# FMDA Lit Review Notes

## *Recent* *Advances…in WRF-SFIRE* Mandel 2014

Coupled atmosphere-fire models; FMDA plus WRF-Chem to model smoke and air quality.

* Intro
  + Small-scale processes, like turbulent air mixing, are affected by large-scale weather
  + Kolmogorov hypothesis: energy propagates from large-scale eddies to small-scale
  + Large-scale weather induces changes in temp and humidity which affect FM
  + Fire highly sensitive to FM
    - Delays ignition
    - Decreases fuel consumption
    - Increases particle residence time
  + Spread rate decreases with increasing FM until extinction-moisture level where no fire propagation (Pyne 1996)
  + Rothermel 1972: fire-spread rate depends on FM through an empirical moisture damping coefficient
  + FM depends on weather and fuel properties
    - Live fuels exhibit seasonal variation driven by physiological processes
    - Dead fuels highly influenced by weather
      * Precipitation, RH, temp, wind, dew, solar radiation
    - Matthews 2010 summarizes modeling processes of dead fuels
  + Daytime variation in fuels often disregarded in small fires, but important for long fires
  + Simulating multi-day fires requires forecasts of FM
  + Synoptic flows affected by topography and land use. Direct numerical simulations too expensive
    - Combustion processes 10^-4 m
    - Plume 10^5 m
    - Planetary-scale weather 10^7 m
  + Coupling mesoscale weather model w 2-D fire spread model captures most behavior
  + Fire influences weather through vapor, burning carbohydrates, & evaporation
    - Updrafts caused by fire create strong winds which affect fire, potentially pyro-cumulus and fire storms
  + WRF-SFIRE
    - two-way coupled fire-atmosphere model
      * Heat fluxes from fire provide forcing to atmosphere
      * Atmospheric changes affect fire
    - Fire-model resolution of a few meters
    - Atmospheric resolution of 100m
    - Validation studies of various aspects of system
* Section 2: Mapping Severity of a potential fire
  + Plot potential fire severity maps to aid prevention
  + Diagnostic var added to maps equal to maximal rate of spread in any direction for the modeled wind speed and land-elevation slope
    - Used to compute reaction intensity immediately upon ignition
    - Provides spatial representation of the potential-fire characteristics
  + **Question for Jan: can I build these maps and get these values?**
* Section 3: Initialization from a fire perimeter
  + Typically fire sim starts at known point and known time
  + Want to initialize WRF-SFIRE from existing fire perimeter at given time
    - Fuel balance and state of atmosphere depend on history of fire which is unknown
  + Create approximate artificial history of fire based on current state
    - Encoded as fire arrival time at nodes of mesh
    - Use artificial arrival time instead of fire-spread model to burn fuel and generate heat
    - Artificial history allows for gradual changes to atmosphere that are realistic
    - At perimeter time, complete coupled model takes over
  + Reverse direction of time in a fire-spread method and shrink fire to one or more ignition points
    - Ignition time at a node is earliest time fire can get to that node from already burning nodes
    - “Minimal fire arrival time”
* Section 4: Fuel-moisture Model
  + First-order ODE run at each node of the surface mesh independently
    - Moisture m approaching equilibrium E with time lag :
    - For constant E & :
      * Difference in E and m decreases to of its initial value over the time
      * Compatible w definition of time lag which is supposed to be time it takes fuel to reach 2/3 of its way to equilibrium with environment
    - Considers a fuel particle as a single reservoir with rate of exchange of water with the environment proportional to difference with equilibrium
    - Simpler but cheaper to run USFS model
  + Over long time in constant temp and RH, moisture approaches drying equilibrium (Van Wagner and Pickett 1995):
    - When starting from the fuel approaches drying Eq
    - When starting from fuel approaches wetting Eq

* + - Time lag ODE run for different definitions of E. No change if fuel between these values.
  + Model run for 1, 10, and 100h time-lag fuel classes as defined by USFS 2014.
    - Equilibrium value same for all classes
  + Live fuel has its on dynamics, model not used for live
    - Live FM map entered as a separate fuel class with a very large time lag and doesn’t change during simulation
  + During rain, E taken to be saturation moisture contents S and the time lag depends on rain intensity.
    - Rain-wetting time is reached for heavy rain asymptotically. For rain intensity and threshold intensity , below which no wetting occurs, and the saturation intensity :
    - Tuned coeffs (but can be manually specified):
      * Saturation content
      * Wetting lag time
      * Threshold intensity
      * Saturation intensity
  + Model maintains FM at center of each atmospheric grid cell for classes 1, 10, 100, & 1000 h
    - Actual fuel is mix of these classes, weight for each class. Determined by table made by past researchers
    - Fine fuels like grass pure 1h, course woody fuels mix of 10 and 100
    - FM on finer mesh interpolated for each fuel class k
  + Adaptive exponential method to integrate FM equations at every grid node. On time interval
    - Approx by averaging atmospheric vars at time end points
    - Rain intensity determined from difference in accumulated rain at times n and n+1
    - Time step performed by evaluating w appropriate Eq:
    - For short time steps, the exponential at the end of above is replaced by Taylor expansion to avoid large rounding error caused by subtracting two almost equal quantities
  + Tested on Barker Canyon Complex fire (Sept 2012) in WA
    - Nested spatial domains with their own time steps
    - No ground-FM observations available within fire domain
      * so 1h initialized with equilibrium value
      * 10, 100, & 1000h approximated with National Fuel-Moisture Database
* Section 5: Assimilation of RAWS FM data
  + RAWS measure 10h fuel w continuous hourly data output
  + Regression used to interpolate covariates from simulation grid to RAWS locations
  + Only 10h measured but simulated independently in 1, 10, and 100h classes
    - Results combined for each fuel type according to relative mass contributions (Albini 1976)
    - Data assimilation modifies equilibria in all fuel classes by a common additive correction
    - Changes made to 10h are transferred to 1 and 100h fuel equilibria. AKA same Eq used for all fuel classes
  + Methodology simplified from Vejmelka 2014. To assimilate data at fuel classes at each grid point
    - Augment model state by perturbations  and of equilibrium moisture values
    - Replace with , with , and S with
    - Add the differential eqs = 0 & = 0
    - Apply extended KF to model in the augmented variables
    - Equilibrium corrections couple the evolution of different fuel-moisture classes together
  + Extend measurements and uncertainty from several RAWS locations to whole domain using trend surface model
    - FM estimate at location s
    - Errors assumed to be iid with variance modeling microscale variability
    - Given measurements   the coefs are found from
    - Errors assumed iid with variance representing error at RAWS station
    - LS solution to regression. Unbiased estimate of residual variance
    - Mean and var of estimated field are obtained by computing LS solution to betas and substituting into trend surface model, for
    - 8 covariates used after variable selection
      * Current 10h FM forecast, air temp, surface pressure, current rain intensity, terrain elevation
      * 3 covariates of long lat and constant
      * **Question: does using temp, rain, and pressure in trend surface model bias results? We use these variables (with RH subbed for pressure) to model FM. So these vars are used to model the truth and the estimate. Doesn’t this lead to bias?**
* Section 6: Data management and Visualization
  + Data is typically in geotiff format
    - Converted into Geogrid files, used in any version of WPS
    - Conversion creates large files, so WPS modified to read GeoTIFF directly
  + NetCDF standard for WRF output
* Section 7: Coupling with smoke transport and chem
* Section 8: Operational use in Israel