We appreciate the thoughtful and constructive comments by the reviewers.

Both reviewers agree that the description of the subsurface warming events found uis very general, and there are some exceptions that have to be noted. The reviewers also list a number of technical/typing errors, and minor changes in the figures, which we have been changed according to the reviewer, unless is specified.

Below we respond to the comments by each reviewer.

Anonymous Referee #1

This manuscript presents new Mg/Ca and d18O results from IODP Site U1314 on the planktonic foraminifer N. pachyderma (sin) for the Early Pleistocene MIS 31-19. N. pachyderma was selected to reconstruct changes in subsurface water mass conditions. The records show warmer and saltier conditions just before and during the maximum occurrences of IRD deposition. These results are interpreted as representing a similar mechanism which was suggested for MIS 3 in the N-Atlantic that accumulated warmer and saltier water leads to instability of the ice sheets and accordingly to the release of ice bergs. The manuscript is well written and provides an interesting addition to the growing collection of records which show the link between subsurface warming in the N-Atlantic, rapid climate oscillations, and ice sheet instability. I only have a few comments, which are detailed below. In summary, I recommend this manuscript for publication in Climate of the Past after minor revisions have been made.

A first main question which came up is “Why MIS31-19?” What makes this interval specifically interesting to perform these reconstructions on?

This interval, between MIS31-19, was chosen because we wanted to demonstrate that persistent suborbital-scale variability in North Atlantic sea-surface and deep-water hydrography were already recognisable and operating at this time, independently of the duration of glacial–interglacial cycles as in the MIS3, and responded to the same mechanism as in the Late Pleistocene (link to equatorial and tropical regions).

In general I do agree that subsurface warming regularly occurs during IRD events, it nevertheless also seems to be quite random. For some events it fits perfectly, but for other maximum temperature events no IRD occurs or a maximum in IRD is accompanied by minimum temperatures (e.g. 960 ka). Even though intensity/duration of each separate event may have been different and therefore the responses may have been different, I wonder if this is not also a case of small age model mismatches and/or the result of the different responses which were found in Mignot et al. (2007). They argue that they only find subsurface warming when intermediate water formation also ceased along with NADW formation. As long as intermediate water formation continued no subsurface warming developed.

This comment agrees with the second reviewer. While we agree that a more detailed description of the features observed in each proxy during the IRD events, we do not think can be called ‘random’. In the example indicated by reviewer (960 ka) indeed there is a maximum of subsurface temperatures at the beginning and during the IRD discharge. The cooling occurs at the IRD maxima, but we do not think that this does not agree with the mechanism proposed here (subsurface warming triggering ice-sheet instability). Following suggestion from Reviewer #2, we provide a more elaborated description of the subsurface warming events.

Mg/Ca on N. pachyderma has never been straightforward to interpret. Therefore, I think it is essential to include the actual Mg/Ca data into the paper/supplement. It is mentioned that Mn/Ca was <0.5 mmol/mol. Such values still seem relatively high. Was there a correlation between Mn/Ca and Mg/Ca or were any samples identified as outliers with high Mn/Ca?

Mg/Ca data has been included in the Supplementary data, and a vertical axis has been included in the Figure 2, next to the Mg/Ca based temperatures. Mn/Ca ratios are bellow 0.5 and the average value is 0.2 mmol/mol. These values are well bellow to those previously shown to be problematic for Mg/Ca-temperature reconstructions (Pena et al., 2005). In addition, the fact that any significant correlation occur between the Mn/Ca and Mg/Ca record (R^2=0.2) and the absence of outliers support that the studied samples do not have any relevant Mg contamination problem associated to the presence of Mn-rich phase.

Minor comments:

Page 4034-13: Change to “Subsurface accumulation of warm waters” 4035/4043: I suggest adding a recent paper by Ezat et al. (2014) who used benthic foraminifer Mg/Ca to show warming during such stadials in the Nordic Seas. Also, Naafs et al. (2013) provide a review of IRD events since the Pliocene, including the studied interval in here.

4036-19: “allow”

4037-8: should be westwards 4037: Properties of the Irminger Current seem to contradict each other between the 2nd and 3rd paragraphs.

This section has been rewritten.

4037-24: “shell”; rephrase the sentence, it seems that it should be two separate sentences. 4038-3: delete “to”; “planktonic”; -6: “on a . . .”

4038-26: The reference “Hernández-Almeida et al., 2013b” is missing.

4039-13: “overestimate”;

-16: delete “ratio”;

-27: delete “the iceberg”

4041-7-10: Please rephrase; the order seems wrong; shouldn’t it be that because of the accumulation of subsurface heat you destabilize the water column which then leads to the increased calving, and then finally AMOC speeds up again?

We think the chronology of events is right. During the weakened AMOC, heat accumulates at subsurface, causing inversion in the water column (Shaffer et al. 2004). Once there is enough heat to melt the ice-sheet, this retreats. According to Mignot et al. (2007), strong vertical temperature inversion facilitates destabilization the water column, inflowing warm Atlantic water is in contact with the surface, and there is an efficient release of heat to the atmosphere, starting convection shortly after the end of the perturbation. We have rephrased last sentence to clarify it.

4042-3: “intensifications”

-22: “orbital-scale”: It would be interesting to show this, is temperature changing similar to the other proxies as shown in Hernandez-Almeida et al. (2010)?

This comment is not clear; do not know what it means with similar change in temperature as in Hernández-Almeida et al. (2010).

4044-9: “at the expense of”

Fig.2-4: Add error bars, both on d18Osw and Mg/Ca of pachyderma these can be quite significant.

The external reproductibility of the Mg/Ca of pachyderma is indicated in the methods section: ‘External reproducibility for Mg/Ca ratio is estimated at 1.8%’

Fig. 3: add MIS numbers to the plots.

Suggested References: Ezat, M., T. Rasmussen, J. Groeneveld (2014). Persistent intermediate water warming during cold stadials in the SE Nordic seas during the last 65 kyr. Geology, doi:10.1130/G35579.1 Naafs, B.D.A., J. Hefter, R. Stein (2013). Millennial-scale ice rafting events and Hudson Strait Heinrich (-like) Events during the late Pliocene and Pleistocene: a review. Quaternary Science Reviews 80, 1-28

Anonymous Referee #2

Review Hérnandez-Almeida et al. Subsurface North Atlantic warming as a trigger of rapid cooling events: evidences from the Early Pleistocene (MIS 31-19). Hérnandez-Almeida et al. present a new record of Mg/Ca-derived temperature of the subsurface dweller Neogloboquadrina pachyderma sinistral for core U1304 for the time interval 1069-779 ka. The Mg/Ca-derived record is furthermore used to deconvolved the sea water d18O and temperature component from the previously published N. pachyderma d18O record and obtained indirect indications about subsurface salinity changes. These new records (subT, d18Osw) are used in combination with previously published (by the same authors and collaborators) records of planktonic and benthic stable isotopes and IRD counts to infer increases in subsurface temperature and salinity in connection with IRD events due to reorganizations of the AMOC. Similar subsurface developments have been reported during MIS 3 also in relation to IRD discharges and AMOC reorganization. To my knowledge, this is the 1st time that such events are described for the around-MPT world and show that climate instability is the norm rather than the exception of glacial times. The manuscript will be of interest for a wide audience of Climate of the Past and I recommend publication after moderate revisions. I find that the main point of the manuscript, warmer+saltier subsurface water accompanying IRD events can be more elaborated to describe differences between different periods. It seems tricky to make a generalization of this mechanism to all the IRD events since some of them happen during interglacials, when maybe there was indeed no sea ice cover for the warm subsurface waters to flow underneath and destabilize.

Although some of the IRD occur during interglacials, the benthic d18O clearly shows that they took place during periods of increased ice volume. The mechanism proposed here does not imply sea-ice formation, but involves large ice-shelves on continents. The subsurface warming would melt and destabilize the ice-sheets, and then those would release the IRD. Sea-ice do not necessary imply IRD discharge.

For example 4040-6 “many of the IRD events”, it is probably more precise to leave it more open, “a number of the IRD events”, “some of the IRD events” and subsequently try to group them and describe which fit in that mechanism of which do not. You could prepare a table in which the information listed below is included (and other info you consider relevant).

IRD ca 1060-1050 ka (MIS 30): warming yes, salt yes, increase plk d13C (=ventilation) yes, also increase in plk d18O (not seen in benthic d18O), likely related to salinity. IRD started before, during cooling.

IRD ca 1033 (MIS 29): warming no, salt yes? (difficult to see in Fig.2), ventilation yes, also increase in plk d18O not seen in benthic d18O, likely related to salinity

IRD ca 1020 (MIS 29): warming no, salt yes, ventilation yes, also increase in plk d18O

IRD ca 1012 (MIS 28): warming very small, salt very small, ventilation yes, no really increase in plk d18O,

IRD ca 1008 (MIS 28): warming yes, salt yes, ventilation yes, before IRD discharge

IRD ca 995 (MIS 27): warming yes, salt yes, ventilation yes, before IRD discharge,

IRD ca 817 (very small, MIS 20): warming yes, salt yes, ventilation yes, no increase in plk d18O

IRD ca 800 (MIS 20): warming no, salt yes, ventilation yes, increase in plk d18O

Table has been included, but instead of included cualitative changes (yes/not), we have included the change in Mg/Ca, d18Osw and d13Cplanktonic.

On view of this listing, my impression is that the subsurface mechanism operated during glacial periods or mild interglacial periods (pre-MPT) when the ice sheets were still close to the critical mass defined by McManus (ben d18O 3.5 per mil) for instability. The IRD events during MIS 21 do not relate with subsurface warming and were more likely caused by the surface cooling described in the 2012 paper. In that paper all IRD were related to surface cooling so it would be good to integrated both interpretations here, for example playing with the critical mass of ice sheets, how a big ice sheet allow to growth sea ice, do we then need the subsurface warming to break that sea ice? Can any of the salt anomalies be related to brine rejection and not to entering of subsurface subtropical derived waters? In general I miss the integration of the nicely presented previous records (MAT-SST, radiolaria and opal for productivity) and I think that the discussion could benefit from some mentioning to those. I suggest a bit more of elaboration on the differences of the events rather than putting them all in the same box.

First of all, thank you for the comments and the suggestion of a table describing the different events. For the IRD events during MIS 21, only the ones at ~ 832 and 828 ka do not show very clear Mg/Ca warming. However, they do show the other features attributed to the general mechanism proposed here: increase in the d18Osw and higher planktonic d13C-smaller planktonic-benthic d13C gradient, which indicate better ventilation at subsurface-intermediate depths. Would the brine rejection favour this better conditions at subsurface? It is a possibility, although we do not have any proxy that may reflect the sea-ice formation and brine rejection. We added this option for events ~ 832 and 828 ka.

We think that including other proxies, especially radiolarians and opal, which are related to productivity, would drift from the main point of the manuscript; subsurface warming.

Comments to the text:

4034: Please note that paleoceanographers have a tendency to use the term AMOC as a synonym of NADW convection. Sensu stricto AMOC refers to latitudinal transports in the Atlantic and there is such latitudinal transport at surface and subsurface (northward) and at depth (southward), being both connected. In this regard it is contradictory to say (4034-10) "enhanced northward transport of subsurface waters in periods of reduced AMOC". You probably mean here periods of reduce NADW/NAIW (NCW) formation. If this is the case, I have difficulties understanding the mechanism that would lead to increase transport of subsurface waters to the north; to my understanding the more NADW convection, the more feeding waters are needed to be transported to the north and subsequently sunk. To me it would make more sense to think that the warm, salty subsurface waters accumulate below the sea ice because they do not sink as NCW (and it is not necessary that more volume is transported). Idem for 4041-17,18

Yes, we agree that there is a period of reduced NADW formation, as we indicate in 4041, due to the increased sea-ice and insulation of surface ocean. Afterwards, are changes in the AMOC that control the events. According to Shaffer et al. (2004) some heat is transported by weak circulation, creating a growing temperature inversion in the northern North Atlantic '; and Mignot (2007) links subsurface warming to a intermediate convection in high latitudes; keeping an weak AMOC and transport warm and salty waters northwards. This situation is what we described in the discussion: shutdown of the NADW, shoaling of convection to intermediate depths and more GNAIW, keeping AMOC transporting warm subsurface waters to the north, that accumulate below ice-sheets. In summary, we think that using the term AMOC it is right. Maybe the words enhanced and reduced in the same sentence can look contradictory (4034-10), so we have changed them.

4036-10, I think that 200 m is the top of the thermocline and not the base (which is at some 1000 m according to your figure 1). Please rephrase.

Yes, it is upper thermocline

4037-25. Idem, according to figure 1 N. pachy inhabits (200 m), the upper thermocline.

4037-27. at the upper thermocline

Same

4041-14. Sensu stricto you cannot speak here of intermediate waters because your Dd13C gradient is between subsurface (ca 200 m) and deep waters and not between intermediate and deep waters. Please rephrase.

Typos, minor edits and rewording:

Please remove the spaces in Mg / Ca, i.e. write Mg/Ca throughout.

4034-5/6, rephrase, it is repetitive, for example: We used Mg/Ca-based temperatures of Neogloboquadrina pachyderma sinistral, a deep dwelling planktonic foraminifera, and paired measurements of Mg/Ca-based temperatures and d18O to estimate d18O of sea water at site U1314.

4034-19, spell out MIS in 1st use in abstract and main text

4035-20, symbol in d18O is missing

4037-3, sensu estricto this referencing is not correct because Paillard and Yiou, 1996 do not present Analyseries 2.0 but 1.0, you can circumvent that by saying only using the Analyseries software.

4037-19, southwards

4037-27, phrase does not read correct. Rephrase, for example "on deep dwelling plk foraminifera N. pachy sin. which inhabits and calcifies. . ."

4038-3. Wording. "Around 50-60 well-preserved test of plk foraminifera N. pachy sin. (> 150 micras) were analysed in 542 samples for Mg/Ca ratio following Pena's et al (2005) procedure"

4038-4, I infer that you used N. pachy sin. non encrusted? Please mention, this information is also missing in the 2012 paper and encrusted and non-encrusted may represent different environmental conditions.

4038-16 to 26, is this detailed description necessary? The records are published and the methods described in the original publications. It would be enough with a sentence referring to those publications otherwise it is misleading and it seems that these records are also new here.

We have removed the description of the analyses, referring the original publications. We keep in which species were made the stable isotopes.

4038-28. Reword. Example: Seawater d18O was calculated introducing paired Mg/Cabsed temperatures and calcite d18O in the paleotemperature equation of Shacklenton (1974).

4039-21,22: it is not clear what you mean, since MIS 25 d18Osw increased by 0.5per mil and T by 0.5◦C, towards present?

Rephrased

4039-27: Wording. Shortly after the iceberg discharge started

4040-27. they exhibit?

4043-14,15, wording + please see considerations about AMOC above

Modified

4044-14. Wording, divide sentence.

Caption Figure 2. For c) benthic d13C the reference Hernández-Almeida et al. 2013a (P3) is missing. Both, Hernández-Almeida et al. 2013a (P3) and 2013b (Boreas) are missing in the reference list.

Figure 3. vertical axis:Mg/Ca (a is missing in Ca)

Figure 4. A running mean though the curve would help readers to pick up the general trends. A color shading for either glacial or interglacial times would also be helpful to evaluate whether there are tendencies with G-I cyclicity (this also for figure 2).

Running mean of the gradient between planktonic and benthic d13C in Fig. 4 has been added. The G-I cyclicty is in the top of the plots; a color shading would interfere with the shading of the subrsurface warming events.

Thanks again for the helpful comments and suggestions.

Iván Hernández-Almeida and co-authors