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The Cryosphere Discussions

Interactive comment on "Unprecedented atmospheric conditions (1948–2019) drive the 2019 exceptional melting season over the Greenland ice sheet" *by* Marco Tedesco and Xavier Fettweis

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Dear reviewer,

please see below our reply. Thanks for the invaluable comments and suggestions.

M. Tedesco and X. Fettweis

Anonymous Referee #1 Received and published: 15 January 2020 This paper focuses on the atmospheric conditions in summer 2019 over Greenland that led to record or

close-to-record values of SMB, runoff and snowfall. The topic is of great contemporary interest as these extreme melt events greatly impact the mass balance of Greenland and thus sea level rise. The authors are the first to present this kind of data for the year 2019. Overall, I highly appreciate the rapid investigation of this recent event. The paper is well written but some small parts in the result section need clarification (see comments). The authors show very well the exceptional character of the 2019 melt season for different properties (runoff, SMB, melt extent, etc). However, as the authors write themselves, that anticyclonic conditions increase SMB loss is known so a more detailed comparison to the 2012 melt season and the melt seasons in general to post 1990 would improve this paper and add to our scientific understanding. Possibly there can be drawn some more conclusions. Main comment: For instance (see comments below): How does Figure 10 differ in the case for 2012, JJA or averaged post 1990, JJA. This anticyclone on the west of Greenland seems to be typically for the time post 1990, (Fig, 4 Noël et al., Sci. Adv. 2019) also prominent in the year 2012 (Tedesco, 2013). Noel et al. describe similar changes in cloud anomaly for the post 1990 as the authors did for the 2019 event. How does the 2019 event compare to that. Is it "just" more persistent or does it differ in position? How to the year 2012? The authors write that persistence was a major driver in 2019, so a comparison to the persistence of the other years would be beneficial (e.g. Plot of a timeline). Can we see a general trend in persistence there? How persistent was 2012?

R: We have replied to this point below when addressing the comments. It is not clear, also, to us what the reviewer means with a "trend" of persistence. We apologize for this and would be more than glad to address this point once clarified.

Minor comments: P3, L 92. What do you mean by that: The overall integrity of the long- term GBI time series is ensured by using homogeneity adjustments (Hanna et al. 2016). Please explain in the text

R: In Hanna et al. (2016), the reanalysis 20CRv2 is used in addition of the NCEP-NCARv1 reanalysis to provide an "homogenous" GBI time series over the whole 20th

century by combining 20CRv2 to NCEP-NCARv1 with the help of some adjustments. Here, we discuss only the NCEP-NCARv1 based GBI index from 1948 (which is the JJA mean Z500 over 60-80°N, 20-80°W) and therefore this sentence is out of context here and we deleted it in the revised version of our manuscript.

P4, L l00. Since you refer to Fig2a, could you please either mention the day number in brackets for the dates in the text or change the axis label to actual dates.

R: We have added the corresponding day of the year

P4, L100-102. Maybe make 2 sentences of this one? The explanation in the brackets is too lengthy and reduces the readability. And how do you come to the statements that the MI ranked 2nd . From Figure 2b red line it doesn't look like that. Or isn't it showing the MI? Please clarify.

R: We have split the sentence and have corrected the fact that indeed 2019 ranks 3rd. thanks for catching this up.

P4, L 102-103. How do you see that? From Figure 2b I can only see the seasonal value.

R: The reference to Fig2b was wrong. Thanks for catching that up.

P4, L 108-110. I think the phrasing is a bit confusing and I needed to read the sentence several times. So are you saying that end of July 73% of the ice surface were melted and the following two days the remaining âĹij 23%? What do you mean by the same atmospheric conditions? Is the anticyclone moving or are the feedbacks increasing the melt area? Please clarify.

R: we rewrote the sentence as follows: Indeed, the persistency of the atmospheric conditions at the end of July that were responsible for promoting melting over 73 % of the ice sheet in a single day (July 31, 2019) was extending melting during the next few days over regions that were not originally involved in the melting on July 31 with cumulative melt extent for the 3-day period (July 31 – August 2) reaching up to $\sim$ 97%

of the ice sheet surface.

P4, L 111 -113. Please make a reference here.

R: Done, thanks !

P4. L113-114. You write the air masses in 2019 came from the east. For completeness, can you please add, where did the air masses in 2012 come from?

R: We mention this in the preceding sentence.

P4, L115-118. Interesting, but, -since it is in the result section- do you have the data or Figures showing that?

R: in the new Figures (attached), we can see the absolute values of the temperature at 700hPa (T700), 500hPa (T500) and mean specific humidity over 700-500hPa from NCEP-NCARv1 reanalysis on the 12th of July 2012 and on the 31st of July 2019. While the temperature anomalies were higher on 31-Jul-2019 than on 12-Jul-2019 with respect to the climatology of Mid-July or of the end of July, the absolute values were higher in 2012 than in 2019. In addition, we can see that the humidity content was also higher in 2012 than in 2019 over the ice sheet, showing the important role of liquid clouds in the 2012 extreme melt event (Bennartz et al., 2013). On this figure, we can finally see that the hot air bubble was centred over the ice sheet in 2012 but was rather along the north-east coast in 2019. These differences in temperature and humidity pattern explain why the 2012 highest melt event was more extreme than the 2019 one. Bennartz, R., Shupe, M., Turner, D. et al. July 2012 Greenland melt extent enhanced by low-level liquid clouds. Nature 496, 83–86 (2013). https://doi.org/10.1038/nature12002

P6, L177- P7, L135. You say that persistence was a major driver in 2019.Was is more than in 2012? I like your definition of persistence showing a time line for 1948-2019 would be interesting. Can we see a trend?

R: we apologize but this question is not clear to us. The persistency of the 5 top 2019 atmospheric patterns is shown in Fig. 14. We are not sure the trend of which variable

the reviewer is asking. Apologies again but this is not clear to us.

Also how does Figure 10 differ in the case for 2012 or post 1990 JJA. This anticyclone on the west of Greenland seems to be typically for the time post 1990, (Fig, 4 Noël et al., Sci. Adv. 2019) also prominent in the year 2012 (Tedesco, 2013). It would be nice to see how the position of the anticyclone differs in respect to post 1990 or 2012.

R: We added a new figure (Fig. 10,) to highlight the differences between the 2012 and 2019 years and added the following text: As a reference, Fig. 11 shows the absolute values of the temperature at 700hPa (T700), 500hPa (T500) and mean specific humidity over 700-500hPa from NCEP-NCARv1 reanalysis on the July 12th 2012 and on the July 31st 2019. While the temperature anomalies were higher in 2019 with respect to the climatology of Mid-July or of the end of July, the absolute values were higher in 2012 than in 2019. In addition, the humidity content was also higher in 2012 than in 2019 over the ice sheet, showing the important role of liquid clouds in the 2012 extreme melt event (Bennartz et al., 2013). These differences in temperature and humidity pattern explain why the 2012 highest melt event was more extreme than the 2019 one. Is it possible to check, whether the occurrence of any of the 28 classes correlated with the GBI anomaly or the SMB anomaly? Could you identify any significant trend? R: This is a very interesting point and we did, indeed, look at this aspect. We found a modest correlation between the GBI and the frequency of SOMs nodes characterized by strong anticyclonic conditions. This is expected in view of the definition of GBI. The strength of the correlation can change year by year. We think that this (together with the "modest" correlation) is due to the fact hat the GBI is an integrated measure of GPH anomalies over a specific geographic region where the atmospheric patterns identified with the SOMs extend well beyond that region. When we looked at the correlation between GBI / SOM frequency and melting we found similar correlations (summer integrated values). We are not sure if the reviewer is asking for trends in the GBI or other quantities.

Figures: Fig 3a: Maybe put " ≤ 5" on the color bar, otherwise the reader might get the

impression there are only 5 melting days.

R: Done

Fig 14a: Could you please add a grid, otherwise the reader gets lost when searching for a specific class in a specific year.

R: we tried to add a grid but the figure became hard to read. As an alternative, we have increased the resolution of the x-axis to improve readability.

Typos: P3, L l76. "." after "("

R: Done.

P3, L l77. check "); ."

R: Done

P6, L167. Something went wrong in the sentence order.

R: thanks for that. We fixed the sentence, References: Noël et al., Rapid ablation zone expansion amplifies north Greenland mass loss, Science Advances, 5, doi: 10.1126/sciadv.aaw0123

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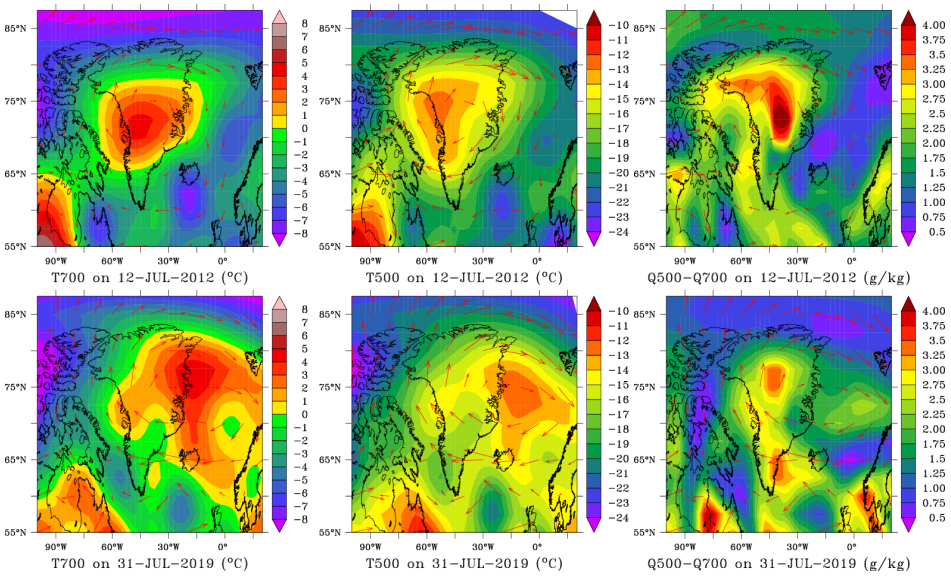
T700 on 12−JUL−2012 (°C)
T500 on 12−JUL−2012 (°C)
Q500−Q700 on 12−JUL−2012 (g/kg)
T700 on 31−JUL−2019 (°C)
T500 on 31−JUL−2019 (°C)
Q500−Q700 on 31−JUL−2019 (g/kg)

Fig. 1.

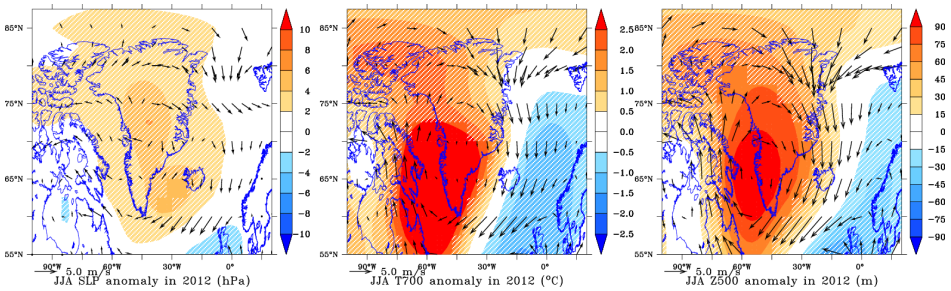
JJA SLP anomaly in 2012 (hPa)
JJA T700 anomaly in 2012 (°C)
JJA Z500 anomaly in 2012 (m)
5.0 m/s

Fig. 2.