Response to reviewers' comments

Review of "Comparison of the predictions of two road dust emission models with the measurements of a mobile van" by M. Kauhaniemi et al.

Response to anonymous Reviewer #1

We would like to thank the anonymous Reviewer #1 for his/her comments and suggestions. Our response to the reviewer comments is provided below. The reviewer's comments are numbered and written in italic.

1.

The authors describe the predictions of two road dust emission models which are compared with mobile measurements of tyre-induced suspension of road surface dust. Neither model performs particularly well and probably the most useful outcome of the paper is a better appreciation of the complexity of describing the processes determining the resuspension flux, and the consequent difficulties in estimating it. Before attempting such an exercise again, the authors need to think very carefully about how best to design their experiments in ways that go well beyond the provisional thinking revealed in their conclusions.

Answer

Yes, we agree on these comments. We will revise the conclusions, including a much more detailed description of the optimal design of future experiments.

2.

One of the key variables in resuspension processes is the surface loading of particulate matter in the appropriate size fraction on the road surface. One of the models appears to have the information to calculate the surface dust loading but does not output the data, whilst the other model depends upon reference values of emission factors for road sanding and non-road sanding periods which are adjusted according to the prevailing road surface conditions. Failure to calculate the road surface dust loading, and failure to verify through measurements is a very important weakness. If such an exercise had been conducted, there would be greater clarity as to the reasons for model under-performance.

Answer

Both models evaluate the surface dust loading. The NORTRIP model calculates the road dust loading due to road wear, salt and sanding (in g/m^2). This is the basis (source) of the suspension presented in the article. The FORE model on the other hand uses a normalised dust loading, so the actual loading (in units of g/m^2) is not known, but is always relative to a maximum value defined relative to a maximum emission factor. We have used the reference emission values measured for Hornsgatan in Stockholm. Unfortunately, no measurements of road dust loading were available in Helsinki and so no comparison could be made for either model with modelled and measured loading. The authors agree with the reviewer that any future campaigns should include measurement of this parameter. The description of the above mentioned evaluation of dust loading should be described more clearly in a revised manuscript.

3.

One of the underlying assumptions in this work is that movement of tyres over the road surface is the process determining resuspension and no consideration is given to turbulence in the vehicle wake as a cause of resuspension. This assumption may be correct but requires justification.

Answer

The suspension in the models is described 'per vehicle' so it is all inclusive. We have not assumed that the vehicle–induced turbulence would be negligible. However, the models are not so advanced that they would distinguish between suspension due to direct tyre suspension and suspension due to vehicle turbulence. The observations on the other hand, taken from behind the wheel of the vehicles, imply that suspension is mainly from this source, though a certain amount of turbulence induced suspension will also be included in these measurements. Also measurements are not available to delineate between these two types of suspension. It is to be expected that the vast majority of suspension comes from the road tyre interaction for light duty vehicles (of the type used by SNIFFER). However, this assumption may not be the case for heavy duty vehicles. The manuscript should be clarified in terms of the impacts of vehicle-induced turbulence.

4.

Another factor requiring some thought is whether for a given tyre type (winter, summer, studded), the configuration of the tyre tread and the extent of wear of the tyre is a significant factor. The SNIFFER mobile laboratory used in this work has to be "calibrated" against emission factors and this exercise has been conducted. However, have the measured relationships changed due to wear or changing of tyres?

Answer

We agree with the referee that the tyre type affects the road wear and also the emission of resuspended road dust as demonstrated and discussed in e.g. Kupiainen & Pirjola (2011). Consequently the tyre type has effects on resuspended emission factors. However, the variability in emission factors between studded and studless winter tyres with speeds 40 and 50 km/h was 10 to 20 percent; these are within the uncertainty observed in the road measurements, Kupiainen & Pirjola (2011). The difference between tyre types, i.e. studded vs studless tyres and also different tread patterns of the winter tyres, is an interesting one and we aim to continue to study and measure them, as new tyre models will come to market. Also these aspects could be discussed in a revised manuscript.

5.

A further point which needs consideration especially in relation to the FORE model is how results will be extrapolated to other street locations. If the emission factors are to be incorporated within an urban model, then they need to be known for a range of street types rather than just a single street. The work with the FORE road dust model used reference values determined on a street in Stockholm but there appears to be no way in which these can be modified or made suitable for use in other locations. This is a huge weakness in the present approach unless a vast amount of work is done to determine reference emission factors for a wide variety of road situations.

Answer

The reference emission factors used in the FORE model can be calculated for other locations according to a fairly simple method described in Omstedt et al. (2005). This method can be used if both urban background and roadside concentrations of NOx and PM are available. In this study, these datasets were not available, and thus, the reference emission values estimated by Omstedt et al. (2005) were used. However, the model could be used in the future for a range of locations (or approximately even for a whole city or whole metropolitan area); but this requires some additional analysis of experimental datasets.

6.

There are also a number of relatively minor points requiring some attention:

(a) On page 4274, reference is made to a fraction of 0.2% PM10 in the applied road sand, based upon previous measurements. Does this percentage change in use as a result of the grinding of the sand by continuous vehicle movement?

Answer

In the application of the NORTRIP model in this article the percentage of sand that is PM10 is fixed, i.e. no grinding of the sand was included. Though this grinding, and also abrasion, process is described in the NORTRIP model, there is not enough observational data available to properly parameterise this with any level of certainty. The FORE model makes no such distinction. As previously mentioned, it uses a normalised loading, in which it is assumed that half of the loading is originated from sanding.

(b) The authors point out that one of the weaknesses relates to use of hourly data on the occurrence and intensity of precipitation (page 4282). Would it be preferable in future work to make on-site measurements of greater temporal resolution?

Answer

In the further studies on-site weather data should be used, if possible. The use of finer temporal resolution is not possible in the current version of the FORE model, as the model uses hourly average input data. The NORTRIP model can use other time steps than 1 hour.

7.

In summary, the paper can be recommended for publication, not because of what new knowledge it creates but because of its contribution to highlighting knowledge deficiencies which require resolution in order to enhance the skill of predictive models. These issues should be reflected more clearly in the final version of the paper.

Answer

We agree with the referee; the deficiencies and difficulties in estimating the processes of the resuspension flux need to be highlighted in the paper more clearly. This will be corrected in the revised manuscript.

References

Kupiainen., K. & Pirjola, L.; Vehicle non-exhaust emissions from the tyre–road interface – effect of stud properties, traction sanding and resuspension. Atmos. Environ., 45, 4141-4146, 2011.

Omstedt, G., Bringfelt, B., and Johansson, C.: A model for vehicle-induced non-tailpipe emissions of particles along Swedish roads, Atmos. Environ., 39, 6088-6097, 2005.

Response to anonymous Reviewer #2

We would like to thank the anonymous Reviewer #2 for his/her comments and suggestions. Our response to the reviewer comments is provided below. The reviewer's comments are numbered.

1.

General comments

The well written manuscript deals with a comparison of measurements and model results for non-exhaust road dust emissions. This is an interesting topic of increasing relevance since traffic PM emissions will be dominated by non-exhaust emissions in the near future. The authors give a detailed introduction to the topic covering lots of previous work and describe both the used measurements and models in great detail (maybe a bit too long). However the attempted comparison of very different type of data has some serious flaws and weaknesses.

There are simply too many unknown parameters and not fully justified underlying assumption involved when comparing 10 second resolution on-road mobile measurements over relatively short periods with modelled 1 hour time series over several years. The measurements are influenced by unaccounted and very local road conditions, variable driving speeds and data with great scatter are averaged to 20-25 hourly averages only. These type of mobile measurements seem to have their strength in studying the

dependencies on single parameters as driving speed; type of tires or spatial variation of the road dust suspension, while less suited for long term measurements monitoring day to day variations.

Answer

We agree with the referee that the low temporal representativity of the measurements is probably the most important limitation of the dataset; we have discussed this in the manuscript. It is also correct that the measurements are influenced by a number of various factors, and it is therefore not so straightforward to conduct such measurement vs. model comparisons in the field. Probably the main importance of this manuscript is, as stated by reviewer 1, "… the most useful outcome of the paper is a better appreciation of the complexity of describing the processes determining the resuspension flux, and the consequent difficulties in estimating it."

2.

The presented models are based on meteorological data from a central location and average road and meteorological conditions. The models were developed and validated for reproducing time variations of average fleet re-suspension emission factors on a very well defined location as done e.g. for Hornsgatan in Stockholm. In order to make modelled total fleet average fleet emissions comparable with the measured van emissions some assumptions about two additional parameters (rpCar=0.7 and rHDV= 10) have to be made. These parameter taken from the literature might be very uncertain (missing sensitivity study) and could be dependent on road and weather condition and vehicle speed and therefor variable from day to day and in-between seasons.

Answer

It is true that the use of parameter values, such as those for r_{pCar} and r_{hdv}, to make the modelled total fleet emission factors comparable with the measured van emission factors brings uncertainty to the study; this has been pointed out in the paper. However, the state-of-the-art is that the exact variation of these parameters on factors, such as those listed by the reviewer, are not known; we have therefore simply used the best available numerical values based on experimental data. The variation of the values of these parameters could be studied in a separate study, and we have actually already planned to perform such emission factor measurements for passenger cars and trucks in the future.

3.

A fixed permanent monitoring site in Helsinki is missing in the study to bridge the gap between both data sets. Such data are needed in order to calibrate the models to reproduce the temporal variation in emissions correctly under Helsinki conditions. In the moment both models rely on data from Stockholm without knowing if they are applicable in Helsinki; in FORE the reference emission factors; in NORTRIP the road wear rates and the suspension factor. Moreover the mobile SNIFFER results could be calibrated when passing the fixed monitoring site.

Answer

Both models (FORE and NORTRIP) have been previously used in combination with dispersion models, and the combined modelling system has been evaluated against stationary air quality measurements, e.g., in Kauhaniemi et al. (2011) and Denby et al. (2013a,b); these studies have been mentioned in the manuscript. In these previous studies, no systematic under-prediction of concentrations was detected.

In Helsinki, there is both a measurement site network maintained by the local council (HSY), and a supersite maintained by the University of Helsinki and the FMI. However, although these measurements are extensive in terms of air pollutants, these do not contain some specific measurement that are important for PM suspension, such as, e.g. detailed measurements of the dust loading and moisture at the road surfaces.

The calibration of the SNIFFER measurements also requires a specifically planned campaign, such as the one described on pp. 4275-4276 in the manuscript. Such a campaign has been conducted in Helsinki, and

used for the calibration of the SNIFFER measurements, as described in the manuscript on the above mentioned pages, and in more detail in Pirjola et al. (2012).

4.

The uncertainty analysis is well done and states a lot of the reasons for the discrepancies between the model and measurements. The conclusion of the authors that "road dust emission models can be directly compared with mobile measurements" is certainly overstating the results in the moment. The presented comparison between the measurements and the two models is very uncertain due to the very few data points. The bias are very high and the correlation partly non-existing. Just the very overall feature of the seasonal variation fits roughly even though there are very few SNIFFER data outside the road dust season. The above mentioned aspects should be reflected in a revised manuscript in case of further publication.

Answer

After reconsidering the results, we agree with the referee: "road dust emission models can be directly compared with mobile measurements" is an overstatement, and needs to be removed throughout the manuscript.

5.

Specific comments

Several of the figures need revision. It is misleading to present the total emission factors graphical together with the measurements, both in the time series plots (Fig 3 + 6) and the scatter plots (Fig 4 + 7). Only EF (van) should be presented. Also it is impossible to relate the exact hourly timing of the measurements to timing in the models, i.e. several measurements appear at virtually the same time in the plot. Therefor consider to a) plot measurements together with both models in one graph in order to show the differences in-between the models as well and b) to show some shorter time periods zoomed around some measured data points. The plots of the modelled values are hard to read in the figures (especially in Fig. 5.+ 6.) due to the frequent and overlapping vertical lines. Consider other ways of plotting e.g. small symbols instead of connecting lines or expanding x- axis / zoom.

Answer

We agree that Fig 5 is hard to read and it will be revised. We also agree that Figs 4 and 7 are not necessary, as the same information is shown in Tables 2 and 4 and in Figs 3 and 6; these will be removed.

References

Denby, B. R., Sundvor, I., Johansson, C., Pirjola, L., Ketzel, M., Norman, M., Kupiainen, K., Gustafsson, M., Blomqvist, G., and Omstedt, G.: A coupled road dust and surface moisture model to predict non-exhaust road traffic induced particle emissions (NORTRIP), Part 1: road dust loading and suspension modelling, Atmos. Environ., 77, 283-300, DOI: 10.1016/j.atmosenv.2013.04.069, 2013a.

Denby, B. R., Sundvor, I., Johansson, C., Pirjola, L., Ketzel, M., Norman, M., Kupiainen, K., Gustafsson, M., Blomqvist, G., Kauhaniemi M., and Omstedt, G.: A coupled road dust and surface moisture model to predict non-exhaust road traffic induced particle emissions (NORTRIP). Part 2: surface moisture and salt impact modelling, Atmos. Environ., 81, 485-503, 2013b.

Kauhaniemi, M., Kukkonen, J. Härkönen J., Nikmo J., Kangas L., Omstedt G., Ketzel M., Kousa A., Haakana M., and Karppinen A.: Evaluation of a road dust suspension model for predicting the concentrations of PM10 in a street canyon, Atmos. Environ., 45, 3646-3654, 2011.

Pirjola, L., Kupiainen, K. J., Ritola, R., Malinen, A., Niemi, J., Julkunen, A., and Virtanen, T.: Non-exhaust PM10 emission factors, Proceedings of Abstracts for the 8th International Conference on Air Quality – Science and Application, 19–23 March 2012, Athens, Greece, p. 10 249, 2012.

List of relevant changes in the manuscript

Added (page 1 line 10):

[4] {Finnish Environment Institute, P.O. Box 140, 00251 Helsinki, Finland}

Changed (page 2 lines 1-3):

The results indicate that road dust emission models can be directly compared with mobile measurements; however, more extensive and versatile measurement campaigns will be needed in the future. → The article illustrates the challenges in conducting road suspension measurements in densely trafficked urban conditions, and the numerous requirements for input data that is needed for accurately applying road suspension emission models.

Added (page 3 line 21):

Omstedt et al., 2011

Changed (page 4 lines 3-5):

The aim of this paper is to evaluate, whether the predictions of two road dust emission models, FORE (Kauhaniemi et al., 2011) and NORTRIP (Denby et al., 2013a, b), can be quantitatively compared with emission factor measurements using a mobile van. → The aim of this paper is to compare the predictions of two road dust emission models, FORE (Kauhaniemi et al., 2011) and NORTRIP (Denby et al., 2013a, b), with emission factor measurements obtained using a mobile van.

Added (page 6 lines 14-16):

Non-studded winter tyres (also called as friction tyres) were used in the SNIFFER van during the whole measurement period, both in 2007 and 2008.

Added (page 9 lines 3-6):

The reference emission factors can be computed according to a method by Omstedt et al. (2005), which allows the model to be used in wide variety of street locations or a whole city. The use of this method requires the data of both roadside and urban background concentrations of NOx, and PM10 or PM2.5.

Added (page 9 line 7):

or the roadside concentrations

Added (page 9 lines 14-16):

The dust loading is normalised; the actual loading (in units of g m^{-2}) can be evaluated relative to a maximum value.

Added (Page 10 lines 1-2):

The model can also be used to evaluate the road dust loading due to road wear, salt and sanding (in g m^{-2}).

Added (page 10 line 32 – page 11 line 3):

In the application of the model in this article, the percentage of sand that is PM10 was assumed to be constant, i.e., no grinding of the sand was included. The observational data was not sufficient to properly parameterise this effect.

Changed (page 14 lines 9-12)

We have also presented the scatter plots of the measured and modelled hourly average suspension emission factors during dry periods in 2007 and 2008 in Kaisaniemenkatu and Sörnäisten rantatie in Fig. 4. The scatter of data points is substantial. → The values of the statistical parameters, such as the index of agreement and the correlation coefficient, indicate from a moderate to weak correlation of the individual predicted and measured data values.

Changed (page 15 line 6)

Fig. 5 → Fig. 4

Changed (page 15 line 14)

Fig. 6 → Fig. 5

Added (page 16 lines 17-22)

The measurements were done with a vehicle that was equipped with non-studded winter tyres during the whole study period. However, both models allow also for suspension emissions from vehicles that are equipped with studded tyres. Clearly, the type of tyre influences the resuspension emission factors. However, the variability in emission factors between studded and studless tyres was found to be moderate by Kupiainen and Pirjola (2011), it varied from 10 to 20 %, at vehicle speeds of 40 and 50 km h^{-1}.

Added (page 18 lines 9-17)

Neither of the models used can distinguish between (i) the suspension caused by vehicle tyres and (ii) the suspension caused by vehicle-induced turbulence. The observations are performed behind a wheel of a laboratory van. This location has been selected, as the suspension caused by vehicle tyres is probably the most important mechanism for light-duty vehicles (such as the SNIFFER van). However, some fraction of suspension will also be caused by the vehicle-induced turbulence associated with the whole traffic flow. Neither measurements nor models can delineate between these two mechanisms for causing suspension emissions. Clearly, the suspension caused by traffic-induced turbulence is more significant for heavy duty vehicles, compared with light-duty vehicles.

Added/changed (page 19 lines 5-7)

However, there are numerous sources of inaccuracy both (i) in conducting suspension emission measurements in an urban traffic environment, and (ii) in determining the input values for the models and conducting the suspension modelling. Consequently, more extensive and versatile measurement campaigns in various environments and conditions would be welcome for the refinement of suspension emission models.

Added/changed (page 20 lines 1-4)

Such a measurement set-up would aim to achieve as good temporal coverage as possible during the selected measurement days and hours. The measurement data should include both peak suspension periods in spring and lower values during other seasons.

Added/changed (page 20 lines 11-22)

The campaign should also include on-site meteorological measurements, especially for precipitation, to avoid inaccuracies caused by the spatial variation of the relevant meteorological quantities in an urban area.

It would be useful to continuously measure the moisture on the street surface; designated equipment is available for this purpose. A road weather model could also be used for a detailed evaluation of the state of the road surface. Measurements of the street pavement structure could be used for a more accurate evaluation of the dust absorption and run-off from the road. It is also valuable to record all the street maintenance activities, such as the use of traction sand and salt, and street cleaning procedures, on a fine temporal resolution. The information regarding the street maintenance activities should ideally also include the mass of used traction sand and salt. This would facilitate a more direct evaluation of the predicted road dust loading (that is predicted by both of the used models) against measurements.

Added (page 24 lines 26-28)

Kupiainen, K. and Pirjola, L.: Vehicle non-exhaust emissions from the tyre-road interface – effect of stud properties, traction sanding and resuspension. Atmos. Environ., 45, 4141-4146, 2011.

Added (page 25 lines 11-14)

Omstedt, G., Andersson, S., Gidhagen, L., and Robertson, L.: New model tools for meeting the targets of the EU Air Quality Directive: description, validation and evaluation of local air quality improvement due to reduction of studded tyre use on Swedish roads, Int. J. Environ. Pollut., Vol 47, No. 1/2/3/4, pp. 79-96, 2011.

Changes in Figures

Scatter plots (Fig. 4 and Fig. 7 in the original manuscript) were removed, as the same information is shown in Tables 2 and 4 and in other figures. Thus the following figure numbers were changed: Fig. 5 → Fig. 4 and Fig. 6 → Fig. 5.

The Fig. 4 (Fig. 5 in the original manuscript) was revised as the old version was hard to read.