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Ideas and perspectives: why Holocene thermokarst sediments of the Yedoma region do not increase the northern peatland carbon pool

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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. Secondly, independent field data and geospatial analyses show that the Siberian Yedoma regions 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 statements made in Walter Anthony et al. (2014) 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.

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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 (updated from Strauss et al., 2013). 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 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 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 deposits in alases of the Yedoma region.

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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 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 and quantification of 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 which can be considered as 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 Supplement 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. (2009), Hugelius et al. (2013a, b, 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. The calculations assume that all Histels in the NCSCDv2 within the Siberian Yedoma region where located in alases and the remaining alas 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 in this manuscript, 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

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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 US 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 to 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 uses 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, including: (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).

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3.2 Classification of Kolyma lowland Holocene thermokarst sediments

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 "Stratified 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 to 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 use of imprecise terminology has caused misleading comparisons in relation to previous stock estimates. These deposits are very different from definitions of peat as being primarily organic material, usually of sedentary 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 mineral alas sediments known to be of Holocene age.

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3.3 The extent of organic soils in the Siberian Yedoma Region

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. 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; Sect. 3.5 in the Supplement). Here we evaluate these statements against independent analyses of geospatial datasets and field inventory data. Both these sources 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 peatland coverage estimated from independent geospatial databases of 3 to 6 % (Fig. 1). It is notable that the degree of overlap between independent datasets is limited, indicative of difficulties with classifications and differences in 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 $\geq 1.3 \pm 1.1$ 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 m).

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).

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 formed into 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.

3.4 Overlap between soil C estimates in Yedoma region alases

Spatial overlap between different studies of soil carbon stocks may mislead data users and cause significant errors in estimates. 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 typically permafrost deposits. 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 (Tarnocai et al., 2009; Hugelius et al., 2013a, b; 2014) resulting in

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a ~ 20 Pg net increase. However, given that the geographical distribution of the sites in the new estimate by Walter Anthony et al. (2014) is limited to the Kolyma river lowlands (see Fig. 1) we do not consider this estimate more robust than previous estimates.

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. Walter Anthony et al. (2014) provide an account for how these estimates overlap. In brief, earlier studies did not include a pool of OC stored taberites, an in situ thawed, diagenetically altered Yedoma deposit, and applied bootstrapping approaches to calculate OC stocks while Walter Anthony et al. (2014) use arithmetic means. There is currently an Action Group of the International Permafrost Association dedicated to more in-depth analyses and synthesis on the extent and properties of Yedoma region sediments (led by Dr. J. Strauss, Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research) and this issue is not further discussed here.

4 Conclusions and recommendations

We conclude that Holocene OC stocks in Siberian Yedoma region alases are primarily stored in mineral soils and lacustrine sediments rather than peat. 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 the Holocene carbon dynamics of these ecosystems. We attribute the misunderstandings to 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.

Information about the supplement

The Supplement contains information on the analyses of land cover from different geospatial databases within the Siberian Yedoma region. All the pedons used as independent ground truth sites will be archived in the open access database of the International Soil Carbon Network (http://iscn.fluxdata.org/Pages/default.aspx). Pending publication of data in other venues, all data is available from the authors upon request.

The Supplement related to this article is available online at doi:10.5194/bgd-12-18085-2015-supplement.

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References

Arino, O., Ramos Perez, J. J., Kalogirou, V., Bontemps, S., Defourny, P., and Van Bogaert, E. Global Land Cover Map for 2009 (GlobCover 2009). European Space Agency (ESA) & Université catholique de Louvain (UCL), doi:10.1594/PANGAEA.787668, 2012.

Bartalev, S., Erchov, D., Isaev, A., and Belward, A.: A new SPOT4-Vegetation derived land cover map of Northern Eurasia. Int. J. Remote Sensing, 24, 9, 1977–1982, 2003.
Czudek, T. and Demek, J.: Thermokarst in Siberia and its influence on the development of lowland relief, Quaternary Res., 1, 103–120, 1970.
Grosse, G., Robinson, J. E., Bryant, R., Taylor, M. D., Harper, W., DeMasi, A., Kyker-Snowman, E., Veremeeva, A., Schirrmeister, L., and Harden, J.: Distribution of late Pleistocene ice-rich syngenetic permafrost of the Yedoma Suite in east and central Siberia, Russia, US Geol. Surv. Open File Rep., 1078, 1–37, 2013.
Hopkins, D. M. and Kidd, J. G.: Thaw lake sediments and sedimentary environments, in: Proceedings, Fifth International Conference on Permafrost, Trondheim, Norway, 2–5 August 1988, 790–795, TAPIR Publishers, 1988.
Hugelius, G., Tarnocai, C., Broll, G., Canadell, J. G., Kuhry, P., and Swanson, D. K.: The Northern Circumpolar Soil Carbon Database: spatially distributed datasets of soil coverage and soil carbon storage in the northern permafrost regions, Earth Syst. Sci. Data, 5, 3–13, doi:10.5194/essd-5-3-2013, 2013a.
Hugelius, G., Bockheim, J. G., Camill, P., Elberling, B., Grosse, G., Harden, J. W., Johnson, K., Jorgenson, T., Koven, C. D., Kuhry, P., Michaelson, G., Mishra, U., Palmtag, J., Ping, C.-L., O'Donnell, J., Schirrmeister, L., Schuur, E. A. G., Sheng, Y., Smith, L. C., Strauss, J., and Yu, Z.: A new data set for estimating organic carbon storage to 3 m depth in soils of the northern circumpolar permafrost region, Earth Syst. Sci. Data, 5, 393–402, doi:10.5194/essd-5-393-2013, 2013b.
Hugelius, G., Strauss, J., Zubrzycki, S., Harden, J. W., Schuur, E. A. G., Ping, C.-L., Schirrmeister, L., Grosse, G., Michaelson, G. J., Koven, C. D., O'Donnell, J. A., Elberling, B., Mishra, U., Camill, P., Yu, Z., Palmtag, J., and Kuhry, P.: Estimated stocks of circumpolar permafrost carbon with quantified uncertainty ranges and identified data gaps, Biogeosciences, 11, 6573–6593, doi:10.5194/bg-11-6573-2014, 2014.
IUSS Working Group WRB: World Reference Base For Soil Resources 2006: First Update 2007, Rep., 103, Food and Agric. Organ., U. N., Rome, 2007.
Joosten H and Clarke D: Wise Use of Mires and Peatlands, International Mire Conservation Group and International Peat Society, Saarijärvi, 2002.
Kanevskiy, M., Jorgenson, T., Shur, Y., O'Donnell, J. A., Harden, J. W., Zhuang, Q., and Fortier, D.: Cryostratigraphy and Permafrost Evolution in the Lacustrine Lowlands of West-Central Alaska. Permafrost Periglac., 25, 14–34, doi:10.1002/ppp.1800, 2014.

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Kivinen, E. and Pakarinen, P.: Geographical distribution of peat resources and major peatland complex types in the world, Annales Academiae Scientarium Fennicae, Series A III, Geologica-Geographica, 132, 1981.

Lappalainen, E.: Global Peat Resources, International Peat Society, Finland, 53–281, 1996.

Lehner, B. and Döll, P.: Development and validation of a global database of lakes, reservoirs and wetlands, J. Hydrol., 296, 1–22, 2004.

Loisel, J., Yu, Z., Beilman, D. W., Camill, P., Alm, J., Amesbury, M. J., Anderson, D., Andersson, S., Bochicchio, C., Barber, K., Belyea, L. R., Bunbury, J., Chambers, F. M., Charman, D. J., De Vleeschouwer, F., Fiałkiewicz-Kozieł, B., Finkelstein, S. A., Gałka, M., Garneau, M., Hammarlund, D., Hinchcliffe, W., Holmquist, J., Hughes, P., Jones, M. C., Klein, E. S., Kokfelt, U., Korhola, A., Kuhry, P., Lamarre, A., Lamentowicz, M., Large, D., Lavoie, M., MacDonald, G., Magnan, G., Mäkilä, M., Mallon, G., Mathijssen, P., Mauquoy, D., McCarroll, J., Moore, T. R., Nichols, J., O'Reilly, B., Oksanen, P., Packalen, M., Peteet, D., Richard, P. J. H., Robinson, S., Ronkainen, T., Rundgren, M., Sannel, A. B. K., Tarnocai, C., Thom, T., Tuittila, E.-S., Turetsky, M., Väliranta, M., van der Linden, M., van Geel, B., van Bellen, S., Vitt, D., Zhao, Y., Zhou, W.: A database and synthesis of northern peatland soil properties and Holocene carbon and nitrogen accumulation, Holocene, 24, 1028–1042, doi:10.1177/0959683614538073, 2014.

Morgenstern, A., Ulrich, M., Günther, F., Roessler, S., Fedorova, I. V., Rudaya, N. A., Wetterich, S., Boike, J., and Schirrmeister, L.: Evolution of thermokarst in East Siberian ice-rich permafrost: a case study, Geomorphology, 201, 363–379, 2013.

Murton, J. B.: Thermokarst-lake-basin sediments, Tuktoyaktuk Coastlands, western arctic Canada, Sedimentology, 43, 737–760, 1996.

National Wetlands Working Group: The Canadian Wetland Classification System, 2nd Edition, edited by: Warner, B. G. and Rubec, C. D. A., Wetlands Research Centre, University of Waterloo, Waterloo, ON, Canada., 68 pp., 1997.

Nilsson, S., Stolbovoi, V., and Shvidenko, A.: Land cover, Land Resources of Russia CD-ROM version 1.1, copyright IIASA and Russian Academy of Sciences, available at: http://webarchive.iiasa.ac.at/Research/FOR/russia_cd/download.htm (last access: 13 March 2015), 2002.

Palmtag, J., Hugelius, G., Lashchinskiy, N., Tamstorf, M. P., Richter, A., Elberling, B., and Kuhry, P.: Storage, landscape distribution, and burial history of soil organic matter in contrasting areas of continuous permafrost, Arct. Antarct. Alp. Res., 47, 71–88, doi:10.1657/AAAR0014-027, 2015

Rydin, H. and Jeglum, J.: The Biology of Peatlands, 2nd Edition, Oxford University Press, Oxford, UK, 382 pp., 2013.

Schirrmeister, L., Grosse, G., Wetterich, S., Overduin, P. P., Strauss, J., Schuur, E. A. G., and Hubberten, H.-W.: Fossil organic matter characteristics in permafrost deposits of the northeast Siberian Arctic, J. Geophys. Res., 116, G00M02, doi:10.1029/2011jg001647, 2011.

Schirrmeister, L., Froese, D., Tumskoy, V., Grosse, G., and Wetterich, S.: Yedoma: Late Pleistocene Ice-Rich Syngenetic Permafrost of Beringia, in: The Encyclopedia of Quaternary Science, vol. 3, edited by: Elias, S. A., Elsevier, Amsterdam, 542–552, 2013.

Schuur, E. A. G., Bockheim, J., Canadell, J. G., Euskirchen, E., Field, C. B., Goryachkin, S. V., Hagemann, S., Kuhry, P., Lafleur, P. M., and Lee, H.: Vulnerability of permafrost carbon to climate change: Implications for the global carbon cycle, BioScience, 58, 701–714, doi:10.1641/B580807, 2008.

Schuur, E. A. G., McGuire, A. D., Schädel, C., Grosse, G., Harden, J. W., Hayes, D. J., Hugelius, G., Koven, C. D., Kuhry, P., Lawrence, D. M., Natali, S. M., Olefeldt, D., Romanovsky, V. E., Schaefer, K., Turetsky, M. R., Treat, C. C., Vonk, J. E.: Climate change and the permafrost carbon feedback, Nature, 520, 171–179, doi:10.1038/nature14338, 2015.

Siewert, M. B., Hanisch, J., Weiss, N., Kuhry, P., Maximov, T. C., Hugelius, G.: Comparing carbon storage of Siberian tundra and taiga permafrost ecosystems at very high spatial resolution, J. Geophys. Res.-Biogeosciences, J. Geophys. Res.-Biogeo., 120, doi:10.1002/2015JG002999, 2015.

Soil Classification Working Group: The Canadian System of Soil Classification, Agric. Agrifood Can. Publ., vol. 1646, NRC Res., Ottawa, Ont., Canada, 187 pp., 1998.

Soil Survey Staff: Keys to Soil Taxonomy, 11th ed., Nat. Resour. Conserv. Serv., U. S. Dep. of Agric., Washington, D. C., 2010

Stolbovoi, V.: Wetland ecosystems, Land Resources of Russia CD-ROM version 1.1, copyright IIASA and Russian Academy of Sciences, available at: http://webarchive.iiasa.ac.at/Research/FOR/russia_cd/download.htm (last access: 18 March 2015), 2002.

Strauss, J., Schirrmeister, L., Grosse, G., Wetterich, S., Ulrich, M., Herzschuh, U., and Hubberten, H.-W.: The deep permafrost carbon pool of the Yedoma region in Siberia and Alaska, Geophys. Res. Lett., 2013GL058088, doi:10.1002/2013GL058088, 2013.

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Tarnocai, C., Canadell, J. G., Schuur, E. A. G., Kuhry, P., Mazhitova, G., and Zimov, S.: Soil organic carbon pools in the northern circumpolar permafrost region, Global Biogeochem. Cy., 23, GB2023, doi:10.1029/2008GB003327, 2009.

Veremeeva, A. and Gubin, S.: Modern tundra landscapes of the Kolyma Lowland and their evolution in the Holocene. Permafrost Periglacial Process., 20, 399–406, 2009.

Walter Anthony, K. M., Zimov, S. A., Grosse, G., Anthony, P. M., Chapin, F. S. I., Finlay, J. C., Mack, M. C., Davydov, S., Frenzel, P., and Frolking, S.: A shift of thermokarst lakes from carbon sources to sinks during the holocene epoch, Nature, 511, 452–456, 2014.

Wetterich, S., Schirrmeister, L., Andreev, A. A., Pudenz, M., Plessen, B., Meyer, H., Kunitsky, V. V.: Eemian and Late Glacial/Holocene palaeoenvironmental records from permafrost sequences at the Dmitry Laptev Strait (NE Siberia, Russia). Palaeogeogr. Palaeocl., 279, 73–95, 2009.

Zimov, S. A., Davydov, S. P., Zimova, G. M., Davydova, A. I., Schuur, E. A. G., Dutta, K., and Chapin, F. S.: Permafrost carbon: Stock and decomposability of a globally significant carbon pool, Geophys. Res. Lett., 33, L20502, doi:10.1029/2006GL027484, 2006.

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Yedoma region thermokarst and the peatland carbon pool

G. Hugelius et al.

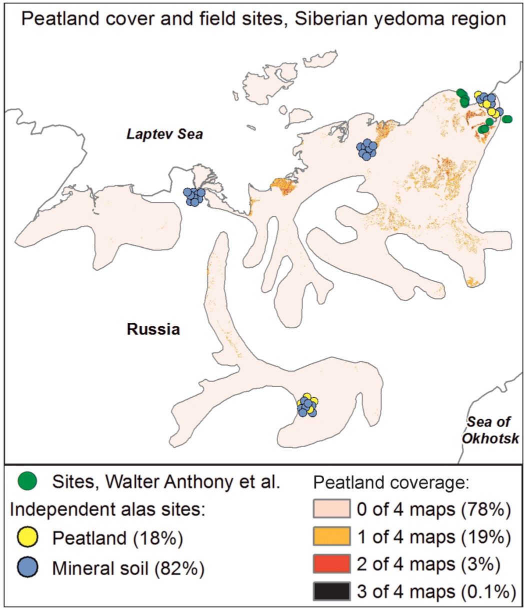

Figure 1. Overview of field sites and estimated coverage of peatlands in the Siberian Yedoma region. Graduated colours within the region show coverage of peatlands in four global/regional map products that are independent from the NCSCD (see Methods). The coverage is shown cumulatively so that the colours 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.

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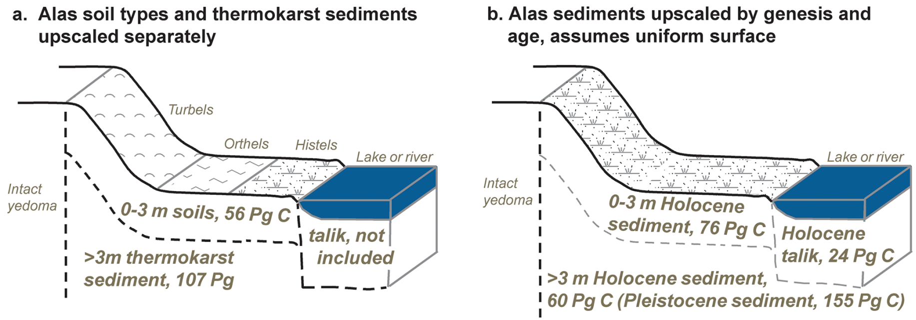

Figure 2. Conceptual diagram illustrating how organic soil/sediment C in Yedoma region alases is described and estimated by **(a)** Hugelius et al. (2014) and **(b)** by Walter Anthony et al. (2014). The graph depicts a Yedoma region alas, including its slopes and any thermoerosional gullies, with 15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