REVIEW – REFEREE#2

The paper by Maffezzoli presents the first data on sea ice coverage of the North Atlantic and the Greenland, Iceland, Norwegian (GIN) Seas based on an ice core recently drilled on a coastal ice cap from East Greenland (Renland ice core). Following the previous approach by Spolaor et al. (2016) they use the Br enrichment above sea salt concentrations (Br_enr) linked to halogen explosions occurring on seasonal sea ice surfaces. In principle, the data and argumentation of the paper are convincing although at some points not explained in detail enough. The paper represents an important contribution to the field that will be of interest for ice core specialists, marine geologists and modelers alike. In its current state, however, the paper still suffers from some language issues (see annotated pdf file attached), some structural deficits and some issues with the argumentations that I outline in my general comments below. I am convinced that these changes can be accommodated and recommend to accept the paper after major revisions.
We really thank Reviewer#2 for the time she/he took in making a constructive review. We now modified the paper structure by incorporating all the analyses in the whole Methods section of the main text (except for a study on 'asian' dust chemical composition in the Appendix). The deglaciation section has been further analyzed and includes two additional PIP records. The Brenr curves are now two ($Br_{enr,Mg}$ and $Br_{enr,Cl}$), depending on how ssNa is calculated (we refer to the answers to Reviewer#1 on this topic). The Brenr-transformation has now been removed. We thank Reviewer#2 for finding the paper interesting and for spending time to produce the annotated pdf.

General comments

- Page 2 Line 17-23, "We compare . . . Belt and Muller, 2013)": This text should only come at the end of section 2
Done.

- Section 2, 2nd paragraph: In this paragraph it is stated that the origin of Renland sea salt is the North Atlantic and the text refers to Appendix B. This is a crucial piece of information and should not be hidden in an Appendix but included in the main text.
This analysis is now part of the Section 2.3 (main text): *"Atmospheric reanalysis: the source region of bromine and sodium for the RECAP ice core"*.

Moreover some more information on this statement would be helpful for the reader:

a) sea salt aerosol has a pronounced seasonal cycle with a broad maximum in the winter half-year. This also holds for eastern coastal sites (Oyabu et al., Polar Science, 2016). Thus, the Renland sea salt record is mainly representative for the winter half-year. The back trajectory analyses should be done both for the winter and summer half-year separately and shown in two panels.
The atmospheric reanalysis has been done on a seasonal basis; the results are shown in the 4 panels (seasons) of Figure 1. We note, however, that although sea salts inputs have winter maxima, bromine explosions occur during springtime and so do Br_enr values, as it has been (broadly) observed in shallow core records (Spolaor et al., 2014, Maffezzoli et al., 2017, Vallelonga et al., 2017).

Note also that due to the limited lifetime of sea salt aerosol, short trajectories are likely to bring more sea-salt aerosol to Renland compared to longer trajectories.
Thanks for the comment. A line has been added: *"…although the ocean regions closer to Renland are expected to be more significant as per the observed chemical signature"*.

b) transport pathway (trajectories) is one side of the coin, the sea ice source is the other. An additional figure/panel showing the multiyear and first year sea ice distribution in spring (at its maximum) would be helpful to support the claim that the source regions identified in the trajectory study are covered by FYSI or OW. The National Snow and Ice Data Center provides this information (https://nsidc.org/data/nsidc-0611).
A sea ice age plot has been added (Figure. 2), showing a representative winter maximum (Feb 1987) and summer minimum (Sept 2012) during the satellite era.

- A method section is missing. Again, this is hidden in an Appendix A but should be part of the main text.
The Method section is now fully described in the main text (Sect. 2) and includes three subsections:
- 2.1: The 2015 RECAP ice core
- 2.2: Experimental: determination of Br, Na, Cl, Ca and Mg by mass spectroscopy
- 2.3: Atmospheric reanalysis: the source region of bromine and sodium for the RECAP ice core

- Page 3 line 15-20, "The Br_enr . . . Holocene value.": This text should be the beginning of section 3
These lines have been now moved to the "Results and Discussion" section (Sect. 4).

- Page 3 line 22-29. Here the NEEM Br_enr record is mentioned and compared to Renland. In order to allow the reader to make this comparison, the NEEM data should be shown in one of the figures!
Done (Fig. 4).

- Page 4 line 1: Here the expression "tipping point" is used. There is no clear definition of what a tipping point is, but in climate science it is usually used for a rapid regime shift (see IPCC). The change from MYSI to FYSI to OW, however, is likely a gradual process. Accordingly, I would suggest to avoid the expression tipping point in the manuscript. Along this line, I think section 3.2 (linearization of the Br_enr record) and its application on the 120 kyr record in section 3.3 does not provide added value and in fact is misleading due to the gradual nature of the MYSI/FYSI/OW transition. Instead of trying to force this mathematically to a monotonous function, I would recommend to just use color bars in the figures underlying the records to indicate where MYSI, FYSI or OW dominate the Br_enr record. Moreover, mean Greenland temperature may not be the only parameter determining the amount of FYSI present (see next comment).
We agree, the term tipping point has now been removed. We also removed the Brenr-transformation.

- The high resolution data presented in Figure 3 clearly show that the YD is the time period of largest Br_enr (clear maximum) during termination I, thus the largest FYSI presence. In particular Br_enr is clearly higher in the YD than in the OD period. Note that there is no similar Br_enr maximum during the OD/BA transition as seen in the YD at the point when temperature during the OD/BA transition is crossing the same temperature as found in the YD. Either this point is just missed in the record (unlikely), or NGRIP temperature alone is not able to fully explain the observations. Here additional information could be used to elaborate on this issue. First of all, FYSI is strongly dependent on the seasonal temperature variation, this should be mentioned somewhere. Models suggest (Buizert et al., Science, 2014) that temperature seasonality during the YD and OD was much higher than during the BA. This could explain why the YD has higher FYSI than the BA. The difference between YD and OD sea ice conditions (Br_enr levels) may potentially be explained by the overall much lower temperatures encountered during the OD than in the YD (Buizert et al., 2014), which may push the OD sea ice

regime toward more MYSI. This difference may be linked to the generally higher AMOC strength in the YD compared to the OD (McManus et al., Nature 2004).
- Page 4 line 29-33: Here the paper by Rasmussen is referred to, but I am not sure based on the text provided - whether it is referred to correctly and whether the statement made in the manuscript is correct. Rasmussen et al. (2016) claim that in the North Atlantic south of Iceland SST warming already starts during stadial conditions, while in the GIN seas the warming starts only with the Greenland DO onset, i.e., when sea ice rapidly declines. Rasmussen et al., do not explicitly discuss the YD/BA/OD transitions and in fact their record does not show a clear early warming during the reduced AMOC conditions of the YD and OD. Accordingly, to make this statement would require high resolution Br_enr data for selected DO events from the Renland record, which are not available yet. I would suggest to remove this statement and also the reference to mean ocean temperatures, Antarctica and CO2.
Thanks for these comment. We will provide a single comment. This section (4.1) has now been analyzed in greater detail. We agree with the comments on the differences between YD/BA and OD, adding also that the availability freshwater from melting ice sheets during the deglaciation could have facilitated the formation of fresh sea ice surfaces. We agree on the comparison with Rasmussen, which has now been removed. We left however the sentence on the mean ocean temperatures, Antarctica and CO2 since we believe it could be a meaningful point for a broader perspective. Two additional PIP records from the Norwegian Sea has been added the Figure 6. The section of the deglaciation now reads:

4.1 The last deglaciation and the dual Br enr regimes
We now consider in further detail the last deglaciation, when a number of ocean temperature, salinity, circulation and sea ice changes are observed in the Nordic seas (Fig. 6). Marine-derived local sea ice records from both the Svalbard margin and the Norwegian Sea indicate (Fig. 6e,f) that near-perennial sea ice (PIP 25 ≈ 0.5-1) was present during MIS 2 until ∼17 kyr (17.6 kyr recorded in the Svalbard margin), the onset of a major breakup of extensive sea ice cover, during Heinrich Event 1 (18 to 15 kyr). Synchronous to within a few centuries, several modifications relevant to the North Atlantic ocean are observed (Fig. 6), including sea water surface freshening and warming in the polar and subpolar North Atlantic (the 67 °N Dokken and Jansen 1999 record is shown as an example in Fig. 6c) and a near total cessation of the Atlantic Meridional Overturning Circulation (AMOC, Fig. 6d). Generally low to intermediate PIP 25 values (PIP 25 ≈ 0-0.5) are reported in the Svalbard Margin and in the Norwegian Sea in the ∼17-12 kyr period (Fig. 6e,f,g), with a slight increasing trend throughout the Bølling-Allerød (BA) and a broad maximum reached during the Younger Dryas (YD), suggesting that seasonal sea ice conditions were dominating this period. Other studies from marine records in the Nordic Seas records also suggest milder sea ice conditions during the BA and increased sea ice during the YD (Belt et al., 2015; Cabedo-Sanz et al., 2016). In contrast, a record from the northern Icelandic Shelf (Fig. 6e) shows that here the sea ice conditions remained near-perennial from 14.7 to 11.7 kyr (PIP 25 ≈ 0.5-1). The authors (Xiao et al., 2017) suggest that this pattern of more severe sea ice conditions in the north of Iceland is, at least during the BA and the YD, linked to the flow of warmer waters from the North Atlantic Current, influencing sea ice melting in the eastern Nordic Seas, whereas the Icelandic shelf is influenced by colder polar waters from the East Greenland Current and the East Icelandic Current.
The RECAP ice core was resampled at sub-centennial resolution to better constrain the timing of sea ice changes through the deglaciation in the 50-85 °N North Atlantic (Fig. 6b, squares). The $Br_{enr,Mg}$ *serie (*$Br_{enr,Cl}$ *would lead to the same results) would indicate that FYSI started to increase in the North Atlantic, concurrent to a reduction of MYSI, at ∼17.5 kyr, synchronous with local PIP 25 decrease in*

the Svalbard margin and eastern Nordic Seas and in response to sea surface temperature warming in the North Atlantic. This findings would also suggest that North Atlantic sea ice changes occurred in concert with temperature and circulation changes of the underlying surface waters. We note that this time period also coincides with the initiation of deglacial changes in mean ocean temperature, Antarctic temperatures and atmospheric CO 2 concentrations toward interglacial values (Bereiter et al., 2018). North Atlantic FYSI continued to increase throughout the BA (except for one point at 12.7-12.4 kyr at the onset of the YD) until a maximum at 12.4-11.8 kyr during the YD, when a clear $Br_{enr,Mg}$ maximum is observed (Fig. 6). From the comparison between the marine and ice core results, we infer that, during the 17-12 kyr period, the 50-85 °N-integrated North Atlantic sea ice changed from MYSI to FYSI. Local sea ice was also melting at ∼17 kyr in the eastern Nordic Seas, likely influenced by the North Atlantic Current, while, at least from 14.7 to 11.7 kyr, sea ice was still near-perennial at the North Icelandic shelf, possibly due to the influence of cold waters carried by the East Greenland Current. Following its maximum value at 12.4-11.8 kyr, Br enr (i.e. FYSI) started to decrease (Fig. 6b). We suggest that from this point-in-time, the Br enr indicator now shifts to the FYSI/OW regime (Fig. 5), and the North Atlantic basin became largely ice free. A retreating FYSI scenario is also recorded in all 5 marine cores (decreasing PIP 25 to ≈ 0-0.4 during the Early Holocene, Fig. 6e,f,g), suggesting that open water conditions progressively developed in the whole North Atlantic basin, sustained by increasing heat transport from the North Atlantic Current and a strengthened AMOC since ∼11.7 kyr (McManus et al., 2004; Ritz et al., 2013).

Since Br enr is assumed to be an increasing function of FYSI, its decrease would point to either OW or MYSI conditions, following either the FYSI/OW or the FYSI/MYSI regimes (Fig. 5). At any point in time, only one regime is considered to be in place, and we suggest a simple model in which a temperature threshold could be the discriminating variable setting the regime type. Since a change of regime is observed during the deglaciation, with maximum Br enr values (i.e. FYSI) at 11.8-12.4 kyr, we set the threshold to be the mean NGRIP temperature reconstructed for that period: T NGRIP =-4.6±0.9 (2σ) °C (the two lines in Fig. 6a). In every ice sample of the 120,000 year record the regime type (FYSI/MYSI or FYSI/OW, see Fig. 5) can thus be determined according to its integrated temperature value with respect to the temperature threshold: FYSI/MYSI for a lower temperature value and FYSI/OW for a higher temperature value.

According to this simple model the deglaciation is characterized by the FYSI/MYSI regime until the onset of the Bølling-Allerød (except few points at which the regime type depends on the chosen threshold value, Sect. 4.2), while the FYSI/OW regime operated from that point forward. We note that there is no similar Br enr maximum at the onset of the Bølling-Allerød as seen in the YD at the point when NGRIP temperature is crossing the same temperature as found in the YD. The NGRIP temperature alone appears therefore not to be able to fully explain the observations. The possible explanation of higher Br enr values during the Younger Dryas compared to the Bølling-Allerød may reside in the higher seasonal temperature variations (Buizert et al., 2014) and freshwater inputs from melting ice sheets in the former period, both promoting the formation of seasonal sea ice. Conversely, the lower Br enr values (hence to greater MYSI in the FYSI/MYSI regime) during the Older Dryas compared to the Bølling-Allerød and the Younger Dryas may be linked to the overall much lower temperatures during this period (Buizert et al., 2014), higher surface water salinity due to less freshwater inputs from melting ice sheets and a generally weaker AMOC.

- Page 6, line 26. Here you refer to the GI numbers. These should be included in the figures
Done.

- Include Fig. 1 in Fig. 2
Fig. 4 now shows all the measured records from RECAP.

- Add the NEEM record in Fig. 2 or provide a separate figure for the NEEM/Renland comparison.
Done (Fig. 4).

- Add color bars for sea ice conditions underlying figure 2
As it is the first plot, no error bars are colored in Figure 4. The colors appear in Figure 7, where the two regimes are discussed.

- add color bars for sea ice conditions underlying figure 3
The two regimes are just indicated with two colored bands (Fig. 6).

- remove figure 5
Done.

- remove the transformed BR_enr in figure 6, add color bars
Done (Fig. 7).

- move Appendix A to a Method section
Done, now Sections 2.1 and 2.2 (Methods).

- move Appendix B to section 2 and add more information as outlined above
Done, now Section 2.3 (Methods).

Specific Comments
- see annotated pdf
We really thank the Reviewer for the annotated pdf.

References

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