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

# SAGE CCI

## *(Sea Ice Age and Drift)*

User Requirements Document (URD)


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# 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) |

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|---|---|
| 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 |

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| 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 Applicable Document

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

The purpose of this document is to provide detailed specifications of the user requirements for the sea-ice Essential Climate Variable (ECV), focusing on sea-ice age and drift, from climate science communities, stakeholders and climate services, including also specific requirements according to different applications. The Global Climate Observing System (GCOS) provides the high-level user requirements for the sea-ice ECV, and these are discussed below in Section 3.1. The ECV products in the SAGE project are:

- Sea-ice drift (SID) - gridded data from passive microwave
- Sea-ice age (SIAge) - derived from microwave remote sensing data combined with SID and sea-ice concentration (SIC)

To effectively characterize the state of sea ice, the GCOS Implementation Plan (2022) outlines seven specific variables: concentration, thickness, drift, age, surface temperature, surface albedo, and snow depth on sea ice. Among the variables related to sea ice, the satellite-based product for sea-ice concentration is the most developed and mature. It encompasses both hemispheres, with several established Climate Data Records (CDR) from various sources, such as e.g. the European Space Agency's (ESA) Climate Change Initiative (CCI) and the European Organization for the Exploration of Meteorological Satellites' (EUMETSAT) Ocean and Sea Ice Satellite Application Facility (OSI SAF). Retrieving sea-ice thickness and drift presents more challenges. However, since GCOS's inclusion of thickness and drift alongside concentration in the sea-ice ECV for over a decade, extensive research and development (R&D) on these variables has been conducted, including efforts by ESA CCI. To improve the sea-ice thickness retrieval, it is crucial to enhance observations, such as monitoring the sea-ice age, which serves as a proxy for thickness and density. Only in 2022, sea-ice age was included in the Sea Ice ECV [GCOS Implementation Plan, 2022] following a strong recommendation from the sea-ice community [Lavergne and Kern et al., 2022]. Although retrievals of the sea-ice age are already available today, they vary significantly in formats, definitions, and attributes or specifications. Additionally, this variable has suffered from limited dedicated R&D activities compared to other variables. The satellite-based retrieval of sea-ice age relies on good and independent sea-ice drift products. Currently, there are too few sustained sea-ice drift CDRs that cover both hemispheres and the entire satellite era since the late 1970s, and they are often provided at coarse resolution.

In preparation for this URD, we have organized a day-long webinar ("daybinar") on September 19th, 2025 (https://climate.esa.int/en/projects/sea-ice-age-and-drift-sage/next-events/news/sage-webinar/). The daybinar, with the title "Beyond Sea Ice Area: Exploring Alternative Diagnostics for Assessing Polar Climate Change" registered a total of 195 people, and recorded a peak attendance of 79 simultaneous participants in the late morning session (Fig. 1 below).

This event had three main objectives:

1. To review the current state of sea-ice ECV products, with a focus on derived metrics that go beyond the traditional sea-ice area and extent;
2. To refine the scientific and technical requirements for a new sea-ice age product to be developed within the SAGE project but benefiting from the community's input;
3. To explore broader issues around polar data, including their robustness and relevance in a changing and increasingly turbulent world.

The daybinar featured invited presentations from leading experts in their field, as well as open discussion sessions. During the meeting, the SAGE members took notes that are used throughout this document to formulate the user requirements. In parallel, a 10-questions survey was organized to collect feedback from the participants (*N*=46). The results of this survey are appended as an Annex to this User Requirement Document [AD11] and have also largely fed the development of the present document. The sample of responses received for this survey represents the diversity of the sea-ice community well, with a majority of experts on remote sensing, followed by model developers and users.

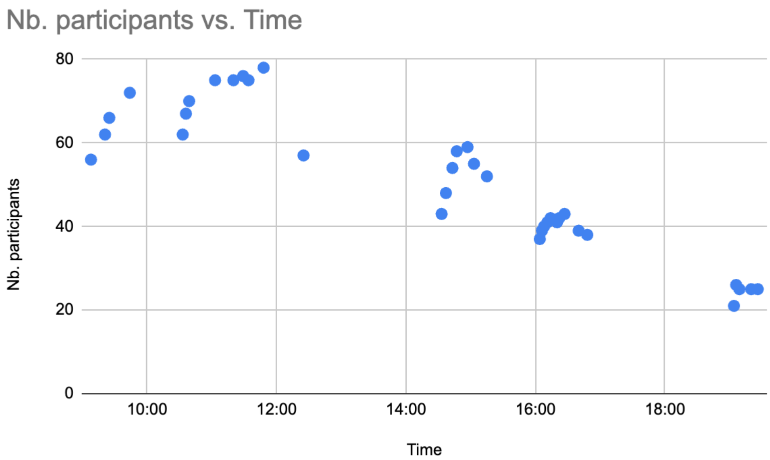


**Fig. 1. Instantaneous number of participants to the SAGE daybinar organized on September 19th, 2025 (times are CEST).**

### 1.2 Document Structures

This document is structured as follows:

- Section 1 introduces this document.
- Section 2 describes the background, including the user groups typology.
- Section 3 analyses the user requirements.
- Section 4 discusses the question of sea ice age definition.
- Section 5 concludes the document and provides an overview of user requirements.

### 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 |
| AD-11 | | AD11_ResultsSurveyDaybinar | 1/10/2025 | 1.0 |

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

# 2 Background

## 2.1 The need for sea-ice ECV products

**Sea ice monitoring:** There is worldwide focus on understanding the ongoing decline of Arctic sea ice extent, thickness and concentration, and the processes controlling their variability and long-term trends under climate change [IPCC (2021)]. Evidence of sustained Arctic sea ice loss and regional Antarctic sea ice changes punctuated by rapid sub-decadal shifts, shows the urgent need to understand the consequences of present and future climate changes on sea ice evolution and to predict its future contribution to ocean–atmosphere interactions, global circulation, and regional climate.

**Cryospheric and polar research:** In recent years, the rapid thinning and retreat of Arctic summer sea ice has spurred significant interest from both the scientific community and the general public, as these changes are key indicators of a warming climate. A major uncertainty in projecting future polar climate is, however, that the processes controlling the seasonal, interannual and interdecadal variability of sea ice are not fully understood. Monitoring these changes at high temporal and spatial resolution is needed to understand the sea ice cover variability and to disentangle effects from various atmospheric and oceanic drivers. New ECV products based on satellite missions provide higher spatial and temporal resolution than previously possible, and changes on weekly timescales and even daily timescales can now be resolved.

**Sea ice and climate modelling:** Long time series of sea ice ECVs can be used to constrain, evaluate and calibrate sea-ice models and, eventually, to intercompare them. Previous Coupled Model Intercomparison Project (CMIP) assessments (e.g., SIMIP community, 2020) have demonstrated how such products are central to the process of assessing the realism of sea ice models. Besides, in focused studies of processes controlling sea ice variability and change, it is necessary to have access to high-resolution observations (e.g., when developing new rheologies or floe size distribution theories).

From that point of view, the CCI programme has gradually become a reliable data provider of satellite-based sea ice products and therefore fills a gap in systematically providing remote sensing data products to monitor the polar sea ice cover.

## 2.2 The specific need for sea ice ECV *age and drift* products

Until recently, the state and evolution of sea ice have been primarily characterised by two ECV products: sea-ice concentration and thickness. These two products provide a first-order perspective on the evolution of sea-ice extent, area and volume, offering insight into broader trends and changes in polar regions. However, these two ECV products alone do not capture the full complexity of the processes influencing sea ice, and while the record of concentration covers the full satellite era since the late 1970s, the record of ice thickness is confined to the 2000s. Indeed sea-ice concentration and thickness provide instantaneous snapshots of the current sea-ice state and its historical context, but fall short of capturing the underlying history or the processes leading to this current state. By contrast, the sea-ice age embodies the history of dynamic and thermodynamic forces that have shaped the ice. Since a vast majority of sea ice is mobile, sea-ice age is closely tied to sea-ice drift, and thus serves as a record of the forces encountered along their travel pathways. Producing an improved continuous record of both sea-ice drift and age therefore opens a new perspective on interpreting the sea-ice state, which is complementary to sea-ice concentration and thickness, as they can reveal the history of the sea-ice state at any time and further highlight the changes taking place in the polar ice packs.

## 2.3 Users of sea ice ECVs in the context of sea ice drift and age products.

Based on the survey (*N*=46 unique participants) [AD11] and the list of registered participants to the daybinar, we have identified five main classes of users.

**Short-term / Operational Users:** These are users needing near-real-time or high-frequency information (hours to days) for navigation, forecasting, or assimilation into operational models. Their main activities include forecasting, operational monitoring, data assimilation, safety of navigation and they operate with typical spatial scales of meters to ~10 km. The variables typically requested are sea ice thickness, drift, deformation, ridges, snow depth; and occasionally the ice age distribution. These users expect high temporal resolution (daily or even sub-daily), fine spatial resolution (1–10 km), clear file formats and minimal pre-processing.

**Process-oriented users:** These are users focusing on understanding sea ice physics and processes at short-term to intermediate time scales (weeks to seasons). Their main activities are remote sensing analysis, field campaigns, algorithm development and they operate with typical spatial scales of meters to ~10's of km. The variables typically requested are sea ice thickness, drift, freeboard, snow depth, melt ponds, roughness, deformation and age. These users consider that weekly resolution is sufficient (but emphasize that daily can be a plus), and need detailed metadata to understand the meaning of the product. Their preferred format is NetCDF and they expect CF-compliance. Pixel-wise uncertainty is preferred if available.

**Climate model users:** These are users researching seasonal to decadal variability and trends (including CMIP comparisons and climate data record building). Their main activities are model development and evaluation and reanalyses production, and they operate with typical spatial scales of 10–100 km or more. The variables typically requested are sea ice concentration, age, extent, thickness, drift, snow depth, deformation, and surface fluxes. These users consider that monthly resolution is sufficient (but weekly can be a plus) and need long, consistent time series produced with stable algorithms to avoid artificial/spurious trends. They need a clear and unambiguous definition of "age" to ensure easy model-observation comparisons. Uncertainty and error estimates are needed and data should be gridded or already provided on common grids (EASE2, polar stereographic).

**Sea ice model and data assimilation developers:** These are users developing or using numerical physical models, and also blending observations and simulations in the context of data assimilation. These activities include physics-aware AI. Depending on the context, they work on spatial scales ranging from meters to several hundreds of km. They welcome ice age as a new sea ice ECV product but also expect ancillary variables (drift, concentration, snow depth and deformation history) to provide some context. They expect well-documented metadata and, importantly, uncertainty estimates for assimilation.

**Algorithm / Product Developers:** These are users producing new sea ice datasets or testing algorithms. Their main activities are remote sensing, CDR generation, and product validation. They operate on time scales from meters to 100 km or more depending on the instrument. They expect to have access to full metadata and input assumptions.

# 3 Analysis of requirements

## 3.1 GCOS requirements

The Global Climate Observing System (GCOS, 2025) represents the scientific and technical requirements of the Global Climate Observing System on behalf of the United Nations Framework Convention on Climate Change (UNFCCC) and Intergovernmental Panel on Climate Change (IPCC). According to GCOS (https://gcos.wmo.int/site/global-climate-observing-system-gcos/essential-climate-variables/sea-ice), efforts should be made to improve satellite observations of sea-ice thickness, which also requires improving observing snow-depth and sea-ice age (proxy for sea-ice thickness and density).

The ECV requirements for sea-ice drift and age are listed in the two tables below. In these tables and in the following:

- Goal (G) is "an ideal requirement above which further improvements are not necessary";
- Breakthrough (B) is "an intermediate level between threshold and goal which, if achieved, would result in a significant improvement for the targeted application". The breakthrough value may also indicate the level at which specified uses within climate monitoring become possible. It may be appropriate to have different breakthrough values for different uses;
- Threshold (T) is "the minimum requirement to be met to ensure that data are useful".

***Table 1: GCOS requirements for sea ice drift.***

| **Sea ice drift** | | *Goal* | *Breakthrough* | *Threshold* |
|---|---|---|---|---|
| Horizontal resolution | km | 1 | 5-25 | 50 |
| Temporal resolution | d | <1 | 1-7 | 30 |
| Timeliness | d | 1-2 | 7 | 30 |
| Required measurement uncertainty | km/d | 0.25 | 3 | 10 |
| Stability | km/decade | | | |

***Table 2: GCOS requirements for sea ice age.***

| **Sea ice age** | | *Goal* | *Breakthrough* | *Threshold* |
|---|---|---|---|---|
| Horizontal resolution | km | 1 | 5-25 | 50 |
| Temporal resolution | d | <1 | 1-7 | 30 |
| Timeliness | d | 1-2 | 7 | 30 |
| Required measurement uncertainty | d | 7 | 182 | >365 |
| Stability | Not set by GCOS Implementation Plan | | | |

## 3.2 CCI+ Sea Ice ECV requirements

Recently, a User Requirements Document (URD) for the Sea Ice ECV within CCI+ PHASE 2 - NEW R&D ON CCI ECVs, was published [Kern, Notz and Ricker (2024); AD12]. Building on, but refining the GCOS requirements (Section 3.1), this document "reflects the outcome of dedicated interviews with users, including those actively involved in the preparation and leadership of the Sea-ice Model Intercomparison Project (SIMIP) that is carried out as part of the seventh phase of the Coupled Model Intercomparison Project (CMIP7)". These interview-based surveys revealed a growing interest from the community in integrated variables such as sea-ice area and sea-ice volume, a growing need for consistent, multi-variable products such as sea-ice sensitivity, and a growing need for estimates of small-scale variability.

Also, a user workshop for the CCI+ Sea Ice ECV held in conjunction with the CMIP6 Sea Ice MIP (SIMIP) community [Notz and Jahn, 2025; AD13] revealed the challenges of model-data comparison, and argued for example that developing "emulators and snow on sea ice, first year versus multi-year sea ice fraction is arguably more important than a more detailed ice-age product, and likely more robust to differences between how models and observations trace ice age". These discussions fed the preparation for the present document.

## 3.3 Statement of Work (SoW) requirements.

The SoW [AD2] states that the project aims to "develop additional Climate Data Records (CDRs) from space that are not yet present in the current ESA CCI Essential Climate Variable portfolio". It also states that the objective of this activity is to place "strong emphasis on intercomparison of ESA CCI/CLIMATE-SPACE ECV products to establish the best algorithm for that particular ECV product."

The SoW has cardinal requirements (CR) relevant to the user requirement analysis. Several of these requirements most relevant for the URD, are listed here together with a brief description of how we will address them in this project:

*CR-1 Develop and validate algorithms to approach the GCOS ECV requirements, and meet the wider requirements of the Climate Community (i.e. long term, consistent, stable, uncertainty-characterized) for global satellite data products from multi-sensor data archives.*

- The user requirements are compliant with GCOS requirements
- Additional user requirements are taken into account based on the survey conducted in September 2025

*CR-2 Produce, validate and deliver consistent time series of prototype satellite ECV data products for climate science. The quantity of prototype products to be delivered shall be at least sufficient to evaluate the quality of the products against the climate-users' requirements.*

- The focus will be placed on climate time scales in priority, with secondary focus on shorter (weather) time scales.
- A strong link with the climate community is ensured through the sea ice MIP project (SIMIP), of which two members of SAGE are active members.

*CR-4 Generate and fully document a production system capable of processing and reprocessing the data in CR-2, with the aim of supporting transfer to operational activities outside CCI.*

- SAGE plans to provide a free and unlimited licence for using the ECV data to ESA and all users, cooperate with ESA and its contractors to transfer copies of the ECV data to the CCI, ensure Open Data Portal for publication, provide public information about the project and document deliverables for publication, assist in the integration of the ECV data products with the CCI Toolbox software.

## 3.4 User-specific requirements collected during the survey

Other remarks were made during the survey conducted between 19th September and 1st of October, 2025 [AD11]

- All users emphasize the need for easy-download protocols (FTP, wget-friendly URLs, APIs, depending on the respondent’s age and seniority) and the use of state-of-the-art data formats (such as NetCDF).
- The preferred grid seems to be EASE2 (EPSG 6931 in the Northern Hemisphere and 6932 in the Southern Hemisphere) but other grids would be usable.
- A user is suggesting to provide examples codes/notebooks to learn how to load/use the data.
- Users stress the need to cover summer months.
- Several users stressed the need to have an ice age distribution (not just an ice age value per grid cell), especially if the resolution is coarse (> 1 km). Many users argued that 100 km resolution would be insufficient because for example, in Antarctica, multi-year fast ice spans at most 100 km.

# 4 The question of sea ice age definition

We now review the question of the sea ice age definition.

## 4.1 SAGE consortium considerations

The SAGE team members exchanged several documents and e-mails around this question of the sea-ice age definition. As of today, there is a coexistence of two definitions of sea ice age, named hereafter "Age1" and "Age2" for convenience (note that the numbers 1 and 2 here have nothing to do with the concept of first-year vs second-year ice, these are simply labels to distinguish between the two definitions).

- "Age1" is defined as the number of days (so, related to SI units) elapsed since ice formation.
- "Age2" is a two-number sequence (*s*,*d*) where *s* is the integer *(s=0, 1, 2, …)* representing the number of melting seasons survived by the parcel, and *d* is the additional number of days elapsed since the start of the most recent freezing season. Note that *s=0* corresponds to "first-year ice", while "s ≥ 1" corresponds to multi-year ice. This second definition implies that a choice must be made on the meaning of the "start of the freezing season".

The "Age1" definition is the one that is largely accepted in the climate modelling community. A passive tracer is deployed in the sea ice model and is advected at each timestep while the tracer's value is incremented by one time step. Methodological choices remain open, such as whether to use area-based or volume-based tracers, whether to apply thresholds to initiate the tracers, and whether to differentiate the tracers per type/class of ice. The SIMIP data request for CMIP7 describes the "siage" variable as: "Age of sea ice since its formation in open water." This "Age1" definition is less suited for observations because it is not possible to deploy tracers on the real sea ice. However, in principle, it should be possible to use Lagrangian tracking algorithms based on satellite sea-ice drift and concentration CDRs to prepare an observational Age1-type sea-ice age CDR, that could then be compared directly to model tracers

The "Age2" definition is the one used in the observational community. In practice, it has been common to neglect the day component (*d*) and classify ice simply by an integer number of years (*s*) since the start of the freezing season (i.e., "*first-year*" ice instead of "*100 days-old since the start of the freezing season*"; or "*second-year*" ice instead of "*one-year and 200 days old since the start of the freezing season*"). There are two main remote sensing approaches to derive Age2: Lagrangian tracking in fields of ice motion and classification based on radiometric or backscatter mapping. A key objective of CCI SAGE is to advance and unite these two observational methodologies into an advanced CDR of the "Age2" quantity.

In both definitions of Age1 and Age2, "age" tracks the time since ice formation, but the difference lies in the way time duration is measured –specifically, whether the occurrence of a melt season increments resets the time counter or not.

Importantly, we note that a mapping between the two definitions is in theory possible, provided we are given the date of the freeze-up (which can be year-dependent and have a spatial dependence).

## 4.2 User feedback

The last question of the survey [AD11] was: *"Finally, what would be your definition of sea-ice age? This definition should be independent of the methodological context (modelling, observations, ...) but inherent to a sea-ice property".* We received 27 responses for this question, which highlighted the very different perceptions of what "age" really means to everyone. These differing definitions reflect different perspectives or priorities within the sample of people surveyed for this study. For example, a modeller emphasized that they would use a thermodynamic definition; a remote sensing participant defined age as "the number of seconds since ice formation" and another user responded "the time since it [sea ice] was formed initially"; other users adopted a more categorical or observational definition based on sea ice properties ("perhaps link to salinity, thickness and roughness" or "must reflect ice density").

The daybinar survey shows that most attendees consider the ice age as "time since ice formation" but without specifying the precision or a starting point. Three respondents explicitly mentioned the Age1 definition (days, or seconds, since ice is formed in water without regard to the start of the freezing season). Nine respondents mentioned the Age2 definition (years, number of seasons survived, annual increments, etc). Five respondents linked the ice age to physical properties: density, colour, ridges, salinity, thickness, roughness, etc. Three respondents explicitly mentioned that a statistical representation of the ice age in a grid cell should be provided: mean/max/median or a distribution of ice ages.

### 4.3 Practical aspects

In practice, a piece of ice with a uniform age is, of course, an idealised abstraction. Both numerical models and satellite observations consider patches of sea ice that are at least several square kilometres in size each. Because of the differentiated history of each patch, this mixture comprises ice parcels of different ages. This mixture is continuously changing due to mixing with neighbouring elements and, even more importantly, due to divergence of older ice and formation of younger ice, or convergence of older ice which reduces old ice area. In numerical models, this distribution of age can be tracked by recording the frequency distribution of age per ice class/thickness category. In Lagrangian tracking, this process is represented by keeping the oldest age or providing a distribution of ice ages in each element. In radiometric mapping, the age of the dominant ice (highest concentration) is provided, although some algorithms aim at the fraction of multiyear vs first-year in a grid cell. Finding a unified definition of “ice age” becomes even more complicated as not only the precision and starting point, but also the method to characterise a mixture of ice ages differ between communities and various approaches.

The need to account for the varying ages within a given ice patch was recognized by the participants to the survey: “The relevant part for me are the physical properties, thus the actual age distribution in the grid cell. This would include refreezing at the ice underside and thin ice formation on leads to lower the average ice age.”

### 4.4 Age definition in the context of model-data comparison

The question of definition becomes particularly evident when the task is to compare model output to observations. Recent research [Davy et al., 2025] has shown that a factor of two can exist between the ice age directly diagnosed as a tracer in the model and the ice age derived by applying a Lagrangian tracking algorithm to the model outputs of sea ice drift and concentration. This finding alone suggests that a future sea ice age product should not only rely on a solid definition that is as universal as possible, but should also be accompanied by a clear methodological documentation on how the age was derived.

### 4.5 Existing age nomenclatures

In addition to the two definitions (Age1 and Age2) mentioned above, different communities use various nomenclatures to describe the age of sea ice. For example, the WMO Sea Ice Nomenclature defines the sea ice "stage of development", which relates largely to the aging state of sea ice; some of these are listed in the left column of Table 3 (WMO, 2014). The WMO Nomenclature was created by the national sea ice services with a focus on describing sea ice conditions relevant for tactical navigation. However, the modelling and remote sensing communities that we address in CCI SAGE use different names, as reported in the right part of Table 3.

**Table 3: Comparing the WMO Sea Ice Nomenclature (WMO, 2014) and widely used terminology in the modelling and EO communities addressed by CCI SAGE.**

| Term | WMO Sea Ice Nomenclature Definition | Terminology in wide use in the modelling and EO communities addressed by CCI SAGE. |
|---|---|---|
| Young ice (2.4) | Young ice: Ice in the transition stage between nilas and first-year ice, 10-30 cm in thickness. May be subdivided into grey ice and grey-white ice. | Part of First-year ice |
| First-year ice (2.5) | Sea ice of not more than one winter's growth, developing from young ice; thickness 30 cm - 2 m. May be subdivided into thin first-year ice/white ice, medium first-year ice and thick first-year ice. | First-year ice |
| Old ice (2.6) | Sea ice which has survived at least one summer's melt; typical thickness up to 3m or more. Most topographic features are smoother than on first-year ice. May be subdivided into residual, second-year ice and multi-year ice. | Multi-year ice |
| Residual ice (2.6.1) | First-year ice that has survived the summer’s melt and is now in the new cycle of growth. It is 30 to 180 cm thick depending on the region where it was in summer. After 1 January (in the Southern hemisphere after 1 July), this ice is called second-year ice. | Second-year ice (part of Multi-year ice) |
| Second-year ice (2.6.2) | Old ice which has survived only one summer's melt; typical thickness up to 2.5 m and sometimes more. Because it is thicker than first-year ice, it stands higher out of the water. In contrast to multi-year ice, summer melting produces a regular pattern of numerous small puddles. Bare patches and puddles usually greenish-blue. | Second-year ice (part of Multi-year ice) |
| Multi-year ice (2.6.3) | Old ice up to 3 m or more thick which has survived at least two summers' melt. Hummocks even smoother than in second-year ice, and the ice is almost salt-free. Colour, where bare, is usually blue. Melt pattern consists of large interconnecting irregular puddles and a well-developed drainage system. | 3rd year and older ice (part of Multi-year ice) |

This underlines that the definitions and nomenclature used for sea-ice age characterization are diverse and at times in contradiction between the communities. It will be critical for the CCI SAGE team to clearly define what we report in our products and what nomenclature we use.

# 5 Conclusions

The user requirements for a future sea ice drift and age product have been collected and synthesised from several sources, including a recent survey targeted to the sea-ice community. According to the respondents to this survey, daily resolution would be optimal but weekly could be sufficient for several applications. The majority of users expressed a preference for horizontal resolution of at least 10 km, with several highlighting the added value of 1 km products for coastal, operational or data assimilation purposes. Since sea ice in a given area (or cell) is always a mixture of different types, providing an age distribution per cell would help link sea ice age with other properties such as ice surface roughness. Experts also underline the need to include (as ancillary data) the byproducts of trajectory calculations, such as the number of divergence/convergence events above a certain threshold, the number of experienced storm events, or the number of days spent near coastal areas. Such information would be valuable for examining the relationship between ice age, surface deformation, and the strength of dynamical ice–atmosphere–ocean coupling by the data we are now gathering. Uncertainty information at the grid-point level was considered essential by most participants. The need for metadata and clear, easy-to-access documentation was considered essential by many. NetCDF was the most frequently requested file format, and CF-compliance was strongly encouraged. The EASE2 or polar stereographic grids were the most cited, and there was a demand for easy access to the data through e.g. an FTP or direct file links.

Importantly, discrepancies in the definitions and nomenclature in use in the different communities were identified, and it will be critical for CCI SAGE to clearly define what we report in our product files and what nomenclature we use.

The production of the new sea ice product will take these requirements into account in the product specification document (PSD).

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