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Supplementary Material

A comparison of smoke modelling tools used to mitigate air quality impacts from prescribed burning

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Supporting Information

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Supporting Information. This file contains 9 supplementary figures, 3 supplementary tables, and supplementary text. Further information is provided on the differences in temporal emissions profiles used with HYSPLIT (Figure S1), the comparison between HYSPLIT-PC-BlueSky and HYSPLIT-Web (Figure S2), details of the smoke tools setup (Table S1), details of the five largest predicted areas of concern by tool (Table S2), and details of the five largest population impact estimates by tool (Table S3). Details about CMAQ model configuration are described on page 2.

CMAQ Model Configuration

The Community Multiscale Air Quality Modeling System (CMAQv5.2.1) (Appel *et al.* 2017) was used to simulate air quality in 2016 across a 948 km x 612 km domain centered over North Carolina at 4-km horizontal grid resolution. Initial and boundary conditions were derived from an annual 2016 CMAQ simulation conducted at 12-km resolution for a larger domain covering the Eastern U.S. Emissions for prescribed burns in NC State Parks were estimated using the BlueSky modeling framework (Larkin *et al.* 2009). Biogenic emissions are based on the Biogenic Emission Inventory System (BEIS version 3.6.1) modeling system (Bash *et al.* 2016). Emissions for all sources other than fires at NC State Parks, including electric generating units, industrial sources, oil and gas operations, commercial marine vessels, agricultural fires, prescribed fires, wildfires, and other area sources, were based on the 2016 beta emissions inventory developed by the National Emissions Collaborative (NEIC 2019). The Weather Research and Forecasting model (WRF version 4.1) (Powers 2017) was used to simulate meteorological fields to drive the air quality model at 4-km horizontal resolution, using the Kain-Fritsch parameterization (Kain 2004) and ACM2 planetary boundary layer (PBL) scheme (Pleim 2007). The air quality impacts of the NC State Parks operational burning program in 2016 were estimated as the difference between simulations including and excluding the program's prescribed fire emissions. Model performance was evaluated by comparing modeled $PM_{2.5}$ concentrations with observations from the U.S. Environmental Protection Agency Air Quality System (AQS) monitoring sites (U.S. EPA 2021). Across the domain, the normalized mean error and normalized mean bias meets recommended benchmarks for photochemical model performance (Emery *et al.* 2017).

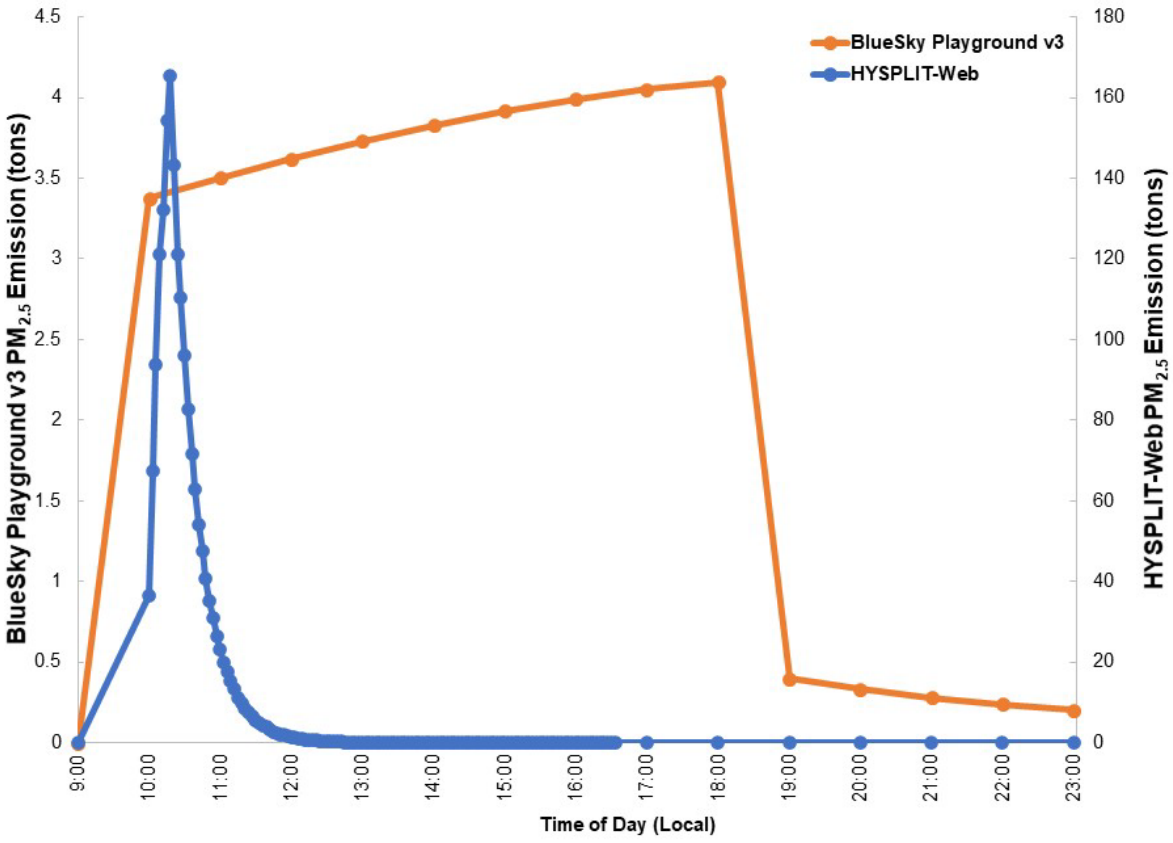

Figure S1. *Temporal $PM_{2.5}$ emissions profiles for simulated prescribed burns from HYSPLIT-Web and BlueSky Playground v3. These profiles shown are for a 140 acre burn at Carolina Beach State Park on March 30, 2016.*

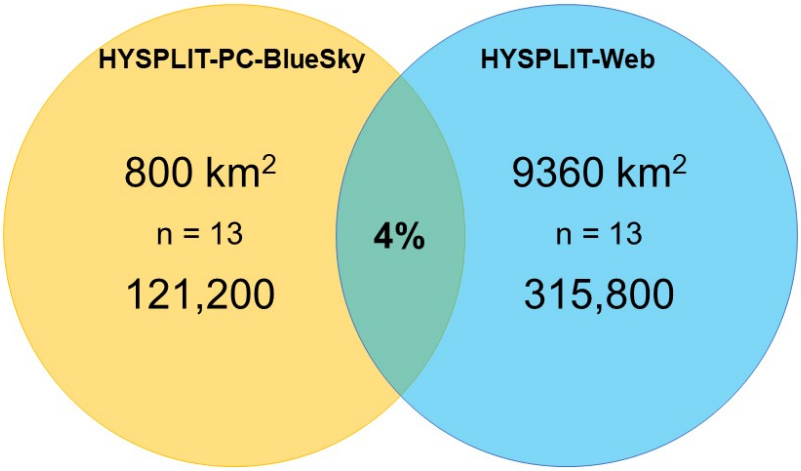

Figure S2. *Total areas of concern due to smoke pollution, and population within them, predicted by HYSPLIT-PC-BlueSky and HYSPLIT-Web for prescribed burns meeting the comparison criteria with both tools (n=13). The average overlap fractions between the tools (4%) was equal for areas of concern and population within them.*

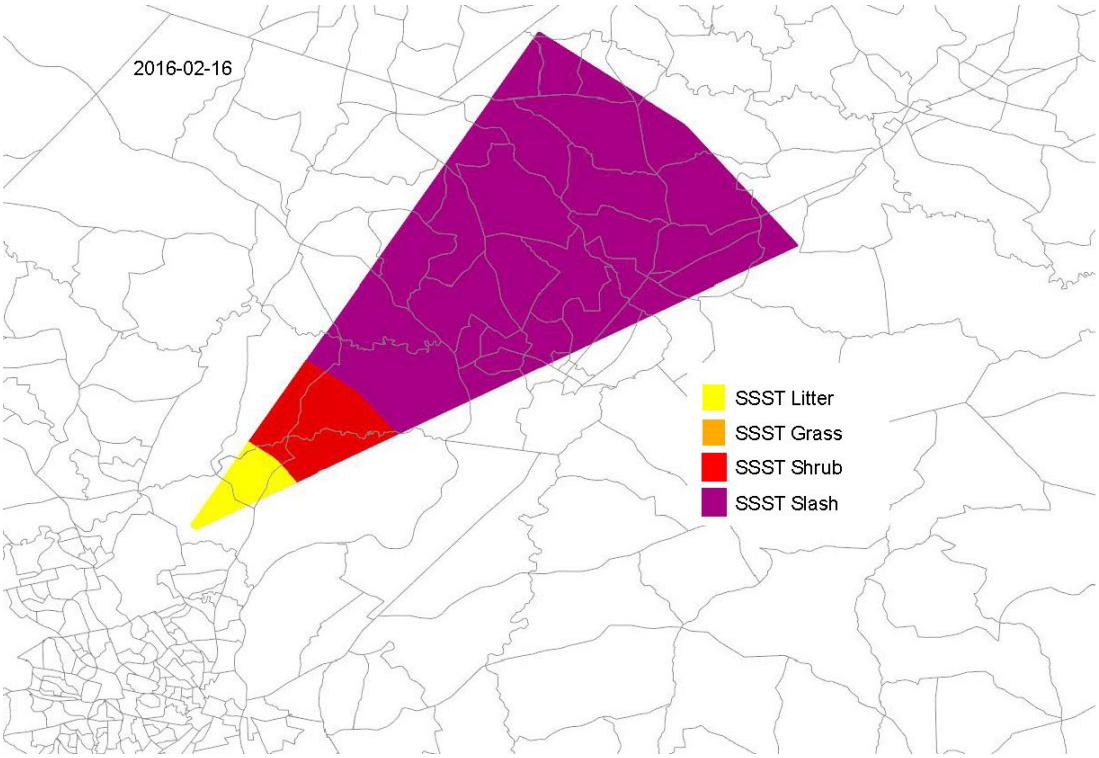

Figure S3. *Comparison of SSST area of concern predicted using the four available fuel type options, shown here for the February 16, 2016 burn at Carver's Creek Park. The area of concern is the same for the Litter and Grass fuels, which produce the smallest area of concern. Slash fuels produce the largest area of concern. Census block groups are outlined in grey.*

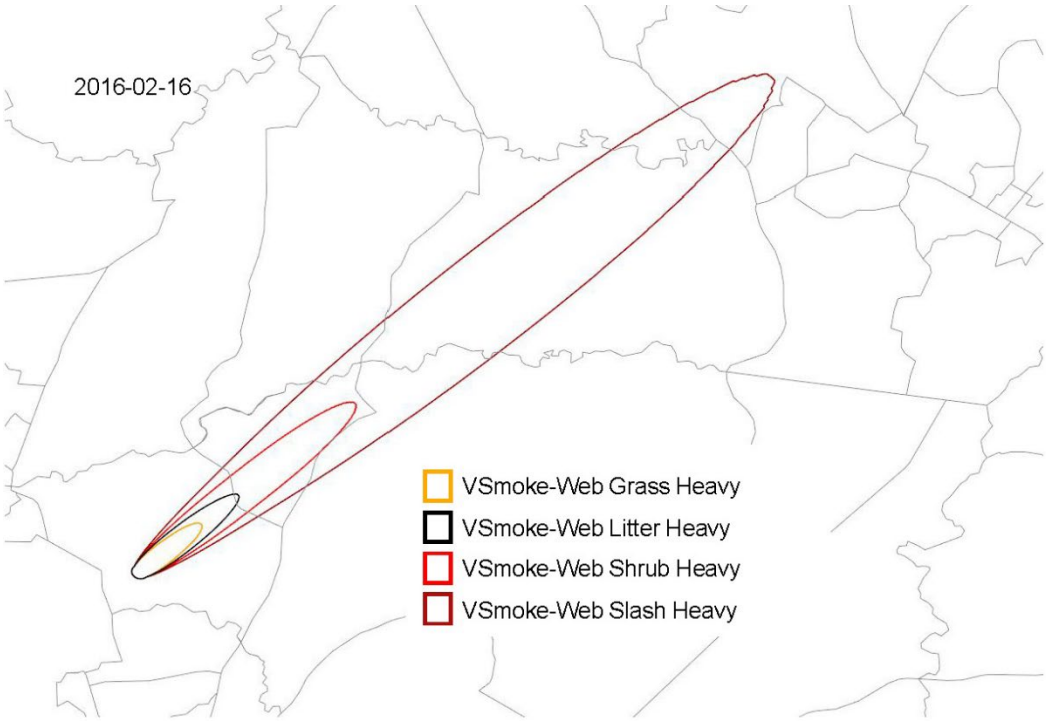

Figure S4. *Comparison of VSmoke-Web predicted area of concern using the four available fuel types at the same fuel loading, shown here for the February 16, 2016 burn at Carver's Creek Park. Grass fuels produce the smallest area of concern while Slash fuels produce the largest. Census block groups are outlined in grey.*

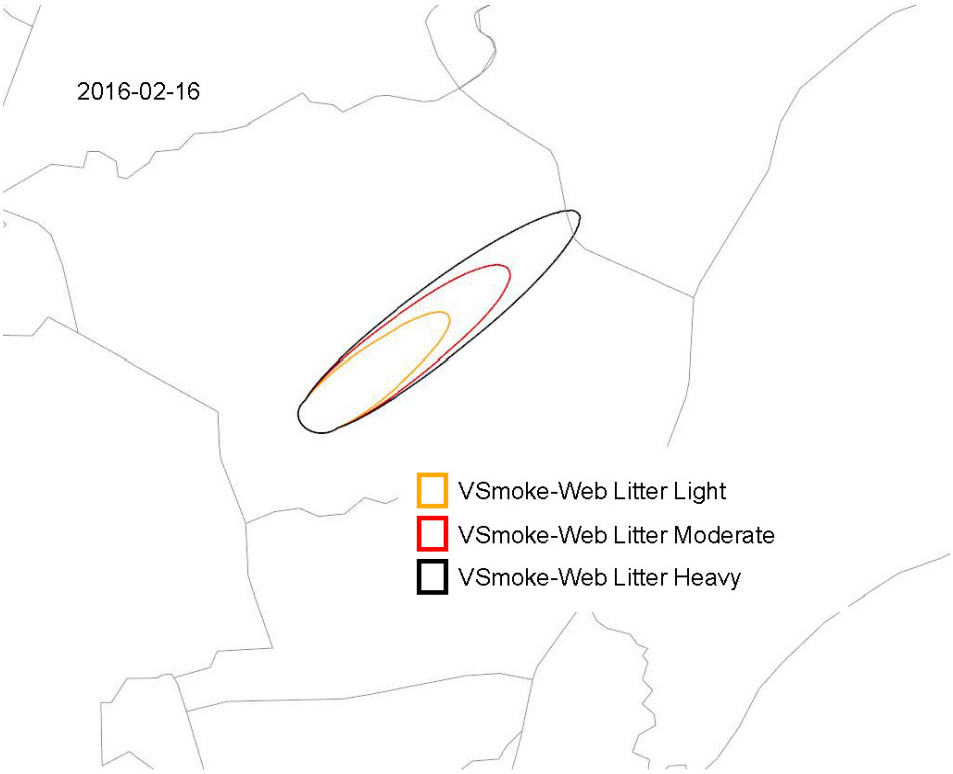

Figure S5. *Comparison of VSmoke-Web predicted area of concern using the three available fuel loading levels for the same fuel type (litter), shown here for the February 16, 2016 burn at Carver's Creek Park. Increasing loading levels lead to increasing area of concern. Census block groups are outlined in grey.*

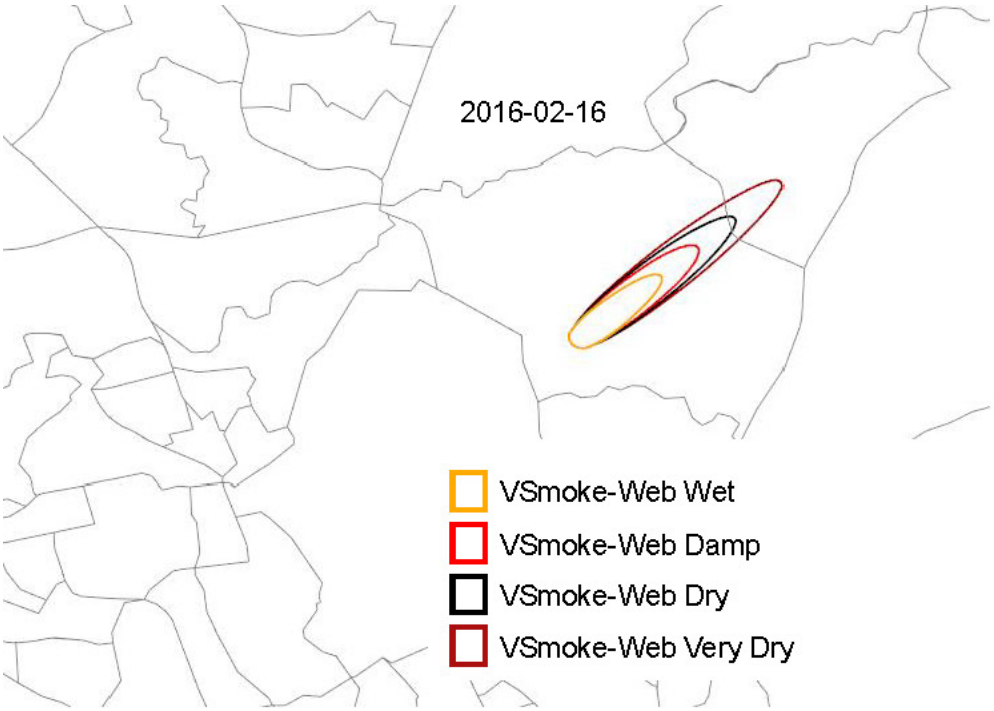

Figure S6. *Comparison of VSmoke-Web predicted area of concern using the four available fuel moisture levels for the same fuel type, shown here for the February 16, 2016 burn at Carver's Creek Park. Increasing dryness leads to increasing area of concern. Census block groups are outlined in grey.*

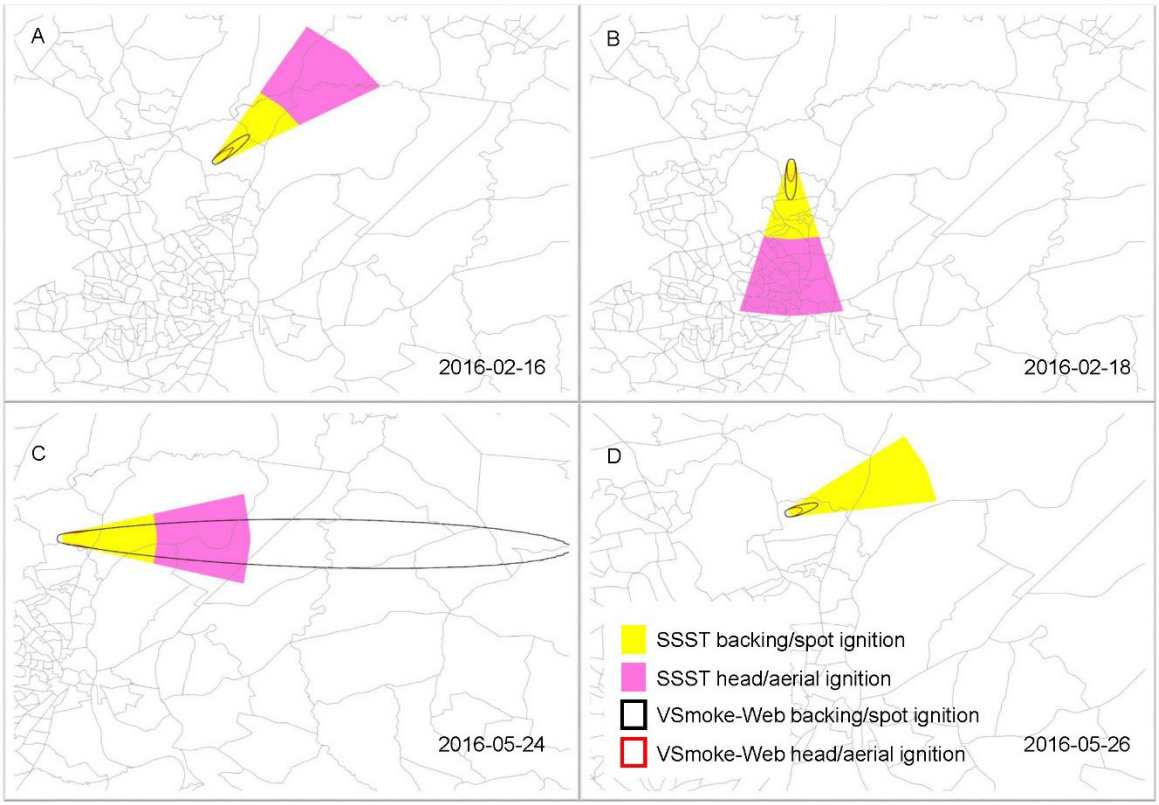

Figure S7. *Comparison of SSST and VSmoke-Web predicted areas of concern using two available ignition methods, shown here for four burns at Carver's Creek Park. When using SSST, a backing/spot ignition most often results in a smaller area of concern than a head/aerial ignition. The opposite is true when using VSmoke-Web. In C, both ignition methods result in the same VSmoke-Web area of concern for the area burned (over 200 acres). In D, both ignition methods result in the same SSST area of concern for the fuel type (grass). Fire in panels A-C use the litter fuel type. Census block groups are outlined in grey.*

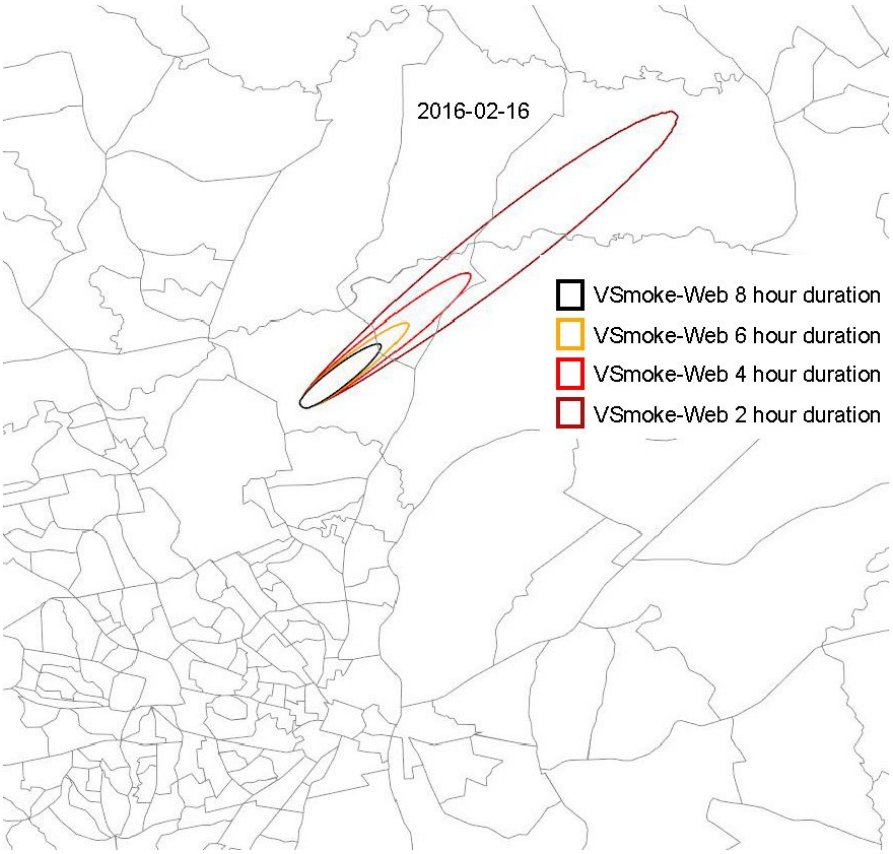

Figure S8. *Comparison of VSmoke-Web predicted areas of concern using varying burn duration times, shown here for the February 16, 2016, burn at Carver's Creek Park. Decreased burn duration increases the area of concern. Census block groups are outlined in grey.*

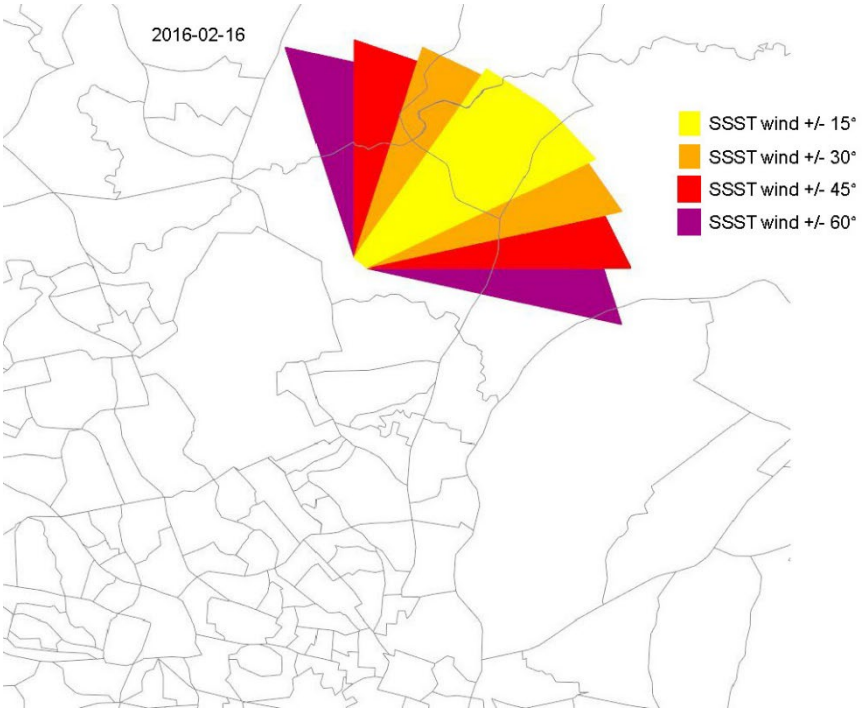

Figure S9. *Comparison of SSST predicted areas of concern using the available wind variability range(+/- degree) increments, shown here for the February 16, 2016, burn at Carver's Creek Park. As the range of wind variability selected increases, the area of concern increases radially. Census block groups are outlined in grey.*

Table S1. *Additional details of smoke tools set-up.*

SSST	
Latitude/Longitude	Based on burn records
Acres	Based on burn records
Fuels	Based on latitude/longitude, Landfire, & Anderson 13 Fire Behavior Fuel Models
Ignition Method	Backing/Spot
Wind direction	Based on meteorology at latitude/longitude
Wind direction ±	Assumed ± 15 degrees
VSmoke-Web	
Latitude/Longitude	Based on burn records
Acres	Based on burn records
Duration	Assumed 8 hours for all burns
Ignition Method	Backing/Spot
Fuel Type	Based on latitude/longitude, Landfire, & Anderson 13 Fire Behavior Fuel Models
Tons/acre	Default value based on Fuel Type selection
Fuel Moisture Scenario	Assumed dry for all burns
% Consumed	Default value based on Fuel Moisture selection
$PM_{2.5}$ Emission Factor	Default value based on Fuel selections
Particulate Emission Rate	Default value based on Fuel selections
Heat Release Rate	Default value based on Fuel selections
Mixing Height	Based on meteorology at latitude/longitude
Transport Wind	Based on meteorology at latitude/longitude
Stability Class	Assumed "moderately unstable" for all burns
Plume Rise Fraction	Default tool value (-0.50)
HYSPLIT	
Lat/Lon	Based on burn records
Deposition	Yes
Release start time	Assumed 10:00 AM local time for all burns
Acres	Based on burn records
Total duration	Assumed 8 hours for all burns
Averaging period/Output interval	1 hour
Top of averaged layer	100 m AGL (minimum allowed)
Pollutant characteristic	Particle
Dry deposition velocity (m/s)	0.0001
Model Run Type (INITD)	Auto switch from INITD=0 to INITD=4 (horizontal and vertical particle to horizontal top-hat puff and vertical particle)

***Table S2**. Burn information and population impact estimates for the five largest areas of concern due to smoke pollution predicted by each tool considered.*

Tool	Smoke Area (km^2)	Date	Acres Burned	Population Impact	State Park
SSST	87	3/9/2016	395	2080	Lake James
	85	6/8/2016	303	26537	Carvers Creek
	83	2/11/2016	253	682	Goose Creek
	82	2/1/2016	210	5927	Carvers Creek
	79	2/29/2016	144	2531	Carvers Creek
VSmoke-Web	508	3/1/2016	460	21561	Morrow Mountain
	474	3/7/2016	232	36523	Pilot Mountain
	443	3/9/2016	395	8241	Lake James
	332	3/22/2016	42	20275	Falls Lake Recreation Area
	319	3/7/2016	113	12850	Carvers Creek
HYSPLIT-Web	2695	3/7/2016	232	29361	Pilot Mountain
	2354	2/11/2016	253	1230	Goose Creek
	2264	2/1/2016	210	172473	Carvers Creek
	2072	3/1/2016	460	220135	Morrow Mountain
	1541	4/14/2016	159	60423	Carvers Creek
HYSPLIT-PC-BlueSky	292	2/29/2016	144	9813	Carvers Creek
	203	2/11/2016	136	45428	Carvers Creek
	196	2/16/2016	64	12887	Carvers Creek
	187	1/13/2016	40	12153	Falls Lake Recreation Area
	70	1/14/2016	45	3339	Pilot Mountain

Table S3. *Burn information and predicted area of concern due to smoke pollution for the five largest population impact estimates based on each tool considered.*

Tool	Population Impact	Date	Acres Burned	Smoke Area (km^2)	Park
SSST	26537	6/8/2016	303	85	Carvers Creek
	12450	2/18/2016	66	21	Carvers Creek
	11775	4/14/2016	159	23	Carvers Creek
	10672	3/1/2016	59	75	Goose Creek
	6915	4/25/2016	59	75	Carvers Creek
VSmoke-Web	36523	3/7/2016	232	474	Pilot Mountain
	24337	5/25/2016	95	275	Carvers Creek
	21561	3/1/2016	460	508	Morrow Mountain
	20275	3/22/2016	42	332	Falls Lake Recreation Area
	14432	6/8/2016	303	40	Carvers Creek
HYSPLIT-Web	220135	3/1/2016	460	2072	Morrow Mountain
	172473	2/1/2016	210	2264	Carvers Creek
	121849	3/7/2016	113	1317	Carvers Creek
	97027	4/15/2016	105	582	Falls Lake Recreation Area
	60423	4/14/2016	159	1541	Carvers Creek
HYSPLIT-PC-BlueSky	45428	2/11/2016	136	203	Carvers Creek
	44695	2/18/2016	66	61	Carvers Creek
	12887	2/16/2016	64	196	Carvers Creek
	12153	1/13/2016	40	187	Falls Lake Recreation Area
	9813	2/29/2016	144	292	Carvers Creek

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