CLIMATE-SPACE - THEME I - B. ADDITIONAL ESSENTIAL CLIMATE VARIABLES (ECVS) - NEW ECV PRODUCTS

SAGE CCI

(Sea Ice Age and Drift)

Product Specification Document (PSD)

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Change Log

Issue	Author	Affected Section	Change	Status
0.5	D. Fantin, S&T	All	Document created	
0.6	FM	All	Document update	First draft
1.0	F. Massonnet, D. Babb, A. Korosov, T. Lavergne, S. Aaboe	All	V 1.0 consolidated	Released to ESA

Acronyms and Abbreviations

AARI	Arctic and Antarctic Research Institute (RUS)
ADP	Algorithm Development Plan
AMSR2	Advanced Microwave Scanning Radiometer 2
AMSR-E	Advanced Microwave Scanning Radiometer for EOS
AR	Annual Review
ASCAT	Advanced Scatterometer
ATBD	Algorithm Theoretical Basis Document
AWI	Alfred-Wegener-Institute for Marine and Polar Research
BGEP	Beaufort Gyre Exploration Project
C3S	Copernicus Climate Change Service
CAR	Climate Assessment Report
CCI	ESA's Climate Change Initiative
CDR	Climate Data Records
CFOSAT	Chinese-French Oceanography Satellite
CMEMS	Copernicus Marine Service
CMIP	Coupled Model Intercomparison Project
CM SAF	The Climate Monitoring Satellite Application Facility
CMUG	Climate Modelling User Group
CP	Communication Package
CRDP	Climate Research Data Package
CRG	Climate Research Group
DAL	Distance Along the Line
DMI	Danish Meteorological Institute (DK)
DNN	Diffusion Neural Network
DOI	Digital Object Identifier
E3UB	End-to-End ECV Uncertainty Budget
ECV	GCOS Essential Climate Variable
ECCC	Environment and Climate Change Canada (CA)
ECMWF	European Center for Medium-Range Weather Forecasts
EO	Earth Observation
ERA5	ECMWF Reanalysis ver. 5
ERS	European Remote-Sensing Satellite
ES	Executive Summary
ESA	European Space Agency
EUMETSAT	European Organization for the Exploration of Meteorological Satellites
FCDR	Fundamental Climate Data Record
FM	Final Meeting
FP	Final Presentation
FR	Final Report
FYI	First-Year Ice
GCOS	WMO/ICO/UNEP Global Climate Observing System
HY-2	Haiyang-2
IABP	International Arctic Buoy Programme
ICESat-2	Ice, Cloud and land Elevation Satellite 2
ICDR	Interim Climate Data Record
IPCC	Intergovernmental Panel on Climate Change
IPS	Ice Profiling sonar
ITT	Invitations to Tender
JAMSTEC	Japan Agency for Marine-Earth Science and Technology (JP)
JAXA	Japan Aerospace Exploration Agency (JP)

KNMI	Royal Netherlands Meteorological Institute
KO	Kick Off
METNO or MET Norway	Norwegian Meteorological Institute
MIZ	Marginal Ice Zone
ML	Machine Learning
MPR	Monthly Progress Report
MS	MileStone
MYI	Multiyear Ice
NASA	National Aeronautics and Space Administration
NERSC	Nansen Environmental and Remote Sensing Center
NIC	National Ice Center
NorESM	Norwegian Earth System Model
NSIDC	National Snow and Ice Data Center (US)
Obs4MIPS	Observations for Model Intercomparison Projects
OSI SAF	The Ocean and Sea Ice Satellite Application Facility
PM	Progress Meeting, Project Manager
PMP	Project Management Plan
PMW	Passive Microwave
PSD	Product Specification Document
PSH	Project Scientific Highlights
PUG	Product User Guide
PVASR	Product Validation and Algorithm Selection Report
PVIR	Product Validation and Intercomparison Report
PVP	Product Validation Plan
QRS	Quarterly Status Reports
QuikSCAT	Quick Scatterometer Mission
RCM	Radarsat Constellation Mission
RID	Review Item Discrepancy
RMSD	Root Mean Square Difference
RMSE	Root Mean Square Error
RRDP	Round Robin Data Package
SAGE	Sea Ice Age and Drift
SAR	Synthetic Aperture Radar
SCAT	Scatterometer
SIC	Sea Ice Concentration
SID	Sea Ice Drift
SIMIP	Sea Ice Model Intercomparison Project
SMMR	Scanning Multichannel Microwave Radiometer
SRD	System Requirement Document
SoW	Statement of Work
SSD	System Specification Document
SSMI,SSM/I	Special Sensor Microwave - Imager
SSMIS	Special Sensor Microwave - Imager/Sounder
SYI	Second-Year Ice
S&T	Science and Technology AS
T2m	2 Meter Temperature
TB	Brightness Temperature
UB	University of Bremen
UCLouvain	Université Catholique de Louvain

UH	University of Hamburg
ULS	Upward-Looking Sonar
UM	University of Manitoba
URD	User Requirement Document
UWR	User Workshop Report
WAI	Warm Air Intrusion
WBS	Work Breakdown Structure
WMO	World Meteorological Organization
WP	Work Package
WPD	Work Package Description
YI	Young Ice

1 Introduction

1.1 Purpose and Scope

This document contains the Product Specification Document (PSD) for the SAGE project for CLIMATE-SPACE - THEME I - B. ADDITIONAL ESSENTIAL CLIMATE VARIABLES (ECVS) - NEW ECV PRODUCTS, in accordance with the contract [AD1], Statement of Work (SoW) [AD2] and proposal [AD3-AD10].

The purpose of this document is to translate the user requirements described in the URD into a complete and consistent set of product specifications, with some degree of trade-off between ideal and practical implementations.

The project will produce data products tuned in an RRDP framework that includes colocated buoy data, remote sensing data, and other available data sources on sea-ice age and type, all reviewed in the next sections.

As foreseen, the URD revealed a high diversity in the definition and requirements for a future sea ice age and drift product. This first PSD will propose specifications that are as compliant as possible with the user needs, but will likely undergo a revision during the project's lifetime when more feedback has been received, for example, from the CMUG.

1.2 Document Structure

In this document, different product specifications are described separately: sea-ice drift, Lagrangian sea ice age, radiometric sea ice type, and a combined sea ice age and type product. The document is structured as follows:

- Section 1 introduces this document.
- Section 2 provides background.
- Section 3 describes the sea-ice drift product specifications.
- Section 4 describes the Lagrangian sea-ice age product specifications.
- Section 5 describes the radiometric sea-ice type product specifications.
- Section 6 describes the combined sea-ice age and type product specifications.

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1.3 Applicable Documents

No	Doc. Id	Doc. Title	Date	Issue/ Revision/ Version
AD-1	4000147560/25/I-LR	ESA Contract No.	12/03/2025	NA
AD-2	ESA-EOP-SC-AMT-2024-36	Statement of Work and Annexes and Appendexes	31/07/2024	1.2
AD-3	DTU-ESA-SAGE-CL-001	SAGE Cover Letter	8/11/2024	1.0
AD-4	DTU-ESA-SAGE-TPROP-001	SAGE Technical Proposal	8/11/2024	1.0
AD-5	DTU-ESA-SAGE-IPROP-001	SAGE Implementation Proposal	8/11/2024	1.0
AD-6	DTU-ESA-SAGE-MPROP-001	SAGE Management Proposal	8/11/2024	1.0
AD-7	DTU-ESA-SAGE-FPROP-001	SAGE Financial Proposal	8/11/2024	1.0
AD-8	DTU-ESA-SAGE-CPROP-001	SAGE Contractual Proposal	8/11/2024	1.0
AD-9	DTU-ESA-SAGE-BF-001	SAGE Background and Facilities	8/11/2024	1.0
AD-10	DTU-ESA-SAGE-CV-001	SAGE Curricula Vitae	8/11/2024	1.0

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

2 Background

Both sea ice drift and sea ice age have been identified as two of the seven Essential Climate Variables (ECVs) required to characterize the state of sea ice by the Global Climate Observing System (GCOS; GCOS Implementation Plan 2022). The other sea ice ECVs are concentration, thickness, surface temperature, surface albedo and snow depth on sea ice. Sea ice concentration is the most developed and mature of the ECVs with several established Climate Data Records (CDR) available from various sources that date back to 1978 when the continuous record of space based passive microwave radiometers began. Sea ice thickness and sea ice drift have both progressed since their inclusion as ECVs over a decade ago, however sea ice thickness is largely confined to the 2000s when the field of satellite altimetry developed while the present CDRs for sea ice drift either only extend to 1991 (Lavergne and Down, 2023), or have challenges with temporal consistency prior to the 1990s (NSIDC Polar Pathfinder Sea Ice Motion).

Sea ice age, along with the other three variables, has only recently been added following a strong recommendation from the sea ice community (Lavergne and Kern et al., 2022). Sea ice age is of particular interest as the inherent relationship between sea ice age and thickness (Tschudi et al., 2016) allows it to serve as a long-term proxy for ice thickness and provide insight into the changes occurring within an ice cover beyond just its extent. Additionally, the physical properties of sea ice vary with age, making it critical to distinguish between sea ice types when estimating sea ice thickness from satellite altimetry or navigating through ice-covered waters (Babb and Howell, 2024). Although retrievals of sea-ice age are available today, they vary significantly in formats, definitions, and performances. Additionally, this variable has suffered from limited dedicated R&D activities, hence the disparity in definitions. The two current methods used to define sea ice age are both hampered by limitations in satellite observations during the melt season, the limited CDR of ice drift and the use of an oversimplified Lagrangian tracking scheme. It is the goal of SAGE to extend the CDR of ice drift and advance our collective understanding of sea ice age and the products that describe sea ice age in the polar ice packs.

In this PSD, we review the method that we will use for observing sea ice drift, the two methods for observing sea ice age, and the combined sea ice age product that will blend the two approaches to overcome their respective limitations. Each section contains a brief overview of the product, background on its methodology and the anticipated specification of the resulting product.

3 Sea-ice drift product

The sea-ice drift (SID) data prepared by CCI SAGE has a specific set of requirements that do not stem from the consultation conducted in the SAGE project. Rather, CCI SAGE is set to prepare a back-processing of sea-ice drift for the period 1979-1990 that is consistent (in trends, file content, and format) with the Sea Ice Drift CDR (OSI-455; OSI SAF 2022) that was prepared and released by the EUMETSAT Ocean and Sea Ice Satellite Application Facility (OSI SAF) for the period 1991-2020. The main objective of the back-extension is to provide input data for the Lagrangian Sea Ice Age production in SAGE (see below), and also to be used in correction schemes implemented by the Sea Ice Type retrievals in SAGE. Additionally, this back-extension of the drift CDR will also be of great interest for the sea ice community at large.

3.1 SID overview

SID products generally provide the two components of the sea-ice drift vectors (dX and dY) on polar grids. Auxiliary data such as measurement uncertainties and processing status flags are required information in the product files. In case of the EUMETSAT OSI SAF sea-ice drift CDR, the drift vectors represent the 24h net Lagrangian displacement from 12 utc (to 12 utc the next day).

3.2 Background on product generation

The processing of the EUMETSAT OSI SAF sea-ice drift CDR is introduced in Lavergne and Down (2023) and in the user documentation accessible from the OSI SAF webpage (https://osi-saf.eumetsat.int/products/osi-455). The core of the processing is a motion tracking algorithm, the Continuous Maximum Cross-Correlation (CMCC) described in Lavergne et al. (2010). The CMCC is applied on pairs of daily averaged brightness temperature maps from passive microwave missions such as SSM/I (85 GHz channels), SSMIS (91 GHz channels), AMSR-E (36.5 GHz channels) and AMSR2 (36.5 GHz channels). During summer, surface melt and atmospheric opacity challenge the retrieval of sea-ice drift from passive microwave imagery, and the CDR rather employs a free-drift model driven by ERA5 winds. This gap-filling during summer and occasional data gaps proves critical for the later computation of sea ice age.

3.3 Detailed SID product specifications

The SID back-extension prepared in CCI SAGE will have the same characteristics as the OSI SAF SID CDR OSI-455, except for the temporal coverage and the satellite data used. These specifications are compliant with the requirements listed in the URD.

- Processing level : L3+L4
- Satellite input : SMMR and SSM/I F08 from CM SAF FCDR R4
- Other input : NWP outputs (Copernicus C3S ERA5)
- Temporal extent : 1979 - 1990
- Temporal sampling : 24 h (daily product files)
- Central time : Displacement from (D-1)@12:00 to D@12:00
- Spatial coverage : Global (two polar products per day)
- Grid / Projection : EASE2 Polar (EPSG 6931 for NH and 6932 for SH)
- Spatial sampling : 75 km
- File Formats : NetCDF4 using the CF and ACDD conventions
- Characteristics & methods : Single and multi sensor analysis. Displacement after 24 hours in km.
- Total estimated data volume (two hemispheres): ~30 GB
- Compliance with CCI Data Standards

The variables in the netCDF files will be:

- Lambert_Azimuthal_Equal_Area : definition of the projection / CRS
- time, time_bnds : definition of the date/time for the product file
- xc, yc, lat, lon : definition of the geographical grid

- t0, t1 : the start and end time of the drift vectors (spatially varying)
- dX, dY, lon1, lat1 : the drift vectors
- status_flag, uncert_dX_and_dY : processing flags and uncertainties of the drift vectors.

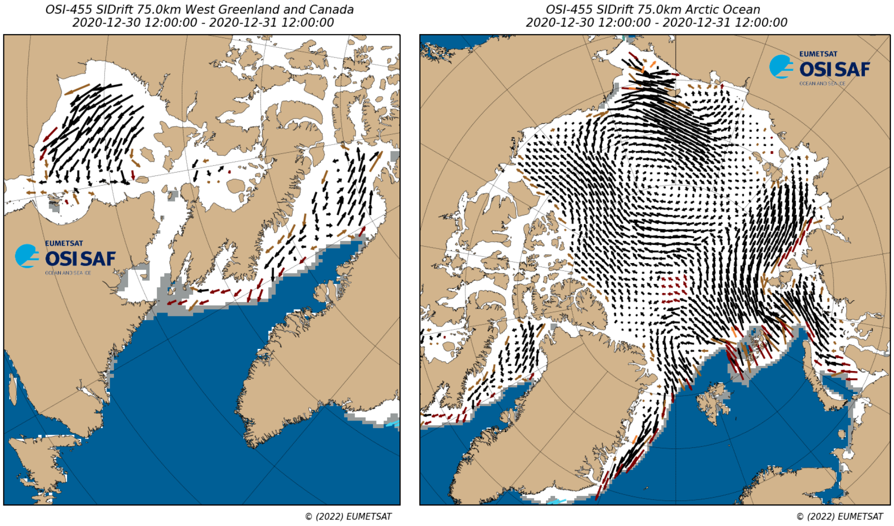

***Fig 1**: Example coverage of the OSI SAF sea-ice drift CDR in the Northern Hemisphere (there is one netCDF product file for the whole NH, that is plotted with two different regional zooms for visualization purposes).*

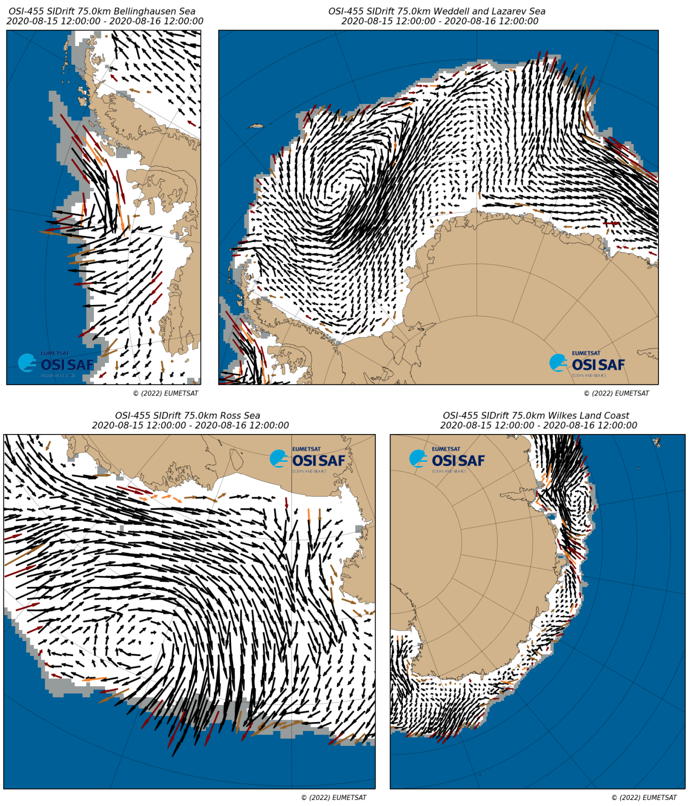

***Fig 2**: Example coverage of the OSI SAF sea-ice drift CDR in the Southern Hemisphere (there is one netCDF product file for the whole SH, that is plotted with four different regional zooms for visualization purposes). Note: not the same date as in the figure above.*

4 Lagrangian Sea-ice age product

The sea-ice age (SIAge) product generated in SAGE is a back-extension of the SIAge product produced previously (Korosov et al., 2025), featuring an improved algorithm and expanded spatial coverage to include more regions in the Arctic and Antarctica.

4.1 SIAge product overview

The SIAge product provides spatial fields with concentrations of ice of different ages, along with associated uncertainties. The dataset is based on a novel Lagrangian advection scheme that is derived from satellite observations of sea ice concentration and drift, and represents fractional age classes per grid cell. The record captures the spatial and temporal evolution of first- to sixth-year ice, including uncertainty estimates that account for both sea ice concentration and drift uncertainties.

The dataset is derived using a novel Lagrangian advection algorithm applied to a triangular mesh. Sea ice age fields are initialised each autumn, when the ice extent reaches its annual minimum and all remaining ice is assumed to be multi-year. The subsequent evolution of the ice age is computed by advecting this initial field using daily satellite-derived sea ice drift vectors, while accounting for deformation and melt based on satellite-derived sea-ice concentration. This approach enables us to reconstruct the continuous age distribution of sea ice in both space and time.

In addition to yearly fractions of sea ice, a daily ice age is computed using a counter, which is initialised upon the freezing of ice (when concentration exceeds a threshold) and is incremented every day until the ice melts. The counter-based age reflects the maximum age of sea ice in the advected element.

4.2 Background on product generation

We compute sea ice age from ice concentration and drift products. A pan-Arctic field of concentration is taken from satellite observations at the end of the melt season, when the ice extent is minimal, and all remaining ice is assumed to be multi-year ice (C_{MY}) since it has survived at least one melting season. The C_{MY} field is repetitively advected (morphed) using daily satellite-derived sea ice drift fields. Changes of concentration due to ice deformation or melting are accounted for during the advection process. Some time after the initialisation of the MYI field advection, the advected field represents the concentration of MYI, which is lower than the total observed concentration (C_{TOT}) and is denoted as C_{A0} (i.e., advected for less than one year). The difference between the total and advected fields yields the concentration of the first-year ice: $C_{1Y} = C_{TOT} - C_{A0}$.

One year after the initialisation, the advected field represents the concentration of sea ice which is at least two years old and is denoted C_{A1} (advected for one year). At that time, the total observed concentration again reaches a minimum, representing the multi-year ice concentration. C_{MY} has higher values than the advected C_{A1} as it also contains a fraction of the second-year ice (older than one year and younger than two years): $C_{2Y} = C_{MY} - C_{A1}$.

This workflow is repeated, and the ice age fraction can be computed using a generic formula $C_{NY} = C_{AN} - C_{A(N+1)}$, where N is an integer number of years of advection of the multi-year ice concentration field.

4.3 Detailed SIAge product specifications

The SIAge back-extension prepared in CCI SAGE will have similar characteristics as the SIAge product, except for the temporal and spatial coverage and the satellite data used. These specifications are compliant with the requirements listed in the URD.

- Processing level : L4
- Input data : SID CDR derived in the SAGE project; OSI SAF Global SID CDR; OSI SAF Global Sea Ice Concentration CDR & interim CDR, release 3

- Temporal extent : 1979 - 2025
- Temporal sampling : 24 h (daily product files)
- Central time : Displacement from (D-1)@12:00 to D@12:00
- Spatial coverage : Global (two polar products per day)
- Grid / Projection : EASE2 Polar (EPSG 6931 for NH and 6932 for SH)
- Spatial sampling : 50 km [TBD]
- File Formats : NetCDF4 using the CF and ACDD conventions
- Methods : Lagrangian advection of a triangular mesh. Counter of the oldest age.
- Characteristics : Distribution of concentration of ice of different ages in each pixel and a maximum age of ice.
- Data volume (two hemispheres): ~30 GB.
- Compliance with CCI data standards

The variables in the netCDF files will be:

- Lambert_Azimuthal_Equal_Area : definition of the projection / CRS
- time, time_bnds : definition of the date/time for the product file
- xc, yc, lat, lon : definition of the geographical grid
- conc_1yi, conc_2yi, conc_3yi, conc_4yi, conc_5yi, conc_6yi, conc_6yi : concentrations of ice of different ages;
- sea_ice_age : weighted average of sea ice age [years];
- Sea_ice_age_uncertainty : Uncertainty in sea ice age computed based on observational and model errors.
- sea_ice_age_max : counter-based age of sea ice [days]
- status_flag : processing flags.

5 Microwave-interpreted Sea-ice type product

5.1 SIType product overview

The sea-ice type (SIType) product provides a categorical description of the sea-ice cover, distinguishing, as a minimum, between first-year ice (FYI; ice that has formed during winter freezing) and multi-year ice (MYI; ice that has survived at least one summer melt). Additional classes may be included in the mapping, e.g., second-year ice or young ice, depending on user requirements. These sea-ice types, or “aging states”, are physically and climatically meaningful categories that reflect the history, strength, salinity, thickness, roughness, and thermodynamic properties of the ice, and therefore provide information essential for understanding the state and evolution of the polar ice pack. Tracking changes in FYI/MYI distribution is critical for detecting shifts in sea-ice regime and resilience, and is relevant for climate studies, ecosystem modelling, and risk assessment for navigation.

SIType is represented not as a continuous physical unit but as discrete age-related classes identifiable by their electromagnetic characteristics. These classes are typically FYI, MYI, and sometimes a third class, such as Young ice (YI). In each grid cell, the classes are expressed as percentages, either in terms of areal concentration or the probability of appearance of the class. Note that the age-related classes in SIType will not cover the same level of details in years as the SIAge; instead, MYI covers several ages over 1 or 2 years, while the SIType classes of YI and FYI can represent the SIAge of 1 year. The final class structure and representation will be refined based on user requirements and consistency with SIAge.

In SAGE, the SIType product will be provided for both the Arctic and Antarctic, supporting the generation of consistent global climate data records.

5.2 Background on product generation

Sea-ice type has traditionally been retrieved from passive microwave (PMW) brightness temperatures and scatterometer (SCAT) backscatter by classifying pixels into first-year ice (FYI) and multi-year ice (MYI), and occasionally second-year ice (SYI) or young ice. Several mature Arctic climate data records exist, including the PMW-based C3S sea-ice type CDR (Aaboe et al, 2023), the multisensor MYI concentration product from the University of Bremen (Ye et al., 2016a and 2016b), and the SCAT-based sea-ice type product from KNMI (Belmonte Rivas et al., 2018). These form the primary heritage for SAGE. In contrast, Antarctic sea-ice type products are less developed due to different ice formation processes, higher ice mobility, the prevalence of pancake ice, and heavy snow loading, which favors snow-ice formation, all of which reduce separability between FYI and MYI. As a result, existing Antarctic sea ice type products (C3S, University of Bremen and OSI SAF) are less consistent and have higher uncertainty. However, MYI is generally confined to coastal landfast ice and the Weddell Sea in the Antarctic, with a majority of the sea ice cover being FYI.

C3S and OSI SAF products use Bayesian classification, combining multi-frequency PMW and/or SCAT features to retrieve type probabilities of FYI and MYI. The University of Bremen product is based on the Environment Canada Ice Concentration Extractor (ECICE; Shokr et al., 2008), which retrieves partial concentrations of different ice types by minimizing the difference between observed and modelled radiometric values. Bayesian, ECICE, and threshold-based approaches (e.g. KNMI) each rely on representative training samples, backscatter or brightness-temperature histograms, and external references such as SAR or ice charts to define tie points, thresholds, or class distributions.

All microwave classification methods perform best during winter and freeze-up, when physical contrasts between ice types are strong. However, they become unreliable during summer, when surface melt and snow wetness mask emissivity and backscatter differences, making classification based solely on microwave information impossible. Misclassifications can also occur outside summer, due to warm-air intrusions, snow wetness, ridging, or metamorphism. To reduce these errors, several algorithms implement correction schemes based on temperature information (Ye et al., 2016a) and/or sea-ice drift constraints (Ye et al., 2016b), which substantially improve the reliability of MYI estimates for climate applications.

5.3 Detailed SIType product specifications

The product specifications of the SIType products prepared in SAGE will be determined during the intercomparison study and will depend on the final retrieval setup. These specifications are compliant with the requirements listed in the URD. Expected specifications are as follows:

- Processing level: L4.
- Satellite input: PMW (SMMR, SSM/I, SSMIS, AMSR-E, AMSR2) and SCAT (QuikSCAT, ASCAT).
- Other input: NWP outputs (Copernicus C3S ERA5) and other sea-ice products (concentration, drift).
- Temporal extent: 1978 October to present is the longest possible CDR based on satellite data.
- Temporal sampling: 24 h (daily product files).
- Central time: 12:00.
- Spatial coverage: Global (two polar products per day).
- Grid / Projection: EASE2 Polar (EPSG 6931 for NH and 6932 for SH).
- Spatial grid sampling: 25 km (TBD).
- File Formats: NetCDF4 using the CF and ACDD conventions.
- Characteristics & methods: Single and multi-sensor analysis (TBD).
- Data volume (two hemispheres): ~30 GB.
- Compliance with CCI data standards.

The variables in the netCDF files will be:

- Lambert_Azimuthal_Equal_Area: definition of the projection / CRS
- time, time_bnds: definition of the date/time for the product file
- xc, yc, lat, lon: definition of the geographical grid
- sea_ice_classification: distribution of the age categories. Unit (TBD)
- status_flag, uncertainty: processing flags and uncertainty estimates.

6 Combined sea-ice age and type product

6.1 Combined product overview

Both standalone sea-ice age and type products have their weak sides: the Lagrangian ice age is produced from relatively coarse resolution ice drift and is, therefore, spatially smooth, i.e., the actual spatial resolution is not very high. At the same time, the ice type derived from passive-microwave or scatterometer data provides only one value per pixel (the dominant ice type) and it distinguishes only two to three stages of ice development. Additionally, it may suffer from atmospheric contamination of the signal and the presence of liquid water at the surface of the ice during the melt season or even short melt events during the growth season, which may lead to misclassification of ice type. The motivation for developing the combined sea-ice age and type product is to merge the strongest features of both approaches: the higher resolution of the radiometric product and the stability/informativeness and year-round applicability of the Lagrangian tracking.

Several approaches to combine ice age and type will be tested during the SAGE project, and the final product specification will be provided at a later stage. Here we list several tentative approaches that require further investigation.

6.2 Tentative approaches for the combination of sea-ice age and type in one product

In the first approach, only radiometric data (PMW and SCAT) will be on the input. A machine-learning (ML) model will be trained with the data from the Lagrangian tracking as the target. Several ML model architectures will be tested:

- Pixel-by-pixel classification or regression using linear regression, support vector machine, random forest, multilayer perceptron, etc.;
- Image-by-image classification or regression using convolutional neural networks, vision transformers, diffusion models, etc.

In the second approach, the radiometric data will be combined with Lagrangian tracking on the input to a machine learning model. The combination can be performed in two different ways:

- Lagrangian advection of the radiometric data itself, and stacking of the drift-corrected observations over several days. Then an ML model can be trained using stacked radiometric data as the input and Lagrangian age data as the target. The advantage of this method is the reduced impact of atmospheric noise and, potentially, the melting events.
- Both the Lagrangian age and the radiometric data can be fed into an ML model. Then it needs to be trained on independent ice age observations to avoid overfitting.

In the third approach, we will assimilate the radiometric data into the data-driven Lagrangian model of sea ice. This model is driven by observations of ice drift and concentration (same as we used for computing SIAge). It simulates the spatial fields of multi-year ice after N ages of advection (as described in Section 4). A forward operator can be constructed using an ML model to predict brightness temperatures and backscatter. The operator can be inverted using a 3DVAR assimilation procedure with updates of the advected MYI fields. Assimilation with minor updates of the state can be performed daily because the data-driven model operates at high speed.

Finally, the Lagrangian ice age can be used only for constraining the outputs of the radiometric ice type algorithm listed in Section 5. Concentrations of ice of different ages can serve as prior probabilities for the Bayesian classification of ice types using PMW and SCAT data.

The specifications below are compliant with the requirements listed in the URD.

6.3 Tentative combined product specifications

- Processing level: L4.
- Satellite input: PMW (SMMR, SSM/I, SSMIS, AMSR-E, AMSR2) and SCAT (QuikSCAT, ASCAT).

- Other input: Other sea-ice products: concentration, drift, Lagrangian age.
- Temporal extent: 1978 October to present is the longest possible CDR based on satellite data.
- Temporal sampling: 24 h (daily product files).
- Central time: 12:00.
- Spatial coverage: Global (two polar products per day).
- Grid / Projection: EASE2 Polar (EPSG 6931 for NH and 6932 for SH).
- Spatial grid sampling: 25 km (TBD).
- File Formats: NetCDF4 using the CF and ACDD conventions.
- Characteristics & methods: Single and multi-sensor analysis (TBD).
- Data volume (two hemispheres): 30 GB.
- Compliance with CCI data standards

The variables in the netCDF files will be:

- Lambert_Azimuthal_Equal_Area: definition of the projection / CRS
- time, time_bnds: definition of the date/time for the product file
- xc, yc, lat, lon: definition of the geographical grid
- conc_1yi, conc_2yi, conc_3yi, conc_4yi, conc_5yi, conc_6yi, conc_6yi : concentrations of ice of different ages;
- status_flag, uncertainty: processing flags and uncertainty estimates.

7 References

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