# Numerical Simulations of the Meteorological Conditions Above a Grassfire on a Slope

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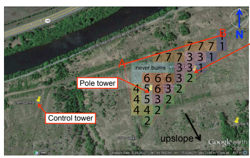
## Introduction

- In this study we utilize the Advanced Regional Prediction System (ARPS) model to examine the meteorological conditions above a grassfire on a steep (~30%) slope
- This work is one part of a two-part modeling effort to simulate smoke behavior associated with a prescribed grassfire at a U.S. Environmental Protection Agency (EPA) Superfund site near Palmerton, PA
- In this presentation we describe a multi-scale atmospheric modeling approach and examine
  - simulated meteorological conditions likely to influence smoke behavior predictions, including mean and turbulent flow in the vicinity of the fire
  - parcel trajectories to help visualize transport of air parcels released from the burn site at different stages during the fire

## Field Experiment

- Prescribed fire was conducted on 14 April 2013 at Lehigh Gap EPA Superfund Site near Palmerton, PA
- The topography in the vicinity of the burn site consisted of a west-southwest – east-northeast oriented ridgeline, with the burn site located on the north-facing slope (left image)
- Vegetation consisted primarily of dried grasses with scattered defoliated trees; areas of exposed shale rock were also present
- Three instrumented flux towers (control, crank-up, pole; center and right images) collected data prior to, during, and following the burn
- Center image: Test burn began in northeast corner at 1212 EST (#1); ignition continued along southeast perimeter 1212-1325 EST (#1-2); fire spread downslope along western perimeter 1325-1346 EST (#4); ignition along northwest flank about 1350 EST (#7), upslope headfire followed; burn completed by 1400 EST



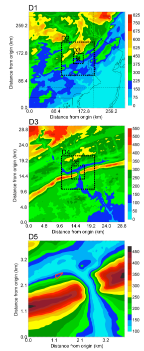
Left: Prescribed fire with smoke, 1355 EST 14 April 2013. The camera is looking south-southeast across Lehigh River. The northwestern boundary of the burn unit is denoted by a thick line (labeled A-B) for comparison to Google Earth image. Photo credit: Cheryl Kunkle.

Center: Burn unit outline with general progression of fire through burn unit indicated with color/number (blue, #1: earliest; orange, #7 last). The northwestern boundary of the burn unit is denoted by thick line (labeled A-B) for comparison to photograph taken across river, and the flux towers are labeled.
Right: Crank-up tower (note the slope is about 30%). Photo credit: Dan Kunkle.

## ARPS Model Overview

- ARPS Version 5.2.12
  - Developed at the University of Oklahoma (Xue et al. 2000, 2001, 2003)
  - Three-dimensional atmospheric modeling system
  - Designed to simulate microscale [O(10 m)] - synoptic scale [O($10^7$ m)] flows
  - Utilizes a terrain-following coordinate system
  - May be initialized with a 3D external dataset (e.g., reanalysis data) or with a single sounding (homogeneous initialization)
  - Numerous options for configuring physical parameterizations (e.g., sub-grid scale turbulence)
  - Extensive suite of post-processing software (e.g., 2D and 3D plotting, sounding extraction, parcel trajectory code, data conversion, model verification)
  - Clean well-documented model code well-suited to user modification [e.g., ARPS-CANOPY (Kiefer et al. 2013)]

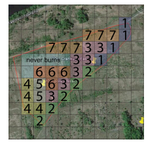
## Model Configuration




Surface elevation in (a) domain 1 (D1), (b) domain 3 (D3), and domain 5 (D5); squares denote additional domains.

| Domain | Grid size | Physical Domain (km) | Dx, Dy | Dz min | Large tstep (sec) | Init time (EST 14 April 2013) | Length of simulation (hr) |
|---|---|---|---|---|---|---|---|
| D1 | 115x115x53 | 302.4 x 302.4 x 16.0 | 2.7 km, 2.7 km | 40 m | 6.0 | 0700 | 12 |
| D2 | 115x115x63 | 100.8 x 100.8 x 15.9 | 900 m, 900 m | 40 m | 2.0 | 0700 | 12 |
| D3 | 103x103x73 | 30.0 x 30.0 x 15.8 | 300 m, 300 m | 18 m | 0.3 | 0700 | 12 |
| D4 | 103x103x83 | 10.0 x 10.0 x 12.0 | 100 m, 100 m | 10 m | 0.1 | 0700 | 12 |
| D5 | 123x123x83 | 3.96 x 3.96 x 6.0 | 33 m, 33 m | 5 m | 0.025 | 0930 (pre-burn sim.) 1130 (burn sim.) | 3 |

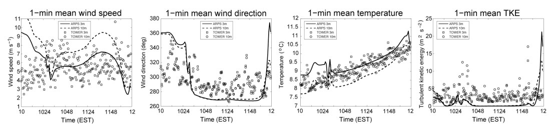
Table. Summary of model domain configurations.




Burn unit (outlined in red) with model grid structure overlaid. Progression of model fire through burn unit denoted by color/number (blue, #1: earliest; orange, #7: last).

- ARPS is run in one-way nested mode with five domains (see table)
- Initial and boundary conditions for D1 provided by 12-km North American Mesoscale (NAM) model
- D1-D4: U.S. Geological Survey (USGS) terrain and land-cover data (30-arc sec) interpolated to model grid
- D5: Shuttle Radar Topography Mission (SRTM) terrain data (3-arc sec) interpolated to model grid; USGS roughness length manually adjusted
- D5: Fire parameterized as surface heat flux. Steady heat flux value (5 kW $m^{-2}$) derived from flux tower data. Timing based on tower data, photographs, and video.

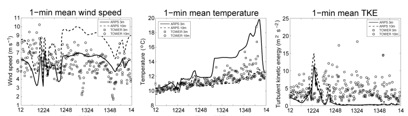
## D5 Assessment (Pre-burn phase: Control Tower)



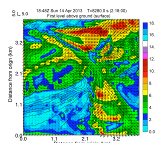

Timeseries of wind speed and direction, temperature, and turbulent kinetic energy (TKE) at the control tower, during two hour period prior to ignition. Simulated fields (lines) interpolated to 3- and 10-m instrument levels (observations: symbols). Note: perturbations are computed from 30-min average quantities and simulated TKE is resolved plus sub-grid scale.

- Wind speed generally overestimated by ARPS; wind direction trend captured
- Simulated temperature trend reasonable, although 10 m AGL temperature too low
- Model turbulent kinetic energy (TKE) trend appears correct, but values are underestimated by model

## D5 Assessment (Burn phase: Crank-up tower)



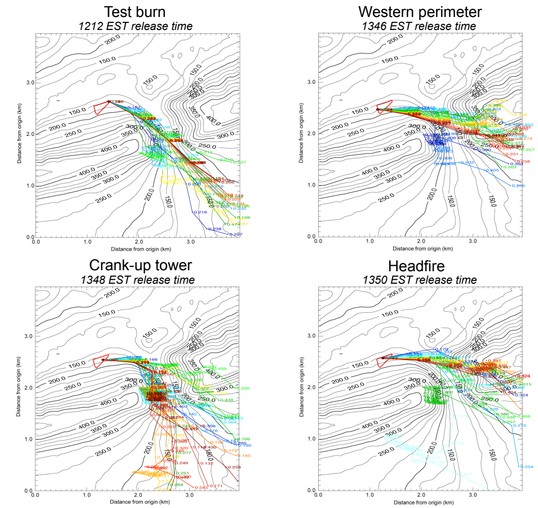

Timeseries of wind speed, temperature, and TKE at the crank-up tower. Wind direction is omitted due to sensitivity of wind direction at the tower site to the fire and differences in fire characteristics between the observed and parameterized fire (e.g., fireline width). See pre-burn assessment figure caption for additional description of panels.



ARPS simulated surface wind speed and horizontal wind vectors (m $s^{-1}$) at 1348 EST. Figure included for comparison to parcel trajectory analysis discussed in next section.

- General overestimation of wind speed at 3 and 10 m AGL
- Model reproduces temperature trend but overestimates temperature: surface heat flux applied in model is too large
- Simulated TKE is too small during period when fire is near tower (1304-1354 EST); Investigation into model TKE error ongoing

## Parcel Trajectory Analysis




A 100-m deep column of parcels is released at four points in model burn unit (see Field Experiment section for definition of parcel release location names), with release time corresponding to time of active burning in each area. Colors correspond to release height (blue closest to ground, red nearest to 100 m AGL) and parcel elevation is indicated at one minute intervals along each trajectory.

- Test burn: Regardless of release height, parcels cross gap, move NW to SE
- Crank-up: Parcels released 80-100 m AGL hug mountainside; parcels released closer to surface more likely to cross gap
- Western perimeter and headfire: Parcels released from western and northern portion of burn unit generally carried east-southeasterly across the gap

## Summary and Conclusions

- ARPS model has been applied to a prescribed fire event at an EPA Superfund Site in complex terrain near Palmerton, PA
- Model produces too little TKE and somewhat overestimates wind speeds at the flux tower locations; temperature is overestimated, although temperature trends are captured by the model
- Parcel trajectory analysis suggests that transport of air parcels through gap is sensitive to where in burn unit parcels are released and whether parcels are released during early or later stages of the burn event
- Ongoing efforts include (1) investigation into TKE underestimation by the model and (2) simulation of smoke transport/diffusion and validation against particulate matter (PM2.5) and carbon monoxide (CO) measurements

## Acknowledgements

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