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CHEMICALLY SPECIATED PARTICULATE MATTER EMISSIONS FROM SHIPS

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Abstract: Harbor emissions represent a small part of ship emissions in total, but they are significant because large port areas can be found in densely populated areas like London, Athens, Istanbul, Rotterdam and St. Petersburg. Harbor emissions should be taken into account in the emission models in order to see the effects of new regulations on the urban air quality. Additional challenges arise from different operational modes of ships; port maneuvers with low engine loads may lead to large variations in emission factors normally applied as constants. Low engine loads have a significant impact on emissions of particulate matter and carbon monoxide. Voluntary speed reduction during voyages (slow steaming), which has been presented as an option to reduce greenhouse gas emissions, can also lead to abnormally low engine loads and increased emissions of other pollutants. The new sulphur restrictions in the Emission Control Areas, like the Baltic Sea and the North Sea, significantly change the way how emissions of ship traffic should be modeled. New sulphur directive (EC/2005/33) requires the vessels to use low sulphur fuel while at berth in the EU area starting from 1st of Jan 2010. Amendments to MARPOL Annex VI of the International Maritime Organization only allow the use of marine fuels which have less than 1.0 % sulphur (w/w) in SO_x Emission Control Areas as of July 1st 2010. These changes will reduce the sulphur emissions from ships and should be accounted for in the emission inventories.

Key words: *Ships, particulate matter, exhaust emissions, marine traffic, Automatic Identification System, AIS*

INTRODUCTION

Emissions from the transport sector are increasing significantly because of the traffic growth. Emissions restrictions concerning cars (EURO I-VI) have been in force for quite some time and aviation sector has recognized its contribution to global emissions. Regulations concerning air emissions of ship traffic have been excluded from i.e. climate negotiations but the public pressure to include shipping sector in emission reduction actions is mounting. In October 2008 the 58th Marime Environoment Protection Committee of the International Maritime Organization revised the MARPOL Annex VI (1998) regulating the air emissions of ship traffic, which now contains gradual moves towards the use of low sulphur fuel on a global level. With the revision of IMO Marpol Annex VI it became possible to designate geographical areas as Emission Control Areas (ECA) of NOx. Similar designation for SO_x already exists in the Baltic Sea (05/2006-), North Sea/English Channel (11/2007), North American waters (08/2012-) and Caribbean (01/2014-). Both SO_x and NO_x emissions will be regulated in North American and Caribbean ECAs, whereas only SO_x rules are enforced in other ECAs. This is expected to change when NECA status will be applied for the Baltic and North Sea areas in the future.

Shipping sector inside the ECAs are facing strict limits for marine fuel sulphur content (<0.1 w/w % sulphur), which inevitably leads to increased costs for transport. At the same time, ships in EU harbours are obliged to use low sulphur fuel during their harbour visits starting from 1st of January 2010. The 0.1 % SECA requirement will be in force as of January 2015 whereas the current maximum level is 1.0 %. These regulatory changes should be reflected in exhaust emission inventories of SO_x and PM, respectively.

Global Positioning System (GPS) is used in vessel navigation. Several navigation aids, like the Automatic Identification System (AIS), utilize GPS in automatic position reporting required by the IMO Safety Of Life At Sea (SOLAS) convention (IMO, 1980). This facilitates the real-time tracking of marine traffic with unprecedented accuracy, limited only by the accuracy of GPS, and enables the construction of ship emission inventories based on real vessel movements and travel speeds. This removes a significant source of uncertainty from the ship emission estimation, which has been greatly limited by the lack of activity data. In addition to AIS data, detailed knowledge of each vessel must be at hand; its physical dimensions, engine setup, hull form, fuel sulphur content, installed abatement techniques and more need to be known for every vessel in order to produce realistic emissions estimates for each ship. The resistance of a vessel in water can be modelled taking all of these into account by the method described in this paper. This approach results in a temporally resolved ship emission inventories which can be applied locally, regionally or globally, if AIS data from the area in question is available. This approach was recently reported in Jalkanen et al. (2009; 2011) and a short description of the improved Ship Traffic Emission Assessment Model (STEAM) and its expansion to PM and CO as well as the application to the Baltic Sea is reported in this paper.

MATERIALS AND METHODS

The results of this paper are based on terrestrial AIS base station network maintained by the Baltic Sea states and covering the Baltic Sea in its entirety. Over 250 million positional updates from ships sailing the Baltic Sea are collected annually and analyzed to construct a regional ship emission inventory. Position reports for fast moving vessels are sent every two seconds, whereas ship in port will update their position every three minutes. This leads to tens of thousands positional updates for vessels with regular schedule, which indicate the actual movements of ships. Technical data for 46 000 vessels are currently included in the internal STEAM database, which is collected from engine manufacturers, ship owners and commercial sources.

Emission factors, load dependency and multi-engine setups

The emissions of CO and PM are very dependent on the operation mode of the engine and the fuel type used. For this purpose, an engine load dependent emission factors were introduced in the revised model version instead of the fixed emission factors usually applied to study ship emissions. The load dependent emission factors are of special importance for harbour emission modelling, because engine loads can be quite different from those used during voyages. Emission factors of PM must take the effect of fuel sulphur content into account. This has a significant impact on hydrated SO4 fraction of particulates, whereas the effect on other sub components of PM may be smaller or unchanged.

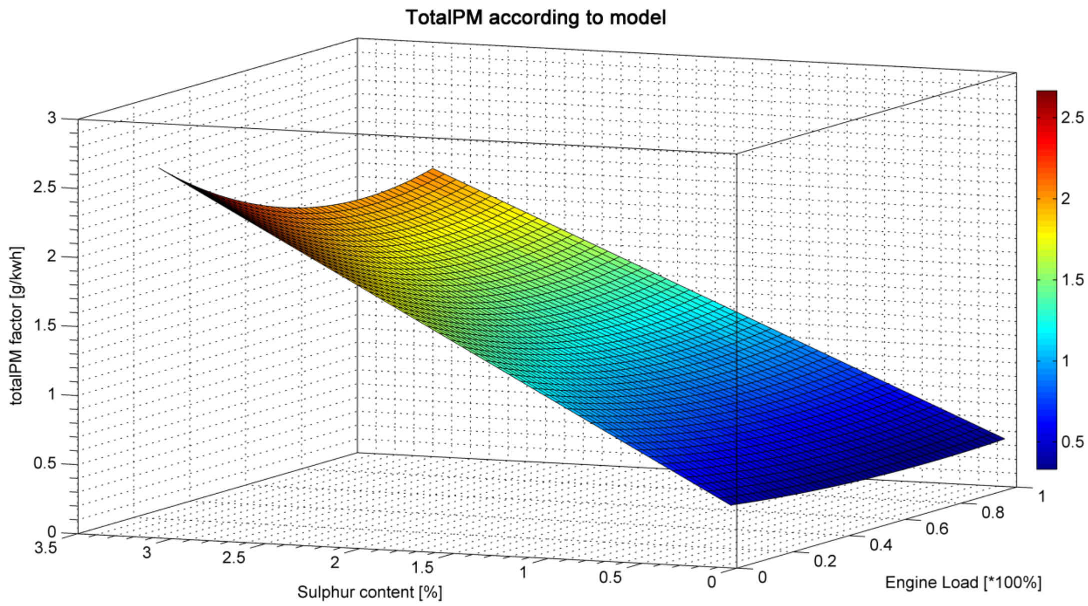

Figure 10. Emission factor for PM as a function of engine load and fuel sulphur content. Taken from Jalkanen et al., 2011

This approach allows for studies of slow steaming, or vessels voluntarily decreasing speed, to conserve fuel and reduce emissions and their impacts on emissions. Emissions and specific fuel oil consumption will increase if marine diesel engines are operated outside the optimum working range of the engine. This effect is currently covered in STEAM as well as the impact of slow steaming in cases of multi-engine setups. In case of multiple engines, those which are not necessarily required can be switched off and the engine load is balanced among the operational engines. This is also covered and STEAM uses a dynamical load balancing scheme to calculate the effect on emission factors and the amount of fuel used. Figure 1 illustrates the variability of PM emission factor as a function of engine load and fuel sulphur content. PM emission factor is a linear function of sulphur content according to Buhaug et al. (2009) and the dependency on engine load follows a similar curve as the specific fuel oil consumption.

RESULTS

Emissions from Baltic Sea shipping peak during the summer months. This is also the season when the largest number of ships can be observed in the area. Amounts of SO_x and PM underwent a significant decrease in May 2006 because of the stringent requirements for the sulphur content of marine fuels. This affected the emitted levels of SO_x, but also the hydrated SO4.

The overall trend of emissions from Baltic Sea shipping is increasing, but the impact of the SECA fuel sulphur regulations can be seen in April-May 2006 (Figure 2). This decreased the SO_x emissions as well as the PM emissions (Figure 3). However, without the SECA, PM emissions from ships would still be on the increase. Elimination of sulphur from marine fuels will not eradicate the PM emissions completely because there are components not containing sulphur (Winnes and Fridell, 2010; Fridell et al., 2008; Cooper, 2003; Kasper et al., 2007; Buhaug et al., 2009). The PM emissions should be modeled by sub components because health and climate effects may be different for various sub components of PM. The recession in Q4/2008-Q3/2009 had only slight impact on ship emissions and annual totals of 2008 and 2009 show about two percent decrease in emissions. Emissions from specific ship types (Containerships, Vehicle carriers, Bulk Cargo) showed largest decrease whereas RoPax ferries with regular schedule were almost unaffected by the economic downturn. This is consistent with the cargo statistics of Eurostat (2010). The overall effect on Baltic Sea ship emissions was small and the emission levels of ships in 2010 are already larger than before the recession.

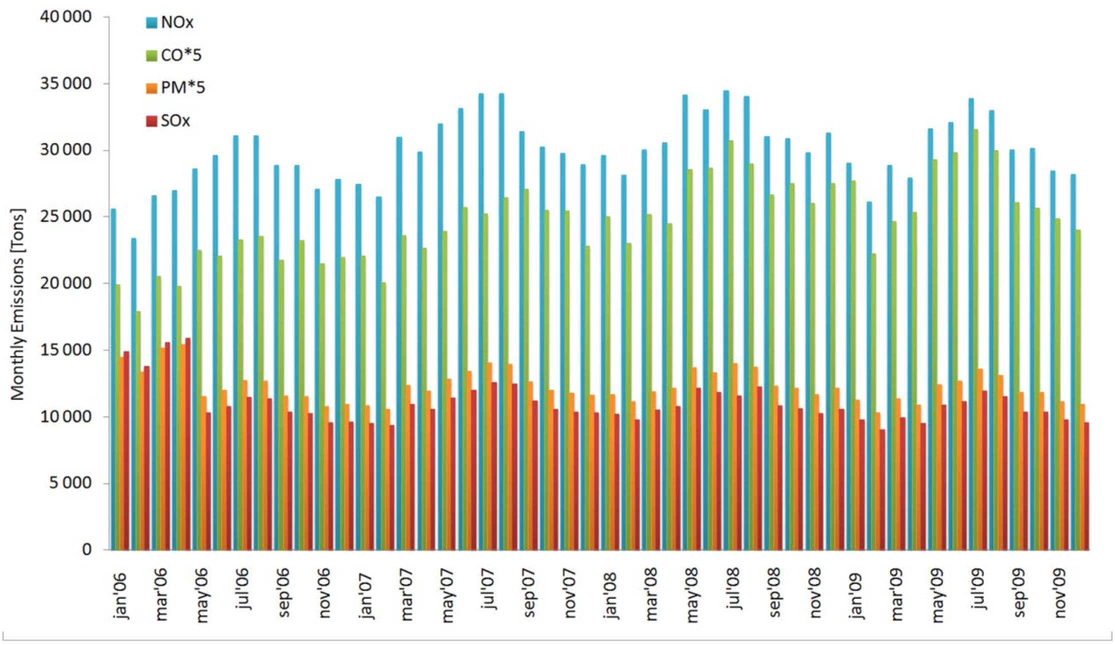

Figure 11. Emissions from Baltic Sea shipping in 2006-2009. Note: SO_x Emission Control Area requirements became effective May 2006.

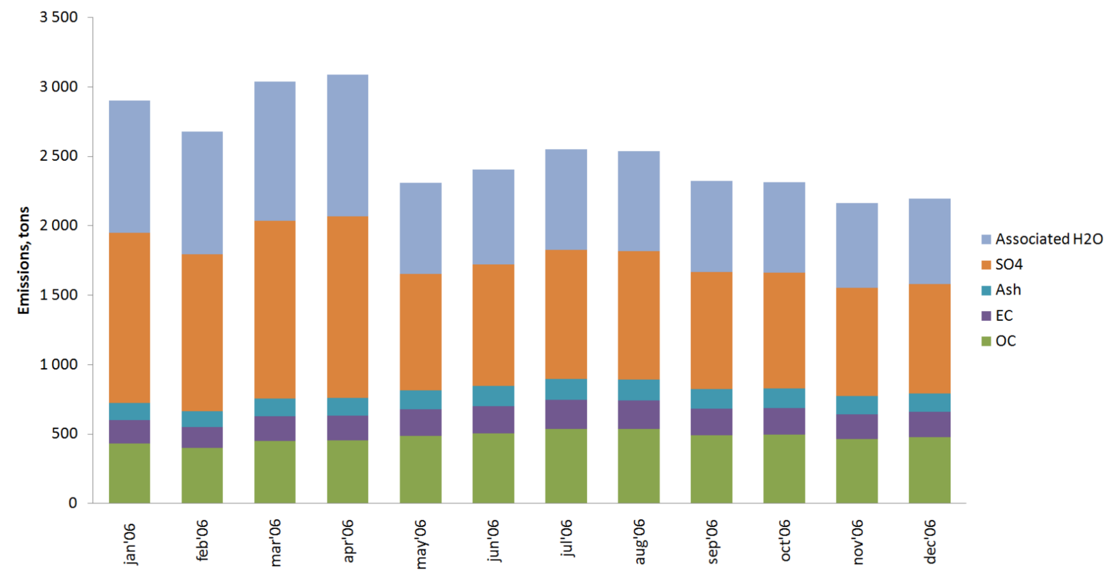

Figure 12. Emissions of PM from Baltic Sea shipping in 2006. Note the change in Apr-May 2006 because of sulphur reduction in fuel.

The geographical distribution of CO emissions reflects the engine load changes during speed changes in vessel movement. Instead of applying constant emission factors, load dependent emissions are used (Figure 4) which shows as large emissions near harbours and densely trafficked areas. The application of constant CO emission factors in exhaust emission modelling should be avoided because this will lead to inaccuracies near port areas. Normally, during steady state loads, marine engines are not a significant source of CO. The strong dependency of CO emissions on engine load changes as well the port emissions should be taken into account in the construction of regional emission inventories.

SUMMARY

Both PM and CO are dependent on engine load and PM emissions vary greatly as a function of the fuel sulphur content whereas CO is sensitive to the changes in engine operation. Large marine diesel engines do not emit much CO during steady conditions, but may do so during variable loads. This variability has a large impact on local scale emissions in port areas where the operation mode of the engines is quite different from those during voyages. In addition different fuels may be used in port areas, which will have an impact on the emitted composition and the amount of PM. These factors should be taken into account in the ship emission inventories because they should reflect the relevant policy changes in order to produce realistic information for the air quality modelling.

Climate and health effect responses to ship PM emissions may be connected to different components of PM, in case of which there is a growing concern regarding the increased amount of black carbon in high latitudes. This already indicates that future inventories of ship emissions should differentiate PM components specifically.

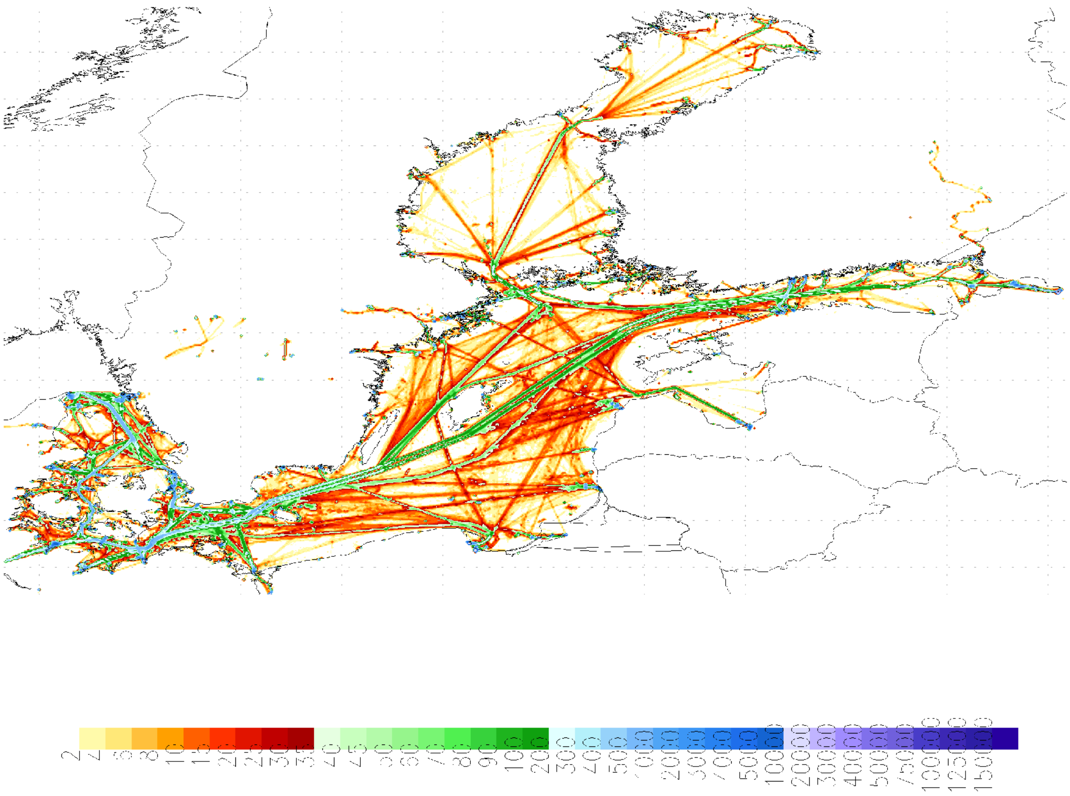

Figure 13. CO emissions from Baltic Sea shipping in Jan 2009. Emissions given in kilograms per grid cell of 1.7 by 3.5 km.

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