SMOKE Emissions Processing

Utah Division of Air Quality

September 11, 2019

Introduction

Utah DAQ used the SMOKE v3.6.5 emissions processing software to prepare inventoried emissions for air quality modeling. SMOKE (Sparse Matrix Operator Kernel Emissions)[1] is a state-of-the-art emissions model whose purpose is to distribute inventoried pollutants in time and space. SMOKE also speciates volatile organic carbon (VOC) and particulate matter (PM) estimates.

Inputs for SMOKE consist of inventory data in the form of county-wide criteria pollutant (CAP) totals (NO_x, VOC, direct PM_{10}, direct $PM_{2.5}$, NH_3, SO_2, and CO). Inventory data exists for four distinct sectors: area, nonroad, mobile, and point.

The area, nonroad, and mobile emissions inventories consist of pollutants summarized by county and EPA Source Classification Code (SCC). An SCC is an eight-to-ten digit number that identifies the process or technology that directly emitted the associated pollutants.

Point sources encompass large emitters such as oil refineries, power plants, and big mining operations. Inventory input is comprised of pollutants totaled for each component of a facility (e.g., electric generators, storage tanks, etc.). Point source emissions are placed at precise locations using latitude/ longitude coordinates.

Other inputs for SMOKE include spatial, temporal, and speciation profiles. A profile is assigned to an individual source in the inventory by linking its SCC to a profile code. These references are important for correctly characterizing the time, space, and VOC/PM composition for a given emissions source.

2D SMOKE gridded emissions output is then input into the air-quality model (CAMx 6.30). CAMx[2] calculates the vertical plume rise from point source stack parameters.

Modeling Domain

UDAQ used two modeling domains in a two-way nested configuration for air quality modeling (Figure 1, below). A larger outer-domain that is 4 km resolution covers the State of Utah and portions of surrounding state. A smaller 1.33 km inner-domain covers the Wasatch Front and Cache Valley, and thus daily PM2.5 nonattainment counties. A vertical resolution of 42 layers is used, matching the WRF inputs (no layer collapsing).

[1] https://www.cmascenter.org/smoke/

[2] http://www.camx.com/

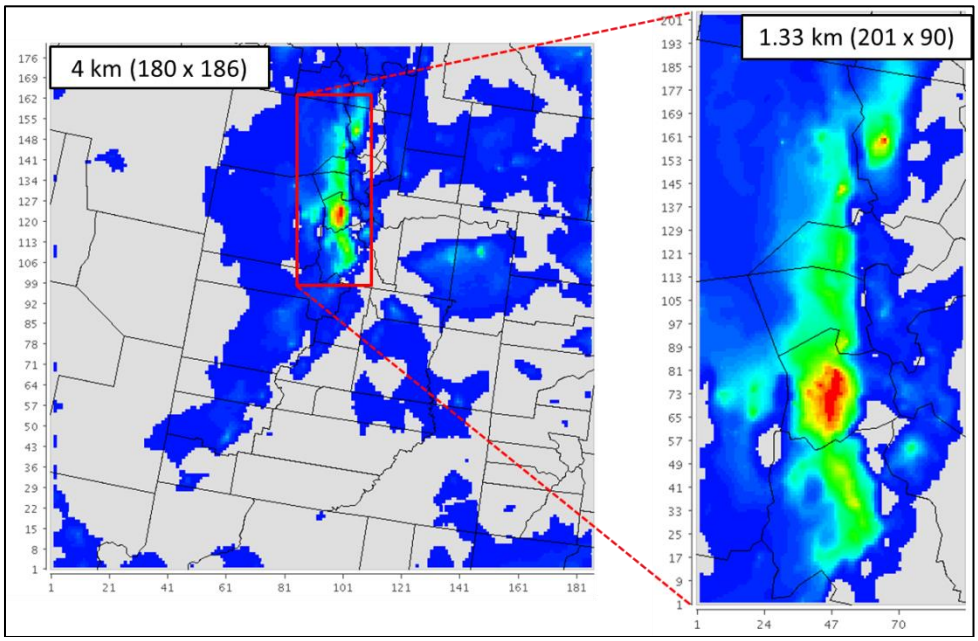

Figure 1: Modeling domains used for air quality modeling. 4 km (left) domain provides initial/boundary conditions for 1.33 km (right) domain.

Residential Wood Smoke

Regulations on residential wood burning have been established for Utah counties that belong to a 24-hour PM2.5 nonattainment area. Since 2014, stricter regulations have established a mandatory ban on residential wood burning for days where forecasted 24-hour average $PM_{2.5}$ concentrations exceed 15 µg/m^3. Residential wood smoke emissions were reduced by factors derived from a recent UDAQ levoglucosan study[3]. For projected years beyond 2014, these compliance rate factors for residential wood smoke are assumed to be the same. County-specific compliance rates used to reduce inventoried residential wood smoke are listed below in Table 1.

County	Compliance Rate
Box Elder	61%
Cache	51%
Davis	61%
Salt Lake	61%
Tooele	61%
Utah	29%
Weber	61%

Table 1: List of estimated wood burn ban compliance rates by county.

[3] https://deq.utah.gov/legacy/programs/air-quality/research/projects/residential-wood-burning/wasatch-front-wood-smoke.htm

Mobile

Utah DAQ worked with the metropolitan planning organizations (MPO's) that serve those counties included (even partially) in the three daily PM2.5 nonattainment areas. Mobile emissions were calculated and projected using the MOVES 2014b model, which were then input into SMOKE as precomputed mobile inventory numbers.

Out of State Emissions

EPA National Emissions Inventory (2014 NEIv2) was used to estimate emissions totals outside of the State of Utah for all inventory sectors. All point source emissions outside of Utah were released at surface level (i.e., treated as fugitive sources).

Spatial Allocation

For spatial processing, SMOKE requires text files that describe relevant geographical information as a function of normalized grid-cell values. Within each county in the modeling domain, these normalized grid-cell values sum up to one. Arc GIS software was used for translating various geographical data-sets to the required text format used by SMOKE.

Population density at gridded 1.33/4 km resolutions was developed using three separate data sets. For counties in the daily PM2.5 nonattainment counties, population by traffic analysis zone is provided by the appropriate metropolitan planning organizations (MPO's). The MPO's and the counties for which they are responsible for (in parenthesis) are: Wasatch Front Regional Council (Salt Lake, Weber, Davis, Box Elder, and Tooele), Mountainland Association of Governments (Utah) and Cache Valley Metropolitan Organization (Cache). The remaining counties in the domain relied on population estimates provided by the Utah Governor's Office of Management and Budget (GOMB).

Population by traffic analysis zone is very high-resolution data, especially in densely populated areas. The data is first converted to densities at 25-meter resolution to capture the fine scale boundaries of the traffic analysis zones. It is then aggregated to a four-kilometer resolution to create the population surrogates.

For outlying counties, population is developed from 1) estimates of population within corporate boundaries and 2) the remaining population in the unincorporated areas of the county. Town populations are placed within corporate boundaries in ArcGIS. Remaining population is assumed to be spread evenly across the rest of the area of the county. Gridded population in the outlying counties is then created in the same manner as that done for the four Wasatch Front counties. Finally, all three data sets are combined into one gridded population data set for the entire modeling domain.

Mobile source emissions data is distributed to the modeling grid using a combination of link-based data and county totals. The data based on county-wide vehicle miles traveled (VMT) is distributed using population density as a surrogate. As with the population data, the VMT distribution is based on several different data sources. The MPO's provided link based data for VMT on arterial roads

and freeways for the four Wasatch Front counties. UDOT provided link based VMT for state roads and interstates in the outlying counties as well as estimates of VMT driven on local roads.

Because link based VMT does not exist for VMT on local roadways, the distribution of local VMT was created by the use of population surrogates. This was done for all counties in the modeling domain. Spatial surrogates for urban, forest, and water areas were developed using U.S. Geological Survey (USGS) land use and land cover data. The following table (Table 2) provides a full list of the spatial surrogates used for emissions allocation:

Profile Code	Profile Description
20	Interstate Highways
40	Arterial Roads
50	Population
110	Housing
150	Residential Heating - Natural Gas
160	Residential Heating - Wood
200	Urban Primary Road Miles
260	Total Railroad Miles
310	Total Agriculture
400	Rural Land Area
500	Commercial Land
501	Commercial Property Point
505	Industrial Land
510	Commercial plus Industrial
515	Commercial plus Institutional Land
535	Residential + Commercial + Industrial + Institutional + Government
700	Airport Areas
861	Construction and Mining

Table 2: List of spatial surrogates used for the spatial allocation of emissions in SMOKE.

For area and nonroad sources where spatial surrogate assignments were unobtainable, *Population* was used as the spatial surrogate. In other words, *Population* was used as the default spatial surrogate for area and nonroad sources. Mobile sources were fully specified in terms of spatial surrogate assignment.

Temporal Allocation

Temporal profiles are meant to characterize large-scale emissions behavior over time. Emissions were distributed in time according to temporal profiles and source assignments gathered from the EPA's 2011v6 modelling platform. In the few instances where temporal profiles didn't exist in the 2011v6 modeling platform for a given SCC, temporal profile assignments were assigned based on SCC description.

Temporal allocation in SMOKE consists of defining emissions distribution across three time-domains:

1. Monthly
2. Weekly
3. Hourly (“ALLDAY”)

Monthly profiles determine how emissions are distributed month-to-month. For example, lawnmower emissions in winter months are small. However, snow blower emissions during that same period are relatively large. Next, weekly profiles determine how emissions are distributed day-to-day during a week. Emissions are often different between weekday and weekend days for example. Finally, hourly (ALLDAY) profiles determine the hour-by-hour behavior of emissions sources for a given day.

Since UDAQ is modeling a wintertime episode, emission categories that have no relevance to wintertime emissions were not included. Some of these include:

- Biogenic emissions
- Unpaved road dust
- Agricultural harvesting and burning
- Wildfires

Speciation

Inventoried VOC estimates were converted to total organic gas (TOG) and then speciated according to source-specific TOG profiles. Speciation profiles and their associated SCC assignments generally came from EPA’s 2011v6 modeling platform. When a source assignment wasn’t found in the 2011v6 modeling platform, assignments were either based on SMOKE defaults or inferred from the source’s SCC description. VOC emissions were speciated for use with the CB6r2h photochemical mechanism. PM was speciated for use with the AERO6 aerosol module.

SMOKE Output Summary

The new implementation rule requires that emissions values shall be either annual total emissions, average-season-day emissions, or both, as appropriate for the relevant (24-hour) $PM_{2.5}$ NAAQS. Also, that the state shall include as part of the plan a rationale for providing annual or seasonal emissions, and the justification for the period used for any seasonal emissions calculations.

Utah’s long-running difficulties with fine PM may be characterized as a short-term (24-hour NAAQS) problem belonging to the winter months when meteorological conditions are conducive to the both the trapping of air in the valleys due to temperature inversions and to the secondary formation of $PM_{2.5}$. Thus, in addressing the problem through quantitative SIP analyses, emissions inventories have historically been adjusted to reflect this seasonality.

“Average-season-day emissions” are defined, in 40 CFR 51.1000, as the sum of all emissions during the applicable season divided by the number of days in that season. Again, Utah’s inventory is compiled using a variety of different averaging periods, and is then gridded into the air model along with an hourly temporal component for each 24 hour period.

Emissions are extracted from SMOKE and reported in time averaged units of “tons-per-day”. Each projection of the emissions inventory is modeled with meteorology reflecting the actual episode used to validate the air quality model. This episode spanning 10 days was incurred from Saturday, January 1st through Monday, January 10, 2011. It is important to note that emissions are different on weekdays than they are on weekends, Saturday differs from Sunday, and even weekday emissions will differ slightly from Monday – Friday.

Thus to report the inventory, emissions are for each 24-hour period belonging to this episode. They are summed and then divided by 10 to arrive at the average episode day emissions for the nonattainment area. The Emissions Inventory (EI) submittal also includes the original calculations as part of the Technical Support Document (TSD).