United States
Department of
Agriculture

Forest Service

Pacific Northwest
Research Station

General Technical
Report
PNW-GTR-508
June 2001

In cooperation with:

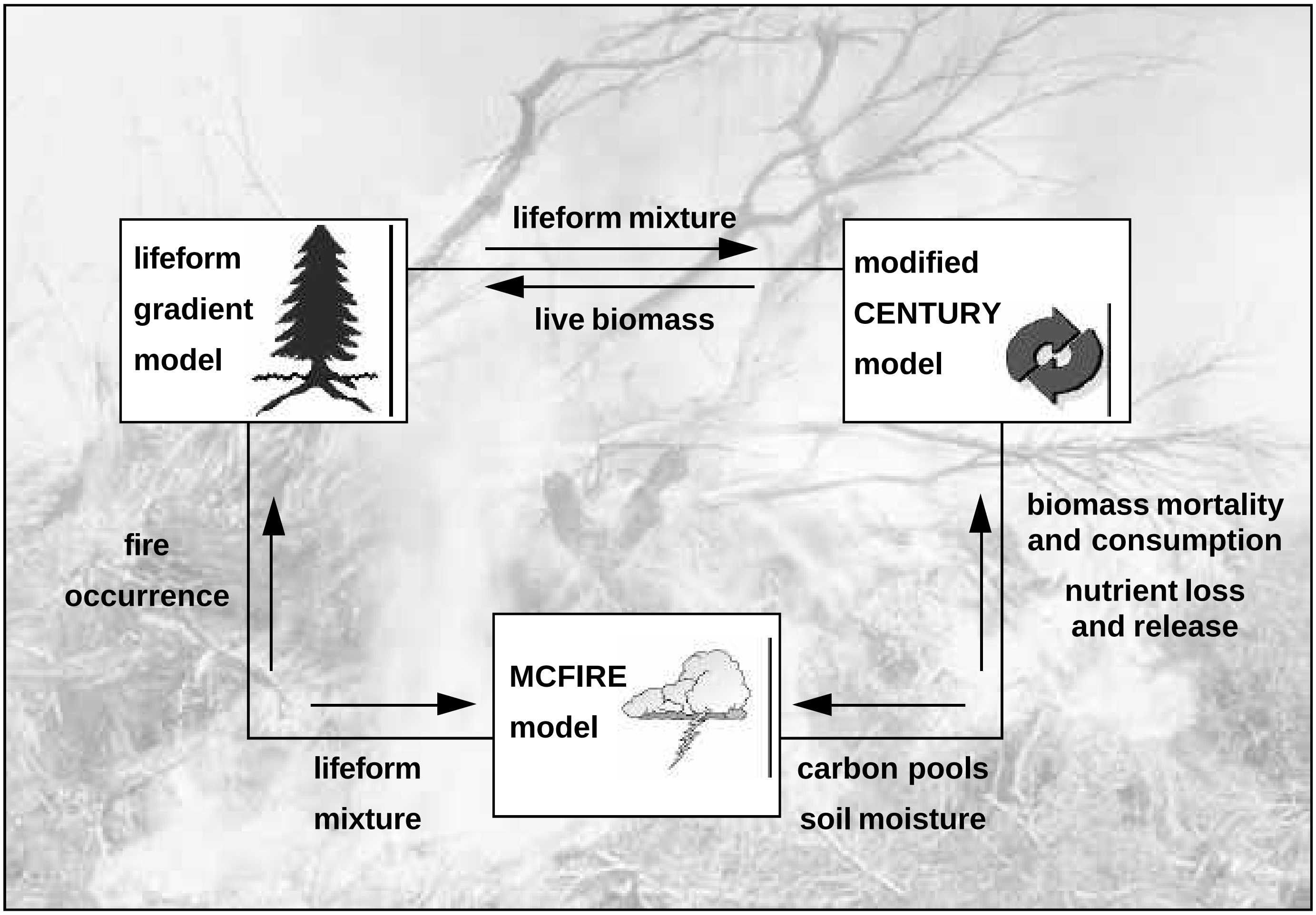
Oregon State
University

Colorado State
University

MC1: A Dynamic Vegetation Model for Estimating the Distribution of Vegetation and Associated Ecosystem Fluxes of Carbon, Nutrients, and Water

Technical Documentation. Version 1.0

Dominique Bachelet, James M. Lenihan, Christopher Daly,
Ronald P. Neilson, Dennis S. Ojima, and William J. Parton



Authors

Dominique Bachelet is an associate professor of bioresource engineering, **James M. Lenihan** is a research associate of botany and plant pathology, and **Christopher Daly** is an assistant professor of geosciences, Oregon State University, Corvallis, OR 97331; **Ronald P. Neilson** is a bioclimatologist, U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, 3200 SW Jefferson Way, Corvallis, OR 97331; and **Dennis S. Ojima** is a research scientist and **William J. Parton** is a senior research scientist, Natural Resource Ecology Laboratory, Colorado State University, Fort Collins, CO 80523.

Cover: Links and feedbacks among the three modules of the dynamic vegetation model MC.

Abstract

Bachelet, Dominique; Lenihan, James M.; Daly, Christopher; Neilson, Ronald P.; Ojima, Dennis S.; Parton, William J. 2001. MC1: a dynamic vegetation model for estimating the distribution of vegetation and associated carbon, nutrients, and water—technical documentation. Version 1.0. Gen. Tech. Rep. PNW-GTR-508. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 95 p.

Assessments of vegetation response to climate change have generally been made only by equilibrium vegetation models that predict vegetation composition under steady-state conditions. These models do not simulate either ecosystem biogeochemical processes or changes in ecosystem structure that may, in turn, act as feedbacks in determining the dynamics of vegetation change. MC1 is a new dynamic global vegetation model created to assess potential impacts of global climate change on ecosystem structure and function at a wide range of spatial scales from landscape to global. This new tool allows us to incorporate transient dynamics and make real time predictions about the patterns of ecological change. MC1 was created by combining physiologically based biogeographic rules defined in the MAPSS model with a modified version of the biogeochemical model, CENTURY. MC1 also includes a fire module, MCFIRE, that mechanistically simulates the occurrence and impacts of fire events.

Keywords: MC1, model documentation, vegetation response, climate change, MAPSS, CENTURY, dynamic global vegetation model.

Contents

Blank Page

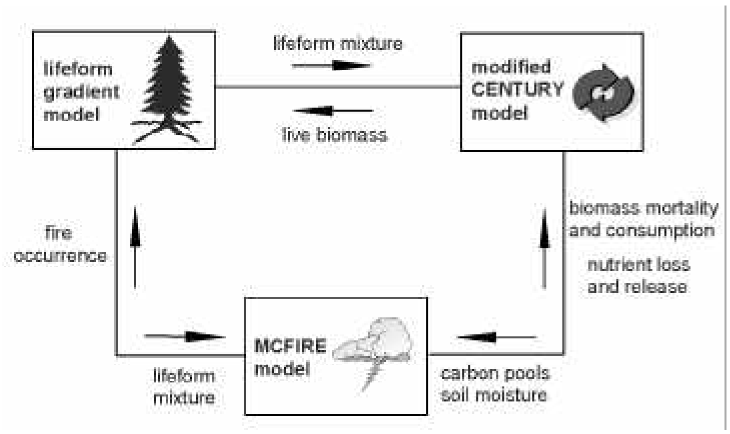


Figure 1—Simplified diagram of MC1. The biogeographic module includes a lifeform “interpreter” that defines four tree lifeforms: deciduous needleleaf (DN), evergreen needleleaf (EN), deciduous broadleaf (DB), and evergreen broadleaf (EB). Two grass lifeforms are included as a function of climate. When the minimum monthly (coldest month) mean temperature (MMT) drops below -15 °C, trees are assumed to be needleleaved; when it is above 18 °C, trees are assumed to be evergreen broadleaved. The relative mixture of tree lifeform also depends on precipitation during the growing season (GSP). The biogeographic module also includes vegetation classification rules that use thresholds of maximum monthly tree and grass LAI (numbers on arrows) to distinguish forest, savanna, shrubland and grassland classes. Specific classes are then determined by the lifeform mixes provided by the lifeform interpreter and a few climatic indices. The biogeochemical module is based on CENTURY (Parton and others 1987) and includes grass and tree live compartments. It includes litter pools and soil organic matter pools. Nitrogen and water fluxes are calculated to modify potential production. Information from the vegetation classifier is used to determine which parameter values are appropriate. The fire module uses information from the biogeochemical module to calculate fuel loading and climatic information to calculate fuel moisture. It uses information from the lifeform interpreter to choose allometric relations for calculating crown and surface fire behavior. Postfire mortality information is used by the biogeochemical module to reduce live plant pools.

1. Introduction

MC1 is a new dynamic vegetation model created to assess the impacts of global climate change on ecosystem structure and function at a wide range of spatial scales from landscape to global. MC1 was conceived at the beginning of the second phase of the Vegetation/Ecosystem Modeling and Analysis Project (VEMAP). The first phase of VEMAP consisted of a comparison of three biogeographic models (BIOME2 [Haxeltine and others 1996, Prentice and others 1992], DOLY [Woodward and others 1995]), and MAPSS ([Neilson 1995]) and three biogeochemical models (CENTURY [Parton and others 1987], BIOME-BGC [Running and Coughlan 1988, Running and Gower 1991], and TEM [McGuire and others 1995]) to determine their responses to climate and carbon dioxide (CO_2) change (VEMAP Members 1995). The goal was to identify areas of uncertainty in the six models and to increase our knowledge of ecological responses to altered forcing. The objectives of the second phase included comparing the same biogeochemical models and newly created coupled biogeographic-biogeochemical models, such as MC1.

Table 1—Interactions among the 3 modules in MC1 and information passed to and from each module

	Passed to:		
Passed from:	**Biogeography**	**Biogeochemistry**	**Fire**
Biogeography		Position along lifeform gradients (which determines the phenology), interpolation between lifeform-specific standard CENTURY parameters	Lifeforms (tree leaf type and used in allometric equations)
Biogeochemistry	Tree and grass leaf carbon		Aboveground carbon pools Turnover and decomposition rates from the carbon pools The value of the index that modifies primary production as a function of available soil moisture
Fire	LAI and climate smoothing period is reset to 0 after the occurrence of a fire	Consumption of dead aboveground carbon, associated with losses by gaseous emissions Nutrient return, calculated as a fraction of the biomass consumed	

MC1 was produced by combining physiologically based biogeographic rules, originally defined in the MAPSS model (Neilson 1995), with biogeochemical processes packaged in a modified version of CENTURY (Parton and others 1987) and a new fire disturbance model, MCFIRE (Lenihan and others 1998). The three linked modules simulating biogeography (lifeform interpreter and vegetation classifier), biogeochemistry, and fire disturbance are represented in figure 1 and their interactions are described in table 1.

The main functions of the biogeographic module (section 3.1) are to (1) predict lifeforms, that is, the composition of deciduous-evergreen tree and C3-C4 grass lifeform mixtures; and (2) classify those lifeforms and their associated biomass into different vegetation classes using a climatologic rule base.

The biogeochemical module (section 3.2) simulates monthly carbon (C) and nutrient dynamics for a given ecosystem. Aboveground and belowground processes are modeled in detail and include plant production, soil organic matter decomposition, and water and nutrient cycling. Parameterization of this module is based on the lifeform composition of the ecosystems, which is updated annually by the biogeographic module.

The fire module (section 3.3) simulates the occurrence, behavior, and effects of severe fire. Allometric equations, keyed to the lifeform composition supplied by the biogeographic module, are used to convert aboveground biomass to fuel classes. Fire effects (plant mortality and live and dead biomass consumption) are estimated as a function of simulated fire behavior (fire spread and fire line intensity) and vegetation structure. Fire effects feed back to the biogeochemical module to adjust levels of various C and nutrient pools and alter vegetation structure (e.g., leaf area index [LAI] levels and woody vs. grass-dominated vegetation; table 1).

2. Model Environment

2.1 Mode of Operation

2.1.1 Equilibrium mode—MC1 is operated in two successive modes: equilibrium and transient (fig. 2). First, the biogeochemical module requires an initial vegetation class for parameterization. This initial vegetation map is provided by MAPSS, an equilibrium model with full water balance simulation and a detailed biogeographical rule base (Neilson 1995). MAPSS is run on long-term mean climate, which consists of 1 year of monthly climate data. MAPSS requires two parameter files: `site`, which includes the soil characteristic thresholds used in the water balance module; and `parameter`, which includes climatic thresholds used in the biogeographic rules. (Parameter files are reviewed in detail in section 4.)

For each vegetation type, the biogeochemical module selects the respective parameters and initial condition files. These consists of (1) the schedule files (`vvegTypex.sch`) where grass and tree types are defined and where fire events are scheduled; (2) the site files (`xfix.100`), which include most of the site characteristics, such as the rates of nitrogen (N) loss, and (3) the parameter files (`vvegTypex.100`), which include initial conditions for soil organic matter and mineral content. The biogeochemical module also reads the files `tree.100` and `crop.100`, which include the physiological parameters used in the C, N, and water cycles. The biogeochemical module runs on the same mean climate until the slow soil C pool (see section 3.2.2.) reaches a steady state. This takes 200 to 3,000 simulation years, depending on the ecosystem being simulated. Because the fire module cannot be run effectively on a mean climate, fire events are scheduled at regular intervals that differ with vegetation type. Grasslands and savannas are assigned 5- to 30-year intervals, and certain forests have fire intervals exceeding 400 years.

2.1.2 Transient mode—Once the vegetation type has been defined and the slow soil C pool has equilibrated, MC1 is run in transient mode on a monthly time step for a user-defined number of years to read the transient climatic data and produce estimates of C and nutrient pools for each simulated vegetation type.

Every year the biogeographic module uses climatic data (MC1 biogeographic thresholds are defined in the file `thres.dat`) and maximum tree and grass LAIs, which are derived from the biogeochemical module's standing biomass data and have been smoothed to reduce interannual variability. When a fire has occurred, the LAI smoothing period (defined in section 3.1.1) is set to zero, thus allowing the lifeform interpreter to predict a period of low cover vegetation following the fire. The appropriate lifeform composition is determined each year to start the next simulation year. The lifeform mixture is used by the fire module for allometric calculations and by the biogeochemical module to determine lifeform-dependent parameter values that are read from the files `tree.100` and `crop.100`.

The biogeochemical module uses climatic data and the vegetation type as defined by the biogeographic module to calculate C and N pools for each vegetation type and for soil water content. It reads tree and grass types from the transient schedule files (`Mapss-Cenx.sch`), soil characteristics from `vvegTypex.100`, physiological parameters from the files `tree.100` and `crop.100`, and some initial conditions from `xfix.100` files.

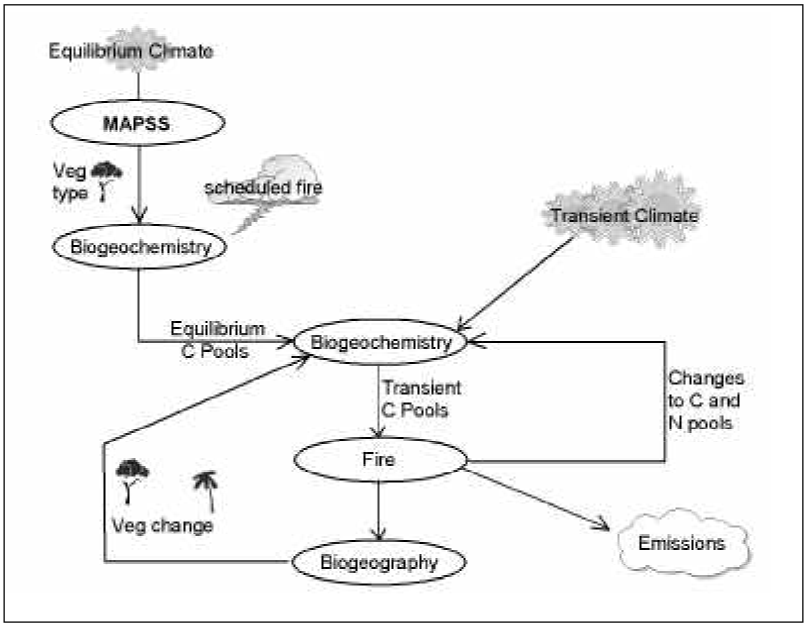


Figure 2—Operational flow of the MC1 model. MC1 is operated in two successive modes: equilibrium and transient. In equilibrium mode, the biogeochemistry module requires an initial vegetation class for parameterization. MAPSS (Neilson 1995) is run on long-term mean climate, which consists of one average year of monthly climate data (usually representing the most recent 30 years of record). The biogeochemistry module is then run on the MAPSS vegetation class by using the same mean climate until the slow soil carbon pool reaches a steady state. This takes 200 to 3000 years, depending on the ecosystem being simulated. Because the fire module cannot be run meaningfully on a mean climate, fire events are scheduled at regular intervals that differ with vegetation type. Grasslands and savannas are assigned 30-year intervals, and certain forests types have fire intervals exceeding 400 years. In transient mode, the biogeochemistry module operates on a monthly time step for a period of years, reading the transient climate data and producing estimates of monthly carbon and nutrient pools. The fire module accesses the same climate data and the biogeochemical carbon pools to estimate fuel load and fuel moisture, and maintains a running probability of fire occurrence. If that probability exceeds a certain threshold, a fire is simulated. The fire module then calculates changes to carbon and nutrient pools, which are passed back to the biogeochemistry module for use in the following month of operation. Emissions from the simulated fire also are calculated. Every year, the biogeography module uses climate data and maximum monthly tree and grass LAI (derived from standing biomass data from the biogeochemistry module) that have been smoothed to reduce interannual variability. When a fire has occurred, the LAI smoothing period is reset to zero, thus allowing the vegetation classifier to simulate a period of low cover vegetation after the fire. Vegetation classification is thus allowed to proceed through a series of successional stages, for example from grassland, to savanna to forest. The appropriate lifeform composition is determined each year to start the next simulation year. The lifeform mixture is used by the fire module for allometric calculations, and by the biogeochemistry module to determine lifeform-dependent parameter values.

Table 2—Resolution and extent of the 3 different spatial scales

Item	Wind Cave	United States	Global
No. of rows, columns	50, 100	48, 115	56, 96
Resolution	50 meters	0.5 lat. x long.	2.75 x 3.5 lat. x long.
Number of cells	5,000	3,261	1,631

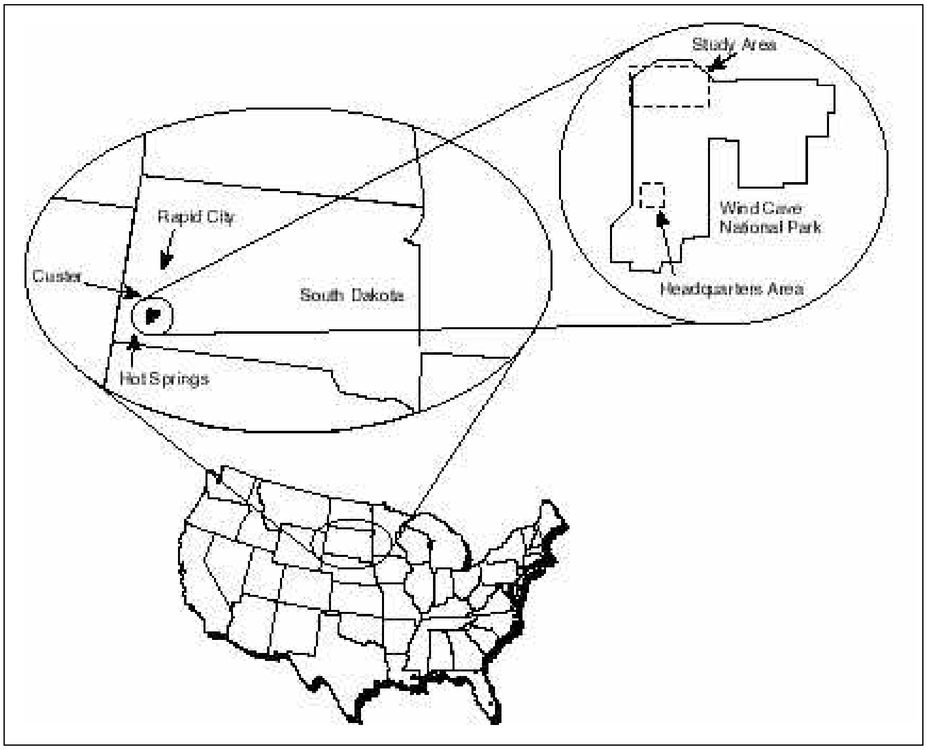


Figure 3—Location of the study site at Wind Cave National Park, South Dakota.

The fire module accesses the same climatic data and the biogeochemical C pools to estimate fuel load and fuel moisture, and it maintains a running probability of fire occurrence. A fire is simulated when thresholds defined in `fire_param.dat` are exceeded. The fire module then calculates changes to C and nutrient pools. These are passed back to the biogeochemical module, which uses them in the following month of operation. Carbon emissions from the simulated fire also are calculated.

2.2 Spatial Scales

To date, MC1 has been run at three different spatial scales (local, national, and global) based on the availability of climatic and soil data at these scales. Table 2 summarizes the resolution and extent of the three different scales. The model was first used at Wind Cave National Park, South Dakota, to study the potential impacts of climate change on the forest-grassland ecotone in the park. It was then run on a global scale in an international comparison effort. Finally, it was run over the conterminous United States for VEMAP. Figure 3 shows the location of the Wind Cave study area. Input data for each of these runs are discussed in the following section.

Table 3—Information on the climate datasets and atmospheric CO_2 concentrations used at each of the 3 spatial scales

Item	Wind Cave	United States	Global
Equilibrium model	Long-term average	1895-1994 average $[CO_2]$[a] = 294.8 ppm	Long–term average $[CO_2]$ = 288.75 ppm
Transient mode:			
Spinup[b]	100 years	1895-1993 detrended $[CO_2]$ = 294.8 ppm	8 x (1931-1960) until NEP = 0 constant $[CO_2]$ = 288.75 ppm
Historical	1895-1994	1895-1993 variable $[CO_2]$	1861-1995 variable $[CO_2]$
Future	Hadley 1995-2094 (uses 200 years for spinup)	HADCM2SUL 1994-2099 variable $[CO_2]$ CGCM1 1994-2100 variable $[CO_2]$	HADCM2SUL 1861-2199 variable $[CO_2]$

[a] $[CO_2]$ = atmospheric carbon dioxide concentration.
[b] Spinup = time it takes for the model to reach reasonable fire frequencies in transient mode.

2.3 Input Data

MC1 requires a gridded, monthly climatic dataset of precipitation (millimeters), mean minimum and maximum temperature (°C), vapor pressure (Pascals), wind speed (ms^{-1}), and solar radiation ($K\ J\ m^{-2}\ day^{-1}$). It also requires gridded maps of soil texture (percentage of sand, silt, and clay), rock fraction (percentage), and depth to bedrock (millimeters). Methods used to develop these datasets incorporated the effects of elevation and topographic exposure on local climate and the relations among landform type, soil depth, and texture.

2.3.1 Climate—Detailed information on the climatic datasets used for each of the three spatial scales is presented in table 3.

Preparation of climatic input data for the Wind Cave study area is discussed in detail in Daly and others (2000) and Bachelet and others (2001).

Historical climatic data and future climate change scenarios for the conterminous United States were produced by the VEMAP Data Analysis Group for the VEMAP project. An overview of the dataset can be found in `http://www.cgd.ucar.edu/vemap` and in Kittel and others (1995, 1997).

The global climate dataset was provided by Wolfgang Cramer from the Potsdam Institute for Climate Impact Research in Potsdam, Germany. This database was developed from the Leemans and Cramer database (Leemans and Cramer 1991) and contains monthly averages of mean temperature, temperature range, precipitation, rain days, and sunshine hours for the land surface of Earth. More detail concerning this database can be found in `http://www.pik-potsdam.de/~cramer/climate.htm`. Wind and vapor pressure datasets were created by Ray Drapek from 0.5 global data (from International Institute for Applied Systems Analysis data, `http//www.iiasa.ac.at`) and were rescaled for the global grid.

In addition to climatic data, the fire module requires the vegetation class provided by the biogeographic rule base, and the aboveground live and dead biomass and soil moisture provided by the biogeochemical module. Fuel moisture and fire behavior are modeled at a daily time step in the fire module, so the monthly values of the climatic data are used to generate pseudo-daily data. For temperature and relative humidity, daily data are generated by simple linear interpolation between monthly values. For precipitation, the monthly totals are divided by the number of rainfall events in each month, and these pseudo-daily values are randomly assigned to days within each month. The number of rainfall events in each month is estimated using a regression function derived from weather station data archived by the National Climate Data Center (WeatherDisc Associates 1995).

2.3.2 Soil—Preparation of soils input data for the Wind Cave study area is discussed in greater detail in Daly and others (2000) and Bachelet and others (2001).

Soils data at the national scale came from national soil geographic (NATSGO) datasets (Kern 1995), which are composed of information collected every 5 years as part of the National Resources Inventory conducted by USDA Natural Resource Conservation Service (NRCS) (Soil Conservation Service 1987). A review of these data can be found in Bachelet and others (1998). The data were later modified for VEMAP (Kittel and others 1995). For global simulations, soil data were obtained from the soil map of the world (Food and Agricultural Organization 1974-79).

3. Model Description

3.1 Biogeography

The biogeographic module predicts spatial and temporal shifts in the relative dominance of individual lifeforms and changes in vegetation classification. The method used was originally derived from the physiologically based biogeographic rules defined in the MAPSS model (Neilson 1995). However, the biogeography module in MC1 has evolved to more explicitly represent lifeform mixtures along dynamic environmental gradients using site production information. The heart of the biogeographic module is a lifeform interpreter (figs. 4 and 5), which delineates continuous gradients of deciduous-evergreen trees and C3-C4 grass lifeform mixtures as a function of climate. Information from the lifeform interpreter (1) forms the basis for categorizing model output vegetation into 21 classes as defined by the VEMAP (VEMAP Members 1995) and (2) allows for dynamic parameterization of the biogeochemistry module (fig. 5). The lifeform interpreter and vegetation classification rule base are presented in this section. Dynamic parameterization is discussed in section 4.2.

3.1.1 Delayed response—The lifeform interpreter distinguishes four tree lifeforms (deciduous needleleaf [DN], evergreen needleleaf [EN], deciduous broadleaf [DB], and evergreen broadleaf [EB]) and two grass lifeforms (C3 and C4) as a function of climate. Shrubs are not explicitly simulated but are considered short-stature trees. Monthly temperature and precipitation data drive the annual lifeform simulations, which are made on an annual time step. Climatic data are smoothed before they are used by the interpreter to reduce interannual variability in lifeform changes and to reflect the

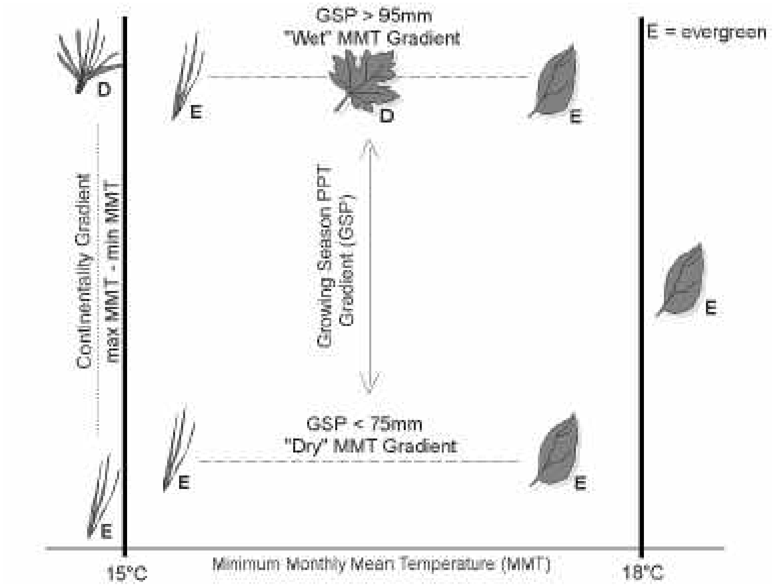


Figure 4—Determination of tree lifeform composition. Trees are assumed to be needleleaved when the minimum (coldest month) monthly mean temperature (MMT) drops below -15 °C, which generally corresponds to daily temperatures at which most temperate broadleaf trees exhibit supercooled intracellular freezing (-41 °C to -47 °C) as calculated by Prentice et al. (1992) and used by Lenihan and Neilson (1993) and Neilson (1995). Within the needleleaved zone, the relative dominance of DN vs EN lifeforms is determined by the value of a continentality index defined as the difference between the minimum and maximum MMT. When the minimum MMT is above 18 °C, trees are assumed to be EB. This corresponds to an area of no seasonal frost, following Neilson (1995). Between the minimum MMTs of -15 °C and 18 °C, the relative mixture of the EN, DB, and EB lifeforms is determined by both the growing season precipitation (GSP) and the minimum MMT. The GSP is calculated as the mean monthly precipitation for the three warmest months of the year (month of warmest temperature of the year, averaged with the month before and the month after). This index was originally used by Lenihan and Neilson (1993) and Neilson (1995) to separate broadleaf forests from needleleaf forests, the latter being favored by dry summers. Above a GSP threshold of 95 mm (e.g., Eastern United States) the relative mixture of lifeforms is defined by the value of a “wet” minimum MMT index. A pure DB lifeform occurs at a minimum MMT of 1.5 °C. A mixture of lifeforms is linearly interpolated at minimum MMTs between 1.5 °C and -15 °C (EN-DB mix) and between 1.5 °C and 18 °C (DB-EB mix). When the GSP is below 75 mm (e.g, Western United States), there is no transition through DB lifeforms and the relative mixture of the EN and EB lifeforms is interpolated along a “dry” minimum MMT gradient. When the GSP falls between 75 and 95 mm, a linearly interpolated mixture of both wet and dry lifeform gradients is calculated.

physiological lags inherent to plant population dynamics. Each monthly temperature and precipitation value is smoothed by calculating a running mean of an exponential response curve of the form:

$$y_t = x_t\,(e^{-1\,\tau}) + y_{t-1}\,[1 - (e^{-1\,\tau})]\,, \tag{1}$$

where x_t and y_t are the current month’s unsmoothed and smoothed climate data values, respectively, y_{t-1} is that month’s smoothed value calculated for the previous year, and τ

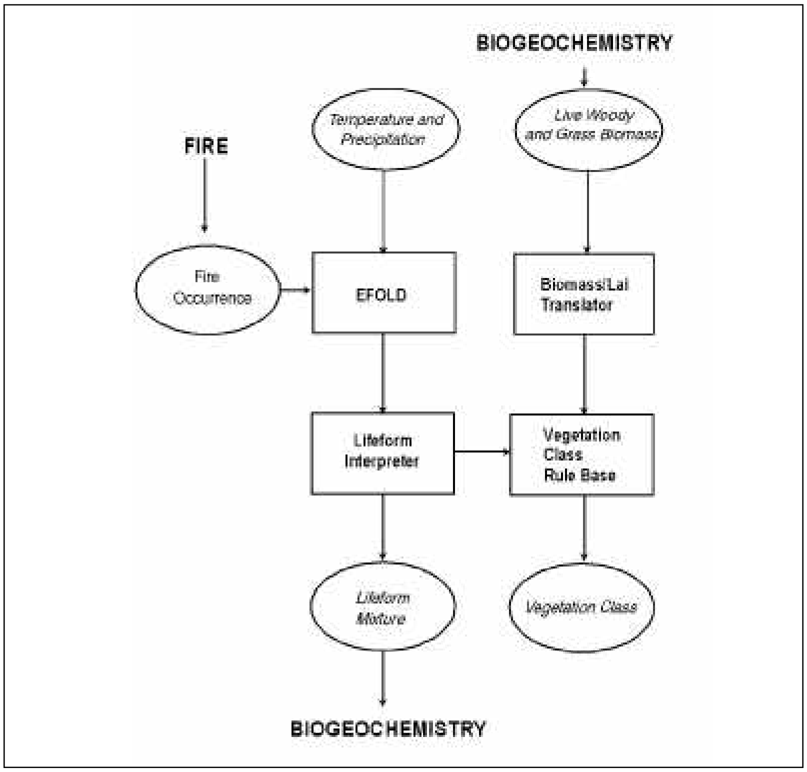


Figure 5—Schematic of the biogeographic module. Monthly temperature and precipitation data drive the lifeform simulations, which are made on an annual time step. The climatic data are smoothed before they are used by the interpreter to reduce interannual variability in lifeform changes and reflect the lags inherent to plant population dynamics. Thresholds of maximum monthly tree and grass LAI are used to distinguish forest, savanna, shrubland, and grassland vegetation classes. The LAI is calculated from leaf carbon in the biogeochemistry module using the standard CENTURY equations. Once the vegetation has been assigned an LAI-based class, specific classes are determined by the lifeform mixes calculated by the lifeform interpreter and other rules. The fire module calculates changes to carbon and nutrient pools. Fire-caused changes in carbon affect the LAI values, which are passed to the biogeography module to help determine vegetation type. The LAI values are smoothed using the same function used for smoothing the climatic values. The occurrence of a fire resets the smoothing period to zero, which allows the biogeography rules to predict an open canopy vegetation type for a few years after a simulated fire.

is the smoothing period in years. With each simulated fire event, τ is reset to zero, then raised incrementally each year (equally for all lifeforms) until the next fire event occurs. This procedure mimics the sensitivity of lifeform establishment to climate soon after disturbance and the increase in inertia of lifeform composition with greater stand maturity.

3.1.2 Lifeform interpreter—Tree lifeforms are distinguished by leaf phenology (evergreen versus deciduous) and leaf shape (needleleaf versus broadleaf) (fig. 4). An environmental gradient algorithm was developed to predict the relative dominance of tree lifeforms and is based on the observed distribution of lifeform mixtures along temperature and precipitation gradients across North America.

Table 4—Lifeform classes used in the biogeographical module[a]

Item	Lifeform mixture	Threshold variable	Value
Boreal gradient, trees	DN-DN/EN	Max. - Min. MMT[b] (°C)	60
	DN/EN-EN	Max. - Min. MMT (°C)	55
Temperate and wet gradient, trees	EN-EN/DB	Minimum MMT (°C)	-15
	Pure DB	Minimum MMT (°C)	1.5
	DB/EB- EB	Minimum MMT (°C)	18
Temperate and dry gradient, trees	EN - EN/EB	Minimum MMT (°C)	1.5
	EN/EB - EB	Minimum MMT (°C)	18
C3-C4 gradient, grasses	C3 - C3/C4	Percentage C3 dominance	66
	C3/C4 - C4	Percentage C3 dominance	33

[a] DN = deciduous needleleaf, EN = evergreen needleleaf, DB = deciduous broadleaf, EB = evergreen broadleaf.

[b] MMT = mean monthly temperature.

At high latitudes, heat-limited lifeforms are determined through a total annual growing-degree-day (GDD) index base (base 0 °C). Thresholds are GDD < 50 for permanent ice, 50 < GDD < 735 for tundra, and 735 < GDD < 1330 for taiga.

Trees are assumed to be needleleaved when the minimum (coldest month) monthly mean temperature (MMT) drops below -15 °C (fig. 4). This generally corresponds to daily temperatures at which most temperate broadleaf trees exhibit supercooled intracellular freezing (-47 °C to -41 °C) as calculated by Prentice and others (1992) and used by Lenihan and Neilson (1993) and Neilson (1995) (table 4). Within the needleleaved zone, the relative dominance of the deciduous versus evergreen needleleaf lifeforms is determined by the value of a “continentality” index (CI), defined as the difference between the minimum and maximum MMT (table 4).

When the minimum MMT is above 18 °C, trees are assumed to be broadleaf evergreen. This corresponds to an area of no seasonal frost, which follows the logic of Neilson (1995) for identifying a broadleaf evergreen zone. Between the minimum MMT of -15 and 18 °C, the relative mixture of the EN, DB, and EB lifeforms is determined by both the growing season precipitation (GSP) and the minimum MMT (fig. 4, table 4). The GSP is calculated as the mean monthly precipitation for the three warmest months of the year (month of warmest temperature of the year, averaged with the month before and the month after). This index was originally used by Lenihan and Neilson (1993) and Neilson (1995) to separate broadleaf forests from needleleaf forests, which grow better in dry summers. Above a GSP threshold of 55 millimeters (such as in the Eastern United States), the relative mixture of the lifeforms is defined by the value of a “wet” minimum MMT index. The EN lifeforms dominate below a minimum MMT of -15 °C, DB lifeforms dominate around 1.5 °C, and EB lifeforms dominate above 18 °C. A mixture of lifeforms is linearly interpolated at minimum MMTs between -15 and 1.5 °C (EN-DB mix) and between 1.5 and 18 °C (DB-EB mix) (table 4). When the GSP is below 55 mm (such as in the Western United States), there is no transition through DB lifeforms, and the relative mixture of the EN and EB lifeforms is interpolated along a “dry” minimum MMT gradient (table 4). When the GSP falls to between 50 and 55 millimeters, a linearly interpolated mixture of both wet and dry lifeform gradients is calculated.

Table 5—VEMAP vegetation classes in MC1

Number	Class
1	Tundra
2	Boreal coniferous forest
3	Maritime temperate coniferous forest
4	Continental temperate coniferous forest
5	Cool temperate mixed forest
6	Warm temperate mixed forest
7	Temperate deciduous forest
8	Tropical deciduous forest
9	Tropical evergreen forest
10	Temperate mixed xeromorphic woodland
11	Temperate conifer xeromorphic woodland
12	Tropical thorn woodland
13	Temperate subtropical deciduous savanna
14	Warm temperate subtropical mixed savanna
15	Temperate conifer savanna
16	Tropical deciduous savanna
17	C3 grasslands
18	C4 grasslands
19	Mediterranean shrubland
20	Temperate arid shrubland
21	Subtropical arid shrubland
22	Taiga (not VEMAP but MC1 specific)
23	Boreal larch forest (not VEMAP but MC1 specific)

The relative dominance of C3 and C4 grasses is predicted by using functions extracted from CENTURY (Parton and others 1987, 1994) that simulate the potential production of pure C3 and pure C4 grass stands from July soil temperature. Soil temperature is estimated from a running average of daily air temperatures interpolated from the monthly mean temperature values. The ratio of C3 potential production to the sum of C3 and C4 potential production (calculated independently of each other) for the site is used to determine the relative dominance of C3 grasses (table 4).

3.1.3 Vegetation classification rule base—MC1 uses a rule-based approach to simulate the distribution of the 21 different vegetation classes (table 5) defined by VEMAP (VEMAP Members 1995). Thresholds of maximum monthly tree and grass LAI (one sided) are used to distinguish the forest, savanna, shrubland, and grassland classes (fig. 6). LAI is calculated from leaf carbon in the biogeochemical module by using the standard CENTURY equations (Parton and others 1987, 1994). Vegetation is considered forest at tree LAI $\geq$ 3.75 and savanna at tree LAI of 2 to 3.75. At tree LAI of 1 to 2, vegetation is classified as shrubland if grass LAI < 1, and as grassland if grass LAI $\geq$ 1 (fig. 6). Vegetation is considered grassland if tree LAI < 1. Shrubs are not explicitly simulated but are considered short-stature trees.

Once the vegetation has been assigned an LAI-based class, specific classes are determined by the lifeform mixes calculated from the lifeform interpreter and other rules. For example, a savanna with an EN lifeform is classified as a temperate coniferous savanna (TCS) (fig. 6). A continentality index threshold of 15 is used to distinguish maritime temperate coniferous forest (MTCF) from continental temperate coniferous forest (CTCF), when the lifeform mixture is EN, DN, or an EN-DN mixture and the

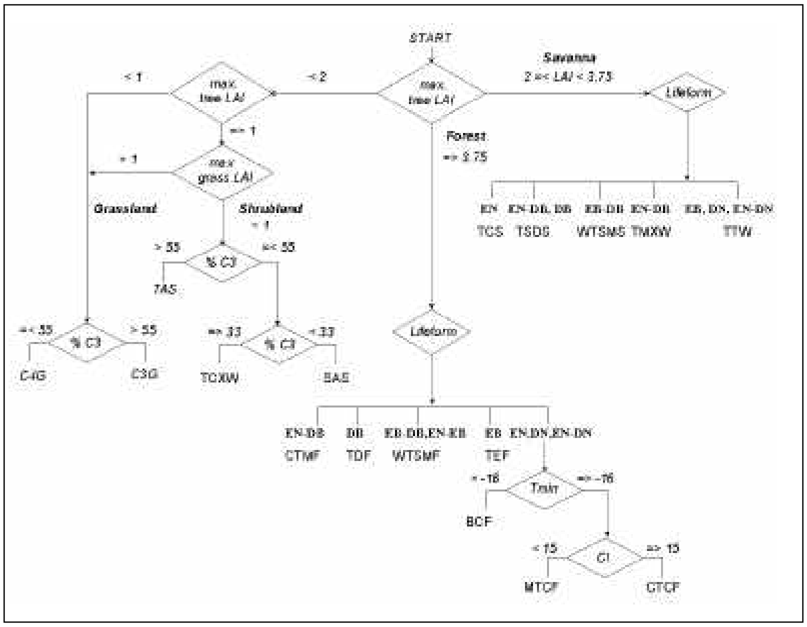


Figure 6—Schematic of the vegetation classification rule base. Thresholds of maximum monthly tree LAI separate shrublands (1 < LAI < 2), savannas (2 < LAI < 3.75), and forests (LAI > 3.75). Climatic thresholds are used to determine the lifeform associated with each LAI range. Below a tree LAI of 1, the vegetation is restricted to grasslands. **Tmin** = minimum MMT; **CI** = continentality index (difference between the minimum and maximum MMT); **E** = evergreen; **D** = deciduous; **N** = needleleaf; **B** = broadleaf; **LAI** = leaf area index; **% C3** = relative dominance of C3 grasses; **C4G** = C4 grasslands; **C3G** = C3 grasslands; **TCXW** = temperate conifer xeromorphic woodland; **SAS** = subtropical arid shrubland; **TAS** = temperate arid shrubland; **CTMF** = cool temperate mixed forest; **TDF** = temperate deciduous forest; **WTSMF** = warm temperate subtropical mixed forest; **TEF** = tropical evergreen forest; **BCF** = boreal coniferous forest; **MTCF** = maritime coniferous forest; **CTCF** = continental temperate coniferous forest; **TCS** = temperate conifer savanna; **TSDS** = temperate subtropical deciduous savanna; **WTSMS** = warm temperate subtropical mixed savanna; **TMXW** = temperate mixed xeromorphic woodland; and **TTW** = tropical thorn woodland.

minimum MMT $\geq$ 16 °C (fig. 6). A minimum MMT < 16 °C puts the forest into the boreal coniferous forest (BCF) class.

The percentage of C3 grasses determines several vegetation classes. Within the shrubland LAI class, the vegetation is classed as temperate arid shrubland (TAS) if the relative composition of C3 grasses is greater than 55 percent. A relative C3 composition of 33 to 55 percent is classified as temperate conifer zeromorphic woodland (TCXW), and < 33 percent C3 becomes subtropical arid shrubland (SAS). Within the grassland LAI class, a relative composition of C3 grasses > 55 percent is classed as C3 grasslands (C3G); 55 percent is classified as C4 grasslands (C4G).

In VEMAP phase 2, vegetation classes were aggregated to facilitate the comparison between model output. Table 6 summarizes the criteria used to define the aggregated classes.

Table 6—Aggregated VEMAP phase 2 vegetation classes with criteria for defining

VEMAP aggregated vegetation types	Criteria for defining[a]
Coniferous forests	Tree types 1 (EN), 7 (DN) and 8 (DN-EN)
Winter deciduous forests	Tree type 3 (DB)
Mixed conifer-broadleaved forests	Tree types (EN-DB, EB, DB-EB and EN-DB)
Broadleaved evergreen drought-deciduous forests	Zone 3 (tropical)
Savannas and woodlands	Tree LAI >= savanna threshold (3.75)
Grasslands and shrublands	
Deserts	Live vegetation C < 600 g

[a] EN = evergreen needleleaf, DN = deciduous needleleaf, DB = deciduous broadleaf, EB = evergreen broadleaf.

3.2 Biogeochemistry

The biogeochemical module consists of a modified version of CENTURY (Parton and others 1987). It simulates monthly carbon and nutrient dynamics for a combined grass and tree ecosystem (CENTURY's savanna mode only). The model includes live shoots (leaves, branches, stems), roots (fine and coarse), and standing dead material (fig. 7). It includes perhaps the most detailed representation of soil processes among current regional and global biogeochemical models and has been tested extensively across the globe for terrestrial systems (Parton and others 1994). Modifications made to CENTURY to build MC1 include a Beer's Law tree and grass shading algorithm, changes to tree and grass vertical root distributions, and the generalization of input parameter sets. These changes are discussed in greater detail in section 3.2.5.

3.2.1 Net primary production—Tree production and grass production are functions of a maximum potential rate modified by scalars representing the effect of soil temperature and soil moisture on growth. For forests, total production, P_t, is calculated as:

$$P_t = P_{tg} * k_t * k_m * k_l \ , \tag{2}$$

where P_{tg} is gross tree production (lifeform specific input), k_t and k_m are coefficients that represent the effect of soil temperature and moisture, respectively, on growth, and k_l is a coefficient relating aboveground wood production to leaf area index.

For grasses, total production P_g is calculated as:

$$P_g = P_{gg} * k_t * k_m * k_b * k_s \ , \tag{3}$$

where P_{gg} is gross grass production (lifeform specific input), k_b is a coefficient that represents the effect of the live-to-dead biomass ratio on growth, and k_s is a coefficient that represents the effect of shading by trees. We have replaced CENTURY's original light competition function by the Beer's Law formulation in the calculation of k_s (Jarvis and Leverenz 1983).

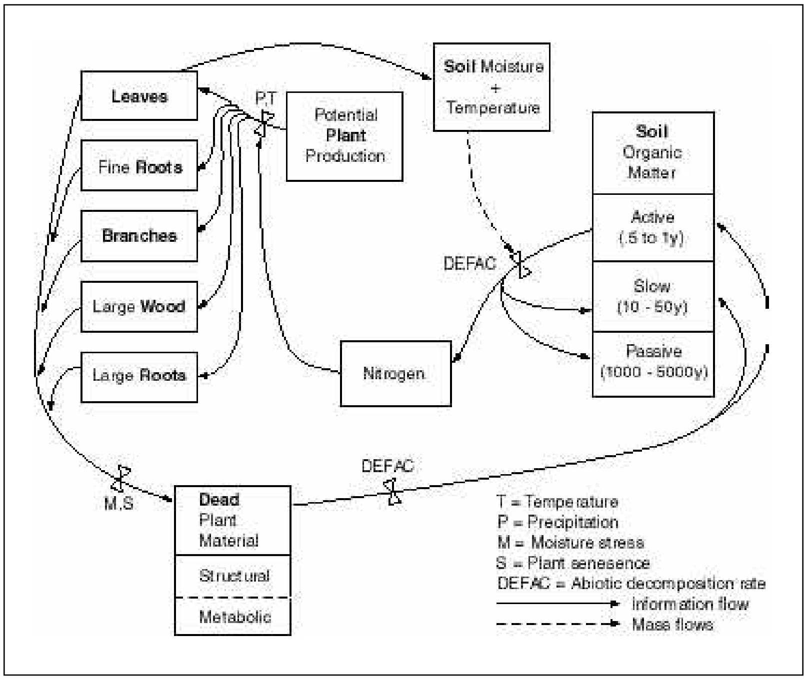


Figure 7—Schematic of the biogeochemical module for a woody lifeform (adapted from Gilmanov and others 1997). Potential plant production is calculated for each lifeform as a function of temperature (T), soil water (P), and nitrogen availability. Live biomass includes leaves, branches (fine and trunk), and roots (fine and coarse). Grasses are represented only by leaf and root carbon pools. Aboveground and belowground plant parts become senescent as a function of time, drought, and cold stress. Dead leaves and branches accumulate in a surface litter pool, where they are transformed into more slowly decomposing organic carbon. Dead roots accumulate in a belowground litter pool that constitutes the active soil organic matter pool. Decomposition transforms active soil carbon into slow and finally passive carbon material. The various soil organic matter pools differ by their turnover times.

The model also includes the effects of documented changes in atmospheric CO_2 (Metherall and others 1993: 3-38). For both trees and grasses, total potential production is enhanced by a coefficient (k_{CO2}) of atmospheric CO_2 concentration, which equals 1.25 when CO_2 concentration reaches 700 ppm. A similar coefficient used on potential transpiration rate equals 0.75 when CO_2 concentration reaches 700 ppm. The effect of elevated CO_2 on C:N ratios is similarly modeled with a $k_{CO2}=1.25$. We assume a linear relation between CO_2 concentration and its effect on plants.

The production coefficient for soil moisture, k_m is defined as:

$$k_m = (M_s + M_p) / PET \ , \tag{4}$$

where M_s is the water available in the soil profile, M_p is monthly precipitation, and PET is potential evapotranspiration.

The number of soil layers (nlaypg) assumed to contain the water necessary for plant growth (M_s) differs among vegetation types (fig. 8). The total number of soil layers (nlayer) differs as a function of soil depth and is one of the site-specific model inputs. Available soil water is accumulated in the surface soil layers (nlaypg) for grasses and in the entire soil profile (nlayer) for trees (fig. 8). The difference in available soil water between grasses and trees corresponds to deep soil water reserves assumed to be accessible only to deep tree roots. This is a modification of the CENTURY configuration,

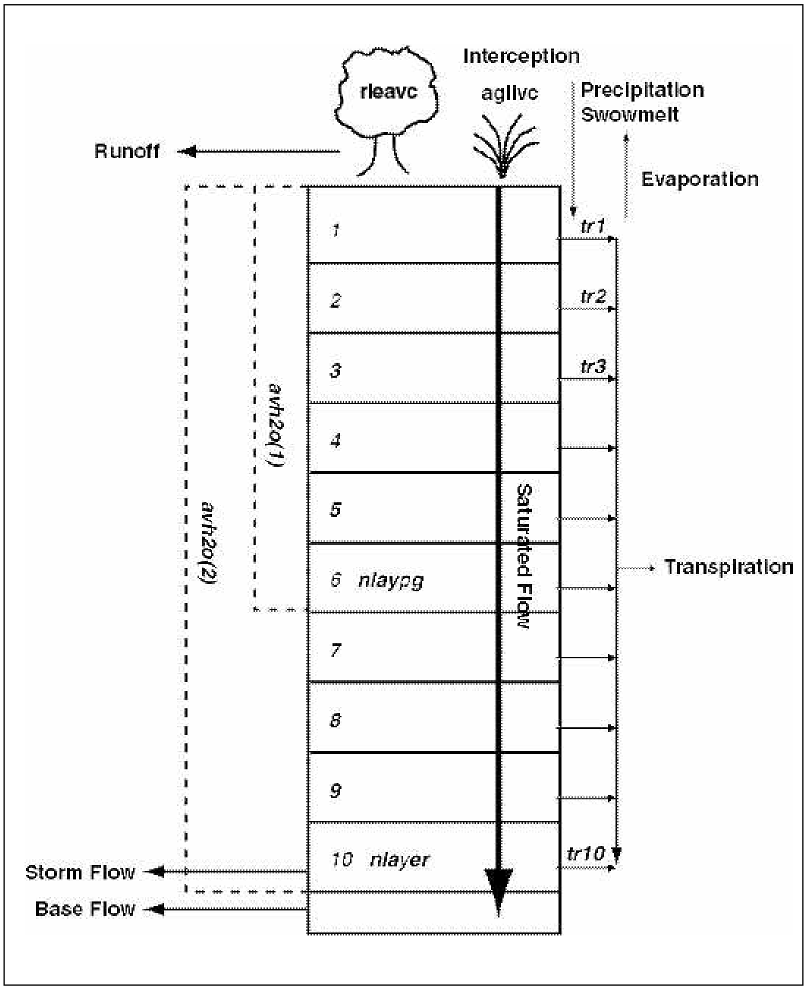


Figure 8—Hydrologic structure in the biogeochemistry module. Rainfall is intercepted by the lifeform canopy. Interception and bare soil evaporation are calculated as a function of leaf biomass, litter, and standing dead material. Runoff is calculated as a fraction of precipitation. Water infiltrates the soil by saturated flow only. Soil depth (nlayer) is an input to the model. The rooted soil layers are identified as nlaypg, and their depth depends on the vegetation type. Transpiration is calculated for each rooted soil layer as a function of potential evapotranspiration, leaf biomass, and rainfall. Stormflow is calculated as 60 percent of the amount of water present in the bottom soil layer. An extra compartment holds the water that does not leave by stormflow or transpiration and is identified as baseflow.

which limited tree water access to the surface soil layers only. The sensitivity of the model to a change in the accessibility of soil moisture was tested by varying the soil layers available to trees and grasses for water uptake.

Finally, production is modified by yet another scalar that is a function of leaf N concentration. In MC1, we assumed no N limitation, such that the calculated N demand is always met (via the symbiotic N fixation flux). Atmospheric N input is a function of annual precipitation. Abiotic soil N fixation is a function of actual evapotranspiration and volatilization is a function of gross mineralization. The leaching rate is a constant read from the `xfix.100` files (see section 4.3.1.).

Further details, such as the shape of the *k* coefficients, can be found in the CENTURY documentation (Metherall and others 1993).

3.2.2 Decomposition—Shoot and root lifeform-specific maximum death rates are modified by functions of available soil water in the whole profile and the plant root zone, respectively. During senescence, shoot death rate is a fixed fraction of live biomass. Standing dead material is transferred to surface litter at a lifeform-specific fall rate. The structural fraction of surface litter and that of belowground litter are further separated into lignin and nonlignin (cellulose, nitrogen-rich compounds) compartments. Lignin-rich compounds decompose directly into the slow organic matter pool, and cellulose-rich compounds migrate through the surface or soil microbe (active soil organic matter pool) compartments first. Soil organic matter is divided into three major components: active, slow, and passive (fig. 7).

Active soil organic matter includes live soil microbes and their products and is assumed to turn over in a few months or years. The slow pool includes resistant plant material such as lignin and soil-stabilized plant and microbial material passed from the active pool. It is assumed to have a turnover time of 10 to 50 years. Passive soil C includes chemically and physically stabilized soil organic matter highly resistant to decomposition and with a turnover time of 1,000 to 5,000 years. Soil organic matter pools have C-to-N ratios that are functions of the mineral N pools. Soil texture affects the turnover rate of the active pool and the size of the flows from either active or slow pools entering the passive compartment. Decomposition of plant residues and soil organic matter is assumed to be performed by the microbiological flora and thus includes a calculation of the associated microbial respiration. Each soil C pool is characterized by a different maximum decomposition rate. That potential rate is then reduced by multiplicative functions of soil moisture (equation 4) and soil temperature.

3.2.3 Hydrology—Potential evapotranspiration (PET) is calculated as a function of average monthly maximum and minimum temperatures from the equations of Linacre (1977). Bare soil water evaporation and interception by the canopy are functions of aboveground biomass, rainfall, and PET. Surface runoff is calculated as 55 percent of monthly rainfall when rainfall exceeds 50 millimeters and 0 when rainfall falls below 50 millimeters. This is based on empirical analyses in Queensland, Australia (Probert and others 1995).

Canopy interception, bare soil water evaporation, and surface runoff are subtracted from monthly precipitation and snowmelt before being added to the top soil layer. Water is then distributed to the different layers by draining water above field capacity from the top layer to the next layer (fig. 8). Unsaturated flow is not simulated in version 1. Soil layers are 0.15 meter thick to a depth of 0.6 meter and 0.3 meter thick below it. The number of soil layers does not exceed 10. Field capacity and wilting point for the different soil layers are calculated as a function of bulk density, soil texture (inputs to the model), and organic matter content from Gupta and Larson's (1979) equations. Water leaching below this soil layer is accumulated and lost to base flow.

Potential transpiration (*PT*) is calculated last as a function of live leaf biomass, PET, and atmospheric CO_2 concentration. Surface evaporation is later subtracted from *PT*.

$$Tr = PT * (M_{s[layer]} * TDDF) / M_s \, , \tag{5}$$

where Tr is actual transpiration per layer, $M_{s[layer]}$ is water available per soil layer, and $TDDF$ is the transpiration depth distribution factor (variable name=awtl).

The sum of water losses to the atmosphere (evaporation, interception, transpiration) does not exceed the PET rate.

3.2.4 Competition for resources—Grasses and trees compete for light, water, and nitrogen. When tree biomass becomes large because of the abundance of available soil water (for example, high rainfall period with low evaporation potential), the model reduces grass growth by assuming a shading effect, which represents the competition for light between the tree canopy and the grass understory. In the hydrology submodel, the amount of water transpired by plants is calculated as a function of the total plant biomass. There is no lifeform-specific calculation of transpiration. Thus, competition for water between trees and grasses occurs through the indirect effect of soil water content on productivity. The production modifier increases for a given lifeform if deep soil water resources are available and if the roots of that lifeform are present at depth. If deep soil water resources are not available (dry soil profile) or both lifeforms are shallowly rooted, the growth modifier of both lifeforms is identical and proportional to the soil water content.

3.2.5 Changes to CENTURY code—Several subroutines not found in CENTURY (Parton and others 1987, 1994) were added to the biogeochemical module. Table 7 lists the new routines and descriptions of the operations they perform.

Some CENTURY subroutines were modified to create the MC1 biogeochemical module. Major modifications (detailed in table 8) include the formulation of drought deciduousness, the modification of the water effect on production (which separates trees from grasses), the equilibration of soil C at the start of the transient mode, the modification of fire effects with the fire module, the removal of N limitation, and the addition of Beer's Law.

Table 7—New subroutines in the biogeochemical module (not found in CENTURY)

Subroutines	Description
cen_init_climate	Changes the units of precipitation from millimeter to centimeter; associates new names with temperature
cen_init_lat	Takes the absolute value of latitude
cen_init_soils	Transforms sand and clay content into percentages; depth changed from millimeter to centimeter; nlayer is calculated here; calculates adep (soil depth of each layer modified by rock fragments)
cen_step	Retrieves climate and soils data from MAPSS; updates schedule file; calculates biogeography indices; includes what is left of readblk; updates fire index; year's end - changes in vegetation type, determines whether fires should happen
cropmix	Modifies CENTURY lifeform-dependent parameter values based on C3/C4 index
eq_test	Checks when som2c (the slow soil organic matter pool) reaches equilibrium
lacalc1	Calculates LAI as a function of leaves; original lacalc subroutine split into lacalc1 and lacalc2
lacalc2	Calculates LAI as a function of wood; also averages with lacalc1 LAI
scale	Finds an average between lifeform-dependent parameters
scale4	Finds an average between lifeform-dependent parameters (with 4 values)
stand_step	Standard CENTURY new file name
statein	Routine disburses CENTURY state variables into proper global variables
stateinit	Initializes all state variables to 0 and then calls statein()
stateout	Collects CENTURY state variables for pass to MAPSS
store_event	Stores scheduled events for use during 1-step operation
treemix	Calculates evergreen/deciduous and needleleaf/broadleaf indices and modifies CENTURY lifeform-dependent parameters
update_event	Overwrites existing events or adds new ones
update_sched	Moves this year's scheduled events from storage arrays into the working arrays
varsin	Distributes CENTURY output variables after pass from MAPSS
varsinit	Initializes CENTURY output variables, call varsin() to distribute 0s to global output variables
varsout	Collects CENTURY output variables for pass to MAPSS
veg_change	Subroutine called on January of 1st year or December of fire years
vetocen	Translates VEMAP vegetation classes into MAPSS vegetation classes
vetofix	Translates VEMAP vegetation classes into CENTURY fixed file names

Other modifications were minor adjustments to prevent mathematical errors that the compiler could not handle (such as negative C or N flows). Some modifications were required because MC1 is also run in transient mode (i.e., CO_2 is read only in transient; original site-specific parameters are not reread in transient mode). Some variable names were modified to adapt the fire module variables to CENTURY variables. Input and output (I/O) were required in subroutines that read in climate and soils data; these data first are read on the biogeography side in MC1 and then are used to create indices passed to the biogeochemical module. Finally, other I/O adjustments were necessary to handle the biogeographic indices now used to modify parameters that were site specific in CENTURY. Table 9 lists files that had minor modifications.

Table 8—Major revisions to CENTURY subroutines

Subroutine	Modification description
eachyr	Saturates the soil with N by using N-deposition (option 2)
extend	Creates new MC1 variables
frem	Fire module adaptation (defines fraction of trees removed by fire)
grem	Fire module adaptation (defines fraction of grasses removed by fire)
nutrlm	Saturates the soil with N using N-fixation (option 1)
potcrp	Uses Beer's Law to calculate shading modifier (sliding extinction coefficient k)
potcrp	Modifies the original curve for low tree LAI (savannas and shrublands); used to calculate the effect of water
potcrp, potfor	Zeros out production below temperature threshold; Tests sensitivity of the model to water availability between grasses and trees
potfor	Splits lacalc into lacalc1 and lacalc2, uses the mix index calculated on biogeographic side
pprdwc	Calibrates entire curve differently for trees vs. grasses to separate availability of water to the two lifeforms
stand_step	Equilibrium threshold when slow pool organic matter reaches equilibrium
treein	New parameter file structure
treein	Adds call to mix(), which determines if tree type should change to a mixed type
trees	Changes function (similar to LAI calculation in lacalc1)
wdeath	Phenology: deciduous tree leaf drop, no longer includes day length, modifies phenology for drought deciduousness, occurs only in tropical zones

Table 9—Minor modifications to CENTURY subroutines

Modification	Subtroutines affected
Transient vs. equilibrium	cen_init, detiv, readblk
Fire variable names	potcrop, potfor, wdeath
Climate input/output	cen_init, detiv
Soils input/output	sitein, cen_init, fixin
Biogeography input/output	cen_init
Miscellaneous input/output	cen_init, detiv, readblk, schedl, treein
Math errors	cutrtn, cycle, dedrem, dshoot, grem, growth, h2olos, killrt, leach, livrem, potcrp, potfor, savarp, simsom, wdeath

3.3 Fire

The fire disturbance module (Lenihan and others 1998) simulates fire occurrence, behavior, and effects (fig. 9). The module dynamically simulates fuel moisture as a function of the temperature, relative humidity, and precipitation data. Carbon stocks in the aboveground pools, supplied by the biogeochemical module, are used to dynamically simulate fuel loading, with the aid of allometric functions keyed to the current mixture of lifeforms predicted by the biogeographic module. The simulated fuel characteristics and climatic data are used to predict the behavior of surface fire, crown fire, and fire effects, the last including vegetation mortality, fuel consumption, nutrient loss, and fire emissions. Fire occurrence is simulated from thresholds of drought and the rate of fire spread. Fire occurrence influences the determination of the lifeform mixture by the biogeographic module, and fire behavior and effects impact biomass and nutrient levels in the biogeochemical module.

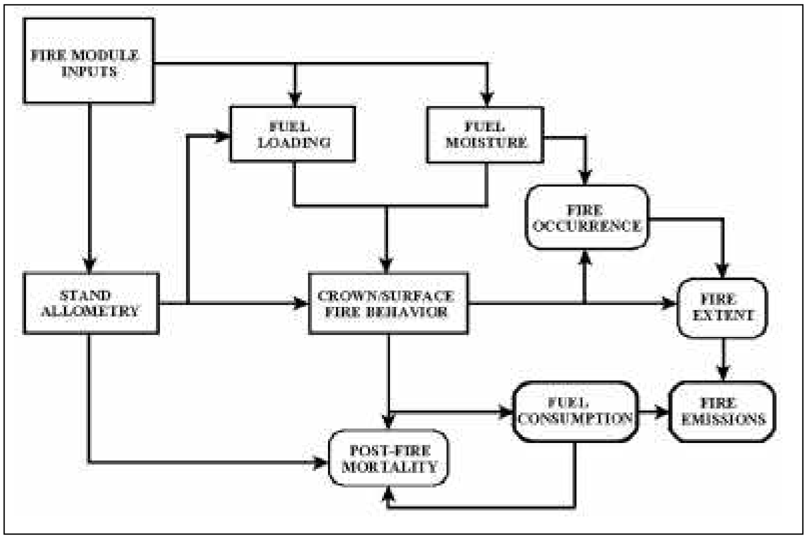


Figure 9—Flow diagram of the fire module. MCFIRE uses climatic (temperature, precipitation, relative humidity), biogeographic (vegetation classes) and biogeochemical (carbon pools and soil moisture) inputs to calculate fuel loading and fuel moisture. A set of lifeform-specific allometric equations is used to estimate average stand dimensions (i.e., height and bole diameter) from aboveground biomass. The stand dimensions are used in another set of allometric functions to allocate biomass into fuel load categories. Live fuel moisture is estimated from an index of plant water stress (Howard 1978). The index is a function of the percentage of soil moisture simulated by the hydrology algorithms in the biogeochemical module. The moisture contents of the four dead fuel classes are estimated by using the time-lag moisture calculations developed by Fosberg and others (Fosberg 1971, Fosberg and Deeming 1971, Fosberg and others 1981). Crown and surface fire behavior is simulated in MCFIRE as a function of fuel load, fuel moisture, and stand structure. Indices of fire behavior (e.g., fireline intensity, rate of spread, and the residence time of flaming and smoldering combustion) are used in the simulation of fire effects in terms of plant mortality and fuel consumption.

3.3.1 Fuel moisture and loading—Calculations of percentage of moisture are made for tree leaves and fine branches, grass leaves, and four size classes of dead fuel (e.g., 1-, 10-, 100-, and 1,000-hour fuels) (fig. 10). The moisture contents of the four classes of dead fuels are estimated from the time-lag moisture calculations developed by Fosberg and others (Fosberg 1972, Fosberg and Deeming 1971, Fosberg and others 1981). For example, a 100-hour dead fuel category corresponds to a particular size class of wood (diameter between 3 and 10 centimeters) that takes 100 hours to come two-thirds of the way toward equilibrium with standard conditions of ambient moisture. Live fuel moisture is estimated from an index of plant water stress (Howard 1978). The index is a function of the percentage of soil moisture simulated by the hydrology in the biogeochemical module.

The fire module estimates loading in the different fuel classes from C in the live and dead aboveground pools simulated by the biogeochemical module. The live grass shoot and live tree leaf pools are summed to estimate the live fine fuel class load, and the standing dead grass shoot and aboveground tree litter pools are summed to estimate the dead 1-hour fuel class load (fig. 11). A set of lifeform-specific allometric equations is used to estimate average stand dimensions (height and bole diameter) from aboveground biomass (fig. 11). The stand dimensions are used in another set of allometric functions

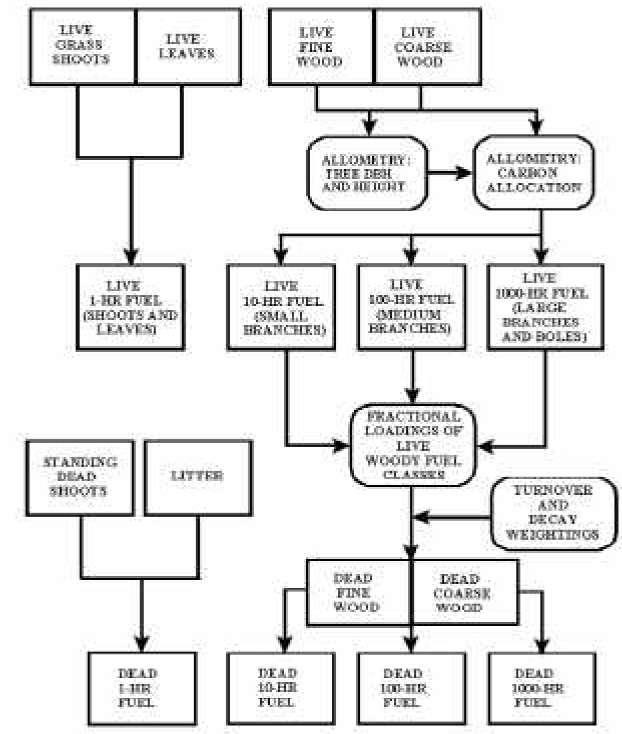


Figure 10—Flow diagram for simulation of fuel loading. MCFIRE estimates the loading in the different fuel classes from carbon in the live and dead aboveground pools simulated by the biogeochemical module. The live grass shoot and live tree leaf pools are summed to estimate the live fine fuel class load, and the standing dead grass shoot and aboveground grass and tree leaf litter are summed to estimate the dead 1-hour fuel class load. A set of lifeform-specific allometric equations is used to estimate average stand dimensions (i.e., height and bole diameter) from aboveground biomass. The stand dimensions are used in another set of allometric functions to allocate the woody biomass into three different structural components (i.e., fine branches, medium branches, and large branches plus boles) (Means and others 1994, Stanek and State 1978). These three live components together with live biomass turnover rates and dead biomass decomposition rates from the biogeochemical module are used to partition the two dead wood carbon pools into the three dead fuel classes (i.e., the 10-, 100-, and 1,000-hr dead fuels).

to allocate the woody biomass into three different structural components (fine branches, medium branches, and large branches plus boles) that correspond to the three live fuel classes (the 10-, 100-, and 1,000-hour live fuels, respectively) (Means and others 1994, Stanek and State 1978). These three live components, together with live biomass turnover rates and dead biomass decomposition rates from the biogeochemical module, are used to partition the two dead wood C pools into the three dead fuel classes (the 10-, 100-, and 1,000-hour dead fuels).

3.3.2 Fire occurrence—For fire to occur in the model, three different conditions must be met: (1) fuels must be exposed to extended drought, (2) fine dead fuels must be highly flammable, and (3) fire spread must reach a critical rate. Our intent is not to simulate every fire that potentially could occur on a landscape, but rather to simulate only the more extensive fires with more significant effects on the vegetation. The moisture

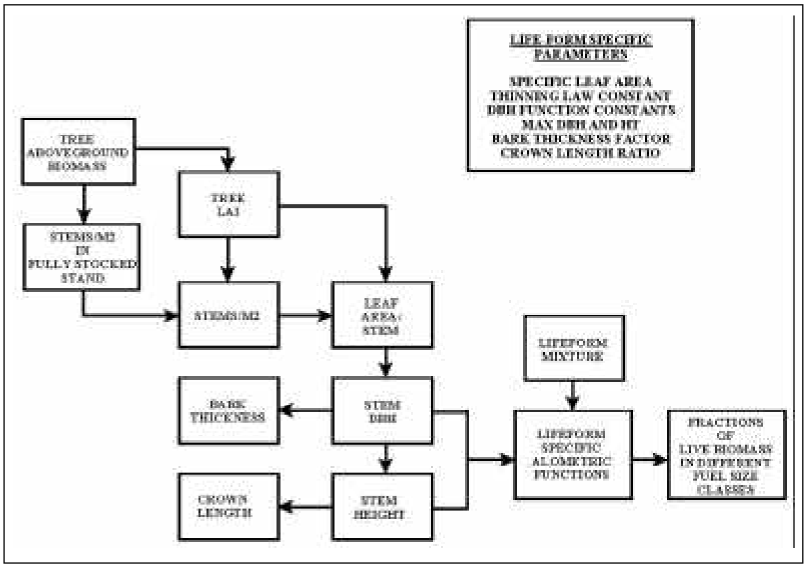


Figure 11—Flow diagram for simulation of stand structure and live fuel classes. A set of lifeform-specific allometric equations is used to estimate average stand dimensions (i.e., height and bole diameter) and lifeform specific parameters from aboveground biomass.

content of the dead 1,000-hour fuel class is used as an indicator of extended drought. Large, dead fuels are very slow to absorb and release moisture (Fosberg and others 1981), so their percentage of moisture content is a good index of extended periods of either dry or wet conditions.

When the 1,000-hour fuel moisture drops below a calibrated drought threshold, the model will simulate a fire if there is also a sufficient fine fuel flammability and fire spread. We used a function from the National Fire Danger Rating system (Bradshaw and others 1984) to calculate a probability of flammability and spread. Flammability is a function of fine fuel moisture and air temperature. The critical rate of spread is a function of the rate of spread estimated by the Rothermal algorithm and a minimum rate of spread for reportable fires (Bradshaw and others 1984). We used a 50-percent threshold value of the National Fire Danger Rating system function to determine fire occurrence in our model. Ignition sources (such as lightning) are assumed to be always available in this version of the model.

If a simulated fire is triggered in a cell, the fire effects are applied uniformly to the entire cell when the resolution of the climate input is high. In VEMAP where resolution is coarse (0.5 lat x lon), the model calculates the fraction of the cell that burns. Currently, there is no provision in the fire module for spatially explicit fire spread within and among cells.

3.3.3 Fire behavior and effects—Both surface fire behavior and crown fire behavior are simulated in the fire module (fig. 12) as a function of fuel load, fuel moisture, and stand structure. Surface fire behavior is modeled with the Rothermel (1972) fire spread equations as implemented in the National Fire Danger Rating System (Bradshaw and others 1984) (fig. 13). Crown fire initiation is simulated with van Wagner's formulation (1993). Indices of fire behavior (such as fireline intensity, rate of spread, and the

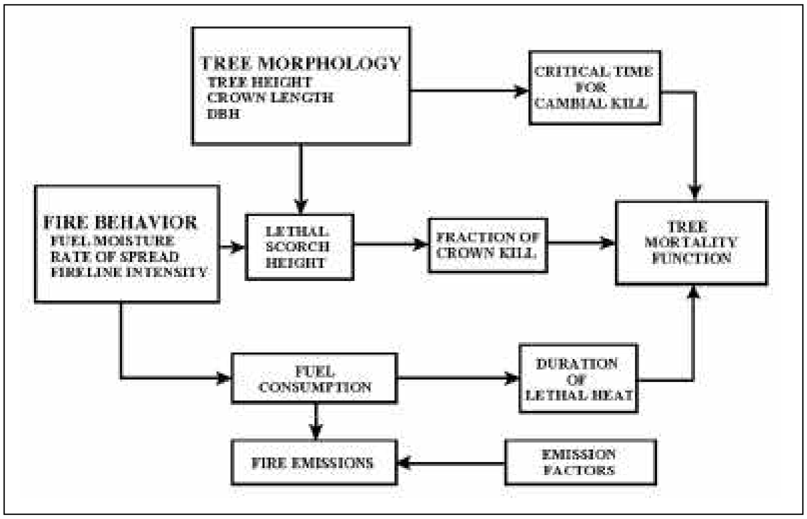


Figure 12—Flow diagram for simulation of fire effects. If a crown fire is initiated in the model, postfire mortality of aboveground live biomass is assumed to be complete. Otherwise, crown mortality is a combined effect of crown scorch and cambial kill simulated in MCFIRE. Crown scorch is a function (Peterson and Ryan 1986) of lethal scorch height (van Wagner 1973) and the average crown height and length as determined by the allometric functions of biomass. Cambial kill is a function of the duration of lethal heat and the bark thickness estimated from average bole diameter (Peterson and Ryan 1986). The percentage of mortality of crown biomass is estimated as a function of crown scorch and cambial kill (Peterson and Ryan 1986). Dead fuel consumption by fire is simulated as a function of the moisture content of the different dead fuel size classes (Peterson and Ryan 1986). Emissions from fuel consumption are simulated for CO_2, CO, CH_4, and particulate matter as the product of the mass of fuel consumed and emission factors for the different emission gases (Keane and others 1997).

residence time of flaming and smoldering combustion) are used to simulate the effects of fire on plant mortality and fuel consumption.

Crown kill—In a simulated crown fire, postfire mortality of aboveground live biomass is assumed to be complete. Otherwise, the percentage of mortality for crown biomass is estimated as a function of crown scorch and cambial kill (Peterson and Ryan 1986). Crown scorch is a function (Peterson and Ryan 1986) of lethal scorch height (van Wagner 1973) and the average crown height and length as determined by the allometric functions of biomass. Cambial kill is a function of (1) the duration of lethal heat and (2) the bark thickness estimated from average bole diameter (Peterson and Ryan 1986).

Root kill—In a simulated fire, the depth of lethal heating is used to estimate mortality of live tree roots and is modeled as a function of the duration of flaming and glowing combustion at the surface (Peterson and Ryan 1986). The depth-versus-duration relation was derived from empirical data presented by Steward and others (1990).

Fuel consumption—The consumption of dead fuel by fire is modeled as a function of the moisture content of the different dead fuel size classes (Peterson and Ryan 1986). Emissions from fuel consumption are modeled for CO_2, carbon monoxide (CO), methane (CH_4), and particulate matter as the product of the mass of fuel consumed and emission factors for the different emission gases (Keane and Long 1998).

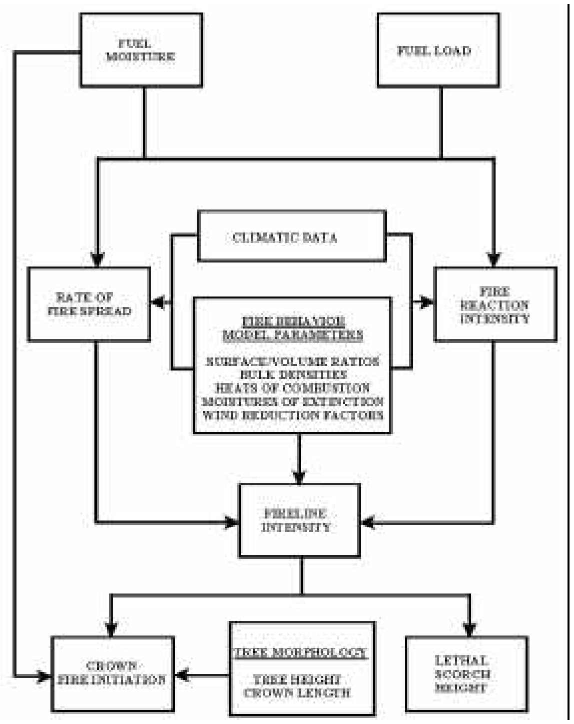


Figure 13—Flow diagram for simulation of fire behavior. Surface and crown fire behavior are simulated in MCFIRE as a function of fuel load, fuel moisture, and stand structure. Surface fire behavior is modeled by using the Rothermel (1972) fire spread equations as implemented in the National Fire Danger Rating System (Bradshaw and others 1983). Crown fire initiation is simulated by using van Wagner's (1993) formulation. Indices of fire behavior (e.g., fireline intensity, rate of spread, and the residence time of flaming and smoldering combustion) are used in the simulation of fire effects in terms of plant mortality and fuel consumption.

3.3.4 Fire feedbacks to biogeochemistry—The standard version of CENTURY (Parton and others 1987) simulates fire as a scheduled series of fires at one of three levels of intensity. The effects of different levels of fire intensity are defined by parameters that set fractions of the live and dead C pools consumed by fire, and fractions of N and other nutrients returned to the soil. In the initialization phase, MC1 uses the same fire schedule as standard CENTURY. But in transient mode, the values of these parameters in the biogeochemical module are set equal to the rates of live and dead fuel consumption simulated by the fire module in MC1 (table 1).

Unlike the standard version of CENTURY, MC1 also simulates live-to-dead C pool turnover caused by postfire mortality. These equations are included in the biogeochemical module. In the case of a simulated crown fire, the model assumes that live leaves and branches are completely consumed. Otherwise, live leaves are consumed and live branches are transferred to the appropriate dead C pool in proportion to the percentage of mortality for the crown. The bole biomass of killed trees or shrubs and the biomass of killed roots also are transferred to dead C pools.

3.3.5 Fire feedbacks to biogeography—The fire module calculates changes to C and nutrient pools. Fire-caused changes in C affect the LAI values, which are passed to the biogeographic module to help determine vegetation type. The LAI values are smoothed by using the same function used for smoothing the climatic values (see equation 1). The occurrence of a fire resets the smoothing period to zero, which allows the biogeographic rules to predict an open canopy vegetation type for a few years after a simulated fire (table 1).

Table 10—Parameters and their values in the MAPSS parameter file, site

Parameter	Units	Value
WhichSoils[a]:		
No soils data		0
FAO soil data		1
SCS soil data**		2
Thickness[SURFACE][b]	millimeters	500.0
Thickness[INTERMEDIATE]	millimeters	1000.0
Thickness[DEEP]	millimeters	1500.0
Rock_frag_max [SURFACE][INTERMEDIATE][DEEP]	fraction	0.50
IgnoreRockFragments:		
Use rock fragment data		0
Ignore rock fragment data		1
Field_potential	pascal	-0.033
#Saturated water holding capacities:		
swhc[SURFACE]	millimeters	210.0
swhc[INTERMEDIATE]	millimeters	420.0
swhc[DEEP]	millimeters	750.0
Field capacity (fraction of swhc), whc [SURFACE][INTERMEDIATE][DEEP]	pascal	0.6
Matrix potential (MPa), used to derive awc, all layers, matrix_pot	pascal	-1.5
Coefficient of soil water potential model:		
a_swp [SURFACE][INTERMEDIATE][DEEP]		-61466.84
c_swp [SURFACE][INTERMEDIATE][DEEP]		4.359
theta_s [SURFACE][INTERMEDIATE][DEEP]		47.7
Exp of saturated percolation (1), increase to reduce percolation:		
exp_perc[SATURATED][SURFACE]		1.0
exp_perc[SATURATED][INTERMEDIATE]		2.5
exp_perc[SATURATED][DEEP]		10.0
Exp of unsaturated percolation (1), increase to reduce percolation:		
exp_perc[UNSATURATED][SURFACE]		2.5
exp_perc[UNSATURATED][INTERMEDIATE]		3.0
exp_perc[UNSATURATED][DEEP]		10.0
Saturated drainage:		
KK[SATURATED][SURFACE]	fraction	0.5
KK[SATURATED][INTERMEDIATE][DEEP]	fraction	0.8
Unsaturated drainage:		
KK[UNSATURATED][SURFACE]	fraction	0.8
KK[UNSATURATED][INTERMEDIATE]	fraction	0.5
KK[UNSATURATED][DEEP]	fraction	0.2

Table 10—Parameters and their values in the MAPSS parameter file, site

Parameter	Units	Value
Texture, text [SURFACE][INTERMEDIATE][DEEP]		1.0
Soil surface condition		1.0
ConductanceEq:		
Old conductance equations		0
New conductance equations		1
Soil constants:		
SoilsConstraints[SURFACE]		0
SoilsConstraints[INTERMEDIATE]		1
SoilsConstraints[DEEP]		2
Variable soil layer constants:		
pp[SURFACE] [INTERMEDIATE]		21.012
pp[DEEP]		19.012
qq[SURFACE] [INTERMEDIATE][DEEP]		-8.0e-2
rr[SURFACE][INTERMEDIATE]		-3.895
rr[DEEP]		-4.3
tt[SURFACE]		4.55e-2
tt[INTERMEDIATE]		3.92e-2
tt[DEEP]		3.42e-2
uu[SURFACE]		-0.03
uu[INTERMEDIATE]		-0.04
uu[DEEP]		-0.05
vv[SURFACE][INTERMEDIATE][DEEP]		8.76e-5

[a] FAO soil data used for global runs; SCS soil data used for US runs. 0 corresponds to sandy loam conditions.

[b] [SURFACE] = soil layer 1: upper 0.5 m of soil.
[INTERMEDIATE] = soil layer 2: 0.5-1.5 m depth.
[DEEP] = soil layer 3: below 1.5 m.

Table 11—Parameters and their values in the MAPSS parameter file, parameters

Parameter		Value
snow0	temp (°C) above which snow fraction equals	05.0
snow1	temp (°C) below which snow fraction equals 1	-7.0
frost	threshold (°C) for beginning, end of growing season	13.0
Tree productivity for growing season used for evergreen/deciduous decision		
evergreen_productivity_tree		10.0
evergreen_productivity_shrub		10.0
evergreen_productivity_tree_lad		10.0
evergreen_productivity_shrub_lad		10.0
evergreen_gdd	growing degree days for evergreen (frost based)	600.0
evergreen_events		40.0
evergreen_events_grow		26.0
evergreen_events_avg		11.0
evergreen_events_grow_avg	(6.0 to 7.5)	7.5
evergreen_events_grow_min		5.00
evergreen_events_grow_std	(1.5 to 2.0)	2.00
evergreen_events_grow_cov		0.30
evergreen_events_grow_rng		4.00
evergreen_gdd_north		250.0
evergreen_gdd_south		600.0
evergreen_gdd_ratio		100.0
evergreen_selection1		12
evergreen_selection2		4
Stage 1 options		
# 12 => EvergreenDrySummerGddRatio		
Stage 2 options		
# 4 => EvergreenAetGdd		
no_melt	temp (C) below which no snow melt occurs	-14.0
melt_slope	temp coefficient for snow melt rate (mm)	4.0
event_ppt	rainfall coefficient for number of events	0.1
event_pet	pet threshold (mm/mo) for max_events determination	50.0
max_events[0]	maximum number of events at pet <= event_pet	5.0
max_events[1]	maximum number of events at pet > event_pet	10.0
interc_lai	maximum ppt interception per event (mm)	3.0
LaiUpperBoundsEnergy[BOREAL][GRASS][NEEDLELEAF][BROADLEAF]		6.0
LaiUpperBoundsEnergy[BOREAL][TREE][NEEDLELEAF][BROADLEAF]		15.0
LaiUpperBoundsEnergy[BOREAL][SHRUB][NEEDLELEAF][BROADLEAF]		3.50
LaiUpperBoundsEnergy[TEMPERATE][GRASS][NEEDLELEAF][BROADLEAF]		6.0
LaiUpperBoundsEnergy[TEMPERATE][TREE][NEEDLELEAF][BROADLEAF]		15.0
LaiUpperBoundsEnergy[TEMPERATE][SHRUB][NEEDLELEAF][BROADLEAF]		3.50
LaiUpperBoundsEnergy[SUBTROPICAL][GRASS][NEEDLELEAF][BROADLEAF]		6.0
LaiUpperBoundsEnergy SUBTROPICAL][TREE][NEEDLELEAF][BROADLEAF]		15.0
LaiUpperBoundsEnergy[SUBTROPICAL][SHRUB][NEEDLELEAF][BROADLEAF]		3.50
LaiUpperBoundsEnergy[TROPICAL][GRASS][NEEDLELEAF][BROADLEAF]		6.0
LaiUpperBoundsEnergy[TROPICAL][TREE][NEEDLELEAF][BROADLEAF]		15.0
LaiUpperBoundsEnergy[TROPICAL][SHRUB][NEEDLELEAF][BROADLEAF]		3.50
LaiUpperBoundsEnergy[ICE][GRASS][NEEDLELEAF][BROADLEAF]		0.0
LaiUpperBoundsEnergy[ICE][TREE][NEEDLELEAF][BROADLEAF]		0.0
LaiUpperBoundsEnergy[ICE][SHRUB][NEEDLELEAF][BROADLEAF]		0.0
LaiUpperBoundsEnergy[TUNDRA][GRASS][NEEDLELEAF][BROADLEAF]		2.0
LaiUpperBoundsEnergy[TUNDRA][TREE][NEEDLELEAF][BROADLEAF]		0.0
LaiUpperBoundsEnergy[TUNDRA][SHRUB][NEEDLELEAF][BROADLEAF]		1.5
LaiUpperBoundsEnergy[TAIGA_TUNDRA][GRASS][NEEDLELEAF][BROADLEAF]		3.0
LaiUpperBoundsEnergy[TAIGA_TUNDRA][TREE][NEEDLELEAF][BROADLEAF]		0.0

Table 11—Parameters and their values in the MAPSS parameter file, parameters (continued)

Parameter	Value
LaiUpperBoundsEnergy[TAIGA_TUNDRA][SHRUB][NEEDLELEAF][BROADLEAF]	2.5
LaiUpperBoundsLifeform[BOREAL][GRASS][NEEDLELEAF][BROADLEAF]	15.0
LaiUpperBoundsLifeform[BOREAL][TREE][NEEDLELEAF][BROADLEAF]	15.0
LaiUpperBoundsLifeform[BOREAL][SHRUB][NEEDLELEAF][BROADLEAF]	15.0
LaiUpperBoundsLifeform[TEMPERATE][GRASS][NEEDLELEAF][BROADLEAF]	15.0
LaiUpperBoundsLifeform[TEMPERATE][TREE][NEEDLELEAF][BROADLEAF]	15.0
LaiUpperBoundsLifeform[TEMPERATE][SHRUB][NEEDLELEAF][BROADLEAF]	15.0
LaiUpperBoundsLifeform[SUBTROPICAL][GRASS][NEEDLELEAF][BROADLEAF]	15.0
LaiUpperBoundsLifeform[SUBTROPICAL][TREE][NEEDLELEAF][BROADLEAF]	15.0
LaiUpperBoundsLifeform[SUBTROPICAL][SHRUB][NEEDLELEAF][BROADLEAF]	15.0
LaiUpperBoundsLifeform[TROPICAL][GRASS][NEEDLELEAF][BROADLEAF]	15.0
LaiUpperBoundsLifeform[TROPICAL][TREE][NEEDLELEAF][BROADLEAF]	15.0
LaiUpperBoundsLifeform[TROPICAL][SHRUB][NEEDLELEAF][BROADLEAF]	15.0
LaiUpperBoundsLifeform[ICE][GRASS][NEEDLELEAF][BROADLEAF]	15.0
LaiUpperBoundsLifeform[ICE][TREE][NEEDLELEAF][BROADLEAF]	15.0
LaiUpperBoundsLifeform[ICE][SHRUB][NEEDLELEAF][BROADLEAF]	15.0
LaiUpperBoundsLifeform[TUNDRA][GRASS][NEEDLELEAF][BROADLEAF]	15.0
LaiUpperBoundsLifeform[TUNDRA][TREE][NEEDLELEAF][BROADLEAF]	15.0
LaiUpperBoundsLifeform[TUNDRA][SHRUB][NEEDLELEAF][BROADLEAF]	15.0
LaiUpperBoundsLifeform[TAIGA_TUNDRA][GRASS][NEEDLELEAF][BROADLEAF]	15.0
LaiUpperBoundsLifeform[TAIGA_TUNDRA][TREE][NEEDLELEAF][BROADLEAF]	15.0
LaiUpperBoundsLifeform[TAIGA_TUNDRA][SHRUB][NEEDLELEAF][BROADLEAF]	15.0
Maximum grass LAI in first month of growing season	
spring_grass[BOREAL] [TEMPERATE][SUBTROPICAL][TROPICAL]	1.5
LAI at which shrub becomes chaparral	
chaparral_lai[BOREAL][TEMPERATE][SUBTROPICAL][TROPICAL]	1.2
LAI below which forest -> savanna	
forest_threshold[BOREAL][NEEDLELEAF][BROADLEAF]	3.75
forest_threshold[TEMPERATE][NEEDLELEAF][BROADLEAF]	3.75
forest_threshold[SUBTROPICAL][NEEDLELEAF][BROADLEAF]	3.75
forest_threshold[TROPICAL][NEEDLELEAF][BROADLEAF]	3.75
min_tree_lai[BOREAL][NEEDLELEAF][BROADLEAF]	1.85
min_tree_lai[TEMPERATE][NEEDLELEAF][BROADLEAF]	1.85
min_tree_lai[SUBTROPICAL][NEEDLELEAF][BROADLEAF]	1.85
min_tree_lai[TROPICAL][NEEDLELEAF][BROADLEAF]	0.65
tree_pet_factor[BOREAL][TEMPERATE][SUBTROPICAL][TROPICAL]	2.55
tallgrass_pet_factor[BOREAL][TEMPERATE][SUBTROPICAL][TROPICAL]	1.22
Woody LAI threshold for light attenuation	
no_attenuation_lai	
[BOREAL][TEMPERATE][SUBTROPICAL][TROPICAL] [NEEDLELEAF]	0.0
[BOREAL][TEMPERATE][SUBTROPICAL][TROPICAL][BROADLEAF]	0.0
full_attenuation_lai	
[BOREAL][TEMPERATE][SUBTROPICAL][TROPICAL][NEEDLELEAF]	5.0
[BOREAL][TEMPERATE][SUBTROPICAL][TROPICAL][BROADLEAF]	5.0
a_surf y-intercept (mm), detention as function of soil surface	0.0
b_surf slope (mm), detention as function of soil surface	0.0
Maximum conductance in tropical forests (mm/sec)	
normal_cond_max[BOREAL][TEMPERATE][SUBTROPICAL]	3.5
normal_cond_max[TROPICAL]	7.6
wue[BOREAL][GRASS][NEEDLELEAF][BROADLEAF]	1.00
wue[BOREAL][TREE][NEEDLELEAF][BROADLEAF]	1.00
wue[BOREAL][SHRUB][NEEDLELEAF][BROADLEAF]	1.00

Table 11—Parameters and their values in the MAPSS parameter file, parameters (continued)

Parameter	Value
wue[TEMPERATE][GRASS][NEEDLELEAF][BROADLEAF]	1.00
wue[TEMPERATE][TREE][NEEDLELEAF][BROADLEAF]	1.00
wue[TEMPERATE][SHRUB][NEEDLELEAF][BROADLEAF]	1.00
wue[SUBTROPICAL][GRASS][NEEDLELEAF][BROADLEAF]	1.00
wue[SUBTROPICAL][TREE][NEEDLELEAF][BROADLEAF]	1.00
wue[SUBTROPICAL][SHRUB][NEEDLELEAF][BROADLEAF]	1.00
wue[TROPICAL][GRASS][NEEDLELEAF][BROADLEAF]	1.00
wue[TROPICAL][TREE][NEEDLELEAF][BROADLEAF]	1.00
wue[TROPICAL][SHRUB][NEEDLELEAF][BROADLEAF]	1.00
Maximum conductance (mm/sec)	
cond_max[BOREAL][GRASS][NEEDLELEAF][BROADLEAF]	3.50
cond_max[BOREAL][TREE][NEEDLELEAF][BROADLEAF]	2.50
cond_max[BOREAL][SHRUB][NEEDLELEAF][BROADLEAF]	1.5
cond_max[TEMPERATE][GRASS][NEEDLELEAF][BROADLEAF]	3.50
cond_max[TEMPERATE][TREE][NEEDLELEAF][BROADLEAF]	2.50
cond_max[TEMPERATE][SHRUB][NEEDLELEAF][BROADLEAF]	1.5
cond_max[SUBTROPICAL][GRASS][NEEDLELEAF][BROADLEAF]	5.50
cond_max[SUBTROPICAL][TREE][NEEDLELEAF][BROADLEAF]	2.50
cond_max[SUBTROPICAL][SHRUB][NEEDLELEAF][BROADLEAF]	1.5
cond_max[TROPICAL][GRASS][NEEDLELEAF][BROADLEAF]	5.50
cond_max[TROPICAL][TREE][NEEDLELEAF][BROADLEAF]	7.6
cond_max[TROPICAL][SHRUB][NEEDLELEAF][BROADLEAF]	1.5
Minimum conductance (mm/sec)	
cond_min[BOREAL][GRASS][NEEDLELEAF][BROADLEAF]	1.0
cond_min[BOREAL][TREE][NEEDLELEAF][BROADLEAF]	1.5
cond_min[BOREAL][SHRUB][NEEDLELEAF][BROADLEAF]	0.8
cond_min[TEMPERATE][GRASS][NEEDLELEAF][BROADLEAF]	1.0
cond_min[TEMPERATE][TREE][NEEDLELEAF][BROADLEAF]	1.5
cond_min[TEMPERATE][SHRUB][NEEDLELEAF][BROADLEAF]	0.8
cond_min[SUBTROPICAL][GRASS][NEEDLELEAF][BROADLEAF]	0.2
cond_min[SUBTROPICAL][TREE][NEEDLELEAF][BROADLEAF]	1.5
cond_min[SUBTROPICAL][SHRUB][NEEDLELEAF][BROADLEAF]	0.8
cond_min[TROPICAL][GRASS][NEEDLELEAF][BROADLEAF]	0.2
cond_min[TROPICAL][TREE][NEEDLELEAF][BROADLEAF]	1.5
cond_min[TROPICAL][SHRUB][NEEDLELEAF][BROADLEAF]	0.8
Maximum conductance (mm/sec)	
cond_surface_max[BOREAL][GRASS][NEEDLELEAF] [BROADLEAF]	5.00
cond_surface_max[BOREAL][TREE][NEEDLELEAF][BROADLEAF]	20.6
cond_surface_max[BOREAL][SHRUB][NEEDLELEAF][BROADLEAF]	9.4
cond_surface_max[TEMPERATE][GRASS][NEEDLELEAF][BROADLEAF]	23.0
cond_surface_max[TEMPERATE][TREE][NEEDLELEAF][BROADLEAF]	20.6
cond_surface_max[TEMPERATE][SHRUB][NEEDLELEAF][BROADLEAF]	9.4
cond_surface_max[SUBTROPICAL][GRASS][NEEDLELEAF][BROADLEAF]	17.1
cond_surface_max[SUBTROPICAL][TREE][NEEDLELEAF][BROADLEAF]	12.1
cond_surface_max[SUBTROPICAL][SHRUB][NEEDLELEAF][BROADLEAF]	9.4
cond_surface_max[TROPICAL][GRASS][NEEDLELEAF][BROADLEAF]	17.1
cond_surface_max[TROPICAL][TREE][NEEDLELEAF][BROADLEAF]	16.1
cond_surface_max[TROPICAL][SHRUB][NEEDLELEAF][BROADLEAF]	9.4
Allowed months of below minimum conductance	
cond_min_months[GRASS][NEEDLELEAF][BROADLEAF]	0.0
cond_min_months[TREE][NEEDLELEAF][BROADLEAF]	1.0
cond_min_months[SHRUB][NEEDLELEAF][BROADLEAF]	1.0

Table 11—Parameters and their values in the MAPSS parameter file, parameters (continued)

Parameter	Value
Maximum LAI/at ratio below at threshold	
max_lai2at[GRASS][NEEDLELEAF][BROADLEAF]	15.0
max_lai2at[TREE][NEEDLELEAF][BROADLEAF]	0.25
max_lai2at[SHRUB][NEEDLELEAF][BROADLEAF]	10.0
Apply max LAI/at ratio below this value	
at_thresh[GRASS][NEEDLELEAF][BROADLEAF]	1000.0
at_thresh[TREE][NEEDLELEAF][BROADLEAF]	1000.0
at_thresh[SHRUB][NEEDLELEAF][BROADLEAF]	250.0
Permanent wilting point (MPa)	
wp[BOREAL][GRASS][NEEDLELEAF][BROADLEAF]	-1.5
wp[BOREAL][TREE][NEEDLELEAF][BROADLEAF]	-1.5
wp[BOREAL][SHRUB][NEEDLELEAF][BROADLEAF]	-6.0
wp[TEMPERATE][GRASS][NEEDLELEAF][BROADLEAF]	-1.5
wp[TEMPERATE][TREE][NEEDLELEAF][BROADLEAF]	-1.5
wp[TEMPERATE][SHRUB][NEEDLELEAF][BROADLEAF]	-6.0
wp[SUBTROPICAL][GRASS][NEEDLELEAF][BROADLEAF]	-1.5
wp[SUBTROPICAL][TREE][NEEDLELEAF][BROADLEAF]	-1.5
wp[SUBTROPICAL][SHRUB][NEEDLELEAF][BROADLEAF]	-6.0
wp[TROPICAL][GRASS][NEEDLELEAF] [BROADLEAF]	-1.5
wp[TROPICAL][TREE][NEEDLELEAF][BROADLEAF]	-1.5
wp[TROPICAL][SHRUB][NEEDLELEAF][BROADLEAF]	-6.0
k_trans_addend[GRASS][NEEDLELEAF][BROADLEAF]	0.00
k_trans_addend[TREE][NEEDLELEAF][BROADLEAF]	0.00
k_trans_addend[SHRUB][NEEDLELEAF][BROADLEAF]	0.00
Coefficient of transpiration ratio model	
k_transp[BOREAL][GRASS][0][NEEDLELEAF][BROADLEAF]	4.00
k_transp[BOREAL][TREE][0][NEEDLELEAF]	1.50
k_transp[BOREAL][TREE][0][BROADLEAF]	1.95
k_transp[BOREAL][SHRUB][0][NEEDLELEAF][BROADLEAF]	8.75
k_transp[TEMPERATE][GRASS][0][NEEDLELEAF][BROADLEAF]	4.00
k_transp[TEMPERATE][TREE][0][NEEDLELEAF]	2.50
k_transp[TEMPERATE][TREE][0][BROADLEAF]	2.95
k_transp[TEMPERATE][SHRUB][0][NEEDLELEAF][BROADLEAF]	8.75
k_transp[SUBTROPICAL][GRASS][0][NEEDLELEAF][BROADLEAF]	4.00
k_transp[SUBTROPICAL][TREE][0][NEEDLELEAF]	2.25
k_transp[SUBTROPICAL][TREE][0][BROADLEAF]	2.70
k_transp[SUBTROPICAL][SHRUB][0][NEEDLELEAF][BROADLEAF]	8.75
k_transp[TROPICAL][GRASS][0][NEEDLELEAF][BROADLEAF]	4.00
k_transp[TROPICAL][TREE][0][NEEDLELEAF][BROADLEAF]	2.70
k_transp[TROPICAL][SHRUB][0][NEEDLELEAF][BROADLEAF]	6.75
This determines which of the AT formulae are to be used	
at_flag Grouped constants	3
Coefficient of PET effects coefficient of conductance	
a_slope[BOREAL][GRASS][NEEDLELEAF][BROADLEAF]	0.002
a_slope[BOREAL][TREE][NEEDLELEAF][BROADLEAF]	0.1
a_slope[BOREAL][SHRUB][NEEDLELEAF][BROADLEAF]	0.030
a_slope[TEMPERATE][GRASS][NEEDLELEAF][BROADLEAF]	0.002
a_slope[TEMPERATE][TREE][NEEDLELEAF][BROADLEAF]	0.1
a_slope[TEMPERATE][SHRUB][NEEDLELEAF][BROADLEAF]	0.030
a_slope[SUBTROPICAL][GRASS][NEEDLELEAF][BROADLEAF]	0.002
a_slope[SUBTROPICAL][TREE][NEEDLELEAF][BROADLEAF]	0.1
a_slope[SUBTROPICAL][SHRUB][NEEDLELEAF][BROADLEAF]	0.030
a_slope[TROPICAL][GRASS][NEEDLELEAF][BROADLEAF]	0.002

Table 11—Parameters and their values in the MAPSS parameter file, parameters (continued)

Parameter		Value
a_slope[TROPICAL][TREE][NEEDLELEAF][BROADLEAF]		0.100
a_slope[TROPICAL][SHRUB][NEEDLELEAF][BROADLEAF]		0.030
pet_int[BOREAL][GRASS][NEEDLELEAF][BROADLEAF]		0.00
pet_int[BOREAL][TREE][NEEDLELEAF][BROADLEAF]		0.0
pet_int[BOREAL][SHRUB][NEEDLELEAF][BROADLEAF]		0.0
pet_int[TEMPERATE][GRASS][NEEDLELEAF][BROADLEAF]		0.00
pet_int[TEMPERATE][TREE][NEEDLELEAF][BROADLEAF]		0.0
pet_int[TEMPERATE][SHRUB][NEEDLELEAF][BROADLEAF]		0.0
pet_int[SUBTROPICAL][GRASS][NEEDLELEAF][BROADLEAF]		0.00
pet_int[SUBTROPICAL][TREE][NEEDLELEAF][BROADLEAF]		0.0
pet_int[SUBTROPICAL][SHRUB][NEEDLELEAF][BROADLEAF]		0.0
pet_int[TROPICAL][GRASS][NEEDLELEAF][BROADLEAF]		0.00
pet_int[TROPICAL][TREE][NEEDLELEAF][BROADLEAF]		0.0
pet_int[TROPICAL][SHRUB][NEEDLELEAF][BROADLEAF]		0.0
_surfrun	coeff of surface runoff (increase to reduce runoff)	1.7
max_infilt	coefficient relating soil texture to maximum infiltration rate	0.0
infilt_thresh	threshold melt plus throughfall attains max infiltration	0.0
broad_ppt_mo[BOREAL][TEMPERATE][SUBTROPICAL][TROPICAL]		-1
broad_ppt_min	minimum monthly ppt for broadleaf, growing season	40.0
s_decid_bound	southern temp threshold of coldest month, deciduous (1.25)	2.25
n_decid_bound	northern temp threshold, deciduous	-16.0
ice_boundary[BOREAL]		0.0
tundra_boundary[BOREAL]		735.0
taiga_tundra_boundary[BOREAL]		1330.0
tundra_boundary[BOREAL]		367.5
taiga_tundra_boundary[BOREAL]		665.0
ice_boundary[TEMPERATE]		0.0
tundra_boundary[TEMPERATE]		615.0
taiga_tundra_boundary[TEMPERATE]		1165.0
tundra_boundary[TEMPERATE]		307.5
taiga_tundra_boundary[TEMPERATE]		582.5
closed_forest_at	annual wood at prohibiting grass fire (mm) (n/a)	480.0
fire_min_at	frost free mean monthly grass at for fire (mm) (n/a)	1000.0
desert_wood_at	annual wood at desert threshold (mm)	200.0
desert_wood_lai	maximum woody lai at < desert_wood_at	3.00
DoFire	5 => the VEMAP fire rule.	5
1	MaxBurnCycles	
fire_threshold_1	threshold for Grass Sum LAI	2.0
fire_threshold_2	threshold for Shrub LAI	2.50
fire_threshold_3	threshold for Tree LAI	3.0
fire_threshold_4	threshold for surface soil moisture	0.0
fire_threshold_5	threshold for pet	100.0
fire_threshold_6	threshold for Precip in High Month	50.0
Hammer woody LAI down before entry into grass/woody competition		
hammer		0
do not hammer		1
k_factor_slope[BOREAL][NEEDLELEAF][BROADLEAF]		-2.50
k_factor_contstraint[BOREAL][NEEDLELEAF][BROADLEAF]		170.0
k_factor_pet_boundary[BOREAL][NEEDLELEAF][BROADLEAF] default (< 0)		-1325.0
k_factor_slope[TEMPERATE][NEEDLELEAF][BROADLEAF]		-2.50
k_factor_contstraint[TEMPERATE][NEEDLELEAF][BROADLEAF]		170.0
k_factor_pet_boundary[TEMPERATE][NEEDLELEAF][BROADLEAF] default (< 0)		-1325.0
k_factor_slope[SUBTROPICAL][NEEDLELEAF][BROADLEAF]		-2.50

Table 11—Parameters and their values in the MAPSS parameter file, parameters (continued)

Parameter	Value
k_factor_contstraint[SUBTROPICAL][NEEDLELEAF][BROADLEAF]	170.0
k_factor_pet_boundary[SUBTROPICAL][NEEDLELEAF][BROADLEAF] default (< 0)	-1325.0
k_factor_slope[TROPICAL][NEEDLELEAF][BROADLEAF]	-2.50
k_factor_contstraint[TROPICAL][NEEDLELEAF][BROADLEAF]	170.0
k_factor_pet_boundary[TROPICAL][NEEDLELEAF][BROADLEAF] default (< 0)	-1325.0
k_factor_winter_boundary_upper	8
k_factor_winter_boundary_lower	4
Temperature between maritime and continental types	
maritime_boundary[BOREAL][SUBTROPICAL][TROPICAL]	20.0
maritime_boundary[TEMPERATE]	18.0
xeric_savanna_threshold	0.50
mediterranean_savanna_threshold	0.75
temperate_conifer_threshold	1.6
temperate_xeromorphic_conifer_threshold	1.2
dry_trop_threshold	2.00
semi_desert_threshold	0.45
short_grass_threshold # was 0.8	1.15
tall_grass_threshold	2.00
desert_grass_sum_threshold	1.20
desert_shrub_threshold	0.175
desert_grass_threshold	0.10
north_hard_threshold # was 11.0	9.00
tsg_threshold	0.60
tsg_threshold	0.50
pj_max_lai_continental	2.10
pj_max_lai_maritime	2.10
pj_xeric_threshold	2.00
max_grass_threshold	1.50
max_grass_shrub_threshold	0.70
cool_grass_threshold	3.00
C3C4 Option	4
# 4 => C3C4CenturyNew	
c3c4_jim_thresh	0.20
c3c4_century_thresh	0.48
# These are the parameters for the internal PET calculations.	
Upper heights	
z[BOREAL][TEMPERATE][SUBTROPICAL][TROPICAL][GRASS]	10.00
z[BOREAL][TEMPERATE][SUBTROPICAL][TROPICAL][TREE]	10.00
z[BOREAL][TEMPERATE][SUBTROPICAL][TROPICAL][SHRUB]	10.00
Roughness lengths	
z0[BOREAL][TEMPERATE][SUBTROPICAL][TROPICAL][GRASS]	0.0005
z0[BOREAL][TEMPERATE][SUBTROPICAL][TREE]	0.01
z0[TROPICAL][TREE]	0.02
z0[BOREAL][TEMPERATE][SUBTROPICAL][TROPICAL][SHRUB]	0.001
Uniform across all terrain all seasons	
wind_speed[BOREAL][TEMPERATE][SUBTROPICAL][TROPICAL]	-5.0
(A negative value means use actual wind values from input files.)	
elevation (A negative value means use actual elevation value from an input file.)	-500.0
grass_snowpack Max depth of snow under which grass will grow (mm of rain).	10.0
Note that this is not a measure of snow depth. It is an amount of water.	
fractional_gcm Fractional GCM	1.0
fractional_wue Fractional WUE	1.0

4. Parameters and Variables

4.1 Generalization of Input Parameters

CENTURY (Parton and others 1987, 1994) was designed primarily for site-specific application to individual ecosystems. It uses a parameter set containing values of tree and grass maximum potential production, temperature growth limits, C:N ratios, leaf turnover rate, soil nutrient concentrations, and other related parameters. The parameter set is selected through an externally supplied ecosystem type, such as a VEMAP vegetation class (VEMAP Members 1995). In MC1, however, the ecosystem type may change over time in response to climatic and successional factors. Early applications of MC1 with step changes in ecosystem types, and thus step changes in parameter sets, produced unacceptable discontinuities in predicted C pools when the ecosystem type changed. In the modified version of CENTURY used in MC1, a method therefore was developed to reduce the number of parameter sets and to smoothly transition from one set to another.

As discussed previously, the biogeographic module calculates climatic indices that describe the lifeform composition of an ecosystem as mixtures of deciduous needleleaf (DN), evergreen needleleaf (EN), deciduous broadleaf (DB), evergreen broadleaf (EB) trees, and C3 and C4 grasses. Parameter values appropriate for pure stands of the four tree lifeforms and the two grass lifeforms were extracted from parameter files previously used with CENTURY. We linearly interpolated between these pure stand values to estimate the biogeochemical module’s parameter values appropriate for the lifeform mixture predicted by the biogeographic model. Transforming CENTURY’s static input structure to a smoothly varying and dynamic system resulted in more realistic and natural transitions of model predictions.

4.2 Biogeographic Parameters and Variables

4.2.1 Equilibrium conditions—

Running equilibrium MAPSS—Running MAPSS requires input from two parameter files: site and parameters. The site file includes site-specific inputs, such as field capacity, saturated drainage, and texture for the three soil layers. The parameters file includes other information necessary to set the parameters of the MAPSS model, such as LAI, PET, and water use efficiency for the various vegetation classes. Tables 10 and 11 show the values of the most important parameters included in those two files.

Table 12—Thresholds from the biogeographic parameter file, thres.dat

Name	Description	Value
forest_thres	LAI threshold for forest vs. savanna	3.75
savanna_thres	LAI threshold for savanna vs. shrubland	2.0
shrub_thres	LAI threshold for shrubland vs. grassland	1.0
C3_thres	c3_c4 index threshold for c3 vs. c4 grassland	55.0
maritime_thres	Continental index threshold for maritime vs. continental coniferous forests	15.0
tundra_thres	Degree-day threshold for tundra vs. taiga	735.0
taiga_thres	Degree-day threshold for taiga vs. boreal forest	1330.0

Running equilibrium CENTURY—The biogeochemical module of MC1 (a modified version of CENTURY) is run independently of the fire module and of the MC1 biogeographic module. Fire events are prescribed in Veg.type specific files (`vvegTypex.sch`). The module is run until som2c (the slow organic matter pool) becomes stable. At this point, simulated values of all C and N pools are saved and can serve as initial conditions for the transient run.

4.2.2 Transient conditions—A set of biogeographic rules (different from those used in MAPSS) was developed for the MC1 biogeographic module. The MC1 rules use LAI thresholds from CENTURY and climatic indices to identify vegetation types. Table 12 lists thresholds from the biogeography parameter file: `thres.dat`.

4.3 Biogeochemical Parameters and Variables

4.3.1 Parameter and initial condition files—For each vegetation type, the biogeochemical module selects respective parameters and initial condition files. Parameter files consist of (1) schedule files (`vvegTypex.sch`), where grass and tree types are defined and where fire events are scheduled for the equilibrium run; (2) the “fixed” files (`xfix.100`), which are separated into seven vegetation types and include most of the site characteristics, such as the rates of nitrogen loss; and (3) the parameter files (`vvegTypex.100`), which include initial conditions for soil organic matter and mineral content. The biogeochemistry module also reads the files `tree.100` and `crop.100`**,** which include the physiological parameters specific to MC1 that differ from one lifeform to another.

Tables 13 through 15 list some examples of the parameter files required by the biogeochemistry module. Tables 16 and 17 are the `tree.100` and `crop.100` files.

Table 13—An example of a schedule file, MapssCenx.sch, required by the biogeochemical module[a]

Value	Description	
1	Starting year	
1	Last year	
vvegType3.100	Site file name	
0	Labeling type	
-1	Labeling year	
-1.00	Microcosm	
0	CO_2 systems	[effect of CO_2 on/off switch]
3	Initial system	[savanna mode]
SUPRG	Initial crop	[MC1 definition of tree and grass types]
SUPRT	Initial tree	
Year Month Option:		
1	Block number temperate mixed	
1	Last year	
1	Repeats number of years	
1	Output starting year	
1	Output month	
0.08333	Output interval (1month)	
M:	Weather choice	
1	1 TFST	[first month of growth - trees]
1	1 FRST	[first month of growth - grasses]
1	12 LAST	[last month of growth - grasses]
1	11 SENM	[senescence month - grasses]
1	12 TLST	[last month of growth - trees]
-999	-999 X	

[a] These files were created for transient mode, and original .sch files from CENTURY are used only in equilibrium mode.

Table 14—An example of an MC1 parameter file, ffix.100, required by the biogeochemical module[a]

Variable	Value	Variable	Value	Variable	Value	Variable	Value
ADEP(1)	15.0	DEC4	0.0045	P3CO2	0.55	RCESTR(3)	500.0
ADEP(2)	15.0	DEC5	0.20	PABRES	100.0	RICTRL	0.015
ADEP(3)	15.0	DECK5	5.0	PCEMIC(1,1)	16.0	RINNT	0.80
ADEP(4)	15.0	DLIGDF	-4.0	PCEMIC(2,1)	10.0	RSPLIG	0.30
ADEP(5)	30.0	DRESP	0.999	PCEMIC(3,1)	0.02	SEED	-1.00
ADEP(6)	30.0	EDEPTH	0.2	PEFTXA	0.25	SPL(1)	0.85
ADEP(7)	30.0	ELITST	0.4	PEFTXB	0.75	SPL(2)	0.013
ADEP(8)	30.0	ENRICH	2.0	PHESP(1)	6.0	STRMAX(1)	5000
ADEP(9)	30.0	FAVAIL(1)	0.90	PHESP(2)	0.0008	STRMAX(2)	5000
ADEP(10)	30.0	FAVAIL(3)	0.5	PHESP(3)	7.6	TEXEPP(1)	1.0
AGPPA	-40.0	FAVAIL(4)	0.2	PHESP(4)	0.015	TEXEPP(2)	0.7
AGPPB	7.70	FAVAIL(5)	0.4	PLIGST(1)	3.0	TEXEPP(3)	0.0001
ANEREF(1)	1.50	FAVAIL(6)	2.0	PLIGST(2)	3.0	TEXEPP(4)	0.00016
ANEREF(2)	3.0	FLEACH(1)	0.2	PMCO2(1)	0.55	TEXEPP(5)	2.0
ANEREF(3)	0.30	FLEACH(2)	0.7	PMCO2(2)	0.55	TEXESP(1)	1.0
ANIMPT	5.0	FLEACH(3)	1.0	PMNSEC(1)	0.0	TEXESP(3)	0.004
AWTL(1)	0.8	FLEACH(4)	0.0	PMNSEC(2)	0.0	TEFF(1)	0.0
AWTL(2)	0.6	FLEACH(5)	0.1	PMNSEC(3)	2.0	TEFF(2)	0.125
AWTL(3)	0.4	FWLOSS(1)	0.8	PMNTMP	0.004	TEFF(3)	0.07
AWTL(4)	0.3	FWLOSS(2)	0.8	PMXBIO	600.0	TMELT(1)	-6.0
AWTL(5)	0.2	FWLOSS(3)	0.65	PMXTMP	0.0035	TMELT(2)	2.0
AWTL(6)	0.2	FWLOSS(4)	0.7	PPARMN(1)	0.0	VARAT1(1,1)	*
AWTL(7)	0.2	FXMCA	-0.125	PPARMN(2)	0.0001	VARAT1(2,1)	*
AWTL(8)	0.2	FXMCB	0.005	PPARMN(3)	0.0005	VARAT1(3,1)	2.0
AWTL(9)	0.0	FXMXS	0.35	PPRPTS(1)	0.0	VARAT2(1,1)	40.0
AWTL(10)	0.0	FXNPB	7.0	PPRPTS(2)	1.0	VARAT2(2,1)	12.0
BGPPA	100.0	GREMB	0.0	PPRPTS(3)	0.80	VARAT2(3,1)	2.0
BGPPB	7.0	IDEF	2.0	PS1CO2(1)	0.45	VARAT3(1,1)	20.0
CO2PPM(1)	350.0	LHZF(1)	0.20	PS1CO2(2)	0.55	VARAT3(2,1)	6.0
CO2PPM(2)	700.0	LHZF(2)	0.40	PS1S3(1)	0.003	VARAT3(3,1)	2.0
CO2RMP	1.0	LHZF(3)	0.80	PS1S3(2)	0.032	VLOSSE	**
DAMR(1,1)	0.0	MINLCH	18.0	PS2S3(1)	0.003	VLOSSG	**
DAMR(2,1)	0.02	NSNFIX	0.0	PS2S3(2)	0.009	VARAT(1,1) 14	
DAMRMN(1)	15.0	NTSPM	4.0	PSECMN(1)	0.0	(dryg, drytrp, g, trp)	
DAMRMN(2)	150.0	OMLECH(1)	0.03	PSECMN(2)	0.0022	VARAT(1,1) 18	
DAMRMN(3)	150.0	OMLECH(2)	0.12	PSECMN(3)	0.20	arc, bor, f	
DEC1(1)	3.9	OMLECH(3)	60.0	PSECOC	0.0	VLOSSE/VLOSSG	0.02
DEC1(2)	4.9	P1CO2A(1)	0.60	RAD1P(1,1)	12.0	arc, bor, f, g, trp	
DEC2(1)	14.8	P1CO2A(2)	0.17	RAD1P(2,1)	3.0	VLOSSE/VLOSSG	0.05
DEC2(2)	18.5	P1CO2B(1)	0.0	RAD1P(3,1)	5.0		
DEC3(1)	6.0	P1CO2B(2)	0.68	RCESTR(1)	200.0		
DEC3(2)	7.3	P2CO2	0.55	RCESTR(2)	500.0		

[a] See list of parameters in section 4.3.2 for definitions.

Table 15—An example of an MC1 parameter file, vvegTypex.100, required by the biogeochemical module

Climate parameters

Value	Parameter
29.61000	PRECIP(1)
30.85000	PRECIP(2)
25.93000	PRECIP(3)
15.09000	PRECIP(4)
10.40000	PRECIP(5)
7.36000	PRECIP(6)
1.76000	PRECIP(7)
4.28000	PRECIP(8)
7.64000	PRECIP(9)
16.65000	PRECIP(10)
35.62000	PRECIP(11)
42.65000	PRECIP(12)
14.83000	PRCSTD(1)
11.14000	PRCSTD(2)
10.12000	PRCSTD(3)
5.41000	PRCSTD(4)
5.21000	PRCSTD(5)
5.24000	PRCSTD(6)
1.63000	PRCSTD(7)
3.59000	PRCSTD(8)
5.64000	PRCSTD(9)
10.66000	PRCSTD(10)
17.69000	PRCSTD(11)
17.39000	PRCSTD(12)
0.00000	PRCSKW(1)
0.00000	PRCSKW(2)
0.00000	PRCSKW(3)
0.00000	PRCSKW(4)
0.00000	PRCSKW(5)
0.00000	PRCSKW(6)
0.00000	PRCSKW(7)
0.00000	PRCSKW(8)
0.00000	PRCSKW(9)
0.00000	PRCSKW(10)
0.00000	PRCSKW(11)
0.00000	PRCSKW(12)
-1.80000	TMN2M(1)
-0.30000	TMN2M(2)
0.50000	TMN2M(3)
1.60000	TMN2M(4)
4.20000	TMN2M(5)
7.20000	TMN2M(6)
9.00000	TMN2M(7)
8.80000	TMN2M(8)
6.10000	TMN2M(9)
3.00000	TMN2M(10)
0.60000	TMN2M(11)
-1.10000	TMN2M(12)
4.00000	TMX2M(1)
6.90000	TMX2M(2)
10.20000	TMX2M(3)
14.00000	TMX2M(4)
18.70000	TMX2M(5)
22.80000	TMX2M(6)
28.00000	TMX2M(7)
27.70000	TMX2M(8)
23.80000	TMX2M(9)
16.10000	TMX2M(10)
7.10000	TMX2M(11)
3.30000	TMX2M(12)

External nutrient input parameters

Value	Parameter
0.05000	EPNFA(1)
0.00700	EPNFA(2)
0.00000	EPNFS(1)
0.00000	EPNFS(2)
0.00000	SATMOS(1)
0.00000	SATMOS(2)
0.00000	SIRRI

Water initial parameters

Value	Parameter
0.00000	RWCF(1)
0.00000	RWCF(2)
0.00000	RWCF(3)
0.00000	RWCF(4)
0.00000	RWCF(5)
0.00000	RWCF(6)
0.00000	RWCF(7)
0.00000	RWCF(8)
0.00000	RWCF(9)
0.00000	RWCF(10)
0.00000	SNLQ
0.00000	SNOW

Site and control parameters

Value	Parameter
0.00000	IVAUTO
1.00000	NELEM
44.25000	SITLAT
122.17000	SITLNG
0.25000	SAND
0.50000	SILT
0.25000	CLAY
1.00000	BULKD
8.00000	NLAYER
5.00000	NLAYPG
1.00000	DRAIN
0.30000	BASEF
0.60000	STORMF
1.00000	SWFLAG
0.20000	AWILT(1)
0.20000	AWILT(2)
0.20000	AWILT(3)
0.20000	AWILT(4)
0.20000	AWILT(5)
0.20000	AWILT(6)
0.20000	AWILT(7)
0.20000	AWILT(8)
0.20000	AWILT(9)
0.30000	AWILT(10)
0.30000	AFIEL(1)
0.30000	AFIEL(2)
0.30000	AFIEL(3)
0.30000	AFIEL(4)
0.30000	AFIEL(5)
0.30000	AFIEL(6)
0.30000	AFIEL(7)
0.30000	AFIEL(8)
0.30000	AFIEL(9)
0.00000	AFIEL(10)
6.00000	PH
1.00000	PSLSRB
5.00000	SORPMX

Organic matter initial values

Value	Parameter
60.00000	SOM1CI(1,1)
0.00000	SOM1CI(1,2)
130.0000	SOM1CI(2,1)
0.00000	SOM1CI(2,2)
2570.0000	SOM2CI(1)
0.00000	SOM2CI(2)
1596.0000	SOM3CI(1)
0.00000	SOM3CI(2)
15.00000	RCES1(1,1)
50.00000	RCES1(1,2)
50.00000	RCES1(1,3)
15.50000	RCES1(2,1)
50.00000	RCES1(2,2)
50.00000	RCES1(2,3)
32.00000	RCES2(1)
117.0000	RCES2(2)
117.0000	RCES2(3)
18.00000	RCES3(1)
62.00000	RCES3(2)
62.00000	RCES3(3)
260.0000	CLITTR(1,1)
0.00000	CLITTR(1,2)
165.0000	CLITTR(2,1)
0.00000	CLITTR(2,2)
165.0000	RCELIT(1,1)

Table 15—An example of an MC1 parameter file, vvegTypex.100, required by the biogeochemical module

Organic matter initial values (cont.)

Value	Parameter
0.00000	RCELIT(1,2)
0.00000	RCELIT(1,3)
66.00000	RCELIT(2,1)
300.0000	RCELIT(2,2)
300.0000	RCELIT(2,3)
0.00000	AGLCIS(1)
0.00000	AGLCIS(2)
0.00000	AGLIVE(1)
0.00000	AGLIVE(2)
0.00000	AGLIVE(3)
0.00000	BGLCIS(1)
0.00000	BGLCIS(2)
0.00000	BGLIVE(1)
0.00000	BGLIVE(2)
0.00000	BGLIVE(3)
0.00000	STDCIS(1)
0.00000	STDCIS(2)
0.00000	STDEDE(1)
0.00000	STDEDE(2)
0.00000	STDEDE(3)

Forest organic matter initial

Value	Parameter
685.0000	RLVCIS(1)
0.00000	RLVCIS(2)
7.70000	RLEAVE(1)
0.00000	RLEAVE(2)
0.00000	RLEAVE(3)
2630.0000	FBRCIS(1)
0.00000	FBRCIS(2)
15.90000	FBRCHE(1)
0.00000	FBRCHE(2)
0.00000	FBRCHE(3)

Forest organic matter initial (cont.)

Value	Parameter
32300.000	RLWCIS(1)
0.00000	RLWCIS(2)
36.20000	RLWODE(1)
0.00000	RLWODE(2)
0.00000	RLWODE(3)
89.00000	FRTCIS(1)
0.00000	FRTCIS(2)
1.10000	FROOTE(1)
0.00000	FROOTE(2)
0.00000	FROOTE(3)
2475.0000	CRTCIS(1)
0.00000	CRTCIS(2)
4.45000	CROOTE(1)
0.00000	CROOTE(2)
0.00000	CROOTE(3)
500.0000	WD1CIS(1)
0.00000	WD1CIS(2)
9500.000	WD2CIS(1)
0.00000	WD2CIS(2)
1900.000	WD3CIS(1)
0.00000	WD3CIS(2)
0.26000	W1LIG
0.26000	W2LIG
0.26000	W3LIG

Mineral initial parameters

Value	Parameter
0.00770	MINERL(1,1)
0.00500	MINERL(2,1)
0.00320	MINERL(3,1)
0.00210	MINERL(4,1)
0.00130	MINERL(5,1)
0.00085	MINERL(6,1)

Mineral initial parameters (cont.)

Value	Parameter
0.00054	MINERL(7,1)
0.00035	MINERL(8,1)
0.00004	MINERL(9,1)
0.00000	MINERL(10,1)
0.00000	MINERL(1,2)
0.00000	MINERL(2,2)
0.00000	MINERL(3,2)
0.00000	MINERL(4,2)
0.00000	MINERL(5,2)
0.00000	MINERL(6,2)
0.00000	MINERL(7,2)
0.00000	MINERL(8,2)
0.00000	MINERL(9,2)
0.00000	MINERL(10,2)
0.00000	MINERL(1,3)
0.00000	MINERL(2,3)
0.00000	MINERL(3,3)
0.00000	MINERL(4,3)
0.00000	MINERL(5,3)
0.00000	MINERL(6,3)
0.00000	MINERL(7,3)
0.00000	MINERL(8,3)
0.00000	MINERL(9,3)
0.00000	MINERL(10,3)
500.0000	PARENT(1)
0.00000	PARENT(2)
0.00000	PARENT(3)
0.00000	SECNDY(1)
15.00000	SECNDY(2)
2.00000	SECNDY(3)
0.00000	OCCLUD

Table 16—MC1 parameter file, tree.100[a]

Parameter	DN	EN	DB	EB
BASFC2	1.0	1.0	1.0	1.0
BASFCT	400.0	400.0	400.0	400.0
BTOLAI	0.012	0.004	0.012	0.007
CERFOR(1,5,1)	600	600	83	150.
CERFOR(1,4,1)	900.0	900.0	140.0	150.0
CERFOR(1,1,1)	100.0	100.0	20.0	20.0
CERFOR(1,2,1)	50.0	50.0	35.0	35.0
CERFOR(1,3,1)	310.	310	80.0	120.0
CERFOR(2,5,1)	80.	80.	500.	300.
CERFOR(2,4,1)	800.0	800.0	140.0	300.0
CERFOR(2,1,1)	100.0	100.0	40.0	40.0
CERFOR(2,2,1)	81.0	81.0	50.0	60.0
CERFOR(2,3,1)	310.	310.	99.	180.
CERFOR(3,5,1)	550.	550.	80.0	155.0
CERFOR(3,4,1)	900.0	900.0	140.0	155.0
CERFOR(3,1,1)	90.0	90.0	40.0	40.0
CERFOR(3,2,1)	80.0	80.0	50.0	76.0
CERFOR(3,3,1)	300.	300.	80.	84.
CO2ICE(1,2,1)	1.25	1.25	1.25	1.25
CO2ICE(1,2,2)	1.0	1.0	1.0	1.0
CO2ICE(1,1,3)	1.0	1.0	1.0	1.0
CO2ICE(1,1,2)	1.0	1.0	1.0	1.0
CO2ICE(1,1,1)	1.25	1.25	1.25	1.25
CO2ICE(1,2,3)	1.0	1.0	1.0	1.0
CO2IPR	1.25	1.25	1.25	1.25
CO2IRS	1.0	1.0	1.0	1.0
CO2ITR	0.75	0.75	0.75	0.75
DECID	1.0	1.0	1.0	1.0
DECW1	0.9	0.9	0.9	0.9
DECW2	0.4	0.4	0.4	0.4
DECW3	0.4	0.4	0.4	0.4
DEL13C	0.0	0.0	0.0	0.0
FCFRAC(1,2)	0.37	0.37	0.34	0.34
FCFRAC(1,1)	0.37	0.37	0.34	0.25
FCFRAC(2,2)	0.34	0.34	0.40	0.25
FCFRAC(2,1)	0.34	0.34	0.40	0.25
FCFRAC(3,2)	0.10	0.10	0.09	0.11
FCFRAC(3,1)	0.10	0.10	0.09	0.10
FCFRAC(4,2)	0.18	0.18	0.15	0.22
FCFRAC(5,2)	0.01	0.01	0.02	0.08
FORRTF	0.450	0.450	0.450	0.450
FCFRAC(4,1)	0.18	0.18	0.15	0.30
FCFRAC(5,1)	0.01	0.01	0.02	0.10
FORRTF(2)	0.0	0.0	0.0	0.0
FORRTF(3)	0.0	0.0	0.0	0.0
KLAI	2000.0	2000.0	1000.0	1000.0
LAITOP	-0.470	-0.470	-0.470	-0.470

Table 16—MC1 parameter file, tree.100[a] (continued)

Parameter	DN	EN	DB	EB
LEAFDR(1)	0.00	0.03	0.00	0.07
LEAFDR(10)	0.00	0.03	0.00	0.07
LEAFDR(11)	0.00	0.03	0.00	0.07
LEAFDR(12)	0.00	0.10	0.00	0.07
LEAFDR(2)	0.00	0.03	0.00	0.07
LEAFDR(3)	0.00	0.03	0.00	0.07
LEAFDR(4)	0.00	0.03	0.00	0.07
LEAFDR(5)	0.00	0.03	0.00	0.07
LEAFDR(6)	0.00	0.03	0.00	0.07
LEAFDR(7)	0.00	0.03	0.00	0.07
LEAFDR(8)	0.00	0.03	0.00	0.07
LEAFDR(9)	0.00	0.03	0.00	0.07
MAXLAI	10.	10.	10.	10.
MAXLDR	1.0	1.0	1.0	1.0
PPDF(1)	15.	15.	25.	30.
PPDF(2)	30.	30.	35.	45.
PPDF(3)	1.0	1.0	1.0	1.0
PPDF(4)	5.0	5.0	3.5	2.5
PRDX(3)	10000	10000	10000	10000
PRDX(4)	250.	250.	250.	250.
SAPK	1500.0	1500.0	1500.0	1500.0
SITPOT	4800.0	4800.0	2400.0	2400.0
SNFXMX(2)	0.0	0.0	0.0	0.0
SWOLD	0.0	0.0	0.0	0.0
WDLIG (1)	0.2100	0.2100	0.2100	0.2100
WDLIG (2)	0.2200	0.2200	0.2200	0.2200
WDLIG (4)	0.3000	0.3000	0.3000	0.3000
WDLIG (5)	0.3000	0.3000	0.3000	0.3000
WDLIG (3)	0.2500	0.2500	0.2500	0.2500
WOODDR(1)	1.0	0.0	1.0	0.0
WOODDR(2)	0.05	0.05	0.04	0.03
WOODDR(3)	0.01	0.01	0.01	0.01
WOODDR(4)	0.0008	0.0008	0.002	0.002
WOODDR(5)	0.001	0.001	0.004	0.004

[a] See parameter list for definitions; DN = deciduous needleleaf, EN = evergreen needleleaf, DB = deciduous broadleaf, EB = evergreen broadleaf.

Table 17—MC1 parameter file, crop.100[a]

Parameter	C3	C4
BIOFLG	1	1
BIOK5	60	60
BIOMAX	400	400
CO2ICE(1,2,1)	1.25	1.25
CO2ICE(1,1,1)	1.25	1.25
CO2IPR	1.25	1.25
CO2IRS	1	1
CO2ITR	0.75	0.75
CRPRTF(1)	0.5	0.5
DEL13C	0	0
EFRGRN(1)	0.5	0.5
FALLRT	.2	.2
FLIGNI(1,1)	0.02	0.02
FLIGNI(1,2)	0.26	0.26
FLIGNI(2,1)	0.0012	0.0012
FLIGNI(2,2)	-0.0015	-0.0015
FRTC(1)	0	0
FRTC(2)	0	0
FRTC(3)	0	0
FSDETH(1)	0.2	0.2
FSDETH(2)	0.95	0.95
FSDETH(3)	0.2	0.2
FSDETH(4)	150	150
FULCAN	100	100
HIMAX	0	0
HIMON(1)	0	0
HIMON(2)	0	0
HIWSF	0	0
PLTMRF	1	1
PPDF(1)	18	30
PPDF(2)	32	45
PPDF(3)	1.2	1.0
PPDF(4)	3.0	3.0
PRAMN(1,1)	20	20
PRAMN(1,2)	30	30
PRAMX(1,1)	30	30
PRAMX(1,2)	40	80
PRBMN(1,1)	40	60
PRBMN(1,2)	0	0
PRBMX(1,1)	50	80
PRBMX(1,2)	0	0
PRDX(1)	300.	400.
RDR	0.05	0.05
RTDTMP	2	2
SNFXMX(1)	0	0
VLOSSP	0.04	0.04

[a] See list of parameters for definitions.

4.3.2 Biogeochemical parameters and variables—

accrst	accumulator of C in straw removed for grass or crop (g·m^{-2})
acrcis(1)	growing season accumulator for unlabeled C production by isotope in forest system coarse root component (g·m^{-2}·year^{-1})
acrcis(2)	growing season accumulator for labeled C production by isotope in forest system coarse root component (g·m^{-2}·year^{-1})
adefac	average annual value of defac, the decomposition factor that combines the effects of temperature and moisture
adep(1,2...)	depth of soil layer 1,2... (only nlayer + 1 values used) (cm)
afbcis(1)	growing season accumulator for unlabeled C production by isotope in forest system fine branch component (g·m^{-2}·year^{-1})
afbcis(2)	growing season accumulator for labeled C production by isotope in forest system fine branch component (g·m^{-2}·year^{-1})
afiel(1,2...)	the field capacity of soil layer 1,2... (fraction); used only if swflag = 0
afrcis(1)	growing season accumulator for unlabeled C production by isotope in forest system fine root component (g·m^{-2}·year^{-1})
afrcis(2)	growing season accumulator for labeled C production by isotope in forest system fine root component (g·m^{-2}·year^{-1})
agcacc	growing season accumulator for aboveground C production (g·m^{-2}·year^{-1})
agcisa(2)	growing season accumulator for aboveground labeled C production for grass or crop (g·m^{-2})
aglcis(1)	aboveground unlabeled C by isotope for grass or crop (g·m^{-2})
aglcis(2)	aboveground labeled C by isotope for grass or crop (g·m^{-2})
aglcn	aboveground live C:N ratio = -999 if either component = 0 for grass or crop
aglivc	C in aboveground live for grass or crop (g·m^{-2})
aglive(1)	N in aboveground live for grass or crop (g·m^{-2})
aglrem	fraction of aboveground live that will not be affected by harvest operations, 0 to 1
agppa	intercept parameter in the equation estimating potential aboveground biomass production for calculation of root-to-shoot ratio (used only if frtc(1) = 0) (g·m^{-2}·year^{-1})
agppb	slope parameter in the equation estimating potential aboveground biomass production calculation of root-to-shoot ratio (used only if frtc(1) = 0) (g·m^{-2}·year^{-1}) Note: agppb is multiplied by annual precipitation (cm)
alvcis(1)	growing season accumulator for unlabeled C production in forest system leaf component
alvcis(2)	growing season accumulator for labeled C production in forest system leaf component (g·m^{-2}·year^{-1})
alwcis(1)	growing season accumulator for unlabeled C production in forest system large wood component (g·m^{-2}·year^{-1})
alwcis(2)	growing season accumulator for labeled C production in forest system large wood component (g·m^{-2}·year^{-1})
aminrl(1)	mineral N in layer 1 before uptake by plants
amt1c2	annual accumulator for surface CO_2 loss due to microbial respiration during litter decomposition
amt2c2	annual accumulator for soil CO_2 loss due to microbial respiration during litter decomposition
anerb	the effect of soil anaerobic conditions on decomposition; used as a multiplier on all belowground decomposition flows

aneref(1)	ratio of rain to potential evapotranspiration below which there is no negative impact of soil anaerobic conditions on decomposition
aneref(2)	ratio of rain to potential evapotranspiration above which there is maximum negative impact of soil anaerobic conditions on decomposition
aneref(3)	minimum value of the impact of soil anaerobic conditions on decomposition; functions as a multiplier for the maximum decomposition rate
animpt	slope term used to vary the impact of soil anaerobic conditions on decomposition flows to the passive soil organic matter pool
as11c2	annual accumulator for CO_2 loss due to microbial respiration during soil organic matter decomposition of surface som1 to som2
as21c2	annual accumulator for CO_2 loss due to microbial respiration during soil organic matter decomposition of soil som1 to som2 and som3
as2c2	annual accumulator for CO_2 loss due to microbial respiration during soil organic matter decomposition of som2 to soil som1 and som3
as3c2	annual accumulator for CO_2 loss due to microbial respiration during soil organic matter decomposition of som3 to soil som1
asmos(1,2...)	soil water content of layer 1,2...(cm)
asmos (nlayer+1)	soil water content in deep storage layer (cm)
ast1c2	annual accumulator for CO_2 loss due to microbial respiration during litter decomposition of surface structural into som1 and som2
ast2c2	annual accumulator for CO_2 loss due to microbial respiration during litter decomposition of soil structural into som1 and som2
astgc	grams of C added with the addition of organic matter ($g \cdot m^{-2}$)
astlbl	fraction of added C that is labeled, when C is added as a result of the addition of organic matter, range 0 to 1
astlig	lignin fraction content of organic matter, range 0 to 1
astrec(1)	C:N ratio of added organic matter
avh2o(1)	water available to grass or crop or tree for growth in soil profile (sum of layers 1 through nlaypg)(cm water)
avh2o(2)	water available to grass or crop or tree for survival in soil profile (sum of all layers in profile, 1 through nlayer) (cm water)
avh2o(3)	water in the first two soil layers (cm water)
awilt(1,2...)	the wilting point of soil layer 1,2... (fraction); used only if swflag = 0, 5, or 6
awtl(1,2...)	weighting factor for transpiration loss for layer 1,2... (only nlayer+1 values used); indicates which fraction of the availability water can be extracted by the roots
basef	the fraction of the soil water content of layer nlayer +1 lost via base flow, 0 to 1
basfc2	(savanna only) a basal factor used to calculate the N reaction; if not running savanna, 1
basfct	(savanna only) a constant used to calculate the tree basal area; equal to (form factor * wood density * tree height); if not running savanna, set to 1.0
bgcacc	growing season accumulator for belowground C production for grass or crop ($g \cdot m^{-2}$)
bgcisa(1)	growing season accumulator for belowground unlabeled C production for grass or crop ($g \cdot m^{-2}$)

bgcisa(2)	growing season accumulator for belowground labeled C production for grass or crop (g·m^{-2})
bglcis(1)	belowground live unlabeled C for grass or crop (g·m^{-2})
bglcis(2)	belowground live labeled C for grass or crop (g·m^{-2})
bglcis(2)	initial value for belowground live labeled C; used only if ivauto = 0 or 2 (gC·m^{-2})
bglcn	belowground live C:N ratio; = -999 if either component = 0 for grass or crop
bglivc	C in belowground live for grass or crop (g·m^{-2})
bglive(1)	N in belowground live for grass or crop (g·m^{-2})
bglrem	fraction of belowground live that will not be affected by harvest operations, 0 to 1
bgppa	intercept parameter in the equation estimating potential belowground biomass production for calculation of root-to-shoot ratio (used only if frtc(1) = 0) (g·m^{-2}·year^{-1})
bgppb	slope parameter in the equation estimating potential belowground biomass production for calculation of root-to-shoot ratio (used only if frtc(1) = 0) (g·m^{-2}·year^{-1}) Note: bgppb is multiplied by annual precipitation (cm)
bioflg	flag indicating whether production should be reduced by physical obstruction (= 0 production should not be reduced; = 1 production should be reduced)
biok5	level of aboveground standing dead + 10 percent strucc(1) C at which production is reduced to half maximum due to physical obstruction by the dead material, used only when bioflg = 1 (gC·m^{-2})
biomax	biomass level above which the minimum and maximum C:N ratios of the new shoot increments equal pramn(*,2) and pramx(*,2) respiration (g biomass·m^{-2})
bulkd	bulk density of soil used to compute soil loss by erosion, wilting point, and field capacity (kg·liter^{-1})
cerfor(1,2,1)	minimum C:N ratio for fine roots
cerfor(1,1,1)	minimum C:N ratio for leaves
cerfor(1,5,1)	minimum C:N ratio for coarse roots
cerfor(1,3,1)	minimum C:N ratio for fine branches
cerfor(1,4,1)	minimum C:N ratio for large wood
cerfor(2,3,1)	maximum C:N ratio for fine branches
cerfor(2,2,1)	maximum C:N ratio for fine roots
cerfor(2,1,1)	maximum C:N ratio for leaves
cerfor(2,5,1)	maximum C:N ratio for coarse roots
cerfor(2,4,1)	maximum C:N ratio for large wood
cerfor(3,1,1)	initial C:N ratio for leaves
cerfor(3,5,1)	initial C:N ratio for coarse roots
cerfor(3,2,1)	initial C:N ratio for fine roots
cerfor(3,3,1)	initial C:N ratio for fine branches
cerfor(3,4,1)	initial C:N ratio for large wood
cgracc	accumulator for grain and tuber production for grass or crop (g·m^{-2})
cgrain	economic yield of C in grain + tubers for grass or crop (g·m^{-2})
cinput	annual C inputs
cisgra(1)	unlabeled C in grain (g·m^{-2}) for grass or crop
cisgra(2)	labeled C in grain (g·m^{-2}) for grass or crop
clay	fraction of clay in soil, range 0 to 1

clittr(1,2)	initial value for surface labeled plant residue; used only if ivauto = 0 ($g \cdot m^{-2}$)
clittr(1,1)	initial value for surface unlabeled plant residue; used only if ivauto = 0 ($g \cdot m^{-2}$)
clittr(1,1)	surface unlabeled residue ($g \cdot m^{-2}$)
clittr(1,2)	surface labeled residue ($g \cdot m^{-2}$)
clittr(2,1)	initial value for soil unlabeled plant residue; used only if ivauto = 0 ($g \cdot m^{-2}$)
clittr(2,2)	initial value for soil labeled plant residue; used only if ivauto = 0 ($g \cdot m^{-2}$)
clittr(2,1)	soil unlabeled residue ($g \cdot m^{-2}$)
clittr(2,2)	soil labeled residue ($g \cdot m^{-2}$)
co2cce(1,1,1)	in a grass or crop system, the calculated effect on minimum C:N ratios of doubling the atmospheric CO_2 concentration from 350 ppm to 700 ppm
co2cce(1,2,1)	in a grass or crop system, the calculated effect on maximum C:N ratios of doubling the atmospheric CO_2 concentration from 350 ppm to 700 ppm
co2cce(2,1,1)	in a forest system, the calculated effect on minimum C:N ratios of doubling the atmospheric CO_2 concentration from 350 ppm to 700 ppm
co2cce(2,2,1)	in a forest system, the calculated effect on maximum C:N ratios of doubling the atmospheric CO_2 concentration from 350 ppm to 700 ppm
co2cpr(1)	in a grass or crop system, the calculated effect on production of doubling the atmospheric CO_2 concentration from 350 ppm to 700 ppm
co2cpr(2)	in a forest system, the calculated effect on production of doubling the atmospheric CO_2 concentration from 350 ppm to 700 ppm
co2crs(1)	in a grass or crop system, the calculated effect on root-to-shoot ratio of doubling the atmospheric CO_2 concentration from 350 ppm to 700 ppm
co2crs(2)	in a forest system, the calculated effect on root-to-shoot ratio of doubling the atmospheric CO_2 concentration from 350 ppm to 700 ppm
co2ctr(1)	in a grass or crop system, the calculated effect on transpiration rate of doubling the atmospheric CO_2 concentration from 350 ppm to 700 ppm
co2ctr(2)	in a forest system, the calculated effect on transpiration rate of doubling the atmospheric CO_2 concentration from 350 ppm to 700 ppm.
co2ice(1,1,1)	in a grass or crop system, the effect on minimum C:N ratio of doubling the atmospheric CO_2 concentration from 350 ppm to 700 ppm
co2ice(1,2,1)	in a grass or crop system, the effect on maximum C:N ratio of doubling the atmospheric CO_2
co2ice(2,2,1)	in a forest system, the effect on maximum C:N ratio of doubling the atmospheric CO_2
co2ice(2,1,1)	in a forest system, the effect on minimum C:N ratio of doubling the atmospheric CO_2
co2ipr(1)	in a grass or crop system, the effect on plant production of doubling the atmospheric CO_2 concentration from 350 ppm to 700 ppm
co2ipr(2)	in a forest system, the effect on plant production of doubling the atmospheric CO_2 concentration
co2irs(1)	in a grass or crop system, the effect on root-to-shoot ratio of doubling the atmospheric CO_2
co2irs(2)	in a forest system, the effect on root-to-shoot ratio of doubling the atmospheric CO_2 concentration
co2itr(1)	in a grass or crop system, the effect on transpiration rate of doubling the atmospheric CO_2 concentration
co2itr(2)	in a forest system, the effect on transpiration rate of doubling the atmospheric CO_2 concentration
co2rmp	flag indicating whether CO_2 effect should be 0 or 1 (= 0 step function; = 1 ramp function)

cproda	annual accumulator of C production in grass or crop + forest = NPP (net primary production; g·m^{-2}·year^{-1})
cprodc	total monthly C production for grass or crop (g·m^{-2}·month^{-1})
cprodf	total monthly C production for forest (g·m^{-2}·month^{-1})
creta	annual accumulator of C returned to system during grazing/fire for grass or crop (g·m^{-2}·year^{-1})
crmvst	amount of C removed through straw during harvest for grass or crop (g·m^{-2}·month^{-1})
crootc	C in forest system coarse root component (g·m^{-2})
croote(1)	N in forest system coarse root component (g·m^{-2})
croote(1)	initial value for N in a forest system coarse root component (gN·m^{-2})
crprtf(1)	fraction of N retranslocated from grass or crop leaves at death, range 0 to 1
crpstg(1)	retranslocation N storage pool for grass or crop (g·m^{-2})
crpval	a numerical representation of the current crop
crtacc	growing season accumulator for C production in forest system coarse root component (g·m^{-2}·year^{-1})
crtcis(1)	initial value for unlabeled C in forest system coarse root component (gC·m^{-2})
crtcis(1)	unlabeled C in forest system coarse root component (g·m^{-2})
crtcis(2)	labeled C in forest system coarse root component (g·m^{-2})
crtcis(2)	initial value for labeled C in forest system coarse root component (gC·m^{-2})
csrsnk(1)	unlabeled C source/sink (g·m^{-2})
csrsnk(2)	labeled C source/sink (g·m^{-2})
cultra(1)	fraction of aboveground live transferred to standing dead, range 0 to 1
cultra(2)	fraction of aboveground live transferred to surface litter, range 0 to 1
cultra(3)	fraction of aboveground live transferred to the top soil layer, range 0 to 1
cultra(4)	fraction of standing dead transferred to surface litter, range 0 to 1
cultra(5)	fraction of standing dead transferred to top soil layer, range 0 to 1
cultra(6)	fraction of surface litter transferred to top soil layer, range 0 to 1
cultra(7)	fraction of roots transferred to top soil layer, range 0 to 1
damr(1,1)	fraction of surface N absorbed by residue, range 0 to 1
damr(2,1)	fraction of soil N absorbed by residue, range 0 to 1
damrmn(1)	minimum C:N ratio allowed in residue after direct absorption
dblit	delta 13C value for belowground litter for stable isotope labeling
dec1(1)	maximum surface structural decomposition rate
dec1(2)	maximum soil structural decomposition rate
dec2(1)	maximum surface metabolic decomposition rate
dec2(2)	maximum soil metabolic decomposition rate
dec3(1)	maximum decomposition rate of surface organic matter with active turnover
dec3(2)	maximum decomposition rate of soil organic matter with active turnover
dec4	maximum decomposition rate of soil organic matter with slow turnover
dec5	maximum decomposition rate of soil organic matter with intermediate turnover
decid	= 0 if forest is coniferous; = 1 if forest is deciduous
deck5	available soil water content at which shoot and root death rates are half maximum (cm)
decw1	decomposition rate for wood1 (dead fine branch) (/year)
decw2	decomposition rate for wood2 (dead large wood) (/year)

decw3	decomposition rate for wood3 (dead coarse root) (/year)
defac	decomposition factor based on temperature and moisture
drain	the fraction of excess water lost by drainage; indicates whether a soil is sensitive for anaerobiosis
edepth	depth of the single soil layer where C, N dynamics are calculated (only affects C, N loss by erosion)
efrgrn(1)	fraction of the aboveground N which goes to grain, range 0 to 1
egracc(1)	accumulator of N in grain + tuber production for grass or crop ($g \cdot m^{-2}$)
egrain(1)	economic yield of N in grain + tubers for grass or crop ($g \cdot m^{-2}$)
elimit	indicator of the limiting element (= 1 if N is the limiting element)
elitst	effect of litter on soil temperature relative to live and standing dead biomass
enrich	the enrichment factor for soil organic matter (SOM) losses
epnfa(1)	intercept value for determining the effect of annual precipitation on atmospheric N-fixation (wet and dry deposition) ($g \cdot m^{-2} \cdot year^{-1}$)
epnfa(2)	slope value for determining the effect of annual precipitation on atmospheric N-fixation (wet and dry deposition) ($g \cdot m^{-2} \cdot year^{-1} \cdot cm\ precipitation^{-1}$)
epnfs(1)	intercept value for determining the effect of annual precipitation on nonsymbiotic soil N-fixation; not used if nsnfix = 1 ($g \cdot m^{-2} \cdot year^{-1}$)
epnfs(2)	slope value for determining the effect of annual precipitation on nonsymbiotic soil N-fixation; not used if nsnfix = 1 ($g \cdot m^{-2} \cdot year^{-1} \cdot precipitation^{-1}$)
eprodc(1)	actual monthly N uptake for grass or crop ($g \cdot m^{-2} \cdot month^{-1}$)
eprodf(1)	actual monthly N uptake in forest system ($g \cdot m^{-2} \cdot month^{-1}$)
ereta(1)	annual accumulator of N returned to system during grazing or fire for grass or crop ($g \cdot m^{-2} \cdot year^{-1}$)
ermvst(1)	amount of N removed as straw during harvest for grass or crop ($g \cdot m^{-2} \cdot month^{-1}$)
esrsnk(1)	N source or sink ($g \cdot m^{-2}$)
eupacc(1)	growing season accumulator for N uptake by grass, crop, or tree ($g \cdot m^{-2}$)
eupaga(1)	aboveground growing season accumulator for N uptake by plants for grass or crop ($g \cdot m^{-2}$)
eupbga(1)	belowground growing season accumulator for N uptake by plants for grass or crop ($g \cdot m^{-2}$)
eupprt(1,1)	growing season accumulator for N uptake by forest leaf component ($g \cdot m^{-2}$)
eupprt(2,1)	growing season accumulator for N uptake by forest fine roots component ($g \cdot m^{-2}$)
eupprt(3,1)	growing season accumulator for N uptake by forest fine branches component ($g \cdot m^{-2}$)
eupprt(4,1)	growing season accumulator for N uptake by forest large wood component ($g \cdot m^{-2}$)
eupprt(5,1)	growing season accumulator for N uptake by forest coarse roots component ($g \cdot m^{-2}$)
evap	monthly evaporation (cm)
evntyp	= 0 for cutting event; = 1 for fire event
fallrt	fall rate (fraction of standing dead that falls each month), range 0 to 1
favail(1)	fraction of N available per month to plants, range 0 to 1
fbracc	growing season accumulator for C production in forest system fine branch component ($g \cdot m^{-2} \cdot year^{-1}$)

fbrchc	C in forest system fine branch component (g·m^{-2})
fbrche(1)	initial value for N in a forest system fine branch component (gN·m^{-2})
fbrche(1)	N in forest system fine branch component (g·m^{-2})
fbrcis(1)	initial value for unlabeled C in forest system fine branch component (gC·m^{-2})
fbrcis(2)	initial value for labeled C in forest system fine branch component (gC·m^{-2})
fbrcis(1)	unlabeled C in forest system fine branch component (g·m^{-2})
fbrcis(2)	labeled C in forest system fine branch component (g·m^{-2})
fcacc	growing season accumulator for C production in forest system (g·m^{-2}·year^{-1})
fcfrac(1,1)	C allocation fraction of new leaves for juvenile forest, range 0 to 1
fcfrac(1,2)	C allocation fraction of old leaves for mature forest, range 0 to 1
fcfrac(2,2)	C allocation fraction of old fine roots for mature forest, range 0 to 1
fcfrac(2,1)	C allocation fraction of new fine roots for juvenile forest, range 0 to 1
fcfrac(3,1)	C allocation fraction of new fine branches for juvenile forest, range 0 to 1
fcfrac(3,2)	C allocation fraction of old fine branches for mature forest, range 0 to 1
fcfrac(4,2)	C allocation fraction of old large wood for mature forest, range 0 to 1
fcfrac(4,1)	C allocation fraction of new large wood for juvenile forest, range 0 to 1
fcfrac(5,2)	C allocation fraction of old coarse roots for mature forest, range 0 to 1
fcfrac(5,1)	C allocation fraction of new coarse roots for juvenile forest, range 0 to 1
fd(1)	fraction of fine root component that dies, range 0 to 1
fd(2)	fraction of coarse root component that dies, range 0 to 1
fdfrem(2)	fraction of surface litter removed by a fire event, range 0 to 1
fdgrem	fraction of standing dead removed by a grazing event, range 0 to 1
feramt(1)	amount of N to be added (gN·m^{-2})
fertot(1)	accumulator for N fertilizer
ffcret	fraction of C in the burned aboveground material that is moved to surface litter by a fire event
fleach(1)	intercept value for a normal month to compute the fraction of mineral N that will leach to the next layer when there is a saturated water flow; normal leaching is a function of sand content
fleach(2)	slope value for a normal month to compute the fraction of mineral N that will leach to the next layer when there is a saturated water flow; normal leaching is a function of sand content
fleach(3)	leaching fraction multiplier for N to compute the fraction of mineral N that will leach to the next layer when there is a saturated water flow; normal leaching is a function of sand content, range 0 to 1
flfrem	fraction of live shoots removed by a fire event, range 0 to 1
fdfrem(1)	fraction of standing dead plant material removed by a fire event, range 0 to 1
flghrv	= 1 if the grain is to be harvested; = 0 otherwise
flgrem	fraction of live shoots removed by a grazing event, range 0 to 1
fligni(1,2)	intercept for equation to predict lignin content fraction based on annual rainfall for belowground material, range 0 to 1
fligni(1,1)	intercept for equation to predict lignin content fraction based on annual rainfall for aboveground material, range 0 to 1
fligni(2,2)	slope for equation to predict lignin content fraction based on annual rainfall for belowground material, range 0 to 1
fligni(2,1)	slope for equation to predict lignin content fraction based on annual rainfall for aboveground material, range 0 to 1
fnue(1)	effect of fire on increase in maximum C:N ratio of shoots

fnue(2)	effect of fire on increase in maximum C:N ratio of roots
forrtf(1)	fraction of N retranslocated from green forest leaves at death, range 0 to 1
forstg(1)	retranslocation N storage pool for forest
fret(1)	fraction of N in the burned aboveground material removed by a fire vent, 0 to 1
frootc	C in forest system fine root component ($g\cdot m^{-2}$)
froote(1)	initial value for N in a forest system fine root component ($gN\cdot m^{-2}$)
froote(1)	N in forest system fine root component ($g\cdot m^{-2}$)
frstc	sum of C in forest system live components ($g\cdot m^{-2}$) (rleavc + frootc + fbrchc + rlwodc + crootc)
frste(1)	sum of N in forest system live components ($g\cdot m^{-2}$) [rleave(1) + froote(1) + fbrche(1) + rlwode(1) + croote(1)]
frtacc	growing season accumulator for C production in forest system fine root component ($g\cdot m^{-2}$)
frtc(1)	initial fraction of C allocated to roots; Great Plains equation based on precipitation, set to 0, range 0 to 1
frtc(2)	final fraction of C allocated to roots, range 0 to 1
frtc(3)	time after planting (months with soil temperature greater than rtdtmp) when the final value is reached; must not equal 0
frtcis(1)	initial value for unlabeled C in forest system fine root component ($gC\cdot m^{-2}$)
frtcis(1)	unlabeled C in forest system fine root component ($g\cdot m^{-2}$)
frtcis(2)	initial value for labeled C in forest system fine root component ($gC\cdot m^{-2}$)
frtcis(2)	labeled C in forest system fine root component ($g\cdot m^{-2}$)
frtsh	additive effect of burning on root to shoot ratio
fsdeth(1)	maximum shoot death rate at very dry soil conditions (fraction/month); for getting the monthly shoot death rate, this fraction is multiplied by a reduction factor, depending on the soil water status, range 0 to 1
fsdeth(2)	fraction of shoots that die during senescence month; must be greater than or equal to 0.4, range 0 to 1
fsdeth(3)	additional fraction of shoots that die when aboveground live C is greater than fsdeth(4), range 0 to 1
fsdeth(4)	the level of aboveground C above which shading occurs and shoot senescence increases
fsysc	total C in forest system: sum of soil organic matter, trees, dead wood, forest litter
fsyse(1)	total N in forest system: sum of soil organic matter, trees, dead wood, forest litter
fulcan	value of aglivc at full canopy cover, above which potential production is not reduced
fwloss(1)	scaling factor for interception and evaporation of precipitation by live and standing dead biomass, range 0 to 1
fwloss(2)	scaling factor for bare soil evaporation of precipitation, range 0 to 1
fwloss(3)	scaling factor for transpiration water loss
fwloss(4)	scaling factor for potential evapotranspiration
fxmca	intercept for effect of biomass on nonsymbiotic soil N-fixation; used only when nsnfix = 1
fxmcb	slope control for eff. of biomass on nonsymbiotic soil N-fixation; used only when nsnfix= 1
fxmxs	maximum monthly nonsymbiotic soil N-fixation rate (reduced by effect of N:P ratio, used when nsnfix = 1)

fxnpb	N/P control for N-fixation based on availability of top soil layer (used when nsnfix = 1)
gfcret	fraction of consumed C that is excreted in faeces and urine, range 0 to 1
gremb	grazing effect multiplier for grzeff types 4, 5, and 6
gromin(1)	gross mineralization of N
grzeff	effect of grazing on production (= 0 grazing has no direct effect on production; = 1 linear impact on agp (agppa+agppb); = 2 quadratic impact on agp and root-to-shoot ratio; = 3 quadratic impact on root-to-shoot ratio; = 4 linear impact on root-to-shoot ratio; = 5 quadratic impact on agp and linear impact on root-to-shoot ratio; = 6 linear impact on agb and root-to-shoot ratio)
harmth	= 0 in nonharvest months; = 1 in a harvest month
hi	harvest index (cgrain/aglivc at harvest) for grass or crop
hibg	fraction of roots that will be harvested, range 0 to 1
himax	harvest index maximum (fraction of aboveground live C in grain), range 0 to 1
himon(1)	number of months before harvest in which to begin accumulating water stress effect on harvest index
himon(2)	number of months before harvest in which to stop accumulating water stress effect on harvest index, range 0 to 12
hiwsf	harvest index water stress factor (= 0 no effect of water stress; = 1 no grain yield with maximum water stress)
idef	flag for method of computing water effect on decomposition (= 1 option using the relative water content of soil [0-15 cm]; = 2 ratio option [rainfall/potential evaporation rate])
irract	actual amount of irrigation (cm water/month)
irramt	amount of water to apply regardless of soil water status (cm)
irraut	amount of water to apply automatically when auirri = 2 (cm)
irrtot	accumulator for irrigation (cm water)
ivauto	use Burke’s equations to initialize soil C pools (= 0 the user has supplied the initial values; = 1 initialize using the grassland soil parameters; = 2 initialize using the crop soil parameters)
klai	large wood mass ($gC \cdot m^{-2}$) at which half of the theoretical maximum leaf area (maxlai) is achieved
laitop	parameter determining relation between LAI and forest production
leafdr (1,2,...,12)	monthly death rate fraction for leaves, range 0 to 1
lhzcac	accumulator for C inputs to 0-20 cm layer from the lower horizon pools associated with soil erosion ($g \cdot m^{-2}$)
lhzeac(1)	accumulator for N inputs to 0-20 cm layer from the lower horizon pools associated with soil erosion ($g \cdot m^{-2}$)
lhzf(1)	lower horizon factor for active pool; = fraction of active pool (som1cI(2,*)) used in computation of lower horizon pool sizes for soil erosion routines
lhzf(2)	lower horizon factor for slow pool; = fraction of slow pool (som2cI(*)) used in computation of lower horizon pool sizes for soil erosion routines
lhzf(3)	lower horizon factor for passive pool; = fraction of passive pool (som3cI(*)) used in computation of lower horizon pool sizes for soil erosion routines
maxlai	theoretical maximum leaf area index achieved in mature forest

maxldr	multiplier for effect of N availability on leaf death rates (continuously growing forest systems only); a ratio between death rate at unlimited vs. severely limited N status, range 0-1
metabc(1)	metabolic C in surface litter (g·m^{-2})
metabc(2)	metabolic C in belowground litter (g·m^{-2})
metabe(1,1)	metabolic N in surface litter (g·m^{-2})
metabe(2,1)	metabolic N in belowground litter (g·m^{-2})
metcis(1,1)	metabolic surface litter unlabeled C (g·m^{-2})
metcis(1,2)	metabolic surface litter labeled C (g·m^{-2})
metcis(2,2)	metabolic belowground litter labeled C (g·m^{-2})
metcis(2,1)	metabolic belowground litter unlabeled C (g·m^{-2})
metmnr(1,1)	net mineralization for N for aboveground metabolic litter
metmnr(2,1)	net mineralization for N for belowground metabolic litter
minerl(1,...1)	initial value for mineral N for layer 1,... (gN·m^{-2})
minerl(1,...1)	mineral N content for layer 1,... (g·m^{-2})
minerl(nlayer +1,1)	deep storage layer for leached N
minlch	critical water flow for leaching of minerals (cm of water leached below 30 cm soil depth)
mt1c2(1)	accumulator for unlabeled surface CO_2 loss due to microbial respiration during litter decomposition
mt1c2(2)	accumulator for labeled surface CO_2 loss due to microbial respiration during litter decomposition
mt2c2(1)	accumulator for unlabeled soil CO_2 loss due to respiration
mt2c2(2)	accumulator for labeled soil CO_2 loss due to respiration
nfix	amount of symbiotic N-fixation (g·m^{-2}/month)
nfixac	accumulator for amount of symbiotic N-fixation (g·m^{-2}/month)
nlayer	number of soil layers in water model (max 9); used only to calculate the amount of water available for survival of the plant
nlaypg	number of soil layers in the top level of the water model; determines avh2o(1), used for growth and root death, range 1 to 10
nsnfix	=1 if nonsymbiotic N-fixation should be based on N:P ratio in mineral pool; otherwise nonsymbiotic N-fixation is based on annual precipitation
ntspm	number of time steps per month for the decomposition submodel
omlech(1)	intercept for the effect of sand on leaching of organic compounds
omlech(2)	slope for the effect of sand on leaching of organic compounds
omlech(3)	the amount of water (cm) that needs to flow out of water layer 2 to produce leaching of organics
p1co2a(1)	intercept parameter that controls flow from surface organic matter with fast turnover to CO_2 (fraction of C lost to CO_2 when there is no sand in the soil)
p1co2a(2)	intercept parameter that controls flow from soil organic matter with fast turnover to CO_2 (fraction of C lost to CO_2 when there is no sand in the soil)
p1co2b(1)	slope parameter that controls flow from surface organic matter with fast turnover to CO_2 (slope is multiplied by the fraction of sand content in the soil)
p1co2b(2)	slope parameter that controls flow from soil organic matter with fast turnover to CO_2 (slope is multiplied by the fraction of sand content in the soil)

p2co2	controls flow from soil organic matter with intermediate turnover to CO_2 (fraction of C lost as CO_2 during decomposition)
p3co2	controls flow from soil organic matter with slow turnover rate to CO_2 (fraction of C lost as CO_2 during decomposition)
pabres	amount of residue that will give maximum direct absorption of N ($gC\cdot m^{-2}$)
parent(1)	initial N value for parent material ($gN\cdot m^{-2}$)
parent(1)	parent material N ($g\cdot m^{-2}$)
pcemic(1,1)	maximum C:N ratio for surface microbial pool
pcemic(2,1)	minimum C:N ratio for surface microbial pool
pcemic(3,1)	minimum N content of decomposed aboveground material, above which the C:N ratio of the surface microbes equals pcemic(2,*)
peftxa	intercept parameter for regression equation to compute the effect of soil texture on the microbe decomposition rate (the effect of texture when there is no sand in the soil)
peftxb	slope parameter for the regression equation to compute the effect of soil texture on the microbe decomposition rate; the slope is multiplied by the sand content fraction
pet	monthly potential evapotranspiration (cm)
petann	annual potential evapotranspiration (cm)
pligst(1)	effect of lignin on surface structural or fine branch and large wood decomposition
pligst(2)	effect of lignin on soil structural or coarse root decomposition
pltmrf	planting month reduction factor to limit seedling growth; should be 1.0 for grass, range 0-1
pmco2(1)	surface; controls flow from surface metabolic to CO_2 (fraction of C lost as CO_2 during decomposition)
pmco2(2)	soil; controls flow from soil metabolic to CO_2 (fraction of C lost as CO_2 during decomposition)
pmnsec(1)	slope for N; controls the flow from mineral to secondary N (yr^{-1})
pmntmp	effect of biomass on minimum surface temperature
pmxbio	maximum dead biomass (standing dead + 10 percent litter) level for soil temperature calculation and for calculation of the potential negative effect on plant growth of physical obstruction by standing dead and litter
pmxtmp	effect of biomass on maximum surface temperature
pparmn(1)	N; controls the flow from parent material to mineral compartment (fraction of parent material flowing to mineral N, P, and S)
ppdf(1)	optimum temperature for production for parameterization of a Poisson density function curve to simulate temperature effect on growth
ppdf(2)	maximum temperature for production for parameterization of a Poisson density function curve to simulate temperature effect on growth
ppdf(1)	optimum temperature for production for parameterization of a Poisson density function curve to simulate temperature effect on growth
ppdf(2)	maximum temperature for production for parameterization of a Poisson density function curve to simulate temperature effect on growth
ppdf(3)	left curve shape for parameterization of a Poisson density function curve to simulate temperature effect on growth
ppdf(3)	left curve shape for parameterization of a Poisson density function curve to simulate temperature effect on growth
ppdf(4)	right curve shape for parameterization of a Poisson density function curve to simulate temperature effect on growth

ppdf(4)	right curve shape for parameterization of a Poisson density function curve to simulate temperature effect on growth
pprpts(1)	the minimum ratio of available water to PET that would completely limit production, assuming water content = 0, range 0 to 1
pprpts(2)	the effect of water content on the intercept; allows the user to increase the value of the intercept and thereby increase the slope of the line
pprpts(3)	the lowest ratio of available water to PET at which there is no restriction on production, range 0 to 1
pramn(1,1)	minimum C:N ratio with 0 biomass
pramn(1,2)	minimum C:N ratio with biomass = biomax
pramx(1,1)	maximum C:N ratio with 0 biomass
pramx(1,2)	maximum C:N ratio with biomass = biomax
prbmn(1,1)	intercept parameter for computing minimum C:N ratio for belowground matter as a linear function of annual precipitation
prbmn(1,2)	slope parameter for computing minimum C:N ratio for belowground matter as a linear function of annual precipitation
prbmx(1,1)	intercept parameter for computing maximum C:N ratios for belowground matter as a linear function of annual precipitation
prbmx(1,2)	slope parameter for computing maximum C:N ratios for belowground matter as a linear function of annual precipitation
prcann	annual precipitation (cm)
prcfal	fallow period precipitation; the amount of rain that falls during the months after harvest until the month before the next planting (cm)
prcskw (1,2...,12)	skewness value for January, February,..., December precipitation
prcstd (1, 2,...,12)	standard deviations for January, February,..., December precipitation value (cm·month^{-1})
prdx(1)	potential aboveground monthly production for crops (gC·m^{-2})
prdx(2)	gross forest production
prdx(3)	maximum forest production excluding respiration
precip (1,2,...,12)	precipitation for January, February,..., December (cm/month)
ps1co2(1)	surface; controls amount of CO$_2$ loss when structural decomposes to som1c
ps1co2(2)	soil; controls amount of CO$_2$ loss when structural decomposes to som1c
ps1s3(1)	intercept for flow from soil organic matter with fast turnover to som with slow turnover (fraction of C from som1c to som3c)
ps1s3(2)	slope for the effect of clay on the control of the flow from soil organic matter with fast turnover to som with slow turnover (fraction of C from som1c to som3c)
ps2s3(1)	slope value that controls flow from soil organic matter with intermediate turnover to soil organic matter with slow turnover (fraction of C from som2c to som3c)
ps2s3(2)	intercept value that controls flow from soil organic matter with intermediate turnover to soil organic matter with slow turnover (fraction of C from som2c to som3c)
psecmn(1)	N; controls the flow from secondary to mineral N
ptagc	growing season accumulator for potential aboveground C production for grass or crop (g·m^{-2}·y^{-1})

ptbgc	growing season accumulator for potential belowground C production for grass or crop ($g{\cdot}m^{-2}{\cdot}y^{-1}$)
pttr	potential transpiration water loss for the month
rad1p(1,1)	intercept used to calculate addition term for C:N ratio of slow som formed from surface active pool
rad1p(2,1)	slope used to calculate addition term for C:N ratio of slow som formed from surface active pool
rad1p(3,1)	minimum allowable C:N used to calculate addition term for C:N ratio of slow som formed from surface active pool
rain	monthly precipitation (cm)
rcelit(1,1)	initial C:N ratio for surface litter
rcelit(2,1)	initial C:N ratio for soil litter
rces1(1,1)	initial C:N ratio in surface organic matter with fast turnover (active som)
rces1(2,1)	initial C:N ratio in soil organic matter with fast turnover (active som)
rces2(1)	initial C:N ratio in soil organic matter with intermediate turnover (slow som)
rces3(1)	initial C:N ratio in soil organic matter with slow turnover (passive som)
rcestr(1)	C:N ratio for structural material (fixed parameter value)
rdr	maximum root death rate at very dry soil conditions (fraction/month); for getting the monthly root death rate, this fraction is multiplied by a reduction factor, depending on the soil water status, range 0 to 1
rtdtmp	physiological shutdown temperature for root death and change in shoot-to-root ratio
relyld	relative yield for grass, crop, or tree production
remf(1)	fraction of leaf live component returned, range 0 to 1
remf(2)	fraction of fine branch live component returned, range 0 to 1
remf(3)	fraction of large wood live component returned, range 0 to 1
remf(4)	fraction of fine branch dead component returned, range 0 to 1
remf(5)	fraction of large wood dead component returned, range 0 to 1
remwsd	fraction of the remaining residue that will be left standing, range 0 to 1
resp(1)	annual unlabeled CO_2 respiration from decomposition ($g{\cdot}m^{-2}$)
resp(2)	annual labeled CO_2 respiration from decomposition ($g{\cdot}m^{-2}$)
retf(1,1)	fraction of C returned in the live leaf component, range 0 to 1
retf(1,2)	fraction of N returned in the live leaf component, range 0 to 1
retf(2,1)	fraction of C returned in the fine branch component, range 0 to 1
retf(2,2)	fraction of N returned in the fine branch component, range 0 to 1
retf(3,2)	fraction of N returned in the large wood component, range 0 to 1
retf(3,1)	fraction of C returned in the large wood component, range 0 to 1
rictrl	root impact control term used by rtimp; used for calculating the impact of root biomass on nutrient availability
riint	root impact intercept used by rtimp; used for calculating the impact of root biomass on nutrient availability
rleavc	C in forest system leaf component ($g{\cdot}m^{-2}$)
rleave(1)	N in forest system leaf component ($g{\cdot}m^{-2}$)
rlvacc	growing season accumulator for C production in forest
rlvcis(1)	unlabeled C in forest system leaf component ($g{\cdot}m^{-2}$)
rlwacc	growing season accumulator for C production in forest system large wood component ($g{\cdot}m^{-2}{\cdot}y^{-1}$)
rlwcis(1)	unlabeled C in forest system large wood component ($g{\cdot}m^{-2}$)
rlwodc	C in forest system large wood component ($g{\cdot}m^{-2}$)
rlwode(1)	N in forest system large wood component ($g{\cdot}m^{-2}$)
rmvstr	fraction of the aboveground residue that will be removed, range 0 to 1

rsplig	fraction of lignin flow (in structural decomposition) lost as CO_2, range 0 to 1
rwcf(1,2...)	relative water content for layer 1,2...
rwcf(1,2...)	initial relative water content for layer 1,2...
s11c2(1)	accumulator for unlabeled CO_2 loss due to microbial respiration during soil organic matter decomposition of surface som1c to som2c
s11c2(2)	accumulator for labeled CO_2 loss due to microbial respiration during soil organic matter decomposition of surface som1c to som2c
s1mnr(1,1)	net mineralization for N for surface microbes som1e(1,1)
s1mnr(2,1)	net mineralization for N for active pool som1e(2,1)
s21c2(1)	accumulator for unlabeled CO_2 loss due to microbial respiration during soil organic matter decomposition of soil som1c to som2c and som3c
s21c2(2)	accumulator for labeled CO_2 loss due to microbial respiration during soil organic matter decomposition of soil som1c to som2c and som3c
s2c2(1)	accumulator for unlabeled CO_2 loss due to microbial respiration during soil organic matter decomposition of som2c to soil som1c and som3c
s2c2(2)	accumulator for labeled CO_2 loss due to microbial respiration during soil organic matter decomposition of som2c to soil som1c and som3c
s2mnr(1)	net mineralization for N for slow pool som2e(1)
s3c2(1)	accumulator for unlabeled CO_2 loss due to microbial respiration during soil organic matter decomposition of som3c to soil som1c
s3c2(2)	accumulator for labeled CO_2 loss due to microbial respiration during soil organic matter decomposition of som3c to soil som1c
s3mnr(1)	net mineralization for N for passive pool som3e(1)
sand	fraction of sand in soil, range 0 to 1
sapk	parameter controlling ratio of sapwood to total stem wood, expressed as $gC \cdot m^{-2}$; equal to both the large wood mass (rlwodc) at which half of large wood is sapwood, and the theoretical maximum sapwood mass achieved in mature forest
sclosa	accumulated C lost from soil organic matter by erosion (total C for entire simulation) ($g \cdot m^{-2}$)
scloss	total C loss from soil organic matter by erosion for current month ($g \cdot m^{-2}$)
sdrema	annual accumulator of C removed from standing dead during grazing or fire for grass or crop ($g \cdot m^{-2}$)
sdrmae(1)	annual accumulator of N removed from standing dead during grazing or fire for grass or crop ($g \cdot m^{-2}$)
sdrmai(1)	annual accumulator of unlabeled C removed from standing dead during grazing or fire for grass or crop ($g \cdot m^{-2}$)
sdrmai(2)	annual accumulator of labeled C removed from standing dead during grazing or fire for grass or crop ($g \cdot m^{-2}$)
secndy(1)	initial N value for secondary N ($gN \cdot m^{-2}$)
secndy(1)	secondary N ($g \cdot m^{-2}$)
seed	random number generator seed value
shrema	annual accumulator of C removed from shoots during grazing or fire for grass or crop ($g \cdot m^{-2}$)
shrmae(1)	annual accumulator of N removed from shoots during grazing or fire for grass or crop ($g \cdot m^{-2}$)
shrmai(2)	annual accumulator of labeled C removed from shoots during grazing or fire for grass or crop ($g \cdot m^{-2}$)
silt	fraction of silt in soil, range 0 to 1
sitlat	latitude of model site (deg) (for reference only)

sitlng	longitude of model site (deg) (for reference only)
sitpot	(savanna only) site potential; the N fraction
snfxac(1)	annual accumulator for symbiotic N-fixation for crop system
snfxac(2)	annual accumulator for symbiotic N-fixation for forest system
snfxmx(1)	symbiotic N-fixation maximum for grass or crop (gN fixed/gC new growth)
snfxmx(2)	symbiotic N-fixation maximum for forest (gN fixed/gC new growth)
snlq	liquid water in the snow pack (cm of water)
snow	snow pack water content (cm of water) output.def
soilnm(1)	annual accumulator for net mineralization of N in soil compartments (soil organic matter + belowground litter + dead coarse roots) (g·m^{-2})
som1c(1)	C in surface microbe pool (g·m^{-2})
som1c(2)	C in active soil organic matter (g·m^{-2})
som1ci(1,2)	initial value for labeled C in surface organic matter with fast turnover; used only if ivauto = 0 (gC·m^{-2})
som1ci(1,1)	initial value for unlabeled C in surface organic matter with fast turnover; used only if ivauto = 0 (gC·m^{-2})
som1ci(1,2)	labeled C in surface microbe pool (g·m^{-2})
som1ci(1,1)	unlabeled C in surface microbe pool (g·m^{-2})
som1ci(2,2)	initial value for labeled C in soil organic matter with fast turnover; used only if ivauto = 0 (gC·m^{-2})
som2ci(1)	initial value for unlabeled C in soil organic matter with intermediate turnover; used only if ivauto = 0 (gC·m^{-2})
som2ci(2)	initial value for labeled C in soil organic matter with intermediate turnover; used only if ivauto = 0 (gC·m^{-2})
som1ci(2,1)	initial value for unlabeled C in soil organic matter with fast turnover; used only if ivauto = 0 (gC·m^{-2})
som1ci(2,1)	unlabeled C in active soil organic matter (g·m^{-2})
som1ci(2,2)	labeled C in active soil organic matter with fast turnover rate (g·m^{-2})
som1e(1,1)	N in surface microbe pool (g·m^{-2})
som1e(2,1)	N in active soil organic matter (g·m^{-2})
som2c	C in slow pool soil organic matter (g·m^{-2})
som2ci(1)	unlabeled C in slow pool soil organic matter (g·m^{-2})
som2ci(2)	labeled C in slow pool soil organic matter (g·m^{-2})
som2e(1)	N in slow pool soil organic matter (g·m^{-2})
som3c	C in passive soil organic matter (g·m^{-2})
som3ci(2)	initial value for labeled C in soil organic matter with slow turnover; used only if ivauto = 0 (gC·m^{-2})
som3ci(2)	labeled C in passive soil organic matter (g·m^{-2})
som3e(1)	N in passive soil organic matter (g·m^{-2})
somsc	sum of labeled and unlabeled C from som1c, som2c, and som3c (g·m^{-2})
somsci(1)	sum of unlabeled C in som1c, som2c, and som3c
somsci(2)	sum of labeled C in som1c, som2c, som3c
somse(1)	sum of N in som1e, som2e, and som3e (g·m^{-2})
somtc	total soil C including belowground structural and metabolic (g·m^{-2})
somtci(1)	total unlabeled C in soil including belowground structural + metabolic
somtci(2)	total labeled C in soil including belowground structural + metabolic
somte(1)	total N in soil organic matter including belowground structural + metabolic
spl(1)	intercept parameter for metabolic (vs. structural) split, range 0 to 1
spl(2)	slope parameter for metabolic split (fraction metabolic is a function of lignin to N ratio), range 0 to 1

st1c2(1)	accumulator for unlabeled CO$_2$ loss due to microbial respiration during litter decomposition of surface structural into som1c and som2c
st2c2(1)	accumulator for unlabeled CO$_2$ loss due to microbial respiration during litter decomposition of soil structural into som1c and som2c
stdcis(1)	initial value for standing dead unlabeled C; used only if ivauto = 0 (gC·m^{-2})
stdcis(1)	unlabeled C in standing dead for grass or crop (g·m^{-2})
stdedc	C in standing dead material for grass or crop (g·m^{-2})
stdede(1)	initial value for N in standing dead; used only if ivauto = 0 (gN·m^{-2})
stdede(1)	N in standing dead for grass or crop (g·m^{-2})
stemp	average soil temperature (°C)
stormf	the fraction of flow from NLAYER to NLAYER+1 which goes into storm flow, 0-1
strcis(1,1)	unlabeled surface litter structural C (g·m^{-2})
strcis(2,1)	unlabeled belowground litter structural C (g·m^{-2})
stream(1)	cm water of stream flow (base flow + storm flow)
stream(2)	N from mineral leaching of stream flow (base flow + storm flow) (g·m^{-2})
stream(5)	C from organic leaching of stream flow (base flow + storm flow) (g·m^{-2})
stream(6)	N from organic leaching of stream flow (base flow + storm flow) (g·m^{-2})
strlig(1)	lignin content of surface structural residue
strlig(2)	lignin content of soil structural residue
strmax(1)	maximum amount of structural material in surface layer that will decompose (gC·m^{-2})
strmax(2)	maximum amount of structural material belowground that will decompose (gC·m^{-2})
strmnr(1,1)	net mineralization for N for surface structural litter
strmnr(2,1)	net mineralization for N for belowground structural litter
strucc(1)	surface litter structural C (g·m^{-2})
strucc(2)	belowground litter structural C (g·m^{-2})
struce(1,1)	surface litter structural N (g·m^{-2})
struce(2,1)	belowground litter structural N (g·m^{-2})
sumnrs(1)	annual accumulator for net mineralization of N from all compartments except structural and wood (g·m^{-2}·y^{1})
sumrsp	monthly maintenance respiration in the forest system (g·m^{-2})
swflag	flag indicating the source of the values for awilt and afield, either from actual data from the site.100 file or from equationsfrom Gupta and Larson (1979) or Rawls and others (1982). swflag = 0 use actual data from the site.100 file swflag = 1 use G & L for both awilt (-15 bar) and afiel (-0.33 bar) swflag = 2 use G & L for both awilt (-15 bar) and afiel (-0.10 bar) swflag = 3 use Rawls for both awilt (-15 bar) and afiel (-0.33 bar) swflag = 4 use Rawls for both awilt (-15 bar) and afiel (-0.10 bar) swflag = 5 use Rawls for afiel (-0.33 bar) with actual data for awilt swflag = 6 use Rawls for afiel (-0.10 bar) with actual data for awilt
swold	labeled C value for forest system fine root component (g·m^{-2})
tave	average air temperature (°C)
tcnpro	total C:N ratio for grass, crop, or tree production
tcrem	total C removed during forest removal events (g·m^{-2})
terem(1)	total N removed during forest removal events (g·m^{-2})
tmax	maximum temperature for decomposition (°C)
tmelt(1)	minimum temperature above which at least some snow will melt
tmelt(2)	ratio between degrees above the minimum and cm of snow that will melt

tminrl(1)	total mineral N summed across layers (g·m^{-2})
tmn2m (1,2,.,12)	January, February,..., December minimum temperature at 2 meters (°C)
tmx2m (1,2,.,12)	January, February,..., December maximum temperature at 2 meters (°C)
tnetmn(1)	annual accumulator of net mineralization for N from all compartments (g·m^{-2}·y^{-1})
tomres(1)	total unlabeled C in soil, belowground, and aboveground litter
tomres(2)	total labeled C in soil, belowground, and aboveground litter
topt	optimum temperature for decomposition (°C)
totalc	total C including source or sink
totale(1)	total N including source or sink
totc	minimum annual total nonliving C, where total is som1c(SOIL) + som1c(SRFC) + som2c + som3c + strucc(SOIL) + strucc(SRFC) + metabc(SOIL) + metabc(SRFC)
tran	monthly transpiration (cm)
tshl	shape parameter to left of the optimum temperature (for decomposition)
tshr	shape parameter to right of the optimum temperature
varat1(1,1)	maximum C:N ratio for material entering som1c
varat1(2,1)	minimum C:N ratio for material entering som1c
varat1(3,1)	amount N present when minimum ratio applies
varat2(1,1)	maximum C:N ratio for material entering som2c
varat2(2,1)	minimum C:N ratio for material entering som2c
varat2(3,1)	amount N present when minimum ratio applies
varat3(1,1)	maximum C:N ratio for material entering som3c
varat3(2,1)	minimum C:N ratio for material entering som3c
varat3(3,1)	amount N present when minimum ratio applies
vlosse	fraction per month of excess N (N left in the soil after nutrient uptake by the plant) that is volatilized, range 0 to 1
vlossg	fraction per month of gross mineralization that is volatilized, range 0 to 1
vlossp	fraction of aboveground plant N that is volatilized (occurs only at harvest), range 0 to 1
volex	volatilization loss as a function of mineral N remaining after uptake by grass, crop, or tree (g·m^{-2})
volexa	accumulator for N volatilization as a function of N remaining after uptake by grass, crop, or tree (total N for entire simulation) (g·m^{-2})
volgm	volatilization loss of N as a function of gross mineralization
volgma	accumulator for N volatilized as a function of gross mineralization (g·m^{-2}) (total N for entire simulation)
volpl	volatilization of N from plants during harvest for grass or crop
volpla	accumulator for N volatilized from plant at harvest for grass or crop (total N for entire simulation) (g·m^{-2})
w1lig	initial lignin content of dead fine branches (fraction of lignin in wood1c), range 0 to 1
w1lig	lignin content of dead fine branches of forest system (fraction lignin in wood1c)
w1mnr(1)	N mineralized from the wood1c (dead fine branch) component of a forest system (g·m^{-2})
w2lig	initial lignin content of dead large wood (fraction of lignin in wood2c), range 0 to 1

w2lig	lignin content of dead large wood of forest system (fraction lignin in wood2c)
w2mnr(1)	N mineralized from the wood2c (dead large wood) component of a forest system ($g \cdot m^{-2}$)
w3lig	lignin content of dead coarse roots of forest system (fraction lignin in wood3c)
w3lig	initial lignin content of dead coarse roots (fraction of lignin in wood3c), range 0 to 1
w3mnr(1)	N mineralized from the wood3c (dead coarse root) component of a forest system ($g \cdot m^{-2}$)
wd1cis(1)	unlabeled C in forest system wood1c (dead fine branch) material ($g \cdot m^{-2}$)
wd2cis(1)	unlabeled C in forest system wood2c (dead large wood) material ($g \cdot m^{-2}$)
wd3cis(2)	labeled C in forest system wood3c (dead coarse root) material ($g \cdot m^{-2}$)
wdfx	annual atmospheric and nonsymbiotic soil N-fixation based on annual precipitation (wet and dry deposition) ($g \cdot m^{-2}$)
wdfxa	annual N-fixation in atmosphere (wet and dry deposition) ($g \cdot m^{-2}$)
wdfxaa	annual accumulator for atmospheric N inputs ($g \cdot m^{-2} \cdot y^{-1}$)
wdfxas	annual accumulator for soil N-fixation inputs ($g \cdot m^{-2} \cdot y^{-1}$)
wdfxma	monthly N-fixation in atmosphere ($g \cdot m^{-2}$)
wdfxms	monthly nonsymbiotic soil N-fixation ($g \cdot m^{-2}$)
wdfxs	annual nonsymbiotic soil N-fixation based on precipitation rather than soil N:P ratio ($g \cdot m^{-2}$)
wdlig(1)	lignin fraction for forest system leaf production, range 0 to 1
wdlig(2)	lignin fraction for forest system fine root production, range 0 to 1
wdlig(3)	lignin fraction for forest system fine branch production, range 0 to 1
wdlig(4)	lignin fraction for forest system large wood production, range 0 to 1
wdlig(5)	lignin fraction for forest system coarse root production, range 0 to 1
wood1c	C in wood1c (dead fine branch) component of forest system ($g \cdot m^{-2}$)
wood1e(1)	N in wood1c (dead fine branch) component of forest system ($g \cdot m^{-2}$)
wood2c	C in wood2c (dead large wood) component of forest system ($g \cdot m^{-2}$)
wood2e(1)	N in wood2c (dead large wood) component of forest system ($g \cdot m^{-2}$)
wood3c	C in wood3c (dead coarse roots) component of forest system ($g \cdot m^{-2}$)
wood3e(1)	N in wood3c (dead coarse roots) component of forest system ($g \cdot m^{-2}$)
woodc	sum of C in wood components of forest system ($g \cdot m^{-2}$)
wooddr(1)	fraction of forest that is deciduous; the fraction of leaves that fall during senescence month or at the end of the growing season, range 0 to 1
wooddr(2)	monthly death rate fraction for fine root component, range 0 to 1
wooddr(3)	monthly death rate fraction for fine branch component, range 0 to 1
wooddr(4)	monthly death rate fraction for large wood component, range 0 to 1
wooddr(5)	monthly death rate fraction for coarse root component, range 0 to 1
woode(1)	sum of N in wood components of forest system ($g \cdot m^{-2}$)

4.4 Fire Parameters and Variables

4.4.1 Fire parameters and descriptions—

Name	Files	Description
ad	fire, fire_beh	exponent in optimum reaction velocity equation
ade	fire, fire_beh	exponent in optimum reaction velocity equation (energy release)
adec1	fuel_load	maximum annual decomposition rate for fine fuels
adec100	fuel_load	maximum annual decomposition rate for coarse fuels
adj_lai	fire_sta post-fire	woody LAI
aet_ann	fire_sta	annual actual evapotranspiration
b_eff	fire, fire_beh	wind effect exponent in phiwnd equation
bark_fac_c		ratio of bark thickness to dbh for conifers
bark_fac_h		ratio of bark thickness to dbh for hardwoods
bed_dep	fuel_load	depth of fuel bed
betbar	fire, fire_beh	packing ratio
betop	fire, fire_beh	optimum packing ratio
betope	fire, fire_beh	optimum packing ratio (energy release)
c_tree_lai	fuel_load	tree LAI estimated from leaf biomass
c_var	fire, fire_beh	intermediate variable in ufact equation
ch[365]	fire, fire_beh	crown height (m)
ck	fire, fire_beh	fraction of crown volume killed
cl[365]	fire, fire_beh	crown length (m)
cl_rat_c		ratio of length to tree height for conifers
cl_rat_h		ratio of crown length to tree height for hardwoods
d_1000hr	fuel_load	dead 1,000-hour fuel load
d_100hr	fuel_load	dead 100-hour fuel load
d_10hr	fuel_load	dead 10-hour fuel load
d_1hr	fuel_load	dead 1-hour fuel load
dbh	fuel_load	tree diameter at breast height
dead	fire_sta	dead grass accumulation
dead_accum	fire_sta	dead herb load
dedrt	fire, fire_beh	ratio in calculation of etamd
dedrte	fire, fire_beh	ratio in calculation of etamd (energy release)
defac	fuel_load	decomposition factor
depth	fire, fire_beh	effective fuel bed depth
dstnd	fuel_load	standing dead grass (from CENTURY)
dwod1	fuel_load	dead fine wood (from CENTURY)
dwod100	fuel_load	dead coarse wood (from CENTURY)
dwood	fuel_load	dead wood (dwod1 + dewod2)

Name	Files	Description
e_eff	fire, fire_beh	wind effect exponent in ufact equation
end	fire, fire_beh	Julian date for end of current month
end_gs	fire_sta	Julian date for end of growing season
etamd	fire, fire_beh	moisture damping coefficient of dead fuels
etamde	fire, fire_beh	moisture damping coefficient of dead fuels (energy release)
etaml	fire, fire_beh	moisture damping coefficient of live fuels
etamle	fire, fire_beh	moisture damping coefficent of live fuels (energy release)
etasd	fire, fire_beh	mineral damping coefficient of dead fuels
etasl	fire, fire_beh	mineral damping coefficient of live fuels
f1	fire, fire_beh	1-hour weighting factor
f10	fire, fire_beh	10-hour weighting factor
f100	fire, fire_beh	100-hour weighting factor
f1000e	fire, fire_beh	1,000-hour weighting factor (energy release)
f100e	fire, fire_beh	100-hour weighting factor (energy release)
f10e	fire, fire_beh	10-hour weighting factor (energy release)
f1e	fire, fire_beh	1-hour weighting factor (energy release)
fd	fire, fire_beh	flame depth
fdead	fire, fire_beh	dead fuel weighting factor
fdeade	fire, fire_beh	dead fuel weighting factor (energy release)
fherb	fire, fire_beh	live herb weighting factor
fherbe	fire, fire_beh	live herb weighting factor (energy release)
fi[days_per_year]	fire, fire_beh	Byram’s fire line intensity
fl[days_per_year R]	fire, fire_beh	flame length
flamm_thres	fire_sta	flammability threshold
flive	fire, fire_beh	live fuel weighting factor
flivee	fire, fire_beh	live fuel weighting factor (energy release)
fwood	fire, fire_beh	live wood weighting factor
fwoode	fire, fire_beh	live wood weighting factor (energy release)
gmamx	fire, fire_beh	maximum reaction velocity
gmamxe	fire, fire_beh	maximum reaction velocity (energy release)
gmaop	fire, fire_beh	optimum reaction velocity
gmaope[365]	fire, fire_beh	optimum reaction velocity (energy release)
grass	lfuel_mc	live grass moisture content

Name	Files	Description
grass_decay	fire_sta d	dead grass decay rate
grass_stress[days_per_year]	fire_sta soil	moisture available to grass roots
hd	fire, fire_beh	dead fuel heat of combustion
hl	fire	live fuel heat of combustion
hn1	fire, fire_beh	1-hour heating number
hn10	fire, fire_beh	10-hour heating number
hn100	fire, fire_beh	100-hour heating number
hnherb	fire, fire_beh	live herb heating number
hnwood	fire, fire_beh	live wood heating number
ht	fire, fire_beh	tree height (m)
ht	fuel_load	tree height
htsink	fire, fire_beh	heat sink
ic[365]	fire, fire_beh	National Fire Danger Rating System (NFDRS) ignition component
ir	fire, fire_beh	reaction intensity
ire[365]	fire, fire_beh	reaction intensity (energy release)
k_coeff		Beer’s Law coefficient
l_1000hr	fuel_load	live fuel load - 1,000 hour (g·m^{-2})
l_100hr	fuel_load	live fuel load - 100 hour (g·m^{-2})
l_10hr	fuel_load	live fuel load - 10 hour (g·m^{-2})
l_1hr	fuel_load	live fuel load - 1 hour (g·m^{-2})
last_yr_snw	fire_dat	snowpack at end of previous year
lat	d_fuel	latitude of cell
lgras	fuel_load	grass carbon (g·m^{-2})
lig1	fuel_load	lignin content of fine dead wood
lig100	fuel_load	lignin content of coarse dead wood
lightn[DAYS_PER_YEAR]	fire_sta	lightning probability
lit_accum	fire_sta	litter load
lit_bd	fire_sta	bulk density (gm/m^{3}) of horizontal fine fuels
litfall	fire_sta	litterfall
littr	fuel_load	litter biomass (g·m^{-2})
livrt	fire, fire_beh	ratio in calculation of etaml
livrte	fire, fire_beh	ratio in calculation of etaml (energy release)
lleaf	fuel_load	leaf biomass (g·m^{-2})
ltree	fuel_load	tree biomass (g·m^{-2})
lwod1	fuel_load	live fine wood biomass (g·m^{-2})
lwod100	fuel_load	live coarse wood biomass (g·m^{-2})
lwood	fuel_load	live wood biomass (g·m^{-2})
m_grass_stress[YEAR]	fire_sta, lfuel_mc	soil moisture available to grass roots
m_pet[12]	fire_dat, fire_sta	monthly potential evaporatranspiration (mm)
m_ppt[12]	fire_dat, fire_sta	monthly precipitation (mm)
m_ppt_rat[12]	fire_dat	rate of monthly precipitation (in·hour^{-1})
m_rad[12]	fire_dat	monthly radiation
m_rh[12]	fire_dat, fire_sta	monthly relative humidity
m_tmp[12]	fire_dat, fire_sta	monthly temperature (°C)
m_tree_stress	lfuel_mc	soil moisture available to tree roots

Name	Files	Description
m_ws[12]	fire_dat	monthly wind speed (m·min^{-1})
mc_1[DAYS_PER_YEAR]	fire, fire_beh	dead fuel moisture: 1-hour fuels
mc_10[DAYS_PER_YEAR]	fire, fire_beh	dead fuel moisture: 10-hour fuels
mc_100[DAYS_PER_YEAR]	fire, fire_beh	dead fuel moisture: 100-hour fuels
mc_1000[DAYS_PER_YEAR]	fire, fire_beh	dead fuel moisture: 1,000-hour fuels
mc_1000hr[365]	d_fuel	dead fuel moisture: 1,000-hour fuels
mc_100hr[365]	d_fuel	dead fuel moisture: 100-hour fuels
mc_10hr[365]	d_fuel	dead fuel moisture: 10-hour fuels
mc_1hr[365]	d_fuel	dead fuel moisture: 1-hour fuels
mc_ext	fuel_load	level of fuel moisture above which a fire is not possible
mc_grass[DAYS_PER_YEAR]	fire, fire_beh	live grass moisture content
mc_grass_max	fire_sta	maximum live grass moisture content
mc_grass_min	fire_sta	minimum live grass moisture content
mc_thres		1,000-hour fuel moisture content threshold for fire events
mc_tree[365]	fire, fire_beh	live tree foliage moisture content
mc_tree_max		max live tree moisture content
mc_tree_min		min live tree moisture content
mclfe	fire, fire_beh	dead_fuel moisture for live-fuel extinction moisture
melt_b	fire_sta	snowmelt coefficient
mlittr	fuel_load	metabolic litter carbon (g·m^{-2})
mixed_bd		bulk density vertical and horizontal fine fuels mix
mxd	fire	moisture extinction of dead fuels
mxd[365]	fire_beh	moisture extinction of dead fuels
mxday	fire_sta	Julian day of maximum lethal scorch height
mxl	fire, fire_beh	moisture extinction of live fuels
mxlsh	fire_sta	maximum lethal scorch height
no_mlt	fire_sta	snowmelt coefficient
p_flamm[DAYS_PER_YEAR]	d_fuel	probability of fire start
p_lightn[12]	fire_dat	probability of lightning
partial cell burn		switch to turn partial burning of grid cells on (1) or off (0)
pet[365]	fire_dat	daily potential evapotranspiration
phislp	fire, fire_beh	slope effect multiplier
phiwnd	fire, fire_beh	wind effect multiplier
pligst	fuel_load	lignin effect on decomposition
ppt[365]	d_fuel, fire_dat	daily precipitation (mm)
ppt_ann	fire_sta	annual precipitation (mm)
ppt_events[12]	fire_dat	number of ppt events per month
ppt_rat[365]	d_fuel, fire_dat	daily rate of ppt (in·hour^{-1})
prf[365]	fire, fire_beh	probability of reportable fire
propr_rat[365]	fire, fire_beh	compaction of fuel
propr_rate[365]	fire, fire_beh	compaction of fuel
rad[365]	d_fuel, fire_dat	daily radiation

Name	Files	Description
rh[365]	d_fuel, fire_dat	daily relative humidity (percent)
rh_corr[365]	d_fuel	relative humidity shade correction
rhobar	fire, fire_beh	weighted fuel density
rhobed	fire, fire_beh	bulk density of fuel bed
rhod	fire, fire_beh	dead fuel particle density
rhol	fire, fire_beh	live fuel particle density
ros[DAYS_PER_YEAR]	fire, fire_beh	rate of spread
ros_thres		threshold of rate of fire spread
sa1	fire, fire_beh	1-hour surface area
sa10	fire, fire_beh	10-hour surface area
sa100	fire, fire_beh	100-hour surface area
sadead	fire, fire_beh	total surface area of dead fuels
saherb	fire, fire_beh	live herb surface area
salive	fire, fire_beh	total surface area of live fuels
sawood	fire, fire_beh	live wood surface area
scn[365]	fire, fire_beh	normalized ros
sd	fire, fire_beh	silica-free mineral fraction of dead fuels
sg1	fire, fire_beh	ratio of 1-hour surface area to volume
sg10	fire, fire_beh	ratio of 10-hour surface area to volume
sg100	fire, fire_beh	ratio of 100-hour surface area to volume
sg1000	fire, fire_beh	ratio of 1,000-hour surface area to volume
sgbrd	fire, fire_beh	ratio of dead fuel characteristic surface area to volume
sgbrde	fire, fire_beh	ratio of dead fuel characteristic surface area to volume (energy release)
sgbrl	fire, fire_beh	ratio of live fuel characteristic surface area to volume
sgbrle	fire, fire_beh	ratio of live fuel characteristic surface area to volume (energy release)
sgbrt	fire, fire_beh	ratio of characteristic surface area to volume
sgbrte	fire, fire_beh	ratio of characteristic surface area to volume (energy release)
sgherb	fire, fire_beh	ratio of live herb surface area to volume
sgwood	fire, fire_beh	ratio of live wood surface area to volume
sh[DAYS_PER_YEAR]	fire, fire_beh	van Wagner’s maximum height of lethal scorch
shrub_bio	fire_sta	shrub biomass estimated from LAI
shrub_ht	fire_sta	height estimated from LAI
sl	fire, fire_beh	silica-free mineral fraction of live fuels
slittr	fuel_load	structural litter carbon ($g \cdot m^{-2}$)
slp	fire, fire_beh	slope
slpfct	fire, fire_beh	slope effect multiplier coefficient

Name	**Files**	**Description**
snow[365]	d_fuel, fire_dat	daily snowpack (mm)
snowfall[365]	d_fuel, fire_dat	daily snowfall (mm)
snowmelt[365]	d_fuel, fire_dat	daily snowmelt (mm)
snw0	fire_sta	snowmelt coefficient
snw1	fire_sta	snowmelt coefficient
start	fire, fire_beh	first Julian day of current month
start_gs	fire_sta	Julian date for start of growing season
std	fire, fire_beh	mineral fraction of dead fuels
stems	fuel_load	number of stems per square meter
stl	fire, fire_beh	mineral fraction of live fuels
tau	fire, fire_beh	residence time of the flaming front
temp_corr[365]	d_fuel	temperature shade correction
temp_corr[DAYS_PER_YEAR]	fire_sta	temperature shade correction
tmp[365]	d_fuel, fire, fire_dat	daily temperature (°C)
total_accum	fire_sta	dead herb load + litter load
tovr1	fuel_load	fine live wood turnover rate
tovr100	fuel_load	coarse live wood turnover rate
tree	lfuel_mc	live tree foliage moisture content
tree_bio	fire_sta	tree biomass estimated from LAI
tree_ht	fire_sta	height estimated from LAI
tree_lai	fire_sta	tree leaf area index ($m^2 \cdot m^{-2}$)
ufact	fire, fire_beh	wind effect multiplier in phiwnd equation
upright_bd		bulk density ($g \cdot m^{-3}$) of vertical fine fuels
w10[365]	fire_beh	10-hour dead fuel load
w100[365]	fire_beh	100-hour load
w1000[365]	fire_beh	1,000-hour load
w100n	fire, fire_beh	combustible 100-hour load
w10n	fire, fire_beh	combustible 10-hour load
w1n	fire, fire_beh	combustible 1-hour load
w1p[DAYS_PER_YEAR]	fire, fire_beh	1-hour load (dead_accum + lit_accum)
wdeadn	fire, fire_beh	weighted net loading of dead fuels
wdedne[365]	fire, fire_beh	weighted net loading of dead fuels (energy release)
wherb	rothermal	live grass fuel load ($g \cdot m^{-2}$)
wherbn	fire, fire_beh	combustible live herb load
wherbp[DAYS_PER_YEAR]	fire, fire_beh	live herb load
wliven	fire, fire_beh	weighted net loading of live fuels
wlivne[365]	fire, fire_beh	weighted net loading of live fuels (energy release)
wndfac	rothermal	wind reduction factor
wndfac[365]	fire_beh	daily wind reduction factor
wndfac_for	fire_sta	forest wind reduction factor
wndfac_grass	fire_sta	grassland wind reduction factor
wndfac_sav	fire_sta	savanna wind reduction factor
wndfc	fire, fire_sta	wind reduction factor
woody_decay	fire_sta	litter decay rate

Name	Files	Description
wrat	fire, fire_beh	ratio of dead to live heating numbers (heating numbers are specified for each fuel class [$lb \cdot ft^{-3}$] and correspond to what must be heated to ignition temperature before flaming combustion begins)
ws[365]	fire, fire_da, d_fuel	daily wind speed ($m \cdot min^{-1}$)
wtmcd	fire, fire_beh	weighted moisture content of dead fuels
wtmcde[365]	fire, fire_beh	weighted moisture content of dead fuels
wtmcl	fire, fire_beh	weighted moisture content of live fuels
wtmcle[365]	fire, fire_beh	weighted moisture content of live fuels
wtot	fire, fire_beh	total load
wtotd	fire, fire_beh	total dead load
wtotl	fire, fire_beh	total live load
wwood	fire, fire_beh	live shrub load
wwoodn	fire, fire_beh	combustible live wood load
zeta	fire, fire_beh	no wind propagating flux ratio (amount of heat energy moving from burning fuels into adjacent unburning fuels ($Btu \cdot ft^{-2} \cdot min^{-1}$); the no-wind calculation of the propagating flux assumes no flame kill due to wind)

4.4.2 Fire parameter values—Tables 18 and 19 list the parameters and values in the MC1 files `fire_param.dat` and `thres.dat.`

Table 18—Parameters and values in MC1 parameter file, fire_param.dat

Parameter	Value	Parameter	Value
bark_fac_c	0.07	mc_grass_max	120
bark_fac_h	0.001	mc_grass_min	30
cl_rat_c	0.4	mc_thres	15.0
cl_rat_h	0.99	mc_tree_max	130
hd	8000	mc_tree_min	80
hl	8000	melt_b	1.5
k_coeff	.50	mixed_bd	4440
lit_bd	4440	no_mlt	1.0

Table 19—Parameters and values in the MC1 parameter file, thres.dat

Parameter	Value	Parameter	Value
partial cell burn	0	slp	12.67
ros_thres	60.0	snw0	3.0
sg1	2500	snw1	0.0
sg10	109	upright_bd	1000
sg100	30	wndfac_for	0.4
sg1000	8	wndfac_grass	0.6
sgherb	2500	wndfac_sav	0.5
sgwood	1500		

4.5 Output Variables

Table 20 includes a selected set of output variables for VEMAP.

Table 20—Selected set of output variables for VEMAP

Module	Variable name	Variable definition
Biogeography	vclass	VEMAP vegetation class (22)
	agg_vclass	Aggregated VEMAP vegetation class (7)
Biogeochemistry	max_tree	Maximum LAI value for trees
	max_grass	Maximum LAI value for grasses
	aglivc	Live grass leaf carbon
	bglivc	Live grass root carbon
	frstc	Total tree live carbon
	rleafc	Live tree leaf carbon
	fcacc	Total tree net primary production
	bgcacc	Grass root net primary production
	agcacc	Grass aboveground net primary production
	mxnfix	Nitrogen-fixation
	nppx	Net primary production (tree + grass)
	nepx	Net ecosystem production (tree + grass + soil)
	aetx	Actual evapotranspiration
	rnfx	Runoff
	vegc	Live vegetation carbon (tree + grass)
	soilc	Soil carbon
	minx	Mineralization
Fire	bio_consume	Biomass consumed
	part_burn	Fraction of grid cell burned

Acknowledgments

GIS assistance was provided by Ray Drapek of the College of Forestry, Oregon State University, Corvallis, Oregon. Documentation of this model was compiled by Lisa Balduman of the USDA Forest Service, Pacific Northwest Research Station, Corvallis, Oregon. Funding was provided by the USDA Forest Service, U.S. Department of Energy - NIGEC, and the USGS Biological Resources Division.

References

Bachelet, D.; Brugnach, M.; Neilson, R.P. 1998. Sensitivity of a biogeography model to soil properties. Ecological Modelling. 109: 77-98.

Bachelet, D.; Daly, C.; Lenihan, J.M. [and others]. 2001. Interactions between fire, grazing, and climate change at Wind Cave National Park, SD. Ecological Modelling. 134: 229-244

Bradshaw, L.S.; Deeming, J.E.; Burgan, R.E.; Cohen, J.D. 1984. The 1978 national fire danger rating system: a technical documentation. Gen. Tech. Rep. INT-169. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 44 p.

Daly, C.; Bachelet, D.; Lenihan, J.M. [and others]. 2000. Dynamic simulation of tree-grass interactions for global change studies. Ecological Applications. 10(2): 449-469.

Food and Agriculture Organization. 1974-79. Soil map of the world. Paris, France: United Nations Educational, Scientific and Cultural Organization. Vol. I-X.

Fosberg, M.A. 1972. Moisture content calculations for the 100-hour timelag fuel in fire danger rating. Res. Note RM-199. [Fort Collins, CO]: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 7 p.

Fosberg, M.A.; Deeming, J.E. 1971. Derivation of the 1- and 10-hour timelag fuel moisture calculations for fire danger rating. Res. Note RM-207. [Fort Collins, CO]: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 8 p.

Fosberg, M.A.; Rothermal, R.C.; Andrews, P.A. 1981. Moisture content calculations for 1000-hr fuels. Forest Science. 27(1): 19-26 .

Gilmanov, T.G.; Parton, W.J.; Ojima, D.S. 1997. Testing the 'CENTURY' ecosystem level model on data sets from eight grassland sites in the former USSR representing a wide climatic/soil gradient. Ecological Modelling. 96(1-3): 191-210.

Gupta, S.C.; Larson, W.E. 1979. Estimating soil water retention characteristics from particle size distribution, organic matter content and bulk density. Water Resources Research. 15: 1633-1635.

Haxeltine, A.; Prentice, I.C.; Cresswell, I.D. 1996. A coupled carbon and water flux model to predict vegetation structure. Journal of Vegetation Science. 7(5): 651-666.

Howard, E.A. 1978. A simple model for estimating the moisture content of living vegetation as potential wildfire fuel. In: 5th conference on fire and forest meteorology; 1978 March 14-16; Atlantic City, NJ. Boston MA: American Meteorological Society: 20-23.

Jarvis, P.G.; Leverenz, J.W. 1983. Productivity of temperate, deciduous, and evergreen forests. In: Lange, O.L.; Nobel, P.S.; Osmond, C.B.; Ziegler, H., eds. Encyclopedia of plant physiology, vol. 12D. Berlin: Springer-Verlag: 234-280.

Keane, R.E.; Long, D.G. 1998. A comparison of coarse scale fire effects simulation strategies. Northwest Science. 72(2): 76-90.

Kern, J.S. 1995. Geographic patterns of soil water-holding capacity in the contiguous United States. Soil Science Society of America Journal. 59: 1126-1133.

Kittel, T.G.F.; Rosenbloom, N.A.; Painter, T.H. [and others]. 1995. The VEMAP integrated database for modelling United States ecosystem/vegetation sensitivity to climate change. Journal of Biogeography. 22: 857-862.

Kittel, T.G.F.; Royle, J.A.; Daly, C. [and others]. 1997. A gridded historical (1895-1993) bioclimate dataset for the conterminous United States: Proceedings of the 10th conference of applied meteorology; 1997 October 20-24; Reno, NV. Boston MA: American Meteorological Society.

Leemans, R.; Cramer, W.P. 1991. The IIASA database for mean monthly values of temperature, precipitation and cloudiness on a global terrestrial grid. Laxenburg, Austria: International Institute for Applied Systems Analysis (IIASA). 62 p.

Lenihan, J.M.; Daly, C.; Bachelet, D.; Neilson, R.P. 1998. Simulating broad-scale fire severity in a dynamic global vegetation model. Northwest Science. 72(2): 91-103.

Lenihan, J.M.; Neilson, R.P. 1993. A rule-based formation model for Canada. Journal of Biogeography. 20: 615-628.

Linacre, E.T. 1977. A simple formula for estimating evaporation rates in various climates, using temperature data alone. Agricultural Meteorology. 18: 409-424.

McGuire, A.D.; Melillo, J.M.; Kicklighter, D.W.; Joyce, L.A. 1995. Equilibrium responses of soil carbon to climate change: empirical and process based estimates. Journal of Biogeography. 22(4-5): 785-796.

Means, J.E.; Hansen, H.A.; Koerper, G.J. [and others]. 1994. Software for computing plant biomass–BIOPAK users guide. Gen. Tech. Rep. PNW-GTR-340. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 184 p.

Metherall, A.K.; Cole, C.V.; Parton, W.J. 1993. Dynamics and interactions of carbon, nitrogen, phosphorus, and sulfur cycling in grazed pastures. In: Proceedings of the 17th International Grassland Congress: [Dates and location of meeting unknown]. [Publisher and location unknown]: 1420-1421.

Neilson, R.P. 1995. A model for predicting continental-scale vegetation distribution and water balance. Ecological Applications. 5(2): 362-385.

Parton, W.J.; Schimel, D.S.; Cole, C.V.; Ojima, D.S. 1987. Analysis of factors controlling soil organic matter levels in Great Plains grasslands. Soil Science Society of America Journal. 51: 1173-1179.

Parton, W.J.; Schimel, D.S.; Ojima, D.S; Cole, C.V. 1994. A general study model for soil organic matter dynamics, sensitivity to litter chemistry, texture, and management. In: Quantitative modeling of soil forming processes. SSSA Spec. Publ. 39. Madison, WI: Soil Science Society of America: 147-167.

Peterson, D.L.; Ryan, K.C. 1986. Modeling postfire conifer mortality for long-range planning. Environmental Management. 10: 797-808.

Prentice, I.C.; Cramer, W.; Harrison, S. [and others]. 1992. A global biome model based on plant physiology and dominance, soil properties and climate. Journal of Biogeography. 19: 117-134.

Probert, M.E.; Keating, B.A.; Thompson, J.P.; Parton, W.J. 1995. Modelling water, nitrogen, and crop yield for a long-term fallow management experiment. Australian Journal of Experimental Agriculture. 35: 941-950.

Rawls, W.J.; Brakensiek, D.L.; Saxton, K.E. 1982. Estimation of soil water properties. Transactions of the American Society of Agricultural Engineers. (Vol. no. unknown):

1316-1328.

Rothermel, R.E. 1972. A mathematical model for predicting fire spread in wildland fuels. Res. Pap. INT-115. [Place of publication unknown]: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 40 p.

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

Running, S.W.; Gower, S.T. 1991. FOREST-BGC, a general model of forest ecosystem processes for regional applications. II: Dynamic carbon allocation and nitrogen budgets. Tree Physiology. 9: 147-160.

Stanek, W.; State, D. 1978. Equations predicting productivity (biomass) of trees, shrubs and lesser vegetation based on current literature. Rep. 183. Victoria, BC: Pacific Forest Research Centre, Canadian Forestry Service. 58 p.

Soil Conservation Service. 1987. Basic statistics, 1982. Natl. Resour. Inven., Stat. Bull. 756. Ames, IA: Iowa State University. 153 p.

Steward, F.R.; Peter, S.; Richon, J.B. 1990. A method for predicting the depth of lethal heat penetration into mineral soils exposed to fires of various intensities. Canadian Journal of Forest Research. 20: 919-926.

van Wagner, C.E. 1973. Height of crown scorch in forest fires. Canadian Journal of Forest Research. 3: 373-378

van Wagner, C.E. 1993. Prediction of crown fire behavior in two stands of jack pine. Canadian Journal of Forest Research. 23: 442-449.

VEMAP Members. 1995. Vegetation/ecosystem modeling and analysis project: comparing biogeography and biogeochemistry models in a continental-scale study of terrestrial ecosystem responses to climate change and CO_2 doubling. Global Biogeochemical Cycles. 9(4): 407-437.

WeatherDisc Associates. 1995. World WeatherDisc: climate data for planet Earth. Seattle, WA: WeatherDisc Associates.

Woodward, F.I.; Smith, T.M.; Emanuel, W.R. 1995. A global primary productivity and phytogeography model. Global Biogeochemical Cycles. 9: 471-490.

Appendix 1: List of Subroutines

Subroutine	File	Called from	Input/output
access_file	bfuncs.c	read_inputs	file, filename, status
AccumulateTranspiration	transpire	TranspireStep	curr_mo, pot_transp, water, soil
add_mapssvars	mapss_1t	century_eq_1d, mapss_1d	cen_outvars, year, data_point
AddAttributes_nc	nc_output	AddAttributes_nc_bgc, AddAttributes_nc_All	fileid, cmdline
AddAttributes_nc_All	nc_output	init_io	cmdline
AddAttributes_nc_bgc	nc_out_bgc	init_io	cmdline
adjilig	adjilig.F	cultiv, partit	oldc, frnew, addc, fract1
adjust_parameters	read_site_parm	load_globals	
AdjustMaxlai	grasses_equil	GrassWoodyEquilibrium	excess, site, tmp, lai, maxlai, grass_lai, deciduous, data_point, curr_mo
Aet2LaiProductivity	grasses_equil	CheckEvergreen	state, tmp, maxlai, at2lai, lifeform
alloc_bgc_buffer	io_general	mapss_2tt, century_equilibrium_2d	data_point, bgc_data, bgc_length
alloc_input_data	io_general	mapss_equilibrium_2d, mapss_2tt, century_equilibrium_2d	input_data, data_size, var_list
alloc_nc_globals	nc_input	OpenAllNCFFiles	max_climate_len
alloc_output_data	io_general	mapss_2tt	mapss_output, years_to_run
annacc	annacc.F	eachyr, prelim	
annual_budget	wbcalc	classic_water_balance	budget, capacity, row, col
ApplyLifeformRules	lifeform_rules	climate_prep	data_point
ArgFileInit	mapss_main.c	process_command_line	files
assign	fire_behav	fire_behav, fire	data_point, i
at_assess	bfuncs	ReiterateLaiCycle	site
Biogeog	biogeog	mapss_1d	data_point
BroadDecid	lifeform_rules	CheckEvergreen, ApplyLifeformRules	cats, productivity, IsTree, SecondTime, data_point
buffer_bgc_data	mapss_1t	century_eq_1d, add_mapssvars, mapss_1d	bgc_outvars, data_point, bgc_data, year, mo
burn_index	dfuel_mc	DFuelMC	
calc_fc_wp	swp	set_drainage_constants	sand, clay, eff_thickness, matrix_pot_a, field_cap, wilt_pt, Theta_m, layer
calc_hycon	swp	saturated_drainage	sand, clay, h2o , layer
calc_swhc	swp	set_drainage_constants	sand clay, eff_thickness, layer
calc_swp	swp	transpire	sand, clay, pct_soil_h2o, layer
calciv	calciv.F	detiv	
CalcPenmon	pet_calc	CalcPet	data_point, lifeform

Subroutine	File	Called from	Input/output
CalcPet	pet_calc	GrassAlone, pet_adjust, InitPet	data_point, lifeform, PetCalc
CalcSatvp	pet_calc	InitPet	data_point
CalcTrbxfr	pet_calc	CalcPet	
calculate_budget	wbcalc	process_data	prev_mo, curr_mo, change, capacity
cen_end	csa_main.F	MAPSS_1T	
cen_init	csa_main.F	MAPSS_1T	yr, vveg, diag_flag, os_flag, state, outvars, path, mx, c3c4, initflag, fm, zn, tmpi, ppti
cen_init_climate	init_climate.F	MAPSS_1T	ppt, tmax, tmin
cen_init_lat	init_lat.F	MAPSS_1T	lat, elev
cen_init_soils	init_soils.F	MAPSS_1T	bd, sand, cly, depth, rock, ws
cen_step	csa_main.F	MAPSS_1d	vveg_in, wbegin, wend, cbegin, cend, csene, wfire, cfire, treec, cropc, state, outvars, mx, mx_out, c3c4, c3c4_out, tname, cname, diag_flag, os_flag, burn_out, burn_count, tmpi, tmpi_out, ppti, ppti_out
century_equilibrium_1d	mapss_1t	century_equilibrium_2d	data_point, input_data, cen_data
century_equilibrium_2d	mapss_main.c	mapss	data_point
CenturyFCarbToMapssLai	mapss_1t	mapss_1d	carbon
CenturyFCarbToMapssLaiSLA	mapss_1t	mapss_1d	grass_carbon, woody_carbon, index, grass_lai, woody_lai
check_at_flag	at_flag	pre_mapss_initialize	
check_param_values	read_site_parm	read_site_specific, read_parameters	
CheckEvergreen	grasses_equil	GrassWoody	data_point, site, lai, grass_lai, maxlai, site_begin, offset_begin, lai_values, c3c4_ratio, canopy_type, mapss_output
CheckStateValues	grasses_equil	GrassWoodyEquilibrium, GrassAloneEquilibrium, LaiCycleEquilibrium	curr_mo, lastyear, threshold, mo, base
ckdata	ckdata.F	cultin, fertin, firein, grazin, harvin, irrgin, omadin, tremin, cropin, sitein, treein	routin, expect, found
classic_water_balance	wbcalc	GrassWoody	ppt, pet, row, col, budget, capacity
ClassifyStation	classification	GrassWoody, CheckEvergreen	dat_point, lai_values, c3c4_ratio, canopy_type
climate_prep	mapss_equil	mapss_equilibrium_1d, mapss_1t	data_point
close_io	io_general	main_finalize	var_list
CloseAllNCFiles	nc_input	close_io	var_list
CloseNCFile	nc_input	CloseAllNCFiles	data_file
CloseOutputNC_All	nc_output	close_io	
cmplig	cmplig.F	eachyr, cropin	cursys, fligni, wdlig, pltlig
cnvrt_units	dfuel_mc	DFuelMC	
co2eff	co2eff.F	eachyr, schedl	time
command_line_defaults	mapss_main.c	process_command_line	data_point
consump	fire_eff	fire_eff, fire	data_point, day
CreateOutputNC	nc_output	CreateOutputNC_bgc, CreateOutputNC_All	nc_idvals, interval, filename, row_begin, row_end, col_begin, col_end, f, filter_length
CreateOutputNC_All	nc_output	init_io	filename, row_begin, row_end, col_begin, col_end
CreateOutputNC_bgc	nc_out_bgc	init_io	filename, row_begin, row_end, col_begin, col_end

Subroutine	File	Called from	Input/output
crop	crop.F	simsom	time, wfunc
cropin	cropin.F	schedl	tomatch
cropmix	cropmix.F	cropin, veg_change	
crown_fire	fire_behav	fire_behav, fire	data_point, mo, day
crown_kill	fire_eff	fire_eff, fire	data_point, mo, day
csched	csched.F	cultiv, declig, dshoot, harvst, litburn, litdec, partit, respir, soilos, somdec, cutrtn, dedrem, grem, growth, killrt, livrem, trees, wdeath	cflow, protop, probot, froma1, tob1, froma2, tob2, frac, accum
cultin	cultin.F	schedl	tomatch, curcult
cultiv	cultiv.F	crop	pltlig
cutrtn	cutrtn.F	frem	accum
cycle	cycle.F	simsom	month, cancvr, wfunc
daily_dat	fire_data	fire_data	
daily_ppt	fire_data	fire_data	data_point
daylen_	daylen.c	simsom	month, sitlat
dead_wood	fuel_load	fuel_load	data_point, mo, yr
declig	declig.F	litdec, woodec	aminrl, ligcon, lyr, nelem, nlr, ps1co2, rnew, rsplig, tcflow, tcstva, csrsnk, cstatv, elstva, gromin, minerl, netmnr, resp, som1ci, som1e, som2ci, som2e
decomp	decomp.F	simsom	dtm, decsys
dedrem	dedrem.F	frem	accum
DesertRules	classification	ClassifyStation	zone
detiv	csa_detiv.F	cen_init	
DFuelMC	dfuel_mc	mapss_1d	data_point, year
DistributePpt	distrib	GrassWoody, LaiCycle	curr_mo, data_point, lai, mo
droot	droot.F	crop	pltlig
DrySoilCheck	transpire	transpiration	curr_mo, SoilData
dshoot	dshoot.F	crop	wfunc
eachyr	eachyr.F	stand_step, cen_step, standard	
efold	mapss_1t	efold_climate, efold_climate_init, efold_lai, efold_biogeog	efold_t, current, previous
efold_biogeog	mapss_1t	mapss_1d, efold_lai	years, data_point
efold_climate	mapss_1t	mapss_1t	year, data_point, input_data
efold_climate_init	mapss_1t	mapss_init	data_point, input_data
efold_lai	mapss_1t		years, data_point, lai_values, lai
emissions	fire_eff	fire_eff	data_point, month, day
eq_test	eq_test.F	stand_step, standard	eq_flag, min_years, final_growth
erosn	erosn.F	simsom	psloss, bulkd, edepth, enrich, lhzci, lhze, nelem
esched	esched.F	declig, litdec, somdec	cflow, tca, rcetob, anps, bnps, labile, mnrflo
EvaluateSite	grasses_equil	GrassWoody	state, data_point, lai
excess_at_events_count	transpire	main_finalize	
extend	extend.F	detiv	in, dowrite
FallFreeze	lifeform_rules	TempZone	data_point
falstd	falstd.F	crop, wthini	pltlig
faterr	faterr.F	weathr	itell1, itell2
fertin	fertin.F	schedl	tomatch, curfert, savedfert

Subroutine	File	Called from	Input/output
final_pet	wbcalc	GrassWoody	pet, pet_adj
find_param_value	read_site_parm	read_site_param	var_name
FindIIndex	lifeform_rules	ApplyLifeformRules	fdd
FindMaxLai	mapss_1t	lai_allocate	lai, lf
FindMeanLai	grasses_equil	GrassWoody, CheckEvergreen, lai_allocate	lai, total_lai, lifeform
FindRatio	lifeform_rules	ApplyLifeformRules	x,slope, y_intercept
FindSlopeYIntercept	lifeform_rules	pre_mapss_initialize	X1, Y1, X2, Y2, slope, y_intercept
FindStartPosition	nc_input	InputNCValues	row, col
Fire	fire		data_point, yr, mo, cen_state
fire_condition	bfuncs.c	GrassWoody	grass_sum_lai, shrub_lai, pet, ppt
FireBehavior	fire_behav	mapss_1d	data_point, mo
FireData	fire_data	mapss_1d	data_point, yr, cen_state, woody_fire, grass_fire
FireEffect	fire_eff	mapss_1d	data_point, mo, cen_state
firein	firein.F	schedl	tomatch, curfire
FireOccur	fire_occur	mapss_1d	data_point, yr, mo
FireSched	fire_sched	mapss_1d	data_point, mo, yr, woody_fire, grass_fire, cen_state
firrtn	firrtn.F	frem	
fixin	fixin.F	detiv	
flammability	dfuel_mc	DFuelMC	
floclr	floclr.F	prelim	
floclr_	floclr.c	prelim	i
flow	flow.F	csched, cultiv, dshoot, erosn, esched, firrtn, harvst, litburn, partit, pschem, respir, soilos, cutrtn, dedrem, grem, growth, killrt, livrem, simsom, trees, wdeath	var1, var2, when, howmch
flow_	flow.c	flow.F	from, to, when, howmuch
flow_err	ferr.c	flowl.c, flow.c	error_num, when
flowl_	flowl.c	flowl.F	from, to, when, howmuch
flowup	flowup.F	calciv, crop, cultiv, harvst, simsom, trees	time
flowup_	flowup.c	flowup.F	time
ForestRules	classification	ClassifyStation	data_point, lai_values, zone
free_bgc_buffer	io_general	mapss_2tt, century_equilibrium_2d	data_point, bgc_data
free_input_data	io_general	mapss_equilibrium_2d, mapss_2tt, century_equilibrium_2d, mapss_equilibrium_2d	input_data, var_list
frem	frem.F	simsom, trees	
fuel_depth	fuel_load	fuel_load	data_point
fuel_mc	dfuel_mc	DfuelMC	data_point, year
FuelLoad	fuel_load	mapss_1d	cen_outvars, cen_state, data_point, yr, mo
get_command_line	mapss_main.c	process_command_line	argc, argv
get_daily	fire_behav	fire_behav, fire	data_point, mo
get_input	io_general	mapss_equilibrium_2d, mapss_2tt	input_data, data_size, var_list
get_jul	fire_behav	fire_behav, fire	data_point, mo

Subroutine	File	Called from	Input/output
get_var_len	nc_input	OpenAllNCFFiles	data_file
GetCheckRowCol	mapss_main.c	process_command_line	arg, name, beg, end
GetFilePath	mapss_main.c	process_command_line	user_path, model, include_path, default_name, default_path
GrassAlone	grasses_equil	GrassWoody	site, lai, conductance, data_point
GrassAloneEquilibrium	grasses_equil	GrassAlone	site, mo, lai, months, row, col
GrassPotAtSatisfied	transpire	TranspireStep	pot_at, curr_mo, conductance, lai, grass_lai, begin_h2o,pot_transp, data_point, mo, curr_canopy_cond_max
GrassRules	classification	ClassifyStation	lai_values, zone, c3c4_ratio, canopy_type
GrassWoody	grasses_equil	LaiCycle	conductance, lai, grass_lai, maxlai, curr_year, prev_year, data_point, site_begin, offset_begin, mapss_output
GrassWoodyEquilibrium	grasses_equil	GrassWoody	site, mo, tmp, lai, maxlai, grass_lai, pet_adj, months, shrubs, deficit, deciduous, data_point, curr_mo
grazin	grazin.F	schedl	tomatch, curgraz
grem	grem.F	simsom	
GrowingDegreeDays	lifeform_rules	ApplyLifeformRules	tmp, degree
growth	growth.F	crop	cisofr
H2oCompetition	transpire	TranspireStep	lai, h2o_fraction, conductance, data_point
h2olos	h2olos.F	cycle	months, aliv, alit, adead, co2val
harvin	harvin.F	schedl	tomatch, curharv
harvst	harvst.F	simsom	month, pltlig
HeatLimitedRules	classification	ClassifyStation	data_point, zone
ignition	fire	fire	data_point, yr, i
infiltrate	drain	transpiration	site, SoilData
init_data_point	mapss_equil	mapss_equilibrium_1d, mapss_1t	data_point
init_data_size	io_general	mapss_equilibrium_2d, mapss_2tt, century_equilibrium_2d	data_size, row, col, years
init_io	io_general	main_initialize	data_point, all_files, cmdlines
init1	fire_data	fire_data	data_point, yr
init2	dfuel_mc	DfuelMC	data_point
Init3	fire_behav	fire_behav, fire	data_point
init4	fire_eff	fire_eff	data_point, start, end
InitConductance	woody_equil	GrassWoody, LaiCycle	conductance, grass, woody
InitOutputFilter	io_general	init_io	filename, f, filter_length
InitPet	misc_init	climate_prep, mapss_1t	data_point
InitPoint	misc_init	init_data_point	data_point
InitSnow	drain	LaiCycle, GrassWoody, GrassAlone	data_point, curr_year
InitSoilWater	drain	LaiCycle,GrassWoody, GrassAlone	curr_year, SoilData
inprac	inprac.F	prelim, cycle	
input_leaf_root_areas	mapss_equil	CheckEvergreen, lai_limit	lai, tmp, offset, grasslai, deciduous, tree_upperbound
InputNCValues	nc_input	get_input	input_data, data_size, var_list
intensity	fire_behav	fire_behav, fire	data_point, i
irrgin	irrgin.F	schedl	tomatch, curirri
killrt	killrt.F	frem	accum
lacalc1	lacalc1.F	potfor	lai, rleavc

Subroutine	File	Called from	Input/output
lacalc2	lacalc2.F	potfor	lai, rlwodc, maxlai, klai
lai_allocate	mapss_1t	mapss_1d	lai_values, lai, data_point
lai_at_adequate	transpire	ReiterateLaiCycle	state, lai, lifeform, tmp, row, col, broadleaf
lai_limit	mapss_equil	mapss_equilibrium_1d	data_point, lai, grass_lai, maxlai, offset
LaiCycle	woody_equil	CheckEvergreen, mapss_equilibrium_1d	maxlai, lai, grass_lai, offset, data_point, site_begin, offset_begin, mapss_output
LaiCycleEquilibrium	woody_equil	LaiCycle	curr_mo, mo, months, equilibrium_factor
leach	leach.F	simsom	amov, nelem, nlayer, minerl, minlch, frlech, stream, basef, stormf
LFuelMC	lfuel_mc	mapss_1d	cen_state, data_point, yr, mo
Lifeform	lifeform	mapss_1d	data_point, lai
LightAttenuate	grasses_equil	GrassWoody, GrassWoodyEquilibrium, AdjustMaxlai, GrassAlone, AdjustMaxLai	tmp, maxlai, grass_lai, lai, deciduous, data_point, site
lightning	fire_data	fire_data	
litburn	litburn.F	firrtn, grem, frem	litrme
litdec	litdec.F	decomp	dtm
live_mc	lfuel_mc	LfuelMC	data_point
live_wood	fuel_load	fuel_load	data_point, mo, yr
livrem	livrem.F	frem	accum
load_arg_file	mapss_main.c	process_command_line	argc, argv
load_globals	mapss_main.c	main_initialize	data_point, all_files
load_init_bgc	nc_out_bgc	mapss_2tt	filename, row, col, dat
LoadOutputFilter	io_general	show_avail_outvars, init_io	f, filter_length
LoadOutputFilter_bgc	io_general	show_avail_outvars, init_io	f, filter_length
main	mapss_main.c	*** THIS IS THE START OF IT ALL	rgc, argv
main_finalize	mapss_main.c	mapss	data_point
main_initialize	mapss_main.c	mapss	data_point, all_files, cmdline
mapss	mapss_main.c	main	argc, argv
mapss_1d	mapss_1t	mapss_1t	data_point, mapss_output, state_mapss_1d, cen_data, year, cen_state
mapss_1t	mapss_1t	mapss_2tt	data_point, mapss_output, input_data, cen_data
mapss_2tt	mapss_main.c	mapss	data_point
mapss_equilibrium_1d	mapss_equil	mapss_equilibrium_2d, mapss_2tt, century_equilibrium_2d	data_point, mapss_output
mapss_equilibrium_2d	mapss_main.c	mapss	data_point
mapss_init	mapss_1t	mapss_1t	initflag, data_point, cen_outvars, input_data
MapssToVemapConvert	classification_bgc	process_command_line, mapss_2tt, century_equilibrium_2d	class
minimum_reserve	drain	ReiterateLaiCycle	site, lai, maxlai, SoilData
MinMaxTemp	lifeform_rules	TempZone	data_point
MixIndex	lifeform_rules	ApplyLifeformRules	data_point
mnracc	mnracc.F	declig, litdec, somdec	mnrflo, gross, net
MonthMin	lifeform_rules	ProcessSeason	current, next, prior, min, period
mortality	fire_eff	fire_eff, fire	data_point, mo, day

Subroutine	File	Called from	Input/output
nc_output_bgc	nc_out_bgc	store_output_bgc	mask, data_point, bgc_data
nc_output_month	nc_output	store_output	data_point, mapss_output
nc_output_year	nc_output	store_output	data_point, mapss_output
NewFireCondition	bfuncs.c	rassWoody	grass_sum_lai, tree_lai, shrub_lai, site, zone, SoilData,broadleaf
NewMonthlyLai	woody_equil	LightAttenuate, LaiCycle, GrassWoody	maxlai, grass_lai, tmp, lai, deciduous, zone, gdd, site
NewProcessSeason	lifeform_rules	BroadDecid	data_point
no_deficit	wbcalc	annual_budget	budget, capacity, row, col
no_excess	wbcalc	annual_budget	budget, row, col
NoDeficits	grasses_equil	GrassWoodyEquilibrium	deficit
NorthernHemiSet	misc_init	climate_prep, century_eq_1d, mapss_1t	
nutrlm	nutrlm.F	restrp	nelem, nparts, cprodl, eprodl, maxec, maxeci, mineci, cfrac, eavail, nfix, sngxmx, snfxzc, elimit, eup
omadin	omadin.F	schedl	tomatch, curomad
OneThreshold	lifeform_rules	TimeInterval	curr_tmp, next_tmp, frost_line
OpenAllNCFiles	nc_input	init_io	data_root, data_set, data_dir, var_list
OpenNCFile	nc_input	OpenAllNCFFiles	data_root, data_set, data_dir, data_file
pad_data	io_general	get_input	input_data, data_size, var_list
part_burn	fire_sched	FireSched	data_point, yr
partit	partit.F	calciv, crop, cultiv, droot, falstd, harvst, cutrtn, grem, killrt, trees, wdeath	cpart, recres, lyr, cdonor, edonor, frlign, friso
pet_adjust	transpire	GrassWoody, GrassWoodyEquilibrium, GrassAlone	lai, data_point
potcrp	potcrp.F	cycle	month, cancvr
Potential	transpire	H2OCompetition	lai, conductance, zone, LaiUpperBoundWater, lifeform, broadleaf
PotentialAt	transpire	TranspireStep	pot_transp, lai, conduct, k0, k1, data_point, lifeform
PotentialAtPenmon	transpire	TranspireStep	curr_canopy_cond_max, lai, stomatal_conduct, k0, data_point, lifeform, mo
PotentialLai	transpire	GrassPotAtSatisfied	k0, k1, transp, pot_transp, conduct, data_point, lifeform
PotentialLaiPenmon	transpire	GrassPotAtSatisfied	k0, k1, transp, stomatal_conduct, data_point, lifeform, mo, curr_canopy_cond_max
potfor	potfor.F	cycle	month
prcgrw	prcgrw.F	cycle	imnth
pre_mapss_initialize	mapss_equil	main_initialize	data_point
predec	predec.F	prelim, cen_step, readblk	sand
prelim	prelim.F	detiv	
prelim	fire_behav	fire_behav, fire	i
process_command_line	mapss_main.c	mapss	argc, argv, all_files, data_point
process_data	wbcalc	annual_budget	prev_mo, curr_mo, capacity
ProcessSeason	lifeform_rules	BroadDecid	data_point, frost_line, ppt_ptr
PS_Century	c3c4_functions	ApplyLifeformRules	meantemp, ratio, canopy
pschem	pschem.F	simsom	dtm
RainfallEvents	lifeform_rules	ApplyLifeformRules	data_point

Subroutine	File	Called from	Input/output
read_inputs	read_site_parm	read_site_specific, read_parameters	file, max
read_parameters	read_site_parm	load_globals	file
read_scale	nc_input	ReadSite, ReadClimate	varid, start, count, dat
read_site_specific	read_site_parm	load_globals	file, SoilData
readblk	readblk.F	detiv, stand_step, standard	years_to_run
ReadClimate	nc_input	InputNCValues	input_data, var_list, start, count
READCLIN	readblk.F	readblk	
ReadFireParams	fire_param	mapss_1t, load_globals	data_point
ReadGeoHeader	nc_input	init_io	geo_header
ReadNCValues	nc_input	read_scale, ReadSoilsData	data_file, start, count, values
ReadSite	nc_input	InputNCValues	input_data, var_list, start, count, full_start
ReadSoilsData	nc_input	ReadSite	start, count, soil_data
ReiterateLaiCycle	woody_equil	LaiCycle	curr_year, prev_year, lai, maxlai, inc_mode, offset, data_point, lifeform
release	fire_behav	fire_behav, fire	i
respir	respir.F	declig, somdec	co2los, nlr, lyr, tcstva, cstatv, csrsnk, resp, estatv, minerl, gromin, netmnr
restrp	restrp.F	growth, trees	nelem, nparts, avefrc, cerat, cfrac, potenc, rimpct, storage, snfxmx, cprodl, eprodl, eup, uptake, elimit, nfix, relyld, snfxac, svuptk
root_kill	fire	fire	data_point, yr, day, cen_state
row_col_init	io_general	init_io	data_point, geo_heade
saturated_drainage	drain	transpiration	site, layer, destination, SoilData
satvp	satvp	CalcSatvp	d_point
savarp	savarp.F	prelim, simsom	
scale	scale.F	cropmix	f, val1, val2, result
scale4	scale4.F	treemix	f, ic, val1, val2, val3, val4, result
schedl			schedl.F cycle
SecondEvergreen	lifeform_rules	BroadDecid	data_point, productivity, IsTree
set_drainage_constants	drain	soil_prep	SoilData
set_hemisphere	mapss_equil	mapss_equilibrium_1d, mapss_1t	row_cur, equator_row
set_initial_bgc_vars	mapss_1t	mapss_1t	data_point
set_lai_bounds	mapss_equil	lai_limit	data_point
set_pm_globals	pm	InitPet	ts_yr, ta_yr, ea_yr, u_yr
set_transpire_constants	transpire	pre_mapss_initialize	
set_var_list	io_general	main_initialize	var_list, run_mode
SetCurrPrev	woody_equil	GrassWoody, LaiCycle	months, site, curr_mo, prev_mo, lai, currlai
SetEffectiveThickness	drain	set_drainage_constants	SoilData
SetOutputElsePoint	station_out	store_output	data_point, class, mapss_output
SetOutputMaskPoint	station_out	store_output	data_point, class, mapss_output
SetUpNCFiles	nc_input	OpenAllNCFFiles	var_list
shade_rad	dfuel_mc	fuel_mc	data_point, year, month
shade_rh	dfuel_mc	fuel_mc	data_point, year, month
shade_temp	dfuel_mc	fuel_mc	data_point, year, month
show_avail_outvars	io_general	process_command_line	
show_version_info	station_out	process_command_line	prog_name, revision, file

Subroutine	File	Called from	Input/output
ShrubRules	classification	ClassifyStation	data_point, lai_values, zone
simsom	simsom.F	stand_step, cen_step, standard	
sitein	sitein.F	detiv	ivopt
SnarfInitialLai	one_step	process_command_line	lai, lai_str
snow_cond	fire_data	fire_data	data_point
SnowAndMelt	lifeform_rules	ApplyLifeformRules	data_point
soil_prep	mapss_equil	mapss_equilibrium_1d, mapss_1t	data_point
soilos	soilos.F	erosn	time, nelem, nlr, flost, somc, somci, csrsnk, some, esrsnk
somdec	somdec.F	decomp	dtm
SouthernHemiSwap	misc_init	climate_prep, century_eq_1d, apss_1t	data_point
spread	fire_behav	fire_behav, fire	data_point, i
SpringThaw	lifeform_rules	TempZone	data_point
stand_step	csa_main.F	MAPSS_1T	state, outvars, eq_flag, final_growth, diag_flag, os_flag
statein	passvars.F	cen_step	state
stateinit	passvars.F	cen_init	state
stateout	passvars.F	cen_init, stand_step, cen_step	state
Stomatal Conductance	transpire	TranspireStep	site, pet, lifeform, conductance, mo, shrubs, zone, broadleaf
store_event	store_event.F	readblk	
store_output	io_general	mapss_equilibrium_2d, mapss_2tt	input_result, mapss_result, mapss_output, data_point
store_output_bgc	io_general	mapss_2tt, century_equilibrium_2d	input_result, bgc_data, data_point
sumcar	sumcar.F	calciv, crop, cultiv, harvst, detiv, simsom, trees	
surface_runoff	drain	transpiration	site, SoilData
SwapYears	woody_equil	ReiterateLaiCycle, GrassWoody	curr_year, prev_year
TempZone	lifeform_rules	climate_prep	data_point
TimeInterval	lifeform_rules	ProcessSeason	curr_tmp, next_tmp, frost_line, period
transpiration	transpire	GrassWoody, GrassAlone, LaiCycle	curr_mo, pet, conductance, lai, grass_lai, mo, data_point
TranspireStep	transpire	transpiration	curr_mo, conductance, lai, grass_lai, pet, mo, data_point
tree_dim	fuel_load	fuel_load	data_point, mo, yr
treein	treein.F	schedl	tomatch
treemix	treemix.F	treein, veg_change	
trees	trees.F	simsom	month, cisotf, wfunc
TreeSavannaRules	classification	ClassifyStation	data_point, lai_values, zone
tremin	treminimumF	schedl	tomatch, curtrm
unsaturated drainage	drain	transpiration	site, layer, destination, SoilData
update_event	update_event.F	cen_step	
update_sched	update_sched.F	cen_step	
varsin	passvars.F	cen_init	outvars
varsinit	passvars.F	cen_init	outvars
varsout	passvars.F	cen_init, stand_step, cen_step	outvars
veg_change	veg_change.F	cen_step	
Vemap2Mon	vemap2_mo	mapss_1d	data_point, mo, cen_state
vetocen	vetocen.c	cen_step	
vetofix	vetofix.c	cen_init	vclass, fixname

Subroutine	File	Called from	Input/output
WaterBalance	transpire	transpiration	site, excess_pot_at
wdeath	wdeath.F	trees	tave, wfunc
weathr	weathr.F	eachyr	precip, prcstd, prcskw, mintmp, maxtmp
woodec	woodec.F	decomp	dtm
wrtbin	wrtbin.F	stand_step, cen_step, standard	time
wthini	wthini.F	readblk	precip, prcstd, prcskw, mintmp, maxtmp
xfer_climate_year	io_general	century_eq_1d, mapss_1t, efold_climate_init, mapss_equilibrium_2d, mapss_2tt, century_equilibrium_2d	input_data, data_point, year, var_list
xfer_site	io_general	mapss_1t, mapss_equilibrium_2d, mapss_2tt, century_equilibrium_2d	input_data, data_point
xfer_to_output	mapss_1t	mapss_1d	data_point, mapss_output, lai_values, lai, burn_year

Appendix 2: Routine Calling Sequence

MC1 is run in two successive modes: equilibrium and transient. First, MAPSS is run to produce an initial vegetation class corresponding to the climax vegetation for the equilibrium climate (case I stops there). This vegetation map is read by the biogeochemical module, which runs for up to 3,000 years—until the slow pool of soil organic matter reaches equilibrium—and generates the initial conditions for the transient run (case II stops here). Finally, transient climate and the initial condition file are read by MC1, which calculates monthly pools of carbon and nitrogen for each lifeform. These pools are interpreted by the biogeographic module to determine if the vegetation types should be changing or not. Pool sizes also are read by the fire module, which can trigger a fire (case III).

CASE I:

MAPSS_EQUILIBRIUM

1) Initialization:

- **main** (mapss_main)
  - **mapss** (mapss_main)
    - **process_command_line** (mapss_main) - i/o
    - **main_initialize** (mapss_main) - opens files, initializes variables

2) EQ MAPSS is first run to give CENTURY an initial vegetation grid.

- **mapss_equilibrium_2d** (mapss_main)
  - Miscellaneous data input and initialization subroutines
  - **mapss_equilibrium_1d** (mapss_equil)
    - **init_data_point** (mapss_equil) - sets various parts of data_point to initial dummy values
    - **set_hemisphere** (mapss_equil) - checks if current row is above or below equator, or set on command line
    - **soil_prep** (mapss_equil) - returns error if missing soils data, checks valid soil data, checks/adjusts soil composition variables
    - **climate_prep** (mapss_equil) - does Southern Hemisphere adjustments to climate, sets temperature zone, snow fall and melt, rain events, growing degree days, vapor pressure deficit with ApplyLifeformRules. Calculates PET (InitPet), checks precipitation limits.
    - **lai_limit** (mapss_equil) - calls set_lai_bounds to set LaiUpperBoundEnergy, calls input_leaf_root_areas to set maxlai
    - **LaiCycle** (woody_equil)
      - **InitConductance** (woody_equil)
      - **InitSoilWater** (drain)
      - **InitSnow** (woody_equil)
      - **SetCurrPrev** (woody_equil)
      - **DistributePpt** (distrib)

transpiration (transpire)
LaiCycleEquilibrium (woody_equil)
ReiterateLaiCycle (woody_equil)
GrassWoody (grasses_equil)
SwapYears (woody_equil)
NewMonthlyLai (woody_equil)
store_output (io_general)
free_input_data (io_general)

CASE II

CENTURY_EQUILIBRIUM

(1) Initialization:
main (mapss_main)
mapss (mapss_main)
process_command_line (mapss_main) - input/output
main_initialize (mapss_main) - opens files, initializes variables

(2) EQ MAPSS is first run to give CENTURY an initial vegetation grid.
century_equilibrium_2d (mapss_main)
Miscellaneous data input and initialization subroutines
mapss_equilibrium_1d (mapss_equil)
See Case I.
MapssToVemapConvert (classification_bgc)

(3) EQ CENTURY takes the vegetation type output by EQ-MAPSS and calculates associated C and N pools corresponding to equilibrium conditions by using long term climate data input (1 year repeated). This runs until slow soil C is stabilized (up to 3,000 years for forest types).
century_equilibrium_1d (mapss_1t)
Miscellaneous data input and initilization subroutines.
cen_init (csa_main) - steps through standard CENTURY to get output and state, until EQ
vetofix - translates VEMAP vegetation classes into CENTURY fix file names
stateinit (passvars) – initializes all state variables to zero. After, calls statein() to disburse zeros to global state variables
detiv (csa_detiv) - CENTURY initialization: determines name of schedule file which contains the name of site file, values of | timing variables, and order of events
fixin - sets values of fixed parameters and initial values (xfix.100 files)
sitein - reads the parameter file (.100 files)
extend - reads from binary file until EOF
cropin - obtains the new crop or forest system values
cmplig - recalculates plant lignin; returns the fraction of residue
cropmix - calculates intermediate values of selected crop.100 parameters based on a C3/C4 index
treein - reads in the new forest type
treemix - calculates an index (function of temperature) and calculates all the lifeform dependent parameters (tree.100 files)
calciv - calculates initial values for temperature, water, and live root carbon variables
sumcar - sums carbon to get annual totals

- **prelim** - preliminary initialization and calculation of variables and parameters
    - **annacc** - resets annual accumulators
    - **inprac** - initializes annual production accumulators
    - **predec** - preliminary set-up (once at the start of each run) for comp. related to decomposition of soil organic matter
    - **savarp** - computes variables for printing or plotting
    - **flowclr** - clears the C and N flow stack
- **readblk** - reads the next block of events from the schedule file
    - **wthini** - determines which weather data will be used
- **varsin** (passvars) - distributes CENTURY output variables after pass from MAPSS
- Reports back to MAPSS with new outvars and state.
- **stateout** (passvars) - collects CENTURY state variables for pass to MAPSS
- **varsout** (passvars) - collects CENTURY output variables for pass to MAPSS
- **xfer_climate_year** - copies climate variables from input_data to data_point for a single year. Assumes monthly data in input_data.
    - **SouthernHemiSwap** or **NorthernHemiSet** - sets up climate data for CENTURY
- **cen_init_climate** (init_climate) - initializes climate data

Monthly loop:

- **stand_step** (csa_main) - runs CENTURY in standard mode once model has been initialized. Broken out from csa_main
    - **readblk** - reads the next block of events from the schedule file
        - **wthini** - determines what weather data will be used
    - **eachyr** - performs tasks that only need to be done once a year (annual loop)
        - **annacc** - resets annual accumulators
        - **weathr** - determines current year values for precipitation, temperature and next year's values for predicting production potential
        - **co2eff** - computes the effect of atmospheric CO_2 concentration
        - **cmplig** - computes plant lignin; returns the fraction of residue
    - **simsom** - simulates flow of carbon and nitrogen (main driver for the model)
        - **cycle** - determines relative water content, available water, and decomposition factor related to temperature and water
            - **schedl** - determines the next set of scheduling options from .sch file
                - **cropin** - reads in the new crop type
                    - **cmplig** - computes plant lignin
                    - **cropmix** - calculates intermediate values of selected crop.100 parameters
                - **co2eff** - computes the effect of atmospheric CO_2 concentration
                - **omadin** - reads in the new omad type
                - **grazin** - reads in the new graze type
                - **firein** - reads in the new fire type
                - **treein** - reads in the new forest type (Read in as default, DN, EN, DB, EB)
                    - **treemix** - calculates an index (function of temp) and all the lifeform dependent parameters
                - **co2eff** - computes the effect of atmospheric CO_2 conc.
                - **tremin** - reads in the new tree removal type
            - **inprac** - initializes annual production accumulators
            - **prcgrw** - computes a growing season precipitation

---

PRODUCTION SUBMODEL

Crop system

- **potcrp** - computes monthly production potential based on monthly precipitation
    - **lacalc1** - calculates LAI as a function of leaf C

Forest system

- **potfor** - computes monthly potential production for a forest
  - **lacalc1** - calculates LAI as a function of leaf C
  - **lacalc2** - calculates LAI as a function of wood; also averages with lacalc1 LAI

Hydrology

- **h2olos** - determines co2 effect on transpiration, calculates all hydrological flows

DECOMPOSITION SUBMODEL

decomp - decomposes structural and metabolic components for surface and soil

Litter

- **litdec** - litter decomposition
  - Computes total C flow out of structural, metabolic in layers: SRFC/SOIL
    - **declig** - decomposes stuff containing lignin (structural and wood)
      - **respir** - computes flows associated with microbial respiration
      - **csched** - schedules C flows for decomposition
      - **esched** - schedules N flow and associated mineralization or immobilization
      - **mnracc** - updates mineralization accumulators
      - **csched** - schedules C flows for decomposition
      - **esched** - schedules N flow and associated mineralization or immobilization
        - **mnracc** - updates mineralization accumulators

Wood

- **woodec** - wood decomposition routine
  - Computes total C flow out of fine branches, large wood, coarse roots
  - **declig** - decomposes stuff containing lignin (structural and wood)
    - **respir** - computes flows associated with microbial respiration
    - **csched** - schedules C flows for decomposition
    - **esched** - schedules N flow and assoc mineralization or immobilization
    - **mnracc** - updates mineralization accumulators

Soil organic matter

- **somdec** - soil organic matter decomposition: SOM1 (surface and soil), SOM2, and SOM3. (som1 to som2, som1 to som3, som 2 to som 3, som 2 to som1,som3 to som1)
  - **respir** - computes flows associated with microbial respiration
  - **csched** - schedules C flows for decomposition
  - **esched** - schedules N flow and associated mineralization or immobilization
  - **mnracc** - updates mineralization accumulators

Final Calculations

- Updates decomposition and nitrogen flows:
  - **flowup** - completes the flows that were scheduled to occur at or before “time”
  - **sumcar** - sums carbon to get totals
  - **erosn** - erosion routine
    - **soilos** - computes soil loss for som1, som2, or som3

DEATH SUBMODEL

Grassland

- **crop** - driver for calling all of crop code
  - **falstd** - simulates fall of standing dead for the month

- **droot** - simulates death of roots for the month
- **dshoot** - simulates death of shoots for the month
- **flowup** - completes the flows that were scheduled to occur at or before ‘time’
- **sumcar** - sums carbon to get totals
- **growth** - simulates production for the month
    - **restrp** - restricts actual production based on C:N ratios. Calculates minimum, maximum whole plant nutrient concentration
        - **nutrlm** - ‘nutrient limitation for plants is based on demand’
- **grem** - simulates removal of crop or grass by fire or grazing for the month

Forest

- **trees** - simulates forest production for the month
    - **wdeath** - death of leaves, fine branches, large wood, fine roots, and coarse roots
    - **flowup** - completes the flows that were scheduled to occur at or before “time”
    - **sumcar** - sums carbon to get totals
    - **frem** - forest removal - fire or cutting (includes storms and litter burning in forest)
        - **livrem** - removal of live biomass from cutting or fire in a forest
        - **dedrem** - removal of dead wood from cutting or fire in a forest
        - **killrt** - death of roots from cutting or fire in a forest
        - **cutrtn** - elemental return from a cutting event
        - **firrtn** - elemental return from a fire event
            - **litburn** - simulates removal of litter by fire for the month

Final calculations

Updates state variables and accumulators and sum carbon isotopes:

- **flowup**
- **sumcar**
    - **harvst** - harvests the crop
- **leach** - computes the leaching of nitrogen, phosphorus, and sulfur

---

Updates state variables and accumulators and sums carbon isotopes:

Updates time.

wrtbin - writes all output values to the binary file

Writes output variables and state to MAPSS for each time step:

stateout

varsout

*** For standard CENTURY runs, runs model only until slow pool organic matter achieves relative equilibrium

eq_test - sets EQ threshhold for SOM2C change in fraction per year

add_mapssvars (mapss_1t)

Saves only last month for seeding transient run.

buffer_bgc_data (mapss_1t) - buffers bgc_outvars array from currnet bgc run into bgc_data for later save to disk store.

cen_end (csa_main) - CENTURY closes file.

store_output_bgc (io_general) - stores data in mapss_output to external file or other store

free_input_data (io_general) - de-allocates space for input variable arrays in input_data structure

free_bgc_buffer (io_general)

III CENTURY_TRANSIENT

(1) Initialization:

- **main** (mapss_main)
  - **mapss** (mapss_main)
    - **process_command_line** (mapss_main) - input/output
    - **main_initialize** (mapss_main) - opens files, initializes variables

    - **mapss_2tt** (mapss_main)
      - **alloc_input_data** (io_general) - allocates space for input data variable arrays in input_data structure
      - **alloc_bgc_buffer** (io_general
      - **init_data_size** (io_general) - sets data_size structure to describe extent of data requested
      - **alloc_input_data** (io_general) - allocates space for input data variable arrays in input_data structure
      - **get_input** (io_general) - reads climate data in from external file and maybe other location
        - **InputNCValues** (nc_input) - read block of data defined in data_size and var_list. Loads into input_data.
          - **FindStartPosition** (nc_input) - filters background points. Determines start position.
          - **ReadClimate** (nc_input) - loads climate variables in var_list. Sets input_data.len to length of each variable array
          - **ReadSite** (nc_input)
      - **xfer_site** (io_general) - copies site variables from input_data to data_point, elevation and soil data now
      - **xfer_climate_year** (io_general) - copies climate variables from input_data to data_point for single year, assumes mo data in input_data

(2) EQ MAPSS is first run to give CENTURY an initial vegetation grid. This was also done in case II (CENTURY_EQUILIBRIUM) but is done here to initialize some variables that are not included in the seed file (that is, zone).

- **mapss_equilibrium_1d** (mapss_equil) - returns GOOD_POINT_RETURN if MAPSS was able to run this point.
  See case I.
- **MapssToVemapConvert** (classification_bgc) sets initial tree and crop mix
- **load_init_bgc** (nc_out_bgc) - loads data from netCDF file for seeding transient run
- **xfer_climate_year** (io_general) - copies climate variables from input_data to data_point for a single year

(3) Transient CENTURY (OneStep CENTURY) - Values of C and N output in EQ CENTURY are used as initialization values for the transient run. Transient climate data are 100 years.

- **mapss_1t** (mapss_1t)
  - **init_data_point** (mapss_equil) - sets various parts of data_point to initial dummy values (should be from seed file)
  - **set_hemisphere** (mapss_equil) - checks if current row is above or below equator, or set on command line
  - **set_initial_bgc_vars** (mapss_1t) - basic biogeocehmical variable initialization (should be read from seed)
  - **xfer_site** (io_general) - copies site variables from input_data to data_point
  - **soil_prep** (mapss_equil) - returns error if missing soils data, check valid soil data, checks or adjusts soil composition variables
    - **set_drainage_constants** (drain)
  - **xfer_climate_year** (io_general) -copies climate variables from input_data to data_point for a single year
  - **SouthernHemiSwap** or **NorthernHemiSet** (misc_init) - sets up climate data for CENTURY

Start of CENTURY-----------------------**cen_init_climate** (init_climate) - passes soils info and latitude to CENTURY assignment for output in xfer_to_output
initialization

- **cen_init_soils** (init_soils) - transforms sand, clay content into percentage; depth changed from mm to cm; nlayer is calculated here;
  calculates adep

- **cen_init_lat** (init_lat) - takes the absolute value of latitude
- **mapss_init** (mapss_1t) - initializes MAPSS parameters at start of a run (should read seed file)
  - **efold_climate_init** (mapss_1t) - seeds efold data with first year's values

- **cen_init** (csa_main) - simulates C and N cycling, steps through standard CENTURY to get output and state, until EQ
  - **vetofix** - translates VEMAP veg classes into CENTURY fix file names
  - **stateinit** (passvars) - initializes all state variables to 0. After, calls statein() to disburse zeros to global state variables
    - **detiv** (csa_detiv) - CENTURY initialization: determines name of schedule file that contains the name of the site file, values of timing variables, order of events
    - **fixin** - sets values of fixed parameters and initial values
    - **sitein** - reads starting values from site-specific parameter file
    - **extend** - reads from binary file until EOF
    - **cropin** - obtains the new crop or forest system values
      - **cmplig** - recalculates plant lignin
      - **cropmix** - calculates intermediate values of selected crop.100 parameters based on a C3/C4 index
    - **treein** - reads in the new forest type
      - **treemix** - calculates an index (function of temp) and calculates all the lifeform dependent parameters
    - **calciv** - calculates initial values for temperature, water, and live root carbon variables
    - **sumcar** - sums carbon to get totals for use in partit
      - **partit** - partitions N into structural and metabolic compartments
        - **csched** - schedules C flows for decomposition (to go to metabolic and structural)
      - **flowup** - completes the flows scheduled to occur at or before "time"
      - **sumcar** - sums carbon to get totals
    - **sumcar** - sums carbon to get totals
      - Sums som1 surface and soil isotopes separately
    - **prelim** - preliminary initialization and calculation of variables and parameters
      - **annacc** - resets annual accumulators
      - **inprac** - initializes annual production accumulators
      - **predec** - preliminary set-up (once at the begininning of each run); computations related to decomposition of SOM
      - **savarp** - computes variables for printing or plotting
      - **flowclr** - clears C and N the flow stack
    - Reads the first block of events:
    - **readblk** - reads the next block of events from the schedule file
      - **wthini** - determines which weather data will be used
        - **predec** - preliminary set-up (once at begininning of each run) for Soil Organic Matter Submodel
    - **varsin** (passvars) - distributes CENTURY output variables after pass from MAPSS
  - **stateout** (passvars) - collects CENTURY state variables for pass to MAPSS
  - **varsout** (passvars) - collects CENTURY output variables for pass to MAPSS
- if fire, then:
  - **ReadFireParams** (fire_param) - reads fire model parameters from data file
- fire_param.dat

START YEAR LOOP

- **xfer_climate_year** (io_general) - copies climate variables from input_data to data_point for a single year
- **SouthernHemiSwap** or **NorthernHemiSet** (misc_init) - sets up climate data for CENTURY
- **cen_init_climate** (init_climate) - passes soils information and latitude to CENTURY assignment for output in xfer_to_output

```
                         If petcalc,
                            InitPet (misc_init)
                                CalcSatVP (pet_calc)
                                CalcPet (pet_calc)
    EFOLDING--------efold_climate (mapss_1t) - applies efolding to data_point.ppt and .tmp
    |------------------------------efold (mapss_1t) - does a single value efold
                            xfer_climate_year (io_general) - copies climate variables from input_data to data_point for a single year
End of CENTURY      climate_prep (mapss_equil) - does Southern Hemisphere adjustments to climate, sets temperature zone, snow fall and melt, rain-
INITIALIZATION------------------events, growing degree days, vapor pressure deficits w/ApplyLifeformRules, calc PET (InitPet), check precipitation limits...
START MONTHLY LOOP  mapss_1d (mapss_1t) - monthly loop to call BGC model monthly time routine, calls MAPSS classification routine, saves
                                   BGC output to cen_data array, saves other output to mapss_output structure
FIRE MODULE---------------------------FireData (fire_data) - estimates daily values of temperature, RH, wind speed, solar radiation, precipitation
(first part)                               intensity, precipitation, snowfall, snowpack, snowmelt
                                           init1 (fire_data) - initializes daily data array variables
                                           daily_ppt (fire_data) - precipitation daily data generator
                                           daily_dat (fire_data) - daily data generator
                                           snow_cond (fire_data) - calculates snowpack and snowmelt
                                           lightning (fire_data) - lightning function
                                       DfuelMC (dfuel_mc) - estimates percentage moisture content of dead fuels in the 1;10;100; and 1,000-hour time
                                           lag classes and flammability
                                           init2 (dfuel_mc) - initializes data point variables
                                           cnvrt_units (dfuel_mc) - converts climatic variables to required units
                                           fuel_mc (dfuel_mc) - calculates dead fuel moisture
                                           shade_temp (dfuel_mc) - corrects temperature for canopy shade
                                           shade_rh (dfuel_mc) - corrects relative humidity for canopy shade
                                           shade_rad (dfuel_mc) - corrects radiation for canopy shade
--------------------------------------------------------------------flammability (dfuel_mc) - estimates fine fuel flammability
                                       cen_step (csa_main) - calls statein (obtains climate, soils data from MAPSS); updates schedule file; calculates all
                                           biogeographic indices; includes whatever is left of readblk; updates fire index; at year’s end - changes vegtype,
                                           determines whether fires should happen
                                           statein (passvars) - routine disburses CENTURY state variables into proper global variables
                                           update_sched - moves this year’s scheduled events from storage arrays into the working array
                                           veg_change - calls treemix, cropmix after passing biogeography indices to MAPSS
                                               treemix - calculates an index (a function of temperature), calculates all the lifeform dependent parameters
                                               cropmix - calculates intermediate values of selected crop.100 parameters based on a C3/C4 index
                                           vetocen - translates VEMAP vegetation classes into MAPSS vegetation classes
                                           update_event - overwrites existing events or add new ones
                                           predec - preliminary set-up (once at the begininning of each run) for Soil Organic Matter Submodel
                                           eachyr - performs tasks that need to be done only once a year
                                               annacc - resets annual accumulators
                                               weathr - determines current year values for precipitation and temperature and next year’s values for
                                                   predicting production potential
                                               co2eff - computes the effect of atmospheric CO2 concentration
                                               cmplig - computes plant lignin
                                           simsom - simulates flow of C and N (main driver for model)
                                               cycle - determines relative water content, available water, and decomposition factor related to
                                                   temperature and water
```

- **schedl** - determines the next set of scheduling options from the sch file
    - begins event loop
    - **cropin** - reads in the new crop type
        - **cmplig** - computes plant lignin
        - **cropmix** - calculates intermediate values of selected crop.100 params
    - **co2eff** - computes the effect of atmospheric CO_2 concentration
    - **omadin** - reads in the new omad type
    - **grazin** - reads in the new graze type
    - **firein** - reads in the new fire type
    - **treein** - reads in the new forest type (as default, DN, EN, DB, EB)
        - **treemix** - calculates an index (function of temperature) and all lifeform dependent parameters
    - **co2eff** - computes the effect of atmospheric CO_2 concentration
    - **tremin** - reads in the new tree removal type
- **inprac** - initializes annual production accumulators
- **prcgrw** - computes a growing season precipitation

PRODUCTION SUBMODEL

Crop system

- **potcrp** - computes monthly production potential based on monthly precipitation
    - **lacalc1** -calculates LAI as function of leaf C

Forest system

- **potfor** computes monthly potential production (forest)
    - **lacalc1** -calculates LAI as function of leaf C
    - **lacalc2** - calculates LAI as a function of wood; averages with lacalc1 LAI

Hydrology

- **h2olos** - determines CO2 effect on transpiration, calculates all hydrological flows

---

DECOMPOSITION SUBMODEL

- **decomp** - decomposes structural and metabolic components for surface or soil layer

Litter

- **litdec** - litter decomposition
    - Computes total C flow out of structural and metabolic in layers: SRFC and SOIL
    - **declig** - decomposes stuff containing lignin (structural and wood)
        - **respir** - computes flows assoc. with microbial respiration
        - **csched** - schedules C flows for decomposition
        - **esched** - schedules N flow and associated mineralization or immobilization
        - **mnracc** - updates mineralization accumulators
        - **csched** - schedules C flows for decomposition
        - **esched** - schedules N flow and associated mineralization or immobilization
        - **mnracc** - updates mineralization accumulators

Wood

- **woodec** - wood decomposition routine
    - computes total C flow out of fine branches, large wood, coarse roots
    - **declig** - decomposes material containing lignin (structural and wood)

    - **respir** - computes flows assoc. with microbial respiration
    - **csched** - schedules C flows for decomposition
    - **esched** - schedules N flow and associated mineralization or immobilization
    - **mnracc** - updates mineralization accumulators

Soil Organic Matter

- **somdec** - soil organic matter decomposition: SOM1 (surface, soil), SOM2, and SOM3 (som1-som2, som1 - som3, som 2-som 3, som 2-som1,som-som1)
    - **respir** - computes flows associated with microbial respiration
    - **csched** - schedules C flows for decomposition
    - **esched** - schedules N flow and associated mineralization or immobilization
    - **mnracc** - updates mineralization accumulators

Final Calculations

Updates decomposition and nitrogen flows:

- **flowup** - completes the flows scheduled to occur at or before 'time'
- **sumcar** - sums carbon to get totals
- **erosn** - erosion routine
    - **soilos** - computes soil loss for som1, som2, or som3

DEATH SUBMODEL

Grassland

- **crop** - driver for calling crop code
    - **falstd** - simulates fall of standing dead for the month
    - **droot** - simulates death of roots for the month
    - **dshoot** - simulates death of shoots for the month
    - **flowup** - completes the flows scheduled to occur at or before "time"
    - **sumcar** - sums C to get totals
    - **growth** - simulates production for the month
        - **restrp** - restricts actual production based on C:N ratios. Calculates minimum and maximum whole plant nutrient concentration
        - **nutrlm** - 'nutrient limitation for plants is based on demand'
    - **grem** - simulates removal of crop or grass by fire or grazing for the month

Forest

- **trees** - simulates forest production for the month
    - **wdeath** - death of leaves, fine branches, large wood, fine roots, coarse roots
    - **flowup** - completes the flows scheduled to occur at or before "time"
    - **sumcar** - sums C to get totals
    - **frem** - forest removal - fire or cutting (includes storms and litter burning in forest)
        - **livrem** - removal of live biomass from cutting or fire
        - **dedrem** - removal of dead wood from cutting or fire
        - **killrt** - death of roots from cutting or fire in a forest
        - **cutrtn** - elemental return from a cutting event
        - **firrtn** - elemental return from a fire event
            - **litburn** simulates removal of litter by fire for the month

Final Calculations

Updates state variables and accumulators and sum carbon isotopes:

- **flowup**
- **sumcar**
- **harvst** - harvests the crop
- **leach** - computes the leaching of nitrogen

- Updates time.
- **wrtbin** - writes all output values to the binary file
- **stateout**
- **varsout**

Vemap2Mon - captures monthly value of VEMAP2 output variables
CenturyFCarbToMapssLaiSLA (mapss_1t) - redoes old biomass-LAI translator, uses published SLAs

---

FIRE MODULE (second part)

Inputs

- **LfuelMC** (lfuel_mc) - estimates percentage moisture content for live herbaceous and tree fuel classes from CENTURY soil moisture indices and water stress vs. moisture content function
  - **live_mc** (lfuel_mc)
- **FuelLoad** (fuel_load) - estimates loading in all live and dead fuel classes from the biogeochemical module of carbon pools and various allometric functions chosen with information from the biogeographic module
  - **tree_dim** (fuel_load) - estimates dbh and height
  - **live_wood** (fuel_load) - estimates branch portion of live wood biomass
  - **dead_wood** (fuel_load) - estimates loads of live branch and stem wood classes
  - **fuel_depth** (fuel_load) - estimates fuel bed depth

Process

- **FireBehavior** (fire_behav)
  - **get_jul** (fire_behav) - gets Julian days for beginning and end of current month
  - **init3** (fire_behav) - initializes some data_point structure members
  - **get_daily** (fire_behav) - creates pseudo daily values for fuel moisture, loading
  - **assign** (fire_behav) - makes local variable assignments from data_point structure, some metric to English conversion
  - **prelim** (fire_behav) - makes some preliminary calculations of spread model input variables
  - **spread** (fire_behav) - rate of spread
  - **release** (fire_behav) - energy release
  - **intensity** (fire_behav) - fireline intensity and related measures
  - **crown_fire** (fire_behav) - crown fire start

Outputs

- **FireEffect** (fire_eff)
  - **init4** (fire_eff) - initializes members of datapoint structure
  - **crown_kill** (fire_eff)
  - **mortality** (fire_eff)
  - **consump** (fire_eff)
  - **emissions** (fire_eff)
- **FireOccur** (fire_occur)
- **FireSched** (fire_sched) - sets CENTURY fire variable values for fires that occurred in current month
  - **part_burn** (fire_sched)

- **add_mapssvars** (mapss_1t)
- **buffer_bgc_data** (mapss_1t) - buffers bgc_outvars from current bgc run into bgc_data for later save to disk
- **lai_allocate** (mapss_1t) - allocates month LAI to lai_values, based on MAPSS vegetation class
  - **FindMeanLai** (grasses_equil)
  - **FindMaxLai** (mapss_1t) - returns the average LAI for the growing season

---

efold_biogeog (mapss_1t) - applies efolding to some biogeographic function inputs

Biogeography Module **efold** (mapss_1t)) - does a single value efold
Biogeog (mapss_1d) - rules to determine vegetation categories

```
-------------------------------------Lifeform (lifeform) - rules to determine lifeforms
                                    xfer_to_output (mapss_1t) - loads mapss_output structure from various variables
                                    add_mapssvars (mapss_1t)
                                    buffer_bgc_data (mapss_1t) - buffers bgc_outvars from current bgc run into bgc_data for later save to disk
END of MONTH            cen_end (csa_main) - does a little clean up and ends this CENTURY session
and YEAR LOOPS          Else:       No CENTURY run here so call it a background point
------------------------------------------------------------------------------------------------------------------------------------------------------------------------

                        store_output_bgc (io_general)
                        store_output (io_general)
                        free_input_data (io_general) - deallocates space for input variabe arrays in input_data structure
                        free_bgc_buffer (io_general)
                    main_finalize (mapss_main)
                        close_io (io_general) - closes files (netCDF only now) at end of run
                        excess_at_events_count (transpire)
```

Appendix 3: Abstracts

Lenihan, James M.; Daly, Christopher; Bachelet, Dominique; Neilson, Ronald P. 1998. Simulating broad-scale fire severity in a dynamic global vegetation model. Northwest Science. 72: 91-103.

Simulating the impact of fire in a broad-scale dynamic global vegetation model (DGVM) used for global change impact assessments requires components and concepts not part of existing fire modeling systems. The focus shifts from fire behavior and danger at the small scale to the system-specific impacts of fire at the broad scale (i.e., fire severity). MCFIRE, a broad-scale fire severity model we currently are developing as part of our MAPSS-CENTURY DGVM, simulates the occurrence and impacts (i.e., vegetation mortality and fuel consumption) of relatively infrequent and extreme events historically responsible for the majority of fire disturbance to ecosystems. The occurrence of severe fire is strongly related to synoptic-scale climatic conditions producing extended drought, which is indicated in MCFIRE by the low moisture content of large dead fuels. Due to constraints posed by currently available datasets, we have been developing our DGVM model on a relatively fine-scale data grid at a landscape scale, but we will implement the model at regional to global scales on much coarser data grids. Constraints on the broad-scale impact of severe fire imposed by the fine-scale heterogeneity of fuel properties will be represented in our coarse-scale simulations by subgrid parameterizations of the fire behavior and effects algorithms for distinct land surface types. Ecosystem structure and function often are constrained by disturbance, so it is critical to include disturbance processes in dynamic vegetation models used to assess the potential broad-scale impact of global change. The ability to simulate the impact of changes in fire severity on vegetation and the atmosphere has been a central focus in the development of the MAPSS-CENTURY DGVM.

Keywords: Fire, simulation, broad-scale, fire severity model, DGVM (dynamic global vegetation model), disturbance.

Daly, Christopher; Bachelet, Dominique; Lenihan, James M.; Neilson, Ronald P.; Parton, William; Ojima, Dennis. 2000. Dynamic simulation of tree-grass interactions for global change studies. Ecological Appplications. 10(2): 449-469.

The objective of this study was to dynamically simulate the response of a complex landscape, containing forests, savannas, and grasslands, to potential climate change. It thus was essential to accurately simulate the competition for light and water between trees and grasses. Accurate representation of water competition requires simulating the appropriate vertical root distribution and soil water content. The importance of differential rooting depths in structuring savannas has long been debated. In simulating this complex landscape, we examined alternative hypotheses of tree and grass vertical root distribution and the importance of fire as a disturbance, as they influence savanna dynamics under historical and changing climates. MC1, a new dynamic vegetation model, was used to estimate the distribution of vegetation and associated carbon and nutrient fluxes for Wind Cave National Park, SD. MC1 consists of three linked modules simulating biogeography, biogeochemistry, and fire disturbance. This new tool allows us to document how changes in rooting patterns may affect production, fire frequency, and whether or not current vegetation types and lifeform mixtures can be sustained at the same location or would be replaced by others. Because climate change may intensify resource deficiencies, it will likely affect allocation of resources to roots and their distribution through the soil profile. We manipulated the rooting depth of two lifeforms–

trees and grasses–competing for water. We then assessed the importance of variable rooting depth on ecosystem processes and vegetation distribution by running MC1 for historical climate (1895-1994) and a global climate model (GCM)-simulated future scenario (1995-2094). Deeply rooted trees caused higher tree productivity, lower grass productivity, and longer fire return intervals. When trees were shallowly rooted, grass productivity exceeded that of trees even if total grass biomass was only a third to a fourth that of trees. Deeply rooted grasses developed extensive root systems that increased nitrogen uptake and the input of litter into soil organic matter pools. Shallow–rooted grasses produced smaller soil carbon pools. Under the climate change scenario, NPP (net primary production) and live biomass increased for grasses and decreased for trees, and total soil organic matter decreased. Changes in the size of biogeochemical pools produced by the climate change scenario were overwhelmed by the range of responses across the four rooting configurations. Deeply rooted grasses grew larger than shallowly rooted ones and deeply rooted trees outcompeted grasses for resources. In both historical and future scenarios, fire was required for the coexistence of trees and grasses when deep soil water was available to trees. Consistent changes in fire frequency and intensity were simulated during the climate change scenario: More fires occurred because higher temperatures resulted in decreased fuel moisture. Fire also increased in the deeply rooted grass configurations because grass biomass, which serves as a fine fuel source, was relatively high.

Keywords: Dynamic vegetation model, MC1, global change, climate change, tree-grass competition, belowground resources, root distribution, water availability, savanna, fire, Wind Cave National Park, grassland, landscape.

Key phrases: MC1 dynamic vegetation model, simulation of tree-grass interactions, model sensitivity to allocation of deep water resources, role of root distribution in maintenance of savannas, effect of climate change on tree-grass competition, role of fire in maintenance of savannas, impact of climate change on fire frequency and intensity, effect of root distribution on simulated fire frequency and intensity.

Bachelet, Dominique; Lenihan, James M.; Daly, Christopher; Neilson, Ronald P. [2001]. Interactions between fire, grazing, and climate change at Wind Cave National Park, SD. Ecological Modelling. 134: 229-244.

Climatically, Wind Cave National Park is at the ecotone between grassland and forest where small climatic variations can lead to dominance by either system. Natural fires promoted by productive grassy areas and moderate grazing by native herbivores have maintained a system where trees and grasses coexist. It is a fragile equilibrium, however, that can be greatly affected by management practices, such as fire suppression or livestock grazing, and also by climatic changes. We used a dynamic vegetation model, MC1, that simulates vegetation distribution, associated biogeochemical cycles, and natural fire occurrence to test the sensitivity of the system. Simulated fire suppression enhances the expansion of forests. Fire, promoted by healthy grasslands, acts as a negative feedback on tree development, because it consumes seedlings and live foliage and thus reduces tree growth and survival. Simulated grazing reduces grass biomass and fuel load thus indirectly reducing fire frequency and enhancing the expansion of forests or woodlands. Future climate projections simulate warmer and drier weather by the end of the next century. This would constrain the growth of trees that rely on the availability of deep water resources and favor shrub and grass development and a shift from forests to savannas. The loss of trees might then be inevitable. To prevent shrub encroachment over grassland areas and to conserve a source of forage for herbivores, park managers will need to restrict the grazing pressure and maintain a frequent fire regime that can prevent establishment of woody seedlings.

Keywords: Management, ponderosa pine, grasslands, simulation model, biogeography, biogeochemistry, carbon, nitrogen, water.

Pacific Northwest Research Station

Web site	http://www.fs.fed.us/pnw
Telephone	(503) 808-2592
Publication requests	(503) 808-2138
FAX	(503) 808-2130
E-mail	desmith@fs.fed.us
Mailing address	Publications Distribution Pacific Northwest Research Station P.O. Box 3890 Portland, OR 97208-3890