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SPICES
Space-borne observations for detecting and forecasting sea ice cover extremes

Deliverable: D5.4

Influence of melt pond fraction on sea ice concentration retrieval

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1 Document details

1.1 Overview of the document

During the Arctic summer, satellite based passive microwave retrievals of the sea ice concentration are compromised due to the surface wetness and presence of melt ponds. To improve this unreliable retrieval, melt pond fraction information is required.

In this document, the two currently published melt pond fraction retrievals are analyzed for their applicability to perform such correction of the sea ice concentration product.

Field spectra of various sea ice surfaces are used to simulate a several frequently observed scenarios regarding melt pond fraction, open water fraction and ice fraction in one satellite pixel. It is shown that for these different subpixel scenarios the resulting top of atmosphere reflectance is similar and the correct melt pond fraction retrieval is impossible from a moderately resolving optical sensor.

Furthermore, comparisons of the melt pond fraction retrievals to very high resolution optical imagery (1x1m, 30x30m) and to retrieved sea ice thickness shows potential inaccuracy of the melt pond fraction products, namely contamination with open water. These products have to be improved first before using them to correct the sea ice concentration retrieval.

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1.3 Document history

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1.4 Reference Documents

- Grant Agreement no: 640161, Annex 1 - Description Of Action (part A)
- Grant Agreement no: 640161, Annex 1 - Description Of Action (part B)
- SPICES D5.2 Statistical relation between MPF/albedo and passive microwave brightness temperatures at frequencies 1.4 to 89GHz
### 1.5 Acronyms

<table>
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<th>Acronym</th>
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<tr>
<td>MPF</td>
<td>Melt pond fraction</td>
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<td>OWF</td>
<td>Open water fraction</td>
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<td>IF</td>
<td>Ice fraction</td>
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<td>SIC</td>
<td>Sea ice concentration</td>
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<td>MPD</td>
<td>Melt Pond Detector, MERIS MPF retrieval algorithm</td>
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<td>ICDC</td>
<td>Integrated Climate Data Center, MODIS MPF retrieval algorithm</td>
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<tr>
<td>MERIS</td>
<td>Medium Resolution Imaging Spectrometer</td>
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<tr>
<td>MODIS</td>
<td>Moderate Resolution Imaging Spectrometer</td>
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<tr>
<td>PM</td>
<td>Passive microwave</td>
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<tr>
<td>VIS</td>
<td>Visible region of spectrum</td>
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<tr>
<td>NIR</td>
<td>Near infrared region of spectrum</td>
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<tr>
<td>TOA</td>
<td>Top of atmosphere</td>
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<td>GFL</td>
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2 Introduction

During Arctic summer in the presence of surface melt, the PM retrievals of SIC are compromised. The presence of meltwater on top of the sea ice changes dielectric properties of the medium so that the so called SIC retrieval tie points (the reference values of BTs for open water and sea ice), which were selected for dry cold sea ice, no longer match the water saturated or covered sea ice. At microwave frequencies, melt ponds cannot be distinguished from open water. In addition, increased atmospheric humidity during Arctic summer affects the SIC retrievals which use high frequencies like 89 GHz band of AMSR-E. All these effects make SIC retrievals in summer inaccurate.

At the same time, a reliable SIC product during Arctic summer is of importance. Despite of the fact that most in situ and airborne campaigns take place in summer, sea ice during Arctic summer is currently poorly characterized on the large scale as the key remote sensing products are unreliable or missing, e.g. SIC, ice drift or sea ice thickness.

A reliable melt pond fraction product can be beneficial on the way towards an accurate sea ice concentration product. In this work, two melt pond products, MPF from MERIS (Zege et al., 2015; Istomina et al., 2015ab) and MPF from MODIS (Rösel et al., 2012) are presented and their potential for improving SIC products is discussed. High resolution optical datasets (Landsat, GFL) are used for quality assurance of the MPF products.

3 Motivation

As mentioned in D5.2, PM based retrievals cannot separate the two classes open water and melt ponds. These two surface types have similar BTs because of high water absorption in the microwave spectral region. Similarly, wet sea ice surface shields the emitted radiation from the sea ice at any common microwave frequency, no matter what may be the penetration depth.

When using an optical MPF retrieval to improve a SIC product, it is important to first investigate whether the above mentioned two surface classes can be well separated at optical wavelengths within the given MPF retrieval, and what is the effect of the water saturated sea ice surface on the MPF retrieval.

The two MPF retrievals by Rösel et al., 2012 and Zege et al., 2015, are based on TOA radiances of moderate resolution radiometers, MODIS and MERIS, respectively. While the first retrieval uses a neural network approach, and the second utilizes an optical forward model of sea ice, both retrievals show contamination with open water (Sec. 4) due to the ambiguity of the TOA signal in the VIS and NIR that MODIS and MERIS sensors deliver; just from the radiometer data, it is impossible to spectrally resolve various subpixel scenarios commonly observed in the field with e.g. darker, melting ice of 100% ice concentration versus brighter ice with some open water in the pixel (Sec. 3.1).

In this context, a quality assurance of the existing MPF product has to be performed before further efforts like improving SIC products during Arctic summer.

![Diagram of subpixel contents](image)

**Figure 1.** Example subpixel contents of one satellite pixel represented by one observed TOA value.
Figure 2. The variety of surface types on the Arctic sea ice. Spectral albedo measured with the ASD portable spectrometer during RV Polarstern cruise IceArc2012 (Istomina et al., 2013).

Figure 3. Linear mixture of dry white ice (dark blue curve), dark melt (green curve) pond and open water (violet line) with the various MPF and OWF. The fractions are defined as in Fig. 1.
3.1 The open water problem in the optical MPF retrievals

The melt ponds of various kinds, open water, dry snow or wet water saturated sea ice appear differently in the field and in the high resolution optical imagery (resolution < 1m, airborne or satellite). All these surface types appear of different color and brightness: light blue or dark blue melt ponds, dark open water, bright white snow or darker grey sea ice. However, when mixed into one satellite pixel which can be as large as 1.2 km x 1.2 km, the various surface types and their fractions are represented with just a single value, with the TOA reflectance. Fig. 1 shows an example for the content fractions of a MERIS pixel in the marginal ice zone during Arctic summer.

The reflective properties of the subpixel surfaces present during the Arctic summer are shown in Fig. 2. The spectral albedos were measured during an RV Polarstern cruise in the Central Arctic in 2012. One can easily see that the pure surface types differ a lot from each other and can be easily discriminated in the field measurements. However, when mixed together into a satellite pixel with given subpixel fractions (Fig. 3), these surfaces produce spectral signals similar to each other for e.g. SIC 90%, 70%, 50% with MPF values of 50%, 30%, 0%, respectively. Without additional information, these different situations all frequent during Arctic summer cannot be resolved at optical wavelengths given the moderate spatial (100m-1500m pixel size) and low spectral resolution of the sensor (4-12 bands in the VNIR).

However, the MPD MPF retrieval from MERIS as well as MPF retrieval from MODIS utilize such sensors. The following Section 4 is dedicated to the quality assurance of these MPF retrievals via comparisons to each other and higher resolving optical sensors.

4 Case studies and quality assurance of the MPF retrievals

4.1 GFL MPF vs MERIS MPF

In order to compare the retrieved MPF to the true MPF high resolution, satellite images from Global Fiducial Library (GFL) have been used. They can be viewed and downloaded from http://gfl.usgs.gov/ free of charge. All of them are 8-bit grayscale images with a spatial resolution of 1 x 1 m. They are geo-referenced and some metadata is provided such as sun zenith and azimuth angles. After manual masking of open water and melt ponds, downsampling and collocation to the MERIS scene, direct comparison of MERIS and GFL scenes is possible, both as grayscale reflectance (Fig. 4) and MPF (Fig. 5). The comparison has been performed for the areas of 100% SIC. The scatter plot of the MPF and GFL MPF is shown in Fig. 6.

Figure 4. MERIS(left) and GFL (right) scene in East Siberian Sea, 09.07.2009.
Figure 5. MPF retrieved from MERIS with the MPD retrieval (left) and corresponding MPF retrieved from the GFL image with manual thresholding.

Figure 6. Scatter plot of the MERIS and GFL MPF shown in Fig 5 for areas of 100% SIC.

Figure 7. Spatial difference of MPD MPF and GFL MPF shown in Fig. 5.
Influence of open water on the MPD retrieval (derived from a 3x3km subset of a GFL image). The errorbars are the uncertainties given by MPD.

Although some scatter is still present, the majority of the data lies near the one-to-one line, with MPD slightly underestimating the MPF. The analysis of the spatial difference between the MPD and GFL (Fig. 7) shows a patchy distribution of the difference, which may indicate various MPD accuracy for various ice types visible in the GFL images (can be distinguished by surface roughness and MPF, not shown here).

In order to investigate the influence of open water on the MPD algorithm, one of the 3x3 km sub-tiles from the image GFL #2 has been manually classified for sea ice and open water. Thus the sea ice concentration can be calculated for each MERIS pixel within this area and Figure 8 shows the comparison of MPF dependent on SIC derived from the corresponding GFL pixels.

We find the same behavior for pixels with sea ice concentrations above 95% as in the previous comparison for fully ice covered regions (Figs. 5, 6). They are mainly located below or close to the main diagonal. However, for sea ice concentrations below 95%, the majority of points is located above the diagonal and the furthestmost pixels show the SIC.

Therefore we conclude that MPD is affected by the open water fraction in the pixel and retrieves an incorrect MPF, dependent on the amount of open water in a pixel, with slightly higher values at SIC is below 90% and slightly lower MPFs for higher SIC.
4.2 Landsat SIC vs MERIS MPF vs ASI SIC

Another consistency check of the MPD retrieval has been done using a Landsat scene (30 x 30 m resolution) in the Beaufort Sea, 2nd July 2011 (Fig. 9). The Landsat scene has been collocated to the corresponding MERIS scene and the time difference between the two scenes is about 30 min. The Landsat TOA reflectance shows much greater spatial variability than that of MERIS. This is the illustration of the surface type mixing examples shown in Fig. 3.

![Collocated Landsat and MERIS scene for Beaufort Sea on the 2nd July 2011. The difference in sensor resolution is obvious, i.e. in the Landsat scene one can recognize the ice floes and open water in between.](image)

In order to perform a consistency check, several nearby located MERIS pixels with the same retrieved MPF have been investigated and the reflectance histogram was plotted. The MERIS TOA reflectance histogram is compared to the reflectance histogram of the same area from Landsat, where the various surface types (Fig. 2) are spatially resolved and can be distinguished by the different spectral behaviour. This comparison for one selected pixel subset is shown in Fig. 10. It can be seen that the area contains some fraction of open water (lower reflectances in the Landsat histogram) which is not visible at all in the MERIS TOA reflectance histogram.

For all the pixels in the selected MERIS scene subset, the MPD retrieval gets similar TOA reflectances as input, even the true SIC is less than 100% and the fractions of ice and open water in each of these MERIS pixels are different. The retrieved MPF (0.5 for this example) is then also similar in accordance to the similar input TOA reflectances.

This is the disadvantage of any optical MPF retrieval from moderate resolving spectroradiometer. The next Section 4.3 presents the comparison of MERIS and MODIS MPF and gives more details on MODIS MPF retrieval which is also water contaminated for the same reason is MERIS MPD.

In order to study the influence of MPF onto the PM SIC retrieval ASI (Spren et al., 2008), the same Landsat scene was used together with the retrieved MPF from MERIS (Fig. 11).
**Figure 10.** Comparison on the TOA reflectance histograms from MERIS and Landsat for a selected subset of MERIS pixels.

**Figure 11.** Comparison of the (a) MPD MPF, (b) Landsat SIC, (c) MERIS SIC and (d) ASI SIC. The (c) MERIS SIC has been produced using the (a) MPF and TOA reflectances of pure sea ice, melt pond and open water taken from the Landsat TOA reflectance at 560nm.
Influence of MPF on ice concentration retrieval

In order to quality assure the MPF product (Fig. 11a) and evaluate the influence of the subpixel open water onto the MPD retrieval, a set of manually derived thresholds is used to produce SIC from the Landsat data (Fig. 11b). At the same time, the TOA reflectance of the pure surface types “sea ice”, “melt pond”, “open water” was determined for a given scene manually and then used together with the retrieved MPF to produce MERIS SIC (Fig. 11c). All the above mentioned products are gridded to a spatial resolution 1km x 1km in order to perform the comparison. The ASI SIC is available at a coarser resolution of 3.125km (Fig. 11d). In order to perform further comparisons of ASI SIC to MERIS MPF and Landsat SIC (Fig. 12), all those products were gridded to ASI spatial resolution to ensure accurate comparison.

Let us compare the reference Landsat SIC (Fig. 11b) and two SIC products in question, the ASI SIC (Fig. 11d) and the MERIS SIC (Fig. 11c). The strong melt influence of the ASI SIC is obvious. In the areas where Landsat SIC shows ice concentrations close to 100%, ASI SIC (Fig. 11d) is only about 70%. MERIS SIC produced with simplistic manual thresholds (Fig. 11c) is much closer to the reference Landsat SIC than the ASI SIC.

The existing MPD MPF product can be used to correct ASI SIC for melt pond effects and to produce an accurate SIC dataset in summer. In the areas of lower true SIC, the correction is not so trivial as the MPD MPF can also be water contaminated in the direction of overestimation. An accurate separation of “water” and “melt pond” in these conditions needs further investigations and usage of additional data, e.g. reanalysis temperature data.

Figure 12. (a) Correlation between the Landsat SIC and the ASI SIC in the presence of surface melt. The color of the dots shows the retrieved MERIS MPF. (b) Correlation between ASI open water fraction = 1-SIC and MERIS MPF. The color of the dots gives the reference Landsat SIC.
Influence of MPF on ice concentration retrieval

4.3 MODIS MPF vs. MERIS MPF

In order to check how the MERIS MPF corresponds to MODIS MPF without water contamination, daily averages of both products have been taken for MYI regions, June-August 2009. The results are given in Fig. 13.

Both datasets agree remarkably well with a RMSD = 0.04 and a high coefficient of correlation \( R^2 = 0.90 \). MPD tends to slightly overestimate the MPF. The tendency of MPD towards higher values is more pronounced for small melt pond fractions and there is an accumulation of points around 0.13 ICDC and 0.05 MPD melt pond fraction. Additionally, several high values from MPD around 0.50 are not well matched. The map of average differences (Fig. 13 right panel) shows a non-uniform distribution with higher values from ICDC north of Franz Joseph Land and higher MPD pond fractions close to the Beaufort Sea. Possible reasons for these disagreements can be identified by investigating the temporal development, ice type and difference in cloud masking.

Unfortunately, the daily MPFs retrieved with the ICDC algorithm are not freely available and the 8-day composite is taken for further comparisons to MPD MPF. 8-day averages have been produced from the MPD MPF to match the ICDC product. The comparison of the 8 day composites to 8 day averages for high SIC (Fig. 14) and low SIC (Fig. 15) show more pronounced difference of higher MPFs for lower SIC (visible as higher MPF in Fig. 15). This is the sign that open water is treated differently in both MPF retrievals.

Regions with lower sea ice concentration are included into the comparison in order to increase the spatial coverage and to include regions with high ICDC melt pond fraction. A minimum of 25% ICDC ice concentration is chosen. The resulting scatter plot is presented in Figure 15. In general, there is a strong correlation between the two datasets and a good match for melt pond fractions below 0.15, yet there is a pronounced tendency of MPD to overestimate the MPFs for values above 0.15. A greater amount of data with MPFs above 0.15 is included here as related to Fig. 14 because of the lower SIC threshold.

Figure 13. Comparison of the daily MODIS (ICDC) and MERIS (MPD) MPF for the high SIC in the MYI areas, June-August 2009.
**Figure 14.** Comparison of ICDC and MPD melt pond fractions for regions with high (>90%) SIC. Shown is data from the years 2003 to 2011, 8 day averages versus 8 day composites.

**Figure 15.** Comparison of ICDC and MPD melt pond fractions including regions with lower SIC (>25%). 8 day averages from MPD versus 8 day composites from ICDC for 2003 to 2011.

### 4.4 MODIS MPF vs MODIS SIC

Data from the years 2003 to 2011 is analyzed to check for a possible dependence between the ICDC SIC and MPF.
The result is presented in Figure 16 as scatter plots for successive periods of 32 days. The ICDC clear sky subset is used with all grid cells screened out that contain less than 90% valid pixels. For the first period we find the majority of points around 0.08 MPF and 0.07 OWF (Fig. 16 (a)). There is a slight autocorrelation between the two quantities. The situation of a fully ice covered grid cell with zero pond fraction is almost never found. In the next period Mid-June to Mid-July we find a different situation (Fig. 16 (b)). The majority of grid cells have an OWF of approximately 0.05 and MPF of 0.13. Pond fractions above 0.13 tend to be seen in combination with an increased open water fraction and the relation between the two quantities appears to be linear. This is even more evident in the next period (Fig. 16 (c)). Such a linear dependency between the melt pond area fraction and the open water fraction is mentioned in Rösel et al. (2012).

Here we show the relative MPF that needs to be multiplied with the SIC to obtain the melt pond area fraction. The conversion is linear and affects only the slope of the dependency. Towards the end of the melt season we find a more blurred distribution with the majority of points around 0.18 of MPF and 0.09 OWF (Fig. 16 (d)).

As there is no obvious geophysical mechanism on why MPF can depend on SIC, we can conclude that the ICDC MPF retrieval has difficulties in separating the two classes "melt pond" and "open water", and/or the effect of varying sea ice albedo (Fig. 2, the curves for the different sea ice surfaces) is affecting the retrieved MPF and SIC.

**Figure 16.** ICDC (MODIS) open water fraction vs. relative melt pond fraction. The plots are cropped to the range [0; 0.5] and white cells contain less than ten points.
5 Conclusions

As PM SIC retrievals are unreliable during the Arctic summer in the presence of surface melt, an MPF product can be used to improve the SIC product. A comparison to high resolution Landsat scene shows a non-linear influence of melt ponds onto the ASI SIC product. An alternative approach, a MERIS SIC dataset can be produced using the retrieved MPF and assumed values of the pond and sea ice albedo.

Our investigations show that the two currently available MPF products, the MPD from MERIS (Zege et al., 2015, Istomina et al., 2015ab) and ICDC from MODIS (Rösel et al., 2012) are both contaminated with open water. This is expected as the discrimination of various surface types and their fractions from a moderate resolving spectroradiometer like MODIS or MERIS alone is not possible and requires additional data (Fig. 3).

Comparisons of MERIS MPF to very high resolution GFL images (1m x 1m) show good correspondence of the retrieved MPF to the reference MPF in the areas of high ice concentration. In the areas of lower ice concentration, an overcompensation takes place, so that a smaller fraction of melt ponds in the pixel is mixed up with a greater fraction of open water so that the resulting melt pond fraction does not change much (Fig. 8).

Additional information sources and more investigation are needed to find out how to improve the existing MPF products. The SIC products such as ASI SIC can be improved using higher resolved optical imagery (Landsat, Sentinel 2 and sensors with even higher spatial resolution like WorldView 2,3, GeoEye, Spot6/7, etc) and with the retrieved MERIS MPF in the cloud free areas.

6 References

Istomina, Larysa; Nicolaus, Marcel; Perovich, Donald K (2013): Spectral albedo of sea ice and melt ponds measured during POLARSTERN cruise ARK-XXVII/3 (IceArc) in 2012. Institut für Umweltphysik, Universität Bremen, doi:10.1594/PANGAEA.815111.


