Authors response to the referee comments on "The melt pond fraction and spectral sea ice albedo retrieval from MERIS data: validation and trends of sea ice albedo and melt pond fraction in the Arctic for years 2002–2011" by L. Istomina et al.

Referee comments in italic, authors response in roman font.

Anonymous Referee 1

There is a lot going on here. Nice to see a dataset amalgamation effort. There appears to be some interesting trends, results, etc … but the paper seems a bit long (I'm starting to lose the message at 30 figures). I might suggest the paper be split in two (one paper focusing first on validation of the MERIS algorithm itself) and then the second one using the validated algorithm to make the comparison between MERIS and the in situ MPF data). However, if I'm an outlier reviewer here with this opinion then I am fine to see it published the way its laid out now. Publish with minor revisions.
Indeed, the paper presents two datasets and both their validation and trends, which in total makes it way too much for the reader to embrace. It was decided to split the paper into two parts, first dedicated to detailed validation of melt pond and albedo products and cloud screening, and second - their comparison to reanalysis data, comparison to Rösel et al., 2012 dataset, and trends of both products and time sequences analysis.
For the convenience of review, currently all changes are implemented into the original paper with the corresponding line numbers, old or based on old section numbering, and figure numbering. The split in two parts is indicated with the text color. The resulting two papers will be created from this new version of the original paper and uploaded together (3 documents). The section and figure numbering will be updated at this stage! The same is valid for the reference Zege et al., 2014, which is now obviously Zege et al., 2015, but for the sake of consistency we keep it like before in this response.

Pg 5234. Lines 3-8. I somewhat disagree that this situation is rare … when snowfalls [during the melt pond season do not occur] very often. I've witnessed snowfalls following a cold front during the melt pond season on numerous occasions that completely cover the 'icescape' for days before the appearance of sufficient shortwave (ie. sunshine) to melt the snow cover (which is close to the melting point) and re-establish the pre-existing melt pond fraction.
The authors are grateful to the reviewer for pointing out this mishap. The cold fronts and ponds covered with ice lids may occur also in the high summer. The performance of the algorithm in this case is a separate important topic, currently the algorithm is only used to retrieve the fraction of open ponds. What was meant here, is that snowfalls do not affect the surface around open (exposed) ponds for a long time due to melting air temperature. The corresponding lines have been rewritten.
P 6, Lines 14-18. Corrected text:
However, this situation is rare, because in the case of an open (exposed) mature pond snowfalls only affect the surrounding ice surface for a short time due to melting temperature. The case of lid covered melt pond is a separate topic, which is discussed in detail in Sect. 3.2.3

Pg 5247. Line 13. Type. Should be FYI .. not MYI (for 0.8)
Thank you for pointing out this typo. It has been corrected.
P19, Line 15. Corrected text: (maximum melt 0.2 on MYI as opposed to up to 0.8 on FYI, Figure 1)

I suggest a few additional references be added to this paper to demonstrate the salient work to this paper by others.
Yackel, J. J., D. G. Barber, and J. M. Hanesiak (2000), Melt ponds on sea ice in the Canadian Archipelago: 1. Variability in morphological and radiative properties, J. Geophys. Res., 105(C9), 22049–22060, doi:10.1029/2000JC900075.

Hanesiak, J. M., Barber, D. G., De Abreu, R. A., and Yackel, J. J. (2001). Local and regional albedo observations of Arctic first-year sea ice during melt ponding. Journal of Geophysical Research (Oceans), 106(C1), 1005-1016.
Barber, D. G., and Yackel, J. J. (1999). The physical, radiative and microwave scattering characteristics of melt ponds on Arctic landfast sea ice. International Journal of Remote Sensing, 20(10), 2069-2090.

The references indeed are a necessary background on melt pond observations which cannot be overlooked. They have been included in the text. The authors thank the referee for the effort and the helpful hints!

P2, Lines24-27. Corrected text: Findings from numerous in situ campaigns (Barber & Yackel, 1999; Hanesiak, Barber, De Abreu, & Yackel, 2001; Yackel, Barber, & Hanesiak, 2000) provide data of excellent quality and detail, but unfortunately lack in coverage. To fill in this gap, a remote sensing approach needs to be employed.

Anonymous Referee 2

The above mentioned paper presents a melt pond and albedo data set derived from MERIS satellite data, shows its validation and trends.
As the title already shows, this paper contains information for minimum two papers, better three.
My suggestion: to make the paper interesting and worth reading it, I address the authors to make major revisions and publish at least two papers out of the material that is presented here.
The subject itself and the outcome have definitely a high value for the science community, therefore I highly recommend to put some more work into this paper and proceed with publishing the results.

The paper indeed would gain in quality if split into parts; the authors have decided to proceed with publishing two papers, one dedicated to the detailed validation effort including cloud screening, and the second paper dedicated to the daily and weekly products, comparison to Rösel et al., 2012 dataset, and to the analysis of time sequences and trends of albedo and melt ponds. For the convenience of review, currently all changes are implemented into the original paper with the corresponding line numbers, old or based on old section numbering, and figure numbering. The split in two parts is indicated with the text color. The resulting two papers will be created from this new version of the original paper and uploaded together (3 documents). The section and figure numbering will be updated at this stage! The same is valid for the reference Zege et al., 2014, which is now obviously Zege et al., 2015, but for the sake of consistency we keep it like before in this response.

Major issues:

The first one should focus on the algorithm and its validation. The methodology of the melt pond/albedo data set is shortly summarized at pp 5231 ff., but there are many open questions, like:
- Why are you using MERIS channels 1,2,3,4,8,10,12,13,14? How do you resolve these information?
- How is the atmospheric correction processed? How do you calculate ri and ti?
- What are the criteria for separating cloud, land and open water pixel? Please specify numbers.
- Mention the "borders values". Please specify numbers.
- Why you choose the Newton-Raphson method?
- How do you calculate the albedo from S?

To understand the paper properly, the algorithm should be comprehensible and reproducible for the reader. In this paper it is not the case due to missing information (see list above).

In the introduction and the validation chapter I found a hint to Zege et al, 2014 (in review) that seems to be a proper algorithm description. If this is the case, please refer also in the data chapter to this paper and provide a manuscript of the paper to the reviewers. But the validation of a product should be part of the algorithm paper…. This is a little bit confusing for me.
Indeed, there are many open questions in the algorithm part of the paper. As the reviewer correctly noticed, this part was intended to be just a very brief summary on the algorithm, and the full algorithm description is a separate manuscript by Zege et al. 2014.
The requested reference to the original algorithm paper is added into the chapter 2: Data used. The algorithm manuscript is available as a draft version and will be uploaded for the reviewers. In the meantime, the algorithm paper is at the end of the review process. We expect it to be accepted in the nearest future, so that we can include the proper reference for the final publication.

The reason that the algorithm and its validation are two separate manuscripts is: the retrieval algorithm is a comprehensive procedure based on a forward model of sea ice and ponds. The algorithm paper contains the description of the model and its verification, and the detailed description of the retrieval and its verification using the modeled test data. Thus, the algorithm paper is dedicated to the theoretical part and that manuscript is already very long as well. It was decided to publish the validation based on field data separately, because we have got so much various field data and need to validate two products at once (albedo and pond fraction). Putting these two manuscripts together was impossible for the volume reasons.

P. 3, Lines 26-27. Inserted text: The present chapter presents a short summary of the MPD retrieval. The full description of the algorithm can be found in (Zege et al., 2014).

Another major point is that there is no detailed product description. Chapter 5 says "…analysis over the whole MERIS dataset" and further on you mention weekly resolution. How are these products created? What are methods to receive a weekly resolution, who do you handle data gaps (i.e. cloud contamination) in this case?
The weekly resolution is explained on p. 5246, Lines 17-18. As with the daily resolution (p.5246, Line 2-6), the method is simple averaging over available pixels over all available overflights, with the condition that there must be at least 50% non-empty pixels to produce a valid grid cell. The corresponding text has been rewritten for the sake of clarity.
P 17, Lines 16-21. Current text:
The weekly resolution has been obtained by averaging the gridded daily product. As in the case of daily resolution, a weekly averaged grid cell is obtained from no less than 50% of valid (cloud free) pixels. Should a given grid cell contain more than 50% of invalid pixels, it is assigned a not a number value. No weight or threshold on STDs is applied. The resulting STD is then written into the resulting NetCDF file together with the averaged value for the broadband albedo and MPF.

Isn't Chapter 4.1 ("Gridding") part of the product description? Why is it in the chapter "Case studies"?
This was done consciously to highlight that all the validation effort before was done on swath data with the best temporal overlap possible, and starting from Chapter 4, the used data is gridded and no longer highest spatial and temporal resolution. However, as the Chapter 4 is the point of split of the manuscript, the subsection 4.1 is now the "data description" and comes right after the introduction. Therefore a structure of the following sections has been added at the end of this part (please note, the section numbering is now kept original to avoid confusion and will be changed correspondingly!):
P 18, Line 26 – P 19 Line 2:
The essential difference in daily and e.g. weekly averages is the data coverage due to cloudiness and smoothness of the resulting product that is why the gridded product has been used for case studies and data analysis on the global scale. This is presented in the following sections: comparison to

reanalysis air temperature for various locations on FYI and MYI (Sect. 4.1), weekly averages analysis for 2007 and 2011 (Sect. 5.1), comparison to MPF data from (Rösel et al., 2012) (Sect. 5.2), spatial trends of MPF (Sect. 5.3) and broadband albedo (Sect. 5.4)

Chapter 5.1 gives a comparison of the ice situation of the summers 2007 and 2011. Roesel and Kaleschke (2012, JGR) did already a similar study on this topic. Are your results different? At least mention their publication in this context.
As it was decided to split the paper, we have got the space for one more subsection and figure, so we have included the comparison and discussion into the Chapter 5.2.

P 22, Line 20 – P 23, Line 31. Inserted text:
P. 66, Line 1-6. Inserted figure and caption.

5.2 Comparison to MPF by Rösel et al., (2012)

An unusual temporal and spatial dynamics of melt ponds in the Arctic Ocean in 2007 and 2011 has been initially discussed by (Rösel & Kaleschke, 2012). In their study, MODIS data and a melt pond retrieval algorithm described in (Rösel et al., 2012) have been used. It is interesting to compare these independent data obtained from a different sensor to the MPD melt pond fraction.
For this comparison, two examples presented in (Rösel & Kaleschke, 2012) are taken, the eight day composites starting on 18.06.2007 and 18.06.2011. These are the cases of prominent difference in melt pond patterns in 2007 and 2011. In order to compare the two datasets, the eight day composites from MODIS (pond fraction relative to ice area) available at the web page of University of Hamburg (http://icdc.zmaw.de/arctic_meltponds.html?&L=1) have been converted into pond fraction relative to pixel area using the provided ice concentration. Corresponding eight day averages have been created from the MPD daily gridded data. The selection of valid grid cells in the dataset by (Rösel et al., 2012) is the following: not less than 50% valid pixels for a valid grid cell, ice concentration greater than 25%, SD of melt pond fraction less than 15%. The comparison plot is shown in Figure 31. It is visible that for the 18.06.2007 both datasets show similar spatial patterns with higher MPF within Queen Elisabeth Islands and Beaufort Sea, and lower MPF in the MYI region north to Greenland and eastern part of the Arctic Ocean. This pond fraction distribution seems plausible when considering the date of observation: before melt onset in the MYI region. The MPF values slightly differ (note the distribution of higher and lower MPF in both datasets e.g. in the Beaufort Sea). The reason for this difference maybe, firstly, the difference in cloud screening methods with MODIS being much better suited for the task of cloud screening over snow results in different fraction of unscreened clouds present in the datasets. The second reason is the different averaging method, with data by (Rösel et al., 2012) being produced as a composite (best or most characteristic observation within the period), whereas MPD data is obtained by averaging. And finally the third reason for the difference is the positive 8% offset of the dataset by (Rösel et al., 2012) as provided in the "Data quality" section at the data source (http://icdc.zmaw.de/arctic_meltponds.html?&L=1). It is unclear whether this bias is constant over the whole melt pond fraction values range and if it is possible to correct for it. (Makynen et al., 2014) suggest that that the bias stems from the possible inaccurate assumption on the sea ice optical properties, which would mean that the bias varies not only with melt pond fraction, but also with weather conditions and location in the Arctic ocean (in some locations the assumption on the surface was correct and in some not).

Considering these various sources of differences, the agreement between the two datasets is good.

The second row of Figure 31 shows the same comparison, but for 18.06.2011. Here again, both algorithms seem to agree on the spatial distribution of the melt ponds, with slight difference in the amplitude, and thus confirms the plausibility of results presented both in Sect. 5.1 and in (Rösel & Kaleschke, 2012).

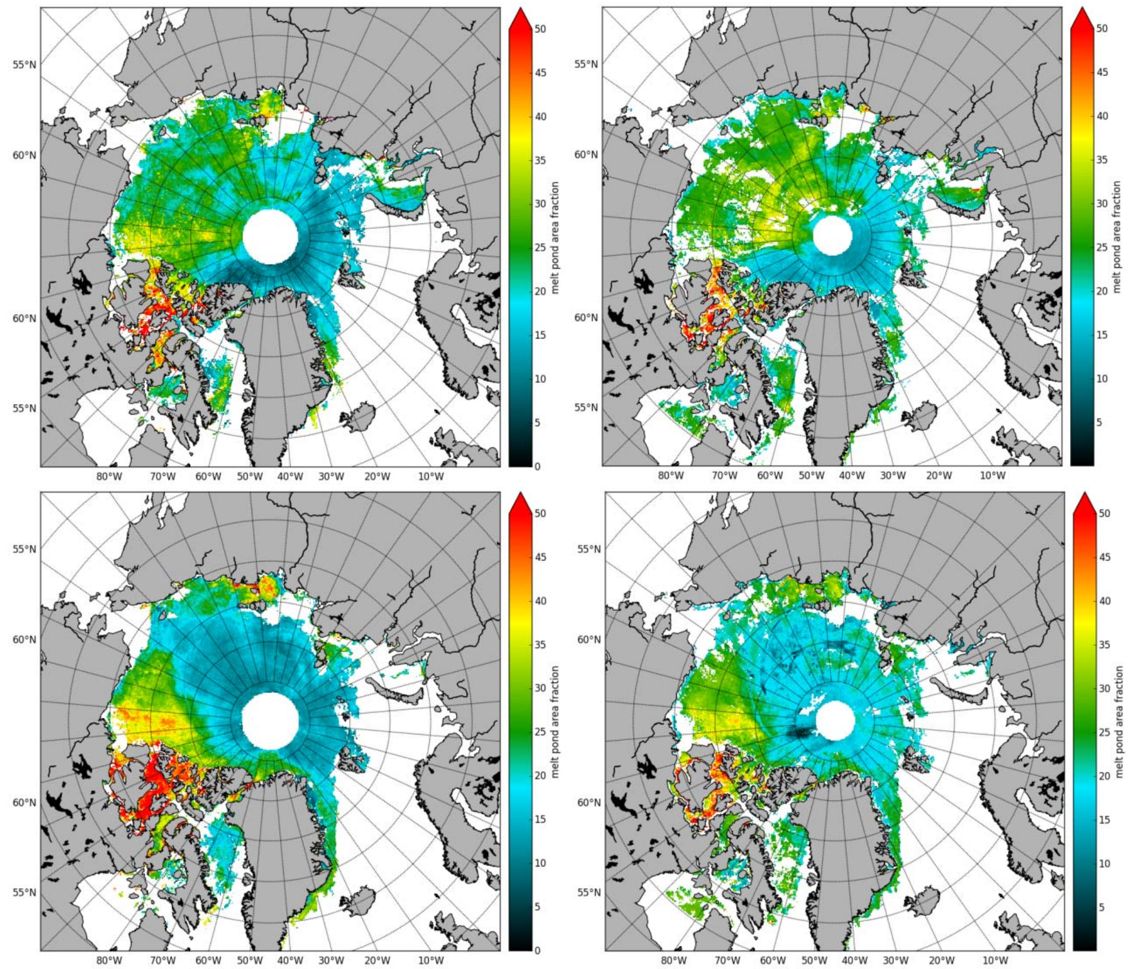

Figure 31. Comparison of the MPD melt pond fraction (8 day average, left column) to the melt pond fraction from (Rösel & Kaleschke, 2012) (8 day composite, right column) for 18.06.2007 (top row) and 18.06.2011 (bottom row).

Minor Issues:

Avoid citation in the abstract.

P 1, Line 23 – Citation has been removed.

I cannot find any of the correlation values given in the abstract in the validation chapter. Please provide the numbers there and not in brackets in the abstract. Why don't you give R_2?

The correlation values are given in the corresponding figure captions.

In the current version the R^2 is given instead and the values appear also in the text, see below:

P11, Line 27 – P12, Line 2. Inserted text:

To conclude, the best correlation for albedo retrieval is observed for the landfast and multiyear ice of high ice concentrations, which are the conditions of the best algorithm performance. The R^2=0.85, RMS=0.068. Correlation for lower ice concentrations, subpixel ice floes, blue ice and wet ice is lower due to complicated surface conditions and ice drift. Combining all aerial observations gives a mean albedo RMS equal to 0.089.

P1, Lines 26-27. Corrected text:
For broadband albedo R^2 is equal to 0.85 with the RMS being equal to 0.068, for melt pond fraction: R^2 is equal to 0.36 with the RMS being equal to 0.065.
P. 14, 13-15. Inserted text:
Overall, the best correlation can be seen for the cases of landfast and multiyear ice of high ice concentrations R^2=0.36, RMS=0.065. Combining all aerial observations gives mean melt pond fraction RMS equal to 0.22.
P. 17, Line 26: R^2 is given instead of R.
P. 16, Line 26-28. Inserted text:
The correlation between the satellite value and observed value: mean R^2=0.044, mean RMS=0.16. The reason for this low correlation is most probably the documentation of varying accuracy within the ASPECT protocol.

You mention a cloud filter in the abstract – I cannot find a proper description of a newly developed "dynamic spatial cloud filter for MERIS over snow and ice" – This is a topic for a separate publication! (See comment above)
Chapter 3.2.2 is dedicated to this cloud screening method – please see the next comment for details.

Is the cloud screening only used for validation data? Why not for the entire dataset?
For the sake of consistency with the original publication Zege et al 2014, the resulting dataset is processed with the methods presented there, and the results are discussed. The insufficient cloud screening is mentioned as one of the main issues of the dataset. The cloud screening presented in Zege et al. 2014 has been also quality assured against AATSR cloud mask as Chapter 3.1. To make an unbiased validation of the melt pond retrieval itself, an additional cloud screening has been developed. Chapter 3.2.2 (old numbering) is dedicated to this additional cloud screening which is based on separate usage of thresholds sensitive to different cloud types and evaluating the result. The current paper presents only a concept of this new cloud screening method, without its validation and with manual selection of thresholds and visual control of quality. This was sufficient to aid with validation, but it cannot be used on the whole dataset before a thorough check. An elaborated version of the method is to be published separately. The included Figure 32 gives an impression on the cloud screening quality.

P67, Line 1-3. Inserted figure and caption:

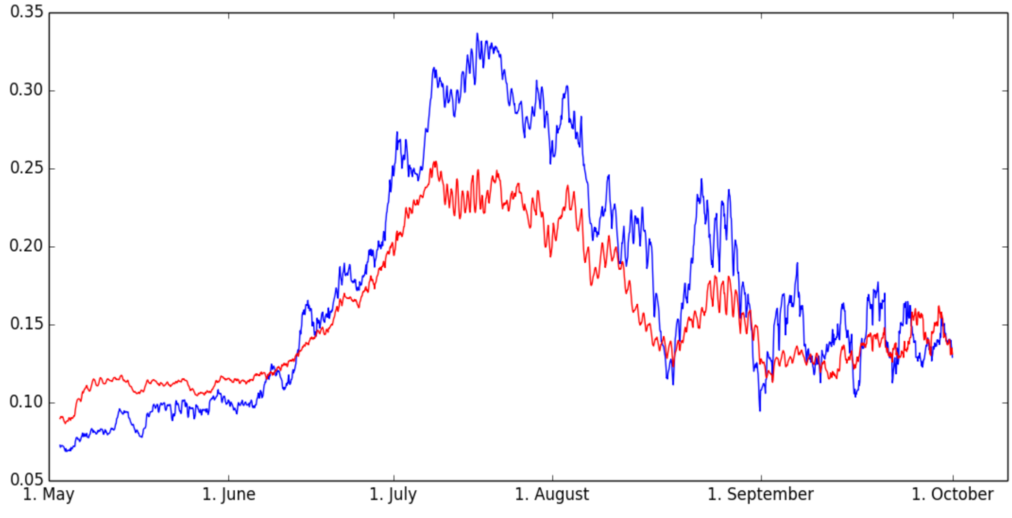

Figure 32. Comparison of the MERIS cloud mask from used in the MPD retrieval to the AATSR cloud mask presented in (Istomina et al., 2010).

P7, Line 24 – P8, Line 15. Inserted text:

3.1 Validation of the cloud screening

In order to test the performance of the cloud screening presented in (Zege et al., 2014), we have employed data from the AATSR sensor onboard ENVISAT – same as MERIS. The advantage of this sensor is that it has a number of infrared channels to aid with cloud screening over snow. For this study, a cloud screening method for AATSR developed by (Istomina et al., 2010) is used. Firstly, the swath data of both MERIS and AATSR was collocated and cut down to only AATSR swath. Then, the two cloud masks (the reference mask by AATSR and test mask by MERIS) have been compared as follows: for each swath, an average pond fraction in cloud free areas as seen by AATSR (Figure 32, blue curve) and by MERIS (Figure 32, red line) has been derived. This has been done for each swath of the period from 01.05.2009 to 30.09.2009. The resulting Figure 32 shows the effect of clouds on the MERIS MPD swath data: before the melt season, the clouds are darker than the bright surface and are seen as melt ponds by the MPD retrieval. This is the reason for the positive offset of MPF in the beginning of the season. In the case of developed melt, the situation is the opposite: the melting surface is darker than clouds, and unscreened clouds are taken as lower pond fraction by the retrieval. Overall, the unscreened clouds in the MPD product result in smoothing out of the pond fraction toward the mean value of about 0.15. Nevertheless, the temporal dynamics of MPF is preserved even in swath data. The problem of unscreened clouds can be partly solved at the stage of gridding of the swath data into daily or weekly averages, by constraining the amount of valid pixels that form a valid grid cell so that cloudy areas which are only partly unscreened in the swath data are still not included in the gridded data.

Table 3: could you plot the data? It would be maybe easier to read as in a table.
The dataset presented in the table is being published for the first time and the objective is to allow the reader to obtain accurate values from the table. The authors therefore would like to keep the table.

Is it possible to plot the validation data together in one or two figures instead of more than 10 (fig 4-18)?
Unfortunately, no. As these validation cases present different ice situation and therefore different retrieval performance, they are discussed separately in the text and shown separately in the figures.

Plot figure 19 and 20 into one figure. That makes comparison easier. Plot also MPF into it.
You probably mean Figure 20 and 21? The MPF is already included there.
The figures have been plotted together as requested.

The conclusion is hard to read and to understand. Please avoid the bullet points and form proper sentences without brackets.
The conclusion has been split and rewritten with proper sentences. The authors thank the referee for the comprehensive and helpful review!
P 26, Line 16 – P 27, Line 25. Chapter 6 is substituted with the following split conclusions:

Conclusion 1

Melt ponds on sea ice affect the radiative properties of the ice cover and its heat and mass balance. In order to assess the change of the energy budget in the region (e.g. with GCM), among other sea ice and melt pond properties, the sea ice reflective properties and the amount of melt ponds on sea ice have to be known. This work has validated a retrieval of MPF and broadband sea ice albedo from MERIS data (Zege et al., 2014) against aerial, in situ and ship-based observations.
The cloud screening presented in (Zege et al., 2014) has been compared to the AATSR cloud screening presented in (Istomina et al., 2010) for swath data of both sensors collocated to AATSR

swath, for the whole summer 2009. The comparison (Figure 32) shows that unscreened clouds are seen as melt ponds before melt onset and as no melt ponds during melt evolution; the effect of unscreened clouds is not constant and depends on the true surface pond fraction. Unscreened clouds tend to smooth out the melt pond fraction values towards a mean value of about 0.15. This effect is prominent in the beginning of the season and during the melt maximum and is the smallest in June.
The albedo data from from spaceborne and airborne observations have been compared and showed high correlation when there is no ice drift (Figures 4,6). Same comparison for MPF highly depends on the ice conditions and melt stage: for FI and MYI in the beginning of melt the correlation is high (Figures 10,11,18), for separate FYI floes the correlation is worse maybe due to ice drift (Figures 12,13). The comparison of ship cruise data to satellite retrieved MPF for FYI and MYI at the end of the melt season shows strong underestimation of satellite retrieval. This might be connected to frozen over ponds undocumented in the ASPECT observations (Figures 16,17).
The presented melt pond fraction and sea ice albedo retrieval can be applied to another radiometers with sufficient amount of channels in the VIS and NIR regions of spectrum, e.g. VIIRS onboard Suomi NPP and OLCI onboard Sentinel-3 ESA mission (planned launch 2014). Thus the continuity of the MPF and sea ice albedo dataset can be achieved, which is important for the dataset use as input to GCM and for self-sufficient studies of MPF and albedo dynamics in the context of global change and Arctic amplification.

Conclusion 2

Current work presents a detailed analysis of the MPD product (Zege et al., 2014, Istomina et al., 2015) consisting of comparison to reanalysis air surface temperatures, detailed analysis of weekly averages for 2007 and 2011 which showed different dynamics of melt pond fraction, but resulted in similar minimum sea ice extent, comparison to the data by (Rösel et al., 2012), and analysis of albedo and MPF trends. The gridded products compare well to independent reanalysis temperature data and show melt onset when the temperature gets above zero (Figure 20), however MPD shows an offset at low MPF of about 10% most probably due to unscreened high clouds. This makes application of the MPD algorithm to a sensor with a more precise cloud mask desirable (VIIRS onboard Suomi NPP or OLCI onboard Sentinel3). Though absolute daily values of MPF and albedo may be affected by unscreened clouds, relative MPF and albedo differences through the temporal axis are significant and the temporal MPF dynamics correspond to that observed in the field for FYI and MYI (Figure 20). This is also applicable to weekly averages based on analysis of MPF behavior in 2007 and 2011 (Figures 22, 23) and on comparison of the MPD product to data by (Rösel et al., 2012) (Figure 31). Thus, the MPD products are suitable for analyzing temporal and spatial dynamics of MPF and sea ice albedo.
Weekly averaged trends show pronounced dynamics of both MPF and albedo: negative MPF trend in the East Siberian Sea connected to change of absolute MPF value in its peak but no temporal shift, positive MPF trend around Queen Elizabeth Islands connected to the earlier melt onset but peak MPF values staying the same (Figures 27, 28, 29). The MPF dynamics in the East Siberian Sea could indicate a temporal change of ice type prevailing in the region, as opposed to Queen Elizabeth Island, where MPF dynamics reacts to melting temperatures occurring earlier in the season. This will be analyzed further in a follow-up publication.