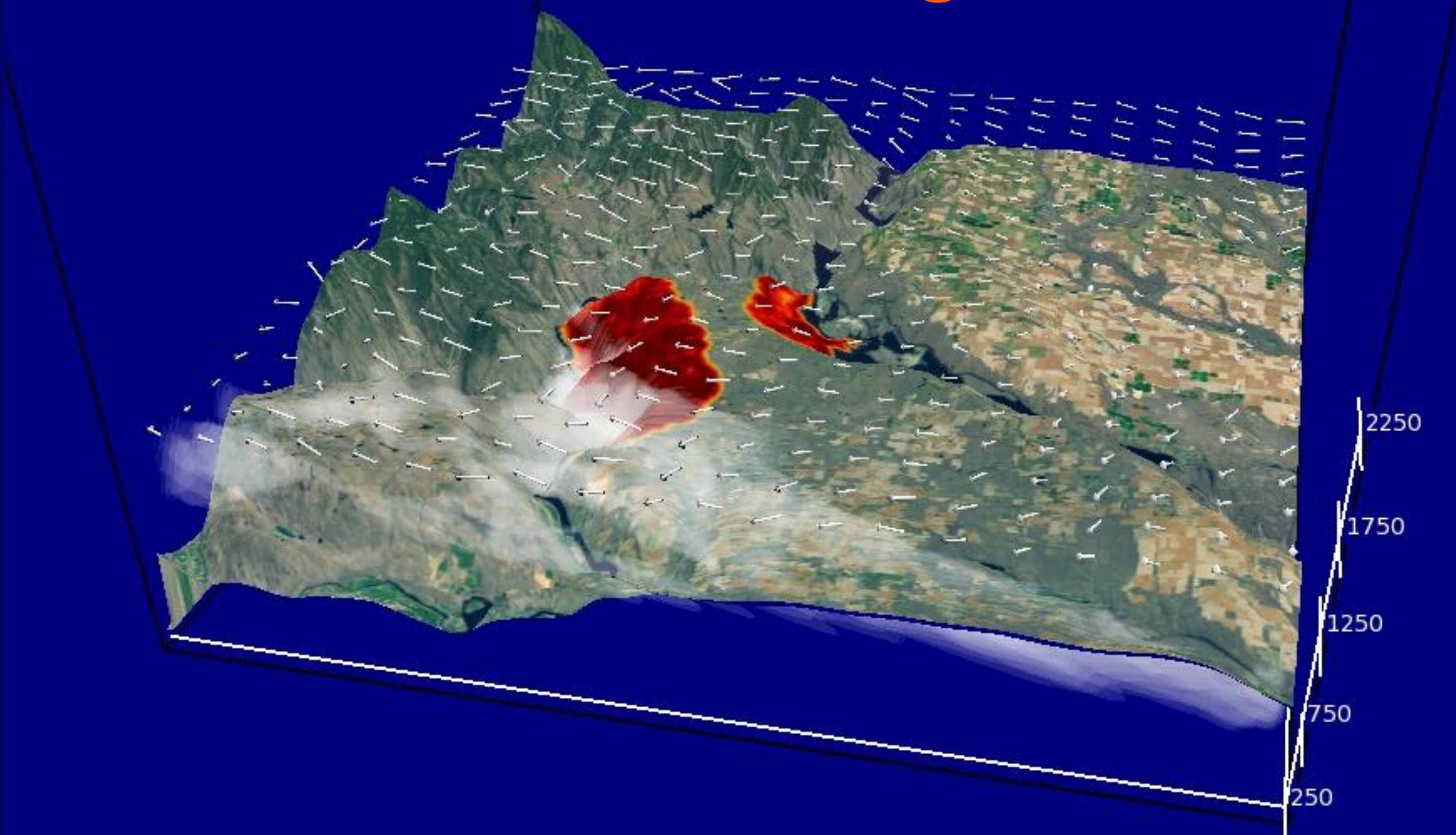
DEPARTMENT OF METEOROLOGY
UNIVERSITY OF UTAH

Multiscale fire modeling with WRF-Sfire



Adam Kochanski, M. A. Jenkins, J. Mandel, J. D. Beezley, K. Yedinak, and B. K. Lamb

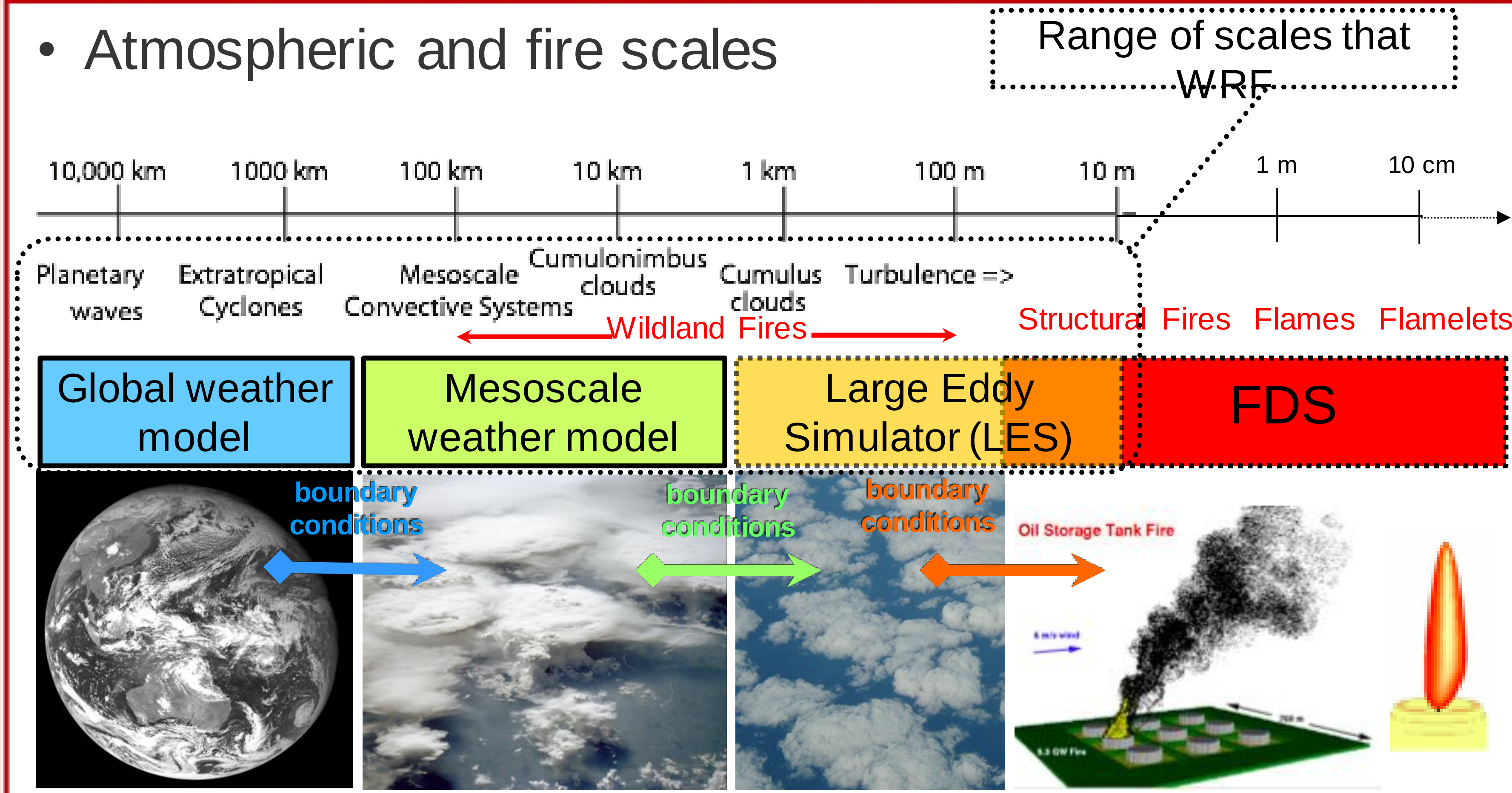
Introduction

Outline:

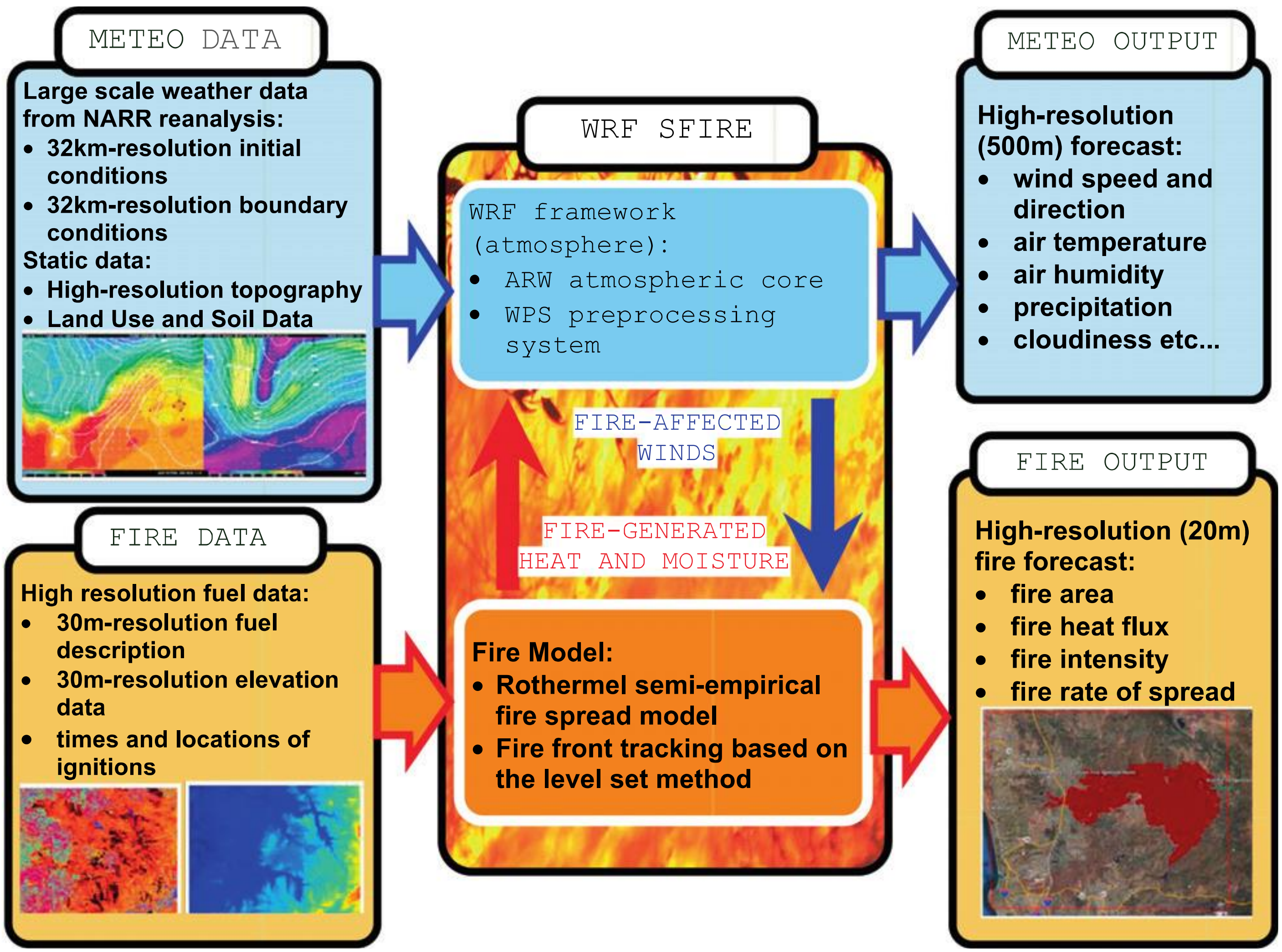
- ➢ Range of scales associated with wildland fires
- ➢ Modeling of Fire-Atmosphere interactions in WRF-Sfire
- ➢ Idealized LES simulations of prescribed burns
    - plume dynamics
    - thermal structure
- ➢ Wildland fire smoke modeling in a coupled fire-atmosphere framework
    - Levels of coupling and role of fuel moisture
    - Plume rise and smoke dispersion forecasting
    - Simulating air quality impacts of wildland fires

Range of scales affecting fires

- Atmospheric and fire scales

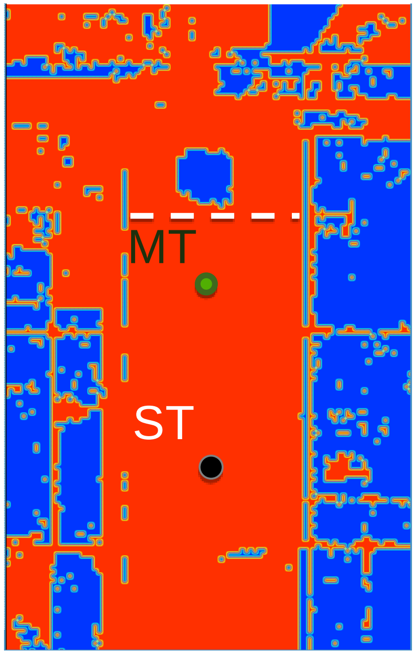


Modeling of Fire-Atmosphere interactions WRF-Sfire

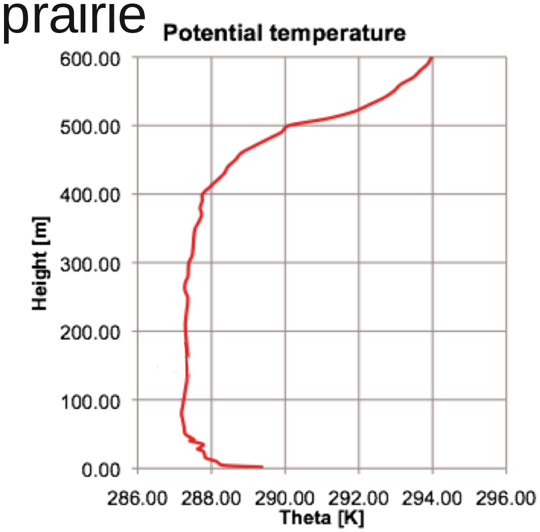


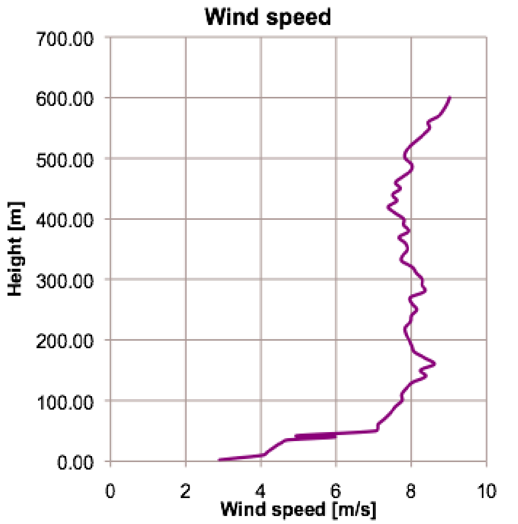
Idealized LES simulation of a small-scale prescribed burn (FireFlux experiment)

- FireFlux prescribed burn of 155 acres (0.63 km^2) prairie
- Model setup:
  - 1 domain, 1000m x 1600m, 10m horizontal resolution
  - 80 vertical levels from 2-1200m AGL
  - Fire grid resolution – 1m



FireFlux picture from Clements et al. 2008





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FireFlux Experiment

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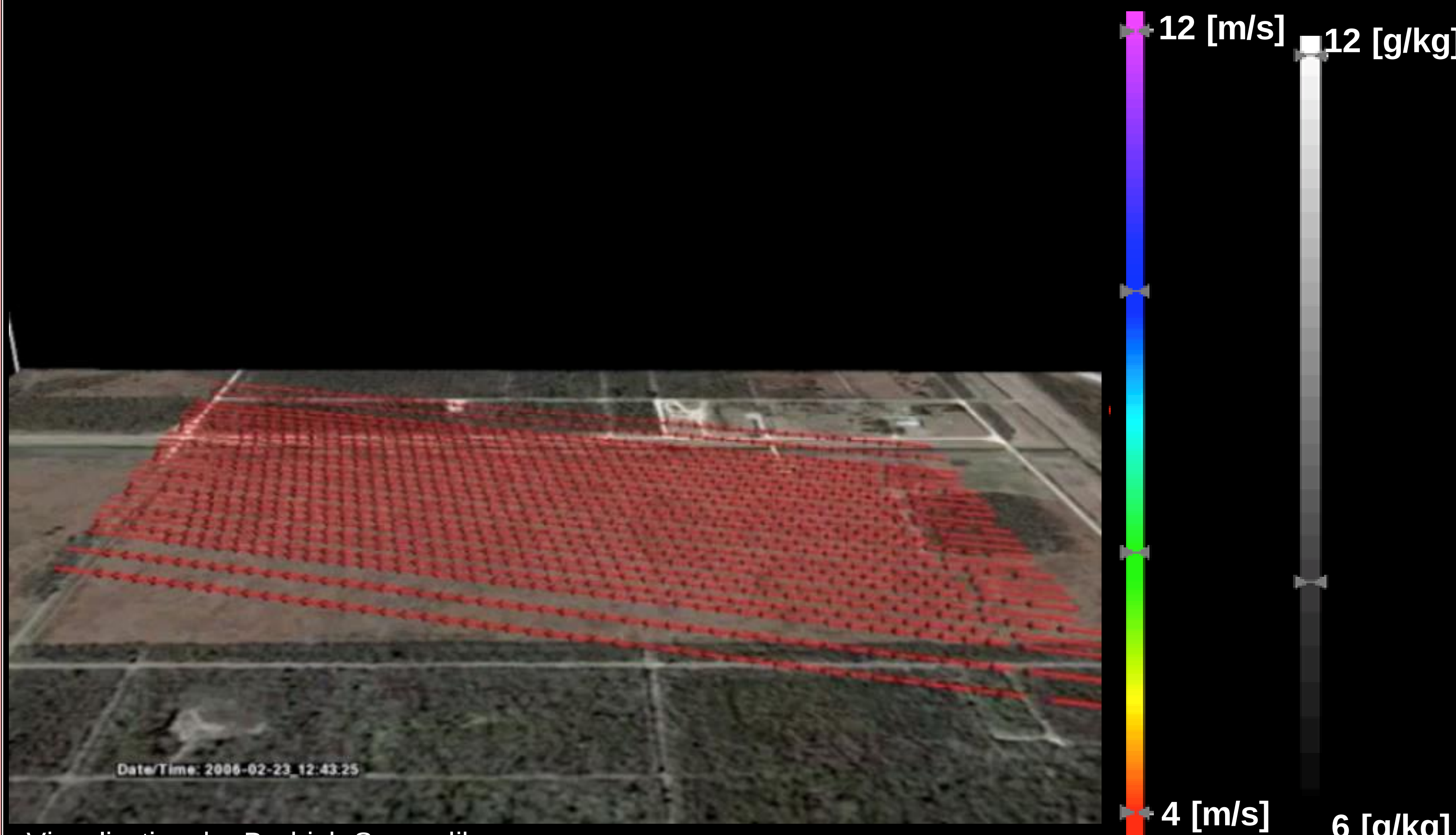
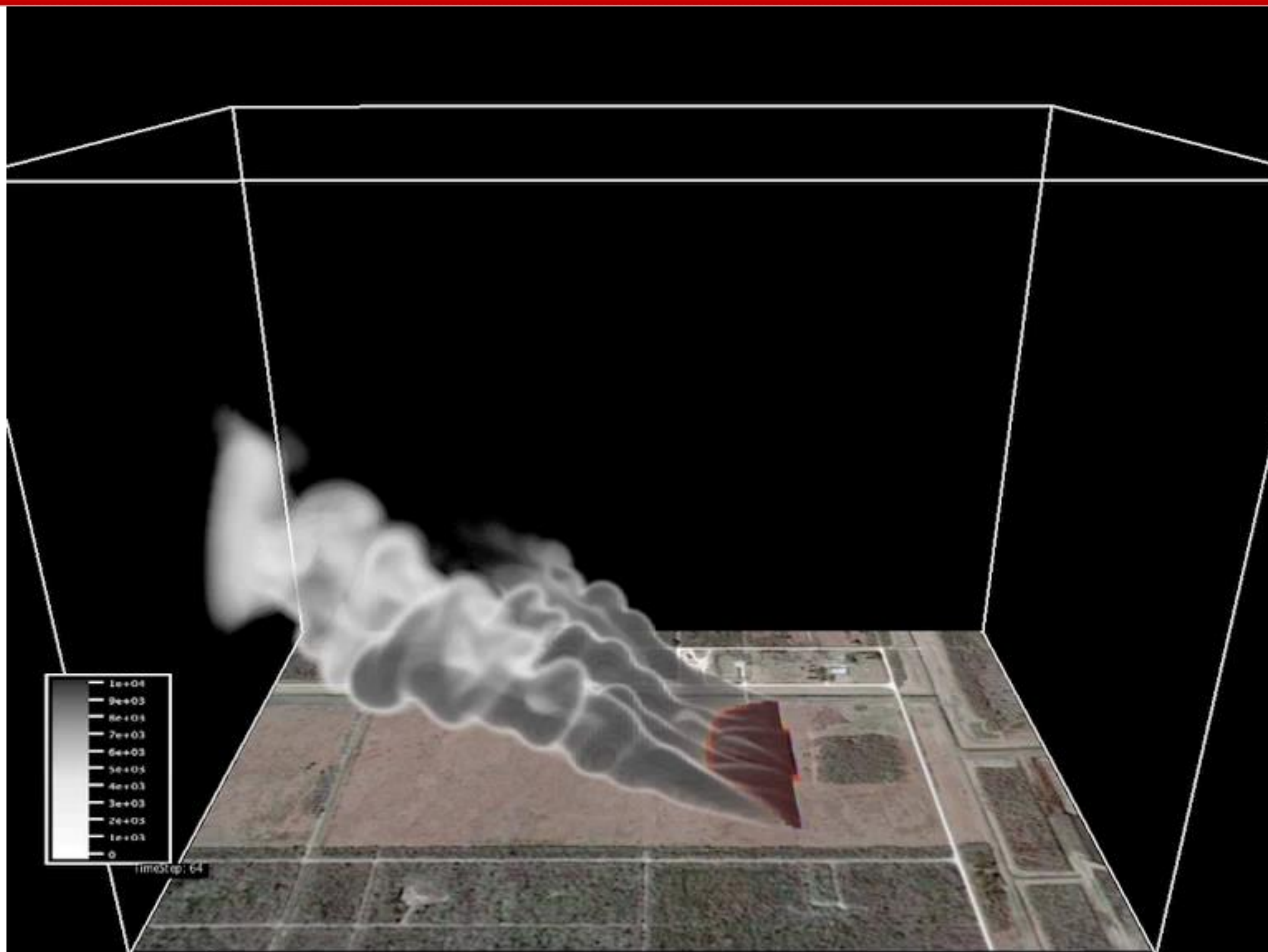
WRF-Sfire LES simulation of the FireFlux experiment (wind speed and water vapor shown)



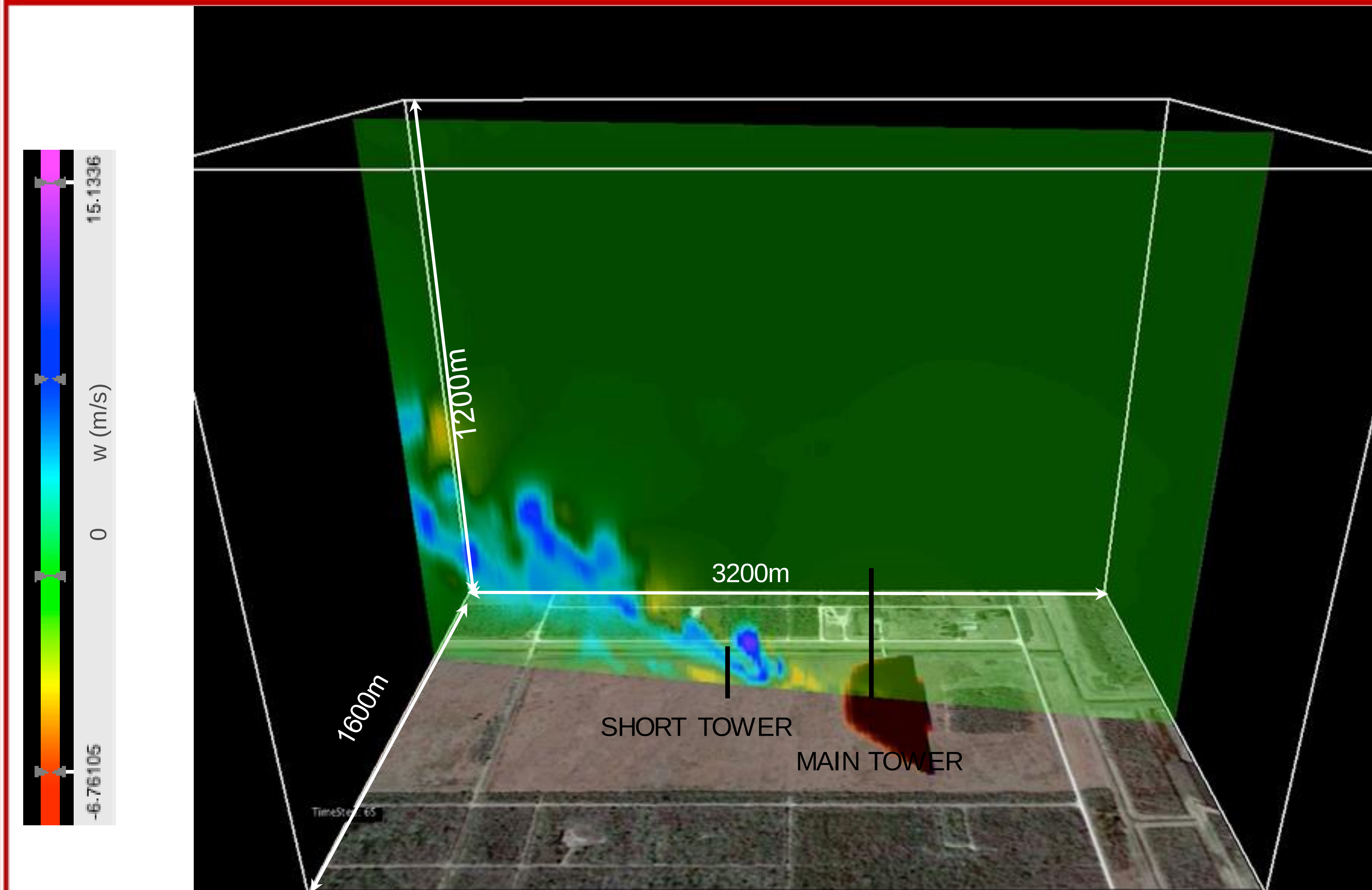
Visualization by Bedrich Sousedik

Idealized FireFlux simulation particulate emission (PM 10)

in-plume concentration ~3000μg /m³ (3mg/m³)



Idealized FireFlux simulation - updraft structure



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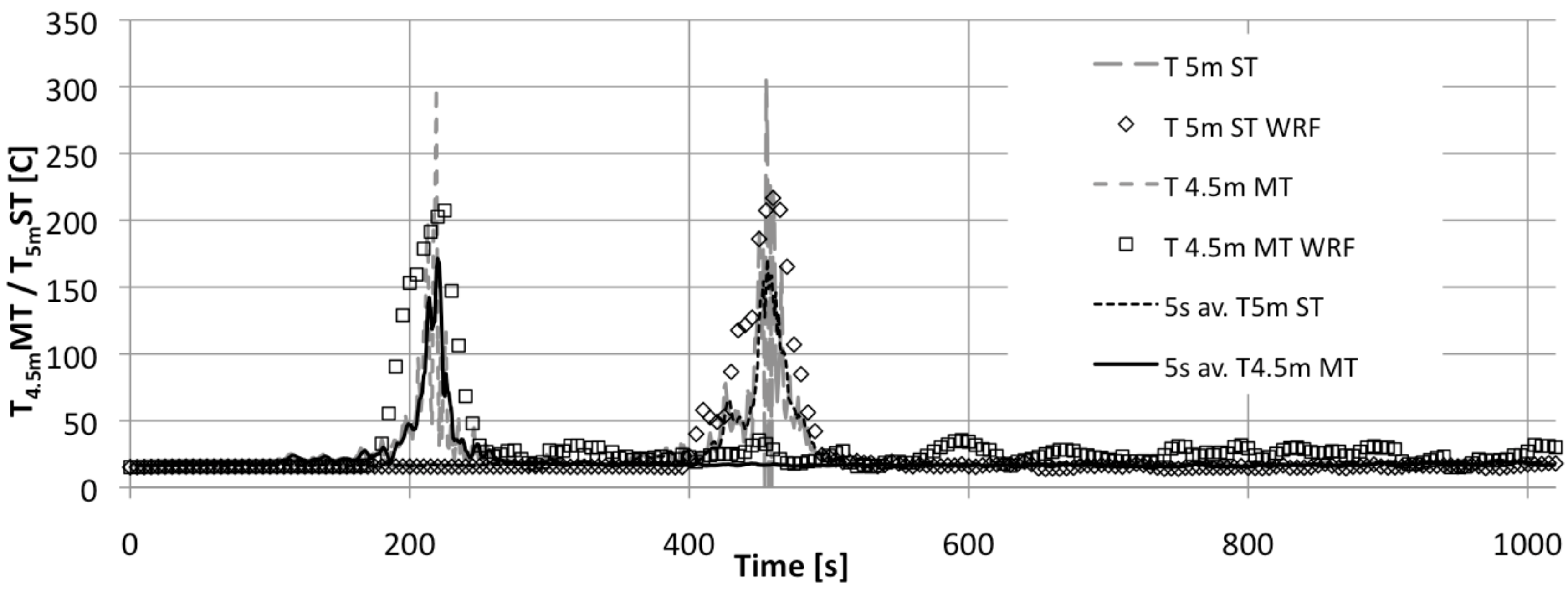
Timing of the fire front passage through the towers (5m and 4.5m air temperature)



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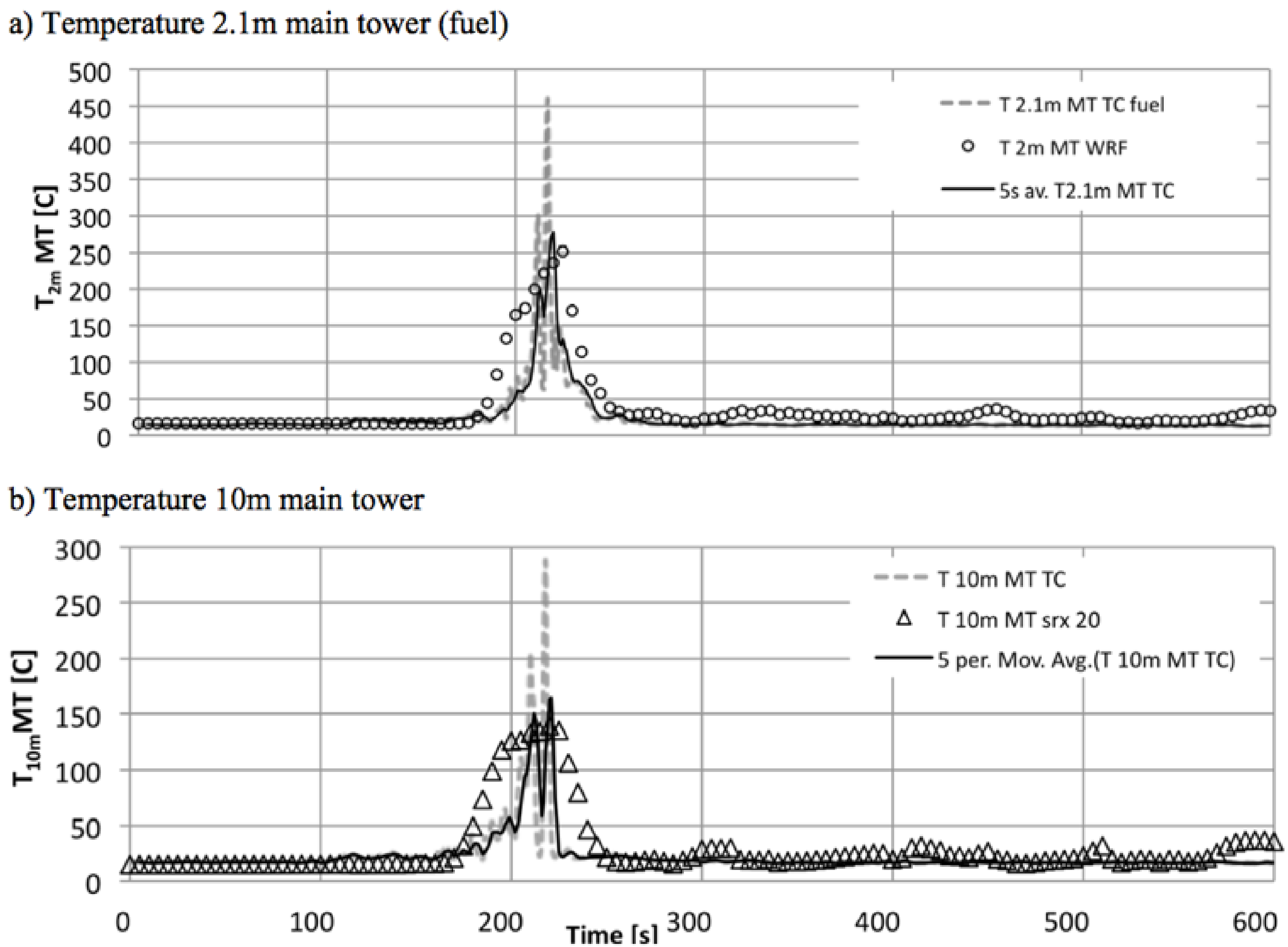
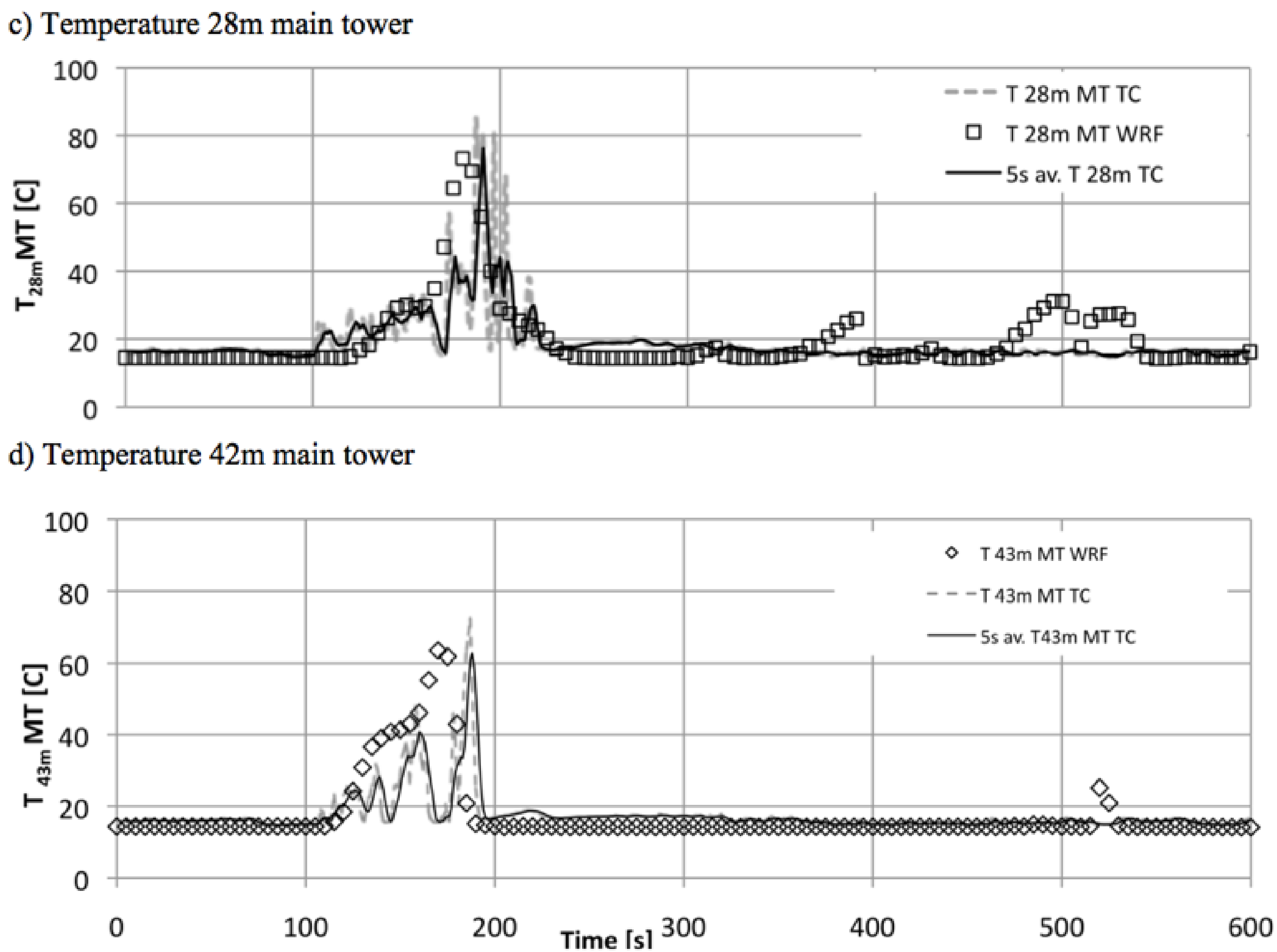
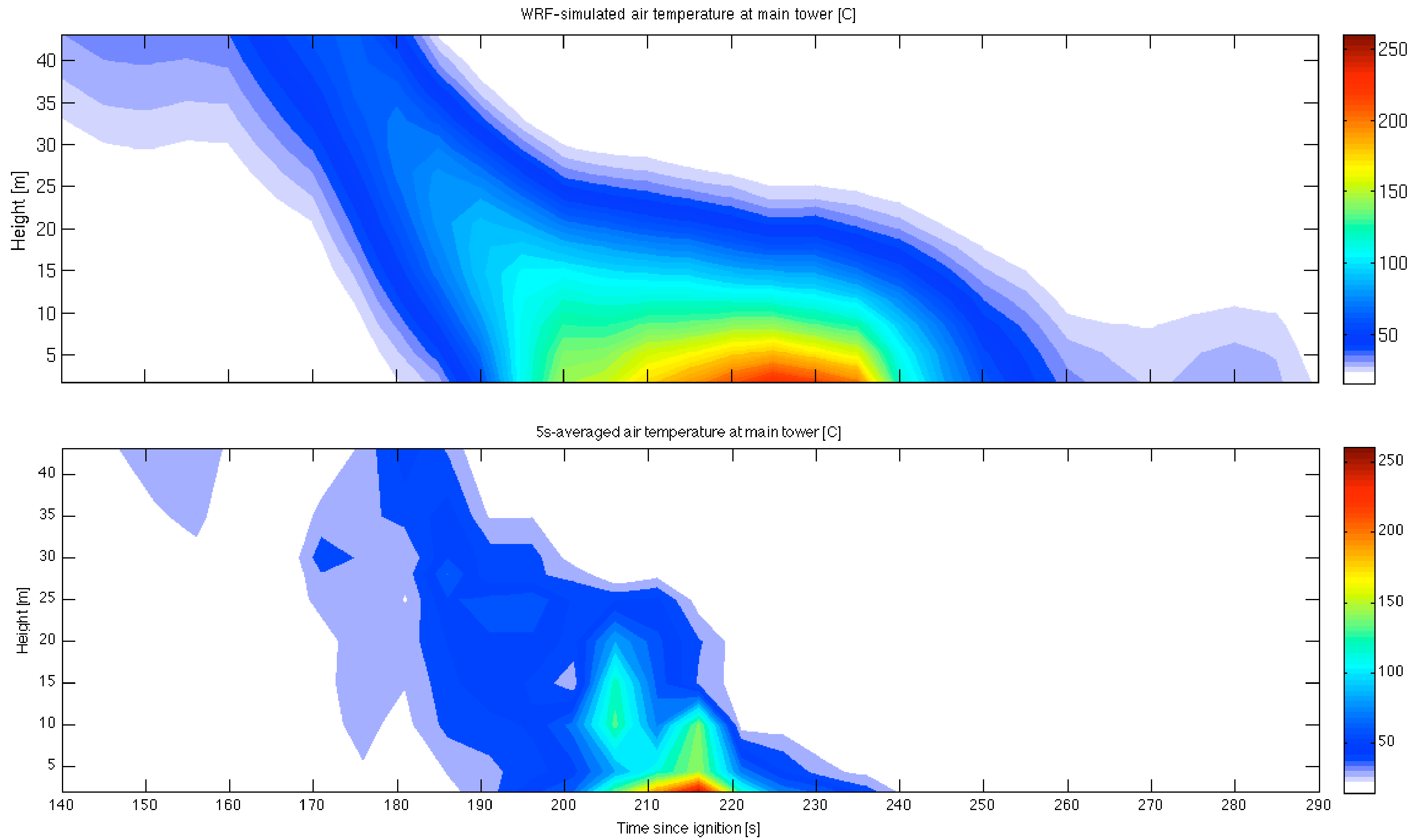
Thermal structure of the fire plume (2m and 10m above the ground)



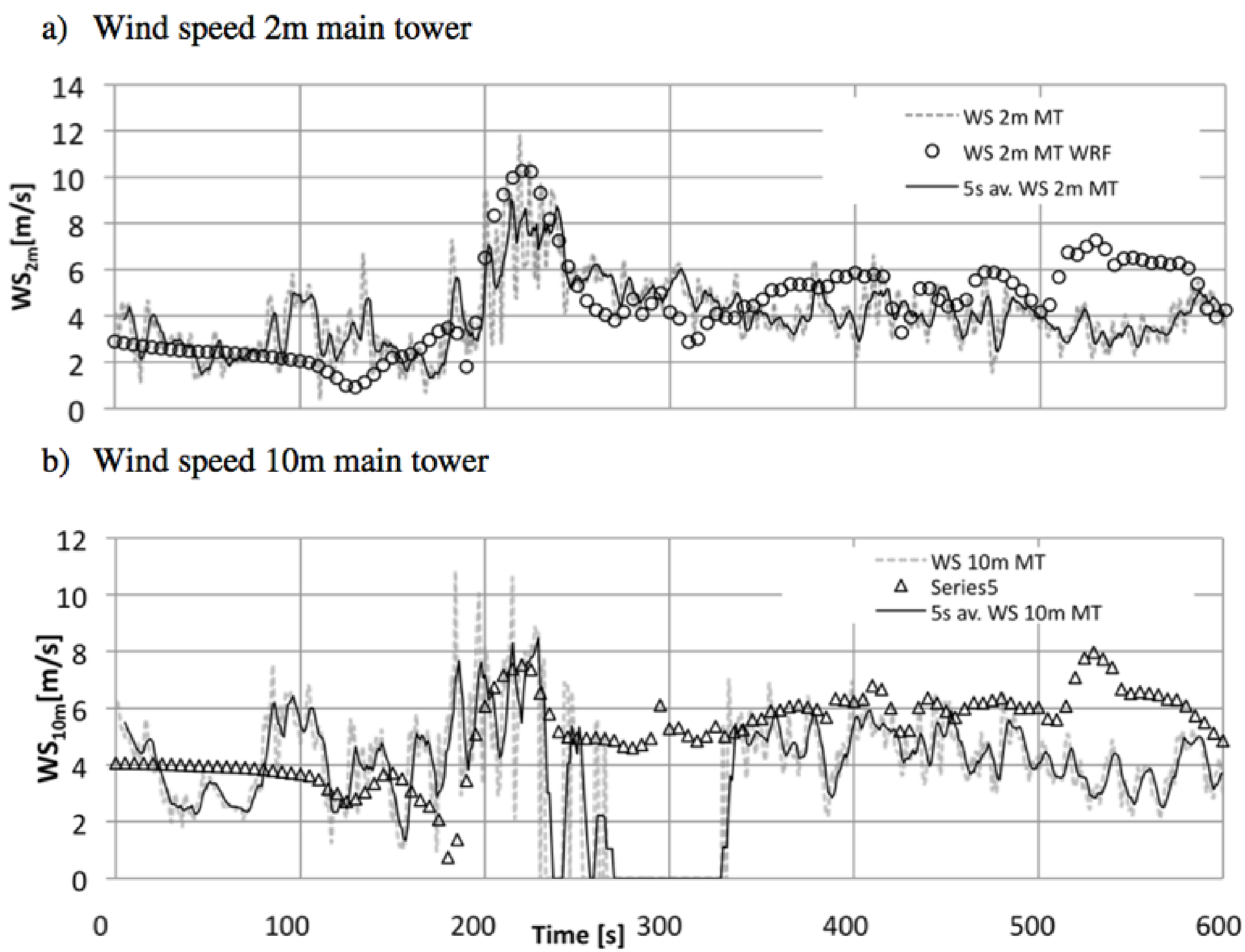
Thermal structure of the fire plume (28m and 43m above the ground)



Thermal structure of the fire plume

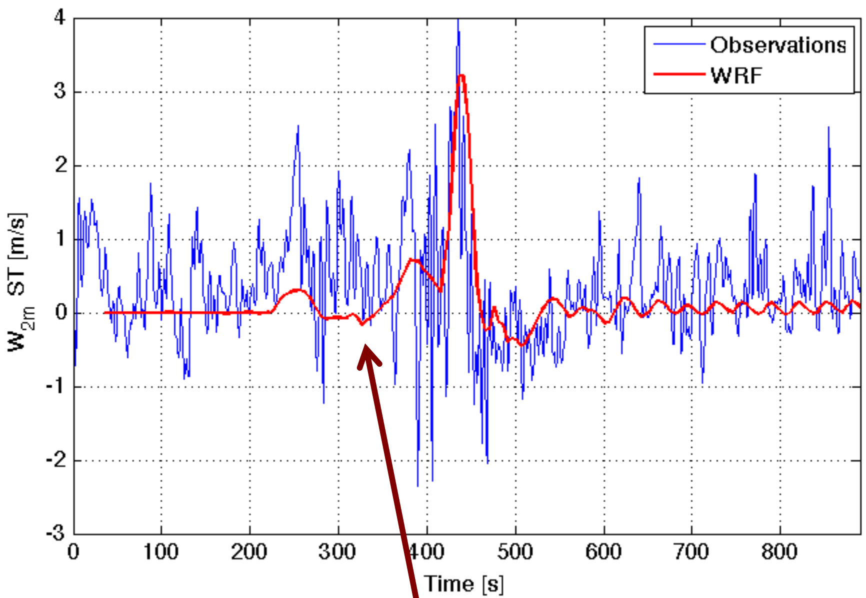


Fire-atmosphere interaction wind speed

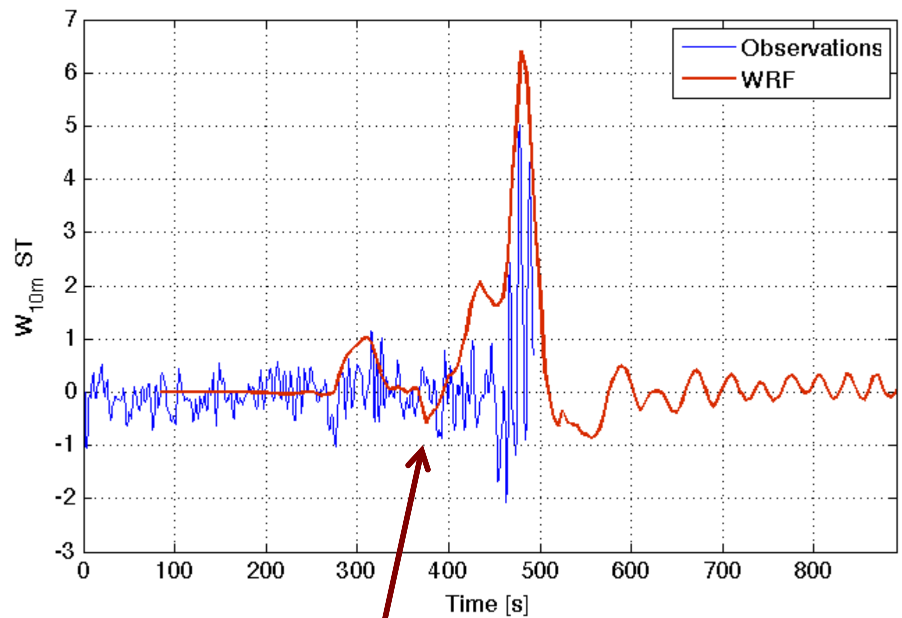


Upward velocity at 2m and 10m AGL - short tower (WRF vs. observations)

Main tower

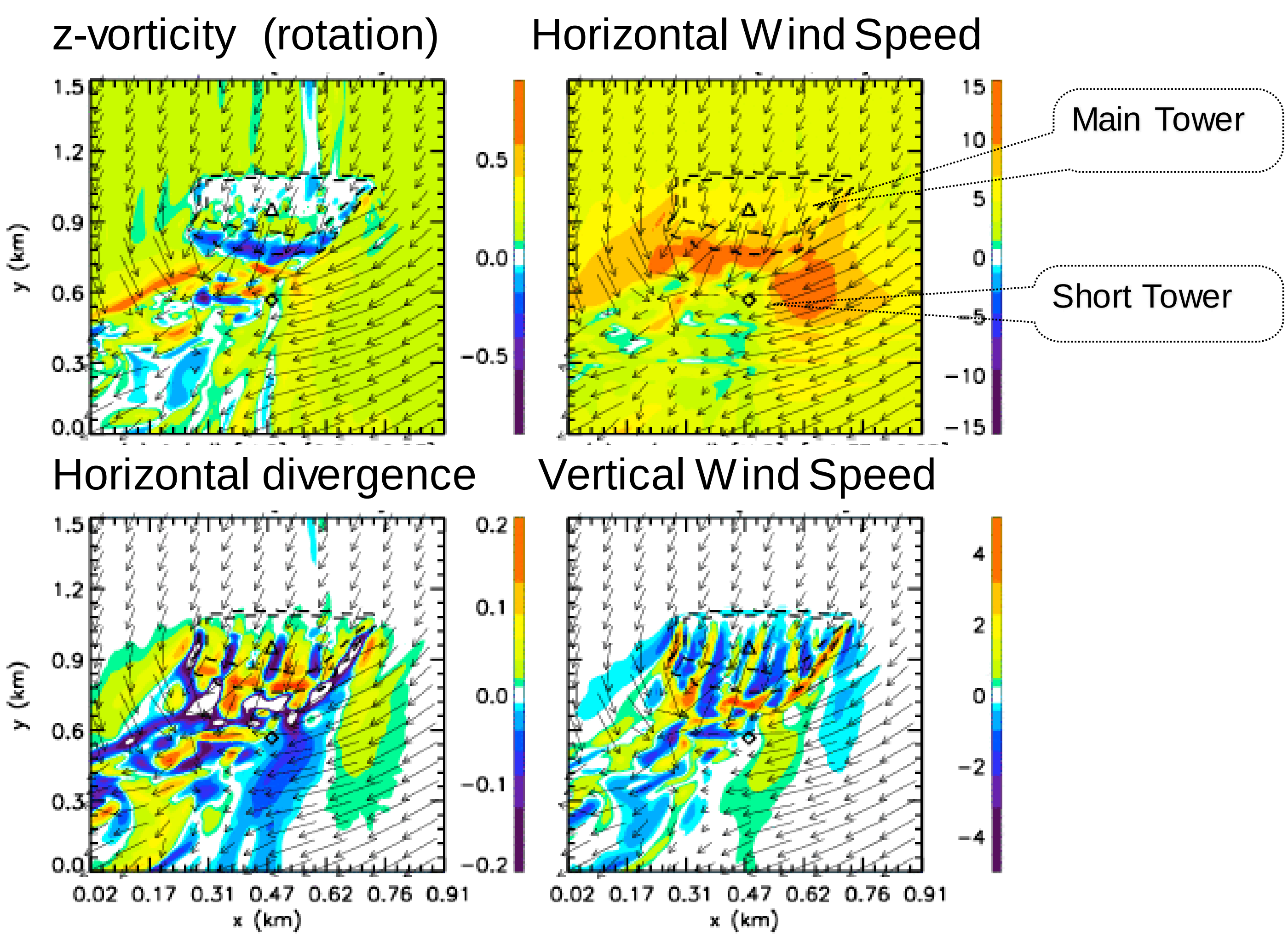


Short tower

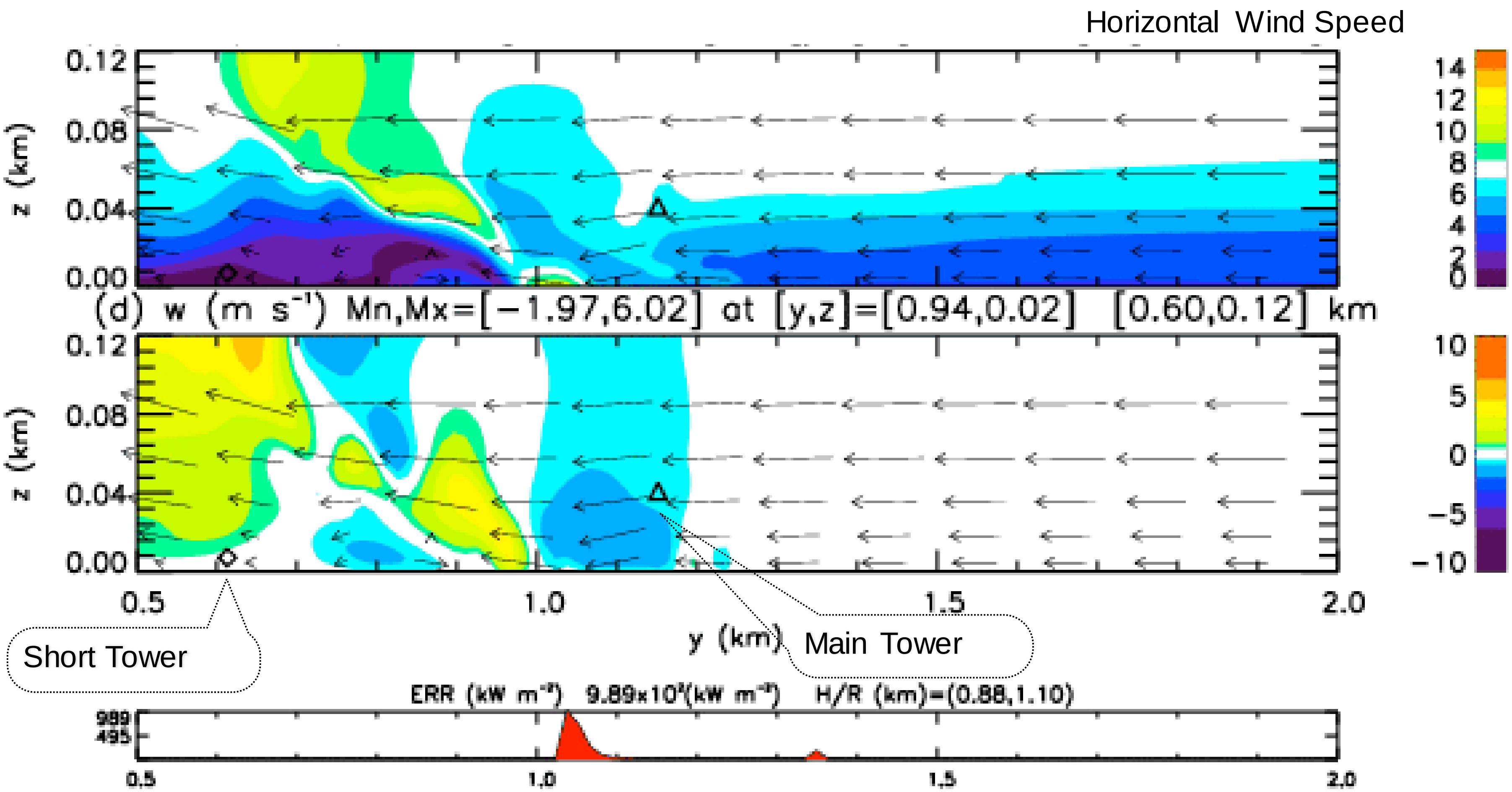


Downdrafts ahead of the fire front

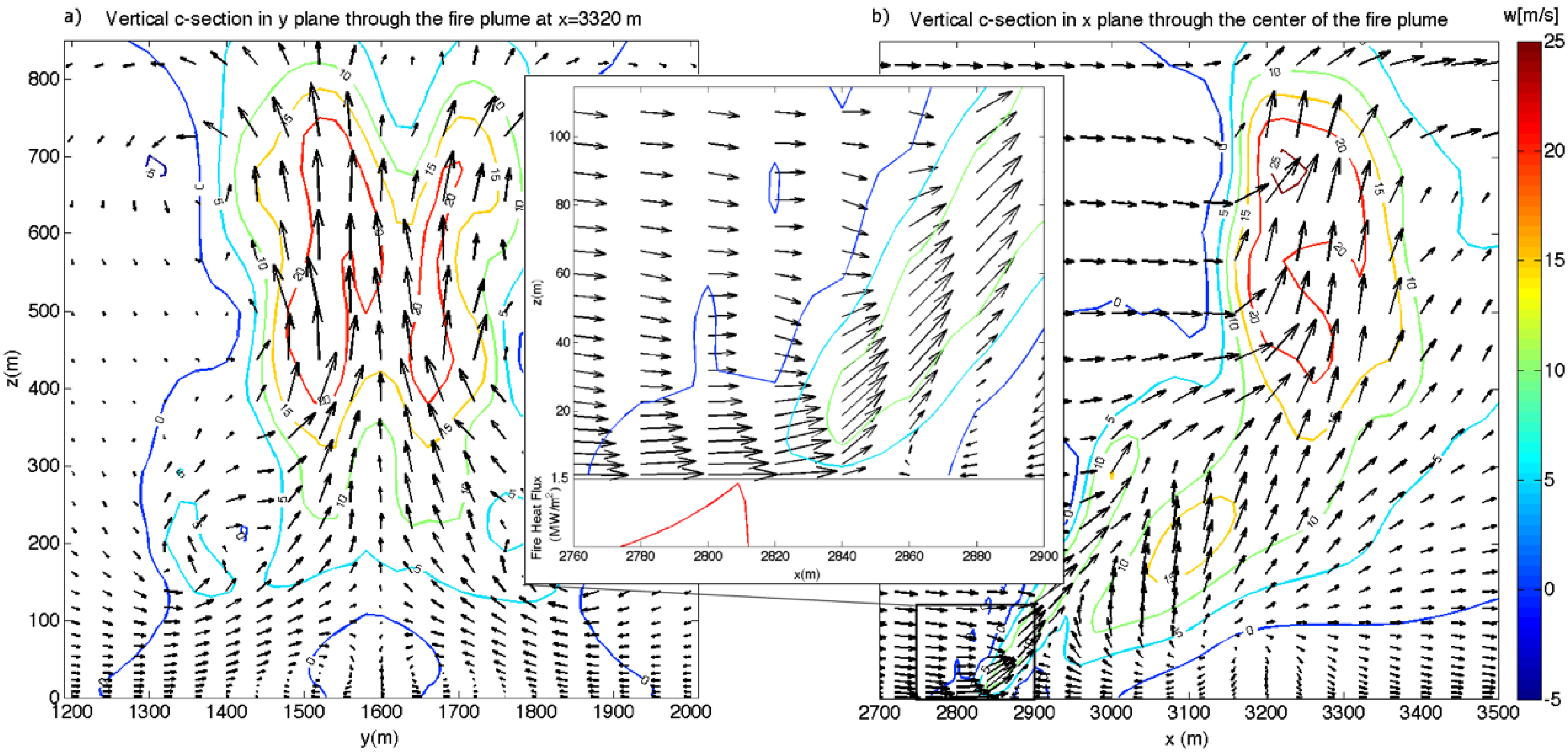
FireFux Simulation look from the top



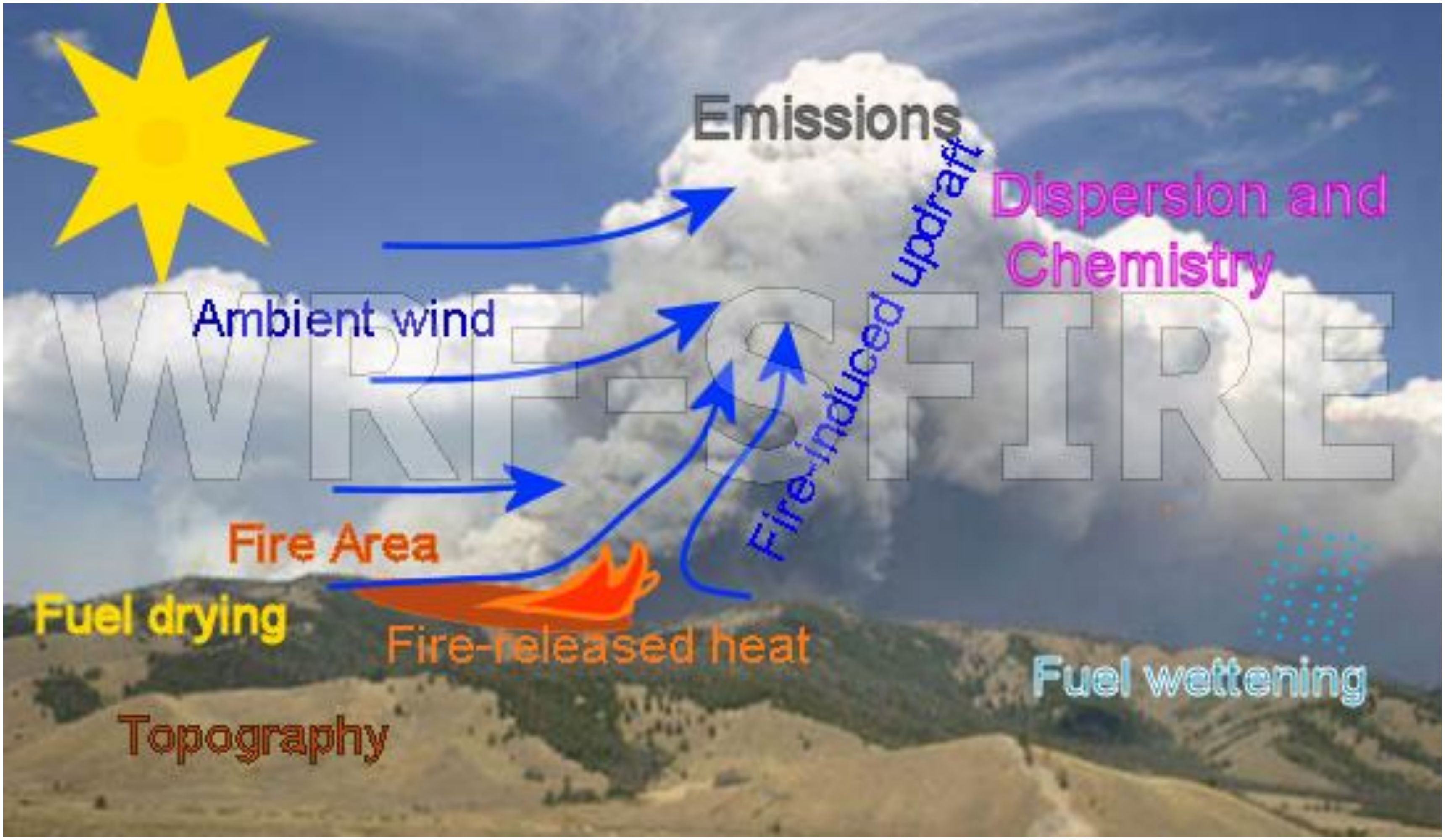
FireFux simulation look from a side



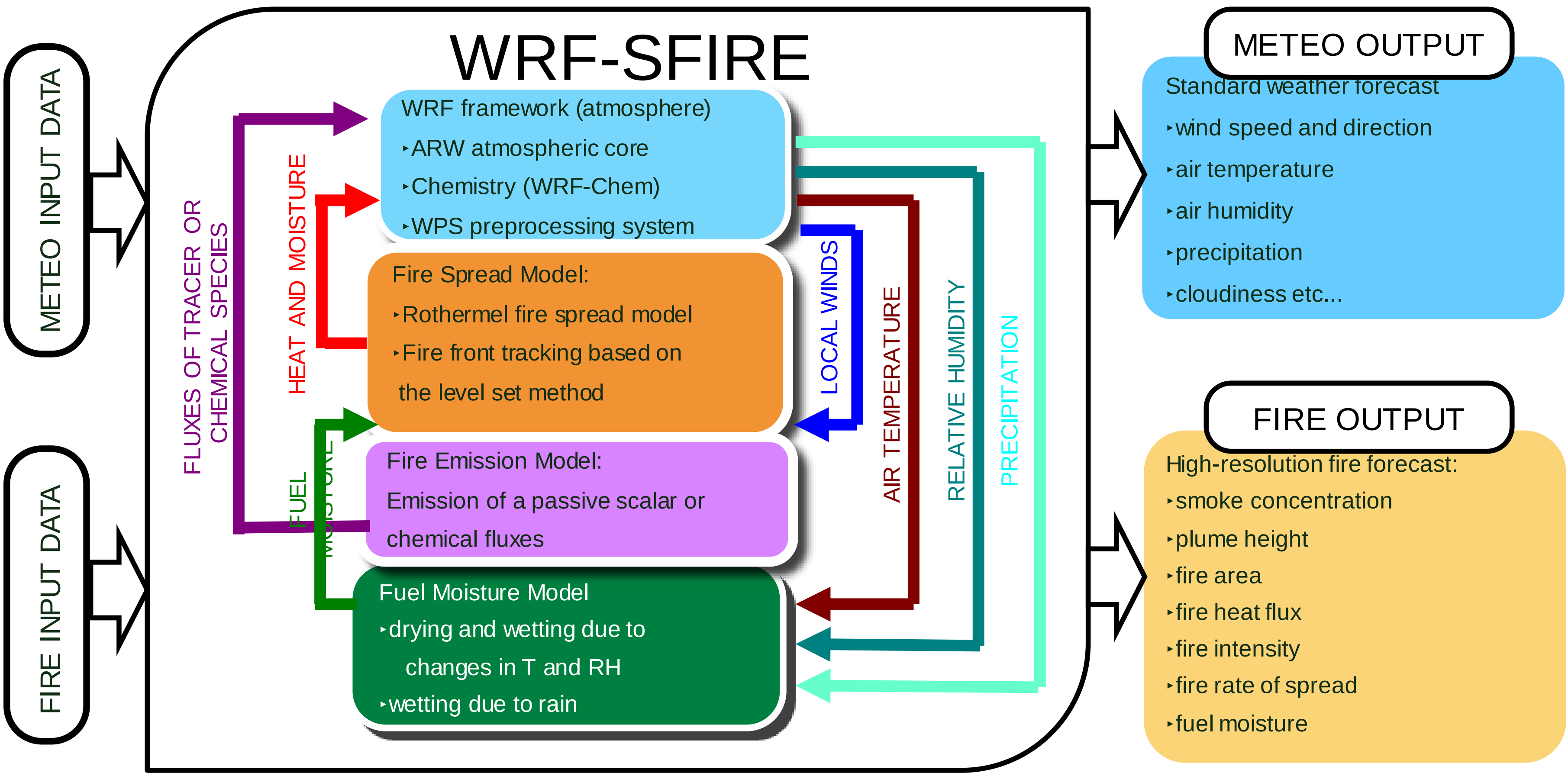
Impact of the fire-atmosphere feedback on the local wind



Smoke modeling in a coupled fire-atmosphere framework

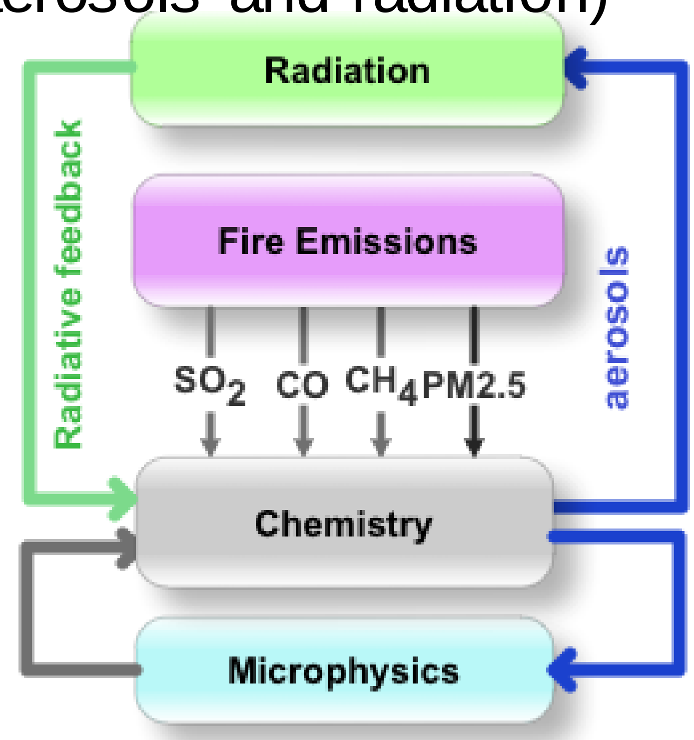


An integrated system for smoke forecasting based on WRF-Sfire



An integrated system for smoke forecasting based on WRF-Sfire

Integrating WRF-Fire with WRF-Chem allows for a representation of interesting fire-atmosphere interactions (aerosols and radiation)



Simplified estimation of fire emissions (passive tracer)

Albini Fuel Categories (13)

MODIS Land Cover Types:
- Mixed Forest
- Shrublands
- Grasslands

Fuel consumption rates

user-define emission factors for a tracer

Emission of tracers

No chemistry

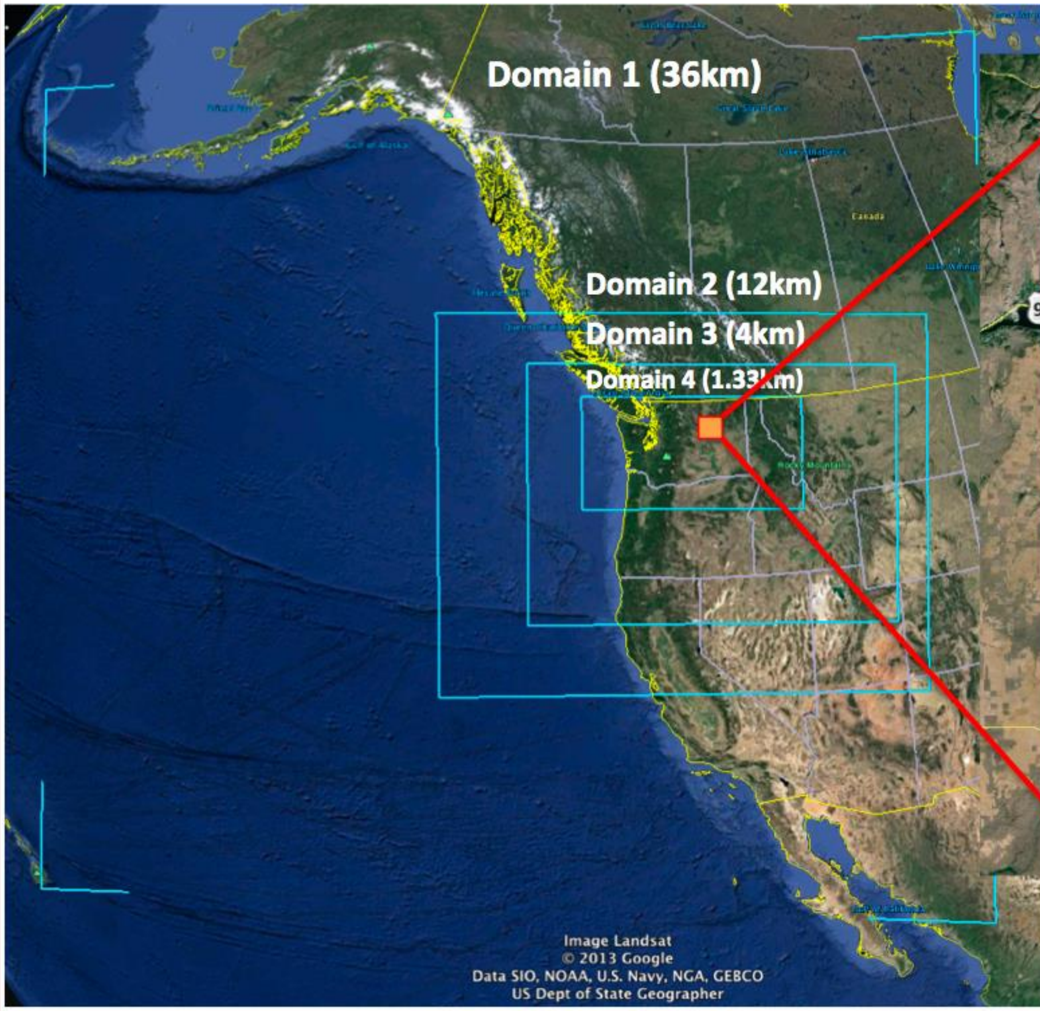
CONCENTRATION OF PASSIVE TRACERS:

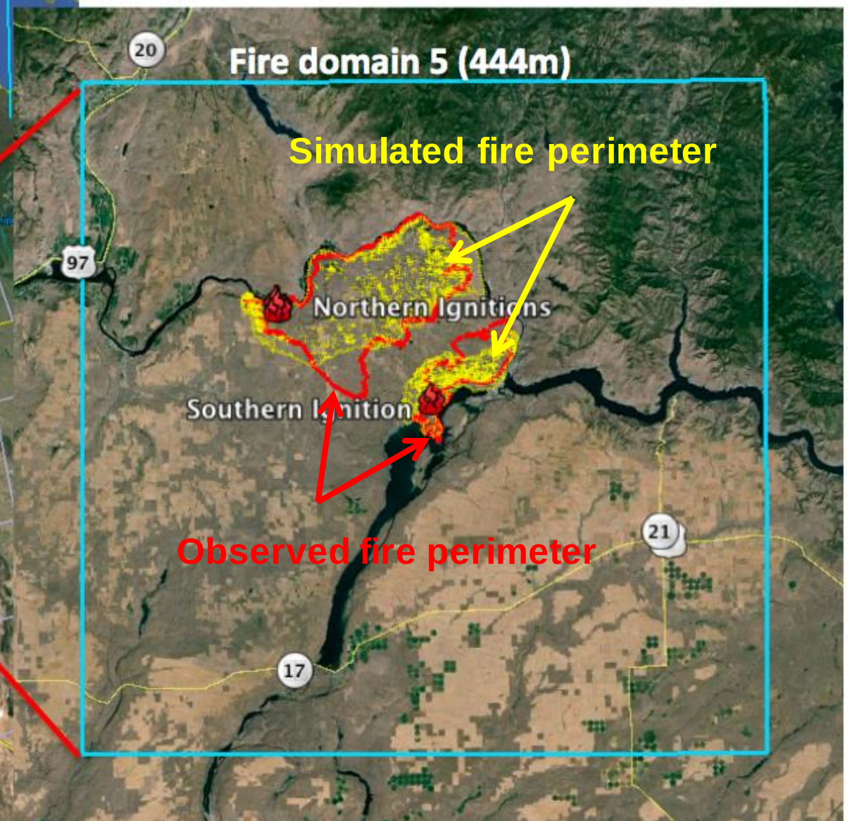
tracer1
tracer2
tracer3
tracer4
tracer5
tracer6
tracer7
tracer8

Simplified approach – no chemistry
96h simulation done in 12h 52min on 640 CPUs, with the first 24h forecast ready in 3h 13min

Simplified approach – no chemistry ➡ fast

Example #1 Simulation of Barker Canyon Fire (smoke as a passive tracer)





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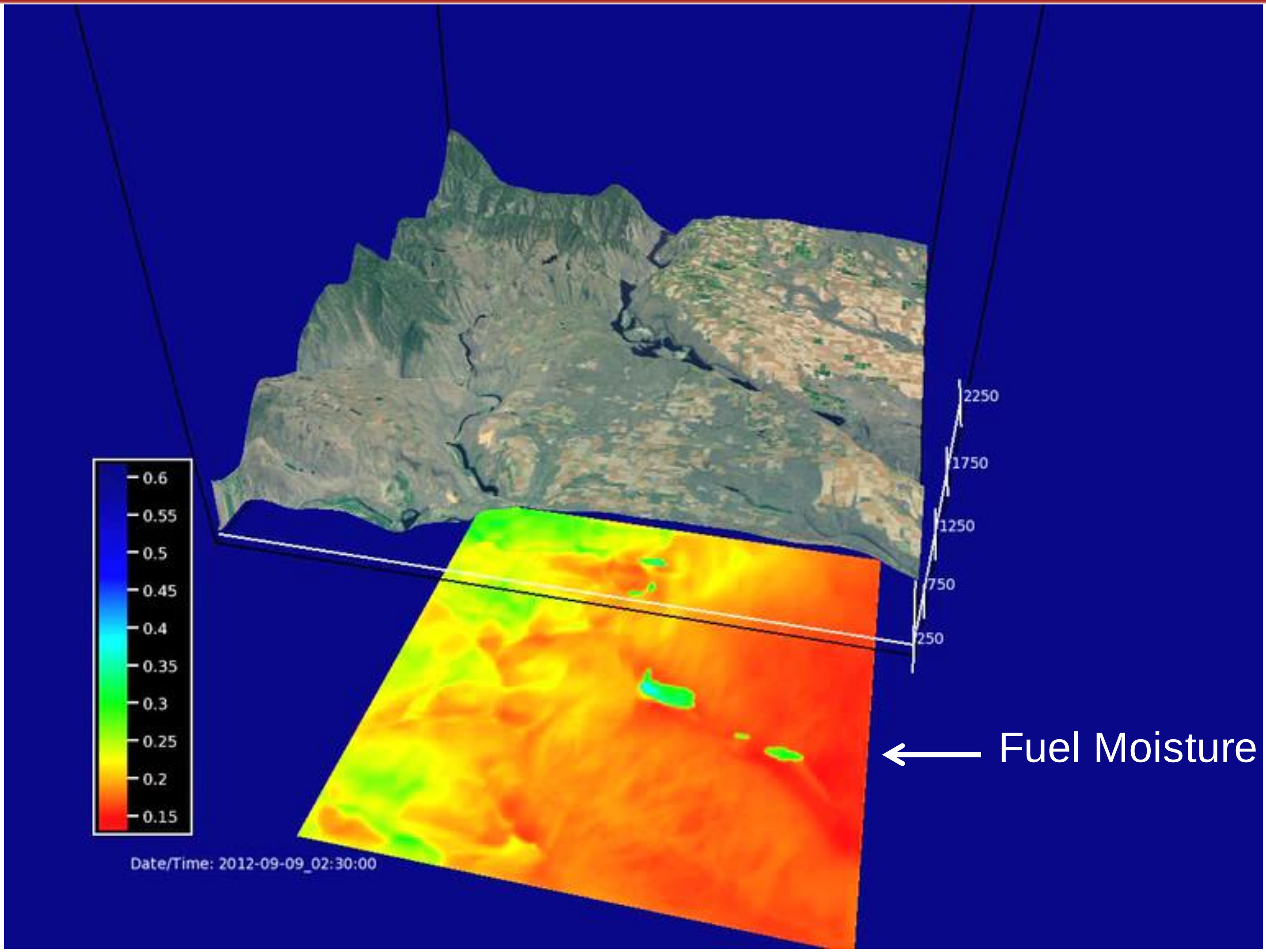
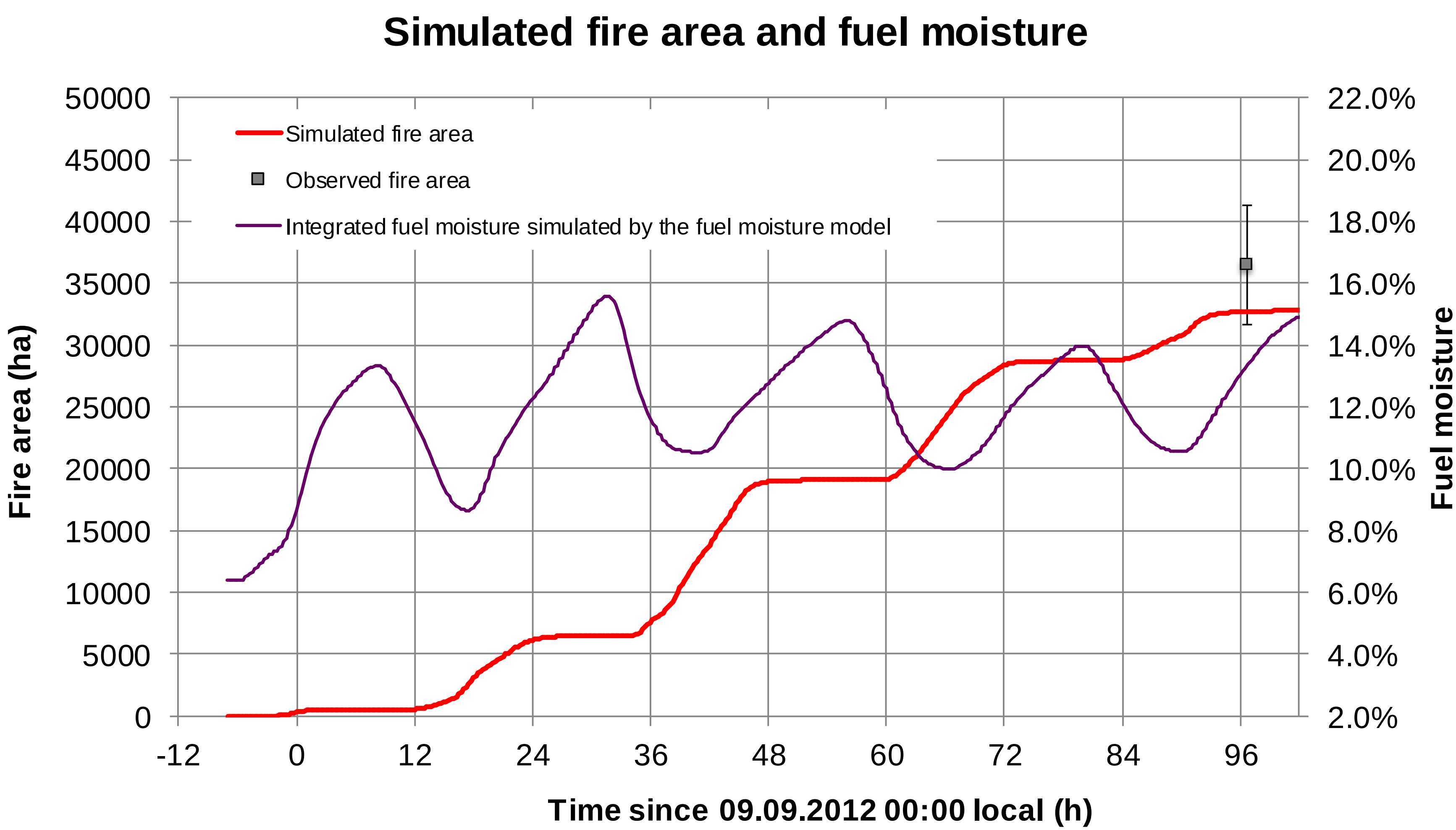
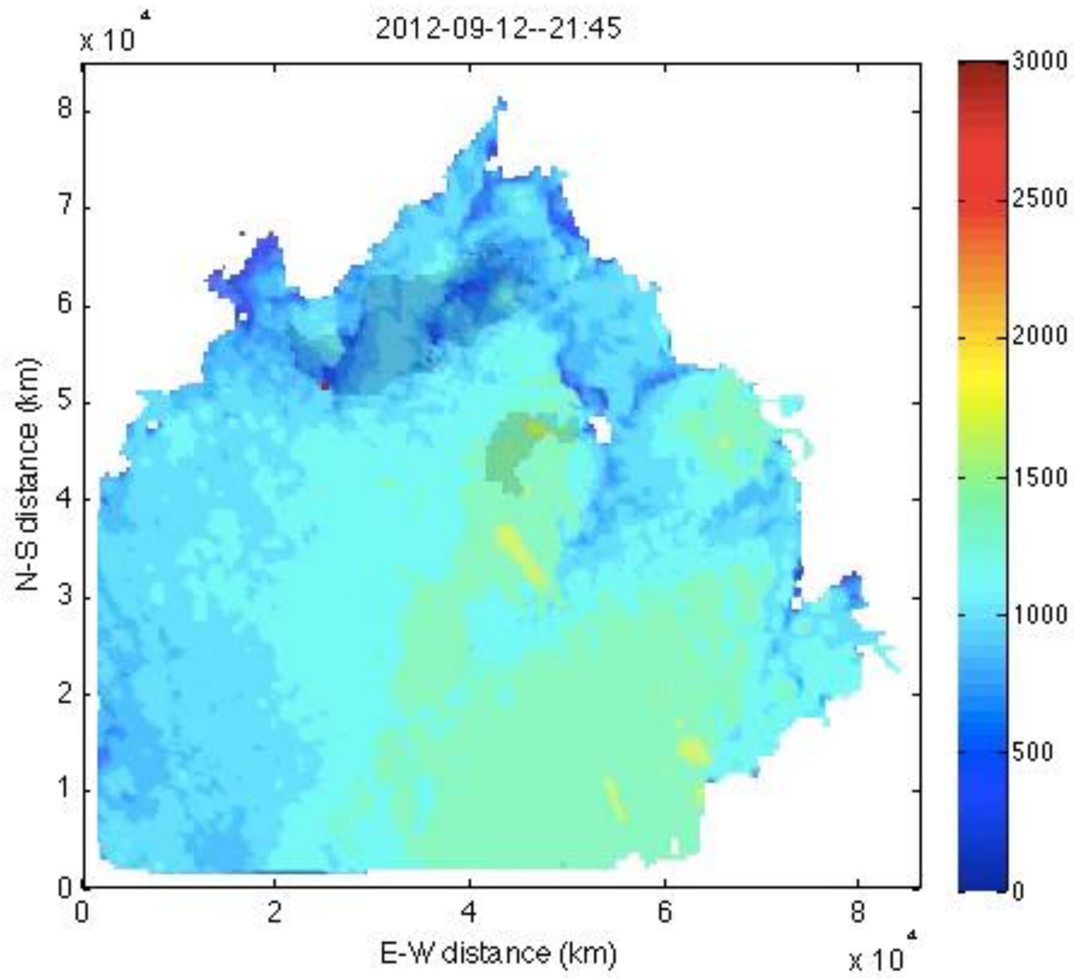


Fuel Moisture

Simulated fire area and fuel moisture for Barker Canyon fire 2012



Simulation of maximum plume height from 2012 Barker Canyon Fire (WA)



Braker Canyon fire (WA): diurnal variations in weather conditions translate into highly variable plume height and smoke dispersion

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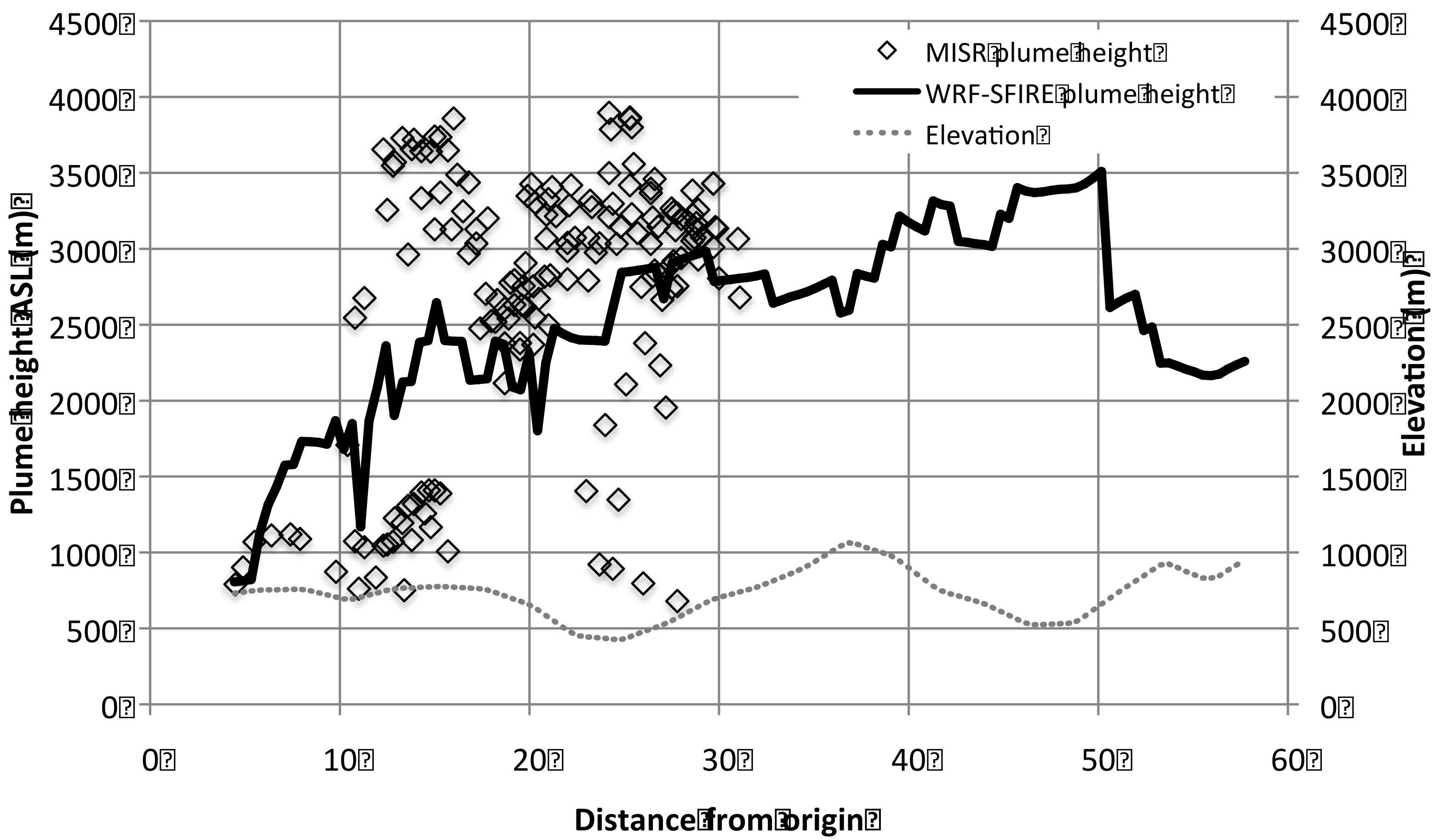
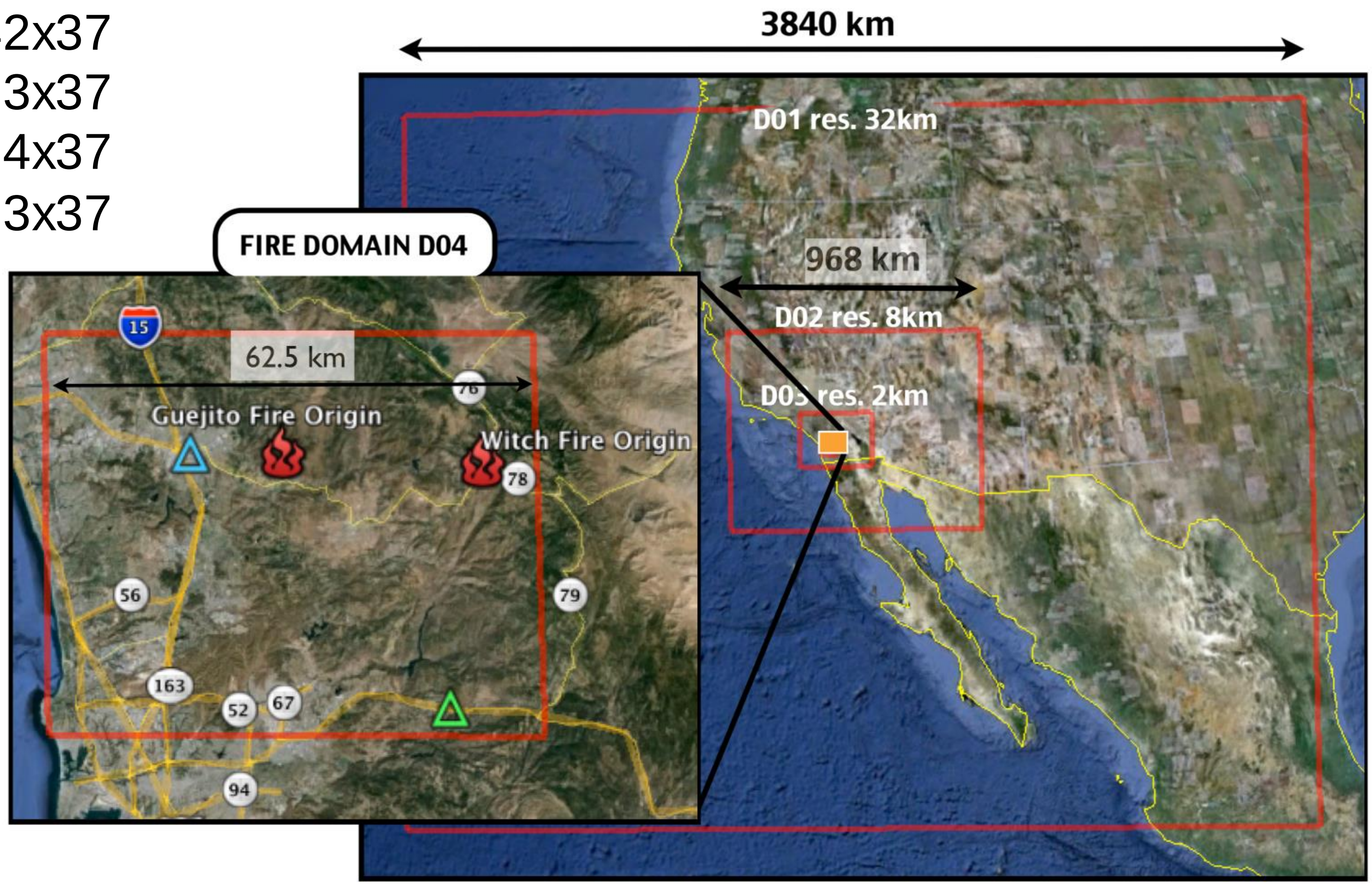
Maximum plume height simulated by WRF-Sfire vs. satellite observations (MISR)



Example #2 Santa Ana fire simulation with full atmospheric chemistry

Domain setup:
D01 151x127x37
D02 184x142x37
D03 406x283x37
D04 712x364x37
D05 196x193x37
Time step:
120s,
40s,
13.3s
4.44s
1.48s



Estimation of fire emissions with full chemistry

Albini Fuel Categories (13)

↓

MODIS Land Cover Types:
- Mixed Forest
- Shrublands
- Grasslands

↓

Fuel consumption rates

↓

FINN emission factors

↓

Emission of chemical species → MOZART

↓

Conversion from MOZART to RADM2 → RADM2

48h WSFC simulation with MOZART chemistry took 29h 56min on 324 CPUs
First 24h forecast ready in 15h (3 times longer than passive racer)

RADM2

co
no
no2
so2
nh3
pm25i
pm25j
oc1
oc2
bc1
bc2

NMOC: ald, csl, eth, hc3, hc5, hcho, iso, ket, mgly, ol2, olt, oli, ora2, tol, xyl

MOZART

co
ch4
h2
no
no2
so2
nh3
p25
oc1
oc2
bc1
bc2

NMOC: bigalk, bigene, c10h16, c2h4, c3h5oh, c2h6, c3h6, c3h8, ch3cooh, ch3oh, cres, glyald, hyac, isop, macr, mek, mvk, tol

Simulated progression of the 2007 Santa Ana fires simulated vs. observed fire progression

10.22.2007 02:45 local time

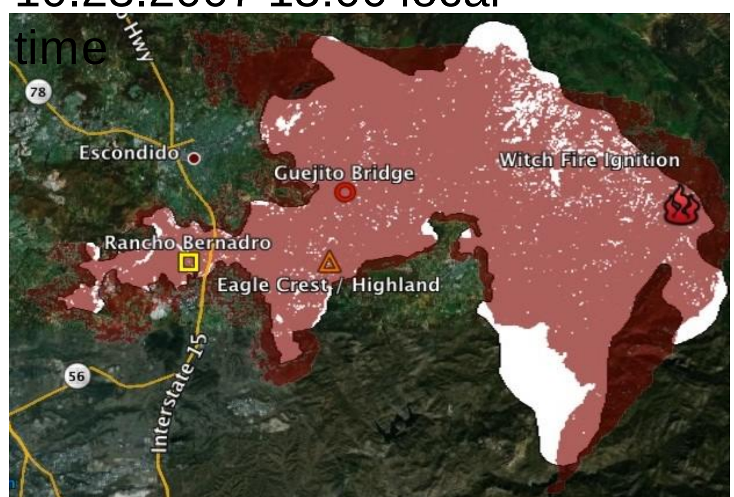
10.22.2007 05:00 local time

Observed fire area

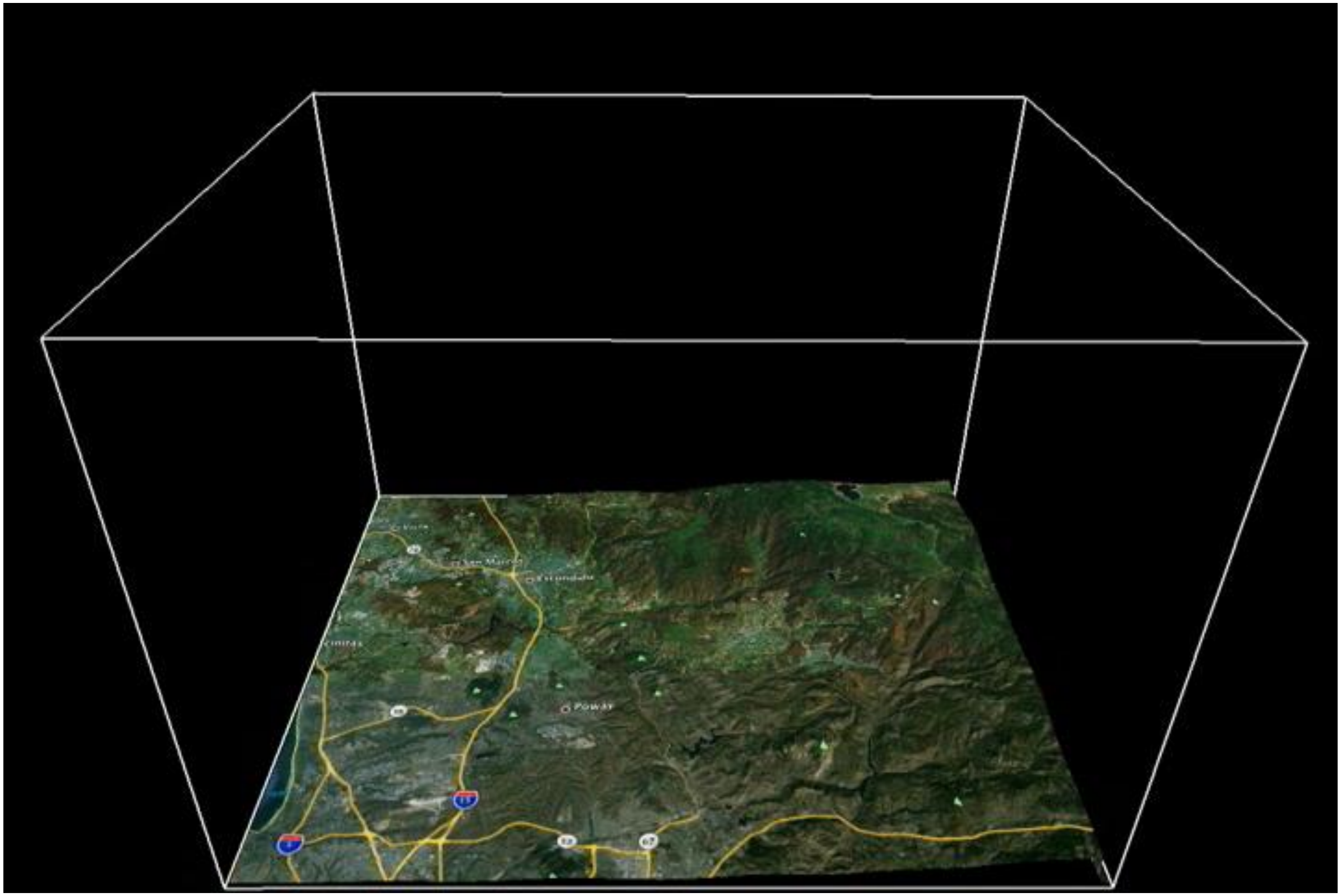
WRF-fire area

10.22.2007 20:00 local time

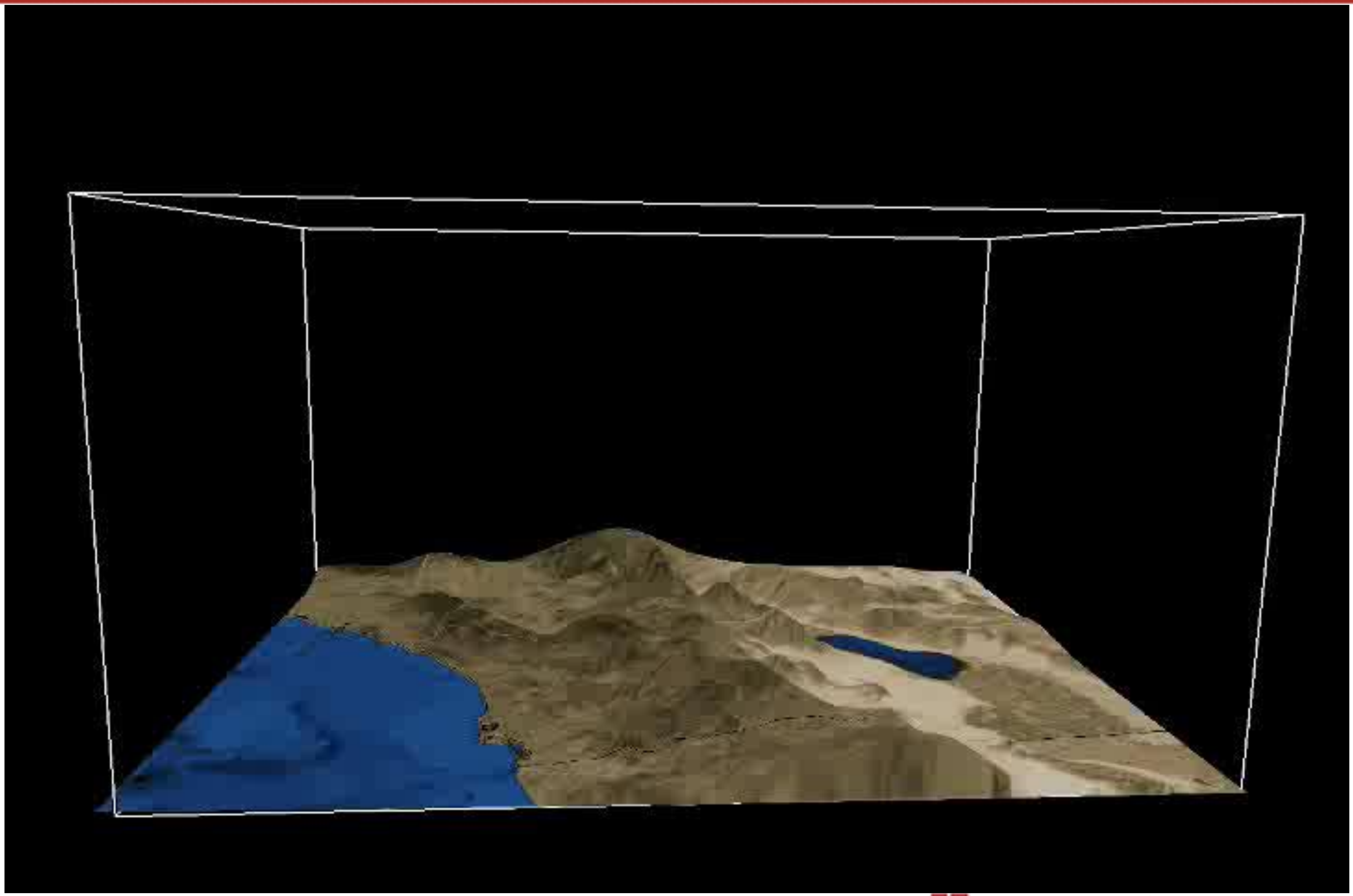
10.23.2007 15:00 local time



Simulation of smoke emissions from 2007 Santa Ana fires (Witch and Guejito) d04 (500m)



Simulation of smoke emissions from 2007 Santa Ana fires (Witch and Guejito) 2km



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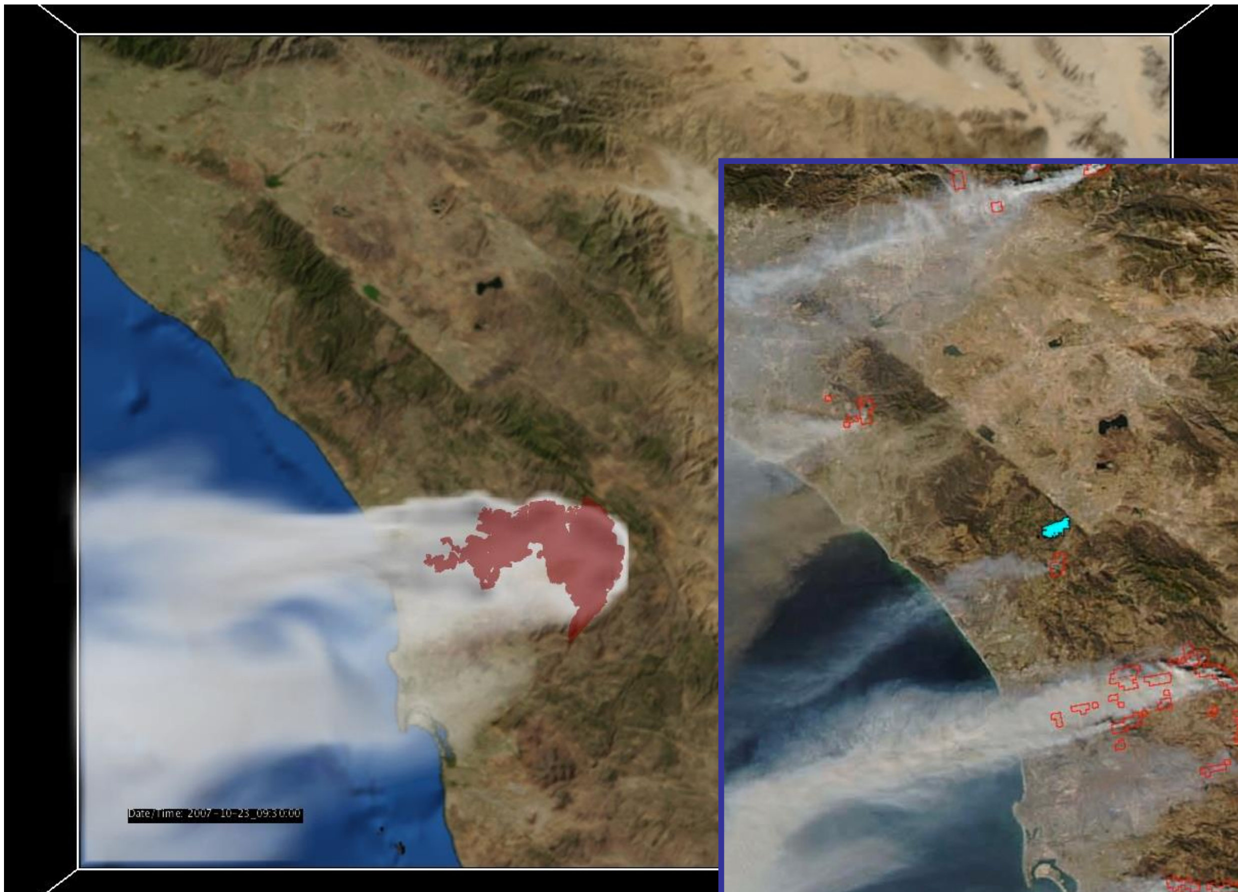
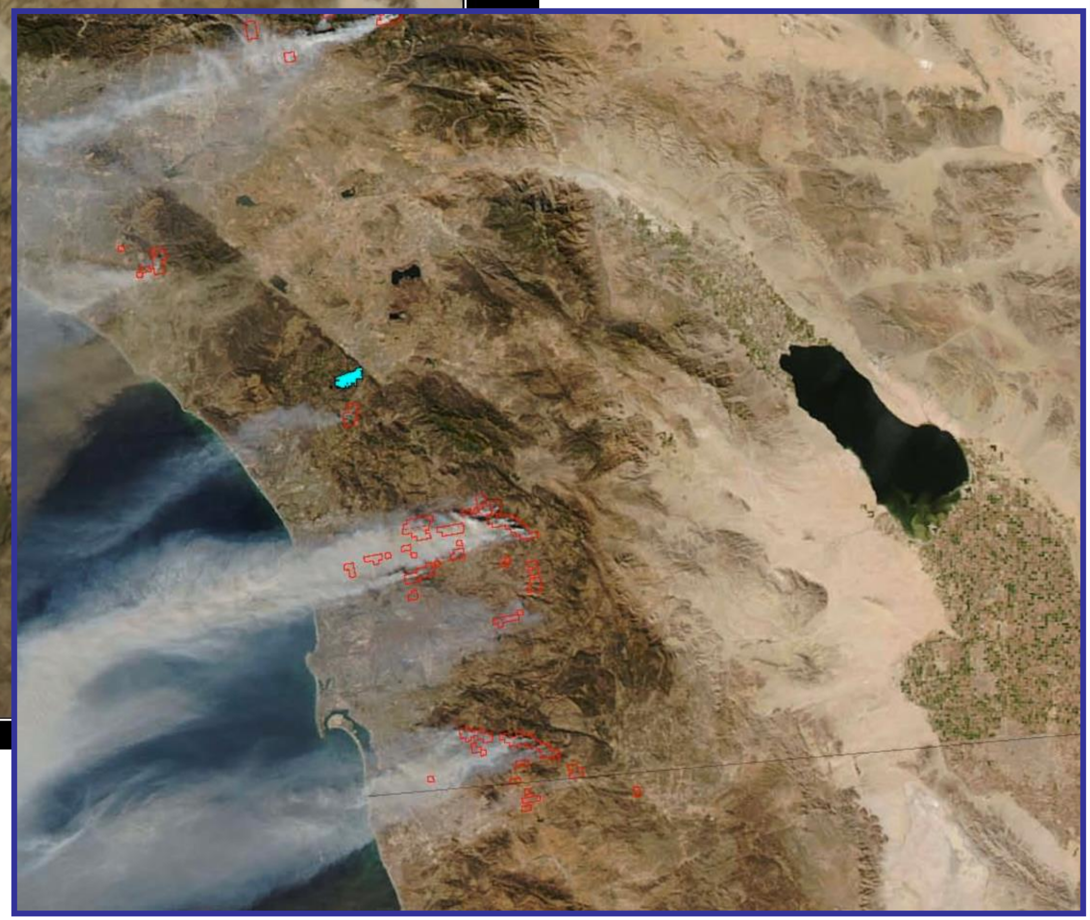
Simulated smoke emission from 2007 Santa Ana fires – WRF-Sfire vs. MODIS

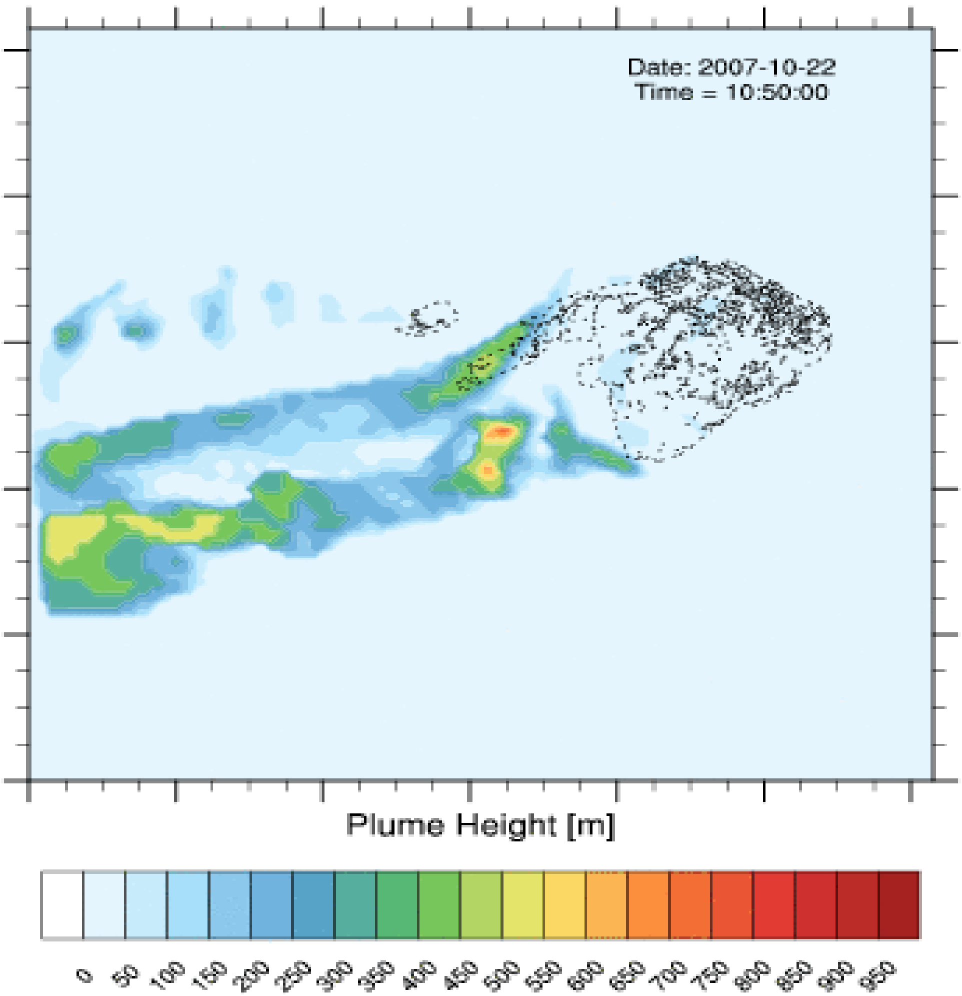


WRF-Sfire 2km

MODIS

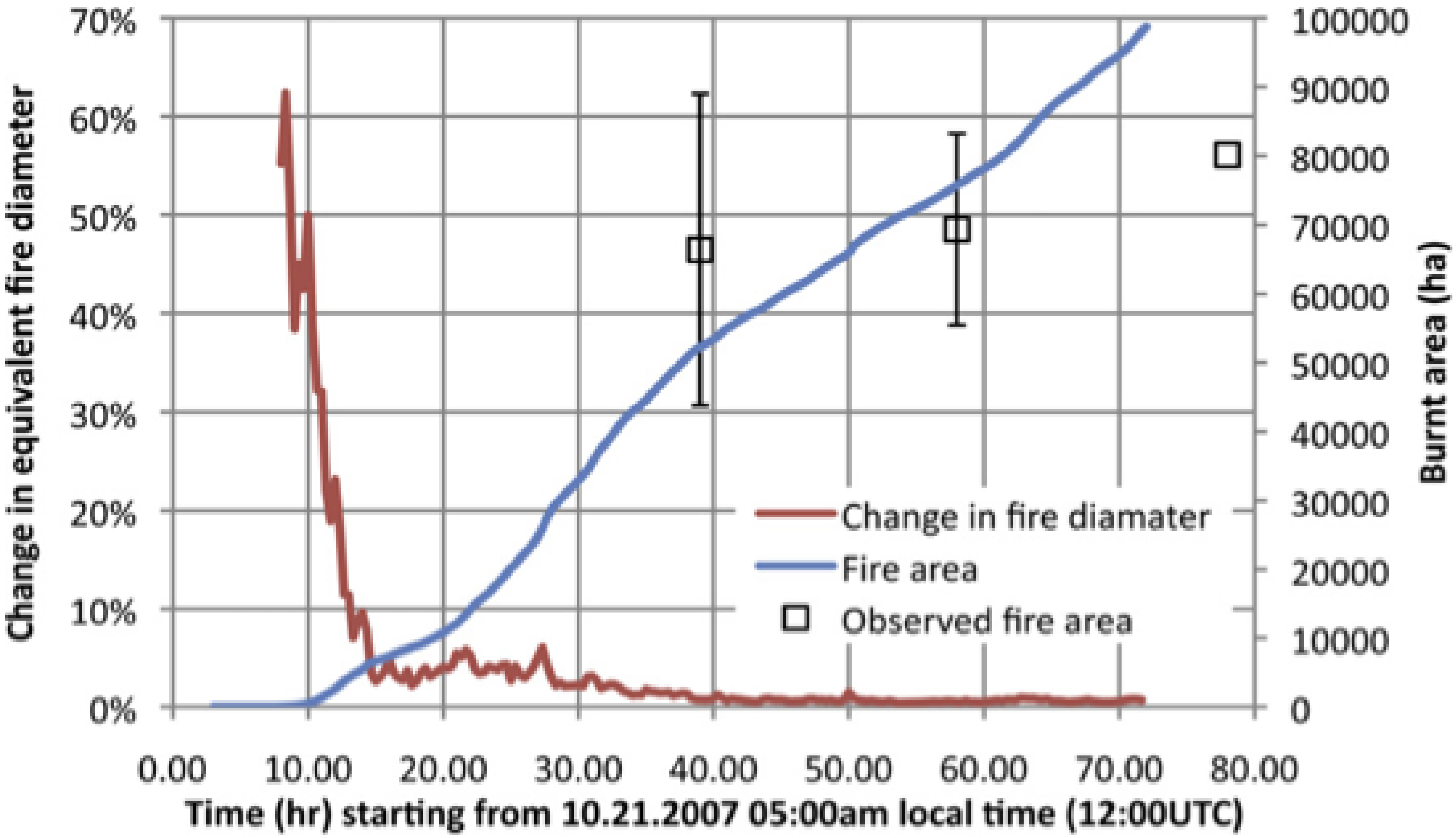


Simulation of maximum plume height from 2008 Santa Ana Fires (Witch and Guejito)



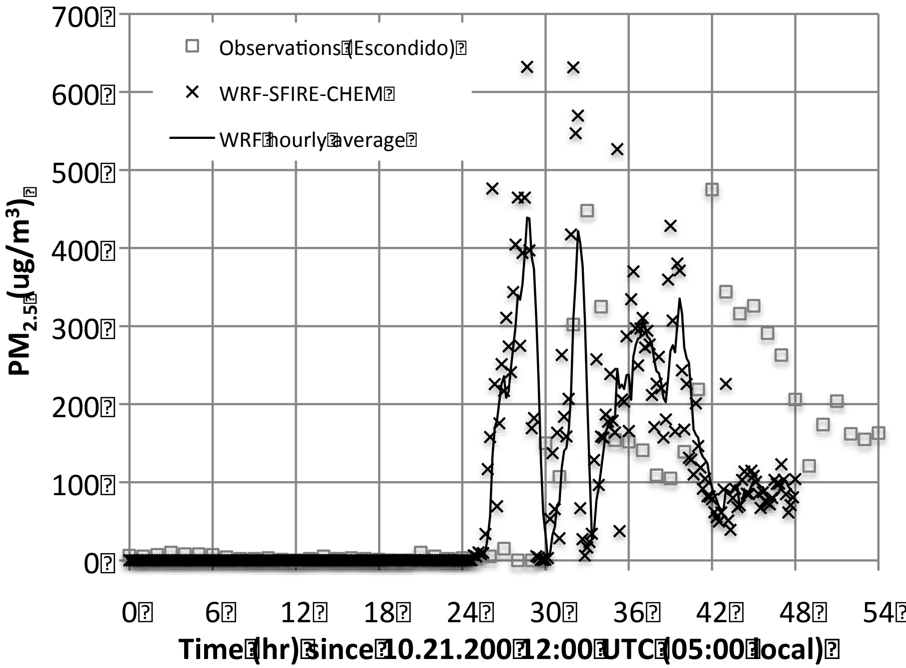
Very dry and and windy conditions during 2007 Santa Ana fires lead to almost no diurnal variability in the plume height and smoke dispersion

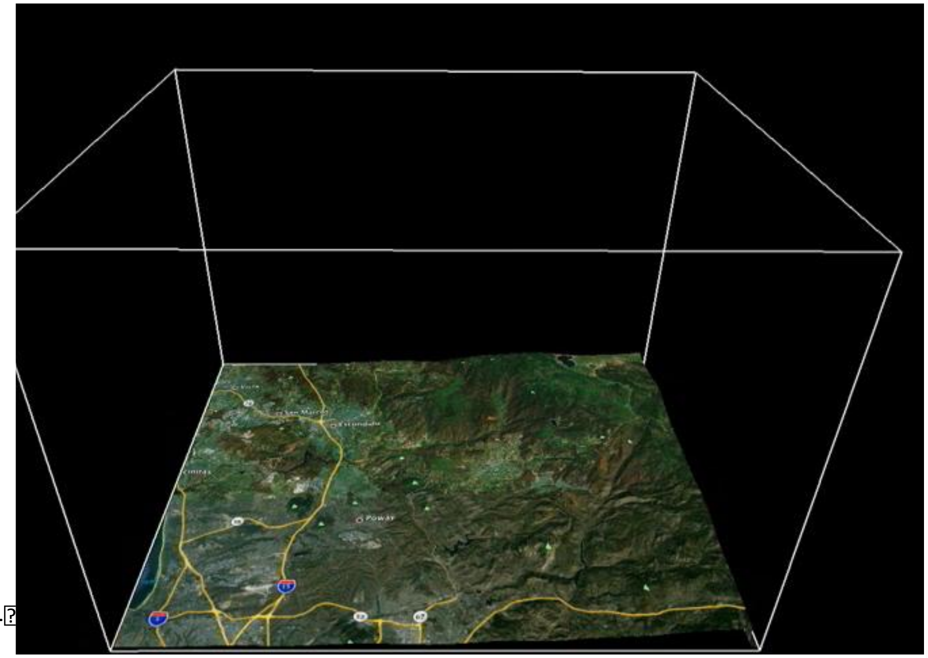
Simulated fire area for 2007 Santa Ana fires (Witch and Guejito)



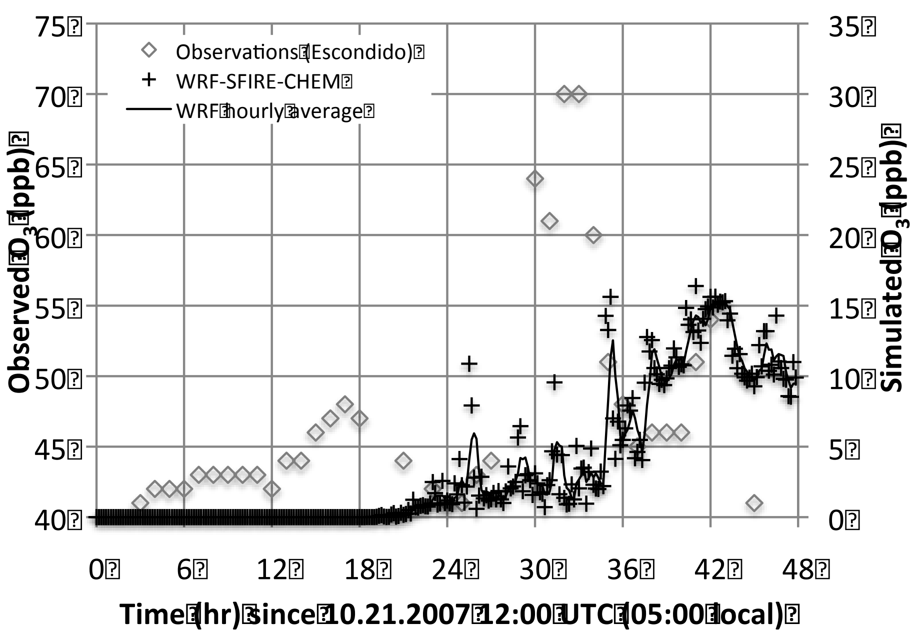
Simulation of PM2.5 emissions from 2007 Santa Ana fires (Witch and Guejito) 500m

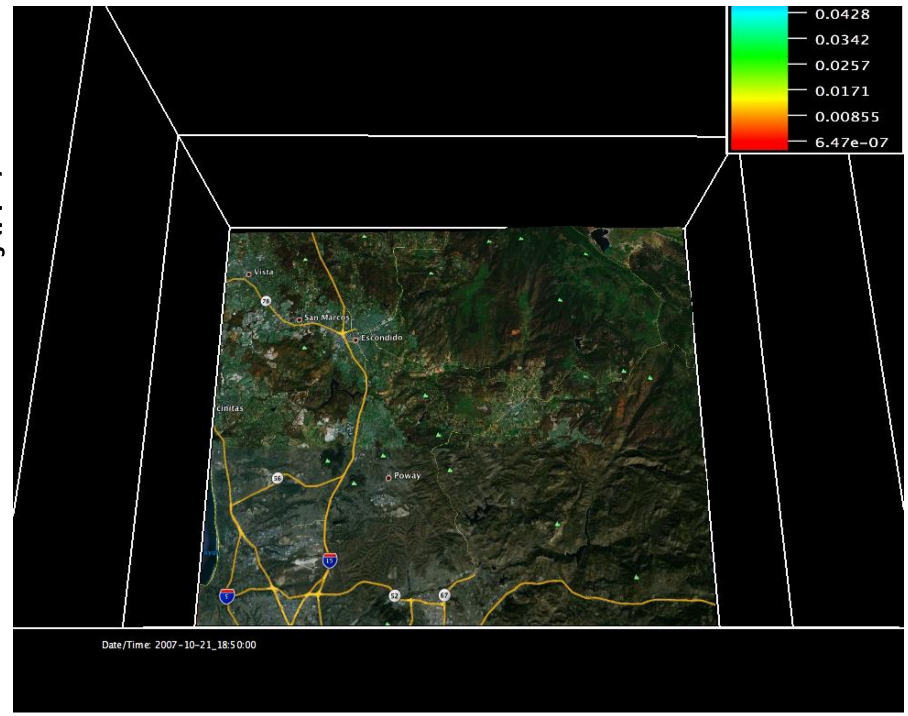
Simulated vs. observed PM2.5 for Escondido





Simulation of ozone from 2007 Santa Ana fires (Witch and Guejito) 2km





Summary (good things ☺)

- WRF-Sfire may be used for idealized simulations of small burns as well as realistic simulations of wildland fires
- Analysis of numerical simulations of field experiments helps in interpretation of the measurement data and gaining a “bigger picture”
- New capabilities have been added to WRF-Sfire that enable simplified representation of the fire smoke as a passive tracer, or as a mixture of chemically active species (coupling with WRF-Chem)
- Fire-atmosphere coupling allowed the model render basic aspects of fire plume rise and dispersion without any external parameterization
- Integration with the fuel moisture model fire enables diurnal variations in fire activity and smoke emissions
- Smoke as a tracer is handled directly by the WRF dynamical core, so its does not increases computational cost significantly

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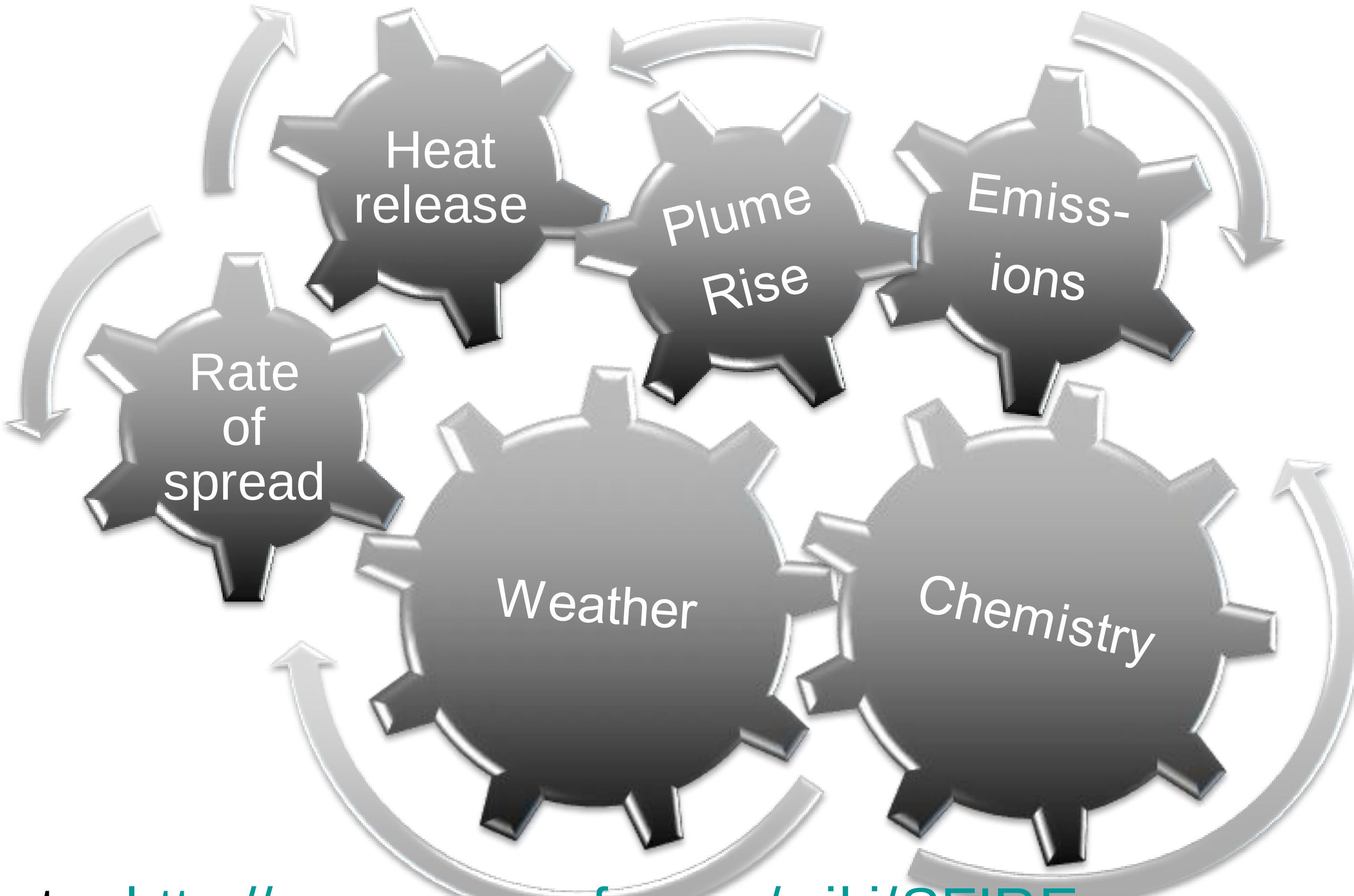
Summary (bad things ☹)

- The newly added components need thorough validation
- Simplicity of the fire spread model may potentially create problems as the fire heat release will be only as good as the fire spread simulation
- The ability of this system to render smoke dynamics is resolution-dependent, so at coarse horizontal resolutions a ‘bridge’ parameterization may be needed to handle sub-grid scale plumes
- Since the model aims to capture, fire intensity, fire-induced winds, fire heat release, injection height and the emissions. The perfect validation dataset would require in-situ simultaneous measurements of the fire and plume properties, as well as the chemical fluxes and meteorology

Thank you!



go to: http://www.openwfm.org/wiki/SFIRE
to get the code, installation instructions and documentation