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

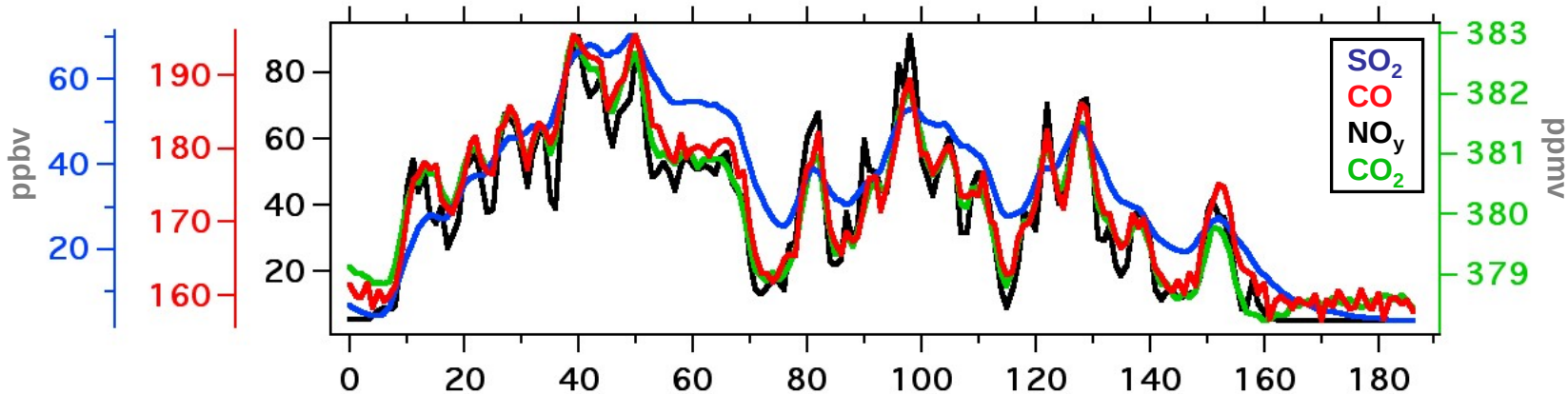
Study and Measurement Particulars

- 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_2CO, and PM)
  AIS - Automated Information System - ship data

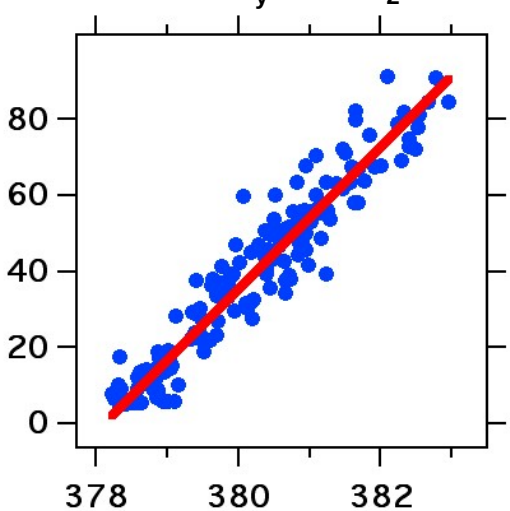
Details at poster: Overview of NOAA R/V Ronald H. Brown Measurements and Activities during TexAQS/GoMACCS 2006
Eric Williams and Tim Bates

Determining Emission Factors (EF) from Measurements

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

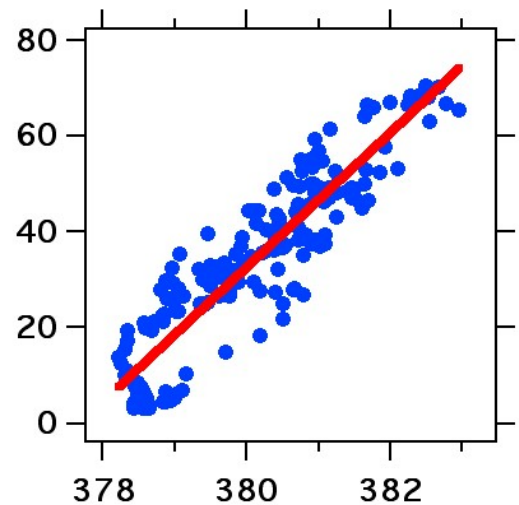


NO_y vs CO_2



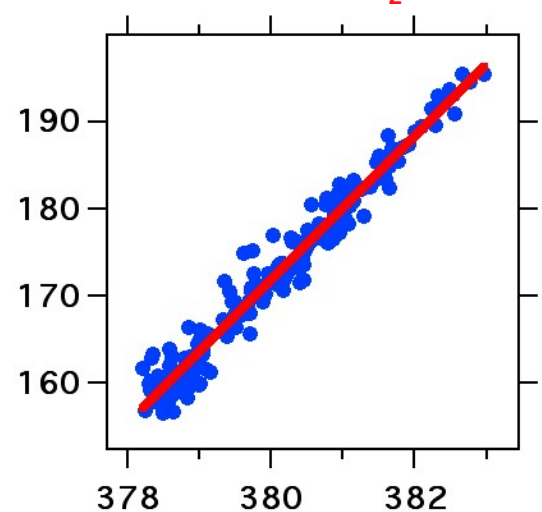
Slope = 18.2 ± 0.5 ppb/ppm
NO_y E.F. = 60.2 ± 1.7 g/kg

SO_2 vs CO_2



Slope = 12.9 ± 0.5 ppb/ppm
SO_2 E.F. = 59.5 ± 2.3 g/kg
(Fuel S content = 3%)

CO vs CO_2

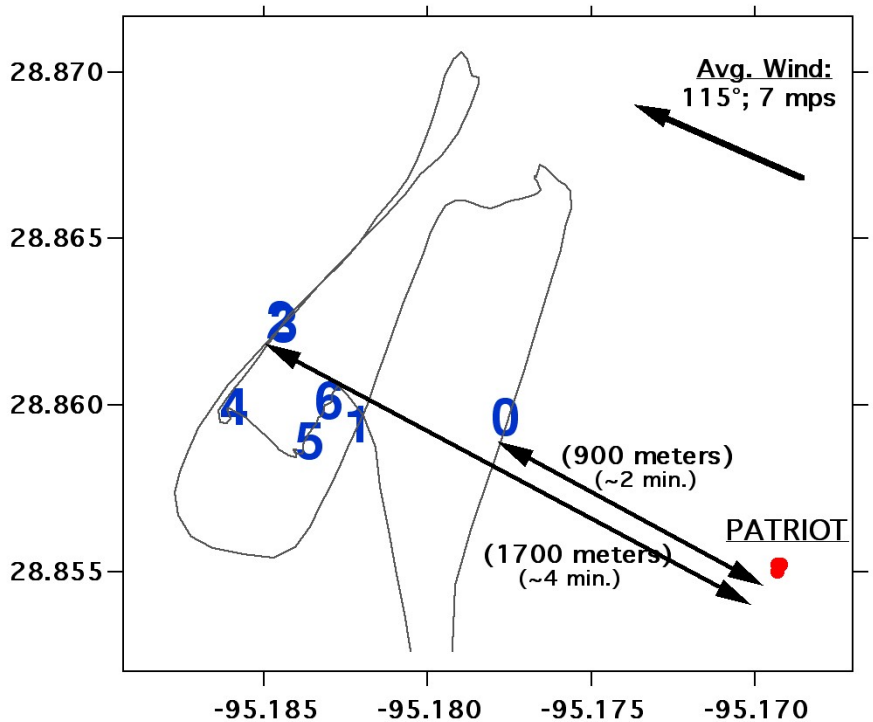


Slope = 8.09 ± 0.13 ppb/ppm
CO E.F. = 16.3 ± 0.26 g/kg

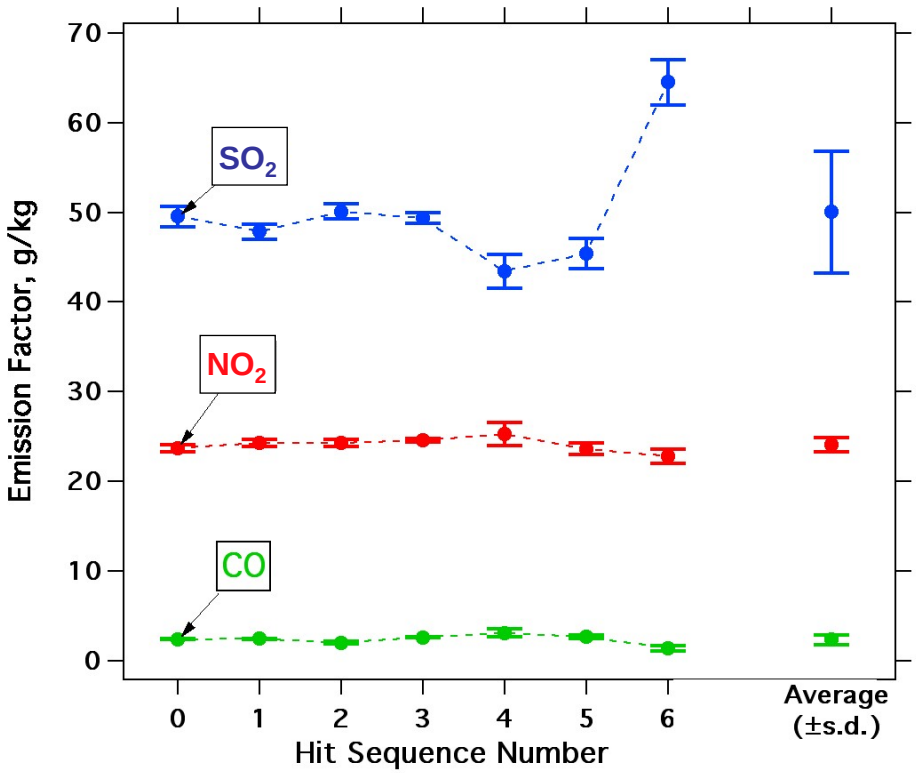
EF Precision Estimates: 08 August 06; 0500-0800 UTC

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

Patriot Situation Map



Patriot Emission Factors



1) Nighttime (no photochemistry); constant wind field
2) Target at anchor: assume constant emissions
3) Emission factor measurement precision:

NO_2: 24.1 ± 0.79; RSD = 3.3%

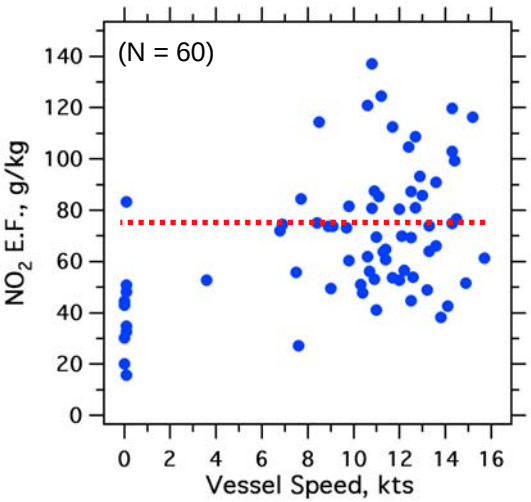
SO_2: 50.1 ± 6.8; RSD = 14%

CO: 2.33 ± 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.)

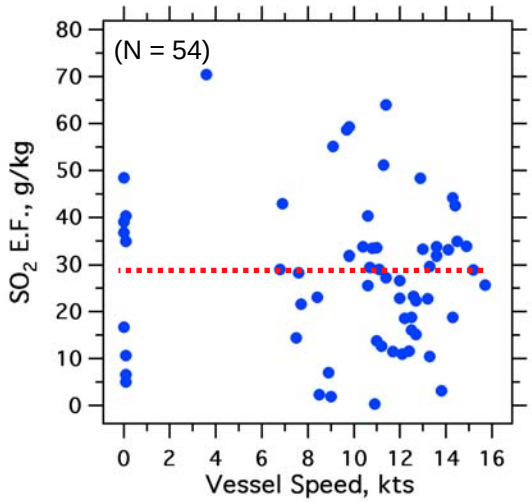
NO_2 E.F. vs. Speed



NO_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)

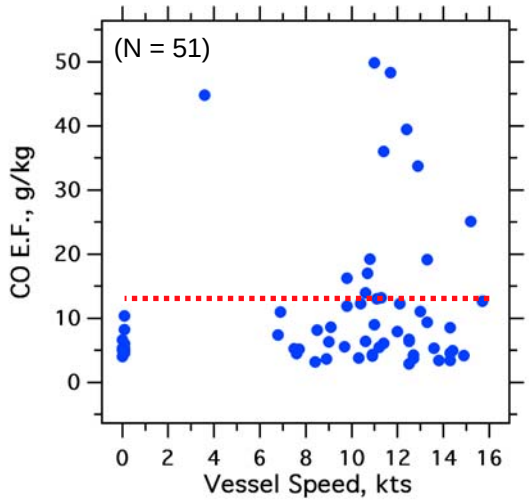
SO_2 E.F. vs. Speed



SO_2 emissions from vessels vary only with fuel S content (SO_2 E.F. = %S X 20)

Average of data = 28 g/kg (red line; avg. fuel S = 1.4%)

CO E.F. vs. Speed



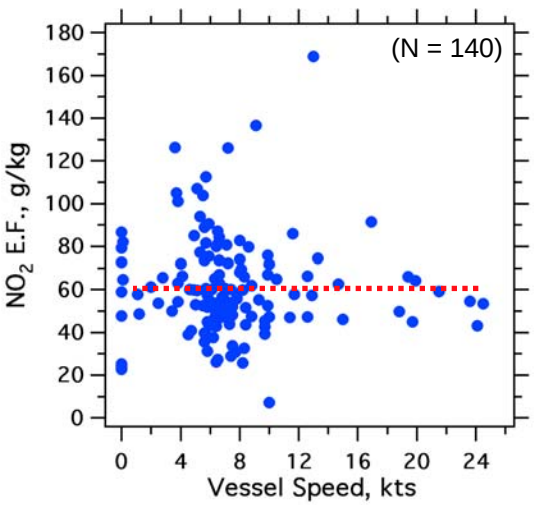
CO emission factors should be low (high temp. combustion); otherwise poor maintenance

Average of data = 12 g/kg (red line; speed > 1 kt)

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

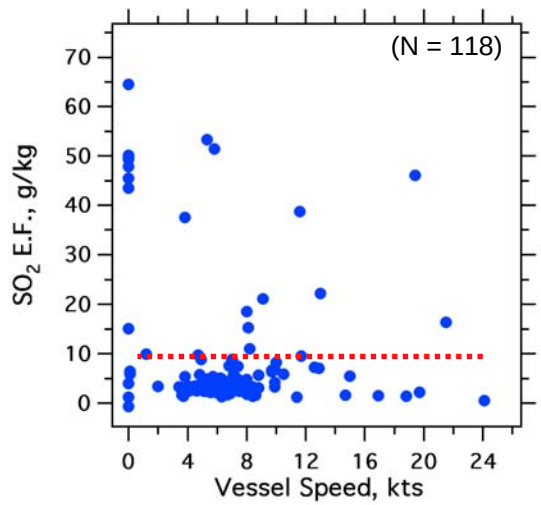
NO_2 E.F. vs. Speed



NO_2 emission factors show no trend with vessel speed (also seen in literature data)

Average of data = 60 g/kg (red line; all data)

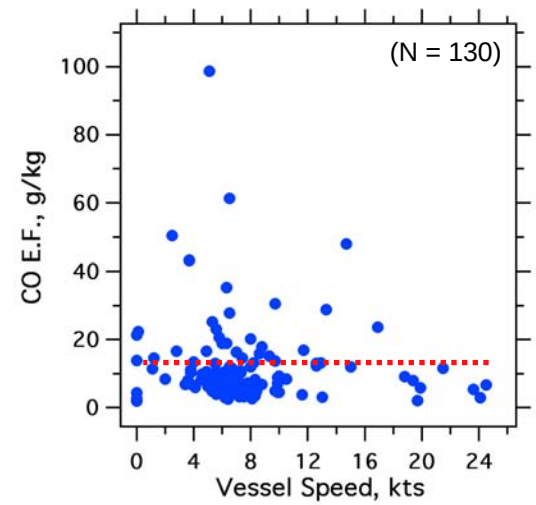
SO_2 E.F. vs. Speed



SO_2 emissions from vessels vary only with fuel S content Fuel blends are typical; not surprising to see high SO_2

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

EF Source	NO_2	CO	SO_2
this work; SSD	74	12	28
this work; MSD	60	16	9
Lloyd's (1995)[1]; SSD	87	7.4	20 X %S
Lloyd's (1995)[1]; MSD	57	7.4	20 X %S
ERG (2007)[2]; SSD[3]	74	4	8
ERG (2007)[2]; H/MSD[3]	54	NA	5

[1]Marine Exhaust Emissions Research Programme, Lloyd's Register, London, 1995.

[2]Houston/Galveston Routine Vessel Identification and Traffic Study, Eastern Research Group, Inc., TCEQ Contract No. 582-04-65564-23, 26 January, 2007.

[3]Averages of vessel types and converted from power to mass with specific fuel consumption = 0.20 kg/kWh

Significance of Marine Vessel NO_x Emissions

1. Use aggregated activity data from ERG report.
   - Sum of SSD engines operating hours (all modes): 28847 hr yr^{-1}
   - Sum of MSD engines operating hours (u'way + man.): 279375 hr yr^{-1}
   - Sum of MSD engines operating hours (hoteling): 315294 hr yr^{-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^{-1} (est. uncertainty: ± x2)
   - Hoteling: 30 kg hr^{-1} (est. uncertainty: ± x10)

   (Total fuel consumption calculated for 2004 from ERG CO_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_2: SSD = 74 g kg^{-1}; MSD = 60 g kg^{-1}
   (and convert from g yr^{-1} to [English short] tons yr^{-1})

4. Commercial ship emission of NO_2:
   - SSD NO_2 = 940 tons yr^{-1}
   - MSD NO_2 = 8010 tons yr^{-1}

   Total NO_2 = 8950 tons yr^{-1}

Marine Vessel vs Stationary Source Emissions

	2004 Point Source Emissions[1] (tons per day)		1999[1] (tpd)
County	NO_2	CO	NO_2
Brazoria	53.77	16.81	86.11
Fort Bend	22.31	23.17	98.07
Galveston	24.62	11.95	73.02
Harris	113.23	53.08	189.09
Ships (this work)[2]	24.5	6.3	
Ships (ERG)[2]	11.65	0.24	

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

Summary and Findings

H_2CO 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