

**Full Title: Quantifying the characteristics and investigating the biogeoscientific and societal impacts of extreme wildland fires in the United States northern Rockies region**

**Short Title: Biogeoscientific and Societal Characteristics of Extreme Fire Events**

For: NASA Research Announcement "Interdisciplinary Research in Earth Science Solicitation", Subelement 1: Integrated Earth System Responses to Extreme Disturbances

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## **1. Scientific/Technical/Management Section**

### **1.1 Objectives and Relevance to NASA**

In recent years wildland fires have become more widespread with significant ecological, social, and economic impacts. Fewer than 5% of all fires account for the majority of area burned and the costs of fire suppression. We propose interdisciplinary research “**Quantifying the biogeoscientific and societal impacts of extreme wildland fires,**” at community and regional scales in the US northern Rockies. In this proposal, biogeoscientific encompasses (biophysical, biogeochemical, and biogeographical) The complex terrain in the northern Rockies offers steep environmental and social gradients to understand how and why landscapes change in response to extreme disturbances, as well as the social and environmental implications of those changes. The social gradient includes wildland interface community experience, while the environmental gradient covers aridlands, such as shrublands and grasslands, to mesic mixed conifer forests and subalpine ecosystems. Fires in these systems result in varying public and policy maker experiences and land management decisions in forested and rangeland ecosystems.

In this proposal we address the need to connect the biophysical impacts and trajectories of the post-fire environment as derived from Earth science research with impacts to human systems. This proposal applies directly to the RFP subcomponent objectives by applying biogeoscientific and social science metrics to:

1. Characterize the nature, magnitude, and distinguishing attributes of extreme wildland fire events;
2. Assess the full impact of the extreme wildland fire events (near-term and long-term) on both natural and human systems;
3. Characterize biophysical and social recovery processes and trajectories from selected extreme fire events; and
4. Understand how human actions to mitigate and/or recover from the impacts of past extreme wildland fire events have succeeded or failed, including the role that adaptive capacity and stakeholder knowledge play in effectively responding to fires.

The proposed synergy of wildland fire remote sensing, ecology, and social science is directly pertinent to the NASA Science Focus areas of “*Carbon Cycle and Ecosystems*”, “*Water and Energy Cycle*”, and “*Climate Variability and Change*”. This proposal directly helps achieve recently identified Earth system research priorities, as we seek to understand the complex inter-connected roles of biological and climate systems, while understanding the consequences for society, mitigation, and feedbacks in a changing climate (Reid et al. 2009). Furthermore, the recently completed “*Wildland Fire and Fuels Research and Development Strategic Plan*” highlighted several key areas where managers need improved knowledge and tools (USDA FS 2006), notably the need for “national monitoring systems for burned areas, fire severity, emissions, watershed impacts, property loss, and other factors, that will support adaptive approaches to management as better data become available on the effects of management activities.” Thus, in addition to meeting NASA’s RFP requirements, the proposed research addresses needs identified by other federal agencies.

Knowledge gained from this project is directly relevant to NASA’s Earth Science Applied Science Program, by improving the capability of Earth science models to predict the successional trajectory and societal feedbacks due to wildland fires; and developing new and standardized products to characterize the ecological impact of disturbances on wildland ecosystems (forests, woodlands, shrublands, and grasslands). Land managers need accessible science-based information and tools to accurately characterize fire behavior and associated fire effects, including air quality, sediment transport, vegetation mortality, ecosystem recovery, and the impacts of fire on human communities and their capacity to adapt to

extreme disturbance. Accessible science and decision support tools are particularly important for extreme fires because these fires occur in areas that threaten important resources, such as clean air and water, property, lives, and aesthetic values.

## 1.2 Qualifications of the Research Team

We have brought together a multi-disciplinary team of wildland fire researchers to address questions that cross traditional boundaries, including physicists, ecologists, and social scientists who are well linked to land managers eager to apply our science findings. Our proposal will connect the data and perspectives from the various disciplines into each of three challenges being investigated. The team's expertise in the science of wildland fires is extensive and includes the following (see vitae for citations):

- Smith has conducted research applying remotely sensed data to characterize wildfire area burned (Smith et al. 2002; Hann et al. 2003; Smith et al. 2007) and to remotely assess fire radiative power and post-fire ecological effects (Smith et al., 2005a,b; Smith and Hudak 2005; Smith and Wooster 2005; Lentile et al. 2006, 2009; Smith et al. 2007). Smith has also conducted research to evaluate fine-scale fire effects and fire modeling (Dickinson et al. 2009) and is an associate editor for the *International Journal of Wildland Fire*.
- Carroll and Hall have conducted research on the relationships of human communities and populations to fire events for approximately 10 years (Carroll et al. 2005, 2006, 2007; Hall and Slothower 2009). Much of this work has focused on the preparation for, mitigation of and recovery from large wildfire events (Paveglio et al. 2009; McCool et al. 2006; Carroll et al. 2004; Hall and Slothower 2009). Carroll has published 19 refereed journal articles and two book chapters on the subject of human/wildfire interactions since 2001 and is co-editor of the recent book, *People, Fire, and Forests*. Hall has extensive experience developing and implementing qualitative and quantitative research methods to study public perceptions of natural resources and factors affecting support for land management policies (Hockett and Hall 2000; Brown et al. 2008; Dedrick et al. 2000). She is the co-Editor in Chief of the international journal, *Society & Natural Resources*.
- Newingham's research focuses on the effects of fire and global change on aridland ecosystems. Previous research has included the effects of fire on soil chemistry and resulting effects on invasive species. Current work includes examining the effects of post-fire restoration practices on soil properties and linking these changes with plant and insect responses. She has extensive experience measuring plant productivity responses to global changes, including elevated CO<sub>2</sub>, nitrogen deposition, precipitation, and physical disturbance (Barker et al. 2006, Smith et al. 2009), as well as working with fire managers.
- The science team has considerable fire modeling experience, including Hicke's work modeling the trajectory of wildland fires and other disturbance events using remote sensing datasets (Hicke et al. 2003); Strand's and Falkowski's experience in the measurement and modeling of forest and woodland structure, succession, disturbances dynamics, and feedbacks (Strand et al. 2006, 2007, 2008, 2009a,b; Falkowski et al. 2005, 2009); Holden's experience in modeling fire-climate interactions (Holden et al. 2007); and Hoffman's research using simulation models to characterize fire behavior in forests affected by insects and diseases (Hoffman et al. 2007).
- Morgan, Hudak, and Holden have conducted considerable research to quantify the extent and severity of wildland fires across multiple United States and global ecosystems (Morgan et al. 2001; Hudak and Brocket 2002; Holden et al. 2005; Lewis et al 2006; Hudak et al. 2007; Lentile et al. 2007), and to relate historical fire patterns to climate (Heyerdahl et al. 2008, Morgan et al. 2008). Morgan is also an associate editor for the *International Journal of Wildland Fire*.

By coupling biogeoscientific and social-science knowledge, we can 1) increase the usage of NASA products in land management, 2) increase our understanding of the characteristics of extreme wildland fire events, and 3) better manage the impacts of extreme wildland fire events. The interdisciplinary team brought together for this project is ideally suited to research these questions and to produce quality science useful in fire management.

### **1.3 Technical Approach and Methodology**

#### **1.3.1 Overview - Extreme Wildland Fires: Burning Questions**

Wildland fires are a key element in the Earth system, acting as a disturbance agent and rapidly transferring biogeochemical and hydrological stocks stored in terrestrial vegetation to the atmosphere. Wildland fires affect vegetation, soils, and airflow with substantial effects on the terrestrial, subterranean, and atmospheric cycles within regional water- and air-sheds. Extreme fire events have considerable ecological, economic, and social impacts, prompting policy changes and other societal responses to land management.

Socio-economic impacts are most likely in communities in the wildland urban interface (WUI), where residential development is within and adjacent to wildland areas (USDA 2001; USDA and USDI 1995). Current estimates indicate that the WUI covers about 9.3 percent of the contiguous United States (Stewart et al. 2007), and it is estimated that in some parts of the western U.S. the WUI could increase by 40 percent by 2030 (USDA 2006). The nature and magnitude of social impacts in the WUI or elsewhere are not only a function of the physical effects of fire on homes but also a function of individual and social factors that increase or decrease the likelihood of property damage, as well as how people respond to and recover from damage. Examples include residents' emotional ties to landscapes, the effect of fire on economic livelihoods, and the ability of local organizations to adapt to evolving fire risk around them through collective action. Such characteristics differ among communities (McCool et al. 2006, Paveglio et al. 2009), and understanding the full socio-economic impacts of fires is an important step in fostering resiliency. Via experience, human systems can develop the ability to adapt and make the social and natural systems more resilient in the face of extreme disturbances (Daniel et al. 2007). There is a need to understand the impact of fires and the characteristics of human systems that promote adaptation and resiliency.

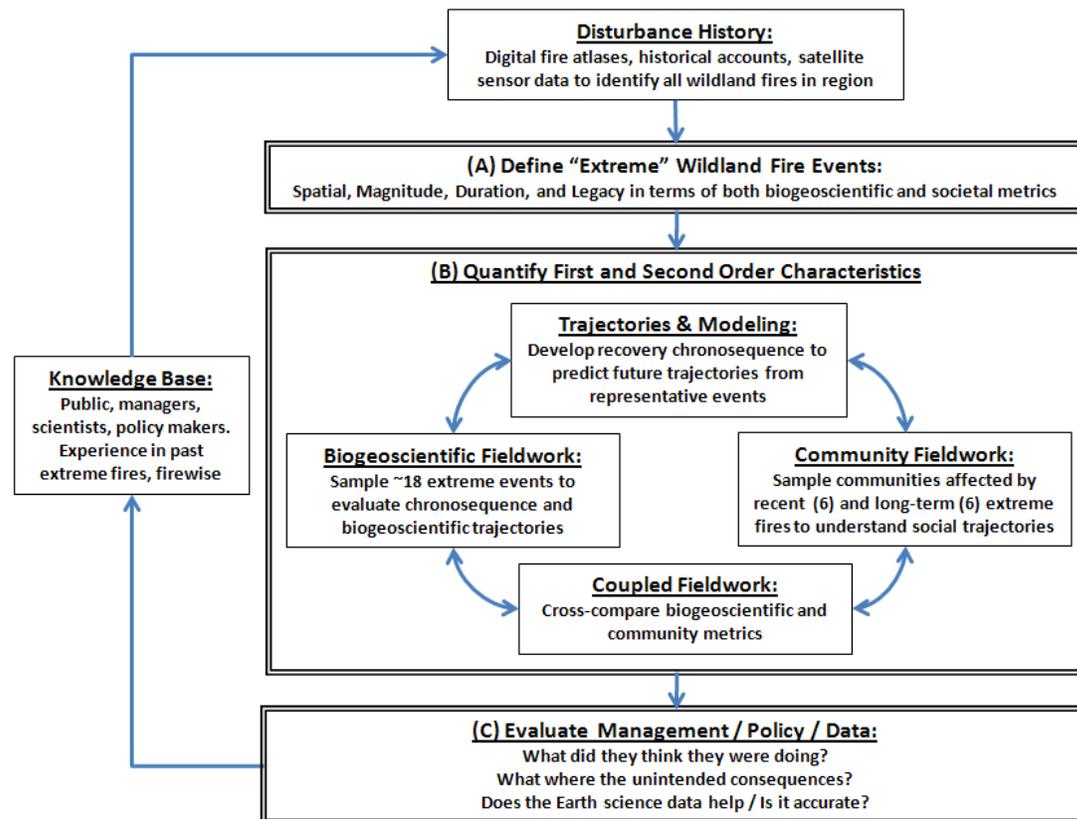
The trajectory of vegetation responses to extreme fire events will change as the post-fire environment becomes greatly altered for many plants. Understanding the long-term trajectories of vegetation responses is critical to shaping appropriate societal and policy responses. Despite intensive efforts at fire suppression, the western US has experienced extensive fires in recent decades, and the area burned in the US may increase to as much as 4-5 million ha per year over the next five years (NWCG 2009). Predictions include larger, severe fires under the influence of climate change (Running 2006; Westerling et al. 2006; Kitzberger et al. 2007). Strategic fire management will require a shift from historical suppression-only responses, to include more controversial actions involving fuels management and use of fire. Such activities are guided by science, but stakeholder and public understanding of that science can limit decision-making space. Research is needed to understand how new knowledge about ecosystem trajectories and recovery is understood by stakeholders and how such information affects their support for fuels management policies and their collective behavior to mitigate risks.

Advancing our understanding how extreme wildland fire events impact ecosystems over extended spatial and temporal scales and identifying similarities and differences across ecosystems will help predict potential future impacts. Several challenges and uncertainties exist related to the magnitude, duration, and drivers of extreme wildland fire events, their

wider impacts (temporal trajectories and spatial characteristics), and feedbacks within and between biophysical and societal processes:

- **Challenge A: Defining Extreme Wildland Fire Events (RFP element 1)**
- **Challenge B: Evaluating the Characteristics and Trajectories of Extreme Wildland Fire Events in Changing Physical and Political Climates (RFP elements 2 &3)**
- **Challenge C: Enabling Future Predictions, Mitigation, and Lessons Learning (RFP element 4)**

Our proposed strategy interconnects multiple disciplines to answer these research challenges in three nested phases (Figure 1):



**Figure 1.** General methodology of the proposed project. At each step (Define, Quantify, and Evaluate) the project will consider both biogeoscientific and societal metrics.

1. **Phase 1:** Define “extreme” in a cross-disciplinary manner for wildland fire events. We will describe extreme wildland fire events in the US northern Rockies using a panel of experts on the social impacts of fire, as well satellite data including MODIS and Landsat. We will focus on specific land use, social, and biophysical gradients relevant to this RFP (e.g., urban to wildland, grassland to forest), which will result in a list of key social and biophysical characteristics of extreme fires for Phase 2.
2. **Phase 2:** Select a stratified random sample of approximately 20-30 extreme fire events for in-depth biophysical analysis, with ~10 fires from each of: 0-10 yrs, 10-30 years, and 30-50 years. By coupling satellite data with historical fire atlas data, we will generate a **Fire Recovery Chronosequence**, which will be validated with field data. For recent fires

we will draw a random sample of residents from six nearby communities and quantify the economic, social, and individual impacts of the fire. A sample of six other communities will be selected for in-depth social science assessments of the long-term trajectory of social change following the fire, using key informant interviews.

3. **Phase 3:** Evaluate feedbacks and efficacy of past decisions in response to extreme wildland fire events. Within the six historic fire case study communities, key informant interviews will be conducted to assess past fire mitigation efforts and their effects, as well as the perceived effects of local, regional, and national fire-related policies. Following the interviews in each community, workshops will be held with community leaders, stakeholders, and citizens to share findings from the chronosequence research and to discuss its implications for nearby ecosystems.

### 1.3.2 Study Region and Time Period

Our study area encompasses wildland and WUI ecosystems in the US northern Rocky Mountain region, including Idaho, Montana west of the Continental Divide, and northeastern Oregon. These ecosystems are biologically diverse and important to people for wood, water, recreation, scenery, and wildlife habitat. Landscapes in the study area are dynamic, and have changed in response to extensive disturbance and land uses that alter composition, diversity, physiological processes, and ecosystem services.

Middle-elevation forests of the US northern Rockies have been identified as highly vulnerable to human-induced changes in fire size and severity (Westerling et al. 2006). Warmer, earlier springs and decreased snowpack predicted for this area (Mote et al. 2005) will lead to altered fire regimes (Running 2006). The proposed research advances our understanding of the resiliency of social and ecological systems in wildland and WUI landscapes and how these landscapes may be affected by future changes driven by climate, fire and land use. We will specifically focus on identifying the presence (or absence) of thresholds for resilience to changes in climate, land use and disturbance with the goal of informing natural resource managers. Our proposed fire recovery chronosequence of post-fire trajectories will inform existing simulation models of vegetation dynamics. In combination with field data, modeling data will be used to explore the implications of past and future landscape dynamics on the resilience of both the human and biophysical systems. We will also investigate how communicating scientific projections of climate, fire and vegetation change affect the knowledge, ability, and willingness of stakeholders to adopt fire mitigation policies and practices.

### 1.3.3 Background for Challenge A

In the case of hurricanes and floods, extreme events are typically characterized by return intervals, for example the "100-year" or "50-year" event. In the case of wildland fires, "extreme" is poorly defined. In recent decades in the United States, wildland fires exceeding 20,000 ha in size are increasingly common ([www.nifc.gov](http://www.nifc.gov)). These fires account for the majority of area burned and escalating suppression costs, as they burn under extreme weather conditions and often threaten people and property (Lentile et al. 2006, Morgan et al. 2008, NWCG 2009). **However, one cannot simply call all large fires extreme.** Many plants and animals are adapted to fire, and fire managers now may take limited suppression actions in the interest of fire fighter safety, reduced fire suppression costs, and providing ecological benefits to the system. Similarly, communities with experience of repeated wildland fire events and knowledge of programs such as Firewise ([www.firewise.org/](http://www.firewise.org/)) may not consider all large wildland fires extreme events, while a fire that is small from an ecosystem perspective may be considered extreme by people whose property or livelihoods have been

damaged. “Fire severity” – commonly linked to either effects on the soils or mortality of the dominant vegetation (Hudak et al. 2007; Smith et al. 2007) – is often used as an indication of extremity, but this is not appropriate for all cases. For example, removal of all vegetation in a grassland or mortality of conifers within a forest may be essential for the natural lifecycle of other species in that region (Smith et al. 2005a,b; Strand et al. 2008).

Are extreme fires best characterized by size, severity, ecosystem metrics relating to productivity and mortality, or by the degree to which social perceptions are negative? Do specific biogeoscientific metrics correspond to specific societal metrics? Multiple theoretical models and metrics have been developed to predict short or long-term impacts of disturbances on a given ecosystem and proximate human communities (Wisner et al. 2004; Turner et al. 2003; Cutter et al. 2003; Cutter 1996). Often this research quantifies diverse system attributes (predominantly biophysical and economic) and links them to possible outcomes (e.g., estimated damage to property, job losses). However, none of these metrics attempts to delineate what constitutes an extreme event for human communities; rather they determine whether and how such events might affect those human communities. Does the perception of extremity differ for people with different knowledge and values (e.g., scientists, land managers, townspeople) or backgrounds (e.g., experience with large fire events)? For example, evidence suggests that public definitions of “severe” are more related to the extent of social disruptions (such as evacuations) or human infrastructure and private property affected than to the area of public land burned (Carroll et al. 2006).

Given these pertinent questions, our first research objective is to:

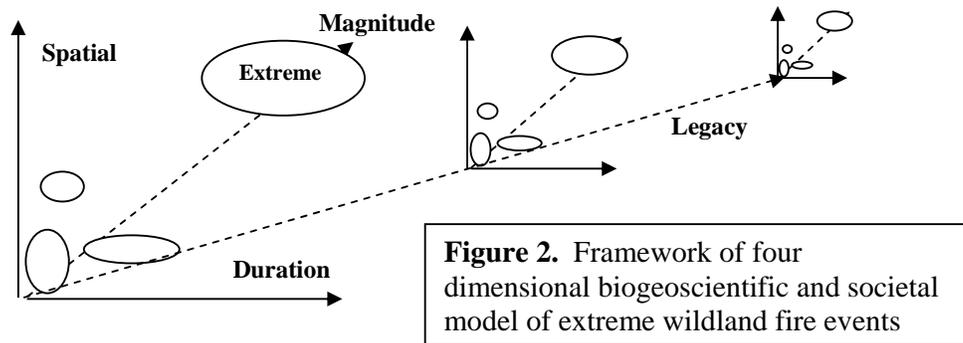
**Establish criteria to define an extreme wildland fires in the US northern Rockies**

**1.3.4 Methodology for Challenge A: Defining Extreme Wildland Fire Events**

Initially, we propose that extreme wildland fire events can be defined by four-dimensions, where each dimension encompasses both biogeoscientific and social perspectives (Figure 2):

- **Spatial Characteristics of the Event:** extent of burned area by land cover type (e.g., forest, rangeland, wildland urban interface), distance to nearest community, etc.
- **Magnitude Characteristics of the Event:** intensity, mortality, loss of property/lives, etc.
- **Duration Characteristics of the Event:** Short-term temporal characteristics (1-3 yrs) of event, duration that communities were evacuated or had loss of services, etc.
- **Legacy Characteristics of the Event:** long-term temporal trajectories (>3 yrs) of social and biophysical recovery, human community ability to adapt, enduring human perceptions of fire, etc.

We will use both biogeoscientific and social science methods to define “extreme” fires.



**Biogeoscientific:** We will obtain freely available satellite sensor datasets and fire management reports (via the National Interagency Fire Center, [www.nifc.gov](http://www.nifc.gov)) for wildland fire events that have occurred in the US northern Rockies over the last 30 years, to match the temporal extent of Landsat data. Older datasets will include aerial photography and ocular assessments with the national Monitoring Trends in Burn Severity (MTBS, [www.mtbs.gov](http://www.mtbs.gov) 1984-present) data. Co-I Holden has access to a newly developed regional digital “Disturbance Atlas” that contains all historical incidents of wildland fire, insect outbreaks, and timber harvesting. We will further collate available coarse and moderate spatial resolution satellite datasets for recent wildland fires (see Section 1.3.8). Fires with biogeoscientific metrics at or above the 95<sup>th</sup> percentile will be defined as extreme.

**Social:** Extreme fires will be identified by using a regional expert panel. Ten experts will be selected by Co-I Hall, Co-I Carroll, and Collaborator Jakes and on the basis of recommendations of professionals who are familiar with the issues under consideration within the region. Such experts could be representatives from a state forester’s office, regional emergency management professionals, or federal land managers. The expert panel will meet at a location convenient for its members and will have an in-depth discussion of the nature of fire impacts on human systems and the capacity of communities to mitigate and adapt to the impacts of fires. A Delphi process (Schuster et al. 1985; Young and Jamieson 2001) will generate consensus about the characteristics of extreme fires. This discussion will also serve as the basis for more in-depth questions for a representative household survey and key informant interviews in selected case study communities (see Section 1.3.6.3).

To quantify impacts of extreme fires on human systems, we will select a sample of six recent fires (1-3 years) and conduct surveys of a representative sample of (~600) households in nearby communities (< 50 miles of the wildland fire event). The number of questionnaires per case study will be proportionately allocated by population density and distance to the wildland fire event. Survey questions will contain multiple item scales to measure perception of fire effects on the multiple social domains identified by the expert panel, which are likely to include aspects such as quality of life, aesthetics, and economic vitality (Martin et al. 2008; Winter and Fried 2000). The data from this social research will be directly compared to the corresponding biogeoscientific data from the same fires used in the social fieldwork sample.

We will also assess how respondents perceive the success or failure of past regional policies to prevent and/or mitigate the impacts of the fires. Key sociodemographic factors likely to be related to perceptions, such as residence (Bright and Burtz 2006), income (Lynn 2003), and education will also be measured. We will include items that measure attitudes toward potential or actual policies and practices (Brunson and Shindler 2004; Kneeshaw et al. 2004; Shindler 2007). Questionnaires will be administered using the drop-off, pick-up method, which results in relatively high response rates (Hall and Slothower 2009; Steele et al. 2001). Data reduction will be performed through factor analysis, and correlation and regression analysis will explore the impact of sociodemographic variables (and other predictors) on the perceptions of fire events.

### **1.3.5 Coupled Background for Challenges B and C**

Following steps to define extreme wildland fire events, we need to describe the post-fire trajectories for the identified characteristics and metrics, in the context of variations in physical, political, and social climates. Prior studies have indicated that biophysical trajectories, such as those for carbon stocks and albedo, vary with aspects of the biophysical environment and climate (Johnstone and Chapin 2006; Goetz et al. 2007). However, research is still required to improve the integration of earth science data, field data, and models to better quantify the long term trajectories of disturbances (Goetz et al. 2007).

The majority of fire ecology research evaluating post-fire effects is limited to short temporal intervals (1-2 years post-fire), with few studies evaluating long-term (20+ years) post-fire trajectories (Lentile et al. 2006). Those studies that have characterized the long-term fire responses have achieved it via modeling or satellite remote sensing (White et al. 1996; Viedema et al. 1997; Hicke et al. 2003; Turner et al. 2003; Hope et al. 2007; Keeley 2009). Most studies of long-term trajectories post-fire do not encompass many sites nor multiple spatial scales including field data collection and remote sensing. Further, the effects of climate change on vegetation and fires depend in part on how resource management and other human actions modify vegetation structure and fuels (McKenzie et al. 2004). Predicting future trajectories under climate change, invasive species, and changing human demands becomes very challenging without a thorough understanding of post-fire successional trajectories (Dombeck et al. 2004). These extended temporal scale unknowns are highlighted by recent reports and publications. For example, although the 2005 North American Carbon Program science plan observed that "*ultimately, the severity of a burn event has important consequences for the long-term (decadal) trajectory of carbon accumulation* (Denning et al. 2005); the precise consequences of severity to the carbon cycle are not well understood.

Fire is both a biogeoscientific and social process. Our fire suppression is very successful as 97–99% of all wildland fires are suppressed while still less than 0.1 ha in area (Stephens and Ruth 2005). In general, the minority of the fires account for the majority of area burned (Kasischke and French 1993; Smith et al. 2007). The fires that grow large when fire suppression fails generally burn under hot and dry windy conditions. As a result, the fires we now experience burn under relatively extreme conditions and are therefore large, severe, and often threatening to people and property. This reinforces a public perception that all fires are extreme and must be suppressed even as our costs of suppression and post-fire rehabilitation grow so rapidly (Dombeck et al. 2004). Fire management costs are enormous (e.g. 48% of the US Forest Service budget in 2009) and must be contained (NWCG 2009). The changing fire management that results will alter the extent and severity of large fires. Further, fire policy changes occur in response to extensive wildfires (Dombeck et al. 2004). Postfire rehabilitation focuses on large fires where post-fire erosion poses risk to people, towns, watersheds and other values people have; these rehabilitation efforts alter trajectories (Robichaud pers. com). Thus we must understand the interactions between fire, climate, human perceptions and actions (Morgan et al. 2001), even as complex interactions change.

Variations in the trajectory of biophysical recovery are likely to be one influence on social recovery trajectories. Additionally, although there is little systematic knowledge of the timeframes for human community recovery from large fire events, evidence suggests that recovery times are at least partially driven by community preparation in advance of fire events and social preconditions that allow quick adaptations to fire hazards (Paveglio et al. 2009; Carroll et al. in press). Moreover, changes in policy at the regional and national levels may impact how human communities adapt to and recover from fire. The National Academy of Public Administration (2004) has concluded that the nation's best opportunity for containing firefighting costs and reducing vulnerability of communities is "to increase the capacity to reduce the accumulation of hazardous fuels and to mitigate wildfire risk to communities". Federal initiatives to reduce the wildland fire threat in the WUI include the National Fire Plan, Healthy Forests Initiative, and Healthy Forest Restoration Act of 2003 (Schoennagle et al. 2009). These policies have generally treated the WUI as a uniform, homogeneous collection of people and human systems, with little recognition of the social complexity and variability that affects policy implementation (Paveglio et al. 2009). In particular, these policies do not take into account the varying abilities of different WUI communities to adapt in ways that increase the resiliency and reduce vulnerability of such

human communities to wildland fire. Little effort has been made to understand how the differential characteristics of individuals, social groups and communities in the WUI factor into the success or failure of these and other policy changes aimed at reducing human risk from extreme fire events (Steelman 2008; Jakes and Nelson 2007; McCaffrey 2004).

Such variations and shifts in physical and political climate lead to several pertinent questions, including: How do changes in physical and associated political and social climates affect the way extreme wildland fire events impact biogeochemical, ecological, and social systems, as well as responses by policy makers and local communities in the immediate area of the fire events? Given what we are learning about the relation of fire occurrence, extent and severity to climate and topography (Holden et al. 2009; Heyerdahl et al. 2008; Morgan et al. 2008), what should we expect under future climate and land-use change and how does that influence social perceptions about fire and the acceptability of management responses?

**Research is needed to characterize the nature of extreme wildland fire events and evaluate how their trajectories (e.g., resistance, resilience, cumulative productivity, recovery) differ under physical, political, and social climate changes.**

Scientific understanding of past and likely future trajectories of recovery from extreme wildland fires can help inform land managers' and communities' decisions about policies and actions. However, this depends on how the social actors understand and assess this technical information, which is inherently complex. The National Wildland Fire Coordination (NWCG 2009) group recently argued that new, flexible management responses are needed to mitigate and manage wildland fires, but that "*these strategies are contingent on public acceptance.*" Accordingly,

**Research is needed to evaluate the success (or failure) of Earth Science research predictions of recovery by both comparisons with field data and through the perceptions of the fire-affected communities.**

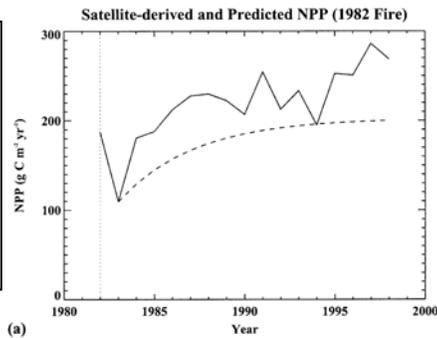
### 1.3.6 Coupled Methodologies for Challenges B and C

#### 1.3.6.1 First and Second Order Characteristics of Extreme Wildland Fire Events

**The biogeoscientific analysis** will build directly on prior studies that characterize wildland fire events by temporal trajectories of satellite remote sensing data (White et al. 1996; Viedema et al. 1997; Hicke et al. 2003; Turner et al. 2003; Goetz et al. 2007; Keeley 2009). As noted in section 1.3.1, we will identify the 21-30 extreme fire events. For each event, we will construct a trajectory curve -using pre- and post-fire data from satellite derived products (Figures 3). The temporal trajectories of biophysical and biogeochemical properties will be determined for each fire event using standard MODIS products (biophysical: land cover, LAI/fPAR, surface albedo, surface emissivity; biogeochemical: GPP/NPP). MODIS products are available back to 2000, and thus we will use these data to characterize the recent section of the chronosequence. Defining trajectories of selected MODIS products is already in progress as part of a NOAA-funded project led by Fei Chen (NCAR); Co-I Hicke is a Co-I on this NOAA project. The trajectory properties for the above products that are of interest to the current proposal, within the locations of interest, will be provided by the NOAA project for use by this (NASA IDS) team. These products will be available by January 2011. To characterize extended spatial and temporal (16 days back to 1984) variations of spectral indices (NDVI, NBR), we will generate averages of spectral indices by segmenting data from the freely available Landsat data archive by land cover type. We will ensure that all data are suitably geometrically and radiometrically corrected. We will also evaluate aerial photography (back to 1930s) to identify historical wildland fire events.

For a given fire event, we can identify both first and second order characteristics. First order characteristics are inherent properties of the events (size, magnitude, mortality, productivity, etc.) Second order characteristics are properties of the trajectories that are produced from the temporal series of the first order metrics. For example, from each trajectory we can evaluate secondary characteristics including resilience (time to return to pre-event levels), resistance (magnitude of metric drop due to event), and duration to obtain net neutral or positive cumulative metrics (given by integral under each trajectory curve). We will assess the variability of these trajectories and metrics through suitable statistical tests, which will be dependent on the distributions and type of data. We will evaluate the resistance and resilience differ across the different identified gradients and have changed with changes in physical and political (regional, state, and local policy) climates.

**Figure 3.** Past Studies have developed pre and post-fire trajectories using spectral index data. Research from Co-I Hicke (Hicke et al 2003: right) shows NPP trajectories for ~20 years post-fire. Most studies assess time to recovery. We will also evaluate the integrals under these recovery curves as cumulative indicators of recovery.

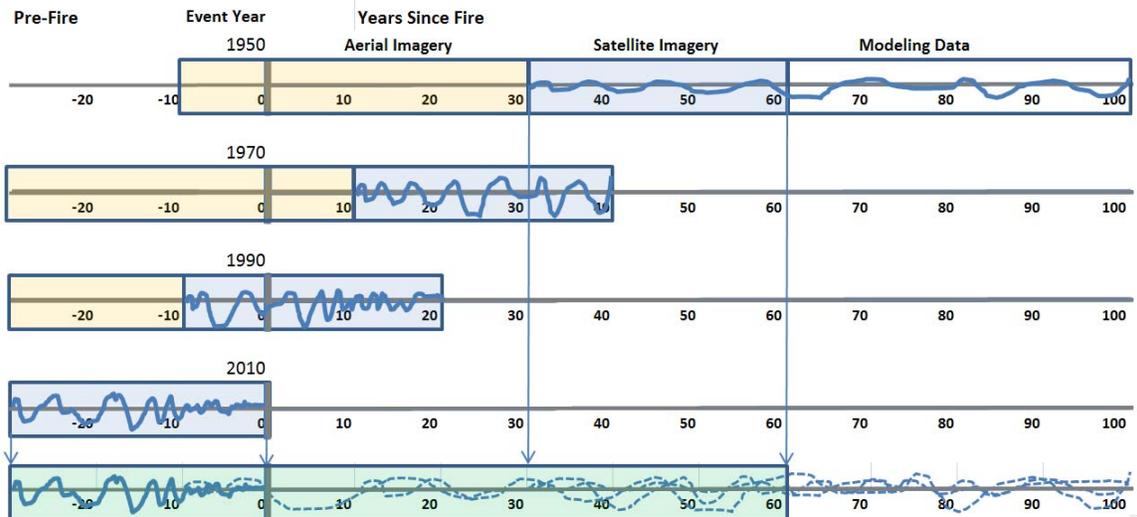


### 1.3.6.2 Development of Extreme Wildland Fire Recovery Chronosequence

Goetz et al (2007) hypothesized generalized post-fire ecosystem responses from low and high "severity" wildland fires in northern latitude boreal forests. These responses take into account carbon stocks and albedo and essentially chart the successional trajectories. In the current study we propose to characterize wildland fire trajectories within our sites through the development of a **Wildland Fire Recovery Chronosequence** by investigating the 21-30 historical extreme wildland fire events in the US northern Rockies. The current satellite record will enable a snap-shot of the trajectory curves for an approximate 30-year window for extreme fire events by connecting the available satellite sensor data with historical fire events (Figure 4). We propose to use these trajectories coupled with succession modeling expertise of Co-Is Strand and Hicke to generate multi-decadal "recovery" curves under different conditions for future extreme wildland fire events. By contrasting the trajectories of spatially and temporally varying extreme fire events, we will develop representative decadal predictions of fire recovery for each wildland cover type.

**To quantify the long-term social trajectories of change**, six communities will be selected in the vicinity of those fires selected to represent intermediate length fire history (3 to 30 years ago). We will conduct an in-depth investigation of the decadal social trajectories of change, using key informant interviews (Elmendorf and Luloff 2006; Krannich et al. 1986) conducted over the course of 15-20 days per community. Questions will address how the community prepared for and responded to the fire, the types of impacts to elements of the social system, and aspects of resiliency and capacity (Donaghue and Sturtevant 2007; Jakes et al. 2007; Jakes and Nelson 2007; Wall and Marzall 2006). Members of the research team will conduct semi-structured interviews with long-term local residents, citizens who are actively engaged in organizations dealing with fire risk (e.g., Firewise, FireSafe Councils), land managers, and local government officials and community leaders in each community selected for study. The latter categories will include key personnel whose official duties include fire preparedness, management or mitigation of fire events. Collection and aggregation of written reports, communicative materials and statistics concerning fire impacts, gathered from

agency, local government and community organizations (including homeowners' associations), will supplement the themes emerging from interviews and triangulate data among researchers. These interviews will help evaluate how past and present policies and practices concerning fire risk reduction, mitigation or recovery have played out at the local level, whether they have been perceived as successful to experts and the local public, and how this history will influence future efforts. Both the expert panels (Challenge A) and these in-depth case studies will help reveal additional dimensions of adaptive capacity and develop strategies to increase adaptive capacity among diverse communities across the region. These results will be compared with the biophysical results from portions of this research to assess how human conceptions of physical disturbance match the scientific assessment.



**Figure 4. Schematic example of a Fire Recovery Chronosequence.** The trajectories will be combined to produce a representative extreme fire chronosequence for each ecosystem.

### 1.3.6.3 Field Assessment of Fire Recovery Chronosequence and Metrics

A common challenge when using Earth Science models is that limited opportunities exist to evaluate whether these models capture the mechanistic details of the processes at finer spatial and temporal scales. We will assess the performance of the Fire Recovery Chronosequence by measuring similar spectral trajectories in-situ at recent and historical wildland fire sites covering the gradient of forested to rangeland ecosystems.

**Biogeoscientific Fieldwork:** A random sample of 18 fires (of the 21-30) will be selected for field surveys of vegetation and spectral data and used to validate the curves. We will use these field data to evaluate whether external factors, such as shifts in land use or climate, have altered the predictions. We will then measure the spectral properties of the post-fire surfaces and install long-term visible/near-infrared dual pointing net radiometers that have built in loggers (developed by L.A. Vierling at UI). These data loggers will capture NDVI every hour for two years and enough sensors will be deployed to capture the spatial variability within each fire. Through application of an ASD field spectroradiometer, we will assess other spectral indices. The field spectral data will be used to create a field-based version of the long-term Fire Recovery Chronosequence and evaluate whether the broad satellite-based approach captures important aspects of the fine spatial and temporal-scales.

The trajectories of NDVI, or modeled net primary productivity, offer just one way to measure ecosystem resilience. Several studies have assessed ecosystem resilience to fire by examining

changes in insect communities (species and/or functional groups). Increases or decreases in NPP may be further explained by changes in plant community composition, which may or may not be desirable. Since many plant invasive species colonize burned areas, it is important to incorporate plant community traits (such as species and functional groups) into measuring ecosystem resilience. This is illustrated in Figure 5, which depicts the NDVI recovery trajectory in 500-year old growth western juniper woodlands and 50-year old sagebrush steppe. In both cases NDVI ‘recovered’ in approximately two years; however, field data have shown that the old-growth trees have been replaced by grass; a change not captured by NDVI. Examining various ecosystem components will increase our ability to assess ecosystem resiliency, as they all contribute to ecosystem function. We will analyze these field data across gradients of ecosystem type, in addition to evaluating similarities and trends between the biophysical trajectories with those produced from the community interviews.

#### **1.3.6.4 Impact of Earth Science Data on Human Communities**

The final step in the community case study research will be to hold a public workshop to present predictions based on the biophysical chronosequences and social trajectory investigations to community leaders, decision makers, and citizens. This will involve presentations from all the Co-Is delivered in lay terms and using appropriate visual representations, such as models and maps produced from Earth Science data to predict the impact of extreme fire events. The presentations will be followed by an open discussion session. A pre-test/post-test quasi-experimental design using both structured and open-ended questions will be used to assess how this presentation and discussion with the research team affects participants’ knowledge; risk perceptions; attitudes toward potential and current fire prevention and mitigation policies; and willingness and ability to collaborate on fire-related issues. Our goal is to understand how the provision of the technical information, and its uncertainties, affect participants’ views on appropriate resource management and social policy. Understanding how communities perceive maps and models generated from these datasets will empower Earth Science researchers and land managers to better inform communities to make well informed decisions.

#### **1.3.7 Earth Science Data Sources**

This study will make use of the following validated Earth Science satellite products in answering Challenges A, B, and C.

**1) Satellite Burned Area and Spectral Products.** The global MODIS Collection 5 burned area product (MCD45A1) is a monthly gridded 500m dataset that described the area burned by day (Roy et al 2005). We will also employ MODIS derived spectral indices, biophysical, and albedo products.

**2) High Spatial Resolution Satellite Data.** We will acquire Landsat TM and ETM+ data with 30m spatial resolution with scenes ~every 16 days. Archived Landsat data are freely available via the USGS. We will use these data to characterize moderate temporal resolution trajectories as a bridge between field and modeled base trajectories.

**3) Complementary Imagery:** We will also use historical digital imagery of wildland fires (aerial photographs and other sensor data) collated by fire atlases, the Disturbance Atlas of Co-I Holden et al (unpub data), and the Monitoring Trends in Burn Severity (MTBS) project.

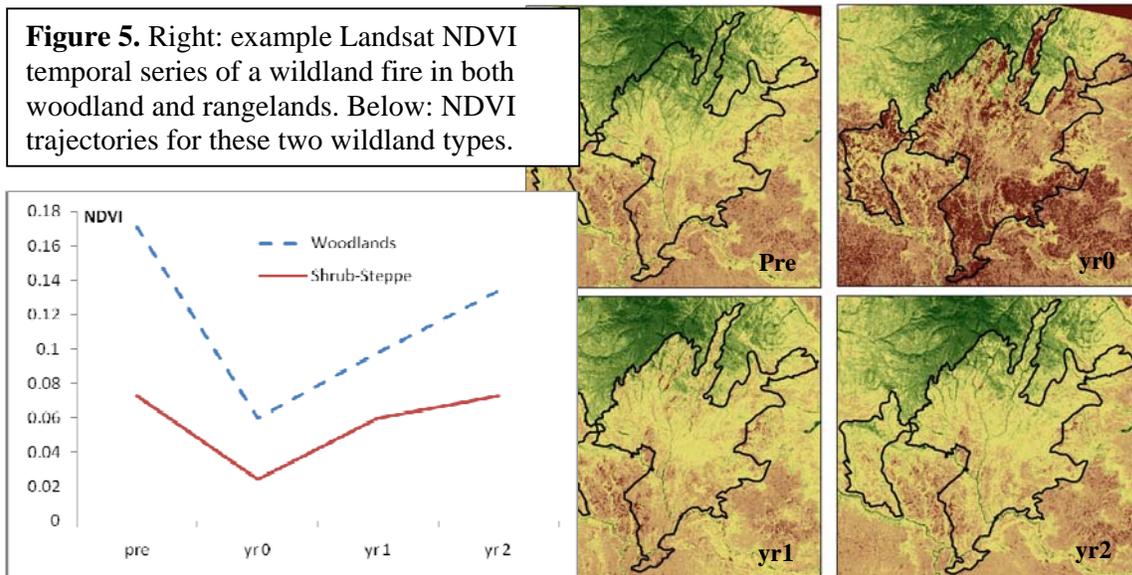
#### **1.3.8 Expected Significance of Proposed Research**

The recent recognition that biological processes can significantly affect the Earth system emphasizes a need to better understand social-biophysical interactions, including potential biophysical feedbacks (Heimann and Reichstein 2008; Reid et al. 2009). Forest ecosystems

are particularly important for regulating the global carbon and hydrologic cycles, and feedbacks between atmospheric carbon and forest carbon storage may already be increasing tree mortality across the globe (van Mantgem et al. 2009). We will further contribute to a better understanding of the variability in recovery time and the drivers behind such variability. NASA satellite image archives will serve as a basis for analysis in recent times, but the addition of early aerial images will enable us to characterize the range of variability in ecosystem recovery and quantify possible trends caused by recent changes in Earth's climate.

Humans have long altered the occurrence, size and severity of fires through suppression, ignition, and altering fuel and vegetation conditions. Fire is clearly both a social and a biophysical process. Understanding, adapting to, and shaping the future of extreme fire events depends on understanding the social and biophysical drivers and consequences of post-fire trajectories. Fire management is actively changing (NWCG 2009), and the proposed research will inform and immediately be applied by fire managers and citizens wrestling with the implications of rapidly changing fire regimes in response to global change. Given the immense cost of fires and their relevance to society, fire managers require the consistent, rapid assessments that remote sensing allows, but effective fire management also needs to be informed by science; our project provides management-relevant science as well as an enhanced understanding of coupled human-natural systems affected by extreme fire events.

**Figure 5.** Right: example Landsat NDVI temporal series of a wildland fire in both woodland and rangelands. Below: NDVI trajectories for these two wildland types.



## 1.4 Management Plan, Data Plan, Project Timeline and Expected Milestones

### 1.4.1 Management Approach

We have brought together a multi-disciplinary team with diverse experiences to complete this proposed project. Our team contains federal and university scientists with a wealth of experience in researching wildland fires and is well balanced between biophysical and social scientists. The three-year project will be managed by the PI, Dr. Alistair Smith (~15% effort). The team will work in close collaboration on all aspects of the proposal coordinated by monthly teleconferences and annual team meetings at the University of Idaho campus in Moscow, Idaho. The College of Natural Resources is familiar with the management of large research grants with numerous dynamics parts. As such, the PI will work with the budget staff of the college to ensure transparent and traceable budget management. Data generated by the project will be disseminated via the FRAMES web portal (<http://frames.nbio.gov/>).

The project will employ a management hierarchy with co-advising of junior personnel to ensure an efficient sharing of knowledge:

- PI Smith and Co-I Hicke will co-advise the biogeoscientific researcher
- Co-Is Carroll and Hall will co-advise the postdoctoral social science researcher
- Each PhD student will have at least 2 advisors from the research team. The identified major professors for these students are: Strand/Morgan, who will focus on fieldwork and remote sensing to evaluate the best metrics to characterize the extreme wildland fire events; Newingham, who will focus on fieldwork assessments of resistance and resilience, in addition to evaluating whether NDVI/NPP are the optimal measures for acquiring this information; and Hall, who will oversee the expert panel and community case studies.

#### 1.4.2 Project Timeline and Expected Milestones

<b>Start: April 2010</b>	- Coordination meeting - Purchase equipment - Hire postdocs, graduate students, and field techs prior to first field season
<b>May - Sept 2010</b>	- Year 1 summer field season - Preliminary data collection for selection of field and community sites - Collation of historical datasets: digital fire atlases, MODIS, AVHRR, and Landsat, data, etc. Data preprocessing.
<b>Oct 2010 - May 2011</b>	- First academic year for PhD students: course requirements etc - Development of sampling designs for the field and community surveys - Selection of community sites by social postdoc - Development of questionnaire and interviews by social postdoc - Development and modeling of Fire Recovery Chronosequence using satellite sensor data and historical fire atlas data by biogeoscientific postdoc
<b>May 2011 - Sept 2012</b>	- Year 2 summer field season - Conduct interviews at half the forest and half the rangeland community sites - Conduct biogeoscientific fieldwork
<b>Oct 2012 - May 2013</b>	- Second academic year for PhD students: prelims, etc - Postdocs work together to evaluate coupling and feedbacks of the biogeoscientific and social trajectories - PhDs work together to evaluate similarities and differences across the different gradients: ecosystem, knowledge base, etc - Present initial results at multiple conferences
<b>May 2012 - Sept 2012</b>	- Year 3 summer field season - Continue interviews for the second half of the sites - Continue biogeoscientific fieldwork
<b>Oct 2010 - May 2011</b>	- Third academic year for PhD students: wrap up. - Reevaluate Fire Recovery Chronosequence using new community data - Reevaluate Fire Recovery Chronosequence using new field data - Present final results at multiple conferences. - Final Report

In addition to the completion of three PhDs and the training of two postdocs, we anticipate the production of ~12 peer reviewed publications from this study. Furthermore, Co-I Strand will lead the development of a series of online lessons (using Toolbook (Sum Total), Camtasia, etc) focusing on processing NASA Earth Sciences data. These will detail the importance of understanding wildland fires, extreme fires, recovery curves, and other general topics related to this project. These modules will be used as resources for several existing upper division and graduate courses of the science and management of wildland fires.

Additionally, as part of the community meetings we will bring our research results to the public and land managers to both query their perceptions and further their education

### 1.4.3 Linkages with Other Projects

This project will directly link to and build on several funded and recently completed efforts of the research team. We will also have a strong coordination with an NSF-funded IGERT project to facilitate complementary data collection, enabling considerably more fires to be evaluated than could be accomplished within the scope of this project alone. Many projects listed below have collected pre-and post-fire field data, which will be leveraged for the proposed research; for example, Strand et al. have three years of pre- and post-fire field data from the Murphy Fire Complex, which burned over 200,000 hectares of shrub steppe in 2007. Morgan et al (JFSP: 03-2-1-02) collected post-fire field and processed remotely sensed data from numerous 12 regional fires.

<b>Project Description</b>	<b>NASA team involvement</b>	<b>Program Info</b>
IGERT: Evaluating resilience of ecological and social systems in changing landscapes: a doctoral research and education program in Idaho and Costa Rica: Collaborators: Hall, Newingham, Strand, Hicke, Smith	CoPI: Morgan	National Science Foundation DGE-0903479. 2009-2014
A Fire Severity Mapping System for real-time fire management applications	Holden, Morgan	Joint Fire Science Program
Local and Regional Climate Controls on Western U.S. Fire Extent and Severity	Morgan, Holden	USDA Forest Service, 2007-2009.
Fire Effects on Soils and Vegetation	Morgan, Hudak	USDA Forest Service, 2007-2010.
Smoke Management: Development of Online Training Resources and Workshops	Smith, Morgan,	National Park Service, 2007-2012
Social diversity in the WUI	Carroll	USDA Forest Service,
Alt. to evacuation during wildland fire	Carroll	USDA Forest Service,
Water resources in a changing climate	Smith, Hicke	NSF: EPS-0814387
Planning For Science and Implementation On Landscape-Scale Fires: Pre- During And Post-Fire Measures In The Field And Remotely	Morgan, Hudak	USDA Forest Service, 2008-2010
Effects of pre-fire vegetation structure and burn severity on post-fire vegetation recovery in western juniper woodlands	Strand	Bureau of Land Management: 2008-2010
Landscape scale assessment of livestock grazing effects on burn severity and vegetation recovery in sagebrush steppe	Strand	David Little Foundation: 2009-2010
Wildfire inputs to regional air quality: remote spatial-temporal measures for improved inventory assessments	Smith	Joint Fire Sciences Program, 2007–2010
Reconciliation of the MODIS active fire and burned product for improved emission and uncertainty estimation	Smith	NASA: Earth Science Applications 2009-2010
Smoke Management: Development of Online Training Resources and Workshops	Smith, Morgan, Hoffman	National Park Service, 2007-2012
Assessing the Causes, Consequences and Spatial Variability of Burn Severity: A Rapid Response Proposal	Morgan, Hudak	Joint Fire Sciences Program 03-2-1-02,

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