We are grateful to the referee for his/her time dedicated to this manuscript and for the constructive comments, which were all taken into account in the revised manuscript. Below, we answer point-by-point all the comments. The comments are reproduced in blue and the authors' responses (AR) are provided in black. The underlined texts are our corresponding changes in the revised manuscript.

The main changes in the revised manuscript include:

- Continuous melt onset (the first day when snowmelt lasts for at least three consecutive days) was added to investigate the pan-Antarctic snowmelt dynamics.
- The introduction section was revised to describe the motivation clearly and concisely.
- The melt detection methods and the evaluation method were described in more detail.
- The comparison between melt extent on the ice sheet and sea ice was removed.
- Figure 5-13 were redrawn, two figures were added as supplements.
- The manuscript was edited by a native English speaker.

Author Response to Referee #2

This study makes use of passive microwave data from AMSRE and AMSR2 to detect melt over the Antarctic Ice Sheet and sea ice regions using a diurnal difference in brightness temperature algorithm. Means and trends in melt onset, number of melt days, and melt day fractions from 2002-2017 are presented and compared with ERA estimates of surface melt based on air temperature, and SSMI melt indices. A method of improving melt detection in marginal sea ice is also presented and validated.

In general the paper is well written and of great interest with excellent figures but a few points need to be addressed. There are many instances where the use (or not) of the definite article is incorrect, I suggest a read through by a native English speaker to correct these.

AR1: We are sorry for the grammatical problems and the inconvenience they caused in reading. The manuscript was thoroughly revised and edited by a native speaker. We hope it can meet the journal's standards.

Early on it should be made clear that satellite algorithms for melt retrieval detect either the presence or absence of liquid water, or the diurnal transition between the two, rather than actual melting events.

AR2: Yes, microwave sensors only detect snow liquid water rather than snowmelt. We clarified this issue in the revised manuscript:

> Therefore, snowmelt can be detected via microwave radiometry by identifying the sharp changes in microwave brightness temperatures (Tb) caused by the presence of snow liquid water (Serreze et al., 1993; Liu et al., 2005).

Various products used in this study, Tb, Tair, SIC were undoubtedly supplied at different projections and swaths and resolutions. Please provide more detail on how these products were coregistered.

AR3: We explained how these products were coregistered:

The sea ice product is provided in the NSIDC EASE-Grid projection, which is the same as the AMSR-E/2 products. The 0.5° gridded ERA-Interim reanalysis was reprojected to the NSIDC EASE-Grid, and resampled to the same spatial resolution as the passive microwave measurements (25 km).

The validation described briefly P5, L28 does not give enough detail. What is the 'melt signal determined by satellite'? How are the accuracy and coefficients referred to calculated? Why is this agreement 'in contrast'? In contrast to what?

AR4: Melt signal determined by satellite is actually the presence of snow liquid water. The overall accuracy and Kappa coefficient were clearly defined. "By contrast" was changed to "However". The evaluation method was described in more details to clarify these issues:

The verification of snowmelt is difficult, especially in the pan-Antarctic where meltwater refreezes quickly, and climatic data are sparse. However, surface snowmelt is determined by atmospheric conditions and agrees well with the Tair distribution pattern (Tedesco, 2007; Liang et al., 2013). In-situ Tair measurements at Zhongshan Station (69.37°S, 76.38°E) obtained from the Chinese National Arctic and Antarctic Data Center (www.chinare.org.cn) were used to evaluate the DAV36 algorithm (Fig. 2). The overall accuracy (p_0, the proportion of observed agreement) and Kappa coefficient $k = (p_0 - p_c)/(1 - p_c)$ were used to measure the coincidence based on the confusion matrix, where p_c is the proportion in agreement due to chance (Cohen, 1960). Tb_{V36A} and Tb_{V36D} showed sharp increases at melt onset, while decreased below the winter mean in the late melt seasons with associated snow metamorphism. However, positive maximum Tair agreed well with melt signals (i.e., the presence of liquid water) determined by the DAV method, with an overall accuracy of 0.93 and a Kappa coefficient of 0.79.

P1, L21. It does not make sense to compare snow melt extents of sea ice and ice sheets when they cover different areas in total. What is the point?

AR5: We agree that the comparison between melt extent and sea ice extent makes little contribution to this work. The comparison and Fig.7a were removed, but we would like to keep Fig. 7b which illustrates the seasonal evolution of surface snowmelt. In addition, melt extent fraction (MEF) will be further discussed in Section 5.3 (Response of the pan-Antarctic surface snowmelt to atmospheric indices).

P1, L28. You mean snow melt leads to an increase in size of snow grains.

AR6: Good catch. We rephrased this sentence:

Intense snowmelt leads to the formation of melt ponds on sea ice and ice sheets, which in turn absorb more radiation and induce further snowmelt through melt-albedo feedback (Tanaka et al., 2016; Bell et al., 2018).

P1, L30. You confuse ice sheets on bedrock, with the hydrofracture on ice shelves which are floating. Separate the discussion of these two impacts.

AR7: Revised as suggested:

Meltwater may fill in the ice crevasses on ice sheets and migrate to the ice-bedrock surface, which can induce the acceleration of ice flow (Zwally et al., 2002; Sundal et al., 2011). Meltwater can also transport heat into crevasses and deepen them, providing the conditions for ice shelves to break up through hydrofracturing (Scambos et al., 2000; van den Broeke, 2005).

P3, L13. It needs to be made clearer why DAV is more likely to detect melt with AMSRE/2. Ie Explain why time of day (rather than period) of the overpasses is important.

AR8: The acquisition time is important for melt detection for two reasons:

- First, measurements with stable acquisition time are superior in the analyses of inter-annual snowmelt dynamics. AMSR-E and AMSR2 operate in controlled-orbits measurements, and the crossing time for the two sensors are nearly the same. By contrast, crossing time differs between SSM/I sensors and also changes significantly over the years of operation due to orbit degradation (Picard and Fily, 2006) (Fig. R1).

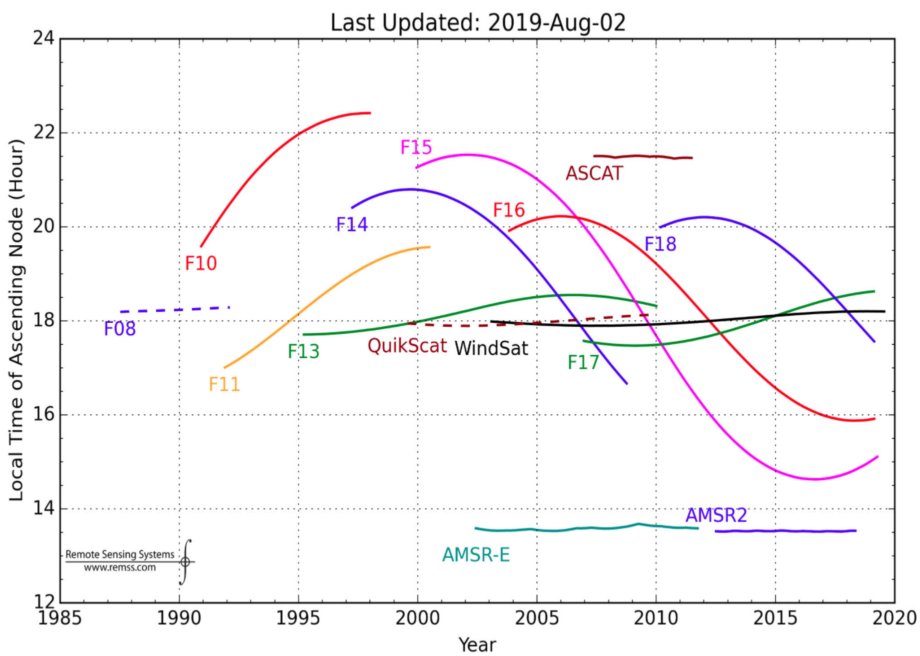

Figure R1. Ascending (solid lines) and descending (dash lines) equatorial crossing times for microwave sensors. The chart was adopted from Remote Sensing Systems (http://www.remss.com/support/crossing-times/).

- Second, the Antarctic diurnal melt area varies approximately as a sinusoid with the peak in the afternoon and the trough in the early morning (Picard and Fily, 2006). Compared with SSM/I, AMSR-E/2 have more opportunities to detect melt events in the pan-Antarctic due to warmer and colder periods for ascending and descending passes and an expected higher DAV. Taking 2002-2003 as an example, the local acquisition time of ascending and descending SSM/I Tb product south of 40° S were 19.17±0.44 and 5.45±0.45, while they were 14.16±0.20 and 0.88±0.20 for AMSR-E Tb product.

We revised this paragraph to make it clear:

Most of these studies investigated surface snowmelt on sea ice and ice sheets based on SSM/I sensors. However, SSM/I observations show considerable variations in local acquisition time because of orbit degradation (Picard and Fily, 2006). By contrast, the Advanced Microwave Scanning Radiometer for the

Earth Observing System (AMSR-E) and the Advanced Microwave Scanning Radiometer 2 (AMSR2) operate in controlled-orbits so that local acquisition time shows little temporal variation (http://www.remss.com/support/crossing-times). AMSR-E/2 measurements with a stable orbit are superior in the analyses of inter-annual snowmelt dynamics. Diurnal melt area in the Antarctic varies approximately as a sinusoid with the peak in the afternoon and the trough in the early morning (Picard and Fily, 2006). AMSR-E/2 can monitor the Antarctic sea ice and ice sheet (referred to as pan-Antarctic) surface snowmelt at the appropriate local acquisition time. Taking 2002-2003 as an example, the local acquisition time of ascending and descending SSM/I Tb products south of 40° S were 19.17±0.44 and 5.45±0.45, respectively, while these values were 14.16±0.20 and 0.88±0.20 for the AMSR-E Tb products. Compared with SSM/I, AMSR-E/2 have more opportunities to detect melt events in the pan-Antarctic due to warmer and colder periods for ascending and descending passes and an expected higher DAV.

P3, L21. 'Meltwater on the AIS always refreezes instantaneously'. Needs a reference. Also,in this case, it would never be detected.

AR9: We thank the referee for pointing out the mistake. We mean meltwater can refreezes quasi-instantaneously. We revised this sentence with appropriate citations:

Meltwater on the Antarctic ice sheet (AIS) can refreeze quasi-instantaneously (van den Broeke et al., 2010a) and contributes little to the surface mass balance (The IMBIE team, 2018).

P4, L7. Changes 'almost shares' to 'shares almost'.

AR10: Done.

P4, L17. This sentence does not make sense. Please rewrite. Which air temperature was used? 2 m?

AR11: Yes, the 2 m Tair from the gridded ERA-Interim reanalysis was used in this study. We rewrote this paragraph:

ERA-Interim is a global reanalysis produced by the European Centre for Medium-Range Weather Forecasts (ECMWF). The ERA-Interim reanalysis includes various surface parameters, describing weather, ocean and land-surface conditions since 1979 (Dee et al., 2011). The 6-hourly air temperature (Tair) from the gridded ERA-Interim reanalysis at 2 m height was used to assist with melt detection based on AMSR-E/2, as well as directly determine snowmelt in this study.

P4, L29. Please move reference to Fig. 1 to later in this paragraph. You have not yet described the simulations.

AR12: Done.

P5, L8. Replace 'opposite' with 'contrasting'.

AR13: Done.

P5, L12. Replace ‘prevailing’ with ‘prevalent’.

AR14: Done.

P5, L19. Replace ‘extensively’ with ‘extensive’.

AR15: Done.

P7, L19. This sentence needs rewording ‘MDF decreases in an opposite trend’ suggests that MDF decreases going from high to low latitudes.

AR16: Good catch. We rewrote this sentence:

> <u>In general, snowmelt shows significant latitudinal zonality. EMO and CMO occur later from the marginal sea ice to the inland of the AIS, from low-latitudes to high-latitudes, while MDF increases in the opposite direction.</u>

P6, L24. How is this definition of frozen based on ERA Tair used in the algorithm?

AR17: This condition was used to mitigate the effect of spurious Tb variations on melt detection based on AMSR-E/2, rather than determine snowmelt.

To avoid confusion, we rephrased this sentence:

> <u>Further, melt detection was constrained to the days with compatible thermal regimes following Belchansky et al. (2004). The days with ERA-Interim Tair > -5°C were first determined, and the DAV36 algorithm was applied henceforth.</u>

P7, L31. Figs. 5k-o? should be g-i?

AR18: Corrected.

P8, L12. Again, what is the point of comparing melt extents of sea ice and AIS?

AR19: We agree that the comparison between melt extent and sea ice extent makes little contribution to this work. We removed this part in the revised manuscript.

P8, L16. It is not clear why the decreasing sea ice extent would lead to an increasing sea ice melt extent? This would only explain the delayed peak in sea ice MEF.

AR20: We mean the peak of sea ice melt extent does not occur in the warmest period because sea ice considerably declines before January. This part was removed in the revised manuscript.

Fig. 9. You should only plot those pixels with a significant trend. Or also plot the p values.

AR21: Good suggestion. We added black points in Fig.9 to indicate the pixels with significant trends above the 90% confidence level.

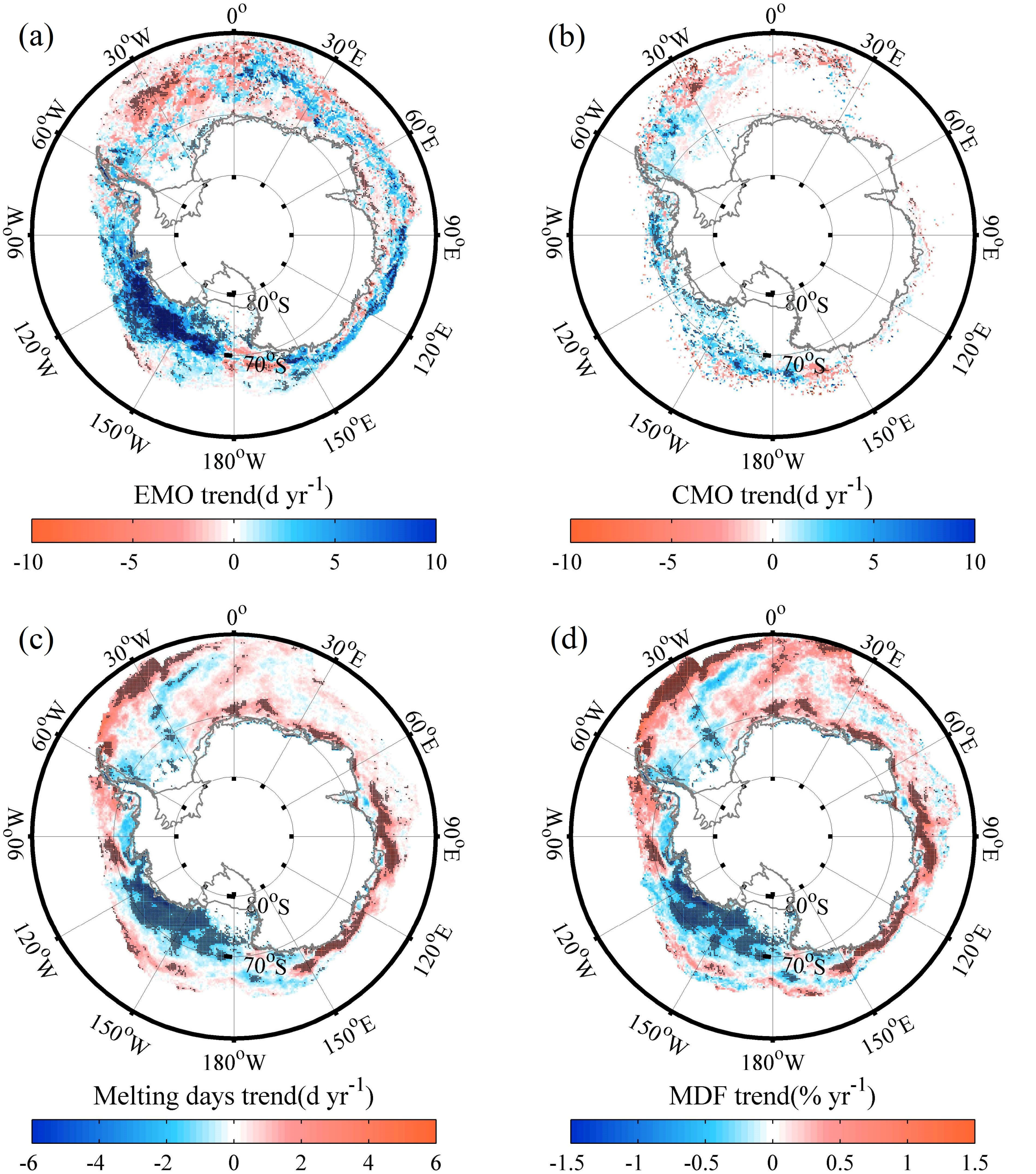

Figure 9. Trends in (a) EMO (b) CMO, (c) melting days and (d) MDF, black points indicate the pixels with statistically significant trends.

P9, L14. You should discuss further implications of the failure of DAV when melt is continuous. This would presumably manifest as a decrease in Melt Days detected where melt temporal continuity became more prevalent. Might this also explain areas with very early melt onset such as in BAS but a surprisingly low number of melt days.

AR22: This is an important point. We added the discussion about this issue in Section 5.2 (Uncertainties):

The regions with snowmelt that became more prevalent would presumably show a decrease in melting days based on the DAV method. Fortunately, unlike the Arctic, surface snowmelt on the Antarctic sea ice is always patchy and relatively short-lived (Drinkwater and Liu, 2000).

Yes, the earliest melt onset was found in BAS, but the highest melting days (37 days) and MDF (17%) were also found in this region. However, in RS, the melt onset was very early but not too many melt events were detected. We mentioned this point in the revised manuscript:

The might also be the reason that the melt onset was very early in RS while few melt events were detected by AMSR-E/2.

P10, L25. Please include these correlations between atmospheric indices and melt in a table.

AR23: We added a table (Table 3) to show the correlations between the atmospheric indices and melt indices.

Table 3. Correlation between snowmelt index and atmospheric index for the Period 2002–2017. Correlation coefficients with *, ** and *** indicate statistical significance at 90%, 95%, and 99% confidence levels, respectively.

Atmospheric index	Melt index	WS	IO	PO	RS	BAS	AIS	All
SAM	EMO	-0.27	0.77***	0.32	0.16	0.25	0.52*	0.31
	CMO	-0.03	0.15	0.03	0.50*	0.53*	0.80***	0.54**
	Melting days	0.37	0.18	0.01	-0.26	-0.42	-0.88***	-0.02
	MDF	0.18	-0.11	-0.07	-0.48*	-0.53*	-0.88***	-0.33
SOI	EMO	0.11	-0.08	-0.01	0.10	0.28	0.55**	0.19
	CMO	0.09	-0.23	0.14	-0.53*	-0.12	0.18	-0.31
	Melting days	0.03	-0.26	0.07	-0.11	0.46*	-0.03	-0.07
	MDF	-0.16	-0.18	0.12	0.15	0.34	-0.03	-0.09
Nino3.4	EMO	-0.28	-0.06	-0.11	-0.02	-0.26	-0.47*	-0.27
	CMO	-0.15	0.19	-0.35	0.66**	0.28	0.01	0.35
	Melting days	0.04	0.42	-0.16	0.08	-0.54**	-0.15	-0.07
	MDF	0.24	0.36	-0.11	-0.22	-0.46*	-0.15	0.13

Other changes in the revised manuscript include:

- We have made mistakes in statistical analyses in the first version, but they do not affect the main conclusion of this study. We corrected these mistakes and checked the manuscript carefully.
- The manuscript was edited by a native English speaker and the grammatical errors were corrected.
- Figure 5-13 was redrawn, two figures were added as supplements.

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