Determination of Emission Factors from Commercial Marine Vessels

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Ships are VERY significant emission sources of pollutants

"... (ships) are set to emit more (pollution) than all land sources combined by 2020
- EU policy on ship emissions (www.ec.europa.eu/environment)

This presentation will show:

1. Measurements and emission factor (EF) calculations
2. EF data summary and comparison to literature values
3. Ship NO_2 emissions vs NO_2 from stationary sources in HGA
4. Summary and findings

Study and Measurement Summary

- Study Texas Air Quality Study (TexAQS) 2006
- Platform: NOAA R/V Ronald H. Brown
- Dates: 02 August - 12 September, 2006
- 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)
  - H_2CO: Quantum cascade laser spectroscopy
  - CO_2: Non-dispersive IR (Li-Cor LI7000)
  - VOCs: GCMS and PITMS
    (extensive PM measurements, as well)
  - AIS - Automated Information System - ship data

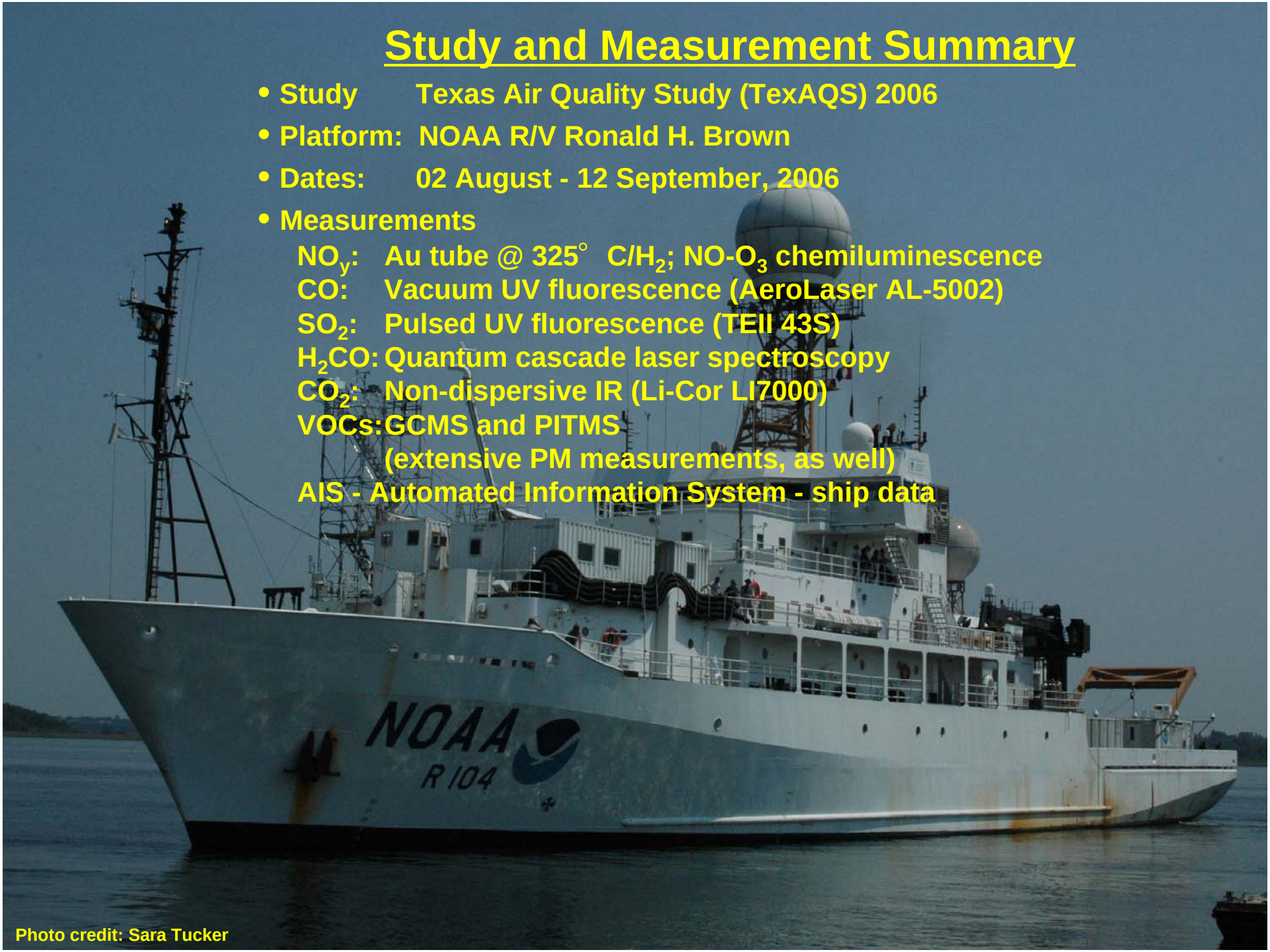
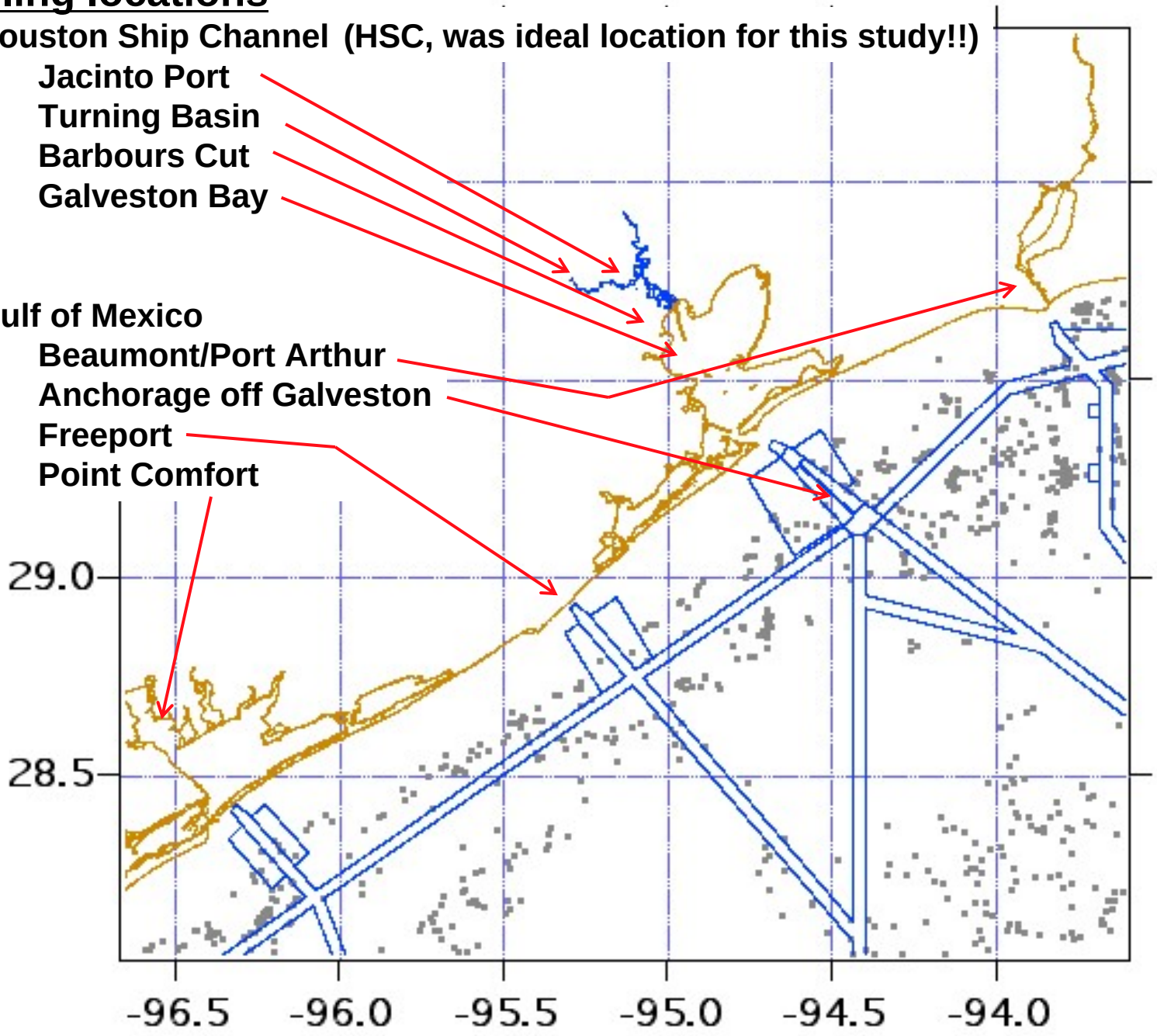


Photo credit: Sara Tucker

Sampling locations

1) Houston Ship Channel (HSC, was ideal location for this study!!)
   - Jacinto Port
   - Turning Basin
   - Barbours Cut
   - Galveston Bay

2) Gulf of Mexico
   - Beaumont/Port Arthur
   - Anchorage off Galveston
   - Freeport
   - Point Comfort



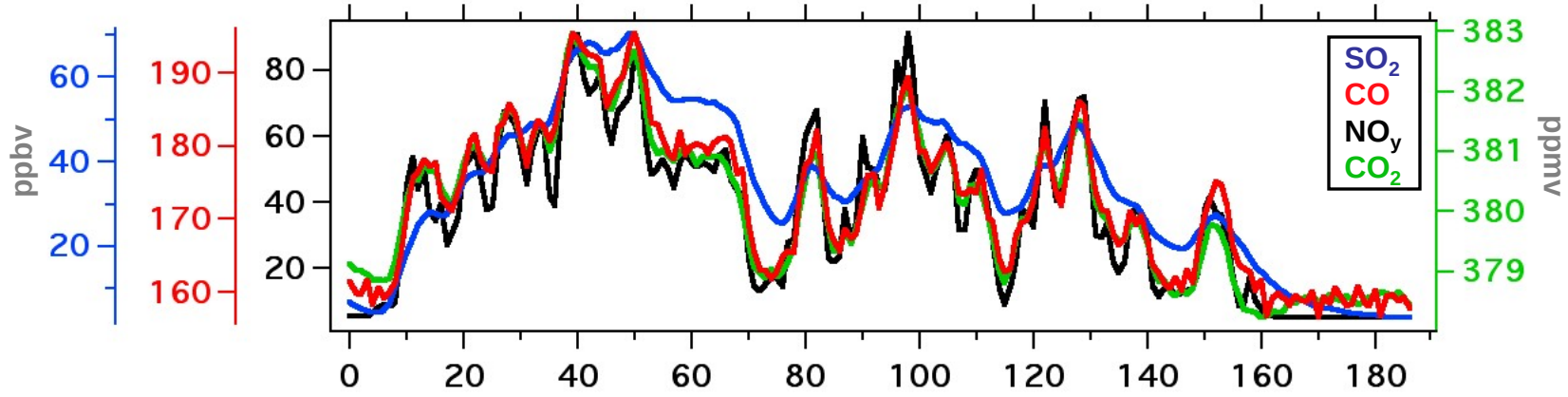
Marine Vessel Propulsion and Emission Characteristics

Slow-speed diesel engine (SSD):	**55% of total fleet: ~58,000 vessels (>95% commer.)** **use residual fuels ("bunkers"; high S; cheap!)** **power: < 10 MW up to ~80 MW**
Medium-speed diesel engine (MSD):	**40% of total fleet: ~42,000 vessels (40% military)** **residual or distillate (low S) fuels** **power: ~1 - 20 MW**
C emissions (CO; CO_2):	**virtually complete combustion!! (CO/CO_2 < 1%)**
N emissions (NO; NO_2):	**mostly from combustion (temperature dependent)**
S emissions (SO_2):	**from fuel S-content (typically <1% to 5% by weight)**
VOC emissions:	**typically undetectable (up to ~ C10); some H_2CO**
Particulate emissions:	**organics (unburned fuel; lube oils); soot; some S**

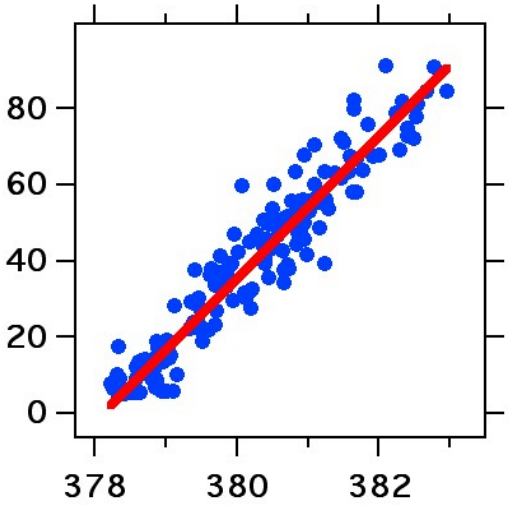
Engine load/fuel variations can cause large deviations from average emission rates

Determining Emission Factors (EF) from Measurements

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

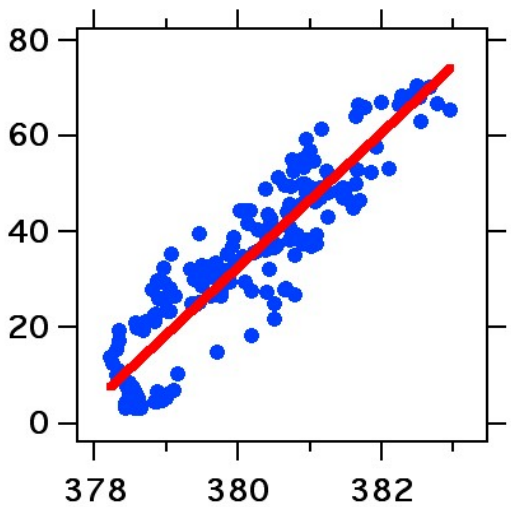


NO_y vs CO_2



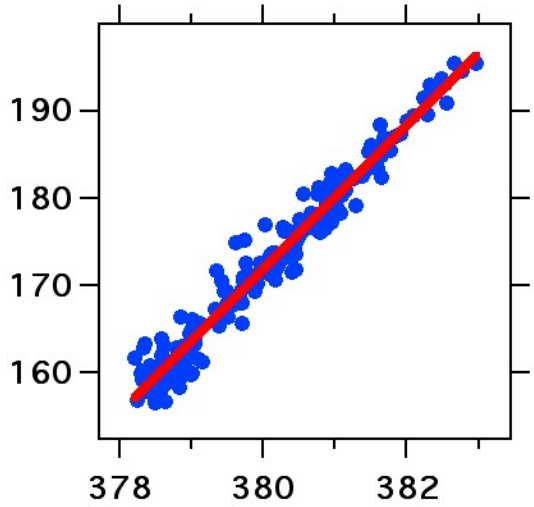
Slope = 18.2 ± 0.5 ppb/ppm
NO_y E.F. = 60.2 ± 1.7 g/kg

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

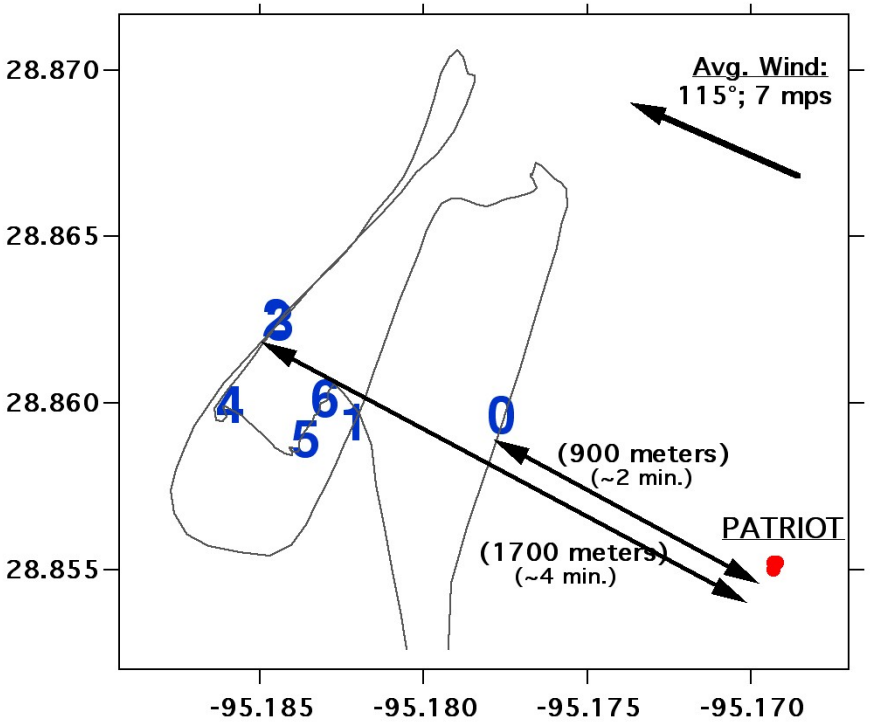


Slope = 8.09 ± 0.13 ppb/ppm
CO E.F. = 16.3 ± 0.26 g/kg

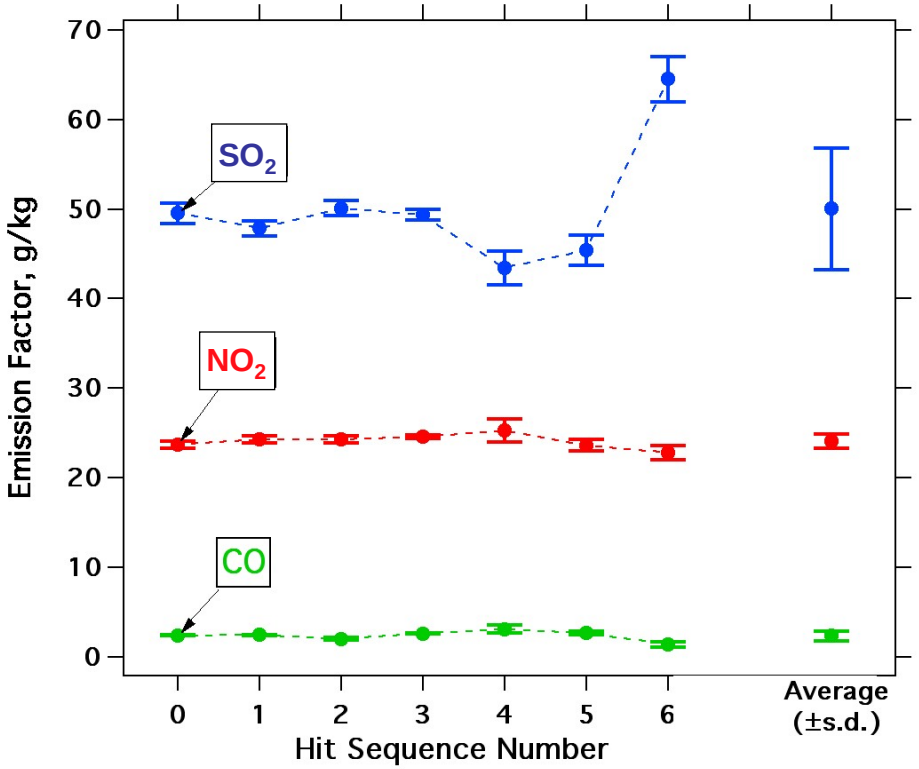
EF Precision Estimates: 08 August 06; 0500-0800 UTC

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

Patriot Situation Map



Patriot Emission Factors



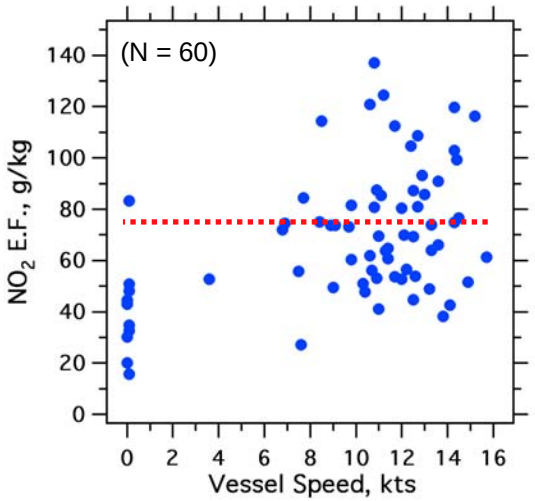
1) Nighttime (no photochemistry); constant wind field
2) Target at anchor: assume constant emissions
3) Emission factor measurement precision:

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.)

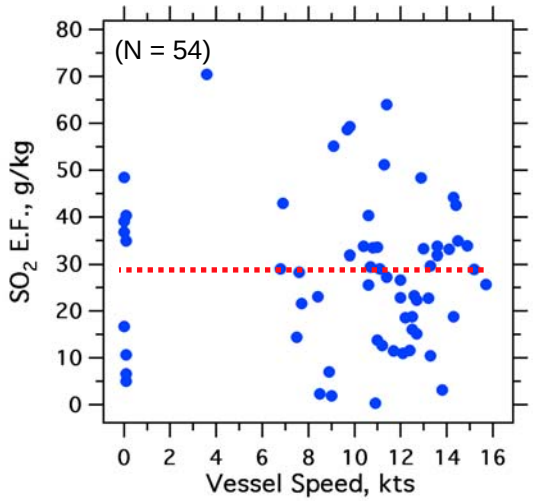
NO_2 E.F. vs. Speed



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)

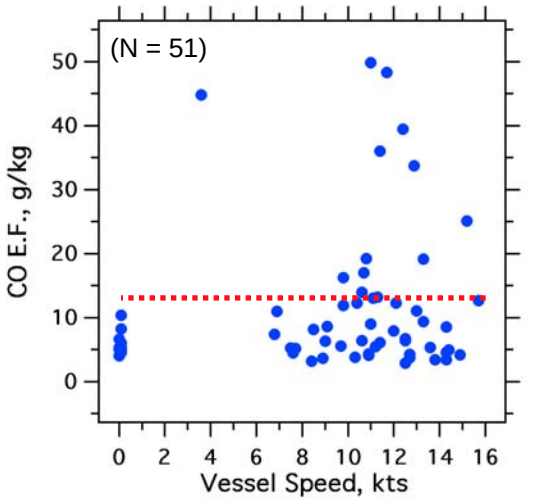
SO_2 E.F. vs. Speed



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



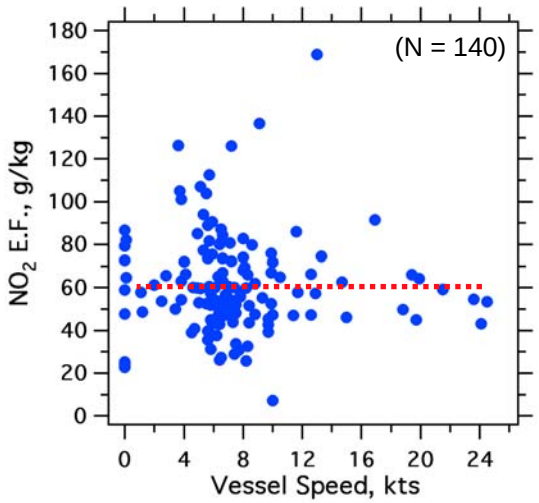
CO emission factors should be low (high temp. combustion); otherwise poor maintenance

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

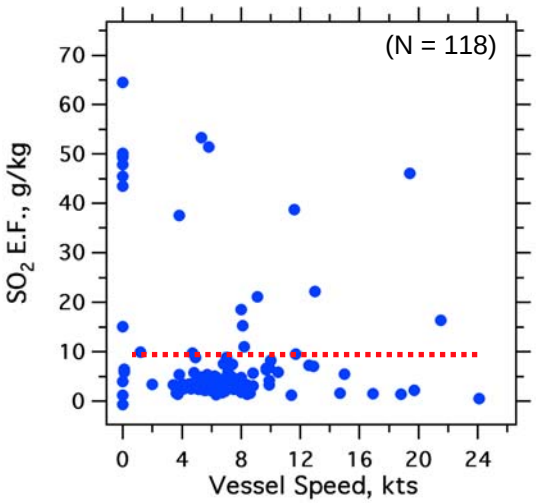
NO_2 E.F. vs. Speed



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)

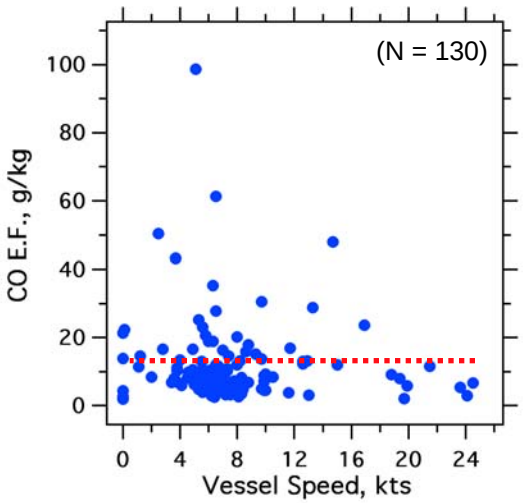
SO_2 E.F. vs. Speed



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%)

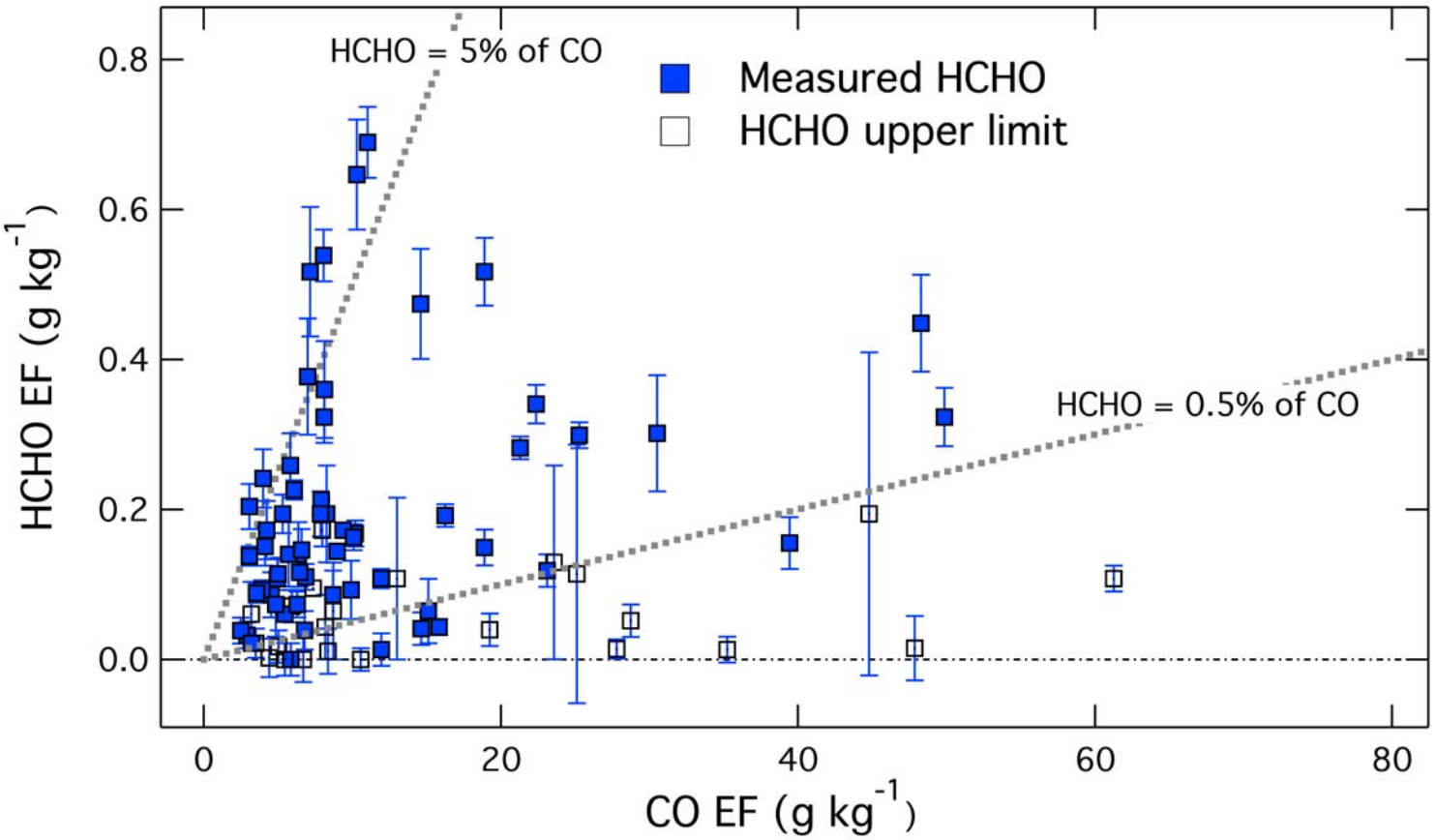
CO E.F. vs. Speed



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

Average of data = 16 g/kg (red line; all data)

Marine Vessel Formaldehyde Emissions



- **HCHO is emitted at between 0.5% and 5% of CO emissions**
- **Even small emissions of HCHO are significant due to its reactivity e.g., early AM photolysis can "kick start" O_3 photochemistry**

Summary of Emission Factor Data

EF Source	NO_2	SO_2	CO
this work; SSD	74 (±24)		28 (±16)
12 (±12)			
this work; MSD	60 (±24)		9 (±14)
16 (±12)			
Lloyd's (1995)[1]; SSD	87	20 x %S	7.4
Lloyd's (1995)[1]; MSD	57	20 x %S	7.4
ENTEC (2002)[2]; SSD	90 (±20%[3])	54 (±10%[3])	2.7
ENTEC (2002)[2]; MSD	65 (±20%[3])	54 (±10%[3])	3.4

Data shown are g kg^{-1} fuel consumed

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

[2]European Commission and ENTEC UK Limited, Quantification of emissions from ships associated with ship movements between ports in the European Community, Final Report, July 2002.

[3]At-sea uncertainties are shown. SO_2 emission factors calculated for HFOs.

Marine Vessel vs Stationary Source Emissions

1. Emission factor comparison.

	Molecules / 1000 Molecules CO_2		
Emission Source	NO_2	CO	SO_2
Ships (SSD)	5 - 41	1 - 25	0 - 15
Power plant (coal)[a]	0.2 - 1	2 - 6	2 - 7
Power plant (nat. gas)[a]	N.D. (SCR)	N.D.	0 (fuel %S=0)

[a]T. Ryerson, NOAA/ESRL

2. Aggregate emissions comparison.

	2004 Point Source Emissions[1] (tons per day)		
County (Texas)	NO_2	CO	SO_2
Brazoria	53.77	16.81	138
Fort Bend	22.31	23.17	150
Galveston	24.62	11.95	16
Harris	113.23	53.08	72
Ships (this work)[2]	24.5	6.3	12[3]

[1]Source: US EPA 1999 NEI; updates to 2004 from CEMS data by Greg Frost at NOAA/ESRL
[2]Activity data from ERG, 2007. Freeport and Texas City ship activity data are not included.
[3]Estimate based on average E.F.

Summary and Findings

- CO ship emissions are probably not significant compared to other sources
- SO_2 ship emissions non-negligible; source strengths are highly variable
  - SO_2 emissions can be controlled: 1) low S fuels (SECA); 2) exhaust gas scrubbing
- NO_2 ship emissions are significant air quality issue for major ports
  - e.g., Houston Ship Channel region: total ship NO_2 emissions are estimated to be similar to large coal-fired power plant NO_2 emissions (tons per day basis)
  - NO_2 emissions are quite variable: operating mode; fuel; age are all important
  - NO_2 emissions can be controlled: 1) engine tuning; 2) exhaust gas treatment (SCR)
- VOC emission - H_2CO is only VOC that could be measured in ship exhaust and is small
- PM emissions - organics, sulfate, size distributions: furthur analysis required

  (Dan Lack, Aerosol Emissions from Commercial Shipping; poster)