Response to reviewer comments

We thank all reviewers for their helpful comments. Please find below our responses in blue.

Response to Reviewer #1

Passive microwave satellite data are frequently used to identify changes of snow properties, especially timing of melt. Mostly spring snowmelt timing is addressed in non- glaciated areas and melt days are extracted over glaciers and ice sheets. This study seeks to detect melt days over non-glaciated snow covered areas as well as investigates options for detection of snow cover (winter) start and end. A range of weak- nesses of the approach are revealed by comparison to in situ measurements. An interpretation of trends and patterns are provided but usefulness questionable (see comment below). Mid-winter patterns have been described before, as well as snow duration analyses. Kim et al. 2011 have also used SSMI to detect surface status. It is stated in the introduction that little is known about the spatial and temporal variability of winter melt events at Pan-Arctic scale (line 44). There are however a number of re-analyses studies available on this topic (e.g. Liston and Hiemstra 2011, Rennert 2009) and also from active microwave satellite data (Bartsch 2010). The observed patterns found in the presented study agree with the above studies, what is not addressed in the discussion.

We thank the reviewer for the comments, but what the reviewer interprets as weaknesses in our methodology, we see as inherent limitations of the PMW sensor that are clearly noted and discussed in the paper.

We have removed Line44, and added Bartsch 2010 in the introduction and discussion. The other references are already cited in the paper. The Kim et al [2011] study was carried out for landscape Freeze/Thaw (FT) detection and they did not differentiate the FT signal coming from snow-covered versus snow-free surfaces. Their results are therefore not comparable with this study, which focuses only on snow-covered regions for winter-snowmelt detection.

There are inconsistencies regarding terminology. The title and abstract refer to 'events', the text/method to melt days. Events might be of several days of duration. In addition, only afternoon data are used. The paper thus presents an account of melt 'afternoons'. The title and abstract should be revised and adjusted to reflect this.

The algorithm does detect winter melt events, but we summarized the results as the number of melt days to avoid the issue of event splitting that can occur with the algorithm. We have now explicitly explained this strategy in Lines 190-192.

The usefulness of the trend analyses of late afternoon melts is questionable. The authors should also include the morning measurements in order to increase the detection capability. Mid-winter melt events are not bound to diurnal-variations. This would still miss out events, but increase the number of samples. Previous studies have actually chosen the characteristic refreeze-pattern instead of melt detection (e.g. Bartsch et al. 2010). Detection of refreeze allows the inclusion of very short melt events which cannot be detected themselves due to the satellite data sampling intervals.

Good point. We have included melt detection from the morning orbits and updated all the results. This has indeed increased the number of melt days in some temperate climate regions (e.g., southern Alaska and northern Europe). However, it has not resulted in much change in either the spatial distribution patterns or the trend analyses.

The abstract includes the information that results are compared to in situ measurements, but not the outcome. Especially short events from ROS are not detected, which are of major interest for wild live and climate change studies. The failure in such cases demonstrates the shortcoming of the approach to use melt only.

We have modified the abstract to include the validation results.

Bartsch et al. 2010 used the increase of backscatter to detect refreeze events from QuikSCAT. However, the record of QuikSCAT is too short for trend analyses. The increase in the spectral gradient of 19 and 37 GHz from the SSM/I data (T_BD) has been widely used for snow water equivalent retrievals [e.g., Chang et al., 1987], which is also used to determine the main snow onset date in the fall in this study. Although all the melt/refreeze events during the winter are associated with a decrease followed by an increase in T_BD (Fig. 2), not all increases in T_BD can be attributed to refreeze events (some are due to snow accumulation). Similar ambiguities apply for refreeze events detection from QuikSCAT data [Bartsch et al., 2010].

This study focuses on winter melt detection, which occurs more often than ROS [Bartsch et al., 2010; Cohen et al., 2015]. With regard to ROS, we have re-examined all events included in Table 2, and added the following to Section 3.1 (Lines 296-301):

"Out of all twelve melt events investigated, six events coincided with observed ROS. Of the six ROS events, half were associated with successful satellite detection. Those ROS events that were successfully detected were followed by a continued warming of air temperatures that likely delayed the re-freezing of the liquid water in the snow. Those ROS events that were not detected fall under the category of a short duration melt event and thus are not detectable, as described above."

How does the performance compare to melt day detection performance commonly used over ice sheets and glaciers?

Melt over ice sheets and glaciers usually occur during the spring/summer melt season (e.g., Tedesco, 2007) which is the time of year we exclude for detecting winter melt events. Thus it is not appropriate to compare the performance of winter melt detection over seasonal snow to those on ice sheets and glaciers. See also Lines 202-204.

How does the approach of melt detection compare to results from Kim et al. 2011 (SSMI) or Naeimi et al. 2012 (ASCAT)? Kim et al 2011 showed that a dynamic threshold is needed.

Kim et al [2011] used a seasonal threshold approach and optimized the threshold values using reanalysis air temperatures. In this sense, the remote sensing retrievals are 'calibrated' using air temperature information. As mentioned earlier, Kim et al [2011] carried out landscape FT detection at a global scale, and did not differentiate the FT signal from snow-covered vs snow-free surfaces. Naeimi et al. 2012 (ASCAT) only showed surface state flags of frozen/unfrozen or snowmelt, they did not show the number of melt days over the winter. Thus the results from the two studies are not comparable with winter melt day results in the current study. Our method also uses dynamic pixel-dependent thresholds to determine the main snow onset, the main melt onset, and the winter melt days. We have clarified this in Section 2.2.

Kim et al. 2012 also analyze passive microwave trend analyses for snow cover. How do patterns compare?

Kim et al [2012] used a similar approach as in Kim et al [2011] and thus did not differentiate the FT signal from snow-covered vs snow-free surfaces. Furthermore, Kim et al [2012] only showed trends for the non-frozen period (as indicated in the title), which is not comparable with the winter melt day trends from this study.

Other comments

Line 48: Semmens et al. 2013 also demonstrated the importance of fog

A reference to fog by Semmens et al [2013] is included in the revised manuscript in line 52.

Line 60: add e.g. before the list of references as there are many more studies published on this Topic
Done

Line 63: Semmens et al. 2013 also used passive microwave data. Grennfell and Putkonen also used passive microwave data

We have modified the sentence and included Grennfell and Putkonen, 2008.

Section 3.2. – results agree with Bartsch 2010

We have added this in the discussion Section.

Additional references

Kim Y, Kimball J S, Zhang K and McDonald K C 2012 Satellite detection of increasing northern hemisphere non-frozen seasons from 1979 to 2008: implications for regional vegetation growth Remote Sens. Environ.121472–87

Bartsch, A. (2010): Ten Years of SeaWinds on QuikSCAT for Snow Applications. Remote Sens. 2010, 2(4), 1142-1156; doi:10.3390/rs2041142;

Naeimi, V., Paulik, C., Bartsch, A., Wagner, W., Kidd, R., Boike, J. and K. Elger (2012): ASCAT Surface State Flag (SSF): ASCAT Surface State Flag (SSF): Extracting Infor- mation on Surface Freeze/Thaw Conditions From Backscatter Data Using an Empirical Threshold-Analysis Algorithm. IEEE Transactions on Geoscience and Remote Sens- ing. DOI: 10.1109/TGRS.2011.2177667.