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

Algorithm Development Plan (ADP)

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Change Log

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

Acronyms and Abbreviations

Acronyms	Explanation
AIS	Antarctic Ice Sheet
CCI	Climate Change Initiative
CCN	Contract Change Notice
DTU	Technical University of Denmark
EAIS	East Antarctic Ice Sheet
ECV	Essential Climate Variable
ENVEO	Environmental Earth Observation
ENVISAT	Environmental Satellite
ERS-1/2	European Remote Sensing satellite 1 & 2
ESA	European Space Agency
GLL	Grounding Line Location
IMBIE	Ice sheet Mass Balance Inter-comparison Exercise
InSAR	Interferometric synthetic-aperture radar
IOM	Input-Output Method
IV	Ice Velocity
MEaSUREs	Making Earth System Data Records for Use in Research
MFID	Mass Flux Ice Discharge
NU	Northumbria University
S1	Sentinel-1
S&T	Science and Technology AS
SAR	Synthetic Aperture Radar
SEC	Surface Elevation Change
SLC	single look complex
SMB	Surface Mass Balance
TCM	Tidal Correction Module
TDX	TanDEM-X
TSX	TerraSAR-X
WAIS	West Antarctic Ice Sheet
WP	Work Package

1 Introduction

1.1 Purpose and Scope

This document contains the Algorithm Development Plan (ADP, O3-D2.1) 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 ADP is delivered as part of WP3200 - Requirements Baseline. - and describes the algorithm development planned in the project for retrieving the main products to be generated in the project: ice velocity (IV) and mass flux ice discharge (MFID) and IOM mass balance (MB).

1.2 Document Structure

This document is structured as follows:

- Chapter 1 contains an introduction to the document
- Chapter 2 provides descriptions of planned algorithm developments for IV, MFID and 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 Planned Algorithm Developments

2.1 Introduction

This project aims to implement a processing line for automatically deriving the ice discharge of outlet glaciers and to generate a homogenized time series of ice flow, discharge and mass balance for the East and West Antarctic Ice Sheets (EAIS and WAIS) in order to fill knowledge gaps and reduce uncertainties. The work extents the CCN-1 "MFID and IV for Antarctic Peninsula", performed by ENVEO in cooperation with Northumbria University (NU), and will provide the basis for a contribution to the next IMBIE assessment.

The main objectives of the work for this option are

- implement a system for estimating the mass flux ice discharge (MFID) for East and West Antarctic glaciers and ice streams, including ice velocity (IV) retrieval from Sentinel-1 SAR, definition of flux gates at the grounding line, quality checking and updating of ice thickness data using surface elevation change (SEC) products along gates, filling of IV data gaps at gates and extrapolation to areas with little or no observations.

- to generate homogenized time series of ice flow velocity in East and West Antarctica by exploiting the extensive archive of Copernicus Sentinel-1 satellite missions since 2017,

- to utilize the generated ice velocity maps, in combination with additional data sets on surface mass balance, surface elevation change, ice thickness and grounding line location, to provide detailed estimates of IOM mass balance for the East and West Antarctic IMBIE basins,

- to exploit these newly acquired homogenized data sets in a study that investigates the spatial and temporal evolution of ice dynamic processes, ice discharge and mass balance in East and West Antarctica since 2017, serving as input for the next IMBIE Antarctic mass balance assessment.

The core algorithms for the required ECV parameters (IV, SEC, MFID) have been developed in the Antarctic Ice Sheet CCI and CCI+ projects or within other projects. In the current phase of the project further developments are foreseen in various aspects of the processing line. The products are generated by applying an integrated approach using multi-sensor and multi-temporal remotely sensed data sets complemented by in-situ field data and models. The planned approach utilizes these datasets to generate a time series of ice surface velocities, ice discharge and IOM mass balance to investigate possible spatial and interannual variations in the last decade. The planned algorithm developments are described below.

2.2 Ice Velocity

The retrieval of ice surface velocities in this project is mainly based on synthetic aperture radar (SAR) satellite imagery acquired by Sentinel-1 (S1). The S1 mission has generated a now over a decade long unique archive of satellite data in Antarctica. Ice velocity is derived from repeat pass S1 single look complex (SLC) data using combinations of InSAR and image correlation techniques (offset tracking). In the framework of ESA CCI and related projects ENVEO has developed an automated system for generation of ice velocity maps from SAR data (Nagler et al., 2015, 2022). The ice velocity processing chain was adapted within the Antarctic Ice Sheet CCI+ project (Phase 1), by including a Tidal Correction Module (TCM), which corrects the ice

velocity on ice shelves and floating extensions of outlet glaciers from the influence of tidally induced vertical motion. ENVEO has already generated a large collection of ice velocity maps, based on Sentinel-1 SAR, covering also both the EAIS and WAIS. In the current project the existing processing lines are utilized to extend the velocity time series data to the present and generate monthly averaged mosaics covering the Antarctic margins. The main focus in this project is on data acquired since 2017 as in the years prior the coverage of Sentinel-1 in East- and West Antarctica is only limited to selected regions. Additionally, we plan to incorporate RADARSAT-2 (left looking) and TerraSAR-X/TanDEM-X data to generate IV maps at the grounding line of Ross Ice Shelf and parts of Ronne-Filchner Ice Shelf, which are not covered by Sentinel-1 due to the polar gap.

2.3 Mass Flux Ice Discharge

In the CCI+ extension of the Greenland Ice Sheet CCI project, ENVEO has developed tools for calculating mass flux ice discharge (MFID) for Greenland outlet glaciers based on monthly IV maps from Sentinel-1. In addition to these developments, both within the framework of the Antarctic Ice Sheet CCI and Greenland Ice Sheet CCI projects, ENVEO also (co-)developed methods for retrieving the ice sheet grounding lines based on Sentinel-1 interferometry. Developed methods and procedures in CCN – Option 1 on homogenized time series of ice flow and ice discharge for the Antarctic Peninsula will also largely be applicable for CCN – Option 3. Special emphasis will be on the development of methods and procedures for extrapolation of ice discharge, where there are gaps in spatial and temporal coverage of ice velocity or thickness, to acquire an accurate region-wide estimate.

In the project flux gates will be used at or near to the grounding line location (GLL). Due to downwasting of glaciers and basal melt under ice shelves the position of the groundling line is subject to significant changes. Therefore, grounding line positions will be updated in the project based on Sentinel-1 InSAR data, with as main focus the dynamic outlet glaciers and ice streams. Newly generated grounding lines from the baseline project will also be included.

Antarctic-wide gridded ice thickness and bed topography is available from Bedmap3 and MEaSUREs BedMachine (Frémand et al., 2023; Morlighem, 2020). The ice thickness at the flux gates will be corrected for surface elevation changes. Surface elevation change (SEC) measurements are derived from ERS-1, ERS-2, ENVISAT, CryoSat-2 and Sentinel-3 radar altimetry which allow assessments of SEC across the Antarctica Ice Sheet since 1991. SEC parameters are generated using the along track plane fit method developed within the AIS CCI project (Shepherd et al., 2019). This method can be applied to satellites which operate in both short 27-35 day orbit repeat periods (ERS, ENVISAT, Sentinel-3) and long 369-day repeat periods (CryoSat-2). The plane fit method grids both ascending and descending fully corrected elevation measurements in a regular polar stereographic grid at 5 km resolution and derives a SEC estimate at the centre of each grid cell by applying a surface model to the measurements within that grid cell. Within WP3210 an algorithm will be developed to combine estimates of ice thickness at the grounding line with time series of SEC to retrieve estimates of ice thickness change to be used for improving the ice discharge calculation. Newly generated time series of SEC using the plane fit method will update these estimates to present day 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.

2.4 IOM Mass Balance

With IOM, the change of grounded ice mass in time (the net mass balance) is computed as the sum of the total net accumulation at the surface (SMB) and the ice export due to discharge at the grounding line. The SMB at a given point on the glacier represents the net sum of precipitation and mass depletion (driven by processes such as snowfall, rain, surface melt, sublimation/evaporation, snow drift). For SMB we use output of the regional climate model RACMO2 (RACMO2.3; Van Wessem et al., 2018). RACMO models atmospheric processes at a relatively high horizontal resolution and has proven to realistically simulate the SMB and its components over Antarctica (Van Wessem et al., 2018). RACMO provides monthly gridded surface mass balance data for the Antarctic ice sheet at a resolution of 27 km. In our planned IOM approach the SMB is integrated for a given basin, considering the fractional coverage at the basin boundaries, and converted to Gigatons per year (Gt/Y).

3 References

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