SEARS

Shipping Emissions to Atmosphere Reporting Service

D1 – User requirements and involvement

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Author(s)	:	Ágnes Mika (BMT ARGOSS) Andreas Richter (IUP) Michel van Roozendael (BIRA) Isabelle de Smedt (BIRA) Yu Huan (BIRA)
Approved by	:	Leslie Gale (BMT ARGOSS)
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Summary

The first deliverable from the SEARS project, document "D1 – User requirements and involvement" is dedicated to establishing the user requirements which form the basis of the study plan.

The user requirements were established during a meeting between EMSA and the SEARS team in April, 2012. The SEARS study plan was modified after the meeting in order to match EMSA's requirements as closely as possible.

In addition to establishing the user requirements, the document also provides the relevant background information, including:

- An overview of regulations on air pollution from shipping;
- EMSA's mandate concerning air pollution from shipping;
- The state of the art on observing air pollution from shipping using satellites.

This document sets the basic guidelines for the SEARS project and it is meant to be consulted regularly during the project to ensure the fulfilment of the user requirements.

Contents

List of abbreviations

EMSA	European Maritime Safety Agency
ESA	European Space Agency
GOME	Global Ozone Monitoring Experiment
IMO	International Maritime Organization
MARPOL	International Convention for the Prevention of Pollution from Ships
OMI	Ozone Monitoring Instrument
SCIAMACHY	SCanning Imaging Absorption spectroMeter for Atmospheric CartograpHY
SEARS	Shipping Emissions to Atmosphere Reporting Service (project)
SECA	Sulphur Emission Control Area

1 Introduction

Although transport by ships is the most energy efficient way of moving freight, a number of factors make air pollution from shipping a problem for the environment:

1. Typical fuels used by ships in international waters are much less clean than that burnt in land-based engines. In fact, the dirtiest fraction of refined oil is burned as bunker oil, leading to much larger emissions of soot, NO_x and SO_2 per amount of fuel used than for other sources of transportation (see e.g., EPA, 2009).

2. The volume of goods transported by ships is still increasing as a result of continued globalisation of industry and trade. Therefore, the relative importance of shipping emissions is expected to grow during the coming years, in particular as environmental regulation on land leads to a decrease in other emission sources (see e.g., Corbett et al., 2007a).

3. Nearly 70% of ship emissions occur within 400 km of land (see e.g., Corbett et al., 1999; Eyring et al., 2005; Endresen et al., 2003). Shipping constitutes the largest single source of acidifying and eutrophying fallout over many countries in Europe. It also contributes significantly to raising the levels of health-damaging fine particles and ozone, significantly affecting the population of (esp.) coastal cities (see e.g., Capaldo et al., 1999; Nel, 2005; Kaiser, 2005; Corbett et al., 2007b).

4. The possible extension of shipping lanes into the Arctic poses the risk of pollution in this pristine and delicate region. For a comprehensive review on the potential effects of shipping on the Arctic environment see e.g., PAME (2009).

In response to the growing problem of air pollution from shipping, a number of regulations have been introduced in European and US waters (see section 2 for a detailed description). Enforcing legislation and being able to quantify the effects of spending tax payers' money to combat pollution requires an efficient method for the monitoring of ship emissions.

The ESA-funded SEARS (Shipping Emissions to Atmosphere Reporting Service) project aims at assessing the potential of current and future satellites towards becoming an aid for EMSA in the monitoring of ship emission and the enforcement of legislation. As a first step, a meeting was held between EMSA and the SEARS team where EMSA's requirements on a monitoring system were established. Their requirements are in contrast with the current capabilities of satellite instruments for monitoring atmospheric composition and a course of action for the study was agreed upon. This document is dedicated to summarising the requirements of EMSA.

The document is set up as follows:

- Section 2 provides an overview on the current and upcoming regulations related to ship emissions.
- Section 3 describes EMSA's mandate in relation to air pollution from shipping.
- In section 4 results from the scientific literature concerning the identification of shipping emissions using satellite observations are summarised.
- In section 5, the requirements of EMSA and their involvement in the project are summarised.

2 Overview of regulations on air pollution from shipping

2.1 International regulations

The International Maritime Organisation (IMO) is responsible for the global regulation of air pollution from ships. The regulations are contained in the "International Convention on the Prevention of Pollution from Ships", known as MARPOL 73/78. On 27 September 1997, the MARPOL Convention has been amended by the "1997 Protocol", which includes Annex VI, "Regulations for the Prevention of Air Pollution from Ships". MARPOL Annex VI sets limits on NO_x and SO_x emissions from ship exhausts, prohibits deliberate emissions of ozone depleting substances and regulates shipboard incineration and the emissions of volatile organic compounds from tankers.

2.1.1 SO_x emissions

MARPOL Annex VI entered into force on 19 May 2005. Regulations 14 and 18 define methods of controlling SO_x emissions on a global basis and include specific regulations in specific areas called Sulphur Emission Control Areas (SECAs). The aim of the legislation is to reduce acidification by limiting the SO_x emissions from ships. This is to be achieved by setting a limit on the sulphur content in marine fuels as follows: the sulphur content on any fuel used on board a ship must not exceed 4.5% by weight. The sulphur content on any fuel used on board a ship operating in a SECA must not exceed 1.5% by weight.

Alternatively, an exhaust gas cleaning system or other approved technological method of reducing the total SO_x emissions from main and auxiliary engines and boilers to a maximum of 6.0 g SO_x/kWh when operating in a SECA can be used. Controls are also set on effluent discharges from such cleaning systems.

Details of the change over operation from high sulphur fuel to low sulphur fuel when entering a SECA are to be recorded in a log book and also when changing over to high sulphur fuel when leaving a SECA for an uncontrolled area. The procedure is to ensure that all fuels exceeding the 1.5% sulphur limit are flushed out of the fuel system prior to entering a SECA. Currently there are two SECAs: the Baltic, established in August 2006 and the North Sea, established in 2007.

In October 2008, IMO adopted amendments to Annex VI which strengthen the requirements on the permitted sulphur levels in ship fuels. The amendments pave the way towards a progressive global reduction of SO_x, NO_x and particulate matter emissions. The amendments entered into force on 1 July 2010. Under the revised MARPOL Annex VI, beginning with 1 January 2012, the global sulphur cap is reduced to 3.5% from the current 4.5%.

2.1.2 NO_x emissions

With respect to NO_x emissions, MARPOL Annex VI includes progressive reductions of such emissions from marine diesel engines. A "Tier II" emission limit applies for engines installed on or after 1 January 2011. Marine diesel engines installed on or after 1 January 1990 but prior to 1 January 2000 are required to comply with "Tier I" emission limits if an approved method for that engine has been certified by an Administration.

The revised measures are expected to lead to a significant reduction of premature deaths caused by air pollution by 2020 and of losses of biodiversity related to acidification and eutrophication.

2.2 European regulations

The EU Directive 1999/32/EC (amended by Directive 2005/33/EC) serves as the EU legal instrument for incorporating the aforementioned MARPOL Annex VI provisions.

In addition, the Directive also introduced a 0.1% maximum sulphur requirement for fuels used by ships at berth in EU ports from 1 January 2010.

The EU Directive 2005/33/EC does not contain provisions to regulate ship emissions of NO_x or PM.

2.3 Upcoming regulations

The revised MARPOL Annex VI envisages a further, progressive, reduction of the global sulphur cap from 3.5% to 0.5% by 1 January 2020. However, this is a subject of a feasibility review which should be completed by 2018.

A further reduction of the limits applicable in SECAs to 0.1% (from the current 1%) becomes effective on 1 January 2015.

With respect to NO_x emissions, a more stringent "Tier III" emission limit applies for engines installed on or after 1 January 2016 operating in SECAs.

3 EMSA's mandate concerning air pollution from shipping

The legal framework for EMSA's responsibilities regarding pollution from shipping is set by the European Parliament and Council Directive 2005/35/EC of 7 September 2005 which was amended by Directive 2009/123/EC of 21 October 2009. This Directive on "ship-source pollution and on the introduction of penalties, including criminal penalties, for pollution offences", states that the European Maritime Safety Agency shall:

a.) work with the Member States in developing technical solutions and providing technical assistance . . . in actions such as tracing discharges by satellite monitoring and surveillance;

b.) assist the Commission in the implementation of this Directive, including, if appropriate, by means of visits to the Member States, in accordance with Article 3 of Regulation (EC) No 1406/2002.

The Directive recognises that EMSA has a key role to play in working with the Member States in developing technical solutions and providing technical assistance relating to the implementation of this Directive and in assisting the Commission in the performance of any task assigned to it for the effective implementation of the Directive.

EMSA is closely involved in the air pollution work within the Community. This involvement includes organising workshops, participation in the inter-service work within the Commission as well as regularly providing expert (technical) opinions to the Commission.

EMSA has prepared an overview regarding the enforcement of Directive 1999/32/EC on marine fuels. The report includes the results of a sampling program where the sulphur content of the fuel carried by various bunker stations was tested by the Member States. The report also includes study results related to the quality of fuel bunkered by ships.

In order to foster the development of alternative fuels and to contribute to the discussion on the impact of the more stringent SECA requirements from 2015, EMSA co-organised two workshops with the main industry stakeholders to identify best practices and bottlenecks in the development of LNG-propelled ships.

EMSA was closely involved in preparing the Commission decision on an equivalency methodology to allow LNG tankers to burn boil-off gas when at berth instead of using fuel with 0.1% sulphur content. The Commission decision was taken in December 2010.

EMSA has also carried out an analysis of the existing studies regarding the implications of new sulphur requirements (0.1% in SECA by 1 January 1015) on the traffic within the SECA-areas. The resulting technical report also lists alternatives for reaching the limits introduced by the 2008 MARPOL amendments issued in 2010. The report was presented in January 2011 at the EU Maritime Directors Meeting.

4 State of the art on observing ship emissions from satellites

At present, there are no globally applicable methods available for the monitoring of ship emissions to air. Such a tool would be vital for enforcing regulations and for assessing the effectiveness of shipping emission measures. Satellites monitoring the composition of the atmosphere also measure constituents relevant for ship emissions among which NO_2, SO_2 and HCHO (formaldehyde). Previous studies have been successful in identifying ship tracks in satellite data. In this section, an overview of the relevant scientific literature is provided to illustrate the current capabilities of satellite data in detecting ship emissions.

4.1 NO_x emissions

The Global Ozone Monitoring Experiment (GOME) was launched in 1995 and provided the first global view of tropospheric NO_2. Nine years later, Beirle et al. (2004) realised that NO_2 from ships can actually be observed in global maps derived from GOME data. They detected a line of enhanced NO_2 concentrations from India to Indonesia that matched the position of ship tracks. No other ship tracks could be detected, mainly due to the large pixel size of GOME ($320\times40\,km^2$). At the same time, more NO_2 from ship tracks were found in data from the SCIAMACHY (SCanning Imaging Absorption spectroMeter for Atmospheric CartograpHY) instrument launched on ENVISAT in 2002 (Richter et al., 2004). These data have better spatial resolution ($60\times30\,km^2$), enabling the detection of shipping NO_2 also in the Red Sea, the Persian Gulf and from Indonesia towards Japan and China.

OMI (Ozone Monitoring Instrument), launched in 2004, has even better spatial resolution and much better coverage which enabled the observation of NO_2 from ships in the Mediterranean Sea (Marmer et al., 2009).

The latest UV/visible instrument providing NO_2 data is GOME-2, launched on Metop-1 in October 2006. Although GOME-2 has a reduced spatial resolution ($80\times40\,km^2$) compared to OMI and SCIAMACHY, the high signal-to-noise ratio of these data resulted in the detection of elevated NO_2 concentrations over shipping lanes not identified in earlier studies (Richter et al., 2011). A line of enhanced NO_2 concentrations was observed around Europe towards the Mediterranean and all the way to the Red Sea. The shipping lanes from Europe around Africa towards Indonesia and in the Black Sea towards the Bosporus were also identified.

Apart from the identification of shipping lanes in satellite data, the evolution of NO_2 concentrations over time was also investigated. Konovalov et al. (2008) derived linear NO_2 trends from GOME and SCIAMACHY NO_2 data over Europe and found a decadal increase in shipping emissions over the Mediterranean Sea. Franke et al. (2009) investigated the temporal evolution of the NO_2 shipping signal from India to Indonesia using data from all available instruments. They found large seasonality, an upward trend and inter-annual variability. Recently, de Ruyter de Wildt et al. (2012) have used all available data from all the four aforementioned satellites to detect non-linear trends over major shipping lanes in the Mediterranean Sea, the Red Sea, the Indian Ocean and the South Chinese Sea. The results correlate closely with shipping statistics and international trade volumes.

A common feature of all the studies is that a large number of images had to be used (averages over one month or longer) to achieve appropriate signal-to-noise ratios for detecting shipping lanes and evaluating trends.

4.2 SO_2 emissions

Of particular interest are ship emissions of SO_2 as SO_2 contributes to particulate matter formation causing adverse health effects and it causes acidification leading to a loss of biodiversity a.o. As shipping fuel often has high sulphur content, large amounts of SO_2 are emitted.

Unfortunately, the sensitivity of satellite observations to SO_2 close to the surface is limited as a result of strong Rayleigh scattering and ozone absorption. SO_2 signals have only been detected so far from strong sources such as volcanic eruptions, smelting facilities and the largest power plants. Shipping SO_2 signals have not been detected from space to date.

4.3 VOC emissions

Formaldehyde (HCHO) is an important indicator of volatile organic compound (VOC) emissions from a.o. combustion sources. Additional signals attributed to ship emissions were reported by Marbach et al. (2009) who, using GOME data, detected an enhancement in formaldehyde in the area where also NO_2 is enhanced around the shipping lane between India and Indonesia. The formaldehyde distribution is somewhat more extended spatially, probably because of secondary formation and longer atmospheric lifetime of formaldehyde. However, the signal is also more difficult to detect and no other formaldehyde enhancements have been reported in the literature so far.

5 User requirements and involvement

In order to establish what kind of shipping emission products would be useful for EMSA in fulfilling its mandate, a meeting was held in April, 2012 between the SEARS team and EMSA's representatives.

During the meeting, EMSA explained to the SEARS team the current directives and legislations pertinent to shipping emissions (see also section 2). In order to enforce the legislations and to measure their effectiveness, EMSA would need a tool for monitoring shipping emissions. The currently available in-situ measurement techniques are cumbersome and can only be carried out in ports or during dedicated fly-bys. Emissions from ships in transit are not monitored on a regular basis.

EMSA is primarily interested in a means of monitoring SO_2 emissions in European waters. Identifying SO_2 emissions from individual ships would provide a tool for legislation enforcement. A comprehensive SO_2 trend analysis in SECAs would be valuable for measuring the effectiveness of legislation. However, as described in section 4, ship SO_2 emissions have never been observed from satellites. Even in the case of NO_2 it is not possible to distinguish emissions from individual ships given the relatively low resolution of satellite data and the signal-to-noise ratio.

NO_x emissions are regulated via engineering standards for vessel engines. The enforcement of the legislation happens in ports by checking the engine specifications, therefore EMSA is less interested in a monitoring tool for NO_x emissions.

There is a clear contrast between EMSA's needs and the capabilities of current satellite instruments. Following a brainstorming, a list of products and study areas were identified which would both benefit EMSA and are feasible given the current capabilities of satellite instruments. The resulting user requirements are summarised in section 5.1. The degree of involvement of EMSA in the SEARS project is described in section 5.2.

5.1 User requirements

5.1.1 UR-01 – Shipping NO_x emissions

Even though current regulations on NO_x emissions from shipping are in the form of engineering standards, estimates of NO_x emissions from shipping could still be useful for EMSA. Such a product can help with the political decision making process, can be used to estimate trends and to identify over-polluted areas. Given EMSA's European mandate, NO_x emission products should be developed for the major shipping lanes in European territorial waters.

UR-01: Deliver NO_x emission estimates for major European shipping lanes.

5.1.2 UR-02 – Shipping SO_2 emissions

EMSA's main interest is in the monitoring of SO_2 emissions. However, as described before, SO_2 emissions from shipping emissions have never been observed from satellites. EMSA is interested in knowing what the detection limits of satellites are and if detecting shipping SO_2 emissions are at all possible.

UR-02: Carry out a feasibility study on the detection of SO_2 emissions from shipping.

5.1.3 UR-03 – Capabilities of upcoming instruments

There are several upcoming satellites dedicated to the monitoring of atmospheric composition, inc. the Sentinel-5 precursor, Sentinel 4, and Sentinel 5. EMSA is interested in knowing what can be achieved with these instruments with respect to the detection of shipping emissions.

UR-03: Carry out a study on the capabilities of upcoming instruments.

5.2 Degree of involvement

The degree of involvement of EMSA in the project was also discussed during the aforementioned meeting. EMSA has agreed to collaborating with the SEARS team in the following areas:

- Contribute to establishing the study requirements (presented in this report);
- Review reports and provide input where needed;
- Take part in the milestone meetings.

References

Beirle, S., Platt, U., von Glasow, R., Wenig, M., and Wagner, T.: Estimate of nitrogen oxide emissions from shipping by satellite remote sensing, Geophysical Research Letters, 31, doi:10.1029/2004GL020312, 2004.

Capaldo, K. P., Corbett, J. J., Kasibhatla, P., Fischbeck, P., and Pandis, S. N.: Effects of ship emissions on sulphur cycling and radiative climate forcing over the ocean, Nature, 400, 1999.

Corbett, J. J., Fischbeck, P. S., and Pandis, S. N.: Global nitrogen and sulfur emissions inventories for oceangoing ships, Journal of Geophysical Research, 104, 3457–3470, 1999.

Corbett, J. J., Wang, C., and Winebrake, J. J. aned Green, E.: Allocation and forecasting of global ship emission, Tech. Rep. 26, Clean Air Task Force and Friends of the Earth International, Boston, MA, 2007a.

Corbett, J. J., Winebrake, J. J., Green, E. H., Kasibhatla, P., Eyring, V., and Lauer, A.: Mortality from ship emissions: a gloal assessment, Environmental Science & Technology, 41, 8512–8518, 2007b.

de Ruyter de Wildt, M., Eskes, H., and Boersma, K. F.: The global economic cycle and satellite-derived NO_2 trends over shipping lanes, Geophysical Research Letters, 39, L01 802, doi:10.1029/2011GL049541, 2012.

Endresen, O., Soergaard, E., Sundet, J. K., Dalsoeren, S. B., Isaksen, I. S. A., Berglen, T. F., and Gravir, G.: Emission from international sea transportation and environmental impact, Journal of Geophysical Research, 108, 2003.

EPA: AP-42, Compilation of Air Pollutant Emission Factors, Volume 1: Stationary Point and Area Sources, United States Environmental Protection Agency, 5 edn., `http://www.epa.gov/ttnchie1/ap42/ch01`, 2009.

Eyring, V., Köhler, H. W., van Aardenne, J., and Lauer, A.: Emissions from international shipping: 1. The last 50 years, Journal of Geophysical Research, 110, D17 305, 2005.

Franke, K., Richter, A., Bovensmann, H., Eyring, V., Jöckel, P., Hoor, P., and Burrows, P.: Ship emitted NO_2 in the Indian Ocean: comparison of model results with satellite data, Atmospheric Chemistry and Physics, 9, 7289–7301, 2009.

Kaiser, J.: EPIDEMIOLOGY: Mounting Evidence Indicts Fine-Particle Pollution, Science, 307, 1858a–1861, 2005.

Konovalov, I. B., Beekmann, M., Burrows, J. P., and Richter, A.: Satellite measurement based estimates of decadal changes in European nitrogen oxides emissions, Atmospheric Chemistry and Physics, 8, 2623–2641, 2008.

Marbach, T., Beirle, S., Platt, U., Hoor, P., Wittrock, F., Richter, A., Vrekoussis, M., Grzegorski, M., Burrows, J. P., and Wagner, T.: Satellite measurements of formaldehyde linked to shipping emissions, Atmospheric Chemistry and Physics, 9, 2009.

Marmer, E., Dentener, F., Aardenne, J. v., Cavalli, F., Vignati, E., Velchev, K., Hjorth, J., Boersma, F., Vinken, G., Mihalopoulos, N., and Raes, F.: What can we learn about ship emission inventories from measurements of air pollutants over the Mediterranean Sea, Atmospheric Chemistry and Physics, 9, 6815–6831, 2009.

Nel, A.: ATMOSPHERE: Enhanced: Air Pollution-Related Illness: Effects of Particles, Science, 308, 804–806, 2005.

PAME: Arctic Marine Shipping Assessment 2009 Report, Tech. rep., Arctic Council, 2009.

Richter, A., Eyring, V., Burrows, J. P., Bovensmann, H., Lauer, A., Sierk, B., and Crutzen, P. J.: Satellite measurements of NO_2 from international shipping emissions, Geophysical Research Letters, 31, doi: 10.1029/2004GL020822, 2004.

Richter, A., Begoin, M., Hilboll, A., and Burrows, J. P.: An improved NO_2 retrieval for the GOME-2 satellite instrument, Atmospheric Measurement Techniques, 4, 1147–1159, doi:10.5194/amt-4-1147-2001, 2011.