New Research on Local Smoke Transport and Diffusion

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What are the issues?

- Smoke from wildland fires can linger near the source area for relatively long periods of time, and its movement can be affected by local topography and forest vegetation.
- Potential health and safety hazards.
- Many current “operational” models/systems are not effective tools for smoke management associated with low-intensity fires that have primarily local smoke impacts.

Predicting the local meteorology is critical!

National Ambient Air Quality Standards (NAAQS)

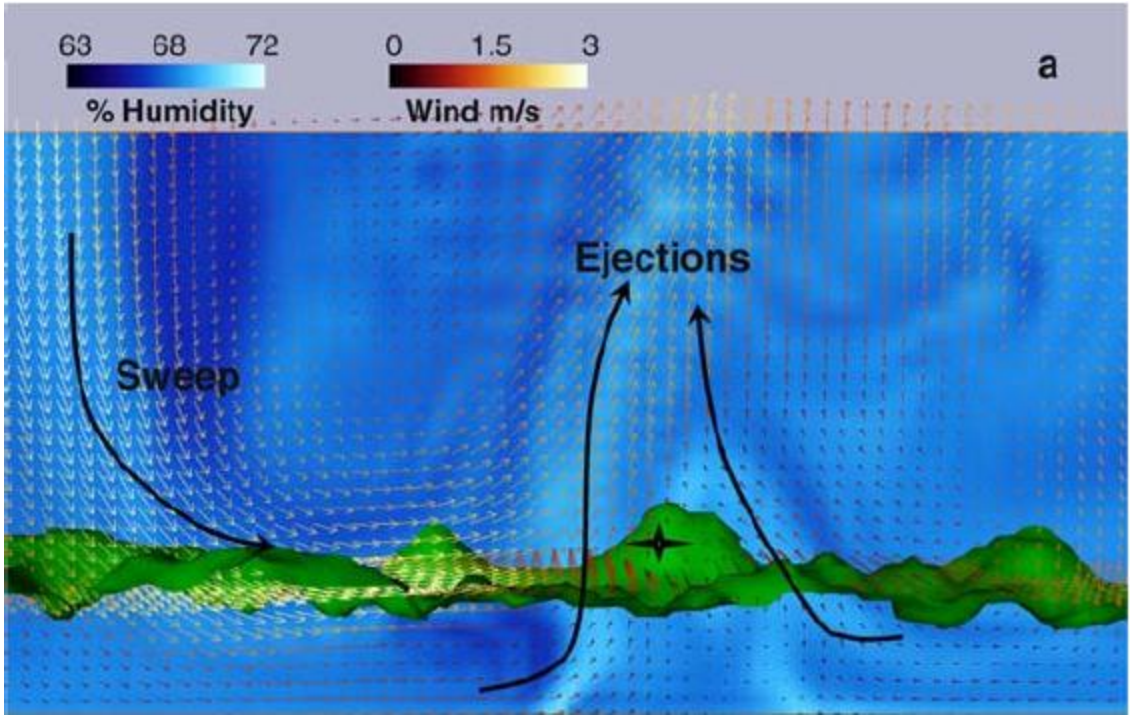
- Carbon monoxide ----- 9 ppm (8 hrs); 35 ppm (1 hr)
- Lead ---------- 15 µg m^{-3} (3 mo. avg.)
- Nitrogen dioxide ------- 53 ppb (annual); 100 ppb (1 hr)
- Ozone ---------- .0075 ppm (8 hrs)
- Particulates ($PM_{2.5}$)--- 15 µg m^{-3} (annual); 35 µg m^{-3} (1 hr)
- Sulfur dioxide ---------- 0.5 ppm (3 hrs); 75 ppb (1 hr)

Nonattainment Areas for $PM_{2.5}$ (2006 Standard)

Forest Canopy Effects on Near-Surface Circulations

- Atmospheric circulations within and above forest canopies are highly complex, even in the absence of fires.
- Surface- or crown-fire induced circulations introduce even more complexity.
- How a smoke plume moves through a forest canopy is governed by these complex circulations.

Ejection-Sweep Dynamics



From Bohrer et al. (2009)

Development of Modeling Tools for Predicting Smoke Dispersion From Low-Intensity Fires

Joint Fire Science Program
Research Supporting Sound Decisions
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- Adapt one or more fine-scale atmospheric dispersion modeling systems to predict local smoke dispersion within and above forest vegetation layers due to low-intensity fires.
- Compare simulation results from the modeling systems to field observations in order to understand the performance of the models for different fire types, environmental settings, and atmospheric conditions.

Prescribed Burn Experiments/Monitoring

Monitoring Approaches

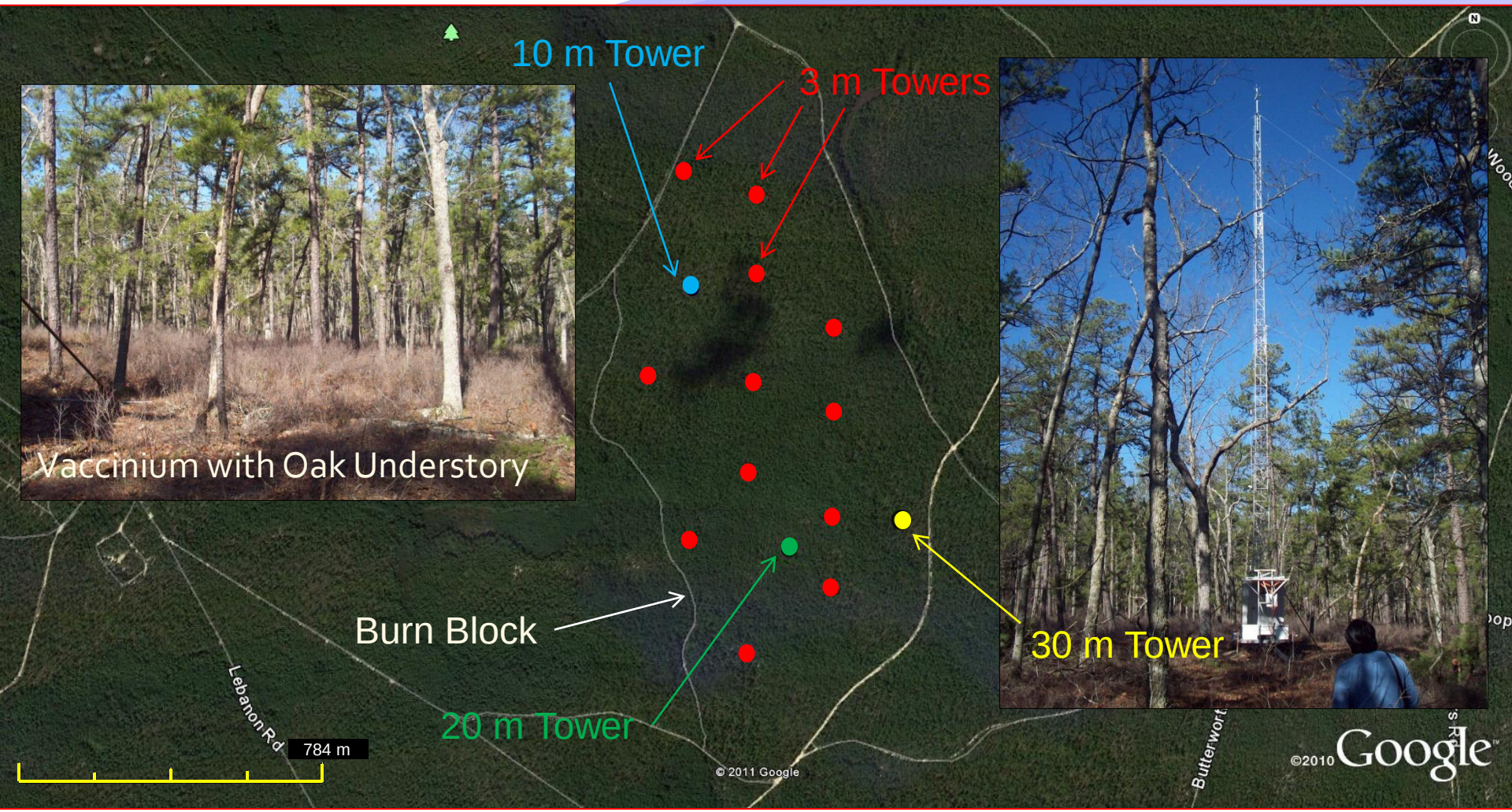
The fire-science community has made great strides in actually monitoring air quality and meteorological processes, including turbulence regimes, within wildfire/prescribed fire environments using *in situ* instrumentation.

- ICFME (1995-2001)
- FIREFLUX (2006)
- RxCADRE (2008, 2011)
- NC TNC Calloway Forest (2010, 2011)
- CA Grass Fires on Slopes (2010)
- NJ Pine Barrens (2011, 2012)

NJ Prescribed Burn Experiments: Location

- Pine Barrens contain some of the most volatile fire cycle vegetation in the East
- Surrounded by wildland-urban-interface areas
- Parts of the region have been designated as non-attainment areas for $PM_{2.5}$ and ozone
- Smoke emissions and air quality are of major concern to the NJ Forest Fire Service

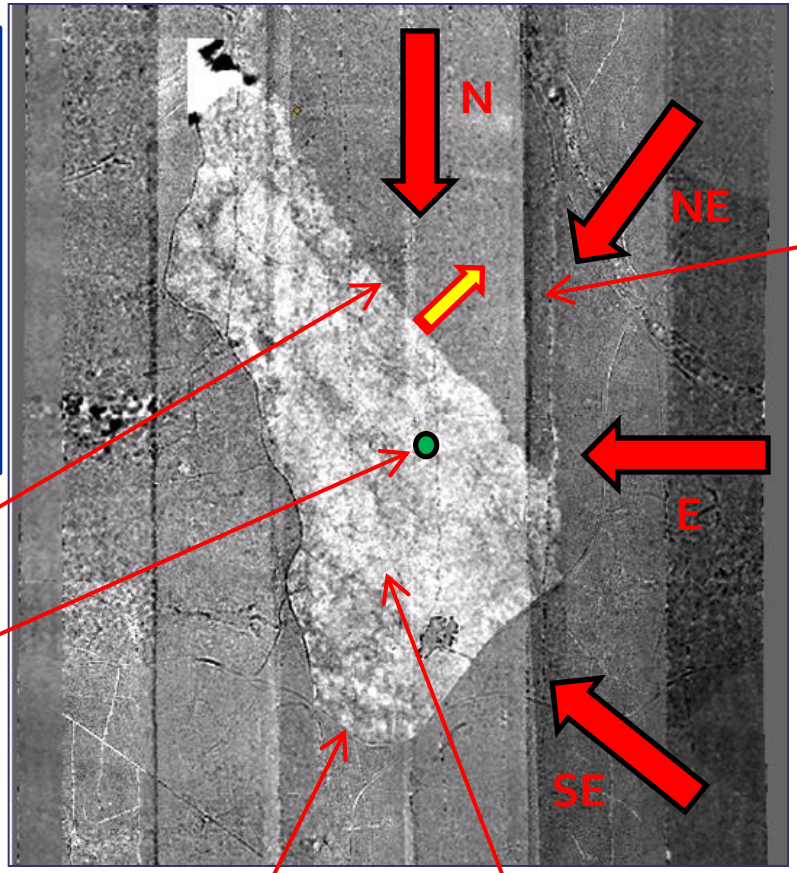
NJ Prescribed Burn Experiments:
Meteorological Monitoring Network – 20 March 2011

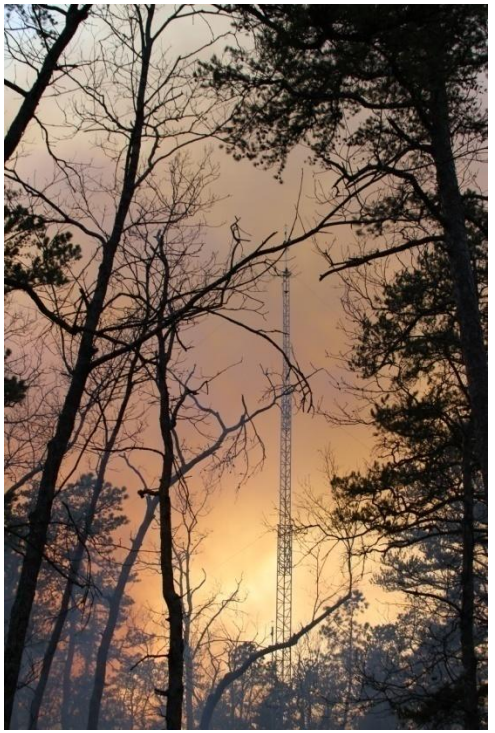


107 hectares (265 Acres); Pitch Pine Overstory (~18 m)

NJ Prescribed Burn Experiment: Fire Line Progression – 20 March 2011

Date: 20-21 March 2011
Ignition: ~1000 EDT
Duration: ~16 hrs
Wind Speed: < 5 ms^{-1}
Wind Dir.: N-NE-E-SE
Fuel Load: 1.48 kg m^{-2}
1 hr FF Moist.: 26.18%
Spread Rate: ~1.5 m min^{-1}





Temperatures

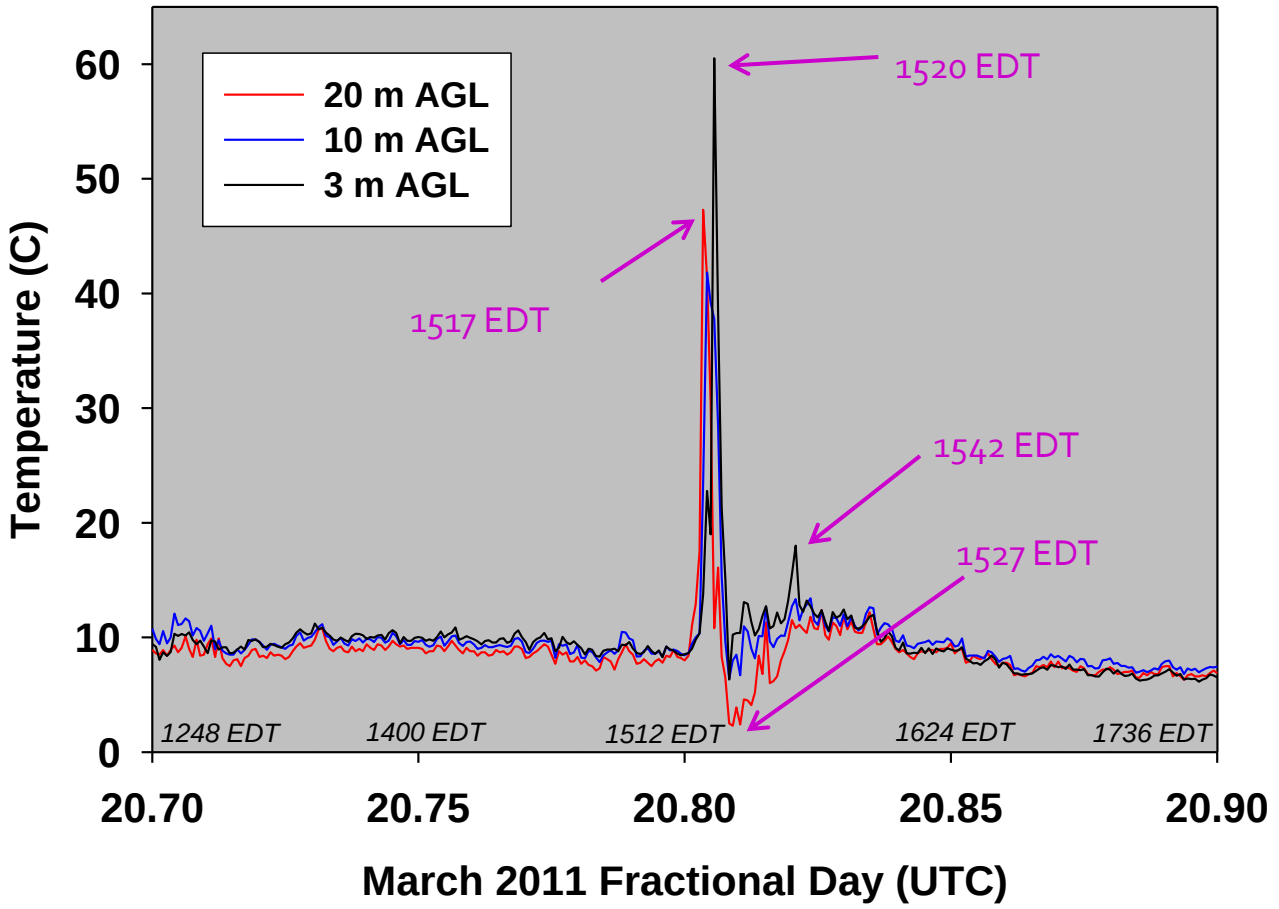
- Convective plume reached the tower top ~3 minutes before fire line passage (enhanced stability 3<z<20m).

- Fire line passage at 1520 EDT (strongly unstable 3<z<20m).

- Temperature dropped ~6 C below ambient temperature at 20 m ~7 minutes after fire line passage (same time as maximum downdrafts).

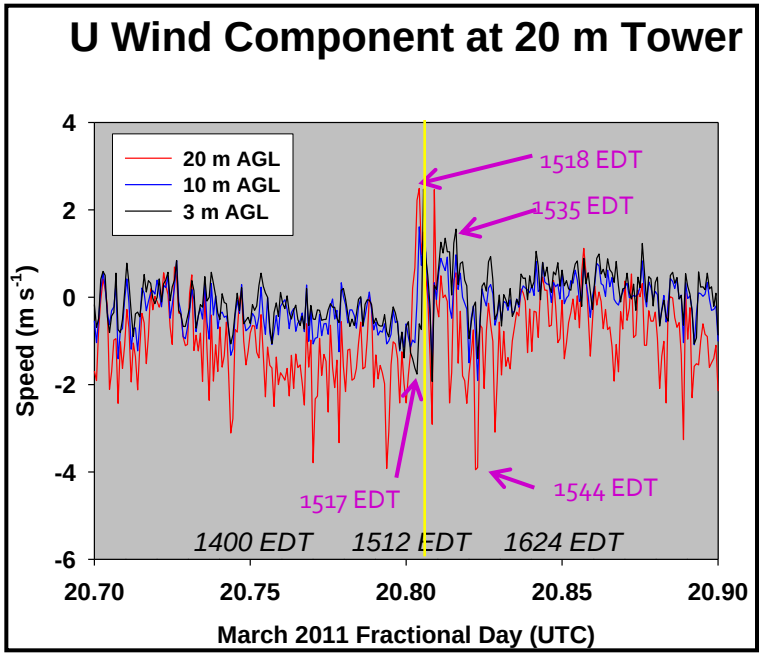
- Temperatures rebounded to ~2-3 C above ambient temperature ~25 minutes after fire line passage and then gradually decreased.

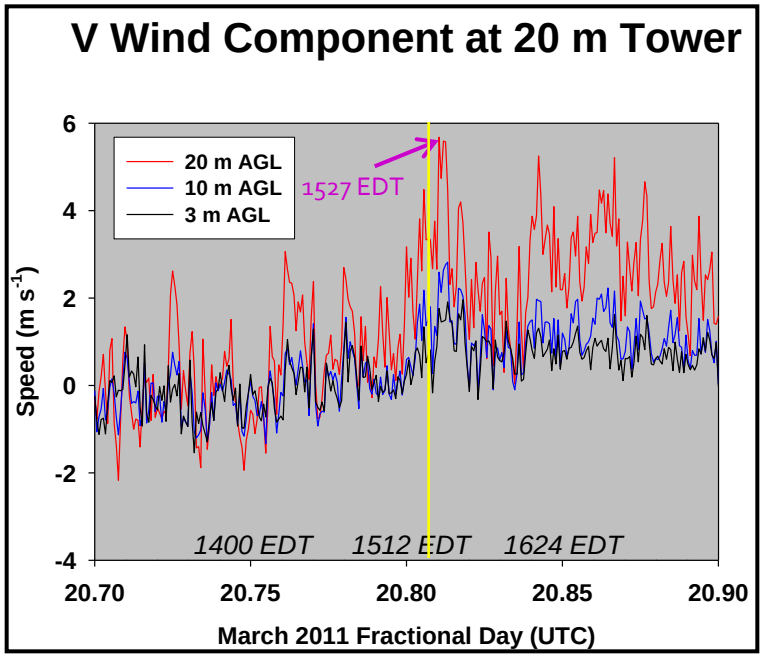
Temperatures at 20 m Tower

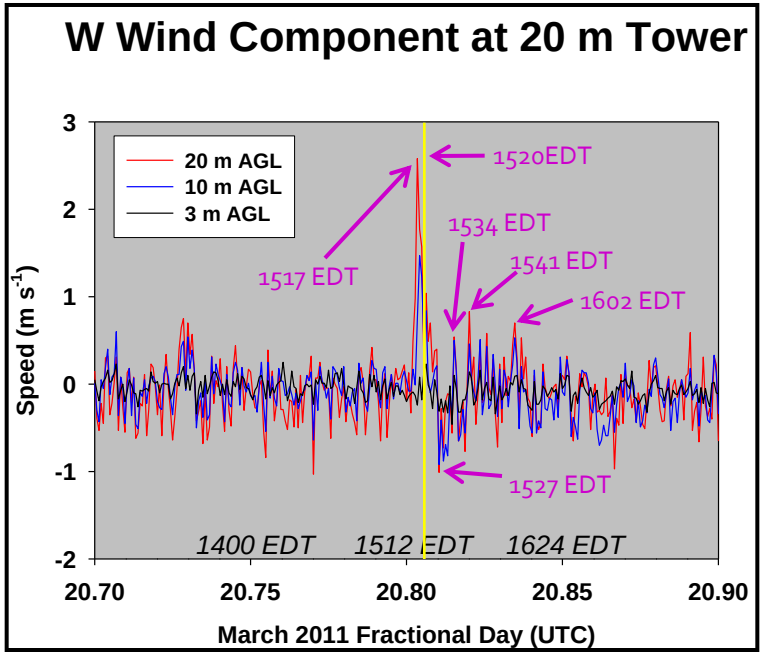


Wind Speed

- Light SE winds (U<0, V>0) before fire line passage.
- Stronger sfc. inflow in front of fire line developed ~10 min. before fire line passage (U most negative at 1517 EDT)
- Stronger SW winds after fire line passage (~20 min.) followed by mostly S to SE winds from the surface upward.
- Maximum updrafts above the canopy ~3 min. before fire line passage; maximum downdrafts ~7 min. after fire line passage.







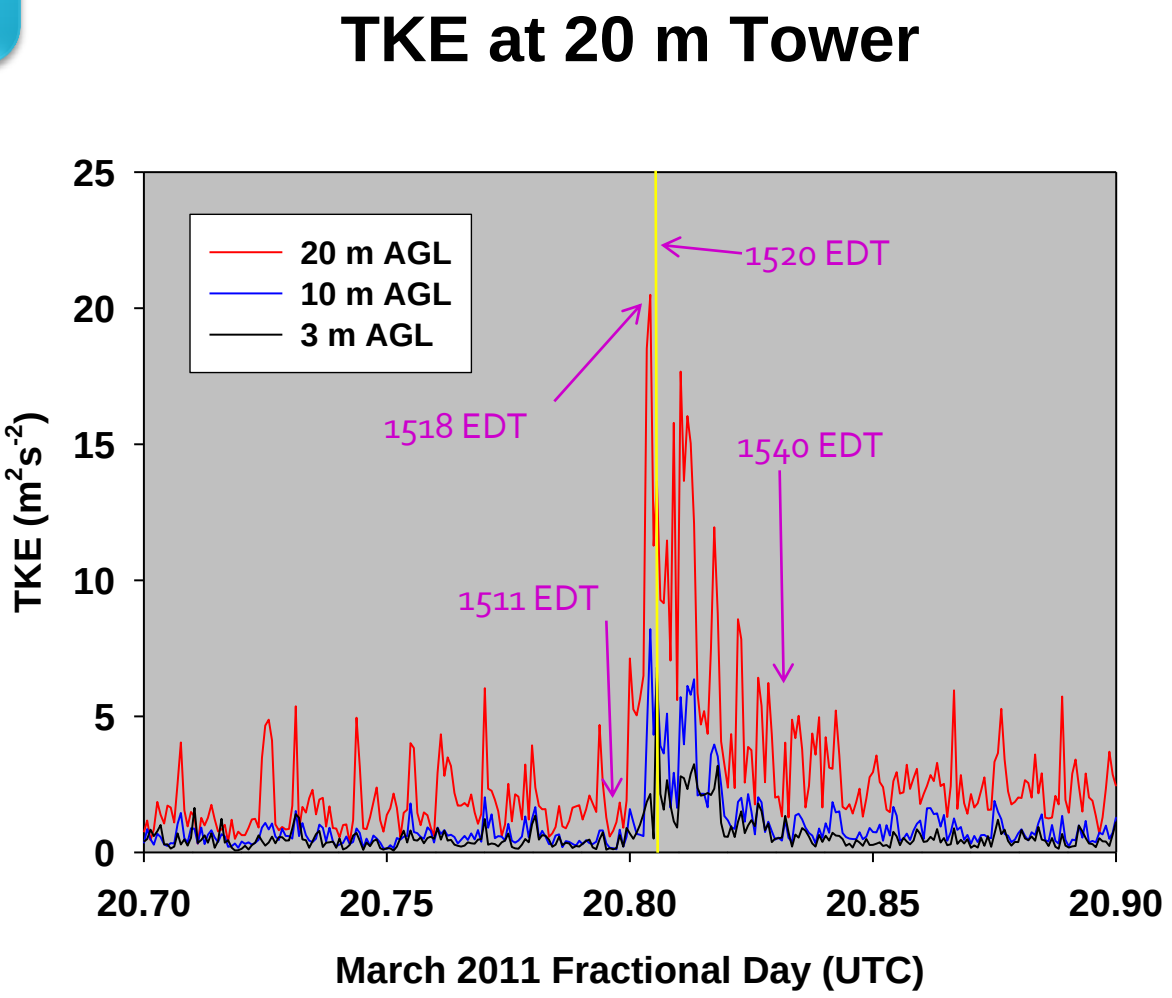
Turbulent Kinetic Energy

- TKE is consistently higher above the canopy than inside the vegetation layer, even during and after fire line passage.

- TKE begins to increase at all levels ~9 minutes before fire line passage.

- Very turbulent during and after fire line passage.

- TKE values near the surface drop to pre-fire line passage values ~20 minutes after fire line passage.



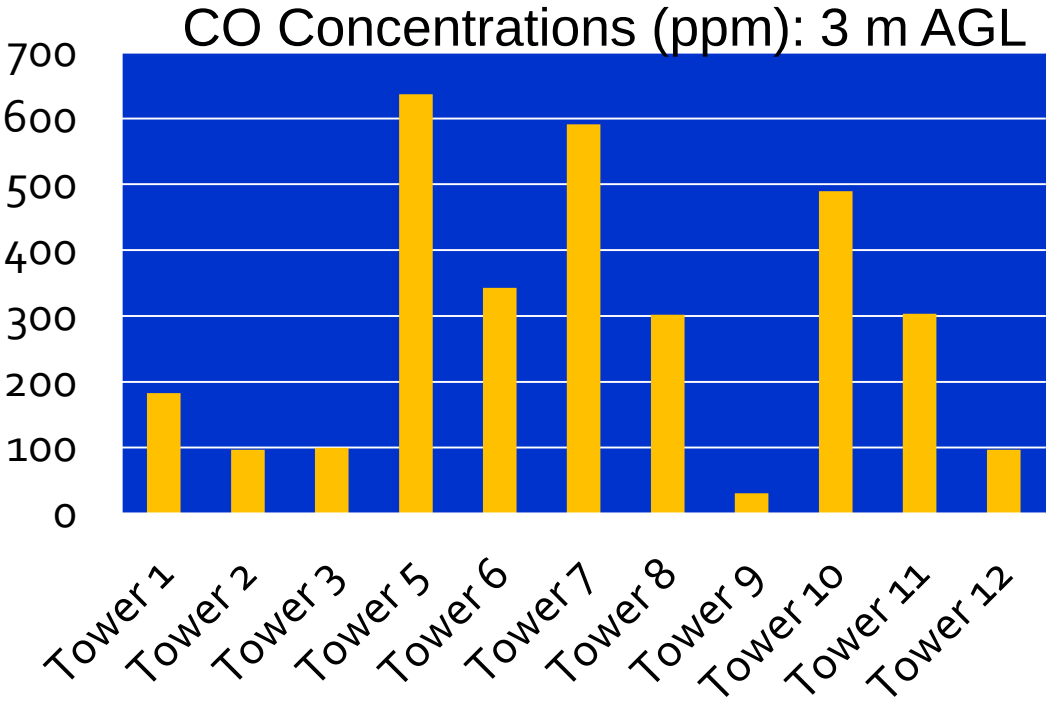
CO Concentrations

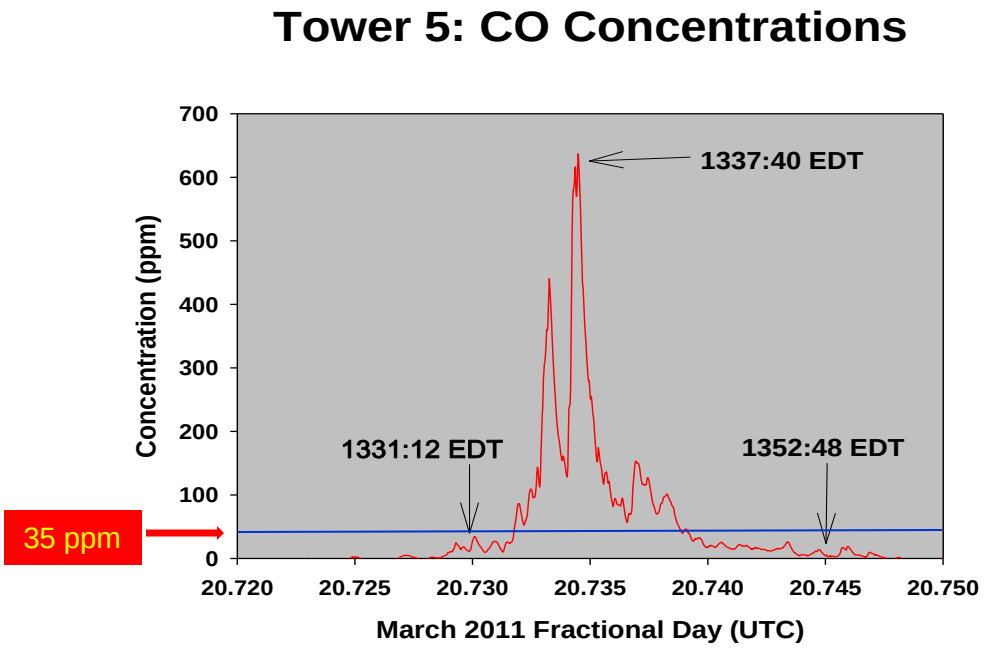
- Maximum CO concentrations varied substantially across the burn unit.

- CO concentrations exceeded 600 ppm at Tower 5 (southern part of burn block).

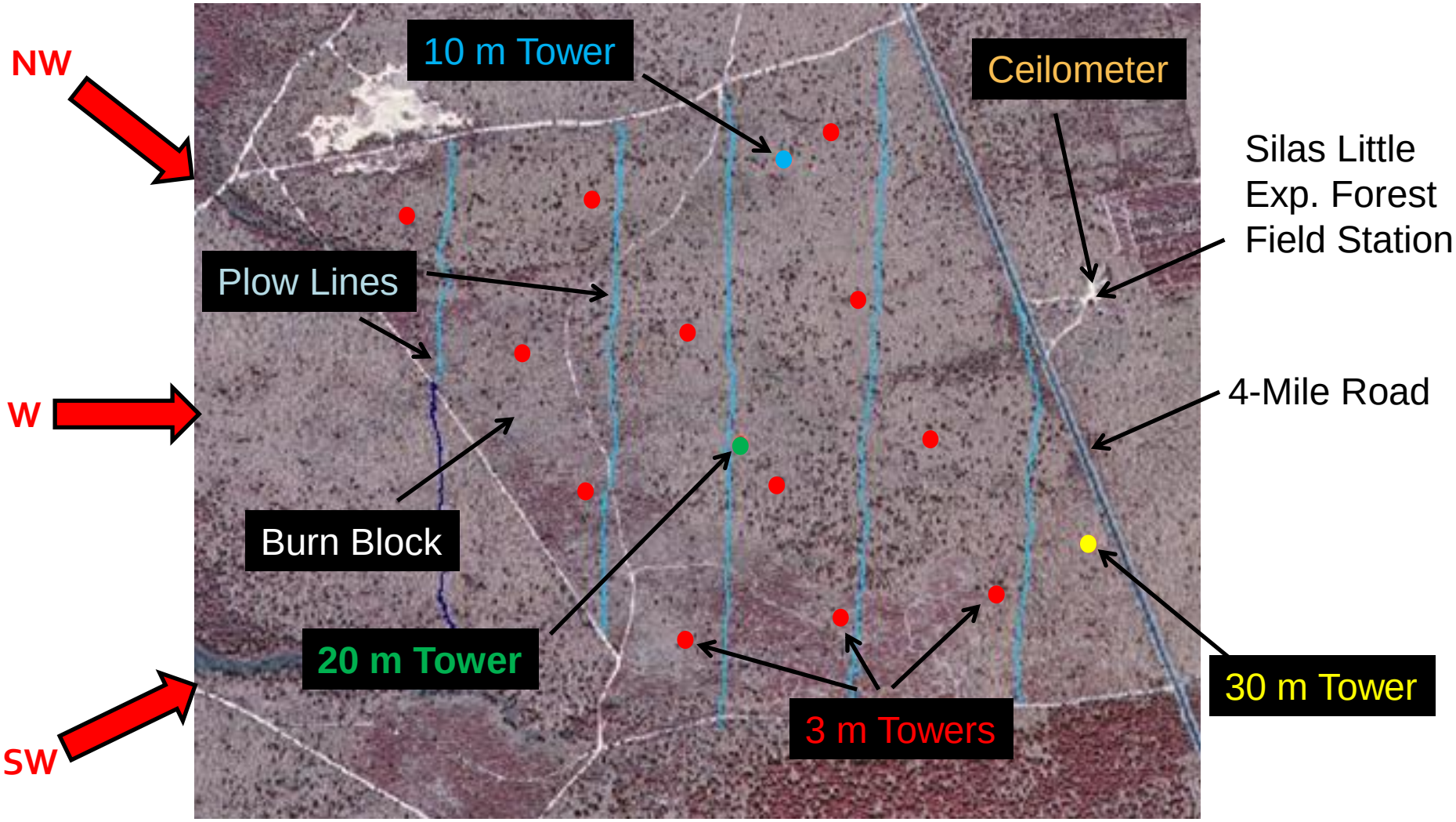
- Maximum CO concentrations occurred at the time of fire line passage at each tower.

- Periods of high CO concentrations were short lived (~ 20 minutes).



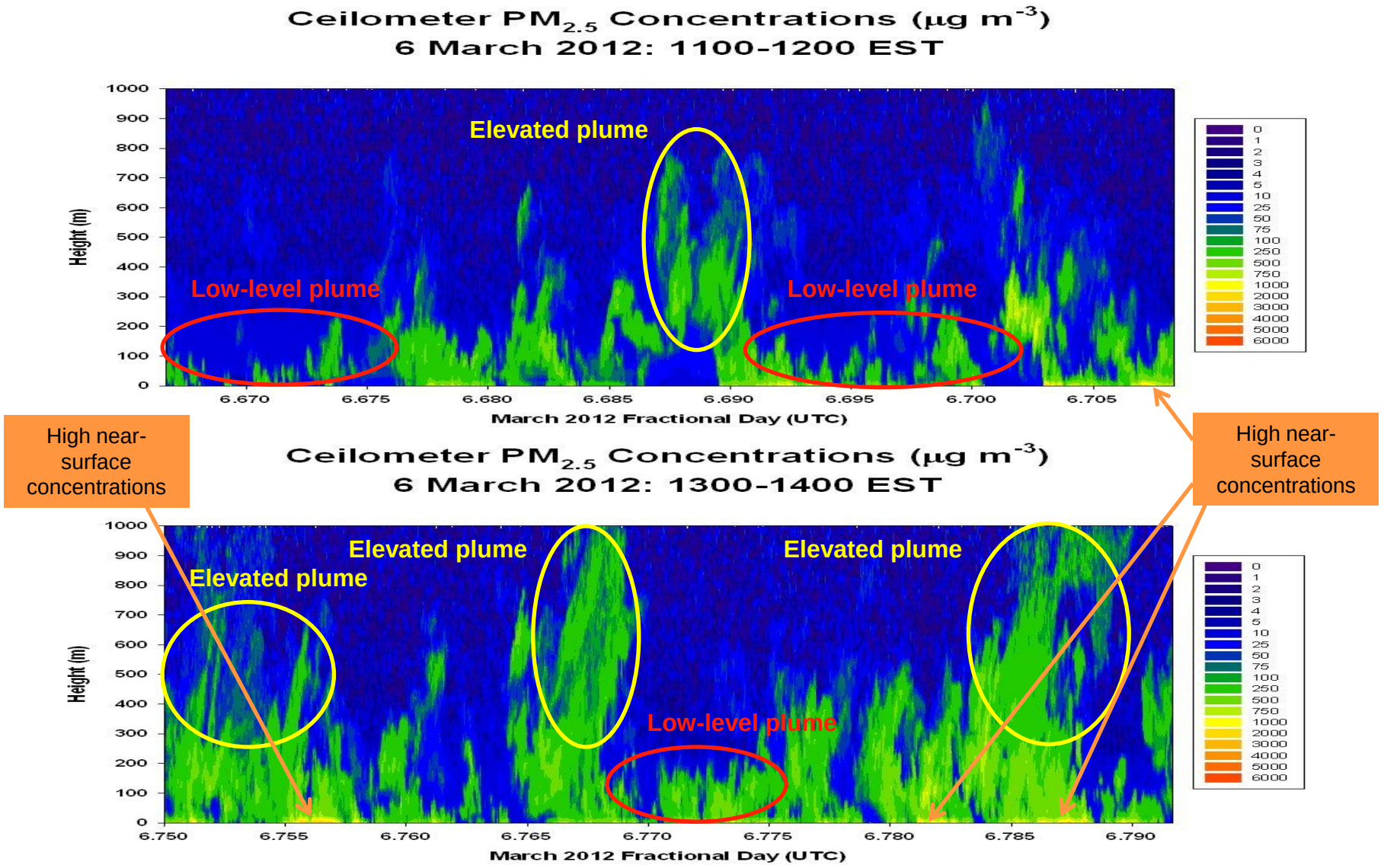


NJ Prescribed Burn Experiments:
Meteorological Monitoring Network – 6 March 2012



97.12 hectares (240 Acres); Pitch Pine Overstory (~18 m)

$PM_{2.5}$ Concentrations



Model Development/Adaptation and Evaluation

Overall Modeling Strategy

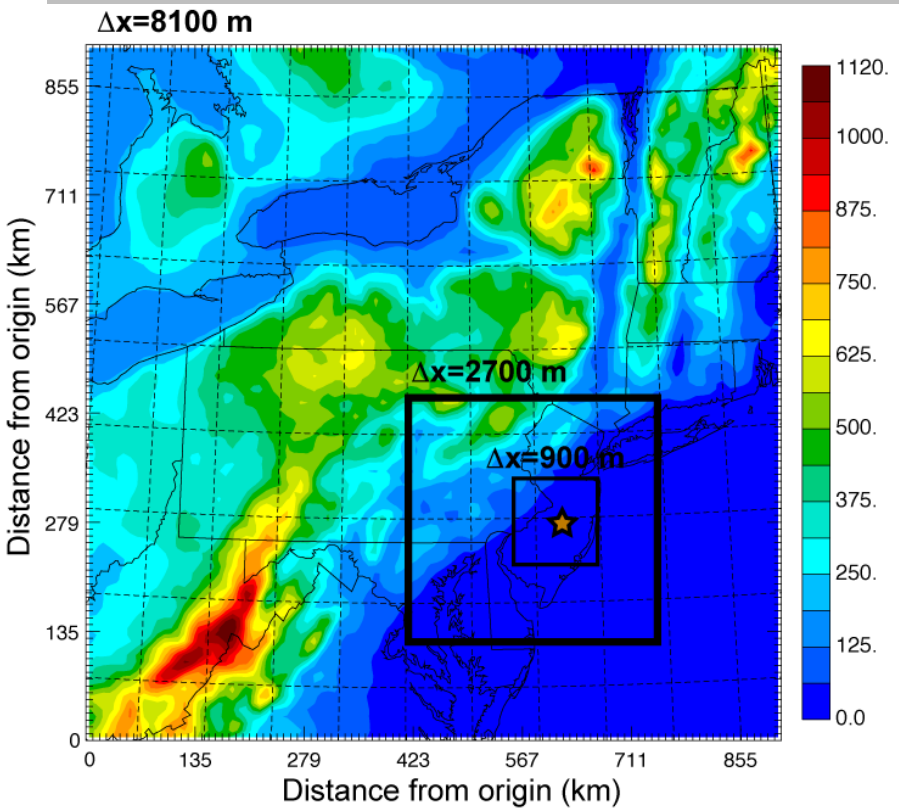
- Run simulations of prescribed fire cases using selected NWP models:
  - Advanced Regional Prediction System (ARPS), WRF, RAFLES
  - Primary validation datasets: 20 March 2011 and Feb.-Mar. 2012 prescribed burns in the NJ Pine Barrens
- Provide meteorological data to dispersion module: FLEXPART

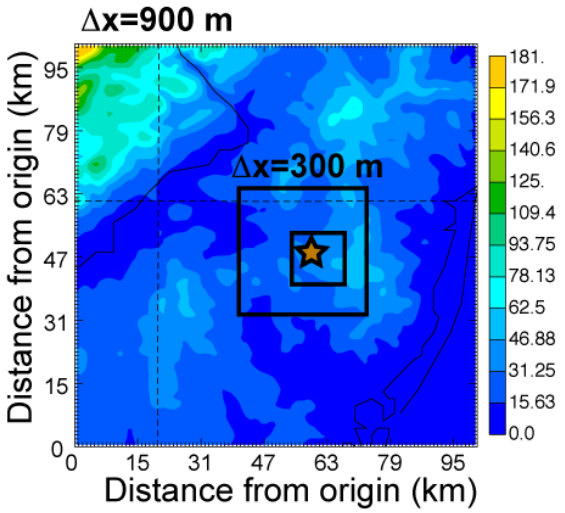
ARPS Model Overview

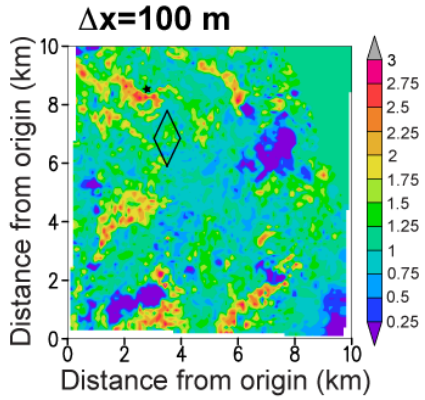
- Advanced Regional Prediction System (ARPS) Version 5.2.12 (Xue et al. 2003)
  - Three-dimensional atmospheric modeling system
  - Designed to simulate microscale [O(10 m)] through regional scale [O(10^6 m)] flows
- Standard ARPS lacks the capability to model atmospheric variables (e.g, wind, temperature) within a multi-layer canopy.
- We modified ARPS so that it can simulate atmospheric conditions (wind, temperature, radiation, turbulence, fluxes) within forest vegetation layers.

Modeling Experiment Design

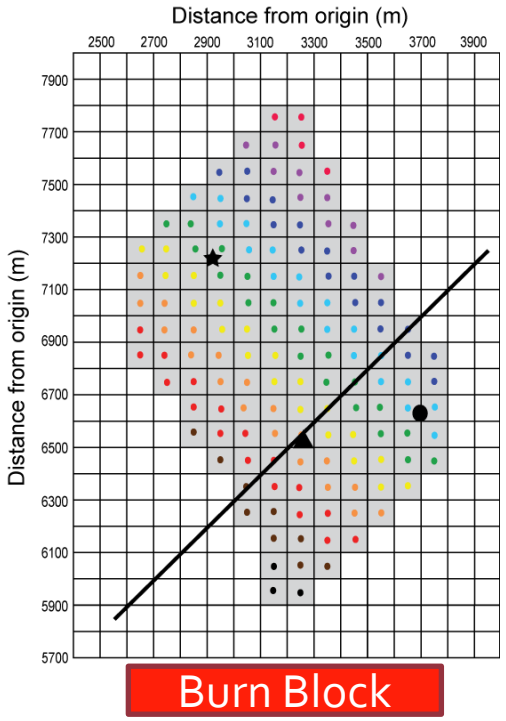
- Model initialized from North American Regional Reanalysis
- Five 1-way nested domains: $\Delta x = \Delta y$ = 8100m, 2700m, 900m, 300m, 100m
- Innermost nest: Vertical grid spacing is 2 m (9 levels, on average, inside canopy)
- Canopy applied to innermost nest only. Bulk effect of canopy represented by frontal area density, which when vertically integrated yields leaf area index (LAI)

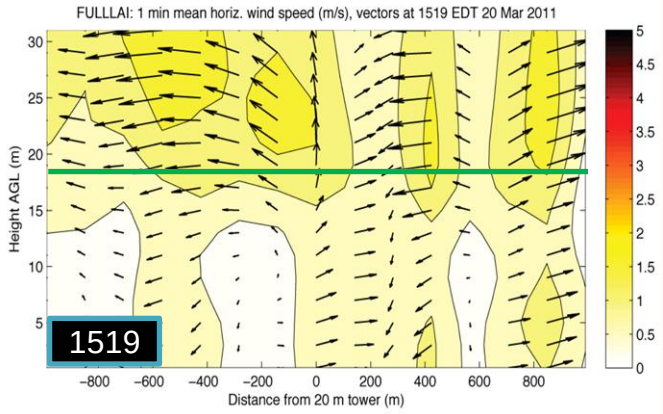


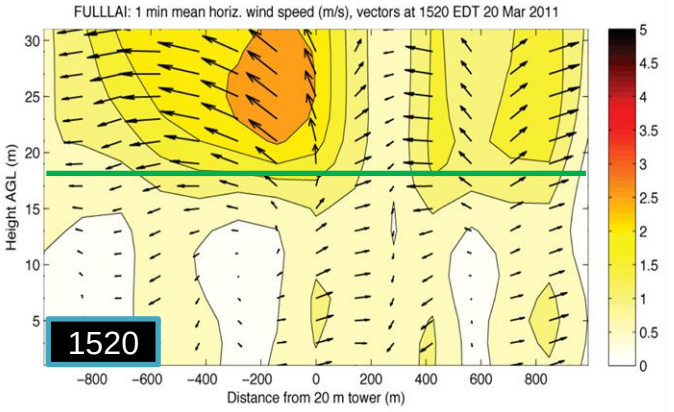


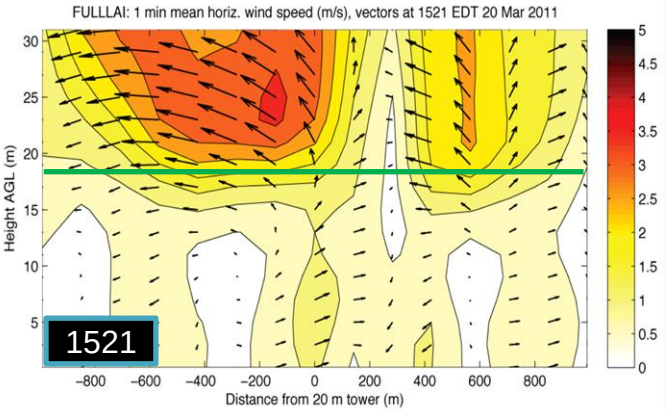


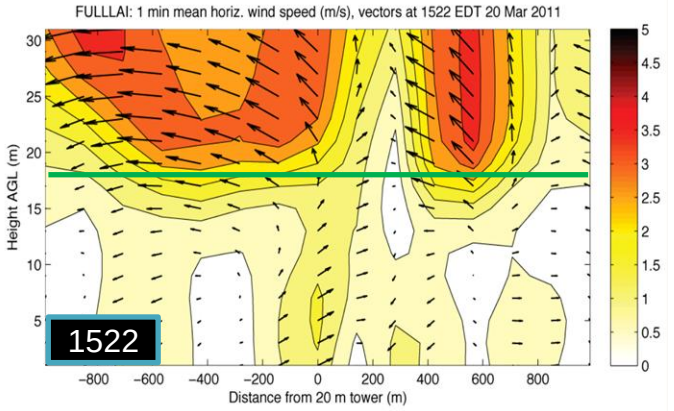
ARPS Horizontal Wind Speed/Direction Predictions: 1519-1524 EDT 20 March 2011

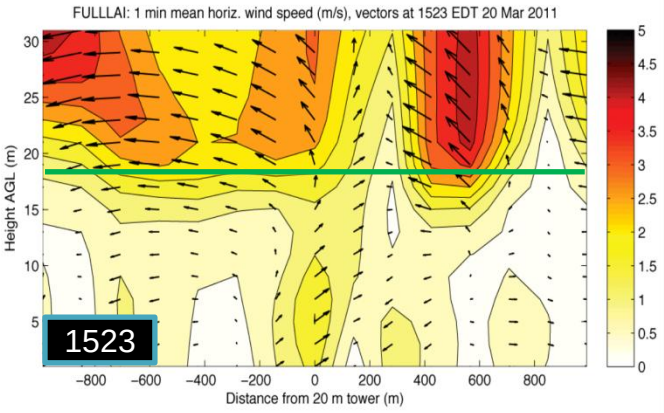


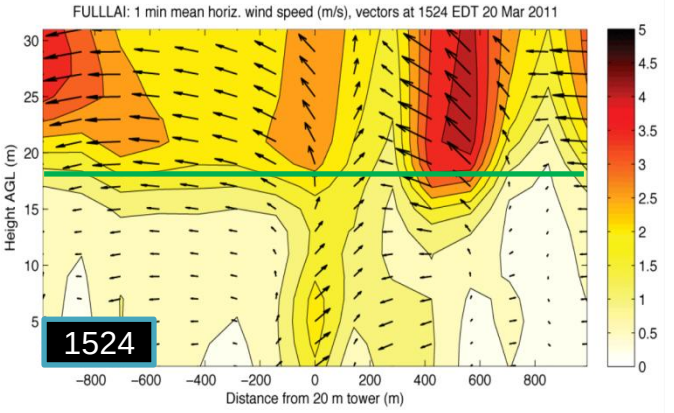




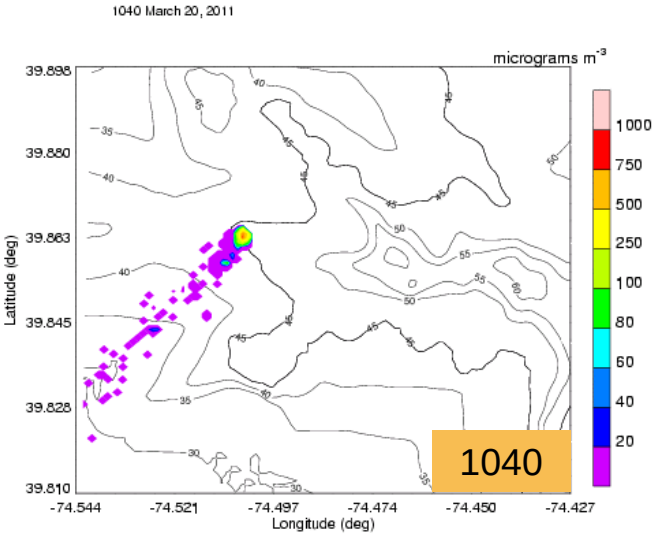


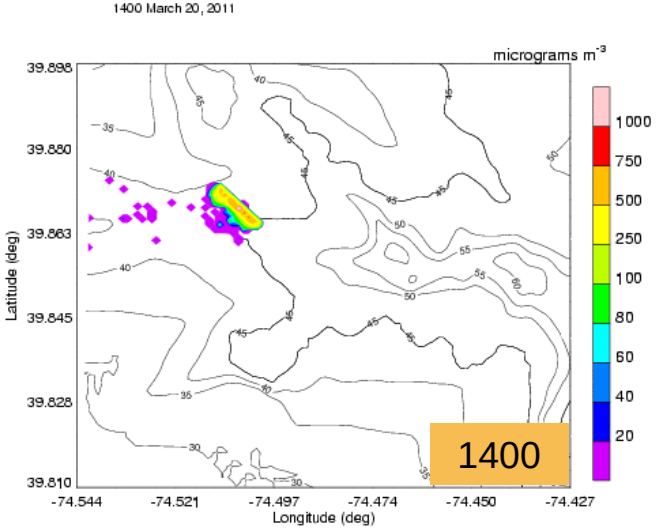


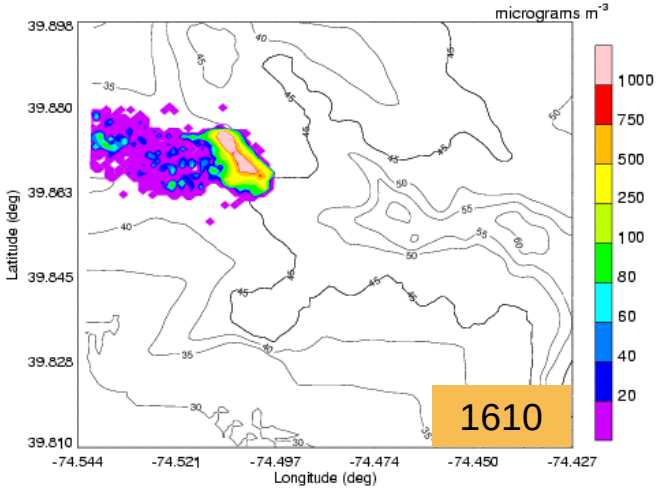


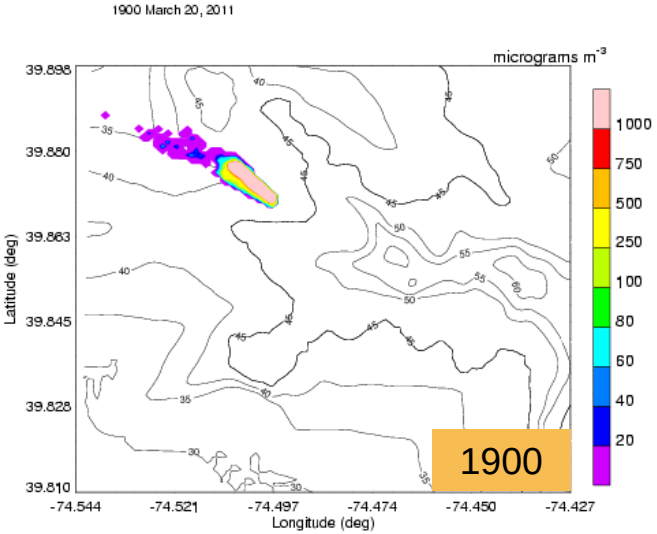


Example FLEXPART Surface $PM_{2.5}$ Concentration Predictions: 20 March 2011









Next Steps

- Continue development and validation of ARPS-FLEXPART, WRF-FLEXPART, and RAFLES modeling systems using observational data from prescribed burn experiments.
- Incorporate one or more of these new systems into the BlueSky framework.

Thank You!