Getting a Handle on Local Smoke Transport During Prescribed Fires

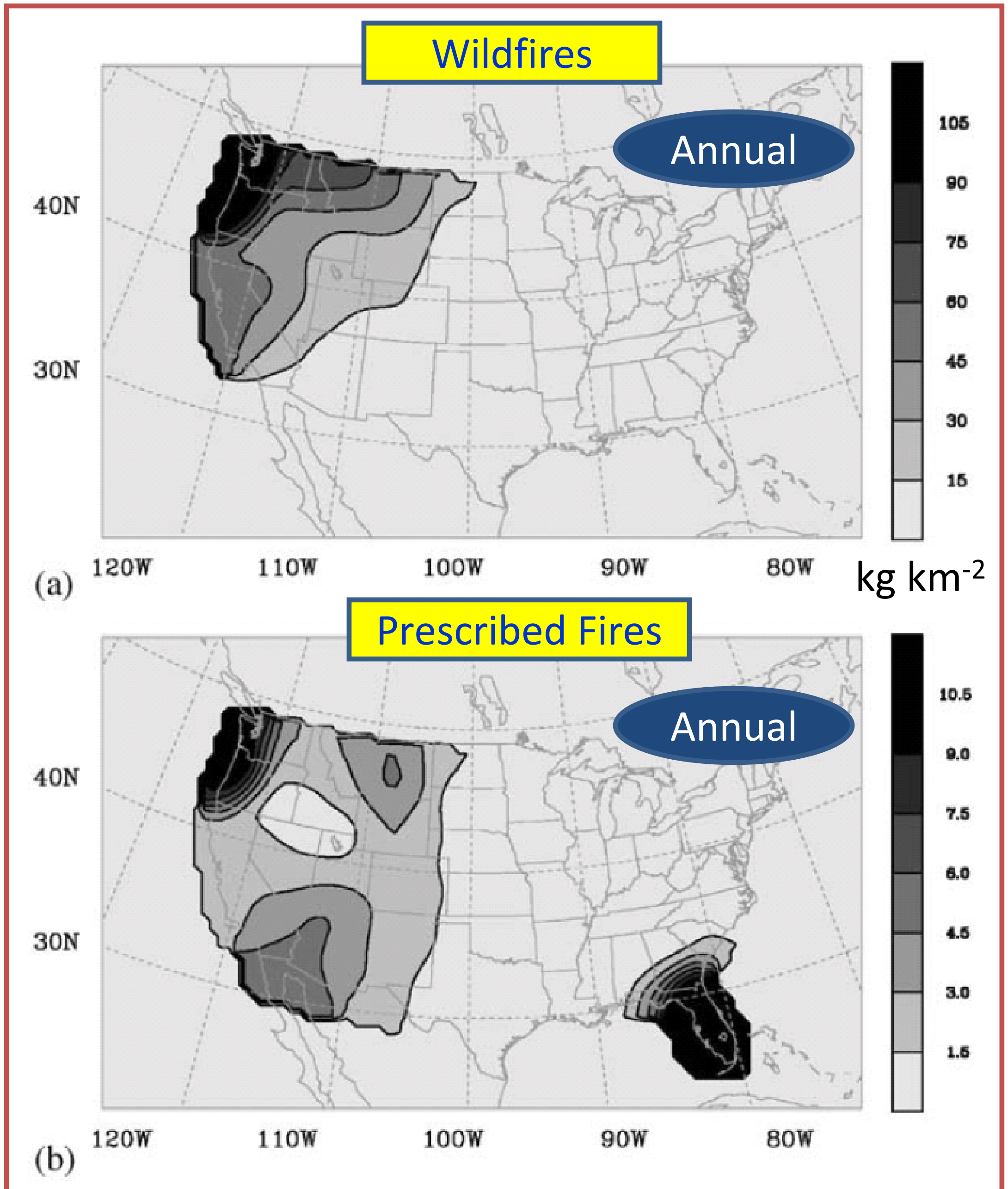
W. E. Heilman, M. T. Kiefer, G. Bohrer, S. Zhong, X. Bian, K. L. Clark, J. L. Hom, N. S. Skowronski, J. J. Charney, M. Gallagher, M. Patterson

Prescribed Burning and Air Quality

- Prescribed burns are a useful tool for resource management.
- But, they have side effects – chief among them being smoke.
- Smoke is a mixture of water vapor and combustion products, including particulates and carbon monoxide, which are regulated by Federal law.
- Health effects
  - Increased hospitalizations and mortality

Particulate ($PM_{2.5}$) Emissions from Wildfires and Prescribed Fires

- Annual particulate emissions from wildfires are ~10x larger than from prescribed fires.
- Emissions largest in the western U.S.
- Prescribed fire emissions largest in SE and NW U.S.



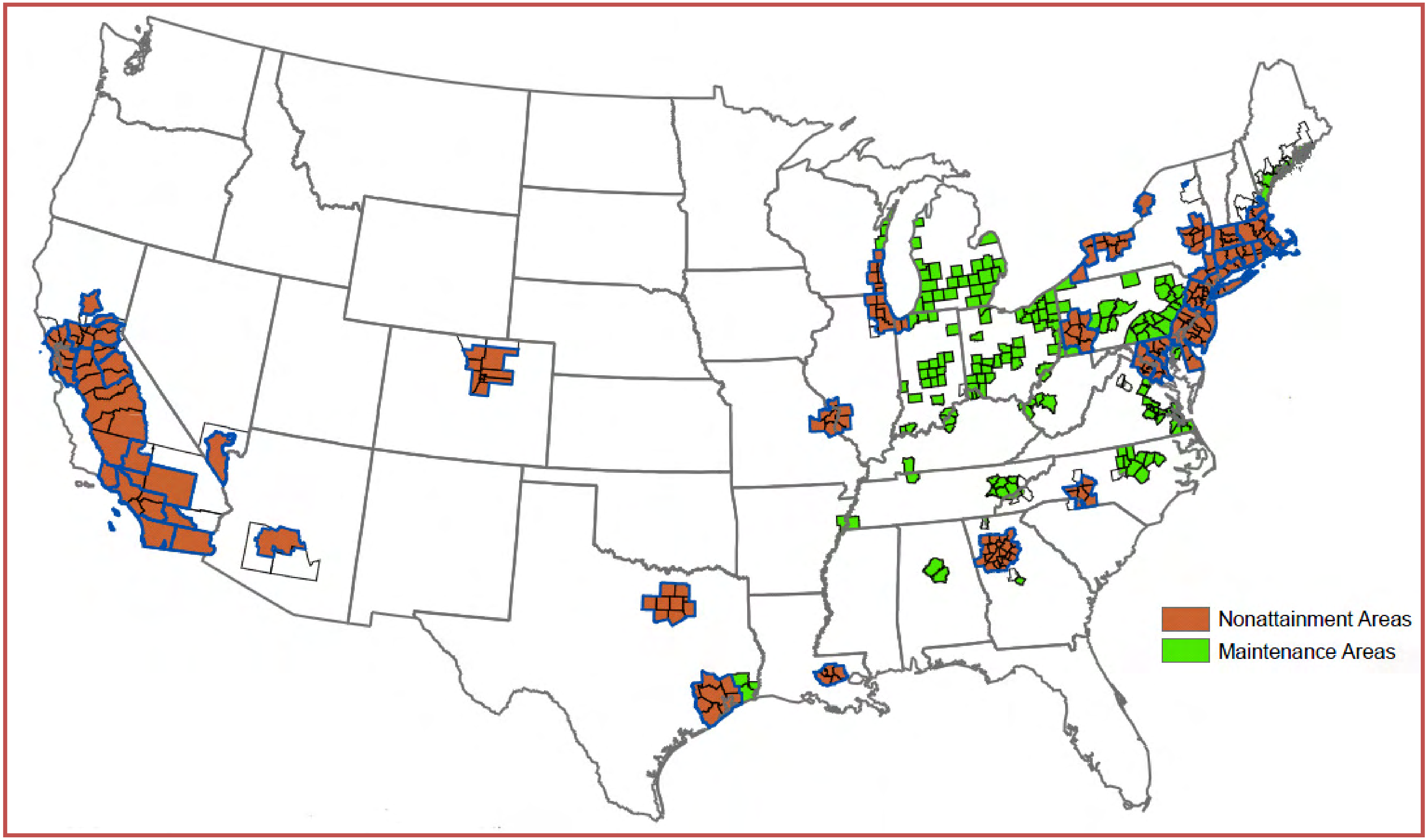
From Liu (2004)

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)

Nonattainment Areas for Ozone



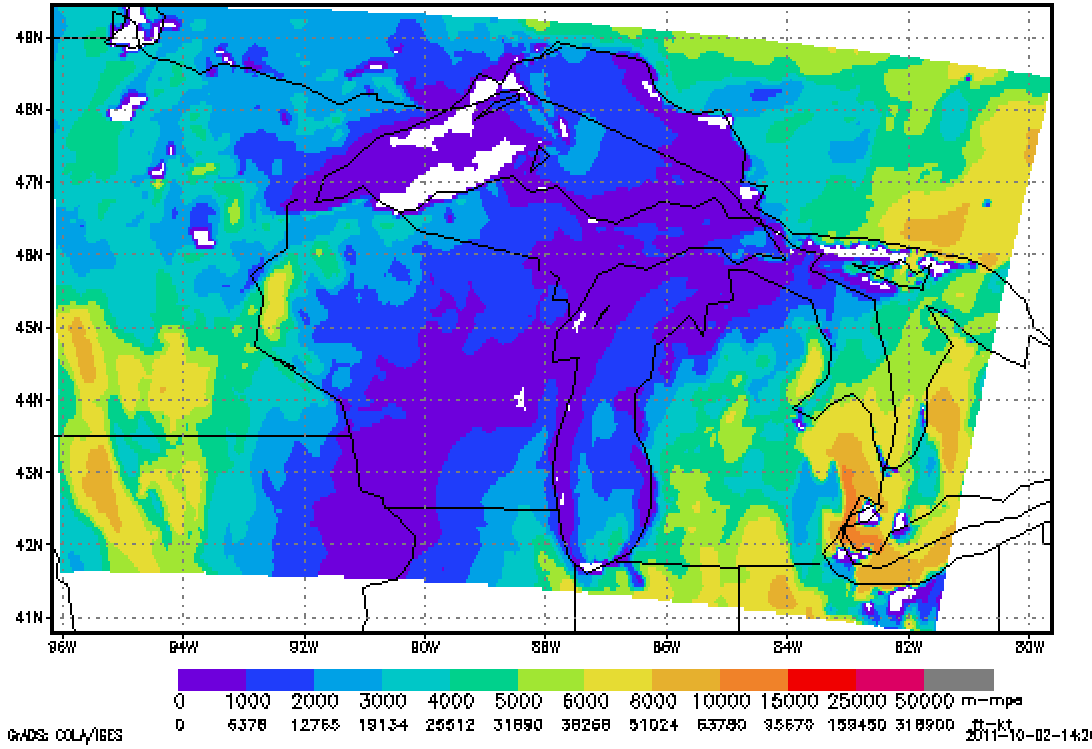
Current Air Quality Predictive Tools

- Ventilation Index
- Atmospheric Dispersion Index
- VSMOKE
- CALPUFF
- HYSPLIT
- BlueSky Framework
- Wildland Fire Decision Support System (WFDSS) – Air Quality Portal

Ventilation Index

- A simple index that characterizes the ability of the atmosphere to disperse smoke.
- VI = mixing height x avg. wind speed in mixed layer
- Daily predictions available from NWS forecast offices and other sources.

VI: 3 October 2011
1400 EDT



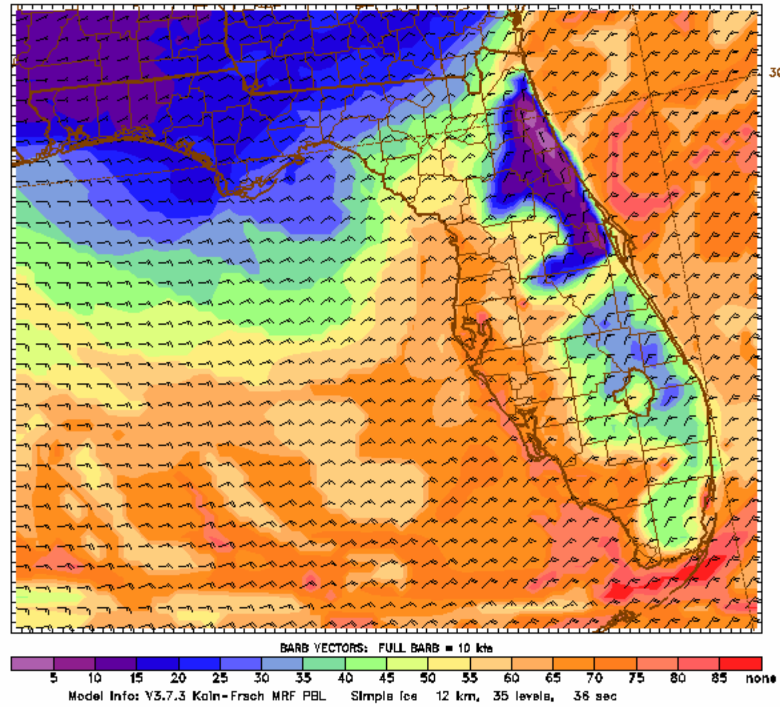
http://www.nrs.fs.fed.us/eamc/products/

VI ($m^2 s^{-1}$)	Smoke Condition
<2,350	Poor
2,350-4,700	Marginal
4,700-7,050	Fair
>7,050	Good

Atmospheric Dispersion Index

- Similar to VI but accounts for stability of the lower atmosphere.
- Daily predictions available from NWS forecast offices and other sources.

ADI: 2 December 2011
1400 EST

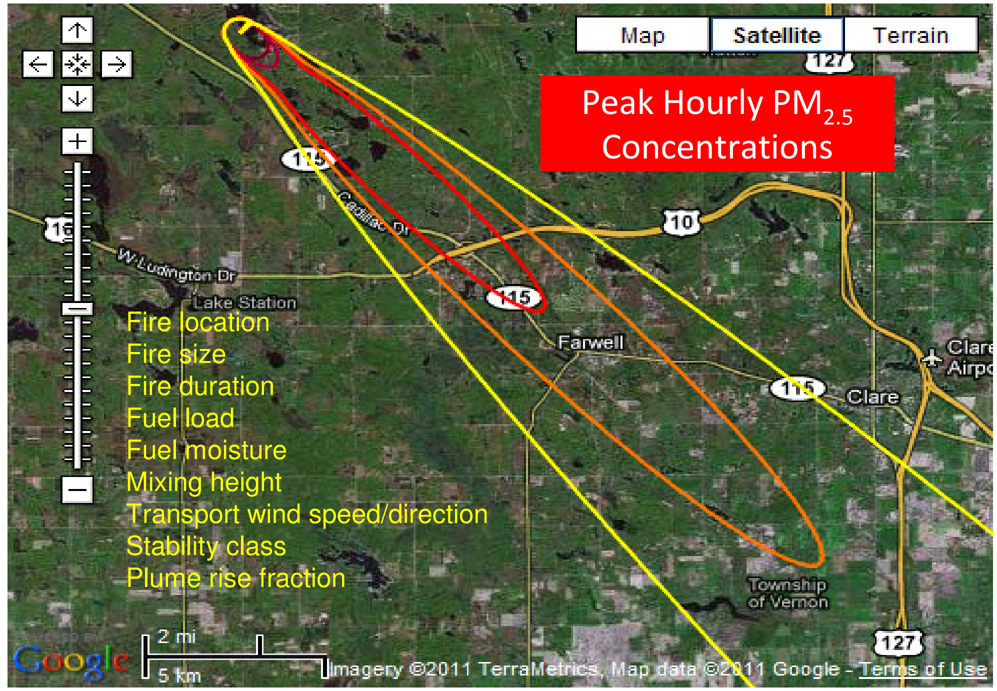


http://shrmc.ggy.uga.edu/smoke/maps/smoke_maps.php

ADI	Smoke Condition
1-6	Very Poor
7-12	Poor
13-20	Poor (Day), Above avg. (night)
21-40	Fair
41-60	Generally Good
61-100	Good
>100	Very Good (hazard. burn conditions)

VSMOKE

- Simple Gaussian plume model to predict surface $PM_{2.5}$ concentrations.
- Plume represented as a straight trajectory based on ambient wind speed/direction.
- Lateral plume spread described by a Gaussian distribution.

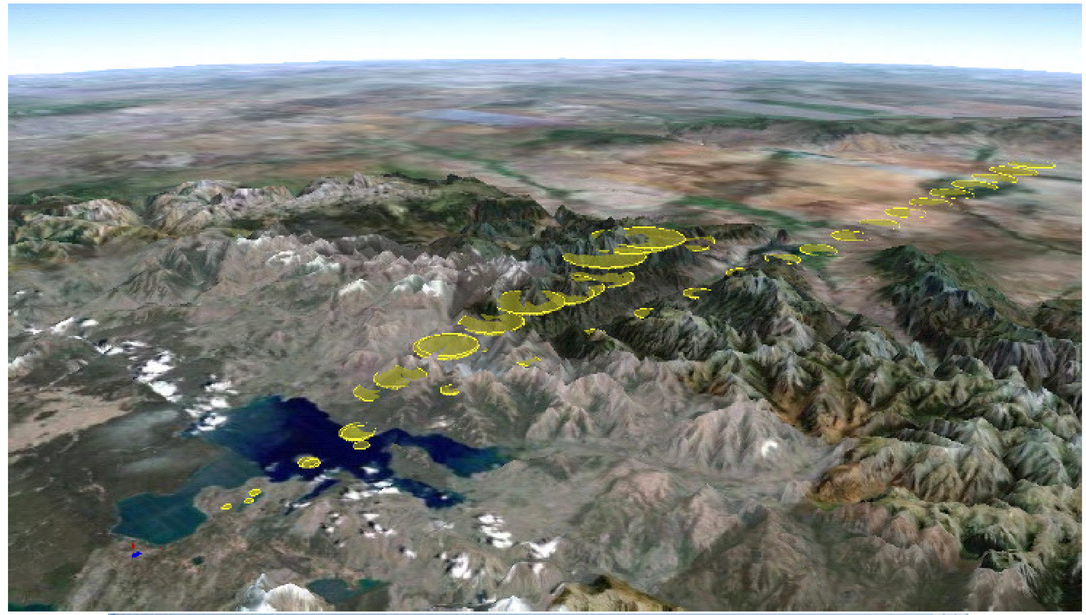


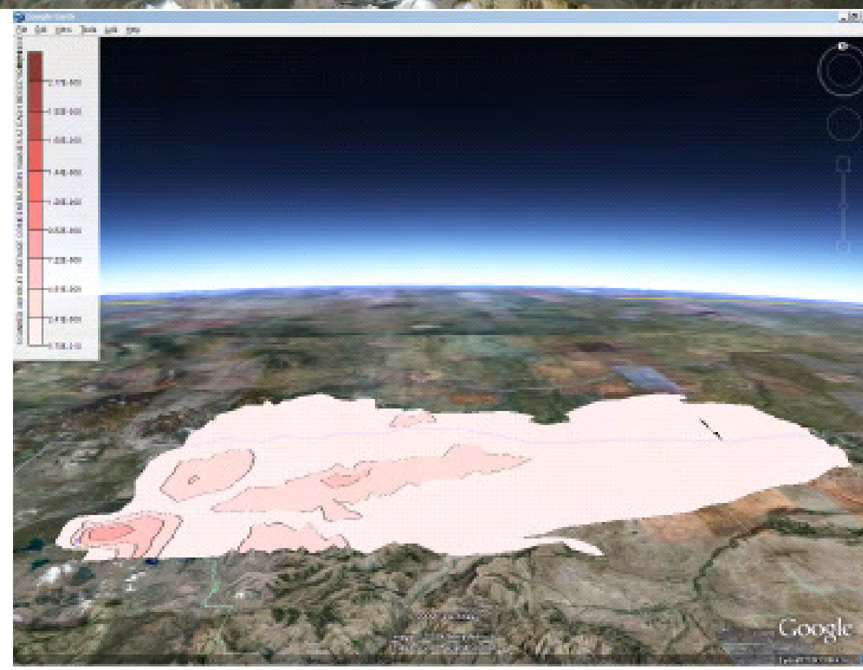
http://shrmc.ggy.uga.edu/maps/vsmoke.html

Levels of Health Concern	AQI Value	Hourly PM 2.5 Conc.	Meaning
Good	0 to 50	0 to 38	Air quality is considered satisfactory, and air pollution poses little or no risk
Moderate	51 to 100	39 to 88	Air quality is acceptable; however, for some pollutants there may be a moderate health concern for a very small number of people who are unusually sensitive to air pollution.
Unhealthy for Sensitive Groups	101 to 150	89 to 138	Members of sensitive groups may experience health effects. The general public is not likely to be affected.
Unhealthy	151 to 200	139 to 351	Everyone may begin to experience health effects; members of sensitive groups may experience more serious health effects.
Very Unhealthy	201 to 300	352 to 526	Health alert: everyone may experience more serious health effects
Hazardous	301 to 500	> 526	Health warnings of emergency conditions. The entire population is more likely to be affected.

CALPUFF

- A "puff" dispersion modeling system consisting of a diagnostic meteorological model (CALMET) and a Lagrangian-Gaussian air-quality model.
- Provides predictions of pollutant transport and concentrations.
- One of U.S. EPA's preferred models for assessing long-range pollutant transport and impacts.
- Available from Atmospheric Studies Group at TRC Solutions, Inc.



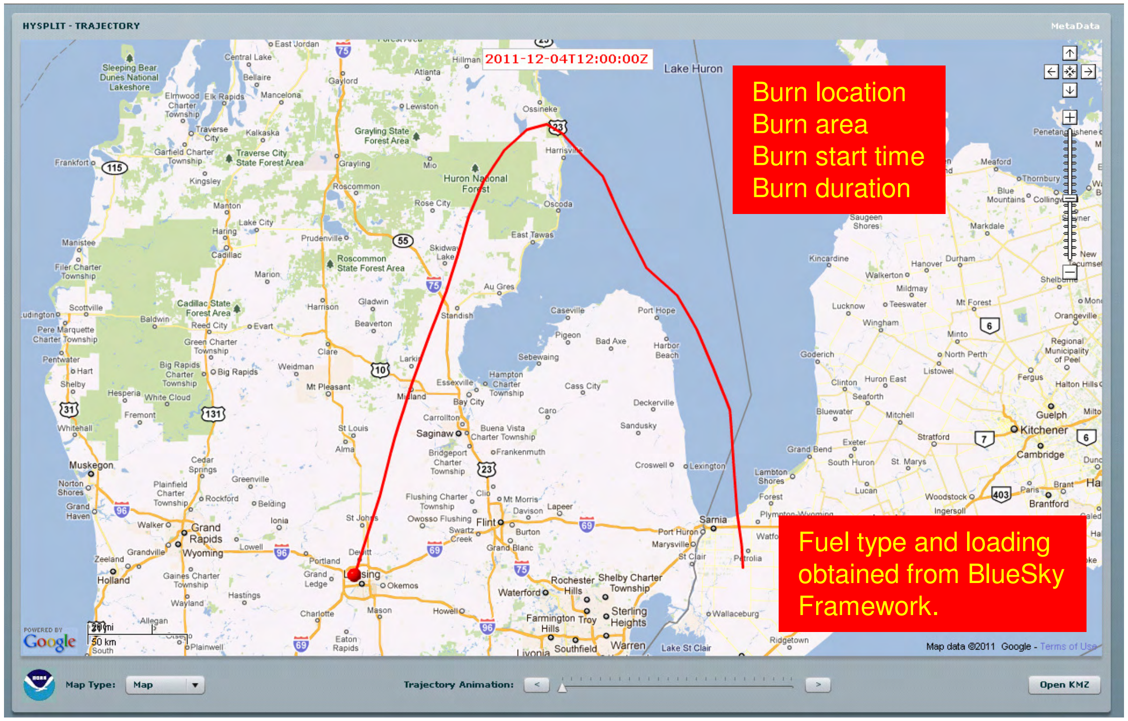


http://www.src.com/calpuff/calpuff1.htm/

HYSPLIT

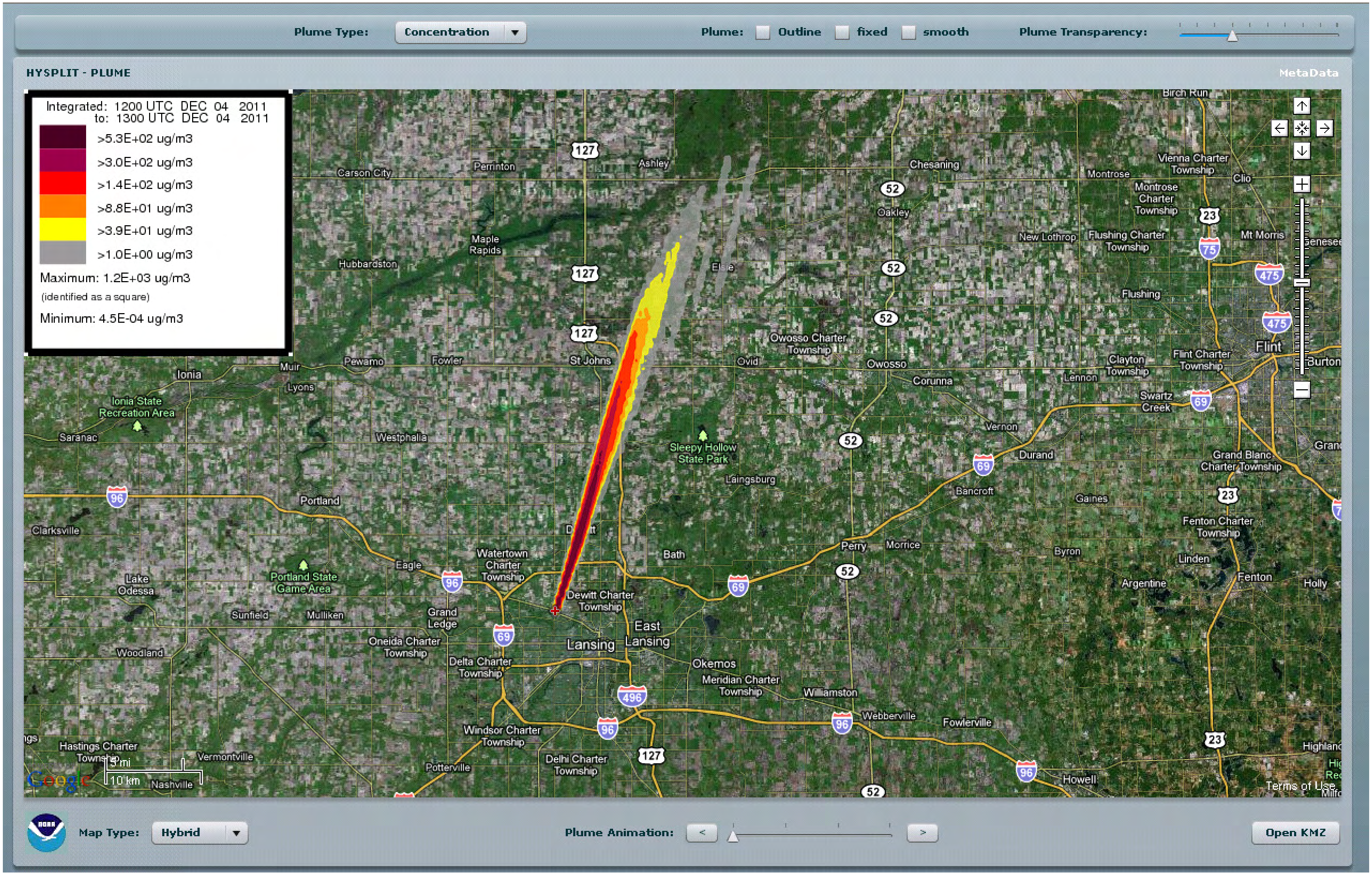
- Hybrid Particle Lagrangian Integrated Trajectory model.
- A complete system for computing simple air parcel trajectories, complex dispersion, and deposition of pollutants.
- The dispersion of a pollutant is calculated by assuming either particle or puff dispersion.
- “Wildland Fire” version of HYSPLIT now available.
- Available from NOAA’s Air Resources Laboratory online READY system.

HYSPLIT Trajectory: 4 December 2011
Emissions from “artificial” prescribed fire at LAN



http://ready.arl.noaa.gov/HYSPLIT.php

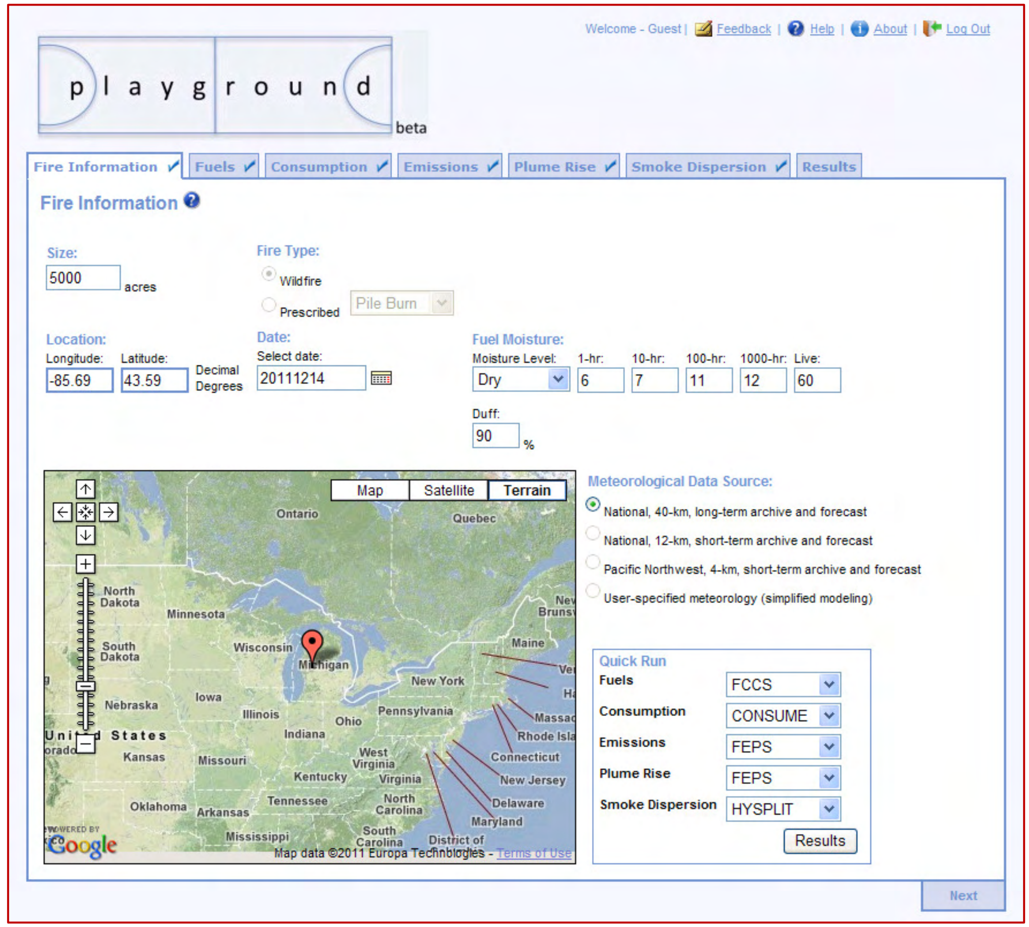
HYSPLIT Predicted $PM_{2.5}$ Concentrations: 0700-0800 EST on 4 December 2011



BlueSky

- A modeling framework that modularly links a variety of independent models of fire information, fuel loading, fire consumption, fire emissions, and smoke dispersion.

- It can enable the:
  - Lookup of fuels information
  - Calculation of fire consumption based on fuels and weather
  - Calculation of speciated emissions
  - Calculation of vertical plume profiles
  - Calculation of smoke trajectories
  - Calculation of downstream smoke concentrations



http://playground.firesmoke.us/index.php

BlueSky Framework

A logical progression

- What is the weather?
- Where is the fire?
- What are the fuels?
- How much fuel got consumed?
- When did they burn?
- What are the emissions?
- How high did the smoke go?
- What are the smoke impacts?

BlueSky Framework

Met

WRF
MM5
GFS
NAM
Other

Fire Info

SMARTFIRE
ICS-209
Rx Sys
Manual
Other

Fuels

FCCS
NFDRS
Hardy
LANDFIRE*
Ag*
Other

Total Consumption

CONSUME 3
FOFEM
FEPS
EPM
ClearSky (Ag)*
Satellite*
Other

Time Rate

Rx / WF
FEPS
FOFEM
EPM
WRAP
Idealized
Manual
Other

Emissions

FEPS
Literature*
EPM
FOFEM
Other

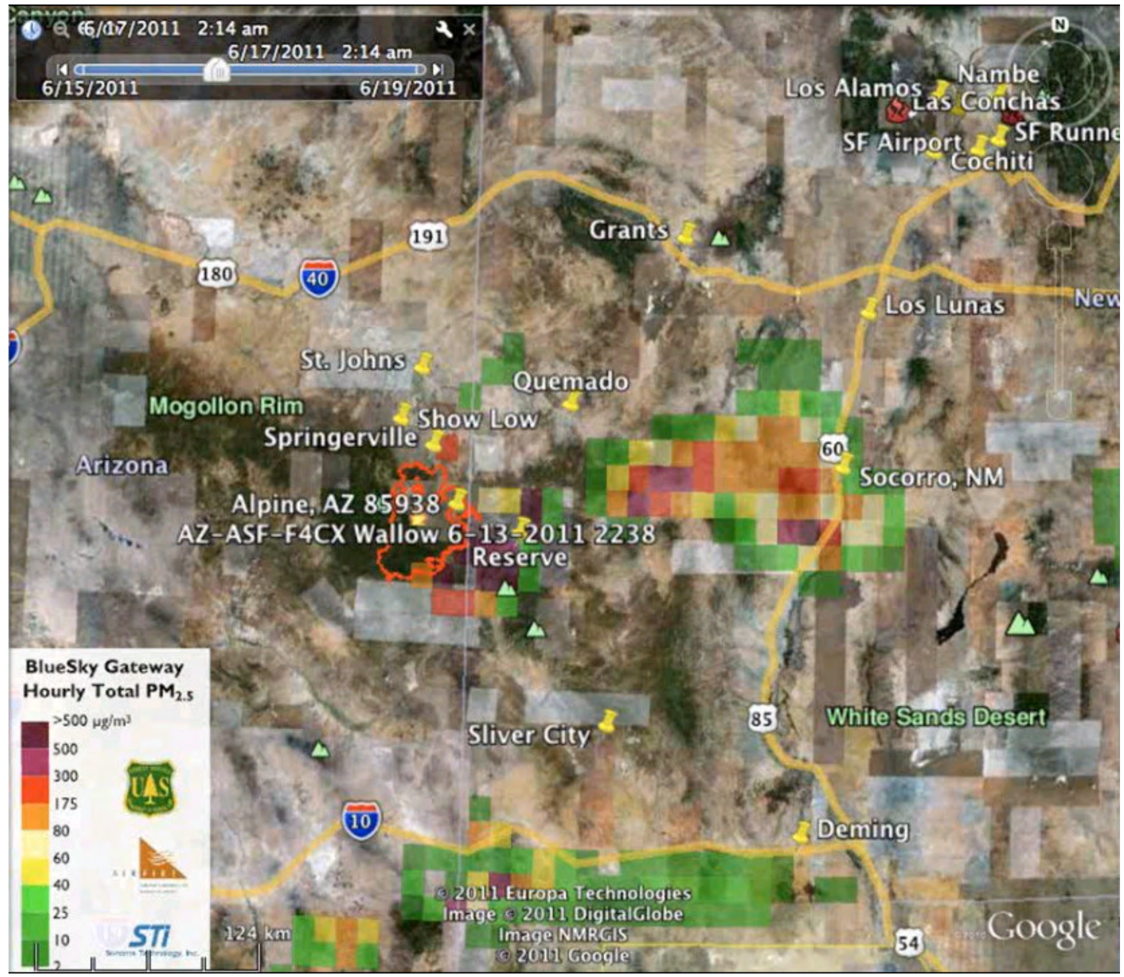
Plume Rise

Briggs
Multi-core**
Daysmoke**
Other

Dispersion / Trajectories

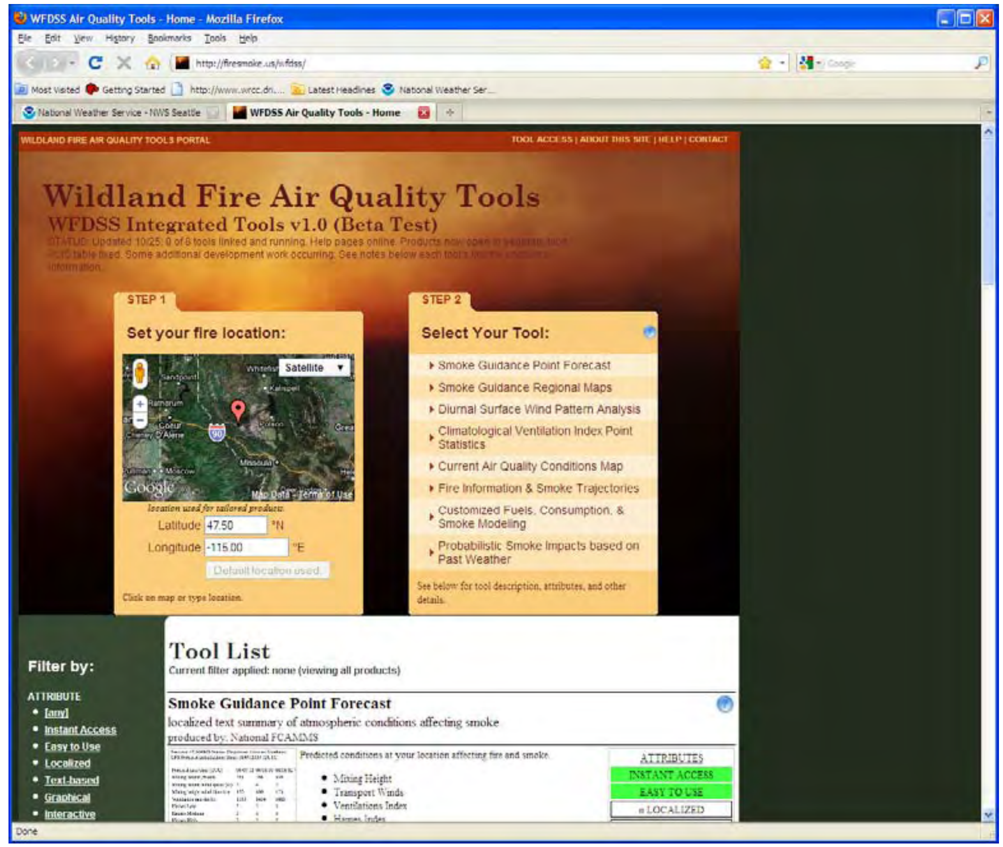
CALPUFF CMAQ
HYSPLIT

Example BlueSky Framework Output $PM_{2.5}$ Concentration Map
Wallow Fire, AZ: 06/17/2011 at 0214 MST



WFDSS-AQ Portal

- Wildland Fire Decision Support System – Air Quality Portal
- Online system chartered by the National Fire and Aviation Executive Board (NFAEB) to assist fire managers and analysts in making strategic and tactical decisions for fire incidents.
- An air quality portal has been added to WFDSS that provides a "one-stop" point of access to a variety of smoke/air-quality descriptive and predictive tools.
- 8 tools are currently available.



http://firesmoke.us/wfdss/

WILDLAND FIRE AIR QUALITY TOOLS PORTAL

TOOL ACCESS | ABOUT THIS SITE | HELP | CONTACT

Wildland Fire Air Quality Tools

WFDSS Integrated Tools v1.0 (Beta Test)

STATUS: Updated 10/25: 8 of 8 tools linked and running. Help pages online. Products now open in separate tabs. VCIS table fixed. Some additional development work occurring. See notes below each tool's link for additional information.

STEP 1

Set your fire location:

location used for tailored products.

Latitude 47.50 °N

Longitude -115.00 °E

Default location used.

Click on map or type location.

STEP 2

Select Your Tool:

- Smoke Guidance Point Forecast
- Smoke Guidance Regional Maps
- Diurnal Surface Wind Pattern Analysis
- Climatological Ventilation Index Point Statistics
- Current Air Quality Conditions Map
- Fire Information & Smoke Trajectories
- Customized Fuels, Consumption, & Smoke Modeling
- Probabilistic Smoke Impacts based on Past Weather

See below for tool description, attributes, and other details.

Filter by:

ATTRIBUTE

- [any]

Tool List

Current filter applied: none (viewing all products)

Smoke Guidance Point Forecast

localized text summary of atmospheric conditions affecting smoke

National FCAMMS Smoke Dispersion Forecast Guidance
GFS Forecast Initialization Time: 08/07/2009 12UTC

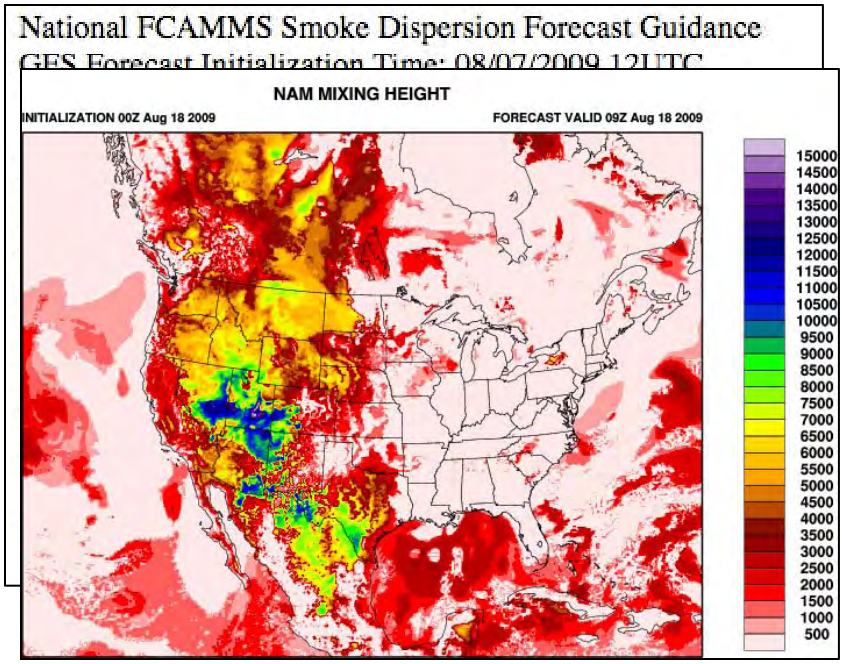
Forecast date/time (UTC)	08/07 12	08/08 00	08/08 12
Mixing height (ft-agl)	354	358	835
Mixing height wind speed (kt)	3	4	7
Mixing height wind direction	150	109	123
Ventilation rate (kt-ft)	1153	1454	5883
Haines Low	3	3	3
Haines Medium	3	3	3
Haines High	2	2	2
PM2.5 surface (ug/m^3)	-999	-999	-999

WFDSS-AQ Tools

- Smoke Guidance Point Forecast
- Smoke Guidance Maps
- RAWS Wind-roses
- Current Air Quality Monitoring Data
- Climatological Ventilation / Mixing Height Statistics
- Probablistic Smoke Impacts based on Climatology
- Custom While-you-wait Trajectories
- Custom While-you-wait Fuels, Fire Consumption, and Smoke Impact Modeling

- Each Tool briefly explained on website
- What is this? & How can I use it? information provided for each tool
- Tools labeled and searchable based on characteristics to help quickly identify what you are looking for

- Tools provided by USFS AirFire, DRI/CEFA, FCAMMS, STI



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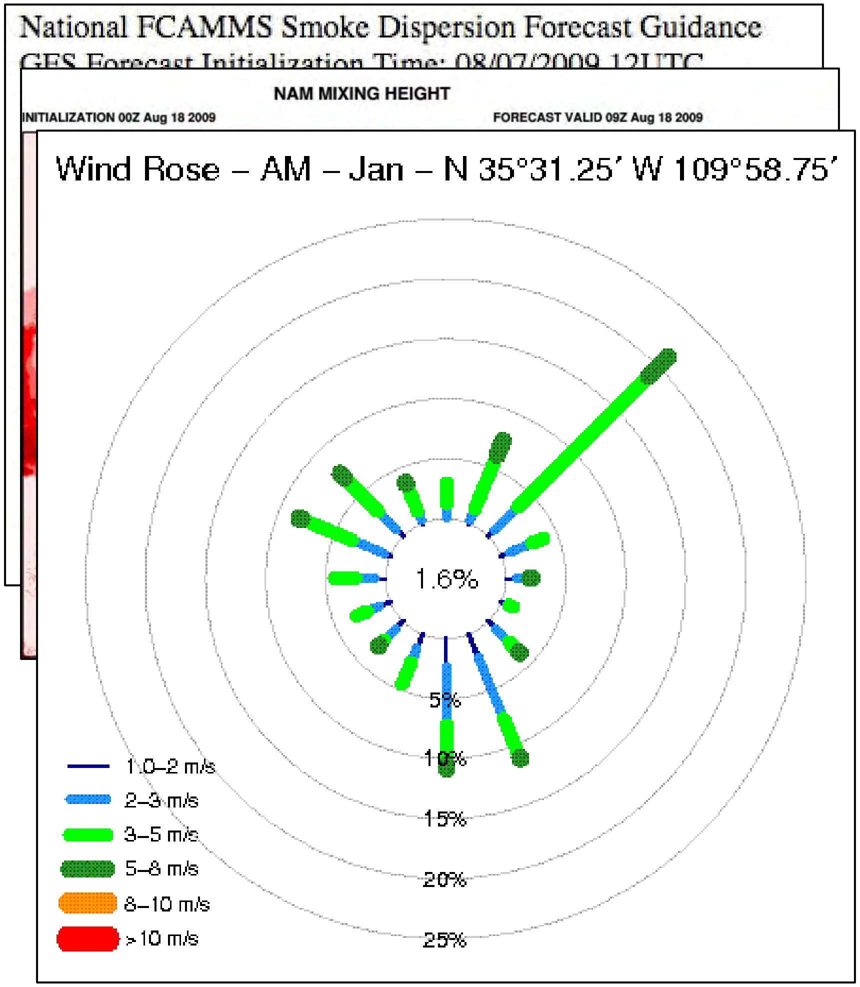

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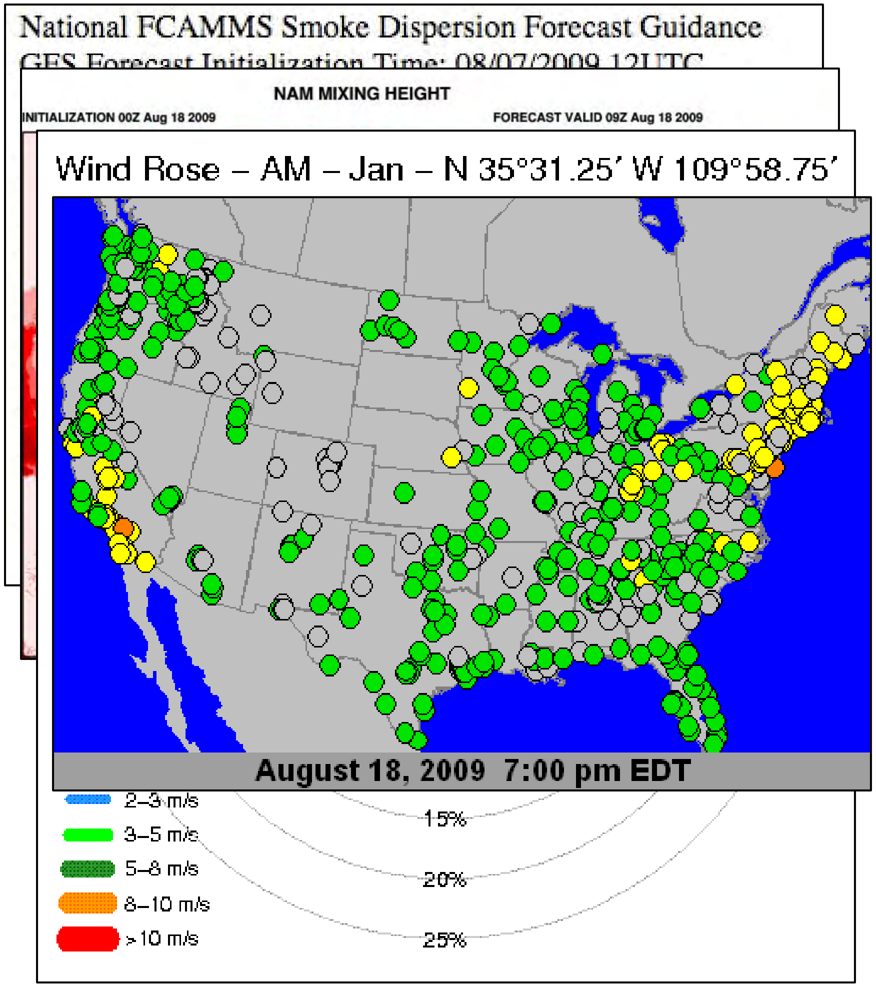

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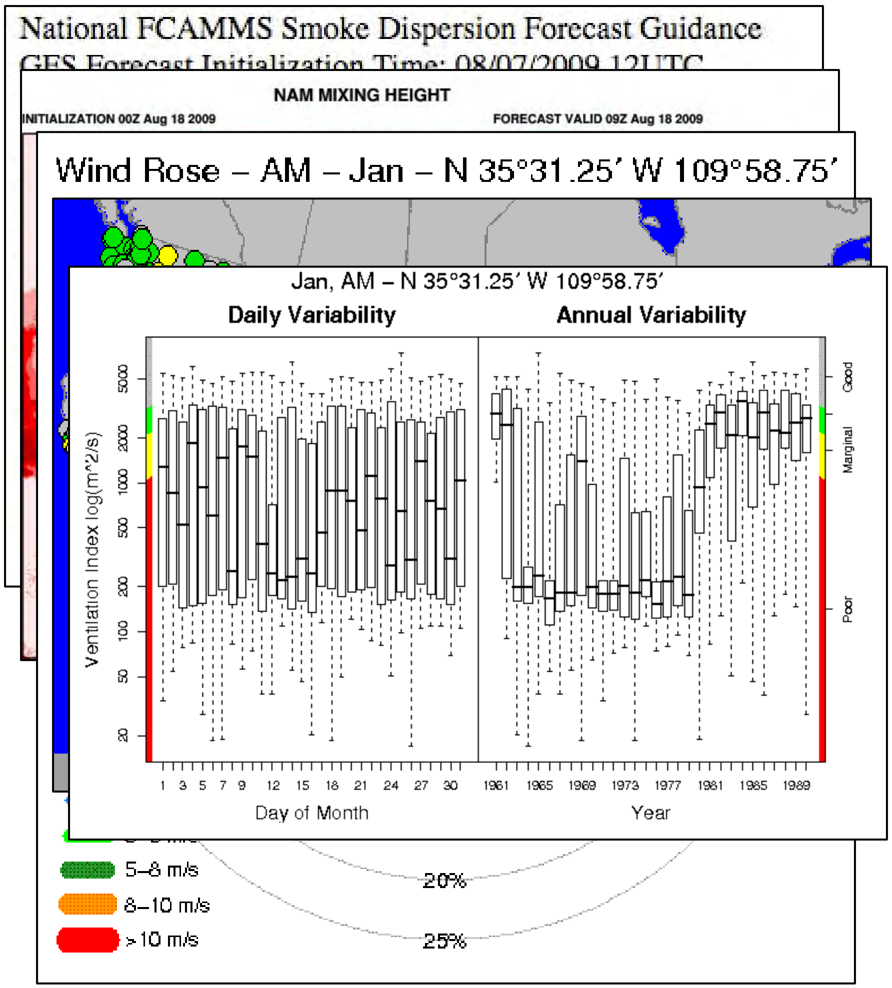

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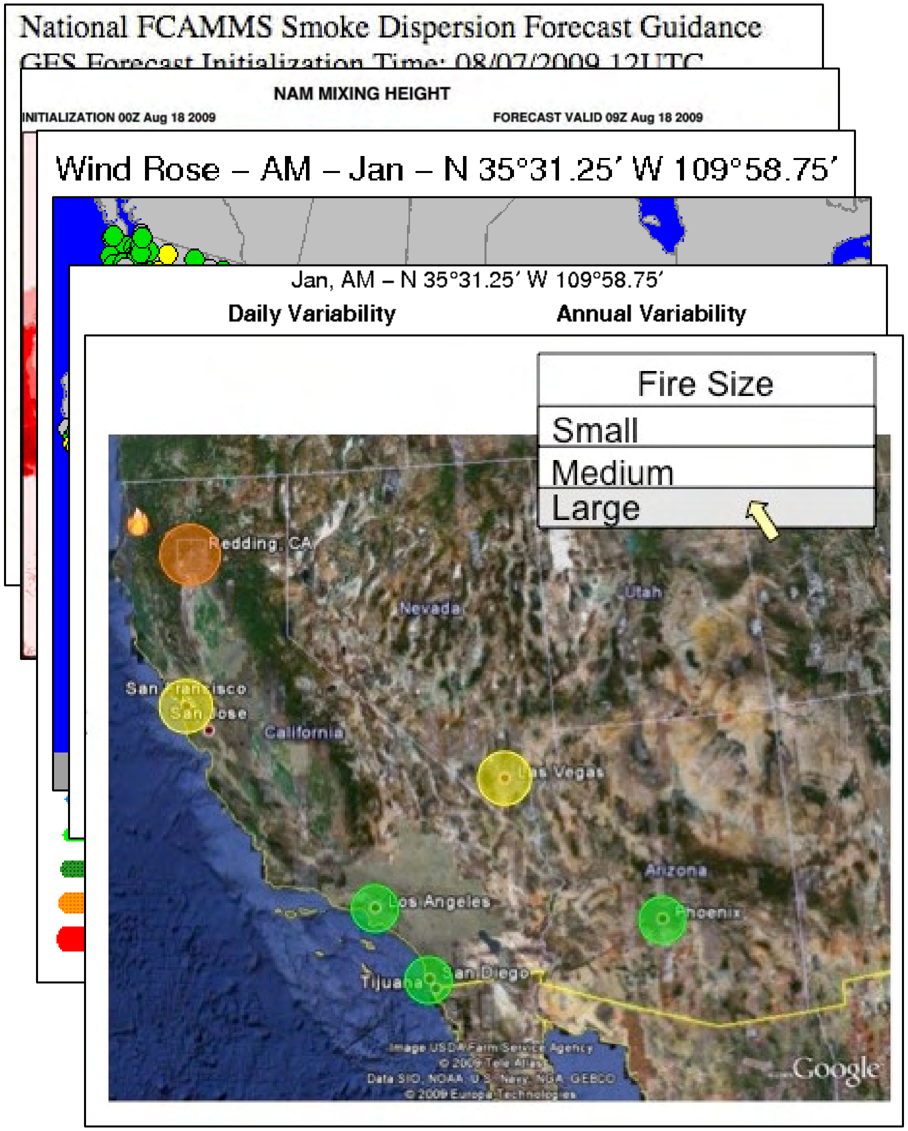

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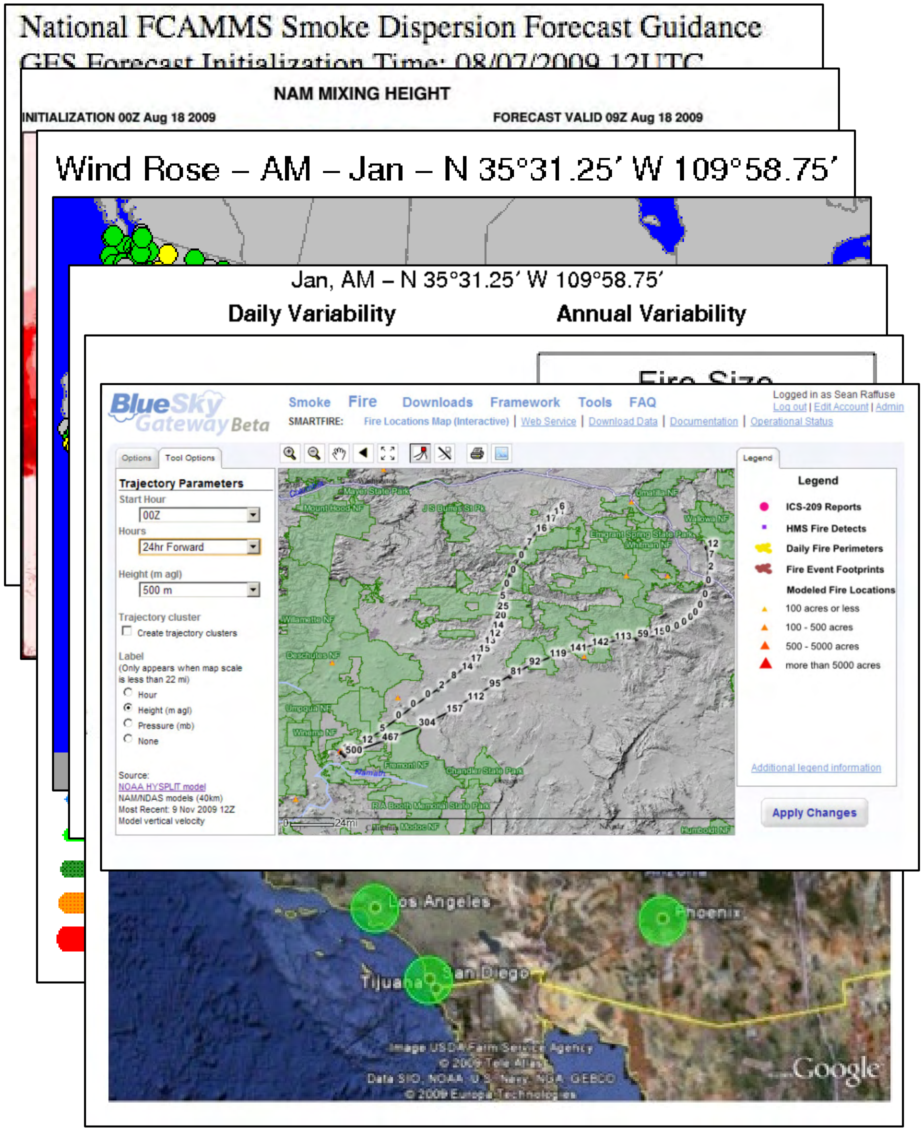

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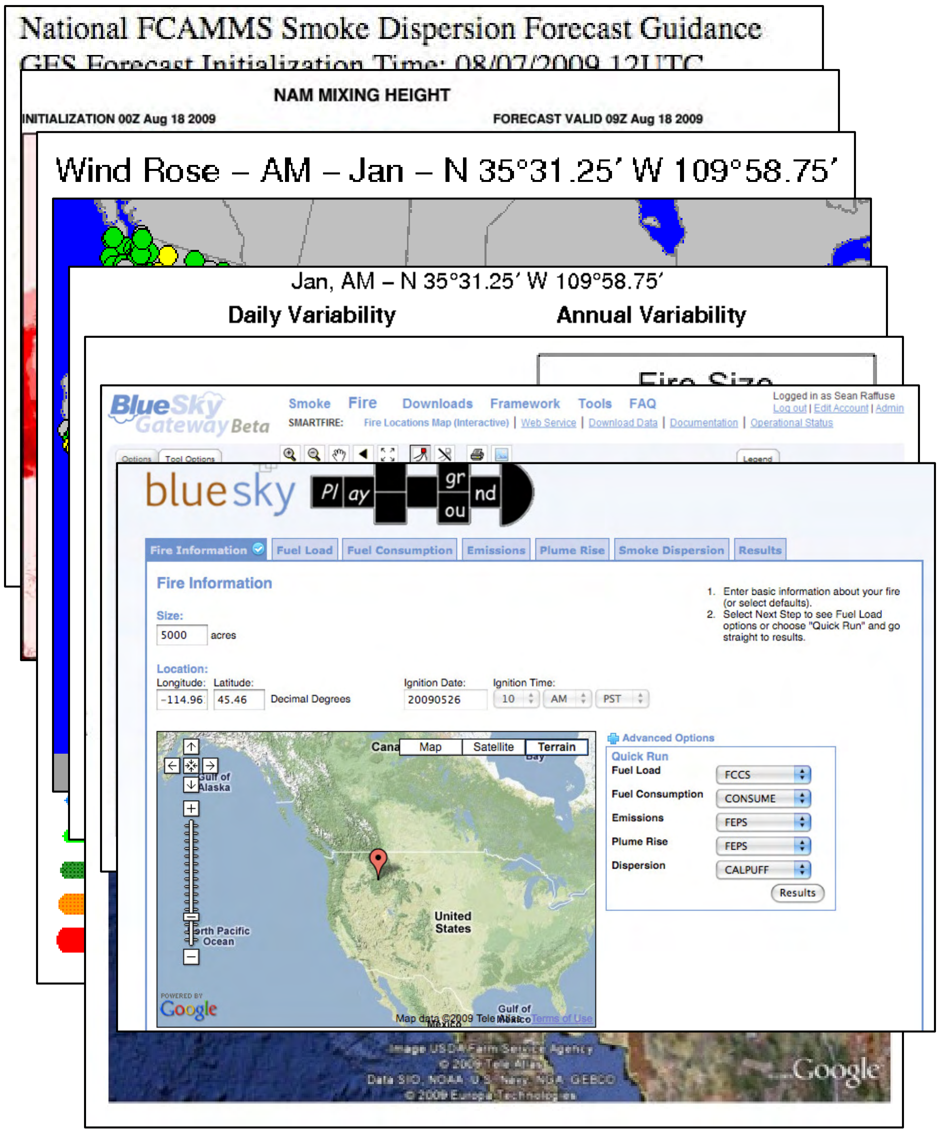

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New Research

- Smoke from low-intensity 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.

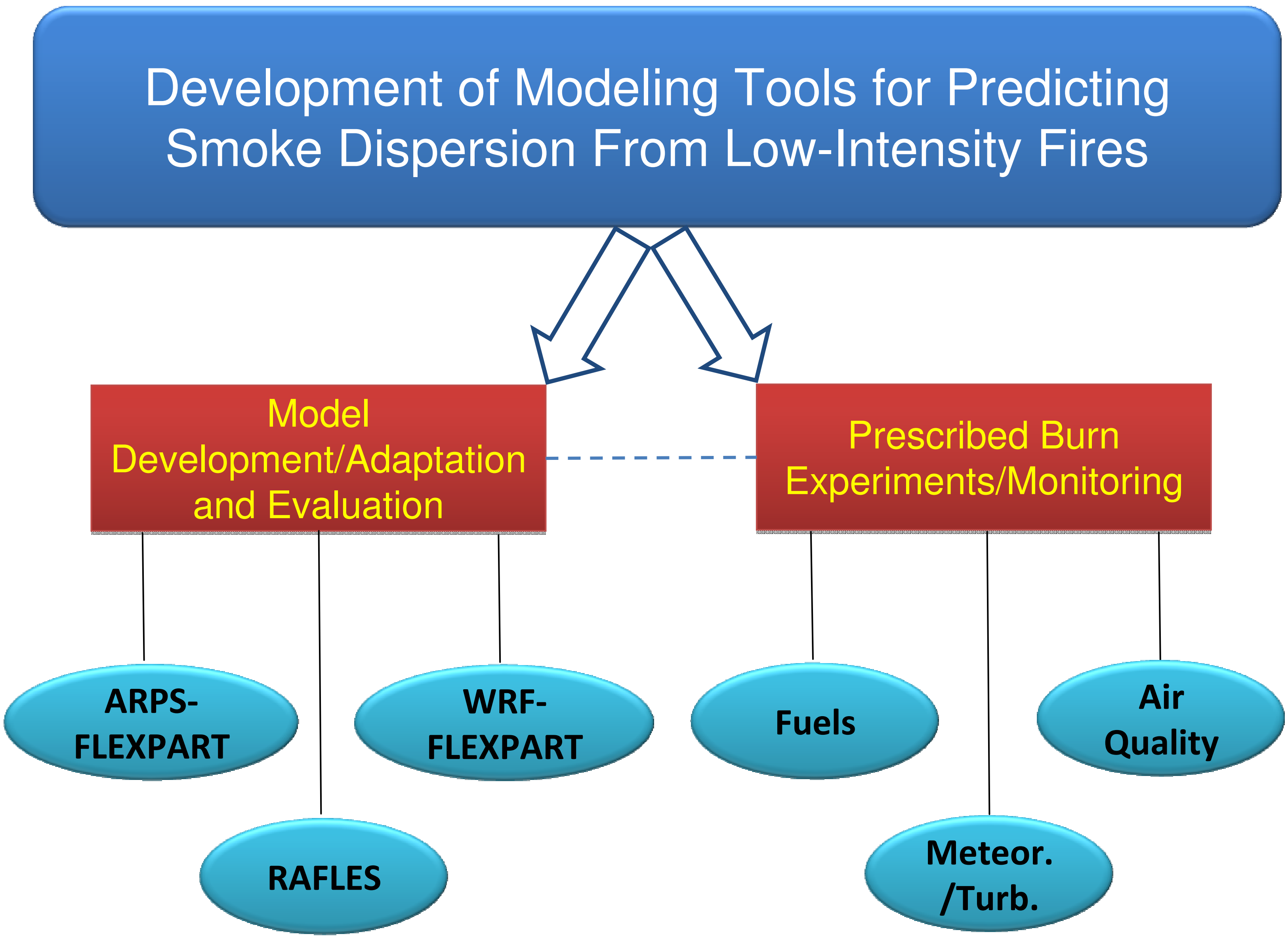
- The ability of current "operational" models/systems for predicting local smoke dispersion from wildland fires is limited because of their relatively coarse model resolutions and their inability to account for local topographic and vegetation effects.

- Thus, most current "operational" models/systems are not effective tools for smoke management associated with low-intensity fires that have primarily local smoke impacts.

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

Joint Fire Science Program
Research Supporting Sound Decisions
www.firescience.gov

- 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.

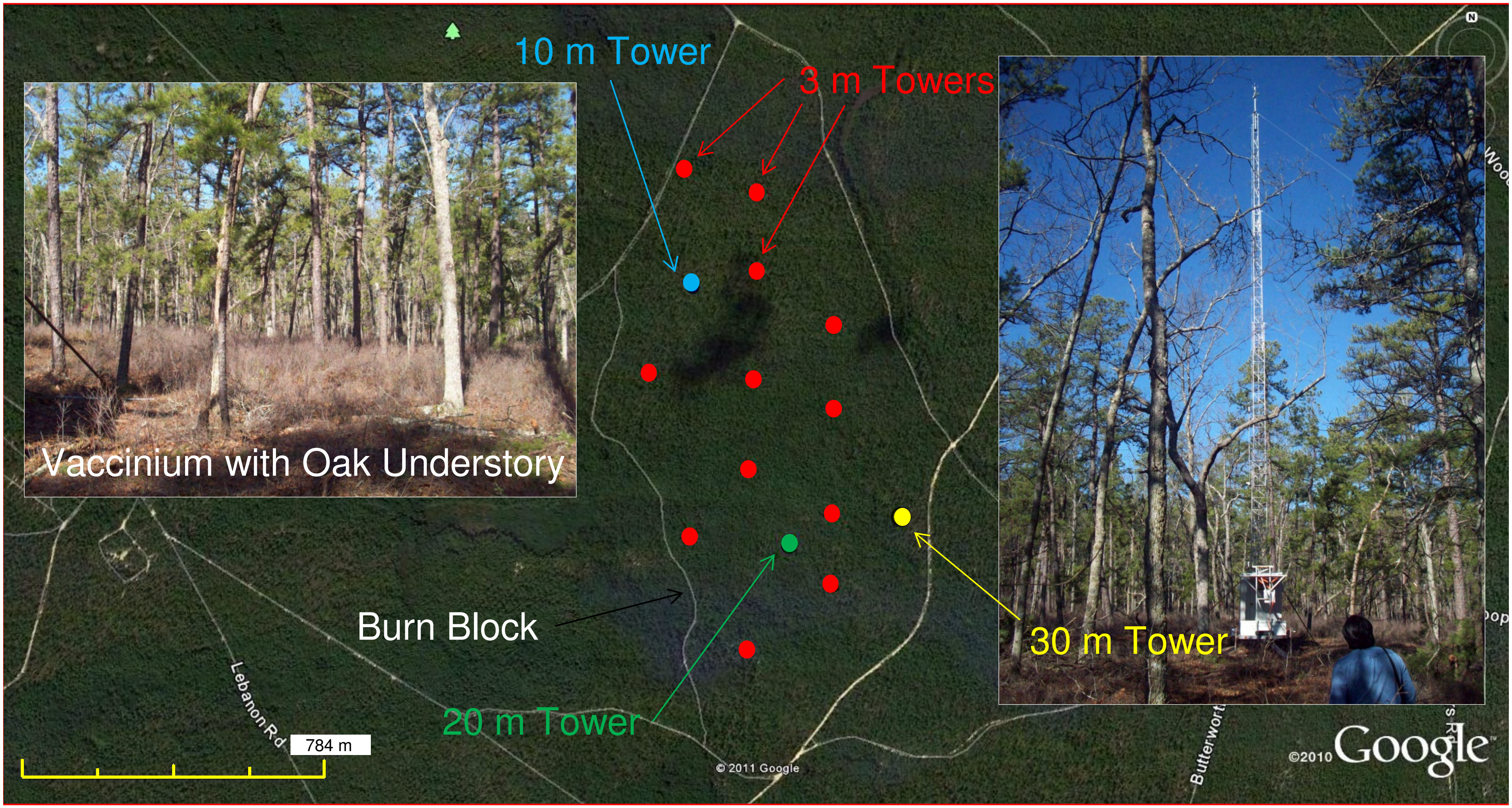

Development of Modeling Tools for Predicting Smoke Dispersion From Low-Intensity Fires
Model Development/Adaptation and Evaluation
Prescribed Burn Experiments/Monitoring
ARPS-FLEXPART
RAFLES
WRF-FLEXPART
Fuels
Meteor. /Turb.
Air Quality

Prescribed Burn Experiments/Monitoring

Prescribed Burn Experiment: 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

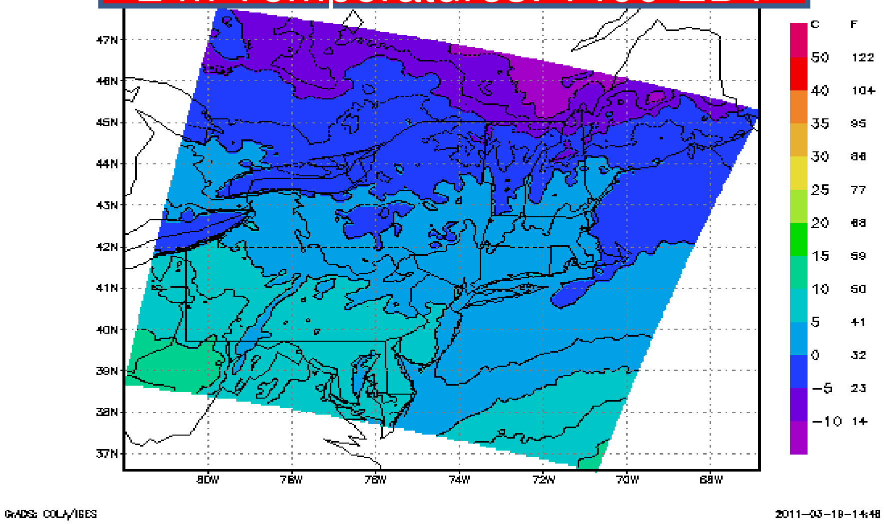
Prescribed Burn Experiment: Meteorological Monitoring Network



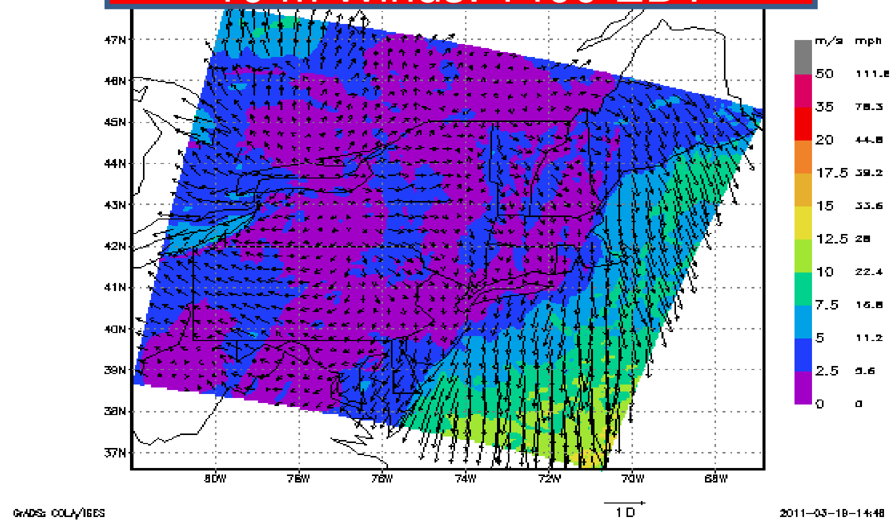
107 hectares (265 Acres); Pitch Pine Overstory (~18 m)

Prescribed Burn Experiment:
Ambient Meteorological Conditions – 20 March 2011

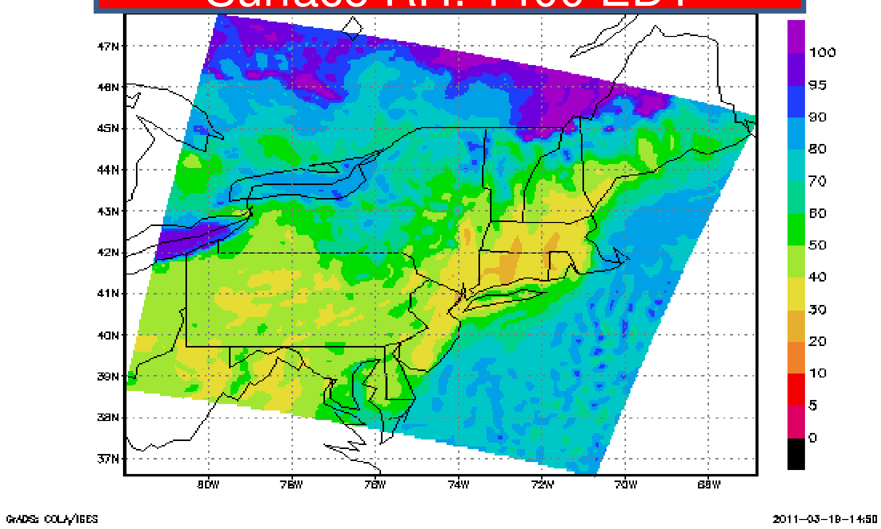
2 m Temperatures: 1400 EDT



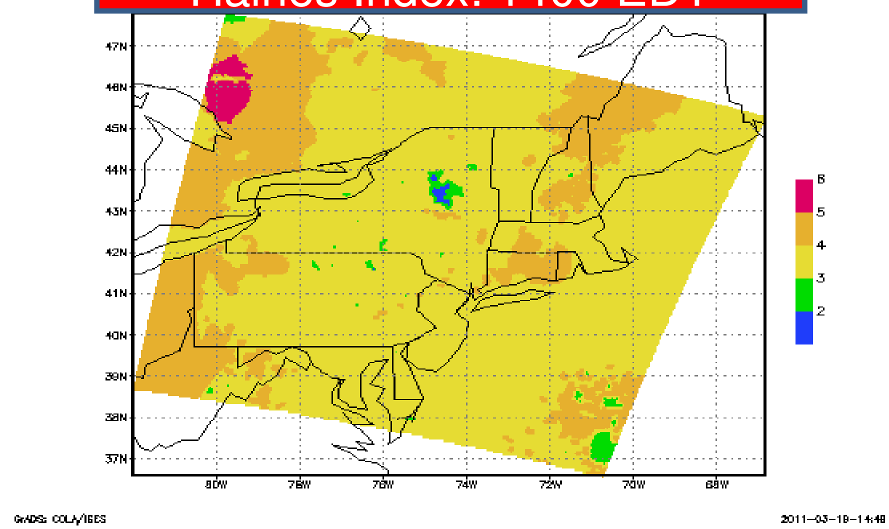
10 m Winds: 1400 EDT



Surface RH: 1400 EDT

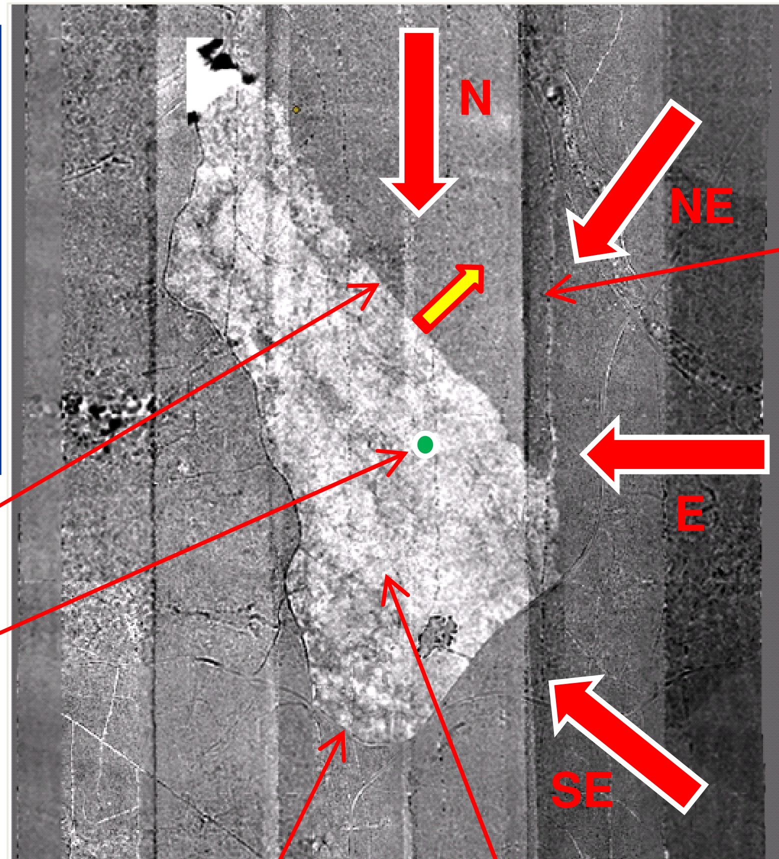


Haines Index: 1400 EDT



Prescribed Burn Experiment: Fire Line Progression

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}



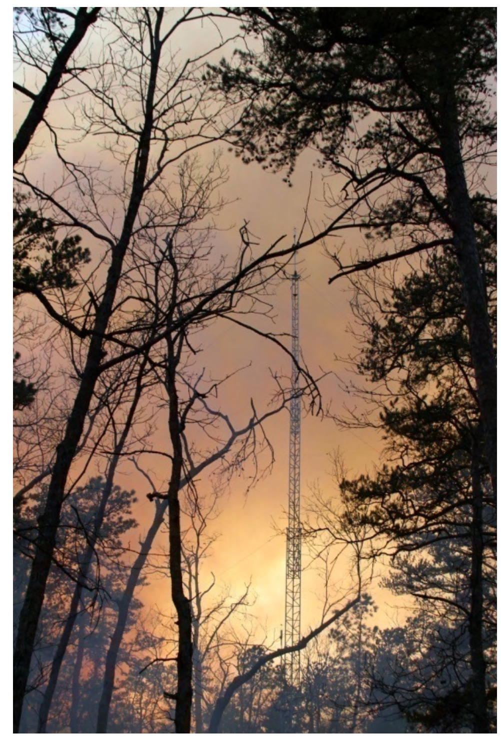
Fire Line Position: ~1715 EDT

20 m Tower

Unburned Area

Initial Ignition: ~1000 EDT

Burned Area



Temperatures

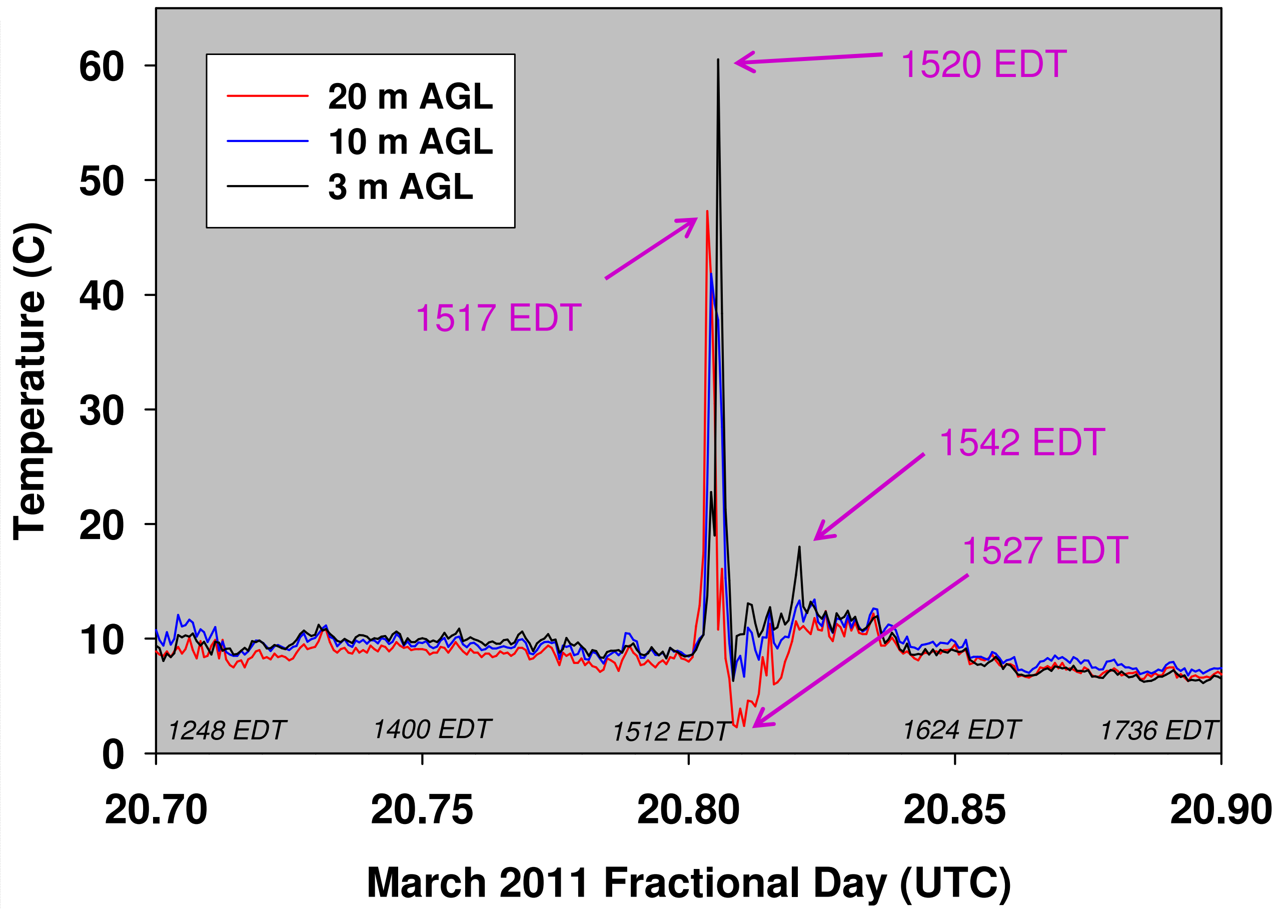
- Convective plume reached the tower top ~3 minutes before fire line passage (enhanced stability 3<z<20m).

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

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

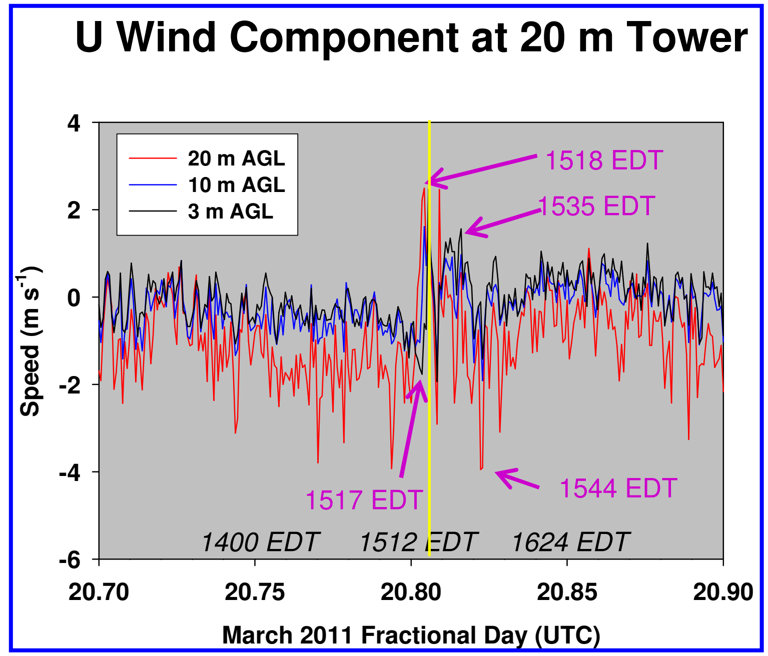
- Temperatures rebounded to ~2-3℃ above ambient temperature ~25 minutes after fire line passage and then gradually decreased.

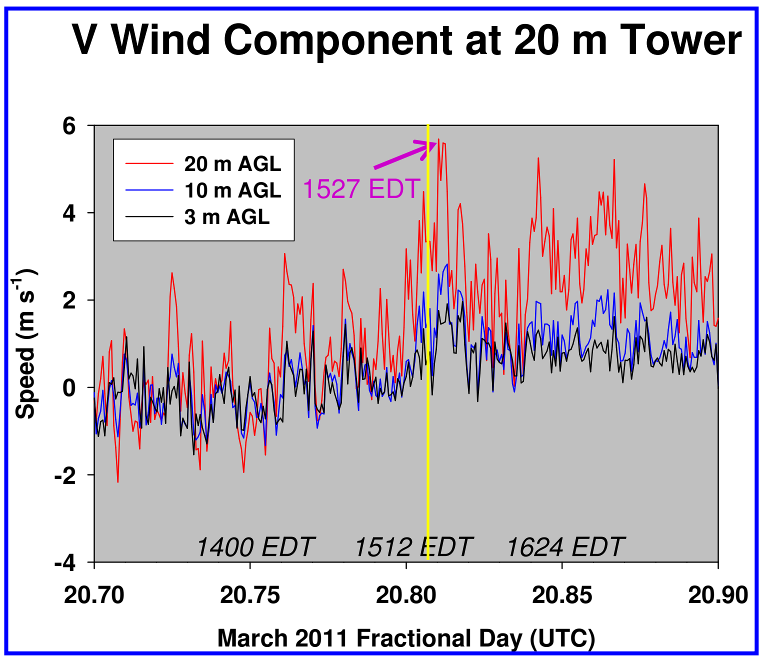
Temperatures at 20 m Tower

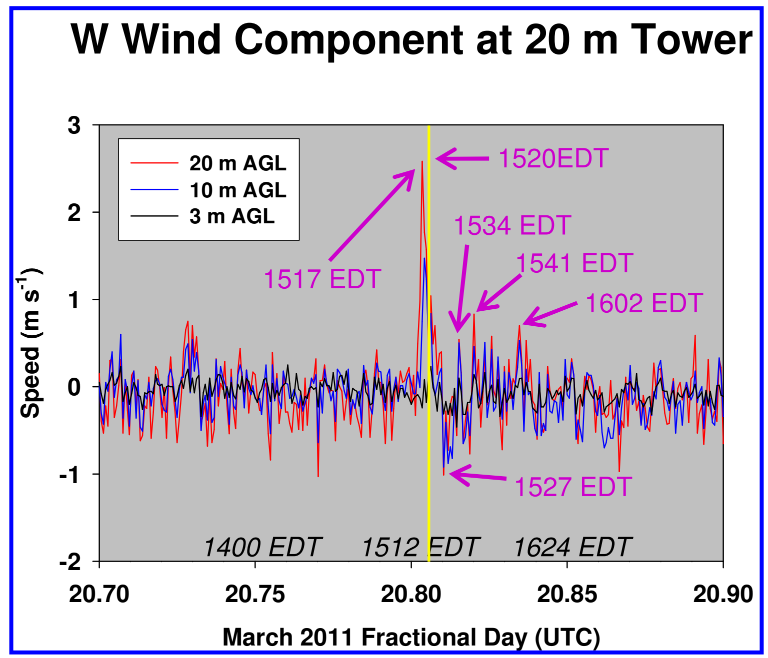


Wind Speed

- 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.







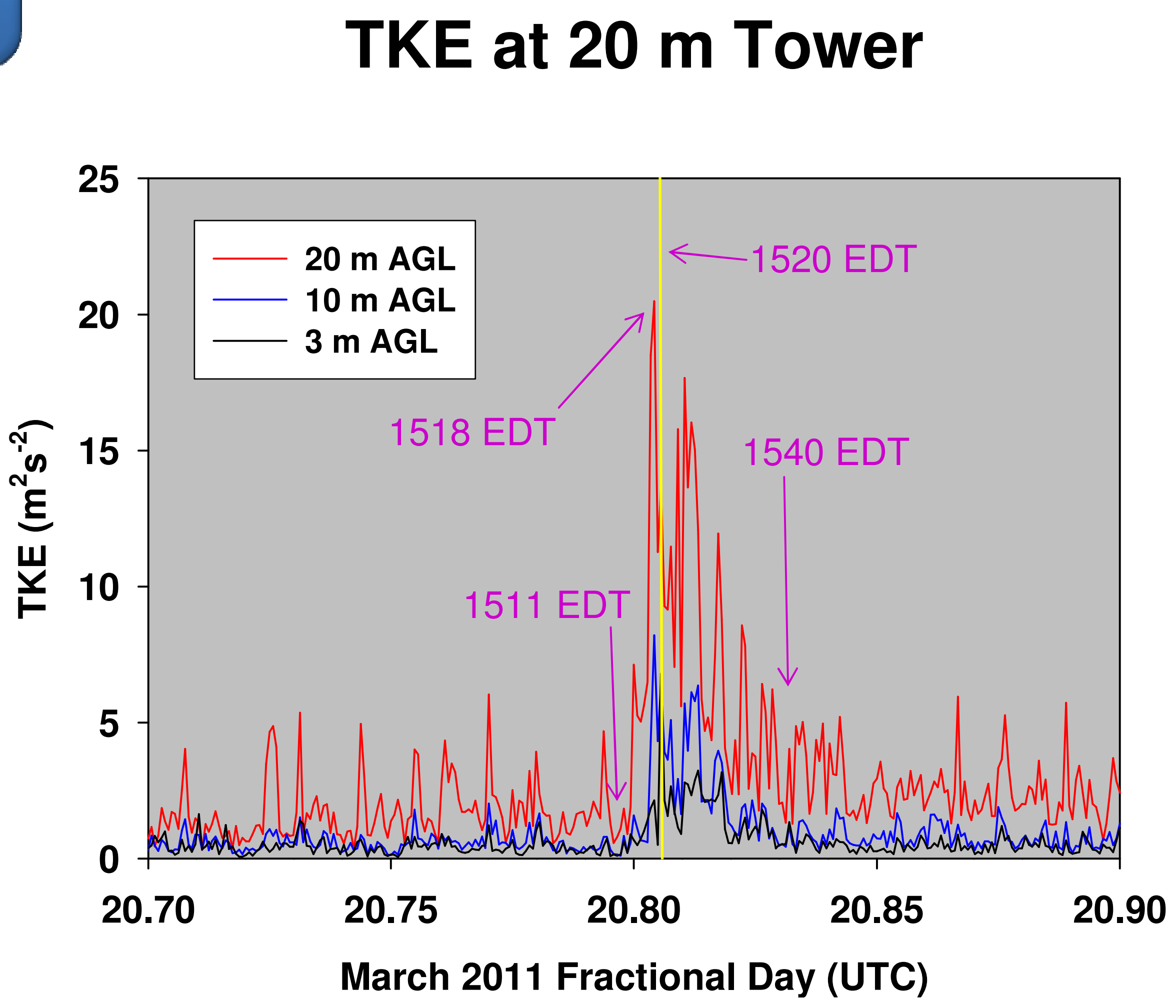
Turbulent Kinetic Energy

- 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.

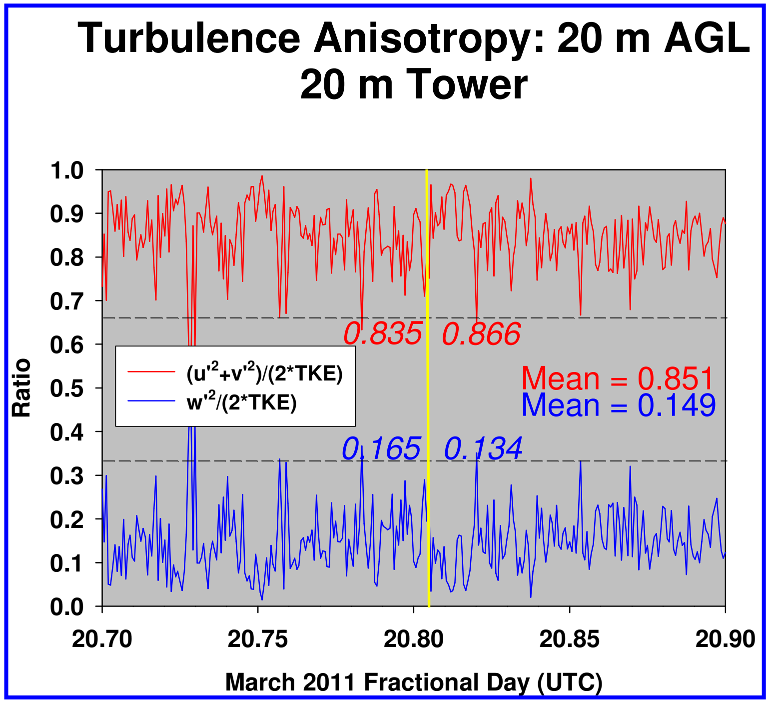
- Very turbulent during and after fire line passage.

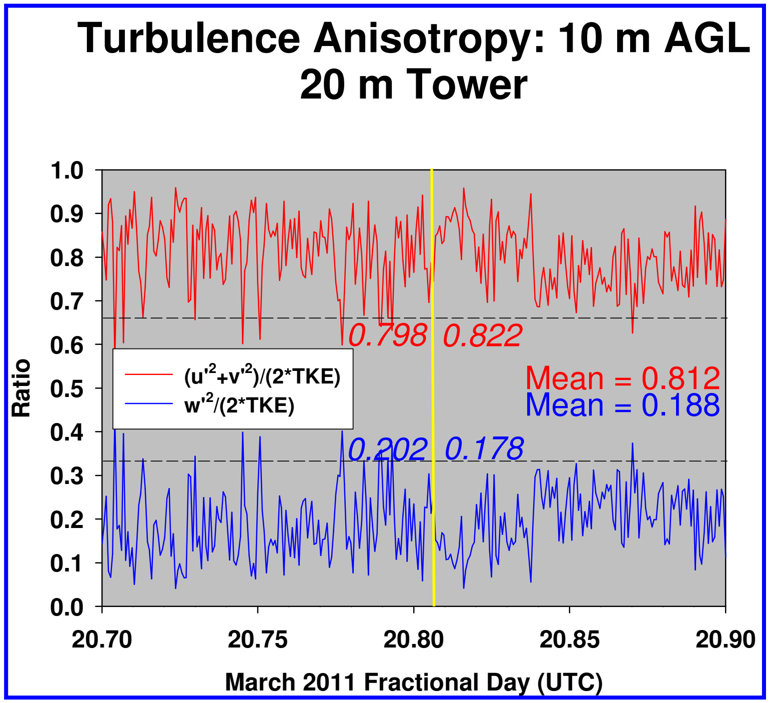
- TKE values near the surface drop to pre-fire line passage values ~20 minutes after fire line passage.

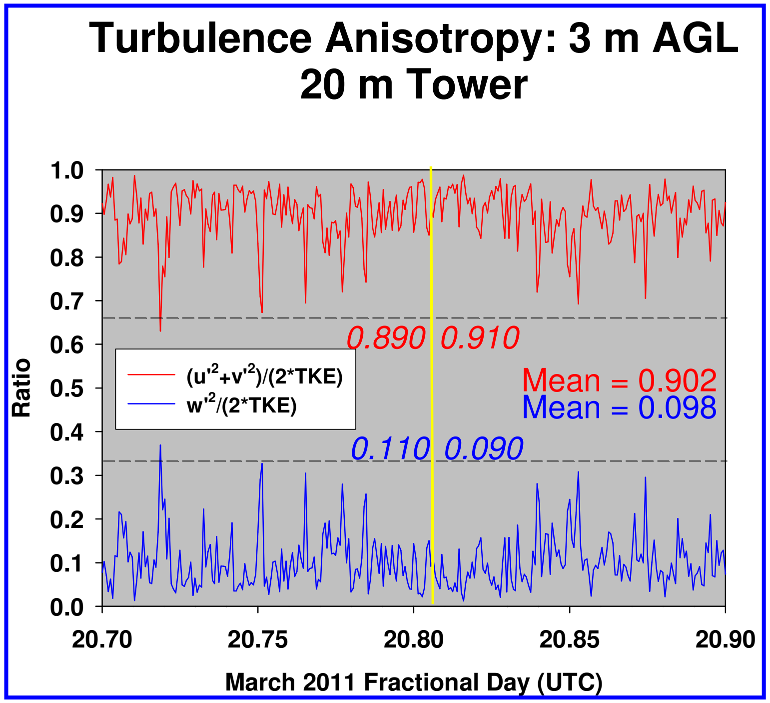


Turbulence Anisotropy

- Turbulence anisotropy is prevalent within and above the forest canopy.
- Most anisotropic near the surface and above the canopy; most of the TKE contained in the horizontal components.
- Turbulence more anisotropic immediately following fire line passage than before.

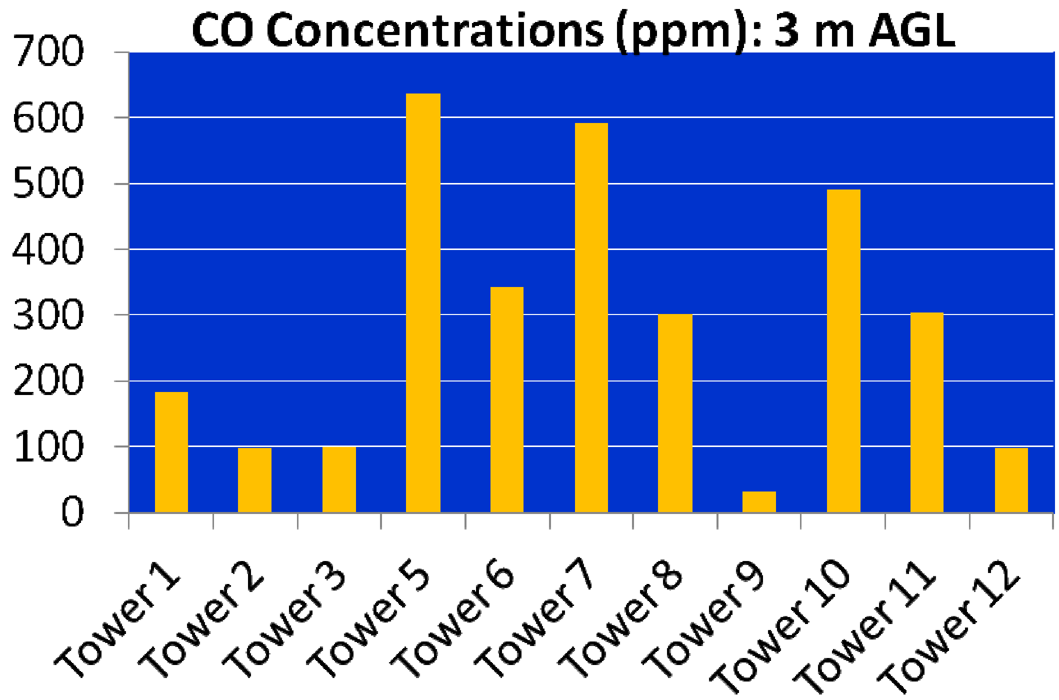




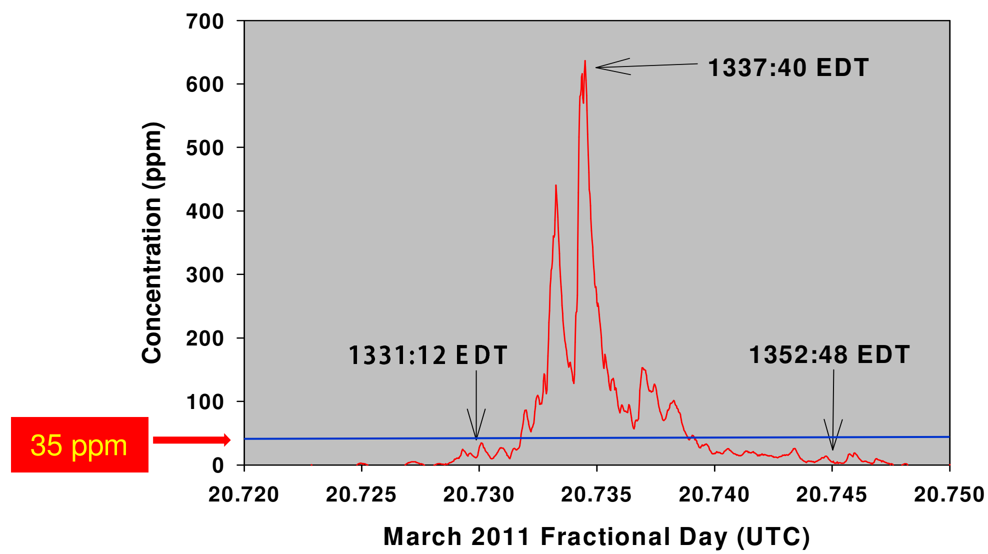


CO Concentrations

- 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).



Tower 5: CO Concentrations



Model Development/Adaptation and Evaluation

Modeling of Smoke Dispersion from Low-Intensity Fires

- Particularly challenging due to the effect on dispersion of critical factors such as
  - near-surface meteorological conditions
  - local topography
  - vegetation
  - atmospheric turbulence within and above vegetation layers
- Important: Exchange of particles through vegetation canopy

Overall Modeling Strategy

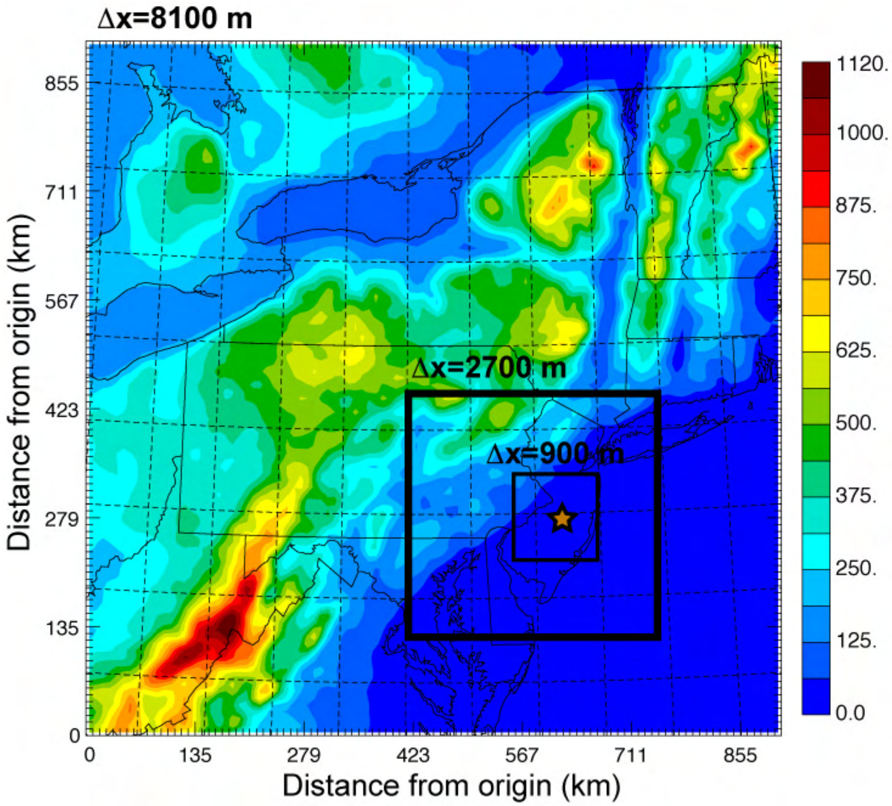
- Run simulations of prescribed fire cases using selected NWP models:
  - Advanced Regional Prediction System (ARPS), WRF, RAFLES
  - Primary validation datasets: 20 March 2011 and Feb.-Mar. 2012 prescribed burns in the NJ Pine Barrens
- Provide meteorological data to dispersion module: FLEXPART

ARPS Model Overview

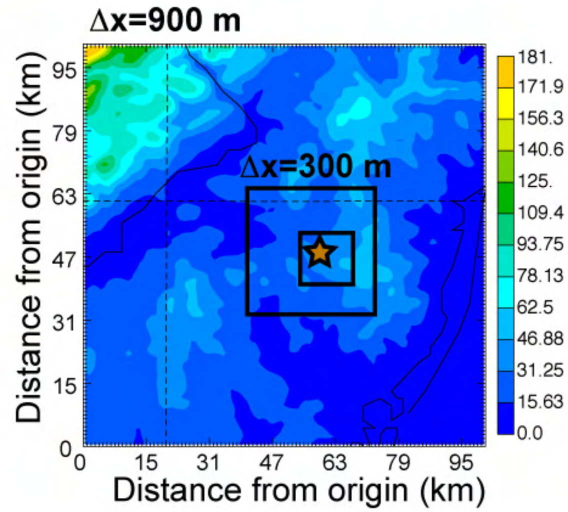
- Advanced Regional Prediction System (ARPS) Version 5.2.12 (Xue et al. 2003)
  - Three-dimensional atmospheric modeling system
  - Designed to simulate microscale [O(10 m)] through regional scale [O(10^6 m)] flows
- Standard ARPS lacks the capability to model atmospheric variables (e.g, wind, temperature) 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

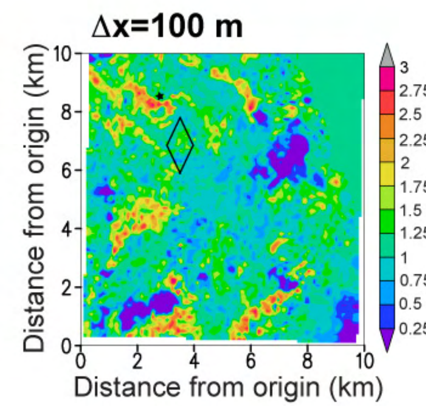
- Model initialized from North American Regional Reanalysis at 00 UTC 19 Mar 2011
- Five 1-way nested domains: $\Delta x = \Delta y$ = 8100m, 2700m, 900m, 300m, 100m
- Innermost nest: Vertical grid spacing is 2 m (9 levels, on average, inside canopy)
- Canopy applied to innermost nest only. Bulk effect of canopy represented by frontal area density, which when vertically integrated yields leaf area index (LAI)



Surface elevation (m)



Leaf area index (LAI)

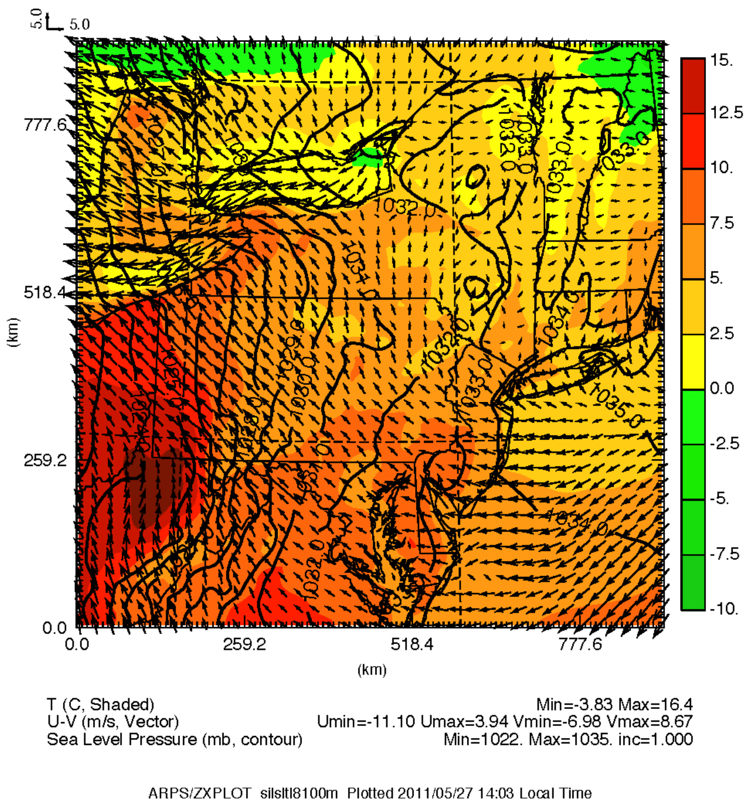


Data source: N. Skowronski, USFS NRS

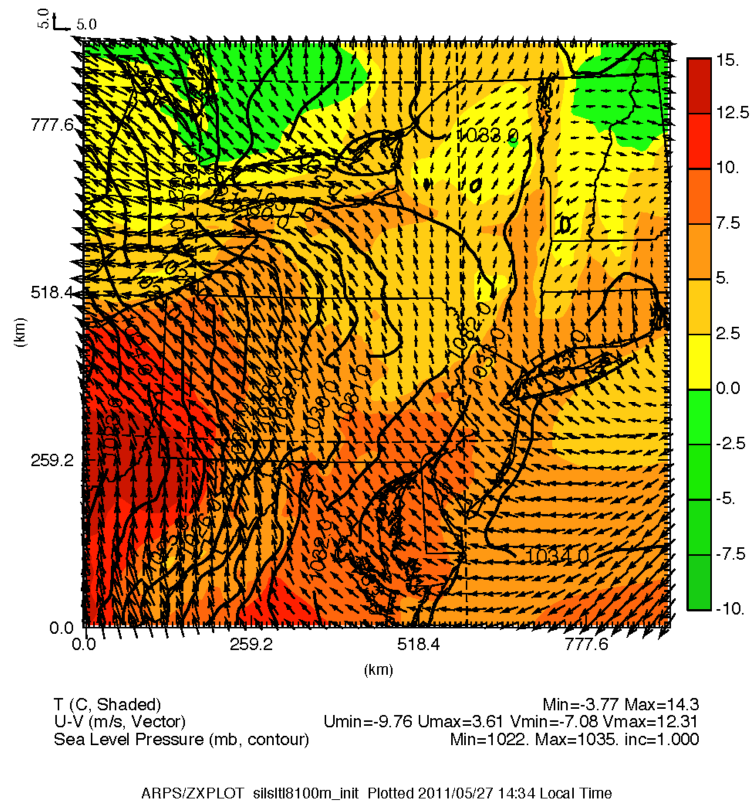
ARPS Simulation Results

Outermost grid: Instantaneous surface fields

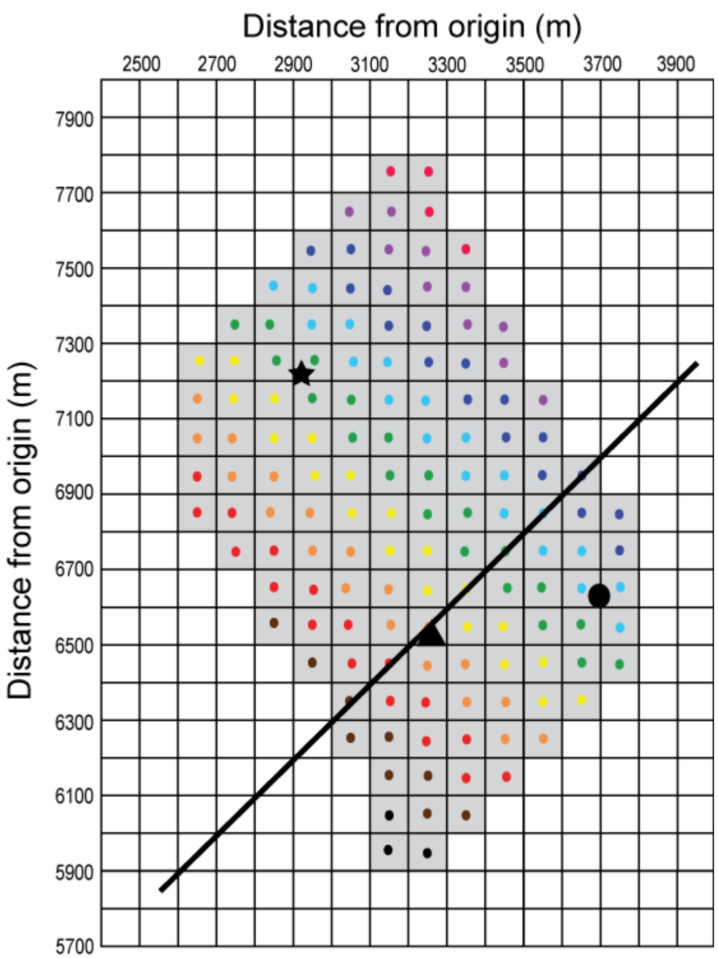
ARPS – 1700 EDT 20 Mar

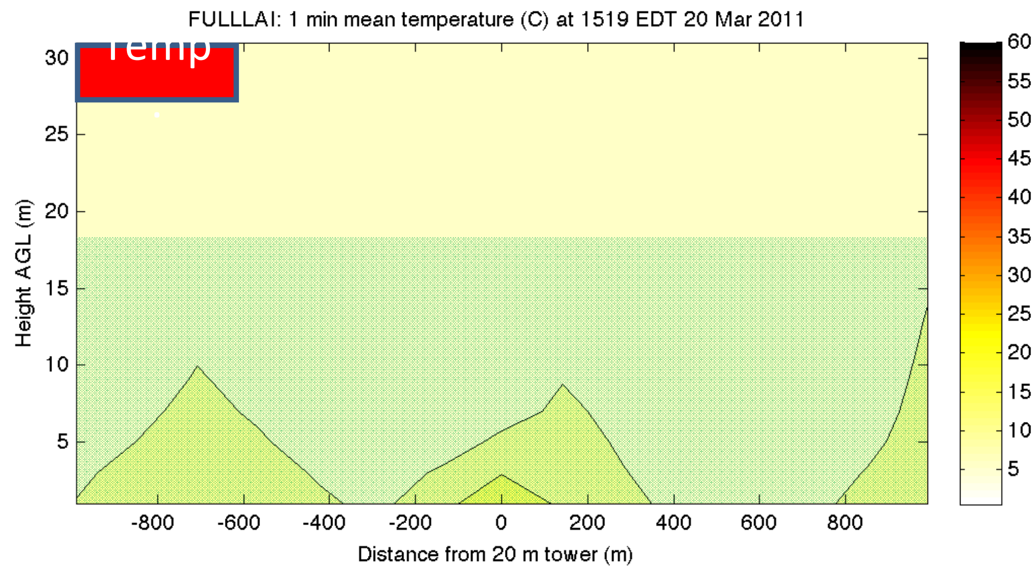


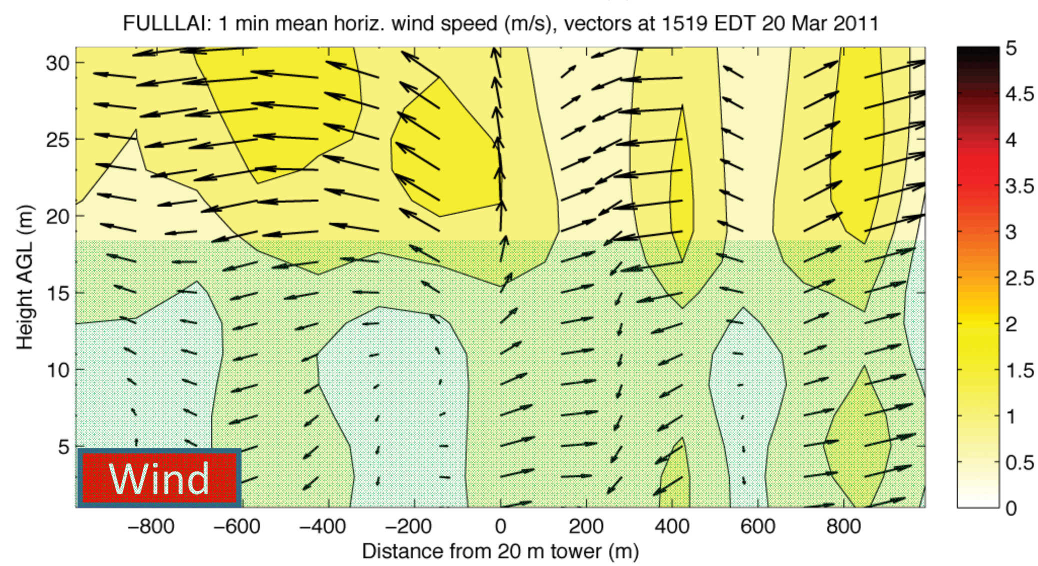
NARR – 1700 EDT 20 Mar



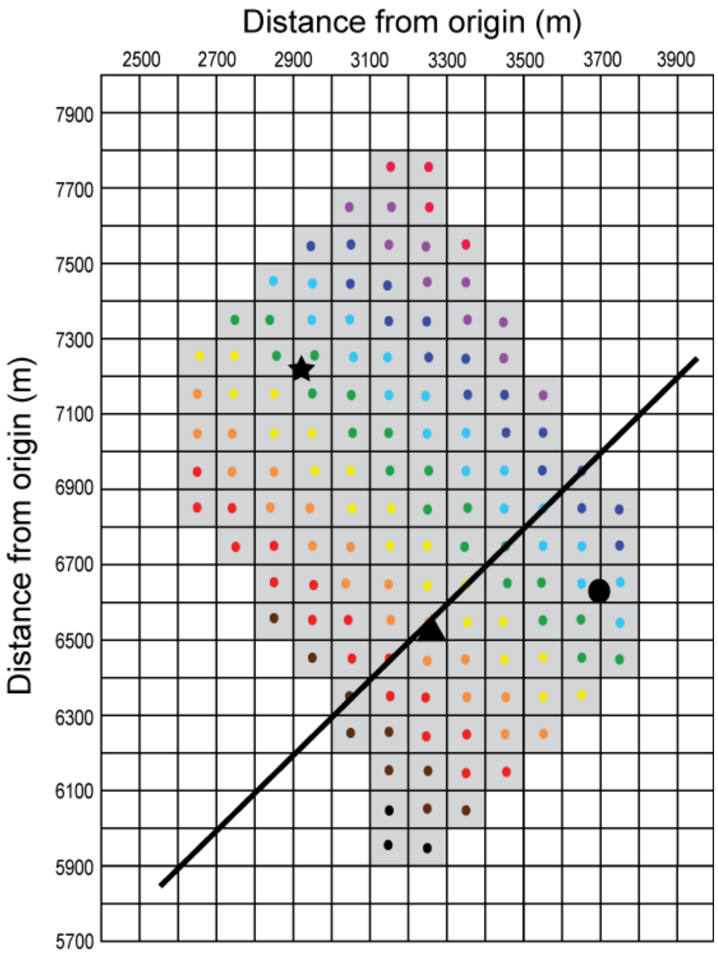
Example Temperature and Wind Predictions: 1519-1529 EDT, 20 March 2011

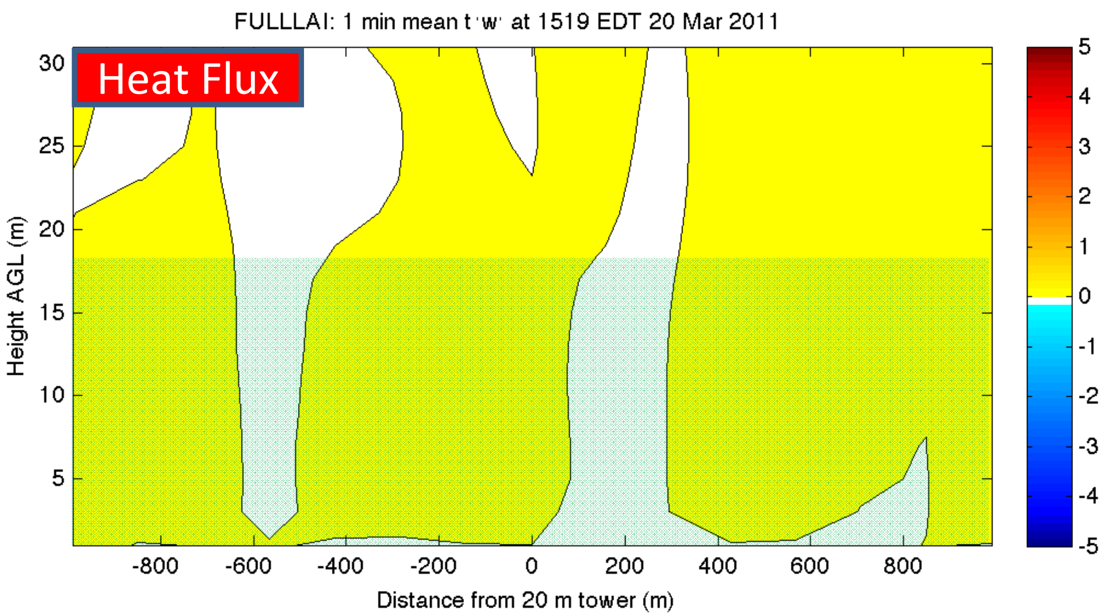




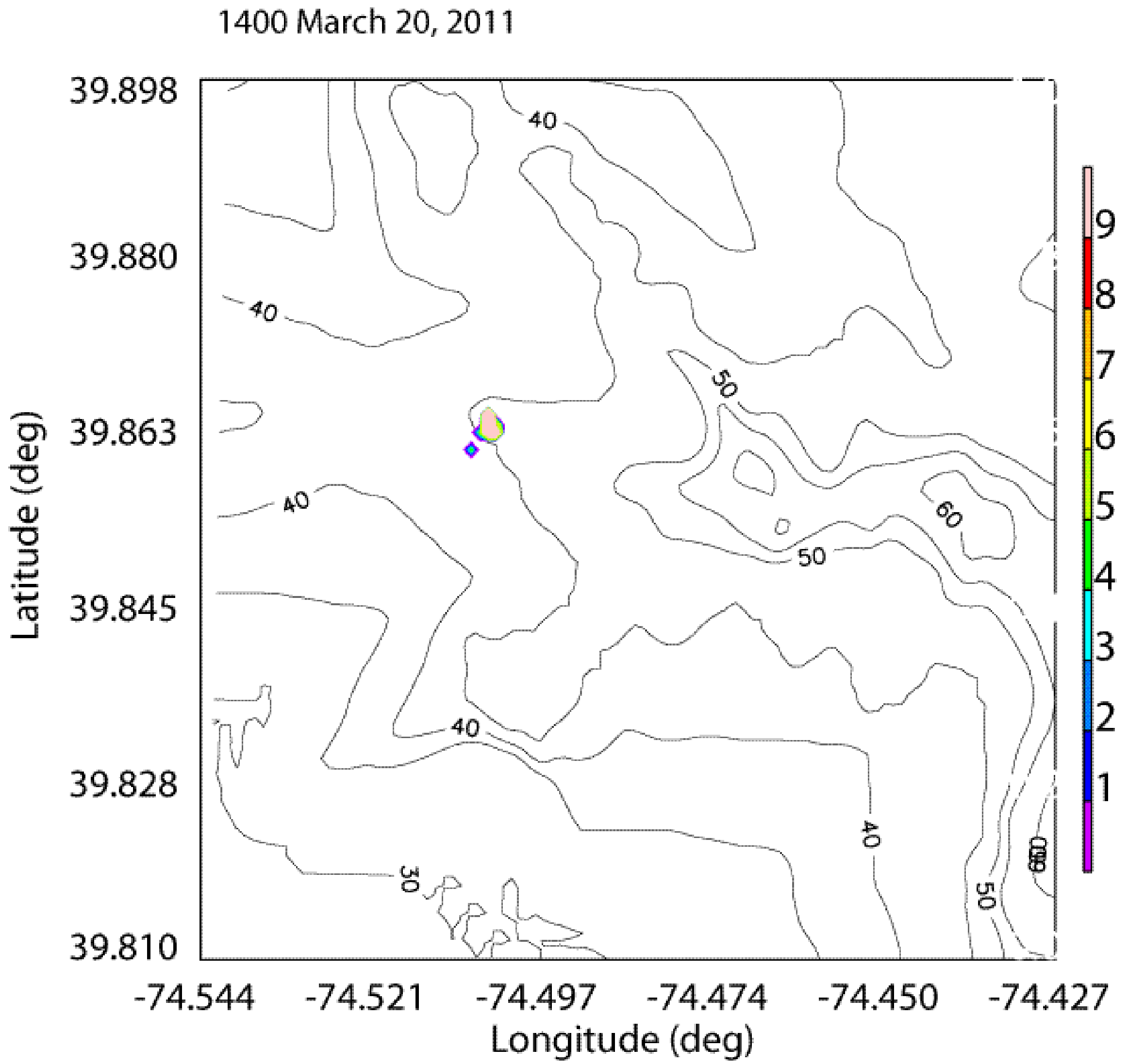


Example Turbulent Heat Flux Predictions: 1519-1529 EDT, 20 March 2011





Example FLEXPART CO Concentration Predictions: 1000-2000 EDT, 20 March 2011



Next Steps

- Complete a 2nd prescribed burn experiment in the NJ Pine Barrens (Feb.-Mar., 2012).
- 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
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