Anonymous Referee #2

The authors present estimates of present-day (2004) and future (2030, 2050) emissions from shipping and oil and gas production in the Arctic. Future conditions are expected to be more favorable to various activities in the Arctic region as sea ice extent is further reduced. Arctic climate may be especially sensitive to endogenous emissions of black carbon and other pollutants.

We thank reviewer 2 for the comments and the opportunity to respond. Most comments here were of a minor nature, though there was some overlap with the critical comments of reviewer 1. We address these below.

I recommend publication in ACP subject to revisions to address the following comments.

1. There is a closely related prior paper by Corbett et al. (2010) in ACP. This prior work should be prominently cited/acknowledged in the introduction. At present there is a brief mention of the prior work at line 12 on page 4930, but only as a source of emission factor data for particulate matter. A few sentences of text outlining differences in methodology & scope would also be appropriate. At a later stage of the paper, the authors might consider comparing their results with prior work if such comparisons are possible.

We made the following changes:

- Paragraph in introduction outlining relevant previous work, not only Corbett et al., but also other studies for shipping and oil and gas
- The introduction was also reorganized to make it a little clearer
- Paragraph outlining differences in method and scope in the method section. We will have a section which clearly describes the coverage of different models as this seems to be a point of confusion.
- A more detailed comparison of our results with others, as also highlighted by reviewer 1, will appear as a separate section.

2. The estimates of future oil & gas production seem plausible, data on emission factors in section 3.3.1 are generally poor, as the authors acknowledge. Is there any reason to believe a dataset based on voluntary reporting by oil and gas companies is accurate? I would expect industry would tend to under-report. Also present-day emissions are heavily dominated by natural gas production in West Russia, with second-tier contributions coming from Alaskan oil production. The discussion of emission factors is not explicit about which oil companies are reporting emissions data for which regions.

A variety of emission estimates are used, but the oil and gas industry ones are taken as defaults; in other words we overwrite the default values in many cases. The country estimates are usually constructed in a top-down way to replicate national estimates of oil and gas emissions. We did a variety of cross checks to ensure consistency with different estimates. This is discussed both in the main article and SI. The SI in particular has a paragraph describing where the estimates for each country came from. However, we will include further clarification and discussion of this (the original text compressed this discussion to save space).

One might expect significantly less if any data reporting for West Russia, and perhaps different production practices (hence different emissions) as well. So while the authors have made good efforts to estimate the locations and possible future amounts of oil & gas production, the associated greenhouse gas and especially short-lived pollutant emissions seem quite weakly based in comparison for this sector.

> This is correct. In terms of locations, we have quite good data on current activities and locations of current explorations and discoveries which helps to guide future locations. In terms of emissions, yes, this is difficult. SLCF, such as black carbon, are particularly difficult. For example, it is basically unknown what emissions of BC occur due to flaring. We make estimates based on a share of the PM emissions, which are better known. In the case of Russia, the default estimates and national data were largely consistent.

Are the authors aware of any prior studies evaluating emissions from oil & gas production, and the accuracy of reported/published emission estimates in comparison to field measurements? Studies from more southerly latitudes could be considered given the general scarcity of data here.

> We discuss more in the article that the type of emission estimates we used are uncommon (emission per unit oil extracted), and an over view of life cycle assessment literature finds very few estimates many of which refer to an "industry source" (not discussed in paper). As mentioned above, where possible, we ensure our emission intensities produce national estimates of oil and gas emissions. Where there is no data to compare, we use defaults which turn out to be quite close to the estimates (see supporting info). We now demonstrate this more clearly in the paper the comparisons that we have done. In the SI we already have a discussion on a country-by-country basis.

3. Given the above uncertainties in emission factors, the precision of the estimates reported in Tables 2-3 seems overly optimistic. I recommend reporting 2-3 significant figures at most, currently they report values that are misleadingly precise.

> Rounded

Technical Corrections

4. In Figure 1, it would be helpful to show the Northern Sea Route. Obscure acronyms such as FRISBEE and AMAP should be avoided here if possible.

> Fixed as described.

5. Figures 4ab there are color scales for transit shipping and oil & gas shipping fuel consumption, but what is shown on the figures is just a single line that appears as one color along its entire length. So the use of a color scale is not working with the way information is being presented in this figure.

> We had difficulty enhancing this line further due to the format of the data (it is actually brighter through the ice, but admittedly, it is hard to see).

6. In Tables 5 and 6, the authors should consider adding total GHG emissions as a further row, using global warming potentials (GWP) to combine CO2, CH4, and N2O emissions into a weighted sum.

This can be done easily, but we decided it would be misleading. If we weight the long-lived greenhouse gases together, but exclude the SLCF then we are missing a part of the climate impact. GWPs and responses for short-lived climate forcers (SLCF) are also highly regionally dependent. A part of the rationale for this paper, and the project of which it is a part, is to assess this regional dependence. If we include both GHG and SLCF using global averages, then we may give misleading estimates. We are currently near to submitting a paper that uses the 2004 emission inventory from this paper to give the radiative forcing across several components and will provide some quantification to these estimates. In the meantime, it is easy for interested readers to estimate CO2-eq emissions if they are happy to accept the assumptions.

Editorial Comments

7. Page 4918, line 7, requiring should be require

Fixed

8. Page 4918, line 12 mid-1990 means June-July 1990. I think what is actually intended here is "the mid-1990s", i.e. around 1995.

Fixed

9. Page 4921, line 16, what does FRISBEE stand for?

Fixed

10. A reference is needed at page 4922, line 8, for the statement about the time lag from investment decision to maximum plateau production being 50-100% longer than in comparable non-Arctic fields.

Clarification added

11. Why are costs in East Arctic Russia twice the existing cost level, whereas everywhere else in the Arctic only 50% higher?

Clarification added

12. Page 4922, line 17, if world oil price is exogenous, what is assumed and where does this information come from?

Clarification added

13. Page 4925, lines 24-25, the references to "information" do not make sense to me. "without better information we keep the information as estimates can be grouped to centralized grid-points if needed"

Reworded

14. Page 4927, lines 1-5, the EDGAR estimates are poorly presented here. It is difficult to read through and make sense of. Perhaps include the EDGAR values that you want to compare with in Table 2 instead so the reader has the numbers lined up better for looking at and evaluating.

This section was reworded to make clear that this comparison is not a solid one! The reason is the oil and gas estimates used in EDGAR are not purely based on oil and gas locations and some of the production is located around population and industrial centres (which is clearly wrong in the Arctic). We chose not to include the numbers in the table as people might assume the numbers are directly comparable. This has now been clarified.

15. Page 4927, line 7, fix grammar problem: we only use *a* bottom-up data based on...

Fixed

16. Page 4928, lines 24-25, I think the parenthetical TEU numbers (3.9 and 5.6 million) are not needed, they make the text harder to read and they are just 1/3 each of the preceding numbers anyway so give no additional useful information.

Removed

17. Page 4929, line 19, like should be "such as" (with no comma)

Fixed

18. Page 4932, line 12, omit "a", we do not find rapid aggregated emission increases (increases is plural)

Fixed

19. Page 4934, I find the legal text Copyright (2011) all rights reserved appearing in the acknowledgments, and the sense of proprietary data and modeling tools being used here to be troubling. My understanding is the authors retain copyright of their paper anyway, so I wonder if this legalistic language is needed? Are the authors willing to share the modeling tools, input data, model outputs, etc. to interested readers who might want to evaluate the numbers more carefully or make use of them in other studies?

The Copyright refers to the gridded oil and gas data. The proprietary data is gridded information on oil and gas facilities with historic production, reserve size, field type, field status, etc. Some of this data can be found via other sources, some cannot. Either way, having this data all compiled in an accessible format was very helpful for the gridding of the oil and gas production (not the output). This is explained, particularly in the SI.

We obtained this data for free with a contract stating that we must suitably modify the data (ie, don't give the unmodified data to others) and fully acknowledge them. They had a text for the acknowledgement that was reworded slightly in the ACPD review process. The original text was "Includes data supplied by IHS Inc., its subsidiary and affiliates companies; Petroconsultants S.A.; Copyright (2011) all rights reserved".

We have now made the wording in the acknowledgements more explicit.