1 **A methodology for calculating transport emissions in cities with limited traffic data: Case**
2 **study of diesel particulates and black carbon emissions in Murmansk**

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30 **Abstract**

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32 This paper presents a methodology for calculating exhaust emissions from on-road transport in
33 cities with low-quality traffic data and outdated vehicle registries. The methodology consists of
34 data collection approaches and emission calculation methods. For data collection, the paper
35 suggests using video survey and parking lot survey methods developed for the International
36 Vehicular Emissions model. Additional sources of information include data from the largest
37 transportation companies, vehicle inspection stations, and official vehicle registries. The paper
38 suggests using the European Computer Programme to Calculate Emissions from Road Transport
39 (COPERT) 4 model to calculate emissions, especially in countries that implemented European
40 emissions standards. If available, the local emission factors should be used instead of the default
41 COPERT emission factors. The paper also suggests additional steps in the methodology to
42 calculate emissions only from diesel vehicles. We applied this methodology to calculate black
43 carbon emissions from diesel on-road vehicles in Murmansk, Russia. The results from
44 Murmansk show that diesel vehicles emitted 11.7 tons of black carbon in 2014. The main factors
45 determining the level of emissions are the structure of the vehicle fleet and the level of vehicle
46 emission controls. Vehicles without controls emit about 55% of black carbon emissions.

1. Introduction

On-road vehicles are a large source of emissions that have a negative effect on air quality (EPA, 2012). On-road transport is the second most significant source of greenhouse gas (GHG) emissions in the US and European Union. In 2013, on-road transport emitted 27% of total GHG emissions in the US (EPA, 2015b) and 19 % in the European Union (EEA, 2015). Globally, transportation is the fourth largest source of emissions after electricity and heat production, industry, and agriculture and forestry (EPA, 2015a).

There are two main approaches to calculating emissions from on-road transport. The first approach is based on monitoring traffic flows. Developed countries use many techniques and detection technologies to monitor traffic flows. Continuous data programs with automatic equipment designed to continuously record the distribution and variation of traffic flows are preferable, though short duration data collection programs are also acceptable. For example, in the USA, many states use short-duration vehicle counts to collect data that represent typical traffic volume on a given segment of road. Some states consider a week-long count with data recorded for every hour of each day to be adequate. In urban areas, the use of shorter intervals, such as 15 minutes, may be appropriate (US Department of Transportation, 2013).

The second approach uses vehicle registries to calculate emissions from road transport. The advantage of this approach is its simplicity; assumptions on fleet distribution by vehicle type, emission standards, and annual number kilometers traveled play an important role in determining the accuracy of emissions calculations. This approach requires up-to-date, accurate registries and reasonable assumptions on annual mileage. It can be difficult to assess annual mileage without extensive surveys, which would make the approach more complex.

Most European and some Asian and African countries use the Computer Programme to Calculate Emissions from Road Transport (COPERT) model to calculate emissions from on-road transport. COPERT is an emission model developed for the EEA. Twenty two countries of the European Union use the COPERT model to calculate road transport emissions (Ntziachristos et al., 2009).

COPERT requires a number of activity data inputs, including the number of vehicles segmented by vehicle type, fuel, and emission standard (Euro class). The model is built on the implicit assumption that vehicle registries are accurate and all registered vehicles are being actively used. Vehicle registries, however, are often outdated and researchers use several approaches to adjust vehicle registries upon using COPERT.

COPERT is widely used to calculate vehicular emissions in many non-European countries. Cai and Xie (2007) estimated vehicular emission inventories in China from 1980 to 2005 using the COPERT 3 model. They adjusted vehicles registry based on the yearly sales data and analyzed emissions of several pollutants including PM₁₀ at the provincial level. Lang et al. (2012) used the methods developed by Cai and Xie to calculate vehicular emissions in the Beijing-Tianjin-Hebei region using COPERT 4. In Malaysia, COPERT 4 was used for the national emission inventory; the authors did not address the issue of vehicle registry quality (Ong et al., 2011). Calculating vehicle emission in Turkey, Soylu (2007) processed standard statistical vehicle data to adjust them according to COPERT 3 requirements and calculate emissions of several pollutants.

COPERT is also actively used for emission calculations in cities. For example, Borge et al. (2012) estimated road traffic emissions in Madrid, Spain for nearly 15,000 road segments using COPERT 4. The input information (e.g. fleet composition, vehicle-kilometers traveled, traffic intensity, road type, etc.) was provided by a Madrid traffic model along with observations from field campaigns. The Madrid traffic model is very sophisticated and uses macroscopic simulation for dynamic equilibrium traffic assignment supported by the Geographic Information System, a level of detail not available in most countries. Agyemang-Bonsu et al. (2010) used the COPERT 3 model to calculate emissions in three major cities in Ghana. The authors acknowledged that the vehicle registry has many shortcomings but did not provide information on how they adjusted the registry for the COPERT model.

Collection of detailed statistical data for different vehicle categories required by COPERT is a long and difficult process. As a result, some authors suggested using other methods, for example socio-economic information for emission estimations (Saija and Romano, 2002).

Previous studies showed that the data from existing registries often cannot be used directly in the emission calculation models for several reasons. First, the classification of vehicles in the registry differs from those in COPERT. Second, data on vehicle fuel types are often missing. Third, the registry does not have information about the emission class of vehicles (Agyemang-Bonsu et al., 2010; Cai and Xie, 2007). In Russia, many transportation experts believe that vehicle registries include many vehicles that are not used or are used only lightly. For example, according to the traffic police data only 75% of registered passenger cars and 65% of registered heavy-duty trucks go through mandatory annual inspections; this suggests that many vehicles are still registered but not being used.

Vehicle registries do not accurately reflect the distribution by type and emission class of the vehicles on city roads. For example, heavy-duty trucks registered in cities may be used somewhere else (for example in rural areas, or they may be banned from entering the city center). Using an uncorrected registry may result in overestimation of vehicular exhaust emissions.

In addition to these two approaches, fuel-based emission factors also can be used to calculate emissions. This approach is very simple and requires only data on fuel sold and fuel-based emissions factor. While data on fuel consumption might be available at the country level, it is difficult to obtain data on fuel consumption at the city level.

Recently, emissions from diesel vehicles has received significant attention. Diesel vehicles are a source of particulate and black carbon (BC) emissions. BC, a product of incomplete fuel combustion, has adverse effects on human health, including respiratory diseases and lung cancer (Fann et al., 2012). In June 2012, the World Health Organization reclassified diesel engine exhaust emissions as carcinogenic (WHO, 2012). Also, BC is a major climate change forcer, the second most powerful climate forcer after carbon dioxide (Bond et al., 2013). BC has a particularly pronounced impact on the climate in the Arctic, where it reduces the reflectance of snow, allowing the Earth to capture more of the Sun's heat (DeAngelo, 2011). Estimating BC emissions from on-road transportation requires separating diesel and gasoline-powered vehicles, which could be a challenge due to the lack of data. Developing a methodology that allows for estimates based on the diesel vehicle inventory is an important task for emission calculations.

This paper presents a methodology for vehicle emission calculations by integrating several approaches. Cities with limited traffic data can use the approach presented in this paper to collect more accurate information about traffic activity and to calculate vehicular emissions.

The rest of the paper is organized as follows. Section 2 provides a description of the proposed methodology. Section 3 discusses the application of the proposed methodology in Russia. Section 4 provides details on data collection in Murmansk, the largest Russian Arctic city. Section 5 shows the results of black carbon emission calculations from diesel vehicles in Murmansk; it also provides additional details on methodology, data collection and analysis. Finally, Section 6 summarizes the key findings.

2. Methodology

We developed a methodology for data collection and emission calculations by integrating several approaches:

- The International Vehicle Emissions (IVE) model (Lents et al., 2005).
- The COPERT model (Ntziachristos et al., 2009).
- Country-specific emission factors (NIIAT, 2008a, b).

We used the vehicle activity methodology developed for IVE to determine the number of vehicles on the roads on a given day. The International Sustainable Systems Research Center (ISSRC) developed a study process to gather the information to properly estimate vehicular emissions in any location worldwide. The US EPA sponsored the development of the IVE model that can be applied to any area to estimate emissions, especially in countries with limited data. The developers of the methodology conducted vehicle activity studies in many cities, and the data collection period took one to two weeks in each study. Though this approach cannot give very precise data on traffic, it helps with understanding of the key parameters of vehicle use in cities.

The IVE data collection approach involves video surveys, parking lot surveys, and driver surveys to determine the total traffic by vehicle type in central and suburban areas. IVE was designed for developing countries with fewer high-quality data sources, and this approach can be effectively used in places with insufficient transportation data. IVE was used at numerous sites for emission estimates, including Almaty (Lents et al., 2007), Beijing (Huan et al., 2005), Lima (Lents et al., 2004a), Mexico City (Davis et al., 2004), Pune (Lents and Davis, 2004), Santiago (Lents et al., 2001), Sao Paulo (Lents et al., 2004b) and Shanghai (Huang et al., 2005). The purpose of these studies was to develop a representative distribution of vehicle types, sizes, and ages of the operating fleet on various roadway types and to calculate vehicular emissions.

Allocation of the vehicle fleet to different emission standards (Euro classes) is key in developing an accurate emission inventory in COPERT (Ntziachristos et al., 2009). Vehicle registries, however, especially in countries where registries are out of date, are inadequate for emission calculations (Lents et al., 2007; Lents et al., 2005). In many countries, traffic police register all on-road vehicles but in many cases detailed data about on-road traffic by vehicle type and class are not available or vehicles registry quality is insufficient for emission modeling.

To accurately assess vehicular emissions, one should carefully determine the vehicle distribution per emissions class. If data on the vehicle emission standard are not available, year of production indicated in the vehicle registry could be used as a proxy for the emission standard. Parking lot

surveys can provide information on the age distribution of passenger cars. The largest transport companies can provide detailed data in the city for heavy-duty vehicles and/or buses. Vehicle inspection stations can provide information on age distribution, emission standards, and percentage of diesel cars.

The COPERT model uses European-specific emission factors, which do not exactly match those in other countries. However, the model allows the users to apply country-specific emissions factors¹. To calculate BC emissions, the BC/PM_{2.5} ratios for various types of vehicles from the European Environmental Agency's air pollutant emission inventory guidebook (EEA, 2013) should be applied.

Fig. 1 shows the integrated methodology for data collection and analysis.

Fig. 1. Methodology for estimating vehicle emissions.

Table 1 summarizes the main steps in collecting data and calculating emissions.

Table 1

¹ The recent study by Smit et al. showed that the COPERT Australia vehicle emission model is generally accurate at the fleet level when compared with similar international studies. However, the authors concluded that COPERT Australia underestimates emissions because the tunnel-based emission study indicated that emission factors in Australia might be higher than defaults in COPERT.

189 Step-by-step algorithm for emission calculations in cities with limited transportation data.

Steps	Results
1. Analyze the vehicle registry	Vehicle distribution by vehicle type, Euro emissions class and fuel type
2. Conduct parking lot surveys	Age of passenger cars; use vehicle age as a proxy for Euro emission standards. Fuel type for light-duty vehicles
3. Obtain information from a sampling of transportation companies	The distribution of heavy-duty trucks and buses by Euro class
4. Conduct video surveys	Vehicle counts by type of vehicles (Advance option is to count vehicles on various types of roads)
5. Adjust registry vehicle distribution	More realistic vehicle distribution Euro emission class and by fuel
6. Calculate average annual daily traffic (AADT)	AADT shows the average vehicles counts per day on various types of roads during all period of video surveys
7. Multiply AADT on each road category by the length of roads	Daily vehicle-kilometers traveled (VKT)
8. Divide VKT per year by the average kilometers traveled by different categories of vehicles	The number of vehicles on roads
9. Apply the adjusted registry vehicle distribution to VKT by vehicle type	The number of vehicles on the roads by vehicle type, Euro class, and fuel
10. Use COPERT	Exhaust emissions (hot emissions for all types of vehicles; cold emissions for light-duty vehicles only)

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191 Results of video surveys can be used to calculate average annual daily traffic (AADT). AADT
192 shows the total volume of vehicle traffic on a road for a year divided by 365 days. If video
193 surveys are conducted at several locations / types of roads, the traffic counts in each category
194 should be averaged to get the AADT for each type of road. We calculated AADT for each
195 vehicle type t on-road category i as the average daily vehicle count (Eq. 1).

$$196 \quad AADT_{ti} = \frac{1}{n} \sum_1^n V_{tni} \quad (1)$$

197 where i is the number of road categories; t is the vehicle type; n is the number of observation
198 spots and V_{tni} is the number of type t vehicles at the location n on-road category i .

199 We multiplied the AADT of each road category by the length of the roads to estimate the daily
200 VKT in the city per day (Eq. 2). VKT is calculated by multiplying the AADT value for each
201 category of road by the length of the roads (in kilometers) and summing all sections to obtain
202 VKT for all roads in the city.

$$203 \quad VKT_{ti} = \sum_1^i AADT_{ti} \times L_i \quad (2)$$

Where VKT_{ti} is vehicle-kilometers traveled by type vehicle t on-road category i ; $AADT_{ti}$ is average annual daily traffic on-road category i (vehicles); L_i is the length of road category i (kilometers).

We did not take into account the seasonal variations in traffic (Section 5 provides details about the difference in traffic activity during the summer and the winter). Hence, we multiplied VKT per day by 365 to estimate vehicle-kilometers traveled per year.

We used custom-made global positioning system (GPS) data loggers produced by the International Sustainable Systems Research Center to track the speed on the three types of roads; the loggers also provided data on road slope. We installed the loggers on a passenger car, bus, and heavy-duty truck to monitor vehicle speeds on the roads. For our study in Russia, we also used data from the Russian Yandex online traffic service to cross-check the speed.

COPERT requires the monthly maximum and minimum temperatures to calculate cold emissions. Local meteorological services can provide information about the meteorological conditions (minimum and maximum temperatures and humidity).

3. Applying the proposed methodology in Russia

We applied this methodology to calculate BC emissions in Murmansk, Russia. The Russian Federation became a member of the Climate and Clean Air Coalition in 2014 and took a voluntary obligation to develop its first BC emission inventory by 2016. Until now, the scale of BC emissions has not been studied sufficiently in Russia. Evans et al. (2015) presented one of the first estimates of BC emissions from diesel sources in Russia's Murmansk Region.

For the study of vehicle emissions in Murmansk, we used data from an independent consulting company that provides information about the registered vehicle fleet in Russian regions, based on the official data. We used the vehicle registry provided by the Russian company Avtostat (Avtostat, 2013).

The Russian government adopted European standards for on-road vehicles; the standards are now applied to both domestically produced and imported cars (Table 2). As a result, it is appropriate to use the COPERT 4 model to calculate emissions from on-road vehicles in Russia.

Table 2
Particulate matter (PM) emission standards for heavy-duty vehicles in the European Union and Russia, g/kWh.

Standard	PM emissions, g/kWh	Enforcement date in the European Union	Enforcement date in Russia
Euro I	0.36	July 1992	-
Euro II	0.15	October 1996	April 2006
Euro III	0.10	October 2000	January 2008
Euro IV	0.02	October 2005	January 2013
Euro V	0.02	October 2008	January 2016
Euro VI	0.01	December 2013	-

Russian research institutes developed several vehicle emission methods of their own. The Russian Scientific Research Institute for Automobiles and Transportation developed a methodology for emission calculations, which is based on COPERT 4 (NIIAT, 2008b). It uses

Russian-specific emission factors for PM_{2.5} based on the average for each emission class on Russian roads. We applied NIIAT emission factors to calculate vehicular emission using the COPERT 4 model.

This simplified version of COPERT, however, has much lower emission factors for cold starts for cars and light-duty vehicles than COPERT 4. As a result, we decided to use NIIAT emission factors for the hot operation stage and COPERT emission factors for cold starts.

4. Data collection and analysis in Murmansk

Murmansk is the largest city in the world above the Arctic Circle. The climate is relatively warm because of the Atlantic current in the Barents Sea. The average monthly air temperature varies between 7° and 14°C in summer and between -8° and -14°C in winter. Because of its extreme latitude, Murmansk experiences white nights during the summer and polar night during the winter.

The population of Murmansk is 300,000, and it is declining slowly, while the vehicle fleet has been growing rapidly. There were 95,500 vehicles registered in Murmansk City in 2012 and 100,200 vehicles in 2013. The number of vehicles per 1,000 inhabitants in Murmansk is higher than the Russian average. There were 334 vehicles per 1,000 people in Murmansk while the Russia-wide number is 257 vehicles per 1,000 people (Redkina, 2014). According to the Murmansk City Administration, there are 37 km of arterial roads, 58 km of highways and 43 km of local roads.

Murmansk is the largest city in the region. The transit traffic is very limited based on local geography the distant location of other major cities. Moreover, our analysis showed that many heavy-duty vehicles registered in the city actually work in the region. The video survey data collection method captures all vehicles on the roads. However, Murmansk accounts for 40% of the region's on-road fleet and there is relatively little transit traffic.

We used the 2012 Murmansk vehicle registry in our analysis (Avtostat, 2013). The vehicle registry shows that 82,500 cars, 8,200 light-commercial vehicles (LCVs), 4,400 heavy-duty trucks, and 470 buses were registered in Murmansk in 2012. About 65% of the trucks and buses were more than 10 years old. The registry does not typically contain the fuel type of the vehicles. We used various techniques described below to determine the percentage of diesel vehicles in the on-road fleet.

An important step in data preparation is the analysis of the vehicle fleet, namely determining the emission standard (i.e., level of controls) and other characteristics of vehicles (e.g., engine volume of cars, weight of heavy-duty trucks, or size of buses) required for emissions models. We began with the (both for Russian-made and imported vehicles). Researchers at Murmansk State Technical University (MSTU) checked information about each model of light-duty vehicles, heavy-duty trucks, and buses in the vehicle registry in Murmansk. We then supplemented this data using parking lot surveys for light-duty vehicles and detailed data from the largest transport companies in the city for heavy-duty vehicles. We also used information from MSTU vehicle inspection station

We collected data using video survey method developed for IVE as well as parking lot and other surveys and inspections. We selected nine representative locations to monitor traffic flows on

three categories of roads in the city – highways (Category I), arterial (Category II), and local roads (Category III). MSTU researchers conducted the video surveys to count total traffic by vehicle type in both central and suburban Murmansk (Supplement Tables S1 and S2 provide additional details about location and dates of the surveys).

Students recorded traffic flows using weatherproof video cameras from 7:00 to 1:00 in 20-minute intervals in June and July 2014. We multiplied the vehicle count during a 20-minute interval by 3 to get the traffic flow during an hour, and then interpolated data for the hours when there was no monitoring to determine the daily traffic. We recorded the traffic flows at each location over several days to minimize the effects of random events such as accidents, traffic jams, and road repairs. Researchers at MSTU counted the number of passenger cars, light-duty vehicles, trucks, and buses at selected locations. Because the volume of traffic depends on the day of week, we recorded traffic flow on weekdays and weekends and used a weighted average to correct the data.

The registry does not provide information on fuel type. We further analyzed the vehicle registry to determine the number of registered diesel vehicles in each category. We analyzed four types of diesel vehicles: passenger cars, light-duty vehicles, buses, and heavy-duty trucks. We did not include gasoline-powered vehicles because of their limited impact on BC emissions (Bond et al., 2004).

We used information about fuel type for various light- and heavy-duty vehicles from vehicle manufactures to determine fuel types of vehicles on the registry. We found that the diesel fleet in the city consisted of 2,600 light-duty vehicles, 3,900 heavy-duty trucks, and 260 buses.

We used parking lot surveys to determine the percentage of diesel cars in the Murmansk vehicle fleet. We selected the largest parking lots in different parts of the city and examined 2,235 cars. We found that the percentage of diesel cars in the fleet in Murmansk is 12%, which is higher than the Russian average (4%). We multiplied the total number of registered cars by the determined percentage of diesel cars and estimated that there are about 14,500 diesel passenger cars in Murmansk. The diesel fleet is growing but its percentage is far less than that in many European countries where the share of the diesel passenger cars is more than 30% (Cames and Helmers, 2013). In Russia, the percentage share of diesel trucks and buses are 62% and 45% respectively.

Based on the parking lot surveys, the average age of diesel cars in Murmansk is 5.6 years. Table S3 shows the results of parking lot surveys.

Our analysis shows that the vehicle registry does not reflect the structure of the vehicle fleet on the roads in Murmansk. We adjusted the registry data to show a more realistic vehicle distribution by emission standard. For passenger cars and light-duty vehicles, we adjusted these numbers based on the parking lot surveys and data from a vehicle inspection station. For trucks and buses, we adjusted the numbers based on data from the largest bus company and other commercial vehicle companies.

Fig. 2 shows the distribution of diesel vehicles by emission class in the registry and our adjusted estimates. The analysis shows that the percentage of vehicles without emission controls (Euro 0) on the roads is much lower than is shown in the registry. This supports our hypothesis that the vehicle registry does not reflect the actual vehicle fleet in the city.

Fig. 2. Distribution of diesel vehicles by emission class in Murmansk.

Table 3 shows the results of the video surveys (Supplement tables S4-S6 provide additional details about vehicle count; Table S7 shows the vehicle distribution by emission class). We used video surveys to calculate AADT on three categories of roads and VKT by type of vehicles in Murmansk.

Table 3

Results of video surveys for diesel vehicles in Murmansk.

	Cars	Light-duty vehicles	Heavy-duty trucks	Buses
Annual Average Daily Traffic (AADT):				
Arterial roads	2,088	772	295	198
Highways	1,818	705	463	94
Local roads	962	456	335	62
Annual Average Daily Traffic (AADT)	4,868	1,933	1,093	354
VKT, per day:				
Arterial roads	77,257	28,576	10,909	7,338
Highways	105,431	40,905	26,840	5,452
Local roads	41,375	19,597	14,416	2,666
VKT, per day, all roads	224,064	89,078	52,164	15,456
VKT, per year	81,783,291	32,513,500	19,039,890	5,641,562
Average annual kilometers traveled	15,000	35,000	35,000	45,000
Number of vehicles on roads, average day	5,453	929	546	124

We divided VKT per year by the average kilometers traveled by different vehicle categories to estimate the total fleet appearing on the roads (Table 4).

Table 4

Number of diesel vehicles on roads in Murmansk (based on video surveys).

	Cars	Light-duty vehicles	Heavy-duty trucks	Buses
Arterial	1,881	298	114	60
Highways	2,565	427	282	43
Local roads	1,007	204	150	22
All roads	5,453	929	546	124

The annual number of kilometers traveled is an important input to the COPERT model. We relied on several data sources to assess the average annual kilometers traveled. Based on information from NIIAT (NIIAT, 2008a), Avtostat (Avtostat, 2010), the MSTU inspection station, and regional transport companies, we made assumptions on the average annual number kilometers traveled by vehicle type. We assumed that cars travel 15,000 kilometers; light-duty and heavy-duty trucks, 35,000 kilometers; and buses, 45,000 kilometers.

Based on the video surveys, we found that Murmansk has a long, relatively stable traffic peak each day. This is a somewhat different peak traffic pattern than that found in many cities, but it matches anecdotal evidence from Murmansk. Fig. 3 summarizes the average traffic intensity by hour in Murmansk on an average summer day.

Fig. 3. Average number of vehicles per kilometer of road in Murmansk, by weekday hour.

We found that on average only 42% of registered diesel vehicles are on the roads on any given day. The ratio of registered vehicles to the vehicles on the roads is 55% for cars, 11% for light-duty vehicles, 34% for heavy-duty trucks, and 45% for buses (Table S.8).

5. Emission calculations and discussion

Using the methodology described, we calculated BC emissions from on-road diesel vehicles in Murmansk. For COPERT, we used the total number of vehicles on the roads because COPERT has only one class of emission factors for urban areas. For the NIIAT methodology for large cities we used three classes of emission factors, for each category of urban roads. In the universal NIIAT methodology we used one class of emission factors for urban roads.

We used NIIAT emissions factors instead of COPERT default emission factors because they better reflects the characteristics of the Russian diesel fleet. Tables S.9 and S.10 show hot stage PM emissions factors by vehicle type in the COPERT model and the NIIAT methodology.

As noted above, the NIIAT methodologies do not have data on BC/PM ratios. According to the EEA emissions guidebook, BC/PM ratios significantly vary for vehicles of various emission classes. For light-duty vehicles, these ratios vary from 0.55 for Euro 0 vehicles to 1 for Euro 5 vehicles. For heavy-duty vehicles (trucks and buses), the BC/PM ratio is 0.5 for Euro 0 vehicles and 0.75 for Euro V vehicles (EEA, 2013).

BC emissions come from two distinct stages of engine operations – cold start and hot operation. The COPERT and NIIAT methodologies take very different approaches to cold start emission calculations. In COPERT, cold start emissions from car and LCVs amount to 29% of the total emissions; the model is designed not to include cold start emissions for trucks and buses because the emission factors for cold starts are not available or cannot be reasonably estimated (EEA, 1997). The NIIAT methodology accounts for cold start emissions from all types of vehicles, but their percentage is much smaller (about 1% of the total emissions). In this regard, COPERT with NIIAT emission factors and the NIIAT model represent two different approaches to calculate vehicular emissions. Table S11 shows PM emission factors for cold starts from the NIIAT methodology, and Table S12 provided information about the engine warming-up time.

Using the COPERT 4 model with NIIAT emission factors for the hot operation stage, we estimated road BC emissions in Murmansk at 11.7 tons in 2014. Table 5 shows the distribution of BC emissions between the two stages of operations for all types of vehicles. The bulk emissions come from the hot stage, but cold starts also play an important role. For cars and light-duty vehicles, 37% of total BC emissions come from cold starts.

Table 5

Cold start and hot stage BC emissions in Murmansk by vehicle type, tons per year

	Cold start emissions	Hot stage emissions	Total
Cars	1.44	2.43	3.87
Light-duty vehicles	0.65	1.09	1.74
Trucks	-	3.90	3.90
Buses	-	2.18	2.18

Total	2.08	9.61	11.7
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Note: COPERT does not calculate cold start emissions for heavy-duty trucks and buses.

Table 6 shows the distribution of BC emissions between Euro classes for each vehicle type (see Table S.13 for additional details).

Table 6

BC emissions from on-road transport in Murmansk calculate using the COPERT 4 model with NIIAT emission factors, tons per year

	Cars	Light-duty vehicles	Trucks	Buses	Total
Euro 0	1.3	0.5	2.9	1.7	6.4
Euro I	0.0	0.0	0.0	0.0	0.1
Euro II	0.6	0.3	0.4	0.3	1.6
Euro III	1.7	0.8	0.5	0.2	3.1
Euro IV	0.1	0.2	0.0	0.0	0.4
Euro V	0.1	0.0	0.0	0.0	0.2
Total	3.9	1.7	3.9	2.2	11.7

About 55% of BC emissions come from Euro 0 vehicles. For example, heavy-duty trucks without emission controls constitute only 3% of the diesel vehicle fleet in Murmansk but emit about 25% of BC emissions from diesel on-road transport in the city. Euro 0 buses also are a large source of diesel exhaust, emitting an additional 14% of BC in the city.

The Russian government began regulating vehicle emissions when it introduced Euro 2 emission standard in 2006. As a result, there are relatively few Euro 1 vehicles. Euro 4 was the minimum standard for new vehicles (both domestically produced and imported) in 2013. The Euro 5 standard is not yet mandatory in most of Russia, and most Euro 5 vehicles in Russia are imported.

To analyze sensitivity, we compared our core calculations (which used COPERT with NIIAT emission factors) against several alternatives:

- NIIAT universal methodology
- NIIAT methodology for large cities
- COPERT 4 with NIIAT emissions factors but without adjusting the registry.

Figure 4 shows the results of these calculations. We used only one class of emission factors (for urban roads) for the COPERT model and the universal NIIAT methodology, while we applied three classes of the emission factors in the NIIAT methodology for large cities (for each category of roads). The main difference in emissions calculated by COPERT with NIIAT emission factors and the universal NIIAT methodology is caused by the difference in emissions from cars and light-duty vehicles. As noted above, how a cold start is considered plays an important role in total emissions from light-duty vehicles. As COPERT does not account for cold start emissions from heavy-duty trucks and buses, NIIAT methodologies account for these emissions.

Fig. 4. BC emissions from on-road transport in Murmansk, different methodologies, tons per year.

The results of emission calculations clearly show the advantage of the proposed methodology. Using uncorrected registry data results in a significant emission overestimation (by a factor of 5). While many studies of BC vehicle exhaust emissions at the national, regional, or even city level are based on information from vehicle registries, our analysis shows that official information, especially in countries with outdated registries, do not reflect the real situation on the roads. Researchers should be aware of this discrepancy to avoid overestimation of emissions from on-road vehicles.

Another important factor in emission estimates is the seasonal variations in traffic. For this study, we monitored traffic flow on three different categories of streets over the summer of 2014. For sensitivity analysis, we also conducted an additional video survey in November and December. Murmansk is located on the coast of the Arctic Barents Sea. The climate is mild due to warm current, but with 180-200 days with snow on the roads, the traffic differs in the winter in three specific ways: 1) the speed is much slower; 2) fewer passenger cars are on the roads; and 3) more buses are on the roads (public transportation companies are required to increase the number of buses on routes). Our analysis shows that emissions from on-road vehicles in the winter are similar to those in the summer. These variations could be more significant in other cities.

There are several sources of uncertainty in emission estimates. The sources include uncertainty in PM emission factors, BC/PM ratios, and assumptions about emission controls and activity data.

We used PM emission factor from the EEA emission guidebook and the NIIAT methodologies. Emission factors in EEA and NIIAT methodologies are functions of the vehicle type (emission standard, capacity, or weight); EEA also accounts traveling speed. Neither of these methodologies report uncertainty in emissions factors.

According to the EEA methodology, uncertainty in BC/PM ratio for cars and light-duty vehicles is 5-10% while uncertainty for heavy-duty vehicles is 20%. The NIIAT methodologies do not include information of BC/PM ratios.

Additional uncertainties exist in assumptions about vehicle usage and distribution by emission class. Video surveys show that there are 546 heavy-duty trucks on the roads on an average summer day, and 42% of the observed trucks have no emission controls. The vehicles registry lists more than 4,400 trucks and more than 50% are Euro 0 vehicles. Murmansk banned heavy-duty trucks from entering the city center, but they actively work at the Murmansk Port. We carefully selected representative roads in the city, but we cannot exclude uncertainty in activity data.

We did not account for emission degradation due to vehicle age. For diesel vehicles, emissions typically are constant for new cars during their first two years of operation, then the emissions increase and stabilize at a much higher level for 10-year-old vehicles (Yan et al., 2011). Without annual emissions checks, it is difficult to assess whether exhaust emissions correspond to the assigned emission standard.

In our study, we did not count super-emitters. Super-emitters are vehicles that use the poorest technology or with the worst maintenance. According to estimates by (Yan et al., 2011), super-emitters consumed 7.3% of fuel in 2010 globally but emitted 39.3% of PM emissions. Poor maintenance of old and even new vehicles can significantly increase emissions.

6. Conclusions

The paper presents a methodology for calculating emissions from on-road vehicles in cities. This methodology can be used in cities with limited or low-quality transportation data to estimate emissions from the vehicle fleet. We also proposed additional steps to calculate PM and BC emissions from diesel vehicles.

The vehicle registries are often outdated and do not reflect the actual vehicle fleet on the roads. Using uncorrected registry data results in a significant emission overestimation. We used parking lot surveys, information from vehicle inspection stations and data from the sampling of the largest transportation companies to correct vehicle registries. These data collection methods provide accurate information about the distribution of vehicles by type, emission class and fuel. Separating diesel vehicles from the total vehicle fleet enables calculation of PM and BC emissions.

The COPERT model provides accurate estimation of exhaust emissions. COPERT also allows users to apply country-specific emission factors that improve the quality of the emission calculations. Users can also apply the default European emission factors if information about the local emission factors is not available.

We used the proposed methodology to calculate BC emissions from diesel on-road vehicles in the populous Murmansk, located in the Russian Arctic. Using information from the largest transportation companies we adjusted the heavy-duty engine distribution by emission class and fuel type. We collected the vehicle traffic data using video surveys on three categories of roads. The video surveys shows that the percentage of the vehicles on the roads to the registered vehicles was 55% for cars, 11% for light-duty vehicles, 34% for heavy-duty trucks, and 45% for buses. Parking lot survey showed that the percentage of diesel passenger cars is 12% and we

adjusted the vehicle registry based on this information. Data from the vehicle inspection station provided additional information about the vehicle distribution by emission class and fuel.

We used the COPERT model and two NIIAT methodologies to calculate PM and BC emissions from diesel vehicles in the city. Our core calculations (which used COPERT with NIIAT emission factors) show that diesel vehicles emitted 11.7 tons of BC in 2014. BC emissions calculations using the COPERT model and the NIIAT methodologies show similar results if using data from video surveys. We found that the main factors determining the level of BC emissions are the structure of the vehicle fleet and the level of vehicle emission controls. About 55% of BC emissions come from Euro 0 vehicles. Old heavy-duty trucks without emissions controls are the largest source of BC emissions.

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