Active Layer Soil Carbon and Nutrient Mineralization, Barrow, Alaska, 2012

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Summary:

This data set consists of bulk soil characteristics as well as carbon and nutrient mineralization rates of active layer soils manually collected from the field in August, 2012, frozen, and then thawed and incubated across a range of temperatures in the laboratory for 28 day periods in 2013-2015.

The soils were collected from four replicate polygons in each of the four Areas (A, B, C, and D) of Intensive Site 1 at the Next-Generation Ecosystem Experiments (NGEE) Arctic site near Barrow, Alaska. Soil samples were coincident with the established Vegetation Plots that are located in center, edge, and trough microtopography in each polygon.

Data included are 1) bulk soil characteristics including carbon, nitrogen, gravimetric water content, bulk density, and pH in 5-cm depth increments and also by soil horizon, 2) carbon, nitrogen, and phosphorus mineralization rates for soil horizons incubated aerobically (and in one case both aerobically and anaerobically) for 28 days at temperatures that included 2, 4, 8, and 12 degrees C.

Additional soil and incubation data are forthcoming. They will be available when published as part of another paper that includes additional replicate analyses.

Please use this citation to reference the data.

Iversen C.M., H.M. Vander Stel, R.J. Norby, V.L. Sloan, J. Childs, D.J. Brice, J.K. Keller, A. Jong, M.P. Ladd, S.D. Wullschleger. 2015. Active Layer Soil Carbon and Nutrient Mineralization, Barrow, Alaska, 2012. Next Generation Ecosystem Experiments Arctic Data Collection, Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tennessee, USA. Data set accessed at http://dx.doi.org/10.5440/1185213.

Users are requested to also reference the following publications when these data are used. Please see Data Characteristics for details.

- **Treat, C.C**., S.M. Natali, J. Ernakovich, C.M. Iversen, M. Lupascu, A.D. McGuire, R.J. Norby, T.R. Chowdhury, A. Richter, H. Santruckova, C. Schädel, E.A.G. Schuur, V.L. Sloan, M.R. Turetsky, M.P. Waldrop. 2015. A pan-Arctic synthesis of CH_4 and CO_2 production from anoxic soil incubations. *Global Change Biology* 21: 2787-2803. doi: 10.1111/gcb.12875

- **Schädel** C, Bader MKF, Schuur EAG, Bracho R, Capek P, De-Baets S, Diakova K, Ernakovich J, Estop-Aragones C, Hartley IP, Iversen CM, Kane E, Knoblauch C, Lupascu M, Natali S, Norby RJ, Donnell J, Roy Chowdhury T, Santruckova H, Shaver G, Sloan VL, Treat C, Waldrop M, Wickland K. 2015. Dominant role of landscape hydrology in controlling the permafrost carbon feedback. *Nature Climate Change, submitted*.

Data Characteristics

There are currently two comma-separated (.csv) files with this data set. These data files are the results of two (out of a total of four) replicate studies that are part of a larger research effort and were specifically used in two publications.

The first data file (replicate study) was used in the Treat et al., 2015 paper:

- The first replicate study included soil from multiple soil horizons incubated for 28 days at 2 and 12 degrees C, both aerobically and anaerobically,

The <u>first and second</u> data files (replicate studies) were both used in the Schädel et al., 2015 paper:

- The second replicate study included soil incubated for 28 days at 4, 8, and 12 degrees C, aerobically only.

Please cite the appropriate reference(s), as listed above, depending upon the data file(s) you use in subsequent analyses.

The **final two replicate studies** (conducted in a manner similar to the second replicate) will be forthcoming once data have been published as part of another paper that includes all replicates in a complete analysis.

Data Files:

The data set includes the following:

1. Treat_and_Schädel_NGEE_Arctic_Barrow_Soil_Incubations_2012.csv

2. Schädel_NGEE_Arctic_Barrow_Soil_Incubations_2012.csv

Data Dictionary

1. **Data dictionary corresponding to:**
   Treat_and_Schädel_NGEE_Arctic_Barrow_Soil_Incubations_2012.csv

column_name	units/format	Description
Region*		North Slope
Locale*		Barrow, Alaska
Administrative_area*		BEO (Barrow Environmental Observatory)
Site*		Intensive Site 1
Plot_type*		Vegetation
Polygon_type*		Area A has low-centered polygons, B has high-centered polygons, C has flat-centered polygons, and D has poorly-defined polygons.
Plot_ID		Unique identifier for each plot (area, replicate polygon number in each area, and microtopographic position)
Area*		Area A has low-centered polygons, B has high-centered polygons, C has flat-centered polygons, and D has poorly-defined polygons.
Polygon_ID*		Replicate polygon within a given area (4 replicates in total).
Microtopography*		The microtopographic position in the polygon where the sample was taken. Values: center (C), edge (E), trough (T).
Latitude	Decimal degrees	Latitude
Longitude	Decimal degrees	Longitude
Authors		Unpublished data set contributors for this manuscript effort. Values: Iversen, Sloan, Norby.
Location		Site location (City or Region). Values: Barrow, AK, USA
Ecosystem		Boreal, sub-arctic, or arctic
AL_PF		Whether soils were collected from the surface active layer (AL) or the permafrost layer (PF).
Permafrost_underlain		Was there underlying permafrost, yes (Y) or no (N)?
Zone		Samples taken from - continuous, discontinuous, sporadic or isolated permafrost zone (according to Brown, J., O.J. Ferrians, Jr., J.A. Heginbottom, and E.S. Melnikov, eds. 1997. Circum-Arctic map of

		permafrost and ground-ice conditions. Washington, DC: U.S. Geological Survey in Cooperation with the Circum-Pacific Council for Energy and Mineral Resources. Circum-Pacific Map Series CP-45, scale 1:10,000,000, 1 sheet)?
Site_type		Indicates individual, unique sites for analysis.
Vegetation		Dominant genus and species at each site.
Date_sampled	yyyy-mm-dd	The soil cores used in this incubation were collected between 2012-07-31 and 2012-08-03. The replicate soil core used in this data set was frozen at -20 degrees C until analysis, then thawed and then incubated for 28 days between 2013-01-16 and 2013-02-13.
Thaw_depth	cm	Active layer depth
TS_Date_sampled	°C	Soil temperature averaged over a period of 3 days (2012-08-01 to 2012-08-03) when cores were harvested.
Depth_category		If 'surface', then soils were within 1 m of the surface.
Soil_Horizon		Whether the data in the row are for the organic layer (O) the mineral layer (Mi) or the deep organic layer (DO) of the soil pedon.
Soil_depth_increment	cm	Categorical soil depth increment
Midpoint_depth_of_soil_layer	m	Mid-point of each core section.
Upper_depth_of_soil_layer	m	Depth at top (surface) (including moss layer) of soil increment section.
Lower_depth_of_soil_layer	m	Depth at bottom of soil increment section.
Carbon_concentration_of_soil_layer	%	Percent of soil carbon per soil mass, measured using elemental analyzer.
Nitrogen_concentration_of_soil_layer	%	Percent of soil nitrogen per soil mass, measured using elemental analyzer.
Carbon_to_Nitrogen_ratio_of_soil_layer		Molar C:N ratio from elemental analyzer.

Moisture_content_of_soil_layer	g g^{-1}	Gravimetric water content (mass of water per mass of dry soil).
pH_of_soil_layer		Initial pH of soils before incubation; Conducted on 2:1 distilled water to soil slurry (for mineral soil) or 4:1 distilled water to soil slurry (for organic soil).
Bulk_density_of_soil_layer	g cm^{-3}	Bulk density of soil depth increment.
Incubation_length		Length of the incubation study in days.
Target_Incubation_Temperature	°C	Incubation temperature set on incubators (Thermo Scientific Precision Model 815 Incubator, Marietta, OH).
CH_4_measured		Was methane (CH_4) measured, yes (Y) or no (N)?
CO_2_measured		Was carbon dioxide (CO_2) measured, yes (Y) or no (N)?
Day_of_Incubation		Measurement day (if multiple measurements over incubation period).
CH_4_per_g_C	µg CH_4-C g C^{-1} $hour^{-1}$	CH_4 production rate per g soil carbon over a given period of the incubation (e.g., between days 1 and 3).
CH_4_per_g_dry weight	µg CH_4-C g dry $weight^{-1}$ $hour^{-1}$	CH_4 production rate per g dry soil over a given period of the incubation (e.g., between days 1 and 3).
CO_2_per_g_C	µg CO_2-C g C^{-1} $hour^{-1}$	CO_2 production rate per g soil carbon over a given period of the incubation (e.g., between days 1 and 3).
CO_2_per_g_dry weight	µg CO_2-C g dry $weight^{-1}$ $hour^{-1}$	CO_2 production rate per g dry soil over a given period of the incubation (e.g., between days 1 and 3).

2. Data dictionary corresponding to:
Schädel_NGEE_Arctic_Barrow_Soil_Incubations_2012.csv

Column_name	Units/format	Description
Region*		North Slope

Column_name	Units/format	Description
Locale*		Barrow, Alaska
Administrative_area*		BEO (Barrow Environmental Observatory)
Site*		Intensive Site 1
Plot_type*		Vegetation
Polygon_type*		Area A has low-centered polygons, B has high-centered polygons, C has flat-centered polygons, and D has poorly-defined polygons.
Plot_ID		Unique identifier for each plot (area, replicate polygon number in each area, and microtopographic position)
Area*		Area A has low-centered polygons, B has high-centered polygons, C has flat-centered polygons, and D has poorly-defined polygons.
Polygon_ID*		Replicate polygon within a given area (4 replicates in total).
Microtopography*		The microtopographic position in the polygon where the sample was taken. Values: center (C), edge (E), trough (T).
Latitude	Decimal degrees	Latitude
Longitude	Decimal degrees	Longitude
Authors		Unpublished data set contributors for this manuscript effort. Values: Iversen, Sloan, Norby.
Data_provider		Data set provider for this manuscript effort. Values: Iversen
Location		Site location (City or Region). Values: Barrow, AK, USA
Ecosystem		Broad ecosystem description from reference.

Column_name	Units/format	Description
Permafrost_zone		Samples taken from - continuous, discontinuous, sporadic or isolated permafrost zone (according to Brown, J., O.J. Ferrians, Jr., J.A. Heginbottom, and E.S. Melnikov, eds. 1997. Circum-Arctic map of permafrost and ground-ice conditions. Washington, DC: U.S. Geological Survey in Cooperation with the Circum-Pacific Council for Energy and Mineral Resources. Circum-Pacific Map Series CP-45, scale 1:10,000,000, 1 sheet)?
Vegetation_species		Species listed if provided from literature.
Date_sampled	yyyy-mm-dd	The soil cores used in this incubation were collected between 2012-07-31 and 2012-08-03. The replicate soil core used in this data set was frozen at -20 degrees C until analysis, thawed and then incubated for 28 days between 2014-07-08 and 2014-08-05.
Thaw_depth	cm	Active layer depth
Soil_Horizon		Whether the data in the row are for the organic layer (O) the mineral layer (Mi) or the deep organic layer (DO) of the soil pedon.
Midpoint_depth_of_soil_layer	cm	Mid-point of each core section.
Upper_depth_of_soil_layer	cm	Depth at top (surface) (including moss layer) of soil increment section.
Lower_depth_of_soil_layer	cm	Depth at bottom of soil increment section.
Carbon_concentration_of_soil_layer	%	Percent of soil carbon per soil mass, measured using elemental analyzer.
Nitrogen_concentration_of_soil_layer	%	Percent of soil nitrogen per soil mass, measured using elemental analyzer.
Carbon_to_nitrogen_ratio_of_soil_layer	ratio	Molar C:N ratio from elemental analyzer.
Bulk_density_of_soil_layer	g cm^{-3}	Bulk density of soil depth increment.

Column_name	Units/format	Description
Moisture_content_of_soil_layer	**%**	Percent soil moisture during incubation.
pH_of_soil_layer	pH units	Initial pH of soils before incubation; Conducted on 2:1 distilled water to soil slurry (for mineral soil) or 4:1 distilled water to soil slurry (for organic soil).
Incubation_length	Days	Length of the incubation study in days.
Target_Incubation_Temperature	°C	Incubation temperature set on incubators (Thermo Scientific Precision Model 815 Incubator, Marietta, OH).
Anaerob_treat		Soil incubations - aerobic or anaerobic
Day_of_Incubation		Measurement day (if multiple measurements over incubation period).
CO_2_per_g_dry weight	mg C/ g dry weight	Cumulative CO_2 production per g dry soil over a given period of the incubation (e.g., between days 1 and 3). A -9999 indicates missing data – see data quality flag column.
CO_2_per_g_dry weight_fl		Data quality flag for cumulative CO_2 production per g dry soil to indicate missing data. V0 is valid value, M1 is missing value because no value is available (a bad injection on the gas chromatograph).
CO_2_per_g_C	mg C/ g C	Cumulative CO_2 production per g C over a given period of the incubation (e.g., between days 1 and 3). A -9999 indicates missing data – see data quality flag column.
CO_2_per_g_C_fl		Data quality flag for cumulative CO_2 production per g C over a given period of the incubation to indicate missing data. V0 is valid value, M1 is missing value because no value is available (a bad injection on the gas chromatograph).

* Values for these location fields have been standardized for NGEE Arctic and are required fields for all data dictionaries. (http://ngee-arctic.ornl.gov/content/metadata-entry-data-upload-and-data-management-help)

Footnotes:
These data columns correspond to a data file provided for data submitted for two publications (Treat *et al*., 2015 and Schädel *et al*., 2015) that focused solely on carbon cycling, with specific parameters of interest, and included only one replicate each of the full data set collected in this effort. These data will be updated and additional categories will become available for the full data set (e.g., ammonification, nitrification, and phosphorus mineralization rates and initial pool sizes).

Example Data Records:

Treat_and_Schädel_NGEE_Arctic_Barrow_Soil_Incubations_2012.csv

Region,Locale,Administrative_area,Site,Plot_type,Polygon_type,Plot_ID,Area,Polygon_ID,Microtopography,Latitude,Longitude,Authors,Location,Ecosystem,AL_PF,Permafrost_underlain,Zone,Site_type,Vegetation,Date_Sampled,Thaw_Depth,TS_Date_Sampled,Depth_category,Soil_Horizon,Soil_depth_increment,Midpoint_depth_of_soil_layer,Upper_depth_of_soil_layer,Lower_depth_of_soil_layer,Carbon_concentration_of_soil_layer,Nitrogen_concentration_of_soil_layer,Carbon_to_Nitrogen_ratio_of_soil_layer,Moisture_content_of_soil_layer,pH_of_soil_layer,Bulk_density_of_soil_layer,Incubation_length,Target_Incubation_Temperature,CH4_measured,CO2_measured,Day_of_Incubation,CH4_per_g_C,CH4_per_g_dry weight,CO2_per_g_C,CO2_per_g_dry weight
,,,,,,,,number,,Decimal_degrees,Decimal_degrees,,,,,,number,,yyyy-mm-dd,cm,degrees_C,,,cm,m,m,m,percent,percent,ratio,g_water_per_g_dry_soil,pH_units,g_per_cm3,days,degrees_C,,,day,microg_C_per_g_C_per_hour,microg_C_per_g_soil_per_hour,microg_C_per_g_C_per_hour,microg_C_per_g_soil_per_hour
North Slope,Barrow,BEO,Intensive Site 1,Vegetation,Low-centered polygons,A3C,A,3,C,71.281637,-156.610314,Iversen_Sloan_Norby,Barrow_AK_USA,Arctic,AL,Y,Continuous,1,"Carex aquatilis, Sarmenthypnum sarmentosum",2012-08-01,37.6,5.79,Surface,O,0-5,0.03,0.00,0.05,33.71,2.06,16.33,3.18,5.39,0.25,28,2,Y,Y,1,0.00,0.00,5.78,1.95
North Slope,Barrow,BEO,Intensive Site 1,Vegetation,Low-centered polygons,A3C,A,3,C,71.281637,-156.610314,Iversen_Sloan_Norby,Barrow_AK_USA,Arctic,AL,Y,Continuous,1,"Carex aquatilis, Sarmenthypnum sarmentosum",2012-08-01,37.6,5.79,Surface,M,5-7,0.06,0.05,0.07,20.34,1.05,19.37,1.79,5.25,0.42,28,2,Y,Y,1,0.00,0.00,1.50,0.30

Schädel_NGEE_Arctic_Barrow_Soil_Incubations_2012.csv

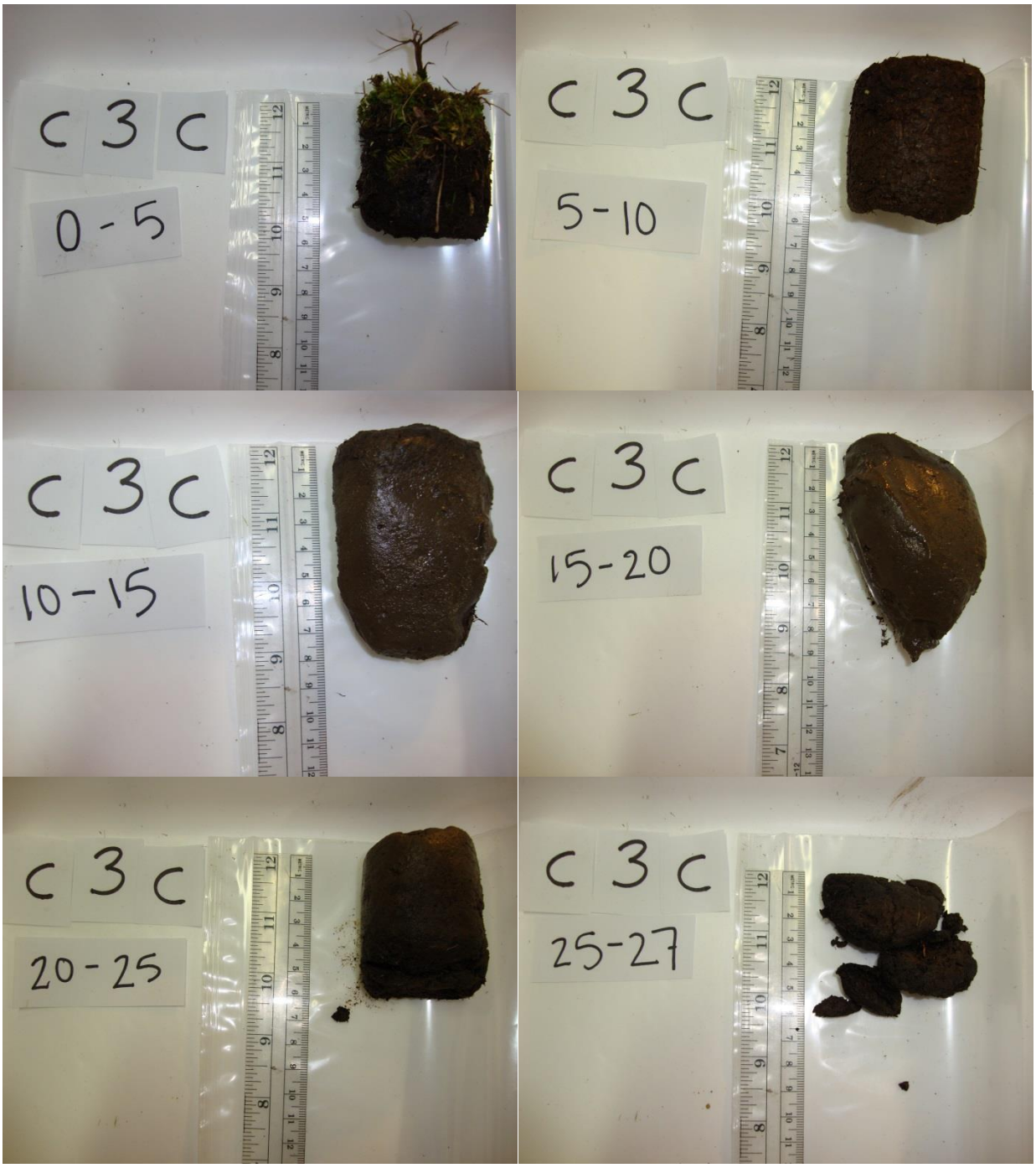
Region,Locale,Administrative_area,Site,Plot_type,Polygon_type,Plot_ID,Area,Polygon_ID,Microtopography,Latitude,Longitude,Authors,Data_provider,Location,Ecosystem,Permafrost_Zone,Vegetation_species,Date_sampled,Thaw_Depth,Soil_Horizon,Midpoint_depth_of_soil_layer,Upper_depth_of_soil_layer,Lower_depth_of_soil_layer,Carbon_concentration_of_soil_layer,Nitrogen_concentration_of_soil_layer,Carbon_to_nitrogen_ratio_of_soil_layer,Bulk_density_of_soil_layer,Moisture_content_of_soil_layer,pH_of_soil_layer,Incubation_Length,Target_Incubation_T

emperature,Anaerob_Treat,Day_of_Incubation,CO2_per_g_dry weight,CO2_per_g_dry weight_fl,CO2_per_g_C,CO2_per_g_C_fl
,,,,,,,,,Decimal_degrees,Decimal_degrees,,,,,,yyyy-mm-dd,cm,,cm,cm,cm,percent,percent,Ratio,g_per_cm3,percent,pH_units,Days,degrees_C,,Day,mg_C_per_g_dry_soil,,mg_C_per_g_C,
North Slope,Barrow,BEO,Intensive Site 1,Vegetation,Low-centered polygons,A1C,Area A,1,C,71.280867,-156.611606,Iversen_Sloan_Norby,Iversen,Barrow_AK_USA,Tundra,Continuous,Carex aquatilis,2012-08-01,36.8,O,7.5,0,15,42.94,2.66,16.17,0.18,409.21,5.37,28,4,Aerobic,1,1.91,V0,4.45,V0
North Slope,Barrow,BEO,Intensive Site 1,Vegetation,Low-centered polygons,A1C,Area A,1,C,71.280867,-156.611606,Iversen_Sloan_Norby,Iversen,Barrow_AK_USA,Tundra,Continuous,Carex aquatilis,2012-08-01,36.8,O,7.5,0,15,42.94,2.66,16.17,0.18,409.21,5.37,28,8,Aerobic,1,3.85,V0,8.95,V0
North Slope,Barrow,BEO,Intensive Site 1,Vegetation,Low-centered polygons,A1C,Area A,1,C,71.280867,-156.611606,Iversen_Sloan_Norby,Iversen,Barrow_AK_USA,Tundra,Continuous,Carex aquatilis,2012-08-01,36.8,O,7.5,0,15,42.94,2.66,16.17,0.18,409.21,5.37,28,12,Aerobic,1,3.41,V0,7.95,V0

Data Acquisition Materials and Methods

At peak growing season in late July, 2012, we manually collected soil cores to the permafrost boundary across gradients of polygonal tundra and microtopographic position on the Barrow Environmental Observatory. Soil samples were collected using a 5.08-cm diameter hammer corer or a tundra knife (to sample 10 cm by 10 cm soil columns) when soil was too wet to retrieve an intact soil sample. Cores were collected in each of four polygon types (poorly defined, low, flat, and high-centered), from the trough, edge, or center microtopographic locations within each polygon (n = 4 polygon types by 4 replicate polygons of each type by 3 microtopographic positions = 48 total soil cores). These locations were within the previously established Vegetation Plots. Upon removal from the soil, the depth of the organic layer was determined as the boundary where soil became largely mineral in texture. The cores were then sectioned into 5 cm increments, placed in separate bags, and kept on blue ice while in the field. When the organic/mineral transition fell within a 5 cm increment, the organic matter and mineral soil were treated separately. Cores were frozen at -20 degrees C before shipping to Oak Ridge National Laboratory, where they were frozen at -20 degrees C until processing.
Given the large number of soil depth increments, processing and month-long soil incubations were performed serially on each replicate polygon (in January 2013, June and September of 2014, and January 2015). For each replicate incubation study, core increments were first thawed overnight at 4 degrees C, then plant material (green moss, fine roots, and rhizomes) was removed and soils were homogenized by hand (organic horizons) or by sieving the soil through an 8-mm sieve (mineral horizons).

Images of the soil core from Plot C3C (Area C, Plot 3, Center of polygon)



The 5-cm depth increments were subsampled for a series of soil characteristics.

- One subsample was used to determine pH using 1:4 or 1:2 ratios of field-moist soil to distilled water for organic and mineral soils, respectively (Beckman 350 pH Meter, Fullerton, CA).
- A second subsample was used for determination of initial extractable ammonium, nitrate, and phosphate by shaking a 1:10 ratio of field-moist soil to 2 M KCl for 1 hour at low speed on a reciprocal shaker. After settling overnight at 4 degrees C, the extractant was filtered through Whatman No.1 filter papers pre-leached with distilled water and frozen at -20 degrees C until analysis for nitrogen and phosphorus on an autoanalyzer (Lachat QuickChem QC8500 Automated Ion Analyzer, Loveland, CO).
- A third subsample was used to determine soil gravimetric water content by drying the soil to a constant mass (3 days) at 70 degrees C.
  AND -- Dried gravimetric water content samples were ground to a fine powder (SPEX SamplePrep 2010 Geno/Grinder, Metuchen, NJ), re-dried, and carbon and nitrogen content were determined on an elemental analyzer (Costech ECS 4010 Elemental Analyzer, Valencia, CA).

To assess soil C and nutrient mineralization response to warming, we incubated soils from three horizons at three temperatures for 28 days.

After initial subsamples were complete,

- We combined 5-cm depth increments into soil horizons: organic, mineral, and deep organic (DO) defined as organic-rich soil near the permafrost boundary.
- We re-sampled these soils for:
  - initial horizon pH, nitrogen and phosphorus, gravimetric water content, and carbon and nitrogen as described above,
- Then approximately 5 g of field-moist soil were sealed into 160-ml serum bottles, which were flushed with compressed air to ensure at least 6 cycles of gas through the headspace. **(Note: the first replicate in January 2013 was incubated both aerobically and anaerobically; the anaerobic incubations were flushed with nitrogen gas rather than compressed air.)**
- Air filled serum bottles served as blanks (6 bottles per replicate) and were incubated with the samples (2 bottles per temperature treatment).
- Bottles were then stored in incubators (Thermo Scientific Precision Model 815 Incubator, Marietta, OH) held at a constant temperature of 4, 8 or 12 degrees C.
- The bottles were sampled on days 1, 3, 7, 14 and 28 of the incubation
- A 1 ml syringe was inserted to the septum and the plunger was pumped vigorously to ensure the air within the bottle was mixed uniformly. A fixed volume of sample (0.4 ml) was collected. Samples were then flushed with air for 6 cycles and returned to the incubators.
- A fixed volume of sample (0.4 ml) was injected into the gas chromatograph (SRI Instruments Greenhouse Gas GC System with 8610C Chassis, Torrance CA) and the methane and carbon dioxide peak areas were recorded.

- For each day of gas chromatography sampling, a set of carbon dioxide (and methane, for anaerobic incubations) standards was run to create a standard curve between carbon content and peak area.
- Following gas chromatograph injection on day 28, the bottle seals were broken, and soil was subsampled for pH, extractable ammonium, nitrate, and phosphate using methods described above.

Carbon mineralization rate was calculated (in both microgram C g $soil^{-1}$ $hour^{-1}$ and microgram C g C^{-1} $hour^{-1}$) for both the incubation time between each sampling day and the total mineralization over the 28 day study.

Nutrient mineralization rate was calculated (microgram nutrient g soil day-1) as the difference between initial and final nutrient content, standardized for soil dry weight.

References

Treat, C.C., S.M. Natali, J. Ernakovich, C.M. Iversen, M. Lupascu, A.D. McGuire, R.J. Norby, T.R. Chowdhury, A. Richter, H. Santruckova, C. Schädel, E.A.G. Schuur, V.L. Sloan, M.R. Turetsky, M.P. Waldrop. 2015. A pan-Arctic synthesis of CH_4 and CO_2 production from anoxic soil incubations. *Global Change Biology* 21: 2787-2803.

Schädel C, M.K.F. Bader, E.A.G. Schuur, R. Bracho, P. Capek, S. De-Baets, K. Diakova, J. Ernakovich, C. Estop-Aragones, I. P. Hartley, C.M. Iversen, E. Kane, C. Knoblauch, M. Lupascu, S. Natali, R. J. Norby, J. Donnell, T. Roy Chowdhury, H. Santruckova, G. Shaver, V.L. Sloan, C. Treat, M. Waldrop, K. Wickland. 2015. Dominant role of landscape hydrology in controlling the permafrost carbon feedback. *Nature Climate Change*, *submitted*.

Data Access:

Disclaimer of Liability

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