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Modelling non-exhaust emissions of PM_{10} in Oslo

Impact of traffic parameters and road maintenance activities using the NORTRIP model

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Scientific report

Preface

This report was requested by the Norwegian Public Roads Administration (Statens vegvesen) to provide information concerning non-exhaust traffic emissions in Oslo and the impact of various traffic parameters and road maintenance activities on these emissions. This report provides the results of calculations made with the NORTRIP model, a recently developed emission model for calculating non-exhaust emissions. This model was developed at NILU in conjunction with institutes from Sweden, Denmark and Finland during the NORTRIP project, funded by the Norwegian Environment Agency (Miljødirektoratet) and the Nordic Council of Ministers (NMR).

Contents

Summary

Non-exhaust traffic emissions are a dominant contributor to PM_{10} concentrations in many Nordic countries. These emissions are largely related to the use of studded tyres, but additional contributions come from the application of sand or gravel for road traction and from other wear sources such as brake and tyre. A range of measures have been introduced to reduce these emissions, but the impact of the measures needs to be better quantified if their effect on air quality is to be understood. In this report the NORTRIP emission model is applied to calculate non-exhaust PM_{10} emissions from traffic in Oslo and to assess the sensitivity of these emissions to a number of parameters such as studded tyre share, heavy duty vehicle fraction and the road maintenance activities of salting and cleaning.

The NORTRIP model is applied in two ways, for a single road (RV4), for which detailed input data is available, and for all of Oslo, where less well defined input data is used. With this model we investigate the sensitivity of the mean concentration and the number of exceedance days to changes in studded tyre share, heavy duty vehicle number and salting and cleaning road maintenance practices. The results indicate that significant changes in PM_{10} concentrations, particularly in the number of exceedance days, can occur as a result of changes in these parameters but these concentrations are also dependent on meteorological factors as well as the contribution of other sources.

For the simulations carried out for the single road RV4 the model correctly simulates the changes in observed concentrations resulting from changes in traffic patterns and meteorology over a three year period (2004-2006). It is found that meteorology plays as large a role as does changes in traffic conditions during this period. Sensitivity tests with the model show that a reduction by half of cars and trucks using studded tyres on RV4 would lead to a reduction in net mean PM_{10} concentrations of 23% - 31% and a reduction in the number of exceedance days of 5 - 12 days. A doubling of heavy duty vehicles (from roughly 5% to 10%) would lead to a 10% - 16% increase in the net mean concentrations and an increase in the number of exceedance days of 4 – 5 days. Sensitivity to the use of $MgCl_2$ (a dust binder) and road cleaning was also investigated. When a cleaning efficiency of 30% is assumed, which is highly uncertain, then the combined use of $MgCl_2$ and road cleaning can half the mean net concentrations and reduce the number of exceedance days by around 35% (from 39 to 21 days). This last point, concerning cleaning, is still uncertain and requires more observational information for its confirmation.

When the NORTRIP model is applied to all roads in Oslo, including all other emission sources, for two calendar years (2008 and 2009), then the resulting mean PM_{10} concentrations are found to be underestimated with a fraction bias of -9% and -13% respectively, when averaged over nine monitoring stations. The non-exhaust emissions are found to account for 33% of the observed PM_{10} concentrations at these sites. Sensitivity tests of the model carried out for 2009 show that a reduction in total studded tyre share of 1%, from 16% to 15%, would lead to an average reduction in mean concentrations at all sites of 0.22 $\mu g/m^3$,

which is roughly 1% of the mean concentrations during this period. The same 1% reduction in the studded tyre share would also lead to an average reduction in exceedance days of 0.8 days. A halving of all heavy duty vehicles in Oslo would result in an average reduction in mean concentrations at the measurement sites of 10% and a reduction in the average number of exceedance days by 40%. This reduction includes the impact of changes in exhaust emissions. The impact of cleaning is also assessed but this is highly uncertain given the lack of available data concerning the cleaning activities and their efficiency.

The results presented in this report are the first application of the NORTRIP model for assessing sensitivities, particularly on the city scale, to various input parameters. To affirm the robustness of the model, a larger number of years should be addressed and improved data concerning road maintenance activities, vehicle speeds, HDV fraction and road pavement types are required. The model also requires more scientific information concerning a number of model processes including cleaning efficiencies, the impact of gravel on road wear, dust binding, HDV wear and suspension rates, salt suspension and wet removal processes. Improving the model description for these processes will require new observational data that is currently not available.

Impact of traffic parameters and road maintenance activities using the NORTRIP model

1 Background and introduction

Non-exhaust emissions are the dominant contributor to PM_{10} concentrations in many Nordic countries. These emissions are largely related to the use of studded tyres but additional contributions come from the application of sand or gravel during the winter as well as from salt. Other wear sources such as brake and tyre wear also contribute.

To reduce the non-exhaust emissions a number of abatement strategies have been introduced in Norwegian cities. These include:

- the reduction of vehicles using studded tyres through fees and public awareness
- the reduction of vehicle speeds using environmental speed limits
- the use of dust binding salts ($MgCl_2$) to keep road surfaces moist
- road cleaning activities

All these strategies come with a monetary cost and may vary in their effectiveness. Quantifying their effectiveness is often difficult and may be based on indicative information rather than on any quantifiable method. In general measures are assessed to be successful if they achieve their aims of compliance with air quality legislation. Assessment of monitoring data in Oslo in the years before and after measures were introduced (Gjerstad et al., 2012) indicate that measures currently in place do have an impact, but exactly how much is due to each individual measure is not known. Some quantification has been carried out. In one case a measurement campaign was established at Riksvei 4 in Oslo over a two year period (2004-2005) to measure the impact of speed reduction on PM_{10} emissions (Hagen et al., 2005). This campaign indicated that speed reduction was an effective method for reducing road wear emissions.

To help quantify the impact of mitigation strategies related to non-exhaust traffic emissions on air quality efforts have been made to develop models that can be applied to assess air quality management strategies. During the NORTRIP project (Johansson et al., 2012), a co-operative project between four Nordic countries, a comprehensive non-exhaust emission model was developed at NILU (Denby and Sundvor, 2012). This model provides the potential for assessing abatement strategies and understanding the impacts of both traffic and meteorological conditions. Though the model is still under development there are a number of applications for which it can be used and which provide insight into the processes affecting non-exhaust emissions.

In this report the NORTRIP model is applied for three years (2004-2006) at RV4 and for two years (2008-2009) for all of Oslo. In the first case comprehensive input data is available to assess and validate the model during the speed reduction experiment carried out at RV4. In the second case the NORTRIP model is included in the general calculations of PM_{10} concentrations for all of Oslo, which includes all other emission sources. After application the model is then used to determine the sensitivity of the non-exhaust emissions, and concentrations, to a number of parameters. These include the fraction of vehicles using studded tyres, the fraction of heavy duty vehicles and the impact of salting, dust binding and cleaning. Though there is a degree of uncertainty related to these results, particularly in regard to cleaning which is still yet to be quantified, the model provides insight into the impact of these processes and can help to better identify effective measures for reducing non-exhaust emissions.

The model calculations carried out for this report are based in previous work in the NORTRIP and TRANSPHORM (www.transphorm.eu) projects in which NILU is involved.

2 Overview of the NORTRIP model

The NORTRIP model calculates the non-exhaust traffic induced emissions and is described and applied in detail in Denby et al. (2013a, 2013b) and Denby and Sundvor (2012). The model uses the mass balance approach for both road dust and for road surface moisture. As such it is split into two sub-models, one for dust and one for moisture, and these are coupled. An overview of the processes described in the model is given in Fig. 1.

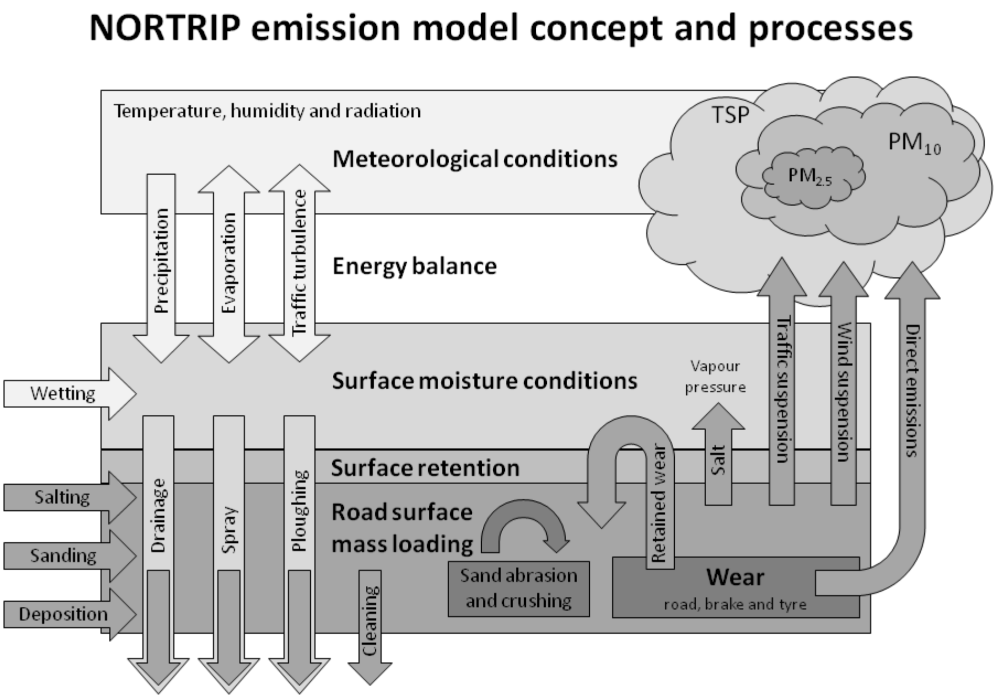


Figure 1: NORTRIP model concept showing the full model processes. Sand abrasion and crushing, as well as windblown suspension, are not included in the current application.

For the road dust sub-model the following major processes are included:

- Road wear based on the Swedish road wear model (Jacobson and Wågberg, 2007)
- Wear and emission of tyre and brake sources
- Direct emission of PM as well as retention of PM on the surface due to surface moisture
- Suspension of accumulated wear during dry periods
- Differentiation between the light and heavy duty contributions to wear and suspension
- Mass balance and suspension of salt
- Mass balance and suspension of sand (not included in this application)
- Removal processes for dust and salt (particularly salt) including drainage, vehicle spray, cleaning and snow ploughing
- Salting and sanding model for generating salt and sand application to the road, if no information is available

For the surface moisture sub-model the following main processes are included:

- Addition of water and/or ice to the surface through precipitation and wetting during salting/sanding activities
- Removal of water through drainage and vehicle spray
- Removal of snow through snow ploughing
- Energy balance model predicting surface temperature, surface melt/freezing and surface evaporation/condensation of moisture
- Impact of salt on the surface freezing temperature and on vapour pressure. Allows for the inclusion of 'dust binding' salts ($MgCl_2$).

Though there are a large number of model parameters defined we provide in Table 1 a short summary of the total wear rates, the PM_{10} fraction of total wear and the vehicle induced suspension rates used in this application. The values are relevant for a vehicle speed of 70 km/h and the wear and suspension rates are taken to be linearly dependent on vehicle speed. Total road wear is determined for studded tyres using the Swedish road wear model (Jacobson and Wågberg, 2007). Total tyre and brake wear, as well as non-studded road wear, is calculated based on literature, e.g. Boulter (2005). PM size fractions for wear particles are based on literature and experimental data, e.g. Snilsberg et al. (2008), and on the application of the model to a range of datasets (Denby et al. 2013a; 2013b; Denby and Sundvor, 2012).

Table 1: Total wear rates, road dust suspension rates and PM_{10} fraction of wear and suspension for light duty vehicles used in the NORTRIP model. Wear and suspension rates for heavy duty vehicles are considered to be 5 and 10 times larger respectively than for light duty vehicles. The reference speed for these parameters is 70 km/h.

	Studded tyres	**Winter tyres**	**Summer tyres**	**PM_{10} fraction of wear (%)**
Road wear (g km^{-1} veh^{-1})	3.8	0.15	0.15	20
Tyre wear (g km^{-1} veh^{-1})	0.10	0.10	0.10	10
Brake wear (g km^{-1} veh^{-1})	0.01	0.01	0.01	80
Road dust suspension rate (veh^{-1})	$1.0x10^{-6}$	$1.0x10^{-6}$	$1.0x10^{-6}$	20

3 Application to RV4 2004-2006

In order to assess the impact of various abatement scenarios it is important to properly evaluate the model for these sensitivities. An extensive validation of the model has been carried out for seven different sites in Scandinavia (Denby and Sundvor, 2012; Denby et al., 2013b). One of these sites was Riksvei 4 (RV4), Fig. 2, where three years of relevant data were collected in the winter and spring periods of 2004, 2005 and 2006. These data were initially collected in regard to a speed control experiment carried out on RV4 (Hagen et al, 2005) where signed speed reductions were introduced in 2005. During the period 2004 and 2005 salting was carried out with NaCl only. In 2006 $MgCl_2$ was applied, both in solution for mixing with NaCl for de-icing but also for dust binding. No cleaning of the roads was carried out in the years 2004 and 2005, to our knowledge, during the measurement period.

The model is applied to all three years which includes variations in speed, traffic volume, studded tyre fraction, meteorology and road maintenance activities. If the model correctly predicts the changes seen in the observed concentrations, based on changes in the input data, then this increases the confidence in the model, particularly its ability to correctly reflect these differences.

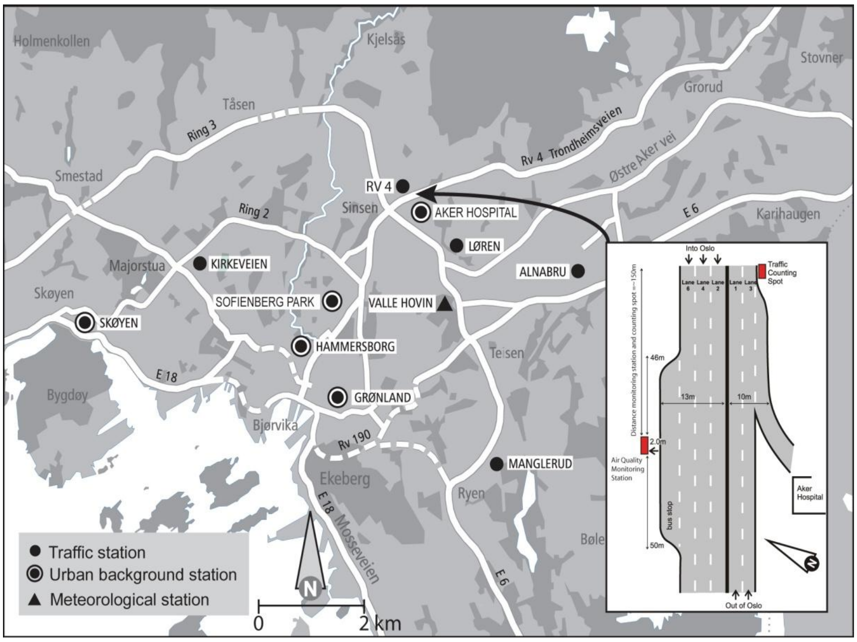


Figure 2: Position of the air quality measurement sites RV4 (road side station) and Aker hospital (urban background station) used in the validation.

3.1 Model setup and input data

The NORTRIP model calculates non-exhaust emissions for traffic, based on a range of input data listed in Table A.1. Conversion of emissions to concentrations for the RV4 case is carried out using the tracer method, i.e. measured NO_x concentrations and estimated NO_x emissions are used to determine a dispersion factor that directly relates emissions to concentrations on an hourly basis. Exhaust emissions are also calculated, based on emission factors, and these are included in the total PM_{10} concentrations shown. The modelling period is from the start of November to the end of April for the three years 2004, 2005 and 2006. Observational data is not available for the entire modelling period (181 days) in 2004 where measurements did not start until 16 January.

Traffic data has been obtained from Statens vegvesen based on traffic counts on RV4 close to the site. Not all months for all years were covered and so representative traffic data has been used to fill in missing data. Heavy duty vehicles (HDV) are defined as traffic longer than 7.5 m. The percentage of passenger vehicles with studded tyres is based on counts in Oslo which varies from year to year. A summary is shown in Table 2. The studded tyre fraction for passenger vehicles decreases from 27% to 20% during these three years. Due to uncertainty in the data we keep the number of HDV's with studded tyres fixed at 10% for all years. Traffic volume was also slightly reduced in 2005, mainly due to an early Easter. The change of signed speed limit lead to an average speed reduction from 75 km/hr (2004) to 64 km/hr (2005).

Road maintenance data was not available for RV4 and so these activities have been taken from logs referring to Ring 3 activities, between Griffenfeldts gate and Marcus Thranes gate. These data were logged by ISS and provided to NILU by Statens vegvessen. During this period experiments were being carried out with the use of $MgCl_2$ and NaCl in solution. It is assumed that only NaCl has been used on

RV4 in the years 2004 and 2005, on request of the experiment carried out there. In 2006 $MgCl_2$ was applied to RV4. A summary is shown in Table 2. According to these data between 36 and 74 tons of salt were applied per km of road, with most being applied in 2006. The number of individual salting events was between 119 and 201.

Street cleaning, of an unknown type, is also included in the road maintenance data but it is assumed to not take place on RV4 in the years 2004 and 2005, due to the experiment undertaken there. In 2006 cleaning did occur. To simulate the impact of cleaning in the model we reduce the dust and salt loading on the road surface by a specified amount for each cleaning event. In this case we attribute a cleaning efficiency of 30% to the cleaning event, i.e. 30% of the surface dust and salt loading is removed due to cleaning. The exact efficiency of cleaning is not known and will depend on the method used, which is also not known in this case. Experiments in Sweden (Gustafsson et al., 2011) show little effect of street cleaning on PM_{10} concentrations but do show that cleaning can be effective in removing surface dust under controlled conditions. Using a wet vacuum and brush system about 40% of the distributed dust (<180 μm) was cleaned from the surface but only 5% of PM_{10} was collected. The value of 30% used here is probably too high, for operational cleaning, but is included to indicate the impact of such a measure. Proper quantification is still required.

Meteorological data has been collected from Valle Hovin, Blindern and Ås (global radiation in 2006 only). This includes wind speed, temperature, humidity, precipitation and global radiation. A summary is shown in Table 3. 2004 differs from the other two years mainly in the precipitation, there was around half as much precipitation and slightly more than half as many precipitation events. The dispersion conditions were slightly worse in 2004, by around 10%, compared to the other two years.

Air quality data are available from the traffic station RV4 and the urban background station Aker Hospital. The positioning of these stations are shown in Fig. 2. Observed NO_X concentrations are used to determine the dispersion, removing the dependence on a dispersion model, and the model results are compared to the observed PM_{10} concentrations. Comparisons are made between the modelled and observed concentrations only when the hourly mean NO_X and PM_{10} concentrations are larger than the background concentrations. For the three years considered this occurs roughly 50 - 70% of the time. In addition a minimum of 7 hours of data is required for a daily mean concentration to be calculated. This means that mean concentrations and number of exceedance days (days with daily mean PM_{10} concentrations > 50 $\mu g/m^3$) are only assessed for those hours with comparable data and so may differ from the ‘official’ statistics for this site.

*Table 2: Traffic and road maintenance summary data for the three years. Period modelled is from November to April (inclusive). * indicates values calculated by the model. The 'Max studded (%LDV)' is the winter season maximum fraction of light duty vehicles using studded tyres, whilst the 'Mean studded' is the mean over the modelling period. These two are not the same as the modelling extends beyond the studded tyre season in two of the years.*

Year	Number of days modelled	Mean ADT	HDV (%)	Mean speed (km/hr)	Mean studded (%LDV)	Max studded (%LDV)	Total salt (ton/km)	Salting events	Sanding events	Cleaning events	Ploughing events*
2004	182	43228	4.6	74.9	26.3	27	46.8	145	0	6	21
2005	181	41435	6.5	64.2	21.3	24	36.9	119	0	2	8
2006	181	42616	4.4	63.6	20.0	20	74.7	201	0	6	17

*Table 3: Meteorological summary data for the three years. Period modelled is from November to April (inclusive). * indicates values calculated by the model*

Year	Number of days modelled	Mean Temperature	Mean RH (%)	Mean global radiation	Mean cloud cover(%)*	Total precipitation (mm)	Frequency precipitation (%)	Frequency wet road (%)*	Mean dispersion factor
2004	182	1.2	79.6	46.4	64.05	255.3	13.2	54.4	0.056
2005	181	1.4	74.2	41.1	66.81	128.7	7.4	45.2	0.048
2006	181	-0.1	79.0	49.7	57.1	245.4	12.8	75.2	0.051

3.2 Model validation

The model is applied for each year using the provided input data and model calculations are compared to the net (traffic site minus background site) concentrations of PM_{10}. In Figs. 3 – 5 daily mean concentrations, surface dust and salt loading and effective emission factors are shown for the three years. In Table 4 the concentration statistics are summarized for the net concentrations and in Table 5 the concentration statistics are summarised for the total (including background) concentrations.

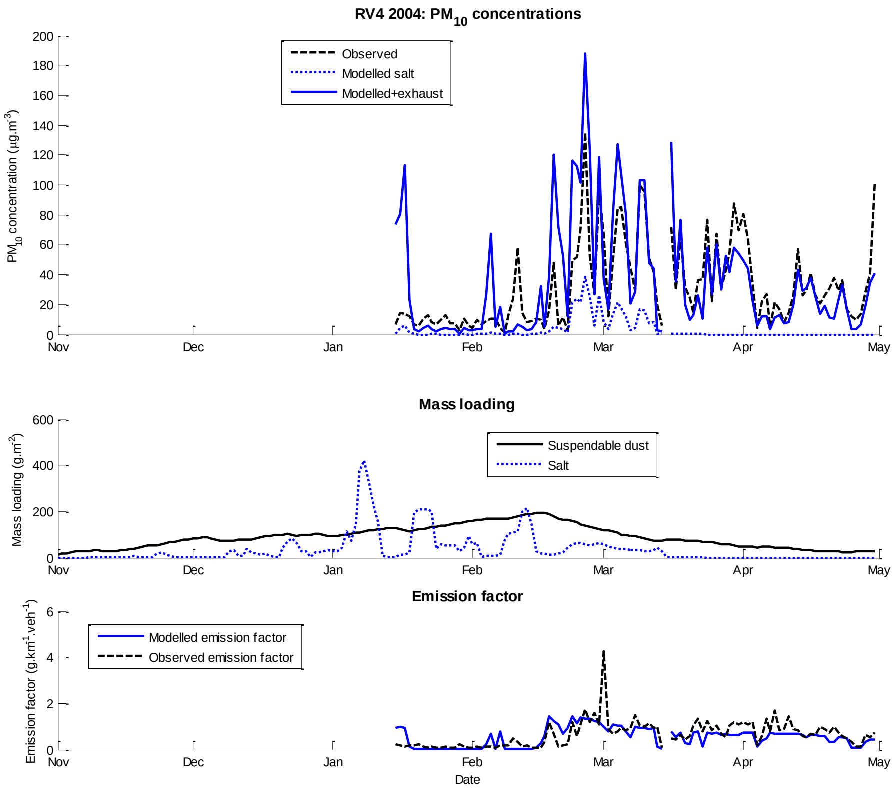


Figure 3: Results of the model application at RV4 for the period November 2003 to April 2004. Top: Daily mean modelled and observed concentrations of PM_{10} including salt contribution. Middle: Surface mass loading of suspendable dust and salt. Bottom: Effective emission factor for PM_{10} calculated by the model and derived from observations.

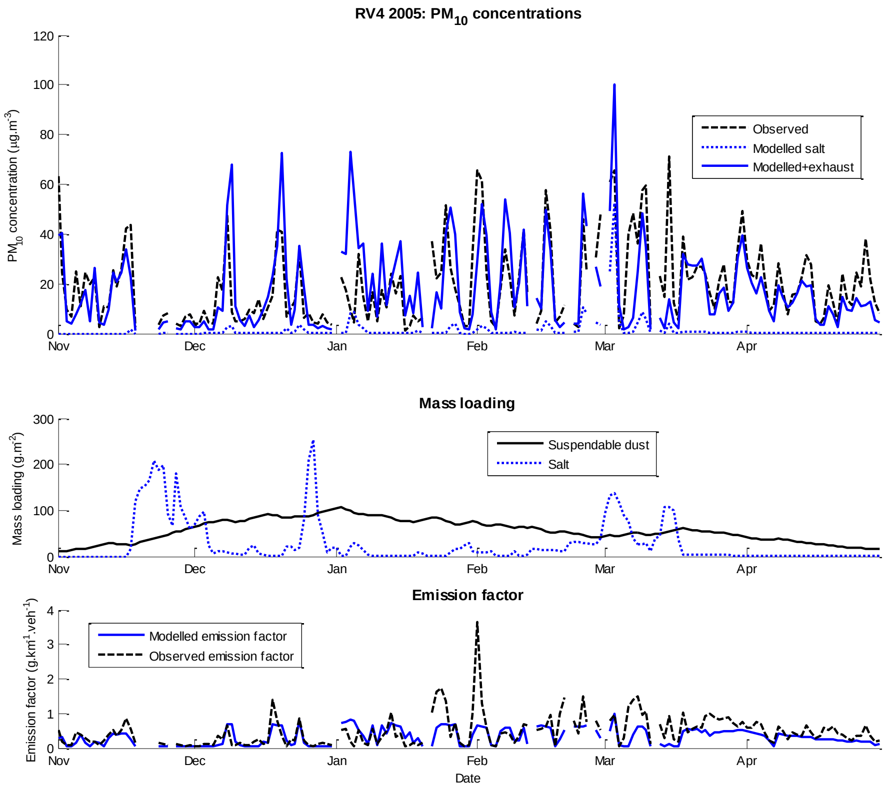


Figure 4: As in Fig 3. but for the period November 2004 to April 2005.

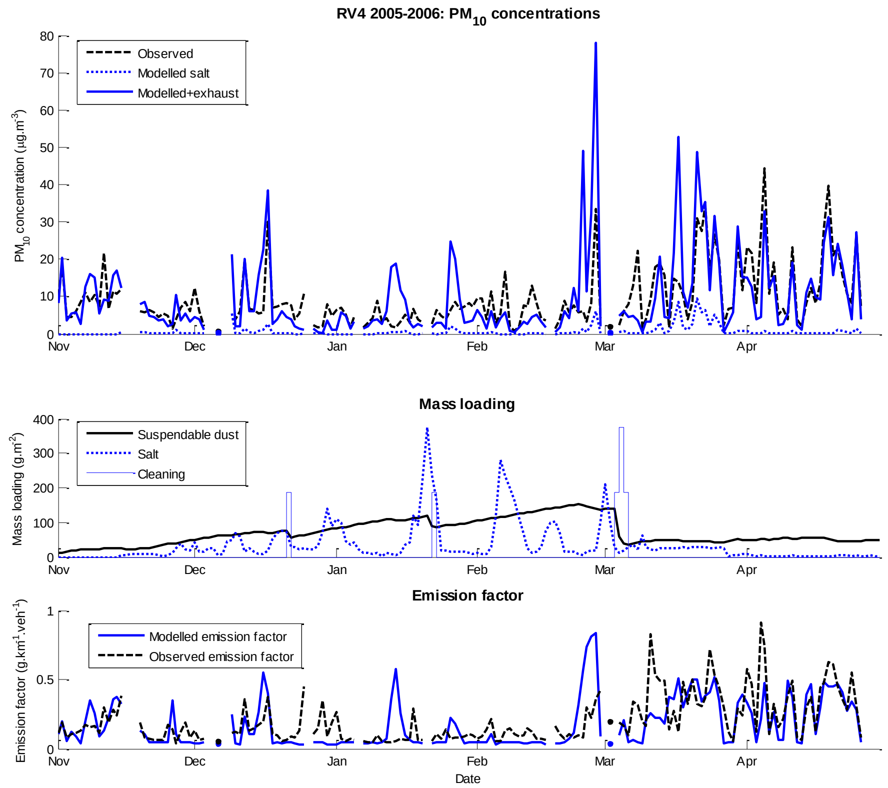


Figure 5: As in Fig 3. but for the period November 2005 to April 2006. Shown is the case including cleaning.

Table 4: Statistical summary of the model validation based on daily mean net concentrations.

Year	Observed mean (µg/m^3)	Modelled mean (µg/m^3)	Observed 90'th percentile	Modelled 90'th percentile	Observed days > 50 (µg/m^3)	Modelled days > 50 (µg/m^3)	Correlation (R^2)	Daily mean RMSE	NRMSE (%)	Fractional bias (%)
2004	32.1	35.1	70.3	102.9	46	43	0.53	26.7	84.9	11
2005	19.1	17.7	42.2	39.5	45	45	0.38	14.5	73.9	-7.3
2006	9.6	9.9	21.5	22.5	11	12	0.46	8.3	88.2	1.5

Table 5: Statistical summary of the model validation based on daily mean total (including background) concentrations.

Year	Observed mean (µg/m^3)	Modelled mean (µg/m^3)	Observed 90'th percentile	Modelled 90'th percentile	Observed days > 50 (µg/m^3)	Modelled days > 50 (µg/m^3)	Correlation (R^2)	Daily mean RMSE	NRMSE (%)	Fractional bias (%)
2004	52.7	55.7	103.1	123.9	48	45	0.62	26.7	51.6	6.8
2005	40.2	38.9	78.2	71.9	48	48	0.69	14.4	35.3	-3.4
2006	27.6	27.9	46.4	47.2	12	13	0.73	8.3	30.2	0.5

In Fig. 6 observed and modelled net mean concentrations are shown as well as the contribution of the background concentrations to the total concentrations. In Fig. 7 the number of exceedance days and 90'th percentile daily mean concentrations, which include background contributions, are shown for the three years. There is a significant decrease in the mean and percentile concentrations over the three year period. Despite this 2005 shows a similar level of exceedances as 2004. This is because the background concentrations are similar to, or higher than, those in 2004 and because the 2005 observations cover a longer period, allowing more exceedances to occur. For this reason it is difficult to inter-compare the exceedances between years. Though exceedances are important indicators for legislative purposes they are poor indicators for assessing and understanding model results. A better indicator for such extremes is the 90'th percentile.

The model follows the changes between years indicating the correct sensitivity to the changes that occur between these years. These changes are indicated in Tables 2 and 3 and include reductions in speed, changes in traffic volume, changes in studded tyre use, changes in HDV, changes in road maintenance activities and changes in meteorological and dispersion conditions.

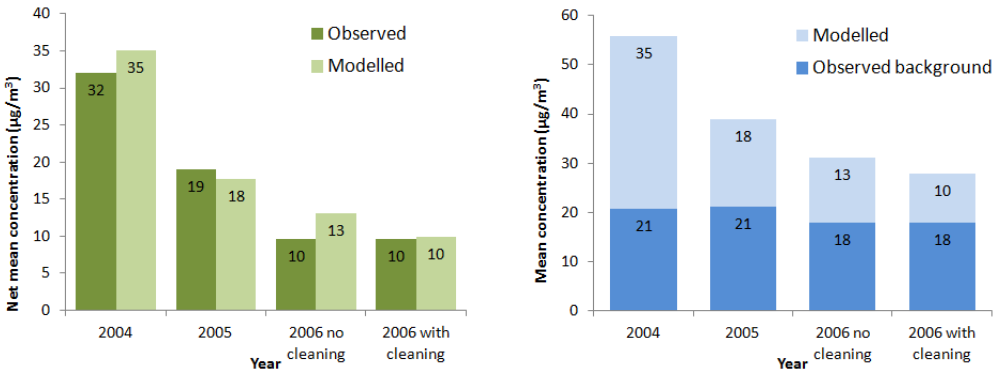


Figure 6: Net mean observed and modelled concentrations, left, and modelled and observed background contribution, right, for the modelling period for the 3 years of data. For 2006 both cases, with and without cleaning, are shown.

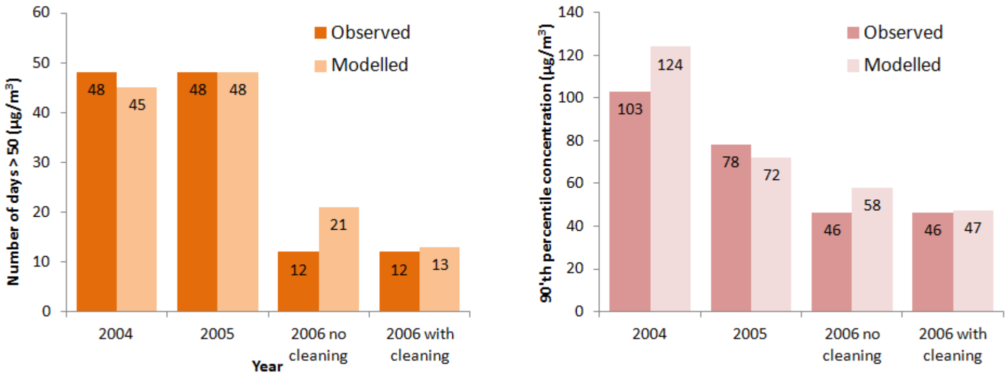


Figure 7: Observed and modelled number of exceedance days (daily mean PM_{10} concentration > 50 µg/m^3), left, and 90'th percentile of the daily mean concentration, right, for the 3 years of data. For 2006 both cases, with and without cleaning, are shown.

3.3 Sensitivity to meteorological conditions and road maintenance activity

In Tables 2 and 3 it can be seen that meteorological conditions, traffic characteristics and road maintenance activities vary for all three years. It is useful to separate the variability due to traffic characteristics and variability due to meteorology, which also includes road maintenance activities as these are dependent on weather conditions. In addition the background concentrations and the period for which monitoring data is available will also impact on the total mean and the number of exceedance days for any given year. To indicate how traffic and meteorological variability leads to differences in concentrations the traffic data from the three different years is applied to all three meteorological years (a meteorological year includes the same road maintenance activities and PM_{10} background values). This results in a 3 x 3 matrix of nine separate model calculations. The results of these calculations are shown for the net mean modelled concentrations (Fig. 8) and the total, including background, number of exceedance days (Fig. 9).

It is clear from Figs. 8 and 9 that meteorology, and associated road maintenance activities, plays a significant role in determining both the mean concentrations and the number of exceedance days during the winter/spring period. Though there is a clear decrease in net mean concentrations and exceedance days from the traffic year of 2004 to the traffic years of 2005 and 2006, the results also show significant changes in the different meteorological years, particularly for the exceedance days. Indeed, the number of exceedances is dominated more by changes in meteorology and associated road maintenance activities than it is by changes in traffic characteristics. This is an important point when assessing the impact of traffic abatement measures.

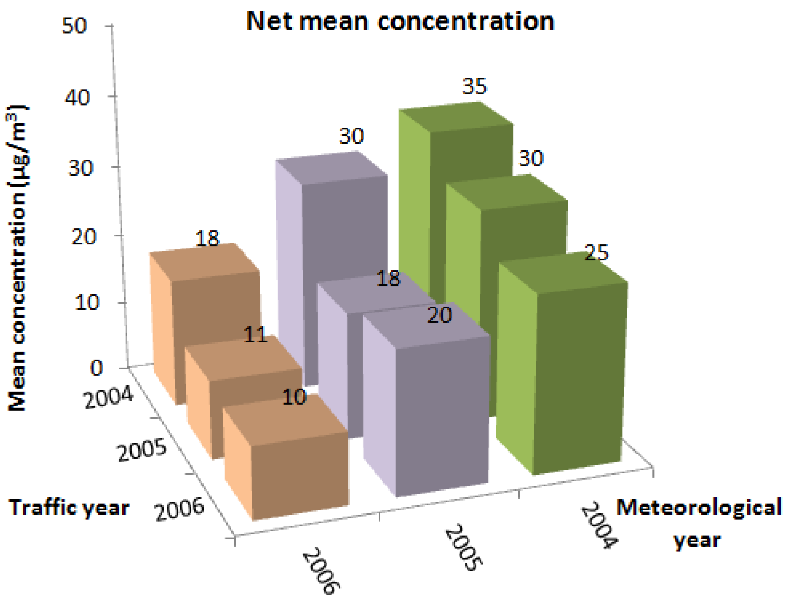


Figure 8: Net mean modelled concentration of PM_{10} showing the impact of different traffic characteristics in different meteorological years. The meteorological year 2006 includes cleaning.

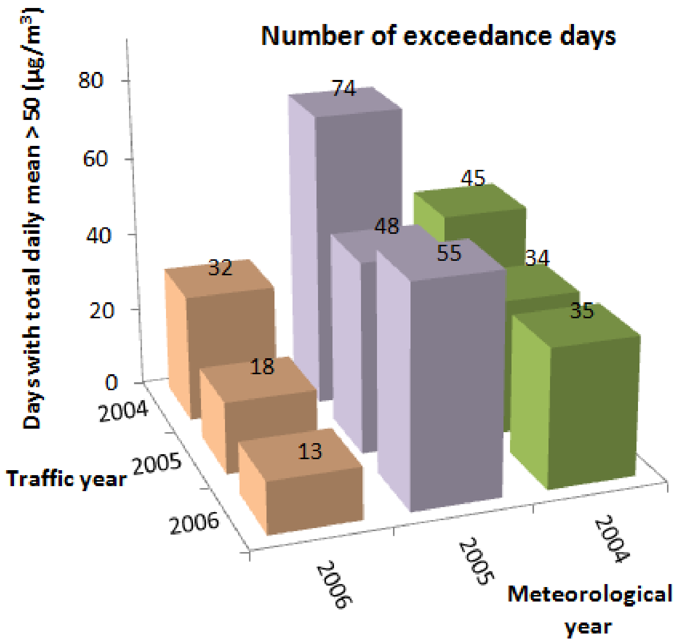


Figure 9: Total number of exceedance days of PM_{10} showing the impact of different traffic characteristics in different meteorological years. The meteorological year 2006 includes cleaning.

3.4 Sensitivity to studded tyre use

According to the model formulation studded tyres enhance the wear rate in a linear fashion. However, not all PM_{10} emissions are the result of studded tyres. Other sources include exhaust, salt, tyre wear, brake wear and road wear from non-studded tyres. The contribution from these sources is best indicated by setting the studded tyre use to 0%. We demonstrate the dependency of PM_{10} concentrations for the 3 traffic and meteorological years by increasing and decreasing the number of vehicles using studded tyres by 50% for each year, including heavy duty vehicles which use 10% studded tyres as default. The results are shown in Fig. 10 and Table 6 where the mean net concentrations and number of exceedance days are presented. Due to differences in meteorology, road maintenance activities and changes in vehicle speeds the three years show different sensitivities.

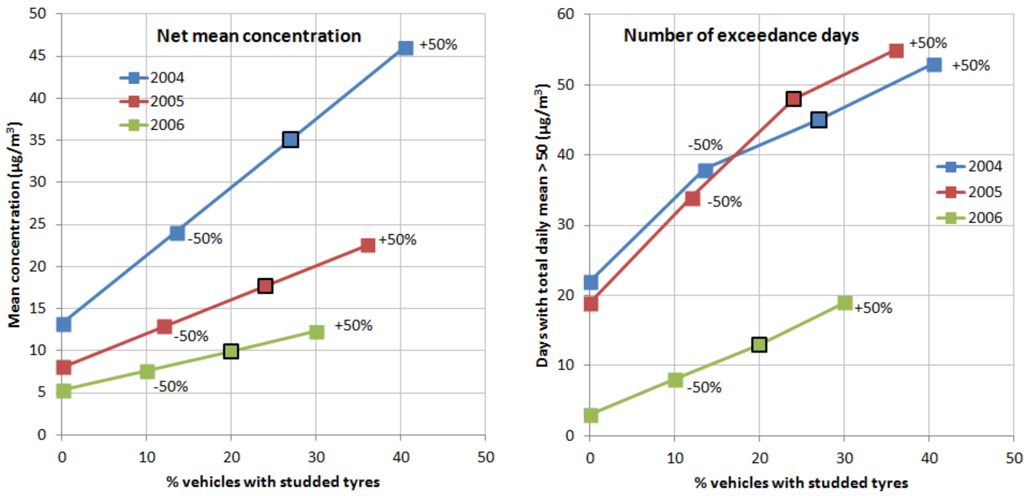


Figure 10: Sensitivity of net mean concentrations, left, and number of exceedance days, right, to changes in the number of vehicles using studded tyres for the three different modelled years. Black bordered marker indicates the default studded fraction for that year.

Table 6: As in Figure 10 but in table form.

Relative change in studded tyre fraction	Studded tyre fraction (%)	Net concentration (µg/m³)	Days > 50 (µg/m³)	Studded tyre fraction (%)	Net concentration (µg/m³)	Days > 50 (µg/m³)	Studded tyre fraction (%)	Net concentration (µg/m³)	Days > 50 (µg/m³)
		2004			**2005**			**2006**	
-100%	0.0	13.2	22	0.0	8.0	19	0.0	5.3	3
-50%	13.5	24.1	38	12.0	12.9	34	10.0	7.6	8
0%	27	35.1	45	24.0	17.7	48	20.0	10.0	13
+50%	40.5	46.1	53	36.0	22.5	55	30.0	12.3	19

Even with no studded tyres there is still a significant emission of PM_{10}. This is shown in Fig. 11 where the source contribution to the mean concentrations is presented for the default case with, and the case without, studded tyres. Studded tyres, given the share for these three years, account for roughly 40% to 65% of the total non-exhaust emissions.

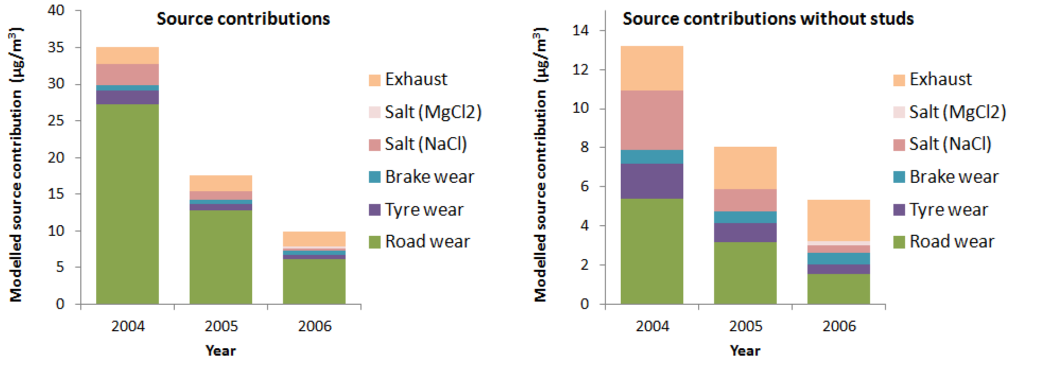


Figure 11: Source contributions to the mean concentrations for the default model case, left, and for the sensitivity run with no studded tyres, right.

3.5 Sensitivity to heavy duty traffic

We apply the model to all three years to assess the impact of heavy duty vehicles (HDV). HDV are described in the model as having wear rates 5 times higher than passenger vehicles and suspension rates 10 times higher than passenger vehicles. In addition vehicle spray is enhanced by a factor of 6 for heavy duty vehicles. For RV4 the measured HDV is between 4.4 – 6.5% (Table 2). We assess the impact of HDV by increasing their number by a factor of two and three and by removing them completely. The number of passenger vehicles is not changed and the fraction of HDV's using studded tyres is held fixed at 10%.

Results are shown in Fig. 12. The contribution of HDV's to the net mean concentration is around 10% for the observed number of HDVs. The change in mean concentrations and exceedance days due to changes in HDV fraction varies from year to year. A doubling of HDV leads to roughly a 10% to 16% increase in net mean concentrations and an increase in exceedance days of 4 – 5 days.

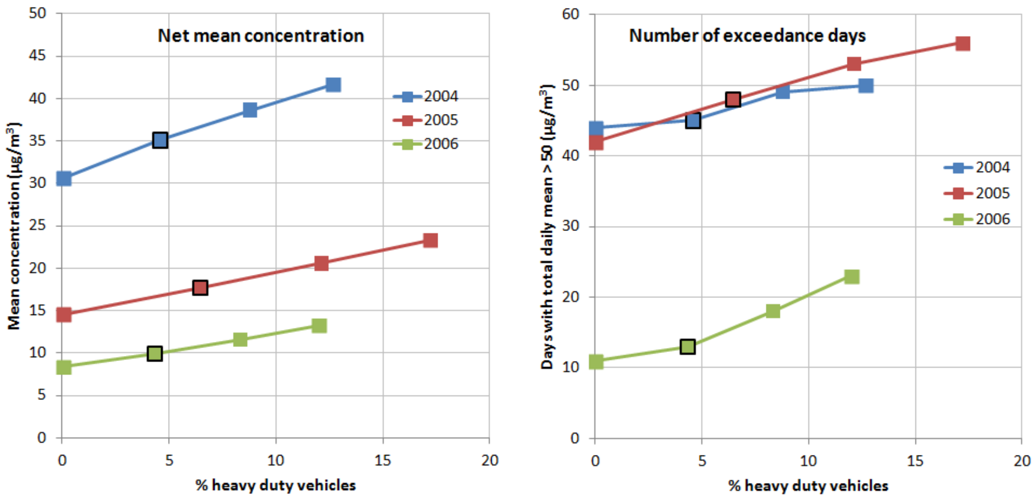


Figure 12: Sensitivity of mean concentrations, left, and number of exceedance days, right, to changes in the number of heavy duty vehicles for the three different modelled years. Black bordered marker indicates the default HDV fraction for that year.

Table 7: As in Figure 12 but in table form.

Relative change in heavy duty vehicle fraction	Heavy duty vehicle fraction (%)	Net concentration (µg/m^3)	Days > 50 (µg/m^3)	Heavy duty vehicle fraction (%)	Net concentration (µg/m^3)	Days > 50 (µg/m^3)	Heavy duty vehicle fraction (%)	Net concentration (µg/m^3)	Days > 50 (µg/m^3)
	2004			**2005**			**2006**		
-100%	0	30.6	44	0	14.5	42	0	8.4	11
0%	4.6	35.1	45	6.5	17.7	48	4.4	10.0	13
+100%	8.8	38.6	49	12.2	20.6	53	8.3	11.6	18
+200%	12.6	41.7	50	17.2	23.3	56	12.0	13.3	23

3.6 Sensitivity to salting and cleaning

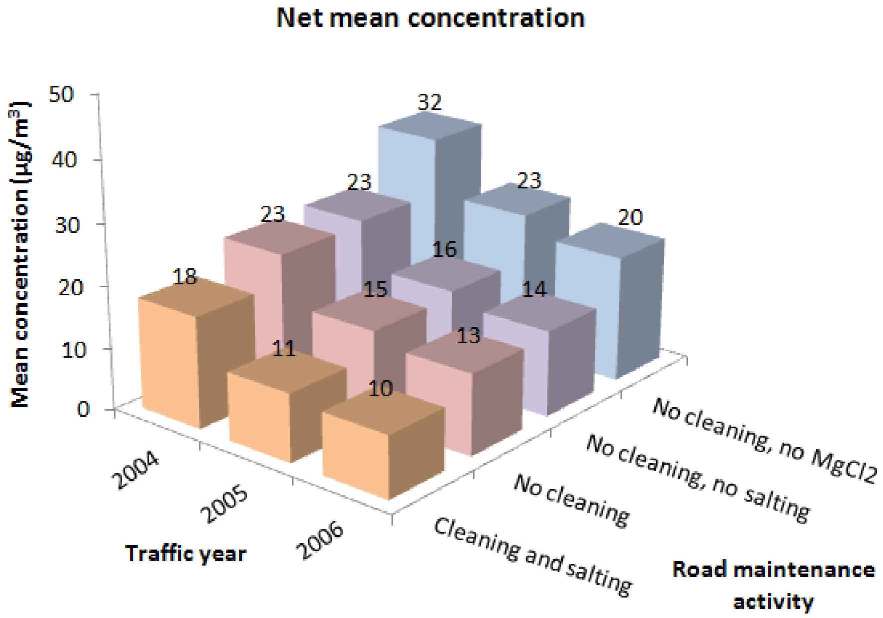
We apply the model using all three traffic years for the meteorological year 2006 to assess the impact of salting, dust binding and cleaning activities. Four different cases are investigated:

1. The default 2006 activity data. This includes NaCl with $MgCl_2$ solution for de-icing (190 events), $MgCl_2$ only in solution for dust binding (17 events) and cleaning (6 events with 30% efficiency).
2. No cleaning but including all salting and dust binding activities
3. No cleaning and no salting at all (neither de-icing nor dust binding)
4. No cleaning and no $MgCl_2$, but includes de-icing using NaCl only

The first of these (1) indicates the current practise for reducing suspension, the last (4) indicates the result if no cleaning or dust binding was used but de-icing with NaCl was applied, as would be the case if no mitigation was undertaken. Case 2 is included to indicate the impact of cleaning alone (but this is dependent on the arbitrary choice of efficiency) and case 3 is chosen to indicate the impact of salting in general, since salt both binds dust through surface moisture as well as contributing to the PM_{10} emissions once the surface dries.

The results, Fig. 13, indicate that significant reduction in both net mean concentrations and in exceedance days is obtained using the current mitigation practises of cleaning and the use of $MgCl_2$, either as dust binding or in solution for use in de-icing. If these two abatements are not applied then the model indicates a significant increase in the number of exceedances days. Even with reduced studded tyres and vehicle speeds, as seen in the 2005 and 2006 traffic years, then the road maintenance activities appear to be essential in reducing the suspension of road dust.

It is important to note that road dust mass is removed almost exclusively through suspension and cleaning in the model, drainage and vehicle spray being given a very low efficiency of dust removal. This means that if dust is retained on the surface through dust binding then the retained dust will eventually be suspended once the surface dries. Changes in the mean net concentrations seen here, without cleaning, are mostly related to the short length of the monitoring period, that stops at the end of April.



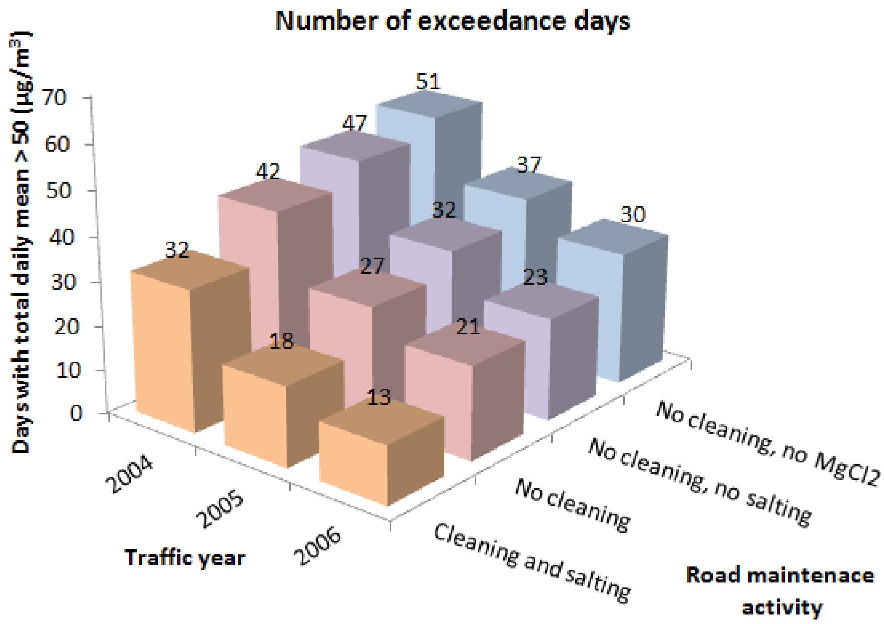


Figure 13: Sensitivity of mean concentrations, top, and number of exceedance days, bottom, to changes in the road maintenance activities for the meteorological year of 2006 and for all three traffic years (2004-2006). Shown are 'cleaning and salting' (default 2006 situation), 'no cleaning' (but with salting), 'no cleaning and no salting' and 'no cleaning and no $MgCl_2$' (but including NaCl salting).

3.7 Uncertainties in the modelling

There are clearly a number of uncertainties connected to the modelling and these have been outlined and discussed in Denby et al. (2013a; 2013b). In regard to the total emissions the most important uncertainties are related to the wear and suspension rates but also to the assumptions concerning NO_x emission factors. These together are estimated to contribute around -20% to +30% to the uncertainties in the mean concentrations.

The contribution of salt to the total PM_{10} mass is also uncertain and will require further assessment. Comparisons with observed salt contributions (Denby et al., 2013a) indicate that the salt contributions to PM_{10} are within ±50% of those observed.

The surface moisture modelling is also uncertain. Comparison of modelled and observed surface moisture (Denby et al., 2013b) indicate that the model correctly predicts the surface moisture state (wet or dry) 85% of the time. The removal of salt and moisture through drainage and spray processes has yet to be confirmed.

Input data concerning road maintenance activities is clearly uncertain since the data used are from a different road. In addition the efficiency of cleaning, given here to be 30% of the suspendable dust and salt load, is not known but it is likely to lie in the range of 0% - 50%. All results concerning cleaning presented here are completely dependent on the choice of 30% efficiency. Clearly lower efficiencies would lead to lower impacts. The efficiency applied here is assumed to be the same for both PM_{10} and the suspendable mass fraction, which is mostly below 200 $\mu g/m^3$. This may not be the case as cleaning efficiencies are probably much lower for PM_{10} than for larger particles (Gustafsson et al., 2011).

Despite these uncertainties the model captures the sensitivity of the changes from year to year well and explains, through the correlation, from 40% - 50% of the net daily mean variability seen in the observations.

3.8 Summary of the sensitivity assessment for the application to RV4

The NORTRIP emission model has been applied to three years of data available at RV4 in Oslo. There are a number of differences between these three years in regard to traffic characteristics, meteorological conditions and road maintenance activities. The model successfully predicts the observed change in concentrations over these three years, both in terms of means and percentiles but also in terms of the number of exceedance days.

The sensitivity of the model to changes in the number of vehicles with studded tyres, the percentage of heavy duty vehicles (HDV) and the impact of salting, dust binding and cleaning has been investigated. The results can be summarized as follows.

1. The observed impact of the reduction in vehicle speed and studded tyres from 2004 to 2005 is also dependent on meteorological conditions. The

reductions in net mean concentrations due to these traffic changes varied from 15% - 40%, depending on the meteorological year applied.

2. The model describes road wear as being linearly dependent on studded tyre fraction, however other sources also contribute (exhaust, salt and other wear sources). As a result a 50% reduction in studded tyres will not lead to a 50% reduction in non-exhaust emissions. For the cases investigated here a 50% reduction in studded tyre share leads to a reduction of from 23% - 31% in net mean concentrations.
3. The impact of studded tyres on the number of exceedance days is strongly dependent on the urban background level (not modelled) as well as the meteorological conditions. For the cases investigated here reductions from 5 to 12 days were achieved by a 50% reduction in studded tyre share. This will likely be higher if the same reductions were applied to the background concentrations as well.
4. The impact of heavy duty vehicles was assessed assuming a 10% share of studded tyres. A doubling of the percentage of HDV (from roughly 5% to 10%) lead to a 10% - 16% increase in the net mean concentrations and an increase in the number of exceedance days of 4 – 5 days. This is due to increased road wear and suspension but also due to increased exhaust emissions. Changes in surface moisture conditions from enhanced spray and vehicle turbulence also play a small role.
5. The impact of salting and cleaning was assessed for one of the meteorological years (2006) using three different traffic years. The current practise of cleaning (assuming a 30% efficiency) and dust binding is predicted by the model to reduce the net mean concentrations by a factor of two, compared to the case with no cleaning and only the application of NaCl. The number of exceedance days is also reduced by 18 days (from 39 to 21 days), averaged over the three traffic years.
6. Non road wear dust sources were found to contribute from 20% to 35 % of the total PM_{10} emissions. Exhaust made up 7% to 20% of this, but salt (NaCl) also contributed from 5% to 10% of the total emissions. Tyre and brake wear were lesser contributors. When NaCl was mixed with $MgCl_2$ this reduced the salt emissions since the road surface was held moist longer, allowing other removal processes (drainage and spray) to remove the salt from the surface.

4 Application to Oslo 2008-2009

The calculations carried out for RV4 in Section 3 show the local contribution of non-exhaust emissions at a kerbside monitoring station. As such the contribution of other roads in Oslo to the PM_{10} contributions is not included in the calculations. This means that the sensitivity of the model to changes in studded tyre share or to road maintenance activities reflects only the local road contribution. A general reduction in studded tyre share in Oslo would also reduce the urban background levels, something that is not reflected in the local road modelling.

In order to assess the total impact of non-exhaust emissions it is necessary to model the entire city of Oslo. Recent modelling activities in the EU TRANSPHORM project (www.transphorm.eu) have lead to improvements in both emissions and models in the Oslo region. The NORTRIP model has been included in this modelling in a slightly simplified form, since the current model version has been developed for a single road with detailed input data and not for use on more than 10 000 road links without the required input data. The simplified version of the model calculates the surface moisture for 3 different road types corresponding to heavily trafficked roads highways, communal roads with low traffic loads and tunnels which are assumed to be dry all the time. In addition the road dust sub-model has been simplified to include removal of road dust only through the processes of suspension and cleaning, which are the two major processes. Salt is included in the moisture model but salt emissions are not included in the road dust model, which will lead to a small underestimation (< 5%) of the annual mean concentrations. Road maintenance activity data is taken from the same road as for RV4 (between Griffenfeldts gate and Marcus Thranes gate) and assumed to be applicable to all highways in Oslo. All roads are assumed to be snow ploughed.

4.1 Model setup

The dispersion model applied is the stand-alone version of the EPISODE model, which is the model used in AirQUIS. This model consists of a gridded (1 x 1 km^2) Eulerian model coupled with a Gaussian line source model for modelling the local contribution at receptor points near roads. The model coupling leads to a double counting of the emissions near roads which has been estimated to contribute a maximum increase of 10 - 20% to the model concentrations at near road receptor points.

Meteorology is generated in the model using the diagnostic wind field model MCWIND based on meteorological measurements from Valle Hovin and Blindern. Data used are vertical temperature gradient, wind speed and wind direction.

Emissions are generated for all known sources, these include:

- Traffic non-exhaust emissions (NORTRIP)
- Traffic exhaust emissions
- Domestic heating emissions (temperature dependent)
- Shipping emissions (updated using STEAM2 data)
- Industrial emissions
- Agricultural emissions (updated to include summer emissions)
- Mobile source emissions (updated for new technology)

Regional background concentrations are derived from the minimum measured concentration in the model domain over a moving 24 hour window. These are compared to data from the regional background station in Birkenes to ensure consistency.

Model calculations are made separately for the calendar years 2008 and 2009. Maximum studded tyre shares are taken to be 16% for all LDVs (including passenger cars) and 8% for HDVs (a slight reduction from 10% compared to the 2004-2006 calculations for RV4 in Section 3).

During this period environmental speed limits were implemented, reducing the signed speed to 60 km/hr during the studded tyre season on RV4 and Ring 3. The model uses signed speed to generate road wear and suspension (linearly dependent on speed) however the signed speed is rarely the actual average speed. For RV4 the average speeds were measured to be 75 and 65 km/hr for the signed speeds of 80 and 60 km/hr respectively. Measurements at Manglerud (Statens vegvesen, 2012) show speeds of 69 and 62 km/hr respectively for the same signed speeds. These measurements are for the hours between 12:00 to 14:00, indicating that the averages speeds are probably even lower. Use of the signed speed may overestimate, or at times underestimate, the actual speed and lead to significant errors in the non-exhaust emissions. For the calculations presented here all roads related to the environmental speed limit are given speeds of 60 km/hr during the studded tyre season and 70 km/hr outside of this season.

The NORTRIP model current does not account directly for road surface abrasion through sand or gravel on the surface. In Oslo gravel is frequently applied on communal roads and kerbs and is evident on the road surface during the winter and spring periods. To reflect this the wear rates of communal roads are doubled in the model. There is significant uncertainty related to this aspect of the modelling.

Salting and cleaning activities for all of Oslo are taken from the ISS activity data (between Griffenfeldts gate and Marcus Thranes gate). In 2008 no cleaning events were noted in these data but in 2009 a large number were carried out. Cleaning, with a cleaning efficiency of 20% in this case, is included in the model for all highways based on these activities. This aspect will be discussed in Section 4.4. According to the ISS activity data no specific dust binding events occurred ($MgCl_2$ only) but $MgCl_2$ in solution was used as a mixture with NaCl according to the normal practise.

4.2 Model validation

Model validation is carried out using the available fixed monitoring stations (9 stations). Daily mean plots are provided in Figs. 14 and 15 for the two years and statistics concerning these data, annual mean, 36'th highest daily mean value, daily mean correlation and number of exceedance days are shown in Figs. 16 and 17. Not all sites measured PM_{10} for the entire period and so means and other statistics are limited to the periods measured.

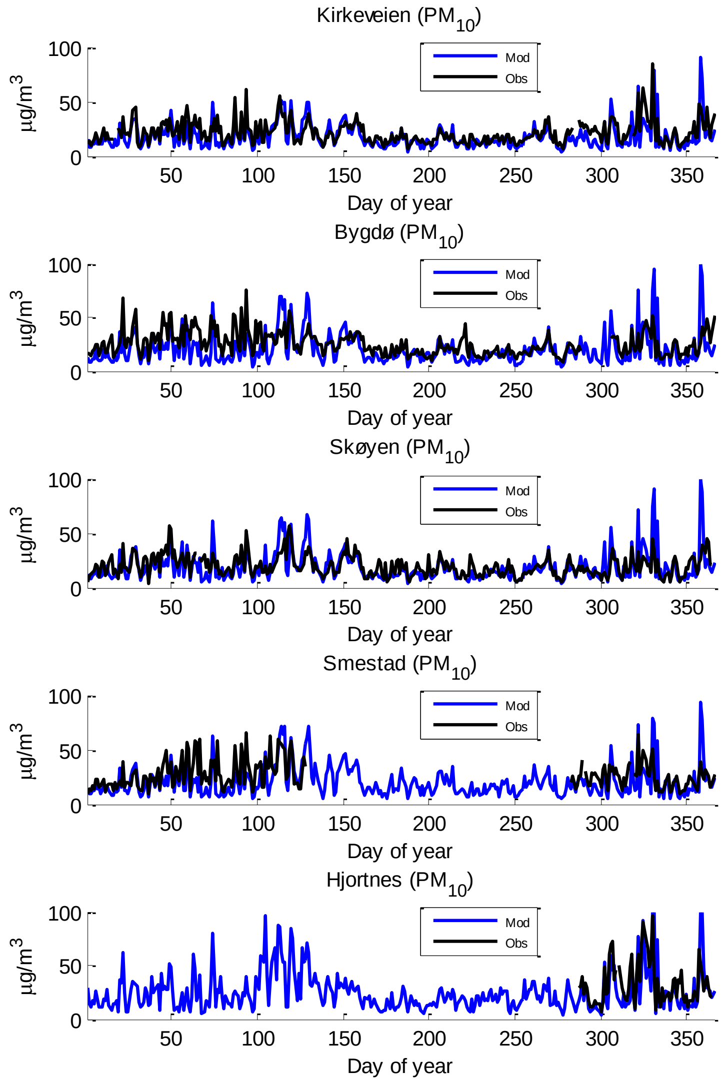


Figure 14: Daily mean PM_{10} concentrations at 9 monitoring sites in Oslo for the calendar year 2008. Blue is the model (including regional background) and black is the observations. The lower right plot indicates the regional background concentrations.

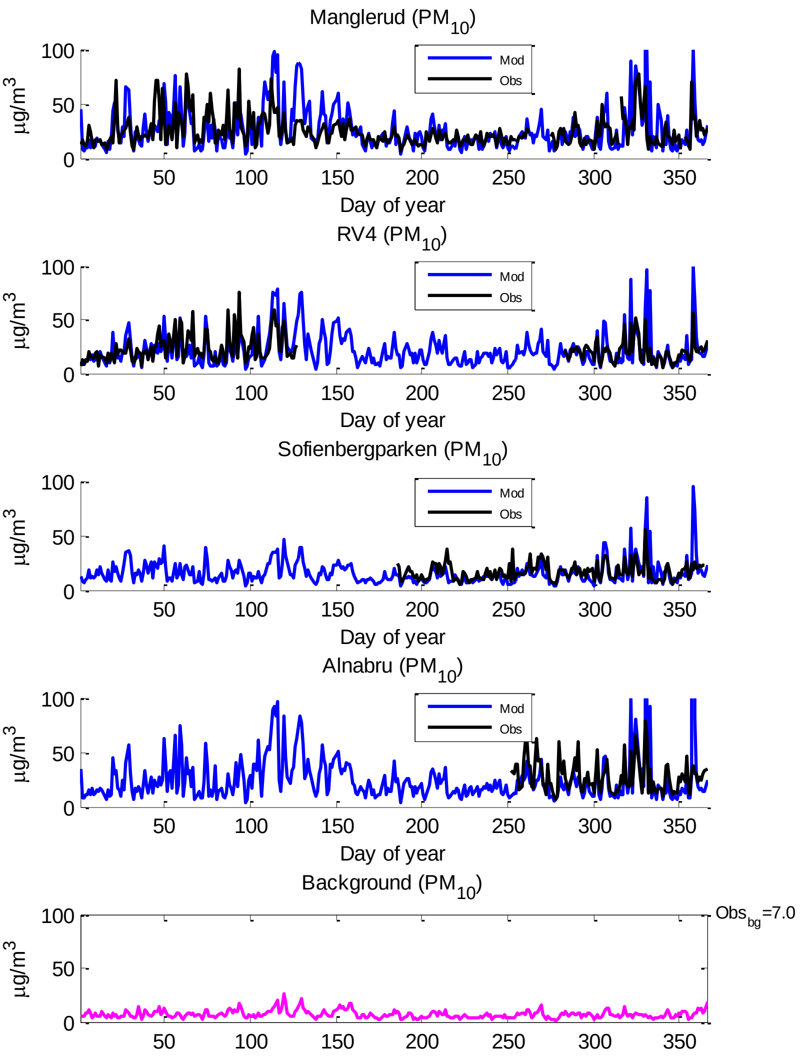


Figure 14: Contd.

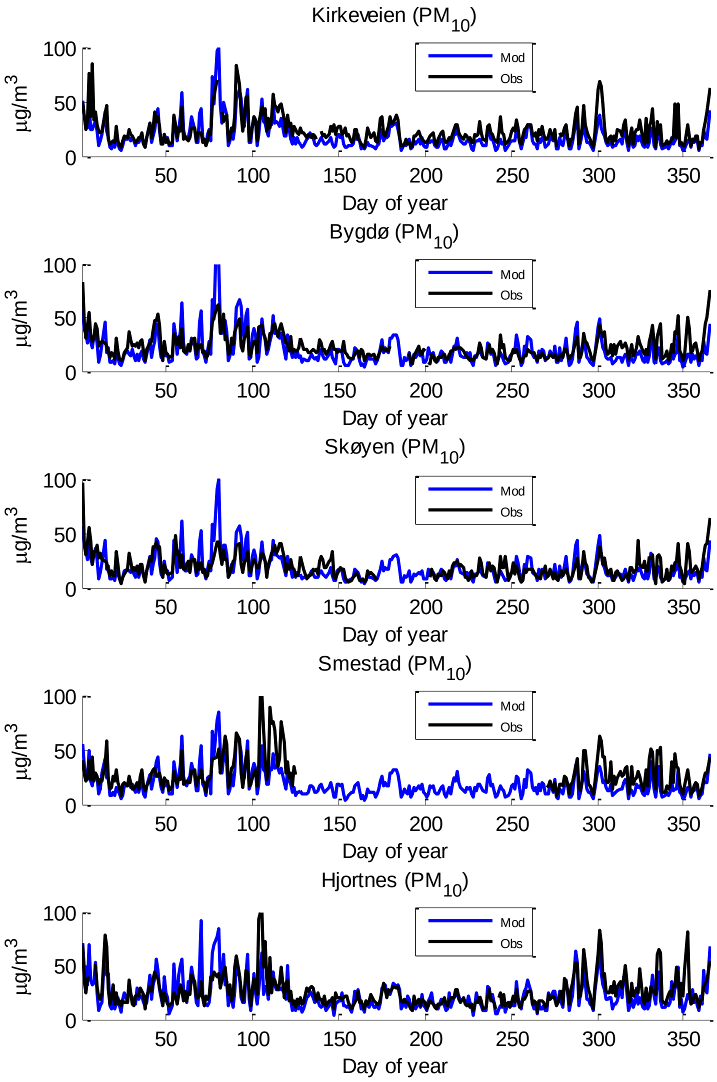


Figure 15: As in Fig. 14 but for the calendar year 2009.

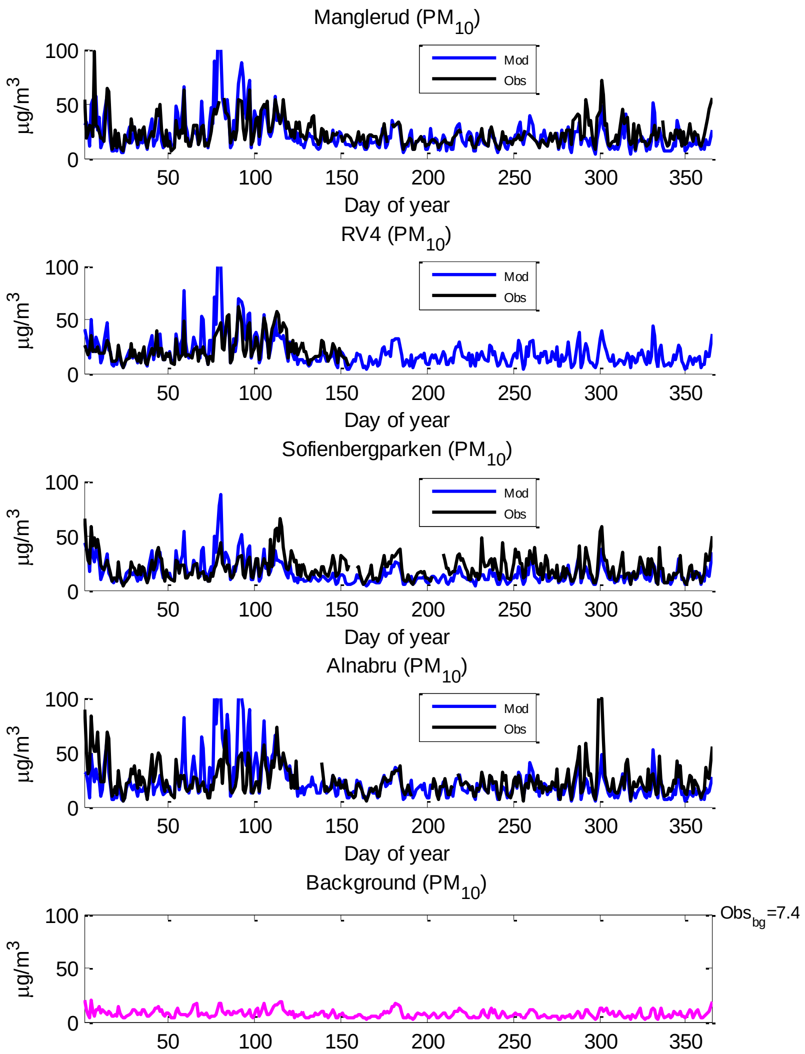


Figure 15: Contd.

The model slightly under predicts the mean concentrations, with an average fractional bias over all stations of -9% (2008) and -13% (2009). The under prediction occurs mostly during the summer period where the model appears to be missing emission sources. The fractional bias per station ranges from -27% to +7% for both years.

The number of exceedance days varies more significantly than does the mean concentration from station to station. This is true for both modelled and observed concentrations. Manglerud shows the largest error in exceedance days in 2008. It is suspected that a part of this error is due to vehicle speeds being lower at Manglerud than indicated by the signage. Road maintenance activities may also be quite different at this site and the number of HDV in the database for this road may also be overestimated. The number of exceedance days is very difficult to predict as only slight changes in concentrations can have a significant impact on the results. Other predictors, such as the 90'th percentile, or 36'th highest daily mean concentration (also shown in Figs. 16 and 17), are more robust indicators and are more useful for model validation.

Daily mean correlation varies from station to station. Kirkeveien has the highest correlation of R^2=0.62 (2009) and Alnabru has the lowest of R^2=0.25 (2009). The correlation indicates if the temporal variability is being correctly represented. This will depend both on the emission variability, due to temperature for wood burning and due to surface moisture for non-exhaust emissions, as well as the meteorological and dispersion conditions. Given the level of available data for calculating the emissions the modelled correlation, for PM_{10}, is considered to be quite high.

We conclude from the validation that the model, given the currently available input data, has an average bias of around -9 – -13% for the two years modelled and an uncertainty in the mean concentrations of -20% - +5%. The error in the number of exceedance days is more significant. Based on the average absolute bias this error is between 30 – 50 %.

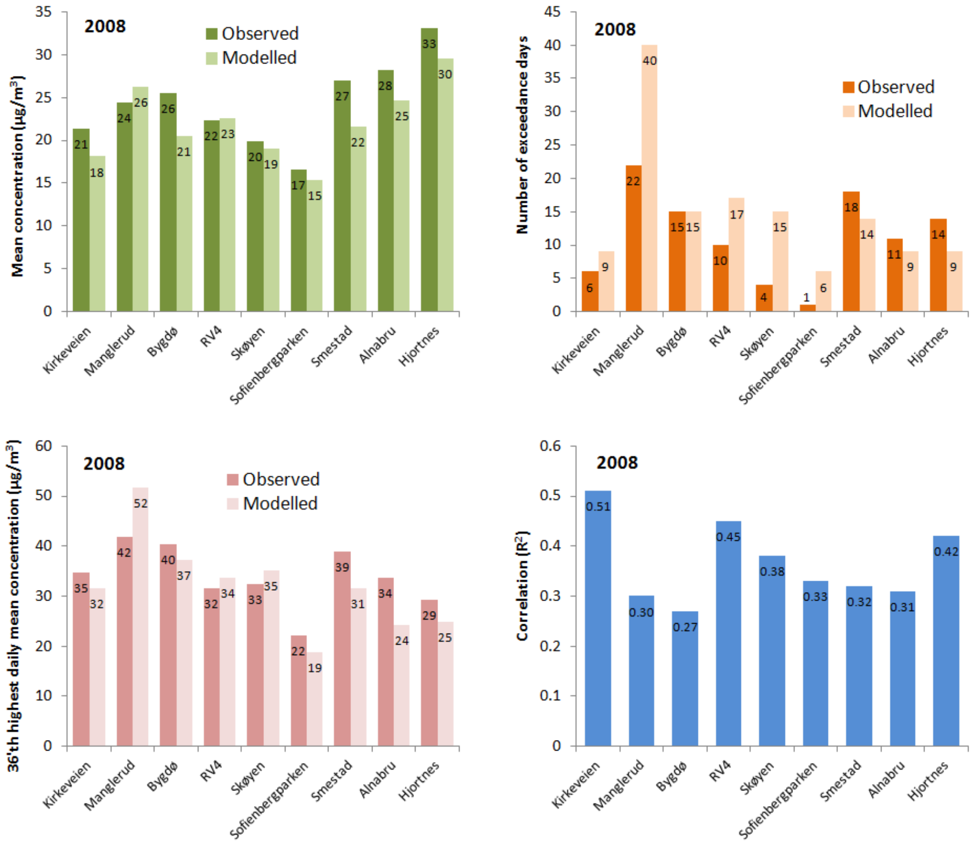


Figure 16: Calculated mean concentrations (left) and number of exceedance days, days with daily mean concentrations of PM_{10} > 50 µg/m^3, (right) for the year 2008 at 9 monitoring stations in Oslo. Model values presented are concurrent with available monitoring data.

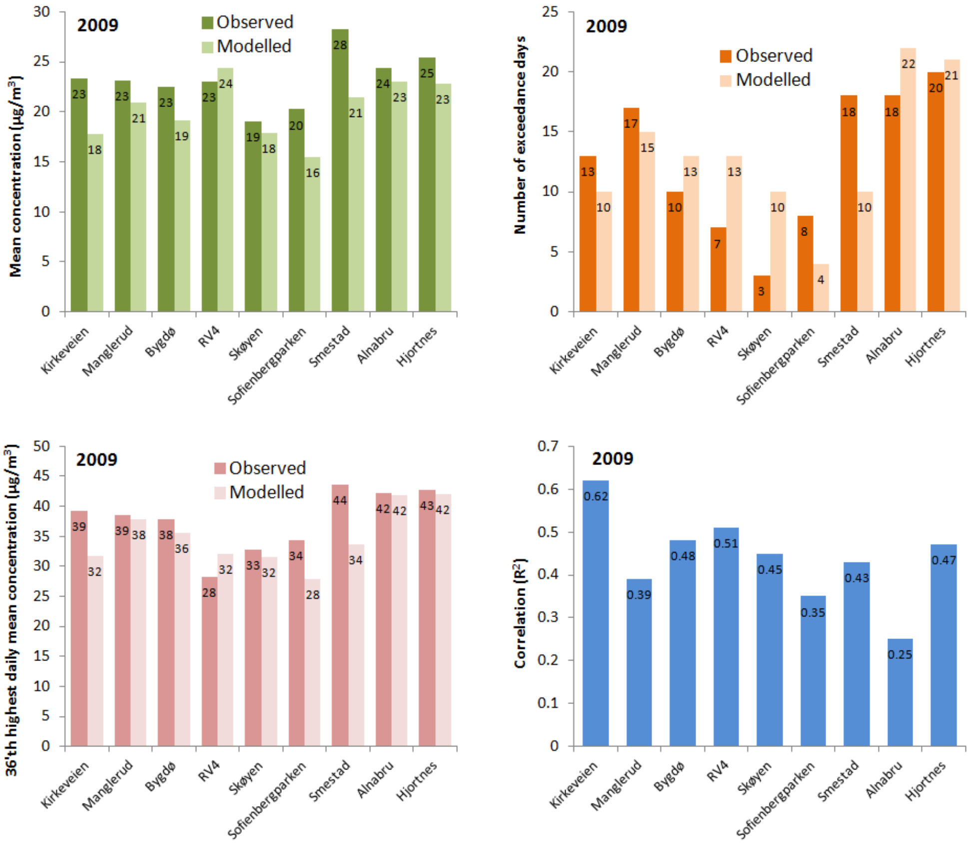


Figure 17: As in Fig. 16 but for 2009.

4.3 Source apportionment

Source apportionment studies have been carried out for 2009 only. The total PM_{10} emissions and the mean concentrations at all 9 sites is shown in Fig. 18. Modelled non-exhaust emissions of PM_{10} make up 33% of the observed PM_{10} concentrations whilst exhaust emissions contribute with 13%. Regional background levels of PM_{10} are 7.5 µg/m^3 and contribute with 32% of the total observed.

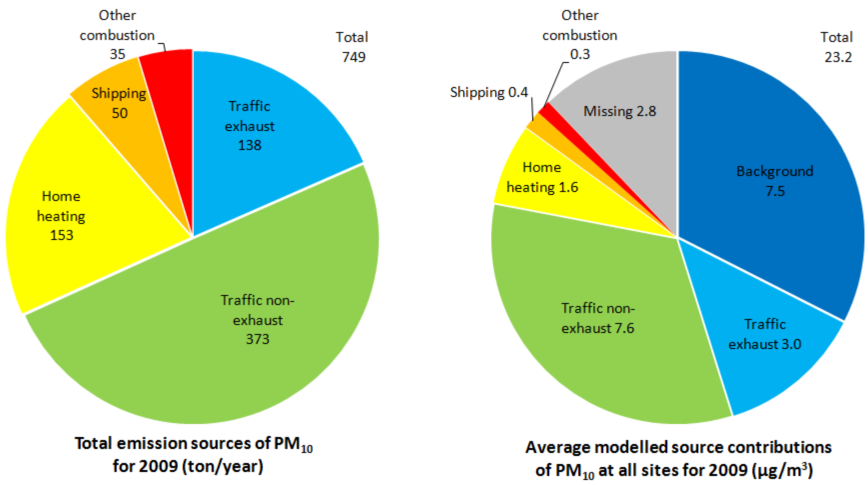


Figure 18: Total emissions of PM_{10} per year in tons (left) and modelled source contribution of mean PM_{10} concentrations for all the measurement sites. 'Missing' is the observed minus total modelled concentrations.

4.4 Sensitivity to studded tyre share

For both years the maximum studded tyre share is set to 16% for LDV (including passenger cars) and 8% for HDV. To indicate the sensitivity of the concentrations to changes in studded tyre share then the share of studded tyres is reduced and increased by a factor of two, for both HDV and LDV. The impact of these changes on annual mean concentrations and number of exceedance days is shown in Fig. 19.

The annual means are not strongly influenced by the change in studded tyre share due to the contribution of other sources to the concentrations. On average, for the current 16% (8% HDV) share of studded tyres, we see a change in annual mean concentration at the monitoring sites of 0.22 µg/m^3 (roughly 1%) as a result of a 1% (0.5% HDV) change in studded tyre share. This means that the total feasible reduction with no studded tyres is a 16% decrease in annual mean concentrations. Around 50% of the non-exhaust contribution to annual mean concentrations is from studded tyres, the rest being from tyre, brake and non-studded road wear. These relative changes depend on the contribution of other sources to the concentrations and cannot be generalised to other situations.

Significant increases and decreases in exceedance days occur as a result of a doubling or halving of the studded tyre share. On average the number of exceedance days is reduced by a factor of two with a halving of studded tyre share and increase by a factor of two with a doubling for the current studded tyre share. This result can also not be generalised further, as it is dependent on the contribution from other sources.

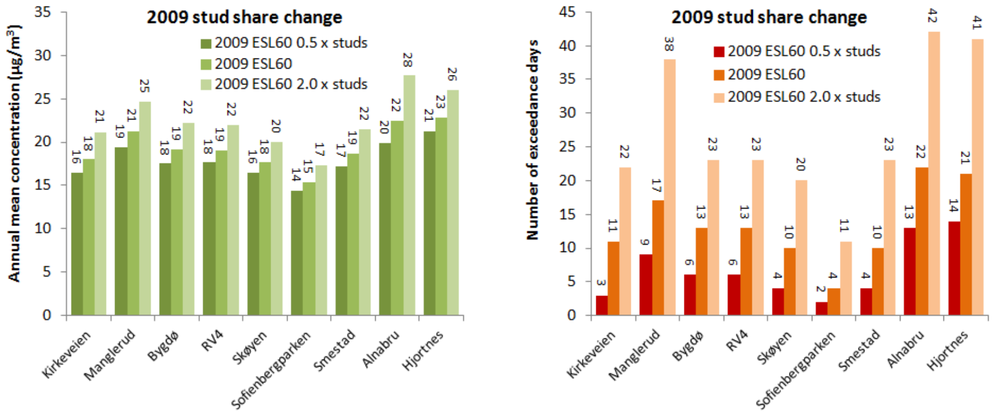


Figure 19: Change in annual mean concentrations (left) and number of exceedance days (right) as a result of a reduction and an increase of studded tyre share by a factor of two. 'ELS60' refers to the default model run using the Environmental Speed Limit of 60 km/hr.

4.5 Sensitivity to heavy duty vehicles

As with studded tyres we assess the sensitivity of the model to changes in HDV fraction by halving and doubling the number of HDV vehicles for all roads. This will impact on the PM_{10} concentrations in four ways: by changing the contribution of exhaust particles, by changing the road wear, by changing the suspension rate and by changing surface moisture spray rates and turbulent heat exchange with the surface. The results are shown in Fig. 20.

A similar pattern occurs as for changes in studded tyre share. A halving of all HDV in Oslo results in an average reduction in mean concentrations at the measurement sites of 10%. A doubling results in an increase of 19%.

Exceedances are also affected by the number of HDV vehicles. Halving the HDV reduces the average number of exceedance days by 40% and a doubling results in an increase of 80%, almost a doubling.

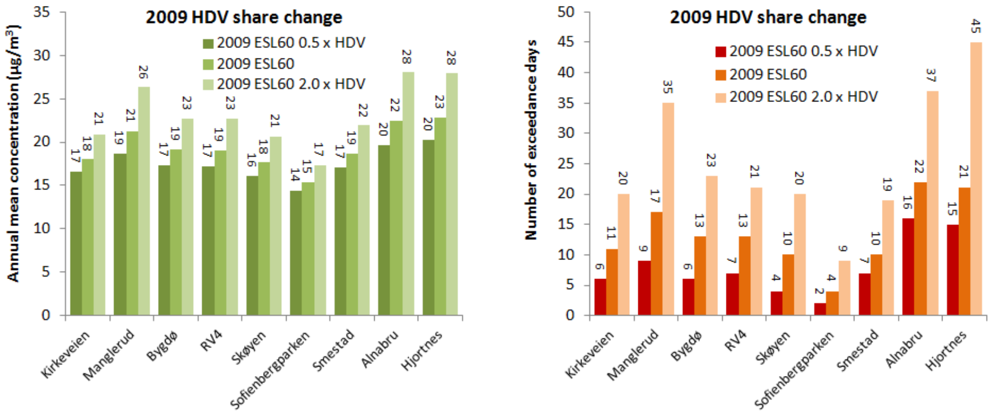


Figure 20: Change in annual mean concentrations (left) and number of exceedance days (right) as a result of a reduction and an increase of HDV share by a factor of two. 'ELS60' refers to the default model run using the Environmental Speed Limit of 60 km/hr.

4.6 Sensitivity to cleaning

During the years 2008 and 2009 no specific dust binding activities occurred, according to the available road maintenance activity data. In 2008 no cleaning events were noted but in 2009 there were 20 cleaning events that occurred in February and March. In the default runs of the model the cleaning has been included with a 20% efficiency. In Fig. 21 the difference between the calculations, with and without cleaning, are shown. Note that in the model calculations cleaning was applied to the motorways and state roads only, not to the communal roads.

The mean concentrations increase by an average of 13% when no cleaning is applied and the average number of exceedance days increases by 66%. The impact of cleaning will clearly depend on the number of cleaning events but also on the defined efficiency of cleaning which may lie anywhere between 0% and 50%. A value of 20% has been used here.

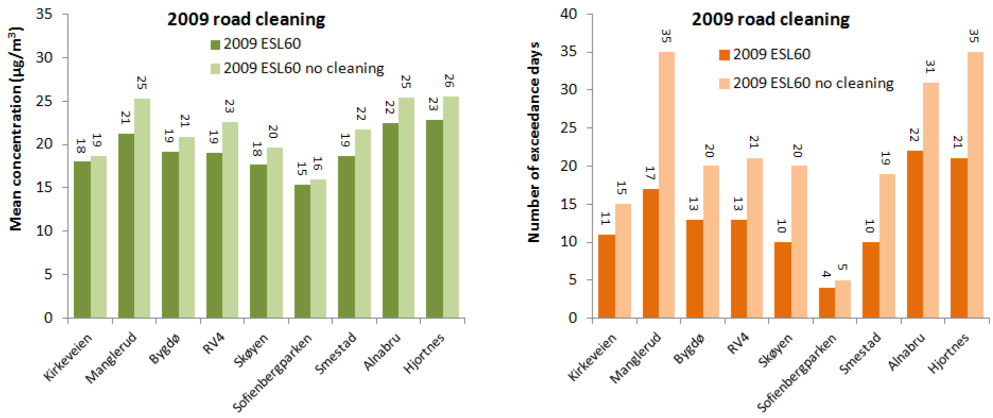


Figure 21. Change in annual mean concentrations (left) and number of exceedance days (right) as a result of not including road cleaning in the model calculations. 20 road cleaning events occurred in the months of February and March, each removing 20% of the surface dust load. 'ELS60' refers to the Environmental Speed Limit of 60 km/hr.

4.7 Summary of the Oslo modelling results

PM_{10} concentrations have been modelled for the years 2008 and 2009 in Oslo. The NORTRIP model, in a simplified form, has been used to calculate the contribution of non-exhaust traffic induced emissions. Based on the model calculations the non-exhaust emissions account for 33% of the observed PM_{10} concentrations, averaged over the nine available monitoring sites that are almost all traffic sites.

Comparison with observations over the two years indicates an average model fractional bias of -11% with a range of -27% to +7% for the individual stations. The model tends to under predict concentrations mostly in the summer where other emissions sources, e.g. windblown suspension or organic contributions, may be missing.

The model error in predicting the number of exceedance days is larger than that found for the mean concentrations, with the model over predicting the total number of exceedance days for all sites by 17% but with an uncertainty for an individual site, based on the absolute bias per station, of approximately 40%. The number of exceedance days can be very sensitive to slight variations in daily mean concentrations and is a poor indicator for model validation.

Sensitivity tests of the model (2009 only) show that a change in the number of vehicles using studded tyres by 1% for LDV and 0.5% for HDV will lead to a change in mean concentrations of 0.22 µg/m^3, which is roughly 1% of the total mean concentrations. The same 1% change in the studded tyre share also leads to an average change of 0.8 exceedance days. These results are specific to this period and the current studded tyre share of 16% for LDV and 8% for HDV. However, these changes are indicative of the sensitivity to the studded tyre share. It is important to note that for the current studded tyre share of 16% that the annual mean contribution of studded tyres is only 50% of the total non-exhaust emissions, the rest resulting from tyre, brake and non-studded road wear.

The sensitivity of the model to the fraction of HDV was also assessed. A halving of all HDV in Oslo results in an average reduction in mean concentrations at the measurement sites of 10%. A doubling results in an increase of 19%. Halving the HDV reduces the average number of exceedance days by 40% and a doubling results in an increase of 80%.

The impact of cleaning was also assessed but these results are highly uncertain since they depend on uncertain information concerning the timing and number of cleaning events as well as the efficiency of the cleaning in removing PM_{10} from the road surface. However, it was found that using a cleaning efficiency of 20% with 20 cleaning events on major roads that cleaning reduced, on average, the mean concentrations by 13% and reduced the average number of exceedance days by 60%.

Uncertainty of the total model results has been assessed by comparison with the available monitoring data, as described above, which indicates levels of uncertainties in mean concentrations of around 20% and in exceedance days of around 40%. However, uncertainties in changes to model input cannot be as easily assessed. For example the assumptions of 5 x higher wear and 10 x higher suspension rates for HDVs, compared to LDVs, are estimates with around a 50% uncertainty attached to them. Similarly cleaning efficiencies are also highly uncertain and input data concerning cleaning events is also poorly defined. Wear rates associated with studded tyres are also uncertain, dependent as they are on pavement types which is also an uncertain input parameter.

5 Conclusion

In this report we have applied the NORTRIP model to calculate PM_{10} non-exhaust emissions from traffic for a single road (RV4), using high quality input data, and for all of Oslo, with less well defined input information. Using this model we have investigated the sensitivity of the mean concentration and the number of exceedance days to changes in a number of input parameters. These include the studded tyre share, heavy duty vehicle number and salting and cleaning road maintenance practices. The results indicate that significant changes in PM_{10} concentrations, particularly in the number of exceedance days, can occur as a result of changes in these parameters but these concentrations are also dependent on meteorological factors as well as the contributions of other sources.

This study has not carried out a systematic assessment of all the available measures, since speed was not included, and how they can be most effectively combined. Instead it has shown the sensitivity of the model to three factors individually, i.e. studded tyre share, HDV fraction and some road maintenance activities. A more systematic approach would be needed if an assessment of the effectiveness of combined measures were to be implemented. In general, however, the different measures can be seen to be additive in their effect of reducing non-exhaust emissions. A combination of measures will always provide the best results.

The results presented here are the first application of the NORTRIP model for assessing sensitivities, particularly on the city scale, to various input parameters. To affirm the robustness of the model, a larger number of years are required and improved data concerning road maintenance activities, vehicle speeds, HDV fraction and road pavement types are required. The model also requires more scientific information concerning a number of model processes including cleaning efficiencies, the impact of gravel on road wear, dust binding, HDV wear and suspension rates, salt suspension and wet removal processes. Improving the model description for these processes will require new observational data that is currently not available.

Of all the processes described the impact of cleaning is the most uncertain as cleaning efficiencies in removing the dust layer are unknown and the cleaning method was not defined in the available data. Despite the uncertainties associated with the model the results are useful in providing insight into the impact of these traffic parameters on the non-exhaust emissions of PM_{10} in Oslo.

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Appendix A

Model information

Table A.1. Input data requirements for the NORTRIP emission model.

Site and road data	**Traffic (hourly)**	**Meteorology (hourly)**	**Road maintenance activity (hourly)**
Number of lanes	Time and date	Time and date	Time and date
Width of lane (m)	Total traffic volume (veh/hr)	Observed atmospheric temperature (^oC)	Sanding mass per hour (g/m^2)
Road width (m)	Total heavy duty vehicle traffic volume (veh/hr)	Wind speed (m/s)	Salting mass NaCl per hour (g/m^2)
Street canyon width (m)	Total light duty vehicle traffic volume (veh/hr)	Relative humidity (%)	Salting mass $MgCl_2$ per hour (g/m^2)
Street canyon height north (m)	Studded tyre heavy duty vehicle traffic volume (veh/hr)	Rain fall(mm/hr)	Road wetting per hour (mm)
Street canyon height south (m)	Studded tyre light duty vehicle traffic volume (veh/hr)	Snow fall (mm/hr)	Road cleaning occurrence
Street orientation (degrees from north)	Winter friction tyre heavy duty vehicle traffic volume (veh/hr)	Global radiation (W/m^2)	Snow ploughing occurrence
Latitude (decimal degrees)	Winter friction tyre light duty vehicle traffic volume (veh/hr)	Cloud cover (fraction) *	
Longitude (decimal degrees)	Summer tyre heavy duty vehicle traffic volume (veh/hr)	Road surface wetness (mV or mm) **	
Elevation (m a.s.l.)	Summer tyre light duty vehicle traffic volume	Road surface temperature (^oC) **	
Height of observed wind (m)	Heavy duty vehicle speed (km/hr)		
Height of observed temperature and RH (m)	Light duty vehicle speed(km/hr)		
Surface albedo (0-1)			
Time difference with UTC (hr)			
Surface pressure (mbar)			
Driving cycle (index)			
Pavement type (index)			

* Not obligatory, cloud cover can be estimated from the global radiation
** Not required directly for the emission modelling but can be used for comparison with observed concentrations

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ABSTRACT
This report was requested by the Norwegian Public Roads Administration (Statens vegvesen) to provide information concerning non-exhaust traffic emissions in Oslo and the impact of various traffic parameters and road maintenance activities on these emissions. This report provides the results of calculations made with the NORTRIP model, a recently developed emission model for calculating non-exhaust emissions. The sensitivity of the modelled emissions to traffic parameters such as studded tyre share and fraction of heavy duty vehicles is investigated. In addition the impact of salting and cleaning is addressed.

NORWEGIAN TITLE
Modellering av ikke eksosutslipp av PM_{10} i Oslo: Påvirkning av trafikk, vei og vinterdrift ved bruk av NORTRIP-modellen .

KEYWORDS		
Air Quality	Modelling	Aerosols and particles

ABSTRACT (in Norwegian)

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