

Fire Management *today*

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On the Cover:



Hotshot crews are conducting a Burnout Operation during the Slide Fire along the mouth of West Fork Canyon north of Sedona, AZ. Crews took extra precautions to prepare the apple trees seen in the foreground. These trees are all that remains of the orchard that was owned by C.S. (Bear) Howard who planted the apples in the 1880s. This is believed to be the first apple orchard planted in Oak Creek Canyon. Photo: Jayson Coil, Sedona Fire District, Flagstaff, AZ.

The USDA Forest Service's Fire and Aviation Management Staff has adopted a logo reflecting three central principles of wildland fire management:

- **Innovation:** We will respect and value thinking minds, voices, and thoughts of those that challenge the status quo while focusing on the greater good.
- **Execution:** We will do what we say we will do. Achieving program objectives, improving diversity, and accomplishing targets are essential to our credibility.
- **Discipline:** What we do, we will do well. Fiscal, managerial, and operational discipline are at the core of our ability to fulfill our mission.



**Firefighter and public safety
is our first priority.**

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by Tom Harbour
Director, Fire and Aviation Management
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THE CITIZEN OF FIRE

Active Citizenship—what does it mean and how does it apply to wildland fire management?

*Definition of an Active Citizen:
“A citizen who takes an active role in his or her community.”*

We have all heard and remember Paul Gleason’s admonishment to be a “student of fire.” That counsel has enriched the lives of many in our community. I think there could be significant value in being a “citizen of fire,” albeit an active citizen. Active citizenship, in the context of our Nation, simply means people getting involved in their communities. In this case, being a citizen of fire means a community can be as small as your local unit’s fire management organization or as large as the entire interagency wildland fire management community. Simple. Or is it? Active citizenship is a combination of knowledge, attitude, skills, and actions that aim to contribute to building and maintaining a better community for tomorrow.

Being an Active Citizen of the Wildland Fire Community

It’s not news that we all work very well together to manage wildfire incidents—that’s a proven fact. We enter unified command with our other Federal, tribal, State, and local partners and work together toward a common goal. That’s a level of active citizenship, but what I am calling for is taking active citizenship to a new level—a higher level. By combining the principles of fire doctrine with the actions of

an active citizen, each of us could make a tremendous difference in moving our community toward a better future.

Actions of an Active Citizen

As active citizens, we should ask ourselves regularly (if not each time we plan a task or action on the ground):

- What are the issues? Am I seeing what others are seeing?
- What’s working, and what’s not?
- What could I learn from this situation and from others?
- Am I focused on the key doctrine and issues? What solutions can I propose?
- How can I best share and interact, offering what I know and what I don’t?

Once engaged and beginning to answer the questions, then, take appropriate actions.

To make our community better, we must all choose to accept accountability for ourselves and, additionally, to be committed to the well-being of the whole. An active

citizen will not wait on, beg for, or dream of the future; rather, he or she will take initiative to identify the issues, get involved in order to solve the problems, propose solutions, share what he or she knows, make informed decisions, and lead others to create a better fire community.

Call for a Revolution

I’ve often wondered about the revolution of democracy that occurred because citizens in ancient Athens became involved and wanted to affect change within their community. I’ve wondered if we could have the same kind of “revolution in fire”—not revolution in the sense of an overthrow of a government, but a revolution of new thinking and new actions that result in new successes.

Today, as we are faced with a multitude of problems that need resolution, both at a national scale and within our profession, each of us needs to become involved—become active citizens of fire and leaders of our “revolution of success.” The success will sustain and maintain our wildland fire management community in the future. ■



HIGH-TECH IS USEFUL BUT COSTLY: MODELING AND SIMULATION CAN HELP WITH TOUGH RESOURCING DECISIONS

David K. Peterson, Ph.D.; Ericson R. Davis; Jeremy M. Eckhause, Ph.D.; Michael R. Pouy; Stephanie M. Sigalas-Markham; and Vitali Volovoi, Ph.D.

With a typical July storm front looming over the mountains—not much rain, but plenty of lightning—Joan Smith is worried. The minimal winter snowpack has again left the forests dry. Last year's fire season had been bad, but it was manageable thanks to the unmanned aircraft systems (UASs) that had been integrated into fire management efforts. Smith manages a detachment of three medium-altitude, long-endurance UASs assigned to Montana's Rocky Mountain central region. She needs to send two aircraft aloft to trail the storm and look for lightning-generated hotspots, but one aircraft is undergoing maintenance, and another has yet to return to base from yesterday's mission. That leaves a single aircraft to cover a 5,000-square-mile area. Smith doubts that one aircraft will be enough.¹

Undoubtedly, high-technology equipment, like UASs, offer distinct advantages in the identification, containment, and control of wild-

land fires. These systems, however, can be costly—and complicated. As Federal and State wildland management agencies plan to incorporate high technology into operations, they must consider how much of their budget should be allocated for the purchase *and sustainment* of such systems. Well-established modeling and simulation techniques can help managers like Smith align their budgetary decisions with their operational, fire-fighting needs.

New Technology; Old Fiscal Realities

The resourcing environment facing all governmental agencies is a complex series of interrelated decisions that span broad time horizons. Typically, strategic resourcing plans consider decisions 5 or more years out, tactical plans span 1 to 5 years, and operational resourcing decisions relate to requirements within the year. In this planning environment, the outputs of one decision become the inputs for the next. For example, tactical decisions decompose strategic budgetary decisions into the physical resources needed, and tactical decisions are translated into monthly, weekly, and daily operational resource employments.

The challenge wildland fire managers face is how to best align these detailed resourcing decisions with operational needs. Unfortunately, no single analytical technique can completely balance resource

requirements against operational risk (e.g., not having enough resources to cover a fire) and achieve the desired blend of system performance, availability, and affordability.

By carefully integrating modeling and simulation into their decision-making, managers can better size equipment capabilities, fine-tune complex resource decisions (across any planning time horizon), and maximize the usefulness and effectiveness of emerging high-technology equipment.

Why Modeling and Simulation?

Why are modeling and simulation useful to wildland fire managers? Modeling and simulation can accommodate the multidimensional resource decisions wildland fire managers face for high-technology systems. For example, the cost for a fleet of UASs or aerial tankers extends well beyond the procurement cost of the aircraft. Total ownership costs include associated operating costs (fuel, manpower, etc.), logistics costs (parts, maintenance, transportation), facilities costs (hangar fees, landing rights, etc.), and other recurring costs (insurance, pilot certification, training, etc.).

The complexity of governmental budget processes also warrants the use of robust analytics (made easier with modeling and simulation) to

¹ A notional scenario for illustrative purposes.

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determine and defend agency budgets. According to the U.S. Office of Management and Budget (2014):

The best government programs use a broad range of analytical and management tools, which collectively comprise an “evidence infrastructure,” to learn what works (and what doesn’t) and improve results. In doing so, they support a culture of continuous feedback and improvement.

Many powerful analytic techniques are well suited to wildland fire resource manager needs. These analytical tools are generally classified as “business analytics,” and use “data, information technology, statistical analysis, quantitative methods, and mathematical or computer-based models to give managers improved insight about their business operations and make better, fact-based decisions” (Evans 2012). By integrating carefully selected modeling and simulation techniques, and complementing them with data analytics, wildland fire managers can better quantify the resources they need to operate and sustain their high-technology equipment.

A Scenario To Consider

Consider the future use of MQ-1 Predators (an unmanned aerial vehicle) that might be assigned to a wildfire surveillance mission within the Western United States. These MQ-1s would operate from a small set of airports chosen to maximize surveillance coverage over forested regions subject to high fire risk as well as areas with a wildland-urban interface. The MQ-1 bases must be self-sufficient for day-to-day operations during the fire season, with limited support available from

higher echelon logistics facilities (e.g., depots and manufacturers) if required.

Strategic Decisions—What and Where?

In an internal research and development project, LMI (a government consulting company) developed an illustrative case study that combined analytical optimizations with modeling and simulation to evaluate the mission coverage that can be achieved with different mixes of aircraft and logistical support.

To develop the support concept, we needed to make two strategic resourcing decisions: how many UASs are needed and where they should be located. With finite resources and a limited number of UASs available, the aircraft needed to be positioned to achieve the greatest coverage with regard to monitoring areas at risk for a wildfire.

Given the nature of fire outbreaks and the uncertainty associated with their discovery, strategic-level planning was difficult. A mathematical programming optimization helped us evaluate resource alternatives. A pre-established reward structure identified the “value” of monitoring different public lands and wilderness areas.

The value of monitoring one area for wildfires may be higher than the value of monitoring other, equally sized areas. For example, a densely timbered area may contain a greater amount of potential fuel than a rangeland with a similar area. Expending resources to monitor the forest could offer greater return. Regions bordered by high population densities and structures are intrinsically more valuable

because of the greater threat to life and property, and the optimization model valued them accordingly.

For strategic planning purposes, we positioned the UASs at sites chosen from a fixed list of airfields. Since there is little value in visiting a single region multiple times in rapid succession, we assumed the marginal benefit of adding aircraft to a given site decreases with each aircraft. Each candidate location was, therefore, given a set of grid spaces that a UAS could visit and return from in a single sortie.

From these strategic decisions, we could establish the number and deployment locations of the MQ-1s, which significantly influenced the amount of logistical resources required to keep them mission ready.

Tactical Decisions—How Much Support?

At the tactical level, the case study considered the maintenance capabilities and inventory investment needed to support the planned UASs’ operations at a desired level of system availability.

To fulfill its missions, an MQ-1 unit depends on the complementary performance of both its airborne and ground-based components. A fully operational MQ-1 unit consists of multiple aircraft, ground control systems (GCSs), and ground data terminals (GDTs) (See figure 1).

We used a readiness-based sparing (RBS) inventory optimization method to compute the maintenance and spares requirements for the MQ-1 deployment, given the strategic-level decisions made earlier.

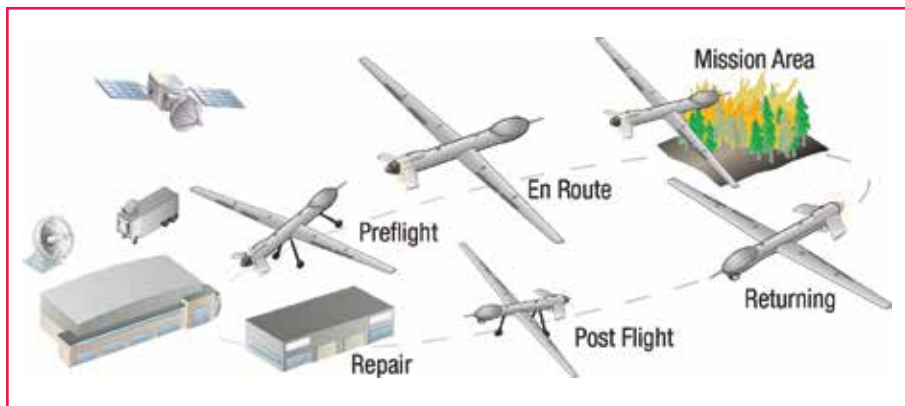


Figure 1—A notional MQ-1 UAS wildfire deployment scenario.

We modeled each aircraft as a composite of its corresponding subsystems (e.g., fuel, engine, structural, electronics), all of which have unique costs, repair capabilities and times, and failure rates.

Since RBS techniques view a system in terms of its major components (sensors, electronics, propulsion, structural components, etc.), our decisions about the range and depth of spares were influenced by fleet size, dispersion, and associated maintenance capabilities.

In our scenario, we modeled an MQ-1 deployment of eight aircraft allocated across three airfields. The logistical solution generated the equivalent of 10 hours per aircraft per day, with an 80-percent aircraft availability across the fleet (See figure 2).

So, the remaining question was, would an average of 64 flying hours per day be achievable and sustainable given the vagaries of real-life aviation and fire operations?

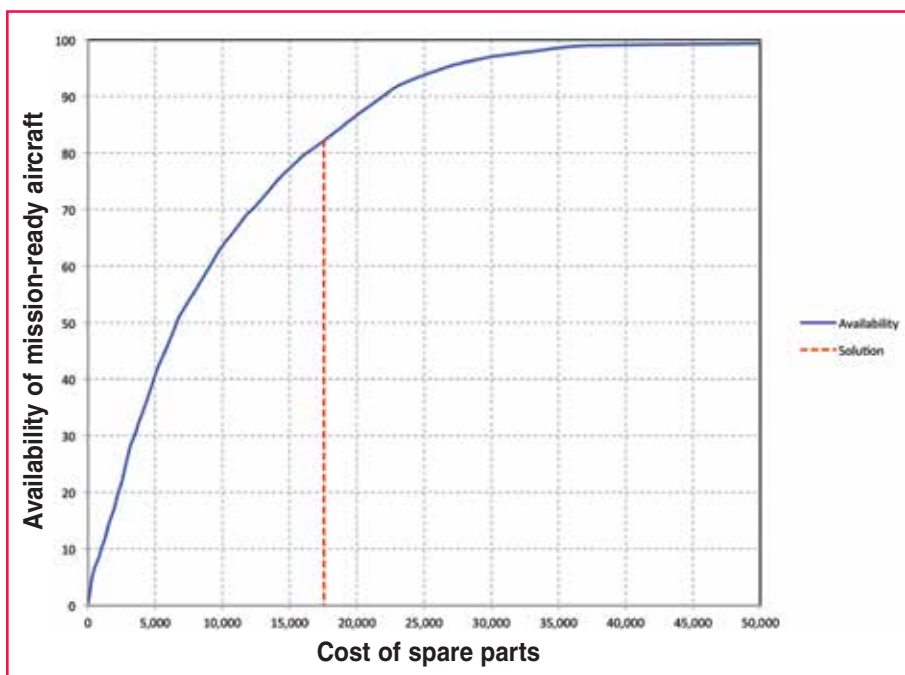


Figure 2—The baseline logistical solution (illustrative costs) demonstrated by the amount of inventory investment (in dollars) needed to furnish maintenance activities with the breadth and depth of spare parts required to maintain a specified level of available mission-ready aircraft.

Operational Decisions—What Can the Systems Do?

Once the strategic and tactical resourcing decisions were made, we needed to evaluate the robustness of these decisions in the face of real-life operational variability.

While RBS methods can assess the availability of individual systems, they cannot fully assess the probability of the system achieving its objective. In our case, a simulation enabled us to better portray the realities of daily flight operations and capture their effect on wildfire surveillance.

Simulation-based methods are well suited to this task, as they can readily capture the complex interdependencies and variability inherent in sophisticated, high-technology systems. Thus, to assess the mission performance of our UAS fleet, we combined RBS analysis with modern simulation tools, such as Abridged Petri Nets (APN) software (Volovoi 2013) to model UAS operations.

APN was used to model the MQ-1 wildfire surveillance mission cycle and served as the framework for adding system-of-system complexities to the model. For example, a local GCS and GDT are both required for the MQ-1 aircraft to fly. Once the aircraft is launched and en route, the local ground systems handoff control to a distant GCS. If either, or both, of the local ground-system components are inoperative, then the mission may be compromised or prematurely curtailed, thereby diminishing the percentage of time wildfire surveillance coverage can be maintained.

APN provides a visual means for modeling complex interaction among relevant entities (called tokens). Figure 3 illustrates the APN simulation that portrays an MQ-1 mission. Aircraft are selected from an available pool and monitored through a preflight check and take-off. After transiting to the mission area, the wildfire surveillance begins. At some point, the MQ-1 must call for a relief aircraft to continue the surveillance. After the original aircraft departs the mission area, it returns to base for a post-flight check and any requisite corrective maintenance. Supporting this mission are the line-of-sight ground-based subsystems (the GCS and GDT), which must be fully operational for MQ-1s to take off and land.

Using a simulation enhances the fidelity of modeling the MQ-1 mission cycle by enabling explicit consideration of key logistical realities (e.g., a corrective maintenance cycle, spares availability, and logistical delays). For the MQ-1 UAS

simulation, using condition-coded colored tokens in APN enhances modeling power by capturing time-varying operational performance aspects.

For example, the green tokens in figure 3 represent fully serviceable systems actively performing their mission; black tokens are mission-ready systems; and red tokens represent systems rendered inoperable as a result of component failures and logistical delays.

Thus, the APN model enabled us to account for the effects of in-flight failures, as well as delays associated with maintenance activities. In addition, APN portrays system failure dependencies by using animated tokens to visualize the effect of failures on the system's performance.

Using the APN simulation, and given the preceding logistical decisions, the percentage of time that MQ-1s were orbiting their assigned regions ranged from 91.7

to 91.9 percent, which confirmed our expectation that achieving a 100-percent orbital coverage was overly optimistic. Clearly, the effect of operational and logistical variability must be taken into account when resourcing and planning the MQ-1 wildfire surveillance missions.

Conclusion

The stage is set for a rapid expansion of high-technology systems use by wildland management agencies. Many choices of aerial and ground-based unmanned technology are available to agencies. These systems come with a price beyond procurement. Agency decisionmakers need to develop (and fund) an infrastructure appropriate to the technology they acquire and select an appropriate operations and support strategy.

Given the current need within the Federal community to better quantify and defend program costs, integrating modeling and simulation in the resourcing decision process can help agencies synchronize the myriad resourcing decisions they face as systems are deployed within their wildland fire management charters.

A modeling and simulation framework, like the one described above, supports these complex decisions by modeling a system's operational and logistical performance. To correspond with the government budgeting process, long-term resourcing decisions can be made first with intermediate tactical decisions determining the logistical resources needed. Given these decisions, near-term system effectiveness can be rapidly evaluated through the simulation of a specific mission.

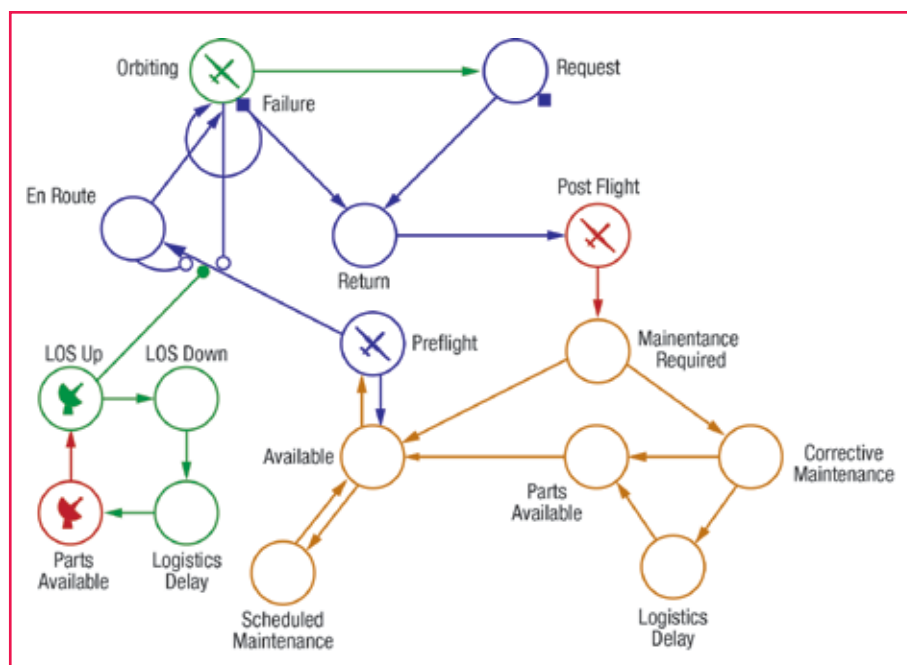


Figure 3—Example of wildfire mission simulation model.

By using integrated modeling and simulation techniques, wildland management agencies can quantify the resources they require to sustain their equipment decisions (which have distinct strategic, tactical, and operational resourcing aspects). The method illustrated by LMI's case study offers wildland fire equipment managers a pragmatic approach for leveraging modern analytical techniques and high-technology systems with wildfire operations.

Modeling and simulation is not an end unto itself. Rather, it is a means for reducing the uncertainty surrounding budgetary, procurement, and operational decisions when lives are at risk, threats to property and natural resources are great, and funding is limited and uncertain.

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Contributors Wanted!

We need your fire-related **articles** and **photographs** for *Fire Management Today*! Blogs should be between 100 and 200 words, Short Articles should be between 500 and 1,000 words, and Feature Articles should be between 1,500 and 2,000 words. Subjects of published material include:

Aviation	Fire History	Preparedness
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Cooperation	Fuels Management	Safety
Ecosystem Management	Firefighting Experiences	Suppression
Education	Incident Management	Training
Equipment and Technology	Information Management (including Systems)	Weather
Fire Behavior	Personnel	Wildland-Urban Interface
Fire Ecology	Planning (including Budgeting)	
Fire Effects		

For more information, contact the managing editor via email at firemanagementtoday@fs.fed.us.

SMARTPHONE APPLICATIONS FOR DATA COLLECTION, DYNAMIC MODELING, AND VISUALIZATION IN THE WILDLAND FIRE ENVIRONMENT

Jim Riddering, Zachary A. Holden, W. Matt Jolly, and Allen Warren

Introduction

Rapid advances in cellular phone technology have transformed portable telephones into “smart” phones; powerful, portable personal computers equipped with Global Positioning System (GPS), cameras, and a suite of tools for accessing and storing information. Smartphones offer the ability to connect to large servers via both cell and wireless networks with a speed and power that is truly remarkable when compared with what was available only 10 years ago. The sheer numbers of smartphones being used globally make them a potent tool for distributing, as well as collecting, information (Kwok 2009).

Smartphone applications (apps) are rapidly being embraced as a tool for collecting data across a range of disciplines in the earth sciences (Kwok 2009). Equipped with GPS, local time information, and a camera, smartphones can be a tool for collecting and storing environmental data. For example, weather modelers at the National Oceanic and Atmospheric Administration

Perhaps the most obvious use of mobile technologies in fire management is in the collection and sharing of weather information. For firefighters, the ability to quickly receive the latest weather information is critical to safely execute their mission.

have developed and promoted an app called mPING (precipitation information near the ground, <http://www.nssl.noaa.gov/projects/ping/>) for collecting information about the form (e.g., hail, snow, rain) and timing of precipitation. Other applications in environmental sciences include collecting of epidemiological information (Aanensen et al. 2009) and identifying and recording the location of bird species (Wood et al. 2011).

Perhaps the most obvious use of mobile technologies in fire management is in the collection and sharing of weather information. For firefighters, the ability to quickly receive the latest weather information is critical. Historically, weather observations were collected and shared via radio communications. The rise of mobile computing allows for digital sharing of weather observations and allows firefighters to access different sources of weather information through the variety of weather applications available for mobile devices. Rapid access

to weather forecasts, observations, and supplemental environmental data have the potential to greatly enhance situational awareness and firefighter safety.

Weather observations are also a critical information source for supporting wildland fire management decisions. Currently, weather information during wildland fire incidents comes primarily from Remote Automated Weather Stations (RAWS). Data from the nearest RAWS are often used to model fuel moistures and predict fire behavior during an incident. However, stations may be located 31 miles (50 km) or more from the incident and are typically placed on south-facing, low-elevation slopes to capture “worst case” conditions. Thus, much of the spatial variability in fuel moisture and fire danger is typically ignored (Holden and Jolly 2011). Secondary weather information comes from wildland firefighters who measure and report hourly weather conditions in the field during active fire

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incidents. While weather observations from firefighters in the field may be less accurate than weather measured at RAWS, the ability to rapidly collect and disseminate weather information may outweigh any potential reductions in data quality (Goodchild and Glennon 2010). These weather observations are typically reported back to a central dispatcher via radio. They are sometimes used by spot fire weather forecasters, but typically remain in paper form, where they are largely inaccessible for further analysis after the incident. The observations, accumulated over time, represent a potentially rich but untapped source of weather and climate information. By embracing digital mobile technologies to collect and share weather information, we can improve decisionmaking and efficiency in fire management.

Methods

A number of smartphone applications have been developed to support wildland fire management. In this article, we will discuss a few specific developments designed to help managers and firefighters better monitor, share, and understand the fire environment. This list is not intended to be comprehensive, but rather, to illustrate a few specific examples currently in use and explore what the future may hold. It includes mobile-specific development, as well as existing science programs that are being modified for use in mobile environments.

Fire Weather Calculator

The number of weather applications available for mobile devices is stunning. These cover anything from sharing forecast data to

interpreting clouds. In fire, however, the ability to use a mobile device to more efficiently calculate fire weather parameters and subsequently share those observations has lagged behind. The Fire Weather Calculator, developed by the National Center for Landscape Fire Analysis, is one example of a mobile app designed to add value to traditional weather observations. This application allows the user to input traditional observations (e.g., dry bulb, wet bulb, etc.) and have the application calculate critical information, such as relative humidity and probability of ignition, which both saves time and ensures consistency between weather observers. More importantly, however, is the ability to archive and share these digital observations with other users and managers in real time. This application allows for more streamlined management of weather information, a critical aspect of any fire event. The ability to share observations, particularly if many users are archiving their observations, will lead to a very useful archive of crowd-sourced data that will be used to create value-added products, such as the calculations of 3-dimensional weather fields that could be shared with personnel to increase their situational awareness.

The Topofire Weather App

The low cost of high-performance computing offers the potential to expand smartphone applications in wildland fire from simple data recorders to the frontier of real-time modeling and ecological forecasting. One example of this type of application is the TOPOFIRE application. Similar to the Fire Weather Calculator app

described above, this application allows users to enter a suite of fire weather observations that are normally collected on incidents. These observations, as well as the time and location, are sent directly to the TOPOFIRE server, where they are permanently archived and can be made available to users and fire weather forecasters. Weather information entered into the phone can then be used to parameterize the WindNinja simulation model, using either current observations or gridded data from the Real-Time Mesoscale Analysis dataset (RTMA). Users can also request forecasts for the next 3 to 12 hours, using data from the National Digital Forecast Database. Model simulations are then run on the TOPOFIRE server, and outputs are returned to the user's phone in the form of a key-hole markup language (.KML) file that can be opened on the phone on GoogleEarth. Although not currently enabled, additional weather variables can also be blended with the RTMA gridded weather model data to provide spatially corrected data for the domain around the fire incident using data collected onsite. Again, this type of two-way interface between phone users and a computer modeling environment demonstrates the potential for development of an operational environment whereby wildland firefighters dynamically inform and retrieve models of the fire environment in real time. Further, these data could be provided immediately upon collection to the fire behavior analysts who are charged with observing and forecasting fire behavior and who typically provide local weather observations to the National Weather Service to improve their incident Spot Weather Forecasts.



Figure 1. The TOPOFIRE smartphone application assimilates weather observations and photographs from wildfire incidents, which can be used by fire managers and fire weather forecasters. Users can also request WindNinja simulation and fire danger forecasts via phone in real time.

The TOPOFIRE Photologger App

Photographs and videos are another key source of information collected during fire incidents. Firefighters are often asked to take pictures or videos of fire behavior to share with incident commanders. Development of tools for rapidly sharing images could dramatically improve communication and could potentially improve situational awareness at every operational level within an incident. Mobile phones now routinely embed location and accurate timestamps into photographs, facilitating the integration of these resources into Geographic Information System applications. One example currently under development is the TOPOFIRE photologger app, which allows users

to collect images and videos with a smartphone and send them directly to a central server where they can be queried spatially and viewed almost instantly by others.

Open Data Kit (ODK)

Applications like ODK (<http://opendatakit.org/>) allow users to translate standard “form” information to digital formats for use on mobile devices. Any kind of form that managers and firefighters currently use can be converted and modified to be easily read and filled on a mobile device. For example, smoke-management observations, critical to many aspects of fire management, can be implemented in a digital framework that allows for simplified data collection and archiving. The form, once convert-

ed, can be used for multiple independent observations. The native digital format allows for embedded error checking, ease of transfer, and subsequent access. Gone are the days of transcription from paper to digital media and the inherent problems associated with the management of those systems.

Future Challenges

Despite the clear potential for integrating mobile computing technologies into operational fire management, a number of organizational, technical, and logistical challenges lie ahead.

Arguably, the largest impediment to wide-spread adoption of mobile technologies is the issue of operating-system specificity (iOS,

Android, etc.) and central information technology (IT) issues. An ongoing debate is which device fire managers should embrace as the default. The merits for picking one operating system over another are beyond the scope of this article. In reality, devices that use Android and iOS operating systems are widely used and are unlikely to disappear. We suggest fire managers consider the decision made by the U.S. Department of Defense and embrace the idea of device agnosticism (USDOD, CIO 2013). This idea dictates that the fire organization would not choose a specific operating system as a standard. Committing to a single operating system/company could lessen the chance for innovation through competitive development.

Instead of setting standards for devices, fire managers would be better served setting standards for data acquisition and management. What are the important data sources? How should those sources be used and managed? What are the true efficiency and information gains? Once those are decided, applications should be developed to support all mobile devices. The development of monolithic standards should be avoided in order to maintain efficient mobile device integration. If comprehensive standards are defined, however, they will almost certainly always lag behind the most current technological advances, resulting in lost efficiency. Recent advances in cross-platform mobile development that leverage HTML and Javascript available on most current mobile devices show promise in allowing the development of applications for most operating systems from a single codebase.

The Way Forward

Collecting, managing, and distributing weather information is just one example of how mobile devices can and will revolutionize wildland fire operations and management. As mobile devices become more powerful and data coverage increases, mobile computing will truly become a vital technology. Mobile devices will allow better collection of critical fire and environmental data while simultaneously allowing data to be converted and quickly shared.

In an era where computing power has become relatively cheap and widely available, a dynamic two-way interface between phone users and computer models running in real time is now possible. Fast connectivity via broadband wireless networks allows rapid sending and retrieval of remotely generated data. This dynamic link between phones and computers has the capacity to expand smartphone applications in environmental sciences from simple data recording and sharing into the next frontier of real-time modeling and forecasting.

One example of using field data to quickly provide useful information is the TOPFIRE application discussed above. The user can provide weather information that feeds a model that provides comprehensive environmental information back to the user within minutes. In the future, one can easily imagine these observations being used to parameterize and calibrate models that quickly return 3-dimensional fire weather data, hydrological and fuel-model information, as well as continuously updated, next-generation fire danger models. The goal of these products is to increase situational awareness and support more efficient and precise decision-making.

Nearly every “smart” mobile device on the market is now equipped with a GPS, making each device spatially aware. A new frontier for fire management lies in the ability of a central server to send or “push” critical information about changing conditions to mobile devices. For example, Fire Weather Watches and Red Flag Warnings are commonly issued by the National Weather Service to highlight regions where wildfire weather conditions may promote intense fire behavior (Figure 2). Future systems could send this critical information as soon as a Watch or Warning is issued to any person who has a phone and is within these areas. This rapid dissemination of this information could be life saving.

Mobile devices are also powerful mapping tools. We are already seeing how these devices are changing the way managers use spatial information in the fire environment. From portable document format (PDF) maps that provide real time context and location information, to geotagging of photographs and field data, there is obvious potential to use portable devices to provide spatial data about the firefighting environment. In the future, these capabilities will improve as we continue to develop a better understanding of disturbance and ecological processes. For example, we will soon have the ability to track Mountain Pine Beetle infestations and monitor changes more effectively by using mobile technologies. With more information and increased understanding, one can easily envision tools that share state-of-the-science information with field personnel. When coupled with improvements in fire behavior modeling, it's easy to see how this direct, real-time connection between observers, the environment, and modeling tools could be

used to enhance the awareness and safety of firefighters, while allowing for more rapid and accurate decisionmaking.

In the near future, we will also see a dramatic rise in the use of sensors and wearable technologies. We are already seeing “wearables” playing an interesting role in how we perceive mobile computing. Google Glass® and the Apple Watch® are examples of what’s to come. One can easily imagine technologies that continuously monitor firefighter health, collect weather data in real-time using sensors connected to the phone, and track their locations in real-time using the phone’s GPS. Bluetooth® connectivity on mobile devices also makes each device a potential hub for any auxiliary wireless device. For example, handheld digital weather instruments, such as Kestrels®, can wirelessly relay information directly to the mobile device without human intervention, making weather tracking more seamless. The continuing development of augmented reality systems shows some intriguing possibilities in how firefighters can interact with each other as well as the fire environment. If all of these technologies are used in a coordinated effort to monitor personnel activity during wildland fire incidents, they will likely lead to some remarkable changes in wildland fire management.

The key challenges for fire managers considering using these technologies will be how to select and implement the latest tools and, afterwards, to find effective ways

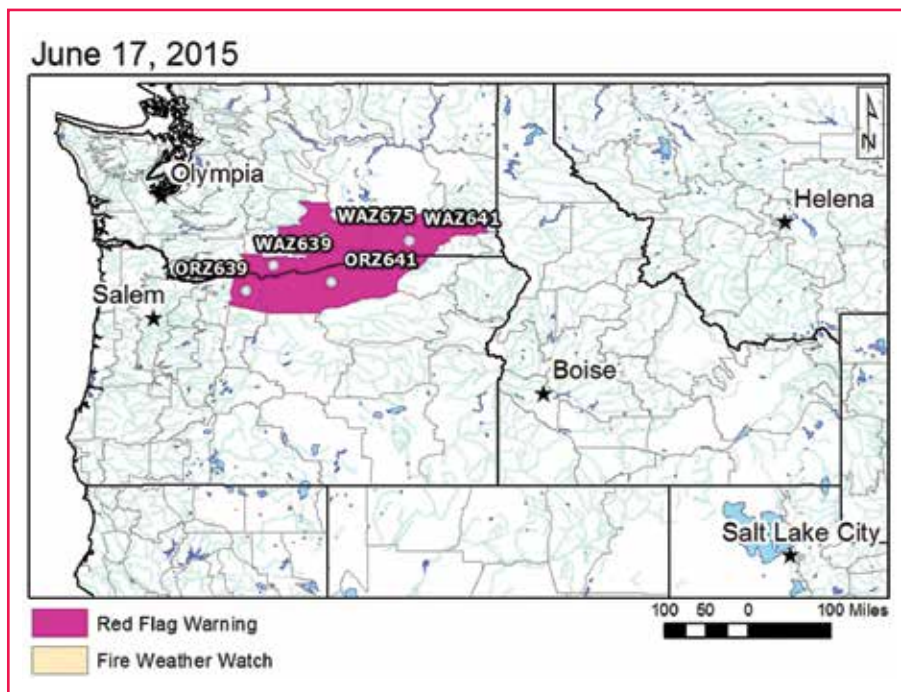


Figure 2.—Example Red Flag Warning Map for the Western United States from June 17, 2015. Source: <http://www.wrh.noaa.gov/firewx/main.php>.

to monitor and evaluate the tools they select. This is not a time for monolithic decisions, rather, fire managers need to be able to identify the best and most *appropriate* tools that can truly support decisionmaking while *not* forcing firefighters to conform to outmoded standards or use less effective tools. Technologically speaking, this is a very exciting time for wildland fire management—the challenges will be in finding a way to efficiently navigate this rapidly changing field in order to bring the best digital tools available to improve how we manage natural resources.

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FIRE MANAGEMENT IN A CHANGING CLIMATE

Elizabeth Reinhardt

“We are now completely certain that there is a climate signal in the observed fire activity.” — Dave Cleaves, former climate change advisor to the Chief of the Forest Service

A Changing Fire Environment

Climate controls the magnitude, duration, and frequency of weather conditions associated with extreme fire behavior. In a warming climate, we are experiencing earlier snowmelt, longer fire seasons, and greater incidence of drought. We expect these trends to increase.

Increasing temperatures and changes in precipitation and snowmelt patterns are increasing the severity and size of wildfires in the West, especially in northern latitudes, including Alaska. Many States have recently experienced their largest and most destructive fires in history:

- Colorado experienced record-setting fires three times between 2012 and 2013 in the High Park Fire, Waldo Canyon Fire, and the Black Forest Fire. Among them, these fires burned more than 1,100 homes and brought about 5 fatalities.
- The annual area burned in interior Alaska has doubled in the last decade in comparison to any

decade since 1970, with three of the largest wildfire years on record also occurring during this time.

- In Arizona and New Mexico, 14 to 18 percent of the forested area was killed by wildfire and bark beetles between 1997 and 2008.
- In 2011, the Wallow Fire burned 536,000 acres of forest and woodland in eastern Arizona and western New Mexico. The largest recorded fire in the conterminous United States, this fire forced the evacuation of 8 communities, involved 4,700 firefighters, cost \$109 million to suppress and \$48 million for rehabilitation measures, and resulted in high consumption of organic material and extensive overstory mortality across much of the burned landscape.

Wildfire Predictions

According to the National Climate Assessment Report, Forest Sector (Vose et al 2012), wildfire will increase throughout the United States, causing at least a doubling of area burned by the mid-21st century. Increased drought will exacerbate stress complexes that include insects and fire, leading to higher tree mortality, slow regeneration, and changes in species assemblages, especially at forest ecotones.

Regional predictions outline details of change trends:

- In interior Alaska, the most important effects of climate change are permafrost thaw and changes in fire regime. South-central Alaska is sensitive to climate change because of its confluence of human population growth and changing disturbance regimes (insects, wildfire, and invasive species).
- In the Northwest, area burned and biomass consumed by wildfire will greatly increase, leading to changes in ecosystem structure and function.
- In the Southwest, large fires and insect outbreaks appear to be increasing in frequency and spatial extent. The fire-insect stress complex may keep many low-elevation forests in younger age classes in perpetuity. Increased fire followed by high precipitation (in winter in California; in early summer in much of the rest of the Southwest), may result in increased erosion and downstream sediment delivery.
- In the Great Plains, increased wildfire hazard, longer droughts, insect outbreaks, and fungal pathogens—individually and in combination—could significantly reduce forest cover and vigor. Reduced tree distribution

Increasing temperatures and changes in precipitation and snowmelt patterns are increasing the severity and size of wildfires in the West, especially in northern latitudes, including Alaska.

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will likely have a negative effect on agricultural systems, given the important role of shelterbelts and windbreaks in reducing soil erosion.

- In the Midwest, increased drought and fire occurrence are expected to have rapid and extensive effects on the structure and function of forest ecosystems. Oak decline and invasive species are expected to become more common, contributing to stress complexes that include nearly two centuries of land use activities.
- Future fire potential is expected to increase in summer and

Increased drought will exacerbate stress complexes that include insects and fire, leading to higher tree mortality, slow regeneration, and changes in species assemblages, especially at forest ecotones.

autumn from low to moderate levels in the eastern sections in the South and from moderate to high levels in the western portions of the South.

Climatologists warn us to expect not just increasing average temperatures, but more extreme events

and variability as climate continues to warm. In addition to increases in fire occurrence, one of our concerns is the occurrence of fire that is outside the range of our existing experience, exposing firefighters, communities, and important resources to increased risk.

The Climate Change Resource Center (CCRC)

The Climate Change Resource Center (CCRC) [<http://www.fs.usda.gov/ccrc>] was created for land managers who have wondered how they can address climate change in their work. It can be difficult to sort through the quantity of online information on climate change to find scientifically vetted and trustworthy sources that are also relevant from a land management perspective. The CCRC Web site was created to fill this need. It serves as an online portal to credible information focused on climate change effects and approaches to adaptation and mitigation in forests and grasslands. The Web site has recently been updated with a new look, more resources, and a better experience for users.

Because different management professionals may approach the subject of climate change from different perspectives, the CCRC sorts information into topics that

natural resource managers might find interesting. For example, topic pages focus on issues such as wildland fire, insect and bark beetle disturbances, forests and carbon storage, and many others. Each topic synthesis explains how the subject is affected by or related to climate change and provides options that are available to managers to respond to those effects. For example, the wildland fire page gives a brief overview of the use of thinning and surface fuel treatments as a way to reduce fire severity and hazard and considerations as to where and when these treatments may be appropriate. More context-specific detail is provided through references, recommended reading, and links. Each topic page is written by a subject-matter expert and is peer reviewed to ensure scientific validity.

The Climate Basics section can help introduce people to how climate change is expected to affect land

management. Videos cover topics ranging from how disturbances like fire and insects are affecting the carbon cycle to the effects of wildfire on fish populations. These videos can serve as training resources or as ways to spark group discussion about possible management strategies in a particular forest or area.

The CCRC began in 2008 as an effort of Forest Service Research and Development in the Western United States. The center has since evolved into a national resource, supported by the Forest Service Climate Change Advisor's Office and Forest Service Research and Development and managed by the CCRC Production Team, with input from the management community. To contact the CCRC with questions or suggestions, please email to ccrc@fs.fed.us.

Changing patterns of temperature and moisture also contribute to fire indirectly. Higher insect populations, such as mountain pine beetle, increase due to warmer winters, and drought-stressed trees are less able to resist insect attack. Extensive areas of dead and dying trees that result contribute to fire hazard.

Interactions of fire and other stressors (drought, insects, and invasive species) have the potential to cause significant changes in forest structure, productivity, and carbon storage across extended landscapes. Increased frequency and severity of fire in some ecosystems may cause long-term changes in species distribution and abundance. This may already be occurring in some parts of Alaska and the American Southwest.

The President's Climate Action Plan

The President's climate action plan directs us to preserve the role of forests in mitigating climate change by reducing wildfire risk and managing forests to be more resilient and to expand forest and rangeland restoration efforts in order to make natural areas and communities less vulnerable to catastrophic fire. How is the Forest Service responding to this mandate?

Wildfire Management in the Forest Service

In wildfire management, we have a few basic tools: we manage fuels and vegetation to mitigate fire risks; we can exercise a variety of suppression tactics; and we have collaborative work with communities to increase community resilience and preparedness—to create

fire-adapted communities. These tools line up with the key areas identified in the National Cohesive Wildland Fire Management Strategy (WFLC 2010): resilient landscapes, fire-adapted communities, and safe and effective wildfire fire response.

The fire management community in general is very good at suppression: about 98 percent of fires are suppressed in initial attack.

The fire-adapted community, in effect, becomes part of a resilient ecosystem—at least in terms of wildfire—and survives without major intervention.

However, recent trends in large fires show that this success rate may not be sustainable. In spite of ramped-up capacity, we are seeing more large fires and more acreage burned. On average, there were seven times as many fires per year greater than 25,000 acres in the last decade when compared to the 1970s. In fact, responding to large fires can swamp our capacity to prepare for them. For example, the Wallow Fire in Arizona in 2011 cost more than \$100 million to suppress, equivalent to about a third of our entire annual national budget for managing fuels to mitigate wildfire risk.

In light of increasing trends in large fire occurrence, we need to continue to ramp up our long-term commitment of increasing both community and ecological resilience—to increase our ability

to live with fire: that is, to create conditions where fire can visit a site with less than devastating outcomes. That is the goal of our fuels management program, as well as our work with partners—States and communities—in helping communities adapt to wildfire.

Our adaptive strategies are not fundamentally different under changing climate conditions, but climate change gives urgency to our efforts. We thin dense stands to reduce drought stress, we remove surface fuels (litter and woody debris), and we remove small trees (ladder fuels). We reintroduce fire to stands where it has been excluded, using prescribed fire under moderate conditions rather than waiting until a wildfire occurs under extreme conditions. All of these strategies remain cornerstones of fuel management.

Ecology

In a changed climate, we can no longer look solely to historical conditions to define a desired end-state for our management activities, although these conditions continue to direct our understanding of natural processes. We have to acknowledge that landscapes are changing and strive to manage forests so that they are still healthy and still resilient, even though changed, and so that they still provide their many benefits to society. Human settlement, land use change, and invasive species have also altered the landscapes we live in and manage. Climate change accelerates this landscape change. In order to practice sustainable land management in a changing world, we need to be committed to adaptive management, and we need to continue our investments in monitoring and in research.

When we respond to wildfire, we look for opportunities to let wildfire do its ecologic work. In some cases, rather than direct suppression tactics, we are able to monitor wildfire and stop its spread toward values at risk, even while it continues its ecologic role elsewhere.

Ideally, where a community is fully adapted to wildfire and the landscape near them is resilient, the fire simply burns around them, causing no damage and, thus, reducing risk to civilians, firefighters, and property. The fire-adapted community, in effect, becomes part of a resilient ecosystem—at least in terms of wildfire—and survives without major intervention. The wildfire leaves behind an area that is less flammable, making the landscape more resilient in the face of the next wildfire and mitigating future risk.

Adapting Management to the Landscape

In some ecosystems, we want to mimic a natural system of more frequent but less damaging fire,

while in others, we want to break up a continuous age class into a mosaic of age classes on the landscape to spread positive and negative effects of fire across time and space. We can't eliminate fire from our landscapes, but we can hope to manage our landscapes and ourselves so that we are less negatively impacted by fire.

In some places, there is a role for harvest and biomass utilization in mitigating fire risk. Unfortunately, at a landscape scale, the costs of harvesting and transporting biomass often make them economically infeasible. The materials that contribute most to wildfire risk are branch-wood, forest floor litter and woody debris, and small trees: not generally valuable materials. Possibly, new technology—for example, portable pyrolysis units that can operate near the source of the material to produce liquid fuel and biochar—can eventually help with this problem. Policy incentives that encourage renewable energy may also result in increased opportunities for biomass to “pay its way”

out of the woods. These options have a potential added benefit in reducing fossil fuel emissions.

The Long View

Foresters and land managers are trained to take the long view; our Forest Service mission has always stressed this. Responding to climate change is a commitment to the future. Our strategies for managing wildfire in a changing climate support the Forest Service mission, “to sustain the health, diversity, and productivity of the Nation's forests and grasslands to meet the needs of present and future generations.”

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Success Stories Wanted!

We'd like to know how your work has been going! Provide us with your success stories within the state fire program or from your individual fire department. Let us know how the State Fire Assistance (SFA), Volunteer Fire Assistance (VFA), the Federal Excess Personal Property (FEPP) program, or the Firefighter Property (FFP) program has benefited your community. Blogs should be between 100-200 words, Articles should be between 500-1,000 words, and Feature Articles should be between 1,500-2,000 words.

Submit your feedback, articles, stories, and photographs by email or traditional mail to:

USDA Forest Service
Fire Management Today

201 14th Street, SW
Washington, D.C. 20250
Email: firemanagementtoday@fs.fed.us

If you have any questions about your submission, you can contact one of the FMT staff at the email address above.

FOREST SERVICE COORDINATED TRIBAL CLIMATE CHANGE RESEARCH PROJECT

Linda E. Kruger and Kathy Lynn

The Forest Service Research All-Station Coordinated Tribal Climate Change Research Project is an interstation collaboration created to better understand and respond to tribal research needs and to learn from American Indian and Alaska Native experiences related to climate change impacts on indigenous lands. The coordinated project works in partnership with tribes and intertribal organizations to address climate change vulnerabilities and to support the sharing of knowledge in ways determined by tribes. So far, the effort has identified key tribal climate change research and information needs, shared research findings, co-hosted workshops, provided training, and contributed to the National Climate Assessment. Some Forest Service research station scientists participate as committee members of Landscape Conservation Cooperatives and are exploring the relationship between western science and tribal traditional knowledge within Federal Government climate change strategies. Climate change and wildland fire science and management are two topics of mutual interest.

Research and Development Tribal Engagement Roadmap

Forest Service Research and Development (R&D) recently

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released a *Tribal Engagement Roadmap* to support and implement the goals and objectives of the agency-wide *Tribal Relations Strategic Plan*. The *Tribal Engagement Roadmap* has five objectives and accompanying actions to achieve the objectives.

- 1. Build new and enhance existing partnerships with tribes, indigenous and native groups, tribal colleges, tribal communities, and intertribal organizations.** Actions include engaging with tribal colleges and tribal institutions to develop research partnerships, conduct joint research, and co-sponsor forums and training that is culturally appropriate and effective. In September 2014, the Forest Service, Pacific Northwest Research Station partnered with the Institute for Tribal Environmental Professionals to sponsor a Climate Change Adaptation Training session hosted at the offices of the Columbia River Inter-Tribal Fish Commission in Portland, OR.

In California, Forest Service Research Ecologist Frank Lake is providing scientific support for the Western Klamath Restoration Partnership. This partnership involves the Karuk Tribe, local watershed and fire safe councils, and national forests with support from The Nature Conservancy's California Klamath-Siskiyou Fire Learning Network. The goal and initial efforts have been to identify, across a 1.2 million-acre area,

“zones of agreement” for the prioritization of hazardous fuels and wildland fire management actions that incorporate agency, tribal, community, industry, environmental, and other public stakeholders’ values. As an integrated plan for restoring fire-adapted landscapes, this “all lands, all hands” approach is a collaborative effort that addresses wildland fire research and management, watershed restoration, and climate change adaptation needs of the region.

- 2. Institutionalize tribal trust responsibilities and engagement within Forest Service R&D.** Actions include staff training on requirements and authorities including tribal engagement, consultation, Federal Indian Law, and procedures for the protection of traditional ecological knowledge and intellectual property rights. Research Memorandums of Understanding and Memorandums of Agreement will be developed with tribes to clarify procedures and responsibilities. Researchers will reach out to tribes when setting research priorities, designing and implementing projects, and analyzing and disseminating results. For example, The Aldo Leopold Wilderness Research Institute initiated a Research Joint Venture Agreement with the Confederated Salish & Kootenai Tribes for research on climate change uncertainty and fire management plan revision.

3. Increase and advance tribal and indigenous values, knowledge, and perspectives within Forest Service R&D, including both operational and research activities.

Actions include encouraging tribal representation in the agency's workforce through recruitment and outreach, the Pathways Program, internships, and other programs. Provide training and professional development within the workforce and in the tribal community. Engage with students in mentoring and educational activities.

4. Network and coordinate within R&D and across deputy areas to increase agency and R&D program efficacy.

Actions include establishing points of contact to increase and advance communication with tribes and develop a process for coordinating and sharing research activities and findings between and among stations and with tribes. The All-Station Climate Change and Tribal Research Project responds to this objective. The Forest Service was a sponsor of the First Stewards Symposium, held July 21–23, 2014, in Washington, DC.

5. Through collaborative and participatory approaches with tribes and tribal organizations, advance research on shared topics of interest.

Federal and tribal managers, scientists, and tribal elders worked together to sponsor a workshop on wildland fire. The workshop was held on the Flathead Indian Reservation of the Confederated Salish Kootenai Tribes in western Montana with funding from the Joint-Fire Sciences Program. At the workshop, tribal elders and

Federal and tribal managers and scientists discussed the integration of tribal stewardship and traditional knowledge in wildland fire management (Mason et al. 2012).

Regular network emails provide links to funding and training opportunities, webinars, and meetings of possible interest to network members. The Web site (<http://tribalclimate.uoregon.edu>) also provides tribal profiles, links to publications and presentations, and an extensive and frequently updated funding guide. The tribal profiles recognize the increasing number of innovative tribal efforts to address climate change through climate change assessments, adaptation, and mitigation. The profiles are intended to be a pathway to increasing knowledge among tribal and nontribal organizations interested in learning about climate change mitigation and adaptation efforts. To join the network, contact Kathy Lynn, tribal climate change project coordinator, at kathy@uoregon.edu. Research social scientist, Linda Kruger (lkruiger@fs.fed.us), is the Pacific Northwest Research Station contact for the network.

Southwest Tribal Climate Change Network

The Southwest Tribal Climate Change Network was established in 2011 and is coordinated by the Institute for Tribal Environmental Professionals (ITEP). The Southwest Network is funded by the Rocky Mountain Research Station to identify tribal climate change efforts in Arizona and New Mexico, to assess research and information needs, and to develop strategies to meet those needs.

Through this project, ITEP has designed and delivered workshops to build knowledge and foster dialogue about needs and opportunities for tribes to engage in climate change planning and action. ITEP also develops climate change outreach materials and has coded transcribed recordings of oral history interviews with long-time Colorado Plateau residents. The network shares resources to facilitate tribal climate change efforts on quarterly conference calls. The network is open to tribes, tribal organizations, agencies, and other interested individuals in Arizona and New Mexico. ITEP also offers training to tribal environmental professionals to build their capacity to address climate change issues. The courses are taught by instructional teams that include staff from ITEP, Federal agencies, universities, and/or organizations, and most importantly, tribal environmental professionals who share their expertise and experience. ITEP also produces a monthly Tribal Climate Change Newsletter with news items, resources, announcements about funding opportunities, conferences and training, and other information relevant to tribal climate change issues. For information, to join the Southwest Network, or to sign up for the ITEP newsletter, contact Sue Wotkyns at Susan.Wotkyns@nau.edu.

Conclusion

Over the past 5 years, the Forest Service Research All-Station Coordinated Tribal Climate Change Research Project has contributed to an increased understanding of the issues that many tribes are confronting, as well as building new partnerships between the Forest Service and tribes to work together to identify and plan for climate

impacts. Support for efforts such as the *Guidelines for Considering Traditional Knowledges in Climate Change Initiatives (Climate and Traditional Knowledges Workgroup 2014)* and a synthesis of literature on climate change and traditional knowledge (Vinyeta and Lynn 2013) are resulting in tools and resources that will help Federal agency managers to engage in tribally led initiatives to address climate change.

The Coordinated Tribal Climate Change Research Project contributes to the overall Coordinated Climate Change Research Strategy. Pacific Northwest Research Station scientist David Peterson summarized the following lessons learned in implementing the Coordinated Climate Change Research Strategy:

- Ongoing communication among all parties involved in assessments and adaptation strategies is critical.
- There is no substitute for face-to-face meetings for good communication.
- Authorization and buy-in by leadership are critical for projects to move forward.
- Projects need to be customized for the needs and preferences of local management units, otherwise the process will not work.

- A strong 1- to 2-year commitment is needed by the primary management units involved.
- Enduring science-management partnerships will have the biggest impact on long-term implementation of assessments.
- Knowing the potential applications of assessment and adaptation information at the start of the project is critical for successful implementation.
- An excellent project Web site is critical.

There are opportunities to bring together the Coordinated Tribal Climate Change Research Project and the Coordinated Climate Change Research Strategy by engaging tribes as partners in several current adaptation efforts including the Blue Mountains Adaptation Partnership, the Northern Rockies Adaptation Partnership, and the North Cascadia Adaptation Partnership. Several partnership goals mirror the goals of the Coordinated Tribal Climate Change Research Project and include assessing vulnerability of cultural and natural resources, developing science-based adaptation strategies, and incorporating climate change adaptation into land management.

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POTENTIAL CLIMATE CHANGE IMPACTS ON FIRE WEATHER IN THE UNITED STATES

Warren E. Heilman, Ying Tang, Lifeng Luo, Shiyuan Zhong, Julie A. Winkler, and Xindi Bian

Introduction

Occurrences of large and sometimes extreme and erratic wildfires in the United States in recent years have raised speculation about what projected future climate conditions might mean for future wildfire activity and fire weather in different regions of the United States. This speculation has led to studies by the scientific community on the possible linkages between long-term global and regional climate change and changes in the frequency of occurrence of short-term weather events that are conducive to large fires and/or erratic fire behavior. In particular, researchers at Michigan State University and the Forest Service's Northern Research Station worked on a joint study to examine the possible effects of future global and regional climate change on the occurrence of fire-weather patterns often associated with extreme and erratic wildfire behavior in the United States. The Haines Index (HI) (Haines 1988), an operational fire-weather index used by fire managers and fire-weather forecasters to characterize how conducive middle and lower atmospheric moisture and thermal stability conditions are to extreme and erratic fire behavior, was computed from multiple future climate projections.

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Researchers at Michigan State University and the Forest Service's Northern Research Station worked on a joint study to examine the possible effects of future global and regional climate change on the occurrence of fire-weather patterns often associated with extreme and erratic wildfire behavior in the United States.

Published results from that study can be found in Luo et al. (2013) and Tang et al. (2015). This article provides a summary of the methodology, key results, and conclusions from those publications.

Methods

To investigate potential changes in regional fire-weather conditions as a result of climate change, we incorporated a subset of the suite of North American regional climate change projections that are currently available from the North American Regional Climate Change Assessment Program (NARCCAP). NARCCAP is an international program designed to develop high-resolution climate-change simulations covering the North American continent using a suite of regional climate models (RCMs). The RCMs are driven by a number of different coupled global-scale atmosphere-ocean general circulation models (AOGCMs) (Mearns et al. 2009, 2012). For our study, we used NARCCAP regional climate simulation data for the "current" climate (1971–2000) and obtained

the future climate (2041–2070) from six AOGCM-RCM combinations involving three RCMs and three AOGCMs. The RCMs included the Regional Climate Model, version 3 (RCM3; Pal et al. 2007), the Canadian Regional Climate Model (CRCM; Caya and Laprise 1999), and the Weather Research and Forecasting model (WRF; Skamarock et al. 2005), all with a horizontal grid spacing of 31 miles (50 km). The driving AOGCMs included the Geophysical Fluid Dynamics Laboratory (GFDL) general circulation model (Delworth et al. 2006), the Canadian Global Climate Model, version 3 (CGCM3; Flato 2005), and the National Center for Atmospheric Research (NCAR) Community Climate System Model, version 3 (CCSM3; Collins et al. 2006). For the future climate (2041–2070) simulations, we forced the driving AOGCMs with the "A2" greenhouse gas emissions scenario that is consistent with a continuously increasing global population and regionally oriented economic growth (Nakicenovic et al. 2000).

Using the 0000 Coordinated Universal Time (UTC) (corresponding to a time of 5:00 p.m. Pacific Daylight Time (PDT) during the summer months) temperature and atmospheric moisture data obtained from the six AOGCM-RCM simulations of the current and future climates, we computed daily HI values at each RCM grid point. As described in Haines (1988), the HI takes on integer values ranging from 2 to 6 depending on the instability and moisture content in the atmospheric layers used to compute the index. HI values of 5 or 6 indicate unstable and dry conditions in the lower to middle troposphere, a feature often associated with extreme fire behavior if fires are present. We focused

our HI analyses on the months of March, August, and October, given that wildfires in the Eastern United States are more likely to occur in the late-winter, early spring, and autumn months, and August is usually the most active month for wildfire occurrence and area burned in the Western United States (Haines et al. 1975, Westerling et al. 2003).

Summary of Key Results

In Luo et al. (2013), we examined changes in the percentage of August days with $HI \geq 5$ at 0000 UTC between current and projected future climate conditions over the Western United States. The scenarios

obtained from the six NARCCAP AOGCM-RCM model simulations all suggest that large areas of the western U.S. region may see an increase in the frequency of $HI \geq 5$ occurrences during the month of August under future climate conditions compared to current climate conditions (figure 1). Note that under current climate conditions, it's typical for about 40 percent of summer (June–August) days in portions of the Western United States to have 0000 UTC HI values equal to 5 or 6 (Winkler et al. 2007, Lu et al. 2011). The CRCM-CCSM3 and CRCM-CGCM3 simulations used in this study project future atmospheric stability and moisture conditions over Wyoming, Colorado, and New Mexico that

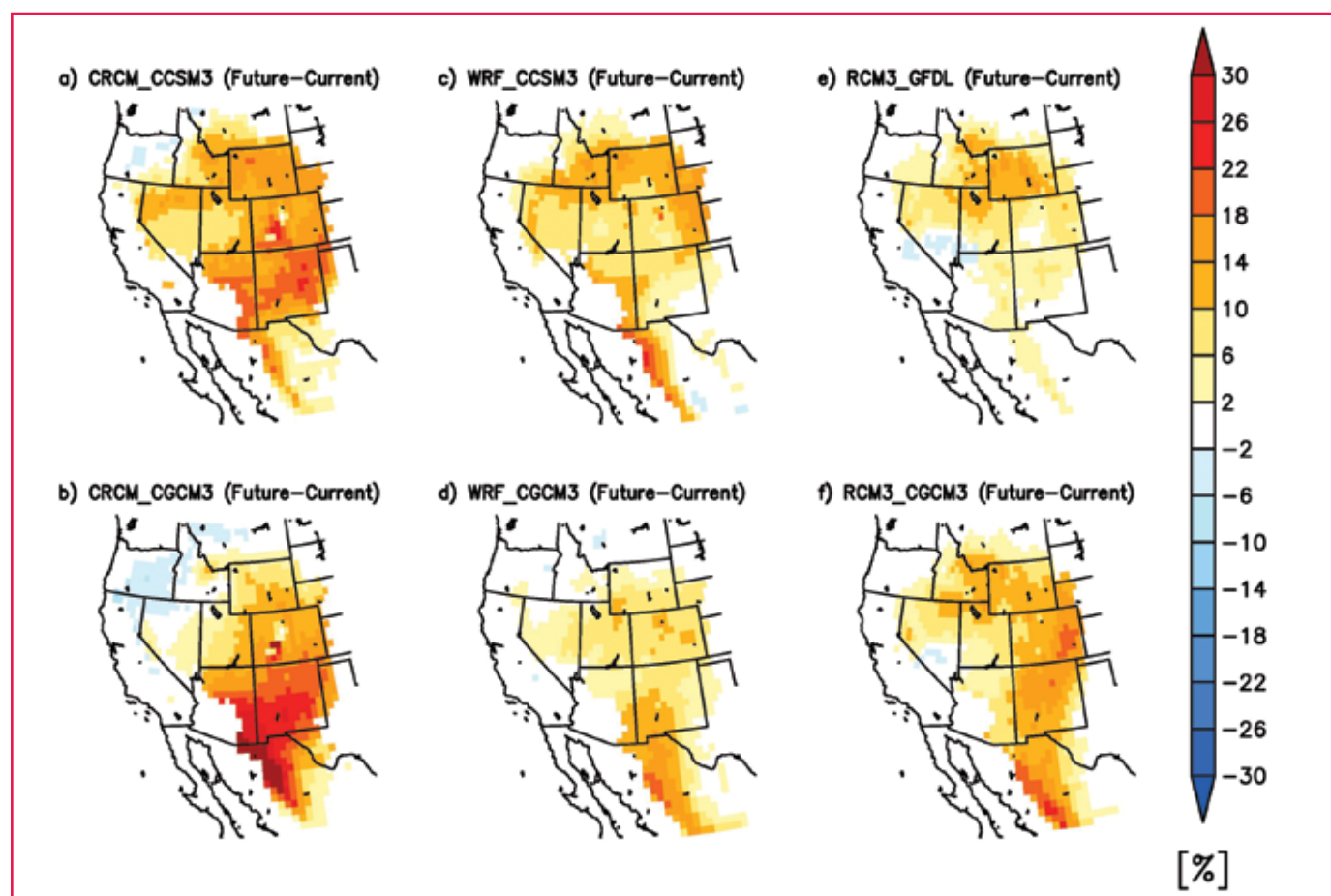


Figure 1. Changes in the percentage of days for which $HI \geq 5$ at 0000 UTC during August between the current (1971–2000) and the future (2041–2070) climate as simulated by the CRCM (left), WRF (center), and RCM3 (right) regional climate models driven by the CCSM3 (top) and CGCM3 (bottom) global-scale atmosphere-ocean general circulation models. For RCM3, CCSM3 is replaced by the GFDL model. (From Luo et al. 2013; © American Meteorological Society; used with permission.)

would lead to a substantial 10- to 26-percent increase in the percentage of August days having HI values equal to 5 or 6 (figures 1.a-b). More moderate increases over much of the Western United States are projected by the four remaining NARCCAP simulations that we used in this study (figures 1.c-f).

Because occurrences of multiday episodes of atmospheric stability and moisture conditions conducive to extreme and erratic fire behavior are also of concern for fire management activities, we examined potential changes in the persistence of high HI values during the month of August across the Western United States. Figure 2 shows projected changes in the average number of consecutive days in August with HI ≥ 5 at 0000 UTC under future cli-

The intent of the analyses is to inform fire and forest managers and policymakers of the possible impacts that regional climate change may have on future extreme fire behavior occurrence in the United States.

mate conditions compared to current climate conditions as derived from the six NARCCAP modeling systems used in this study. Five of the six simulations suggest future climate conditions may lead to large areas in the Western United States that experience increases in

the duration of HI ≥ 5 events. The largest increases in the length of HI ≥ 5 events in August are projected by the CRCM-CCSM3 simulations, with events projected to last on average up to 7 to 9 days longer than the present over much of the Intermountain West. Smaller increases are suggested by the other NARCCAP modeling systems.

Building upon the analyses of the Western United States conducted in Luo et al. (2013), we extended the analyses to the entire United States, as presented in Tang et al. (2015). In addition to August, we included the months of March and October in our analyses because wildfires in the Eastern United States are more frequent during the spring and autumn seasons.

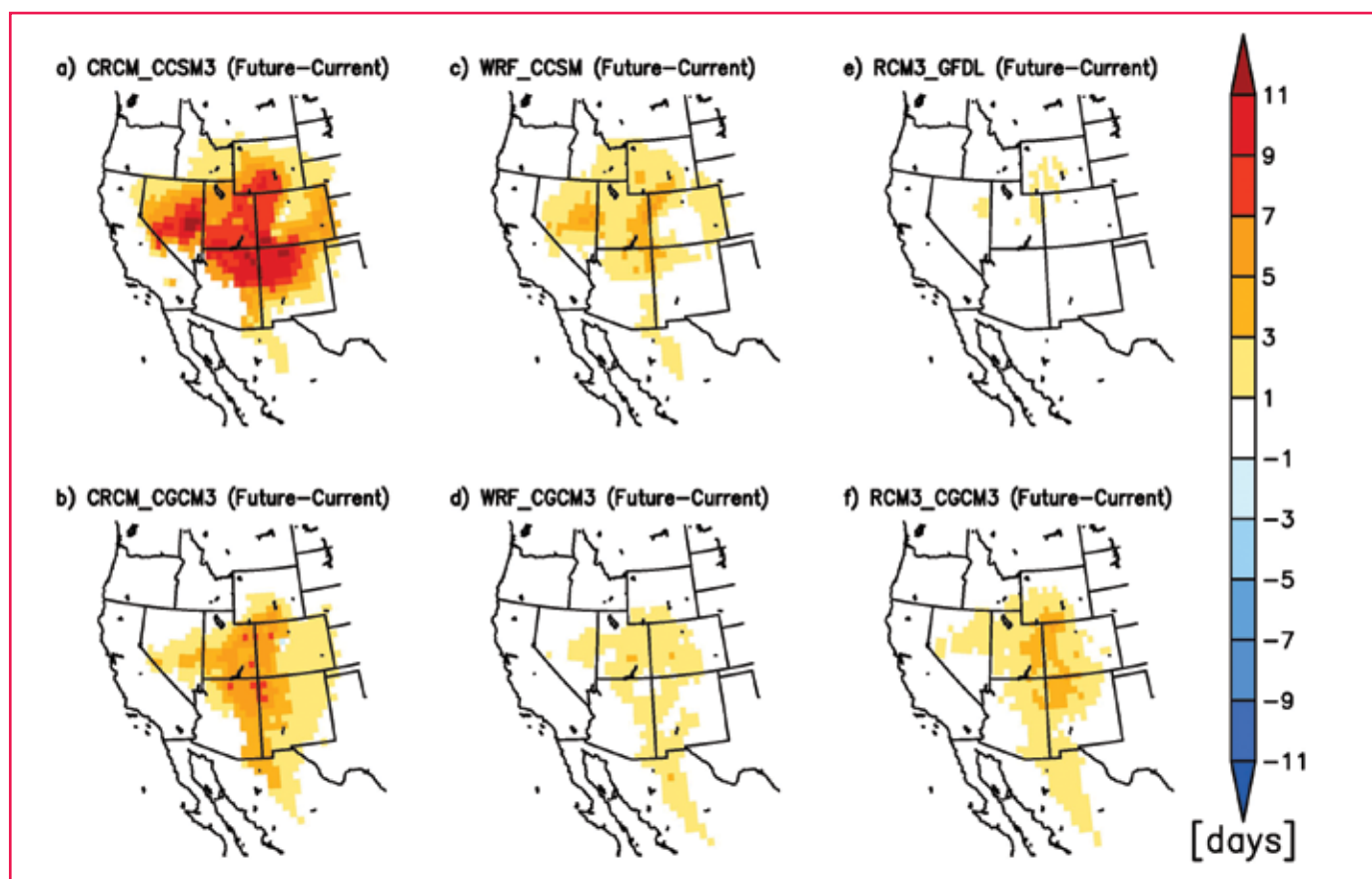


Figure 2. Same as figure 1, except for changes in the average duration of consecutive days with HI ≥ 5 . (From Luo et al. 2013; © American Meteorological Society; used with permission.)

Averaging the six NARCCAP simulations, we found mean projected changes in the percentage of days with $HI \geq 5$ at 0000 UTC over the entire United States to be much more substantial during August than during March or October. The largest projected increases during August are found over regions of the Intermountain West, as previously mentioned in the Luo et al. (2013) summary, and over portions of the Midwest, including Ohio, western Pennsylvania, West Virginia, and eastern Kentucky and Tennessee (figure 3). Average projected increases in these areas

reach as high as 10 to 14 percent, corresponding to an additional 3 to 4 days each August, under future climate conditions, that could have high HI values. Based on the analysis of Winkler et al. (2007) of current HI patterns over the United States, this increase would result in some areas of the Western and Eastern United States experiencing, on average, about 15 and 10 high HI days, respectively, in August under future climate conditions.

For March and October, we found the spatial patterns of projected changes in the percentage of days

having high HI values across the United States to be highly variable (-10 to $+10$ percent) and inconsistent among the six AOGCM-RCM simulations. Because of this inconsistency, the averages of the projected changes in high HI occurrence during March and October as computed from the six AOGCM-RCM simulations are relatively small (<5 percent). This inconsistency limits our confidence in concluding from this study that regional climate change in the United States will lead to specific changes in the occurrence of atmospheric conditions conducive to

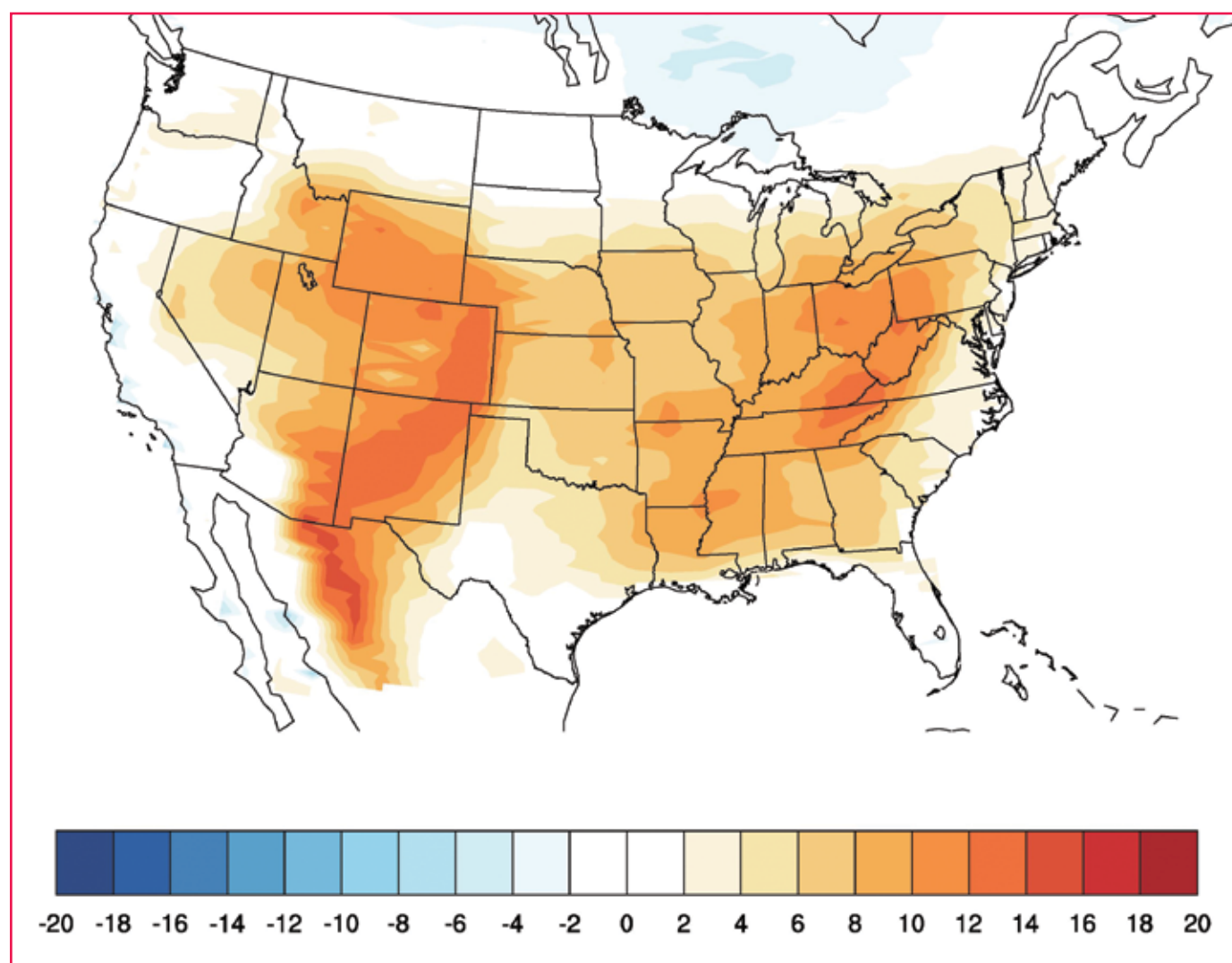


Figure 3. Changes in the percentage of days for which $HI \geq 5$ at 0000 UTC during August between the current (1971–2000) and the future (2041–2070) climate based on an average of the North American Regional Climate Change Assessment Program climate simulation results from six different coupled AOGCM-RCM modeling systems reported in Tang et al. (2015).

extreme fire behavior during the spring and autumn seasons.

The ensemble of AOGCM-RCM projections in Tang et al. (2015) also suggest that future climate conditions could lead to longer duration summertime high HI events, not only in the Intermountain West region as noted in Luo et al. (2013), but also over the southern Great Plains (figure 4). Averaging over the six AOGCM-RCM modeling systems used in our study, we found projected mean increases in the average length of HI ≥ 5 events during August to be as high as 4

to 5 days over portions of Texas, Oklahoma, Colorado, Utah, Arizona, and New Mexico. No areas of the United States are projected to have decreases in the mean length of HI ≥ 5 events during August. For March and October, the average of the six AOGCM-RCM projections yielded changes in the duration of high HI events that are minimal (0 to 2 days) across the entire United States. Again, this result is a reflection of the substantial variability and inconsistency in the computed spring and autumn HI patterns across the United States between the different AOGCM-RCM simulations.

Conclusions

The analyses of Luo et al. (2013) and Tang et al. (2015) provide new insight into how changing climate conditions could affect future fire weather in the United States, particularly during the summer season when wildfires are common in the Western United States. Potential summertime increases in the number of days having high HI values and the number of consecutive days with high HI values over portions of the Western United States, as highlighted in these analyses, suggest more frequent extreme wildfires are a possibility there.

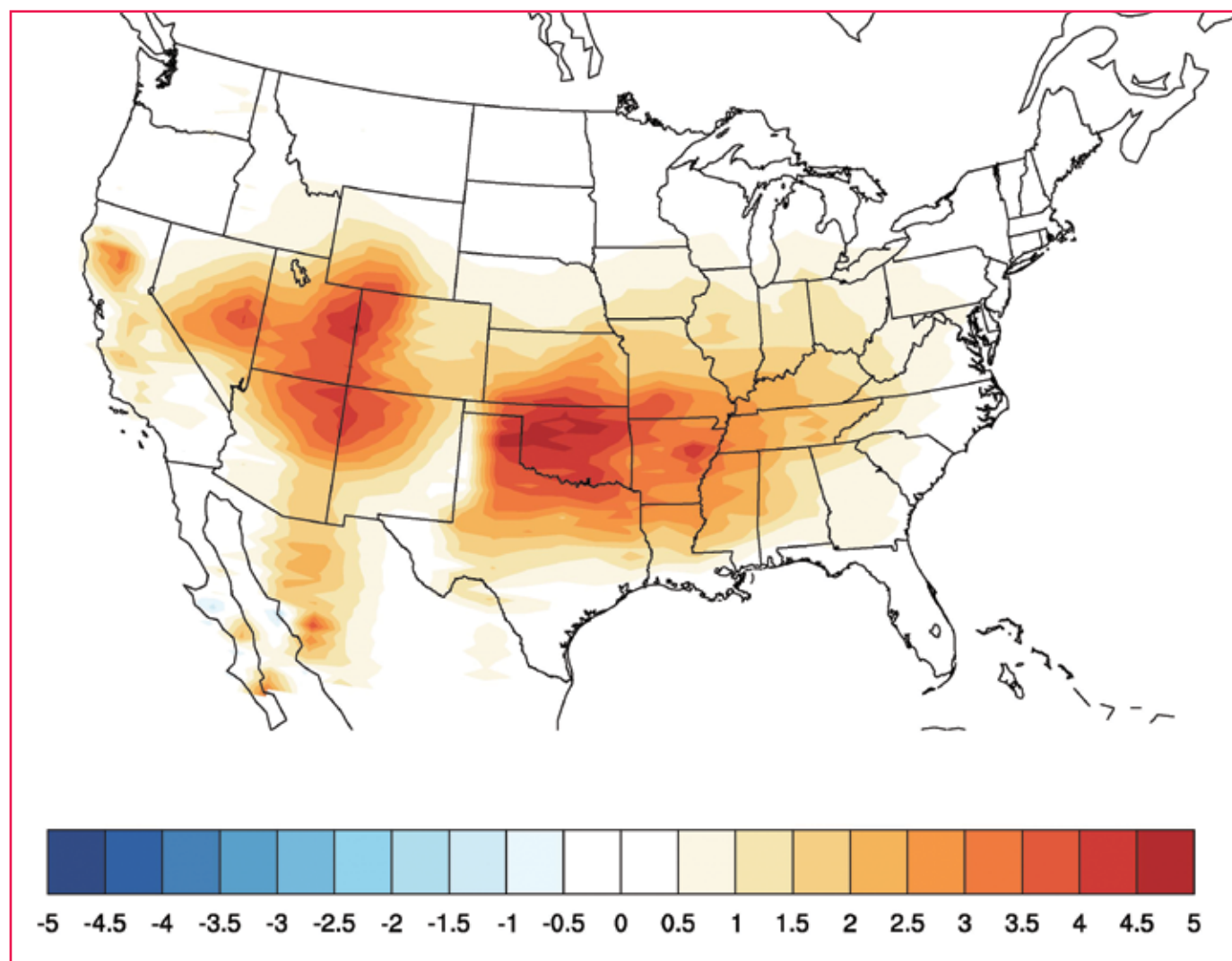


Figure 4. Same as figure 3, except for changes in the average duration of consecutive days with HI ≥ 5 .

However, substantial variability and inconsistency in the patterns of high HI occurrence during the months of March and October, as derived from six regional climate projections, make it more difficult to offer definitive statements on the likelihood of future atmospheric conditions being more conducive to extreme wildfires in the United States during the spring and autumn seasons.

We recognize that other factors such as fuel conditions and fire-suppression activities also affect the risk of large and extreme wildfires. We also recognize the limitations in using only one fire weather index in our analyses instead of a suite of indices to characterize current and future fire weather. The use of regional climate simulation data at 31-mile (50-km) resolution for analyses of fire-weather patterns, particularly over areas of complex terrain and significant land-cover variations, adds further uncertainty to the fire-weather projections. Nevertheless, the analyses of Luo et al. (2013) and Tang et al. (2015) do suggest potential linkages between climate change and fire weather. The intent of the analyses is to inform fire and forest managers and policymakers of the possible impacts that regional climate change may have on future extreme fire behavior occurrence in the United States via atmospheric factors alone and to provide additional climate-science information for developing long-term fire and fuels management strategies in the United States.

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STUDYING THE EFFECTS OF A CHANGING CLIMATE ON WILDFIRES AND THE IMPACTS TO THE UNITED STATES' AIR QUALITY

Maria Val Martin, Jeffrey R. Pierce, and Colette L. Heald

In the United States, wildfires burn millions of acres every year, releasing large amounts of gases and particles to the atmosphere. For example, in the summer of 2014, six wildfires burned more than 135,000 acres (54,600 ha), polluting fairly populated areas of California, such as Napa County (Inciweb 2014). The amount of acres burned does not account for smaller and more remote fires that continued to burn throughout the State. Smoke from fires negatively impacts humans and ecosystems. While direct smoke inhalation is potentially lethal, sublethal con-

centrations adversely affect human health for particularly sensitive populations (e.g., children and elderly) in both the short and the long term, and for individuals who are occupationally exposed and may inhale smoke under conditions of highly aerobic physical activity. Smoke particles with aerodynamic diameter below 2.5 micrometers (i.e., $PM_{2.5}$) are particularly toxic since they can penetrate into the lungs, with protracted effects from even a single exposure (Pope et al. 2002).

Smoke concentration levels near the fire are of primary concern for human health. In addition, smoke can be transported hundreds of miles downwind by prevailing winds or convective winds generated by fires themselves with concentrations sufficient to make it the most significant source of air pollution over large areas (Val Martin et al. 2013). Smoke from long-distance fires can also adversely affect

visibility in national parks and wilderness areas designated federally as “Class I” because of their pristine air quality. In these Class I protected areas, within both the Western and the Southeastern United States, conditions of lower visibility are most often associated with wildfires upwind (figure 1) (U.S. EPA 1999).

Fire activity is strongly related to weather and climate. Observations over the Western United States have shown an upward trend of area burned resulting from increasing fire activity, most likely due to climate change (Westerling et al. 2006). In California, which is experiencing intense drought conditions, 4,172 wildfires were recorded from January to August 2014, a 30-percent increase from the average of 3,198 fire events from the previous 5 seasons. Current modeling efforts consistently suggest that fire activity will continue to rise dramatically over the next century

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Figure 1. An example of Yosemite National Park during a clear day (left) versus a hazy day, showing air quality degradation from wildfire smoke (right). Photo: Interagency Monitoring of Protected Visual Environments <<http://vista.cira.colostate.edu/improve/>>.

(Xue et al. 2013). Climate-driven changes in fire emissions can be an important factor controlling $PM_{2.5}$ concentrations. For example, previous studies have projected that increased fire activity over the Western United States will nearly double carbonaceous aerosol by 2050 and produce a significant increase in annual mean $PM_{2.5}$ and haze (Spracklen et al. 2009, Xue et al. 2013).

Current meteorological conditions, such as high temperature, low precipitation, and low relative humidity, affect the extent of area burned by fires, regardless of whether the fires are started by lightning or by human activity (Westerling et al. 2006). In addition, meteorological conditions experienced during the months or years preceding the fire may influence the amount of fuel and fuel moisture, which in turn can significantly affect the area burned (Westerling et al. 2006). On the other hand, land-use management and fire suppression may help reduce wildfire severity (Prichard et al. 2010, Kloster et al. 2010). Addressing these concerns requires coupling of climate, vegetation, and fire models.

Fire models have been used in recent years to simulate present day and future fire activity and emissions. These fire parameterizations were developed by regressing meteorological variables and fire indexes onto observed area burned (Spracklen et al. 2009) by empirical functions based on state variables such as soil moisture, temperature, relative humidity, and road and population density (Thonicke et al. 2001, Crevoisier et al. 2007) or by complex process-based fire parameterization schemes (Li et al. 2012). Current estimates of increased area burned, however, show little

consistency across models, with ranges from 50 to 150 percent in 2050 to 20 to 100 percent in 2100. In addition, and quite surprisingly, only two studies to date (Spracklen et al. 2009, Yue et al. 2013) have projected the effects of future fires on surface air quality. These papers only focused on the effects of wildfires on black carbon and organic aerosol over the Western United States and at a rather coarse (~250 x 311 miles [~400 x 500 km]) spatial resolution.

Smoke can be transported hundreds of miles downwind by prevailing winds or convective winds generated by fires themselves with concentrations sufficient to make it the most significant source of air pollution over large areas (Val Martin et al. 2013).

To project fire smoke impacts on air quality due to climate change over the United States at the regional scale, climate inputs at resolutions fine enough to capture the spatial variability of both climate and land cover are required (McKenzie et al. 2014). Global atmospheric and climate models typically run at horizontal grid spacing of 62 x 311 miles (100 to 500 km). However, grid resolutions of 2.5 to 22 miles (4 to 36 km) better capture spatial variability, although local phenomena important for fire are not resolved even at these smaller scales (McKenzie et al., 2014). Regional climate models

provide this increased horizontal resolution, but cannot simulate closed systems, such as atmospheric, oceanic, and land-surface processes and their interactions. For this reason, these models need to be fed by boundary conditions obtained from global model outputs, with potential biases introduced when “downscaling” climate projections from the global to the regional model.

Under the scope of a 2014 Joint Fire Science Program Grant, we are currently investigating future wildfire activity and consequences on air quality over the United States. In this study, we focus on major air pollutants, such as $PM_{2.5}$ and ozone, and employ the global Community Earth System Model (CESM) using an unprecedented fine scale (31 x 31 mile [50 x 50 km]) with the new Intergovernmental Panel on Climate Change (IPCC) Representative Concentration Pathway (RCP) climate projections. We have incorporated into the model a complex fire parameterization (Li et al. 2012) directly coupled with the climate projections to better predict future areas burned and fire emissions, including changes in biogenic emissions and vegetation. We also take into account projections in anthropogenic emissions (figure 2).

Our approach of using a high-resolution global model is preferred to downscaling climate projections to drive a regional model because: (1) CESM is producing self-consistent and fully coupled simulations, where the climate dynamics drive natural emissions, including also fire emissions, and is directly linked to air quality; (2) the 31- x 31-mile (50- x 50-km) resolution is comparable to that of many regional models; and (3) CESM is

also accounting for changes in fire emissions from regions outside the United States, such as Mexico and Canada, to simulate air quality over the United States.

With this project, we aim to quantify potential changes in fire occurrence and severity resulting from changes in climate in the mid-21st century, develop global daily averages of area burned and fire emissions at 31- x 31-miles (50- x 50-km) for the mid-21st century to be used in future regional modeling studies, and quantify future contributions from fires to ambient levels of PM_{2.5} and ozone over different regions of the United States. The research project will be finalized September 2016.

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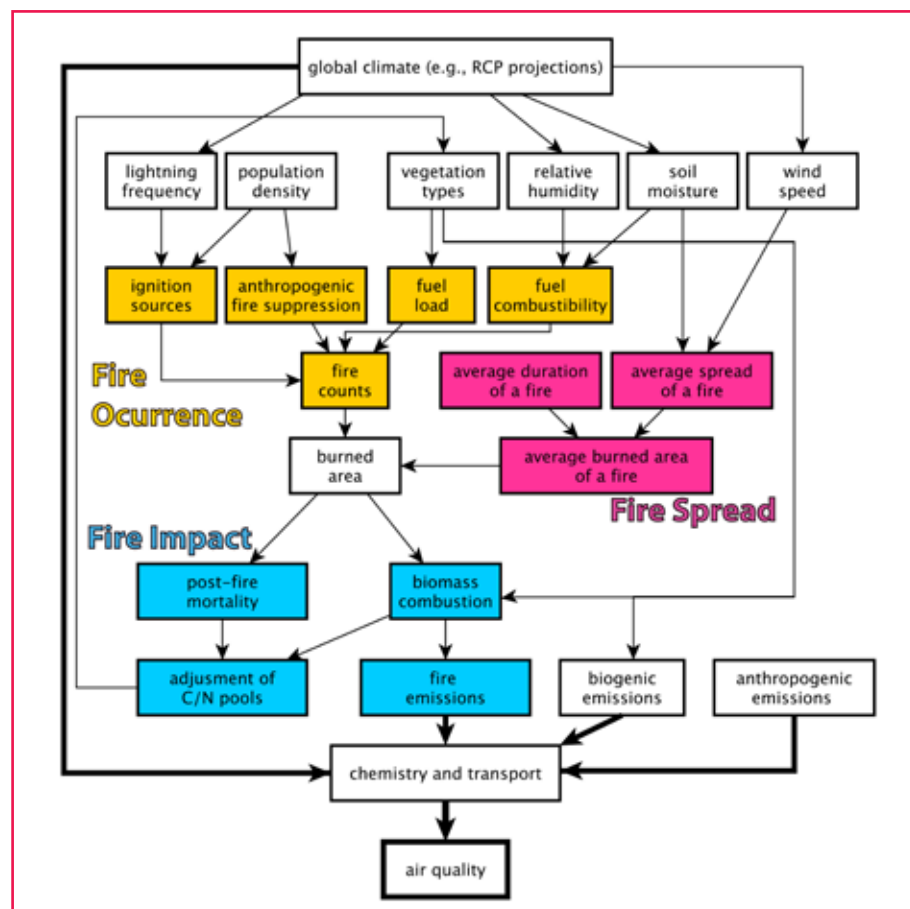


Figure 2. Diagram of our modeling approach to project fire smoke impacts on air quality due to climate change. The fire parameterization used in the study is depicted in the flow chart and summarized as fire spread, occurrence, and impact. Thin lines connect mainly the elements of the fire parameterization and thick lines connect main items of the modeling system. Flowchart adapted from Li et al. 2012.

SMOKEY BEAR AND 70 YEARS OF VIGILANCE

Fred Hernandez

It's difficult to imagine that Smokey Bear celebrated his 70th Anniversary in August 2014. Most of us were introduced to Smokey Bear and fire prevention through childhood school programs and public service announcements on television and radio. As firefighters, land managers, and stewards of public lands, we have an apprecia-

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tion of the role that the Smokey Bear program has in preventing accidental, human-caused wildfires. Over these 70 years, like any program with a similar longevity, there has been an evolution to remain relevant and effective with the changing times.

To put this in perspective, when Smokey Bear was created, our Nation was in the midst of World War II, the population of the United States was approximately 133 mil-

lion, and the average cost of a gallon of gasoline was 15 cents. Today, advances in technology give us many options and mediums to use to communicate fire prevention messages. The Smokey Bear program has always been about promoting a sense of personal ownership in preventing accidental wildfires. In 2001, the slogan "Only You Can Prevent Forest Fires" was modified to "Only You Can Prevent Wildfires" and still serves to instill a sense of individual responsibility.



1944



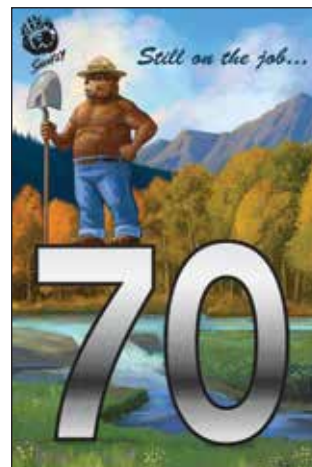
1953



1966



1989



2014

Program evolution is about maintaining effective communications, keeping fire prevention messages relevant, and involving the public and stakeholders in community fire prevention programs.

In 2013, the “bear hug” campaign was launched and was intended to thank individuals for doing their part in taking correct actions towards the prevention of wildfires. The most recent Smokey Bear campaign commemorates his 70th birthday with a continuation of the “bear hug” theme showing individuals returning the hug and wishing Smokey Bear a happy birthday and thanking him for all his fire prevention contributions over the years.

The Cooperative Fire Prevention Program (CFPP) partners—the Advertising Council, the National Association of State Foresters, and the Forest Service—are responsible for managing and maintaining the relevance of the Smokey Bear program. Some recent changes to the Smokey Bear program include the development of advertising campaigns with an increased focus on educational content. Traditional and social media tools are used to disseminate messages with the goal of adjusting human behaviors to reduce accidental wildfires. Public service announcements and the increased use of social media allow us to deliver fire prevention messages in a variety of formats

to a wide demographic. In-person appearances by Smokey Bear with localized fire prevention education messaging are still a vital part of the program and an essential component for developing lasting partnerships with communities and stakeholders.

On average, 9 out of 10 wildfires are caused by humans, so we will continue our wildfire prevention work with our partners and with Smokey. All of these combined efforts have helped reduce the number of accidental, human-caused wildfires. For more information on the Smokey Bear program, visit <http://www.smokeybear.com/>. ■

THE STRUCTURAL, GEOGRAPHIC, AND FINANCIAL IMPACTS OF WILDFIRE IN THE UNITED STATES

Thomas Jeffery

Wildfire is often a naturally occurring process, hence the term “natural hazard,” but unlike other natural, potentially disastrous weather-related events, such as hurricanes, tornadoes, and floods, there are two critical human elements unique to a wildfire: it is the only natural hazard that can be directly caused by intentional (or even unintentional) human actions, and it is also the natural hazard that humans have been most successful at controlling. According to National Interagency Fire Center (NIFC) data, on average, humans start 62,631 fires per year, which is more than 6 times the number of wildfires caused by lightning. The distinct human elements create a complex and fascinating dynamic that has shaped our experience with wildfire over recent decades. As science and technology evolve, we’ve become better equipped to contain blazes and adopt new construction materials and other mitigation techniques that protect individual properties from the effects of fire. Yet, at the same time, population growth, expanding real estate development, and changing environmental factors are contributing to the increased risk, as well as a greater financial impact, associated with property damage caused by wildfires. As science and technology continue to improve

Thomas Jeffery is a lead scientist on development of hazard risk datasets, including wildfire risk, coastal storm surge risk, earthquake risk, and Florida sinkhole risk for CoreLogic.

It has never been more important for homeowners to proactively evaluate and mitigate the wildfire risk for their properties. Complete reliance on responders only makes the responders’ job more difficult, and the alternative of relying completely on the insurer does nothing to prevent a fire from damaging a home.

over time, the ability to directly combat the hazard, as opposed to only post-disaster response, means there is potential to save more lives and protect more homes.

Historic fires provide us with an insight into how humans interact with and respond to wildfire activity. Fire size and frequency have changed over time and continue to evolve. A common thread among fires from 150 years ago and fires today, however, is the damage and destruction that result from these blazes. Several of the largest blazes of the last two centuries were the Peshtigo Fire in 1871 (Wisconsin, 1.2 million acres), the 1881 Thumb Fire (Michigan, 1 million acres), and Idaho-Montana-Washington’s Great Fire (the Big Burn) of 1910 (3 million acres). These and many other large-scale fires burned through extensive swaths of land and destroyed entire towns, taking thousands of lives in the late 19th and early 20th centuries. At that time, there was little that could be

done to contain these blazes once they began, and anyone in the path of the fire was at the mercy of the wind-driven flames.

When we compare these historic fires with what we’ve experienced in the past decade, what is the difference, if any? There was the Cedar Fire in 2003 (280,000 acres) and the October 2007 California fires (127,000 acres) (California Fire 2014). More recently, in 2012, Colorado experienced the Waldo Canyon Fire (18,000 acres) and, in 2013, the Black Forest Fire (14,000 acres). The obvious difference is that the more recent fires covered a smaller geographic area, though a smaller burned area does not necessarily mean less destruction. These four recent fires alone were responsible for the loss of more than 4,500 homes and at least 25 deaths. Were it not for the ability to contain and restrict the growth of these fires, it is likely that the losses would have been greater.

When comparing wildfire activity at different points in history, it is difficult to make direct comparisons due to the changes in the environment and technological advancements that enable us to manage wildfire differently today. Air support, hotshot firefighting crews, and chemical retardants were not readily available 100 years ago, but they now serve as some of the most valuable tools used to restrict the movement and growth of many wildfires.

One of the most significant factors influencing wildfire risk is the population of the United States, which has increased from approximately 50 million in 1880 to more than 317 million today (U.S. Census Bureau 2014). The population has increased sixfold in this 134-year span and, in turn, has increased the potential for property damage from wildfire. The simplistic equation of *more people = more homes* results in more residential structures both within, and in closer proximity to, higher wildfire risk areas. As residential development pushes outward from the city boundaries, these urban-edge areas, commonly referred to as the wildland-urban interface (WUI), present the unique problem of an increase in the number of residences in precisely the area that, in many cases, are at the highest risk for wildfire.

Changes in Burn Patterns and Destruction Over Recent Decades

There is a continuing conversation that involves the perceived changes in wildfire activity within the last 10, 20, or 30 years. This more recent timeframe provides a comparative view of both wildfire activity and human response to

these fires. A review of NIFC wildfire statistics reveals an interesting dichotomy: based on recent activity, the number of wildfires that occur each year (1985–2013) tends to fluctuate, but, over the last 8 years, that number has trended downward (figure 1). While certainly not conclusive, nor predictive of future fire activity, it does indicate that the annual number of fires is being reduced, at least temporarily. Figure 2 provides an examination

of how each year's total deviates from the 29-year average. In addition to the current 8-year decline, it is clear that 8 out of the last 12 years have seen a below average number of fires; however, that does not mean less destruction or fewer acres burned.

If the acres lost to wildfire are examined over the same time period, figure 3 reveals an increasing trend in the amount of total area

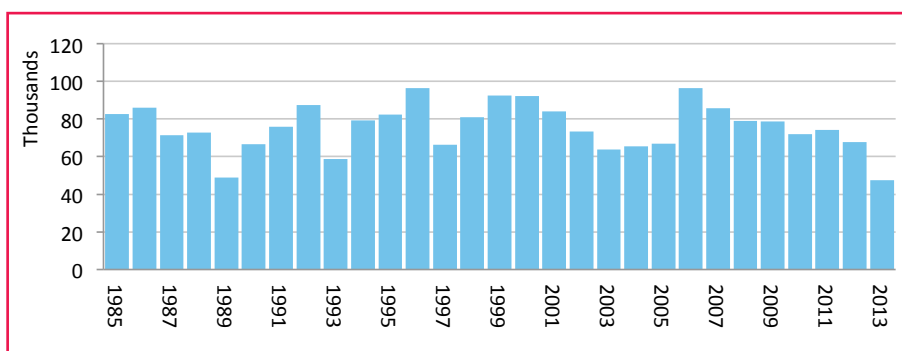


Figure 1.—Annual number of wildfires (1985–2013).
Source: CoreLogic graph of NIFC data (2014).

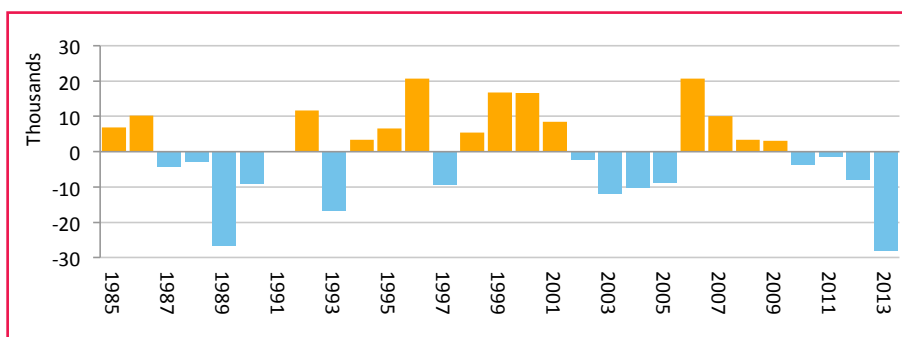


Figure 2.—Annual wildfire deviation from the mean (1985–2013).
Source: CoreLogic graph of NIFC data (2014).

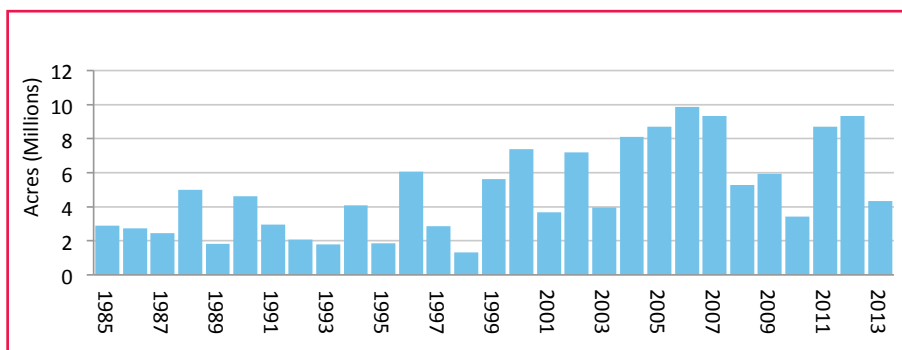


Figure 3.—Annual number of acres burned (1985–2013).
Source: CoreLogic Graph of NIFC data (2014)

that has burned each year. Again, there is significant fluctuation in the total acreage from year to year, but the overall trend is towards a larger acreage lost to wildfire over this time period. Larger fires are often an indication of more intense burns that are difficult to suppress. Figure 4, which again compares each year with the median or average acreage burned over that 29-year period, results in an obvious increase in wildfire acreage in 9 out of the last 12 years, indicating above average acreage lost to wildfire.

Based on those two factors, one might assume that larger fires may be the result of a reduction in suppression efforts. However, the amount of Federal money spent on suppression has increased quite dramatically over this time period.

Following a trend that more closely parallels the increasing acreage burned, the annual cost of suppression reached \$1 billion for the first time in 2000 and has only barely dropped below that threshold twice in the last 14 years. Suppression cost escalates along with the size of fires and represents the effort necessary to combat these large burns that have the ability to threaten extensive numbers of homes simultaneously, especially if they occur in the WUI.

What Increasing Costs Mean for the Insurance Industry and Homeowners

There are three ways to view the cost of wildfires. The first is by evaluating the cost of the response to a fire, usually in the form of the

firefighting crews and equipment that are dispatched in an attempt to extinguish or suppress the progression of an active fire. Suppression cost has increased substantially in the last 30 years and is often charged to multiple government agencies at the Federal, State, and local levels. Barring any radical regulatory action, suppression costs are likely to increase as long as wildfires continue to propagate and as long as homes continue to be built in the WUI.

The second major cost associated with wildfire is attributed to homeowner mitigation efforts that can be performed on both the land on which a home is built and on the home itself. The Firewise Communities Program has its origins in the late 1980s with both the Forest Service and U.S. Department of the Interior contributing to the National Fire Protection Association's efforts to educate homeowners on the correct procedures for remediating their homes and properties. The cost of mitigation or remediation of a single property can effectively reduce the opportunity for wildfires to inflict damage. Given the tendency for new home construction to occur on the urban edge, often in the WUI, it would only seem logical for homeowners to prepare by implementing certain changes to the buildings and landscaping on their property to help reduce the potential impact of a future fire. This preemptive implementation is sometimes the most difficult for homeowners to adopt since it increases the cost of the home and the amount of annual maintenance on the property, but it is crucial.

The mitigation of an individual property can be as simple as removing wood piles from next to the

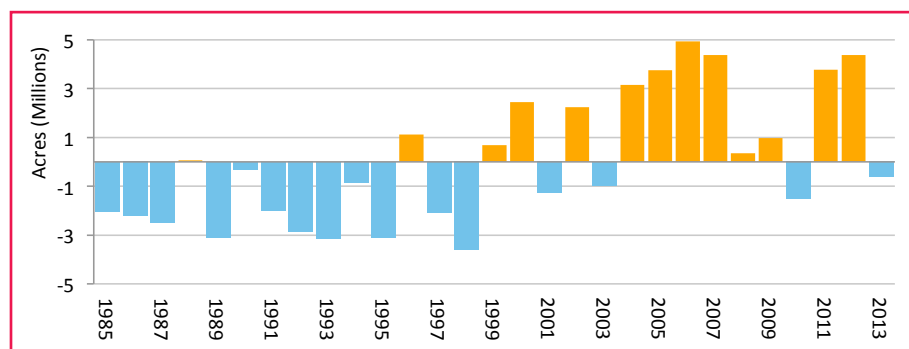


Figure 4.—Burn deviation from the mean (1985–2013).
Source: CoreLogic Graph of NIFC data (2014).

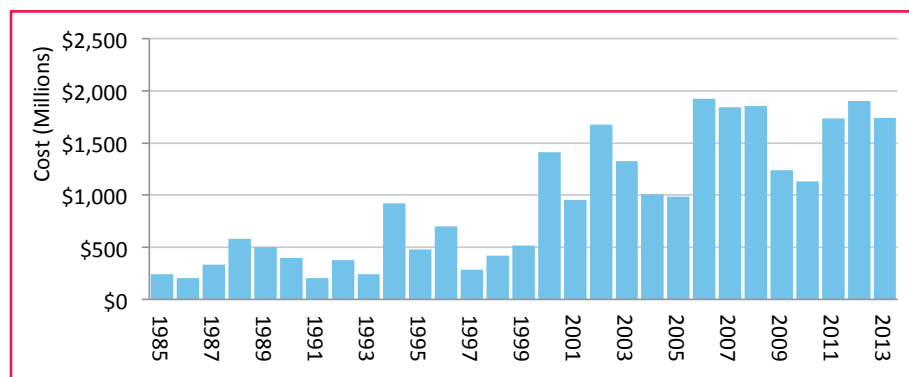


Figure 5.—Annual Federal fire suppression cost.
Source: CoreLogic Graph of NIFC data (2014)

home, clearing eaves and gutters of debris, clearing brush located near the home, and removing low-hanging limbs from trees. Additional efforts can be implemented during the construction of a new home, though they can also be costly. Architectural decisions to install tile roofs instead of wood shake or fiberglass roofing can reduce the opportunity for airborne embers to ignite roofing material. Fire retardant materials used for external siding and decking also reduce the opportunities for ignition and contribute to a more fire-resistant home. Of course, the more mitigation factors that are implemented, the less likely a wildfire will cause catastrophic damage to a property. The downside for the homeowner is that each of these processes has an associated cost, either initially during construction, or annually in the form of maintenance. It has never been more important for homeowners, however, to proactively evaluate and mitigate the wildfire risk for their properties. Complete reliance on responders only makes the responders' job more difficult, and the alternative of relying completely on the insurer does nothing to prevent a fire from damaging a home. Ultimately, the reduction in risk for each individual home will have the cumulative effect of reducing the opportunity for large fires in the WUI to migrate throughout a community and will allow responders to more effectively fight these fires.

The third cost of wildfire to consider is the actual damage done by the fire, often based on the damage or destruction of property. This cost is usually borne by insurance com-

panies and directly by homeowners through the cost of their policies. For example, the 2012 Waldo Canyon Fire in Colorado destroyed 511 homes with an estimated loss of \$453 million (NWCG et al. 2012). The 2003 Cedar Fire in California destroyed 2,232 homes with a total loss estimate of \$1.2 billion (<http://www.fire.ca.gov>). With losses like that, it is apparent that modern wildfires continue to be a costly natural hazard not to be taken lightly.

Insurance companies are actively searching for ways to evaluate the potential for wildfire damage by investigating where wildfire risk is located and whether or not it is likely to affect a specific property. Knowing the location of the risk, the location of the property, and the likelihood that wildfire could migrate onto that property is the basis for understanding not only single property risk, but also risk concentration. While it may be acceptable to write policies for a handful of properties in a neighborhood that is at an elevated risk of wildfire, historic loss events have proven that overexposure by one company in an area prone to risk may result in disproportionately high losses for a single insurer.

Wildfires are part of a natural environmental cycle and will continue to be a part of our planet's processes along with other weather-related disaster events. But the unique ability of humans to suppress and contain the flames, as well as mitigate the damage, means we have an opportunity to protect against and reduce the risk associated with wildfires at a level that doesn't exist in the case of other hazards.

Over the last 15 years, there have been 149 wildfires that have burned at least 100,000 acres or more in the United States. All wildfires, but especially those that cover a large geographic area, can pose a threat to homes. Yet, we can reduce the susceptibility of property if landowners understand the risk and adopt mitigation strategies to better prepare for wildfire activity. Given the propensity for newly constructed homes to be located on the edge of urban areas and often in close proximity to areas designated higher wildfire risk, it is imperative for homeowners, insurers, emergency responders, and many others to realize the true threat these fires pose. Using that knowledge as the basis for remediation and mitigation will reduce the risk for an individual landowner and, if performed in combination with other residents in a community, can reduce the overall risk to everyone in the area. As a result, the cost of wildfire, whether borne by the agencies funding suppression or insurance companies, will decrease.

* All statistical information not cited was extracted from the National Interagency Fire Center (2014).

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FUNNY RIVER FIRE

Diana Campbell

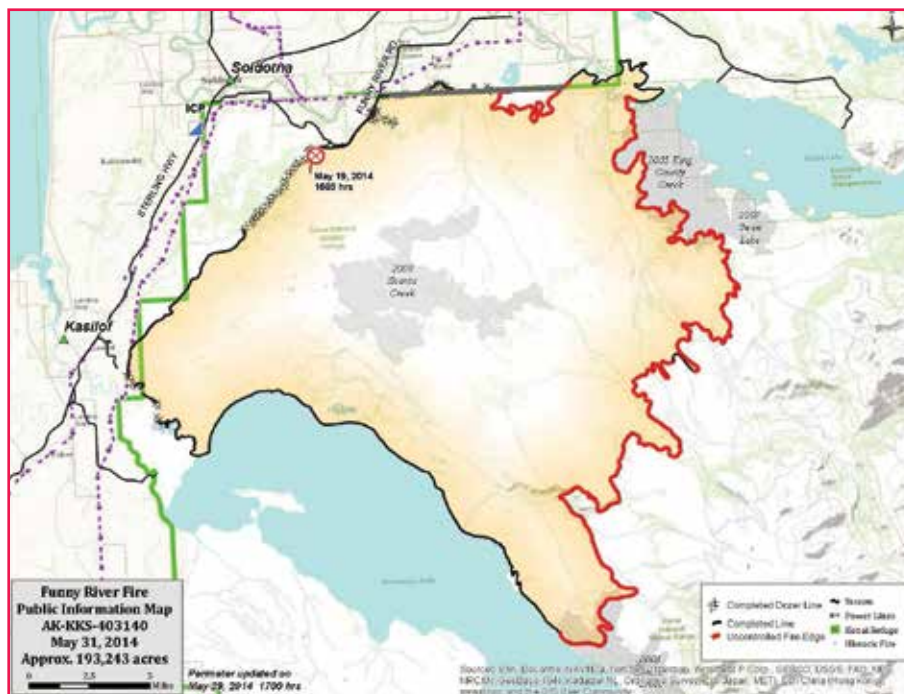
In the fire-fuel-heavy forests of the Kenai Peninsula, Alaska, homesteaders followed their dreams of living off the land and staked claims in the early 1960s. Now descendants of the original pioneers live with their forebears and retirees who've joined the community.

Fire danger stayed with them. "We're in an isolated area with only one road out," said Melody Newberry, a local homeowner. "There have been fires, and they've come about every 50 years. Knowing that it's a cycle, we've got the land around the house cleared. We have tractors and farm equipment available to make fire breaks."

And, the fires came. On May 19, 2014, during unusually dry weather, a fire started in a popular recreational area near Funny River Road in the Kenai, near Newberry's home. The wind pushed it through dry grasses and into insect-killed stands of spruce. By the end of the day, fire had consumed 2,500 acres (1,000 ha). Four days later, the Funny River Fire, as it was now being called, became the Nation's highest fire priority. By day 6, officials gave evacuation orders to about 1,000 households in the area. The fire was now at 158,585 acres (64, 200 ha).

More than 750 people, including Type II teams, came to fight the fire. The Alaska Division of Forestry also called for a new tool to help fight the fire. The division asked

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Funny River Fire Perimeter

the Alaska Center for Unmanned Aircraft Systems Integration (ACUASI), part of the Geophysical Institute at the University of Alaska Fairbanks, to bring the ScanEagle to help monitor fire activity. The ScanEagle, manufactured by Insitu, can fly for more than 20 hours, can be fitted for multiple payloads of up to 7 pounds (3.2 kilos), and can cruise at between 50 and 60 knots. It is 5.1 feet (1.6 m) long with a wingspan of 10.2 feet (3.1 m) and can fly at altitudes of up to 22,000 feet (6,700 m).

The ScanEagle, which is launched via catapult and brought back to land with a catch wire, was used at the Funny River Fire to identify threats to people and structures, as well as to identify hot spots and fire boundaries from an altitude of

1,200 to 2,500 feet (366 m to 762 m). Infrared sensors were used to see through dense smoke.

The Funny River Fire mission had benefits and challenges. A big advantage was that the ScanEagle could fly at night, when manned aircraft were grounded, to look for hotspots and map the fire. Unmanned aircraft are usually less expensive to operate than manned aircraft, but the trip to Funny River from Fairbanks would be a nearly 500-mile drive across Alaska.

Other challenges included finding a suitable launch location and coordinating with the Federal Aviation Administration, the Alaska Division of Forestry, the U.S. Department of the Interior, and other fire and emergency government agencies.

The real issue facing any unmanned aircraft use is how to integrate the system into an already established and tightly run operation, such as wildfire response. In the end, none of the challenges really mattered, because people are beginning to see how unmanned aircraft could be a benefit in so many public and private uses.

“We see it as the wave of the future,” said Ty Miller, air support group supervisor for a Type II Division of Forestry team. “The possibilities are only limited by your mind.”

After meeting various governmental requirements and finding a suitable launch location on Melvin Tachik’s 160-acre homestead, the ACUASI team finally flew the ScanEagle over the fire 10 days after it started. By then, the fire boundaries had grown to 160,000 acres (64,700 ha).

The aircraft’s imagers found 15 hot spots within the fire perimeter that first night.

“It was invaluable because it can fly at night to look for hot spots in cooler evening hours,” said Celeste Prescott, public information officer



Day of Deployment from Fairbanks

with Alaska Interagency Incident Management. “The only other aircraft that could do that, which would be manned, would have to come from the Lower 48.”

The ScanEagle was also able to map the fire boundaries more accurately because it can fly at a lower altitude than manned aircraft, Prescott said.

“We are happy with our first flight’s results, which identified some hot spots in locations the incident command asked us to check,” said Marty Rogers, ACUASI director and Funny River Fire unmanned aircraft system (UAS) mission director. “After making improvements to our

antenna, we will be able to observe a larger set of objectives during future flights.”

Rogers called in Matt Parker, of the Oregon-based Precision Integration Programs, to lead the flight team. A UAS team consists of a pilot-in-command, an operator, observers, and support staff. Parker is considered a ScanEagle expert, but had never flown one in a wildfire.

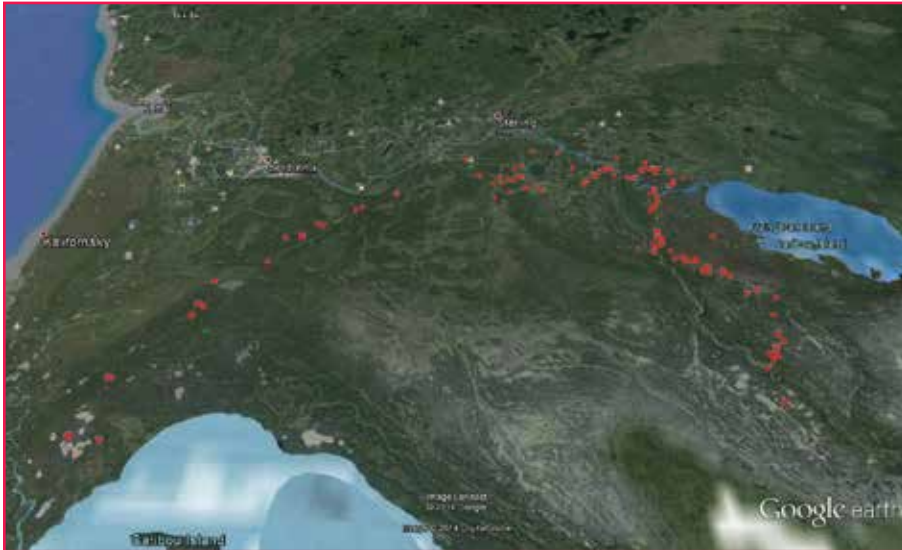
“There are no con ops [concept of operations] for that,” Parker said. “You can’t pull something up and say this is how you use an unmanned aircraft on a fire.”

Altogether, the ACUASI team launched five flights, all at night. After the flights, the team gave fire officials the night’s findings in time for morning briefings. It soon became apparent that better images were needed, but that issue could only be solved by using updated equipment. Also, the images had to fit into fire management’s system and software.

“The university needed to have the opportunity to see what kind of data we needed,” said Miller. “It wasn’t the quality we needed, but the drone worked well; it flew



ScanEagle on a 160 acre field



Over 75 Hot-Spots mapped

in the winds and rain. The smoke didn't bother it and it's fairly portable."

"Finding out those issues is important to ACUASI," said Ro Bailey, ACUASI deputy director. In late 2013, the Federal Aviation Administration (FAA) granted University of Alaska, Fairbanks (UAF)/ACUASI test site status, one of six in the United States. The test site, called the Pan-Pacific Unmanned Aircraft Systems Test Range Complex (PPUTRC), will help FAA bring unmanned aerial vehicles into public use. PPUTRC has 58 partners, with key partnerships among Alaska, Oregon, and Hawaii. The test site will collect data needed for the FAA to establish public use regulations for both unmanned aircraft and operators.

The Funny River fire was a good case model, Bailey said. "I expect that a significant benefit from this real-world mission will be the procedures developed by FAA for air traffic control and the data gathered on how well those procedures work to protect aviation safety while enhancing the safety and effectiveness of the firefighting operations."

The Funny River Fire was not the first time ACUASI has been called upon to work on wildfire issues. In late 2012, the University of Alaska Unmanned Aircraft Program, as ACUASI was then known, was part of the United States' largest and most complex prescribed burn research project in over 40 years. The unmanned aircraft team was part of 90 scientists who made up the Combustion and Atmospheric Dynamics Research Experiment, or Rx-CADRE, led by the Forest Service. In the research project, scientists performed a prescribed burn on more than 3,000 acres (1,200 ha) of forest and grasslands located on Eglin Air Force Base in Florida in order to better understand how wildfires behave.

UAF's aircraft — the Aeryon Scout, a mini quadcopter, and the ScanEagle — collected information related to smoke transport, air quality, flame dynamics, and fire progression using long-wave infrared imagers, visible cameras, and an aerosol mass concentration and black carbon sensor.

"In the exercise debrief, UAF's support was assessed as critical to the overall success of this high-

priority research mission," said Greg Walker, then of the University of Alaska's Unmanned Aircraft Program. "This was the largest and most complex mission related to wildfires carried out in the United States since the 1960s."

A major logistical challenge of the campaign proved successful when up to six airborne platforms were deployed at once, including fixed-wing aircraft, unmanned aircraft, and a gas-filled aerostat that all operated at various altitudes within the same airspace, Walker said.

The operations gave the team a chance to substantially advance the use of unmanned aircraft systems in scientific research. The Rx-CADRE team recorded the fire's behavior, meteorology, smoke particulates, and other fire phenomena. All the information was combined into an integrated database that is used worldwide for controlled burns, said Roger Ottmar, who managed the Rx-CADRE team.

In 2009, UAF's unmanned aircraft group was called to the Crazy Mountain Complex fires in Alaska. The university team partnered with the FAA; the U.S. Department of Interior, Bureau of Land Management; and the Alaska Fire Service. Lightning strikes caused the fires, requiring 311 employees to work the blazes that burned more than 440,000 acres (180,000 ha), over 100 miles (160 km) north of Fairbanks, AK, according to the Alaska Interagency Coordination Center.

A couple of ScanEagles were equipped with infrared cameras for mapping operations. The aircraft collected data that allowed fire personnel to track the progression of fires and current hot spots.

This work had proven difficult with manned aircraft. Dense and widespread smoke had grounded or severely limited logistical support from the air.

With the infrared sensors aboard the unmanned aircraft, operators identified where the edge of the fire was, noted Bailey. This information was used to improve fire map accuracy. The infrared cameras performed exceptionally well. The equipment has the ability to peer through dense smoke as the unmanned aircraft fly above active fires. The call-out made the University of Alaska the first entity, other than National Aeronautics and Space Administration or the U.S. Department of Defense, to receive an FAA emergency certificate of authority to fly in civil airspace with an unmanned aircraft beyond line of sight. “This was a chance for us to take what we’re doing in research and give it back to the community,” Bailey said. “We’ve learned valuable things as we’re going along, too, so this was a great opportunity for everyone involved.”



ScanEagle Antenna @ 50ft

Back at the Funny River Fire, Melody Newberry and her family also learned a lot about this new high-tech system. The ACUASI mission was based in Melvin Tachik’s horse pasture. Tachik is Newberry’s father, and her parents live on one

side of the pasture, while her family lives on the other. The family spent many hours visiting with the unmanned aircraft team.

“It gave you a sense of security,” Newberry said. “Not only to know that pilots weren’t at risk, but we were getting more information to protect ourselves.”

Newberry’s mother, Faye Tachik, enjoyed the company. She and her husband were newlyweds in 1961 when they moved to the area to claim their homestead. Melvin Tachik built an airplane landing strip that for a time was the only one in the area, providing a place for the first planes to land. The ScanEagle became Funny River airstrip’s first unmanned aircraft.

“This ScanEagle was a new way to be a pioneer,” Faye Tachik said. ■

The Funny River Fire in the Kenai National Wildlife Refuge burned a total of about 194,000 acres and cost nearly \$6.1 million.

UTAH'S CATASTROPHIC WILDFIRE REDUCTION STRATEGY

Nathan Barrons

During the summer of 2012, the State of Utah faced a particularly active wildland fire season. Fires throughout the State caused considerable damage to resources, infrastructure, and personal property. Following this severe fire season, Governor Gary Herbert charged State land managers with the task of developing a cooperative strategy to reduce the size, intensity, and frequency of catastrophic wildfires in Utah.

Following the Governor's decree, a Catastrophic Wildfire Reduction Strategy Steering Committee was convened. The committee functions under the authority of the Utah Conservation Commission and is chaired by the Division of Forestry, Fire and State Lands. The steering committee brings coordination of local, State, and Federal governments and natural resource agencies, along with private-sector stakeholders, to a joint and unified effort. The committee recommended that a significant additional investment be made by the State and affected stakeholders for mitigation and prevention activities to reduce the threat of catastrophic wildfires.

Subsequently, the Utah legislature authorized funding the Catastrophic Wildfire Reduction Strategy with approximately \$2 million of State funds. This fund-

The significance of the allotment cannot be overstated; it represents the first time that State funds have been dedicated to wildfire issues not directly related to suppression costs.

ing allotment represents the first time State funds have been dedicated to wildfire issues not directly related to suppression costs. The statewide steering committee established a work group for each of the six regional areas of the Division

of Forestry, Fire and State Lands. Each work group consists of local stakeholders representing private, State, and Federal interests. Efforts are now underway to stand up a Web-based risk assessment portal based on data provided by the West Wide Assessment. The goal is to furnish an additional science-based tool that the regional workgroups can use to assess risk and prioritize actions in their respective regions. Once decisions have been made at the regional level, the proposed actions will be passed to the steering committee for statewide prioritization.

This prioritization process, directed from the regional level, is an integral component of the Catastrophic Wildfire Reduction Strategy. The



State fuels crew at work in Argyle Canyon, UT.

Nate Barrons is the Catastrophic Wildfire Reduction Strategy coordinator for the Utah Division of Forestry, Fire and State Lands

risk assessment and prioritization allows agencies and land managers to focus and distribute funds as efficiently as possible. The process also provides a scientific platform on which to base justification for specific expenditures. An additional goal of the risk assessment process/prioritization is to identify gaps that exist in relation to the National Cohesive Wildland Fire Management Strategy (Cohesive Strategy). One example is evaluating Utah's rural communities and their capacity to respond to wildfire incidents.

The three interdependent goals of the Cohesive Strategy are at the heart of Utah's Catastrophic Wildfire Reduction Strategy effort.

As the program matures, the vision of State forestry managers is to sustain efforts to improve landscape resilience through fuels mitigation and prescribed fire projects, assist and educate populations with ways to prepare for and withstand fire events, and continue to provide and improve timely and effective fire suppression response.

Reducing the threat of catastrophic wildfire in Utah requires landscape-scale modification of vegetation, reintroduction of managed fire, and substantial action by and with communities. Changes of this magnitude necessitate broad social and political awareness, understanding, and support. Efforts are underway to reach out to communities

throughout the State to ensure that all understand the importance of actively participating in mitigation and response programs such as creating Community Wildfire Protection Plans.

Many of the initial projects designated for funding by the Catastrophic Wildfire Reduction Strategy were designed to augment existing State and Federal cooperator projects. For example, the Division of Forestry, Fire and State Lands' project, east of Moab in the Willow Basin area, lies directly adjacent to fuels treatments recently completed by the Manti La Sal National Forest. Additionally, a fuel break project in Sanpete County was completed using program

What Is the National Cohesive Wildland Fire Management Strategy?

In response to the Federal Land Assistance, Management and Enhancement (FLAME) Act, the U.S. Department of the Interior and the U.S. Department of Agriculture set forth to develop a strategy to improve wildfire management, protect lives and property across the country, and restore our landscapes.

The Departments designed the National Cohesive Wildland Fire Management Strategy (Cohesive Strategy) effort as a three-phased process to allow for inclusiveness and understanding of the complexities of managing wildfire risks across the country. Throughout the entire effort, environments were created to foster and sustain stakeholder engagement and increase col-

laboration between Federal, State, and local governments and partner organizations. The Departments used the best available science to develop a National Cohesive Strategy that will help guide the future of wildland fire management.

Cohesive Strategy Vision:

To safely and effectively extinguish fire when needed; use fire where allowable; manage our natural resources; and as a Nation, to live with wildland fire.

Cohesive Strategy Goals:

1. Resilient Landscapes
2. Fire-Adapted Communities
3. Safe and Effective Wildfire Response

The National Strategy: The Final Phase in the Development of the National Cohesive Wildland Fire Management Strategy was released in April 2014 by the Secretaries of the U.S. Department of Agriculture and the U.S. Department of the Interior. The national strategy explores four broad challenges:

1. Managing vegetation and fuels;
2. Protecting homes, communities, and other values at risk;
3. Managing human-caused ignitions; and
4. Effectively and efficiently responding to wildfire.

To learn more about the Cohesive Strategy, visit <<http://www.forestandrangelands.gov/strategy>>.



Mt. Dell/ Boy Scouts of America fuel break, Sanpete County, UT.

funds and is the culmination of a nearly 5-year effort involving the Boy Scouts of America, numerous home owners associations, and the State of Utah.

Utah land management stakeholders understand that it is necessary to take a holistic approach to the challenges of wildfire within the State. Without public participation

and approval, it will be impossible to create meaningful lasting changes. Without broad cooperation among stakeholders, both public and private, resilient landscapes cannot be restored or maintained.

Perhaps most importantly, with sustained funding, the time and efforts of dedicated professionals can be focused on these pressing issues. Governor Herbert has explicitly expressed his desire to limit the exposure of the people of Utah to the cost and effects of catastrophic wildfire. The State legislature has authorized an initial expenditure of taxpayer funds. Land managers are now in the process of implementing a holistic approach to dealing with the challenges faced by the State at the heart of the Intermountain West's fire adapted environment. ■

THE QUADRENNIAL FIRE REVIEW— A TOOL FOR THE FUTURE

Sandra L. Burnett and Russell Johnson

History

The source idea for the Quadrennial Defense Review (QFR) was the U.S. Department of Defense's Quadrennial Defense Review (QDR) model. For several decades, the QDR model has served as a vehicle for the U.S. military to reexamine shifts in military strategy and changes in organization tactics and capabilities. Similarly, the intention of the QFR is to evaluate current wildland fire management strategies and capabilities against best estimates of the long-term (10 to 20 year) future environment. The first QFR was prepared in 2005, with a subsequent strategic assessment process conducted every 4 years thereafter. Recently, the final report for the third iteration of the QFR was released.

The 2014 QFR

The QFR is not a formal policy or decision document, but rather a strategic evaluation of the potential future circumstances and long-range direction of wildland fire management. It is designed to look far into the future to explore potential risks, challenges, and opportunities that may affect the wildland fire community's ability to meet its mission. Moreover, it will inform strategic planning, investments, operational capabilities, and

positioning to help ensure the community can achieve its goals over the next 20 years.

The QFR links closely with, and is complementary to, the wildland fire community's multiphase National Cohesive Wildland Fire Management Strategy (Cohesive Strategy) process. The 2005 and 2009 QFRs helped set the stage for the three goals outlined in the Cohesive Strategy, which assesses the current situation and outlines actions to improve near-term effectiveness. The QFR extends the community's vision by exploring a range of alternative futures for wildland fire management, offers an analytical underpinning to inform the next revision of the Cohesive Strategy, and encourages present-day preparation for emerging change.

As asserted in the Cohesive Strategy, fire plays a necessary, important, and natural role on the landscape. While, risk to communities and other high-value resources must be mitigated, decades of fire exclusion have impeded the ecological benefits that result from fire in many areas. Fire exclusion has allowed the accumulation of unnaturally high levels of fuel on the landscape, which can contribute to fires of similarly unnatural severity. While fires that will benefit the landscape should be allowed where practicable, unnaturally severe fire can negatively affect natural processes and create increased

risk for firefighters, the public, and other values, particularly when fire occurs near communities that are not fire adapted.

The wildland fire management community has been extremely successful over the past several decades in suppressing approximately 97-98 percent of unwanted fires in the initial attack phase. Many of the remaining fires that escape initial attack, however, have become increasingly extreme. The QFRs have identified contributing factors for more severe fire (and commensurately higher fire risk) in the future as:

- Continued accumulation of fuels in forests and grasslands.
- Continued growth of the wildland-urban interface with insufficient planning and zoning to ensure a fire-adapted landscape.
- Continued drought in the American West, expanding to other areas of the country.
- A general increase in temperatures across the United States.

Based on current trajectories, it is reasonable to conclude that these risk factors will continue to get worse over the next 20 years, leading to more destructive wildland fires than the American public is prepared to handle.

Paradoxically, a key finding of the 2014 QFR report is that the path to avoiding the worst possible impacts of wildland fire is for the general

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public and governments at all levels to become more comfortable with prescribed fire and wildfire—based in part on improved outreach and public understanding of the ecological role of fire. This finding and associated actions for consideration are addressed in detail in the report.

The wildland fire management community faces other critical risk factors such as the impact of smoke on the public, water resource scarcity in the West, continued threats from human-caused fires, climatic factors, and other potential future threats. Wildland fire may also

emerge over the next 10 to 20 years as an issue of concern in areas where it has not been for decades, for example, in areas like the Southeast, if prescribed burning is used less, or in the upper Midwest due to climate change.

Conclusion

Addressing these issues will require the community to adjust its message to stakeholders and its means of reaching them. The wildland fire community needs to develop new approaches to measure risk and gauge the impact of fire management actions and to take advantage of emerging technologies. At the

same time, the community must also sustain and enhance core programs at levels that enable continued success at historical levels. These actions will be crucial to both implementing the key goals outlined in the Cohesive Strategy and the actions for consideration in the QFR, while operating under fiscal constraints and pressure to tie future funding to measurable return on investment.

To read the 2014 Quadrennial Fire Review report, please visit <<http://www.forestsandrangelands.gov/QFR/index.shtml>>. ■

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