WRF fire simulation coupled with a fuel moisture model and smoke transport by WRF-Chem

Adam K. Kochanski[1], Jonathan D. Beezley[2] Jan Mandel[2] and Minjeong Kim[2]

[1]Dept of Atmospheric Sciences University of Utah, Salt Lake City, UT,

[2]Department of Mathematical and Statistical Sciences, University of Colorado, Denver

THE UNIVERSITY OF UTAH Department of ATMOSPHERIC SCIENCES

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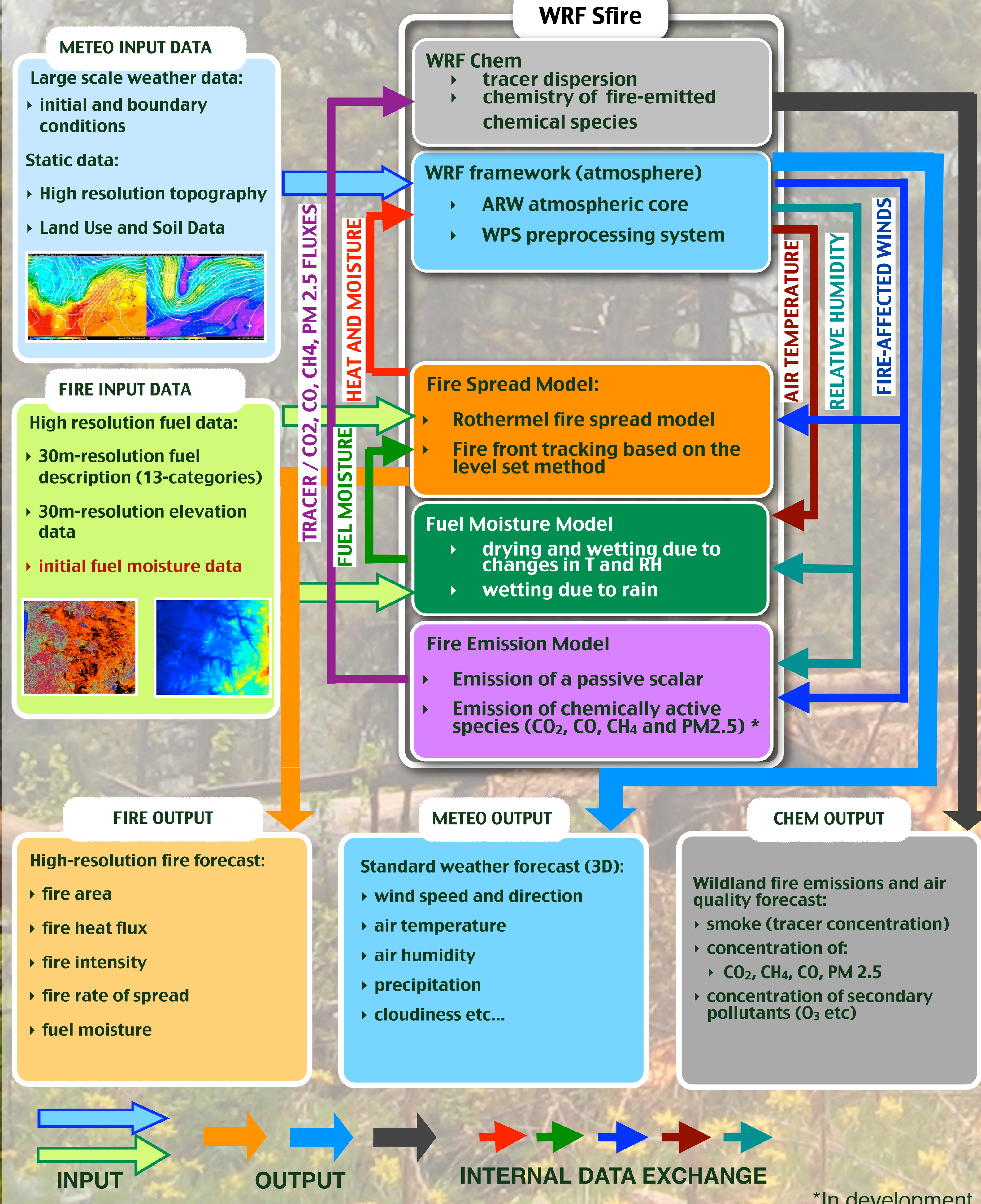
Motivation:

Capabilities of the recent version of the WRF-Sfire in terms of real wildland fire simulations and its potential usefulness for fire managers were limited due to:

- **very simple representation of the fuel moisture (constant in time and space)**
- **lack of representation of the fire-generated smoke**

This poster presents newly developed functionalities addressing these limitations of the WRF-Sfire.

WRF-Sfire coupled with WRF-Chem and the new fuel moisture model



*In development

Contact: adam.kochanski@utah.edu

The new additions to WRF-Sfire include the fuel moisture model and integration with WRF-Chem, allowing for more advanced coupling between the fire and the atmosphere:

- the heat and moisture fluxes from the fire are fed into the weather model, which responds to the fire by changing the atmospheric temperature, moisture, pressure and consequently also the wind field (model captures the fire-induced winds)
- meteorological conditions like the air temperature, relative humidity and precipitation controls the fuel moisture content, which in turn affects the fire behavior and the amount of heat and moisture released into the atmosphere
- fuel combustion is associated with tracer emissions corresponding to the smoke dispersion within the atmosphere
- ultimately, the fire emissions will be treated as chemically active fluxes of CO_2, CO, CH_4 and particular matter (PM 2.5), that will undergo chemical reactions and interact with radiation and microphysical schemes*

Fuel Moisture Model

- The fuel moisture model bases on Van Wagner and Pickett (1985). It computes the fuel equilibrium moisture content for drying (E_d) and wetting (E_w) using WRF-simulated air temperature (T) and relative humidity (H).

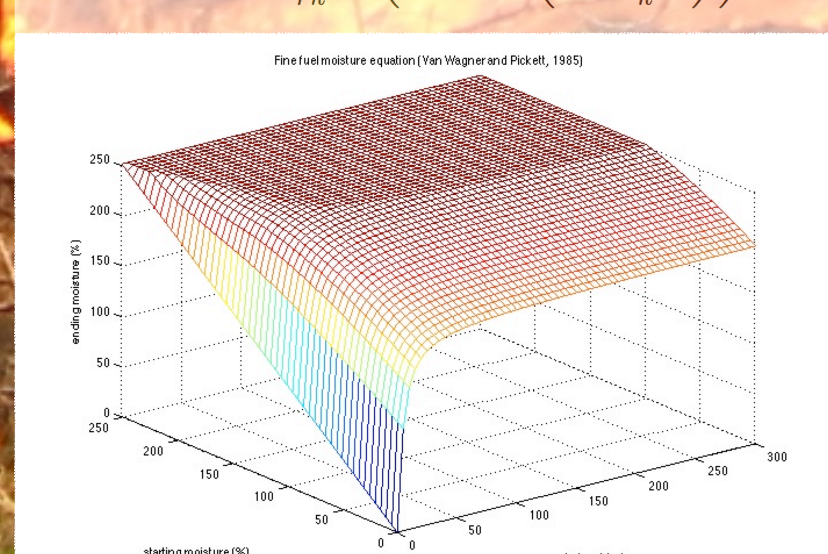
$$E_d = 0.924H^{0.679} + 0.000499e^{0.1H} + 0.18(21.1 + 273.15 - T)(1 - e^{-0.115H}),$$
$$E_w = 0.618H^{0.753} + 0.000454e^{0.1H} + 0.18(21.1 + 273.15 - T)(1 - e^{-0.115H}).$$

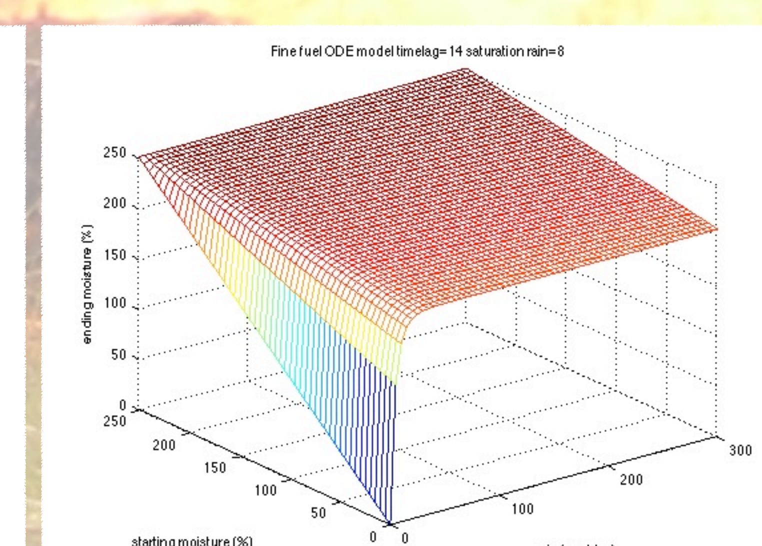
- The fuel is considered as a combination of time-lag classes (f.e. 1h, 10h, 100h and 1000h fuels). Each fuel class (k) has its own time lag (T_k) which is then used to compute time changes in the fuel moisture within each class k (dm_k/dt).

$$\frac{dm_k}{dt} = \begin{cases} \frac{E_d - m_k}{T_k} \text{ if } m_k > E_d \\ 0 \text{ if } E_d < m_k < E_w \\ \frac{E_w - m_k}{T_k} \text{ if } m_k < E_w \end{cases}$$

- During rain events, the equilibrium moisture E_w is replaced by the saturation moisture contents S, and the above equation is modified to achieve asymptotically the rain-wetting lag time T_{rk} only for heavy rain (when the rain intensity r is large):

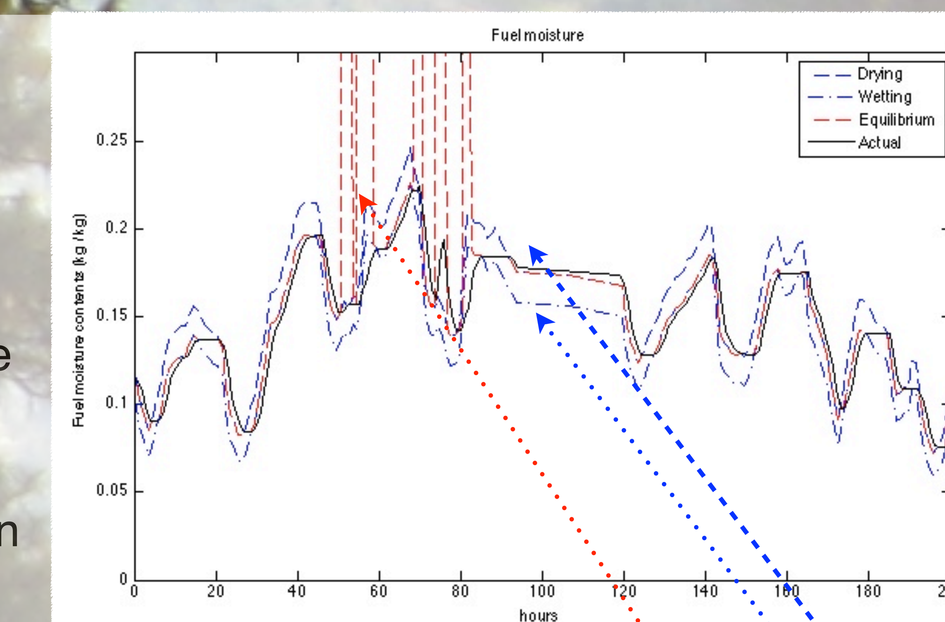
$$\frac{dm_k}{dt} = \frac{S - m_k}{T_{rk}}\left(1 - \exp\left(-\frac{r - r_0}{r_k}\right)\right), \text{ if } r > r_0,$$





Fuel Moisture Simulations:

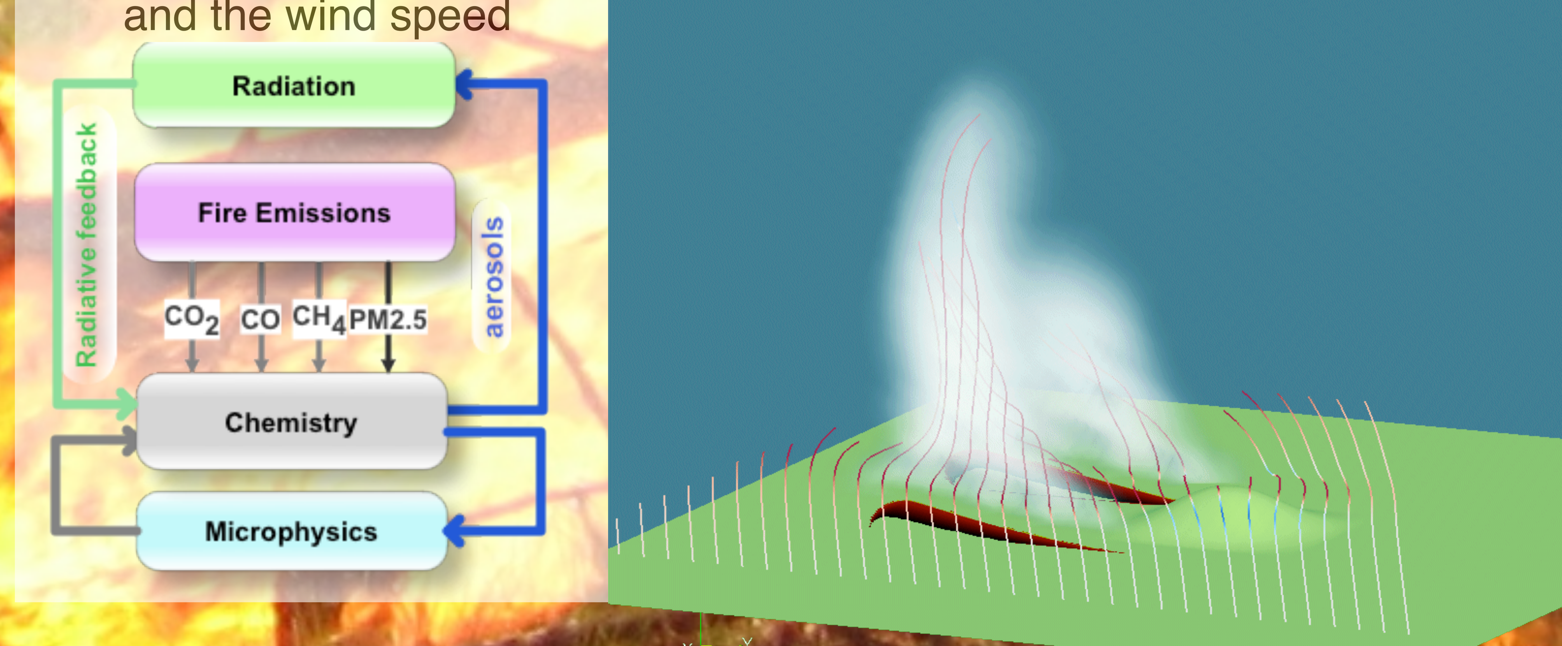
- for no-rain conditions the air temperature and relative humidity from WRF are used to compute the equilibrium moisture content toward which the fuel moisture approaches asymptotically with a given times scale.



- if the fuel moisture is greater than the drying EMC (equilibrium moisture content), the fuel moisture decreases toward the drying equilibrium (E_d)
- if the fuel moisture is smaller than the wetting EMC (equilibrium moisture content), the fuel moisture increases toward the wetting equilibrium (E_w)
- during precipitation events fuel moisture tends toward the saturation moisture content with a time scale dependent on the rain intensity

Smoke Simulations

- tracer option (`chem_opt=14`):
  - smoke is treated as a passive tracer, and chemistry is turned off
  - amount of emitted smoke (`p_smoke`) is proportional to the heat released by the fire
- full chemistry option (in development)
  - fire smoke is represented as a mixture of CO_2, CO, CH_4 and PM 2.5
  - emissions of smoke gasses are computed following the Fire Emission Production Simulator by Anderson (2004), based on the amount of fuel burnt, and the smoldering correction computed from atmospheric humidity and the wind speed



Conclusions

Extended capabilities of the WRF-Sfire allows for:

- more realistic simulations of the fire spread thanks to variable fuel moisture content, driven by atmospheric conditions and precipitation
- generating fuel moisture forecasts
- forecasting smoke transport and dispersion
- simulating air quality effects associated with wildland fires
- simulating interactions between fire plume, radiation and microphysics*