



FIRE, FUEL, AND SMOKE SCIENCE PROGRAM
2013 RESEARCH ACCOMPLISHMENTS
MISSOULA FIRE SCIENCES LABORATORY
ROCKY MOUNTAIN RESEARCH STATION
U.S. FOREST SERVICE

Faith Ann Heinsch,
Robin J. Innes,
Colin C. Hardy, and
Kristine M. Lee,
Editors





FIRE, FUEL, AND SMOKE SCIENCE PROGRAM
Missoula Fire Sciences Laboratory
Rocky Mountain Research Station
U.S. Forest Service
5775 US Highway 10 West
Missoula, MT 59808-9361
<http://www.firelab.org>

Citation: Heinsch, Faith Ann; Innes, Robin J.; Hardy, Colin C.; Lee, Kristine M., editors. 2014. Fire, Fuel, and Smoke Science Program 2013 Research Accomplishments. On file at: Missoula, MT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Missoula Fire Sciences Laboratory. 70 p.

Cover photos: Top photo: Schoolhouse Fire. Photo courtesy of Duncan Lutes / FFS. Left bottom photo: Burn chamber with fire whirl. Photo courtesy of Richard Barnes / OTTO. Right bottom photo: Prescribed fire. Photo courtesy of Richard Barnes / OTTO. Photo on opposite page: Flame structure of a fire whirl. Photo courtesy of Richard Barnes / OTTO.

FIRE, FUEL, AND SMOKE SCIENCE PROGRAM
2013 RESEARCH ACCOMPLISHMENTS
MISSOULA FIRE SCIENCES LABORATORY
ROCKY MOUNTAIN RESEARCH STATION
U.S. FOREST SERVICE

Faith Ann Heinsch, Robin Innes, Colin C. Hardy,
and Kristine M. Lee, Editors

TABLE OF CONTENTS

The Fire, Fuel, and Smoke Science Program	2
2013 Year in Review: Innovative Approaches in Wildland Fire	6
Partnerships.....	10
From the Archives: Fire Management Planning	11
Physical Fire Processes	13
Fuel Particle Heat Exchange.....	14
Understanding Burning Rate and Residence Time Using Wood Cribs.....	16
Pyrolysis Composition and Convective Ignition of Live Forest Fuels.....	17
Flame Structure in Spreading Laboratory Fires	18
Ignition Potential of Rifle Bullets	19
Near Surface Wind Measurements.....	20
RxCADRE—A Collaborative Research Campaign.....	21
Fuel Dynamics	24
A Comparison of Sampling Techniques to Estimate Wildland Surface Fuel Loading in Montane Forests of the Northern Rocky Mountains.....	25
Analyzing the ‘Spring Dip’ in Foliar Moisture Content and Its Relationship to Crown Fire Activity in the Great Lakes.....	26
Linking Satellite Mapping of Beetle Attacks to Fuel Changes in the Northern Rockies	27
Smoke Emissions and Dispersion	28
Experiments to Improve Agricultural Smoke Decision Support Tools	29
Fire Ecology	30
Central Oregon Fire and Forest Histories	31
Climate Change Impacts on Fire Regimes	32
Fire and Fuel Management Strategies	34
Mapping Wildland Fire Potential.....	35
New Tools for Mapping and Understanding Fire Severity	36
A Spatial Database of U.S. Wildfires	38
Western Spruce Budworm Alters Crown Fire Behavior through Reduced Canopy Density	39
New Firefighter Safety Zone Guidelines.....	40

Table of Contents

Science Synthesis and Delivery	42
FireFamilyPlus 4.1	43
Release of New Version of WindNinja and Upgrade to Include Momentum Solver	44
FEAT-FIREMON Integrated.....	45
Fire Danger Characteristics Charts.....	46
Fire Effects Information System Updates	47
Quantifying Wildfire Risk to Structures in the Island Park Sustainable Fire Community	48
Fire Management in Nepal	49
Modeling Fire Danger for Sandia National Laboratories.....	51
The Research Continues.....	52
Describing and Scaling Physio-chemical Properties of Live and Dead Fuels to Parameterize Physics-based Fire Behavior Models.....	53
Surface Fuel Characteristics, Temporal Dynamics, and Fire Behavior of Masticated Mixed-Conifer Fuel Beds of the Southeast and Rocky Mountains.....	54
Coupled Fire-Atmosphere Behavior in Complex Topography: Identification of Critical Phenomena of Past Fire Events.....	55
Development and Validation of Combustion Process-based Emission Models	56
New Initiatives of the RMRS Smoke Emissions and Dispersion Team.....	57
Evaluating Assumptions Related to Thermal Infrared Remote Sensing of Fire	58
Development of a Code Block Framework for Fire Modeling Systems	59
Fuel Treatment Plan for Fort Huachuca, Arizona.....	60
Education and Outreach.....	61
2013 Publications	64



Photo: Burn chamber at the Missoula Fire Sciences Laboratory, showing the fire whirl generator. The burn chamber is 40 feet wide, 40 feet long, and 70 feet tall. Made of metal and concrete, it provides a climate-controlled laboratory for research. Photo courtesy of Richard Barnes / OTTO.

THE FIRE, FUEL, AND SMOKE SCIENCE PROGRAM

The Fire, Fuel, and Smoke Science Program (FFS) of the U.S. Forest Service, Rocky Mountain Research Station, focuses on fundamental and applied research in wildland fire, from fire physics and fire ecology to fuels management and smoke emissions. Located at the Missoula Fire Sciences Laboratory in Montana, the scientists, engineers, technicians, and support staff in FFS conduct national and international, cutting-edge work in wildland fire research and develop research and management tools and applications designed to improve understanding of wildland fire as well as safe and effective fire, fuel, and smoke management. The research is divided among six general focus areas of study.



Photo: FFS Research Forester Mark Finney, FFS Research Physical Scientist Jack Cohen, and Forestry Intern Andrew Gorris view an experimental fire in the Missoula Fire Sciences Laboratory's wind tunnel. Temperature, relative humidity, and wind speed can be controlled in the wind tunnel, allowing for fires under defined conditions. Photo courtesy of Richard Barnes / OTTO.

The Fire, Fuel, and Smoke Science Program

Physical Fire Processes



Laboratory studies and theoretical physical modeling, informed and validated by field observations, are used to examine physical fire processes. This research is designed to improve understanding of the fundamental, multi-scale, physical processes that govern fire behavior, including

combustion processes, heat and energy transfer, atmospheric dynamics, and transitions from one type of fire behavior to another. Scientists analyze the combustion process and the factors that determine fire behavior with the goal of developing a comprehensive physics-based fire modeling system that includes the full range of combustion environments and fire events observed in wildland fuels. New physics-based understanding will be incorporated into models suitable for use by fire and fuels managers both for characterizing fire danger and predicting fire behavior. Scientists need to model fire behavior for a wide range of purposes including site-specific vegetation simulation, global carbon accounting, and predicting loss of life or property.

Fuel Dynamics

Research on fuel dynamics helps land managers describe the vegetation that burns during wildland and prescribed fires. FFS scientists investigate and design consistent, accurate, and comprehensive methods for quantifying wildland fuels, which vary spatially, differ in size, and change with time. Through laboratory and field studies, FFS scientists are developing tools to predict seasonal and multi-year changes in fuels that allow managers to more accurately predict fire behavior and fire effects. Improved data for fire behavior modeling and fuel hazard assessment and improved fuel dynamics algorithms for temporal models of fire behavior, fire danger, and fire effects are critical additions for the next generation of fire models.



Smoke Emissions and Dispersion

Officials charged with supporting public health and safety need better tools to estimate effects of wildfire on smoke emission levels, visibility standards, and carbon budget applications as well as to anticipate the movement of smoke across the country and around the globe. FFS researchers are developing and testing methods

Left photo: Passive crown fire, or torching, and smoke production from the 2013 Beaver Creek Fire in Hailey, Idaho. Photo courtesy of Faith Ann Heinsch / FFS, Right photo: Fuel sampling on the Helena National Forest for FEAT-FIREMON Integrated. Photo courtesy of LaWen Hollingsworth / FFS.

The Fire, Fuel, and Smoke Science Program

for implementing a real-time emissions inventory and dispersion models for smoke emissions from wildland fires. Researchers are integrating field observations, satellite data, and smoke chemistry with models of emissions, smoke composition, and movement either within a fire plume or through layers of the atmosphere to improve understanding and prediction of smoke emissions and dispersion. This work applies to issues relating to National Ambient Air Quality Standards under the Clean Air Act, regional haze issues, and continental and global climate change questions.

Fire Ecology

To predict post-fire succession, managers require better understanding of interactions between fire-adaptive traits of plant species and fire severity. They also need improved understanding of treatments, such as prescribed fire with and without harvest, mechanical treatment, and/or herbicide application, and resulting effects on fundamental ecosystem characteristics, such as nutrient cycling, carbon storage, long-term fuel dynamics, and weed invasion. Understanding how treatments interact is important as well. Field and laboratory studies address how fires and, more specifically, the associated heat transfer, fuel consumption, and fire duration,



Photo: Prescribed fire on the Helena National Forest. Photo courtesy of LaWen Hollingsworth / FFS.

The Fire, Fuel, and Smoke Science Program

affect plants and plant communities, how fires alter the flow of carbon and nutrients in ecosystems, and how fire influences native and nonnative species. Research results contribute to improved conservation, appropriate ecological use of fire, improved management strategies for ecosystem restoration and maintenance, and better, more defensible fuel management treatments.

Fire and Fuel Management Strategies

To improve predictive ability for future fire regimes, FFS scientists and their research partners simulate landscape-level interactions among changing climate, fire regimes, and vegetation under different management scenarios. To better understand the drivers of historical fire regimes, they conduct fire history research. To improve the predictability of fire's impacts on the biota, the atmosphere, and human health and safety, they use case studies, ecological research, and models based on physical fire processes and fuel dynamics research. FFS research improves fire and fuel management policies and practices, resulting in increased forest resilience, maintenance of forest cover, increased carbon capture and storage, and better understanding of the complex interactions between climate change and fire regimes. Moreover, improved fire danger rating and fire behavior prediction systems support sound fire and fuel management decision making.

Science Synthesis and Delivery

Scientific publications form the foundation of science delivery. Synthesis of past research builds on this foundation. FFS is committed to delivering new science knowledge in forms usable by scientists and resource managers alike. While FFS

synthesis and delivery efforts are anchored in refereed scientific publications, science delivery includes the entire range of communications media to help land managers apply new and existing research, including computer programs, photo guides, and mentoring. Additional products include presentations, classes, field tours, and training materials. To develop and test products, FFS personnel collaborate with users and other stakeholders to design new ways to exchange information and bring science into application. FFS personnel provide educational programs for children and young adults. They also maintain <http://www.firelab.org>, where information about FFS publications and products is available. The Program's Fire Modeling Institute (FMI, page 61) is an essential component of this focus area.



Photos: Clark's nutcracker and fireweed are two fire-adapted species described in the Fire Effects Information System (FEIS, page 47). Photos courtesy of Nadine Hergenrider (Clark's nutcracker, top photo) and Terry Spivey, U.S. Forest Service, Bugwood.org (fireweed, bottom photo).

2013 YEAR IN REVIEW: INNOVATIVE APPROACHES IN WILDLAND FIRE

The mission of our Fire, Fuel, and Smoke Science Program (FFS) is to improve the safety and effectiveness of fire management through the creation and dissemination of basic fire science knowledge. Our core scientific functions and accomplishments are led by individuals assigned to positions classified by the U.S. Office of Personnel Management (OPM) as “scientists.” Research executed by scientists is defined by OPM as “systematic, critical, intensive investigation directed toward discovering, disseminating, and applying new or expanded knowledge in a professional discipline.” These scientists are evaluated on their impacts and stature under a protocol called the Research Grade Evaluation Guide, which, within U.S. Forest Service Research and Development (R&D), recognizes six types of research accomplishments: 1) knowledge discovery, 2) knowledge development, 3) knowledge synthesis and assessment, 4) modeling and systems integration, 5) special assignments, and 6) leadership. No scientist is expected to have one of each type of accomplishment; in fact, most scientists will have accomplishments within only two or three types. Within FFS, we strive for an overall portfolio of R&D that addresses and balances the six types of research.

To accomplish our work, our Program’s 10 scientists organize teams from among our 3-4 post-doctoral scientists, 20 professionals, 12+ term-appointment support personnel, as many as 25 students and temporaries, and numerous resident contractors and cooperators, as well as scores of external partners and institutions. These teams take innovative approaches to discover new knowledge and refine existing knowledge to better understand the role, behavior, and effects of wildland fire. We’re proud to present what these teams have accomplished in 2013.

Knowledge Discovery

FFS scientists are on the forefront of knowledge discovery in fire sciences. These scientists are developing new technologies and techniques to adequately measure energy transport and fire spread in both the laboratory and the field. For example, FFS scientists are examining flame residence time and burning rate of fuel structures to better understand fire spread and fire effects predictions (page 16), examining how fuel particles heat to ignition during fire spread (page 14), and evaluating flame dynamics that allow forward spread of fires (page 18). These expansions of fundamental knowledge help researchers develop more accurate models to anticipate fire behavior in diverse conditions and contribute to tools managers need to better assess risk leading to more rigorous risk-based decisions.

Research on fuels conducted by FFS scientists continues to provide a greater understanding of the relationships of wildland fire to climate change, ecosystem resilience, and the carbon cycle. In 2013, FFS researchers provided managers with a better understanding of how insect infestations influence the behavior of wildland fires. For example, FFS researchers examined changes in predicted fire behavior with mountain pine beetle-induced fuel changes (page 27) and examined how western spruce budworm defoliation alters crown fire behavior (page 39). A better understanding of how the impacts of insect infestations might influence the behavior of wildland fires can improve firefighter safety.

An assessment of current protocols and procedures is important in assuring accurate data are incorporated into fire behavior and effects models used to plan, prioritize, design, and implement important fuel treatments that could

2013: Year in Review

save lives and property. In 2013, FFS scientists evaluated three commonly used sampling methods for estimating surface fuels and found many of these methods were inaccurate (page 25). Assessing wildland fuel is important to fire managers because, unlike weather and topography, fuels can be directly manipulated to achieve management goals such as restoring ecosystems, reducing fire spread, and reducing plant mortality.



Knowledge Development

Climate change will likely change fire patterns via changes in atmospheric patterns that affect fire weather. These changes in turn impact the structure and composition of North American forests and other ecosystems. Managers need better understanding of the complex interactions between climate, fire, and ecosystems. In 2013, two very different projects focused on better understanding of these intricate, complex relationships: one looking to the past to improve our understanding of historical fire on the landscape (page 31) and one looking to the future to project how fire and climate change will interact with ecosystems during the next 50 years (page 32).

In 2013, FFS scientists incorporated new knowledge into existing fire decision support products to improve firefighter safety. For example, current wildland firefighter safety zone guidelines are based on studies that assume flat terrain, radiant heating, finite flame width, constant flame temperature, and high flame emissivity. However, firefighter entrapments and injuries occur across a broad range of vegetation, terrain, and atmospheric conditions. FFS researchers are developing new firefighter safety zone guidelines that include better understanding of how humans are injured by heat and smoke (page 40). These kinds of research projects build on the foundation of existing research and address the rapidly changing needs of wildland fire management.

Photo: FFS collaborator Kyle Shannon adjusts the gas flow to the "Flame Wall," which allows FFS researchers to study flame structure.. Photo courtesy of Richard Barnes / OTTO.

2013: Year in Review

Knowledge Synthesis and Assessment

Knowledge synthesis and assessment is an important aspect of our program. In 2013, we continued to sustain our focus on syntheses, which often lead to improved understanding. The Program's Fire Effects Information System (FEIS, <http://www.feis-crs.org/beta/>) published a number of new and updated products for use by land managers (page 47). Syntheses provided by FEIS and the technology transfer teams of our Fire Modeling Institute contribute to a better understanding of the complex and dynamic challenges faced by natural resources managers.

FFS scientists maintain close communication with managers in the field to identify pressing research needs and ensure that decision makers

have the information and tools they need to protect the long-term health of the nation's wildlands. This ongoing communication helps researchers transfer research results into models, computer applications, publications, and trainings that are useful to wildland managers and firefighters.

Modeling and Systems Integration

Managers need decision support products to make sound decisions during wildland fire operations. In 2013, FFS researchers developed a comprehensive set of tools and procedures to create, evaluate, and deliver fire severity maps for all phases of fire management (page 36). FFS scientists also improved models used by fire managers and other decision makers to include

more real-world representations of fire spread and behavior. In 2013, FFS scientists improved several such products, including FireFamilyPlus (page 43), WindNinja (page 44), FEAT-FIREMON Integrated (page 45), and Fire Danger Characteristics Charts (page 46). A complete list of FFS products is available at <http://www.firelab.org>.

Special Assignments and Leadership

FFS scientists participate in special assignments to further fire behavior research, identify knowledge gaps, and outline strategic directions for continued research. One area of concern has been the lack of integrated data for development and evaluation of fuels, fire behavior, smoke, and fire effects models. FFS scientists are part of the Prescribed Fire Combustion and Atmospheric Dynamics Research



Photo: FFS Program Manager Colin Hardy leads the 2005 Rapid Response deployment to the Dragon Fire Use Complex, North Rim of the Grand Canyon, one of six incidents visited as part of the Joint Fire Science Program-funded project. Photo courtesy of Dan Jimenez / FFS.

2013: Year in Review

Experiment (RxCADRE, page 21). The purpose of this research project is to develop processes and collect research data across fire-related disciplines before, during, and after the active burning periods of prescribed fires to identify interactions between fuels, fuel consumption, fire behavior, smoke management, and fire effects measurements to help develop and evaluate fire models.

The RMRS Smoke Emission and Dispersion Research Team, composed of FFS researchers, was asked to participate in a large, interagency research project organized by the Environmental Protection Agency (page 29). This project was designed to obtain the data necessary to improve air quality models used by smoke managers in the Northwest. Results from this research may assist smoke managers in protecting public health while helping to safeguard the economic livelihood of the Northwest's agricultural communities.

Fundamental research conducted by FFS scientists coupled with innovative field investigations are leading to more precise models to predict fire behavior. Because wildland managers and firefighters rely on these models, this research can directly contribute to more cost-effective management decisions and healthier wildlands, and it may even save lives and property.

Looking ahead, researchers in the Fire, Fuel, and Smoke Science Program will continue to pursue novel approaches and develop the fundamental knowledge and tools managers and others need to address modern challenges and maintain healthy ecosystems.

Colin Hardy, Program Manager,
Fire, Fuel, and Smoke Science Program



Photo: The Story Tree is a cross-section from the stump of a ponderosa pine that grew to be approximately 600 years old and survived at least 13 fires between 1523 and 1889. It was found on a mountainside north of Missoula, Montana. It is used in the FFS Conservation Education Program (page 61).

PARTNERSHIPS

Fire, Fuel, and Smoke researchers at the Missoula Fire Sciences Laboratory work collaboratively with national and international partners to improve wildland fire research that maintains healthy, productive ecosystems and reduces risk to people and property. The summaries included in this report include collaborations with other federal agencies, Tribes, state and local governments, universities, and nongovernmental organizations. In 2013, FFS investigators collaborated with diverse teams of researchers at a number of universities around the country as well as with other federal agencies including the Bureau of Land Management, Department of Defense, Environmental Protection Agency, National Aeronautics and Space Administration, and U.S. Agency for International Development. Nationally, FFS researchers collaborated with scientists from Florida to Washington to better understand a range of topics, including physical fire processes, fuel dynamics, smoke emissions, and fire ecology. For example, as members of the National Fire Decision Support Center (NFDSC; <http://www.wfmrda.nwcg.gov/nfdsc.php>), FFS researchers worked to better understand the fundamental physics of fire, while FFS researchers and other members of the Wildland



Fire Science Partnership (WFSP; <http://www.firesciencepartnership.org>) are working together to better understand the interactions of fire, weather, and fuels in the field. Partnerships such as these combine each member's strengths to produce more effective and far-reaching research and to develop and deliver new tools and scientific understanding. Developing partnerships and creating cross-disciplinary research teams are critical in addressing the growing number of increasingly complex questions related to wildland fire.

Internationally, FFS researchers have developed partnerships with colleagues from nearly every continent, including North America, South America, Africa, Europe, Asia, and Australia. International partnerships take advantage of FFS researchers' scientific expertise, technological capability, and on-the-ground experience in fire ecology, fire climatology, and fire management. Projects underway or completed in 2013 include climate change landscape fire simulation modeling in Australia and New Zealand; an evaluation of methane emissions from burning forest residues in power generation plants in Chili; a synthesis of knowledge on the use of fire in forest and woodland restoration in China, France, Portugal, Russia, and Spain; an examination of climate change and fire regimes in the Sierra de Manatlán in Mexico; a presentation on geospatial decision support tools for modeling wildland fire in Nepal; an analysis of the impact of forest, shrub, and grassland fires in northern Eurasia on regional and global climate and air quality; and development and implementation of a South African national fire danger rating system. Engagement with the international community is essential for leveraging resources, sharing techniques, and learning innovative practices.

Photo: Complex vegetation and topography in Cabin Gulch on the Helena National Forest. Photo courtesy of LaWen Hollingsworth / FFS.

FROM THE ARCHIVES: FIRE MANAGEMENT PLANNING

In 2014, the nation celebrates the 50th anniversary of the Wilderness Act. The 1964 Act called for select federal lands to be managed to “leave them unimpaired for future use and enjoyment as wilderness,” and to protect “their wilderness character.” And yet, the U.S. Forest Service policy at the time was to fight all wildland fires, even those in fire-dependent wilderness areas.

In 1970, the Missoula Fire Sciences Laboratory’s Bob Mutch and U.S. Forest

Service, Region 1 Forester Dave Aldrich developed a fire management plan to allow what Mutch later referred to as “this radical idea of letting nature do its thing.” After an extensive reconnaissance and more than a year of data collection in the White Cap drainage of the Selway-Bitterroot Wilderness, they recommended specific responses to fire, depending on location, time of year, and conditions on the ground. On August 17, 1972, U.S. Forest Service Chief John McGuire approved their plan and, the very next day,

lightning ignited the Bad Luck Creek fire. Following the plan’s prescriptions, Orville Daniels, Supervisor of the Bitterroot National Forest, allowed the fire to burn naturally. It extinguished itself after four days, covering only 7 x 7 m (24 x 24 feet).

The next summer was unusually dry and lightning ignited several more fires in the White Cap area. But Daniels stuck with the new plan, encouraging others to develop wilderness fire management plans of their own. Based in part on the success of the White Cap Fire Management Plan, in 1973 Chief McGuire announced that the Division of Fire



Photo: The day after U.S. Forest Service Chief John McGuire officially approved the plan, lightning ignited the Bad Luck Creek Fire. Following the plan’s prescriptions, the fire was observed and allowed to burn naturally. It extinguished itself after four days. The Bad Luck Fire proved to be good luck for the reintroduction of wildland fire into wilderness areas. Photo courtesy of Bob Mutch / U.S. Forest Service (retired).



Control would henceforth be known as the Division of Fire Management. This new approach would not lower “our capabilities as a top-notch fire suppression outfit,” McGuire wrote, but it would help “raise the quality of our performance” in professional fire management. And then, in 1978, the U.S. Forest Service revised its policy of

extinguishing all fires, encouraging more proactive fire management planning for all wildland fires, particularly those in wilderness areas.

For more information, contact: Diane Smith at dianemsmith@fs.fed.us

PHYSICAL FIRE PROCESSES

In the laboratory, in the field, and through computer simulations, experiments in physical fire processes are designed to improve our understanding of fire at its most basic level. Research during 2013 occurred in all three settings. In the laboratory, FFS researchers investigated convective and radiant heat transfer from fire using equipment designed at the Missoula Fire Sciences Laboratory. They burned wood particles, wood cribs, live fuels, and high-cellulose cardboard fuel beds to isolate and measure the mechanisms of heat transfer. This research is designed to improve fundamental understanding of how fuels ignite and fire spreads. A unique laboratory experiment was conducted to determine if bullets fired from commonly available modern rifles could ignite wildland vegetation – they can. In the field, a study designed to examine the effect of complex terrain on wind flows also assisted in improving the WindNinja computer model. Finally, an extensive, multi-agency collaborative campaign, RxCADRE, was conducted at Eglin Air Force Base, Florida, to generate comprehensive datasets on prescribed fire to inform a number of research activities at the Missoula Fire Sciences Laboratory and elsewhere.

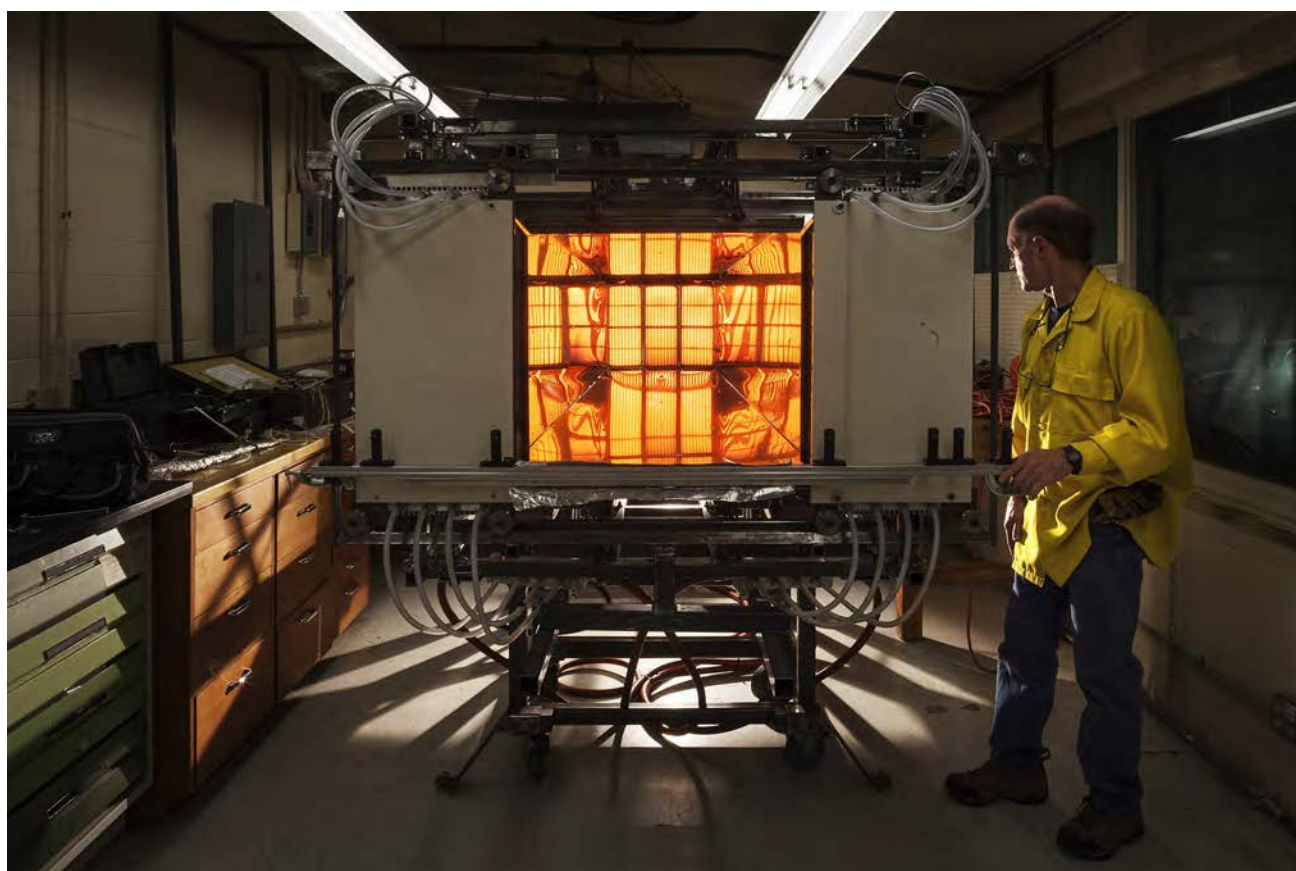
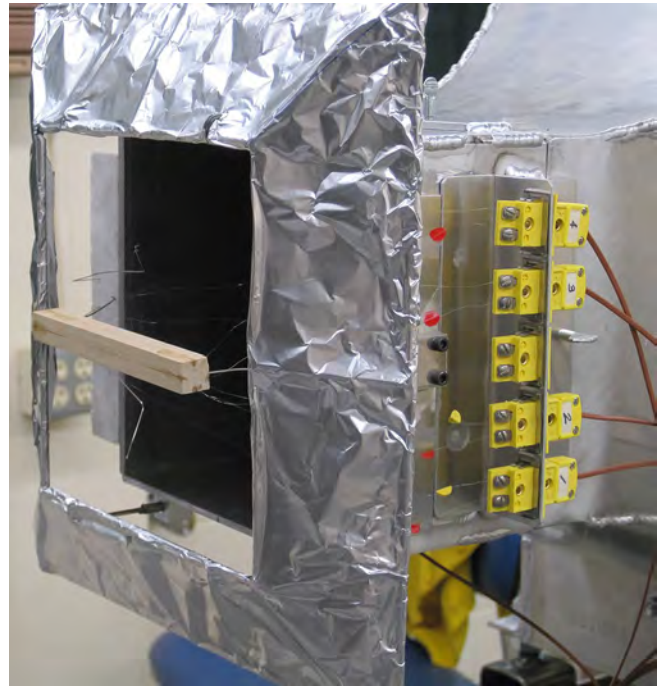


Photo: FFS Research Physical Scientist Jack Cohen demonstrates use of the glowing radiant panel. Surrounded by reflections from elliptical mirrors, the panel allows researchers to examine the effects of radiant heat on ignition rates. Photo courtesy of Richard Barnes / OTTO.

Fuel Particle Heat Exchange

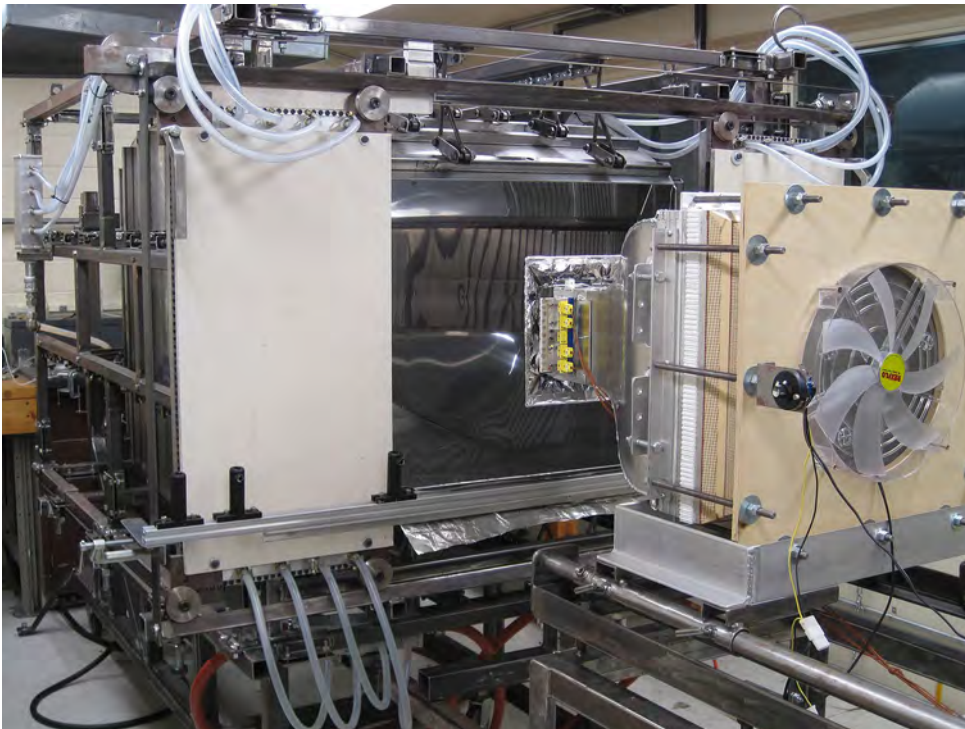
Modelers of wildland fire spread have assumed how fuel particle heat exchange occurs during fire spread without the benefit of experimental evidence. Modelers have largely assumed that radiation is the primary mechanism governing wildland fire spread. However, our observations and preliminary experiments indicate that radiation may not be sufficient to ignite fine fuels, which are primarily responsible for fire spread. The heating of fuel particles before ignition and the heat exchange at the fuel surface during fire spread have not been experimentally described. It is not exactly known how fuel particles heat to ignition during fire spread.

FFS Research Physical Scientist Jack Cohen examined fuel particle heat exchange experimentally and through the use of numerical modeling. Instrumented wood fuel particles were exposed to both radiant heating from a heat source and convective cooling from ambient air.



A specially built apparatus allowed them to control and measure this radiation and

convection. Fuel particles of various sizes were instrumented with thermocouples to measure temperature at the fuel surface, a result of the net heat exchange. The thermal boundary layer of the heated fuel particle was imaged using Schlieren and shadowgraph techniques. In addition, instrumented fuel particles were attached to laser-cut cardboard fuel beds along with measurements of the particles' radiation and convective conditions during experimental fires in the Missoula Fire Sciences Laboratory's wind tunnel.



Top photo: Thermocouple instrumented fuel particle in holder, thermocouple connectors, and reflecting shroud attached to wind tunnel. Bottom photo: The fuel particle heat exchange apparatus, including gas flame radiant panel, elliptical reflectors, shutter doors and heat exchanger, fuel particle holder and reflecting shroud, and low speed wind tunnel.

Fuel Particle Heat Exchange



Data from these experiments were analyzed using a two-dimensional numerical heat transfer model.

Experiments indicated that fuel particle size significantly affected the net heat exchange of fuel particles and thus the amount of time required for ignition. When only radiative heating on a particle's facing side was considered, coarse particles experienced a higher net rate of heating than fine particles. For example, a 12 mm (0.47 in) particle positioned horizontally and perpendicular to incoming radiation heated to ignition while a 1 mm (0.04 in) particle with the same orientation did not. This occurred because convection heat transfer was greater for the smaller 1 mm particle; the 1 mm particle sufficiently cooled from convection to prevent ignition while the 12 mm particle did not.

Fuel particles attached to the laser-cut cardboard fuel beds during experimental wind tunnel fires indicated that the primary mode of heating is convection during flame contact because there is not enough radiation for ignition. In this case, fine fuel particles ignited before coarse fuel particles. Model analysis also showed increasing convective heat transfer with decreasing fuel particle size. Thus, with radiation heating only, fine fuels convectively cool more than coarse particles and, therefore, do not ignite. These results indicate convection heating through flame contact is a primary mode of heat transfer for fire spread in fine fuels both in the laboratory and in actual fire conditions. This, in turn, indicates that wildland fire models need to describe non-steady flame characteristics that produce flame contact with adjacent fuels.

For more information, contact: Jack Cohen at jcohen@fs.fed.us

Photo: An instrumented fuel bed composed of laser-cut cardboard. These uniform fuel beds are burned in the wind tunnel to determine rate of spread and other physical characteristics of fire.

Understanding Burning Rate and Residence Time Using Wood Cribs

Flame residence time is critical to the spread of wildland fires; if it is less than the ignition time, the fire won't spread. Although even surface fires demonstrate spread thresholds, this is of particular concern when discussing the thresholds for crown fire spread, a currently poorly understood aspect of wildland fire. Curiously, no single theory exists for the prediction of flame residence time. Expressions in the literature vary from linear to quadratic dependence of flame residence time on fuel thickness. Better understanding of flame residence time and burning rate of fuel structures will allow for better fire spread and fire effects predictions.

Research Mechanical Engineer Sara McAllister studied the burning rate of fuel structures to better understand residence time using three-dimensional grids of sticks called cribs, commonly used in the fire protection engineering (structural fire) literature. Cribs were built with different stick thicknesses and densities to vary the burning rate of the source fire. Even though wildland fuels do not have the same predictable arrangement as cribs, wildland fuels are similar to cribs in that they are essentially individual fuel particles arranged with some spacing distance between them. Thus, the fundamental understanding of what governs the burning rate of a crib would apply to the wildland fire context.

Burning rates of cribs with a wide variety of layouts and geometries were explored to determine whether results from structural fire hold in the wildland context. Comparisons included the effect of stick dimension (length and width) ratios and the

effect of spacing distance between the crib and the support platform. Cribs tested with geometries similar to those tested in literature matched predicted values well. However, the burning rate of cribs built with sticks of large length-to-thickness ratios (such as long, thin sticks) was considerably lower than predicted, indicating that there is insufficient airflow inside the crib not predicted by current models. The effect of spacing distance between the crib and the support platform was strongly dependent on the stick length-to-thickness ratio, with no difference seen for cubic cribs and a >60 percent change for cribs with large stick length-to-thickness ratios. Experiments indicated that cribs with large length-to-thickness ratios required a substantial amount of airflow through the bottom of the crib. As the crib-platform spacing increased, however, the burning rate of the large length-to-thickness ratio cribs increased to more closely match the predicted values.

For more information, contact: Sara McAllister at smcallister@fs.fed.us



Photo: Change in burning regime for a large length-to-thickness ratio crib as the crib-platform spacing increases. Clockwise from top left: no spacing; 1.27 cm (0.5 in) spacing; 7.62 cm (3 in) spacing; and 2.54 cm (1 in) spacing. Photos courtesy of Sara McAllister / FFS.

Pyrolysis Composition and Convective Ignition of Live Forest Fuels

Thermal decomposition and moisture loss during ignition by rapid convective heating of live and dead plant material is not known. Wildland fires in dead fuels will not spread above some threshold of fuel moisture content, typically assumed to be between 10% and 40%. However, in crown fires, live fuels with moisture contents well above 70% are what carry fire. Unlike dead fuels, live foliage can be as much as half non-structural carbohydrates such as sugars and starches, a number that changes throughout the growing season. Although easily measured, the apparent moisture content of the fuel can change solely due to changes in dry weight, while the relative amount of water stays constant. Clearly there is a complicated and as yet unknown relationship between chemical composition and moisture content that has a significant effect on the ignition of live fuels. By better understanding convective ignition and the composition of the fuel vapors produced by the decomposition of live fuels, resource managers will be better able to predict when crown fire will occur and model its spread.



FFS Research Mechanical Engineer Sara McAllister with collaborators from the Missoula Fire Sciences Laboratory and the University of Montana built an apparatus called an “air torch” using two 6.5 kW electrical heaters to heat gas (air, nitrogen, etc.) over a range of temperatures from ambient up to 1,200 °C (2,192 °F). The flow

rate of the air torches is adjustable. In the first set of experiments, a wide range of both live and dead forest fuels were convectively heated. Fuels from across the United States, including Florida, Montana, Utah, and California, were used. Hot air temperatures ranging from 100 to 600 °C (212 to 1,112 °F) were evaluated to examine the full range of possible pyrolysis products and rates of production. A high accuracy mass spectrometer was used to sample and analyze the pyrolysis products. Water and carbon dioxide evolution were measured using a differential gas analyzer. Ignition times were recorded both visually and with the aid of a thermocouple mounted above the fuel.

The results from the mass spectrometer measurements are still being analyzed, but some interesting trends in the water and carbon dioxide evolution and ignition delay times were noted. Almost all of the live fuels made audible popping and crackling noises while heating, but none of the dry or rehydrated fuels did. These noises have been noted by other researchers, and it is speculated that they are due to the sudden bursting of cell walls and expulsion of water in live fuels. Fuels did not ignite until the air temperature reached 500 °C (932 °F), at which point flaming ignition was seen for all dead fuels, while live fuels mostly showed glowing ignition. At 600 °C (1,112 °F), all fuels showed flaming ignition within 1 to 26 seconds. Interestingly, all live fuels were still actively releasing water at ignition, implying there are steep temperature gradients within these physically thin fuels. Simple heat transfer analysis in conjunction with the water evolution information helped to explain the differences in ignition times due to fuel geometry.

For more information, contact: Sara McAllister at smcallister@fs.fed.us

Photo: Bubbles and blisters on live fuels illustrating the complex way in which live fuels decompose and lose moisture during burning. Left and center: gallberry. Right: manzanita. Photos courtesy of Sara McAllister / FFS.

Flame Structure in Spreading Laboratory Fires

Experimental evidence now shows that flame impingement is required for ignition of fine fuel particles responsible for the spread of wildland fires. However, the characteristics of the non-steady flame zone that produce convective heating of fuel particles has not been studied. It is not known how to describe, qualitatively or mathematically, the flame dynamics that allow forward spread of wildland fires.

Flame structure studies were conducted and particle heating signals were evaluated by FFS Research Forester Mark Finney and collaborators from the University of Maryland, University of Kentucky, and Los Alamos National Laboratory in laboratory fires spreading through laser-cut cardboard fuel beds and in stationary flames from gas-fed burners. High-speed video and infrared imagery were used to capture flame dynamics to compare with thermocouple measurements.

Flame structure and dynamics were found to be remarkably similar to heated boundary layers that are well known from fluid dynamics research. Flame fronts in stationary and spreading fires were seen to divide into “peak and trough” patterns produced by instabilities of air inflow to the flame zone produced by the upward buoyant force. These instabilities result in paired-streamwise vortices (Görtler vortices) that force flames down into the fuel bed at convergence zones. Secondary instabilities result in apparent forward pulsing that extends flames into the unburned fuels at frequencies that appear to scale inversely with flame length but proportionally to wind speed. Results indicated that buoyant dynamics of the flame zone appear to govern the time-varying heating of fuel particles and the distance ahead of the front that heating takes place.

For more information, contact: Mark Finney at mfinney@fs.fed.us



Photo: Downwind view of fire spreading through laser-cut cardboard fuel beds in the Missoula Fire Sciences Laboratory's wind tunnel. The U-shaped depressions from left to right are related to the presence of Görtler vortices that force the fire downward into the fuel bed.

Ignition Potential of Rifle Bullets

In the United States, outdoor target shooting has been suspected as the source of numerous wildland fires. The ammunition involved in most incidents is thought to be of ordinary commercial varieties with bullets composed of inert materials including lead, steel, and copper. No scientific studies have specifically addressed projectile behavior or properties related to ignition of wildland vegetation or organic materials. FFS Research Forester Mark Finney and collaborators from the San Dimas and Missoula

Technology Development Centers conducted experiments to examine the potential for rifle bullets to ignite organic matter after impacting a hard surface. The tests were performed using a variety of common cartridges (7.62x51, 7.62x39, 7.62x54R, and 5.56x45) and bullet materials (steel core, lead core, solid copper, steel jacket, and copper jacket). Bullets were fired at a steel plate that deflected fragments downward into a collection box containing oven-dried peat moss.

The researchers found that bullets could reliably cause ignitions, specifically those containing steel components (core or jacket) and those made of solid copper. Lead core-copper jacketed bullets caused one ignition in these tests. Ignitions of peat also occurred in a small set of tests using solid copper bullets and a granite target. Thermal infrared video and temperature sensitive paints suggested that the temperature of bullet fragments could exceed 800 °C (1,472 °F). The size of bullet fragments also facilitated ignition, with larger fragments being more likely to cause ignitions. Bullet fragments from solid copper and steel core/jacketed bullets collected from a water



tank were larger than those from lead core bullets.

This research found that the kinetic energy of bullets is transformed into thermal energy by plastic deformation and fracturing of bullets because of high-strain rates during impact. Fragments cool rapidly but can ignite organic matter, particularly fine material, if it is very dry and close to the impact site. Prior to this study, there had been no scientific basis to inform policy concerning shooting on public lands. This research showed that ignition by commonly available ammunition was physically possible. The BLM in Utah and Nevada have already used this information to issue Fire Prevention Orders restricting the use of steel core/jacketed bullets during dry summer months. Further research will be directed toward testing under field conditions.

For more information, contact: Mark Finney at mfinney@fs.fed.us

Photo: Smoldering ignition from a hot bullet fragment as first detected in peat moss. Smoldering spot is approximately 1 cm (0.4 inches) in diameter.

Near Surface Wind Measurements

Wind predictions in complex terrain are important for a number of applications including wildland fire behavior, transport and dispersion of pollutants, and wind energy applications. Fine-scale changes in topography and vegetation substantially alter the flow field, and thus, accurate modeling for these applications in complex topography requires near-surface flow field predictions at a high spatial resolution. Two high-resolution wind models with varying degrees of sophistication have been developed at the Missoula Fire Sciences Laboratory in response to these needs; however, evaluation and improvement of these models is limited by a lack of high-resolution datasets in complex terrain under various weather scenarios. In response to this need, FFS Research Mechanical Engineer Bret Butler, with collaborators from Washington State University and the U.S. Forest Service's Moscow Forestry Sciences Laboratory, collected several high-resolution surface wind datasets over a variety of terrain features and under a range of meteorological conditions. At Big Southern Butte,

ID, investigators installed more than 50 weather towers that recorded 10-foot average wind speed, wind direction, and gusts, covering an area of roughly 30 square miles. In addition, they installed four SONIC Detection And Ranging instruments (SODARs), two radar wind profilers, approximately six sonic anemometers, and numerous balloon sondes. These datasets will be used to investigate terrain-induced effects on wind flows, such as mechanical channeling and thermally driven slope flows, as well as to develop and evaluate high-resolution numerical wind and weather prediction models in complex terrain. Preliminary exploration of the data revealed unique local-scale mechanically and thermally driven flow features that will be of interest in future model evaluations. Preliminary model evaluations indicate that wind predictions from routine weather forecasts can be improved in complex terrain by downscaling the data to a fine resolution with the WindNinja model.

For more information, contact: Bret Butler at bwbutler@fs.fed.us



Photo: FFS Physical Scientist Mark Vosburgh stands next to a wind anemometer installed to improve the accuracy of models used to simulate wind speed and direction in complex terrain.

RxCADRE – A Collaborative Research Campaign

An integrated, comprehensive, quality-assured dataset has been identified as a critical need to develop, validate, and evaluate the next generation of fire and smoke models. The lack of co-located, multi-scale measurements of pre-fire fuels, active fire processes, and post-fire effects hinders our ability to tackle fundamental fire science questions. To begin the acquisition of an integrated fire-atmospheric dataset, a group of scientists collaboratively instrumented and collected fire and fuels data on prescribed fires in the southeastern United States in 2008 and 2011. This effort was called the Prescribed Fire Combustion and Atmospheric Dynamics Research Experiment (RxCADRE). Scientists involved in the RxCADRE project include the U.S. Forest Service's Rocky Mountain Research Station, Northern Research Station, Pacific Northwest Research Station, Southern Research Station, and Region 8; the Department of Defense's Eglin Air Force Base, Jackson Guard, and Eglin Air Force Base Test Wing; the Environmental Protection Agency; National

Aeronautics and Space Administration; Los Alamos National Laboratory; the University of Montana; San Jose State University; University of Idaho; University of Alaska Fairbanks; Georgia Institute of Technology; and Scion Research, a New Zealand Crown Research Institute.

In 2012, the Joint Fire Science Program funded the improvement and continuation of the RxCADRE effort, focusing on integrated, fine-scale and operational-scale scientific measurements within six identified core fire science disciplines including 1) fuels, 2) meteorology, 3) surface fire behavior, 4) event-scale fire mapping, 5) smoke, and 6) fire effects. The project targeted critical data needs as outlined by members of the fire modeling community.

To date, the RxCADRE effort has collected integrated datasets on 20 prescribed fires over the three sampling years, ranging in scale from 1.5 to 1,500 ha. On each of these fully instrumented fires, data has been collected on pre-fire fuel loads, post-fire consumption,



Photo: Casey Teske, a cooperator from the University of Montana, prepares an in situ video camera prior to ignition on one of the large grass/shrub burn plots at Eglin Air Force Base in November 2012.

RxCADRE – A Collaborative Research Campaign



ambient weather, *in situ* convective dynamics, plume dynamics, radiant and total heat release (both from *in situ* and remote sensors), flame temperatures, *in situ* fire behavior, and selected fire effects. The various fuel types ranged from predominantly grass and grass/shrub to flatwoods, sandhills, and southern pine forest.

RxCADRE has already provided a high quality, integrated fire dataset that is being used for many research activities, including fire growth and emissions model testing and evaluation. A formal data repository has been configured to accept all metadata and data from the RxCADRE burns for 2012, 2011, and 2008 (see page 23). Data from RxCADRE will provide the fire modeling community with information necessary to improve the next generation fire and smoke models. Improved models and model results will provide resource managers with information that can better inform decisions regarding both

wildland and prescribed fire. Data gathered during the research campaign will also provide valuable information on fire activity in a variety of fuel types for which it is currently difficult to model fire activity. Findings from this effort have already been incorporated in research projects designed to improve guidelines for firefighter safety zones, fire growth modeling, and linking remote sensed data to *in situ* fire energy release.

For more information, contact: Dan Jimenez at djimenez@fs.fed.us or Bret Butler at bwbutler@fs.fed.us

Photo: FFS employees erecting anemometer towers around one of the large grass/shrub burn plots at Eglin Air Force Base in November 2012. Each burn plot was instrumented with approximately 80 anemometers in order to capture surface winds prior to and during each burn event.

RxCADRE – A Collaborative Research Campaign



Data Management

The data management plan RxCADRE specified that there would be a central repository for data. This repository serves as a data sharing site for the RxCADRE team during the project, a means to facilitate documentation using formal metadata, and a means to coordinate the transfer of datasets to a permanent archive at the conclusion of the project. Data management and documentation are important to ensure that the data are usable long after the project is completed.

The repository chosen for RxCADRE had to be accessible by external partners, have a high-bandwidth connection, and store two terabytes of project data. FFS Remote Sensing Scientist Bryce Nordgren, in collaboration with Roger Ottmar from the Pacific Northwest Research Station, explored options to meet these needs. The best option available was the Internet2 proof-of-concept network housed at the Missoula Fire

Sciences Laboratory. The network met accessibility, bandwidth, and capacity requirements at a substantial discount compared with a commercial hosting alternative.

To facilitate the authoring of formal metadata by members of the RxCADRE team, Nordgren adopted and modified Geonetwork opensource, a free and open source cataloging application. The application allows scientists and archivists to edit metadata using a simple web-based form and also allows metadata on the site to be categorized to streamline workflow. In the future, this project aims to improve metadata record attachment functionality to make this function more robust and less prone to failure.

For more information, contact: Bryce Nordgren at bnordgren@fs.fed.us

FUEL DYNAMICS

Fuel is always changing, yet models of fire behavior, fire danger, and smoke emissions require an accurate description of that fuel. In 2013, FFS scientists conducted research to improve estimates of fuel loading, fuel moisture, fuel chemistry, and impacts of insect attacks on fuels. All experiments combined laboratory work with field work to better understand fuel dynamics. In the Northern Rocky Mountains, FFS scientists examined three methods used to sample fuel loading to determine which methods were most accurate. This required creating verification fuel beds in the Missoula Fire Sciences Laboratory parking lot as well as testing the three sampling methods in the field. In the Great Lakes area, crown fire activity occurs most often in spring between snowmelt and green-up, when live fuels are changing most rapidly. FFS scientists examined the chemistry and moisture content of live fuels in Wisconsin to determine their effects on spring crown fire activity. In the West, there have been major changes on the forested landscape due to a widespread outbreak of the mountain pine beetle. These changes are difficult to map but greatly affect fuel condition and thus, fire behavior. FFS researchers combined field-measured beetle-induced fuel changes with satellite imagery from the Northern Rocky Mountains to improve estimates of fuel changes in beetle-attacked forests over time.



*Photo: FFS Research on surface fuel consumption leads to better understanding of how surface fuels and moisture affect burn severity.
Photo courtesy of Mick Harrington / U.S. Forest Service (retired).*

A Comparison of Sampling Techniques to Estimate Wildland Surface Fuel Loading in Montane Forests of the Northern Rocky Mountains



differences in fuel load values among techniques and the differences in fuel load between each method and the reference sample obtained using the synthetic fuel beds. They also evaluated various sub-methods and sampling intensities within each of the three sampling methods. Totals in each fuel category for each method were compared with totals from the reference sample.

Results indicated that the three conventional wildland fuel sampling methods that use widely accepted protocols do not provide accurate and precise

Designing fuel sampling methods that accurately and efficiently assess wildland fuel loads at relevant spatial scales requires knowledge of each sampling method's strengths and tradeoffs. Few studies have evaluated sampling methods as to their effectiveness in estimating accurate fuel loadings across all surface fuel components. In this study, FFS Research Ecologist Bob Keane and collaborators at the Missoula Fire Sciences Laboratory compared three sampling methods (planar intercept, fixed microplot, and microplot photoload) for estimating eight surface fuel components (litter and duff, downed dead woody materials in 1-, 10-, 100-, and 1000-hour classes, shrubs, and herbs). Sampling methods were evaluated by sampling synthetic fuel beds of known fine woody fuels (1-, 10-, and 100-hour) and field sampling all surface fuel components at various locations in western Montana.

For each of the eight surface fuel components, Keane and colleagues compared the relative

estimations of fuel loadings. The planar intercept and fixed microplot sampling techniques were only accurate when an impractical number of transects or microplots was used. They also found that the traditional diameter classes of woody fuels introduced additional variation into the sampling effort. It appears that to get an accurate estimate of woody fuel loadings, the diameters and length of each fuel particle must be measured to the nearest centimeter. Results from this study will be used to guide fuel inventory and monitoring sampling designs and help resource managers select the most appropriate techniques for each fuel component and the fuel sampling objective.

For more information, contact: Robert Keane at rkeane@fs.fed.us

Photo: A synthetic fuel bed created in the parking lot of the Missoula Fire Sciences Laboratory.

Analyzing the 'Spring Dip' in Foliar Moisture Content and Its Relationship to Crown Fire Activity in the Great Lakes

Both firefighters and fire scientists have observed a period of peak crown fire activity in the Great Lakes area during spring when a dip in foliar moisture content occurs. For decades, the cause and timing of this 'dip' have been poorly understood. It is therefore important to understand the drivers of this dip in order to improve wildland firefighter preparedness and situational awareness during a period of dynamic fuel changes.

Working with local firefighters from south-central Wisconsin, FFS Research Ecologist Matt Jolly, in collaboration with the Wisconsin Department of Natural Resources, the Eastern Area Fire Science Consortium, and the University of Wisconsin-Stevens Point, developed a sampling scheme to determine the causes of spring moisture content changes and to determine their effect on flammability. Foliar samples were taken from red pine and jack pine throughout the 2013 growing season and needle moisture, chemistry, heat content, and flammability were determined in the laboratory. During that time, local firefighters documented fire behavior on wildland fires throughout the study area.

Results indicated that foliar chemistry, rather than absolute

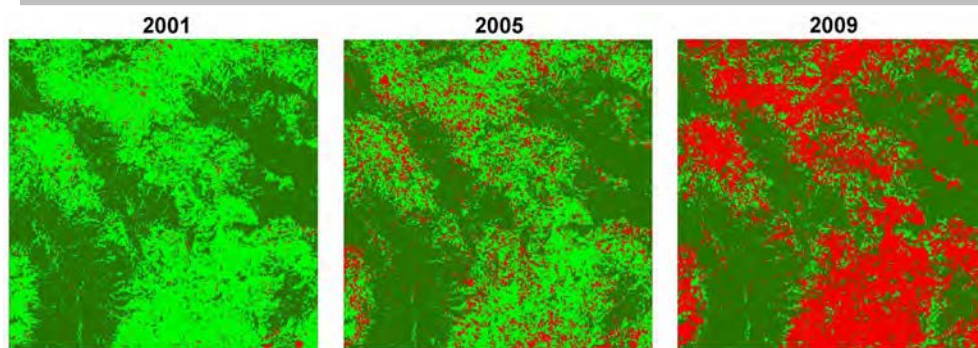
foliar water content itself, drove the apparent changes in measured live foliar moisture content. Results confirmed that the period of highest flammability occurred during the moisture content dip and was coincident with the timing of the most extreme fire behavior observed by local firefighters. Fire seasons in the Great Lakes occur rapidly after snowmelt and the timing of both snowmelt and this needle moisture dip can vary by more than a month from year to year. This information will help Great Lakes firefighters prepare for and respond to wildland fires.

For more information, contact: Matt Jolly at mjolly@fs.fed.us



Photo: Aerial view of the Germann Road Fire in northwestern Wisconsin, May 2013. This fire is typical of the high-intensity crown fires found in jack pine forests during the 'spring dip'. Photo courtesy of Phil Miller, Pilot, Wisconsin Department of Natural Resources

Linking Satellite Mapping of Beetle Attacks to Fuel Changes in the Northern Rockies



Dense forests and drier climate conditions have facilitated a widespread outbreak of the mountain pine beetle, a bark beetle native to western North America. Fire and fuel managers need up-to-date information regarding the location and nature of beetle attacks because beetle attacks can substantially alter fuel conditions, which can increase risks to firefighters and communities in affected areas.

U.S. Forest Service personnel have hand-mapped beetle attacks from aircraft for many years, but the extent of the land area makes it difficult to comprehensively map all areas each year, and differences between observers can also complicate analysis. To resolve this, FFS Research Ecologists Russ Parsons and Matt Jolly, working with their partners from U.S. Forest Service, Region 1, and the University of Montana, developed a system to map the progression of beetle attacks over time using MODIS satellite imagery and field-measured fuel changes. They developed and tested a system to apply the field-measured fuel changes to fuels maps used for modeling fire behavior.

Their satellite imagery provided consistent and geographically comprehensive maps of beetle

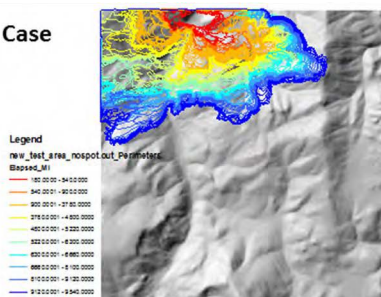
attacks over time, which compared favorably with field-measured data. Fuel changes associated with beetle attacks were found to vary depending on time since attack. Comparisons of fire behavior using fuel maps with and without

beetle-induced fuel changes over time suggested significant increases in predicted fire behavior with beetle-induced fuel changes.

Beetle effects on fuels and fire behavior are an area of active research. As this work advances, it has potential to be integrated with current fire and fuel management and future planning and to be extended to other geographic regions.

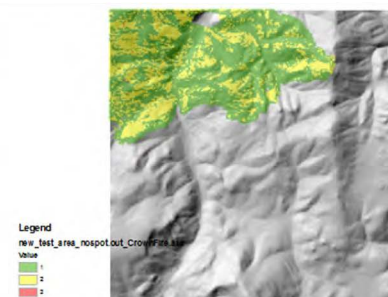
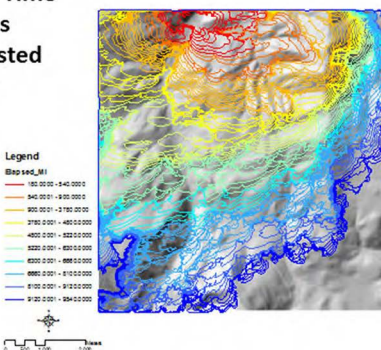
For more information, contact: Russ Parsons at rparsons@fs.fed.us or Matt Jolly at mjolly@fs.fed.us

Base Case

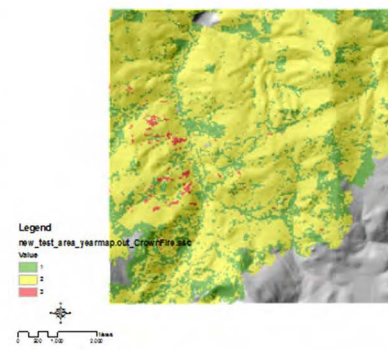


Fire Perimeters

MPB Time Series Adjusted Case



Fire Type



Top image: Observed Mountain pine beetle mortality maps produced from MODIS remote sensing data. Cumulative presence (red) and absence (green) are shown for three years. Bottom image: Comparison of simulated fire perimeters (left) and fire type (right; green = surface, yellow = torching, and red = active crown fire) using same inputs with (lower panel) and without (upper panel) mountain pine beetle effects for a small area. This comparison shows that inclusion of beetle effects in fuel maps significantly affects outcomes. Images courtesy of Russ Parsons / FFS.

SMOKE EMISSIONS AND DISPERSION

Where there is fire, there is smoke, and the amount of smoke varies in both quantity and chemical content. Smoke can have a large impact on human health, leading to active research in smoke emissions, smoke chemistry, and smoke movement. In 2013, FFS researchers examined emissions from prescribed fires in agricultural fields of the Pacific Northwest, providing datasets that may assist smoke managers in protecting public health



Photo: Smoke plume from the burning of wheat residue north of Walla Walla, Washington. The field was burned using a backfire. The light color of the smoke plume indicates low soot content. Photo courtesy of Emily Lincoln / FFS.

Experiments to Improve Agricultural Smoke Decision Support Tools

Agriculture is a vital part of the Northwest's economy and is critical to the region's rural communities. The production cycle of cereal crops and grasses, which are important agriculture products of the Northwest, includes burning fields of post-harvest residue such as wheat stubble. Like smoke from forest fires, smoke produced by agricultural burning can have harmful effects on public health. To protect public health, smoke management agencies of the Northwest regulate agricultural burning by deciding how much, if any, field burning can occur on a given day. They use air quality forecasting models that predict the amount and composition of smoke produced and the dispersion of the smoke and its concentration at population centers. Smoke managers have reported that the models do not work well under certain conditions resulting in significant smoke impacts on local populations. The developers of the air quality models and smoke managers need an extensive dataset of *in situ* observations of agricultural smoke production and dispersion in order to improve these critical air pollution forecasting tools.

The RMRS Smoke Emission and Dispersion Research Team, composed of FFS researchers at the Missoula Fire Sciences Laboratory, was asked to participate in a large research project organized by the Environmental Protection Agency (EPA). The project was designed to obtain the data necessary to improve the air quality models used by smoke managers in the Northwest and included researchers from the EPA's Region 10 and Office of Research and Development, the U.S. Forest Service's Pacific Northwest Research Station, the USDA's Beltsville Area Agricultural Research Service, Washington State University, Washington State Department of Ecology, and the Nez Perce Tribe. The Smoke Emission and Dispersion Research Team used

smoke chemistry measurement instruments on a U.S. Forest Service Cessna aircraft to measure emissions and smoke dispersion from seven agricultural fires in Idaho and Washington during August 2013.



An important initial finding of this study was that the method used to burn a field appeared to impact the amount of soot particles produced. The smoke plumes produced from burning wheat residue using head fires contained more soot than plumes produced using backfires. Soot particles are black aerosol composed primarily of elemental carbon. The World Health Organization reports that soot particles may have significantly greater negative health impacts than other particle types found in smoke and air pollution since these particles can act as a carrier for toxic combustion-derived chemicals. While results are still preliminary, early indications are that this research may assist smoke managers in protecting public health while helping to safeguard the economic livelihood of the Northwest's agricultural communities.

For more information, contact: Shawn Urbanski at surbanski@fs.fed.us

Photo: Smoke plume from the burning of wheat residue on the Nez Perce Reservation. The field was burned using a head fire. The dark color of the smoke plume indicates high soot content. Photo courtesy of Emily Lincoln / FFS.

FIRE ECOLOGY

Fire varies across the landscape, requiring ecosystems to adapt to differing fire severity and fire return intervals. Fire is not the only stressor affecting ecosystems; changing climate also plays a role. In 2013, two very different projects focused on better understanding these intricate, complex relationships: one looking to the past to improve our understanding of historical fire on the landscape and one looking to the future to project how fire and climate change will interact with ecosystems during the next 50 years.



Photo: Fire burns in an existing fire scar. Photo courtesy of Rachel Loehman / FFS.

Central Oregon Fire and Forest Histories

Central Oregon contains extensive fire-adapted forests, yet managers and other decision-makers lack the information they need to assess current forest departure from historical conditions and to understand the effects of climate variation on past fires in order to anticipate the possible effects of future climate change. FFS researchers Emily Heyerdahl and Rachel Loehman are filling these data gaps by reconstructing fire and forest histories from tree rings. In cooperation with the Central Oregon Fire Management Service, The Nature Conservancy, and University of Arizona, these FFS researchers have sampled tree rings at seven sites covering a range of forest types (mixed conifer, lodgepole pine, mountain hemlock, and western juniper) to reconstruct spatial variation in historical fire regimes and forest conditions. In addition, seven frequent-fire sites in ponderosa pine forests were sampled to reconstruct the influence of climate on regional fire years.

The researchers sampled more than 6,000 trees and quantified the historical range of variation in historical fire regimes among and within forest types. They found that lodgepole pine forests on central Oregon's pumice plateau historically sustained extensive mixed-severity fires, but the exclusion of fire since the late 1900s has altered forest and fuel structure such that mixed-severity regimes are no longer sustainable. In contrast, a 1,000-year record of western juniper woodlands in the region revealed that fire was insignificant. The researchers combined these data with simulation modeling of fire behavior to improve understanding of the drivers and impacts of fire. This

research will help managers and others anticipate and plan for possible fire and vegetation dynamics as well as better plan for future climate change and disturbances.

For more information, contact: Emily Heyerdahl at eheyerdahl@fs.fed.us or Rachel Loehman at raloehman@fs.fed.us



Photo: Researchers sampled tree rings in several forest types to reconstruct spatial variation in historical fire regimes and forest conditions. Photo courtesy of James P. Riser II / USFS

Climate Change Impacts on Fire Regimes

Global and regional temperatures have been increasing in the past 160 years and the rates of temperature increases have accelerated from 1979 to 2005, according to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC). In North America, several regions have already been experiencing the impacts of climate change. For example, much of the Southwest is experiencing drought and water shortage. These conditions may result in more frequent and widespread catastrophic fires that damage forests, disturb ecosystem balance, affect the timber industry, and increase air pollution. However, there is very limited knowledge regarding the potential impacts of climate change on the future landscape and the atmosphere in North America.

The RMRS Smoke Emission and Dispersion Research Team, composed of FFS scientists, has been cooperating with the French Nuclear Energy

Commission (CEA), France's premier national science and engineering laboratory, to investigate the impacts of climate change on current and future fire regimes and air quality in the United States from 2000 to 2050. These researchers studied climate impacts on vegetation type and condition (e.g. moisture content and fuel loading), frequency of fires, length of fire season, and spatial-temporal distribution of fire locations, burned areas, and daily, monthly, seasonal, and annual emissions at a 50-km (31 mile) resolution over the continental United States. The joint project leveraged the Team's strengths in fire science, satellite remote sensing, and fire emissions and the CEA's expertise in carbon cycling, atmospheric chemistry, and supercomputing.

The first phase of the joint project was completed in 2013, during which researchers simulated the daily impacts of climate change on wildfires

Decadal trend of fuel moisture between 1981-2010

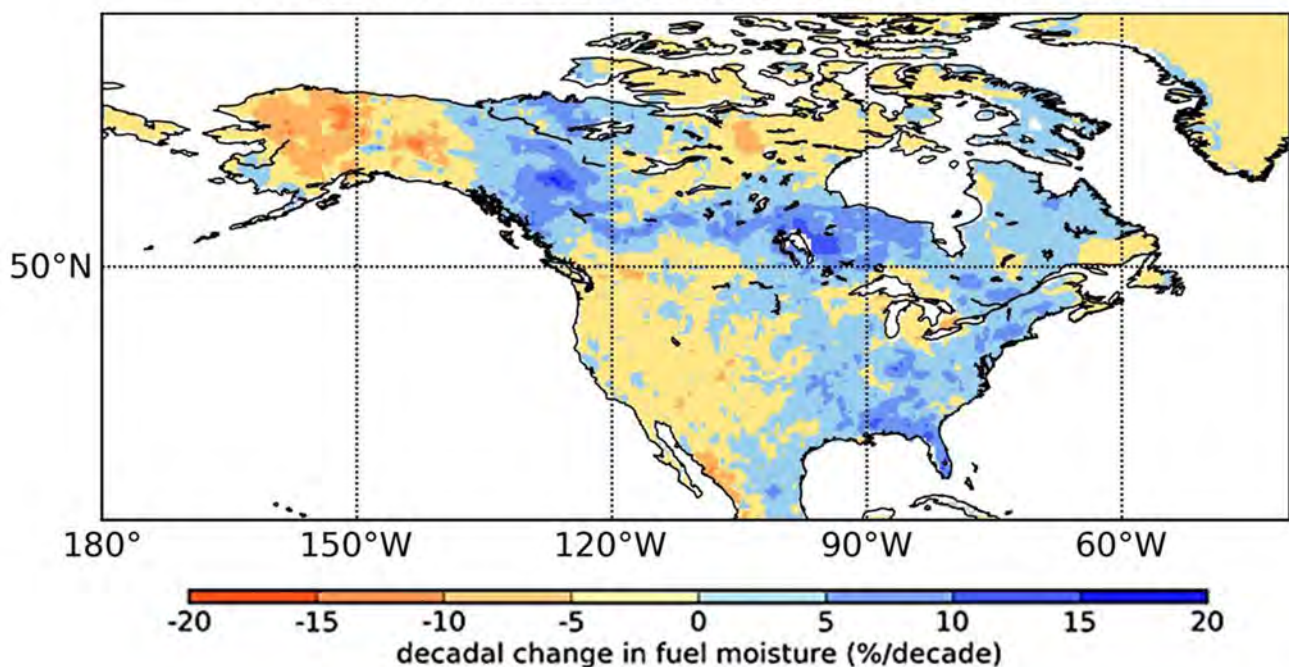


Image: Decadal changes of surface fuel moisture content between 1981 and 2010 in the United States and Canada at 50 km x 50 km (31 mi x 31 mi) resolution as simulated by the ORCHIDEE-SPITFIRE model.

Climate Change Impacts on Fire Regimes

globally at a 50-km resolution. They studied and simulated current land cover and fire regimes using a state-of-the-art global dynamic vegetation model called ORCHIDEE (Organizing Carbon and Hydrology in Dynamic Ecosystems) coupled with a fire regime module SPITFIRE (Spread and Intensity of Fire).

The ORCHIDEE-SPITFIRE model is the land-surface component of the Institut Pierre Simon Laplace-CM5 Earth System Model that was used in the new IPCC Fifth Assessment Report as well as in previous IPCC reports. The ORCHIDEE-SPITFIRE is a very powerful tool that can zoom into any spatial and temporal resolution provided that the high-resolution input parameters are available.

A key preliminary result of the simulations is a decadal trend of fuel moisture levels in North America over the past 30 years. The most pronounced decrease in fuel moisture content in the continental United States occurred in the Southwest and Northwest. A moderate increase in fuel moisture occurred in the Southeast. This information is a crucial component for estimating historical trends in fire behavior, emissions, and air quality and predicting future fire regimes.

For more information, contact: Wei Min Hao at whao@fs.fed.us

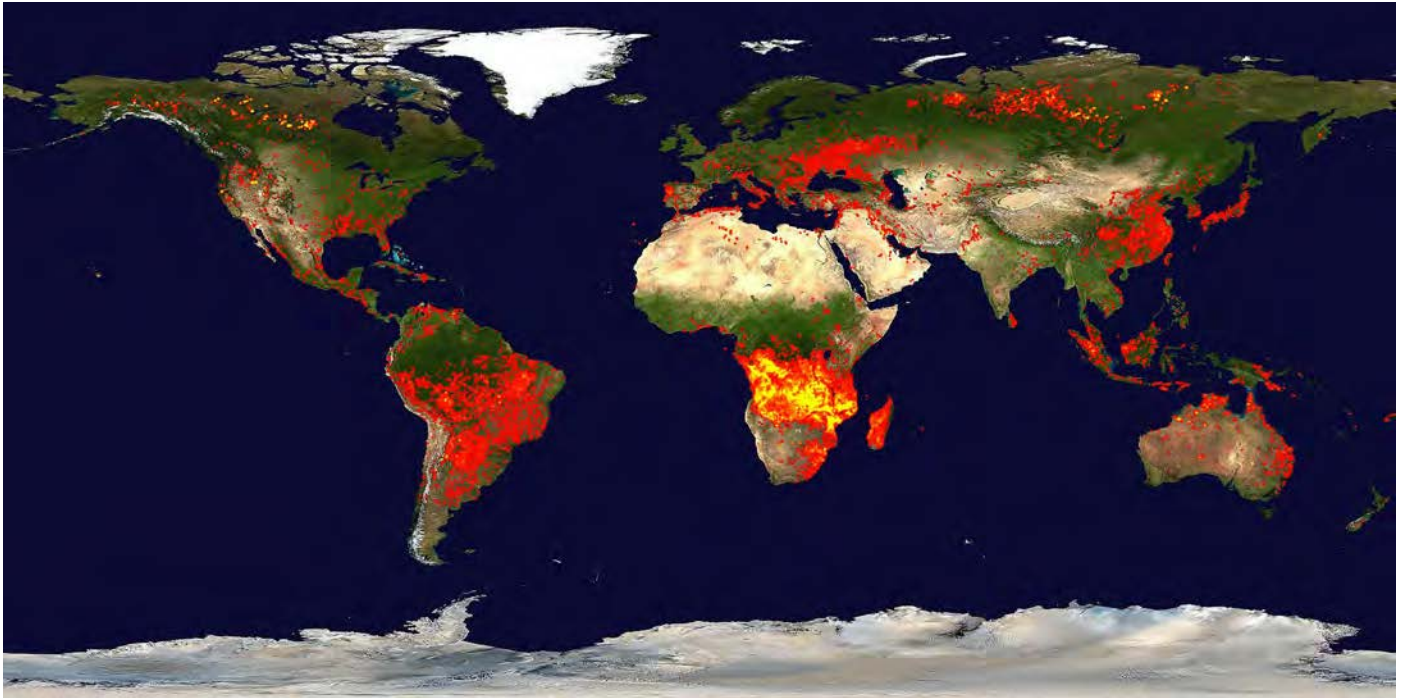


Image: MODIS 10-day global fire detection for August 9-18, 2013. Image courtesy of NASA.

FIRE AND FUEL MANAGEMENT STRATEGIES

Land managers make daily decisions about how to best manage the land, yet results may not be apparent for years. FFS scientists and staff are charged with providing scientific background for those decisions that assist managers in understanding how different management strategies affect the landscape as well as human health and safety. In 2013, FFS researchers contributed to this goal in several ways. Estimating the potential for future wildland fires is critical for successful landscape management, and FFS analysts provided maps of wildland fire potential that can be used for large-scale planning. To provide guidance on the ecological effects of burn severity in the western U.S., FFS researchers developed a comprehensive set of tools and procedures to create, evaluate, and deliver fire severity maps for all phases of fire management. Wildland fires occur across the U.S., but no single database existed that combined federal and non-federal fires until FFS researchers developed one. This database will support numerous research activities at FFS and elsewhere. Other researchers examined changes in crown fire behavior resulting from western spruce budworm infestations. Researchers were able to identify precise links between western spruce budworm disturbance and fire behavior changes. To improve firefighter health and safety, FFS scientists linked slope, wind, and fire intensity to firefighter safety zone size to make recommendations for safe separation distances from fires to avoid firefighter injury due to direct exposure to hot, toxic gases and thermal injury to skin.



Photo: Whether severe fire is viewed as a positive or negative force depends on the ecological context – namely, the type of forest ecosystem that burned and the extent to which the ecosystem is adapted to high-severity fire.

Mapping Wildland Fire Potential



The Wildland Fire Potential (WFP) map is a raster geospatial product covering the conterminous United States that can be useful in assessments of wildfire risk or hazardous fuels prioritization at broad geographic scales. The WFP map builds upon, and integrates, estimates of the probabilistic components of wildfire risk developed via simulation modeling for all Fire Planning Units across the United States by RMRS scientists.

In 2013, FFS Spatial Fire Analyst Greg Dillon developed an updated version of the WFP map, and released it by means of a website where users can download GIS data, map graphics, and supporting documentation. Since its release, the updated WFP map has garnered significant national and local attention, leading to direct technology transfer contacts with users from a wide array of entities, including: U.S. Forest Service, Bureau of Land Management, Bureau of Indian Affairs, Department of Interior, National Fire Protection Association, Xcel Energy, and

USAA Insurance. The Environmental Systems Research Institute (ESRI) created a GIS map service for WFP and featured it in their online Wildfire Public Information Map. In addition, Dillon presented an award-winning poster on the WFP mapping process at the 2013 ESRI International User Conference.

As a product built on simulation modeling outputs from RMRS scientists, the WFP map provides a perfect opportunity for FFS to highlight the foundational work being done by U.S. Forest Service research in the arena of wildfire risk assessment. In the coming year, FFS will continue to provide technology transfer and application of the latest risk assessment science through the WFP map and other risk assessment products.

For more information, contact: Greg Dillon at gdillon@fs.fed.us

Image: Wildland Fire Potential (WFP) map, classified into very low, low, moderate, high, and very high WFP classes. Image courtesy of Greg Dillon / FFS.

New Tools for Mapping and Understanding Fire Severity

Measuring fire severity has involved measurements like “acres burned” or “amount of canopy consumed” that are fairly easy to collect after fire and they focus attention on what a fire has done to the landscape. However, statistics for area burned are not always useful to managers. When wildfire spreads through an area, it also creates a mosaic that includes low-, medium-, and high-severity burn patches. Managers often need the total number of acres burned broken down by these severity classes for planning after wildfire has passed.

The Fire Severity (FIRESEV) Mapping Tools project, a collaboration with the University of Idaho, was funded by the Joint Fire Sciences Program and the National Fire Plan. The purpose was to develop a comprehensive set of tools and procedures to create, evaluate, and deliver fire severity maps for all phases of fire management, including 1) real-time forecasts and assessments in wildfire situations, 2) wildfire rehabilitation efforts, and 3) long-term planning. These products can be used in many fire management applications and time frames to help managers understand burn potential in the western U.S.

and provide guidance on the ecological effects of burn severity.

One of the products created by the FIRESEV project is the Severe Fire Potential Map (SFPM), a 30-m (98-foot) resolution raster dataset covering the conterminous western U.S. It depicts the relative potential at each 30-m pixel for fires to result in high severity effects, conditional on that pixel experiencing fire at 90th percentile weather conditions. The SFPM is intended to be an online resource that managers can download and use to evaluate the potential ecological effects associated with new and potential fire starts. It can also be used to aid in strategic fire management planning, including prioritization and placement of fuels treatments across large landscapes. Mosaics of the SFPM by 17 mapping regions are available online for managers to download and explore.

Another tool that was greatly enhanced from results of the FIRESEV project is the Wildland Fire Assessment Tool (WFAT) Simulated Fire Severity Mapping Program. This tool was developed by the National Interagency Fuels

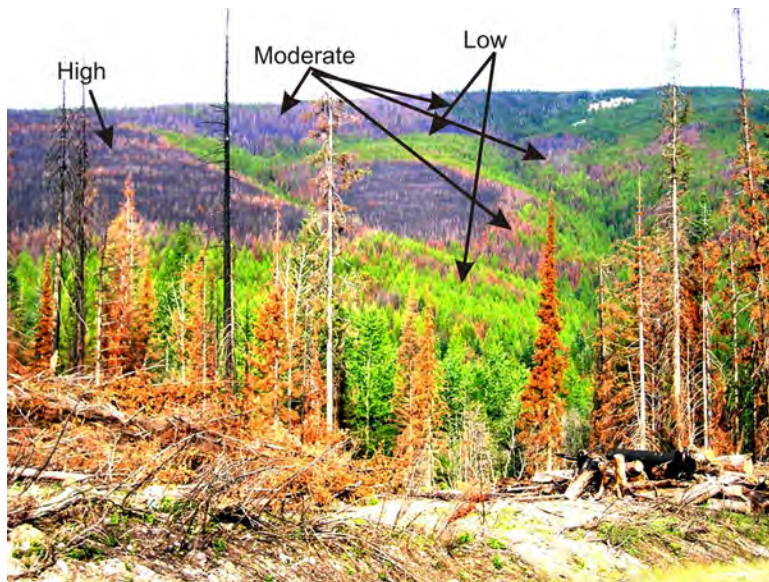


Photo: When a wildfire sweeps through an area, it usually creates a mosaic of low-, medium- and high-severity burned areas, with implications for post-fire operations such as erosion control, land rehabilitation, hazard mitigation, and lumber salvage operations. Photo courtesy of Terrie Jain / RMRS.

New Tools for Mapping and Understanding Fire Severity

Technology Transfer (NIFTT) team to spatially identify and plan fuel treatments. Based on information gained from the FIRESEV project, a new fire severity option was included to allow managers to produce more accurate fire severity predictions for short-term studies when accurate weather forecasts are available. It is used mainly for rehabilitation efforts after wildfire.

An Integrated Fire Severity Mapping Procedure is also under development by FFS researchers from the FIRESEV project. This procedure integrates simulation modeling of fire effects collected during or after a wildfire with satellite indices to improve estimates of severity on the landscape. The procedure, when complete, can be used to create maps useful in post-fire hazard mitigation, rehabilitation, and restoration planning.

Several other products were created during the FIRESEV project that could set the stage for a new era in fire severity research and aid in the development of other helpful management tools. Two of the most important are conceptual products that were developed to help managers

understand the effects of fire on fuel beds in the U.S. as well as the challenges associated with the concepts of fire severity. The first of these is a Fire Severity Classification System that can help managers understand how fire effects are related to on-site surface fuels and moisture levels. The classification system can be used by managers to more precisely predict and/or describe fire severity based on fuels, moisture conditions, and fire characteristics. The second is a critical appraisal of severity assessments to date that highlights the conceptual and practical difficulties involved with assessing and interpreting fire severity and suggests future directions for measuring, classifying, and mapping severity. Future directions would include data collection and remote sensing procedures that are based on specific measurements or endpoints, which would accommodate new science and technological advances and be more useful for managers to improve burn severity estimates.

For more information, contact: Robert Keane at rkeane@fs.fed.us

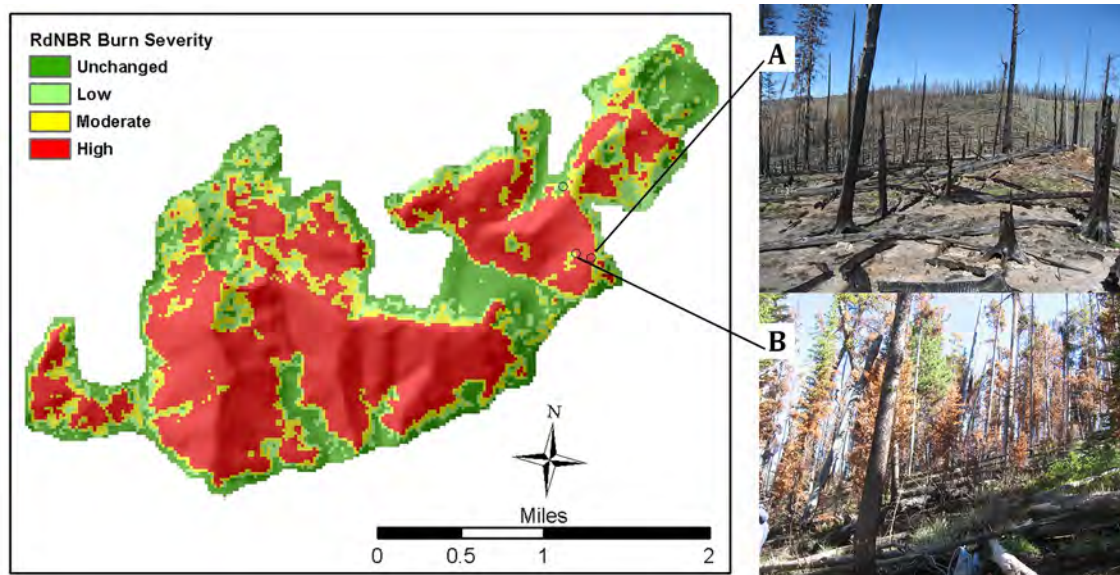


Image: A map of burn severity for a single fire obtained from satellite imagery. This kind of data was used to create the Severe Fire Potential Map. Photo A illustrates high-severity fire effects with overstory mortality and consumption of most surface fuel. Photo B illustrates low- to moderate-severity fire effects, with needle scorch on some trees and only partial consumption of surface fuels. Image courtesy of Greg Dillon / FFS.

A Spatial Database of U.S. Wildfires

Wildfire occurrence records provide baseline information that is essential for wildfire management and research in the United States. However, there are multiple federal, state, and local entities with wildfire protection and reporting responsibilities in the United States, and no single, unified system of wildfire record keeping currently exists. To conduct even the most basic interagency analyses of wildfire numbers and area burned based on official and final fire reports, one must harvest records from dozens of disparate databases with inconsistent information content. After pooling data from different sources, one must check for and purge redundant records of the same fire, including records of multijurisdictional incidents with responses reported by several agencies or departments.

Due to the difficulty of compiling wildfire occurrence data from the numerous reporting systems, analyses of United States wildfire activity are often based on final fire reports from a single federal agency, like the U.S. Forest Service, or rely on summary statistics from the National Interagency Coordination Center (NICC), which keeps running tallies of fire numbers and acres burned throughout the year. The NICC estimates are based largely on daily situation reports from participating wildland fire dispatch centers, not individual fire records, and can only be spatially resolved to the reporting unit.

To support research and other applications that require high-resolution spatial wildfire occurrence data for the United States from recent decades, FFS Research Ecologist Karen Short acquired, standardized, error-checked, compiled, and evaluated the completeness of wildfire records for the period 1992-2011 from federal, state, and local wildfire reporting systems.

Nearly 2.6 million records were obtained from 36 sources of federal and non-federal wildfire data. After discarding records lacking values for core data elements and removing redundant reports, the resulting dataset consisted of 1.6 million wildfire records, each indicating the

fire's reported point of origin, discovery date, and final size. Additional unrequired elements, like fire name and cause, were included in the database and populated with values as available. While not part of the original fire reports, record identifiers that could be used to link to related wildfire data products, including a national dataset of satellite-derived fire perimeters, were also included for a subset of the fires.

While necessarily incomplete in some aspects, the database is intended to facilitate fairly high-resolution geospatial analysis of United States wildfire activity over the past two decades, based on available information from the authoritative systems of record. The database was developed to support the national, interagency Fire Program Analysis (FPA) system, but has widespread utility in the fields of wildland fire science and management as well as areas of ecological and geophysical research, including the carbon and climate sciences.

For more information, contact: Karen Short at kcshort@fs.fed.us

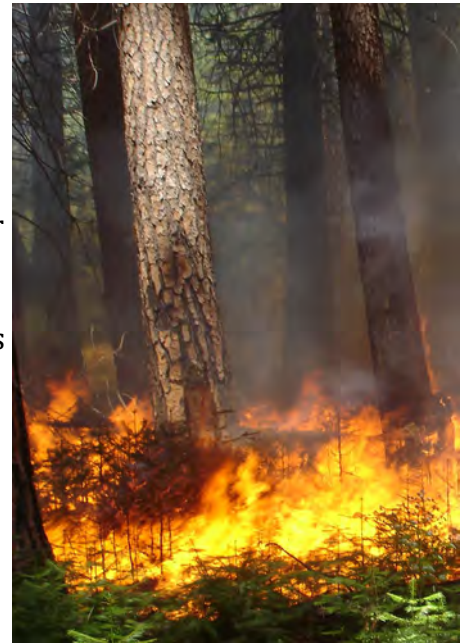


Photo: Fire moving through a ponderosa pine forest. The "cat face" or fire scar on the ponderosa pine reveals that this tree has survived several past fires. Photo courtesy of Ilana Abrahamson / FFS.

Western Spruce Budworm Alters Crown Fire Behavior through Reduced Canopy Density

Western spruce budworm outbreaks are often decades long in the interior West, however their impact on fire behavior is poorly understood. Insects are often thought to increase fire hazard or behavior due to high tree mortality. However, western spruce budworm kills few trees. Scientists have little understanding of how removing foliage alone affects fire behavior, and it is difficult to make precise links between historical western spruce budworm outbreaks and fire.

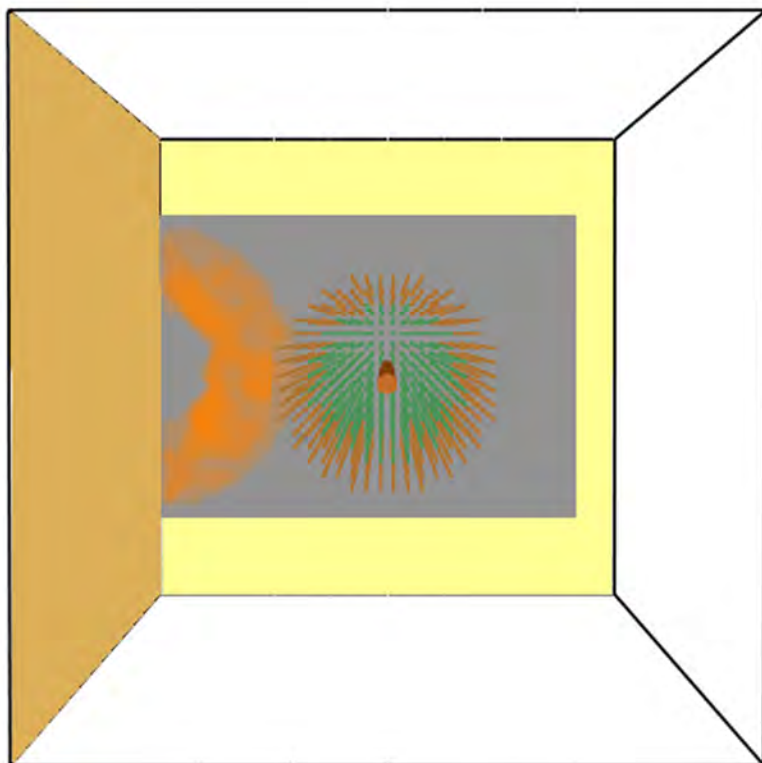
To isolate the effect that defoliation has on crown fuels, FFS Forester Greg Cohn and FFS Research Ecologist Russ Parsons, along with collaborators from the University of Oregon, simulated single tree torching across a range of crown fuel changes that occur during western spruce budworm infestation. By isolating the effects on a single tree and simulating the tree in a three-



dimensional fire model called the Wildland-Urban Interface Fire Dynamics Simulator (WFDS), these researchers were able to identify precise links between western spruce budworm disturbance and fire behavior changes. Development of WFDS was a joint project between the U.S. Forest Service Pacific Northwest Research Station and the National Institute of Standards and Technology (NIST) in Maryland.

Results indicates that defoliation, when modeled as reduced foliar density, dampens crown fire behavior by inhibiting fire spread between crowns and increasing the surface fire intensity necessary to ignite a single tree crown. This change in crown ignition is unique because it results from reduced crown fuel without a change to crown fuel base height.

For more information, contact: Greg Cohn at gcohn@fs.fed.us



Top photo: Western spruce budworm defoliated branches of a Douglas-fir in Montana. Bottom image: The Wildland-Urban Interface Fire Dynamics Simulator is used to model western spruce budworm-induced foliage reduction. This image shows a defoliated tree from above as a fire moves beneath the tree (from left to right).

New Firefighter Safety Zone Guidelines

As a consequence of 11 firefighters being killed on the Inaja Fire in 1957, the U.S. Forest Service issued a report recommending that firefighters identify safety zones at all times when fighting fire. This recommendation has been further developed into a requirement for all wildland firefighters. It is the intent that safety zones be available and accessible in the event that fire behavior or intensity increases suddenly making current tactics unsafe.

More than 50 years after the Inaja Fire, firefighters continue to be injured or killed by fire entrapments. Wildland firefighters must estimate fire behavior prior to implementing tactics and then continually adjust estimates as conditions change through the burning period. Current wildland firefighter safety zone guidelines are based on studies that assume flat terrain, radiant heating, finite flame width, constant flame temperature, and high flame emissivity. However, firefighter entrapments

and injuries occur across a broad range of vegetation, terrain, and atmospheric conditions and are not confined to radiant heating or flat terrain. Convective heating should be considered as a potential heating mode, and therefore complex terrain must also be considered. The objectives of this study were to briefly review current understanding of heat transfer in wildland flames, summarize current knowledge of how humans are injured by heat and smoke,

compare current safety zone guidelines, define the primary factors that should be evaluated within the context of safety zones, recommend new guidelines that account for convective heating, and suggest future research needs.

FFS Research Mechanical Engineer Bret Butler first evaluated how energy is released from wildland fires. Direct measurements of radiative and convective heating from actual fires were



collected and studied to better understand heat transfer in wildland flames. Measurements reported by collaborators from interagency hotshot crews and incident management teams, Brigham Young University, Eglin Air Force Base, and the Bureau of Land Management were included. To summarize current knowledge of how humans are injured by heat and smoke, safety zone modeling and experimental studies were reviewed and a selection of wildland fire

Photo: FFS Mechanical Engineer Jason Forthofer (left), collaborator Kyle Shannon (center), and FFS Mechanical Engineer Dan Jimenez (right), deployed in situ cameras and sensors in a research burn outside of Fairbanks, Alaska.

New Firefighter Safety Zone Guidelines



entrapment case studies were examined. More than 800 computer simulations were completed to evaluate the effect of wind, slope, and fire intensity on exposure level. Injuries occurred when firefighters were exposed to heating levels greater than 6 or 7 kW/m² for durations longer than 60 seconds. Firefighter injury was found to be due to direct exposure to fire through three mechanisms: 1) inhalation of toxic gases that poison biological functions, 2) inhalation of hot gases resulting in tissue swelling to the point of obstructing air exchange to the lungs, and 3) thermal injury to skin either through convective or radiative heating. Ideally, the wildland firefighter safety zone should be selected to

prevent injury from all three mechanisms.

New guidelines are under development that will link slope, wind, and fire intensity to safety zone size. These guidelines are expected to take the form of simple rules, Pocketcards, and smart phone apps. Ultimately this research will make fire managers and firefighters safer and more effective.

For more information, contact: Bret Butler at bwbutler@fs.fed.us

Photo: Fire intensity sensor installed on a fire on the Tenderfoot Creek Experimental Forest in western Montana. Data were used to establish heating ranges and durations from exposure to wildland fire.

SCIENCE SYNTHESIS AND DELIVERY

Research by FFS scientists and staff is produced in a variety of ways, such as through scientific research projects, data products, and computer applications. Scientific publications are one means FFS researchers disseminate information about research conducted. A list of scientific publications published in 2013 can be found starting on page 64. Software programs are also created and managed by FFS personnel, with the release of four computer program updates in 2013, ranging from fire danger rating to wind modeling and ecological monitoring. Synthesis of past research is another important component of science delivery. Through the Fire Effects Information System, a website that provides syntheses and reviews of information about fire regimes and fire effects on plants, lichens, and animals, FFS staff produced a number of new and updated products for use by land managers. Managers often seek out the expertise of FFS staff to apply fire science research to specific, local issues, such as those for Island Park and Sandia National Laboratories.



Photo: Field studies in ecological monitoring with FEAT-FIREMON Integrated. Photo by Duncan Lutes / FFS.

FireFamilyPlus 4.1

FireFamilyPlus 4.1 was officially accepted and released in June 2013. FireFamilyPlus is an agency-independent desktop application that supports the spectrum of analysis tools required by fire managers to successfully use the U.S. National Fire Danger Rating System. It can be used to calculate historical fire danger rating indices and components and summarize both fire and weather data. The program can statistically analyze historical relationships between fire danger indices and fire occurrence, displaying data in various formats. It also generates Fire Danger Rating Pocketcards required by the 30-Mile Abatement Plan and supports Predictive Services' functions at all Geographic Coordination Centers. FireFamilyPlus is the computational and

analysis cornerstone for the biennial Advanced Fire Danger Rating course at the National Advanced Fire and Resource Institute (NAFRI) and annual Intermediate Fire Danger Rating (S-491) courses held by the various Geographic Area Training Centers throughout the country. It also provides climate summaries for techniques taught in the Long Term Fire Risk Assessment course (S-495) at NAFRI. The updated version includes new analysis variables, new station metadata, new processing options, a weather term module, and numerous fixes and enhancements.

For more information, contact: Larry Bradshaw at lbradshaw@fs.fed.us

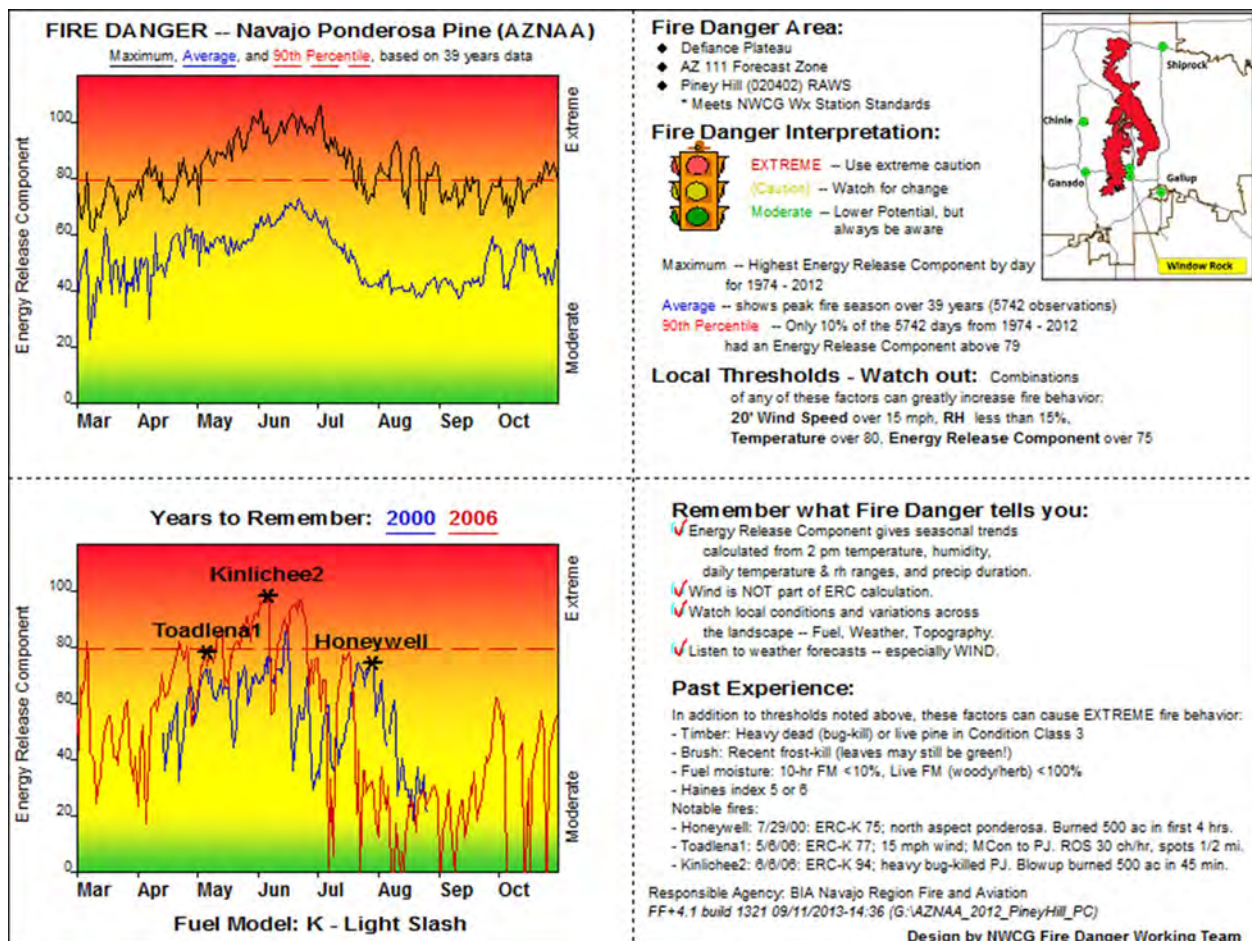
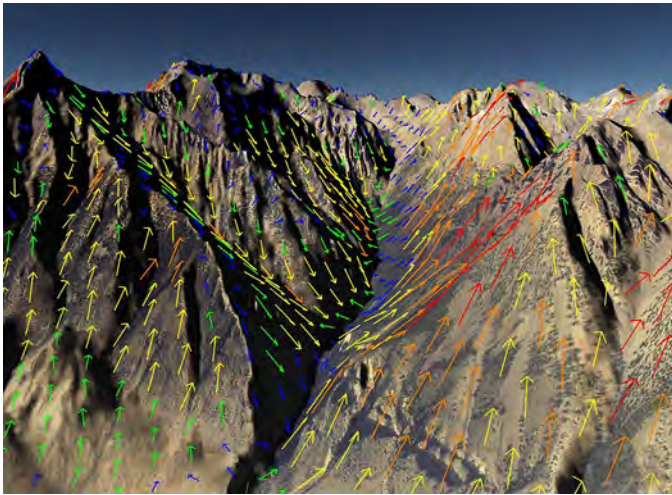


Image: A Pocketcard, given to firefighters to aid in understanding local fire danger, can be produced with FireFamilyPlus. Image courtesy of the Bureau of Indian Affairs.

Release of New Version of WindNinja and Upgrade to Include Momentum Solver

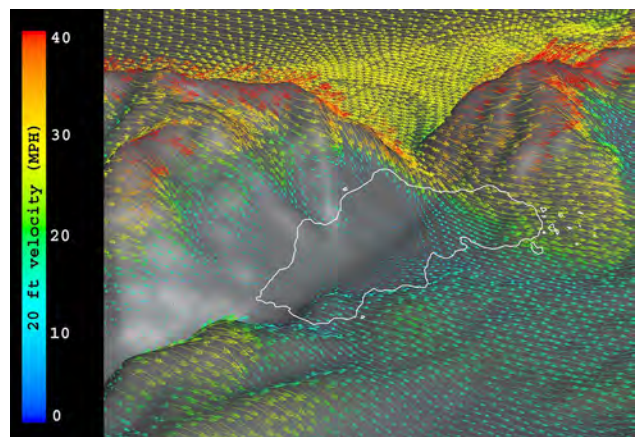


Changes in wind can dramatically change fire intensity, spread, and direction, and errors in fire predictions can result from inadequate descriptions of local winds. In an effort to provide more detailed descriptions of local wind flow for improved firefighter safety and improved fire model accuracy, two wind models, WindWizard and WindNinja, were developed by FFS scientists and staff. The WindWizard model is now being combined into WindNinja. WindNinja was developed to quickly simulate (less than 1 minute) terrain effects on wind flow for time sensitive emergency response applications. It requires elevation data, mean initial wind speed and direction, and specification of the dominant vegetation in the area. Use of WindNinja over the past 5 years has demonstrated that high-resolution wind data can improve fire model accuracy, provided that fire growth model parameters are set appropriately. It also appears that as complexity of the wind model increases, the accuracy of the fire growth simulations increases.

FFS Research Mechanical Engineer Bret Butler, with collaborators from GCS Research, Tridiagonal Solutions, Washington State University, and the Forest Services' Moscow

Forestry Sciences Laboratory, released a new version of WindNinja in 2013 that allows users to initialize flow calculations using National Weather Service forecast model data. This version of WindNinja provides users with an unprecedented capability to simulate winds at a resolution sufficient to address local fire spread. It also includes an option for users to acquire elevation data directly. A Momentum Solver application is currently being developed that will allow users to either select a fast, less accurate model prediction or a slower but more accurate prediction. The option selected would depend on decision time as well as the location for which the simulations are planned. Further developments include a turbulence submodel that will substantially improve wind model prediction accuracy in complex terrain, such as terrain characterized by steep dissected hills and drainages. Work is also underway to include a dust and ash entrainment option that can be used to simulate post-fire erosion and assess dispersion and impacts on air quality. The information provided by these enhancements has utility in wildland fire accident investigations, fire management, firefighter and public safety, and emissions monitoring applications.

For more information, contact: Bret Butler at bwbutler@fs.fed.us



Top image: Simulation of diurnal wind flow using the WindNinja model. Terrain can have a large impact on both wind speed and direction. Bottom image: Wind vectors simulated using WindNinja are often used in modeling spatial fire behavior. Images courtesy of Jason Forthofer / FFS.

FEAT-FIREMON Integrated

FEAT-FIREMON Integrated (FFI) is an interagency, science-based, ecological monitoring software application that is designed to assist managers in meeting inventory and monitoring requirements as mandated by Federal law and agency policy. It is used in the U.S. Forest Service, National Park Service, Bureau of Land Management, U.S. Fish and Wildlife Service, U.S. Geological Survey, Bureau of Indian Affairs, and by Tribes, state, and local governments, nongovernmental organizations, and universities.

FFI uses plot-based data collected using a variety of sampling protocols to consistently describe ecological systems and monitor change over time. It incorporates the components necessary to conduct a successful monitoring program, including an integral database, analysis and reporting tools, and modular GIS component.

The FFI development team is nearing completion of FFI-lite, a SQL Server CE-based version of FFI. This new application was developed in response to user requests for a version of FFI that is easier to install and manage. While FFI-lite does not allow multiple simultaneous users like FFI does, it includes the full complement of error checking, data form customization, and reporting tools found in the full version of FFI, and will be the desired application for units with smaller monitoring programs that do not need the functionality of a SQL Server-based application. An

additional benefit is that FFI-lite can be used for collecting electronic data on field computers, eliminating the time needed to copy data from hardcopy field forms into FFI and reducing the opportunity for data entry errors. Finally, a new GIS toolbar compatible with Arc GIS 10.1 was distributed in 2013.

Members of the FFI development team presented a four-hour workshop at the Fifth International Fire Ecology and Management Conference in Portland, OR, and a four-day training course at the Southern Area Advanced Fire and Aviation Academy in Birmingham, AL. The four-day course included two field days covering field sampling and data collection methods and two classroom days providing hands-on instruction with FFI software.

For more information, contact: Duncan Lutes at dlutes@fs.fed.us



Photo: FFS Ecologist Duncan Lutes leads a classroom session during the FEAT-FIREMON Integrated training course at the Southern Area Advanced Fire and Aviation Academy in Birmingham, AL.

Fire Danger Characteristics Charts

A fire characteristics chart is a graph that represents either U.S. National Fire Danger Rating System (NFDRS) indices or fire behavior characteristics (surface fire or crown fire). The NFDRS and the operational fire behavior systems (such as BehavePlus and FARSITE) are based on the same fundamental mathematical fire models. This relationship makes fire characteristics charts possible. The Fire Characteristics Chart software program was developed to produce fire characteristics charts for both fire danger and fire behavior. Charts produced by the program can be included in briefings, reports, and presentations.

The fire behavior characteristics chart was released in 2012. This chart shows the relationship among rate of spread, flame length, fireline intensity, and heat per unit area. It helps communicate and interpret modeled or observed fire behavior. Example fire behavior applications include fire model understanding, observed crown fire behavior, ignition pattern effect on fire behavior, prescribed fire planning, briefings, and case studies. Separate charts are available for surface fire and crown fire because of differences in the flame length model used for each.

The fire danger characteristics chart was released in 2013. This chart displays the relationship among three NFDRS indices, Spread Component, Energy Release Component, and Burning Index, by plotting the three values as a single point. Indices calculated by FireFamilyPlus, an application used for analysis of fire danger indices and weather, can be imported into the Fire Characteristics Chart program. Example applications include comparing fire seasons, weather stations, and fuel models.

For more information, contact: Faith Ann Heinsch at faheinsch@fs.fed.us

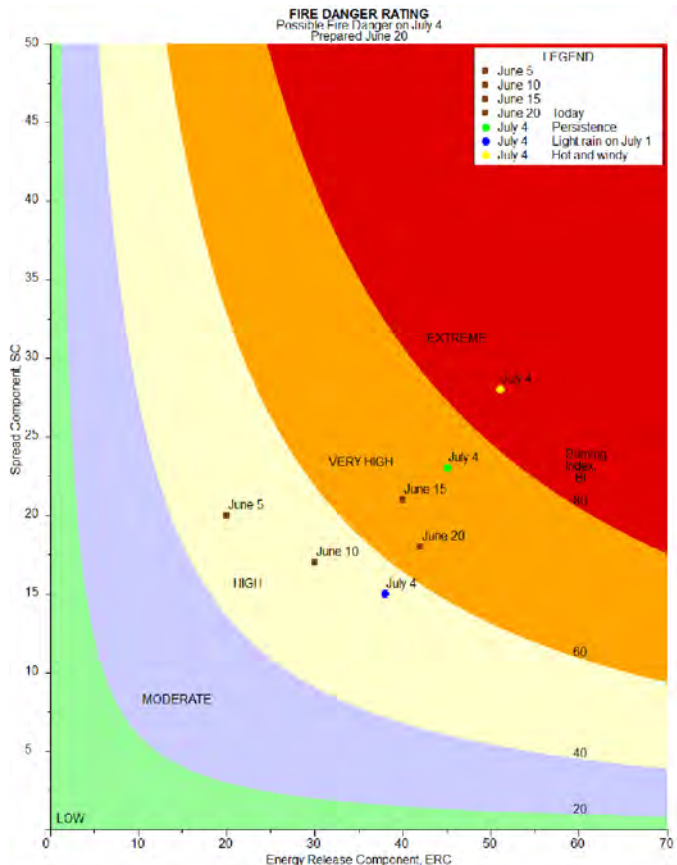


Image: A sample fire danger characteristics chart showing past fire danger rating and three possible forecasts of fire danger.

Fire Effects Information System Updates

The Fire Effects Information System (FEIS, <http://www.feis-crs.org/beta/>) continued to serve managers in 2013, its twenty-eighth year. FEIS provides online syntheses of scientific knowledge about more than 1,100 species and their relationships with fire. Reviews cover plants and animals throughout the United States, providing a wealth of information for resource management, restoration, rehabilitation, and fire management.



FEIS had 557,524 visitors in 2013, an increase of 22 percent over the previous year. The system had visitors from all of the United States, with most

visits from Washington, Oregon, California, Texas, Florida, and New York. FEIS received visits from more than 120 countries outside the United States.



Fourteen reviews covering 16 species were published in FEIS in 2013. These reviews offered over 500 pages of synthesized information

documented by almost 2,000 references. Most of these replaced older reviews published in the late 1980s and early 1990s. For example, a review on mule deer published in 1991 included information from 58 references; the 2013 review on mule deer synthesized up-to-date information from 372 references. Other Species Reviews published this year covered northern goshawk,

Florida scrub jay, white-tailed deer, thimbleberry, and red-osier dogwood.



In addition to Species Reviews, four Fire Studies were published in FEIS in 2013, including a Management Project Summary that was written in conjunction with The Nature Conservancy in

Texas. The Fire Studies completed in FEIS this year included fire effects information on 93 species reviewed in FEIS and added information on 79 additional species.

Literature used for FEIS reviews is stored in the Fire Effects Library at the Missoula Fire Sciences Laboratory and documented in the Citation Retrieval System (CRS). CRS contains more than 80,000 citations. In 2013, FEIS staff added approximately 1,160 new citations to CRS.

For more information, contact: Jane Kapler Smith at jmith09@fs.fed.us



Quantifying Wildfire Risk to Structures in the Island Park Sustainable Fire Community

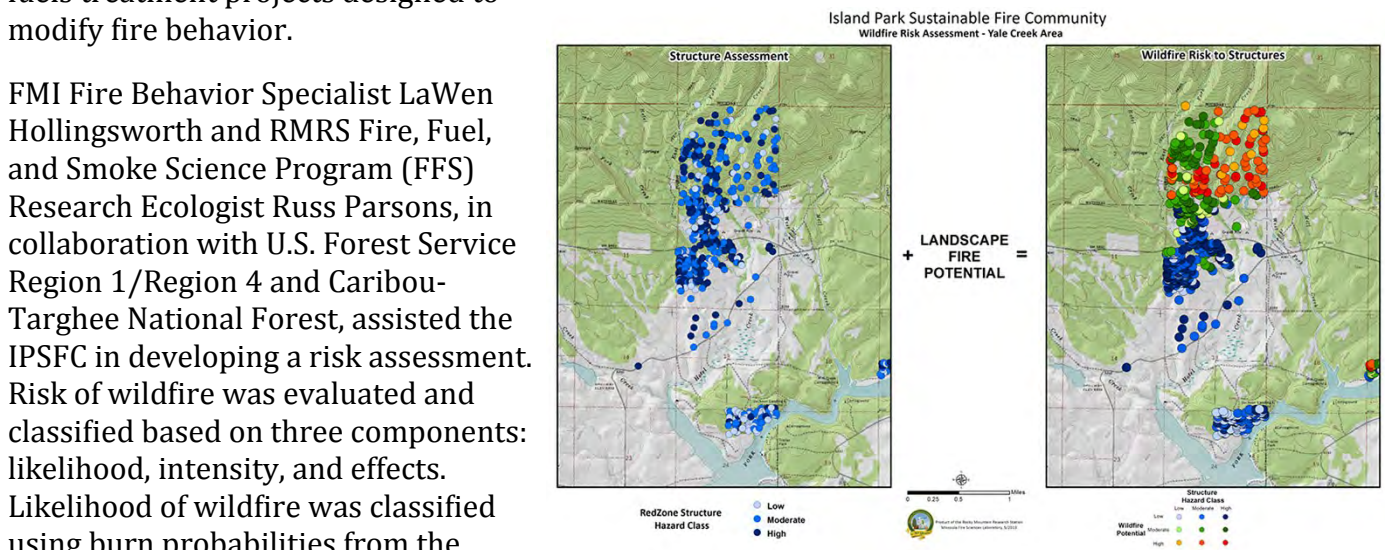
The communities of Island Park, ID, and West Yellowstone, MT, are situated just outside the western entrance to Yellowstone National Park amid grasslands, sagebrush, and aspen and conifer forests. As part of the broader interagency Cohesive Wildfire Management Strategy policy created in

response to the FLAME Act of 2009, a collaborative group called the Island Park Sustainable Fire Community (IPSFC) formed to develop a dynamic long-term strategy for a 314,000-ha (750,000-acre) area encompassing the two communities. The IPSFC recognized the need to evaluate the existing wildfire risk in the area to facilitate prioritization efforts for future fuels treatment projects designed to modify fire behavior.

FMI Fire Behavior Specialist LaWen Hollingsworth and RMRS Fire, Fuel, and Smoke Science Program (FFS) Research Ecologist Russ Parsons, in collaboration with U.S. Forest Service Region 1/Region 4 and Caribou-Targhee National Forest, assisted the IPSFC in developing a risk assessment. Risk of wildfire was evaluated and classified based on three components: likelihood, intensity, and effects. Likelihood of wildfire was classified using burn probabilities from the

Large Fire Simulator (FSim), a system used to estimate burn probability and variability in fire behavior across large landscapes. Fire intensity is summarized using flame lengths from the geospatial fire behavior system, FlamMap. Burn probabilities and flame length data were combined to produce a map of wildfire potential across the landscape. The effect, or value, is supplied by structure hazard assessments within the project area conducted in the Island Park and West Yellowstone communities. These data detailed ingress, egress, building materials, and hazards adjacent to structures such as overhanging vegetation or propane tanks. The structure assessment data were classified into low, moderate, or high structure hazard classes, which were then combined with the landscape wildfire potential data to create a matrix displaying the wildfire risk to structures. The risk assessment data will be used by IPSFC to evaluate and prioritize fuels projects and inform homeowners of potential risks from wildfires and their responsibilities to mitigate those risks.

For more information, contact: LaWen Hollingsworth at lhollingsworth@fs.fed.us



Top image: Landscape fire potential for the Island Park Sustainable Fire Community (IPSFC) project area. Bottom image: The wildfire risk assessment map for the Yale Creek area, part of the IPSFC project area located directly north of Island Park Reservoir.

Fire Management in Nepal

In April, 2013, Forester and Spatial Fire Analyst Chuck McHugh spent two weeks in Nepal providing comment and review of the Nepalese fire management program. His visit was coordinated with U.S. Forest Service International Programs, the U.S. Agency for International Development (USAID), the U.S. Department of State, and World Wildlife Fund Nepal (WWF Nepal). He presented materials during a workshop and gave three other presentations to a variety of audiences including members of USAID, WWF Nepal, Embassy of the United States Kathmandu, Nepal's Ministry of Forests and Soil Conservation (MoFSC), Nepal Police, local Community Forest User Groups (CFUGs), and the Nepal Institute of Forestry. He also visited several Forest Districts where he met with local



managers, reviewed projects focused on reducing fire risk, and observed CFUGs suppressing active fires.



The primary objectives of the visit were to 1) attend the “Developing Forest Adaptation Strategies under Changing Climate Scenarios: Geospatial Support Systems for Improved Forest Fire Management” workshop and present an invited talk on “Geospatial Decision Support Tools for Modeling Wildland Fire”; 2) provide targeted technical support and comments regarding fire and fire management on the USAID-WWF Nepal funded Hariyo Ban Project; and 3) provide comments and observations to MoFSC regarding fire management issues in Nepal.

The workshop was attended by 30 senior officials from Bangladesh,

*Top Photo: On April 15, 2013, Chuck McHugh visited a recent wildfire on the Kapilvastu Forest District with the district fire crew, unit foresters, and WWF Nepal. Note burned area in the background, left.
Bottom Photo: Local CFUG using traditional firefighting methods observed on a wildfire along the East-West Highway on the Rupandehi Forest District on April 16, 2013.*

Fire Management in Nepal

Bhutan, India, Myanmar, Nepal, and Pakistan. McHugh was joined by experts from the U.S. Forest Service Remote Sensing Applications Center (RSAC), NASA, and SERVIR-Himalaya, an initiative at the International Centre for Integrated Mountain Development (ICIMOD) supported by USAID. The event included two days of technical training on operational forest fire detection and monitoring systems followed by a day-long discussion on fire and forest management policy. The workshop helped identify gaps in technology, capacity, and policy in the Hindu Kush Himalayan region and fostered regional cooperation for improving forest fire management.

McHugh concluded his trip with a formal briefing to MoFSC on his observations of fire and fire management in the country. He concluded that although Nepal faces many challenges as it continues to develop its fire management policy



and response, these challenges offer many opportunities to address issues and formulate policy and strategies specific to Nepal's unique circumstances.

For more information, contact: Chuck McHugh at cmchugh@fs.fed.us



Top photo: Local CFUG observed on a wildfire along the East-West Highway on the Rupandehi Forest District on April 16, 2013. This CFUG had not received any basic firefighting training or equipment. Bottom Photos: Left: On April 17, 2013, the Raniban CFUG received basic firefighting training and equipment provided by WWF Nepal. Right: Formal briefing to the Secretary, Under Secretary, and other officials within the Ministry of Forests and Soil Conservation, Kathmandu, Nepal on April 18, 2013.

Modeling Fire Danger for Sandia National Laboratories

Sandia National Laboratories, located at the Kirtland Air Force Base in Albuquerque, NM, conducts tests at its Aerial Cable Facility and Burn Site (ACF) in conjunction with a land use agreement between Kirtland Air Force Base and the U.S. Forest Service. Historically, Kirtland Air Force Base set the National Fire Danger Rating level for the area one level above that of the nearby U.S. Forest Service Sandia Ranger District, which uses observations from a Remote Automated Weather Station (RAWS) for computing daily fire danger rating across the District.

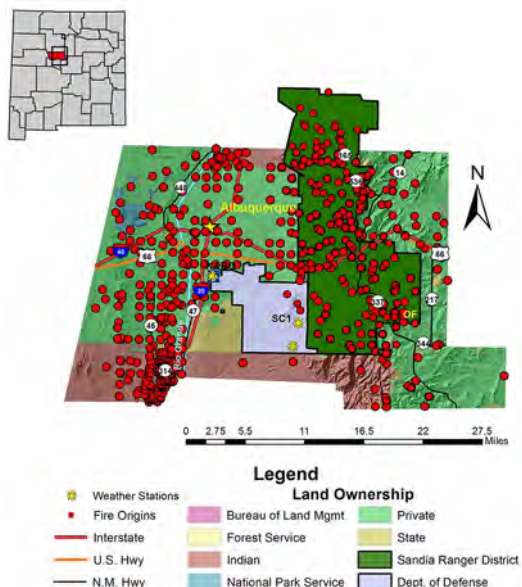
Kirtland Air Force Base worked with FFS Meteorologist Larry Bradshaw and Physical Scientist Faith Ann Heinsch to develop more accurate fire danger ratings for the Sandia National Laboratories. These FFS researchers compared site-specific data and fire danger ratings for the Sandia Ranger District's RAWS, the National Weather Service's weather station in Albuquerque, the Old School House weather station, and a Fire Program Analysis grid point to develop climatology and fire business thresholds specific to the ACF. FireFamilyPlus was used to



calculate fire danger rating indices and components for comparison with fire occurrence data. Fire occurrence data from 1995-2011 were combined with weather data to determine potential thresholds for fire danger at the study site.

Results from this study provided insights into the fire danger of the area. Fire danger ratings developed using the Old School House weather station, the closest weather station to ACF, and RAWS were different but showed similar trends; they were most divergent during March through June, the active fire season. Preliminary results from this study indicated that the previous plan was overly restrictive. Results from this study will be used by Sandia National Laboratories to develop a fire danger operating plan for their facility that more accurately represents the fire danger of the area. Thus, the new plan should increase the number of test days while maintaining operational restrictions when necessary for safety.

For more information, contact: Larry Bradshaw at lbradshaw@fs.fed.us or Faith Ann Heinsch at



Top photo: Location of the Aerial Cable Facility and Burn Site (ACF) and four weather datasets included in analyses (National Weather Service's Albuquerque Forecast Office (KABQ), Old School House, U.S. Forest Service's Remote Automated Weather Station (291402 - Oak Flats), and a Fire Program Analysis grid point (FPA Grid Point 19, 176)). Bottom photo: Fires occurrence data from 1995-2011 and local weather data were combined to determine potential thresholds for fire danger.

THE RESEARCH CONTINUES

Research to enhance current understanding of wildland fire behavior and its effects is ongoing as represented by research begun in 2013 by researchers in the Fire, Fuel, and Smoke Science Program. Improved understanding of fire behavior, particularly in the area of fuels will improve our ability to model that behavior. Quantifying emissions from wildland and prescribed fires and improving the ability to model them will improve our understanding of the processes underlying those emissions. New research summarizes our current understanding and outlines plans for filling the knowledge gaps. The current suite of fire behavior systems is instrumental in understanding fire behavior, but updates are needed. Designing new systems will start from the lowest common denominator among systems to provide a more unified, portable approach to modeling. Finally, collaboration continues with development of a fuel treatment plan for an area inhabited by the Mexican spotted owl.



Photo: RMRS collaborator Terrie Jain and FFS Forester Jim Reardon install instrumentation at an older mastication project site on the Priest River Experimental Forest (page 54). Photo by Pam Sikkink / FFS.

Describing and Scaling Physio-chemical Properties of Live and Dead Fuels to Parameterize Physics-based Fire Behavior Models

Considerable effort is expended to determine fuel loadings and to map those loadings across the landscape, yet there is little or no work being done to determine how to incorporate those measurements into the next generation of fire behavior models, such as physics-based models. Identifying critical spatial and temporal fuel characteristics required by these models may help to refine field sampling procedures and ensure a tight coupling between how fuels are measured and how those measurements are then used to assess potential fire behavior.

FFS Research Ecologist Matt Jolly, FFS Research Forester Russ Parsons and other FFS researchers at the Missoula Fire Sciences Laboratory are developing a three-part project that describes and scales the physio-chemical properties of live and dead fuels to parameterize physics-based behavior fire models. For the first part of this project, litter and foliage samples from a variety of grass, shrub, and tree species common throughout the Rocky Mountains will be analyzed to provide a full suite of seasonal physical and chemical fuel properties and determine their flammability. This research may help to elucidate linkages between physical and chemical fuel properties, as well as provide much needed input parameters to support the testing and application of physics-based fire models. The second part of this project will develop methods to integrate field-measured fuels data into physics-based fire models. This will entail developing methods for integrated heterogeneous fuel beds into physics-based models, such as FIRETEC and the Wildland-Urban Fire Dynamics Simulator (WFDS),

with the ultimate goal of developing a standard set of surface fuel models that allows for the flexibility of integrating a range of field measurements. This will help bridge the gap between large-scale spatial fuel mapping projects such as LANDFIRE and these emerging physics-based fire models.

The final component of this project is to perform model simulations to evaluate the sensitivity of physics-based fire models to key physio-chemical inputs at scales from leaves to plots in an effort to determine important fuel characteristics and to refine fuel field sampling protocols to accommodate these models. Using laboratory burns, researchers will be able to determine how well physics-based models using these fuel characteristics are able to predict fire heat release.

For more information, contact: Matt Jolly at mjolly@fs.fed.us or Russ Parsons at rparsons@fs.fed.us



Photo: The Goblin Gulch Fire was a mixed-severity fire in western Montana. This photo of low-severity surface fire burning through live and dead fuels was taken on August 5, 2012.

Surface Fuel Characteristics, Temporal Dynamics, and Fire Behavior of Masticated Mixed-Conifer Fuel Beds of the Southeast and Rocky Mountains

Fuel mastication, or the mechanical modification of live and dead surface and canopy biomass, to reduce the potential of extreme fire behavior is becoming the preferred fuel treatment for many fire hazard reduction projects in areas where reducing fuels using prescribed fire is challenging. For mixed-conifer ecosystems, much research has been done concerning how fire in masticated fuel beds affects soils, how compressed fuels affect fire behavior, and how different ways of masticating fuels affects vegetation response. However, little is known about how fuel particle and fuel bed characteristics and properties change over time. When masticated materials are freshly created, fuel beds consist of abundant amorphous chopped or crushed woody pieces. Initially, their moisture content is high but subsequent drying increases the short-term likelihood that these fuels will ignite easily and carry flames across a landscape. The long-term effects of masticating

fuels have also not been well documented. Little is known about how moisture is retained in different fuel beds types throughout the summer and fall months when potential for burning is high; how *in situ* fuel moisture content fluctuates in different regions; what types of structural, physical, and chemical changes masticated fuels undergo; or how these changes affect fire behavior when burned. To fill these knowledge gaps, FFS Research Ecologist Robert Keane and colleagues from RMRS and the University of Idaho will be examining fuel moisture and fuel bed dynamics of masticated fuel beds in mixed-conifer forests in the Rocky Mountains and the Southeastern U.S. These researchers will use these properties to predict the potential of sustained smoldering. This information will help managers assess potential risks of and responses to prescribed or wildland fire in masticated fuels.

For more information, contact: Robert Keane at rkeane@fs.fed.us



Left photo: Fuel sampling plot at the Priest River Experimental Forest. Right photo: Sampling frames overlying masticated fuels. The fuels were masticated in 2012. The large frame outlines the collection area for depth measurements, while the small frame outlines the area where materials were collected for physical and chemical analysis. Photos courtesy of Art Sikkink.

Coupled Fire-Atmosphere Behavior in Complex Topography: Identification of Critical Phenomena of Past Fire Events

While operational models provide an excellent means to capture aspects of fire behavior, such as fire spread rate and direction, they are not able to capture all of the complex interactions among fire behavior, fuels, atmospheric condition, and complex terrain common to severe fire events such as the Mann Gulch Fire that resulted in the death of 13 firefighters in 1949. FFS Research Ecologist Russ Parsons and scientists at the Los Alamos National Laboratory have partnered to further develop a physical-process model called FIRETEC. Combining physical-process models like FIRETEC with observed weather, fuel, topography, and fire behavior allows researchers to validate model performance during critical periods of fire behavior and explain the evolution of events that lead to specific transitions in fire behavior. These researchers will use simulations of portions of past extreme fire events, including the 1949 Mann Gulch Fire in Montana and the 2011 Las

Conchas Fire in New Mexico, as well as the 1994 South Canyon and the 2012 Waldo Fires in Colorado, to 1) validate FIRETEC's ability to capture the observed, often complex fire behavior of these severe events; 2) evaluate atmospheric, fuels, and topographic factors that resulted in transitions in fire behavior during these events; and 3) establish new perspectives concerning critical phenomena during these events. These high-resolution FIRETEC simulations will be the first of their kind, providing detailed time-dependent characterization of the interactions among turbulent winds, heterogeneous vegetation, fire-induced in-drafts, and complex topography. This study should provide quantitative information that helps in the development of the next generation of operational decision making tools, and thus help fire personnel anticipate, and avoid, situations in which rapid changes in fire behavior can lead to tragic results.

**For more information,
contact:** Russ Parsons at
rparsons@fs.fed.us



Photo: Upper Crossing Trail, Bandolier National Monument, NM, after the Las Conchas Fire. Photo courtesy of National Park Service.

Development and Validation of Combustion Process-based Emission Models



Wildland fires emit a substantial amount of atmospheric pollutants including carbon monoxide, methane, non-methane organic compounds, nitrogen oxides, fine particulate matter (PM_{2.5}), and black carbon. These emissions can have major impacts on regional air quality and global climate. The RMRS Smoke Emission and Dispersion Team is heading a project that tackles the fundamental research question of what role fuel moisture and fuel structure play in the production of pollutants from the combustion of wildland fuels. Since fuel moisture and fuel structure play an important role in the ignition and combustion of fuels, it has long been assumed that these variables must also influence the partitioning of gas emission products. However, no study has definitively verified or disproven this hypothesis. Experiments at the Missoula Fire Sciences Laboratory will identify relationships between fuel moisture/structure and combustion characteristics and develop empirical models to

predict the emission of pollutants. The empirical models developed in this project will be validated using independent field data. The expected outcomes of this project, including empirical models, will support the improvement of management and decision support tools. For example, uncertainties and application limits of the models will be quantified, and these models will be available for integration into widely used smoke management tools such as the First Order Fire Effects Model (FOFEM) and the Fire Emission Production Simulator (FEPS) software programs. The models developed in this project will also be published in peer-reviewed publications for use by the broader science community involved in biomass burning, atmospheric chemistry, and climate research.

For more information, contact: Shawn Urbanski at surbanski@fs.fed.us

Photo: Smoke column from the Beaver Creek Fire, August 15, 2013. Photo courtesy of Faith Ann Heinsch / FFS.

New Initiatives of the RMRS Smoke Emissions and Dispersion Team

The RMRS Smoke Emissions and Dispersion Team developed and recently initiated two climate-related projects. The first project will examine climate change impacts on future vegetation conditions, fire activity, fire emissions, and air quality in the United States. The objectives of this interdisciplinary, comprehensive project are to predict and assess the daily, monthly, seasonal, and annual changes and trends of vegetation and fuel conditions; fire season length (start and end date); fire activity (location, burned areas); fire intensity and emissions; and the effects of fires on air quality at local and regional scales in the continental U.S. from 2000 to 2060. This project, led by Supervisory Research Chemist Wei Min Hao, is based on state-of-the-art fire science, high-resolution global and regional climate models, and advanced air quality models. Results will be used by land, fire, and air quality managers to 1) support and guide the development of forest planning, air quality planning, and smoke management with respect to climate change and 2) comply with current and potential new air

quality regulations of the National Ambient Air Quality Standards as well as the Regional Haze Rule. Results, for example, on the length of the fire season, will also affect how land managers practice prescribed burning.

The second project will examine impacts of fire emitted black carbon on accelerated melting of Arctic ice. Black carbon, formed by combustion of fuel, is a short-lived warming aerosol that is particularly damaging to the Arctic because it darkens ice, thereby hastening melting. Decreasing black carbon emissions is one strategy to mitigate near-term global warming. The U.S. initiative on black carbon emissions, supported by the U.S. Department of State, addresses the most significant contributors of black carbon emissions that reach the Arctic. The Smoke Emissions and Dispersion Team will assess the impacts of black carbon emissions from forest, shrubland, and grassland fires in northern Eurasia on accelerated melting of Arctic ice. The Team will quantify the spatial and temporal variability of fire-emitted black carbon

deposition on Arctic ice from 2002-2012. Daily deposition will be reported during peak months of deposition. This project will be carried out in collaboration with the French Atomic Energy Commission, a leading national laboratory in France.

For more information, contact: Wei Min Hao at whao@fs.fed.us

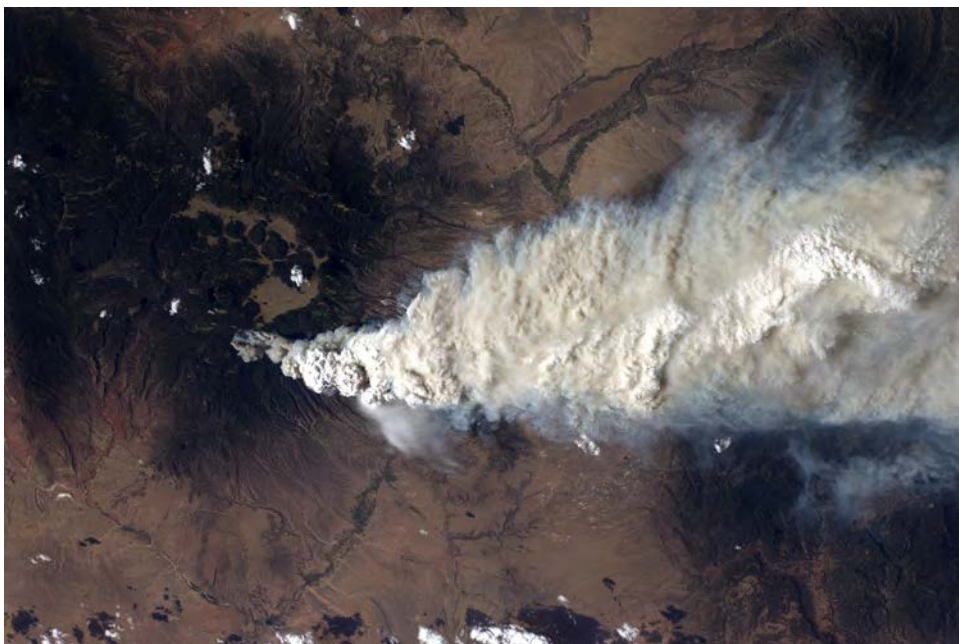


Photo: Photo taken of a fire in New Mexico by a crew member aboard the International Space Station on June 27, 2011. Research by the RMRS Smoke Emissions and Dispersion Team analyzes such fires to determine their chemical content, dispersion path, deposition, and ecosystem impacts. Photo courtesy of National Aeronautics and Space Administration.

Evaluating Assumptions Related to Thermal Infrared Remote Sensing of Fire

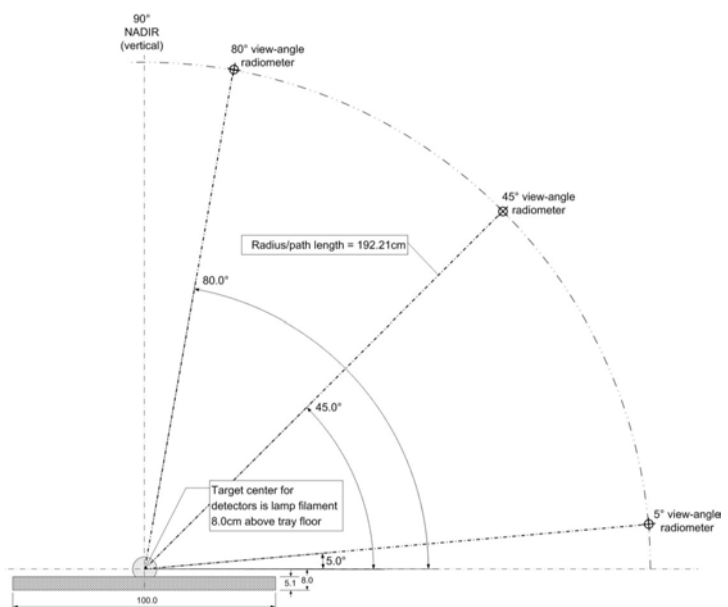


Thermal infrared remote sensing (TIR) is an increasingly popular approach for characterizing rate of combustion, flame geometry, and fire spread, as well as radiative energy budgets of wildland fires. TIR

measurements of fire have been acquired from space, aircraft (piloted as well as Unoccupied Aerial Systems), towers and booms, in situ field deployments, and bench-scale laboratory experiments. Spatial and temporal scales among these approaches vary by orders of magnitude, and sensor-to-target view angles and geometry vary greatly as well. Measurements from space, aircraft, and some tower or boom deployments are typically from nadir (directly overhead) with a view angle that is nearly perpendicular to the ground, while *in situ* and other tower- or boom-based observations are more oblique, or “side-looking”, relative to the flame structure of typical wildland (or even laboratory) fires. Yet, in most deployments, basic assumptions are both made and accepted regarding numerous aspects of TIR. FFS Program Manager Colin Hardy and collaborators are investigating three of what they believe to be the most significant assumptions: 1) that directionality of radiant emittance is hemispherically isotropic (the same from all directions); 2) that emissivity is greater than 0.95 (although it has been observed by others to range

from less than 0.20 to nearly 1.0); and 3) that flames are optically thick, even though studies have shown that flame optical depth (path length) varies from 0.5 to 3.0 times the flame height. The researchers are conducting a series of experiments that explore directionality using an observation system comprised of nine narrow-angle radiometers (TIR detectors), installed at three elevational angles above the horizontal (5°, 45°, and 80°) at each of three 120° directional azimuths around each burning flame bed. This array provides nine sampling points in the hemisphere of each flame bed. The radiometer array is supplemented by several high-speed TIR camera systems as well as visual cameras and thermocouples. Because the flame envelope is not spherical, both the path length and emissivity vary as a function of view-angle and view-height. These experiments will characterize those differences and will inform subsequent experiments that will explicitly address assumptions of emissivity and path length.

For more information, contact: Colin Hardy at chardy01@fs.fed.us



Top Photo: Observation system designed to test directionality of radiant emittance from a flame envelope.
Image: Schematic of the system design showing radiometers at three elevational angles above the horizontal.
Photo and image courtesy of Colin Hardy / FFS.

Development of a Code Block Framework for Fire Modeling Systems

Current fire danger, fire behavior, and fire effects modeling systems are used nationally and internationally by scientists and land managers from federal, state, and local agencies as well as university faculty and students. FFS researchers and staff develop and maintain fire modeling systems that continue to support research analyses and all aspects of wildland fire management including suppression, prevention, prescribed fire, fuel hazard analysis, and budgeting. These systems, based on a foundation of published mathematical models, are among the most widely used globally and include the BehavePlus fire modeling system, FARSITE: Fire Area Simulator, FireFamilyPlus, the First Order Fire Effects Model (FOFEM), FlamMap, the Wildland Fire Assessment System (WFAS), and WindNinja.

Existing systems are aging, and it is difficult to update systems with new research results. In response, FFS researchers are developing a new modeling framework based on current computer programming standards. Robust, reusable, consistent, and documented code blocks will be defined and developed such that they are replaceable with minimal impact to the rest of the code blocks and the systems containing them. These code blocks will then be used to develop prototypes of the next generation of fire behavior, fire danger, and fire effects systems.

For more information, contact: Mark Finney at mfinney@fs.fed.us or Matt Jolly at mjolly@fs.fed.us



Fuel Treatment Plan for Fort Huachuca, Arizona

Fort Huachuca is a U.S. Department of Defense facility in southeastern Arizona that is home to the Mexican spotted owl, a federally protected species. Fort Huachuca supports eleven Mexican spotted owl Protected Activity Centers (PACs) within its borders. Protection of the Mexican spotted owl, as required under the Endangered Species Act, requires preservation of habitat conditions necessary to provide roosting and nesting habitat. Decades of fire suppression have altered forest structure and species composition and led to increased surface fuel loading, compromising the resiliency of existing vegetation in this fire-adapted ecosystem. Potential fire effects were exemplified by the Monument Fire that burned adjacent lands in the Huachuca Mountains in June 2011. Fueled by drought and weather, this fire affected approximately 11 of 13 Mexican spotted owl PACs within the fire area. A wildfire within installation boundaries has the potential to drastically alter forest characteristics from that of the current multi-storied, multi-aged, pine and oak habitat required for Mexican spotted owl protection and recovery.



The purpose of this project is to alter vegetation and surface fuels to reduce the potential of widespread high-severity, stand-replacing fire within the Huachuca Mountains on Fort Huachuca, while maintaining and developing habitat conditions conducive for the owl and its prey. Fuel management activities (combinations of mechanical and/or prescribed fire treatments) will be designed to change the structure of wildland vegetation and biomass distribution for the purpose of modifying potential fire behavior.

The resulting fuel treatment plan will be based on landscape fire simulations to allow Fort Huachuca to treat minimum area for maximum benefit and produce forest structure and fuel characteristics that will reduce the likelihood that future wildfires will cause large, rapid changes in biophysical conditions in and around designated Mexican spotted owl habitat.

For more information, contact:

LaWen Hollingsworth at
lhollingsworth@fs.fed.us



Top photos: Topography and vegetation typical of Mexican spotted owl habitat. Bottom photo: Fort Huachuca has complex vegetation and topography, which must be considered in any fuel treatment plan. Photos courtesy of LaWen Hollingsworth / FFS.

EDUCATION AND OUTREACH

As the U.S. population increases and becomes more urban, the public becomes less familiar with the reality of wildland fire and its effects on ecosystems and human communities. At the same time, development continues in the wildland-urban interface, and fires have become more frequent and larger than in the mid-20th century. Increased understanding of the history of fire in America's wildlands, the principles of fire spread, and the nature of fuels is essential for the public to contribute to wise decisions on fire and resource management. The Missoula Fire Sciences Laboratory's Conservation Education Program provides tours, curriculum, teacher workshops, and presentations to increase the public's understanding of the science of wildland fire. FFS and the Fire Modeling Institute (FMI) located within FFS contribute to this conservation education effort in many ways.

Future Fire Science Managers

For students in grades 3-12, FFS staff provided tours for approximately 250 students and 15 teachers and other adults in 2013. Tours included activities focusing on fire safety, fire spread, fire ecology, and potential careers in fire research. One tour, provided for high school students from Browning, MT, investigated the flaming and smoldering properties of different kinds of wood used in traditional fire carriers. While attending the Fifth International Fire Congress in Portland, OR, FFS staff visited two schools near Salem, OR, introducing elementary school students in Kindergarten and Grades 4-5 to the FireWorks curriculum. This curriculum includes topics in fire safety, fire physics, and fire ecology. FFS staff also collaborated with teachers to test an Internet-based learning activity that explores the probability of fire and fire effects based on various scenarios of climate change, development in the wildland-urban interface, fuel treatments, and fire management.

For college students, FFS staff demonstrated principles of fire behavior at the Traditional Knowledge Workshop sponsored by the Northern Rockies Fire Science Consortium at Salish Kootenai College,



Photo: Fireweed, a fire-adapted species, is one of the species described in the FireWorks curriculum. Photo courtesy of Wknight94, Wikipedia Commons.

Education and Outreach

Pablo, MT. FFS staff also presented information on the Fire Effects Information System to a fire science class at the University of Montana. Undergraduate students from the University of Idaho visit the lab annually as part of their fire behavior and fire and fuel modeling courses, while students from the University of Montana toured the Missoula Fire Sciences Laboratory and spoke with FFS researchers and staff about current research projects. Students from the University of Kentucky that are pursuing graduate research in fire sciences visited FFS scientists and staff and used equipment available only at the Missoula Fire Sciences Laboratory.

Professional Development

FFS provided a two-day teacher workshop for teachers and agency educators on the FireWorks program, a curriculum and trunk filled with materials for hands-on activities that explore the physical and biological sciences of wildland fire. They also provided a one-hour demonstration of the FireWorks program for fire science professionals at the Fifth International Fire Congress in Portland, OR, and demonstrated principles of fire behavior at teacher workshops sponsored by the Glacier Institute and “A Forest for Every Classroom” program.

A number of college students from across the U.S. worked at the Fire Sciences Laboratory through internships, work-study programs, and volunteer opportunities. Students came from a variety of disciplines, including journalism and forestry. These students worked side-by-side with FFS researchers and staff, gaining valuable insight



and first-hand experience in many aspects of fire science and research.

Agency personnel from the U.S. Forest Service, Bureau of Land Management, and National Park Service participated in a mentorship program with the Fire Modeling Institute, in which they learned details of operational fire modeling systems such as FlamMap specifically tailored for their home units. University researchers and a research scientist from Bulgaria also participated in the mentorship program, increasing their knowledge of fire behavior modeling in their local areas.

Members of FFS also instructed a number of regional and national courses administered by the National Wildland Fire Coordinating Group. National-level courses included Advanced National Fire Danger Rating System and Geospatial Fire Analysis Interpretation and Application (S-495). Regional courses, taught in the Northern Rockies and Great Basin, included Introduction to Fire Effects (RX-310), Smoke Management Techniques (RX-410), Advanced Fire Behavior Calculations (S-490), and

Photo: Teachers and agency fire specialists investigate fuel properties in the FireWorks master class, February 2013.

Education and Outreach

Intermediate National Fire Danger Rating System (S-491).

Fire Modeling Institute

The Fire Modeling Institute is a national and international resource for fire managers. The three branches of FMI—Application Team, Information Team, and Modeling Team— provide different roles and assistance to managers and scientists in the application of fire science. The Application Team provides analysis, development, training, and support in fire behavior, fire ecology, modeling, and fuel treatment effectiveness. The Information Team develops literature reviews and other synthesis documents on how fire interacts with plants and animals of the United States. The Modeling Team maintains and develops a suite of fire behavior modeling systems that includes BehavePlus, FireFamilyPlus, FlamMap, and FARSITE. They also manage the operation, support, and expansion of the Wildland Fire Assessment System (WFAS) and the Weather Information Management System (WIMS). In 2013, FMI continued to help managers all over the world incorporate the most accurate, current knowledge, data, and technology available in fire

and natural resources sciences to address land management problems. The staff at FMI worked with a range of national and international partners, including other agencies, state and local governments, academia, and nonprofit groups. For example, in 2013, FMI staff provided fuels and fire behavior modeling, operations, and planning support during fire incidents occurring throughout the northern Rocky Mountains, Intermountain West, and Southwest, and a member of the FMI Modeling Team spent two weeks in Nepal providing comments and observations regarding fire management issues in Nepal to the Ministry of Forests and Soil Conservation.

Public Outreach

In addition to educational outreach, FFS researchers and staff provided tours and/or science demonstrations to members of the general public, agency administrators, and international visitors. These tours showcase the breadth of work done at the Missoula Fire Sciences Laboratory, including research performed in the combustion chamber and wind tunnel. Throughout the year, journalists from a variety of news media were provided with scientific background and information on a number of topics, including fire behavior, mountain pine beetle effects, and growth of wildland fires. For example, FFS researchers and staff hosted journalists from the New York Times, providing information for the article “Into the Wildfire: What Science is Learning about Fire and How to Live with It.”

For more information, contact: Kris Lee at kristinelee@fs.fed.us



Photo: Teachers attending the FireWorks master class use feltboard materials to tell the story of lodgepole pine's relationship with fire, February 2013.

2013 PUBLICATIONS

The Fire, Fuel, and Smoke Science Program of the U.S. Forest Service Rocky Mountain Research Station focuses on basic and applied research related to wildland fire, including wildland fire processes, terrestrial and atmospheric effects of fire, and ecological adaptations to fire. Results from this research are disseminated in a number of ways, including publications. The following list, separated by the focus areas outlined on pages 2-5, provides an overview of articles published in 2013. Links are provided for all publications.

Physical Fire Processes



Adam, Brittany A.; Akafuah, Nelson K.; Finney, Mark; Forthofer, Jason; Saito, Kozo. 2013. A study of flame spread in engineered cardboard fuelbeds. Part II: scaling law approach. In: Seventh international symposium on scale modeling (ISSM-7); 2013 August 6-9; Hirosaki, Japan. International Scale Modeling Committee. 10 p. <http://treesearch.fs.fed.us/pubs/44782>

Butler, B. W.; Ottmar, R. D.; Rupp, T. S.; Jandt, R.; Miller, E.; Howard, K.; Schmoll, R.; Theisen, S.; Vihnanek, R. E.; Jimenez, D. 2013. Quantifying the effect of fuel reduction treatments on fire behavior in boreal forests. *Canadian Journal of Forest Research*. 43(1): 97-102. <http://treesearch.fs.fed.us/pubs/43710>

Finney, Mark A.; Forthofer, Jason; Grenfell, Isaac C.; Adam, Brittany A.; Akafuah, Nelson K.; Saito, Kozo. 2013. A study of flame spread in engineered cardboard fuelbeds. Part I: correlations and observations. In: Seventh international symposium on scale modeling (ISSM-7); 2013 August 6-9; Hirosaki, Japan. International Scale Modeling Committee. 10 p. <http://treesearch.fs.fed.us/pubs/44781>

Finney, Mark A.; Cohen, Jack D.; McAllister, Sara S.; Jolly, W. Matt. 2012. On the need for a theory of wildland fire spread. *International Journal of Wildland Fire*. 22(1): 25-36. <http://dx.doi.org/10.1071/WF11117>

Finney, Mark A.; Maynard, Trevor B.; McAllister, Sara S.; Grob, Ian J. 2013. A study of ignition by rifle bullets. Res. Pap. RMRS-RP-104. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 31 p. <http://treesearch.fs.fed.us/pubs/43918>

Frankman, David; Webb, Brent W.; Butler, Bret W.; Jimenez, Daniel; Forthofer, Jason M.; Sopko, Paul; Shannon, Kyle S.; Hiers, J. Kevin; Ottmar, Roger D. 2012. Measurements of convective and radiative heating in wildland fires. *International Journal of Wildland Fire*. 22(2): 157-167. <http://dx.doi.org/10.1071/WF11097>

Frankman, David; Webb, Brent W.; Butler, Bret W.; Jimenez, Daniel; Harrington, Michael. 2012. The effect of sampling rate on interpretation of the temporal characteristics of radiative and convective heating in wildland flames. *International Journal of Wildland Fire*. 22(2): 168-173. <http://dx.doi.org/10.1071/WF12034>

Maynard, Trevor; Finney, Mark; McAllister, Sara; Grob, Ian. 2013. Ignition potential of rifle bullets. Tech Tips 5100: 1351 1301-SDTDC. San Dimas, CA: U.S. Department of Agriculture, Forest Service, National Technology and Development Program, Fire Management, San Dimas Technology and Development Center. 4 p. <http://treesearch.fs.fed.us/pubs/44776>

Photo: Flame from burning crib (page 16). Photo courtesy of Sara McAllister / FFS.

2013 Publications

McAllister, S.; Finney, M. 2013. Effect of crib dimensions on burning rate. In: Bradley, D.; Makhviladze, G.; Molkov, V.; Sunderland, P.; Tamanini, F., eds. Proceedings of the seventh international seminar on fire and explosion hazards (ISFEH7); 2013 May 5-10; Providence, RI. College Park, MD: University of Maryland, Research Publishing. 10 p. http://www.fs.fed.us/rm/pubs_other/rmrs_2013_mcallister_s001.pdf.

Fuel Dynamics



Andrews, Patricia L.; Cruz, Miguel G.; Rothermel, Richard C. 2013. Examination of the wind speed limit function in the Rothermel surface fire spread model. *International Journal of Wildland Fire*. 22(7): 959-969. <http://dx.doi.org/10.1071/WF12122>.

Keane, Robert E. 2013. Describing wildland surface fuel loading for fire management: a review of approaches, methods and systems. *International Journal of Wildland Fire*. 22(1): 51-62. <http://dx.doi.org/10.1071/WF11139>

Keane, Robert E.; Gray, Kathy; Bacciu, Valentina. 2012. Spatial variability of wildland fuel characteristics in northern Rocky Mountain ecosystems. Res. Pap. RMRS-RP-98. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 56 p. <http://treearch.fs.fed.us/pubs/42170>

Keane, Robert E.; Herynk, Jason M.; Toney, Chris; Urbanski, Shawn P.; Lutes, Duncan C.; Ottmar, Roger D. 2013. Evaluating the performance and mapping of three fuel classification systems using Forest Inventory and Analysis surface fuel measurements. *Forest Ecology and Management*. 305: 248-263. <http://dx.doi.org/10.1016/j.foreco.2013.06.001>

Lutes, D. C. 2013. Predicted fuel consumption in the Burnup model: sensitivity to four user inputs. Res. Note RMRS-RN-51WWW. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 11 p. <http://treearch.fs.fed.us/pubs/43326>

Lutes, Duncan C.; Hardy, Colin C. 2013. Lodgepole pine bole wood density 1 and 11 years after felling in central Montana. *Western Journal of Applied Forestry*. 28(3): 116-120. <http://treearch.fs.fed.us/pubs/44777>

Smoke Emissions and Dispersions



Akagi, S. K.; Yokelson, R. J.; Burling, I. R.; Meinardi, S.; Simpson, I.; Blake, D. R.; McMeeking, G. R.; Sullivan, A.; Lee, T.; Kreidenweis, S.; Urbanski, S.; Reardon, J.; Griffith, D. W. T.; Johnson, T. J.; Weise, D. R. 2013. Measurements of reactive trace gases and variable O₃ formation rates in some South Carolina biomass burning plumes. *Atmospheric Chemistry and Physics*. 13: 1141-1165. <http://dx.doi.org/10.5194/acp-13-1141-2013>

Urbanski, Shawn P. 2013. Combustion efficiency and emission factors for wildfire-season fires in mixed conifer forests of the northern Rocky Mountains, US. *Atmospheric Chemistry and Physics*. 13: 7241-7262. <http://dx.doi.org/10.5194/acp-13-7241-2013>

- Urbanski, Shawn P.; Kovalev, Vladimir A.; Hao, Wei Min. 2013. Airborne and lidar measurements of smoke plume rise, emissions, and dispersion. Data Catalog RDS-2013-0010. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. <http://dx.doi.org/10.2737/RDS-2013-0010>
- Wold, Cyle E.; Kovalev, Vladimir A.; Petkov, Alexander P.; Hao, Wei Min. 2012. Data processing technique for multiangle lidar sounding of poorly stratified polluted atmospheres: Theory and experiment. Extended abstract #12. In: Proceedings of aerosol and atmospheric optics: Visibility and air pollution specialty conference; 2012 September 24-28; Whitefish, MT. Pittsburgh, PA: Air and Waste Management Association. 7 p. <http://treesearch.fs.fed.us/pubs/44341>
- Yokelson, R. J.; Burling, I. R.; Gilman, J. B.; Warneke, C.; Stockwell, C. E.; de Gouw, J.; Akagi, S. K.; Urbanski, S. P.; Veres, P.; Roberts, J. M.; Kuster, W. C.; Reardon, J.; Griffith, D. W. T.; Johnson, T. J.; Hosseini, S.; Miller, J. W.; Cocker, D. R.; Jung, H.; Weise, D. R. 2013. Coupling field and laboratory measurements to estimate the emission factors of identified and unidentified trace gases for prescribed fires. *Atmospheric Chemistry and Physics*. 13: 89-116. <http://dx.doi.org/10.5194/acp-13-89-2013>

Fire Ecology



Harrington, Michael G. 2012. Duff mound consumption and cambium injury for centuries-old western larch from prescribed burning in western Montana. *International Journal of Wildland Fire*. 22(3): 359-367. <http://dx.doi.org/10.1071/WF12038>

Hood, Sharon M.; Smith, Helen Y.; Wright, David K.; Glasgow, Lance S. 2012. Management guide to ecosystem restoration treatments: two-aged lodgepole pine forests of central Montana, USA. Gen. Tech. Rep. RMRS-GTR-294. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 126 p. <http://www.treesearch.fs.fed.us/pubs/42173>

- Keane, Robert E.; Cary, Geoffrey J.; Flannigan, Mike D.; Parsons, Russell A.; Davies, Ian D.; King, Karen J.; Li, Chao; Bradstock, Ross A.; Gill, Malcolm. 2013. Exploring the role of fire, succession, climate, and weather on landscape dynamics using comparative modeling. *Ecological Modeling*. 266: 172-186. <http://dx.doi.org/10.1016/j.ecolmodel.2013.06.020>
- McWethy, D. B.; Higuera, P. E.; Whitlock, C.; Veblen, T. T.; Bowman, D. M. J. S.; Cary, G. J.; Haberle, S. G.; Keane, R. E.; Maxwell, B. D.; McGlone, M. S.; Perry, G. L. W.; Wilmshurst, J. M. 2013. A conceptual framework for predicting temperate ecosystem sensitivity to human impacts on fire regimes. *Global Ecology and Biogeography*. 22(8): 900-912. <http://dx.doi.org/10.1111/geb.12038>
- Sikkink, Pamela G.; Renkin, Roy; Chong, Geneva; Sikkink, Art. 2013. Assessing five field sampling methods to monitor Yellowstone National Park's northern ungulate winter range: the advantages and disadvantages of implementing a new sampling protocol. Final Report: Assessing Sampling Methods YNP 2013. Unpublished paper on file at: Missoula, MT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Missoula Fire Sciences Laboratory. 41 p. <http://treesearch.fs.fed.us/pubs/44773>

2013 Publications

Fire and Fuel Management Strategies



Fay, Bret; Hollingsworth, LaWen. 2012. Bald Mountain Fire long term fire assessment - V1.0 9/24/2012. Missoula, MT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Missoula Fire Sciences Laboratory. 20 p. <http://www.treesearch.fs.fed.us/pubs/44344>

Hollingsworth, LaWen. 2012. Bald Mountain Fire, Eagle Cap Wilderness Area, Wallowa-Whitman National Forest, FARSITE analysis. Missoula, MT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Missoula Fire Sciences Laboratory. 4 p. <http://www.treesearch.fs.fed.us/pubs/44343>

Keane, Robert 2013. Disturbance regimes and the historical range of variation in terrestrial ecosystems. In: Levin, Simon A., ed. Encyclopedia of biodiversity, second edition. Waltham, MA: Academic Press: 568-581. <http://dx.doi.org/10.1016/B978-0-12-384719-5.00389-0>

Ryan, Kevin C.; Knapp, Eric E.; Varner, J. Morgan. 2013. Prescribed fire in North American forests and woodlands: history, current practice, and challenges. *Frontiers in Ecology and the Environment*. 11(Online Issue 1): e15-e24. <http://www.esajournals.org/doi/pdf/10.1890/120329>

Ryan, Kevin C.; Opperman, Tonja S. 2013. LANDFIRE - A national vegetation/fuels data base for use in fuels treatment, restoration, and suppression planning. *Forest Ecology and Management*. 294: 208-216. <http://dx.doi.org/10.1016/j.foreco.2012.11.003>

Salis, Michele; Ager, Alan A.; Arca, Bachisio; Finney, Mark A.; Bacciu, Valentina; Duce, Pierpaolo; Spano, Donatella. 2012. Assessing exposure of human and ecological values to wildfire in Sardinia, Italy. *International Journal of Wildland Fire*. 22(4): 549-565. <http://dx.doi.org/10.1071/WF11060>

Sikkink, Pamela G.; Keane, Robert E. 2012. Predicting fire severity using surface fuels and moisture. Res. Pap. RMRS-RP-96. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 37 p. <http://treesearch.fs.fed.us/pubs/41470>

Thompson, Matthew P.; Calkin, David E.; Finney, Mark A.; Gebert, Krista M.; Hand, Michael S. 2013. A risk-based approach to wildland fire budgetary planning. *Forest Science* 59(1): 63-77. <http://dx.doi.org/10.5849/forsci.09-124>

Science Synthesis and Delivery

Abrahamson, Ilana L. 2013. Fire regimes in Hawai'ian plant communities. In: Fire Effects Information System, [Online]. Missoula, MT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Missoula Fire Sciences Laboratory (Producer). <http://www.feis-crs.org/beta/>

Abrahamson, Ilana L. 2013. *Goodyera repens*. In: Fire Effects Information System, [Online]. Missoula, MT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Missoula Fire Sciences Laboratory (Producer). <http://www.feis-crs.org/beta/>

2013 Publications

- Abrahamson, Ilana; Lyon, Katie. 2012. An annotated bibliography of scientific literature on research and management activities conducted in Coram Experimental Forest. Missoula, MT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Missoula Fire Sciences Laboratory (Producer). 68 p. <http://www.fs.fed.us/rm/coram/docs/bibliography.pdf>
- Fryer, Janet L., compiler. 2013. Research Project Summary: Forest floor and plant responses to experimental fires in an Alaskan black spruce/feather moss community. In: Fire Effects Information System, [Online]. Missoula, MT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Missoula Fire Sciences Laboratory (Producer). <http://www.feis-crs.org/beta/>
- Fryer, Janet L., compiler. 2013. (Revised from Uchtyl, Ronald J., compiler, 1991.) Research Project Summary: The effects of experimental fires in an Alaskan black spruce/feather moss community. In: Fire Effects Information System, [Online]. Missoula, MT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Missoula Fire Sciences Laboratory (Producer). <http://www.feis-crs.org/beta/>
- Gucker, Corey. 2012. *Cornus sericea*. In: Fire Effects Information System, [Online]. Missoula, MT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Missoula Fire Sciences Laboratory (Producer). <http://www.feis-crs.org/beta/>
-  Gucker, Corey. 2012. *Rubus parviflorus*. In: Fire Effects Information System, [Online]. Missoula, MT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Missoula Fire Sciences Laboratory (Producer). <http://www.feis-crs.org/beta/>
- Innes, Robin J. 2013. *Eriophorum viridicarinum*. In: Fire Effects Information System [Online]. Missoula, MT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Missoula Fire Sciences Laboratory (Producer). <http://www.feis-crs.org/beta/>
- Innes, Robin J., editor. 2013. Fire Modeling Institute FY2012 annual report: Bridging scientists and managers. Unpublished paper on file at: Missoula, MT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Missoula Fire Sciences Laboratory. 38 p. <http://www.firelab.org/fmi/projects>
- Innes, Robin J. 2013. Fire regimes of Alaskan coastal herbaceous communities and active inland dunes. In: Fire Effects Information System, [Online]. Missoula, MT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Missoula Fire Sciences Laboratory (Producer). <http://www.feis-crs.org/beta/>
- Innes, Robin J. 2013. Fire regimes in Alaskan tundra communities. In: Fire Effects Information System, [Online]. Missoula, MT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Missoula Fire Sciences Laboratory (Producer). <http://www.feis-crs.org/beta/>
- Innes, Robin J. 2013. *Odocoileus hemionus*. In: Fire Effects Information System, [Online]. Missoula, MT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Missoula Fire Sciences Laboratory (Producer). Available: <http://www.fs.fed.us/database/feis/>
- Innes, Robin J. 2013. *Odocoileus virginianus*. In: Fire Effects Information System, [Online]. Missoula, MT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Missoula Fire Sciences Laboratory (Producer). <http://www.feis-crs.org/beta/>

Photo: Cushenbury milkvetch is one of the species added to the FEIS database during 2013.

2013 Publications

Meyer, Rachelle. 2012. *Aphelocoma coerulescens*. In: Fire Effects Information System, [Online]. Missoula, MT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Missoula Fire Sciences Laboratory (Producer). <http://www.feis-crs.org/beta/>

Meyer, Rachelle. 2012. *Corydalis sempervirens*. In: Fire Effects Information System, [Online]. Missoula, MT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Missoula Fire Sciences Laboratory (Producer). <http://www.feis-crs.org/beta/>

Meyer, Rachelle. 2012. *Ranunculus glaberrimus*. In: Fire Effects Information System, [Online]. Missoula, MT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Missoula Fire Sciences Laboratory (Producer). <http://www.feis-crs.org/beta/>

Reemts, Charlotte. 2012. Management Project Summary: Response of woody species to crown fires in oak-juniper woodlands (Texas). In: Fire Effects Information System, [Online]. Missoula, MT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Missoula Fire Sciences Laboratory (Producer). <http://www.feis-crs.org/beta/>

Sclafani, Christie J. 2012. *Berberis nevadensis*. In: Fire Effects Information System, [Online]. Missoula, MT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Missoula Fire Sciences Laboratory (Producer). <http://www.feis-crs.org/beta/>

Sclafani, Christie J. 2012. *Ceanothus ophiochilus*. In: Fire Effects Information System, [Online]. Missoula, MT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Missoula Fire Sciences Laboratory (Producer). <http://www.feis-crs.org/beta/>

Sclafani, Christie J. 2013. *Astragalus albens*. In: Fire Effects Information System, [Online]. Missoula, MT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Missoula Fire Sciences Laboratory (Producer). <http://www.feis-crs.org/beta/>

Sclafani, Christie J. 2013. *Dodecahema leptoceras*. In: Fire Effects Information System, [Online]. Missoula, MT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Missoula Fire Sciences Laboratory (Producer). <http://www.feis-crs.org/beta/>

Short, Karen C. 2013. Spatial wildfire occurrence data for the United States, 1992-2011 [FPA_FOD_20130422]. Data Catalog RDS-2013-0009. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. <http://www.fs.usda.gov/rds/archive/Product/RDS-2013-0009>

Short, K. C. 2013. A spatial database of wildfires in the United States, 1992–2011. Earth System Science Data Discussion. 6: 297-366. <http://www.earth-syst-sci-data.net/6/1/2014/essd-6-1-2014.html>.

Smith, Diane. 2013. Yellowstone National Park and the summer of fire. Rural Connections. 7(1): 31-34. http://wrwc.usu.edu/files/publications/publication/pub_7956191.pdf

Smith, Diane M.; Hardy, Colin C. 2012. Fire, Fuel, and Smoke Science Program: 2012 research accomplishments. Unpublished paper report on file at: Missoula, MT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Missoula Fire Sciences Laboratory. 44 p. http://www.firelab.org/Publications/2012_FFS_Annual_Report.pdf



2013 Publications

- Smith, Jane Kapler. 2013. Developing high-quality syntheses: guidelines for syntheses that meet fire manager's needs and are scientifically defensible. Final Report to Joint Fire Science Program, Project 11-S-2-4. Boise, ID: Joint Fire Science Program. Unpublished paper on file at: Missoula, MT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Missoula Fire Sciences Laboratory. 7 p. http://www.firescience.gov/projects/11-S-2-4/project/11-S-2-4_final_report.pdf
- Stein, S. M.; Menakis, J.; Carr, M. A.; Comas, S. J.; Stewart, S. I.; Cleveland, H.; Bramwell, L.; Radeloff, V. C. 2013. Wildfire, wildlands, and people: understanding and preparing for wildfire in the wildland-urban interface— a Forests on the Edge report. Gen. Tech. Rep. RMRS-GTR-299. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 36 p. <http://treesearch.fs.fed.us/pubs/43016>
- Stone, Katharine R. 2013. *Accipiter gentilis*. In: Fire Effects Information System, [Online]. Missoula, MT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Missoula Fire Sciences Laboratory (Producer). <http://www.feis-crs.org/beta/>
- Zouhar, Kris, compiler. 2013. Research Project Summary: Plant succession following clearcutting and slash burning in the western Cascade Range, Oregon. In: Fire Effects Information System, [Online]. Missoula, MT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Missoula Fire Sciences Laboratory (Producer). <http://www.feis-crs.org/beta/>



Photo: FFS Research Forester Mark Finny studies flame structure with changing slope. Photo courtesy of Richard Barnes / OTTO.

The U.S. Department of Agriculture (USDA) prohibits discrimination in all its programs and activities on the basis of race, color, national origin, age, disability, and where applicable, sex, marital status, familial status, parental status, religion, sexual orientation, genetic information, political beliefs, reprisal, or because all or part of an individual's income is derived from any public assistance program. (Not all prohibited bases apply to all programs.) Persons with disabilities who require alternative means for communication of program information (Braille, large print, audiotape, etc.) should contact USDA's TARGET Center at (202) 720-2600 (voice and TDD). To file a complaint of discrimination, write to USDA, Director, Office of Civil Rights, 1400 Independence Avenue, S.W., Washington, DC 20250-9410, or call (800) 795-3272 (voice) or (202) 720-6382 (TDD). USDA is an equal opportunity provider and employer.

Federal Recycling Program



Printed on Recycled Paper