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Biogeosciences Discussions

Interactive comment on "Effects of soil rewetting and thawing on soil gas fluxes: a review of current literature and suggestions for future research" *by* D.-G. Kim et al.

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Dear Referee Dr. Ana Rey:

First of all, we authors appreciate your insightful comments and suggestion on the manuscript bg-2011-222.

In this response letter, at first we described major additions and changes in the revised manuscript and then we responded to each of comments and suggestions addressed by you and two other referees.

First, there are new additions in the revised manuscript as following: 1. Rate of soil

flux change following rewetting and thawing events by ecosystems types; Table 2 and relevant texts were inserted.

2. Section '3.6 Overall change of gases fluxes following rewetting and thawing' was removed. On the other hand, section '4. Effects of rewetting and thawing on soil gas fluxes: compiled dataset analysis' was added. The section 4 includes two new findings and relevant discussion with two new figures and two new tables as following:

a. Pre-change flux versus flux change by gas type and event type (rewetting and thawing); Figure 5, Table 4 and respective discussion in the manuscript.

b. Mean annual temperature versus flux change, by gas and event type; Figure 6, Table 5 and respective discussion in the manuscript

3. Number of studies used for the analyses in this study: Table 1 and 3, texts in section '2 Methodology'

4. Importance of NO and NH3 gas fluxes in addition to greenhouse gas CO2, CH4 and N2O; Introduction section

5. A figure showing soil CO2 flux increase following rewetting change observed with high temporal resolution measurements in the field; now Figure 2

6. Conclusion section was revised (i.e., including new results)

7. References: references were added as suggested by reviewers and recently published studies

Second, there are substantial changes in the revised manuscript as following:

1. Detail description on uncertainties of CO2 and N2O fluxes in section 5.1 and 5.2 were moved to relevant places in section 3.

2. Previous sections 5.1 and 5.2 were merged with section '5.1. Uncertainties in understanding the responses and mechanisms' and revised throughout the section.

3. Mechanisms were distinguished between biological and physical in section 3.

4. Section '5 A Blog for open discussion and web based open databases' was shortened and moved to 'Supplementary information'.

Finally, we acknowledged three reviewers' constructive and valuable comments in the 'Acknowledgments' section.

We responded to each of your comments and suggestions as following:

The manuscript needs further improvement and deeper analyses of the studies presented to produce more general results exploiting such a large database. In particular, I think that some parts are very descriptive and detailed (in particular the section 3) and others too general (uncertainties and conclusions). The conclusions reached could be more specific to the analyses done on the studies considered (although it is not clear whether such analysis have actually been done) with more general conclusions about different ecosystem types, vegetation types, timing and intensity of events, etc.

Response: We appreciate the comments and suggestions. We have revised the paper according with the comments and we have done the best we could in addressing them. We added new results from the database analyses in section 3 and 4 and also we revised conclusion adding general summary of the new results.

The methods should be explained in more detail to understand whether the comparison between the responses of different gases, different ecosystems, etc, has been done and how (see below). The description of the experiments included in this review is not sufficiently presented. As explained below the abstract could be improved in some parts. Thus, I think that the manuscript could be improved considerably. My main general concern is that I think that the review is rather descriptive and much more information and conclusions could be drawn from the studies considered. Since a large number of studies have been gathered, I wonder whether it could be possible to analyse the data by vegetation type (grasslands, croplands, forests, savannahs

and deserts etc.), ecosystem type (arid, temperate, tropical, boreal, etc.), etc. as the response will clearly differ among them and may help explaining observed patterns. Instead of describing individual studies in such detail, it would be much more interesting to the reader and it would make a much more interesting review on the topic, if the authors presented the results in a more general manner by drawing conclusions of the different studies by vegetation type, ecosystem type, type of experiment, etc.

Response: Through analysing collected data further more, we added 1) rate of soil flux change following rewetting and thawing events by ecosystems types, 2) Pre-change flux versus flux change by gas and rewetting or thawing, 3) Mean annual temperature versus flux change, by gas and rewetting or thawing. We also added description of the experiments (data used for the analyses) through out the manuscript.

Other aspects most relevant for the response, such as duration of the drought prior to rewetting, thawing, intensity of the event, etc, could also be analysed and prove very useful for a more general but thorough discussion on the mechanism behind the observed responses or trends. As stated in the Abstract, the database revealed conflicting results but the explanations behind are not properly addressed and the analyses suggested may help elucidate whether such conflicting results may be clarified.

Response: We have conducted various statistical analyses to find out more useful information from the collected database including testing relation between gas flux response and environmental variables such as duration of the drought prior to rewetting, thawing and intensity of the event as the reviewer suggested. Through analysing collected data further more, we found some results regarding 1) rate of soil flux change following rewetting and thawing events by ecosystems types, 2) Pre-change flux versus flux change by gas and rewetting or thawing, 3) Mean annual temperature versus flux change, by gas and rewetting or thawing. Unfortunately, we were not able to find meaningful information to address the conflict results. We addressed the issues in the section 5 Knowledge gaps and future directions and encouraged further studies.

Meanwhile, mechanisms could be separated more clearly into biological and physical processes mediating the observed responses.

Response: We appreciate the comments and we revised them to separate biological and physical processes.

Abstract

- The abstract states that the analyses done revealed conflicting results ranging from large increases in gas fluxes to no responses. The following sentence states the main conclusions of the review is that the responses follow a power function with no significant differences among gases. This may seem contradictory and in any case not clear enough.

Response: We removed the result regarding a power function with no significant differences among gases.

- The "database" and the "published field studies" do not refer to the same thing? Are the published field studies part of the complete database? Are the results only applicable to field studies? What about the lab studies? Figure 3 shows both field and laboratory experiments.

Response: We removed the figure and relevant texts.

- Apart from that minor thing of the wording, the concern refers to the main conclusion of the study: (1) that the response to rewetting/thawing is the same, an increase described by a power function (not linear), and (2) that the response is the same for all gases considered. With regard to the first conclusion, it is not clear how it has been tested. As for the second conclusion, it is not clear whether the response is observed because all gases were plotted together with higher fluxes for CO2 and N2O and smaller fluxes of the other gases. Is the power function applicable for each individual gas?. In that case, are all individual gas curves the same? And therefore, the second conclusion stands, otherwise, it is not correct to assert that there were no

significant differences between gases.

Response: We removed the result and figure regarding a power function with no significant differences among gases.

- The relevance of these major results and the mechanisms behind are not really discussed, but instead the individual mechanisms of each gas.

Response: As we mentioned in Introduction, one of objectives is to discuss the potential underlying mechanisms and drivers of variation of soil gas fluxes following rewetting and thawing. Through analyzing the collected database, we added several new results that provide meaningful information to improve our understanding on soil gas fluxes following rewetting and thawing.

- Another important outcome of the study stated in the abstract is the importance of temporal resolution in order to capture the responses of gas fluxes since the responses are often transient and disappear after a few days. However, it is not clear whether this conclusion has been drawn from the studies analysed here altogether, or from the individual studies. One of the main conclusions of the literature review (although it is not clear if that is what they have found) and thus a consideration for future research, is the need for a more intensive temporal sampling in order to properly estimate the relevance and contribution of the observed responses to the total annual gas budgets.

Response: The importance of temporal resolution of measurements has been addressed by some studies and also the result of this review (i.e., increased soil gas flux after rewetting and thawing in short-term (ca. 6–24 h) but substantial effect on annual budgets) supports it.

- A very important point highlighted at the end of the abstract but that I feel it has not been properly addressed in the text, is the need to separate clearly biological from physical responses, as they are controlled by different drivers.

Response: The mechanisms were distinguished biological and physical ones in section

3.

- A sentence to end the abstract with the major conclusions for future research directions would be desirable.

Response: We appreciated the comment but due to word limit in the abstract we felt it is difficult to add further remarks in addition to current ending statement as below:

“Finally, we propose that future studies should investigate the interactions between biological (i.e. microbial community and gas production) and physical (i.e. flux, diffusion, dissolution) changes in soil gas fluxes, and explore synergistic experimental and modelling approaches.”

Introduction

- Very good introduction. Only some minor comments. First, in page 9850 line 5 it is stated that sudden flushes of water and nutrient that occur upon rewetting and thawing lead to major changes in plant and microbial activity. However, I think this depends very much on the intensity and timing of the rainfall event (in the case of rewetting) as sometimes rainfall events large enough to activate microbial communities are not enough to trigger plant activity. Therefore, the sentence should be rephrased.

Response: We revised the sentence as: The sudden flush of water and nutrients that occurs after rewetting and thawing induce changes in plant and microbial activity, with organisms shifting rapidly from dormant or senescent states to active ones (Kieft et al., 1987; Schimel and Clein, 1996; Kemmitt et al., 2008).

- In paragraph 25 a very important point is discussed, the contribution of such responses to the total gas balance at annual scale. Jarvis et al. 2007 quantified the importance of such losses at ecosystem scale in several Mediterranean ecosystems. Some other studies missing are: Harper et al. 2005, Rey et al. 2005 who carried out specific studies on rewetting. These references should be included. Meanwhile, the phenomenon of an increase in fluxes upon rewetting is well known and was first

described by Birch who has not been cited.

Response: We added Birch (1958) and Jarvis et al. (2007)

Throughout the manuscript, due to concern on the length of the manuscript and easy reading we minimized the number of references cited in the texts just in case if the references are clearly recorded in the database. Readers can easily find out relevant references in the database. We also apologized for the authors whose work has not been cited in section Acknowledgement.

- Throughout the text when the authors write “response” do they mean increase?

Response: We have included the text “We define response as the behaviour or reaction of the different soil gas fluxes that result from rewetting or thawing of soils. The responses may vary in intensity and/or duration depending on the gas analyzed as seen in the results section.” in lines 168-171 to clarify the term “response”.

Methodology

- The number of studies that measured each gas is not clearly specified and would be most useful for interpretation. Meanwhile, other details about the studies would be desirable, manipulation versus natural, intensity of events, etc. A more comprehensive description of the studies used in the review is needed. Maybe a detail description of the experiments included in the review could be presented in another table.

Response: We have added the information in the texts and tables 1 and 3.

- Individual gas flux change rates were calculated but did they plot the response per gas individually or just altogether? How was it tested that the response of the different gases was the same? Between the two processes? Not statistics is described.

Response: We have removed the part.

- I like how this section is presented following each gas where the general patterns and the mechanism behind the observed responses are discussed. However, each section

could specify how many studies are included.

Response: We added the information (number of studies used for analyzing in the database) in the revised texts and tables (1, 3). However, the number does not actually represent how many studies have been conducted since studies which do not provide quantified information on the response were not included in the database.

- The results should be presented rather than individually which is rather tedious for the reader and less informative for the conclusions, by grouping them according to the observed responses, ecosystem type, type of experiment, etc.

Response: To provide more generalized information, we added new results: 1) rate of soil flux change following rewetting and thawing events by ecosystems types, 2) Pre-change flux versus flux change by gas and rewetting or thawing, 3) Mean annual temperature versus flux change, by gas and rewetting or thawing.

- A discussion of how different ecosystem types may respond to the same event would be good.

We added rate of soil flux change following rewetting and thawing events by ecosystems types. However, we found there are limitations of the results due to the limited available dataset for each ecosystem type (n = 1 to 9) so we were not able to discuss the results further more.

- I would rather see the biological and physical responses discussed separately.

Response: The mechanisms were distinguished biological and physical ones in section 3.

- At least three major processes may contribute to the rapid apparent stimulation of soil respiration following rainfall. First, large amounts of CO2 stored in the air spaces resulting from inorganic sources and soil microbial activity during the dry period are physically displaced and released-physical process (Huxman et al., 2004). Second, precipitation pulses can liberate carbon held in large soil pools of soil carbonates-when

ecosystems are placed on carbonate soils (Emmerich, 2003; Inglima et al., 2009). Third, soil rewetting rapidly increases decomposition processes of readily available carbon accumulated during the previous dry period-biological response (Kieft et al., 1998). Inorganic carbon is not mentioned and may be relevant in some cases.

Response: Due to limited information on the issue we only deal with organic carbon for this study. However, 'physically displaced and released-physical process' was clearly mentioned in line 284-286.

- Jarvis et al. 2007 present a historical review of mechanisms involved in rewetting responses.

Response: We added the reference as below:

"The growing number of studies on the separate effects of rewetting and thawing specifically on CO2 and N2O fluxes have been the focus of several reviews (Henry, 2007; Jarvis et al. 2007; Matzner and Borken, 2008; Borken and Matzner, 2009; Groffman et al., 2009)."

- The section on CO2 is much more detail for rewetting response than for thawing effects. Is that because there are many less studies? Less well known?. This should be explained.

Response: Throughout the review, CO2 and N2O sections (especially rewetting events) have relatively detail and larger amount of information than other sections because more studies have been conducted on the topics. It was mentioned in the section '5.1. Uncertainties in understanding the responses and mechanisms' as below:

"Compared to CO2 and N2O fluxes, our understanding of the effect of rewetting and thawing on CH4, NO and NH3 fluxes and mechanisms and drivers of the variation is limited, with large uncertainties. We encourage the scientific community to perform experiments and observations to better understand their magnitudes and mechanisms."

- Page 9854. line 7. Correct hypothesized for spelling consistency

Response: We corrected it.

- The mechanisms are not really discussed just described. Why would the response be larger in colder temperatures?. Because mineralization is limited and thus more carbon sources are accumulated and available at thawing?

Response: We revised them as:

Studies show that the magnitude of increased CO2 flux following thawing is controlled by characteristics of thawing events. For example, frozen soils in colder temperatures show greater increase of CO2 flux following thawing, possibly as a result of higher amounts of substrate cumulated in colder temperatures (Matzner and Borken, 2008; Goldberg et al., 2008).

- Page 9855. Line 11. This result is very interesting and could be included in the abstract, the value of SWC below which an increase in CO2 fluxes are observed.

Response: At this stage, the threshold in soil moisture at 12–20% can be only available for soil CO2 flux and the implication of the result is still very limited. So it may not be suitable to mention in abstract section which should provide overall results for all the gases.

- Page 9856, line 16. peatlands.

Response: We change from 'peatland' to 'peatlands'.

- Page 9856. 4.1. Remove OF

Response: we corrected it.

- Page 9856. Line 17. tropical forests-

Response: We change from 'tropical forest' to 'tropical forests'.

- Page 9857. Line 1. g dry mass

Response: In West and Schmidt (1998), the authors reported as 'g dry weight'. So we

used it.

- Page 9857. Line 10. peatlands or in a peatland

Response: We change from 'peatland' to 'peatlands'.

- The presentation of the results is too specific to the individual case studies and more general results should be presented. Again, how many studies? It is just said that there are many less published studies reporting CH4 fluxes.

Response: In 'General patterns of responses' sections for each gas, we provided a couple of representative examples to help readers understand and then we provided general results which were obtained from collected database. We also added some more general results and number of studies by gas type in the revised manuscript.

- For N2O similar problem, separate biological from physical effects, separate by ecosystem type, etc.

Response: We separated the mechanisms and added analyses by ecosystem types.

- There are many more studies on CO2 than in other gases and therefore, the sole power function fitted to all data may be misleading and surely the conclusion that there are no differences in the response of different gases must be taken with caution.

Response: We removed the result regarding power function fitting and have updated the results section.

- Page 9867 Line 2. Jarvis et al. 2007 is missing.

Response: we added the reference

Uncertainties and conclusions

- I would not say that there are few studies when more than 300 studies are reported in this review. Please, remove.

Response: we have removed it.

- I think that this section is too general. It basically says that there are not many studies, which is not the case, but more in depth uncertainties should be discussed.

Response: We revised the section. We edited the text arguing lack of studies in the section and moved some information on response and mechanisms to section 3. Now the section consists of 1) Uncertainties in understanding the responses and mechanisms, 2) Temporal and spatial resolution, 3) Experimental designs and 4) Model improvement. Now we believed that each part has not only general overview but also detail information and discussion for each issue.

- The discussion on the N2O fluxes is too detailed and probably should be moved the corresponding section on Mechanisms and drivers of this gas instead. It does not fit in this section.

Response: we moved the discussion on the N2O flux into mechanisms section.

- Although the temporal and spatial resolution of flux measurements is crucial for a good understanding of the effect of these processes, it is not clear to me whether these conclusions are drawn from a thorough analyses of the studies included in the review. Please, specify. Again, it would be much more relevant if the uncertainties and future research needs are directly drawn from a deeper and clear analysis of the studies presented.

Response: The importance of temporal and spatial resolution of measurements has been addressed by some studies and also the result of this review (i.e., increased soil gas flux after rewetting and thawing in short-term (ca. 6–24 h) but substantial effect on annual budgets) supports it.

- 4.4. Experimental designs rather than settings.

Response: we change from “Experimental settings” to “Experimental designs”

- The study of microbial community analyses and isotopic techniques is very important but it is not really explained how they can contribute to improve our understanding of

the responses of soil gas fluxes to rewetting and thawing. The paragraph is too general.

Response: we revised the part as following:

An area of significant promise involves combining microbial community analyses (Kim et al., 2008; Smith et al., 2010; Sawicka et al., 2009) and/or stable isotope techniques (Wagner-Riddle et al., 2008; Goldberg et al., 2009; Gaudinski et al., 2009) with flux measurements. Whether performed in the lab or field, such experiments could improve our understanding of rewetting and thawing effect on soil gas fluxes, identifying source processes and mechanisms and quantifying their contributions to overall responses.

- Although the blog is an excellent idea and this kind of initiatives should continue to grow and be encouraged, I am not sure whether this is the place to advertise it. It may be included in the Appendix or Acknowledgement Section by shortening it.

Response: We think both Blog and open database are new types of information sharing methodology: two-ways communication, self-growing and discussion encouraging platform. Our Blog has been viewed by 470 times by visitors mainly from US, Germany, Canada, Sweden, China and New Zealand and 19 comments are posted since we opened the Blog.

Section ‘5 A Blog for open discussion and web based open databases’ was shortened and moved to ‘Supplementary information’ after ‘Acknowledgment’ as following:

Supplementary information We have created a ‘Blog’ (web-based discussion) entitled ‘Rewetting, thawing and soil gas fluxes’ (http://rewettingandthawing.blogspot.com/) and we have uploaded a current version of this review paper section by section as an individual post in the Blog; comments can be left under the separate posts. Open-access datasets, which can be modified by the users, are linked to the Blog: ‘Rewetting, thawing and soil gas fluxes database’ (https://spreadsheets.google.com/spreadsheet/ccc?key=0AjWu6bR8SA9idHY4Tk5TdDZDM The dataset contains detailed information in the reported studies on soil gas peak flux

following rewetting and thawing. The dataset is hosted in web-based spreadsheets and is easily accessible and modified. The authors do not have any relationship with the companies currently being used to host the Blog and databases. Finally, version 1 of this dataset has been archived at the Oak Ridge National Laboratory Distributed Active Archive Center (http://daac.ornl.gov/; A Global Database of Gas Fluxes from Soils after Rewetting or Thawing, Version 1.0) and is available for reproducing the results presented in this study.

- Again the Response conclusion is rather general and does not really relate to what it has been found in the review. It should be more focused.

Response: We revised the conclusion part by adding overall results and findings from database analyses.

Tables and Figures - A table containing the detail information of the studies is needed as mentioned earlier.

Response: We added the number of studies used for the analysis in tables and texts.

- Fig 1 seems the same (apart from the control baseline of panel b). Is it really needed?

Response: We need both panel A and panel B since they represent different experimental designs.

- Fig 4. Not clear, symbols do not differ sufficiently. In any case, it is not clear whether all gases respond in the same way.

Response: we removed the figure.

Other references to be included: Harper et al. 2005. Increased rainfall variability and reduced rainfall amount decreases soil CO2 flux in a grassland ecosystem. Global Change Biology 11, 322–334. Munson et al. 2010. Soil carbon flux following pulse precipitation events in the shortgrass steppe. Ecol Res 25: 205–211 Rey et al. 2005. Effect of temperature and moisture on rates of carbon mineralization in a Mediterranean

oak forest soil under controlled and field conditions. European Journal of Soil Science 56, 589–599. Jarvis et al. 2007. Drying and wetting of Mediterranean soils stimulates decomposition and carbon dioxide emission: the “Birch effect”. Tree Physiology 27, 929–940. Birch, H.F. 1964. Mineralisation of plant nitrogen following alternate wet and dry conditions. Plant Soil 20:43–49.

Response: we added the references (Jarvis et al. 2007 and Birch, 1964) in relevant places in the revised manuscript.

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