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Final Report for BOREAS Project TE-19

Modeling Climate-Biosphere Interactions in the Boreal Forest

[NAG5-2290; 1993-1998]

PI: Steve Frolking, University of New Hampshire

The overall goal of this BOREAS Program was to develop, test, and apply a model of the carbon balance of boreal forest sites with a significant groundcover component (moss or lichen). The basic question addressed with this model was:

What is the sensitivity of the boreal forest carbon balance to weather variability?

More specifically:

- What are the differences in the sensitivities of carbon gains (photosynthesis) and carbon losses (respiration) of the various components of the ecosystem?
- Are there different seasonalities to their sensitivities (e.g., warmer springs will have one effect, warmer summers a different effect)?
- What are the effects of different patterns of successive weather years (wet/dry, warm/cool)?
- What, for example, would be the difference in effects of two "warmer than normal" months—one with each day warmer than normal, and the other with three normal weeks and one very hot week?
- Due to weather variability, how "noisy" will any carbon flux or carbon pool signal be that we might use to try to detect change?

The project resulted in the development of a new boreal forest ecosystem model (Frolking et al. 1996; Frolking 1997). This model was the first model in the BOREAS project to look closely at the role of mosses in the ecosystem carbon balance, and also was the first model in the BOREAS project to look closely at interannual variability in carbon fluxes. Along with the work of many other groups, TE-19 modeling analysis pointed to the need for a second, longer field season in 1996, with particular focus on the spring and fall transitions and on ground vegetation.

BOREAS groups TE-19 (Frolking), TGB-1 (Crill) & TGB-3 (Moore & Roulet) analyzed BOREAS data and other published and unpublished data to develop a relationship between peatland ecosystem productivity and incoming radiation (Frolking et al. 1998), which is quite distinct from the upland ecosystem relationships observed in other studies. This collaboration between groups at UNH and McGill Univ. has been very fruitful, and we are continuing this line of research in our BOREAS Guest Investigator Project, working in conjunction with an NSERC-funded project (led by Nigel Roulet) on developing a peatland carbon model.

SUMMARY OF ACCOMPLISHMENTS

WORKSHOP PARTICIPATION

Participated in four BOREAS Science workshops (Williamsburg, Annapolis, Toronto, Portland). Participated in a BOREAS modeling workshop (Missoula MT; Feb. 1994). Organized, hosted, and led a smaller BOREAS workshop on Carbon (Durham NH, March 1996, about 40 participants). Invited to serve as a US BOREAS representative to two Canadian planning workshops (Waskesiu, Feb. 1996; Toronto, Dec. 1996).

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Dr. Diane Wickland
Terrestrial Ecology Program
NASA HQ
Code YSE
300 E. Street SW
Washington DC 20546

June 15, 1998

Dear Diane,

Here is the final report for my BOREAS Project (TE-19; Modeling Climate-Biosphere Interactions in the Boreal Forest; NAG5-2290; 1993-1998).

This was a very rewarding project to work on, especially as a first post-doctoral experience in research. Being part of the productive and cordial collaboration of so many scientists and disciplines was a great way to start a career.

My BOREAS work has led to several direct collaborations with other groups, and to 2 funded and 3 pending proposals for additional research building on and extending what I did during BOREAS. I take that as a good measure of the success of the project.

Thank you for your support.

Sincerely,

Steve Frolking

Steve Frolking

REFEREED PUBLICATIONS (reprints of published manuscripts (attached) have also been sent to the BOREAS project office)

Frolking, S, ML Goulden, SC Wofsy, S-M Fan, DJ Sutton, JW Munger, AM Bazzaz, BC Daube, PM Crill, JD Aber, LE Band, X Wang, K Savage, T Moore, and RC Harriss (1996) Temporal variability in the carbon balance of a spruce/moss boreal forest, *Global Change Biology*, 2:343-366.

Frolking, S (1997) Sensitivity of spruce/moss boreal forest carbon balance to seasonal anomalies in weather, *J. Geophysical Research*, 102: 29,053-29,064..

Frolking S, Bubier JL, Moore TR, Ball T, Bellisario LM, Bhardwaj A, Carroll P, Crill PM, Lafleur PM, McCaughey JH, Roulet NT, Suyker AE, Verma SB, Waddington MJ, Whiting GJ (1998) The relationship between ecosystem productivity and photosynthetically-active radiation for northern peatlands, *Global Biogeochemical Cycles*, 12:115-126.

In preparation:

Bubier, Frolking, Crill, Linder, Moore et al. Seasonal carbon balances and their uncertainties for a northern peatland complex in Manitoba, Canada.

NON-REFEREEED PUBLICATIONS

Frolking S (1995) Temporal variability in the carbon balance in a spruce/moss boreal forest, *EOS Trans. AGU*, 76(17):S117, Spring Meet. Suppl.

Frolking, S and J Aber (1995) Modeling daily carbon exchanges in a spruce/moss boreal forest, *Bulletin of the Ecol. Soc. Am.*, 76(2):87, Ann. Meet. Suppl.

Frolking S (1996, poster) Spruce/Moss Boreal Forest Net Ecosystem Productivity Sensitivity to Seasonal Anomalies in Weather, *AGU Fall Meeting*.

Frolking S (1996) Future Canadian Research in the Global Carbon Cycle: A Perspective From BOREAS, in *Directions in Climate Measurement Research Workshop, Dec. 10-11, 1996*, Canadian Atmospheric Environment Service, Downsview, Ontario, pp. 10-19.

Roulet, Nigel T., Anu Bhardwaj, Neil Comer, Matt Letts, Tim Moore, Charlotte Roehm , David Hilbert, Steve Frolking (1997) Modelling biospheric - climatic feedbacks in peatland ecosystems, presented at "Impact of Climate Change to Inland Wetlands: A Canadian Perspective" workshop, Oak Hammock March Centre, Oak Hammond MB, April 1997.

Frolking S, Bubier JL, Moore TR, Ball T, Bellisario LM, Bhardwaj A, Carroll P, Crill PM, Lafleur PM, McCaughey JH, Roulet NT, Suyker AE, Verma SB, Waddington JM, Whiting GJ (1997, poster) NEE-PAR Relationships for Northern Peatlands, *Ecological Soc. Am.*, Albuquerque NM.

Frolking S. Modeling Soil Respiration at the Site Scale: Issues, Methods, and Evaluation of Results. SSSA Annual Meeting, Anaheim CA. Oct. 1997.

Frolking S , Hirsch A. (poster 1997) 'Comparing modeled and observed carbon fluxes in a boreal forest upland soil', AGU Fall Meeting, San Francisco, Dec. 1997.

Frolking S, Kyle McDonald, Reiner Zimmermann, JoBea Way, John Kimball, Steve Running, Can Space-Based Radar Observations Determine the Growing Season Length of Boreal Ecosystems? EOS Transactions Supplement, 79:S149, 1998 Spring AGU, Boston.

Scheduled:

Bubier J, Crill P, Frolking S, Moore T, Environmental controls on the carbon balance of boreal peatlands, Manitoba, Canada. 1998 Spring AGU, Boston.

Frolking S, Kyle McDonald, Reiner Zimmermann, JoBea Way, John Kimball, Steve Running, Site-Scale Ecosystem Carbon Balance Significance of Space-Based Radar Observations of Terrestrial Ecosystem Freeze/Thaw Dynamics, 1998 Snow Hydrology Conference, Oct. 1998.

Way JB, McDonald K, Running SW, Kimball J, Frolking S, Zimmermann R (1998) Radar-based measure of interannual vegetation phenology for monitoring global change responses of vegetation. IGARSS, 1998.

INVITED TALKS

"Temporal Variability of Terrestrial Trace Gas Fluxes", Woods Hole Res. Center, MA, 1/95.
"Temporal Variability of the Carbon Balance in a Spruce/Moss Boreal Forest", Ecosystems Center, Marine Biological Laboratory, Woods Hole, MA, 3/95.
"Temporal Variability in Terrestrial Trace Gas Exchange", Centre for Climate and Global Change Research, McGill Univ., Montreal, 3/95.
"Future Canadian Research in the Global Carbon Cycle: A Perspective From BOREAS", Atmospheric Environment Service, Downsview, Ontario, 12/96.
"Slow Carbon/Water/Energy Cycling - Annual to Interannual Variations in Climate and the Carbon Cycle Variations in Carbon/Water/Energy Flux Dynamics at the BOREAS Tower Sites", BOREAS Science meeting, Annapolis MD, Mar 1997.
"Modeling Soil Respiration at the Site Scale: Issues, Methods, and Evaluation of Results" SSSA Annual Meeting, Anaheim CA. Oct. 1997.

FUNDED NEW PROJECTS THAT CONTINUE THE RESEARCH EFFORT

1) 'Scaling Peatland CO_2 and CH_4 Fluxes From Chambers to the BOREAS Northern and Southern Study Areas', Steve Frolking, Patrick Crill, Jill Bubier.
ABSTRACT: We will combine analysis of field data and remote sensing imagery with process modeling to scale peatland CO_2 and CH_4 fluxes from the chamber scale to the fen scale and to the BOREAS Northern and Southern Study Areas. The primary method will be to empirically scale our chamber flux data; the second method will be to develop a process model of peatland fluxes that can be applied at the landscape scale. We will develop remote sensing image classification algorithms based on insights into controlling factors gained from a careful analysis of BOREAS (and other) peatland chamber flux data and the spectral characteristics of the important vegetation groupings. We will explore the impact of spatial resolution of remote sensing imagery on regional flux predictions through two comparisons: (1) At the NSA and SSA fen scale, we will compare estimated fluxes using both high spatial resolution (CASI: ~1-2 m) and moderate spatial resolution (LANDSAT: ~30 m) images. Using supervised classifications for each sensor, we will apply empirical CO_2 and CH_4 flux factors based on BOREAS field data, and also run a process model to simulate CO_2 and CH_4 fluxes. Each method will be tested against BOREAS tower flux data from the NSA and SSA fens. (2) At the BOREAS Northern and Southern Study Area scale, we will compare empirically driven peatland CO_2 and CH_4 flux estimates using LANDSAT images classified with our vegetation classification scheme and LANDSAT and lower resolution AVHRR imagery (~1000 m) classified by the BOREAS staff (see http://boreas.gsfc.nasa.gov). We will also conduct error analyses to assess the loss of information as the scale resolution decreases.

2) 'Monitoring Global Change Responses of Vegetation' JoBea Way, Steve Running, Steve Frolking, Kyle McDonald, John Kimball. John Tenhunen. Reiner Zimmermann
ABSTRACT: Recent results from the BOReal Ecosystem Atmosphere Study (BOREAS; Sellers et al. 1995) indicate the boreal forest has a near net zero annual carbon flux-i.e., carbon intake through photosynthesis nearly balances carbon release through respiration. A change in temperature due to global warming may upset this balance in either direction. Keeling et al. (1996) recently reported an observed phase advance in their measured seasonal atmospheric CO2 cycles suggesting a lengthening of the growing season. Jacoby et al. (1996) report wide annual growth rings in the last century in 450 year old Siberian pine trees-another indication of a lengthening of high latitude growing season. A first step in assessing and monitoring year-to-year changes in the boreal net carbon flux is to determine the annual variation in growing season length.

We propose to integrate maps of the freeze/thaw state of the boreal forest landscape derived from spaceborne imaging radar observations with local and regional scale carbon flux models over a period of years to determine the interannual variability in growing season length. Our initial objective is to assess the utility of using radar-derived freeze/thaw state as (1) a surrogate for growing season length, and (2) a long term monitor of variations in growing season length relating to climate change within the global boreal forest. These results should improve our understanding of site morphologic, terrain, and latitudinal effects on freeze/thaw status which should improve our ability to predict regional carbon exchange processes. We will obtain multi-temporal radar imagery of selected north-south transects in the North American and Eurasian boreal forests with the European and Canadian imaging radars (ERS-1/2 and RADARSAT). We will also obtain multi-temporal regional scale scatterometer observations with the NASA Scatterometer (NSCAT). From these data, landscape freeze/thaw state will be inferred by monitoring shifts in backscatter relative to winter frozen conditions. The inferred landscape freeze/thaw state will be validated against temperature measurements obtained from a distributed temperature monitoring network and from meteorological observations from selected stations located along the transects. A local scale model (Frolking et al. 1996) will be used to develop the relationship between freeze/thaw and ecosystem carbon flux, and a regional scale model (Running and Hunt 1993) will use the freeze/thaw state as input to estimating regional carbon flux. As a final step, multiyear estimates of annual boreal carbon flux will be determined using growing season periods derived from imaging radar.

Three additional proposals resulting from this work are under review at this time (one to NIGEC, one to NASA Terrestrial Ecology Program, and one to NASA ESSP Program). All involve collaborations developed during the BOREAS program.