Response

We want to thank the three anonymous reviewers for the constructive review. The comments are a great help to improve the manuscript. Below you can find our detailed responses (bold) to the comments:

Anonymous Referee #1

The manuscript extends the Alewell (2011) paper and puts the concept into a geomorphic context. The data and the ideas are original, well-founded and deserve publication and further study. However, some issues are insufficiently explained or discussed and require further attention. Given the knowledge (or at least the specific ideas) about the distribution of the isotopic signature of soil carbon in palsa peatlands in the Abisko region, the hypotheses appear a little timid. As noted in chapter 2, you had more specific ideas about this.

Reply: Thank you, we will take it into consideration and modify it in the revised manuscript.

Why don’t you make chapter 2 a part of the introduction, as the theoretical concept has already presented (as chapter 2) in the Alewell (2011) paper?

Reply: The theoretical concept by Alewell et al. (2011) was refined in this study and adapted to the four investigated sites. We extended the sampling strategy by taking samples in three transects from hummocks and hollows including the degraded sites of hollows and hummocks from three palsa peatlands. So, we think it is better to separate the introduction and the concept in different chapters. The four sites are described in the theoretical concept including a figure illustrating the theoretical concept of this paper this would go beyond the scope of an introduction.

Is the “degradation” of palsa hollows really degradation in the sense soil scientists are using it? From the manuscript, I understand that peat from the edge of the hummock falls into the hollow and accumulates on top of the portion of the hollow adjacent to the hummock. I wouldn’t call that degradation.

Reply: You’re right the degraded hollows are the part where peat from the edge of the hummock falls into the hollow and accumulates. We call it degradation, because the previous soil function, including biogeochemical processes, of the hollows has most likely been changed by the added hummock material. And thus these sites differ from the non-degraded hollows, where no hummock material is accumulated.

Ch. 4.1/4.2: The turning point signal isn’t always clear to me and I have the impression that, at some sampling points, it could be elsewhere. Isn’t it possible to generate some quantitative measures to support your (turning) points?

Reply: The turning points in our study are the lowest measured δ^{13}C values in the profiles with a clear change from increasing values above and decreasing values below the turning point. We used

the same statistical test we did in the first paper. The regression analyses give us in numerous profiles a significant relationship between the $\delta^{13}C$ values and depth. Additionally, the coefficients of determination are in some profiles primarily high in the upper as well as the deeper parts of the hummock profiles.

Ch. 4.2, last paragraph: Why is the C-N ratio in more strongly decomposed peat lower? Given the low recalcitrance of many N compounds, shouldn't it be higher? Couldn't the high N content be a sign of lateral N import?

Reply: Various studies have shown that the C/N ratio is lower in more strongly decomposed peat (e.g. Malmer and Holm, 1984; Kuhry and Vitt, 1996), because nitrogen is relative enriched compared to carbon. In N limited ecosystems, such as peatlands, decomposition leads to a relative higher loss of C compared to N, because organism respiring organic substances will retain the N in the systems.

Ch. 4.3/4.4: The C-N-ratio appears to be lower in the degraded hollows compared to the non-degraded hollows. Is that so? If yes, what could that mean?

Reply: This is a good point. Several degraded hollow profiles show low C/N ratios of about 20. In general, the non-degraded hollows show higher C/N ratios indicating that the peat material is less decomposed. Lower C/N ratio in degraded hollows compared to non-degraded hollows would indicate that the decomposition processes in the degraded hollows are higher, potentially because of the added hummock material (see previous comment and answer).

P 1384, L 26: Join the two sentences: ". . .Jungkunst et al., 2012), so this region contains. . ."

Reply: Yes, done

P 1392, L 23: ". . .in more strongly decomposed soil. . ."

Reply: Insert

P 1392, L 24: "favour", not "favours"

Reply: Changed

P 1394, L 10: "significantly", not "significant"

Reply: Changed

Anonymous Referee #2

general comments:

According to introduction MS by Kruger et al. "Degradation changes stable carbon isotope depth profiles in palsa peatlands" deals with arctic climate change, on geo-graphical area being threatened by climate change bringing changes to basics factors of palsa existence and also making changes to storage pattern of 270 Pg of carbon sequestered in northern permafrost zone. δ13C values of peat are used to evaluate degradation in hummocs and hollows of palsa peatlands in Abisko in discontinuous permafrost area, in Northern Sweden. The difference there being preferential release of 12C during aerobic mineralization leading to enrichment of 13C values and anaerobic mineralization keeping 13C intact or decreasing it. And thus accelerated permafrost thawing (degradation of peatland surfaces) can be identified by δ13C values of peat depth profiles. Introduction gives impression that we are dealing with current climate change, but what I rather see is normal palsa processes, since changes in bulk C isotopes collected in 40 mm resolution can not follow current processes. So, this is showing the situation just now, which might be changing in future due to warming climate also in regard of peat stable isotopic composition. Change is already seen from annual increasing depth of active layer depth measured by steel rod (price ∼ 100 €, but not with IRMS (price 200k€. This MS is interesting visualization of palsa and its surrounding lawn. However, results and discussion show that current climate change is not seen from stable isotopes of peat, since the change, indicated as turning point, was happening 100 or 800 years before present. And it is unclear was it then due to natural ageing of palsas or some other phenomen. This MS is a sister article to "Stable carbon isotopes as indicators for environmental change in palsa peats by Alewell et al. 2011, (Biogeosciences, 8, 1769-1778). In this MS sampling was done in Sept. 2012 from same area, but from three location. Also there theoretical depth profiles of δ C values and turning point was discussed, so I can't find much new in this MS in its current form.

Reply: Our manuscript is dealing with stable isotopes as indicator of palsa degradation and it was hypothesised, that degraded and non-degraded site will differ in their isotope depth profile due to different decomposition processes. We agree that the process of palsa degradation is a natural ageing process, but it is accelerated due to the increasing active layer depth by raising air temperatures due to climate change in this region. The increasing depth of the active layer could be measured with steel rod, but we could show, that the decomposition process changed from anaerobic to aerobic in the hummock profiles which is supported by the change in the C/N ratios, indicating the uplifting of the hummock material by permafrost. This could not be seen with the steel rod only. Moreover, stable isotope measurements integrate processes over longer period of time whereas direct measurements of the active layer depths provide snapshots only. Additionally, we found that the degradation of the hummocks influences the adjacent hollows which could increase the degradation rates by the eroded material in the hollows. In comparison to the Alewell et al. (2011) article, we extended the sampling strategy, by taking samples in three transects from hummocks and hollows including the degraded sites of hollows and hummocks from three palsa peatlands. Additionally, we refine the theoretical concept of Alewell et al. (2011) to our four sites. Furthermore, we took 36 cores from four different sites in three peatlands compared to eight cores from two sites in two peatlands in Alewell et al. (2011).

Specific comments

I think that palsa peatlands are connected here too tightly to permafrost areas: (Row 7 p.1385). Luoto and Seppälä (2003) is dealing with Finnish Lapland, which is – to my knowledge - not permafrost region, permafrost is found only inside palsas in there. Furthermore: “Palsas are mounds with a permafrost core covered by peat located at the outer margin of the permafrost zone in Fronzek, 2014: (Climate change and the future distribution of palsa mires: ensemble modelling, probabilities and uncertainties (Monographs of the Boreal Environmental Research No. 44).

Reply: Yes, thank you we inserted “discontinuous”, new sentence: “… to climate conditions in the discontinuous permafrost region …”. The study sites in the paper by Luoto and Seppälä (2003) is placed in the discontinuous permafrost zone in the northern part of Finnish Lapland. Our study was also done in the discontinuous permafrost region (Åkerman and Johansson, 2008) where palsa peatlands are widespread, too (Malmer et al., 2005; Olefeldt et al., 2012).

Repo et al. 2009 may be replaced (or added) by Marushchak (2011), since there peats that are uplifted by frost (palsas and peat plateaus) are measured and described instead of peatlands only in permafrost area and besides northern Russia also from northern-Finland in quite similar climate as that in Abisko: Marushchak M.E., Pitkämäki A., Koponen H., Biasi C., Seppälä M. and Martikainen PJ. (2011) Hot spots for nitrous oxide emissions found in different types of permafrost peatlands. Global Change Biology 17: 2601-2614.

Reply: We will add Marushchak et al. (2011) to the revised manuscript.

Methods seem to be OK for isotope analyzes, but since C/N ratio is expressed, it will be nice to know how C% and N % were measured and standardized to get C/N ratio.

Reply: C and N content as well as the stable carbon isotopes were measured with a mass spectrometer (Thermo Finnigan Delta plus XP coupled with a Flash EA 1112 Series elemental analyser; both instruments supplied by Thermo-Finnigan, Waltham, MA, USA). The C/N ratio represents the atomic relationship between carbon and nitrogen content of the peat material. Information will be added to the revision.

Results: I am not sure about this, but if precision is expressed to be better than ± 0.5‰ is it then better to express results rounded to only one digit?

Reply: The precision of replicates from the same soil core are better than ± 0.5‰ representing the heterogeneity of peat. The instrumental standard deviation of the mass spectrometer (Thermo Finnigan Delta plus XP coupled with a Flash EA 1112 Series elemental analyser; both instruments supplied by Thermo-Finnigan, Waltham, MA, USA) for $\delta^{13}C$ is 0.1%. So we think the values could be expressed with one decimal place. We will change all $\delta^{13}C$ values in the text and tables to one decimal place.

Turning point timing ranges from 120 yr to 800 yr. in same area, according to authors indicating that degradation started then since peat got then to dryer conditions when it was lifted from anaerobic conditions to aerobic ones. This might rise question of Suess effect, since peat is this old.

Reply: This is a good point. We think the Suess effect played a minor role in the palsa peat profiles, because the turning points are much older and it will only be documented in the upper centimeter of the profile (Alewell et al., 2011). Suess effect is documented for the last approximately 50-100 years and is thus much younger than our turning points. The increase of $\delta^{13}C$ with depth is comparable to well drained soils where aerobic decomposition selective loss of ^{12}C (Nadelhoffer and Fry, 1988).

The C/N ratios is often used in soil literature and peat and sediment profile studies, but would it be better to have (also) values for both C% and N% separately mentioned (at least for some points) to get impression of real amounts especially in articles dealing with biogeochemical processes? Knowing N% and C% gives more information about what might be happening in future with these C and N stores.

Reply: Yes, we agree. We will add a supplementary table with C% and N% data for all sites and depth profiles if the editor agrees. In general the C content is between 45.0 and 50.0 % and the N content between 0.1 and 3.0 % as typical for peat soils.

p. 1393, r. 25. This gets rather speculative: when no change in stable isotope values is detected even there is visible changes in peat, then this shows that there is not yet any changes in stable isotopic composition of peat?

Reply: These palsas are recently degraded and because of that the degradation is not yet imprinted in the stable isotope depth profiles of bulk organic substances. Previous studies (Klaminder et al., 2008; Alewell et al., 2011) found low or no degradation at the Storflaket peatland, whereas we found some visible degradation at the margins of this palsa peatland.

Table 1. Age of turning point seems to be calculated straight from depth divided by accumulation rate, except in Stordalen, where deeper point is younger with same accumulation rate, or then rows have been mixed here.

Reply: Yes, thank you for the comment. Ages of turning points were calculated based on the accumulation rates from Alewell et al. (2011). In Table 1 at the Stordalen site the depths were swapped, so we change SDhu 2 from 5.52 cm to 6.32 cm and SDhu 3 from 6.32 cm to 5.52 cm. Thank you for pointing that out.

In table 3, same method to calculate age is used, even they are then degraded hummocs, which may not be accumulating carbon any more? Could these data be combined to one table?

Reply: Yes, we agree with reviewer 2 and we will combine the two tables to one. The table with the degraded hummocks shows that in some of the degraded profiles still the turning point is pictured and the stable isotope depth profile is not mixed to a uniform or zigzag depth pattern until now. In some profiles the turning point is still present, but in most of the degraded hummocks the depth pattern was changed due to the degradation.

Fig. 2. Transect schematics figure is vital, before it I did not understand the site selection. However, naming rim of palsa as degraded hollow is misleading to me. Would pair for this be rather a hollow near not degraded palsa? This part is in any case (degraded or not) the point, where snow accumulates keeping rim warmer, also nutrients and water from palsa drain there. And it is differed from hollow further from palsas, where palsa is not giving its shelter and nutrients.

Reply: We selected the sites by clear visual impressions. Degraded hummocks have still the hummock vegetation (dwarf shrub and lichen), but it is subsided and/or eroded at the edge of the palsas. Therefore, the degraded hummocks are water saturated and show cracks and block erosion and are usually on the margin of the hummock plateau or the dome shaped hummocks. The degraded hollows have distinct hollow vegetation (sphagnum and carex) but are influenced by the eroded hummock material from the palsas.

Fig 3.4, 5 and 6. Figure sets of all measured data (36 times d13C and C/N ratio from profiles) is heavy. I don't know is there any other solution to this. Alewell et al. 2011 combined three measurement to one figure, would it help? In figures δ13C is only in two cases of 36 heavier than -24 ‰ but still all figure scales are same and starting from -20‰. However scale is changing in C/N ratios, so why not here? Furthermore figures could be combined and made bigger to panels by not repeating titles.

Reply: We decided to show the results of $\delta^{13}C$ and C/N ratio depth profiles as a single numbers as part of an aggregated figure, because than it is easier to read and the relationship between $\delta^{13}C$ and C/N ratios is clearer. More than two figures have samples with values heavier than -24.0 ‰, so we will maintain the figure scales. Only at some hollows in the figure the C/N ratio scale is higher than 100. Our focus is on $\delta^{13}C$ depth profiles so we decided to maintain the $\delta^{13}C$ scales and only change the C/N ratio scale were it is necessary to preserve good legibility and comparability. We will keep the figures separate, but will not repeat the titles.

technical corrections p. 1388, row 5. cycle -> circle

Reply: Changed

Anonymous Referee #3

General Comments Palsa peats are reservoirs of large amounts of organic carbon vulnerable to climate change. The present paper is a follow up study of Alewell et al. 2011, presenting a similar set of data and supporting most of the conclusions of the 2011 study. The two sampling sites of 2011 were re-visited and another site was included in the current study. However, the authors included degraded hummocks and hollows in the current analysis to evaluate stable carbon isotope depth profiles as indicators of aerobic and anaerobic degradation as well as peat uplifting. Thus, the current study is not without merit and has some novelty. The manuscript is well structured and easy to follow.

Specific comments

Issues/Questions The material and methods section lack details on the statistical analyses that were applied and lacks a rational on the choice of analyses. It remains unclear whether the data followed a normal distribution. Please include such information.

Reply: Yes, thank you for the suggestion. The relationship between $\delta^{13}C$ and depth was analysed with a linear regression in the software R2.15.1. The data are not normal distribution and we changed the correlation analyses. We used now a Spearman correlation for the relationship between $\delta^{13}C$ and C/N ratio.

One point that needs clarification is, why methanogenic degradation is considered as a prerequisite for unchanged isotopic signature of peat in greater depths.

Reply: This is a good point. Several studies (e.g. Clymo and Bryant, 2008) found uniform depth trends of $\delta^{13}C$ in water saturated soils with no fractionation. In peatland soils where methane could be produced the opposite fractionation effects of CO_2 and CH_4 production resulted in a uniform depth trend of $\delta^{13}C$ values (Clymo and Bryant, 2008). Another possibility is that the $\delta^{13}C$ values of the source material (vegetation) have been preserved due to anoxic conditions in the peat and no isotopic fractionation occurred.

Technical Corrections

P1386L26 Typo. Be rather than by.

Reply: Changed

P1390L7 For how long were samples transported? Were the samples cooled and oxygen penetration to deeper peat layers minimized by the “wrapping method”?

Reply: After taken the samples in the palsa peatlands they were transported directly to the lab, where they were cut into slices and dried at 40-50°C for 72h in an oven. The procedure was done at the day of sampling. Samples were transported and stored until preparing for drying at air temperature (average of 3°C in Oct. in Abisko). Oxygen penetration could not be prevented due to

wrapping samples in plastic foil, but peat was dried directly after sampling, as mentioned above. Sorry for not mentioned this, we will add the information in the revised version.

L1396 Typo. Surplus “s” of hummocks.

Reply: Done

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