Ocean & Sea Ice SAF

Low Resolution Sea Ice Drift Product User's Manual

GBL LR SID — OSI-405-b

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OSI SAF Ocean and Sea Ice

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v1.1	-	19.02.2009	TL	Add a forgotten `flag_meanings` description
v1.2	4.0	01.10.2009	TL	Description of the multi sensor product and of the product files
v1.3	4.0	15.11.2009	TL	Change value of the `time` dataset in product files (see p. **??**). Document the change in directory achitecture at the FTP server (section 4.6).
v1.4	4.0	17.03.2010	TL	Document the EUMETCast dissemination (section 4.6.2) and the direction of the `dY` axis (figure 3).
v1.5	4.1	25.01.2012	TL	Document SH production and add a Product Change History (appendix C).
v1.6	4.1	01.11.2013	TL	Document switch from SSM/I to SSMIS data.
v1.7	5.0	15.03.2015	TL	Introducing GCOM-W1 AMSR2 data.

The software version number gives the version of the OSI SAF High Latitude software chain introducing the changes leading to the new product version.

Table of contents

Table of contents

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 (SST), Surface Solar Irradiance (SSI) and Downward Longwave Irradiance (DLI). The sea ice products include sea ice concentration, the sea ice emissivity, sea ice edge, sea ice type and sea ice drift and sea ice surface temperature (from mid 2013).

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 and Danish Meteorological Institutes.

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

This document is one of the product manuals dedicated to the OSI SAF product users. It describes the low resolution sea ice drift product. Two sets of ice motion products are delivered by the SAF:

- Low resolution ice drift product (OSI-405);
- Medium resolution ice drift product (OSI-407).

This Product Manual only pertains to the low resolution product (OSI-405).

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, along with up-to-date validation and monitoring information.

General information about the OSI SAF is given at http://www.osi-saf.org.

Chapter 2 presents a brief description of the algorithms and chapter 3 gives an overview of the data processing. Chapter 4 provides detailed information on the file content and format, and chapter A proposes some visualization example of the product.

1.3 Overview

Low resolution ice drift datasets are computed on a daily basis from aggregated maps of passive microwave (e.g. SSMIS, AMSR2) or scatterometer (e.g. ASCAT) signals. The typical resolution/spacing of those input images is 12.5 km. Wide swaths, high repetition rates and independence with respect to the atmospheric perturbations permit daily coverage of most of polar sea ice. During fall, winter, and spring, the excellent coverage makes it possible to extract 48 hours global ice drift vectors at a spatial resolution of 62.5 km.

In the OSI SAF chain, one such ice drift map is derived for each sensor used as input to the processing chain (single sensor product). An additional *merged* (multi-sensor) dataset is distributed which combines the low resolution products in a daily analysis.

The duration of 48 hours for the drift vectors is the result of a compromise between operational user need, and accuracy. On the one hand, operational users prefer short time resolution for the vectors to allow ingestion in their Data Assimilation time-window, and/or monitor day-to-day changes in ice dynamic regimes. On the other hand, the satellite sensor processed in this product have a rather coarse imaging resolution (10-25 km pixel size). This resolution is a limiting factor for the accuracy of the drift vectors, and using shorter motion duration increases the (relative) noise level.

Product timeliness is nominally better than 5 hours (from last recorded swath). This means that, on day 0 around *0500 UTC*, low-resolution ice drift datasets are distributed which cover the period from day -3 to day -1. For example, ice drift from 2008/02/16 to 2008/02/18 is delivered on 2008/02/19 around *0500 UTC*.

Due to atmospheric noise and surface melting, it is not possible to track sea ice during the melt season with the sensors and microwave frequencies we process at present (see table 1). On-going research is conducted to allow summer ice motion tracking from the 18.7 GHz channels of AMSR2 instrument (Kwok, 2008). This will be included in later updates of the product.

1.4 Glossary

ASCAT	Advanced SCATterometer
AVHRR	Advanced Very High Resolution Radiometer
AMSR2	Advanced Microwave Scanning Radiometer - 2
AMSR-E	Advanced Microwave Scanning Radiometer - EOS
CDOP	Continuous Development and Operations Phase
CF	Climate and Forecast
DMI	Danish Meteorological Institute
DMSP	Defense Meteorological Satellite Program
EDC	EUMETSAT Data Center
GCOM-W	Global Change Observation Mission for Water ("Shizuku")
HL	High Latitudes
JAXA	Japan Aerospace Exploration Agency
MET Norway	Norwegian Meteorological Institute
NetCDF	Network Common Data Form
NH	Northern Hemisphere
SAF	Satellite Application Facility
SH	Southern Hemisphere
SSM/I	Special Sensor Microwave/Imager
SSMIS	Special Sensor Microwave Imager Sounder
Tb	Brightness Temperature
TOA	Top Of Atmosphere

2. Algorithms

In this section, we briefly describe the algorithms used to extract ice drift information from pairs of daily low resolution satellite images. Note, however, that a detailed Algorithm Theoretical Basis Document (ATBD) is available from the web pages, which intends at giving an in depth understanding of the science and algorithm behind the low resolution ice drift product.

First, we introduce the preprocessing steps implemented to prepare daily maps of satellite signal from individual swath data. In the second section, we describe the tracking methodology to compute drift vectors, as well as the filtering of obviously erroneous estimates from the vector field. Finally, the merging strategy to obtain a multi sensor ice drift product is presented.

2.1 Building daily maps of satellite signal

Details on pre-processing of satellite data are in ATBD, chapter 2. Key features are summarized hereunder.

The ice tracking processor implemented in the OSI SAF first builds daily average maps of satellite signals. The satellite signal is either brightness temperatures for passive microwave instruments (e.g. SSMIS, AMSR2) or radar backscatter for scatterometers (e.g. ASCAT). The specific wavelengths and polarization used are discussed at a later stage.

2.1.1 Daily average field of satellite signal

Because ice drift is tracked between two images, each daily run begins by building two average daily images, with central time *1200 UTC*. All swath data relevant to one of the two dates of interest are collected and remapped in a common grid. At each grid location in the daily image is affected an average of the values coming from the selected swathes. Because sea ice moves during the 24h aggregation temporal window, a strategy is implemented to reduce the blurring due to motion. It is based on a temporal weighting function when computing the average. More details are in ATBD, section 2.2.2.

2.1.2 Laplacian filter

As proposed in Ezraty et al. (2007) a Laplacian filter is applied to the daily maps resulting from the previous section. This step aims at enhancing the signal's intensity patterns that are to be tracked by the ice drift processor. The ice tracking described in the next section is applied on pairs of Laplacian fields and not on pairs of daily average images. More details are in ATBD, section 2.2.3.

2.2 Ice motion tracking

Details on all aspects of motion tracking are in ATBD, chapter 3. Key features are summarized hereunder.

2.2.1 Individual ice motion tracking using the CMCC method

As the case for the majority of ice drift products, the vectors are optimized independently from the others, using a pattern matching algorithm which boils down to finding maximum cross correlations between sub-images (aka patterns). These are extracted respectively from the start and end images of the drift.

Continuous Maximum Cross Correlation

The algorithm implemented in the OSI SAF chain is, however, more advanced than the classical Maximum Cross Correlation (MCC) which is usually chosen, for example by Ezraty et al. (2007) or Haarpaintner (2006). Indeed, it implements the CMCC (Continuous Maximum Cross Correlation) method, which allows the formulation of the image matching problem in a continuous formalism, and thus strongly limit the quantization noise (*aka* tracking noise). The latter is an artifact of the MCC-based datasets and is responsible for their limited angular resolution when applied with lowresolution signal on short time spans. Figure 1 shows the better angular resolution a CMCC-based product (left panel) can have, with respect to one based on the MCC (right).

It is noteworthy that the product on the left of figure 1 (CMCC) is not a smoothing of the one on the right (MCC). Smoothing the MCC vector field would not bring such a spatial continuity and would not bring any extra information in the regions with very small motion.

In order for the CMCC implementation to be fully described, some parameters have to be known, such as 1) the size and shape of the sub-images, 2) the size of the search area and 3) the spacing between the drift locations on the output product grid. Those are 3 tuning parameters which have an influence on the retrieved vectors and that are decided upon by taking into account the pixel resolution of the images. Refer to section 3.3 for numerical values implemented in the OSI SAF chain.

Merging of polarization channels

As part of the enhanced ice-tracking methodology, the OSI SAF chain maximizes the sum of the cross correlations of all the channels available, instead of delivering several products for a given satellite. In the case of the SSMIS 91 GHz product, for example, two pairs of images are available. One for the vertically polarized channel and the other for the horizontal polarization. Instead of applying the ice tracking processor twice and merging the two independent products at a later stage (like in Haarpaintner (2006)), the OSI SAF ice drift processor directly maximizes the sum of two cross correlations, each using the differently polarized pairs of images. As introduced in Lavergne et al. (2008), this is an efficient way of taking into account the different uncertainty deriving from each channel and constitutes a

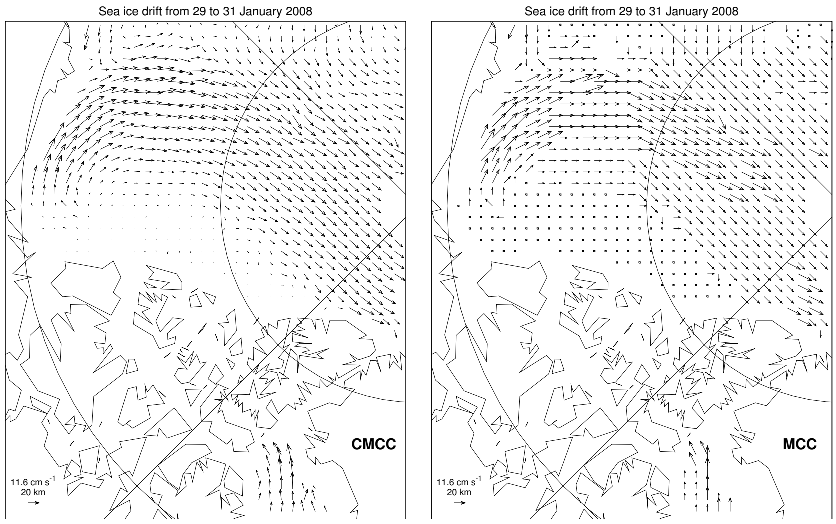

Figure 1: Example ice drift product in the Beaufort Sea retrieved from AMSR-E imagery (37 GHz). Both are 48 hours ice drift from 29th to 31st January 2008. The product on the right hand side was computed using MCC while the product on the left is retrieved with the CMCC. The removal of the quantization noise on the right hand side ice drift field enhances the angular resolution and spatial smoothness of the motion vectors. Figure reproduced from Lavergne et al. (2010).

first level of merging between ice drift datasets (intra-platform merging). This is also the reason why only one ice drift product is available per sensor, although two frequency channels are often used.

Varying pattern dimensions

As in Haarpaintner (2006), the size of the sub-image is modified close to open water, land or missing data to try and have vectors as close as possible to the border of the ice field. In those cases, half the nominal radius (in km) is used. This behaviour is documented in the product file and accessible to the user in the product flag (section 4.3).

2.2.2 Filtering of the vector field

Once all ice drift vectors in the product grid have been estimated independently from each other, a limited number look obviously wrong. Those need to be removed or corrected by a filtering step, whose strategy is described in more details in ATBD, section 3.5.

Drift vectors that are discarded or corrected by the filtering step are flagged and the information is included in the product file, as described in section 4.3.

A final filtering level is implemented which discards vectors having too low a maximum cross correlation value. This is also reported in the `status_flag` dataset, in the product file.

2.3 Merging daily products in a daily multi-sensor analysis

Details on multi-sensor merging are in ATBD, chapter 4. Key features are summarized hereunder.

The OSI SAF HL ice drift processing chain produces and distribute single sensor, daily products from all available instruments. Each of those products can be used as such for assimilation in geophysical models but might not be optimal when it comes to the tasks of forcing an ice model or performing process studies. This for three reasons :

- The start and end times of single sensor products are not homogeneous over the grid. This means that ice drift vectors in one product file do not correspond to exactly the same period of time. This is only an issue in regions presenting long drift vectors, when combined with rapidly changing drift directions, like is the case when an atmospheric low pressure system travels above sea ice.
- The single sensor ice drift products have a tendency to exhibit areas of missing data. Those might be due either to failure in the processing or from missing input swath data. The latter is particularly true for the AMSR-E instrument for which we are often missing swath data when the processing chain starts (this is much better with AMSR2).
- There is a region with constantly missing value close to North Pole due to the lack of satellite observations at very high latitudes.

In order to cope with those aspects and acknowledge that the various single sensor products have different quality statistics, a pragmatic merging procedure is implemented which has two steps:

1. "optimal" merging at sea ice grid locations with vectors from at least one single-sensor drift vector;
2. interpolation from neighbours at sea ice grid locations with no single-sensor drift vector.

More details are in ATBD, chapter 4.

2.4 Accuracy and Validation statistics

The validation of both single-sensor and multi-sensor ice drift products is documented in a dedicated validation report (VALR). Trajectories of in-situ GPS drifters and high-accuracy SAR-based ice motion products are used as reference data in a 2 years period.

Results show a yearly, hemispheric, averaged accuracy of about 2.5 km (standard deviation of 48 hours displacement in both vector components) for the AMSR2 single-sensor product, 3.5 km for SSMIS, and 4.5 km for ASCAT. The accuracy of the MULTI product is around 2.6 km. No bias is documented at the scale of the Northern Hemisphere.

The product is nonetheless challenged by highly dynamic conditions in the outskirt of the Arctic Ocean, e.g. in the Fram Strait and East Greenland Sea. The value of `status_flag` influences the validation results.

As expected, the new AMSR2 (SSMIS) products perform similarly to the older AMSR-E (SSM/I) ones.

All details are in VALR.

3. Processing scheme

3.1 Overview

The delivered products are 48 hours sea ice drift, whose start and end time are centered on *1200 UTC*. The choice of *1200 UTC* is mostly to be consistent with all other OSISAF sea ice products (sea ice concentration, edge, type, emissivity,...) that all use the same central time. The sensors used for the OSI SAF High Latitude low resolution sea ice drift processing are summarized in table 1. We also give a brief overview of the data flow and external data sources that are used for the processing of each sensor.

Table 1 lists only the instruments that are (or have been) used in the daily processing. Other sensors have been used for reprocessing activities but are no more active. Check the OSI SAF sea ice web portal http://osisaf.met.no for an updated list of those sensors.

3.2 Primary processing

3.2.1 Satellite data

All instrument swath data are used as NetCDF file formats and come from earlier processing in the OSI HL chain. Some of those processing steps are described in the Product User's Manual for OSI SAF sea ice products (Andersen et al., 2011).

3.2.2 Ancillary data

Sea ice mask

An ice mask product is needed for the processing. It should provide, on a daily basis, the sea ice extent as well as the ocean and land surface mask. The operational, multi sensor, sea ice edge product of the OSI SAF is used for this purpose. This product is described in the sea ice PUM (Andersen et al., 2011). Two sea ice edge products are used in daily sea ice drift processing : one for the start image and one for the end image.

3.3 Daily calculations

Daily calculations are performed each day (D) at *0400 UTC* and are based on data collected from two earlier days : D-3 and D-1. The sea ice drift chain is run right after the concentration, type and edge daily analysis since it relies on those daily sea ice state products (e.g. sea ice edge product, etc...).

3.3.1 sea ice mask

The 10 km gridded NH (SH) operational sea ice edge product is remapped to a 12.5 km resolution polar stereographic grid. The same 12.5 km grid is used for remapping the swath data and constitute the daily images.

Sensor	Platform	Channels	Sampling [km]	Footprint [km]	Last active date
SSMIS	DMSP-F17	91 GHz, H+V pol.	12.5	14x16	Active
ASCAT	Metop-A	C band σ^0	12.5	(25-34)x(25-34)	Active
AMSR2	GCOM-W1	37 GHz, H+V pol.	10	12x7	Active
AMSR-E	EOS Aqua	37 GHz, H+V pol.	10	14x8	Oct 3rd 2011
SSM/I	DMSP-F15	85 GHz, H+V pol.	12.5	14x16	Jan 19th 2013

Table 1: Sensors and corresponding channels used in the OSI SAF low-resoluion ice drift processing.

3.3.2 Daily images

Swath files are remapped and averaged on a 12.5 km polar stereographic grid, the same as for the ice mask. When several channels are present for a given instrument (e.g. two polarizations) they are kept in the same file. The average sensing time for each pixel is also recorded. The details of the remapping algorithms are in ATBD, chapter 2.

3.3.3 Laplacian filtering

Laplacian filtering is applied to sea ice pixels only. The ice mask is used. When a pixel is close to the sea ice edge, to land, or to missing data, the Laplacian computation is adapted to exclude those neighbor pixels which are not over sea ice, according to the mask. The laplacian fields (one for each of the instrument's channel) are appended to the file storing the daily average images.

3.3.4 Ice motion extraction and filtering

As they share large portion of software code, the ice motion extraction algorithm implementing the CMCC and the filtering are performed in the same software. This software takes as input the following parameters :

- Radius of the sub-image : the radius (in kilometers) of the sub-images to be cross-correlated at each step of the CMCC. The pattern's shape approximate a disk which is computed once, at North (or South) Pole. The disk is contained in a 11x11 pixels square.
- Maximum ice drift velocity : The maximum expected speed for the pattern's displacement. Once integrated over the time span separating the start and end images (48 h) this parameter gives a maximum drift distance (in km) in which the CMCC will search for the maximum of the correlation function. The value used is 0.45 $m.s^{-1}$.

- Output product grid : The ice drift computations are only performed at location on this grid. It is a polar stereographic 62.5 km grid covering the domains of the other OSI SAF ice-state products. The parameters for the grid are given in section 4.5. In practice it means that ice drift locations are every 5 image pixels and, thus, that the sub-images used in the correlation matching do overlap. Those are the same values as those used by Ezraty et al. (2007).
- Maximum distance to average vector : For the filtering step (Δ_{max}). This is set to 10 km.
- Minimum cross correlation threshold : As a last filtering step, all vectors with a cross correlation of less than 0.3 are discarded and flagged.

3.3.5 Multi sensor merged product

The merging step does not imply any image correlation computation. It is implemented in a different module and starts by searching for all the available single sensor products for the day, then apply the strategy described in section 2.3.

3.3.6 Summer products

Due to surface melting and a denser atmosphere, sea ice drift vectors cannot be retrieved reliably during summer from the instruments and channels we are currently using.

Therefore, and for disrupting as little as possible operational assimilation schemes using the ice drift datasets, empty product files are made available through the normal distribution methods (see section 4.6). Those files are formatted as normal ice drift product files, but contain no valid vectors, while the `status_flag` dataset is set accordingly (see table 2).

> The summer period runs from April 30th to October 1st for the NH grid, and from 31st October to 1st April for the SH grid.

4. Data description and distribution

4.1 Overview

The OSI SAF ice drift products are available in NetCDF format. They are all built on the same model and include a `status_flag` dataset which is also described in this section. Results from validation exercises and, especially, the bias and uncertainty estimates resulting from them are available in a separate validation report (VALR), at the OSI SAF Sea Ice web portal http://osisaf.met.no.

The ice drift product files are designed to follow the CF conventions for gridded products (CF-community, 2011). Those conventions give rules to present attributes, units and map projection as well as dimensions.

An example product file header in CDL notation is given in appendix B (page 22).

4.2 Sea ice drift datasets

4.2.1 Drift parameters : Definitions and units

A sea ice drift estimate is defined by 6 values : $\mathtt{lat}_0$, $\mathtt{lon}_0$, $\mathtt{t}_0$, $\mathtt{lat}_1$, $\mathtt{lon}_1$ and $\mathtt{t}_1$, where subscript 0 (respectively 1) refers to the start (resp. stop) time and position for the displacement. The ice drift product thus expresses that a parcel of ice which was at position $\mathtt{lat}_0$, $\mathtt{lon}_0$ at time $\mathtt{t}_0$, is at position $\mathtt{lat}_1$, $\mathtt{lon}_1$ at time $\mathtt{t}_1$. From those 6 quantities, all other ice drift datasets (like drift distance, direction, eastward component, etc...) can be computed by interested users.

Although they too can be retrieved from the above mentioned 6 quantities, the drift components along the X and Y axis of the product grid (dX and dY) are included in the product file. This is because :

1. their later derivation is more complex due to the use of the Earth mapping function;
2. they are the primary variables the CMCC estimates;
3. the uncertainty estimates of the ice drift product are given for those two parameters in the validation report (VALR), as they do not scale with latitude.

All geographical coordinate fields are given as degrees (latitude or longitude). The X and Y drift components have unit of km.

As any sea ice drift product processed from pair of satellite images (Ezraty et al., 2008; Haarpaintner, 2006; Kwok et al., 1998), the product at hand does not define an ice velocity, neither instantaneous nor averaged. The only information contained in the dataset is that an ice parcel observed at position ($\mathtt{lat}_0$, $\mathtt{lon}_0$) is at another position ($\mathtt{lat}_1$, $\mathtt{lon}_1$) at the end of the drift period (48 hours). Particularly, the dataset does not say anything about the trajectory (hence the velocities) of the ice between the two reference times $\mathtt{t}_0$ and $\mathtt{t}_1$. Although an arrow symbol is commonly used for representing the displacement, a straight line trajectory is not implied. This is the reason why the name for the dataset is not `sea_ice_velocity` and the unit is not $m.s^{-1}$.

In the NetCDF file, the provided datasets are : `lat`, `lon`, `lat1`, `lon1`, `dX` and `dY`. The later two contain CF standard_name `sea_ice_x_displacement` and `sea_ice_y_displacement`, respectively. Definitions for these quantities are given in the CF standard names table and reads (for dY):

> "y" indicates a vector component along the grid y-axis, when this is not true latitude, positive with increasing y. "Displacement" means the change in geospatial position of an object that has moved over time. If possible, the time interval over which the motion took place should be specified using a bounds variable for the time coordinate variable. A displacement can be represented as a vector. Such a vector should however not be interpreted as describing a rectilinear, constant speed motion but merely as an indication that the start point of the vector is found at the tip of the vector after the time interval associated with the displacement variable. A displacement does not prescribe a trajectory. Sea ice displacement can be defined as a two-dimensional vector, with no vertical component. A y displacement is calculated from the difference in the moving object's grid y coordinate between the start and end of the time interval associated with the displacement variable.

4.2.2 Time information

An ice drift vector must come with two time values (see above for t_0 and t_1). In the product file, we give 4 of them. Depending on the usage the ice drift product is intended for, users can chose between two types of time information :

- Because our processing is performed from daily maps, it can be considered a fair approximation that t_0 and t_1 are *1200 UTC* for all drift vectors. This date and time information is given at two locations in the product file :
  - Global attributes `start_date` and `stop_date` in a string format (*e.g.* 2008-01-01 12:00:00).
  - Dataset `time_bnds[2]`: `time_bnds[0]` = t_0 and `time_bnds[1]` = t_1. Those values are given as seconds since 01/01/1978.
- More accurate time information is additionally available for each individual vectors. This is because the scan pattern of the instrument and the orbit parameters of the platform all influence the time at which a particular region of the surface is sensed, even after a daily averaging of all available swath. This *average sensing time* is recorded while constituting the daily average. The accurate ice drift vectors are provided in each product file as 2 variables :
  - `dt0` is a map of begin time, expressed as seconds since `time_bnds[0]`.
  - `dt1` is a map of end time, expressed as seconds since `time_bnds[1]`.

  A consequence of these space varying start and stop times is a space varying duration of the drift vectors, which is thus not exactly 48 h in the product grid. Figure 2 plots example maps of `dt0`, `dt1`, and drift duration for an AMSR2 (GCOM-W1) and a SSMIS (F17) ice drift product. Note how the three time-related datasets vary across the product grid, as a consequence of the orbit and swath configurations of the satellite instrument.

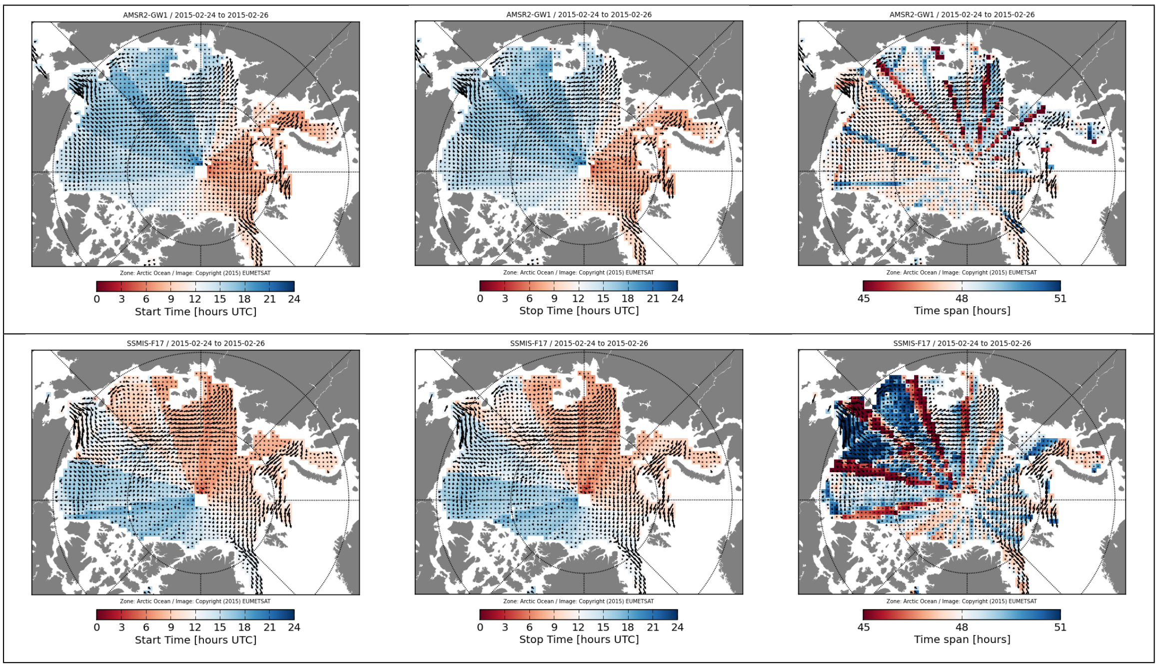

Figure 2: Maps of `dt0` (left), `dt1` (middle), and drift duration (right) for the ice drift vectors from 25th to 27th February 2015. Top row is for the AMSR2 (GCOM-W1) single-sensor product and bottom row is for the SSMIS (F17) product.

For compliance with CF (and COARDS) format conventions, a scalar value has to be specified for the `time` dimension. Since the ice motion we report is a time-extensive quantity (from t_0 to t_1), this scalar value has little meaning and was decided upon arbitrarily. As of version 1.3 of the product (November 2009), the value of the `time` dataset is t_1. This is to ensure that the suite of daily OSI SAF sea ice products (concentration, edge, type, drift, etc...) all have the same `time` value and can be displayed on the same time stamp.

4.3 Rejection and Quality Index flags

Except for the `lat` and `lon` datasets, all the above mentioned fields have valid values only when the ice drift product could be retrieved and is of acceptable quality. A `status_flag` dataset is thus also included in the product file to indicate for each pixel :

- if no valid retrieval could be made at this location, why;
- if a valid retrieval is proposed, what is its a-priori quality.

Flags of the first flavor are called rejection flags while those from the second flavor are quality index flags. Flags are encoded following CF conventions, that is with `flag_values` and `flag_meanings` attributes. Both flavors are encoded in a unique `status_flag` dataset, since both form a non-overlapping partition of the pixels.

Value	Meaning	Reason
0	`missing_input`	Missing image data. Whether because one or more swath are missing or because of the observation hole close to North Pole.
1	`over_land`	Location is over land
2	`no_ice`	Location is over open water (or open ice)
3	`close_to_coast_or_edge`	Location is over ice, but too close to land or ice edge to be processed.
4	`summer_period`	Untrusty vector was removed because in Summer period (start date between May 1st to September 30th).
5-9	*not used*	*reserved for later use.*
10	`processing_failed`	The optimization of the correlation function (CMCC) failed.
11	`too_low_correlation`	Vector was removed because the maximum cross correlation was below the minimum threshold.
12	`not_enough_neighbours`	Vector lies on its own and cannot be assessed by enough neighbours.
13	`filtered_by_neighbours`	Vector was removed because too inconsistent with the average drift vector from neighbouring pixels.
14-19	*not used*	*reserved for later use.*

Table 2: Value and meaning for the Rejection Flags entering the `status_flag` dataset.

4.3.1 Rejection flags

Rejection flags range from 0 to 19. All pixels having a value of the `status_flag` dataset in this range do not have a valid value for the other ice drift datasets. Table 2 lists the values and meaning of the rejection flags for ice drift products.

4.3.2 Quality index flag

Quality index flags range from 20 to 30. All pixels having a value of the `status_flag` dataset in this range have a valid value for the other ice drift datasets. A `status_flag` between 20 and 29 is reported to draw the attention of the user to vectors with possible degraded quality. A value of 30 indicates vectors which we trust have nominal quality. Table 3 lists the values and meaning of the quality index flags for ice drift products.

Recent validation study (VALR) suggest that vectors with `status_flag` 30 have much higher accuracy than those with values between 20 and 29. Especially values 21 and 22 should be used with caution, if possible enlarging the associated uncertainties. `status_flag` 20 is more reliable.

Value	Meaning	Reason
20	smaller_pattern	The CMCC was applied with a smaller radius for the sub-images, due to the proximity to coast, edge or missing value.
21	corrected_by_neighbours	The vector was not retrieved in the first CMCC step but was constrained using the neighbouring vectors.
22	interpolated	The vector was not retrieved by CMCC but was interpolated from the neighbouring vectors. Only appears in the multi-oi product.
23-29	*not used*	*reserved for later use.*
30	nominal_quality	The vector was retrieved by CMCC, independently of others.

Table 3: Value and meaning for the Quality Index Flags entering the status_flag dataset.

4.4 Global attributes to the product file

Following the CF convention, global attributes are added to describe the product file content. They are mainly intended to be read by users (like the abstract) but some of them might also be parsed and analyzed by visualization software or help find the product files in metadata search tools. Global attributes for an example file are included in the CDL example file in appendix B (page 22).

4.5 Grid characteristics

The ice drift product grid is adapted from the 10 km grid used for the other OSI SAF ice product. Below are given the details of the grid definitions and approximate maps of the grid extents, corner coordinates are referenced to pixel center. Projection definitions in the form of PROJ-4 initialization strings are also given (see http://www.remotesensing.org/proj for details).

Projection	Polar sterographic projection true at $70°$ N
Central Meridian	$45°$ W
Corner point	$35.14838°$ N;$10.30485°$ W | X: -3750 km; Y:5750 km
Earth's shape	a = 6378273 m / b = 6356889.44891 m
PROJ-4 string	+proj=stere +a=6378273 +b=6356889.44891 +lat_0=90 +lat_ts=70 +lon_0=45
Resolution	62.5 km
Size	119 columns, 177 lines

Table 4a: Geographical definition for Northern Hemisphere grid, NH

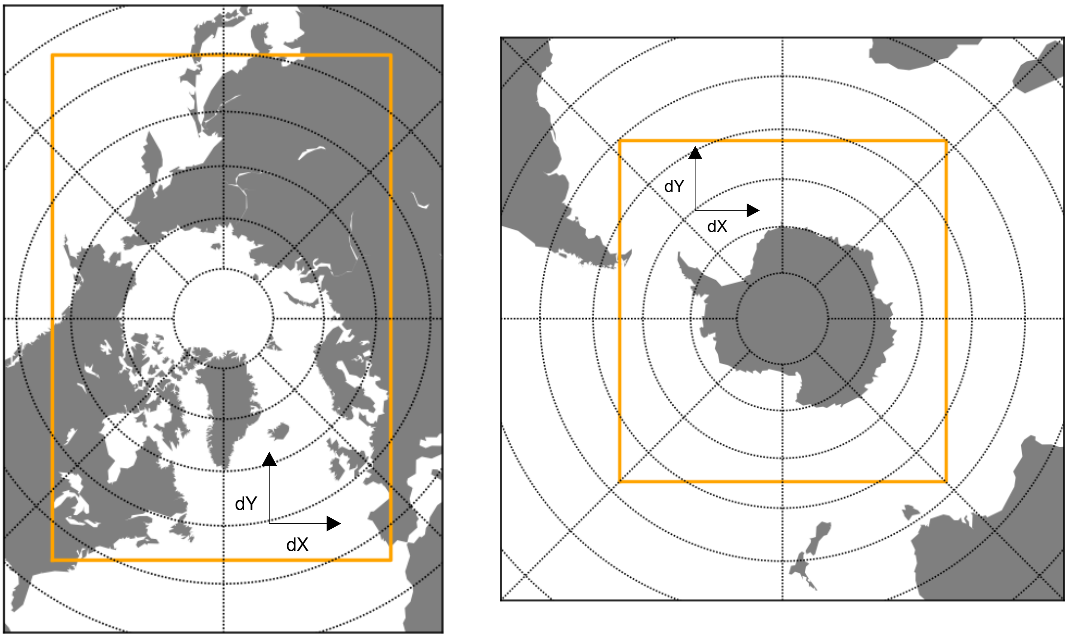

Figure 3: Coverage of the Northern and Southern Hemisphere grids is shown with the orange boxes.

Projection	Polar sterographic projection true at $70°$ S
Central Meridian	$0°$ (Greenwich)
Corner point	$40.1782°$ S;$42.3575°$ W | X: -3875 km; Y:4250 km
Earth's shape	a = 6378273 m / b = 6356889.44891 m
PROJ-4 string	`+proj=stere +a=6378273 +b=6356889.44891 +lat_0=-90 +lat_ts=-70 +lon_0=0`
Resolution	62.5 km
Size	125 columns, 131 lines

Table 4b: Geographical definition for Southern Hemisphere grid, SH

Note that `xc` and `yc` datasets in the NetCDF file contain the grid coordinates (in km) of the center of each cell. These define an equally spaced grid with 62.5 km spacing. Figure 3 plots the area covered by the grid described in table 4a and 4b.

The direction (sign) of `dX` and `dY` variables are defined to follow the CF convention, which states:

> "y" indicates a vector component along the grid y-axis, when this is not true latitude, positive with increasing y.

Particularly, southwardly export along the East Coast of Greenland will have *negative* `dY` values. Note that `dY` had the opposite sign in earlier versions of the product (until `v1.p3`, see appendix C). See also maps of `dX` and `dY` in appendix A.

4.6 Data distribution

4.6.1 Sea Ice FTP server

Sea ice drift product files can be collected at the OSI SAF Sea Ice FTP server. At the OSI SAF Sea Ice FTP server ftp://osisaf.met.no/prod/ice/ the products are available on NetCDF format (under directory `drift_lr`). Here, products from the last 31 days can be collected. In addition there is a separate directory with archive of all the sea ice drift products under ftp://osisaf.met.no/archive/ice/drift_lr. The file name convention for these products is given in the table below.

Naming convention for ice drift files at OSI SAF FTP server
`ice_drift_<area>_<gridInfo>_<source>_<startdate12>-<enddate12>.nc`

`<area>`	`nh` (`sh`) for Northern (Southern) Hemisphere product.
`<gridInfo>`	projection/grid information, `polstere-625`.
`<source>`	Instrument used for the product. One of `amsr-aqua`, `ssmi-fxx`, `ascat-metopA` or `multi-oi`.
`<date12>`	Start or Stop date and time of the product, on format `YYYYMMDDhhmn`.

Note that the primary separating character is _ (underscore) and that the secondary one is - (dash). For compatibility with the other sea ice products from OSI SAF, a secondary level separator appears between the two dates. This is because the two dates form together a unique `timeInfo`.

The architecture at the OSI SAF Sea Ice FTP server is:

```
ftp://osisaf.met.no
`-- prod
    `-- ice
        `-- drift_lr
            |-- merged
            |   `-- ice_drift_*.nc
            `-- single_sensor
                |-- amsr2-gw1
                |   `-- ice_drift_*.nc
                |-- ascat-metopA
                |   `-- ice_drift_*.nc
                `-- ssmis-f17
                    `-- ice_drift_*.nc
```

4.6.2 EUMETCast dissemination and archiving at EDC

As of now, only the merged (multi-sensor) products are disseminated through EUMETCast.

Naming convention for ice drift files on EUMETCast
`S-OSI_-NOR_-MULT-NH_LRSIDRIFT-<enddate12>Z.nc.gz`
`S-OSI_-NOR_-MULT-SH_LRSIDRIFT-<enddate12>Z.nc.gz`

Since the file name convention for OSI SAF files on EUMETCast does not allow for using two date-stamps, it was chosen to use the *end* date for the motion as a date-stamp.

These multi-sensor product files are centrally archived at the EDC, with acronym `OSIDRGB`[1].

[1] http://eoportal.eumetsat.int/userMgmt/protected/dataCentre.faces?acronym=OSIDRGB

A. Examples of products

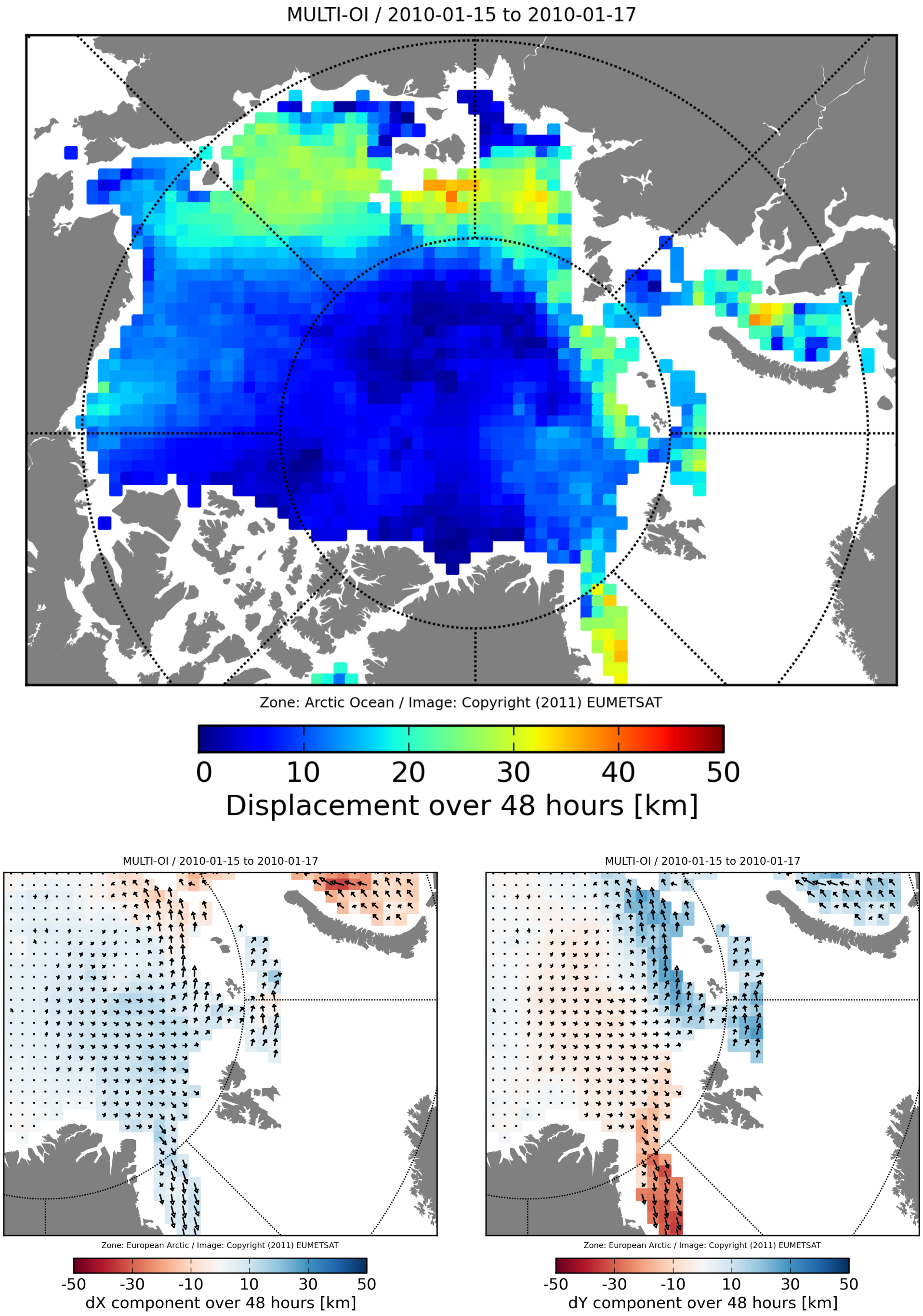

Figure A.1: Multi-sensor drift maps from 15^{th} to 17^{th} Jan 2010 over the Northern Hemisphere (zoomed over the Arctic Ocean, and the European Arctic regions). Top panel displays total displacement in km from blue (little movement) to red (long displacements). Bottom panels display components `dX` (left) and `dY` (right). Note the sign of `dY` : it is negative for southwardly export across Fram Strait and along the East Coast of Greenland.

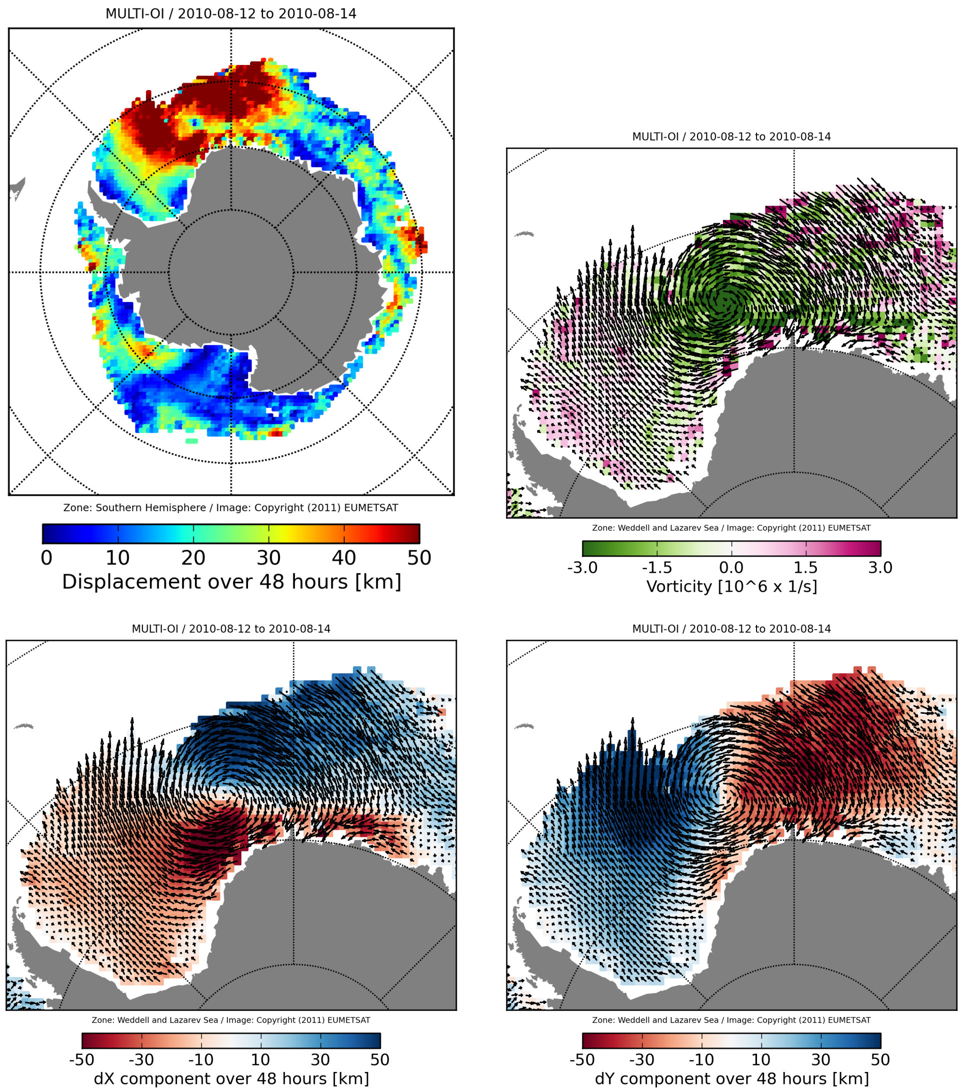

Figure A.2: Multi-sensor drift maps from 12th to 14th Aug 2010 over the Southern Hemisphere (whole area, and zoomed over the Weddel and Lazarev Seas). Top panel displays total displacement in km (left) and vorticity of the displacement field (right). Bottom panels display components `dX` (left) and `dY` (right). Note the sign of `dY` : it is positive for northwardly drift along the Eastern coast of the Antarctic Peninsula. The vorticity (*aka* curl) is not part of the product file but is easily computed from `dX` and `dY`. It allows efficient characterization of larger scale rotation motion like when an atmospheric low-pressure travels over sea ice.

B. Sea Ice drift products in NetCDF format

```
netcdf ice_drift_nh_polstere-625_multi-oi_201501031200-201501051200 {
dimensions:
        time = 1 ;
        nv = 2 ;
        xc = 119 ;
        yc = 177 ;
variables:
        int Polar_Stereographic_Grid ;
                Polar_Stereographic_Grid:grid_mapping_name = "polar_stereographic" ;
                Polar_Stereographic_Grid:straight_vertical_longitude_from_pole = -45.f ;
                Polar_Stereographic_Grid:latitude_of_projection_origin = 90.f ;
                Polar_Stereographic_Grid:standard_parallel = 70.f ;
                Polar_Stereographic_Grid:false_easting = 0.f ;
                Polar_Stereographic_Grid:false_northing = 0.f ;
                Polar_Stereographic_Grid:semi_major_axis = 6378273.f ;
                Polar_Stereographic_Grid:semi_minor_axis = 6356890.f ;
                Polar_Stereographic_Grid:proj4_string = "+proj=stere +a=6378273 +b=6356889.44891 +lat_0=90 +lat_ts=70 +
                       lon_0=-45" ;
        double time(time) ;
                time:axis = "T" ;
                time:long_name = "reference time of product" ;
                time:standard_name = "time" ;
                time:units = "seconds since 1978-01-01 00:00:00" ;
                time:calendar = "standard" ;
                time:bounds = "time_bnds" ;
                time:comment = "As of version 1.3 of the product, the \'time\' scalar dataset contains the _end_ date of
                       motion (was\n",
                          "begin date in previous versions)." ;
        double time_bnds(time, nv) ;
                time_bnds:units = "seconds since 1978-01-01 00:00:00" ;
        double xc(xc) ;
                xc:axis = "X" ;
                xc:units = "km" ;
                xc:long_name = "x coordinate of projection (eastings)" ;
                xc:standard_name = "projection_x_coordinate" ;
        double yc(yc) ;
                yc:axis = "Y" ;
                yc:units = "km" ;
                yc:long_name = "y coordinate of projection (northings)" ;
                yc:standard_name = "projection_y_coordinate" ;
        float lat(yc, xc) ;
                lat:long_name = "latitude coordinate" ;
                lat:standard_name = "latitude" ;
                lat:units = "degrees_north" ;
        float lon(yc, xc) ;
                lon:long_name = "longitude coordinate" ;
                lon:standard_name = "longitude" ;
                lon:units = "degrees_east" ;
        int dt0(time, yc, xc) ;
                dt0:long_name = "delta time for start of displacement" ;
                dt0:units = "seconds" ;
                dt0:_FillValue = 2147483647 ;
                dt0:valid_min = -43200 ;
                dt0:valid_max = 43200 ;
                dt0:grid_mapping = "Polar_Stereographic_Grid" ;
                dt0:coordinates = "lat lon" ;
        float lon1(time, yc, xc) ;
                lon1:long_name = "longitude at end of displacement" ;
                lon1:units = "degrees_east" ;
                lon1:_FillValue = -1.e+10f ;
                lon1:grid_mapping = "Polar_Stereographic_Grid" ;
                lon1:coordinates = "lat lon" ;
        float lat1(time, yc, xc) ;
                lat1:long_name = "latitude at end of displacement" ;
                lat1:units = "degrees_north" ;
                lat1:_FillValue = -1.e+10f ;
                lat1:grid_mapping = "Polar_Stereographic_Grid" ;
                lat1:coordinates = "lat lon" ;
        int dt1(time, yc, xc) ;
                dt1:long_name = "delta time for end of displacement" ;
                dt1:units = "seconds" ;
                dt1:_FillValue = 2147483647 ;
                dt1:valid_min = -43200 ;
                dt1:valid_max = 43200 ;
                dt1:grid_mapping = "Polar_Stereographic_Grid" ;
                dt1:coordinates = "lat lon" ;
        float dX(time, yc, xc) ;
                dX:long_name = "component of the displacement along the x axis of the grid" ;
                dX:standard_name = "sea_ice_x_displacement" ;
                dX:units = "km" ;
                dX:_FillValue = -1.e+10f ;
```

```
                dX:grid_mapping = "Polar_Stereographic_Grid" ;
                dX:coordinates = "lat lon" ;
        float dY(time, yc, xc) ;
                dY:long_name = "component of the displacement along the y axis of the grid" ;
                dY:standard_name = "sea_ice_y_displacement" ;
                dY:units = "km" ;
                dY:_FillValue = -1.e+10f ;
                dY:grid_mapping = "Polar_Stereographic_Grid" ;
                dY:coordinates = "lat lon" ;
        byte status_flag(time, yc, xc) ;
                status_flag:long_name = "rejection and quality level flag" ;
                status_flag:standard_name = "sea_ice_x_displacement status_flag" ;
                status_flag:valid_min = 0b ;
                status_flag:valid_max = 30b ;
                status_flag:grid_mapping = "Polar_Stereographic_Grid" ;
                status_flag:coordinates = "lat lon" ;
                status_flag:flag_values = 0b, 1b, 2b, 3b, 4b, 10b, 11b, 12b, 13b, 20b, 21b, 22b, 30b ;
                status_flag:flag_meanings = "missing_input_data over_land no_ice close_to_coast_or_edge summer_period
                     processing_failed too_low_correlation not_enough_neighbours filtered_by_neighbours smaller_pattern
                     corrected_by_neighbours interpolated nominal_quality" ;
                status_flag:flag_descriptions = "\n",
                        "  0 -> missing satellite image data\n",
                        "  1 -> grid point is over land\n",
                        "  2 -> grid point is not over sufficient ice\n",
                        "  3 -> grid point is too close to coast or edge\n",
                        "  4 -> unreliable vector was removed because in summer period\n",
                        " 10 -> optimization of the correlation (CMCC) failed\n",
                        " 11 -> vector removed because too low cross-correlation \n",
                        " 12 -> vector removed because not enough neighbouring vectors\n",
                        " 13 -> vector removed because motion is not consistent with neighbours\n",
                        " 20 -> vector processed using a smaller matching window\n",
                        " 21 -> vector corrected using the neighbouring vectors\n",
                        " 22 -> vector interpolated from the neighbours (multi-sensor product)\n",
                        " 30 -> vector was retrieved with nominal CMCC algorithm" ;

// global attributes:
                :title = "Daily Low Resolution Sea Ice Displacement from OSI SAF EUMETSAT" ;
                :product_id = "OSI-405" ;
                :product_name = "osi_saf_lr_ice_drift" ;
                :product_status = "operational" ;
                :abstract = "Gridded ice displacement fields obtained from  satellite  image\n",
                        "processing. It is a low resolution product (62.5km resolution).\n",
                        "The time span of  the  ice  displacement  is  approximately  48\n",
                        "hours. This dataset is intended both for  process  studies  and\n",
                        "data assimilation. Daily products  are  freely  available  from\n",
                        "the  OSI SAF distribution chain." ;
                :topiccategory = "Oceans ClimatologyMeteorologyAtmosphere" ;
                :keywords = "Sea Ice Motion,Sea Ice,Oceanography,Meteorology,Climate,Remote Sensing" ;
                :gcmd_keywords = "Cryosphere > Sea Ice > Sea Ice Motion\n",
                        "Oceans > Sea Ice > Sea Ice Motion\n",
                        "Geographic Region > Northern Hemisphere\n",
                        "Vertical Location > Sea Surface\n",
                        "EUMETSAT/OSISAF > Satellite Application Facility on Ocean and Sea Ice, European Organisation for
                             the Exploitation of Meteorological Satellites" ;
                :northernmost_latitude = 90.f ;
                :southernmost_latitude = 31.96109f ;
                :easternmost_longitude = 180.f ;
                :westernmost_longitude = -180.f ;
                :activity_type = "Space borne instrument" ;
                :area = "Northern Hemisphere" ;
                :instrument_type = "Multi-sensor analysis" ;
                :platform_name = "Multi-sensor analysis" ;
                :start_date = "2015-01-03 12:00:00" ;
                :stop_date = "2015-01-05 12:00:00" ;
                :project_name = "EUMETSAT OSI SAF" ;
                :institution = "EUMETSAT OSI SAF" ;
                :PI_name = "Thomas Lavergne" ;
                :contact = "osisaf-manager@met.no" ;
                :distribution_statement = "Free" ;
                :copyright_statement = "Copyright 2015 EUMETSAT" ;
                :references = "OSI SAF Low Resolution Sea Ice Drift Product User\'s Manual, Lavergne, T., Eastwood S., v1
                     .5, October 2011\n",
                        "Validation and Monitoring of the OSI SAF Low Resolution Sea Ice Drift Product, Lavergne, T., v3,
                             October 2011\n",
                        "http://osisaf.met.no\n",
                        "http://www.osi-saf.org" ;
                :history = "2015-01-06 creation" ;
                :product_version = "1.4" ;
                :software_version = "5.0" ;
                :netcdf_version = "3.6.3" ;
                :Conventions = "CF-1.4" ;
}
```

C. Product Change History

C.1 From 1.5 to 1.6 : Early 2015

C.1.1 Product Characteristics:

- **MAJOR**: Introduce AMSR2 from GCOM-W1;

C.1.2 Algorithms:

- MINOR: Computation of sea ice drift vectors is extended to "open ice" areas (>=40% SIC);
- MINOR: Use TOA Brightness Temperatures, instead of Tbs corrected for atmospheric influence;

C.1.3 File Format:

- Nothing to report;

C.2 From 1.4 to 1.5 : Early 2014

C.2.1 Product Characteristics:

- **MAJOR**: Replace SSM/I F15 (85 GHz) with SSMIS F17 (91 GHz);

C.2.2 Algorithms:

- Nothing to report;

C.2.3 File Format:

- Nothing to report;

C.3 From 1.3 to 1.4 : Early 2012

C.3.1 Product Characteristics:

- **MAJOR**: Extend processing to Southern Hemisphere;
- **MAJOR**: the `dY` dataset is given the opposite sign wrt earlier versions to follow the CF (Climate and Forecast) definition of `sea_ice_y_displacement` standard name;

C.3.2 Algorithms:

- Nothing to report;

C.3.3 File Format:

- **MAJOR**: the `status_flag` dataset changes from type `short` to `byte`;
- MINOR: `status_flag` is better self-documented with attribute `flag_descriptions`;

C.4 From 1.x to 1.3 : December 2009

C.4.1 Product Characteristics:

- Nothing to report

C.4.2 Algorithms:

- Nothing to report

C.4.3 File Format:

- **MAJOR**: the `time` dataset changes from holding the *start* to *stop* time;

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