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Simulating Broad-Scale Fire Severity in a Dynamic Global Vegetation Model

Abstract

Simulating the impact of fire in a broad-scale Dynamic 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 are currently 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 sub-grid parameterizations of the fire behavior and effects algorithms for distinct land surface types. Ecosystem structure and function are often 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 Dynamic Global Vegetation Model.

Introduction

Simulating broad-scale disturbance is the *terra incognita* of fire modeling (Simard 1991). Process-based fire behavior models are commonly used to simulate the real-time behavior of individual fires (Andrews 1986) or to rate daily fire danger (Bradshaw et al. 1983) at the scale of a stand of vegetation or a forest district. But fire-related processes at temporal scales longer than a day and spatial scales larger than a forest district are poorly understood, and empirical data are generally not available at these scales (McKenzie et al. 1996). Nevertheless, there is an increasingly critical need to relate wildland fire to broader scale issues such as the potential impact of global climate change on terrestrial ecosystems (Ryan 1991, Gardner et al. 1996). The composition and function of ecosystems are constrained by disturbance, and ecosystem change often occurs as abrupt transitions due to changes in disturbance regimes (Davis and Botkin 1985). Global climatic change is predicted to alter significantly disturbance patterns (Overpeck et al. 1990) and thus ecosystem change could be sudden and extensive. Fire regimes may be especially sensitive to climatic change (Clark 1990), and changes in the frequency and severity of fire could have greater impacts on of the rates of ecosystem change than more direct effects of global warming. In addition to the impact on terrestrial ecosystems, more severe fire regimes could also result in a greater transfer of carbon to the atmosphere, thus contributing even further to global warming and ecosystem instability (Neilson and King 1992, Neilson et al. 1994). The ability to simulate vegetation change and feedbacks to the atmosphere due to changes in fire severity is a key requirement for the broad-scale Dynamic Global Vegetation Models (DGVM) currently under development for use in global change impact assessments (McKenzie et al. 1996).

In this paper we describe the MCFIRE model, a broad-scale fire severity model we are developing for use in our MAPSS-CENTURY DGVM. MCFIRE is being developed around four requirements for simulating changes in broad-scale fire severity under a changing climate. The first was the dynamic simulation of fuel constraints on fire behavior, that is, changes in fuel moisture and fuel loading with changes in climate. Fuel moisture is directly tied to climate, but controls on the dynamics of fuel loading are more indirectly related through climatic effects on vegetation productivity and decomposition (Agee 1993).

The second requirement was to dynamically simulate the various impacts of fire that determine fire severity (Simard 1991). Unlike physically-based measures of fire behavior (e.g., rate of spread, fireline intensity, etc.) and the various indices of fire danger, measures of broad-scale fire severity are necessarily system-specific. For example, fire severity from the standpoint of the impact on ecosystems includes the portion of the vegetation killed, the amount of biomass consumed, and the loss of soil nutrients. Emissions of different gaseous and particulate species are an appropriate measure of the impact on the atmosphere.

The third requirement was the ability to predict the timing and location of severe fire events. In order to simulate the broad-scale impact of fire, it may not be necessary to model fire behavior and effects across the entire range of fire intensity and extent that occur on a landscape. The vast majority of fires, while important in the maintenance of ecosystem properties and the spatial heterogeneity of landscapes, may nevertheless be insignificant from the standpoint of broad-scale fire severity. Only a very low percentage of fires are, in fact, responsible for a very high percentage of the fire-caused damage to ecosystems, the atmosphere, and society (Strauss et al. 1989). These infrequent, high-intensity fires of large extent are commonly associated with a specific, synoptic-scale sequence of weather events that greatly reduces the spatial heterogeneity in fuel flammability and further increases the burn connectivity of the landscape through wind-driven enhancement of fire spread. Typically a blocking high pressure system, with a duration of a month or more, promotes extreme and extensive drying of fuels due to prolonged high temperatures, low humidity, and light winds. Partial or complete breakdown of the high pressure ridge followed by a cold front passage or the buildup of convectional storms provide the lightning that ignites and wind that promotes the spread of one or more fires through the drought-conditioned, highly flammable fuels (Johnson 1992). Essentially the same relationship between the incidence of high severity fire and this specific synoptic-scale weather sequence has been reported for systems as disparate as the boreal forests of Canada (Bessie and Johnson 1995), the maritime coniferous forests of the Pacific Northwest (Huff and Agee 1980, Pickford et al. 1980), and the ponderosa pine forests of the southwestern United States (Swetnam and Betancourt 1990).

And finally, since our DGVM will eventually be implemented at grid cell resolutions of 10 km or greater, spatial heterogeneity at the subgrid level in factors like fuel moisture and loading had to be accounted for in our coarse scale simulations of fire behavior and effects. The relative heterogeneity of fuels and weather in space and time is a fundamental determinant of fire severity, so simplifying assumptions of homogeneity characteristic of fire modeling systems at finer levels of scale (McKenzie et al. 1996) are not appropriate in a broad-scale fire severity model. Greater spatial heterogeneity of fuel properties, weather, and topography generally promotes lower fire severity at landscape to regional scales. Fire severity at the stand level may be high at specific positions in the landscape, but at the broader scale and under normal weather conditions, spatial heterogeneity tends to produce a lower severity regime characterized by a patchy distribution of smaller fires (Minnich 1983; Heinselman 1985). Forces that alter spatial heterogeneity tend to alter the intensity and extent of fire. For example, timber harvesting systems that increase the fragmentation of the landscape can reduce connectivity from the standpoint of fire spread (Green 1989, Turner et al. 1989), thus decreasing average fire size. On the other hand, fire suppression policies tend to increase both the homogeneity and flammability of landscapes and can lead to more extensive and higher intensity fire (Habeck 1985). Insects and wind can increase or reduce landscape fragmentation, depending on the scale, pattern, and intensity of the disturbance, with consequence effects on the broad-scale fire regime (Knight 1987). Fire by itself, or in concert with other agents of disturbance, can alter the level of spatial heterogeneity thus influencing the severity of subsequent events (Lotan et al. 1985).

MAPSS-CENTURY DGVM Overview

We are developing the MAPSS-CENTURY DGVM to assess the potential impact of global climate change on ecosystem structure and function at wide range of spatial scales from the landscape to the globe. The DGVM consists of three linked models (Figure 1): a biogeographic rule-base model extracted from MAPSS, the Mapped Atmosphere Plant Soil System (Neilson 1995), the CENTURY biogeochemical model (Parton et al. 1992, 1993), and the new MCFIRE model.

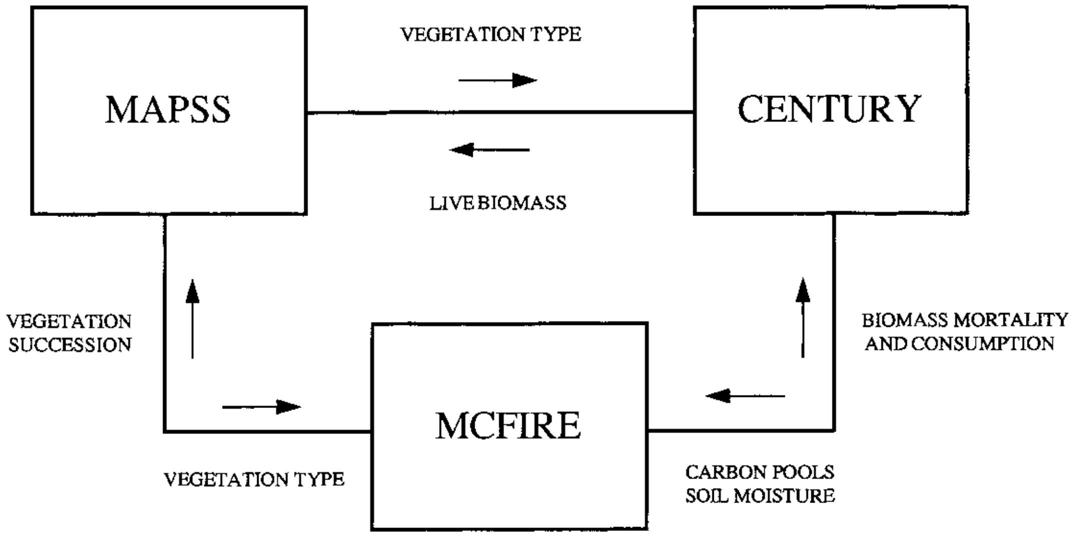

Figure 1. Linkages and feedbacks among the three modules comprising the MAPSS-CENTURY Dynamic Vegetation Model.

The MAPSS rule-based model predicts the spatio-temporal distribution of 21 different vegetation classes defined by the Vegetation/Ecosystem Modeling and Analysis Project (VEMAP participants 1995). The rule-base distinguishes vegetation classes according to climatic zone, woody and grass life-form dominance, and vegetation density. Thermal and effective moisture indices are derived from climatic time-series data that are inputs to the DGVM, and thresholds of these indices in the rule-base are used to predict climatic zone and lifeform dominance (e.g., temperate evergreen needleleaf conifer with C3 grass, or subtropical deciduous shrub with C4 grass) at a pixel. Threshold values of the aboveground plant biomass simulated by the CENTURY biogeochemical model are used to position the vegetation type along a gradient of vegetation density from desert grassland to shrub or tree savanna to closed forest. Vegetation succession in the DGVM is modeled as shifts in the relative dominance of individual lifeforms. Succession is driven by long-term trends in the climatic input data relative to the climatic thresholds in the rule-base model. Climatically-induced vegetation transitions occur on an annual time-step in the DGVM, and only after the occurrence of a simulated disturbance event (i.e., severe fire).

CENTURY is a biogeochemical model that simulates carbon and nutrient dynamics for grassland, savanna, and forest ecosystems. The different ecosystems have different plant production submodels which are linked to common submodels for soil organic matter and hydrology. The CENTURY model requires a separate parameterization to simulate biogeochemical cycling in each of the VEMAP vegetation classes. The primary feedback from the MAPSS rule-base to the CENTURY model is the specification of vegetation class for selection of the proper CENTURY parameter set. Aboveground biomass simulated by CENTURY is the feedback to the MAPSS rule-base that determines shifts along the vegetation density gradient (e.g., from forest to savanna).

The MCFIRE model simulates the occurrence, behavior, and effects of severe fire in the DGVM. As noted above, the occurrence of a simulated fire in the model triggers a re-evaluation of the vegetation class by the MAPSS rule-base. Fire effects (i.e., plant mortality and live and dead biomass consumption) are estimated by MCFIRE as a function of simulated fire behavior and vegetation structure. Fire effects feedback to the CENTURY model as adjustments to levels of the different live and dead carbon and nutrient pools.

The MCFIRE Model

The following is a brief description of the overall structure and functionality of the MCFIRE model (Figure 2).

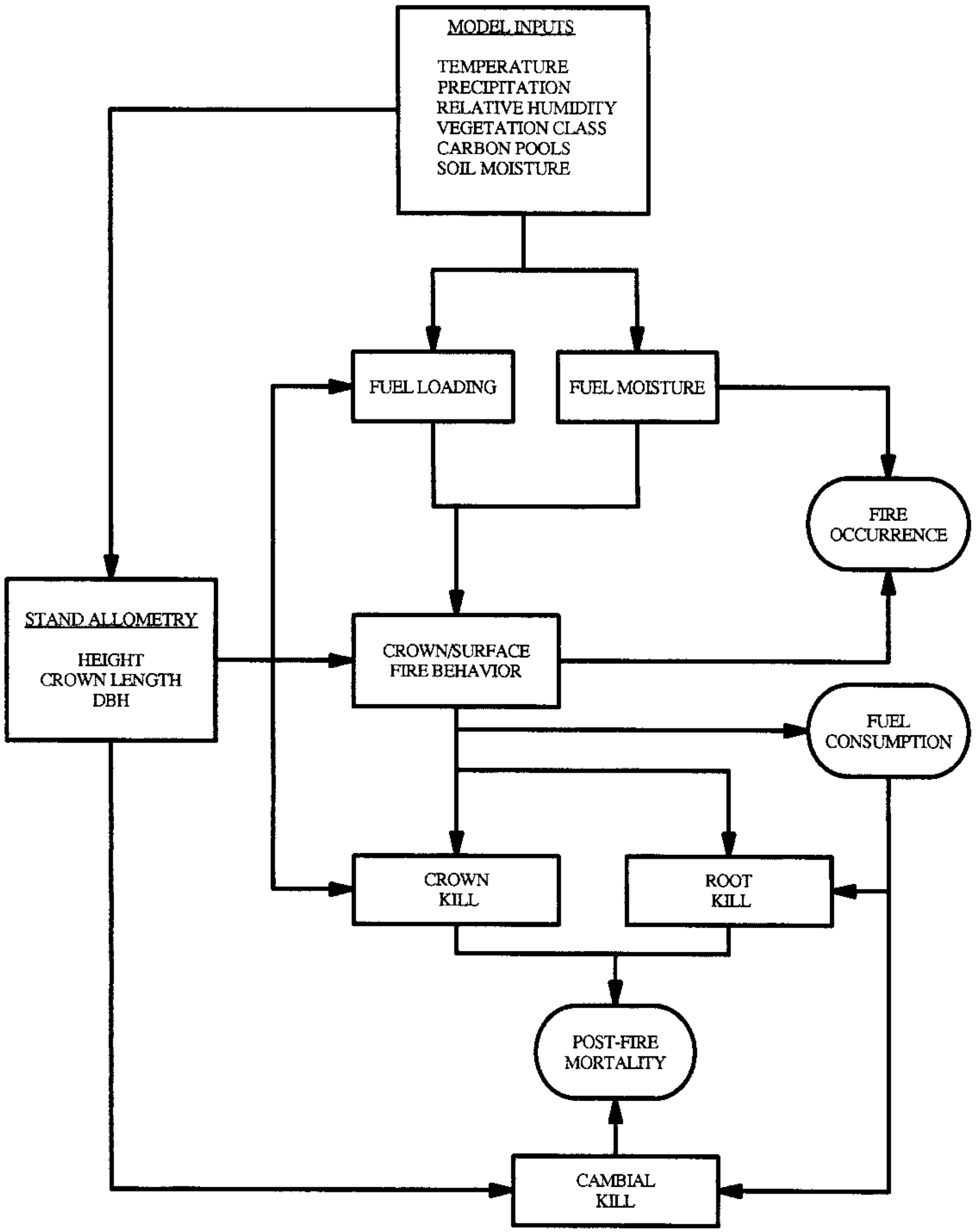

Figure 2. Flow diagram for the MCFIRE module.

Model Inputs

Data inputs to the MCFIRE model are the same long-term time-series data used by the entire DGVM. These data include average monthly temperature, total monthly precipitation, and average monthly relative humidity. Wind speed is treated as a constant in the model due to the unavailability of long-term, distributed data. In addition to climatic data, MCFIRE requires the vegetation class provided by the MAPSS rule-base, and the aboveground live and dead biomass and soil moisture provided by CENTURY.

Fuel moisture and fire behavior is modeled at a daily time-step in MCFIRE, so the monthly values of the climatic data are used to generate psuedo-daily data. In the case of 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 events in each month, and these psuedo-daily values are randomly assigned to days within each month. The number of events in each month is estimated using a regression function derived from weather station data archived by the National Climate Data Center (WeatherDisc Associates 1990).

Fuel Moisture and Loading

The percent moisture and weight per unit area of fuels are estimated for four dead fuel classes (i.e., 1-, 10-, 100-, and 1000-hr fuels) and three live fuel classes (i.e., overstory leaves and understory woody and herbaceous vegetation). We use a combination of the Canadian Fine Fuel Moisture Code (van Wagner 1987) and the National Fire Danger Rating System (Bradshaw et al. 1983) equations to estimate the moisture content of the four dead fuel classes. Live fuel moisture is estimated from an index of plant water stress (Howard 1978). The index is a function of the percent soil moisture simulated by the CENTURY hydrology submodule.

The MCFIRE model obtains estimates of live and dead biomass in a few aboveground pools from the CENTURY model. The biomass is partitioned into fuel classes using life-form specific allometric functions that first estimate average plant dimensions (e.g., bole diameter and canopy height) from biomass, and then the allocation of biomass into different structural components (e.g., leaves, small and large branches, and boles) that correspond to the different fuel size classes.

Potential Fire Behavior and Effects

Both surface and crown fire behavior are simulated in MCFIRE. Surface fire behavior is modeled using the Rothermal (1972) fire spread equations as implemented in the National Fire Danger Rating System (Bradshaw et al. 1983). Crown fire initiation is simulated 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.

If a crown fire is initiated in the model, post-fire 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 (Peterson and Ryan 1986) of the duration of lethal heat and the bark thickness estimated from average bole diameter. A function of crown scorch and cambial kill (Peterson and Ryan 1986) is used to estimate the percentage mortality of the crown biomass.

The mortality of live roots due to a simulated fire is estimated from the depth of lethal heating in the soil. The depth of lethal heating is modeled as a function of the duration of flaming and glowing combustion at the surface (Peterson and Ryan 1986). We derived the depth vs. duration relationship from empirical data presented by Steward et al. (1990).

In the case of a simulated crown fire, we assume live leaves and branches are completely consumed. Otherwise, live leaves are consumed and live branches are transferred to the dead carbon pools in CENTURY in proportion to the percentage mortality of the crown. The bole biomass of killed trees or shrubs and the biomass of killed roots are also transferred to dead carbon pools. The consumption of dead biomass is modeled as functions of the moisture content of the different fuel size classes (Peterson and Ryan 1986). Dead fuel consumption feeds back to

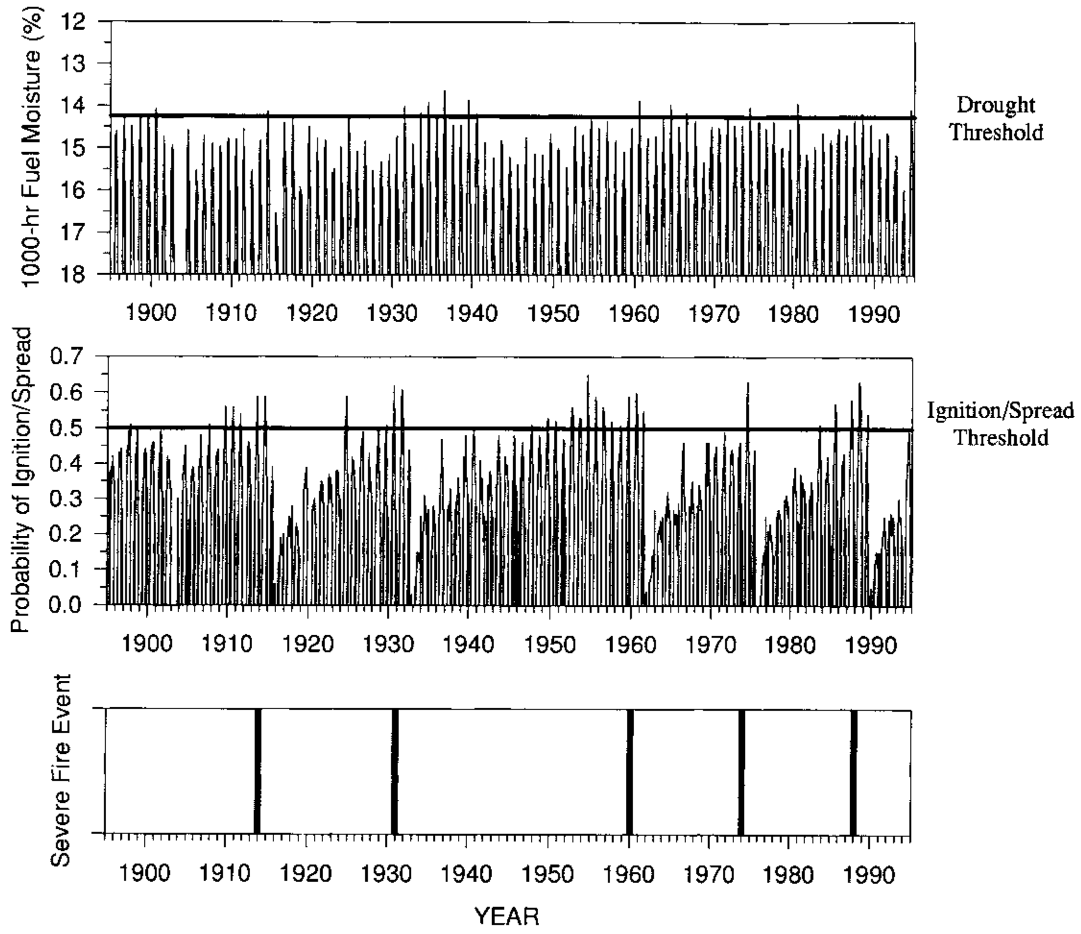

Figure 3. Determination of severe fire occurrence during a 100-year simulation with MCFIRE: a) the drought threshold relative to 1000-hr fuel moisture, b) the ignition/spread threshold relative to probability of ignition and spread, c) the severe fire events triggered when both thresholds were simultaneously exceeded.

CENTURY as reductions in the dead carbon and nutrient pools.

Fire Occurrence

The potential fire effects simulated in the model do not feedback to the CENTURY model unless MCFIRE determines that a fire has occurred. The occurrence of fire in the model is triggered by threshold values of extended drought and a joint probability of fire ignition and spread (Figure 3). We use the moisture content of the dead 1000-hr fuel class as an indicator of extended drought. Large dead fuels are very slow to absorb and release moisture (Fosberg et al. 1981), so their percent moisture content is a good index of extended periods of either dry or wet conditions.

When the 1000-hr fuel moisture drops below a calibrated drought threshold in the model, a simulated fire will occur if there is also a greater than 50% probability of fire ignition and spread. To calculate a joint probability of ignition and spread, we use an estimate of fine fuel flammability and a ratio of the simulated rate of spread to a critical rate of spread for reportable fires (Bradshaw et al., 1983). Lightning as the ignition source is another constraint on fire occurrence. Currently we are using a very crude climatic indicator of the presence or absence of lightning.

When both the drought and ignition/spread thresholds are exceeded, a fire event is triggered in the model. In the example presented in Figure 3, five fire events were triggered during a 100-yr simulation.

Development and Preliminary Testing of the DGVM

Much of the development and initial testing of MCFIRE and the rest of our MAPSS-CENTURY DGVM is taking place within a 12.5 square kilometer study area that is part of Wind Cave National Park (WCNP) in the Black Hills of South Dakota. The implementation of the DGVM at WCNP is one part of a larger study to assess the impact of global change on the Central Grasslands Region at landscape to regional scales (Neilson et al. 1996). The primary advantage of first implementing the model at the landscape-scale is the availability of model input data. We were able to generate a 100-yr monthly climatic dataset for the study area that is distributed on a 50 meter grid and includes all the necessary inputs to the DGVM. Long-term, distributed climate datasets at broader scales are not currently available, although a historical gridded climate dataset for the conterminous United States at a 60 km resolution will be produced by the VEMAP project in 1998 (Kittel et al. 1997).

As a model testbed, WCNP offers the additional advantage of including several of the Central Grassland vegetation types simulated by the DGVM, including temperate evergreen conifer and mixed forests, temperate evergreen savanna, both C3 and C4 grasslands, and deciduous hardwoods in riparian/wetter areas. Here we show some results for three data cells representing the evergreen conifer forest, evergreen conifer savanna, and C4 grassland types (Figures 4-6).

Results for the evergreen conifer forest (Figure 4) show a gradual increase in tree leaf biomass from initially low levels over the 100 year simulation. About midway through the simulation, tree leaf biomass crosses the threshold level for the transition from grassland to savanna, and then becomes high enough near the end of the simulation to be interpreted as closed forest by the MAPSS rule base. Live grass biomass exhibits a steady decline due to increasingly greater competition with the overstory for light, water, and nutrients. Climatic conditions in this cell, which represents the moist extreme of a moisture gradient in the study area, are never sufficiently dry to trigger a severe fire over the 100 years of simulation.

The results for the evergreen conifer savanna cell (Figure 5) demonstrate the effect of including the impact of fire in the DGVM. With fire turned off in the model, the results (Figure 5a) are similar to those for the forest cell (Figure 4), although climatic conditions at the savanna cell are somewhat drier. Tree leaf biomass reaches a level interpreted by the MAPSS rule base as characteristic of forest, not savanna. With fire turned on, the potential tree leaf biomass is reduced to savanna levels by simulated fires that return ev-

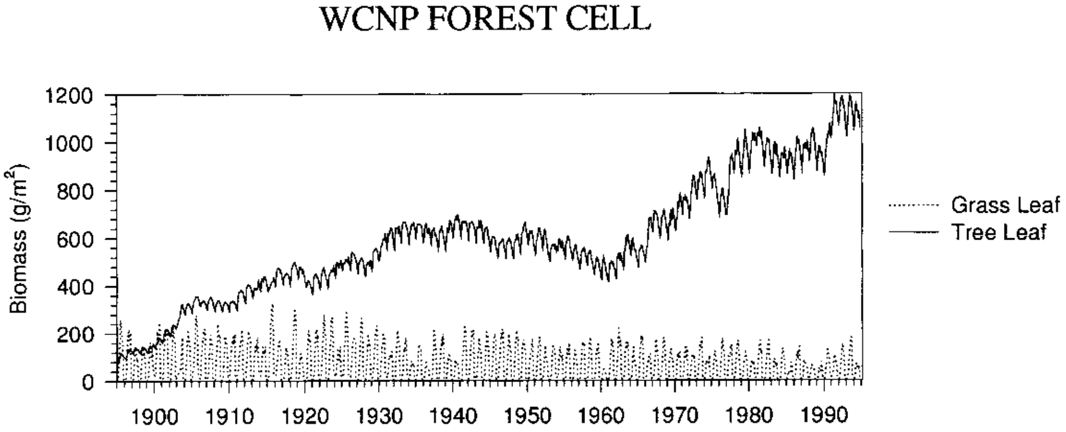

Figure 4. Tree and live grass biomass simulated by the MAPSS-CENTURY DVGM in a Wind Cave National Park (WCNP) data grid cell representing evergreen conifer forest.

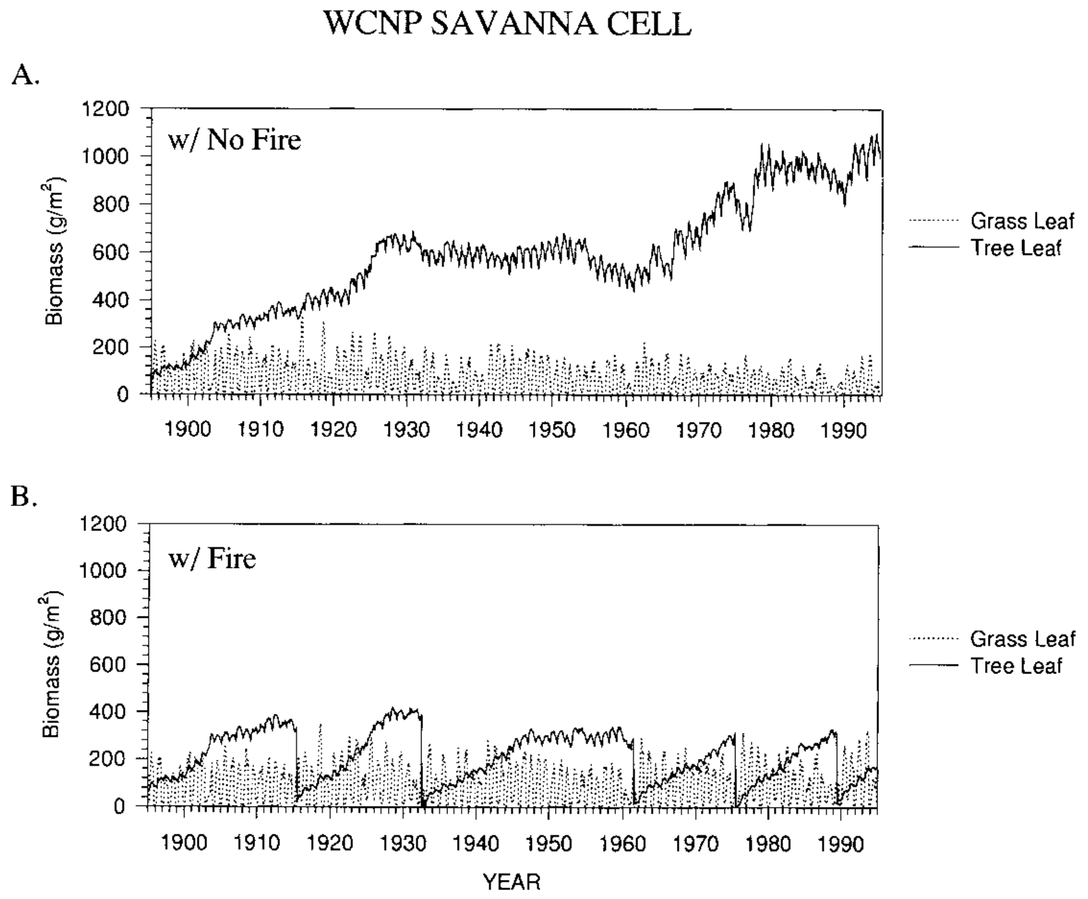

Figure 5. Tree and live grass biomass simulated by the MAPSS-CENTURY DVGM in a Wind Cave National Park (WCNP) data grid cell representing evergreen conifer savanna: a) without fire, b) with fire.

ery twenty years on average (Figure 4b). Live grass biomass exhibits a repetitive cycle, with fast regrowth in the absence of competition from woody vegetation, and then a gradual decline with increasing competition until consumption by the next fire event.

Model simulation results for the C4 grassland cell (Figure 6) indicate that fire is also necessary to maintain the vegetation structure observed at the dry extreme of the moisture gradient. Without fire (Figure 6a), tree leaf biomass very gradually reaches a level similiar to that maintained by fire in the savanna cell (Figure 5b), and live grass biomass is very low. With the inclusion of fire in the simulation (Figure 6b), tree leaf biomass is reduced to levels below the grassland-savanna threshold by fires returning on the average every 30 years, and live grass biomass increases to a level commensurate with those observed along grassland transects in WCNP (Ojima, personal communication).

Incorporating Sub-Grid Heterogeneity into Broad-Scale Simulations

When running our model on the WCNP data grid, we can safely assume that the spatial distribution of factors like fuel moisture and fuel loading are relatively homogeneous with each of the 50 m grid cells. This is a critical assumption because the algorithms used to model fire behavior were developed at a stand level under the assumption of homogeneity in fuel properties (Rothermel 1972; McKenzie 1996).

However, once we obtain the VEMAP historical gridded climate dataset, we will be

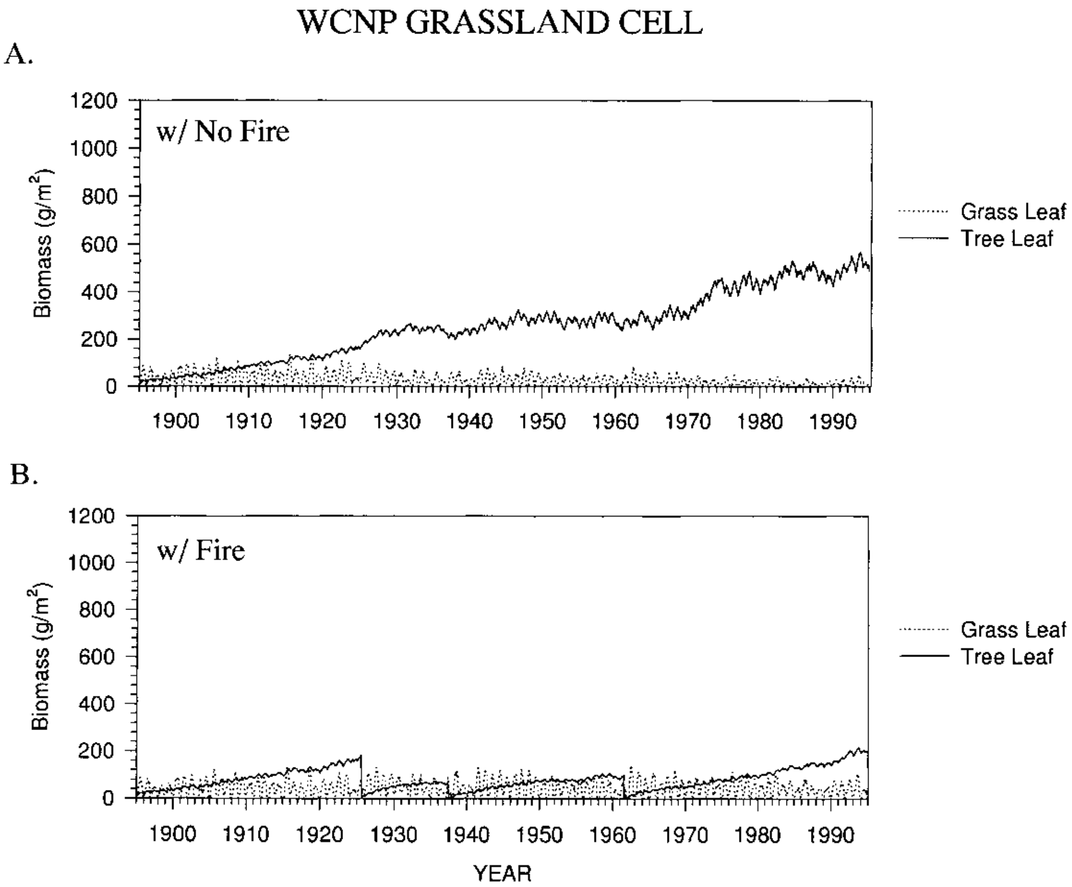

Figure 6. Tree and live grass biomass simulated by the MAPSS-CENTURY DVGM in a Wind Cave National Park (WCNP) data grid cell representing C4-dominated grassland: a) without fire, b) with fire.

implementing our DGVM on a coarser 60 km grid within the Central Grasslands region and across the entire conterminous United States. Eventually we also expect to implement our DGVM globally at even coarser resolutions. For these simulations, our assumption of within-cell homogeneity will no longer be tenable. There will be considerable patchiness in the occurrence and intensity of severe fire in any area the size of one of these coarse grid cells. Much of this patchiness will be related to variation in topographically-controlled factors like slope steepness, aspect, and vegetation characteristics that determine fuel properties. Thus to adequately represent fire behavior and effects for coarse grid cells as a whole, we must account for the spatial heterogeneity within grid cells.

Land surface type (LST) parameterization has emerged as one means of modeling sub-grid cell heterogeneity in regional climate models (Avissar and Pielke 1989, Pielke and Avissar 1990). An LST is a portion of the grid cell that is physiographically distinct. For example, all north-facing slopes within a specified elevational band can be represented in a regional model as a single LST with a specified area, although in reality north-facing slopes may be scattered throughout the cell. Within the grid-cell, spatial patterns of the different LSTs are not explicitly modeled. Grid cell output to the atmosphere equals the area-weighted mean of the LST outputs.

For example, we used a 90 m digital elevation model (DEM) and a topographic shading algorithm (Frew 1990) to distinguish eight different LSTs in a 10 km cell centered over the H.J. Andrews Experimental Forest in the southern Oregon Cascades (Figure 7). We also used a Gaussian filter on the DEM to examine the effects

Figure 7. Land surface types distinguished by exposure to solar radiation (cold, warm, or hot) and slope steepness (gentle or steep) in a 10 km cell centered over the H.J. Andrews LTER in the Oregon Cascade Mountains. Contour interval is 100 m.

of three different smoothing levels on the LST distribution. Exposure to radiation and slope steepness, characteristics likely to influence fuel moisture and fire behavior, were selected to distinguish the LSTs in this example.

Once LSTs have been distinguished within a coarse grid cell, our DGVM will be parameterized for each LST via a downscaling of the grid cell level input data. Of key importance in formulating the downscaling methods will be relationships between climate and elevation, slope, and aspect (Daly et al. 1994). We will derive these relationships by modeling the climate in select regions across the United States at both fine and coarse resolutions. Once the DGVM is parameterized, we will run the model once for each LST, calculating the results for the entire grid cell as an area-weighted average of the results for each LST. For example, the amount of gaseous and particulate emissions emitted to the atmosphere by a fire simulated within a coarse grid cell would be calculated as the average of the emissions emitted from each LST weighted by the total cell area occupied by each LST.

Discussion

In order to construct a broad-scale fire model for use in assessing the potential impact of global change on fire severity, one of our key requirements was the ability to model the impact of climate change on fuel dynamics via effects on the growth and decomposition of vegetation. Dynamic simulation of fuel loading was accomplished by linking MCFIRE to the CENTURY biogeochemistry model to provide estimates of the sizes of different live and dead carbon pools that could be allometrically converted to loadings in different fuel classes. Other fire behavior models we examined (e.g., Bradshaw 1983, Andrews 1986) used static fuel models to define typical fuel loads in a limited number of broadly defined vegetation types. One exception is the FIRE-BGC model (Keane et al. 1996) which, like MCFIRE, is coupled with a biogeochemistry model. However, FIRE-BGC is fundamentally a forest gap model in both process and scale, and requires a very detailed parameterization and initialization for multiple species. As such, we were unable to adapt it for use as the type of fire severity model required by our DGVM (i.e., broad-scale, life-form based, and globally-parameterized) .

Another requirement was to dynamically simulate fire occurrence in the DGVM. For the purposes of global change impact assessment, we felt it was critical not to impose fire frequencies on our model, but rather let them be an emergent property of the simulations. In other long-term fire simulations of which we are aware (e.g., Keane et al. 1996a, 1996b; Turner et al. 1989), fire occurrence is usually some function of the historical fire frequencies observed in specific vegetation types.

In MCFIRE, the use of a low drought threshold to trigger fire occurrence (e.g., 14% moisture content of 1000-hr fuels in WCNP example) restricts the type of simulated fires to relatively infrequent, severe events. The 20 and 30 year fire return intervals that were simulated for the WCNP savanna and grassland cells respectively are sufficient to constrain woody biomass to levels that produce a correct classification of these vegetation types by the MAPSS rule-base. However, these return intervals are just within the ranges reported for Black Hills ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.) savanna (12-25 years) and dry mixed grass prairie (20-30 years) (Wright and Baily 1982). Lower severity fires not associated with extended drought periods also contribute to observed return intervals, but the occurrence of low severity fire is difficult to model deterministically due to its inherently stochastic nature. We recognize the importance of low severity fire in the maintenance of ecosystem properties and the spatial heterogeneity of landscapes. But before we determine whether or not a special provision needs to be made for low severity fire in the MCFIRE model, we need to examine the performance of our current strategy for starting fires over a broader range of vegetation types and within the context of our land surface type parameterization scheme.

Running MCFIRE for individual LSTs will tend to produce a mixture of different fire severity levels within coarse-scale grid cells, especially in cells that are topographically diverse. The spatial pattern of fire severity within a cell will not be explicitly simulated, but the cell-wide effect of different levels of fire severity will be represented in the area-weighted average of the fire effects simulated for the individual LSTs. Process-based fire growth models such as the FARSITE model (Finney 1994) and cellular automata (Turner and Romme 1994, Gardner et al. 1996) and percolation (Von Niessen and Blumen 1988) models have been used to simulate fire spread, shape, and contagion at the scale of the watershed or landscape. Their use for explicitly simulating the spatial patterning of fire severity within coarser-scale cells would pose serious difficulties in terms of both parameterization and computer resources (Keane and Long 1998). In coarse-scale applications of our DGVM, the focus is less on spatial pattern within cells and more on accurate cell-wide averages of properties that feedback to even coarser-scale General Circulation Models. For fine-scale applications of our DGVM, it may be apropriate simulate fire spread among grid cells when enough data are available to adequately parameterize a fire growth model. In coarse-scale simulations, among-cell contagion of fire events will be promoted by the use of the drought index to trigger fire occurrence in MCFIRE, because episodes of extended drought are often regional and uniform in extent.

The MCFIRE model, like the rest of our DGVM, is still a work in progress. Our plans for future enhancements of MCFIRE include a more robust lightning occurrence function which will be derived from data provided by the National Lightning Detection Network (Reap and MacGorman 1989). A fire emissions function (Ward and Hardy 1991) will also be added to model the impact of simulated fires on the atmosphere. After the coarse-scale, gridded climate dataset for the conterminous United States developed by the VEMAP project is acquired, the DGVM will be run for the entire United States under both historic and potential future climates. For the historical portion of the continental-scale simulations, we will validate the output of the MCFIRE model using fire records obtained from the U.S. Forest Service.

Terrestrial ecosystems are often constrained by disturbance, and changes in disturbance regimes can lead to abrupt changes in ecosystem structure and function. Fire is the primary natural disturbance in many different ecosystems, and fire regimes may be especially sensitive to climate change. A lack of understanding regarding the reponse of broad-scale fire severity to climate change limits our ability to predict potential changes in ecosystem structure and function and feedbacks to the atmosphere (McKenzie et al. 1996). It is critical to account for the role of fire in dynamic vegetation models used to assess the potential impacts of climate change. In preliminary tests of the MCFIRE module in the MAPSS-Century DGVM, the accurate simulation of ecosystem structure and function under current climatic conditions is dependent upon fire effects in the model simulations, especially at the interface between forest and grassland.

Acknowledgements

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