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

*Forrest G. Hall and Jaime Nickeson, Editors*

## Volume 54

## BOREAS RSS-8 BIOME-BGC Model Simulations at Tower Flux Sites in 1994

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**Goddard Space Flight Center**
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# BOREAS RSS-8 BIOME-BGC Model Simulations at Tower Flux Sites in 1994

John S. Kimball

## Summary

BIOME-BGC is a general ecosystem process model designed to simulate biogeochemical and hydrologic processes across multiple scales (Running and Hunt, 1993). In this investigation, BIOME-BGC was used to estimate daily water and carbon budgets for the BOREAS tower flux sites for 1994. Carbon variables estimated by the model include gross primary production (i.e., net photosynthesis), maintenance and heterotrophic respiration, net primary production, and net ecosystem carbon exchange. Hydrologic variables estimated by the model include snowcover, evaporation, transpiration, evapotranspiration, soil moisture, and outflow. The information provided by the investigation includes input initialization and model output files for various sites in tabular ASCII format.

## Table of Contents



## 1. Model Overview

### 1.1 Model Identification

BOREAS RSS-08 BIOME-BGC Model Simulations at Tower Flux Sites in 1994

### 1.2 Model Introduction

BIOME-BGC simulates biogeochemical and hydrologic processes across multiple biomes based on the logic that differences in process rates between biomes are primarily a function of climate and general life-form characteristics. The carbon balance portion of BIOME-BGC utilizes daily meteorological data in conjunction with general stand and soil information to predict net photosynthesis, growth, maintenance, and heterotrophic respiration at a daily time-step. BIOME-BGC is general in the sense that the surface is represented by singular, homogeneous canopy and soil layers.

Detailed descriptions of BIOME-BGC logic are given by Running and Coughlan (1988) and Running and Hunt (1993). A description of the components of the model relating to the prediction of hydrologic and carbon balance characteristics within different boreal forest stands is given by Kimball et al. (1997a,b). A summary of the important components of BIOME-BGC relating to the prediction of daily carbon allocation and exchange is given below.

## 1.3 Objective/Purpose

In this investigation, BIOME-BGC was used to estimate daily and annual hydrologic and carbon budgets for different boreal forest stands associated with the BOReal Ecosystem-Atmosphere Study (BOREAS) tower flux sites, and net carbon flux estimates were compared with results derived from tower flux and biomass measurement data. These results were used to assess the important climate and stand characteristics that control stand hydrologic characteristics, estimated productivity respiration, and surface-atmosphere carbon exchange.

These results constitute the initial effort in 1996 to simulate hydrologic and carbon exchange processes for different boreal forest stands. The results are expected to change as the models are further modified and developed to reflect insight gained from new research regarding boreal forest processes. These results are intended to provide a framework for evaluating the sensitivity of the boreal forest regional carbon balance to global warming.

## 1.4 Summary of Parameters and Variables

Model daily Greenwich Mean Time (GMT) input requirements:

- Maximum and minimum daily air temperature (°C)
- precipitation (cm)
- total daily solar radiation (kJ)
- daylength (s)

There is also a site initialization file that describes stand morphology and soil characteristics. Parameters included in this file are discussed in Section 1.5. Site initialization files that were used to generate model results for the sites in this investigation are provided.

Model daily (GMT) carbon outputs:

Net photosynthesis gross primary production (GPP); maintenance (Rm), growth (Rg), heterotrophic (Rh), and total respiration (Rtot); net ecosystem carbon exchange (NEE). Rm represents the daily sum of estimated Rm rates from coarse and fine root, sapwood, and foliar carbon pools. Foliar respiration is computed as the sum of estimated day and night foliar respiration rates. GPP is computed as the difference between gross photosynthesis and day leaf respiration. Net primary production (NPP) is determined as the difference between GPP and Rm. Rg was estimated as 32% of the daily difference between GPP and Rm. Rh is estimated as a proportion of prescribed soil and litter carbon pools; estimated soil water potential and soil temperature conditions regulate this proportion. Rtot is estimated as the sum of Rm, Rg, and Rh. NEE is estimated as the difference between GPP and Rtot.

Model daily (GMT) hydrologic outputs:

Evaporation, transpiration, evapotranspiration, soil moisture, snow water equivalent.

## 1.5 Discussion

BIOME-BGC simulates biogeochemical and hydrologic processes across multiple biomes based on the logic that differences in process rates between biomes are primarily a function of climate and general life-form characteristics. The carbon balance portion of BIOME-BGC utilizes daily meteorological data in conjunction with general stand and soil information to predict net photosynthesis, growth, maintenance and heterotrophic respiration at a daily time-step. BIOME-BGC is general in the sense that the surface is represented by singular, homogeneous canopy and soil layers. Detailed descriptions of BIOME-BGC logic are given by Running and Coughlan (1988) and Running and Hunt (1993). Kimball et al. (1997a,b) gives a description of the components of the model relating to the prediction of hydrologic and carbon characteristics within different boreal forest stands. A summary of the important components of BIOME-BGC relating to the prediction of daily carbon allocation and exchange is given in Section 3.

### 1.6 Related Models

These results represent site-specific model runs using BIOME-BGC. BIOME-BGC will also be used within the context of a Regional Hydro-Ecological Simulation System (RHESSys) to generate landscape-level estimates of 1994 daily hydrologic and carbon fluxes within the BOREAS 1000-km x 1000-km study region. A detailed description of the RHESSys model is given by Band et al. (1991, 1993).

## 2. Investigator(s)

### 2.1 Investigator(s) Name and Title

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### 2.2 Title of Investigation

BIOME-BGC simulations of stand hydrology, productivity, surface-atmosphere carbon and water exchange at selected BOREAS tower flux sites for 1994

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## 3. Model Theory

The sole input to the carbon budget in BIOME-BGC is the photosynthetic fixation of $CO_2$ by the vegetation canopy. All outputs are in the form of respired $CO_2$, coming either from plant tissues because of growth or maintenance respiration, or from the litter and soil carbon pools as the result of heterotrophic respiration.

GPP represents the system's total gain of carbon by net photosynthesis and is defined as the daily sum of gross photosynthesis and daily foliar respiration. The current representation of photosynthesis differs significantly from previously published descriptions of the BGC family of models (Running and Hunt, 1993; Hunt and Running, 1992; Running and Coughlan, 1988). The original FOREST-BGC representation of photosynthesis relies primarily on the parameterization of a mesophyll conductance to $CO_2$, estimating the rate of fixation as a diffusion process, driven by a prescribed internal $CO_2$ concentration. FOREST-BGC also does not implement an explicit treatment of the photosynthetic biochemical pathways. The original version of BIOME-BGC presents a more detailed representation of photosynthesis, relying on explicit models of photosynthetic biochemistry (Leuning, 1990; Farquhar et al., 1980). The original BIOME-BGC also includes an iterative calculation of intracellular $CO_2$ concentration (Ci), as well as an explicit calculation of the $CO_2$ compensation point. The current implementation of photosynthetic biochemistry is closely related to the original BIOME-BGC logic in that it is based on the Farquhar biochemical model, but the resulting set of equations is somewhat different because of differences in the logical constraints applied: a quadratic system of equations is solved by eliminating Ci, instead of by specifying a value as an initial condition. Other differences include a more detailed dependence of the kinetic parameters on temperature (Woodrow and Berry, 1988) and a simplifying assumption that empirically relates the maximum rate of electron transport to the maximum carboxylation velocity (Wullschleger, 1993).

Photosynthesis is regulated by the canopy conductance to $CO_2$ (gc), leaf maintenance respiration, and daily meteorological conditions, including air pressure, air temperature, and photosynthetically active photon flux density (PPFD). The maximum canopy conductance to $CO_2$ (gc max) defines the upper boundary of the photosynthetic rate and is determined by leaf area index (LAI) and prescribed leaf-scale boundary layer, cuticular, and maximum stomatal conductances; gc is reduced when air temperature, vapor pressure deficit (VPD), PPFD, or soil water potential deviate from prescribed optimal conditions (Leuning, 1990; Running and Coughlan, 1988; Jarvis and Morison, 1981). BIOME-BGC represents the canopy as a "big leaf" in that all units of leaf area in the canopy are represented using a single, canopy-averaged conductance. This assumption is generally not valid at subdaily (e.g., hourly) time-steps because the reduction of irradiance at lower vertical layers of the canopy reduces conductances at the bottom of the canopy. The big leaf assumption is strengthened, however, by the integrative effects of a daily time-step and by the implicit assumption that the allocation of leaf nitrogen between light harvesting and carbon fixing enzymes over depth in the canopy varies in response to the canopy light environment, allowing an optimized use of intercepted radiation (Evans, 1989).

Total respiration from the system (Rtot) is estimated on a daily basis as the sum of the maintenance (Rm), heterotrophic (Rh) and growth (Rg) respiration components. Rm represents the total loss of carbon due to day and night leaf respiration (Rdl + Rnl), sapwood (Rsw), coarse root (Rcr) and fine root (Rfr) respiration. Respiration is estimated as a daily proportion of carbon in living tissue that is released as the result of cellular metabolic processes, excluding any growth processes. Rm is calculated from mean daily air temperatures and prescribed leaf, root, and sapwood carbon pools using an exponentially increasing function of respiration with temperature following Amthor (1986). The magnitude of the respiration response to temperature is governed by a prescribed rate defined at a reference temperature (i.e. 15°C) and a proportional change in rate for a 10°C change in temperature (Q10). In all cases except leaf maintenance respiration, the daily average temperature is used, and a single value is calculated for the mass lost to maintenance respiration for the day. In the case of leaves, however, Rdl and Rnl rates are calculated from estimated day and night air temperatures, respectively, because Rdl is required to determine GPP. Daily growth respiration was not determined explicitly by the model in this investigation; instead, Rg was computed as a proportion (32%) of the daily difference between GPP and Rm (Penning de Vries et al., 1974).

The heterotrophic respiration term in BIOME-BGC represents the system's loss of carbon caused by soil microbial respiration. Daily Rh is estimated as a proportion of prescribed soil and litter carbon pools. The proportion of litter carbon being respired on a daily basis is regulated by soil water potential and soil temperature conditions following Orchard and Cook (1983), Andren and Paustian (1987), and Running and Coughlan (1988). The proportion of soil carbon respired on a daily basis was estimated as 1% of the proportion of litter carbon respired based on data for boreal coniferous and deciduous stands (Fox and Van Cleve, 1983; Cole and Rapp, 1981).

NPP represents the net accumulation of carbon by the stand and is determined as the difference between GPP and the sum of Rm and Rg. NEE represents the net accumulation or loss of carbon by the entire soil-stand system and is determined as the difference between GPP and Rtot. Positive fluxes in this investigation denote a net uptake of carbon by the system while negative fluxes denote a net loss. Standards for denoting positive and negative fluxes generally vary between different disciplines, however, and net carbon uptake is often denoted as a negative flux in the literature.

BIOME-BGC uses daily maximum and minimum air temperatures, humidity, incident solar radiation, and precipitation to determine daily carbon and water fluxes. Average daily incident shortwave radiation (Qi) was simulated using MT-CLIM logic described by Running et al. (1987). Average daily net solar radiation (Qn) was estimated using a prescribed, constant albedo for vegetation. Qn was attenuated through the vegetation canopy using Beer's formulation and a prescribed extinction coefficient modulated by LAI to derive the amount of solar radiation transmitted through the canopy (Qt). The amount of solar radiation absorbed by the canopy (Qa) was estimated as the difference between Qi and Qt. PPFD was estimated based on the assumption that photosynthetically active radiation represents approximately 50% of Qa (Running and Coughlan, 1988).

Mean daily air temperature (Ta) was estimated as the average of the measured daily maximum and minimum air temperatures. Minimum daily air temperature was assumed equal to the mean daily dew point and was used to estimate the mean daily VPD. Daily soil temperatures at a 30-cm soil depth (Tsoil) were estimated using an 11-day running average of Ta (Zheng et al., 1993). Soil water potential (PSI) was estimated from soil water content, soil depth, and texture information following Cosby et al. (1984). Ta, VPD, PPFD, and PSI were used to estimate gc and GPP following Jarvis and Morison (1981) and Farquhar and von Caemmerer (1982), respectively. Ta and Tsoil were used to estimate Rm, while Tsoil and PSI were used to estimate Rh (Running and Coughlan, 1988).

## 4. Equipment

BIOME-BGC is written in C with no specific hardware requirements.

## 5. Data Acquisition Methods

The model requires a daily meteorological data file. This file consists of six columns that are space delimited with each row of the file representing a specific day of the year. Column 1 represents the day of year (Julian day format, 1-365), column 2 represents precipitation (cm), column 3 represents maximum 24-hr daily air temperature (°C), column 4 represents minimum 24 hr daily air temperature (°C), column 5 represents total daily solar radiation (direct+diffuse, kJ), and column 6 represents the daylength (s). A second file is also required that defines site initialization parameters such as soil, litter, leaf and sapwood carbon pools, and soil type and condition. A detailed discussion of the development of the tower site initialization parameter files is presented below.

BIOME-BGC requires general information about stand morphology and soil characteristics in order to simulate the water and carbon balance at a site. Information required by the model to define initial hydrologic characteristics of the study sites is given by Kimball et al. (1997a,b). A list of critical parameters used to define soil and stand carbon characteristics at the eight study sites can be found there in Table 1. These parameters were held constant throughout the model runs. Soil parameters were derived from measurements collected at the sites during 1994 by Cuenca et al. (1997) and values reported in the literature for representative soil types (Hillel, 1980). The soil depth was set at 0.5 m and assumed homogeneous in regard to soil mineralized carbon, structure, and soil moisture characteristics. Mean daily stand solar albedos for snow-free conditions were estimated from site observations (Sellers et al., 1995).

Estimates of average annual LAI were derived from effective LAI measurements conducted over approximately three periods during the 1994 growing season at each study site by Chen (1996). Effective LAI was measured using a LI-COR LAI-2000 plant canopy analyzer and adjusted for foliage clumping. Specific leaf area (SLA) and leaf nitrogen levels were determined from plucked needle and leaf measurements at the spruce, jack pine, and aspen sites by Margolis et al. (1996 unpublished data). The amounts of leaf nitrogen in ribulose bisphosphate carboxylase-oxygenase (RuBisCO) were estimated from the literature for representative cover types (Field and Mooney, 1986). Leaf carbon was derived from LAI and SLA information. Sapwood carbon was estimated from sapwood biomass measurements collected by Gower et al. (1996 unpublished data) at the black spruce, aspen and jack pine sites and estimates of the relative proportions of sapwood live cells (Waring and Schlesinger, 1985). Coarse root carbon was estimated to be approximately 25% of sapwood carbon (e.g., Grier et al., 1981; Grier and Logan, 1977).

The amount of carbon attributed to fine root biomass is highly variable depending on species type, stand age, and nutrient availability. Processes governing the partitioning of carbon between root and foliar biomass are generally poorly understood and not well quantified in the literature. Observations have shown, however, that fine root biomass is generally greater than foliar biomass in nutrient-limited systems, which often occur in boreal and cold temperate forests and may represent an adaptation to maximize nutrient uptake (Nadelhoffer et al., 1985; Keyes and Grier, 1981; Tetrealt et al., 1978). Soil carbon attributed to fine roots was estimated from 1.5 Southern Study Area Old Aspen (SSA-OA) to 3.5 SSA-Old Jack Pine (OJP) times the estimated leaf carbon based on observations from boreal and cold temperate coniferous and deciduous stands on nutrient-poor sites (Gower et al., 1992; Comeau and Kimmins, 1989; Nadelhoffer et al.; 1985; Linder and Axelson, 1982; Perala and Alban, 1982; Keyes and Grier, 1981). Soil litter and mineralized organic carbon pools within the prescribed 0.5-m soil depths were estimated from soil layer depth, bulk density and percent organic carbon measurements conducted at each of the study sites by Anderson et al. (1995 unpublished data).

Leaf, stem, coarse, and fine root maintenance respiration coefficients were estimated from measured rates for coniferous and deciduous cover types (Sprugel et al., 1995). All other ecophysiological parameters were obtained from the literature for general cover types (e.g., Sprugel et al., 1995; Nobel, 1991; Waring and Schlesinger, 1985).

# 6. Observations

## 6.1 Data Notes

None.

## 6.2 Field Notes

None.

# 7. Data Description

## 7.1 Spatial Characteristics

### 7.1.1 Spatial Coverage

These results constitute point simulations of the BOREAS NSA-Old Black Spruce (NOBS) and Young Jack Pine (NYJP) and SSA-Old Aspen (SOA), Old Black Spruce (SOBS) and Old Jack Pine (SOJP) tower flux sites.

### 7.1.2 Spatial Coverage Map

Not applicable.

### 7.1.3 Spatial Resolution

Tower site.

### 7.1.4 Projection

Not applicable.

### 7.1.5 Grid Description

Not applicable.

## 7.2 Temporal Characteristics

### 7.2.1 Temporal Coverage

BIOME-BGC was run over a 2-year period at each study site. The model was initialized using 1989 AMS mesonet station meteorological data from the Thompson airport (55.8° N, 97.9° W) for study sites in the Northern Study Area (NSA), and from Prince Albert airport (53.2° N, 105.7° W) and Waskesiu Lake (53.9° N, 106.1° W) for study sites in the SSA (Shewchuk, 1997). All analyses of model results were done for the second year using the 1994 meteorological data base described in Section 7.3.

### 7.2.2 Temporal Coverage Map

Not applicable.

### 7.2.3 Temporal Resolution

Daily.

## 7.3 Data Characteristics

BIOME-BGC requires two input files (daily meteorological data and initialization data) to generate two output files of daily estimates of site hydrologic and carbon balance characteristics. The initialization file provides site-specific information about stand morphology, soil type, and soil condition. The meteorological data file and output files are described further in subsequent sections.

Organized by site, the names of the initialization, meteorology, and output files provided are:

```
NSA-OBS-FLXTR.IN_INI
NSA-OBS-FLXTR.IN_MET
NSA-OBS-FLXTR.OUT_CARB
NSA-OBS-FLXTR.OUT_HYD

NSA-YJP-FLXTR.IN_INI
NSA-YJP-FLXTR.IN_MET
NSA-YJP-FLXTR.OUT_CARB
NSA-YJP-FLXTR.OUT_HYD

SSA-9OA-FLXTR.IN_INI
SSA-9OA-FLXTR.IN_MET
SSA-9OA-FLXTR.OUT_CARB
SSA-9OA-FLXTR.OUT_HYD

SSA-OBS-FLXTR.IN_INI
SSA-OBS-FLXTR.IN_MET
SSA-OBS-FLXTR.OUT_CARB
SSA-OBS-FLXTR.OUT_HYD

SSA-OJP-FLXTR.IN_INI
SSA-OJP-FLXTR.IN_MET
SSA-OJP-FLXTR.OUT_CARB
SSA-OJP-FLXTR.OUT_HYD
```

Air temperature, solar radiation, and precipitation were measured at approximate 15-minute intervals at each of the study sites during 1994. These data were obtained from BOREAS principal investigators at each study site and the Saskatchewan Research Council's mesonet data base (BOREAS Science Team 1995). The 1994 meteorological records for each study site were incomplete because of periods of instrument malfunction, calibration, and measurement inactivity. Continuous meteorological records for 1994 were obtained for each study site by temporally interpolating missing data or substituting data from adjacent sites. Daily maximum and minimum air temperatures, precipitation, and solar radiation were then derived from the continuous data records for each site and used to generate model results.

### 7.3.1 Parameter/Variables

```
Input Meteorological data:

   DOY PCP TMAX TMIN SOLIN DAYLEN

Output Hydrologic Data:

   DOY SNOWW SOILW T ET E Q

Output Carbon data:

   DOY GPP Rdl Rnl Rsw Rcr Rfr Rh Rm Rg NPP NEE Rtot

**NOTE: NEE denoted with a (-) sign indicates net carbon release
from the stand to the atmosphere, while a positive sign indicates
net carbon uptake by the stand.
```

### 7.3.2 Variable Description/Definition

Input Meteorological data:

| | |
|---|---|
| DOY | Day of year (1-365) |
| PCP | daily precipitation (cm) |
| TMAX | maximum 24-hour air temperature (°C) |
| TMIN | minimum 24-hour air temperature (°C) |
| SOLIN | total daily solar radiation (kJ) |
| DAYLEN | daylength (s) |

Output Hydrologic Data:

| | |
|---|---|
| DOY | julian day |
| SNOWW | Snow water equivalent of the snowcover (mm) |
| SOILW | Water held in the soil layer (mm) |
| T | Transpiration from the canopy ($kg/m^2$ day) |
| ET | Evapotranspiration ($kg/m^2$ day) |
| E | Evaporation from the canopy and surface ($kg/m^2$ day) |
| Q | outflow (mm/day) |

Output Carbon data:

| | |
|---|---|
| DOY | Julian day |
| GPP | Net daily photosynthesis or gross primary production (mg $C/m^2$ day) |
| Rdl | Daytime leaf respiration (mg $C/m^2$ day) |
| Rnl | Night leaf respiration (mg $C/m^2$ day) |
| Rsw | Sapwood respiration (mg $C/m^2$ day) |
| Rcr | Coarse root respiration (mg $C/m^2$ day) |

| | |
|---|---|
| Rfr | Fine root respiration (mg C/m$^2$ day) |
| Rh | Heterotrophic respiration (mg C/m$^2$ day) |
| Rm | Maintenance respiration (mg C/m$^2$ day) |
| Rg | Growth respiration (mg C/m$^2$ day) |
| NPP | Net primary production (mg C/m$^2$ day) |
| NEE | Net ecosystem carbon exchange (mg C/m$^2$ day); (-) sign indicates net release to the atmosphere, while a positive sign indicates net carbon uptake by the stand. |
| Rtot | Total respiration (mg C/m$^2$ day) |

### 7.3.3 Unit of Measurement

Input Meteorological data:

| | |
|---|---|
| DOY | days |
| PCP | centimeters |
| TMAX | degrees Celcius |
| TMIN | degrees Celcius |
| SOLIN | kilo-Joules |
| DAYLEN | seconds |

Output Hydrologic Data:

| | |
|---|---|
| DOY | day |
| SNOWW | mm |
| SOILW | mm |
| T | kg/m$^2$ day |
| ET | kg/m$^2$ day |
| E | kg/m$^2$ day |
| Q | mm/day |

Outut Carbon data:

| | |
|---|---|
| GPP | mg C/m$^2$ day |
| Rdl | mg C/m$^2$ day |
| Rnl | mg C/m$^2$ day |
| Rsw | mg C/m$^2$ day |
| Rcr | mg C/m$^2$ day |
| Rfr | mg C/m$^2$ day |
| Rh | mg C/m$^2$ day |
| Rm | mg C/m$^2$ day |
| Rg | mg C/m$^2$ day |
| NPP | mg C/m$^2$ day |
| NEE | mg C/m$^2$ day |
| Rtot | mg C/m$^2$ day |

### 7.3.4 Data Source

Daily meteorological data were derived from approximate 15 minute measurements obtained from SRC mesonet and flux tower sites for 1994 (BOREAS Science Team 1995; Shewchuk, 1997). The initialization data files were created using information obtained from measurements by other BOREAS investigators and the literature for similar stand types (see Section 5).

Hydrologic and carbon data were outputs from the BIOME-BGC model.

### 7.3.5 Data Range

None given.

### 7.4 Sample Data Record

Sample records from selected input and output files are:

```
Input Meteorological data file sample:

1 0.00 -28.50 -42.00 16.40 24467
2 0.00 -25.50 -42.40 28.70 24554
3 0.04 -15.70 -30.70 23.40 24649


Output Hydrologic data file sample:

DOY SNOWW SOILW T ET E Q
1 55.39 190.00 0.00 0.01 0.01 0.00
2 55.78 190.00 0.00 0.01 0.01 0.00
3 55.77 190.00 0.00 0.01 0.00 0.00

Output Carbon data file sample:

DOY GPP Rdl Rnl Rsw Rcr Rfr Rh Rm Rg NPP NEE Rtot
1 11 43 92 39 10 278 0 462 0.0 -451 -451 462
2 14 46 91 41 10 289 0 477 0.0 -463 -463 477
3 22 53 113 48 12 338 0 564 0.0 -542 -542 564
```

## 8. Data Organization

### 8.1 Data Granularity

The smallest unit of obtainable data is the entire modeling data set, which contains a total of 20 input and output American Standard Code for Information Interchange (ASCII) files, and this document.

### 8.2 Data Format(s)

The model input and output files are in ASCII format with space-delimited columns.

## 9. Data Manipulations

See Kimball et al. (1997a,b) and Running and Hunt (1993) for detailed descriptions of model, methods, and processing steps.

### 9.1 Formulae

See Section 9.

#### 9.1.1 Derivation Techniques and Algorithms

See Section 9.

### 9.2 Data Processing Sequence

See Section 9.

#### 9.2.1 Processing Steps

See Section 9.

### 9.2.2 Processing Changes

See Section 9.

### 9.3 Calculations

See Section 9.

### 9.3.1 Special Corrections/Adjustments

Not applicable.

### 9.3.2 Calculated Variables

See Sections 7.3.1 and 7.3.272.

### 9.4 Graphs and Plots

Not applicable.

## 10. Errors

### 10.1 Sources of Error

BIOME-BGC is a process-level model designed to be general enough to apply at regional to global scales. The model uses several simplifying assumptions regarding stand and meteorological conditions in order to facilitate application at regional scales. A fundamental model assumption for this investigation was that stand physiological conditions such as age, stand structure, LAI, and carbon storages were spatially and temporally uniform on an annual basis. Soil conditions such as depth, density, and moisture content were also assumed spatially uniform with no lateral or subsurface drainage. Stand conditions at the study sites were both spatially and temporally diverse and were composed of different age types, biomass densities, and species compositions (Sellers et al., 1995). Some sites also had significant vegetation understories that were not explicitly modeled in this investigation. Evidence suggests that these vegetation types contributed significantly to the daily carbon budget (e.g., Black et al., 1996). Further discussion of potential error sources for this investigation is given by Kimball et al. (1997a,b).

### 10.2 Quality Assessment

See Section 10.1.

### 10.2.1 Model Validation by Source

Model results were compared with daily carbon and water fluxes derived from site tower flux measurements for 1994. Model estimates of annual NPP were also compared with NPP estimates derived from site biomass measurements and allometric equations for 1994 (Gower et al., unpublished data). Model estimates of SNOWW and SOILW were compared with measured data for 1994 (Shewchuck, 1997). Detailed discussions of these comparisons are given by Kimball et al. (1997a,b).

### 10.2.2 Confidence Level/Accuracy Judgment

Currently, there is not enough information regarding measurement error associated with model inputs or model sensitivity to these inputs to establish documented confidence levels in model results. This problem is currently being addressed using sensitivity analyses with multiple-year data and spatial aggregations of remote sensing inputs for the BOREAS region. This work is being funded under a different, but related, project with the jet propulsion Laboratory (JPL) . Also see Section 10.2.1.

### 10.2.3 Measurement Error for Parameters

See Section 10.2.2.

### 10.2.4 Additional Quality Assessments

See Sections 10.1 and 10.2.1.

### 10.2.5 Data Verification by Data Center

BOREAS Information System (BORIS) staff have looked at the input and output files and reviewed the model documentation.

## 11. Notes

### 11.1 Limitations of the Model

See Sections 10.1 and 10.2.1.

### 11.2 Known Problems with the Model

See Sections 10.1 and 10.2.1.

### 11.3 Usage Guidance

None.

### 11.4 Other Relevant Information

None.

## 12. Application of the Model

These results constitute the initial effort in 1996 to simulate hydrologic and carbon exchange processes for different boreal forest stands. These results are expected to change as the models are further modified and developed to reflect insight gained from new research regarding boreal forest processes. These results are intended for comparison with other models.

## 13. Future Modifications and Plans

This model will be used in the context of RHESSys to generate landscape-level estimates of daily and annual water and carbon exchange processes over the 1,000-km x 1,000-km BOREAS grid at a 1-km spatial resolution.

Carbon allocation, growth respiration, and nitrogen cycle routines will be activated (see Running and Hunt, 1993), and model runs will be conducted over longer time periods (50 to several hundred years) to investigate the effects of interannual climate variations on site to regional water and carbon budgets.

A sensitivity analysis with multiple-year data and spatial aggregations of remote sensing inputs for the BOREAS region is currently underway. This work is being funded under a different, but related, project with JPL.

## 14. Software

### 14.1 Software Description

BIOME-BGC was written in C on a UNIX platform.

### 14.2 Software Access

To request a copy of the model, please send email to one of the individuals from the University of Montana listed in Section 2.3.

### 14.3 Software/Platform Limitations

None known.

# 15. Data Access

The RSS-08 BIOME-BGC model files are 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

Model results are stored as ASCII files and are available either online or by contacting BORIS staff directly. See Section 15.1.

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### 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
DAAC     - Distributed Active Archive Center
DAYLEN   - daylength (s)
DOY      - day of year or Julian day
E        - Evaporation from the canopy and surface (kg/m2 day)
EOS      - Earth Observing System
EOSDIS   - EOS Data and Information System
ET       - Evapotranspiration (kg/m2 day)
gC       - Canopy Conductance
GMT      - Greenwich Mean Time
GPP      - Gross Primary Production (mg C/m2 day)
GSFC     - Goddard Space Flight Center
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JPL     - Jet Propulsion Laboratory
LAI     - Leaf Area Index (m2/m2)
NASA    - National Aeronautics and Space Administration
NEE     - Net Ecosystem Carbon Exchange (mg C/m2 day)
NPP     - Net Primary Production (mg C/m2 day)
NSA     - Northern Study Area
OA      - Old Aspen
OBS     - Old Black Spruce
OJP     - Old Jack Spruce
ORNL    - Oak Ridge National Laboratory
PANP    - Prince Albert National Park
PCP     - Daily Precipitation (cm)
PPFD    - Photosynthetically Active Photon Flux Density
PSI     - Soil Water Potential
Q       - Outflow (mm/day)
Rcr     - Coarse root respiration rate (mg C/m2 day)
Rdl     - Daytime leaf respiration rate (mg C/m2 day)
Rfr     - Fine root respiration rate (mg C/m2 day)
Rg      - Growth respiration (mg C/m2 day)
Rh      - Heterotrophic respiration (mg C/m2 day)
RHESSYS - Regional Hydro-EcologicalSimulation System
Rm      - Maintenance respiration (mg C/m2 day)
Rnl     - Nighttime leaf respiration rate (mg C/m2 day)
RSS     - Remote Sensing Science
Rsw     - Sapwood respiration rate (mg C/m2 day)
Rtot    - Total respiration (mg C/m2 day)
RuBisCO - Ribulose Bisphosphate Carboxylase-Oxygenase
SLA     - Specific leaf area (m2/kg C)
SOILW   - Water held in the Soil Layer (mm)
SOLIN   - Total Daily Solar Radiation (kJ)
SNOWW   - Snow Water Equivilent of the Snowcover (mm)
SSA     - Southern Study Area
T       - Transpiration from the canopy (kg/m2 day)
TE      - Terrestrial Ecology
TMAX    - maximum 24-hour air temperature (°C)
TMIN    - minimum 24-hour air temperature (°C)
URL     - Uniform Resource Locator
YJP     - Young Jack Pine
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**13. ABSTRACT** *(Maximum 200 words)*

BIOME-BGC is a general ecosystem process model designed to simulate biogeochemical and hydrologic processes across multiple scales (Running and Hunt, 1993). In this investigation, BIOME-BGC was used to estimate daily water and carbon budgets for the BOREAS tower flux sites for 1994. Carbon variables estimated by the model include gross primary production (i.e., net photosynthesis), maintenance and heterotrophic respiration, net primary production, and net ecosystem carbon exchange. Hydrologic variables estimated by the model include snowcover, evaporation, transpiration, evapotranspiration, soil moisture, and outflow. The information provided by the investigation includes input initialization and model output files for various sites in tabular ASCII format.

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