Statistical Analysis of the Concentrations Measured in the Street Canyon in St. Petersburg

A contribution to subproject SATURN

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Summary

Results of the statistical analysis of data obtained during the measurement campaign in St. Petersburg at Pestelya Street are considered here. The concentrations were measured by two DOAS instruments installed at two, street and roof, levels. Data cover the time period of December, 1998 – May, 2001 and include concentrations of benzene, toluene, NO and NO_2, ozone and SO_2. Concentrations of all these pollutants are similarly influenced by vehicular emissions. Therefore the additional emphasis in this work has been made on the evaluation of joint characteristics of concentrations of different species.

The analysis of the probability distribution functions (PDFs) of measured concentrations shows that most of them do not follow the lognormal distribution but rather close to it in the interval of moderate values. PDFs of different pollutants were tested for their closeness using the Kolmogorov-Smirnov test. It was found that pollutants directly emitted by the traffic have similar distributions. The distributions of the daily and weekly maximum values (MAX) of concentrations (CON) and differences of concentrations measured at the street and roof levels (DIF) have been investigated as well. It turned out that PDFs of MAX_CON were more or less close to the double exponential distributions and PDFs of MAX_DIF did not fit this law too well.

Relatively high cross-correlations of the concentrations (CON) of different pollutants at the street and roof levels and of their differences DIF were found for non-reactive pollutants. It confirmed, in particular, that these pollutants were emitted mainly from the same source. Then principal components were found as eigenvectors of correlation and covariation matrices of pollutants. It was found that first 5 factors (principal components) covered about 90% of the total variance. It means that rather limited number of factors could explain temporal variations of concentrations. Since the similarity in variations of species can be evidently attributed to variation of the traffic, more detailed investigation of the diurnal cycle of the concentrations was carried out by the same method of the principal component analysis. In case of NO_2, for example, first 5 factors also cover more 90% of variance. In both cases of main component decompositions, the originally estimated factors (non-rotated) were compared with those obtained after the Varimax rotation. The second approach seems to be more informative because it helps to distinguish better between different types of daily variations of concentrations of pollutants.

Introduction

In the framework of the Danish-Russian project “Monitoring and analysis of the air pollution in St. Petersburg”, two DOAS instruments were installed in St. Petersburg on Pestelya Street, which could be considered as a street canyon (Genikhovich, et al., 2000). The concentrations were measured by two DOAS instruments installed at two (street and roof) levels. Data cover the time period of December 1998 – May 2001 and include concentrations of benzene, toluene, NO and NO_2, ozone and SO_2. The statistical analysis of results of measurement campaigns in different cities is reported in numerous publications (*e.g.*, Hargreaves, et. al.,2000; Karppinen, et. al., 2000). In our work an additional emphasis was put on evaluation of joint characteristics of concentrations of different species.

Results

As the first step, PDFs of concentrations of different species were estimated from the samples and compared with several frequently used analytical expressions. It was found that the Weibull distribution provides better fit with empirical PDFs than the lognormal distribution. An example of PDF for benzene is given on Fig.1 where straight line should correspond to Weibull's PDF (the best linear fit for the actual curve gives here R^2 = 0.9845).

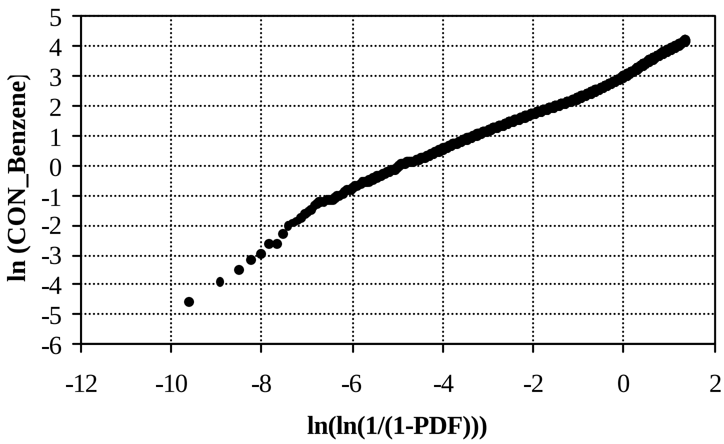

Figure1: PDF for benzene at the street level.

Distributions of highest concentrations were analysed separately for daily and weekly maximums. As an example, PDFs of daily MAX_CON for benzene (left-hand panel) and MAX_DIF of its concentrations (right-hand panel) are shown on Fig.2; straight lines on this figure should correspond to the double exponential distribution. It seems to be plausible that this distribution could be used to describe the frequencies of occurrence of highest concentrations in cities. Quantile-quantile plots for PDFs of concentrations and daily maximums of two different species are shown on Fig. 3 and 4, respectively. It looks like these two plots are rather similar. Relatively high cross-correlations (from 0.74 to 0.95) between the

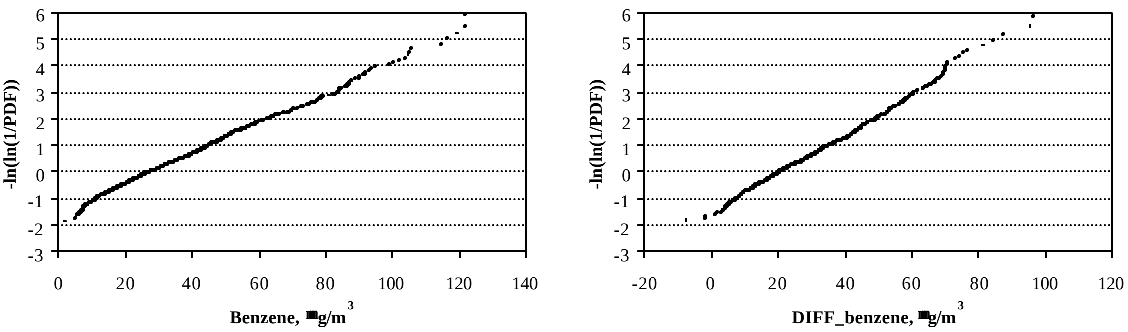

Figure 2: Distribution of the daily maximums.

concentrations at the street and roof levels and between the differences (DIF) of concentrations at the street and roof levels were found for non-reactive pollutants. It confirms, in particular, that these pollutants are emitted mainly by traffic. Slightly lower correlations for differences in comparison with those for concentrations could be attributed to higher level of noise in differences.

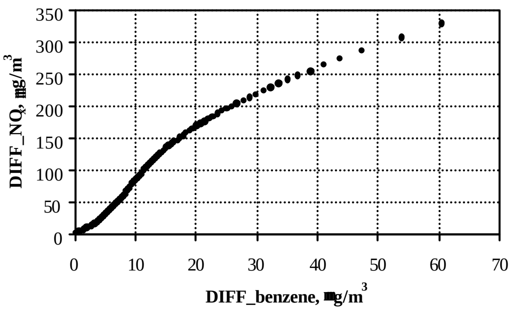

Figure 3: Quantile-quantile plot for differences of the concentrations.

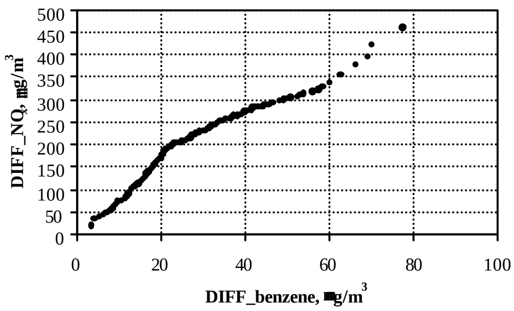

Figure 4: The same as Fig.3 but for daily maximums.

To investigate contribution of different factors and understand better what number of pollutant should be monitored independently, we estimated principal components (eigenvectors) of correlation and covariation matrices. It was found that first 5 factors

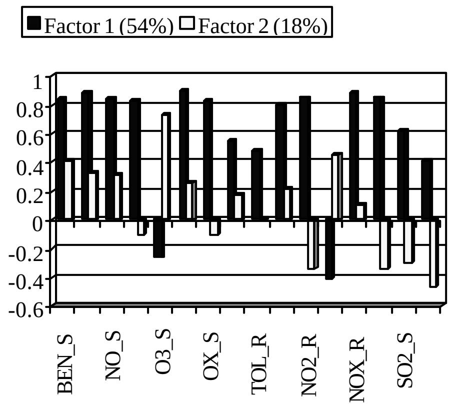

Figure 5: Two factors with maximum weights (unrotated).

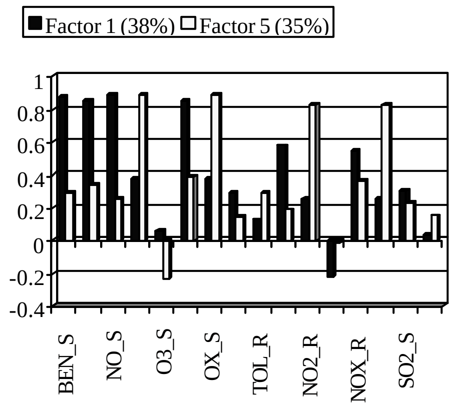

Figure 6: Two factors with maximum weights (after Varimax rotation)

(components) cover more than 90% of the total variance. Fig. 5 and 6 show distributions of the two main factors obtained initially (unrotated) and after the Varimax rotation. Percents in brackets indicate the part of the total variance, which corresponds to the particular factor. It can be seen that the total variance in both plots is nearly the same but the distribution of factors over the pollutants differs. First plot confirms that there is the main factor, which determines the concentration levels. Factors on Fig. 6 could be attributed to primary and secondary pollutants.

The same technique of principal component analysis was applied to correlations/covariances of concentrations corresponding different hours of the day to analyse the main factors influencing the diurnal variations. Fig. 7 shows the first two eigenvectors (factors), which cover the 76% of the total variance (first 4 eigenvectors would explain here about 90% of the variance). These components are not rotated. After the Varimax rotation (Fig.8) the shape of the first factors changed drastically. Physical processes responsible for these "new" factors should be analysed additionally.

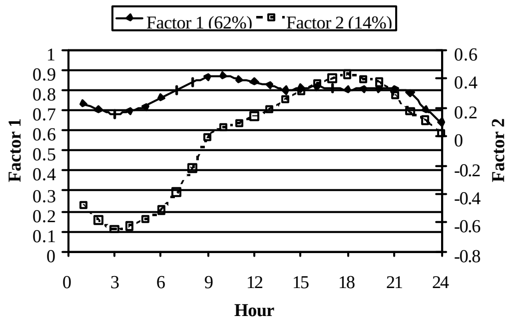

Figure 7: Two first principal components in decomposition of the NO_2 diurnal variation (unrotated).

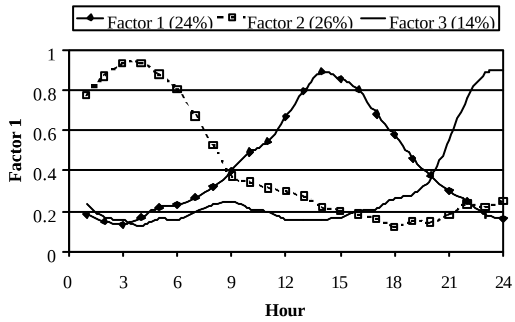

Figure 8: The same as Fig. 6 but for three rotated (Varimax) factors (total % of variance is nearly the same)

Conclusions

Standard monitoring data are usually used either in environmental decision-making or in validation of dispersion models. We think that detailed statistical analysis of these data could provide additional insights into regularities of forming urban air pollution.

Acknowledgements

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References

Genikhovich E., Ziv A., Iakovleva E., Palmgren F., Berkowicz R., 2000: Monitoring and Analysis of Air Pollution in St. Petersburg. A contribution to subproject SATURN. *Eurotrac Newsletter* **22**, p. 27.

Hargreaves P., Leidi A., Grubb H., Howe M., Mugglestone M., 2000: Local and seasonal variations in atmospheric nitrogen dioxide levels at Rothamsted, UK, and relationships with meteorological conditions *Atmospheric Environment* **34**, 843-853

Karppinen A., Kukkonen J., Elolakhde T., Konttinen M., Koskentalo T., Rantakrans E., 2000: A modelling system for predicting urban air pollution: model description and applications in the Helsinki metropolitan area. *Atmospheric Environment* **34**, 3723-3733.