Getting a Handle on Local Smoke Transport During Prescribed Fires

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)
<table>
<thead>
<tr>
<th>Pollutant</th>
<th>Standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon monoxide</td>
<td>9 ppm (8 hrs); 35 ppm (1 hr)</td>
</tr>
<tr>
<td>Lead</td>
<td>15 µg m$^{-3}$ (3 mo. avg.)</td>
</tr>
<tr>
<td>Nitrogen dioxide</td>
<td>53 ppb (annual); 100 ppb (1 hr)</td>
</tr>
<tr>
<td>Ozone</td>
<td>0.0075 ppm (8 hrs)</td>
</tr>
<tr>
<td>Particulates (PM$_{2.5}$)</td>
<td>15 µg m$^{-3}$ (annual); 35 µg m$^{-3}$ (1 hr)</td>
</tr>
<tr>
<td>Sulfur dioxide</td>
<td>0.5 ppm (3 hrs); 75 ppb (1 hr)</td>
</tr>
</tbody>
</table>
Nonattainment Areas for PM$_{2.5}$ (2006 Standard)
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.

\[ VI = \text{mixing height} \times \text{avg. wind speed in mixed layer} \]

- Daily predictions available from NWS forecast offices and other sources.

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**Smoke Condition**

<table>
<thead>
<tr>
<th>VI (m(^2) s(^{-1}))</th>
<th>Smoke Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;2,350</td>
<td>Poor</td>
</tr>
<tr>
<td>2,350-4,700</td>
<td>Marginal</td>
</tr>
<tr>
<td>4,700-7,050</td>
<td>Fair</td>
</tr>
<tr>
<td>&gt;7,050</td>
<td>Good</td>
</tr>
</tbody>
</table>

http://www.nrs.fs.fed.us/eamc/products/
Atmospheric Dispersion Index

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

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

<table>
<thead>
<tr>
<th>ADI</th>
<th>Smoke Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-6</td>
<td>Very Poor</td>
</tr>
<tr>
<td>7-12</td>
<td>Poor</td>
</tr>
<tr>
<td>13-20</td>
<td>Poor (Day), Above avg. (night)</td>
</tr>
<tr>
<td>21-40</td>
<td>Fair</td>
</tr>
<tr>
<td>41-60</td>
<td>Generally Good</td>
</tr>
<tr>
<td>61-100</td>
<td>Good</td>
</tr>
<tr>
<td>&gt;100</td>
<td>Very Good (hazard. burn conditions)</td>
</tr>
</tbody>
</table>
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
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

Fuel type and loading obtained from BlueSky Framework.

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

- Latitude 47.50 °N
- Longitude -115.00 °E

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.

Tool List
Current filter applied: none (viewing all products)

Smoke Guidance Point Forecast
localized text summary of atmospheric conditions affecting smoke
WFDSS-AQ Tools

- Smoke Guidance Point Forecast
- Smoke Guidance Maps
- RAWS Wind-roses
- Current Air Quality Monitoring Data
- Climatological Ventilation / Mixing Height Statistics
- Probabilistic 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
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.
• 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

- ARPS-FLEXPART
- RAFLES

Prescribed Burn Experiments/Monitoring

- 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

- 3 m Towers
- 10 m Tower
- 20 m Tower

Meteorological Monitoring Network

- 107 hectares (265 Acres); Pitch Pine Overstory (~18 m)
- Vaccinium with Oak Understory

Burn Block

30 m Tower

20 m Tower

10 m Tower

3 m Towers
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

Initial Ignition:
~1000 EDT

Burned Area

Unburned Area
Temperatures at 20 m Tower

- 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.
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.

Turbulence Anisotropy: 10 m AGL
20 m Tower

Turbulence Anisotropy: 20 m AGL
20 m Tower

Turbulence Anisotropy: 3 m AGL
20 m Tower

Mean = 0.851
Mean = 0.149
Mean = 0.812
Mean = 0.188
Mean = 0.902
Mean = 0.098
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).
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
Run simulations of prescribed fire cases using selected NWP models:

- Advanced Regional Prediction System (ARPS), WRF, RAFLES

Provide meteorological data to dispersion module: FLEXPART
• Advanced Regional Prediction System (ARPS) Version 5.2.12 (Xue et al. 2003)
  – Three-dimensional atmospheric modeling system
  – Designed to simulate microscale \[O(10 \text{ m})\] through regional scale \[O(10^6 \text{ m})\] 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: $\Delta x = \Delta y = 8100\text{m}, 2700\text{m}, 900\text{m}, 300\text{m}, 100\text{m}$
- 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)

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

[Graph showing temperature and wind predictions]
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 2\textsuperscript{nd} 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