Ocean & Sea Ice SAF

Global Sea Ice Edge and Type Validation Report

GBL SIE OSI-402-c and GBL SIT OSI-403-c

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The EUMETSAT
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1.1	10.04.2015	SAA	Amended according to comments from the ice review
2.0	26.05.2016	SAA	Inclusion of Metop-B ASCAT, F18 SSMIS and introduction of new sensor GW1 AMSR2. New: Section 2.1, Chapter 4 and 5. Validation of Southern Hemisphere is delayed due to validation algorithm problems.
2.1	01.09.2016	SAA	Amended according to review comments. Major changes are: Inclusion of summer data (May-August 2016) and validation on Southern Hemisphere.

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Glossary

SSMIS	Special Sensor Microwave Imager/Sounder.
AARI	Arctic and Antarctic Research institute.
AMSR2	Advanced Microwave Scanning Radiometer 2.
ASCAT	Advanced Scatterometer.
ATBD	Algorithm Theoretical Basis Document.
CDOP	Continuous Development and Operations Phase.
DMI	Danish Meteorological Institute.
DMSP	Defense Meteorological Satellite Program.
EUMETSAT	European Organization for the Exploitation of Meteorological Satellites.
GCOM-W	Global Change Observation Mission for Water.
GW1	GCOM-W1.
HL	High Latitude.
JAXA	Japan Aerospace Exploration Agency.
MET-Norway	Norwegian Meteorological Institute.
Metop	Meteorological Operational polar satellite program.
MODIS	Moderate-resolution Imaging Spectroradiometer.
NH	Northern Hemisphere.
NIC	U.S. National Ice Service.
OSI SAF	Ocean and Sea Ice SAF.
OSI-402	OSI SAF Sea Ice Edge product.
OSI-403	OSI SAF Sea Ice Type product.
PMW	Passive Micro Wave.
PUM	Product User's Manual.
SAF	Satellite Application Facility.
SAR	Synthetic Aperture Radar.

SH   Southern Hemisphere.

SIE   Sea Ice Edge.

SIT   Sea Ice Type.

SSM/I   Special Sensor Microwave/Imager.

STD   Standard deviation.

WMO   World Meteorological Organization.

1. Introduction

1.1 The EUMETSAT Ocean and Sea Ice SAF

For complementing its Central Facilities capability in Darmstadt and taking more benefit from specialized expertise in Member States, EUMETSAT created Satellite Application Facilities (SAFs), based on co-operation between several institutes and hosted by a National Meteorological Service. More on SAFs can be read from www.eumetsat.int.

The Ocean and Sea Ice Satellite Application Facility (OSI SAF) is producing on an operational basis a range of air-sea interface products, namely: wind, sea ice characteristics, Sea Surface Temperatures, Surface Solar Irradiance and Downward Longwave Irradiance. The sea ice products include Sea Ice Concentration, Sea Ice Emissivity, Sea Ice Edge, Sea Ice Type, Sea Ice Drift, and latest also Sea Ice Surface Temperature (from mid-2014).

The OSI SAF consortium is hosted by Météo-France. The sea ice processing is performed at the High Latitude processing facility (HL centre), operated jointly by the Norwegian Meteorological Institute (MET-Norway) and Danish Meteorological Institute (DMI).

Note: The ownership and copyrights of the data set belong to EUMETSAT. The data is distributed freely, but EUMETSAT must be acknowledged when using the data. EUMETSAT's copyright credit must be shown by displaying the words "copyright (year) EUMETSAT" on each of the products used. User feedback to the OSI SAF project team is highly valued. The comments we get from our users is important argumentation when defining development activities and updates. We welcome anyone to use the data and provide feedback.

1.2 Scope

The purpose of this report is to present validation results for the EUMETSAT OSI SAF global Sea Ice Edge (OSI-402-c) and Sea Ice Type products (OSI-403-c).

1.3 Overview

The global Sea Ice Edge and Sea Ice Type products are both classification products that distinguish between the following classes:

- Sea Ice Edge (OSI-402 series) – distinguish between open water, open sea ice and closed sea ice
- Sea Ice Type (OSI-403 series) – distinguish between first-year ice and multi-year ice.

Both products are multi-sensor products derived from passive and active microwave remote sensing data combined in a Bayesian approach. They are computed for both hemispheres on the standard OSI SAF grid with 10 km spatial resolution.

In the start of the operational production in 2005 the development of the sea ice products used passive microwave data from SSM/I onboard the DMSP satellites. In 2009 ASCAT scatterometer data from Metop-A was introduced in the operationel products of Ice Edge (OSI-402) and Ice Type (OSI-403). In 2013, the SSM/I data was replaced by SSMIS data from DMSP F17, and the products thereby changed label to OSI-402-a and OSI-403-a, respectively [Aaboe et al., 2013]. The two sea ice products improved in 2015 by introducing a dynamical training data set and changed label to OSI-402-b and OSI-403-b, respectively. For the present upgrade, OSI-402-c and OSI-403-c, the following new data are introduced to the analysis:

- ASCAT data from Metop-B, which for a period will run parallel with Metop-A.
- SSMIS data from F18, taking over for F17.
- AMSR2 from JAXA's GCOM-W1 is introduced as an additional sensor.

Note: At present the OSI SAF Sea Ice Type product delivered for Southern Hemisphere classify all sea ice as "ambiguous". The reason for this is that there has still not been carried out enough studies for the Antarctica sea ice classes to do a Southern Hemisphere ice type classification. Similarly for the Northern Hemisphere, in the summer period from mid-May until mid-October the sea ice is classified as "ambiguous". This is due to wet ice and melting ponds on the ice which makes it more difficult to distinguish between first-year ice and multi-year ice.

More detailed information on the algorithm, the input satellite data and technical issues regarding the products, are given in the corresponding *Product User's Manual* [PUM, Aaboe et al., 2016b] and the *Algorithm Theoretical Basis Document* [ATBD, Aaboe et al., 2016a].

See http://osisaf.met.no for real time examples of the products and updated information. General information about the OSI SAF is given at http://www.osi-saf.org.

Section 2 presents the data used for the present validation and Section 3 describes the methodology used for validating the products. Results of the validation of the products and discussions are presented in Section 4 and Section 5 concludes the validation.

2. Data

2.1   Input satellite data

The present upgrade is based mainly on the introduction of the new passive microwave sensor AMSR2 which has higher spatial resolution than the SSMIS. In addition, SSMIS onboard DMSP F18 and ASCAT onboard Metop-B are introduced. For ASCAT there is a period with parallel coverage from Metop-A and -B. In this period all the available data for each sensor are merged and used together (see more details on this in the ATBD [Aaboe et al., 2016a]).

In April 2016, one of the channels on SSMIS onboard F17 got calibration problems and was causing problems for the ice products of concentration, edge and type. Due to this, the OSI SAF team made a switch in mid-April from applying data from F17 to use F18 data in these operational ice products (see information from April 2016 on the OSI SAF HL web page http://osisaf.met.no/news/). In the validation results of ice edge and ice type presented in this report, the SSMIS data from F17 are completely omitted in all of April in order to avoid disturbance in the monthly estimates. The operational and new products for April have been reprocessed using SSMIS data from only F18.

Available satellite data for the present validation is given in Table 1.

| | ASCAT | | SSMIS | | AMSR2 |
	Metop-A	Metop-B	DMSP F17	DMSP F18	GW1
2015 Nov	daily	daily	daily	6.-30.	6.-10.,12.-30.
2015 Dec	daily	daily	daily	daily	daily
2016 Jan	daily	daily	daily	daily	1.-29.
2016 Feb	daily	daily	daily	1.-8.	1.-8.
2016 Mar	daily	daily	daily	9.-31.	9.-31.
2016 Apr	daily	daily	-	daily	1.-15.,17.-30.
2016 May	daily	daily	-	daily	daily
2016 Jun	daily	daily	-	daily	daily
2016 Jul	1.-26.,30.-31.	1.-26.,30.-31.	-	daily	daily
2016 Aug	daily to 25.	daily to 25.	-	daily to 25.	daily to 25.

Table 1: Overview of the available data from the different sensors and satellites used in this validation of the OSI SAF sea ice edge and type products.

Todays operational algorithm for Sea Ice Edge and Sea Ice Type will in the following be referred to as the *Oper*-algorithm. The upgraded algorithm, which products are validated here, is referred to as the *New*-algorithm and it includes all the sensors presented in Table 1 as long as they are available.

The measured brightness temperature received from passive microwave (PMW) sensors needs an atmospheric correction based on numerical model data before they are used in the ice algorithms. Due to an archiving malfunction of the corrected brightness temperatures, the archive at MET-Norway of the new PMW data from F18 and GW1 is at present

limited to the period after November 2015 and in addition lacks data in a larger period from mid-February to mid-March, and a few single days (see Table 1). However, the days with lacking data test out how well the New algorithm performs when AMSR2 data are missing. According to the algorithm desccription in the ATBD [Aaboe et al., 2016a] the SSMIS and AMSR2 data are included into the combined multi-sensor analysis as an optimized PMW field in the following way:

> "The AMSR2 data are prioritized over SSMIS data due to the better sampling resolution. This means, that as default the PMW input to the multi-sensor is based on AMSR2 data only. However, any missing AMSR2 grid data or gaps due to *Gross Error* data, are filled with SSMIS grid data to archive the best possible PMW daily grids at any time to be used as input to the multi-sensor calculations." [Aaboe et al., 2016a, Sec 3.6]

If AMSR2 data are missing the algorithm will still run on the available SSMIS data.

2.2   Validation data set

The OSI SAF sea ice edge product for both the Northern Hemisphere (NH) and the Southern Hemisphere (SH) is validated against ice charts originating from the following operational ice chart divistions:

- DMI (http://www.dmi.dk/en/groenland/hav/ice-charts/)

- MET-Norway (http://polarview.met.no/)

- USA National/Naval Ice Center (NIC) (http://www.natice.noaa.gov/)

- Russian Arctic and Antarctic Research Institute (AARI) (http://www.aari.ru).

The ice charts will be used as "ground truth" against which the OSI SAF ice edge product will be compared. As the ice charts are manual interpretation of satellite data (mainly SAR), they are not proper in situ data. The ice categories used in the ice charts are representative for a larger area, as the ice charter draws polygons. Even so, these charts are the best available source for validation.

2.2.1   Ice charts from Northern Hemisphere

At the ice charting division at DMI is produced ice charts covering Greenland Waters. The validation against these charts is carried out at DMI on a weekly basis.

On a daily (weekdays) basis the Norwegian Ice Service at MET-Norway produces ice charts which cover the area from the Fram Strait to the Barents Sea with main emphasis on the Svalbard area. An example of Svalbard ice chart from the 3rd of November 2014 is shown in Figure 1.

The ice charts are to a large extent based on a subjective interpretation of high resolution satellite data, predominantly Sentinel-1 Extra-Wide and RADARSAT-2 ScanSAR Wide but also some COSMO SkyMed, MODIS optical images, and AMSR-2 sea ice concentration
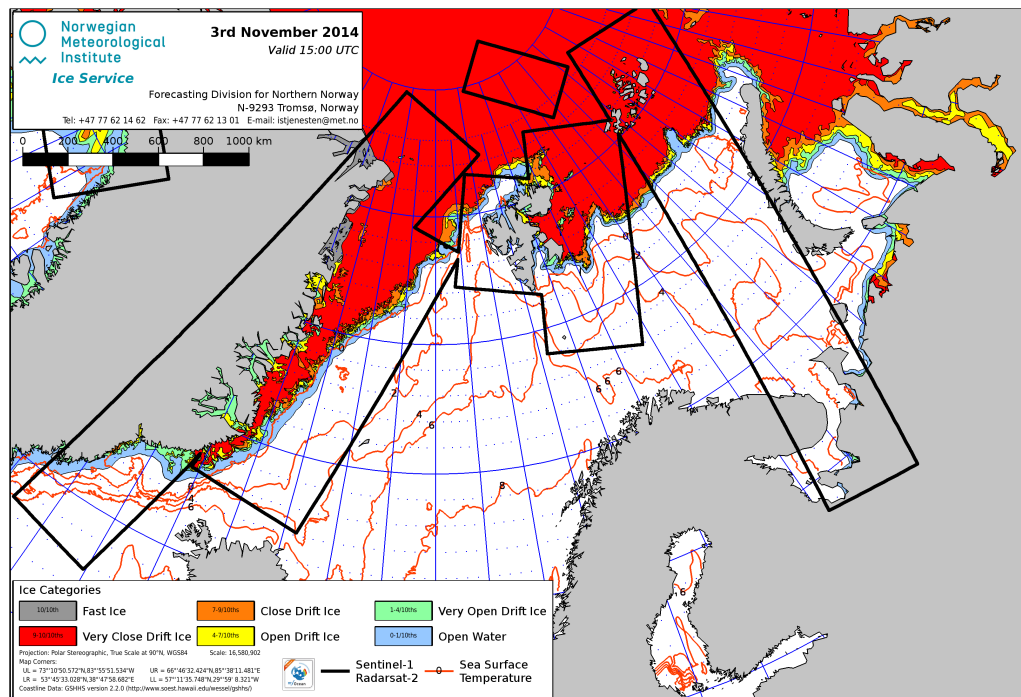
Figure 1: Svalbard region ice chart dated 3rd November 2014 from the Norwegian Ice Service (http://polarview.met.no/). The colors, labeled in the lower left box, indicate the ice concentration where *red* indicates highest concentration and *blue* the lowest concentration. Red lines represents isolines of the sea surface temperature. The regions marked with black boxes indicate where detailed SAR (in this case Sentinel-1 and RADARSAT-2) data existed that day.

from University of Bremen. The detailed interpretation of satellite images and a subsequent mapping procedure are carried out by skilled (experienced and trained) ice analysts.

In areas where high resolution data are not available for subjective analysis the ice analyst might use SSMIS data and OSI SAF products. Therefore, for each MET-Norway ice chart, the ice analyst select target areas where detailed SAR data are available for their subjective interpretation. Only these areas are qualified as being an independent source for the OSI SAF ice products and can be used in the validation. In the ice chart example in Figure 1, the black boxes represent such target areas which are used in the validation.

2.2.2   Ice charts from Southern Hemisphere

In operation, the Southern Hemisphere OSI SAF sea ice edge product is today validated with a pixel-by-pixel comparison (see Section 3.1.1) against the weekly ice charts produced at the U.S. National Ice Center.

In addition, a collaborative Antarctic sea ice product is now developed since 2016 between the U.S. National Ice Center (NIC), Arctic and Antarctic Research Institute (AARI), and Nor-

wegian Ice Service (MET-Norway) which provides a weekly comprehensive Antarctic chart throughout the year. This new collaborative product will be continuous and will also include more high resolution products due to each institutes ability to share efforts [P. Wagner, Norwegian Ice Service, pers. comm., April 14th 2015]. Ice charts are available since December 2014 on the project webpage http://ice.aari.aq/antice. MET-Norway provides a weekly Weddell Sea ice chart during the Southern Hemisphere summer period - mainly between October and April, whereas the ice charts form NIC and AARI cover the entire Antarctic sea ice region. All the Southern Hemisphere ice charts are developed from satellite data collected within the previous days - typically 2-4 days, but up to maximum 7 days. In Figures 2 and 3 are shown examples of the ice charts from the different ice services from the 2016-03-29 and 2016-03-31, respectively.
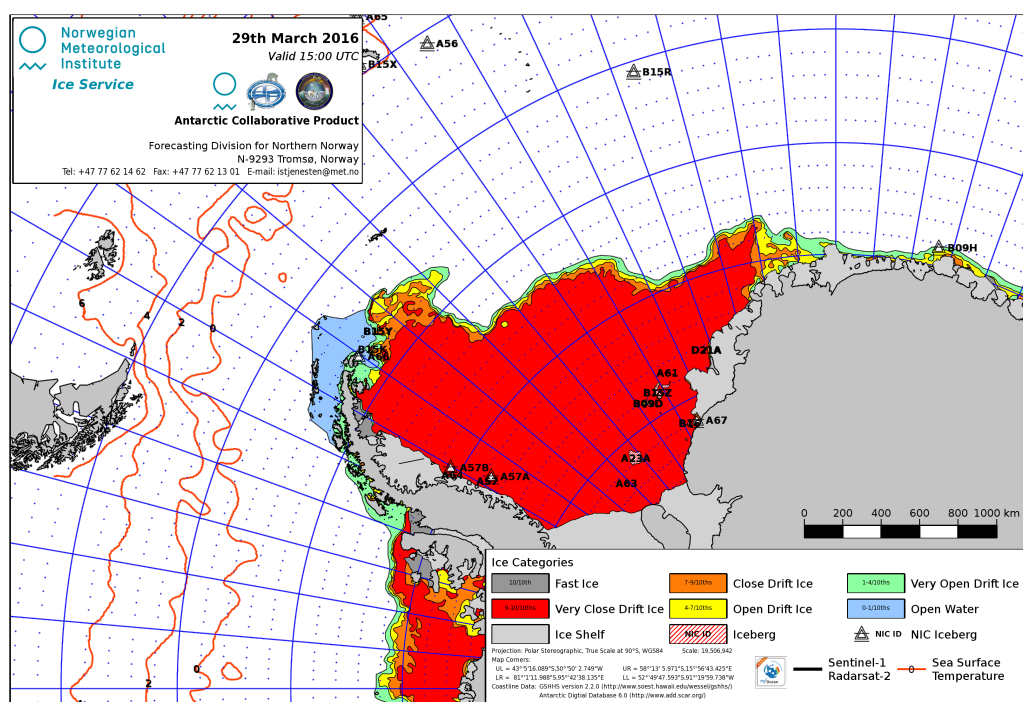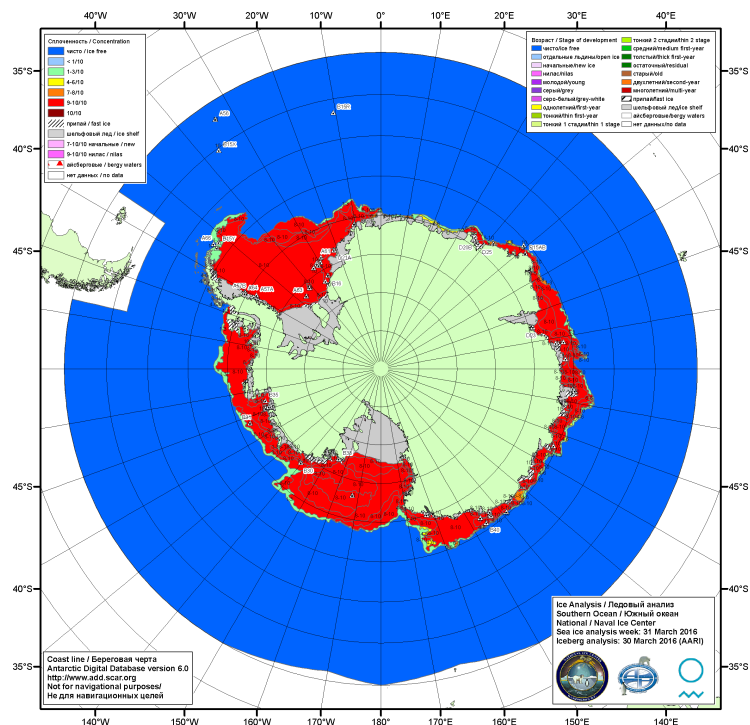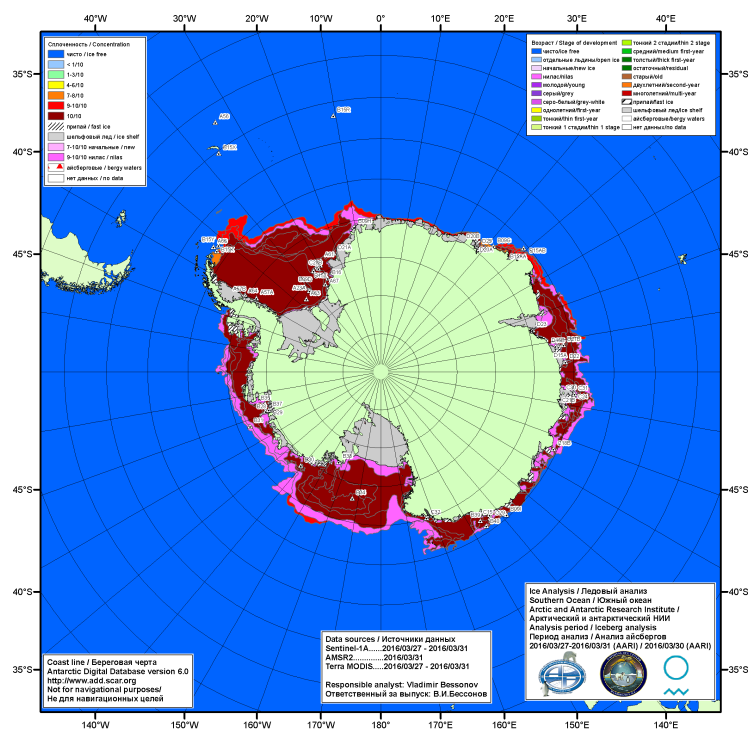

Figure 2: Weddell Sea ice chart produced on the 29th of March 2015 at the Norwegian Ice Service (http://polarview.met.no/). The colors, labeled in the lower left box, indicate the ice concentration where *red* indicates highest concentration and *blue* the lowest concentration. Red lines represents isolines of the sea surface temperature.

(a) NIC

(b) AARI

Figure 3: Antarctic sea ice charts produced on the 31th of March 2016 at (a) NIC and (b) AARI, (http://ice.aari.aq/antice). The color code for the ice concentration is labeled in the upper left box, and indicates *red/dark red* for the highest ice concentration and *blue/-green/yellow* for the lowest concentration.

3. Validation methodology

The quality control of OSI SAF edge and type products is twofolds: the continuous validation of the operational product presented in the Half Yearly Reports, and the quality control after a new upgrade of the algorithm which is presented in this report. The method is the same for both cases.

3.1 Sea ice edge

The comparison of the OSI SAF ice edge product against the ice charts is evaluated in two ways:

- The pixels within the validation area are compared, pixel by pixel, and the occurrences of agreements/disagreements between the ice chart and the OSI SAF product are counted.

- The mean distance between the two ice edges is calculated (in km)

The pixel-by-pixel comparison gives an overall validation of the product, while the distance between the two ice edges gives details of the most interesting area around the ice edge.

The real ice edge partly depends on the scale one is observing on and the ice charts have much higher resolution than the OSI SAF product. Therefore, before the comparison, the ice chart is averaged onto the OSI SAF grid, which is a polar-stereographic grid with 10 km spatial resolution.

The ice charts give ice concentration from 0% (no ice) to 100% (fully ice-covered sea), whereas the OSI SAF ice edge product has the classes *open water*, *open ice*, and *closed ice*. In order to compare the two products a threshold must be drawn for the ice charts, determining what to classify as "ice" and what to call "ice free". Here, ice concentrations higher than or equal to 35% are considered to classify as "ice", and the lower ice concentrations are translated to "no ice". The threshold of 35% corresponds to the boarder between the WMO sea ice nomenclature "very open drift ice" with ice concentration within the range $\frac{1}{10}$ to $\frac{3}{10}$ and the "open drift ice" with concentration range $\frac{4}{10}$ to $\frac{6}{10}$ (WMO publication No. 259, Suppl. No. 4).

	OSI SAF classes	Ice chart concentration
ice	*open ice*, *closed ice*	$\geq 35\%$
no ice	*open water*	$< 35\%$

3.1.1   The *match* between ice products by pixels

Within the validation area a pixel-by-pixel comparison is carried out between the two gridded ice products, and the occurrences of each of the following four possibilities are counted:

1. *no ice* in OSI SAF and *no ice* in the ice chart

2. *no ice* in OSI SAF but *ice* in the ice chart

3. *ice* in OSI SAF but *no ice* in the ice chart

4. *ice* in OSI SAF and *ice* in the ice chart

In case *1 (no ice, no ice)* and *4 (ice, ice)* the OSI SAF product agrees with the ice chart. The term *match* is defined as the probability of "true" detection of ice or no ice:

$$match = \frac{N_1 + N_4}{N} \cdot 100\% \tag{3.1}$$

Here, N_1 and N_4 represent the number of pixels with occurrence *1* and *4*, respectively. N is the total number of pixels used in the comparison, that is $N = N_1 + N_2 + N_3 + N_4$. In order to see if the OSI SAF sea ice cover has a bias toward either underestimating or overestimating the sea ice cover in the ice charts the following two terms for the OSI SAF product are also defined:

$$underestimate = \frac{N_2}{N} \cdot 100\% \tag{3.2}$$

$$overestimate = \frac{N_3}{N} \cdot 100\% \tag{3.3}$$

Here, N_2 and N_3 represent the number of pixels with occurrence *2* and *3*, respectively. The three terms *match*, *underestimate*, and *overestimate* add up to 100%.

3.1.2   The mean distance between product ice edges

The following is done for each pixel within the validation area:

> When a pixel in the ice chart is found to contain ice (according to the threshold set above), the surrounding eight pixels are checked. If any of these eight belong to the category *no ice*, the ice chart ice edge is located. The next step is then to find the distance to the nearest (*ice, no_ice*) neighboring pair of pixels in the OSI SAF product. The nearest pixels are checked first, and then expanding to pixels further away until an OSI SAF ice edge is found and the distance (*dist*) is computed.

The *mean edge difference* is defined as the average of the calculated distances for all the *edge*-pixel:

$$mean\_edge\_difference = \frac{\sum_i dist(i)}{N_{edge}} \tag{3.4}$$

Here, $dist(i)$ is the edge distance calculation for a single edge-pixel (i), and N_{edge} is the total number of edge-pixels for which a distance is calculated. The $mean\_edge\_difference$ is given in km.

Note, that if the status flag for a pixel in the OSI SAF ice edge product is anything other than *nominal*, the pixel is skipped and does not contribute to the validation. Pixels near land or near areas of missing data, or pixels lacking ice information for other reasons are thereby not allowed to reduce the quality of the validation. Conference the PUM [Aaboe et al., 2016b] for a list of possible status flags.

At present, the edge distance validation is only carried out operationally for MET-Norway Svalbard ice charts. However, with the new collaborative Antarctic sea ice chart product (see Section 2.2.2), the edge distance validation has started for the Southern Hemisphere ice edge product. The results are presented in this validation report, but are at present not included in the OSI SAF half-yearly operations report.

3.1.3   Target accuracy for sea ice edge

The target accuracy for the OSI SAF sea ice edge product is defined in the OSI SAF CDOP-2 Product Requirement Document [OSI SAF project team, 2016]. In this document it is stated that the OSI SAF global sea ice edge has the following accuracy requirements:

Target accuracy - NH: 20 km distance to ice edge (yearly average)
Target accuracy - SH: 45 km distance to ice edge (yearly average)

There is no accuracy requirement for the *pixel-by-pixel* comparison.

3.2   Sea ice type

3.2.1   Monitoring of the ice type variability

The multi-year ice is assumed not to have rapid changes in the horizontal coverage, and therefore the OSI SAF ice type product quality assessment is done as a monitoring of the temporal variation of the multi-year ice area coverage.

The monitoring is in two steps:

1. Monitoring of the daily differences of the area extent of the multi-year ice from its 11-days running mean. According to the assumption of no rapid changes, these daily differences should not be too large in periods with normal data input.

2. Calculation of the monthly standard deviation (STD) in the daily difference from step 1.

In days with spatial gaps due to missing satellite input data the estimates of the multi-year ice area can be influenced if the gaps are within this region. Therefore days where missing data area exceeds 200.000 km^2 are removed before the monthly statistics are carried out. The monthly std (in step 2) of the multi-year ice area coverage is used to monitor the variability of the *detrended* product where the 11-days running mean has been removed from the daily area extent.

3.2.2   Target accuracy for sea ice type

The target accuracy for the OSI SAF sea ice type product is defined in the OSI SAF CDOP-2 Product Requirement Document [OSI SAF project team, 2016]. In this document it is stated that the global sea ice type has the following accuracy requirements:

Target accuracy: 100.000 km^2 monthly std in difference from running mean.

4. Results and discussion

For the present validation of the OSI SAF global sea ice products, the Sea Ice Edge and Sea Ice Type have been reprocessed for the period from November 2015 to August 2016 with both the upgraded *New* algorithm and todays operational algorithm (*Oper*) for comparison. Here, results from the Northern Hemisphere and the Southern Hemisphere are presented.

4.1 Validation of sea ice edge

In Figure 4 is shown a single day example from April 2016 of the Sea Ice Edge outcome from the *New*-algorithm based on AMSR2 and ASCAT data and the *Oper*-algorithm based on SSMIS and ASCAT data. Along the ice edge is seen more details and smaller scale features are captured in the *New* product compared to the the *Oper* product. By manual inspection of the outcomes for the whole reprocessed 10-months period, this is a general difference between the two products for both Southern Hemisphere and Northern Hemisphere whenever AMSR2 data are present. Below in Figure 5 are picked out three examples

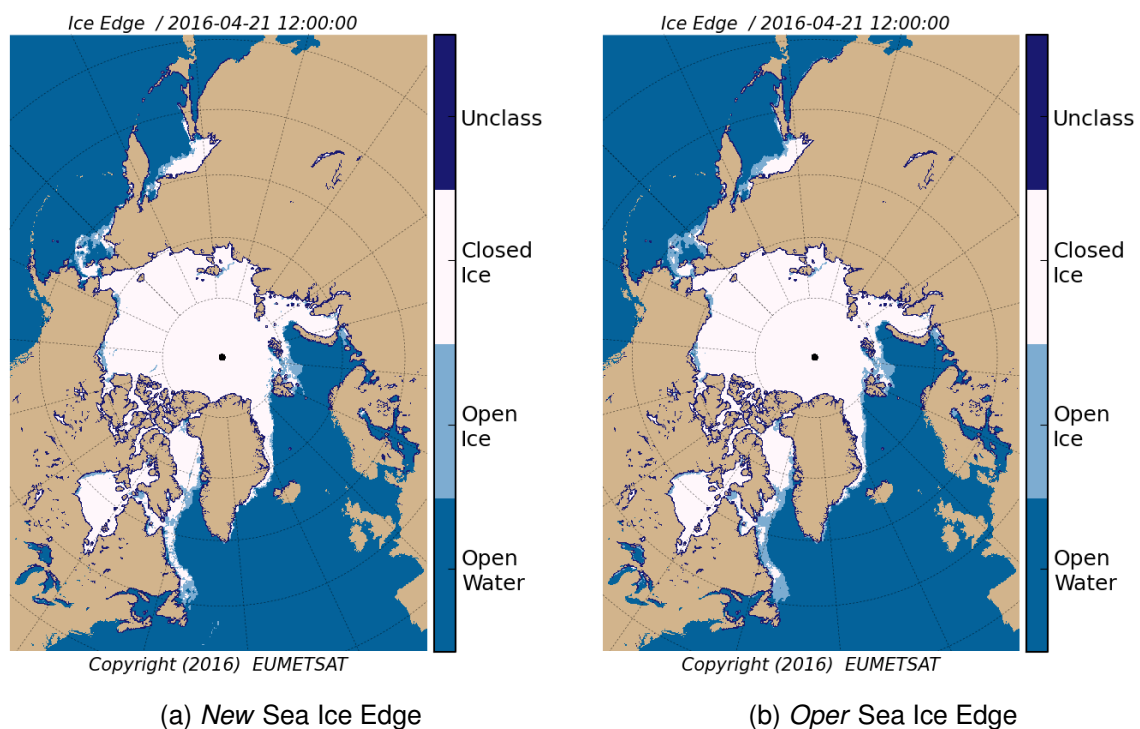(a) *New* Sea Ice Edge   (b) *Oper* Sea Ice Edge

Figure 4: OSI SAF Sea Ice Edge for the Northern Hemisphere (2016-04-21): (a) *New* Sea Ice Edge based on AMSR2 and ASCAT, and (b) *Oper* Sea Ice Edge based on SSMIS and ASCAT.

where the higher resolution from including AMSR2 differs from todays operational product. All three examples are from the region around Svalbard which is the part of the marginal ice

zone that has the largest variability. For comparison the MET-Norway ice charts based on SAR date are included in Figure 6 for the corresponding days.

In the ice chart from the 14th of December 2015 (Figure 6a) a long and narrow tongue of open drift ice is stretching from the northeast toward south of the small island *Kong Karls Land*. This is well reproduced by the *New* Sea Ice Edge product seen in Figure 5a but not as good in the *Oper* product in Figure 5b. Similarly, in the end of March 2016, an ice tongue consisting of a mixture of open and close drift ice almost reached the Bear Island south of Spitsbergen, see Figure 6b. This feature is captured very well in the *New* product (Figure 5c) which also shows both open and closed ice toward the Bear Island. In the *Oper* product this ice pattern is not reproduced at all on this day (Figure 5d).

Whereas, the *New* Sea Ice Edge product captures more smaller scale features along the ice edge, it appears that in some periods the AMSR2 product shows more noise in the classification between open ice and closed ice. Figures 5e and 5f show a 'worst case' of this from the 1st of February 2016 where a large region of open ice appears north of the ice edge north of Svalbard in the *New* Sea Ice Edge product. This is much less pronounced in the *Oper* product and in the corresponding ice chart, seen in Figure 6c, no open ice is seen in that region. This open ice noise seems to be an atmospheric effect as it arises suddenly and can last for several days before it dissapears. The dynamic PDF's (Probability Density Functions) for AMSR2 is compared with the PDF's for SSMIS in the ATBD [Aaboe et al., 2016a, Sec 4.1.1] and it shows that the AMSR2 PDF's for the Open Ice class stand out from the SSMIS PDF's by having larger standard deviation for the lower frequencies. This may cause more ice to be classified as open ice. However, at present no smaller adjustments to the algorithm have managed to remove this noise without disturbing other parts of the product. Therefore, the OSI SAF Sea Ice Edge product is mainly meant for localization of the ice edge between ice and water, and not as much meant for differentiating between open ice and closed ice.

4.1.1   Northern Hemisphere

In the following is presented results for NH from the general validation analysis described in Section 3.1.

Figure 7 shows the monthly time series of the *mean_edge_differences* (Equation 3.4) for both the *New* (blue) and *Oper* (red) products compared with MET-Norway ice charts from around Svalbard. The *New* time series shows a better performance than that of the *Oper* algorithm along the ice edge during all the ten months and with a variability between 10.2 km and 31.2 km compared to the 12.6 km to 38.5 km for the *Oper* product. For the target accuracy requirement given in Section 3.1.3 is needed a yearly average which at present is limited to the 10 months from November to August. The 10 months average of the *mean_edge_differences* for both the *New* and the *Oper* products are given in Table 2. Included in the table is the recent annual averages for the operational product for comparison. Both the *New* and the *Oper* products fulfill the accuracy requirement of 20 km, but the average for the *New*-product is more than 3 km closer to 'true' ice edge than the corresponding *Oper* average.

(a) *New* Sea Ice Edge

(b) *Oper* Sea Ice Edge

(c) *New* Sea Ice Edge

(d) *Oper* Sea Ice Edge

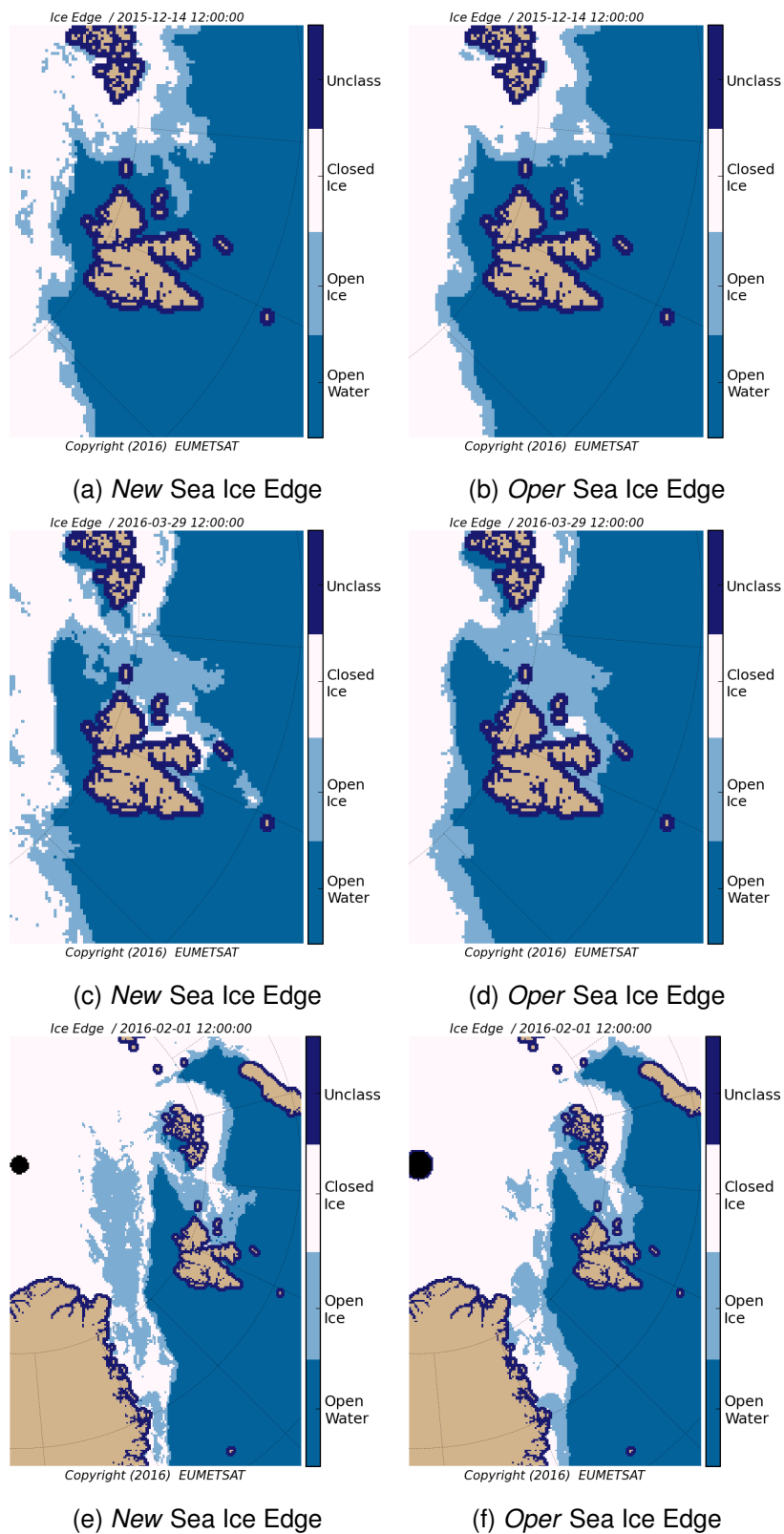(e) *New* Sea Ice Edge

(f) *Oper* Sea Ice Edge

Figure 5: OSI SAF Sea Ice Edge for the Svalbard region with *New*-products in left column and *Oper*-products in right column: (a) and (b) 2015-12-14. (c) and (d) 2016-03-29. (e) and (f) 2016-02-01.
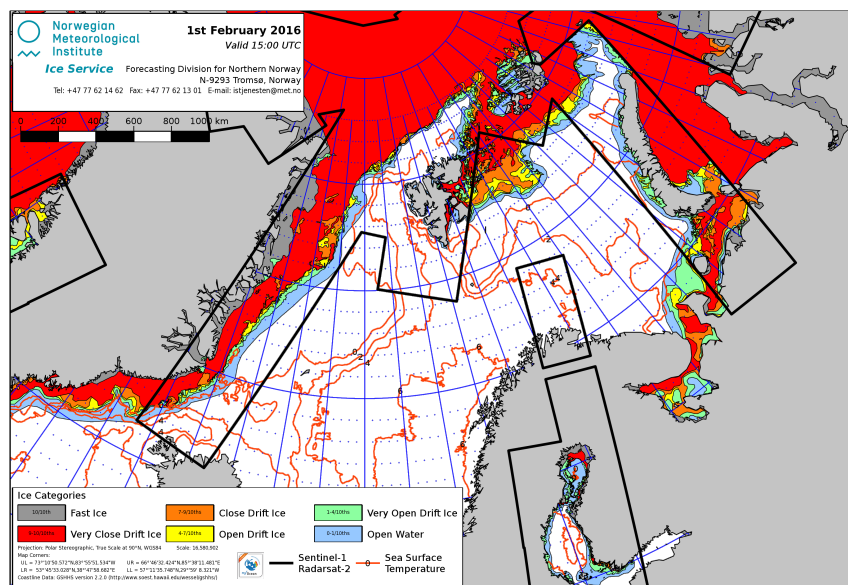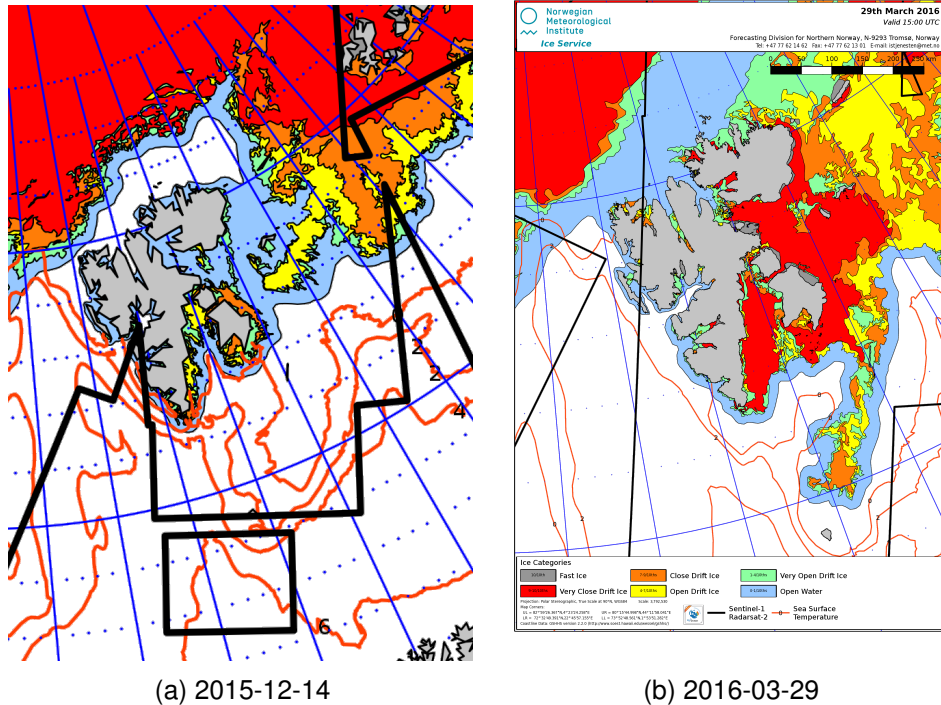
(a) 2015-12-14

(b) 2016-03-29

(c) 2016-02-01

Figure 6: Svalbard region ice charts from the Norwegian Ice Service (http://polarview.met.no/) for three different days: (a) 2015-12-14. (b) 2016-03-29. (c) 2016-02-01. The colors represent different ice classes and are labeled in 6b and 6c

(a) *Mean_edge_difference* [km]

(b) N_{edge}

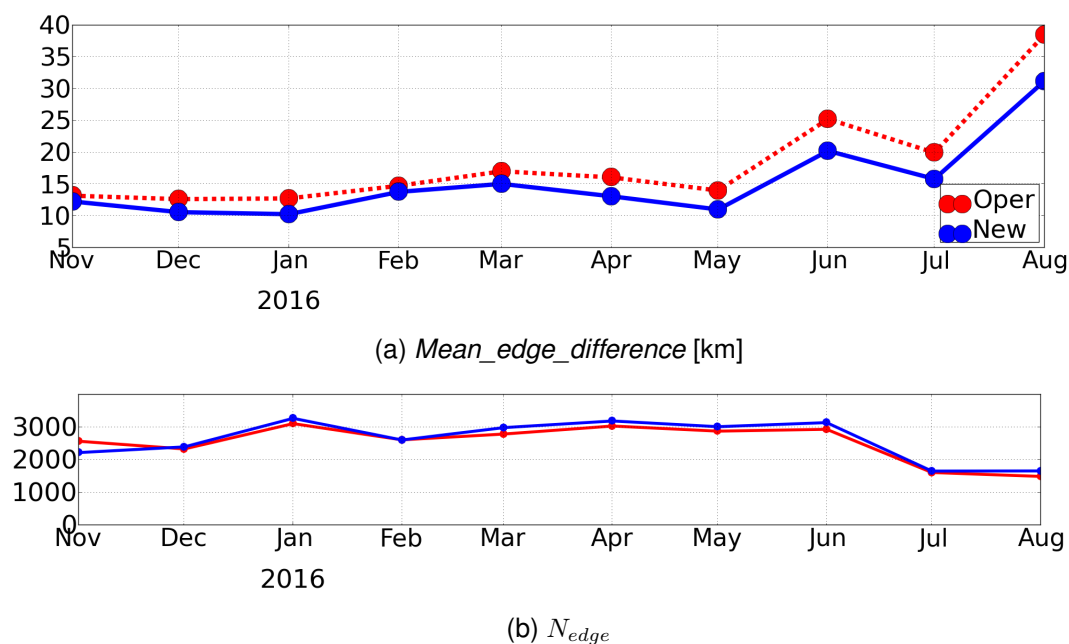Figure 7: Monthly time series of the *mean_edge_difference* validation around the Svalbard region (see Equation 3.4) for the *New* (blue) and the *Oper* (red). (a) The mean distance [km] between the OSI SAF sea ice edge and the ice edge from the MET-Norway ice charts. (b) N_{edge} is the total number of edge-pixels used in the estimate.

Year	Mean_edge_difference [km] *New*	Mean_edge_difference [km] *Oper*	N_{edge}
2015 Nov-2016 Aug	15.33	18.41	26157
2014		17.11	38552
2013		18.28	46248
2012		16.38	55032
2011		19.48	42246
2010		19.29	38383

Table 2: The annual mean distance between the OSI SAF ice edge and the MET-Norway ice chart edge (Northern Hemisphere). The mid-column shows the value resulting from the *New* algorithm, while the right column shows the corresponding values from the *Oper* algorithm. N_{edge} is the total number of edge-pixels used in the estimate.

Figure 8 shows the monthly time series of the pixel-by-pixel comparison [%] between OSI SAF Sea Ice Edge and MET-Norway ice charts around Svalbard. All the three terms of the pixel-by-pixel comparisons, the *match*, the *underestimate*, and the *overestimate*, are very similar for the *New* and the *Oper* products. Despite November 2015, there is a slightly better match for the *New* product to agree with ice chart (see Equation 3.1).

(a) *Match* [%] (see Equation 3.1)

(b) *Underestimate* [%] (see Equation 3.2)
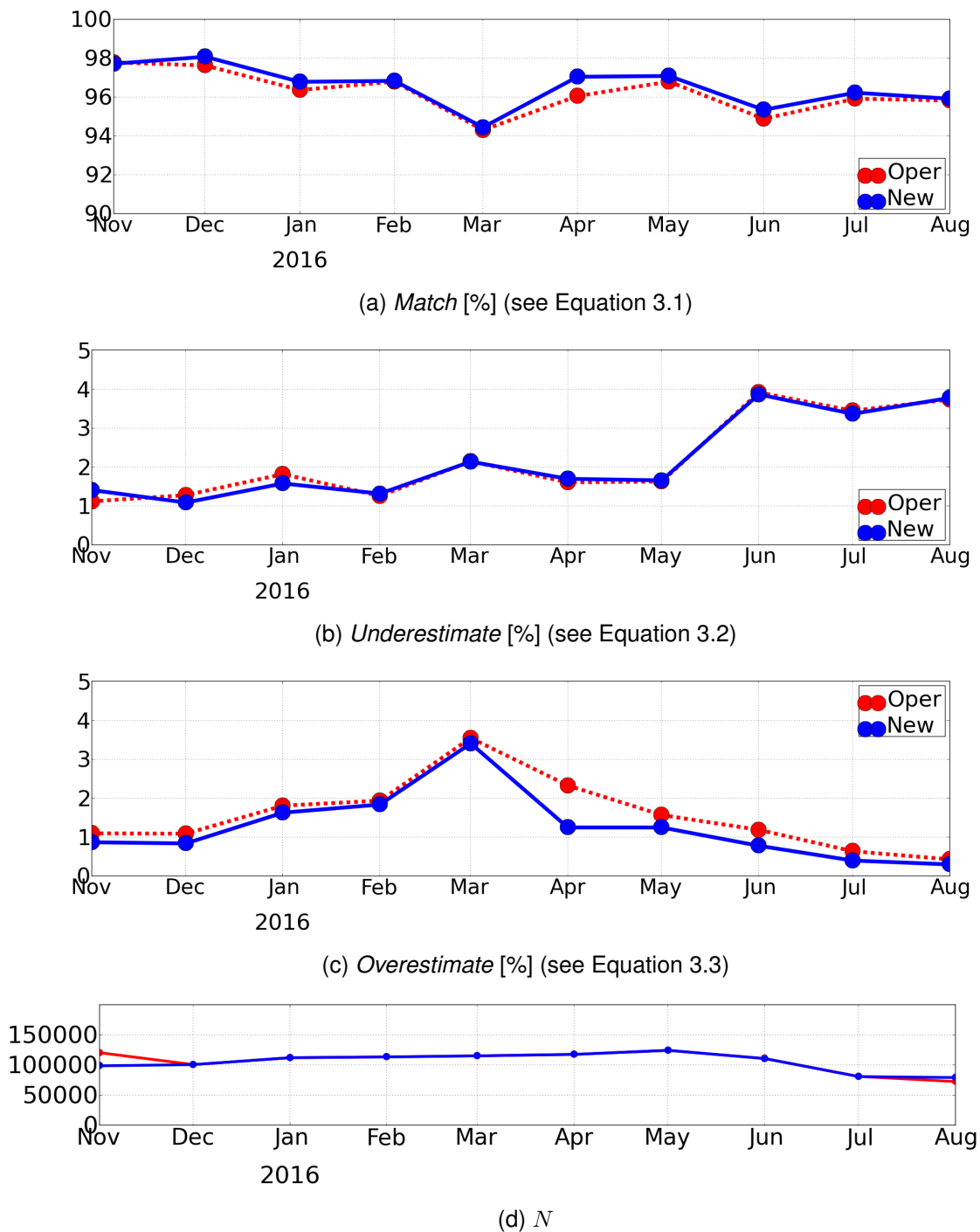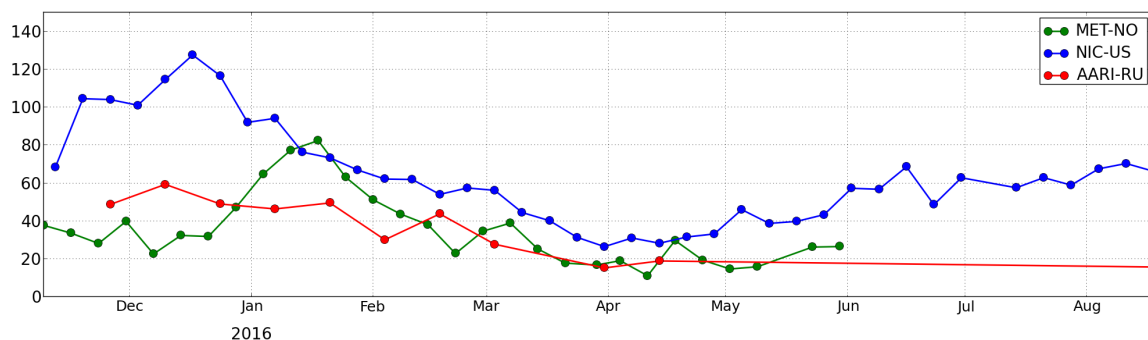

(c) *Overestimate* [%] (see Equation 3.3)

(d) N

Figure 8: Monthly time series of the pixel-by-pixel validation of the OSI SAF Sea Ice Edge product against MET-Norway ice charts around the Svalbard region. The validation is given in terms of (a) *match*, (b) *underestimate* and (c) *overestimate* which are defined in Section 3.1. (d) N is the total number of pixels used in the comparison.
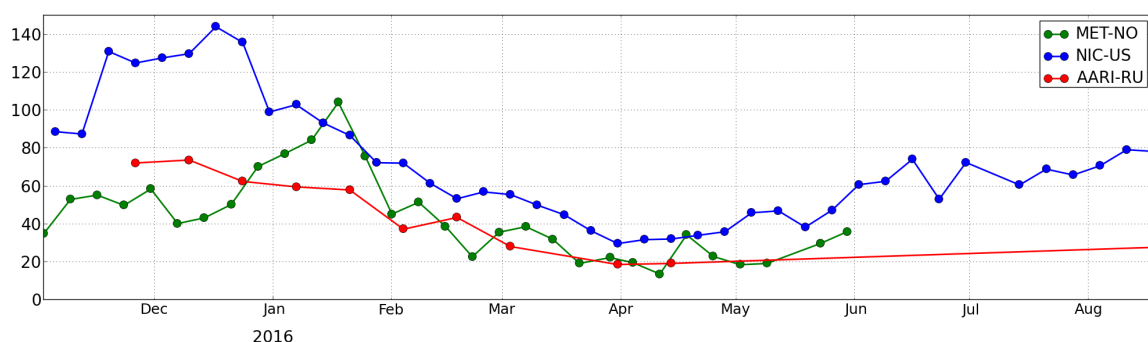
4.1.2   Southern Hemisphere

The OSI SAF Sea Ice Edge product for SH is compared with ice charts from both NIC, AARI and MET-Norway.

Figure 9 shows the weekly time series of the *mean_edge_difference* (Equation 3.4) for each of the three ice centers with NIC (blue) covering the entire 10 months period, MET-Norway (green) covering Southern Hemisphere summer period and AARI (red) with useful icecharts from late November 2015 to mid-April 2016 and then again in August.

In far the most cases the *New* product has a better performance to the weekly ice charts than the *Oper* product. Estimates of the monthly means always show lower distance values for *New* than for *Oper* (not shown here). The monthly values for *New* vary between 20.53–71.70 km, 31.20–109.96 km, and 15.89–53.88 km for MET, NIC and AARI, respectively. Similarly, the monthly values for *Oper* vary between 23.47–85.19 km, 33.73–127.04, and 19.36–72.27 km for MET, NIC and AARI, respectively. The yearly averages of the entire time series for each of the three ice services are given in Table 3 showing 8–9 km smaller edge distance for the *New* product independent of the ice service. The MET-Norway operational validation estimates for the 2010-2014 Antarctic-summers are included for comparison.

(a) *New* products

(b) *Oper* products

Figure 9: Weekly time series of the mean distance [km], *mean_edge_difference*, validation in Southern Hemisphere (see Equation 3.4) between the OSI SAF Sea Ice Edge and the ice edge from ice charts from *MET-Norway* in green, *NIC-US* in blue, and *AARI-RU* in red. (a) *New* product. (b) *Oper* product.

According to the target accuracy requirement of *45 km in SH* given in the Product Require-
ment Document [OSI SAF project team, 2016], the validation against MET-Norway ice charts
is weighted the highest since these charts are delivered on a daily basis. The present val-
idation results for 2015/2016 in Table 3 show that the target accuracy requirment indeed is
fulfilled for both MET-Norway and AARI data.

Ice service	Period	*Mean_edge_diff New* [km]	*Mean_edge_diff Oper* [km]	N_{edge}
MET	Nov - May	35.64	44.04	21810
NIC	Nov - Aug	63.94	71.29	100213
AARI	Nov - Apr, Aug	35.65	44.63	32457
MET	2014		34.07	21800
	2013		40.54	17620
	2012		32.89	1001
	2011		55.44	2182
	2010		35.93	2462

Table 3: The annual mean distance between the OSI SAF ice edge and the ice chart edge
(Southern Hemisphere) from the ice services of MET-Norway, NIC-US and AARI-RU.

The annual mean distances in Table 3 are all higher than the corresponding values from
the Northern Hemisphere in Table 2 Several components can cause the higher values of
mean_edge_differences in the Southern Hemisphere. The values - especially from MET and
AARI - are dominated by validation ice charts during Antarctic summer months. From several
years experience of similar validation from the Northern Hemisphere the summer values are
often a factor 2 higher or more relative to the rest of the year. This is also seen from the
full year NIC ice charts in Figure 9. Therefore, a full annual average of mean_edge_diff
including also the Antactic winter months is expected to lower the estimates for MET-Norway
and AARI given in Table 3.

In addition, the Antarctic ice charts have in general less good coverage of high resolution
satellite data, predominantly Sentinel-1 SAR, since the region does not have high accuracy
priority for receiving data. The charts are produced once a week and is based on a mosaic
of satellite data within the last days (with highest priority on the most recent data). Due to a
larger time span in the input data the ice chart are drawn with more coarse polygons than
used in Northern Hemisphere ice charts [H. Larsen, Norwegian Ice Service, pers. comm.,
April 13th 2015]. So the Antarctic ice charts themselves do not have the same quality as the
Arctic ice charts. In Section 4.1.3 the influence of validating a daily product with weekly ice
charts is presented in a small study by including a time lag in the validation analysis.

4.1.3   Influence of validating daily product with weekly charts

Due to the collection of satellite data over several days to cover the Antarctic, an ice chart
which is submitted for a certain day will to some degree represent the ice conditions from
the previous days. This again gives uncertainties for which day the OSI SAF Sea Ice Edge
product should represent. In Tables 4 - 6 are presented the mean_edge_differences taking
into account a time lag between the ice chart and the OSI SAF product. A lag of 1 day means

that the OSI SAF product represents 1 day earlier than the submission of the ice chart; lag of 2 days considers the OSI SAF product 2 days earlier than the ice chart, etc. The time lag which for a certain month gives the lowest mean distance between OSI SAF product and ice chart is marked in **bold** and it is seen that there is often a better comparison when including a time lag larger than 0. However, no fixed time lag is preferred for all months.

Year Month	Lag 0	Lag 1	Lag 2	Lag 3	Lag 4
2015 Nov	34.98	25.51	**23.47**	24.37	31.50
2015 Dec	34.30	28.07	28.31	23.71	**23.42**
2016 Jan	71.70	65.84	57.77	55.34	**52.98**
2016 Feb	40.49	35.09	36.74	**34.55**	35.00
2016 Mar	**25.64**	25.63	31.03	32.34	38.79
2016 Apr	20.53	**16.72**	26.33	34.98	40.90
2016 May	**21.86**	21.91	24.89	34.44	45.32

Table 4: The monthly mean distance between the OSI SAF ice edge and the MET-Norway ice chart edge (Southern Hemisphere) for different time lag. *Lag 1* compares the ice chart with the OSI SAF product from 1 day earlier, etc. **Bold** values mark the best comparison for each month.

Year Month	Lag 0	Lag 1	Lag 2	Lag 3	Lag 4
2015 Nov	92.47	91.84	81.84	75.54	**73.32**
2015 Dec	109.96	102.13	99.18	92.60	**87.94**
2016 Jan	78.81	76.03	71.13	67.27	**65.89**
2016 Feb	59.18	58.95	57.04	**55.68**	57.12
2016 Mar	**39.03**	41.66	47.42	50.12	52.03
2016 Apr	31.20	**30.69**	31.24	35.59	40.72
2016 May	**42.05**	43.46	43.81	46.99	51.89

Table 5: The monthly mean distance between the OSI SAF ice edge and the NIC-US ice chart edge (Southern Hemisphere) for different time lag. *Lag 1* compares the ice chart with the OSI SAF product from 1 day earlier, etc. **Bold** values mark the best comparison for each month.

Year Month	Lag 0	Lag 1	Lag 2	Lag 3	Lag 4
2015 Nov	48.86	42.92	41.00	**39.68**	41.94
2015 Dec	53.88	46.18	43.03	**38.32**	39.02
2016 Jan	47.91	45.03	42.85	39.84	**36.09**
2016 Feb	42.70	44.59	43.83	44.12	**41.43**
2016 Mar	**21.26**	24.78	32.11	34.35	39.36
2016 Apr	**19.07**	23.35	26.76	35.23	41.94
2016 May					

Table 6: The monthly mean distance between the OSI SAF ice edge and the AARI-RU ice chart edge (Southern Hemisphere) for different time lag. *Lag 1* compares the ice chart with the OSI SAF product from 1 day earlier, etc. **Bold** values mark the best comparison for each month.

4.2   Validation of sea ice type

In Figure 10 is shown a single day example from April 2016 of the Sea Ice Type outcome from the *New*-algorithm based on AMSR2 and ASCAT data and the *Oper*-algorithm based on SSMIS and ASCAT data.
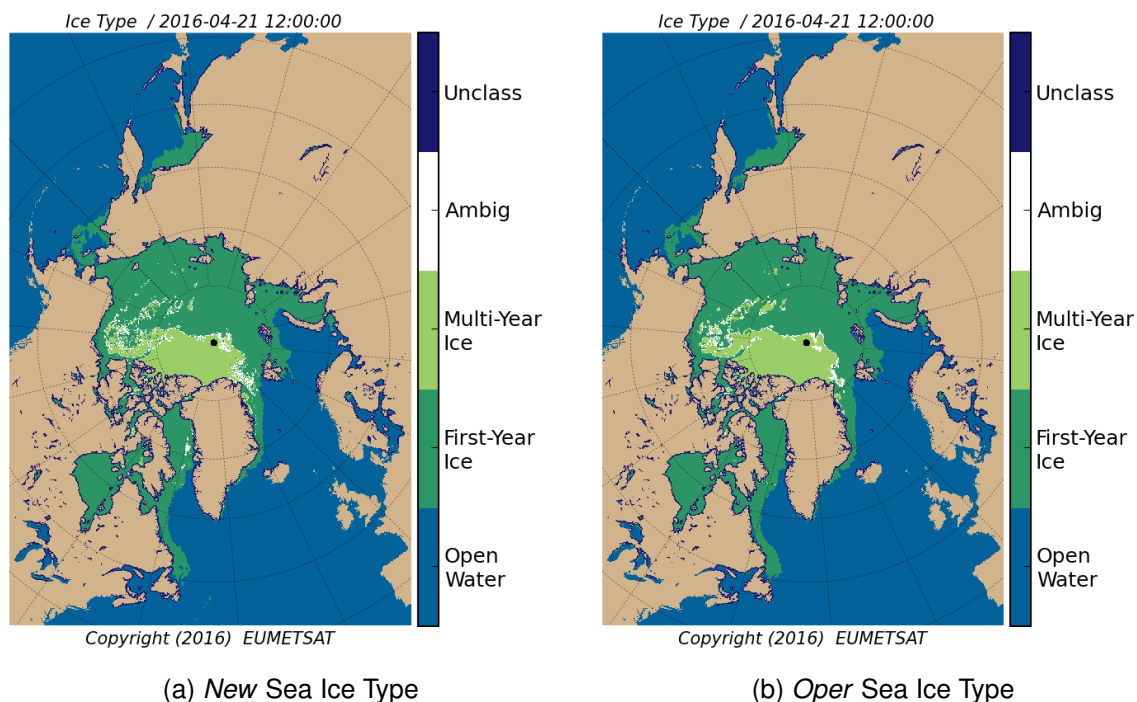

(a) *New* Sea Ice Type   (b) *Oper* Sea Ice Type

Figure 10: OSI SAF Sea Ice Type for the Northern Hemisphere (2016-04-21): (a) *New* Sea Ice Type based on AMSR2 and ASCAT, and (b) *Oper* Sea Ice Type based on SSMIS and ASCAT.

The time series of the daily multi-year ice extent [km^2] is shown in Figure 11 together with the running mean and the corresponding running standard deviation. In Figure 11a the extent is given for the upgraded *New* algorithm, and in Figure 11b the ice extent is given for the operational algorithm. The two time series are very similar and show a multi-year ice coverage around 2.000.000 km^2 with a decrease in April and May.

In Figure 12 is shown the daily differences of the multi-year ice extent from its running mean for *New* and *Oper* products, respectively. The target accuracy requirement says that the monthly standard deviation of this temporal variability should be less than the threshold of 100.000 km^2 given as red lines in the plots. Again, the time series for the two algorithms are very similar and the larger differences that exceed the threshold are seen in both algorithms. Around the 30th of December 2015 both algorithms show a sudden reduction of the multi-year ice, first in the East Greenland current and thereafter north of the Fram Strait. This leads to the large negative difference in Figure 12. Disregarding the single estimate from the 30th of December the sea ice type monitoring is summarized in Figure 13 which shows the monthly standard deviation (STD) of the daily variability of the multi-year ice extent for the *New* algorithm. All monthly std-values are well below the accuracy requirement of 100.000 km^2, see Section 3.2.2.
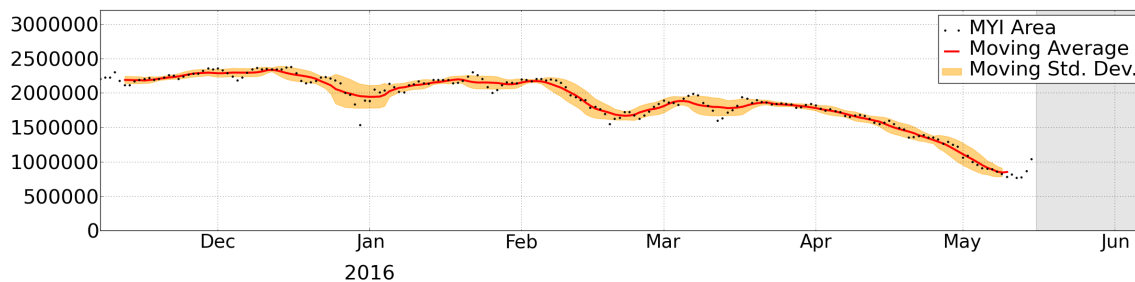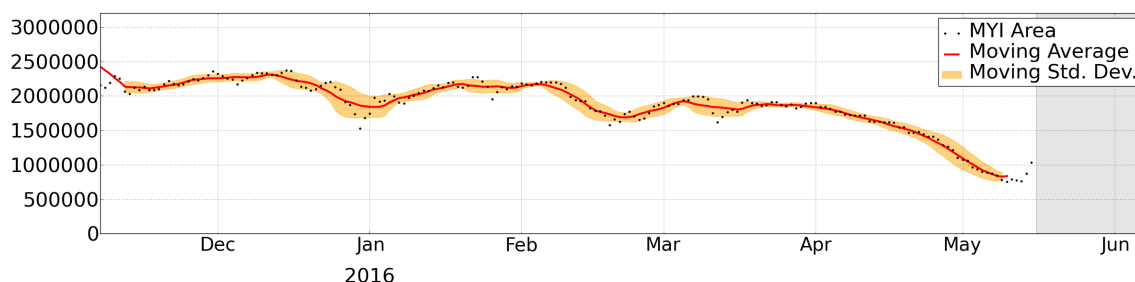
(a) *New* multi-year ice coverage.

(b) *Oper* multi-year ice coverage.

Figure 11: Time series of the total coverage [km^2] of multi-year ice in the Northern Hemisphere. Black dots are daily values. Red line is the 11-days running mean, and the orange shaded regions indicate the 11-days running standard deviation.
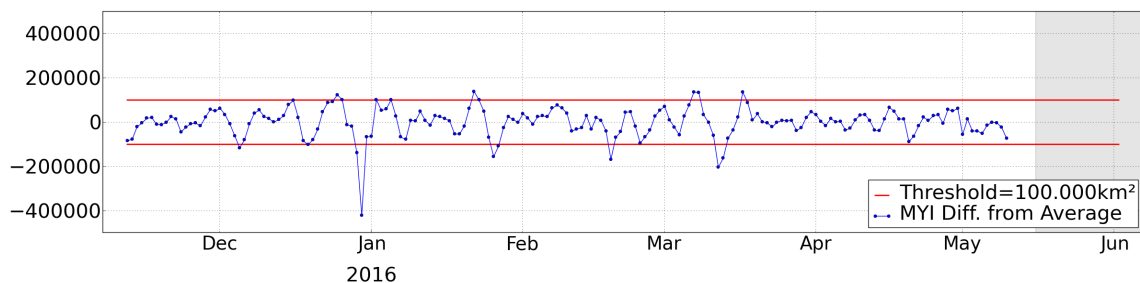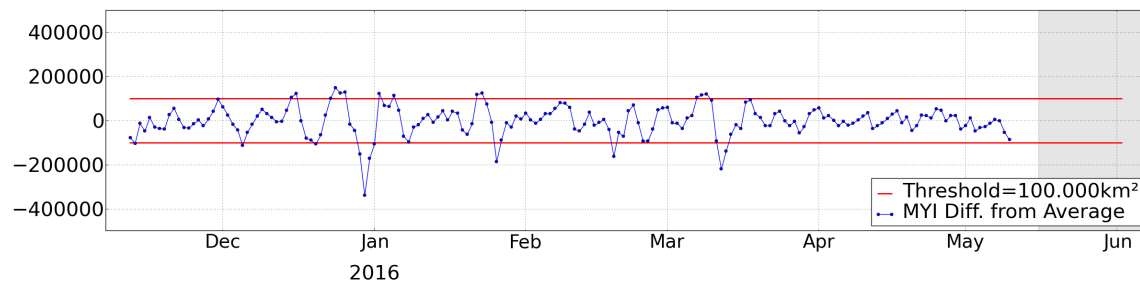

(a) *New* multi-year ice variability.

(b) *Oper* multi-year ice variability

Figure 12: Time series of the daily difference of the multi-year ice coverage from the 11-days running mean [km^2] in the Northern Hemisphere. The red lines indicate the target accuracy threshold for the monthly values.
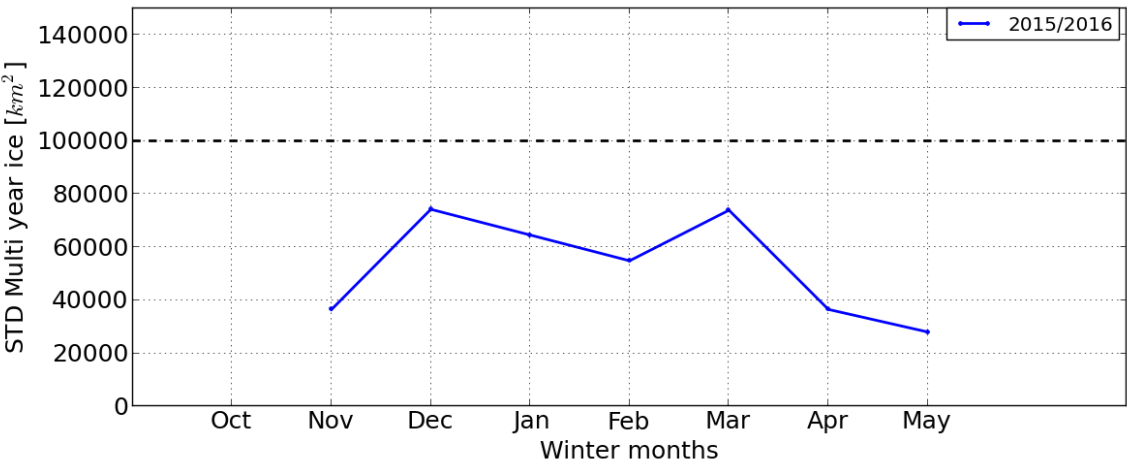
Figure 13: Monthly variability of the total coverage [km^2] of multi-year ice in the Northern Hemisphere. The dashed black line represents the 100.000 km^2 accuracy requirement.

5. Conclusion

The operational OSI SAF Sea Ice Edge and Sea Ice Type products are based on a probabilistic (Bayesian) approach to combine active and passive microwave satellite data. Today's operationel algorithm is based on Metop-A ASCAT data and DMSP F18 (previously DMSP F17) SSMIS data. The proposed upgrade of the two ice products includes the introduction of the AMSR2 data from GW1, in addition to including SSMIS and ASCAT data from DMSP F18 and Metop-B, respectively. Whereas the inclusion of DMSP F18 and Metop-B is not expected to cause any changes in the ice products, the introduction of AMSR2 differs from SSMIS by the higher resolution of AMSR2.

The figures and discussion in the previous chapters show how the use of AMSR2 data in the Sea Ice Edge and Sea Ice Type multi sensor product performs, and how the results compare with the present operational products.

- **Sea ice edge**

  - **Northern Hemisphere** The performance of the *New* product for Sea Ice Edge is within the target accuracy requirements of the product. When the results for the *New* product are compared with the performance of the operational product, the results show that the *New* product gives significantly better results in the marginal ice zone with more details and smaller scale features. In the overall comparison (pixel-by-pixel) the *New* results perform slightly better than the operational.

  - **Southern Hemisphere** The performance of the *New* product for Sea Ice Edge is within the target accuracy requirements of the product when validated against the daily ice charts from MET-Norway (and also AARI ice charts). The *New* product gives significantly better comparison to the ice charts in the marginal ice zone than the *Oper*, indicating that the inclusion of AMSR2 certainly improves the OSI SAF representation of the ice edge. In addition, a simple study including a time lag between the OSI SAF product and the ice chart shows that the weekly Antarctic ice charts, consisting of satellite data from several different days, effects the validation results.

- **Sea ice type**

  - **Northern Hemisphere** The monitoring of the Sea Ice Type product is very similar for the *New* product and the *Oper* product, both regarding the total coverage estimate of the multi-year ice and its monthly variability. The performance of *New* product for Sea Ice Type are within the target accuracy requirements of the product (when disregarding a single day estimate with extreme values in both *New* and *Oper* results).

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