Author response letter, Hugelius et al. BG 2016

Summary of relevant changes:

- Changed manuscript structure with added supplemental methods.
- Extended discussion on vulnerability of organic vs mineral soil material and different peatland formation processes
- Provided more discussion and details on calculations of overlap.
- Updated both figures and added additional maps to the supplement with more details.
- Addressed all minor editorial issues

Below are point-by-point responses to all reviewers.

Dear Reviewer 1

Thank you for this constructive review of our submitted manuscript.

We agreed with your major suggestion of reformatting the manuscript into three main sections and remove the Method section. Since there were also many requests for expansion and clarification of topics in the other reviews we very briefly mention methods in the main text as suggested by you, but that a longer and more detailed method text is added as a supplement.

All the minor editorial comments are clear and helpful. We have incorporated these into a revised manuscript.

On behalf of the co-authors, Gustaf Hugelius

Dear Reviewer 2

Thank you for this constructive review of our submitted manuscript.

You suggest two main ways in which a resubmitted manuscript could alter the focus to provide clearer insight into the issues (see detailed responses below) and go on to list suggestions regarding all three arguments that we make in our manuscripts and how these need to be clarified. We find all of these suggestions constructive and have tried to follow them. We find that the updated manuscript is more informative and with clearer argumentation.

Your main comment 1 is that the readers need more information and clarity regarding the calculations of overlap between estimates (figure 2). Specifically, we do not want the readers to have to go back to other papers to evaluate the issue. This is a good point and something we strived to do in this revised manuscript. We extended the caption to include more explanations. Further we now give the details of how all calculations were made in an extended Method supplement for any reader with a special interest in delving into the details (see corresponding response to Reviewer 1).

Your main comment 2 is that the discussion on terminology is of less importance and that the focus here should be diverted somewhat. We agree that this is not the main issue and that it can be toned down. We have now made this discussion more pertinent by referring to studies that show how soils with higher organic carbon (i.e. true peats) are expected to respond differently to changed environmental conditions (see input from Reviewer 3 who has strong suggestions for additions here). We do think that it is important to high-light how terminology varies and that it is important to account for this when comparing results across disciplines.

We also updated the map and added extra maps in the supplement for readers that want to scrutinize them more closely.

In addition to these main comments a number of smaller comments were provided, both editorial and requests for more information or clarity. All these minor comments are clear and helpful. We have incorporated them into the revised manuscript.

On behalf of the co-authors, Gustaf Hugelius

Dear Reviewer 3

Thank you for this constructive review of our submitted manuscript.

Your suggestion for including the potential lability of mineral vs organic soil material in the discussion was very good. This also helped us to high-light that the distinction between different soil types is not only a semantic issue of language use, but something that affects the potential biogeochemical feedbacks to climate of these deposits.

Your suggestion for broadening the discussion on peat terminology across disciplines is helpful and it would help readers to get a perspective to the discussion. The different ways in which peatlands are formed (paludification vs terrestrialization) are pertinent to the discussion and we have added some text on this topic in section three of the revised manuscript.

Regarding the second issue of potential overlap in C stocks, as well as the different methodologies applied by Strauss et al. (2013) and Walter Anthony et al. (2014), the reviewer correctly states that one-to-one comparisons between estimates are not directly applicable. We mention this issue only briefly, referring the reader to the original studies and the references therein. We have updated and expanded this text somewhat. However, we feel that it is outside the scope of this manuscript to go into the details of the calculations for the full Yedoma region carbon budget. Please note that a discussion comment associated with our current manuscript by Walter Anthony et al. provide more in depth discussion on their views of these overlaps and differences between estimates. An action group of the International Permafrost Association is currently updating and consolidating these numbers and we wish to defer in depth discussions of total yedoma region stocks to that group (see: http://ipa.arcticportal.org/images/stories/AG_reports/AG4_for_website.pdf).

On behalf of the co-authors, Gustaf Hugelius

We also wish to note that we have responded to some of the suggestions made by **Katey Walter Anthony, Sergey Zimov, Guido Grosse, Miriam Jones, Peter Anthony, F. S. Chapin III, Jacques Finlay, Michelle Mack, Sergei Davydov, Peter Frenzel and Steve Frolking.** Most notably we include more mention of similarities in upscaled total stocks as well as numbers they provided on how many of their original sites are classified as organic soils in a pedological perspective.

Ideas and Perspectives: "Why Holocene thermokarst sediments of the Yedoma permafrost region do not increase the northern peatland carbon pool"

Gustaf Hugelius[1], Peter Kuhry[1] and Charles Tarnocai[2]

[1] Department of Physical Geography, Stockholm University, SE-106 91 Stockholm, Sweden. [2] Research Branch, Agriculture and Agri-Food Canada, 960 Carling Ave., Ottawa, Ontario K1A0C6, Canada.

Abstract

Permafrost deposits in the Beringian Yedoma region store large amounts of organic carbon (OC). Walter Anthony et al. (2014) describe a previously unrecognized pool of 159 Pg OC accumulated in Holocene thermokarst sediments deposited in Yedoma region alases (thermokarst depressions). They claim that these alas sediments increase the previously recognized circumpolar permafrost peat OC pool by 50%. It is stated that previous integrated studies of the permafrost OC pool have failed to account for these deposits because the Northern Circumpolar Soil Carbon Database (NCSCD) is biased towards non-alas field sites and that the soil maps used in the NCSCD underestimate coverage of organic permafrost soils. Here we evaluate these statements against a brief literature review, existing datasets on Yedoma region soil OC storage and independent field-based and geospatial datasets of peat soil distribution in the Siberian Yedoma region. Our findings are summarised in three main points. Firstly, the sediments described by Walter Anthony et al. are primarily mineral lake sediments and do not match widely used international scientific definitions of peat or organic soils. They can therefore not be considered an addition to the circumpolar peat carbon pool. We also emphasize that a clear distinction between soil types is important since they show very different vulnerability trajectories under climate change. Secondly, independent field data and geospatial analyses show that the Siberian Yedoma regionsregion is dominated by mineral soils, not peatlands. Thus, there is no evidence to suggest any systematic bias in the NCSCD field data or maps. Thirdly, there is spatial overlap between these Holocene thermokarst sediments and previous estimates of permafrost soil and sediment OC stocks. These carbon stocks were already accounted for by previous studies and cannot be added to the permafrost OC count. We suggest that these inaccurate statements made in Walter Anthony et al. (2014) mainly resulted from misunderstandings caused by conflicting definitions and terminologies across different geoscientific disciplines. A careful cross-disciplinary review of terminologies would help future studies to appropriately harmonize definitions between different fields.

1. Introduction

Soils and sediments of the northern permafrost region have accumulated large stocks of organic carbon (OC) over millennia (Tarnocai et al., 2009). As the global climate warms there is a concern that thawing permafrost will expose soil organic matter (SOM) that was previously protected in permafrost to decomposition, causing a positive permafrost-carbon-feedback to climate (Schuur et al., 2008; 2015). Hugelius et al. (2014) provide the most recent integrated estimate of Northern circumpolar permafrost region soil and sediment OC stocks with total stocks estimated at 1307 Pg and a 95% confidence interval of 1140–1476 Pg. Of this roughly 800 Pg is perennially frozen with the remainder stored in active layer or talik deposits. A substantial part of the perennially frozen OC is stored in the Beringian Yedoma region with estimated permafrost deposit OC stocks of 213 Pg with an uncertainty range of 164–267 Pg. Schirrmeister et al. (2013) provide an in depth discussion and review on various aspects of these deposits. Schuur et al. (2015), in a recent review of the permafrost carbon feedback, ~~highlights~~highlight that there is considerable spread in estimates of Yedoma region permafrost OC stocks. In a study describing the Holocene C dynamics of Siberian thermokarst lakes Walter Anthony et al. (2014) estimate a pool of 456±45 Pg C in the Beringian Yedoma region. This estimate includes a previously unrecognized pool of 159±29 Pg OC accumulated in Holocene aged sediments deposited in drained thermokarst-lake basins (hereafter called alases) of the Yedoma region. They conclude that these alas sediments increase the previously recognized circumpolar permafrost peat OC pool by 50%. It is further stated that previous integrated studies of the permafrost OC pool (Tarnocai et al., 2009; Hugelius et al., 2013a) have failed to account for these deposits because of biases in the Northern Circumpolar Soil Carbon Database (NCSCD). Walter Anthony et al (2014) argue that the field site data of the NCSCD is biased towards non-alas sites and that the soil maps on which the database is based are too generalized to show the distribution of, primarily organic, deposits in alases of the Yedoma region. Note that the term alas is used in a wide sense to describe former thermokarst lake basins. Following initial permafrost degradation and thermokarst, these basin have typically been (partly) terrestrialized (e.g. through lake drainage or evaporation of lake water) and re-aggraded permafrost.

Here we examine these important statements by evaluating the findings and data presented by Walter Anthony et al. (2014) against (1) a brief review of vulnerability to climatic changes and scientific definitions of peat, peatlands, organic soils and thermokarst sediments, (2) independent field data as well as independent geospatial databases showing the extent of organic soils and/or peatlands in the Siberian Yedoma region and (3) by analysing the spatial overlap between these new estimates and existing datasets of Yedoma region soil and sediment OC storage.

2. ~~Methods~~

~~All geospatial analyses~~ Vulnerability and ~~quantification~~definitions of organic soils and sediments

Walter Anthony et al. ~~areal extents of classes were calculated in equal area projections using Geographical Information Systems (software ArcGIS 10.3, ESRI, Redlands, California, USA). The extent of the Siberian Yedoma region was digitised from Grosse et al. (2013) and, where applicable, snapped~~

to correspond to the Arctic Ocean coastlines of the NCSCDv2 (Hugelius et al., 2013b). Soil and non-soil coverage within this region in the NCSCDv2 was extracted. To provide estimates of mapped coverage of peatlands and wetlands for the Siberian Yedoma region considered independent from the NCSCD the following international geospatial datasets were used: Nilsson et al. (2002); Bartalev et al. (2003); Lehner and Döll (2004) and Arino et al. (2012). The thematic classes that corresponded to peatlands were identified and their respective coverage in the Siberian Yedoma region quantified. See the supplemental material for an overview of the detailed coverage of different classes in the respective geospatial datasets.

The independent field validation sites were classified and sampled using a transect-based semi-random approach during field campaigns in August (2010 and 2013), see Palmtag et al. (2015) and Siewert et al. (2015) for details. The starting point and direction of transects were chosen to cut across representative landscape types. After this, pedons (a pedon is a three-dimensional body of soil as sampled, described and classified in soil studies) were described and sampled at equidistant intervals. In three out of nine sites, the bottom of deep peat deposits was not reached when sampling.

Calculations of overlap in soil carbon stocks between different estimates and datasets are based on data on soil and/or sediment carbon stocks from Tarnocai et al. (2014) claim that 159 Pg of OC has accumulated in deep Holocene thermokarst deposits across alases in the Yedoma region increase the previously recognized permafrost peat OC pool by 50%. However, we argue that the use of imprecise terminology has caused misleading comparisons in relation to previous stock estimates. We argue that these Holocene thermokarst deposits do not meet the criteria of peat (or organic soils) used in any regional or circumpolar peat carbon stock study. Therefore they cannot be claimed to increase peat carbon stocks. They simply increase the stock of alas sediments known to be of Holocene age.

We emphasize that the classification of organic and mineral soil material is not a mere issue of semantics or putting a different label on a soil sample depending on your scientific background. The properties of mineral and organic soil material is very different and the distinction is especially important in permafrost regions where studies have consistently shown that organic and mineral soils differ both in their vulnerability to thaw and in the potential post-thaw lability of soil OM. Due to differences in soil thermal properties, organic soils are much less vulnerable to active layer deepening under climate warming than are mineral soils (Shur and Jorgenson, 2007; Jorgenson et al., 2010). High-resolution modelling of active layer dynamics from a Russian low-Arctic site showed that organic soil are projected to remain stable until the end of this century while near surface permafrost degraded in mineral soils (Hugelius et al., 2011). Organic soils also show different vulnerabilities to thermokarst. Thick surface O-horizons can reduce lateral expansion rates of thermokarst (Jorgenson and Osterkamp, 2005) and modelling studies suggest that thermokarst lake taliks formed into organic soils are shallower than their mineral counterparts (West and Plug, 2008). Sjöberg et al. (2013) suggest that thermokarst lake formation and orientation in peatland terrain may partly be controlled by different processes than for mineral soil thermokarst. They also demonstrated that peat substrate thermokarst lake shorelines display more pronounced and heterogeneous erosion patterns than mineral substrate shorelines, both in shoreline morphology and lake geometry. Harden et al (2006) also describe multiple feedbacks between the thickness of surface organic soil horizons and the vulnerability of ecosystems to combustion by wildfires, where deep organic layers could often preserve thermal and biological properties of soils through repeated fire cycles.

While organic soils are thus less vulnerable to permafrost thaw and combustion than mineral soils, other studies have demonstrated that SOM in organic soils is typically less decomposed and thus assumed to be more vulnerable to microbial decomposition. In multiproxy analyses of Yedoma and thermokarst sediment, Strauss et al. (2015) showed that high OC% content is associated with less degraded SOM as indicated by multiple geochemical proxies. In sub-Arctic tundra, SOM in peatlands has been shown to be significantly less degraded than mineral soil SOM (Hugelius et al., 2012; Routh et al., 2014). Incubation studies have also confirmed these findings. In a circumpolar incubation synthesis, the loss of soil OC was a factor 2 to 4 higher from organic soils compared to mineral soils (over 50 incubation years at 5° C) (Schädel et al., 2014;). Weiss et al. (2015) compared surface soils on intact Yedoma to thermokarst basins and found that mineral subsoil samples with lower %OC (and more degraded SOM as indicated by elemental and stable isotope ratios of C and N) had significantly higher respiration rates per g C in short term incubations than did organically enriched samples. This is a result which high-lights that this topic warrants further attention.

In light of these, and other, studies showing clear differences in the properties and potential vulnerabilities of mineral and organic soils it is clear that clear definitions and distinctions are needed to properly assess and predict the response of these vulnerable landscapes under a changing climate. Below we provide a brief review of different definitions and classifications currently used in studies of periglacial terrain.

2(2009), Hugelius et al. (2013a; 2013b; 2014), Walter Anthony et al. (2014) and Zimov et al. (2006). By using the reported depth ranges and soil carbon densities of the different studies, the overlap between estimates has been calculated following the same methods used in the original studies. We assumed that all Histels in the NCSCDv2 within the Siberian Yedoma region where located in alases and the remaining soil area was subdivided between the Turbel and Orthel suborders of the Gelisol soil order. The calculations are made assuming 15% coverage of lakes/rivers in the Siberian Yedoma region.

Note that the term alas is used in a wide sense to describe former thermokarst lake basins. Following initial permafrost degradation and thermokarst, these basin have typically been (partly) terrestrialized (e.g. through lake drainage or evaporation of lake water) and re-aggraded permafrost.

3. Results and discussion

3.1 A brief review of definitions of peat, peatlands, organic soils and sediment facies

Across different scientific disciplines (and countries) the definition of what is peat varies. A commonly used definition states that peat is sedentarily accumulated material consisting of at least 30% (dry weight) of dead organic material while peatlands are areas (with or without vegetation) with a naturally accumulated peat layer (Joostens and Clark, 2002). Many studies have employed a minimum depth criterion of the surface peat layer to the definition of peatland, most frequently 30 cm (Kivinen and Pakarinen, 1981; Lappalainen 1996; Joostens and Clark, 2002). The Canadian definition of an organic wetland (or peatland) includes a depth of organic soil material (of 17% OC or 30% organic material) of at least 40 cm.

Soil classification systems define organic soil material (or peat) based on organic carbon content, while the thickness of organic soil material in the upper soil column determines whether a soil is primarily considered to be a mineral soil or an organic soil. The U.S. soil taxonomy (Soil Survey Staff, 2010) and the World Reference Base for Soil Resources (IUSS Working Group WRB, 2007) defines waterlogged soil with more than 12–18% OC (dry weight; range depending on clay content) as organic soil material while the Canadian System of Soil Classification (Soil Classification Working Group, 1998) defines soil with more than 17% OC (or 30% organic material; dry weight) as organic soil material. All these soil classification systems define a soil as an organic soil if there is 40 cm or more of accumulated organic soil material in the upper soil column (the Canadian system employs 60 cm for highly fibric moss-peat).

The literature describing sediments of thermokarst basins and lakes includes many different definitions of different facies or deposit types. These definitions are often not based on quantified physical or chemical properties of sediments, but rather reflect descriptive characteristics and the environments in which they formed. In addition to ~~sedentary~~ *in situ* peat, previous studies have described organic rich sedimentary thermokarst facies such as: *(1) "detrital peat"* described as layered organic deposits formed on beaches or in shallow waters (Murton, 1996) or as lee-shore deposits (Hopkins and Kid, 1988); *(2) "organic rich silts"* (or "lacustrine organic silt") where primarily mineral lake sediments are interspersed with sedentary or allochtonous detrital organic sediments layers (Murton, 1996; Kanevskiy et al., 2014) and (3) "Mud/muddy peat" which differs from detrital peat based on a higher mud content. These deposits may contain blocks of peat or other materials and typically form thick sediment layers in deep water thermokarst lake environments by suspension settling of fine and/or low-density material (Hopkins and Kidd, 1988; Murton et al., 1996).

~~3.2 Classification~~The bulk of ~~Kolyma lowland~~the Holocene ~~thermokarst sediments~~

OC described~~The Beringian Yedoma region can be subdivided into areas of intact Yedoma (ca. 30% by area), areas that have been affected by thermokarst and subsequently re-aggraded permafrost (56%) and areas of open water (14%) which are commonly underlain by taliks (Strauss et al., 2013). The study~~ by Walter Anthony et al. (2014) ~~uses an identical spatial subdivision of this region but uses different data and computational methods to estimate the volume and OC stocks of the various sediments and deposit types in the region. Walter Anthony et al. (2014) present valuable new data from Yedoma and thermokarst deposits in the Kolyma Lowlands. Extrapolated from 28 sampled exposures Walter Anthony et al. (2014) estimate that 159 Pg of OC has accumulated in deep Holocene thermokarst deposits across the Yedoma region. The bulk of this Holocene OC~~ has accumulated in sediment facies they descriptively call "S*tratified muddy peat*". The authors state that this facies corresponds to strata that previous authors have called *"Mud/muddy peat~~" (see 3.1 above).~~".* These facies are described as deep-water lake sediments, predominantly of minerogenic origin and with an OC content of only 3–4% by weight (Walter Anthony et al., 2014; fig. 2 and extended data table 2). ~~Walter Anthony et al. (2014) claim that these sediments increase the previously recognized permafrost peat OC pool by 50%. However, we argue that the~~Their use of ~~imprecise~~ terminology ~~has caused misleading comparisons~~is in ~~relation to~~line with previous ~~stock estimates. These~~ studies of thermokarst sedimentary facies. But the classification, origin and properties of these deposits are clearly very different from ~~definitions of~~ pedologically defined peat as being a primarily organic material, usually of ~~sedentary~~terrestrial or shallow water origin ~~(see 3.1 above). We consider it inappropriate and misleading to directly contrast these mineral lake sediments to organic peat stocks described following strict pedological definitions by e.g. Tarnocai et~~

al. (2009). As these Holocene thermokarst deposits do not meet the criteria of peat (or organic soils) used in any regional or circumpolar peat carbon stock study they cannot be claimed to increase peat carbon stocks. They simply increase the stock of alas sediments known to be of Holocene age.

3.2 Extent of organic soils in the Siberian Yedoma Region

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The Beringian Yedoma region can be subdivided into areas of intact Yedoma (ca. 30% by area), areas that have been affected by thermokarst and subsequently re-aggraded permafrost (56%) and areas of open water (14%) which are commonly underlain by taliks (Strauss et al., 2013). The study by Walter Anthony et al. (2014) uses an identical spatial subdivision of this region but with different data and computational methods to estimate the volume and OC stocks of the various sediments and deposit types in the region. The study by Walter Anthony et al. presents valuable new data from Yedoma and thermokarst deposits in the Kolyma Lowlands. Extrapolated from 28 sampled exposures stocks of Holocene and Pleistocene OC is quantified, including the thermokarst-basin Holocene carbon pool (159 ±24 Pg) which the authors claim to be a newly recognized OC pool that has not been captured in previous studies. The authors present their reasoning for reaching this conclusion (see Walter Anthony et al. 2014, supplementary material section 3.5).The discussion by Walter Anthony et al. (2014) surrounding Holocene-aged alas deposits in the Yedoma region are based on the assumption that these alases are peat deposits. However, this reasoning is based on the assumption that the Siberian alases (70% of the landscape) are fully covered by peat deposits. They conclude that the NCSCD is underestimating the spatial coverage of Histels (permafrost peatland soils) and that the pedon dataset of the NCSCD is biased towards non-alas soils (see Walter Anthony et al. .2014, supplementary material section 3.5). Here we evaluate these statements against independent inventories of geospatial datasets and field inventory data. Both these sourcesTo provide independent estimates of Siberian Yedoma region peatland coverage four different geospatial datasets were used (Nilsson et al.,2002; Bartalev et al., 2003; Lehner and Döll, 2004; Arino et al., 2012). Thematic classes that corresponded to peatlands were identified and their respective coverage quantified. The independent field validation sites are all located in alases or thermoerosional gullies from across the Siberian Yedoma region and were classified and sampled using a transect-based semi-random approach during field campaigns in August (2010 and 2013). For detailed method descriptions and calculations we refer to the online supplementary materials.

Both the geospatial datasets and field inventory data show a limited extent of organic soils in the Siberian Yedoma region (Fig 1). The Histel coverage in the Siberian Yedoma region in the NCSCD is 9%. This is comparable, but somewhat higher, than to peatland coverage estimated from independent geospatial databases of 3–6% (Fig 11a). It is notable that the degree of overlap between independent datasets is limited, indicative of difficulties with classifications and class definitions when mapping peatland extent (Fig. 1). Our independent compilation of field sites located in alases or thermoerosional gullies from across the Siberian Yedoma region reveals that only 9 out of 49 sites are peatlands (fig 1.). The surface peat depth of these nine peatland sites was ≥1.3±1.1 m (mean±std), with a range of 0.4 m to >3.7 m. A spatial overlay analyses of regional land-cover and wetland characterization maps (Nilsson et al., 2002; Stolbovoi, 2002) suggest that ~3% of the region is covered by deep peat bogs while 19% is characterized as swamps with very shallow peat (0.1–0.5 meters). Our independent compilation of field sites located in alases or thermoerosional gullies from across the Siberian Yedoma region reveals that 16% of sites are peatlands (fig 1b; 9 out of 49 sites). The surface peat depth of these nine peatland sites was ≥1.3±1.1 m (mean±std), with a range of 0.4 m to >3.7 m.

Reclassifying the original data from Walter Anthony et al. (2014) following pedological definitions yields a remarkably similar result with 16% of the studied thermokarst features adhering to the soil science definition of an organic soil (Walter Anthony et al., 2016).

Walter Anthony et al. (2014) base the argument that there is a bias towards non-alas soils in the NCSCD pedon dataset v2 on the fact that only nine out of 60 pedons in the Siberian Yedoma region are classified as Histels. However, the assumption that all pedons in alas deposits should be classified as Histels is erroneous and likely based on a misunderstanding caused by conflicting terminologies between fields. Descriptions of geomorphological settings of the pedons presented by Hugelius et al. (2013a) actually describe 13 additional mineral soil pedons sampled in alases or thermokarst deposits in the Siberian Yedoma region. The geomorphological setting of the remaining sites of the NCSCDv2 cannot be fully resolved since many of them lack metadata describing their geomorphological location (Hugelius et al., 2013a).

Peatlands typically form (and expand) through paludification or terrestrialization. Terrestrialization describes peatlands formed via gradual in-filling of water bodies. Paludification is the processes by which peatlands expand into other established terrestrial ecosystems and considered the most common form of boreal peatland formation (Kuhry and Turunen, 2006). The Holocene deposits described by Walter Anthony et al. (2014) were mainly formed through a terrestrialization process (in combination with permafrost dynamics). However, the characteristics of peatland sites sampled during the independent field surveys presented above indicate that paludification of e.g. poorly drained upland tundra or taiga environments has also been an important peatland forming process in the region.

All of these combined lines of evidence support an interpretation that peatlands are locally present in alases of the Siberian Yedoma region, but rarely cover large surfaces. The alases are dominated by mineral soils, often formed intoon parent material of e.g. reworked yedoma or lacustrine sediments. This interpretation is also supported by previous scientific studies from this region (e.g. Czudek et al. 1970; Veremeeva and Gubin, 2009; Wetterich et al., 2009; Schirrmeister et al., 2011; Morgenstern et al., 2013). We find no support to the claim that the maps or pedon dataset of the NCSCD are systematically biased.

3.34. Overlap between soil C estimates in Yedoma region alases

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Spatial overlap between different studies of soil carbon stocks may mislead data users and cause significant errors in estimates. Here we show that the OC stocks in Holocene alas sediments described by Walter Anthony et al. (2014) were already accounted for by previous studies. The calculations of overlap in soil carbon stocks between different estimates and datasets for the Siberian Yedoma region are based on data on soil and/or sediment carbon stocks from Tarnocai et al. (2009), Hugelius et al. (2013a; 2013b; 2014), Walter Anthony et al. (2014) and Zimov et al. (2006). By using the reported depth ranges and soil carbon densities of the different studies, the overlap between estimates has been calculated following the same methods used in the original studies. We refer to the online method section for more details on the calculations.

Previous integrated estimates of carbon stocks in the Beringian Yedoma region (Tarnocai et al. 2009; Hugelius et al. 2014) are based on soil maps linked to field-based soil data for the upper three m and generalized estimates of Yedoma region deposits for deeper deposits (Zimov et al., 2006; Strauss et al., 2013). The Holocene thermokarst deposits described by Walter Anthony et al. (2014) overlap these previous estimates in space, but they differ in their characterisation of the sediment (Fig. 2). An important difference compared to previous studies is that Walter Anthony et al. ~~(2014)~~ include ≃24 Pg carbon in Holocene deposits assumed to occur in taliks (perennially thawed ground) under present day lakes and rivers. We recognize that these estimates are new, but they are also outside the scope of the studies by Tarnocai et al. (2009) and Hugelius et al. (2014) as they are per definition not soils, nor are they permafrost deposits. ~~This leaves ~~~Out of the 159 Pg of Holocene alas carbon reported by Walter Anthony et al., this leaves 135 Pg of Holocene carbon to be reconciled with previous estimates for soil/sediment that occupy the same physical space. For the upper three meters, Walter Anthony et al. estimate ≃76 Pg of Holocene carbon. This overlaps soils from previous estimates with carbon stocks of 53–58 Pg ~~(~~resulting in a ~20 Pg net increase (range based on different versions of the NCSCD from Tarnocai et al., 2009; Hugelius et al., 2013a; 2013b; 2014~~)~~ ~~resulting in a ~20 Pg net increase.~~). However, given that the geographical distribution of the sites ~~in the new estimate~~used by Walter Anthony et al. is limited to the Kolyma river lowlands (see figure 1) we do not consider this estimate more robust than previous estimates based on the NCSCD.

For alas deposits below three meters, the estimate by Walter Anthony et al. (2014) includes ≃60 Pg of Holocene OC and ≃155 Pg of Pleistocene OC which overlaps with ~~recent~~ estimates of ~110 Pg of OC in refrozen thermokarst sediments (Strauss et al., 2013; updated in Hugelius et al. 2014). The differences between estimates are primarily ~~caused by methodological differences in how stocks are calculated rather than large differences in field data or terminologies. In brief, earlier studies (1)~~ due to two reasons. Firstly, the previous estimates (Strauss et al., 2013; Hugelius et al., 2014) did not include ~~a~~the pool of OC stored in subaqueous thawed sediments (estimated to 23 Pg C) or taberites~~,~~ ~~an~~. Taberites are *in situ* thawed, diagenetically altered Yedoma ~~deposit, and (2)~~deposits. Walter Anthony et al. estimate that these taberite deposits store 97 Pg C. Second, the previous estimates applied medians from bootstrapping approaches to ~~calculate~~estimate OC stocks in thermokarst sediment below 3 m depth while Walter Anthony et al. ~~(2014)~~ use arithmetic means. These different methods yield significant differences in estimated stocks. Walter Anthony et al. ~~(2014) provide an account for~~discuss how these estimates overlap and ~~can be reconciled and this is~~comparisons of these separate estimates or their methodological differences are not further discussed here.

~~4~~5. Conclusions and recommendations

We conclude that Holocene OC stocks in Siberian Yedoma region alases overlap estimates from previous studies are primarily stored in mineral soils and lacustrine sediments rather than peat and do not increase estimates of circumpolar permafrost peat carbon stocks. In fact, the differences between the estimates of Hugelius et al. (2014) and Walter Anthony et al (2014)are rather small. If storage in taberites and subaqueous sediments sediments is accounted for, the difference in estimated Yedoma region alas OC stocks is only ~10 Pg C, which is well within the reported uncertainty ranges. There is no evidence or reasoning to suggest that these deposits increase the northern peatland pool or that the NCSCD is systematically biased against upland soils. ~~It is relevant and important to contrast the Holocene accumulation of carbon in alas sediments to that estimated for peatlands. But it is important to note that the Holocene thermokarst sediments described by Walter Anthony et al. (2014) do not add to circumpolar permafrost peat carbon stocks.~~

We emphasize that our concerns regarding use of terminology and spatial overlap of estimates in the discussed study in no way affects the validity of their other important findings regarding Holocene carbon dynamics of these ecosystems. It is relevant and important to contrast the Holocene accumulation of carbon in alas sediments to that estimated for peatlands. We attribute the misunderstandings to confusing overlap between terminologies in the respective fields of science that study soils and sediments in periglacial landscapes. We suggest that a careful and exhaustive review of these terminologies would help future studies to harmonize classifications and definitions. The need for reconciliation of terminologies is emphasized by accumulating evidence that the differing properties of mineral and organic soil affect their vulnerability under future climatic changes.

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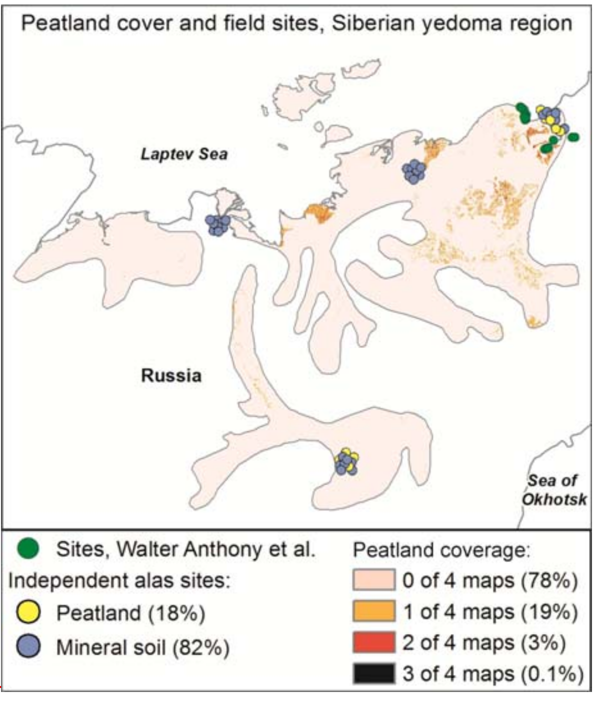
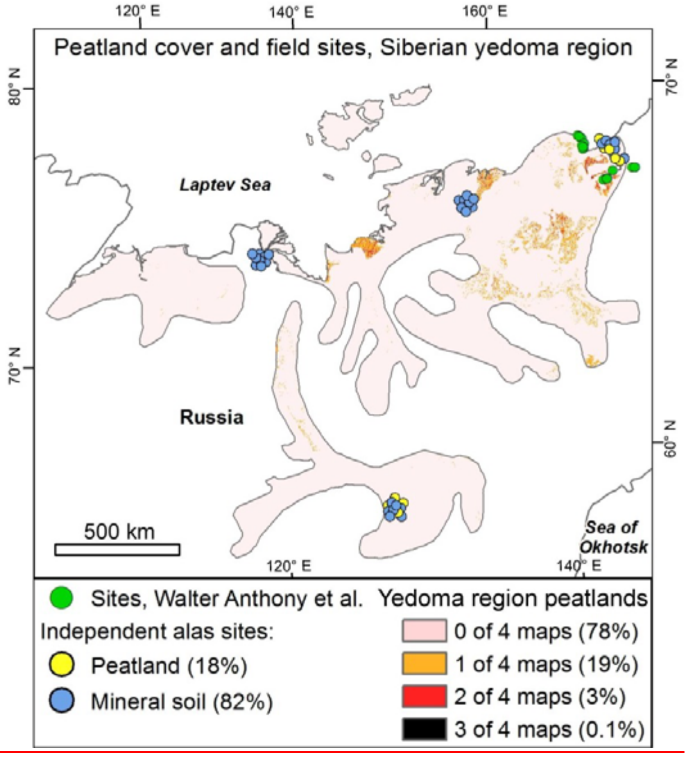
Figures

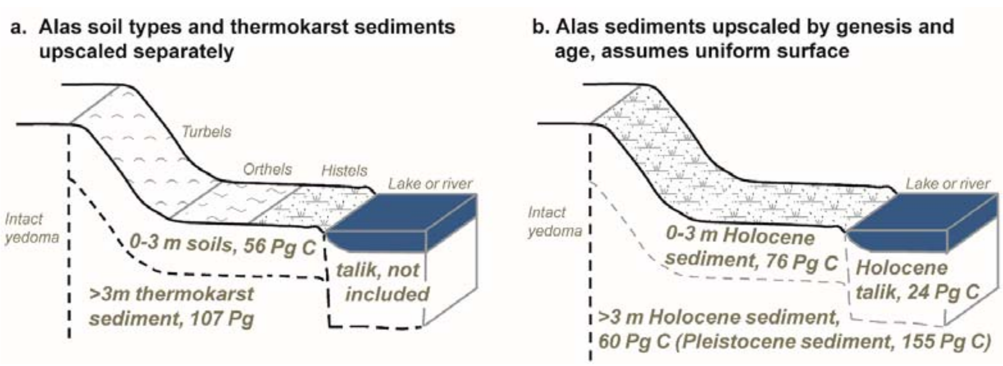


Peatland cover and field sites, Siberian yedoma region
Laptev Sea
Russia
Sea of Okhotsk
Sites, Walter Anthony et al.
Independent alas sites:
Peatland (18%)
Mineral soil (82%)
Peatland coverage:
0 of 4 maps (78%)
1 of 4 maps (19%)
2 of 4 maps (3%)
3 of 4 maps (0.1%)



120° E
140° E
160° E
Peatland cover and field sites, Siberian yedoma region
80° N
70° N
70° N
60° N
Laptev Sea
Russia
500 km
120° E
140° E
Sea of Okhotsk
Sites, Walter Anthony et al.
Independent alas sites:
Peatland (18%)
Mineral soil (82%)
Yedoma region peatlands
0 of 4 maps (78%)
1 of 4 maps (19%)
2 of 4 maps (3%)
3 of 4 maps (0.1%)

Figure 1. Overview of field sites and estimated coverage of peatlands in the Siberian Yedoma region. Graduated colours within the region show coverage of peatlands in four global/regional map products that are independent from the NCSCD (see ~~Methods).~~online supplementary material for detailed methods). The coverage is shown cumulatively so that the colours reflect how many of the four products that map peatlands in any given location. Points show locations of the Holocene alas profiles used by Walter Anthony et al. as well as independent soil profiles for validation (classified as mineral soils or peatlands). All of the independent validation points are known to be located in alases or thermoerosional gullies.



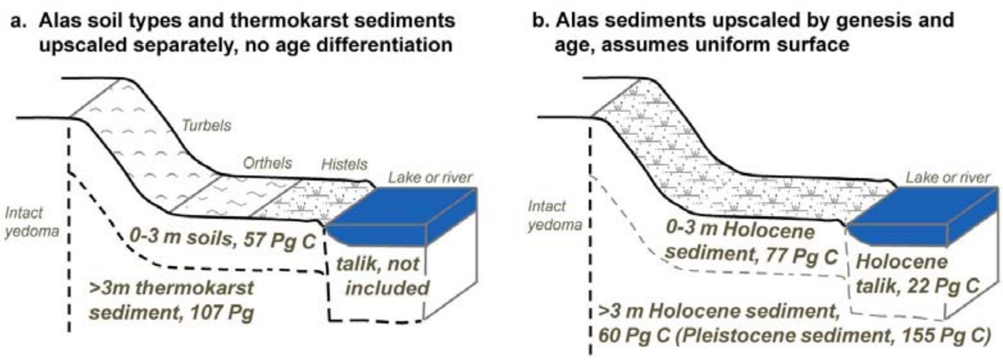


Figure 2. Conceptual diagram illustrating how organic soil/sediment C in Yedoma region alases is described and estimated by **(a)** Hugelius et al. (2014) and **(b)** by Walter Anthony et al. (2014). The graph depicts a Yedoma region alas, including its slopes and any thermoerosional gullies, with ~~15~~14% water coverage. In **(a)** ~~the~~all numbers are derived from Hugelius et al. (2014). The near surface ~~(,~~ 0-3 m~~)~~, soil carbon stocks ~~are~~ (57 Pg C) were extracted from the NCSCDv2, ~~deeper~~thermokarst sediment carbon storage ~~is modified~~below 3 m depth (107 Pg C) was calculated based on data from Strauss et al. (2013) and subaqueous sediments, which are typically non-permafrost, ~~are~~were not included. ~~In~~

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(b) carbon stocks are upscaled based on sedimentary facies descriptions which account for the age and genesis of sediment. Walter Anthony et al. (2014) does not actually separate near surface and subaqueous Holocene sediments in upscaling but in (b) these different compartments are shown to enable comparison to (a). Note that the in **(a)** the soil surface is subdivided to represent the areal coverage of different soil classes used in upscaling: Turbels 69%, Orthels 19% and Histels 13%.

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In **(b)** all numbers are derived from Walter Anthony et al. (2014) where carbon stocks are upscaled based on sedimentary facies descriptions which account for the age and genesis of sediment. Walter Anthony et al. (2014) do not actually separate near surface and subaqueous Holocene sediments in upscaling but in **(b)** these different compartments are shown to enable comparisons. The Pleistocene sediment C pool of 155 Pg C in **(b)** can be subdivided into 23 Pg C stored in subaqueous sediments and 132 Pg C stored in terrestrial sediments within 10 m of the soil surface. See the online supplementary methods for details of calculations.