June 26, 2017

# SPRUCE S1 Bog Sphagnum CO2 Flux Measurements and Partitioning into Re and GPP

## Summary:

This data set provides (1) the results of *in-situ Sphagnum*-peat hourly net ecosystem exchange (NEE) measured using a LICOR 8100 gas exchange system and (2) the component fluxes -- gross primary production (GPP) and ecosystem respiration (Re), derived using empirical regressions.

NEE measurements were made from 6 June to 6 November 2014 and 20 March to 10 May 2015. Three 8100 chambers per dominant species (*S. magellanicum* or *S. fallax*) were placed in the S1 Bog in relatively open ground where there was no obvious hummock-hollow microtopography. The 8100 chambers were not located in the SPRUCE experimental enclosures. Measured site meteorological data used as model drivers are also included.

**The data have been analyzed and reported on in the following paper:**

Anthony P. Walker, Kelsey R. Carter, Lianhong Gu, Paul J. Hanson, Avni Malhotra, Richard J. Norby, Stephen D. Sebestyen, Stan Wullschleger, David J. Weston. 2017. Biophysical drivers of seasonal variability in Sphagnum gross primary production in a northern temperate bog. Journal of Geophysical Research – Biogeosciences, vol 122(5), pp 1078-1097.
http://onlinelibrary.wiley.com/doi/10.1002/2016JG003711/full

Figure 1. LICOR 8100 clear top soil respiration chambers as installed in S1 Bog to measure Sphagnum NEE.

# Data Citation:

**Cite this data set as follows:**

Walker, A.P., K.R. Carter, P.J. Hanson, W.R. Nettles, J.R. Philips, S.D. Sebestyen, and D.J. Weston. 2017. **SPRUCE S1 Bog Sphagnum CO2 Flux Measurements and Partitioning into Re and GPP.** Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy, Oak Ridge, Tennessee, U.S.A. http://dx.doi.org/10.3334/CDIAC/spruce.039

# Data and Documentation Access:

**Get Data:**

**For public access to SPRUCE data please visit the SPRUCE Web Site:**
http://mnspruce.ornl.gov/

**Description and Links to Supplemental Information:**

**Marcell Experimental Forest Website:** /http://www.nrs.fs.fed.us/ef/locations/mn/marcell/

**SPRUCE Project Website with project plans and additional information:**
http://mnspruce.ornl.gov/

**SPRUCE Data Policy - Sharing, Access, and Use Recommendations:**
http://mnspruce.ornl.gov/content/spruce-data-policies

**Related Data Sets**:

Hanson, P.J., J.S. Riggs, C. Dorrance, W.R. Nettles, and L.A. Hook. 2015. SPRUCE Environmental Monitoring Data: 2010-2016. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy, Oak Ridge, Tennessee, U.S.A. http://dx.doi.org/10.3334/CDIAC/spruce.001

## SPRUCE Project Description

SPRUCE (Spruce and Peatland Responses Under Climatic and Environmental Change) is an experiment to assess the response of northern peatland ecosystems to increases in temperature and exposures to elevated atmospheric $CO_2$ concentrations. It is a key component of the Terrestrial Ecosystem Science Scientific Focus Area of ORNL's Climate Change Program, focused on terrestrial ecosystems and the mechanisms that underlie their responses to climatic change. The experimental work is to be conducted in a *Picea mariana* [black spruce] – *Sphagnum* [peat moss] spp. bog forest in northern Minnesota, 40 km north of Grand Rapids, in the USDA Forest Service Marcell Experimental Forest (MEF). The site is located at the southern margin of the boreal forest. It is an ecosystem considered especially vulnerable to climate change, and anticipated to be near its tipping point with respect to climate change. Responses to warming

and interactions with increased atmospheric $CO_2$ concentration are anticipated to have important feedbacks on the atmosphere and climate, because of the high carbon stocks harbored by peatlands.

Experimental work in the 8.1-ha S1 bog will be a climate change manipulation focusing on the combined responses to multiple levels of warming at ambient or elevated $CO_2$ (eCO2) levels. The experiment provides a platform for testing mechanisms controlling the vulnerability of organisms, biogeochemical processes and ecosystems to climatic change (e.g., thresholds for organism decline or mortality, limitations to regeneration, biogeochemical limitations to productivity, the cycling and release of $CO_2$ and $CH_4$ to the atmosphere).

The manipulation will evaluate the response of the existing biological communities to a range of warming levels from ambient to +9°C, provided via large, modified open-top enclosures. All temperatures, ambient through the +9°C warming treatment, will also be conducted at eCO2 (in the range of 800 to 900 ppm). Both direct and indirect effects of these experimental perturbations will be analyzed to develop and refine models needed for full Earth system analyses.

## Marcell Experimental Forest

Streamflow, weather, and well data collection began on the Marcell Experimental Forest in 1960. This 1100-ha site has six calibrated watersheds, each consisting of a mineral soil upland and organic soil peatland; an intermittent or perennial stream drains each peatland and its larger watershed. Formally established in 1962, the Marcell contains two units on land owned by the USDA Forest Service, Chippewa National Forest, State of Minnesota, Itasca County, and a private individual. Previous and ongoing research addresses the ecology and hydrology of peatland. Research concerns typical upland/wetland watersheds in the Lake States, atmospheric chemistry, nutrient cycling, soil quality, tree-stand dynamics, and a variety of watershed treatments applied to upland or bogs to investigate impacts on water yield, peak streamflow, water quality and nutrient processing.

## SPRUCE Sponsor

Research sponsored by the Office of Biological and Environmental Research within the U.S. Department of Energy's Office of Science.

The SPRUCE experiment is a multi-year cooperative interaction among scientists of the Oak Ridge National Laboratory operated by UT-Battelle, LLC and the U.S. Forest Service, Northern Research Station, Marcell Experimental Forest.

# 1. Data Set Overview:

This data set provides (1) the results of *in-situ Sphagnum*-peat hourly net ecosystem exchange (NEE) measured using a LICOR 8100 gas exchange system and (2) the component fluxes -- gross primary production (GPP) and ecosystem respiration (Re), derived using empirical regressions.

NEE measurements were made from 6 June to 6 November 2014 and 20 March to 10 May 2015. Three 8100 chambers per dominant species (*S. magellanicum* or *S. fallax*) were placed in the S1 Bog in relatively open ground where there was no obvious hummock-hollow microtopography. The 8100 chambers were not located in the SPRUCE experimental enclosures. Measured site meteorological data used as model drivers are also included.

# 2. Data Characteristics:

There are three files provided in comma separated value (*.csv) format.

| Data File Names | Description |
|---|---|
| spruce.039_8100flux_variables.csv | Results of *in-situ Sphagnum*-peat hourly net ecosystem exchange (NEE) measured using LICOR 8100 gas exchange system |
| spruce.039_met_variables.csv | Measured site meteorological variables |
| spruce.039_model_variables.csv | The component fluxes -- gross primary production (GPP) and ecosystem respiration (Re), derived using empirical regressions. |

## Spatial Coverage

All measurements were made at the 8.1-ha S1 bog forest site in northern Minnesota, 40 km north of Grand Rapids, in the USDA Forest Service Marcell Experimental Forest (MEF). These coordinates are the central location of the S1 bog.

## Temporal Coverage

The data reported in these data files were collected beginning in August 2015 with the initiation of WEW. More recent data will be added periodically. Treatments are expected to operate through 2025.

**Site boundaries:** Latitude and longitude given in decimal degrees.

| Site (Region) | Westernmost Longitude | Easternmost Longitude | Northernmost Latitude | Southernmost Latitude | Elevation (meters amsl) | Geodetic Datum |
|---|---|---|---|---|---|---|
| S1 Bog, Marcell Experimental Forest | -93.48283 | -93.48283 | 47.50285 | 47.50285 | 418 | WGS84 |

# Data Dictionary

**Missing Values** -- Missing values are represented by "NA".

## spruce.039_8100flux_variables.csv

| Column Name | Format / Units | Description |
|---|---|---|
| Date | YYYY-MM-DD | Measurement date |
| Time | HH:MM | Measurement time |
| DateTime | YYYY-MM-DD HH:MM | Measurement time is the center of averaging interval. Time zone is CST. |
| Chamber | | |
| NEE | gC m-2yr-1 | Net Ecosystem* Exchange. Chamber measurement |
| NEE.gap_filled | gC m-2yr-1 | Gap filled using calculated GPP – Reco |
| Reco | gC m-2yr-1 | Ecosystem* respiration from empirical flux partitioning using water table and temperature |
| Reco.gap_filled | gC m-2yr-1 | As above with NEE substituted in for nighttime Reco and correction factor applied during daytime. |
| correction_factor.Reco | | Reco correction factor when temperature and water table used in flux partitioning |
| correction_factor.Reco_T only | | Reco correction factor when temperature only used in flux partitioning |
| GPP | gC m-2yr-1 | Gross Primary Production*. NEE + Reco.gap_filled |
| GPP.gap_filled | gC m-2yr-1 | As above, with negative values replaced with zero, gap filled using empirical relationship to PAR and water table. |
| correction_factor.GPP | | GPP correction factor when temperature and water table used in flux partitioning |
| correction_factor.GPP_To nly | | GPP correction factor when temperature only used in flux partitioning |

**Sphagnum* & peat ecosystem components only

## spruce.039_met_variables.csv

| Column Name | Format / Units | Description |
|---|---|---|
| Date | YYYY-MM-DD | Measurement date |
| Time | HH:MM | Measurement time |
| DateTime | YYYY-MM-DD HH:MM | Measurement time is the center of averaging interval. Time zone is CST. |
| Temperature | Deg C | |
| PAR | umol m-2s-1 | Photosynthetically active radiation |
| Precip | mm | |
| Water_Table_Depth | mm | |

**spruce.039_model_variables.csv**

| Column Name | Format / Units | Description |
|---|---|---|
| Date | YYYY-MM-DD | Measurement date |
| Time | HH:MM | Measurement time |
| DateTime | YYYY-MM-DD HH:MM | Measurement time is the center of averaging interval. Time zone is CST. |
| PAR | umol m-2s-1 | Photosynthetically active radiation |
| Temperature | Deg C | |
| Water_Table_Depth | mm | |
| Resistance.internal | | |
| Resistance.boundary | | |
| Can_scaling.k | | Light extinction coefficient |
| SAI | m2m-2 | Stem area index (SAI). |
| Can_scaling.omega | | Canopy clumping coefficient |
| Can_scaling.p3 | | Parameter in SAI = f(Water Table) |
| GPP | gC m-2d-1 | |

# 3. Quality Assessment:

These data are considered at **Quality Level 1**. Level 1 indicates an internally consistent data product that has been subjected to quality checks and data management procedures. Established calibration procedures were followed.

# 4. Methods and Materials:

Empirical data were combined with statistical and mechanistic modeling to improve mechanistic understanding of the biophysical drivers of *Sphagnum* GPP. The aim of this study is to characterise the effects of water, temperature, and light on the seasonal dynamics of *Sphagnum* GPP.

See Walker et al. (2017) for data collection and modeling details. Excerpts are included here for general information.

At the S1 bog of the Marcell Experimental Forest, *in-situ Sphagnum*-peat hourly NEE was measured using a LICOR 8100 system, Reco and GPP was estimated using empirical flux [*Barr et al.*, 2004].

A simple mechanistic *Sphagnum* photosynthesis model [*Williams and Flanagan*, 1998; *Weston et al.*, 2015] is used to help investigate and assess quantitative understanding of the drivers of *Sphagnum* GPP. We use the model as a set of mathematically defined hypotheses to illuminate

which hypotheses are necessary to explain the dominant modes of variability in *Sphagnum* GPP estimated by net gas-exchange and flux-partitioning.

### *NEE field measurements*

In June 2014, six automated 8100-104C 20cm diameter clear top chambers (LI-COR, Lincoln Nebraska, USA) and the associated control system (LI-8100A; LI-COR, Lincoln Nebraska, USA) were installed in the S1 bog (Figure 1) to measure *Sphagnum*-peat $CO_2$ uptake from the atmosphere. Hereafter we refer to *Sphagnum*-peat $CO_2$ uptake as NEE while recognising this is not true NEE as there are fluxes from other components of the ecosystem that we have not quantified.

Three chambers per dominant species (*S. magellanicum* or *S. fallax*) were placed in the bog in relatively open ground where there was little clear hummock-hollow definition (Figure 1). The automated chambers are designed to minimise PAR attenuation, they equalize chamber pressure with the atmosphere, and maintain a well-mixed air sample. They were programmed to take a 120s air sample from each chamber every hour and use a deadband of 30s.

Measurements were made 6$^{th}$ June – 6$^{th}$ November 2014 and 20th March – 10th May 2015 on which date the instrument failed—a hazard of working with such water sensitive instruments in a water saturated environment. Water table height is expressed with zero at the *Sphagnum* surface, which was estimated from observations of when the *Sphagnum* in the chambers were submerged, though there was some variability (±20mm) in the mean *Sphagnum* surface height. A positive water table height represents the water table above the *Sphagnum*.

### *Partitioning NEE into GPP and Re*

Data processing and analysis was done in R [R Core Development Team, 2011]. Hourly Sphagnum-peat NEE flux data from the 8100 chambers were partitioned into the component fluxes Re and GPP using empirical relationships to temperature and light based on the method of Reichstein et al., [1995] and Barr et al., [2004], modified to account for the influence of water table height on C fluxes in this water-sensitive Sphagnum-peat system. Including water table height in the empirical relationships resulted in models with lower Akaike Information Criterion (AIC).

At SPRUCE a vertical profile of air and soil temperature measurements are recorded and for the flux partitioning we used the temperature at 100mm above the mean hummock height as this explained the most variation in nighttime Re—see D'Angelo et al., [2016] for an investigation of synchronising temperatures and flux measurements. PAR used was a mean of open-sky measurements situated above the bog surface and semi-shaded measurements in hollows as the 8100 chambers were sited in a relatively open position (Figure 1).

In brief, the flux-partitioning method derived empirical flux-environment relationships for Re and GPP. For Re an empirically derived Q10 relationship of nighttime C fluxes (i.e. Re) with temperature (T) and water-table height (Wh) was used to calculate all daytime Re data and missing nighttime Re (<2% of night-time data) from measured T and Wh. GPP was calculated by summing Re and NEE. An empirical relationship of GPP with photosynthetically active radiation (PAR) and Wh was then calculated and used to gap fill missing GPP values (<2% of the time series). Finally, NEE was gap-filled (<2% of timeseries) by subtracting calculated Re from GPP.

### *Modeling Sphagnum photosynthesis*

A simple 'canopy'-scale Sphagnum photosynthesis model was used to investigate the drivers of GPP. The multi-assumption architecture and testbed (MAAT v0.s1; https://github.com/walkeranthonyp/MAAT), written in R, was used as a framework for the Sphagnum model. The Sphagnum photosynthesis model is based on that of Williams and Flanagan, [1998] and is similar to that used in Weston et al., [2015]. The model was made specific to Sphagnum by accounting for tissue resistance to CO2 transport from the atmosphere to the chloroplast, after Williams and Flanagan, [1998] and when the Sphagnum were submerged a resistance of the water layer was calculated based solely on diffusion. High extinction coefficients for light penetration into the Sphagnum 'canopy' were used [Williams and Flanagan, 1998].

The model is based on the enzyme kinetic model of photosynthesis Farquhar et al., [1980]. Net $CO_2$ assimilation (A, µmol C $m^{-2}s^{-1}$) is the minimum of the rubisco limited carboxylation rate ($w_c$, µmol C $m^{-2}s^{-1}$) and the electron transport limited carboxylation rate ($w_j$, µmol C $m^{-2}s^{-1}$), scaled to account for photorespiration, minus mitochondrial respiration ($R_d$).

# 5. References:

Hanson, P. J., J. S. Riggs, C. Dorrance, and L. A. Hook, (2011), SPRUCE Environmental Monitoring Data: 2010-2011, Carbon Dioxide Information Analysis Center (CDIAC), doi:10.3334/CDIAC/spruce.001.

Hanson, P. J., J. S. Riggs, W. R. Nettles, M. B. Krassovski, and L. A. Hook (2015), SPRUCE Deep Peat Heating (DPH) Environmental Data, February 2014 through July 2015, Carbon Dioxide Information Analysis Center (CDIAC), doi:10.3334/CDIAC/spruce.013.

Krassovski MB, Riggs JS, Hook LA, Nettles WR, Boden TA, Hanson PJ (2015) A comprehensive data acquisition and management system for an ecosystem-scale peatland warming and elevated CO2 experiment. Geosci Instrum Methods Data Syst 4:203–213. doi:10.5194/gi-4-203-2015

# 6. Data Access:

This data is available through the Oak Ridge National Laboratory (ORNL) Carbon Dioxide Information Analysis Center (CDIAC)

### Data Archive Center:

### Contact for Data Center Access Information:

E-mail: http://cdiacservices.ornl.gov/feedback.cfm