MODELLING THE IMPACT OF THREE SETS OF FUTURE VEHICLE EMISSION STANDARDS ON PM CONCENTRATIONS IN THE LOWER FRASER VALLEY

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1.0 INTRODUCTION

A modeling study was conducted to analyse the impact of three sets of future vehicle emission standards (hereafter "the emission standards") on ambient levels of particulate matter (PM) in the Lower Fraser Valley (LFV), which includes part of southwestern British Columbia, Canada, and northwestern Washington State, United States. The modeling system used in the study is a modified version of Models–3/CMAQ (EPA, 1999) based on CMAQ version 4.1, SMOKE versions 1.4 and 2.0, MM5 version 3, and MCIP version 2.2. Our major modifications to the system include a modularized AERO2 module, a new secondary organic aerosol submodule, an improved biogenic emissions model, and a new CMAQ post–processor for generating size–resolved PM concentrations based on aerodynamic diameter (Jiang et al., 2004a; 2004b). The model simulations were conducted for two nested grid domains with 15 km and 5 km resolution, respectively. The analysis is focused on the first layer of the 5 km domain featuring the LFV and surrounding areas. More detailed information about the modeling system, the domain, and input preparation are available in Jiang et al. (2004a).

2.0 THE MODELLING SCENARIOS

The following four emission scenarios were simulated and the results analysed.

1. The Pacific '93 base case scenario (BA): 0:00 July 31 to 24:00 August 7, 1993, PDT, during the Pacific '93 field study;
2. The 2020 future base case scenario (FBA): BA projected to 2020 without considering the three sets of emission standards;
3. The 2020 future non mobile scenario (FNM): Modified FBA with all on–road mobile source emissions removed;
4. The emission standards scenario (ES): Modified FBA with the implementation of the following three sets of vehicle emission standards (SENES/AIR, 2002):
   1) The light–duty Tier 2 vehicle emission standards to be implemented from 2004;
   2) The heavy–duty vehicle NMHC and NO_x emission standards to be implemented from 2004;
   3) The heavy duty vehicle NO_x and PM emissions and low sulphur on–road diesel standards to be implemented from 2007.

Figure 1 shows a comparison of the total and source–category–based emissions for the four scenarios. Total emissions of NO_x, VOC, SO_x, NH_3, $PM_{2.5}$, and PM_{10} in ES are 43.5%, 0.3%, 9.1%, 0%, 6.3%, and 6.6% lower, respectively, than the emissions in FBA.

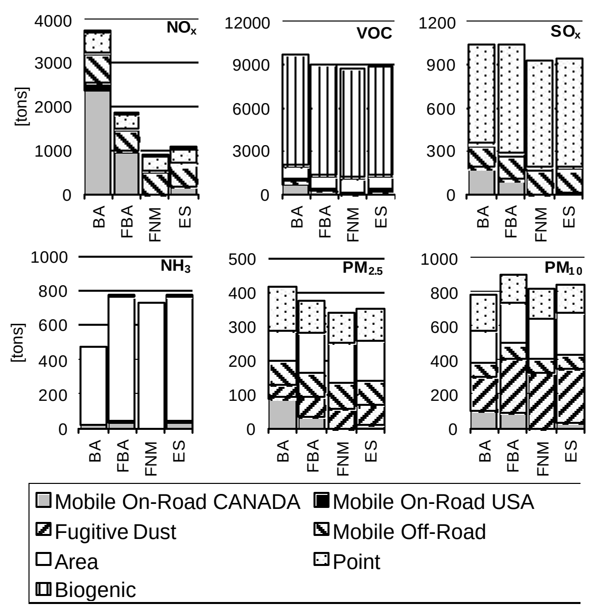

Fig. 1 Comparison of total and source–category–based emissions of NO_x, VOC, SO_x, NH_3, $PM_{2.5}$ and PM_{10} for the four modeling scenarios.

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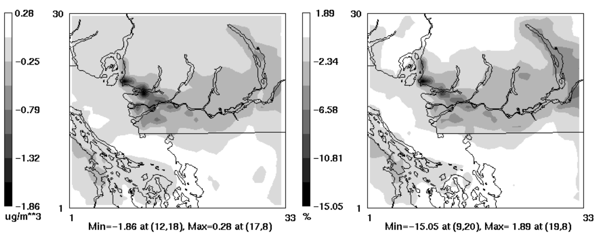
3.0 IMPACT OF THE EMISSION STANDARDS ON $PM_{2.5}$

3.1 Spatial and temporal patterns of the impact

The impact of the emission standards on $PM_{2.5}$ concentrations is analysed from four different perspectives.

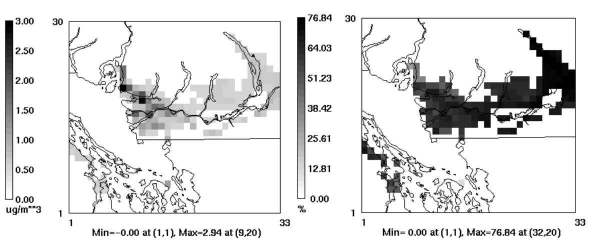
1. Spatial impact on episode–average $PM_{2.5}$:
   Figure 2 shows the absolute and relative spatial impact of the emission standards on episode–average $PM_{2.5}$ mass concentrations across the domain in 2020. Note the $PM_{2.5}$ reductions in the valley with the highest reduction in the urban area close to Vancouver. The $PM_{2.5}$ reductions also appear over Harrison Lake in the northwest and along Highway 1 on Vancouver Island.



(a) (b)

Fig. 2 (a) Absolute and (b) relative spatial impact of the emission standards on episode–average $PM_{2.5}$ mass concentrations in 2020.

2. Spatial impact on on–road mobile source contributions to episode–average $PM_{2.5}$ in Mobile–Impacted Areas (MIA):
   A MIA is an area where on–road mobile sources contribute meaningfully to the ambient $PM_{2.5}$ loading. Figure 3 (a) shows a MIA in which on–road mobile sources contribute at least 0.5 $\mu g\ m^{-3}$ to episode–average $PM_{2.5}$ mass concentrations in 2020.

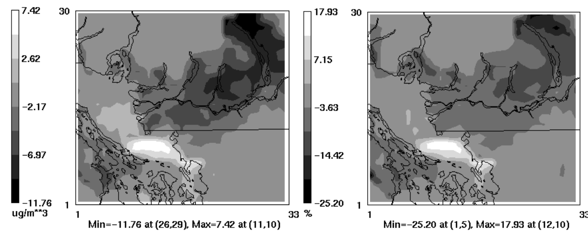


(a) (b)

Fig. 3 (a) A MIA in which on–road mobile sources contribute at least 0.5 $\mu g\ m^{-3}$ to episode–average $PM_{2.5}$ mass concentrations in 2020, and (b) % reduction in on–road mobile source contributions to $PM_{2.5}$ in the MIA due to the implementation of the emission standards.

   Figure 3 (b) shows % reduction in on–road mobile source contributions to $PM_{2.5}$ in the MIA due to the implementation of the emission standards.

3. Spatial impact on maximum 1–hour $PM_{2.5}$:
   Figure 4 shows the absolute and relative impact of the emission standards on maximum 1–hour $PM_{2.5}$ concentrations across the modeling domain. $PM_{2.5}$ is reduced in most areas in the valley and in some areas around the southern part of Vancouver Island. Most of the population in the modeling domain live in these areas and would reap the benefit of the $PM_{2.5}$ reductions.



(a) (b)

Fig. 4 (a) Absolute and (b) relative impact of the emission standards on maximum 1–hour $PM_{2.5}$ concentrations across the modeling domain.

4. Temporal impact on domain–average $PM_{2.5}$:
   Figure 5 shows the absolute and relative temporal impact of the emission standards on domain–averaged $PM_{2.5}$ concentrations. The absolute and relative changes in domain–averaged $PM_{2.5}$ concentrations show similar temporal patterns. They both reach maximum reductions at the same time that the domain–averaged $PM_{2.5}$ concentration reaches the maximum (not shown).

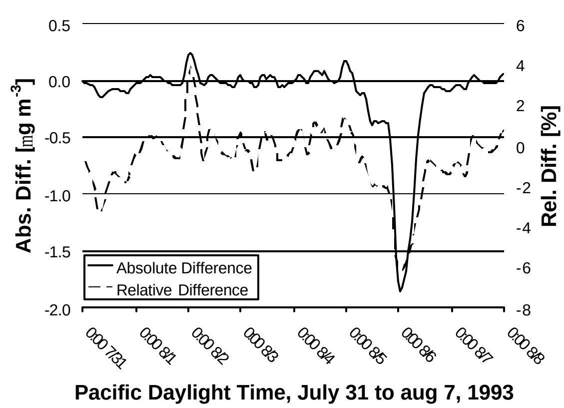


Fig. 5 Temporal variation of the absolute and relative impact of the emission standards on domain–averaged $PM_{2.5}$ concentrations.

3.2 Location and time at which significant impact appears

The emission standards tend to cause more significant $PM_{2.5}$ reductions in places where maximum 1–hour concentrations of $PM_{2.5}$ are high or the incremental contributions of on–road mobile sources to ambient $PM_{2.5}$ are more significant.

In general, the $PM_{2.5}$ reductions due to the emission standards also tend to be more significant at the hours when ambient $PM_{2.5}$ concentrations are high.

3.3 Magnitude of the impact

Table 1 summarises the magnitude of the impact from the four perspectives analysed in Section 3.1. Negative and positive values in the table indicate reductions and increases, respectively, of the $PM_{2.5}$ concentrations caused by the implementation of the emission standards.

Table 1. Magnitude of the impact of the emission standards on $PM_{2.5}$ concentrations.

	Impact			
	unit	**most +**	**Most -**	**Average**
Episode-average $PM_{2.5}$	$\mu g\ m^{-3}$	0.3	-1.9	-0.1
	%	1.9	-15.1	-1.2
Mobile contributions to episode-average $PM_{2.5}$ in the MIA	$\mu g\ m^{-3}$	-0.1	-1.9	-0.5
	%	-10.8	-76.8	-64.0
Maximum 1-hour $PM_{2.5}$	$\mu g\ m^{-3}$	7.4	-11.8	-2.1
	%	17.9	-25.2	-3.7
Hourly domain-average $PM_{2.5}$	$\mu g\ m^{-3}$	0.3	-1.9	-0.1
	%	3.9	-6.2	-0.7

Averaged over both the modelling domain and the episode, the $PM_{2.5}$ reduction caused by the emission standards is very minor at 1.2%, although it reaches 15.1% at a specific location on a time–average basis and 6.2% at a particular hour on a domain–average basis. This low average reduction is due to the fact that the on–road mobile source contributions to ambient $PM_{2.5}$ concentrations in 2020 are already very low even without the three sets of emission standards modeled in this paper.

In terms of the maximum 1–hour $PM_{2.5}$ concentrations in the grid cells across the domain, the emission standards cause a 3.7% reduction on a domain–average basis. At a particular location of the domain, the emission standards can cause as much as 25.2% reduction or 17.9% increase in $PM_{2.5}$ concentrations.

Despite the relatively low impact of the emission standards on average $PM_{2.5}$ concentrations across the whole domain and episode, the emission standards are very effective in reducing incremental contributions of the on–road mobile source emissions to the ambient $PM_{2.5}$ concentrations. In the grid cells where on–road mobile sources contributed at least 0.5 $\mu g\ m^{-3}$ to $PM_{2.5}$ on an episode–average basis, the emission standards cause a maximum of 76.8% and a minimum of 10.8% reduction in the on–road mobile source contributions to ambient $PM_{2.5}$. On average, the emission standards reduce ambient $PM_{2.5}$ concentrations due to on–road mobile sources by 64.0%.

4.0 OTHER ANALYSIS

The impact of the emission projections from the BA to FBA scenario and the cumulative impact of emission changes from the BA to ES scenario were also analysed in this study.

In addition to the impact on total $PM_{2.5}$ concentrations, analyses were also conducted for three major inorganic species (ANH4, ANO3, ASO4), three groups of organic species (AORGPA, AORGA, AORGB), and the combined group of all organic species (AORG) on the basis of the spatial distributions of their episode–average concentrations. These analyses revealed some important factors contributing to the behaviour of the system. For the behaviour of the inorganic species, the contributing factors of note include the interconnected impact of NO_x and SO_x emission reductions accompanying the scenario changes and the NH_3 emission increases from the BA to FBA scenario. For the organic PM groups, their concentrations are indirectly impacted by the NO_x emission reductions, which help increase ozone concentrations in some areas and subsequently cause a slight increase in organic PM species concentrations. It is also worth noting that on average, biogenic organic PM species have higher concentrations than anthropogenic organic species because of the dominant biogenic VOC emissions in the inner LFV modelling domain.

5.0 SUMMARY

The modeling results indicate that the emission standards will be effective in controlling on–road mobile source contributions to ambient

$PM_{2.5}$ levels. However, the average impact on the total ambient $PM_{2.5}$ concentrations will vary noticeably, depending on the location and time. Reductions in ambient $PM_{2.5}$ levels due to the emission standards will be most evident in areas where maximum 1–hour $PM_{2.5}$ concentrations are high, where on–road mobile source contributions are significant, and in the hours when domain–average ambient $PM_{2.5}$ concentrations are high. Changes in other areas and hours are expected to be minor, and may dilute or offset the positive impact of the emission standards when averaged over the whole domain or episode.

6.0 UNCERTAINTIES AND CAUTIONARY NOTE

Uncertainties exist both in PM science and in emissions of primary particles and PM precursors. Due to the extreme complexity in PM composition, structure, and formation and removal processes, PM science is still not mature and is still evolving. Therefore, all PM models currently in use, including the modelling system used in this study, contain significant uncertainties in their scientific algorithms. In addition, the emission inputs to the model inherit uncertainties in the emission raw data, in the models used for calculating emission factors, and in the emission processing streams to spatially, temporally, and chemically allocate the emissions. It is extremely difficult to quantify these uncertainties.

Notwithstanding the aforementioned uncertainties, results in this paper reflect the best understanding and information currently available. When used appropriately, they can provide qualitative guidance in future policy development and implementations, although caution should always be exercised when the results from any PM model are used at this time.

It should also be noted that the results in this report are generated for the LFV domain, which is special in its geographical situation and its emission profiles. When the same modelling system is used in other regions, some of the results presented in this paper may change.

7.0 ACKNOWLEDGMENTS

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