not apply (i.e. is performed automatically) when other software products are used or when DEMs are provided in GeoTif format. However, the information is provided above in the case that it is required (the syntax might be slightly different for other software products, but the principle of the decoding will be the same). When ASTER GDEM tiles are downloaded and converted, the above principle is the same but the cell size (*XDIM* and *YDIM*) will be different (1" instead of 3").

3.3 Output products

3.3.1 Overview

The output product of the macro-module is a shapefile with the meta-information being part of the attribute table (that is basically a .dbf file that can also be analysed with other software products). The shapefile format is widely used for vector data and in the public domain. It can be transformed to several other software specific formats if required.

3.3.2 Format and technical content

The specific format of a shapefile and the required attributes are described in full in sections 3.4 and 3.5 of the [PSD](#) (Glaciers_cci, 2011a) and are thus not repeated here.

3.4 Test and validation data sets

There are no specific datasets available to validate the glacier area product. As glaciers are constantly changing their extent and snow conditions vary on a short time scale, the availability of appropriate reference datasets for product validation is indeed very limited. Very often the independent digitization by non-glaciologists (e.g. cartographers) or the use of aerial photography with seasonal snow hiding parts of the glacier outline as a base for glacier outlines can not be used to validate the generated outlines. However, the lessons learned from the round robin as documented in the [PVASR](#) (Glaciers_cci, 2012a) and experience from previous studies have shown a number of possibilities to improve and determine the accuracy (or at least the precision) of the generated data sets nevertheless.

The first point to consider is that the basic glacier outline mapping from the applied algorithm has little impact on the final accuracy as all outlines have to be manually checked and many of them have to be corrected by on-screen digitizing. The latter is strongly facilitated when high resolution data are available for comparison, in particular for debris-covered glaciers or glacier parts located in shadow. These datasets can be checked in Google MapsTM Google EarthTM (including a topographic impression) or similar tools. When coherence images are available (e.g. from PALSAR) they can be used to increase the quality of the manual delineation for debris-covered parts under conditions of high solar elevation and little optical contrast (e.g. Strozzi et al., 2011; Frey et al., 2012). A next step is to obtain quantitative information about the accuracy or precision of the final result. This can be obtained by comparison with an independently digitized reference data set (accuracy) or, if this is not available, by a multiple digitizing of a couple of glaciers with different sizes as performed for the round robin and described in Paul et al. (2013). The standard deviation of the area differences is a good measure of the analysts precision and should always be reported along with the results (e.g. Davies and Glasser, 2012).

4. Elevation change: DEM differencing

4.1 Input products

4.1.1 Overview

ASTER DEMs

These data will be used directly as provided from the USGS NASA LP DAAC through NASA WIST as AST14DMO on demand product. The DEM of this product has a spatial resolution of 30 m over 60 by 60 km and a vertical accuracy of roughly 15 m for suitable surface conditions (e.g. Hirano et al., 2003; Kääb, 2002). The product comes with orthorectified satellite image bands.

SPOT5 HRS SPIRIT

For selected polar regions DEMs from SPOT5 high resolution stereo are available as compiled during the SPIRIT programme. SPOT5 HRS consists of a forward looking and a backward looking channel. The resulting stereo DEMs were produced by the French mapping agency and have a reported uncertainty of 10–25 m vertically and greater than 15 m in the horizontal plane (Korona et al., 2009). These DEMs have a resolution of 40 m and are also provided with a correlation mask that aids the removal of poor data.

SRTM DEM

The Shuttle Radar Topography Mission (SRTM), launched in February 2000, mapped the Earth from 60° N to 56° S using single-pass synthetic aperture radar (SAR) interferometry at a nominal resolution of 3" (or 90 m). SAR interferometry uses the phase differences between two radar images acquired with a small base-to-height ratio. These phase differences are the photogrammetric equivalent to a "parallax" measurement allowing retrieval of topography. We will use the SRTM 3" V2 dataset without void filling and V4 from the CGIARS consortium.

National DEMs

National DEMs have been generated in many countries from photogrammetric techniques applied to aerial photography or from Laser Scanning (LIDAR DEMs). These DEMs often come with national restrictions for redistribution and can be rather expensive for small regions covered (also depending on the acquisition technique and accuracy or spatial resolution of the DEM).

4.1.2 Format and technical content

DEMs are available in a variety of formats including geotiff, dt2, bil, arcgis raster format etc. In most cases, the file type consists of a matrix file and a header which contains the geolocation information. The AST14DMO ASTER products, SRTM V4 from CGIAR, and the SPOT5-HRS DEMs are provided as geotiff. Additionally The SRTM V4 is supplied with an additional mask file to filter out areas that have been filled with alternate products. The SPOT5-HRS DEMs are also supplied with a correlation mask as geotiff to filter bad elevation files. An example of the header information provided with a geotiff file can be seen in Fig. 6.1. Other descriptions for data provided in geographic coordinate systems and the processes of merging is described in section 3.2. For the specific geotiff reference, see <http://www.remotesensing.org/geotiff/spec/geotiffhome.html>.



```

Filename: 'C:\temp\downloads\AST14DMO_00307122003125213_20110321145503_32680_DEM.tif'
FileModDate: '13-nov-2012 15:36:57'
FileSize: 17952720
Format: 'tif'
FormatVersion: []
Height: 2988
Width: 3000
BitDepth: 16
ColorType: 'grayscale'
ModelType: 'ModelTypeProjected'
PCS: 'WGS 84 / UTM zone 33N'
Projection: 'UTM zone 33N'
MapSys: 'UTM_NORTH'
Zone: 33
CTProjection: 'CT_TransverseMercator'
ProjParm: [7x1 double]
ProjParmId: [7x1 cell]
GCS: 'WGS 84'
Datum: 'World Geodetic System 1984'
Ellipsoid: 'WGS 84'
SemiMajor: 6378137
SemiMinor: 6356752.31424518
PM: 'Greenwich'
PMLongToGreenwich: 0
UOMLength: 'metre'
UOMLengthInMeters: 1
UOMAngle: 'degree'
UOMAngleInDegrees: 1
TiePoints: [1x1 struct]
PixelScale: [3x1 double]
SpatialRef: [1x1 spatialref.MapRasterReference]
RefMatrix: [3x2 double]
BoundingBox: [2x2 double]
CornerCoords: [1x1 struct]
GeoTIFFCodes: [1x1 struct]
GeoTIFFTags: [1x1 struct]
ImageDescription: 'SILC TIFF'

```

Fig. 3: Example of the header information provided with a geotif file as read by Matlab.

4.1.3 Input interface

Below we provide an overview of the variables for the input and output interface.

Elevation change input

- DEM_time1 = a DEM possibly containing multiple layers depending upon source
- head_DEM1 = auxiliary data describing the bounding box, resolution, DEM centre etc.
- DEM_time2 = a DEM possibly containing multiple layers depending upon source
- head_DEM2 = auxiliary data describing the bounding box, resolution, DEM centre etc.
- auxiliary shapefile_masks = glaciers, lakes, ocean, stable terrain etc.

Elevation change output

- Multilayer1 = a multilayer output containing the elevation differences and quality masks and indicator masks
- Header1 = describes the basic information of grid size, location, projection etc. and description of how the elevation differences were generated.

4.2 Auxiliary data

4.2.1 Overview

Auxiliary data for the DEM differencing module include a stack of shapefiles for denoting glaciers to define stable terrain. Such shapefiles are the typical output of the glacier area macro-module and are created within the Glaciers_cci project or are obtained from the GLIMS database. Geotif files come with additional information, called Geotif tags. This information is not stored in a separate file, but within the header of the raw file itself. An example of the information provided here is shown in Fig. 3.



4.2.2 Format and technical content

The format for shapefiles is described in section 3.4 of the PSD (Glaciers_cci, 2011a). In particular the shapefiles will contain polygon objects where the specific X and Y locations of vertices are provided.

The important technical content within the Geotiff tags include the projection information and the corner coordinates from which to reference each individual pixel to a geographic location on the ground. It is important that each pixel is defined by the geographic location of the centre of the pixel ('Postings') rather than the pixel corner ('cells') when operating in Matlab. This information can be found in the 'SpatialRef' field of the Geotif tag when imported into Matlab or in the .hdr file when imported in ENVI.

4.3 Output products

4.3.1 Overview

The output product consist of a multi-layer (multi-bands) geotiff including the elevation difference grid, a land/glacier boolean mask, quality masks along with a header file/metadata info. If the associated quality masks of the DEMs are available, these will be transferred. However, not all DEMs have an associated quality mask. The header file will provide information about the DEMs used, the time of the DEMs, the mean changes of stable terrain and those over ice, error estimates for the mean ice elevation change and other information (see Table 4.3 in the [PSD](#)).

4.3.2 Format and technical content

The format and technical content can be found in Tables 4.3 and 4.4 of the [PSD](#) (Glaciers_cci, 2011a). The geotiff information is identical to that shown in section 5.1 (Fig. 5.1).

4.4 Test and validation data sets

The created datasets are unique and cannot be compared to other datasets unless temporally coincident ground data or DEMs from other satellites is available, a rare scenario. Therefore, for each individual output product from the DEM differencing system, internal validation and error estimates is provided by comparisons of the DEMs over stable terrain.



5. Elevation change: Altimetry

5.1 Input products

5.1.1 Overview

The input dataset of the altimetry macro-module consists of the ICESat level 1B GLAS06 products (release v33), available from the NSIDC website (<http://nsidc.org/data/icesat/>). The datasets are delivered in granules, which are product-specific data packets. Each granule file is uniquely identified with a 23 character long string which reports file attributes with a standard nomenclature. GLAS granules are delivered as scaled integer binary files containing fixed-length records. Each record has a unique ID and consists of several data elements. An element is either an Item or an Array of Items. In the latter case it often represents a one-second interval which contains forty laser impulses. Specific flags are assigned when data is absent or damaged. More details of the GLAS data format can be found in a data specification document (online: http://glas.wff.nasa.gov/files/documents/gsas_prod_spec_1_v8.pdf) which covers formats and structure with detailed descriptions and explanations (Brittingham and Lee, 2005).

5.1.2 Format and technical content

Tools for reading GLAS data and converting them to ASCII files are available at ICESat National Snow and Ice Data Center project website (<http://nsidc.org/data/icesat/tools.html>). The NGAT tool in particular extracts the elevation and geoid data from GLAS06 altimetry products and outputs latitude, longitude, elevation, and geoid in ASCII columns. The NGAT runs under IDL (Interactive Data Language) or IDL Virtual Machine. The system, through the input interface, needs to be able to run this software, which is an executable file. A batch file is necessary as input to the NGAT tool. This file contains the initial settings of the same parameters needed for the correct extraction of the information mentioned above. The following information has to be entered at the command line prompt (marked with '%'):

indir - required, it is the location of input files, must end with '/'

%indir=/nfs/a59/earft/icesatv33/input/GLA06.033/

outdir - optional, defaults to indir if not present, it is the location of the output files, must end with '/' as well

%outdir=/nfs/a59/earft/icesatv33/output/GLA06.033/

infile – required, file or list of files (separated with ';') to process

%infile=./2003.02.20/GLA06_633_1102_001_0073_1_01_0001.DAT;./2003.02.20/GLA06_633_1102_001_0072_4_01_0001.DAT;

outfile - required: file or list of files to write the output

%outfile=./2003.02.20/GLA06_633_1102_001_0073_1_01_0001.out;./2003.02.20/GLA06_633_1102_001_0072_4_01_0001.out;

prod_num - required: the GLA product number you are running. (06, 12, 13, 14, or 15)

%prod_num=06



release - required: the release number of the data.
%release=33

show_saturation_gain_correction - set this flag to 1: in this way the output will contain the saturation range correction and gain
%show_saturation_gain_corrections=1

nrec - defaults to -1 which does the entire file. Each record has 40 samples, invalid samples are not output
%nrec=-1

rec1 - defaults to 0 which is the first record in the file
%rec1=0

notify - shows a pop-up notify message if this is 1
%notify=0

subset – subset keyword has to be specified when the output data is requested within a specific region, otherwise this line of the batch file needs to be commented; the lat and lon boundaries have to be provided in this order: [latmin, lonmin, latmax, lonmax];
%subset = [74.136, -86.521, 75.995, -78.787]

In particular, this information can be obtained by means of a User Interface, through which the user will be able to provide this information based on the selected area chosen.
Once the NGAT software has run, the output data look like this (not all columns are shown):

```
372403915 03/07/2004 00:33:11.540 69.711446 209.602310 134.482 -0.220000
372403915 03/07/2004 00:33:11.565 69.712961 209.601311 135.949 -0.225128
372403915 03/07/2004 00:33:11.590 69.714476 209.600318 138.315 -0.230256
...
```

Columns are:

Record Number	- 1 record (40 samples)
Date	- MM/DD/YYYY
Time	- HH:MM:SS.sss
Latitude	- 'i_lat' converted to degrees
Longitude	- 'i_lon' converted to degrees
Elevation	- the 'i_elev' field for the chosen product number, converted to metres
geoid	- the 'i_gdHt' values, interpolated for each shot also converted to metres

However, the altimetry macro-module needs a slightly different format. In particular, all the special characters (/ and :) need to be removed and replaced by blank spaces. As a result, the structure of the file required as input is (not all columns are shown):

```
372403915 03 07 2004 00 33 11.540 69.711446 209.602310 134.482 -0.220000
372403915 03 07 2004 00 33 11.565 69.712961 209.601311 135.949 -0.225128
372403915 03 07 2004 00 33 11.590 69.714476 209.600318 138.315 -0.230256
...
```

where:

column 1 - record number
column 2 - month of acquisition
column 3 - day of acquisition
column 4 - year of acquisition
column 5 - hour of acquisition
column 6 - minute of acquisition
column 7 - second of acquisition
column 8 - latitude
column 9 - longitude
column 10 - elevation
column 11 - geoid
column 12 - gain correction
column 13 - gain value
column 14 - time

During processing, and thus not part of the input sequence, the following columns are added:

column 15 – x coordinate for the geographical location of DEM reference system
column 16 – y coordinate for the geographical location of DEM reference system
column 17 – interpolation value of DEM at the ICESat footprint location
column 18 – difference between ICESat elevation and the DEM interpolated elevation from the DEM subtraction module

This is the format of the file which needs to be created in the input interface. Then, the interface needs to read and load the 2D array variable, named *mtx_icesat* in the [DPMv1](#) (Glaciers_cci, 2012c). It is worth noting that the elevation provided by the ICESat level 1B GLAS06 product refers to the same ellipsoid as TOPEX/Poseidon and Jason-1 where the equatorial radius is 6378136.30 m and reciprocal flattening ($1/f$) is 298.257. Differences between the ellipsoid used by ICESat/GLAS and the WGS 84 ellipsoid are summarized in Table 5.1:

Parameter	TOPEX/Poseidon	WGS 84
Equatorial radius (a)	6378136.30 m	6378137.00 m
Polar radius (b)	6356751.600563 m	6356752.314245 m
Reciprocal flattening ($1/f$)	298.2570	298.25722356
Eccentricity (e)	0.081819221456	0.081819190843

Table 5.1: Topex/Poseidon ellipsoid and the WGS-84 ellipsoid parameters.

Thus, the ellipsoid used by ICESat/GLAS is about 70 cm smaller than the WGS 84 ellipsoid. As a consequence, comparison of GLAS elevations to those obtained from other sources must take into account the potential effect of ellipsoid differences. The GLAS elevations tend to be higher than the elevations measured with respect to the WGS-84 system, but the differences in latitude and longitude will produce a horizontal displacement of less than a metre. The horizontal displacement caused by different ellipsoids is well below the GLAS accuracy in horizontal geolocation, so it can be ignored. The characteristics of the ellipsoid used with non-GLAS data (i.e. GPS, airborne lidar surveys, etc.) need to be ascertained before comparing

those data to GLAS elevations. The adjustment of elevation to account for different ellipsoids with adequate accuracy is a straightforward function of latitude. NSIDC distributes IDL programs to convert between ellipsoids via FTP at the following address:

<ftp://sidacs.colorado.edu/pub/DATASETS/icesat/tools/idl/ellipsoid/>.

5.1.3 Input interface

Other quantities are necessary for the right functioning of the altimetry macro-module. These can be provided by means of a User Interface or, in some cases, can be fixed as internal constants. In Table 5.2 we provide an overview of these variables.

Variable	Description	Data Type	Units
Input			
<i>gain_th</i>	gain threshold	scalar integer	none
<i>down_factor</i>	downscale factor	scalar integer	none
<i>min_points</i>	minimum number of valid epochs for computing the trend	scalar integer	none
<i>N_th</i>	imum number of measurements at one epoch in each grid cell	scalar integer	none
<i>N_xo_th</i>	number of measurements withing a grid cell identifying a cross-over point	scalar integer	none
<i>N_er_th</i>	error threshold	scalar real	m/yr
<i>med_th</i>	median threshold	scalar integer	none
<i>alpha</i>	significance level representing the probability of the error committed in rejecting the assumption that the true elevation trend falls within an interval (confidence interval) around the estimated elevation trend	scalar real	none
<i>mtx_icesat</i>	ICESat data	2D array of real elements	m
<i>DEM_proj</i>	DEM projection	string of 30 chars	none
<i>DEM_ellip</i>	DEM ellipsoid	string of 30 chars	none
<i>mtx_DEM</i>	DEM	3D array of real elements	m
Output			
<i>x_coord</i>	latitude or the corresponding quantity expressed in a different reference system	1D array of real elements	degree
<i>y_coord</i>	longitude or the corresponding quantity expressed in a different reference system	1D array of real elements	degree
<i>ele</i>	temporal average over the time seasons of the elevation resulting from the average of the laser measurements whose locations are inside eachgrid cell (spatial average)	1D array of real elements	m
<i>dhdt</i>	elevation trend	1D array of real elements	m/yr
<i>error</i>	error	1D array of real elements	m/yr
<i>start_date</i>	start of acquisition	string of 8 chars	none
<i>end_date</i>	end of acquisition	string of 8 chars	none
<i>proj</i>	projection used for expressing x_coord and y_coord	string of 30 chars	none
<i>datum</i>	datum used for expressing x_coord and y_coord	string of 30 chars	none

Table 5.2: List of user input and output variables for the altimetry processing.

5.2 Auxiliary data

5.2.1 Overview

The auxiliary dataset of the altimetry macro-module consists of a DEM.

5.2.2 Format and technical content

The input interface needs to be able to read any format of the DEM available (i.e. a Geotif file, a binary file, etc). In particular, it is important that it will extract from the auxiliary DEM file (i.e. metadata, header files) the information on the latitude and longitude corresponding to the upper left corner of the DEM and all the other information necessary to create a grid of the latitude and longitude for each elevation value (i.e. pixel resolution, number of rows and columns). In particular, the latitude grid must be a 2D array where the columns are copies of the latitude values covered by the DEM and the longitude grid must be a 2D array where the rows are copied of the longitude values covered by the DEM. Then, the input interface needs to be able to load the elevation value in a 2D array having the same number of rows and columns of the latitude and longitude arrays. Afterwards, these three arrays need to be compacted in a 3D array, which is the format of the input required and whose corresponding variable has been named as *mtx_DEM* in the [DPMv1](#) (Glaciers_cci, 2012c). The first index will vary from 1 to 3 with the following meaning:

mtx_DEM(1,*,*) – identifies the longitude grid or 2D array

mtx_DEM(2,*,*) – identifies the latitude grid or 2D array

mtx_DEM(3,*,*) – identifies the elevation

5.3 Output products

5.3.1 Overview

The output product is an ASCII file. It will list, together with the geographical coordinates of each repeat track footprint, the acquisition time, the elevation value, the accuracy of this measurement, the elevation changes and its estimated accuracy.

5.3.2 Format and technical content

The format of the output file is described in Table 4.6 of the [PSD](#) (Glaciers_cci, 2011a).

5.4 Test and validation data sets

The airborne measurements carried out during the IceBridge NASA mission and the airborne measurements available from the CRYOVEX campaigns (CryoSat Validation EXperiment) form the test and validation datasets. The NASA Operation IceBridge mission flies the Airborne Topographic Mapper (ATM) and the Airborne Topographic Mapper 3 (ATM3) scanning lidars and a Ku-Band Radar Altimeter. The CryoVEX campaign operates both with a laser scanning altimeter (ALS) and with a radar altimeter system (ASIRAS). More details on the campaigns and the datasets are reported in the [DARD](#) (Glaciers_cci, 2011b), and [PVP](#) (Glaciers_cci, 2011c).

For each instrument of the Operation IceBridge mission, Table [5.3](#) reports the datasets available, the information contained in each dataset and the relative format. Where the files



are in a binary format, special tools for converting them to a readable format (e.g. ASCII), are available at the website <http://nsidc.org/data/icesat/tools.html>.

IceBridge Instrument	Dataset	Description	Format
Airborne Topographic Mapper (ATM)	IceBridge ATM L1B Qfit Elevation and Return Strength (ILATM1B)	The dataset contains spot elevation measurements; the data were collected as part of Operation IceBridge funded aircraft survey campaigns	The fundamental form of the ATM topography data is a sequence of laser footprint locations acquired in a swath along the aircraft flight track. The data are stored in qfit output files organized as 32 bit, 4 byte, binary integer words scaled to retain the precision of the measurements. Surveys from 2009 and Spring 2010 are in big-endian format. Starting with the 2010 Antarctica campaign, the format of the qfit data files have been changed to little-endian binary. In the past, the .qi files were output in big-endian byte order. The qfit files are now in little-endian byte order. The format of the file content has not changed; only the 'endianness' of the files has changed. The beginning of each file contains a header of one or more records followed by a data segment in which there is one record per laser shot
	IceBridge ATM L2 Icessn Elevation, Slope, and Roughness (ILATM2)	The dataset contains resampled and smoothed elevation measurements; the data were collected as part of Operation IceBridge funded aircraft survey campaigns, and are available for periodic, ongoing campaigns from 31 March 2009	The data files are in fixed-width, space-delimited ASCII text format
	Pre-IceBridge ATM L2 Icessn Elevation, Slope, and Roughness (BLATM2)	The data set contains resampled and smoothed elevation measurements; the data are available for periodic campaigns from 23 June 1993 through 02 August 2008.	The data are stored in ASCII text format
Ku-Band Radar Altimeter	IceBridge Ku-Band Radar L1B Geolocated Radar Echo Strength Profiles	The dataset contains measurements for time, latitude, longitude, elevation, and surface, as well as flight path charts and echograms images. The data were collected as part of Operation IceBridge funded campaigns, and are available for periodic, ongoing campaigns from 26 March 2010 to the present.	The data files are in binary, MATrix LABoratory (MATLAB), Joint Photographic Experts Group (JPEG), and Keyhole Markup Language (KML) formats.

Table 5.3: IceBridge datasets and the corresponding format.

For the CRYOVEX data products, the file format definition for the ASIRAS Level 1b product and the format of Digital Elevation Models derived from aircraft laser scanner are described in Cullen (2010), an ESA document that is online available under:

https://earth.esa.int/c/document_library/get_file?folderId=87248&name=DLFE-1870.pdf.

6. Velocity from optical sensors

6.1 Input products

6.1.1 Overview

Optical image matching will mainly be based on orthorectified Landsat data and ASTER orthoimages. Access conditions for Landsat and ASTER data are described in section 3.1.2 of the DARD (Glaciers_cci, 2011b). We will use both 30 m bands and, for Landsat 7 ETM+, 15 m-pan bands. The performance of both was tested in the algorithm development phase (Glaciers_cci, 2012a). For ASTER we will use the orthoimages as part of the AST14DMO product. Vertical DEM errors translate into horizontal errors in orthoimages. These can be evaluated by comparing the band 3N and 3B orthoimages.

6.1.2 Format and technical content

The format and technical content of the Landsat images is provided in section 3 (Tables 3.1 and 3.2) of this document and not repeated here. The ASTER orthophotos have identical format to the ASTER DEMs, as described in Section 5.1 and 5.2.

6.1.3 Input interface

Ice velocity input

- `opt_image1` = an optical image containing multiple bands depending upon sensor
- `head_image1` = the header that is provided with the optical image describing bounding boxes, resolution, image centre etc.
- `opt_image2` = an optical image containing multiple bands depending upon sensor
- `head_image2` = the header that is provided with the optical image describing bounding boxes, resolution, image centre etc.
- `auxiliary shapefile_masks` = glaciers, lakes, ocean, stable terrain etc.

Ice velocity output:

- `Multilayer1` = a multilayer output containing the displacements in x and y directions, the quality of the displacements, potentially multiple quality masks, and potentially multiple algorithms
- `Header1` = describes the basic information and description of how the displacements were generated.

6.2 Auxiliary data

6.2.1 Overview

Auxiliary data for the optical ice-velocity module include shapefiles for denoting glaciers that are output from the glacier area module or as retrieved from the GLIMS database. Format and technical content refer to section 3.4 of the PSD (Glaciers_cci, 2011a).

6.2.2 Format and technical content

The format for shapefiles is described in section 3.4 of the PSD (Glaciers_cci, 2011a). In particular the shapefiles will contain polygon objects where the specific X and Y locations of vertices are provided.

6.3 Output products

6.3.1 Overview

The output product consists of a multilayer product and a header as described in the PSD (Glaciers_cci, 2011a). The multilayer data product contains the displacement in x and y direction from the master image (image 1) to slave image (image 2) and a quality indicator (e.g. correlation value or a signal to noise ratio) in map geometry. The header contains meta-information (in table format) describing details of the source data (i.e. time of acquisition, sensor, raw image name) and the processing, including, optionally, statistics over stable terrain computed for error-budget estimate.

6.3.2 Format and technical content

The output is provided as a csv file described in the PSD (Glaciers_cci, 2011a) which contains the following columns:

- X and Y coordinate
- The displacement from master to slave image in the x and y direction
- The magnitude and direction of displacement
- Correlation value of the match between master and slave image
- The signal to noise ratio as a quality indicator of the match.

Additionally, meta-information in the form of a text document will be provided that lists details and names of the raw input data, the time of the imagery and summarized statistics of the image matching over stable terrain for use in error budget calculations.

6.4 Test and validation data sets

The validation of glacier displacements from space against independent data with equal or better resolution, accuracy and precision is very difficult, because (i) glacier movement is temporally highly variable, (ii) glacier displacement measurement from repeat images requires image windows to be compared and thus the obtained displacement is representative for a certain area. As a consequence, glacier velocity products should also be validated internally (i.e. from the product itself).

Most matching algorithms provide directly, or after additional processing, quantities that describe the degree of similarity between the matching image windows, e.g. the correlation coefficient (CC) or signal-to-noise ratios (SNR). These parameters are an indication for the reliability of an individual match and are provided directly with the product (see description of output products above). However, this measure is not strict, i.e. bad matches might actually accurately reflect the true displacement, or vice-versa. As a consequence, this measure cannot be used alone for validation.

Matching stable ground in the image set, if present, gives a good indication for the overall co-registration of the repeat images, and some general idea of the matching accuracy under the specific image conditions. Statistics over stable terrain computed for error-budget estimates can be specified in the meta-information. Although subjective, visual interpretation of the derived velocity field should be done by a glaciologist in order to check for unnatural patterns or outliers and to verify the consistency of the velocity fields with glacier outlines.



7. Velocity from microwave sensors

7.1 Input products

7.1.1 Overview

The required input data for the microwave velocity macro-module are two multi-temporal SAR images with associated headers, and optionally a stack of shapefiles for denoting glaciers and terrain assumed to be stable (i.e. no ocean, lakes, glaciers etc.) and a DEM. For best matching, the two SAR images have to be from the same sensor and orbit. Although image-matching is performed with intensity images and thus SAR data as multi-look precision images (PRI) might also be considered, we limit the input products of the processing system to single look complex (SLC) digital images generated from raw SAR data using up-to-date auxiliary parameters.

7.1.2 Format and technical content

The format of a SLC dataset is different depending on the sensor and processing facility. For example, in the case of ERS data provided by ESA PAFs real and imaginary part of the SLC data are in 2 byte integer format and are stored in the image data file. Each record corresponds to a single range line. Metadata is provided in the data leader file, following the typical CEOS format. ENVISAT ASAR data (and more recently also for newly processed ERS SAR data) are instead provided in the form of a single file containing metadata and image data. Tools for reading SAR images in SLC format from various sensors and processing facility are widely available from commercial and public domain software packages and are not described here. In addition to the SLC data in the format defined in the processing system, all information concerning sensor and acquisition mode, geographical coordinates, acquisition time and SAR processing also have to be stored.

Detailed descriptions of the data format for several SAR systems can be found at the following web pages:

ERS, ENVISAT-ASAR:

<http://envisat.esa.int/handbooks/asar/CNTR2-5.htm#eph.asar.prodalg.leva>

TerraSAR-X:

http://www.astrium-geo.com/files/pmedia/public/r460_9_030201_level-1b-product-format-specification_1.3.pdf

ALOS-PALSAR:

<http://www.eorc.jaxa.jp/ALOS/en/doc/format.htm>

Cosmo-Skymed:

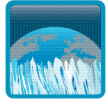
www.e-geos.it/products/pdf/csk-product%20handbook.pdf

7.1.3 Input interface

Below we provide an overview of the variables for the input and output interface.

Ice velocity input:

- `image1` = master satellite image (SAR, 2D array of real respectively complex elements, for the format of the array please refer to the PSD)
- `head_image1` = parameters of master satellite image



- image2 = slave satellite image (SAR, 2D array of real respectively complex elements, for the format of the array please refer to the PSD)
- head_image2 = parameters of slave satellite image
- auxiliary shapefile_masks = shapefile with glaciers, lakes, ocean, stable terrain etc.
- auxiliary DEM = DEM (3D array of real elements, for the format of the array please refer to the IODDv1)

Ice velocity output (microwave):

- mtx_dx1 = displacement in x-direction from master image (image 1) to slave image (image 2) in map geometry as geotiff or equivalent NetCDF (metres)
- mtx_dy1 = filtered displacement in y-direction from master image (image 1) to slave image (image 2) in map geometry as geotiff or equivalent NetCDF (metres)
- mtx_score = quality indicator (e.g. correlation value or a signal to noise ratio (SNR)) in map geometry as geotiff or equivalent NetCD
- stat = statistics over stable terrain for error budget estimate

7.2 Auxiliary data

7.2.1 Overview

Optional auxiliary data for the microwave velocity macro-module include a stack of shapefiles for denoting glaciers and terrain assumed to be stable (i.e. no ocean, lakes, glaciers etc.) and a DEM. A description of DEMs is already given in the previous sections (e.g. 3.2 and 5.1) and not repeated here. Shapefiles for denoting glaciers are the typical output of the glacier area module and for format and technical content we refer to section 3.4 of the [PSD](#) (Glaciers_cci, 2011a).

7.2.2 Format and technical content

Shapefiles for the terrain masks and DEMs as described in sections 3.2 and 5.1.

7.3 Output products

7.3.1 Overview

The output product consists of a multilayer data and header information. The multilayer data lists the displacement in x and y direction from master image (image 1) to slave image (image 2) and a quality indicator (e.g. correlation value or a signal to noise ratio) in map geometry as geotiff or equivalent NetCDF. Meta-information (in csv format) describes details of the source data and the processing, including, optionally, statistics over stable terrain computed for error-budget estimate.

7.3.2 Format and technical content

The format of the output file has been described in the [PSD](#) (Glaciers_cci, 2011a) and is thus not repeated here.

7.4 Test and validation data sets

Validation and quality measures are similar as for the velocity product derived from optical images and can be found in section 6.4 of this document.

8. References

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Abbreviations

ALOS	Advanced Land Observing Satellite
ASAR	Advanced Synthetic Aperture Radar
ASTER	Advanced Spaceborne Thermal Emission and Reflection radiometer
CGIAR	Consultative Group on International Agricultural Research
DARD	Data Access Requirements Document
DEM	Digital Elevation Model
ERS	European Remote Sensing Satellite
ESA	European Space Agency
ETM+	Enhanced Thematic Mapper plus
GDEM	Global DEM
GIS	Geographic Information System
GLAS	Geoscience Laser Altimeter System
GLIMS	Global Land Ice Measurements from Space
GLS	Global Land Survey
GPS	Global Positioning System
ICESat	Ice, Cloud, and Elevation Satellite
ID	IDentification number
InSAR	Interferometric SAR
L1T	Level 1 T (terrain corrected)
LIDAR	Light Detection And Ranging
NASA	National Aeronautic and Space Administration
NIR	Near InfraRed
PALSAR	Phased Array type L-band SAR
PSD	Product Specifications Document
PVP	Product Validation Plan
SAR	Synthetic Aperture Radar
SLC	Single Look Complex
SNR	Signal to Noise Ratio
SPOT	System Pour l'Observation de la Terre
SRTM	Shuttle Radar Topography Mission
SWIR	Short Wave InfraRed
TM	Thematic Mapper
USGS	United States Geological Survey
UTM	Universal Transverse Mercator