NILU OR: 30/97

NILU : OR 30/97
REFERENCE : O-92064
DATE : OCTOBER 1997
ISBN : 82-425-0879-8

Source oriented model for exposure calculations in Teplice area

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Summary

Aim of co-operation

The Teplice health programme started in 1991 to assess possible effects of pollution in the district. The assessment is based on correlation between effects on one hand and exposure to pollution on the other hand. Measurements of air pollution concentrations characterize air quality close to the measuring stations. To characterize air quality outside the neighbourhood of stations supplementary information based on data for emissions, wind and dispersion conditions may be used. Exposure estimating based on concentration measurements and results of dispersion calculations is used in Norway, and was also done as a part of the Norwegian contribution to the Teplice program. Modelling of air pollution is provided to

- calculate concentration distributions in space and time based on data on emissions, wind and dispersion conditions;
- describe source/receptor relationships for future control of air pollution.

Combination of observed and calculated concentration values

Calculated concentration distributions are evaluated and adjusted to measured concentration values at measuring stations. The following factors have been accounted for:

- Pollution from sources outside the Teplice district has been taken into account by using measurements far from the influence of local sources and by using results of regional model calculations;
- Deviations between observed and calculated concentration values were not correlated in space except in episodes. Measuring stations to give data for assimilation have been selected to spatially representative. The adjustment were then carried out by simple statistical interpolation ("Kriging").

Elements of the model

The results of dispersion calculations describe the location of pollution concentration gradients. Based on this, expected variations in exposure in different residential areas are estimated for the health programme, accounting for whether the receptor location is within or outside the polluted zones.

The calculated concentration distributions may be used as supplementary data for exposure estimation.

Results of the following Czech and Norwegian models have been combined in this study:

- Regional scale dispersion model developed at Charles University in Prague has been used to provide information on pollution contribution from sources outside the Teplice district, and on long term average concentrations within the area;
- Dynamic wind field model developed at the Institute of Physics of the Atmosphere, The Academy of Sciences of the Czech Republic, has been used to provide typical distributions of wind and dispersion conditions in the area;
- Local and urban scale dispersion models developed at the Norwegian Institute for Air Research (NILU) have been applied to calculate local concentration distributions based on background concentration values and data on local emission and dispersion.

The following data were used as input to the models:

- concentration measurements and emission data provided by Teplice Institute of Hygiene (OHS);
- concentration measurements and meteorological data from the Czech Hydrometeorological Institute (CHMU).
- A local co-ordinate system provided by Teplice Institute of Hygiene, was used for the location of sources and receptor points.

Preparation of input data and modification of formats were carried out to meet requirements of each model. The work was carried out in several steps during the period 1992-1996. The need to separate between large scale and local scale pollution concentration distributions for exposure calculations was clarified. The review and guidance provided by the two peer review meetings were important for the progress of the project.

Results

The results of model calculations based on background concentration, emission and dispersion indicate that

- contribution of pollution from sources outside the area was of minor importance to explain concentrations of primary components i.e. SO_2 and NO_x. For the secondary components i.e. ozone, sulfate and nitrate, the regional scale pollution becomes important;
- centralized heating plants and home heating in small ovens were the most important sources for SO_2-pollution;
- the air pollution episodes in the district occurred during stagnating high pressure situations. The local wind systems varying in space and time provoked accumulation of local emissions. Both high level and low level sources are expected to contribute to accumulation of pollution concentrations in such episodes.

The model is now operational and the calculation period may be extended or the calculations may be carried out for different components when input data on emissions, wind and dispersion are available.

Examples of individual exposure calculations

The model calculations, i.e., the hourly concentrations in receptor points were used to estimate individual exposure for participants in the Teplice health studies. Around 8,000 individuals with known home and work/school address were given a simplified exposure estimate based on outdoor exposure to SO_2 at their home/ work address in the period 1.10.-31.12.1991. 50% participants were exposed to the period average below 7 $\mu g/m^3$, with 5% being exposed to period average over 40 $\mu g/m^3$. However, for 5% of participants the maximum hourly exposure was estimated to be over 380 $\mu g/m^3$. This implies that the 10-minutes value of 500 $\mu g/m^3$ (short-term air quality guideline, WHO) might have been exceeded for those participants.

The exposure estimates provided here are examples to illustrate the differences between individuals, that will not be captured by giving them an exposure estimate based on a measuring site results. The method, based on hourly estimates of outdoor estimate, and to define several types of long-term (period) estimates. Such estimates are important when trying to establish relationships between pollution concentrations and health indicators.

By changing the emission data in the model, an estimate of outdoor exposure to other non-reactive air pollutants may be provided, such as to PAH, benzene, or heavy metals. The period of calculation may be extended, based on input data for emissions and meteorology in the new calculation period.

Improvements and quality assurance of the estimation. One large and several small urban areas including large industrial sources exist in the Teplice district and several pollution maxima occur as a result of this urban structure. The results of the local sub-grid model may be improved by using data on emissions with better spatial resolution.

For the high pollution episodes, the dynamic wind field model should be further developed. Results of model calculations on local wind regimes should be assimilated to a sufficient number of wind observations in order to improve the description of pollution accumulation in the district. In particular the importance of both high level and low level sources should be clarified. Data based on results of receptor models is important and further work should be carried out to combine the results of source oriented and receptor oriented models.

The calculated concentration values will be used for individual exposure estimating. To assess the accuracy of these exposure estimates, personal monitoring would be advisable.

Source oriented model for exposure calculations in Teplice area

1. Introduction

Teplice Health Program started in 1991. This program is a Czech research program on effects of air pollution on the health of the population in the Teplice district (Kotesovec, Sram and Jelinek, 1992, 1993 and 1994). Important air pollution sources in this region are coal-fired power plants, glass works and other industry, home heating with coal, and road traffic. Prachatice, a relatively clean area in South Bohemia, is used as control area.

Norwegian Institute for Air Research (NILU) has contributed to the investigations by the following activities:

- Monitoring of air pollution : Evaluation of the monitoring program and establishment of QA/QC program.
- Modelling of air pollution : Establishment and preparation of input data base, evaluation of dispersion models, and preliminary SO_2 distribution calculations.
- Health Symptom monitoring : Plan for a health symptom monitoring study in Teplice based on measured and calculated concentration distribution.

An objective for the Norwegian contributions to this program is to transfer equipment, analysis tools and support to Czech partners and groups, for use by them to provide better data on air pollution and exposure, for use within the various health studies of the program.

NILUs computer programs calculating pollution concentration distributions as a function of time have been installed on the following two computers in Prague:

- SUN SPARC workstation at the Czech Hydrometeorological Institute (CHMU);

A description and an evaluation of the NILU models are given by Grønskei et al. (1993,1995).

Charles University, Prague, team of Dr. Brechler established a data base including the following data on emissions, wind, dispersion conditions, and pollution concentrations.

- Data on SO_2 emission, provided by Teplice Institute of Hygiene (OHS). The survey covers all point sources in the Teplice district and the large point sources in the surrounding areas for 1991;
- Data for height of topography in the area of calculations, with a resolution of 1x1 km^2;

- Data on pollution concentration in the area including the stations Teplice, Liberec, Litomerice, Most, Usti nad Labem, and Chomutov;
- Meteorological data for the period 1 October 1991-31 December 1991 from the stations number 11438, 11464, 11467, 11502;
- Prague Libus Upper Air Soundings: for the period 1 October 1991 to 31 December 1991.

The NILU model may be further developed to account for data characterizing the local wind and the structure of the boundary layer. Data presented in the Proceedings of the experiments Kopex-86 (Kopisty/Tusimice 2 June-7 July 1986) may be used for this purpose (Csechoslovak Academy of Sciences, 1988).

In some situations it is necessary to consider wind and dispersion conditions by the dynamic approach, Svoboda (1990).

More data have been available for the project, particularly data on air quality and meteorology. Emission intensity and emission distributions vary from year to year. Since these data were not available, the period October-December 1991 was used for calculations. The contributions from five source groups were specified. When the source intensity varies for each group, the concentration contribution varies accordingly. A proportionality model may be used to predict concentration variations as a result of changes in emissions. Calculations of the relative contribution from groups of sources may also be used to combine results of source oriented dispersion calculations with results of receptor oriented model calculation (Stevens et al., 1994, 1995).

2. Model description

To evaluate, analyze and quantify air quality with regard to sources, the relationship between emissions, air pollution concentrations and deposition has to be described in a quantitative way i.e. modelled.

Figure 1 illustrates the different model elements, input data and interaction between different scales of pollution concentrations to be considered, i.e.

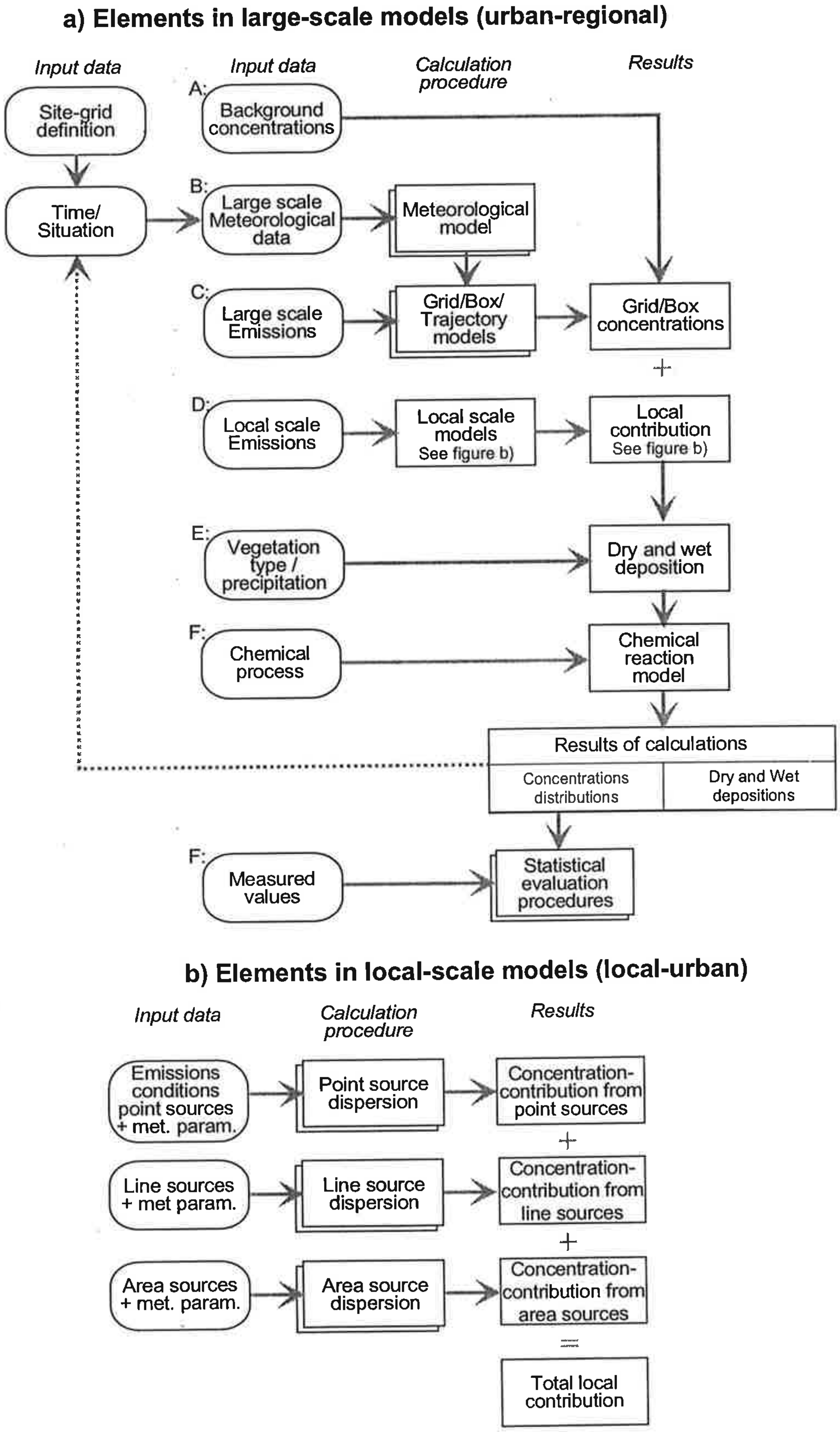


Figure 1: Model elements and necessary input data to describe a multiscale pollution problem (local-urban-regional-global).

A. Background concentrations to be added to pollution concentrations and deposition caused by large scale and local scale emissions. The values have to be measured or estimated based on measured values from regional air pollution stations. The CHMU data from the stations located between Teplice and the German border are used for this purpose. The minimum concentration value of the measurements from Nova Ves, Krupka and Flaje is used as an estimate for the background concentrations in combination with calculated values. The calculated regional background concentrations are based on contribution from sources located outside the study area (Brechler and Grønskei, 1994). The regional scale model has been developed by Brechler and Bednar, 1990.

B. and C. Data for large scale emission and dispersion conditions to account for the general source receptor relationship in the Teplice area. For many applications it is important to measure the large scale contribution to local pollution concentration when the impact of emission from a single road or a single chimney in an urban area is going to be evaluated. The input data are described in Chapter 3.

D. Data for local scale emissions and meteorological conditions. Models based on the Gaussian dispersion formulae are available for three different types of sources, i.e. point source emissions, line source emission and area source emissions. On site meteorological measurements are recommended for local scale assessment studies.

A spatial average contribution from roads and small chimneys is given for each grid square. The method used is described in Appendix B. The small scale contribution from large chimneys is calculated for the center of each grid square. Errors in the spatial location of this local pollution contribution may occur, and this source of uncertainty is considered in the model evaluation described in Chapter 4.

E. When dry and wet deposition are going to be calculated, data on vegetation type and intensity of precipitation are required.

F In addition to deposition at the ground, the ambient air pollution concentrations may be modified as a result of chemical reactions, i.e.

- photochemical components;
- aerosols containing sulphate and nitrate;
- nitrogen dioxide.

G Measured values of concentrations and depositions are of vital importance for the description of pollution problems. The measurements are compared with calculated values for model evaluation, with limit values and with air quality guidelines to clarify impact and effects. Supplementary data on emissions, dispersion and background concentrations has to be used in air quality models to clarify source-receptor relations and air quality variations in space and time.

The processes A-F together determine the time variation and the spatial distributions of pollution concentrations and depositions.

2.1 The urban-regional scale model

The dispersion is partly caused by the time variation of the wind field and partly by turbulent exchange. Wind $(\mathbf{v}_h + w\mathbf{k})$ and pollution concentrations (c_i) are divided for each grid element in an average value $(\bar{\ })$ and deviations from the average values $(')$, i.e.

Concentrations	:	$c_i = \overline{c_i} + c_i'$
Horizontal wind velocity	:	$\mathbf{v}_h = \overline{\mathbf{v}_k} + \mathbf{v}_h'$
Vertical wind speed	:	$w = \overline{w} + w'$

For each of the pollution components time variation of pollution concentrations in a grid system is found as the sum of the values for the different processes listed below:

I : horizontal advection, $\overline{\mathbf{v}}_h \cdot \nabla_h \overline{C_i}$

II : vertical advection, $\overline{w}\dfrac{\partial \overline{c_i}}{\partial z}$

III : turbulent exchange vertically, $\dfrac{\partial\left(\overline{w'c_i'}\right)}{\partial z}$

IV: turbulent exchange horizontally, $\nabla_h\left(\overline{\mathbf{v}_h' c_h'}\right)$

V : emission, Q_i

Modern numerical methods have been applied to calculate the processes in each of the layers shown in Figure 2.

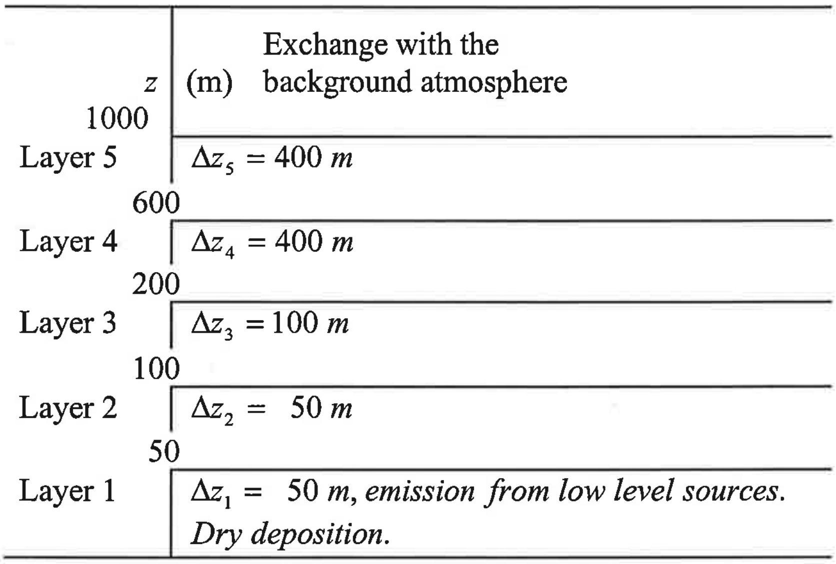


Figure 2: The vertical structure of the model.

A formal description of the calculation procedure is given by Grønskei et al. (1993).

2.2 Subgrid model based on plume formulae

Point sources

The contribution from point sources is estimated by a puff model using the formulae presented in Appendix B.

Line sources

For further application it is possible to specify the local contribution from line sources within a certain zone of influence. The existing roads within the area did not give particularly high SO_2-concentration close to the road. However, for other pollution components the locations of "hot spot" areas close to roads are well known.

Area sources

In urban areas, home heating takes place in centralized heating plants with emissions through single chimneys or in many small ovens with small emissions on the roof. Emissions from centralized heating plants are treated as point sources. Emissions from small ovens are treated as area sources where the data on total emissions in Teplice area are distributed in the grid proportional to the population distribution in the area.

Small emissions from many stacks are not treated individually, but the emissions are averaged over each km^2 and accounted for by the formulae presented in Appendix B. In addition to the area sources intensity, the average height of the houses and the average emission height are used as input.

In low wind conditions it is assumed that the effective emission height is two times the building height as a result of exit velocity and temperature of the small emissions.

The contribution to the grid system is accounted for by specifying the horizontal and vertical fluxes to neighbouring grid squares (see Appendix B).

3. Description of input data

3.1 Topography

The participants in the health studies live and work in the Teplice region. Calculations are needed for pollution concentrations in specified areas or buildings. In these aeras concentration measurements and other input data for the calculation procedures should be known with high accuracy, i.e. location of emission, wind and dispersion conditions and concentration measurements.

The area of calculation is shown in Figure 3.

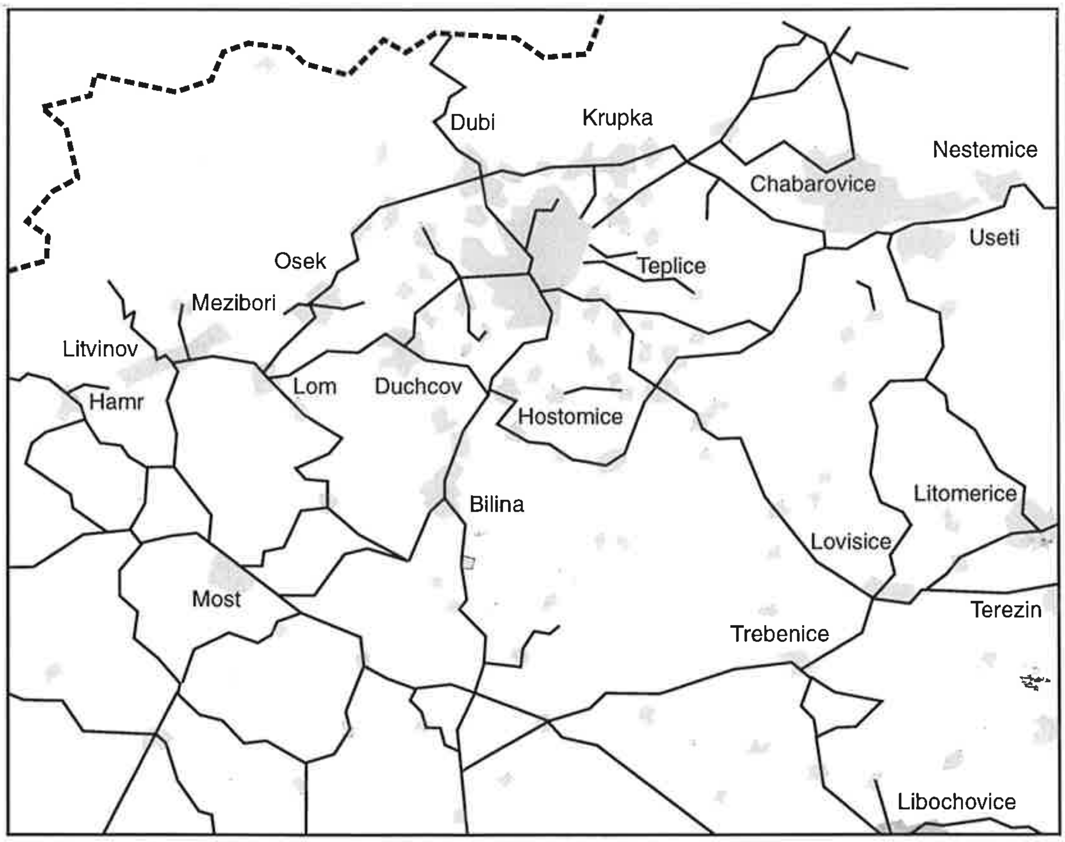


Figure 3: The area of calculations.

To avoid co-ordinate transformations of emission data, the following area of calculations were defined.

Latitude :	Lower bound	50.40°N
	Upper bound	50.76°N
Longitude:	Lower bound	13.50°E
	Upper bound	14.14°E

The area is divided in 46x38 grid squares. The grid squares are 1 km^2 wide. The co-ordinate system is terrain-following.

Location of emissions and population were specified in the same geographic information system used in the health study.

3.2 Wind and dispersion conditions

The data which were prepared for the actual period of investigation include measurements of wind speed and direction, air temperature and dispersion parameters such as vertical temperature profile and turbulence intencity. The meteorological measurements cover the various meteorological/topographical domains of the model area including low level and high level stations, in the following manner:

- horizontal wind measurements close to the ground;
- upper air data on wind and turbulence intensity are based on sodar and radiosonde measurements.

Low level stations:

- Usti nad Labem Kockov;
- Zatec-Velemysleves
- Tusimice.

Upper air stations/regional stations:

- Milesovka;
- Prague-Libus upper air sounding station;
- Kopisty.

Results of the local wind field model for the area were used to describe hourly input data for the area using measurements from Prague-Libuse airport as input.

3.3 Concentration measurements and results of receptor models

The measurement program at monitoring stations in Teplice/Most area are shown in Table 1. For model evaluation, measurements from the stations marked with x are used.

Table 1: Measurement program at monitoring stations in Teplice/Most area.

Station			Respon-sibility	Compounds					
No	Name/Location			SO_2	NO_x	SP	O_3	CO	Other
1	Teplice Hygiene Institute	x	OHST	c	c	c	c		VAPS, HIVOL
2	Teplice Downtown	x	CHMU	c	c	c	c	c	
3	Kockov/Ustí n.L.		CHMU	c	c				
4	Ustí center		CHMU	c	c				
5	Chabarovice		CHMU	c	c				
6	Bilina Gymnasium	x	OHST	c					
7	Bilina Poliklinika	x	OHST	c					
8	Most center		CHMU	c	c	c			
9	Most Hygienic Inst.		OHSM	c	c	c	c		
10	Mezibori		OHSM	c					
11	Litvinov		OHSM	c		i			
12	Osek	x	OHST	c					
13	Duchcov	x	OHST	c					
14	Vsechlapy		CHMU	c	c	c			
15	Krupka Martin	x	CHMU	c	c	c			
16	Flaje		CHMU	c					

c - Continuous monitor.
i - Integrating method (24 hour average).
x - Observations used in the evaluation of the SO_2-model.

The following description is given of the stations used in model-evaluations.

1. ***Teplice Hygienic Institute (OHST)***
The station is located downtown Teplice, Wolkerova street, on 3rd floor of the building (under the roof). The station is surrounded by streets and houses with local heating systems (coal, gas).

2. ***Teplice Downtown, CHMU Container***
Located in a park in the town center, away from influences from local sources nearby.

6. ***Bilina Gymnasium, Coulograph (OHST station)***
The station is located under the roof (4th floor) of the secondary school building, facing the backyard. The secondary school is downtown Bilina, surrounded by roads and chimneys for local heating.

7. ***Bilina Poliklinik, Coulograph (OHST station)***
The station is located near the hospital, up from the valley floor. The residential area surrounding the station is heated by long distance heating.

13. ***Duchcov, OHST station***
The station is located in the town hall, facing the backyard. Coal heating in surrounding houses.

Additional stations, which may be used to estimate background concentrations in the area are:

14. ***Všechlapy, CHMU container***
    The station is located near a lake, in a rural setting. The only nearby source is a farm close to the station, to the north.

15. ***Krupka Martin, CHMU container***
    The station is located 550 m.a.s.l. up on the Ore Mountain hill. Exposed to power plant emission (high stacks).

16. ***Fláje, CHMU station***
    Located high up on Ore Mountain hill, exposed to emissions from power plant stacks.

In some periods, measurement campaigns have been carried out for different purposes:

"The Czech Air Toxics Study (CATS)" carried out in the period February-March 1992 (Stevens et al., 1994, 1995) in order to collect supplementary measurements for a risk assessment for pollution health effects in the area. The supplementary measurements included concentrations of

- metals attached to coarse and fine particles in the area;
- sulphur and nitrogen compounds;
- polynuclear aromatic hydrocarbons (PAH);
- volatile organic compounds (VOC).

Scanning electron microscopy were carried out to study the composition of individual particles.

Ambient air sampling was carried out close to the most important sources and at the OHS-Teplice station. This station is considered to be a representative station for the urban area of Teplice.

Results of receptor models in the Teplice area. (The results are reported by Stevens et al., 1994)

Twelve hour ambient samples were collected in Teplice (7PM to 7AM) between February 16 and March 31, 1992. The samplers collected separately fine and coarse particles, semi-volatile organic species and ionic species. The samples were analyzed for SO_2, HNO_3, nitrates, sulfates and aerosol acidity.

In addition data are available from other stations on sulfur dioxide, carbon monoxide, nitrogen oxides and PM_{10}.

Data on emission of particles, supplied with information of source signature (elemental and chemical compound composition) has to be collected when using a receptor model based on analyses of many chemical components at receptor points. The analysis is useful to identify the contribution of pollution from different groups of sources.

In order to characterize source signatures, samples were taken close to the main sources i.e.:

- industrial chimneys;

- mobile sources (car traffic);
- home heating;
- regional contribution (Medenec site);
- coal fired power plants.

Results indicate that up to 80% of fine particles observed in inversion episodes comes from home heating and power plant emissions. Mobile sources, incineration emissions and windblown dust are responsible for the rest of ambient pollution concentration.

Home heating and power plants burning lignite were found to be the dominant contributors to ground level concentrations of sulfate and toxic metals.

Guidelines for the SO_2 and particle concentrations are frequently exceeded. Other components, in particular components attached to particles coming from combustion of lignite coal, may cause adverse health effects.

3.4 Emissions

Point sources

An inventory of the emissions in the Teplice district include emissions estimates of SO_2 and NO_x from point sources and from area sources (i.e. home heating and road traffic).

The survey covers all sources of SO_2 and NO_x in the Teplice area and only larger point sources in the surrounding area (Kopriva, 1991).

- Small low level sources are not treated separately, but included in the area sources with a spatial resolution of 1x1 km^2;
- The remaining point sources in Teplice area are located with an accuracy of 100x100 m^2 to obtain subgrid concentration data in the central area of calculations.

Home heating

The following data have been collected and used:

- fuel consumption, per house or individual, for each heating process;
- the distribution of various home heating processes in the different parts of the area;
- emission factors for each process.

Road traffic

- Position of the end points of each road link, within the grid co-ordinate system;
- Traffic data for the main road links (daily traffic, distribution of passenger cars/ trucks, velocity);
- Emission factors.

The time resolution of the emission data varies from compound to compound:

- Compounds with accute health effects require data with high temporal resolution (~1 hour);
- Compounds with long term effects require only little time resolution (month, year).

4. Model evaluation for sulphur dioxide

Based on data for emissions, dispersion and background concentrations the pollution distribution is calculated on hourly basis. Emission data on hourly basis was not available and the calculated values were averaged to daily mean concentrations for model evaluation.

The first results of evaluation were presented at the 2nd Peer Review Workshop at Castle Trest. The comments included:

- averaging time for testing the model;
- the application of measurements to estimate background concentrations;
- improved description of vertical exchange;
- the behaviour of elevated subsidence inversions in the region;
- the influence of high level point sources;
- development of a source apportionment scheme;
- communication with the air quality team and the health effects scientists.

4.1 Background concentrations

Measurements at background stations:

The concentration measurements show that low SO_2-concentrations are observed at some stations even during pollution episodes. This indicates that local sources, accounted for in the calculations, give the most important contribution to the pollution concentrations in the area.

In particular the measured concentrations from the stations located at Duchcov and at Nova Ves support this conclution.

Based on a larger scale model developed at Charles University in Prague (Brechler and Bednar, 1990) the average contribution from sources outside the area was calculated in a 5x5 km grid. SO_2-concentration distributions close to the ground are presented in Figure 4.

The Figure 4 shows that the average contribution is small compared to the influence of local sources. The maximum values are located along the southern border. Emission data for sources north of the area of calculations (Germany and Poland) reports were not available.

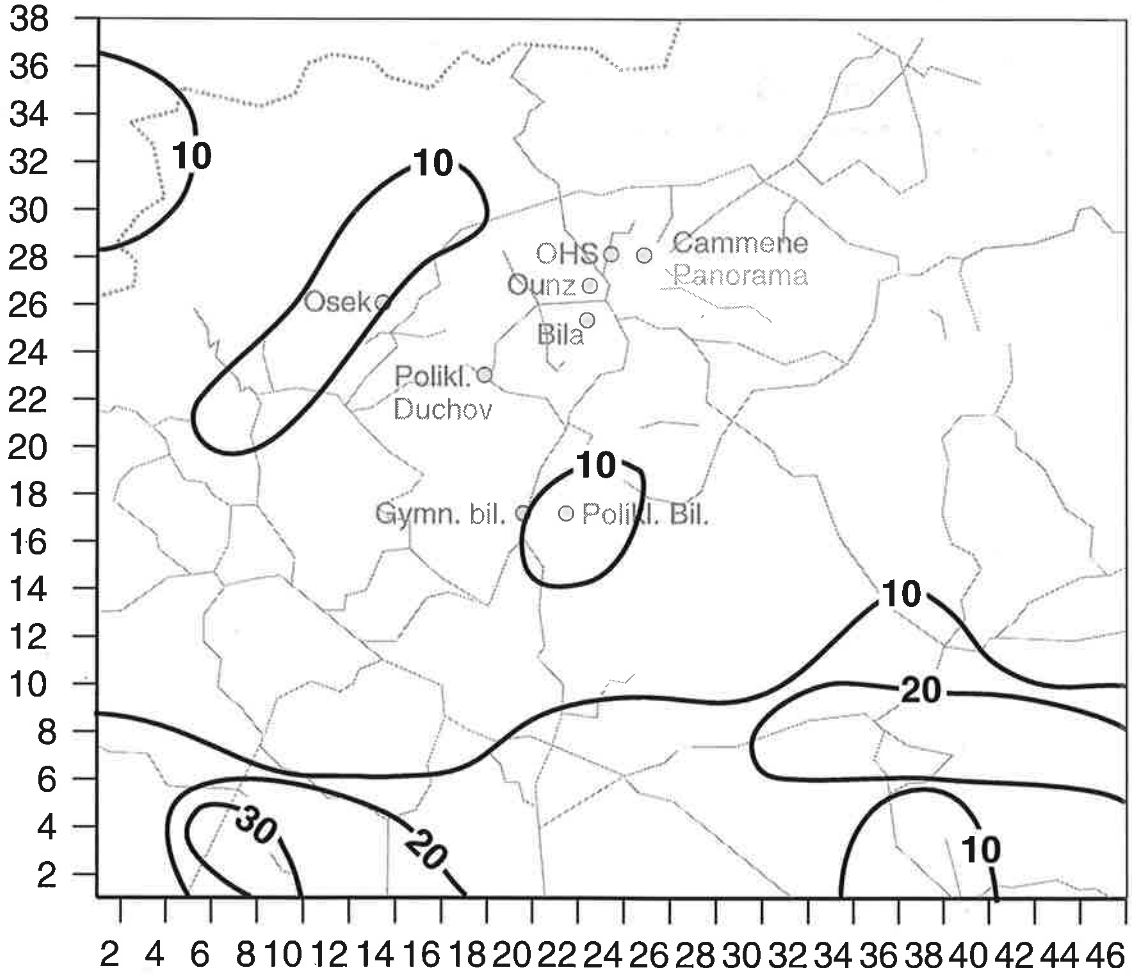


Figure 4: Average SO_2 concentrations calculated as a result of sources outside the area of calculations.
Unit: $\mu g\ SO_2/m^3$..

Large scale concentration distributions have also been calculated by another group of modellers (Ap. Simon et al., 1997), including emission data from the area north of the Teplice region (Poland and East Germany). The concentrations were calculated using a 10x10 km grid nested within the EMEP-model. The results indicate that the polluted Katowice area may influence the northern part of our calculation area (the mountains) in episodes. However, the urban areas in the Teplice region are influenced mainly by local sources. Regarding secondary pollution components, contributions from sources located outside the area of calculations become more important. These include photochemical oxidants, sulfate, nitrate, and particulate matter.

4.2 Evaluation of calculated SO_2-concentration distributions

Table 2 show statistical parameters for observed and calculated time series of 24 hour mean concentration values. The spatial average value of each grid square is compaired with observations carried out in the same km2-square. Possible local scale contribution to pollution at the measuring station may cause important deviations between observed and calculated values.

Table 2: Statistical evaluation parameters for source oriented model calculations of 24-hour SO_2 concentrations (C) in Teplice 1.10.-31.12.1991.

Station		$(\bar{C})$	σ	Max	r	I_a	Best-r	N
	Unit	μg/m3		μg/m3				
OHS, Teplice	Observed Calculated	147 143	131 69	767 347	0.79	0.88	0.90	90
Gym, Bilina	Observed Calculated	84 149	67 61	313 311	0.72	0.70	0.96	72
Kamenne Lazne, Teplice	Observed Calculated	120 127	117 58	628 320	0.79	0.78		73
Panorama, Teplice	Observed Calculated	105 127	103 57	636 321	0.74	0.77	0.94	89
Bila Cesta, Teplice	Observed Calculated	103 83	115 64	561 74	0.69	0.45	0.90	61
OUNZ, Teplice	Observed Calculated	101 78	86 41	511 185	0.78	0.74	0.96	83
Duchcov	Observed Calculated	78 167	76 63	561 328	0.30	0.46	0.88	92

$(\bar{C})$: Average value for the evaluation period 1.10.-31.12.1991.
σ : standard deviation
r : correlation
I_a : index of agreement
Best-r : within a distance of one km from the stations, the calculated concentration values with minimum deviations from the observed values are used when Best - r correlations to observed values are calculated.
N : number of observations

Figure 5 show the calculated long term average SO_2-concentrations. The distribution is characterized by sharp gradients in concentration around the urban and industrial areas. SO_2-emissions from car traffic were not taken into account. Figure 6 show the contribution calculated for each of the following source groups:

A. Home heating in small sources;
B. Power plants;
C. Home heating in centralized heating system;
P. Industry.

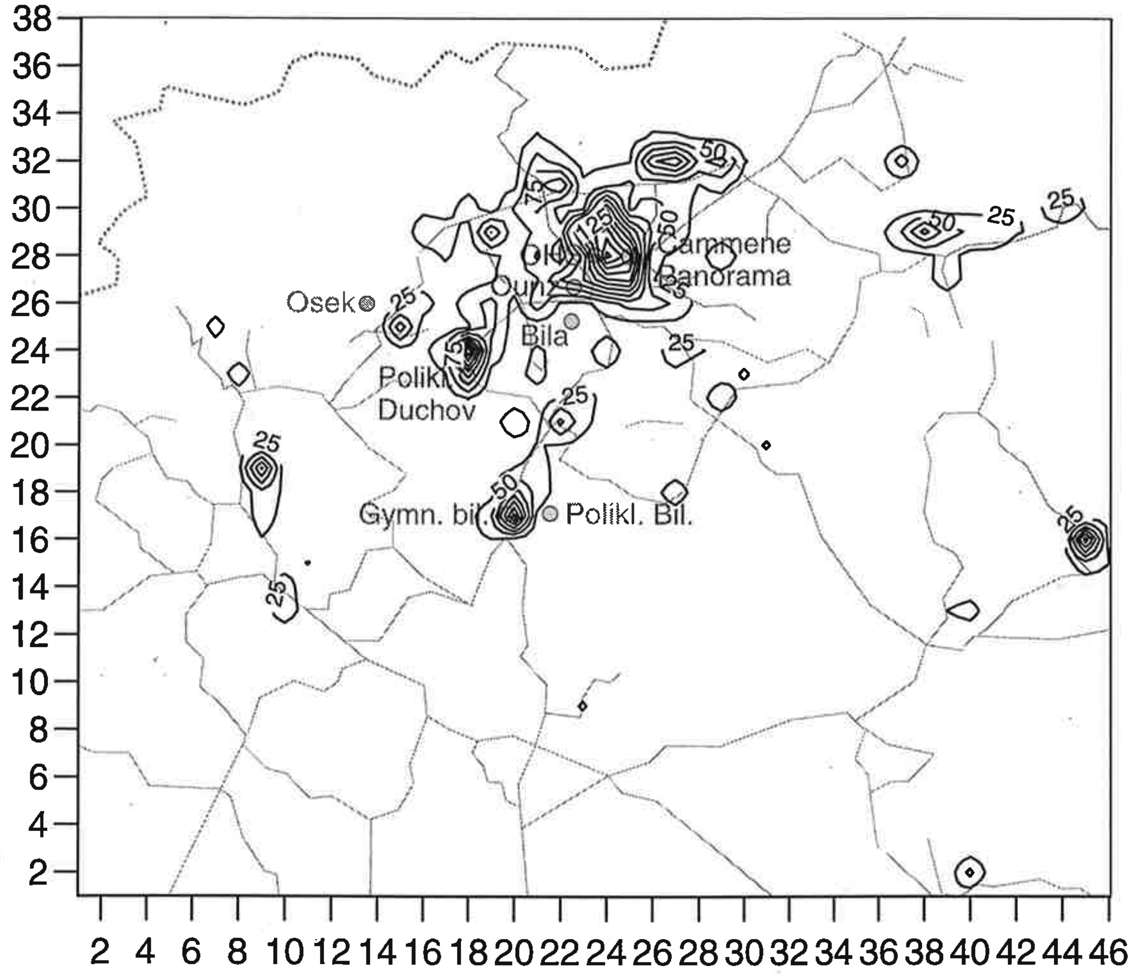


Figure 5: Spatial distribution of long term SO_2-concentrations. Unit: $\mu g\ SO_2/m^3$.

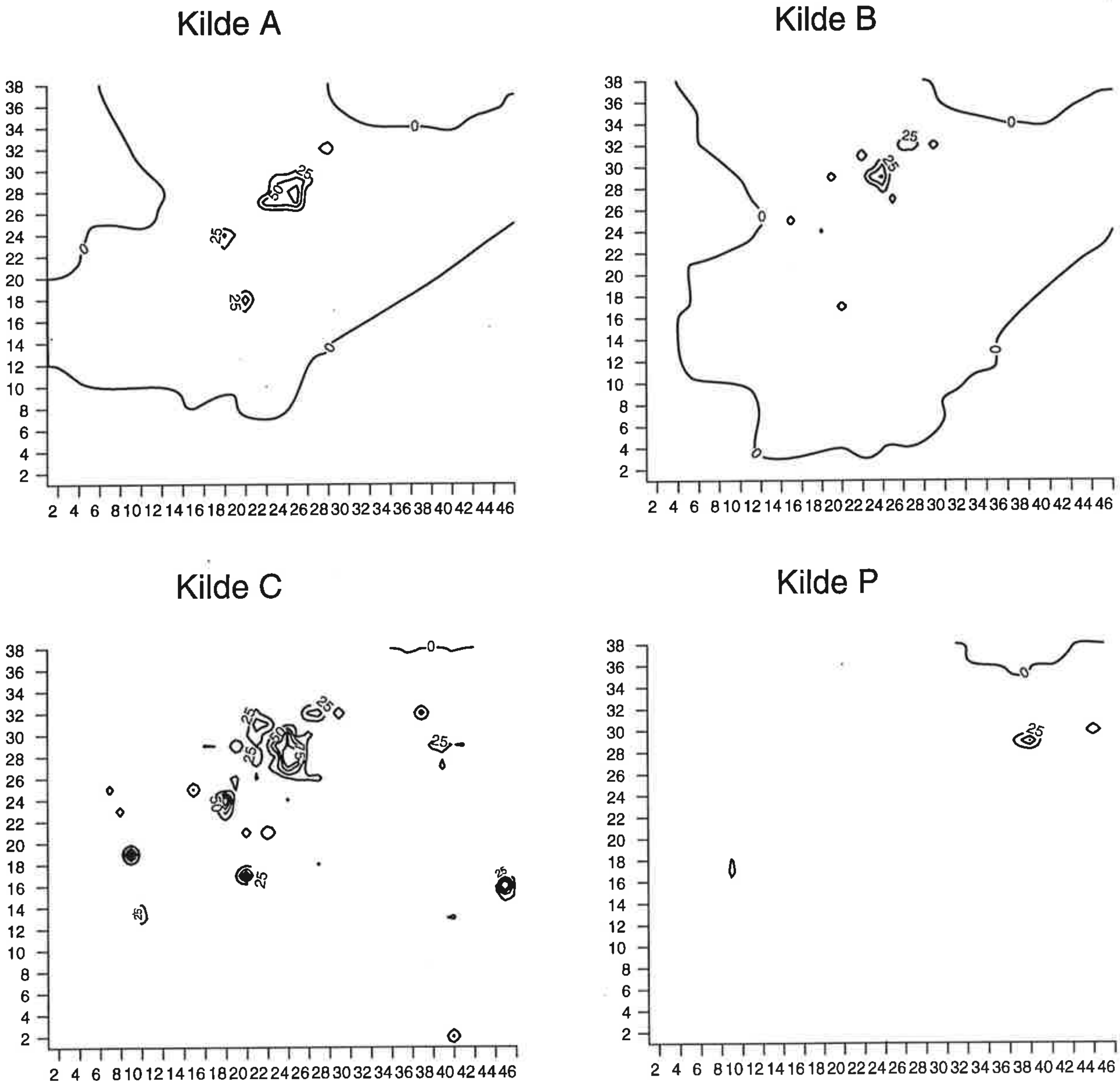


Figure 6: Spatial distribution of the SO_2-contribution from each of the following source groups:
A: Home heating in small sources.
B: Power plants centralized.
C: Home heating from centralized heating systems.
P: Industry - point sources.

Daily variations in observed and calculated concentrations for 6 stations are shown in Figure 7-Figure 12. In Figure 7-Figure 9 the values from three stations in the center of Teplice are shown.

Pollution concentration measurements are representative for areas within each grid square. To account for spatial uncertainty the maximum and the minimum values in the neighbouring grid squares are shown together with the observation at the station.

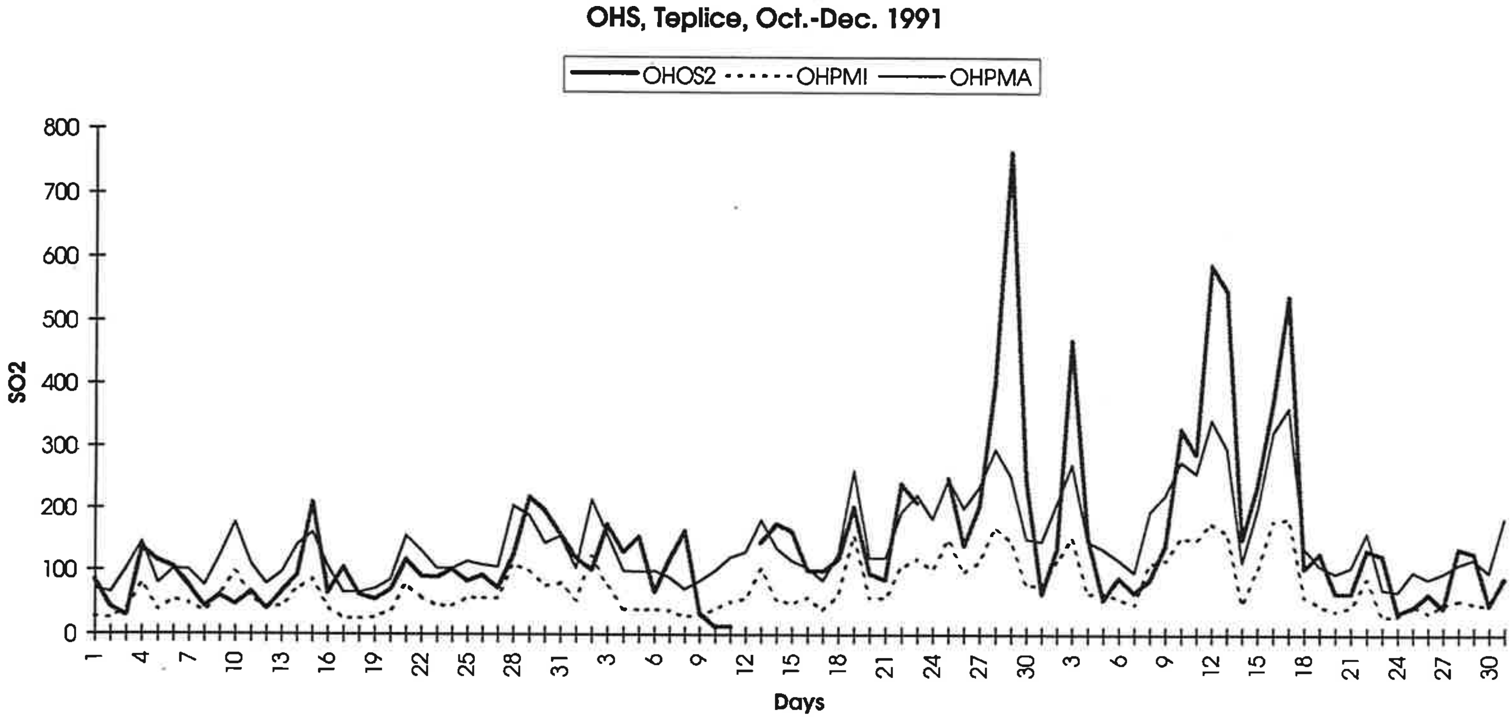


Figure 7: 24 hour mean observed concentrations at the OHS-station, Teplice, (OHOS2). Maximum (OHPMA) and minimum (OHPMI) calculated values in grid squares surrounding the station location are shown by a thin line (——) and a dotted line (,.....) respectively.,

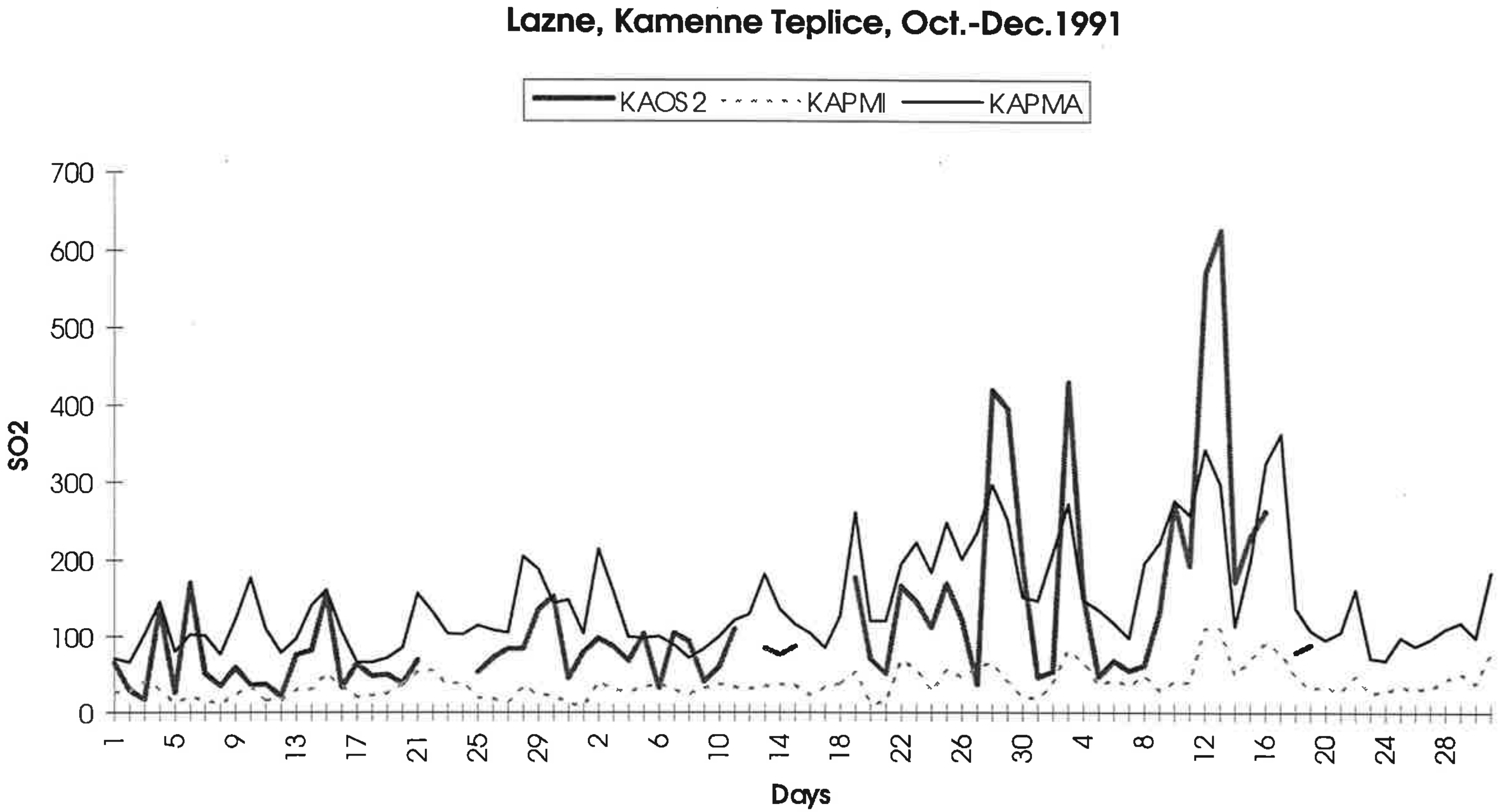


Figure 8: 24 hour mean observed concentrations at Kamenne Lazne, Teplice, (KAOS2). Maximum (KAPMA) and minimum (KAPMI) calculated values in grid squares surrounding the station location are shown by a thin line (——) and a dotted line (,.....) respectively.

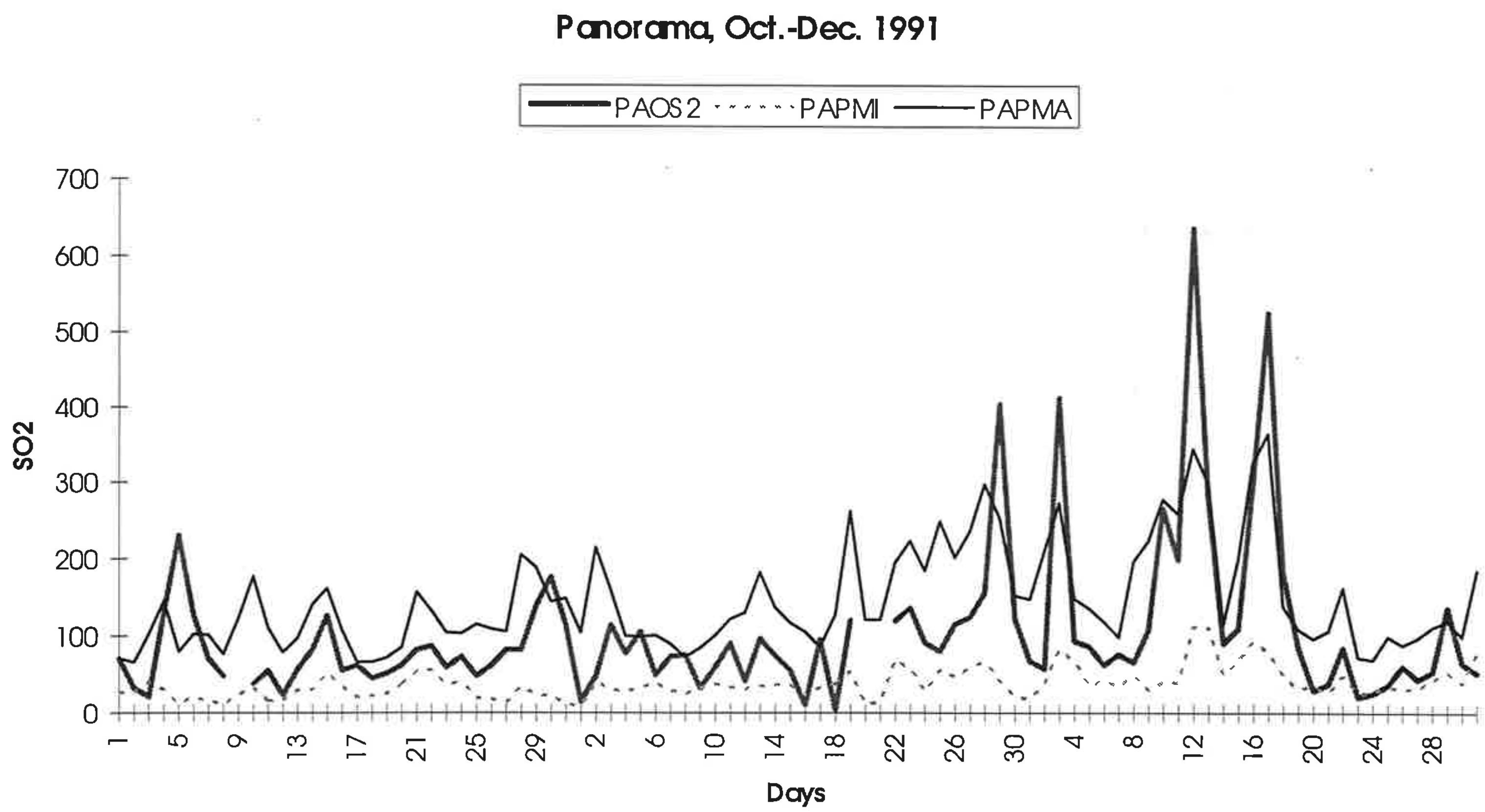


Figure 9:24 hour mean observed concentrations at Panorama Teplice (PAOS2). Maximum (PAPMA) and minimum (PAPMI) calculated values in grid squares surrounding the station location are shown by a thin line (——) and a dotted line (,.....) respectively.

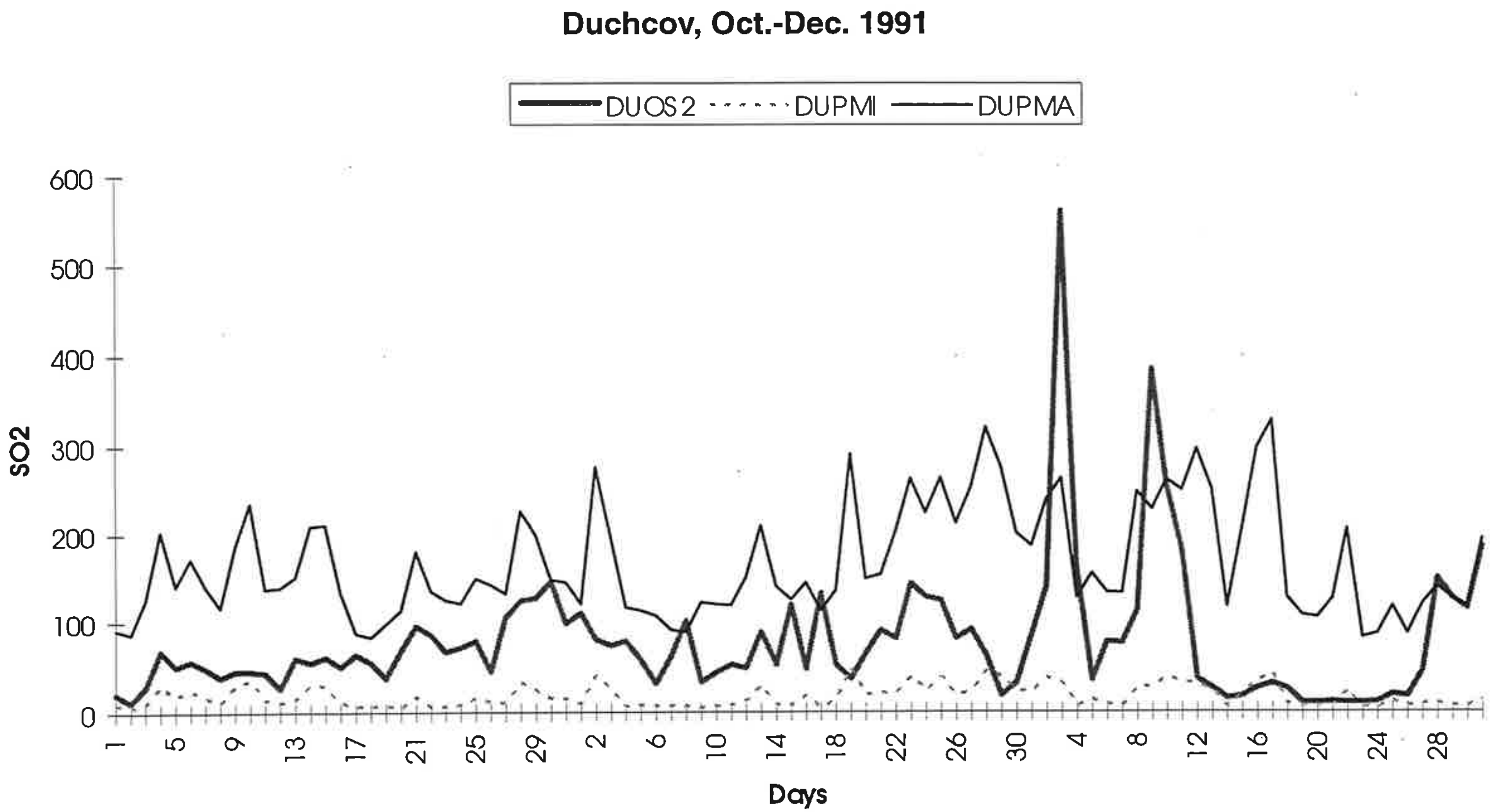


Figure 10: *24 hour mean observed concentrations at Duchcov (DUOP2). Maximum (DUPMA) and minimum (DUPMI) calculated values in grid squares surrounding the station location are shown by a thin line (——) and a dotted line (......) respectively.*

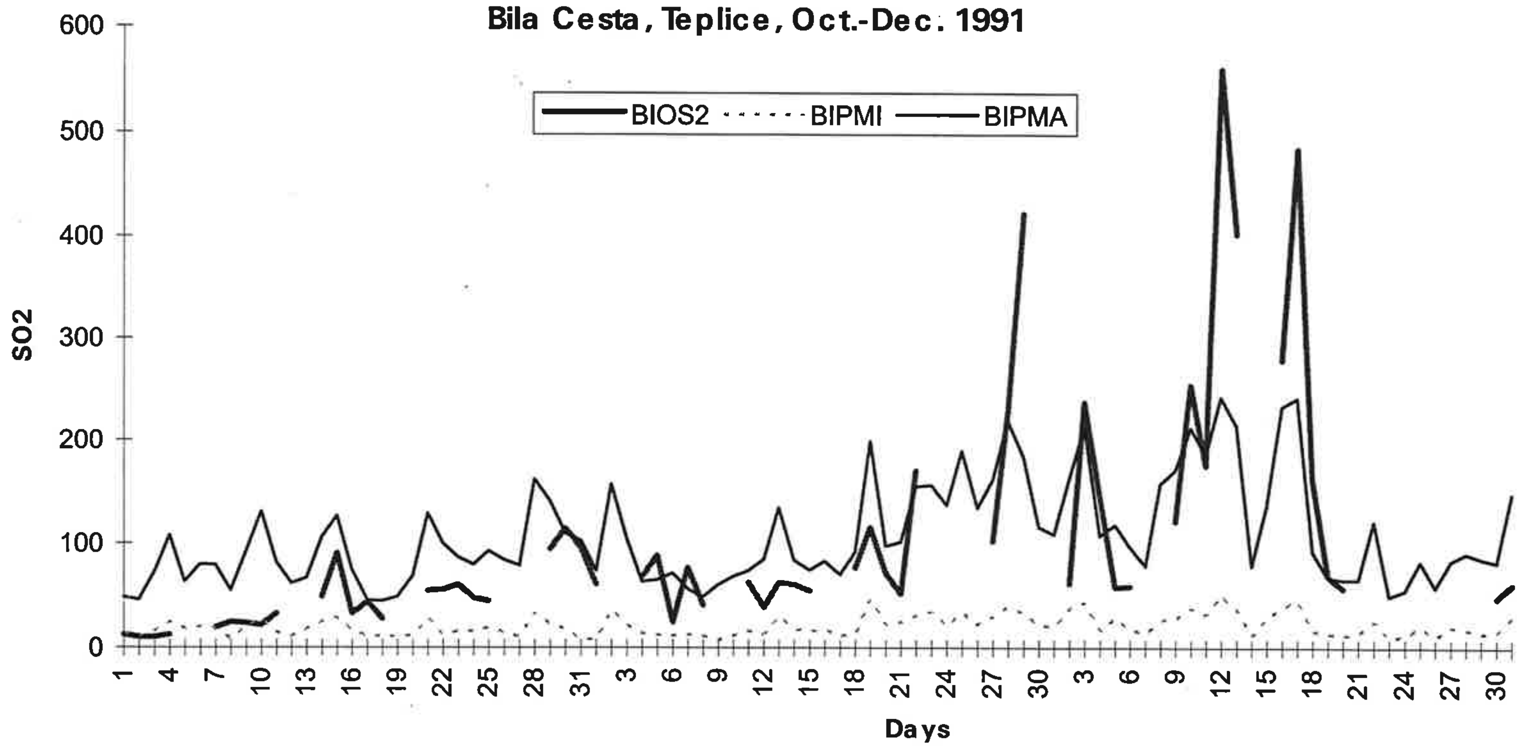


Figure 11: 24 hour mean observed concentrations at Bila Cesta, Teplice (BIOS2). Maximum (BIPMA) and minimum (BIPMI) calculated values in grid squares surrounding the station location are shown by a thin line (——) and a dotted line (......) respectively.

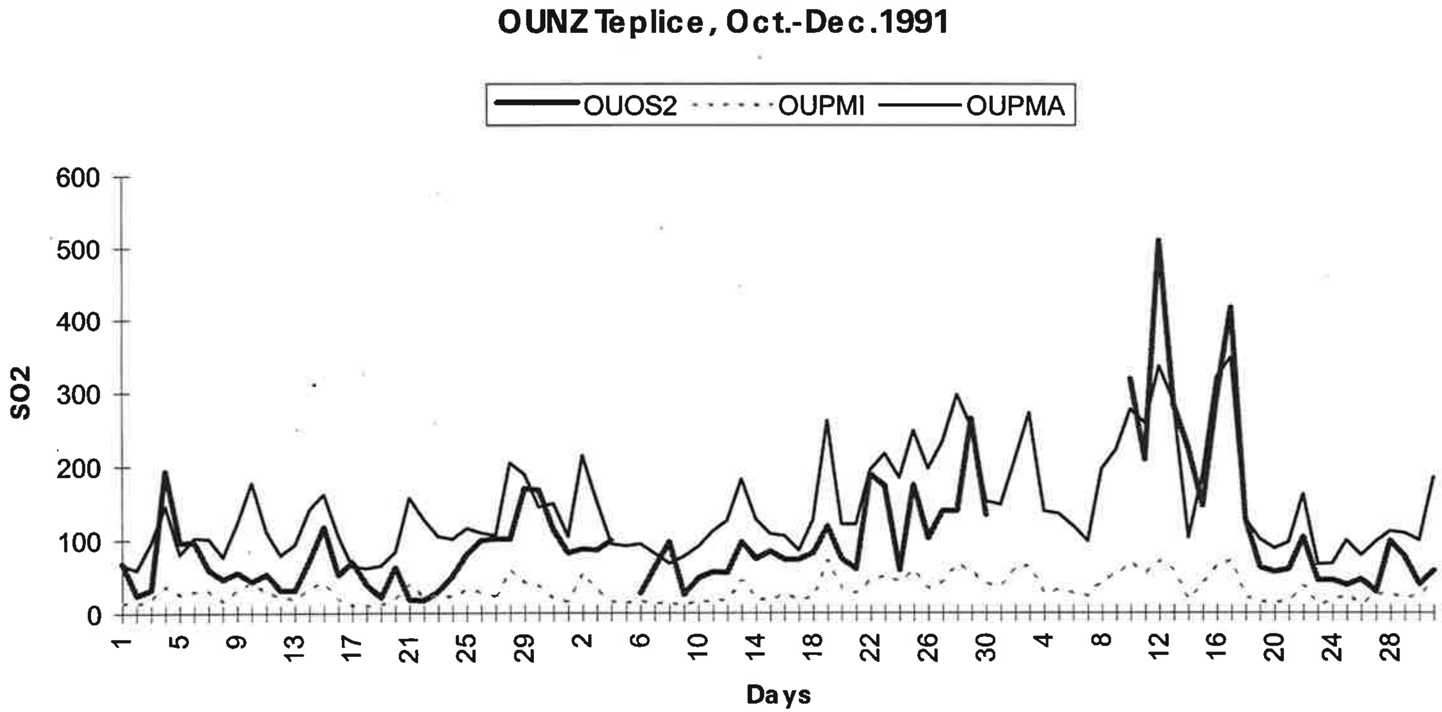


Figure 12: 24 hour mean observed concentrations at OUNZ, Teplice (OUOS2). Maximum (OUPMA) and minimum (OUOMI) calculated values in grid squares surrounding the station location are shown by a thin line (——) and a dotted line ,.....) respectively.

The Figure 7-Figure 12 show that observed values largely fluctuate between maximum and minimum concentrations calculated for the neighbourhood of the station, except in three to four episodes where the calculated values clearly underestimate observed concentrations at the three stations. The same episodes are also observed at the stations Bila Cesta and OUNZ in the south-western part of the urban area of Teplice city.

Two of the episodes are also found at Duchcov. The high episodic concentrations may be explained by accumulation of pollution as a result of fluctuating local wind and dispersion conditions that are not accounted for by the wind model and the meteorological measurements.

4.3 Contribution from sources within the area

The source contributions in the grid are estimated as fluxes determined as specified below:

Influence of **point sources** is described as segmented plumes where the pollution mass within each segment is transferred to the grid system when the segment is comparable to the grid size horisontally or vertically.

Influence of **line sources** is described as a pollution cloud advected along the wind direction. The flux is described by the wind close to the ground and the height of the cloud depending on the distance from the road and the dispersion conditions.

Influence of **area sources** is calculated by the flux of pollution downwind of the area source.

The results of receptor model calculations and of source oriented model calculations indicate that the survey of the use of lignite and other fuel types for home heating and small industries is required. In particular the influence of sources close to the measuring stations should be clarified, and the application of source oriented models should be included in the recommendations for future work. To account for possible interactions between pollution components it is important to characterize the contribution of different source categories throughout the Teplice region.

4.4 Description of episodes

High SO_2-concentration values in the area occur in episodes during meteorological situations characterized by high pressure and large scale subsidence over central Europe. These situations favour development of local circulations in the Teplice region. During the episodes the wind varies with time and with height in the area, leading to accumulation of pollution emissions within the local airshed.

Figure 13 shows recorded wind directions as a function of height and time over Tusimice-power plant during one episode (29.11.1991). At the height of 100 m above ground level, the easterly wind direction dominates except during one hour in the afternoon. At 250 m and close to the ground the wind direction changed to opposite direction 7-8 times during the day. This type of wind regime may also be combined with vertical exchange of pollution as a result of interaction with the topography and inhomogeneous heat exchange close to the ground. Under such conditions the pollution accumulates within the area and high level emissions may be mixed down to ground level.

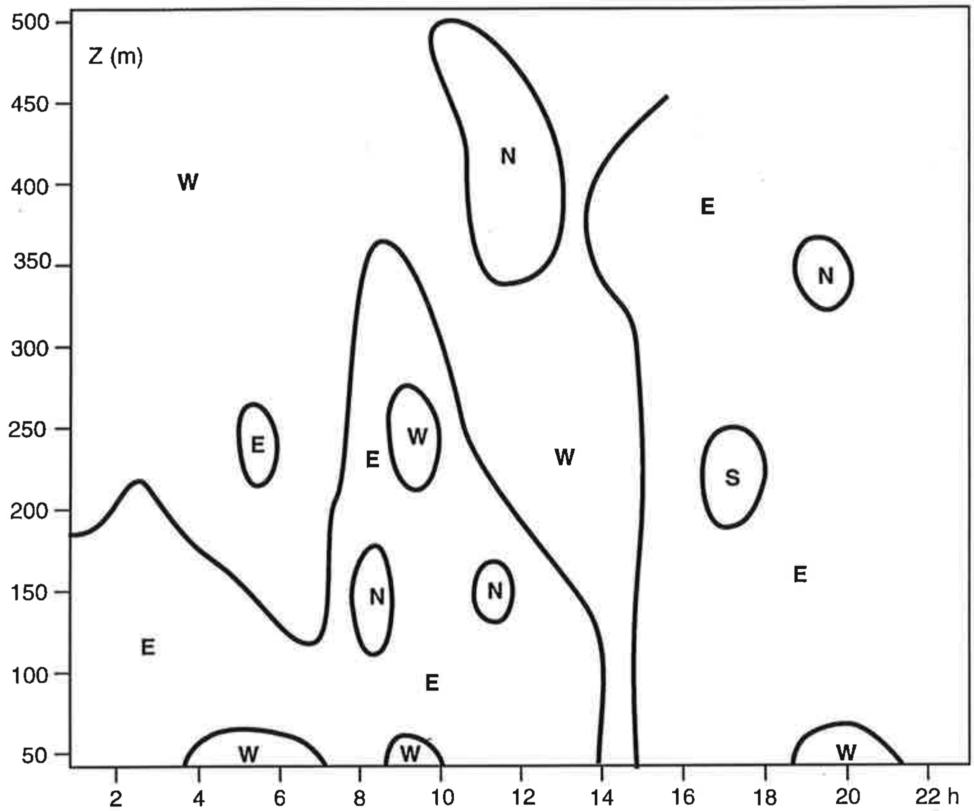


Figure 13: Time variation of wind-direction as a function of height 29.11.1991.
Typical wind speed on an hourly basis is 1 m/s.
E = wind blowing from easterly directions.
W = wind blowing from westerly directions.
N = wind blowing from notherly directions.
S = wind blowing from souterly directions.

The local wind model developed by Svoboda (Svoboda, 1990) should account for these effects. However, the local processes may be very complex as demonstrated the SODAR measurements from Tucemice. Since the area of calculations and the input data is limited, the accumulation of pollution during these episodes is not properly described. The input data to Svoboda's wind model do not account for the processes resulting in hour to hour local fluctuations in the area.

However, Svoboda's model provides a powerful research tool in combination with measurements. In the present application it did not account for all meteorological processes, in particular not during the episodes. More work is needed to apply the results of the wind model properly in the air quality model.

5. Combination of observed and calculated concentration values for exposure estimation

Hourly calculated concentration distributions were ajusted in accordance with measured concentration values at six measuring stations. The ajustments were carried out in three steps.

1. Background concentrations may be added to concentration values from local emissions. Background concentrations are determined by an optimizing proceedure giving weight to measurements far from the local pollution cloud (i.e. upwind stations). Negative values for background concentrations are not accepted.

   The optimizing proceedure have been described and evaluated by Grønskei, Walker and Gram (1993); Grønskei and Walker (1995). The background values in Teplice area were found to be of minor importance the corrections were not performed.

2. Some measuring station have been selected, for the measurements to be representative for wide areas, avoiding influence of local "hot spots". Accordingly "Simple Kriging" was applied for the assimilation of measurements from these stations with the calculated concentration values.

3. The polluted zones close to "hot spots" are taken into account by using a subgrid model.

Available data on pollution concentrations, emissions, wind and dispersion conditions are used to specify modelled concentration distributions, equal to measured values at the measuring stations. These adjusted concentration distributions will be used to estimate exposure based on location of receptor points.

The remaining errors in calculated concentration values may be due to stochastic variations in local emissions and/or in spatial uncertainty in the position of pollution clouds.

The calculated concentration values within a distance of one km from the stations with minimum deviations from the observed values are used for calculation of correlations between observed and calculated values. Table 2 shows that by this proceedure the correspondance between observed and calculated concentration values increases substantially. Since sharp concentration gradients occur in the area, subgrid models may improve the calculated concentrations, when improved data on emissions and local wind conditions are collected.

6. Examples of individual exposure calculations

The model calculations, i.e., the hourly concentrations in each grid cell, were used to estimate individual exposure for participants in the Teplice health studies. Around 8.000 individuals with known home and/or work/school address were given a simplified exposure estimate based on outdoor exposure to SO_2 at their home or home/work address in the period 1.10.-31.12.1991. 50% participants were exposed to the period average below 7 $\mu g/m^3$, with 5% being exposed to period average over 40 $\mu g/m^3$. However, for 5% of participants the maximum hourly exposure was estimated to be over 380 $\mu g/m^3$. This implies that the 10-minutes value of 500 $\mu g/m^3$ (short-term air quality guideline, WHO) might have been exceeded for those participants.

The exposure estimates provided here are examples to illustrate the differences between individuals, that will not be captured by giving them an exposure estimate based on a measuring site results. The method, based on hourly estimates of outdoor air pollutant concentrations, makes it possible to define a flexible short-term exposure estimate, and to define several types of long-term (period) estimates. Such estimates are important when trying to establish relationships between health outcome and air quality.

By a simple extension of the model, an estimate of exposure from the outdoor air to non-reactive air pollutants may be provided, such as to PAH, benzene, or heavy metals. The period of calculation may be extended, however, for this new data are needed that describe meteorology and emissions in the new calculation period.

7. Examples of individual exposure calculations.

The aim of the dispersion modelling, from the point of view of the health studies, is to provide estimates of personal exposure to outdoor air for the participants. The dispersion models describe the gradients in air pollution concentrations in the investigation area, and show their size and location. From these results it may be seen that an appropriate type of personal exposure would provide a more precise classification of individuals participating in the health studies, regarding pollution exposure. This will lead to a more accurate analysis of relations between the health outcomes and air pollution.

In order to calculate personal exposure, information is needed about both time and place of the most frequent locations of the subjects. Further, it is necessary to define the period of interest, and type of exposure that should be calculated. The exposure based on dispersion models offers considerable flexibility, as indicators may be given for peak or medium exposure, for cumulative exposure over a period of time, or for recurrent peak exposures (such as from traffic, or in the vicinity of specified large sources).

We have calculated a simplified exposure estimate based on the data from health projects. Over 8,000 individuals participated in the health studies done prior to 1994. For these individuals, the address of their home and work/school, has been coded into the geographic system devised for the study. Exposure to SO_2 was then calculated for each hour for these participants for the period 1.10.-31.12.1991.

For calculating the exposure, we have assumed that those who also provided a work address were at work between 07:00 and 16:00 hours, while they were at home for the rest of the day. Where only the home address is available, the exposure is calculated for that location for 24 hours a day. The results are given in Table 3, split by studies where only home and both home/work address are available. The table demonstrates that there is a large proportion of individuals exposed only to low values, however, a group of individuals exposed to values above the WHO air quality guidelines can be identified. The table also shows that taking into account both time and place of the exposure, the estimates differ substantially.

To illustrate the method further, Table 4 shows concentration gradients of period average exposure of home addresses for 15 selected adjacent squares (for square identification, see f.ex. Figure 3). The table illustrates large local gradients, and the fact that some of the the high-exposure areas for SO_2 correspond with residence areas. However, an estimate of exposure based on one of the grid squares (e.g., represented by a measuring site), would lead to serious misclassification of exposure of a group of individuals.

Table 3: Summary of the estimated hourly values of home address or home/ work address exposure to SO_2, for the period 1.10.-31.12.1991.

	Per cent of population exposed	Average estimate equal to or below	98-th percentile of estimated hourly. exposure equal to or below	Maximum estimated hourly exposure equal to or below
1. Only home address	5%	4 µg/m3	12 µg/m3	28 µg/m3
available (5718	50%	7 µg/m3	21 µg/m3	43 µg/m3
individuals)	95%	42 µg/m3	132 µg/m3	383 µg/m3
2. Home and work	5%	4 µg/m3	12 µg/m3	28 µg/m3
address available	50%	6 µg/m3	20 µg/m3	43 µg/m3
(2284 individuals)	95%	12 µg/m3	38 µg/m3	81 µg/m3

Table 4: Example of exposure gradient within the Teplice district, together with number of residents in each grid.

Grid	Period average SO_2 (µg/m3) exposure			Number of home addresses in each grid square		
co-ordinates:	16	17	18	16	17	18
19	20	45	-	7	30	0
20	29	138	76	133	151	1
21	16	42	32	15	274	15
22	10	17	17	7	133	8
23	-	12	-	0	1	0

With the current operational model, the exposure may be calculated for chemically non-reactive species such as heavy metals, benzene or PAH, for the period 1.10.-31.12.1991. A model for NO_2 may also be developed, as a NO_x emission database exists. However, this involves accurate description of ozone fields which currently is not available. An indicator of exposure for this period may be a suitable measure of individual load, as this period is likely to cover the most frequent air pollution situations. The period of calculation may be extended, provided that input data are made available and transferred into the format needed to run the exposure calculations.

8. References

Brechler, J. and Bednar, J. (1990) Air-pollution Model. In: *Research Activities in Atmospheric and Oceanic Modelling*. (WMO/ICSU-Report No. 17).

Brechler, J. and Grønskei, K.E. (1994) Atmospheric dispersion modelling. Report for the Teplice Program 2nd Peer Review Workshop. Castle Trest, Czech Republic, October 23-28.

Czechoslovak Academy of Sciences (1988) KAPG-III-1 Structure of the boundary layer over non-homogeneous terrain. Proceedings of the field experiment kopex-86. Kopisty/Tusimice 2 June-7 July 1986. Prague, Institute of Physics of the Atmosphere.

Grønskei, K.E. and Walker, S.-E. (1995) A stochastic receptor model based on source oriented structure function. In: *Air Pollution III. Porto Carras, Greece, 1995. Vol. 1*, pp. 239-247. Southamton, Computational Mechanics Publications.

Grønskei, K.E., Walker, S.-E. and Gram, F. (1993) Evaluation of a model for hourly spatial concentration distributions. *Atmos. Environ., 27B*, 105-120.

Kopriva, E. (1991) Vypocet znecisteni ozdusi v okresech. Teplice a Prachatice. EK-Computing Most 1991.

Kotesovec, F., Sram, R.J. and Jelinek, R. (1992) Program Teplice, 1. Peer review Workshop. Liblice Castle Czech Republic, Sept. 21-25.

Kotesovec, F., Sram, R.J. and Jelinek, R. (1993) Panel review of Teplice Program. Prague, November 25 and 26.

Kotesovec, F., Sram, R.J. and Jelinek, R. (1994) Teplice Program 2nd Peer Review Workshop. Castle Trest, Czech Republic, October 23-28.

Lowles, I., Ap. Simon. H., Juda-Rezler, K., Zwozdziak, J., Brechler, J., Cudlin, P. and Kubiznakova, J. (1996) Emission abatement strategies and the environment (EASE) for the Black Triangle. European Unions Cooperation in Science and Technology with Central and Eastern European Countries. (In print.)

Petersen, W.B. (1980) User's Guide for HIWAY-2; A Highway Air Pollution Model. Research Triangle Park, N.C., US Environmental Protection Agency (EPA-600/8-80-018).

Stevens, R.K. et al. (1994) Czech air quality monitoring and receptor modelling study. Research Triangle Park. NC, US Environmental Protection Agency.

Stevens, R.K., Pinto, J.P., Willis, R.D., Mamane, Y., Novak, J.J. and Benes, I. (1995) Monitoring and modelling methods for developing air pollution control strategies: A case study in the Northwest Czech Republic. Research Triangle Park, NC, US Environmental Protection Agency (EPA/600/A-95/033).

Svoboda, J. (1990) Numerical modelling of the atmospheric boundary layer over a hilly landscape. *Studia geoph. et geod., 34*, 167.

Szulenyiova, A. (1992) Diagnostic wind field in a complex terrain. Contributions of the Geophysical Institute of the Slovak Academy of Sciences. (Series of Meteorology Vol 12), pp. 85-98.

Watts, R., Lewtas, R. Stevens, Hartlage, T., Pinto, J., Williams, R., Hattaway, K., Miskova, I., Benes, I, Kotesovece, F. and Sram, R. (1994) Czech-US EPA Health study: Assessment of personal and ambient mutagenes in the Teplice district of Northern Bohemia. *Intern. J. Environ. Chem., 56*, 271-287.

Zwozdziak, J.W. and Zwozdziak, A.B. (1991) Chemical composition of aerosol and rime ice samples collected at the Summit of Szrenica, Sudeten, Poland. *Wissenscaft und Umwelt, 3-4.*

Appendix A

Input data on emission, wind and dispersion conditions

A1 Data on emission

Data on SO_2 and NO_x-emissions from three groups of sources in 1991 were provided for by the Hygienic Institute in Teplice (Kopriva, 1992). The following three types of sources were considered:

Rezzo 1: Stack emission from large sources (power of boilers >5 MW);
Rezzo 2: Emission from small heating plants and industry (power of boilers (<5 MW);
Rezzo 3: Emissions from home heating.

The survey has been worked out by Emil Kopriva. Supplementary information was provided for all large point sources, including data on emission conditions type of industry production materials, consumption of energy etc. Due to its complex form the data was difficult to use in dispersion calculations. However, the extensive database that are available can be used for different type of analyses accounting for source receptor relationships. Datafiles with geographical co-ordinates (longitude and latitude) of point sources with stack heights lower than/higher than 100 m were also provided.

In order to harmonize the methods for plume rise calculations, empirical formulas for stack diameters were developed.

Home heating in small ovens

Data on the yearly consumption of fuel for home heating in the districts of Teplice, Usti n/L and Most in 1990 have been provided by the Institute for Hygiene. The following fuel types are accounted for

- brown coal;
- black coal;
- natural gas;
- gas (from coal);
- koke.

The consumption and accordingly the emission of pollution are distributed over the districts proportionally to the distribution of population. The total yearly emission from home heating in Teplice district is shown in Table A1.

Table A1: Total yearly emission from home heating in Teplice from different types of fuel.
Unit: ton/year.

	Brown coal	Black coal	Natural gas	Koke	Gas	Total
SO_2	2 156	2.5	-	58	4.2	2 220
NO_x	137	0.3	1.3	6.5	94.7	240
CO	4 117	8.4	0.2	193		4 335

It is assumed that 80% of the consumption for home heating is used during winter (1 October-1 April). The total number of inhabitants in Teplice was 127 872.

Traffic

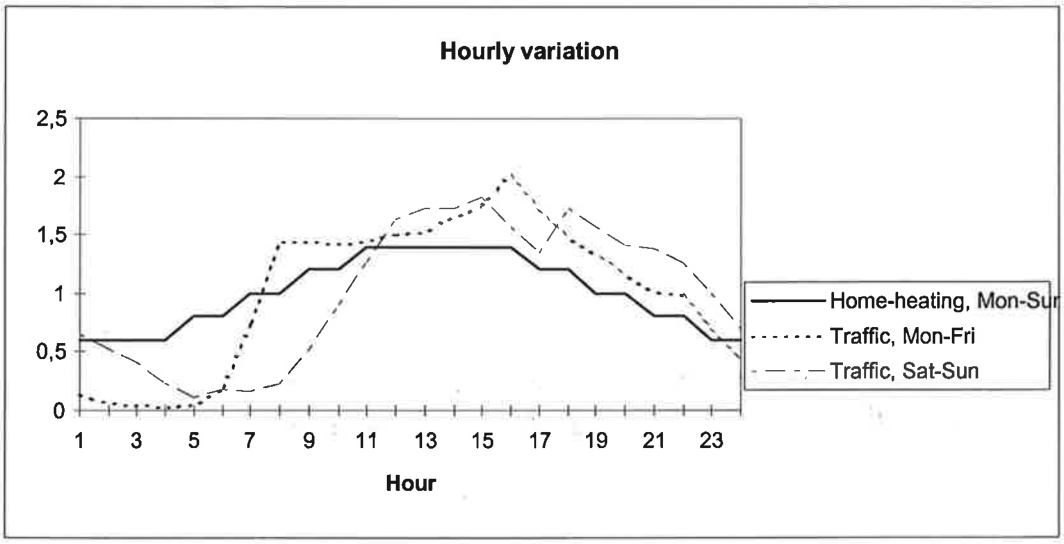
The transport department for the region provided data on average daily traffic intensity on the main roads within the Teplice district. The roads were broken up in segments in each of the grid squares. Based on these input data the emissions from car traffic were calculated within each square km^2. The emission factors are a function of driving speed for different types of vehicles, as shown in Table A2.

Table A2: Emission factors for car traffic in Teplice 1991.

V (km/h)	CO (g/km vehicle)	NO_x (g/km vehicle)	Particles (g/km vehicle)	NM-VOC (g/km vehicle)
Gasoline passenger cars				
50	41.0	3.1	0.040	3.10
80	29.0	3.7	0.040	1.46
Diesel light duty				
50	0.90	1.77	0.045	0.19
80	0.70	1.70	0.045	0.13
Diesel 3.5-16 tonnes				
50	12.0	8.3	1.3	1.5
80	8.0	6.5	1.3	1.8
Diesel >16 tonnes				
50	12.33	16.67	1.3	2.4
80	8.0	15.0	1.3	2.7

Time variation of emission

Calculation of time variation of total emission is based on empirical knowledge on the variation in home heating and in traffic with day of the week and with hour of the day. These variations are shown in Figure A1. In addition to the normal variation in emission with hour of the day and day of the week, home heating varies with temperature. Regarding traffic separate pattern is used for week-day traffic and for weekend-traffic (Saturday and Sunday).



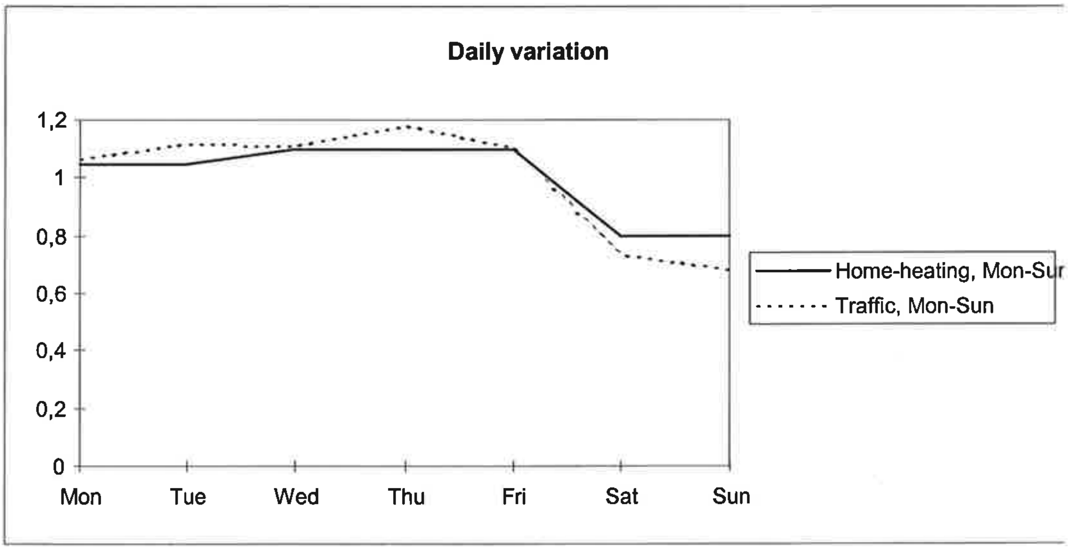


Figure A1: Time variation of emission from home heating and from car traffic.

A2 Description of data on wind and dispersion

In the first calculations, data from the following meteorological stations were used as input:

Tusimice : 50° 13'N, 13° 20'E, 326 m.a.s.l.
Usti nad Labem-Kockov : 50° 41'N, 14° 02'E, 376 m.a.s.l.
Zatec Velemysleves : 50° 23'N, 13° 34'E

Based on hourly wind measurements spatial interpolation/extrapolation by "ordinary kriging" is carried out to provide hourly wind data in grid points. By using this method of interpolation, an average value of the three wind observations is obtained far from the station locations.

Temperature observations from the station Milesovka is used together with the temperature observation from Zatec Velemysleves to specify the stability conditions in the atmosphere. The stability conditions together with the wind speed determine the dispersion conditions in the atmosphere characterized by the standard deviation of wind fluctuations (σ_v and σ_w) and the Lagrangian time scale t_L.

In the elevated layers i.e. 50, 100, 200, 600 m.a.s.l. observed values from the Tucimice Sodar-measurements characterizing the wind and dispersion conditions in the area.

Wind and dispersion conditions based on the local wind model

Wind observations from the radio sonde station at Prague Libus were used to select appropriate wind fields in the area of calculation. An average value of wind in the layer from Earth's surface to the height 3,000 m above the sea level was used to select the scenario which was most similar to the measured averages. The temperature observations were used to determine an average temperature stratification for selection.

The selection from 48 precalculated scenarios was the based on:

Wind direction	:	360, 45, 90, 135, 180, 225, 270, 315 [degree]
Wind speed	:	4, 8, 16 [m/s]
Temperature stratification	:	dT/dZ [100 m]

0.6	0.0	+2.0	for wind speed 4 m/s
0.6	0.0		for wind speed 8 m/s
0.6			for wind speed 16 m/s

The wind fields were given for 5 levels above terrain: 10, 30, 50, 100, 300 m above terrain.

An example of the wind distribution is presented in Figure A.2.

The selected wind scenarios were modified with respect to measured wind velocities in order to minimize errors between observed and calculated wind fields. "Simple kriging" was used for the modification for the observed winds to observed velocities at the wind stations. Far away from the wind observations, the calculated values were used.

Teplice 29.11.91 kl. 18, lag 4

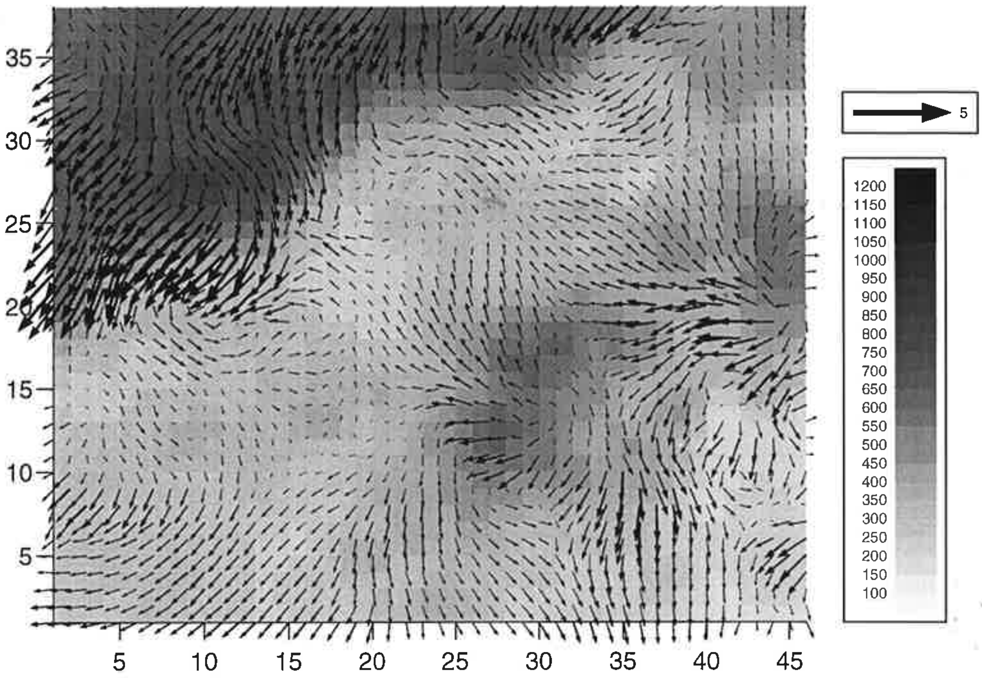


Figure A2: A wind field for the area calculated by the local wind model.

Appendix B

Formulae for subgrid calculation procedures

B1 Point sources

The Gaussian plume equation was used to estimate downwind concentration of pollution emitted from a single source.

Constant average transport speed and a fixed wind direction is used in the subgrid model. Local wind shear in the boundary layer is not considered. In accordance with these assumptions for subgrid concentration calculations, the procedure calculates the downwind concentration distribution as follows:

$$C(x,y,z) = \frac{Q}{2\pi U\sigma_y\sigma_z}\exp\left[-\frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2\right]\left\{\exp\left[-\frac{1}{2}\left(\frac{z-H}{\sigma_z}\right)^2\right]+\exp\left[-\frac{1}{2}\left(\frac{z+H}{\sigma_z}\right)^2\right]\right. \quad \text{(Eq. B.1)}$$

Where:

(x,y,z)	=	location of the receptor point given in rectangular co-ordinates with the origin at ground level at the source location and x-axis parallel to wind direction.
Q	=	continuous source emission rate of the air pollutant
H	=	effective plume height
u	=	mean transport wind speed
σ_y, σ_z	=	standard deviation of the concentration in the horizontal and vertical directions respectively being functions of transport time.

To account for variations in emission intensity and in wind the plume is segmented as shown in Figure B1.

Each individual plume segment is defined by the following set of parameters:

Horisontal position	:	X,Y	(m)
Vertical position	:	H	(m)
Length	:	L	(m)
Direction	:	DD	(°)
Time since release	:	T	(s)
Horizontal dispersion parameter	:	σ_y	(m)
Vertical dispersion parameter	:	σ_z	(m)
Emission rate	:	Q	(g/s)
Mass	:	M	(g)

The horisontal position of the plume is initially at the source.

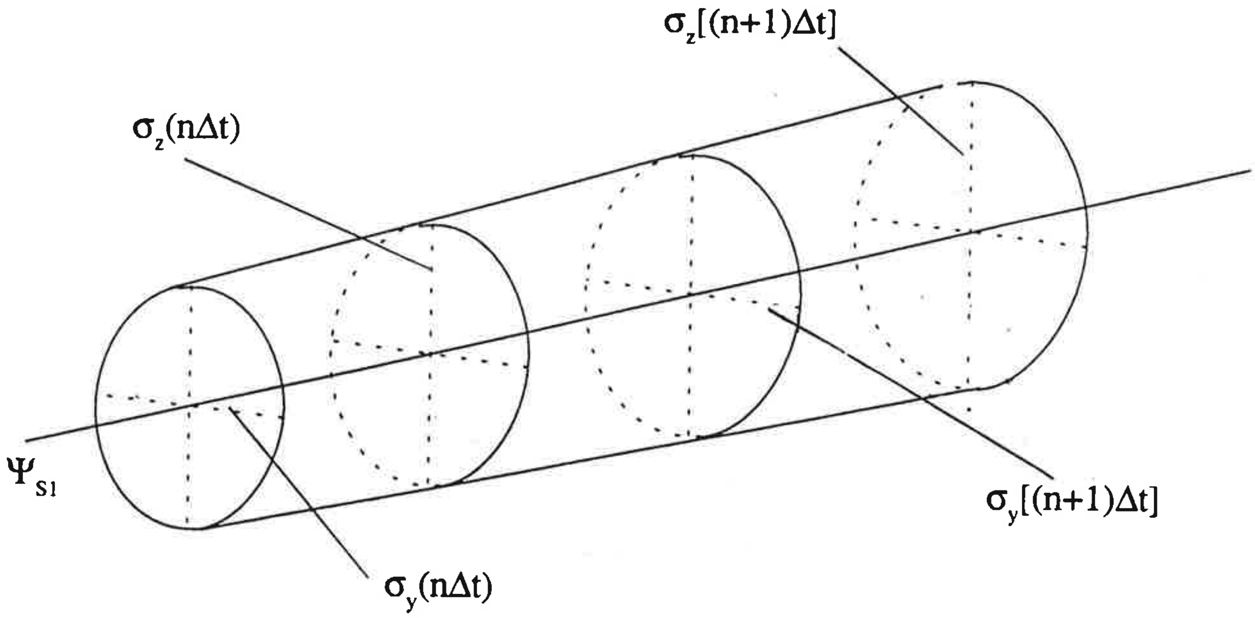


Figure B1: The geometry and position of plume elements along a trajectory (denoted by φ_s).

The vertical position of the plume or plume height is calculated on the basis of temperature and velocity of the emissions.

The length (LL) of the plume segment is initially calculated as:

$$LL = FF*\Delta t$$

where FF is the windspeed at the plume height.

The direction of the plume DD is initially set equal to the wind direction at the source. The time T is the number of second elapsed since time of release.

Emission rate Q is set equal to the source emission. The plume segment mass is calculated as

$$M = Q*\Delta t.$$

The Gaussian dispersion parameters σ_y and σ_z are initially set equal to the source diameter.

B2 Line sources

The line source model calculates concentrations at receptor points downwind from a given line source (road) based on the same type of model as the US EPA Hiway-2 model (Petersen, 1980). This is a steady-state Gaussian model that can be applied to determine ground-level receptor concentrations where there are relatively uncomplicated (smooth) terrain. Each lane of the road is modelled as a finite uniformly emitting line source of pollution.

The air pollution calculated for a downwind receptor point is found by numerical integration along the length of the road:

$$C = \frac{q_l}{u} \int_o^D f dl \qquad \text{(Eq. B2)}$$

where

q_l	=	emission intensity from the line source,	$[g/ms]$
u	=	wind speed,	$[m/s]$
D	=	line source length,	$[m]$
f	=	point source dispersion function (Equations B3-B5),	$[m^{-2}]$.

For application of this model to a road segment in relatively open terrain, an estimate for the wind speed, u, at approximately 2 meters height above ground is suitable.

For stable conditions:

$$f = \frac{1}{2\pi\sigma_y\sigma_z} \exp\left[-\frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2\right]\left\{\exp\left[-\frac{1}{2}\left(\frac{z-H}{\sigma_z}\right)^2\right] + \exp\left[\frac{1}{2}\left(\frac{z+H}{\sigma_z}\right)^2\right]\right\}$$

(Eq. B3)

where:

σ_y	=	standard deviation of the concentration distribution in the crosswind direction, m
σ_z	=	standard deviation of the concentration distribution in the vertical direction, m
z	=	receptor height above ground, m
H	=	effective source height, m.

In unstable or neutral conditions, if σ_z is greater than 1.6 times the mixing height (L), the distribution below the mixing height is uniform with height regardless of source or receptor height, provided both are less than the mixing height:

$$f = \frac{1}{\sqrt{2\pi}\sigma_y L} \exp\left[-\frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2\right] \qquad \text{(Eq. B4)}$$

L : mixing height

In all other unstable or neutral conditions:

$$f = \frac{2}{2\pi\sigma_y\sigma_z}\exp\left[-\frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2\right]\left\{\left[-\frac{1}{2}\left(\frac{z-H}{\sigma_z}\right)^2\right]+\exp\left[-\frac{1}{2}\left(\frac{z+H}{\sigma_z}\right)^2\right]\right.$$

$$+\sum_{N=1}^{N=\infty}\left[\exp\left(--\frac{1}{2}\left(\frac{z-H-2NL}{\sigma_z}\right)^2\right)+\exp\left(-\frac{1}{2}\left(\frac{z+H+2NL}{\sigma_z}\right)^2\right)\right.$$

$$\left.\left.+\exp\left(-\frac{1}{2}\left(\frac{z-H+2NL^2}{\sigma_z}\right)\right)+\exp\left[\left(-\frac{1}{2}\left(\frac{z+H+2NL}{\sigma_z}\right)^2\right)\right]\right]\right\} \quad \text{(Eq. B5)}$$

The infinite series in Equation B5 converges rapidly, and more than four or five sums of the four terms are seldom required. In each of the three equations above, σ_y and σ_z are evaluated for the given stability class and downwind distance. If z, H or both are zero, the resulting simpler forms of Equations B3, B4 and B5 are used by the computer program.

The windspeed is taken from the wind model in the grid square where the line source is situated. The emission height H is set equal to 0. For unstable and neutral conditions the Turner stability class used in the model is set equal to 4 and the mixing height is set equal to 1000 m. For slightly stable and stable conditions the Turner stability class is set equal to 6 and the mixing height (height of limiting lid) is set equal to 30 m. Calculations of dispersion parameters sigma-y and sigma-z as a function of downwind distance from the road is further done using the ordinary Paquill-Gifford-Turner stability classes and formulae for the increase in sigma-y and sigma-z given in Peterson, 1980.

B3 Area sources

Vertical pollution distribution as a result of dispersion from a line source is approximated by a Gaussian distribution.

***Dispersion formulae*:**

$$C = \frac{Q_A\, dx}{\sqrt{2\pi}\, u\,\sigma_z}\left\{\exp\left[-\frac{1}{2}\left(\frac{z+H}{\sigma_z}\right)^2\right]+\exp\left[-\frac{1}{2}\left(\frac{z-H}{\sigma_z}\right)^2\right]\right\} \quad \text{(Eq. B.6)}$$

x	: horizontal co-ordinate perpendicular to the line source	$[\mathrm{m}]$
z	: vertical co-ordinate	$[\mathrm{m}]$
C	: pollution concentration	$[\mathrm{g/m^3}]$
$Q_A dx$	: source intensity of a line source	$[\mathrm{g/m \cdot s}]$
u	: wind velocity perpendicular to the line source	$[\mathrm{m/s}]$
σ_z	: standard deviation in the vertical pollution distribution	$[\mathrm{m}]$
H	: effective emission height	$[\mathrm{m}]$.

Assumptions made in NILUs multiple source models

For area sources it is assumed that part or all of the effluent pollution from small sources circulate within the aerodynamic cavity that forms in the lee of the buildings. In previous calculations, a partial entrainment was assumed in the following way:

$$H = 2\, h_B \qquad \text{(Eq. B.7)}$$

h_B : building height
H : effective emission height.

In many urban areas H varies between 30 m in the centre and 10 m in the surroundings, not accounting for high, narrow buildings. It is further assumed that the influence of the wake causes an initial mixing σ_{zo}:

$$\sigma_{zo} = H / 2.15 \qquad \text{(Eq. B.8)}$$

For emission from ground sources the same initial mixing was assumed.

Equation (B.2) is integrated to consider an area source with constant emission intensity Q_A:

$$C_H = \frac{Q_A}{\sqrt{2\pi}} \int_o^D \frac{1}{u\sigma_z} \left\{ \exp\left[-\frac{1}{2}\left(\frac{z+H}{\sigma_z} \right)^2 \right] + \exp\left[-\frac{1}{2}\left(\frac{z-H}{\sigma_z} \right)^2 \right] \right\} dx \qquad \text{(Eq. B.9)}$$

The pollution concentration close to the ground (C_o) is relevant for exposure calculation.

$$C_o = \sqrt{\frac{2}{\pi}} \frac{Q_A}{u} \cdot F \qquad \text{(Eq. B.10)}$$

$$F = \int_o^D \frac{1}{\sigma_z} \left\{ \exp\left[-\frac{1}{2}\left(\frac{H}{\sigma_z} \right)^2 \right] \right\} dx \qquad \text{(Eq. B.11)}$$

Since the contribution from different area sources is additive, the decay in the concentration at a distance L-D from an area source with diameter D is found:

$$C_D(L) = \sqrt{\frac{1}{2}} \frac{Q_A}{u} \int_{L-D}^{L} \frac{1}{\sigma_z} \cdot \exp\left[-0.5 \cdot \left(\frac{H}{\sigma_z} \right)^2 \right] dx \qquad \text{(Eq. B.12)}$$

The following assumptions used for the calculations in Teplice are considered:

a) Area source along the ground (traffic) in the suburban areas H = 0 m σ_{zo} = 4.6 m.

b) Area sources as a result of home heating in the suburban area H = 10 m σ_{zo} = 4.6 m.

c) Area source along the ground (traffic) in the center of urban areas H = 0 m; σ_{zo} = 14 m.

d) Area source as a result of home heating in the center of urban areas H = 30 m; σ_{zo} = 14 m.

The parameter describing emission height and initial dispersion correspond to the values used in the calculations for Oslo.

Area sources along the ground (car traffic) and above the roof of the houses (home heating) is shown. Two curves are drawn for each source. One curve shows the F-values as the area source extend beyond 2,000 m. The second curve shows the increase and decrease in concentration in an 1,000 m wide area source.

In Figure B2 the F-function is shown for air pollution episodes (inversion situations) and for normal atmospheric conditions.

The figure shows the importance of emission height, and further the relative importance of car traffic emission and of emission from home heating for the concentration along the ground.

The figure further shows that 0.5-1 km from the edge of the area source, the pollution contribution is about the same whether it is car traffic or home heating.

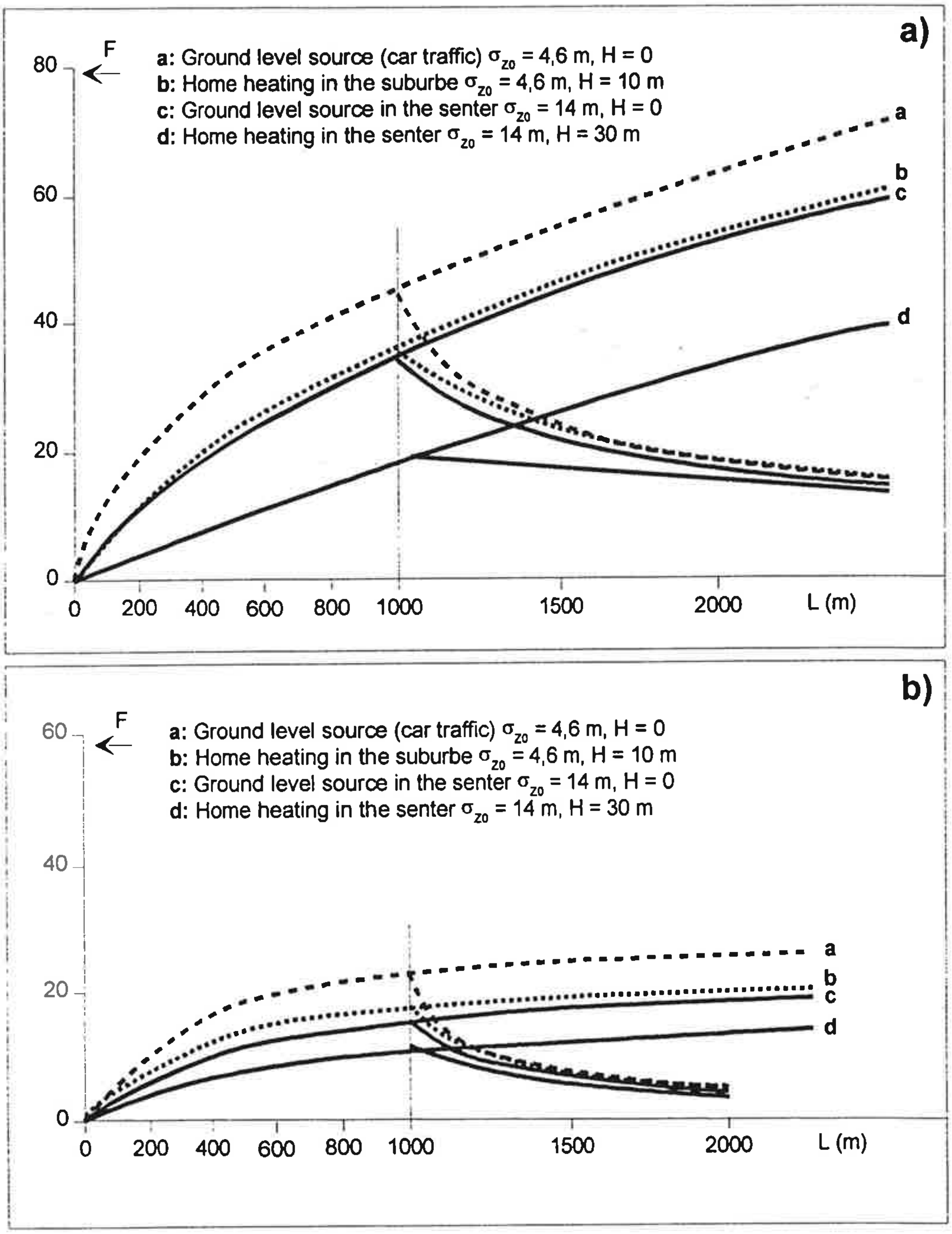


Figure B2: Normalized pollution concentration (F) as a function of the size of the area source (L). The decay in F downwind of a 1 km wide area source is shown in the same figure for each of the area sources.
a) Normalized concentration in pollution episodes.
b) Normalized concentration for normal conditions.

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REPORT SERIES OPPDRAGSRAPPORT	REPORT NO. OR 30/97	ISBN-82-425-0879-8	
DATE 31.10.97	SIGN. Øystein Hov	NO. OF PAGES 53	PRICE NOK 90,-
TITLE Source oriented model for exposure calculations in Teplice area		PROJECT LEADER Knut Erik Grønskei	
		NILU PROJECT NO. O-92064	
AUTHOR(S) Knut Erik Grønskei, Alena Bartonova, Josef Brechler, Sam-Erik Walker, Atle Riise and Steinar Larssen		CLASSIFICATION * A	
		CONTRACT REF.	

REPORT PREPARED FOR:
Norwegian Pollution Control Authority and
Teplice Health Program

ABSTRACT
A method to provide hourly concentration distributions is developed and evaluated. The method is based on data for emissions from five groups of sources, wind and dispersion conditions. Measurements of daily mean SO_2-concentrations are used to evaluate the model. The evaluation shows that the results are reasonable. Observed concentrations are underestimated in pollution episodes characterized by synoptic scale subsidence in the atmosphere and local winds that varies in space and time. Results of a local wind model based on hydrodynamic equation fail to explain these wind and dispersion conditions. When observed and calculated concentration values are combined, receptor model calculations indicate that high level as well as low level emissions accumulate in the air-sheed.

NORWEGIAN TITLE

Kildeorientert modell for konsentrasjonsfordelinger i Teplice området.

KEYWORDS		
Dispersion	Teplice	Modelevaluation

ABSTRACT (in Norwegian)
En metode for å beskrive timevise konsentrasjonsfordelinger i Teplice området er utviklet og evaluert. Målinger av daglige SO_2 konsentrasjoner brukes til å evaluere modellen. Tilfredsstillende evalueringsresultater presenteres. Maksimale avvik mellom observerte og beregnete konsentrasjoner forekommer i forurensningsepisoder som karakteriseres av subsidens på synoptisk skala. Lokale vinder er variable i tid og rom. Når observerte og beregnete konsentrasjonsverdier kombineres indikerer resultatene at utslipp fra både høye og lave utslipp i området akkumuleres i en betydelig del av området i episodene.

** Classification*
A Unclassified (can be ordered from NILU)
B Restricted distribution
C Classified (not to be distributed)