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Urban air pollution caused by motor-traffic

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Abstract

Experimental investigations on urban air pollution caused by motor-traffic have taken place in Munich, a super-city in the southern part of Germany. From sum-mer 1990 through spring 1993, stationary and non-stationary measurements of the „classical“ near-to-ground air pollutants NO, NO_2, O_3 and CO were taken in a mobile measuring system. This consisted of a van with gas analysers together with a trailer for the power supply. The results, presented in this article, show the dependence of air pollution levels upon traffic density, meteorological conditions, urban structures, street canyon situations and various vehicular tunnels.

1 Introduction

The dispersion and dilution of air pollutants emitted by vehicles is one of the most investigated topics within urban meteorology (Theurer et al. [1], Clifford et al. [2]). Air pollution has become a serious health hazard to the inhabitants of many mega-cities (Raga and Le Moyne [3], Lam et al. [4]), and its fundamental impact on the environment affects cities of all sizes. The issues which arise in ur-ban planning concern the average and peak val-ues of various air pollutants as well as their temporal trends and spatial variability.

A special experimental investigation on air pollution caused by motor-traffic within urban spaces has taken place, hereby known in its abbreviated form IMKRAL (Mayer and Haustein [5, 6], Haustein and Mayer [7]). It was mainly conducted in Munich, a city of about 1.3 million inhabitants, located in Southern Germany. The aim of IMKRAL was to draw specific information about the dispersion, dilution and distribution as well as photochemical reactions of air pollu-tants within different urban structures, some examples being street canyons, green spaces, industrial zones, and various types of street tunnels.

2 Measuring system

A mobile measuring system on a „Volkswagen"-van basis, which was equipped with gas analysers for the „classical" air pollutants NO, NO_2, O_3 and CO, was used to record air pollution and meteorological data within different urban struc-tures. Three-dimensional wind speed, global radiation as well as dry-bulb and wet-bulb temperatures were also measured in order to interpret the air pollution data. The sampling height for air pollutants could be varied between 0.5 and 3.5 m above ground. The measuring height for three-dimensional wind speed was 3.0 m, for global radiation 2.0 m as well as for dry-bulb and wet-bulb temperature 0.5, 1.0 m and 2.0 m above ground. All data was collected with a sampling rate of 10 s, and was recorded digitally on a data logger within the van. The batteries in the trailer provided approximately eight hours of electric current for the whole measuring system.

Measurements taken during IMKRAL were divided into two categories: (1) stationary measurements, in which air pollutants and meteorological parameters were collected over a period of at least eight hours. During this time the van was parked at selected sites in Munich. (2) Car traverses, in which data solely concerning air pollution was recorded whilst the car was moving. A report was made for each traverse in which the exact time and location of the van was not-ed. Together with the use of special timing in the employment of each gas analyser, these enabled conclusions to be drawn concerning the association of particular peaks in mixing ratios of air pollutants with specific locations on the route. This same method was used some years before by Luria et al. [8]. However, it cannot be applied to detect different species of volatile organic compounds, for which one needs a gas chromatograph operating in a quasi-stationary mode.

3 Results

3.1 Air pollution and traffic density

Urban air pollution on the street level depends largely on traffic density. This is illustrated for NO, NO_2 and NO_X in Figure 1. Recordings were taken during the morning rush-hour at a six-lane ring-road in Munich. The additional influence of meteorological conditions on the dilution and dispersion of air pollutants is shown in Figure 2, which illustrates the concentrations of NO, NO_2 and NO_X within an underpass. Despite a lower traffic density, these results are much high-er than in Figure 1. The main reason for this stems from the conditions for turbulent air mass exchange, which is much less pronounced inside the underpass than on the ring-road.

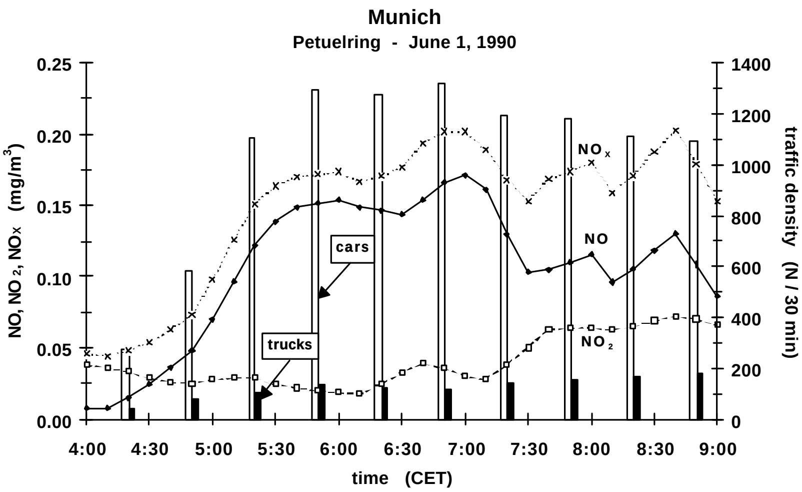

Figure 1: The dependence of concentrations of NO, NO_2 and NO_X upon traffic density on a ring-road, 0.5 m above ground, average values for 10 minutes running (after Mayer and Haustein [5]).

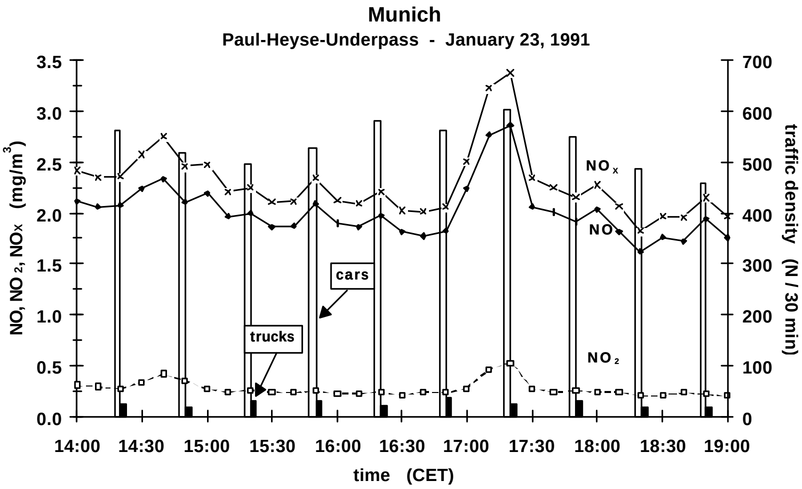

Figure 2: The dependence of concentrations of NO, NO_2 and NO_X upon traffic density within an underpass, 1.5 m above ground, average values for 10 minutes running (after Mayer and Haustein [5]).

3.2 Air pollution within different urban structures

During the early summer 1991 on days with clear weather, six single car traverses were conducted at noon on the route „English Garden“. This led from the university in the northern centre of Munich through the English Garden (a popu-lar recreation park in the northern part of Munich), then through a vehicular tun-nel with heavy traffic, back to the starting point. Average results demonstrate the behaviour within different urban structures of air pollutants emitted by vehicles (Figure 3).

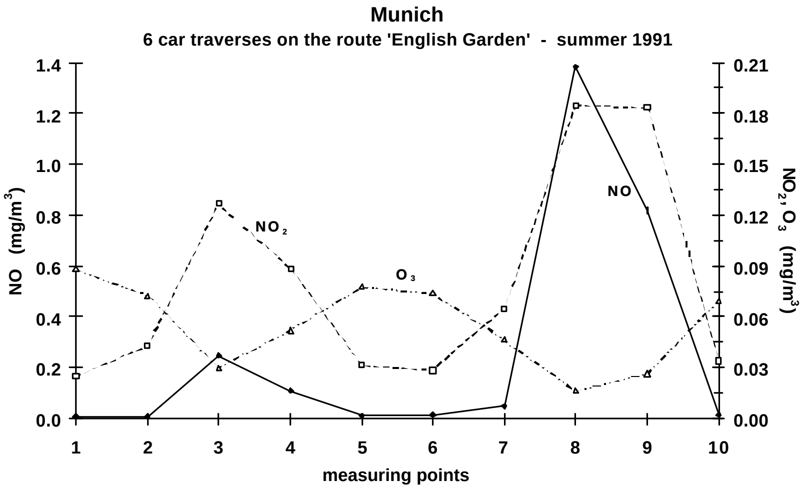

Figure 3: Average concentrations of NO, NO_2 and O_3 in 2 m above ground at selected points based on recordings during car traverses (after Mayer and Haustein [5]).

The results reveal great spatial variability within the investigated air pollutants. The concentrations of O_3 at site 1, which was in the backyard of the university campus, were comparatively high, whilst those of NO and NO_2 were low. At site 3, which was a street crossing in a very built-up area with a high traffic density, levels of NO and NO_2 increased, whilst those of O_3 went down. The opposite oc-curred at sites 5 and 6, which were located within the English Garden. Here con-centrations of NO and NO_2 were low, and those of O_3 were high. The highest concentrations of NO and NO_2 occurred at site 8, which was inside a tunnel.

The separate graphs shown in Figure 3 for NO and NO_2 reveal a higher concentration of the latter even on most of the traffic-free sites.

3.3 Air pollution within street canyons

The concentration levels within street canyons of air pollutants near the ground depend on several factors, including the geometry of the street canyon, traffic density and meteorological conditions. Wind direction above roof level is partic-ularly important. In Figure 4 (easterly wind) this was perpendicular to the orientation of the street canyon, producing upwind and downwind effects on air pollu-tion. Levels of concentration of NO, NO_2 and

CO were therefore much higher on the east side than on the west side. The question one must ask, however, is which site within a street canyon provides the best representation for recordings of near the ground air pollutant levels.

In the case of lower wind speeds above roof level than in Figure 4, concentrations of NO, NO_2 and CO are on the increase.

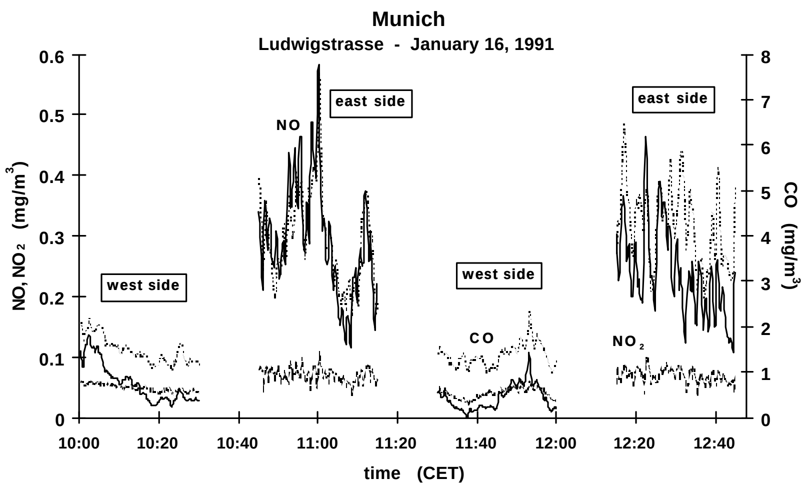

Figure 4: Concentrations of NO, NO_2 and CO (2 m above ground) at west and east sides of an urban street canyon (height: 21 m, width: 38 m, number of lanes: 6, azimuth of street canyon: 17.5 deg.), wind direction above roof level: 110 deg., wind speed above roof level: 4 m/s.

3.4 Air pollution within different vehicular tunnels

Levels of air pollution within various types of vehicular tunnels in Munich were also investigated during the research programme IMKRAL (Table 1). These tunnels were: „Altstadtringtunnel“ (ALT), „Paul-Heyse-Unterführung“ (PAU), „Trappentreutunnel“ (TRA), „Brudermühltunnel“ (BRU) and „McGraw-Gra-ben“ (MAC), the latter being a street below ground-level with an open top.

Table 1: Specifications of the vehicular tunnels investigated in Munich.

	tunnel

	ALT	PAU	TRA	BRU	MAC
direction	E-W	N-S	N-S	E-W	NNW-SSE
length	610 m	218 m	625 m	875 m	635 m
traffic lanes	6, both directions	4, both directions	3, one direction	3, one direction	4, both directions
ventilatingsystem	fresh-air in-let along tunnel centre-line	none	fans blowing in travelling direction	fans blowing in travelling direction	none

The results in Figures 5 through 8 are drawn from several car traverses, which took place in summer 1992 and winter 1992/1993, and contain average concentrations of NO, NO_2, CO and O_3 both inside and outside of the vehicular tunnels investigated. The results show a tendency towards a higher concentration of the main vehicle-emitted air pollutants (as well as NO_2) inside the tunnels than outside. The main reason is the limited space for dispersion and dilution of air pollutants inside the tunnels. O_3, however, which is formed by photochemical processes from precursor air pollutants, had its higher values outside the tunnels in summer (Figure 8). Unexpected were the higher average concentrations of NO and CO inside the ALT- and PAU-tunnel in summer than in winter.

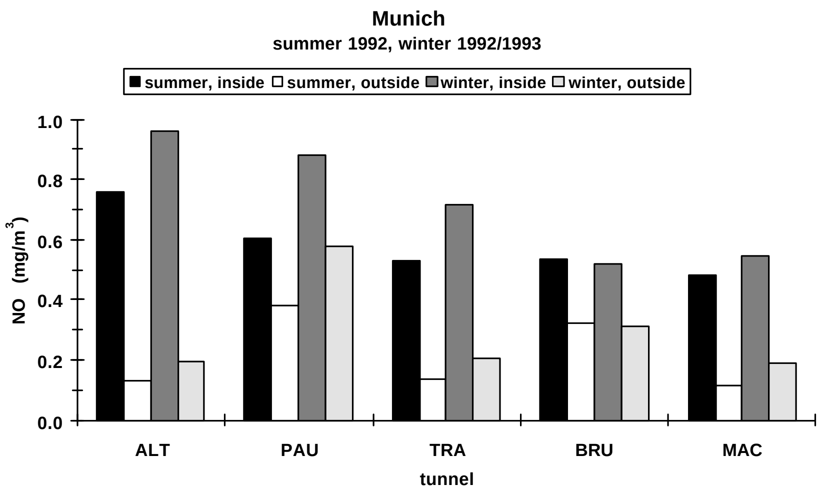

Figure 5: Average concentrations of NO inside and outside of various vehicular tunnels in Munich in different seasons (after Mayer and Haustein [5]).

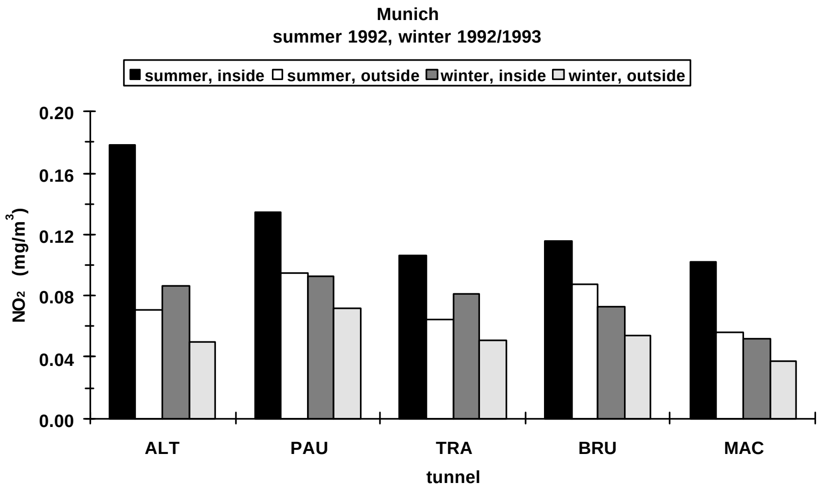

Figure 6: Average concentrations of NO_2 inside and outside of various vehicu-lar tunnels in Munich in different seasons (after Mayer and Haustein [5]).

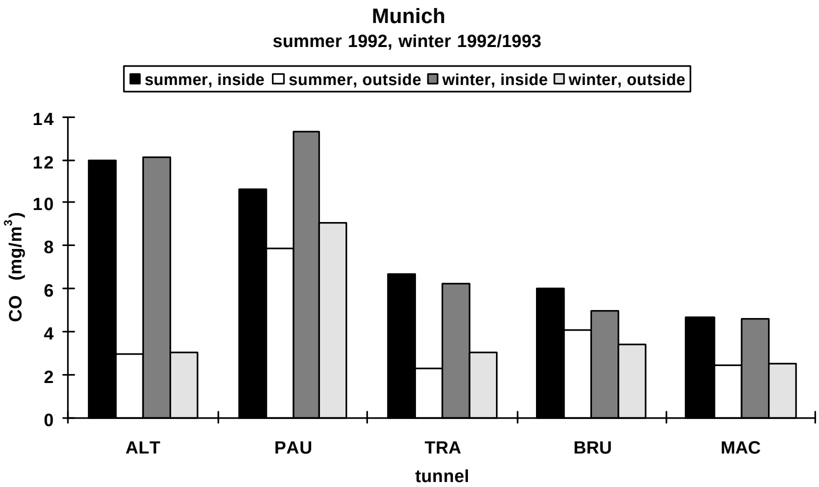

Figure 7: Average concentrations of CO inside and outside of various vehicular tunnels in Munich in different seasons (after Mayer and Haustein [5]).

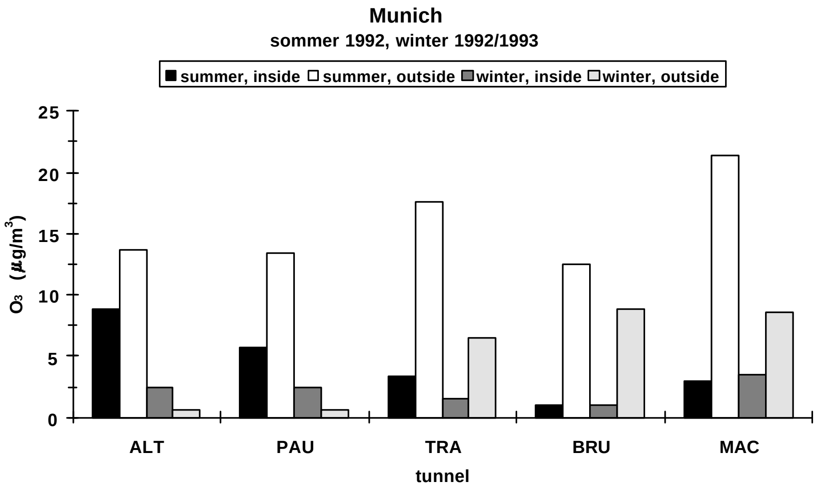

Figure 8: Average concentrations of O_3 inside and outside of various vehicular tunnels in Munich in different seasons (after Mayer and Haustein [5]).

The outside levels of concentration of the air pollutants investigated seemed to depend more upon the exposure to the traffic situations within the city of Munich than upon the character of the tunnels itself.

3.5 Influence of a city on the formation of O_3

The influence of an area of greater agglomeration upon the formation of O_3 was investigated by some car traverses which led from a forest (Ebersberger Forest) east of Munich, through the city of Munich, to a forest (Planegger Forest) west of Munich, and back through the city to the forest east of Munich. The results in Figures 9 and 10 contain mixing ratios of O_3 which were recorded during two car traverses on sunny days with different wind directions. On July 20, 1992, wind in the Greater Munich area was eastern, whereas at the following day it blew from the west. Mixing ratios of O_3 recorded at 2 and 40 m above ground at the site „Ebersberger Forest“

served as reference values. The measuring height of 2 m were within the trunk space of the Ebersberger Forest, which consists of spruce trees, and the measuring height of 40 m was about 7 m above the stand.

In east wind the starting point of the car traverse was at the upwind side of Munich, and the turning point at the downwind side. For this reason Figure 9 shows about 15 ppb higher mixing ratios of O_3 at the turning point „Planegger Forest“ than at the reference site.

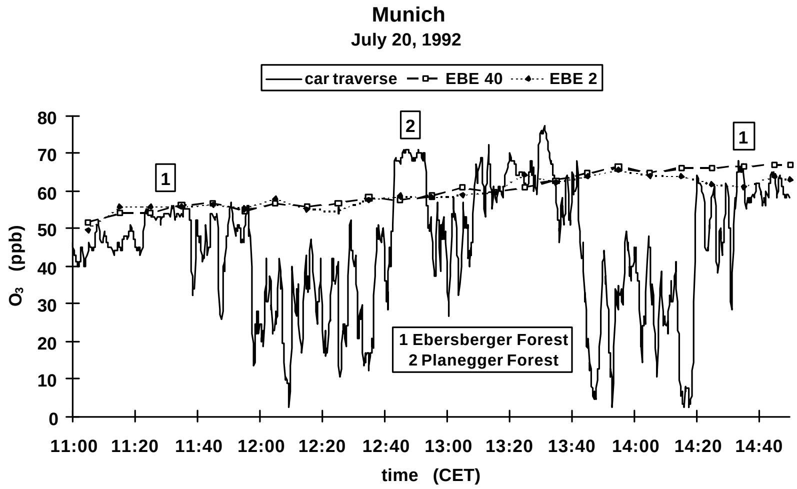

Figure 9: Concentrations of O_3 at 2 m above ground during a car traverse from the eastern to the western outskirts of Munich and back on a sunny day, easterly winds (after Mayer and Haustein [5]).

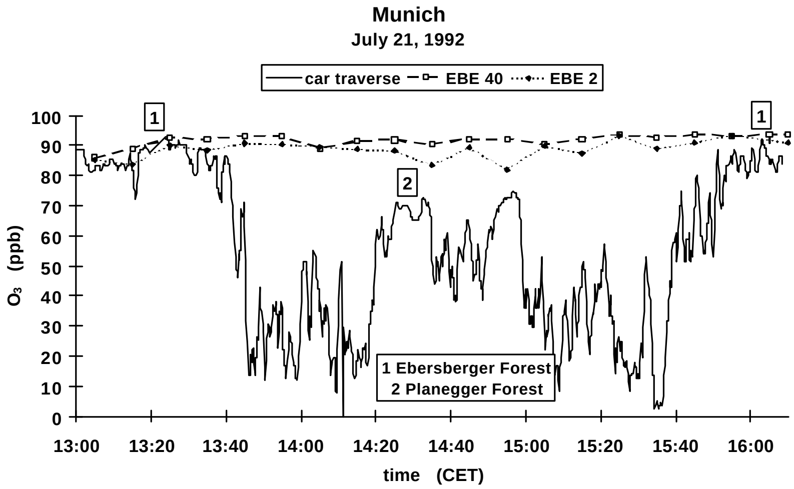

Figure 10: Concentrations of O_3 at 2 m above ground during a car traverse from the eastern to the western outskirts of Munich and back on a sunny day, westerly winds (after Mayer and Haustein [5]).

The increase of O_3 was produced by photochemical reactions in the urban plume, which formed additional O_3 from precursor air pollutants emitted by man-made activities within the city. At the end of the car traverse, mixing ratios of O_3 recorded by the van and the reference system in the trunk space conformed well to one another.

On the day with the westerly winds (Figure 10), mixing ratios of O_3 were dis-tinctly lower at the „Planegger Forest“ (turning point) than at the „Ebersberger Forest“ because the starting point of the car traverse was in this case at the downwind side of Munich.

4 Conclusions

The research project IMKRAL provided specific results on the spatial and temporal behaviour of „classical“ air pollutants within typical urban structures such as street canyons or vehicular tunnels. All the results show a great spatial variability which complicates a human-biometeorological evaluation of air pollution within different urban structures using conventional standards of air pollution control. Planners of vehicular tunnels should respect the advantages related to air pollution which are produced through having separate tunnels for each driving direction.

References

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