Soil Respiration Maps for the ABoVE Domain, 2016-2017

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Documentation Revision Date: 2022-04-20

Dataset Version: 1

Summary

This dataset provides gridded estimates of carbon dioxide (CO_2) emissions from soil respiration occurring within permafrost-affected tundra and boreal ecosystems of Alaska and Northwest Canada at a 300 m spatial resolution for the period 2016-08-18 to 2018-09-12. The estimates include monthly average CO_2 flux (gCO_2 C m-2 d-1), daily average CO_2 flux and error estimates by season (Autumn, Winter, Spring, Summer), estimates of annual offset of CO_2 uptake (i.e., vegetation GPP), annual budgets of vegetation gross primary productivity (GPP; gCO_2 C m-2 yr-1), and the fraction of open (non-vegetated) water within each 300 m grid cell. Belowground sources of respiration (i.e., root and microbial) are included. The gridded soil CO_2 estimates were obtained using seasonal Random Forest models, information from remote sensing, and a new compilation of in-situ soil CO_2 flux from Soil Respiration Stations and eddy covariance towers. The flux tower data are provided along with daily gap-filled flux observations for each Soil Respiration station forced diffusion (FD) chamber record. The data cover the NASA ABoVE Domain.

There are 28 data files with this dataset; 25 data files in GeoTIFF (*.tif) format and three files in comma-separated value format (.csv).
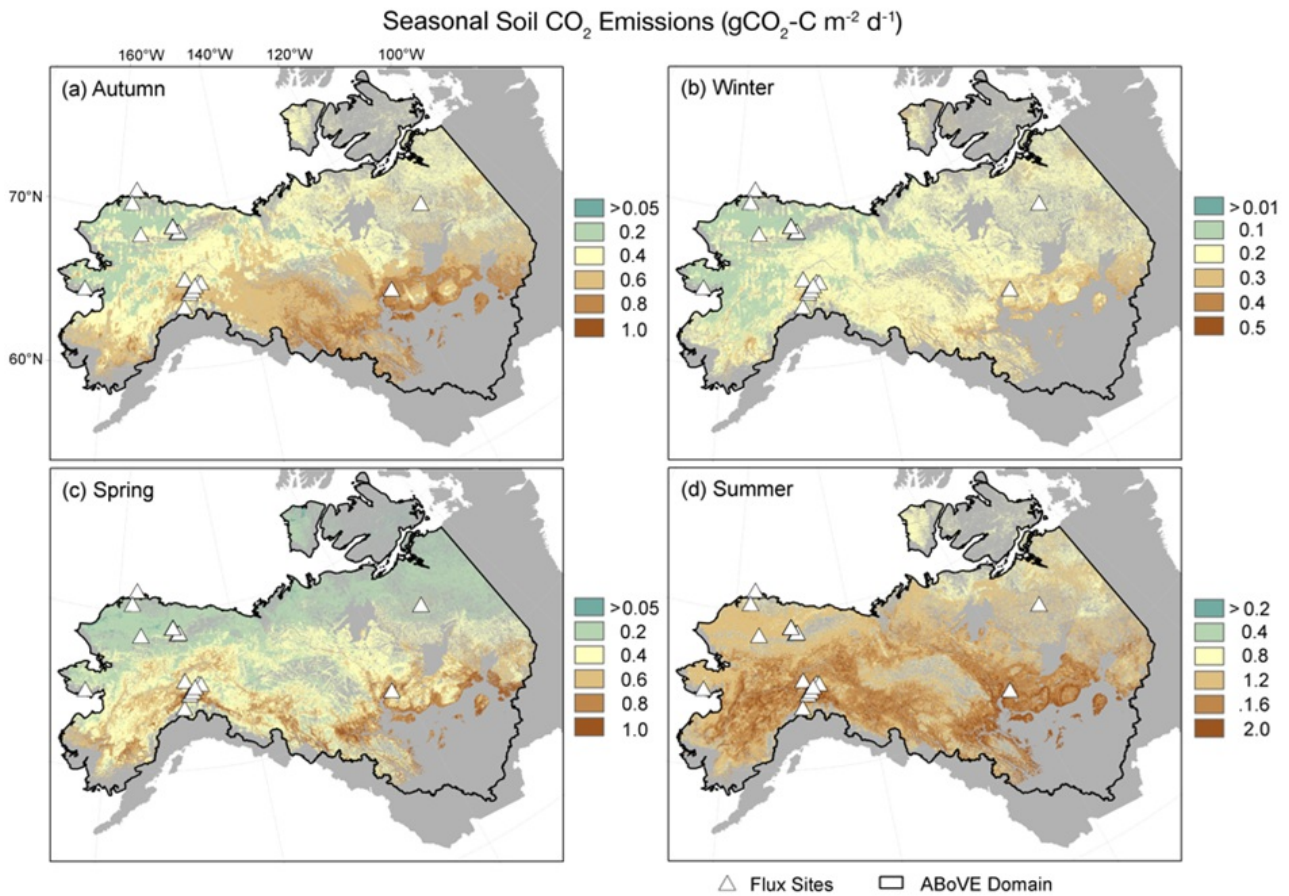
Figure 1. Seasonal average soil respiration emissions (gCO_2 C m-2 d-1) for autumn (September-October), winter (November-March), spring (April-May), and summer (June-August) at a 300 m spatial resolution. Source: Watts et al. (2021)

Citation

Watts, J.D., S. Natali, and C. Minions. 2022. Soil Respiration Maps for the ABoVE Domain, 2016-2017. ORNL DAAC, Oak Ridge, Tennessee, USA. https://doi.org/10.3334/ORNLDAAC/1935

Table of Contents

1. Dataset Overview

This dataset provides gridded estimates of carbon dioxide (CO_2) emissions from soil respiration occurring within permafrost-affected tundra and boreal ecosystems of Alaska and Northwest Canada at a 300 m spatial resolution for the period 2016-08-18 to 2018-09-12. The estimates include monthly average CO_2 flux (gCO2 C m-2 d-1), daily average CO2 flux and error estimates by season (Autumn, Winter, Spring, Summer), estimates of annual offset of CO_2 uptake (i.e., vegetation GPP), annual budgets of vegetation gross primary productivity (GPP; gCO2 C m-2 yr-1), and the fraction of open (non-vegetated) water within each 300 m grid cell. Belowground sources of respiration (i.e., root and microbial) are included. The gridded soil CO_2 estimates were obtained using seasonal Random Forest models, information from remote sensing, and a new compilation of in-situ soil CO_2 flux from Soil Respiration Stations and eddy covariance towers. The flux tower data are provided along with daily gap-filled flux observations for each Soil Respiration station forced diffusion (FD) chamber record. The data cover the NASA ABoVE Domain.

Project: Arctic-Boreal Vulnerability Experiment

The Arctic-Boreal Vulnerability Experiment (ABoVE) is a NASA Terrestrial Ecology Program field campaign focused on Alaska and western Canada. Research for ABoVE links field-based, process-level studies with geospatial data products derived from airborne and satellite sensors, providing a foundation for improving analysis and modeling capabilities needed to understand and predict ecosystem responses to, and societal implications of, climate change in the Arctic and Boreal regions. Our ABoVE-sponsored study focuses on the spatiotemporal patterns and magnitudes of soil CO_2, which are not well quantified across rapidly warming pan-Arctic ecosystems.

Related Publication

Watts, J.D., S.M. Natali, C. Minions, D. Risk, K. Arndt, D. Zona, E.S. Euskirchen, A.V. Rocha, O. Sonnentag, M. Helbig, A. Kalhori, W. Oechel, H. Ikawa, M. Ueyama, R. Suzuki, H. Kobayashi, G. Celis, E.A. Schuur, E. Humphreys, Y. Kim, B.-Y. Lee, S. Goetz, N. Madani, L.D. Schiferl, R. Commane, J.S. Kimball, Z. Liu, M.S. Torn, S. Potter, J.A. Wang, M.T. Jorgenson, J. Xiao, X. Li, and C. Edgar. 2021. Soil respiration strongly offsets carbon uptake in Alaska and Northwest Canada. Environmental Research Letters 16:084051. https://doi.org/10.1088/1748-9326/ac1222

Related Dataset

Minions, C., S. Natali, J.D. Watts, S. Ludwig, D. Risk 2019. ABoVE: Year-Round Soil CO_2 Efflux in Alaskan Ecosystems, Version 2. ORNL DAAC, Oak Ridge, Tennessee, USA. https://doi.org/10.3334/ORNLDAAC/1762

Acknowledgments

2. Data Characteristics

Spatial Coverage: permafrost-affected tundra and boreal landscapes in Alaska and Canada (ABoVE core domain); excludes barren lands and water bodies

> **ABoVE Reference Locations**
>
> Domain: Core ABoVE
>
> Grid cells (240 m "A" cells): Ah000v000, Ah000v00, Ah001v002, Ah002v002, Ah003v002, Ah001v000,Ah002v000, Ah003v000, Ah000v001, Ah001v001, Ah002v001, Ah003v001

Spatial Resolution: 300 m grid cells, point resolution for site data

Temporal Coverage: 2016-08-18 to 2018-09-12

Temporal Resolution: daily, monthly

Study Area: Latitude and longitude are given in decimal degrees.

Site	Westernmost Longitude	Easternmost Longitude	Northernmost Latitude	Southernmost Latitude
Alaska and Canada	-169.5052	-98.7366	76.6874	55.8072

Data File Information

There are 25 data files in GeoTIFF (*.tif) format and three files in comma-separated value format (*.csv) included in this dataset.

Table 1. File names and descriptions

File Name	Units	Description
soil_resp_flux_YYYY-XX.tif	g m^{-2} d^{-1}	Twelve files. Daily average emissions from soil respiration (gCO$_2$ C m^{-2} d^{-1}) over monthly time steps where YYYY is 2016 or 2017 and XX for the 2016 files is 09–12, and for the 2017 files is 01–08. Missing values are represented by 0.

File Name	Units	Description
soil_resp_flux_AAA_YYYY.tif	$g\ m^{-2}\ d^{-1}$	Four files. Average estimates (gCO_2 C m^{-2} d^{-1}) for sampling periods, where AAA is the season and YYYY is the year. Missing values are represented by 0.
soil_resp_flux_est_error_AAA_YYYY.tif	$g\ m^{-2}\ d^{-1}$	Four files. Average flux estimate error (gCO_2 C m^{-2} d^{-1}) for sampling periods, where AAA is the season and YYYY is the year. Missing values are represented by -3.
soil_resp_budget_annual_2016-2017.tif	$g\ m^{-2}$	Annual soil respiration budgets (gCO_2 C m^{-2}) for September 2016–August 2017. Missing values are represented by 0.
soil_resp_budget_annual_percent_offset_GPP_2016-2017.tif	percent	Annual percentage offset of growing season GPP by soil respiration emissions for September 2016–August 2017. An offset of 100% indicates that soil respiration equaled or exceeded annual GPP. Missing values are represented by 0.
GPP_budget_annual_2016-2017.tif	$g\ m^{-2}$	Annual GPP budgets (gCO_2 C m^{-2}) averaged for the 2016–2017 growing seasons. A composite of SMAP, GOSIF, and MODIS GPP products. Missing values are represented by 0.
ecosystem_resp_budget_annual_percent_offset_GPP_2016-2017.tif	percent	Annual percentage offset of growing season GPP by ecosystem (soil + aboveground) respiration forSeptember 2016–August 2017. An offset of 100% indicates that ecosystem respiration equaled or exceeded annual GPP. Missing values are represented by 0.
fractional_water.tif	1	Provides 300 m grid fractional water (FW) information for the study domain, derived from Wang et al. (2019). FW values of 1 indicate that the 300 m pixel contains 100% surface open water coverage. Missing values are represented by 0.
soil_resp_station_descriptions.csv		Provides descriptive data of site respiration stations. See Table 2 for variable descriptions. Missing values are represented by -9999.
site_monthly_soil_respiration_flux.csv		Table of average monthly soil respiration fluxes for the ABoVE domain in gCO_2 C m^{-2} d^{-1}, used to develop the Random Forest models. These include flux data from Soil Respiration Stations and eddy covariance sites for 2016–2017 (Watts et al., 2021). The Soil Respiration Station record also includes more recent data for 2018. See Table 3 for variable descriptions. Missing values are represented by -9999.
soil_resp_station_daily_soil_respiration_flux_gap_filled_2016-2018.csv		Table of daily gap filled flux observations for each Alaska Soil Respiration station forced diffusion (FD) chamber record (Watts et al., 2021). The record includes all available data from 2016–2018. See Table 4 for variable descriptions. Missing values are represented by -9999.

Data File Details

- Scaling factors: For the file fractional_water.tif (water mask), the scaling factor is 100.
- CRS: Cylindrical Equal Area, WGS 84 datum, EPSG: 6933.
- Missing data values: Missing values are represented by -3 for the files named soil_resp_flux_est_error_AAA_YYYY.tif, 0 for other GeoTIFF files, and -9999 for CSV files.

Table 2. Variables names and descriptions for the file soil_resp_station_descriptions.csv.

Variable	Units	Description
site_code		Abbreviated site station name
site_name		Site station name
latitude	Decimal degrees	Latitude of site
longitude	Decimal degrees	Longitude of site
description		Site description (vegetation type, burned information)

Table 3. Variables names and descriptions for the file site_monthly_soil_respiration_flux.csv.

Variable	Units	Description
site		Abbreviated site station name
system		System used to collect data: EC (eddy covariance towers), SRS (Soil Respiration Stations), or Eosense FD (forced diffusion chamber)

Variable	Units	Description
latitude	Decimal degrees	Latitude of site
longitude	Decimal degrees	Longitude of site
month		Month of measurement
flux	g m^{-2} d^{-1}	Monthly average flux observations (gCO_2 C m^{-2} d^{-1}) from Soil Respiration Stations and eddy covariance towers

Table 4. Variables names and descriptions for the file soil_resp_station_daily_soil_respiration_flux_gap_filled_2016-2018.csv.

Variable	Units	Description
date		Abbreviated site station name
XXX_FDZZ (site code names_chamber record)	g m^{-2} d^{-1}	Gap-filled flux data (gCO_2 C m^{-2} d^{-1}) for 31 respiration sites, in columns B–AF, for each soil respiration station forced diffusion (FD_ZZ) chamber record. For site code names, refer to Table 2.

3. Application and Derivation

The soil emission and budget maps provide new insight into the regional patterns of soil respiration within the domain. The resulting respiration budgets can be used in baseline comparisons against estimates from regional process-based and Earth System models.

4. Quality Assessment

Soil respiration emissions were derived from models trained using a new CO_2 flux database for the ABoVE domain (Watts et al., 2021). The flux database includes observations from 10 Soil Respiration Stations (Minions et al. 2019), one Eosense eosFD station, and 15 eddy covariance towers. In total, 268 monthly average flux (gCO_2 C m^{-2} d^{-1}) estimates, from September 2016 to August 2017, were used to develop the regional soil respiration models.

Uncertainty was measured from Random Forest model error using Root Mean Square Error (RMSE), coefficient of determination (R^2), and Mean Absolute Error (MAE) based on internal and external accuracy assessments (Table 2). Regional uncertainty maps (Fig. 3) for each seasonal Random Forest model were obtained using the quadrature method: sqrt(global RMSE^2 + (pixel-level uncertainty – global RMSE)^2). Pixel-level level uncertainty was obtained through bootstrapping of the Random Forest input observations (20% removed) to provide an estimate of deviation (uncertainty) around the estimated mean.

Table 5. Accuracy assessments for seasonal Random Forest models. RMSE$_1$ and MAE$_1$ (gCO_2 C m^{-2} d^{-1}) are provided from the internal out-of-bag accuracy assessments; RMSE$_2$ and MAE$_2$ are based on an external accuracy assessment using 1,000 bootstrapped samples where 80% of data were used for model training and 20% were withheld for validation.

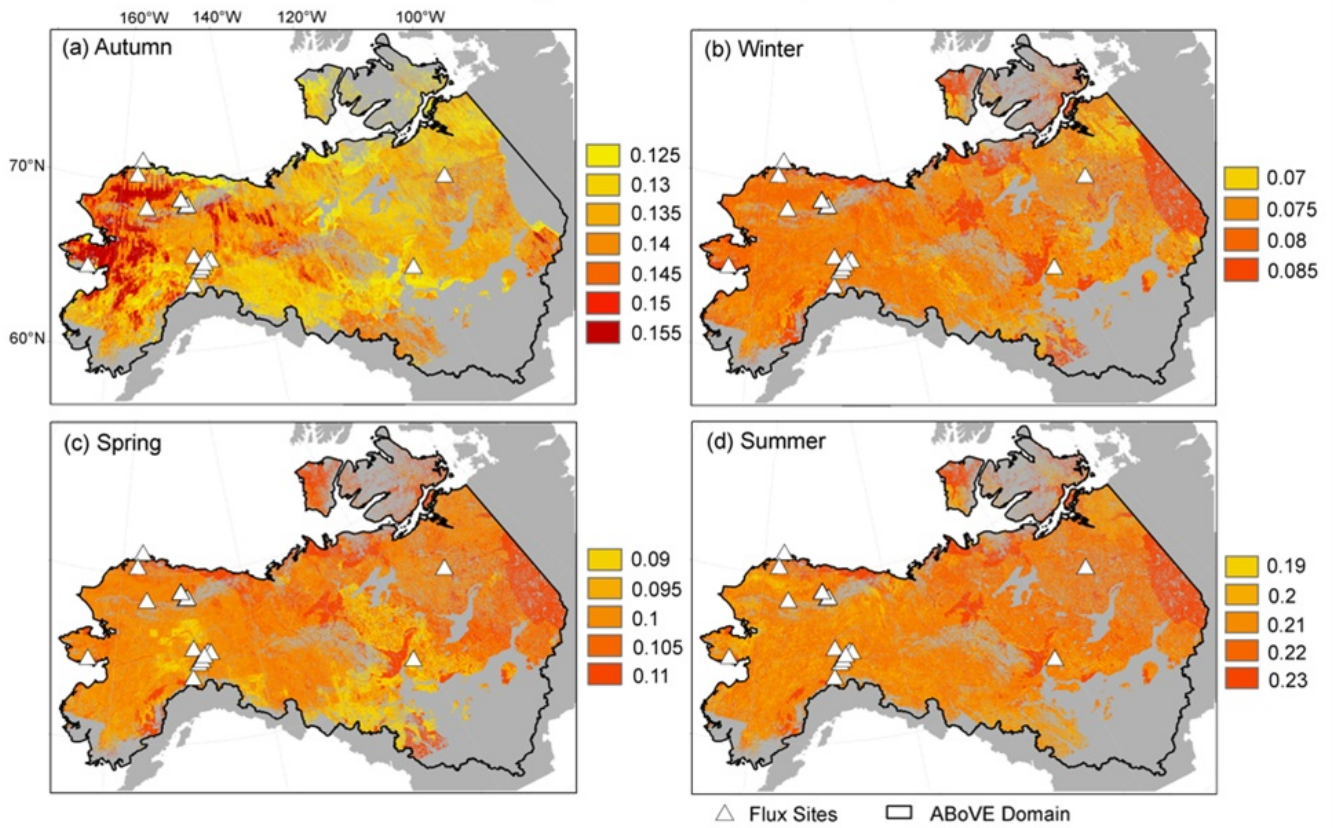| Season	R^2	RMSE$_1$	MAE$_1$	RMSE$_2$	MAE$_2$
Summer	0.68	0.16	0.05	0.35	0.31
Autumn	0.57	0.12	0.09	0.24	0.20
Winter	0.65	0.06	0.04	0.10	0.08
Spring	0.76	0.08	0.11	0.25	0.19

Figure 2. Seasonal average uncertainties for soil respiration emissions (gCO$_2$ C m^{-2} d^{-1}) in autumn (September–October), winter (November–March), spring (April–May), and summer (June–August) at a 300 m spatial resolution. Source: Watts et al. (2021)

5. Data Acquisition, Materials, and Methods

Soil respiration emissions were derived using a new CO$_2$ flux database for the ABoVE domain (Watts et al., 2021) that includes observations from 10 Soil Respiration Stations (Minions et al., 2019), one Eosense eosFD station, and 15 eddy covariance towers. In total, the flux database provided 268 observations of monthly average flux (gCO$_2$ C m^{-2} d^{-1}) spanning September 2016 to August 2017. Fourteen of the sites are in tundra ecosystems; 12 sites are in the boreal biome; three sites are in burned ecosystems.
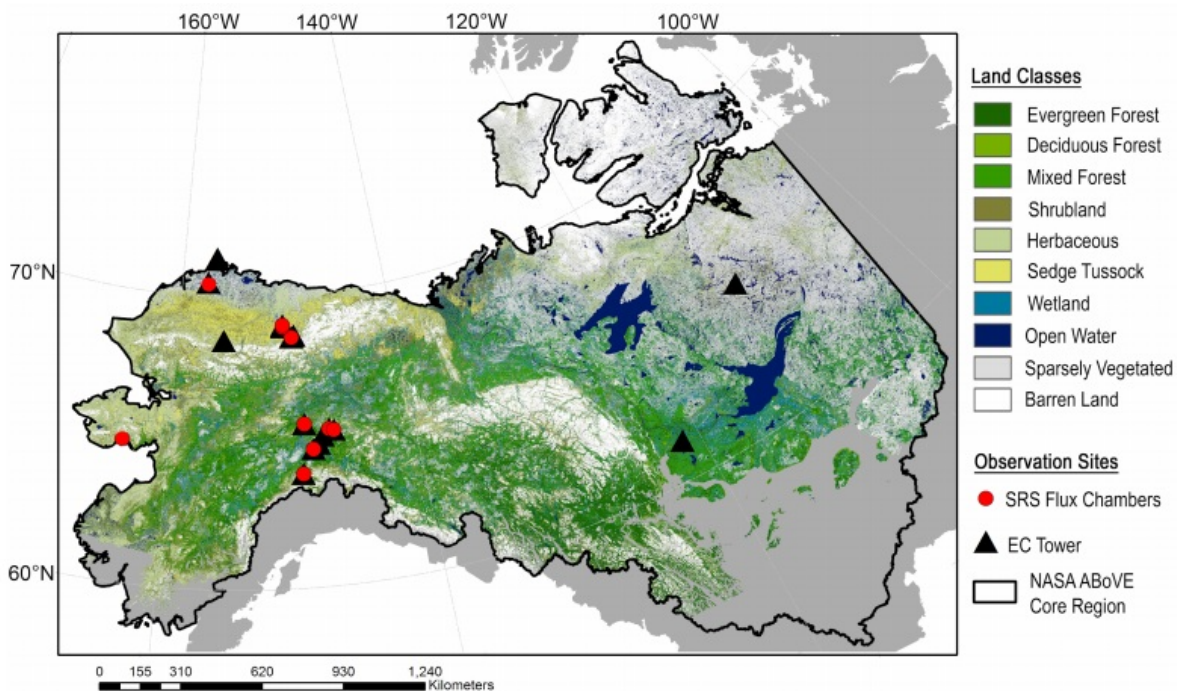

Figure 3. Locations of soil respiration stations (SRS) and eddy covariance (EC) towers were considered in this study. The study domain is part of the NASA ABoVE core region. The sites span climate and vegetation gradients (tundra to boreal) within Alaska and Northwest Canada. Landscapes evaluated in this study do not include barren land, open water, or where permafrost was absent (indicated in grey). Landcover classes are from Wang et al. (2019).

The soil respiration fluxes were scaled to permafrost-affected landscapes within the ABoVE domain (2.68 x 10^6 km^2) using seasonal Random Forest models developed for autumn (September–October), winter (November–March), spring (April–May), and summer (June–August). A summary of the satellite remote sensing and ancillary geospatial inputs selected as model predictors is provided in Table 6. These include information about ecosystem GPP, soil organic carbon pools, tree cover and greenness, thermal condition (i.e., permafrost status, soil temperature, land temperature, snow cover), and ecosystem moisture (i.e., soil moisture, landscape moisture indices, soil texture). A summary of the model accuracy assessments is provided in Table 5.

Table 6. Geospatial predictors used in the seasonal Random Forest models to estimate soil respiration emissions within permafrost-affected landscapes of the NASA ABoVE domain (Watts et al., 2021).

Variable	Description	Native Resolution	Source	Reference
Autumn RF Model				
Permafrost Zonation Index	Relative likelihood of permafrost presence; static	1 km	Geo.uzh.ch	Gruber et al. (2012)
Soil Organic Carbon	Total carbon 0–30 cm; static	250 m	SoilGrids; isric.org	Hengl et al. (2017)
Root Zone Soil Moisture	Monthly average	9 km	SMAP; nsidc.org	Reichle et al. (2018)
Downwelling Shortwave Radiation	Monthly total	9 km	SMAP; nsidc.org	Reichle et al. (2018)
Soil Temperature (Layer 4)	Monthly average	9 km	SMAP; nsidc.org	Reichle et al. (2018)
Winter RF Model				
Permafrost Zonation Index	Relative likelihood of permafrost presence; static	1 km	Geo.uzh.ch	Gruber et al. (2012)
Leaf Area Index	MCD15A36; 2016 summer average	500 m	MODIS; modis.gsfc.nasa.gov/data	Myneni et al. (2015)
Enhanced Vegetation Index	LC8_L1T; 2014–2016 summer average	30 m	Landsat; usgs.gov/core-science-systems/nli/	Gorelick et al. (2017)
Normalized Difference Water Index	LC8_L1T; 2014–2016 summer average	30 m	Landsat; usgs.gov/core-science-systems/nli/	Gorelick et al. (2017)
Gross Primary Productivity	MOD17A2H; 2016 summer total	500 m	MODIS; lpdaac.usgs.gov	Running et al. (2015)
Normalized Difference Snow Index	2016/2017 winter average	500 m	MODIS	Schaaf & Wang (2015)
Root Zone Soil Moisture	Volumetric; monthly average	9 km	SMAP; nsidc.org	Reichle et al. (2018)
Soil Temperature (Layer 3)	Monthly average	9 km	SMAP; nsidc.org	Reichle et al. (2018)
Spring RF Model				
Permafrost Zonation Index	Relative likelihood of permafrost presence; static	1 km	Geo.uzh.ch	Gruber et al. (2012)
Soil % Clay Content	0–30 cm depth; static	250 m	SoilGrids; isric.org	Hengl et al. (2017)
% Tree Cover	MOD44B; 2016 summer average	250 m	MODIS; lpdaac.usgs.gov	Dimiceli et al. (2015)
Gross Primary Productivity	MOD17A2H; 2016 summer total	500 m	MODIS; lpdaac.usgs.gov	Running et al. (2015)
Surface Soil Moisture	Volumetric; monthly average	9 km	SMAP; nsidc.org	Reichle et al. (2018)
Enhanced Vegetation Index	LC8_L1T; 2014–2016 summer average	30 m	Landsat; usgs.gov/core-science-systems/nli/	Gorelick et al. (2017)
Land Surface Temperature	MOD11A1; monthly average	1 km	MODIS; lpdaac.usgs.gov	Wan et al. (2015)
Summer RF Model				
Gross Primary Productivity	MOD17A2H; 2017 summer total	500 m	MODIS; lpdaac.usgs.gov	Running et al. (2015)
Leaf Area Index	MCD15A36; 2017 summer average	500 m	MODIS; modis.gsfc.nasa.gov/data	Myneni et al. (2015)

Variable	Description	Native Resolution	Source	Reference
% Tree Cover	MOD44B; 2016 summer average	250 m	MODIS; lpdaac.usgs.gov	Dimiceli et al. (2015)
Soil % Sand Content	0–30 cm depth; static	250 m	SoilGrids; isric.org	Hengl et al. (2017)
Normalized Difference Vegetation Index	MCD43A4; monthly average	500 m	MODIS; lpdaac.usgs.gov	Schaaf & Wang (2015)

The monthly average soil respiration emission estimates (gCO_2 C m^{-2} d^{-1}) from the Random Forest models were scaled to the terrestrial spatial domain within each 300 m x 300 m grid cell. Fractions of open water (derived from the 30 m Wang et al. (2019) land cover map) were removed during the per-grid cell carbon budget calculations. The resulting 300 m resolution annual soil respiration emission (gCO_2 C yr^{-1}) maps for permafrost-affected terrestrial surfaces were used to obtain seasonal and annual soil respiration budgets for the ABoVE domain (Fig. 1.).

To determine the extent that which soil respiration offsets the annual ecosystem uptake of CO_2 (i.e., GPP) on a per grid-cell basis across the region, estimates of GPP were obtained from NASA MODIS MOD17 (MOD17A2H.006; Running et al., 2015), NASA Soil Moisture Active Passive (SMAP) Level 4 Carbon (L4_C) (Kimball et al., 2014) and Global OCO-2 SIF (GOSIF) GPP data products (Li & Xiao, 2019) for the 2016 and 2017 growing season. Finally, literature-based flux ratios (Watts et al., 2021) were used to obtain estimates of emissions from aboveground respiration, in addition to our estimates of soil respiration, providing estimates of total ecosystem respiration (ER). These were used to develop 300 m continuous gridded surfaces of the annual offset of GPP by ER (Fig. 4).
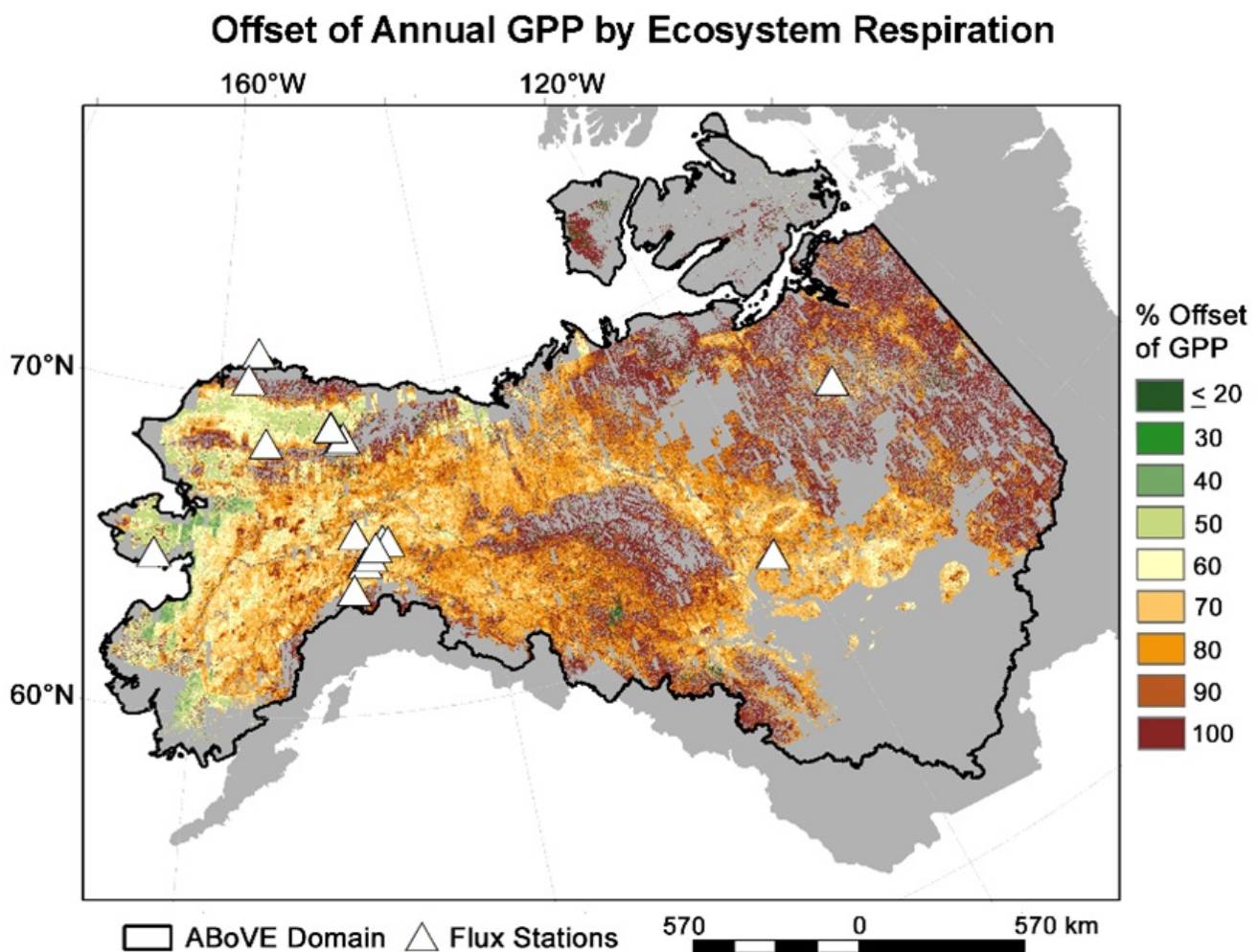

Figure 4. The annual offset of GPP by ecosystem respiration.

6. Data Access

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

Soil Respiration Maps for the ABoVE Domain, 2016-2017

Contact for Data Center Access Information:

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

7. References

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