Reply to reviewer #1:

We thank the reviewer for the relevant comments and remarks which we believe considerably improved the quality of the paper. We answered all comments below and we prepared revised version of the manuscript in two supplement files, one file where all modifications (suppressions in red and addings in blue) are shown and a second one without track changes.

General Comments:

1 **Referee:** Considering that the purpose of the Boereboom paper is to assess the source of snow feeding the ice wedges and paleoenvironmental conditions during the formation of ice wedges (I think as it is not clearly stated in the paper), it is unclear how this study contributes to further our understanding of the use of ice wedges for paleoclimate / paleoatmospheric reconstructions in northern Siberia. Especially when a regional summary of paleoclimate / paleoatmospheric reconstructions based on ice wedges that formed in the "Ice Complex" was recently published (Wetterich et al., 2011; this study is not cited in the text).

Response: *We agree, the purpose of the paper needed to be more clearly stated. As stated now in the revised version, it is actually two-folds:* a) to improve our understanding of the imprint of the contrasted Holocene/Pleistocene climatic and environmental conditions on the ice wedge properties and infilling processes using a multiparametric approach and b) to interpret the specific deuterium excess signature of the two ice wedges in terms of potential changes in atmospheric sources *. The introduction has been rewritten to clarify these objectives and the reference to Wetterich et al. 2011 has been added and used.*

2 **Referee:** A general discussion of the results and interpretations of the Boereboom et al. paper to other similar studies performed on ice wedges in northern Siberia and elsewhere in the Arctic would be beneficial (rather than a comparison with glacial firnified/basal ice). For example, the authors compare the ISW-28 "ribbon-like structure" to basal ice formation and ignore previous studies that described the formation of ice-sand wedges (i.e., Romanovsky 1976; Meyer et al., 2002). They also weakly link previous studies of isotope variations in ice wedges in the Ice Complex and underlying units in terms of broader regional paleo-climatic and paleo-atmospheric circulation in northern Siberia.

Response: *The text has been adapted to link this study to other studies on ice wedges properties (e.g. St Jean et al. 2011) and on broader regional paleo-climatic views (e.g. Wetterich et al., 2011); in the introduction and in section 5.2 of the discussion*

Yet, the comparison to basal ice formation for the "ribbon-like" structure has been made because we have not found in the ice wedge (and ice-sand wedge) literature the description of such a specific crystallographic facies. Our approach consists in bringing a "glaciologist point of view" on ice forming at bedrock interfaces to the interpretation of this new facies in terms of geomorphological and environmental conditions of its genesis.

3 **Referee:** The structure of the discussion section needs improvement to achieve the objectives of the study. At the moment, the discussion is divided in three sections that relates to the methods used in the study. The reader has to read the paper in its entirety to understand the direction the authors are trying to reach. For example, they indicate that the ice wedges formed under warm/cold conditions in sub-sections ice crystallography and gases measurements, but it is not until the third sub-sections that they discuss the timing of formation of their ice wedges (Holocene/Pleistocene) and their potential formation by freezing of snowmelt water. In order to achieve the objectives of their study and facilitate the flow of the arguments in the text, the authors should re-organize the discussion: 1)

mechanism of formation of each ice wedges (IW-26; IW- 28; ISW-28) and clearly indicate if the ice wedges and ice-sand wedge formed by snow compaction, vapor-diffusion, freezing of spring snow meltwater; mixture of snow and snow meltwater; 2) sources of snow feeding the ice wedges; 3) occluded gas measurements and its significance; 3) paleo-climatic / paleo-atmospheric reconstruction and regional assessment with other studies in northern Siberia.
Response: *We agree with the referee. We have totally re-organized the discussion section along the lines of the referee's comments: in a first sub-section, we focus on what our multiparametric data set brings to the understanding of the ice wedges genesis and infilling processes and in a second sub-section we discuss the links to the regional paleoclimatic interpretation.*

4 **Referee:** Chronology issues. Are the units A, B, C (ice complex) and D found along the various coastal bluffs in northern Siberia correlated between each other? In the Boereboom study, one ice wedge was sampled from the Late Pleistocene age "Ice Complex" (dated to between 55-28 ka years in Meyer et al. 2002 and between 27.2-14.5 ka BP in Schirmeister et al. 2008) and the second one from the underlying unit A. However, the age of Unit A is not provided in the text. Meyer et al. (2002) reports an age of 200 +/- 3 ka BP for this unit, whereas Schirmeister assigns an age of ca 60 ka BP to Unit A. Knowing the age of Unit C (Ice Complex) and Unit A in this study would greatly improve the scope of the manuscript as it would provide a relative chronological marker when discussing Pleistocene climate variations for the ice wedge (IW-28) and ice-sand wedge (ISW-28) found in Unit A. If the authors can't assign at least a "relative" age to the ice wedges, than the discussion on paleo-climate and paleo-atmospheric reconstruction becomes largely irrelevant because we can't constrain the timing of these changes. This is one of the conclusions of the paper "our ice wedges can be interpreted in terms of contrasting paleoclimatic and paleoenvironmental conditions between the Pleistocene and the Holocene" but we already know that environmental conditions during the Pleistocene were very different than during the Holocene.
Response: *Figure 2 has been modified to include a scheme of the cliff structure and show the precise location of the two ice wedges. Available data on chronology have been added. Information and correlations between stable isotopes in ice wedges studies and the chronology has been added in the Introduction and we believe the 5.2 discussion section has been improved.*

5 **Referee:** Stable O-H isotope and origin of ice wedges. The authors are using stable O-H isotope measurements to identify the source of water and origin of ice wedges. This is of extreme value in an effort to derive a paleo-climatic and paleo-atmospheric record from ice wedges as only those that formed from compaction of snow and that show no isotope fractionation during freezing of liquid water inside the ice wedge can be used. But the origin of the two ice wedges and the ice-sand wedge is not clearly stated in the text. In the ice texture and fabric section, the authors suggest that IW-26 formed from an increase in meltwater, ISW-28 from freezing of liquid water and IW-28 show evidence of freezing by liquid water in the early stage of ice wedge growth. In the gas composition section, they indicate that all three ice wedges formed by meltwater freezing in snow. In the stable O-H isotope section, the authors indicate that IW-26, for which the samples are distributed along a regression slope of 6.6, it formed by freezing of liquid water under warm climate conditions of the Holocene. However, for IW-28 and ISW-28, they do not discuss their mechanism of formation and immediately interpret the results in term of climate and atmospheric changes ("water cycle processes") and "post-depositional processes". The authors should first discuss "initial" depositional process from which IW-28 and ISW-28 formed. They indicate that during formation of ice wedges by freezing of liquid water (snow meltwater) that there is no isotope fractionation (based on the study of Michel, 1982). But, why did IW-26 plot along a freezing slope and not IW-28 and ISW-28? Conversely, the study of Lauriol et al. (1995)

clearly indicate that there is isotope fractionation during formation of ice wedges formed by freezing of liquid water and that the 18O-D composition snow meltwater from which they form is higher than that of the initial snow. This isotope fractionation during freezing of late stage snowmelt water will also cause a reduction in d values. In this case, the 18O and d values in the ice wedges can difficultly be used as climatic and atmospheric proxies. The authors should explain why IW-26 plots along a freezing slope and not IW-28 and ISW-28 (could it be related to: 1) sampling interval in the ice wedges? i.e., if the complete individual ice vein is sampled, than the effect of isotope fractionation during freezing would not be observe as mass balance would be preserved (this was observed in the case of pingo by sampling of yearly growth layers); or 2) freezing conditions during formation of ice wedges?). Only when the authors prove that no isotope fractionation occurred could they discuss past climate records. They might be right, but at the moment, the authors are using a circular argument.

Response: *As stated above, we have re-organized the discussion section in order to first focus on how our multiparametric approach considerably improves our understanding of the contrasted genetic processes of ice wedges infillings between the Pleistocene and the Holocene. We have included in this first section all our detailed argumentation on the isotopic signature, in order to show that melting-refreezing processes cannot have affected significantly the paleoclimatic signature of our ice wedges. We have also made it clearer that the main reason for that is indeed the resolution of the sampling which is of the same order as the size of the annual incrementation of the ice wedge. We have also rewritten our argumentation explaining why small scale melting-refreezing effects or evaporation-sublimation processes might have contributed to a slight decrease of the co-isotopic slope in IW-26. We therefore join in the effort of the very few and very recent papers (2010-2011) following a similar approach, while showing potential discrepancy in the interpretation and adding original data (total gas content, specific textures and fabrics, the ribbon facies...). We also show that the delta-ranges of our two independently dated ice wedges correspond to those of similar ages in Wetterich's review, in which the eligibility of ice wedges as paleoclimatic archives is recognized. We are therefore confident in discussing further our data in the regional paleoclimatic context of the second section of the discussion.*

6 **Referee:** How do the 18O-D compositions of the three ice wedges in this study compare to ice wedges in the Ice Complex (Unit C) and Unit A in other studies? Considering that there is a vast amount of similar studies in northern Siberia, it would be nice to see if paleo-climate and paleo-atmospheric reconstructions from this site is consistent with other regional studies (rather than a comparison with Greenland ice cores).

Response: *The section 5.2 has been adapted and now compares our data to available data from ice wedges coming from the same area and from other regions such as Alaska. The Introduction has also been changed in that respect.*

7 **Referee:** Gas measurements. The authors attribute the CO2-CH4 gas concentration in the ice wedges to microbial activities (methanogenesis under anaerobic conditions). Although it is a possibility, they make a weak case by comparing their occluded gases results to glacial ice rather than to the extensive literature on potential microbial processes in ice wedges. The authors could improve their case by discussing microbial diversity studies from Late Pleistocene age ice wedges (which mainly identified aerobic microbes –i.e., Katayama et al. 2007; Steven et al., 2007; 2008), or the biodiversity of northern Siberian permafrost and cryopegs beneath Unit C (the suite of Gilichinsky et al. papers). They also do not make reference to the study of Lacelle et al. (2011 in EPSL), the only study thus far that combined both microbial diversity and gas measurements to infer microbial activities in ice wedges (and other types of ground ice).

Response: *The discussion about the diversity of the microbial activities in ice wedge is not the main purpose of our study, nevertheless we observe their influence on the gas composition and this is why we are referring our observation to other studies in glaciology (see section 5.1). We have now included the paper by Lacelle et al. 2011 and calculated δ-gas ratios and show these indicate similar processes.*

Specific comments:

8 **Referee:** P.2 Line 19: Can the authors provide details about which aspects of permafrost are changing because not all aspects are changing and the rate of changes is not equal across all permafrost regions.
Response: *This sentence has been deleted in the new version of the Introduction section.*

9 **Referee:** P.2 Line 24: "depth of permafrost table has increased over the last decade". This statement is not true for all continuous permafrost regions. Based on CALM website, an active layer thickness has not been increasing in Arctic Canada and a reduction in active layer has been observed in Scandinavia over the last 5 years. Authors should specify which region they are referring too.
Response: *This sentence has been deleted in the new version of the Introduction section.*

10 **Referee:** P.3 Line 1: Please specify how an increase in liquid water will help to produce more methane in these regions. Rate of methane production is limited by anaerobic conditions.
Response: *This sentence has been deleted in the new version of the Introduction section.*

11 **Referee:** P. 4 Line 24: "IW-28 has been attributed to unit A" What do the authors mean here? Either IW-28 is part of unit A or it is not.
Response: *Figure 2 has been improved showing a schematic of the cliff structure and showing the precise location of the two ice wedges.*

12 **Referee:** P.8 section 4.4. Is it possible for the authors to quantify the amount of organic matter and carbonate in their samples rather than a visual description of bubbly activity (i.e., LOI method).

Response: *As we have now specified in the text more clearly, we cannot provide a better quantification due to the very limited amounts of samples (and therefore sediments) that were available.*

Technical corrections

13 **Referee:** P. 3 Line 3-11: The 9 lines long sentence is incomplete.
Response: *This sentence has been deleted in the new version of the Introduction section.*

14 **Referee:** P.3 Line 12-14: "In this paper, we propose a multi-parameter approach using stable isotope composition, total gas content, gas composition, texture and fabric of two ice wedges from the Laptev Sea coast." This sentence is also incomplete. If you propose a multiparameter approach, you must specify for which purpose. Maybe re-phrase to say that you USE a multi-parameter approach, consisting of stable isotope..., for the study of 2 ice wedges?
Response: *The sentence has been adapted along the lines of the referee.*

15 **Referee:** P.3 Line 25: "outcrop" is the wrong word here. Replace with "coastal bluff"
Response: *It is done.*

16 **Referee:** P.5 Line 9: Insert “are” between analyses derived
Response: *Ok.*

17 **Referee:** P.5 Line 25: Replace “given” with “presented”
Response: *Ok.*

18 **Referee:** P.6 Line 20, Line 24; P.7 Line 2, Line 6: Replace “co-isotope” with “D-18O”
Response: *Ok.*

19 **Referee:** P.6 Line 24-25: The sentence “This distinction : : : two facies” repeats what is mentioned in the previous sentence. Remove this sentence.
Response: *Ok.*

20 **Referee:** P.8 Line 14-15: Replace “values” with “concentration”
Response: *Ok.*

21 **Referee:** P.11 Line 4: Remove “living”
Response: *This sentence has been deleted in the new version.*

22 **Referee:** P.12 Line 4: Replace “are currently not available” with “were not performed” Unless, if these analyses are available now, they could be inserted in the text.
Response: *This sentence has been deleted in the new version.*