Impact of Emissions from Commercial Shipping during TexAQS II

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(TexAQS II Data Workshop; Austin, TX; 30 May 07)

Relevant to SIP Questions
C: Comparison of observations to estimates from inventories
D: Emission source distributions from observations
E: Emission sources NOT in inventories

This presentation will show:
1. Measurements and emission factor (EF) calculations
2. EF data quality and comparison to literature values
3. Estimate of ship emissions in HGA
4. Ship NO$_2$ emissions vs NO$_2$ from stationary sources in HGA
5. Summary and findings
Study and Measurement Particulars

• Platform: NOAA R/V Ronald H. Brown
• Dates: Leg 1: 02 August - 18 August
  Leg 2: 21 August - 12 September
• Sampling locations:
  1) Houston Ship Channel; anchorage off Galveston; Gulf of Mexico
  2) ports of Houston; Jacinto Port; Galveston; Freeport; Beaumont; Port Arthur; Point Comfort (Matagorda Bay)
  3) container terminal at Barbours Cut
• Measurements:
  NO$_y$: Au tube @ 325°C/H$_2$; NO-O$_3$ chemiluminescence
  CO: Vacuum UV fluorescence (AeroLaser AL-5002)
  SO$_2$: Pulsed UV fluorescence (TEII 43S)
  CO$_2$: Non-dispersive IR (Li-Cor LI7000)
  (also VOCs, H$_2$CO, and PM)
  AIS - Automated Information System - ship data

Details at poster: Overview of NOAA R/V Ronald H. Brown Measurements and Activities during TexAQS/GoMACCS 2006
Eric Williams and Tim Bates
Determining Emission Factors (EF) from Measurements

FUTURA: Chemical/oil carrier; 15980 Gt; 2004; L: 170 meters; 9.5 MW engine

\[ \text{Slope} = 18.2 \pm 0.5 \text{ ppb/ppm} \]
\[ \text{NO}_y \text{ E.F.} = 60.2 \pm 1.7 \text{ g/kg} \]

\[ \text{Slope} = 12.9 \pm 0.5 \text{ ppb/ppm} \]
\[ \text{SO}_2 \text{ E.F.} = 59.5 \pm 2.3 \text{ g/kg} \]
(Fuel S content = 3%)

\[ \text{Slope} = 8.09 \pm 0.13 \text{ ppb/ppm} \]
\[ \text{CO E.F.} = 16.3 \pm 0.26 \text{ g/kg} \]
EF Precision Estimates: 08 August 06; 0500-0800 UTC

PATRIOT: Crude oil tanker; 53772 Gt; 1992; L: 248 meters; 10 MW engine

1) Nighttime (no photochemistry); constant wind field
2) Target at anchor: assume constant emissions
3) Emission factor measurement precision:
   - \( \text{NO}_2: 24.1 \pm 0.79 \); RSD = 3.3%
   - \( \text{SO}_2: 50.1 \pm 6.8 \); RSD = 14%
   - \( \text{CO}: 2.33 \pm 0.54 \); RSD = 23%
Measured Emission Factors for Slow-Speed Diesels

Slow-speed diesels (SSD): largest engines (10-100 MW rated power) use residual fuels (HFO); 1%-5% S content; cheap biggest vessels (container ships, tankers, etc.)

**NO\textsubscript{2} E.F. vs. Speed**

- NO\textsubscript{2} emission factors show no trend with vessel speed (also seen in literature data).
- Average of data = 74 g/kg (red line; speed > 1 kt)
- \((N = 60)\)

**SO\textsubscript{2} E.F. vs. Speed**

- SO\textsubscript{2} emissions from vessels vary only with fuel S content (SO\textsubscript{2} E.F. = %S X 20)
- Average of data = 28 g/kg (red line; avg. fuel S = 1.4%)
- \((N = 54)\)

**CO E.F. vs. Speed**

- CO emission factors should be low (high temp. combustion); otherwise poor maintenance
- Average of data = 12 g/kg (red line; speed > 1 kt)
- \((N = 51)\)
**Measured Emission Factors for Medium-Speed Diesels**

Medium-speed diesels (MSD): mid-range engines (1-10 MW power rating) distillate fuels (MDO); <0.1% - ~1% S content smaller vessels (tugs, ferries, fishing boats) auxiliary generators on many ships

- **NO₂ E.F. vs. Speed**
  - NO₂ emission factors show no trend with vessel speed (also seen in literature data)
  - Average of data = 60 g/kg (red line; all data)

- **SO₂ E.F. vs. Speed**
  - SO₂ emissions from vessels vary only with fuel S content
  - Fuel blends are typical; not surprising to see high SO₂
  - Average of data = 9.1 g/kg (red line; avg fuel S = 0.46%)

- **CO E.F. vs. Speed**
  - CO emission factors should be low (high temp. combustion); otherwise poor maintenance
  - Average of data = 16 g/kg (red line; all data)
### Summary of Emission Factor Data

<table>
<thead>
<tr>
<th>EF Source</th>
<th>NO₂</th>
<th>CO</th>
<th>SO₂</th>
</tr>
</thead>
<tbody>
<tr>
<td>this work; SSD</td>
<td>74</td>
<td>12</td>
<td>28</td>
</tr>
<tr>
<td>this work; MSD</td>
<td>60</td>
<td>16</td>
<td>9</td>
</tr>
<tr>
<td>Lloyd's (1995)¹; SSD</td>
<td>87</td>
<td>7.4</td>
<td>20 X %S</td>
</tr>
<tr>
<td>Lloyd's (1995)¹; MSD</td>
<td>57</td>
<td>7.4</td>
<td>20 X %S</td>
</tr>
<tr>
<td>ERG (2007)²; SSD³</td>
<td>74</td>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td>ERG (2007)²; H/MSD³</td>
<td>54</td>
<td>NA</td>
<td>5</td>
</tr>
</tbody>
</table>

³Averages of vessel types and converted from power to mass with specific fuel consumption = 0.20 kg/kWh
Significance of Marine Vessel NO\textsubscript{x} Emissions

1. Use aggregated activity data from ERG report.
   - Sum of SSD engines operating hours (all modes): $28847$ hr yr\textsuperscript{-1}
   - Sum of MSD engines operating hours (u'way + man.): $279375$ hr yr\textsuperscript{-1}
   - Sum of MSD engines operating hours (hoteling): $315294$ hr yr\textsuperscript{-1}
   (Includes all ports and waterways in HGA except Texas City and Freeport; data from year 2004)

2. Estimate average fuel consumption rates from ERG engine/load data.
   - Underway/maneuvering: $400$ kg hr\textsuperscript{-1} (est. uncertainty: $\pm x2$)
   - Hoteling: $30$ kg hr\textsuperscript{-1} (est. uncertainty: $\pm x10$)
   (Total fuel consumption calculated for 2004 from ERG CO\textsubscript{2} data: $0.07$ Tg/yr [±30%])
   (Total fuel consumption estimated for 2004 from these data: $0.13$ Tg/yr [±x2])
   (Total fuel consumption estimated for 2002 from STEEM [Wang et al., 2007]: $0.32$ Tg/yr [±50%])

3. Emission factors for NO\textsubscript{2}: SSD = $74$ g kg\textsuperscript{-1}; MSD = $60$ g kg\textsuperscript{-1}
   (and convert from g yr\textsuperscript{-1} to [English short] tons yr\textsuperscript{-1})

4. Commercial ship emission of NO\textsubscript{2}:
   - SSD NO\textsubscript{2} = $940$ tons yr\textsuperscript{-1}
   - MSD NO\textsubscript{2} = $8010$ tons yr\textsuperscript{-1}
   - Total NO\textsubscript{2} = $8950$ tons yr\textsuperscript{-1}
# Marine Vessel vs Stationary Source Emissions

<table>
<thead>
<tr>
<th>County</th>
<th>NO₂</th>
<th>CO</th>
<th>NO₂</th>
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<tbody>
<tr>
<td>Brazoria</td>
<td>53.77</td>
<td>16.81</td>
<td>86.11</td>
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<tr>
<td>Fort Bend</td>
<td>22.31</td>
<td>23.17</td>
<td>98.07</td>
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<tr>
<td>Galveston</td>
<td>24.62</td>
<td>11.95</td>
<td>73.02</td>
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<tr>
<td>Harris</td>
<td>113.23</td>
<td>53.08</td>
<td>189.09</td>
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<table>
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<tr>
<th>Ships (this work)</th>
<th>NO₂</th>
<th>CO</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>24.5</td>
<td>6.3</td>
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<tr>
<th>Ships (ERG)</th>
<th>NO₂</th>
<th>CO</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>11.65</td>
<td>0.24</td>
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</table>

1Source: US EPA 1999 NEI with updates to 2004 from CEMS data by Greg Frost at NOAA/ESRL
2Freeport and Texas City ship activity data are not included.
**Summary and Findings**

H$_2$CO is only VOC emission from these vessels - that we could measure PM emissions - sulfate, organics, carbon (see Dan Lack's talk tomorrow!) CO emissions from this source are probably not significant NO$_2$ emissions from ships are significant

Most recent inventory of ship NO$_2$ emissions from Jan., 2007, by ERG NO$_2$ emission factors are within ± 10% of our data ERG inventory based on hours-in-use and power-hours Our estimate based on average fuel consumption: need data!! ERG estimate and this estimate of ship NO$_2$ emissions differ by X2

As stationary and on-road emissions are reduced by regulation, ships become more important, but will be difficult to regulate ALL vessels due to non-US flags

More work needed for SO$_2$ and PM EFs; probably not relevant to O$_3$ SIP (fuel use data will be essential for accurate SO$_2$ inventory work)

Manuscript has been prepared and is under internal review