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Technical Report Series on the Boreal Ecosystem-Atmosphere Study (BOREAS)

Forrest G. Hall and Andrea Papagno, Editors

Volume 180
BOREAS TE-19 Ecosystem Carbon Balance Model

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National Aeronautics and
Space Administration

Goddard Space Flight Center
Greenbelt, Maryland 20771

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BOREAS TE-19 Ecosystem Carbon Balance Model

Steve Frolking

Summary

The BOREAS TE-19 team developed a model called the Spruce and Moss Model (SPAM) designed to simulate the daily carbon balance of a black spruce/moss boreal forest ecosystem. It is driven by daily weather conditions, and consists of four components: (1) soil climate, (2) tree photosynthesis and respiration, (3) moss photosynthesis and respiration, and (4) litter decomposition and associated heterotrophic respiration. The model simulates tree gross and net photosynthesis, wood respiration, live root respiration, moss gross and net photosynthesis, and heterotrophic respiration (decomposition of root litter, young needle and moss litter, and humus). These values can be combined to generate predictions of total site net ecosystem exchange of carbon (NEE), total soil dark respiration (live roots + heterotrophs + live moss), spruce and moss net productivity, and net carbon accumulation in the soil. To date, simulations have been of the BOREAS NSA-OBS and SSA-OBS tower sites, from 1968-95 (except 1990-93). The files include source code and sample input and output files in ASCII format.

Table of Contents

1) Data Set Overview
2) Investigator(s)
3) Theory of Measurements
4) Equipment
5) Data Acquisition Methods
6) Observations
7) Data Description
8) Data Organization
9) Data Manipulations
10) Errors
11) Notes
12) Application of the Data Set
13) Future Modifications and Plans
14) Software
15) Data Access
16) Output Products and Availability
17) References
18) Glossary of Terms
19) List of Acronyms
20) Document Information

1. Model Overview

1.1 Model Identification

BOREAS TE-19 Ecosystem Carbon Balance Model

1.2 Model Introduction

The Spruce and Moss Model (SPAM) is a model of the daily carbon balance of a black spruce/moss boreal forest ecosystem. It is driven by daily weather conditions, and consists of four components: (1) soil climate, which exerts controls on the dynamics of ecosystem productivity and respiration; (2) tree photosynthesis and respiration; (3) moss photosynthesis and respiration; and (4) litter decomposition and associated heterotrophic respiration. The soil climate component of the model is based on the peatland soil climate model of Frolking and Crill (1994). The tree canopy component of the model carbon balance is a daily time-step version of the PnET model (Aber and Federer, 1992; Aber et al., 1996). A similar photosynthesis and respiration model was developed for the moss, based on published physiological behavior of feathermosses. The decomposition component determines heterotrophic respiration as a function of litter age and soil temperature and moisture. The model operates on a daily time-step and considers only short-term simulations. It ignores features of the forest carbon balance that are important in longer scenarios (e.g., wood growth and storage, limb turnover, tree mortality, changing nutrient constraints on productivity, fire). The model simulates tree gross and net photosynthesis, wood respiration, live root respiration, moss gross and net photosynthesis, heterotrophic respiration (decomposition of root litter, young needle and moss litter, and humus). These values can be combined to generate predictions of total site net ecosystem exchange of carbon (NEE), total soil dark respiration (live roots + heterotrophs + live moss), spruce and moss net productivity, and net carbon accumulation in the soil.

1.3 Objective/Purpose

Under the premise that mean annual air temperature and/or precipitation are the dominant controls of net ecosystem productivity (net carbon exchange between a terrestrial ecosystem and the atmosphere), Dai and Fung (1993) applied a simple model of terrestrial ecosystem production and respiration, driven by these variables, at a global scale. This model predicted deviations (from an assumed global equilibrium for 1920-49) in net carbon flux between the atmosphere and terrestrial ecosystems. Their results suggested that interannual variabilities in mean annual air temperature and total annual precipitation have had a significant impact on the global carbon balance, and may account for some of the so-called "missing sink" for atmospheric CO_2. Their model also suggested that the northern boreal zone was the dominant region for carbon sequestration over the past several decades. Steve Frolking has developed a model of the daily carbon balance of a spruce/moss boreal forest stand that can be used to address the general question:

- 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 (respirations)?
- Are there different seasonalities to these sensitivities? For example, will a warmer spring have one effect and a warmer summer a different effect?
- What is the effect of an earlier (later) snowmelt and spring thaw?
- How different are the carbon balance sensitivities of the overstory tree species and the often ubiquitous moss or lichen ground cover?
- Due to weather variability, how noisy will any carbon flux or carbon pool signal be that we might use to try to detect change?

1.4 Summary of Parameters

The model requires basic site description (masses of organic horizon, sapwood, foliage, roots) and daily weather data (maximum/minimum air temperatures, precipitation, also Photosynthetically Active Radiation (PAR) and relative humidity if available). The model outputs are daily values for soil temperature profiles, soil moisture profiles, and carbon exchanges of various ecosystem components (tree, moss, and soil).

1.5 Discussion

This model is a daily time-step model with submodels of soil climate, tree net primary production (NPP), moss NPP, and decomposition. Our goal was to develop parameters from non-BOReal Ecosystem-Atmosphere Study (BOREAS) literature (at least initially) and see how well these, along with BOREAS site description data, could emulate observed fluxes. A related non-BOREAS model is PnET Model (Aber and Federer, 1992; Aber et al., 1996).

1.6 Related Models and Data Sets

BOREAS RSS-08 BIOME-BGC Model Simulations at Tower Flux Sites in 1994
BOREAS RSS-08 BIOME-BGC SSA Simulations of Annual Water and Carbon Fluxes
BOREAS TE-01 SSA Soil Lab Data
BOREAS TE-01 Soils Data over the SSA Tower Sites in Raster Format
BOREAS TE-05 Soil Respiration Data
BOREAS TE-06 NPP for the Tower Flux, Carbon Evaluation, and Auxiliary Sites
BOREAS TE-17 Global Primary Efficiency Model
BOREAS TE-20 SSA Site Characteristics Data
BOREAS TE-20 NSA Soil Lab Data
BOREAS TGB-12 Soil Carbon Data over the NSA

2. Investigator(s)

2.1 Investigator(s) Name and Title

Steve Frolking
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2.2 Title of Investigation

Modeling Climate-Biosphere Interactions in the Boreal Forest

2.3 Contact Information

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3. Model Theory

Each component of the model takes a fairly standard and simple approach.

Soil temperatures and heat flow are determined by 1-D heat diffusion; freeze/thaw by apparent heat capacity method (see, for example, Lunardini, 1981).

Soil moisture is determined using the modified bucket for surface organic layer, with a simplified Richards Equation for mineral soil (gravity flow only, or unit hydraulic gradient) (see, for example, Hillel, 1980).

Tree NPP is determined from layered canopy (light level changes); photosynthesis is a function of temperature, water, and light, with base rate determined by leaf nitrogen (or specified). Foliar respiration is a function of leaf mass and temperature. Sapwood and root respiration are functions of temperature and volume (sapwood) or nitrogen (roots), (see Aber and Federer, 1992).

Moss NPP is similarly determined with a layered canopy (light level and temperature change). Respiration is a function of moss temperature and moss water content (see Frolking et al., 1996).

The decomposition model tracks annual litter cohorts. These each have a base decomposition rate, which declines as the litter ages. The realized rate of decomposition is this base rate modified by temperature and moisture. After a specified number of years (about 20-40), the litter is transferred to a single humus pool, with a fixed decomposition rate, which is also modified by soil temperature and moisture (see Frolking et al., 1996).

4. Equipment

The model is currently run on an SGI Indigo system. The software is written in standard FORTRAN and should be very portable. The model does not require a lot of space, and 1-year simulations take only a few minutes.

5. Data Acquisition Methods

The model requires two input files: (1) site description, file names, etc., and (2) daily weather data. Once these are in place, just run the model. When it is done, there will be nine output files (input information, soil temperature, soil moisture, soil ice, one each for the daily carbon balance of moss, trees, decomposition, site, and an accumulating carbon balance). These are just text files, with one line for each day (see Sections 7.3 and 7.4 for details).

6. Observations

6.1 Data Notes

The model requires a daily weather file: maximum and minimum air temperatures, total precipitation, daily average relative humidity, and daytime average PAR (_mol photon/meters2/second). These last two can be calculated internally if they are unavailable (relative humidity by assuming saturation at minimum daily temperature, and PAR by a fit from 1994 BOREAS Northern Study Area (NSA)-Old Black Spruce (OBS) data to diurnal temperature range).

6.2 Field Notes

Not applicable.

7. Data Description

7.1 Spatial Characteristics

7.1.1 Spatial Coverage

The model is 1-D, so a single run covers a single 'uniform' plot, e.g., very roughly 1 ha.

7.1.2 Spatial Coverage Map

To date, simulations have been run for the NSA-OBS and Southern Study Area (SSA)-OBS tower sites. The North American Datum of 1983 (NAD83) coordinates for these sites are:

	Latitude	Longitude
NSA-OBS	55.88007° N	98.48139° W
SSA-OBS	53.98717° N	105.11779° W

7.1.3 Spatial Resolution

Not applicable.

7.1.4 Projection

Not applicable.

7.1.5 Grid Description

Not applicable.

7.2 Temporal Characteristics

7.2.1 Temporal Coverage

Simulations are generally one to several years (up to about 20 years so far).

7.2.2 Temporal Coverage Map

To date, simulations have been from 1968-95 (except 1990-93).

7.2.3 Temporal Resolution

Daily time-step.

7.3 Input Data Characteristics

Input information for the model is contained in two tabular American Standard Code for Information Interchange (ASCII) files. File number one contains needed duration and 'weather' data. File number two contains site information and input and output file names. Samples of these files are provided. The weather data file contains n+1 records where n is the number of days of the simulation. The values on each record are separated by commas.

INPUT FILE #1 (WEATHER DATA):

File contents:

Record Number	Variable Name	Description	Measurement Units
1	year	Year in which simulation begins	year
	nday	The day of year on which the simulation begins	date
	Days of simulation	The number of days to be simulated	count
	mean annual air temp	The mean annual air temperature	degrees Celsius
	depth of constant temp in soil	The soil depth at which the temperature remains constant during the year	centimeters
	latitude	The latitude of the location being simulated	degrees
	permafrost flag	The flag indicating whether or not permafrost is present	1=yes, 0=no
2 to n+1	doy	The day of year	date
	Tmin	The minimum air temperature for the given day of year.	degrees Celsius
	Tmax	The maximum air temperature for the given day of year	degrees Celsius
	daily ppt	The daily precipitation for the given day of year	millimeters
	relative humidity	The average relative humidity for the given day of year	percent
	PPFD (daytime average)	The average photosynthetic photon flux density for the given day of year	micromole /meters^2/second

Record Number	Variable Name	Description	Measurement Units
1	ground veg type	The coded value that designates the dominant type of ground vegetation at the site. (1=feathermoss; 2=sphagnum; 3=lichen)	Coded but unitless value
	tree type	The coded value that designates the dominant type of trees at the site. (0=none; 1=maple, 2=oak, 3=pine; 4=spruce)	Coded but unitless value
	shrub type	The coded value that designates the dominant type of shrub at the site. (0=none; 1=deciduous)	Coded but unitless value
2	canopy closure	The fraction of canopy closure expressed from 0.0 to 1.0.	unitless
	stem area index	The stem area index.	unitless
	LAI (not used)	The Leaf Area Index.	unitless
	total live fine root mass	The total Carbon mass density in live fine roots at the site.	grams Carbon/meter^2
	sapwood volume	The sapwood volume density at the site.	meters^3/meter^2
3	average annual foliar litterfall	The average annual foliar litterfall density at the site.	grams/meter^2
	fine root turnover rate	The rate of fine root density turnover	grams/meter^2/year
	total mass of organic layer	The total mass density of the organic layer	grams/meter^2
	total mass of old carbon layer	The total mass density of the old carbon layer, which is the bottom-most part of the surface organic layer.	grams/meter^2
4	Mineral soil layer #1 SOC content	The soil organic carbon content of the 0-10 cm deep mineral soil layer.	grams Carbon/meter^2
	Mineral soil layer #2 SOC content	The soil organic carbon content of the 10-30 cm deep mineral soil layer.	grams Carbon/meter^2
	Mineral soil layer #3 SOC content	The soil organic carbon content of the 30-70 cm deep mineral soil layer.	grams Carbon/meter^2
	Mineral soil layer #4 SOC content	The soil organic carbon content of the 70-150 cm deep mineral soil layer.	grams Carbon/meter^2

5	first year litter mass loss rate	The first year litter mass loss rate based on AET, Berg et al 1993. (generally 0.05-0.15 for BOREAS sites)	year-1
6	climate modifier for decomposition	The climate modifier for decomposition. (generally around 200)	unitless
	decomp parameter (generally 1)	The decomposition parameter. (ignore for soil climate runs)	unitless
7	mineral soil type	The coded value that designates the mineral soil type. (1=sand; 2=loam; 3=clay; 4=peat)	Coded but unitless value
8	thickness of mineral soil layers	The thickness of mineral soil layers used in the model [leave alone for now].	centimeters
9	number of layers plus 1	The number of soil layers plus 1. (4 organic + 4 mineral + 1) (keep at 9)	count
10	initial soil temp profile	The initial temperature of each soil layer at the start of the model run.	degrees Celsius
11	file name for input weather file	The name of the input file containing weather information.	None
12	Output Temperature file	The name of the output file to contain the temperature data.	None
13	Output Soil Moisture file	The name of the output file to contain the soil moisture data.	None
14	Output Soil Ice file	The name of the output file to contain the soil ice data.	None
15	Output Other things file	The name of the output file to contain the other things data.	None
16	Output Litter Respiration file	The name of the output file to contain the litter respiration data.	None
17	Output moss file	The name of the output file to contain the moss data.	None
18	Output tree file	The name of the output file to contain the tree data.	None
19	Output Daily Carbon file	The name of the output file to contain the daily carbon total data.	None
20	Output Carbon Accumulations file	The name of the output file to contain the daily accumulating carbon data.	None

7.3.4 Input Data Source

The weather and site data used were gathered during the BOREAS field campaigns in 1994 and 1996. See Sections 15 and 16 for data availability.

7.3.5 Data Range

None given.

7.4 Output Data Characteristics

Output information from the model is contained in nine tabular ASCII files. File number:

- - General Information
- - Soil Temperature
- - Soil Moisture
- - Soil Ice
- - Tree Carbon Balance
- - Moss Carbon Balance
- - Decomposition Carbon Balance
- - Site Carbon Balance
- - Site Carbon Accumulations

The output file records contain combinations of text and output values. Those records with lists of column headings or numbers have the strings and values separated by blank spaces.

OUTPUT FILE #1 (GENERAL INFORMATION)

File contents:

Record Number	Variable Name	Description	Measurement Units
1	Repeats much of the input data, lists the input and output filenames, and describes the soil profile.	See variable name.	See variable name.

See variable name. OUTPUT FILE #2 (SOIL TEMPERATURE)

Record Number	Variable Name	Description	Measurement Units
1	column headings	The column headings.	none
2 to n	nday	The day of the simulation.	date
	doy	The day of year.	date
	tair	The mean air temperature.	degrees Celsius
	ppt	The daily precipitation.	centimeters
	sog	The snow depth.	centimeters
	ice	The thickness of the soil ice.	centimeters
	T1	The soil temperature at the top of the moss layer.	degrees Celsius
	T2	The soil temperature at the bottom of the moss layer.	degrees Celsius
	T3	The soil temperature at the bottom of the litter layer.	degrees Celsius
	T4	The soil temperature at the bottom of the humus layer.	degrees Celsius
	T5	The soil temperature at the top of the mineral layer.	degrees Celsius
	T6	The soil temperature at the bottom of the first mineral layer.	degrees Celsius
	T7	The soil temperature at the bottom of the second mineral layer.	degrees Celsius
	T8	The soil temperature at the bottom of the third mineral layer.	degrees Celsius
	T9	The soil temperature at the bottom of the fourth mineral layer.	degrees Celsius

OUTPUT FILE #3 (SOIL MOISTURE)

Record Number	Variable Name	Description	Measurement Units
1	column headings	The column headings.	None
2 to n	nday	The day of the simulation.	date
	doy	The day of year.	date
	tair	The mean air temperature.	degrees Celsius
	ppt	The daily precipitation.	centimeters
	sog	The snowdepth.	centimeters
	gvw	The water content of the moss.	fraction of saturation
	llw	The water content of the litter layer.	fraction of saturation
	hlwl	The water content number 1 of the humus layer.	fraction of saturation
	hlw2	The water content number 2 of the humus layer.	fraction of saturation
	oclw	The water content of the 'old carbon layer'.	fraction of saturation
	slw1	The water content number 1 of the mineral soil layer.	fraction of saturation
	slw2	The water content number 2 of the mineral soil layer.	fraction of saturation
	slw3	The water content number 3 of the mineral soil layer.	fraction of saturation
	slw4	The water content number 4 of the mineral soil layer.	fraction of saturation
	gloss	The rate of water loss from the moss layer.	millimeters/day
	lloss	The rate of water loss from the litter layer.	millimeters/day
	hloss	The rate of water loss from the humus layer.	millimeters/day
	aet	The total actual evapotranspiration.	centimeters/day
	ttrns	The tree transpiration.	centimeters/day
	strns	The shrub transpiration.	centimeters/day
	pet	The potential evapotranspiration.	centimeters/day
	vpd	The vapor pressure deficit.	kiloPascals
	drain	The rate of water drainage.	millimeters/day

OUTPUT FILE #4 (SOIL ICE)

Record Number	Variable Name	Description	Measurement Units
1	column headings	The column headings.	None
2 to n	nday	The day of the simulation.	date
	doy	The day of year.	date
	tair	The mean air temperature.	degrees Celsius
	ppt	The daily precipitation.	centimeters
	sog	The snowdepth.	centimeters
	ice	The thickness of the soil ice.	centimeters
	top1	The depth to the top of the first ice layer.	centimeters
	bot1	The depth to the bottom of the first ice layer.	centimeters
	top2	The depth to the top of the second ice layer.	centimeters
	bot2	The depth to the bottom of the second ice layer.	centimeters
	ice1	The ice content of layer 1 (moss) in the model.	fraction of frozen content
	ice2	The ice content of layer 2 (litter) in the model.	fraction of frozen content
	ice3	The ice content of layer 3 (humus) in the model.	fraction of frozen content
	ice4	The ice content of layer 4 (old carbon layer) in the model.	fraction of frozen content
	ice5	The ice content of layer 5 (0-10 cm mineral) in the model.	fraction of frozen content
	ice6	The ice content of layer 6 (10-30 cm mineral) in the model.	fraction of frozen content
	ice7	The ice content of layer 7 (30-70 cm mineral) in the model.	fraction of frozen content
	ice8	The ice content of layer 8 (70-150 cm mineral) in the model.	fraction of frozen content

OUTPUT FILE #5 (TREE CARBON BALANCE)

Record Number	Variable Name	Description	Measurement Units
1	column headings	The column headings.	None
2 to n	nday	The day of the simulation.	date
	doy	The day of year.	date
	tair	The mean air temperature.	degrees Celsius
	ppt	The daily precipitation.	centimeters
	sog	The snowdepth.	centimeters
	trlai	The leaf area index (projected).	unitless
	shlai	The foliar mass.	kilogram/meter^2
	tgrpsn	The gross photosynthesis of the trees.	grams Carbon/meters^2/day
	tnetpsn	The net foliar photosynthesis of the trees.	grams Carbon/meters^2/day
	sgrpsn	The gross photosynthesis of the shrubs.	grams Carbon/meters^2/day
	snetpsn	The net foliar photosynthesis of the shrubs.	grams Carbon/meters^2/day
	tlitfal	The litterfall from the trees.	kilogram/meter^2
	slitfal	The litterfall from the shrubs.	kilogram/meter^2
	dvpd	The vapor pressure deficit multiplier for photosynthesis (0-1).	unitless
	dwater	The soil water multiplier for photosynthesis (0-1).	unitless
	dtemp	The temperature multiplier for photosynthesis (0-1).	unitless

OUTPUT FILE #6 (MOSS CARBON BALANCE)

Record Number	Variable Name	Description	Measurement Units
1	column headings	Column headings.	None.
2 to n	nday	The day of the simulation	date
	doy	The day of year	date
	tair	The mean air temperature	degrees Celsius
	ppt	The daily precipitation	centimeters
	sog	The snowdepth	centimeters
	par	The daily average photosynthetically active radiation at the top of the tree canopy	micromole/m^2/second
	iomoss	The daily average photosynthetically active radiation at the top of the moss canopy	micromole/m^2/second
	grpsn	The gross photosynthesis	grams Carbon/$meters^2$/day
	grres	The gross respiration	grams Carbon/$meters^2$/day
	netpsn	The net photosynthesis	grams Carbon/$meters^2$/day
	F1(T)	The moss temperature multiplier for photosynthesis (0-1)	unitless
	F2(W)	The moss water multiplier for photosynthesis (0-1)	unitless
	F3(L)	The photosynthetically active radiation multiplier for photosynthesis (0-1)	unitless
	fr(W)	The moss water multiplier for respiration (0-1)	unitless
	fr(T)	The moss temperature multiplier for respiration (0-i)	unitless

OUTPUT FILE #7 (DECOMPOSITION CARBON BALANCE)

Record Number	Variable Name	Description	Measurement Units
1	column headings	The column headings.	None
2 to n	nday	The day of the simulation.	date
	doy	The day of year.	date
	tair	The mean air temperature.	degrees Celsius
	ppt	The daily precipitation.	centimeters
	sog	The snowdepth.	centimeters
	llres	The decomposition respiration of the litter layer.	grams Carbon/meter^2/day
	hlres	The decomposition respiration of the humus layer.	grams Carbon/meter^2/day
	oclres	The decomposition respiration of the old carbon layer.	grams Carbon/meter^2/day
	droot1	The decomposition respiration of the dead roots in the moss layer (always 0).	grams Carbon/meter^2/day
	droot2	The decomposition respiration of the dead roots in the litter layer.	grams Carbon/meter^2/day
	droot3	The decomposition respiration of the dead roots in the humus layer.	grams Carbon/meter^2/day
	droot4	The decomposition respiration of the dead roots in the mineral soil layer #1.	grams Carbon/meter^2/day
	droot5	The decomposition respiration of the dead roots in the mineral soil layer #2.	grams Carbon/meter^2/day
	droot6	The decomposition respiration of the dead roots in the mineral soil layer #3.	grams Carbon/meter^2/day
	droot7	The decomposition respiration of the dead roots in the mineral soil layer #4.	grams Carbon/meter^2/day
	liveroot	The respiration of the live roots	grams Carbon/meter^2/day
	sapwood	The sapwood respiration.	grams Carbon/meter^2/day
	lrdtemp	The soil temperature multiplier for respiration (0-i).	unitless

OUTPUT FILE #8 (SITE CARBON BALANCE)

Record Number	**Variable Name**	**Description**	**Measurement Units**
1	column headings	The column headings.	None
2 to n	nday	The day of the simulation.	date
	doy	The day of year.	date
	tair	The mean air temperature.	degrees Celsius
	ppt	The daily precipitation.	centimeters
	sog	The snowdepth.	centimeters
	psndorm	The photosynthesis dormancy multiplier.	unitless
	tnetpsn	The foliar net primary production of the trees.	grams Carbon /meter^2/day
	snetpsn	The foliar net primary production of the shrubs.	grams Carbon /meter^2/day
	mnetpsn	The net primary production of the moss.	grams Carbon /meter^2/day
	rootrsp	The respiration of the live roots.	grams Carbon /meter^2/day
	hetresp	The total heterotrophic respiration.	grams Carbon /meter^2/day
	woodresp	The sapwood respiration.	grams Carbon /meter^2/day
	totresp	The total respiration.	grams Carbon /meter^2/day
	netcx	The net ecosystem exchange.	grams Carbon /meter^2/day

OUTPUT FILE #9 (SITE CARBON ACCUMULATIONS for 01-Jan through 31-Dec)

Record Number	Variable Name	Description	Measurement Units
1	column headings	The column headings.	None
2 to n	nday	The day of the simulation.	date
	doy	The day of year.	date
	tair	The mean air temperature.	degrees Celsius
	ppt	The daily precipitation.	centimeters
	sog	The snowdepth.	centimeters
	mgrresp	The accumulation of the gross respiration of the moss.	grams Carbon/meter^2
	mgrpsn	The accumulation of the gross photosynthesis of the moss.	grams Carbon/meter^2
	shgrrsp	The accumulation of the foliar gross respiration of the shrubs.	grams Carbon/meter^2
	shgrpsn	The accumulation of the foliar gross photosynthesis of the shrubs.	grams Carbon/meter^2
	tgrresp	The accumulation of the foliar gross respiration of the trees.	grams Carbon/meter^2
	trgrpsn	The accumulation of foliar gross photosynthesis of the trees.	grams Carbon/meter^2
	hetresp	The accumulation of the heterotrophic respiration of the soil.	grams Carbon/meter^2
	rootrsp	The accumulation of the respiration of the live roots.	grams Carbon/meter^2
	woodrsp	The accumulation of the respiration of the live sapwood.	grams Carbon/meter^2
	netcx	The accumulation of the net ecosystem exchange.	grams Carbon/meter^2

7.4.4 Data Source
The files are output files from the model.

7.4.5 Data Range
None given.

7.5 Sample Data Records

The following are sample records from the two input and the nine output data files.

```
INPUT FILE #1 (WEATHER DATA):
288, 1537, 0.5, 200.0 , 56., 0
288 3.2 5.8 0.25 52.7 93.1

INPUT FILE #2 (SITE DATA):
1,4
0.75, 1.0, 2.0, 400.0, 0.0083
80., 0.25, 24000.
0.15
198., 1.0
3
10.0, 20.0, 40.0, 80.0
8
2.0, 2.0, 2.0, 2.0, 2.0, 2.0, 2.0, 2.0
thom.67-89.cli
gwr.temp.67-89.14
gwr.wat.67-89.14
gwr.ice.67-89.14
gwr.other.67-89.14
gwr.carb.67-89.14
gwr.moss.67-89.14
gwr.tree.67-89.14
gwr.sum.67-89.14
gwr.accum.67-89.14

OUTPUT FILE #1 (GENERAL INFORMATION)
Run of model bcm6t.f

soil type (1=sandy,2=loamy,3=clayey,4=wetland): 3 permafrost present
(0=no,1=yes): 0

ground veg.(1=feathermoss,2=sphagnum,3=lichen): 1 trees
(0=none,1=maple,2=oak,3=pine,4=spruce): 4 fraction of canopy closure:
0.75
sapwood volume [m3/m2]: 0.0083
stem area index: 1.00
leaf area index: 2.00

average annual tree foliar litterfall [g/m2/y]: 80.0
soil organic horizon (live+L+F+H) mass [g/m2]: 24000.0 annual mass loss
rate for first year litter: 0.150
annual turnover rate for fine root biomass: 0.250
total live fine root biomass carbon [g C/m2]: 400.0
total dead fine root biomass carbon [g C/m2]: 666.7

weather data input file name: nelhse.94-95.cli
soil temperature output file name: gwr.temp.94-5.14 soil moisture output
file name: gwr.wat.94-5.14
soil ice output file name: gwr.ice.94-5.14
litter respiration output file name: gwr.carb.94-5.14 moss output file
name: gwr.moss.94-5.14
```

tree output file name: gwr.tree.94-5.14
daily carbon output file name: gwr.sum.94-5.14
annual accums output file name: gwr.accum.94-5.14

model layer thicknesses [cm]: 3.0 2.3 10.6 10.6 10.0 20.0 40.0 80.0

litter layer has 14 cohorts:
#2 cohort mass (g/m^2) is 113.04
#11 cohort mass (g/m^2) is 52.00
#21 cohort mass (g/m^2) is 0.00
bottom cohort mass (g/m^2) is 44.07

organic layer masses [g/m^2]:
live veg.: 990.0 litter: 876.7 humus: 20426.7

organic horizon water contents [cm water depth]:
minimum no drainage field cap. saturation porosity ground veg 0.040 0.168 0.520 2.924 0.975
litter layer 0.043 0.173 0.519 2.174 0.942
humus layer 0.532 4.256 6.384 19.643 0.923

OUTPUT FILE #2 (SOIL TEMPERATURE) [all temps in degC]
nday doy tair ppt sog ice T1 T2 T3 T4 T5 T6 T7 T8
808 365 -22.0 0.0 21.3 16.1 -2.04 -1.48 -1.30 -0.72 -0.02 0.04 0.13 0.30

OUTPUT FILE #3 (SOIL MOISTURE) [all water content as fraction of saturation]
nday doy tair ppt sog gvw llw hlw1 hlw2 slw1 slw2 slw3 slw4 gloss lloss hloss aet trans vpd drain runoff
808 365 -22.05 0.00 21.34 0.102 0.239 0.224 0.158 0.513 0.537 0.533 0.570 0.000 0.000 0.000 0.018 0.000 0.020 0.01 0.00

OUTPUT FILE #4 (SOIL ICE) [soil layer ice content given as fraction frozen, 0-1]
nday doy tair ppt sog ice top1 bot1 top2 bot2 ice1 ice2 ice3 ice4 ice5 ice6 ice7
808 365 -22.0 0.0 21.3 16.1 0.0 -16.1 0.0 0.0 1.00 1.00 0.93 0.37 0.00 0.00 0.00

OUTPUT FILE #5 (TREE CARBON BALANCE) [all C fluxes in g C/m^2/d; pools in g C/m^2]
nday doy tair ppt sog lai folmas grspsn netpsn litfall dvpd dwater dtemp canopytrans
808 365 -22.0 0.0 21.3 2.88 720.0 0.00 0.10 0.00 1.00 0.22 0.00 0.00

OUTPUT FILE #6 (MOSS CARBON BALANCE) [all C fluxes in g C/m^2/d; pools in g C/m^2]
nday doy tair ppt sog par iomoss grpsn grres _netpsn f1(T) F2(W) F3(L) fr(W) fr(T)
808 365 -22.0 0.0 21.3 155.400 4.357 0.000 0.000 0.000 0.000 0.890 0.025 0.000 0.000

```
OUTPUT FILE #7 (DECOMPOSITION CARBON BALANCE) [all C fluxes in g C/m2/d;
pools in g C/m2]
nday doy tair ppt sog llres hlres droot1 droot2 droot3 droot4 droot5
droot6 liveroot sapwood lrdtemp
nan 38.8697
206.5596 199.0533
808 365 -22.0 0.0 21.3 0.081 0.129 0.000 0.008 0.018 0.012 0.040 0.000
0.000 0.000 0.927

OUTPUT FILE #8 (SITE CARBON BALANCE) [all C fluxes in g C/m2/d; pools in
g C/m2]
nday doy tair ppt sog tnetpsn mnetpsn rootrsp hetresp soildr totresp
netcx
808 365 -22.0 0.0 21.3 0.099 0.000 0.000 0.288 0.288 0.387 0.387

OUTPUT FILE #9 (SITE CARBON ACCUMULATIONS) [all C fluxes in g C/m2; pools
in g C/m2]
nday doy tair ppt sog tnetpsn tgrpsn mnetpsn mgrresp rootrsp woodrsp
hetresp soilresp soildresp netcx
808 365 -22.0 0.0 21.3 0.10 0.00 0.00 0.00 0.00
0.00 0.29 0.29 0.29 0.39
```

8. Data Organization

8.1 Data Granularity

This data set comprises the source code file for the model along with the two input files and nine output files.

8.2 Data Format(s)

The Compact Disk-Read-Only Memory (CD-ROM) files contain ASCII numerical and character fields of varying length separated by commas. The character fields are enclosed with single apostrophe marks. There are no spaces between the fields.

9. Data Manipulations

9.1 Formulae

Tree NPP = foliar NPP + wood respiration + root respiration

9.1.1 Derivation Techniques and Algorithms

None given.

9.2 Data Processing Sequence

9.2.1 Processing Steps

The model is run, and the results are then studied.

9.2.2 Processing Changes

The model was revised periodically as mistakes were discovered or new applications were attempted. Contact the Principal Investigator (PI) for the latest version.

9.3 Calculations

9.3.1 Special Corrections/Adjustments

None given.

9.3.2 Calculated Variables

None given.

9.4 Graphs and Plots

None given.

10. Errors

10.1 Sources of Error

Sources of error are abundant, including an incomplete understanding of the ecosystem, an imprecise description of the site, and the averaging of nonlinear processes.

10.2 Quality Assessment

10.2.1 Model Validation by Source

Model results have been compared to tower flux, chamber flux, soil temperature, and soil moisture measurements for the BOREAS NSA-OBS site (Frolking et al., 1996). Unpublished comparisons were made with SSA-OBS tower flux.

10.2.2 Confidence Level/Accuracy Judgment

As BOREAS data become available, input data should generally be adequate (i.e., not the weak link). Output quality is harder to evaluate. Terrestrial Ecology (TE)-19 feels that the absolute numbers are 'spot-on' (i.e., generally within 50% of reality). TE-19 has more confidence in the overall sensitivity of the model results to weather variability. Model output, particularly overall site carbon balance, is very sensitive to some model parameters that are poorly constrained by current data sets (see discussion in Frolking et al., 1996).

10.2.3 Measurement Error for Parameters

Latest r^2 of model against the preliminary tower data (daily NEE) for NSA-OBS 1994-95 is about 0.6 (n~300).

10.2.4 Additional Quality Assessments

See Frolking et al., 1996.

10.2.5 Data Verification by Data Center

Model information was examined for general consistency and clarity.

11. Notes

11.1 Limitations of the Model

The model contains vegetation parameters for two boreal tree types: pine and spruce, and three boreal groundcovers: feathermoss, sphagnum moss, and lichen (e.g. cladina). Virtually all of the model evaluation has been done for spruce and feathermoss. The other parameterizations have been run, and although they produced seemingly unbelievable results, they have not been evaluated adequately.

11.2 Known Problems with the Model

Several components of the model are poorly tested or untested, and several are clearly wrong. Among these are:

- The algorithm for the location of ice layers in soil does not work, particularly for soils with permafrost. The model considers soil water to freeze from 0 to 100% as soil temperature drops from 0 to -1 °C; this leaves an ambiguous 'slush' zone. The total ice thickness within the profile is probably a more reasonable number.
- Site water balance is not well tested; simulated surface run-off and drainage from the bottom of the profile are not reliable.
- Spruce foliar and root litterfall are the same each year, and occur on a single day. There is undoubtedly interannual variability in the field. Timing of litterfall may or may not have a strong influence on site carbon balance.
- There are indications from the tower data that the vegetation's photosynthetic machinery takes a while to get up to full speed after thawing; the model does not include a phenological factor and thus overestimates early growing season productivity.

11.3 Usage Guidance

The model results may not be reliable as absolute numbers; interannual and intra-annual trends and relative numbers are the main objective of the study. The comparison of sensitivities of moss, trees, and decomposition to weather variability was an additional objective.

11.4 Other Relevant Information

None given.

12. Application of the Model

Anyone is welcome to obtain a copy of the model and use it for their own research. Contact the personnel listed in Section 2.3.

13. Future Modifications and Plans

The development of versions/parameterizations for pine/lichen, pine/moss, and aspen/hazel is in progress. The development of a peatland version is planned.

14. Software

14.1 Software Description

The model source code is in FORTRAN and runs on a Unix workstation; the code does not use any machine-specific commands, and there should not be any platform limitations. It reads ASCII files as input and generates ASCII files as output.

14.2 Software Access

The source code is available to anyone. Please send an e-mail to the PI (see Section 2.3).

15. Data Access

The ecosystem carbon balance model is available from the Earth Observing System Data and Information System (EOSDIS) Oak Ridge National Laboratory (ORNL) Distributed Active Archive Center (DAAC).

15.1 Contact Information

For BOREAS data and documentation please contact:

ORNL DAAC User Services
Oak Ridge National Laboratory
P.O. Box 2008 MS-6407
Oak Ridge, TN 37831-6407
Phone: (423) 241-3952
Fax: (423) 574-4665
E-mail: ornldaac@ornl.gov or ornl@eos.nasa.gov

15.2 Data Center Identification

Earth Observing System Data and Information System (EOSDIS) Oak Ridge National Laboratory (ORNL) Distributed Active Archive Center (DAAC) for Biogeochemical Dynamics http://www-eosdis.ornl.gov/.

15.3 Procedures for Obtaining Data

Users may obtain data directly through the ORNL DAAC online search and order system [http://www-eosdis.ornl.gov/] and the anonymous FTP site [ftp://www-eosdis.ornl.gov/data/] or by contacting User Services by electronic mail, telephone, fax, letter, or personal visit using the contact information in Section 15.1.

15.4 Data Center Status/Plans

The ORNL DAAC is the primary source for BOREAS field measurement, image, GIS, and hardcopy data products. The BOREAS CD-ROM and data referenced or listed in inventories on the CD-ROM are available from the ORNL DAAC.

16. Output Products and Availability

16.1 Tape Products

None.

16.2 Film Products

None.

16.3 Other Products

Source code and sample input and output files are available on the BOREAS CD-ROM series.

17. References

17.1 Model Documentation

Some documentation is in the model code as comments, and some is in the publications listed in Section 17.2.

17.2 Journal Articles and Study Reports

Aber J.D. and C.A. Federer. 1992. A generalized, lumped parameter model of photosynthesis, evaporation and net primary production in temperate and boreal forest ecosystems. Oecologia, 92, 463-474.

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Sellers, P. and F. Hall. 1994. Boreal Ecosystem-Atmosphere Study: Experiment Plan. Version 1994-3.0, NASA BOREAS Report (EXPLAN 94).

Sellers, P. and F. Hall. 1996. Boreal Ecosystem-Atmosphere Study: Experiment Plan. Version 1996-2.0, NASA BOREAS Report (EXPLAN 96).

Sellers, P., F. Hall, and K.F. Huemmrich. 1996. Boreal Ecosystem-Atmosphere Study: 1994 Operations. NASA BOREAS Report (OPS DOC 94).

Sellers, P., F. Hall, and K.F. Huemmrich. 1997. Boreal Ecosystem-Atmosphere Study: 1996 Operations. NASA BOREAS Report (OPS DOC 96).

Sellers, P., F. Hall, H. Margolis, B. Kelly, D. Baldocchi, G. den Hartog, J. Cihlar, M.G. Ryan, B. Goodison, P. Crill, K.J. Ranson, D. Lettenmaier, and D.E. Wickland. 1995. The boreal ecosystem-atmosphere study (BOREAS): an overview and early results from the 1994 field year. Bulletin of the American Meteorological Society. 76(9):1549-1577.

Sellers, P.J., F.G. Hall, R.D. Kelly, A. Black, D. Baldocchi, J. Berry, M. Ryan, K.J. Ranson, P.M. Crill, D.P. Lettenmaier, H. Margolis, J. Cihlar, J. Newcomer, D. Fitzjarrald, P.G. Jarvis, S.T. Gower, D. Halliwell, D. Williams, B. Goodison, D.E. Wickland, and F.E. Guertin. 1997. BOREAS in 1997: Experiment Overview, Scientific Results and Future Directions. Journal of Geophysical Research 102(D24): 28,731-28,770.

17.3 Archive/DBMS Usage Documentation

None.

18. Glossary of Terms

None.

19. List of Acronyms

```
ASCII   - American Standard Code for Information Interchange
BOREAS  - BOReal Ecosystem-Atmosphere Study
BORIS   - BOREAS Information System
CD-ROM  - Compact Disk-Read-Only Memory
CFS     - Canadian Forest Service
DAAC    - Distributed Active Archive Center
DOY     - Julian Day of Year
EOS     - Earth Observing System
EOSDIS  - EOS Data and Information System
GIS     - Geographic Information System
GSFC    - Goddard Space Flight Center
HTML    - HyperText Markup Language
IFC     - Intensive Field Campaign
MIX     - Mixed Wood
NAD83   - North American Datum of 1983
NASA    - National Aeronautics and Space Administration
NEE     - Net Ecosystem Exchange of Carbon
NOAA    - National Oceanic and Atmospheric Administration
NPP     - Net Primary Production
NSA     - Northern Study Area
OA      - [illegible]
OBS     - Old Black Spruce
ORNL    - Oak Ridge National Laboratory
PANP    - Prince Albert National Park
PAR     - Photosynthetically Active Radiation
PI      - Principal Investigator
SPAM    - [illegible] s Model
SSA     - Southern Study Area
TE      - Terrestrial Ecology
TF      - [illegible]
URL     - Uniform Resource Locator
UTM     - Universal Transverse Mercator
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13. ABSTRACT *(Maximum 200 words)*

The BOREAS TE-19 team developed a model called the Spruce and Moss Model (SPAM) designed to simulate the daily carbon balance of a black spruce/moss boreal forest ecosystem. It is driven by daily weather conditions, and consists of four components: (1) soil climate, (2) tree photosynthesis and respiration, (3) moss photosynthesis and respiration, and (4) litter decomposition and associated heterotrophic respiration. The model simulates tree gross and net photosynthesis, wood respiration, live root respiration, moss gross and net photosynthesis, and heterotrophic respiration (decomposition of root litter, young needle and moss litter, and humus). These values can be combined to generate predictions of total site net ecosystem exchange of carbon (NEE), total soil dark respiration (live roots + heterotrophs + live moss), spruce and moss net productivity, and net carbon accumulation in the soil. To date, simulations have been of the BOREAS NSA-OBS and SSA-OBS tower sites, from 1968-95 (except 1990-93). The files include source code and sample input and output files in ASCII format.

14. SUBJECT TERMS
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