Sea Ice CCI+

ESA CCI+ CLIMATE CHANGE INITIATIVE

PHASE 1: NEW R&D ON CCI ECVS

Contract number:

4000126449/19/I-NB

CCI+ Sea Ice ECV
PRODUCT VALIDATION PLAN
(PVP)

Reference: D1.3

Issue: 1.0

Date: 28 June 2019

	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

Contract PHASE 1 OF THE CCI+ CLIMATE CHANGE INITIATIVE NEW R&D ON CCI ECVS SEA ICE ECV	**Deliverable** D1.3 Product Validation Plan
CLIENT European Space Agency	**CLIENT REFERENCE** 4000126449/19/I-NB
Revision date: 28 June 2019	**Approval**

Principal Authors

Henriette Skourup, Technical University of Denmark - DTU Space
Leif Toudal Pedersen, Technical University of Denmark - DTU Space

Thomas Lavergne, Norwegian Meteorological Institute
Mari Anne Killie, Norwegian Meteorological Institute
Atle M. Sørensen, Norwegian Meteorological Institute
Stefan Hendricks, Alfred Wegener Institute
Robert Ricker, Alfred Wegener Institute
Rasmus Tonboe, Danish Meteorological Institute
Ruth Mottram, Danish Meteorological Institute
Eero Rinne, Finnish Meteorological Institute
Dirk Notz, Max Planck Institute for Meteorology

Change Record

Issue	Date	Reason for Change	Author(s)
1.0	28 June 2019	First version	Henriette Skourup Leif Toudal Pedersen

Document Approval

Role	Name	Signature
Edited by:	Mari Anne Killie	
Checked by:	Thomas Lavergne	
Approved by:	Anna Maria Trofaier	

Contents

1 INTRODUCTION **6**
1.1 Purpose 6
1.2 Scope 6
1.3 Document Status 6
1.4 Applicable Documents 6
1.5 Acronyms and Abbreviations 6
1.6 Executive Summary **8**
1.6.1 Sea Ice Concentration (SIC) 8
1.6.2 Sea Ice Thickness (SIT) 8
2 SEA ICE CONCENTRATION **9**
2.1 Current State CCI Phase 1 and 2 9
2.1.1 The near-100% sea-ice concentration reference data set 9
2.1.2 Open water SIC evaluation (0%) 11
2.1.3 Collocation and evaluation metrics 12
2.1.4 Collocation at different resolutions 13
2.2 Inputs new data EMSR 14
2.3 New validation data in RRDP+ 14
2.4 Schedule, Access and Quality Control 14
2.5 Format 14
2.6 Strategy for semi-automated validation procedures 14
3 SEA ICE THICKNESS RRDP **16**
3.1 Current state (SICCI) 16
3.1.1 Validation data 16
3.1.2 Round Robin Data Package Phase 2 (RRDP-2) 17
3.2 Inputs new data (ERS-1/2, S3, CS2 post SICCI) 19
3.2.1 Validation data 19
3.3 New validation data in RRDP+ 19
3.4 Schedule, Access and Quality Control 20
3.5 Collocation 21
3.6 Format 22
4 REFERENCES **23**

1 INTRODUCTION

1.1 Purpose

This document is the Product Validation Plan (PVP) 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 describes in detail the validation plan for all the steps and data to be included.

1.2 Scope

The document includes the PVP contribution for both the Sea Ice Concentration (SIC) and Sea Ice Thickness (SIT) aspects. Chapter 2 deals with the Sea Ice Concentration and chapter 3 deals with Sea Ice Thickness.

1.3 Document Status

This is the first formal issue of the PVP. The document will be updated after year 1 based on experience from year 1 and feedback from the first validation exercise.

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

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

1.6.1 Sea Ice Concentration (SIC)

An automated validation procedure that allows evaluation of SIC datasets will be implemented and applied. The procedure will be based on reference data from an extended version of the SICCI Round Robin Data Package at 0% and 100% sea ice concentration.

1.6.2 Sea Ice Thickness (SIT)

The SICCI+ sea ice freeboard and thickness validation will be an extension of previous validation work. New validation data will be included to form an extended Round Robin Data Package (RRDP+) both to cover the ERS period 1991-2002 and post 2017. In addition, newly published ground-truth data allowing the evaluation of the new level-4 SIT product (inside the polar observation hole) will be added. Automatization will be adopted when necessary.

2 SEA ICE CONCENTRATION

2.1 Current State CCI Phase 1 and 2

A considerable amount of validation of the previous versions of the CCI sea ice concentration (SIC) datasets has been carried out at 0% and 100% sea ice concentration using reference datasets established as part of building the so-called Round Robin Data Package (RRDP) during CCI Phase 1 and 2.

This will constitute the baseline validation of the new datasets also.

2.1.1 The near-100% sea-ice concentration reference data set

For the evaluation of the SIC products at 100% sea-ice concentration, we use the Round Robin Data Package version 2 (RRDP2) near-100% reference sea-ice concentration data set developed within the ESA-CCI and further expanded in EU-SPICES project (Pedersen et al., 2018). In short, for this reference data set, areas of ~100% sea-ice concentration are found by identifying areas of interest (AOI) of approximately 100 km x 100 km size with net convergence in the ice drift pattern on two consecutive 1-day periods. Information about convergence is derived from the PolarView / MyOcean / CMEMS ice drift data set derived from Envisat ASAR, RADARSAT-2 SAR and Sentinel-1 SAR imagery. By choosing AOIs in high-concentration regions, near 100% sea-ice concentration can be assured (see e.g. Kwok, 2002; Andersen et al., 2007) in Winter. Each AOI contains up to 100, 10 km x 10 km cells for which the SAR ice drift is computed. The number of cells depends on SAR image coverage. Convergence in the ice drift pattern results in a decrease in the total area of these cells. A cell is included in the dataset of ~100% sea-ice concentration if the area reduction between day 1 and day 2 is between 0% and 2% and if more than 40% of the AOI contains cells with such an area reduction. The RRDP2 near-100% sea-ice concentration reference data set contains the AOI centre geographic latitude and longitude, time, total sea-ice concentration (100%) and AOI average area reduction due to net ice convergence. It is available for years 2007 through 2015 for both hemispheres and will be extended to 2019 or 2020 in the current CCI+ project. It cannot be easily extended back in time due to the lack of SAR drift data.

We only use AOIs for winter months, i.e., November through March (Arctic) and May through September (Antarctic). By doing so we ensure that potential openings, which may remain in an area of high ice concentration and net ice convergence, are frozen and thus sea-ice concentrations are very close to 100%. We use only AOIs for which the average area reduction between day 1 and day 2 is between 0.4 and 1.5%.

Figure 2.1 and 2.2 illustrates the spatial distribution of selected AOIs for both hemispheres. The RRDP2 near-100% sea-ice concentration reference data set contains basically no AOIs in the Eastern Antarctic because of the lack of sufficiently frequent SAR image acquisitions required for the ice drift product used to generate it. Interestingly, the AOIs in the Arctic cover both first-year and multi-year ice areas.

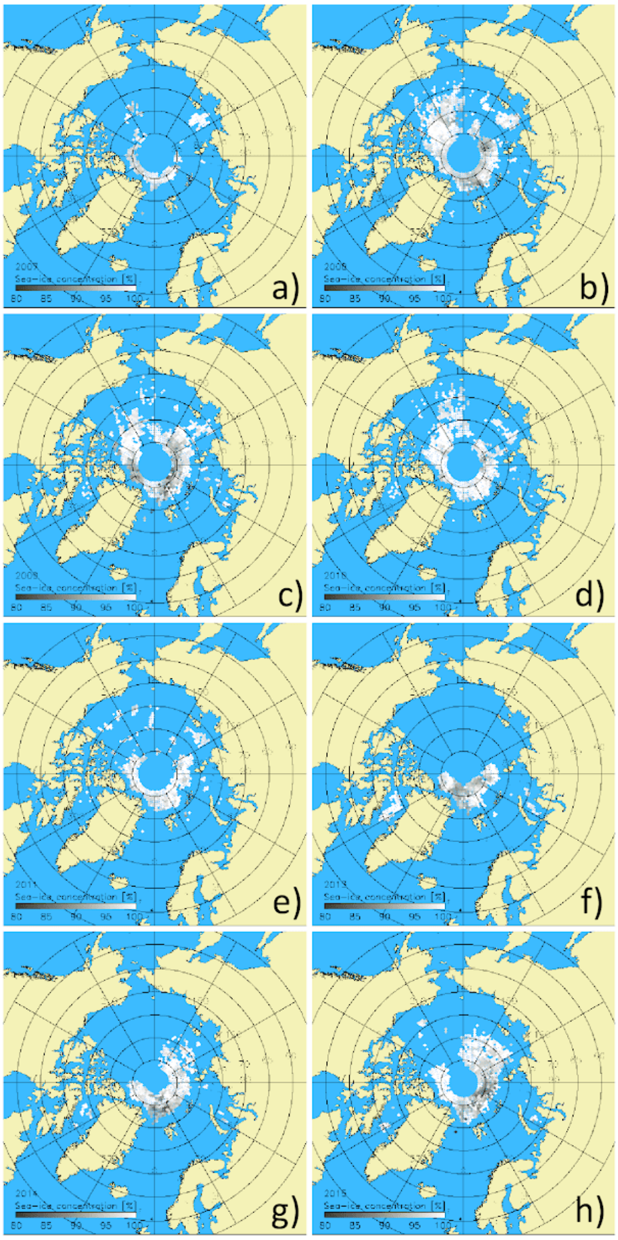


Figure 2.1 Distribution of the co-located near 100% data pairs for AMSR-E years 2007 through 2011 (images a) through e)) and for AMSR2 years 2013 through 2015 (images f) through h)) for the Northern Hemisphere. Shown is the OSI-450 sea-ice concentration of the respective winter months.

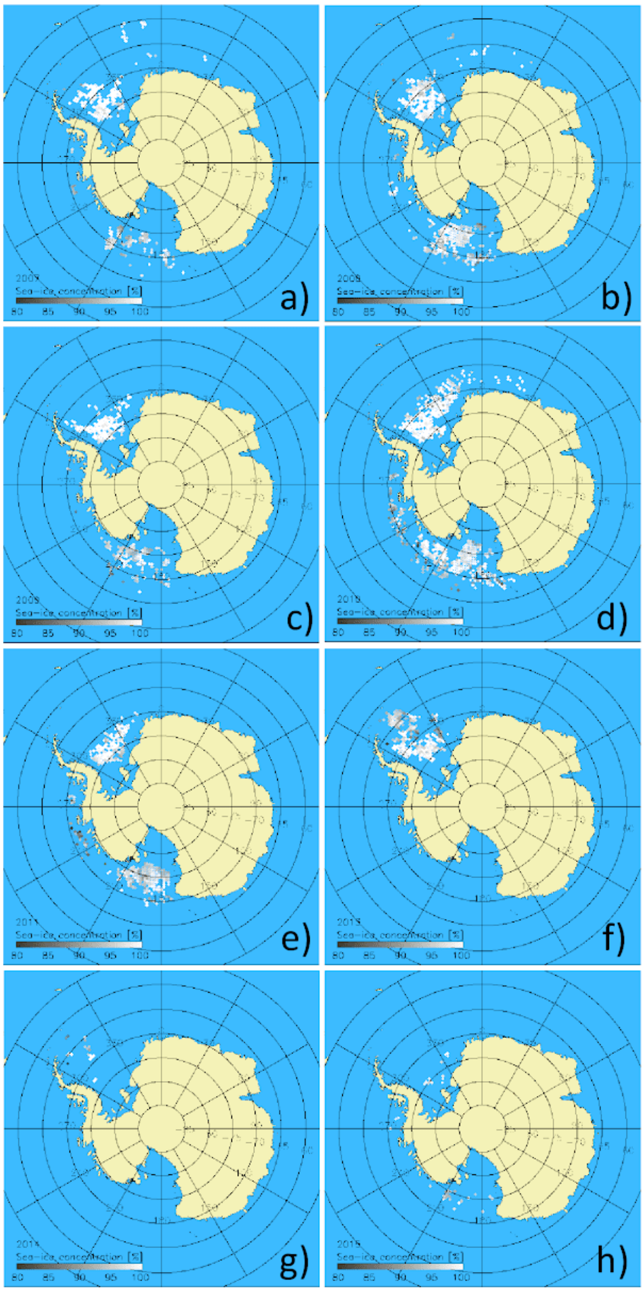


Figure 2.2 Distribution of the co-located near 100% data pairs for AMSR-E years 2007 through 2011 (images a) through e)) and for AMSR2 years 2013 through 2015 (images f) through h)) for the Southern Hemisphere. Shown is the OSI-450 sea-ice concentration of the respective winter months.

2.1.2 Open water SIC evaluation (0%)

In the SIC RRDP2 data set, the Open Water evaluation data are extracted at fixed locations close to the climatological sea-ice extent zonal maximum during Winter and Summer respectively. Different locations have been chosen for summer and winter in order to account for the seasonal variation of the sea-ice extent. We use five locations in the Northern Hemisphere and five (winter) and four (summer) locations in the Southern Hemisphere.

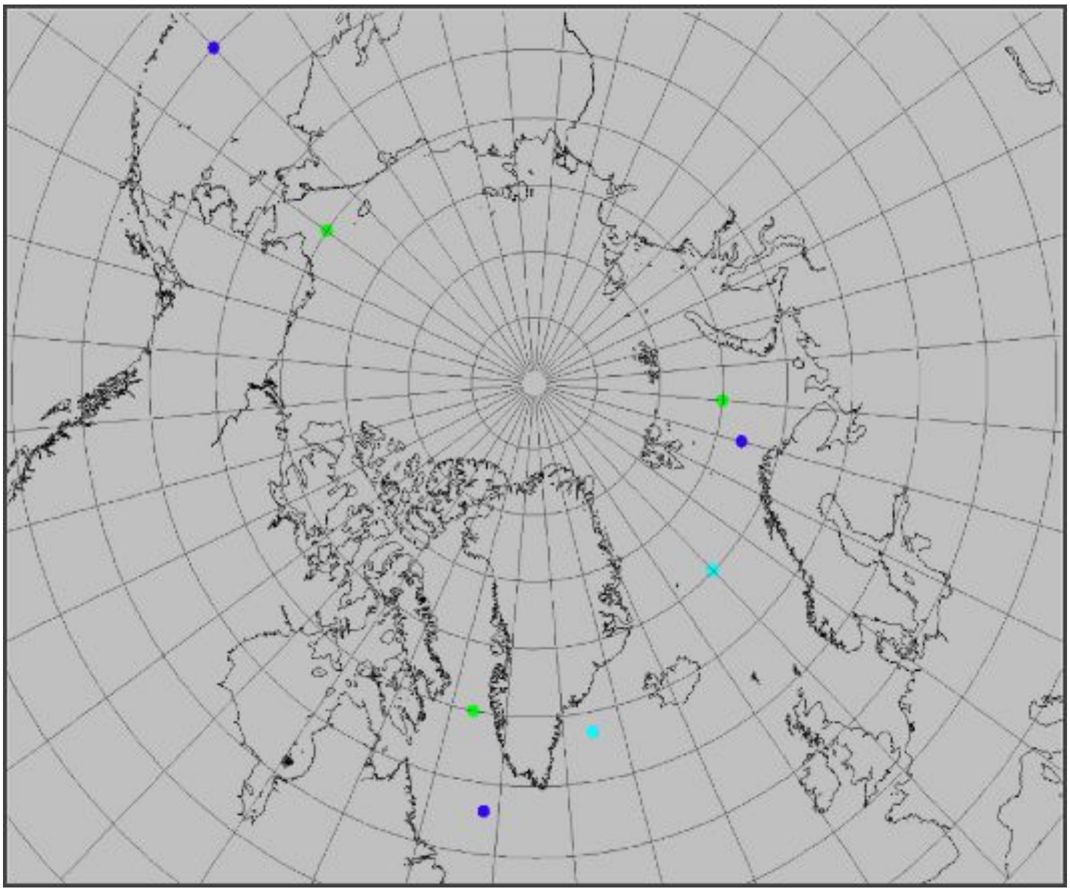


Figure 2.3. Location of 0% ice concentration reference data points for the Northern Hemisphere. Cyan coloured points are for Summer and Winter, Blue locations are used in Winter only and Green points are for Summer only.

2.1.3 Collocation and evaluation metrics

At the 100% SIC locations, we co-locate the sea-ice concentrations of the products with the selected AOI grid cells by computing the minimum distance between AOI grid cell centre and grid cell centre of the respective sea-ice concentration product. For this step, we convert the geographic coordinates of all data sets into cartesian coordinates taking into account the different projections. The 100% SIC locations are only available during winter months (see above). During these winter months, we additionally test the sensitivity to the 2m-air temperature from ERA-Interim, which is also included in the RRDP2 data set. For example, we can constrain the collocation to those AOIs with an ERA-Interim 2m-air temperature below -10°C.

The co-location to the Open Water locations is similarly done via finding the product grid cell at smallest distance. The OW validation data exists for all months, and we consider both winter and summer seasons: January / February, i.e. Northern Hemisphere winter and Southern Hemisphere summer, and August / September, i.e. Northern Hemisphere summer and Southern Hemisphere winter.

We evaluate the sea ice concentration products at their native grid resolution and do not apply any spatial averaging. For each product, we compute the mean difference to truth (“product minus 100%" or "product minus 0%") and its standard deviation, as well as the cumulative distribution function of the differences.

For both 0% and 100% SIC evaluation, the un-filtered and non-thresholded SIC products are used.

At the 100% SIC locations, using the filtered SIC product does not result in meaningful validation because the variability of the SIC values around 100% (caused by the variability of the brightness temperatures around the ice tie point(s)) is altered by the threshold at 100% (only the lower half of the histogram is available). The impact of using thresholded vs non-thresholded fields during evaluation of SIC products at 100% SIC locations is discussed in depth in Kern et al. (2019, *under review*).

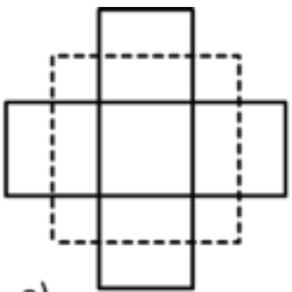
At the 0% SIC locations, the unfiltered SIC product is used. Using the filtered SIC product does not result in meaningful validation because the true variability of the SIC values around 0% (caused by the variability of the used brightness temperatures around the open water tie point) is fully suppressed by the weather filter. However, the variability of both the brightness temperatures and the retrieved SIC is a measure of the quality of the correction of the weather influence by the radiative transfer modeling applied, the suitability of the tie points used, and the selected SIC algorithm.

In addition to the retrieved SIC we can also compare the retrieval uncertainty and the total uncertainty at these locations.

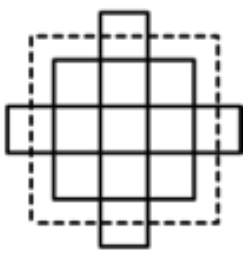
2.1.4 Collocation at different resolutions

During SICCI Phase 2, we investigated whether the evaluation results would substantially depend on the grid resolution at which the collocation was conducted. We thus repeated the evaluation procedure at 50 km, by averaging the two CDRs with the finer grid resolution, i.e. 12.5 km (SICCIHF) and 25.0 km (SICCILF) to a coarser 50 km grid.

One obvious way to do this would be to block-average the finer resolved CDRs onto the grid with 50 km grid resolution. This would, however, change the center coordinate of the grid cells co-located with the validation data grid cells. Therefore, in order to benefit from the more precise co-location at the two finer resolved CDRs we averaged the SIC over grid cells adjacent to the co-located grid cell at 25 km and 12.5 km grid resolution as illustrated in Figure 2.4. At least three of these grid cells need to have valid values to be used for the evaluation.



a)



b)

Figure 2.4 Illustration of grid cells used for the 25 km product (a) and the 12.5 km product (b) to approximate the area covered by the 50 km product (dashed square) and compute ~50km averages of the SIC and its retrieval error.

It turns out that this does not change the evaluation results substantially. For open water (SIC = 0%), the precision (bias) does not change by more than 0.1% in both hemispheres. The accuracy deteriorates by 0.1% to 0.2% in the Northern Hemisphere and improves by 0.1% to 0.2% in the Southern Hemisphere. The retrieval uncertainties do not change. For sea ice (SIC = 100%), the precision (bias) does not change by more than 0.1% in both hemispheres – if it changes at all. The accuracy improves by 0.1% to 0.2%. The retrieval uncertainties do not change.

2.2 Inputs new data EMSR

The ESMR data period in the 1970s only allows our procedure for validating the SICs at 0% ice concentration, whereas a 100% ice concentration dataset does not exist (no SAR ice drift and deformation data are available for the 1970s) and will thus be very difficult to establish.

2.3 New validation data in RRDP+

The existing Round Robin Data Package from previous phases of the CCI project will constitute the majority of our validation data for the new and updated datasets. This will allow a direct comparison of previous and new versions.

The RRDP will be extended into the more recent years (up until 2019 or 2020) for both SIC0 and SIC1, using exactly the same procedures as before. An extension into the 1970s for the SIC0 will also be established as explained in section 2.2.

2.4 Schedule, Access and Quality Control

The RRDP already exists and the automated procedures for validation (section 2.6) will be implemented during the first 9 months of 2019, in order to be able to validate the first new dataset at the end of 2019. The new automated procedure will at the same time be used to reproduce validation results obtained during Phase 2 for the existing SICCI and OSISAF datasets, to check reproducibility of the method.

2.5 Format

The RRDP is a set of ASCII text files with columns of latitude, longitude, time and reference sea ice concentration as well as selected co-located NWP and auxiliary satellite data.

2.6 Strategy for semi-automated validation procedures

All SIC datasets from previous versions as well as new versions will be in the same format, so an automated validation procedure is being implemented that allows an easy comparison between each dataset and the reference 0% and 100% sea ice concentration datasets in the updated RRDP. For each datapoint in the reference dataset, co-located ice concentrations, uncertainties and other relevant metadata will be extracted and summary statistics similar to the ones shown in Figure 2.5 below will be produced.

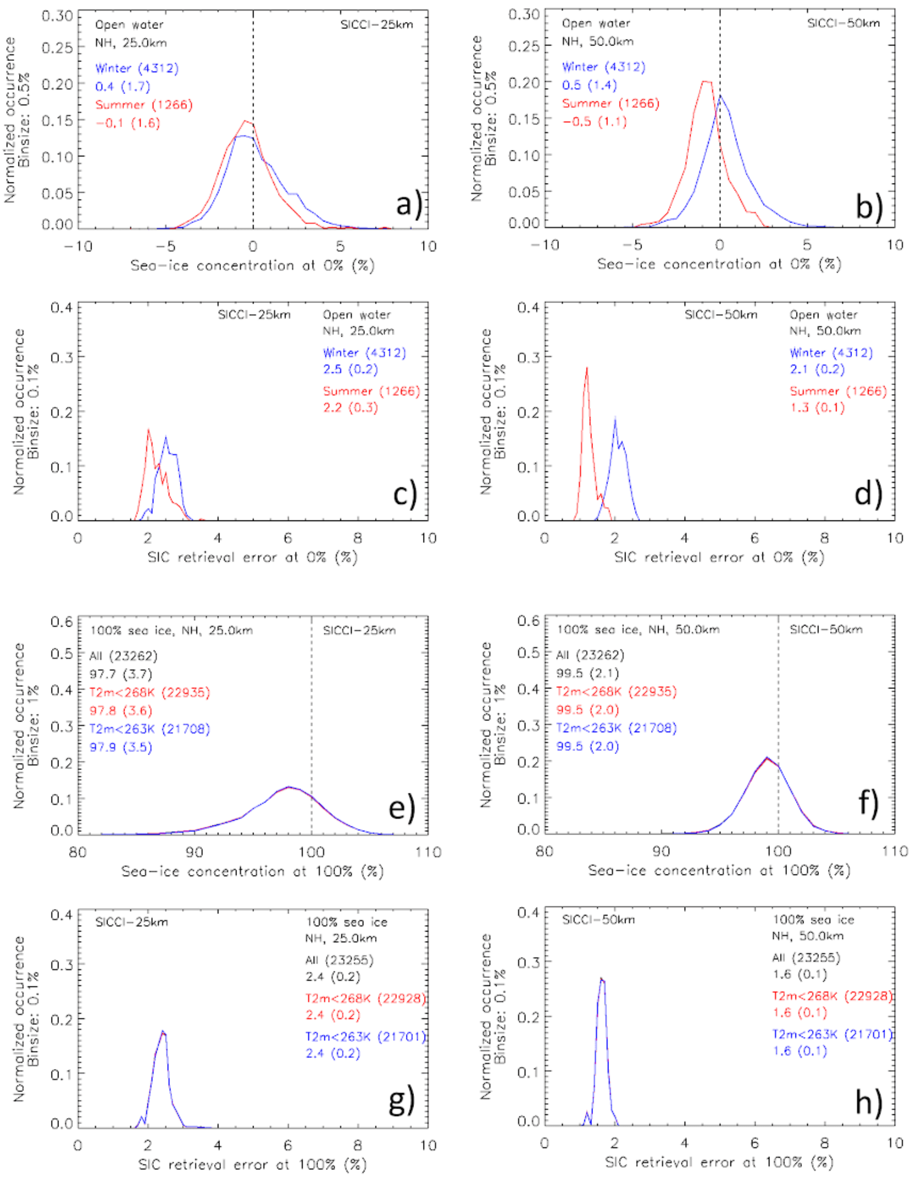


Figure 2.5 a) to d) Distribution of the difference 0% minus SICCI 2 SIC (SIC error) at the RRDP 2 open water locations in the Northern Hemisphere (left hand side) together with the distribution of the SIC retrieval error at these locations (right hand side) for SICCI-25km (a, b) and SICCI-50km (c, d). Winter (Jan./Feb.) and summer (Aug./Sep.) values are denoted in blue and red, respectively. e) to h) Distribution of the sea-ice concentration and the retrieval error at the RRDP 2 near-100% reference SIC locations in the Northern Hemisphere for SICCI-25km (e, f) and SICCI-50km (g, h). Curves in black, red and blue denote all data, data with co-located

ERA-Interim 2m-air temperature < -5degC and < -10degC, respectively. Values of the statistics: mean (standard deviation) are given in respective colors.

3 SEA ICE THICKNESS RRDP

3.1 Current state (SICCI)

SICCI phase 2 sea ice thickness (SIT) and sea ice freeboard (SIF) products are available for the time period 2002-2012 based on ENVISAT (SGDR v2.0) and the period 2010-2017 based on CryoSat-2 (Baseline C) for the Arctic and Antarctic Regions. For the Arctic only data from October to April are included, whereas the experimental data set for Antarctica covers year-round estimates of SIT and SIF. The latest version 2.0 of the SICCI SIT and SIF products were released June 20, 2018.

3.1.1 Validation data

Here is a short summary of validation data included in validation of the SICCI-2 SIT product, as included in PVIR (SICCI-PVIR-P2-SIT v1.1). As the SICCI-2 SIT and SIF product version 2.0 was released too late to be included in the latest version of the PVIR, most of the evaluation work is based on the previous dataset version 1.0 or even version 0.9. The only difference between v1.0 and v0.9 is related to the uncertainties of the products, and does not affect the SIT and SIF. Version 2.0 provides a number of improvements, compared to previous versions (v1.0), which include improved sea-ice thickness retrievals from ENVISAT data, an experimental data record in the southern hemisphere, the delivery of trajectory-based Level 2 products and the availability of freeboard data in Level 2 and 3 products.

Arctic:

- In situ measurements of sea ice freeboard, sea ice thickness and snow depth from North Pole Drifting Station NP37-39, October-April 2009-2012
- Airborne electromagnetic (EM) sounding of total sea ice thickness Arctic March (<5%)/April 2003-2014
- Moored upward looking sonar (ULS) of sea ice draft from Norwegian Polar Institute (NPI) Fram Strait moorings 2002/03-2012/13 and Beaufort Gyre Exploration Project (BGEP) 2003/04-2014/15
- NASA Operation IceBridge (OIB) airborne sea ice freeboard obtained from snow depth from snow radar and total sea ice freeboard from ATM March/April 2009-2016 (IDCS4 2009-2013, quiklooks 2013-2016)

Antarctic:

- In situ measurements of sea ice thickness from ASPeCt-BIO 2002-2007
- Airborne electromagnetic (EM) sounding from ISPOL 2004-2005, WWOS Sep/Oct 2006, and ANTXXIX/6 and /7 in 2013 (AWECS)
- Moored upward looking sonar (ULS) from AWI ULS Weddell Sea (2003-2012)

In addition to evaluate SICCI-2 SIF and SIT products to the above listed observations a considerable amount of evaluation efforts was carried out by inter-comparison of independent other sea-ice thickness data sets (ICESat and other CS-2 products).

3.1.2 Round Robin Data Package Phase 2 (RRDP-2)

As the original plan was to use the RRDP-2 for other purposes than validation work it only includes SIF, sea ice draft and snow depth data. The data included is listed below and plotted in the maps of Figure 3.1:

RRDP-2:

Arctic:

- In situ measurement of sea ice freeboard and snow depth from North Pole Drifting Stations NP37-39, October-April 2009-2012
- Sea ice draft from Beaufort Gyre Exploration Project (BGEP) moored upward looking sonars (ULS) 2003/04-2014/15
- NASA Operation IceBridge (OIB) airborne sea ice freeboard obtained from snow depth from snow radar and total sea ice freeboard from ATM March/April 2009-2016 (IDCS4 2009-2013, quiklooks 2013-2016)
- Snow depth from Alfred Wegener Institute (AWI) drifting snow depth buoys 2013-2016
- Observations of snow depth and air surface temperature from drifting ice mass balance (IMB) buoys from Cold Region Research and Engineering Laboratory (CRREL) 2006-2015

Antarctic:

- NASA Operation IceBridge (OIB) airborne total freeboard from ATM IDCS4 October 2009/2010
- Snow depth from Alfred Wegener Institute (AWI) drifting snow depth buoys 2013-2016

The observations in the RRDP-2 have been prepared to match the satellite scales; thus the airborne observations are averaged in 50km sections along-track, and observations from drifting buoys are averaged by using standard EASE grid cells of 50km. If the buoys are left in one grid cell for more than 30 days, a new mean is calculated, see an example of AWI snow depth buoy 2014S10 in Figure 3.2.

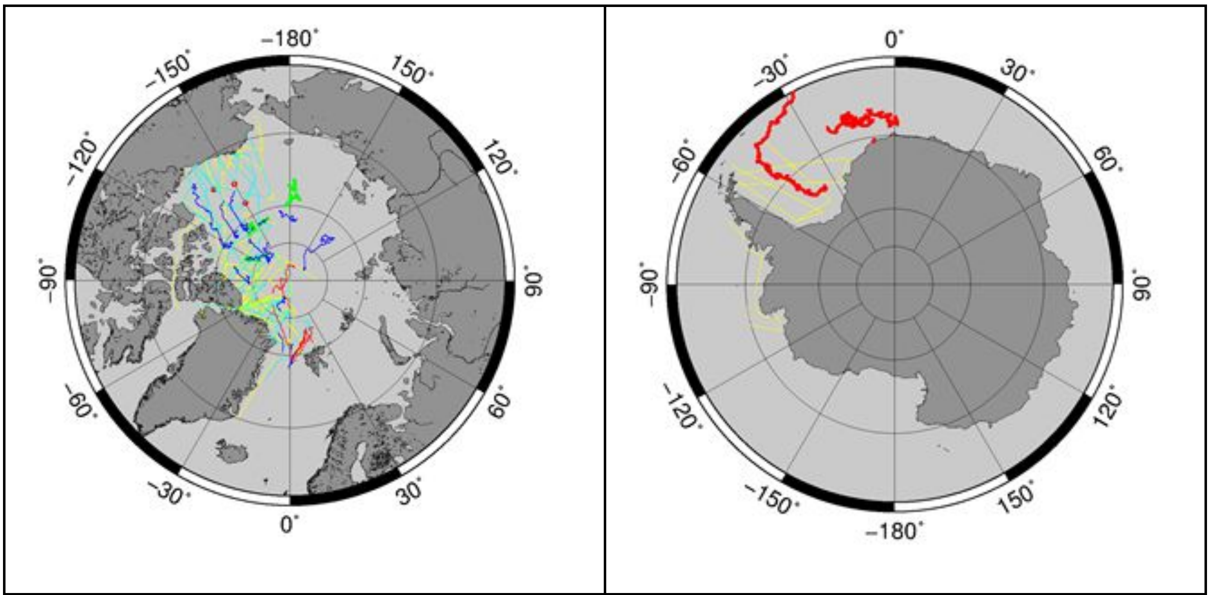


Figure 3.1: Overview of sea ice freeboard, draft and snow depth observations included in the existing RRDP-2; OIB IDCS4 (yellow) and quicklooks (cyan), ULS BGEP (red dots), NP drifting stations (green), IMB CRREL (blue) and Snow depth buoys AWI (red lines).

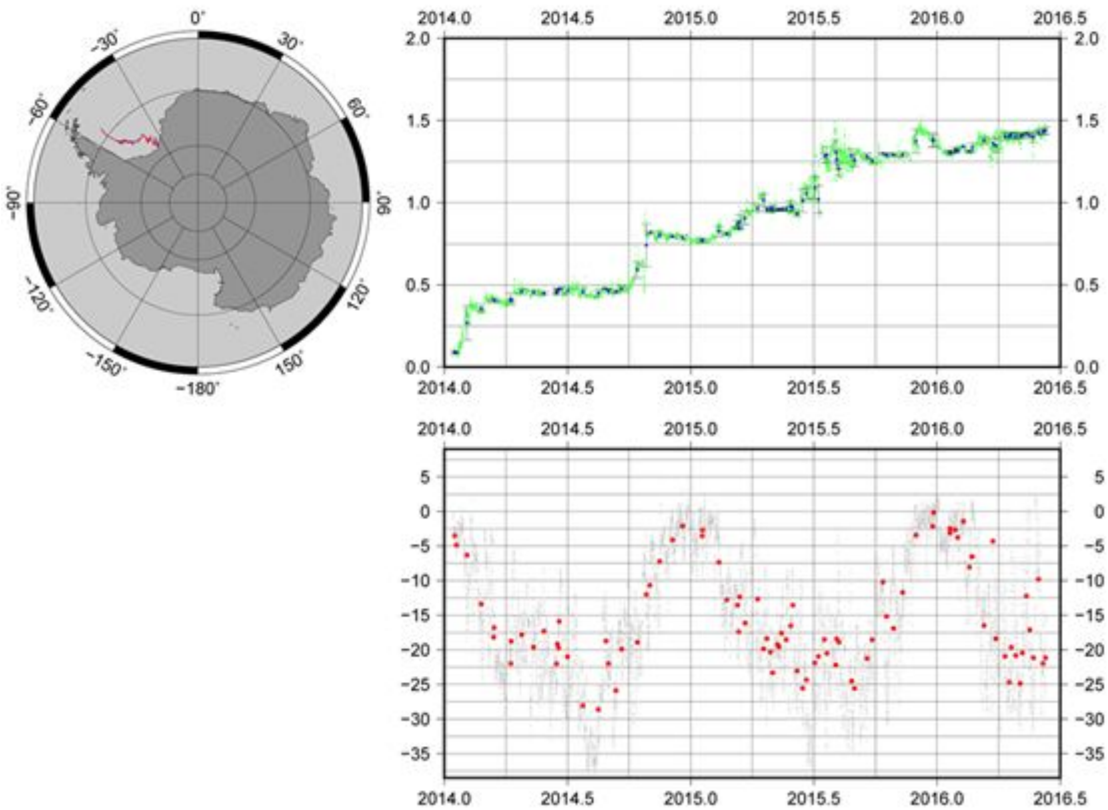


Figure 3.2: Example of snow depth (upper plot) and air surface temperature (lower plot) from AWI drifting snow depth buoy 2014S10 in the Weddell Sea. The blue/red dots are the averaged observations included in the RRDP-2.

3.2 Inputs new data (ERS-1/2, S3, CS2 post SICCI)

The primary task of SICCI+ SIT is to extent the current SICCI-2 time series (2002-2017) back in time (1991-2002) to include SIT estimates based on ERS-1/2, together with time series post 2017 based on CryoSat-2 and potential Sentinel-3 for both hemispheres. Also the existing products, as described in Section 3.1 will be updated with new planned versions of ENVISAT (SGDR v3.0) and CryoSat (Baseline D).

3.2.1 Validation data

In SICCI+ the RRDP+ will include all validation data used throughout the project. Thus, one of the main tasks of the validation work is to update the existing RRDP-2 to include existing SICCI-2 validation data (see Section 3.1), together with inclusion of data to support validation in the extended time-periods 1991-2002 and post 2017, but also to include new available validation data published post SICCI-2.

As was the case during SICCI-2 a considerable amount of evaluation was carried out by inter-comparing independent other sea-ice thickness data sets (ICESat and other CS-2 products which were outside the RRDP-2) the majority of SICCI+ evaluation will be based on a similar kind of data included in the RRDP+.

Special focus will be given to validate products in the overlap periods between ERS-1/2 and ENVISAT to get a consistent multi-mission time series.

As the largest uncertainties in the SIT production chain is by converting the sea ice freeboard (SIF) into thicknesses [Giles et al (2007)] primarily due to the lack of knowledge of the seasonal variation in the snow depth, the validation work will evaluate SIF and SIT independently taking advantage of the nature of the various validation data sets.

Validation of SIT products from updated ENVISAT (SGDR v3.0) and CryoSat (baseline D) includes inter-comparison to previous versions of CCI SIT. Dedicated sub-tasks will be given to validate level-4 product of gap-filled pole hole by use of North Pole Environmental Observatory (NPEO) ULS data, and validation of SIT product from feasibility study (WP 2230) using radar freeboard to thickness conversion based on PM brightness temperatures. Example geographical and yearly distribution of the NPEO data set is shown in Figure 3.3.

3.3 New validation data in RRDP+

The validation of SICCI+ SIT products will make use of existing RRDP-2 and validation data as reported in SICCI-2 PVIR from CCI covering 2002-2016 for both hemispheres. Additional, the RRDP will be updated to include validation data (primarily submarine data) covering the ERS-1/2 era 1991-2003, but also to extend the time series beyond CCI 2002-2017 time series covered by CryoSat-2 and Sentinel-3A/B.

Input RRDP+:

- RRDP-2 as described in Section 3.1
- SICCI-2 validation data as described in Section 3.1
- Sea ice draft from Submarine data SCICEX cruises 1993-1997, 2005, 2011, (2012), 2014, (2016) primarily to validate ERS-1/2 products
- Submarine data from HMS Tireless to validate ERS-1/2
- Sea ice draft from NPEO ULS moorings 1991-2016 to validate ERS-1/2 and gap-filled pole hole level-4 product
- AWI sea ice draft from moored ULS, Antarctic, to validate ERS-1/2
- Sea ice draft from ULS/ADCP mooring in Laptev Sea (2003 - 2016)
- CryoSat-2/Sentinel-3 Beyond 2016
    - NASA Operation IceBridge (2016-2019)
    - ESA CryoVEx campaign data (2016-)
    - AWI IceBird (2016-)
    - MOSAiC (2019-2020)
    - Beaufort Gyre Exploration Project (2016-)
    - CRREL/AWI ice mass balance buoys (2016-)
    - North Pole Environmental Observatory ULS from drifting stations (2016-)

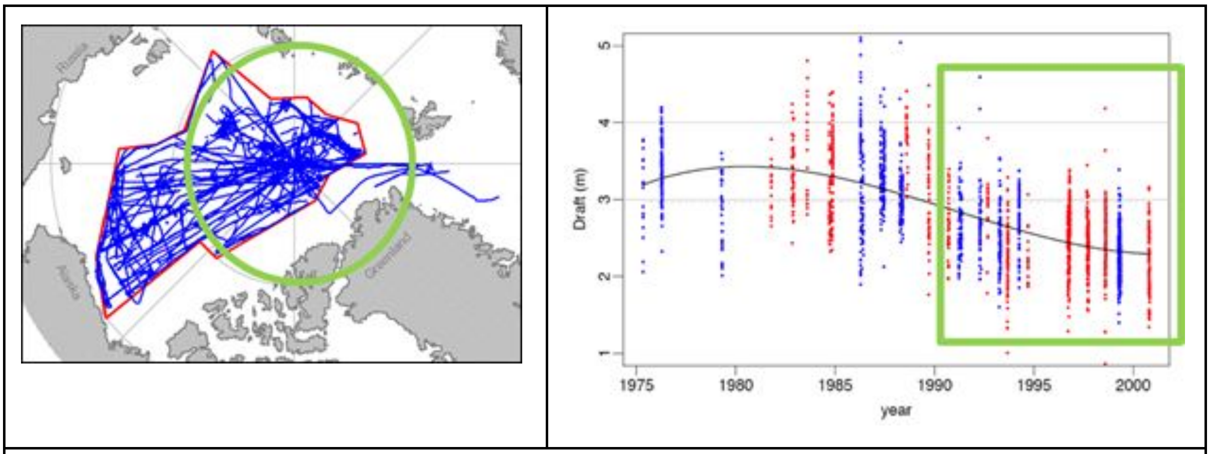


Figure 3.3: Geographical and yearly distribution of SCICEX submarine cruises with markings of 81.5N ERS-1/2, ENVISAT and Sentinel-3 pole hole and timeline of CCI+ time series.

3.4 Schedule, Access and Quality Control

The validation work will follow the yearly cycles of the product evaluation plan as described in ADP. For each cycle the RRDP+ will be updated with new available validation data covering the extended periods of the updated SIT product, and a complete validation will follow of the updated output products taking advantage of the extended RRDP+. According to the evaluation plan, the validation work in specific cases has to be carried out multiple times, thus a dedicated emphasis will be made to automatize the validation work routines.

Outcome of the validation of SIT and SIF products are reported in the product validation report (PVIR D4.1), which is updated after each validation cycle. Following the final cycle of year 3, the RRDP+ will be published and assigned a DOI. All data described above is available to the CCI team.

The three yearly cycles and related validation work is described below:

Year 1:

- Extend existing CCI RRDP to include available in situ data to allow validation of the extended time period covering ERS-1/2 (1991-2003) and extension of CryoSat-2/Sentinel-3
- Extend existing CCI RRDP to include SIT validation data used in CCI
- First validation of updated ENVISAT (SGDR v3.0) and CryoSat (baseline D) including intercomparison to previous versions of CCI SIT
- First validation of Sentinel-3A/B L2 ICE (if available)

Year 2:

- First validation of ERS-1/2 SIT and SIF
- Include new validation data from 2019 in RRDP
- Updated validation of 2019 years CS2, S3
- Validation of Level 4 product of gap-filled pole hole by use of North Pole Environmental Observatory (NPEO) ULS data
- Validation of SIT product from feasibility study WP 2230 using radar freeboard to thickness conversion based on PM brightness temperatures

Year 3:

- Include new validation data from 2020 in RRDP
- Final validation of ERS-1/2, ENVISAT, CS2, S3 SIF and SIT products

3.5 Collocation

In order to compare the validation data with the satellite observations these should be averaged to similar geographic and temporal scales. Different methods for co-locating the validation and SIT/SIF products have been applied during SICCI-2, see SICCI-2 PVIR. In general airborne observations are averaged in 50km sections along-track, and observations from drifting buoys or stations are averaged by using standard EASE grid cells of 50km. If the buoys are left in one grid cell for more than 30 days, a new mean is calculated. Point measurements e.g. moored upward looking sonars have been averaged over 30 days to sample the monthly satellite measurements.

An example of collocated sea ice thickness from AWI IceBird airborne EM and CryoSat-2 observations of total thickness is provided in Figure 3.4. This comparison show excellent correlation (0.9) using a subset of CryoSat-2 data covering only the 7 days of airborne observations instead of a full month. For the SICCI+ it is possible to form such sub-sets of the SICCI+ SIT/SIF products for validation purposes. This approach will be optimized for each of the validation data sets to achieve the most optimal inter-comparison between validation data and/or satellite missions.

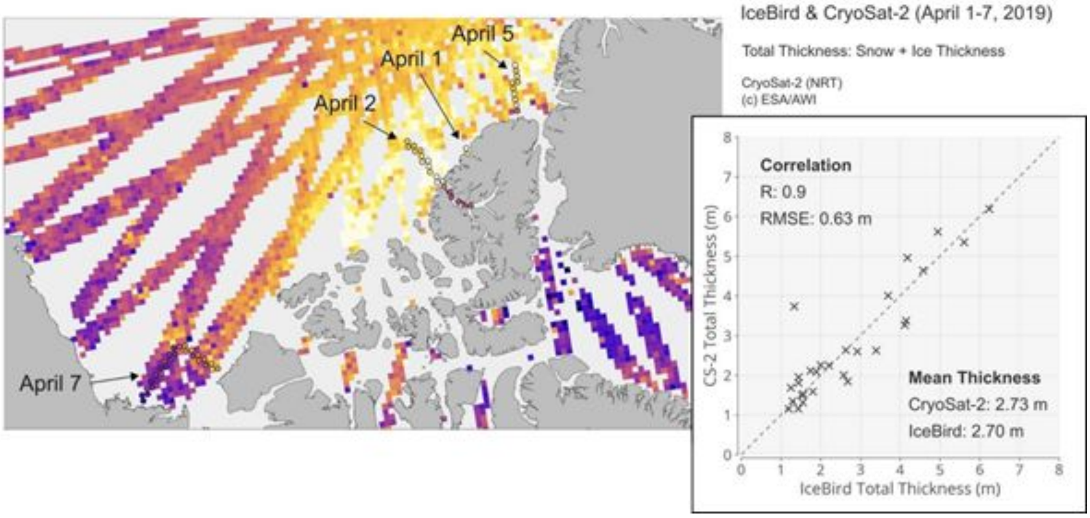


Figure 3.4: Example of collocated sea ice thickness from AWI IceBird airborne EM and CryoSat-2. This comparison show excellent correlation (0.9) using subset of CryoSat-2 data covering the 7 days of airborne observations.

3.6 Format

As the volume of the spatial and temporal averaged validation data is rather small each validation data set is compiled in ASCII files.

4 REFERENCES

Andersen, S., Pedersen, L. T., Heygster, G., Tonboe, R. T., and Kaleschke, L.: Intercomparison of passive microwave sea ice concentration retrievals over the high concentration Arctic sea ice, J. Geophys. Res., 112, C08004, https://doi.org/10.1029/2006JC003543, 2007.

Kern, S., Lavergne, T., Notz, D., Pedersen, L. T., Tonboe, R. T., Saldo, R., and Soerensen, A. M.: Satellite Passive Microwave Sea-Ice Concentration Data Set Intercomparison: Closed Ice and Ship-Based Observations, The Cryosphere Discuss., https://doi.org/10.5194/tc-2019-120, in review, 2019.

Kwok, R.: Sea ice concentration estimates from satellite passive microwave radiometry and openings from SAR ice motion, Geophys. Res. Lett., 29(9), 1311, https://doi.org/10.1029/2002GL014787, 2002.

Pedersen, L. T., Saldo, R., Ivanova, N., Kern, S., Heygster, G., Tonboe, R. T., Huntemann, M., Ozsoy, B., Girard-Ardhuin, F. and Kaleschke, L.: Reference dataset for sea ice concentration, https://doi.org/10.6084/m9.figshare.6626549.v6, https://figshare.com/articles/Reference_dataset_for_sea_ice_concentration/6626549, 2019.