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Evaluation of The Fire Plume Dynamics Simulated by WRF-Fire

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Photo of Meadow Creek fire
from http://www.postindependent.com

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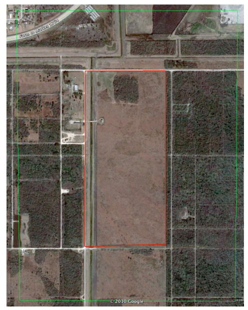
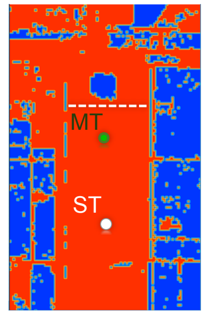
Motivation

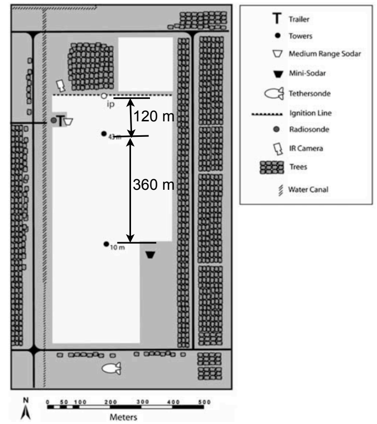
- So far most of grass fire field experiments focused on the fire front shape and the rate of the fire spread
- No fire atmosphere interaction was captured so far due to the poor meteorological instrumentation:
  - Wind speed and direction measured long distance upwind from the fire
  - Wind speed (only) measured on the corners of the burnt area
- Limited set of experimental data allowed only for a basic validation of the fire models in terms of the fire spread rate and the fire front shape.
- To asses how well fire-atmosphere feedbacks, and fire plume dynamics are simulated by coupled fire-atmosphere model (WRF-fire), we use FireFlux data - first meteorological observations collected during the fire front passage

FireFlux experimental setup

- Prescribed burn of experimental, 155 acres (0.63 km^2) prairie
- Relatively simple setup but:
  - with complex land use and roughness characteristics
  - patch of trees upwind from the fire line
  - Short distance between the ignition point and the main tower



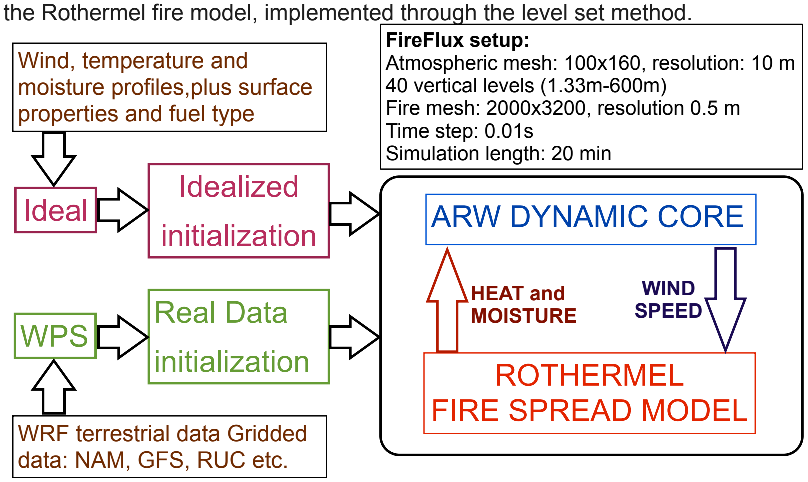




FireFlux picture from Clements et al. 2008

WRF-Fire and its setup for the FireFlux

- Coupled atmosphere-fire model based on the ARW atmospheric core and the Rothermel fire model, implemented through the level set method.



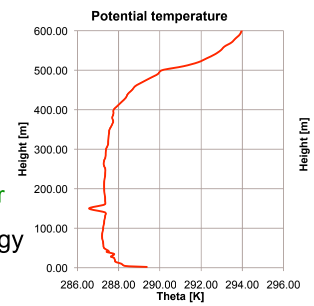
Model validation (initial) based on the FireFlux dataset

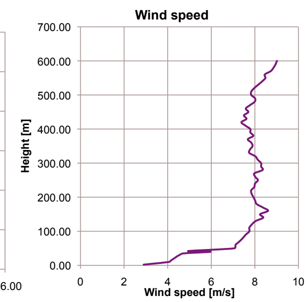
- Speed of the fire spread
  - Time when the fire front reaches the first tower
  - Time interval between the moments when the fire reaches the main tower and the short tower
- Updraft velocities
- Air temperatures
- Horizontal wind speed
  - 2m AGL
  - 10m AGL
  - 28m AGL
  - 42m AGL

  } Main tower
  - 2m AGL
  - 10m AGL

  } Short tower
- Turbulent Kinetic Energy

Tower, radiosonde, thetersonde, and sodar data has been combined to create vertical profiles of the wind speed, temperature and moisture used for model initialization

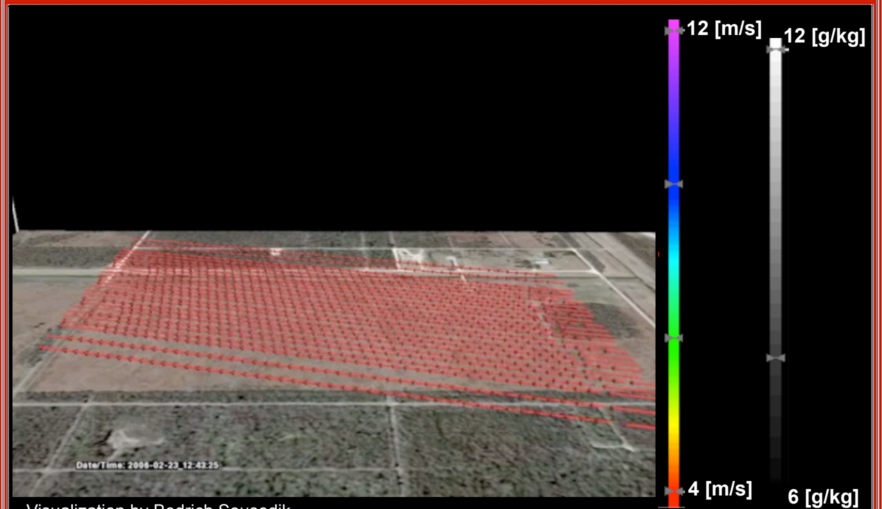




Movie from the FireFlux experiment

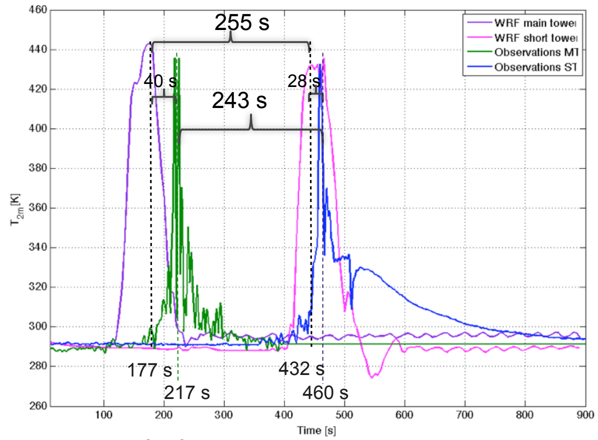
Movie by Craig Clements

Simulated wind speed and water vapor (WRF-fire)



Visualization by Bedrich Sousedik

Timing of the front passage, and air temperature at 2m AGL - main and short towers (WRF vs. Observations)



$T_{max\ MT\ WRF}$ = 442K
$T_{max\ MT\ Obs\ LP}$= 438K

$T_{max\ ST\ WRF}$ = 436K
$T_{max\ ST\ Obs\ LP}$ = 434K

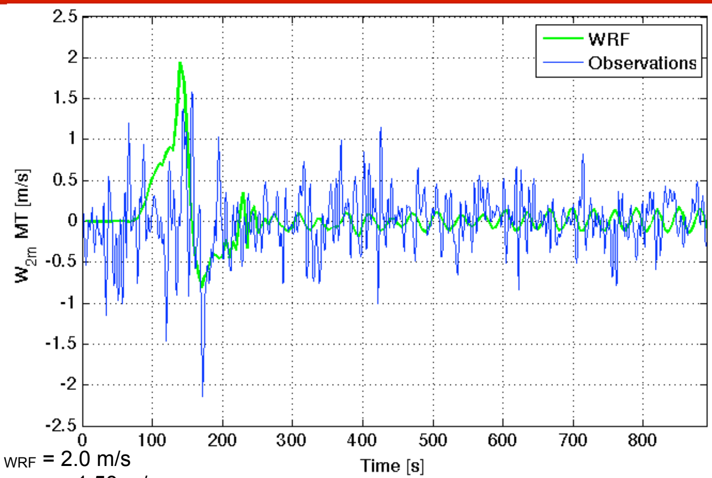
$t_{MT\ WRF}$=177s
$t_{MT\ OBS}$=217s

$t_{ST\ WRF}$=432s
$t_{ST\ OBS}$=460s

Dt_{WRF}=255s
Dt_{OBS}=243s

WRF-simulated fire front reaches the towers slightly too early (MT: 40 s, ST: 28 s too early)
Simulated time required for the fire front to propagate from MT to ST is 12 s longer than observed (WRF Ros=1.41 m/s, observed Ros=1.48 m/s: 4.7% difference)

Upward velocity at 2m AGL - main tower (WRF vs. Observations)



$W_{max\ WRF}$ = 2.0 m/s

$W_{max\ Obs\ LP}$ = 1.58 m/s

($W_{max\ Obs\ raw}$= 2.68 m/s)

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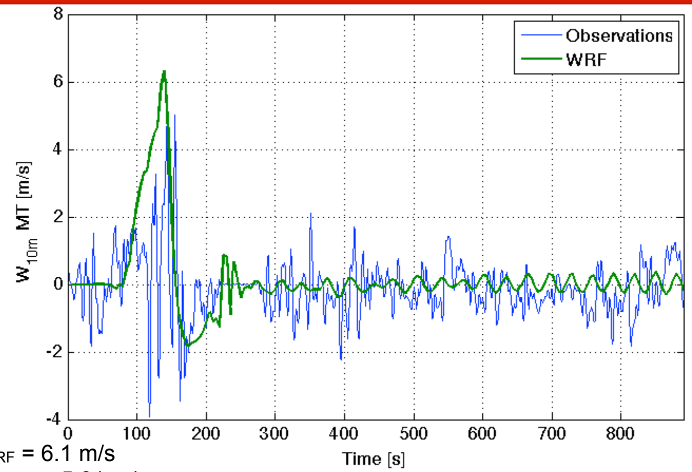
Upward velocity at 10 m AGL - main tower (WRF vs. observations)



$W_{max\ WRF}$ = 6.1 m/s

$W_{max\ Obs\ LP}$ = 5.01 m/s

($W_{max\ Obs\ raw}$ = 5.16 m/s)

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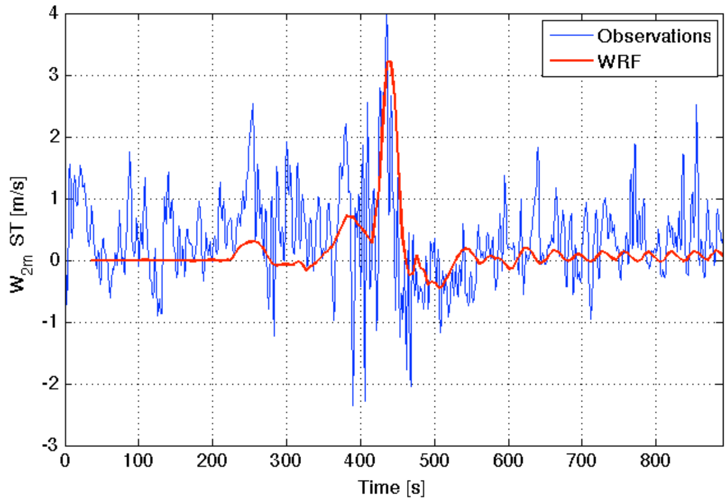
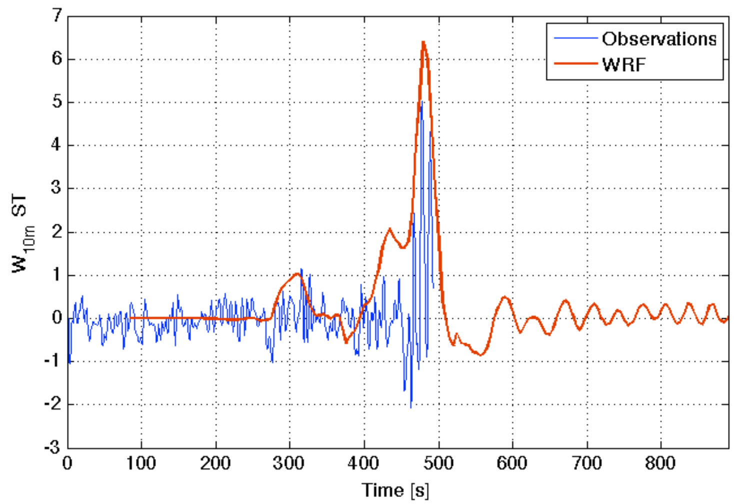
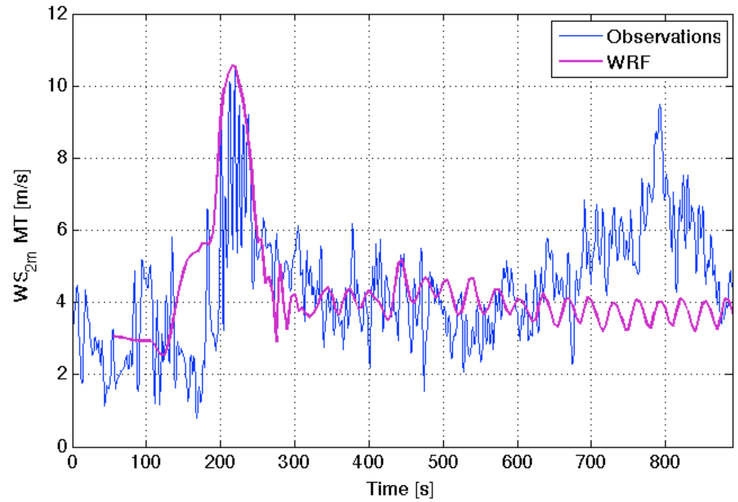
Upward velocity at 2m AGL - short tower (WRF vs. observations)



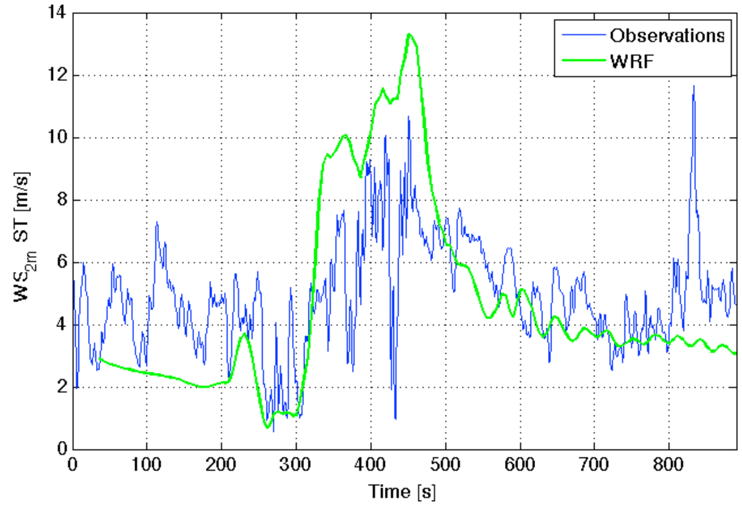
Upward velocity at 10m AGL - short tower (WRF vs. observations)



Wind speed at 2 m AGL - main tower (WRF vs. observations)



Wind speed at 2m AGL - short tower (WRF vs. observations)



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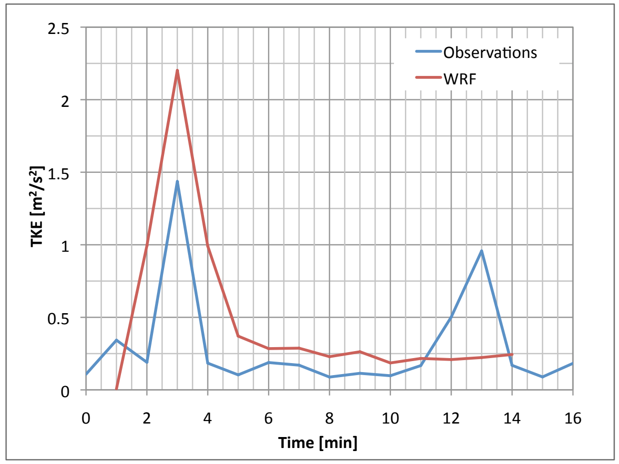
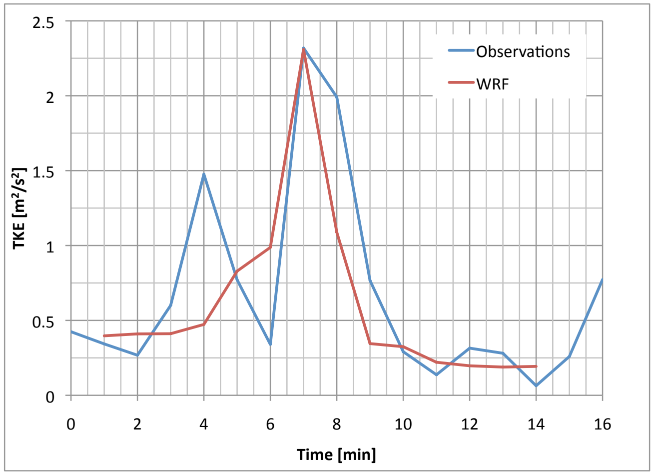
TKE at 2 m AGL - main tower (WRF vs. observations)



TKE at 2 m AGL - short tower (WRF vs. observations)



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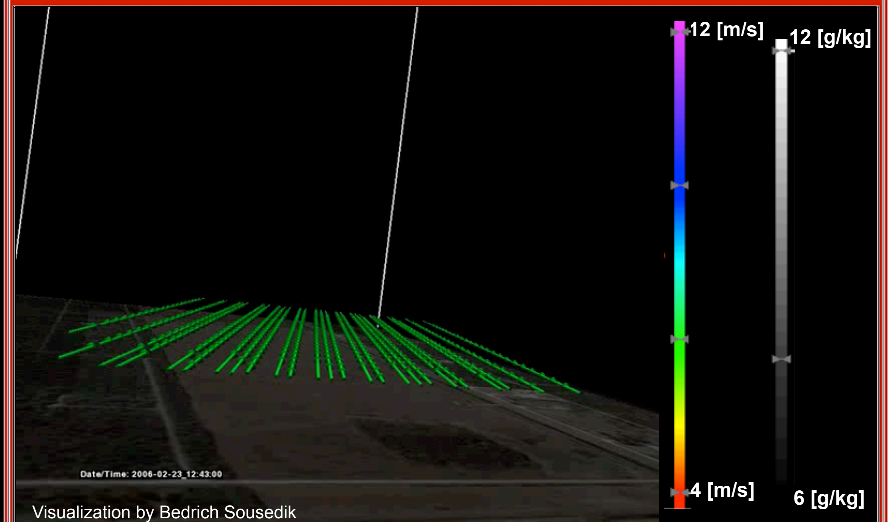
Summary and future work

- Initial results from numerical simulation of the FireFlux experiment show that WRF-fire is able to capture basic plume properties associated with the fire front passage
- Timing of the fire front passage between towers (once the fire spread equilibrates) is captured well; however the initial unsteady stage of the fire propagation, which may be affected by the ignition procedure is not simulated correctly
- An experimental setup with the main tower further downstream would be better suited for model validation, since the fire would have a chance to get steady before the measurements are taken
- For this scenario, the biggest modeling challenge seems to be realistic representation of the initial fire growth, which is almost 3 slower than the steady growth, as well as capturing the background flow turbulence
- The fire spread model itself is a big limitation since it is not designed for coupling with the atmospheric model
- Atmospheric properties close to the surface, directly affected by the fire are captured well by the model; however, the the flow properties at higher elevations, affected more strongly by the background flow characteristics are not simulated well, mostly due to the applied idealized boundary conditions
- More fire field experiments providing in situ data and design especially for model validations, as well as numerical experiments performed using fire resolving models are needed for better understanding of limitations, and improvement of the currently used fire-atmosphere models.

Thank You!



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