Sea Ice CCI+

Norwegian Meteorologic Institute

ESA CCI+ CLIMATE CHANGE INITIATIVE
PHASE 1: NEW R&D ON CCI ECVS

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DTU

Danmarks Meteorologiske Institut

Max-Planck-Institut für Meteorologie

Norwegian Meteorological Institute

The Norwegian Meteorological Institute (METNO)
Henrik Mohns Plass 1

N-0313 Oslo

Norway

Phone: + 47 22 96 30 00

Fax: + 47 22 96 30 50

E-Mail: thomas.lavergne@met.no

http://www.met.no

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Principal Authors

Dirk Notz, Max Planck Institute for Meteorology
Thomas Lavergne, Norwegian Meteorological Institute

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Role	Name	Signature
Written by:	Dirk Notz, T. Lavergne	
Checked by:	T. Lavergne, M.A. Killie	
Approved by:	A. M. Trofaier	

Contents

1 INTRODUCTION

1.1 Purpose

This document is the User Requirements Document for the Sea Ice ECV within CCI+ PHASE 1 - NEW R&D ON CCI ECVs, which is being undertaken by a METNO-led consortium. It builds on the information collected in the User Requirements Document from CCI Phase 1 (May 2012) and CCI Phase 2 (July 2018). This document will be updated throughout the course of the Sea Ice ECV project within CCI+ to reflect new requirements that become apparent throughout the course of this project.

1.2 Scope

The scope of the work is to

1. Outline specific needs of the users of the sea-ice concentration and sea-ice thickness datasets that are developed and improved throughout CCI+ Phase 1.

2. Discuss how these needs will be met by the Sea Ice CCI+ consortium.

3. Obtain assessment of the two sea ice ECVs in CCI+ Phase 1 from the perspective of the climate modelling community, represented by Dirk Notz from the Max Planck Institute for Meteorology.

1.3 Document Status

This is the revised 2nd version of the Sea Ice ECV URD in the CCI+ phase 1 project (2019-2022), prepared for KO+12. Over the next two years, this document will be refined based on additional user input, discussions with CMUG, insights gained from specific workshops, and, where possible, feedback from users of CCI+ test data.

1.4 Applicable Documents

Table 1 below lists the Applicable Documents referred to in this document.

Table 1: Applicable Documents

Document ID	Document referred to
URD Phase I	User Requirement Document of SICCI Phase 1, SICCI-URD-02-122, May 2012
URD Phase II	User Requirement Document of SICCI Phase 2, SICCI-URD-08-15, July 2018

1.5 Acronyms and Abbreviations

The table below lists the acronyms and abbreviations used in this volume.

Table 2: Acronyms and Abbreviations. Acronyms for the deliverable items (URD, etc…) and partner institutions (AWI,..) are not repeated.

Acronym	Meaning
AMSR-E / AMSR2	Advanced Microwave Scanning Radiometer (for EOS / #2)
AOGCM	Arctic Ocean General Climate Model
AR5, AR6	WMO IPCC Assessment Report series
ASAR	Advanced Synthetic Aperture Radar
C3S	EU Copernicus Climate Change Service
CCI	Climate Change Initiative
CDR	Climate Data Record
CMEMS	EU Copernicus Marine Environment Monitoring Service
CMIP5, CMIP6	Coupled Model Intercomparison Project series
CMUG	Climate Modelling User Group
CRG	Climate Research Group
CS-2	ESA's CryoSat-2
DEWG	CCI Data Engineering Working Group
EASE grid	Equal-Area Scalable Earth Grid
ECMWF	European Centre for Medium-Range Weather Forecasts
ECV	Essential Climate Variable
ENVISAT	ESA's Environmental Satellite
EO	Earth Observation
ERS	European Remote Sensing Satellite
ESA	European Space Agency
ESMR	Electrically Scanning Microwave Radiometer
EUMETSAT	European Organization for the Exploitation of Meteorological Satellites
FoV (*alt* FOV)	Field-of-View
FY3	Feng Yun 3
FYI	First Year Ice
GCOS	WMO's Global Climate Observing System
GCW	WMO's Global Cryosphere Watch
ICDR	Interim Climate Data Record
IMB	Ice Mass Balance buoy
IPCC	WMO's Intergovernmental Panel on Climate Change
L1b, L2, L3C, ...	Satellite data processing Level (Level-1b, …)
MERIS	MEdium Resolution Imaging Spectrometer
EPS, EPS-SG	EUMETSAT's Polar System, EPS Second Generation
MIZ	Marginal Ice Zone
MODIS	Moderate Resolution Imaging Spectroradiometer
MWI	MicroWave Imager (EPS-SG)
MWRI	Micro-Wave Radiation Imager (Feng Yun 3)
MYI	Multi-Year Ice
NASA	National Aeronautics and Space Administration
NOAA	US National Oceanic and Atmospheric Administration
NSIDC	US National Snow and Ice Data Centre
OE	Optimal Estimation
OIB	Operation Ice Bridge
OSI SAF	EUMETSAT Ocean and Sea Ice Satellite Application Facility
OWF	Open Water Filter
PMR	Passive Microwave Radiometer
PMW	Passive Microwave
RA	Radar Altimeter
RRDP	Round Robin Data Package

SIC	Sea Ice Concentration
SIT	Sea Ice Thickness
SAR	Synthetic Aperture Radar
SIRAL	Synthetic Aperture Radar (SAR) Interferometer Radar Altimeter
SOA	Service Oriented Architecture
SMMR	Scanning Multichannel Microwave Radiometer
SMOS	Soil Moisture and Ocean Salinity
SSM/I	Special Sensor Microwave/Imager
SSMIS	Special Sensor Microwave Imager/Sounder
ULS	Upward Looking Sonar
WMO	World Meteorological Organisation
WSM	Wide Swath Mode

1.6 Executive Summary

Through a series of detailed interviews and discussions carried out throughout Sea Ice CCI+, we have identified the characteristics and requirements of two different groups of EO-users. We here denote these two groups as "Expert Users" and "Non-expert users".

Expert users have a detailed understanding of EO methods and data handling, and have a specific research interest for the variable at hand. Hence, they can deal with low-level EO-data, including swath data and detailed uncertainty information.

In contrast, non-expert users are not specifically focused on understanding the details of our datasets, and instead often prefer a clean product. They will often not consider the additional uncertainty information and expect the EO data providers to carry out all necessary filtering themselves.

In response to the requirements of these two groups, the EO team of Sea ice CCI+ outlines to which degree they can cater for them both. These replies are then put into context by the climate user group.

2 SUMMARY OF PHASE AND PHASE USER REQUIREMENT SURVEY

2.1 Summary of Phase 1 User Requirement Survey

At the onset of Phase 1 of the Sea Ice CCI, a broad survey was carried out to obtain an overview of the general requirements of the end users of Sea Ice CCI products. The results of this survey were summarised in URD Phase II roughly as follows:

- The requirement analysis focussed on needs for sea ice concentration and sea ice thickness data for use cases such as sea ice model development, data assimilation and climate model evaluation. The survey was designed as a follow-up of the more general user requirements for climate research defined by GCOS, WMO and others, where quantitative requirements for data coverage, measurement accuracy and long-term stability of the observing systems are addressed.
- The user survey was conducted as an on-line questionnaire with a total of 91 respondents. These covered applications of sea-ice data for climate and sea ice modelling, model evaluation, data assimilation, ice charting and forecasting, marine biology, fisheries and ecosystem research, marine transportation and offshore operations in ice-covered seas.
- In contrast to existing sea-ice data sets, a transparent characterisation of errors and uncertainties is a vital part of the entire line of CCI sea ice ECVs. A particular focus of the survey was hence on the respective user needs of these information with a focus on three different error parameters:
BIAS: defined as the offset of the mean satellite observations from the "true" values;
PRECISION: defined as scatter of multiple measurements of a constant target
STABILITY: defined as drift in observed mean value of a constant target over a decade.
Many respondents replied that they did not have a clear view on requirements on error characterization and therefore their replies were based on intuition. Some respondents replied that error characterization was "not relevant" or they had no idea how to respond to this question.
- The survey primarily addressed the requirements for data on sea ice concentration and sea ice thickness, which are the main constituents of the sea ice ECV. For ice concentration, the majority of the respondents required daily sampling, 10-20 km spatial resolution and measurement precision better than 10 %. For ice thickness, the majority of the respondents required spatial resolution better than 50 km and measurement precision better than 20 cm. Temporal resolution of ice thickness data is envisaged to be about a month for satellite altimeter retrievals. The requirement for long-term stability is 2 % per decade for ice concentration and 5 cm per decade for ice thickness.
- Also requirements for other sea ice parameters such as ice drift, ice volume, snow cover, meltpond fraction, albedo, surface temperature, and sea ice salinity were investigated. All these parameters were required by between 16 and 38 out of the 91 respondents. Most of the respondents required daily or weekly temporal sampling and spatial resolution of 20 km or better. The ongoing project will not provide data sets on these parameters, but recommendation is made to extend sea ice data sets with more parameters in future studies of sea ice data in climate research.
- The survey addressed some practical aspects of the sea ice data sets such as gridded versus swath-based data sets, map projection and formats. Users were also asked to choose between long-term stability of timeseries and higher accuracy of newer data for shorter timeseries, which is normally the case for satellite retrievals. The replies were distributed 50 – 50 % between the two choices.

2.2 Summary of Phase 2 User Requirement Survey

For the user requirement survey of phase 2, it was decided that little new would be learned by repeating a survey similar to the one carried out in phase 1. Instead, the survey in phase 2 was specifically addressed at all users who have downloaded and used phase 1 SICCI data to learn from their experience with using that data.

The survey focused on the two main products of SICCI, namely the sea-ice concentration product and the sea-ice thickness product.

For sea-ice concentration, the results of the user survey in phase 2 can be summarized as follows:

- The use cases of SICCI sea-ice concentration vary widely, reflecting the ease of use and the flexibility of the data set. Purposes for which the data were used include climate-model evaluation, algorithm intercomparison and assessment of algorithm uncertainty, detailed analysis of weather filters, data assimilation for example for re-analysis studies, support analysis of in situ sea-ice measurements, analysis of regional and temporal trends of Arctic sea-ice coverage and of their drivers, analysis of navigation conditions in the Arctic and an analysis of large-scale atmospheric drivers of sea-ice evolution

- Users were generally happy with the quality of the data set. In particular, they commend the uncertainty information included in SICCI products. There were no technical problems in downloading or using SICCI data. Also the quality of the metadata and the documentation generally received positive ratings.

- The survey also resulted in some specific suggestions for improvements. These have largely been addressed during SICCI phase 2. In particular the shortness of the data sets was pointed out as a major drawback, which now has been addressed by the transparent transfer of SICCI expertise to the OSISAF consortium. Other concerns raised include the coastal correction, which also has been improved in SICCI phase 2. For the documentation, the users requested an update of the Product User Guide (PUG) following, for example, the format of the NSIDC user guides. Also this has been at least partly addressed during SICCI phase 2.

- Issues that have not fully been addressed in SICCI 2 include information on the temporal and spatial correlation of errors, clearer guidance on the difference between near-real time and the final product and an improved understanding of biases and uncertainties in particular during summer. Addressing these issues is some of the focus of the sea-ice ECV in CCI+.

For sea-ice thickness, the results of the user survey in phase 2 can be summarized as follows:

- The use cases of SICCI sea-ice thickness vary widely, reflecting the ease of use and the flexibility also of this data set. Purposes for which the data were used include a detailed analysis of various sea-ice thickness products to estimate the uncertainties of remotely-sensed ice-thickness information, climate-model evaluation, to obtain regional ice-thickness information, analysis of the time evolution of pan-Arctic sea-ice volume and for student exercises.
- All users pointed out significant differences of the phase 1 SICCI SIT product compared to other SIT data sets. These discrepancies resulted in a severe lack of confidence regarding the quality of the SICCI SIT data set. As a consequence, this data set was deemed to not be usable for quantitative studies requiring reliable sea-ice thickness data. These major shortcomings of the phase 1 SICCI SIT data set have to a substantial degree been addressed during phase 2.
- Users also pointed out a too poor spatial or temporal resolution of the data sets, the lack of thin-ice thickness, and the too large pole hole in parts of the product. Many of these issues are direct consequences of the physical limitations of the existing CryoSat and Envisat data sets of ice freeboard and can currently not fully be addressed. However, the spatial resolution requirements of approximately 22 % of the users from phase 1 survey were met in phase 2 when increasing the resolution from 100 km to 25 km (50 km for the Southern Hemisphere).
- Users also pointed out the lack of reliable uncertainty information. This has been addressed during phase 2.

3 USER SURVEY IN CCI+

For CCI+, we continued the strategy of further refining the user requirements from one phase of the Sea Ice ECV to the next one. Hence, after the broad user survey in phase 1 and the survey among end users of our products in phase 2, we now had detailed discussions with individual researchers to examine the needs of a broad range of users. The researchers from which we had input so far cover the range of large-scale climate research with no particular focus on sea-ice, large-scale climate research with a particular focus on sea-ice, sea-ice model development and evaluation, data assimilation for seasonal and decadal climate forecasts, and data assimilation for reanalyses. Discussions were also held with end-users such as authors of IPCC AR6 to best understand their need in the context of IPCC reports.

Based on these discussions, which we will continue to further refine throughout the duration of this project, we established that independent of the detailed use cases that became apparent in the phase 2 survey, the users of our sea-ice data can broadly be divided into two groups. The requirements of each of these two groups is fairly independent of the actual sea-ice variable (concentration, thickness), which is why in the following we split the discussion of user needs primarily along these groups rather than along the actual sea ice ECV products.

3.1 Expert users

3.1.1 Characterisation

We define as expert users those users of our data who have a detailed understanding of data handling, who have at least a first-order understanding of the various levels of the underlying algorithms that translate satellite raw data into a given EO end product, and whose research deals at least in part with the technical details of comparing EO data with model output or with the assimilation of EO data into a modelling chain.

The research of these users often deals with understanding processes, and in particular always relies on detailed knowledge of the uncertainty of both the model output and of the EO data. To obtain such knowledge, these users will usually read the product description of the observational data they use.

3.1.2 Requirements

Given their experience and knowledge, these users have the following requirements of a given EO product:

- Expert users are prepared to push their models towards raw observation data, e.g. they can deal with using for example level 2 or level 3 EO data and would prefer to use such data if this reduces uncertainties for their application.
- Expert users prefer consistency across a range of EO data whenever such consistency can be obtained during the processing chain of the EO data. However, if the removal of inconsistencies can only be obtained by an ad-hoc removal, expert users prefer to deal with remaining inconsistencies themselves.
- Expert users can deal with off-range data
- Expert users will consider uncertainty information in most of their work, and profit from detailed information of the individual sources of uncertainty

Based on these requirements, expert users have the following requirements of sea-ice ECVs that go beyond the requirements established in the previous phases:

- For SIT, uncertainty of all existing estimates of remotely-sensed sea-ice thickness is rather high. Hence, expert users will usually not use sea-ice thickness information provided, but would use less uncertain estimates for example of sea-ice freeboard. Given the

uncertainty that arise during the determination of physical freeboard, expert users would often prefer to use the radar freeboard for model evaluation and data assimilation. Guidelines for the use of radar freeboard would be helpful to these users.

- For SIC, in addition to the generic requirements outlined above, expert users will exploit information on off-range SIC, of swath-based SIC, and can deal with the differentiation of melt-pond free sea-ice coverage and total sea-ice coverage.

3.1.3 Response by CCI Team

Starting in CCI+, sea-ice concentration will also be provided in individual swaths. At this stage, it is still open if the data really should be in swath projection (on irregular lat-lons with varying orientation of the fields-of-view, ordered in along-track/across-track dimensions), or if users (despite being expert) would prefer if the individual swaths were gridded to the same EASE2 grid as the final daily files (the added value wrt daily files would still be access to the exact sensing time for each swath of each instrument). It would be interesting if CCI, CMUG, and/or CRG could liaise with expert users interested in accessing swath data, and help us define the most useful product.

Due to uncertainties in snow load and ice density the thickness uncertainty is indeed high, and expert users should be encouraged to use radar freeboard if that is a possibility in their application. The radar freeboards will be included in both the daily Level-2 trajectory-based SIT product as well as in the monthly Level-3 gridded product. The radar freeboard (and freeboard) use cases shall be included in the Product User Guide with due notice on the smaller uncertainties of radar freeboard and freeboard in contrast to that of SIT. For those expert users interested in using thickness data, the uncertainty estimates of Level-3 product will be redefined from phase 2, incorporating the statistics of the error components in a grid cell rather that averaging the Level-2 uncertainties.

3.1.4 Conclusions by Climate User Group

We find that the responses by the two research teams on sea-ice concentration and sea-ice thickness very nicely align with the stated requirements of the expert users that are described in section 3.1.2. In particular, we welcome that the two research teams will allow expert users direct access to intermediate results from within the "engine room" of the high-level algorithms. In our view, this approach is a fine example of ongoing efforts to better inlink the observational community and the modelling community. We will examine throughout the 2nd year of the CCI project if this example can be used to formulate a generic paper in a high-ranking journal on best-practices of distributing EO-data and their uncertainties to expert users. We are also happy to assist all efforts to help refining the requirements as requested by the CCI team.

3.2 Non-expert users

3.2.1 Characterisation

We define as non-expert users those users whose primary interest does not lie in the details of sea-ice data analysis, for example, but who primarily use existing data for their often large-scale research interests of which sea ice is just one aspect. In practice, these users are for example concerned with a quick-look evaluation of model results, and will often use integrated measures such as pan-Arctic sea-ice area and sea-ice volume. For such efforts, non-expert users might for example use automated evaluation products such as ESMValTool, which is in part developed by CMUG.

Because of the broad variety of data these users deal with, they in practice will often not read any detailed product description, and will sometimes even take EO retrieved products as representing the truth. Hence, they will often not use the provided uncertainty information,

and do not want to spend time in removing artefacts in the data that arise for example from the impact of weather. Instead, these users might even be tempted to judge such artefacts as a negative reflection on the quality of a specific product, even if an alternative "nice-looking" product might primarily have resulted from heavy filtering.

3.2.2 Requirements

Given their experience and knowledge, these users have the following requirements of a given EO product:

- Non-expert users require a product where all judgements of possible filtering is taken by the data provider
- Non-expert users often require reliable integrated data with as-long-as-possible time series, rather than state-of-the-art high-resolution information
- Non-expert users can profit from the inclusion of NaNs in the data, rather than the provision of data with substantial uncertainties, as these uncertainties might be ignored in the interpretation of the data
- Non-expert users can profit from a one-stop shop of reliable integrated data

Based on these general requirements, the following specific requirements arise for the two sea-ice ECVs:

- For SIC, in addition to a filtered data set where the Sea-Ice CCI+ team has used its expert judgement regarding the degree of filtering, the non-expert users would profit from integrated time series in particular of sea-ice area derived from SIC data. In addition, the sea-ice CCI team should provide clear guidance on the relationship between their data product and the longer time series of the OSISAF team, to ensure that the intellectual contribution of the sea-ice CCI team for the longer OSISAF product is clear to all users. In particular, we recommend that a clear naming suggestion is jointly developed by the CCI team and the OSISAF team to allow for a consistent reference to their project by user groups.

- For SIT, the substantial uncertainties of the end-product sea-ice thickness are a clear challenge for non-expert users. In particular, the SIT sea-ice CCI+ team cannot expect that the non-expert users will examine the provided uncertainty information in much detail. Instead, the underlying uncertainties must be folded into the product in a way that is almost fail-safe for non-expert users. This might include the provision of only a very limited amount of robust SIT information, for example integrated over larger regions or several years, rather than the standard distribution of actual gridded time series.

3.2.3 Response by CCI Team

Following the SoW, the project is set to prepare weekly, monthly, seasonally, and yearly averaged sea-ice concentration product files. These will however still be in the form of maps, *i.e.* not integrated indicators like sea-ice area/extent. There is undoubtedly room for computing such indicators as downstream products of our data records, but this has so far been considered an activity our users would do (the sea-ice products are on equal-area grids, so easier to handle than, e.g. NSIDC). Users of indicators might also be interested in comparing sea-ice area (and trends) from different providers. For this application, it will be important to use the same methodology on all data records, which is not something the CCI EO team can prioritize. To meet these user needs, a solution might be that the CCI Climate Research Group team (either from Sea Ice, or CMUG, or both) drive the process of computing and distributing such high-level sea-ice indicators (in collaboration with the EO teams). How to consistently propagate uncertainties from daily gridded products to high-level indicators is still an open question (for Sea Ice), but will probably share some aspects with other ECVs (for example, the Sea Level CCI seems quite advanced here). Finally, we note that the design and production of "weekly, monthly, seasonally, and yearly averaged sea-ice concentration product files" as requested in the SoW will be time-consuming, and that we (the EO team) so far have not been in contact with users requiring these (to the exception of monthly averaged product files). It would be interesting if the Sea Ice CRG (in liaison with the users, CMUG, and

the other CCI CRGs) could assess and recommend how much effort should be put in producing and maintaining these (and if uncertainty propagation part is required).

Concerning the credit of CCI input to the OSI SAF sea-ice data records, this is definitely something one can progress upon. The link is clearly established in the documents, at the dataset landing pages, in the global attributes to each files, but the non-expert user will not find (or process) the information there. For the non-expert user, a dataset downloaded from an OSI SAF website will be "OSI SAF" (full stop). We note that crediting the source, and R&D contribution, is a general issue. The OSI SAF team has the same challenge when their data record is brokered (re-distributed as-is) in the Copernicus Climate Change Service (C3S) and the Copernicus Marine Environment Monitoring Service (CMEMS). At NSIDC, the products redistributed from Nasa Goddard Space Flight Center are very often referred to as "NSIDC". It is also clear that CCI (starting with the CCI+ phase) faces very similar issues with respect to Copernicus. We do not see any straightforward, full-proof solutions but are looking forward to discuss this further with ESA, the other CCI Science Leads, C3S, and the SAFs. The non-expert users will never fully understand (nor be interested in) the subtleties of the interaction between all these initiatives, so that the simplest solutions (showing the two logos side by side, naming the data records "C3S/CCI Sea Ice ECV", etc...) will probably be the only solution in the long run. This requires the funding/planning agencies to agree on such blending first.

The distribution of a monthly gridded SIT product is one of the technical requirements of the CCI+ project and thus it should not be revised to distribution of larger scale products only. Furthermore, even the format of the product is already set to CF compliant NetCDF files so there is very little room to adjust the products so that they can not be used without understanding their limitations - large uncertainty being the foremost. However, the project shall produce higher level products such as sea ice volume time series for different regions in WP5100 which will address parts of the non-expert user requirements.

Instead of creating a fail-safe product that can be used without reading and understanding the documentation we shall concentrate on the quality of the documentation aimed for non-expert users which go through the strain of actually reading it. However, this is a problem not unique to the sea ice thickness project and should be discussed between all of the different CCI+ projects.

3.2.4 Conclusions by Climate User Group

We welcome the response by the two research teams on sea-ice concentration and sea-ice thickness and in particular fully understand the given reasons for why there is only limited possibility to deal with all the requirements of non-expert users as part of this project.

For the major integrated measure of sea-ice concentration, namely sea-ice area, we have established over the past year a standard algorithm for its consistent calculation for different SIC products. These data sets form, for example, the basis of all sea-ice area related analyses in IPCC AR6. Throughout year 2, we plan to distribute this reference data set of sea-ice area for the most widely used SIC products. We expect that such reference data set will widely be used. As such, any further guidance on the possible naming of the data products arising from the collaboration of OSISAF and SICCI will be very welcome. We also plan to describe the calculation algorithm in a paper for a high-profile journal, including an analysis of observed trends.

We will also pursue efforts to better understand possible requirements of sea-ice data averaged over longer periods. From our own perspective, we see very limited value of weekly and seasonal data sets, and are unaware of any studies that would use gridded data on these time scales. The integration of daily data to monthly data is, however, very welcome. Any efforts to reasonably estimate the uncertainty of such averaged product seems of far higher value than spending work on providing products for other averaging periods than monthly.

We also understand and appreciate the response by the sea-ice thickness team that provision of a data product directed at non-expert users will be difficult within this project. As a

possible work around, we suggest a one-line statement on the uncertainty of the data to be prominently displayed wherever this data can be downloaded. We are happy to further discuss this issue with the SIT team and to examine possible alternative ways forward.