Implementation of a climate-vegetation based early warning and prediction system for interagency fuels management

Final Report – November 2010

Principal Investigator: Dr. Timothy J. Brown, Desert Research Institute
Co-Principal Investigator: Dominique M. Bachelet, Conservation Biology Institute
Co-Principal Investigator: Robert S. Webb, NOAA Earth System Research Laboratory
Collaborator: Paul M. Schlobohm, National Park Service

Reporting Period: Final

Agency Sponsor: NOAA National Climate Transition Program

Award Number: NA07OAR4310462

Synopsis

The primary purpose of this project was to link existing seasonal climate forecasts to an existing dynamic vegetation model, and transition these combined operational and research elements to produce seasonal predictions for national and regional planning of fire management fuels treatment programs. The project addressed an agency request for climate-vegetation predictive information to provide specific operational information for fuels management decision-making and strategic planning. The project was leveraged with tasks and funds from the National Interagency Fuels Coordination Group (NIFCG). NIFCG served as the stakeholder forum for project feedback, and is anticipated to be one of the primary product users, though regional stakeholders are likely to utilize the decision-support tool as well. A web site for the operational decision-support products was created and is accessible at the Desert Research Institute program for Climate, Ecosystem and Fire Applications (CEFA); http://cefa.dri.edu/mc1.

1. Introduction

The USDA Forest Service, Bureau of Land Management, National Park Service, and US Fish and Wildlife Service as well as state forestry agencies utilize prescribed fire and other treatment methods to meet several primary land management objectives including hazardous fuel reduction, ecosystem and habitat restoration, forage for grazing and fuel breaks for wildland fire. According to statistics reported at the National Interagency Fire Center (NIFC; http://www.nifc.gov), nearly two million acres are burned on average annually by prescribed fire. It is desired to increase this amount to meet objectives outlined in federal fire policies such as the National Fire Plan (http://www.fireplan.gov) and the Healthy Forests Restoration Act of 2003 (http://www.healthyforests.gov). However, interannual climate variability often impacts treatment implementation. Prescription windows are specific to fuel type, and are defined in terms of temperature, humidity, wind and fuel moisture, and air quality regulatory guidelines. Prescribed fire cannot be utilized on fuels that are too wet or dry because either they will insufficiently burn, or burn at an undesirable high intensity and risk escape from the control perimeter, respectively. In either case, the desired management objective will not be successfully met.

A large amount of climate information is potentially available for input into prescribed fire decisions, though this information is largely under-utilized (Kolden and Brown 2010). Raw climate data (such as precipitation anomalies or drought indices), and even many value-added products, do not provide a maximum benefit to land management decision-makers because this information is not directly linked or calibrated to on-the-ground decisions. For example, a standardized drought index number, say -1, has little value for a land manager unless it is directly related to some impact or activity. From the land management perspective, climate anomalies are an impact on fuels affecting short- and long-term strategic implementation plans and budgets. Thus, it is desirable to have a decision-support product that indicates the impact of climate directly on fuels (e.g., vegetation stress or health), but is also directly related to decisions. The primary agency interest of projected seasonal climate-fire forecasts, whether national or regional, is to allocate budget priorities and resources to maximize fuel management accomplishments.

The primary purpose of this project was to link existing seasonal climate forecasts to an existing dynamic vegetation model, and transition these combined operational and research elements to produce seasonal predictions for national and regional planning of fire management fuels treatment programs. The project was leveraged with tasks and funds from the National Interagency Fuels Coordination Group (NIFCG). NIFCG served as the stakeholder forum for project feedback, and is anticipated to be one of the primary product users, though regional stakeholders are likely to utilize the decision-support tool as well.

2. Project Participants

The Principal Investigators for the project included Dr. Timothy Brown, Desert Research Institute (DRI); Dr. Dominique Bachelet, Oregon State University (OSU) and Conservation Biology Institute (CBI); and Dr. Robert Webb and Dr. Jeffrey Whitaker, NOAA Earth System Research Laboratory (ESRL). Paul Schlobohm, National Park Service, was the initial stakeholder project collaborator. Dr. Ron Neilson (USFS) led a team at OSU in the dynamic vegetation model development that included Dr. Jim Lenihan, Jesse Chaney, John Wells and Dr. Ray Drapek. Dr. Gary Bates at NOAA ESRL provided North American Regional Reanalysis (NARR) data and other model data guidance. Hauss Reinbold and Domagoj Podnar at DRI provided data formatting, model implementation and web support, and Nick Nauslar at DRI provided the climate and fire index calculations. The National Interagency Fuels Coordination Group (NIFCG) provided stakeholder feedback.

3. Tasks

Problem identification

NIFCG at the National Interagency Fire Center (NIFC) in Boise, Idaho had indicated a national need for climate monitoring information and seasonal prediction that could be utilized directly as a decision-support tool for fuels treatment planning. At least two NOAA products were readily identified that could provide climate information for this need including the North

American Regional Reanalysis (NARR; Mesinger 2005) and the National Centers for Environmental Prediction (NCEP) Climate Forecast System (CFS; Saha et al., 2005). A dynamic vegetation model (MC1; Bachelet 2001a) used by the USDA Forest Service (USFS) for regional to global scale change research is available to provide monthly-seasonal fire index and drought forecasts. The challenge was to link these models together, and relate model output to decisions on the ground.

Tasks

Below is a summary of the two primary project tasks undertaken.

<u>Identify MC1 output thresholds for managed fires</u>

A unique aspect of the final product is that it provides forecasts of climate and fire index thresholds calibrated with managed fires (prescribed burns and wildland use fires), rather than just forecasts of climate related indices. A federal fire database was acquired that contained historical records of prescribed burns and wildland use fires. Fire date and locations were used to collocate grid points from the MC1 model and PRISM-derived Standardized Precipitation Index (SPI) (http://www.prism.oregonstate.edu/docs/index.phtml). Prescribed fires are usually single day events, but can continue up to a few days; wildland fires are long-duration events that can last up to two or three months depending upon the management objective. The first date of the event (ignition date) is associated with the climate and fire indices, which in MC1 are monthly. For example, an ignition on 1 June would be assigned the June monthly indices, as would 30 June. The managed fire database covered the period (1980-2008).

Though several indices were examined (e.g., Palmer Drought Severity Index, energy release component) the final indices used include the SPI, rate of spread (ROS) and fire line intensity (FLI). These were chosen because they showed the strongest signals with the managed fires. The SPI is a commonly used drought index in which values are standardized such that they have the same quantitative meaning regardless of geographic location. (http://lwf.ncdc.noaa.gov/oa/climate/research/prelim/drought/spi.html). A of value -1 and less indicates dry anomalies with increasing drought severity, while +1 and greater indicate anomalously wet conditions. The ROS represents the unit distance of spread rate of a fire, and FLI indicates the amount of energy at the flaming front. Typically, ROS and FLI are associated with a daily computation of the National Fire Danger Rating System (NFDRS), or even a lesser time step (e.g., hourly to minutes) given specific fire behavior interests. For this project purpose, the ROS and FLI are monthly, and thus are representing a climate time scale.

The climate and fire indices were determined spatially by region as outlined from Geographic Area Coordination Centers (GACC; Figure 1). These areas were chosen because they represent operational and logistical regions for interagency fire management. Figure 2 shows cumulative histograms of 1-month SPI counts for each GACC. The SPI can be calculated at various integrated time scales (e.g., 3-month, 12-month, 48-month) of interest. In this project, several time scales were examined, but for all cases, the result was similar; thus, only the 1-month is shown for content considerations. Each GACC threshold was determined by noting the location of a sharp change in the distribution – a breakpoint. The histograms for each GACC show a fairly consistent pattern regardless of region, that is, approximately 75% of all managed fires occurred when the SPI was near -1 or greater. This means that a large majority of burns occur given normal to wet precipitation conditions. This is not surprising; it would not be desired to conduct most burns under extremely dry conditions given concerns of burning vegetation too hot (increased fire severity) or losing control of the burn.

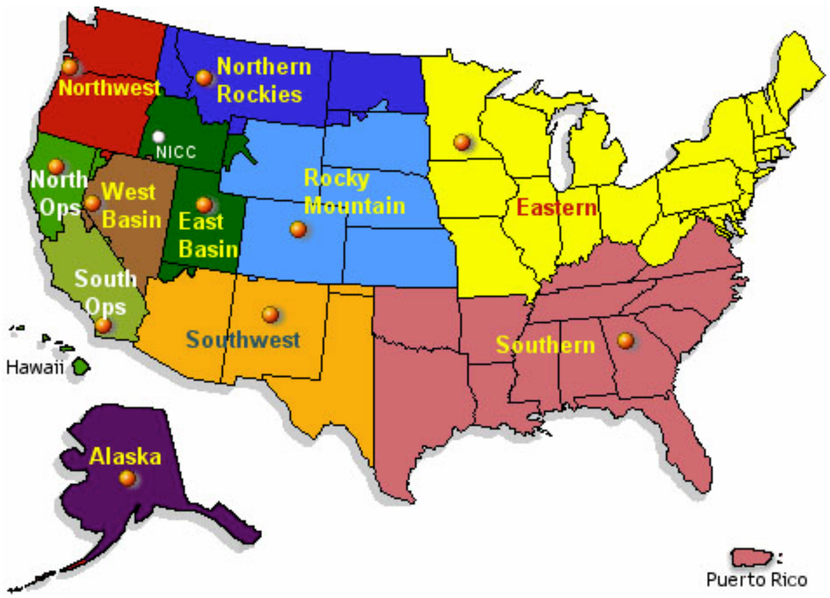
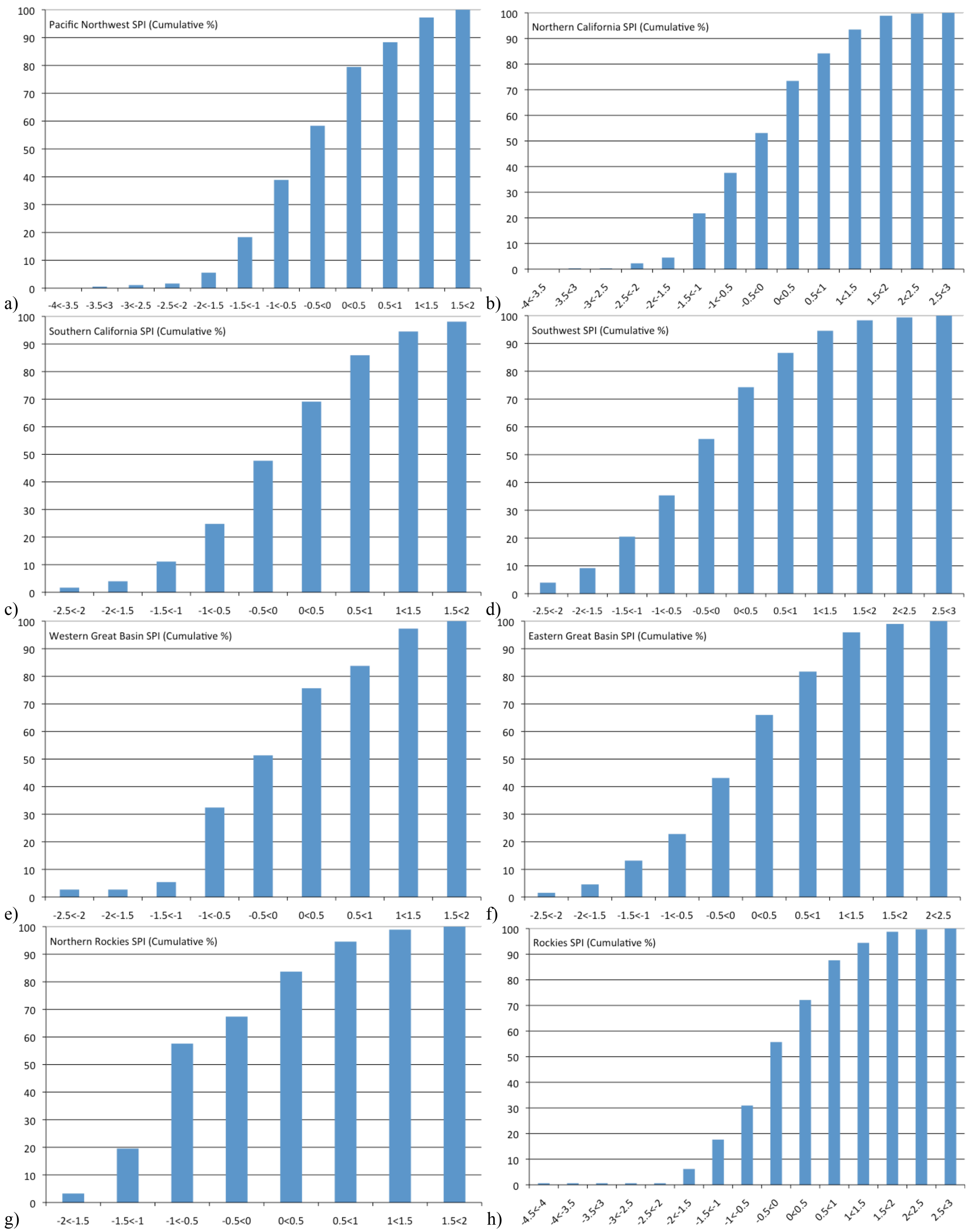
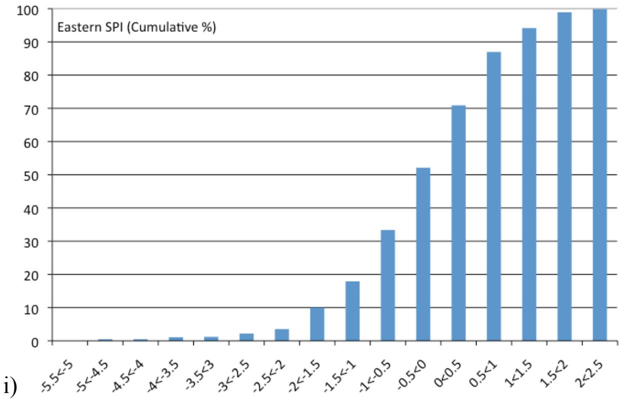


Figure 1. Geographic Area Coordination Center regions. (Source: National Interagency Coordination Center)

It is of interest to briefly discuss the remaining fourth of the fires, and several factors could explain why roughly 25% of the burns occur in drought conditions. One might be the date of the fire versus the monthly index. For example, an early month burn may have taken place under normal to wet conditions, but it was the remainder of the month that was dry influencing the index value overall. Though probably not a significant issue, a second reason could be date errors in the fire occurrence database. A third reason might be that some burns did take place that required a hotter fire to meet the management objective. For example, a hotter burn may be required to eradicate an invasive species. A fourth reason, and perhaps the most interesting, is that for prescribed burns, the fires were unknowingly lit in more extreme dry conditions, and fortunately the fire did not escape. This case is of particular interest because historically there has been a lack of climate information explicitly utilized in fire management (Kolden and Brown 2010). Climate is not explicitly incorporated into prescribed burn plans; weather is the primary consideration.



a)
Pacific Northwest SPI (Cumulative %)
-4<-3.5 -3.5<3 -3<-2.5 -2.5<-2 -2<-1.5 -1.5<-1 -1<-0.5 -0.5<0 0<0.5 0.5<1 1<1.5 1.5<2
b)
Northern California SPI (Cumulative %)
-4<-3.5 -3.5<3 -3<-2.5 -2.5<-2 -2<-1.5 -1.5<-1 -1<-0.5 -0.5<0 0<0.5 0.5<1 1<1.5 1.5<2 2<2.5 2.5<3
c)
Southern California SPI (Cumulative %)
-2.5<-2 -2<-1.5 -1.5<-1 -1<-0.5 -0.5<0 0<0.5 0.5<1 1<1.5 1.5<2
d)
Southwest SPI (Cumulative %)
-2.5<-2 -2<-1.5 -1.5<-1 -1<-0.5 -0.5<0 0<0.5 0.5<1 1<1.5 1.5<2 2<2.5 2.5<3
e)
Western Great Basin SPI (Cumulative %)
-2.5<-2 -2<-1.5 -1.5<-1 -1<-0.5 -0.5<0 0<0.5 0.5<1 1<1.5 1.5<2
f)
Eastern Great Basin SPI (Cumulative %)
-2.5<-2 -2<-1.5 -1.5<-1 -1<-0.5 -0.5<0 0<0.5 0.5<1 1<1.5 1.5<2 2<2.5
g)
Northern Rockies SPI (Cumulative %)
-2<-1.5 -1.5<-1 -1<-0.5 -0.5<0 0<0.5 0.5<1 1<1.5 1.5<2
h)
Rockies SPI (Cumulative %)
-4.5<-4 -4<-3.5 -3.5<3 -3<-2.5 -2.5<-2 -2<-1.5 -1.5<-1 -1<-0.5 -0.5<0 0<0.5 0.5<1 1<1.5 1.5<2 2<2.5 2.5<3

i) 

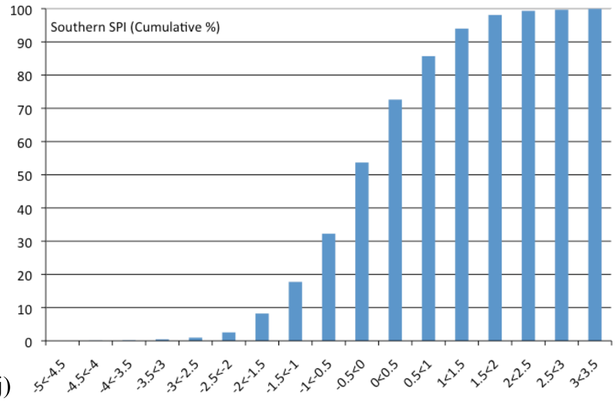
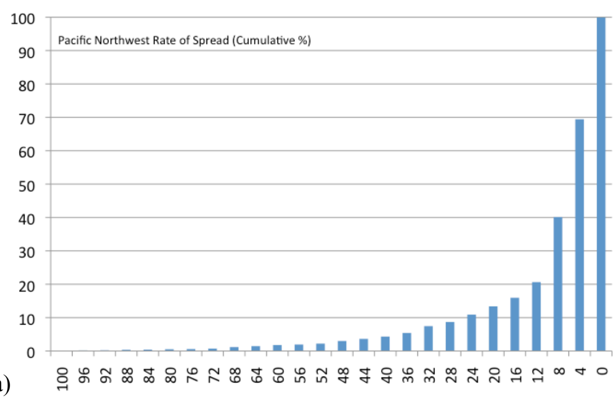
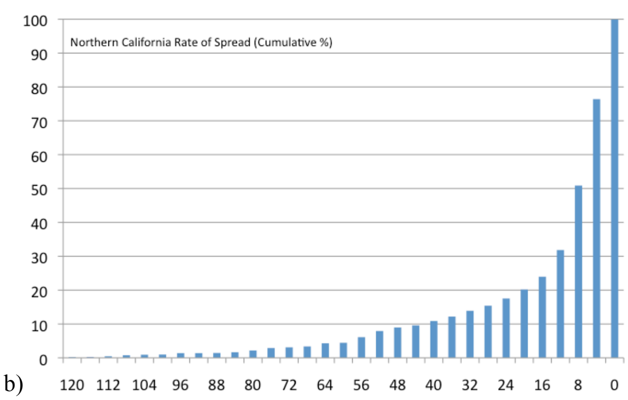
j) 

Figure 2. Cumulative histograms of 1-month SPI for the GACCs of a) Pacific Northwest; b) Northern California; c) Southern California; d) Southwest; e) Western Great Basin; f) Eastern Great Basin; g) Northern Rockies; h) Rocky Mountain; i) Eastern; j) Southern. X-axis is SPI, and y-axis is cumulative percent.

Figure 3 shows cumulative histograms of Rate of Spread (ROS; ft/sec) for each GACC. The ROS ranges mostly from 0 to 100 ft/sec, and in general shows a major change in slope around 16, which is approximately 75% of the counts. Because there is some variability by GACC, a 75% threshold value was chosen for each GACC to match the more consistent SPI. These values are shown in Table 1.

Figure 4 shows cumulative histograms of Fire Line Intensity (FLI; Btu/ft/sec) for each GACC. The FLI exhibits much more variability than ROS, with maximum values ranging from 200 to 2410 Btu/ft/sec across the GACCs. This range is largely a reflection of the varied fuel types by region. As with ROS, the 75% cumulative value was chosen as the threshold, and is given in Table 1. As expected from the histograms, these values vary considerably by GACC.

a) 

b) 

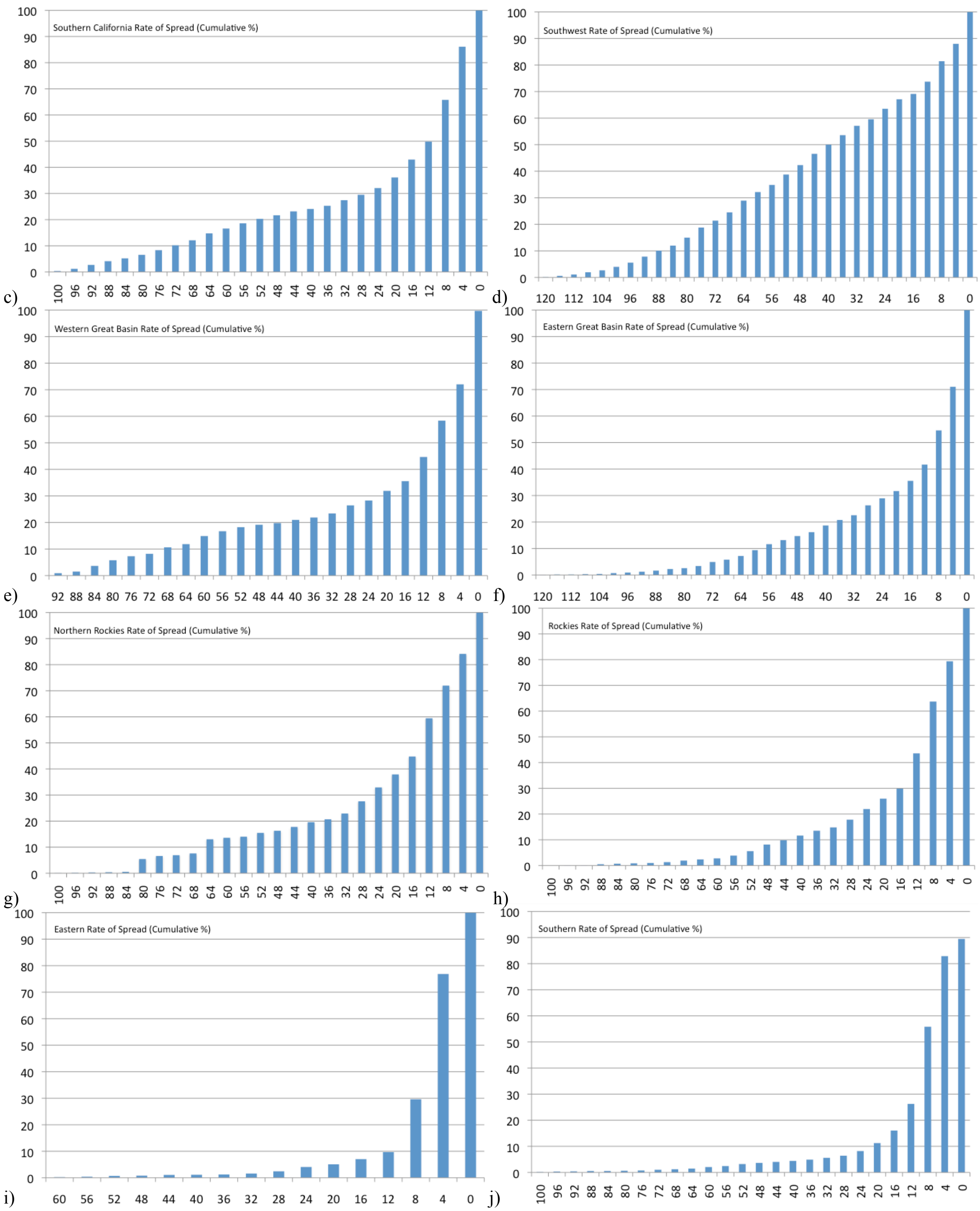
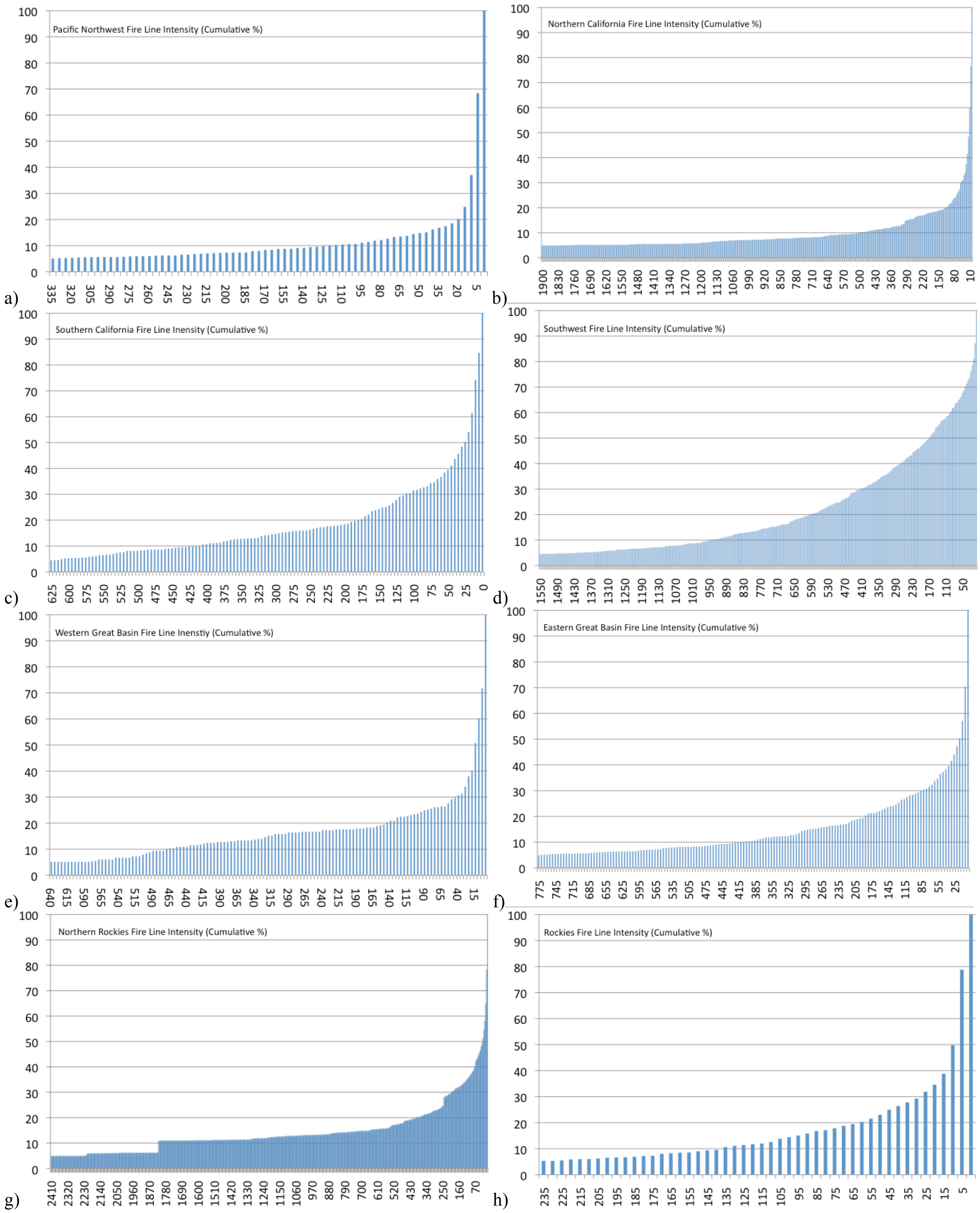
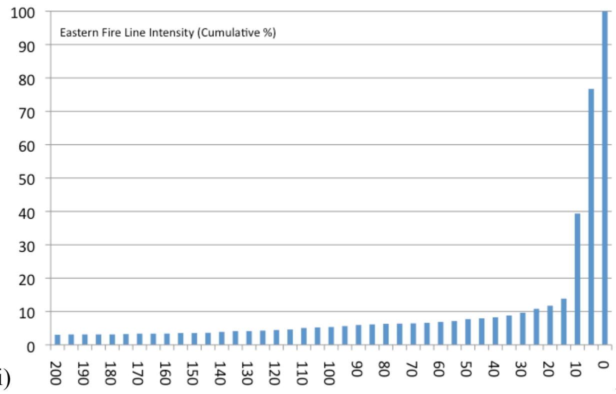
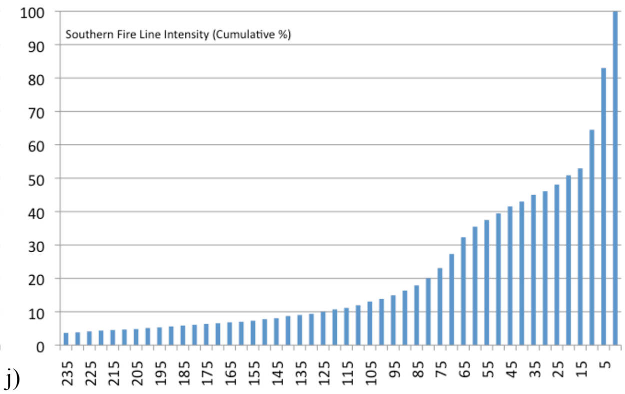


Figure 3. Cumulative histograms of Rate of Spread for the GACCs of a) Pacific Northwest; b) Northern California; c) Southern California; d) Southwest; e) Western Great Basin; f) Eastern Great Basin; g) Northern Rockies; h) Rocky Mountain; i) Eastern; j) Southern. X-axis is rate of spread in ft/sec, and y-axis is cumulative percent.


Pacific Northwest Fire Line Intensity (Cumulative %)
Northern California Fire Line Intensity (Cumulative %)
Southern California Fire Line Inensity (Cumulative %)
Southwest Fire Line Intensity (Cumulative %)
Western Great Basin Fire Line Inenstiy (Cumulative %)
Eastern Great Basin Fire Line Intensity (Cumulative %)
Northern Rockies Fire Line Intensity (Cumulative %)
Rockies Fire Line Intensity (Cumulative %)
a)
b)
c)
d)
e)
f)
g)
h)



i)



j)

Figure 4. Cumulative histograms of Fire Line Intensity for the GACCs of a) Pacific Northwest; b) Northern California; c) Southern California; d) Southwest; e) Western Great Basin; f) Eastern Great Basin; g) Northern Rockies; h) Rocky Mountain; i) Eastern; j) Southern. X-axis is rate of spread in Btu/ft/sec, and y-axis is cumulative percent.

Table 1. ROS, FLI and SPI thresholds based on 75% cumulative percentage for each GACC.

GACC	ROS	FLI	SPI
Pacific Northwest	11	15	-1
Northern California	16	70	-1
Southern California	36	140	-1
Southwest	68	480	-1
Western Great Basin	30	90	-1
Eastern Great Basin	30	130	-1
Northern Rockies	32	245	-1
Rocky Mountain	16	45	-1
Eastern	8	18	-1
Southern	12	74	-1

The thresholds in Table 1 were used to map monthly forecasts from the MC1. This is discussed further in the Deliverables section of this report.

<u>Link MC1 with CFS forecasts</u>

The subsections below describe the protocol to run MC1 with CFS.

Equilibrium mode: initialization phase.

The MAPSS equilibrium biogeography model (Neilson 1995) is first run (stand-alone mode) with mean 1895–2009 monthly climate data and soil information to produce an initial potential vegetation map. The MC1 biogeochemistry module is initialized with this vegetation map and run with the same mean climate to calculate corresponding initial carbon and nitrogen pools. The run terminates when the slow-turnover soil organic matter pool reaches steady state, which may require up to 3000 simulation years for certain vegetation types (Daly et al. 2000). This phase corresponds to the initialization of all MC1 variables, and because MC1's fire module cannot be run meaningfully on a mean climate, fire frequency is prescribed for each vegetation type.

Transient spin-up phase.

Once the slow-turnover soil carbon pool has equilibrated, MC1 is run in transient mode using a climate time series of approximately 1000 years using the historical time series (1985-2010) repeatedly. A high-pass filter is used to get rid of the long term trend in the time series so that the filtered value for any given month is equal to the target mean plus the deviation of the actual historical value for that month from the 30-year moving average centered on the given month. The target means for the spin-up dataset were originally the means of the first 15 years (1895-1909) of the historical period, but have now been modified in the 2010 version of the model to the first 50 years of the historical period to avoid anomalous decadal periods. Implicit in this protocol is the assumption that ecosystem carbon pools are in equilibrium with climate means for the period 1895-1944 at the beginning of the historical period simulation. The MC1 fire module is only turned on in transient mode, and requires the spin-up phase to attain its expected spatially variable fire frequency. The spin-up phase length is set so that an overall dynamic equilibrium in net ecosystem carbon exchange (NEP near zero) is reached.

Transient historical run

Gridded monthly climate data from 1895 to present have been provided by the PRISM group at Oregon State University (Daly *et al*. 2008). The PRISM climate mapping method has been described extensively elsewhere (e.g. Daly *et al*. 1994; Daly *et al*. 2008). PRISM uses available meteorological station data within a reasonable radius of the target point when estimating climate for that point. The climate input data for temperature consists of three monthly series: the monthly means of the daily extremes (*tmin*, *tmax*) and the monthly mean dewpoint temperature (*tdmean*) used to calculate vapor pressure deficit. Monthly mean temperature is estimated as the average of the *tmin* and *tmax* values. The model also requires monthly precipitation also provided by the PRISM group.

The North American Regional Reanalysis (NARR) dataset was originally proposed as an additional "climate" dataset for this project. Some testing was done with this dataset; however, longer-term developments regarding the MC1 (see Future Developments section below) plans for PRISM to be continued as an integral part of the future modeling effort.

Transient future run

Once the model has been run for the historical period, it is run again in transient mode using future climate scenarios. Future climate datasets can be provided by a variety of sources. In this project, CFS products constitute the future projections to be formatted for running the MC1 model, though four other models were also included (see Deliverables section). The following subsection describes the protocol used to create future climate datasets using future climate data that may be provided at a different spatial grain as the historical climate records than the PRISM group.

Downscaling protocol to create future scenarios

Future climate scenarios are often provided at a scale different from the research project needs, and thus requires to be downscaled before the model MC1 can be run with them. The downscaling process consists of several steps (Rogers 2009, Conklin 2009). First, a one-year monthly baseline climatology is constructed from historical climate averages for the period 1971-2000, provided by the PRISM team (Daly et al. 2008). Secondly, a one-year monthly baseline climatology at the spatial resolution of the forecast model is constructed using its output for the period 1971-2000. Thirdly, a time series of climate anomalies for January 2007 through December 2099 (at the spatial resolution of the forecast model) is constructed from the future climate time series, referenced to the forecast model baseline climatology. Temperature anomalies are calculated by subtracting baseline climatology values from future climate values. Precipitation anomalies are calculated by taking the ratio of future climate values to baseline climatology values, except when base climatology values are zero or when the ratio is very large, in which case the precipitation anomaly is capped at a maximum ratio of 5 (Rogers 2009). Finally, the time series of climate anomalies is downscaled to the project spatial grain size using binomial interpolation and applied to the PRISM-derived baseline climatology.

Challenges to modify CFS products to match the MC1 needs and lessons learned

To be used by MC1, input data needs to be translated into latitude-longitude coordinates and up/downscaled to the spatial grain of the PRISM-derived climate baseline. CFS products are available in Lambert Conformal Conic projection. Their spatial resolution is 32km resolution, while the PRISM group has provided baseline data at 50, 12, 10, and 8km, as well as 800m spatial grain.

The MC1 model requires single files for each climate variable for the entire time period of interest. CFS products are provided as monthly files so they needed to be aggregated in the format used by the MC1 model.

To remedy these simple logistical problems, Dominique Bachelet's team at Conservation Biology Institute (CBI) is now writing software that will be able to access datasets in various formats and manipulate them to create usable inputs for the MC1 model. CDO software has been used to create short but powerful scripts that save computing time and efforts to solve such problems. K. Ferschweiler, CBI programmer, has now written CDO scripts to automate the downscaling process. This will allow rapid translation of future forecasts into MC1 usable currency whether the future climate scenarios are provided as CFS or AR5 products.

Finally, Dr. Conklin, CBI research scientist and previously programmer for MAPSS team, has modified the MC1 code so that it can now use available climate variables and simply calculate from them unavailable but needed inputs (e.g. using Tdmean to calculate VPD).

4. Methodology

NCEP CFS

The Climate Forecast System (CFS) is the NOAA/NCEP operational fully coupled ocean-land-atmosphere dynamical seasonal prediction system (Saha et al., 2005). CFS has demonstrated a level of skill in forecasting U.S. surface temperature and precipitation that is comparable to the skill of the statistical methods used by the NCEP Climate Prediction Center (CPC). The atmospheric component of the CFS is the Global Forecast System (GFS) operational 2003 at NCEP as global weather prediction model run at T62 (~200 km grid) and a finite differencing in the vertical with 64 sigma layers 2003 (Moorthi et al. 2001). The oceanic component is the GFDL Modular Ocean Model V.3 (MOM3; Pacanowski and Griffies 1998). MOM3 uses spherical coordinates in the horizontal with a staggered Arakawa B grid and the z-coordinate in the vertical. The ocean surface boundary is computed as an explicit free surface from 74°S to 64°N. The longitudinal resolution is 1° whereas the latitudinal resolution is 1/3° between 10°S and 10°N and increases until fixed at 1° poleward of 30°S and 30°N. There are 40 layers in the vertical with 27 layers in the upper 400 m, and the bottom depth is around 4.5km. The atmospheric and oceanic components are coupled with no flux adjustment correction. These two components exchange daily averaged quantities, such as heat and momentum fluxes, once a day. Coupling between atmospheric and oceanic components occurs between 65°S to 50°N. The observed climatology is used to prescribe SSTs and sea ice extent poleward of 74°S and 64°N. A latitude-dependant weighted average of the observed climatology and model-calculated SSTs are used between 74°S and 65°S, and between 64°N and 50°N. One forecast run is produced every day for nine target months. Initial conditions are from the NCEP/DOE Reanalysis-2 for the atmosphere and from NCEP global ocean data assimilation system for the ocean.

MC1

MC1 is a dynamic general vegetation model (DGVM) that simulates lifeform mixtures and vegetation types (Figure 5), ecosystem fluxes of carbon, nitrogen, and water and fire disturbance. Publications of research results using the model have been listed and made available on a dedicated web site (http://www.fsl.orst.edu/dgvm/publications.htm). MC1 is routinely implemented (Daly *et al*. 2000; Bachelet *et al*. 2001a; Aber *et al*. 2001; Lenihan *et al*. 2003) on spatial data grids of varying resolution (900 m^2 to about 2500 km^2) where the model is run separately for each grid cell. MC1 has a monthly time-step with interacting modules for biogeography, biogeochemistry and fire disturbance (Bachelet *et al*. 2001b). The biogeography rules were adapted from the MAPSS model (Neilson 1995). The biogeochemistry module is a modified version of the CENTURY model (Parton *et al*. 1994), which simulates plant productivity, organic matter decomposition, and water and nutrient cycling. Plant productivity is constrained by temperature, effective moisture (i.e., a function of soil moisture and potential evapotranspiration) and nutrient availability. Along with vegetation information, model output includes several fire related indices and a drought index. Dr David Conklin has been archiving versions of the MC1 code used in various projects on the subversion source repository at the Oregon State University Open Source Laboratory (https://envision.osuosl.org/svn/). Two additional URLs created and supported by Dr. Dave Conklin and Ken Ferschweiler, Conservation Biology Institute staff using MC1 in their research, provide support for MC1 model users: (1) a site where information is shared about on-going changes to the MC1 model code (https://sites.google.com/site/mc1dgvmusers/) and (2) the home page for a Google group of MC1 users sharing experiences and research results using the model (http://groups.google.com/group/mc1-dgvm-users). CBI staff is currently developing an on-line version of the MC1 model that will be available to users to run on the Amazon cloud.

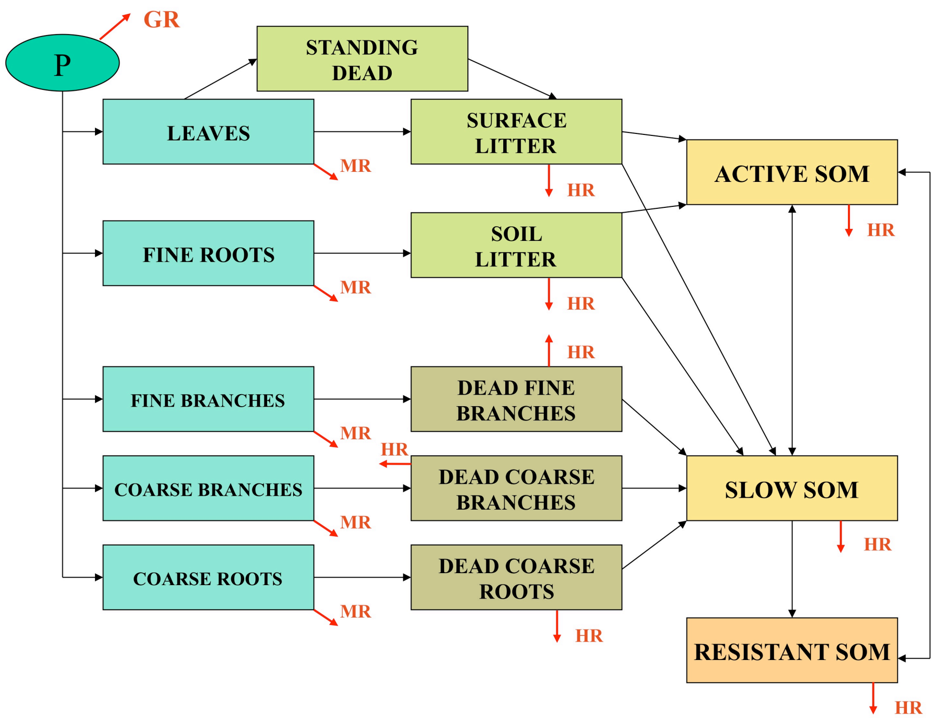


Figure 5. Diagram illustrating the various plant compartments simulated by the MC1 dynamic global vegetation model. The model simulates carbon, nitrogen and water pools associated with each of the compartments. (P: production, GR: growth respiration, MR: maintenance respiration, HR: heterotrophic respiration)

5. Benefits

Relevance to NCTP goals and priorities

This project met several of the NCTP program goals and priorities:

1. It is a response to a decision-maker requirement for climate information.
    - The product was requested by national fire agencies.
2. It provides a mechanism that embeds research sustainability into operations.
    - Dynamic vegetation model research was integrated into operational seasonal forecasts to produce an operational monthly value-added product.
3. It develops a new deliberate bridge of research into an application.
    - Further development of the MC1 model is planned (the fire model would be run on the Amazon cloud every month acquiring new climate products from the CFS

data center and results automatically displayed and made available for manipulation on databasin.org (http://app.databasin.org/app/pages/galleryPage.jsp?id=53a663d283ac49358e907 43ba321104c), and it is anticipated to utilize this work to improve the operational product.

4. It increases scientific and operational capacity to improve a specific stakeholder risk management outcomes.
   - The product will be used as guidance to assist wildfire and land managers with strategic planning and budgeting.
5. It results in products that have value to regional and local climate-sensitive decision-making processes (fuel treatments).
   - The project resulted in a climate product tailored for specific applications having immediate value to regional decision-making.
6. It is adaptive as the demand for climate services increases.
   - The product supports the increased demand for climate service information and products that support land management agency preparedness and responses.
7. It develops a supporting infrastructure for value-added climate information delivery.
   - By allowing partner agencies to define the climate information needs and to determine how to best produce appropriate information to meet those needs, the resulting climate information product was integrated into the suite of CEFA operational decision-support tools.

Benefit to public and scientific community

This project addresses a several billion dollar a year environmental problem of effective and efficient management of the nation's public lands. One of the primary management objectives that this project supports is providing predictive information for fuel treatment planning for the reduction of risk from catastrophic wildland fire to people, communities and natural resources while restoring forest and rangeland ecosystems for diversity, function and dynamics. State managed forests will receive the same benefits as federal lands from this project. Many managed forests are privately owned for timber sales, and thus this project can provide information leading to potential direct economic benefit.

Though this proposal did not specifically address model research, some insight was gained in the linking of climate and ecosystem models (see Challenges subsection above). Besides some of the technical challenges, a primary challenge for the climate modeling community at large is improving the prediction skill of the seasonal forecasts. The project did demonstrate a new use of the MC1 model. Though it was developed for research, and is used to produce monthly fire forecasts, it had not been considered as a potential tool for fuel management prior to this project.

NOAA mission goals

This proposed project directly supports one of NOAA's primary mission goals of the utilization of climate information for decision-makers and resource managers. It supports NOAA's climate service mission to improve understanding and prediction of changes in climate, and inform a climate-resilient society by providing authoritative and timely information products and services about climate change, climate variability and impacts, and by informing decision-making and management at the local, state, regional, national and international levels. Seasonal climate model forecasts are a necessary component of this project, and represent an important information need for the land management agencies.

Benefit analysis

In federal FY 2005, the USFS total fire operations budget was slightly over $1B, and hazardous fuel reduction was approximately $300M (USFS, 2005). This does not account for costs from Department of Interior land management agencies, state and private sectors. Typically, prescribed fire costs from approximately $70 to $150 per acre for treatment compared to suppression costs that can range from $500 to $8000 per acre depending upon the actions required. Clearly, performing treatments at low cost for reducing fire risk and restoring ecosystem health is a large benefit over suppression. Recent yearly suppression costs have been escalating, and hazardous fuel treatment is one of the strategies to reduce these costs (WFLC 2004). Fires in the wildand-urban interface (WUI) have been both a societal impact (e.g., southern California fires in 2003) and the focus of many treatment programs. These are potentially high impact and high cost areas of which effective treatments are invaluable.

Usage of project results

The seasonal predictions from this project will be used as decision-support information for national and regional planning of fuel treatment opportunities, and budget and resource requests. Fuel treatments, in particular prescribed burning, are weather and climate dependent. If an area is either too wet or too dry, this will likely reduce opportunities to meet management objectives and annual goals. But if one region of the country cannot accomplish burns as desired, perhaps another region can. Confidence in a seasonal forecast can aid in the strategic planning of resources and budgets. Though the this project was initiated with a national and regional focus, local level decision-makers will also find benefit in the product for similar reasons of resource and budget allocations.

6. Deliverables

The primary project deliverables are seasonal forecast maps of prescribed burning potential and an operational web site where the forecasts are updated monthly (approximately mid-month). The web site address is http://cefa.dri.edu/mc1, and is maintained by the CEFA group.

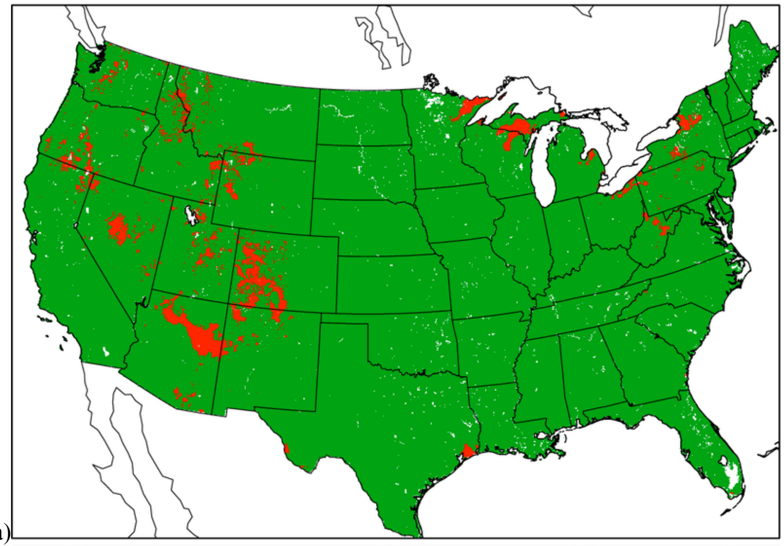
While CFS is one of the forecast models, it was realized during the course of the project that other seasonal models would also be of value in that they 1) provide a general indication of model uncertainty, and 2) could potentially be combined into an ensemble forecast. The four additional models include COLA, ECHAM, ECPC and NSIPP.

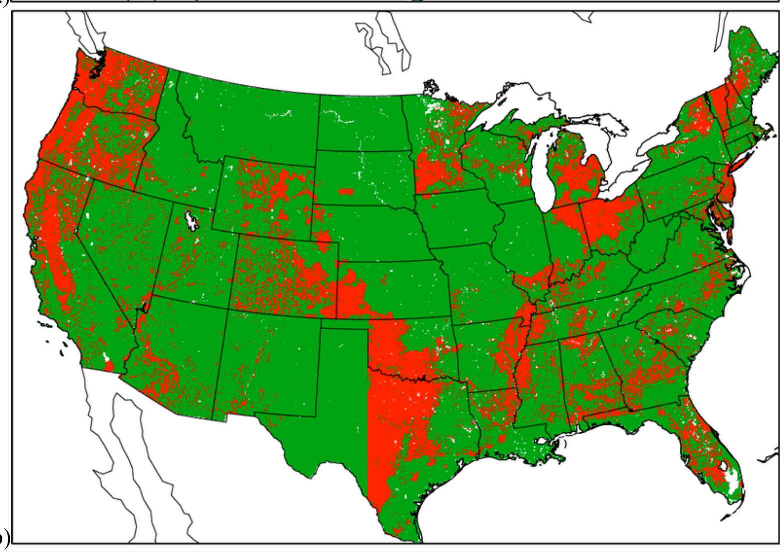
Figure 6 shows example forecast maps for SPI, ROS and FLI for March 2011 based on the median of the four models. March was chosen as representative of generally a time for prescribed burning for several parts of the country (e.g., Southeast and Southwest). The maps are constructed by checking whether the forecast for a particular element threshold (SPI, ROS and FLI) is exceeded for each map grid cell. If it is, then the grid cell is given a red color, otherwise green. The idea is to provide a quick glance at a region to determine where and how much of the area is shown to exceed the forecast threshold (red). Those areas that are green indicate climate conditions conducive to managed burning based on the forecast, while red indicates potential problematic areas. With the threshold pre-determined based on historical burns, the forecast colors directly tie a climate forecast with historical management decisions via a breakpoint value. Obviously many other factors also determine whether or not a prescribed burn will take place, thus this product serves as a climate guidance tool.

In the March example (Figure 6), the SPI (a) map shows only minimal red areas suggesting much of the country conducive to prescribed burning if solely based on climate precipitation factors[1]. In Figure 6b, the ROS shows larger areas of red indicating that these locations could be problematic for prescribed burning based on this fire index. The solid red cutoff line in Oklahoma-Texas is a function of GACC boundaries and a different threshold between the Southwest and Southern areas. Figure 6c shows red areas based on the FLI index. Taken together, the ROS and FLI show potential problematic areas in the Southeast. March is a time of prescribed burning in this region; thus, if the forecast were to verify, seasonal burning target goals and management objectives might not be met. From a strategic planning perspective, and if managers had confidence in the forecast, they could decide to focus resources and budget priorities to another part of the country that was in green. In this March example, that might be the Southwest.

---

[1] Kolden and Brown (2010) note human factor barriers to completing prescribed burns. These are often greater inhibitors to burn accomplishments than climate factors.


a)


b)

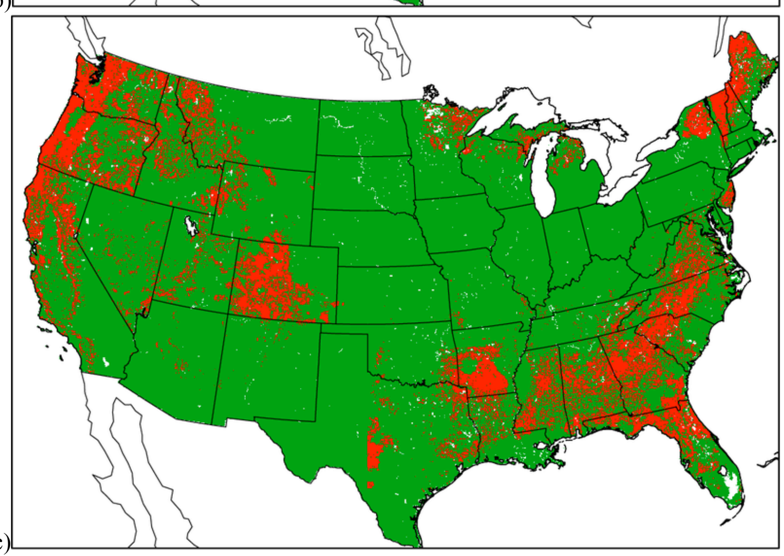

c)

Figure 6. Example forecast maps for March 2011 based on the median of the four climate forecast models for a) SPI; b) ROS; and c) FLI.

7. Future developments

USFS staff (Drs Drapek and Lenihan) and CBI staff (Dr Bachelet, programmers B. Ward, N. Stevenson-Molnar, and K. Ferschweiler, as well as lead GIS technician W. Peterman) met to discuss the methodological challenges of porting James Lenihan's fire forecast model specifically to the Amazon cloud, automating the acquisition of climate data (assuming some sort of map service from the PRISM group that provides updated historical and current climate datasets and from NOAA CFS to use the latest forecasts). The model would be run on the Amazon cloud, and the results would be summarized and transformed into spatial datasets to be uploaded in Arc format in Data Basin (databasin.org). As an example of simple display making, the data widely available AND easily manipulated and overlaid with other datasets, we uploaded the latest fire forecast for October 2010 (http://app.databasin.org/app/pages/galleryPage.jsp?id=53a663d283ac49358e90743ba321104c). We talked about options for visualization of model output including animations in Data Basin.

As of Dec 1, 2010, the model has been ported to the Amazon cloud and tests are being run to edit the code, and reconcile results between runs of the model produced on and off the cloud. The next step will be to address the issue of data transfer from the PRISM group and from NOAA CFS to be used by the model run on the cloud every month with updated weather forecasts.

Because the first forecast products began to appear at the termination of project grant, a formal evaluation has yet to be undertaken. To date, only stakeholder feedback has been incorporated. We plan to continue this evaluation effort via support and feedback from NIFCG, as well as making new contacts with some regional stakeholders. For example, the USDA Forest Service in the Southern area has expressed interest in this product to aid in resource availability decisions and budgeting. Interaction in this region will provide valuable feedback for a location that undertakes extensive prescribed burning.

8. Acknowledgements

We thank NOAA OAR for project support under Award Number NA07OAR4310462. We also very much thank the National Interagency Fuels Coordination Group for project input and feedback.

9. References

Aber, J., R.P. Neilson, S. McNulty, J. Lenihan, D. Bachelet, and R. Drapek. 2001: Forest processes and global environmental change: predicting the effect of individual and multiple stressors. 2000. *BioScience* **51**(9), 735-751.

Bachelet, D., J.M. Lenihan, C. Daly, R.P. Neilson, D.S. Ojima, W.J. Parton. 2001a: MC1: A dynamic vegetation model for estimating the distribution of vegetation and associated ecosystem fluxes of carbon, nutrients, and water. USDA General Technical Report PNW-GTR-508. 95 pp.

Bachelet,D., R.P. Neilson, J.M. Lenihan, and R.J. Drapek. 2001b: Climate change effects on vegetation distribution and carbon budget in the United States. *Ecosystems* **4**, 164-185.

Daly, C., D. Bachelet, J.M. Lenihan, W. Parton, R.P. Neilson, and D. Ojima. 2000: Dynamic simulation of tree-grass interactions for global change studies. *Ecological Applications* **10**(2), 449-469.

Kolden, C., and T. Brown, 2010: Beyond wildfire: understanding climate impacts on managed fire in the U.S.A. International Journal Wildland Fire, 19, 364-373.

Lenihan J.M., Drapek R.J., Bachelet D. & Neilson R.P., 2003: Climate change effects on vegetation distribution, carbon, and fire in California. *Ecological Applications* **13**, 1667-1681.

Mesinger, F., G. DiMego, E. Kalnay, P. Shafran, W. Ebisuzaki, D. Jovic, J. Woollen, K., Mitchell, E. Rogers, M. Ek, Y. Fan, R. Grumbine, W. Higgins, H. Li, Y. Lin, G., Manikin, D. Parrish, and W. Shi, 2005: North American Regional Reanalysis. *Bull. Amer. Meteor. Soc*., submitted.

Moorthi, S., H.-L. Pan, P. Caplan, 2001: Changes to the 2001 NCEP operational MRF/AVN global analysis/forecast system. *NWS Technical Procedures Bulletin*, 484, 14 pp.

Neilson RP. 1995. A model for predicting continental-scale vegetation distribution and water balance. Ecological Applications 5: 362–385.

Pacanowski, R. C. and S. M. Griffies, 1998: *MOM 3.0 Manual*, NOAA/Geophysical Fluid Dynamics Laboratory, Princeton, USA 08542.

Parton, W.J., D.S. Schimel, D.S. Ojima, and C.V. Cole, 1994: A general model for soil organic matter dynamics: sensitivity to litter chemistry, texture and management. Pages 147-167 in R.B. Bryant and R.W. Arnold, editors. Quantitative modeling of soil farming processes. SSSA Special Publication 39. ASA, CSSA, and SSA, Madison, Wisconsin, USA.

Saha, S., S. Nadiga, C. Thiaw, J. Wang, W. Wang, Q. Zhang, H. M. van den Dool, H. L. Pan, S. Moorthi, D. Behringer, D. Stokes, G. White, S. Lord, W. Ebisuzaki, P. Peng, P. Xie , 2005: The Climate Forecast System at NCEP. Submitted to the *J. Climate*.

USFS, 2005: Fiscal Year 2006 President's Budget Overview, February, 2005, 54 pp. Available at http://www.fs.fed.us/publications.

WFLC, 2004: Large Fire Suppression Costs: Strategies for Cost Management, August 2004, 59 pp. Available at http://www.fireplan.gov/reports.