Lessons Learned from MOVES and SMOKE Modeling

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Presentation Overview

- Background
- SMOKE-MOVES Modeling System
- Spatial and Temporal Resolutions
- Development Timeline
- Uncertainties
- Recommendations
- Acknowledgments
Background – VMT, NOx and VOCs by states

Mobile Source 2007 Annual VMT State Totals

Mobile Source NOx State Totals, January - December 2007

Mobile Source 2007 Annual VPOP State Totals

Mobile Source VOC State Totals, January - December 2007
Background

spatial distributions of mobile NOx and CO

NOx in MANEVU+VA
annual emissions

CO in MANEVU+VA
7pm on 08/03/2007
Background

MOVES can be run in two modes:

<table>
<thead>
<tr>
<th>Inventory mode</th>
<th>Emission rate mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>county scale</td>
<td>regional scale</td>
</tr>
<tr>
<td>monthly averaged temperature</td>
<td>hourly temperature</td>
</tr>
<tr>
<td>non-modeling inventory</td>
<td>modeling inventory</td>
</tr>
<tr>
<td>conformity analysis</td>
<td>air quality modeling</td>
</tr>
</tbody>
</table>

- Emission rate mode is often referred as lookup table mode (focus of this presentation);
- Due to SMOKE input requirement (VMT/VPOP by SCC), both inventory mode and emission rate mode are needed to generate lookup tables for a regional modeling inventory

county level by month  
grid cell by hour
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SMOKE-MOVES Modeling System

For developing regional emission inventory, the modeling system consists of 3 components:

- **MOVES**
  - MOVES2010a (released in September 2010)
  - updated from MOVES2010 (released in December 2009)

- **SMOKE-MOVES Integration Tool**
  - undergone many version changes;
  - most recent version released in September 2011

- **SMOKE**
  - undergone many version changes;
  - most recent version (v3.0) released in September 2011
SMOKE-MOVES System

Processing Flowchart

(1) SMOKE-MOVES Integration Tool

(2) pre-processor
   (Windows or Linux)

(3) post-processor
   (Windows or Linux)

Files transfer across platforms is necessary if MOVES in run on Windows
Run Time

MOVES

<table>
<thead>
<tr>
<th>Model (1 county, 1 month)</th>
<th>MOVES2010</th>
<th>MOVES2010a</th>
</tr>
</thead>
<tbody>
<tr>
<td>inventory mode</td>
<td>1 – 2 hours</td>
<td>1 hours</td>
</tr>
<tr>
<td>lookup table mode</td>
<td>3 – 5 days</td>
<td>25 hours</td>
</tr>
<tr>
<td>cloud computing (3 nodes)</td>
<td>N/A</td>
<td>14 hours</td>
</tr>
</tbody>
</table>

-- MOVES run time comparison is based on one county and one simulated month;
-- Inventory mode often runs with individual county;
-- On the other hand, emission rate mode often run with representative county;
-- Virginia has 134 counties, making it even more difficult to run MOVES.

cloud computing (distributed processing):
take advantage of multiple MOVES installed in multiple machines to reduce run time
MOVES Run Time -- example

Lookup Table Mode for MANEVU

- 49 MANEVU representative counties, 2 fuel months

**MOVES 2010:** 4 days (per county per month) * 49 * 2 = 392 days

**MOVES 2010a:** 25 hrs (per county per month) * 49 * 2 = 102 days

Cloud computing: 14 hrs (per county per month) * 49 * 2 = 57 days

Adding an extra fuel month increases run time by 50 days

- VA conducts MOVES runs on Linux cluster with cloud computing capability

- OAQPS and consulting companies run MOVES on Linux
## Run Time

### SMOKE

<table>
<thead>
<tr>
<th>Model</th>
<th>SMOKE v2.7</th>
<th>SMOKE v2.7.5 beta</th>
<th>SMOKE v3.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 rep county, 1 episode month</td>
<td>6 hours</td>
<td>11 minutes</td>
<td>8.6 minutes</td>
</tr>
<tr>
<td>49 rep counties (MANEVU), 12 episode months (annual)</td>
<td>150 days</td>
<td>4.5 days</td>
<td>3.5 days</td>
</tr>
</tbody>
</table>

-- SMOKE run time assumes only one computer being used;
-- Even when work was split among modeling centers, SMOKEv2.7 still took two weeks to complete MANEVU+VA region;
-- SMOKE2.5.7b (or thereafter) has reduced run time considerably.

### Timeline:

- **MOVES2010** (Dec 2009)
- **SMOKE-MOVES Tool** (Jul 2010)
- **MOVES2010a** (Sep 2010)
- **SMOKE2.7.5beta** (May 2011)

- **~9 months**
- **~10 months**
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Resolutions in Time/Space

To reduce excessively long run time, MOVES lookup table mode is simplified in time and space resolutions:

- Fuel Month – time
- Representative County – space
- Temperature – grid cells in hours

- Temperature effect is the driving force to run MOVES in lookup table mode;
- Fuel month and representative county are for reducing run time.
-- Twelve-month fuels get lumped into MOVES modeling in two groups: summer and winter fuels;  
-- May to September is assumed for summer fuels, and October to April for winter fuels;  
-- All modeling centers in the US have used the two fuel months approach;  
-- Resolution of two fuel months may be too coarse.
Resolution in Space

Each county is represented by many grid cells; Resolution in county level is too coarse.
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Development Timeline

Summary

- **December 2009**
  - MOVES2010 released

- **July 2010**
  - SMOKE-MOVES Integration Tool released

- **September 2010**
  - MOVES2010a released

- **September 2010 – September 2011**
  - Over a dozen issues addressed and enhancements made to all 3 components (MOVES, Integration Tool, and SMOKE)
<table>
<thead>
<tr>
<th>Mon/Year</th>
<th>Event</th>
<th>Models</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>12/2009</td>
<td>MOVES2010 released</td>
<td>MOVES</td>
<td>excessive long run time for lookup mode</td>
</tr>
<tr>
<td>07/2010</td>
<td>SMOKE-MOVES released</td>
<td>Integration Tool</td>
<td>Integration Tools always released in conjunction with SMOKE</td>
</tr>
<tr>
<td>09/2010</td>
<td>MOVES2010a released</td>
<td>MOVES</td>
<td>combining 2010a and Integration Tool reduced run time significantly</td>
</tr>
<tr>
<td>09/2010</td>
<td>bugs with out-of-T range and non-consecutive fuel months</td>
<td>met4moves</td>
<td>beta version released, tested, and fixed</td>
</tr>
<tr>
<td>10/2010</td>
<td>redundant road types in run spec, slowing down MOVES</td>
<td>MOVES</td>
<td>road types removed in run spec, run time improved drastically (5 days -&gt; 1 day)</td>
</tr>
<tr>
<td>12/2010</td>
<td>Inadequate (state level only) SMOKE reports</td>
<td>SMOKE</td>
<td>duplicate runs avoided; detailed SIP quality reports by county and by SCC</td>
</tr>
<tr>
<td>01/2011</td>
<td>SMOKE enhancements</td>
<td>Integration Tool and SMOKE</td>
<td>aggregation of processes, SMOKE auxiliary files, run time reduced</td>
</tr>
<tr>
<td>02/2011</td>
<td>HONO dilemma (NO/NO2/HONO split)</td>
<td>MOVES, integration tool, and SMOKE</td>
<td>either NOx or NO/NO2 splits is fine; HONO included in lookup tables eventually</td>
</tr>
<tr>
<td>02/2011</td>
<td>abnormal rates at warmest T bin in lookup tables</td>
<td>Integration Tool</td>
<td>RD lookup tables re-generated by correcting error in post-processing script</td>
</tr>
<tr>
<td>02/2011</td>
<td>no VOC in SMOKE reports</td>
<td>SMOKE</td>
<td>fake species VOC_INV get-around added</td>
</tr>
<tr>
<td>03/2011</td>
<td>unexpected missing roatypes in representative counties</td>
<td>Integration Tool</td>
<td>missing rates derived from similar road types in post-processing script</td>
</tr>
</tbody>
</table>
## Development Timeline -- Details
(releases, problems, updates, and bugs/fixes)

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<th>Event</th>
<th>Models</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>(12) 03/2011</td>
<td>missing or incorrect extended idle rates</td>
<td>Integration Tool</td>
<td>an external MySQL database with national idle rates released by EPA</td>
</tr>
<tr>
<td>(13) 04/2011</td>
<td>VMT/VPOP not conserved in MOVES</td>
<td>MOVES</td>
<td>no resolution</td>
</tr>
<tr>
<td>(14) 05/2011</td>
<td><strong>SMOKE2.7.5b beta testing</strong></td>
<td>SMOKE</td>
<td>run time for on-road reduced significantly (150 days-&gt;4.5 days for 49 MANEVU rep counties)</td>
</tr>
<tr>
<td>(15) 06/2011</td>
<td>VOCs sudden drop/jump when fuel month switches</td>
<td>SMOKE</td>
<td>no resolution</td>
</tr>
<tr>
<td>(16) 06/2011</td>
<td>identical rates across all T bins for missing road-types</td>
<td>Integration Tool</td>
<td>fixed query criteria used in the road-types Replacements</td>
</tr>
<tr>
<td>(17) 07/2011</td>
<td>RPP sector cannot handle finer T (i.e. 5C) increments</td>
<td>met4moves</td>
<td>beta version (SMOKEv3.0) released for testing</td>
</tr>
<tr>
<td>(18) 07/2011</td>
<td>extended idle database mishap (two versions)</td>
<td>Integration Tool</td>
<td>OTC states obtained correct database; no change needed</td>
</tr>
<tr>
<td>(19) 08/2011</td>
<td>zero rates in lookup tables for leap year (i.e., 2020)</td>
<td>MOVES</td>
<td>problem fixed by using two blocks of monthvmtfractions with IsLeapYear both Y/N</td>
</tr>
<tr>
<td>(20) 09/2011</td>
<td><strong>SMOKE v3.0 released</strong></td>
<td>Integration Tool, SMOKE</td>
<td>included all updates, fixed, improvements, etc.</td>
</tr>
<tr>
<td>(21) 11/2011</td>
<td>MOVES data exchange among RPOs</td>
<td>SMOKE</td>
<td><strong>work in progress</strong></td>
</tr>
<tr>
<td>(22) 11/2011</td>
<td>speed profiles in SMOKE</td>
<td>SMOKE</td>
<td><strong>work in progress</strong></td>
</tr>
</tbody>
</table>
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Uncertainties

- Conservation of Activities
- Approach of Two Fuel Months
- Effect of Speed Profiles
- RPOs Inventory Merge
- Effect of Relative Humidity: cannot be simulated under current modeling framework
Conservation of Activities

Violation of basic principle of conservation

inputs \neq outputs

(VMT, VPOP) \neq (VMT, VPOP)

<table>
<thead>
<tr>
<th>County/State</th>
<th>VMT (% change)</th>
<th>Loss/Gain</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>York, VA</td>
<td>minimal</td>
<td>gain</td>
<td>after adjustments</td>
</tr>
<tr>
<td>Fairfax, VA</td>
<td>0.01%</td>
<td>loss</td>
<td>no adjustment</td>
</tr>
<tr>
<td>Mercer, NJ</td>
<td>0.6%</td>
<td>gain</td>
<td>no adjustment</td>
</tr>
</tbody>
</table>

-- MOVES activity outputs get fed into SMOKE; Important!
-- None of the counties modeled conserves activities (either loss or gain);
-- Adjustments can be made to recover some VMT and VPOP losses;
-- for example, adding CNG will recover almost all loss of VPOP, but not loss of VMT;
-- Question: are the loss “real”? SMOKE loss is real, and if loss in inventory mode is real too, then emissions will be affected.
-- VMT loss/gain has not been resolved yet.
For NOx and PM2.5, RPD dominates among the three sectors, accounting for >80% of the two pollutants. By contrast, for CO and VOCs, RPV is the dominating sector, whereas RPP is the least contributor to VOCs among the three. Usage of winter or summer fuel affects CO and VOCs, causing both to have sudden drop and jump in fuel transition months (May and October). Emission rates for CO and VOCs are higher with winter fuel than with summer fuel.
Constant speeds by SCC are assumed in SMOKE-MOVES modeling.

- LDGV releases more NOx and CO at higher temperatures, but emits more PM2.5 at lower temperatures.
- The lower the speed an LDGV travels, the higher the emissions for all pollutants.
- Winter and summer fuels affect CO only. Winter fuel has higher CO emission rates than summer fuel.
Modeling and Data Collection

balance between accuracy and data availability

Fuel Months

If modeling more than 2 fuel months:
(1) long run time expected
(2) most states have no monthly RVP data

Speed Profiles vs Constant Speed

SMOKE can handle 24-hr speed profiles:
(1) field measurements by SCC needed
(2) run time/effect unknown

SCC = fuel types + vehicle types + road types
(1) Virginia is part of both OTC and SESARM;
(2) Mobile emissions must be generated for all three regions for air quality modeling;
(3) In reality, emissions also include LADCO, CENRAP and MRPO.
Ideal Inventory – Option Four

From OTC’s perspective:

- Done
- Done
- To be generated

(1) Ideally, OTC would conduct MOVES runs using its own meteorology to generate emissions for SESARM region (in orange);
(2) Difficulty: No MOVES inputs; Prohibitive in time/resources;
(3) Ideal inventory is what has been done in the past with MOBILE6 (and other source sectors). It is the option 4 listed in the proposal by Zac Adelman of UNC.
Alternatives involve exchanging lookup tables (and met data) between two RPOs to avoid time-consuming MOVES runs;
None of these options (even for option three) maintains meteorological consistency;
Option three looks to be - but is not - the ideal inventory because of inherent RH in the lookup tables received, although it is the closest;
OTC and SESARM domains have different regional coverage. Option one therefore needs domain transformation;
If viewed from SESARM’s perspective, everything should be reversed.
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Recommendations

- Develop/Release MOVES for Linux
- **Modeling Guidance (by EPA):**
  a. conservation of activity
  b. fuel months
  c. CO and VOC profiles
- **Systematic Sensitivity/Comparisons:**
  a. lookup mode vs inventory mode
  b. RVP (Reid Vapor Pressure)
  c. summer VMT/Temp both high but VOCs low??
  d. speed profiles
  e. annual VMT vs monthly VMT
**Recommendations (cont.)**

- **More Research:**
  - a. evaluate MOVES against observations
  - b. lookup tables exchangeable?

- **Remaining Issues:**
  - relative humidity

- **Open/Constructive Communications:**
  - OTAQ (MOVES)
  - OAQPS (SMOKE-MOVES)
  - UNC (SMOKE)
  - RPOs (emission leads)
  - states and other end users
Acknowledgments

- MARAMA
- NESCAUM
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- GADEP
- UNC
- Alpine Geophysics