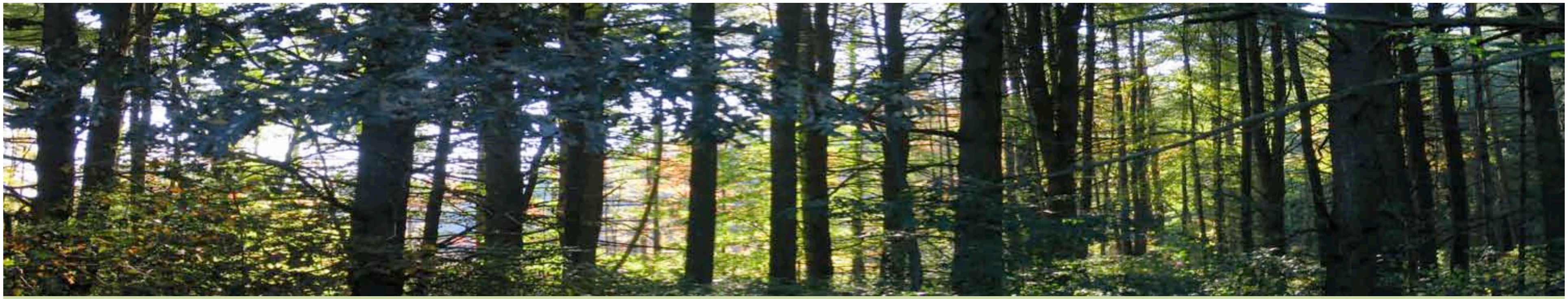

Development of a Canopy Atmospheric Modeling System for use in Simulating Smoke Dispersion from Low-Intensity Fires

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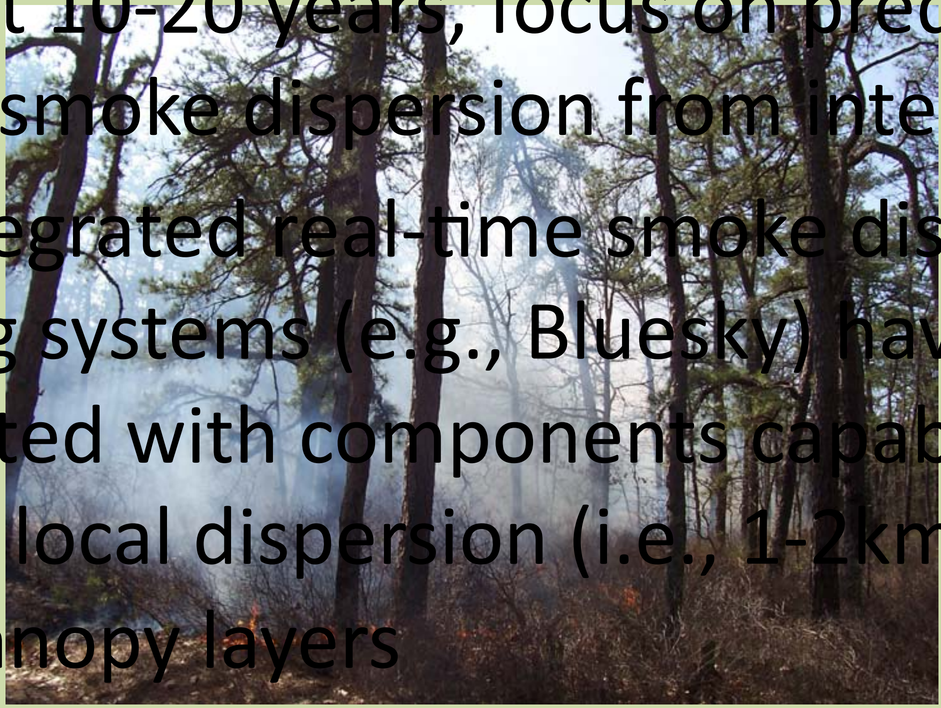
Motivation

- Smoke dispersion from wildland fires is a critical health and safety issue
- Over past 10-20 years, focus on prediction has been on smoke dispersion from intense fires
- Most integrated real-time smoke dispersion modeling systems (e.g., Bluesky) have not been tested with components capable of handling local dispersion (i.e., 1-2km away) within canopy layers



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

- Ob evelop ric
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  - es: Adv on
    WRF, R
  - ule: Pa
    Laboratory (PNNL) Integrated Lagrangian
    Transport (PILT) Model
- Evaluate performance of models with existing datasets & recent burn data
  - e.g. Silas Little Experimental Forest: 20 Mar 2011

Overall Modeling Strategy

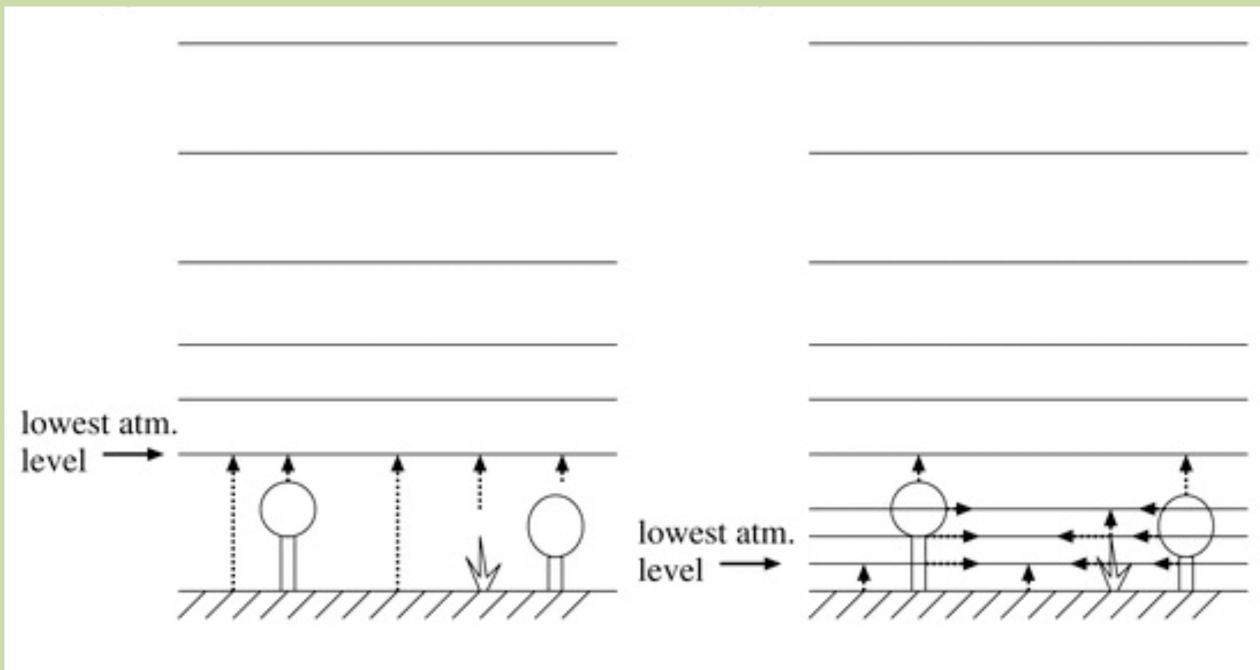
- As a preliminary step we validate the canopy model using data from the Canopy Horizontal Array Turbulence Study (CHATS)
  - We are not actually simulating a low-intensity fire here.
  - Goal: Reproduce the observed evolution of mean flow properties and the shape of the mean profiles (e.g., wind speed) in and above a vegetation layer

Model Overview

- Advanced Regional Prediction System (ARPS) Version 5.2.7 (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
- Standard ARPS accounts for the bulk effect of a vegetation canopy on the free atmosphere within single layer

Surface layer Modeling

Standard ARPS　　　　Modified ARPS



Adapted from Masson and Seity (2009, J. Appl. Meteor. Climatol., V 48, 1377-1397)

LES Modeling

- ARPS is run in Large Eddy Simulation (LES) mode
  - The model resolves turbulence larger in scale than the grid spacing, and parameterizes smaller scales
- ARPS retains equations for: momentum, potential temperature, pressure, moisture, turbulent kinetic energy (TKE)
- ARPS parameterizes: radiation, sub-grid scale (SGS) turbulence, microphysics, surface processes

Modifications to ARPS code

- Canopy dynamic parameterization
  - **Dupont and Brunet (2008,2009)**
    - Momentum Equation: Pressure and Viscous Drag force term: $-\eta\bar{\rho}C_d A_f \sqrt{\tilde{u}_j\tilde{u}_j}\,\tilde{u}_i$
    - SGS TKE Equation: Wake energy sink (eddies larger than canopy elements lose TKE to wake scales and heat): $-2\eta C_d A_f \sqrt{\tilde{u}_j\tilde{u}_j}\,e$
  - **Kanda and Hino (1994)**
    - SGS TKE Equation: Wake energy production (mean flow and resolved eddies interact with canopy elements): $+\eta\alpha C_d A_f \sqrt{\tilde{u}_j\tilde{u}_j}^{\,3}$

η	: Vegetation fraction	$\tilde{u}_i$	: Instantaneous velocity component
C_d	: Canopy drag coeff.	α	: wake production coefficient
A_f	: Frontal area density	e	: subgrid-scale turbulent kinetic energy

Modifications to ARPS code

- Canopy heat source parameterization
  - **Yamada (1982), Sun et al. (2006)**
    - Radiation Scheme: Net radiation at canopy top:

$$R_{Nh} = (1-\alpha_t)S + \varepsilon_c (R_{Lh}\downarrow - \sigma T_c^4)$$

    - Radiation Scheme: Profile of net radiation inside canopy:

$$R_{Np}(z) = R_{Nh}\left[\exp\{-kL(z)\} - \eta\left(1-\frac{z}{h}\right)\exp\{-kL(0)\}\right] \qquad L(z) = \int_z^h A_f dz$$

α_t	: Canopy albedo	R_{Nh}	: Net radiation flux at canopy top	T_c	: Canopy top temperature
S	: Incoming solar rad.	$R_{Lh}\downarrow$	: Longwave absorbed at canopy top	h	: Canopy height
ε_c	: Emissivity of trees	$L(z)$	: Local leaf area index	k	: Attenuation coefficient

Modifications to ARPS code

- Canopy heat source parameterization
  - **Yamada (1982), Sun et al. (2006)**
    - <u>Thermodynamic Equation</u>: Heat source inside canopy:

$$\frac{\partial \theta}{\partial t} = \underbrace{\frac{(1-\eta)}{\rho_a C_p}\frac{\partial R_N}{\partial z}}_{\textit{Clearing fraction}} + \underbrace{\frac{\eta}{\rho_a C_p + \rho_c C_c}\left(1+\frac{1}{B}\right)^{-1}\frac{\partial R_{Np}}{\partial z}}_{\textit{Vegetated fraction}}$$

    - <u>Land Surface Model</u>: Ground net radiation flux:

$$R_{NG} = \underbrace{\eta R_{Nh}\exp[-kL(0)]}_{\textit{Vegetated fraction}} + \underbrace{(1-\eta)[(1-\alpha_G)S + \varepsilon_G(R_{LG}\downarrow - R_{LG}\uparrow)]}_{\textit{Clearing fraction}}$$

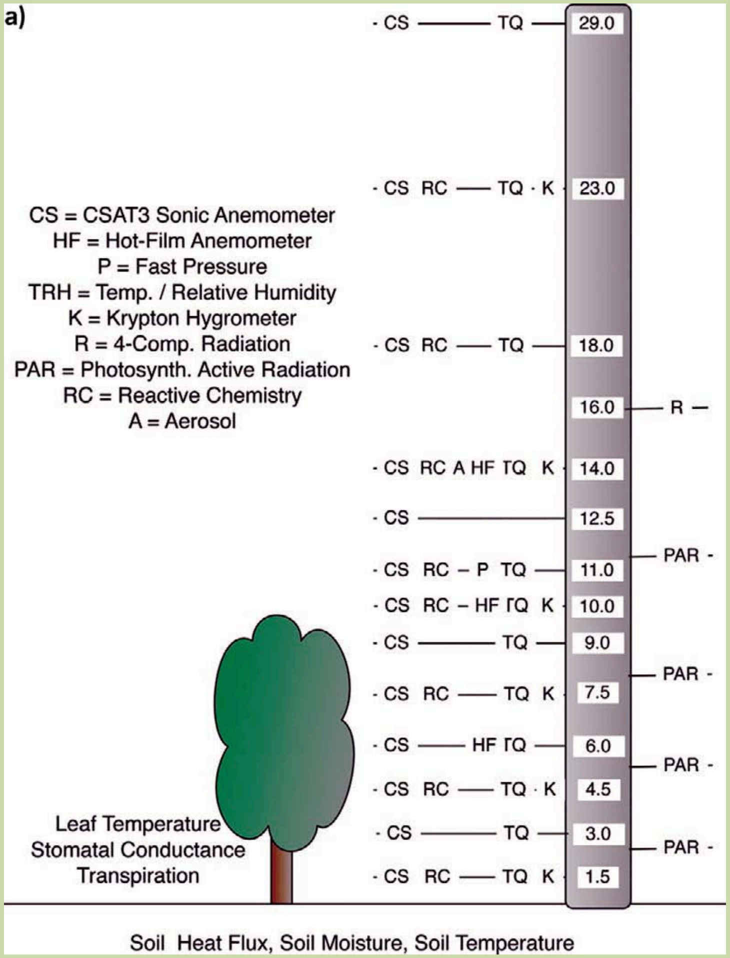
θ : Potential temperature	C_p : Specific heat of air	
ρ_a : Air density	C_c : Specific heat of canopy	R_{NG}: Net radiation flux at ground
ρ_c : Canopy density	B : Bowen ratio	R_{LG}: Longwave radiation at ground

Canopy Horizontal Array Turbulence Study (CHATS)

Dixon, CA: 15 Mar – 12 June 2007

From Patton et al. (2011, Bull. Amer. Met. Soc., V 92, 593-611)

30 m Tower



From Patton et al. (2011, Bull. Amer. Met. Soc., V 92, 593-611)

CHATS Summary

Pre leaf-out

Post leaf-out

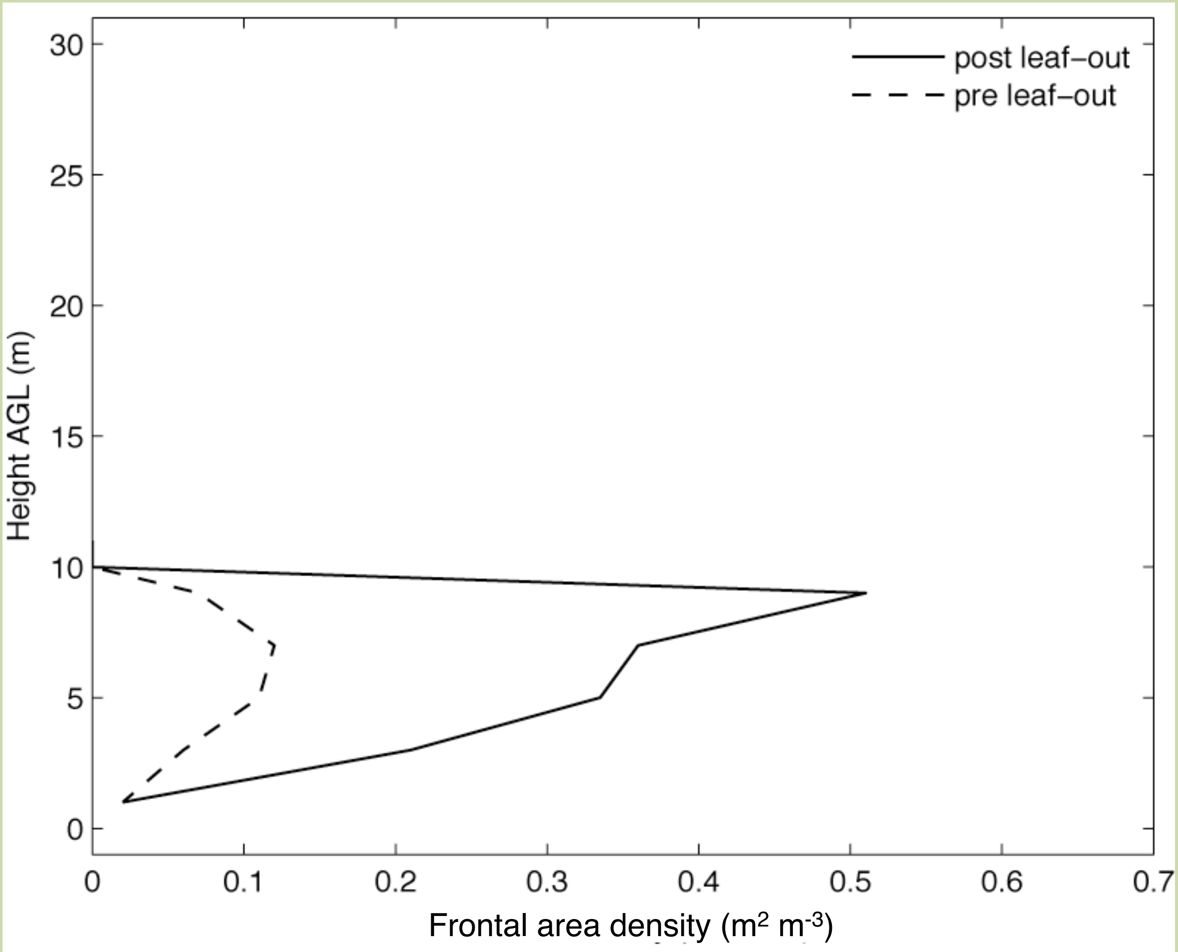
From Patton et al. (2011, Bull. Amer. Met. Soc., V 92, 593-611)

Model Strategy

- 3D simulations with 83 x 83 x 83 grid points
  - $\Delta x = \Delta y$ = 90 m
  - Δz = 2 m up to z = 84 m AGL, vertically stretched above
- Initialized with single sounding; periodic BC applied
- Initialized at 1200 UTC (0500 LT), run for 12 hours
- Homogeneous canopy, uniform flat terrain
- Microphysical parameterization omitted
- Initial soil temperature & moisture derived from CHATS measurements
- Domain centered on tower (38.488 N; -121.846 W)

CHATS Cases: Vegetation Profiles

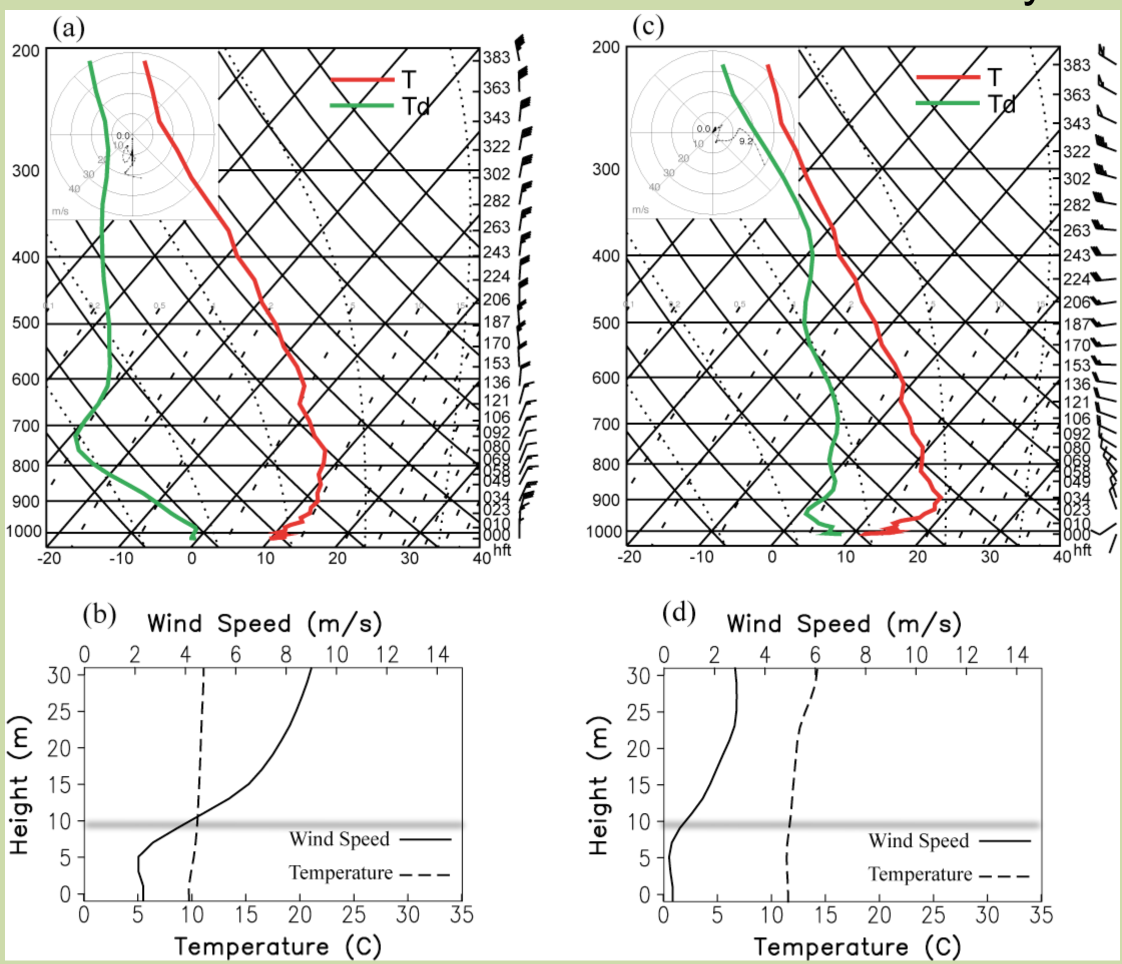
Averaged profiles measured by Li-Cor LAI-2000



CHATS Cases: Meteorology

1200 UTC (0500 LT)

Pre leaf-out: 29 March 2007 Post leaf-out: 20 May 2007

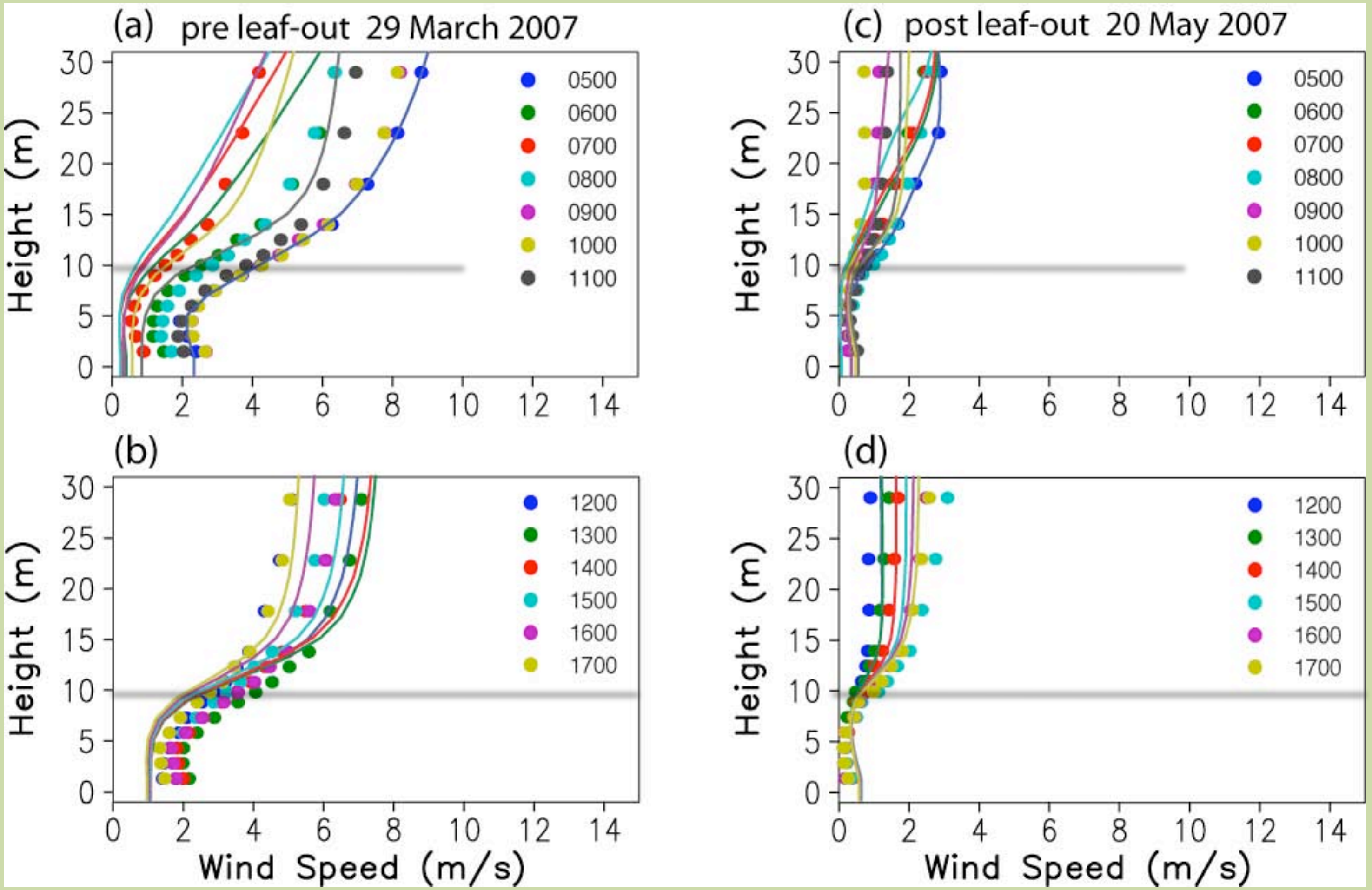


Model Validation

Mean Wind Speed

AM

PM

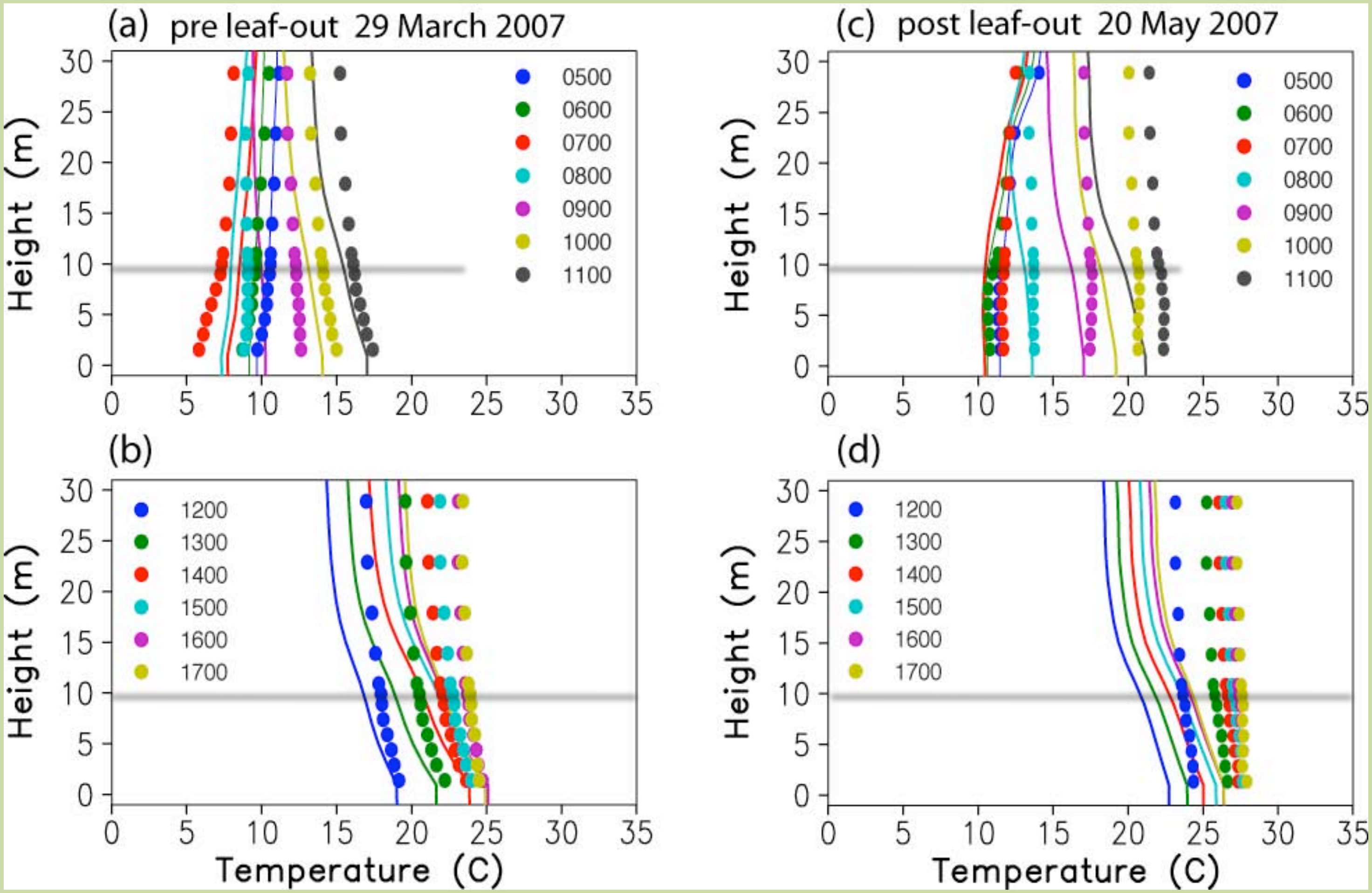


Model Validation

Mean Temperature

AM

PM

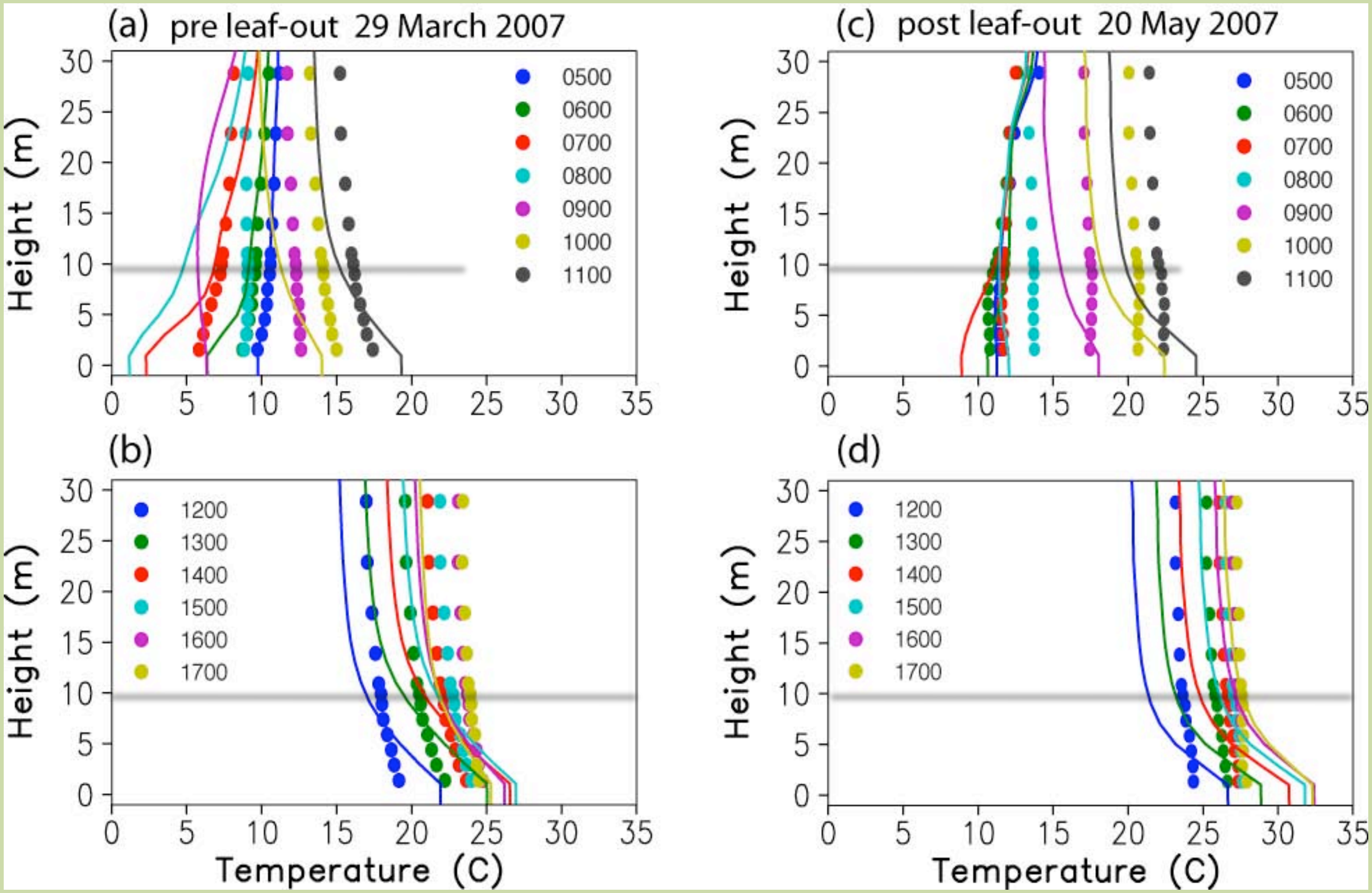


Sensitivity Experiments : No Canopy

Mean Temperature

AM

PM



Summary

- ARPS model code modified to allow modeling of flow through a multi-layer canopy
- Canopy modeling system validated against data from CHATS experiment
- Wind speed assessment very promising
- Temperature assessment reveals underlying model cool bias (independent of canopy modification)

Ongoing Efforts

- Apply CHATS validation findings to real-case simulations with low-intensity fires
- Pass meteorological fields to dispersion module
- Evaluate performance of models (ARPS,WRF) against data collected during March 2011 prescribed burn in NJ Pine Barrens

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http://www.geo.msu.edu/firesmoke/