

# Particle Emissions from Ship Engines: Emission Properties and Transformation in the Marine Boundary Layer

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## INTRODUCTION

Gaseous and particulate matter emissions from ship engines currently gain increasing attention regarding a possible environmental impact. They can influence the atmospheric composition and in particular the ozone chemistry in the troposphere considerably. As for any combustion source, ship engine exhaust also contains particulate matter. Exhaust particles are composed of combustion aerosol particles consisting of elemental and organic carbon, sulphate and ash (Petzold et al., 2004), and of volatile particles forming outside the combustion process in the cooling exhaust plume.

Elemental or black carbon (BC) is the most efficient particulate absorber of atmospheric solar radiation and has therefore a strong impact on the atmospheric radiation balance. Additionally, combustion particles can act as nuclei for the formation of cloud droplets and affect by that means the life cycle and radiative properties of stratus clouds at the top of the marine boundary layer.

In particular the emission of particles and their fate in the marine environment are however widely unknown. From observations so far mainly bulk aerosol properties like mass concentrations are reported, while detailed chemical analyses and aerosol microphysical data are missing.

In the framework of a combined effort ship emission studies were conducted in 2004 as part of the European Integrated Project HERCULES (High Efficiency R&D on Combustion with Ultra Low Emissions for Ships). Detailed aerosol microphysics and chemistry was measured in the exhaust gas of a single-cylinder test bed engine, which was operated at various load conditions, running on fuel with a sulphur content of 3.45 wt.-%.

The emission studies were complemented by airborne aerosol transformation studies in the marine boundary layer as part of the ICARTT-ITOP (Intercontinental Transport of Ozone and Precursors) experiment in 2004. Research flights using the DLR aircraft Falcon 20 E-5 were conducted in the English channel and in a single plume of a large container ship.

## METHODS

On board of the research aircraft, an extensive set of instruments was operated for measuring aerosol microphysical properties of both the secondary volatile aerosol, the primary combustion aerosol and trace gases H<sub>2</sub>O, NO, NO<sub>x</sub>, O<sub>3</sub>, CO, CO<sub>2</sub>, and SO<sub>2</sub>.

Figure 1 shows the flight track of the aircraft during the plume study in the exhaust of the container ship. The colour of the symbols represents the black carbon mass concentration in the plume. The plume encounters observed during the Single Plume Study are shown in Figure 2. The strength of the plume event was rated according to the CO<sub>2</sub> measured above the background signal (excess CO<sub>2</sub>: ΔCO<sub>2</sub>).

Close to the source, ΔCO<sub>2</sub> exceeded a value of 10 ppm, ranging up to > 100 ppm. Simultaneously, the BC mass concentration reached values of close to 10 μg m<sup>-3</sup>, while the Condensation Particle Counters (TSI 3760A) were above their upper detection limit of 20,000 cm<sup>-3</sup>.

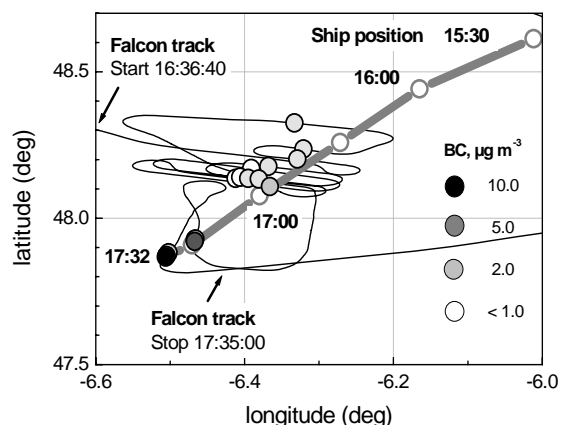


Figure 1. Tracks of the source ship and the research aircraft Falcon during the Single Plume Study; symbol colours represent Black Carbon mass concentrations in the plume.