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From the Ground Up: New Fire Weather Model Boosts Accuracy

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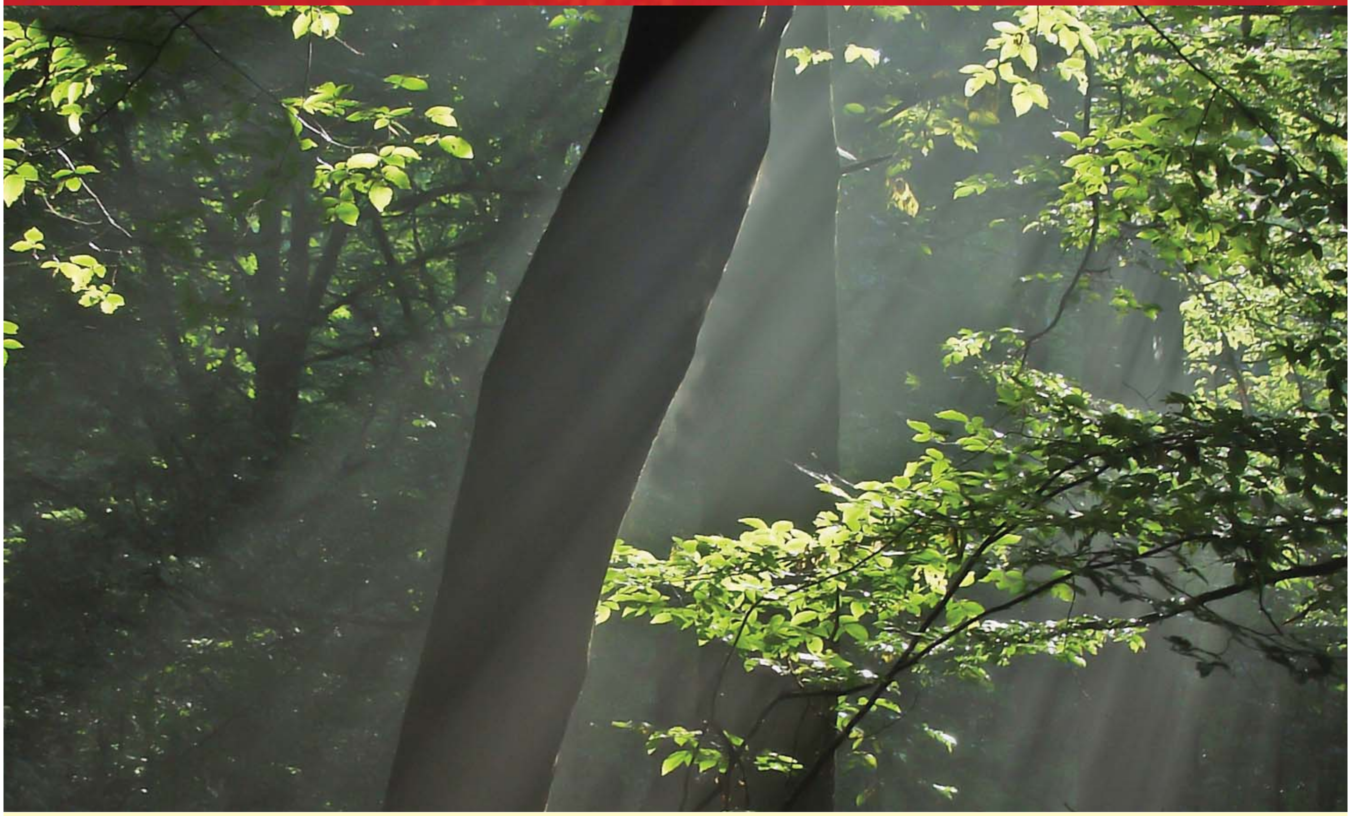
Joint Fire Science Program

Fire Science Brief

RESEARCH SUPPORTING SOUND DECISIONS



It's three o'clock. Do you know where your heat flux is? Credit: Aleksander Bolbot© / www.dreamtimes.com.

From the Ground Up: New Fire Weather Model Boosts Accuracy

Summary

Accurate regional weather forecasts are critical to successful wildfire operations and prescribed burns. Computer forecast models produce indispensable information about atmospheric conditions, but they can also generate some significant inaccuracies, most notably in relative humidity, ambient temperature, wind speed and direction. Accurate forecasts of these weather components are vital for successful assessment of fire danger. This project sought to improve the accuracy of forecast models, like MM5, which was used until recently by the USDA Forest Service, Rocky Mountain Center to predict fire weather over the western U.S. This project increased forecast accuracy by coupling MM5 with a new forecast model called FORFLUX. The combination, known as MFF, improves accuracy by measuring how much moisture will end up in the atmosphere as a result of ecosystem processes taking place at the earth's surface. MFF improves weather forecasts by providing more data about of the interactions between vegetation, soil and atmosphere and their resulting impacts on regional fire weather.

Key Findings

The MFF model improves forecast accuracy by providing:

- Marked improvement in air temperature and relative humidity forecasts.
- Slight improvement in wind forecast.
- Better predictions of precipitation amounts and timing.
- Improved fire danger indices through more accurate estimates of moisture content in live and dead vegetation.

Tracking down inaccuracies

The accuracy of forecasts produced by regional weather prediction models can make or break efforts to manage fire and smoke successfully. Forecasts of temperature, humidity, wind speed and direction and fuel moisture are critical components in the assessment of fire danger and allocation of fire fighting resources.

Over the last few decades mesoscale (regional) weather forecasts have improved considerably with current, widely used models: WRF, RAMS and MM5. Although these models describe atmospheric physics in great detail, they often fail to simulate realistic conditions at the earth's surface. That's because they provide only a simplified simulation of the complex interactions between vegetation and the atmosphere that impact temperature and humidity.

Like the systems they simulate, these models are perpetually evolving. Researchers are always working to bring predictions closer to reality. When inaccuracies are identified, scientists work to ferret out the cause and devise improved approaches to solving discrepancies between predicted and observed conditions.

Resolving these inaccuracies is of primary importance to the researchers at the Rocky Mountain Center for Advanced Modeling of Meteorology and Smoke (RMC). They specialize in the development and deployment of science-based computer applications for real-time delivery of fire weather information and smoke forecasts that support wildland fire operations, prescribed burns, and air-resource management in the western U.S. For over 5 years, RMC used the MM5 model to predict regional fire weather and smoke behavior. Although MM5 was a workhorse, it was known to generate some significant inaccuracies, especially with surface air temperatures and relative humidity. MM5 would routinely predict maximum daily temperatures that were too low, and nighttime temperatures that were too high. Relative humidity predictions were overestimated as well, in some cases as much as 41 percent.

In a project funded by the Joint Fire Science Program (JFSP), RMC scientists Ned Nikolov and Karl Zeller took a close look at the discrepancies between predicted and actual conditions and traced them to how the model was assessing the complex conditions at the earth's surface. They hypothesized that all of the regional forecast models, including MM5, lacked critical information about the interactions between soil, vegetation and the atmosphere, and that this information gap was leading to inaccuracies in forecasts, especially with regard to fire weather.

"Including detail about these interactions is critical for accuracy," explains Nikolov. "Managers allocate fire fighting resources and try to prevent fires by issuing alerts based on the immediate forecast of fire danger. The accuracy of the forecast has potential economic impacts as well as ramifications for human life and safety."

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The team solved the problems by merging MM5 with a model called FORFLUX which Nikolov had developed previously in collaboration with the Forest Service, Rocky Mountain Research Station. FORFLUX provides highly detailed information about the exchange of water, CO_2, and other trace gases between terrestrial ecosystems and the atmosphere. The resulting, combined model, known as MFF, represents a significant improvement over previous regional forecast models employed worldwide.

The new fire weather model, MFF, improves accuracy by using intricate details from atmospheric and biological processes taking place at the earth's surface—such as measurements of the amount of water evaporating off individual leaves. Credit: designsbydarren.com.

Touchy around the edges

A weather model is like a transparent, virtual box placed over a given geographical area. The sides of the box represent the edges or boundaries of the region for which a prediction will be generated. Energy and mass are constantly moving around and through these vertical and horizontal planes. Weather model boundaries are exceptionally sensitive to the interaction of conditions that intersect them, known as *boundary conditions*. This means that even small changes in the conditions at the edges of the box can lead to large shifts in predicted weather over a short period of time—changes that Nikolov and Zeller found can be as small as the amount of water evaporating from a single leaf—the butterfly effect in action.

In their research, they zeroed in on these sensitive boundaries looking for clues about what was throwing off the predictions in temperature and humidity in MM5. Specifically, they investigated the way the model represented the action taking place along the bottom of the box, where the atmosphere mingles with the soil and vegetation on the land surface. Known as the *lower boundary layer*, this lowest segment of the atmosphere is constantly teeming with chemical interactions and energy exchanges. This is the zone where soil, plants and evaporation exert considerable influence on atmospheric conditions. Nikolov and Zeller suspected that forecasts could be improved by supplying more accurate data in the lower boundary layer.

Targeting water's whereabouts

Nikolov's FORFLUX was designed to provide exactly what they needed. It's a land/surface, biophysical model which means that it applies physics to biological processes. It provides multilayered detail of the processes taking place in the lowest part of the boundary layer, known as the surface layer. It's unique in that it provides very fine details about the physics that govern how water moves up, through and out of plants and into the atmosphere—the information that MM5 was missing.

Nikolov and Zeller reshaped FORFLUX so that it would interface with the familiar MM5, to see if coupling the two models would solve the forecast inaccuracies. The resulting combination, now known as MFF, produced noticeable improvements. It generates markedly improved forecasts of surface air temperature, significantly more accurate predictions of relative humidity and slightly improved wind forecasts—all good news for anyone involved in wildfire fire operations.

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Flux matters

The merging of FORFLUX with MM5 generates more accurate fire weather forecasts because the combination enables more detailed information about—and prediction of—solar radiation's split personality: sensible heat flux and latent heat flux.

Solar radiation is the dominant form of energy received by the earth's surface, where it is initially absorbed by vegetation and soils. After absorption, the energy splits into two different types, the ratio of which determines how heat and moisture move through the air. One type of energy evaporates water. The other type heats the air by increasing the temperature of plants and soils. The more water available on the land surface, the more energy is applied to the task of evaporation (i.e., to convert water from liquid into vapor). The less water available for evaporation the more energy is used to heat the land surface and the air adjacent to it.

The energy that goes into raising the air temperature is called sensible heat flux, because we can feel, or sense this kind of energy. The energy that evaporates water is called latent heat flux because we can't feel it. It's hidden (latent) from our senses. The ratio of total energy converted into sensible vs. latent heat flux depends on current weather conditions and availability of water on the land surface. Water availability is determined by vegetation density and type, and the depth and texture of the soil.

This ratio strongly affects conditions in the surface layer. Sensible heat flux produces warming air that rises, impacting atmospheric stability. Latent heat flux impacts humidity by evaporating water. Accurate prediction of temperature, humidity and near-surface air flow is dependent on accurate prediction of this ratio.

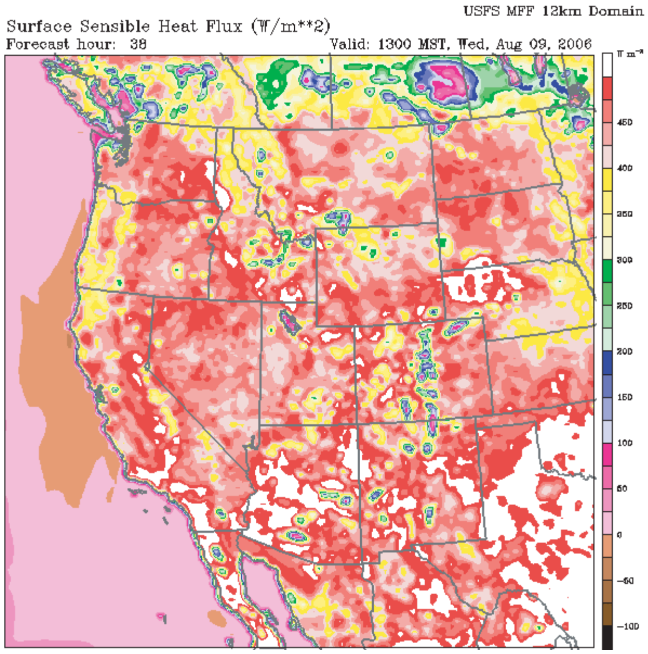
A ratio dominated by sensible heat indicates drier, warmer weather conducive to fire, and potentially increased fire danger. A ratio dominated by latent heat indicates higher humidity and potentially increased fuel moisture, which could reduce fire danger. This is why an incorrect ratio will significantly de-rail a fire weather forecast. The differences between predictions made by MM5 vs. the new MFF are compared in the figures on the following page.

Starting small and scaling up

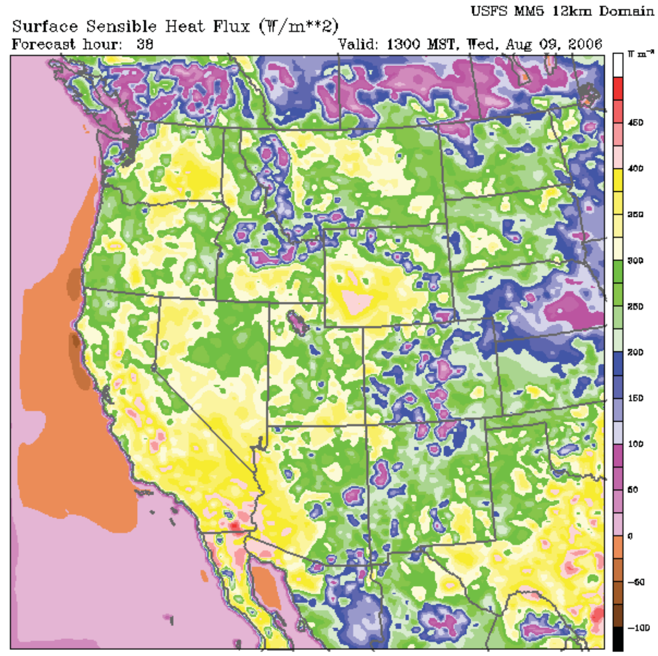
FORFLUX is able to predict this vital ratio accurately because it calculates the amount of water available for evaporation out of foliage and soil, which in turn tells us all we need to know about that very influential latent heat flux. It pulls this off by using high resolution satellite imagery to untangle and measure everything that's going on throughout the intricate layers of the canopy. Light, shade and wind speed vary throughout different canopy depths and densities, as do rates of transpiration. The microclimate in any given layer can differ from adjacent layers. FORFLUX uses a calculation called Leaf Area Index (LAI) that measures the area of foliage directly over a square meter of ground. A LAI of 2 means that you have 2 meters of leaves stacked over a given square meter of earth.

Intricate calculations are made at the level of each *individual leaf* and scaled up to determine the amount of water vapor being emitted by the entire canopy. It reflects seasonal changes by computing LAI for individual days

Sensible Heat Flux Predicted by MFF

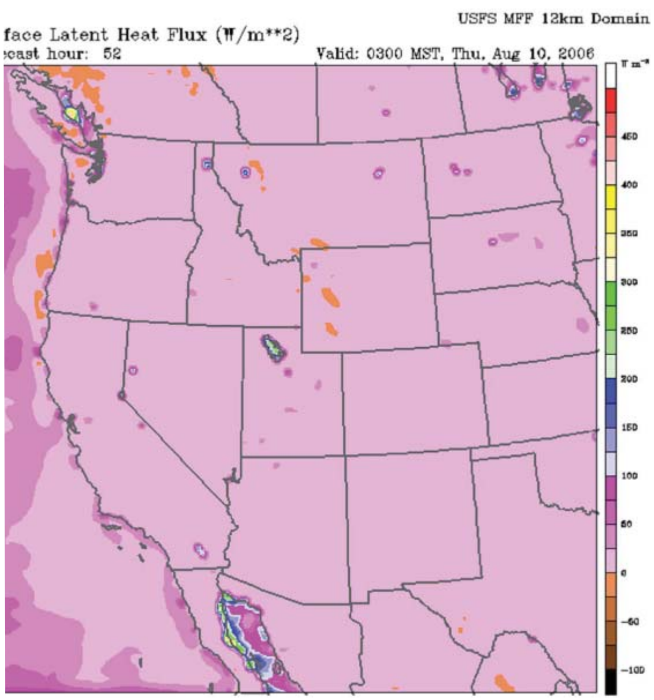


Sensible Heat Flux Predicted by MM5

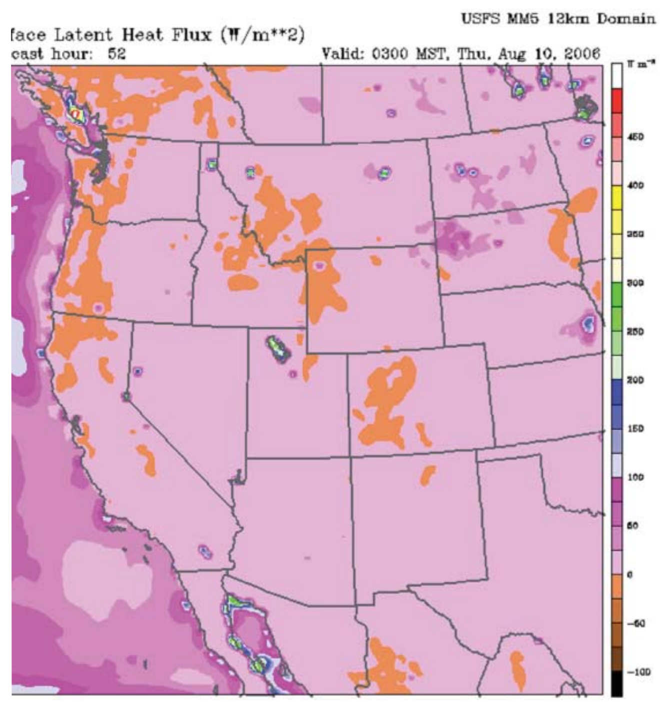


Left image shows daytime fields of sensible heat flux predicted by the new model MFF. Right image shows predictions made by the previous version of MM5 area, both for 13:00 MST on August 9, 2006.

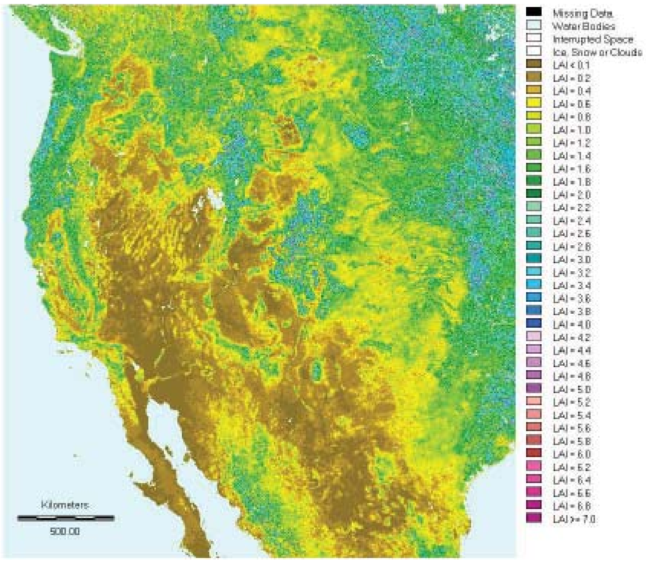
Latent heat flux predicted by new model MFF



Latent heat flux predicted by MM5



Left image shows nighttime fields of latent heat flux predicted by the new model MFF with MM5 prediction shown in the image on the right. 13:00 MST on August 9, 2006.



Summer maximum canopy Leaf Area Index over the western U.S. derived from 1-kilometer resolution AVHRR multi-spectral satellite images (Nikolov and Zeller) used by the new MFF weather forecast model. Via LAI, MFF predicts a much more realistic gradient of latent heat flux between arid and vegetated areas.

of the year. The satellite derived LAI values are validated against ground measurements from a variety of ecosystems in the continental U.S.

Perpetual improvement

"We are always striving to keep improving the forecast," Nikolov says. "You may have an algorithm that is perfect, but algorithms work with data. If your data is faulty the output won't be accurate. We are always working to better data sources to improve function even further."

Currently MFF uses MM5's 20 original soil categories (sand, loam, clay, etc.) and 24 vegetation types in its calculations, but Nikolov is perpetually working to add even more detail. He wants to be able to break down soil layers by the percentage of soil type in each, and to separate soil layers by depth. Currently, the model assumes that all soil is one meter deep, which of course is inaccurate, especially in the west where soils are shallow.

MFF is available online 24 hours a day, 7 days a week on RMC's interactive website.

MFF is available online 24 hours a day, 7 days a week on RMC's interactive website. It runs operationally twice per day for the western U.S. at two grid resolutions (12 and 8 kilometers) at the Forest Service, Rocky Mountain Center in Colorado. The site provides computations of fire danger indices based on based on temperature, humidity and precipitation and provides a verification feature that divides the U.S. into four windows with a total 1,200 weather stations. This allows the user to see how the model does on average, over the whole country or for individual regions.

Management Implications

- Delivers significantly more accurate fire weather forecasts improving fire operations, fire danger assessment and firefighter safety.
- Creates possibilities for improvement of existing NFDRS indices and development of novel indices using more accurate estimates of moisture content in live and dead vegetation.
- Saves time and computational resources without sacrificing forecast quality because of the ability to run at coarser resolutions.
- Provides improved fire-weather forecasts available 24/7 via user-friendly interactive web site.

Nikolov spells out the value of the work when he says, "If you have better accuracy—there you go—you have a better fire decision." Go hunt down your heat flux by visiting http://fireweather.info and click on RAWS sites forecast.

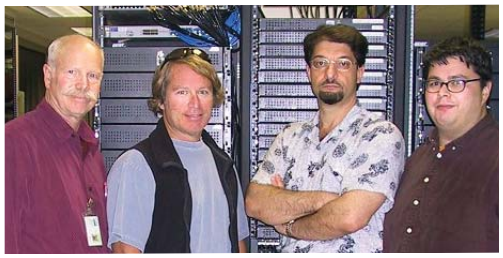
Further Information: Publications and Web Resources

RMC website: http://www.fireweather.info

RMC is one of the five regional members of the USDA Forest Service, Fire Consortia for Advanced Modeling of Fire and Smoke (FCAMMS): http://www.fs.fed.us/fcamms

Nikolov, N. and K. Zeller. 2003. *Forecasting of Fire Weather and Smoke Using Vegetation-Atmosphere Interactions*. JFSP project 03-1-3-02. Final report to Joint Fire Science Program online at: http://www.firescience.gov/projects/03-1-3-02/project/03-1-3-02_final_report.pdf

Scientist Profiles



The RMC Team: Karl Zeller, John Snook, Ned Nikolov, Michael Fajardo, and Luiz Teixeira (not pictured).

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Results presented in JFSP Final Reports may not have been peer-reviewed and should be interpreted as tentative until published in a peer-reviewed source.

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