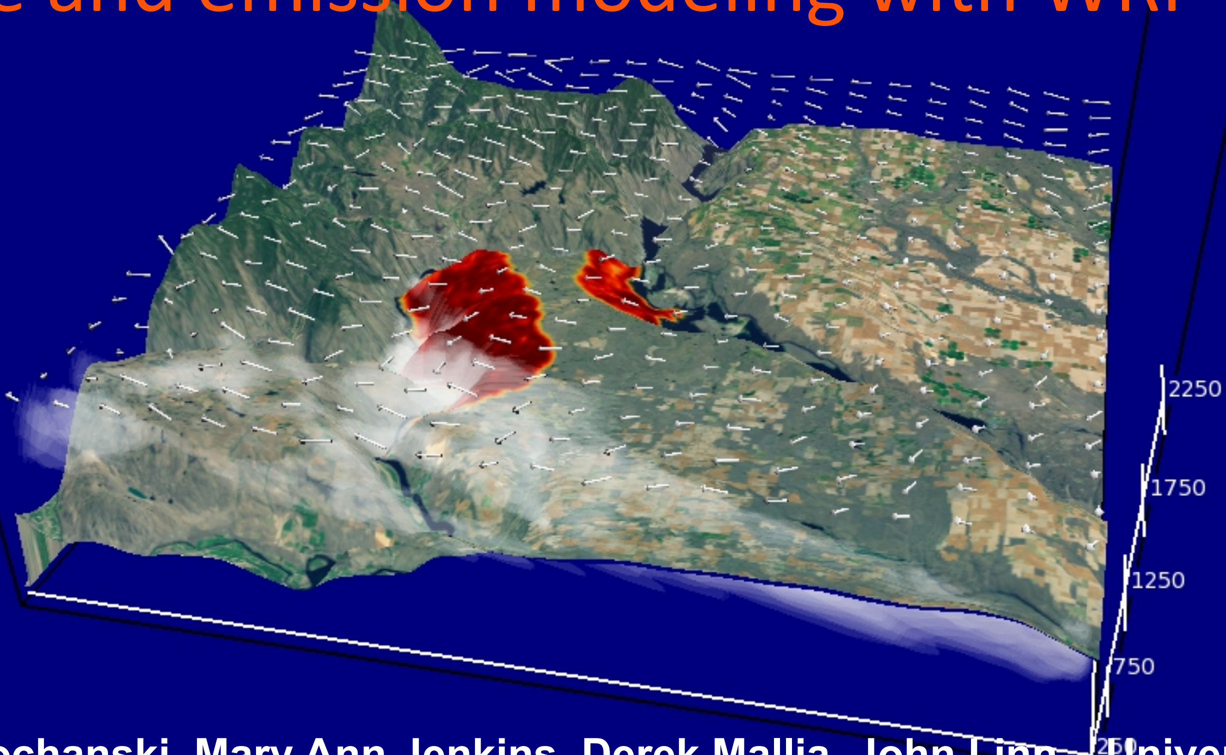
DEPARTMENT OF METEOROLOGY
UNIVERSITY OF UTAH

NASA

Fire and emission modeling with WRF-Sfire



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Jan Mandel, Martin Vejmelka – University of Colorado, Denver
Kara Yedinak, Brian Lamb – Washington State University
Sher Shranz – Colorado State University, NOAA

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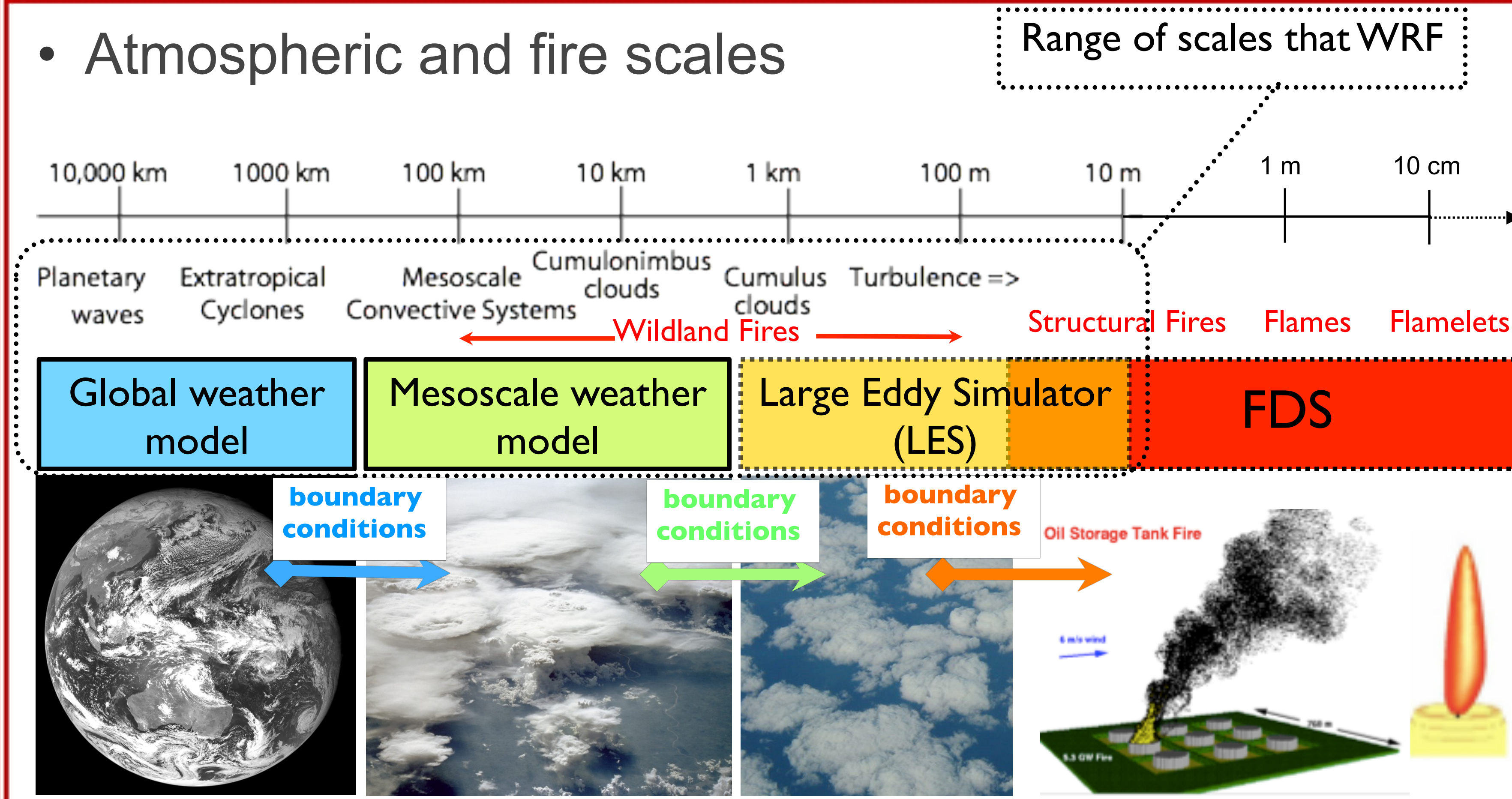
Introduction

Outline:

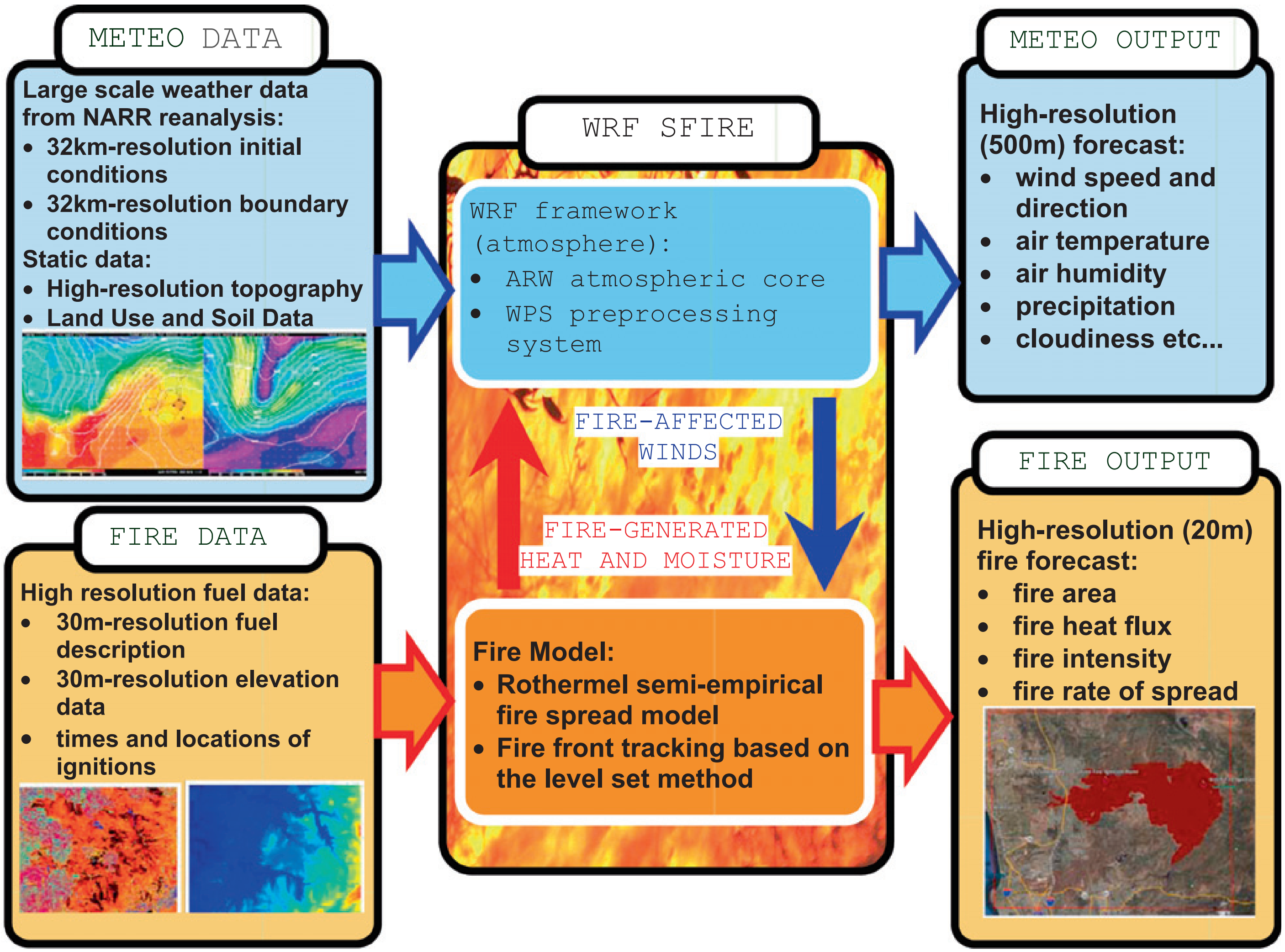
- ➢ Range of scales associated with wildland fires
- ➢ Modeling of Fire-Atmosphere interactions in WRF-Sfire
- ➢ Idealized LES simulations of prescribed burns
    - plume dynamics
    - thermal structure
- ➢ Wildland fire smoke modeling in a coupled fire-atmosphere framework
    - Levels of coupling 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



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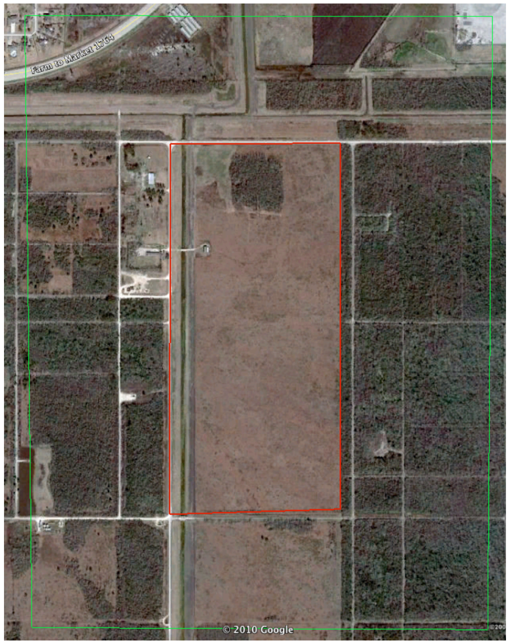
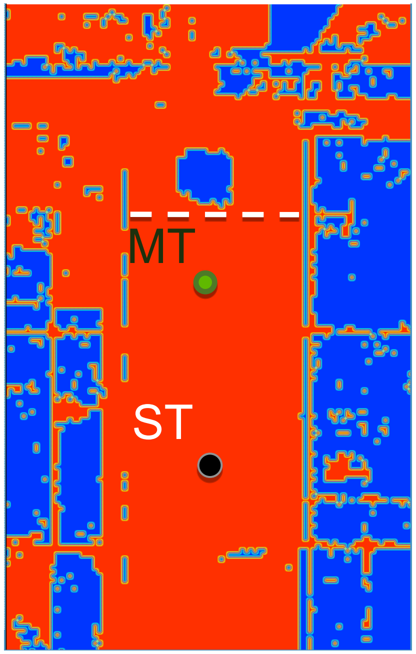
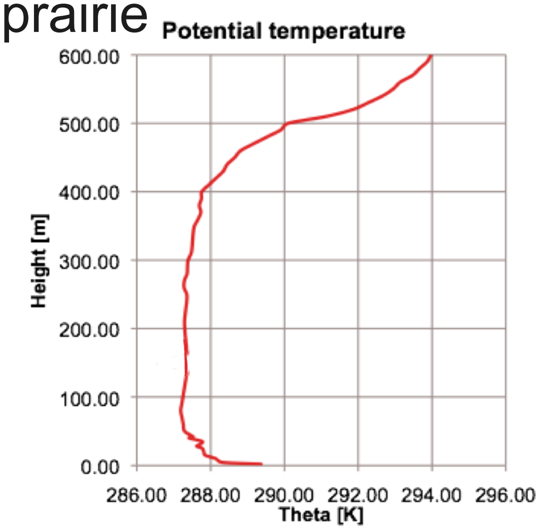
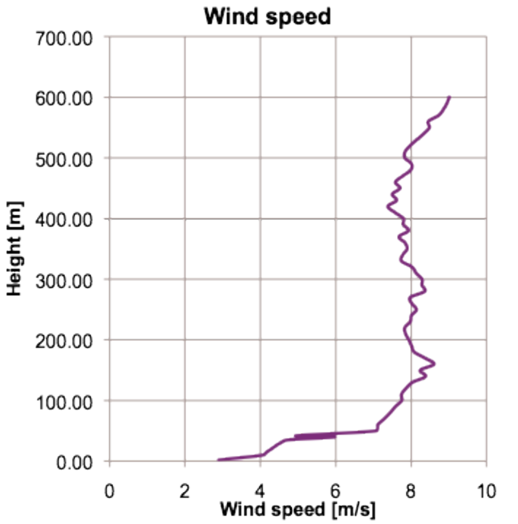
Idealized LES simulation of a small-scale prescribed burn (FireFlux experiment)

- 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







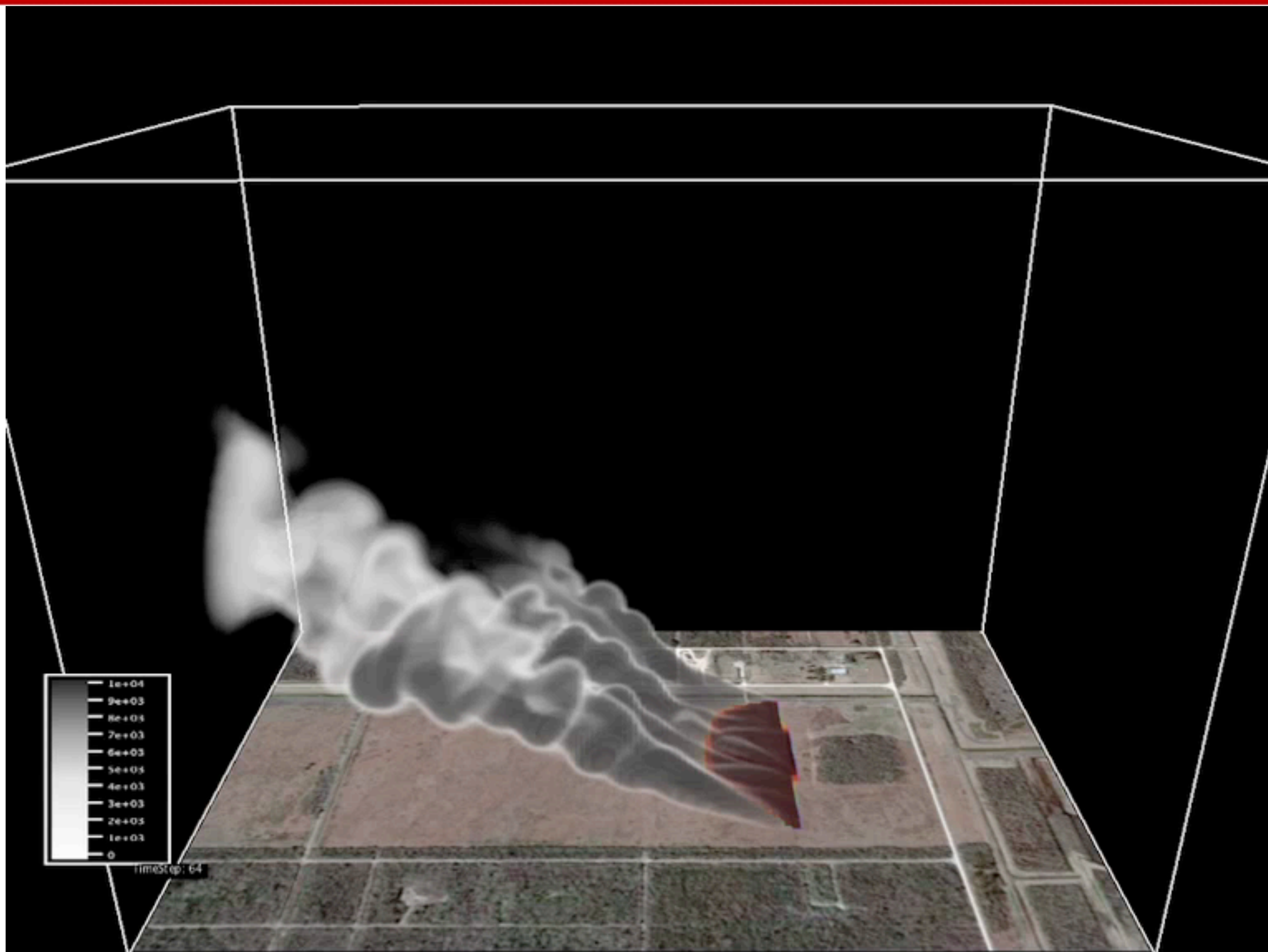


FireFlux picture from Clements et al. 2008

FireFlux Experiment

Idealized FireFlux simulation particulate emission (PM 10)

in-plume concentration ~3000 $\mu g/m^3$ (3mg/m^3)



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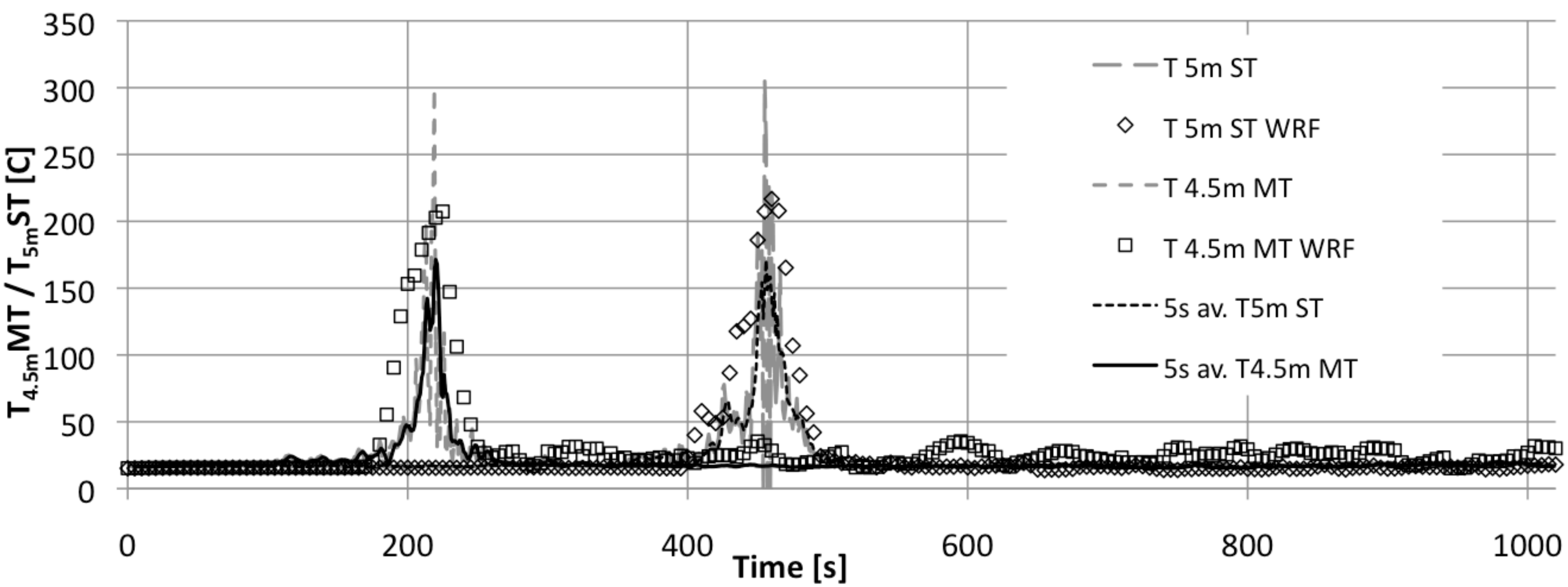
Timing of the fire front passage through the towers (5m and 4.5m air temperature)



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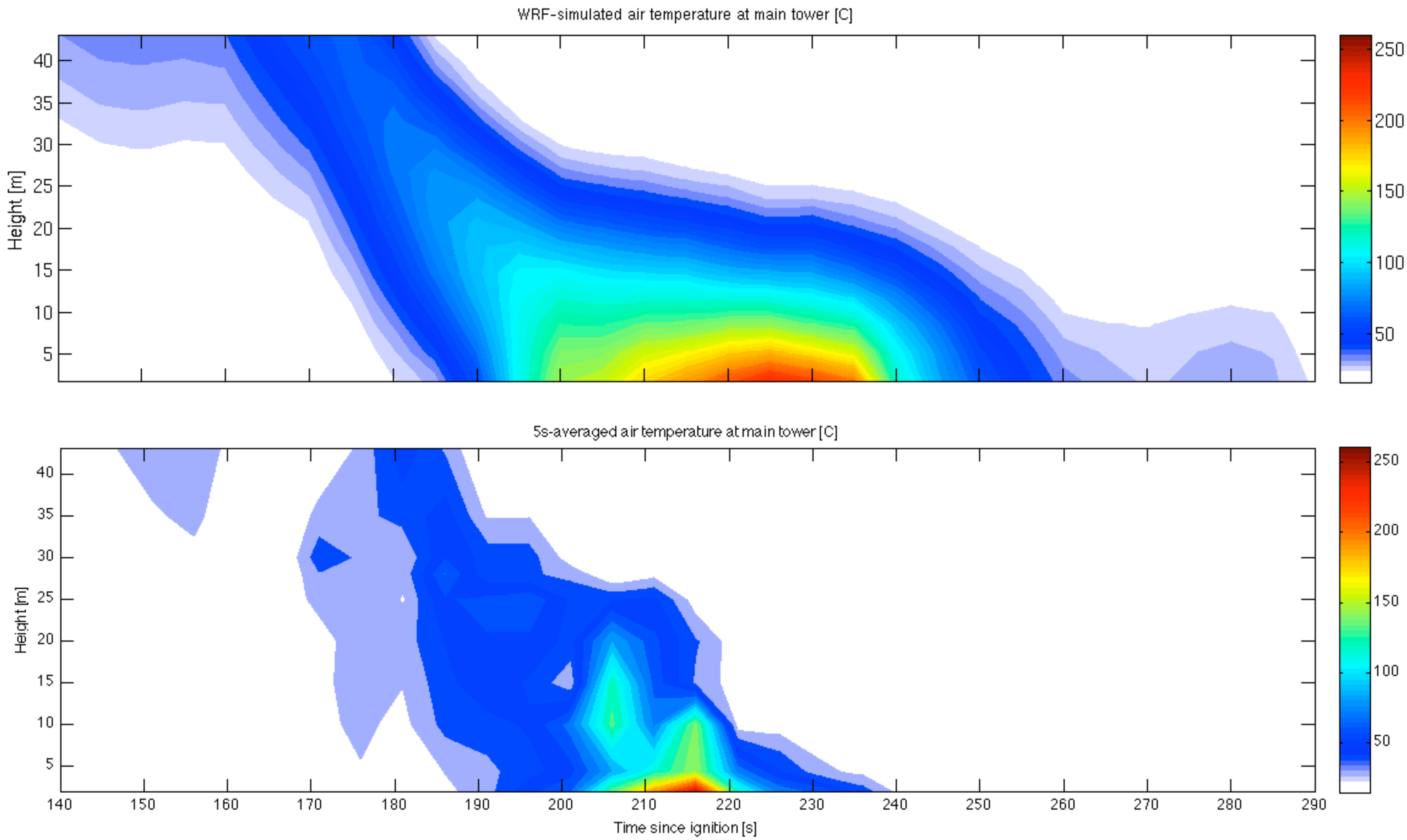
Thermal structure of the fire plume



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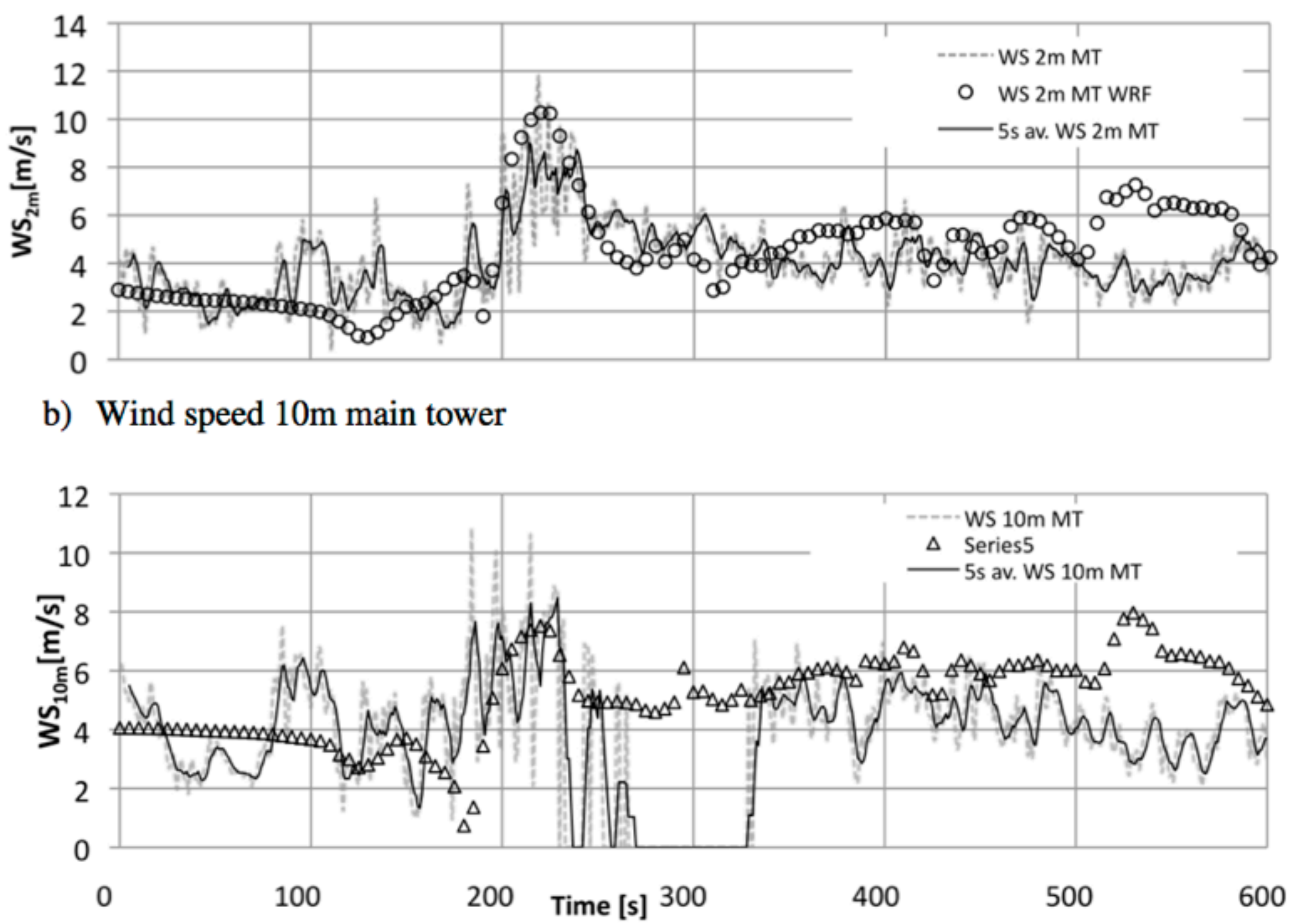
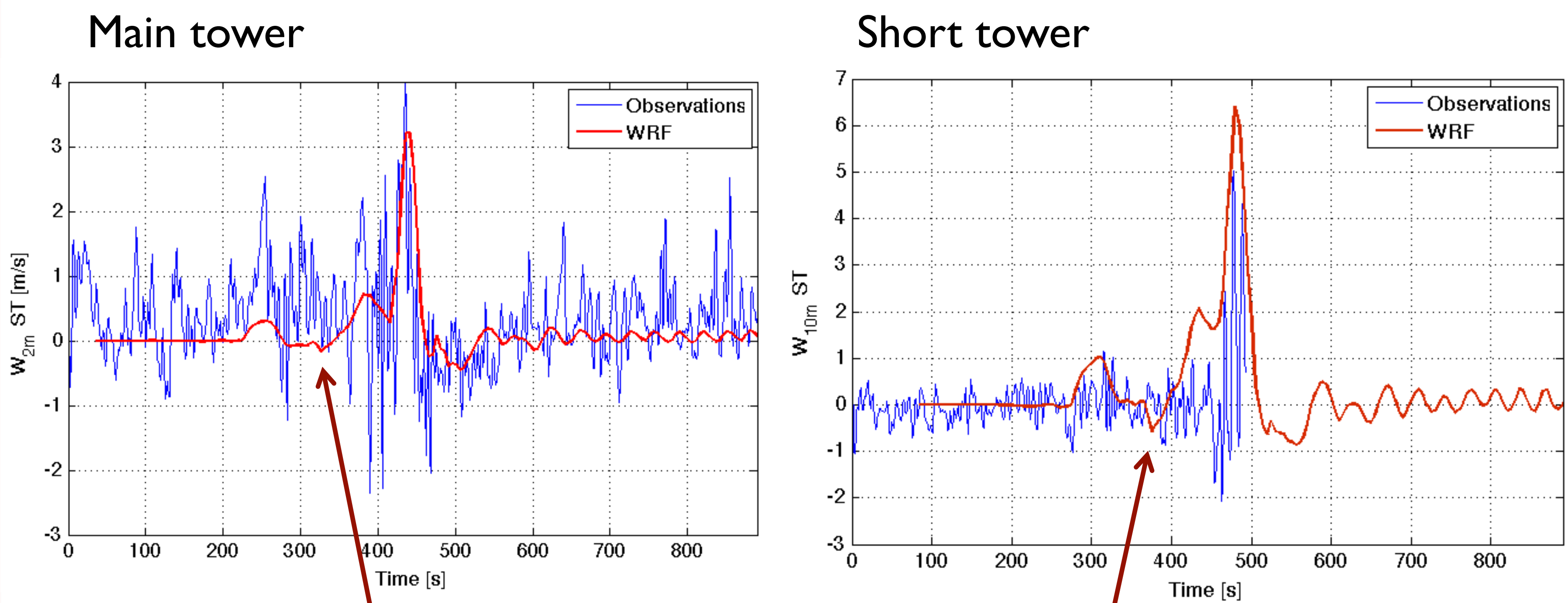
Fire-atmosphere interaction wind speed

a) Wind speed 2m main tower

b) Wind speed 10m main tower

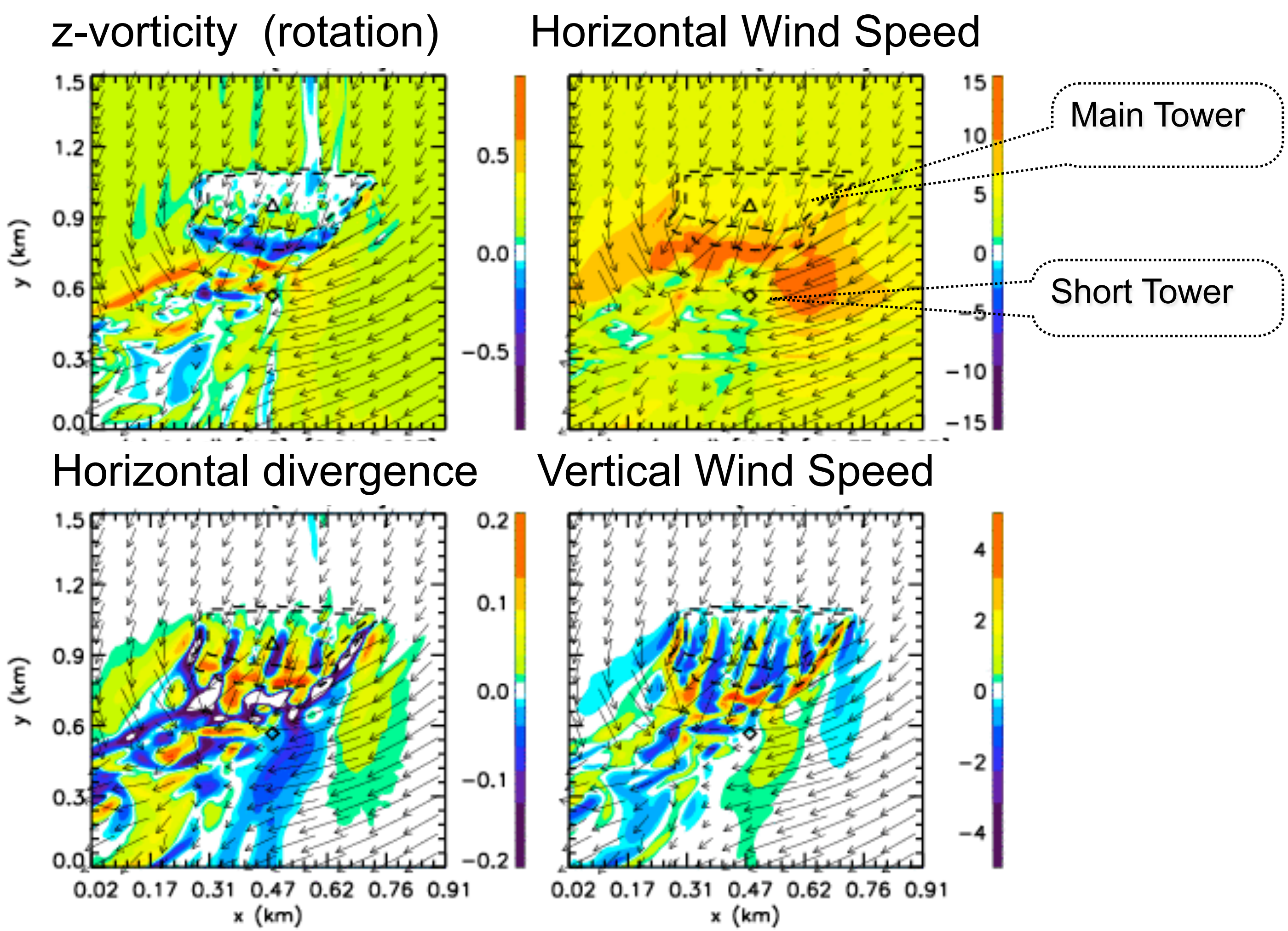


Upward velocity at 2m and 10m AGL - short tower (WRF vs. observations)

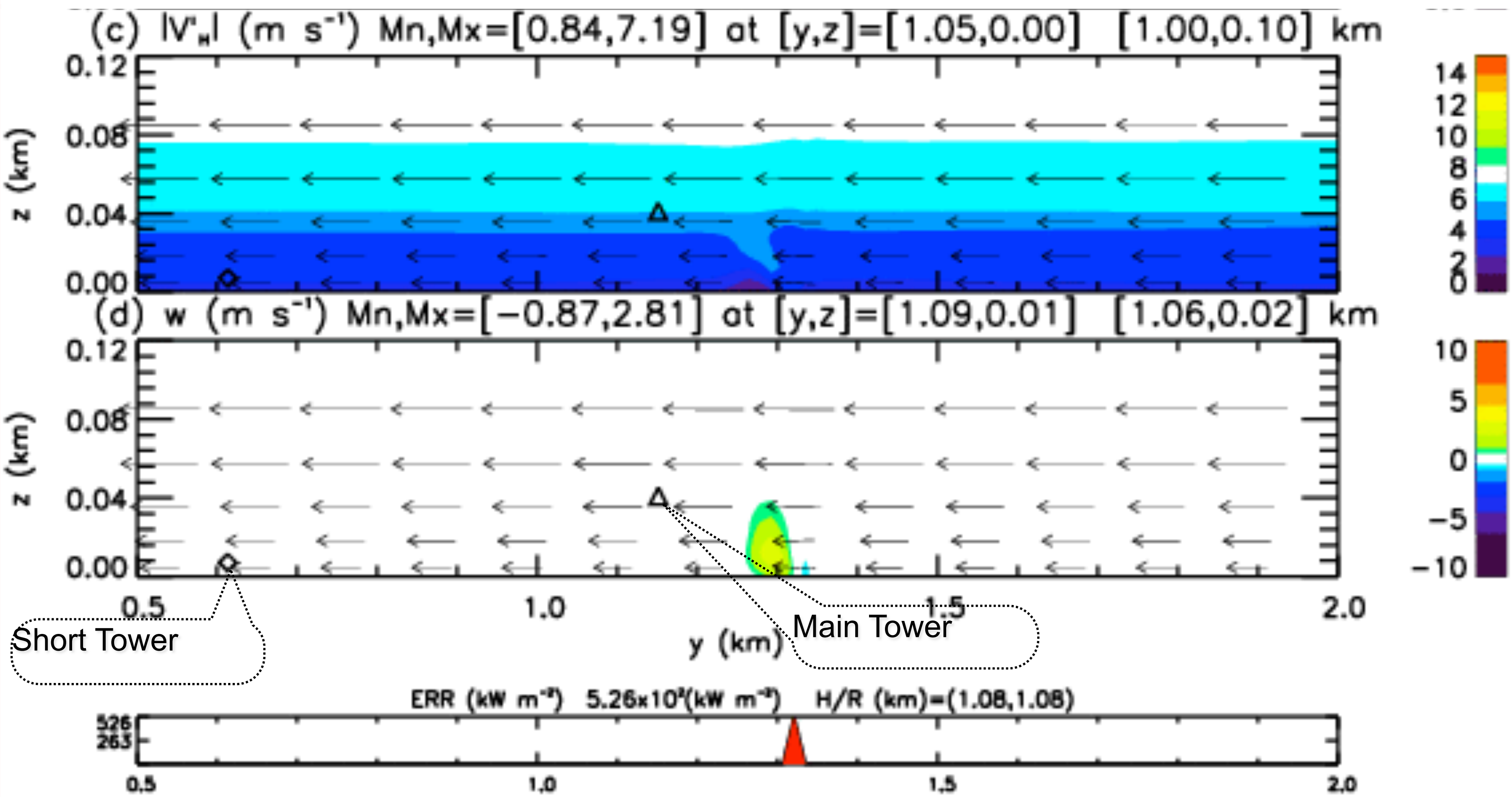


Downdrafts ahead of the fire front

FireFux Simulation look from the top



FireFux simulation look from a side



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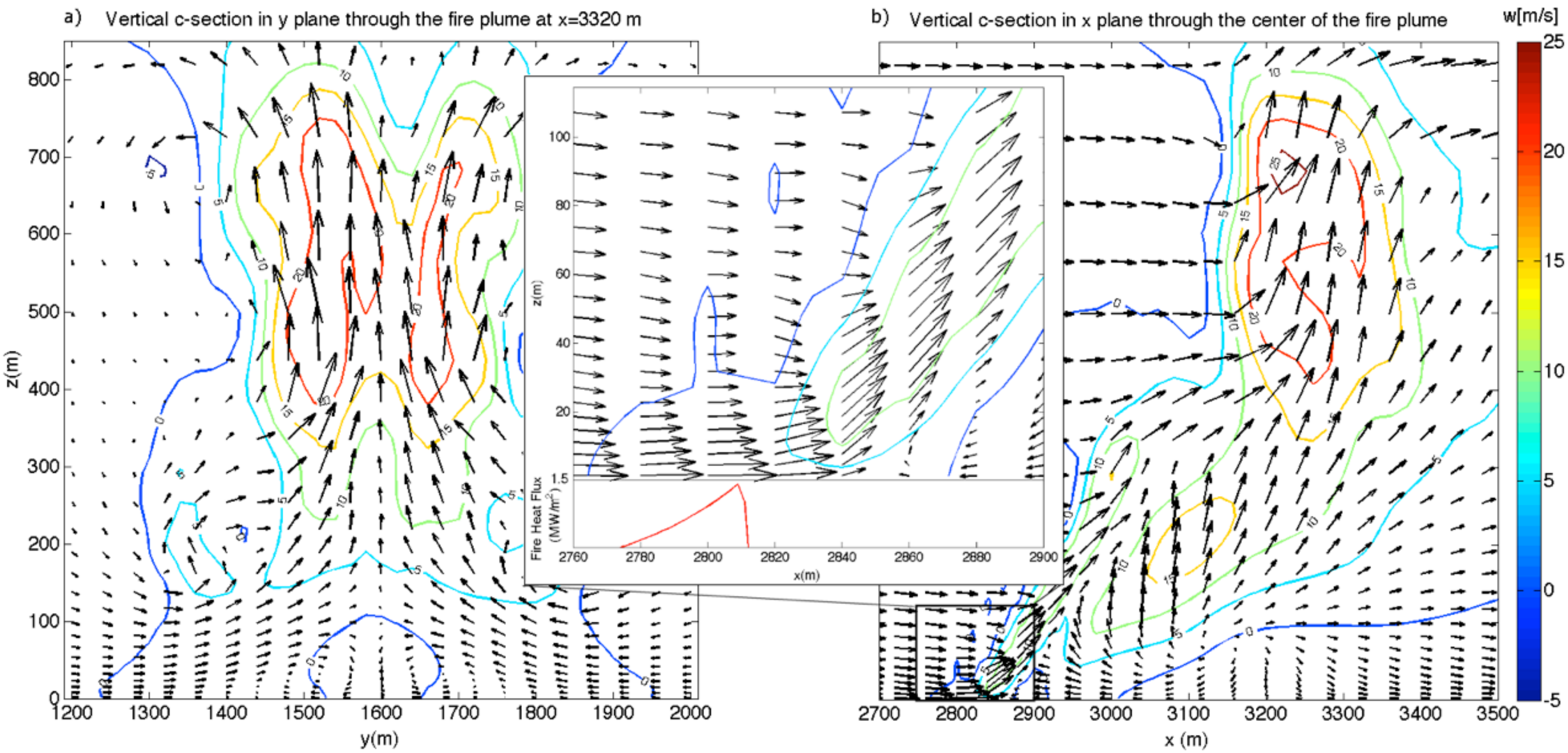
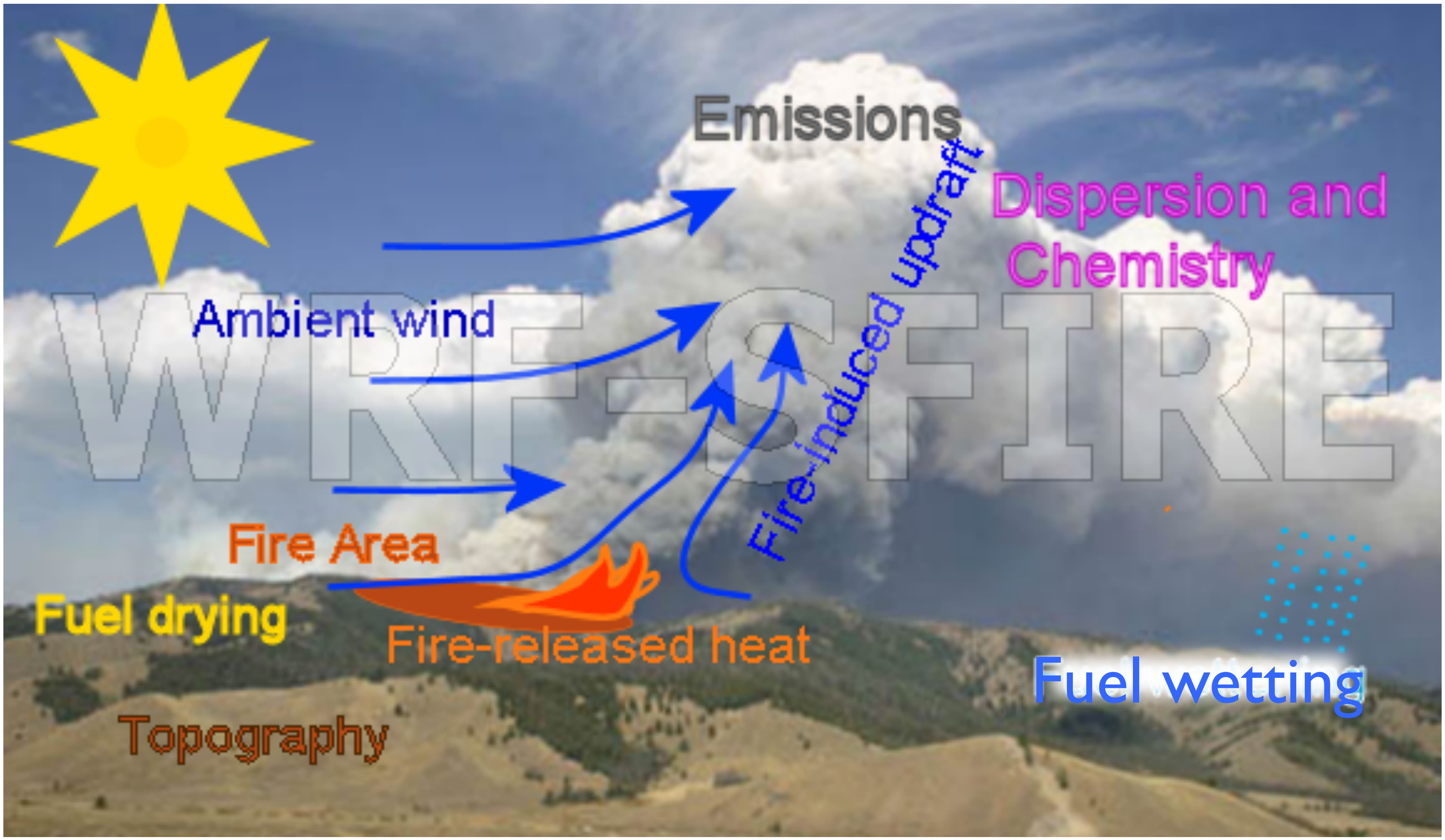
Impact of the fire-atmosphere feedback on the local wind



Smoke modeling in a coupled fire-atmosphere framework



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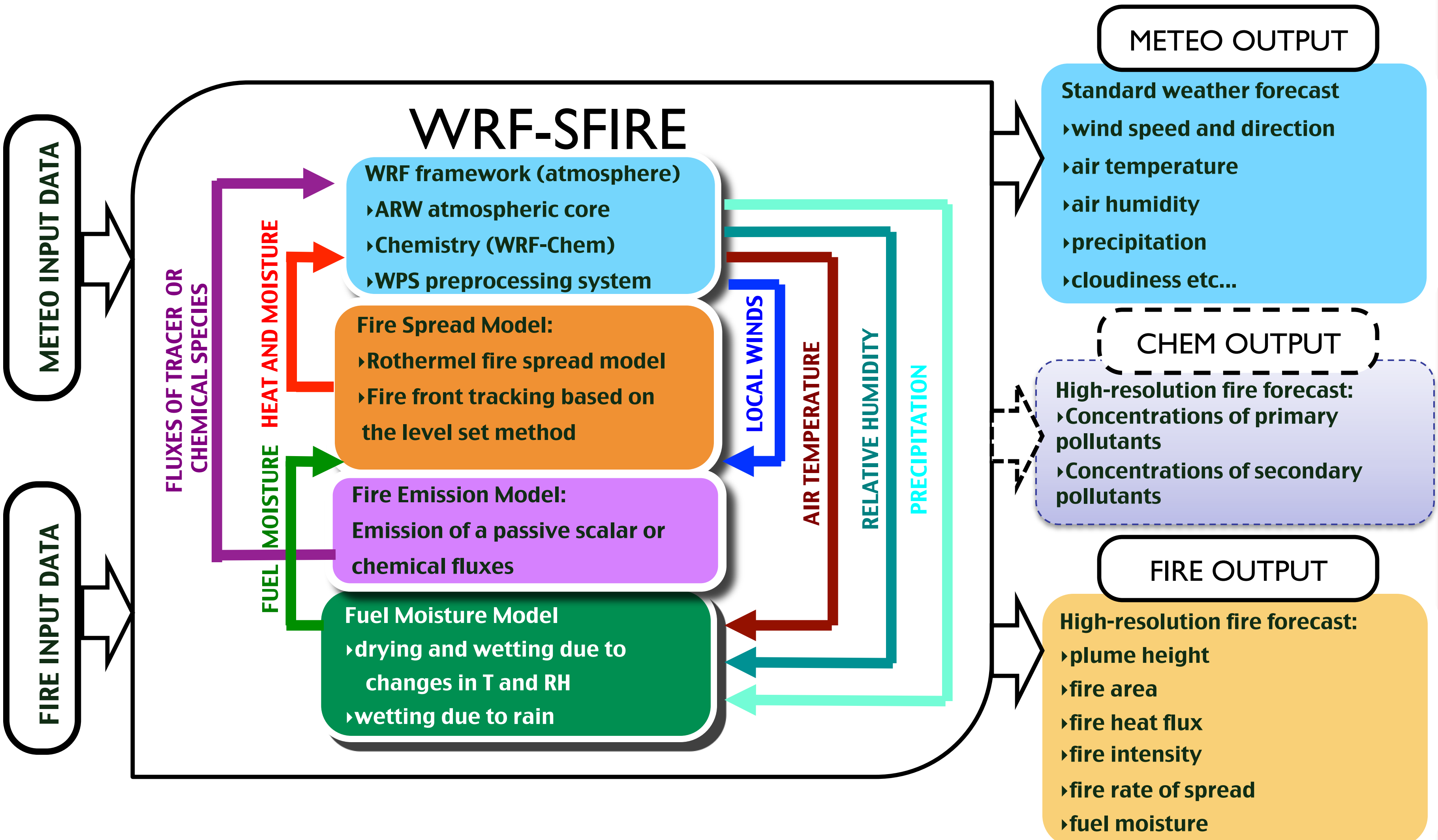
An integrated system for smoke modeling based on WRF-Sfire



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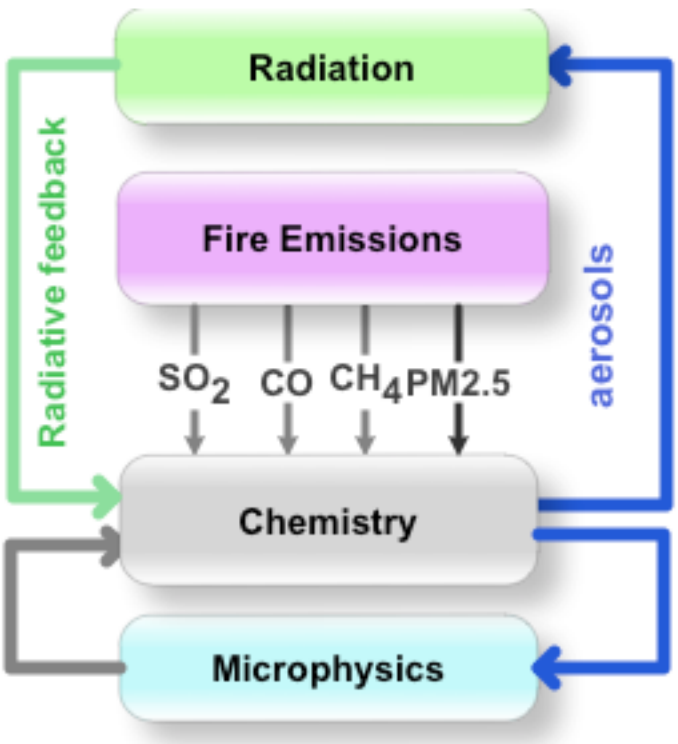
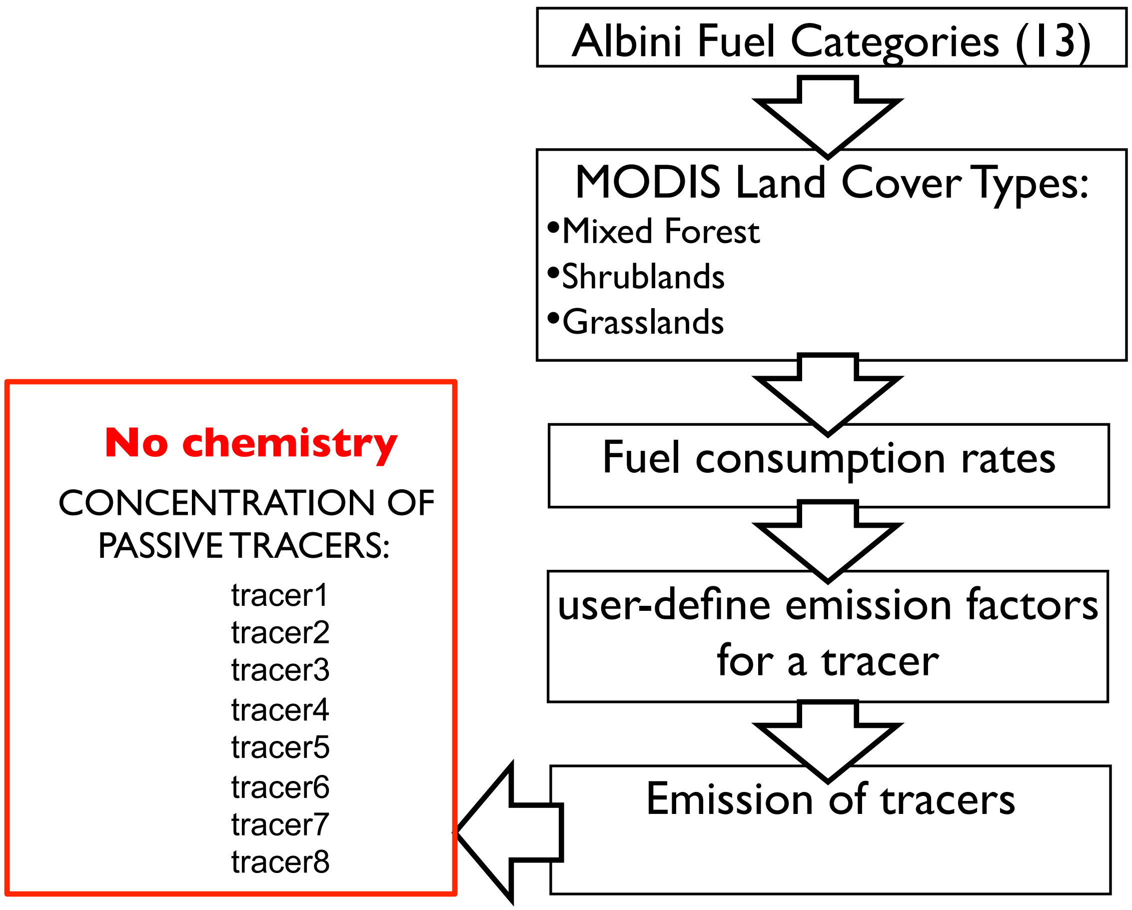
An integrated system for smoke forecasting based on WRF-Sfire

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



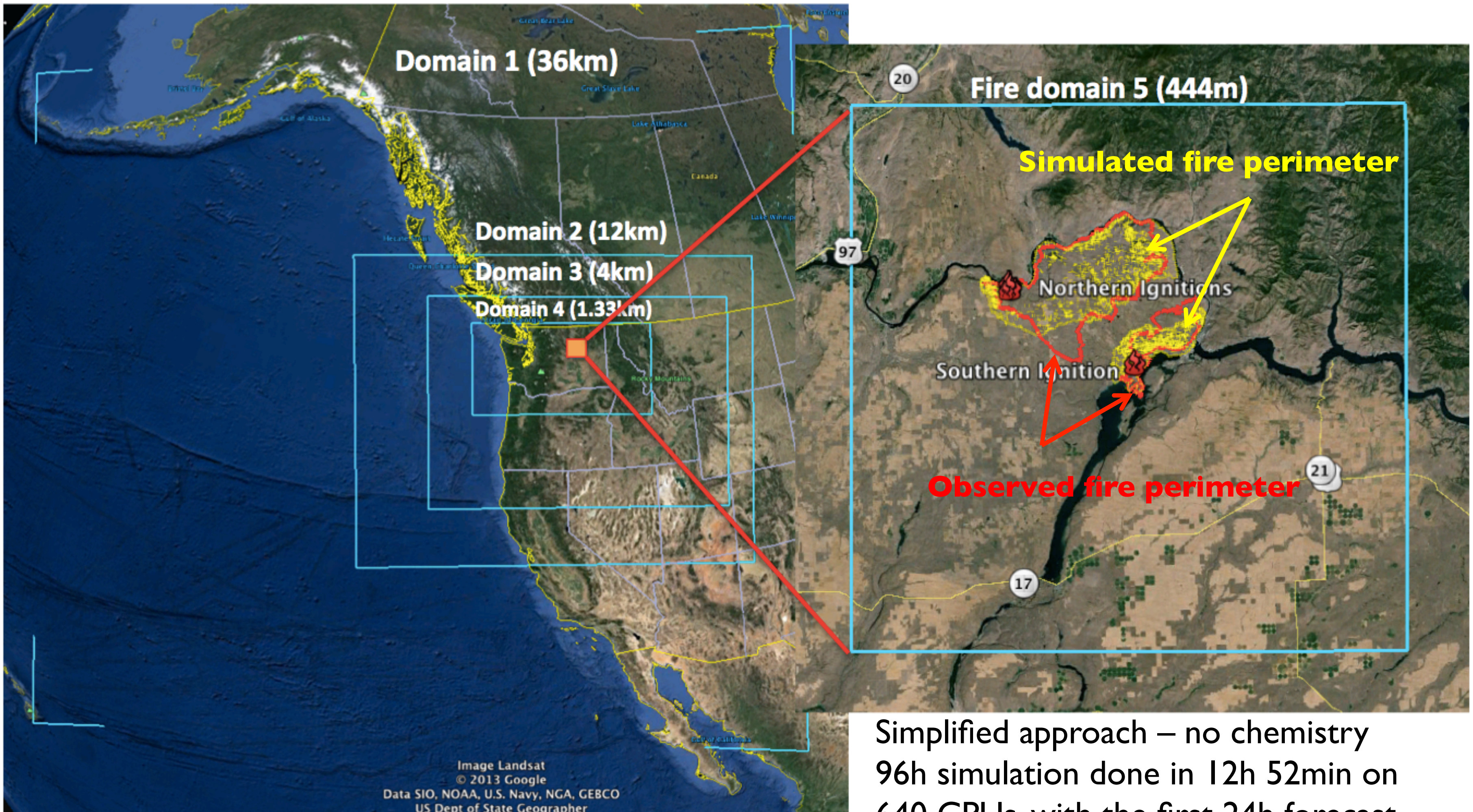
Simplified estimation of fire emissions (passive tracer)



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)



Simplified approach – no chemistry
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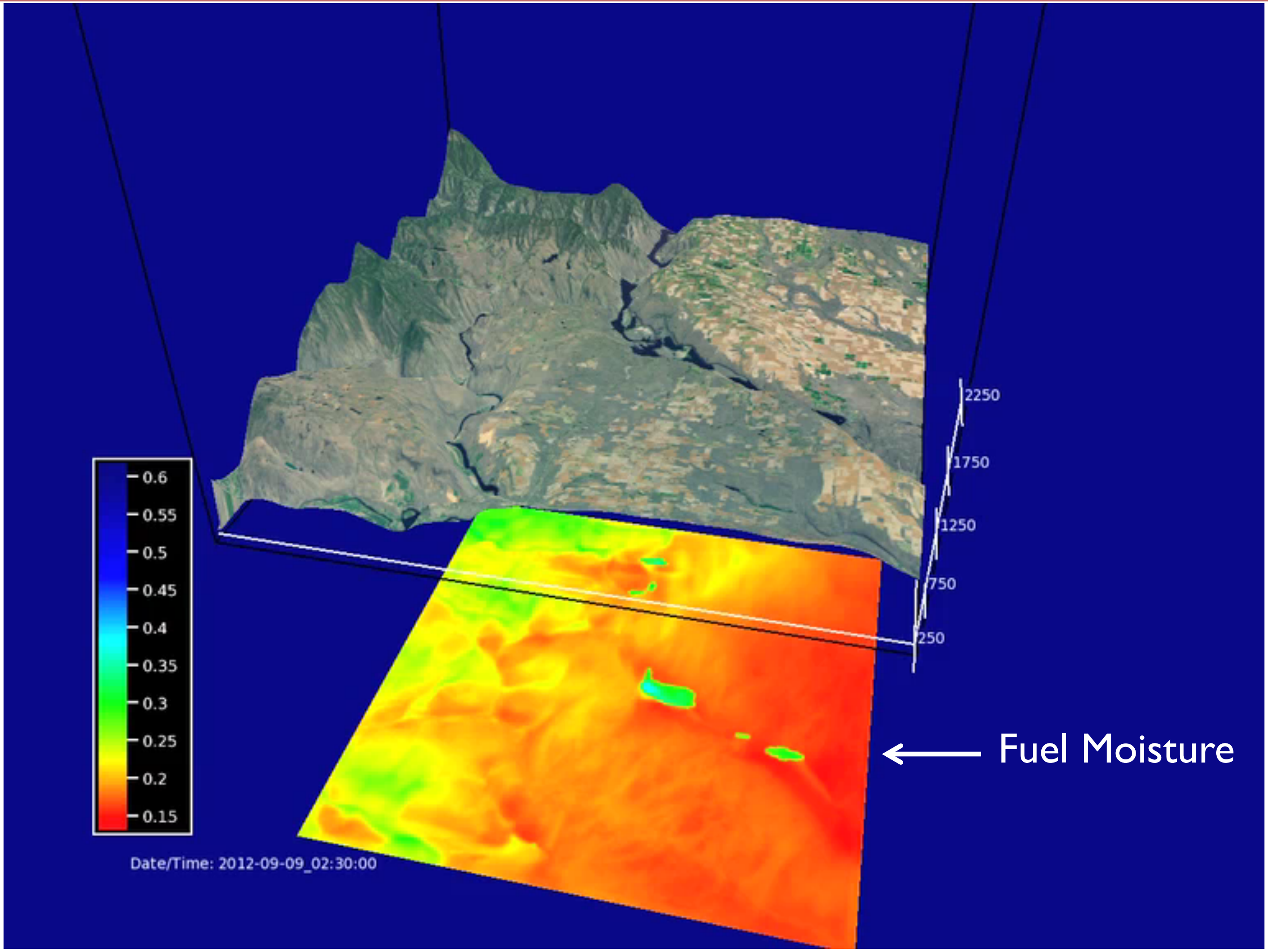
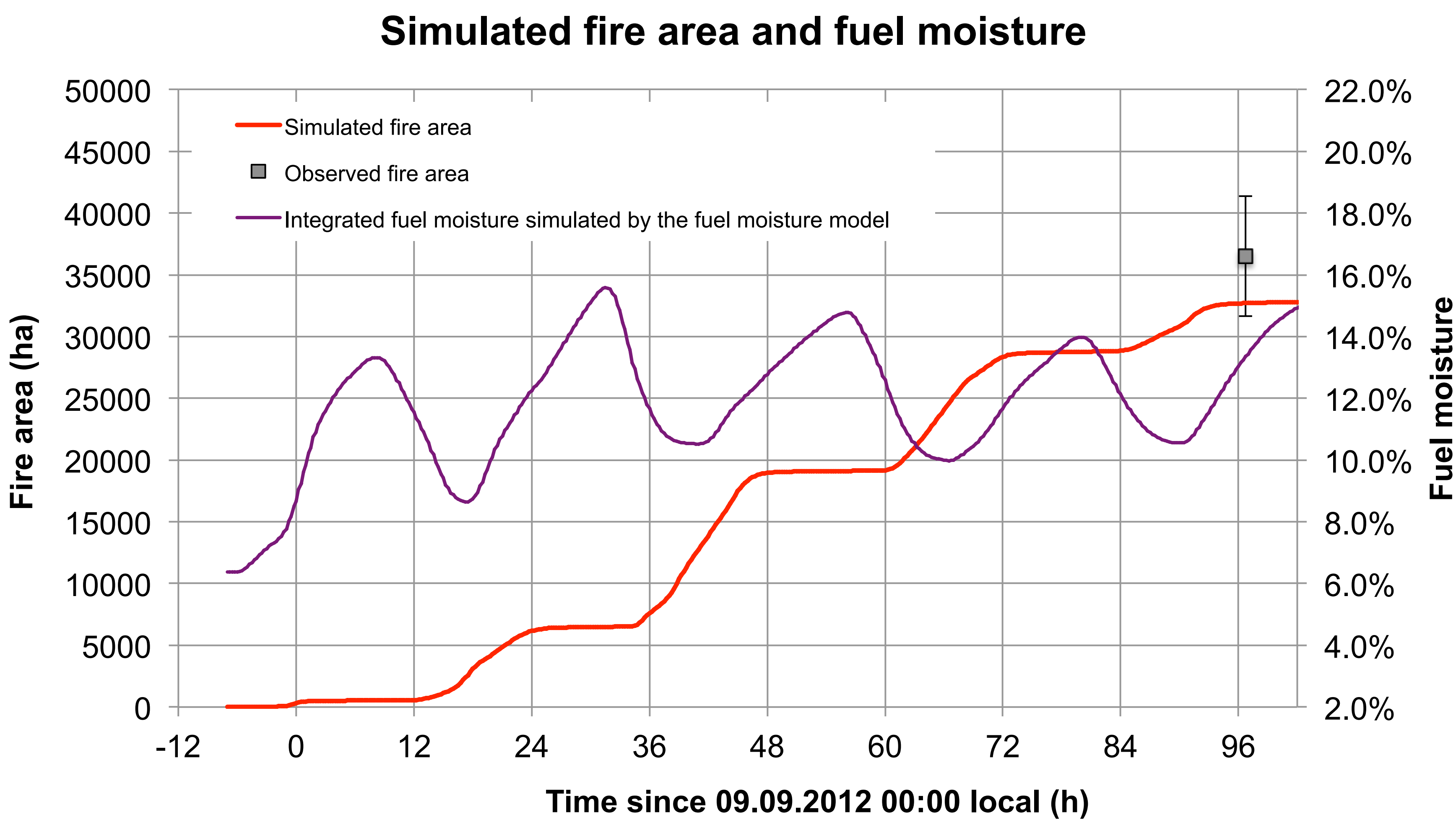
Example #1 Simulation of Barker Canyon Fire (smoke as a passive tracer)



Simulated fire area and fuel moisture for Barker Canyon fire 2012



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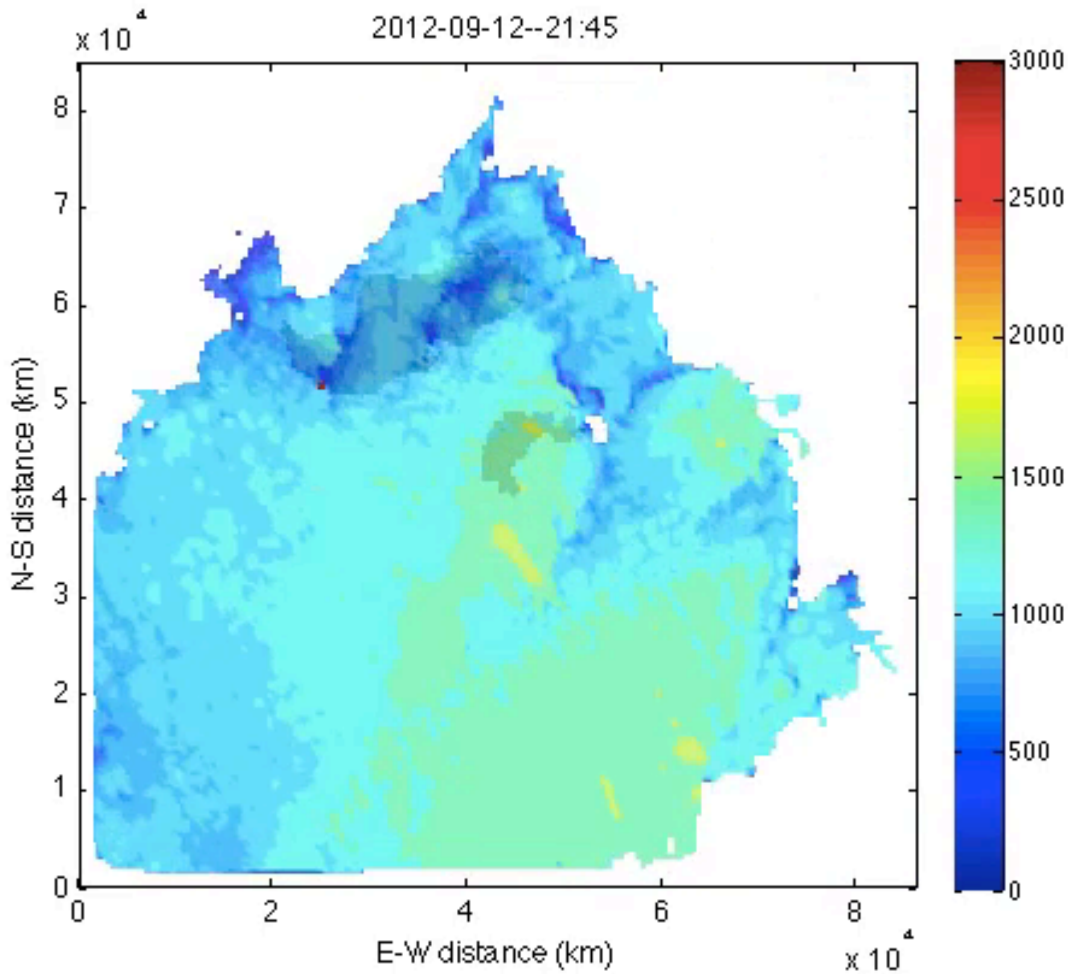
Simulation of maximum plume height from 2012 Barker Canyon Fire (WA)



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

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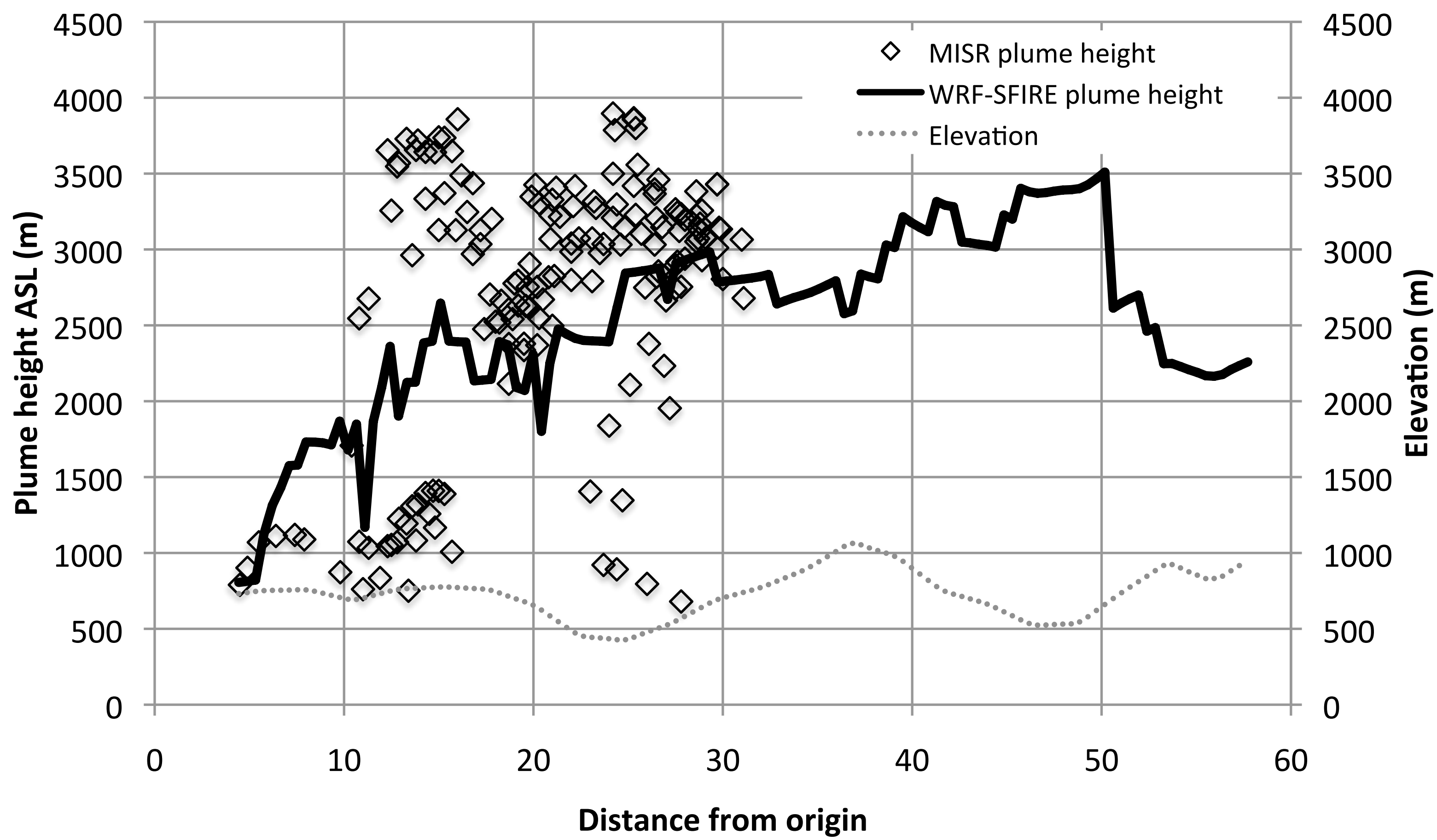
Maximum plume height simulated by WRF-Sfire vs. satellite observations (MISR)



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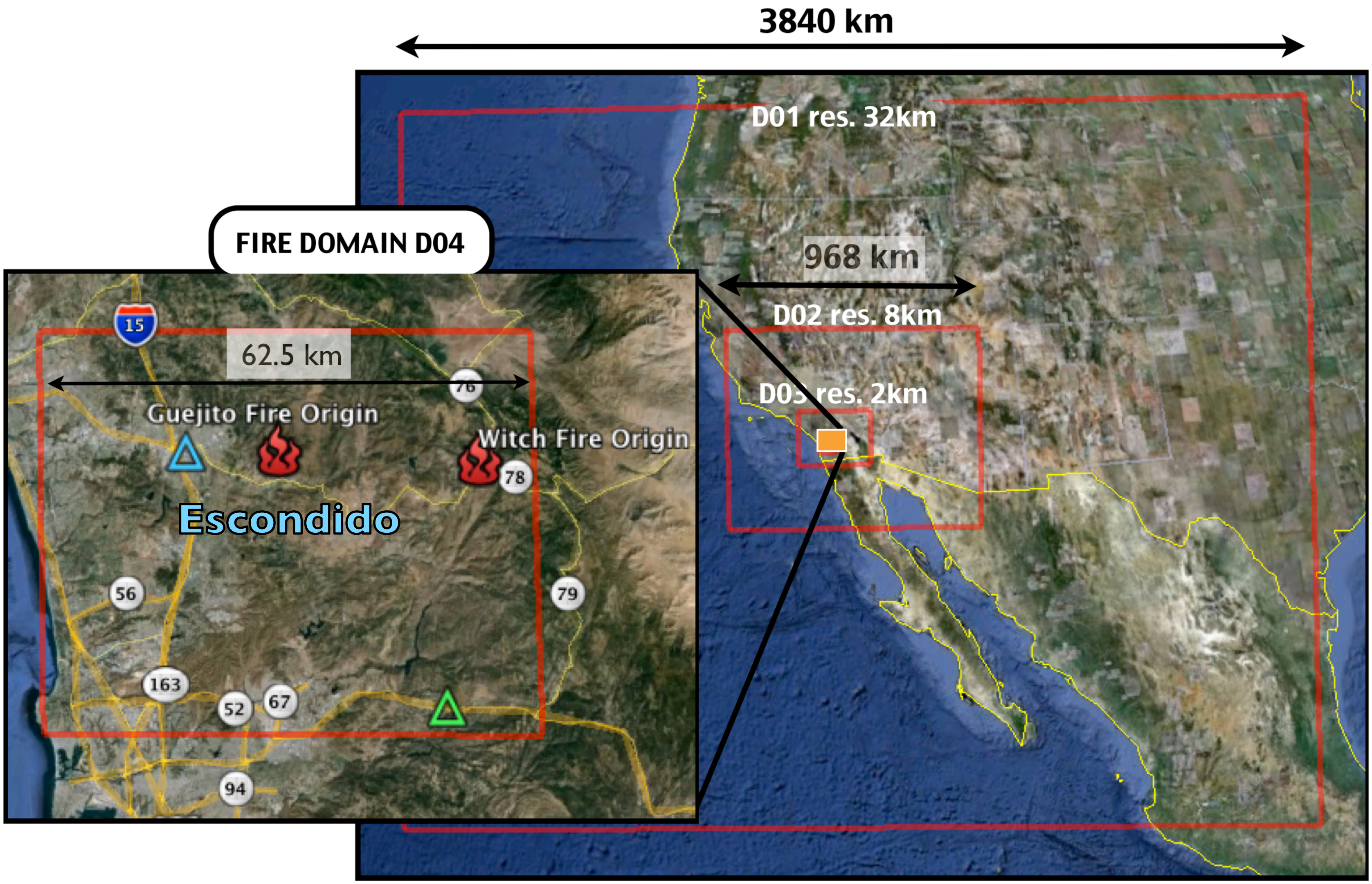
Example #2 Santa Ana fire simulation with full atmospheric chemistry



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

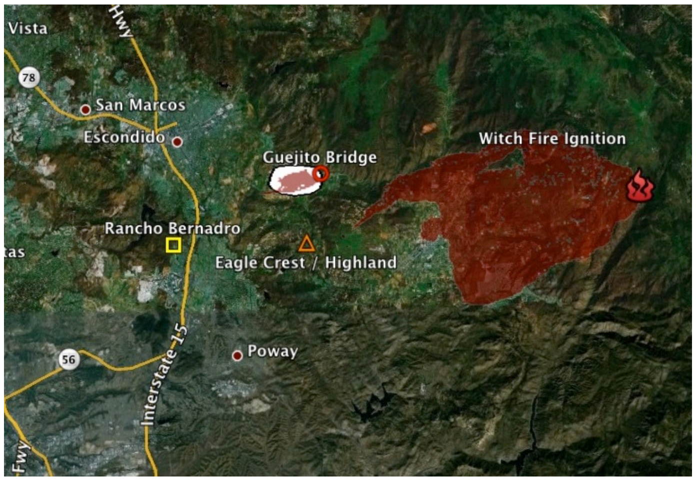
MOZART

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

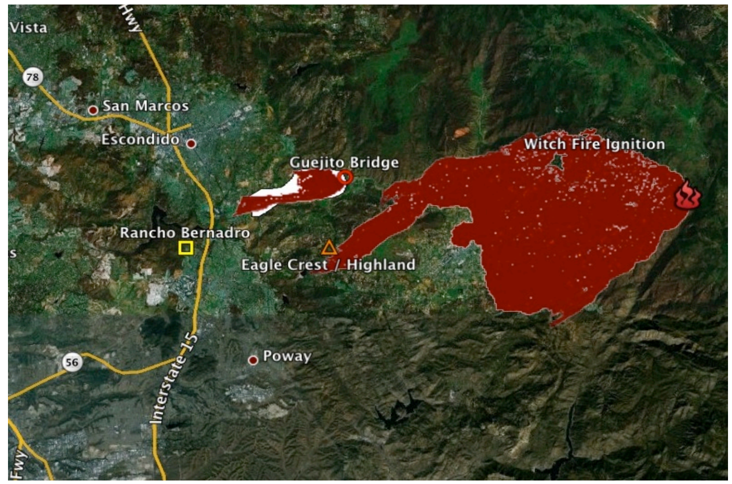
NMOC: bigalk, bigene, c10h16, c2h4, c3h5oh, c2h6, c3h6, c3h8, ch3cooh, ch3oh, cres, glyald, hyac, isop, macr, mek, mvk, tol

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

10.22.2007 02:45 local time



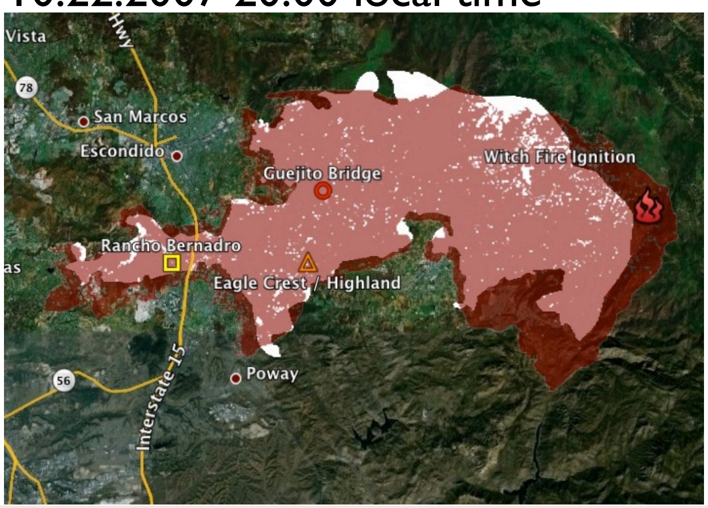
10.22.2007 05:00 local time



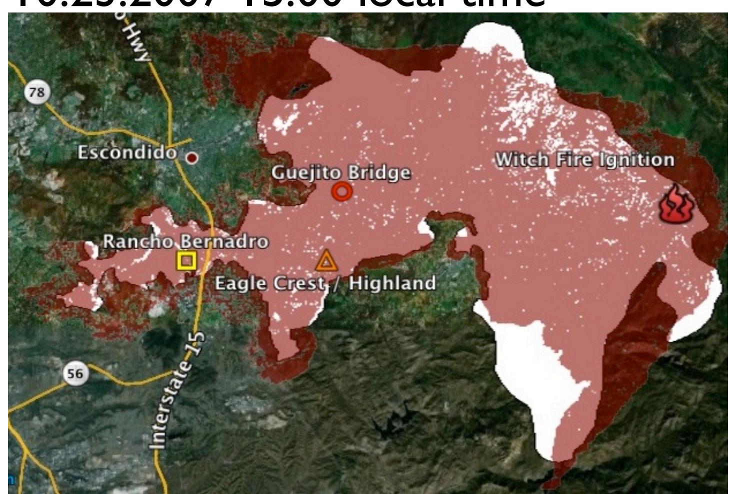
Observed fire area

WRF-fire area

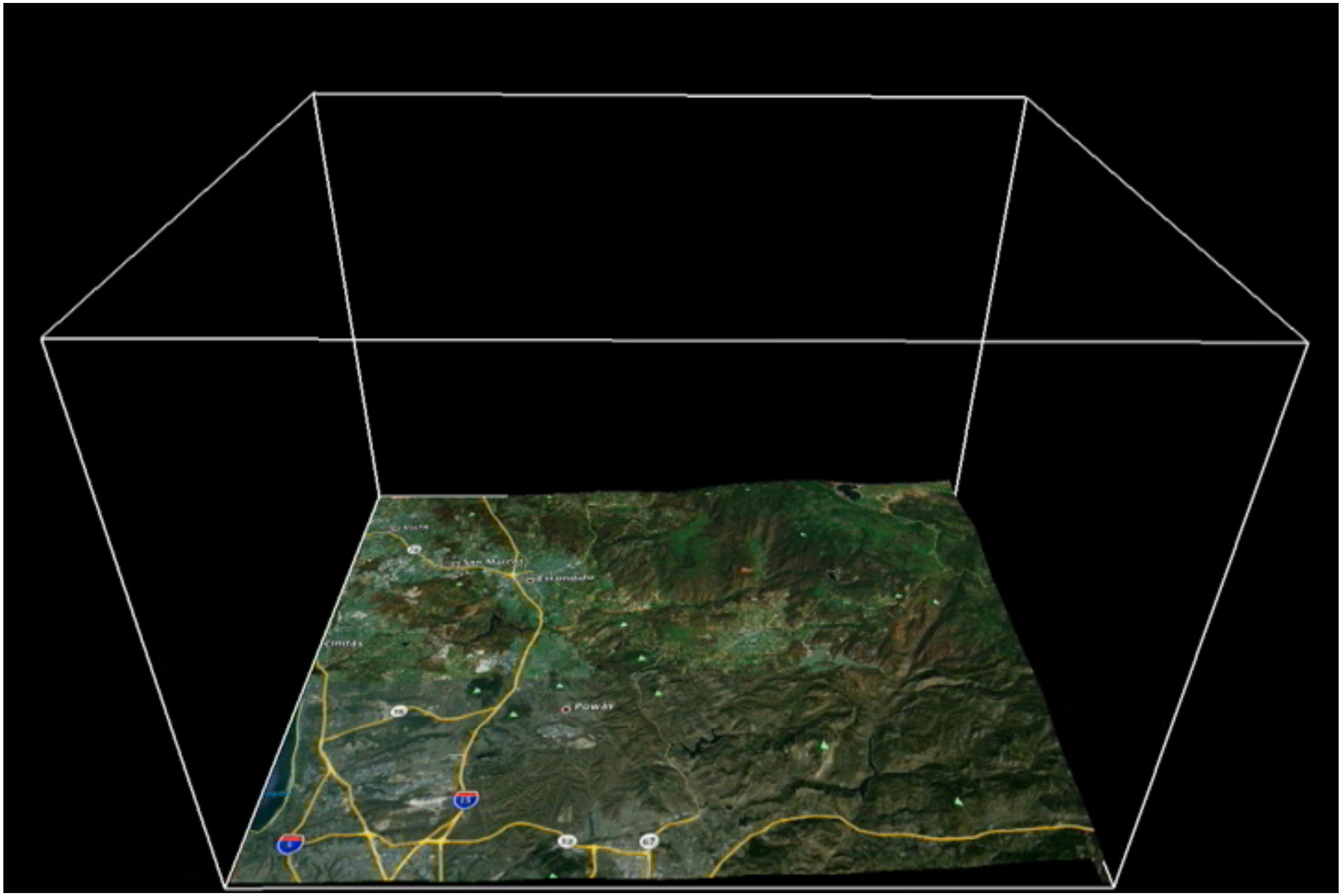
10.22.2007 20:00 local time



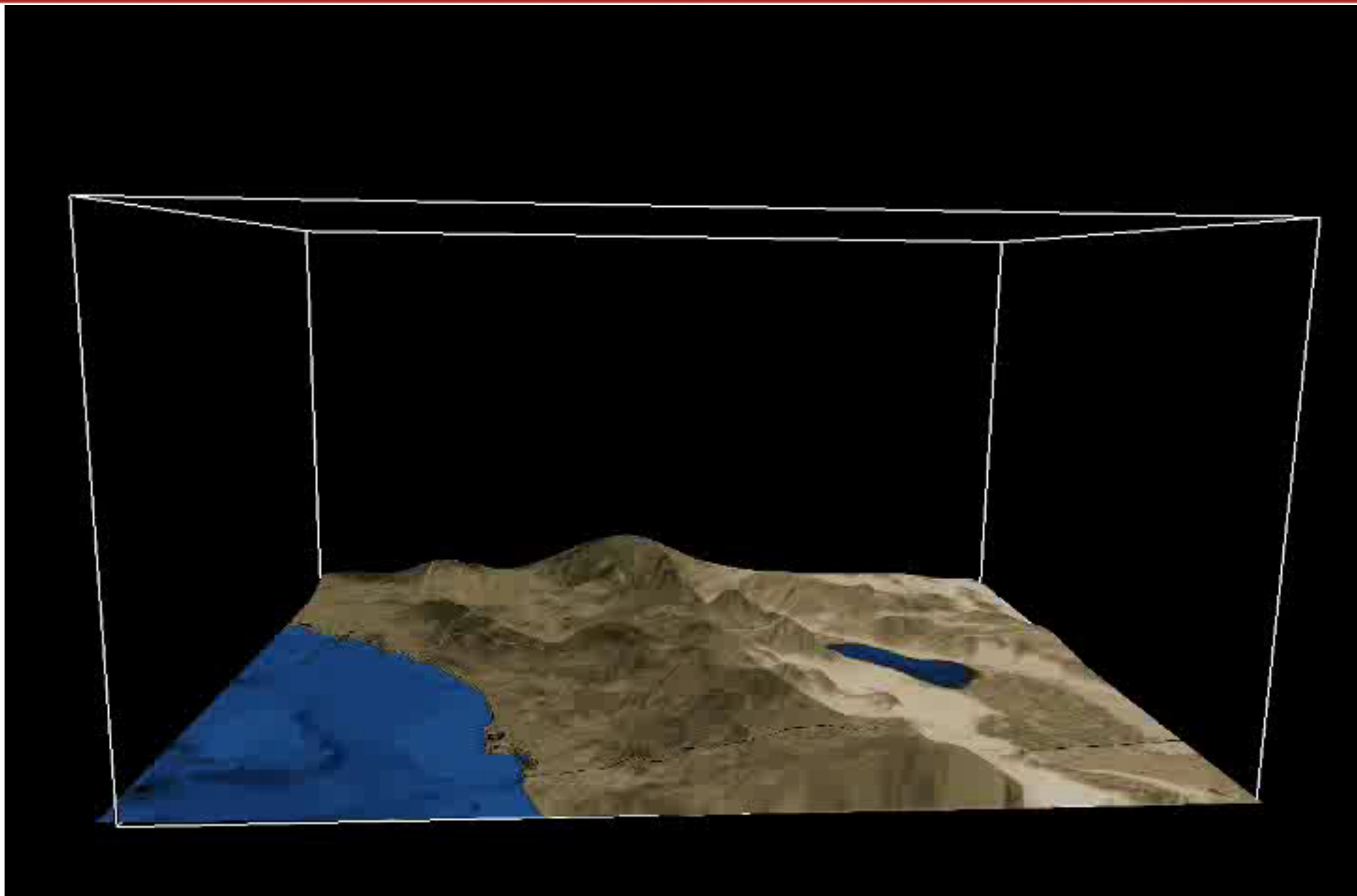
10.23.2007 15:00 local time



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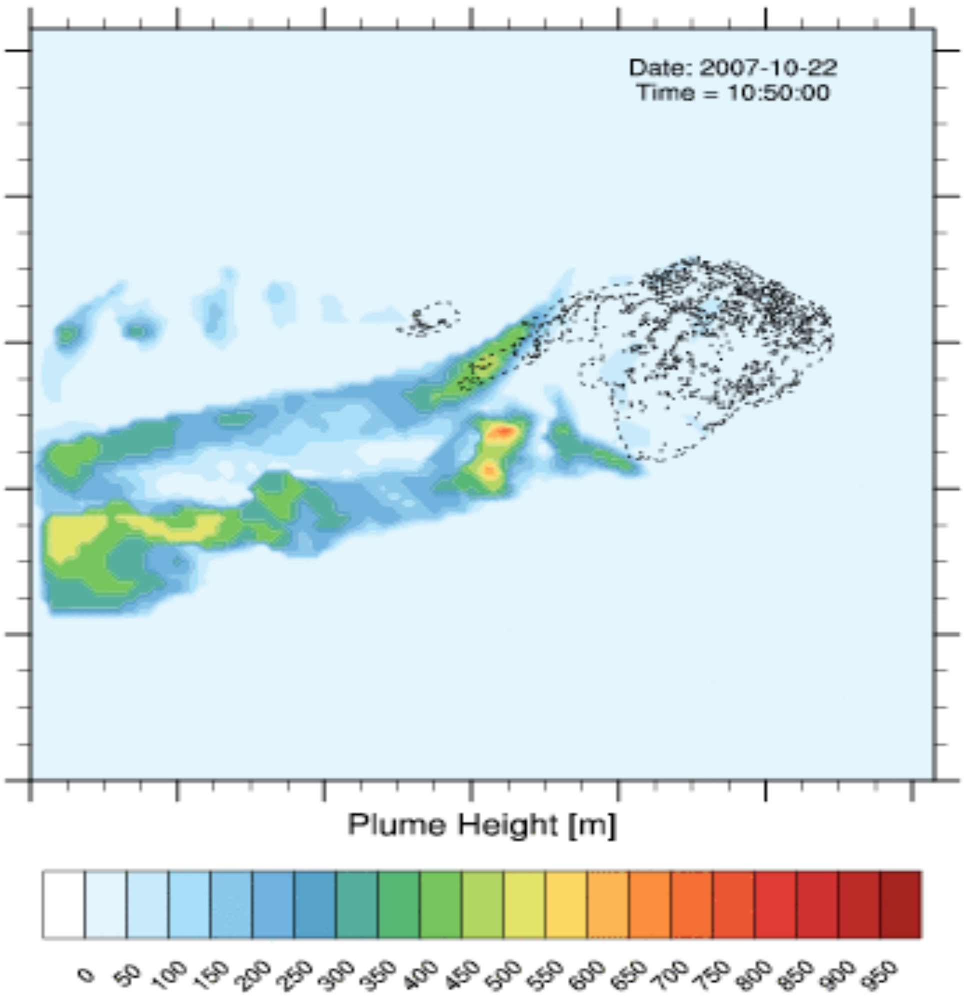
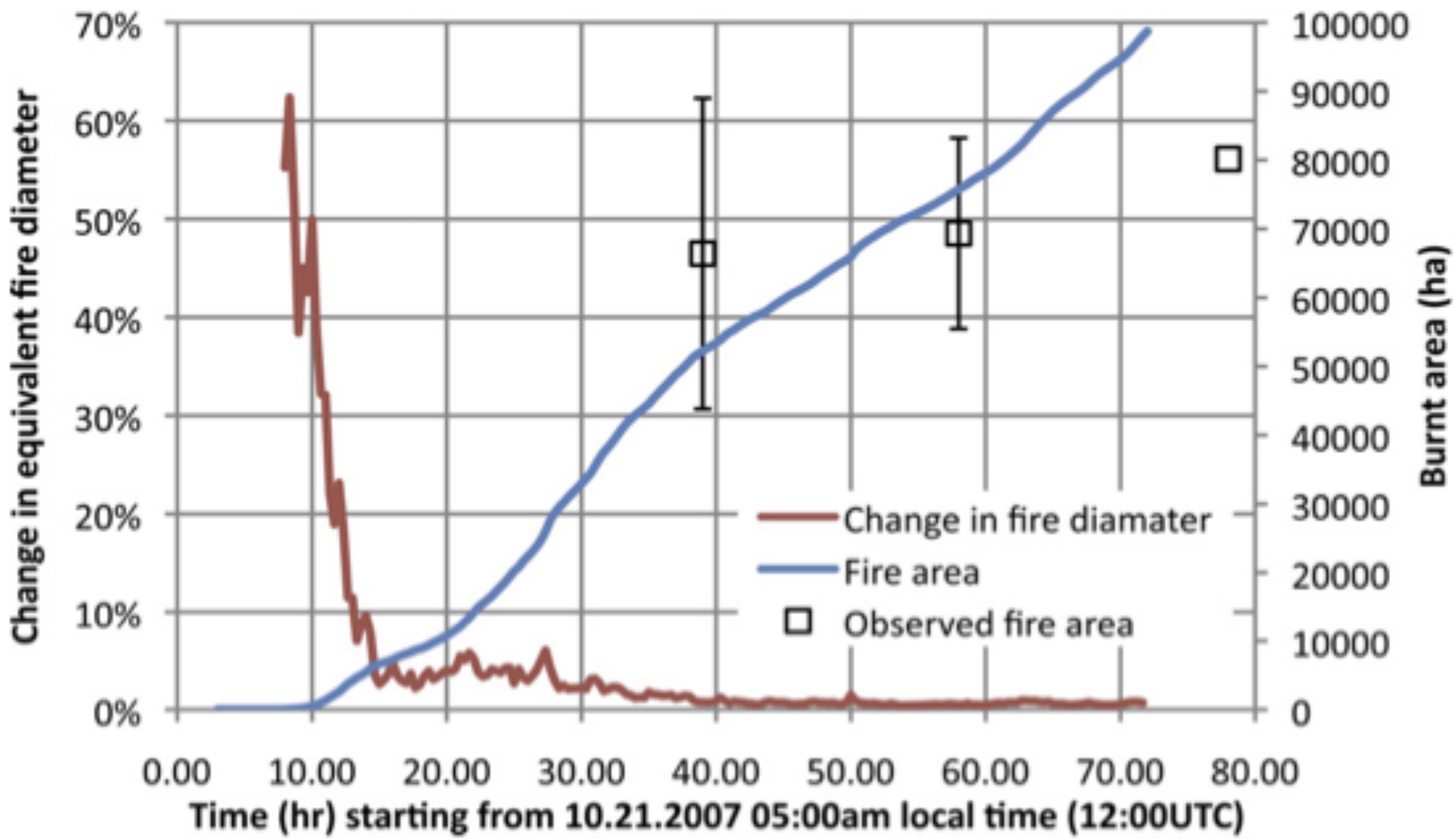
Simulation of maximum plume height from 2008 Santa Ana Fires (Witch and Guejito)



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)



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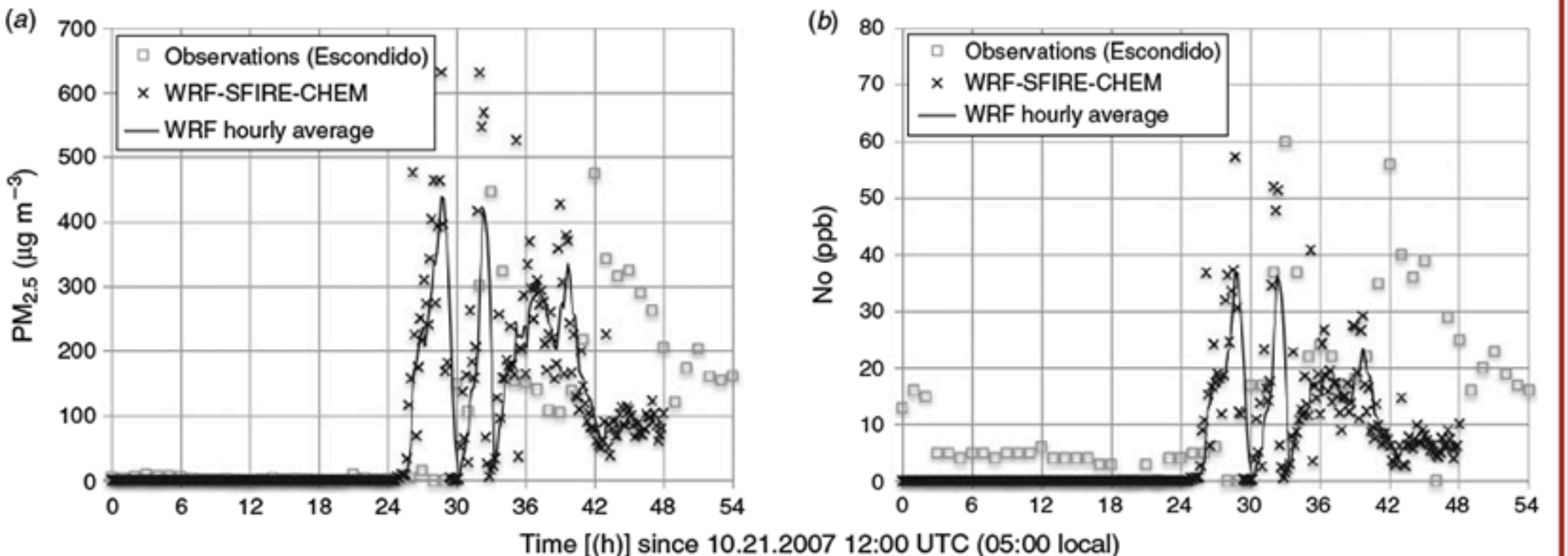
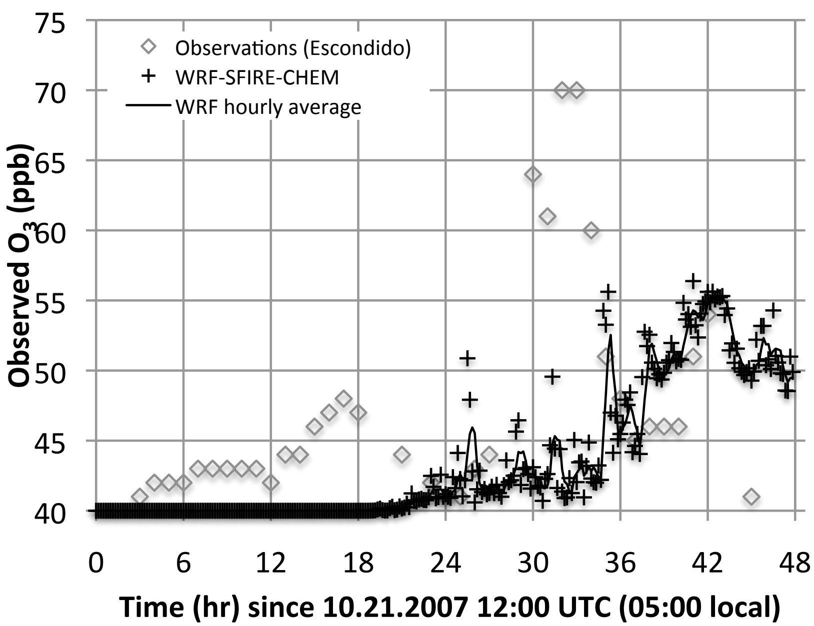
Simulation of PM2.5 emissions from 2007 Santa Ana fires (Witch and Guejito) 500m

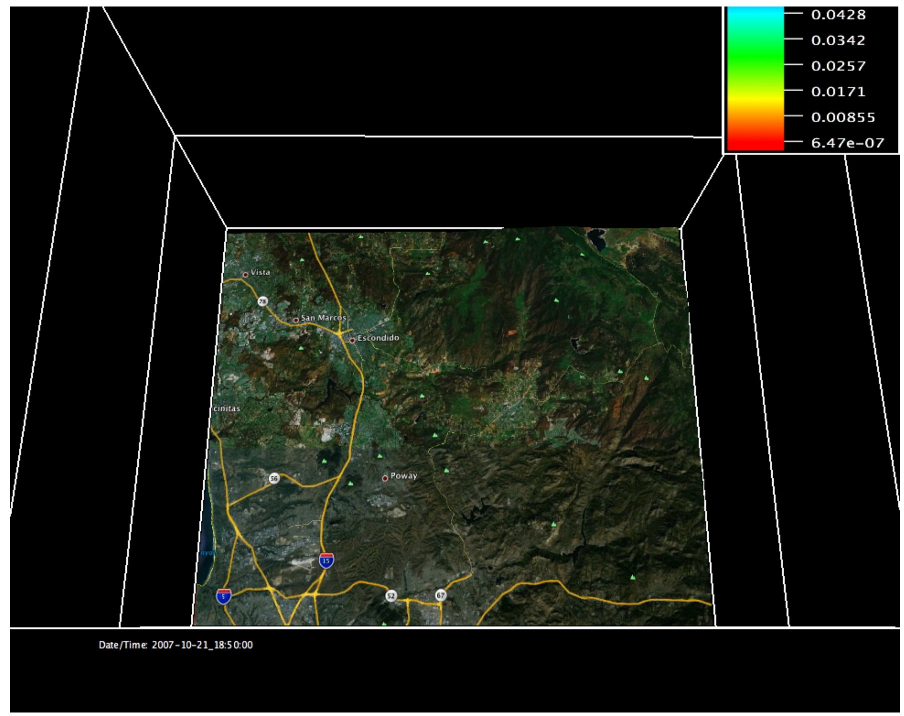
Simulated vs. observed PM2.5 for Escondido

Simulated vs. observed NO for Escondido



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





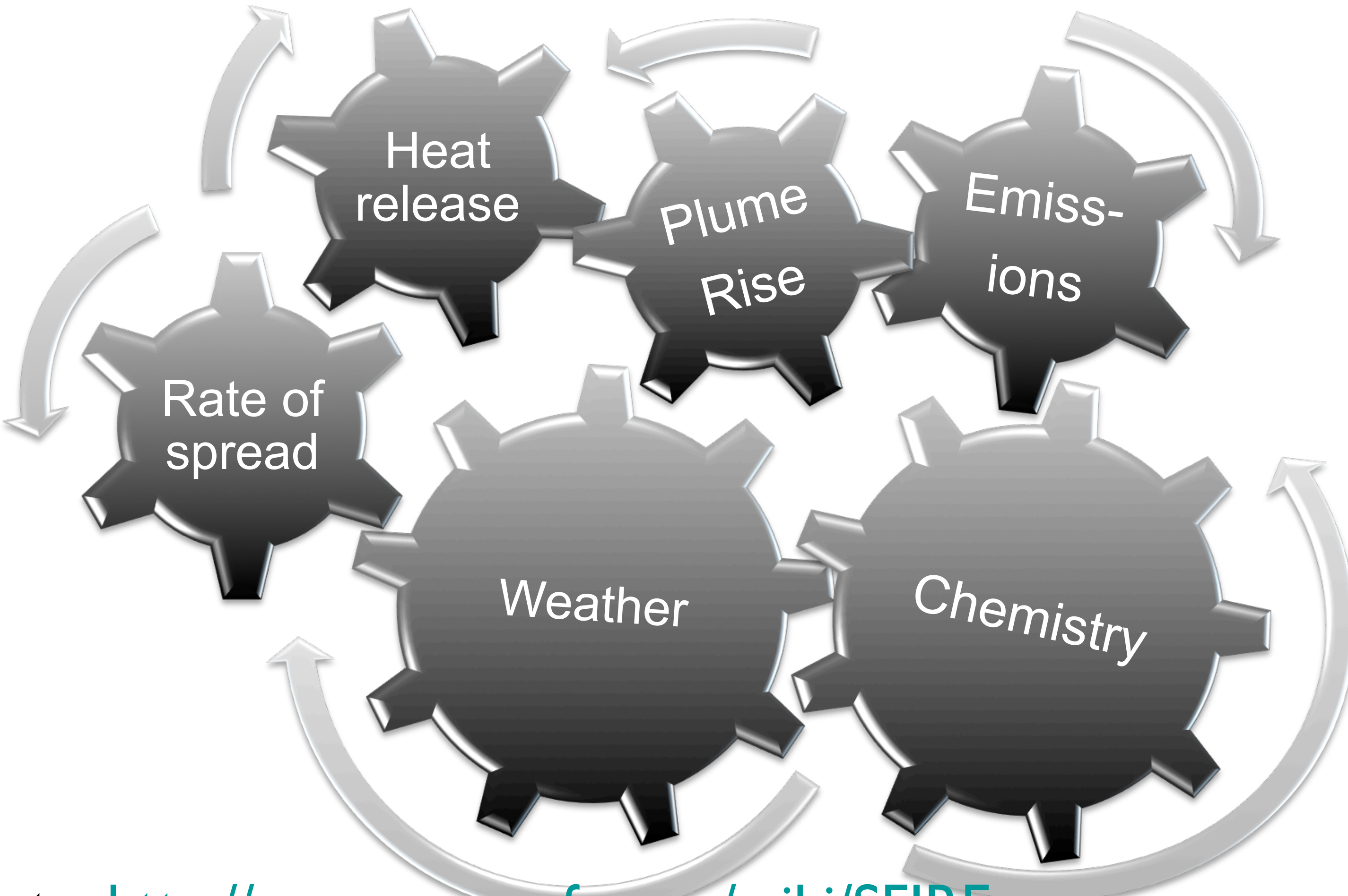
Summary #1

- 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 seeing a “bigger picture”
- WRF-Sfire renders the fire smoke as a passive tracer, or as a mixture of chemically active species (through coupling with WRF-Chem)
- Fire-atmosphere coupling allows 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

Summary #2

- The newly added components need thorough validation we invite other researchers to share data validate the model and contribute to its development
- 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
- Chemical simulations are computationally expensive, so in operational application two approaches are possible:
  - WRF-Sfire resolves plume rise and emission of basic species as tracers that are then used in a coarser chemical transport model
  - if the air quality and fire contributions are important only for certain locations WRF may be used to drive Lagrangian chemical transport models

Thank you!



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

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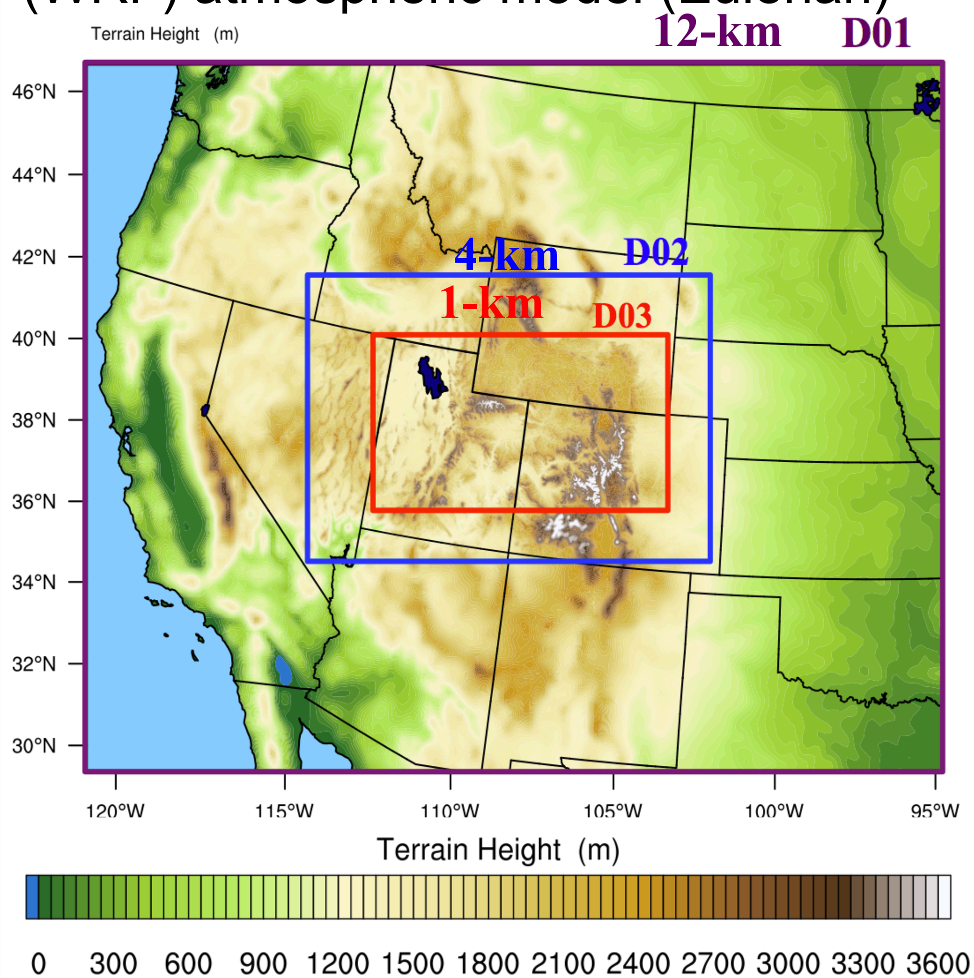
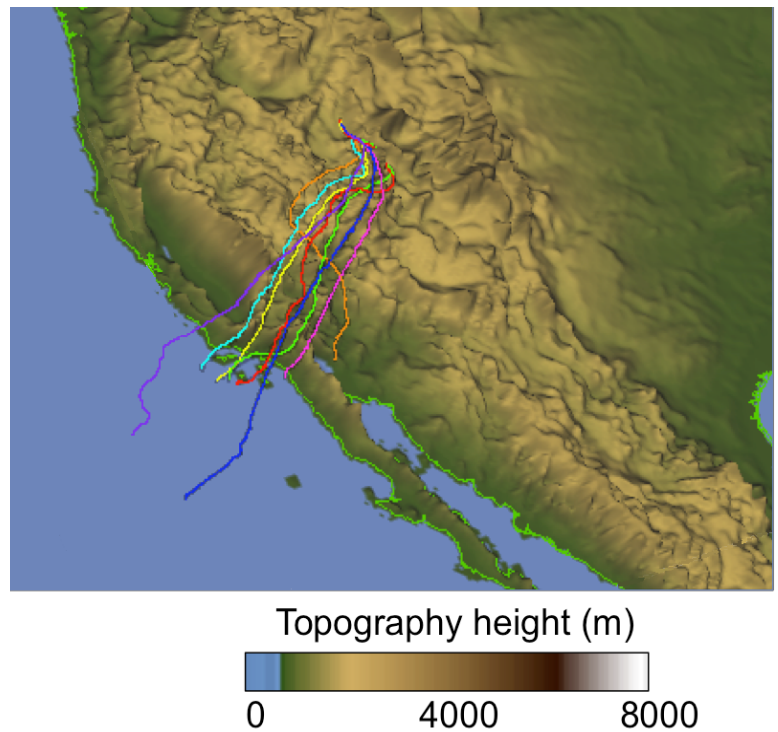
Assessing air quality impacts of Wildland Fires using Lagrangian framework

Weather Research and Forecasting (WRF) atmospheric model (Eulerian) → **Stochastic Time-Inverted Lagrangian Transport (STILT) model [*Lin et al.*, 2003]**



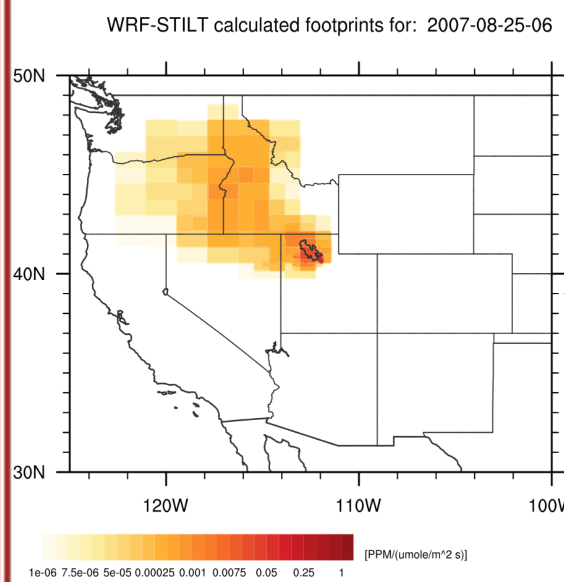


WRF wind fields drive the backward trajectories generated by the STILT model

Skamarock et

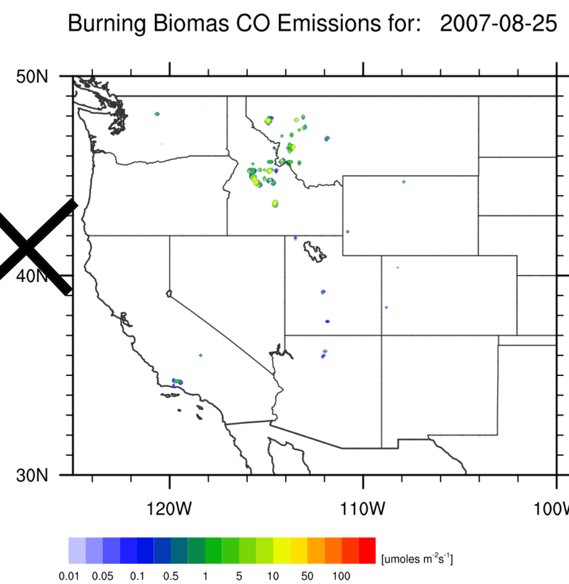
Assessing air quality impacts of Wildland Fires using Lagrangian framework

Footprint
(ppm/μmole m^{-2} s^{-1})



×

Fire Emission
(μmole m^{-2} s^{-1})



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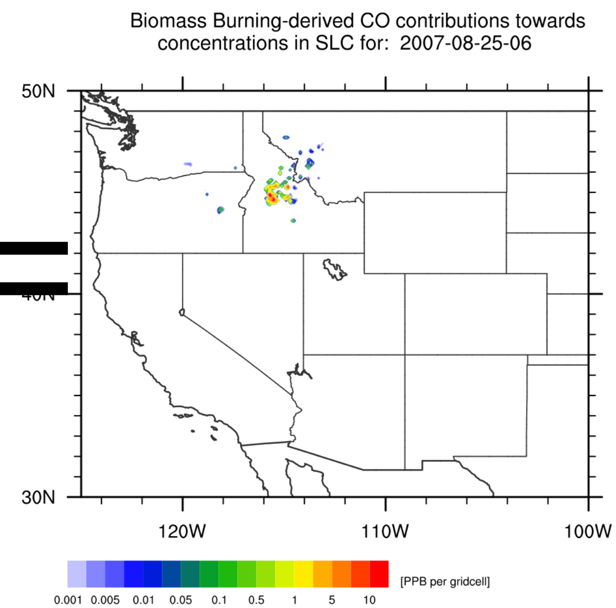
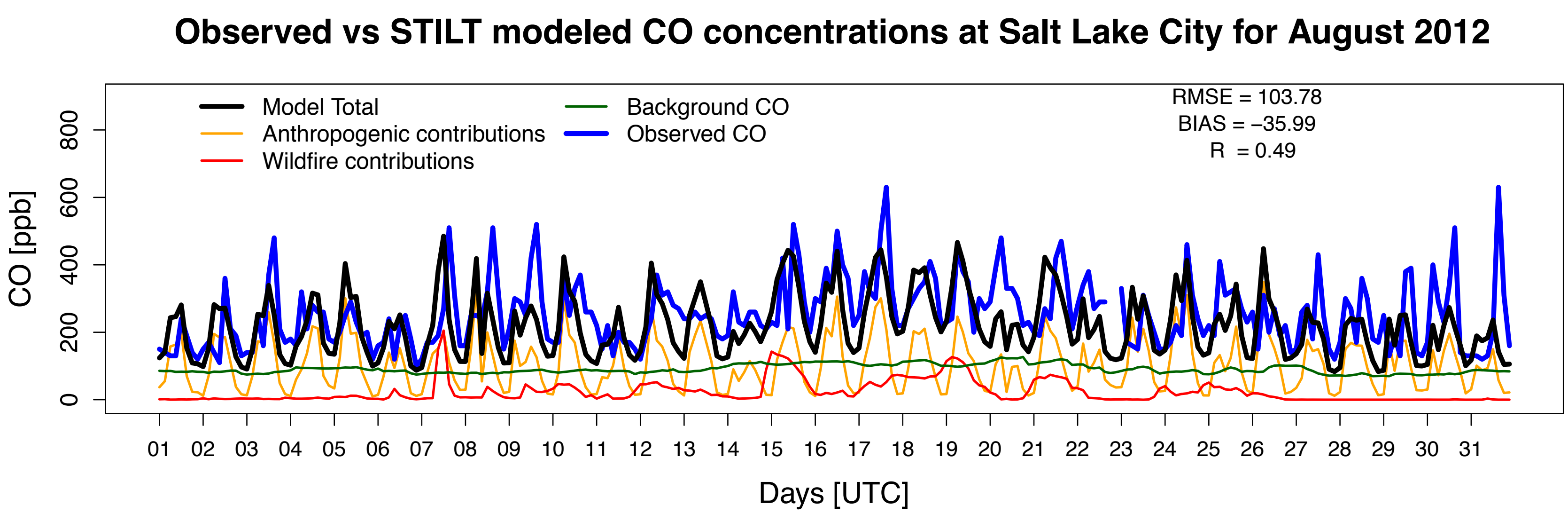
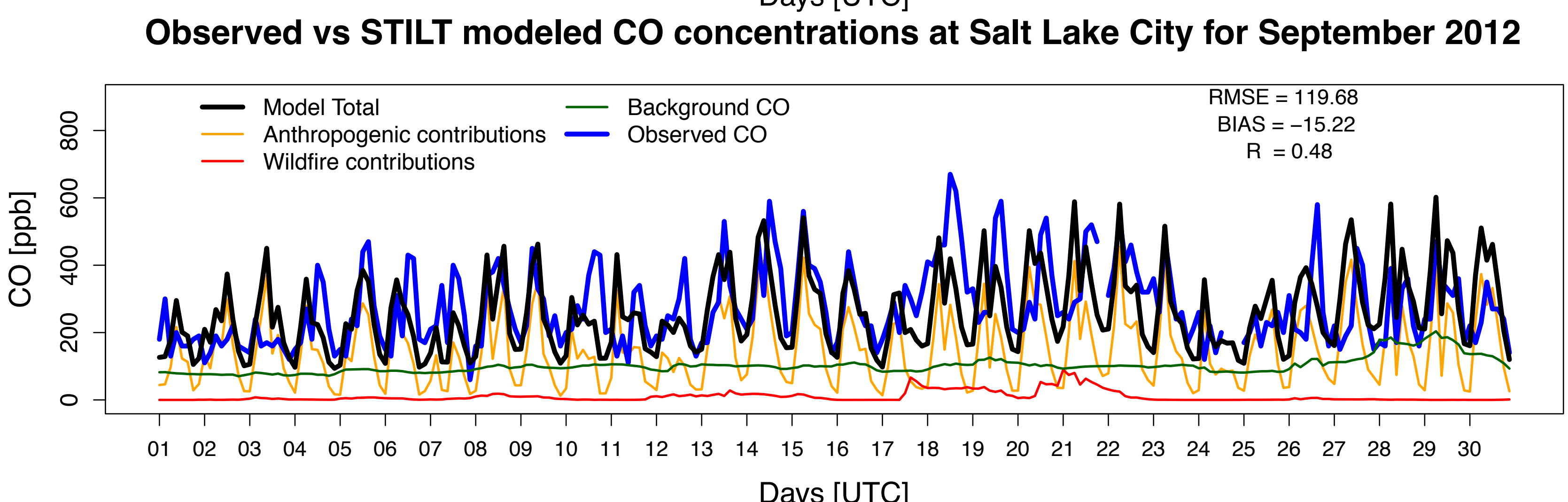
Fire contribution
(ppm)



Assessing air quality impacts of Wildland Fires using Lagrangian framework





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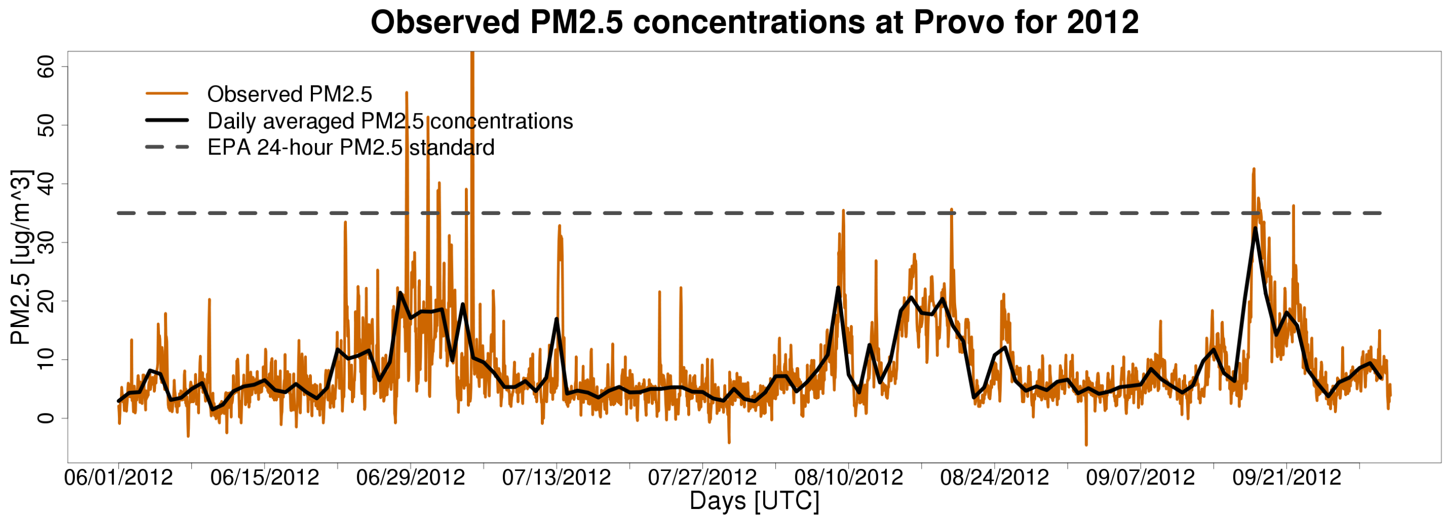
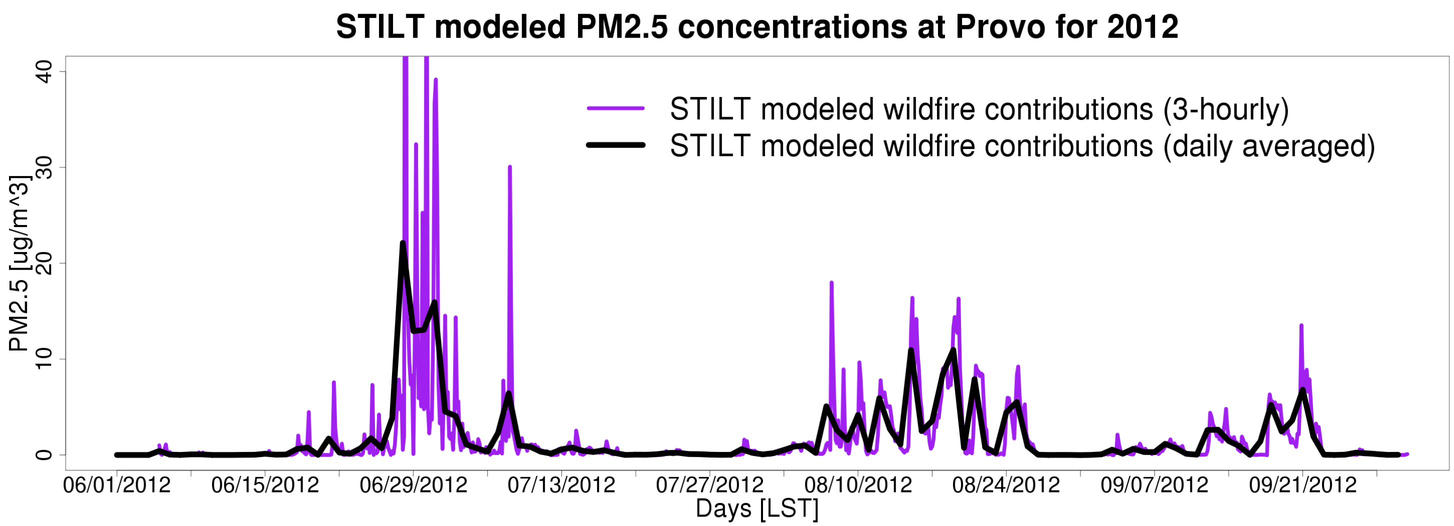
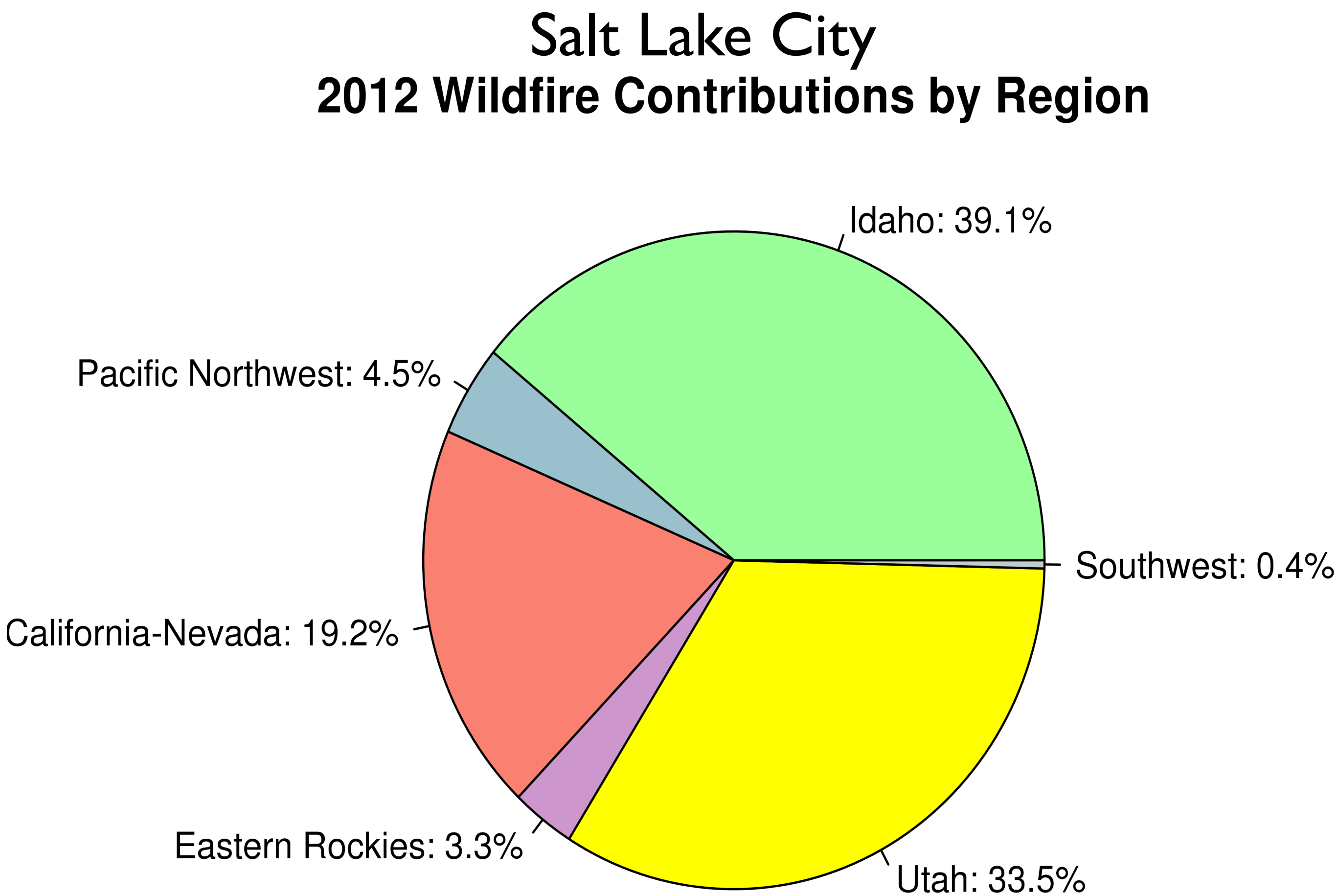
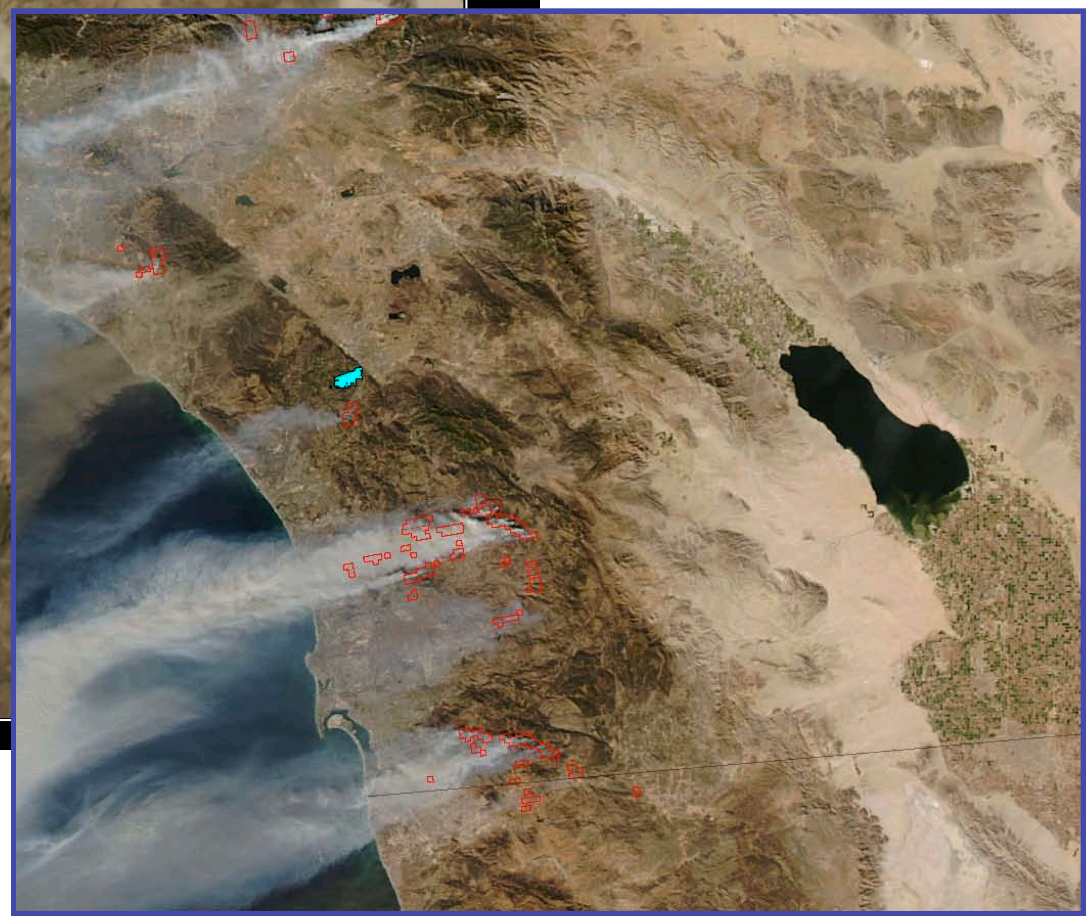




Assessing air quality impacts of Wildland Fires using Lagrangian framework



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



MODIS

WRF-Sfire 2km