NASA/TM—2000–209891, Vol. 55

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

Forrest G. Hall and Jaime Nickeson, Editors

Volume 55

BOREAS RSS-8 BIOME-BGC SSA Simulations of Annual Water and Carbon Fluxes

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August 2000

Available from:

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7121 Standard Drive
Hanover, MD 21076-1320
Price Code: A17

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
Price Code: A10

BOREAS RSS-8 BIOME-BGC SSA Simulations of Annual Water and Carbon Fluxes

John S. Kimball

Summary

The BOREAS RSS-8 team performed research to evaluate the effect of seasonal weather and landcover heterogeneity on boreal forest regional water and carbon fluxes using a process-level ecosystem model, BIOME-BGC, coupled with remote sensing-derived parameter maps of key state variables. This data set contains derived maps of landcover type and crown and stem biomass as model inputs to determine annual evapotranspiration, gross primary production, autotrophic respiration, and net primary productivity within the BOREAS SSA-MSA, at a 30-m spatial resolution. Model runs were conducted over a 3-year period from 1994-1996; images are provided for each of those years. The data are stored in binary image format.

Note that some of the data files on the BOREAS CD-ROMs have been compressed using the Gzip program. See Section 8.2 for details.

Table of Contents

1. Model Overview

1.1 Model Identification
BOREAS RSS-08 BIOME-BGC SSA Simulations of Annual Water and Carbon Fluxes

1.2 Model Introduction
The Biome Biogeochemistry Model (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. BIOME-BGC uses daily meteorological data in conjunction with general stand and soil information to predict components of the hydrologic budget (e.g., transpiration, evaporation, snowcover, soil water, runoff) and carbon budget

(e.g., net photosynthesis, autotrophic 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]. Model descriptions relating to the prediction of carbon and hydrologic processes within the BOReal Ecosystem-Atmosphere Study (BOREAS) region are given by Kimball et al. [1997a,b; 1998].

1.3 Objective/Purpose

The purpose of this investigation is to assess the effects of boreal forest interannual weather variability and landcover heterogeneity on regional water and carbon flux simulations using BIOME-BGC. Remote sensing-derived maps of landcover type and crown and stem biomass were used as model inputs to determine regional evapotranspiration (ET), net primary production (NPP), gross primary production (GPP), and autotrophic respiraton (R) within the BOREAS Southern Study Area (SSA) Modeling Sub-Area (MSA). Model simulations were conducted using input data at a 30-m spatial scale. These results are used to investigate the importance of subgrid scale landcover variability on regional biogeochemical processes over a 3-year period, from 1994 to 1996.

1.4 Summary of Parameters

Model Daily Input Requirements:

BIOME-BGC uses a spatial data base composed of soil, vegetation, and daily meteorological characteristics registered to a common projection format, as well as an array of critical physiological constants that define the environmental response curves of individual biome types within the spatial domain (see Kimball et al. [1997a,b; 1998]). Remote sensing-derived crown and stem biomass and landcover classification maps were used to drive model simulations within the SSA-MSA. More detailed information regarding remote sensing and stand biophysical inputs is provided in Section 5.

BIOME-BGC uses daily maximum and minimum air temperatures, solar irradiance (direct + diffuse), and precipitation to determine daily carbon and water fluxes. Daily meteorological data were interpolated over a 1-km-resolution digital elevation map (DEM) of the SSA-MSA using a daily meteorological interpolator [Running et al., 1987; Thornton et al., 1997], digital elevation information (i.e., elevation, slope, aspect), and daily meteorological data from approximately 60 weather stations within the BOREAS region. Gridded daily meteorological data were produced for the 3-year (1994-96) study period.

Model Outputs:

BIOME-BGC determines water and carbon components on a daily basis. The maps provided in this data set represent annual accumulations of daily results. NPP represents the net accumulation of carbon by the stand and is determined as the daily difference between gross photosynthesis and respiration from autotrophic (R) and growth respiration processes. GPP represents the total gain of carbon to the system by net photosynthesis and is defined as the daily sum of gross photosynthesis and daily foliar respiration. R represents the total loss of carbon from the system due to day and night foliar respiration and sapwood, coarse root, and fine root respiration components. ET is computed as the daily sum of transpiration and evaporation from surface, snow, and canopy components.

1.5 Discussion

Since its inception as a point-scale model, BIOME-BGC has evolved to simulate regional scale processes by incorporating spatially distributed daily meteorological fields derived from a microclimate simulator, and remote sensing-derived surface parameter maps to define important landscape characteristics. The model uses a biome-level stratification of landcover conditions to minimize spatial variability in conversion efficiencies and potential environmental controls. For landscape simulations, BIOME-BGC uses a spatial data base composed of soil, vegetation, and daily meteorological characteristics registered to a common projection format, as well an array of critical physiological constants that define the environmental response curves of individual biome types within the spatial domain (see Kimball et al. [1997a,b; 1998]). These physiological constants were obtained from

BOREAS field measurements when possible. When these data were unavailable, values were selected from the literature for representative cover types under similar environmental conditions. For more detailed information regarding the extraction of model inputs, see Section 5.

1.6 Related Models

BIOME-BGC represents the evolution of a forest ecosystem process model (FOREST-BGC) to include biophysical representations of additional growth forms and biome characteristics. Descriptions of FOREST-BGC are provided by Running and Coughlan [1988], while descriptions of BIOME-BGC development and logic are provided by Running and Hunt [1993]. BIOME-BGC and FOREST-BGC models have also been coupled with remote sensing and gridded daily microclimate information to assess ecological processes at landscape and global scales [Kimball et al., 1998; Pierce et al., 1994; Running et al,. 1987, 1989].

Other BOREAS data sets related to this are:

BOREAS TE-06 NPP for the Tower Flux, Carbon Evaluation, and Auxiliary Sites
BOREAS TE-09 NSA Canopy Biochemistry
BOREAS TE-09 NSA Photosynthetic Response Data
BOREAS TE-18 Landsat TM Maximum Likelihood Classification Image of the SSA
BOREAS TE-18 Landsat TM Physical Classification Image of the SSA

2. Investigator(s)

2.1 Investigator(s) Name and Title

Dr. Steven W. Running
Dr. John S. Kimball

2.2 Title of Investigation

BIOME-BGC Regional Simulations of Annual Water and Carbon Fluxes within the BOREAS SSA-MSA

2.3 Contact Information

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3. Theory of Measurements

See documentation for Remote Sensing Science (RSS)-16, Terrestrial Ecology (TE)-18, TE-09, and TE-06 data sets referenced within.

4. Equipment

Not applicable.

5. Data Acquisition Methods

Crown and stem biomass and landcover classification maps derived from remote sensing were used to drive model simulations within the SSA-MSA. Crown and stem biomass maps were derived from 1994 airborne synthetic aperture radar (AIRSAR) remote sensing measurements of the SSA-MSA collected from a DC-8 aircraft [Sellers and Hall, 1994; Saatchi and Rignot, 1997]. A landcover classification map of the SSA-MSA was also obtained from AIRSAR data collected during the 1994 growing season [Saatchi and Rignot, 1997]. These maps are currently available from the BOREAS RSS-16 team. A second landcover classification map, derived from 1994 Landsat Thematic Map (TM) information, was obtained from the BOREAS TE-18 team and was used to distinguish broadleaf deciduous stands within areas defined as mixed forest within the AIRSAR landcover classification.

The RSS-16 landcover classification maps were used to define the number of individual biome types represented in the ecosystem model, while RSS-16 biomass maps were used to define leaf area index (LAI) and foliar and stem carbon pools within each grid cell. The classification map was used to distinguish six landcover classes within the SSA-MSA, representing dry conifer, wet conifer, open water, disturbed, mixed deciduous/conifer forest, and wetland areas. Dry conifer areas were mainly composed of jack pine stands while wet conifer areas consisted mainly of black spruce stands. Wetland areas were composed of a mixture of black spruce, bog, and fen sites, while disturbed sites represented a mixture of recently logged and burned areas, roads, and other sparsely vegetated and nonwater surfaces. Mixed deciduous/conifer forest areas represented a mixture of aspen forest and mixed jack pine/aspen forest with no clear dominance of either species type. Our analysis focused on vegetated areas within the SSA-MSA only. Open water areas were not represented in the model and were masked from further analysis.

The mass of living stem carbon was derived from the RSS-16 AIRSAR stem biomass map and estimates of the relative proportions of living and total stem biomass, and the proportions of living cells in sapwood tissue. This information was obtained from BOREAS TE-06 team's biomass harvest plots within the SSA-MSA and information reported in the literature for representative vegetation types [Gower et al., 1997; Waring and Running, 1998]. The mass of living coarse root carbon was estimated as a proportion of live stem carbon using allometric relationships for representative cover types [Grier et al., 1981; Vogt, 1991; Steele et al., 1997]. The mass of living fine root carbon was estimated from 1.5 to 3.0 times foliar carbon estimates based on SSA-MSA biomass measurements and information reported in the literature for nutrient-limited arctic, boreal, and cold temperate environments [Bigger and Oechel, 1982; Mitsch and Gosselink, 1993; Schimel et al., 1996; Gower et al., 1997; Steele et al., 1997].

The mass of foliar carbon was derived from the RSS-16 AIRSAR crown biomass (i.e., leaves and branches) map and estimated proportions of foliar to crown biomass obtained from the TE-06 biomass harvest plots within the SSA-MSA [Gower et al., 1997]. LAI was derived from foliar carbon maps and specific leaf area (SLA) values obtained from canopy biophysical measurements within the SSA-MSA collected by team TE-09 [Dang et al., 1997b]. The LAI for coniferous vegetation was held constant over each year. For deciduous vegetation, LAI was regulated between a prescribed seasonal minimum (i.e., 0.0) and the remote sensing-defined seasonal maximum using a phenology model based on daily meteorological predictions of satellite-observed dates of greenness onset and offset

[White et al., 1997]. The model predicts the onset of greenness using a combined thermal and radiation summation, while offset is determined using a thermally adjusted photoperiod trigger. The foliar carbon pool was increased on a daily basis using a stepped 45-day linear ramping function between the onset date and the RSS-16 AIRSAR-derived LAI, while foliage drop occurred at the offset date.

Foliar leaf nitrogen concentrations strongly influence the photosynthetic capacity of the system and are directly related to the amount of radiation absorbed by the canopy [Pierce et al., 1994]. Because canopy absorption is also related to LAI, foliar nitrogen was estimated as a proportion (0.7-4.5%) of leaf carbon. These fractions were derived from TE-09 site measurements within BOREAS aspen, jack pine and black spruce stands [Dang et al., 1997b; Sullivan et al., 1997] and values reported in the literature for representative cover types [Aerts et al., 1992; Mitsch and Gosselink, 1993; Schimel et al., 1996].

Soil rooting depth and water holding capacity information were derived from a 1:1,000,000-scale digital soils inventory data base of Canada obtained through BOREAS staff from the Land Resource Research Centre of Agriculture Canada [Acton et al., 1991] and volumetric soil moisture and soil survey measurements conducted at several sites within the SSA by the BOREAS Hydrology (HYD)-01 team [Sellers and Hall, 1994; Cuenca et al., 1997]. Soil b-parameter values define the slope of the functional soil water potential (j) response to changes in soil water and were derived from values reported in the literature for representative soil types [Cosby et al., 1984]. Soil structural characteristics were assumed constant within the area represented by each landcover class.

Daily meteorological data were interpolated over a 1-km-resolution DEM of the SSA-MSA using a daily meteorological interpolator [Running et al., 1987; Thornton et al., 1997], digital elevation information (i.e., elevation, slope, aspect), and daily weather data from approximately 60 stations within the BOREAS region. Gridded daily meteorological data were produced for the 3-year (1994-96) study period. The meteorological data were obtained from the National Climatic Data Center's Global Surface Summary of the Day data base, the Saskatchewan Research Council's Automatic Meteorological Stations data base, and BOREAS tower flux site measurements within the SSA-MSA [National Weather Service, 1988; Sellers and Hall, 1994; Shewchuk, 1997]. DEM information was provided by the BOREAS HYD-08 team and BOREAS staff [Sellers and Hall, 1994].

Daily model simulations were conducted for the BOREAS SSA-MSA study region from 01-Jan-1994 to 31-Dec-1996. Meteorological conditions were defined using the 3-year gridded daily meteorological fields, while 1994 landcover type and biomass maps defined surface physical conditions for the 3-year period. Spatially distributed estimates of initial soil water and snow water equivalent depth were required to initialize the 1994 water balance. The model was initialized with a uniform snow water equivalent depth of 3.3 cm and a soil water depth set at 95% of field capacity. These values were determined from BIOME-BGC point simulations at BOREAS SSA-MSA tower sites using 1993 daily meteorological data from Nipawin Airport (53.20N 104.00W) near the SE corner of the SSA-MSA.

Deciduous and coniferous canopies within mixed cells were simulated separately because of marked differences in biophysical characteristics and physiological responses to environmental controls. Dry and Wet Conifer classes were assumed to be composed entirely of coniferous vegetation. Disturbed, mixed conifer/deciduous, and wetland classes were represented as a mixture of 50% deciduous and 50% coniferous lifeforms. Landcover classification information derived from Landsat TM data was used to distinguish broadleaf deciduous stands (see above) within AIRSAR-defined mixed conifer/deciduous areas. These areas were assumed to be 100% deciduous, while other mixed conifer/deciduous areas were represented as a mixture of 50% coniferous and 50% deciduous. Ideally, information on deciduous and coniferous proportional cover characteristics could be used to simulate the relative contributions of different lifeforms to the total water and carbon flux within each grid cell. Unfortunately, that information was not available for this investigation and thus simplifying assumptions were necessary.

6. Observations

6.1 Data Notes

None.

6.2 Field Notes

Not applicable.

7. Data Description

7.1 Spatial Characteristics

7.1.1 Spatial Coverage

The image files cover the entire area within the BOREAS SSA-MSA (approximately 40 km x 50 km). However, model runs were limited by the extent of available AIRSAR data; unknown and open water landcover classes were also masked from model analyses so that the actual size of the simulated surfaces represent a smaller area of approximately 1200 km^2. Model results were generated with a minimum pixel size of 30 m, which represents the spatial resolution of the AIRSAR data. The coordinates of the upper-left corner of the upper-left pixel are (North American Datum of 1983 (NAD83)):

Longitude	Latitude	UTM Easting	UTM Northing
105.46023° W	54.28602° N	470039.5	6015442.5

7.1.2 Spatial Coverage Map

None.

7.1.3 Spatial Resolution

The spatial resolution of the images is 30 m x 30 m.

7.1.4 Projection

The area mapped is projected in the ellipsoidal version of the Albers Equal Area Conic (AEAC) projection. The projection has the following parameters:

```
Datum:                NAD83
Ellipsoid:            GRS80 or WGS84
Origin:               111.000° West longitude
                      51.000° North latitude
Standard Parallels:   N 52° 30' 00"
                      N 58° 30' 00"
Units of Measure:     kilometers
```

7.1.5 Grid Description

The data are gridded in 30 m intervals based on projection described in Section 7.1.4.

7.2 Temporal Characteristics

7.2.1 Temporal Coverage

The images represent annual accumulations of daily model results for 1994, 1995, and 1996.

7.2.2 Temporal Coverage Map
None.

7.2.3 Temporal Resolution
The images represent annual accumulations of daily model output.

7.3 Input Data Characteristics

7.3.1 Input Parameter/Variable
See Section 1.4.

7.3.2 Variable Description/Definition
See Section 1.4.

7.3.3 Unit of Measurement
See Section 1.4.

7.3.4 Data Source
See Section 1.4.

7.3.5 Data Range
See Section 1.4.

7.4 Output Data Characteristics

7.4.1 Output Parameter/Variable
GPP, NPP, R, ET.

7.4.2 Variable Description/Definition
See Section 1.4.

7.4.3 Unit of Measurement
GPP, NPP and R (kg C/m^2/yr). ET (kg/m^2/yr).

7.4.4 Data Source
GPP, NPP, R, and ET images represent annual accumulations of BIOME-BGC daily output.

7.4.5 Data Range
Not applicable.

7.5 Sample Data Records
Not applicable.

8. Data Organization

8.1 Data Granularity

The smallest unit of data is the complete set of simulated images described in this document.

8.2 Data Format(s)

8.2.1 Uncompressed Files

This data set contains the following 13 files:

```
 file         description
------   ----------------------
   1      Evapotranspiration 1994
   2      Gross Primary Production 1994
   3      Net Primary Production 1994
   4      Autotrophic Respiration 1994
   5      Evapotranspiration 1995
   6      Gross Primary Production 1995
   7      Net Primary Production 1995
   8      Autotrophic Respiration 1995
   9      Evapotranspiration 1996
  10      Gross Primary Production 1996
  11      Net Primary Production 1996
  12      Autotrophic Respiration 1996
  13      AIRSAR-derived Landcover 1994
```

The first 12 files contain three years of model output of ET, GPP, NPP, and R for 1994, 1995, and 1996. File 13 is the AIRSAR-based landcover image of 1994. Files 1-12 contain 1120 logical records (lines), each 3000 bytes long. Each line for these 12 files contain 1500 2-byte values (pixels), for a total of 3000 bytes in each of 1120 lines. File 13 is a single-byte image and thus has just 1500 bytes (pixels) in each of the 1120 lines.

BIOME-BGC output image data are presented as binary image maps of annual ET, GPP, NPP, and R. As stored, the values are scaled integers that can be converted to physical units by using the following equations:

GPP, NPP and R (kg C/m^2/yr) = (DN/1000)-5
ET (kg/m^2) = (DN/10)-1

The six-class landcover image (used for the model simulations) is a single-byte image. This image was extracted from the RSS-16 AIRSAR landcover map [Saatchi and Rignot, 1997]. This image is spatially equivalent to the BIOME-BGC output images. Landcover values correspond to the following landcover types: 0 = Unknown, 1 = Dry conifer, 2 = Disturbed, 3 = Water, 4 = Wet conifer, 5 = Mixed forest, 6 = Fen/Wetland.

The size of the modeling area was governed by the extent of available AIRSAR data used to provide landcover information. Unknown and open water landcover classes were masked from model analyses. Similarly, areas outside the bounds of available AIRSAR coverage were also masked. Masked pixels are designated with a missing data "-9999.0" flag.

8.2.2 Compressed CD-ROM Files

On the BOREAS CD-ROMs, the image files have been compressed with the (Gzip) GNU zip compression program (file_name.gz, version 1.2.4, using the high compression (-9) option (Copyright (C) 1992-1993 Jean-loup Gailly). Gzip uses the Lempel-Ziv algorithm (Welch, 1994) also used in the zip and PKZIP programs. The compressed files may be uncompressed using gzip (with the

-d option) or gunzip. Gzip is available from many Web sites (for example, the ftp site prep.ai.mit.edu/pub/gnu/gzip-*.*) for a variety of operating systems in both executable and source code form. Versions of the decompression software for various systems are included on the CD-ROMs.

9. Data Manipulations

9.1 Formulae

See Kimball et al. [1997a,b; 1998].

9.1.1 Derivation Techniques and Algorithms

See Kimball et al. [1997a,b; 1998].

9.2 Data Processing Sequence

9.2.1 Processing Steps

BOREAS Information System (BORIS) staff copied the American Standard Code for Information Interchange (ASCII) and compressed the binary files for release on CD-ROM.

9.2.2 Processing Changes

None given.

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, and carbon storages were spatially and temporally uniform on an annual basis. Soil conditions such as rooting 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 (BOREAS Science Team, 1995). Some sites also had significant vegetation understories that were not explicitly modeled in this investigation. Recent research indicates that understory processes can contribute significantly to annual carbon and water budgets. Other factors such as stand disease and mortality effects and soil nutrient variability were also not addressed. Although much of the boreal forest is relatively flat, subgrid scale variability in precipitation, wind, solar irradiance, albedo, and the surface energy balance may induce greater heterogeneity in surface fluxes than we were able to distinguish using a 1-km gridded daily meteorological data base and a 30-m landcover data base. Other major uncertainties include the relative proportions of deciduous and coniferous vegetation within each landcover class and amounts of fine and coarse root biomass for different stands. These factors strongly influence stand environmental response curves and respiration rates but are difficult to quantify from available BOREAS data. Further discussion of potential error sources for this investigation is given by Kimball et al. [1997 a,b; 1998].

10.2 Quality Assessment

10.2.1 Model Validation by Source

Modeled AIRSAR-derived landcover, biomass, and LAI inputs have been compared with similar results derived from optical remote sensing data, surface optical LAI, and biomass measurements (e.g., Saatchi and Rignot, 1997). Model outputs have been compared with tower flux site daily water and CO_2 flux estimates, as well as soil water, snowcover, and biomass allometric measurements (e.g., Kimball et al., 1997a,b). Annual 1994 NPP results averaged approximately 2.7 (±0.4), 3.4 (±0.3), 1.9 (±0.3), 2.1 (±0.3), 1.0 (±0.5), and 2.0 (±0.6) Mg C/ha/yr for wetland, mixed conifer/deciduous, dry and wet conifer, disturbed, and broadleaf deciduous stands, respectively. These values were approximately 24% (NPP) smaller for 1995 and 1996 in response to cooler spring and warmer, drier summer conditions. Simulated ranges and landcover differences in NPP were similar to observations reported by other investigators using above- and below-ground biomass measurements and allometric relationships within SSA black spruce, jack pine, and aspen stands [Gower et al., 1997; Steele et al., 1997]. NPP observation data for fen and other wetland areas were not available within the SSA-MSA. However, model simulations were similar to the magnitudes and ranges of NPP (above-ground only) reported in the literature for northern bog marshes, rich fen, forested peatland, and fen forest sites within Canada and the northern U.S.; reported values range from 0.5-9.7 Mg C/ha/yr [Mitsch and Gosselink, 1993].

Annual 1994 ET results averaged approximately 23.3 (±1.7), 23.7 (±1.7), 21.4 (±1.6), 24.6 (±2.1), 19.3 (±0.3), and 22.3 (±0.7) cm/yr for wetland, mixed conifer/deciduous, dry and wet conifer, disturbed, and broadleaf deciduous stands, respectively, and decreased from 0.04-5.6% for 1995 and 1996. The magnitudes and relative differences in ET between landcover classes were similar to 1994 cumulative ET estimates obtained from tower eddy-flux measurements at SSA black spruce [Jarvis et al., 1997], jack pine [Baldocchi et al., 1997], and aspen sites [Black et al., 1996]. Earlier comparisons between model results and field measurements at individual tower sites showed that model results explained approximately 62 and 98 percent of the respective variances in observed daily ET and soil water [Kimball et al., 1997b].

10.2.2 Confidence Level/Accuracy Judgment

See Sections 10.1 and 10.2.1.

10.2.3 Measurement Error for Parameters

See Sections 10.1 and 10.2.1.

10.2.4 Additional Quality Assessments

See Sections 10.1 and 10.2.1.

10.2.5 Data Verification by Data Center

BORIS staff viewed the imagery to verify image size and type and to establish data ranges.

11. Notes

11.1 Limitations of the Model

See Section 12.

11.2 Known Problems with the Model

See Section 10.1.

11.3 Usage Guidance

See Sections 10.1 and 12. Before uncompressing the Gzip files on CD-ROM, be sure that you have enough disk space to hold the uncompressed data files. Then use the appropriate decompression program provided on the CD-ROM for your specific system.

11.4 Other Relevant Information

See Section 12.

12. Application of the Model

These data represent research in progress. We expect our results to improve as existing data sets improve and additional remote sensing parameter maps and measurement data regarding stand and soil morphology become available. These results are intended for visual interpretation, assessment of yearly variations in annual fluxes, and comparison with other models and additional measurement data.

13. Future Modifications and Plans

This model will be coupled with gridded daily meteorological data, soil, and remote sensing parameter maps (e.g., landcover, LAI, radar freeze-thaw) to generate landscape-level estimates of water and carbon exchange processes over the 1 x 106 km^2 BOREAS grid at a 1-km spatial resolution. There are currently no plans to generate further high-resolution (30 m) results.

14. Software

14.1 Software Description

FOREST-BGC is currently available in C format and can be obtained via ftp download. BIOME-BGC is still under development and is not available for public release at this time. Gzip (GNU zip) uses the Lempel-Ziv algorithm (Welch, 1994) used in the zip and PKZIP commands.

14.2 Software Access

The Numerical Terradynamic Simulation Group (NTSG) Web site (see Section 2.3) currently provides software updates and download information on model changes and availability (web site: http://www.forestry.umt.edu/ntsg/). Gzip is available from many Web sites across the Internet (for example, FTP site prep.ai.mit.edu/pub/gnu/gzip-*.*) for a variety of operating systems in both executable and source code form. Versions of the decompression software for various systems are included on the CD-ROMs.

14.3 Platform Limitations

The FOREST-BGC family of models has been written and compiled on UNIX AIX platforms but should compile with any standard C compiler (web site: http://www.forestry.umt.edu/ntsg/).

15. Data Access

The BIOME-BGC SSA simulations 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

The data can be made available on 8-mm or Digital Archive Tape (DAT) media.

16.2 Film Products

None.

16.3 Other Products

These data are available on the BOREAS CD-ROM series.

17. References

17.1 Model Documentation

Welch, T.A. 1984. A Technique for High Performance Data Compression. IEEE Computer, Vol. 17, No. 6, pp. 8-19.

17.2 Journal Articles and Study Reports

Acton, D.F., G.A. Padbury, and J.A. Shields. 1991. Soil landscapes of Canada-Saskatchewan digital map data: scale 1:1000000. CanSIS No. SK018200, version 90.11.30, CLBRR Archive, Agriculture Canada Research Branch, Ottawa, Canada, No. 91-107D.

Aerts, R., H. De Caluwe, and H. Konings. 1992. Seasonal allocation of biomass and nitrogen in four Carex species from mesotrophic and eutrophic fens affected by nitrogen supply. J. Ecol., 80, 653-664.

Baldocchi, D.D., C.A. Vogel, and B. Hall. 1997. Seasonal variation of energy and water vapor exchange rates above and below a boreal jack pine forest canopy. Journal of Geophysical Research 102(D24): 28,939-28,951.

Bigger, C.M. and W.C. Oechel. 1982. Nutrient effect on maximum photosynthesis in arctic plants. Holarctic Ecology, 5, 158-163.

Black, T.A., G. den Hartog, H.H. Neumann, P.D. Blanken, P.C. Yang, C. Russell, Z. Nesic, X. Lee, S.G. Chen, and R. Staebler. 1996. Annual cycles of water vapour and carbon dioxide fluxes in and above a boreal aspen forest. Global Change Biol., 2, 219-229.

Cosby, B.J., G.M. Hornberger, R.B. Clapp, and T.R. Ginn. 1984. A statistical exploration of the relationships of soil moisture characteristics to the physical properties of soils. Water Resour. Res., 20, 682-690.

Cuenca, R.H., D.E. Stangel, and S.F. Kelly. 1997. Soil water balance in a boreal forest. Journal of Geophysical Research 102(D24): 29,355-29,365.

Dang, Q.L., H.A. Margolis, M. Coyea, M. Sy, and G.J. Collatz. 1997a. Regulation of branch-level gas exchange of boreal trees: roles of shoot water potential and vapor pressure difference. Tree Physiol., 17, 521-535.

Dang, Q.L., H.A. Margolis, M. Sy, M.R. Coyea, G.J. Collatz, and C.L. Walthall. 1997b. Profiles of photosynthetically active radiation, nitrogen and photosynthetic capacity in the boreal forest: Implications for scaling from leaf to canopy. Journal of Geophysical Research 102(D24): 28,845-28,859.

Farquhar, G.D. and S. von Caemmerer. 1982. Modelling of photosynthetic response to environmental conditions. In Encyclopedia of Plant Physiology, New Series, vol. 12B, Physiological Plant Ecology II, edited by O.L. Lange, P.S. Nobel, C.B. Osmond, and H. Ziegler, Springer-Verlag, Berlin, Germany, 549-587.

Gower, S.T., J.G. Vogel, J.M. Norman, C.J. Kucharik, S.J. Steele, and T.K. Stow. 1997. Carbon distribution and aboveground net primary production in aspen, jack pine, and black spruce stands in Saskatchewan and Manitoba, Canada. Journal of Geophysical Research 102(D24): 29,029-29,041.

Grier, C.C., K.A. Vogt, M.R. Keyes, and R.L. Edmonds. 1981. Biomass distribution and above- and belowground production in young and mature Abies amabilis zone ecosystems of the Washington Cascades. Can. J. For. Res., 11, 155-157.

Hunt, R.E. and S.W. Running. 1992. Simulated dry matter yields for aspen and spruce stands in the North American boreal forest. Can. J. Remote Sens., 18, 126-133.

Hunt, R.E., S.C. Piper, R. Nemani, C.D. Keeling, R.D. Otto, and S.W. Running. 1996. Global net carbon exchange and intra-annual atmospheric CO_2 concentrations predicted by an ecosystem process model and three-dimensional atmospheric transport model. Global Biogeochemical Cycles, 10(3), 431-456.

Jarvis, P.G., J.M. Massheder, S.E. Hale, J.B. Moncrieff, M. Rayment, and S.L. Scott. 1997. Seasonal variation of carbon dioxide, water vapor, and energy exchanges of a boreal black spruce forest. Journal of Geophysical Research 102(D24): 28,953-28,966.

Kimball, J.S., M.A. White, and S.W. Running. 1997a. BIOME-BGC simulations of stand hydrologic processes for BOREAS. Journal of Geophysical Research 102(D24): 29,043-29,051.

Kimball, J.S., P.E. Thornton, M.A. White, and S.W. Running. 1997b. Simulating forest productivity and surface-atmosphere carbon exchange in the BOREAS study region. Tree Physiol., 17, 589-599.

Kimball, J.S., S.W. Running, and S.S. Saatchi. 1998. Sensitivity of boreal forest regional water flux and net primary production simulations to sub-grid scale landcover complexity. Journal of Geophysical Research (submitted 1998).

Lavigne, M.B. and M.G. Ryan. 1997. Growth and maintenance respiration rates of aspen, black spruce and jack pine stems at northern and southern BOREAS sites. Tree Physiol., 17, 543-551.
Mitsch, W.J. and J.G. Gosselink. 1993. Wetlands, 2nd. ed., Van Nostrand Reinhold, New York.

National Weather Service. 1988. Surface observations. Federal Meteorological Handbook No. 1, (FCM-H1-1988), Office of the Federal Coordinator, Department of Commerce, Washington, DC.

Newcomer, J., D. Landis, S. Conrad, S. Curd, K. Huemmrich, D. Knapp, A. Morrell, J. Nickeson, A. Papagno, D. Rinker, R. Strub, T. Twine, F. Hall, and P. Sellers, eds. 2000. Collected Data of The Boreal Ecosystem-Atmosphere Study. NASA. CD-ROM.

Penning de Vries, F.W.T., A. Brunsting, and H.H. Van Laar. 1974. Products, requirements and efficiency of biosynthesis: A quantitative approach. Journal of Theoretical Biology. 45:339-377.

Pierce, L.L., S.W. Running, and J. Walker. 1994. Regional-scale relationships of leaf area index to specific leaf area and leaf nitrogen content. Ecol. Appl., 4(2), 313-321.

Running, S.W. and J.C. Coughlan. 1988. A general model of forest ecosystem processes for regional applications, I. Hydrologic balance, canopy gas exchange and primary production processes. Ecol. Model. 42, 125-154.

Running, S.W. and R.E. Hunt. 1993. Generalization of a forest ecosystem process model for other biomes, BIOME-BGC, and an application for global-scale models. In Scaling Physiologic Processes: Leaf to Globe, edited by J.R. Ehleringer and C.B. Field, Academic Press, San Diego, CA.

Running, S.W., R.R. Nemani, and R.D. Hungerford. 1987. Extrapolation of synoptic meteorological data in mountainous terrain and its use for simulating forest evapotranspiration and photosynthesis. Canadian Journal of Forest Research 17:472-483.

Running, S.W., R.R. Nemani, D.L. Peterson, L.E. Band, D.F. Potts, L.L. Pierce, and M.A. Spanner. 1989. Mapping regional forest evapotranspiration and photosynthesis by coupling satellite data with ecosystem simulation. Ecology, 70(4), 1090-1101.

Saatchi, S.S. and E. Rignot. 1997. Classification of boreal forest cover types using SAR images. Remote Sens. Environ., 60(3), 271-281.

Schimel, J.P., K. Kielland, and F.S. Chapin III. 1996. Nutrient availability and uptake by tundra plants. In Landscape Function and Disturbance in Arctic Tundra, edited by J.F. Reynolds and J.D. Tenhunen, Springer, New York, 203-213.

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.

Shewchuk, S.R. 1997. Surface mesonet for BOREAS. Journal of Geophysical Research 102(D24): 29,077-29,082.

Steele, S.J., S.T. Gower, J.G. Vogel, and J.M. Norman. 1997. Root mass, net primary production and turnover in aspen, jack pine and black spruce forests in Saskatchewan and Manitoba Canada. Tree Physiol., 17, 577-587.

Sullivan, J.H., B.D. Bovard, and E.M. Middleton. 1997. Variability in leaf-level CO_2 and water fluxes in Pinus banksiana and Picea mariana in Saskatchewan. Tree Physiol., 17, 553-561.

Thornton, P.E., S.W. Running, and M.A. White. 1997. Generating surfaces of daily meteorological variables over large regions of complex terrain. J. Hydrol., 190, 214-251.

Vogt, K. 1991. Carbon budgets of temperate forest ecosystems. Tree Physiol., 9, 69-86.

Waring, R.H. and S.W. Running. 1998. Forest ecosystems analysis at multiple scales, Academic Press. San Diego, CA.

White, J.D. and S.W. Running. 1994. Testing scale dependent assumptions in regional ecosystem simulations. J. Veg. Sci., 5, 687-702.

White, M.A., P.E. Thornton and S.W. Running. 1997. A continental phenology model for monitoring vegetation responses to interannual climatic variability. Global Biogeochemical Cycles, 11(2), 217-234.

17.3 Archive/DBMS Usage Documentation

None.

18. Glossary of Terms

None.

19. List of Acronyms

AEAC	- Albers Equal-Area Conic
AIRSAR	- Airborne Synthetic Aperture Radar
ASCII	- American Standard Code for Information Interchange
BIOME-BGC	- Biome Biogeochemistry Model
BOREAS	- BOReal Ecosystem-Atmosphere Study
BORIS	- BOREAS Information System
CD-ROM	- Compact Disk-Read-Only memory
DAAC	- Distributed Active Archive Center
DAT	- Digital Archive Tape
DEC	- Broadleaf deciduous landcover
DEM	- Digital elevation model
DN	- Digital Number (scaled binary image value)
DSTRB	- Disturbed landcover
EOS	- Earth Observing System
EOSDIS	- EOS Data and Information System
ET	- Evapotranspiration (kg/m^2)
GIS	- Geographic Information System
GPP	- Gross Primary Production or net photosynthesis ($kg\ C/m^2$)
GSFC	- Goddard Space Flight Center
Gzip	- GNU zip
LAI	- Leaf Area Index (m^2/m^2)
MSA	- Modeling Sub-Area
NAD83	- North American Datum of 1983
NASA	- National Aeronautics and Space Administration
NPP	- Net Primary Production ($kg\ C/m^2$)
NSA	- Northern Study Area
NTSG	- Numerical Terradynamic Simulation Group
ORNL	- Oak Ridge National Laboratory
PANP	- Prince Albert National Park
R	- Autotrophic or maintenance respiration ($kg\ C/m^2$)
RSS	- Remote Sensing Science
SLA	- Specific Leaf Area ($m^2/kg\ C$)
SSA	- Southern Study Area
TE	- Terrestrial Ecology
TM	- Thematic Mapper
URL	- Uniform Resource Locator

20. Document Information

20.1 Document Revision Date
Written: 18-Sep-1998
Last Updated: 31-Aug-1999

20.2 Document Review Date(s)
BORIS Review: 30-Nov-98
Science Review:

20.3 Document ID

20.4 Citation

When using these data, please reference the following publications as well as other relevant papers in Section 17.2:

Kimball, J.S., M.A. White, and S.W. Running. 1997ba. BIOME-BGC simulations of stand hydrologic processes for BOREAS. Journal of Geophysical Research 102(D24): 29,043-29,051.

Kimball, J.S., P.E. Thornton, M.A. White and S.W. Running. 1997b. Simulating forest productivity and surface-atmosphere carbon exchange in the BOREAS study region. Tree Physiol., 17, 589-599.

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If using data from the BOREAS CD-ROM series, also reference the data as:

Running, S.W. and J.S. Kimball, "BIOME-BGC Regional Simulations of Annual Water and Carbon Fluxes within the BOREAS SSA-MSA." In Collected Data of The Boreal Ecosystem-Atmosphere Study. Eds. J. Newcomer, D. Landis, S. Conrad, S. Curd, K. Huemmrich, D. Knapp, A. Morrell, J. Nickeson, A. Papagno, D. Rinker, R. Strub, T. Twine, F. Hall, and P. Sellers. CD-ROM. NASA, 2000.

Also, cite the BOREAS CD-ROM set as:

Newcomer, J., D. Landis, S. Conrad, S. Curd, K. Huemmrich, D. Knapp, A. Morrell, J. Nickeson, A. Papagno, D. Rinker, R. Strub, T. Twine, F. Hall, and P. Sellers, eds. Collected Data of The Boreal Ecosystem-Atmosphere Study. NASA. CD-ROM. NASA, 2000.

20.5 Document Curator

20.6 Document URL

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	August 2000	Technical Memorandum

4. TITLE AND SUBTITLE
Technical Report Series on the Boreal Ecosystem-Atmosphere Study (BOREAS)
BOREAS RSS-8 BIOME-BGC SSA Simulations of Annual Water and Carbon Fluxes

5. FUNDING NUMBERS
923
RTOP: 923-462-33-01

6. AUTHOR(S)
John Kimball
Forrest G. Hall and Jaime Nickeson, Editors

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS (ES)
Goddard Space Flight Center
Greenbelt, Maryland 20771

8. PEFORMING ORGANIZATION REPORT NUMBER
2000-03136-0

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS (ES)
National Aeronautics and Space Administration
Washington, DC 20546-0001

10. SPONSORING / MONITORING AGENCY REPORT NUMBER
TM—2000–209891
Vol. 55

11. SUPPLEMENTARY NOTES
J. Kimball: University of Montana; J. Nickeson: Raytheon ITSS

12a. DISTRIBUTION / AVAILABILITY STATEMENT
Unclassified–Unlimited
Subject Category: 43
Report available from the NASA Center for AeroSpace Information,
7121 Standard Drive, Hanover, MD 21076-1320. (301) 621-0390.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

The BOREAS RSS-8 team performed research to evaluate the effect of seasonal weather and landcover heterogeneity on boreal forest regional water and carbon fluxes using a process-level ecosystem model, BIOME-BGC, coupled with remote sensing-derived parameter maps of key state variables. This data set contains derived maps of landcover type and crown and stem biomass as model inputs to determine annual evapotranspiration, gross primary production, autotrophic respiration, and net primary productivity within the BOREAS SSA-MSA, at a 30-m spatial resolution. Model runs were conducted over a 3-year period from 1994-1996; images are provided for each of those years. The data are stored in binary image format.

14. SUBJECT TERMS
BOREAS, remote sensing science, water and carbon fluxes.

15. NUMBER OF PAGES
17

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	UL

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39.18
298-102