J10D.2 DEVELOPING THE SPATIAL PROGRAMS AND MODELS NEEDED FOR THE IMPLEMENTATION OF THE LANDFIRE PROJECT

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1. INTRODUCTION

The LANDFIRE (www.landfire.gov) project was initiated to provide scientifically credible, comprehensive, and critical mid-scale spatial data to implement the National Fire Plan, both at the national and local level. The objective of LANDFIRE is to provide the spatial data and predictive models needed by land and fire managers to prioritize, evaluate, plan, complete, and monitor fuel treatment and restoration projects, essential to achieving the goals targeted in the Joint Cohesive Strategy and National Fire Plan of the United States (see Rollins et al. this issue for more details on the LANDFIRE project)[1]. Two laboratories are responsible for the successful completion of LANDFIRE. The USGS EROS Data Center (EDC) in Sioux Falls, SD is responsible for mapping all vegetation characteristics using LANDSAT 7 Thematic Mapper imagery. The US Forest Service Fire Sciences Laboratory in Missoula, Montana is responsible for the development, modeling and mapping of all fire management layers and analysis tools.

LANDFIRE is divided into two separate, but intimately linked, efforts. The first phase, called the LANDFIRE prototype, is primarily concerned with researching, developing and testing LANDFIRE methods, programs, and protocols for two large areas in the western United States: central Utah and western Montana (Figure 1). This prototype has been fully funded and it is currently in its second year with final products due April 2005. The implementation of these prototyped LANDFIRE methods for the entire nation is the objective for the National LANDFIRE effort. Protocols developed for the prototype effort will be implemented for all 68 mapping zones comprising the contiguous US.

LANDFIRE will deliver over 13 spatial data layers at 30-meter pixel resolution for the entire United States. One key data layer is the Fire Regime Condition Class (FRCC) map that will be used to allocate fire resources (monies, equipment, time, and people) and prioritize treatment areas throughout the nation. Another set of key layers is the eight input layers needed to run the fire growth model FARSITE for wildfire and prescribed fire situations. All LANDFIRE layers are being created from a series of complex, integrated models and statistical analyses that depend on a set of spatial analysis tools for their completion (Figure 2). This paper describes, in general, the software and database tools used in LANDFIRE protocols. All models and programs developed in LANDFIRE will be available for use by land and fire management for application at finer and coarser scales (www.landfire.gov).

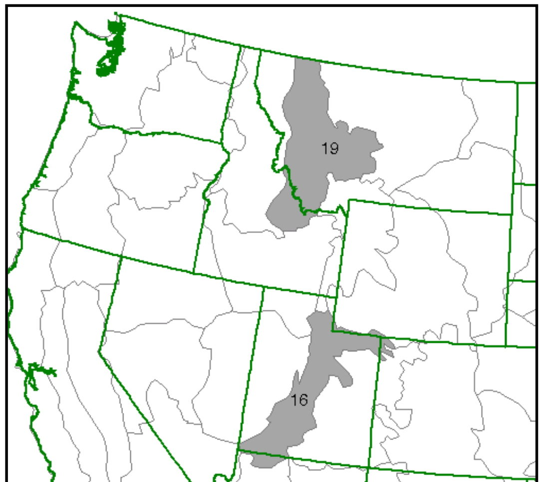

Figure 1 -- The two study areas for the LANDFIRE prototype effort

The first set of LANDFIRE tools are those used in the mapping of vegetation, fuels, and biophysical settings, and they include DAYMET (a 1 km resolution spatial database for 18 years of daily weather), WXFIRE (a program that extrapolates and summarizes DAYMET weather to finer resolutions), and LF-BGC (a biogeochemical model that simulates the flow of carbon, water, and nitrogen). The next set of programs is used in the calculation of fire regime condition class (FRCC), which is an index that compares historical conditions with current conditions. LANDSUMv4 (a landscape fire succession model for simulating fire and vegetation interactions spatially over long time periods) is used to quantify the historical range and variation of important landscape and stand characteristics. The statistical program HRVSTAT uses output from LANDSUMv4 to statistically analyze simulated historical conditions and then compare these statistics to

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current conditions to compute the FRCC index. The last tool, a program called FIREHARM, is used to assess fire hazard over time and space by computing the probability of a fire event occurring over the DAYMET weather record. Fire events are described by fire behavior, fire danger, and fire effects calculations. This paper will discuss each tool and its integration into the LANDFIRE process. All tools discussed here can be used independent of any LANDFIRE product.

2. MAPPING TOOLS

2.1 Reference Database

The first, and most important, tool in the LANDFIRE software bundle is the LANDFIRE Reference Database (LRDB) (Figure 2). This database contains data from thousands of georeferenced plots collected after 1980 and stored in the FIREMON (www.firelab.org/firemon) database structure. These data are used to 1) describe training sites and spectral classes in image classification, 2) assess accuracy of developed maps, 3) parameterize models, and 4) validate model output. These data were obtained from every conceivable source including government inventory and monitoring efforts, university research projects, state data collection efforts, and any field data collected by the private sector. To qualify for inclusion in LANDFIRE, plot data must have georeferenced coordinates and quantification of at least one of the categories or entities mapped by LANDFIRE (or the data needed to key to a map category). At present, there are over 20,000 plots in this database for the two prototype areas. These data will be extremely valuable to other mapping and modeling efforts.

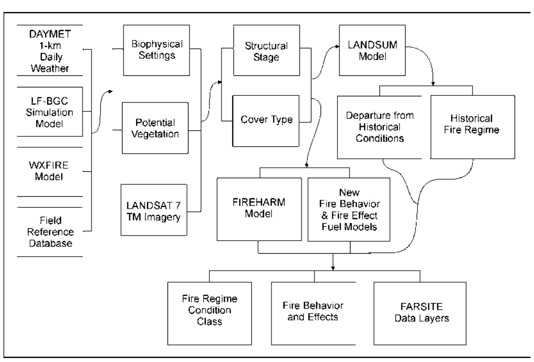

Figure 2 -- Flow of map, database, and software products from the LANDFIRE project

2.2 DAYMET database

The second database tool is the DAYMET weather database (Figure 2). DAYMET is a national database that stores the daily weather for each 1 km^2 pixel that comprises the contiguous US from 1980 to 1997 (18 years). The daily weather is described by five variables: 1) maximum temperature (deg C), 2) minimum temperature (deg C), 3) precipitation (cm), 4) vapor pressure deficit (Pa) (relative humidity), and 5) solar radiation (kW m^{-2}). This large database, nearly 1 terrabyte, was developed by Thornton et al. (2000) with the Numerical Terradynamics Simulation Group (NTSG) at the University of Montana in Missoula. These data are used in all phases of LANDFIRE. Many environmental characteristics can be mapped using data summarized from DAYMET (e.g., WXFIRE; see next paragraph). In addition, fire hazard is mapped using output from fire models linked to DAYMET for daily weather. The DAYMET database was created by extrapolating meteorological weather data collected at various base stations (e.g., National Weather Service, SNOWTEL, RAWS) across the landscape using a spatial convolution of a truncated Gaussian weighting filter and a dynamic computation of lapse rates for temperature and precipitation (Running and Thornton 1996, Thornton and Running 1999, White et al. 2000).

2.3 WXFIRE weather program

The next two LANDFIRE tools require the DAYMET database as inputs. The WXFIRE model computes annual averages of over 100 biophysical variables for each polygon in a user-created list that represents an input landscape. The model uses the 18-year DAYMET daily weather sequence and an inventory of all input parameters needed for simulation for each polygon (Figure 2). The user has the option of averaging important biophysical attributes over all or some of the 18-year weather record and for all or part of the 365 daily weather year. WXFIRE does not simulate spatial interactions or dependencies between input polygons or pixels. Instead, the user enters a list of polygons that are assigned the suite of input parameters (e.g., soil depth, elevation) needed to run the program. The model then simulates or calculates estimates of various weather, climate, and ecosystem process variables and then writes these estimates to an output file by input polygon. This output file can be imported into a GIS to map the biophysical estimates by linking them to the polygon layer. These WXFIRE output layers will be used to develop critical LANDFIRE layers such as fuel models, potential vegetation types, cover type, and biophysical setting.

The host of biophysical layers generated from WXFIRE can be grouped into four types. A first set of weather variables summarizes those attributes used to describe general weather dynamics and they include average annual estimates of temperature, precipitation, radiation, and humidity. A second set, the climate variables, describe the climatic regime of the environment or ecosystem and they include soil temperature, days since last rain, and net radiation at the ground. The ecosystem variables describe those climate variables as they interact with the biota, such as PET (Potential EvapoTranspiration), AET (Actual EvapoTranspiration), and soil water potential. And last, the fire variables are those attributes that describe the fire environment and are taken mostly from the fire danger rating systems of the United States and Canada (Deeming et al. 1978, Group 1992). They include burning index, fire weather index, and Keetch-Byram drought index. The user has the option of averaging the fire variables over a selected day range (Julian Days) that is different from the other set of variables.

2.4 LF-BGC ecosystem simulation model

Another LANDFIRE mapping tool is the simulation model LF-BGC also used to map critical LANDFIRE variables such as fuel models and potential vegetation type (Figure 2). LF-BGC is a modification of the ecosystem process model BIOME-BGC developed at the NTSG laboratory. LF-BGC simulates complex ecophysiological processes to compute various ecosystem dynamic characteristics such as gross and net primary productivity (GPP, NPP), autotrophic and heterotrophic respiration (AR, HR), and evapotranspiration (ET) (Thornton and White 1996, Kimball et al. 1997, Thornton 1998, White et al. 2000, Thornton et al. 2002). LF-BGC uses the DAYMET weather and a number of specific ecophysiological parameters for each polygon in an input list to compute these ecosystem variables as annual averages. Similar to those layers generated by WXFIRE, LF-BGC estimates are then used as predictive variables in predicting LANDFIRE mapping variables, such as potential vegetation type.

3. MODELING HRV TOOLS

The computation of Fire Regime Condition Class (FRCC) requires the comparison of current conditions to a chronosequence of historical conditions. The elements or conditions used in FRCC are fire regime, species composition (cover type), and stand structure (structural stage). In LANDFIRE, current conditions are quantified satellite imagery (LANDSAT TM 7) and the simulated layers previously mentioned. But, how can the historical conditions be quantified? LANDFIRE uses a modeling approach where the landscape fire succession model LANDSUMv4 is used to simulate 1,000-5,000 year chronosequences using fire and succession parameters quantified from historical data.

3.1 LANDSUMv4 fire succession model

The LANDscape SUccession Model version 4.0 (LANDSUMv4) is a spatially explicit vegetation dynamics simulation C++ program wherein succession is treated as a deterministic process and disturbances (e.g., fire, insects, and disease) are treated as stochastic processes. LANDSUMv4 is the fourth major revision of the original model LANDSUM, developed by Keane et al. (1997) to simulate alternative management scenarios on small landscapes delineated by polygons. The original LANDSUM was descended from the coarse scale model CRBSUM used to simulate vegetation dynamics in the interior Columbia River Basin at a 1 km pixel resolution (Keane et al. 1996).

LANDSUMv4 simulates succession within a patch (adjacent similar pixels) or polygon using the multiple pathway fire succession modeling approach somewhat similar to that presented by Kessell and Fischer (1981). This approach assumes all pathways of successional development will eventually converge to a stable or climax plant community called a Potential Vegetation Type (PVT) (Figure 3). A PVT identifies a distinct biophysical setting that supports a unique and stable climax plant

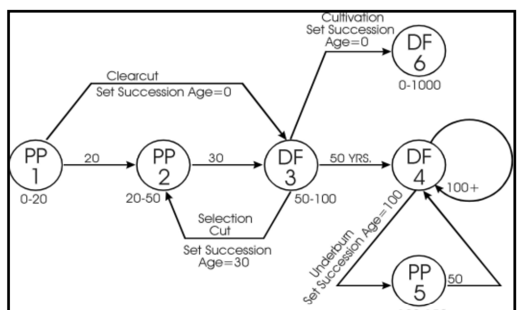

Figure 3-Example of a multiple pathway model for a Douglas-fir (DF) PVT. PP-Ponderosa pine, 1-seedling, 2-pole, 3-mature, 4-oldgrowth multistrata, 5-

community under a constant climate regime. In LANDFIRE, the PVT layer is mapped from WXFIRE and LF-BGC output layers. There is a single set of successional pathways for each PVT present on a given landscape (Arno et al. 1986). Successional development within a patch is simulated as a change in structural stage and cover type (together called a succession class) simulated at an annual time step. The length of time a patch remains in a succession class (transition time-years) is an input parameter that is held constant throughout the simulation. Disturbances disrupt succession and can delay or advance the time spent in a succession class, or cause an abrupt change to another succession class. Occurrences of human-caused and natural disturbances are stochastically modeled from probabilities based on historical frequencies. All disturbances were simulated at a patch scale, except for wildland fire, which is simulated as an independent spread process based on topography, wind, and fuels.

The primary use of LANDSUMv4 in LANDFIRE is the development of simulated historical chronosequences to be used as reference for computing FRCC. However, the LANDSUMv4 model can be used for many other applications, such as predicting the effect of a fire management plan on landscape dynamics over the next 100 years. Or, the model can be used to simulate the effect of weed invasion and fire treatments on landscape structure and composition.

3.2 HRVSTAT statistical package

LANDSUMv4 generates output that describes landscape and stand conditions at user specified intervals (e.g., every 50 years). These outputs include the extent of cover types, structural stages, and fire across the landscape. This chronosequence is used as reference to compare with current conditions on associated landscapes. A statistical protocol is then needed to synthesize the chronosequence into a set of statistics that can be compared with summaries of current condition to obtain an index of departure from historical conditions.

A statistical program, called HRVSTAT, is being developed by Dr. Brian Steele at the University of Montana to analyze the simulated historical chronosequence from LANDSUMv4 and then compare it to current conditions to compute an index of departure using a number from 1 to 100. This statistical program will accept spatial data at any scale, and it can be used to calculate an index of departure for stand-level data that is not spatially explicit.

The HRVSTAT program can accept any chronosequences of historical conditions as a reference. A time series of historical landscape characteristics from sources other than simulation models can also be input to HRVSTAT. For example, chronosequences of landscape conditions can be summarized from a set of historical aerial photos.

4.0 FIRE HAZARD TOOLS

What can the fire manager do with all the LANDFIRE databases and data layers? One tool being developed for LANDFIRE for the sole purpose of fine scale analysis is a program called FIREHARM, a FIRE HAzard Rating Model.

4.1 FIREHARM program

FIREHARM calculates four fire behavior variables (fireline intensity, spread rate, flame length, crown fire potential), five fire danger variables (spread component, burning index, energy release component, Keetch-Byram drought index, ignition component), and five fire effects variables (smoke, fuel consumption, soil heating, tree mortality, scorch height) for every day in the DAYMET 18-year record for each polygon in a user-specified list. The program simulates moisture conditions for each dead fuel component (e.g., duff, litter, downed woody, logs) and live fuel component (e.g., shrubs, herbs, trees) using a complex set of biophysical equations. FIREHARM then calculates the probability of a user-specified event occurring during the 18-year record. A user-specified threshold must be exceeded for an event to occur. For example, FIREHARM might calculate the probability of a fire burning 50 percent of the total fuel load across the 18-years of daily computations (6574 days). The user can narrow the computation to a set of years or a set of days within the years. FIREHARM computes the probabilities and annual averages for all fire behavior, danger, and effects variables and for all polygons in a user-created list. These probabilities can then be mapped onto the landscape using GIS techniques and the resultant layers can be used to prioritize, plan, and implement fire treatments.

FIREHARM also has the option of calculating the fire variables for a user-specified set of conditions. The user enters the fuel moistures and ambient weather conditions for a given situation and the program will calculate values for the fire variables for this situation. This is especially useful if a fire severity map is desired. The user can key to a fire severity class based on estimates of the fire effects variables. This map can be used to design rehabilitation treatments.

4. OTHER LANDFIRE TOOLS

There are many other software and database tools developed for LANDFIRE that have great use for planning at local levels. First, there will be an extensive set of GIS AMLs (i.e., a set of GIS commands to do a spatial task) available for the fire manager to easily perform a wide variety of complex GIS analyses. For example, there will be AMLs available to 1) prepare layers for LANDSUMv4 execution, 2) map WXFIRE variables into the GIS, 3) assign ecological attributes based on LANDFIRE map products (PVT, cover type, structural stage), 4) prepare fuels layers for FARSITE simulation, and 5) prepare layers for mapping fire hazard with FIREHARM.

New sets of fire behavior and fire effects fuel models are being developed specifically for the LANDFIRE project (Figure 2). Fire behavior scientists at the Fire Sciences Laboratory (Finney, Andrews, and Burgan) and Systems for Environmental Management (Joe Scott, leader) have developed a new system that is a major modification of the original 13 Anderson (1982) fuel models. The new set of 44 fuel models adds significantly finer resolution to timber, shrub, grass, and shrub/grass fuel types for the modeling of fire behavior. A set of fuel loading models is also being developed to simulate fire effects in models such as FOFEM (Reinhardt and Keane 1998) and CONSUME (Ottmar et al. 1993). Fuel loading data from across the nation is being compiled and analyzed to produce a classification of fuel loading models that can be keyed in the field and mapped using LANDFIRE products. Also provided by LANDFIRE is a map of Fuel Characteristic Classes (FCC) as developed by Sandberg et al. (2001).

5. SUMMARY

The LANDFIRE project will provide an extensive series of GIS layers of important fire management themes including FRCCs, fuel models, cover type, structural stage, and potential vegetation type. In addition, LANDFIRE will provide an extensive set of tools that can be used to 1) create finer scale maps for local applications, 2) create maps of other locally important ecosystem characteristics, 3) analyze the LANDFIRE and other maps for landscape and fire planning, 4) simulate areas to predict historical and future landscape dynamics, and 5) develop layers of fire hazard. However, this list should not be restricted to only fire management analysis activities because all tools mentioned in this paper have use in many other natural resource applications. All current information on the availability of LANDFIRE GIS products and analysis tools can be obtained from the LANDFIRE web site: www.landfire.gov.

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