LMAPCD Ozone Formation Study: MPE and Sensitivity Test Results

Presented to the Multi-Pollutant Stakeholder Group
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Agenda

01 Emissions Inventory

02 Ozone Model

03 Model Performance Evaluation

04 Sensitivity Modeling
Goal of Ozone Formation Study is to refine our understanding of ozone formation in Louisville/Jefferson County ozone nonattainment area to inform strategic policy decisions.

Objectives:

1. Develop a comprehensive emissions inventory suitable for modeling Louisville/Jefferson County ozone formation.
2. Develop a modeling tool useful for analyzing ozone formation processes.
3. Understand the sensitivity of Louisville/Jefferson County ozone to emissions precursors.
Emissions Inventory
Overview of Emissions Inventory

- Use United States Environmental Protection Agency’s (USEPA) 2016beta inventory
- Update key source sectors to better represent the Louisville ozone nonattainment area and surrounding counties
- Pollutants included in the emissions inventory:
  - Ozone precursors: nitrogen oxides (NOx), volatile organic compounds (VOC), and CO;
  - Primary PM$_{10}$ and PM$_{2.5}$; and
  - Precursors of PM$_{10}$ and PM$_{2.5}$: NOx, sulfur dioxide (SOx), VOC, and ammonia (NH$_3$)
- Develop 2016 base year inventory for the ozone season (March 1 to October 31)
Ozone Precursor Inventory

• USEPA 2016beta emissions inventory platform includes:
  • Electric Generating Units (EGUs)
  • Non-EGU point sources
  • On-road mobile sources
  • Non-point sources
  • Biogenic sources
  • Non-road and residential sources
  • Fires

• USEPA 2016beta emissions are updated using Louisville-specific inputs for:
  • On-road sources
  • Non-point sources
    • Bulk gas terminals/plants – converted to point source
    • Publicly Owned Treatment Works (POTW) – converted to point source
    • Industrial natural gas combustion
    • Land clearing debris
Spatial Plots of Emissions

Total NOx emissions

Total VOC emissions
Ozone Model
Modeling Overview

- Simulated the 2016 ozone season (March 1, 2016 – October 31, 2016)
- Leveraged the 2016Beta platform developed by EPA
- Models:
  - Air Quality Model – CAMx Version 6.5 (modified)
  - Meteorological Model – WRF Version 3.8
  - Emissions Model – SMOKE Version 4.6
Model Domain

Gridded model used two domains centered on Louisville/Jefferson County:

- 12-km grid size domain and
- 4-km grid size domain

Vertical resolution

- Used WRF vertical resolution for CAMx (i.e., no layer collapsing)
- 35 vertical layers up to a 50 millibar height
Flexi-nesting

The native 12-km resolution meteorology and emissions are modeled at a 4-km grid resolution.

Locations of point sources relative to 12-km grid cells.
CAMx Model Inputs

• In addition to model-ready emissions data, the following inputs were prepared for the flexi-nested 12-km and 4-km domain:
  • Gridded Meteorological data: extract and process the LMAPCD 12-km domain area from USEPA 2016 WRF data
  • Boundary Concentrations: re-run USEPA CONUS 12-km domain to produce necessary three-dimensional files
  • Initial Concentrations: use 10-day spin up preceding the ozone summer modeling period
  • Landuse: extract the LMAPCD 12-km domain area from USEPA 2016 platform data
  • Photolysis Rates and ozone column information: re-run TUV and OzoneMAP for LMAPCD 12-km domain
    • Used 2016 Ozone Mapping and Profiler Suite (OMPS) satellite data
Model Performance Evaluation
Model Performance Evaluation (MPE)

- Base Case results compared to measured ambient air concentrations
  - Used Atmospheric Model Evaluation Tool (AMET)
  - Evaluated maximum daily average 8-hour (MDA8) ozone, NOx, and NO₂
- Overall performance is good, bias and error often within:
  - Established performance goals
    - Normalized Mean Bias (NMB) < ±5%
    - Normalized Mean Error (NME) < 15%
  - And performance criteria
    - NMB < ±15%
    - NME < 25%
Ozone Summary Statistics

Normalized Mean Bias (NMB)

- **Spring**
  - Model is biased low
  - Cannons Lane doesn’t meet performance criteria
- **Summer**
  - Model is biased high, *except* at Cannons Lane
  - All sites meet performance criteria

Normalized Mean Error (NME)

- **Spring**
  - Cannons Lane doesn’t meet performance goal, but does meet the criteria
- **Summer**
  - Model meets goal *only* at Cannons Lane, other sites meet the criteria
Model is biased high in summer for all sites except Cannons Lane.

All sites meet criteria.
Summer MDA8 Timeseries: Cannons Lane

LMAPCD - 4km

2016 USEPA - 12km
NOx and NO\textsubscript{2} Concentrations March to October: Cannons Lane
Three time periods selected to examine hourly ozone concentrations:

- June 9 – June 11
- June 29 – July 1
- July 18 – July 19*
  - * This period will be discussed first

The selected periods capture four of the top ten highest observed MD8A ozone concentrations days at Cannons Lane (Site 211110067)

Hourly ozone concentrations movies for each period are shown in the following slides
• Movies show the evolution and transport of ozone concentrations throughout the 4-km domain

• Event has consistently high surface ozone concentrations throughout the domain over several days
  • Good example of typical ozone diurnal pattern: night-time and early morning depletion, afternoon build-up and transport

• Model performance is good during this period
  • Spatial and temporal patterns shown in the movie relatively similar to observations
Louisville experiences some of the largest fluctuations in ozone concentrations in the modeling domain, on the scale of hours to days.

- For example peak hourly modeled ozone concentrations reach ~90 ppb on June 10-11, followed by a peak of only ~50 ppb on June 15.
- Model underpredicts MDA8 concentrations by ~10 ppb on average during period.
Highest MDA8 in 2016 is measured at Cannons Lane on June 30

Ozone concentrations in Louisville change significantly throughout the day
- Modeled hourly concentrations range from 5 - 90 ppb

Event is of particular interest when analyzing sensitivity to VOC and NOx emissions reductions

Model underpredicts MDA8 concentrations by ~10 ppb on average during period

Note: Gaps in hourly ozone concentrations at Cannons Lane indicate observational data was not available at that time.
Sensitivity Tests
Sensitivity Modeling

• Assess Louisville-Jefferson County’s ozone sensitivity to nitrogen oxides (NOx) and VOC concentrations:
  • Case 1: Decrease regional NOx emissions by 25%, run CAMx and compare results
    
    \[ [\text{D8MAXozone}]_{\text{base year}} - [\text{D8MAXozone}]_{\text{NOx reduction}} \]
  • Case 2: Decrease regional VOC emissions by 25%, run CAMx and compare results
    
    \[ [\text{D8MAXozone}]_{\text{base year}} - [\text{D8MAXozone}]_{\text{VOC reduction}} \]

• Analysis focused on the average MDA8 concentration during the top 10 ozone days at Cannons Lane in 2016
Sensitivity Modeling: NOx Sensitivity Test

2016 Base Case

NOx Sensitivity

NOx Sensitivity - 2016 Base Case

NOx emissions reductions decrease Top10 MDA8 ozone by 3.8 ppb in Jefferson County and 6.2 ppb overall (in southeast)
Sensitivity Modeling: VOC Sensitivity Test

2016 Base Case

VOC Sensitivity

Top 10 MDA8 by 1.3 ppb

Reductions are most effective in Jefferson County
Sensitivity Test Results – Nonattainment Area

VOC emissions reductions decrease Top10 MDA8 by 1.3 ppb near Cannons Lane
NOx emission reductions for Top10 MDA8 are least effective near Cannons Lane
Compare MDA8 concentrations from Sensitivity Tests paired with MDA8 Base Case concentrations

- In general, NOx emission reductions (blue) are more effective than VOC emission reductions (orange)
- Except June 30 shows larger ozone decreases due to VOC reductions than NOx reductions
Cannons Lane hourly Ozone:

- VOC reductions lead to ozone decreases on June 30
- NOx reductions less effective at reducing ozone than VOC on June 30
Spatial Analysis of June 30

- At noon on June 30, modeled ozone concentration was high (~84 ppb)
- NOx emissions reduction cause 9 ppb increase in hourly ozone in Jefferson County
- VOC reduction was most effective in reducing ozone concentration in Jefferson County
Conclusions
Summary

- A model-ready emissions inventory was developed using data available to LMAPCD
- Model has acceptable performance for ozone
- When regional emissions are reduced, Louisville/Jefferson County ozone is more NOx sensitive than VOC sensitive
  - NOx emissions reductions decrease MDA8 ozone by 3.8 ppb in Jefferson County vs. 1.3 ppb for VOC emissions reductions (based on average of Top 10 days)
- On select days, ozone within Jefferson County has similar response to NOx and VOC emissions reductions
Recommendations for Further Investigation

- Compare Louisville modeling emissions inventory to USEPA 2016 National Emissions Inventory Version 1
- Analyze and update VOC speciated emissions with local point source emissions information
- Assess year 2016 representativeness in terms of emissions events
- Apply NOx and VOC emissions reductions to just Louisville/Jefferson County to analyze ozone sensitivity to local emission reduction measures
- Evaluate the ozone formation potential of 1,3-butadiene releases
- Evaluate the periods when the model under-predicts ozone formation
- Evaluate periods with effective VOC emission reductions in more detail
Questions?