High Resolution Weather Modeling for Improved Fire Management

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ABSTRACT

A critical element to the accurate prediction of fire/weather behaviour is the knowledge of near-surface weather. Weather variables, such as wind, temperature, humidity and precipitation, make direct impacts on the practice of managing prescribed burns and fighting wild fires. State-of-the-art Numerical Weather Prediction (NWP), coupled with the use of high performance computing, now enable significantly improved short-term forecasting of near-surface weather at a 1-3 km grid resolution.

This proof of concept project integrates two complementary model types to aid federal agencies in real-time management of fire. (1) A highly complex, full-physics mesoscale weather prediction model (MM5) which is applied in order to estimate the weather fields up to 72 hours in advance. (2) A diagnostic fire behavior model (FARSITE) takes the near-surface weather fields and computes the expected spread rate of a fire driven by wind, humidity, terrain, and fuels (i.e. vegetation).

General Terms

Management, Design, Reliability, Human Factors, and Theory.

Keywords

Numerical Weather Prediction, Fire Behavior, Parallel Computing.

1. INTRODUCTION

The Maui High Performance Computing Center (MHPCC) hosts a weather modeling consortium known as the Hawaii/Weather and Climate Modeling Ohana (HWCMO). Participants include the University of Hawaii (Meteorology Department, Dr. Duane Stevens)), SCRIPPS Experimental Climate Prediction Center (Dr. John Roads), the USDA Forest Service (Riverside Office, Dr. Francis Fujioka; Mark Finney, Rocky Mountain Research Station), the National Centers for Environmental Prediction (NCEP), and MHPCC (operated by the University of New Mexico). The goal of the HWCMO is to develop high-resolution experimental predictions of weather and climate for the Hawaiian Islands and other areas of national interest [1,2,3,4]. This group has also been involved in improving the USDA Forest Service's Fire Weather Index and general fire/weather behavior issues.

2. Background

The HWCMO has been active during the past four years developing and implementing two mesoscale models to produce reliable daily forecasts in the Hawaiian Islands:

(a) The Regional/Mesoscale Spectral Model (RSM/MSM) developed by the National Center for Environmental Prediction (NCEP) [5,6,7].

(b) The Mesoscale Model 5 (MM5), a wide spread community model with strong user support developed by the National Center for Atmospheric Research (NCAR) [8].

Over the past three years, our weather products have been produced on a daily basis, gradually improving as we develop various aspects of the system. Presently, we make daily forecasts, up to 48 hours in duration, for the Hawaiian Islands on five nested domains with the MSM model: the Hawaiian archipelago and the four counties of Hawaii, Maui, Honolulu/Oahu, and Kauai. Forecasts are made publicly available as images on the World Wide Web at http://www.mhpcc.edu/projects/wswx. The model output data is also available in GIS/ARCinfo format for download. Model grid sizes for the five domains are variable and flexible, depending on the scientific/societal problem and the computing resources available. Presently, for the MSM we use approximately the same number of grid points for each domain and insist that the boundaries are completely over the oceans; grid resolutions are 10, 4, 3, 2, and 2 km respectively.

As for MM5, we apply the conventional 3:1 nesting scheme for two-way interactive domains. Because of this, the number of grid points for each domain varies greatly as opposed to the format used in the MSM model. The largest domain covers an area of approximately 4800 km by 4800 km with 27 km grid resolution. It is then nested down to 9 km around the Hawaiian Islands and then down to 3 km for each of the 4 counties. The finest resolution is a 1 km gridded domain around the Haleakala summit (on the island of Maui) used by the Institute for Astronomy for their telescope operations.

The HWCMO has been producing a fire weather index for the Hawaiian Islands for the USDA Forest Service. This effort has been helpful in predicting were there is a higher possibility for fire based on many factors such as wind speed, relative humidity, surface air temperature, etc. Because of our interest in fire behavior and our connection with the USDA Forest Service we experimented with coupling our NWP models with the FARSITE fire behavior model in August 2000. The results were very promising and there was much interest from the USDA Forest Service in pursuing a more reliable system with a quick response time.

3. Problem Description

Fires are highly dependent on wind and terrain, which require the forecasts to be done at a high resolution. Currently the National Weather Service produces forecasts on the order of 30-50 km resolution and has publicly stated that they do not intend to go below 10 km. Since fires can travel rapidly (especially uphill) and their spread rates are strongly dependent on winds, it is important to have wind forecasts and terrain information at a much finer resolution than 10 km. If the terrain data given to the NWP models is not at a fine level, details such as ridges and valleys will be missed. Additionally the model will "think" the mountains are smaller because it is only an average terrain height. An example of how this can be a problem is the Idaho/Montana fires of 2000 (See Figure 1) where fire spread rapidly through mountainous regions.

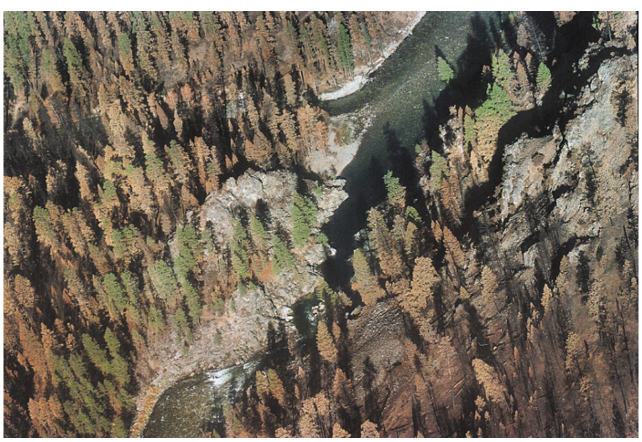

Figure 1: The Pistol Creek fire swept down the canyon, crossing the Middle Fork and blasting the hillside.

The fire fighters/incident managers were relying on coarse forecasts to predict how the weather would behave; this caused problems because the forecasts were generated using data that prevented the model from accurately seeing the terrain details. A resulting problem was higher wind speeds than what was predicted. Even though finer resolution (i.e. 1 km resolution) simulations may still not be perfect (there may still be deficiencies in the physics behind the model, unpredicted events, and sub-kilometer information [9] that could be relevant for wind channel effects) it would be a significant improvement over what is currently available.

4. Methodology & Implementation

The procedure for enabling incident managers to utilize fine resolution weather forecasts consists of many segments:

(a) Prescribed burn or wildfire is identified

(b) Required resolution is requested (i.e. 3 km, 1 km, etc.)

(c) Forecast length and interval output requirement is inputted into the model

(d) Nested domains are created to cover fire

(e) MM5 collects global analysis data (and possibly observational data) and does pre-processing to put the data in a format useable by the model

(f) Simulation is run

(g) Data is converted to a format suitable for FARSITE and made ready for download

(h) Incident managers in the field download the data

(i) Incident Managers do fire behavior simulations using this data

An example of the time required after (c) would be as follows:

(a) 2-3 hours to create domains that will accurately handle the required area to be covered.

(b) MM5 collection of global analysis data from NCEP takes about a ½ hour to download. Observational data is harder to determine as it is dependent on the sources but since the data files are usually very small it rarely takes more than a few minutes. Pre-processing usually takes about 5 minutes for a 24 hour forecast (10 for a 48 hour forecast).

(c) 3 hours for a 24-hour forecast (this is a rough number as the required area coverage and resolution determine run size but 3 hours were required for a 1 km resolution 24 hour MM5 simulation over the little pistol creak fire of 2000 in Idaho). Run time would be linear if the forecast time is changed to a 48 hour forecast, under the same conditions, it would take approximately 6 hours.

(d) Approximately ½-1 hour to produce the required data for the fire behavior simulation (again depending on the length of the forecast).

(e) Since the simulations the incident managers do in the field to determine the appropriate course of action is beyond the scope of this paper, this will not be included in the time estimation; although the simulations are generally done on laptops in a few minutes.

In short, an initial 24-hour forecast would require approximately 7 hours to complete (a initial 48 hour forecast would require 10 hours). Subsequent 24-hour forecasts in the same area would require 4 hours (7 for 48-hour). A flow chart of the operation can be seen in Figure 2. The next two subsections describe in more detail the methodology and implementation of the numerical weather model and the fire behavior simulation.

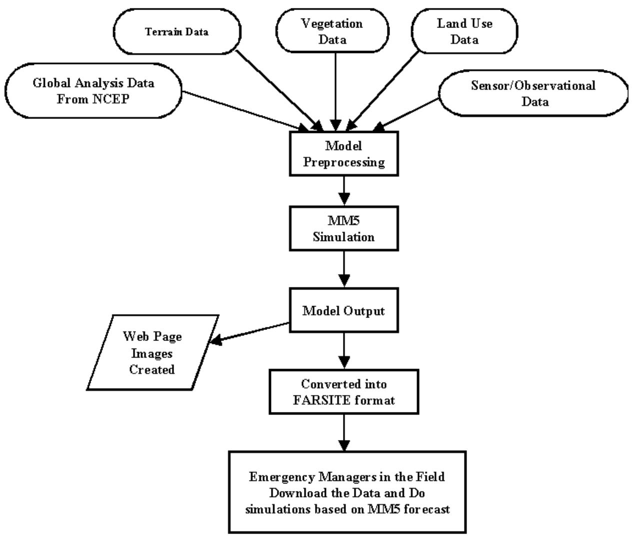

Figure 2: Operation Flow chart from start to finish.

4.1 Numerical Weather Modeling

The numerical weather model used for this project is NCAR's Mesoscale Model Version 5 (MM5). It was chosen because it has many desirable features:

(a) Ease of relocatability of the model's domains

(b) Multiple nested grid capability

(c) The ability to include observational data into the model

(d) The terrain portion of the model includes vegetation and land use data

(e) Model is capable of being run in parallel on MHPCC'S IBM SP3

Ease of relocatability has been explained earlier and is a key asset in allowing us to have a quicken response time in emergency events. The nested grid capability allows us to run a coarse mesh over a large area in little compute time while still being able to operate on finer resolution grids for specified locations. Being able to operate on multiple nested grids means that the model is capable of handling multiple incidents simultaneously (meaning the model can be doing simulations over multiple fires in the same run). The ability to include observational data allows us to start the model with a better "first guess", which in turn allows the model to "spin up" quicker.

Finally, the ability for the model to be run in parallel is important because it allows us to produce high-resolution output in a reasonable time frame (when the forecast is still a prediction). Benchmarks have been done for the parallel version of MM5 (using MPI), but it is not easy to make comparisons since the simulation's domains change in shape, size, and sometimes resolution. (See NCAR's web page on parallel performance at http://www.mmm.ucar.edu/mm5/mpp.html). The benchmark for the Hawaiian Islands run that we (the HWCMO) produce daily (24-hour forecast) is in Table 1:

Table 1: MM5, Hawaiian Islands, Benchmarks

	Time (secs)	Time (H:M)	Relative Speedup	Parallel Efficiency
16	17639	4:54	1.00	1.00
32	10462	2:54	1.69	0.85
64	7452	2:04	2.37	0.59
128	5203	1:27	3.39	0.42

A relative speedup is used because the job had a high memory requirement that forced it to be run on no less than 16 processors. Even though this benchmark may not seem so impressive at first, this is a very complex set of nested domains.

A much simpler benchmark would be that of the Idaho Pistol Creek area. The grid was nested down from a 27 km resolution grid (covering about 2000 square miles) to a 1 km resolution around the location of the fire. Benchmarks for this run are as follows:

Table 2: MM5, Little Pistol Creek Fire, Benchmarks

	Time (secs)	Time (H:M)	Relative Speedup	Parallel Efficiency
4	4954	1:23	1.00	1.00
8	2570	0:43	1.93	0.96
16	1301	0:22	3.81	0.95
32	836	0:14	5.93	0.74

This is much more indicative of how the code will perform when operating on a single fire. The Hawaiian benchmarks give a better idea of how the code will perform when operating on multiple (4+) fires simultaneously.

Additional capabilities have been added to the process of obtaining these forecasts. They include:

(a) Highly reliable (fault tolerant) scripts that allow for quick changes

(b) Script will retrieve the most recent pre-processing data (global analysis, observational data, etc)

(c) Parallel image and data post-processing for web posting

The fault tolerant script ensures that the operation will adjust and continue even in the face of an error or will report that there is a process ending error. The script has been written to be smart enough to retrieve the latest pre-processing data if it is not already present on the system; this ensures that the simulation will have the most recent data and/or avoid downloading data that is already present. Parallel image and data processing (through the use of child processes on a 16 way SMP) has been shown to achieve a speedup close to the number of images/fields being produced for each domain. For example, we achieve a speedup of approximately 6 when processing 7 images (image production takes about 7½ minutes in parallel relative to 45¼ minutes sequentially for a 24 hour forecast in the Hawaiian Islands). This is a significant savings and clearly cuts down on the response time for when the data is available to incident managers.

Examples of the images (and the corresponding data behind them) produced for use by incident managers can be seen in Figures 3 & 4:

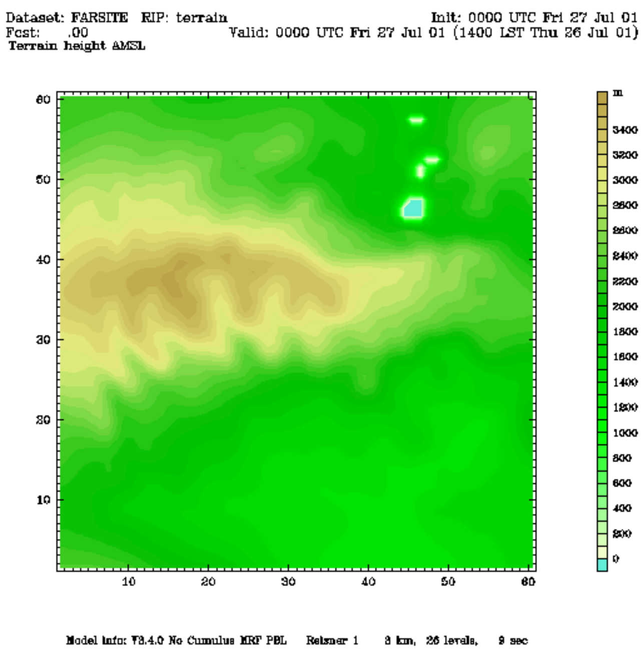

Figure 3: Terrain map for Little Pistol Creek fire (at 1 km)

4.2 Fire Behavior Simulation

4.2.1 FARSITE Background

The FARSITE Fire Area Simulator [10,11] is a program for Personal Computers that simulate the growth and behavior of a fire as it spreads through variable fuel and terrain under changing weather conditions. It includes surface and crown fire spread and intensity, transition to crown fire, and spotting models. FARSITE has been used to project the growth of ongoing wildfires and prescribed fires, and in planning activities for suppression, prescribed fire, prevention, and fuel assessment [12].

The FARSITE program was initially developed for management support of prescribed natural fires (PNFs). The model was intended for both planning and operational phases. Among the many potential uses for fire growth simulations [13], the most relevant to FARSITE are short and long term projections of active and potential PNFs. The Windows interface offers flexibility for office or field prediction of fire growth. Fire growth and behavior scenarios can be developed relatively quickly using short-term weather forecasts or long-term weather projections. Examples of this are:

Active Fires

- Short-term projections could be used in preparing daily fire situation analyses.
- Short and long term projections could help with fire monitoring activities based on the projected arrival, fire behavior, or fire effect.
- Long-term projections using weather extremes could help define potential fire variability and range of outcomes.
- Short-term projections could help with assigning priorities to multiple fires.

Potential Fires

- Effects of ignition locations, fire weather patterns, and fuel or prescribed fire treatments could be examined for comparing different fire management alternatives.
- Fire spread patterns and behavior under historic weather could help refine prescriptions or define fire management zones.

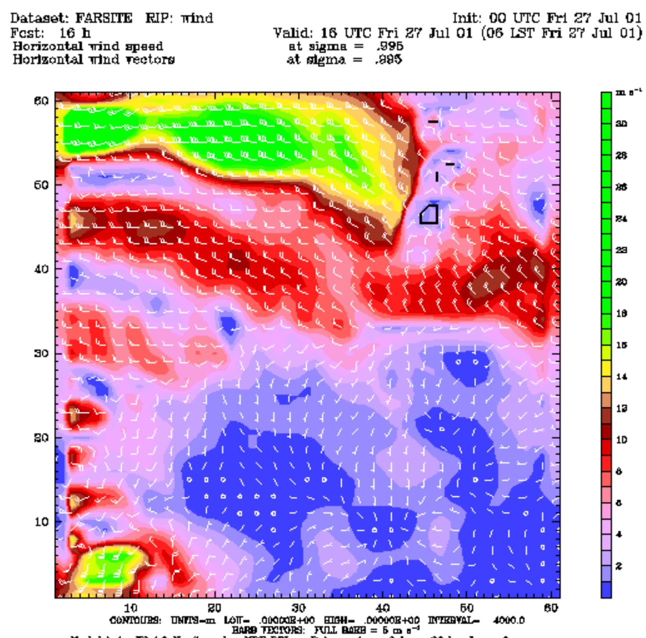

Figure 4: Surface wind speed and direction for area around Little Pistol Creek (at 1 km).

4.2.2 FARSITE integration

After the fine resolution forecasts have been produced, incident managers in the field download the data and input it into the FARSITE fire behaviour simulation. Since the data fields are not large (on the order of 20 Kbytes per field per hour uncompressed) the managers can download them to the laptops in a reasonable amount of time to still do their simulations. Although the manner in which the managers use the FARSITE program is beyond the scope of this paper, it has been made clear by the creator of FARSITE, Mark Finney, that simulations can be done in a matter of minutes even on laptop computers. An example of what the FARSITE program operating on the Little Pistol Creek Fire of 2000 can be seen below in Figure 5.

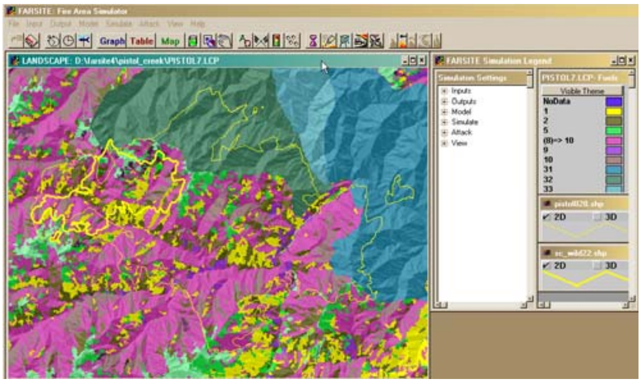

Figure 5: FARSITE display from the western US, summer 2000. This image is a fuel map of where the pistol creek fire of 2000 occurred in Idaho. The yellow lines indicate the area the fire encompassed. The FARSITE simulation takes in inputs for weather conditions and the user inputs starting fire conditions; from this the fire is simulated.

5. Conclusions and Future Work

We have created a methodology that will produce fine resolution weather forecasts. These forecasts can provide useful information for the management of prescribed burns and wildfires. This methodology is focused on providing the required forecasts in a timely manner as to be useful to the incident managers who will do simulations based on these forecasts in order to more effectively manage their available resources.

Future work would entail increasing the resolution of the model (i.e. sub-kilometer resolution simulations), decreasing the response time of the entire operation, and expanding the coverage area.

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