Validation and Monitoring Document for OSI SAF Medium Resolution Sea Ice Drift

OSI-407-a

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1. Introduction

Two sea ice drift products are processed at the High Latitude centre of the Ocean & Sea Ice Satellite Application Facility (EUMETSAT OSI SAF). Both ice drift data sets, a medium and a low resolution product, are developed in the Continuous Development and Operations Phase of the OSI SAF (CDOP). Those datasets are introduced and documented in dedicated Product User's Manuals [PUM_mr] [PUM_lr] that can be found on http://osisaf.met.no.

The High Latitude processing facility (HL centre) is jointly operated by the Norwegian and Danish Meteorological Institutes. See http://osisaf.met.no for real time examples of the products as well as up-dated information. The latest version of this document can also be found there. General information about the OSI SAF is given at http://www.osi-saf.org. This Validation and Monitoring report only deals with the Medium Resolution (MR) sea ice drift product (OSI-407), that is based on VIS and IR data from the AVHRR instrument on board Metop Satellites. During summer we use VIS data, because of large contrast between snow/ice and water in the visible channels during that period. From October to May we use Thermal IR data because of large thermal contrast during this period.

The low resolution ice drift product, based on passive micro wave (PMW) imagery, is documented in a dedicated report [Laverne2009]. The aim of this report is to document the level of agreement between the OSI SAF MR sea ice drift product and ground-based truth. In chapter 2 the datasets used for validation is presented, while chapter 3 documents the validation strategy and the way collocation is handled. Chapter 4 provides graphical and quantitative analysis of the validation results, including validation of the ice drift uncertainty estimates. In Chapter 5 the operational validation and monitoring plan is described. Concluding remarks can be found in chapter 6.

Note that the OSI SAF MR sea ice drift product will not be introduced in depth in this report. For technical descriptions please refer to the ATBD [RD.2] and for user oriented issues, refer to the Product User Manual [RD.1]. Let us nonetheless remind that the OSI SAF MR ice drift product comes as daily vector fields obtained by processing medium-resolution infrared (IR) and visible (VIS) data recorded by the AVHRR instrument on board the Metop Satellite. It is computed on a Northern Hemisphere grid and delivered all year round. However, the number of ice drift vectors produced, vary largely in both time and space. In the annual cycle a minimum number of vectors are produced during summer, where the production is based on VIS data, and a maximum number of ice drift vectors are produced during the winter period, using IR data. Also a great variation in number of produced ice drift vectors occur from day to day. These variations reflect the opacity of the atmosphere for the VIS and IR electromagnetic wavelength. The number of vectors produced range from zero to several thousand. It is a 24 hour ice drift product at 20 km resolution produced in a polar stereographic grid.

1.1. Glossary

Acronym	Description
AMW	Active MicroWave
Argos	worldwide location and data collection system
ASAR	Advanced Synthetic Aperture Radar

AVHRR	Advanced Very High Resolution Radiometer
CDOP	Continuous Development and Operations Phase
DTU-space	Danish Technical University, national space institute
DMI	Danish Meteorological Institute
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
GMM	Global Monitoring Mode
GTS	Global Telecommunication System
IABP	International Arctic Buoy Programme
Ifremer	French Research Institute for Exploitation of the Sea
IR	Infra Red
lr	low resolution
MCC	Maximum Cross Correlation
met.no	Norwegian Meteorological Institute
Metop	EUMETSAT OPerational METeorological polar orbiting satellite
MR	Medium Resolution
NH	Northern Hemisphere
NSIDC	National Snow and Ice Data Centre
OSI SAF	Ocean and Sea Ice Satellite Application Facilities
PMW	Passive MicroWave
PUM	Product User Manual
MAE	Mean Absolute Error
QUIKSCAT	NASA's Quick Scatterometer
SAR	Synthetic aperture radar
SSM/I	Special Sensor Microwave/Imager
VIS	visible
WMO	World Meteorological Organization
WSM	Wide Swath Mode

1.2. Reference and Applicable documents

Refernce documents

[RD.1] Gorm Dybkjaer
Medium Resolution Sea Ice Drift Product User Manual, OSI-407-a
SAF/OSI/CDOP3/DMI/TEC/MA/137, Version 2.0, 19 September 2018

[RD.2] Gorm Dybkjaer
Algorithm Theoretical Basis Document for OSI SAF Medium Resolution Sea Ice Drift Product, OSI-407-a
SAF/OSI/CDOP3/DMI/SCI/MA/132, Version 2.3, 19 September 201

Reference to a Reference Document within the body of this document is indicated as reference in the list above, e.g. [RD.1].

Applicable documents

[AD.1] OSI SAF;*CDOP 3 Product Requirement Document (PRD)*

SAF/OSI/CDOP3/MF/MGT/PL/2-001, Version 1.1, 20/11/2017

[AD.2] OSI SAF; *Service Specification (SeSp)*

SAF/OSI/CDOP3/MF/MGT/PL/003, Version 1.3, 14/12/2017

Reference to an Applicable Document within the body of this document is indicated as reference in the list above, e.g. [AD.1].

1.2.1. EUMETSAT Disclaimer

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2. Validation dataset

The ice drift reference datasets that constitute the most applicable ground truth dataset for validation in near real time (NRT) that at the same time include a sufficient number of data for this in-depth validation work, is retrieved from the GTS network of buoy data. As mentioned above, each ice drift field only contains data in areas with clear skies; hence the data coverage can be very sparse and scattered. Therefore it is essential for the reliability of the validation that a large number of validation data are available. This can be obtained from drifters monitored by the Argos data retrieval system and distributed by WMO's GTS network. See snapshot of buoy distributions in the Arctic Ocean in figure 1.

A large number of buoys are deployed in the ice covered ocean to measure atmospheric, cryosphere and oceanic variables (e.g. Mean Sea Level Pressure, ice thickness and temperature). Of interest to us is the fact that they regularly and automatically report their position via the Argos system and broadcast to users via the GTS data distribution network. Ultra accurate GPS positions are occasionally part of the buoy data stream, but these are not used here. In a comprehensive ice drift inter-comparison study this product is validated and compared to other ice drift products using only accurate GPS positions [Hwang and Lavergne, 2010].

Validation data from drifting buoys from the period September 2008 to July 2009 are used to validate the ice drift data. Ice drift uncertainty is validated using another data set (see below).

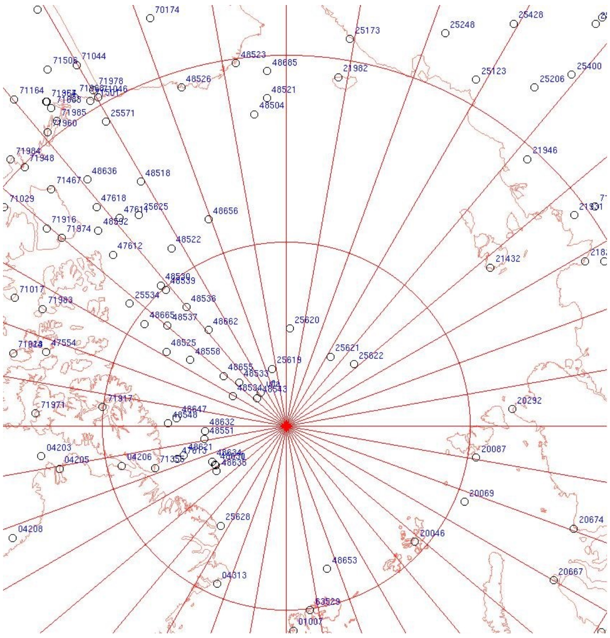

Figure 1 Position of buoys (and WMO stations on land) on March 3rd 2009 1200z from which positions are determined from the Argos positioning system.

2.1. Uncertainty validation dataset

During CDOP-2 an uncertainty algorithm was developed to provide uncertainties for individual ice drift vectors in the product. The ice drift vector uncertainty validation is presented below.

Data from a half-year period, December 2016 to mid-May 2017, are used to validate the uncertainty algorithm, which is not overlapping with the validation period for the ice drift product, mentioned above. All ice drift vectors are associated with seven statistically determined uncertainty metrics (**Sigma, Mdist, Gdist, PPR, PRMRS, RMSE, Ratio**), as defined in the ATBD (2018) and collocated with ice drift observations from drifting buoys. Half of the collocated buoy and satellite ice drift data pairs are used for training of a regression algorithm that determines a statistically based error estimate for a given ice drift vector (E_{calc}, eq. 2 in the ATBD). The other half of the collocated data pairs are used to test the performance of the subsequent calculation of total ice drift vector uncertainty ((U_{total}, eq. 3 in the ATBD)). The test and training data sets are based on satellite ice drift from TIR satellite data only, because no VIS based satellite ice drift were collocated with buoy drift data in the validation period, due to low data coverage of VIS data in the validation period.

The satellite and buoy drift data are collocated using following criteria:

- Maximum 60 minutes mismatch at both start and end times.
- Start position of the centre satellite pixel must be within 25 km of a buoy position.
- Maximum satellite ice drift is 25,000 m in each perpendicular drift direction within 24 hours.
- Buoy data are filtered manually for unrealistic speed and positions and other obvious odd behaviours.

The 7 uncertainty metrics used to estimate the ice drift uncertainty are calculated using different statistical means (see ATBD 2018). For approximately 25% of all ice drift vectors at least one of the associated uncertainty metrics is an outlier due to sensitive estimation procedures. It is attempted to filter drift vector outliers, as well as filter out unrealistic values of the 7 uncertainty metrics, from the collocated training and test data sets. From approximately 2000 data pairs in the complete match-up data set, approximately 1500 data pairs passed the outlier filters, before used for algorithm training and validation.

The filters imposed before regression of the uncertainty algorithm are:

Maximum ice drift error = 15.000 m

Sigma: ≥ 0.0 and <=50.0

Mdist: >=0.0 and ≤ 0.0015

Gdist: ≥ 0.0 and ≤ 50.0

PPR: > 0.0 and ≤ 1.0

PRMRS: > 0.0 and <=120.0

RMSE: ≥ 0.0 and ≤ 0.2

Ratio: ≥ 1.0 and ≤ 20.0

2.2. Buoy data

From Figure 1 it is clear that the distribution of buoys in the Arctic is not homogeneous. Only few drifter data are available from the Russian side of the Arctic Ocean and also Fram Strait is sparsely populated with buoys. This is a consequence of the strong transpolar drift pattern that generally advects sea ice from Eastern Siberia across the middle of the Arctic Ocean and eventually flushes sea ice and drifter out through the Fram Strait. The American side of the Arctic Ocean relatively well represented by drifters, but the distribution of drifting buoys changes from year to year. Figure 2 shows trajectories from 4 drifters in the validation dataset for the validation period 200808-200910.

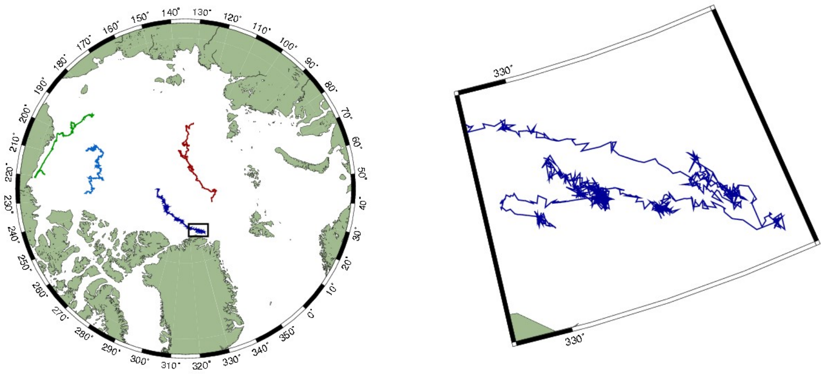

Figure 2 On the left are trajectories from 4 buoys from the validation data set during the period August 2008 to October 2009 (green – buoy48504, light blue – buoy48656, red – buoy25622 and dark blue – buoy48630). On the right is a zoom of the trajectory of buoy48630, the area indicated by black rectangle on the left.

The quality of Argos position is categorized into four location classes, namely class 3, 2, 1 and 0 indicating accuracies better than 250 m, 500 m, 1500 m and worse than 1500 m, respectively. In present reference/validation data set no filtering of buoys is done, in order to maximize the number of buoys for the validation. We assume that the mixed precision of the positions of the applied buoys will affect the validation results, in terms of too large errors. We assume that the drift bias is unaffected. The occasionally random looking spikes on the zoomed trajectory in figure 2 are up to 3 km in length, which reflect the fact that the reference data belong to Argos location class 0, with accuracy >1500 m. It is therefore assumed and confirmed that the overall validation of present ice drift data set will improve if higher quality reference data are used for the validation [Hwang and Lavergne, 2010].

3. Validation Methodology

The validation methodology and strategy is introduced in this section. It covers the generation of trajectories suited for satellite based ice displacement data and the collocation with satellite drift data. We also present a validation plot and the applied statistical properties.

3.1. Variables of interest

As introduced in the sea ice drift PUM [RD.1], an ice drift vector is fully described with 6 values: the geographical position of the starting point (lat0 and lon0), the starting time of the drift (t0), position at the end point of the drift (lat1 and lon1) as well as the end time of the drift (t1). However, the primary variables to be validated are dU and dV, the two perpendicular displacement components along the U and V axes of the Polar Stereographic product grid [RD.1].

3.2. Buoy data

Buoy positions and times from the Argos data retrieval system are available at DMI via the GTS network. Every hour a BUFR file holding positions (latitudes and longitudes with 2 or 3 decimals) and times from drifters are dumped in the archive. The BUFR data are converted into ascii files holding a buoy-id, position and time for each line of output file. From these files the best match to corresponding satellite based ice drift vectors is found.

3.3. Collocation strategy

In order to compare the OSI SAF sea ice drift product with the validation trajectories, they need to be collocated one with the other. Collocation is the act of selecting or transforming one or both datasets so that they represent the same quantity, i.e. the same period for an appropriate geographical area. As this ice drift product is based on swath data (see [PUM_mr]) all drift data are defined to have the same start and stop times, t0 and t1, respectively.

The in-situ drift data are defined from the start time (drifter_t0) and the end time record (drifter_t1). The times closest to t0 and t1, or more precisely [t0-1h] < drifter_t0 < [t0+1h] and [t1-1h] < drifter_t1 < [t1+1h] define the validation trajectory. From the corresponding positions the buoy drift in U and V directions, dU_drifter and dV_drifter, are computed. All satellite based displacement data for which positions [lat0, lon0] are within 50 km of the drifter position at time drifter_t0 are paired. It can be argued that only the nearest satellite displacement vector shall be matched with a buoy displacement data (Hwang and Lavergne, 2010), but in this report all drift vectors that comply with the match–up criteria are used for higher data volume. Because the ice drift vectors are nearly independent, due to correlation matrix size of 40km and sampling size of 20km, this strategy is assumed statistically sound.

3.4. Graphs and statistical measures

As noted in section 3.1, this report is concerned with validation of ice drift components dU and dV. The statistical characteristics of the two ice drift components in comparison to the chosen in situ measurement, the drifter data, are presented both graphically and with standard error values.

3.5. Scatter plot – Product vs. Reference

The graphical validation is a scatter plot of the in situ displacement versus the satellite displacement estimates. The scatter plots use the x-axis for reference and the y-axis for the product displacement. In an ideal comparison, all (reference, product) pairs are aligned on the 1-to-1 line. The spread around this ideal line can be expressed by the statistical correlation coefficient between Reference and Product.

3.6. Error statistics of dV, dU – Reference vs. Product

In addition to above mentioned error plot, various numerical measures are calculated as indicators for the accuracy of the product versus the reference data set. The standard statistical is calculated: correlation, bias and mean absolute error give users an idea of the overall quality of the data set and an idea whether this data set can be used for a given purpose. Other statistical measures are specifically aiming at data assimilation schemes. These quantities are the entries for the covariance matrix, namely the standard deviation of errors of both dU and dV, and the covariance of errors.

3.7. Standard error statistics

Here the standard error statistics used in the subsequent chapters is described. The basic quantities dU_{ref}/ dU_{prod} and dV_{ref}/ dV_{prod} are displacements along U and V directions of the product projection for reference and product data set, respectively. Bias and errors, dU_{err} and dV_{err}, are calculated as dU_{ref}-dU_{prod} and dV_{ref}-dV_{prod}, respectively.

I. Bias of dU and dV: ε_{dU} and ε_{dV}

II. Mean absolute error of dU and dV: MAE_{dU} and MAE_{dV}

III. Correlation between dU_{prod}, dU_{ref} and dV_{prod}, dV_{ref}: ρ_{dU} and ρ_{dV}

IV. Standard deviation of the errors of dU and dV: σ_{dUerr} and σ_{dVerr};

V. Covariance between errors of dU and dV: $Cov(dU_{err}, dV_{err})$

The measures I-V are standard statistical measures to indicate general accuracy of the product. The two latter, the standard deviation and the covariance of dU_{err} and dV_{err}, enter the covariance matrix of errors, $Cov(dU_{err}, dV_{err})$, which is of prime importance to any data assimilation scheme.

The co-variance matrix of dU_{err} and dV_{err} is:

$$Cov(dU_{err}, dV_{err}) = \begin{bmatrix} Cov(dU_{err}, dU_{err}) & Cov(dU_{err}, dV_{err}) \\ Cov(dV_{err}, dU_{err}) & Cov(dV_{err}, dV_{err}) \end{bmatrix} = \begin{bmatrix} \sigma^2_{dUerr} & Cov(dU_{err}, dV_{err}) \\ - & \sigma^2_{dVerr} \end{bmatrix}$$

Where, $\mathrm{Cov}(dU_{err}, dV_{err}) = \mathrm{Cov}(dV_{err}, dU_{err})$; $\mathrm{Cov}(dU_{err}, dU_{err}) = \sigma^2_{dUerr}$ and $\mathrm{Cov}(dV_{err}, dV_{err}) = \sigma^2_{dVerr}$

4. Validation results

The validation results presented here are split into monthly and full-period validation and into the sensor type, IR and VIS. The results are also put into perspective of other ice drift products with varying spatial and temporal properties.

The product accuracy requirements according to the Product Requirement Review Document [AD.1] for OSI-407a are: 5 km/24 hours, 2 km/24 hours and 1 km/24 hours for threshold, target and optimal accuracies, respectively. The OSI SAF requirement for this product is to comply with the target requirement, i.e. the standard deviation of drift errors must be less than 2 km, on annual mean basis.

To illustrate temporal properties of the product density, figure 3 show the ice drift vector productivity throughout the validation period. From this figure it is clear that winter and spring is the period of relative high ice drift vector production and summer and autumn is the period of low production of ice drift vectors. This occasionally affects the statistical robustness of the monthly validation, resulting in only 28 data pairs to validate in the poorest represented month, namely in September 2009 for VIS data. Opposite, the validation month with most number of drift pairs is March 2009 for IR data, with 3860 data pairs. The monthly validation results must therefore be interpreted with the number of counts in mind. The aggregated number of product/buoy data pairs for IR and VIS based products are 11,494 and 2,217, respectively, as shown in figures 4 and 5. Thus the validation results for the full period are statistically robust.

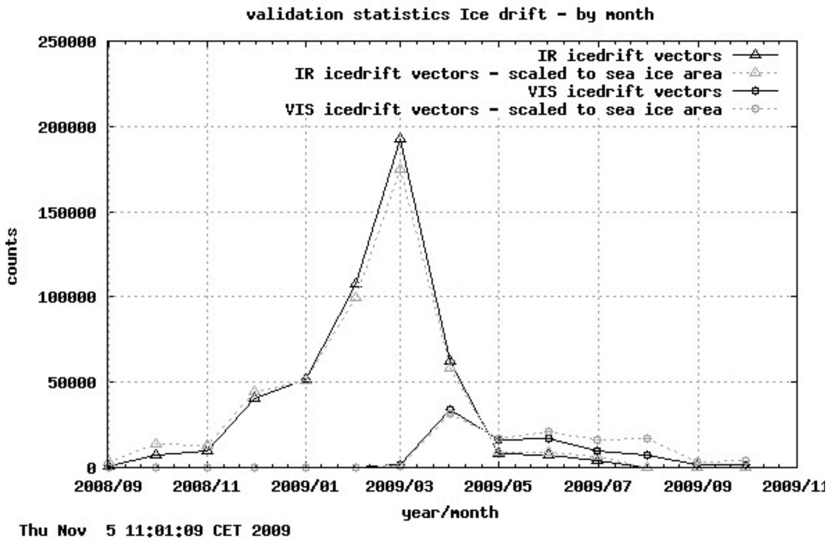

Figure 3 Monthly frequencies of ice drift vectors. Black lines are absolute numbers and grey lines are scaled against total sea ice area. I.e. the grey curves are proxy for atmospheric opacity and therefore product efficiency. Triangles represent icedrift data based on IR data and squared represent data based on VIS data.

In table 1 and 2 the monthly stratified validation results are shown for IR and VIS data respectively. For both the IR and VIS based products the correlation values between buoy displacement and product are high and corresponding bias values are low. Furthermore, the mean absolute error are general below pixel size of 1 km. Exceptions from this general pattern can be seen in month with poor statistics, i.e. few collocated buoy/satellite displacement pairs. The year average error is well below target requirement and occasionally even below optimal requirement.

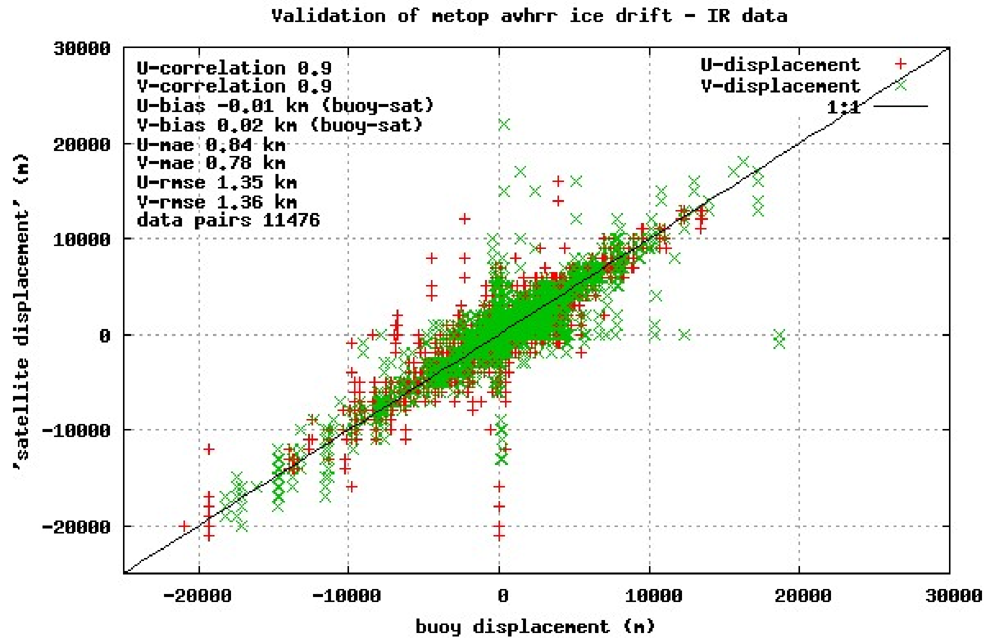

Figure 4 Scatter plot of dU_{prod} and dU_{ref} (red crosses) and dV_{prod} and dV_{ref} (green crosses), for the period 200809 to 200907. The production is based on infra red data and the corresponding statistics is written in table 1.

Tabel 1 Full statistics for IR based ice drift validation. ρ is correlation, ε is the bias, MAE is Mean Absolute Error, σ is the Standard Deviation of errors, Cov is the co-variance and U/V correspond to the two perpendicular displacement components of the output grid.

Month	ρ_{dU}	ρ_{dV}	ε_{dU} (km)	ε_{dV} (km)	MAE_{dU} (km)	MAE_{dV} (km)	σ_{dUerr} (km)	σ_{dVerr} (km)	Cov (dU_{err};dV_{err}) (km^2)	No. of obs.
200809	0.31	0.89	-0.07	-0.03	1.51	0.99	3.14	1.46	-3.6	33
200810	0.85	0.74	0.17	0.36	1.29	1.52	2.34	2.21	-1.97	725
200811	0.97	0.76	0.31	0.55	0.84	1.04	1.09	2.57	-1.25	134
200812	0.93	0.9	0	-0.07	0.9	0.7	1.34	1.13	0.2	1482
200901	0.95	0.94	0.09	-0.08	0.6	0.77	0.80	1.17	0.12	673
200902	0.85	0.72	0.06	-0.04	0.82	0.85	1.26	1.50	-0.1	2390
200903	0.84	0.92	-0.09	0.06	0.77	0.58	1.66	1.42	-0.28	3860
200904	0.92	0.95	-0.04	-0.03	0.87	0.86	1.30	1.36	-1.14	2046
200905	0.94	0.84	0.03	-0.21	1.02	0.47	1.50	0.56	-0.23	53

200906	0.93	0.55	-0.77	-0.86	1.61	1.44	3.12	2.58	3.67	43
200907	0.59	0.95	0.19	0.38	0.66	0.46	1.00	0.75	0.28	55
Full period	0.9	0.9	-0.01	0.02	0.84	0.78	1.35	1.36	-0.2	11494

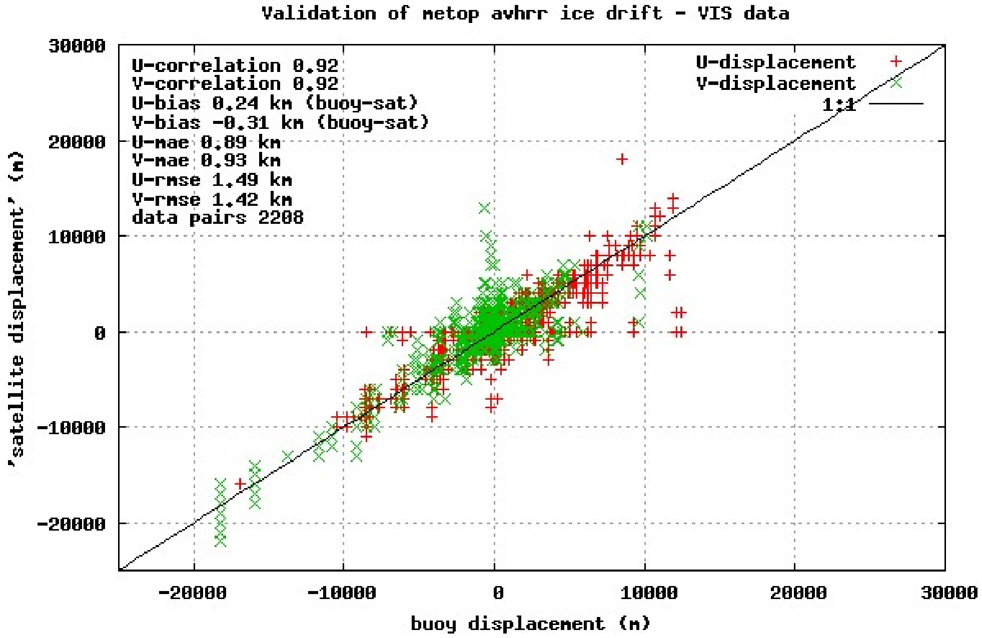

Figure 5 Scatter plot of dU_{prod} and dU_{ref} (red crosses) and dV_{prod} and dV_{ref} (green crosses), for the period 200903 to 200910. The production is based on visible data and corresponding statistics is written in table 2.

Tabel 2 Full statistics for VIS based ice drift data validation. ρ is correlation, ε is the bias, MAE is Mean Absolute Error, σ is the Standard Deviation of errors, Cov is the co-variance of the errors and U/V correspond to the drift direction component of the output grid.

Month	ρ_{dU}	ρ_{dV}	ε_{dU} (km)	ε_{dV} (km)	MAE_{dU} (km)	MAE_{dV} (km)	σ_{dUerr} (km)	σ_{dVerr} (km)	Cov (dU_{err};dV_{err}) (km^2)	No. of obs
200903	0.83	0.98	0.46	0.24	0.69	1.09	0.73	1.45	0.23	55
200904	0.7	0.7	0.37	-0.38	0.98	0.96	1.46	1.44	-1.18	461
200905	0.91	0.35	-0.17	-0.5	1.01	0.94	1.54	1.43	-0.74	189
200906	0.95	0.89	0.18	-0.24	0.78	0.91	1.1	1.37	-0.37	855
200907	0.94	0.88	0.2	-0.51	0.83	1.09	1.23	1.41	-0.23	447
200908	0.73	0.77	0.85	-0.1	1.67	0.72	3.25	1.31	-1.64	138
200909	0.98	0.97	-0.11	0.02	0.84	0.53	1.13	0.65	-0.06	28
200910	1	0.21	-0.05	-0.53	0.18	0.65	0.23	0.74	-0.02	44
Full	0.92	0.92	0.24	-0.31	0.89	0.93	1.48	1.39	-0.6	2217

period										

In a previous ice drift validation and inter-comparison work by Hwang and Lavergne (2010) the directional errors of both the IR and VIS based ice drift products were estimated to be less than 1 km. Here the match-up criteria were 20km maximum distance lag and 1 hour time lag. Buoy positions were determined with GPS and only the nearest satellite ice drift vector to a GPS displacement was used. The validation results found in this report are important as reference to the on-the-fly validation plan for this product, as Argos positions are available in near real time.

4.1. Rough inter-comparison

A comparison of present ice drift vector accuracy to other ice drift data sets of varying resolutions and coverage is done here, to see present validation results perspective. This is <u>not</u> an 'in depth' comparison, as only the most crucial characteristics of the various data sets are given and only the Standard deviation for each data set it used for quantitative comparison.

The input data type for each drift product is given, along with the re-sampled input data resolution or minimum input data resolution, if the product is a multi-sensor product (Input data). The respective reference data set are given along with the estimated error (Reference data). The period of the drift estimates is given in hour (Drift period). Average values of standard deviations of errors of the dU_{err} and dV_{err} components of drift (**σ**) are given. Finally the reference to the each drift data sets is listed in column 'Reference'.

Tabel 3 Comparison of Standard Deviations of errors to other ice drift data set.* - calculated from absolute drift errors assuming equal errors for the two drift components (dU_{err} and dV_{err}). ** - value is based on 68 reference-product data pairs only.

Input data	Reference data	Drift period	**σ (km)**	Reference
Avhrr Pathfinder ~5km	IABP ?m	24h	~2.8	[Fowler2009]
Quickscat ~2.2 km	IABP 300m	48h	~2.8	[Harpaintner2006]
Merged SSMI+Quickscat >10km	IABP ?m	72h	~5.3*	[Ifremer2008]
Mixed PMW >6km	IABP <150m	48h	~3.5 ~2.3(amsr only)	[Laverne2009]
Mixed ASAR ~300m and ~1km	IABP <150m	24h	~1.6**	[Saldo2009]
Avhrr ~1km	ARGOS GTS >1500m	24h	~1.4	This document

The comparison reveals that present data set is the most accurate with respect to standard deviation of errors. From tables 1 and 2 we have that the bias of present data set is close to zero, which should make this data set attractive for assimilation and validation purposes, at least in periods of large ice drift vector production. However, in periods of frequent cloud cover, summer and autumn, the MW based products show much denser ice drift vector production, and may in those periods be more applicable for model work.

4.2. Ice drift uncertainty validation

A statistical approach is chosen to determine uncertainties of individual ice drift vectors in the OSI-407 product. A multivariate linear regression analysis between 7 ice drift uncertainty metrics (or indicators) and the corresponding observed ice drift errors were used to calculate the error of a given ice drift vector, E_{calc}. This is defined in the ATBD [RD.2].

In the ATBD [RD.2] three assumptions about E_{calc} were made: 1) The mean observed error will increase with increasing E_{calc}, 2) The STD of observed ice drift errors is high among ice drift vectors with large E_{calc} and the STD of errors is low among ice drift vectors with low E_{calc}-values, and 3) following the second assumption, E_{calc} can be used as a proxy for total calculated uncertainty, U_{total}.

The first assumption is confirmed in figure 6, where observed mean errors plus/minus 1 STD are plotted as a function of the calculated error (in bins of 300 m). The figure shows that the mean observed error increases linearly with E_{calc}, and follow the 1:1 line, except for the Ecalc bin 0-300 m. In the second assumption it is assumed that the STD of observed errors increases with E_{calc}. This is also confirmed in figure 6 where the observed STD (green vertical bars, within 300 m bins of E_{calc}) increases with increasing E_{calc}. The third assumption is confirmed in figure 7, where the observed STD of errors are plotted as vertical bars on top of the ideal (theoretical) uncertainty lines (black punctured line), Here E_{calc} clearly resembles the theoretical uncertainty curve well, if a simple linear scaling is applied to E_{calc}. The calculated uncertainty, U_{total}, is successfully determined if the STD of observed errors fit within and intersect with the 1:1 dashed lines of the ideal uncertainty line.

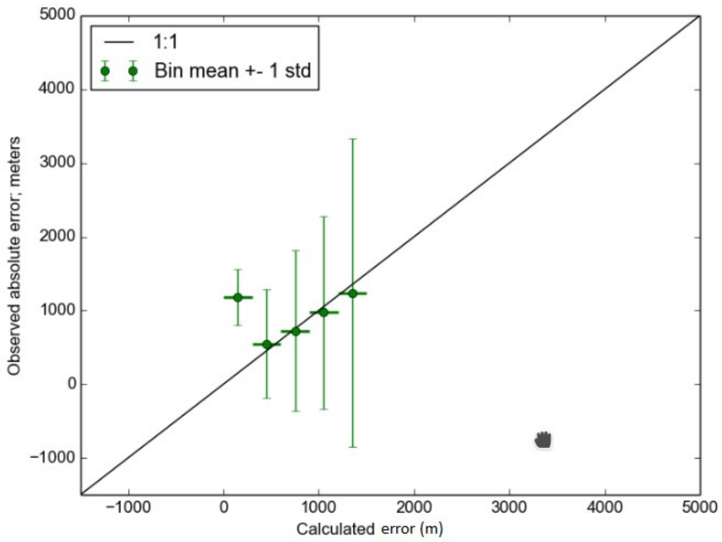

Figure 6 Mean values (green dots) of observed ice drift errors as a function of calculated error, E_{calc}, within 300m-bins. Vertical green bars are plus-minus 1 STD of the observed errors within each bin. Only bins with more than 10 observations are included. All plotted values are given in table 4.

This validation technique was used in the validation report of the OSI SAF Low Resolution ice drift data set (Lavergne, 2016) and elsewhere. The general performance of the uncertainty algorithm, U_{total}, seems to perform fine. The continuous and official ice drift uncertainty of the OSI-407 product, U_{total}, is illustrated by the blue dotted line in figure 7 and the two horizontal red dotted lines. The latter represent the lower and upper limits of the product uncertainties, as explained in the ATBD [RD.2].

Tabel 4 Statistics of uncertainty performance. Values are also plotted in figures 2 and 4 for number of samples greater than 10.

Range (m)	**σ**, STD (m)	**ε,** mean (m)	No. of Obs.
0-300	382	1184	10
300-600	740	550	202
600-900	1094	725	330
900-1200	1305	974	95
1200-1500	2096	1241	18
1500-1800	4093	1958	7
1800-2100	437	611	3
2100-2400	2543	5573	5
2400-2700	498	498	2
2700-3000	181	818	4

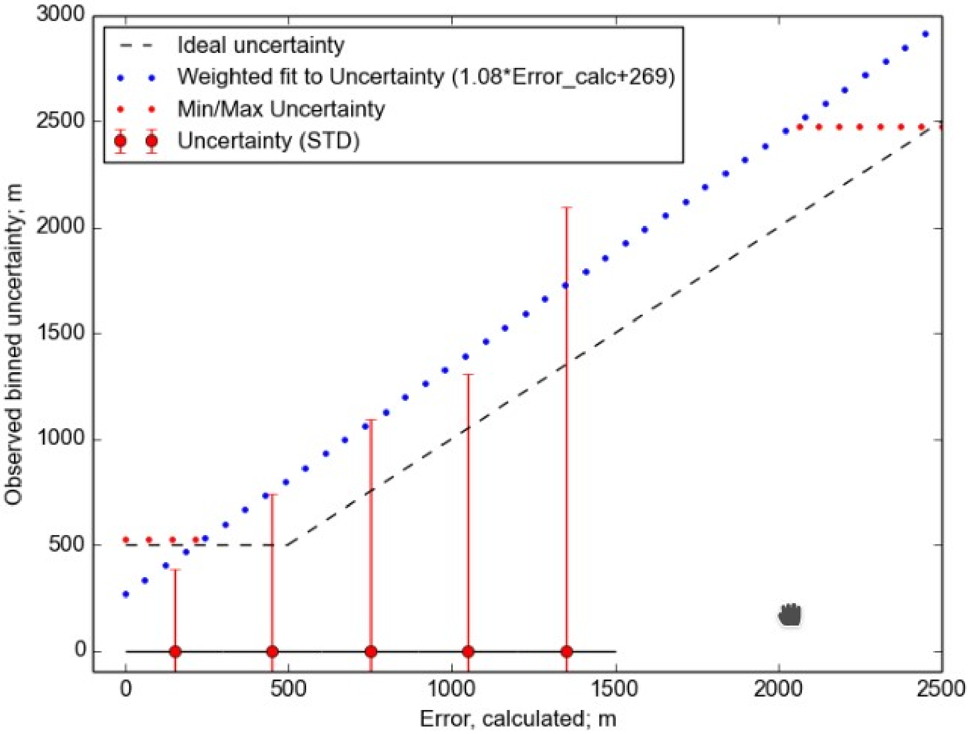

Figure 7 Validation of uncertainties of the OSI-407 product. The x axis is the calculated error, E_{calc}, and the y axis is the corresponding observed error. One STD of the binned observed errors within each 300 m bin of calculated errors is shown by the vertical red lines. The blue dotted line is a weighted linear fit to all STD values with 10 or more samples, which transform the E_{calc} to product uncertainty, U_{total} (see text and ATBD [RD.2] for explanation). The red dotted lines represent the minimum and maximum uncertainty limits. Black punctured line is the theoretical and ideal uncertainty limit for observed uncertainty plotted against theoretical uncertainty.

5. Routine monitoring and validation

Figure 3 displays the temporal evolution of the drift vector productivity. The evolution in ice drift vector productivity reflects the cloudiness any given month and hence the success of this ice drift production. Half-year validation reports, including the measures shown in figure 4 and 5 and corresponding statistics like that shown in table 1 and 2 are produced. Calculation of the error statistics is performed after the production of each ice drift data set and compiled monthly in tables and graphs.

The validation is based on data from the Argos positioning system that is distributed via the GTS network. As mentioned in chapter 2, this reference data set is not the most accurate for validation of ice displacement fields, but is the only feasible system for routine validation, due to the amount of buoys in the system and also due the operational stratus of these data.

6. Conclusion

This report deals with the validation and monitoring of the OSI SAF 24h medium resolution ice drift product based on IR and VIS data. The region validated here is the Northern Hemisphere and the validation period is from September, 1st 2008 to November 1st 2009.

Results are analysed and conclude that the OSI SAF ice drift parameters dU and dV are mostly unbiased and mean absolute errors of less than 1 km. Standard deviation values for the two drift directions U and V are: 1.35 km and 1.36 km for IR based ice drift data, respectively. Corresponding values for VIS based ice drift estimates are 1.48 km and 1.39 km. The results comply with the OSI SAF target requirements of STD of errors below 2 km/24 hours. Also the covariance of errors are given, which along with the standard deviation values enter the error covariance matrix used in data assimilation schemes.

The Validation result show low standard deviation of errors, the lowest of the data sets chosen for a rough inter-comparison. Also bias in both U and V directions are small. Due to frequent atmospheric opacity to IR and VIS sensors in the Arctic region this data set has its limitations in comparison to ice drift data sets based on AMW and PMW data. Large data gaps and occasional ‘no-data’ are present as well as long periods with very few produced ice drift vectors, especially during summer and autumn.

The error statistics of this product improve if more accurate *in situ* data are applied for the validation. However, due to periodically very large data gaps in this product, a validation scheme against GPS reference data is not feasible, as the validation record on a monthly or quarterly basis will become insignificant. This report and the joint validation report by Hwang and Lavergne (2010) document that the ice displacement accuracy of the OSI-407 product complies even with the ‘optimal accuracy’ demand from the Ocean and Sea Ice SAF CDOP3 Product Requirement Document (PRD) [AD.1].

Finally, the uncertainty estimates are included in the product and they seem to perform well. A re-evaluation of the uncertainties will be done during CDOP-3. There are no requirements to the performance of the uncertainty product.

This report is a living document that will be updated whenever new relevant validation information is available. The latest version of the present report and Product User Manuals are always available from the OSI SAF Ice web portal: http://osisaf.met.no or by contacting the author.

7. Reference

Dybkjaer, Gorm. 2017 Evaluation of Medium Resolution Ice Drift Uncertainties - Input to MR-Icedrift (OSI-407) validation report, Version 2.1

Fowler, C. 20091120. http://nsidc.org/data/docs/daac/nsidc0116_icemotion/avhrr.html

Haarpaintner, J. 2006. Arctic-wide operational sea ice drift from enhanced-resolutionQuikScat/Sea-Winds scatterometry ands its validation, IEEE Trans. Geoscie. Remote Sens.,vol. 44, no.1, pp.102-107.

Hwang, P. and T. Lavergne, 2010. Validation and Comarison of OSI SAF Low and Medium Resolution and IFREMER/Cersat Sea Ice drift products. Reference: CDOP-SG06-VS02. http://osisaf.met.no/docs/OSISAF_IntercomparisonIceDriftProducts_V1p2.pdf

Ifremer, 2008. Fanny Girard-Ardhuin, Robert Ezraty, Denis Croizé-Fillon and Jean-François Piollé,IFREMER. Sea ice drift in the central Arctic combining QUIKSCAT and SSM/I. Sea ice drift data USER'S MANUAL, Version 3.0, April 2008.

Laverne, T. 2009. Validation and Monitoring of the OSI SAF Low Resolution Sea Ice Drift Product. http://saf.met.no and http://www.osi-saf.org

Lavergne, T. 2017. Validation and Monitoring of the OSI SAF Low Resolution Sea Ice Drift Product - GBL LR SID — OSI-405-c. Version 5 (http://saf.met.no and http://www.osi-saf.org), July 2016.

PUM_lr. 2018. Low Resolution Sea Ice Drift Product User Manual. SAF/OSI/CDOP/DMI/TEC/MA/137, v 1.5.1. GBL MR SID – OSI 405.

Saldo, R, 2009. Personal Communication. Preliminary validation results of ASAR WSS and GMM data by Phil Hwang, SAMS. DTU-space.