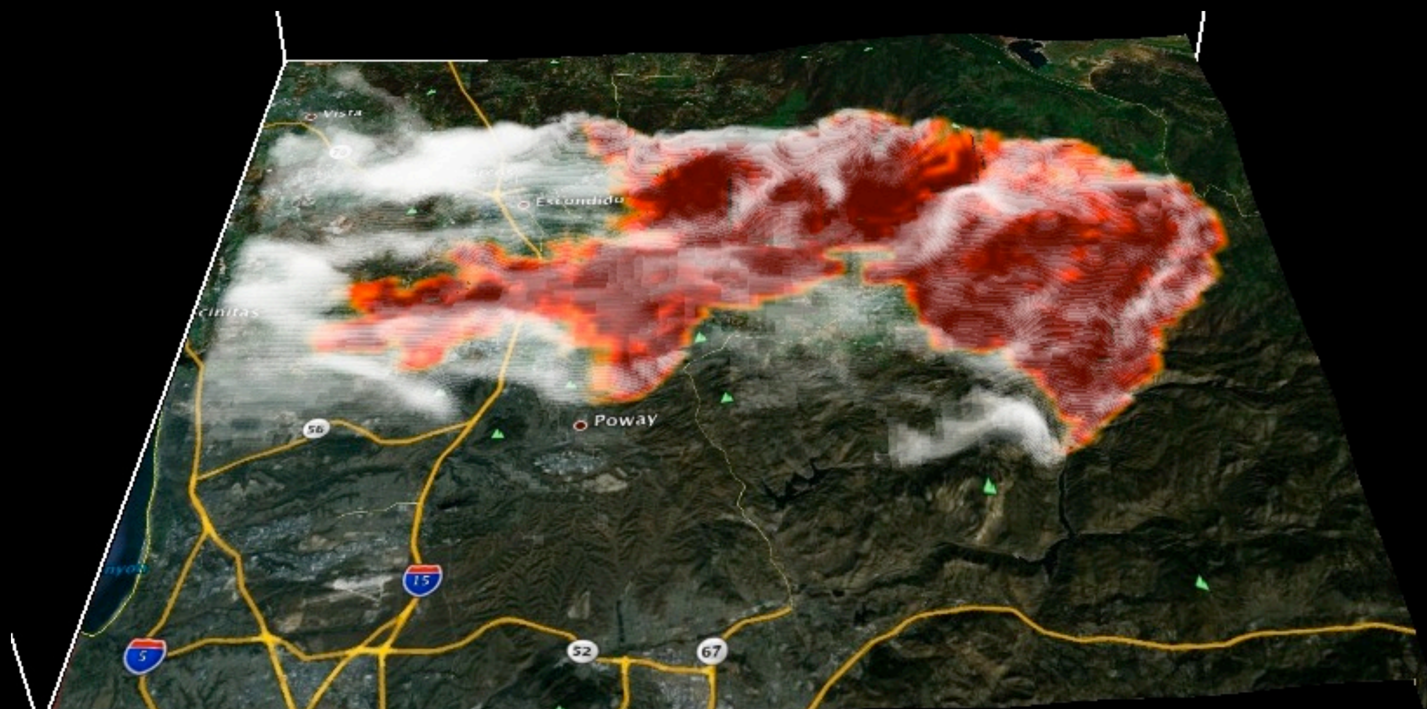
DEPARTMENT OF METEOROLOGY UNIVERSITY OF UTAH

Forecasting of smoke and wildfire emissions using WRF-Sfire



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Motivations

- Forecasting of emissions from prescribed and wildland fires
- Investigation of the impact of fire emissions on air quality
- Forecasting of transport and dispersion of fire smoke
- Forecasting of air quality impact of secondary pollutants generated from fire emissions
- Investigation of the interaction between the fire and the atmosphere

Wildfire smoke transport modeling #1

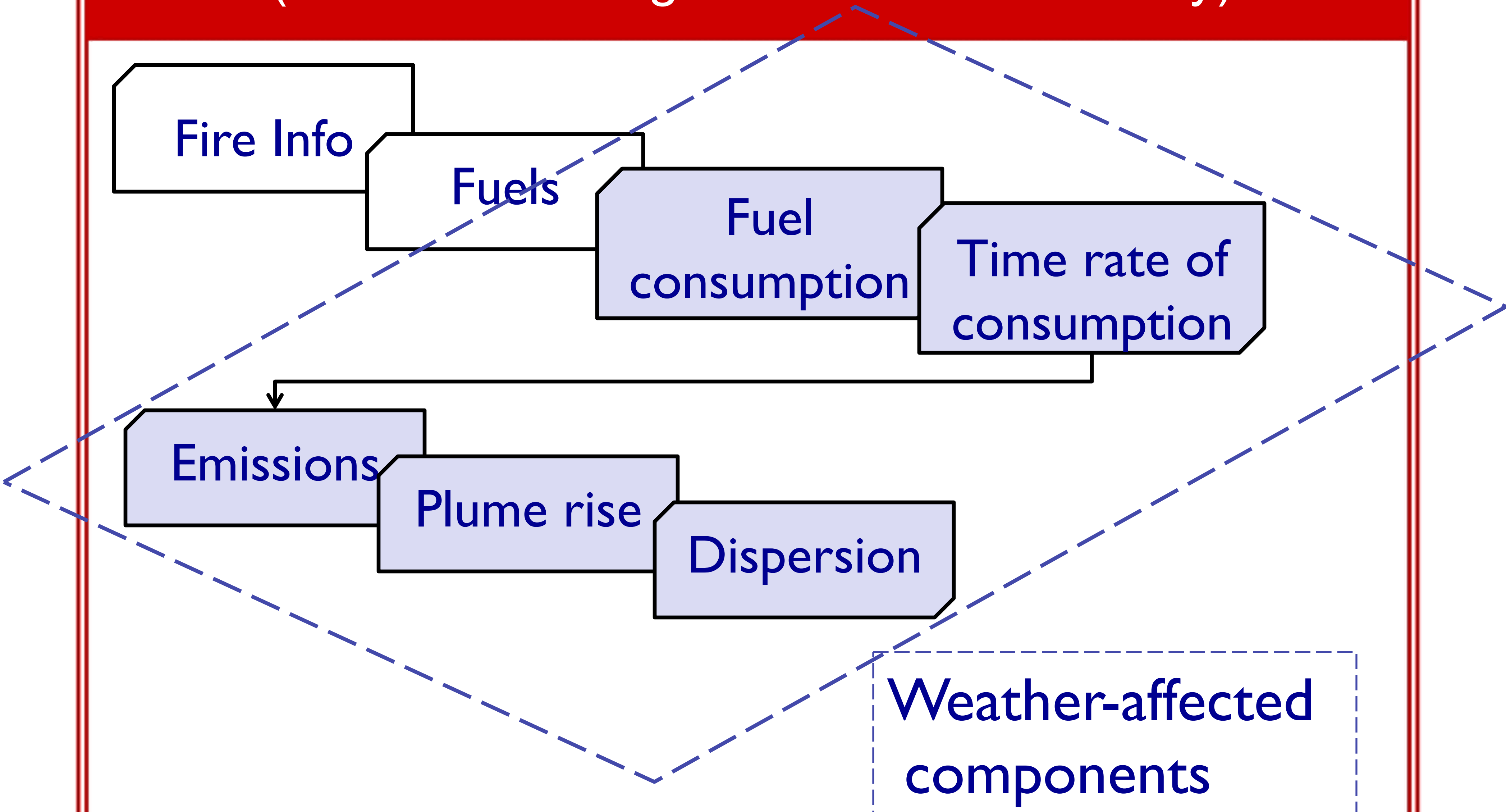
- There is a wide range of models that can be used for modeling of smoke emissions that largely differ in complexity:
  - Box models (VALBOX) – dilution of the smoke within the mixed layer (assumes instantaneous and uniform mixing)
  - Gaussian plume models (VSMOKE) provide a time snapshot based on constant wind speed and direction, cross-wind distribution assumed to be Gaussian. Vertical plume distribution and meteorology must be obtained externally,
  - Puff models (CALPUFF) – smoke is represented as discrete source emissions released periodically during the fire event. Non-steady state air-quality model driven by an external source of meteorological data. Parameterizes buoyant plume rise, diffusion and entrainment.
  - Lagrangian (Particle) models – smoke dispersion is resolved in flow-following coordinate system, air parcels change their properties as their environment changes.

Wildfire smoke transport modeling #2

- Eulerian grid models (CMAQ, CHIMERE) – computes smoke dispersion on a stationary grid, take into account atmospheric chemistry and aerosol physics. Uncoupled with the atmospheric model, must be driven by a weather model.
- CFD models (ATHAM, WRF-Chem) – treat plume rise, transport and dispersion of the smoke based on the Navier-Stokes equations. Capture the fluid dynamics together with the plume behavior. Need some estimate of the fire emissions.
- Smoke modeling frameworks (Blue Sky)

Fire Information	Fuel Loading	Consumption	Time Rate	Emissions	Plume Rise	Dispersion
SMARTFIRE	FCCS* NFDRS HARDY	CONSUME* FEPS BURNUP	WRAP WF* FEPS RX*	FEPS*	FEPS*	CALPUFF* HYSPLIT SMOKE CMAQ

Wildfire smoke transport modeling #3
(smoke modeling frameworks - BlueSky)



Wildfire smoke transport modeling #4

- Fully coupled models (WRF-Sfire-Chem) – a single model simulates in a coupled way:
  - meteorology,
  - fire spread,
  - smoke emission,
  - dispersion and smoke-related chemistry.

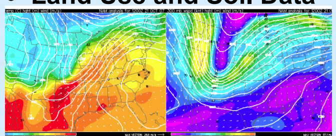
- Local weather conditions affect:
  - fuel properties (temperature and moisture),
  - fire spread and fire intensity (winds),
- Which in turn affect
  - fuel consumption rates, smoke emissions and plume rise.
- Chemical species and aerosols may undergo in the atmosphere chemical reactions and physical processes, affecting the cloud formation, radiative processes etc.

Modeling of Fire-Atmosphere interactions WRF-Sfire

METEO INPUT

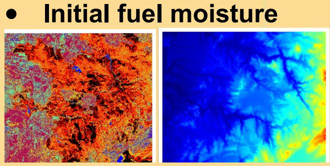
Large scale weather data from NARR reanalysis:
- 32km-resolution initial conditions
- 32km-resolution boundary conditions

Static data:
- High-resolution topography
- Land Use and Soil Data



FIRE DATA

High resolution fuel data:
- 30m-resolution fuel description
- 30m-resolution elevation data
- times and locations of ignitions
- Initial fuel moisture



WRF SFIRE

WRF framework (atmosphere):
- ARW atmospheric core
- WPS preprocessing system

FIRE-AFFECTED WINDS

FIRE-GENERATED HEAT AND MOISTURE

Fire Spread Model:
- Rothermel semi-empirical fire spread model
- Fire front tracking based on the level set method

FUEL MOISTURE

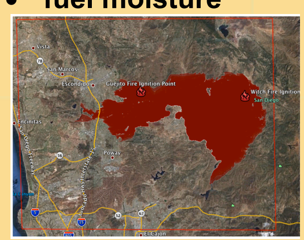
Fuel Moisture Model (Van Wagner and Pickett)
- Drying and wetting due to changes in T and RH
- Wetting due to rain
- Explicit treatment of different fuel classes

METEO OUTPUT

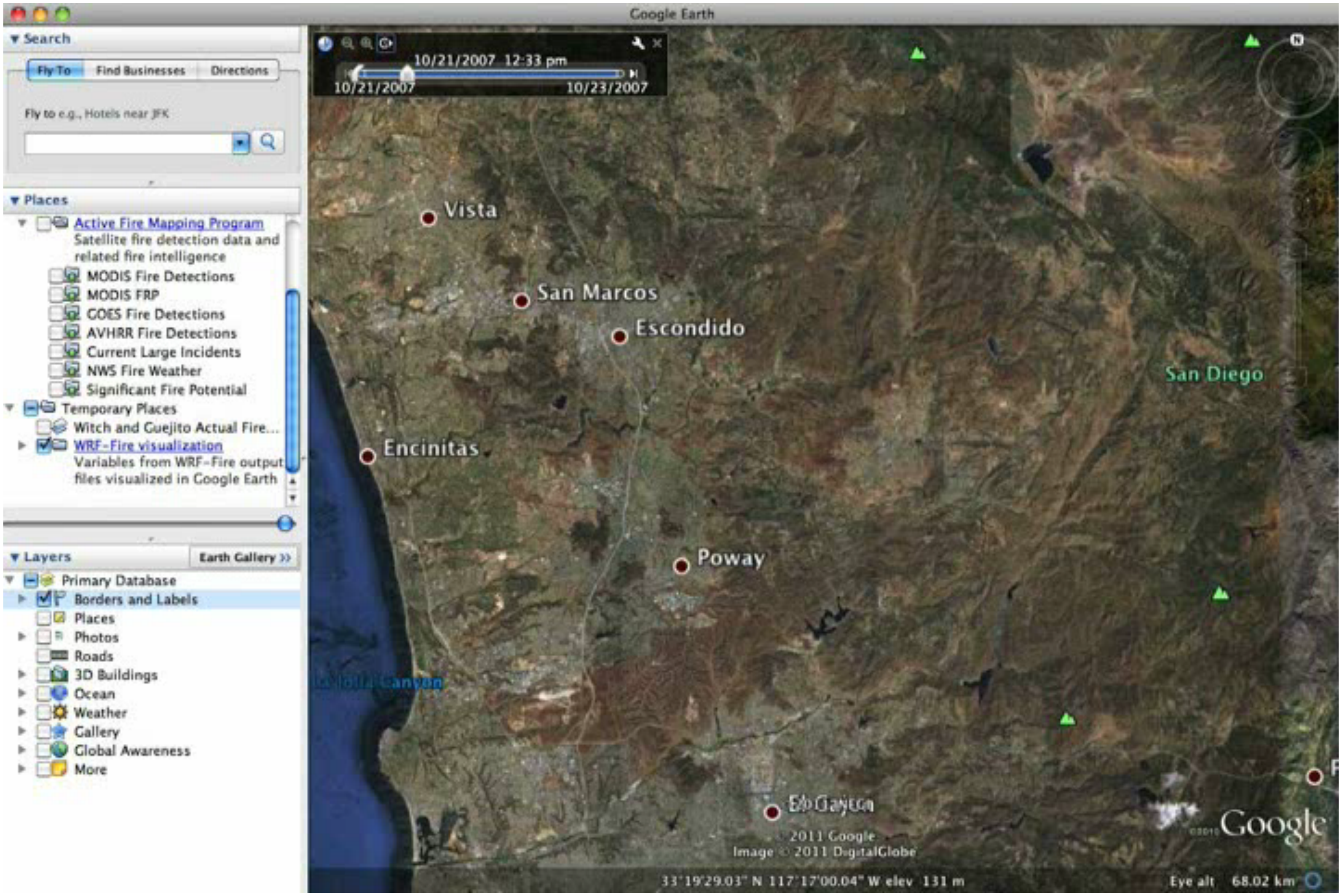
High-resolution (500m) forecast:
- wind speed and direction
- air temperature
- air humidity
- precipitation
- cloudiness etc...

FIRE OUTPUT

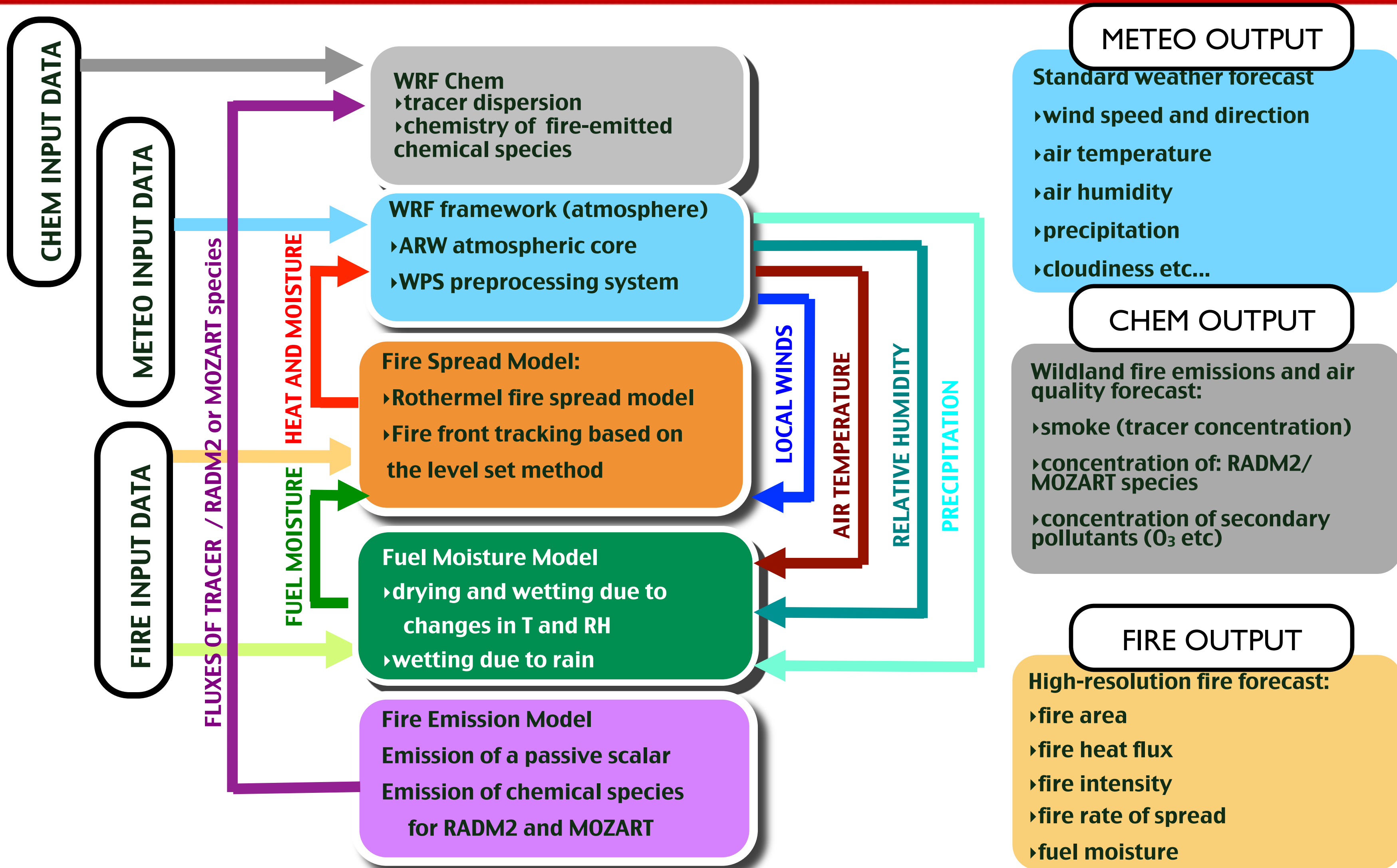
High-resolution (20m) fire forecast:
- fire area
- fire heat flux
- fire intensity
- fire rate of spread
- fuel moisture



Numerical fire spread modeling using WRF-Sfire



Modeling of Fire-Atmosphere interactions WRF-Sfire + Moisture + WRF-Chem



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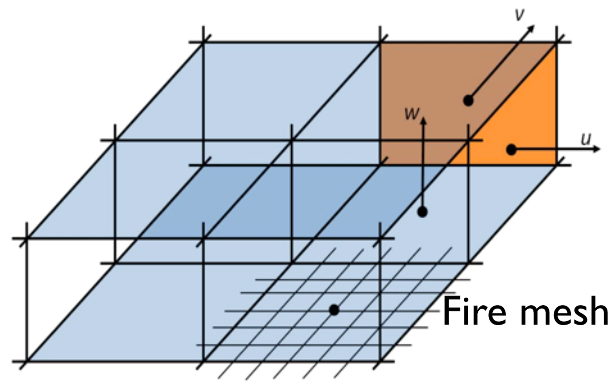
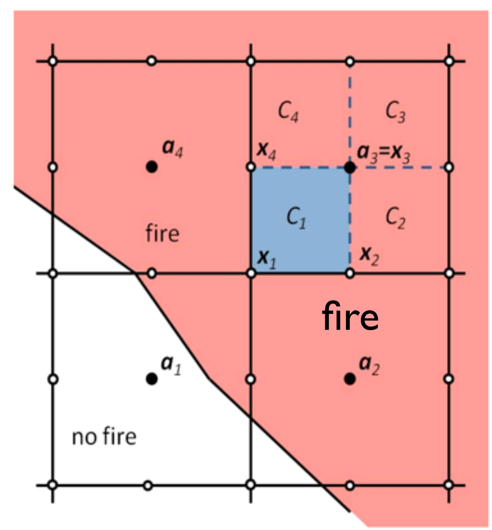
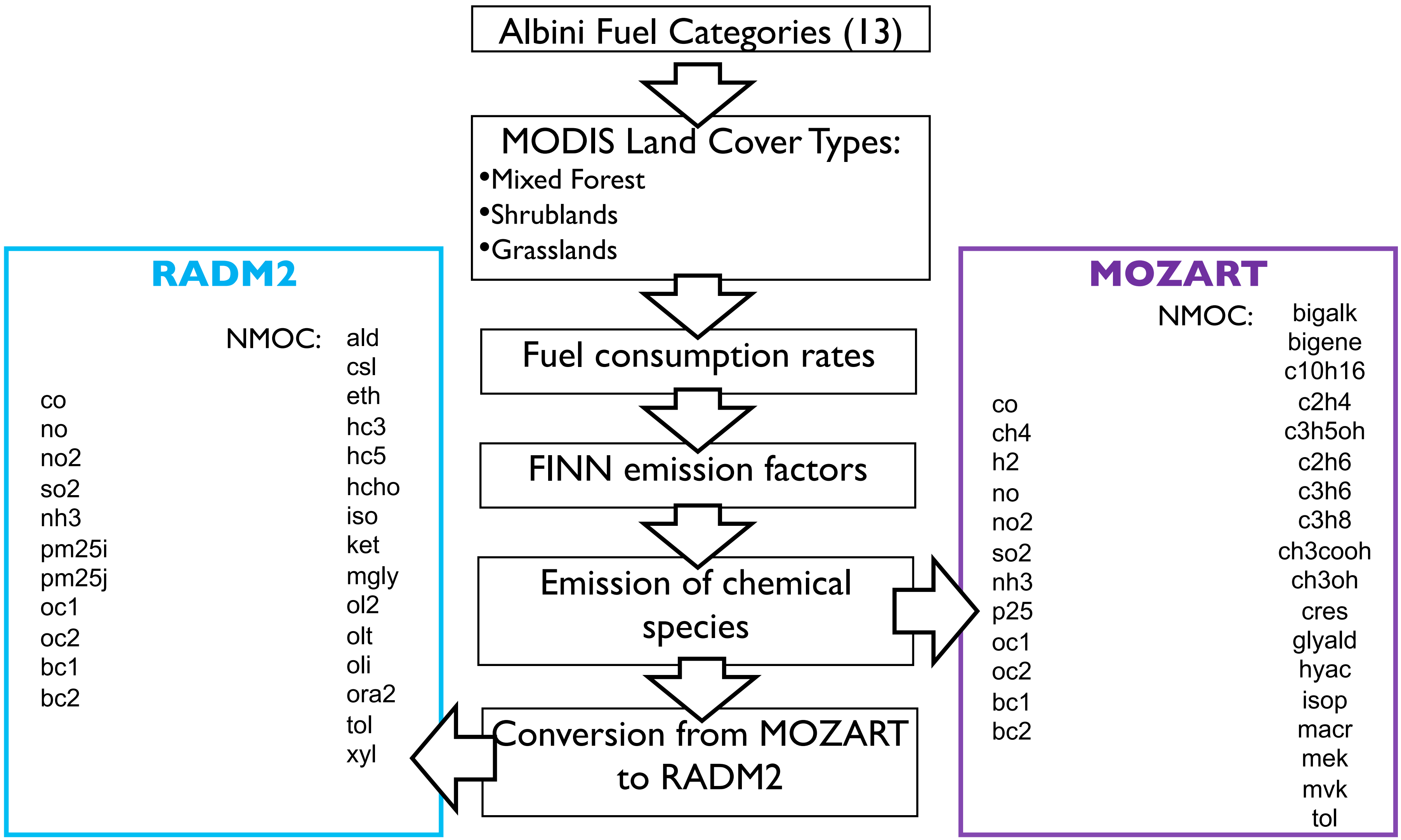
Estimation of fire emissions

- Model has two separate grids, one for the atmospheric model and one for the fire model (fire mesh, and atmospheric mesh).
- The fire progression as well as fuel consumption are computed on the fine fire mesh.
- Based on the fire fuel type, initial fuel load, and the fire intensity the rate of fuel consumption is computed (mass of fuel per unit time)
- Mass of the fuel burnt is converted to emissions of chemical species based on the emission factors from FINN (C. Wiedinmyer 2011)
- Fluxes of chemical species are integrated over the atmospheric grid ingested into the first model layer
- For a simple option with a passive tracer, fire emission is computed based on fire heat release or fuel consumption



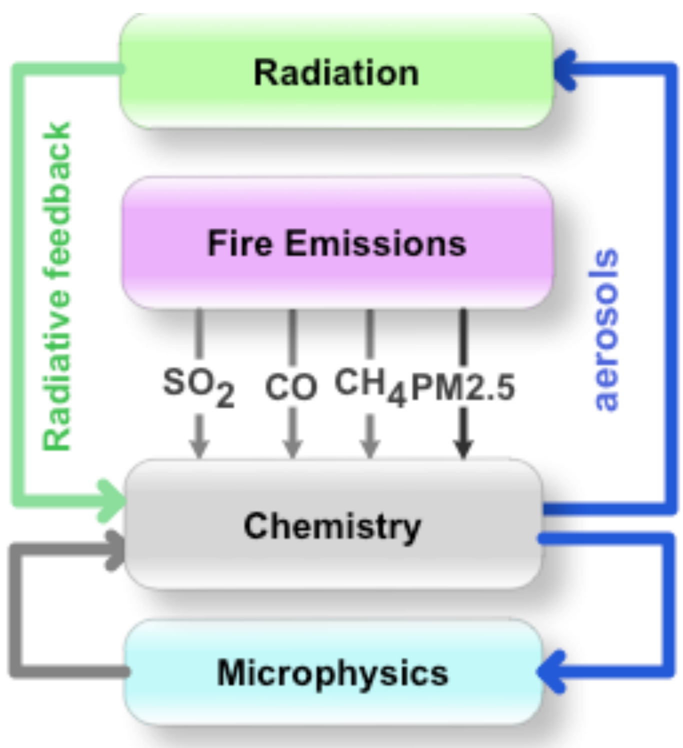


Estimation of fire emissions



Fire-atmosphere interactions

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



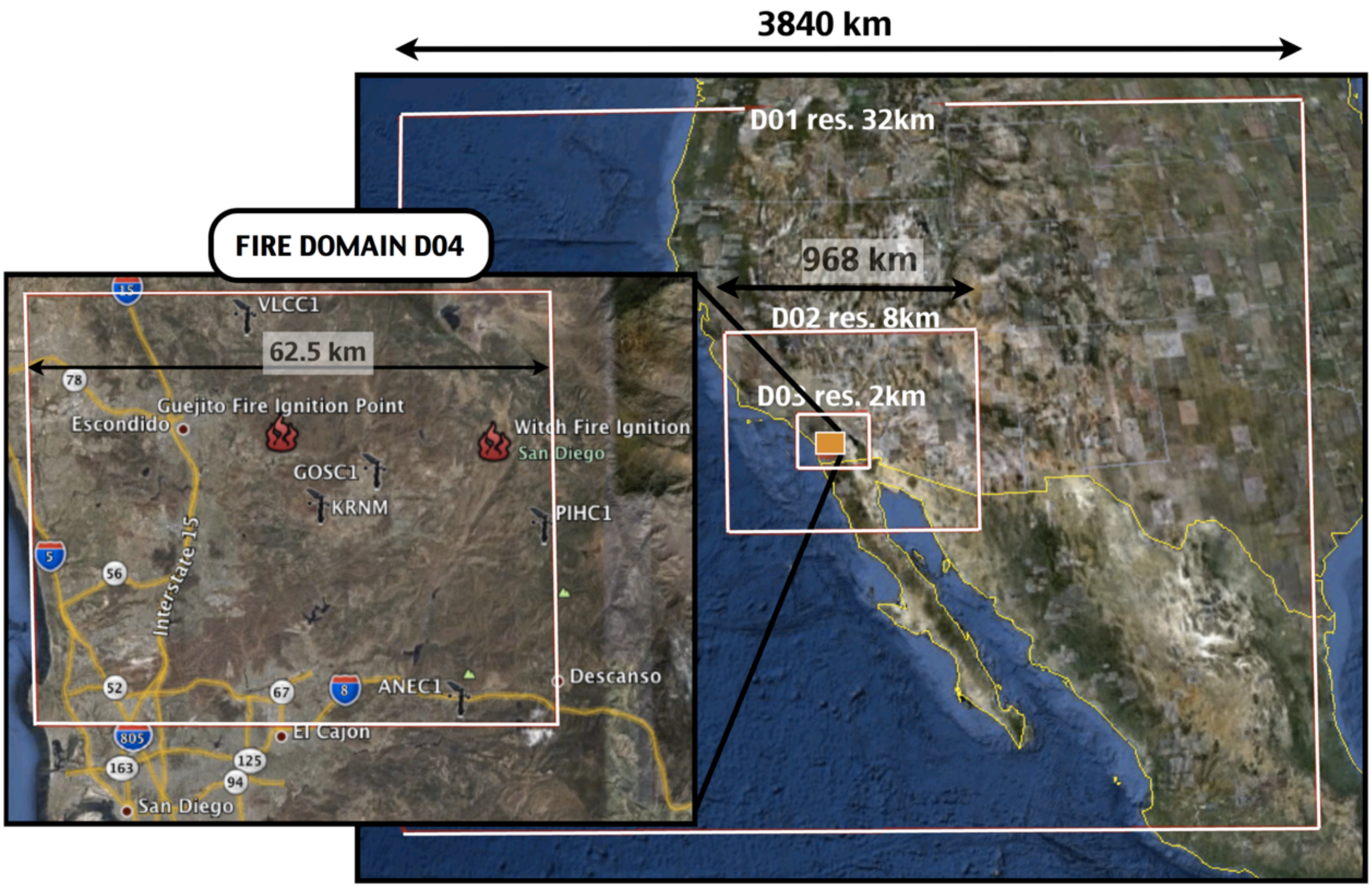
Real setup for Santa Ana fire simulation

Model Setup:

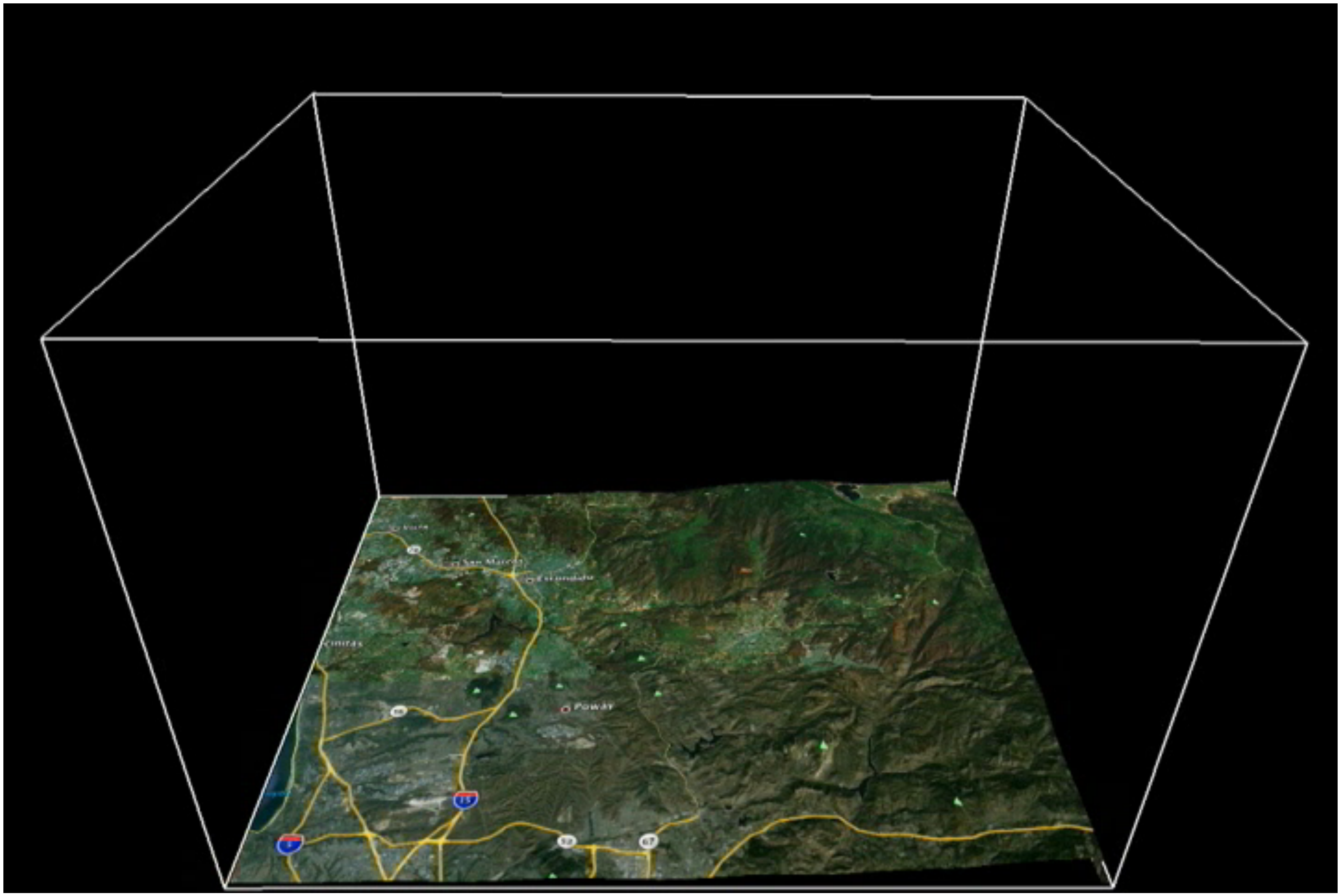
- Santa Ana event is a multiscale problem. We have to cover an area large enough to capture the large-scale synoptic pattern driving this event (High over Northern Nevada), but ultimately we need to resolve small-scale local flow near the fire.

- In order to accomplish that we use the nested setup with 4 domains:
  - D01 120x96 32km resolution
  - D02 121x97 8km resolution
  - D03 137x105 2km resolution
  - D04 185x165 500m resolution
  - Fire grid resolution 20m (1/25 refinement ratio)

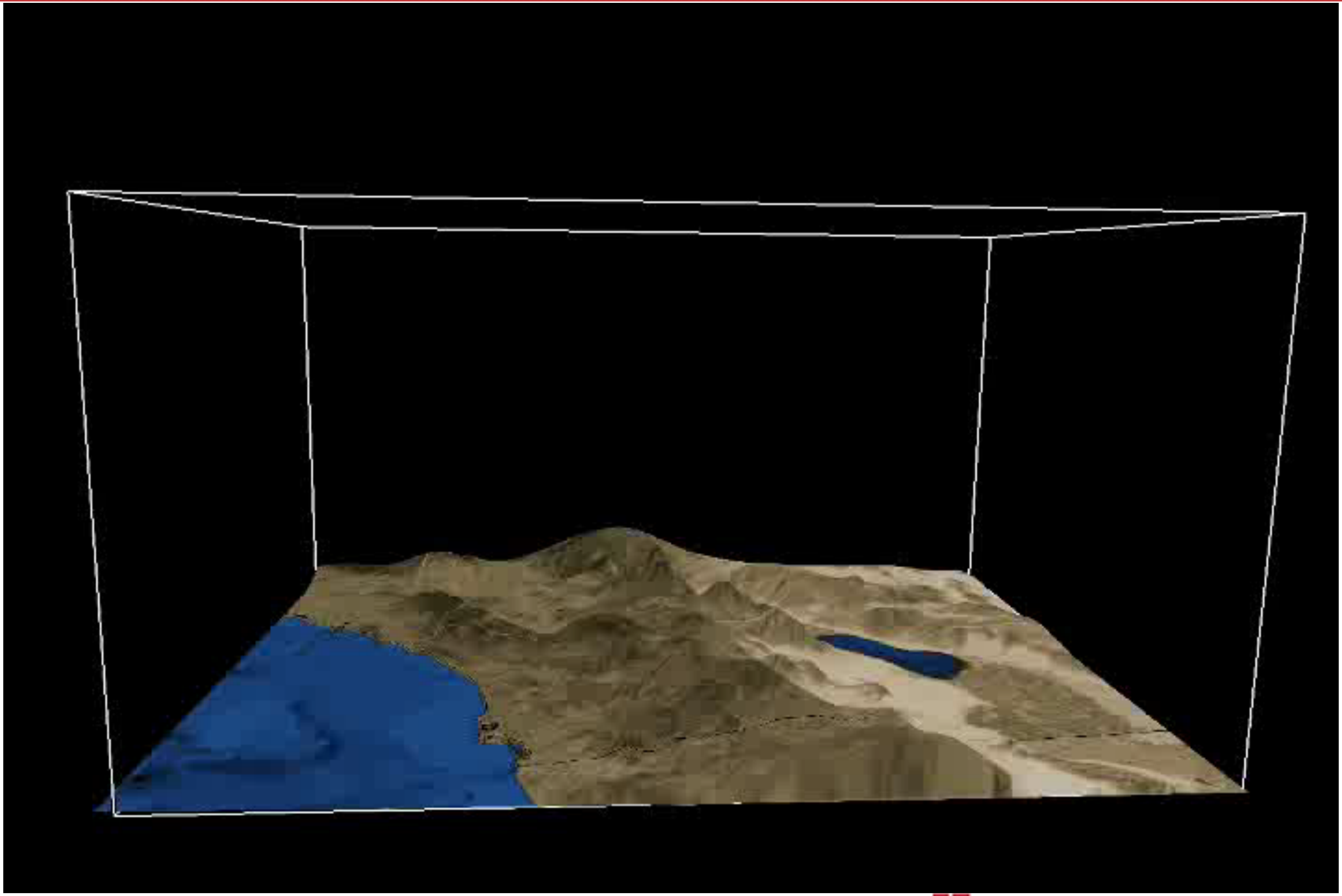
Multi-scale setup for Santa Ana fire simulation



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



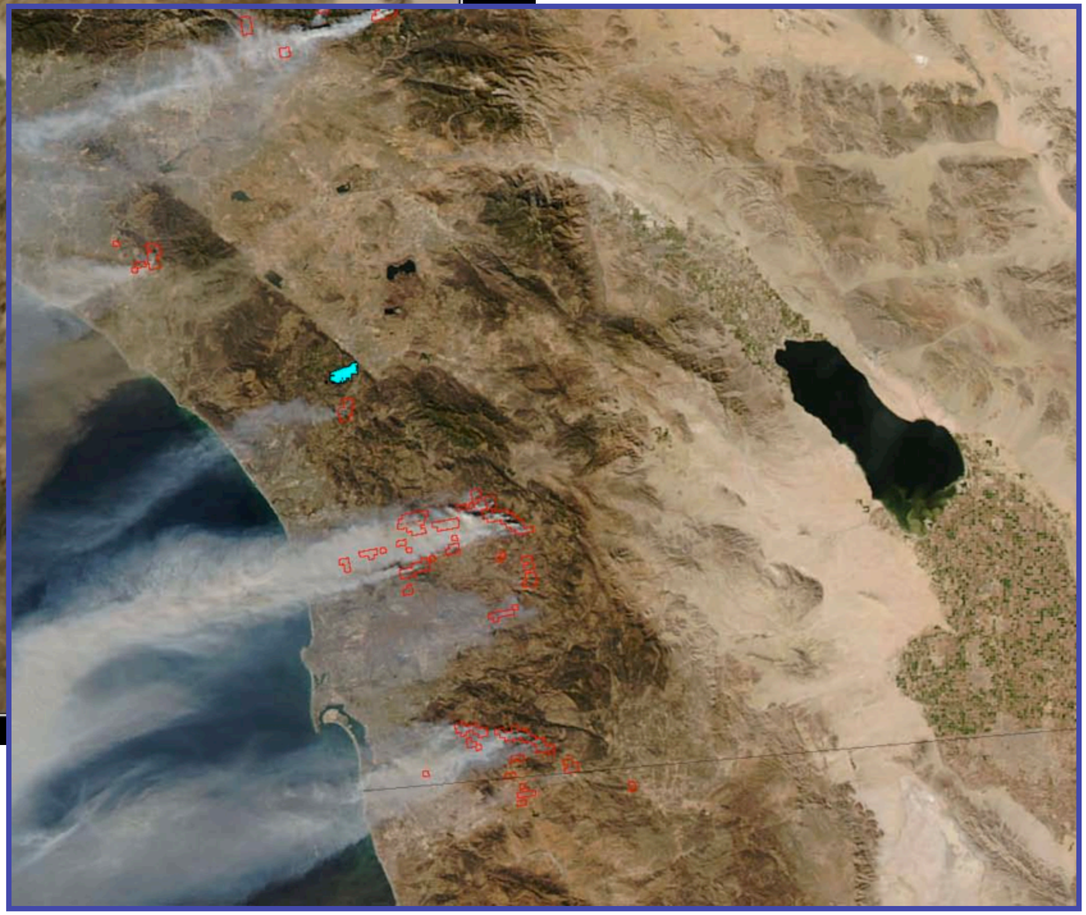
Simulation of smoke emissions from 2007 Santa Ana fires (Witch and Guejito) 2km



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

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

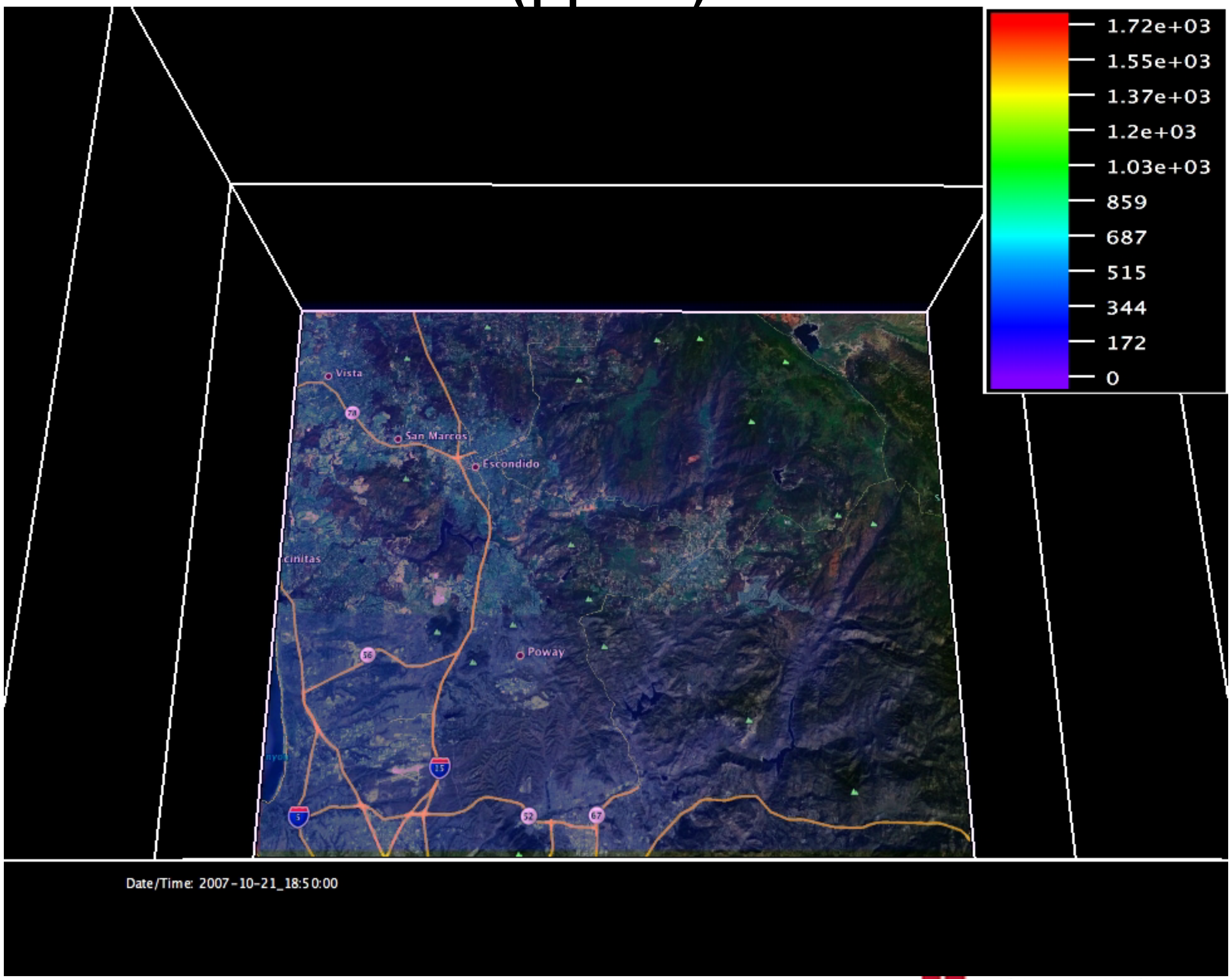
MODIS



WRF-Sfire 1.33km

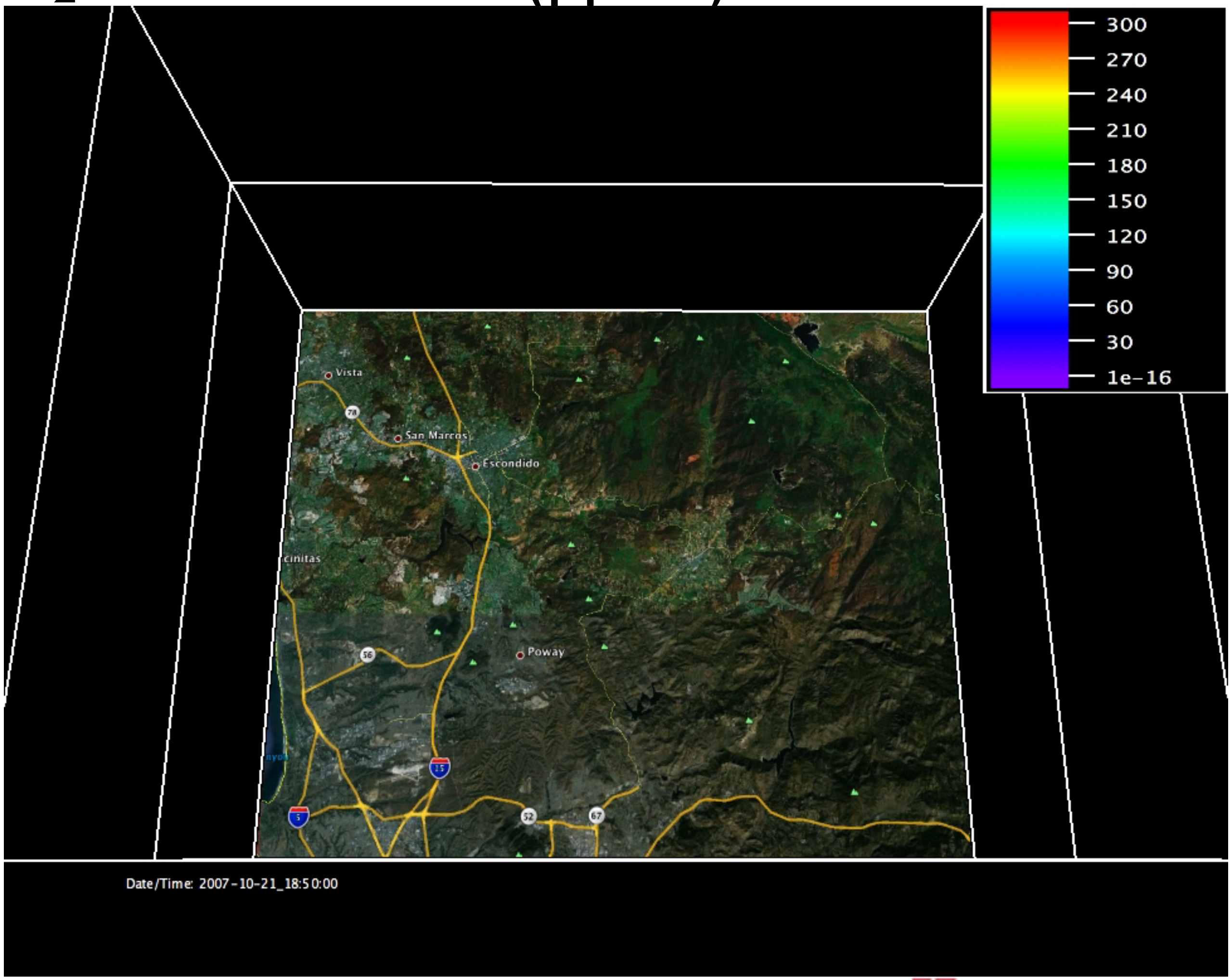
Simulated CO emission from Witch fire (one of 2007 Santa Ana fires)

Fire CO concentration (ppmv)



Simulated NO_2 emission from Witch fire (one of 2007 Santa Ana fires)

Fire NO_2 concentration (ppmv)



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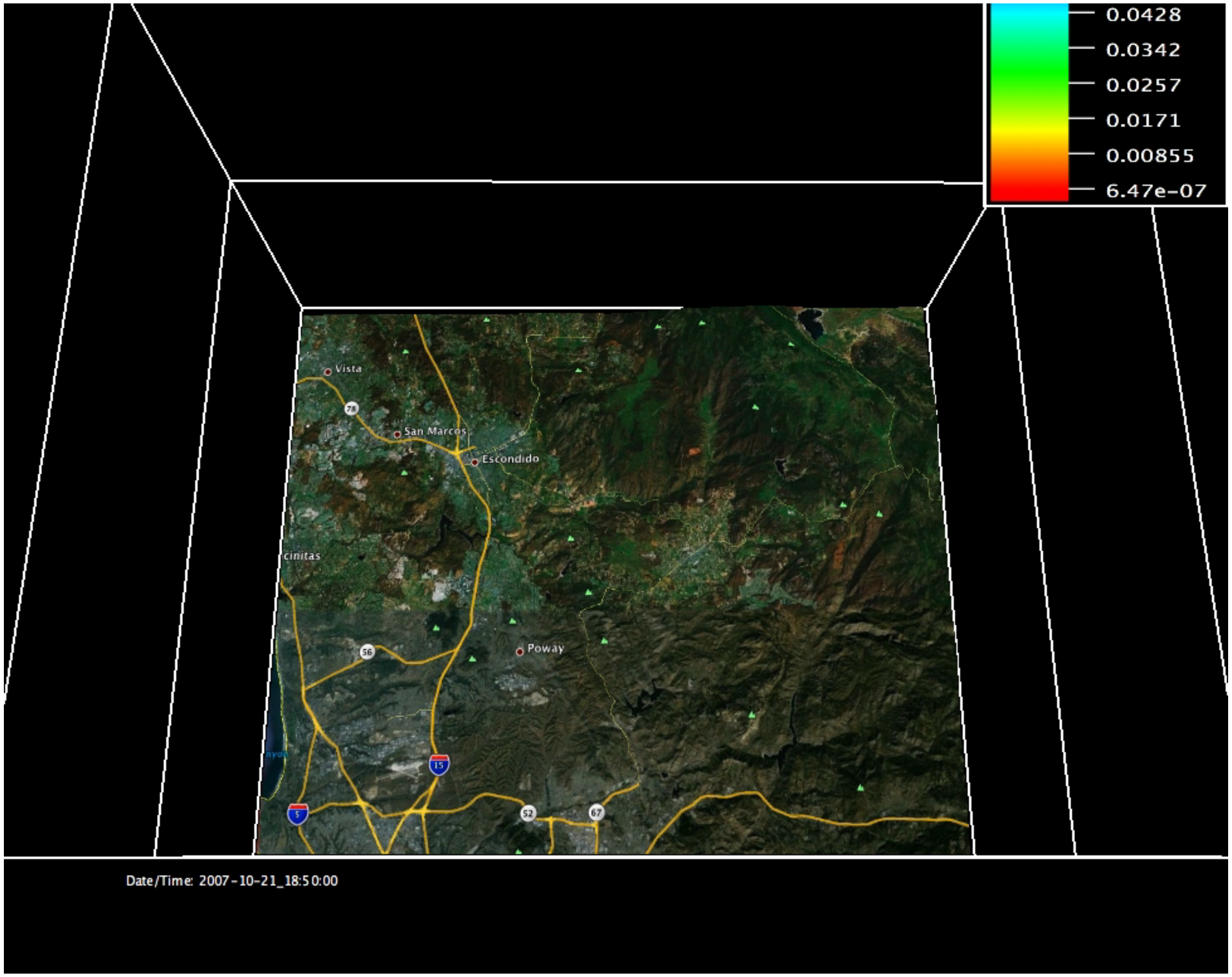
Simulated increase in O_3 concentration associated with Witch Fire

Elevated ozone concentrations in the wake of the 2007 Witch fire (ppmv)



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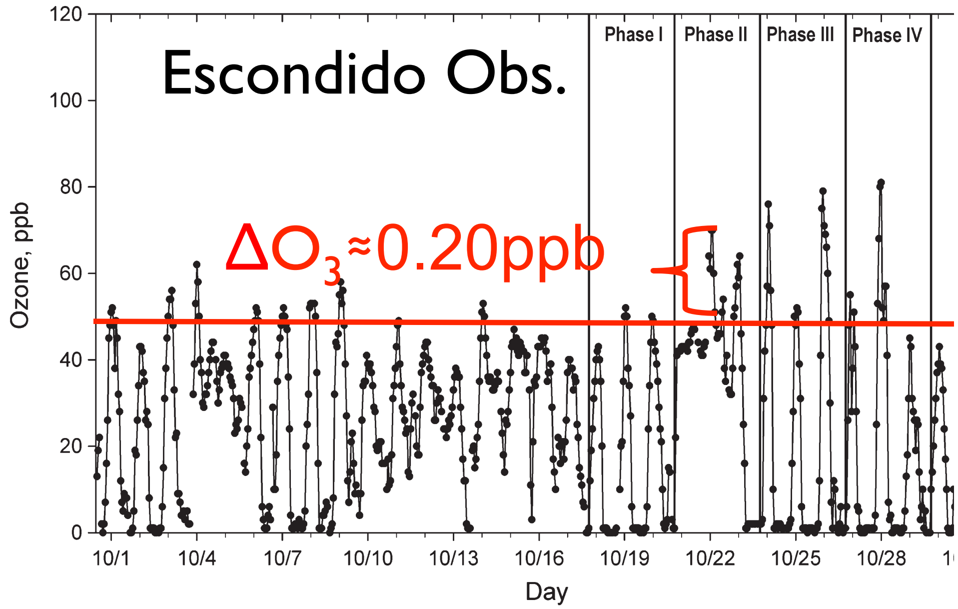

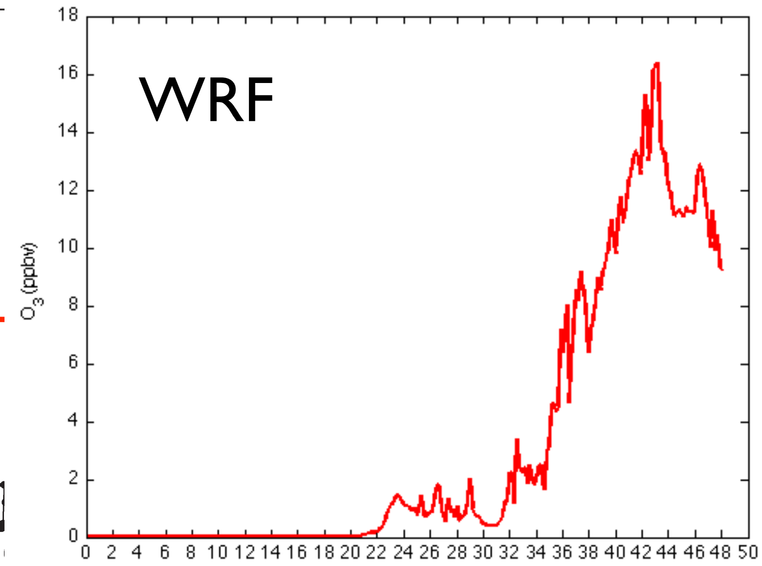

Observational data plot from Bytnerowicz et al. 2010

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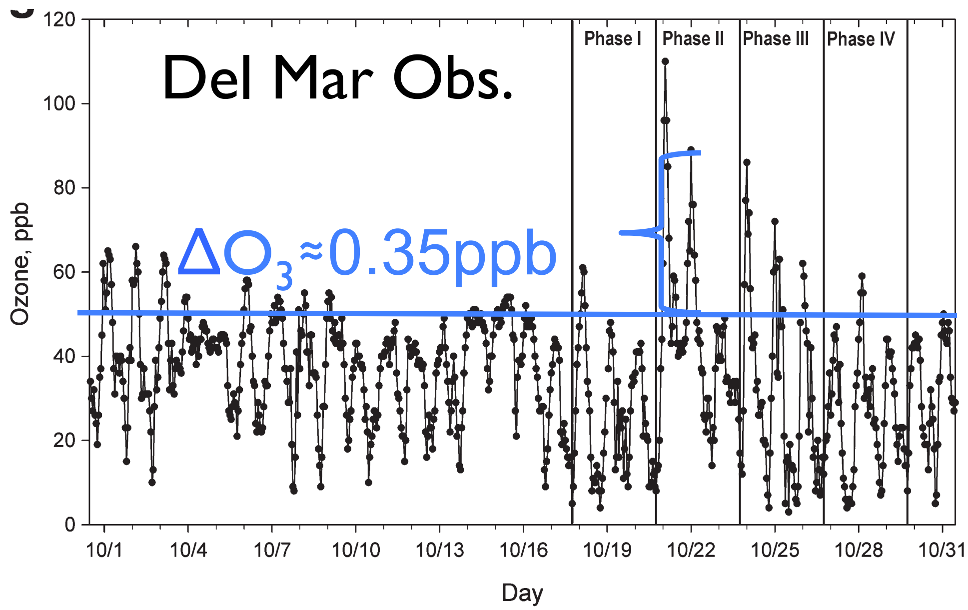

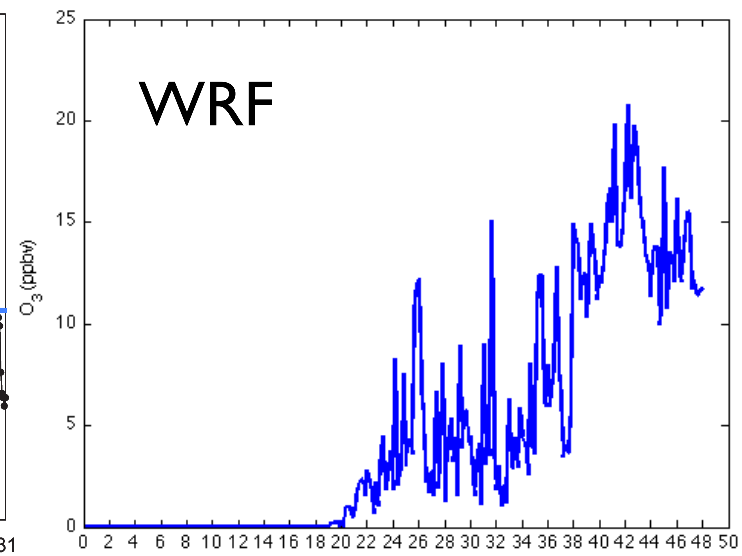

Time since 10.21.2007 12Z (5:00 local)

Observational data plot from Bytnerowicz et al. 2010

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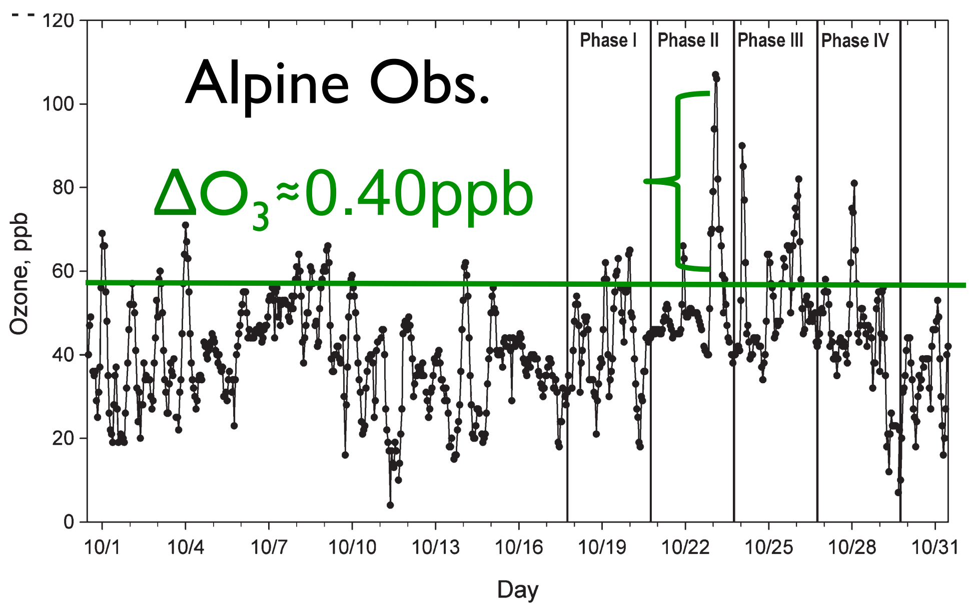

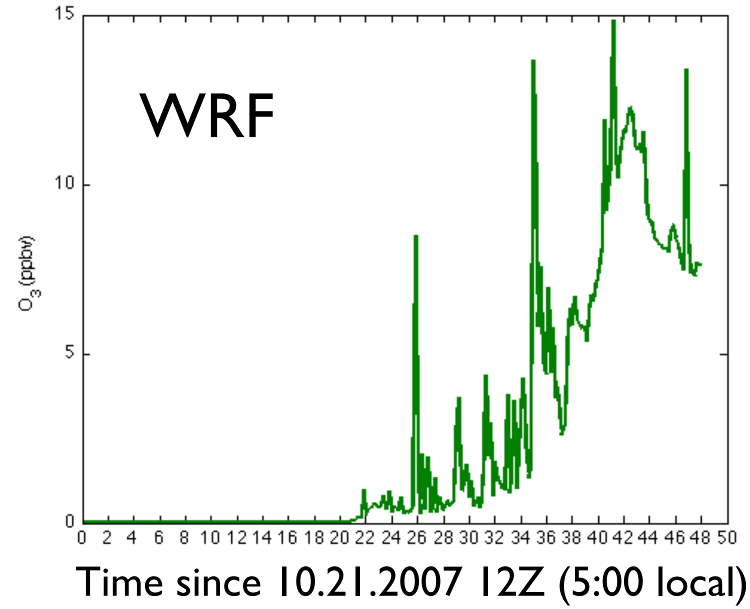

Observational data plot from Bytnerowicz et al. 2010

Summary

- New capabilities have been added to WRF-Sfire, but not validated yet:
  - fire smoke emission and dispersion - tracer
  - more detailed emission and dispersion of aerosols and chemical species
- The current way of defining emissions though the FINN global emission factors is very crude
- The conversion between the fire behavior classes and land use classes may introduce additional errors
- More detailed emission factors, with fuel characteristics are needed for a realistic estimation of actual fire emissions
- 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.

Thank you!

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