Contribution to:

IWAQFR 4TH International Workshop on Air Quality Forecasting Research

Geneva, Switzerland, 12-14, December, 2012

AN OPERATIONAL FORECASTING SYSTEM FOR WILDLAND FIRES OVER SPAIN USING WRF-FIRE (SFIRE)

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OBJECTIVES:

- The PROMETEO project is focused on improving the capabilities to fight against the wildland fires in the IBERIAN peninsula.
- It includes partners on all aspects related to the wildland fires: helicopter teams, wildland fire simulations, spread of on-site sensores (temperature, humidity, etc.), use of permanent observational meteorological networks, real-time satellite data sets, etc.
- UPM as a research partner of INDRA SISTEMAS S.A. company who contributes to produce the best estimations of Fuel Moisture Content (FMC) as a key input parameter into the Wildland fire simulations.

STRATEGY

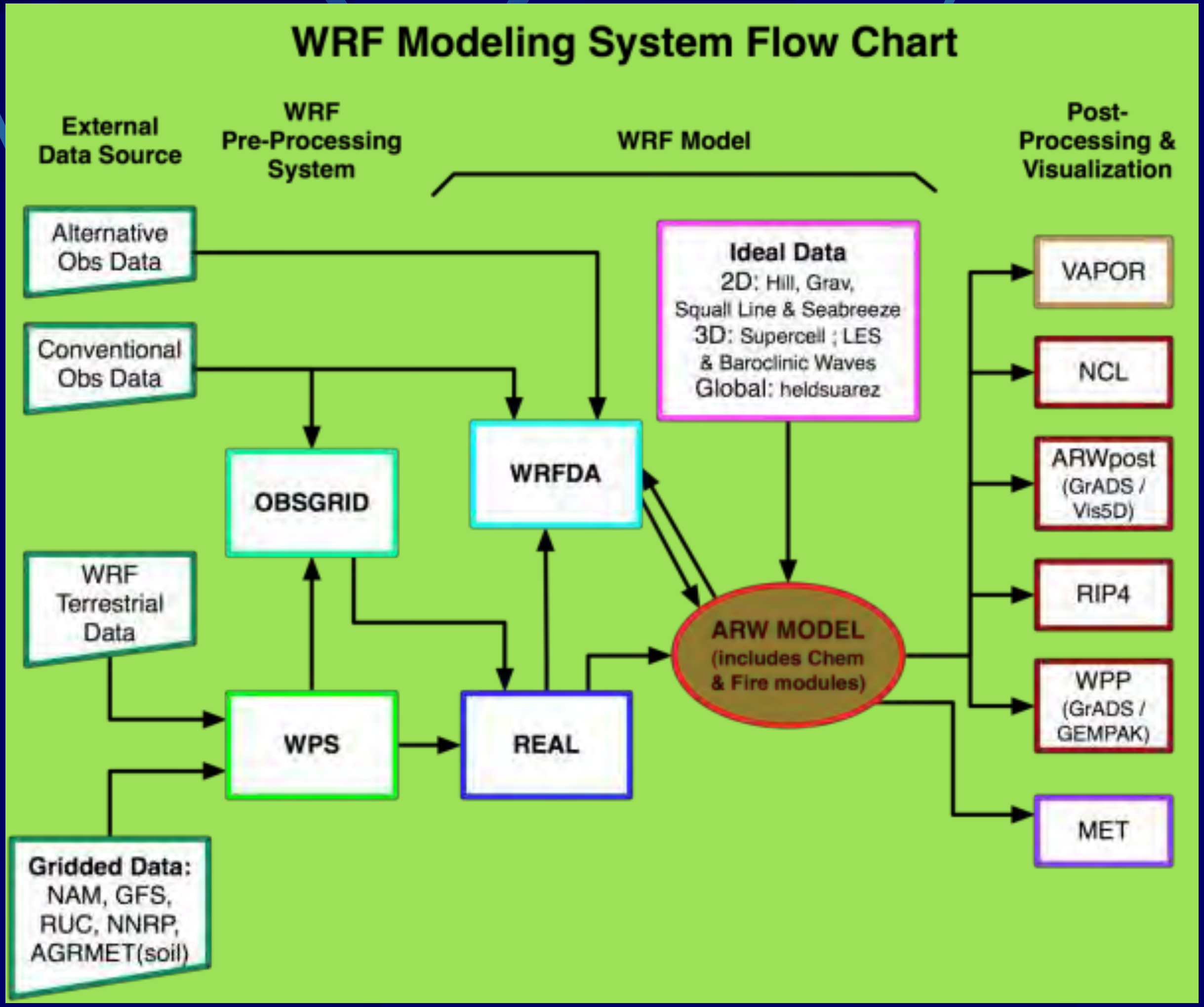
- FMC is usually classified as "live" or "dead" fuel. Live FMC is classified into wood and grass materials and the calculation process involves the estimations of LST and NDVI to estimate the live FMC for these two materials.

- The dead FMC is representing the wood material which is found in the forests as thin dead wood material and larger material. This is usually classified as 1 h, 10 h and 100 h materials. The 100 h material represents the large tree trunks laying on the floor.

- Since the observational FMC data sets are very scarce, we decided to use our own wildland fire models (based on WRF/FIRE and FIRELIB – fast version - modules) to validate our selection of FMC values. The results are compared with a real wildfire in Spain where we have the fire extension as a shape file.

WRF METEOROLOGICAL MODEL

3-D non-hydrostatic prognostic model that simulates mesoscale atmospheric circulations. WRF was developed at the National Center for Atmospheric Research (NCAR) and University Corporation for Atmospheric Research (UCAR). Version 3.3.1 (September 2011)



WRF METEOROLOGICAL MODEL

- **Cumulus Parameterization:**

_GRELL-DEVENYI ENSEMBLE SCHEME (_Grell, G. A., and D. Devenyi, 2002: A generalized approach to parameterizing convection combining ensemble and data assimilation techniques. Geophys. Res. Lett., 29(14), Article 1693.)

- **PBL Scheme and Diffusion:**

Yonsei University (_YSU) PBL_ (Hong, S.-Y., Dudhia, J., 2003. Testing of a new non-local boundary layer vertical diffusion scheme in numerical weather prediction applications. In: Proceedings of the 16th Conference on Numerical Weather Prediction, Seattle, WA.)

- **Explicit Moisture Scheme :**

LIN et al.SCHEME microphysics (Lin, Y.L., R. D. Farley, and H. D. Orville, 1983: Bulk parameterization of the snow field in a cloud model. J. Appl. Meteor., 22, 1065-1092)

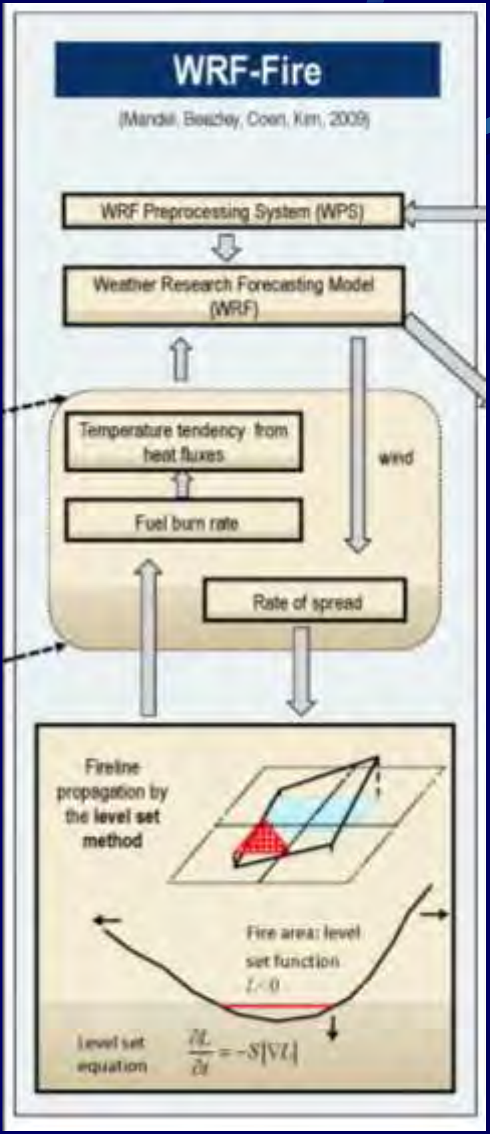
WRF METEOROLOGICAL MODEL

•**Radiation Schemes:**

Rapid Radiative Transfer Model (RRTM) longwave radiation *(E.J. Mlawer, S.J. Taubman, P.D. Brown, M.J. Iacono and S.A. Clough, Radiative transfer for inhomogeneous atmospheres: RRTM, a validated correlated-k model for the longwave, J. Geophys. Res. 102 (D14) (1997), pp. 16663–16682*)

***Simple cloud-interactive shortwave radiation scheme Dudhia radiation (* Dudhia, Numerical study of convection observed during the winter monsoon experiment using a mesoscale two-dimensional Model, *J. Atmos. Sci.* 46 (1989), pp. 3077–3107)**

WRF-Fire



WRF-Fire combines the Weather Research and Forecasting model (WRF) with a fire code implementing a surface fire behavior model, called SFIRE, based on semi-empirical formulas calculate the rate of spread of the fire line (the interface between burning and unignited fuel) based on fuel properties, wind velocities from WRF, and terrain slope. The fire spread is implemented by the level set method. The heat release from the fire line as well as post-frontal heat release feeds back into WRF dynamics, affecting the simulated weather in the vicinity of the fire

Mandel, J., J. Beezley, and A. Kochanski (2011). Coupled atmosphere-wildland fire modeling with WRFfire. Geoscientific Model Development Discussions 4, 497–545.

Level-set method

$\forall x \in R^n, \ \forall t \in [0, T_f] \ \varphi(x,t) + F(x, \varphi(.,t), t) \|\nabla_x \varphi(x,t)\|_2 = 0$

φ *is the level set function and* F *is the velocity which depends on the front through its dependence upon* φ*. Then we will replace* φ *with the signed distance.*

- Hamilton-Jacobi equation >>>>> viscosity solution under given assumptions (unique solution).
- Two-level methods deal with topological changes that occur in wildland fire however it deals with higher dimensional space.
- Marching method –when it can be used – provides a highly efficient algorith.
- The main reservation may be the lack of proof of convergence for certain problems.

Mallet V. et al. (2009) Modeling wildfire propagation with two level set methods.

FMC MODEL INTO WRF-Fire

Fine dead fuel (1 Hour): NOBLE, I.R., BARY, G.A.V. and GILL, A.M. 1980. Mc Arthur´s fire-danger meters expressed as equations. Australian Journal of Ecology 5: 201-203

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

H and H_{surf} are the air humidity at 1.5 meters and surface levels

T is the temperature at 1.5 meters

C is the degree of curing (%) and is considered as 100% for the calculation of dead FMC

FMC MODEL INTO WRF-Fire

Condensation effect (1 hour): VINEY, N.R. and HATTON, T.J. 1990. Modelling the effect of condensation on the moisture content of forest litter. Agricultural and Forest Meteorology 51: 51-62

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

W is the surface fuel mass

G is the soil heat flux

N is the net 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

Q y Q_{surf} are the specific humilities at 1.5 meters and surface levels respectively

FMC MODEL INTO WRF-Fire

Coarse dead fuel (10 and100 hours): Nelson, Ralph M. Jr. 2000. Prediction of diurnal change in 1-h fuel stick moisture content. *Can. J. For. Res.* 30: 1071-1087. (2000)

Bevins, Collin D. 2004.
Adapting Nelson's dead fuel moisture model for wildland fire modeling

Heat Loss = Heat Gain
Conduction + Longwave Radiation + Evaporation = Solar Heating + Convective Heating

Nelson equations describe the transfer of heat and moisture at the surface and within a stick are derived and then solved numerically. The model simulated the change in moisture content and temperature to cylindrical wood sticks of any practical size.

FMC MODEL INTO WRF-Fire

Live fuel (Herbaceous and wood): Sawarvanu Dasgupta, John J. Qu and Xianjun Hao. Evaluating remotely sensed live fuel moisture estimations for fire behavior predictions. EastFIRE conference 2005.

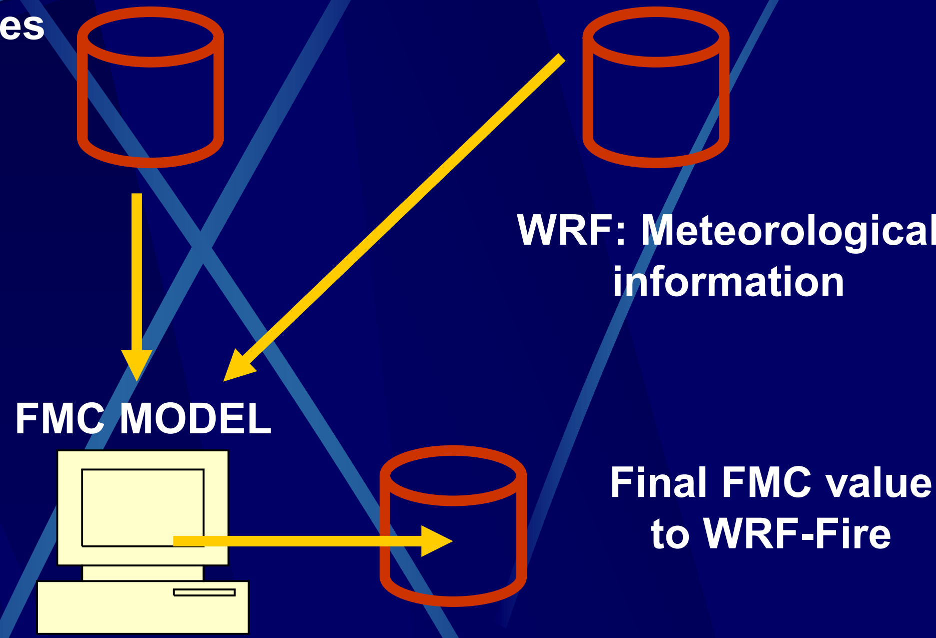
Correlation between the ratio vegetation greenness / surface temperature (vg/LsT) and its moisture content.

Normalized Difference Vegetation Index (NDVI) can be used in estimating live FMC as value of vegetation greenness

FMC MODEL INTO WRF-Fire

Fuel model from CLC land uses

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



Individual outputs from FMC model:

- FMC dead fine (1h)
- FMC dead coarse (10h)
- FMC dead coarse (100h)
- FMC live wood
- FMC live herbaceous

Agregation*

* These 5 values are aggregated based on a weight average. Weight factors are taken from other fire models as BehavePlus, Farsite and FlamMap. This aggregation use information from the fuel model

UPM

SYSTEM DOMAINS

Iberian Peninsula 15 Km spatial resolution (86*71 grid cells)

Centered on ignition point 3Km spatial-resolution (30*30 grid cells)

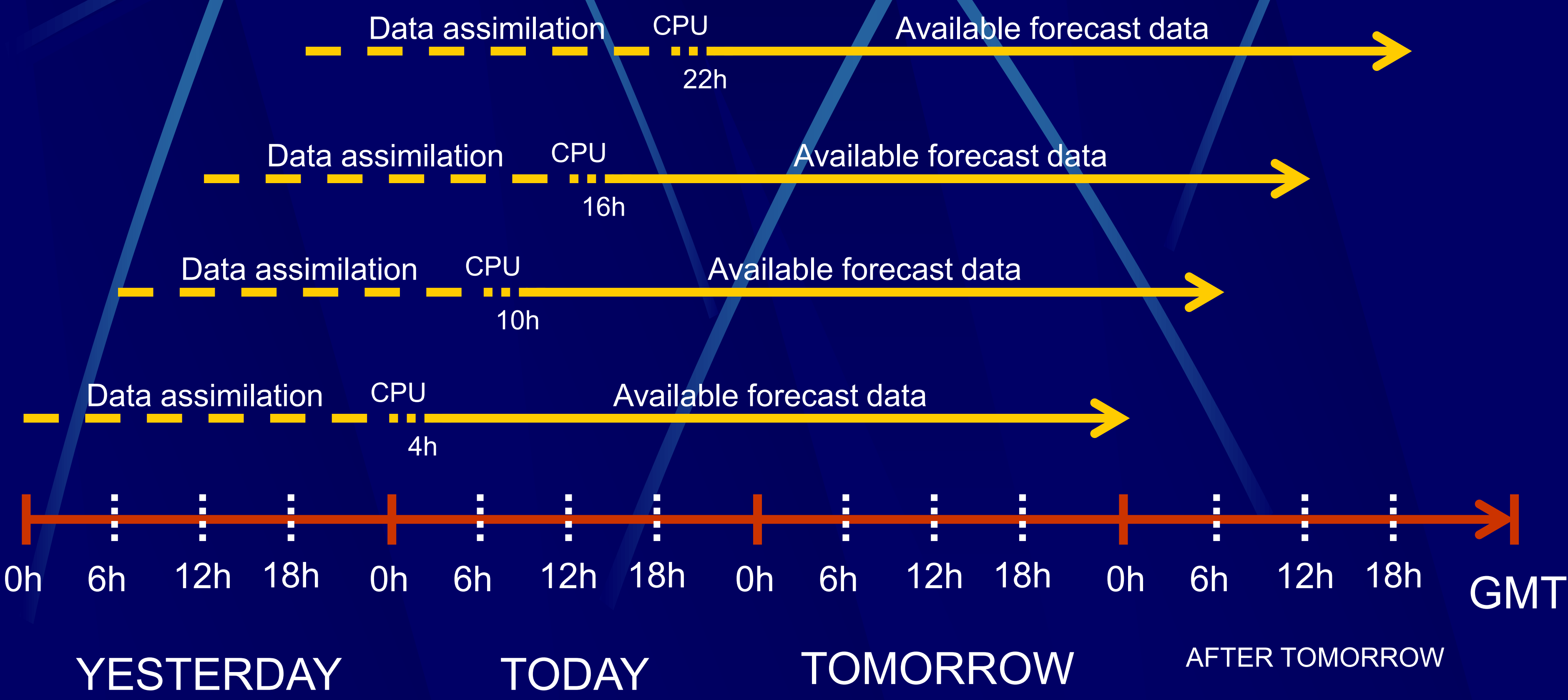
23 vertical levels (up to 100 mb)

Fire grid 20 meters spatial resolution for meteorological data

200 m. spatial resolution (436*436 grid cells). Interpolation

OPERATIONAL MODE: FIRST VERSION

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. The global meteorological conditions are downloaded automatically from the Global Forecasts System (GFS)



WEB INTERFACE

Header with last update and link to the 3 last historical runs

maps and zoom capaBILITIES

Display options and fire management

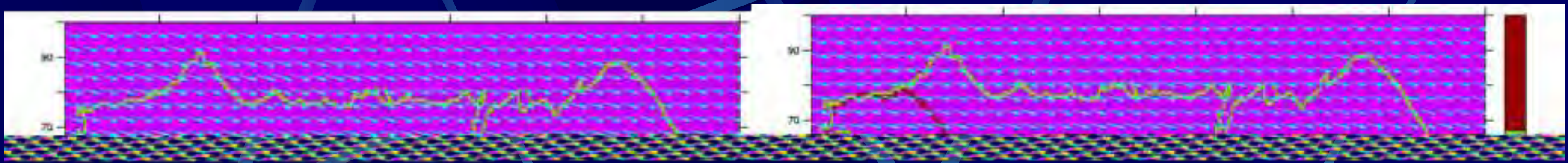
INTERFAZ WEB - EXAMPLE

Time series FMC (%) (12/06/2012 16:00 – 14/06/2012 12:00). Central point of the Iberian Peninsula.

A REAL CASE FOREST FIRE SIMULATION

- The fire ignited in a region of Murcia (Spain) on September 07, 2010 19:09.
- The final burned area is an area of 7 Km x 1 Km after 9 hours.
- Fire perimeter at the end of the fire event is available.
- The simulation was started at 19:00, 9 minutes before the estimated ignition points and stopped at 04:00 of the next day. The spatial resolution is 20 m.
- Fire-fighters have made numerous attacks on the fire in order to constrain the fire but this information is not available.

A REAL CASE FOREST FIRE SIMULATION



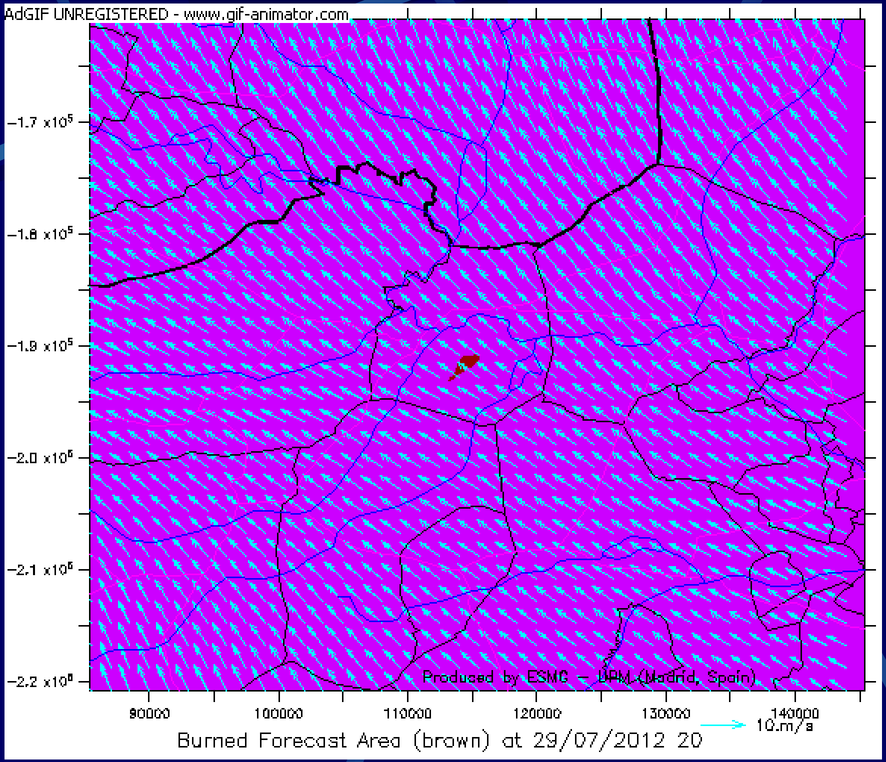
Observed fire line after 9 hours after ignition (green) to the modeled fire line (brown) at 1 (upper-left),3 (upper-right) ,6 (bottom-left), and 9 (bottom-right) hours and simulated winds.

ANALYSIS: SCORING THE MODEL RESULTS

- 78.75 % Gridcells: forecast and real data is o.k.
- 13.93 % Gridcells: Overestimatio: simulated burned gridcells but in fact they were NOT burned.
- 7.32 % Gridcells. Underestimation: non burned gridcells but in fact they were burned. These gridcells are DOUBLE scored in the final score.

Final score: 0.7875 – 0.1393 - (2 x 0.0732) = 0.5018

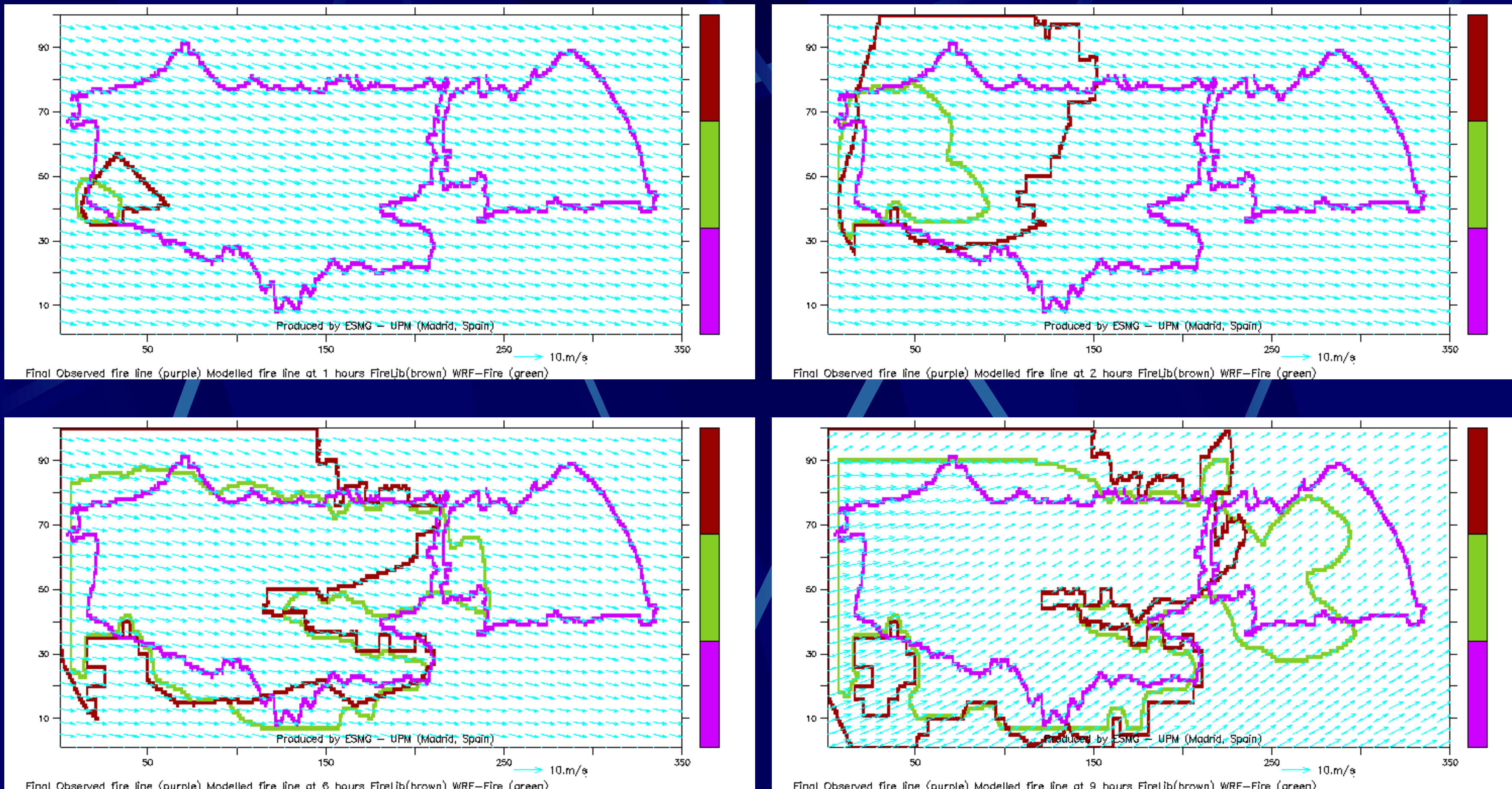
FIRELIB SIMULATION ON THE WEB



FireLib is a C language function library for predicting the spread rate, intensity, flame length, and scorch height of free-burning surface fires. It is derived directly from the BEHAVE fire behavior algorithms for predicting fire spread in two dimensions, but is optimized for highly iterative applications such as cell- or wave- based fire growth simulations

COMPUTER REQUIREMENTS

- Due to the numerics involved in the Level set Method, the computer time is increased exponentially with the spatial resolution used in the SFIRE model. (Courant Law in Level - set method.
- The CPU time required with our two dual-core parallel system is about 90’ to produce a 9h simulation.
- Using the fire-lib model which is similar to the SFIRE model included into WRF, the CPU Time is reduced to 9’.
- A comparison between both model results has been done.



Time evolution of the Murcia test case after 1, 3, 6 and 9 hours with WRF-FIRE (green), FIRE-LIB (brown) and observational data (purple). The simulations have been performed with the same input data sets, the same domain size and the same spatial resolution.

CONCLUSIONS

- We have developed an operational and integrated simulation forecasting system for fires based on WRF/FIRE.
- In the first test, the fire appears to propagate too fast compared to observations, but the inclusion of a moisture model alleviate this problem
- 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 fire physics
- The effect of external factors such as human interventions on the model cannot be accurately estimated because lack of data.

ACKNOWLEDGEMENTS

- FMC model developed within the project CENIT-Prometeo ("INTEGRAL TECHNOLOGIES FOR FIRE FOREST FIGHTING AND CONSERVATION OF OUR FORESTS "), funded by CDTI Spanish Agency, and in collaboration with Indra Sistemas SA.

- Special thanks to the Civil Protection Unit of the Region of Murcia (Spain) for providing real data of the wildfire evolution.

- The authors thankfully acknowledge the computer resources, technical expertise and assistance provided by the Centro de Supercomputación y Visualización de Madrid (CeSVIMA).