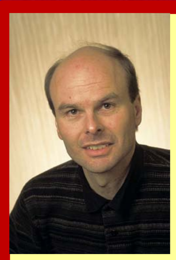

Development and Validation of Modeling Tools for Predicting Smoke Dispersion During Low-Intensity Fires

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Project Goal and Hypotheses

Study Goal

Adapt three existing numerical models for predicting short-range smoke transport and diffusion from low intensity fires and evaluate their performance using observational data from prescribed burn experiments.

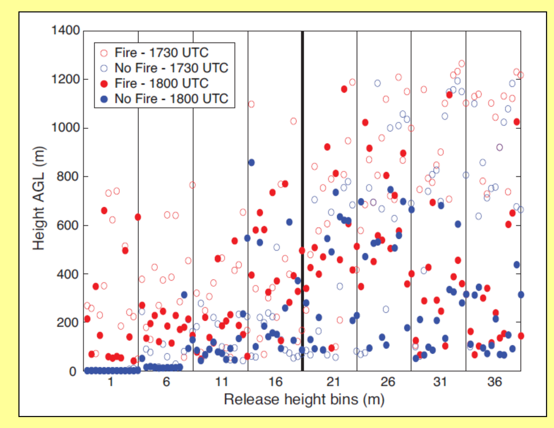
Study Hypotheses

- Land-surface characteristics, such as terrain and forest vegetation, and near-surface atmospheric processes induced by variations in terrain and vegetation can have significant impacts on smoke transport and diffusion from low-intensity fires.
- Improved understanding of these impacts will lead to better predictions of smoke transport and dispersion over areas of complex terrain and forest vegetation.

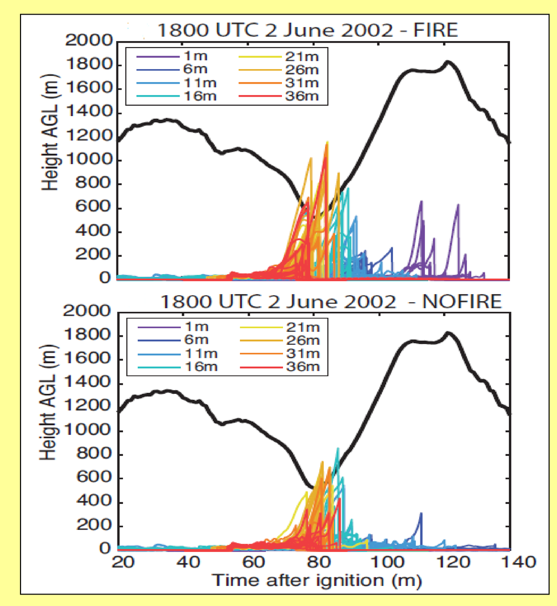
ARPS-FLEXPART

The Advanced Regional Prediction System (ARPS) (Xue et al. 2000) coupled with the FLEXPART particle dispersion model (Fast and Easter 2006) has been modified/adapted to predict the local atmospheric transport and diffusion of smoke from fires within forest vegetation layers and to simulate the effects of forest vegetation on that transport.

Test simulations have been carried out (nested grids from 9 km to 100 m grid spacing) of a 1-km diameter low-intensity surface "fire" within an 18 m tall forest with a surface heat flux of 800 W m^{-2} "ignited" at 1700 UTC in the New Jersey Pine Barrens at the same location where the 2 June 2002 Double Trouble State Park wildfire occurred, using the same "meteorology" that occurred that day. The movement of air parcels released at different heights within and above the vegetation layer immediately upwind of the "fire" was analyzed.



The figure to the left is a scatter plot of maximum parcel height organized by parcel release height and time of release (1730 UTC or 1800 UTC). Parcels to the left (right) of the thick vertical line were released below (above) the canopy top.



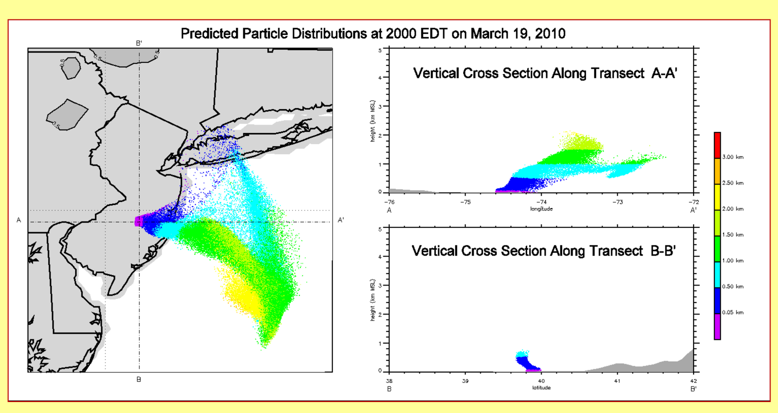
The figures above show predicted parcel heights as a function of time after ignition (1700 UTC, 2 June 2002) for parcels released at 1800 UTC. Each color indicates a different parcel release height. Thick contour denotes PBL height.

Test simulations with ARPS suggest that (1) even a low-intensity fire can lead to the vertical transport of near-surface air parcels deep within a vegetation layer to substantial heights within the boundary layer, and (2) a low-intensity fire could enable air parcels that would otherwise have remained in the lower portion of the PBL to ascend into the free atmosphere above the PBL.

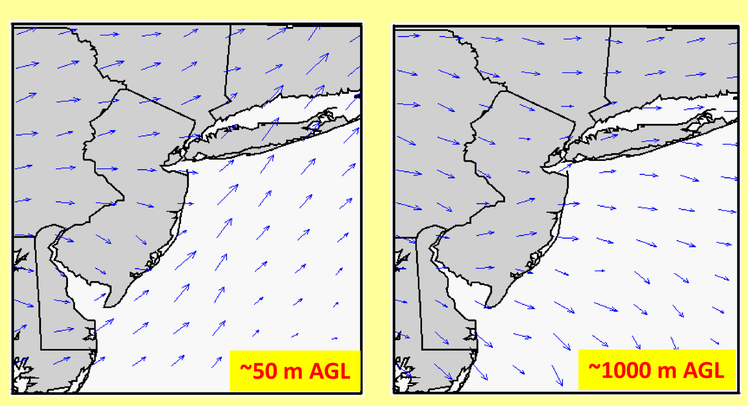
WRF-FLEXPART

We are implementing a canopy sub-model in the Weather Research and Forecasting (WRF) system (Skamarock et al. 2005) coupled with the FLEXPART particle dispersion model (Fast and Easter 2006) to predict local and regional atmospheric transport and diffusion of smoke from fires within forest vegetation layers.

Test simulations have been carried out without the canopy sub-model to determine how the meteorological conditions during the March 19, 2010 experimental burn in the NJ Pine Barrens could have distributed smoke particles over the NE U.S.



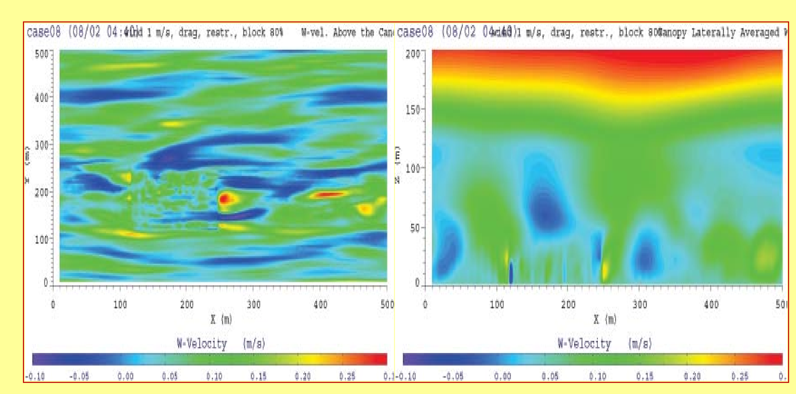
Predicted particle distributions at 2000 EDT from WRF-FLEXPART. Particle locations are color coded according to height AGL.



Predicted wind speeds and directions at 2000 EDT on March 19, 2010 from WRF (min. ≈ 2 m s^{-1}; max. ≈ 19 m s^{-1}).

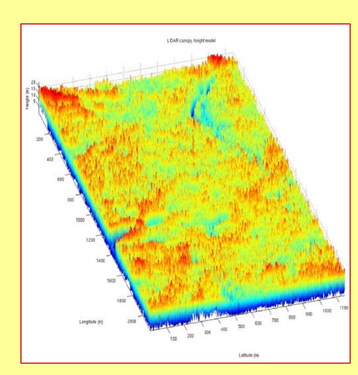
RAFLES

The Regional Atmospheric Modeling System based Forest Large Eddy Simulation (RAFLES) model (Bohrer 2007) is being adapted for very high resolution (~5-10 m) simulations of circulations and smoke particle transport/diffusion within 3-dimensional heterogeneous vegetation layers where surface fires are occurring. To date, virtual experiments have been conducted to test the model's ability to resolve flow structures (without fire) within and above heterogeneous vegetation layers similar to those that exist in the New Jersey Pine Barrens experimental burn units (see below).



Mean vertical velocity across a horizontal cross-section (left) and a vertical cross-section (right) in a RAFLES simulation domain that includes a block of dense canopy (dashed black lines). The simulation represents mild wind (1 m/s above the canopy and a neutrally buoyant boundary layer). RAFLES was able to resolve an updraft persisting at the downwind wake of the vegetation patch (dashed ellipse).

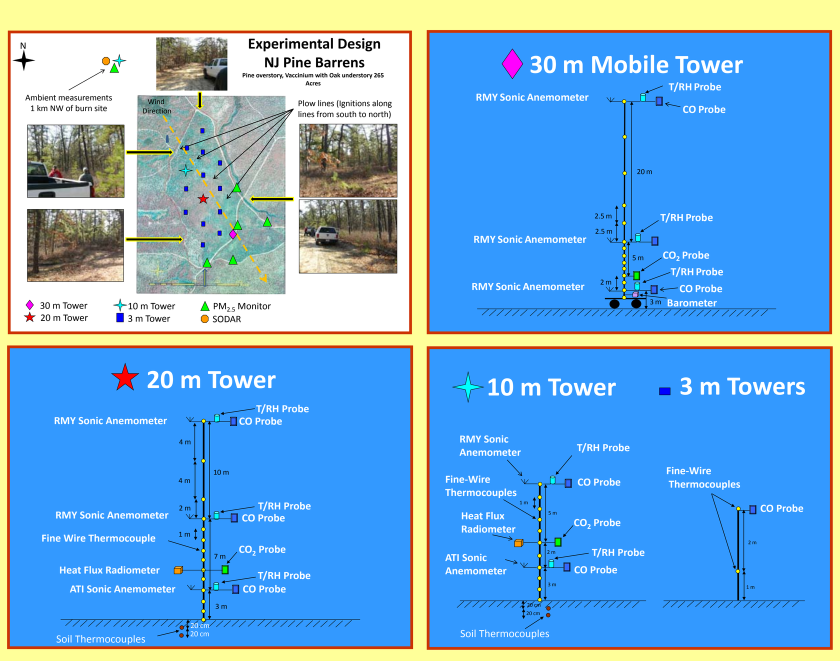
RAFLES is able to incorporate high resolution canopy height and leaf area density data obtained from LIDAR measurements for characterizing the three-dimensional structure of vegetation layers, which is critical for simulating the effects of forest vegetation on smoke dispersion. The figure to the right is a LIDAR-based three dimensional representation (1 m x 1 m x 1 m) of forest canopy height for the New Jersey study site.



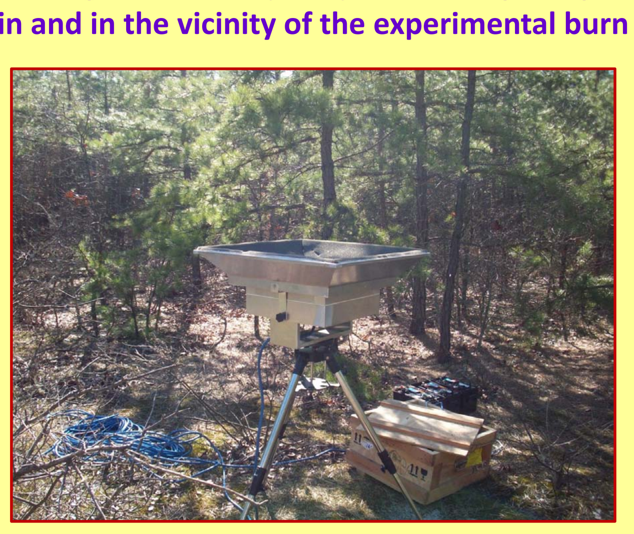
Meteorological and Smoke Monitoring

The experimental site for the monitoring component of this study is located in the NJ Pine Barrens Administrative Area and National Reserve. The Pine Barrens have some of the most volatile fire cycle vegetation in the East (Pitch Pine, scrub oaks and shrubs). Smoke emissions and air quality are major concerns here.

30 m instrumented tower set up inside the burn unit.



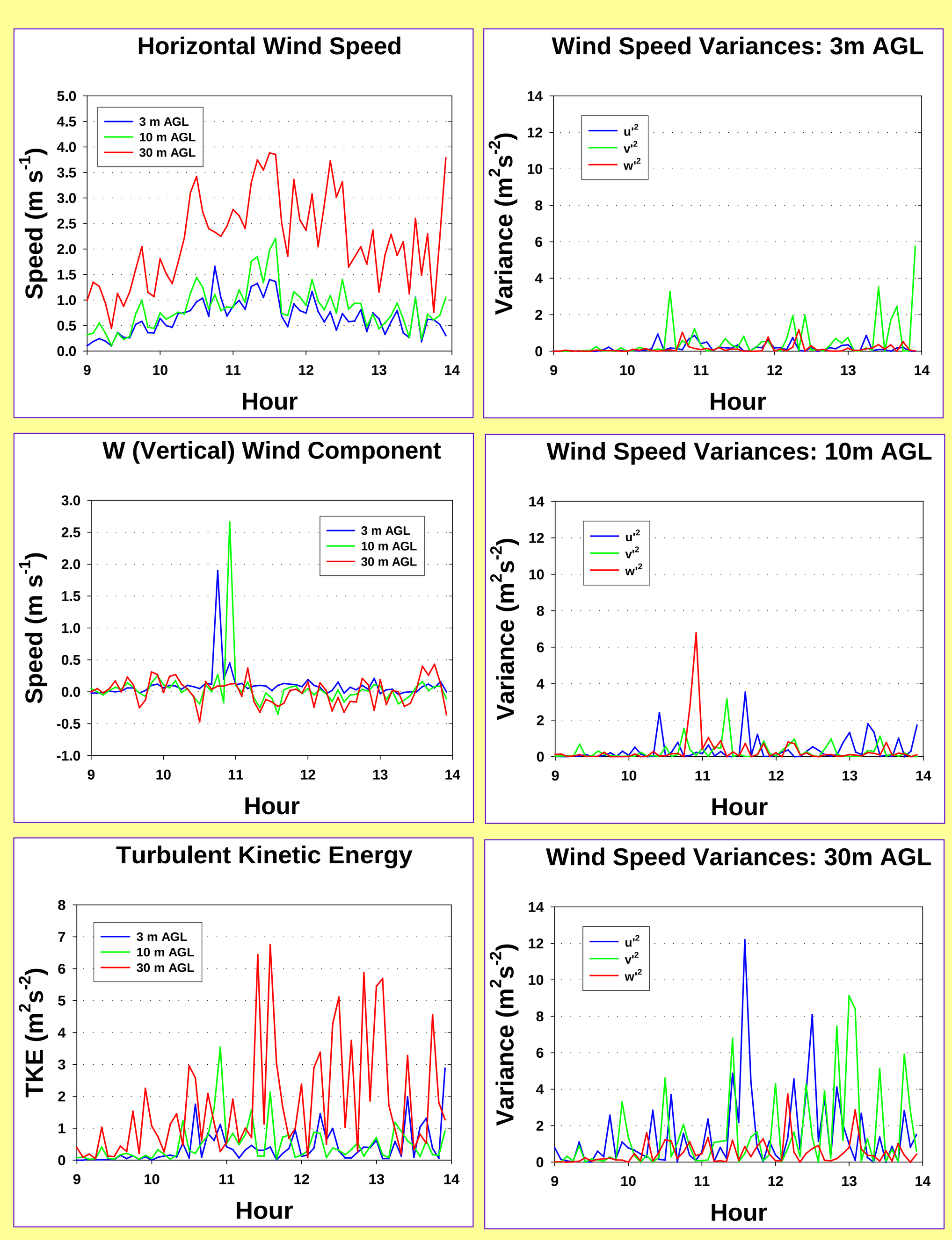
Meteorological and air-quality monitoring design set up within and in the vicinity of the experimental burn unit.



SODAR for measuring wind speeds and directions above the canopy.

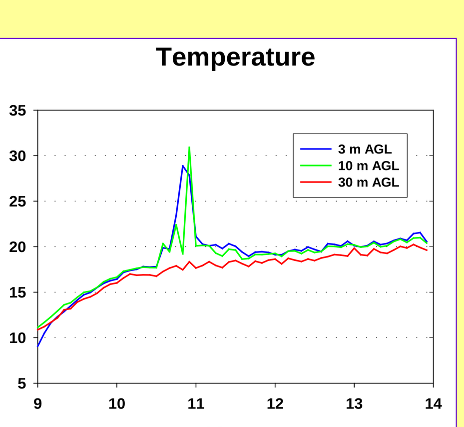
$PM_{2.5}$ monitor for measuring near-surface particulate matter concentrations in the vicinity of the experimental burn.

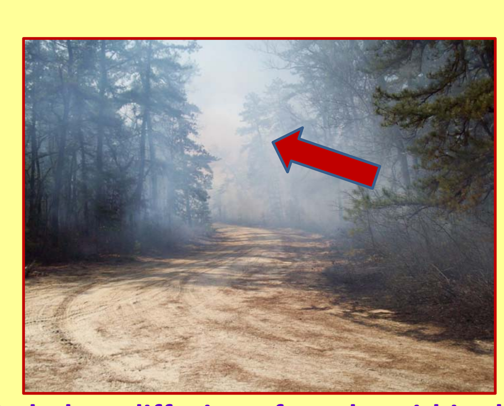
A prescribed burn experiment (backing fire) was initiated by the New Jersey Forest Fire Service (NJFFS) on 03/19/2010 around 1015 EDT under light northwesterly winds (25% relative humidity). Burning was initiated in the vicinity of the 30 m instrumented tower located at the southeastern boundary of the burn unit. Burning continued in the vicinity of the tower until ~1230 EDT, when the NJFFS shut down the fire due to adverse fire-weather conditions. The graphs and photos below show some of the meteorological and air quality conditions observed near the 30 m tower.



Horizontal wind speeds were less than 2 m s^{-1} within the vegetation layer. Mean vertical wind speeds at the 3 m and 10 m levels reached maxima of 1.9 and 2.6 m s^{-1} in response to the surface fire burning adjacent to the tower. Updrafts and heating at the 30 m level in response to the fire were minimal. Substantial turbulence (TKE) due to vertical wind shears in the horizontal winds occurred at the 30 m level. TKE and wind speed variance plots suggest vertical turbulent diffusion of smoke was more significant at the 10 m level than near the surface or near the canopy top while horizontal turbulent diffusion of smoke was more significant at the 3 m and 30 m levels.

Surface fire initiated near the 30 m tower.





Turbulent diffusion of smoke within the vegetation layer toward the southeast.