Anonymous Referee #1

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Referee Comment "Arctic Shipping Emissions Inventories and Future Scenarios (ACP, Corbett et al., acp-2010-236)

General comments:

The paper calculates present-day and future Arctic ship emission inventories for greenhouse gases, black carbon and other pollutants on a high-resolution grid of 5 km x 5 km for in-Arctic shipping and potential diversion traffic due to receding sea ice and determines the corresponding climate forcing. In general, the paper represents a substantial contribution to the scientific progress especially due to the high resolution of the inventory and the focus on black carbon. The overall scientific quality is good and further related work is considered. Concerning the presentation quality, the overall structure would be clearer if some descriptions of performed working steps are moved from the Results and Discussion sections to the Methods section. Figures, tables and language are clear and concise.

Specific comments:

1.) p.10275, l.14: I do not exactly understand how the shipping routes are determined. The routes follow longitude and latitude coordinates of each ship movement if available. How are the routes determined if these are not available?

The AMSA Report clearly addresses how routes were determined in the Current Marine Use and The AMSA Shipping Database, page 70-72 (Arctic Council 2009). A sentence has been added to Section 2.1 with clearer reference to work performed for the AMSA Report.

Given that this paper does not perform route assignments, but uses the AMSA Shipping Database of shipping routes, no further discussion in this paper is merited. However, since one of the authors worked on ship routing and AMSA database development, we include further detail in this response for the reviewer and open-comment forum. The approach to closing data gaps was variable on account of the inconsistent nature of the raw data. Specifically, that report documents that "where data was found to be insufficient for 2004, data from later years was provided and used for those areas only" … and " where route data was unavailable or contained obvious errors, such as passages across land, the information has been adjusted to follow known shipping routes." In addition to this approach, the AMSA project also used narrative descriptions provided by Arctic states. If no known shipping routes applied and no additional Information was available, the most sensible and direct course between the port of origin and destination was mapped. The specifics of how these data were managed are recorded in the database file for each country and are included in the AMSA database.

2.) p.10275, l.15: The authors use ship activity data provided by Arctic nations and used in the AMSA analysis. How is the Arctic region for emission inventories of in-Arctic ship activity determined in this study? Do the authors analyse the ship movements of all Arctic nations or only those movements starting and/ or ending north of the polar circle. Furthermore, what geographical area is the basis for the calculation of emission totals in Table 5?

The AMSA database and GIS files provide the geographical area that is the basis for the calculation of emission totals in this work. A sentence has been added to Section 2.1 documenting that the AMSA study domain covers the extent of the Arctic as “defined according to the internal policies among Arctic Council member states”.

In other AMSA documentation, namely the Arctic Marine Activity Database For the Circumpolar North Region 2004: Overview of Methodologies and Data Development (2009), the definition is articulated more explicitly. “The traditional definition of the Arctic is the region north of 60°. Because each Arctic state defines the extent of its own Arctic waters, some states reported vessel activity that is below 60 degrees north. To embrace the data submitted by all Arctic states, the AMSA database

encompasses data for the arctic marine regions north of 55° excluding the Gulf of Alaska, the North Sea, the Baltic Sea and the Sea of Okhotsk. Included is the Bering Sea to the Aleutian Island chain." Other than these noted exceptions, route data were clipped to 55° and any data reported south of 55° was not included in the database.

3.) p.10276, l.5: Activity-based emissions from fishing vessels are calculated differently than those from transport vessels and not provided geospatially. Can the authors mention some suggestions how emissions from fishing vessels can be distributed geospatially if calculated by number of days at sea and no geographical route information is available? Do they have geographical route information for fishing vessels at all?
We modified the discussion of fishing vessels in Section 2.2 to address these points, partly by reference to the very clear discussion in the AMSA study where answers to most of these comments are documented.
Since fishing vessels do not travel along a defined course but drift across areas in search of catch, the fishing vessel data is best presented by area as opposed to routes. These data are contained in a geospatial dataset defining areas (polygons) based on the Large Marine Ecosystems (LME). Although the format and resolution of the raw fishing vessel data varied, it was generally submitted based on areas. The number of days a vessel fished was defined by the activity dates. The number of days was then summed based on the area, the LME, in which the activity occurred. Emissions were calculated based on these values. The AMSA Report does clearly address this question. Refer to the Current Marine Use and AMSA Shipping Database section, p. 77 - 78.

4.) p.10278, l.8-12: The comparison of the resulting in-Arctic ship emission inventory to other studies should be moved from the Methods to the Results or Discussion part.
This section has been moved to section 3.1 in the Results.

5.) p.10278, l.20: Which prior study gives the global inventory coverage of Arctic regions in Fig. 1a?
The following reference has been added to reference this omission.
Wang, C., Corbett, J. J., and Firestone, J.: Improving Spatial Representation of Global Ship Emissions Inventories, Environ. Sci. Technol., 42, 193–199, 2008.

6.) p.10281, l.24: Does Table 7 show the percentage of ship activity (movements) by vessel type like the figure caption says or the percentage of emissions by vessel type like the text says?
Table 7 shows percentage of emissions. The Table caption has been corrected.

7.) p.10282, l.7-18: The detailed description of both future scenarios should be moved to the chapter 2.6 ìIn-arctic future year scenariosî.
This section has been moved.

8.) p.10282, l.20, - p.10283, l.22: The part on the method of developing emission inventories of diversion traffic should be moved from the Results section to the Methods section to make a clear distinction between methods and results.
A new section (2.7) has been added that discusses the Diversion Through-Arctic future year scenarios.

9.) p.10283, l.11-22: I find it really difficult to follow the authors' explanations how they found the percent diversion values for 2020, 2030 and 2050. Perhaps this description could be more clarified. What is the uncertainty of this approach? How did they develop the estimations in Table 12 which

determine the dependence of the location of future Arctic shipping routes on the state of receding sea ice (depending on seasons and time in future)?
We clarified this section. See below:
"We produce Arctic diversion inventories for potential opening of routes diverting current global ship traffic by the following process:

1. *We assume annual growth in global shipping (from 2004) to be 3.3% per year (a central value between the IMO base case and high-growth scenarios);*
2. *An assessment of drivers toward diversion timing and quantity was made by assessing current literature regarding the feasibility of Arctic shipping (see initial discussion in Section 2.7) and shipping volumes through the Suez and Panama Canals (~4% and ~8% of global trade volume, respectively (Egyptian Maritime Data Bank, 2010; GlobalSecurity.org, 2010)). These two statistics give an indicator of shipping volume attracted by global shipping 'shortcuts'.*
3. *Acknowledging uncertainty as to when diversion traffic may emerge, we chose to scale the percent diversion beginning in 2020 at 1% of global shipping, increasing to 2% in 2030, and increasing to 5% in 2050. "*

10.) p.10286, l.2, - p.10287, l.5: Parts of the climate forcing section in the Discussion chapter should be moved to the Methods and Results chapters in order to clarify the overall structure.
For this section we feel that, as an application of the emissions inventory that has been developed in the rest of the paper, keeping all of this information together in one section will make it simpler to digest.

Technical corrections:
1.) p.10275, l.15: The word ìnationsî appears twice.
Corrected

2.) p.10278, l.1: I think there is a typo concerning the indices. It should be average engine load factor for vessel j on route k in order to be consistent with the indices of other input variables.
Corrected

3.) p.10279, l.3: Following the text flow the sequence of tables is incorrect. Table 5 (p.10279, l.3) is mentioned before Table 4 which is named Table 5 by mistake (l.18). Furthermore Table 6 in p.10281, l.6 should be Table 5.
Corrected

Anonymous Referee #2
Received and published: 23 June 2010

The comment was uploaded in the form of a supplement:
http://www.atmos-chem-phys-discuss.net/10/C4375/2010/acpd-10-C4375-2010-supplement.pdf

Summary: The manuscript; "Arctic shipping inventories and future scenarios" by J.J. Corbett et al. describes a new emission inventory for emissions of trace gases and aerosols in the Arctic region for present day and future scenarios taking into account, for example, possible increases in shipping due to reductions in summer sea-ice. The topic is interesting and warrants publication in ACP. However, there are several points which need to be addressed before the paper can be published.

The paper focuses largely on the input data used for the construction of the BC emissions but there is not much discussion about emissions of others species, in particular NOx. Some additional information should be added to the text.
No change to the text is made in this regard. NOx and other species are presented and discussed throughout the paper. Most emissions in uncontrolled combustion systems at known (or defined) operating and fuel conditions are proportional to activity (engine load, duty cycle, hours, and fuel consumption); therefore, describing one pollutant (BC) of keen interest to the Arctic seems appropriate and is not unique to this paper. NOx (and SOx and other species besides BC) certainly are described in the construction of the inventories where the modeling and scenario analyses treated them differently. For example, the introduction discusses all species, and section 2.3 makes clear that NOx and SOx (at least) will be affected by new regulation and explains within several paragraphs why NOx and SOx legislation may not produce proportional reductions in BC and other pollutants. Section 2.5 makes clear that all pollutants listed are provided in the inventory. And Section 3 uses NOx as a comparator with other literature that did not include BC or some other pollutants, while Section 4 makes clear that NOx and SOx do not demonstrate the same patterns of growth (or decline) as other emissions in scenarios. The paper makes proper reference to publications that more fully describe NOx (in particular), and the paper indeed does recognize in the narrative the emerging attention on BC.

Also, there are some estimates about the climate impact of increased Arctic shipping emissions with the main estimate given in the abstract. However, the text provides very little detail about how these numbers were derived and I suggest removing this part (see comment below).
We have added citations to the paper that address this comment by illustrating that both Global Warming Potential (GWP) and Global Temperature-change Potential (GTP) are both (a) useful simplifications that are used in the peer-reviewed literature to communicate potential impacts, and (b) hotly debated among scientists and highly uncertain. This work does not further the derivation of these, but applies them to achieve (a) and acknowledge (b) so that the value of including these scenarios in Arctic research may be conveyed.
We think that one important contribution of this paper is to discuss the potential impact of the Arctic shipping emissions scenarios that motivate including these scenario inventories in future Arctic research related to climate change. In fact, the Maximum Feasible Reduction (MFR) scenario is motivated by the clear need to assess impacts and potential mitigation nearly simultaneously, if decisions about short-lived forcers in the Arctic are to be made as soon as scientists and policy makers are discussing. We acknowledge that research deriving the climate impact of BC is sparse and emerging, and we agree that we have not estimated climate impact for potentially changing emissions of other pollutants. However, Section 4.1 provides detail about how we apply numbers from the existing literature. Similar calculations have been presented explicitly in other peer-reviewed literature; for example, Shine et al, Climatic Change, 2005, has been cited more than 42 times - at least several times to directly apply global temperature change potential derived by them.

The abstract and conclusions should focus on summarising the main work presented in the paper which is the development of the Arctic shipping inventory for present-day and future conditions.
We believe the abstract does this.

My more specific comments follow:

1. Does the paper address relevant scientific questions within the scope of ACP? Yes.

2. Does the paper present novel concepts, ideas, tools, or data? Yes, the paper presents a new emission inventory for Arctic ship emissions.

3. Are substantial conclusions reached? A new dataset is described – an attempt is made to apply the emission changes to estimate equivalent changes in future GWPs etc. However, very little detail is given about how the numbers in Table 15 have been derived. My suggestion is to remove this section and to include a short discussion about possible implication of their scenarios in the Discussion section. A much more thorough analysis would needed if something more concrete were to be included on this topic. It is rather dangerous to include such estimates when it is not clear what they were based on. In any case there are many uncertainties related to making such estimates warranting a separate, more detailed study. There is no conclusions section.
   See comment above regarding climate impact assessment. We have added citations to the paper that address this comment with regard to the acknowledged need for further analysis, which we call for using these first-order calculations as motivating evidence - in agreement with this comment. Citations to the basis of the GWP and GTP ratios were already included. Other ACPD papers end with Discussion sections; many journals do not like a conclusion to repeat information in the abstract.

4. Are the scientific methods and assumptions valid and clearly outlined? Yes, in general although certain points need to be addressed:
   a. - emissions from fishing are not included in this inventory – this should be made clear at the beginning of the paper and some further discussion should be included about the contribution this source makes to the totals (it varies between species).
      Addressed in response to comment 3 for Referee #1, above.
   b. - emission factors – there should be some discussion about the uncertainties giving a range for current emissions
      Uncertainties in emissions factors exist, and are known to be much greater for BC and other PM species than for gaseous emissions, and have been demonstrated to contribute similar or less uncertainty to fleetwide estimates than uncertainty introduce by uncertainty in emissions factors, uncertainty in engine assumptions, and uncertainty in activity assumptions (Cooper, 2004; Corbett and Koehler, 2003). Our 2004 estimates compare well with other published work that quantifies uncertainty, and we believe our work is not differently uncertain from the studies cited. Moreover, our scenarios cover ranges of defined assumptions much broader than uncertainties in emissions, engines, or vessel activity would affect.
   c. - p6 : engine load factors – where were these numbers taken from ?
      We added a sentence that explains these load factors are similar to those used in other work; information regarding Arctic shipping supported using these common inventory engine load assumptions.
   d. - it would be useful in Table 3 to give the % of total global ship emissions – also the totals in Tables 3, 4 and 5 should match up.
      The totals were mismatched due to rounding prior to summing. These have been corrected. A note in Table 3 now makes the percent comparison calculation using CO2 reported in the table and global CO2 estimates in the Introduction section.

e. - p8 : more detail is needed about how the future scenarios (BAU, hi-growth and MFR) were constructed for the different species – for example, there is no discussion about NOx.
There was discussion about NOx and other species being affected by regulatory controls in Section 2.3. We added sentences in this section that describe this integration to the scenario explicitly and refer to Section 2.3.

f. - p11 – it's not very clear why the authors also chose to include diversions through Suez as well as through Panama in their estimates of % diverted shipping to the Arctic. The references for these diversions are from either a website or from a report which is not cited – how good are these estimates?
This has been addressed. See response to reviewer 1 comments.

g. - Is there any possible overlap between growth in Arctic shipping and diverted shipping to the Arctic which could impact their assumptions?
This appears to be at least one of two very good questions – neither explicitly evaluated in this paper.
First, potential overlap with current inventories may be interpreted in this comment. Based on our knowledge of geospatial assignment of current global shipping emissions, in-Arctic shipping reported here are likely data largely omitted in other global data sets. Perhaps some overlap exists, and this may be evaluated in future work, but at first order these detailed inventories may be mostly additive. No diversion routes as defined in these scenarios exist; therefore they do not overlap with current global inventories.
Second, the scenarios developed here treated growth of in-Arctic shipping (i.e., serving regional functions) independently from global trade patterns shifting to use shorter through-routes in Arctic diversion. Interactions may be expected, but complex. Other scenarios can be constructed in the future that manipulates the in-Arctic and diversion shipping jointly, but this would likely also move routes, etc. By presuming independence we simplify the scenario analysis, and imply (perhaps) that these interactions will be second or third order effects.

h. - It needs to be made clearer in the text what is presented in Figure 3 by referring to the relevant tables. Also, there is a lack of detail regarding how the scenarios were derived for the different pollutants. The number of tables could be reduced if the figures are showing the same thing.
The detail regarding scenario changes for pollutants is partly address in comment e (p8) above, where we explain that all pollutants are increased proportional to activity, and then emission controls aimed at one or more pollutant are applied. This is similar to the IMO study (Buhaug et al, 2009), except as noted in Section 2.3. The figures do show the same information as the tables, but we believe some readers grasp images visually and other readers will need to access the estimates in the tables.

i. - Tables 13 and 14 are hardly discussed at all and the labels are not very clear – why do « non-Arctic » and « global with Arctic » give the same totals for certain years (2004, 2030)?
These totals have been corrected.

5. Are the results sufficient to support the interpretations and conclusions? – see points above.

6. Is the description of experiments and calculations sufficiently complete and precise to allow their reproduction by fellow scientists (traceability of results)? In general OK but there is a lack of detail as noted previously.
   See responses to previous comments.

7. Do the authors give proper credit to related work and clearly indicate their own new/original contribution? Yes, although there maybe be newer references that could be used, for example, in the Introduction in this discussion about sea-ice.
   We updated citations to more current research relevant to this paper and useful in responding to the good comments by Referees.

8. Does the title clearly reflect the contents of the paper? Yes.

9. Does the abstract provide a concise and complete summary? Yes, but needs to be amended (see above).

10. Is the overall presentation well structured and clear? Yes, in general.

11. Is the language fluent and precise? Yes.

12. Are mathematical formulae, symbols, abbreviations, and units correctly defined and used? Yes.

13. Should any parts of the paper (text, formulae, figures, tables) be clarified, reduced, combined, or eliminated?

    a. - p7, parag 3 : wording is unclear – how were the errors estimated ?
    b. - p9, line 7 : what is HFO ? This has been defined earlier.
    c. - p10, line 9 : correct to ‘ …. produced by …’ corrected
    d. - p11, last line – GlobalSecurity.org is not reference. corrected
    e. - p12, first parag. of the Discussion section – strange use of the word « asymmetric » - I think the authors mean « different » trends Asymmetric term is used to better illustrate the growth characteristics of different vessel types.
    f. - Tables – see previous comments. Also, there are 15 tables in the paper – if any of the material could be provided graphically with the tables in supplementary material this would help the readability of the paper.

We prefer to leave them in the paper for readers who access either or both tabular and graphical information; we can consider moving tables to supplementary material, depending on editorial guidance.

g. - Figures – I had trouble printing the figures so there may be a formatting issue. The figure captions are not properly laid out – use of capital letters etc – see ACP format.
Format has been changed.

14. Are the number and quality of references appropriate? Yes.

14. Is the amount and quality of supplementary material appropriate? Not applicable.