Concept for a project on the climate impact of shipping

prepared by
Robert Sausen[a], Christos Zerefos[b], Ivar Isaksen[c], Veronika Eyring[a], David S. Lee[d]

[a] Deutsches Zentrum für Luft- und Raumfahrt (DLR), Institut für Physik der Atmosphäre, Oberpfaffenhofen, D-82234 Wessling, Germany; email: robert.sausen@dlr.de
[b] Academy of Athens, 28 Panepistimiou Avenue, 10679 Athens, Greece
[c] Center for International Climate and Environmental Research–Oslo (CICERO), P.O. Box 1129 Blindern, N-0318 Oslo, Norway
[d] Centre for Air Transport and the Environment (CATE), Department of Environmental and Geographical Sciences, Manchester Metropolitan University, Chester Street Manchester M1 5GD, United Kingdom

1. Rationale

While the Kyoto gas emissions from most sectors have been decreasing or only slightly increasing since 1990 in the European Union, the emissions of CO_2 equivalent from the transport sector[e] exhibit a strong increase of 26% from 1990 to 2006 in EU-15, not including aviation and marine bunkers fuels. (This is also true for many other countries outside.) The relative increase of aviation and shipping (bunker fuels) was even larger: 102% and 61%, resp., in EU-15. The faction of total equivalent CO_2 emissions in EU-15 from transport, aviation bunkers and marine bunkers rose from 20.0%, 2.1% and 2.9%, resp., in 1990 to 23.1%, 3.3% and 4.4% in 2006[f]. It is this increase, which brought transport, and in particular aviation and shipping, in to the focus of policymakers and interest groups.

Beyond these environmental impact, which are mainly related to the burning of fossil fuels, many other environmental effects are due to transport: Transport emissions impact climate by the emission of gases and particles beyond the long-lived Kyoto gases: (1) by emission of further greenhouse gases, such as water vapour, which is of particular importance in the case of aviation, (2) by the emission of precursors of greenhouse gases, such as NOx which in most cases leads to formation of additional ozone; (3) by the emissions of particles (e.g., soot) or precursors of particle (e.g., SOx); (4) by triggering of additional clouds and modifying natural clouds (e.g., ship tracks). In addition to the climate effects transport emissions have inverse effect on air quality, e.g., due to additional ozone formation (from NOx and unburned hydrocarbon emissions) and due to enhanced abundances of aerosol (emission of particles and precursors of particles). Both enhanced ozone and aerosol levels negatively impact human health and have further negative effects such as acid rain, impact on constructions, or reduced PH levels of the oceans.

2. Focus on shipping

While the climate impact of aviation has been a science topic for nearly two decades and the impact of land transport on air quality has been studied even for longer period, shipping only recently gain more interest from science, potentially because ships are not so visible than other modes of transport for the vast majority of the population. The large fraction of NOx and SO_2 emitted from ships, in addition to that the emissions occur in pristine regions make

[e] As aviation and bunker fuel are not included and as nation aviation and shipping only play a minor role in EU, these transport emissions are mainly from land transport.
[f] Note that aviation and shipping still are small fraction of the total emissions, i.e., these sectors may benefit from an open emission trading system

ship emissions of short-lived compounds of particular interest. Therefore, it is necessary to devote more resources to explore the environmental impacts of shipping in greater detail and weigh the shipping effects to those from other sector of human activity, in particular from other modes of transport. Furthermore, shipping is a sector where the increase in emissions over the last decade has been particularly large.

3. On-going assessments

Currently several assessment of the climate impact of shipping are being performed. Within the EU funded Specify Support Activity ATTICA[g] the impact of different transport modes on climate is assessed based on the results of the EU funded Integrated Project QUANTIFY[h] and further information published in science and engineering journals. The ATTICA assessments are currently in the review process. Among these is an assessment of the shipping effects: Eyring et al., 2009[i].

Additionally, the IMO study on greenhouse gas emissions from ships has been updated recently (Buhaug et al., 2008[j]). The objectives of Phase 1 of this study have been (1) to undertake an assessment of present day CO_2 emissions from international shipping; (2) to estimate future CO_2 emissions from international shipping emissions towards 2050; (3) to compare CO_2 emissions from shipping with other modes of transport; and (4) to assess the impact of CO_2 emissions from shipping on the climate. This report will be followed by a Phase 2 report which will address emissions and climate impacts of other greenhouse gases than CO_2 and the possibilities and mechanisms for reductions in GHG emissions.

These assessment reports summarize the present state of the art but leave many questions open, which would provide important information for decision making in politics.

4. Open questions

Corning the contribution of shipping to climate change and the impact of shipping on local and regional air quality, questions like the following need to be answered:

1. *What are the critical loads/air quality in costal areas?* As both, emissions from shipping and emissions from sources on land contribute to the aerosol load and to air quality, we need to know in particular emissions from shipping with significantly smaller errors. Furthermore, additional uncertainty exists with respect to aerosol modelling (both aerosol dynamics and transport of aerosol) and with respect modelling to heterogeneous chemistry in the marine boundary layer and in the ship plumes.
2. *How large is the radiative forcing from indirect sulphate?* Presently, several estimates of the radiative forcing (RF) from indirect sulphate, i.e., via cloud formation and modification, exists, which deviate by factor 3. We need to reduce the uncertainty in this negative RF, which is due to uncertainties in inventories of ship emissions and in representing clouds in climate models.

---

[g] http://ssa-attica.eu
[h] http://ip-quantify.eu
[i] Eyring, V, I.S.A. Isaksen, T. Berntsen, W.J. Collins, J.J. Corbett, O. Endresen, R.G. Grainger, J. Moldanova, H. Schlager, and D.S. Stevenson (2009): Assessment of Transport Impacts on Climate and Ozone: Shipping. Submitted to *Atmos. Environ*.
[j] Buhaug, Ø.; Corbett, J. J.; Endresen, Ø.; Eyring, V.; Faber, J.; Hanayama, S.; Lee, D. S.; Lee, D.; Lindstad, H.; Mjelde, A.; Pålsson, C.; Wanquing, W.; Winebrake, J. J.; Yoshida, K., 2008: Updated Study on Greenhouse Gas Emissions from Ships: Phase I Report. International Maritime Organization (IMO) London, UK.

3. *What is the relative importance NOx-induced RF, positive from O_3 and an negative from CH_4?* Recent studies show that ratio of the CH_4 RF to the O_3 RF is larger for shipping than for other modes of transport (with a rather large model uncertainty). In order to better calculate the net effect on climate and to estimate the trade-off between the CO_2 and NOx effects, the uncertainty needs to be reduced. A further problem arises from the fact the impact on the CH_4 abundance is only indirectly determined (from estimates of the CH_4 live time), here a direct simulation of the methane chemistry (with flux boundary conditions) is necessary.
4. *How large are the efficacies for the various types of ship emissions?* We know from the aviation sector that the aviation induced climate change is not proportional to the respective radiative forcings (RFs), e.g.. aviation-induced ozone changes cause a temperature rise larger than would be expected from the corresponding RF, in contrary contrails cause a smaller temperature rise than would be expected from the corresponding RF. On global scale, this effect can be accounted for by the so-called efficacies, a kind of adjusting factor. The efficacies for the shipping effects are unknown so far, most probably they will differ from 1.
5. *What do the ship-induced climate change pattern look like?* As the shipping induced perturbations of the Earth's radiative budget exhibit quite a inhomogeneous spatial pattern (apart from the CO_2 and CH_4 related forcings), the resulting pattern in temperature change will differ from mode to mode. In order to know potential compensating effects among positive and negative RFs, we need to know these pattern, including their temporal evolution.
6. *What is the appropriate metric?* Currently, there is no consensus which metric would be most appropriate the weigh the effects of long-lived species (like CO_2 or CH4) and the effects arising from short-lived atmospheric perturbations (such as indirect cloudiness) on a common scale. Such knowledge is necessary for, e.g., an appropriate inclusion of non-Kyoto gases in emission trading. The situation becomes even more complicated if impacts on climate and air quality are to be compared.
7. *Which scenarios are appropriate to describe potential future developments of shipping?* The relative importance of the various shipping induced climate impacts depend on the future evolution of the corresponding emissions and their geographical distributions. Due to technological development, we cannot assume that all non-CO_2 emissions scale with CO_2 or fuel burn. Therefore suitable story lines are necessary in order to estimate the impact of shipping on future climate change. Furthermore, the different ship types have different traffic patterns and different growth rates (container transport growing particularly fast). This needs to be taken into account in estimates of future impact.

5. Tasks

In order to answer questions like those listed above (a) future project(s) should address the following topics:

1. *Revised emissions inventories*. Revised emission inventories, based on more information about actual routings and actual power settings, should be established. This would help to reduce the large uncertainty concerning the actual emissions by shipping and the pattern of geographical and temporal distributions of the emissions.[k]

[k] Geographical and temporal distributions of the emissions have a large impact on the associated radiative forcings and climate change.

2. *Development of scenarios of future emissions from shipping.* Revised emissions scenarios (incl. geographical and temporal distributions of the emissions), taking into account the differences in growth rate and traffic patterns for the different ship types, should be developed. These emission scenarios should be consistent with the IPCC scenarios of total anthropogenic emissions (incl. the background scenarios for the developments of population and economy) but they also should account for the various options to reduced ship emissions by technological, operational and regulatory means, e.g., the EU 20-20-20 policy or the. the new IMO standards.

3. *Effective emission indices.* Currently, large scale atmospheric models still lack of a commonly accepted parameterisations of the transformation and removal processes in the plume of ships (and in the near field), so-called effective emission indices. Here more measurements behind large vessels in different atmospheric background conditions are necessary. These measurements should form the bases for evaluating the various approaches towards effective emission indices.

4. *Impact on chemistry*. Large uncertainty exits with respect to primary ozone production on the on hand side, and methane destruction and secondary ozone destructions. Therefore global chemistry models need to be improved such that they become able to directly simulate the impact on methane[l], i.e. flux boundary conditions need to be implemented and model simulations extending over several decades (with variable meteorological conditions) are necessary. By means of these improved models the impact of various scenarios of ship emissions on the global chemistry will be simulated, potentially including the effect of effective emission indices.

5. *Impact on clouds.* Using the latest generation of atmosphere models, which include aerosol dynamics and improved cloud-aerosol interaction, the impact of ships emissions on cloudiness (cloud cover and cloud micro-physical and optical properties) should be simulated for various scenarios. Satellite observations of clouds should be analysed in order to provide some evaluation of the modelled cloud changes. Furthermore, a multi-year climatology of ship tracks is necessary.[m]

6. *Radiative forcing.* The radiative forcings (and the latitudinal-longitudinal-time dependent perturbations of the radiative fluxes) associated with the ship-induced changes in the atmospheric composition (gases and particles) and cloudiness should be calculated. The uncertainties in the radiative forcings need to be determined, taking interdependencies among the various components of the radiative forcings into account.[n]

7. *Climate change pattern and efficacies.* As many of the ship-induced forcing are geographically quite inhomogeneously distributed, the spatial pattern of climate response arising from the various ship-induced forcings will be different from a CO_2-induced climate change.[o] Therefore, these pattern need to be calculated. At the same

---

[l] Currently, the impact on methane is estimated by calculating the change in methane lifetime from the change in the abundance of OH.

[m] On global scale ship tracks have only be diagnosed for a short period of time.

[n] Note that taking the interdependencies will reduce the uncertainty of the total forcing as some positive and negative RFs are correlated.

[o] Climate models (and potentially also the real climate system) tend to respond in a particular mode, which is most easily triggered. Nevertheless experience from other studies show that the climate response pattern can differ substantially for different forcings.

time the associated efficacies can be calculated, which most probably will be different from one.[p]

8. *Development and testing of metrics.* The relative importance of non-CO_2-effects in comparison to CO_2 depends on the metric applied for comparing the various effects. Currently, several metrics, e.g., GWP and GTP based are being discussed for comparing the effects of short-lived species with the effect arising from CO_2. The comparison of the ship effects should be performed for various metrics and emission scenarios. Beyond the metrics which mainly account for the global mean effects we need to develop metric for comparing the regional effects and for comparing the climate effects with other effects from shipping such as the impact on air quality.

6. A potential new project

Assuming a funding of 400 000 Euro for a new project, not all of the above mentioned questions and tasks can be thoroughly addressed, rather a concentration on selected topics would be necessary.

Due to the on-going discussion concerning potential compensations between the CO_2 and cloud effects arising from shipping, a concentration of Tasks 5.5, 5.6, 5.7 and 5.8 would make sense. From the point of view of policymaking 5.8 would be the most interesting one. This can however only be addressed if Task 5.7 is performed at least for present day emissions.

An alternative approach (with lower priority from our point of view) would be assessing what shipping could contribute to the EU 20-20-20 policy. (However, this would require Task 5.8 and some of Task 5.2 as input.)

---

[p] E.g., in the case of aviation the induced ozone changes have an efficacy larger than one, i.e., the climate reacts more sensitively to aircraft-induced ozone than it does for CO_2 perturbations. On the other hand, the efficacy of contrails is smaller than one.