MELT DETECTION OVER GREENLAND USING SMAP RADIOMETER OBSERVATIONS

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ABSTRACT

Microwave measurements have been previously used to detect melt events due to their sensitivity to the presence of liquid water in snow. Since NASA's SMAP mission offers a valuable set of low frequency radiometer measurements, SMAP measurements have been used as a tool to detect melt events. SMAP's L-band radiometer also covers virtually the entire Greenland ice sheet twice daily. The overpasses center on morning and evening hours as the satellite is on a 6AM/6PM equator-crossing orbit, and the spatial resolution of the instrument is about 40 km. In this paper, the response of L-band measurements to surface melting of the ice sheet from 2015 through 2019 melt seasons is investigated. It is shown that the Greenland ice sheet experienced an unusually strong melt event at the end of July 2019, which extended the melt area across much of dry snow zone of the ice sheet over a period of two days.

Index Terms— Greenland, ice sheet, melt events, microwave remote sensing, SMAP radiometer

1. INTRODUCTION

Monitoring the melt extent and timing of the Greenland ice sheet is important for the ice sheet's mass and energy balance as well as the global and Arctic climates [1]. About 8% of the world's ice is located on the Greenland ice sheet, and melting from the ice sheet is estimated to have about a 7% contribution to the current rise in sea level [2]. Due to their all-weather operational capability and sensitivity to liquid water in snow, both microwave radar and radiometer systems have been used as powerful remote sensing tools to detect melt events over Greenland [3-6]. While radar has the potential for very high spatial resolution, the revisit times of spaceborne radars are typically very long. The radar of NASA's SMAP mission [7], launched in January 2015, had the potential to change this but it failed in July 2015. However, the L-band (1.4 GHz) radiometer on the SMAP mission continues nominal operations and provides approximately twice daily coverage of Greenland.

In this study, we investigated the response of SMAP L-band measurements to surface melting of the ice sheet from the 2015 through 2019 melt seasons.

2. DATA AND METHODS

The presence of even a small amount of liquid water in snowpack significantly impacts the electrical properties of snow at microwave frequencies. This results in large changes in microwave measurements, which permits melt detection. Low frequency microwave measurements have also been recently used to gain insight into ice sheet dynamics [8]. In this paper, we use SMAP L-band (1.41 GHz) brightness temperature measurements to gain insight into Greenland ice sheet dynamics. In order to detect melt events, our algorithm uses a normalized polarization ratio (NPR) computed from vertically and horizontally polarized SMAP L-band brightness temperatures (T_{B_v}, T_{B_h}) and examines the time series NPR difference from winter conditions. The NPR for SMAP L-band radiometer observations is given by

$$NPR = \frac{T_{B_v} - T_{B_h}}{T_{B_v} + T_{B_h}} \quad (1)$$

One significant advantage of this algorithm is that the melt signal derived from the NPR does not depend on estimates of any physical surface parameters.

We compared the SMAP NPR changes to 2-meter air temperature (TA) recorded at the National Oceanic and Atmospheric Administration (NOAA) weather station at Summit Station (72.58°N, 38.46°W), located at 3,216 m elevation (a.s.l) at the highest point on the interior of the Greenland ice sheet.

3. RESULTS AND DISCUSSION

The changes in brightness temperature caused by surface melt differs in the ablation zone, active melt areas, and the interior's dry snow zone. During winter conditions, NPR is large in the melting zone of the ice sheet due to the ice sheet's internal structure, while it is small in the dry snow and ablation zones due their differing internal properties. The NPR on a polar grid over Greenland during winter is shown in Fig. 1. In contrast, during warm conditions surface layers may start to melt, which creates a layer with a polarization difference and attenuates signal from deeper layers. As a result, NPR increases in the dry snow and ablation zones, while it decreases in the melting zone.

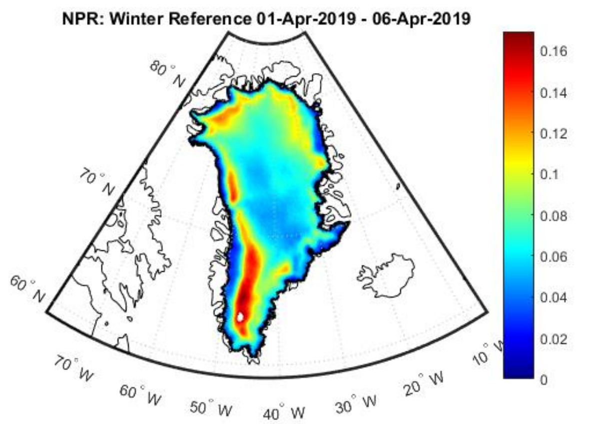

Fig. 1. The normalized polarization ratio (NPR) winter reference over Greenland from April 01, 2019 through April 06, 2019.

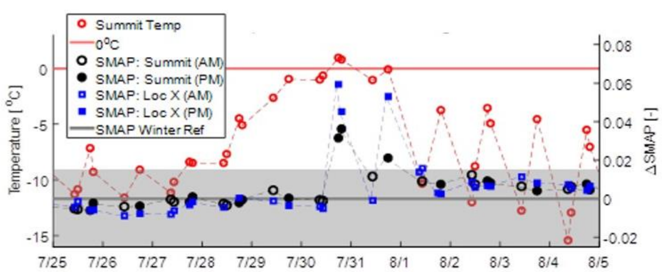

Fig. 2. Comparison of NOAA Summit air temperature and SMAP NPR change from winter conditions before and after the July 30-31 melt event. The shaded area show the melt detection threshold for ΔNPR.

The SMAP NPR deviation from winter conditions (ΔNPR) and the summit air temperature are shown in Fig. 2. On July 30, 2019 the 2-meter TA was at or above freezing for more than 11 hours, a record melt duration for the last 12 years during which climate-quality observations have been available from NOAA's in-situ instruments. Cooling on the evening of July 30 to 31 was modest, to approximately -2.5 degrees Celsius, and an unprecedented second day of above-freezing maximum temperatures occurred on July 31, 2019, when temperatures were above freezing for more than five hours and reached a maximum of 1.1 degrees Celsius for a 10-minute period. It can be observed that ΔNPR increases as the TA rises above freezing at the end of July over a period of two days, and it drops as the TA drops below freezing. However, ΔNPR does not follow the gradual increase or the sawtooth swings of TA below freezing. The figure also includes a similar ΔNPR time series for another location (Location X) in the Greenland interior (73°N, 35° W, about 125 km to the NE of Summit) where ΔNPR was particularly high during the melt event showing overall similar behavior as the summit location.

The annual melt extent derived from SMAP ΔNPR from 2015 through 2019 is shown in Fig. 3. The pattern of melt area is similar to that obtained from earlier studies of prior year conditions [9-10]. It can be observed that the melt extent during 2019 is the largest and also covers a significant portion of the dry snow zone of the ice sheet.

The daily melt area from 2015 through 2019 is shown in Fig. 4. The melt area is the largest in 2019 at the end of July, which corresponds to the high SMAP ΔNPR value at the end of July reported in Fig. 2. The evolution of the cumulative melt area extent for the years 2015-2019 is also shown in Fig. 5. Here cumulative area is defined such that any location that experiences melt on any date prior to or on the date of interest is added to the total. Cumulative areas show "step jumps" that occur at similar times during most years. These steps correspond to warmer conditions in a given year that increase the melt area; the flat values that typically follow indicate a return to colder conditions that do not increase cumulative melt area. Melt onsets occur in early May, early June, and late July in most of the years, and 2018 does not have a step in May and 2015 illustrates a differing pattern that year. The extreme melt event in July 2019 stands out clearly, with two distinct step increases. This results in the significantly larger total melt area of 2019 relative to the four previous years.

4. SUMMARY AND CONCLUSIONS

NASA's SMAP radiometer offers a valuable set of low frequency (1.41 GHz) measurements since April 2015 to monitor melt events over Greenland. The melt detection algorithm uses SMAP NPR of vertically and horizontally polarized L-band brightness temperature measurements and examines the NPR difference from winter conditions. It was shown that the Greenland ice sheet experienced a strong melt event at the end of July 2019 over a period of two days, which corresponds to the recorded above freezing summit TA for those two days. The NPR values over the ice sheet showed that the melt area extended across much of dry snow zone of the ice sheet due to this strong melt event in 2019.

5. ACKNOWLEDGEMENTS

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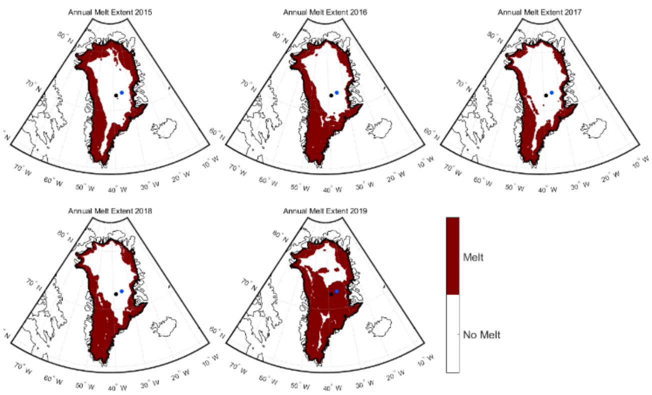

Fig. 3. Annual melt extent derived from SMAP ΔNPR from 2015 through 2019. Summit Station and location X are marked by black and blue dots, respectively.

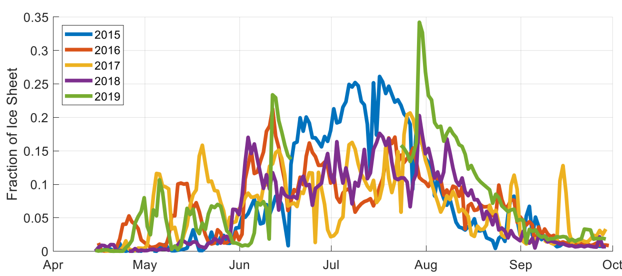

Fig. 4. Annual melt extent derived from SMAP ΔNPR from 2015 through 2019.

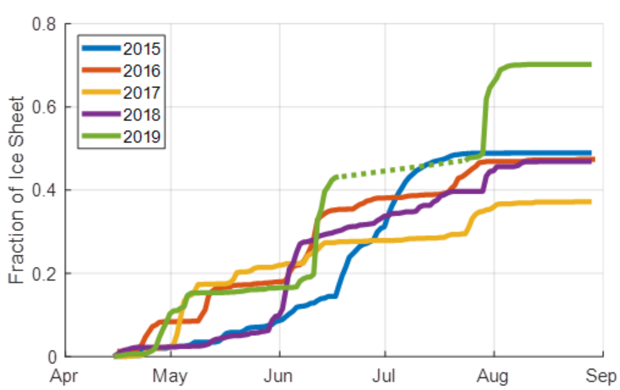

Fig. 5. The evolution of the melt area index from 2015 through 2019. . There is a gap in the 2019 line because of the outage of the SMAP satellite from June 19 to July 22, 2019.

6. REFERENCES

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