Modeling Fire Behavior on Tropical Islands With High-Resolution Weather Data[1]

John W. Benoit[2], Francis M. Fujioka[2], and David R. Weise[2]

Abstract

In this study, we consider fire behavior simulation in tropical island scenarios such as Hawaii and Puerto Rico. The development of a system to provide real-time fire behavior prediction in Hawaii is discussed. This involves obtaining fuels and topography information at a fine scale, as well as supplying daily high-resolution weather forecast data for the area of interest. FARSITE, the fire simulation program we use, works with the fuel models commonly found in the contiguous United States, so vegetation found on an island needs to be mapped to fuel models accordingly. We examine a specific fire incident in detail, looking at how well it can be modeled given output from the system under development. Analysis of such examples can help in fire behavior prediction system calibration for real-time use. There are several potential causes of error between simulated and actual fire perimeter. Different methods of eliminating this error and improving accuracy of the simulation are considered. Finally, we discuss further work and challenges once a developing fire behavior prediction system becomes operational.

Introduction

Fire behavior in much of the world's larger land areas has been studied and modeled for some time. However, less is known of wildfires occurring in tropical island scenarios, such as Puerto Rico and the Hawaiian islands. More attention is now being focused on such fires for several reasons. Land use change, such as the movement of wildland urban interface boundaries, is resulting in the need for greater fire prevention and suppression. Areas inhabited by plants or animals that are now threatened or endangered may need special protection from fire. In some island locations, fire-fighting resources may not be readily available, stressing the importance of longer lead-times on fire activity. Wildfires on tropical islands may appear to be minor threats compared to those that occur on larger landmasses, but damages can be very costly.

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[2] Computer Specialist, Research Meteorologist, and Research Forester, respectively, Riverside Forest Fire Laboratory, Pacific Southwest Research Station, USDA Forest Service, Riverside, CA 92507

The U.S. Forest Service and other agencies have begun adapting existing fire behavior analyses and technology to better suit conditions found in Hawaii and similar environments. There has been recent work on mapping and modeling Hawaiian fuels (Weise and others 2005, Wright and others 2002, Clark and others 2004). A version of the U.S. National Fire Danger Rating System, originally designed for use in the contiguous United States, has been modified for use in the Hawaiian Islands. In this paper, we discuss a process for running a fire behavior simulation program in Hawaii, which had been designed for use on the U.S. mainland. These are tools that fire-fighting crews on the ground can use.

Cooperators in the Meteorology department at the University of Hawaii (UH), Manoa, are producing daily high-resolution weather forecasts for the state. Each daily forecast run is generated on a cluster computer running the MM5 weather model, and consists of 48 consecutive hourly forecasts at points spatially aligned on square grids over the Hawaiian Islands (see http://www.soest.hawaii.edu/MET/Faculty/mm5/). There are five grids, or domains, with varying spacings *(table 1)*. At each grid point, forecast values are computed for temperature, relative humidity, precipitation, wind speed and direction, and cloud cover.

Table 1—*Domains for the UH MM5 daily forecast.*

Domain	Grid spacing (km)	East-west points	North-south points
State 9		75	87
Kauai County	1.5	45	51
Oahu County	1.5	51	63
Maui County	3	48	72
Hawaii County	3	69	90

We worked with UH and a cooperator from the Institute of Computational Earth System Science (ICESS) at the University of California, Santa Barbara (UCSB) to make the output from the weather forecast model available as input into a computer program that predicts fire behavior called FARSITE (Finney 1998). FARSITE has been in use for some time in the contiguous U.S., but has seen little application in Hawaii. To simulate fire spread and other characteristics, FARSITE requires several input sources, namely topography, fuels information, and weather conditions. Topography and fuels information for fire-prone areas is often readily available to fire managers well in advance of a fire event. These data layers can be imported into FARSITE to create maps of wildland areas of concern. Accurate weather information, however, is harder to obtain. Weather data is dynamic in a FARSITE run – a different collection of variable values may be used for each hour of simulation run. In the case of real-time fire simulation, forecasted weather data is needed to predict future fire behavior. The daily production of FARSITE-ready weather forecast data from UH and UCSB fulfills this need for the Hawaiian Islands.

A Specific Case: The Waiohuli Fire

A recent fire incident gave us opportunity to test simulation runs in an island scenario. The Waiohuli fire was spotted on January 23rd, 2007 in a remote area on Mount Haleakala's western slope in Maui, Hawaii. Cause was attributed to a cigarette left close to a nearby hiking trail. The fire burned over 930 ha in seven days and cost more than $340,000 to contain. No structures were damaged, but many sandalwood trees and rare plants were destroyed. The state's Department of Land and Natural Resources' Division of Forestry and Wildlife (DOFAW) and others on the scene captured valuable information during the event, which helped greatly with our analysis. With this, along with available GIS data and weather data supplied by UH and UCSB, we assembled some fire simulations to compare with the actual behavior.

Because FARSITE is typically used with fuel models that occur commonly on the U.S. mainland, we had to adjust these fuel models to better match Hawaiian fuel characteristics. As mentioned earlier, some work has been done on statewide classification of vegetation into fuel models. However, we used information from a recent fire assessment study by the Pacific Disaster Center (PDC), located on Maui. The PDC study had a detailed analysis of fuels specifically for Maui, relating them to fuel models commonly used on the U.S. mainland *(table 2)*. PDC had also assembled fuels and topographic maps at 30-m resolution for Maui. We imported both of these maps into FARSITE.

Table 2—*Maui fuels from PDC study. Vegetation was mapped to the fuel models defined by Anderson 1982. FARSITE uses these fuel models, but allows custom fuel models to be defined. Equivalent NFDRS fuel models are also shown (Deeming and others 1972).*

Description NFDRS	fuel model	Anderson fuel model
Grass, kiawe trees, shrubs	L	1
Discontinuous pukiawe / 'a'ali'i	T	2
Fountain / guinea grass	N	3
Gorse shrub	B	4
Continuous pukiawe / 'a'ali'i	F	5
Fire-proof forest / shrub / scrub	R	8
Ironwood trees	H	8
Eucalyptus trees	G	10
Missing data, developed / cultivated land, deciduous forest, non-fuel, water	*n/a*	*0, 94, 95, 97, 98, 99*[a]

[a] treated as unburnable area.

PDC had collected satellite imagery of the area and overlaid it with the observed fire perimeter *(fig. 1)*. We used this to help verify that the landscape loaded into FARSITE was aligned with actual geography and fuels.

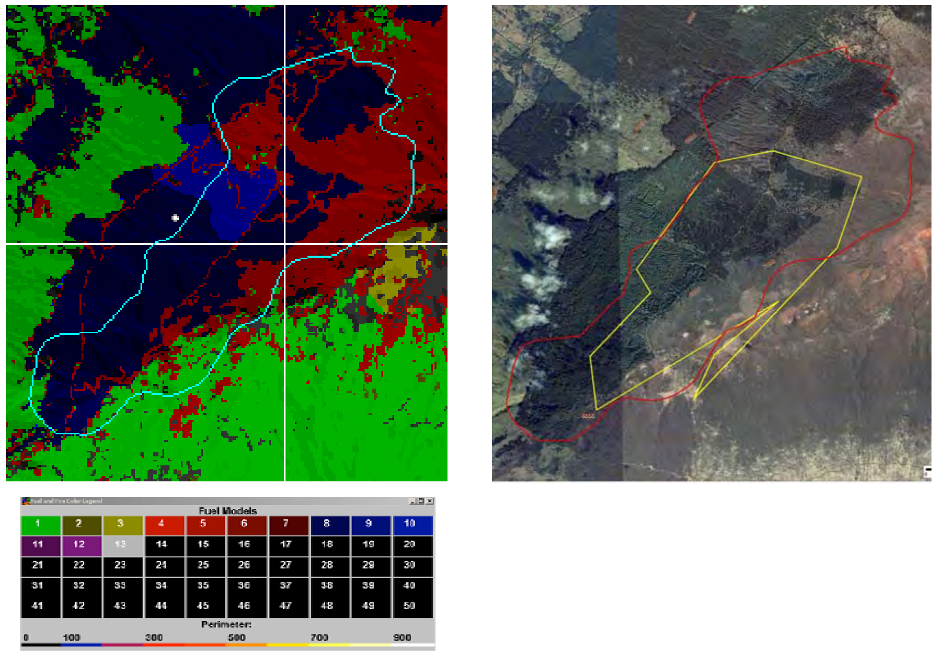

Figure 1—Comparison of digital landscape in FARSITE (topographic and fuels data) and actual satellite imagery. The yellow perimeter in the satellite image was observed on January 27th, 2007. The similarly shaped perimeters in the FARSITE landscape (cyan) and satellite image (red) represent the observed perimeter on January 28th, 2007. This perimeter data was available from PDC in a format that could be imported into FARSITE and overlaid on the displayed landscape. The displayed Fuel Models legend shows the fuel models associated with the colors in the FARSITE landscape.

Our UH and UCSB cooperators supplied daily weather forecast information for the days of the fire. Because the fire had already occurred and was not presently active, the needed forecast runs were retrieved from archive. Separate forecast runs for each day the fire burned had been made – January 24th through 29th of 2007. Each daily forecast run contained 48 consecutive 1-hour sets of forecasted weather variables. This meant that the latter portion of each forecast run overlapped the next day's run. Therefore, we used only the first 24 hours of each run and joined these together into a single progression of hourly forecast data. Another scheme may have been to use all 48 1-hour sets of data from every other daily forecast (in other words, January 24th, 26th, and 28th), but forecast accuracy is believed to decrease in the latter portion of each run, so it seemed desirable to use the latest model output for each hour being forecasted.

Our UCSB cooperator made the weather forecast data ready for direct import into FARSITE. Forecasted values of temperature, relative humidity, precipitation, wind speed, wind direction, and cloud cover over a square grid for every hour the fire burned were used. The spacing between grid points for Maui, where the Waiohuli fire occurred, was about 3 km *(table 1)*.

In this study, we used version 3 of FARSITE, though a more recent version is now available (see http://www.farsite.org). Version 3 allows the import of temperature and relative humidity fields over a regular grid, and adjusts fire behavior calculations accordingly. This feature was taken out of later versions because it competed for computing resources with a newer feature. In version 4, only single hourly values for temperature and relative humidity represent the entire landscape. Gridded wind information, however, is accepted by all FARSITE versions.

In our initial fire simulation run, we used the terrain, fuels, and forecasted weather for the entire island of Maui. The simulated fire ignition point was taken as the starting location and time of the actual fire as determined by DOFAW *(fig. 2)*.

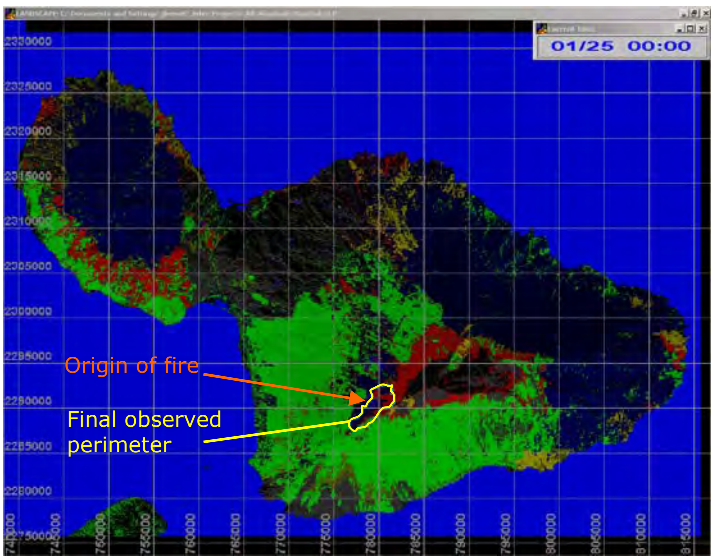

Figure 2—Waiohuli fire simulation using entire island domain. The simulated fire was started at the location given as the origin of the actual fire (pointed to by orange arrow). Also shown is the final perimeter of the Waiohuli fire (yellow).

Incorporating all of Maui in the simulation allowed us to view larger-scale features such as fuel and wind patterns over the entire island. However, small details were difficult to see, and only coarse features of the simulated fire perimeter growth could be seen. There was also a strain on computer resources. The simulation was computationally slow, and the FARSITE program frequently crashed during the run.

We ran a second simulation, cropping the input maps to a close-up rectangle around the fire area, enabling us to see finer details of the simulated perimeter *(fig. 3)*. The smaller amount of landscape data loaded into FARSITE also meant that less computer memory was needed, and the simulation run completed without crashing.

The perimeter grew nearly circular for the first 3 days during which it burned in fuel model 8. When the fire reached an area dominated by fuel model 10 (eucalyptus trees), the symmetry broke and spread rate increased in that part of the perimeter.

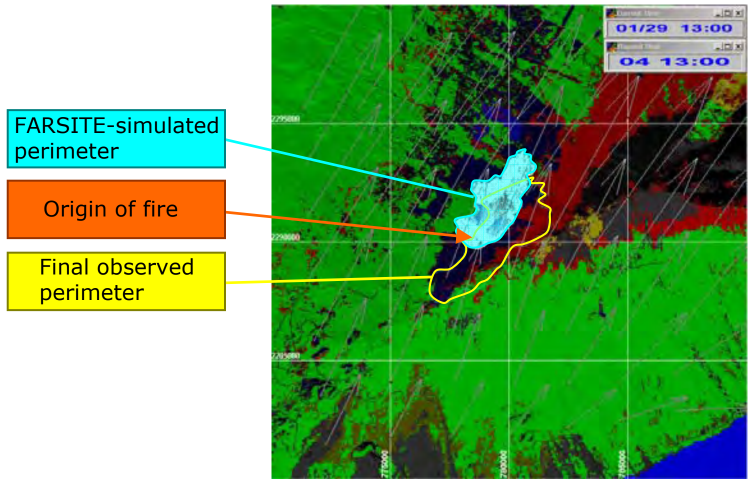

Figure 3—Close-up simulation run of Waiohuli fire area. Finer detail can be seen than in the island-wide run. The displayed predicted perimeter (cyan) is about a day before the actual final perimeter (yellow). However, perimeter size and shape varied little during the rest of the run. Forecasted wind vectors (white arrows) are also displayed, showing upslope winds during this point in the run.

At one point the fire grew near an area marked as fuel model 1 (grass, kiawe trees, shrubs), but surprisingly burned *around* this area, staying within denser woods (fuel model 8). This peculiar behavior may need to be investigated further. The simulated fire moved upslope, to the northwest, which matched the predominant direction of the forecasted winds. The actual Waiohuli perimeter, however, appears to have covered a more downslope (southwesterly) area than the simulation. This discrepancy may signify possible inaccuracy in the setup or running of the simulation, in the recording of the observed fire behavior, or both.

The Waiohuli fire's reported starting location was only an approximation determined by on-scene fire investigators, so next we considered the simulated fire behavior if the starting location were changed by a small amount. We tried simulation runs by specifying starting locations a short distance from the reported actual location, keeping all other initial conditions the same (weather, fuels, topography, and start time). The perimeters simulated from different starting locations varied greatly. For example, by 'igniting' the simulation at a point about 441 m from the reported observed starting location, we found a simulated perimeter that matched the observed perimeter much closer at times as it grew *(fig. 4)*. The simulated perimeter then continued growing, however, until it was much beyond the observed one. This difference in perimeter size may be due to fire suppression efforts hindering the actual fire growth that were unaccounted for in the simulation. FARSITE is capable simulating suppression activity, but there was not enough information about what actions were taken on the Waiohuli fire to use in our runs.

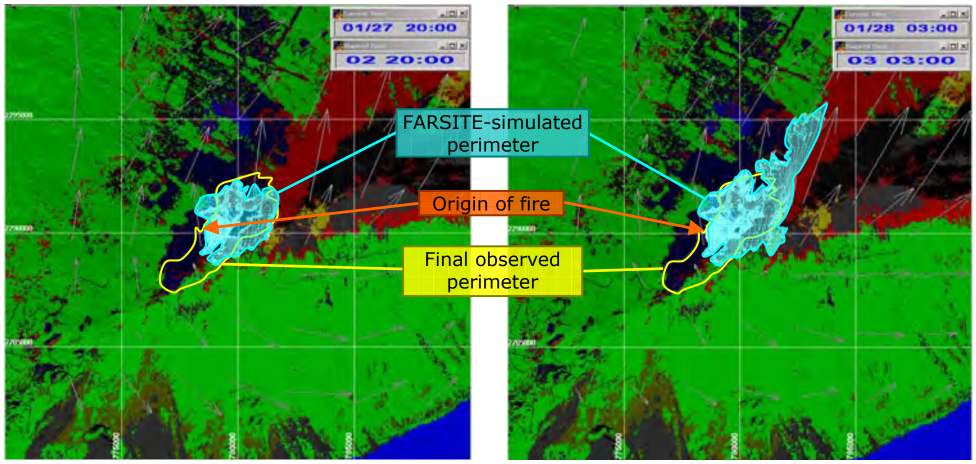

Figure 4—Simulation run with ignition started 441 m southeast of the reported starting location. Simulated perimeters (cyan) are shown at two different times. On the left (January 27th, 8pm), the simulated perimeter matches closer to the actual perimeter than the run that was started at the reported starting location. The right-hand image shows a later time (January 28th, 3am), where the simulation ran beyond the observed perimeter, though the Waiohuli fire burned longer (to January 29th).

The difference in perimeter size and shape, with only small changes in location, was surprising. In *figure 5*, the ignition point was specified only 40 m east of that specified in *figure 3*; no other initial conditions were changed. Note that FARSITE generates fire perimeters deterministically based on initial conditions. If all conditions remain the same in two runs, output should be identical[3]. Likewise, discrepancy in the perimeters from a pair of runs must solely be due to changes in initial conditions or imported weather, and not random behavior at run-time.

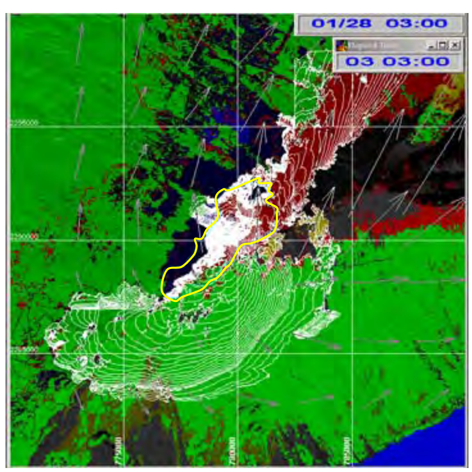

Figure 5—Run with ignition point set 40 m to the east of the reported starting location. The perimeter (white) was much larger than that produced when the

[3] FARSITE can simulate randomly generated spot fires, but we chose not to use this feature.

simulation started at the reported location (*fig. 3*). Note that the time of the im age in *figure 3* occurred over a day *after* the time of the image in this figure.

We also tried altering the starting *time*. Like the reported starting location, the starting time was approximated based on investigation. By testing ignitions at different times during the day, we got an idea of its sensitivity. *Figure 6* shows a frame from a run started six hours later than the previous simulations. Similar to the left image in *figure 4*, for some time during the run, the perimeter matched the observed fire line closer than in *figure 1* (where the simulation was started at the reported starting time and location).

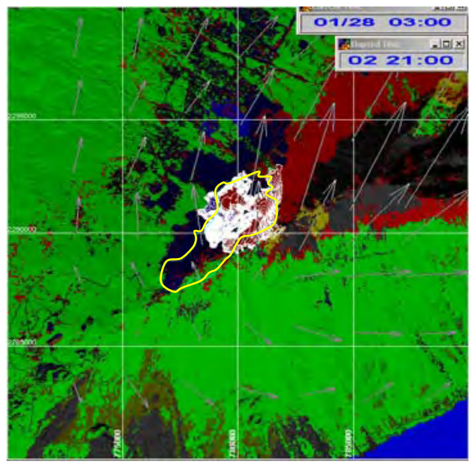

Figure 6—Run with ignition starting 6 hours later than the actual reported time.

We did not try simulations with changes made to any other initial conditions (weather, fuels, or topography data). Nor had we tested altering more than one variable simultaneously, such as both ignition location *and* time. A great deal of further work can be done on simulations run with these combinations of changes.

Conclusions

In this study, we were interested in the effectiveness of real-time fire behavior prediction in a tropical island environment. We wanted to know what technical difficulties must be overcome, how well the weather and fire predictions perform, and how we can improve the overall process. The specific case discussed here – the Waiohuli fire – was *not* a real-time test of the process. However, it gave insight into the challenges that must be met in the workings of a fire behavior prediction system. We also believe that the gained experience from looking at such an example can be extended to similar island environments other than Hawaii.

The fire behavior simulation program we used – FARSITE – is flexible and has several features, many of which we did not employ here. If fuels, topographic, and weather information can be accurately specified within FARSITE, it is likely to be suitable for use in a tropical island scenario. We encountered some technical problems during simulation runs, mostly relating to computer memory issues. These were resolved by clipping out landscape data distant from the area of interest before importing it into FARSITE. We also employed version 3 of FARSITE, which accepted gridded values of forecasted temperature and relative humidity. It is not known if the gridded data does actually improve fire behavior prediction over single values. We would expect improved accuracy to depend on the size and complexity of the landscape in the simulation.

The simulation of fire behavior within FARSITE was quite sensitive to small changes in initial conditions, such as ignition location and time. We believe the variability in predicted behavior extends to small perturbations in other factors as well, such as fuel parameters and forecasted weather patterns. There are several other possible causes for discrepancy between simulated and actual perimeters, such as not accounting for relevant environmental factors, errors in the simulation setup, lack of precision in the fire behavior model, and inaccuracy in recording the observed fire. We did not account for suppression activity that took place on the Waiohuli fire, which probably had a large influence on the resulting fire line. Capturing such activity is often difficult in real-time scenarios when fire-fighting crews have other priorities. However, if the location of actual fire line could be captured at time intervals and fed into a simulation program, this information could reinitialize the simulation to match reality closer.

Observing the simulated fire growth over time, we noticed how different fuel types considerably altered the speed of fire spread. The slope and wind also had a strong affect on the direction and speed of the growing perimeter. We will probably need to investigate further why the predicted perimeter burned around a grass fuel model area rather than through it – an unexpected behavior given that the fire instead stayed within a denser wood fuel model. This may indicate incorrectly specified fuel model parameters in the simulation program.

In further work, we may examine better ways to quantify error between predicted and actual fire perimeters (for example, Fujioka 2002). Quantitative measurements can be used to iteratively test simulation runs with different initial conditions to search for optimal sets of parameter values. This may help calibrate the simulation model or determine the likely time or location of a fire ignition.

Once an efficient fire behavior prediction system is ready for use in a real-time fire scenario, fire managers would need to know how to use it. This would probably involve a cycle of interaction between those involved and the model itself – a feedback loop for calibration. Thus, a small amount of additional work may be required on the part of those on the actual fire line, but the return is a more accurate forecast of future fire behavior.

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