Answer to Referee #1

This paper examines accumulation over Greenland and its potential changes during different climate states, in particular Early Holocene (EH) and Last Glacial Maximum (LGM). The authors analyzed both thermodynamic and dynamic factors that drive accumulation changes over Greenland.
Some of the results of the paper are already known and the authors should make clear what are the new results coming out from this study (starting from the abstract: see General Comment #2), which can represent an interesting addition in understanding the changes in Greenland accumulation in different climate states. I think this paper may be suitable for publication in CP after addressing the following comments.

We thank the referee for the careful review and the constructive comments. Please find the answers to all specific comments below.

General comments:

1) The authors has pointed out several time as one of their results that "accumulation records from different ice cores sites cannot be expected to look alike since they include a distinct local signature". I found this statement imprecise: first of all, the authors do not specified on which temporal scale this statement holds true: daily, monthly, interannual, decadal, centennial. Second of all, I would not expect at all, that proxies that are hundreds km apart, with complex orography in the middle to look alike on daily, monthly or interannual timescale. On the other hand, I do expect to be similar on centennial/millennia time scale. Hence, if one is trying to reconstruct the NAO variability of the last few centuries, he/she needs to be careful on the choice of the location of the ice-core and on the local signature, whereas if he/she cares about millennial oscillation I would expect that NGRIP and DYE3 are synchronous and are telling the same story.

This is indeed a valid comment and we have made an effort to clarify the time scale in each of these statements. We completely agree that in particular on shorter time-scales (daily to inter-annual) the accumulation records include a local signature whereas on orbital time scales (glacial vs. interglacial) the signal has a large-scale structure, e.g., accumulation at NGRIP and DYE3 experience both a strong reduction under LGM conditions vs. PI (Fig. 4 in manuscript). However, comparing the mean accumulation in the EH-simulations (Fig. 5 in manuscript), we observe that the sensitivity to ice sheet topography changes, which typically occurs on centennial to millennial time-scales, exerts a different response in accumulation in different Greenland regions so the NGRIP and DYE3 accumulation signal do not necessarily have to look alike even on longer time scales.
However, we have tackled this issue and specified the statements in the abstract and the two paragraphs listed in your minor comments g) and i):

P3846 LL23--
„Thereby, the differences in mean accumulation between PI and EH_{PD} (see Fig. 4c) and among all EH simulations (see Fig. 5d-f) exhibit strong spatial variability emphasizing that accumulation records from different ice core sites can differ even on centennial to millennial time scales. This is especially true during time periods of changing GrIS topography (as the early Holocene) when any change in ice sheet topography, in particular if altering the position of the marginal slopes, has a strong impact on local (mainly orographically-induced) precipitation (see Fig. 5). In contrast, accumulation reacts rather uniformly to LGM conditions, where we observe a strong decrease all over Greenland compared to pre-industrial conditions (see Fig. 4d). This means that accumulation records from different Greenland sites are expected to synchronously register the glacial-interglacial cycles but can still vary on long time-scales (centennial or millennial). Moreover, the independence between different regions is particularly strong regarding short-term (daily to inter-annual) accumulation variability as previously shown by Hutterli et al. (2005), whose regional accumulation indices are not significantly correlated with each other (with the exception of CW and SW)."

P3850 L17
„The only uniform accumulation signal throughout Greenland is the strong decrease for the glacial LGM conditions and the increase associated with the recent rise in GHG concentrations."

2) The abstract seems more an introduction than actually a resume of the main results of the manuscript: it is difficult to understand what is new and why this paper is relevant. I invite the authors to better stress what are the main results and the novelty of the paper.

Thank you for this valuable feedback. We have rewritten the abstract and come up with a more condensed version which hopefully better highlights the key findings of the manuscript.

New abstract:
„Changes in Greenland accumulation and the stability in the relationship between accumulation variability and large-scale circulation are assessed by performing time-slice simulations for the present, the pre-industrial, the early Holocene, and the last glacial maximum (LGM) with a comprehensive climate model. The stability issue is an important prerequisite for reconstructions of Northern Hemisphere atmospheric circulation variability based on accumulation or precipitation proxy records from Greenland ice cores. The analysis reveals that the relationship between accumulation variability and large-scale circulation undergoes a significant seasonal cycle. As the contributions of the individual seasons to the annual signal change, annual mean accumulation variability is not necessarily related to the same atmospheric circulation patterns during the different climate states. Interestingly, within a season, local Greenland accumulation variability is indeed linked to a consistent circulation pattern, which is observed for all studied climate periods, even for the LGM. Hence, it would be possible to deduce a reliable reconstruction of seasonal atmospheric variability (e.g., for North Atlantic winters) if an accumulation or precipitation proxy were available, which resolves single seasons. We further show that the simulated impacts of orbital forcing and changes in the ice-sheet topography on Greenland accumulation exhibit strong spatial differences emphasizing that accumulation records from different ice core sites regarding both inter-annual and long-term (centennial to millennial) variability, cannot be expected to look alike since they include a distinct local signature. The only uniform signal to external forcing is the strong decrease in Greenland accumulation during glacial (LGM) conditions and an increase associated with the recent rise in greenhouse gas concentrations.“

3) The stability issue on interannual time scale has been addressed on other studies that the authors should refer to, in particular: Langen and Vinther 2009 (Clim. Dynam.) where they analyze the response in northern hemisphere atmospheric circulation and the resulting changes in moisture sources for Greenland precipitation to LGM boundary conditions using an AGCM. Pausata et al. 2009 (CP), where they show in a model intercomparison set-up the changes in seasonality for 2 different locations in Greenland as well as the effects of changes in the leading mode of the atmospheric circulation in terms of potential recorded temperature and precipitation between PI and LGM. Kim, 2004 (Clim. Dynam.) and Pausata et al. 2011 (CP) show the impact of different boundary conditions (topography, GHG, etc) in altering atmospheric circulation. I would invite the authors to include those references in the introduction and/or when discussing the stability during past climate changes.

Thank you for recommending these papers. We have included several of them in the introduction and discussion. We have not included Kim (2004) as this paper does not study accumulation or atmospheric circulation. The other three references have been added to the following paragraphs:

P3828 L23
Previous studies assessing the relationship between accumulation and atmospheric circulation in a paleoclimate context focused on the LGM (Pausata et al., 2009; Langen and Vinther, 2009) in order to identify glacial/interglacial differences.

P3848 L23
"In agreement with Pausata et al. (2011) we observe weaker westerly winds over the high latitudinal North Atlantic and a southward shift in the storm tracks (Hofer et al., 2012a) which leads to an amplification of the drying conditions over Greenland. Langen and Vinther (2009) further show that the moisture sources at Greenland ice core sites differ substantially for LGM compared to present-day conditions, also supporting the important role of dynamics in explaining the glacial-interglacial precipitation differences."

P3850 L5
It also connects to the findings by Pausata et al. (2009), who showed that the annual cycle of precipitation at Greenland ice core sites is very different for LGM compared to present-day conditions which can cause a bias in annual mean temperature estimates based on water isotopes.

Minor Comments:

a) Abstract: L10 delete "on" in ": : : on on various : : :"
done

b) P3830 L1: I assume the authors mean that they use prescribed SST when they use the expression "a data input model". If so I would suggest to use "prescribed SST" is less confusing.

We indeed prescribe time-varying SSTs as lower boundary conditions. We have removed the expression "data input model" which is somewhat confusing.

"This setup has no ocean component so time-varying sea surface temperatures (SST) are prescribe as lower boundary conditions."

c) P3830 L9: pre-industrial simulations as well as the GHG concentrations used in your paper refer to the year 1750 not 1850, please change it.

done

d) P3836 L4: "not shown": Aren't the sublimation rates shown in Table 2?
That is correct – we have replaced the "not shown" with the corresponding reference.

"The fact that due to the colder climate the sublimation rates are reduced as well (see Table 2), can by no means compensate the precipitation reduction."

e) P3844 LL21-23: why the low pattern correlation in EH8ka would be due to a "deviating signal in a far-afield areas"? If so I would expect to see this effect also in the other EH or the LGM simulations? Please, explain better.

The CW and SW EH_{8ka} patterns are indeed similar with the PD winter patterns over Greenland but the signal over Europe is contrary to PD (see Fig. A1). In case of the EH_{8ka} CW pattern the high-pressure system over southern Greenland extends far into Europe whereas in PD a weak low pressure is simulated over Europe. As the domain used for calculating the pattern correlation (see Fig. 7 in manuscript) includes a substantial fraction of Europe, the differing signal over Europe lowers the pattern correlation $r_{PD\text{-}EH8ka.}$ Somewhat surprisingly, the other EH as well as the LGM simulations match the PD pattern more closely even over Europe resulting in higher pattern correlation values.

We avoid the expression "far-field" and have adapted the paragraph P3844 LL21-25 in the manuscript to clarify this.

„The EH_{8ka} SW and CW winter patterns compare well with the PD patterns over Greenland and the North Atlantic domain but show differing pressure anomalies over Europe (not shown). As the domain used for calculating the pattern correlation includes a substantial part of Europe (see frame in Fig. 7a) , the differing signal over Europe lowers the pattern correlation. The other EH and the LGM simulations match the PD pattern more closely even over Europe resulting in higher pattern correlation values."

f) P3844 LL23-25: where is it shown that PD patterns over Greenland compare well to EH8ka patterns? Please specify.

The EH_{8ka} patterns are indeed not shown in the manuscript as we did not show all patterns of all simulations in figures in order not to confuse and fatigue the readers with too many figures. We have added a "not shown" in the manuscript at the according position. However, the comparison of PD and EH8ka patterns is included in the answer to minor comment e).

g) P3846 LL23-35 and P3850 LL13-17: see General Comment #1.

done, see answer to General Comment #1

h) P3848 LL17-24: the authors could refer/discuss the papers or some of the papers suggested above.

As stated in the answer to general comment #3, we have included two of the suggested references here.

i) P3850 LL13-17: see General Comment #1.

done, see answer to General Comment #1

Figures

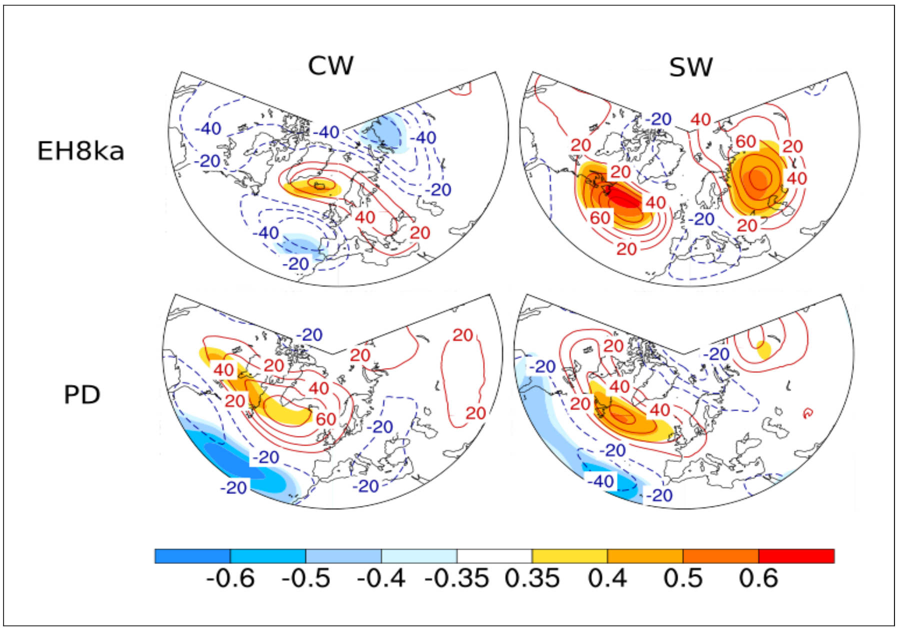

Fig. A1: DJF mean z500 correlation and plus-minus composite patterns associated with seasonal mean accumulation in CW (left) and SW (right) for the EH8ka (top) and the PD (bottom) simulation. Shading illustrates the correlation pattern significant at the 5% level (t-test statistics) and contour lines illustrate the z500 plus-minus composite (in geopotential height meters).