

## Monitoring shipping emissions in the German Bight using MAX-DOAS measurements

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Shipping is generally the most energy efficient transportation mode, but, at the same time, it accounts for four fifths of the worldwide total merchandise trade volume. As a result, shipping contributes a significant part to the emissions from the transportation sector. The majority of shipping emissions occurs within 400 km of land, impacting on air pollution in coastal areas and harbor towns. The North Sea has one of the highest ship densities in the world and the vast majority of ships heading for the port of Hamburg sail through the German Bight and into the river Elbe.

A three-year time series of ground-based MAX-DOAS measurements of NO<sub>2</sub> and SO<sub>2</sub> on the island Neuwerk in the German Bight has been analyzed for contributions from shipping emissions. Measurements of individual ship plumes as well as of background pollution are possible from this location, which is 6-7 kilometers away from the main shipping lane towards the harbor of Hamburg. More than 2000 individual ship plumes have been identified in the data and analyzed for the emission ratio of SO<sub>2</sub> to NO<sub>2</sub>, yielding an average ratio of 0.3 for the years 2013/2014. Contributions of ships and land-based sources to air pollution levels in the German Bight have been estimated, showing that despite the vicinity to the shipping lane, the contribution of shipping sources to air pollution is only about 40%.

Since January 2015, much lower fuel sulfur content limits of 0.1% (before: 1.0%) apply in the North and Baltic Sea Emission Control Area (ECA). Comparing MAX-DOAS measurements from 2015/2016 (new regulation) to 2013/2014 (old regulation), a large reduction in SO<sub>2</sub>/NO<sub>2</sub> ratios in shipping emissions and a significant reduction (by a factor of eight) in ambient coastal SO<sub>2</sub> levels have been observed.

In addition to that, selected shipping emission measurements from other measurement sites and campaigns are presented.

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