EVALUATION OF ATMOSPHERIC BENZENE CONCENTRATIONS IN THE HELSINKI METROPOLITAN AREA IN 2000-2003

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INTRODUCTION

Ambient air concentrations of benzene were both measured and predicted in the Helsinki Metropolitan area. Two-weekly measurements were conducted in 2000, 2002 and 2003 at seven measurement stations using diffusive adsorbent sampling; additional two-hourly measurements were also performed. An urban dispersion modelling system was utilised for modelling the spatial concentration distributions of benzene for 2000. According to both measurements and predictions, the annual mean benzene concentrations were below the upper assessment threshold ($3.5 \ \mu g \ m^{-3}$) set by the European Union, while the lower assessment threshold ($2 \ \mu g \ m^{-3}$) was exceeded at one urban station (Töölö) during the year 2000.

The concentrations measured in the Helsinki Metropolitan Area were also compared with those at rural and remote stations in Finland. In the winters of 2000 and 2003, the concentrations at the remote and rural stations of Utö, Hyytiälä and Pallas were close to the concentrations at the urban background station of Kallio, while in the summers of 2000 and 2003, the concentrations at Kallio were substantially higher.

The predicted concentrations in 2000 were highest in the vicinity of major roads and streets, and at their junctions. At all the stations, the predicted yearly averaged concentrations agreed fairly well with the measured data; the differences between measured and predicted values ranged from 10 to 31 %. According to the measurements, and also the emission and dispersion computations, the most important source categories were exhaust emissions from local vehicular traffic, and the long-range transported background.

For a more detailed discussion of this study, the reader is referred to Hellen et al. (2005).

MATERIALS AND METHODS

The measuring locations and equipment

The measurements of benzene were conducted at six air quality monitoring stations of the Helsinki Metropolitan Area Council (YTV; Töölö, Leppävaara, Ruskeasanta, Tikkurila, Kallio and Luukki), and on the roof of an office building of the Finnish Meteorological Institute (Herttoniemi). The stations used in this study represent urban traffic (Töölö), suburban traffic (Leppävaara, Ruskeasanta and Tikkurila) and industrial environments (Herttoniemi), together with the urban background (Kallio). Regional background concentrations were monitored in a rural environment at Luukki, located approximately 20km north-west of the centre of Helsinki.

Background measurements of benzene are conducted at three stations in Finland. The station of Hyytiälä is a so-called SMEAR II (Station for Measuring forest Ecosystem–Atmosphere Relations) station, located in a rural area in central Finland. The EMEP station of Utö is located on a small remote island in the Baltic Sea. The Global Atmospheric Watch (GAW) station of Pallas is situated in a remote area in Northern Finland on top of a fell.

In Helsinki ambient air samples were collected using both diffusive and pumped adsorbent sampling. For the diffusive sampling, Perkin–Elmer stainless steel sample tubes pre-packed with Carbopack-B (60/80) were used. Samples at the background stations of Pallas and Utö were taken twice a week at around midday using evacuated stainless steel canisters.

Modelling methods

In the present study, the fraction of benzene in THC emissions was estimated based on the hydrocarbon emission measurements by Hellen et al. (2003), and other nationally conducted corresponding measurements. We utilized the THC emission factors estimated by Laurikko (1998). These are based on European emission factors produced in the COST 319 action, and in the MEET project, and the values are in accordance with the emission evaluations conducted at VTT by Mäkelä (2001). In the present study, the emissions of THC in Finland were assumed to be as follows: for a petrol vehicle with a catalytic converter from 190 to 340 mgkm^{-1}, for a petrol vehicle without a catalytic converter 1700 mgkm^{-1} and for a diesel vehicle from 62 to 150 mgkm^{-1} (Mäkelä, 2001).

We utilised the CAR-FMI road network dispersion model (Contaminants in the Air from a Road; Härkönen et al., 2002) combined with the MPP-FMI meteorological pre-processing model (Karppinen et al., 2000). CAR-FMI is a mathematical model for predicting the dispersion of traffic-originated pollution from a road network. The model is based on a semianalytic solution of the Gaussian diffusion equation for a finite line source. The model also includes an emission model, a chemical transformation model and statistical analysis of the computed time series of concentrations).

The regional background concentrations were evaluated based on the benzene measurements at the station of Luukki in 2002. The benzene emissions from traffic as well as the meteorological time-series correspond to the year 2000. Meteorological data consists of observations from the synoptic stations of Helsinki–Vantaa and Helsinki–Isosaari, and the sounding station of Jokioinen; these have been pre-processed by the MPP-FMI meteorological pre-processing model (Karppinen et al., 2000).

The hourly time-series of benzene concentrations in 2000 were computed for approximately 8000 receptor points. The receptor point network covers the whole area; the largest grid intervals are 500 m. A more densely spaced grid was applied in the Helsinki downtown area, the grid interval there being 100 m. In the vicinity of the major roads in the area, the smallest grid interval was 50 m. A variable receptor grid is required in order to evaluate concentration isolines from the computed data with adequate accuracy.

RESULTS AND DISCUSSION

The seasonal variation of the measured concentrations

The seasonal variation of the measured two-weekly benzene concentrations is presented in Figs. 1 a–c. The two-weekly averages exceed the value of 2 μg m^{-3} at three stations: at Töölö during all 3 years considered, at Tikkurila during both the years considered (2000 and 2003), and at Leppävaara in 2002. In most cases, the highest two-weekly mean concentrations occurred at the urban station of Töölö, but the annual average concentrations at the suburban station of Tikkurila were almost as high in 2000, and even higher in 2003. As expected, the lowest concentrations were observed at the regional background station of Luukki. The concentrations at the urban and suburban stations were on average from 1.8 to 2.5 times higher than those at Luukki in 2002 and 2003. This indicates that the long-range transported background is of the same order of magnitude as the contribution from all local urban sources.
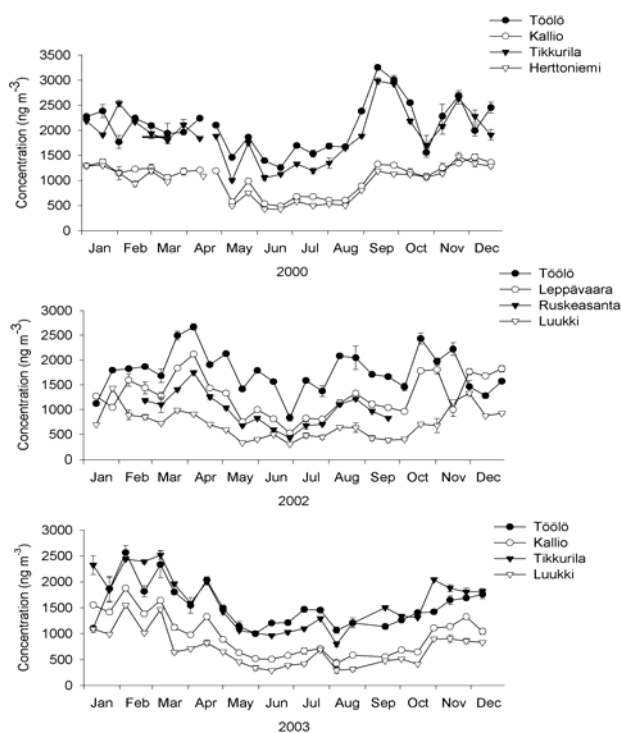
Figs. 1. (a–c) Measured seasonal variation of two-weekly concentrations of benzene at various stations in 2000, 2002 and 2003. The error bars for some data points show the standard deviations of simultaneously measured triplicate samples (Hellen et al., 2005).

The benzene concentrations in summer (defined here as June–August) are expected to be lower than those in winter (defined as December–February), due both to the reactions of benzene with OH radicals (Finlayson-Pitts and Pitts, 2000) and lower emissions associated with the shorter cold starts. On the average, this is indeed the case for all the sites during all the years considered.

However, there are also substantial differences between the seasonal variation of concentrations during the 3 years considered; these are mainly caused by the corresponding year-to-year variations in the meteorological conditions.

Predicted spatial concentration distributions

The predicted spatial distribution of the annual average benzene concentrations ($\mu g\ m^{-3}$) at the ground level in the Helsinki Metropolitan Area in 2000 is presented in Fig. 5. The concentrations are the highest in the vicinity of the main roads and streets, and in the central area of Helsinki. This is due to the major contribution originating from local vehicular emissions, and in the case of the downtown area, also by the largest traffic volumes within the area. The figure shows especially the distinct influence of the ring roads (situated at distances of about 8 and 15km from the city centre), the major roads leading to the Helsinki city centre, and the junctions of major roads and streets. At all of the 8000 receptor point the modelled values were below the upper assessment threshold (3.5 $\mu g\ m^{-3}$); the lower assessment threshold (2 $\mu g\ m^{-3}$) was exceeded in some areas.

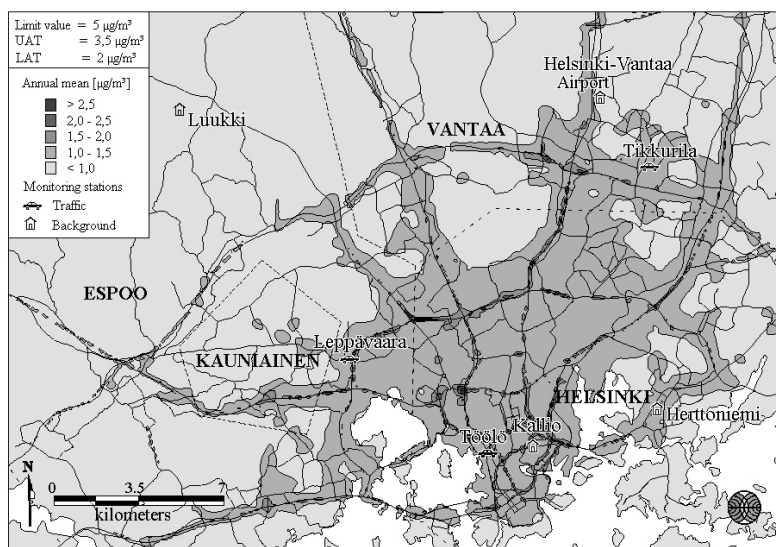*Fig. 5. Predicted spatial distribution of the yearly means of benzene concentrations ($\mu g\ m^{-3}$) in the Helsinki Metropolitan Area in 2000. The legend in the top left-hand corner shows the absolute values of the pollutant concentrations. The locations of the YTV monitoring stations utilised in this study are also indicated (Hellen et al., 2005).*

Predicted versus measured annual average concentrations

The model computations do not include all emission source categories, such as evaporative and wood-burning emissions. We have therefore not conducted a detailed statistical analysis of the differences between the measured and predicted sequential hourly time series (as these are not strictly comparable). However, it is useful to compare the annual average values of measured and predicted concentrations, e.g., this gives an indication of the completeness of the emission inventory.

In 2000, concentrations of benzene were measured in the Helsinki metropolitan area at three monitoring stations. The predicted benzene concentrations agree fairly well with the measured concentrations at all three monitoring stations. The measured values are underpredicted by approximately 10% at Töölö, overpredicted by approximately 10% at Kallio, and underpredicted by approximately 31% at Tikkurila (Hellen et al., 2005).

CONCLUSIONS
We have evaluated the atmospheric concentrations of benzene in the Helsinki Metropolitan Area, both by using two-weekly and two-hourly measurements in 2000, 2002 and 2003 at seven measurement stations, and by atmospheric dispersion modelling. Both the measured annual average and the two-weekly maximum values at all stations were below the upper assessment threshold; the two-weekly averages exceeded the value of 2 μg m^{-3} at three stations.

ACKNOWLEDGEMENTS

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