WRF-Fire: A Wildland Fire Behavior module for WRF

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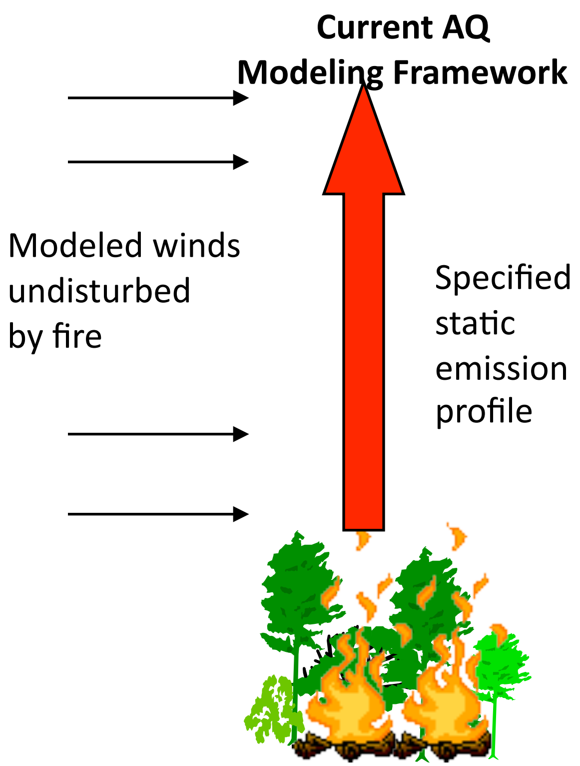
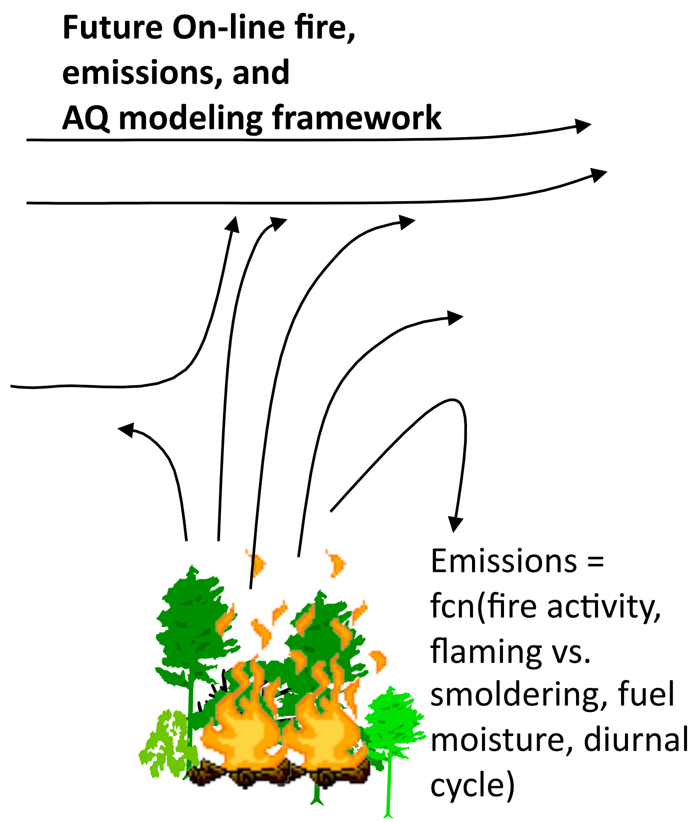
Applications

- Framework for fire weather community collaboration
- Studies of fire behavior:
  - Causes of extreme fire behavior 1-10's of m grid spacing
  - Weather-fire dynamics – 100s of m
  - Forecasting of fire progressions – 1000s of m
- Future connection to other WRF modules. Ex. WRF-Fire + WRF-Chem
  - Air Quality impacts of fires on both event scale and regional air quality





Fire model components

- Fire behavior
  - Current
    - Surface fire spread velocity from wind and terrain slope; includes many physical effects, such as pre-heating and drying
  - Future
    - Crown fire (i.e. fire traveling through treetops), was in the previous CAWFE model
    - Explicit modeling of fuel pre-heating and drying by radiation
    - Jumping fire breaks
    - Combustion/CFD surface atmosphere layer model
- Fire interactions
  - Current
    - Wind drives the fire spread
    - Fire model produces latent and sensible heat fluxes (and a tracer smoke flux) to the lowest levels (exponential decay set by a scaling factor) of the atmospheric model
  - Future: more complete exchange of state
    - Emissions feed to chemical model
    - Fuel moisture response to weather
    - Retention of heat in the ground

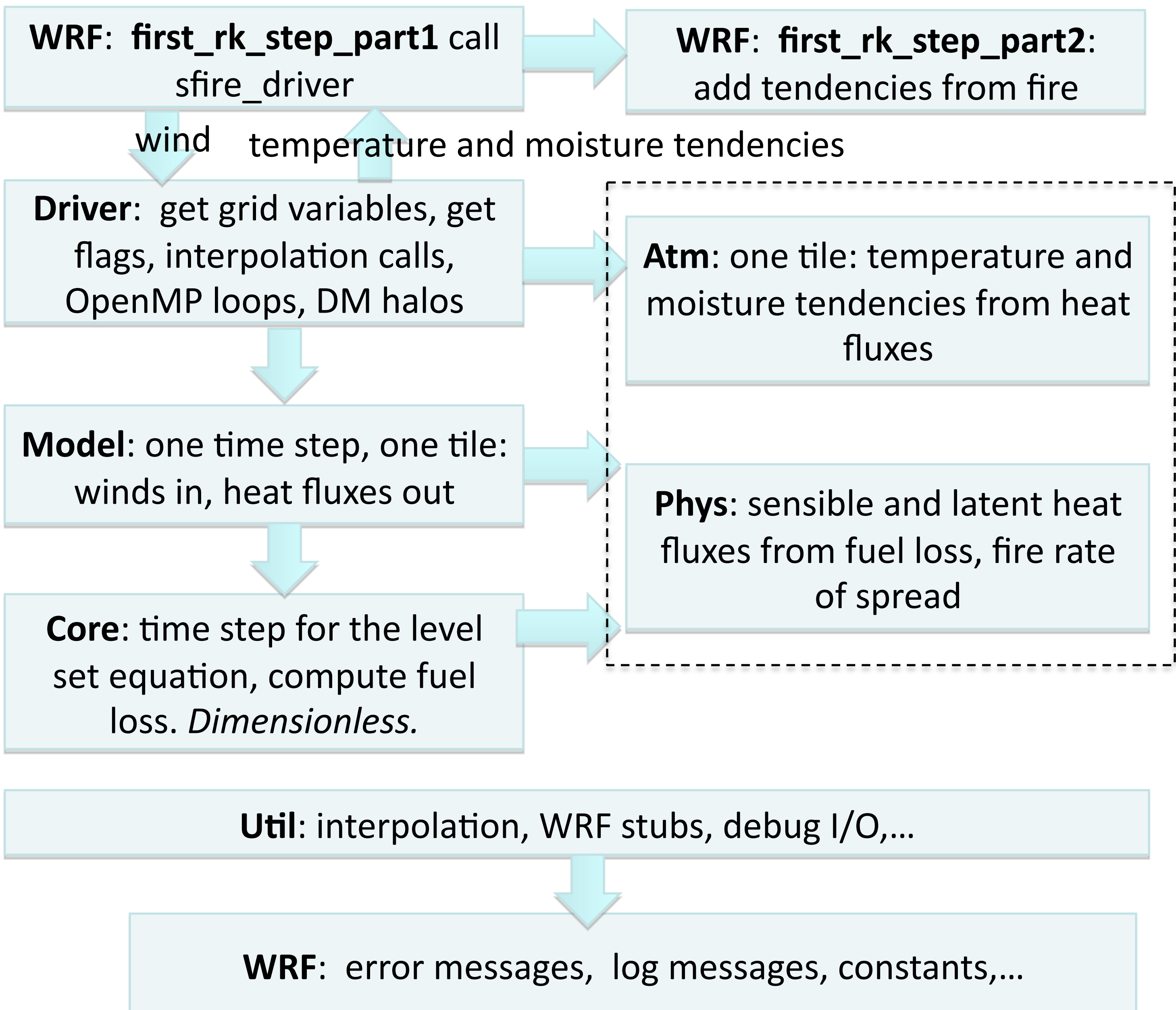
Fire input data

- Terrain - need finer than 30 sec.
  - Current: interpolated from surface height in WRF, blocky fire and wind behavior
  - Future: create terrain height data in WPS both for atmosphere and fire from a single high resolution data set, smoothing
- Fuel data on subgrid:
  - Current: Surface fuel category data (1 integer per subgrid cell) from LANDFIRE (http://landfire.cr.usgs.gov/) input through WPS
  - Future: Fuel state (fuel moisture), vertical fuel profile: canopy fuel (amount, physical characteristics, state)
- Longitude and latitude: need < 1m resolution
  - Current: subgrid coordinates interpolated from single precision WRF arrays; easily 20% error in fire mesh size/shape due to rounding
  - Future: create higher accuracy subgrid node coordinates in WPS (double precision, or an offset scheme)

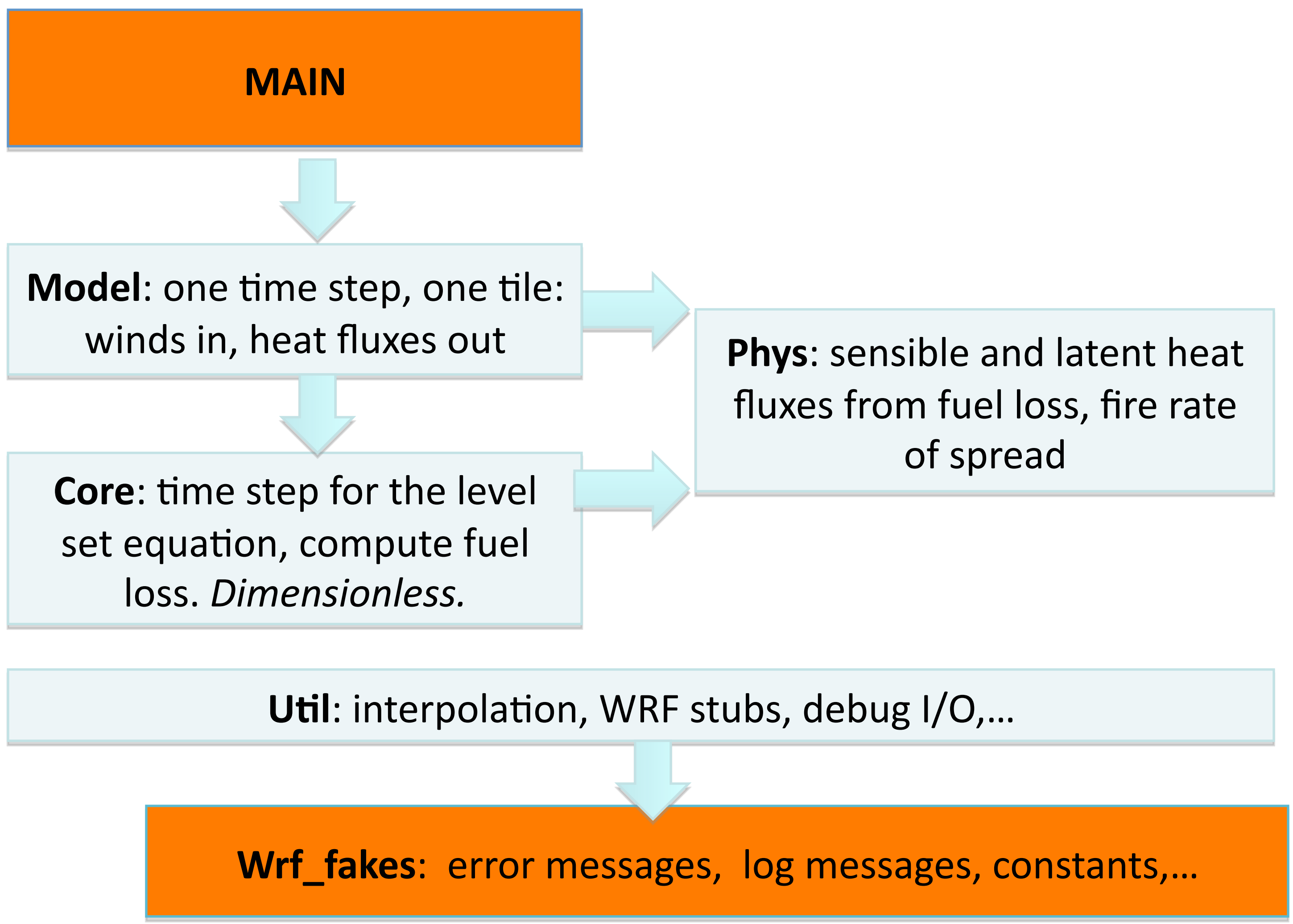
Fire namelist parameters

- Number of fires
- Ignition time and location
- Type of ignition: spot (with radius) or line (with thickness)
- Parameters of the numerical methods (for testing or support only)

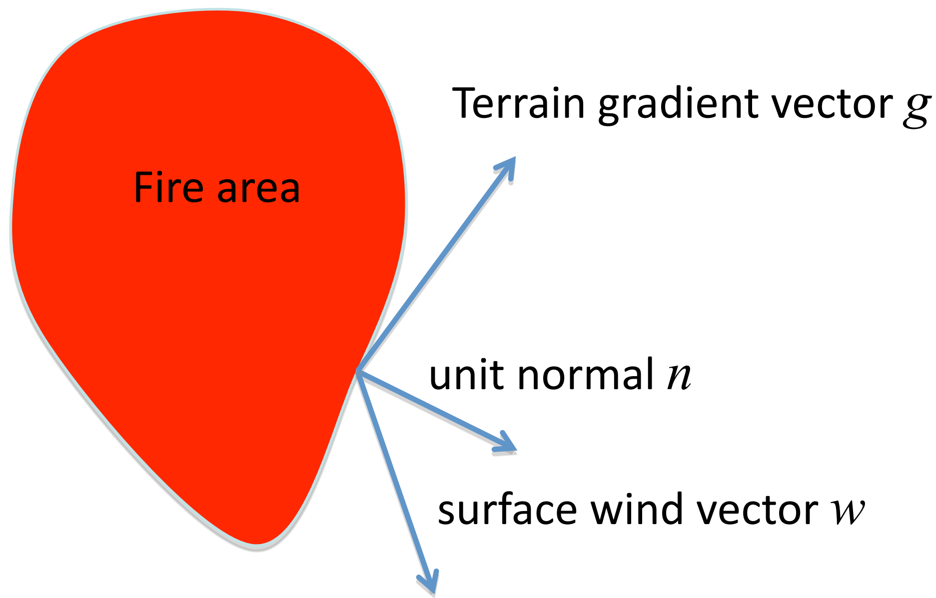
Coupled model



Standalone model



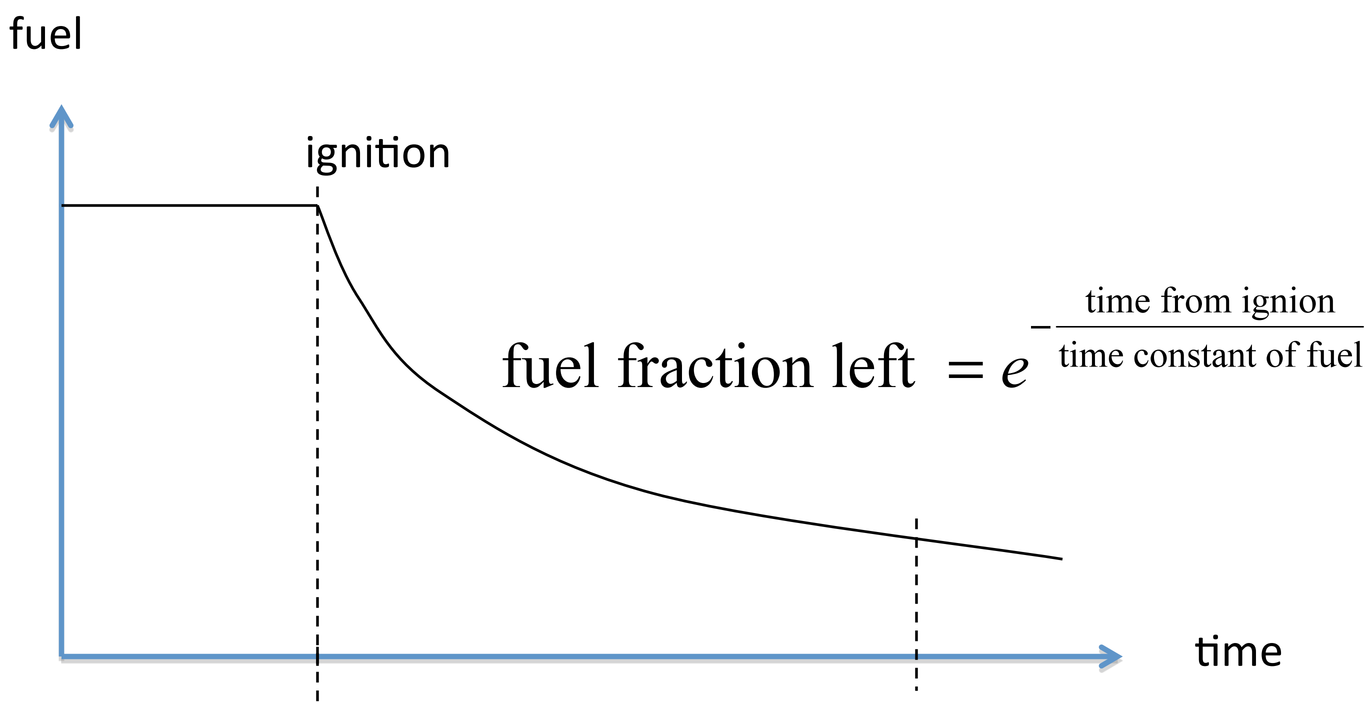
The fire model: fireline propagation



Rate of spread of a surface fire in the normal direction n is a function of fuel properties r modified by winds near the surface w and terrain slope g:

$$S = r + c(w \cdot n)^{\alpha} + d(g \cdot n)^{\beta}$$

The fire model: fuel consumption

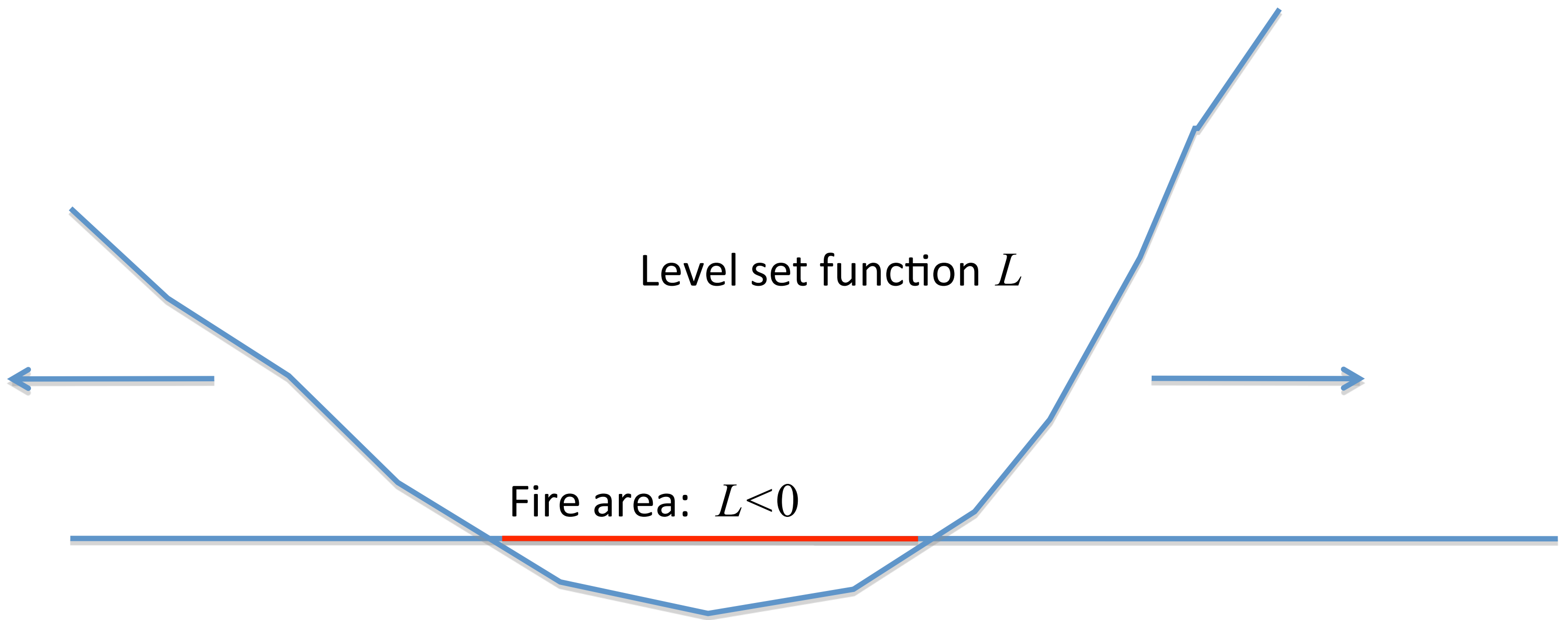


Time constant of fuel:

30 sec - Grass burns quickly

1000 sec – Dead & down branches(~40% decrease in mass over 10 min)

Evolving the fireline by the level set method

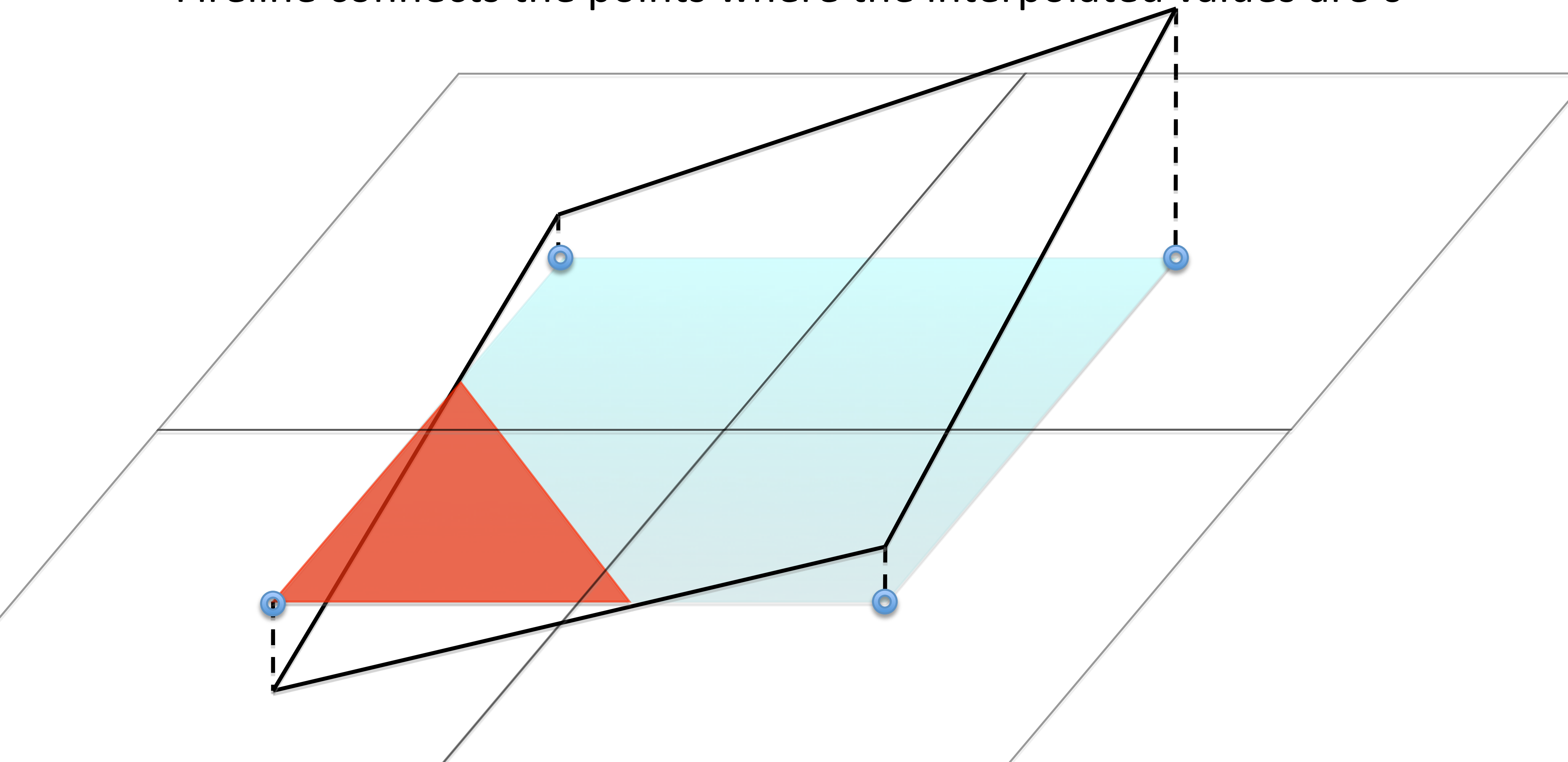


Level set equation $$\frac{\partial L}{\partial t} = -S\left|\nabla L\right|$$

Right-hand side < 0 → Level set function goes down → fire area grows

Representation of the fire area by a level set function

- The level set function is given on center nodes of the fire mesh
- Interpolated linearly, parallel to the mesh lines
- Fireline connects the points where the interpolated values are 0



Numerical methods

- All arrays based at fire grid cell centers
- The level set equation is advanced by 2nd order Runge-Kutta method, with special modifications developed for the stability of the level set method
- One level-set equation time step per call from WRF
- Error exit if the time step is too short for stability. Not a problem because, so far, the WRF restriction on step size has been more stringent, for the atmosphere/fire refinement ratio 10:1.
- Fuel loss computed by numerically over a local submesh in every fire cell, at least 2x2

Registry fire variables on the fire mesh

- All fire variables based at the centers of the fire grid cells
- State:
  - LFN - level set function
  - TIGN_G - time of ignition of ground fire
  - FUEL_FRAC - fuel amount remaining, between 0 and 1
- For one timestep only
  - UF, VF - winds interpolated to fire mesh (input)
  - FRGNHFX, FQRNHFX - heat and moisture flux (output)
  - LFN_OUT – a copy of LFN, needed because of parallelism
- Set once and then constant
  - FXLONG, FXLAT, ZSF - coordinates of fire mesh nodes
  - FUEL_TIME, BBB, BETAFL, PHIWC, R_0, FGIP, ISCHAP – fuel coefficients

Relevant registry variables on the atmosphere mesh

- Needed on the finest mesh (innermost domain) only
- Accessed in the driver from grid and config_flags
- Input variables (existing in the registry)
  - XLONG, XLAT, HT – surface nodes coordinates
  - Z_AT_W, DZ8W
  - U2, V2 – horizontal wind components
- Output variables (added to the registry)
  - RTHFRTEN, RQVFRTEN – temperature and moisture tendencies

Files affected

- dyn_em/module_first_rk_step_part1.F
  - added call sfire_driver
- dyn_em/module_first_rk_step_part2.F
  - tendencies from the fire added to the arguments of update_phy_ten
- dyn_em/Makefile
- dyn_em/module_initialize_fire.F
- phys/module_physics_addtendc.F
  - loops to add temperature and vapor tendencies
- Registry/Registry_EM
  - Added fiew variables and halos
- phys/module_fr_sfire_*.F
  - the fire model itself
- phys/Makefile
  - added the new files
- namelist.input
  - added fire parameters

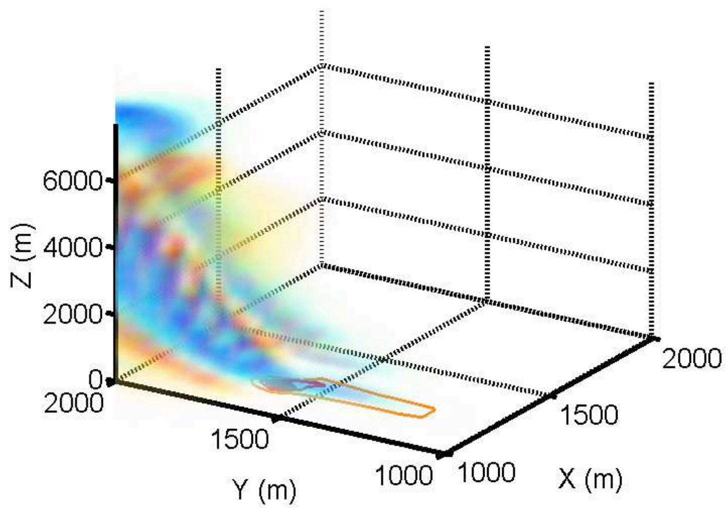
Subgrid data support in WPS

- Need to produce met files compatible with WRF i/o:
  - Dimensions named `south_north_subgrid` and `west_east_subgrid`
  - Refined from atmospheric grid by a factor of `sr_x/sr_y` as given in WRF namelist.input
- Experimental implementation is available:
  - New GEOGRID.TBL data parameter, `subgrid=yes` indicates that the given data field should be created as a WRF subgrid array
  - New namelist.wps parameters, `sr_x/sr_y,` gives subgrid refinement for the given domain
- Limitations of the current experimental implementation:
  - No parallel support
  - Not all interpolation options supported on subgrid fields
  - Not thoroughly tested

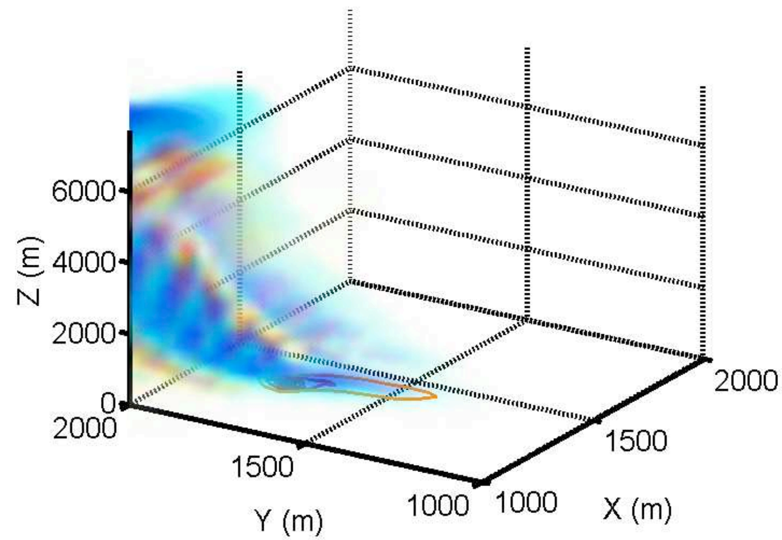
Data assimilation

- Issues
  - Standard DA methods do not work
  - The state distribution is strongly non-gaussian, centered around burning and not burning states at every point
  - Need to use spatial corrections, not amplitude only
- Current
  - Morphing EnKF shows promise
  - Replaces linear combinations in EnKF by intermediate states by deformation of the domain
  - Prototype code exists
  - Observation function = whole array
- Future
  - Release-quality code
  - New observation functions for aerial fire photographs and fire sensors (airborne, UAV, satellite)
  - Reuse existing observation functions for weather
  - Develop new algorithms for assimilation of time series of point-based data (sensors, weather station) in the morphing filter

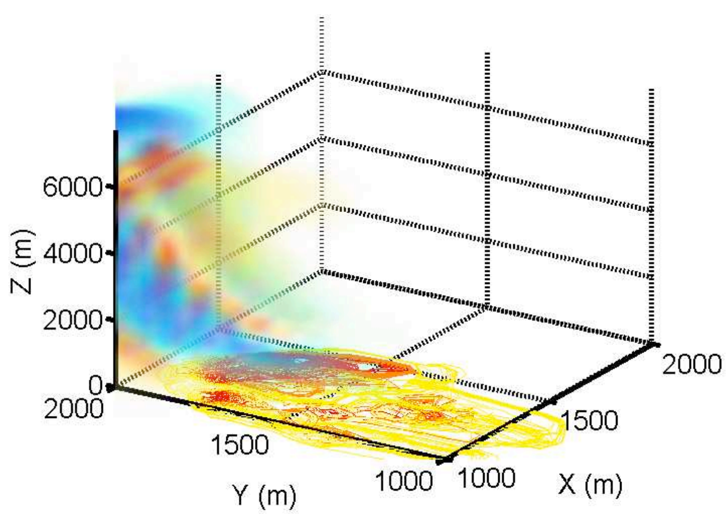
Preliminary data assimilation results



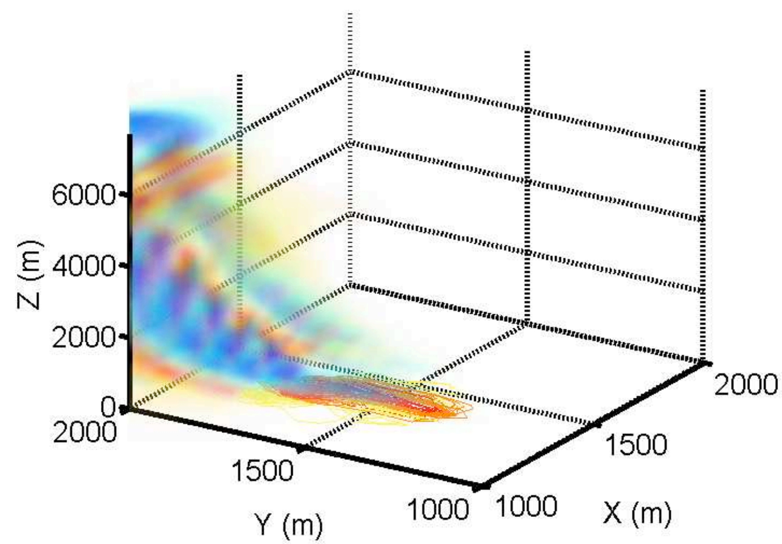
Forecast



Data



Analysis - standard EnKF



Analysis - morphing EnKF