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Canada

Canadian Shipping: Evaluating Marine Exhaust Emissions in the Real World

Mark McCurdy
Emissions Research and Measurement Section
Air Quality Research Division
Environment Canada

Presentation Overview

- Context and drivers for marine exhaust emissions research
- Role of EC and ERMS
- ERMS marine research program
- Results summary
- Challenges
- Next steps

Drivers - Environmental

- Marine traffic and related port activities contribute to air pollution in many cities, ports, and along inland waterways
- By 2030, marine emissions of NO_X are predicted to double and $PM_{2.5}$ to triple[1] if no control measures are taken
- Marine transport contribution to total Canadian mobile source pollution[2]:
  - NO_X 11%, $PM_{2.5}$ 16%, SO_X 89%
- Marine fuels among the lowest quality of all fuels used in Canada
- What are the actual air emission profiles of marine transport in Canadian waters?

[1] US EPA, 2010
[2] 2010 Canadian National Pollutant Release Inventory (NPRI), Feb 2012

Drivers - Regulatory

- IMO, U.S. EPA, Transport Canada
  - NO_X emission limits depending on engine speed and age
- Implementation of ECAs (Emission Control Areas) around the world and now also in North America
  - Regulating fuel sulphur content to achieve emission targets
  - Tightening NO_X emission rates within ECAs
- Clean Air Regulatory Agenda (CARA):
  - Measurement and analysis of exhaust emissions from transportation sources to support:
    - Method development for sampling and analysis
    - Evaluation of emissions control technologies and strategies
    - Development of emissions factors and inventories

ERMS Mobile Source Field Testing

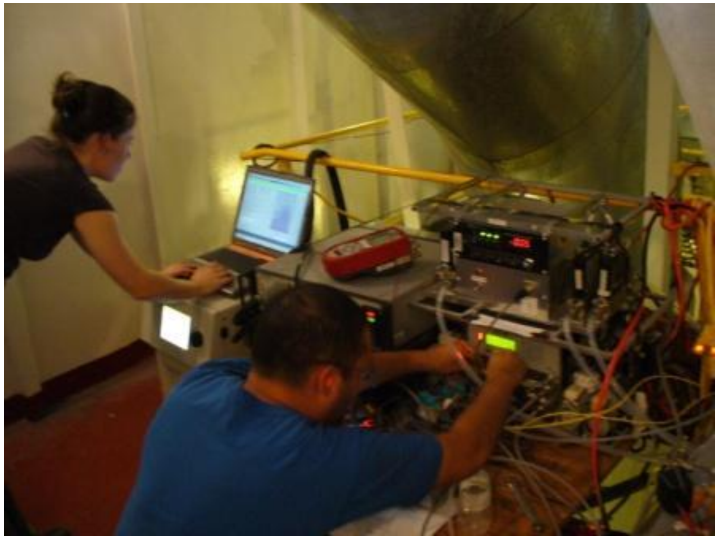
- Support policy and regulatory development
- Evaluate and compare fuels and emission control technologies in “real world” operation
- Detailed characterization of exhaust emissions from non-road sources such as construction, marine and locomotive equipment
- Unique portable exhaust emissions sampling systems, designed to be adapted for a variety of mobile source research programs

ERMS Marine Research History

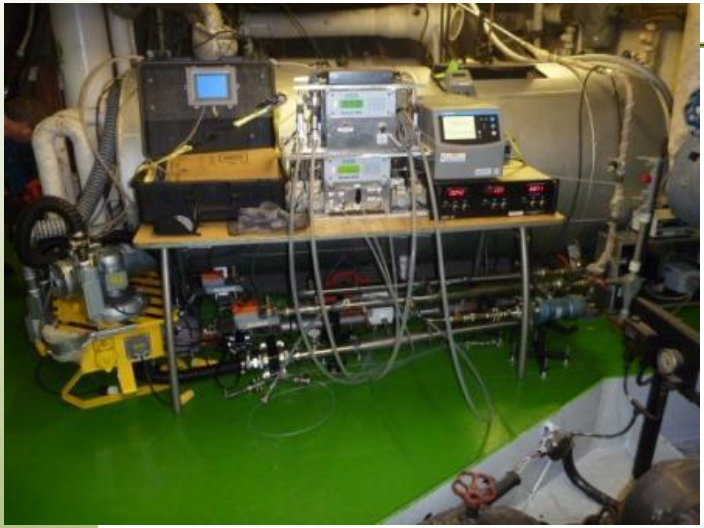
- 1995 – 2001: On-board gaseous emissions measurement for marine inventory development
  - Commercial freight vessels, Coast Guard, and ferries
  - Included VOCs from oil tank cargo holds
- 2004 – 2005: On-board emissions measurements of alternative fuels and emissions control strategies on marine vessels
  - Biodiesel, retrofit emissions controls, water injection optimization
- 2007: On-board emissions measurements of large cruise ship testing effects of seawater scrubber system
  - 57% reduction in PM, 75% reduction in SO_2
- 2008 – 2012: On-board measurements to characterize particulate and gaseous emissions from a variety of vessels at in-use operating conditions

Current Program

- Successful collaborations with vessel operators in Canadian waters to perform detailed in-service experiments
  - Comparing impacts of a variety of fuels (HFO, IFO, and MDO), engine and vessel configurations, and operation modes
  - Developing robust and accurate sampling techniques
  - Looking for opportunities to explore emissions control technologies



Methodology – ISO 8178



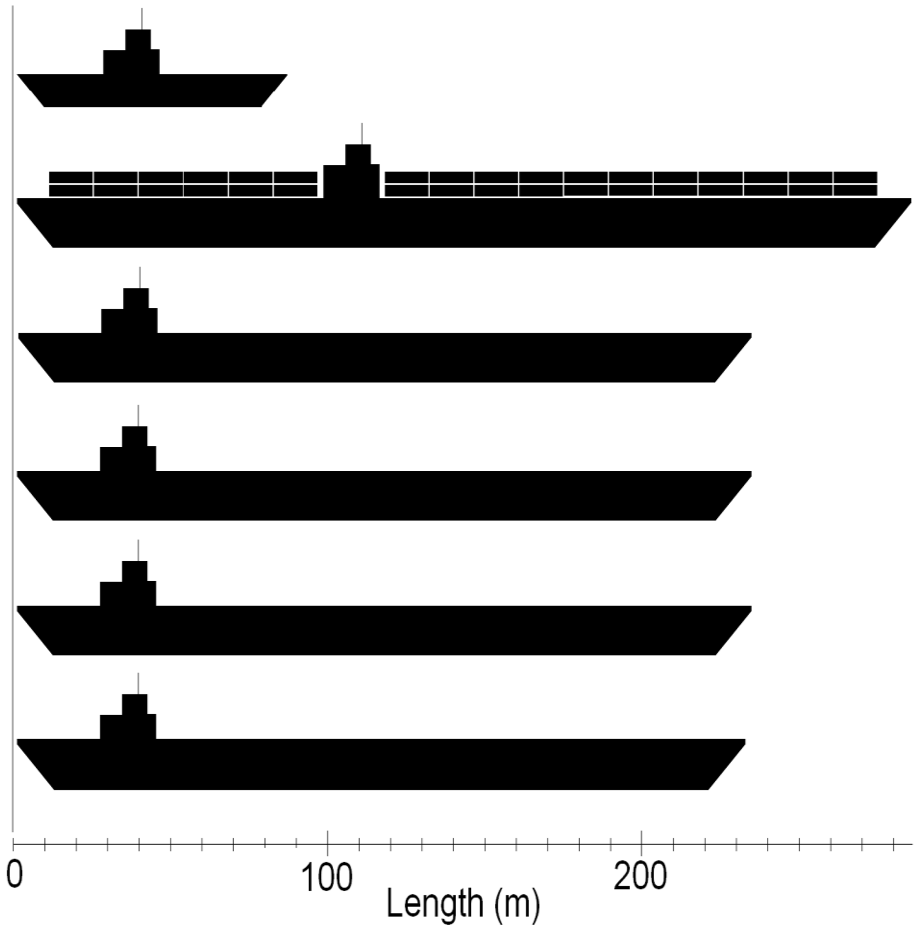
- Reciprocating Internal Combustion Engines – Exhaust Emission Measurement – “Field Conditions”
- Gaseous samples collected directly from exhaust stack for analysis
- Particulate matter samples require dilution with ambient air to control temperature and humidity
- Organic vapour samples require dilution to achieve suitable ranges for analysis
- Partial flow dilution method
  - Sampling a portion of the raw exhaust flow, then mixing in dilution air to allow control of humidity and temperature in dilution tunnel
- Equipment intensive and time consuming to set up, but allows multiple frequent repeats
  - Permits comparisons of engine modes, fuel types, emission controls, etc.

Sampling Parameters

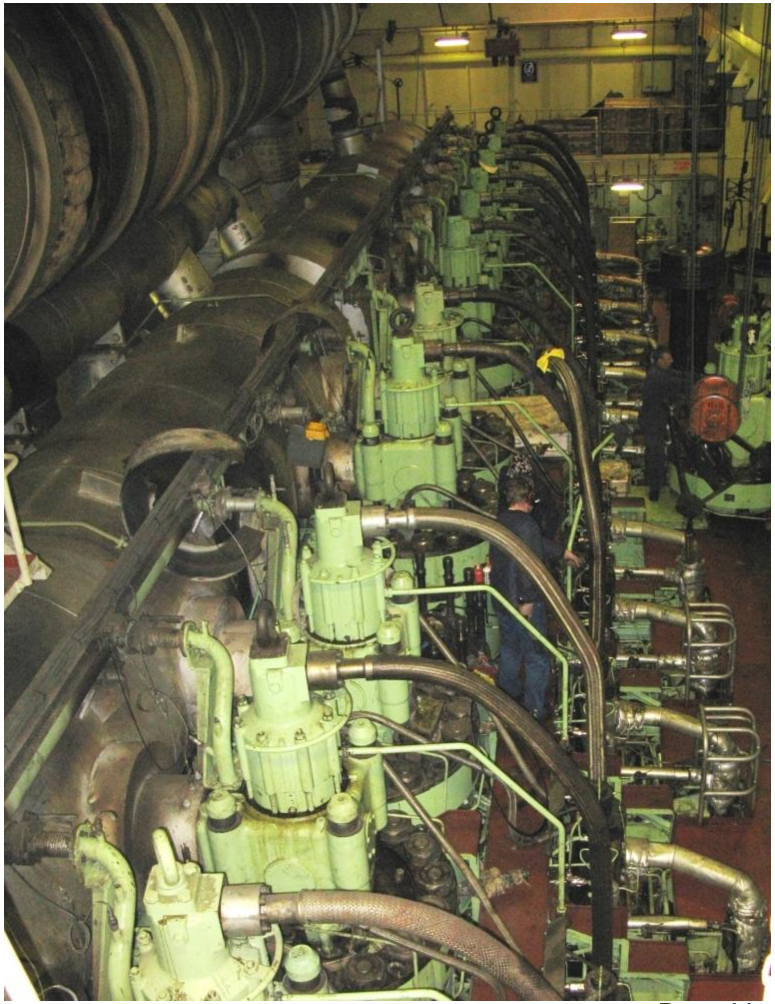
- Gaseous emission factors
  - Raw exhaust measurements (NO_X, SO_2, CO, CO_2)
  - Dilute sample collection in canisters (N_2O, VOCs, LHCs)
  - PAHs, nitro-PAHs, and carbonyls
- Particulate Matter emission factors
  - TPM, $PM_{2.5}$, trace metals, SO_4, Organic Carbon (OC), Elemental Carbon (EC)
- Ultrafine Particle Analysis
  - Number concentrations and size distributions from 10 - 700 nm
- Operational conditions
  - Fuel rates, engine load, engine operating parameters, ambient conditions, detailed fuel sample analysis

2008-2010 Test Vessel Parameters

Vessel	Vessel Type	Engine Speed	Power (kW)	Fuel
A	Icebreaker	Medium	17 000	ULSD
B	Container	Slow	43 000	HFO and MDO
C	Cargo Laker	Medium	6 500	IFO60
D	Cargo Laker	Slow	8 000	IFO380
E	Cargo Laker	Medium	6 500	IFO60
F	Cargo Laker	Medium	7 000	IFO180 and MDO



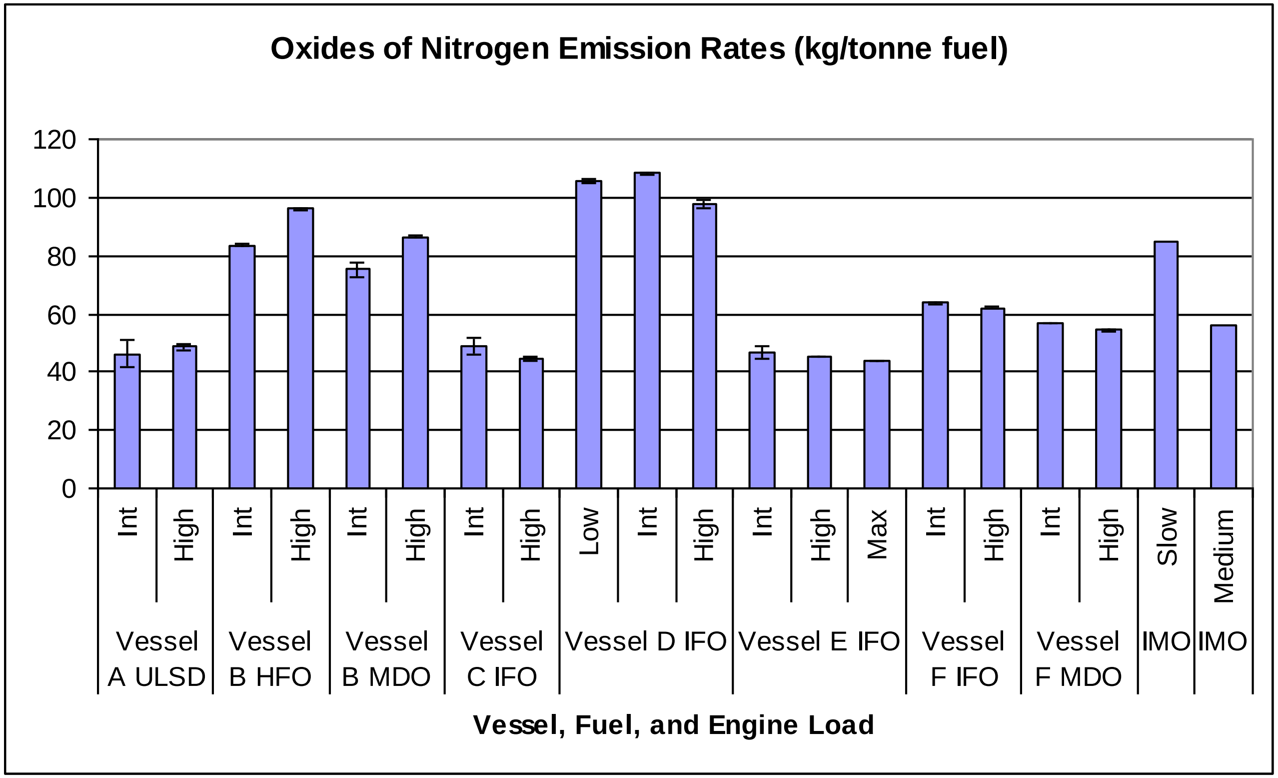
Vessel Parameters (cont'd)



- Various fuels tested:
  - Heavy Fuel Oil (HFO), also known as residual oil or bunker fuel, low cost and low quality
  - Marine Diesel Oil (MDO), distillate fuel, much more expensive than residual
  - Intermediate Fuel Oil (IFO), blend of residual and distillate
  - Ultra Low Sulphur Diesel (ULSD), on-road quality fuel
- Sulphur content in fuel ranged from 19 ppm ULSD to 2.3% (23,200 ppm) HFO
- Engine types tested:
  - Slow speed (60-200 rpm)
  - Medium speed (300-1000 rpm)

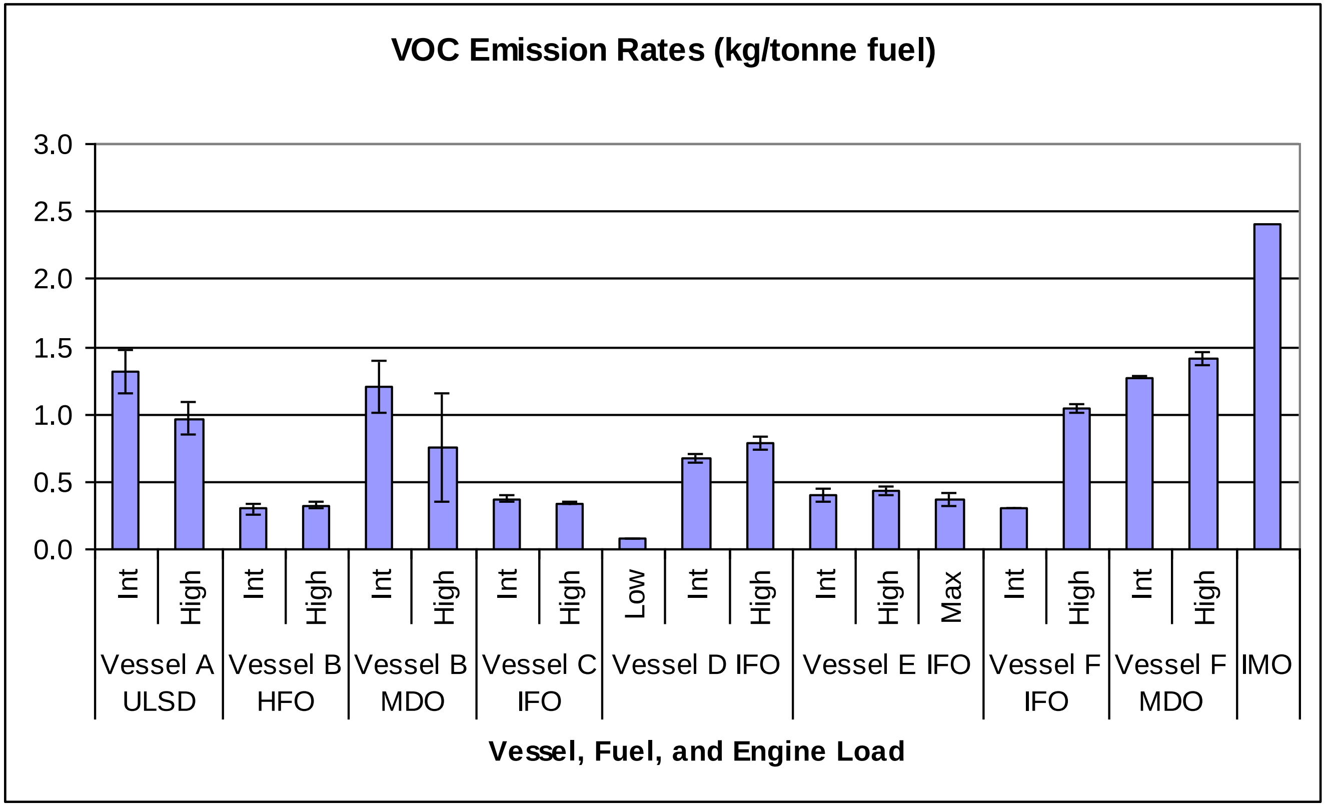
NOx Emission Rates

- Raw continuous measurement of oxides of nitrogen, a tropospheric ozone precursor
- Measured emission rates show good agreement with IMO emission factors for slow and medium speed engines



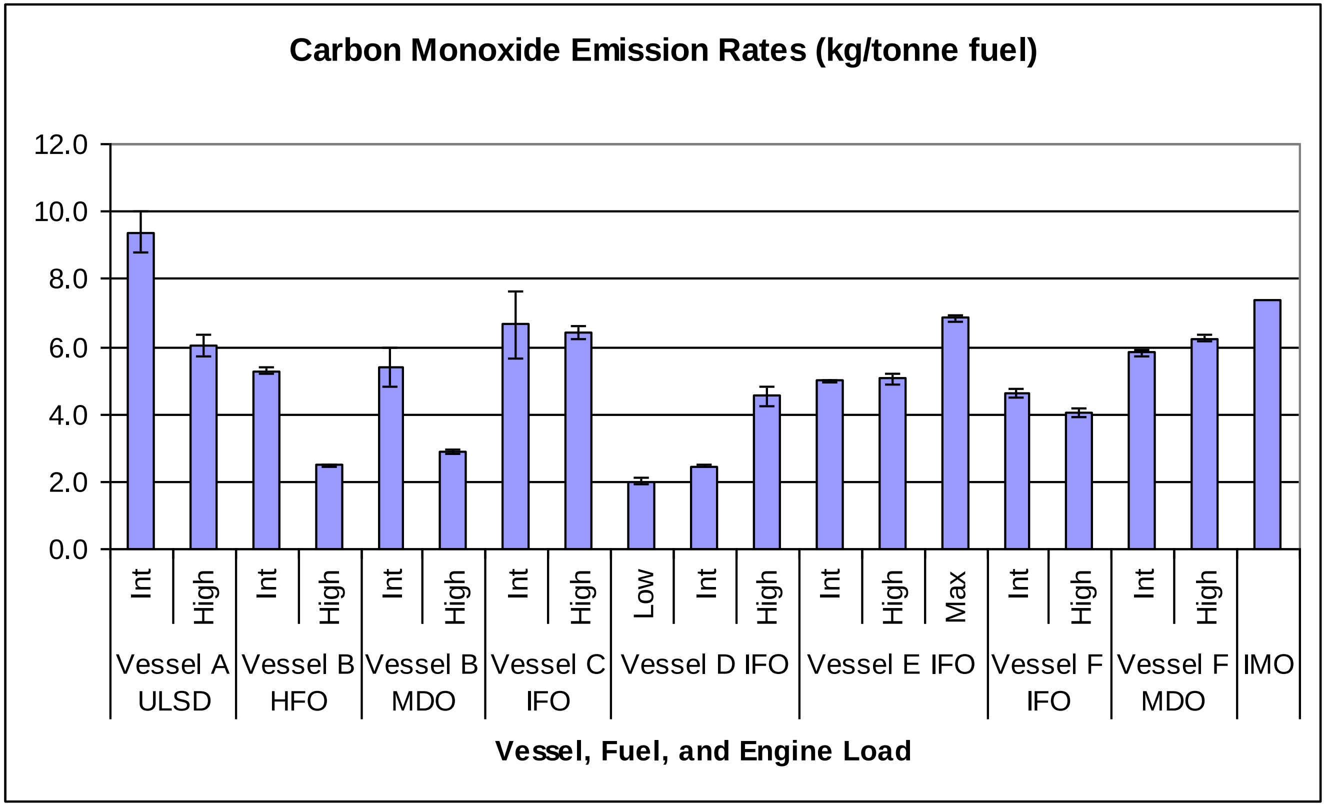
VOC Emission Rates

- Diluted samples collected in Summa™ canisters analysed for non-methane volatile organic compounds, a tropospheric ozone precursor
- Measured emission rates are lower than IMO emission factor



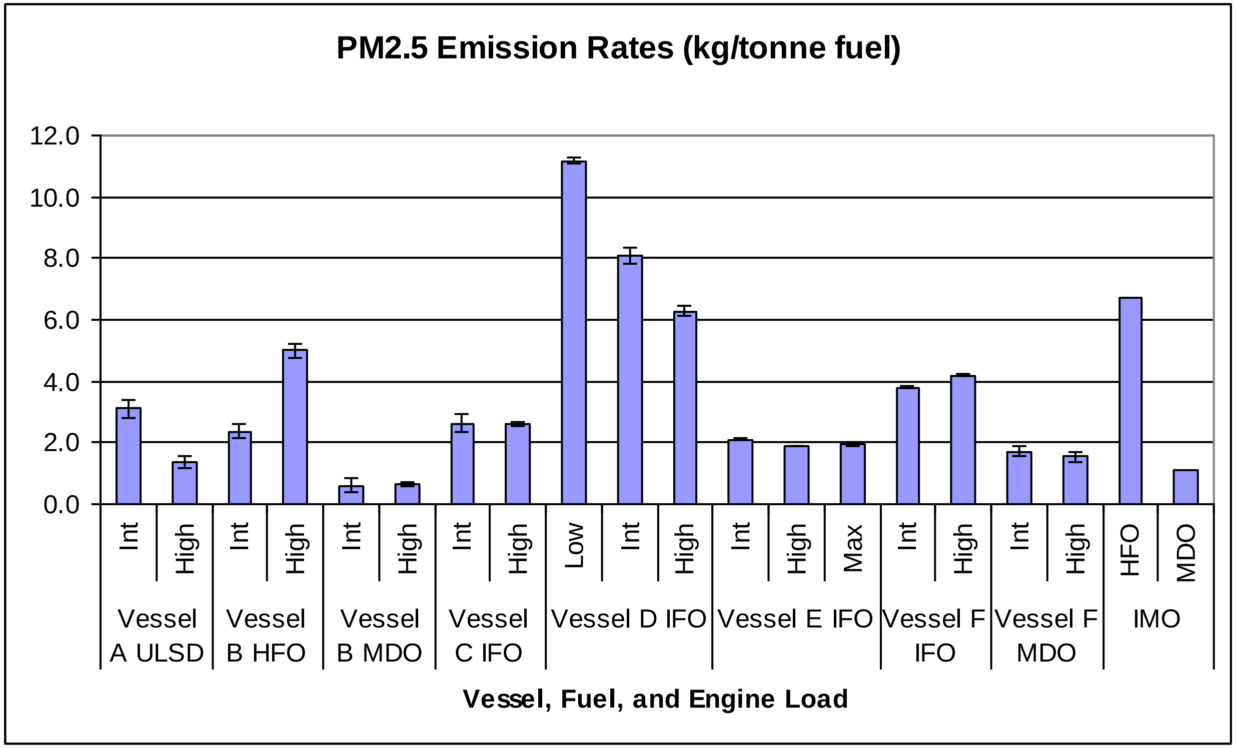
Carbon Monoxide Emission Rates

- Raw continuous measurement of carbon monoxide, a tropospheric ozone precursor
- Measured emission rates show good agreement with IMO emission factor



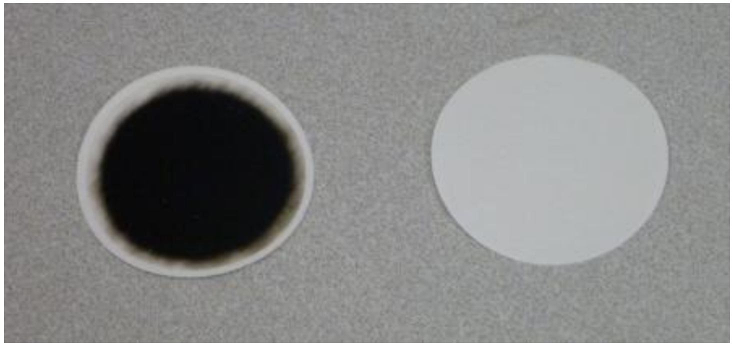
$PM_{2.5}$ Emission Rates

- Diluted samples collected on Teflon filters and analyzed gravimetrically under climate-controlled conditions
- Measured emission rates show relatively good agreement with IMO emission factors for both fuel types, significantly affected by fuel sulphur content



Black Carbon Determination

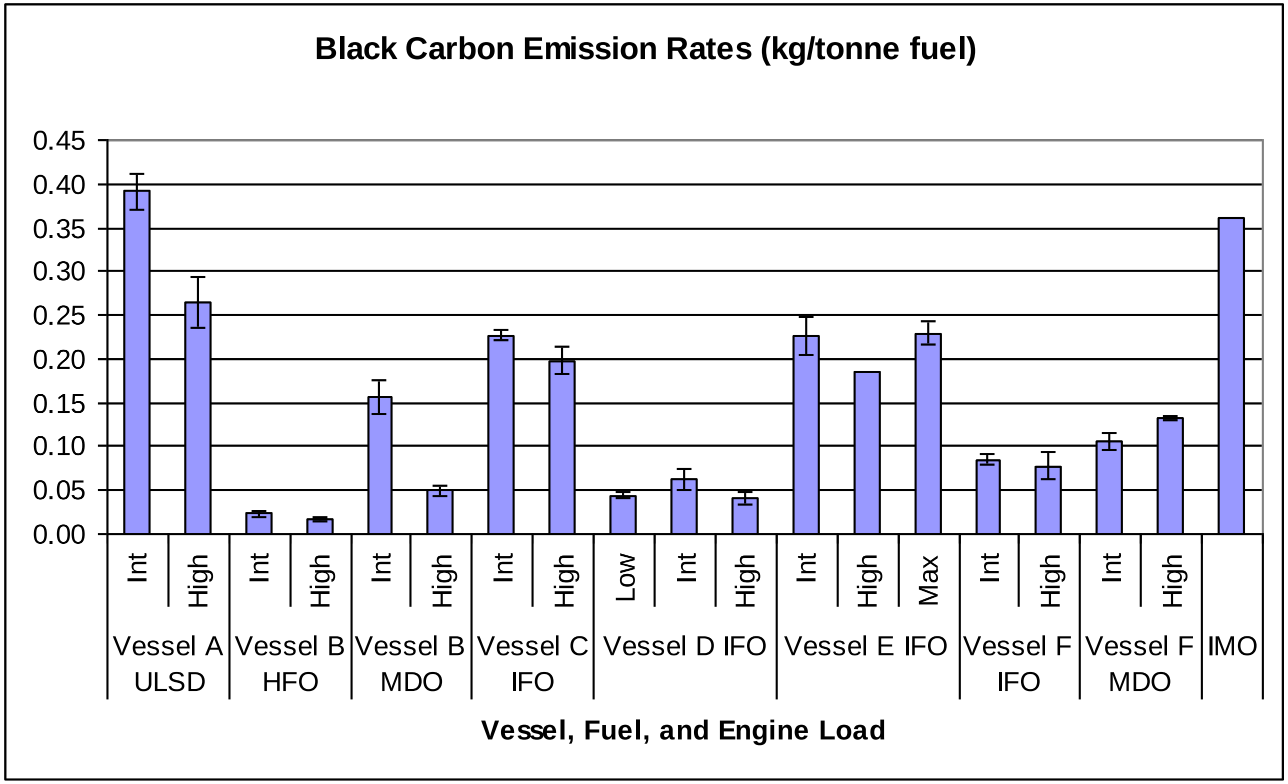
- Definition of "black carbon" still under development as applied to various emission sources and measurement protocols
- Elemental carbon is quantified using filter-based thermal speciation
  - capturing diluted exhaust particulate samples on fired quartz filter media and analyzing for organic and elemental carbon (OC/EC) using NIOSH 5040 thermal-optical-transmittance method
- Exhaust particulate matter is a complex mixture of OC, EC, by-products from the fuel and lubricating oil (sulphates, ash, additives, trace metals), and trace metals from engine wear
- OC is typically linked to unburned or partly combusted fuel or lubricating oil
- EC is the soot or black smoke particle emissions, often referred to as black carbon
- Future studies will include real-time black carbon measurements using a micro Aethelometer
  - Optical method captures soot on a filter and compares light absorption to clean filter



47mm quartz filters, new filter on the right, sampled filter on the left

Black Carbon Emission Rates

- Diluted samples collected on quartz filters and analyzed as elemental carbon by NRCan using NIOSH 5040 thermal-optical-transmittance method
- Measured emission rates show relatively good agreement with IMO emission factor, but are generally lower than the IMO factor



Challenges

- Vessel operation parameters – engine load, fuel rates not available on older vessels
- Vessel operation schedules – vessels are in service during testing and must react to weather, traffic, hazards
  - Difficult to get consistent test repeats
- Ambient conditions – temperature, vibrations, fumes, weather
- Logistics and transport of crew and equipment
- Correlation of results with other studies considering variables encountered in the sampling techniques

Next steps…

- Wide variety of parameters that affect emissions:
  - Fuel, engine, vessel configurations
  - Further research to investigate relationships
- Many older vessels are grandfathered under regulations
  - Need to consider and prove emissions control retrofits
- New emissions control strategies being developed
  - Updated scrubber designs
  - Scaled-up after-treatment equipment
  - Fuel additives and modifiers
- Arctic fuels and ambient conditions
  - Quantify emission rates in sensitive ecosystem

Thank you

- Special thanks to ERMS colleagues for contributions to field testing, equipment preparation and operation, laboratory analysis, data analysis, and presentation

- Questions?

Mark McCurdy
Environment Canada
(613) 998-9590 x275
Mark.McCurdy@ec.gc.ca