Ocean and Sea Ice SAF

OSI-407

Validation and Monitoring Document for OSISAF
Medium Resolution Sea Ice Drift

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Glossary

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

OSISAF – 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

WSM – Wide Swath Mode

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 OSISAF (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 updated 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 sea ice drift product (OSI-407), that is based on VIS and IR data from the AVHRR instrument on board Metop-A Satellite. 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 medium resolution sea ice drift product and ground-based truth.

This is done partly graphically, by displaying the match between this satellite product and the in-situ datasets, and partly by reporting the quantitative estimates of errors and uncertainties of the product.

Chapter 2 presents the datasets used as validation data, the ground truth, while chapter 3 documents the validation strategy and the way collocation is handled. Chapter 4 provides graphical and quantitative analysis of the validation results. Chapter 5 describes the operational *on-the-fly* validation and monitoring plan. Concluding remarks can be found in chapter 6.

Note that the OSI SAF medium resolution sea ice drift product will not be introduced in depth in this report. Refer to the PUM [PUM_mr] and http://osisaf.met.no for information on the algorithms, processing schemes and data format. Let us nonetheless remind that the OSI SAF medium resolution ice drift product comes as daily vector fields obtained by processing medium-resolution infrared (IR) and visible (VIS) data recorded by the AVHRR instrument onboard 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.

2. Validation dataset

In this section, we introduce 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. 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. 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, cryospheric 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. The used positions are retrieved from the Argos positioning system on board each satellite in the Argos network. 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].

As mentioned, only in-situ trajectories have been used as ground truth. SAR-based ice drift products as those produced at the Danish Technical University, may be included in the NRT validation procedure at a later stage.
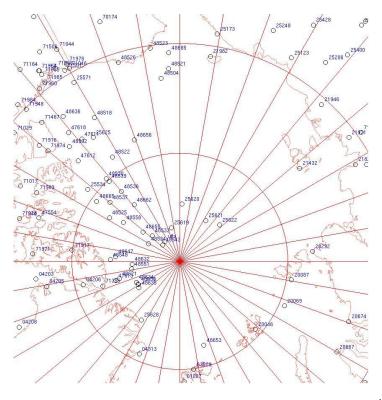

Figure 1 *Position of buoys (and wmo stations on land) on March 3rd 2009 1200z from which positions are determined from the Argos positioning system.*

3. Buoy data

All available drifter data (data from drifting buoys) north of the 70th parallel from the GTS network are used for
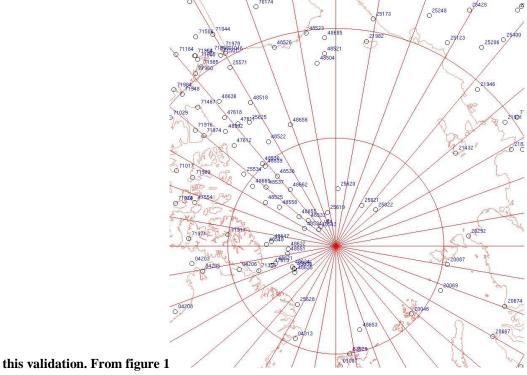

this validation. From figure 1

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. Inversely is the American side of the Arctic Ocean well represented by drifters. Figure 2 shows trajectories from 4 drifters in the validation dataset for the validation period 200808-200910.
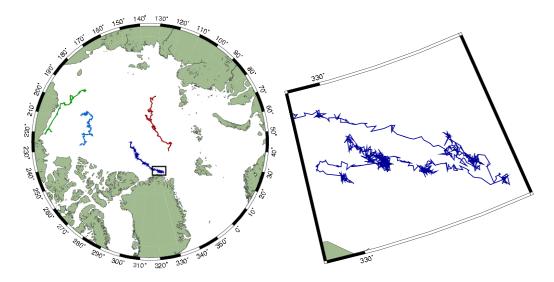

Figure 2 *On the left are trajectories from 4 buoys from the validation data set during the period August 2008 to October 2009 (green – buoy48504, light blue – buoy48656, red – buoy25622 and dark blue – buoy48630). On the right is a zoom of the trajectory of buoy48630, the area indicated by black rectangle 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 250m, 500m, 1500m and worse than 1500m, respectively. In present reference/validation data set no stratification using these location classes is done. This is in order to maximize the statistical volume for validation. 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 >1500m. 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]. E.g. if Argos location classes 0 and 1 are excluded, the overall validation may improve, but possible on the expense of monthly validations, as the available data volume will be reduced.

4. 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.

1. Variables of interest

As introduced in the sea ice drift PUM [PUM_mr], an ice drift vector is fully described with 6 values: the geographical position of the start point (lat_0 and lon_0), the start time of the drift (t_0), position of the end point of the drift (lat_1 and lon_1) as well as the end time of the drift (t_1). However, the primary variables the ice drift processing software are dU and dV , the components of the displacement vector along the U and V axes of the Polar Stereographic product grid [PUM_mr]. Those are thus the two variables we are aiming at validating.

2. Validation data reformatting

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 3 decimals) and times from drifters are dumped in the file 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. 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. However, the effect of these two sampling strategies will be evaluated in the CDOP2 project where a work package is dedicated for uncertainty estimation.

4. Graphs and statistical measures

As noted in section 4.1, 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.

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.

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 error quantities of correlation, bias and mean absolute error are calculated and will give users of the ice drift data 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.

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

$Cov(dV_{err}, dV_{err}) = \sigma^2_{dVerr}$

5. 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.

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.
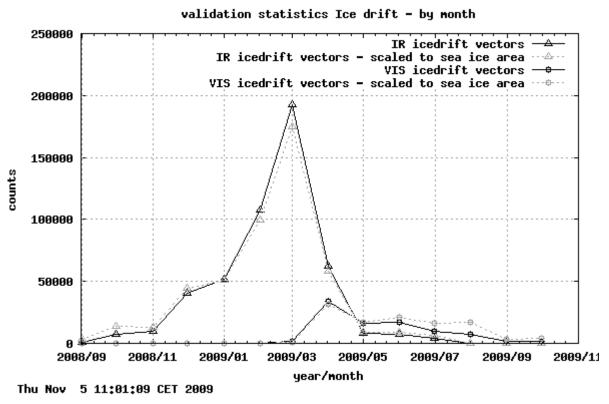

Figure 3 *Monthly frequencies of ice drift vectors. Black lines are absolute numbers and grey lines are scaled against total sea ice area. I.e. the grey curves are proxy for atmospheric opacity and therefore product efficiency. Triangles represent icedrift data based on IR data and squared represent 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.
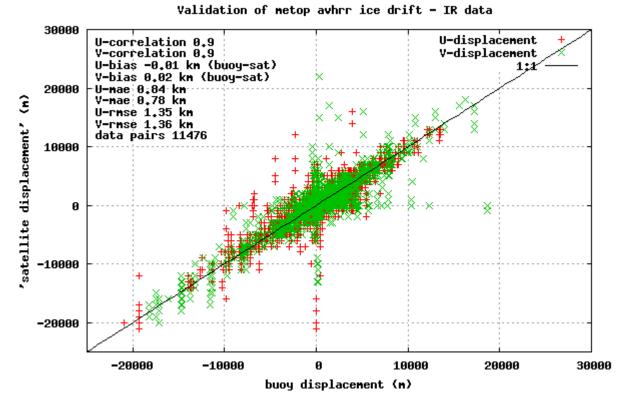
Figure 4 *Scatter plot of dU_{prod} and dU_{ref} (red crosses) and dV_{prod} and dV_{ref} (green crosses), for the period 200809 to 200907. The production is based on infra red data and the corresponding statistics is written in table 1.*

Tabel 1 *Full statistics for IR based ice drift validation*

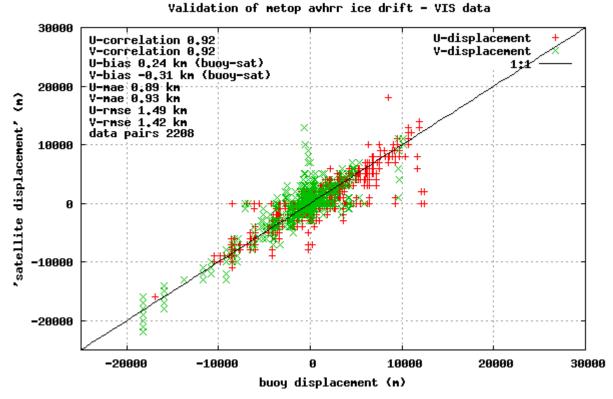| Month	ρ_{dU}	ρ_{dV}	ε_{dU} (km)	ε_{dV} (km)	MAE_{dU} (km)	MAE_{dV} (km)	σ_{dUerr} (km)	σ_{dVerr} (km)	$Cov(dU_{err};dV_{err})$ (km^2)	Counts
200809	0.31	0.89	-0.07	-0.03	1.51	0.99	3.14	1.46	-3.6	33
200810	0.85	0.74	0.17	0.36	1.29	1.52	2.34	2.21	-1.97	725
200811	0.97	0.76	0.31	0.55	0.84	1.04	1.09	2.57	-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.*

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)	Counts
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 period	0.92	0.92	0.24	-0.31	0.89	0.93	1.48	1.39	-0.6	2217

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.

8. 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 not 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 the dU_{err} and dV_{err} components of drift (err_stdiv) 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	Err_stdiv (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.

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6. On-the-fly monitoring and validation

Figure 3 displays the temporal evolution of the drift vector productivity. This evolution in productivity can thus be seen as proxy for 'mean' opacity of the atmosphere for any given month and hence for the success rate of this ice drift production. Despite the fact that the statistical volume for monthly validation occasionally is weak (mainly summer and autumn) quarterly *on-the-fly* statistics of this product is part of the OSISAF chain:

Quarterly scatter plots, like those shown in figure 4 and 5, and corresponding statistics like that shown in table 1 and 2 are produced. The standard deviation of errors and covariance of errors is like wise be generated on a quarterly basis. 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 be the most accurate for validation of ice displacement fields, but is the only feasible system for on-the-fly validation, due to the amount of buoys in the system and also due the operational stratus of these data.

7. 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 under study is the Northern Hemisphere and the validation period is from September, 1st 2008 to November 1st 2009.

Results are analyzed 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: 1.35kmm and 1.36km for IR based ice drift data, respectively. Corresponding values for VIS based ice drift estimates are 1.48km and 1.39km. 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 comply even with the 'optimal accuracy' demand from the Ocean and Sea Ice SAF CDOP Product Requirement Document (RPD).

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.

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