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Identifying contributions of on-road motor vehicles to urban air pollution using travel demand model data

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ABSTRACT

Ambient concentrations of pollutants are correlated with emissions, but the contribution to ambient air quality of on-road mobile sources is not necessarily equal to their contribution to regional emissions. This is true for several reasons such as the distribution of other pollution sources and regional topology, as well as meteorology. In this paper, using a dataset from a travel demand model for the Sacramento metropolitan area for 2005, regional vehicle emissions are disaggregated into hourly, gridded emission inventories, and transportation-related concentrations are estimated using an atmospheric dispersion model. Contributions of on-road motor vehicles to urban air pollution are then identified at a regional scale. The contributions to ambient concentrations are slightly higher than emission fractions that transportation accounts for in the region, reflecting that relative to other major pollution sources, mobile sources tend to have a close proximity to air quality monitors in urban areas. The contribution results indicate that the impact of mobile sources on PM_{10} is not negligible, and mobile sources have a significant influence on both NO_x and VOC pollution that subsequently results in secondary particulate matter and ozone formation.

1. Introduction

The transportation sector accounts for a large fraction of air pollutant emissions in the US. To connect air quality and transportation planning activities, transportation conformity is required by the Clean Air Act; i.e., highway and transit projects must be consistent with the air quality goals set by a state implementation plan (SIP) (US Department of Transportation, 2007; US Environmental Protection Agency, 2007a). Air quality in the US has been improving over the past several decades. However, ozone and particulate matter are still challenging problems, especially in non-attainment and maintenance regions. Current vehicle fleets emit significant amounts of carbon monoxide (CO), nitrogen oxides (NO_x), total organic gases (TOGs) or reactive organic gases (ROGs, more commonly known as volatile organic compounds (VOCs)), particulate matter (PM_{10}), and carbon dioxide (CO_2). The VOC and NO_x are precursors to secondary ozone formation and aerosols and, more importantly, particulate matter and ozone are the two criteria pollutants of greatest concern causing human health damage and leading to a social cost (ExternE, 1998; McCubbin and Delucchi, 1996).

Ambient concentrations of pollutants are correlated with emissions, but the contribution to ambient air quality of on-road mobile sources is not necessarily equal to their contribution to regional emissions. This is true for several reasons such as the distribution of other pollution sources and regional topology, as well as meteorology. The complexity of spatial and

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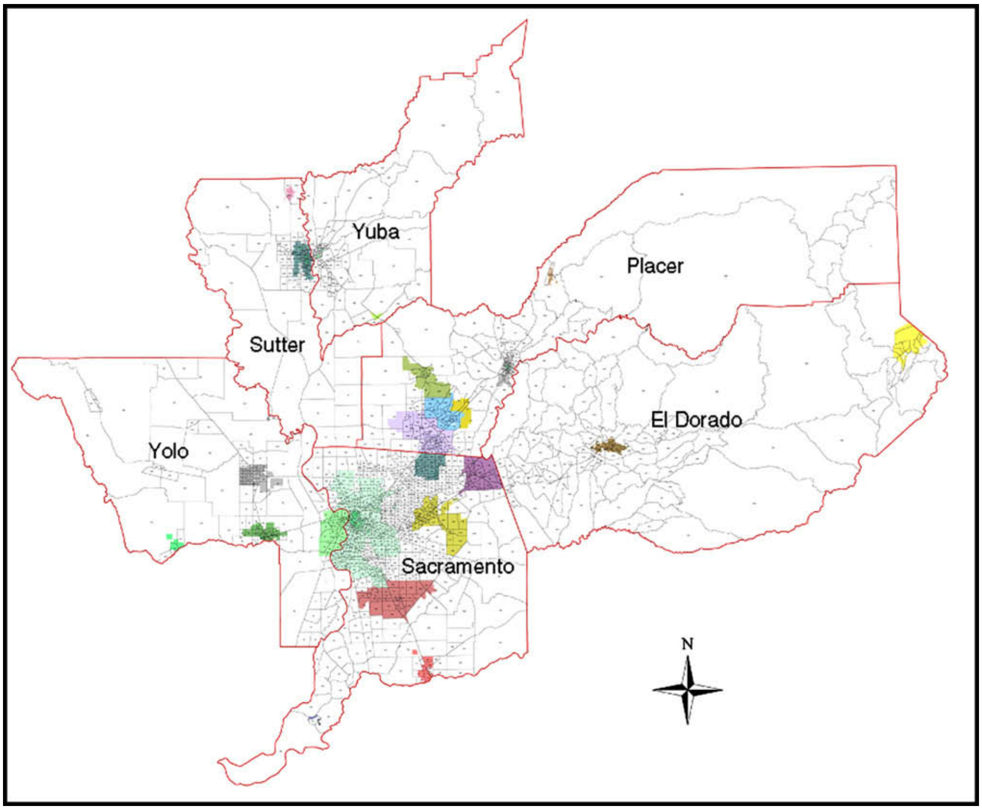

Fig. 1. Sacramento metropolitan area and traffic analysis zones.

temporal distributions of vehicle emissions/activities and the mobility of vehicles make it very hard to quantify the proportions of ambient air pollutant concentrations attributable to on-road mobile sources. This study improves our understanding of how much mobile sources account for the overall air pollution in metropolitan areas. We select the Sacramento metropolitan area as the setting and using a travel demand model dataset for year 2005, regional vehicle emissions are estimated and disaggregated into hourly, gridded inventories. Transportation-related concentrations of primary pollutants are then predicted using a Gaussian dispersion model. In short, we estimate the part of the ambient concentration due to motor vehicles. Then we compare them to actual measurements.

2. Methodology

2.1. Overview of methodology

The modeling domain of this study, the Sacramento metropolitan area, includes six counties: Sacramento, Yolo, Sutter, Yuba, Placer, and El Dorado, shown in Fig. 1 (SACMET2005, 2005). This region corresponds to the Sacramento Area Council of Governments (SACOG), a metropolitan planning organization (MPO).

A flow chart of the methodology and modeling sequence in this study is presented in Fig. 2. We first run the California mobile emissions model, EMFAC2007, to derive emission rates for all vehicle classes in the region. For each vehicle class, annual average emission rates for the six-county region are approximated by Sacramento County summer emissions.[1] Next, we use two intermediate models (i.e., CONVIRS4 and IRS4) to aggregate emission factors across all vehicle types. This produces a fleet averaged emission factor, which is applied throughout the region. Meanwhile, we employ data on the regional transportation networks and activities from a travel forecasting model, SACMET2005, which gives spatially detailed traffic flows for each road link, for several multi-hour time periods for a typical weekday. Thus, we combine SACMET traffic flow data with emission rate data to estimate spatially specific emissions. We run an hourly, gridded emission inventory model, DTIM4.02, to assign regional emissions to predefined grid cells at a 1 × 1 km resolution, to address the spatial difference, which is important to subsequent atmospheric dispersion models[2]. Then, using the Typical Meteorological Year (TMY2) conditions as meteorological

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[1] This is justified because emission factors in the region do not vary much over the year, and most of the traffic takes place in Sacramento County.

[2] This methodology could be useful for secondary air pollution models such as the Urban Airshed Model (UAM) for ozone formation in other studies.

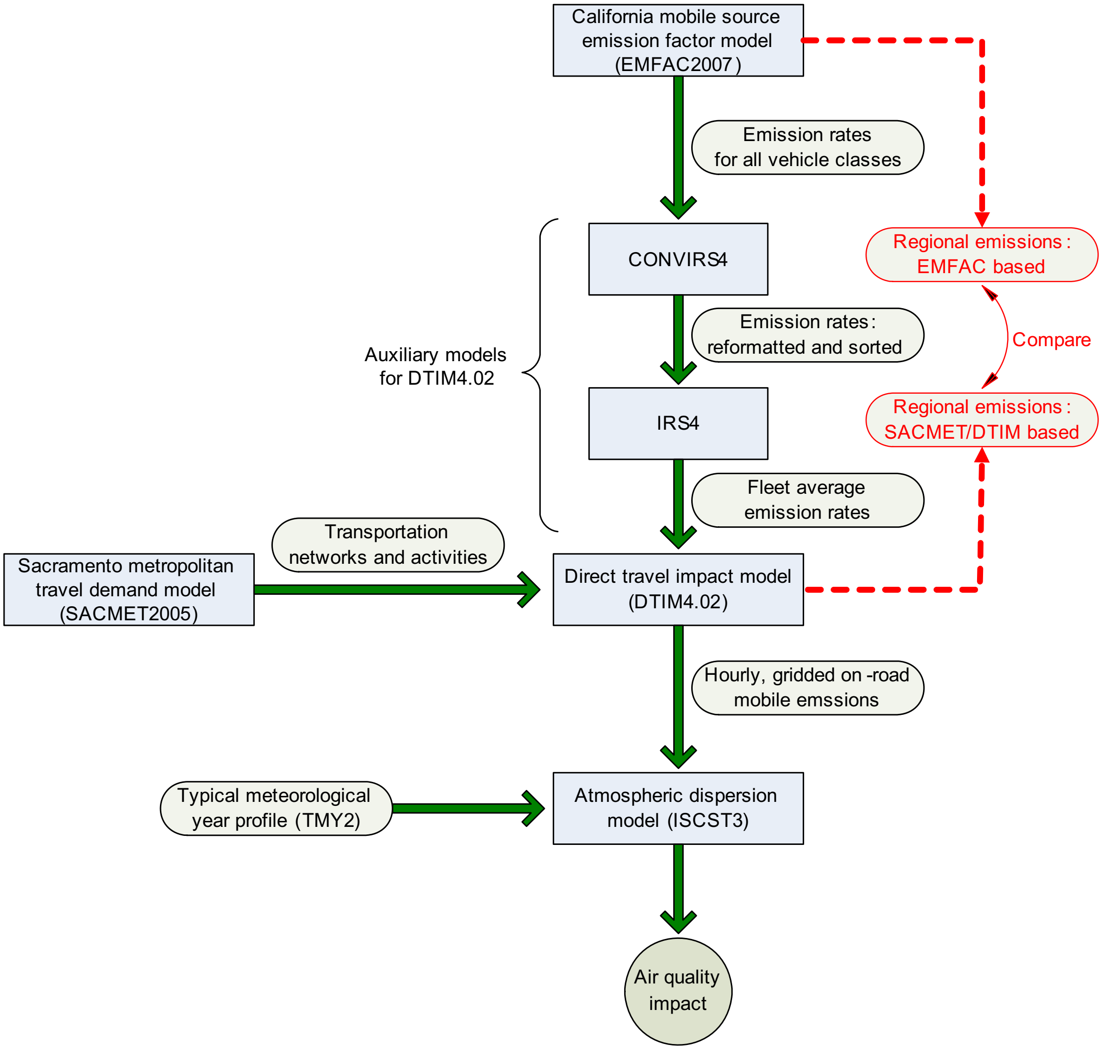

Fig. 2. Framework of the methodology and modeling processes.

input and the gridded area pollution source input (i.e., DTIM model outcomes) to a Gaussian dispersion model, ISCST3, the air pollutant concentrations associated with the regional on-road motor vehicles are estimated. Finally, we compare the predicted transportation-related concentrations with the measured ambient pollution levels and estimate the fractional contributions of on-road mobile sources to urban air pollution.

2.2. The EMFAC model

EMFAC2007 (version 2.3, released in November 2006) is the latest version of the California mobile source emissions model. It is an officially approved regulatory model, which calculates emission inventories for motor vehicles operating on roads in California by combining vehicle emission rates with local specific vehicle activity data (EMFAC2007, 2007). The basic application is to generate emission factors for on-road motor vehicles at a county, air basin, or state level. EMFAC is also capable of estimating regional emissions by running its BURDEN module. Here we use EMFAC2007 to provide emission rates for the predefined 13 vehicle classes, as shown in Table 1.

The following air pollutants and their associated emission processes are considered (Table 2): NO_x, TOG or ROG (i.e., VOC), and particulate matter (PM_{10}). Only primary emissions that are directly from emission sources are included. No secondary atmospheric formation, such as secondary particulate matter and ozone, is considered. We choose the six-county Sacramento metropolitan area as the modeling domain, and emissions outside the domain are not taken into account.

The EMFAC model can provide emission estimates for both summer and winter scenarios, but the seasonal variations in the daily vehicle emissions appear insignificant in the Sacramento region, based on results generated by running EMFAC for summer and winter, respectively. For simplicity, a typical daily emission inventory is developed based on the summer 2005

Table 1
Vehicle classes modeled in the EMFAC2007 model.

Vehicle class	Fuel type	Description	Weight class (lbs)	Abbreviations
1	All[a]	Passenger cars	All	LDA
2	All[a]	Light-duty trucks	0–3750	LDT1
3	Gas, diesel	Light-duty trucks	3751–5750	LDT2
4	Gas, diesel	Medium-duty trucks	5751–8500	MDV
5	Gas, diesel	Light–heavy-duty	8501–10,000	LHDT1
6	Gas, diesel	Light–heavy-duty	10,001–14,000	LHDT2
7	Gas, diesel	Medium–heavy-duty	14,001–33,000	MHDT
8	Gas, diesel	Heavy–heavy-duty	33,001–60,000	HHDT
9	Gas, diesel	Other buses	All	OB
10	Diesel	Urban buses	All	UB
11	Gas	Motorcycles	All	MCY
12	Gas, diesel	School buses	All	SBUS
13	Gas, diesel	Motor homes	All	MH

Source: EMFAC2007 (2007).
[a] Includes gasoline, diesel, and electric.

Table 2
Vehicle emission processes and activities.

Pollutant	Emission processes and sources
NO_x	Running exhaust, idle exhaust, and starting exhaust
TOG or ROG (VOC)	Running exhaust, idle exhaust, starting exhaust, diurnal, hot soak, running loss, and resting loss
PM_{10}	Running exhaust, idle exhaust, starting exhaust, tire wear, and brake wear

vehicle emission rates for Sacramento County; i.e., we use the summer 2005 vehicle emission rates to represent the annual (including both summer and winter) average emission rates. The regional emission inventories are derived by adding up the county-level emissions.

2.3. The CONVIRS and IRS models

Two auxiliary models, CONVIRS4 and IRS4, are used to develop an estimate of the fleet average emission rates. The application of CONVIRS4 reformats and sorts the emission rates from EMFAC2007. Then, IRS4 generates fleet average emission rates. In this step, vehicle class weights in the fleet are determined and weighted average emission rates for the specific fleet are derived. Typically, the vehicle class weights are the proportions of VMT by each vehicle class in the fleet (California Department of Transportation, 2001).

2.4. The SACMET model

Transportation networks and activities for 2005 are extracted from the Sacramento Metropolitan travel demand model (SACMET2005), specifically developed for SACOG. The SACMET model applies a traditional four-step travel forecasting procedure, i.e., trip generation, trip distribution, mode choice, and trip assignment (DKS Associates, 2002). Vehicle trips and loaded networks are estimated based on the regional travel demand. Loaded networks refer to the base networks with assigned forecasted traffic (e.g., vehicle volume and speed). Fig. 3 shows the year 2005 transportation network links.

The modeling domain, composed of six counties, is divided into 1398 traffic analysis zones (TAZs) for the purpose of transportation planning rather than mobile emissions control (see minor zones in Fig. 1). Generally, a TAZ is not the same as a census tract, and a zone centroid is usually predefined to reflect travel between TAZs in a travel demand forecasting model (Niemeier et al., 2004). In SACOG's database, TAZs are aggregated into 73 regional analysis districts (RADs).

SACMET2005 generates traffic data such as traffic volume, congested speed, and travel time for four time periods, based on roadway link attributes (e.g., road capacity, free-flow speed, link length, and number of lanes). The four modeled time periods are AM peak (6am–9am, 3 h), midday (9am–3pm, 6 h), PM peak (3pm–6pm, 3 h), and evening (6pm–6am, 12 h). The model results are multi-hour aggregate data for a weekday. A subsequent model is required to disaggregate them into hourly data for each grid cell.

2.5. The DTIM model

The next step in the modeling procedure is to apply the Direct Travel Impact Model (DTIM4.02) to generate hourly, gridded emission inventories to address temporal and spatial distributions of motor vehicle emissions (California Department of Transportation, 2001). Vehicle emission processes in DTIM are the same as those in the EMFAC scenario (Table 2).

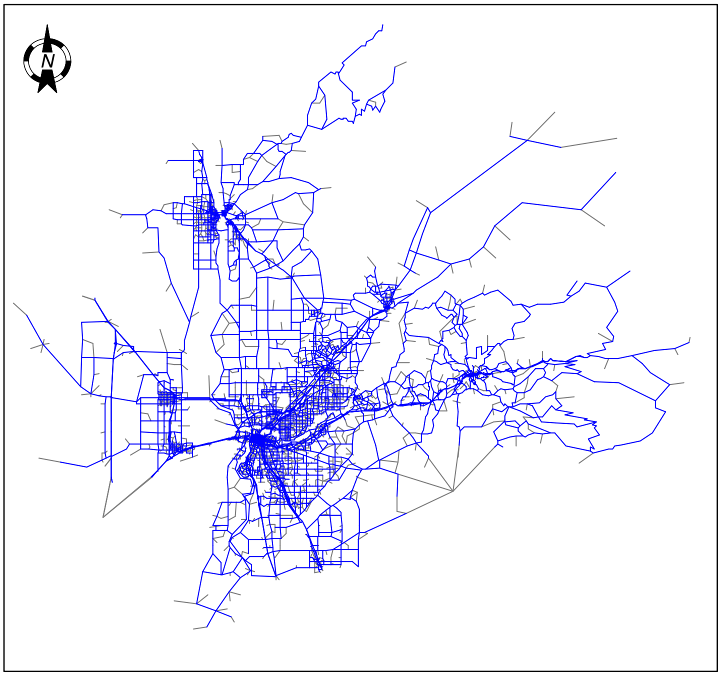

Fig. 3. Transportation networks in the Sacramento metropolitan area.

As stated earlier, SACMET only provides four time-period aggregate traffic data. DTIM is capable of disaggregating time-period emissions into hourly emissions by using a data file of region-specific vehicle starts/parks/stables distributions. With respect to spatial distribution of emissions, the following three categories are considered in DTIM in order to derive grid-level emissions: (a) stabilized running exhaust emissions that occur during interzonal vehicle trips at the link (roadway segment) level; (b) starts/parks emissions associated with interzonal trip-ends; and (c) running/starts/parks emissions associated with intrazonal trips (travel within a traffic analysis zone).

Both trip-end and intrazonal emissions are assigned to the grid cell where the TAZ centroid is located. A zone centroid is not designated for emission purposes and emission activities do not necessarily occur at or near a TAZ centroid (Niemeier and Zheng, 2004). However, it is currently the most common method for estimating gridded vehicle emissions. In the Sacramento region, 99% of TAZs are larger than the 1 × 1 km grid cell resolution (Niemeier and Zheng, 2004). Generally, it would be ideal that TAZs and grid cells have a comparable size. Although TAZs in suburban and rural areas are much larger than those in urban areas and central business districts (CBDs), we expect that the urban TAZs contribute more to urban air pollution. In addition, most, if not all, TAZs do not have a regular geometric shape and, thus, the length of one side is not necessarily larger than 1 km although the area of this zone is possibly much larger than 1 km^2. Therefore, the 1 × 1 km grid cells are reasonable in terms of resolution, and accordingly emissions at this grid level will be generated.

In summary, we divide the modeling domain into 48400 (=220 × 220) grid cells at a 1 × 1 km resolution, according to the Universal Transverse Mercator (UTM) coordinate system. The regional emissions are assigned, by running DTIM, to each grid cell by hour based on the actual transportation networks and activities derived from SACMET.

2.6. The ISC model

The Industrial Source Complex Short Term (ISCST3) model is a steady state Gaussian plume dispersion model (ISCST3, 2006). This model works directly for point, area, volume, and open pit sources of pollution, and by approximation to a series of long, thin area sources or volume sources, a line source of pollution could be simulated as well (US Environmental Protection Agency, 1995). It also can be used to assess air pollution from a variety of sources simultaneously.

Grid-based emissions from on-road motor vehicles are treated as area sources of pollution. Specifically, the running emissions from links can be assigned to the appropriate grid cells, given the coordinates of link nodes and other location information from SACMET. Usually, the running emissions account for the majority of the grid cell emissions. The trip-end (starts/parks) emissions are assigned to the TAZ-centroid grid cells, as discussed above. The intrazonal (within-zone) emissions, including running, starts, and parks, are assigned to the TAZ-centroid grid cells as well. Finally, the hour-of-day emission rates of the grid cell area sources are input to the ISCST3 model.

2.7. The TMY2 dataset

Like most air quality models, ISCST3 needs an annual cycle of local or regional meteorological information to predict the pollutant dispersion. The Typical Meteorological Year (TMY2) dataset, developed by the National Renewable Energy Laboratory (NREL), consists of months selected from 30 years (from 1961 through 1990) to form a hypothetical complete year, so it represents a statistically typical (rather than a worst-case), long-term meteorological condition in a specific region (TMY2, 2006). TMY2 provides the following hourly inputs to ISC: the hour of day, wind direction, wind speed, ground-level ambient temperature, atmospheric stability class, rural mixing height, and urban mixing height.

We use Sacramento County TMY2 data to represent the whole region; i.e., throughout all the six counties, the meteorological factors are assumed to be uniformly the same as that typically in Sacramento County. We compare the TMY2-based concentrations due to motor vehicles to the measured ambient concentrations at air quality monitoring stations. Fig. 4 presents the 2005 Sacramento windrose, including wind speeds and directions (Western Regional Climate Center, 2008), which is very typical of this region. Comparing major TMY2 and 2005 meteorological data show that TMY2 can be representative for 2005 conditions and, thus, the concentration results will not change much. Moreover, running the analysis for an entire season ("annual average") may, at least to some extent, average out the impact of short-time occasional occurrences and non-typical effects throughout the year.

2.8. The AQS system

The air quality system (AQS) has measured hourly pollution data for monitoring stations throughout the country (US Environmental Protection Agency, 2007b). Nine air quality stations located within or near urban Sacramento are chosen to represent the urban pollution levels (see Fig. 5). Note that these nine sites are serving as the dispersion model pollution receptors as well. The ambient concentrations are calculated based on the AQS measured data for 2005. Thus, we can compare the transportation-based concentrations with the ambient measurements and eventually identify the contributions of on-road mobile sources to urban air pollution. However, there are some limitations with respect to the AQS dataset; e.g., not every station has data for all pollutants, some stations do not have any data, and some measured data are not good quality.

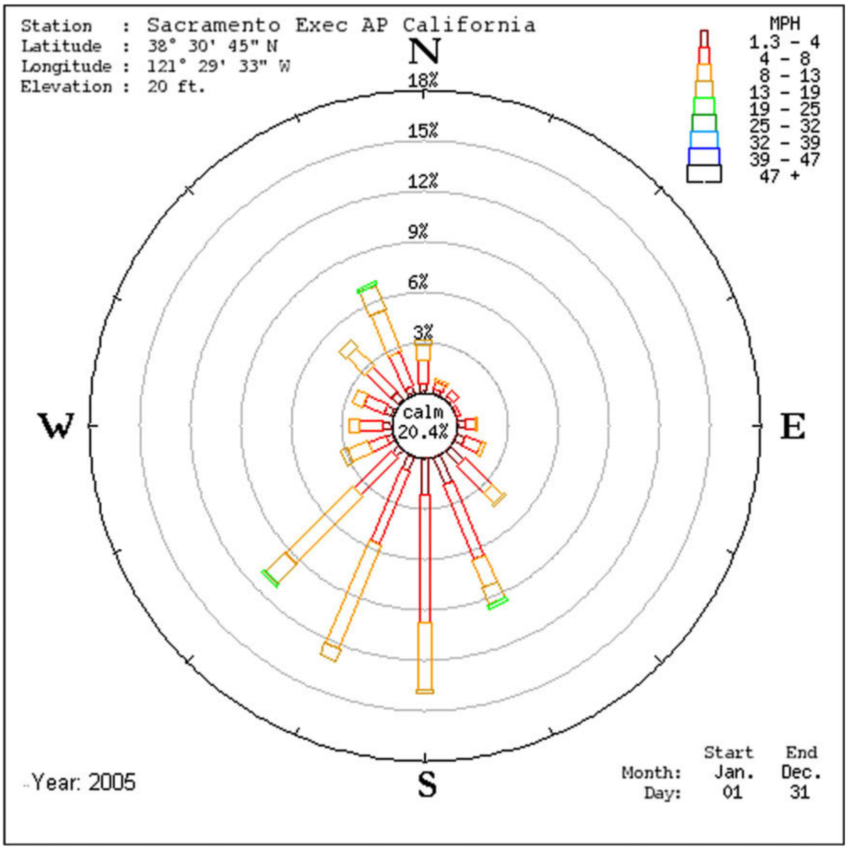

Fig. 4. Sacramento windrose for 2005 (including wind speeds and directions) *Source*: Western Regional Climate Center, (2008).

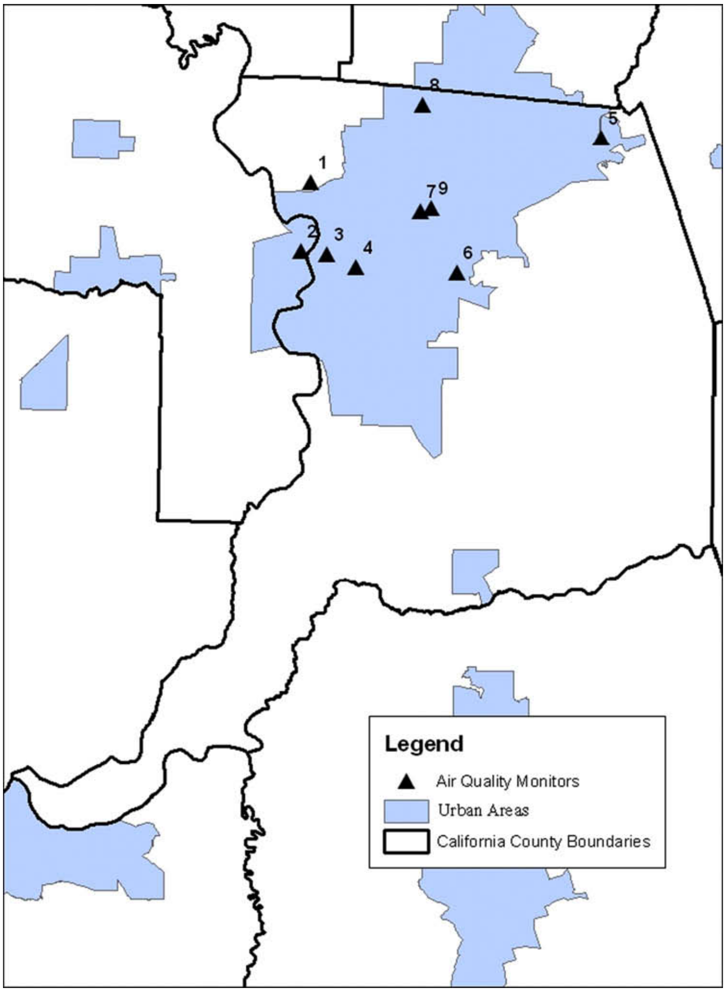

Fig. 5. Nine air quality monitoring stations in urban Sacramento.

3. Results and discussion

3.1. A simple check of EMFAC and SACMET/DTIM outputs

Table 3 presents the representative emissions and transportation activities per weekday generated by SACMET2005/DTIM4.02 and EMFAC2007, respectively, using the Sacramento County temperature and relative humidity (RH) for summer 2005.

The trips estimated by SACMET are about 57% of the EMFAC outputs. It seems that there is a serious inconsistency between SACMET2005 and EMFAC2007 outcomes in this case. Note however that they are two different model systems and possess different assumptions. In addition, SACMET only takes into account those vehicle trips where both trip-ends (origin

Table 3
Estimated emissions and transportation activities per weekday.

	EMFAC output (BURDEN)							SACMET/DTIM output	Diff. (%)	Emis. adj. factor
	Sacramento	Yolo	Yuba	Sutter	Placer	El dorado	Total			
VMT/1000	32,513	5733	1606	2443	10,359	4550	57,204	48,471	−15.3	N.A.
Trips	6,927,320	1,065,340	324,685	498,280	1,988,100	1,086,740	11,890,465	6,782,185	−43.0	N.A.
TOG (kg)	29,468	5097	1986	2975	8979	5043	53,549	42,543	−20.6	1.259
NO_x (kg)	47,055	13,006	2367	8762	20,997	4979	97,167	53,592	−44.8	1.813
PM_{10} (kg)	1986	553	91	354	925	200	4109	3220	−21.6	1.276

and destination) are within the Sacramento metropolitan area. Therefore, the trips produced per day from the modeling domain are equal to those attracted by the same modeling region. In other words, external trips are not included in SACMET. Another possible reason is that EMFAC's results are derived from six independent runs of the model, with each run for each county; thus, the trip from one county to another might be counted twice, each for each county. EMFAC can only provide aggregate traffic data at a county, air basin, or state level, while SACMET generates data at a link or TAZ level.

Because EMFAC is an officially approved regulatory emissions model and widely recognized, the difference in emissions estimation by SACMET/DTIM, relative to EMFAC, is defined as

$$Diff. = \frac{DTIMoutput - EMFACoutput}{EMFACoutput} \times 100\%. \tag{1}$$

DTIM, based on inputs from SACMET, tends to estimate both fewer travel activities (i.e., VMT and number of trips) and fewer emissions than EMFAC with the BURDEN module run (Fig. 2 and Table 5). In fact, estimated transportation-related emissions are lower by 21% for TOG, 22% for PM_{10}, and 45% for NO_x, respectively. This phenomenon has been recognized and some improvements have been proposed, including speed processing algorithm, queuing algorithm, and peak spreading algorithm (California Department of Transportation, 2001). Bai et al. (2007) analyzed the impact of speed post-processing methods on regional mobile emissions estimation based on a case study of the Sacramento metropolitan area during the morning peak period, and concluded that speed post-processing could result in a 10–40% increase in TOG emissions and a 7–15% increase in NO_x emissions relative to the base travel demand model emissions scenario, varying by hour and depending on post-processing methods. We use hourly, gridded emission results from the SACMET/DTIM sequence, and consequently the estimated air pollution due to transportation tends to be lower than with EMFAC.

To carry out the comparison on a consistent basis, we adjust the SACMET/DTIM regional emissions to match the EMFAC emission levels. The emission adjustment factor (Table 3) is defined as

$$Emission\ Adjustment\ Factor = \frac{EMFACoutput\ emissions}{DTIMoutput\ emissions}. \tag{2}$$

Since EMFAC provides regional emissions rather than gridded emissions, it is not sufficient for air quality modeling. Only the SACMET/DTIM sequence generates emissions at the grid level, whereas its aggregate regional emissions are less than the EMFAC results. We can simply apply the regional emission adjustment factor to SACMET/DTIM gridded emissions for each grid cell and, subsequently, the same air quality model ISCST3 can be run to estimate pollutant concentrations corresponding to the EMFAC emissions. This approach is based on EMFAC regional emissions and called the "alternative method" to distinguish it from the primary method that is based on SACMET/DTIM regional emissions. The regional emission adjustment factor is not necessarily equal to each of the gridded emission adjustment factors, and it just represents the average of them.

3.2. Spatial patterns of gridded emissions: the case of the AM peak period

Another intuitive check of DTIM results is to look at the spatial patterns of gridded emissions, derived by using the primary method with SACMET/DTIM emissions data. Figs. 6–8 indicate spatial patterns of gridded TOG, NO_x, and PM_{10}

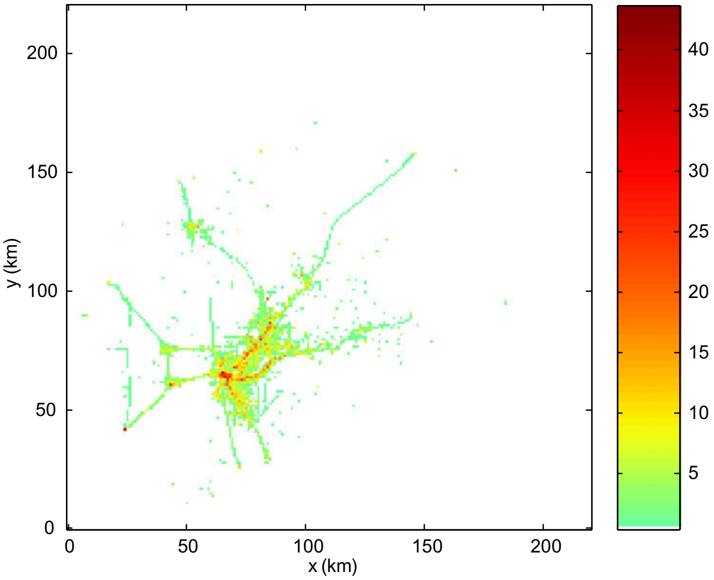

Fig. 6. Spatial pattern of gridded TOG emissions during the 3-h AM peak period. The modeling domain comprises 220 × 220 grid cells at a 1 × 1 km resolution, and emissions are in units of kg/km^2.

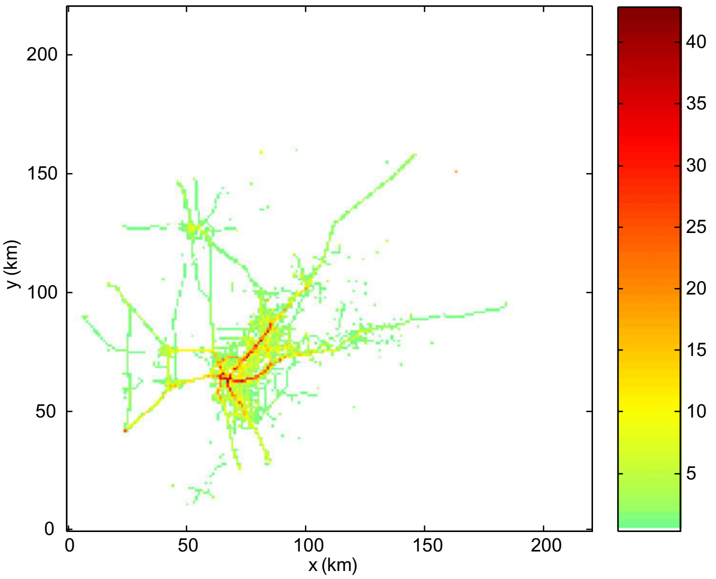

Fig. 7. Spatial pattern of gridded NO_x emissions during the 3-h AM peak period. The modeling domain comprises 220 × 220 grid cells at a 1 × 1 km resolution, and emissions are in units of kg/km^2.

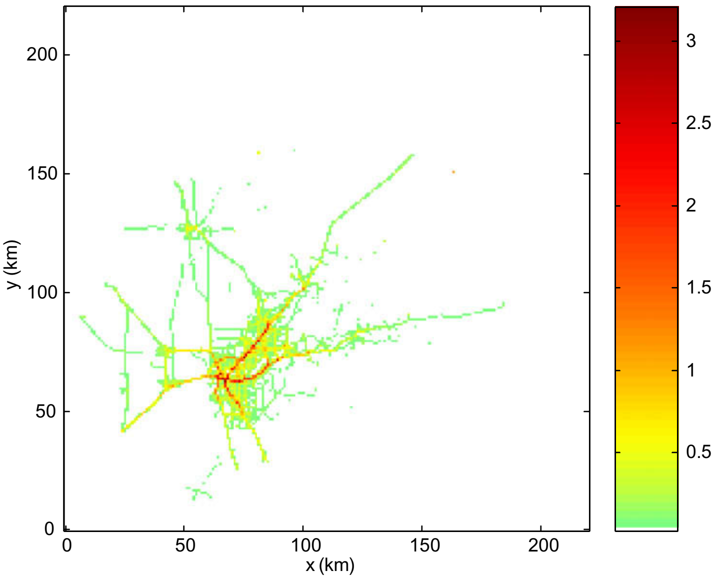

Fig. 8. Spatial pattern of gridded PM_{10} emissions during the 3-h AM peak period. The modeling domain comprises 220 × 220 grid cells at a 1 × 1 km resolution, and emissions are in units of kg/km^2.

emissions during the 3-h AM peak period, based on DTIM runs. The patterns are consistent with the regional urban–rural land use (see Fig. 1) and transportation networks (see Fig. 5). For example, downtown Sacramento corresponds to the highest emissions for all pollutants. Obviously the major emissions stretch along freeways and arterials. Not all rural grid cells are associated with vehicle emissions: either there are no traffic or vehicle activities in some rural areas or their emissions are assigned to a TAZ-centroid grid cell.

3.3. Predicted annual concentrations of pollutants due to on-road mobile sources

Figs. 9–11 present the predicted annual average concentrations due to on-road mobile sources by receptor site, derived by using the primary method with SACMET/DTIM emissions data. Receptors 3 and 4 (denoted by R3 and R4) correspond to the

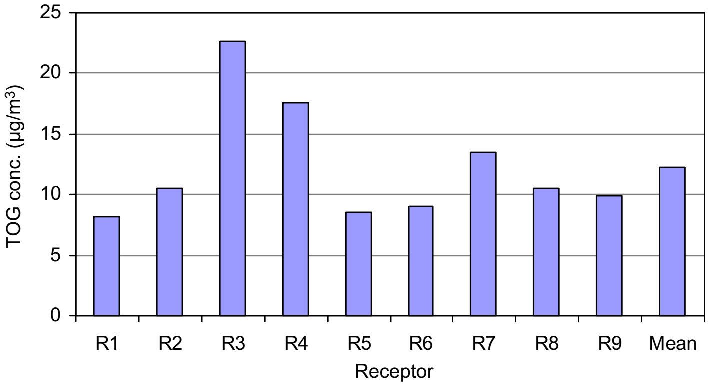

Fig. 9. Predicted annual average TOG concentrations by receptor site.

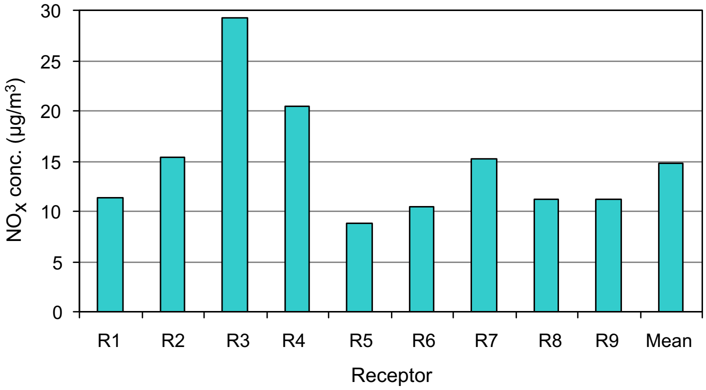

Fig. 10. Predicted annual average NO_x concentrations by receptor site.

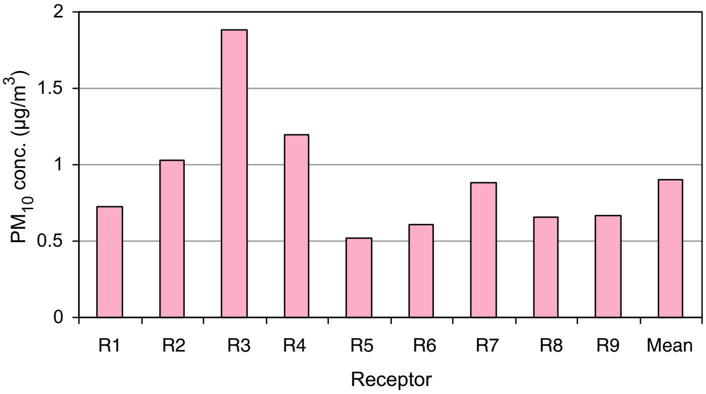

Fig. 11. Predicted annual average PM_{10} concentrations by receptor site.

highest concentrations. This makes sense because the two receptors are located in downtown Sacramento and there are several major freeways nearby (Fig. 3). In fact, the level of mobile source emissions in the vicinity of downtown Sacramento is also the highest (Figs. 6–8). This reflects that primary pollutants have a different pollution episode location issue, as compared to secondary ozone formation; e.g., peak ozone concentrations usually occur miles away downwind of the source of emissions (Wang et al., 2007).

Transportation-related NO_x and TOG have a comparable pollution level, and both are roughly an order of magnitude higher than PM_{10}. The spatial distribution of pollution levels are similar for the three pollutants, which is likely due to

Table 4
Estimated contributions of on-road mobile sources to urban air pollution in 2005.

Pollutant	Measured ambient annual conc. (μg/m^3)[b]	Based on SACMET/DTIM emissions			Based on EMFAC emissions		
		Transp. annual conc. (μg/m^3)	Conc. fraction (%)	Emis. fraction (%)	Transp. annual conc. (μg/m^3)	Conc. fraction (%)	Emis. fraction[c] (%)
TOG	N.A.	12.3	N.A.	13.7	15.4	N.A.	17.2
VOC[a]	36.9	11.3	30.6	27.6	14.2	38.5	34.7
NO_x	43.2	14.8	34.3	30.0	26.9	62.2	54.4
PM_{10}	20.4	0.906	4.4	2.2	1.16	5.7	2.8

[a] VOC accounts for 92% of the mass fraction of TOG on an on-road mobile source basis, derived from data for the Sacramento metropolitan area (California Air Resources Board, 2007). For non-mobile sources, this mass fraction does not necessarily hold.

[b] Measured ambient data are from the US EPA AQS system; due to limitations on data availability, they are not averaged over all the nine receptors (e.g., the concentration of PM_{10} is a two monitors average).

[c] Emission fractions are based on year 2005 estimated regional annual average emissions data from the CARB website (California Air Resources Board, 2007), and these emissions were estimated by CARB using EMFAC data.

the fact that emissions of the three pollutants co-exist for any transportation activities and they are released into the air simultaneously, at the same location – (i.e., within the same grid cell), and roughly in proportion. In addition, no chemical reaction or other decaying mechanism is involved in our air quality model, which partly explains the similar distribution.

The results shown in Figs. 9–11 are from transportation emissions only and thus account for only part of ambient pollution levels. Measurements of ambient concentrations include all the source contributions, including industrial, commercial, residential, transportation, and electric sectors.

3.4. Comparison to measured ambient concentrations

By comparison to the annual measurements, contributions of on-road motor vehicles to urban air pollution are identified, based on the primary method directly using SACMET/DTIM emissions data (Table 4). Considering the fact that using travel demand data from current transportation models tends to underestimate regional emissions and we know the extent to which SACMET/DTIM results are lower than EMFAC results (Table 3), transportation pollution is also estimated by using EMFAC emissions, i.e., the alternative method (Table 4). Accordingly, the two methods generate two sets of estimates, i.e., lower and higher concentrations.

In our case study, the concentration fractions are slightly higher than the corresponding emission fractions that transportation accounts for in the region, as shown in Table 4, although the calculation method could be based on either SACMET/DTIM or EMFAC regional emissions. This is possible since vehicles have a closer proximity to air quality monitors and humans than major stationary sources such as power plants which are usually located downwind of urban centers. Note that there might be an inconsistency between measured 2005 concentrations and predicted concentrations based on TMY2 meteorological data and year 2005 traffic data; however, running the analysis for an entire season or a complete year averages out the impact of such occurrences. In other words, the predicted results are not supposed to compare with measured results on a daily basis since actual year 2005 meteorology is not used.

In summary, based on the primary method directly using SACMET/DTIM emissions data, on-road mobile sources cause urban annual ambient concentrations 11.3 μg/m^3 of VOC, 14.8 μg/m^3 of NO_x, and 0.906 μg/m^3 of PM_{10}, and, as a result, contribute 30.6% of VOC, 34.3% of NO_x, and 4.4% of PM_{10} to urban ambient concentrations. Similarly, based on the alternative method using EMFAC emissions data, on-road mobile sources cause urban annual ambient concentrations 14.2 μg/m^3 of VOC, 26.9 μg/m^3 of NO_x, and 1.16 μg/m^3 of PM_{10}, and, therefore, contribute 38.5% of VOC, 62.2% of NO_x, and 5.7% of PM_{10} to urban ambient concentrations. In contrast, on-road mobile sources contribute to regional emissions 27.6% (or 34.7%) of VOC, 30.0% (or 54.4%) of NO_x, and 2.2% (or 2.8%) of PM_{10}, corresponding to different modeling methods used. The concentration fractions of each pollutant are slightly higher than the corresponding emission fractions that transportation accounts for in the region, regardless of either regional emission scenario used.

These contributions show that mobile sources have a significant impact on NO_x and VOC pollution that in turn results in secondary particulate matter and ozone formation. Vehicular particulate matter, on average, has a smaller aerodynamic diameter in size and is closer to human exposure than major stationary sources, so the impact of mobile sources on the directly emitted particulate matter is not negligible.

3.5. Further discussion on predicted concentrations

The ratios of the predicted concentration relative to the PM_{10} concentration are very close to those ratios of predicted emission relative to the PM_{10} emission (Table 5), using the example of results from the primary method. First, these primary pollutants are correlated with one another and they are released into the air simultaneously. Moreover, vehicle running emissions account for a dominant proportion of transportation emissions, regardless of pollutant types. Again, dividing the whole region into grid cells is still somewhat a means of aggregating emissions, which further reduces individuality of pollutants and emission processes. In this sense, concentrations of the other pollutants could be estimated based on the concentration of one pollutant (say, PM_{10}) by using emission ratios.

Table 5
Comparison of emission and concentration ratios.

Pollutant	Predicted transp. annual conc. ($\mu g/m^3$)	Conc. ratio relative to PM_{10}	Predicted transp. emis. (kg/day)	Emis. ratio relative to PM_{10}
TOG	12.3	13.5	42,543	13.2
VOC	11.3	12.5	39,139	12.2
NO_x	14.8	16.4	53,592	16.6
PM_{10}	0.906	1	3220	1

4. Conclusions

We sequentially applied a series of models to identify the contributions of on-road motor vehicles to urban air pollution, using travel forecasting data for 2005. Based on the primary method directly using SACMET/DTIM emissions data, on-road motor vehicles contribute 30.6% of VOC, 34.3% of NO_x, and 4.4% of PM_{10} to urban ambient concentrations. However, based on the alternative method using EMFAC emissions data, on-road mobile sources contribute 38.5% of VOC, 62.2% of NO_x, and 5.7% of PM_{10}. The concentration fractions are slightly higher than the corresponding emission fractions that transportation accounts for in the region, regardless of either method used, reflecting that relative to other major pollution sources, mobile sources tend to have a close proximity to air quality monitors in urban areas. These contribution results indicate that the impact of mobile sources on PM_{10} is not negligible, and mobile sources have a significant influence on both NO_x and VOC pollution that subsequently results in secondary particulate matter and ozone formation.

The analysis also provides evidence supporting that emissions calculated based on the traditional travel demand modeling process tend to be underestimated compared to EMFAC and are not sufficiently accurate for air quality research. However, officially approved regional emission inventory models such as EMFAC do not have adequate spatial resolutions. In future work, we suggest developing an efficient and consistent approach to improving the quality of both regional and gridded emissions estimation.

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