Report for IOMASA Deliverable 4.1:

Data sets and day 0 algorithms for sea ice retrieval

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DMI

IOMASA Phase1 report for Part4 (sea ice concentration)

This report describes the day 0 algorithms and data sets established during phase 1 of the IOMASA project. It is intended to constitute the report part of IOMASA deliverable 4.1. The report is in two parts, 1) a description of day 0 models and algorithms and 2) a description of the data inventory built in the course of phase 1.

Day 0 models and algorithms

The following categories of models and algorithms were defined:

- Microwave radiative transfer models
- Ku-band wind models function
- Sea ice concentration algorithms from SSM/I
- Ice type algorithms from Quikscat
- Synergistic SSM/I-Quikscat ice concentration algorithm

The results for each category will be reported in the following.

1) Microwave radiative transfer models

It makes sense to distinguish between fast radiative transfer codes that are simple parameterisations of the radiative transfer equation, neglecting scattering effects and the more accurate general radiative transfer models that solve the complete radiative transfer equation. Of the first class the model by Wentz (1997) as well as RTTOV7 (http://www.met-office.gov.uk/research/interproj/nwpsaf/rtm/index.html) have been identified. While the Wentz model is not defined for the 85 GHz, RTTOV7 returns brightness temperatures for the full range of SSM/I channels. It remains to be seen if RTTOV7, neglecting scattering is sufficiently accurate at 85 GHz, however. In the second class two models, MWMOD [Fuhrhop et al., 1998] and ARTS (http://www.sat.uni-bremen.de/arts/) have been identified. While the development and maintenance of MWMOD has ceased and the model is only moderately documented, ARTS is an ongoing project and is thoroughly documented. In addition ARTS-1.1 handles polarised radiative transfer and 3 dimensional scattering. All models are available as computer source code.

2) Ku-band wind model function

NSCAT 2 [Wentz and Smith, 1999] describes the normalised radar cross section of the ocean surface as function of wind speed and direction. It is available as computer source code.

3) Sea ice concentration algorithms from SSM/I

A total of nine passive microwave ice concentration algorithms have been selected for analysis. These are:

- NASA/Team [Cavalieri and Gloersen, 1984],
- Bootstrap [Comiso, 1986],
- Cal-val [Ramseier, 1991],
- Norsex [Svendsen et al., 1983],
- Bristol [Smith, 1996],
- NASA/TEAM2 [Markus and Cavalieri, 2000].
- Near 90 GHz algorithm [Svendsen et al., 1987],
- TUD hybrid algorithm [Pedersen, 1998] and

These algorithms are readily available in the form of computer source code. The first 6 offer concentration retrieval at resolutions corresponding to the 19 or 37 GHz channels while the latter 2 algorithms offer increased resolution through the use of the 85 GHz channel. In addition newer approaches such as the ASI/Artist algorithm [Kaleschke, 2002] and Sealion [Kern and Heygster, 2001] may be obtained.

4) Ice type algorithms from Quikscat

In Ku band the ice type discrimination in terms of firstyear (FY) and multiyear (MY) ice is primarily relying on backscatter, although a certain signal is present in the polarisation as well. By additionally taking radiometer data into account, it is possible to discriminate new ice as well. These two techniques are described in Tonboe and Haarpaintner (2003) and Tonboe and Ezraty (2002), respectively. The expertise is available within the IOMASA team at DMI.

5) Synergistic SSM/I-Quikscat ice concentration algorithm

Where for ice edge detection the combined use scatterometer and radiometer has matured into an operational stage, very little published work exists on the synergistic use for sea ice concentration analysis. Grandell et al. (1999) describe a framework, where scatterometer information is used in combination with the NASA/TEAM algorithm to delineate the ice edge. Thereby the need for removing weather contamination is avoided in a subsequent concentration retrieval based on SSM/I and the treatment of mixed pixels is improved. Additionally, the scatterometer information is used to improve the ice type classification, that is unreliable when based on SSM/I data alone. An additional technique is represented by the EUMETSAT SAF on Ocean and Sea Ice, ice edge algorithm (Breivik et al., 2001). However, it resolves the concentration only in fairly wide intervals.

Data inventory

DMI is obligated to provide the following data sets within IOMASA:

- 2 years of SSM/I and Quikscat swath data
- Validation strategy and data

At the IOMASA kick-off meeting a 2 year offline study period was agreed for the years 2001 and 2002. In addition an online period is defined to cover 2003 and 2004, where validation data in the form of SAR scenes will be acquired in addition to the SSM/I and Quikscat data. The plans for acquisition and use of validation data is described in a separate document entitled "IOMASA sea ice validation plan" provided in annex 1 of this report. In the following the SSM/I and Quikscat data are described.

1) SSM/I data

The SSM/I data have been acquired in near real time from UK Met Office and archived at DMI. The data are relayed from NOAA/NESDIS as TDR (Temperature Data Record) data and are repacked in BUFR format at ECMWF. Steve English from UK Met Office issue made us aware of a switch of antenna pattern correction performed February 23 2000. On this occasion, the antenna pattern correction for the F14 and F15 were set to match that for the F13 SSM/I. This does not interfere with the present study period of IOMASA. The data can be unpacked using standard BUFR libraries and DMI can provide unpacking binaries for SUN and Linux. Each SSM/I BUFR message contains one scanline of data organised as follows:

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 1: 0 01 007 SATELLITE IDENTIFIER                                  CODE TABLE 001007
 2: 0 05 040 ORBIT NUMBER                                          NUMERIC
 3: 0 05 041 SCAN LINE NUMBER                                      NUMERIC
 4: 0 30 193 POSITION NUMBER ALONG SCAN                            NUMERIC
 5: 0 04 001 YEAR                                                  YEAR
 6: 0 04 002 MONTH                                                 MONTH
 7: 0 04 003 DAY                                                   DAY
 8: 0 04 004 HOUR                                                  HOUR
 9: 0 04 005 MINUTE                                                MINUTE
10: 0 04 006 SECOND                                                SECOND
11: 0 05 001 LATITUDE (HIGH ACCURACY)                              DEGREE
12: 0 06 001 LONGITUDE (HIGH ACCURACY)                             DEGREE
13: 0 13 202 TYPE OF SURFACE                                       CODE TABLE 013202
14: 0 08 003 VERTICAL SIGNIFICANCE (SATELLITE OBSERVATIONS)    CODE TABLE 008003
15: 0 12 063 BRIGHTNESS TEMPERATURE                                K
16: 0 12 063 BRIGHTNESS TEMPERATURE                                K
17: 0 12 063 BRIGHTNESS TEMPERATURE                                K
18: 0 12 063 BRIGHTNESS TEMPERATURE                                K
19: 0 12 063 BRIGHTNESS TEMPERATURE                                K
20: 0 12 063 BRIGHTNESS TEMPERATURE                                K
21: 0 12 063 BRIGHTNESS TEMPERATURE                                K
22: 0 05 001 LATITUDE (HIGH ACCURACY)                              DEGREE
23: 0 06 001 LONGITUDE (HIGH ACCURACY)                             DEGREE
24: 0 13 202 TYPE OF SURFACE                                       CODE TABLE 013202
25: 0 08 003 VERTICAL SIGNIFICANCE (SATELLITE OBSERVATIONS)    CODE TABLE 008003
26: 0 12 063 BRIGHTNESS TEMPERATURE                                K
27: 0 12 063 BRIGHTNESS TEMPERATURE                                K
28: 0 05 001 LATITUDE (HIGH ACCURACY)                              DEGREE
29: 0 06 001 LONGITUDE (HIGH ACCURACY)                             DEGREE
30: 0 13 202 TYPE OF SURFACE                                       CODE TABLE 013202
31: 0 08 003 VERTICAL SIGNIFICANCE (SATELLITE OBSERVATIONS)    CODE TABLE 008003
32: 0 12 063 BRIGHTNESS TEMPERATURE                                K
33: 0 12 063 BRIGHTNESS TEMPERATURE                                K
34: 0 05 001 LATITUDE (HIGH ACCURACY)                              DEGREE
35: 0 06 001 LONGITUDE (HIGH ACCURACY)                             DEGREE
36: 0 13 202 TYPE OF SURFACE                                       CODE TABLE 013202
37: 0 08 003 VERTICAL SIGNIFICANCE (SATELLITE OBSERVATIONS)    CODE TABLE 008003
38: 0 12 063 BRIGHTNESS TEMPERATURE                                K
39: 0 12 063 BRIGHTNESS TEMPERATURE                                K
40: 0 08 193 TIME QUALIFIER                                        CODE TABLE 008193
41: 0 26 193 YEAR                                                  YEAR
42: 0 26 194 MONTH                                                 MONTH
43: 0 26 195 DAY                                                   DAY
44: 0 26 196 HOUR                                                  HOUR
45: 0 26 197 MINUTE                                                MINUTE
46: 0 26 198 SECOND                                                SECOND
47: 0 08 193 TIME QUALIFIER                                        CODE TABLE 008193
48: 0 26 193 YEAR                                                  YEAR
49: 0 26 194 MONTH                                                 MONTH
50: 0 26 195 DAY                                                   DAY
51: 0 26 196 HOUR                                                  HOUR
52: 0 26 197 MINUTE                                                MINUTE
53: 0 26 198 SECOND                                                SECOND
54: 0 08 193 TIME QUALIFIER                                        CODE TABLE 008193
55: 0 26 193 YEAR                                                  YEAR
56: 0 26 194 MONTH                                                 MONTH
57: 0 26 195 DAY                                                   DAY
58: 0 26 196 HOUR                                                  HOUR
59: 0 26 197 MINUTE                                                MINUTE
60: 0 26 198 SECOND                                                SECOND
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The total volume per satellite is 43 GB for the 2 year period.

2) Seawinds data

Seawinds level 2 data is acquired at DMI from NOAA/NESDIS in BUFR format and is archived routinely. Until around April 2002, the data was archived on CDROM’s, and after that it has been archived in the DMI mass storage system. It turned out that the CDROM archive for 2001 and 2002 had one large gap and therefore it has been decided to order Seawinds level 2A data on tapes from the JPL PODAAC for the total period 2001-2002. This data is in HDF format and is described in

the QuikSCAT Science Data Product User's Manual available at: ftp://podaac.jpl.nasa.gov/pub/ocean_wind/quikscat/doc/QSUG4-4.pdf.
Unpacking binaries for both BUFR and HDF can be provided for SUN and Linux. The total volume of the 2001-2002 data is 73 GB.

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IOMASA sea ice validation plan

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Introduction

There has been a number of recent improvements in Numerical Weather Prediction (NWP) modeling, radiative transfer models and passive microwave remote sensing of sea ice. This has enhanced the reliability and accuracy of the methods for sea ice retrieval over open water and low ice concentrations [e.g. Thomas & Heygster, 1996; Kern, 2002; Andersen & Kern, 2003]. The EUMETSAT Satellite Applications Facility (SAF) on Ocean and Sea Ice concentration product [Breivik et al., 2001] is the first operationally based sea ice fields where the ice edge delineation is not left to thresholding based on the SSM/I brightness temperatures. On the contrary, it is based on the removal of the atmospheric influence as given by NWP models combined with a choice of algorithm that matches algorithm sensitivities to the quality of the NWP model fields. Unfortunately the factors influencing the microwave radiation from sea ice covered surfaces are much more complex and poorly understood [Fuhrhop et al., 1998]. Examples of gross errors related to ice surface effects are abundant in literature and among the most prominent is probably the layering effects reducing NASA/TEAM ice concentrations, which led to the development of the NASA/TEAM2 algorithm [Markus and Cavalieri, 2000]. Conversely, the Bootstrap algorithm tends to produce low estimates near the Antarctic continent and in parts of the Central Arctic [Comiso et al., 1997]. Information from the 85 GHz SSM/I channels is not sensitive to some of the surface effects that affect the NASA/TEAM algorithm. However, the authors have found cases primarily in conjunction with air temperature fluctuations (e.g. warm temperatures to very cold temperatures) where large day-to-day fluctuations occur that can only be explained as surface effects. Such an example is also given in Andersen (2000). While such fluctuations may seem modest, even small open water areas within the ice can lead to large fluxes due to the high temperature difference between atmosphere and ocean.

The IOMASA sea ice remote sensing activities aim at addressing exactly this point, through the use of multiple sensors. This primarily includes scatterometry and passive microwave radiometry as well as auxiliary information such as the air temperature history to aid in detecting conditions where a particular ice concentration algorithm is likely to fail. It is simple to validate sea ice concentrations over open water as the true concentration is known to be zero. Over ice covered surfaces, the true ice concentration mostly remains known only within 10-20% in navigational ice analyses, which are broadly believed to be the most accurate operational source of information on the sea ice. To support the development and to help validate the different approaches, high resolved ice information is necessary. While visible and infrared sensors can contribute useful information, their use is hampered by clouds, that are very difficult to mask over ice. More importantly, by excluding cloudy situations, they will not be representative of the range of atmospheric settings that actually occur. SAR data are cloud independent, and mostly influenced by the surface wind over open water. Although situations occur, where SAR data are useless for sea ice determination, the range of useful physical settings is much larger than for optical sensors. As mentioned, navigational ice analyses are only accurate to within 10% at the very best, and the concentration assessment is very much influenced by subjective decisions. To maximize the objectivity of the comparisons, the intention is therefore to carefully analyze each SAR scene. This is envisaged though a manual selection of samples of different surface types and subsequent use of this information to compute ice concentrations by automatic classification. The classification step could be done as in Kern et al. (2002) or by extensions to the framework by Gill (2003 b), a comparison of the methods will be carried out. It must be stressed that even the automatic classification will be supervised by skilled ice analysts and rejected if in error.

SAR data around Greenland can to some extent be provided by the routine acquisitions made by the Greenland Ice Service at DMI. However, as these acquisitions are governed by navigation around Greenland large areas in the interior of the ice cover will not receive coverage. From the outset, the intention was to exploit relevant ENVISAT ASAR Announcement of Opportunities (AO's) that could be available within the project consortium and among interested institutions external to the project. In addition to this, IOMASA has funding available for the purchase of 29 k€ worth of SAR scenes. The following gives an overview of the anticipated data availability, proposes an acquisition strategy and gives status as well as immediate plans concerning the use of the automatic SAR scene classification methods. It is intended as an internal work paper to the IOMASA project.

Study period data types and area

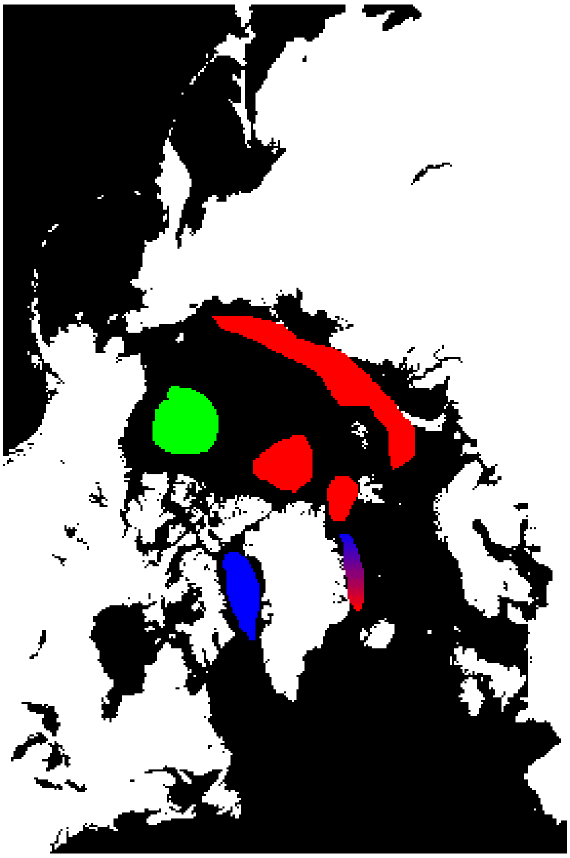

Figure 1: Areas of interest, colors refer to the most likely source of SAR scenes: Envisat AO data: Red; DMI ice service data: Blue; Lower priority and uncertain data source: Green

The study period of IOMASA has been agreed to cover 2002 and 2003. Given the footprint of today's passive microwave radiometers and scatterometers, a large coverage is required from the SAR scenes to provide a sensible comparison. Effectively, this means that only wide swath SAR (with a typical swath width of 500 km) data is of interest. Ideally, an average of 4-5 SAR scenes per month should be available covering the entire European sector of the Arctic as well as the Baffin Bay. To this end five main areas of interest may be defined:

1) The Eastern Arctic Ocean, primarily containing first-year ice.
2) The Central Arctic Ocean North of Greenland, multiyear ice.
3) The Fram Strait area, mixed ice types.
4) The East Greenland Current, mixed ice types.
5) The Baffin Bay, first-year ice.

In addition comes a lower priority area, which could be covered half as frequently or less:

6) The Western Arctic off Canada, containing multiyear ice, possibly different from that in point 2.

This selection of areas should ensure the representation of all commonly encountered Arctic ice types and surface conditions.

Relevant AO's and projects

A total of 5 AO's have been identified within the IOMASA consortium. A number of these focus on the ice edge and are therefore not directly applicable to the main objectives of IOMASA. Ice edge data may however be envisaged for some aspects of the planned work but it is assumed that such data will be abundant and an ad-hoc strategy based on images already acquired is therefore advised in these cases. With this precondition a number of three AO's have been identified to best fulfill the requirements of IOMASA.

Type	Name:Number	Consortium	Principal area	Scenes/duration
AO	Assist:170	Ifremer, TUD, met.no	Kara, Barents Seas to Fram Strait	52 stripes/1 year
AO	311	TUD,DMI	N.E. Greenland to central Arctic E. Greenland from November till April	50
AO	Cryosat:1270	TUD, DMI and others	Entire Arctic	Many/2003-2005
EU	Greenice	DMI	N.E. Greenland to central Arctic	12 high resolution Radarsat/2003-2005
AO	287	DMI,TUD	Mainly Ice edge and S. Greenland	N/A / 2003-2006
AO	N/A	U. Bremen	Ice edge	N/A

Possible coverage by AO data

Especially 3 AO's are of special interest to IOMASA:

1) The Assist AO project aims at covering the Arctic from the Barents Sea to the Fram Strait once a week for one year. The geographic coverage match the requirements of IOMASA very well and at least for a year it may provide the main coverage of the Arctic Ocean. If the period can be extended, perhaps with less frequent updates, it will create perfect coverage of the entire Eastern Arctic.
2) The TUD-DMI AO covers the remainder of the Arctic Ocean and to some extent the East Greenland Current

3) The Cryosat AO in April 2003 provides intensive coverage of the Fram Strait in April 2003, however it is run by a large consortium so we will not have much influence on area and periods.

The remaining AO's and Greenice may provide interesting scenes now and then. In summary, on the assumption that the study period of Assist can be extended, the entire Arctic Ocean and Fram Strait area will be able to receive coverage from AO data exclusively.

Possible fill-in with Greenland Ice Service data

The acquisition of SAR data for the Greenland Ice Service is governed by the needs of the Service to provide relevant guidance for navigation. The acquisition can therefore not take into account the specific needs of research projects such as IOMASA. However, to the extent the data can be useful to IOMASA their use can be provided on the condition that DMI is properly acknowledged as the owner of the data. The data cannot be distributed among project partners unless by special arrangement. By such a special arrangement the data can be used only for scientific studies and any publication arising of such a study must include DMI as co-author. Since the sea ice development and validation effort will take place at DMI this is not considered to be problematic. In fact the contributed SAR scenes can be regarded as part of DMI's contribution to IOMASA.

The Greenland Ice Service primarily assists navigation around Greenland. As a consequence of the primary shipping routes and distribution of the Greenlandic population, SAR data purchases are concentrated around Southern and Western Greenland most of the year. The East Greenland area North of Scoresby Sound is covered in limited periods during the summer when ship traffic occurs. With respect to IOMASA, it is probable that the requirements for coverage of the internal parts of the ice once a month can be fulfilled to a large degree in the Baffin Bay and Davis Strait region. East Greenland will likely receive coverage from July through November.

Proposed IOMASA purchases

The IOMASA purchases depend on whether the Assist period can be extended. If this is the case, AO and Ice service data will provide ample coverage and only a few extra images need to be purchased, most likely in the East Greenland Current. This would allow for the purchase of Radarsat HH mode scenes coinciding with ASAR VV mode data permitting the use of polarization information to improve the classification results. If this is not the case, the most efficient strategy is probably to ensure coverage in the Arctic by allocating the IOMASA funded scenes.

Status on automatic classification methods

At this stage, semi-automatic classification of Radarsat images by a fuzzy logics approach has been described by Gill (2003 b), however additional work is required to adapt the method for use in concentration retrieval. The Neural Network approach described by Kern et al. (2002) has been obtained from Lars Kaleschke of the University of Bremen, installed at DMI and the ingestion of Radarsat data has been added. What remains is essentially the identification of the most useful input features, an ASAR ingestion module and a user interface allowing the ice analyst to operate the classification algorithm. These could be different from those used in the present ERS configuration. In particular the use of uncalibrated SAR data in conjunction with information of incidence angle will be considered as an alternative to the a-priori assumed incidence angle relationships. This work will include results and ongoing work on SAR texture features by Gill (1996, 1999, 2001, 2003a/b) and will be done in close cooperation with Lars Kaleschke. The on-line classification efforts are therefore expected to begin by late summer 2003.

Conclusions

The IOMASA requirements can likely be fulfilled in the Arctic with data from the Assist and TUD-DMI Envisat AO's, provided the study period of Assist can be extended beyond one year. It is considered useful to invite IFREMER (PI on Assist) to cooperate in the IOMASA activities, as hopefully we share a great deal of interests. DMI Ice Service SAR scenes will most likely provide the main coverage in the Baffin Bay. With regards to the use of the IOMASA funding for purchase of SAR data, the strategy depends mainly on the access to and duration of the Assist data. If the Assist data are found not to cover the entire period of interest, we will have to use the funding to get adequate coverage of the Arctic. Otherwise the funding can be used to acquire overlying alternate polarization SAR data, which will probably help the classification and is interesting in its own right.

With respect to the classification activities, the work is in progress and it is anticipated that we will be able to show the first Radarsat based results at the IOMASA project team meeting in April 2003.

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