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Interactive Comment

Interactive comment on "Permafrost soils and carbon cycling" *by* C. L. Ping et al.

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D. Konyushkov (Referee) dkonyushkov@yandex.ru Received and published: 3 December 2014 General comments. This paper gives a comprehensive review of literature on specific features of permafrost environments and soils and their impact on carbon cycling. In some cases, this impact is quite evident and can be easily illustrated. In particular, this concerns cryoturbation as a specific mechanism of "cryosequestration" of organic carbon in the deep mineral layers through burial of surface organic horizons. In other cases, the impact of cryogenic processes on the organic carbon storage and cycling is not so evident and requires further explanation. Thus, the relationships between the behavior of organic carbon and the formation of cryogenic soil structures have to be explained. It is probable that structures are important in the context of the thermal and water regimes in microloci, and, hence, in the context of potential activity of biota and microbiota. Anyway, it will be interesting to see definite links to carbon cycling in such sections. This is not always easy. It might be reasonable to add a paragraph devoted to unsolved problems and challenges for future research.

After reading the paper, a reader might conclude that permafrost-affected soils with active cryogenic processes favor the organic matter storage in the soil profiles. On one hand, this is true. The role of permafrost soils in carbon sequestration is great, and these soils store more carbon (in % of the global soil carbon pool) than their own percent in the soil cover of the planet. On the other hand, it is not quite correct to directly link soil carbon storage with cryogenic processes. As truly mentioned by the authors, Gelisols of Antarctica are very poor in organic carbon (in fact, except for some ornithogenic soils). The high storage of organic carbon is typical of the Gelisols in the northern circumpolar region and is explained not only by the influence of permafrost and cryogenic phenomena. Other factors, including evolution of these soils in the Pleistocene, are no less important!

There are two major effects of permafrost and cryogenic processes on carbon cycling. First and foremost, this is impeded organic matter decomposition because of cold temperatures in the soil profile, short duration of the active season, and, often, reducing conditions (even in subarid and arid ultracontinental environments due to minimal internal drainage of the profiles). At the same time, heat, moisture, and nutrient supplies of the upper horizons (in the northern circumpolar region) are sufficient to ensure significant (relative to decomposition) phytomass production. The resulting carbon balance is positive. The second effect is mentioned in the paper, but, from my point of view, should be better articulated and requires more attention of researchers. Cryogenic processes (including thermokarst) are responsible for the high spatial heterogeneity of carbon distribution with the creation of diverse ecological niches of carbon accumulation in the soil profile (often, not only in the surface horizons) and in the landscape; they also create the zones of carbon depletion (e.g., during extrusion of the mineral mass from the deep horizons onto the surface). Thus, they make the ecosystem structure

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more diverse, and this is an important mechanism ensuring sustainable functioning of the entire system in the severe environments. We appreciate the Reviewer's insight in the effects of permafrost and cryogenic processes on carbon cycling. Although we have covered these points but not as clearly defined as the Reviewer, thus we have revised the manuscript accordingly to emphasize especially the effects of cryogenesis on the diversity of carbon distribution and cycling.

I agree with most of the already published interactive comments. In the list below, some additional comments are listed.

Specific comments. p. 711, line 23 - "Cryozem in the Russian system (Shishov et al., 2004)." No, this is an erroneous (though common) perception of Cryozem in the new Russian soil classification system (2004). In fact, this system has no equivalent to Cryosols/Gelisols/Permagelic soils. Cryozem is just one of the representatives of permafrost-affected soils in this system. There are many other soils (Gleysols, Palevye Soils, Cryometamorphic soils, etc.) that may meet the requirements of Cryosols. In the new Russian system, the presence of permafrost (1 or 2 m) and cryoturbation are taken into account at lower taxonomic levels. Permafrost-affected soils is a group of soils without definite taxonomic "weight".

In the previous "factor-based" system (its structure was most clearly explained by E.N. Ivanova in her abstract to the 6th ISSS Congress in Paris (1956)) the notion of permafrost-affected soils (in Russian, merzlotnye) was widely applied and the corresponding term (merzlotnye) was added to soil names. In English translations, it often appeared as "frozen" soils (taiga frozen soils, tundra frozen soils, etc.). However, the group of "frozen" (permafrost-affected) soils was not recognized at the highest level of the taxonomic hierarchy. "Zonal" soil names were higher. Thus, though the notions of permafrost-affected soils and its narrower "relatives" - Gelisols/Cryosols - exist in Russian literature, their taxonomic positions are not strictly determined; in general, they are lower. These are informal soil groups rather than strictly specified taxa (in the official soil classification systems).

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We thank the Reviewer for pointing this out and providing us the background. We revised the para to reflect this change: “Permafrost-affected soils are referred to as Cryosols in both the World Reference Base (WRB) (IUSS [International Union of Soil Sciences] Working Group WRB. 2014) and the Canadian soil classification system (Soil Classification Working Group, 1998), Gelisols in the U.S. system (Soil Survey Staff, 1999), and permagelic suborders in the Chinese system (Gong et al., 1999). The Russian system has no equivalent to Cryosols/Gelisols and in the new Russian system (Shishov et al., 2004) the presence of permafrost (1 or 2 m) and cryoturbation are taken into account at lower taxonomic levels.

p. 717, line 6. "When the water of ground ice in fine-grained sediments exceeds the pore space of the soil," - probably, "volume of ground ice". However, this is still not quite clear. Ground ice is formed in soil pore space (and makes it larger!); it cannot exceed the volume of soil pore space. Though, it can exceed (and, probably, almost always exceeds!) the volume of soil pore space after soil thawing... Better, rephrase.

We rephrased the first sentence: Freezing of fine-grained soil attracts water to the freezing front from unfrozen soil below. Water content of frozen soil increases and ice occupies a pore space increases it and even forms lenses and layers of ice. Total amount of ice can greatly increase a volume of pores in soil prior freezing.

p. 719,line 11 "promote formation of soil biotic crusts" - a longer explanation is required. Ice, surely, participates in soil structuring, including specific structures of biotic crusts. In some cases (in arid environments) it can serve as the source of water and thus promote biota. As for admixture of the SOM at the surface, this seems to be the product of biotic crusts rather than their "starter".

In this process small amounts of surface-accumulated organic matter can be mixed with the top few centimeters of mineral soil promoting aggregation, disrupting root establishment and favoring biotic crust formatio (Michaelson et al., 2008; 2012).”

p. 718, line 11 "soil respiration during the shoulder winter season" - I cannot under-

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stand "shoulder" - colder? Or something else? The relationship between zero curtain, its "thickness" and duration, and soil respiration in winter is an interesting question.. Probably, we need more data.

To clarify this we changed the “shoulder winter season” to “late-fall to early winter period.”

p. 722, line 6: Change Kerzhntser to Kerzhentsev Corrected as suggested.

p. 723, lines 29, 30 - p. 724, line 1. I’m afraid, I do not understand exactly about the proportion of cryoturbated carbon - its percent of the total soil carbon storage? What is the reason for a decrease in the portion of cryoturbated carbon in the southern part of the transect - less active cryoturbation, or higher carbon storage in the surface organic horizons? As the patterned ground transitioned from simple frost cracking in the High Arctic to well-formed nonsorted circles at the Low Arctic, the landcover types changed from polar-desert to tundra and to shrub tundra in the south with increased dominance of vascular plants (Walker et al., 2008;). Ping et al. (2008a) found that soil carbon stores were directly related to biomass production but the proportion of cryoturbated C did not follow the same trend. Rather, the proportion of cryoturbated carbon stored in the upper permafrost reached a peak near the middle of the transect where tussock tundra dominates the landscape and then dropped off further south where shrub tundra dominates the landscape (Michaelson et al., 2008; Ping et al., 2008a). This trend corresponds to the decreased frost heave in shrub tundra where the higher canopy, thicker ground moss layer and the increased snowfall provide increased insulation which retard cryoturbation (Rodionov et al., 2007; Kade and Walker, 2008; Walker et al; 2008).

p. 726, line 2-4. "organic matter that is typically more decomposable than that of non-permafrost mineral soils" - I guess, potentially decomposable is better... We changed “typically” to “potentially”.

p. 726, line 14. Yakutian alases as "a depression with deep peat" (Smith et al., 1995).

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Unfortunately, I'm not familiar with this paper. There are different versions about etymology of the word 'alas' in Yakutian. As I know, meadow, glade, or open space are more adequate than "deep peat". It is better to delete "deep peat", as it gives an erroneous view of alases. Detailed data on alases can be found (in Russian) in the monograph by R.V. Desyatkin (2007). Some illustrations from this book were included in the "Northern Circumpolar Soil Atlas." Alas is a "mature" stage in the evolution of thermokarst depressions (earlier stages have their own names in Yakutian). Thick peat is not the major feature. Alases are under grassy vegetation or under intermittent lakes; limnic deposits (sapropel type) are more common in them than peat accumulation proper.

We revised the text as: Some thermokarst lakes eventually turn into drained basins, or "alases", a Yakutian term for a depression withthermokarst basin and its formation passes through a sequence of landforms and soil types; lakes, swamp, wet meadow and grassland (Desyakin, 2007). In the intermediate stage, Permafrost organic soils (Histels) were found in alas at Duvaany Yar, the extensively studied Yedoma formation along the Kolyma River upstream from Cherskiy (Smith et al., 1995). Deep (50-70cm) Sphagnum peat deposits were also found in some thermokarsting depression in yedoma-like formations in NW Alaska (Kanevskiy et al., 2014). [Note:We maintain the existence of Histels (organic soils affected by permafrost) in some alases because we described and analyzed these soils during a 1994 international expedition in the Lower Kolyma.]

p. 728. first paragraph. Overestimation of organic carbon determined by chemical oxidation methods (Walkley-Black?) compared to modern ignition methods (dry combustion?). The methods need to be specified. The statement itself is open to argument. Coefficients higher than 1 (1.28 to 1.41 and more!) are often used to recalculate C obtained by Walkley-Black method into dry combustion results [Amacher, M.S., R.E. Henderson, R.N. Brupbachir, and J.E. Sedberry. 1986. Dichromate-oxidizable and total organic carbon of representative soils of the major areas of Louisiana. Commun.

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Soil Sci. arld Plarzt Atzal. 17(10): 1019- 1032.; Gillman, G.P., D.F. Sinalir, and T.A. Beech. 1986. Recovery of organic carbon by the Walkley and Black procedure in highly weathered soils. Commun. Soil Sci. arzd Plant Anal. 17(8):885-892.]. Large datasets on the organic carbon determination by Tyurin's method (generally analogous to Walkley-Black) and by dry combustion methods were analyzed by B.M. Kogut, who concluded that, in most cases, dry combustion gives higher results. For weakly decomposed organic matter of litters the coefficient 1.2 was applied [unfortunately, I only know about publications in Russian. Some information can be obtained from a paper by Rojkov et al published by IIASA (WP-96-060_IIASA)]. Thus, overestimation of Corg by chemical methods (as in the case of the soils studied by Michaelson et al (2013)) cannot be considered a general rule and requires more detailed consideration. The chemical methods usually do not oxidize all the organic matter in the sample and, hence. underestimate rather than overestimate its amount. However, overestimation is possible, if the sample is rich in reduced forms of elements (bivalent iron compounds), such as in the gley horizons. In this case, their oxidation can be "misinterpreted" for the organic matter oxidation.

We agree with the reviewer that chemical methods usually underestimate rather than overestimate the organic matter. But the problem is that the conversion factor of the chemical methods was based on 58% carbon content in soil organic matter. This assumption is fine with soils from the temperate regions where the organic matter is more decomposed thus more humified, hence higher %C. However in the cold regions, the SOM is relatively fresh, less decomposed or humified, thus they have lower %C, about 50%. By this way, the chemical methods overestimate the %C. Thus it is necessary to establish such correlations in different ecoregions.

We revised the text as:

Modern high temperature ignition methods for determination of soil organic C are more direct measurements of soil C but prior to the 2000 soil organic C was commonly estimated using variations of the chemical acid-chromate oxidation method (Walkley-Black

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method) and these procedures required calibration or estimation of a recovery factor for the method and group of soils being analyzed. Recovery factors were generally calculated using soils from temperate and warmer environments and varied from for example 0.46-0.87 with mean of 0.71 (Amacher et al., 1986) and close to the factor of 0.77 recovery used for the USDA-NRCS Alaska data set (Soil Survey Staff, 2014). Michaelson et al. (2013) found that in the USDA-NRCS Alaska data set, the commonly used chemical oxidation method using the recovery factor of 0.77, over-estimated the OC in Alaska Gelisols by an average of 12% ($R2=0.98$) when compared to the analysis by ignition methods. Soil C for other soil Orders found in the Alaska data set were over-estimated by 3-18%, yet these data are commonly used for pedon carbon assessment(Tarnocai et al., 2009 and Hugelius et al., 2013. New pedotransfer functions were developed and used by Michaelson et al. (2013) to update Alaska USDA-NRCS soil pedon C data where 57% of the pedons representing Alaska were determined only by the chemical chromate-oxidation method.

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