Texas SIP Photochemical Modeling Update

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Texas Commission on Environmental Quality
Chief Engineer’s Office
Air Quality Division

Presented at the
2012 EPA Regional/State/Local Modelers Workshop
Topics

- Modeling with MOVES in the Dallas-Fort Worth area (Boyer)
- Improvements to Oil & Gas Emission Inventories (Boyer)
- Model Performance Evaluation Using the Texas Air Quality Study II (TexAQS II) Data (Smith)
- Dynamic Model Performance Evaluation (Smith)
- Texas Flare Study (Smith)
Motor Vehicle Emission Simulator (MOVES)  
On-Road Emissions Inventory Development

- Macro-level estimation per county, day type, and year:
  - VMT for 28 vehicle types in MOBILE6 and 23 in MOVES
  - 3 pollutants (NO$_X$, VOC, and CO) in MOBILE6 and 5 pollutants in MOVES
    (NO and NO$_2$ estimated separately)
  - 84 total calculations for MOBILE6 and 115 for MOVES

- DFW SIP-quality 2012 analysis for one day type:
  - 81,556 total links and zones from the travel demand model
  - VMT for each vehicle type
  - 24 hours per day
  - 11 emission pollutant/process combinations in MOBILE6:
    - exhaust running and start for NO$_X$ and CO
    - both listed above plus crankcase, diurnal, hot soak, resting loss, and running loss for VOC
  - 33 emission pollutant/process combinations in MOVES:
    - running exhaust, crankcase running exhaust, start exhaust, crankcase start exhaust, extended idle exhaust, and crankcase extended idle exhaust for NO, NO$_2$, NO$_X$, and CO
    - all listed above plus evaporative permeation, evaporative fuel vapor venting, and evaporative fuel leaks for VOC
  - **602,861,952 total calculations for MOBILE6**
  - **1,125,641,280 total calculations for MOVES**
## Current On-Road Emission Data Sets for Ozone Season Modeling

<table>
<thead>
<tr>
<th>Geographic Area</th>
<th>On-Road Emissions Model</th>
<th>VMT Activity Source</th>
<th>Calendar Years</th>
<th>Season / Month</th>
<th>Day Types</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dallas-Fort Worth (DFW)</td>
<td>MOVES2010a Emission Rates</td>
<td>Local Travel Demand Model (TDM) “Links”</td>
<td>2006 / 2012</td>
<td>School and Summer</td>
<td>Weekday (Monday-Thursday Average)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
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<td>Friday</td>
</tr>
<tr>
<td>Houston-Galveston-Brazoria (HGB)</td>
<td>MOVES2010a Default Emissions</td>
<td>HPMS Roadway Types</td>
<td>2006 / 2008</td>
<td>Summer Only</td>
<td>Saturday</td>
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<tr>
<td></td>
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<td></td>
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<td>Sunday</td>
</tr>
<tr>
<td>Remaining Texas Counties</td>
<td>MOVES2010a Default Emissions</td>
<td>MOVES2010a Default Activity</td>
<td>2012 / 2018</td>
<td>July</td>
<td>Average Day or Average Weekday Adjusted to Day Types Listed Above</td>
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<tr>
<td>Northern Mexico</td>
<td>MOBILE6-Canada</td>
<td>2006 NEI - 2% Annual VMT Growth</td>
<td>2012 / 2018</td>
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</tr>
</tbody>
</table>

- HPMS stands for the Highway Performance Monitoring System.
- Day type emission ratios by pollutant from Texas data sets applied to non-Texas inventories.
- Hourly emissions distribution by pollutant from Texas data sets applied to non-Texas inventories.
- Mexico and Canada emissions adjusted to other years using combination of VMT and emission rate changes.
Eastern Texas 2006 Summer Weekday On-Road NO\textsubscript{x} at 4 km Resolution (tx\_4km)

- DFW and HGB areas are based on MOVES2010a link-level TDM analyses.
- Remaining Texas counties are based on MOVES2010a HPMS analyses.
- Non-Texas U.S. portions of the modeling domain are based on MOVES2010a default analyses.
- Mexico on-road emissions are based on the 1999 NEI projected to 2006 with the MOBILE6-Mexico model and 2% annual VMT growth assumed.
MOBILE6.2 vs. MOVES2010a Nine-County DFW Area On-Road Emission Estimates

**NO\textsubscript{x} Summer Weekday**

<table>
<thead>
<tr>
<th></th>
<th>MOBILE6.2 (tpd)</th>
<th>MOVES 2010a (tpd)</th>
<th>Difference (tpd)</th>
<th>% Change</th>
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</thead>
<tbody>
<tr>
<td>2006</td>
<td>225.31</td>
<td>259.11</td>
<td>33.80</td>
<td>15%</td>
</tr>
<tr>
<td>2012</td>
<td>122.47</td>
<td>181.40</td>
<td>58.93</td>
<td>48%</td>
</tr>
<tr>
<td>Diff (tpd)</td>
<td>-102.84</td>
<td>-77.71</td>
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</tr>
<tr>
<td>% Change</td>
<td>-46%</td>
<td>-30%</td>
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**VOC Summer Weekday**

<table>
<thead>
<tr>
<th></th>
<th>MOBILE6.2 (tpd)</th>
<th>MOVES 2010a (tpd)</th>
<th>Difference (tpd)</th>
<th>% Change</th>
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<tbody>
<tr>
<td>2006</td>
<td>105.04</td>
<td>111.02</td>
<td>5.98</td>
<td>6%</td>
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<tr>
<td>2012</td>
<td>79.77</td>
<td>80.48</td>
<td>0.71</td>
<td>1%</td>
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<tr>
<td>Diff (tpd)</td>
<td>-25.27</td>
<td>-30.54</td>
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<tr>
<td>% Change</td>
<td>-24%</td>
<td>-28%</td>
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2006 Impact of MOVES in CAMx

Difference of eight-hour daily ozone maxima between 2006 MOVES and MOBILE6.2 on-road emissions

Increases of 0-5 ppb throughout the nine-county area during the episode (4.3 ppb increase shown)

Decreases of 0 – 1.3 ppb on cloudy days (non-exceedance days)
Stars show high ozone days.
Peak Eight-Hour Ozone Concentration, Observed versus Modeled for June 16 - July 2, 2006

Observed  MOBILE6.2  MOVES2010a

Stars show high ozone days.
May 31 - July 2, 2006
Eight-Hour Error and Bias by Monitor

Eagle Mountain Lake

MOVES MOBILE6.2
2012 Impact of MOVES in CAMx

Difference of eight-hour daily ozone maxima between 2012 MOVES and MOBILE6.2 on-road emissions

Increases of 0–7 ppb throughout the nine-county area during the episode (6.0 ppb increase shown)

Decreases of 0 – 0.6 ppb on cloudy days (non-exceedance days)
Example Eight-Hour Ozone Future Design Value Calculation

Baseline Design Value (ppb) * Relative Response Factor = Future Design Value (ppb)

Weighted Design Value Average

<table>
<thead>
<tr>
<th>Year</th>
<th>2004</th>
<th>2005</th>
<th>2006</th>
<th>2007</th>
<th>2008</th>
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<tbody>
<tr>
<td>2004</td>
<td>87</td>
<td>103</td>
<td>98</td>
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<tr>
<td>2005</td>
<td>103</td>
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<tr>
<td>2006</td>
<td>98</td>
<td>84</td>
<td>85</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4th Highs

- 87
- 103
- 98
- 84

DV

93.3

DV_B

Example RRF

0.91

RRF

84.9

DV_F
## 2012 Future Design Values (DVF) (ppb)

<table>
<thead>
<tr>
<th>Monitor</th>
<th>2006 Baseline DV&lt;sub&gt;B&lt;/sub&gt;</th>
<th>MOBILE 6.2 RRF</th>
<th>MOBILE6.2 2012 DV&lt;sub&gt;F&lt;/sub&gt;</th>
<th>MOVES RRF</th>
<th>MOVES 2012 DV&lt;sub&gt;F&lt;/sub&gt;</th>
<th>Diff. (ppb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Denton</td>
<td>93.33</td>
<td>0.808</td>
<td>75.37</td>
<td>0.825</td>
<td>77.03</td>
<td>1.66</td>
</tr>
<tr>
<td>Eagle Mountain Lake</td>
<td>93.33</td>
<td>0.815</td>
<td><strong>76.05</strong></td>
<td>0.836</td>
<td><strong>78.06</strong></td>
<td><strong>2.01</strong></td>
</tr>
<tr>
<td>Keller</td>
<td>91.00</td>
<td>0.822</td>
<td>74.83</td>
<td>0.840</td>
<td>76.45</td>
<td>1.62</td>
</tr>
<tr>
<td>Grapevine Fairway</td>
<td>90.67</td>
<td>0.823</td>
<td>74.67</td>
<td>0.840</td>
<td>76.17</td>
<td>1.50</td>
</tr>
<tr>
<td>Fort Worth Northwest</td>
<td>89.33</td>
<td>0.826</td>
<td>73.78</td>
<td>0.844</td>
<td>75.36</td>
<td>1.58</td>
</tr>
<tr>
<td>Frisco</td>
<td>87.67</td>
<td>0.832</td>
<td>72.93</td>
<td>0.849</td>
<td>74.45</td>
<td>1.52</td>
</tr>
<tr>
<td>Parker County</td>
<td>87.67</td>
<td>0.813</td>
<td>71.3</td>
<td>0.829</td>
<td>72.71</td>
<td>1.41</td>
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<tr>
<td>Dallas North</td>
<td>85.00</td>
<td>0.819</td>
<td>69.64</td>
<td>0.837</td>
<td>71.15</td>
<td>1.51</td>
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<tr>
<td>Dallas Exec Airport</td>
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<td>0.816</td>
<td>69.4</td>
<td>0.830</td>
<td>70.58</td>
<td>1.18</td>
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<tr>
<td>Cleburne</td>
<td>85.00</td>
<td>0.827</td>
<td>70.26</td>
<td>0.834</td>
<td>70.85</td>
<td>0.59</td>
</tr>
<tr>
<td>Arlington</td>
<td>83.33</td>
<td>0.827</td>
<td>68.95</td>
<td>0.844</td>
<td>70.32</td>
<td>1.37</td>
</tr>
<tr>
<td>Dallas Hinton</td>
<td>81.67</td>
<td>0.814</td>
<td>66.52</td>
<td>0.831</td>
<td>67.89</td>
<td>1.37</td>
</tr>
<tr>
<td>Pilot Point</td>
<td>81.00</td>
<td>0.814</td>
<td>65.97</td>
<td>0.831</td>
<td>67.35</td>
<td>1.38</td>
</tr>
<tr>
<td>Midlothian Tower</td>
<td>80.50</td>
<td>0.811</td>
<td>65.31</td>
<td>0.828</td>
<td>66.63</td>
<td>1.32</td>
</tr>
<tr>
<td>Rockwall Heath</td>
<td>77.67</td>
<td>0.804</td>
<td>62.47</td>
<td>0.815</td>
<td>63.27</td>
<td>0.80</td>
</tr>
<tr>
<td>Midlothian OFW</td>
<td>75.00</td>
<td>0.815</td>
<td>61.09</td>
<td>0.830</td>
<td>62.24</td>
<td>1.15</td>
</tr>
<tr>
<td>Kaufman</td>
<td>74.67</td>
<td>0.794</td>
<td>59.27</td>
<td>0.809</td>
<td>60.42</td>
<td>1.15</td>
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<tr>
<td>Granbury</td>
<td>83.00</td>
<td>0.821</td>
<td>68.18</td>
<td>0.839</td>
<td>69.66</td>
<td>1.48</td>
</tr>
<tr>
<td>Greenville</td>
<td>75.00</td>
<td>0.786</td>
<td>58.97</td>
<td>0.799</td>
<td>59.96</td>
<td>0.99</td>
</tr>
</tbody>
</table>

Note: The table includes the 2006 baseline values, MOBILE 6.2 RRF values, MOBILE6.2 2012 DV<sub>F</sub> values, MOVES RRF values, MOVES 2012 DV<sub>F</sub> values, and the difference (Diff.) in parts per billion (ppb) between the baseline and future design values. The values in green highlight the changes from the baseline to the future design values.
## 2012 Future Design Values (ppb)

<table>
<thead>
<tr>
<th>Monitor</th>
<th>MOBILE6.2 2012 Future Design Value</th>
<th>MOVES 2012 Future Design Value</th>
<th>Difference (ppb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Denton</td>
<td>75.37</td>
<td>77.03</td>
<td>1.66</td>
</tr>
<tr>
<td>Eagle Mountain Lake</td>
<td><strong>76.05</strong></td>
<td><strong>78.06</strong></td>
<td><strong>2.01</strong></td>
</tr>
<tr>
<td>Keller</td>
<td>74.83</td>
<td>76.45</td>
<td>1.62</td>
</tr>
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<td>74.67</td>
<td>76.17</td>
<td>1.50</td>
</tr>
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<td>73.78</td>
<td>75.36</td>
<td>1.58</td>
</tr>
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<td>74.45</td>
<td>1.52</td>
</tr>
<tr>
<td>Parker County</td>
<td>71.3</td>
<td>72.71</td>
<td>1.41</td>
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<tr>
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<td>71.15</td>
<td>1.51</td>
</tr>
<tr>
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<td>69.4</td>
<td>70.58</td>
<td>1.18</td>
</tr>
<tr>
<td>Cleburne</td>
<td>70.26</td>
<td>70.85</td>
<td>0.59</td>
</tr>
<tr>
<td>Arlington</td>
<td>68.95</td>
<td>70.32</td>
<td>1.37</td>
</tr>
<tr>
<td>Dallas Hinton</td>
<td>66.52</td>
<td>67.89</td>
<td>1.37</td>
</tr>
<tr>
<td>Pilot Point</td>
<td>65.97</td>
<td>67.35</td>
<td>1.38</td>
</tr>
<tr>
<td>Midlothian Tower</td>
<td>65.31</td>
<td>66.63</td>
<td>1.32</td>
</tr>
<tr>
<td>Rockwall Heath</td>
<td>62.47</td>
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<td>0.80</td>
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<td>Midlothian OFW</td>
<td>61.09</td>
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<td>Granbury</td>
<td>68.18</td>
<td>69.66</td>
<td>1.48</td>
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<tr>
<td>Greenville</td>
<td>58.97</td>
<td>59.96</td>
<td>0.99</td>
</tr>
</tbody>
</table>
MOVES Inventories and Helpful Info

- **Using MOVES to Develop Regional On-Road Emission Inputs**
  - Chris Kite’s presentation at EPA’s MOVES workshop
  - Run specs, batch mode, computer run times

  - ftp://amdaftp.tceq.texas.gov/pub/Mobile_EI/DFW/eps3/ for DFW area
  - ftp://amdaftp.tceq.texas.gov/pub/Mobile_EI/HGB/eps3/ for HGB area
  - ftp://amdaftp.tceq.texas.gov/pub/Mobile_EI/Statewide/eps3/ for non-DFW and non-HGB Texas areas
  - ftp://amdaftp.tceq.texas.gov/pub/Mobile_EI/USA/eps3/ for non-Texas U.S. portions of modeling domain
  - ftp://amdaftp.tceq.texas.gov/pub/Mobile_EI/ALL/eps3/ for merged inputs from all areas
Oil and Gas EI Development

Lower 48 states shale plays

Source: Energy Information Administration based on data from various published studies.
Updated: May 9, 2011

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Modeling Inventory Development

- On-shore Drill Rig Activity (ERG, 2009)
  - Surveyed operators for engine details
  - Texas well depth by county
  - NONROAD calculated emissions
- 2010 Oil and Gas Production (ERG, 2010)
  - Surveyed operators/literature for production source types
  - Estimated county-based emissions for 33 source types
  - Excel-based calculator available
- Railroad Commission of Texas Well Data
- TCEQ Barnett Shale Special Inventories
- TCEQ Engine Rules (DFW & East Texas)
Oil and Gas Production Emissions
Geographic Distribution (NOX)

2006

Legend (Tons/Day)

< 0.000
0.000 - 0.001
0.000 - 0.010
0.000 - 0.050
0.050 - 1.000
1.000 - 2.000
2.000 - 5.000
> 5.000

Max: 1294.71 (DFW)-Min: 0.00

Diurnal Profile

2012

Legend (Tons/Day)

< 0.000
0.000 - 0.001
0.000 - 0.010
0.000 - 0.050
0.050 - 1.000
1.000 - 2.000
2.000 - 5.000
> 5.000

Max: 4334.61 (DFW)-Min: 0.00

Diurnal Profile
2006 and 2012 Oil and Gas Production Geographic Distribution

Texas Railroad Commission
Well Locations 2001-2009

2012 Production
Oil and Gas Drilling Emissions
Geographic Distribution (NO$_{X}$)

2006

2012

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## 2006 and 2012 DFW SIP 9-County Oil and Gas Emission Estimates

<table>
<thead>
<tr>
<th>Oil &amp; Gas Category</th>
<th>2006 NO$_x$ TPD</th>
<th>2012 NO$_x$ TPD</th>
<th>2006 VOC TPD</th>
<th>2012 VOC TPD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drill Rigs</td>
<td>18.1</td>
<td>8.7</td>
<td>1.3</td>
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<td>2-Cycle Lean Burn Compressor</td>
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<td>0.3</td>
<td>0.0</td>
<td>0.1</td>
</tr>
<tr>
<td>4-Cycle Lean Burn Compressor</td>
<td>0.8</td>
<td>0.5</td>
<td>0.2</td>
<td>0.3</td>
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<tr>
<td><strong>4-Cycle Rich Burn Compressor</strong></td>
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<td><strong>0.1</strong></td>
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<td>Gas Fugitives</td>
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<td>Gas Well Blowdowns</td>
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<td>1.7</td>
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<td><strong>Pneumatic Devices</strong></td>
<td><strong>21.5</strong></td>
<td><strong>57.2</strong>*</td>
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<td>Produced Water</td>
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<td>0.5</td>
<td>2.2</td>
</tr>
<tr>
<td><strong>Total (Tons/Day)</strong></td>
<td><strong>68.3</strong></td>
<td><strong>18.4</strong></td>
<td><strong>73.5</strong></td>
<td><strong>113.7</strong></td>
</tr>
</tbody>
</table>

* Barnett Shale pneumatic device survey results yield 7.4 tpd
Oil and Gas Contribution

Eagle Mountain Lake (C75) 2006 8-Hour APCA (MOVES)

Eagle Mountain Lake (C75) 2012 8-Hour APCA (MOVES)

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Model Performance Evaluation
Using the TexAQS II Data
The Texas Air Quality Study II (TexAQS II) Background

- Major field study held in 2005-6
  - Covered eastern Texas, most intense sampling was conducted in the Houston area
  - Results used in 2010 Houston/Galveston/Brazoria (HGB) Ozone Attainment Demonstration Model Performance Evaluation (MPE)

- Study Participants:
  - Federal:
    NOAA, JPL, MMS, NCAR, EPA, DOE, DOD, TVA
  - TCEQ and local entities
  - 30 institutes of higher learning
  - 15+ additional participating entities
TexAQS II Sampling Platforms

- NOAA Research Vessel Ronald H. Brown
- NOAA WP-3D Orion
- University of Houston Moody Tower supersite
- Houston Triangle (3 surface sites)
- Baylor Aztec
- Solar Occultation Flux
- NOAA Twin Otter
- Ozone and GPS Sondes
- Upper-air meteorology
- Special inventory of highly-reactive VOC emissions
- Satellites
TexAQS II Measurements

• Full suite of surface and upper-air meteorological variables

• Gas-Phase Measurements:
  – $O_3$, CO, CO$_2$, NH$_3$, SO$_2$, NO, NO$_2$, HCHO, NO$_Y$, HNO$_3$, PANs, NO$_3$, N$_2$O$_5$, RONO$_2$, OH, HO$_2$, RO$_2$, H$_2$SO$_4$, H$_2$O, H$_2$O$_2$, HONO, Speciated Hydrocarbons, Oxygenated VOCs

• Particle-Phase Measurements:
  – Aerosol size and composition, scattering, absorption, number, size distribution, hygroscopic growth, light extinction, backscatter

• Photolysis rates:
  – $O_3$, HNO$_3$, HONO, HCHO + 16 others
Model Performance Evaluation
Using Ship Data

- R.V. Ronald H. Brown
- Deployed Aug 1 – Sep 12, 2006
Model Performance Evaluation
Using Ship Data

NOAA RV Ron Brown Observed O₃ Concentration (ppb)
31AUG 08:00 to 31AUG 16:30, 10 Minute Averages

CAMx Modeled O₃ Concentration (ppb)
31AUG 08:00 to 31AUG 16:30, 10 Minute Averages

Observed and Modeled O₃ Concentrations (ppb)
31AUG 08:00 to 31AUG 16:30, 10 Minute Averages

Modeled vs. Observed O₃ Concentrations (ppb)
31AUG 08:00 to 31AUG 16:30, 10 Minute Averages

Run Name: camx453_pl05_b0c08aqc/reg10.2006/ep1_etc/chem/fields/monthly/monthly_inputs/monthly.pm1

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Model Performance Evaluation Using Ship Data

NOAA RV Ron Brown Measured O3 Mixing Ratios
07SEP 13:20 to 07SEP 16:35, 5 Minute Averages

CAMx Reg20 Modeled O3 Mixing Ratios
07SEP 13:20 to 07SEP 16:35, 5 Minute Averages

Observed and Modeled O3 Mixing Ratios
Houston Ship Channel, 30 Minute Averages

Observed and Modeled NO Mixing Ratios
Houston Ship Channel, 30 Minute Averages

Observed and Modeled NO2 Mixing Ratios
Houston Ship Channel, 30 Minute Averages
Model Performance Evaluation Using Ship Data
Model Performance Evaluation
Using Aircraft Data

- NOAA WP3-D Orion
- Deployed Sep 11 – Oct 13, 2006
Model Performance Evaluation Using Aircraft Data

NOAA P3 Measured O3 Mixing Ratio

CAMx Reg10 Modeled O3 Mixing Ratio

Observed and Modeled O3 Mixing Ratios

Modeled vs. Observed O3 Mixing Ratios

Run Name: bc06acp1_reg10sl2008sep1_ela_cibemis_5ddals_newulsssal_newulsssal

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Model Performance Evaluation
Using Aircraft Data

- NOAA Twin Otter
- Deployed Aug 2 – Sep 15, 2006
- TOPAZ Downward-looking Ozone Lidar
Model Performance Evaluation Using Sonde Data

- Tropospheric Ozone Pollution Project (TOPP) – Ongoing & Ron Brown (RHB)

Ozone Profiles August 30, 2006

Hour 11, RHB

Hour 12, UH

Hour 18, RHB

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Model Performance Evaluation Using Supersite Data

- University of Houston Moody Tower
  - ~ 60 m AGL, Model layer 2
Summary –TexAQS II MPE

• The TexAQS II provided a unique opportunity to explore rarely-seen aspects of model performance:
  – Upper-air meteorology
  – Speciated hydrocarbons
  – Three-dimensional characterization of pollution transport
  – Intermediate reaction products
  – Marine boundary layer dynamics and chemistry
  – Radical chemistry
Dynamic Model Performance Evaluation (MPE)
Dynamic vs. Static Model Performance Evaluation

- Static MPE compares base-case modeled concentrations with measurements.

- Can be very extensive:
  - Multiple pollutants: ozone, precursors, intermediate or product species
  - Multiple analysis techniques: statistics, 1, 2, and 3-dimensional graphics, animations, probing tools, sensitivity analyses
  - Special purpose data: field studies, aircraft, marine, sondes, supersites, satellites

- But cannot directly address the most important question: *Does the model respond appropriately to changes in inputs?*
Dynamic vs. Static Model Performance Evaluation

- Dynamic MPE is designed to address the model’s response to changes in inputs.
  - Sensitivity analysis and direct-decoupled method (DDM) are common forms of dynamic MPE.
  - Retrospective analysis compares modeled predictions with observed air quality in a projection year.
  - Weekday-weekend analysis takes advantage of day-of week changes in emission patterns (mostly on-road mobile) to see if the model can mimic observed changes in ozone concentrations.
### Dallas/Fort Worth Ozone Monitoring Sites
(Sites Referred To In This Presentation)

<table>
<thead>
<tr>
<th>Site Code</th>
<th>Site Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>FRIC</td>
<td>Frisco C31</td>
</tr>
<tr>
<td>DHIC</td>
<td>Dallas Hinton C60</td>
</tr>
<tr>
<td>DALN</td>
<td>Dallas North C63</td>
</tr>
<tr>
<td>REDB</td>
<td>Dallas Exec C402</td>
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<td>DENT</td>
<td>Denton C56</td>
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<td>MDLT</td>
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<td>FWMC</td>
<td>Fort Worth NW C13</td>
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<td>KELC</td>
<td>Fort Worth Keller C17</td>
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<td>EMTL</td>
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<td>Rockwall C69</td>
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<tr>
<td>WTFD</td>
<td>Weatherford C76</td>
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</table>

Sites in green have both 2006 and 1999 ozone design values.
Retrospective Modeling
“Predicting” a Prior Year’s Ozone Design Values

- To evaluate model response to emission changes in the Dallas-Fort Worth area, 1999 was modeled as if it were a future year.
  - Used a baseline 1999 inventory developed for a previous attainment demonstration.
  - Calculated 2006-to-1999 RRFs, just like projecting to a future year.
  - Calculated 1999 DV$p$s by multiplying the 2006-to-1999 RRFs by the 2006 DV$b$s.
  - Compared the 1999 DV$p$s with the actual 1999 baseline DVs.
    - 1999 DV$b$ = Average of 1999, 2000, 2001 DVs
## Retrospective Modeling

<table>
<thead>
<tr>
<th>Site</th>
<th>Monitor</th>
<th>1999 Baseline DV (ppb)</th>
<th>1999 Modeled Average (ppb)</th>
<th>2006 to 1999 RRF</th>
<th>1999 Projected DV (ppb)</th>
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<tr>
<td>DENT</td>
<td>Denton</td>
<td>101.5</td>
<td>96.48</td>
<td>1.161</td>
<td>108.37</td>
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<td>Keller</td>
<td>96.33</td>
<td>97.59</td>
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<td>FWMC</td>
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## Retrospective Modeling

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- At five sites the model was within 3 ppb of actual 1999 baseline DV.
Retrospective Modeling

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- At five sites the model was within 3 ppb of actual 1999 baseline DV.
- At the remaining 3 sites the model over-predicted the 1999 baseline, indicating that the model responded more to emission changes at these sites than did the actual airshed.
Weekday-Weekend Analysis

- Different weekday-weekend traffic patterns form a “natural laboratory” to assess how the airshed (and models) respond to emission changes.
  
  - Weekend increases in ozone concentration may indicate that ozone formation is VOC-sensitive. This phenomenon is often referred to as the “weekend effect.”

  - Weekend decreases may be an indication of NO$_X$-sensitive ozone formation.
Modeled 2006 DFW NO\textsubscript{X} and VOC Emissions (MOBILE6.2)

![Graph showing 6 AM NO\textsubscript{X} and VOC Emissions](image_url)
Weekday-Weekend Analysis

- The weekday-weekend effect is rather subtle compared with meteorological variability, so many observations are needed to allow meaningful conclusions.
  - We used observations from five ozone seasons: May 15 – October 15, 2005-2009.

- It is not practical to model enough days to see how the model responds to weekend emission changes.
  - DFW episode is May 31 - July 2, 2006.
Weekday-Weekend Analysis
All Wednesday-Saturday-Sunday Model Runs

- To overcome the limitations of the small number of days modeled, every day of the episode was run as a Wednesday, a Saturday, and a Sunday.

- To account for possible overnight carryover of pollutants, a series of four runs was performed:
  - Every day as a Wednesday (Since Tuesday & Wednesday emissions are similar, Wednesday can serve as its own predecessor)
  - Three sequences of Fri-Sat-Sun-Fri-Sat-Sun-etc., starting each sequence on a different day – this allowed each episode day to be modeled as a Saturday and as a Sunday with the appropriate predecessor.
The all-WSS runs actually serve two functions:

- First, they increase the number of available Wednesdays, Saturdays, and Sundays to 32 each (we discarded May 31 since it had no predecessor day).

- Second, the runs effectively remove the meteorological effects from the comparison, since now all three day-types are run with identical meteorology.
Weekday and Weekend NO\textsubscript{x} and Ozone Concentrations

Median NO\textsubscript{x} and ozone concentrations expressed as a percentage of Wednesday; Observed concentrations from May 15 - October 15, 2005-9, Modeled concentrations from All-WSS runs.
Weekday-Weekend Analysis
All Wednesday-Saturday-Sunday Model Runs

• The all-WSS model runs suggest that the model is somewhat NO\textsubscript{X}-sensitive, but observed ozone concentrations show a less-clear picture.

• But the observations include a number of non-ozone-conducive days (rain, wind, clouds, etc.), while the modeled days were selected to represent ozone-conducive periods.

• Instead of just using the median of the observed concentrations, let’s also look at the 90\textsuperscript{th} percentiles.
Weekday and Weekend NO\textsubscript{X} and Ozone Concentrations

As before, except median observed ozone is replaced with 90\textsuperscript{th} percentile to better represent high ozone days similar to periods selected for modeling.
Dynamic Model Performance Evaluation - Conclusions

The retrospective analysis indicated that the model’s response to 1999-2006 emission changes was reasonably consistent with the actual airshed’s, except at three sites where the airshed appeared to be less responsive.

The weekday-weekend analysis indicates that overall the airshed appears more responsive to emission changes than the model, at least for on-road mobile source emissions.
Objectives

- Assess the impact of high turndown (low flow) rate of vent gas on flare destruction and removal efficiency (DRE) and combustion efficiency (CE).
- Assess if flares operating within 40 Code of Federal Regulations ( CFR) §60.18 achieve the assumed hydrocarbon DRE of at least 98% at high turndown, varying assist ratios, and vent gas heat content.
- Identify and quantify the hydrocarbon species in flare plumes.
Limitations

- Limited vent gas composition: Tulsa natural gas, propylene, and nitrogen
  - Propane was used for limited test runs.
  - Hydrogen was not included in any test run.
- Two flare tip sizes and assist configurations were tested.
- High turndown (low flow) operating conditions were focus of study.
- Study was not designed to evaluate:
  - Flare operations under upset or emergency conditions
  - Hydrogen flares
  - Flares specifically designed for routine, low flow applications
Operating Conditions

• Vent gas streams with heat content of 350, 600, and 2,149 British thermal units per standard cubic foot (Btu/scf)
  
  40 CFR §60.18 minimum heating value for an assisted flare is 300 Btu/scf.

• Vent gas streams with low flow rate
  
  - 0.1% and 0.25% of rated design capacity

• Flare configurations tested represent flares commonly used in both routine process and emergency service (dual service).
Operating Conditions

- Assist rates varied between zero assist to over assist near flameout (snuff point).
- Measurements were taken at points between the incipient smoke point and near snuff point.
  Four to six points per test series with up to three repetitions per point.
- Tip velocity of vent gas, including center steam, was between 0.6 and 2.0 feet per second (fps).
Extractive Sampler

Extractive sample inlet

Flue gas eductor

Pitot

GPS

Sample lines

Elevation chain

Positioning chains
Results: High DRE Measured

- The flares tested were able to achieve greater than 99% DRE and CE for vent gas streams with low heating value at low flow rate conditions.
- For the conditions tested, the highest DRE and CE was achieved at or near the incipient smoke point.
- Extremely limited assist operating range to achieve high DRE with 350 and 600 Btu/scf vent gas.
Steam-Assisted Flare DRE

Constant Vent Gas Flow Rate of 2,342 lb/hr

Incipient smoke points

High Btu curve identical to 1983 CMA testing

Test results were similar regardless of vent gas flow rate

DRE % Propylene

Steam-to-Vent Gas Ratio lb/lb

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Test Point S4.2

<table>
<thead>
<tr>
<th>Vent Gas</th>
<th>Btu/scf</th>
<th>Steam to VG Ratio</th>
<th>DRE (%)</th>
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</thead>
<tbody>
<tr>
<td>2,342 lb/hr</td>
<td>350 Btu</td>
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## Test Point S4.7

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<td>2,342 lb/hr</td>
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Test Point S4.3

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<th>Vent Gas</th>
<th>Btu/scf</th>
<th>Steam to VG Ratio</th>
<th>DRE (%)</th>
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<tbody>
<tr>
<td>2,342 lb/hr</td>
<td>350 Btu</td>
<td>1.05</td>
<td>27.3</td>
</tr>
</tbody>
</table>
Results: Air Assist Rates Critical

The air-assisted flare DRE measured greater than 97% when the excess air factor was less than 10.

- Excess air factor: The amount of air in excess of what is required to achieve theoretical stoichiometric combustion represented as a factor.
- Example: 15 pounds of air is required to burn 1 pound of propylene. If the air assist rate is 150 pounds of air per pound of propylene, the excess air factor would be 10.
DRE Versus Excess Air

Excess Air Factor of 10

Incipient smoke points

DRE - Propylene (%) vs. Excess Air Factor

- A5: 80 lb/hr Hydrocarbon
- A6: 131 lb/hr Hydrocarbon
- A3: 200 lb/hr Hydrocarbon
- A4: 330 lb/hr Hydrocarbon
The flares tested were able to achieve greater than 99% DRE and CE for vent gas streams with low heating value and low flow rate conditions.

The most efficient operation, as measured by the DRE and CE, was achieved at or near the incipient smoke point.

Flares were easily over-assisted.
2010 TCEQ Flare Study
Key Conclusions

• Center steam negatively impacts DRE.

• Vent gas with low heating values has a narrow operating range for assist to vent gas ratios.

• A flare can be operated under 40 CFR §60.18 criteria and not achieve 98% DRE.
Questions?

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512 239-1941

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Staff of the TCEQ Air Quality Division

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References