ESA Climate Change Initiative (CCI+)

Essential Climate Variable (ECV)

Greenland_Ice_Sheet_cci+ (GIS_cci+)

Algorithm Development Plan

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Change Log

Issue	Author	Affected Section	Change	Status
1.0	L.Sørensen	All	Document Creation	
	L. Sørensen	All	Input on ECVs	

Acronyms and Abbreviations

AIS	Antarctic Ice Sheet
AMAP	Arctic Monitoring and Assessment Programme
ATBD	Algorithm Theoretical Basis Document
CAR	Climate Assessment Report
CCI	Climate Change Initiative
CEOS	Committee on Earth Observation Satellites
CFL	Calving Front Location
CMUG	Climate Modelling User Group
CPROP	Contractual Proposal
CR	Cardinal Requirement
CRDP	Climate Research Data Package
CRYOVEX	CryoSat Validation Experiment (airborne and in-situ campaigns)
CRG	Climate Research Group
CS2	CryoSat-2
C3S	Copernicus Climate Change Service
DARD	Data Access and Requirements Document
DEM	Digital Elevation Model
DInSAR	Differential Interferometric Synthetic Aperture Radar
DMI	Danish Meteorological Institute
DTU-S	DTU Geodynamics Group
DTU-N	DTU Microwaves and Remote Sensing Group
ECV	Essential Climate Variable
EO	Earth Observation
ENVEO	ENVironmental Earth Observation GmbH
ESA	European Space Agency
E3UB	End-to-End ECV Uncertainty Budget
FCDR	Fundamental Climate Data Record
FPROP	Financial Proposal
GCOS	Global Climate Observation System
GEUS	Geological Survey of Denmark and Greenland
GCP	Ground Control Point
GIA	Glacial Isostatic adjustment
GIS	Greenland Ice Sheet
GLL	Grounding Line Location
GMB	Gravimetry Mass Balance
GIS	Greenland Ice Sheet
IGOS	Integrated Global Observing Strategy
IMBIE	Ice Sheet Mass Balance Inter-comparison Exercise
InSAR	Interferometric Synthetic Aperture Radar

IOC	Intergovernmental Oceanographic Commission
IPCC	Intergovernmental Panel of Climate Change
IPP	Interferometric Post-Processing
IPROP	Implementation Proposal
IPY	International Polar Year
IV	Ice Velocity
IW	Interferometric Wideswath
MFID	Mass Flux and Ice Discharge
MPROP	Management Proposal
NBI	Niels Bohr Institute, University of Copenhagen
NERSC	Nansen Environmental Research Institute
PARCA	Polar Areas Regional Climate Assessment project (NASA)
PM	Progress Meeting/ Project Management
PMP	Project Management Plan
PROMICE	Danish Program for Monitoring of the Greenland Ice Sheet
PSD	Product Specification Document
PUG	Product User Guide
PVIR	Product Validation and Intercomparison Report
RA	Radar Altimetry
RFQ	Request For Quotation
S&T	Science and Technology AS
SAR	Synthetic Aperture Radar
SLBC cci	Sea Level Budget Closure cci project
SEC	Surface Elevation Change
SOW	Statement of Work
SSD	System Specification Document
SVALI	Stability and Variability of Arctic Land Ice (Nordic project)
SWIPA	Snow, water, Ice and Permafrost in the Arctic
SVR	System Verification Report
TBD	To Be Decided
TPROP	Technical Proposal
TSX/TDX	TerraSAR-X/TanDEM-X SAR mission
TUDr	Technische Universität Dresden
UL	University of Leeds
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
URD	User Requirement Document
WBS	Work Breakdown Structure
WMO	World Meteorological Organization

1 Introduction

1.1 Purpose and Scope

This document contains the Algorithm Development Plan v.1 for the Greenland_Ice_Sheet_cci (GIS_cci) project for CCI+ Phase 1, in accordance to contract and SoW [AD1 and AD2].

The purpose of the document is to outline the conceptual principles for algorithm developments, especially for novel ECV products which include [RD1]:

o SEC from IceSat-2 photon counting,

o GMB for GRACE-FO satellite

o IV improvements in interior, slow-moving regions,

o lakes products,

o MFID principles for estimating mass discharge.

The ADP (D.1.2.1) will be delivered as an annex to the PMP [RD1].

1.2 Document Structure

This document is structured as follows:

- Chapter 1 provides an introduction to the document.
- Chapter 2 provides short descriptions of planned algorithm developments within each ECV/data

1.3 Applicable and Reference Documents

Table 0.1: List of Applicable Documents

No	Doc. Id	Doc. Title	Date	Issue/ Revision/ Version
AD1	ESA/Contract No. 4000126023/19/I-NB, and its Appendix 1	CCI+ PHASE 1 - NEW R&D ON CCI ECVS, for Greenland_Ice Sheet_cci		
AD2	ESA-CCI-EOPS-PRGM-SOW-18-0118 Appendix 2 to contract.	Climate Change Initiative Extension (CCI+) Phase 1, New R&D on CCI ECVs Statement of Work	2018.05.31	Issue 1 Revision 6

Table 0.2: List of Reference Documents

No	Doc. Id	Doc. Title	Date	Issue/ Revision/ Version
RD1	ST-DTU-ESA-GISCCI+-PMP-001	Project Management Plan	April 2017	1.1
RD2	ST-DTU-ESA-GISCCI-ATBD-001	Algorithm Theoretical Baseline Document	Aug 2017	3.2

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

2 Planned Algorithm Developments

2.1 Surface elevation changes

The algorithms implemented to derive surface elevation changes (5 yr trends) from the long time series of ESA radar missions is described in details in the ATBD [RD2]. These include true repeat-track, along-track, plane-fit and cross-over algorithms (Sørensen et al., 2018). No changes to these algorithms are planned within the CCI+ project.

Planned algorithm developments within the CCI+ project include:

- Increasing temporal resolution to allow for 3-monthly surface change grids.
- Extracting SEC from IceSat-2 (photon counting) data. The algorithm will likely apply to the ATL06 downsampled data set (due to the very large data files for the ATL03 full photon cloud data). The algorithm will enable to fully take advantage of the 6 laser beams providing across-track topography. (data set description https://nsidc.org/data/icesat-2/data-sets)
- Update of Envisat RA-2 and CryoSat-2 data to the latest release. This might introduce new algorithms used in the data pre-processing. (RA2 data set description https://earth.esa.int/web/sppa/mission-performance/esa-missions/envisat/ra2/products-and-algorithms/products-information).
- Alignment (e.g. bias correction) in the SEC time series with the inclusion of Sentinel-3 data, to ensure a long stable time series into the coming years.

2.2 Ice Velocity

Ice velocity (IV) measurements will be continued using the algorithms described in the ATBD[RD2]. The main development will be related to the use of interferometry for Sentinel-1 Interferometric Wideswath (IW) data. Interferometry enables a potential order of magnitude increase in resolution and accuracy compared to the offset-tracking methods so far employed to measure IV from Sentinel-1 data. However, it provides only relative measurements of the line-of-sight component of the velocity, and works only on coherent pairs, limiting its use to relatively slow-moving regions of the ice sheet e.g. the interior parts and the inner part of the North-East Greenland Ice Stream.

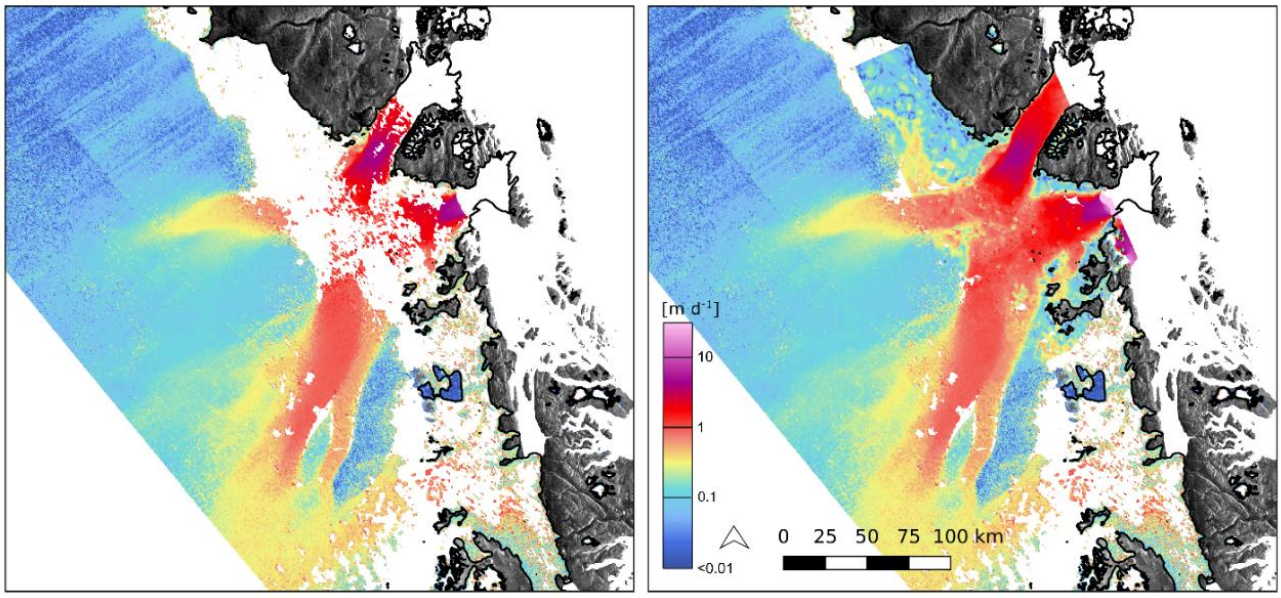
Interferometry applied to IW data, which are acquired in the Sentinel-1 specific TOPS mode, presents special challenges compared to conventional stripmap data, since the data are acquired in bursts, during which the line-of-sight of the radar beam changes from aft to forward looking. At the edge between two bursts, an unknown azimuth component of scene motion will be projected on to different line-of-sight directions in the two bursts and lead to a phase discontinuity at the burst boundary. This can affect the phase unwrapping severely if not compensated.

In the CCI+ project, and in synergy with other projects, the following developments are planned:

- Adapting the interferometric processor to ingest Sentinel-1 IW pairs.
- Development of methods for phase unwrapping across bursts. This could include use of a-priori velocities to estimate azimuth motion.
- Using combined ascending/descending tracks for deriving 2D/3D velocities from interferometry.
- Calibration of the unknown constant line-of-sight offset (absolute phase) inherent in interferometric measurements using e.g. ground control points.
- Increasing the spatial resolution of the CCI Sentinel-1 IV products from 500m to 250m, and developments and tests towards improved spatial resolution of ~100 m pixel spacing.
- Revision of outlier removal and interpolation scheme in order to improving the accuracy and quality of the velocity field and reduce gaps.

IV retrieval from high resolution optical data will be further developed and automated, including advancing tools for synergistic use of SAR and Optical IV. The focus will be on time-series of key outlet glaciers during summer in areas with surface melt (Figure 1). The planned algorithm developments within the CCI+ project include:

- Upgrade of asynchronous query and download of Sentinel 2 data from Amazon Web Service archive.
- Upgrade of current mosaicking algorithm.
- Implementation automatic validation and inter-comparison routines.



Figur 1: Synergistic S1 + S2 IV maps - main improvements expected in melting regions of glaciers during summer

2.3 Gravimetric Mass Balance

We plan to use the methods described in the ATBD [RD2] to continue the gravity mass balance (GMB) ECV with new data from the GRACE-FO. For GMB the performance of GRACE-FO will be a key factor.

We continue with a collaboration of the two consortia partners DTU and TuDr, applying different algorithms for GMB processing, to enhance the products, and cooperate on improvements. The GMB ECV implementation will be done as soon as first GRACE-FO data are available.

Planned algorithm developments within the CCI+ project include:

- Ensure best possible continuation of existing time series. We expect to use the existing algorithms used for GRACE but will modify if needed
- Use combinations of other ECV data in combination with HIRHAM-driven PISM models and/or GNET GPS uplift data to make a "bridging" GMB product for the 2016-18 mission gap.
- Drainage basin definitions may need to be modified to accommodate the MFID basins
- The filters and regularization in the GMB production

2.4 Mass Flow Rate and Ice Discharge

We will use the methods described in Mankoff et al. (2019) to estimate the mass flow rate. These methods include:

- Automatic gate location selection ~5 km upstream of recent ice termini.
- Estimating ice thickness where intuition suggests reported ice thickness may be invalid.
- Estimating un-observed mass loss (coverage) at each time when any observations exist, due to spatial gaps in the velocity product.

Modifications required to make that work meet the project requirements include

- Incorporating the CCI IV product.
- Verifying that any comparison is performed using the same basin outlines – ideally based on the best estimate of basin delineation.

2.5 Lakes

Our aim is to detect supraglacial lakes within two areas of interest (part of Jakobshavn Glacier and Zachariae Isstrøm). The methods are described in ATBD of cci_glacier option 6, where Asiaq is part of the consortium and carried out an inventory of ice marginal lakes in Greenland. Within GIS cci+, we will expand the existing inventory and add supraglacial lakes. Planned algorithm developments within the CCI+ project include:

- Extraction of supraglacial lakes within the two areas of interest with Sentinel-2, supplemented with Sentinel-1
- 3-monthly temporal resolution within the summer months / melting season, and size threshold of - more than 25.000m2
- Examination of a possible link between ice velocity speed-ups and supraglacial lake drainage with help of other relevant ECV data produced within this project

References

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Mankoff, K. D., Colgan, W., Solgaard, A., Karlsson, N. B., Ahlstrøm, A. P., van As, D., Box, J. E., Khan, S. A., Kjeldsen, K. K., Mouginot, J. and Fausto, R. S. (2019). Greenland Ice Sheet solid ice discharge from 1986 through 2017. *Earth System Science Data*, 11, 769-786, DOI:10.5194/essd-11-769-2019