Gridded Winter Soil CO2 Flux Estimates for pan-Arctic and Boreal Regions, 2003-2100

Get Data

Documentation Revision Date: 2019-09-12

Dataset Version: 1

Summary

This dataset provides gridded estimates of soil CO2 flux (g C m-2 d-1) for the winter non-growing season (NGS) across pan-Arctic and Boreal permafrost regions (>49 Deg N), at 25 km spatial resolution. The data are the daily average flux over a monthly period for two climate periods: the baseline climate period represents 2003-2018 and the future climate scenarios period represents 2018-2100 under Representative Concentration Pathways (RCP) 4.5 and 8.5. The data were produced by applying a Boosted Regression Tree machine learning approach to create gridded estimates of emissions based on in situ observations of NGS fluxes provided in a related dataset. The resulting monthly average flux data records can be used to calculate annual NGS soil CO2 flux budgets from 2003-2100.

There are three soil CO_2 flux data files in netCDF (*.nc4) format: one for the baseline period, and one each for the RCP 4.5 and RCP 8.5 future periods. Supplemental data files of (1) vegetation land cover to allow spatial delineation of fluxes according to land cover types used in the modeling and (2) a fractional lake map to calculate terrestrial land area for each pixel used to obtain total budget estimates (gCO_2-C) for each pixel are provided in GeoTIFF (*.tif) format. There are also 19 data quality files in GeoTIFF (*.tif) format, with average NGS estimate error for both Baseline and Future Climate BRT simulations.

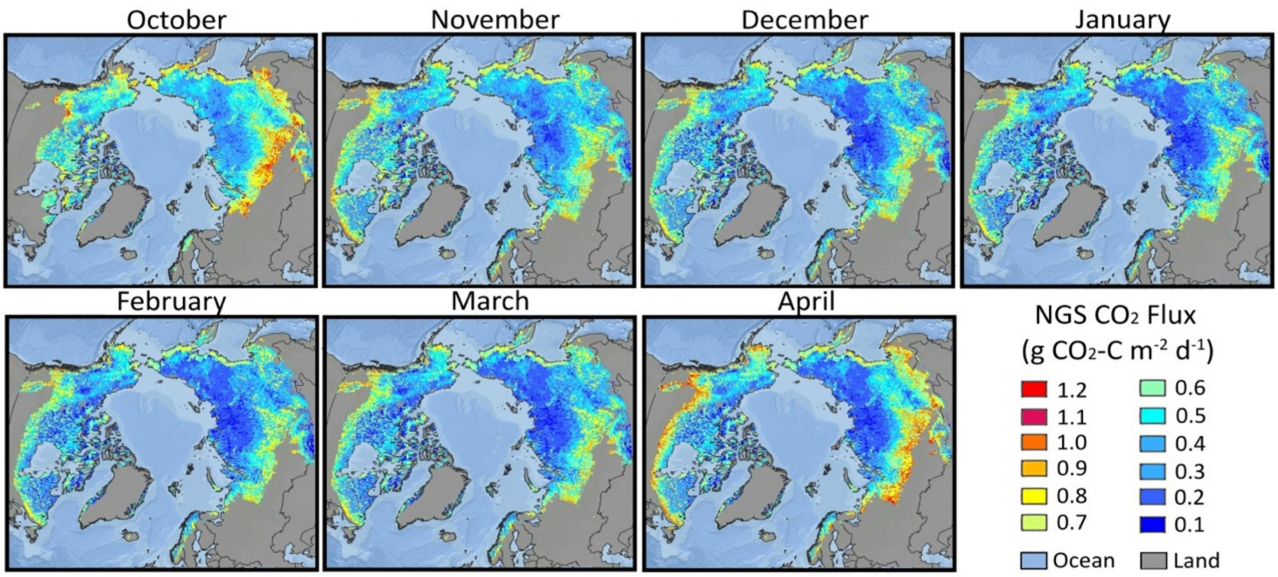

Figure 1. Soil CO2 flux estimates for the Arctic-boreal permafrost region, during the non-growing season (NGS), Julian days 274 through 120. (Source J.D. Watts)

Citation

Watts, J.D., S. Natali, S. Potter, and B.M. Rogers. 2019. Gridded Winter Soil CO2 Flux Estimates for pan-Arctic and Boreal Regions, 2003-2100. ORNL DAAC, Oak Ridge, Tennessee, USA. https://doi.org/10.3334/ORNLDAAC/1683

Table of Contents

1. Dataset Overview

This dataset provides gridded estimates of soil CO2 flux (g C m-2 d-1) for the winter non-growing season (NGS) across pan-Arctic and Boreal permafrost regions (>49 Deg N), at 25 km spatial resolution. The data are the daily average flux over a monthly period for two climate periods: the baseline climate period represents 2003-2018 and the future climate scenarios period represents 2018-2100 under Representative Concentration Pathways (RCP) 4.5 and 8.5. The data were produced by applying a Boosted Regression Tree machine learning approach to create gridded estimates of emissions based on in situ observations of NGS fluxes provided in a related dataset. The resulting monthly average flux data records can be used to calculate annual NGS soil CO2 flux budgets from 2003-2100.

Project: Arctic-Boreal Vulnerability Experiment

The Arctic-Boreal Vulnerability Experiment (ABoVE) is a NASA Terrestrial Ecology Program field campaign conducted in Alaska and western Canada between 2016 and 2021. Research for ABoVE links field-based, process-level studies with geospatial data products derived from airborne and satellite sensors, providing a foundation for improving the analysis, and modeling capabilities needed to understand and predict ecosystem responses to, and societal implications of, climate change in the Arctic and Boreal regions.

Related Publication:

Natali, S. J.D. Watts, S. Potter, B.M. Rogers, and S.M. Ludwig et al., 2019. Large loss of CO2 in winter observed across the northern permafrost region. Nature Climate Change.

Related Dataset:

Natali, S., J. Watts, S. Potter, B.M. Rogers, S. Ludwig, A. Selbmann, P. Sullivan, B. Abbott, K. Arndt, A.A. Bloom, G. Celis, T. Christensen, C. Christiansen, R. Commane, E. Cooper, P.M. Crill, C.I. Czimczik, S. Davydov, J. Du, J. Egan, B. Elberling, S.E. Euskirchen, T. Friborg, H. Genet, J. Goodrich, P. Grogan, M. Helbig, E. Jafarov, J. Jastrow, A. Kalhori, Y. Kim, J.S. Kimball, L. Kutzbach, M. Lara, K. Larsen, B. Lee, Z. Liu, M.M. Loranty, M. Lund, M. Lupascu, N. Madani, A. Malhotra, R. Matamala, J. McFarland, A. McGuire, A. Michelsen, C. Minions, W. Oechel, D. Olefeldt, F. Parmentier, N. Pirk, B. Poulter, W. Quinton, F. Rezanezhad, D. Risk, T. Sachs, K. Schaefer, N. Schmidt, E. Schuur, P. Semenchuk, G. Shaver, O. Sonnentag, G. Starr, C. Treat, M. Waldrop, Y. Wang, J. Welker, C. Wille, X. Xu, Z. Zhang, Q. Zhuang, and D. Zona. 2019. Synthesis of Winter In Situ Soil CO2 Flux in pan-Arctic and Boreal Regions, 1989-2017. ORNL DAAC, Oak Ridge, Tennessee, USA. https://doi.org/10.3334/ORNLDAAC/1692

Acknowledgements:

This research was funded as part of NASA's Arctic Boreal Vulnerability Experiment under grant number NNX15AT81A. This work was also supported by the Permafrost Carbon Network (PCN). The PCN is part of the Study of Environmental Arctic Change (SEARCH) project headed by the University of Alaska Fairbanks and Northern Arizona University. Both PCN and SEARCH seek to connect the science of Arctic change with decision makers and the main objective of PCN is to synthesize existing research about permafrost carbon and climate in a format that can be assimilated by biospheric and climate models, and that will contribute to future assessments of Intergovernmental Panel on Climate Change (IPCC).

2. Data Characteristics

Spatial Coverage: Permafrost landscapes in the circumpolar Arctic-boreal region of the northern hemisphere above 49 degrees latitude.

Spatial Resolution: 25 km

Temporal Coverage (YYYY-MM): Baseline: 2003-10 to 2018-04 and Future Climate: 2018-10 to 2100-04

Temporal Resolution: Monthly during the winter non-growing season of each year

Study Area: (all latitude and longitude given in decimal degrees)

Site	Westernmost Longitude	Easternmost Longitude	Northernmost Latitude	Southernmost Latitude
Arctic-Boreal Region	-180.00	179.90	89.98	-84.69

Data File Information:

There are three soil CO_2 flux data files in netCDF format: one for the baseline period, and one each for the RCP 4.5 and 8.5 future periods. Ancillary data files of (1) vegetation land cover to allow spatial delineation of fluxes according to land cover types used in the modeling and (2) a fractional lake map to calculate terrestrial land area for each pixel used to obtain total budget estimates (gCO_2-C) for each pixel are provided in GeoTIFF (*.tif) format. There are also 19 data quality files in GeoTIFF (*.tif) format, with average NGS estimate error for both Baseline and Future Climate simulations.

Filename	Description
Flux Data	
Baseline.Soil.CO2.Flux.2003-2017.nc4	Daily average flux (gCO_2-C m^{-2} d^{-1}) over a monthly period for baseline period 2003-2018
RCP45.Soil.CO2.Flux.2017-2100.nc4	Daily average flux (gCO_2-C m^{-2} d^{-1}) over a monthly period for RCP 4.5 future climate period 2017-2100
RCP85.Soil.CO2.Flux.2017-2100.nc4	Daily average flux (gCO_2-C m^{-2} d^{-1}) over a monthly period for RCP 8.5 future climate period 2017-2100
Quality Files	
Baseline.Soil.CO2.QA.0310.tif	Contains average NGS estimate error (gCO_2-C m^{-2} d^{-1}) for Baseline BRT simulations for years

	2003 through 2010.
Baseline.RCP45.Soil.CO2.QA.1020.tif	Contains average NGS estimate error (gCO_2-C m^{-2} d^{-1}) representing Baseline and RCP 4.5 future climate BRT simulations for years 2010 through 2020.
Baseline.RCP85.Soil.CO2.QA.1020.tif	Contains average NGS estimate error (gCO_2-C m^{-2} d^{-1}) representing Baseline and RCP 8.5 future climate BRT simulations for years 2010 through 2020.
RCP45.Soil.CO2.QA.2030.tif	Contains average NGS estimate error(gCO_2-C m^{-2} d^{-1}) for RCP 4.5 future climate BRT simulations for years 2020 through 2030.
RCP45.Soil.CO2.QA.3040.tif	… for years 2030 through 2040.
RCP45.Soil.CO2.QA.4050.tif	… for years 2040 through 2050.
RCP45.Soil.CO2.QA.5060.tif	… for years 2050 through 2060.
RCP45.Soil.CO2.QA.6070.tif	… for years 2060 through 2070.
RCP45.Soil.CO2.QA.7080.tif	… for years 2070 through 2080.
RCP45.Soil.CO2.QA.8090.tif	… for years 2080 through 2090.
RCP45.Soil.CO2.QA.9000.tif	… for years 2090 through 2100.
RCP85.Soil.CO2.QA.2030.tif	Contains average NGS estimate error (gCO_2-C m^{-2} d^{-1}) for RCP 8.5 future climate BRT simulations for years 2020 through 2030.
RCP85.Soil.CO2.QA.3040.tif	… for years 2030 through 2040.
RCP85.Soil.CO2.QA.4050.tif	… for years 2040 through 2050.
RCP85.Soil.CO2.QA.5060.tif	… for years 2050 through 2060.
RCP85.Soil.CO2.QA.6070.tif	… for years 2060 through 2070.
RCP85.Soil.CO2.QA.7080.tif	… for years 2070 through 2080.
RCP85.Soil.CO2.QA.8090.tif	… for years 2080 through 2090.
RCP85.Soil.CO2.QA.9000.tif	… for years 2090 through 2100.
Ancillary Data	
fractional_water.tif	Provides 25 km grid fractional water information for the Arctic-boreal study domain (and beyond). FW values of 0 indicate that lake area is absent within the 25 km pixel. FW values of 1 indicate that the 25 km pixel contains 100% water and terrestrial area is absent. The FW data are in the same format as the corresponding Spatial Data except that the data type is float 32-bit.
vegetation_landcover.tif	Vegetation land cover map, 25 km resolution, for the Arctic-boreal study domain (and beyond). Values indicate the dominant plant community types used to inform the BRT model simulations. The vegetation data are in the same format as the corresponding Spatial Data except that the data type is 32-bit unsigned integer. Land cover classes for the vegetation map are listed in Table 1.

Data File Properties

Flux Data Files in NetCDF format: The no-data value = 0; Grid cells are at 25-km spatial resolution; EPSG = 6933 (EASE-GRID Version 2): All geospatial data were regridded to the National Snow and Ice Data Center Equal Area Scalable Earth (EASE) 2.0 format at a 25-km spatial resolution prior to the CO2 flux upscaling and simulations.

QA and Ancillary Files in GeoTIFF format: All GeoTIFF files contain a single band of data. The no-data value for QA files is 0 and for the ancillary files it is -9999; Grid cells are at 25-km spatial resolution; EPSG = 6933 (EASE-GRID Version 2).

Table 1. Vegetation classes for land cover provided in *vegetation_landcover.tif*. Pixel count indicates the number of 25 km equal area pixels for each land cover type within the study domain. Land cover represents merged Circumpolar Arctic Vegetation Map (CAVM) and Climate Change Initiative (CCI) grids.

Source	Land Cover Code	Pixel Code	Land Cover Description	Pixel Count
CAVM	P2	1	Prostrate dwarf shrub and forb tundra	739
CAVM	S1	2	Erect dwarf shrub tundra	1166
CAVM	S2	3	Erect low shrub tundra	920
CAVM	G1-G4	4	Graminoid tussock and non-tussock (sedge, moss, minimal shrub)	2078
CAVM	W1	5	Wet sedge, grass and moss tundra	129
CAVM	W2	6	Wet sedge, shrub and moss tundra	413
CAVM	NMC	7	Noncarbonate mountain complex (barren; minimal plant	723

			cover)	
CAVM	CMC	8	Carbonate mountain complex (barren; minimal plant cover)	33
CCI	SBV	9	Sparse boreal vegetation (tree, shrub, herb)	6922
CCI	BDF	10	Deciduous broadleaved forest, closed to open canopy	484
CCI	DNF	11	Deciduous needle leaf forest, closed to open canopy	7322
CCI	ENLF	12	Evergreen needle leaf forest, closed to open canopy	6952
CCI	BSW	13	Shrub or herb cover, flooded	1372
			Total	29,253

3. Application and Derivation

The dataset provides gridded average monthly soil carbon fluxes (gCO_2-C m^{-2} d^{-1}) for the NGS (October-April) over the Arctic-boreal region from 2003-2100. The gridded fluxes were used to obtain regional NGS soil CO_2 emission budgets (gCO_2-C; Figure 3). The budgets can be used in baseline comparisons against estimates from regional process-based and Earth System models.

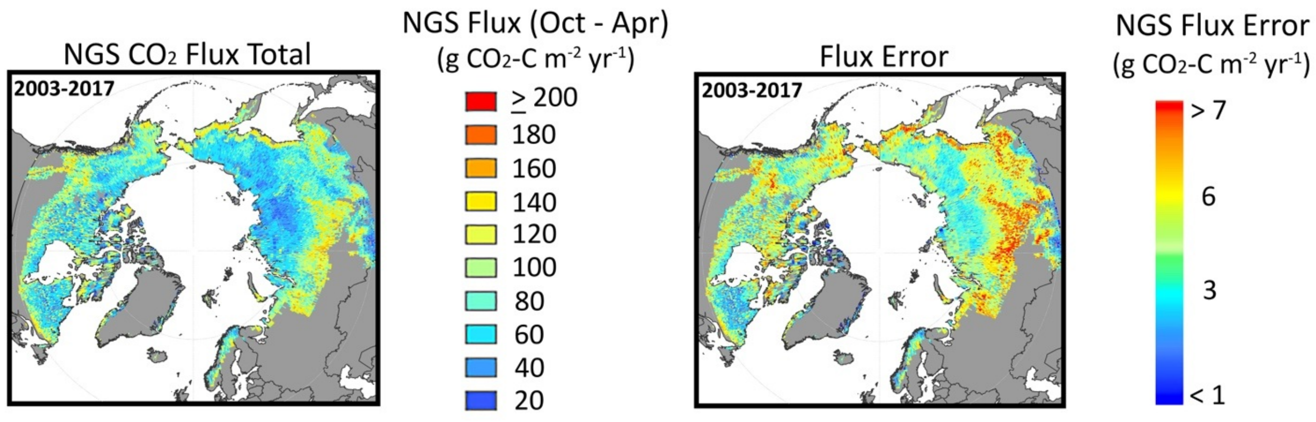

Figure 2. Average per-pixel soil CO_2 emission budgets for the NGS, years 2003-2017. Pixels represent 25 km equal area grids. Source J. Watts.

4. Quality Assessment

The data set was generated using the "In-situ nongrowing-season CO_2 flux synthesis dataset for the northern Arctic-Boreal permafrost domain" compilation of NGS (October-April) soil flux records. Over 1,000 flux observations were collected from literature and data records, spanning the period 1989 to 2016. The in-situ soil fluxes are reported in gCO_2-C m^{-2} d^{-1} averaged over a monthly observation period and were collected for permafrost regions within the Arctic-boreal domain (>49 °N) using flux chamber, chamber-snow, diffusion, soda lime and eddy covariance methods. The fluxes characterize loss of CO_2 from the soil to the atmosphere stemming from soil respiration (heterotrophic and root autotrophic) processes.

5. Data Acquisition, Materials, and Methods

The data set was generated using data from 'Synthesis of Winter In Situ Soil CO2 Flux in pan-Arctic and Boreal Regions, 1989-2017' (https://doi.org/10.3334/ORNLDAAC/1692), a compilation of NGS (October-April) soil flux records. The in-situ soil fluxes are reported in gCO_2-C m^{-2} d^{-1} averaged over a monthly observation period and were collected for permafrost regions within the Arctic-boreal domain (>49 °N) using flux chamber, chamber-snow, diffusion, soda lime and eddy covariance methods. The flux measurements characterize loss of CO_2 from the soil to the atmosphere stemming from soil respiration (heterotrophic and root autotrophic) processes. Over 1,000 flux observations were collected from literature and data records, spanning the period 1989 to 2016.

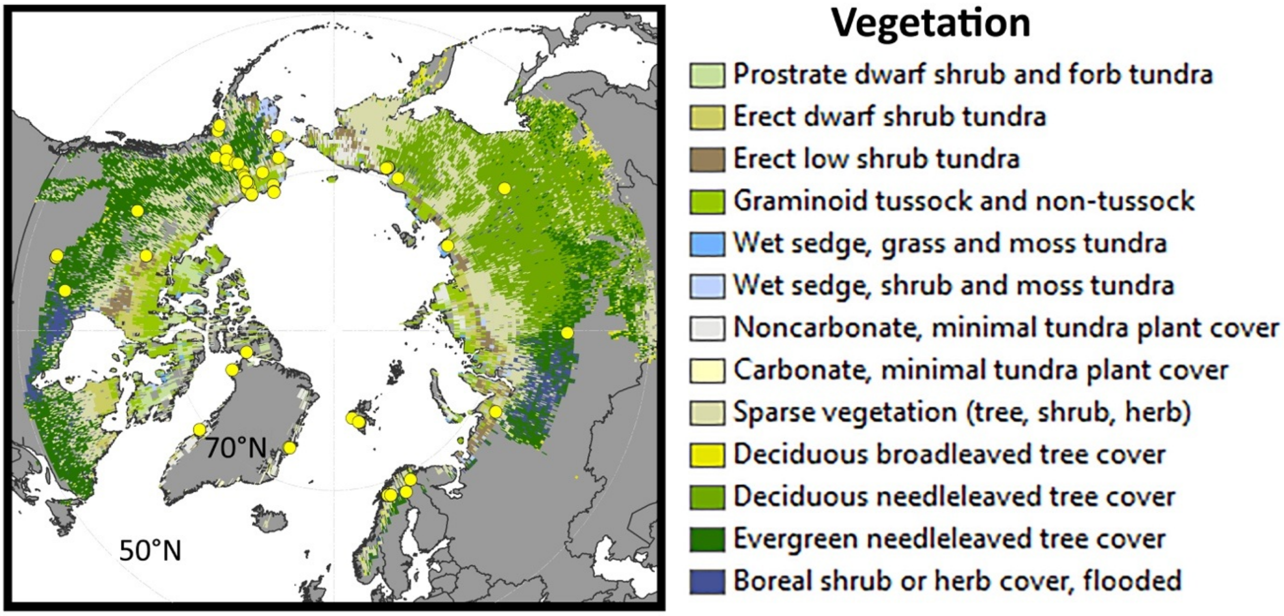

Figure 3. Land cover classes used in the model simulations. Yellow circles indicate the locations of soil CO_2 flux measurements used to develop the model. Source J. Watts.

The fluxes were scaled to the Arctic-boreal permafrost domain (>49°N), which includes 16.95 x 10^6 km^2 of tundra and boreal forest lands, using a boosted-regression tree (BRT) machine learning approach. A summary of satellite remote sensing, reanalysis and ancillary geospatial inputs used as predictors in the *baseline* climate (years 2003-2018) BRT models are provided in Table 2. These predictors include merged Circumpolar Arctic Vegetation Map (CAVM) and Climate Change Initiative (CCI) vegetation cover (Table 1; Figure 1). Inputs from global SoilGrids maps include sand, clay and organic carbon properties. Inputs from satellite remote sensing include Moderate Resolution Imaging Spectroradiometer (MODIS) leaf area index and tree cover; Soil Moisture Active Passive (SMAP) vegetation gross primary productivity; Advanced Microwave Scanning Radiometer (AMSR) surface and litter soil moisture. Inputs from reanalysis include Modern-Era Retrospective analysis for Research and Applications Version 2 (MERRA2) air temperature at 2 m and layer 1 soil temperature. The MODIS derived fractional lake cover was used to determine terrestrial land area for CO_2 budget calculations following the BRT flux simulations.

Table 2. Input predictor datasets used for BRT mapping of "baseline" (2003-2018) climate years. *Lake fraction cover is used to calculate per-pixel terrestrial area for CO_2 emission budget calculations.

Variable	Description	Native Resolution	Source	Reference
Land Cover	Vegetation type	1 km	CAVM/CCI	1, 2
MODIS LAI	Annual summer max. leaf area index (m^2/m^2)		MODIS	3
MODIS Tree Cover	Annual tree cover (%)	500 m	MODIS	4
Lake Cover*	Fractional lake cover (%) within grid cell	250 m	MODIS	5
% Sand	Soil sand content (percent) in top 30 cm	250 m	Soil Grids	5
% Clay	Soil clay content (percent) in top 30 cm	250 m	Soil Grids	5
Soil Organic Carbon	Organic carbon stock (kgC/m^2) in top 30 cm	250 m	Soil Grids	6
GPP	Annual summed vegetation gross primary productivity (GPP; $gC/m^2/yr$)	9 km	SMAP Level 4 Carbon	7
Air Temperature	Average air temp (K) at 2 m height during measurement month	1/2 x 2/3º	MERRA2	8
Soil Temperature	Average layer 1 soil temp. (K) during measurement month	1/2 x 2/3º	MERRA2	8
Soil Moisture	Average surface soil moisture (cm^3/cm^3) during measurement month	25 km	AMSRE	9
Soil Moisture	Average surface soil moisture (cm^3/cm^3) for prior June-July period	25 km	AMSRE	9

[1]Walker et al. 2005, [2]ESA 2014, [3]Myneni et al. 2015, [4]Hansen et al. 2003, [5]Carroll et al. 2017, [6]Hengl et al. 2017, [7]Jones et al. 2017, [8]Reichle et al. 2017, [9]Du et al. 2017

Geospatial predictors used for *future climate scenarios* are summarized in Table 3 and were obtained from ensemble (version r1i1p1) Earth System Model (ESM) outputs from the Fifth Coupled Model Intercomparison Project (CMIP5; Knutti et al. 2013) for RCPs 4.5 and 8.5. The RCP 4.5 assumes a peak in greenhouse gas emissions around 2040 and stabilized Earth radiative forcing at 4.5 Watts m^{-2} at year 2100; emissions in RCP 8.5 continue to rise during the 21^{st} century with a global radiative forcing of 8.5 Watts m^{-2} at year 2100. Tree cover and fractional lake cover used in future climate scenario BRT analysis were taken from average baseline climate conditions as they were not available in CMIP5 ESM outputs.

BRT model performance was determined using correlations between predicted and observed values using training flux observations withheld during model fitting, and the deviance explained by the model relative to the point-based flux synthesis dataset. Training data correlation (r) was 0.81 and mean correlation resulting from cross-validation was 0.71. Estimated model mean residual deviance was 0.05 gCO_2-C m^{-2}. Bootstrapped runs for 1,000 individual BRT model simulations were used to provide error maps constraining 95% confidence levels for each decadal period.

The resulting BRT model was applied on a per-month basis over the 2003-2018 baseline NGS period and from 2019-2100 over the RCP 4.5 and 8.5 future emission scenario NGS periods to produce gridded monthly average soil emission estimate maps (gCO_2-C m^{-2} d^{-1}) for the Arctic-boreal domain.

Table 3. Earth System Model (ESM) input datasets used for BRT mapping for "future climate" RCP 4.5 and 8.5 scenario (Jan. 2019-Apr. 2100) years. The 'x' indicates ESM model ensemble combinations used for each predictor.

ESM	GPP	LAI	Air Temp.	Soil Temp.	Soil Moist.
ACCESS1-3			x	x	x
CanESM2		x			x
CCSM4	x	x	x		x
CMCC-CM			x	x	
CNRM-CM5				x	x
CSIRO-Mk3-6-0			x		
GISS-E2-H	x		x	x	x
GISS-E2-R	x		x	x	x
HadGEM2-CC			x		x
HadGEM2-ES			x		x
IMNCM4	x	x	x	x	x
MIROC5			x	x	x
MIROC-ESM			x	x	x
MPI-ESM-LR	x	x	x	x	
MPI-ESM-MR	x		x		
MRI-ESM1				x	
NorEsm1-M	x	x	x	x	x

6. Data Access

These data are available through the Oak Ridge National Laboratory (ORNL) Distributed Active Archive Center (DAAC).

Gridded Winter Soil CO2 Flux Estimates for pan-Arctic and Boreal Regions, 2003-2100

Contact for Data Center Access Information:

- E-mail: uso@daac.ornl.gov
- Telephone: +1 (865) 241-3952

7. References

Brodzik, M.J., Billingsley, B., Haran, T., Raup, B., & Savoie, M.H. Correction: Brodzik, M.J. et al. EASE-Grid 2.0: Incremental but Significant Improvements for Earth-Gridded Data Sets. *ISPRS Int. J. Geo-Inform.* 3, 1154-1156 (2014). https://doi.org/10.3390/ijgi1010032

Carroll, M.L. *et al.* Development of an operational land water mask for MODIS Collection 6, and influence on downstream data products. *Int. J. Digit. Earth*. 10, 207–218 (2017). https://doi.org/10.1080/17538947.2016.1232756

Du, J. *et al.* A global satellite environmental data record derived from AMSR-E and AMSR2 microwave Earth observations. *Earth Syst. Sci. Data*. 9, 791–808 (2017). https://doi.org/10.5194/essd-9-791-2017

ESA. Climate Change Initiative-Land Cover-PUG, ESA Land Cover CCI Product User Guide V2 (2014).

Hansen, M.C. Global percent tree cover at a spatial resolution of 500 meters: first results of the MODIS vegetation continuous fields algorithm. *AMS*, (2003). https://doi.org/10.1175/1087-3562(2003)007%3C0001:GPTCAA%3E2.0.CO;2

Hengl, T. *et al.*, SoilGrids250m: Global gridded soil information based on machine learning. *PLoS One*. 12, e0169748 (2017). https://doi.org/10.1371/journal.pone.0169748

Jones, L.A. *et al*. The SMAP Level 4 Carbon Product for Monitoring Ecosystem Land–Atmosphere CO_2 Exchange. *IEEE Trans. Geosci. Remote Sens.* 55, 6517–6532 (2017). http://dx.doi.org/10.1109/TGRS.2017.2729343

Knutti, R., Masson, D. & Gettelman, A. Climate model genealogy: Generation CMIP5 and how we got there. *Geophys. Res. Lett.* 40, 1194–1199 (2013). https://doi.org/10.1002/grl.50256

Myneni, R. *et al*. MOD15A2H MODIS Leaf Area Index/FPAR 8-Day L4 Global 500m SIN Grid V006. NASA EOSDIS Land Processes DAAC (2015). http://doi.org/10.5067/MODIS/MOD15A2H.006 (Terra) http://doi.org/10.5067/MODIS/MYD15A2H.006 (Aqua)

Reichle, R.H. *et al*., Assessment of MERRA-2 Land Surface Hydrology Estimates. *J. Clim.* 30, 2937–2960 (2017). https://doi.org/10.1175/JCLI-D-16-0720.1

Walker, D.A., Raynolds, M.K., Daniëls, F.J., Einarsson, E., Elvebakk, A., Gould, W.A., Katenin, A.E., Kholod, S.S., Markon, C.J., Melnikov, E.S. and Moskalenko, N.G., 2005. The circumpolar Arctic vegetation map. *Journal of Vegetation Science*, *16*(3), pp.267-282. http://dx.doi.org/10.1111/j.1654-1103.2005.tb02365.x