Machine learning-based NO2 estimation from seagoing ships using TROPOMI/S5P satellite data

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Summary

The marine shipping industry is one of the strongest emitters of nitrogen oxides (NO_x), a pollutant detrimental to both ecology and human health. Over the last 20 years, the pollution produced by power plants, the industry sector, and automobile vehicles has been constantly decreasing. In contrast, the pollution impact of maritime transport persists and continues to increase. This generates a big societal pressure, resulting in regulations proposed by the International Maritime Organization. These regulations impose restrictions on emission levels that can be produced by individual ships. While various methods are used to assess the emission from ships in ports and off-coastal areas, monitoring over the open sea has been infeasible until now. The game-changer is the TROPOMI instrument on board the Sentinel 5 Precursor Satellite – studies show that NO_2 plumes from some individual seagoing ships can be distinguished on TROPOMI images. The objective of this thesis is to pave the way toward the application of the TROPOMI instrument for the monitoring of compliance of seagoing ships with the regulations of the International Maritime Organization. This is being achieved through the innovative fusion of the methods of advanced machine learning, feature engineering, and data integration. Each chapter of this thesis builds upon the findings of its predecessor, as a whole, representing state-of-the-art knowledge in the application of TROPOMI satellite data for the monitoring of NO_2 emissions from individual seagoing ships.

Following the introductory chapters, in Chapter 3, using a developed machine learning-based methodology, we examine the sensitivity limits of the detection system using TROPOMI data concerning the detection of NO_2 plumes from ships. The insights gained in this chapter establish the scope for the rest of this study. In Chapter 4, we present a method for automated delineation of a part of a TROPOMI image that corresponds to a ship under study. This way, one can exclude unnecessary pieces of information from the analysis and focus attention on the parts of a TROPOMI

image, where the ship plume is expected to be located. Such an advancement opens a possibility for a large-scale processing of the ship plume data. In Chapter 5, we presented a machine-learning-based method for automated segmentation of NO_2 plumes produced by individual ships. The results presented in the Chapter suggest that by using machine learning for the task of ship plume segmentation we are able to correctly segment plumes that are hardly or not-at-all detectable by the human eye. Lastly, in Chapter 6, we present a methodology for the automated detection of potentially anomalously emitting ships. The presented approach allows the automatic processing of a huge amount of satellite remote sensing data in order to select for the inspection ships that consistently emit more than can be inferred based on their properties and sailing conditions. The proposed methodology provides a potential path toward the development of a scalable recommendation system for ship inspectors that is rooted in satellite-based observations.

To conclude, we can state that with the work presented in this thesis, we notably moved forward with the state-of-the-art concerning the application of satellite observations for the task of continuous and global monitoring of emissions from individual ships. At the onset of the work for this thesis research, all we knew was that some of the plumes from individual ships could be distinguished with the TROPOMI instrument. When reaching the end, we know the sensitivity limits of the detection system of ship NO_2 plumes using TROPOMI data, how to process the TROPOMI signal to extract information about the ship emissions automatically, and how to automatically select ships that are potential anomalous emitters. These advancements lay a solid foundation for the future of the application of satellite-based technologies for continuous monitoring of anthropogenic emissions on a global scale.

Summary