Earth System Science Data Discussions
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The Northern Circumpolar Soil Carbon Database: spatially distributed datasets of soil coverage and soil carbon storage in the northern permafrost regions

G. Hugelius[1], C. Tarnocai[2], G. Broll[3], J. G. Canadell[4], P. Kuhry[1], and D. K. Swanson[5]

[1]Department of Physical Geography and Quaternary Geology, Stockholm University, 106 91 Stockholm, Sweden
[2]Research Branch, Agriculture and Agri-Food Canada, 960 Carling Ave., Ottawa, Ontario K1A0C6, Canada
[3]Institute of Geography, University of Osnabrück, 49069 Osnabrück, Germany
[4]Global Carbon Project, CSIRO Marine and Atmospheric Research, GPO Box 3023, Canberra, ACT 2601, Australia
[5]National Park Service, Fairbanks Administrative Center, 4175 Geist Road, Fairbanks, Alaska 99709, USA

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Abstract

High latitude terrestrial ecosystems are key components in the global carbon (C) cycle. Estimates of global soil organic carbon (SOC), however, do not include updated estimates of SOC storage in permafrost-affected soils or representation of the unique pedogenic processes that affect these soils. The Northern Circumpolar Soil Carbon Database (NCSCD) was developed to quantify the SOC stocks in the circumpolar permafrost region (18.7×10^6 km^2). The NCSCD is a polygon-based digital database compiled from harmonized regional soil classification maps in which data on soil order coverage has been linked to pedon data ($n = 1647$) from the northern permafrost regions to calculate SOC content and mass. In addition, new gridded datasets at different spatial resolutions have been generated to facilitate research applications using the NCSCD (standard raster formats for use in Geographic Information Systems and Network Common Data Form files common for applications in numerical models). This paper describes the compilation of the NCSCD spatial framework, the soil sampling and soil analyses procedures used to derive SOC content in pedons from North America and Eurasia and the formatting of the digital files that are available online. The potential applications and limitations of the NCSCD in spatial analyses are also discussed.

The database has the doi:10.5879/ecds/00000001. An open access data-portal with all the described GIS-datasets is available online at: http://dev1.geo.su.se/bbcc/dev/ncscd/.

1 Introduction

High latitude terrestrial ecosystems are key components in the global carbon (C) cycle (McGuire et al., 2009) and soils in northern permafrost regions store large amounts of soil organic C (SOC) (Schuur et al., 2008). Permafrost is a thermal condition in which ground (soil or rock, including ice and organic material) remains at or below 0 °C for at least two consecutive years (van Everdingen, 1998). Permafrost underlies

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approximately 24 % of the exposed land surface of the Northern Hemisphere (Zhang et al., 1999). Low temperatures and water-logging in permafrost terrain reduces decomposition rates, which has led to the accumulation of large stocks of soil organic carbon (SOC) in mineral permafrost soils and organic soils (Davidson and Janssens, 2006).

The major soil classification systems have some differences in their classification of cold region soils. The US *Soil Taxonomy* (Soil Survey Staff, 1999; used in this study) and the *Canadian System of Soil Classification* (Soil Classification Working Group, 1998) considers the presence of permafrost as a first order classification criterion and groups all permafrost soils as Gelisols or Cryosols, respectively, while unfrozen organic soils are grouped as Histosols. The *World reference base for soil resources* (IUSS Working Group WRB, 2007) considers the presence of thick organic horizons as a first order classification criterion and groups all organic soils as Histosols (with the added prefix Cryic if they are permafrost soils). Permafrost is the second order classification criterion and mineral permafrost soils are classified as Cryosols.

Perennially frozen mineral and organic soils are critical Earth C pools because of their vulnerability to climate change. This vulnerability results from the remobilization of C through permafrost thaw and changed surface hydrological conditions (Gruber et al., 2004). If widespread permafrost thaw occurs, large pools of soil organic matter (SOM) that were previously protected from decomposition may become available for biological decomposition leading to increased greenhouse gas fluxes to the atmosphere from northern environments (Khvorostyanov et al., 2008; Schuur et al., 2009; Schaefer et al., 2011).

Most global SOC mass (SOCM) estimates converge around 1500–1600 Pg C for the top meter of the soil, with an additional 500–900 Pg C stored in the second meter (Eswaran et al., 1993; Batjes, 1996; Jobbagy and Jackson, 2000; Amundson, 2001; Hiederer and Köchy, 2011). However, many global estimates of SOC do not account for pedogenic processes unique to permafrost environments (Tarnocai and Broll, 2008) and the recently updated Harmonised World Soil Database (FAO/IIASA/ISRIC/ISS-CAS/JRC, 2012) does not include a separate classification of permafrost soils.

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Further, the number of pedons available to describe soils of high-latitude/altitude areas is limited. For example, the combined tundra and alpine ecosystems of the world (≈ 8–8.8×10^6 km^2) are represented by 21, 48 and 51 sites in the studies by Schlesinger (1977), Post et al. (1982) and Jobbagy and Jackson (2000), respectively.

The Northern Circumpolar Soil Carbon Database (NCSCD; Tarnocai et al., 2007) was compiled to address this lack of knowledge of the role of permafrost affected soils in the global C cycle. The NCSCD links 1647 pedons from the northern permafrost regions to several digitized regional/national soil maps to produce a combined circumpolar coverage. Together these datasets have been used to quantify SOC storage in the topsoil (0–30 cm depth) and down to a depth of 1 m. Using this database, Tarnocai et al. (2009) estimated SOCM in the northern permafrost region to be 191 Pg for the topsoil and 496 Pg for the upper meter of soil. Based on limited field data, Tarnocai et al. (2009) estimated SOCM to a soil depth of three meters to be 1024 Pg of which Gelisols contributes 818 Pg and Histosols 93 Pg. With larger uncertainty, the SOCM in deeper deposits (> 3 m) are estimated to be 407 Pg for Pleistocene loess deposits (Yedoma deposits) and 241 Pg for deltaic deposits. Altogether, the total estimated SOCM is 1672 Pg, of which 1466 Pg is stored in perennially frozen ground. Based on this study and others, the review by McGuire et al. (2009) provides an estimated range of 1400–1850 Pg C for the combined arctic SOC pool in mineral soils, peatlands, deep alluvial sediments and Yedoma deposits.

Results from these and other studies focusing on SOC storage in permafrost terrain (see also Zimov et al., 2006; Ping et al., 2008a), suggest that estimates of global SOC stocks may underestimate storage in subarctic and arctic ecosystems by a factor of 2 or more. The lower global estimates may be caused by an underestimation of storage in cryoturbated soil horizons (cryoturbation are processes by which organic matter may be transported into deeper soil layers due to repeated freeze-thaw cycles) and organic soils (e.g., see Bockheim, 2007; Tarnocai and Broll, 2008; Ping et al., 2008b; Tarnocai et al., 2009; Hugelius and Kuhry, 2009, Hugelius et al., 2010, 2011). However, comparison between different studies is difficult, as terminology and definitions differ, as do the

sizes of the upscaling regions. The northern permafrost regions (18.7×10^6 km^2 of land following Brown et al., 1997) used by Tarnocai et al. (2009) include alpine and tundra ecosystems ($\approx 8.8 \times 10^6$ km^2 in global estimates), as well as regions of boreal forest in North America and Siberia (boreal forest cover $\approx 12 \times 10^6$ km^2 in global estimates). The extent of the northern permafrost regions also includes discontinuous permafrost zones, where the majority of the landscape may actually be permafrost-free.

This paper describes the creation of the NCSCD database as a polygon GIS dataset derived from different regional soil maps from around the circumpolar permafrost region (Fig. 1). It also describes a new set off gridded datasets that have been derived from the original polygon-based database to facilitate use of the NCSCD in further research (available as TIFF files and Network Common Data Form files). We also briefly discuss possibilities and potential limitations to the applications of these open access databases in further research.

2 Materials and methods

2.1 Sampling and analyses of soils

The soil map data used for the NCSCD were obtained from different regions/countries (Table 1), these maps were compiled using a variety of methods over a time span of several decades. Efforts were made to harmonize the data; however, some discrepancies still remain.

2.1.1 Soil sampling

North American section: at each site a representative pedon (a three dimensional body of soil) was investigated by digging soil pits measuring 1 m $\times$ 2 m in area and up to 2 m in depth. The soil sampling and soil description methods for the North American pedons were carried out in accordance with the Expert Committee on Soil Survey (1983) and

Soil Survey Staff (1993). Exceptions were made for cryoturbated permafrost-affected mineral soils (Fig. 2). These soils are commonly associated with patterned ground and contain distorted and/or discontinuous horizons. By definition, the pedon includes a whole cycle of the patterned ground (Soil Classification Working Group, 1998). For all pedons, a cross section of at least one meter square was excavated. Excavation of the permafrost section of the pedon was carried out using either a gasoline driven power hammer or the CRREL (also called SIPRIC) corer (Tarnocai, 1993). In cryoturbated permafrost-affected mineral soils, the active layer was generally 50 to 70 cm deep, but excavation extended to more than the one meter depth in order to include the upper permafrost layers, which store considerable amounts of organic carbon. Perennially frozen organic soils (Fig. 3) were sampled with either the CRREL corer or a chain saw that was able to cut out blocks of frozen peat and expose the soil profile (Tarnocai, 1993). Unfrozen organic soils were sampled using a fixed volume peat auger (known as Russian Peat Corer or Mini-Mized MaCauley peat auger, Sheppard et al., 1993).

Eurasian section: the sampling method used in the Eurasian part of the NCSC region was similar to that described above for the active layer of permafrost soils and for unfrozen organic soils. The permafrost layer was sampled by hammering a steel tube into the frozen soil in 5 cm increments and retrieving frozen cores in between hammering. This type of coring leads to a displacement of soil material into the core due to the relatively thick wall of the pipe (resulting in soil cores that are longer than the actual depth of coring), which should be taken into consideration when calculating the sample volume.

2.1.2   Analytical methods

Carbon concentration: for the North American pedons, the SOC concentration (weight %) was determined by using either the Walkley-Black method or the LECO-CHN analyzer (after treating the samples with HCl to remove inorganic carbon). The SOC concentration data generated by the Walkley-Black method is associated primarily with the older samples, but a majority of the North American samples were

analysed using the LECO analyser (Sheldrick, 1984; Carter, 1993 and Soil Survey Staff, 1996).

A variety of methods have been used to determine the SOC concentration for Eurasian pedons. Some of the SOC concentration was determined using the Tyrian (1965) method while others were compatible with the Walkley-Black method (Kogut and Frid, 1993) or the wet acid-dichromate digestion method (Arinushlina, 1970). For mineral horizons in which carbon content had been determined by wet acid-dichromate digestion, the coefficient 1.28 was used to convert data to dry digestion (Kogut and Frid, 1993). For organic horizons, except those in which carbon content had been determined by wet acid-chromium oxide digestion (Arinushlina, 1970; Kogut and Frid, 1993), the carbon content was calculated from Loss-on-Ignition (Dean, 1974) using the coefficient 0.57 (Botch et al., 1995).

Bulk Density: bulk density (BD) for mineral and organic soils was determined by the core sampling method or by the clod method (Culley, 1993). Relatively undisturbed core samples were collected by using a thin metal cylinder pressed into the soil, or by using a fixed volume peat auger, or by using the CRREL sampling tool. In cases where a thicker steel pipe was used (permafrost coring in the Russian pedons), a correction factor was used to compensate for soil displacement from the wall of the pipe when calculating the volume of the core. The cores were generally 4–5 cm in diameter and 5–7 cm in length. These samples were oven dried at 105°C for 2 to 3 days in order to determine the dry weights. The clod method uses undisturbed saran-coated clods to maintain the shape and volume (Soil Survey Staff, 1996). BD was not determined in some routine analyses, so some values had to be determined using pedotransfer functions or rules (Bouma and Van Lanen, 1987). Other commonly used methods were: (1) mean BD was computed for each profile and this BD was used for soil horizons with missing BD data, or (2) mean BD was determined for each textural class (sand, silt and clay) and substituted for all horizons with missing BD data. For some Russian pedons (Usa River Basin, European Russian Arctic), missing BD data was approximated from a relationship between organic carbon content and BD in the range of bulk densities

from 0.40 to 1.80 g cm^{-3} (R^2 = 0.83; Kuhry et al., 2002). For organic horizons of mineral soils a mean bulk density value of 0.135 was adopted (Botch et al., 1995).

Coarse fragments and ice content: the percent distribution of coarse fragments (> 2 mm size) was estimated during the sampling or determined by using the sieve method. Ice content was either estimated or determined by using core samples.

2.2 Soil maps as the spatial database of the NCSCD

The original NCSCD (Tarnocai et al., 2007) consists of 10 regional polygon files (ESRI Arc/INFO shape files). The spatial data covers permafrost affected areas in Alaska, Canada, Contiguous USA (Conus), Europe, Greenland, Iceland, Kazakstan, Mongolia, Russia and Svalbard. The regional or national soil maps that form the base of the NCSCD were compiled for geographic scales ranging from 1 : 250 000 to 1 : 7 500 000 (Table 1), and the NCSCD was not intended to be presented at a scale larger than 1 : 1 000 000.

All of the data for North America and Europe is available in digital form in local soil databases that have been compiled from existing soil survey maps (Table 1). For remote areas in North America, where less detailed survey maps are available, data from other sources, such as pedon, climate and vegetation data, together with Landsat TM satellite imagery, were used to delineate polygons.

Spatial soil information for Russia, Greenland, Iceland, Kazakhstan, Mongolia and Scandinavia including Svalbard was available only as hard copy maps, which had to be digitized (Table 1). During this process, especially in the case of the Russian maps, the map symbols and classification terms had to be translated into English and the soil classification terms had to be converted to the US *Soil Taxonomy* (Soil Survey Staff, 1999). Special meetings of the Cryosol Working Group (International Permafrost Association and IUSS) were held in Europe and North America from 1998 to 2003 to harmonize the data and to ensure that no information loss occurred during translation and data conversion.

2.3 Calculating SOC stocks

The NCSCD provides the spatial framework and the data needed to determine the organic carbon stocks in the soils of the permafrost region. The NCSCD contains many thousands of polygons (> 78 000), with each polygon containing one or more named soils or soil taxa that form the basis for determining the carbon stocks. Representative pedons for each soil taxa (in Eurasia and Greenland; total number of pedons: 609) or named soils (in Canada and United States; total number of pedons: 1169) were selected. These pedons contain all the data needed to calculate soil carbon content (see Eq. 1). The data for the layers that compose each soil (Canada and United States) were entered into the database and were used to calculate the carbon content of each named soil in the polygon while data from pedons of each soil taxa (Eurasia and Greenland) are used to calculate their carbon contents, which were then entered into the database.

The soil organic carbon content (SOCC, kg m^{-2}) was calculated for each of the named soil (Canada and United States) and for the representative pedons for each soil taxa (Eurasia and Greenland) using the formula:

$$SOCC = C \times BD \times T \times (1 - GF) \tag{1}$$

where C = organic carbon (% weight), BD = bulk density (g cm^{-3}), T = depth of soil layer (0–30 cm and 0–100 cm) and CF = coarse fragments and/or segregated ice content (% weight). The SOCC data are then stored in the database to be used for further calculations or to generate carbon content maps.

The SOCM (kg C) was then determined by multiplying the SOCC of the specific soil by the area of each such soil component in the polygon. These data provide information on the SOCM of each soil in each permafrost zone in the northern circumpolar region and for the production of SOCM maps. The areal and SOCC/SOCM attributes were calculated by projecting each region into an Azimuthal equal area projection relevant to that region. Note that the published dataset described in this paper does not

include SOC data from the individual pedons, only the derived calculations of SOCC and SOCM.

2.4 Description of the NCSCD GIS-polygon files

All GIS-analyses have been performed using the ESRI software package ArcGIS 10.0 (ESRI, 2011). Separate polygon files (ESRI ArcMap shape-files) are available for the regions Alaska, Canada, Contiguous USA (Conusus), Europe, Greenland, Iceland, Kazakstan, Mongolia, Russia, Scandinavia and Svalbard. The spatial coverage is limited to polygons that either intersect the extent of permafrost terrain described by Brown et al. (1997) or with > 0 % of Gelisol mapped in the polygon.

Each shape-file is connected to a database (polygon attribute table) that contains data on coverage of different soil types, coverage of non-soil areas as well as calculated SOCM and SOCC for each mapped polygon. See Table 2 for detailed information on the data contained in the polygon attribute tables.

In addition to the separate regional files, a merged polygon shape-file covering the whole circumpolar permafrost region is also available. This file contains all polygons from the separate regions and the full associated data, with the exception of the separate regional ID fields and ESRI identifiers.

The polygon vector files are available in geographic latitude/longitude format (World Geodetic System; datum: WGS84) or projected in the Lambert Azimuthal Equal Area Projection (Datum: WGS84, Units: meters, Longitude of Centre of Projection: = $0°0'0.00''$, Latitude of Centre of Projection: $90°0'0.00''$, False Easting: 0.0, False Northing: 0.0).

2.5 New gridded NCSCD datasets of SOC storage and soil coverage

To facilitate use of the NCSCD for applications requiring gridded GIS-data, selected parts of the data stored in the polygon shape-files have been converted to a common geo-referenced gridded format (also called raster files, based on a rectangular grid of

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pixels that store one data value in each pixel; file format used is TIFF-files) which can be read by most desktop GIS-applications and to the Network Common Data Form format (NetCDF-files). As with the polygon files, the gridded files are available for the separate permafrost affected regions and for the whole circumpolar permafrost region.

The following variables were converted into gridded data: SOCC 0–30 cm depth, SOCC 0–100 cm depth, and percent coverage of Turbels (cryoturbated permafrost soils), Histels (organic permafrost soils), Orthels (non-cryoturbated permafrost-affected mineral soils), Histosols (organic soils without permafrost), other soils (all mineral soils without permafrost), and non-soil areas (see Table 3 for more detailed description of the gridded variables). Each variable is stored in a separate gridded file; to describe the full soil/non-soil coverage in any pixel all five grids describing coverage are needed.

To avoid storing floating-point numbers in the gridded datasets (floating point rasters have larger file sizes) while still maintaining a precision equivalent to one significant decimal of a kg C, the unit hectogram (hg) $C m^{-2}$ was used for the SOCC grids (divide number by ten to get $kg C m^{-2}$). For the circumpolar region there are also grids showing the extent of the permafrost region. To derive some rasters, information from several different polygon attribute table columns were combined.

To minimize errors along polygon edges, initial rasterization was done with a pixel resolution of 100 m. Pixels that stretched across the border of several polygons are assigned the mean value of the affected polygons. The high-resolution (100 m grid-size) rasters were subsequently resampled (using bilinear interpolation) to coarser resolution: 0.012 degree (0.012 degrees longitude are equivalent to 1 km at ≈ 42.5 degrees latitude which is the southernmost extent of the NCSCD) or 1 km pixel size for regional datasets and 0.05, 0.1, 0.25, 0.5 and 1 degree pixel resolution for circumpolar datasets. Datasets are available in geographic latitude/longitude format (World Geodetic System; datum: WGS84) or projected in the Lambert Azimuthal Equal Area Projection. All rasterization and resampling was done using the TIFF data format in the Lambert Azimuthal Equal Area Projection. In the final stages of data processing, files were projected to WGS84 and converted to NetCDF-format.

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3 Discussion

The NCSCD is a scientific resource that can be utilized to determine stocks of SOC in the northern circumpolar permafrost region and to explore carbon-climate feedbacks resulting from its vulnerability to climate change. The spatial base of the NCSCD is polygon shape files originally derived from regional soil classification maps, with a new addition of gridded products to facilitate research applications using such data (TIFF-files and NetCDF-files).

If possible, we recommend researchers to base analyses on the separate regional datasets rather than merged circumpolar datasets. This is because the spatial soil maps for the separate regions are comprised at different times with different methods and at different spatial scales. Before using the NCSCD, refer to the information in Table 1 and consider the given references and scale of regional soil maps for guidance. The NCSCD was compiled at scales intended for analyses at circumpolar or large regional scales, and therefore, any applications of the NCSCD in analysis should be consistent with this and caution needs to be taken when the database is used for local scale analyses (see Kuhry et al., 2010 for examples and discussion).

Map production always includes a degree of generalization, and maps compiled at small scales will be more generalized. The issue is a case of the Modifiable Areal Unit Problem (MAUP) and/or ecological fallacy, both well-known issues in geographical analyses (Openshaw, 1984). The core of MAUP is that geographical analyses of spatially continuous variables impose arbitrary spatial delineations of zones depending on the scale of the analysis. In essence, the soil map polygons of the NCSCD partly reflect the mapping scale and the choices made by scientists/cartographers that made the maps. If the mapping was repeated at a different scale, the results would likely be different. An ecological fallacy occurs when it is inferred that results based on analysis of grouped data (such as a generalized soil map polygon) is valid for individual data points contained within that group or region (Openshaw, 1984). In the context of the NCSCD, this applies to the individual pixel values of the gridded products (TIFF-files

and NetCDF-files). The individual pixels have fixed and relatively high resolution, but the data in them are derived from spatial polygon units of varying resolution and degree of resolution. Therefore, the gridded NCSCD datasets should not be used for local scale analyses based on a small number of pixels. Individual pixel values should rather be seen as reflecting their immediate spatial domain and the conditions in the surrounding region. There are currently no quantitative measures of the uncertainties/errors associated with using the NCSCD to estimate SOC storage. Tarnocai et al. (2009) assigned different confidence levels (ranging from very low to high) to the different partitions of the circumpolar SOCM estimates. Storage in the 0–1 m soil depth for the North American sector was ascribed a confidence level of medium to high (66–80 %) while confidence in the data for the Eurasian sector was set at low to medium (33–66 %) because of data scarcity. In a regional study of SOC storage from the western Russian Arctic, Hugelius (2012) demonstrated that the combined uncertainties in landscape SOC estimates introduced by variability in sampled populations and spatial errors in upscaling maps were within ± 11 % (at a 95 % confidence level). However, uncertainties depend on the landscape complexity and scale of the study, and studies performed at a circumpolar scale are expected to have considerably higher variability and uncertainty.

While there are limitations to potential local scale applications of the NCSCD, the database remains a highly useful scientific asset for spatial analyses covering larger areas. To date, the NCSCD is the only comprehensive dataset dedicated to quantifying the globally significant permafrost C pool of the northern circumpolar region.

4 Data access

The NCSCD is currently hosted by the Bert Bolin Centre for Climate Research at Stockholm University, Sweden. The database has the doi:10.5879/ecds/00000001. An open access data-portal with all the described GIS-datasets is available online at: http://dev1.geo.su.se/bbcc/dev/ncscd/.

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Table 1. Data sources for the soil maps constituting the spatial base of the NCSCD.

Country or region	Scale	Soil map type	Reference
USA[1]	1 : 250 000	Digital	Soil Survey Staff (1997)
Canada	1 : 1 000 000	Digital	Tarnocai and Lacelle (1996)
Russia	1 : 2 500 000	Printed	Fridland (1988); Naumov (1993)
Kazakhstan	1 : 2 500 000	Printed	Uspanov (1976)
Mongolia	1 : 3 000 000	Printed	Dorzhgotov and Nogina (1990)
Greenland	1 : 7 500 000	Printed	Jakobsen and Eiby (1997)
Scandinavia[2]	1 : 1 000 000	Digital	European Soil Bureau (1999)
Iceland	1 : 1 500 000	Printed	Arnalds and Gretarsson (2001)

[1] Includes Alaska and the lower contiguous USA
[2] Includes Svalbard

Table 2. Description of the data contained in the polygon attribute tables of NCSCD. The table gives a description of the data, the column field name, the precision of numeric fields (Prec) the data format the variable is stored in (Form: F = float numeric field, I = integer numeric field, S = string) and the number of decimal values of float numeric fields (Dec).

Description	Fieldname	Prec	Form	Dec
Area of Polygon (m^2)	AREA	14	F	3
Perimeter (m)	PERIMETER	14	F	3
Internal ESRI #	Varies	5	I	–
Internal ESRI ID	Varies	5	I	–
Link to original source*	Varies	5	I	–
Gelisol % of polygon	GELISOL_PCT	3	I	–
Histosol % of polygon	HISTOSOL_PCT	3	I	–
Mollisol % of polygon	MOLLISOL_PCT	3	I	–
Vertisol % of polygon	VERTISOL_PCT	3	I	–
Aridisol % of polygon	ARIDISOL_PCT	3	I	–
Andisol % of polygon	ANDISOL_PCT	3	I	–
Entisol % of polygon	ENTISOL_PCT	3	I	–
Ultisol % of polygon	ULTISOL_PCT	3	I	–
Spodosol % of polygon	SPODOSOL_PCT	3	I	–
Inceptisol % of polygon	INCEPTISOL_PCT	3	I	–
Alfisol % of polygon	ALFISOL_PCT	3	I	–
Natric soils % of polygon	NATRIC_PCT	3	I	–
Aqu soils % of polygon	AQU_PCT	3	I	–
Water % of polygon	WATER_PCT	3	I	–
Rockland % of polygon	ROCKLAND_PCT	3	I	–
Glacier % of polygon	GLACIER_PCT	3	I	–
Miscellaneous % of polygon	MISC_PCT	3	I	–
Gelisol-Turbel % of polygon	TURBEL_PCT	3	I	–
Gelisol-Orthel % of polygon	ORTHEL_PCT	3	I	–
Gelisol-Histel % of polygon	HISTEL_PCT	3	I	–
Total	TOTAL_PCT	3	I	–
Permafrost extent	EXTENT	4	S	–
Gelisol area (m^2)	GE_AREA	16	F	1
Alfisol area (m^2)	AL_AREA	16	F	1
Entisol area (m^2)	EN_AREA	16	F	1
Inceptisol area (m^2)	IN_AREA	16	F	1
Spodosol area (m^2)	SP_AREA	16	F	1
Natric soils area (m^2)	NA_AREA	16	F	1
Aqu soil area (m^2)	AQ_AREA	16	F	1
Vertisol area (m^2)	VE_AREA	16	F	1
Mollisol area (m^2)	MO_AREA	16	F	1
Histosol area (m^2)	HI_AREA	16	F	1
Aridisol area (m^2)	AR_AREA	16	F	1
Andisol area (m^2)	AN_AREA	16	F	1
Ultisolarea(m^2)	UL_AREA	16	F	1
Turbel area (m^2)	GET_AREA	16	F	1
Orthel area (m^2)	GEO_AREA	16	F	1
Histel area (m^2)	GEH_AREA	16	F	1
Rockland area (m^2)	ROCK_AREA	16	F	1

Table 2. Continued.

Description	Fieldname	Prec	Form	Dec
Glacier area (m^2)	GLACIER_AREA	16	F	1
Miscellaneous area (m^2)	MISC_AREA	16	F	1
SOCM 30 cm depth Gelisol (kg)	GE_30SOCM	16	F	1
SOCM 30 cm depth Alfisol (kg)	AL_30SOCM	16	F	1
SOCM 30 cm depth Entisol (kg)	EN_30SOCM	16	F	1
SOCM 30 cm depth Inceptisol(kg)	IN_30SOCM	16	F	1
SOCM 30 cm depth Spodosol(kg)	SP_30SOCM	16	F	1
SOCM 30 cm depth Natric (kg)	NA_30SOCM	16	F	1
SOCM 30 cm depth Aqu soils(kg)	AQ_30SOCM	16	F	1
SOCM 30 cm depth Vertisol (kg)	VE_30SOCM	16	F	1
SOCM 30 cm depth Mollisol (kg)	MO_30SOCM	16	F	1
SOCM 30 cm depth Histosol (kg)	HI_30SOCM	16	F	1
SOCM 30 cm depth Aridisol (kg)	AR_30SOCM	16	F	1
SOCM 30 cm depth Andisol (kg)	AN_30SOCM	16	F	1
SOCM 30 cm depth Ultisol (kg)	UL_30SOCM	16	F	1
SOCM 30 cm depth Turbel (kg)	GET_30SOCM	16	F	1
SOCM 30 cm depth Orthel (kg)	GEO_30SOCM	16	F	1
SOCM 30 cm depth Histel (kg)	GEH_30SOCM	16	F	1
SOCM 100 cm depth Gelisol (kg)	GE_100SOCM	16	F	1
SOCM 100 cm depth Alfisol (kg)	AL_100SOCM	16	F	1
SOCM 100 cm depth Entisol (kg)	EN_100SOCM	16	F	1
SOCM 100 cm depth Inceptisol (kg)	IN_100SOCM	16	F	1
SOCM 100 cm depth Spodosol (kg)	SP_100SOCM	16	F	1
SOCM 100 cm depth Natric (kg)	NA_100SOCM	16	F	1
SOCM 100 cm depth Aqu (kg)	AQ_100SOCM	16	F	1
SOCM 100 cm depth Vertisol (kg)	VE_100SOCM	16	F	1
SOCM 100 cm depth Mollisol (kg)	MO_100SOCM	16	F	1
SOCM 100 cm depth Histosol (kg)	HI_100SOCM	16	F	1
SOCM 100 cm depth Aridisol (kg)	AR_100SOCM	16	F	1
SOCM 100 cm depth Andisol (kg)	AN_100SOCM	16	F	1
SOCM 100 cm depth Ultisol (kg)	UL_100SOCM	16	F	1
SOCM 100 cm depth Turbel (kg)	GET_100SOCM	16	F	1
SOCM 100 cm depth Orthel (kg)	GEO_100SOCM	16	F	1
SOCM 100 cm depth Histel (kg)	GEH_100SOCM	16	F	1
SOCC 30 cm depth polygon (kg m^{-2})	SOCC_30CM	8	F	1
SOCC 100 cm depth polygon (kg m^{-2})	SOCC_100CM	8	F	1
Soil Area (m^2)	SOIL_AREA	16	F	1
SOCM 30 cm depth polygon (kg)	SOCM_30CM	16	F	1
SOCM 100 cm depth polygon (kg)	SOCM_100CM	16	F	1

[*] This polygon-identification field is only found in the regional polygon datasets, not in the merged Circumpolar dataset. Also note that the field has different names in different regions (e.g. SMU/MUID/MAPUNIT_ID etc.), the different fieldnames correspond to the nomenclature used when digitizing that specific regional soil map.

Table 3. Description of the NCSCD variables that have been converted to gridded file formats (TIFF-files and NetCDF-files). Each variable is stored in a separate gridded file; to describe the full soil/non-soil coverage in any pixel all five grids describing coverage are needed.

| Variable	Description
SOCC 0–30 cm depth	SOCC (hgC m^{-2}) in the 0–30 cm depth interval
SOCC 0–100 cm depth	SOCC (hgC m^{-2}) in the 0–100 cm depth interval
Coverage Turbels	Coverage (%) of cryoturbated permafrost soils
Coverage Histels	Coverage (%) of organic permafrost soils
Coverage Orthels	Coverage (%) of mineral, non-cryoturbated permafrost soils
Coverage Histosols	Coverage (%) of organic soils (permafrost free)
Coverage Other soils	Coverage (%) of all permafrost free mineral soil taxa
Coverage non-soil	Coverage (%) of non-soil areas (i.e. water, rockland, glacier and misc.)
Extent of permafrost region	Mask for pixels that fall within the NCSCD permafrost extent
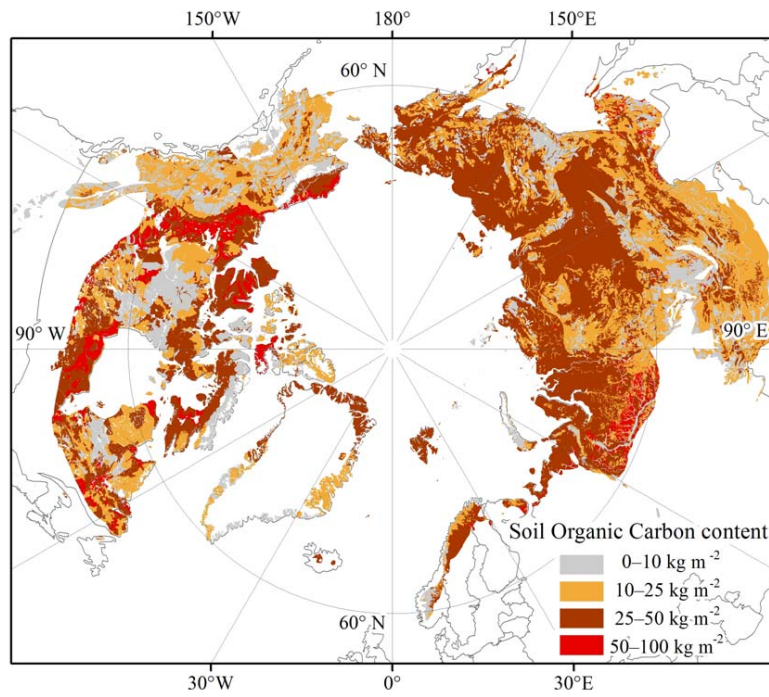
Fig. 1. Map showing the spatial extent of the NCSCD and the estimated SOCC to a depth of 1 m.

Fig. 2. Example of strongly cryoturbated, perennially frozen, mineral soil (Turbel). This soil is associated with the earth hummock type of patterned ground. It contains large concentrations of cryoturbated organic materials (the black areas) in the subsoil and has a high ice content.

Fig. 3. Example of perennially frozen organic soil (Histel) developed on moss peat with a high ice content (white areas) in the subsoil.

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