ESA Climate Change Initiative

Antarctica Ice Sheet CCI+

Option 3 - Timeseries of ice discharge and IOM mass balance for the East and West Antarctic Ice Sheets from Sentinel-1

Product Specification Document (PSD)

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Change Log

Issue	Author	Affected Section	Change	Status
1.0	Jan Wuite	All	First Verion	

Acronyms and Abbreviations

Acronyms	Explanation
AIS	Antarctic Ice Sheet
ALOS-1/2	Advanced Land Observing Satellite-1/2
API	Antarctic Peninsula
CCI	Climate Change Initiative
CCN	Contract Change Notice
CRS	Coordinate Reference Systems
CSV	Comma Separated Value
DEM	Digital Elevation Model
ENVEO	Environmental Earth Observation
ENVISAT	Environmental Satellite
ERS-1/2	European Remote Sensing satellite 1 & 2
ESA	European Space Agency
GIS	Geographic Information System
GLL	Grounding Line Location
GPS	Global Positioning System
InSAR	Interferometric synthetic-aperture radar
IV	Ice Velocity
MEaSUREs	Making Earth System Data Records for Use in Research
MFID	Mas Flux Ice Discharge
PALSAR	Phased Array type L-band Synthetic Aperture Radar
PSD	Product Specification Document
PVP	Product Validation Plan
RES	Radio Echo Sounding
SAR	Synthetic Aperture Radar
TDX	TanDEM-X
TSX	TerraSAR-X
UL	University of Leeds
WP	Work Package
XML	extensible markup language

1 Introduction

1.1 Purpose and Scope

This document contains the Product Specification Document (PSD, O3-D1.1) for CCN Option-3 as part of the Antarctic Ice Sheet CCI+ project Phase 2, in accordance with contract and proposal [AD1 and AD2]. The PSD is delivered as part of WP3100 - Requirements Baseline – and specifies the geophysical products on ice velocity (IV) and mass flux ice discharge (MFID) that will be generated during the project, including geophysical data content, data format, resolution, coverage, product grid and geographic projection and known limitations of the product. The document also defines the glacier basin outlines for the East and West Antarctic Ice Sheets (EAIS and WAIS) that are used for the mass flux ice discharge (MFID) and IOM Mass Balance (MB) calculations.

1.2 Document Structure

This document is structured as follows:

- Chapter 1 contains an introduction to the document
- Chapter 2 provides an overview of the product specifications for IV, MFID and IOM MB
- Chapter 3 lists the references

1.3 Applicable and Reference Documents

Table 1.1: List of Applicable Documents

No	Doc. Id	Doc. Title	Date	Issue/ Revision/ Version
AD1	ESA/Contract No. 4000143397/23/I-NB CCI+ PHASE 2 - AIS	CCI+ PHASE 2 - NEW R&D ON CCI ECVS for AIS CCI	13.02.2024	1
AD2	ENVEO-NU-DTU-SNT-AISCCI+-P2-Option3-MFID-001_v06	Technical proposal for Option 3	01.12.2023	

Table 1.2: List of Reference Documents

No	Doc. Id	Doc. Title	Date	Issue/ Revision/ Version
RD1				
RD2				

Note: If not provided, the reference applies to the latest released Issue/Revision/Version

2 Product Specification

2.1 Introduction

Table 2.1 summarises the product specifications for the products that will be produced in the project: Ice Velocity (IV), Mass Flux Ice Discharge (MFID) and IOM Mass Balance (MB).

Table 2.1: Summary of the product specifications.

Product	**Input Data**	**Temporal Range**	**Temporal Frequency** (depending on SAR data availability)	**Spatial Coverage**	**Spatial Resolution**
IV	Sentinel-1 (TSX/TDX, RS-2 where gaps exist)	2017-present	monthly	EAIS & WAIS	200m
MFID	IV maps, ice thickness, SEC, grounding line/flux gates	2017-present	monthly	EAIS & WAIS	200m
Mass Balance	MFID, SMB	2017-present	monthly	EAIS & WAIS	Basin-scale

2.2 Ice Velocity

2.2.1 Product Geophysical Data Content

The ice velocity (IV) product is based on synthetic aperture radar (SAR) satellite imagery acquired by Sentinel-1 (S1) using feature tracking and InSAR techniques. The velocity grid for a given file represents the average ice surface velocity over the respective repeat pass period used for feature tracking as indicated by the file name (see below for file naming convention). The basic IV products contain the Easting V_e, Northing V_n and vertical components V_z, of the velocity vector. The horizontal surface velocities are derived from measured displacements in radar geometry (range, azimuth). The vertical velocity is derived from the interpolated height at the end position of the displacement vector minus the elevation at the start position, taken from a DEM [RD1]. The main data variables are defined on a three-dimensional grid (x, y, z), where x and y are the geographic coordinates, in the projection given by the attributes of the Coordinate Reference Systems (CRS) variable. The main data variables are given in Table 2.2. The velocity maps for single image/track repeat pairs are used to generate monthly mosaics.

Table 2.2: IV main data variables.

Variable name	**Variable description**
land_ice_surface_easting_velocity (v_x)	Ice velocity East component [m/day]
land_ice_surface_northing_velocity (v_y)	Ice velocity North component [m/day]
land_ice_surface_vertical_velocity (v_z)	Ice velocity Vertical component [m/day]
land_ice_surface_velocity_magnitude (v_v)	Ice velocity magnitude [m/day]
land_ice_surface_measurement_count	Valid pixel count [#]
land_ice_surface_easting_stddev	Standard deviation easting [m/day]
land_ice_surface_northing_stddev	Standard deviation northing [m/day]

Along with the ice velocity maps the products include a valid pixel count map providing the number of valid slant range and azimuth displacement estimates at the output pixel position and used in the averaging, as well as an uncertainty map (based on the standard deviation).

2.2.2 Product Data Format

The IV is provided as raster products and is provided in NetCDF format. The product format can be readily ingested and displayed by any GIS package and is largely self-documenting. The monthly velocity mosaics are provided as NetCDF file with separate layers for the velocity components: vx, vy, vz, along with layers showing the magnitude of the horizontal components, the valid pixel count and uncertainty. For all variables, a NoData value, indicating missing data, of 3.4028234663852886e+38 is used.

2.2.3 File Naming Convention

For ice velocity raster products the file naming follows largely the common CCI filenaming convention:

20141001-ESACCI-L3C-AIS-IV-S1-1M_200m-fv1.0.nc

<Indicative Date>-ESACCI-<Processing Level>-<CCI Project>-<Data Type>-<Product String>-<Additional Segregator>-fv<File Version>.<format>

Example filename: 20141001-ESACCI-L3C-AIS-IV-S1-1M_200m-fv1.0.nc

Where: <Indicative Date> specifies the start date of the (monthly) product (YYMMDD); <Processing Level> specifies the processing level corresponding to RDAC (Regional Data Assembly Centre) in the GHRSST file naming convention, L3C standing for: observations combined from a single instrument into a space-time grid; Data Type IV stands for Ice Velocity; Product String S1 stands for Sentinel-1 sensor; The Additional Segregator 1M_200m indicates the period over which the data are aggregated (1M= 1 month) and the posting of the product (200m). The file format for the monthly ice velocity mosaics is NETCDF.

2.2.4 Product Grid and Projections

The IV maps are gridded at 200 m. The raster products over the Antarctica are in Antarctic Polar Stereographic projection with latitude of true scale at -71 degrees (EPSG: 3031).

2.2.5 Product Known Limitations

The following lists some known product limitations:

1) The IV products contain 3 layers representing the horizontal (Easting, Northing) and the vertical components of velocity. This is not the true 3D velocity, which requires both ascending and descending image pairs acquired close in time. The vertical component is derived from the difference in height of start and end position of the displacement vector taken from a DEM.

2) The IV products do not have a time stamp for a single date, but give the average velocity over the time-period covered by the mosaic (i.e. monthly).

3) For various reasons the tracking software sometimes fails to find matching features leading to gaps in the velocity fields. This can be caused by a lack of surface features or when features, for example crevasses, rapidly change due to shearing leading to low correlation. Other

reasons for gaps in the IV maps can be areas affected by radar shadow or anomalous pixels that are filtered out. We apply a simple distance-weighted averaging filter to get rid of outliers and to fill small gaps in the data (<5 pixels), further filtering/gap filling is left to the user if required.

4) Due to different acquisition modes, sensor type, resolution and processing strategy there are some differences between IV products that complicate a direct comparison between the data sets. Because of differences in resolution, the image patches used for feature tracking have different dimensions impacting the type of features that can be resolved.

5) In-situ GPS data for validation of ice velocity is only sparsely available. In the absence of this product quality assurance largely depends on intercomparisons with existing ice velocity products and products from different sensors.

2.3 Mass Flux Ice Discharge

2.3.1 Product Geophysical Data Content

The main input for the mass flux ice discharge (MFID) products are the IV products described in Section 2.2. The IV fields are combined with gridded estimates of the ice thickness (e.g. BEDMAP2, BedMachine) to calculate ice discharge at pre-defined flux gates at or near the grounding line location (GLL) of the drainage basins. The ice discharge provides a best estimate of the mass flux through the flux gate averaged for the period of the IV field (i.e. monthly). The mass fluxes are provided in Gt/yr, assuming an ice density of 900 kg m^{-3}.

2.3.2 Drainage Basin Definition

For the project, drainage basins definitions are available from the MEaSUREs Antarctic Boundaries dataset (Mouginot et al, 2017) and IMBIE-2 project (The IMBIE team, 2018).

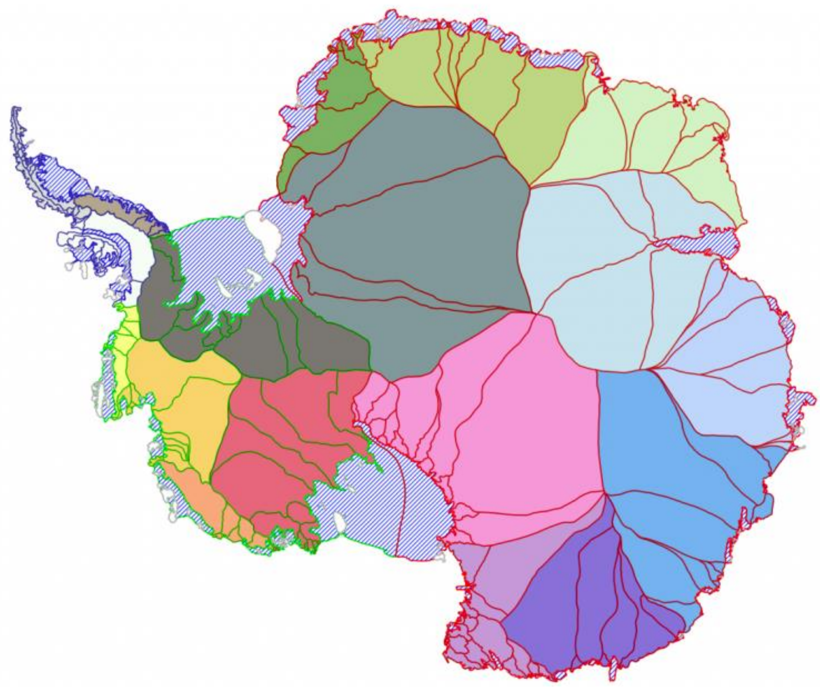

Figure 2.1: Antarctic basins, the shapefile depicted includes the coastline, the grounding line, an ice shelf mask (striped), as well as IMBIE and refined basins. Also provided is a regional separation in East Antarctica (red lines), West Antarctica (green lines), and the Antarctic Peninsula (dark blue lines).

2.3.3 Product Data Format

The discharge estimates are provided in CSV table format in Gigatons per year (Gt/Y) averaged for a specified time period. The temporal resolution depends primarily on the velocity data used for the discharge estimate, in the project we provide monthly estimates.

2.3.4 Product Known Limitations

The solid ice discharge estimates rely on accurate ice thickness and ice velocity measurements. The capabilities and limitations are therefore largely determined by the quality of the thickness and velocity data.

As only surface velocity can be detected from satellite imagery, assumptions must be made to derive the depth averaged velocity. In case of a freely floating glacier or ice shelf the depth-averaged velocity V_m is equal to the surface velocity V_s, but in other cases a correction factor f, whereby $V_m=fV_s$ is usually applied to account for this, with values for f ranging between 0.8-1.0. (Cuffey and Paterson, 2010)

As radio echo sounding (RES) radar flight tracks are often incomplete, especially along fast-moving glaciers that flow through steep and/or narrow fjords, data gaps exist that need to be filled in. The gridded ice thickness data sets use an optimal approach to fill these gaps, but nevertheless uncertainties can be significant, in particular for glaciers with few observations and/or a large imbalance.

To minimize the uncertainty associated with ice thickness, the ice thickness at the flux gates will be corrected for surface elevation changes. For this newly generated time series of SEC, updated to present day, will be used at key locations across the grounding line where they are needed to evolve estimates of ice thickness required to calculate ice discharge. Special emphasis will be given on the quality of SEC products at the grounding line and their combination with ice thickness data sets to produce reliable estimates of ice thickness change.

Available IV maps are often incomplete, requiring spatial or temporal interpolation, while for some glaciers it might not be possible at all to provide a meaningful discharge estimate.

2.4 IOM Mass Balance

2.4.1 Product Geophysical Data Content

In the IOM approach the change in ice mass of grounded ice is calculated by differentiating between the surface mass balance (SMB), i.e. the net snow accumulation at the surface (input), and the discharge of solid ice to the ocean (output). The main input for the mass balance estimates are the mass flux ice discharge (MFID) products described in Section 2.3 and SMB taken from the regional climate model RACMO2 (RACMO2.3; Van Wessem et al., 2018). The mass balance estimates provide a best estimate of the mass balance for a specific drainage basin averaged for the period of the IV field (i.e. monthly). The mass balance estimates are provided in Gt/y r, assuming an ice density of 900 kg m^{-3}.

2.4.2 Product Data Format

Similar as the discharge estimates, the IOM mass balance estimates are provided in a CSV table format in Gigatons per year (Gt/Y) averaged for a specified time period. The temporal resolution depends primarily on the velocity data used for the discharge estimate, in the project we provide monthly estimates.

2.4.3 Product Known Limitations

The mass balance estimate are based on the MFID estimates and SMB. The capabilities and limitations are therefore determined by those of MFID (See Section 2.3) and the limitations of the SMB model (Van Wessem et al., 2018).

3 References

Cuffey KM and Paterson WSB. 2010. The physics of glaciers, 4th edn. Butterworth-Heinemann, Oxford

Mouginot, J., B. Scheuchl, and E. Rignot. 2017. MEaSUREs Antarctic Boundaries for IPY 2007-2009 from Satellite Radar, Version 2. [Indicate subset used]. Boulder, Colorado USA. NASA National Snow and Ice Data Center Distributed Active Archive Center. doi: http://dx.doi.org/10.5067/AXE4121732AD.

The IMBIE team. Mass balance of the Antarctic Ice Sheet from 1992 to 2017. Nature 558, 219–222 (2018). https://doi.org/10.1038/s41586-018-0179-y

van Wessem, J. M., van de Berg, W. J., Noël, B. P. Y., van Meijgaard, E., Amory, C., Birnbaum, G., Jakobs, C. L., Krüger, K.,Lenaerts, J. T. M., Lhermitte, S., Ligtenberg, S. R. M., Medley, B., Reijmer, C. H., van Tricht, K., Trusel, L. D., van Ulft, L.H., Wouters, B., Wuite, J., and van den Broeke, M. R.: Modelling the climate and surface mass balance of polar ice sheets using RACMO2 – Part 2: Antarctica (1979–2016), The Cryosphere, 12, 1479–1498, https://doi.org/10.5194/tc-12-1479-2018, 2018.