# Spruce and Peatland Responses Under Climatic and Environmental change

## First Friday All Climate Change Talks

## 1 May 2015


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SPRUCE

*http://mnspruce.ornl.gov*

Climate Change Science Institute AT OAK RIDGE NATIONAL LABORATORY

FOREST SERVICE U S DEPARTMENT OF AGRICULTURE

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# SPRUCE

- An experiment to assess the response of northern-peatland, **high-carbon** ecosystems to whole-ecosystem increases in temperature and exposures to elevated atmospheric $CO_2$ concentrations.
- Funded by the Office of Biological and Environmental Research within the US Dept. of Energy's Office of Science.
- A cooperative venture between ORNL and the USDA Forest Service with interested university cooperators.

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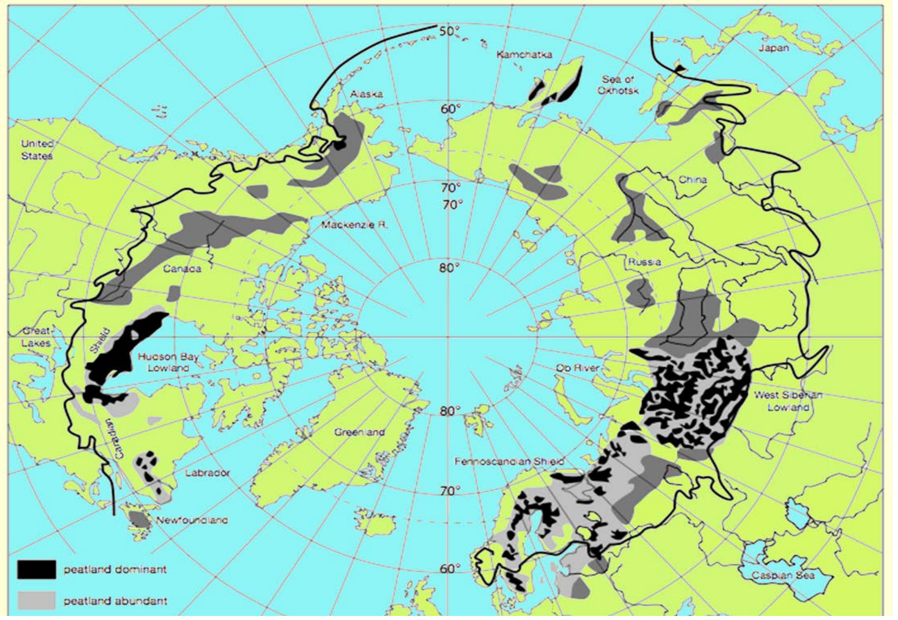
# Key Science Questions

- Will deep belowground warming in the future release 10,000 years of accumulated carbon from peatlands that store 1/3 of the earth's terrestrial carbon? At what rate?
- Will releases of C be in the form of $CO_2$ or $CH_4$ with 30 times the warming potential?
- Are peatland ecosystems and organisms vulnerable to atmospheric and climatic change? What changes are likely?
- Will ecosystem services (e.g., regional water balance) be compromised or enhanced by atmospheric and climatic change?

# WHY ARE NORTHERN PEATLANDS IMPORTANT?

- Culturally and aesthetically important.
- As habitat for fauna and unique flora.
- As sources of forest products, horticultural peat, and biofuels.
- As records of past environmental conditions,
- Storage of organic matter (i.e. carbon).
  - Regulate greenhouse gases in the atmosphere.
  - Have feedbacks on global climate.

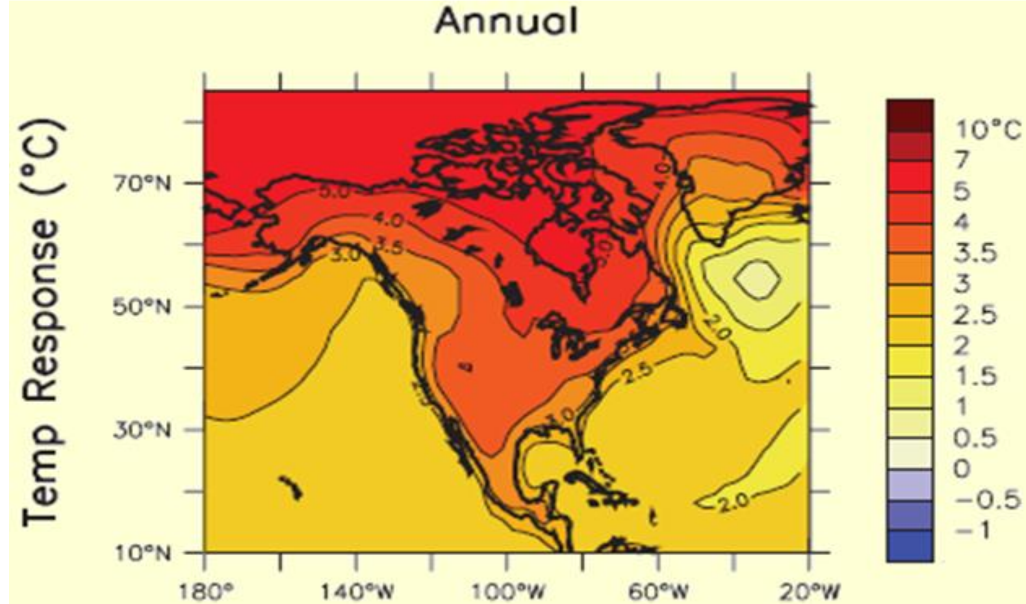


# Why study the response of a peatland to warming and elevated $CO_2$?

- → Conduct research on an understudied ecosystem
- → They systems has a potential to show dramatic carbon cycle and organismal responses under projected environmental and atmospheric change
- → An ecosystem located at the southern extent of the boreal forest considered vulnerable to climate change.
- → It is expected to generate important greenhouse gas feedbacks to the atmosphere (both $CO_2$ and $CH_4$)
- → Provide quantitative data to enhance ecosystem and global circulation models with a limited capacity to capture high-carbon wetland response

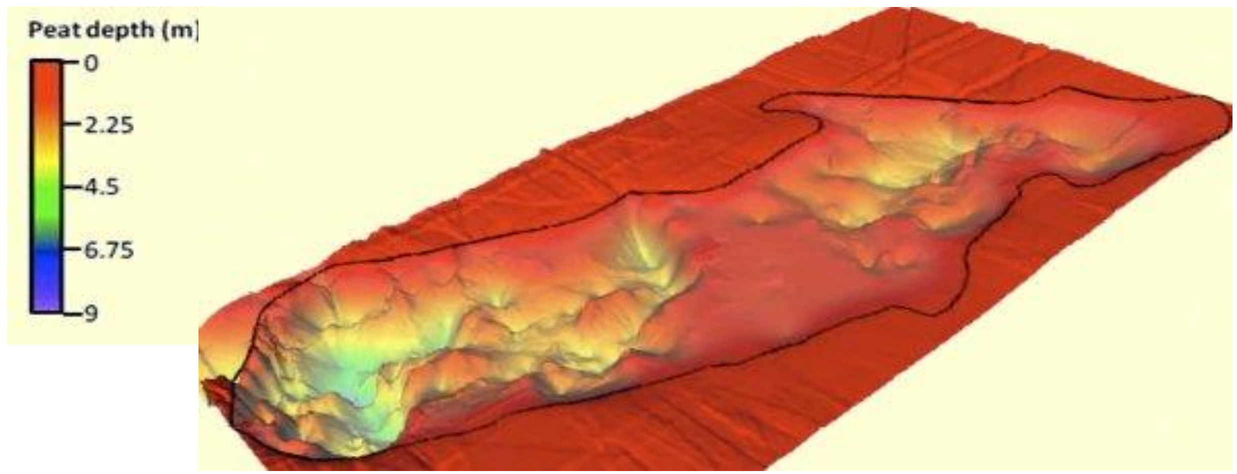
# WHAT IS A HIGH-CARBON, VULNERABLE, ECOSYSTEM?

- Seasonal and annual air temperatures will be warmer and atmospheric greenhouse gas concentrations will be higher by the end of the century.
- **Temperature shifts will be greater at higher latitudes**.
- Peatlands along the northern- and southern-most fringes are expected to be most vulnerable to shifts in ecosystem regimes.




**An 8 ha peatland at the Marcell Experimental Forest**

11,200 ton of stored C = Amount of C emitted from 4100 Hummer H3's in 1 year

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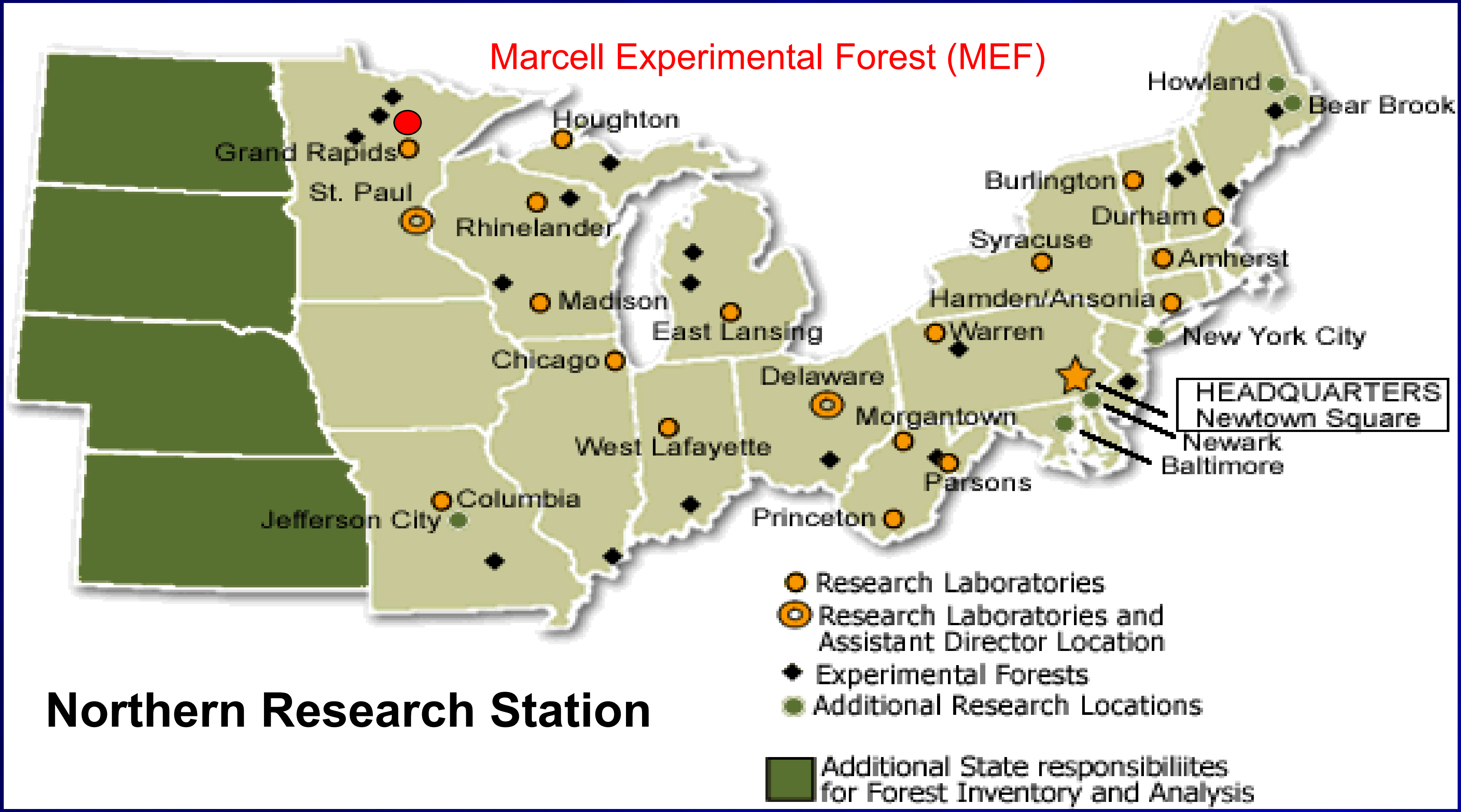
# Marcell Experimental Forest



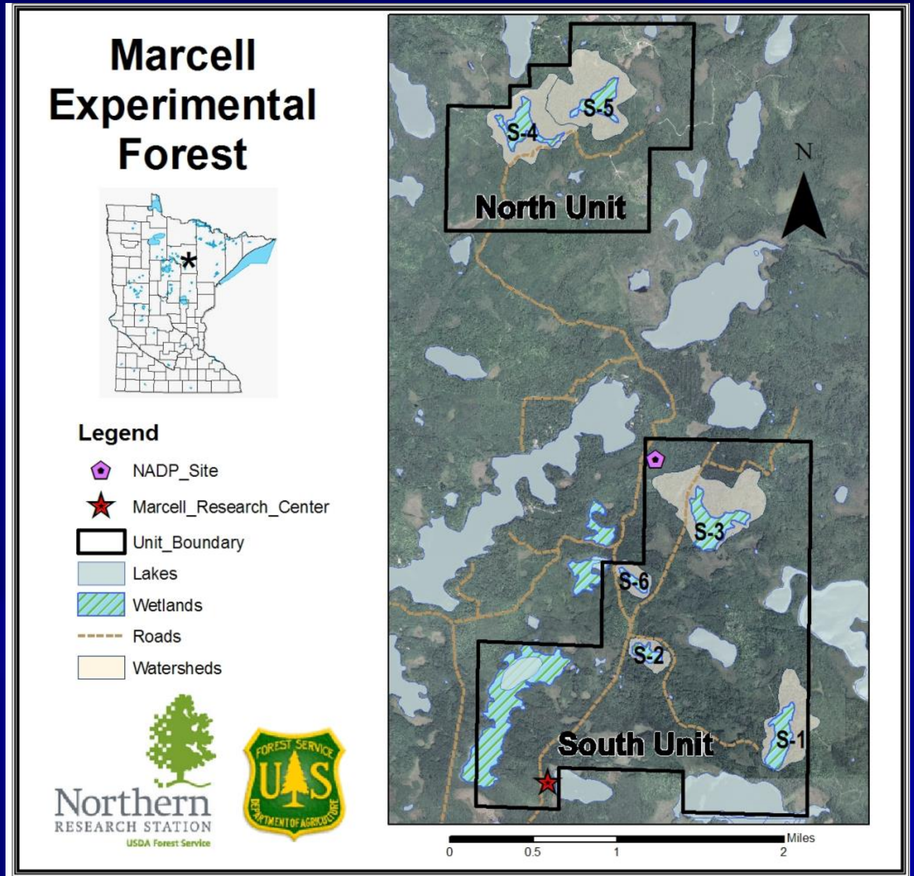
# MEF Long-Term Data Bases

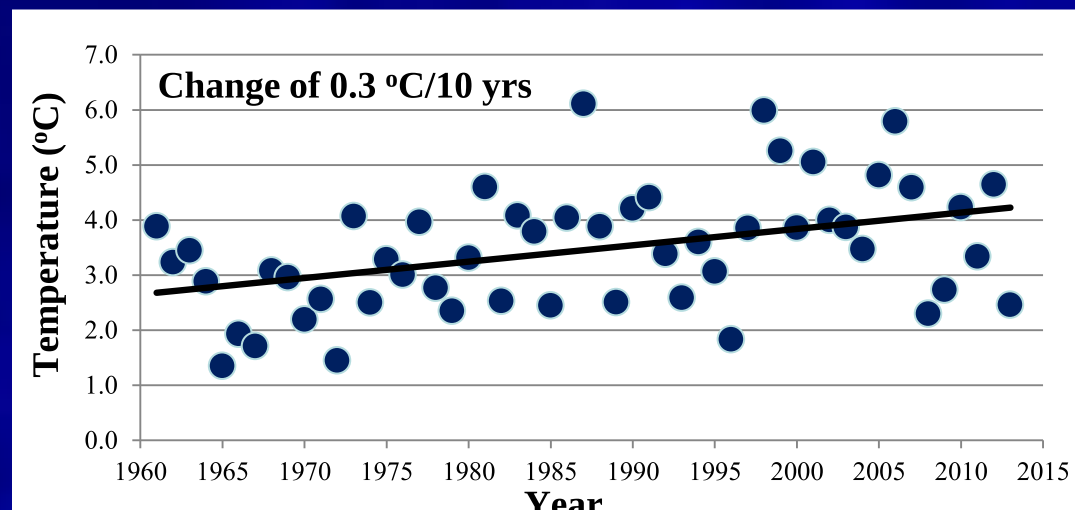
- **Streamflow (1960)**
- **Water Quality (1982)**
- **Water Table (1960)**
- **Climate (1960)**
- **Precipitation Quality (1977)**
- **Soil Temperature (1989)**
- **Soil Moisture (1960)**
- **Frost (1960)**
- **Snowpack (1960)**
- **Upland Runoff (1972)**
- **40+ Thesis/Dissertations, 320+ papers**

- **http://nrs.fs.fed.us/ef/marcell/data/**

# MEF Research Program

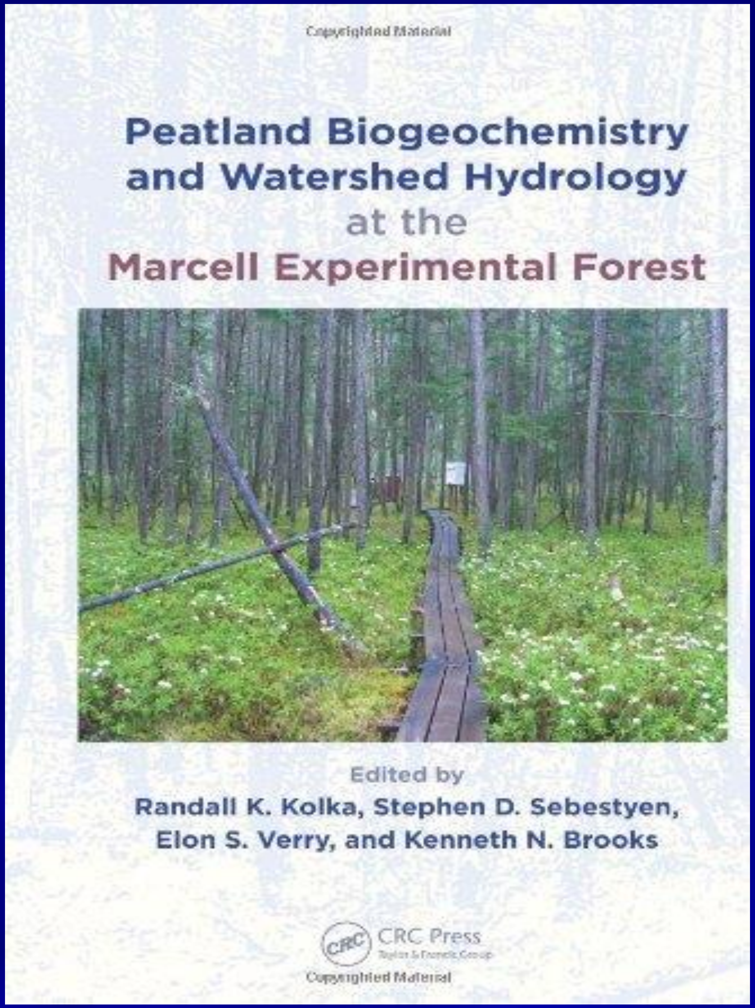
- **Peatland Hydrology and Soils**
- **Forest Management Effects on Water Quality and Quantity**
- **Biogeochemical Cycles**
- **Mercury**
- **Climate Change/Carbon Science**



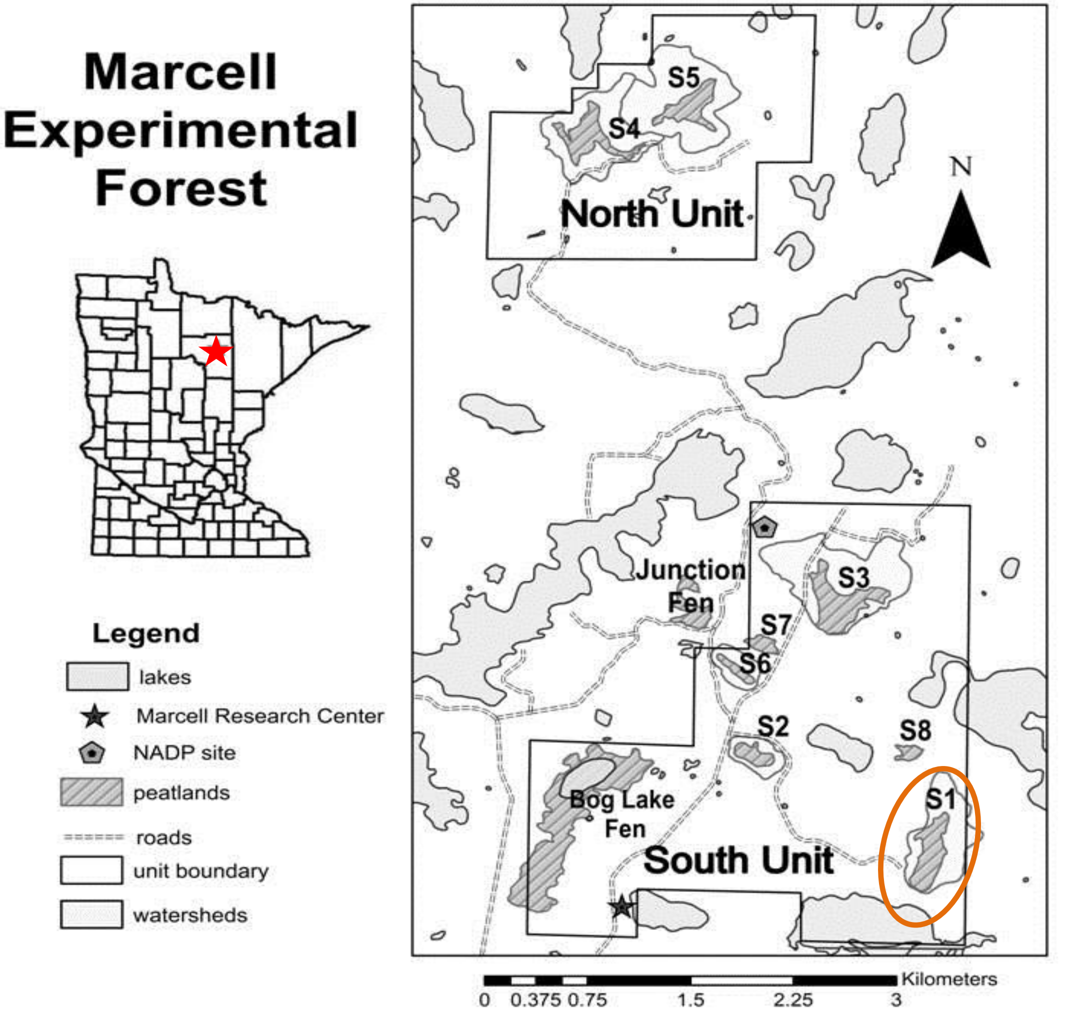



# MEF Synthesis of 50 Years of Research

- Kolka, R.K., S.S. Sebestyen, E.S. Verry, and K.N. Brooks (Eds.). 2011. *Peatland Biogeochemistry and Watershed Hydrology at the Marcell Experimental Forest.* CRC Press, Boca Raton, FL, 488 pp.



# Project Setting – S1 Bog at the MEF

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# The SPRUCE *Picea-Sphagnum* Bog

PFTs:
- Trees (*Picea, Larix*)
- Shrubs (Spp)
- *Sphagnum* (Spp)
- Aerobic Microbes
- Anaerobic Microbes

Soil: Histosol 2 to 3 m deep with seasonally variable water table.

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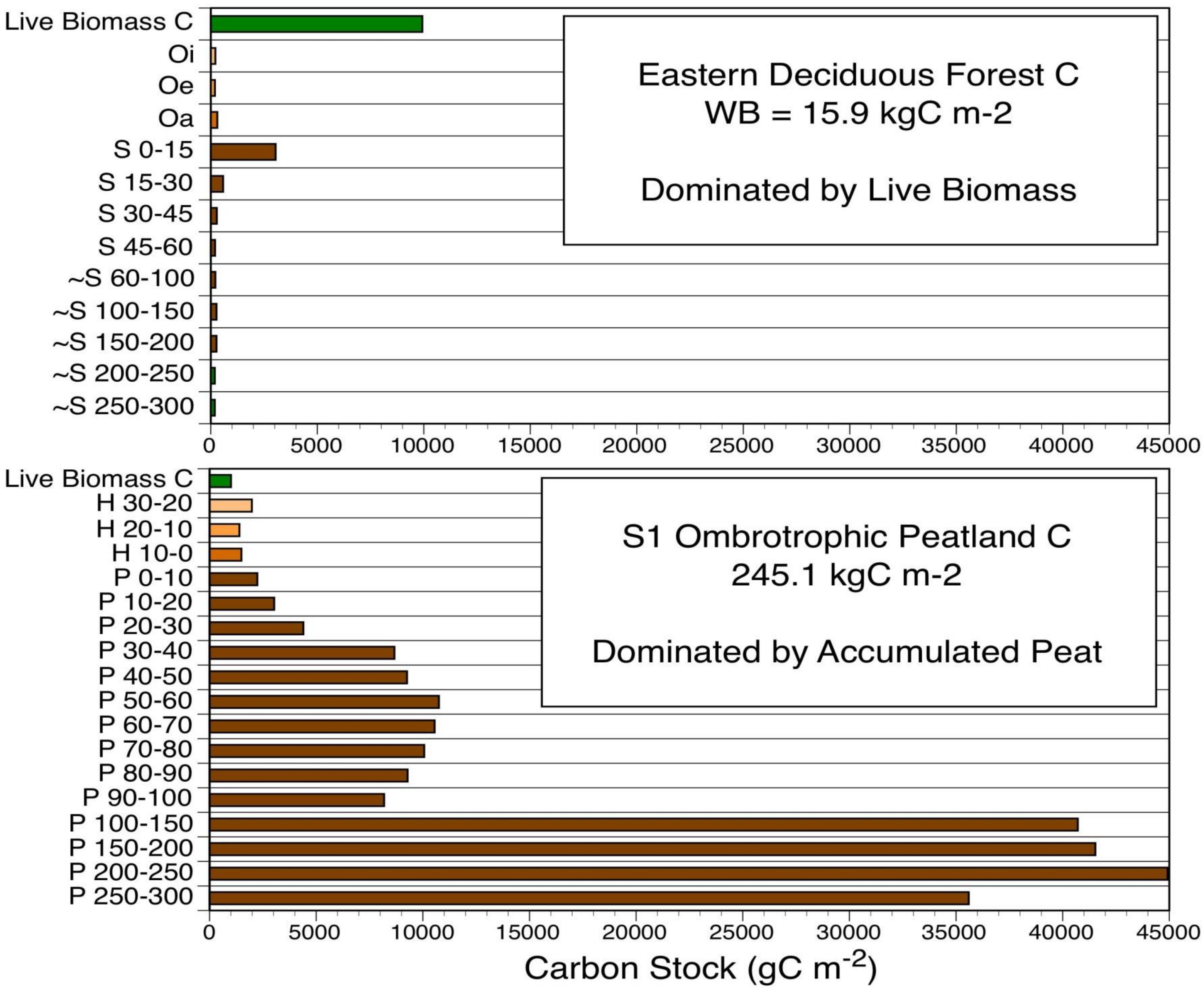
# S2-Bog Profile

# Terrestrial vs. Peatland Ecosystem Carbon

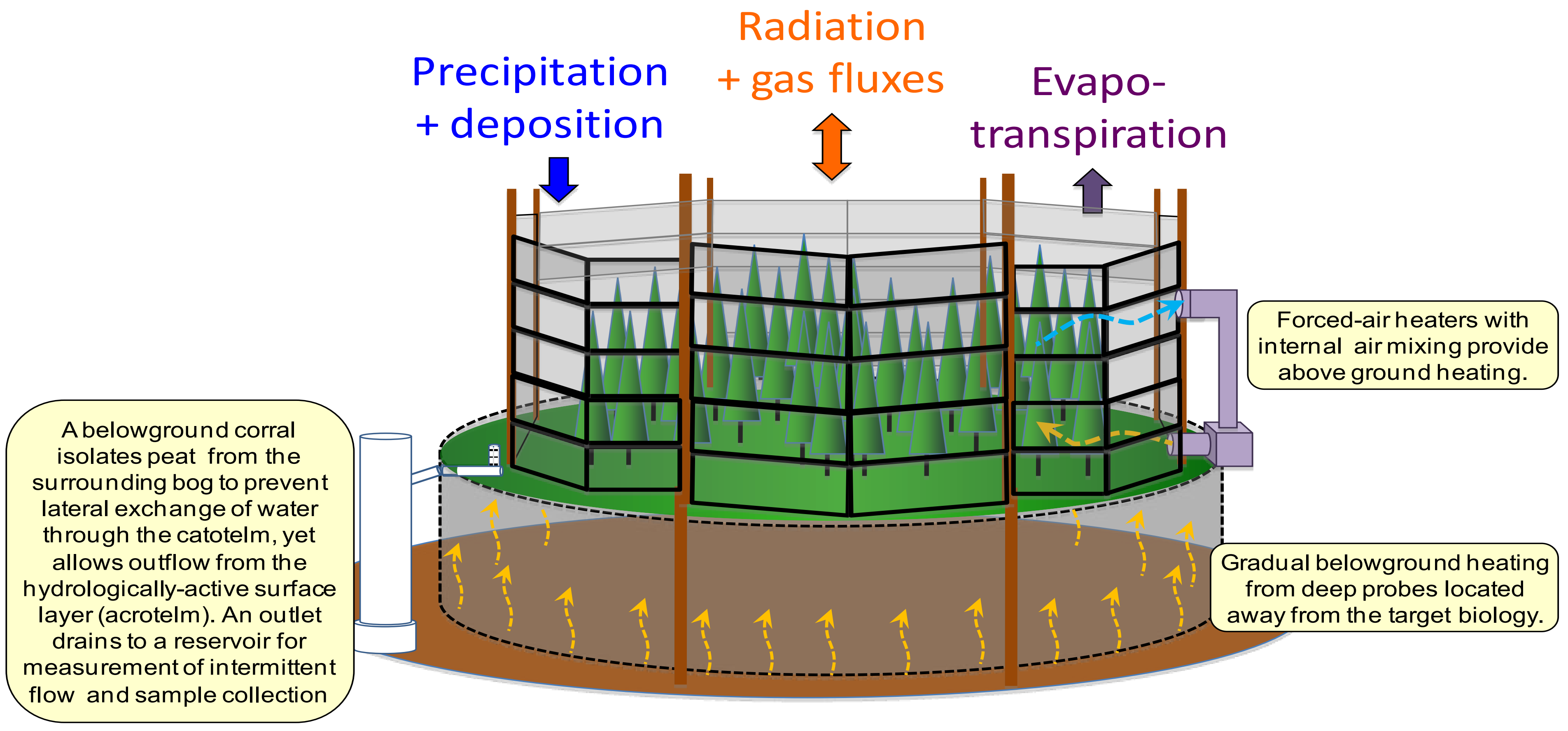



Peatlands contain 15 times more C than occurs in a healthy regrowth forest of the Eastern US. Ecosystems

# Experimental Goal: Whole-Ecosystem Warming

- A new warming approach that encompasses target ecosystem diversity, and enables decade-long observations and sampling
- An approach for long-lived and ‘tall’ stature vegetation able to produce plausible future conditions both above and belowground
- An approach to manipulate intact ecosystems (i.e., from the tops of the trees through deep soil microbial communities).

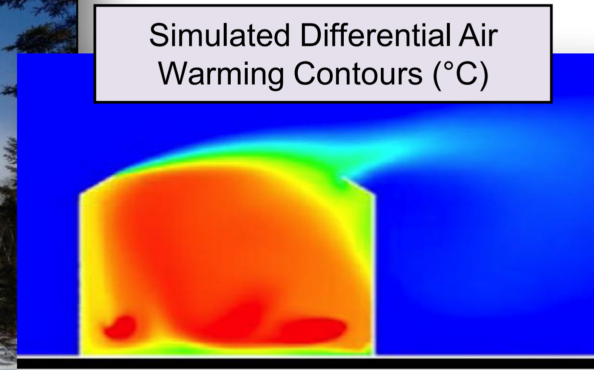
# A method for whole-ecosystem warming

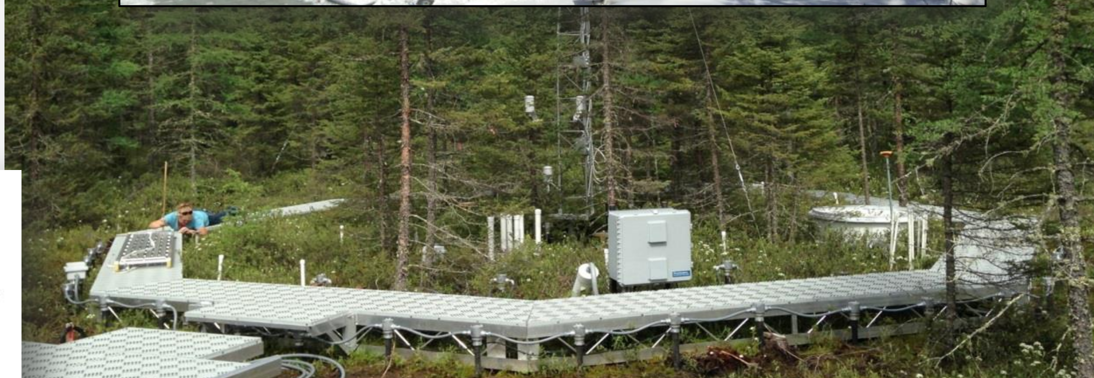



- 12-m diameter internal study area.
- +8-m tall aboveground chamber.
- Deep soil Heating to -2 to -3 meters within peat.
- Belowground environment enclosed in a subsurface chamber.

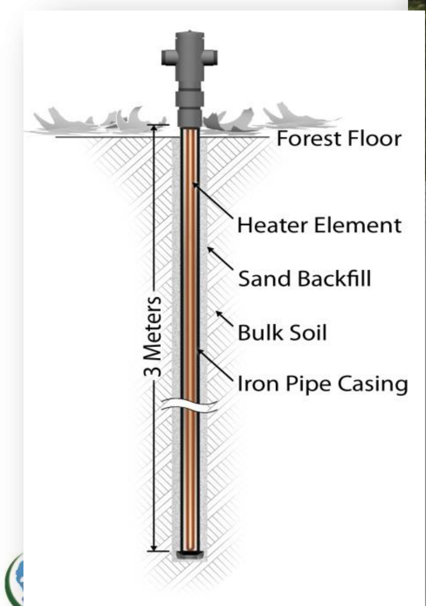
  (Hanson et al. 2011, Barbier et al. 2012)

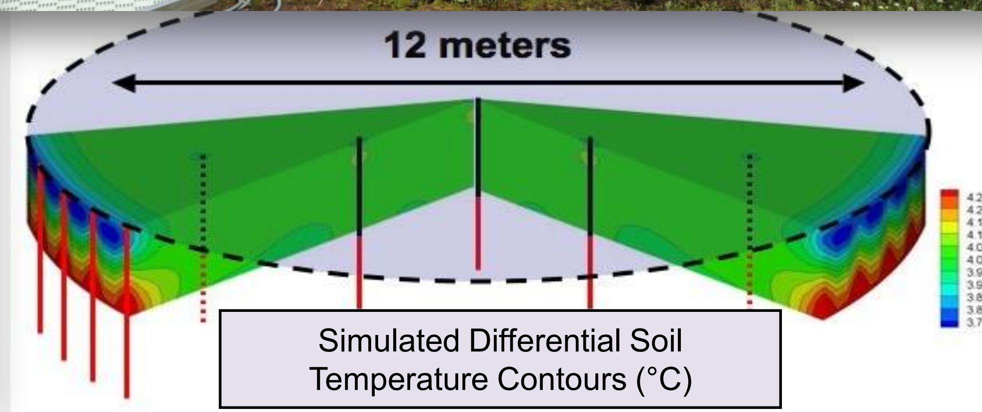
SPRUCE



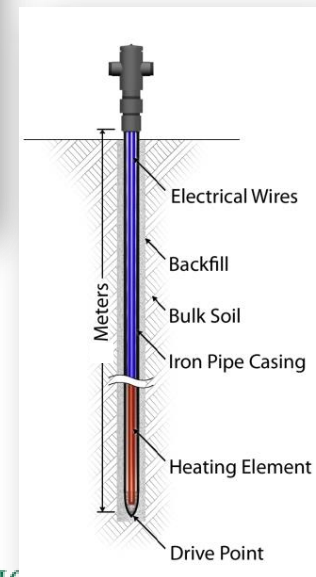



# Exterior Soil Heater




# Interior Deep Soil Heater



# PAST FOREST MANAGEMENT EXPERIMENT

1968

RR Bay photo

1969

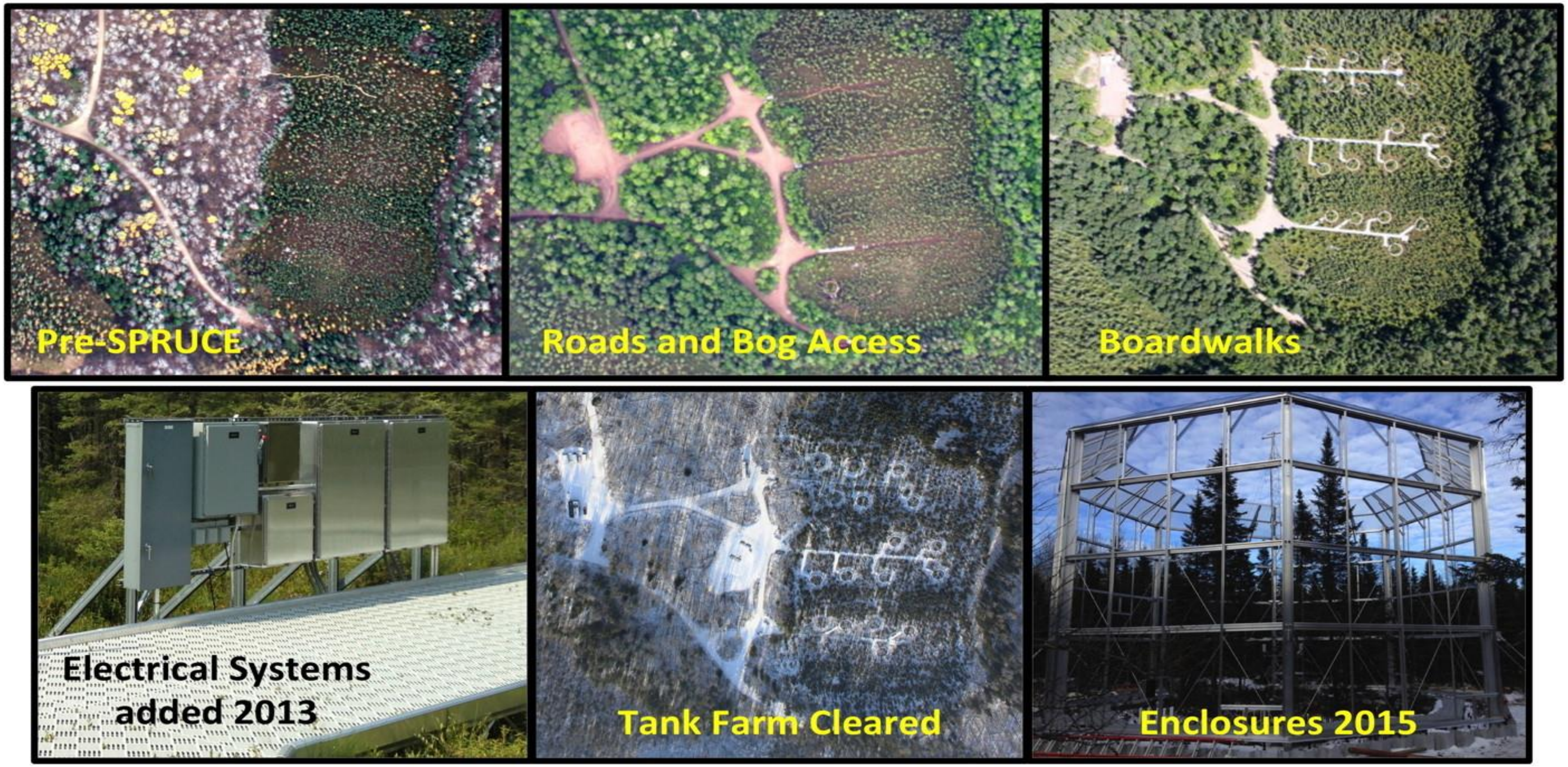
RR Bay photo

1974

ES Verry photo

# S1-Bog Infrastructure Development

October 2011 May 2012 August 2012




November 2014

# Site Status – April 16, 2015

- April 16 – All above/below chamber structures built, glass has been installed, currently working on the duct/heater systems and runoff system.
- Plan is to "flip the switch", mid to late June – Open House Celebration August 26

# Our experimental treatments are not explicit scenarios for the future, but rather a range of temperature and elevated $CO_2$ environments intended to inform mechanisms of response

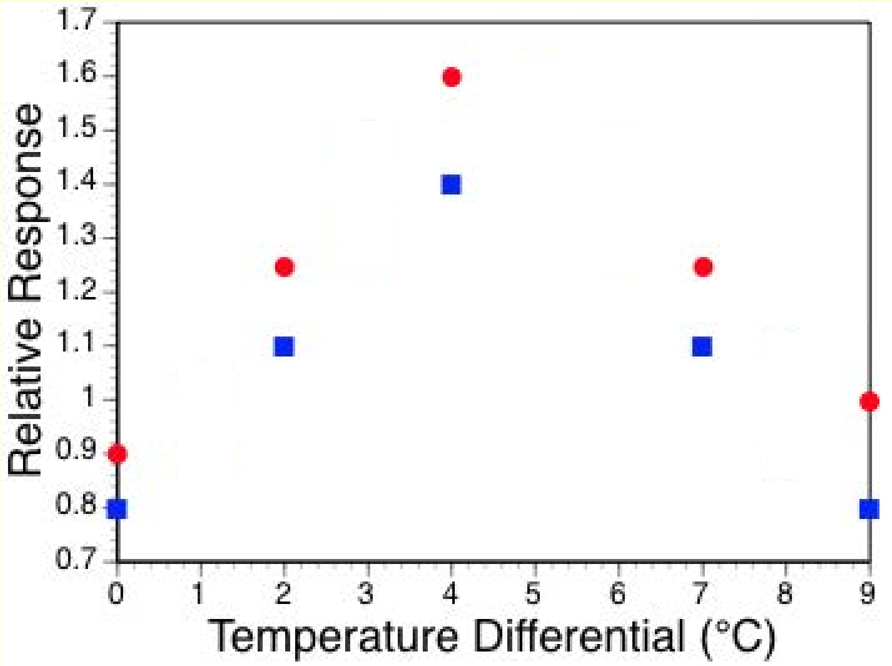
Multiple levels of warming at ambient and elevated $CO_2$ levels:

- Soil and air temperature levels from +0 to +9° C
  - +0, +2.25, +4.50, +6.75, and +9 ° C
  - Unchambered Controls
- Elevated $CO_2$ approaching 900 ppm which is over twice current levels, but consistent with end-of-century projections for atmospheric [$CO_2$].

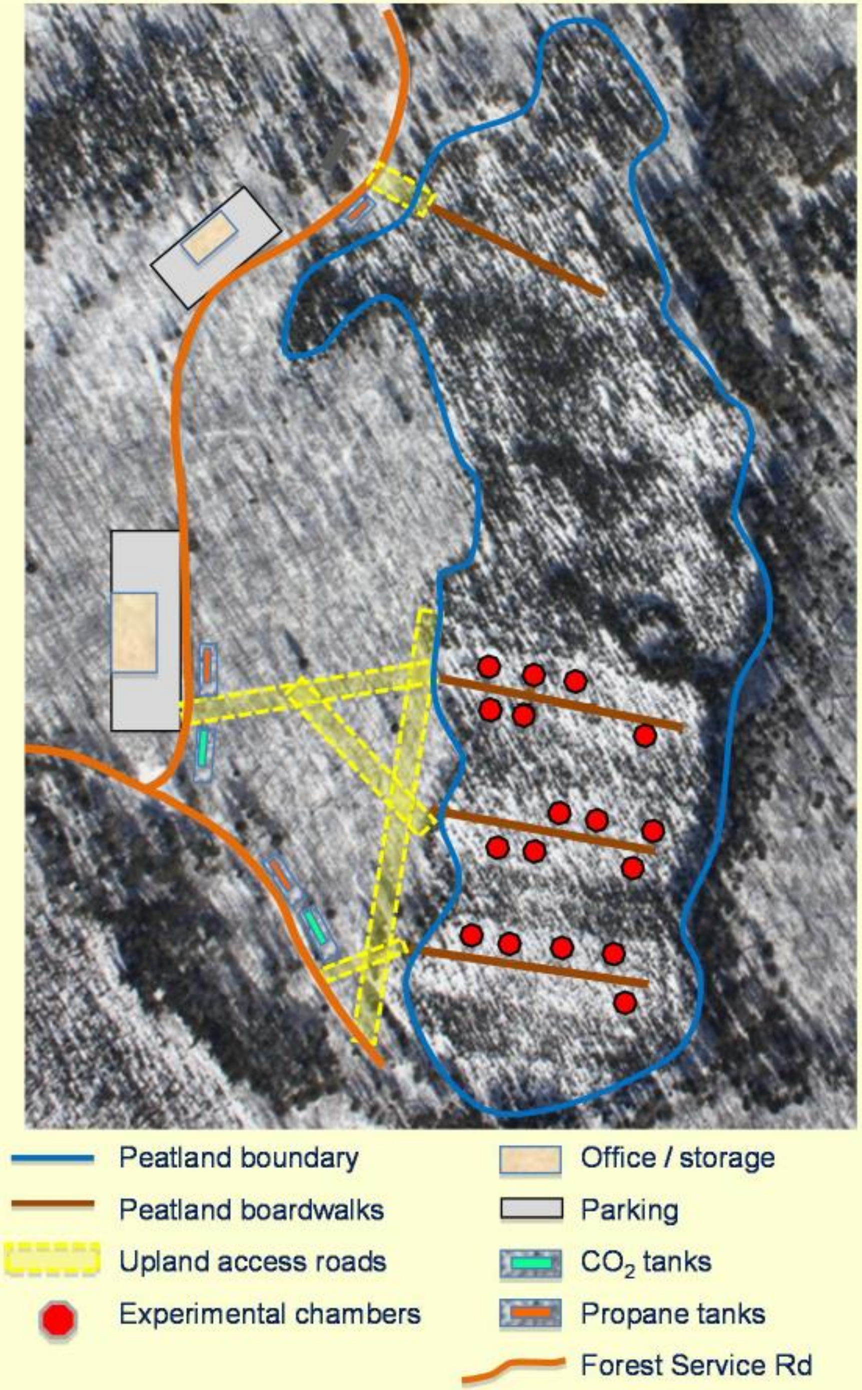
# Warming Treatment Assignments to a Regression Design (half will receive elevated $CO_2$)

# Regression design with elevated $CO_2$ will be applied to characterize the shape of temperature response curves for a range of response variables

10- Planned Experimental Units




Five temperature treatments with and without elevated carbon dioxide



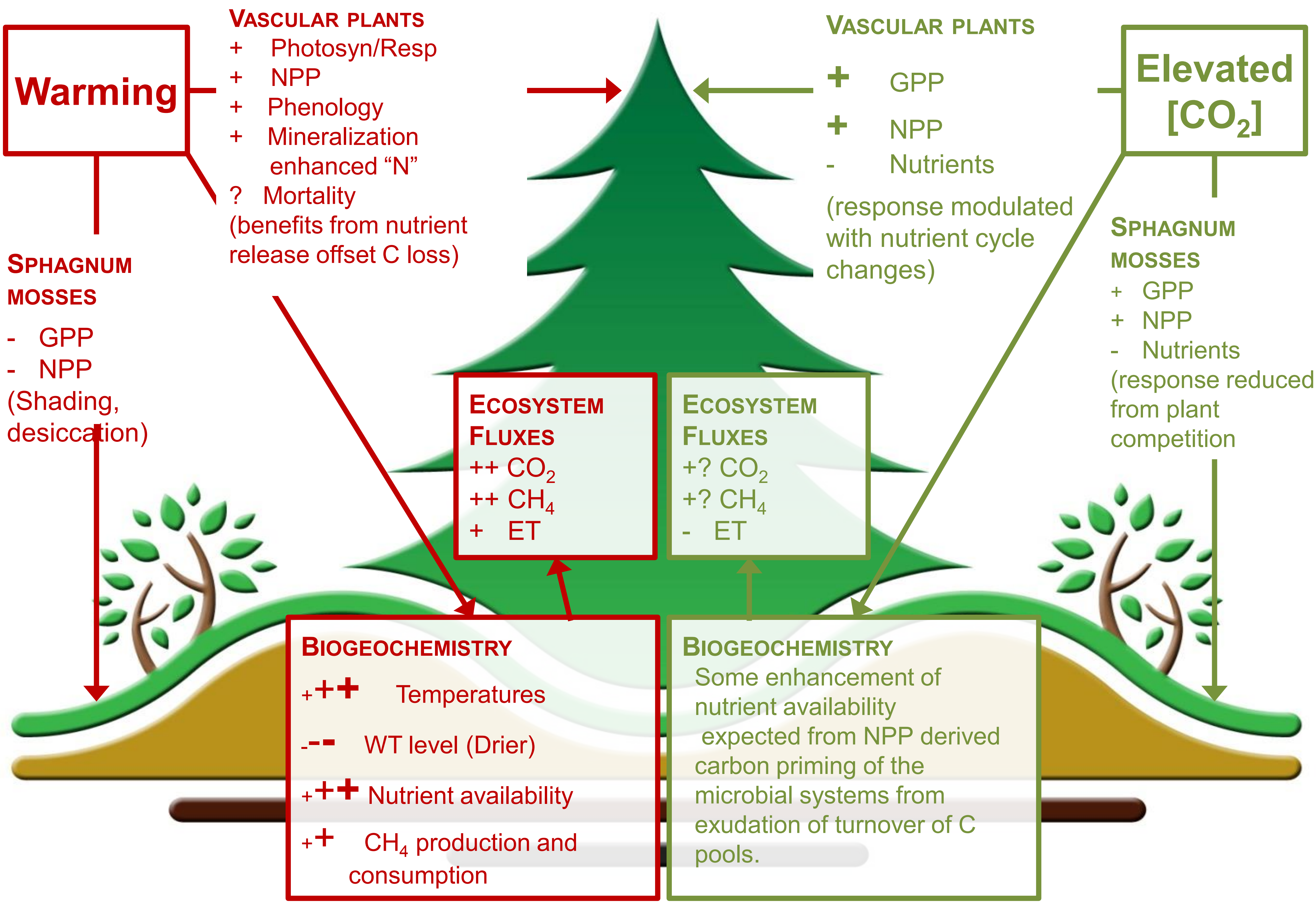
# ENVIRONMENTAL MONITORING AND SCIENTIFIC MEASUREMENTS

Data will be archived for sharing with scientists, educators, and the public.

- Environmental monitoring: temperature, precipitation, wind speed/direction, solar radiation.
- Tree, shrub, grass/sedge, and *Sphagnum* growth; respiration; mortality; community composition; primary productivity; root growth; litter fall; and seed dispersal.
- Soil microbial community composition and function.
- Phenology.
- Plant tissue chemistry.
- Foliar gas exchange.
- Decomposition rates.
- Trace gas (carbon dioxide, methane) and water vapor emissions.
- Precipitation, runoff, and pore water chemistry for nutrients, organic matter, pH, alkalinity, ions, and trace metals.
- Peat volume, chemistry, and physical properties.
- Availability and cycling of carbon, nutrients, and mercury.
- Surface runoff and water table levels.
- High-resolution microtopography surveys.

# SPRUCE

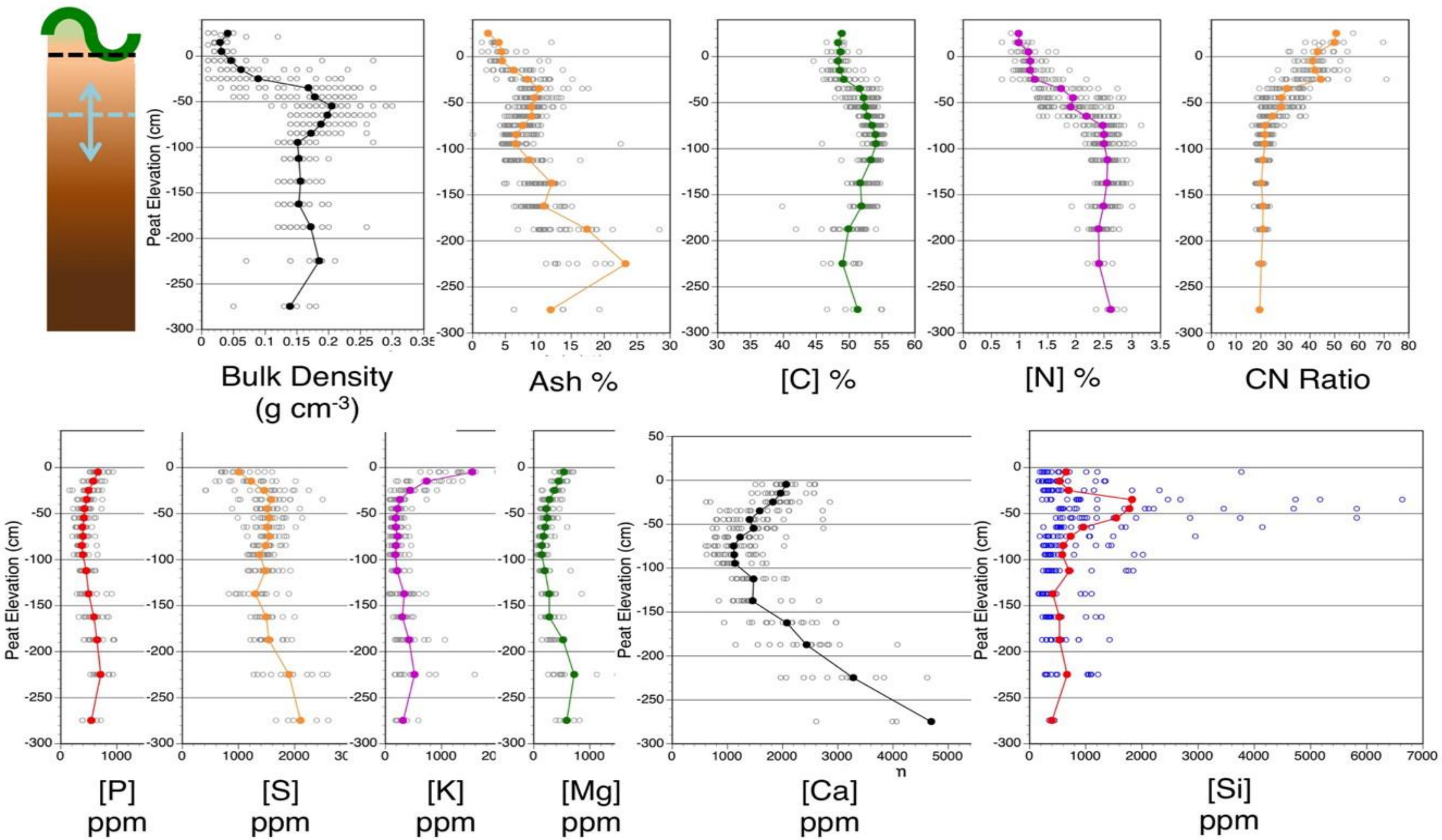
# “Hypothesized Responses”


Warming
VASCULAR PLANTS
+ Photosyn/Resp
+ NPP
+ Phenology
+ Mineralization
enhanced "N"
? Mortality
(benefits from nutrient release offset C loss)
SPHAGNUM MOSSES
- GPP
- NPP
(Shading, desiccation)
ECOSYSTEM FLUXES
++ $CO_2$
++ $CH_4$
+ ET
BIOGEOCHEMISTRY
++ Temperatures
-- WT level (Drier)
++ Nutrient availability
+ $CH_4$ production and consumption
Elevated $[CO_2]$
VASCULAR PLANTS
+ GPP
+ NPP
- Nutrients
(response modulated with nutrient cycle changes)
SPHAGNUM MOSSES
+ GPP
+ NPP
- Nutrients
(response reduced from plant competition
ECOSYSTEM FLUXES
+? $CO_2$
+? $CH_4$
- ET
BIOGEOCHEMISTRY
Some enhancement of nutrient availability expected from NPP derived carbon priming of the microbial systems from exudation of turnover of C pools.

# Pretreatment Observations:

## Setting the Stage for a Decade-Long Manipulation

# Peat Profile Characterization – All Chambers

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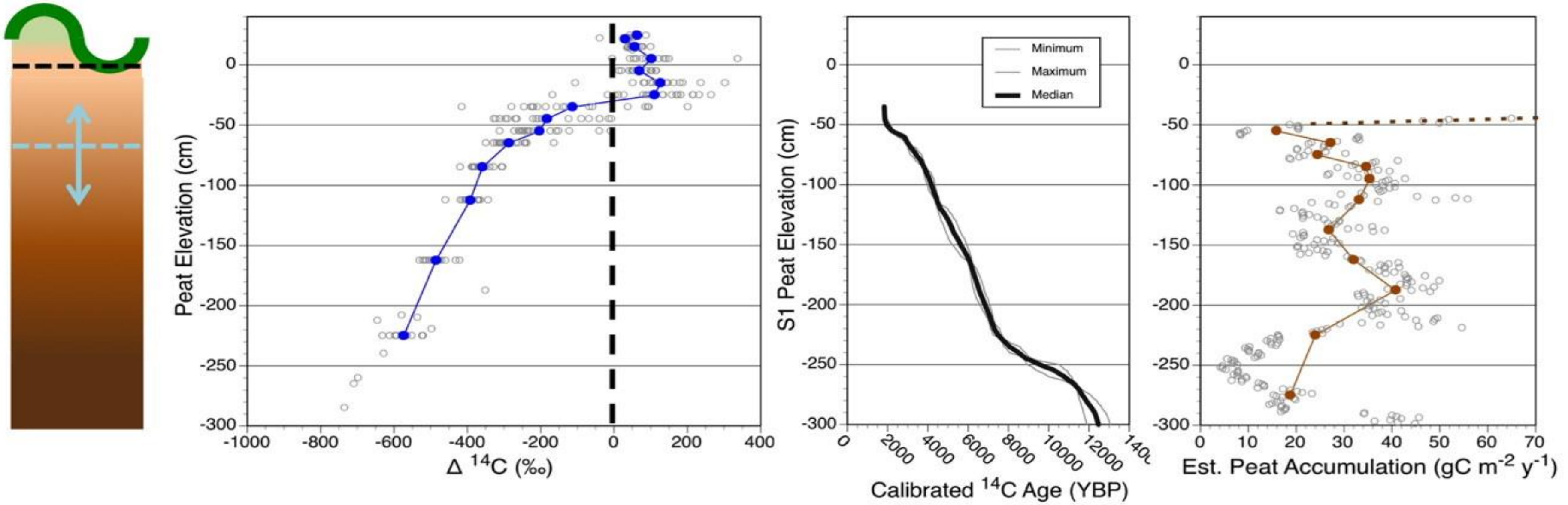
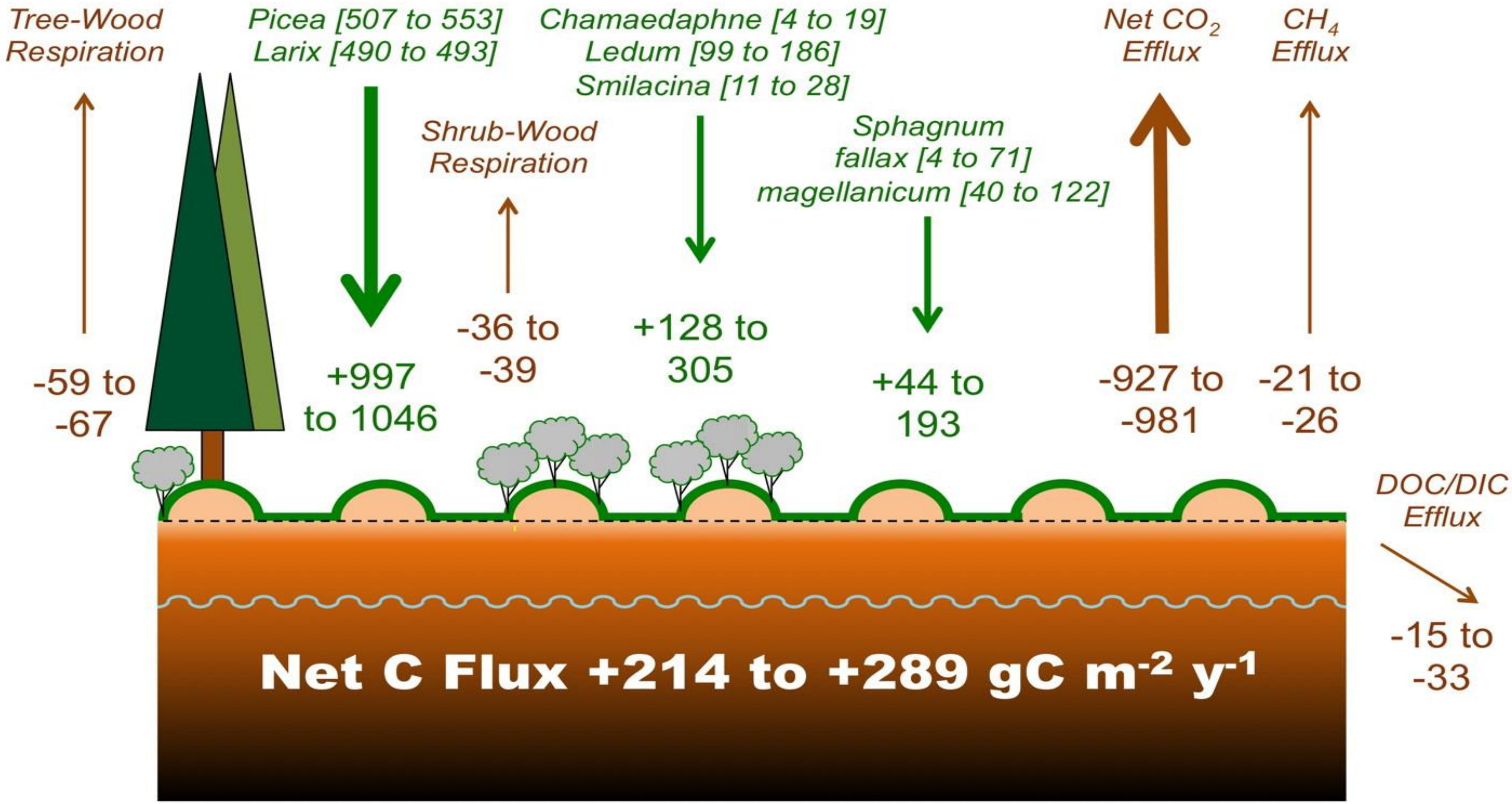
# Peat C Age Characterization




- The mean net C accumulation rate throughout the 10,000-year peat development period was 21 g C $m^{-2}$ $y^{-1}$.

# S1-Bog 2012-2014 C-Cycle Interpolations

**(Multi-year range for C Fluxes in gC $m^{-2}$ $y^{-1}$)**

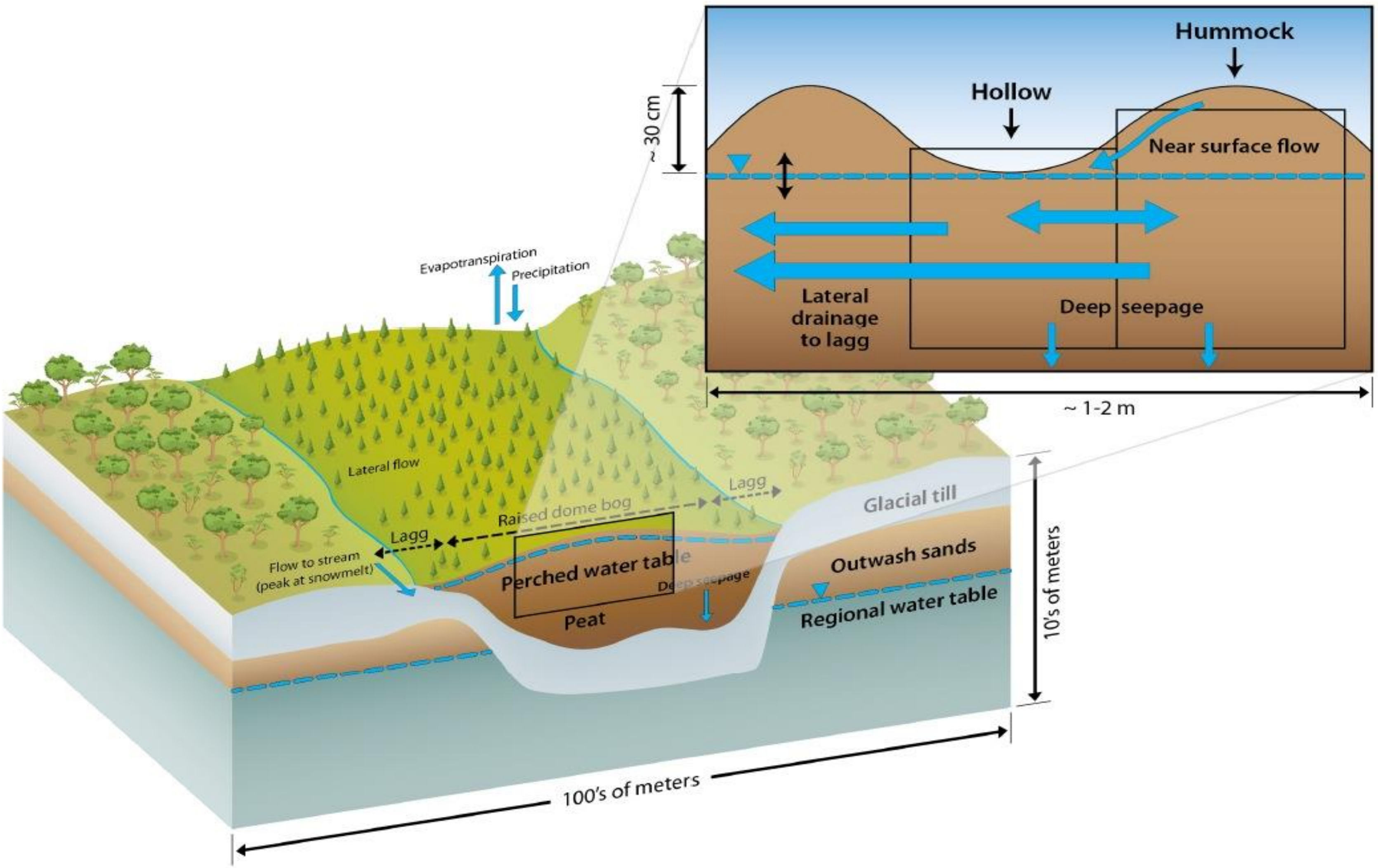


Modeling Wetland Processes

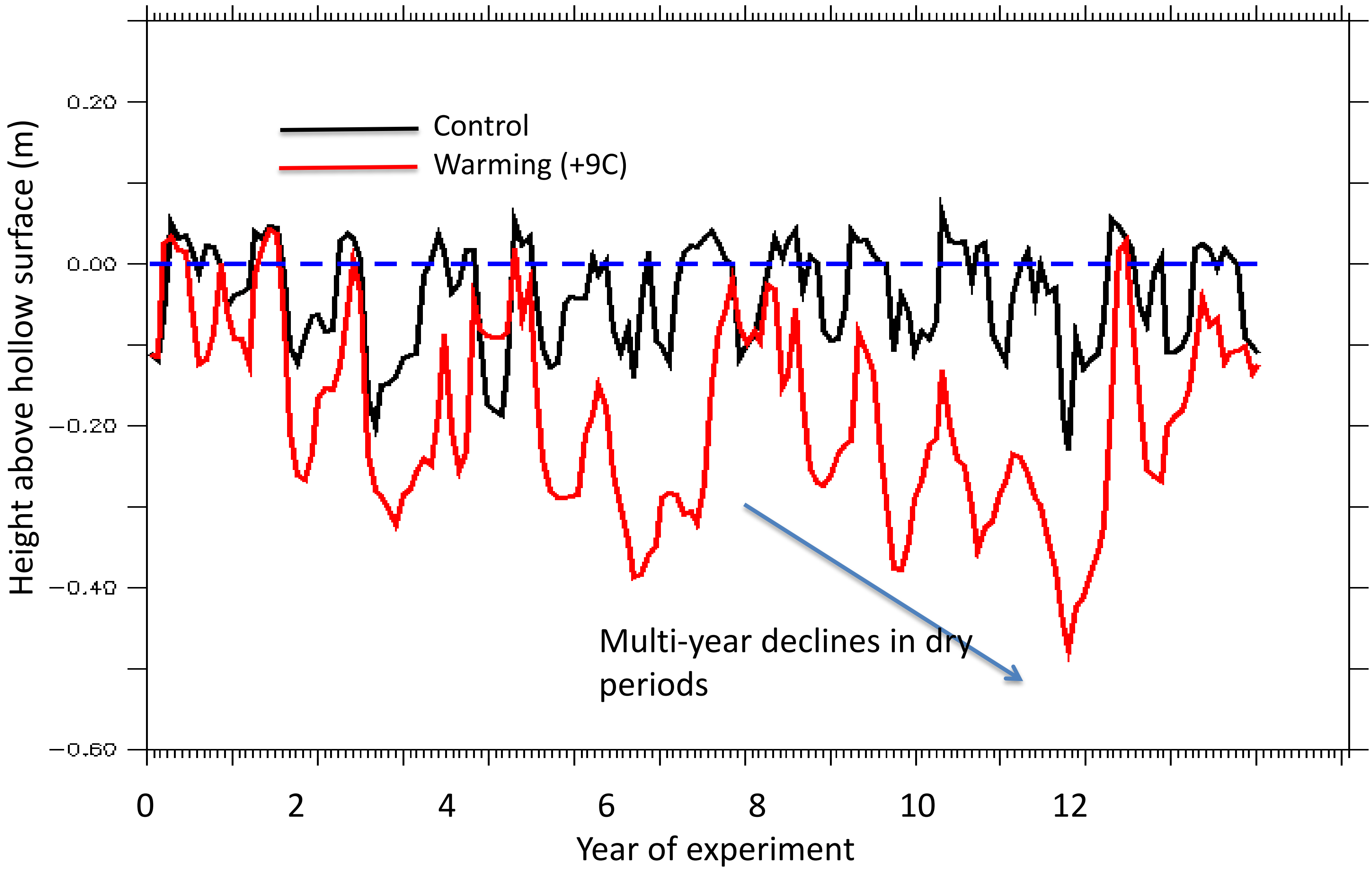
A Challenge for Global Circulation Models

# Community Land Model (CLM) and SPRUCE

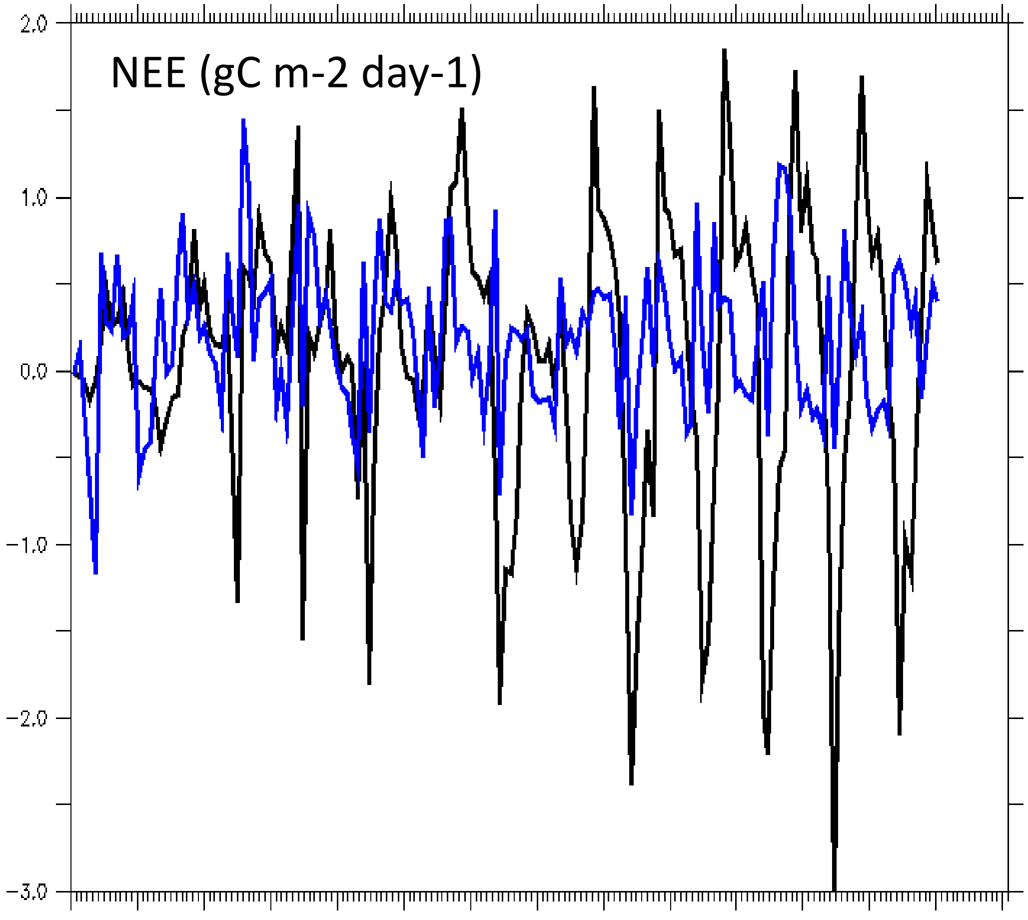
## An improved land model for global wetlands (CLM-Wetlands) is being developed and tested with SPRUCE

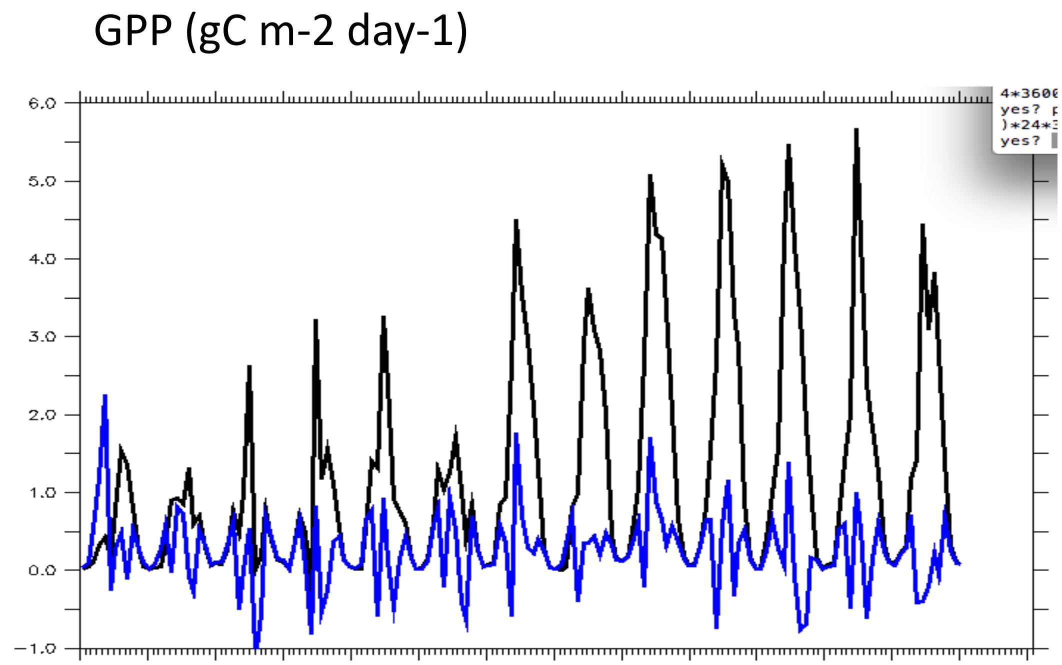


# Water table height warming response



# $CO_2$ flux warming response



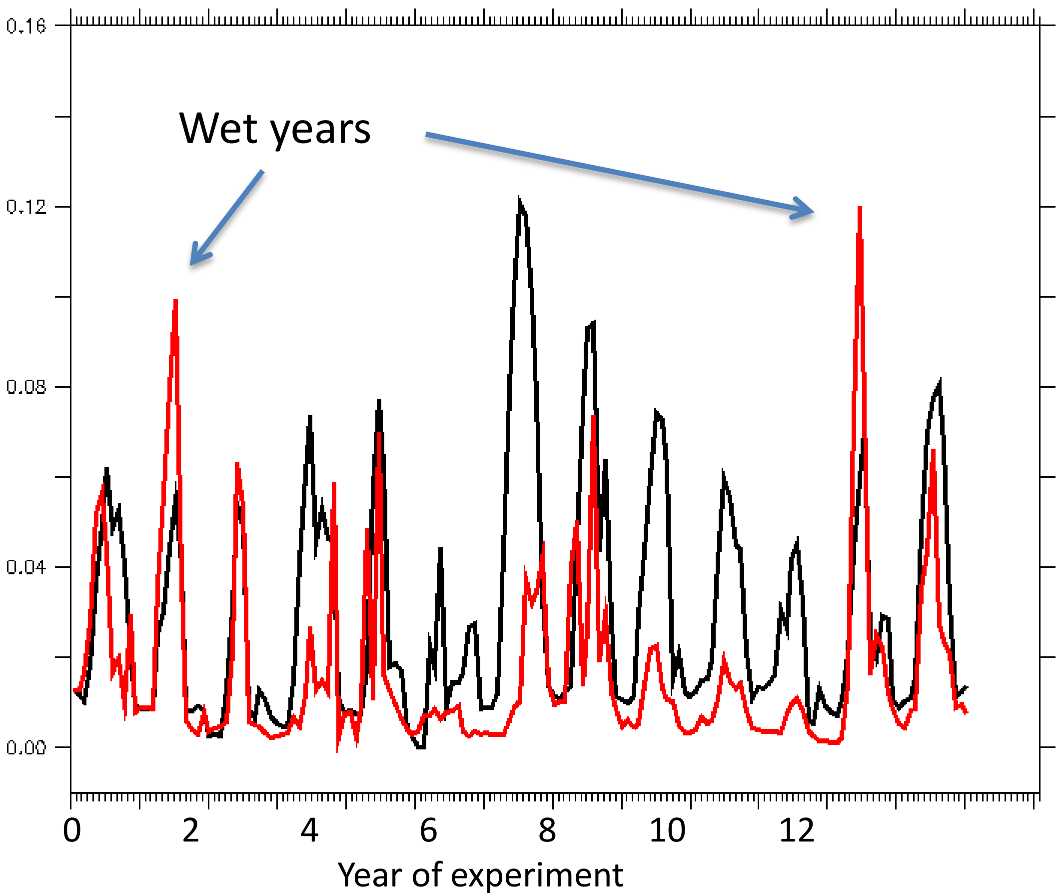




Hollow diff
Hummock diff

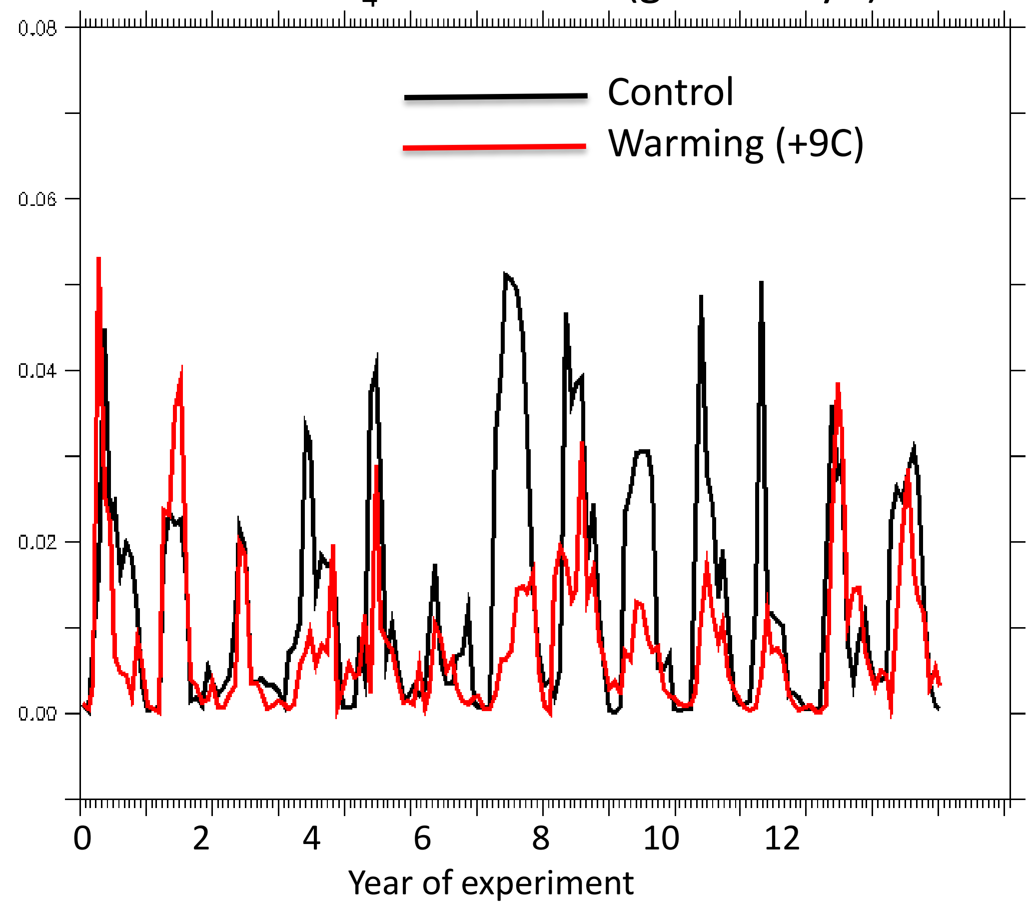
# Methane warming response

- Currently uses CLM4Me model (Riley et al., 2011).
- More mechanistic treatment of microbes, methane production (Xu et al., in review) currently being calibrated with SPRUCE pre-treatment data.
- Large uncertainties

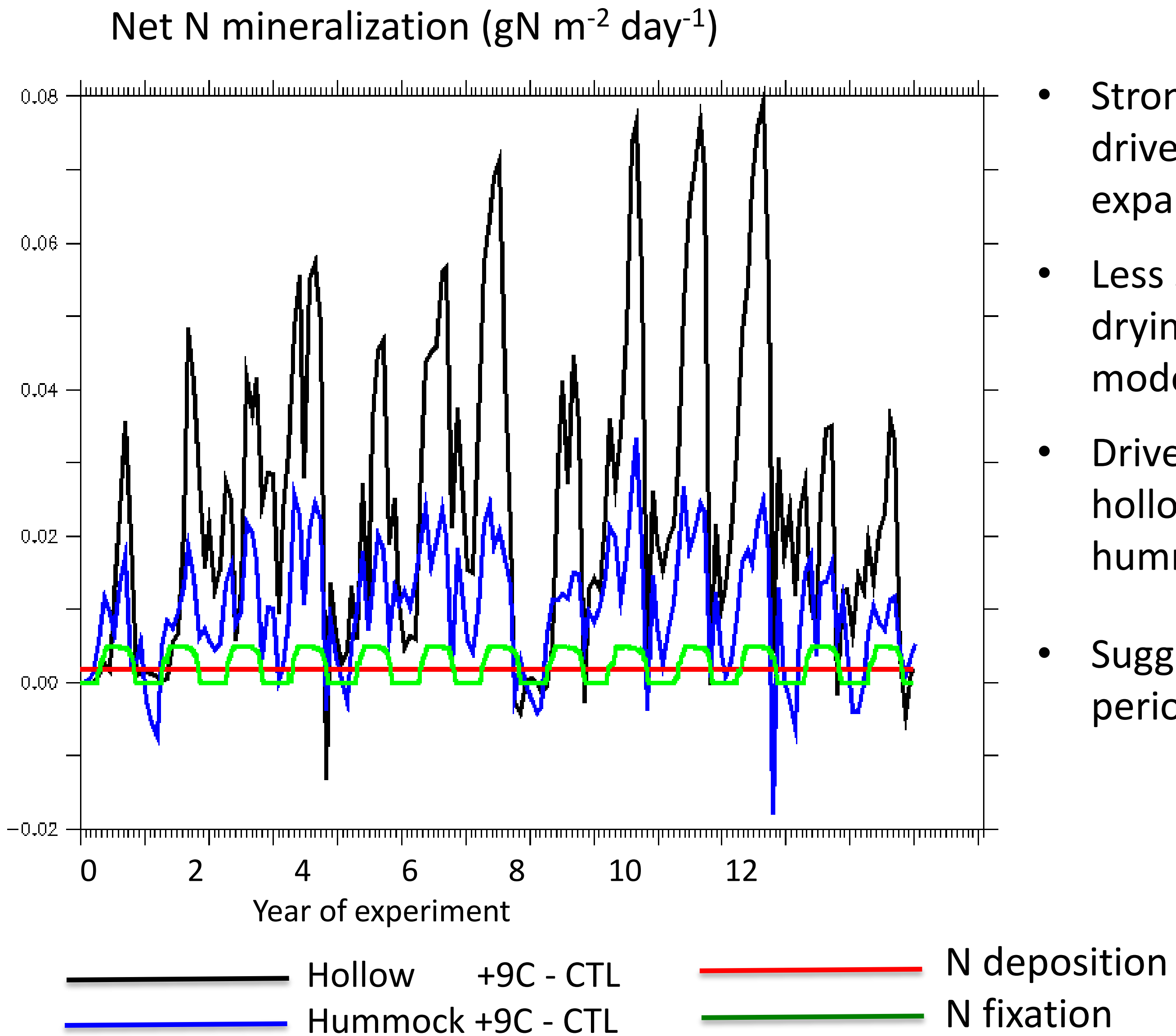
Hollow $CH_4$ production (gC $m^{-2}$ $day^{-1}$)




Hollow $CH_4$ surface flux (gC $m^{-2}$ $day^{-1}$)



# Nitrogen warming response

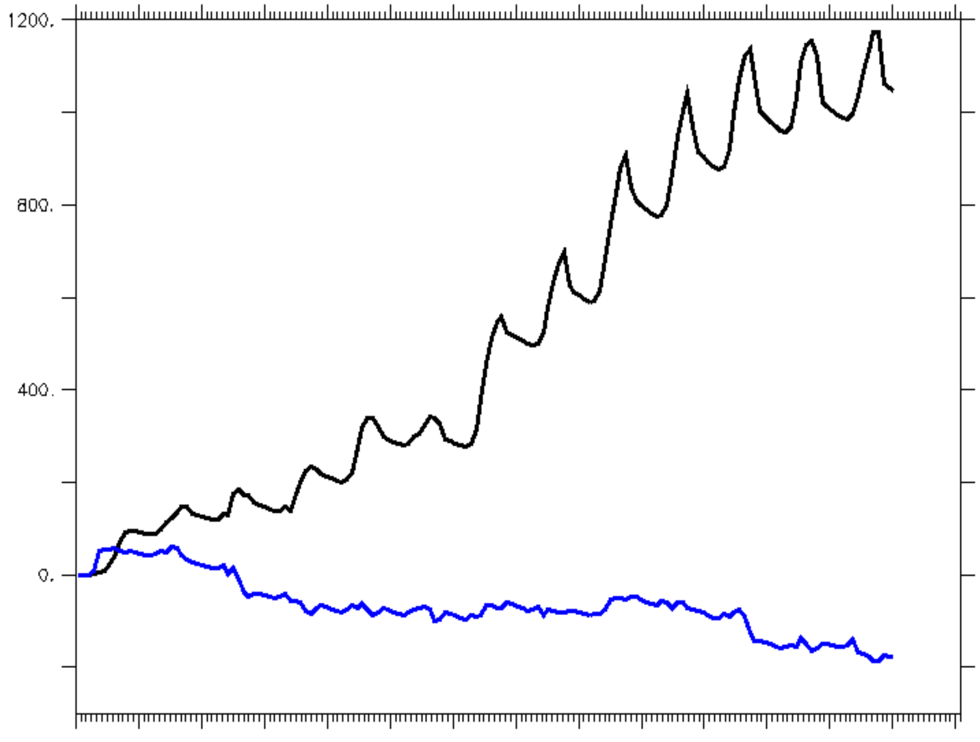



- Strong increases in hollow N mineralization driven by combination of peat warming and expansion of aerobic layer.
- Less significant changes in hummock as drying occurs in deeper layer with less modeled available labile C.
- Drives significant vegetation growth in hollows, leaf area begins less than 50% of hummocks, catches up in 10 years.
- Suggestion of long term decline late in the period as litter quality declines.

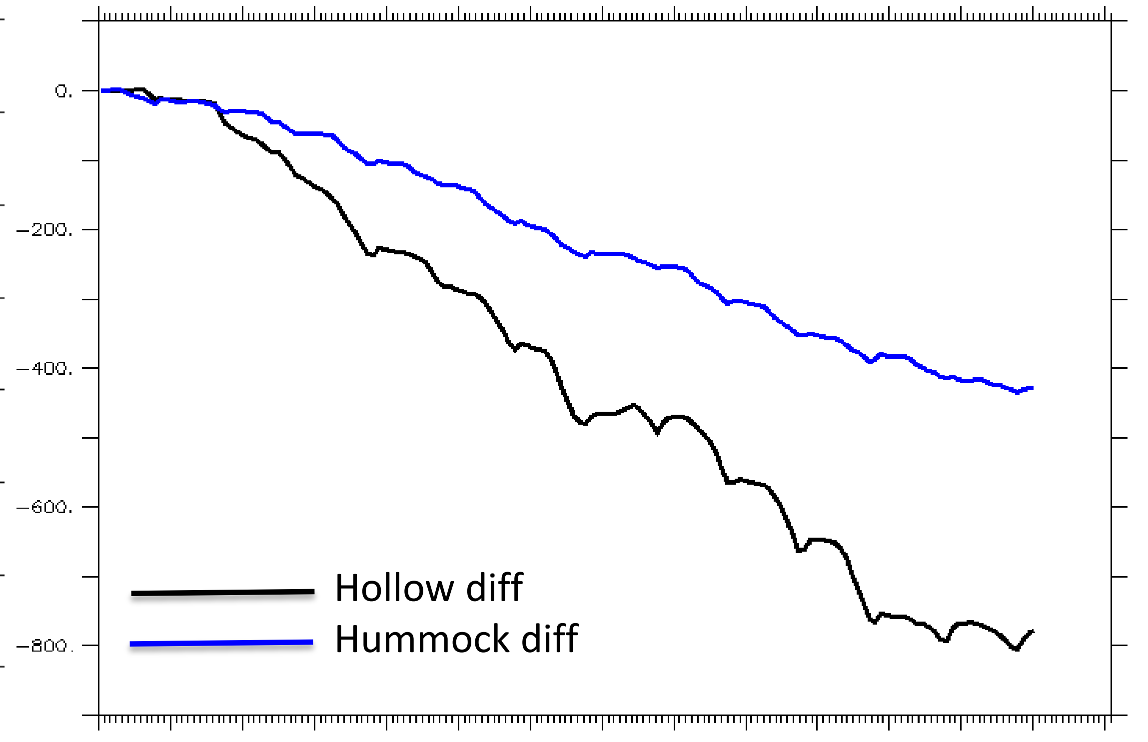
# Warming response of carbon stocks

- Significant increase of vegetation carbon in the hollows, slight decline in hummocks.
- More significant decline of soil organic matter carbon in hollows
- Hollows slight net sink, hummocks become moderate source
- Large model uncertainties: Sphagnum response, shading/canopy radiation changes, Changes in C allocation strategies, mortality.

Total vegetation carbon




Total SOM carbon

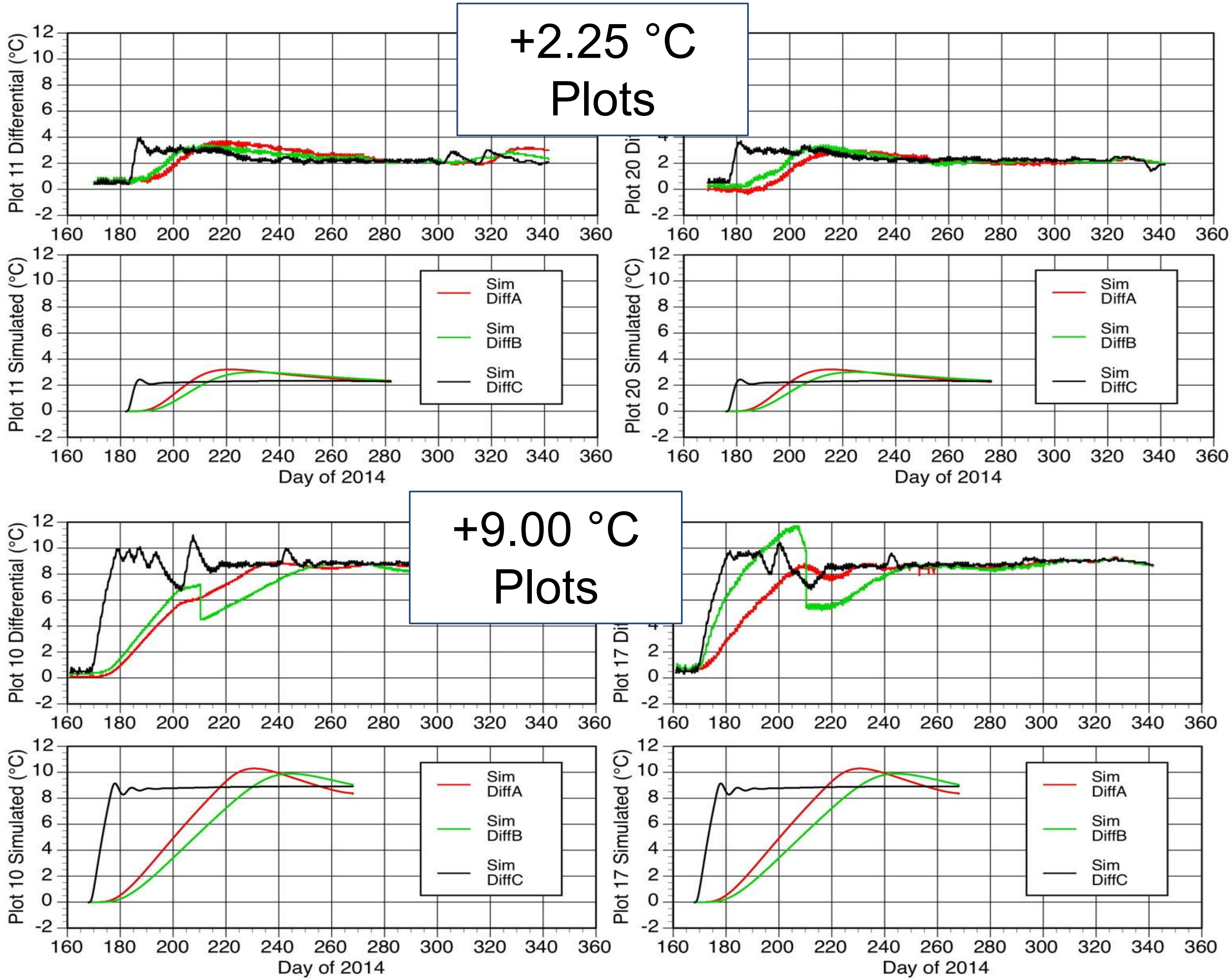


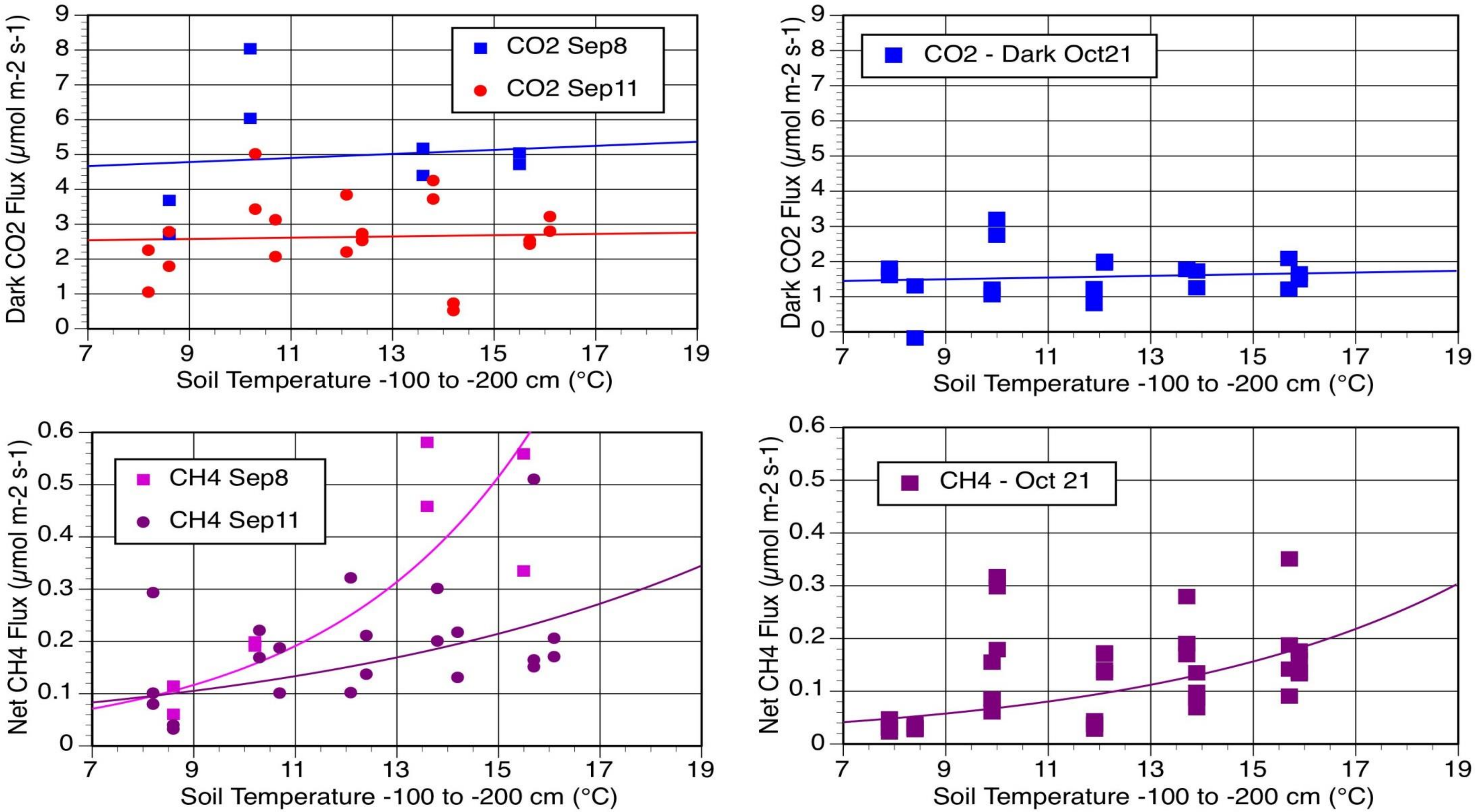
# Deep Peatland Heating

- Deep Peat Heating was initiated in 2014 to take advantage of installed infrastructure, get a head-start on the the slow belowground warming process, and enable testing of the sensitivity of deep and old carbon stocks to warming.
- By September 9$^{th}$ the deep peat heating protocol had produced a wide range of temperatures by depth allowing for the assessment of a range of variable responses to deep peat heating (e.g., DOC, enzyme activity, microbial community composition, available nutrients).

# DPH Treatment Development at -2 m

Warming levels were achieved over a 25-day (+ 2.25 °C) to a 60-day (+9 °C) period in general agreement with *a priori* energy balance model simulations.






- DPH which had limited impact on surface temperatures in the aerobic surface layers did <u>not</u> enhance dark $CO_2$ efflux rates.
- Following a couple of months of heating, ground-level net surface flux of $CH_4$ was correlated to deep soil temperature differences.

# TIMELINE

| 2009 | 2010 | ↔ | 2014 | 2015 | ↔ | 2024 | → |
|---|---|---|---|---|---|---|---|
| **DESIGN** | | **CONSTRUCTION** | | **IMPLEMENTATION** | | | **COMPLETION** |
| **Research discussions begin** | Field testing to develop sensors and protocols | | | **Experiment begins** | | **Experiment ends** | |
| Research proposed, reviewed, & approved | NEPA assessment prepared, reviewed, released, & approved | | | | Collect data, analyze samples, post data, archive samples | | Decommission and remove infrastructure |
| DOE funds the project through ORNL | | **Design, prototype, initiate monitoring, prepare site, and construct** | | | Report and publish initial results | Report and publish final findings Revise global climate models to reflect results | |

# SPRUCE ORGANIZATION CHART

**SPRUCE Project**

**Project Support**
Kathy Huczko
Terry Pfeiffer

**Project Coordination**
ORNL: Paul J. Hanson
USDA FS: Randy Kolka

**Scientific Advisory Panel**

**Experimental Systems and Environment**
Paul J. Hanson
W. Robert Nettles
Jeff Riggs

**Data Quality, Archives and Web Presence**
Les Hook
Misha Krassovski
Ranjeet Devarakonda

**Plant Community Assessments**
Plant Community Diversity
- Brian Palik, USFS
- Cassandra Ott

Lichen Studies
- Nelson, Spickerman, McCune, Jovan

Microbial Communities and Function
- Chris Schadt
- Meg Steinweg
- Kostka & Chanton
- Bridgham & Keller
- Hofmockel & Hobbie

**Plant Growth and NPP**
Trees and Shrubs
- Paul J. Hanson
- Jana Phillips
- Les Hook
- Stan D. Wullschleger

Bryophytes
- Rich Norby
- Cassandra Ott
- Joanne Childs

**Phenology**
W. Robert Nettles
Andrew Richardson
Paul J. Hanson

**Belowground Processes**
Root Growth
- Colleen Iversen
- Joanne Childs

Decomposition and Mineralization
- Colleen Iversen
- Randy Kolka, USFS
- Joanne Childs

**Plant Physiology**
Plant Water Use
- Jeff Warren
- Anna Jensen
- Joanne Childs

Carbon Physiology
- Jeff Warren
- Anna Jensen
- Stan D. Wullschleger

Bryophyte Physiology
- David Weston

**Ecosystem Modeling**
CLM-Wetlands
- Daniel M. Ricciuto
- Xiaoying Shi
- Xiaofeng Xu
- Jiafu Mao
- Peter Thornton

LPJ-WHyME
- Paul Miller

Ecosys
- Robert Grant

LaRS
- Jeff Amthor

Others
- Zhuang ...

**Biogeochemical Cycling (stocks, flux, isotopes)**
Hydrologic Cycle
- Steve Sebestyen, USFS
- Natalie Griffiths
- Jeff Warren

Nitrogen and Phosphorous Cycles
- Colleen Iversen
- Deanne Brice
- Randy Kolka, USFS
- Rich Norby
- Natalie Griffiths
- Erik Hobbie

Carbon/Methane Cycle
- Paul J. Hanson
- Lianhong Gu
- Steve Sebestyen, USFS
- Jana Phillips
- Deanne Brice
- Kostka & Chanton
- Bridgham & Keller
- Karis McFarlane
- Adrian Finzi

Mercury and Sulfur Cycles
- Toner & Nater
- Randy Kolka, USFS
- Steve Sebestyen, USFS

**Collaborative Research Project Participants**
Boston University – Adrian Finzi
Chapman University – Jason K. Keller
Florida State University – Jeff Chanton, Malak Tfaily et al.
Georgia Inst. of Tech. - Joel Kostka et al.
Harvard University – Andrew Richardson
Iowa State University – Kirsten Hofmockel
Lancaster University – Kate Orwin
Lawrence Livermore National Laboratory – Karis McFarlane
Lund University – Paul Miller
Oak Ridge National Laboratory – Melanie Mayes
Oregon State University – Peter R. Nelson, Kaleigh Spickerman, Bruce McCune
Purdue University – Qianlai Zhuang
University of Alberta – Robert Grant
University of Minnesota – Brandy Toner, Ed Nater, Olga Furman
University of New Hampshire – Erik Hobbie
University of Oregon – Scott Bridgham
University of Tennessee – Aimee Classen
University of Toronto-Scarborough – Carl Mitchell, Kristine Haynes
USDA Forest Service – Erik Lilleskov, Sarah Jovan

# SPRUCE

# Independently-Funded Collaborators

1. **The response of soil carbon storage and microbially mediated carbon turnover to simulated climatic disturbance in a northern peatland forest: revisiting the concept of soil organic matter recalcitrance**. Principal Investigators: Joel E. Kostka, Georgia Institute of Technology & Jeff Chanton, Florida State University (2012-2013)
2. **Toward a predictive understanding of the response of belowground microbial carbon turnover to climate change drivers in a boreal peatland**. Principal Investigators: Joel E. Kostka Georgia Institute of Technology & Jeffrey P. Chanton, William T. Cooper Florida State University (2014 to present)
3. **Understanding the mechanisms underlying heterotrophic $CO_2$ and $CH_4$ fluxes in a peatland with deep soil warming and atmospheric $CO_2$ enrichment**. Principal Investigators: Scott D. Bridgham, University of Oregon & Jason Keller, Chapman University (2013 to present, with renewal pending)
4. **Can microbial ecology inform ecosystem level c-n cycling response to climate change?** Principal Investigators: Kirsten Hofmockel, Iowa State University & Erik Hobbie, University of New Hampshire (2014 to present)
5. **Mercury and sulfur dynamics in the spruce experiment.** Principal Investigators: Brandy Toner and Ed Nater, University of Minnesota & Randy Kolka and Steve Sebestyen, USDA Forest Service MN (2103 to present)
6. **Improving models to predict phenological responses to global change**. Principal Investigator: Andrew D. Richardson, Harvard University (2013 to present)
7. **Lichen community responses to warming.** Principal Investigators: Bruce McCune, Oregon State University, Sarah Jovan, USDA Forest Service OR (2013 to present)
8. **Fungal, bacterial, and archaeal communities mediating C cycling and trace gas flux in peatland ecosystems subject to climate change**. Principal Investigator: Erik Lilleskov, USDA Forest Service MI and Michigan Technological University with Joint Genome Institute Support (2013 to present)

# SPRUCE Collaborators Continued

9. **Effects of experimental warming & elevated $CO_2$ on trace gas emissions from a northern Minnesota black spruce peatland: measurement and modeling**. Principal Investigator: Adrian Finzi, Boston University (2014-present)
10. **Functioning of wetlands as a source of atmospheric methane: a multi-scale and multi-disciplinary approach**. Principal Investigator: Karis McFarlane and Xavier Mayali, Mike Singleton, Ate Visser, Jennifer Pett-Ridge, Brad Esser, Tom Guilderson Lawrence Livermore National Laboratory (2014-present)
11. **Using microbial enzyme decomposition models to study the effects of peat warming and/or $CO_2$ enrichment on peatland decomposition**. Principal Investigator: Brian H. Hill and Colleen M. Elonen, Terri M. Jicha, Mary F. Moffett US Environmental Protection Agency (2014-present)
12. **Peatland Mercury Cycling in a Changing Climate: A Large-Scale Field Manipulation Study.** Carl Mitchell, University of Toronto Scarborough (2014-present)
13. **The role of the Sphagnum microbiome in carbon and nutrient cycling in peatlands - JGI's Community Science Program**. Joel E. Kostka and Gen Glass Georgia Institute of Technology, David Weston Oak Ridge National Laboratory, Erik Lilleskov USDA Forest Service – Houghton, MI, Jon Shaw Duke University, and Susannah Tringe at the Joint Genome Institute. (2015-present)
14. **Soil fauna biodiversity sampling at SPRUCE**. Zoë Lindo University of Western Ontario. (starting in 2015)
15. **Monitoring warming and elevated $CO_2$ induced changes in photosynthetic efficiency via canopy spectral reflectance.** Michael J. Falkowski University of Minnesota, Evan Kane Michigan Technological University, Brian Benscoter Florida Atlantic University, & Randy Kolka US Forest Service.
16. **Wood decomposition rates and functional types in a shifting climate**. Jonathan Schilling and Jason Oliver, University of Minnesota, Randy Kolka, United States Forest Service (starting in 2015)

# SPRUCE Effort Investment

| Institution - Job Category | Personnel Effort<br>FTEs |
|---|---|
| Oak Ridge National Laboratory | |
| Science Staff | 3.9 to 4.3 |
| Technical Staff | 3.4 to 3.9 |
| USDA Forest Service (In-Kind Effort) | |
| Science Staff | 0.5 |
| Technical Staff | 0.75 |
| SPRUCE Collaborators | 14 Groups / 20 Institutions |

# SPRUCE Development Investment

| 2010 through 2015 Site Development | Cost ($K) |
| --- | --- |
| ORNL In-House Costs [NEPA, Prototypes, MN Construction Managed through ORNL] | $1,254K |
| Subcontracted Effort [e.g., boardwalks, electric, enclosures, etc.] | $9,225K |
| **Total Development $** | **$10,479K** |

| | |
| --- | --- |
| **Total Annual Operations Cost** | **$1,400K** |

# Take-Home Messages

- Large-scale manipulations like SPRUCE provide a reality check for prediction models where analogs in the historical and observational record are not available for end-of-century warming and atmospheric $CO_2$ levels.

- Together, large-scale manipulations, landscape observations through time and model projections provide key inputs for National and IPCC Assessment activities.