Remote Quantification of Stack Emissions from Marine Vessels

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Extended Abstract # 944

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INTRODUCTION

Emissions from marine vessels can negatively impact air quality in communities located near major port areas. For this reason FluxSense Inc. in cooperation with Chalmers University of Technology has carried out a comprehensive five week field study in which we measured the actual emission rates (g/s) of nitrogen dioxide (NO_2) and the emission factors (g/kg_{fuel}) of SO_2, NO_x and particulates from individual ships maneuvering or mooring within the harbor areas of both, the Port of Los Angeles and the Port of Long Beach. The study was carried out on behalf of the South Coast Air Quality Management District (SCAQMD). The instruments and methodologies[1-5] have been developed by Chalmers University of technology and the technique is also used in several places in Europe to monitor whether by-passing ships use compliant fuel with regards to sulfur. The measurement techniques developed to characterize individual ship emissions will be discussed along with the results obtained from this extensive field campaign.

METHOD

Stationary and mobile (i.e. on-vessel) measurements of ship specific emission factors (g/kg_{fuel}) and total emission (g/s) were carried out in the port of Los Angeles and Long Beach from October 3 until November 10, 2015 by FluxSense Inc. and Chalmers University of Technology. The measurements were first carried out from a van for 5 days at the Coast Guard site at the Port of Los Angeles, then the equipment was moved to a research vessel run by the South Coast Marine Institute from which ships were tracked moving in and out of the ports for about two weeks. This was succeeded by stationary, land-based measurements from the van at the South Coast Marine Institute from October 27 to November 1 and at the ground of the Port of Long Beach Command and Control Center at the entrance of the Port of Long Beach between November 2 and November 10.

The data were obtained with a zenith DOAS technique for NO_2 and "in-situ" sniffer technique for SO_2, NO_x, CO_2 and particulates, which are shown in detail in Table 1. The measured particle properties corresponded to particulate number, particulate mass and black (BC) and organic carbon (OC). Total emissions of NO_2 from the harbors were also obtained through mobile optical zenith sky measurements by circumventing the whole harbor area with both the research vessel and a van. In addition, the potential VOC emissions were investigated when fueling the ships and other VOC sources in the harbor using techniques like the Solar Occultation Flux (SOF) technique, see paper 947. A custom software making use of wind information and automatically transmitted Automatic Identification System (AIS) information from the vessels calculated the sulfur fuel content and NO_x emission factors.

Table 1. Techniques used, parameters measured and their detection limits. These included fast responding SO_2, NO_x, CO_2, particulate matter, and Black Carbon (BC) analyzers. Further species like VOCs were measured using the Solar Occultation Flux (SOF) and the Fourier Transform InfraRed (FTIR) technique. Such measurements were then used to estimate "actual" emission factors for individual ships in real-time and total emissions in various modes of ship operation.

Species	Property measured	Method	Sample rate	Detection limit
CO_2	Mixing ratio	Cavity ring down spectrometer. Custom software.	2 Hz	0.2 ppm
SO_2	Mixing ratio	Fluorescence (modified)	1 Hz/0.016 Hz	1 ppb
NO_x	Mixing ratio	Chemiluminescence (modified)	1 Hz	0.5 ppb
NO_2	Column	Zenith sky DOAS	1 Hz	20 ppb (over 50 m)
PN (PM)	Number size distribution 5-500 nm	Electrostatic mobility	10 Hz	n/a
PN (PM)	Number size distribution 300-10000 nm	Laser scattering	1Hz	n/a
BC	Mass (BC and OC)	Aethalometer	1 Hz	100 ng/m^3

The measurements from the research vessel *Yellow Fin*, Figure 1, were carried out during 10 days, in the ports of LA and Long Beach. A gas and particle inlet on the mast was connected to the instruments inside the ship via 8 meter long tubings. The optical particle sensor, measuring the number of particles between 300 nm to 10 µm was positioned on the roof to reduce losses. Two spectrometers were positioned on the upper deck for remote sensing measurements of NO_2 and VOCs.

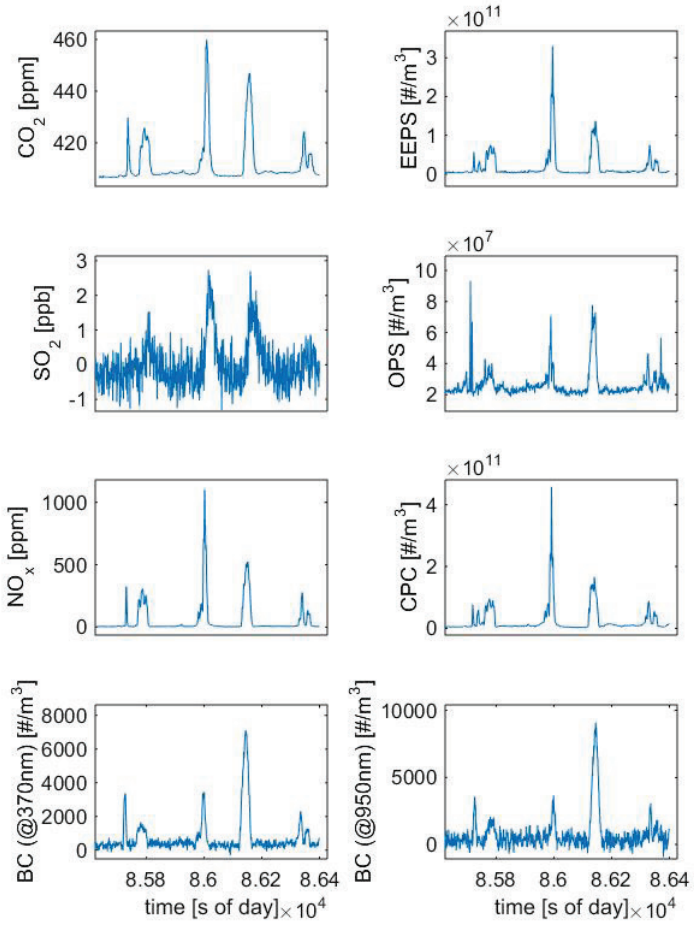
Figure 1. The research vessel Yellow Fin that was used for tracking ships from open sea to berth at the harbor to investigate emissions at various modes of operation. The sample inlet and the wind meter are mounted on the opposite ends of the mast's horizontal yard.

The emission rate in g_{NO2}/s is obtained from the optical measurements of NO_2 by combining wind and ship speed information.

The main objective with the measurements was to track individual ships from open to sea to berth, in order to measure their emissions during different modes of operation and about 25 such measurements were carried out. In addition, we also measured ship specific emission factor data for numerous ships (tankers, containers, cruise ships, tugs) at anchor, at berth and ships passing the harbor entrances of port of Los Angeles and port of Long Beach respectively. The data is still being evaluated but our first observations indicate that tug boats have rather high particle emissions. Several ships running on non-compliant high sulfur fuel were measured in real time from the research vessel. In the future, it would be rather interesting to carry out such measurements at the 200 nautical mile limit of defined in MARPOL Annex VI[6]. We did not observe any apparent VOC emission when the ships were being fueled from bunker barges. The data could be directly used to validate ship emission models based on activity using recorded AIS information and for further modelling of the impact of shipping on air quality.

In Figure 2, a typical measurement record of the sniffer instruments from repeated traverses by the research vessel through the same emission plume of another vessel is shown. The peaks in the mixing ratios and concentrations, respectively, due to the emitted combustion products of the vessel can clearly be seen. The emission factors can be calculated by the integration of the exceeding peak above the ambient baseline of each species for each peak and the respective ratio over the integrated CO_2 value[1-5].

Figure 2: Measurement of different species during a repeated traverse through a ship plume.



An example of a case study where one ship was traced continuously while it is changing its operational mode from constant, i.e. steady-state operation to maneuvering is presented in Table 2. It was even seen that this vessel was using fuel exceeding the common sulfur regulation for this area, which could be repeatedly being seen for each individually evaluated transect through the plume of this vessel.

Table 2: Example measurements of a traced cargo vessel with exceeding sulfur emissions.

Time [UTC]	**Speed [kn]**	**SO_2 [g/kg$_{fuel}$]**	**NO_x [g/kg$_{fuel}$]**	**PN (CPC) [#/kg$_{fuel}$]**	**PN (EEPS) [#/kg$_{fuel}$]**	**BC (590 nm) [mg/kg$_{fuel}$]**	**VCD(NO_2) [mg/m^2]**
10/16 00:09	10 (constant)	42.1	8.4	$1.4 \cdot 10^{16}$	$1.9 \cdot 10^{16}$	71.6	143.5
10/16 00:22	6 (maneuvering)	37.4	17.9	$8.9 \cdot 10^{15}$	$1.2 \cdot 10^{16}$	68.9	220.8
10/16 00:30	6 (maneuvering)	41.3	9.3	$7.4 \cdot 10^{15}$	$9.8 \cdot 10^{15}$	67.8	117.2

SUMMARY

Ship emission data from fixed and mobile platforms were obtained during 5 weeks in October and November of 2015. The main objective was to study the "real life" ship emissions of gases and particles in different modes of ship operation in the vicinity of the harbor, from open sea to berth. These emissions can be used to calculate the impact of shipping activities on air quality in the Los Angeles basin. Since ships are supposed to run on low sulfur fuel it is interesting how the new low sulfur fuel impacts also emissions of particles, in addition to sulfur. During the project we found ships running on high sulfur fuel.

During the presentation we will describe the method and show example of data from the project.

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REFERENCES

1. Beecken, J.; Mellqvist, J.; Salo, K.; Ekholm, J.; and Jalkanen, J.-P. Atmos. Meas. Tech. **2014**, 7, 1957–1968

2. Beecken J. et al, Atmos. Chem. Phys. Discuss., **2014**, 14, 25931-25965

3. Beecken J. Ph.D. Thesis, Chalmers University of Technology, **2015**

4. Berg, N.; Mellqvist, J. et al, Atmos. Meas. Tech., **2012**, 5, 1–14,

5. Mellqvist, J., Ekholm, J., Salo K. and Beecken J., Final report to Vinnova: *Identification of Gross Polluting Ships to Promote a Level Playing Field within the Shipping Sector*, RG Report (Göteborg) No. 11, Chalmers University of Technology, **2014**

6. Marine Environment Protection Committee (MEPC), Resolution MEPC.176(58), IMO, London, United Kingdom, **2008**