Sea Ice CCI+

ESA CCI+ CLIMATE CHANGE INITIATIVE

PHASE 1: NEW R&D ON CCI ECVS

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CCI+ Sea Ice ECV
CLIMATE ASSESSMENT REPORT (CAR)

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Contract PHASE 1 OF THE CCI+ CLIMATE CHANGE INITIATIVE NEW R&D ON CCI ECVS SEA ICE ECV	**Deliverable** D5.1 Climate Assessment Report
CLIENT European Space Agency	**CLIENT REFERENCE** 4000126449/19/I-NB
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Change Record

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1.0	24.08.2020	First version	Laura Niederdrenk Dirk Notz
1.1	15.10.2020	Minor updates addressing RIDs from ESA TO	Laura Niederdrenk Dirk Notz
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Document Approval

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Contents

1 INTRODUCTION

1.1 Purpose

This document is the CCI+ Sea Ice ECV Climate Assessment Report (CAR) for sea ice thickness and sea ice concentration for the Sea Ice ECV within CCI+ PHASE 1 - NEW R&D ON CCI ECVs, which is being undertaken by a METNO-led consortium.

1.2 Scope

This document describes early results of user's experience with the Sea Ice Data within CCI+ PHASE 1. At this state, that is version 2 for the SIC CRDP and v3.0-preview2 for SIT CRDP, the data is in a preliminary state and for internal use only. Thus this report refers in parts to what will be done with the data when it is finalized. It describes the user-base's experience with the sea-ice thickness and sea-ice concentration data sets, examining how the products meet user requirements. Furthermore, a maturity matrix will be established in a later version of this document.

1.3 Document Status

This is the second version CAR for the Sea Ice variables released to ESA as part of the project's contractual deliverable set. This version does focus on internal consistency of the dataset, while external evaluation will be considered in future versions.

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
D3.2	CCI+ Sea Ice ECV CLIMATE RESEARCH DATA PACKAGE
D4.2	CCI+ Sea Ice ECV SEA ICE CONCENTRATION PRODUCT USER GUIDE and CCI+ Sea Ice ECV SEA ICE THICKNESS PRODUCT USER GUIDE

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)
CRDP	Climate Research Data Package
CDO	Climate data operator
CMIP6	Coupled Model Intercomparison Project (Phase 6)
EASE2 grid	Equal-Area Scalable Earth Grid
ENVISAT	ESA's Environmental Satellite
ESA	European Space Agency
EUMETSAT	European Organization for the Exploitation of Meteorological Satellites
FB	Freeboard
HadISST	Hadley Centre Sea Ice and Sea Surface Temperature data set
NetCDF	Network Common Data Format
NSIDC	US National Snow and Ice Data Centre

OSI SAF	EUMETSAT Ocean and Sea Ice Satellite Application Facility
PIOMAS	Arctic Sea Ice Volume Reanalysis from the Pan-Arctic Ice Ocean Modeling and Assimilation System
PMR	Passive Microwave Radiometer
PUG	Product User Guide
RFB	Radar freeboard
SIA	Sea Ice Area
SIC	Sea Ice Concentration
SIE	Sea Ice Extent
SIT	Sea Ice Thickness
SSM/I	Special Sensor Microwave/Imager
SSMIS	Special Sensor Microwave Imager/Sounder
Tb	Brightness temperature
WCRP	World Climate Resarch Programme

2 TECHNICAL ASSESSMENT OF THE DATA

The CRDPv3 datasets are for internal use only and will not yet be released outside the project group. They are currently available from:

https://thredds.met.no/thredds/catalog/mtusers/thomeasl/SICv3_CRDP/v0.2/catalog.html

and

ftp://ftp.awi.de/sea_ice/pvrojects/cci/crdp/3p0-preview2/

for SIC and SIT, respectively.

The temporal and spatial coverage of the sea-ice thickness and the sea-ice concentration data is described in the Climate Research Data Package (CRDP) [D3.2]. A technical product description, covering content, format, naming as well as known limitations are given in the Sea Ice Concentration Product User Guide (PUG) [D4.2] for sea-ice concentration and sea-ice thickness, respectively.

Sea-ice data is available for both the Northern and the Southern Hemisphere. The full annual cycle is available for both hemispheres for the SIC retrieval and the southern hemisphere for SIT. In the northern hemisphere the SIT record is limited to the winter months, October – April. Both CRDPv2 datasets cover the time period from January 2002 to December 2019. In addition, the SIT dataset provides an ongoing record until present and a prototype ERS-1 and ERS-2 data record (1993-2003). These are substantial improvements regarding temporal coverage compared with earlier versions, which is of high importance for many climate research users.

2.1 ESA CCI+ Sea Ice Concentration (SIC)

In the current release, the ESA CCI+ Sea Ice project provides a total of five complementary SIC CDRs, three from the SSMIS instrument and two from the AMSR instrument. Each of the CDRs consists of daily global maps of sea-ice concentration, with associated processing flags and per grid-cell uncertainties (with the exception of the 12.5km reSICCI3LF-ssmi record). The ice concentration values are processed from medium resolution, space-borne Passive Microwave Radiometer (PMR) data, namely the Special Sensor Microwave-Imager/Sounder (SSMIS) and Advanced Microwave Scanning Radiometer2 (AMSR2). Different ice-concentration algorithms, using distinct combinations of brightness temperature (Tb) changes, lead to different spatial resolutions. Sea-ice concentration is available on a Lambert Azimuthal Equal Area (EASE2) grid in a resolution of 25 km and on 12.5 km.

2.2 ESA CCI+ Sea Ice Thickness (SIT)

Each SIT file contains a multitude of variables, including ice thickness, radar freeboard, ice freeboard and uncertainties of these. The product files are distributed for each combination of satellite platform, hemisphere and two product levels: Level 2 (pre-processed) contains the daily orbit data at full sensor resolution; Level 3 (collated) contains the gridded geophysical parameters, auxiliary data and the status flag.

Level 3 values of successful altimeter measurements are mean values inside a grid cell. No fraction of open water is considered for the mean ice thickness. However, the Level 3 data sets also contain the variable SIC, such that computation of mean ice thickness including the open water area is possible.

Monthly SIT, radar freeboard (RFB) and freeboard (FB) Level 3 data is available on a grid resolution of 25 km for the Arctic and 50 km in the Antarctic, together with many grid cell statistics which are intended mainly for product development and will presumably not be included in the final product.

Un-gridded Level 2 data contains less statistics (but several uncertainty estimates) but provides daily files at full altimeter resolution.

2.3 Assessment with several software tools

The data is available in the Network Common Data Format netCDF, which is a community standard for sharing scientific data.

The ncdump tool generates a text representation of such netCDF file, which allows the user to get quick and easy information about the metadata of the product.

The Climate Data Operators (CDO) are command-line operators to analyze climate data.

Ncview is a visual browser for netCDF format files. It allows to get a quick and easy look at the data with the possibility to view simple movies and view along various dimensions.

The Python netCDF4 module is a standard python interface to the netCDF C library which can be used to read netCDF files.

After downloading the data we tested the above mentioned software tools on the available data and could easily access thereby the meta data, the temporal and spatial resolution information and the data itself. We do not report any problems with the technical assessment of the data so far.

However, when testing some post-processing with CDOs on the monthly mean files, it turned out that for the calculation of the grid area the grid corner information is missing within the files[1]. Therefore, CDO cannot calculate the area of the grid cells as it needs the bounds of each cell for doing so. This can and should be included in the data once it is ready for use.

Furthermore, the Python netCDF4 module does not find a valid _FillValue for some of the variables in the SIT files. Those values, if provided, help to standardize the output and reduce the number of warnings raised. Also this should ideally be addressed for the final version of the data.

3 SCIENTIFIC ASSESSMENT OF THE DATA

To meet the user requirements the data should comply with the following standards concerning the continuity of the data, both in space and time, the regional properties, the temporal evolution and additional information about the uncertainty of the data.

3.1 Continuity of the data

We will test if there are spurious gaps or unreasonable jumps in the data which could be caused by retrieval problems or mistakes within the algorithms. Jumps in the data will be investigated locally by deriving anomalies from low-pass filtered time-series and a comparison with expected fluctuations. The continuity is specifically important for the gridded data as such inconsistencies could lead to problems in further analysis or post-processing that are very difficult to detect retrospectively.

For this version of the CAR we did test another subset of the available files for data gaps and could not find anything of concern. A more complete assessment of continuity will become more beneficial once more mature data versions are available.

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[1]
```
[prompt] cdo gridarea ice_conc_nh_ease2-125_N90LIN-amsr_200802011200.nc test.nc
[out]: cdo    gridarea (Abort): grid_cell_area: Cell corner coordinates missing!
```

The SIT data record is based on measurements of four satellite missions with temporal overlap. This gives the opportunity for a continuous SIT data record. However, some long-term applications require the transition from one mission/sensor to the following one to be smooth and free of biases.

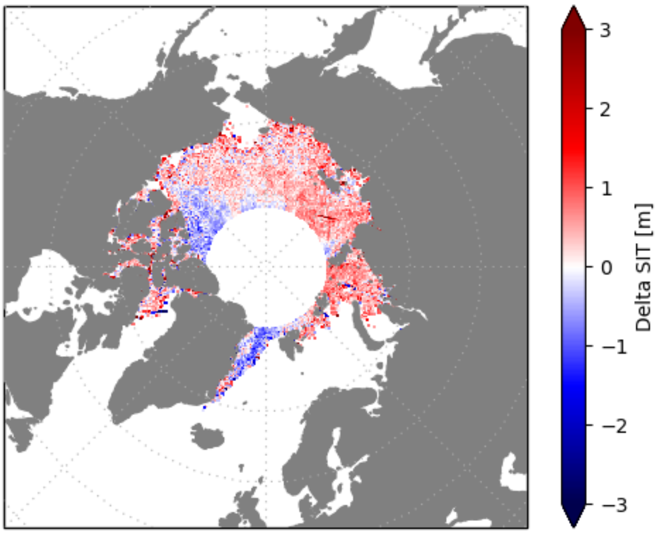

Figure 1: *Difference in Arctic SIT for November 2010 from Envisat minus Cryosat-2.*

Figure 1 shows the difference of the SIT products from two different platforms and reveals that SIT estimates regularly differ on the scale of meters. The RMSE between the two is 0.75m and the difference of the mean SIT (bias, using all valid locations in Figure 1) is 26cm. These current differences will for now prohibit the use of these missions as continuous data record for many users.

3.2 Regional pattern

It is of importance that the data resembles regional patterns in high resolution: This is true for SIC as this might be used to calculate sea-ice area (SIA) or other areal means for certain sub-regions. But it is also important for SIT, especially because the uncertainty in this variable is large.

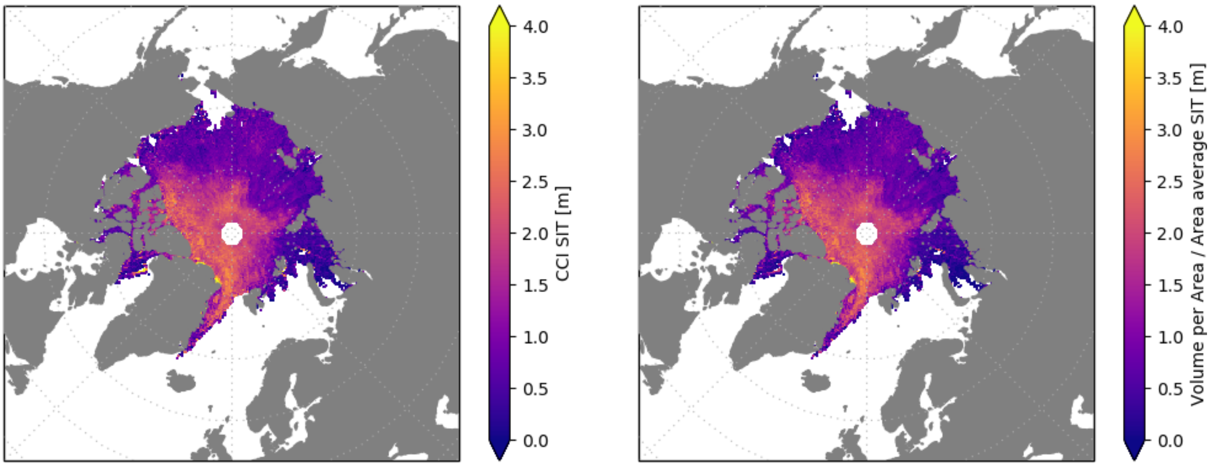

Figure 2: *SIT (left) and SIV per grid area (right) for November 2010 from Cryosat-2*

The Arctic SIT distribution (Figure 2) looks as expected, with high SIT near Greenland and north of the Canadian archipelago. Taking into account the SIC (i.e. converting the average ice thickness of ice measurements to an average ice thickness within a grid cell) does not change these findings noticeably (compare Figure 2 left and right panel).

3.2.1 Regional pattern of SIC

We will examine the suitability of the SIC data set for climate-research applications in comparison to the three most widely used existing satellite data products, namely OSI SAF, NASA-Team and Bootstrap from National Snow and Ice Data Center (NSIDC).

In many ways the human eye is superior to automatic routines in identifying patterns and inconsistencies therein. Therefore, and given the time constraints, we generated animations of the seasonal development of the SIC for 2008 and the 25 km SSMIs SICCI3LF data record (exemplary). These animations are embedded below for both hemispheres and have been distributed with this document:

- NH: https://drive.google.com/file/d/1aU-eYv_uq-o8mxw6XEvjlogZxhK9kV9v/view?usp=sharing
- SH: https://drive.google.com/file/d/1_1k2lhReKNPNA51Jtj9Np_kQtMh29MqB/view?usp=sharing

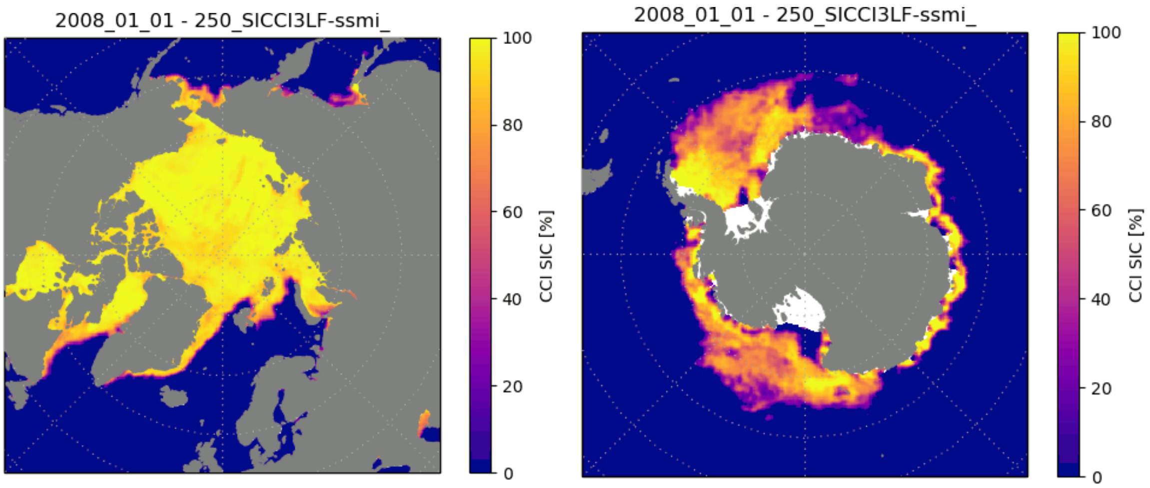

Figure 3: *Animations of 2008 SIC from the 25 km SSMIs SICCI3LF data record for northern (left) and southern (right) hemispheres.*

As can be seen in Figure 3, the spatial patterns of SIC are physically plausible and appear to be continuously moving. In late summer (July-August) we see some quickly changing patterns of reduced SIC (60-80%) in the central Arctic which could be related to melt ponds but cannot be ruled out visually to be related to interference of weather.

3.3 Temporal evolution

For statistical analysis it is of relevance to have a preferably long and continuous time series of observational data.

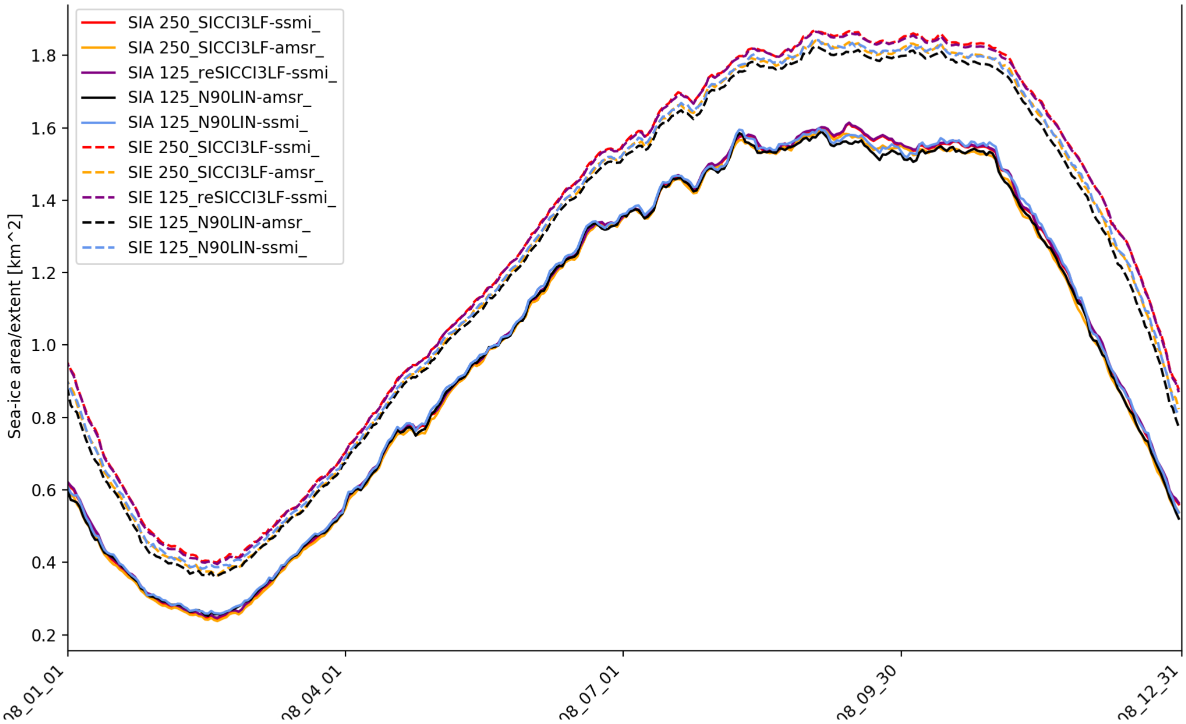

Figure 4: *SIA (solid lines) and SIE (dashed lines) of southern hemisphere level 3 SIC records.*

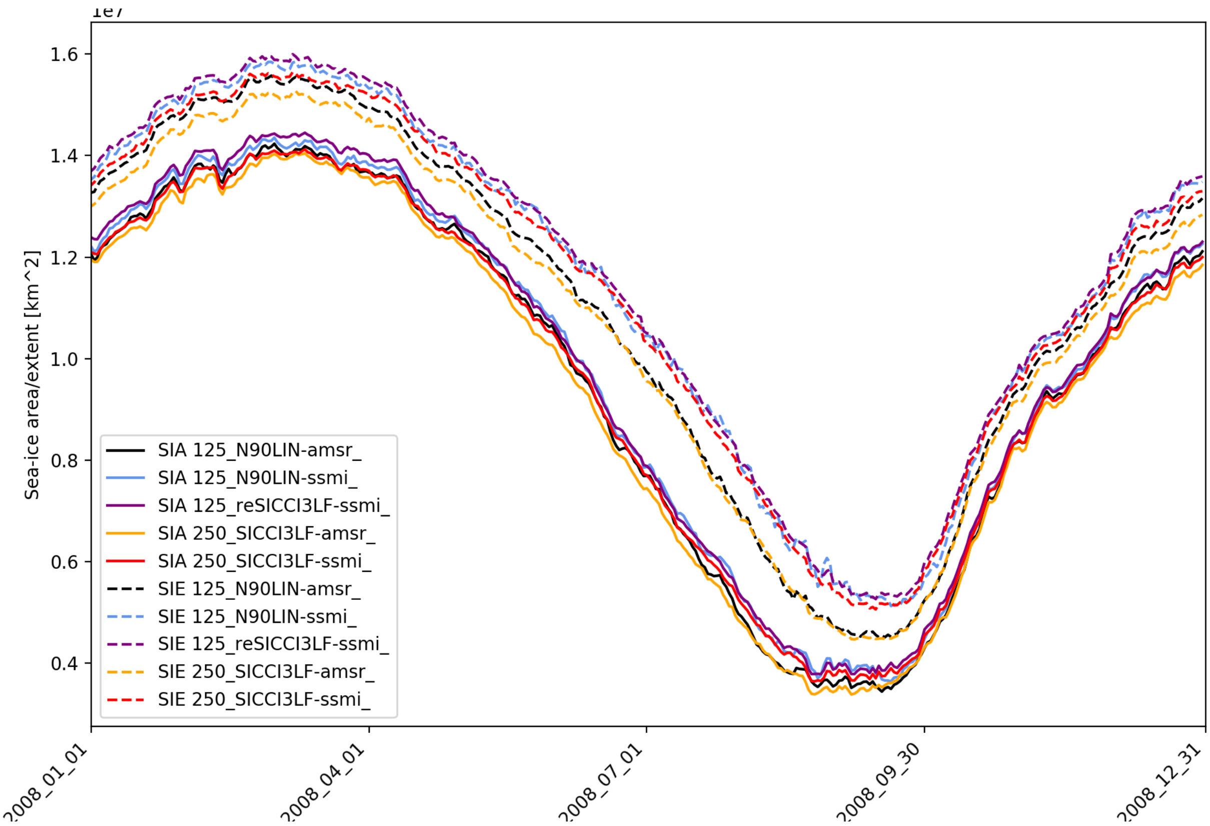

Figure 5: *SIA (solid lines) and SIE (dashed lines) of northern hemisphere level 3 SIC records.*

In figures 4 and 5 we show the Sea Ice Area (SIA) and Extent (SIE) (using a SIC threshold of 15%) for each of the five CCI SIC data records. These are common metrics used to evaluate models' variability and skill to realistically simulate today's climate.

As can be seen, as expected SIE is larger than the SIA and there are also larger SIE differences within the records. The range of SIE estimates is roughly 500000km² depending on the algorithm and resolution and roughly 200000km² for the SIA. These values are not strongly dependent on the season or hemisphere (compare Figure 4 and Figure 5). Somewhat surprisingly, there is no indication for data with finer grid spacing (12.5 km vs 25.0 km) to have a smaller SIE. The rationale behind such an expectation would be that with increasing resolution, SIC would approach a more binary state (an infinitesimal small grid cell is either ice covered, or it is not), in which case the SIE would approach the (smaller) SIA. However, data from AMSR has a smaller SIE than data from SSMI, which is expected as AMSR sensor has finer spatial resolution than the SSMI sensor.

In future we plan to compare the time-series to other observational data that are available. This might involve the following observations and reanalysis data:

- sea-ice concentration from EUMETSAT Ocean and Sea Ice Satellite Application Facility (OSI SAF)
- sea-ice index from the National Snow & Ice Data Center (NSIDC)
- Arctic Sea Ice Volume Reanalysis from the Pan-Arctic Ice Ocean Modeling and Assimilation System (PIOMAS)

Time-series will be made for summer / minimum and for winter / maximum months of the data as well as for the annual cycle (or October to April for the northern hemisphere).

3.4 Uncertainty information

It is crucial to know the uncertainties arising from the retrieval, the underlying resolution and algorithm for data evaluation. It is also highly important for many applications where the confidence in the observational data needs to be considered, e.g. when used for model assimilation or evaluation. The local uncertainties are provided within the data file which we use to test the consistency between different data records. In other words, are the differences between algorithms/resolutions well represented in the algorithmic uncertainty?

For this we take the Arctic SIC fields for February and September (representing high and low SIA examples) for two SIC algorithms (N90LIN and SICCI3LF) and calculate the differences in those fields for the two different sensors (AMSR and SSMIs). Those differences are normalized (divided) by the local combined uncertainty ($sigma\_combined=sqrt(sigma\_AMSR^2+sigma\_SSMI^2)$), where sigma is the provided algorithmic uncertainty. The two fields are defined at the same locations and are hence likely to suffer from errors due to interpolation in the same way. The differences between them are therefore assumed to represent only the influence of the algorithmic uncertainty, not the total uncertainty, which is the reason why we use the former for this analysis.

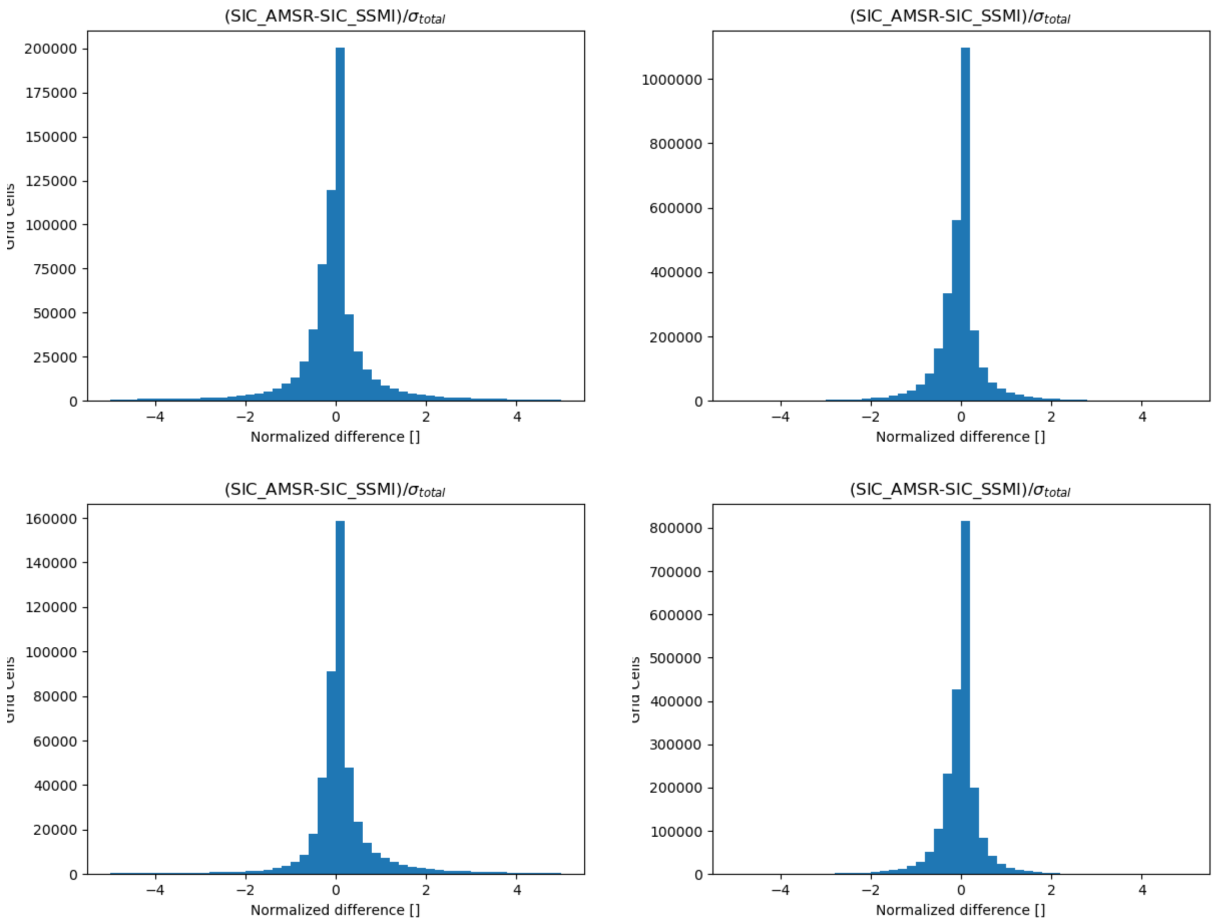

Figure 6: *Histograms of SIC differences between SSMI and AMSR estimates, normalized by the combined algorithmic uncertainty. Based on daily maps for all of February 2008 (top row) and September (bottom row), using the 25km SICCI3LF algorithm (left) or the 12.5km N90LIN algorithm.*

The inter-data-record differences generally fall within three standard deviations (Figure 6) which is an indication for the provided uncertainties to be of appropriate size. The fact that most differences are within two standard deviations is not necessarily a sign of uncertainty overestimation but can be well explained by the shape of the distribution.

We perform a similar test for the SIT and normalize the local SIT differences from Figure 1 by the combined SIT uncertainty. Figure 7 shows that also for the SIT, most differences are within a three sigma range, which indicates that, even though the differences are quite high, they appear to be reasonably well represented by the provided uncertainties.

We note that the SIT dataset contains nonphysical negative ice thickness estimates, which can be attributed to uncertainties. For some applications it can be beneficial that these values are not filtered out (e.g. replaced by zeros), as long as users are aware of this fact and do not accidentally take negative SIT estimates by face value. Further we want to note that several locations of negative SIT have smaller provided uncertainties than they are negative, i.e. uncertainties which must be underestimated. In general, the SIT uncertainty is relatively high and starts to drop below half of the SIT values themselves only from about 1m SIT onwards (Figure 8)

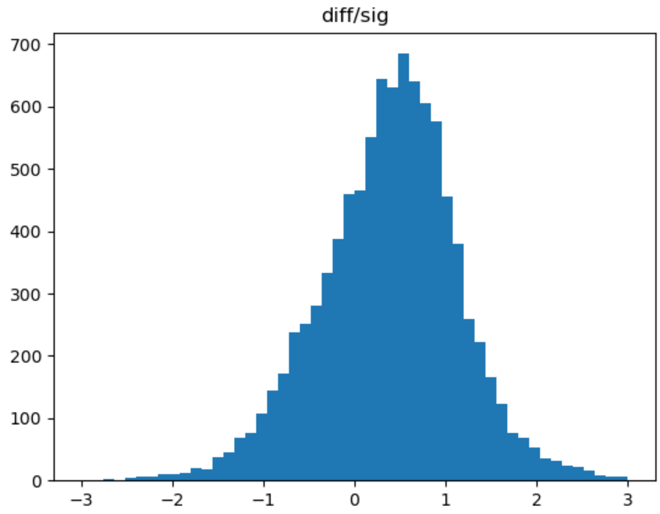

Figure 7: *Grid cell histogram of Envisat to Cryosat2 SIT differences as shown in Figure 1 normalized by the combined Envisat-Cryosat2 SIT uncertainties.*

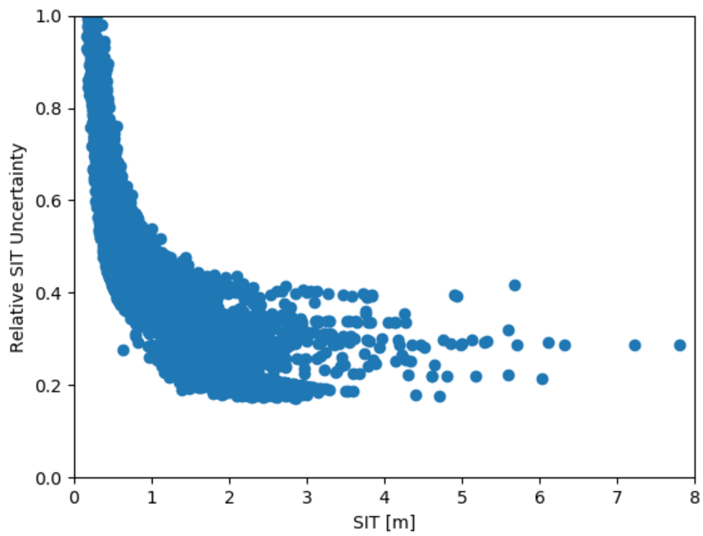

Figure 8: *Cryosat2 SIT uncertainty divided by corresponding SIT (y-axis) as function of SIT*

3.5 Comparison with climate models

The ESA CCI+ Sea Ice data product is not only important for data assimilation approaches within the modeling community but also to evaluate the model's capabilities to simulate today's climate.

We will use the simulations from the World Climate Research Programme (WCRP) Model Intercomparison Project Phase 6 (CMIP6). The simulations from the numerous climate models show a large spread in their representation of the sea ice properties.

3.6 Maturity Matrix

To allow users to quickly grasp the maturity of the products, a maturity matrix of both the SIC and the SIT data is to be assessed and published in collaboration with the data development team.

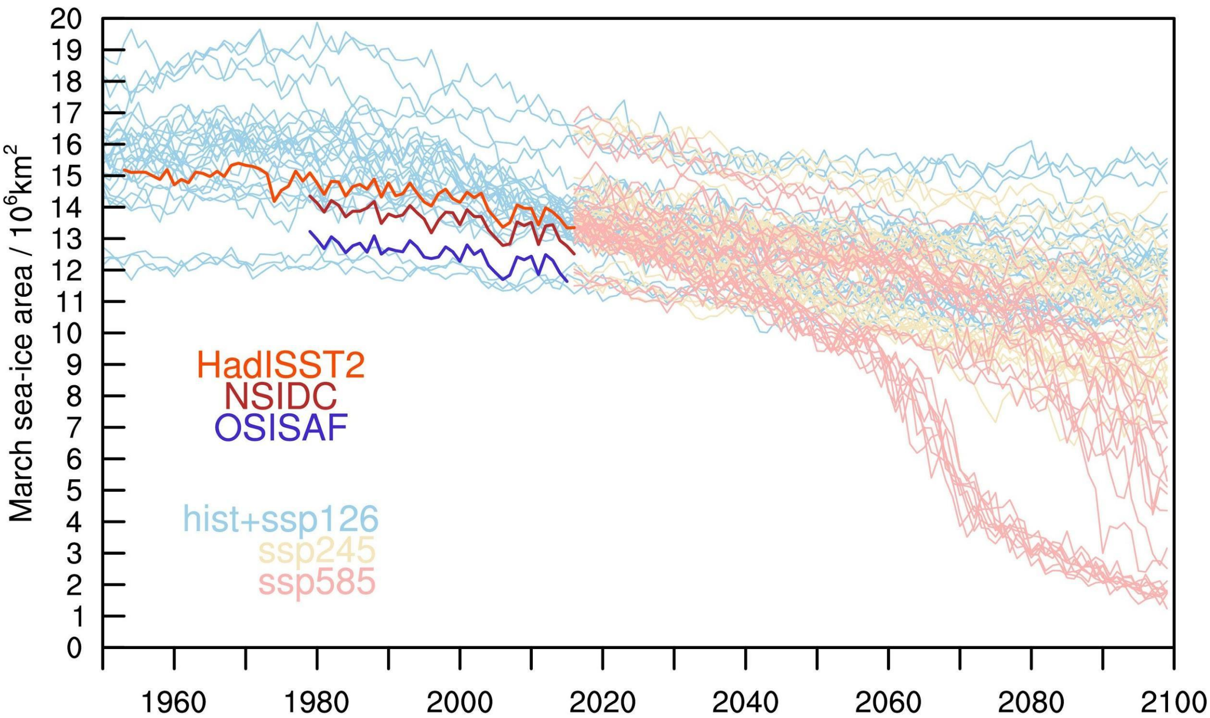

Figure 9.: Arctic sea-ice area for March. *In pale blue, yellow and pink simulations from several models contributed to the CMIP6 projects. The different colors refer to different emission scenarios. Observational datasets are given in orange for HadISST, dark red for the NSIDC sea-ice index and in blue for OSI SAF. This is an example plot with the data we will compare the ESA CCI+ Sea Ice data product with.*