SMOKE-MOVES
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SMOKE and Modeling Emissions for AQ

inventory emissions: ascii county inventory pollutants (e.g. NOx, VOC) annual/monthly

AQ model-ready emissions: binary gridded AQ species (e.g. NO2, NO, HONO, Acetaldehyde, Ethene, ...) hourly

SMOKE

AQ model
SMOKE and MOVES Previous Approach

MOVES inventory emissions: state, monthly

NMIM county to state ratios

MOVES/NMIM inventory emissions: county, monthly

AQ model-ready emissions, PM adjusted

AQ model-ready emissions

recent regulatory examples: Transport Rule, Light-Duty GHG
Motivation

- More closely integrate MOVES into the emissions modeling process
  - Automation of the emissions process
  - Previously needed MOVES and NMIM runs for each future year or representative future years

- Emissions sensitive to temperature
  - Initially focused on PM
  - See significant T sensitivity for other pollutants

- Computation considerations
  - Keep computation demands “reasonable”
  - Representative counties
  - Lookup tables for emission factors
Temperature - Gasoline

![Graph showing NOx emissions as a function of temperature for CY 2005, CY 2015, and CY 2020. Emissions are expressed as a percentage change. The graph shows a decrease in emissions with increasing temperature, with a more pronounced decrease for CY 2020.](image)
Temperature - Gasoline

Total PM$_{2.5}$

- CY 2005
- CY 2015
- CY 2020

Emissions (% change)

Temperature (F)
SMOKE-MOVES Integration Tool

Meteorological Preprocessor (Met4Moves) → Driver Script → MOVES

SMOKE

→ AQ model-ready files

Post-processing Script
SMOKE-MOVES Overview

- **Met4Moves**
  - Produces temperature ranges, diurnal temperature profiles, and relative humidity (RH) values for specific counties

- **MOVES**
  - Runs series of scenarios for each of the temperature profiles and temperature bins
  - Produces emission factors (EF)

- **SMOKE**
  - Takes EF, activity data (VMT, SPEED, VPOP) and temperature data
  - Produces AQ model-ready emissions
Overview: Reference County

- Reduces the computational burden of running MOVES on every county in your modeling domain.
- Represent a set of similar counties (i.e., inventory counties) called a county group.
- Key emission rates for the single reference county in MOVES can be utilized to estimate emissions for all counties in the county group through SMOKE.

- *Criteria*: Similar fuel parameters, fleet age distribution and I/M programs.
Overview: Fuel Month

- Similar to the reference county, the fuel month reduces the computational time of MOVES by using a single month to represent a set of months.
- Represent a particular set of fuel properties over the months used in MOVES.
- Example: Run MOVES for January, use that run to represent a series of months with similar fuel types (e.g. Oct, Nov, Dec, Jan, Feb, Mar).

- **Criteria**: Fuel supply data in the MOVES database for each reference county.
Overview: Emission Processes

- **Rate-per-distance (RPD)**
  - On-roadway emissions
  - Exhaust, evaporative, brake and tire wear

- **Rate-per-vehicle (RPV)**
  - Off-network emissions
  - Exhaust, evaporative

- **Rate-per-profile (RPP)**
  - Off-network emissions
  - Parked vehicles, including diurnal (when the vehicle is parked during the day) and hot soak (immediately after a trip)
  - Evaporative fuel vapor venting
Met4Moves

Meteorological Preprocessor (Met4Moves)

- Reference county X-ref
- Fuel month X-ref
- Spatial Surrogates
- Gridded/Hourly meteorology

Output for MOVES Driver Script (Reference County)
Output for SMOKE (Inventory County)
Met4Moves: Output for MOVES

- Representative counties
- Representative months

# DESC Sample Met input file for MOVES Driver script
PD_TEMP_INCREMENT 5
PV_TEMP_INCREMENT 5
PP_TEMP_INCREMENT 10

<table>
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<tr>
<th>Ref. County</th>
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<th>temperatureProfileID</th>
<th>RH</th>
<th>Temp1 (Min)</th>
<th>Temp2 (Max)</th>
<th>Temp3</th>
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<th>Temp24</th>
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<td>...</td>
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</tr>
</tbody>
</table>
Met4Moves: Output for MOVES

- Diurnal T profiles for RPP
- Normalized 24 hr T profiles based on min/max T of county group
**Met4Moves: Output for SMOKE**

- Monthly or Daily temperature ranges for RPP
- All counties in domain

<table>
<thead>
<tr>
<th>Inventory County</th>
<th>fuelMonth</th>
<th>Month</th>
<th>JulianDate</th>
<th>RH</th>
<th>Temp (Minimum)</th>
<th>Temp (Maximum)</th>
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<td>25.8</td>
<td>62.1</td>
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<td>61.1</td>
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<td>66.6</td>
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<td>63.7</td>
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<td>61.1</td>
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<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
</tbody>
</table>
MOVES Driver Script

- Creates the input data tables for import
- Creates run specification (runspec) XML files to run MOVES for large number of conditions
  - Separate runs for each T bin or T profile and for each reference county and fuel month
- Generates specific T and RH csv files based on Met4Moves output
- Creates scripts to run all the importers and all the MOVES scenarios
MOVES Post-processing Scripts

- Convert MOVES MySQL tables to SMOKE-ready EF tables
  - Produces 3 types of EF tables RPD, RPV, RPP EF tables
  - Produces separate set of tables for each reference county and fuel month

- Maps MOVES PM species to SMOKE PM species
  - Appropriate for CB05 with SOA
  - e.g. PMC, POC, PNO3, ...

- Maps MOVES emission processes to SMOKE emission processes
  - Optionally consolidate down to “typical” SMOKE modes: EVP, EXH, BRK, TIR
## MOVES Post-processing Scripts: Emission Processes

<table>
<thead>
<tr>
<th>Emission Rate Lookup Table</th>
<th>Units</th>
<th>SMOKE ProcesID</th>
<th>Emissions Process</th>
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</thead>
<tbody>
<tr>
<td>RatePerDistance</td>
<td>Gram/mile</td>
<td>EXR</td>
<td>Running Exhaust</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CXR</td>
<td>Crankcase Running Exhaust</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TIR</td>
<td>Tire Wear</td>
</tr>
<tr>
<td></td>
<td></td>
<td>BRK</td>
<td>Brake Wear</td>
</tr>
<tr>
<td></td>
<td></td>
<td>EVP</td>
<td>On-road Evaporative Permeation (roadTypeID=2,3,4,5)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>EFL</td>
<td>On-road Evaporative Fuel Leaks (roadTypeID=2,3,4,5)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>EFV</td>
<td>On-road Evaporative Fuel Vapor Venting (roadTypeID=2,3,4,5)</td>
</tr>
<tr>
<td>RatePerVehicle</td>
<td>Gram/vehicle/hour</td>
<td>EXS</td>
<td>Start Exhaust</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CXS</td>
<td>Crankcase Start Exhaust</td>
</tr>
<tr>
<td></td>
<td></td>
<td>EVP</td>
<td>Off-network Evaporative Permeation (roadTypeID=1)</td>
</tr>
<tr>
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<td>EFL</td>
<td>Off-network Evaporative Fuel Leaks (roadTypeID=1)</td>
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<td></td>
<td>CEI</td>
<td>Crankcase Extended Idle Exhaust</td>
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<tr>
<td></td>
<td></td>
<td>EXT</td>
<td>Extended Idle Exhaust</td>
</tr>
<tr>
<td>RatePerProfile</td>
<td>Gram/vehicle/hour</td>
<td>EFV</td>
<td>Off-network Evaporative Fuel Vapor Venting (roadTypeID=1)</td>
</tr>
</tbody>
</table>
SMOKE Modeling System

- **RPD (grams/miles) : On-roadway Emission Process EFs**
  - Lookup Fields: SCC, speed (optional 24-hr speed profiles), fuel month, and temperature.

- **RPV (grams/vehicle-hr) : Off-network Emission Process EFs**
  - Lookup Fields: SCC, fuel month, temperature, local time (hourID).

- **RPP (grams/vehicle-hr) : Off-network Vapor Venting Evap. EFs**
  - Lookup Fields: SCC, fuel month, temperature profiles, local time (hourID).
SMOKE: On-roadway Processing (RPD)
SMOKE: Off-network Processing (RPP, RPV)
SMOKE: Final Merging

- Run separately (RPD, RPV, RPP)
- RPD, RPV are run for every day using hourly gridded MCIP files
- RPP could be run for average day (representative day per month) using monthly averaged meteorological output from Met4Moves OR could be run every day using daily meteorological output from Met4Moves
National Run

- 103 reference counties, 2 fuel months
- MOVES was run using cloud computing
- 12km national domain for SMOKE
  - Post-processed to 36km national domain and 2 12km domains (East and West U.S.)
- Using separate permeation mode (5th SMOKE mode, EPM) – new speciation profiles
- Some of the toxics and the NOx components (NO, NO2, HONO) were modeled directly
National Run: Timing

- **Initial computational approach**
  - 13 minutes/model day for 1 representative county (RPD)
  - Scaled almost linearly with representative counties
  - Estimated timing for our national domain: 1 year
  - Profiled the code
    - Majority of the time was in reading/processing the EF tables
    - EF tables were being processed every hour
    - Another significant process is generating the reports: 2x per day loop

- **Enhanced computational approach**
  - Moved reading EF tables to outer loop & added header to EF tables
  - Limited reports to once per day loop
  - 20 seconds/model day for 1 representative county (RPD)
  - Estimated timing for our national domain: 9 days
Recent Developments

- Improved computational efficiency of Movesmrg
- Updates to post-processor script
  - New header for EF tables
  - Extended idle
  - PMC for Brake and Tire modes
- Met4moves averaging period
  - Daily vs. Monthly ranges (SMOKE output)
  - New header
- QA reports from Movesmrg
  - Source level reports
  - Speciated reports
Recent Developments

- Support for weekday/weekend hourly speed profiles (RPD)
- Support for monthly activity data in FF10 format
- Updated Emission Processing Input Data
  - Chemical speciation profiles and cross-reference input files
  - Temporal profiles and cross-reference files
  - Surrogates
References

- **SMOKE:**
  http://www.smoke-model.org/

- **SMOKE-MOVES User’s Guide:**
Acknowledgement

- OTC, NESCAUM, MARAMA, SESARM
- ENVIRON International Corporation
- US EPA Office of Transportation and Air Quality (OTAQ)
Appendix
MOVES: RatePerVehicle (RPV) Approach

- Assigns each binned temperature to all hours of a run day
- RatePerVehicle emission rates depend on - Temperature - Humidity - Hour - Day type
MOVES: RatePerDistance (RPD) Approach

- Assigns binned temperatures to hours of the day
- RatePerDistance emission rates depend on:
  - Temperature
  - Speed
  - Humidity
Evaporative Fuel Vapor Venting emissions affected by temperatures in previous hours

- When the vehicle is parked Including diurnal (when the vehicle is parked during the day) and hot soak (immediately after a trip when the vehicle parks) emissions types

(min, max) temperatures:
(30, 30) (40, 40) (50, 50) (60, 60) (70, 70) (80, 80) (90, 90)
(30, 40) (40, 50) (50, 60) (60, 70) (70, 80) (80, 90)
(30, 50) (40, 60) (50, 70) (60, 80) (70, 90)
(30, 60) (40, 70) (50, 80) (60, 90)
(30, 70) (40, 80) (50, 90)
(30, 80) (40, 90)
(30, 90)

From ENVIRON
SMOKE: Movesmrg RPD

- Stores EFs by SCC, speed bin, temperature value, process, and pollutant
- Map every county to corresponding reference counties for appropriate EF
- Map actual date to corresponding fuel month for appropriate EF
- Estimates hourly emissions for every grid cell in the domain using hourly gridded MCIP files

- $\text{Gridded/hourly/speciated Emission} = \text{EF} \times \text{hourly VMT} \times \text{Grid cell fraction} \times \text{Speciation fraction}$
RPV mode: Store EFs by weekday/weekend, SCC, local hour, temperature value, process, and pollutant

RPP mode: Store EFs by weekday/weekend, SCC, local hour, temperature profile, process, and pollutant

RPV estimates hourly emissions for every grid cell in the domain using hourly gridded MCIP files

RPP estimates emissions by inventory county using appropriate temperature profile based on Met4Moves profiles

Map every county to corresponding reference counties for appropriate EF

Map actual date to corresponding fuel month for appropriate EF

Gridded/hourly/speciated Emission = EF * Vehicle populations * Grid cell fraction * Speciation fraction