Integrating Fire, Climate, and Societal Factors into Decision Support for Strategic Planning in Wildland Fire Management

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Abstract—*An El Niño winter in 1998-99, followed by a strong La Niña winter in 1999-2000, set the stage for potentially large wildfires in the southwestern, southeastern, and northwestern forests of the United States. Researchers at the University of Arizona organized a three-day workshop to discuss the relationship between synoptic scale climate conditions and wildland fire probability. Over the three days, fire managers, fuels managers, fire ecologists, climatologists, and other experts began the task of not only learning from each other, but also figuring out how to talk to each other. The workshop exceeded the organizers' expectations and has led to the institutionalization of annual fire-climate workshops. The initial workshop also provided the foundations for a subsequent project, completed in July 2004, to build a GIS model that integrates fire, climate, and societal values in a manner that specifically supports strategic planning in wildland fire management. This paper describes the two parallel paths that emerged from the 2000 fire-climate workshop and discusses the benefits and challenges of interdisciplinary, collaborative research projects for building regional and local-scale sustainability in the face of multiple societal and natural stressors.*

Introduction

Millions of acres are at risk of wildland fire in the United States. The General Accounting Office has noted that, "Primarily as a result of human activities, ecological conditions on 211 million acres – or almost one-third of all federal lands and about 10 percent of the nation's total surface area – continue to deteriorate. According to a 2001 update of federal wildland fire management policy, these ecological conditions have increased 'the probability of large, intense fires beyond any scale yet witnessed'" (GAO 2002, p.8; for source of embedded quotation, Interagency Federal Wildland Fire Policy Review Working Group 2001). Statistics compiled by the National Interagency Fire Center (NIFC) indicate a sharp rise in acres burned and in suppression costs over the past decade (table 1) (see http://www.nifc.gov).

While over-zealous suppression is cited as one of the primary reasons for the problem, many other factors play a role. Climate can be influential in periodic, regional-scale fire regimes, and can be an important factor in fire use as well as fire suppression planning. Development of lands adjacent to and within wildland areas presents increasing challenges not only with regard to fire suppression and fuels management strategies, but also with regard to the nature and level of interactions with residents and interest groups who seek to influence wildland and fire management policy. Scientific advances in understanding the patterns, drivers, and impacts of wildland fire and its management offer opportunities for addressing the dilemmas facing managers, decision makers and the public alike. This paper chronicles two related initiatives, one to introduce climate into wildland fire decision-making processes, and the other to develop an integrated Geographic Information Science (GIS) model for use in strategic planning. Both projects

Table 1. Acres Burned and Suppression Costs 2000-2004 and 10-Year Average.

Year	Acres Burned	Cost
2004 (to date)	7,381,166	Not yet available
2003	2,695,156	$1,326,138,000
2003	6,334,283	$1,661,314,000
2001	2,904,868	$917,800,000
2000	6,482,016	$1,362,367,000
10-year average	3,193,463	

Source: National Interagency Fire Center, http://www.nifc.gov; accessed 9/1/04.

are based on an integrated, iterative conceptual model, described below.

Integrated, Collaborative, and Iterative Science for Decision Support

The research activities described in this paper draw on concepts of integrated assessment as a model for investigating questions, through scientific synthesis, that cannot be answered from a singular disciplinary perspective. Such research involves explicit efforts to deliver the resulting knowledge in ways that are useful to society for thinking about issues and making more informed decisions (CIESIN 1995, Parson 2995, Rotmans and vanAsselt 1996, Cohen and others 1998).

The Regional Integrated Science and Assessment (RISA) program within the National Oceanic and Atmospheric Administration's Office of Global Programs (NOAA-OGP), is an example of a program that supports regional integrated climate impacts assessment projects in several regions of the United States. RISA specifically supports experimentation in alternative structures and methods for carrying out integrated assessments and is one example of the types of funding programs that are explicitly interested in bridging the science-society gap. RISA focuses on determination of the impacts of climate variability and change and identification of ways in which climate information may reduce vulnerability and increase resilience and adaptation capacity. The program recognizes that "a variety of climatological, social, economic and ecological circumstances that interact over different spatial and temporal scales…" and details RISA research components as involving (1) interdisciplinarity, including syntheses of related scientific knowledge, (2) bridging the gap between climate and societal interactions on different temporal and spatial scales, and (3) development of decision support and services" (Pulwarty 2002).

More broadly, integrated assessment today constitutes an important mechanism for addressing compelling societal dilemmas, such as management of wildland fire, that occur in complex biophysical and societal contexts. Many of the assessments underway accord bridging the science-society divide a high priority, in recognition that significant benefits can accrue from close and sustained collaboration with entities ("stakeholders") who have a stake in the questions being addressed. In particular, iterative research models that encourage ongoing exchanges and interactions between stakeholders and researchers in the co-development of science and policy (see Jasanoff and Wynne 1998) provide a promising avenue for assuring not only that the science remains focused on pragmatic questions, but also that the products emanating from the research activity are relevant, useful, and usable (Baldwin 2000, Gibbons 2000). Indeed, high levels of iterativity have been seen as offering potential for greater innovation and, ultimately, greater societal utility and impact (Lemos and Morehouse forthcoming).

The research activities described in this paper were based on these types of iterative integrated research endeavors. The climate-fire-fuels forecasting effort was carried out under the auspices of the Climate Assessment for the Southwest (CLIMAS) project, funded through the NOAA-OGP RISA program described above (the current cooperative agreement number for CLIMAS is NA 16GP2578). Development of the Fire-Climate-Society GIS model was funded through a grant from the US Environmental Protection Agency's Science to Achieve Results (STAR) program (grant number GR-828732-01-0).

The following sections provide a brief background on climate and wildland fire in the US Southwest, and a discussion of how integrated, iterative assessment was directed toward accomplishing knowledge exchange and decision support through a series of fire-climate workshops, as well as through the Fire-Climate-Society GIS model project, which grew out of the first fire-climate workshop. The paper concludes with reflections on future initiatives that build on the synergies established through these endeavors.

Climate and Wildland Fire In The US Southwest

As noted above, wildland fuel conditions across the United States remain problematical. This is certainly the case for the Southwest: fuel loads in many areas are extremely high, forests are densely packed with small-diameter trees, and dead fuels litter the landscape. The wildlands of the region tend to be fire-adapted, reflecting centuries of recurrent fire patterns at local to regional scales. Today, forest managers and scientists explicitly recognize the positive role fire plays in promoting forest health (Brown 1985, Baker 1992, Covington and Moore 1994, Pyne and others 1996), though fire suppression remains a dominant factor in fire management operations. Far less well adapted are societal policies and practices, including many decades (50-100 years) of fire suppression policy, continued and accelerating land-use encroachments on wildlands, and public intolerance of risk and reluctance to allow any fire – and especially smoke – to affect their geographical areas of habitation, recreation, and work. Forested lands dot the landscape in

Arizona and New Mexico; all attract heavy recreational usage and livestock grazing occurs in many areas. Some logging also occurs but is generally not a major land or resource use at the present time.

In managing fire risk and assessing conditions for fire use in the Southwest, as elsewhere, managers routinely take fire weather into account. However, they have tended not to pay much attention to predictions made for monthly to seasonal and interannual time scales. By contrast, over the past decade, climatologists have improved their forecasting ability in some areas, including prediction of El Niños and La Niñas, and other scientists have determined that climate exerts an important influence on fire regimes in some areas of the United States. The El Niño-Southern Oscillation (ENSO) plays a particularly important role in modulating wildland fire risk in the US Southwest (fig. 1), as well as in the Pacific Northwest and the US Southeast (Swetnam and Betancourt 1998, Swetnam and others 1999).

Improvements in ENSO forecast accuracy and skill has opened the door to possibilities for introducing climate forecasts into strategic planning for management of wildland fire and for fire use (including timing and location of prescribed burns). ENSO-related climate conditions that began in the winter of 1997-1998 provided an unusually good opportunity to bring climate forecasters and fire/fuels managers together to initiate a dialogue on how climate information might be integrated into fire management decision processes. Researchers associated with the CLIMAS project partnered with fire ecology and climate specialists to organize a workshop aimed at facilitating this dialogue.

The Climate-Fire Workshops

El Niño brought unusually wet winters in the Southwest and Southeast in 1997-1998; the Southwest also experienced a very wet summer in 1999. These conditions produced regional abundances of fine fuels. The winter of 1998-1999 in the two regions, was, by contrast, unusually dry, due the effects of La Niña in those regions. By late summer 1999 it became apparent that the two regions would be likely to experience a second dry La Niña-spawned winter. Research indicates that such combinations of conditions have, in the past spawned regionally extensive fire seasons. Indeed, over the past 400 years, the sequence of a wet El Niño winter followed by dry La Niña winter conditions is closely correlated with extensive wildfire occurrences (fig. 2) (Swetnam and Betancourt 1998).

NOAA's Climate Prediction Center (CPC) issued a La Niña forecast for the winter of 1999-2000 with

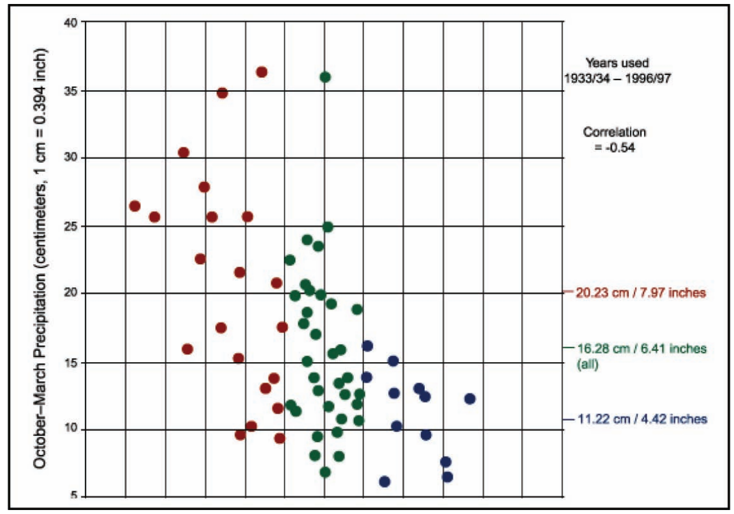

Figure 1. ENSO Patterns in the US Southwest. Source: Climate Assessment for the Southwest.

a high degree of confidence, prompting a decision to hold a workshop, under the auspices of CLIMAS, that would bring fire managers and researchers together with climatologists, meteorologists, and climate impacts researchers to discuss the implications of the forecast for fire management and more broadly to explore interactions between climate (defined as processes and observations occurring over time scales from a month to millennia; "weather" encompasses processes and observations occurring over time scales from immediate to about 3-4 weeks) and wildfire regimes.

The initial climate-fire workshop took place in late February 2000, and included climatologists, fire managers, and fuel managers from the Southwest, Southeast, and Northwest, all areas that could potentially benefit from ENSO forecasts and other climate information products (see Morehouse 2000). The workshop afforded opportunities for climatologists to educate fire/fuels managers about what sorts of forecasts and other information were available, and what the climate forecasts for the coming fire season were, as well as some basics about the science behind the forecasts. In turn, the fire and fuels managers provided insights into their areas of expertise and activity to the climatologists. Fire profes-

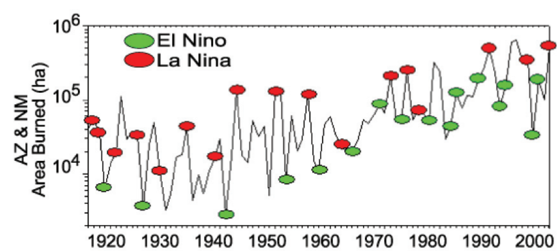

Figure 2. ENSO and Fire in the US Southwest.

sionals learned about the difference between "weather" and "climate," what climate parameters can and cannot be predicted, and which parameters have not yet been explored, and uncertainties associated with the science of forecasting, regional differences in forecasts. They also learned about issues associated with downscaling, particularly the point at which downscaling degrades data quality to an unacceptable level in terms of both time and space; and about what types of climate information can be usefully be applied at local scales. Climatologists learned from fire experts about topics such as the nature and practice of fire management, what types of climate information products fire managers want, what types of information are needed, and what research topics might be most productively pursued.

Information needs identified at the workshop included a call for "one-stop shopping" rather than having to thread one's way through a thicket of web pages; keeping a focus on commonly used products requested by the fire management community as well as new products; providing basic climate information at the regional level to allow assessment of climate norms and extremes; product and information guides pitched at the appropriate technical level; and more opportunities for interaction/feedback. Final recommendations included, among others, development of tools that integrate climate into environmental impact statement (EIS) processes and into large-scale National Environmental Protection Act (NEPA) planning efforts; development of tools for use in planning and decision making, including climate-fire regime modeling tools; and assignment of climatologists to teams revising land management plans. These latter recommendations inspired a group of UA researchers to write of a proposal to the EPA-STAR program to fund a three year project to develop an integrated fire-climate society GIS model (described later in this paper). Establishment of an ongoing, dynamic assessment process and holding another meeting of the workshop group were also suggested. These latter recommendations were addressed through two more years of workshops, followed by efforts to operationalize an annual fire-climate assessment process.

During the following year, 2000-2001, the organizers convened two workshops, with the goal of building on the success of the first year's endeavors (see Garfin and Morehouse 2001). While the climate forecasts for the winter season were not as compelling as those that had prompted the previous workshop, the devastating 2000 fire season, at that time the worst in 75 years, provided a strong impetus to reconvene for the purposes of further exploring the potential links between climatology and fire/fuels management. In addition, the higher level of uncertainty associated with the 2000-2001 winter forecasts provided an opportunity to explore the implications of inherent variabilities in climate forecasting skill and accuracy, topics of potentially critical interest to decision makers poised to integrate such information into their decision processes.

The first of the two workshops was held in mid-February 2001. Based on the previous year's experience, the organizers recognized a critical need to also inform individuals higher up in fire management organizational structures about the potential utility of climate information for fire management and the value of the interactions generated through the workshop process. For this workshop, regional-level representatives were invited from the fire management, fire research, integrated assessment, and climate science communities, covering much of the United States and Alaska. Members of the Joint Fire Science Program also participated. A second workshop, held in mid-March 2001, focused specifically on climate-fire linkages in the Southwest and adjacent area of Mexico, and on building relationships between southwestern fire and fuels managers and key climatologists.

The workshops occurred in a climatological context of persistently drier and warmer-than-normal weather prevailing over many of the nation's forested areas, leading in turn to record dryness of fuel loads in some areas. Reductions in spring rainfall, including a failure of May-June rains in the Northwest and northern Rockies, poor recovery of relative humidity and a general moisture deficit provided an unprecedented opportunity to continue the fire-climate dialogue. Workshop topics included examination of links between fire and long and short-term climate variations, communication and interpretation of forecasts and the uncertainties associated with those forecasts, and stakeholder-driven integrated assessment initiatives having a bearing on fire management. A retrospective look at the 2000 fire season, including the spring 2000 Cerro Grande fire in Los Alamos, New Mexico provided a focal point for discussion of the challenges facing fire managers and of potential uses of climate information for reducing vulnerability to damages caused by large wildland fires.

Presentations were also made regarding initiatives being supported by the Joint Fire Science Program and about integrated assessment activities, including a first introduction to the Fire-Climate-Society GIS modeling project, newly funded by EPA-STAR and formally initiated in February 2001. As with the previous year's meeting, recommendations for research and climate information development were proposed, including (among others) improvement in knowledge transfer processes and rationalization in delivery of information from disparate sources to make locating information easier; improvements in observation networks, data collection; data and database access at scales from local to global; more scientific analysis of key variables, such as wind and its association with synoptic climatology; better access to fire data (e.g., fire starts); research into linkages between climate and the Fire Danger Rating System; inclusion of climate into existing fire model software; and development of a climatology primer for fire managers and decision makers. While not all of these recommendations have been acted upon, the list remains an important source for identifying and supporting additional research and development efforts.

A third workshop was held in the winter of 2001-2002. This time topics included, in addition to climate forecasting, presentations on smoke modeling, improvements in long-range predictions for land management, a talk by a representative of a city fire department, and a special session on social science perspectives on fire. One output of the meeting was the first-ever climate-fire consensus forecast, developed in a side meeting by the group of climatologists who participated in the meeting. The meeting was important for cementing synergies within and among the climatology and fire management communities, and for reinforcing the links between fire scientists and managers more broadly.

The winter of 2003 saw a transition from the original workshop format to a national process collaboratively organized by the Predictive Services Office of the National Interagency Fire Center (NIFC) and CLIMAS. Persistent drought conditions throughout much of the US West provided a pivotal theme for the meeting (Brown 2003). The meeting, held in late winter 2003, brought together climatologists, fuels specialists, and fire meteorologists from the Geographical Area Coordination Centers (GACCs) to develop national and regional maps representing fire-climate forecasts for the coming fire season. The effort resulted in the first-ever integrated fire-climate-fuels forecast map, as well as forecast maps for each of the GACCs (Garfin and others 2003). The exercise was repeated in 2004, again resulting in production of special forecasts for fire management (fig. 3). The effort is now transitioning from an experimental effort under CLIMAS auspices to an operational effort under the headed up by NIFC's Predictive Services Office.

The workshop process and the operationalization of the fire-climate forecasting effort exemplify a successful employment of an iterative, integrated, and collaborative research process to address some of the multiple stresses decision makers regularly confront. The fire-climate forecasting process, which began as a process of exploration of potential common interests and synergies, has evolved into a process by which researchers, climate forecasters, and decision makers continue to meet to co-develop and co-produce forecasts specifically tailored for wildland fire management.

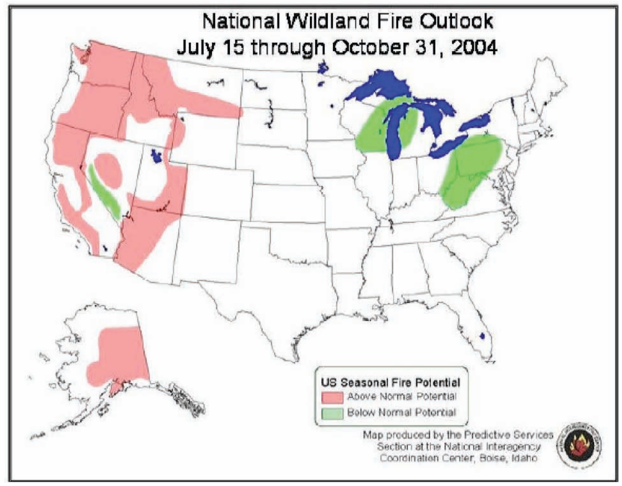

Figure 3. Example of National Wildland Fire Outlook. Source: National Interagency Fire Center, http://www.nifc.gov, accessed 9/1/04.

The Fire-Climate-Society Integrated GIS Model for Decision Support

As noted above, an outcome of the first fire-climate workshop was the writing of a research proposal to the EPA-STAR program to develop an integrated fire-climate-society GIS model to be used for decision support (Morehouse and others 2000). The project, funded for three years, involved an interdisciplinary team of researchers from the University of Arizona who represented fuels, climate, remote sensing, fire history, GIS, social science, and public outreach expertise. Over the course of the research and development process, Fire-Climate-Society, Version 1 (FCS-1) took shape as a GIS-based tool that could be used not only by fire experts but also by community members to explore fire risk conditions under different climate scenarios and component weighting schemes.

The model, which is supported on the University of Arizona's Wildfire Alternatives (WALTER) web site, allows users to construct maps at a scale of one kilometer (the lowest level to which climate data could be downscaled) for four specific study areas: the Catalina-Rincon Mountains adjacent to Tucson, Arizona; the Huachuca Mountains adjacent to Sierra Vista, Arizona and Fort Huachuca Army Base; the Chiricahua Mountains in rural southeastern Arizona, and the Jemez Mountains adjacent to Los Alamos, New Mexico.

The model includes two submodels, one representing fire hazard components, and the other representing values at risk components. The user selects a climate scenario from a special climate scenario selector, then proceeds to assign weights to the models components through pair-wise comparisons of the components within each submodel, then of the two submodels. Based on these inputs, the model produces maps of each component and each submodel, and a fire risk map that combines all components.

The WALTER web site also features options whereby stakeholders can organize group-level as well as individual participation in the modeling exercise. This feature is designed to foster communications about fire management issues not only across expert communities but also between expert and community groups. Development of FCS-1 involved highly interdisciplinary interactions among the project researchers and a series of iterative meetings with potential users of the model. These meetings were especially important for obtaining feedback early enough in the development process to allow adjustments and for identifying sources of information and insight not otherwise available to the team.

FCS-1 includes nine components, divided between two submodels. The fire hazard submodel includes five components: fire return interval departure, fuel moisture stress index, large fire ignition probability, lightning probability, and human factors of fire ignitions. The values-at-risk submodel includes four components: recreation value, species habitat richness, property value, and personal landscape values. A schematic of the model and details about each of the components are available on the WALTER web site (http://walter.arizona.edu). With this array of variables, FCS-1 goes beyond existing fire models that incorporate weather and in some cases basic economic variables to provide options based on climate scenarios relevant to the four study areas and to include a richer array of societally important values at risk from wildland fire.

Based on user input, FCS-1 produces fire risk maps that may be analyzed at multiple scales, ranging from the entire mountain range to a 1 kilometer^2 pixel. Users may experiment by running the model using different climate scenarios and/or different weightings in the pair-wise comparison of the model components, and they have the option of saving the maps they have produced so that they can refer to them later for purposes such as making detailed comparisons of the similarities and differences shown on the maps or for sharing results in group settings.

FCS-1 is accompanied by additional information on the WALTER web site, including an interactive explanation of key legal policies, dynamic vegetation maps, fire history maps, and a wildfire-climate regression tool. The WALTER web site itself is designed with usability very much in mind: navigation is easy, and strong effort was directed toward ensuring that the content is easily understood. Importantly, the model allows use of the kinds of climate forecasts developed through the fire-climate workshop process: the user consults the forecast for the coming fire season, and selects one or more closely analogous scenarios available for the model.

In explicitly seeking to draw ordinary citizens as well as experts into exploration of wildfire alternatives, the WALTER web site and FCS-1 represent an innovative approach to co-development and use of fire models through interdisciplinary research and development, and through collaborative iteration between scientists, decision makers, and community members in the four study areas. Both the web site and the model encourage exploration of how different factors influence fire risk, and provide a framework for participatory decision making processes. In providing a means, through climate scenario analogues, for reflecting climate forecasts in the running of the model, FCS-1 provides a direct connection with the ongoing fire-climate forecast initiative described above.

Conclusions and Looking to the Future

The fire-climate workshops and the FCS-1 modeling effort represent parallel but interconnected paths for linking science and society in a common effort to improve strategic planning for wildland fire management. In part, the success of these efforts derives from a confluence of events: climatic conditions posing high threat of fire risk, increased public awareness of the unsustainable conditions of the nation's forests, and heightened interest among governmental funding agencies in supporting efforts to bring science to bear on these problems. Success also derives from the willingness of scientists, fire managers, and other decision makers to commit to an ongoing, multi-year effort of collaboration and iteration to make sure that the multi-directional knowledge transfer process was maximally productive in terms of development of useful, relevant, and usable decision tools.

Good foundations have been set, but much remains to be done. Research needs range from improvements in knowledge about paleo, historical, and future climate variability and change to improvements in climate and fuels forecasting, vegetation modeling, fire emissions, fire-climate relationships, and understanding of ecological variability and change. Also needed are research efforts that explicitly take into account land use and land use changes, focus on continued development of state-of-the-art decision support tools, examine of decision processes associated with use (or non-use) of these tools, and assess the roles of human values, behaviors, and philosophies in heightening or diminishing wildland fire risk and vulnerability to fire impacts. In fire-climate-society integrated modeling, advances that need to be made include being able to integrate dynamical capabilities such as bringing real-time climate forecasts into the model and developing capabilities to integrate dynamical change in variables such as vegetation cover and fire perimeters. Expansion of the model to other sites, particularly within the Southwest is also a crucial future step.

Those who have participated in the fire-climate workshop and FCS-1 development activities are committed to continuing to build upon the existing iterative model of integrated research in support of decision making, and to sustaining the synergies that have been developed. Given the prospect of continued high fire hazard over the foreseeable future (GAO 2004, Westerling and Swetnam 2003, Dale and others 2001), the effort is an important one.

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