FIRE SCIENCE DIGEST
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# Capturing Fire:
## RxCADRE Takes Fire Measurements to Whole New Level

**Models of fire behavior and effects do not always make accurate predictions, and there is not enough systematically gathered data to validate them. To help advance fire behavior and fire effects model development, the Joint Fire Science Program is helping fund the RxCADRE, which is made up of scientists from the U.S. Forest Service and several universities who orchestrate and collect data on prescribed burns in the southeastern United States. The RxCADRE-prescribed burns are yielding a comprehensive dataset of fire behavior, fire effects, and smoke chemistry and dynamics, with measurements taken systematically at multiple, cascading scales. RxCADRE data will help scientists and modelers test their models and develop better ones, ultimately making models more reliable. The RxCADRE team is pioneering new data-gathering technologies and new approaches to collaborative science.**

It is 1155 hours, November 10, 2012, at Eglin Air Force Base, on the Gulf Coastal Plain of the Florida Panhandle. A mild southeast breeze riffles the tawny grass on Test Area B-70, Eglin's sole land test area. Thirty-six scientists stand alert at their assigned stations, waiting for the go signal.

The scientists represent a spectrum of fire-related disciplines—fire ecology, fire behavior, fire effects, meteorology, and smoke science. They have spent the previous week measuring every conceivable aspect of this 400-hectare study plot. They have clipped patches of grass and shrubs down to the soil and weighed and measured the clippings. They have scanned the study site with LiDAR instruments, gathering stunningly detailed maps of vegetation in three-dimensional space.

They've laid packages of heat-measuring instruments, wrapped in fireproof silver skins, all over the site to measure air temperature, flame radiance, vertical and horizontal mass flow, and radiant and convective heat flux.

They've mounted video and infrared cameras on towers to capture the fire's rate of spread and lengths of its flames. They've launched a weather balloon to measure ambient atmospheric conditions. They've placed 75 anemometers around the plot perimeter to measure wind speed and direction and 13 electronic beta attenuation monitors (EBAMs) to take ground-level readings of smoke particles, temperature, humidity, and wind speed at 5-minute intervals.

Next to the burn unit, six levels of additional meteorological instruments are laddered up a mobile, 30-meter-tall steel telescoping tower from California State University, called CSU-MAPS (Mobile Atmospheric Profiling System). A Doppler LiDAR and a microwave profiler are set up on the back of a pickup truck, ready to track the movement of the smoke plume.

Overhead, a twin-engine Piper Navajo patrols the airspace between 6,000 and 10,000 feet of altitude, reading the wind and weather and preparing to take a time-lapse movie of the fire's radiation as the fire front passes below. Two thousand feet below the Navajo, another twin-engine airplane, a DeHavilland Twin Otter, gets ready to chase the smoke plume. Two and a half thousand feet below the Twin Otter, two unmanned aircraft, loaded with instruments, loiter in an adjacent airspace, ready to swoop in under the airplanes and map the fire's progression and heat release at high resolution.

1159 hours. A second balloon, equipped with sensors to measure chemicals and particulate matter in smoke, is released in the pathway of the soon-to-be-ignited fire. It rises to 300 feet and bumps gently against its tether. A third unmanned aircraft, a mini helicopter called a Scout, buzzes up like a wasp from the fire line, its camera ready to capture infrared images of the flames.

1200 hours. It's go time. Yellow-suited firefighters move through the grass on their all-terrain vehicles, dripping flame from torches. The fire catches, wavers, and bellies gently before the wind. It spreads unevenly, then comes together, licking the grasses.

The Twin Otter moves downwind to catch the rising smoke. The pilot banks steeply and begins a spiral around the plume, sucking samples in through ports jutting from the sides of the plane's fuselage. The largest of the waiting unmanned aircraft, the ScanEagle, moves in and circles the perimeter of the burn unit, capturing and streaming infrared imagery to the control center.

Randy Gon, U.S. Air Force

Fire ecologist Brett Williams takes wind readings before the fire.

Roger Ottmar, USFS

Brian Gullett and the team from the Environmental Protection Agency prepare to launch a balloon into the smoke plume to measure emissions from the forested research burn block.

Ellen Eberhardt, USFS

This unmanned aircraft system from the University of Alaska Fairbanks prepares to launch and collect infrared and visible imagery over an RxCADRE research burn block for assessment of fire behavior.

Randy Gon, U.S. Air Force

A member of Eglin Air Force Base's Jackson Guard awaits the order to ignite the RxCADRE prescribed fire.

Beneath the ScanEagle, the other two unmanned aircraft make ribbon-candy passes over two smaller subplots with coffee cans of glowing charcoal marking their corners. These aircraft capture a stream of visible and infrared images of the flame front. Thanks to careful programming and remote control, they deftly avoid hitting the towers and balloons.

Eglin Air Force Base, one of the Air Force's largest bases, has a bombing range that spans many thousands of hectares, but no bombs are falling today. Instead, 36 scientists watch as fire's ancient energy is captured, photographed, mapped, sensed, counted, measured, weighed, and rendered into data.

## Closely Watched Fires

In the mid-2000s, there was growing concern within the fire science and management communities that the models being used to predict fire and smoke behavior were not reliable. "So in 2005," says Roger Ottmar, "a group of scientists put together an ad hoc group to meet once or twice a year and decide what to do about it." What they did was initiate one of the largest collaborative fire research efforts in the United States. In the process, they created some of the most closely watched fires in the history of humankind.

Ottmar is a research forester with the U.S. Forest Service Fire and Environmental Research Applications Team in Seattle. He is the prime mover behind RxCADRE, which stands for Prescribed Fire Combustion and Atmospheric Dynamics Research Experiment. Models currently used for predicting fire behavior, fire effects, and smoke dynamics may be built on the best information available, Ottmar says. Yet there is not enough real-life data to test them and identify their strengths and weaknesses. "To validate these models," he says, "you have to know not only what goes into the model, but what comes out—not only how much fuel was out there, for example, but how much of it was actually burned. You can't evaluate your model with the same data you used to build it."

The RxCADRE team is building just such a validation dataset—a suite of coordinated measurements taken before, during, and after a set of prescribed fires. So far they have carried out three sets of carefully designed, intensively measured experimental burns in simple fuelbeds, grass and shrubs, mostly. The 2012 burns at Eglin Air Force Base were the latest of the three (the others were in 2008 and 2011), and, thanks to funding from the Joint Fire Science Program (JFSP), the most richly instrumented to date.

## Replicas of Reality

Fire plays a central role in human history and culture, and for that reason, humans throughout the ages have tried to understand it. Modern scientists have plumbed some of fire's mystery by building models—computer-aided mathematical or statistical simulations of how a wildfire behaves and how it transforms the landscape. True to its name, a model is a replica of reality—"like a scale model of a ship or an airplane," says Gary Achtemeier, a U.S. Forest Service research meteorologist who helped the RxCADRE team develop its study plan. "It's an approximation of a process—in this context, a physical process, like the behavior of fire or smoke."

An approximation, of course, is not the same as the real thing. Part of the reason why fire is so hard to model is that it is a product of unique conditions of a given landscape in a given place and time. There are infinite variations in factors that influence fire behavior and effects. "Here's a quote I stole from a colleague," says research ecologist Matt Dickinson of the U.S. Forest Service Northern Research Station, who led RxCADRE's event-scale fire mapping group. "'Fire science is not rocket science—it's way more complicated.'"

Models fall into two broad categories: statistical/empirical and physical process-based. Statistical/empirical models typically draw on information gathered from past fires in laboratory settings and on the land, burning under a variety of conditions. This information has been collected by different people for different reasons in different ecosystems and at different scales.

A statistical/empirical model is reliable only when it is applied in circumstances that closely resemble those from which its data were gathered. The wider the disparity between model data and the conditions at hand, the less reliable the predictions will be.

Physical process models, in contrast, are based on scientists' understanding of physical processes, as represented by equations that describe combustion in grass or shrubs, for example, or heat sinking into the soil. In theory, these models are more universally applicable, because they don't depend on historically limited data. Yet, most have not been fully validated—their projections have not yet been compared to measurements taken from actual burns. In addition, most physical process-based models are too complicated to use operationally. Many of the models in common use today are semiempirical—they augment a statistical approach with some physical process equations to improve the accuracy of predictions.

It is not always obvious when a model is off base. Yet, as they have become essential tools for land managers for predicting the behavior of a fire (where it will burn, how fast it will spread, how high the flames will reach, how hot it will burn) and its effects on the land and air (how much fuel it will consume, how much it will scorch the soil, how much smoke it will produce, where that smoke will drift and what it will carry), models need to mimic reality as closely as possible. They need to be validated against known data, in much the same way one would validate a car's odometer against mileposts along the highway. This is where RxCADRE comes in. "When we did our review of the literature," Ottmar says, "we found there wasn't any really strong dataset out there that could be used for this validation."

## Hierarchical Linkages

A key strength of the RxCADRE project is the stepwise, hierarchical structure of its data. Just as fine-scale arrangement of fuels governs fire behavior, aspects of fire behavior—energy release, flame height, patterns of fire-front advancement—govern fire effects such as tree mortality, soil heating, and smoke emitted. Fuel consumption in turn governs smoke production. Smoke production, together with atmospheric conditions, governs how far smoke travels and what it carries. Within the RxCADRE study plan, each level of data feeds the next.

An example of this linkage, says Joe O'Brien, is the way in which small variations in the amount, type, and arrangement of fuel can make a big difference in how a fire burns and spreads. "Until recently," says O'Brien, a U.S. Forest Service research ecologist who led the fire effects disciplinary team, "the lack of spatially explicit fire measurements at fine scales has severely limited our ability to connect the process of combustion with both fuels and fire effects."

At Eglin last November, O'Brien carried an infrared camera up onto a 26-meter-tall boom lift to capture images of the small plot fires at very high resolution, less than 1 square centimeter. "The technological advances that brought us high-resolution

Roger Ottmar, USFS

Joe Restaino, with the University of Washington, clips and collects biomass in the forested research block to determine fuel loading for each fuelbed component.


Joe O'Brien, USFS

Infrared and still camera captures fire spread from a 26-meter-tall boom lift positioned upwind of a research burn block.


Randy Gon, U.S. Air Force

Tara Strand and Susan O'Neal check over an electronic beta attenuation monitor, an instrument for measuring smoke concentrations downwind from the research burns.


Roger Ottmar, USFS

Joe O'Brien and Ben Hornsby, both with the U.S. Forest Service, prepare infrared and visible cameras to measure fire behavior from an 85-foot boom lift.

thermal imaging," he says, "have allowed us to explicitly connect the impact of patterns of burning on postfire ecological processes like mortality and regeneration. They have also shed light on how the spatial arrangement of fuels drives fire intensity and fire spread."

At the other end of the chain, researchers used ground-based, airborne, and balloon-mounted instruments to analyze the smoke as it rose from the forested operational burn. A team led by Brian Potter, a U.S. Forest Service research meteorologist, measured the smoke's particulate matter, as well as temperature, humidity, and wind speed, with EBAMs and other ground-based sensors. The team also used airborne instrument platforms—the airplanes, plus a tethered helium balloon called an aerostat—to gather measurements of particulate matter, black carbon, carbon monoxide, carbon dioxide, volatile organic compounds, and other pollutants at a range of altitudes.

In addition, Potter's team positioned video and still cameras outside the fire's perimeter to capture time-lapse photos of the developing smoke plume. The cameras were co-located to take video and still pictures from the same perspective. They were equipped with GPS locators, so that the images could be correlated, frame by frame, with wind velocity readings taken at the same moment. Modelers will be able to use this multidimensional information to reconstruct the plume's complex movements; they will even be able to track the interactions of separate plume segments with wind currents.

The RxCADRE team forged many such cross-linkages by capturing the same event from different spatial and temporal perspectives and with different instruments. "I really appreciated this comprehensive approach," says Bret Butler, a U.S. Forest Service research mechanical engineer who headed the fire behavior disciplinary team. Butler's team used ground-based instruments placed within the fire to measure air temperature and flow and radiant and convective heating, and they also placed an array of anemometers around the burn site to measure wind direction and speed.

"I've worked on many research burns in the past, and it seems like I nearly always come away wishing we'd measured something more," Butler says. "I haven't had that feeling with this project. I believe it represents the most complete characterization ever of wildland fire in a natural setting."

The RxCADRE researchers are now processing the mountain of data that came out of the 2012 burns. "We collected 10 terabytes," says Ottmar. "That's

Randy Gon, U.S. Air Force

Casey Teske, University of Montana scientist, places an instrument on a plot to be burned.

huge." Each scientist is responsible for describing his or her own data, organizing it, labeling it, uploading into an accessible repository, and working with data manager Bryce Nordgren of the U.S. Forest Service Rocky Mountain Research Station to document it accurately. The goal is to make the data available, and maximally useful, to any modeler or scientist who wants them. The RxCADRE team hopes to have all the data processed and available by December 2013.

## Collaboration

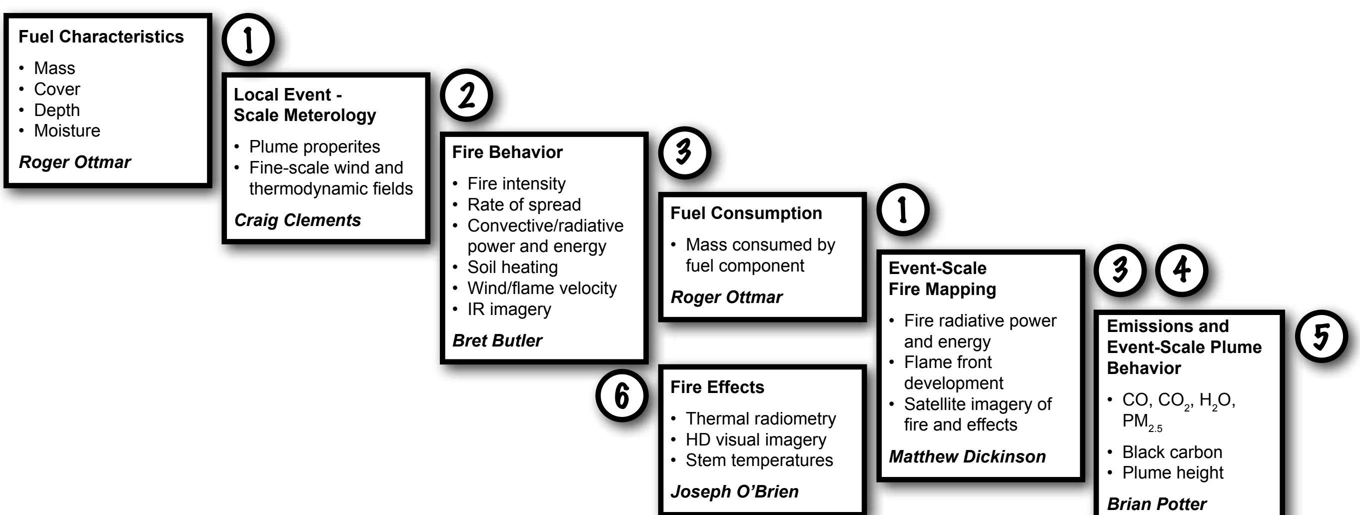
When Ottmar's scientists first met informally in 2005, they had no official sponsorship and no targeted research money. After talking about the various models and their data issues, they agreed to pool their funding and equipment and design a project. In 2008, they gathered at Eglin Air Force Base and the Joseph W. Jones Ecological Research Center, a longleaf pine forest in south Georgia that was once the private quail hunting reserve of a Coca-Cola CEO. They conducted their first prescribed burns in longleaf pine stands with understories of grass, saw palmetto, and turkey oak.

The 2008 exercise was, as much as anything, a proof of concept. Was it possible for more than three dozen scientists from diverse agencies, with diverse resources and objectives, to work in a multidisciplinary way? Such widespread collaboration is rare in the scientific world, says Ottmar. "The first challenge was to have everyone understand that they had to work together and leave their egos at the door." If they couldn't, "they were out."

The 2008 burns were successful, and in February of 2011 the team reassembled and conducted three more prescribed fires at Eglin. This time they were joined by scientists from NASA, the National Oceanic and Atmospheric Administration, Environmental Protection Agency, and Department of Defense, each of whom brought additional resources to the project.

As before, the researchers worked closely with the modeling community, enlisting scientists Gary Achtemeier, Mark Finney of the U.S. Forest Service Fire Sciences Laboratory in Missoula, Rod Linn of the Los Alamos National Laboratory, and William "Ruddy" Mell of the U.S. Forest Service Pacific Wildland Fire Sciences Laboratory, to help them develop a study plan that captured precisely the information modelers would need.

Also in 2011, the team tested a novel data-collecting technology: unmanned aircraft systems (UASs), also known as drones. These radio-controlled craft can go where humans can't, such as the hot, smoky airspace above a fire, and capture information from a range of altitudes. The three UASs flown in the




Roger Ottmar, USFS

The RxCADRE team organized their data into six interrelated disciplines and identified the variables to be measured under each one.

## Validating a Physics-Based Fire Behavior Model

"Imagine a computational grid covering a volume—say a forest stand 100 meters on a side," says William "Ruddy" Mell, a combustion engineer with the U.S. Forest Service Pacific Wildland Fire Sciences Laboratory. "In their most comprehensive form, physics-based models will solve all the equations governing the physical processes at each of the grid points." They have to crunch a lot of numbers to do that. This computational muscle, Mell says, makes physics-based models more true to life than the empirical or semiempirical kind, and hence better able to simulate complicated processes like fire spread rate over a range of environmental conditions. "For example, the same physics-based model can be used to simulate fire spreading through a single tree, a forest stand, a grass field, a pine needle bed, or a combination of these."

But physics-based models are costly in time and computer horsepower; a single run can take hours or days. If you're a manager who needs to do something about a fast-moving fire in real time, you can't wait. For that reason, fire managers rely on relatively user-friendly empirical or semiempirical models, such as BEHAVE and FARSITE.

These too have their tradeoffs. In practice, operational models are routinely applied to fuel, weather, and slope conditions that are outside those under which they were derived. This will reduce their accuracy, but it's impossible to know just how far off the mark a given prediction might be. In addition, it's important for the user to have a measure of how sensitive a model's prediction is to uncertainty in the input—say, wind speed.

Well-validated physics-based models, says Mell, can contribute to better fire management by helping managers get their arms around these limitations in current operational models. "They can help us understand where a model will be most wrong, how wrong it will be, and what we can do about it."

But first, physics-based models need to be tested against operational-scale fire measurements. In an earlier JFSP-supported project (JFSP Project No. 07-1-5-08), Mell and two colleagues validated their WFDS (Wildland-urban interface Fire Dynamics Simulator) model, using the best data then available: a large set of measurements from an RxCADRE-like study of prescribed fires in Australia in the early 1990s (Cheney, Gould, and Catchpole 1993). WFDS is a model suite, containing both a physics-based component and a simpler empirical component that is comparable to FARSITE, the most widely used landscape fire-spread model.

Mell and his colleagues found that both WFDS empirical (when properly tuned) and physics-based models predicted measured fire-front evolution pretty well in relatively simple situations. But under more complex conditions that included slopes, fuel breaks, and interacting fire lines, the empirical model differed from the physics-based approach because it could not account for important fire-atmosphere interactions. This is not news—it's well known that empirical models are limited in their capacity to simulate complex conditions. But Mell's study also shows the potential of physics-based models to improve the reliability of commonly used empirical models, such as BEHAVE and FARSITE.

"The promise of physics-based models is not to replace the use of simpler and faster models," says Mell, "but to provide a well-founded understanding of the limitations of simpler models and a means of improving them." Mell's work fed directly into the RxCADRE's study plan. The Australian data gave him a better idea of what kinds of real-life information are still needed to test physics-based models. "Now that RxCADRE has this great dataset," he says, "and we're better equipped to continue this kind of work."

2011 experiment carried long- and short-wave infrared sensors, carbon sensors, and instruments to measure relative humidity and wind, as well as a short-wave infrared camera and regular optical video cameras, which fed real-time video back to the command center. The 2011 findings were added to RxCADRE's growing database, and several of the scientists shared lessons learned from exercises at the 2009 Wildfire Congress in Savannah, GA.

By 2012, the RxCADRE project was fully fledged. More than 90 scientists and technicians were on board. Roger Ottmar, the prime mover behind RxCADRE, made a successful proposal to the JFSP for funding. The team further refined the data-gathering strategy, organizing it into six disciplinary categories. A noted scientist stepped forward to lead each discipline. And

Randy Gon, U.S. Air Force

An unmanned aircraft system is launched.

in the early summer of 2012, the team headed back to Florida.

## Developing the Methods

Eglin Air Force Base is an ideal place to study fire. As the home of the Air Force's 96th Test Wing, the base is located on 188,000 hectares of flat Gulf Coast shoreline just east of Pensacola. The area's natural community is characterized by longleaf pine savanna interspersed with flatwoods and wetlands. It's a landscape ecologically adapted to frequent low-level fire.

Eglin's Natural Resources Branch, known as the Jackson Guard, carries out an active prescribed fire program, burning more than 40,000 hectares a year to enhance wildlife habitat and knock back the woody plants that would invade in the absence of fire. They burn nearly year round—Eglin's mild coastal climate makes for predictable burning weather.

Eglin was convenient also because its ground and airspace are controlled by military, not civilian, authorities. The RxCADRE study plan called for deploying unmanned and manned aircraft at several altitudes at the same time. In a civilian setting, this would have been cumbersome and fraught with restrictions. Eglin's military authorities, moreover, were eager to demonstrate that military tools like UASs could benefit civilian science.

An added benefit was Eglin's willingness to handle RxCADRE's complicated logistics. The base's prescribed fire expertise helped the researchers focus on deploying their hundreds of instruments in exactly the right places, with no worries about managing the fires or directing traffic. "We just flooded everything with equipment," says Dan Jimenez, U.S. Forest Service research engineer and RxCADRE's program manager, "and told the igniters, go."

The team met at Eglin early in the summer for a detailed scoping session. They had already thought hard about what kinds of data they wanted, and at what scales. Now it was time to translate the wish list into a field methodology. "They came down, they walked the site, they talked about instruments," says Kevin Hiers, a fire ecologist with the RxCADRE team who is also the prescribed burn manager at Eglin. "Just burning something is relatively easy—you start the fire, you hold the fire, you keep people and property safe. But when you have all these research objectives layered in, things get complicated fast."

The study plots had to be carefully arranged in time and space. For example, vegetation in the areas for measuring fire behavior had to be left intact, which meant that the "clip plots" for sampling preburn fuels had to go somewhere else. Pathways for people and equipment had to be carefully routed around the study plots to avoid compaction of the fuels and damage to instruments. The team spent a week making decision after decision: where to concentrate the data gathering for each discipline, how to organize and spatially stage the complement of expensive instruments, and how to gather needed data within the constraints of a safe controlled burn.

The initial study plan called for two large operational-scale burns (up to 500 hectares) on land covered with grass and grass/turkey oak vegetation. Nested within these large plots were several smaller highly instrumented plots (HIPs) of 20 by 20 meters. The large burns, including the HIPs, were loaded with instruments to measure larger scale fire behavior and fire-atmospheric interactions, including smoke dynamics. Alongside the operational burn plots were

Roger Ottmar, USFS

Personnel from Eglin Air Force Base's Jackson Guard ride all-terrain vehicles to ignite a 200-hectare forested burn block.

Randy Gon, U.S. Air Force

An RxCADRE prescribed fire consumes trees and shrubs at Eglin Air Force Base, Florida.

six replicated 5-hectare plots, with instruments to measure fire behavior and fire effects at smaller scales.

The choice of a grass/shrub fuelbed near sea level may seem counterintuitive—a tame substitute for, say, a mid-elevation lodgepole pine forest in the Rockies. However, the decision was strategic and quite deliberate, Ottmar says. "The modelers told us they needed a good validation dataset starting with simpler fuelbeds. They said, 'Start with grass or grass/shrub, and then maybe move up to something more complicated.' So that's what we did, and it enabled us to collect a really comprehensive, quality dataset."

Logistics also urged simplicity. "We wanted to be reasonably sure we'd be able to burn as planned," Ottmar says. "The worst thing in the world is to bring all these scientists in and then have them sit around for a month, waiting for the fire."

After the two operational grass burns were laid out, it became clear that they would not be adequate for measuring smoke as thoroughly as it needed to be measured. "Even a 200-meter grass plot is literally a flash in the pan—it's up and over in a moment," says Ottmar. The team revised the study plan to include the third operational-scale burn in a longleaf pine stand, so that the smoke component could be adequately captured.

## Logistical Challenges

The team gathered at Eglin again in November. The weather was mild and bright, perfect for burning. Incident commander Brett Williams worked with the scientists to develop a detailed timetable for each of the 5 burn days: 1 day each for the three operational burns, plus 2 more days for the smaller plots.

The biggest logistical challenge was stacking five layers of aircraft safely in a small atmospheric cube, Hiers says. "We had to present our plan to the Air Force safety board and get approval through mission control for the way we had choreographed the aircraft. This was the most complicated burn operation we've ever conducted. It stretched us."

Because Eglin's airspace is closed to civilian traffic, RxCADRE was designated as an official Air Force mission, complete with mission number, and assigned exclusive airspace. The two manned airplanes were staged at a nearby municipal airport and received into Eglin's air traffic control system as they approached the study site. The UASs were deployed from the base (drones in civilian airspace are subject to many restrictions). After launch, they hung out in a "loitering zone" adjacent to the study site until it was time for them to fly in.

The piloted airplanes had to maintain a safe zone of about 1,500 feet above and below and about 1 nautical mile between craft at the same altitude. The UASs also were required to maintain smaller but still substantial safe zones. All the aircraft had to fly in a pattern that optimized the capture of data while avoiding collisions with one another, instrument towers, and balloons.

Thanks to the elaborate planning, plus a bit of luck in the form of perfect burning weather, all the experiments came off without a hitch. "We burned everything in 2 weeks, and we didn't have a day off," says Jimenez. "It was an amazingly fluid team, and we got a lot accomplished."

## Testing New Technologies

The 2012 experiments made it clear that RxCADRE is a fruitful proving ground for new hardware and new concepts. "It was an excellent test of innovative instrumentation," says Ottmar. The UASs, for example, are important not only as a research technique, but also as a potential management tool, capable of gathering data during an actual wildfire.

Another innovation was the use of co-located aerial and ground-based LiDAR to map and measure fuels. LiDAR tools are being perfected to characterize fuels in three dimensions over large areas, with potential to supplement or even supplant the tedious, expensive hand collection of data needed to characterize fuels accurately. "The LiDAR resolution was unbelievable," says Hiers. "We were literally identifying species from the point clouds—woody goldenrod, turkey oak." Ottmar was similarly

Roger Ottmar, USFS

The ground LiDAR TEAM, led by Carl Seielstad, prepares terrestrial LiDAR for capturing imagery for assessing fuels on the large, operational grassland burn block.

## A Gold Mine for Scientists

RxCADRE data will be valuable not only for land managers and modelers but for fire scientists, who use models to work toward a more subtle and precise understanding of the physics of fire. This inquiry process is an iterative loop, says Gary Achtemeier, in which the new data may answer some pressing question, only to raise other questions—which can be answered only with newer data.

Achtemeier, a U.S. Forest Service research meteorologist, is exploring the complicated territory of fire-atmosphere coupling—how fire responds to the ambient air currents and, at the same time, drives changes in these currents as it pours its heat into the atmosphere. Atmospheric currents are critically important in predicting the updraft of a smoke plume (or, more often, multiple plumes), and hence how fast heat, chemicals, and particulates are carried from the fire. These factors, in turn, are important in assessing the effects of smoke on air quality for neighboring communities.

Achtemeier is working with a plume-rise model called Daysmoke, which received early support from the JFSP (JFSP project #08-1-6-06). Daysmoke is actually a combination of three models: one to calculate smoke plume pathways, one to simulate the trajectory of smoke particles, and one to link these smoke models to weather data. To simulate smoke plume rise and dispersion, Daysmoke needs information on how the fire front is advancing. For this, it relies on another model Achtemeier developed called Rabbit Rules, a set of decision pathways that simulates the advance of the fire front by means of forward spotting—the governing analogy is of a rabbit hopping from one spot on the ground to the next.

Models like Rabbit Rules and full-physics fire models, Achtemeier says, can reveal a great deal about fire-atmosphere interactions because the model's physical process equations have the power to simulate these interactions from a range of hypothetical starting points, enabling the modeler to see how they differ. "But you can't know how accurate your output is until you validate the model," says Achtemeier. That requires starting with initial conditions that have been measured and tied to real output, such as the smoke measurements from the RxCADRE burns. Achtemeier is already using some of the RxCADRE's 2011 smoke and atmospheric data to refine Daysmoke and make it more useful for both managers and scientists.

The 2012 burns promise to yield even more information. For example, the infrared and video images of the fire front can be correlated with data on fire behavior and fire effects from the instruments on the ground. The resulting behavior of the fire front can then be compared with a Rabbit Rules simulation to see how closely the model's output matches real life.

impressed: "The LiDAR can pick up a single blade of grass."

"LiDAR does a good job of identifying shrubs, grass cover, and bare ground," agrees team member Carl Seielstad, a fire ecologist and fuels expert from the University of Montana. "It gets us part of the way there to fuels mapping, because you can overlay fuel classifications," making it possible to map LIDAR's distinctive spectral signatures of grasses, shrubs, and bare ground to already-developed classification systems that define these types in terms of their characteristics as fuel.

The larger point, says Hiers, is that the co-location of the LIDAR and other instruments—the ability to take simultaneous readings from different angles and at different scales—makes for a very rich dataset, giving modelers a multiscaled set of measurements that can be used at a range of resolutions, from a very fine plot level to a landscape scale.

## Synergy

After three fruitful data-collecting projects, RxCADRE is establishing a name for itself, says Roger Ottmar: "It's almost a household word among scientists and managers." He credits the JFSP for facilitating the team's extraordinarily effective collaboration. "When the JFSP funded our discipline groups, each of us then went out and enlisted other partners who brought their own funding," he says. "It was amazing how many people showed up, just because the Joint Fire Science Program put in this initial funding."

This collaborative research model, Ottmar says, is "the way of the future. With government research dollars drying up, we have to cooperate. And when we do, we can get these huge datasets with one organizational structure and one set of funds. Everybody wanted to piggyback on our project, and we said, 'All right! The more the merrier.' And everyone worked so hard and stepped up to the plate to help each other."

Adds Joe O'Brien: "I'm convinced the synergy among the researchers that has developed out of RxCADRE will go far beyond achieving the stated goals of this project. It's also the most fun and exciting work I do."

## Suggested Reading


Cheney, N.P., J.S. Gould, and W.R. Catchpole. 1993. The influence of fuel, weather and fire shape variables on fire-spread in grasslands. International Journal of Wildland Fire 3 (1): 31-44.

Daily Planet. 2012. Controlled Burn. Discovery Channel Canada. http://watch.discoverychannel.ca/#clip918742.

Macholz, L., C. Hardy, H. Heward, M. Hilbruner, P. Morgan, L. Queen, and C. Seielstad. 2010. Collaborative Research on Active Fires: An Investigation of Current Practices. National Center for Landscape Fire Analysis, University of Montana. http://firecenter.umt.edu/files/publications/LFC_Investigation_FinalReport.pdf.

Meares, M. 2009. Fire management integral to environment, military mission. Eglin Air Force Base, FL. http://www.eglin.af.mil/news/story.asp?id=123144578.

Ottmar, R., J.K. Hiers, and B. Williams. 2012. RxCadre: A Novel Approach to Wildland Fire Research. Southern Fire Exchange Fire Lines (newsletter), 2 (1). http://www.southernfireexchange.org/newsletters/v2-1.pdf.

Systems for Environmental Management. 2013. Public Domain Software for the Wildland Fire Community. http://www.fire.org/index.php?option=com_frontpage&Itemid=1.

U.S. Forest Service. 2012. Fire on the Base. Compass Live (newsletter). Southern Research Station, Asheville, NC. http://www.srs.fs.usda.gov/compass/2012/04/10/fire-on-the-base-4/.

U.S. Forest Service. Fire and Environmental Research Applications Team. Combustion-Atmospheric Dynamics Research Experiments (Rx CADRE) information page. http://www.fs.fed.us/pnw/fera/research/targeted/rxcadre.shtml.

U.S. Forest Service. Fire, Fuel, and Smoke Science Program. RxCADRE information page, http://www.firelab.org/research-projects/physical-fire/205-rxcadre.

Wildland Fire Science Partnership. Fire Measurements in the Southeastern United States. U.S. Forest Service, Rocky Mountain Research Station, University of Montana, and University of Idaho. http://www.firesciencepartnership.org/FL_RxCadreFactsheet.pdf.


Randy Gon, U.S. Air Force

A Jackson Guard member moves ahead of the smoke from an RxCADRE fire.

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