Simulating Prescribed Burn Events in the New Jersey Pine Barrens using ARPS-CANOPY

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Introduction

- Smoke from prescribed fires can impact the health and safety of operational fire personnel and the general public, mainly through degraded air quality and visibility
- Smoke prediction products are a component of the suite of tools used by land management personnel to make decisions about potential burns
- A new smoke dispersion prediction system has been developed specifically for application to prescribed fires, with a high-resolution numerical model as the meteorological driver
- ARPS-CANOPY, a modified version of the ARPS (Advanced Regional Prediction System) model, has been chosen as the meteorological driver
- In this study, we evaluate the performance of ARPS-CANOPY against meteorological data collected during a low-intensity prescribed fire

Field Experiment Description

- A prescribed fire was conducted in the New Jersey Pine Barrens (Fig. 1a) on 20 March 2011
- Ignition occurred at 0955 EDT, and the fire was extinguished about 16 hours later
- Three instrumented towers of 10-, 20-, and 30-m height were located inside the burn unit, with a second 10-m tall tower located approximately 1 km northwest of the burn perimeter. Also, 3-m towers were set up to sample temperature and smoke (see tower map in Fig. 1b)
- 20- and 30-m towers were instrumented with sonic anemometers, temperature/relative humidity probes, and thermocouples (see tower schematics in Figs. 1c-d for other instrumentation)
- Continuous measurements were taken beginning at 0100 EDT 19 March 2011 and continuing until approximately 0800 EDT 21 March

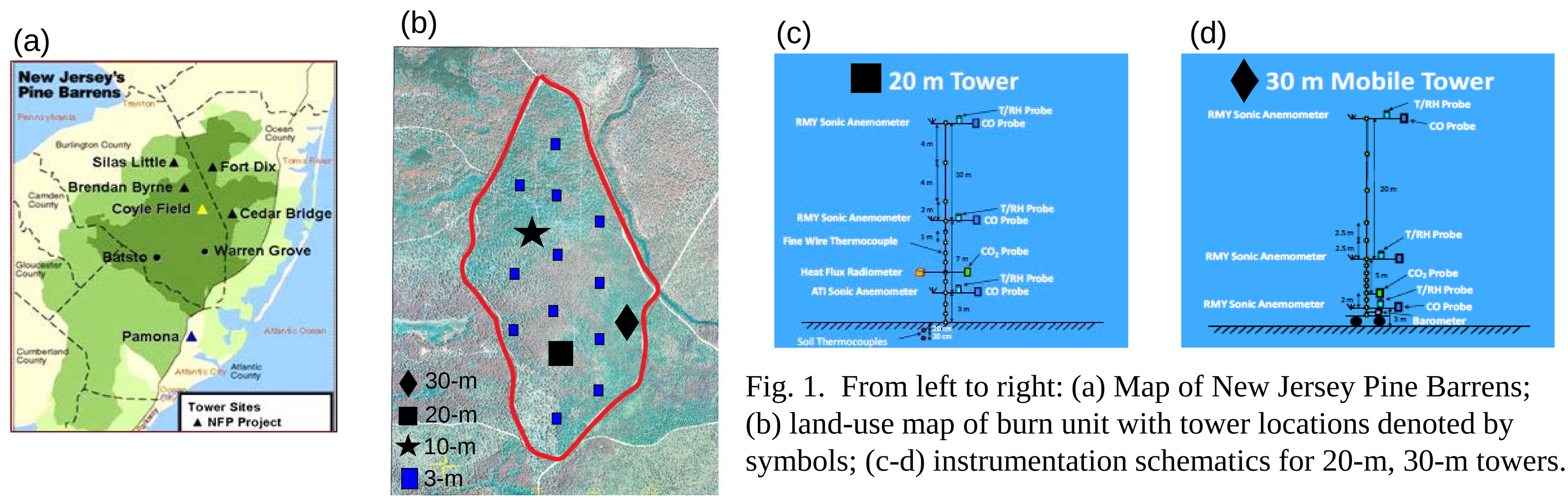


Fig. 1. From left to right: (a) Map of New Jersey Pine Barrens; (b) land-use map of burn unit with tower locations denoted by symbols; (c-d) instrumentation schematics for 20-m, 30-m towers.

ARPS-CANOPY 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)] - synoptic scale [O(10^7 m)] flows
- Standard version of ARPS has been modified in the following ways:
  - Impact of drag forces on mean and turbulent flow through a vegetation canopy is accounted for via production and sink terms in the momentum and subgrid-scale (SGS) turbulent kinetic energy (TKE) equations
  - Attenuation of net radiation by vegetation elements is accounted for with a downward decaying net radiation profile inside the canopy, and by reducing ground net radiation before it is passed to the ARPS soil model
  - Canopy represented in ARPS-CANOPY as a height-varying vertical profile of plant area density (A_p; m^2 m^{-3}). See *3D Plant Area Density Dataset* section for further details on an A_p dataset in the NJ Pine Barrens.

Model Configuration

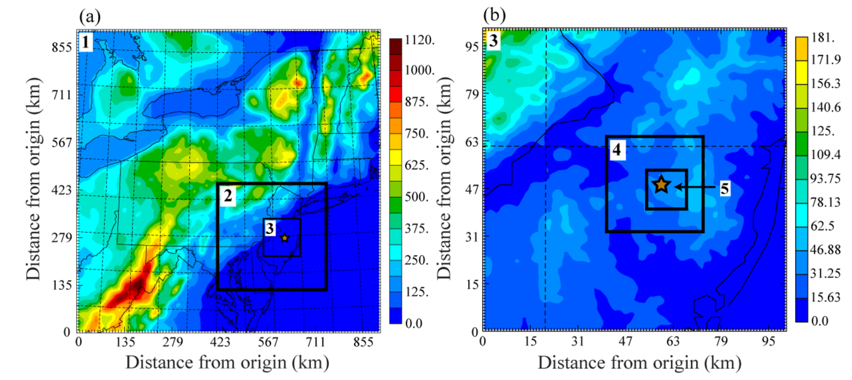
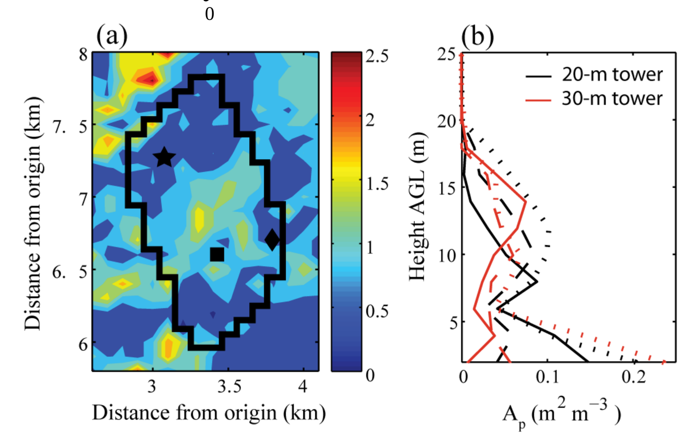


Fig. 2. Maps of surface elevation (m) from (a) domain 1 (D1), with outlines of D2 and D3 overlaid, and (b) D3, with outlines of D4 and D5 overlaid. Star: Butler Place site.

- A series of one-way nested simulations are performed (Fig. 2), with horizontal grid spacing ranging from 8.1-km (D1) to 100-m (D5) (Note: Δz = 2 m in D5)
- D1: Initialized from NARR (North American Regional Reanalysis)
- In D1-D4, standard ARPS model is employed; in D5, ARPS-CANOPY is applied and a fire parameterization is implemented
- D1-D4: simulations initialized at 2000 EDT 18 March 2011, run for 60 hours
- D5: two 12-hour simulations, initialized at 0800 EDT 19/20 March 2011
- The remainder of this presentation will focus on results from D5

3D Plant Area Density Dataset

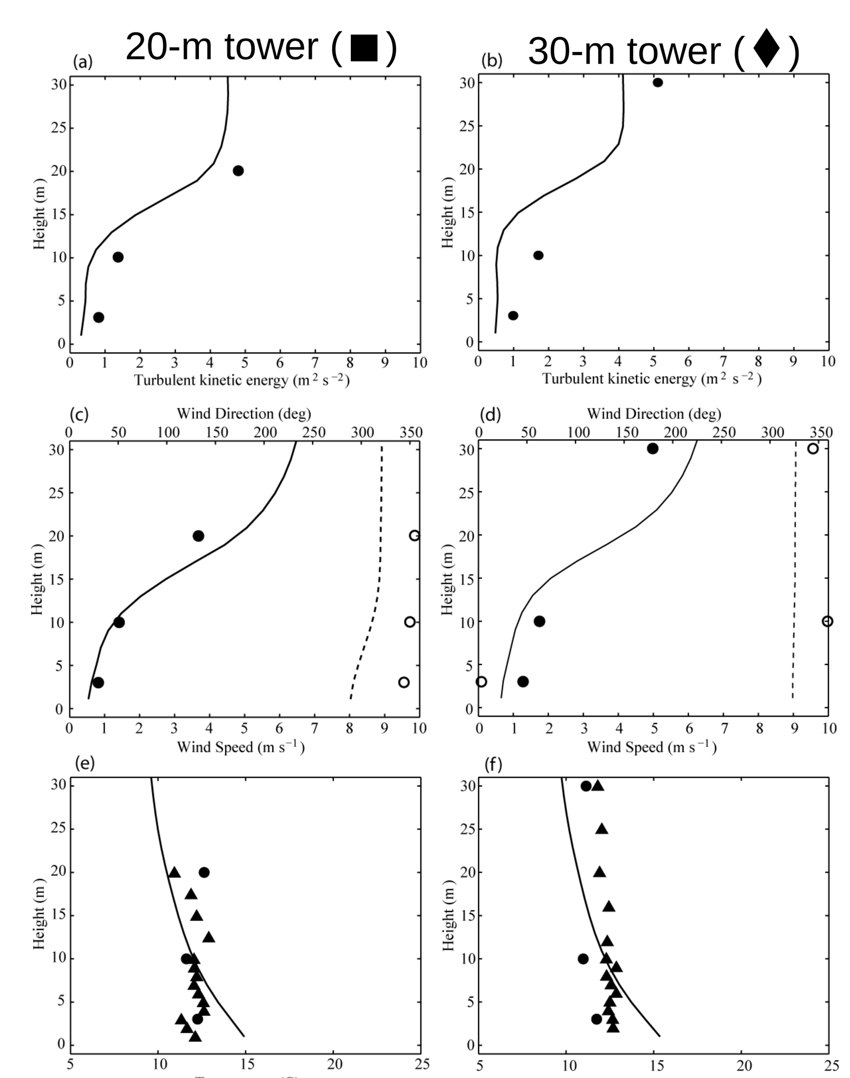
$$PAI = \int_0^h A_p(z)dz$$



- For D5, estimates of A_p at 100-m horizontal resolution and 2-m vertical resolution were obtained through an integration of multiple airborne laser scanning (ALS) datasets and field-based destructive sampling
- Map of plant area index (PAI) (Fig. 3a) shows heterogeneity in the vicinity of the burn unit, with PAI inside the burn unit varying from 0 to ~1.6
- Average canopy height at 20 and 30 m towers is 18 m (Fig. 3b)

Fig. 3. Summary of A_p dataset: (a) horizontal plan view of PAI around burn unit; (b) vertical profiles of A_p at grid points nearest to the 20-m and 30-m towers. The symbols in (a) indicate: 10-m (star), 20-m (square) and 30-m (diamond) towers.

Results: 19 March 2011 (Pre-burn Day)



- The shapes of the mean TKE and wind speed/direction profiles overall agree with observations (Figs. 4a-d)
- Model captures wind direction variation observed inside canopy
- Local lapse rates generally agree with thermocouple measurements (Figs. 4e,f)

- TKE consistently underestimated by model (Figs. 4a-b)
- Wind speeds somewhat underestimated inside canopy, overestimated above canopy (canopy top is about 18 m AGL) (Figs. 4c-d)
- Temperatures too warm near surface, too cool above canopy top (Figs. 4e-f)

- Overall: ARPS-CANOPY reproduces the basic features of the mean profiles

Fig. 4. Vertical profiles of 1430-1730 EDT mean (a-b) TKE, (c-d) wind speed/direction, and (e-f) temperature, at the 20-m and 30-m towers. Simulated fields are averaged around three grid points in the vicinity of each tower. Symbols represent observations: circles (sonic anemometer); triangles (thermocouple). In (c-d), filled circles/solid lines indicate speed, open circles/dashed lines denote direction.

Methods & Results: 20 March 2011 (Burn Day)

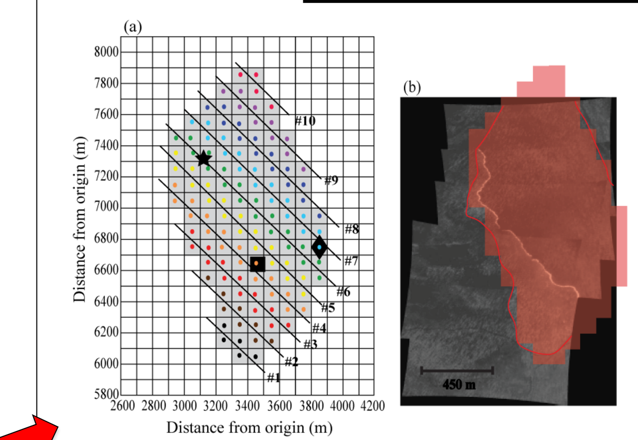


Fig. 5. (a) Model burn unit; (b) infrared image of fireline; model burn unit overlaid.

- Ignition occurred at 0955 EDT; backing fires progressed slowly northeast through the day (~1.5 m min^{-1})
- First-order effect of fire, heat, is represented in model as a vertical profile of heat flux, strongest at the surface
- Burn unit grid cells grouped into "burn zones" (Fig. 5a)
- Heat flux derived from observations at 20-m tower
- 15.5 kW m^{-2} surface turbulent heat flux applied steadily in each zone for ~90 min. (zone #4: 1437-1615 EDT)

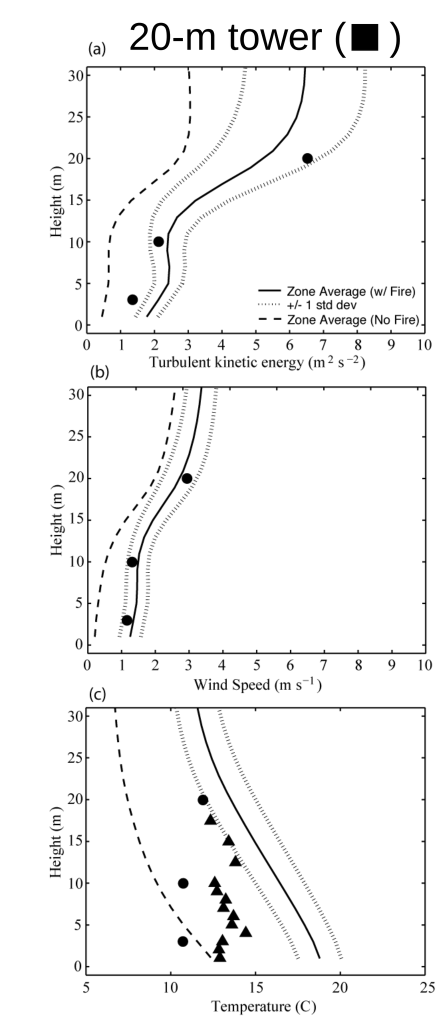
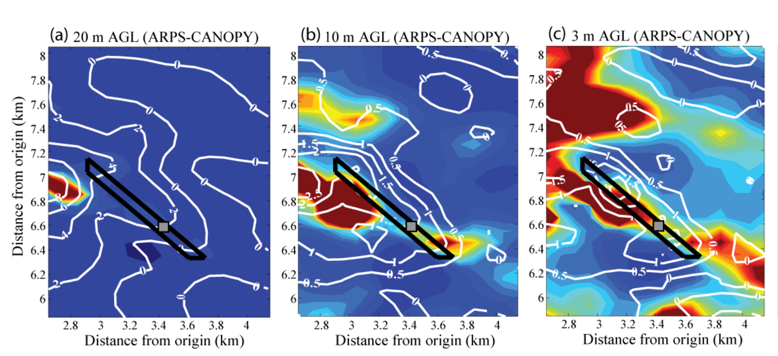


Fig. 6. Vertical profiles of 1510-1610 EDT mean (a) TKE, (b) wind speed, and (c) temperature, at the 20-m tower. Simulated fields are averaged across all grid cells in burn zone #4. For line types, see legend in (a); For symbols, see Fig. 4.

- The shapes of the TKE and wind speed profiles are in agreement with the observations (Figs. 6a-b)
- Removal of the fire yields smaller mean TKE and wind speed, and subsequently, greater model error
- The local lapse rates generally agree with the observations, although temperature errors are evident (Fig. 6c)
- For all variables, observation points are mainly within one standard deviation of the ARPS mean
- Temperature overestimation shows challenge of representing narrow fireline in model with 100-m horizontal grid spacing



$$Ri = \left[\frac{\text{buoyancy production/destruction}}{\text{shear production}}\right]$$

Ri	Primary Turbulence source
Ri ≤ -0.03	Buoyant production
-0.03 ≤ Ri < 0	Shear and buoyant production
0 < Ri ≤ 0.25	Shear production

Fig. 7. Richardson number (shaded), with TKE difference field (fire sim. - no fire sim.) overlaid. Black quadrilateral denotes model burn zone #4; gray square indicates location of 20-m tower.

- Variation in mean TKE along fireline evident (Fig. 7)
- Axis of large negative Ri evidence of strong heating
- Buoyancy is the dominant source of turbulence throughout the model domain, with shear playing a secondary role away from the immediate fireline

Summary and Conclusions

- Goal: assess the performance of ARPS-CANOPY in fire and non-fire conditions
- ARPS-CANOPY profiles of mean TKE, wind speed/direction, and temperature largely agreed with the observations during the pre-burn phase of the field experiment and the period of time the tower was sensing the fire
- Buoyancy was found to be the dominant source of turbulence in the vicinity of the parameterized fire, with shear playing a secondary role further away from the fire
- Overall findings are encouraging for smoke prediction efforts since transport of smoke from low-intensity fires is highly sensitive to the near-surface meteorology, and in particular, turbulent flows
- Ongoing work: Evaluating smoke dispersion model and simulating second burn case (6 March 2012)

Acknowledgements

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