Traffic induced road dust emission modelling: The NORTRIP model

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Abstract

Non-exhaust traffic induced emissions are a major source of particle mass in most European countries. This is particularly important in Nordic and Alpine countries where winter time road traction maintenance occurs and where studded tyres are used. In this paper a brief description of the NORTRIP (NOn-exhaust Road TRansport Induced Particle) emission model is provided along with two example applications in the cities of Stockholm and Copenhagen. The model provides a generalised process based formulation of the non-exhaust emissions, with emphasis on the contribution of road wear, suspension, surface mass loading and the possibility to include salt and sand in the emissions. Two examples demonstrate the importance of surface retention and suspension on the temporal variability of the emissions. In addition the impact of studded tyres, of salting and of the road surface material is discussed. These factors can have a larger impact on traffic induced PM_{10} emissions than the exhaust emissions themselves.

Introduction

Particle matter is still a problem in most EU member states with many exceedances of the limit values still occurring. In 2010 33 % of the traffic sites exceeded the 24-hour limit value for PM_{10} indicating that traffic is a significant source (EEA, 2012). Whilst European legislation addresses exhaust emissions (EC, 1998), non-exhaust emissions remain unregulated. This is despite the fact that non-exhaust emissions of PM_{10} are estimated to contribute as much to the total traffic related emissions in European cities as exhaust emissions (Gehrig et al , 2004; Querol et al., 2004). Indeed European legislation (EC, 2008) actually allows exceedances resulting from road maintenance activities, salting and sanding, to be negated for compliance checking purposes. Non-exhaust emissions are particularly important in Nordic and Alpine countries where winter time road traction maintenance occurs and where studded tyres are used.

Modelling the non-exhaust emissions is a challenging task as they are sensitive to environmental factors such as road surface moisture, road maintenance activities (salting and sanding) and tyre and vehicle types. The ability to model these emissions is desirable as this provides the potential for more effective road management and improved assessment of mitigation strategies for reducing emissions. Most emission models, used for air quality applications, treat the non-exhaust emissions as emission factors. Some may include the impact of surface wetness, usually through some parameterisation related to atmospheric humidity and/or precipitation, e.g. Pay et al. (2011), to account for the retention of particles on the surface under wet conditions. However, these models do not account for the build up of dust on the road surface and cannot be used to assess mitigation strategies to any effective degree.

The NORTRIP (NOn-exhaust Road TRansport Induced Particle) emission model has been developed within the Nordic project NORTRIP (Johansson et al., 2012) and builds upon existing road dust emission models (Berger and Denby, 2011; Omstedt et al., 2005), combined with field and laboratory measurements. The NORTRIP model is a comprehensive and generalised process based model for non-exhaust emissions, with emphasis on the contribution of road wear, salt and sand to the emissions. This approach provides the potential for the model to be used as a tool for air quality management.

In this paper the model concept is briefly outlined before providing two model applications. A complete description of the model can be found in Denby and Sundvor (2012). We emphasise here that the reduction of traffic related PM emissions cannot be obtained through exhaust emission controls alone and that non-exhaust emissions, and the processes affecting these,

must also be understood and controlled if significant reductions in traffic related PM emissions are to be achieved.

A conceptual outline of the model

There are some basic elements to the model that need to be described if it is to fulfil its aim as a process based modelling tool to aid air quality planning. These include:

1. Determination of vehicle related wear rates (road, tyre and brake), and their direct emission or accumulation on the road surface. Emissions are dependent firstly on wear and then secondly on size distribution of that wear. These may be vehicle type, tyre type, vehicle speed or wear source dependent.

2. A description of emissions through traffic induced suspension of road dust, sand and salt loading. The suspension will depend on vehicle tyre type, vehicle speed, road surface characteristics and importantly surface moisture.

3. Calculation of the road dust and salt loading, dependent on the road dust and salt mass balance, is required to estimate suspension rates.

4. Retention of the direct and suspended emissions based on road surface conditions, requiring a description of surface wetness. Surface moisture modelling to achieve this, if no observations are available, also requires a mass and energy balance approach and will need to include processes such as evaporation, drainage, vehicle spray, etc.

The key elements of the NORTRIP modelling system, as described in Denby and Sundvor (2012), are presented schematically in Figure 1.

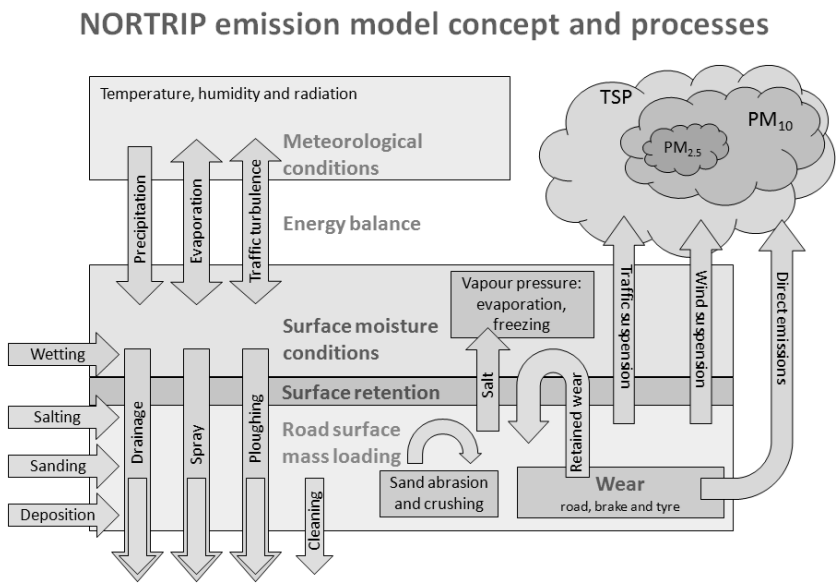

Figure 1: Schematic outline of the NORTRIP emission model.

The four conceptual elements outlined above are included in two coupled sub-models: A road dust sub-model and a road surface moisture sub-model.

Road dust sub-model: This predicts the road dust and salt and sand loading through a mass balance approach as well as the emission through direct wear and through suspension of these loadings. Mass is deposited on the surface by wear (road, tyre and brake) and by the addition of salt and sand. Mass is removed by suspension, drainage, splash/spray and by road maintenance activities.

Road surface moisture sub-model: This determines road surface conditions (water and ice) essential for the prediction of retention of road dust mass and suspension from the road

surface. A surface mass balance approach is also applied here, including evaporation/condensation, drainage, splash/spray, precipitation, refreezing and road maintenance activities.

Example applications

The model has been applied to 14 datasets from 7 different sites in Stockholm, Helsinki, Oslo and Copenhagen. At all of these sites traffic and background concentrations of PM_{10} and NO_X are available. NO_X is used as a tracer, in conjunction with estimated NO_X emissions, in order to convert PM emissions to concentrations at the measurement sites. In all cases the observed net concentrations (traffic – background) are compared to the model. In this paper we present results chiefly from two sites where observed moisture is available to determine surface retention. This reduces the uncertainty related to moisture modelling and provides more insight into the road wear and suspension processes.

Impact of surface retention and studded tyres: Hornsgatan, Stockholm.

Five years of data are available from this street canyon site. In the last two years a ban on studded tyre use was implemented and this reduced the proportion of cars using studded tyres from around 70% to 35%. In Figure 2 we show an example (October 2008 – July 2009) of the model calculations. The studded tyre season starts in November and finishes at the end of April. Shown are the daily mean concentrations, the surface mass loading and the effective emission factor. For this period the contribution from road wear is estimated to be 75% of the total PM_{10}. Of this approximately half is the result of suspension of retained dust.

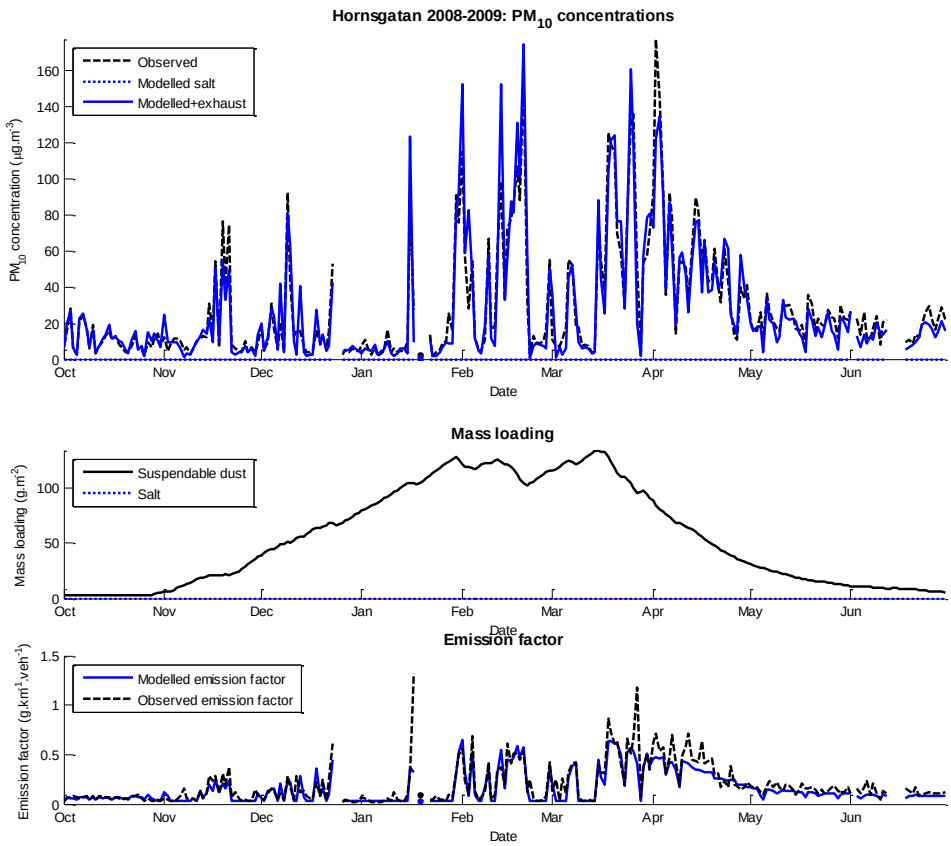

Figure 2: Results of the model application at Hornsgatan for the period October 2008 to June 2009. Top: Daily mean modelled and observed concentrations of PM_{10}. Middle: Surface mass loading of suspendable dust (no salt applied in this case). Bottom: Effective emission factor calculated by the model and derived from observations. Observed surface moisture is used for the model runs.

Contribution of salt: H.C. Andersen Boulevard (HCAB), Copenhagen.

Two years of data are available from this open street canyon site. No studded tyres are used in Copenhagen but salting information is available. This street is known (Wåhlin et al., 2006) to give higher PM_{10} emissions than other streets in Copenhagen and it is suspected that this is a result of the material used in the road surface, consisting of steel slag. The wear rate for non-studded tyres, based on observed concentrations, is estimated to be around 4 – 5 times higher than for Hornsgatan.

An example for 2007-2008 is shown in Figure 3 where salt has also been included in the calculation. The inclusion of salt leads to an enhancement of the PM_{10} emissions by around 17%. Indeed the salt contribution is estimated, for the study period, to be very similar to the exhaust contribution. The contribution from road wear to the total PM_{10} is estimated to be 55% in this case. Such estimates are confirmed by other studies at the same site using receptor modelling (Wåhlin et al., 2006), In that study the contribution to PM_{10} from salt was found to be 23% and from road dust 43% for a four week period in 2003-2004.

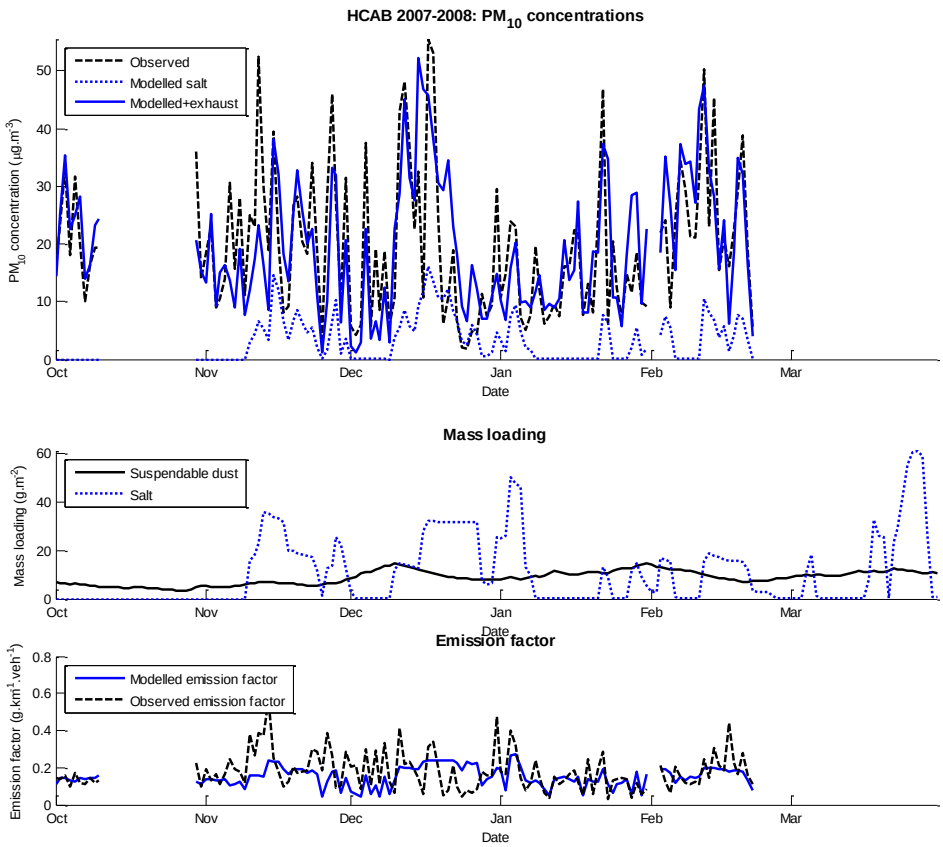

Figure 3: Results of the model application at HCAB for the period October 2007 to April 2008. Top: Daily mean modelled and observed concentrations of PM_{10} including salt. Middle: Surface mass loading of suspendable dust and salt. Bottom: Effective emission factor calculated by the model and derived from observations. Observed surface moisture is used for the model runs.

Summary of the model results at the two sites

In Figure 4 we show the mean PM_{10} concentrations and in Figure 5 the daily mean PM_{10} correlation for the seven datasets from these two sites. To emphasise the importance of surface retention the model is run with retention/suspension, as in Figures 2 and 3, and without retention/suspension. For HCAB the results with retention also include salt. For Hornsgatan the surface moisture has a very large impact on the temporal variation (correlation) of the emissions but has less impact on the total means. For HCAB the correlation is lower but improves with the inclusion of retention/suspension.

The contribution from road wear

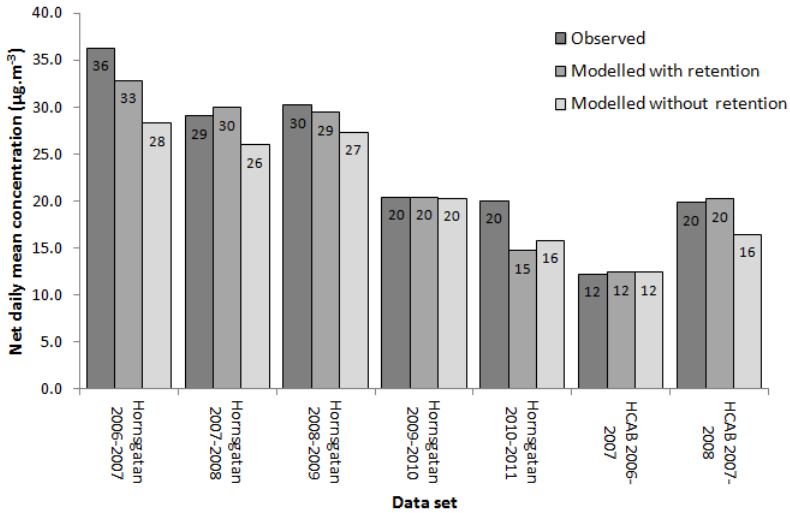

Figure 4: Net mean concentration of observed and modelled PM_{10} for the 7 data sets. The period modelled for Hornsgatan is October – June and for HCAB the period is October – May. Shown are the results with and without retention/suspension in the model. Observed moisture is used for the model runs.

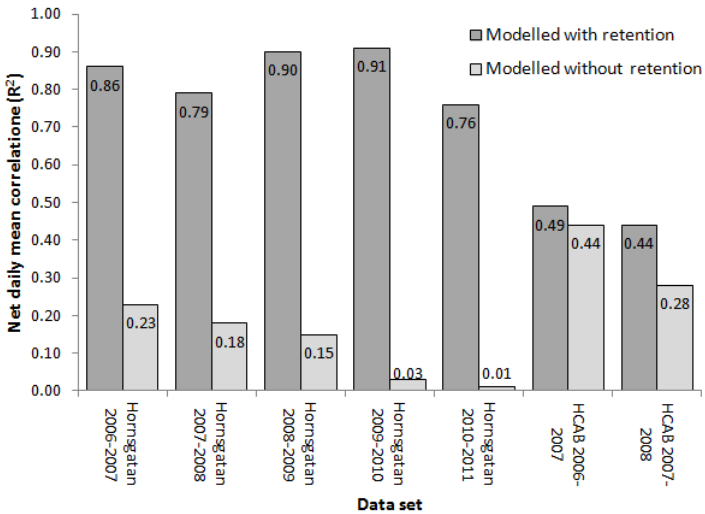

Figure 5: As in Figure 4 but showing the net daily mean correlation (R^2) of modelled and observed PM_{10}.

Conclusions

We present here two example applications of the NORTRIP model where the impact of surface retention/suspension, studded tyres, road salting and road surface material has a significant impact on the non-exhaust traffic induced emissions. The model provides very good correlation for the Hornsgatan site and follows the reduction in the studded tyre fraction well. The surface moisture is shown to be very important in predicting the temporal variation of the emissions but is less important in estimating the mean concentrations. Approximately 75% of the modelled emissions come from road wear and roughly half of this is the result of retention and suspension, for the example year shown.

Modelling at the Copenhagen site showed lower correlation but this is improved with the inclusion of surface retention and suspension as well as the inclusion of salt. The modelled contribution of salt at this site (17%) is similar to other estimates using receptor modelling and is

as large as the contribution from exhaust. Road wear was estimated to make up 55% of the total modelled PM_{10} concentrations.

Uncertainties are large for a number of model parameters and these have been necessarily confined using observational data. In Denby and Sundvor (2012) a number of model parameters were estimated using 14 datasets, including the 7 presented here. Further measurement campaigns that can concurrently determine the source contributions, the surface mass loading, the surface wetness, etc., are required to further refine these model parameters.

Acknowledgments

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