Original comments are given in black, our reply is given in red.

The manuscript by Roth et al. describes the impact on atmospheric CO2, 13C and nutrients distribution of a deepening of the Particulate Organic Matter (POM) remineralization depth.100 kyr long sensitivity experiments are performed with an Earth System Model of Intermediate complexity, which also includes a sediment model. It has been previously suggested that a deepening of POM remineralization during glacial times could have played a role in decreasing atmospheric CO2 (Matsumoto 2007, Matsumoto et al. 2007, Kwon et al. 2009, Menviel et al. 2012 and Chikamoto et al. 2012). This study is thus relevant to understand glacial/interglacial changes in the carbon cycle and I recommend its publication in ESD with minor revisions.

We thank the reviewer for his valuable comments that helped to improve the manuscripts and for his time and effort to review this manuscript.

1) Introdution:

In general I find the Introduction a little messy with some inaccuracy and redundancies. Some specific examples include:

a) the latest references have been chosen to illustrate the hypotheses brought forward to discuss glacial changes in pCO2 whereas I think that it might make more sense to cite the original reference. For example, even if Volker and Kolher 2013 paper is very interesting I think it makes more sense to cite Toggweiler et al. 2006.

Done. Siegenthaler and Wenk (1984) is cited as an early paper on the role of ocean circulation for atm. CO_2. In addition we refer the reader now explicitly to available reviews by modifying the text to read: (see reviews by Sigman and Boyle, 2000; Archer et al., 2000; Sigman et al., 2010; Fischer et al., 2010). It is beyond the scope of this MS to provide a comprehensive review and to cite all important papers on this subject of the last years.

b) Please do not only quote the abstract of Kwon et al. 2009, but instead it might more relevant to say that a 24m increase in the efolding depth of the POM remineralization leads to a 10ppmv decrease. The 27 ppmv is obtained when export production is kept constant.

Done. Text modified to read: "Kwon et al. (2009) simulate a CO_2 drawdown by 10 and 27 ppm for an increase in the e-folding depth of POM remineralisation of 24 m in their nutrient-restoring and constant export-production model setups."

c) the impact of changes in viscosity on the speed of temperature (Taucher et al. 2014) is discussed both on lines 14 and 28 of p475.

Done. Text clarified. The mechanism is generally discussed on lines 10 to 21 in the original MS, while quantitative results obtained for the different studies are given on

line 21 ff, An new paragraph is started on line 21 and text on line 21ff of the original MS is modified to read: "The mechanism of a deepening of the POM remineralisation has been discussed and quantified in several studies…"

d) A little more information on Menviel et al. 2012 study in the introduction would be relevant. For example that a progressive increase of the POM and DOM remineralization depth over the glaciation led to a 31 ppmv pCO_2 decrease, while the increase back to initial condition during the deglaciation led to a 21 ppmv increase, thus suggesting that ocean-sediment interactions could play a role in amplifying the pCO_2 decrease and thus motivated the present study.

Done. Text modified to read: "Menviel et al. (2012) performed transient model simulations over the last glacial cycle with the Bern3D model applying a temperature-dependent remineralisation rate. They simulated a 31 ppm decrease in atmospheric CO_2 for a progressive increase of the POM and DOM remineralization depth over the glaciation, while CO_2 increased by 21 ppm due to altered remineralization over the deglaciation. This suggests that ocean-sediment interactions may contribute to the reconstructed atmospheric CO_2 variations, motivating the present study."

e) At the end of the introduction L14-18, I am not sure I agree with "previous estimates...underestimate the long term feedback". I would suggest to rephrase that sentence as either long previous studies could not study that feedback due to their model/experiment set up or they did point out that on timescales greater than 10kyr ocean sediment interactions could amplify the signal.

Done. Text modified to read: "We show that previous estimates of the sensitivity of POM remineralisation rate changes are not applicable for glacial-interglacial time scales as they do not include the long-term feedback, but point to a potential importance of this mechanism to explain low-frequency CO_2 and $^{13}CO_2$ variations."

2) Experiments:

This section needs some revision. The "closed system" set up might need some more explanation: usually in a closed system the riverine input balances the burial of organic matter and/or $CaCO_3$. Apparently here another method is used, indicating that the sediment model has been disabled, therefore there is no burial. Also I don't see how that is similar to "Kwon et al. 2009" as they use in their experiments "surface nutrient restoring" or "constant export".

Done. Sentence referring to Kwon et al. deleted and text defining "closed system" modified to read: "We also run the system in an atmosphere-ocean only setup without sediment and no river input and burial, referred-to as 'closed system'."

L 2, p483. Please rephrase as "Our discussion mainly focuses on ..."

Done. Text modified as suggested.

L.5-6, p483, please rephrase.

We restrict our analysis to idealized changes in in the remineralisation length scale (parameter α and l_{POM}) as the relationship between remineralisation and temperature changes is not well understood."

3) Icalc:
Experiments in which Icalc is changed are not described at all in the experiments section.

This is not true. The first sentence in section 2.4 reads: "Sensitivity experiments are performed where l_{POM} (or equivalently α) and/or l_{calc} are changed in a step-wise manner." In response to the comment we added a reference to equation 6 to point explicitly to the link between l_{calc} and the flux of calcium carbonate particles. We also modified the text before eq. 6 to read: "The downward flux of calcite (including other forms of calcium carbonate such aragonite or high-magnesium calcite particles) F_{calc} decreases exponentially with depth with a length scale l_{calc}"

It is as cryptic in most of section 3.2. as it is not mentioned in the text by how much Icalc is changed or any specificity. One has to wait until the end of paragraph 3.2. to get an example on what has been changed. Figure 10, where the Icalc results are shown is only discussed in the following paragraph.

Done. The first paragraphs of section 3.2 were modified and the text reads now:

 "It has been suggested that changes in the rate of $CaCO_3$ dissolution in the upper ocean will be a significant feedback affecting atmospheric CO_2 concentrations and future climatic changes (e.g. Barett et al., 2014). To this end, we prescribe in a further set of sensitivity simulations a step change in the e-folding dissolution length scale l_{calc} governing the dissolution profile of $CaCO_3$ particles within the water column (see eq. 6). l_{calc} is changed at the end of the spin up from its standard value of 2900 m to values ranging from 2100 to 3700 m; then the run is continued for another 50,000 years with the new value of l_{calc}. Export fluxes both of POC and calcite remain constant as changes in the dissolution of calcite do not affect productivity in our model.

The experimental setup with the assumption of an e-folding remineralisation profile for calcium carbonate particles (Eq. 6) is highly idealised. The mechanisms for the dissolution of calcite and other forms of $CaCO_3$ (e.g. aragonite or high-magnesium calcite) within the water column are quantitatively not well understood. Generally, dissolution of $CaCO_3$ particles within the water column is thought to be linked to low (undersaturated) concentration of carbonate ions in the surrounding water. However, considerable $CaCO_3$ dissolution may occur in the upper ocean (Berelson, 2007) in waters that are saturated with respect to $CaCO_3$ in the mineral form of calcite or even of aragonite, perhaps due ..
.. .. The results for these additional sensitivity experiments are as follows. … "

4) EOF:
EOF are a useful statistical method to highlight modes of variations and is widely used in oceanography, meteorology... Here the authors spend some time explaining

the method in section 2 and mention their EOF a little bit everywhere (abstract, introduction, section 3.1). While I have no doubt that EOF can be very useful I am a little bit more skeptical about their use here. Moreover because the 2nd EOF explains only 0.27% of the variance. Technically one would say that the 2nd EOF is not significant. A deepening of the POM remineralization leads to a DIC increase at depth, while the alkalinity might be little affected at first. This thus induces a decrease in deep [CO3] and eventually dissolution
of CaCO3. Deep [CO3] thus increases again. So basically it seems that the 2nd EOF is showing this initial deep [CO3] decrease. If the only thing you want to show by using the EOF is that deep [CO3] first decreases before increasing, there might be an easier and cleaner way to do that than using the EOF. I would thus suggest taking out all that is related to the EOF in the paper. For example I think that the "closed system" experiments provide all you need to make the point. I would first suggest to add the evolution of POM export, calcite export... for the closed system in Figure 3. Then you could add in the text that the experiments in
the "open system" follow the ones of the "closed system" for a few thousand years after which ocean-sediment interactions start to play a significant role. Another way would be to make Hovmoller diagram as the one shown in Fig8b.

We agree with the reviewer's suggestion and removed the EOF-related text and figure from the MS.

5) C13:
L2, p 491, I would avoid "isotopically enriched calcite".

Done. Sentence modified to read: "Similarly, burial of calcite, a flux which is isotopically enriched compared to the POM and the total burial flux (POM and calcite), is reduced …"

And I doubt this has a significant effect on deep d13C.

The statement by the reviewer is not correct.

The isotopic signature of calcite particles is with 3 ‰ very similar to that of DIC (~0 ‰). Changes in the calcite cycle within the ocean (closed system) do hardly modify the ^{13}C signature of DIC and atmospheric CO_2. On the other hand, the calcite burial flux is isotopically enriched by about 15 ‰ relative to the total carbon burial/weathering flux. The δ^{13}C difference between calcite burial flux and weathering input flux is (on absolute terms) with 15 ‰ even twice as large than the difference of 7 ‰ between the POM burial flux and the weathering input. Thus, changes in calcite burial do affect ^{13}C signatures.

The text has been modified to clarify this point:
"(i) The excess burial of isotopically light POC (δ^{13}C ~ -20‰) during the first 50 kyr tends to increase the average δ^{13}C signature in the ocean-atmosphere system; the δ^{13}C signature of the POC burial flux is with -20‰ about 7‰ lower than the signature of the total carbon weathering/burial flux (-12.6‰). (ii) Similarly, burial of isotopically enriched calcite (δ^{13}C ~ 3‰) is reduced (relative to initial conditions and the weathering flux) during the first 100 kyr; this tends to increase d^{13}C during this period; the calcite burial flux is enriched by about 15‰ compared to the average signature of the weathering/burial flux.

Additionally the changes in d13C simulated are fairly small.

Simulated changes are order 0.1‰ in the ocean and atmosphere for an increase in the POM remineralisation length scale from 250 to 275 m. This may be compared with LGM-Holocene variations in whole ocean and atmospheric d13C of order 0.3 ‰ and an LGM-late Holocene difference of about 0.1‰ (Schmitt et al, 2012.)

I am quite surprised by the fact that the simulations do not reach an equilibrium after 200ky.

This fact is indeed interesting and mainly results from the CO_2-dependent fractionation during photosynthesis. The reasons for the long timescales are discussed in the MS starting from L26, p491.

6) Conclusions: L 21, p497: Deep Atlantic Cd/Ca content was increased during the LGM indicating a greater deep [PO4] content.

Done. We agree- thank you. Text clarified to read: "As deep glacial Cd/Ca ratio in the North Pacific, .."

L25p 497: " a 25m increase in the efolding..."

Done. Typo corrected.

There are some typos throughout the text. Some examples: L3, p479 : "calcifier" iof "calcifer".
L 28, p 481 "so" is missing.
L16, p483 "induced".
L 16, p 488 " As a result".
L8, p 495, "the experiments".
L 14, p 495 "fixed".

Thank you. Typos corrected.

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