MERSEA IP

Marine Environment and Security for
the European Area - Integrated Project

WP 2.4, Remote sensing of Sea Ice

Report on development and operationalization of a Sea Ice type product based on use of QuikScat data.

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1. SEA ICE PRODUCTS IN MERSEA

A main goal of WP 2, *remote sensing* in MERSEA is to make ocean parameters as derived from remote sensing data available for operational ocean modelling in Europe. The Eumetsat Ocean & Sea Ice Satellite Application Facility (OSI SAF) is therefore established as the sea ice centre for MERSEA. The sea ice products are described at

http://saf.met.no/.

The OSI SAF provides an operational analysis system which derives sea ice products by combining satellite data from different sensors. Three products are defined:

- Ice concentration (%)
- Ice edge: probability of ice coverage
- Ice type: probability of multi-year/ first-year

The products are presented on 10 km horizontal resolution polar stereographic grids covering Northern Hemisphere and Southern Hemisphere. The data are provided once daily and are availed on http://saf.met.no/.

The developments of the OSI SAF sea ice algorithms have been presented in Breivik et al. (2001). The products will be evolved during the MERSEA project. This report describes the work and results on improved sea ice type products.

2. SEA ICE ANALYSIS

2.1. Bayesian multi sensor approach

A general tool for combining various data sources containing uncertain information is given by the Bayesian approach or “inverse method”. Using this approach several measured parameters can be combined to yield an optimal estimate.

Applied on ice type analysis the Bayesian approach is based on pre-knowledge of the averaged relationship between each *ice type* and the satellite-measured parameter. In addition knowledge of the scatter of the expected measurement value for each ice type is needed. This knowledge can be expressed as a probability density distribution for the measurement parameter *given the ice type*. Allowing ice types, *MY*: multi year and *FY*: first year, an algorithm can be derived. We then need to estimate probability density distributions for the given ice type, *p(A|MY)* and *p(A|FY)*. Setting both the prior probabilities for *MY* and *FY*, *P*(*MY*) and *P*(*FY*) equal to 50%, we get

$$p(MY \mid A) = \frac{p(A \mid MY)}{p(A \mid MY) + p(A \mid FY)} \quad . \qquad (1)$$

The method can be generalised for combining several satellite-measured parameters to an optimal ice class estimate analysing several mutually independent ice types, classes etc. Assume that we have *n* measured parameters A_1, A_2, …, A_n, which are independent given a certain ice type. A general expression can then be derived for the probability of an ice class I_k given the measured parameters:

$$P(I_k \mid A_1,\ldots,A_n) = \frac{p(A_1 \mid I_k)\cdot p(A_2 \mid I_k)\cdot\ldots\cdot p(A_n \mid I_k)}{\sum_j p(A_1 \mid I_j)P(I_j)\cdot\ldots\cdot p(A_n \mid I_j)P(I_j)} P(I_k) \quad . \qquad (2)$$

The method works in such a way that the measured parameter, which the statistics shows to be most secure in distinguishing between ice class, is the one that gives most impact in the analysis. Further we do not only obtain an estimate of the most probable ice class, but also of the uncertainty of this estimate.

2.2. Estimation of Ice type probabilities

2.2.1. SSM/I

Due to increased internal scattering in multi-year ice the change in radiation as a function of frequency might be used to distinguish between ice types. For SSM/I the gradient ratio of the 19 and 37 GHz vertically polarized channels

$$GR(19,37,V)=(Tb_{37v} - Tb_{19v}) / (Tb_{37v} + Tb_{19v})$$

has proved particularly useful. Mean values and standard deviations of this parameter are given in Table 1. The data used to derive the statistics are based on measurements in areas where the ice type is known.

Table 1: Mean values and standard deviations of the SSM/I gradient ratio GR(19,37,V) based on a dataset from the spring season 2000.

Parameter	Mean first-year	Std first-year	Mean multi-year	Std multi-year
GR(19,37,V)	-1.7	1.1	- 6.3	1.3

Using these values probability distribution functions can be derived. In this case and for all exampled described in the current report we have assumed Gaussian probability distributions. An example of the operational OSI SAF ice type product based on SSM/I data are given in Fig. 1.

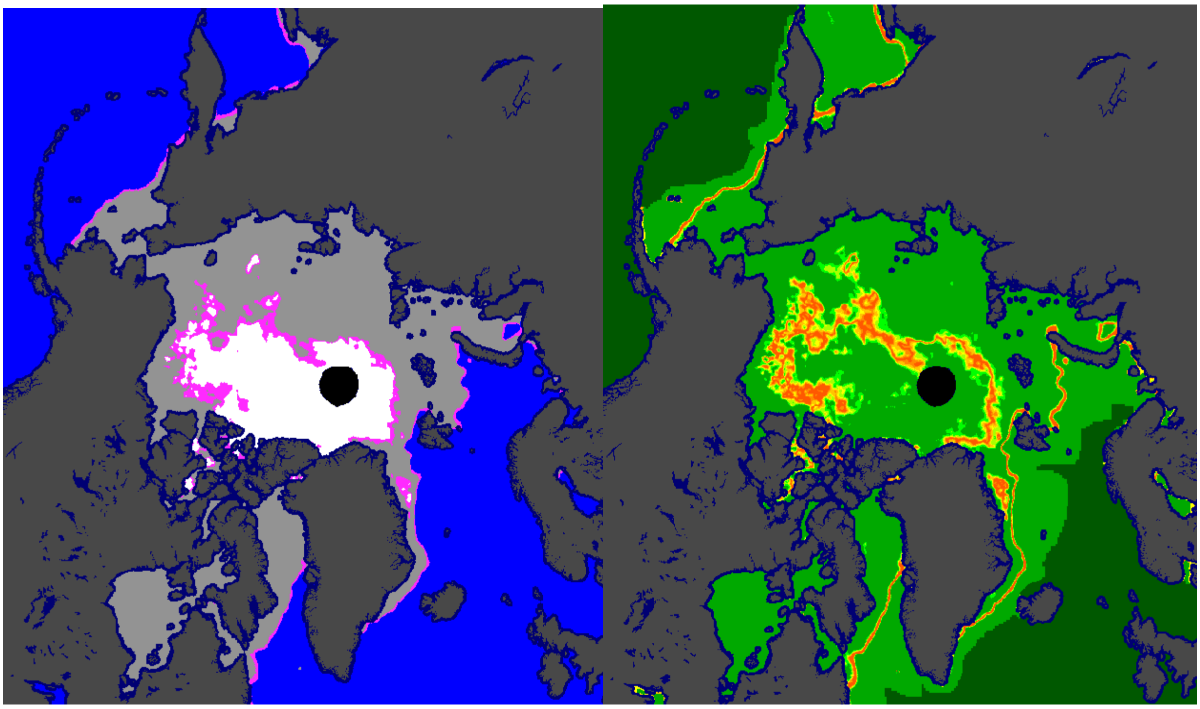


Figure 1. Ice type analysis from one day of SSM/I data January 4, 2006.

Left panel: Sea Ice type product. White: high probability of multi year ice, grey: high probability of first year ice, pink: uncertain / mixture.

Right panel: Probability of ice type class in the product. Green colors: high probability values close to 100%. Red/yellow: low probability. These areas are typically in between the areas with FY and MY ice and are classified as uncertain.

2.2.2. ERS Scatterometer

The normalized scatterometer backscatter σ^0 from sea ice is dependent on ice type. Multi-year ice is rougher than first-year, and hence the backscatter is larger. Multiyear ice, in particular during winter, will also have an additional backscatter signature compared to first year ice as a result of volume scattering. In addition the change of backscatter with incidence angle, *D*, is larger for first-year ice compared to multi-year ice. Mean values and standard deviation of backscatter, $B = 100 \times \sigma^0(linear)$ for 5 different incidence angles, cell numbers, are given in Table 2.

The data used to derive the statistics given in Table 2 are based on measurements in areas where the ice type is known. The first-year sea ice data are taken from the areas east of Novaya Zemlya and the multi-year ice data are from the areas north of Greenland.

Table 2: Mean values and standard deviations of the averaged backscatter B *for 5 different cell numbers across the ERS scatterometer swath based on a dataset from spring 2000.*

Cell number	Mean first-year	Std first-year	Mean multi-year	Std multi-year
1	7.7	5.2	9.0	4.5
5	4.3	1.6	6.3	2.4
10	2.9	1.1	4.9	2.0
15	2.2	0.8	3.8	1.6
19	1.6	0.6	3.0	1.5

3. ICE TYPE ANALYSIS USING QUIKSCAT DATA

3.1. QuikScat Ice class analysis

The Seawind instrument on QuikScat is a Ku band scatterometer with two rotating beams, outer beam using vertical polarisation (VV) and inner beam are using horizontals polarization (HH). For additional information on QuikScat see http://winds.jpl.nasa.gov/missions/quikscat/.

The sensitivity of QuikScat data for various ice types and concentrations where investigated in an OSI SAF study in 2003. Data from QuikScat was collocated with sea ice type analysis performed by the Danish Meteorological Sea Ice Service. The sea ice where divided into the following classes:
Closed ice: 70 -100 % ice concentration
medium ice: 30-70 % ice concentration
open ice: 0-30 % ice concentration
These concentration intervals where then divided into First Year (FY) and Multi Year (MY) ice giving al together 6 ice classes. The statistics where derived for four seasons: winter, spring, summer and autumn. In Table 3 statistics from three parameters that are sensitive to sea ice are given:

- *backscatter coefficients for HH and VV*
- *polarization ratio PR defined as the ratio of the difference over the of HH and VV*

For more details and results see Tonboe and Haarpainter (2003).

Table 3: Mean values and standard deviations of the averaged QuikScat parameters derived from a winter season:

Closed MY	***Closed FY***	***Medium MY***	***Medium FY***	***Open MY***	***Open FY***	***Water***	
0.124489	0.043202	0.066314	0.047886	0.044299	0.046253	0.005012	*HH MEAN*
0.050469	0.025798	0.028628	0.022969	0.022882	0.027978	0.030000	*HH std*
0.087328	0.026434	0.048110	0.033969	0.036863	0.036303	0.005012	*VV MEAN*
0.035703	0.015396	0.018811	0.015696	0.017076	0.018610	0.030000	*VV std*
0.178566	0.237171	0.147329	0.172085	0.073029	0.095336	-0.03000	*POL MEAN*
0.073488	0.067682	0.086058	0.137423	0.106064	0.120393	0.130762	*POL std*

Based on this statistics an ice class analysis algorithm has been developed using the Bayesian approach described in 2.1 above. Gaussian distributions are assumed for the probability density functions *p(A_i|ice class)* where A_i are the three parameters *HH, VV* and *POL.* The analysis algorithm has been implemented in a semi operational scheme parallel to the operational OSI SAF system and used in daily ice class analysis. The results are given on the 10 km resolution grid as described in the Sea Ice product manual (Product Manual for Sea Ice products at http://saf.met.no/docs) and the products are available on test basis on the OSI SAF ftp server http://saf.met.no/. An example from January 4 is given in Fig.2.

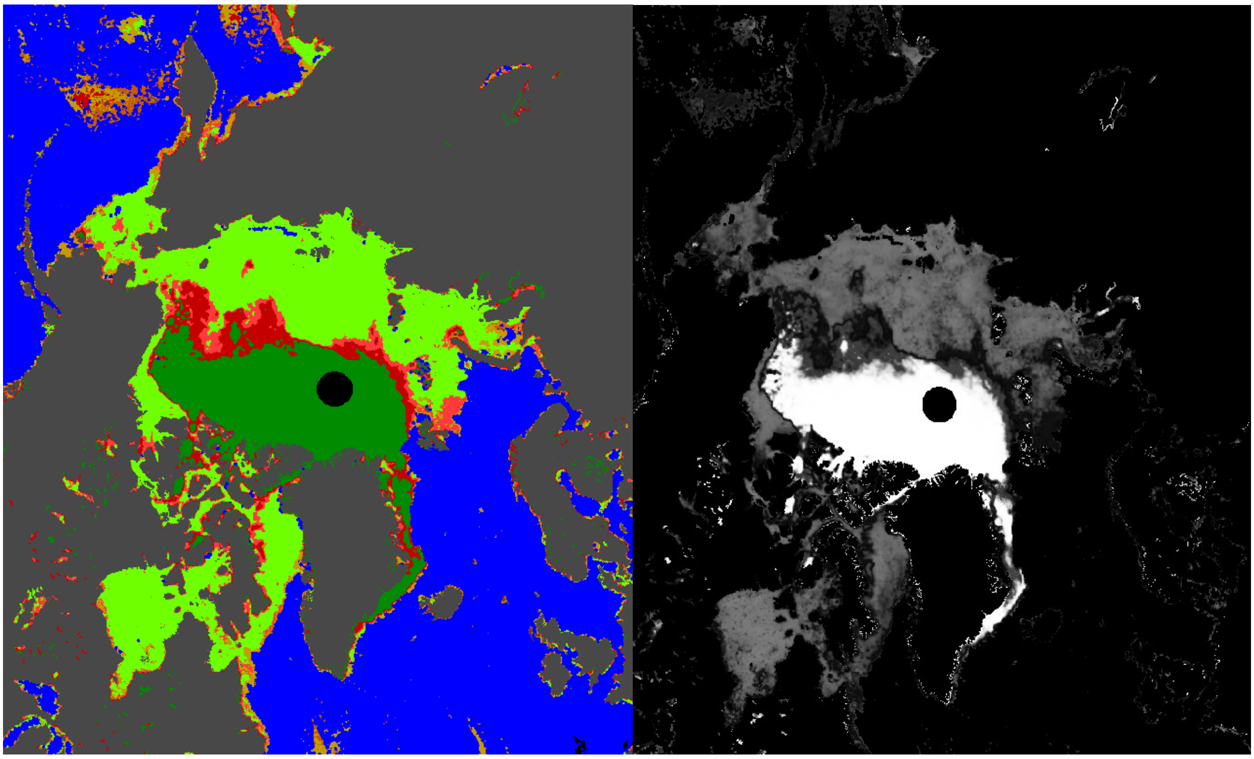
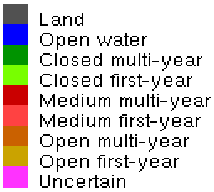


Figure 2. Sea ice class analysis from one day of QuikScat data valid January 4, 2006.
Left panel: Ice classes,



Right panel: probabilities of estimated ice classes. White/bright indicates high probability while dark indicate low probability. Open water and land is black.

In Fig.2 it is seen that between the areas dominated by multi year and first year there are areas with low probabilities for any classes. This can be interpretated as areas with mixed ice classes.

For comparison the operational sea ice analysis valid at January 4 from Met.no sea ice service is given in Fig. 3. The QuikScat ice chart on Fig. 2 also shows some more details in the ice edge (boarder between ice and water) compared to the product derived only from SSM/I data. However it is a challenge to automatically distinguish between ice and wind induced noise. Currently QuikScat data is not in use in the operational OSI SAF ice edge product.

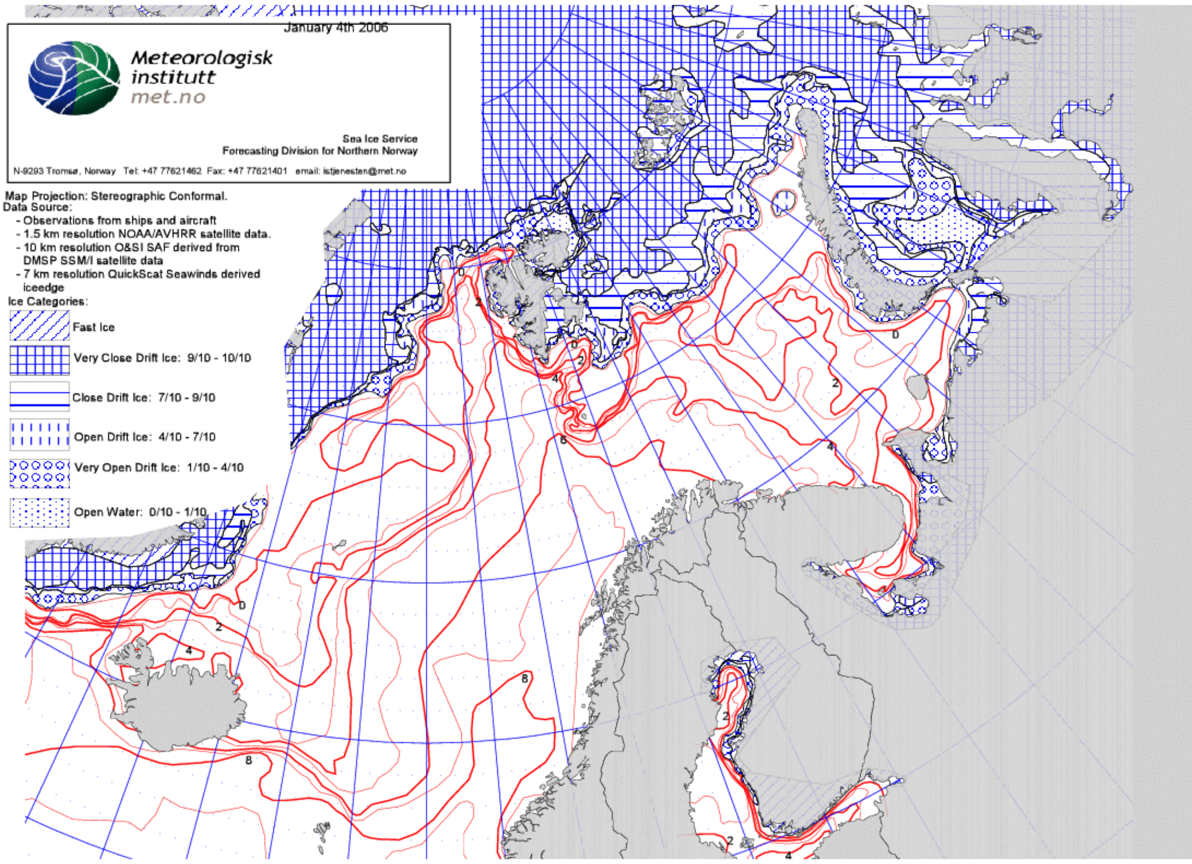


Figure 3: Sea ice service analysis valid January 4, 2006.

3.2.Multi sensor ice type analysis

Generally it is difficult to validate the quality of ice type products as there are few good independent observations. However a good feeling of the quality can be obtained by looking at areas where the ice is well known to be of a certain type. Due to the drift of ice cross the polar ocean, the sea ice north of Greenland is always Multi Year, while for example in the Hudson Bay and in the Barents Sea new ice is formed yearly. Figure 1,2 and 4 showing ice type products based on SSM/I, QuikScat and a combination respectively, all give realistic results in these areas.

The OSI SAF Sea Ice type product is currently based on SSM/I data, as described in 2.2.1 and with an example shown in Fig. 1. However the products are known to have weaknesses in particular in areas where there is a mixture of first year and multi year ice. This has become evident in areas continuously monitored by the operational sea ice services as a part of the OSI SAF project in particular the east Greenland coastal current (Lind, Hansen and Andersen, 2005). These areas are characterized by a mixture of multi year ice transported from the polar areas southward along the Greenland coast. In the SSM/I based product currently operational in the OSI SAF the probability for multi year ice is underestimated in these areas as seen at Fig. 1. Here the east Greenland oceans are dominated by first year ice. This is in contradiction to what is regularly reported from the operational ice services. However, in the ice class analysis derived from QuikScat as described in the previous section and seen on Fig. 2, these areas are more dominated by multi year ice.

To explore both the information in the QuikScat products as well as SSM/I a Bayesian multi sensor analysis has been developed and implemented following the approach described in section 2.1. The statistics used are given in Table 1 for SSM/I and Table 3 for QuikScat. For QuikScat the values for closed ice are used. An example of the resulting analysis is given in Figure 4. Here we see that the domination of MY ice along the east Greenland coast is more realistically classified.

The multi sensor Sea Ice type product is available at http://saf.met.no in test mode.

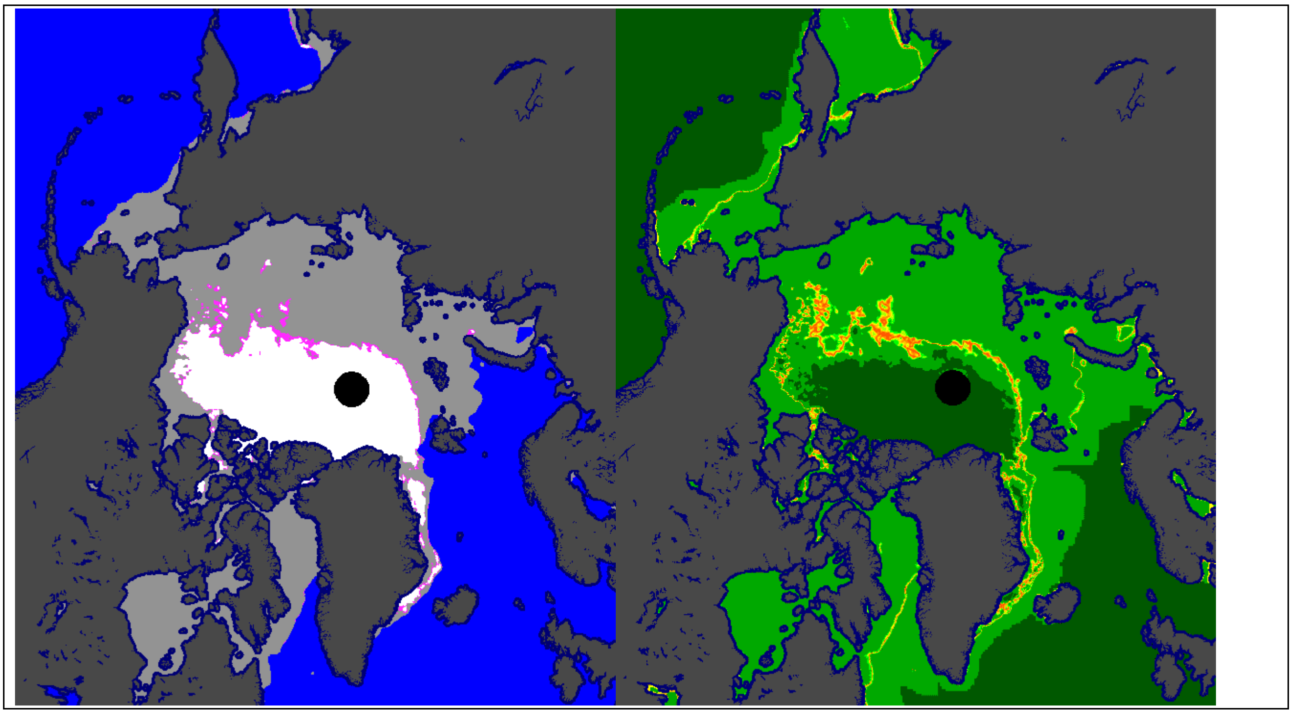


Figure 4. Ice type analysis from one day of QuikScat data and SSM/I data January 4, 2006.

Left panel: white: high probability of multi year ice, grey: high probability of first year ice, pink: uncertain / mixture.

Right panel: Green colors: high probability values close to 100%. Red/yellow: low probability. These areas are typically in between the areas with FY and MY ice and are classified as uncertain.

References

Breivik, L.A. et al, 2001, *Sea Ice products for EUMETSAT Satellite Application Facility*, Canadian Journal of Remote Sensing, Volume 27 No , 5

Lind, M, K. Hansen, S. Andersen, 2005, *Validation of Ice products January 2002 – March 2005,* http://saf.met.no/docs

Tonboe, R and J Haarpainter, 2003, *Implementation of Quickscat Sea Winds data in the EUMETSAT Ocean & Sea Ice ice product.* http://www.dmi.dk/dmi/index/viden/dmi-publikationer/tekniskerapporter.htm