SENSITIVITY ANLYSIS OF FIRE BEHAVIOUR SIMULATIONS OVER SPAIN WTH WRF-FIRE

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Abstract: Wildland fire spread and behavior are complex phenomena due to both the number of involved physical chemical factors, and the nonlinear relationship between variables. Spain is plagued by forest and brush fires every summer, when extremely dry weather sets in along with high temperatures. The use of fire behavior models requires the availability of high resolution environmental and fuel data; in absence of realistic data, errors on the simulated fire spread con be compounded to produce o decrease of the spatial and temporal accuracy of predicted data. The effect of input values on the accuracy of WRF-Fire simulations was evaluated to assess the capabilities of the new system for wildland fire in accurately forecasting fire behavior. .The results confirm that the use of accurate meteorological data and a custom fuel moisture content model is crucial to obtain accurate simulations of fire behavior.

Keywords: WRF-FIRE, Fire Behavior Model, Fuel Moisture Content, Fuel Model, Wildland Fire

INTRODUCTION

One of the main causes of destruction of the vegetation in the last years is wildfire. Wildfires are responsible for an important share of global greenhouse gas emission and soil degradation. Forest fires are problem in most of the south European countries. In Spain the number of self-ignited fires has been increased, also high temperatures and dry winds and vegetation help the fire propagation.

To get detailed meteorological information we have used the mesoscale meteorological model Weather & Research Forecasting system (WRF) developed by NCAR and others (Michalakes et al., 2001;Skamarock et al., 2005). WRF model is combined with a spread model by the level set method and the final system is called WRF-Fire, which is the core of our system. WRF-Fire is the successor to the CAWFE model (Clark et al. 1996). The algorithms for fire spread and fuel combustion in WRF-Fire are based on the model of Rothermel (1972), using the fuel descriptors of Anderson (1982). Description of the WRF-Fire physical model with the numerical algorithms used is presented in Mandel et al. (2011).
In order for the propagation model to be efficient, forest fuels must be described in a particular way, in which the fuel characteristics are represented by certain average values. The set of these representative values is called "fuel model". We have used the 13 fuel models of Anderson (1982)

2. MAIN TEXT

This paper describes an operational information system for wildland fires forecast over Spain with Wrf-Fire and the results of preliminary simulations of a real fire. The core of the system is the WRF meteorological model, to fire behavior we have the Sfire model, integrated into the WRF model. We use the WRF assimilation capability to ingest measurement data. Finally a new Fuel Moisture Content (FMC) model has been developed and integrated into the WRF-Fire system. The FMC mode will be described in the next part.

A mother domain has been setup with 86 x 71 grid cells and 15 Km. resolution over Iberian Peninsula.. One nested domains are required to scale the simulation down from the atmospheric mother domain to the atmospheric domain of 3 Km. with 30 x 30 grid cells, this domain is centered on the fire ignition line. The meteorological information of the inner domain is interpolated to 200 m. resolution. Finally meteorological information is interpolated to the fire grid resolution with 20 m. The meteorological domains have 23 vertical layers. The global meteorological conditions are downloaded automatically from the Global Forecasts System (GFS) website, four times by day corresponding with the 4 initializations of the GFS (00, 06, 12, 18). The objective is always to have the most recently data available. GFS data have a 6 hour output frequency. This domain architecture is based on the CPU time restrictions. In a more powerful computational platform the resolution can be improved without problems.

The system runs 4 times by day, starting at 00, 06, 12, 18 hours GMT, waiting for a fire notification. Simulations are run for 72 hours, with 24 hours of past time to make available the assimilation of measurement data. After 4 hours the results are available with a forecast period of 44 hours. The information is supplied through a web interface where users can view FMC data, temperature, winds, and fire evolution, Figure 1. The web interface shows the last 4 simulations available, from the right panel the user can select several options: geographic information, winds, domain, product, time period, color scale. The user can also download the data in a TIF file. Zoom capabilities can be used to focus over an specific area and it is possible to exec temporal queries for a specific point, showing the temporal evolution of the product selected. The computer platform is composes of 2 dual core and the system has been designed to be capable of running applications in robust, automatic model and with great reliability.

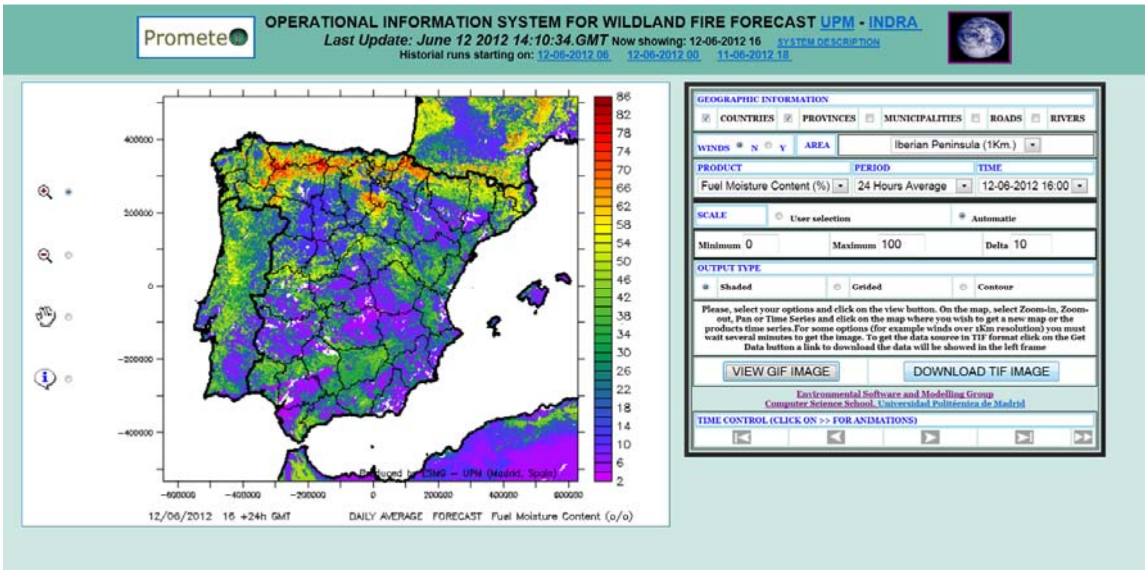

Figure 1: Web interface showing FMC (%) map over Iberian Peninsula, 1 Km. resolution. 24 hours average (12/06/2012 16:00 – 13/06/2012 16:00)

McArthur developed a monogram for predicting the moisture content of cured grass, as part of his Grassland fire Danger Meter (GFDM) (McArthur, 1966). The GFDM was converted to equations by Noble et al.(1980), where the prediction of fuel moisture is given by equation (1). This equation is used as base of our FMC calculations for fine dead fuel (1 hour dead fuel)

(1)

$$m = \frac{97.9 + 4.06H}{T + 6} - 0.00854 H_{surf} + \frac{3000}{C} - 30$$

H and H_{surf} are the air humidity at 1.5 meters and surface levels, T is the temperature at 1.5 meters and C is the degree of curing (%) and is considered as 100% for the calculation of dead FMC. This equation has now become more accepted that the original meters of McArthur. The GFDM has been found to perform well in predicting moisture content of aerial fuels in pine forest, mallee-heath and buttongrass moorlands.

One of the problems was the lack of consideration of the effects of condensation was a major shortcoming in the prediction of FMC, to solve this, we use the physical model to quantify the effects of nocturnal condensation on the moisture content of leaf litter (Viney and Hatton, 1990). Although the model is complex, because contain many parameters, these input data can be get from the meteorological model WRF. Here is the equation:
(2)

$$\Delta m = \frac{100}{W} \int_{\Delta t} \frac{G - N}{L + C_p (T - T_{surf}) / (Q - Q_{surf})} dt$$

where W is the surface fuel mass, G is the soil heat flux, N is the ne all-wave radiation flux, L is the latent heat of vaporization or sublimation, Cp is the specific heat of air at constant pressure, T and T_{surf} are the temperature at 1.5 meters and surface levels and Q y Q_{surf} are the specific humilities at 1.5 meters and surface levels respectively.

In case of not fine dead fuel, as 10 hours and 100 hours dead fuel, we have implemented into WRF-Fire the Nelson model (Nelson, 2000) modified to make operational (Belvis and Colins, 2004). Nelson equations describing the transfer of heat and moisture at the surface and within a stick are derived and then solved numerically. The model simulated change in moisture content and temperature to cylindrical wood sticks of any practical size.

FMC in live fuels is a critical factor driving wildfire susceptibility and wildfire behavior. Live FMC is calculated following the correlation between vegetation greenness and its moisture content, consequently the Normalized Difference Vegetation Index (NDVI) can be used in estimating live FMC. Live FMC estimations can be improved by including the Land Surface Temperature (LST), because LST would be expected to increase in drier plants on account of reduced evapotranspiration. Specifically the ratio NDVI/LST was found to be very useful (Sawarvanu et al., 2005).

The FMC module produces 5 FMC values, 3 for dead fuels (1, 10, 100 hours) and 2 for live models (wood and herbaceous fuels). These 5 values are aggregated based on a weight average. Weight factor are taken from other fire models as BehavePlus, Farsite and FlamMap. This aggregation use information from the fuel model. The fuel model classification is made with information about landuses from Corine Land Cover (CLC 2000) with 100 meters of spatial resolution. The final fuel load map was derived by assigning a fuel class to each land uses. The allocation matrix is given in Table 1

FUEL MODEL	CLC LANDUSES
1-Short grass	18,22,26,32,36,12,19,20
2-Timber grass and understory	21,24,29,33,35
4- Chaparral	25,27,15
6- Dormant brush	22
8- Compact timber litter	23

Table 1: Equivalents between fuel model classes and land uses from Corine Land Cover classification (CLC 2000)

A preliminary model validation was tested on a real case of forest fire in the territory of Murcia (Spain). We have used our operational system based on WRF-Fire to simulate a real wildland fire using our data sources in order to evaluate its ability to predict fire´s propagation in real time.

The fire ignited in a region of Murcia (Spain) on September 07, 2010 19:09. The final burned area is 7Km by 1 Km after 9 hours. We have only the fire perimeter at the end of the fire event. In addition, it is known that fire-fighters have made numerous attacks on the fire in order to constrain the fire. As there is no precise data available to these attacks, we ran the simulation without taking into account the effect of the fire-fighters.

The simulated area was discretized by a matrix of 350 x 100 cells, the cell resolution was 20 m. The simulation was started at 19:00, 9 minutes before the estimated ignition points and stopped at 04:00 of the next day, so the time total o simulation was 9 hours.

We have the following data available: topography available from local authorities at up to 4 meters resolution. Land uses datasets available from Corine Land Cover (CLC 2000) at up to 100 meters resolution. The landuses were translated into fuel model, according to the Table 1.

Figure 2 represents the superimposition of the real fire and simulated fire at 1 hour, 3 hours, 6 hours and 9 hours after ignition. Real fire contour after 9 hours from ignition is displayed as green, and simulated contour fire is represented as brown color. Arrows indicate the simulated winds from the meteorological model WRF. The fire was increase rapidly after the 3 first hours. The fire was propagating according the wind direction and taking into account the fuel available.

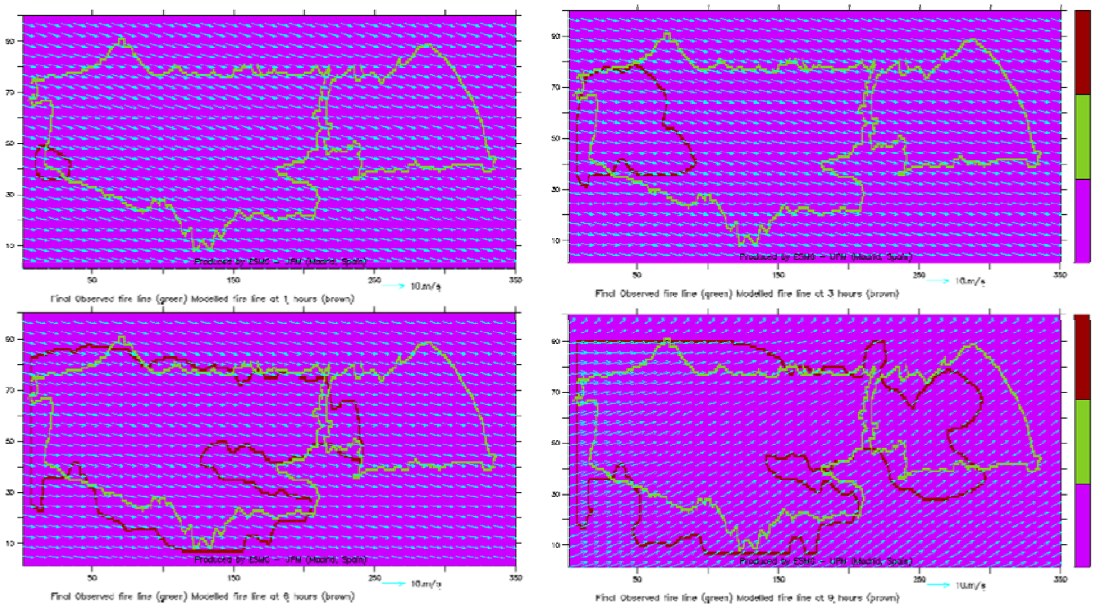

Figure 2: Observed fire line after 9 hours after ignition (green) to the modeled fire line (brown) at 1 (upper-left),3 (upper-right) ,6 (bottom-left), and 9 (bottom-right) hours and simulated vector winds

The results of the simulation looks good since few areas of the real fire don´t appear to be burnt in the simulation and few areas, which were not burnt, are computed to be “burnt”. Some differences are probably due to the attack of the fire fighters, because these actions are not modeled. The results of the simulation show a significant fit with the real data.

CONCLUSIONS

We have developed an operational and integrated simulation forecasting system for fires based on WRF-Fire. Results show that the proposed system can produce realistic simulations using the geographical information available of the fire in a real case scenario. A graphical approach is used to compare the fire perimeters and burned areas. The comparisons show that simulation results are consistent with that real data, so the system perform adequately in predicting the of the fire physics. The validation of the accuracy of the current fire propagation models is a big problem. The effect of external factors such as human interventions on the model cannot be accurately estimated. Further enhancements to the simulation system are planned based on more test of real fire scenarios. For example we will try to improve the meteorological information because the interpolation from 3 km to 20 meters cannot capture accurate local atmospheric features, but this is the only possibility to run the system quick and an operational way at this time.

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