THE SYNTHESIS OF A VEHICLE EMISSION MODEL, A SHORT RANGE DISPERSION MODEL AND A REGIONAL CHEMICAL TRANSPORT MODEL

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INTRODUCTION

Vehicle-generated pollution is the largest single contributor to reduced air quality in Canadian cities. Approximately two thirds of emissions from motor vehicles are generated in urban areas, making this the largest single contributor to smog and pollution in our cities. The resulting reduction in air quality has a significant effect on public health. Also, photochemical smog, caused by traffic in large cities, causes urban and regional haze that has the potential to contribute significantly to climate change as well. The role of particulate matter in cloud nucleation is a well known aspect of climate change and vehicular emissions that lead to the formation of atmospheric particulate matter thus will have an increasingly important effect on regional – and possibly global - climate in the future.

The *MOBILE* emission model (developed by the United States Environmental Protection Agency (EPA)) is widely used in North America to estimate vehicle emissions at national, state or provincial, and local levels. A number of independent evaluation field studies on the *MOBILE* models, however, have indicated the unreliability of their results. Thus it is very important to develop a more accurate vehicle emission factor model for air quality modelling and the assessment of health effects.

The Waterloo Centre for Atmospheric Sciences (WCAS) has developed a detailed micro-scale model, *MicroFac*, that can provide accurate emissions from a vehicle fleet under specified conditions of meteorology, fleet composition, vehicle age distribution and speed. The *MicroFac* emission model is now being coupled with high resolution dispersion models to produce a tool that will give the local concentrations of these emissions with high temporal and spatial resolution. These high resolution local concentrations will be incorporated into regional models in the future via a dual-kernel local-regional modelling procedure. This system will treat the chemistry and dispersion of the primary and secondary vehicle-related pollutants with the resolution of the local dispersion model and transfer them to the regional model when their spatial extent is comparable to that model's resolution. This will greatly increase the accuracy with which their effects on regional air quality can be determined.

MICROFAC EMISSION MODELS

A comprehensive and up-to-date database of emission rates is an important part of any emission model. Rapid changes in vehicle technology and fuel for the multiplicity of vehicles available make it essential to update the database frequently. The *MicroFac* modelling framework can incorporate new information from a variety of sources without time-consuming and expensive re-compilation.

MicroFac Algorithm

In contrast to the aggregated nature of the *MOBILE* model, the algorithms used in *MicroFac* give emissions in terms of the details of the specific vehicle fleet being considered. MicroFac models convert emissions based on driving cycles (test cycles consisting of a series of speed-time profiles) for different vehicles (by class, age and technology) into site-specific emissions by applying correction factors for speed, fuel, ambient temperature, etc. for the situation being considered. The resulting emission rates are then applied to the vehicle fleet under consideration to calculate the emission factors.

MicroFac requires only a few input variables to characterize the fleet. The main variables give the time and day of the year, the ambient temperature and relative humidity and specify the percentage of vehicles exceeding certain emission standards. Primary emission rates are calculated for both light- and heavy- duty vehicle classes based on their fuel use, weight and emission categories (normal and high emitters). *MicroFac* defines high emitters as those vehicles which fail emission standards set by the relevant regulating agency. MicroFac calculates the fraction of vehicles in each category for a 25-year age-wise distribution and then groups these into normal and high emitting categories. Then the vehicle miles accumulated for each vehicle is calculated based on the model year. The vehicle miles accumulated are then used to calculate normal and high emission rates in g/km. MicroFac then calculates correction factors for vehicle type, model year and emission level. Finally, the individual emission rates for the specified vehicles are calculated, and these are multiplied by the fraction of vehicles in that model year and vehicle class. The sum of these yields the composite emission factor (CEF) for the specified vehicle fleet.

$$\mathbf{CEF} = \sum_{\mathbf{i,j}} \mathbf{ER}_{\mathbf{i,j}} \times \mathbf{VEH}_{\mathbf{i,j}}$$

Where $ER_{i,j}$ is the Composite emission rate for vehicle type i and model year j, and $VEH_{i,j}$ is the fraction of vehicles for vehicle type i and model year j.

MicroFac Evaluation

Roadway tunnel studies are very effective in determining fleet emission rates from vehicles. Therefore, *MicroFac* was evaluated using reported tunnel data from four tunnel studies. In all cases, the vehicle fleet distribution and model years of the vehicles were known. One study was during 1995 in the Callahan Tunnel, which runs under the Boston Harbour in Massachusetts carrying traffic between North Boston, East Boston and Logan International airport. In this case, the traffic fleet was dominated (93.5% to 97.7%) by light-duty vehicles (< 8500 lbs) and the average speed and ambient temperature respectively ranged from 22.6 to 49.1 km/h and 10.0 to 20.6° C. Another study was done during 1995 in the Lincoln Tunnel, which runs under the Hudson River between Weehawken, New Jersey and Manhattan Island. In this case, light-duty vehicles comprised only 82.6% to 90.7% of the fleet; the average speeds were 32.6 to 48.0 km/h and the ambient temperatures were 28.1 to 32.6° C.

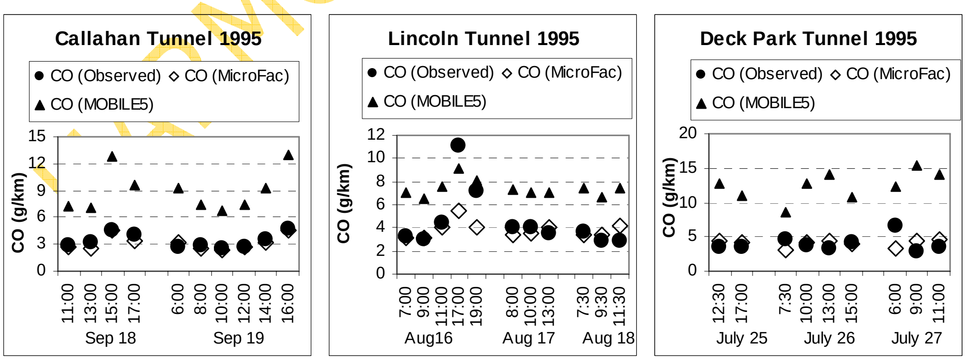


Fig 1. Comparison of Observed, MicroFac and MOBILE5 CO Emission Factors

Another 1995 study was in the Deck Park Tunnel, which is on an urban freeway running under downtown Phoenix. This study evaluates the model at high speeds (94.1 to 99.0 km/h) and high ambient temperatures (29.4 to 46.1° C). Light-duty vehicles comprised between

92.7% to 97% of the overall vehicle fleet. Figures 1 and 2 show the observed, *MicroFac* and *MOBILE5* emission factors for CO and NOx, respectively.

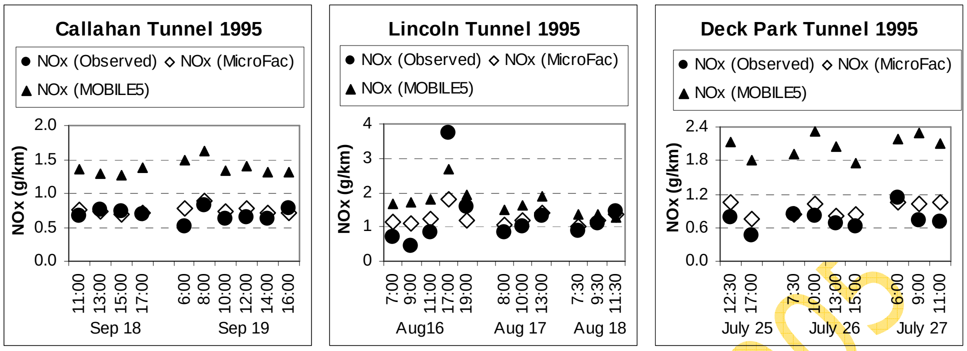


Fig 2 Comparison of Observed, MicroFac and MOBILE5 NOx Emission Factors

The fourth study was done in the Tuscarora Mountain Tunnel in south central Pennsylvania. The speeds varied from 85.6 to 99.3 km/h and light-duty vehicles ranged from 13.7% to 88.6%. In this case, real-time PM10 measurements were performed using a laser-photometer. Figure 3 compares the observed, *MicroFa*c and *MOBILE6* emission factors for PM2.5 and PM10, respectively.

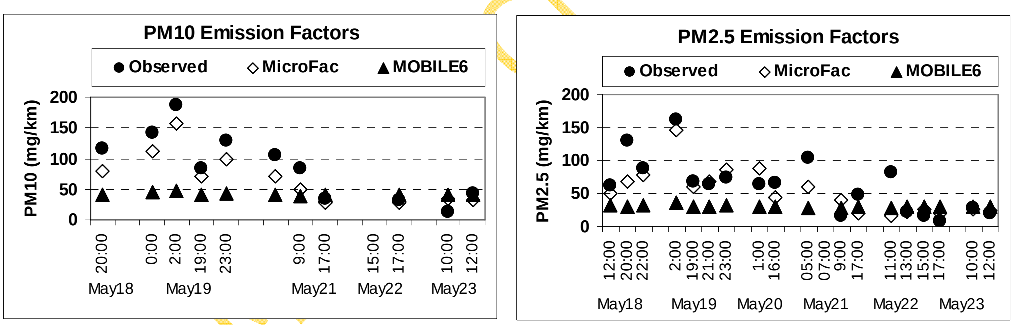


Fig 3 Comparison of Observed, MicroFac and MOBILE6 PM10 and PM2.5 Emission Factors

COUPLED *MICROFAC* - DISPERSION MODELS

The effects of pollutants depend on their concentrations at the locations of specified receptors, so it is necessary to compute the dispersion of the vehicle-generated emissions into the surrounding atmosphere. To do this, the *MicroFac* models are being coupled with *CALINE4*, *AERMOD* and *CALPUFF*, each of which has a different range of applicability. *CALINE4* is designed for line sources such as roadways. It uses a Gaussian diffusion equation and assumes uniform emissions along the road. It can predict concentrations of pollutants for receptors located within about 500 metres of the roadway. *AERMOD*, which simulates line sources as a series of volume sources, is more complex. It quantifies the turbulence and vertical profiles and also has simple chemistry. The *CALPUFF* algorithm can simulate near-source behaviour including concentrations that vary along the line source. Its major features include an ability to handle multiple point sources and buoyant line sources; finite buoyant point and line source plume rise; plume enhancement due to multiple sources; vertical wind shear in plume rise (which leads to puff splitting and differential advection and dispersion); terrain adjustment for plume path and time-dependent pollutant decay.

Example of coupling *MicroFac* with CALINE4

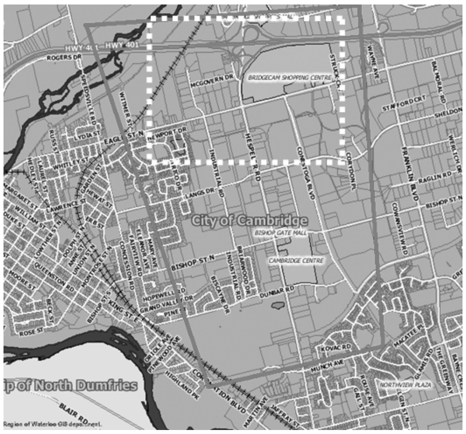


Fig 4. Map showing the site location

The ambient $PM_{2.5}$ concentrations produced by *CALINE4* using emissions calculated by *MicroFac* are presented in Figures 4 and 5. Figure 4 shows the site, which is the intersection (at the top centre of the dotted rectangle) of a busy freeway with a major urban street . Figure 5 shows the calculation for June 7, 2002 between 10:00 and 11:00. The average traffic speed, wind speed and ambient temperature were 32 km/h, 2.0 m/s, 280º and 26ºC, respectively. The left side shows the PM concentrations for the actual wind direction (280º); the right hand panel shows the result if the wind direction is parallel to road. Note, these examples do not include background PM2.5 ambient concentrations. The $PM_{2.5}$ contribution from local traffic is more than 30 µg/m³.

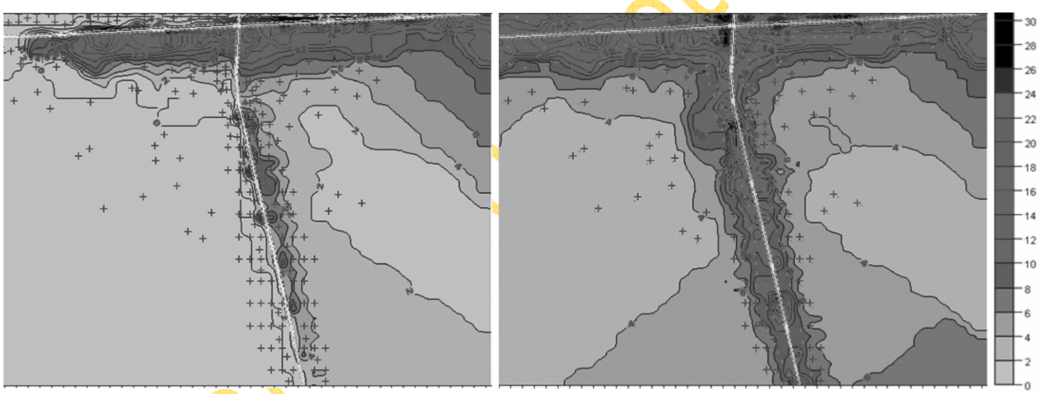


Fig 5 Ambient $PM_{2.5}$ concentrations on June 7, 2002 (11:00 hr). (Scale: µg/m^3)

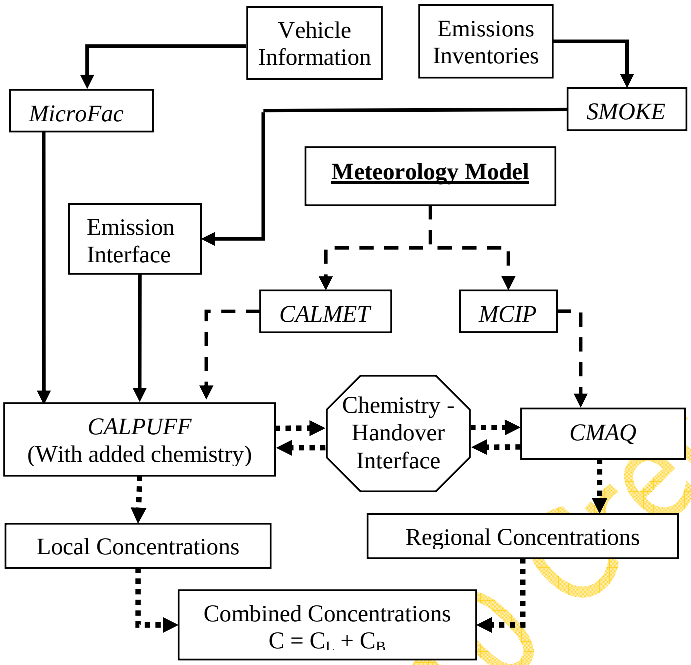
COUPLED LOCAL - REGIONAL AIR QUALITY MODELLING SYSTEM

The proposed scheme for coupling a local Lagrangian dispersion model with an Eulerian regional model is outlined in Figure 6. The US EPA's Models-3/*CMAQ* system is used as the regional model and *CALPUFF* is taken as the dispersion model for this example. In the coupled system, *CMAQ* and *CALPUFF* use the same meteorology driver, through *MCIP* and *CALMET* respectively. Concentration information is exchanged *via* an interface subroutine that updates the regional concentrations as appropriate and supervises the handover of the puff. The chemistry involving the localized emissions is calculated by the dispersion model using a subset of the regional model's chemistry solver. The resulting high resolution local concentrations (C_L) are combined with the regional scale concentrations ($C = C_L+C_B$). The resolution of the former is retained for the area covered by the dispersion model.

IMPLICATIONS FOR URBAN PLANNING

The ability to calculate accurate vehicle emissions with high temporal and spatial resolution is extremely important for urban planning. The transportation sector in Ontario emits about 63 percent of the NO_x in the Province and is responsible for the highest NO_2 level (27.1 ppb) recorded in Toronto[1]. The main pollutant linked with non-traumatic deaths and hospitalization in the Greater Toronto Area is NO_2 (45%)[2]. Recent studies have reported associations between respiratory symptoms and residential proximity to traffic[3] and in view of the deleterious effects of vehicle-generated pollutants, the location of sensitive facilities (schools, hospitals) with respect to major thoroughfares must be considered with particular care. The models reported in this study will permit the prediction of vehicle-related pollution with an accuracy and spatial resolution that is more than adequate for such planning decisions.

Fig 6. Coupled CALPUFF – CMAQ system



CONCLUSIONS

Effective air pollution management on the local scale requires the ability to carry out detailed scenarios that explore the temporal and spatial effects of variations in parameters such as fuel composition, fleet make-up special traffic lanes and so forth. This level of detail is not possible using aggregated emissions models and approaches that average emissions over Eulerian model grids. To achieve a computationally-reasonable resolution in the regional modelling of areas containing large urban areas, it is necessary to start with detailed site-specific emissions profiles (especially for traffic sources) and calculate their dispersion using a flexible Lagrangian model. The results may then be coupled into the regional model, increasing the accuracy.

REFERENCES

[1] *"Air Quality in Ontario", Ontario Ministry of the Environment, 2001*

[2] *"Toronto's Air: Let's make it healthy", Toronto Public Health Office, 2000*

[3] *Kim,J.J.; Smorodinsky,S.; Lipsett,M.; Singer,B.C.; Hodgson,A.T.; Ostro,B. "Traffic-related air pollution near busy roads - The East Bay children's respiratory health study", American Journal of Respiratory and Critical Care Medicine,* ***170****(5) 520, (2004).*