Authors' comments on Review #1

RC C676: 'Review comments on "Black carbon emissions from Russian diesel sources" by M. Evans', Anonymous Referee #1, 12 Mar 2015

Black carbon emissions from Russian diesel sources: case study of Murmansk

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MAJOR COMMENTS

Comment 1. **For data such as emission factors and BC/PM ratios for different sources, the use of the data needs to be clearly justified. The source of the data also needs to be specified; some references were missing in the manuscript**

Emission factors for on-road vehicles came from two sources:
a) Russian methodologies, developed by the Scientific Research Institute of Automobiles and Transportation (NIIAT):
- NIIAT: Calculation instruction (methodology) for emission inventory from vehicles into the air (in Russian). Scientific Research Institute of Automobiles and Transportation, Moscow, Russia, 2008a.
-NIIAT: Calculation instruction (methodology) for emission inventory from vehicles into the air (in Russian), Scientific Research Institute of Automobiles and Transportation, Moscow, Russia, 2008b.

b) European vehicular emissions model:
Emisia: COPERT 4 (Computer programme to calculate emissions from road transport), Prepared for the European Environment Agency (EEA), available at:
http://www.emisia.com/content/copert-download (last access: 15 July 2014), 2011.

COPERT model is the source for BC ratios (speciation, fractions) of PM (f-BC) for on-road transport. The BC/PM ratios for on-road transport also can be found in

EEA, 2013. EMEP/EEA Air Pollutant Emission Inventory Guidebook — 2013. European Environment Agency, Copenhagen, Denmark. http://www.eea.europa.eu/publications/emep-eea-guidebook-2013/part-b-sectoral-guidance-chapters/1-energy/1-a-combustion/1-a-3-b-road-transport . (Table A4-2, Page 154).

Emission factors for other diesel sources are taken from: EEA, 2013. EMEP/EEA Air Pollutant Emission Inventory Guidebook — 2013. European Environment Agency, Copenhagen, Denmark.

Per reviewer's suggestion, we have used BC/PM ratios from EEA emissions guidebook to make the calculations consistent. As a result, we changed our BC and OC emission estimates (throughout the text).

Changes to the text

COPERT model is the source for BC/PM ratios for on-road transport. COPERT model includes data for EC fractions of PM (f-EC) as well as OM/EC ratios. Additional detail on our methodology can be found in (Evans et al., 2012).

For other sources, we used emission factors and speciation ratios from EMEP/EEA Air Pollutant Emission Inventory Guidebook (Table 1). We decided to use the European Monitoring and Evaluation Programme (EMEP) data for consistency. However, U.S. EPA has more rigorous procedure for determination of BC/PM ratios. EMEP is currently updating its emissions factors and speciation ratios.

Table 1. $PM_{2.5}$ emission factors and BC/PM ratios for diesel sources

Sector	*$PM_{2.5}$, gkg^{-1}*	*Source*	*BC/PM*	*Source*
Transport				
Rail	*1.44*	*EEA, 1.A.3.c, Table 3.1.*	*0.65*	*EEA, 1.A.3.c, Table 3.1.*
Other transport	*4.31*	*EEA, 1.A.4., Table 3-2*	*0.5*	*EEA, 1.A.4., Table D.1*
Industry				
Mining and quarrying	*3.551*	*EEA, 1.A. 4., Table 3-2*	*0.62*	*EEA, 1.A.4., Table D.2*
Construction	*4.308*	*EEA, 1.A. 4., Table 3-2*	*0.62*	*EEA, 1.A.4., Table D.2*
Other industry	*4.308*	*Same as construction*	*0.62*	*EEA, 1.A.4., Table D.2*
Other sectors				
Agriculture/forestry	*3.755*	*EEA, 1.A. 4., Table 3-2*	*0.57*	*EEA, 1.A.4., Table D.2*
Residential	*6.0*	*Data from (Bond, 2004)*	*0.66*	*Data from (Bond, 2004)*
Commercial and public services	*6.0*	*Data from (Bond, 2004)*	*0.66*	*Data from (Bond, 2004)*
Fishing	*1.4*	*EEA, 1.A.3.d, Table 3-2*	*0.31*	*EEA, 1.A.3.d, Table 3-2*
Fishing ($gkWh^{-1}$)	*0.3*	*EEA, 1.A.3.d, Table 3-10*	*0.31*	*EEA, 1.A.3.d, Table 3-1*

Comment 2. First paragraph in Section 2, I would suggest the authors use equations to explain how the emissions were calculated for each source with fuel consumption, activity and emission factor.

Calculations of black carbon emissions from all sources (except on-road transport) are very simple and can be expressed by the following equation

BC emissions = fuel (kg) x $PM_{2.5}$ emission factor (g/kg) x BC/$PM_{2.5}$ ratio

Source: EEA: EMEP/EEA Air Pollutant Emission Inventory Guidebook – 2009, European Environment Agency, Copenhagen, Denmark, 2009.
http://www.eea.europa.eu/publications/emep-eea-emission-inventory-guidebook-2009/part-

b-sectoral-guidance-chapters/1-energy/1-a-combustion/1.a.3.b-road-transport-gb2009-update.pdf

The Supplement provides detailed calculation of BC emissions from on-road transport.

Changes to the text

"Calculations of black carbon emissions from all sources (except on-road transport can be expressed by Eq.1 (EEA, 2009):

$$BC\ emissions = fuel\ (kg) \times PM_{2.5}\ emission\ factor\ (gkg^{-1}) \times BC/PM_{2.5}\ ratio \qquad (1)"$$

Comment 3. Second paragraph in Section 2, the statements are vague. The authors need to clearly explain what the "Russian methodologies" are. What are the "other methodologies" used? Do "methodologies" mean "emission factors" or others?

The Russian Methodologies are (NIIAT, 2008a, b)

- NIIAT: Calculation instruction (methodology) for emission inventory from vehicles into the air (in Russian). Scientific Research Institute of Automobiles and Transportation, Moscow, Russia, 2008a.

-NIIAT: Calculation instruction (methodology) for emission inventory from vehicles into the air (in Russian), Scientific Research Institute of Automobiles and Transportation, Moscow, Russia, 2008b.

The "methodology" means not only emission factors but also how the emissions can be calculated. For example, there are different approaches to calculate cold start emissions in NIIAT and COPERT models.

Changes to the text

"Wherever possible, we used Russian methodologies or PM emission factors (NIIAT, 2008a, b)"

Please also see the changes to the Supplement described in Comment 5.

Comment 4. Second paragraph in Section 3, how was the "consolidated estimate" was performed as the data are different for summary data, detailed data and estimated consumption? What is the difference (exact numbers) among the three datasets?

A "consolidated estimate" is our assumption about diesel consumption in Murmansk region. We used information from different sources and data collection methodologies were not always clear. The "summary data" and "more detailed data" refer to official information from the Murmansk Statistical Office. The "summary data" is the total diesel consumption in the region while "more detailed data" reflect the consumption in various sectors.

Our consolidated estimate (in many cases using the bottom-up approach) of diesel consumption in Murmansk region is 242,500 tons in 2012. The Murmansk Statistical Office

reports diesel consumption at 391,900 tons including 68,300 tons consumed by fishing ships. Our bottom-up calculations show that fishing ships consumed only 3,000 tons while in Russian territorial waters.

We have changed the text as follows:

"The summary data from the Murmansk Statistical Office and the more detailed data from various sectors appear to have some methodological differences. The summary data appear to include different categories across different years, causing major swings in the total reported fuel use. For example, the Murmansk Statistical Office reports diesel consumption at 391 900 t in 2012 while the total diesel consumption was 599 120 t in 2011. The official statistical data also includes bunker fuel for marine transport. The Murmansk Statistical Office reports that fishing ships consumed 68 300 t. Our bottom-up calculations show that these ships consumed only 3 000 t while in Russian territorial waters".

Comments 5. Third paragraph in Section 4.1, the paragraph is not well organized and difficult to follow. The authors really need to provide more details about NIIAT method and COPERT either in the main text or as supplemental materials (some of them are in Section 4.2 now). Full names of NIIAT and COPERT and the brief introduction need to be provided when they first appear. Moreover, the four methods in Table 3 need a clearer explanation.

We moved *Table 2. Main data sources on vehicle fleet and activity* to *Section 2. Methodology* and provided additional details about NIIAT and COPERT methodologies.

We have changed the text as follows:

"The Scientific Research Institute of Automobiles and Transportation (NIIAT) developed the Russian emission models. These models are based on COPERT 4 model with some simplifications. COPERT (COmputer Programme to calculate Emissions from Road Transport) is an emission calculator developed by EMISIA SA for the European Environment Agency (EEA)."

We added the following text to the Supplement.

"We used the COPERT model to calculate emissions from on-road transport. COPERT (COmputer Programme to calculate Emissions from Road Transport) is an emission calculator developed by EMISIA SA for the European Environment Agency (EEA). The COPERT 4 methodology is part of the EMEP/EEA air pollutant emission inventory guidebook for the calculation of air pollutant emissions and is consistent with the 2006 IPCC Guidelines for the calculation of greenhouse gas emissions.

COPERT has been developed for official road transport emission inventory preparation in EEA member countries. It can be downloaded for free at http://emisia.com/copert

The Russian emission model was developed by the Scientific Research Institute of Automobiles and Transportation (NIIAT). The model is based on the COPERT 4 model with some simplifications.

The NIIAT methodology is designed to calculate emissions from on-road transport in urban conditions. The main provisions are harmonized with the European methodology. NIIAT provided copies of the methodologies. There is no software developed for the NIIAT methodology. We developed an Excel spreadsheet for emission calculations.

Table R1-1 provides additional details about the models.

Table R1-1. Inputs for NIIAT and COPERT models

Input	*NIIAT*	*COPERT*
Temperature	*Time of warming up (cold starts) depends on temperature*	*Min/max, monthly*
	NIIAT	*COPERT*
Length of trip, km		+
Warming time, min	+	*...*
Number of cold starts per day	+	- *(calculated based on trip length)*
Fleet (number of registered vehicles), vehicle types	+ *(and ecological classes)*	+ *(and ecological classes)*
Average annual mileage, km	+	+
Speed, km/h	-	+
Average temperature, Celsius	+/+-	+
Slope effect	-	*+ (advance option)*
Load effect	-	*+ (advance option)*
RVP (pressure)	-	+
Humidity, %	-	+
Fuel quality	-	+

We calculated BC emissions from on-road transport using 4 different approaches to test for sensitivity. First, we used the COPERT model to calculate BC emissions using default European emission factors (EF) for various types and Euro class vehicles. Then we substituted the default emission factors with specific Russian EF to reflect the specifics of the Russian fleet. We also cross-checked the results using the NIIAT methodology with Russian emissions factors. Finally, instead of using the vehicle count from video surveys, we used COPERT to calculated emissions from the entire registered vehicle fleet. This allows us to show that using the registry data significantly overestimates the emissions in the city."

Section 8, Uncertainty analysis, needs be expanded with more information about uncertainty calculation (equations), values of uncertainty (at least added in Table 5). Can the authors separate the uncertainties for activity and emission factors and create another table to show the values?

We used a summary analysis of BC uncertainty ranges for the EF's from the Bond et al. inventory.

Bond, T. C., Streets, D. G., Yarber, K. F., Nelson, S. M., Woo, J.-H., and Klimont, Z.: A technology-based global inventory of black and organic carbon emissions from combustion, Journal of Geophysical Research: Atmospheres, 109, 10.1029/2003jd003697, 2004.

Table 2. Emission factor uncertainty (%)

Source Category	Low/Mid, %	High/Mid, %
Mining	50	230
On-road transport	50	180
Construction	50	230
Agriculture	50	230
Locomotives	50	230
Diesel generators	50	230
Fishing	50	230

The algorithm for uncertainty calculations was adopted from:

IPCC: IPCC good practice guidance and uncertainty management in national greenhouse gas inventories, Institute for Global Environmental Strategies, Hayama, Japan, 4-88788-000-6, 2000.

We made the following changes to the Supplement:

"Uncertainty estimates include uncertainty in activity data - uncertainty in fuel use and existence of emission controls. Activity data uncertainty is based on expert judgments.
We used a summary analysis of BC uncertainty ranges for the BC emission factors from the Bond inventory (Bond et al (2004).

Table S18. Emission factors uncertainty (%)

Source Category	*Low/Mid, %*	*High/Mid, %*
Mining	*50*	*230*
On-road transport	*50*	*180*
Construction	*50*	*230*
Agriculture	*50*	*230*
Locomotives	*50*	*230*
Diesel generators	*50*	*230*
Fishing	*50*	*230*

The algorithm for uncertainty calculations was adopted from:
IPCC: IPCC good practice guidance and uncertainty management in national greenhouse gas inventories, Institute for Global Environmental Strategies, Hayama, Japan, 4-88788-000-6, 2000.

Activity data uncertainty (U activity) is a combination of uncertainty on emission controls (U controls) and uncertainty in fuel consumption (U fuel).

$U\ activity = (U\ fuel^2 + U\ controls^2)^{1/2}$

The relative uncertainty in the emission for each activity and fuel combination is calculated as the square root of the sum of squares of the relative uncertainties in both activity data and the emission factors. The absolute uncertainty in the emission of each activity and fuel combination is derived by multiplying the relative uncertainty with the emission value.

We built two estimates which show possible minimum and maximum BC emissions in Murmansk region. The minimum emissions estimate reflects possible lower fuel consumption and higher use of emission controls. This estimate also accounts the lower level of uncertainty in emission factors. The maximum emissions scenario assumes a possible increase in emissions due to large diesel consumption and lack of controls. Tables S19 and S20 show calculations of low/middle and high/middle relative uncertainty of the inventory.

Table S19. BC emissions uncertainty, low /middle estimate

Source Category	BC emissions (t)	Fuel use,%	Assumptions on control,%	Activity data uncertainty (%)	Emission factor uncertainty (%)	Combined relative uncertainty (%)	Absolute uncertainty, (t)
Mining	279.3	5	50	50.2	50	70.9	198.0
On-road transport	53.7	10	10	14.1	50	52.0	27.9
Construction	12.0	50	30	58.3	50	76.8	9.2
Agriculture	3.9	10	20	22.4	50	54.8	2.1
Locomotives	22.3	10	20	22.4	50	54.8	12.2
Diesel generators	27.1	50	100	111.8	50	122.5	33.2
Fishing	5.3	5	30	30.4	50	58.5	3.0
Total	403.7					195.06	203.31

Table S20. BC emissions uncertainty, high /middle estimate

Source Category	BC emissions (t)	Fuel use (%)	Assumptions on control (%)	Activity data uncertainty (%)	Emission factor uncertainty (%)	Combined relative uncertainty (%)	Absolute uncertainty, (t)
Mining	279.3	20	5	20.6	230	230.9	645.0
On-road transport	53.7	200	30	202.2	180	270.7	145.4
Construction	12.0	30	5	30.4	230	232.0	27.8
Agriculture	3.9	10	0	10.0	230	230.2	8.9
Locomotives	22.3	30	0	30.0	230	231.9	51.7
Diesel generators	27.1	20	0	20.0	230	230.9	62.6

Fishing	*5.1*	*200*	*0*	*200.0*	*230*	*304.8*	*15.6*
Total	*403.42*					*658.37*	*667.00*

The relative uncertainty in BC emissions in Murmansk region is from -50% to +165%.

Section 9, I think this section needs either to be deleted or to be expanded to show the details on how the emissions are estimated for different sources for whole Russia, including activities and emission factors. I would rather suggest the authors to use the space for more discussions to interpret the emission data estimated with their method, possibly more graphs in addition to Table 5. How would the results be compared with BC emission in other parts of the world? Would it be possible for the authors to shown how the estimated emission can be applied in models to further understand its contribution to the Arctic BC concentration and BC climate impact?

We have added an explanation of the rationale for this section and additional details on the calculations. We believe that this simple estimation of Russia-wide black carbon emissions from diesel sources is important for future research. Emissions mitigation policies, especially emission standards, should be adopted at the national level. We showed that off-road vehicles are a significant source of BC emissions in the country. By adopting PM emission standards for these vehicles Russia can significantly reduce BC emissions in the future.

We made the following changes to the text

"Table 6. Diesel consumption in Russia, 2010

Sector	*Diesel, thousand t*
Transport	
Road transport	*12 508*
Rail	*1444*
Other transport	*1051*
Industry	
Mining and quarrying	*1152*
Construction	*631*
other industry	*765*
Other sectors	
Agriculture/forestry	*2829*
Residential	*1357*
Commercial and public services	*1165*
Fishing	*351*
Total	*23 253*

Source (IEA, 2012)

We decided to use the IEA data for consistency but used NIIAT estimates for the distribution of diesel consumption by types of vehicles.

PM emission factor is 4 gkg^{-1} fuel for Euro 0 vehicles, 1.1 for Euro 1 and Euro 2 vehicles and 0.8 gkg^{-1} fuel for higher ecological classes. We estimated total PM emissions from on-road diesel vehicles in Russia in 2010 at 33 404 t. We applied the BC/PM ratios to determine BC emissions (EEA, 2013)."

"NIIAT fuel based emission factors are low compared to international practice. For example, Bond et al (2004) used fuel-based emission factor for the former Soviet Union region at 4.4 gPM kgfuel^{-1}.

As a result, we cross-checked our calculations with the EEA methodology using bulk emissions factors (EEA, 2013). Suggested bulk emission factors (gkg-1 fuel) for former Soviet Union countries are the following: 4.95 for cars, 4.67 for LCV, 2.64 for heavy-duty trucks and 2.15 for buses. The total emissions from on-road transport were 33 404 t of PM, 19 892 t of BC and 5968 t of OC. The difference in BC calculations using NIIAT and EEA approaches is 16%.

We also calculated emissions using the NIIAT bottom-up estimate of diesel consumption by on-road vehicles in Russian (17.3 million t). The total emissions from on-road transport would be 44 252 t of PM, 27 544 t of BC and 8263 t of OC.

Table 8 shows the results of BC emission calculations from all sectors.

Table 8. PM2.5, BC and OC emissions from diesel sources in Russia, 2010 (t)

Sector	*PM2.5*	*BC*	*OC*
Transport			
On-road	*33 404*	*19 892*	*5968*
Rail	*2 079*	*1352*	*270*
Other transport	*4 530*	*2265*	*680*
Industry			
Mining and quarrying	*4091*	*2536*	*761*
Construction	*2718*	*1685*	*506*
Other industry	*3296*	*2043*	*613*
Other sectors			
Agriculture/forestry	*10 623*	*6055*	*1817*
Residential	*8142*	*5374*	*1075*
Commercial and public services	*6990*	*4613*	*923*
Fishing	*491*	*152*	*30*
Total	*76 364*	*45 967*	*12 641*

The largest sources of diesel BC emissions in Russia in 2010 were on-road transport (43%), agriculture/forestry (13%) and residential sources (12%)".

MINOR COMMENTS

(1)The manuscripts need to be proofread with professional English as there are some grammatical errors. Some of the paragraphs are very difficult to understand at the first time of reading.
Accepted

(2) Page 3259, Line 1, the sentence is verbose and needs to be rephrased. I think the authors only need to say that "BC is a major component of PM 2.5".
Accepted

We have changed the text as follows:
"BC is a major component of $PM_{2.5}$"

(3) Page 3259, Line 25, how much higher? What is "older estimates"?

We have adjusted the text as follows:

"In Murmansk, we found that 12% of light-duty passenger vehicles used diesel, which is somewhat higher than older estimates Russia wide".

We will add that "The Russian company Avtostat estimated that the share of diesel cars driving in Russia in 2012 was 4%. The share of newly-sold diesel cars was 6%".

(4) The authors should be consistent to use Euro 4, Euro 5 or Euro IV, Euro V.
In the European methodology, by convention, light duty vehicles are marked with Arabic numerals while Roman numbers are used for heavy-duty vehicles (trucks and buses).

(5) Page 3261, Line 16, "we used similar methods to estimate organic carbon (OC) emissions". I don't think this sentence is necessary because OC emission is not discussed in the manuscript.
We did not discuss OC calculations in the text but in Table 5, page 3282 (now table 9) and a new table 8 contain the results of all emission calculations, including OC.

We have adjusted the text as follows:

Table 8. $PM_{2.5}$, BC and OC emissions from diesel sources in Russia, 2010 (t)

Sector	*$PM_{2.5}$*	*BC*	*OC*
Transport			
On-road	*33 404*	*19 892*	*5968*
Rail	*2079*	*1352*	*270*
Other transport	*4530*	*2265*	*680*
Industry			
Mining and quarrying	*4091*	*2536*	*761*
Construction	*2718*	*1685*	*506*
Other industry	*3296*	*2043*	*613*

Other sectors			
Agriculture/forestry	*10 623*	*6055*	*1817*
Residential	*8142*	*5374*	*1075*
Commercial and public services	*6990*	*4613*	*923*
Fishing	*491*	*152*	*30*
Total	*76 364*	*45 967*	*12 641*

Table 9. $PM_{2.5}$, BC and OC emissions in Murmansk Region, 2012 (t).

Activity	*$PM_{2.5}$*	*BC*	*OC*
On-road transport in Murmansk Region	*98.9*	*53.7*	*36.2*
Mines	*450.5*	*279.3*	*83.8*
Locomotives	*30.5*	*19.8*	*4.0*
Construction	*15.6*	*9.7*	*2.9*
Agriculture	*5.0*	*2.9*	*0.9*
Diesel generators	*52.8*	*34.8*	*7.0*
Ships (in Russian waters)	*13.4*	*4.2*	*0.8*
Total	*666.7*	*404.4*	*135.5*

(6) Page 3268, Line 20, what is the "EPA speciation ratio"?

The "EPA speciation ratio" is the EPA defined BC/PM ratio (0.77)
Source: EPA: Report to Congress on Black Carbon, US Environmental Protection Agency, Washington DC EPA-450/R-12-001,2012.

However, per the reviewer's suggestion, we applied EEA emission factors and BC/PM ratios.

We have adjusted the text as follows:

"The BC/PM ratio is 0.57 (EEA, 2013)."

"We thus estimated total PM emissions from agricultural equipment in Murmansk Region at 5.0 t of $PM_{2.5}$, 2.9 t of BC and 0.9 t of OC."

(7) Table S1, what does "adjusted data" mean?

Table S1. shows bottom–up calculations of fuel consumption by on-road diesel vehicles in Murmansk Region. We corrected the registry in two ways: 1) We applied the distribution by Euro class that we found in our parking lot surveys. 2) We also apply the ratio between registered and observed vehicles in the city to the registry in the region. We reduced the number of vehicles in the region to factor out vehicles that are not in use.

(8) References missing

a. Page 3258, line 24

Bond, T. C., and Sun, H.: Can Reducing Black Carbon Emissions Counteract Global Warming?, Environ. Sci. Technol., 39 (16), 2005

b. Page 3266, Line 24
We have adjusted the text as follows:
"The BC/PM ratio is 0.62 (EEA, 2013)".

c. Page 3267, Line 10 – 12
We have adjusted the text as follows:
"The speciation ratio for BC/$PM_{2.5}$ for locomotives is 0.65 (EEA, 2013)."