Chapter 4: Urban Field Campaigns

P. Mestayer[1], R. Almbauer[2], O. Tchepel[3]

[1] Equipe Dynamique de l' Atmosphere Habitee, Laboratoire de Mecanique des Fluides, Ecole Centrale de Nantes, F-44321 Nantes Cedex 3, France

[2] Graz University of Technology Institute for Internal Combustion Engines and Thermodynamics, A-8010 Graz, Austria

[3] Department of Environment and Planning, University of Aveiro, P-3810 Aveiro, Portugal

4.1 Introduction

One of the primary aims of the field campaigns within SATURN was to provide measuring data of good quality allowing evaluation of numerical tools. Dispersion models need to be validated in various urban environments and for the whole range of meteorological conditions occurring in the real atmosphere. However, experimental data for model validation are particularly scarce for some specific conditions such as a stable atmosphere with calm or light winds, coastal breeze and mountain-valley circulation, etc. In order to enrich existent set of validation data, experimental campaigns within SATURN have been designed. Related activities contributed also to a significant improvement of our understanding of airflow, dispersion and chemical transformation processes at the local and urban scales.

This chapter summarises the results of field experimental activities planned and executed in the frame of SATURN. The experiments are subdivided into local scale campaigns, urban scale campaigns and urban experimental activities of monitoring character. The attempt is made that for all campaigns the major objectives of measurements are identified, the experimental set-up completely described and the set of data obtained properly presented and discussed.

4.2 Local scale (street scale) campaigns

4.2.1 Runeberg St., Helsinki

The experimental campaign in the street canyon Runeberg St. in Helsinki developed a dispersion dataset gathered during the intensive measuring period and is suitable for the evaluation of street scale models. The street canyon dispersion model OSPM was evaluated against this dataset in co-operation of the Finnish Meteorological Institute (FMI), the Helsinki Metropolitan Area Council (YTV) and the National Environmental Research Institute, Denmark (NERI).

Major scientific issues investigated (Runeberg St., Helsinki)

In climatic conditions of northern Europe a stable atmospheric stratification with light wind speeds may prevail for extensive periods. For instance, it is not uncommon for such conditions to last for several days in the southern part of Finland, particularly in winter and spring (Kukkonen et al. 1999; Karppinen et al. 2001). The main objective of this work was thus to produce good-quality street canyon data, which could be utilised for model evaluation especially in light wind speed conditions.

The street canyon dispersion model OSPM was evaluated against this dataset for the so-called intensive measurements period (Kukkonen et al. 2000 and 2001a). A preliminary discussion of the measurements during the entire experimental period (one year) is presented elsewhere (Wallenius et al., 2001). The data was also used for the evaluation of the combined application of microscale traffic simulation and street canyon dispersion models (Granberg et al. 2000).

Relevance to SATURN aims (Runeberg St., Helsinki)

The measurement campaign provides street canyon data that can be utilised for model evaluation. The dataset can also be utilised for studying the chemical transformation processes of NO_x and O_3.

Experimental set-up (Runeberg St., Helsinki)

In 1997, a measuring campaign was conducted in a street canyon (Runeberg St.) in Helsinki. Hourly mean concentrations of CO, NO_x, NO_2 and O_3 were measured at street and roof levels, the latter in order to determine the urban background concentrations. The relevant hourly meteorological parameters were measured at roof level; these included wind speed and direction, temperature and solar radiation. Hourly street level measurements and on-site electronic traffic counts were conducted throughout the whole of 1997. Roof level measurements were conducted for approximately two months, from 3 March to 30 April 1997, the so-called intensive measurements period. The experimental set-up is illustrated in Fig 4.1.

Main results (Runeberg St., Helsinki)

The OSPM model was used to calculate the street concentrations and the results were compared with the measurements. The overall agreement between measured and predicted concentrations was good for CO and NO_x (fractional bias were -4.2 and +4.5 %, respectively), but the model overpredicted the measured NO_2 concentrations (fractional bias was +22 %).

The agreement between the measured and predicted values was also analysed in terms of its dependence on wind speed and direction; the latter analysis was performed separately for two categories of wind velocity. An example of these analyses is presented in Fig. 4.2a and b, in which the measured and modelled normalised NO_x concentrations are shown, plotted against the wind direction. The background concentrations measured at the roof station have been subtracted from the street level concentrations, and this concentration has been normalised by the actual emission value, (C(street level) – C(roof level))/Q. The data presented are for daytime hours only (from 6 to 23 hours).

The differences between normalised measured and predicted concentrations can be attributed to the uncertainties in the concentration measurements, to the uncertainties in the estimations of the emissions and to the inaccuracies of the dispersion model.

Fig. 4.2 shows a clear dependence of both measured and predicted concentrations on the wind direction. This dependence is much more pronounced for higher wind speeds ($u > 2$ m s^{-1}) than for lower wind speeds ($u \leq 2$ m s^{-1}). When the measuring point is on the windward side, concentrations are substantially lower, compared with the corresponding results for the leeward side.

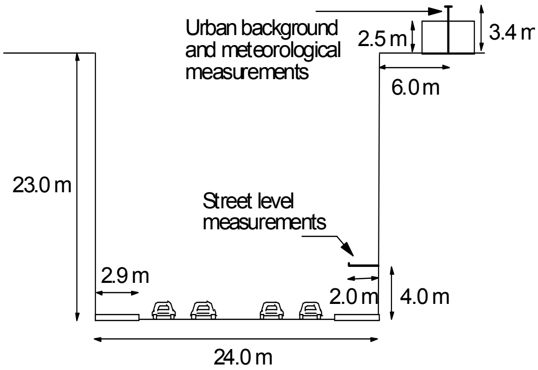


Fig. 4.1. Vertical cross-section of the Runeberg street canyon in Helsinki showing the locations of the measurement points at street and roof levels

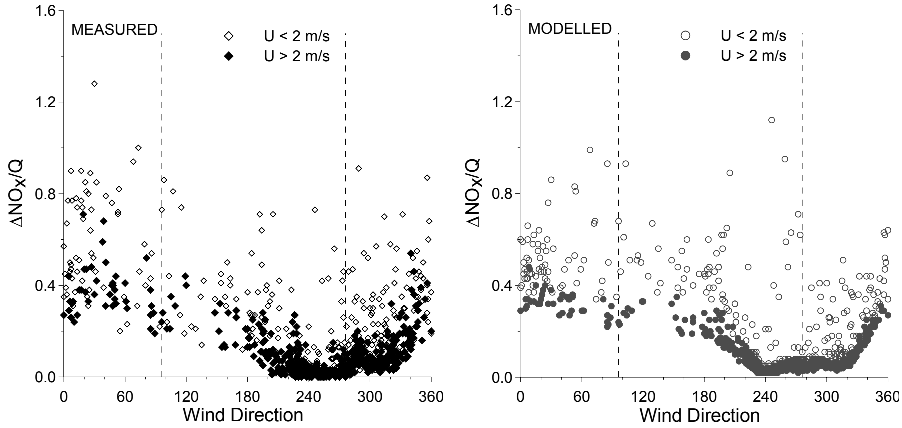


Fig. 4.2. Influence of the wind direction on the measured normalised hourly NO_x concentrations, (C(street level) – C(roof level))/Q, where Q is the emission strength, and corresponding predicted normalised NO_x concentrations. The dotted vertical lines indicate wind direction perpendicular to the street

Although measurements are only available from one side of the street, the clear difference between the leeward and windward sectors provides strong evidence for the formation in the street of a vortex in conditions of higher wind speeds. The flow structure in the street definitely might be more complex than the simple assumption of a single vortex made in the OSPM model, but the experimental data presented here does not provide any clear evidence against this simplification.

In the case of low wind speeds, there is no clear dependence of concentrations on wind direction, according to both measured and predicted results. Evidently, the formation of a stable vortex is much less likely at lower wind speeds, and this results in a more homogeneous distribution of pollution across the street canyon.

The database, which contains all measured and predicted data, is available for further testing of other street canyon dispersion models. The dataset clearly contains a larger fraction of low wind speed cases, compared with datasets from previous street canyon measurement campaigns conducted, for instance, in Denmark. A limitation of this measurement campaign is that no flow or turbulence measurements within the street canyon are available. The concentration measurements also do not contain particulate matter.

4.2.2 Elimäki, Finland

The experimental campaign in a roadside environment in Elimäki in Southern Finland developed a dispersion dataset suitable for the evaluation of street scale dispersion models. Graz University of Technology, Austria, and Finnish Meteorological Institute (FMI) have evaluated a Gaussian finite line source dispersion model (CAR-FMI) and a Lagrangian dispersion model (GRAL) against this data set (Öttl et al. 2001).

Major scientific issues investigated (Elimäki, Finland)

The experimental campaign was designed specifically for model evaluation purposes. In this campaign, the dispersion of NO, NO_2 and O_3 was investigated on both sides of a road depending on traffic densities and relevant meteorological parameters (Kukkonen et al. 2001b).

Relevance to SATURN aims (Elimäki, Finland)

The measuring campaign provides roadside data that can be utilised for model evaluation. The dataset can also be utilised for studying the chemical transformation processes of NO_x and O_3. The dataset is properly documented and it is available for evaluation of other roadside dispersion models.

Experimental set-up (Elimäki, Finland)

The experimental set-up is illustrated in Fig. 4.3.

Main results (Elimäki, Finland)

The agreement of measurements and CAR-FMI model predictions was good, taking into consideration various statistical parameters. For all data (N = 587), the index of agreement (IA) was 0.83, 0.82 and 0.89 for the measurements of NO_x, NO_2 and O_3, respectively.

The difference between model predictions and measured data in terms of meteorological parameters was also investigated by Kukkonen et al (2001b). At wind speeds lower than approximately 2 m s^{-1}, there are excessively high predicted concentrations, compared with the measured data. Model performance deteriorates for situations with the lowest wind speeds.

The model overprediction at low wind speeds could be caused by the assumption of steady-state, homogeneous wind flow made in Gaussian line source models. The variation in wind direction tends to increase with decreasing wind speed, causing increased plume meandering. Substantial meandering can cause measured concentrations to be much lower, compared with those computed assuming a homogeneous wind flow (e.g., Benson 1992).

Öttl et al. (2001) extended the above mentioned evaluation, by comparing the performance of the Lagrangian dispersion model GRAL against the Elimäki dataset; this yielded information on the validity of two types of dispersion models. The agreement of measured and predicted datasets was good for both models considered, according to various statistical parameters used. For instance, considering all NO_x data, the index of agreement values varied from 0.76 to 0.87 and from 0.81 to 1.00 for the CAR-FMI and the Lagrangian models, respectively.

The above mentioned Lagrangian model provides special treatment to account for enhanced horizontal dispersion in low wind speed conditions; while such adjustments have not been included in the CAR-FMI model. This type of Lagrangian model therefore predicts lower concentrations in conditions of low wind speeds and stable stratification, in comparison with a standard Lagrangian model.

Öttl et al. (2001) also analysed the difference between the model predictions and measured data in terms of the wind speed and direction. Fig. 4.4 shows data gathered in one specific wind direction quadrant, extending from a wind direction perpendicular to the road (air flow from a direction of 120°) to a wind direction parallel with the road (air flow from a direction of 210°, cf. Fig. 4.3). For simplicity, wind direction has been normalised, with a direction of 0° corresponding to the direction parallel to the road and 90° to that perpendicular to the road.

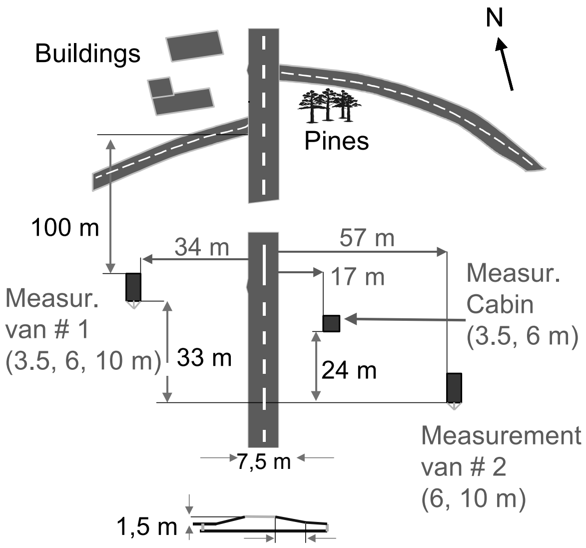


Fig. 4.3. Scheme of the measuring units and their environment in the roadside campaign at Elimäki, Finland. The measuring heights have also been indicated in parentheses

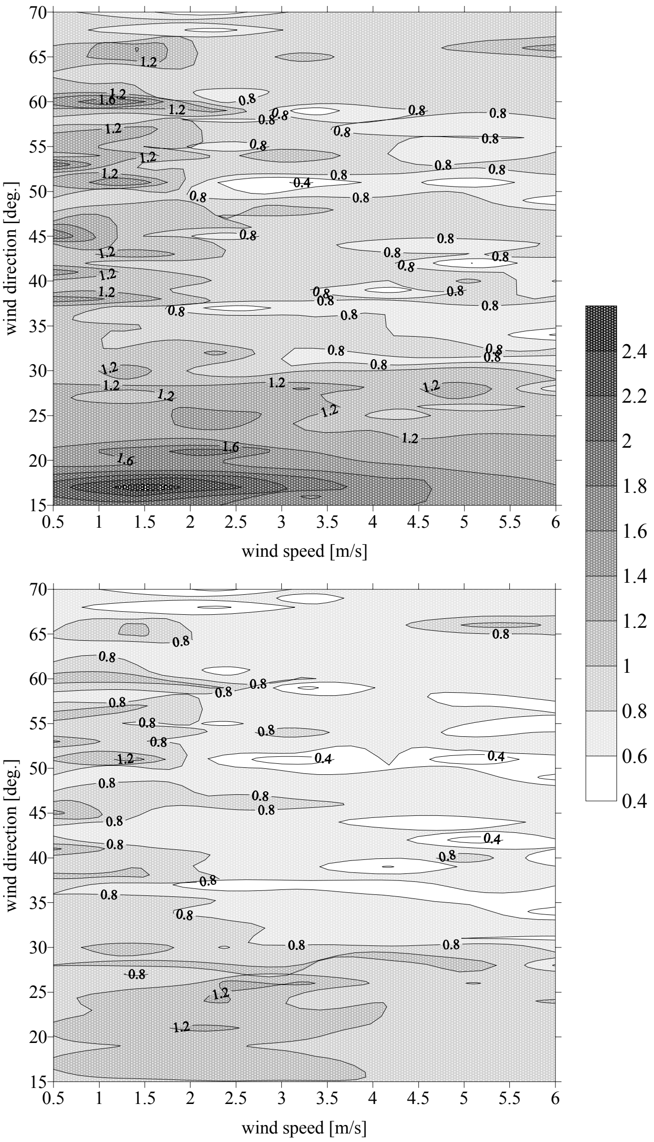


Fig. 4.4. The dependency of the ratio of predicted and observed concentrations on wind speed and direction for the CAR-FMI (top) and GRAL (bottom) models for the measurement site at Elimäki, at 34 m from the road. Data from all measurement heights were used.

Both models underestimate concentrations in the regime of higher wind speeds and non-parallel wind directions; this underprediction is more pronounced for the GRAL model. The CAR-FMI model overestimates concentrations in low wind speed conditions, regardless of the wind direction, and in near-to-parallel wind conditions. This overprediction cannot therefore be entirely caused by the assumption of steady-state, homogeneous wind flow (for a perpendicular-to-road wind, this has only a minor influence). Both of these trends accumulate to produce relatively high inaccuracies in a regime with a lower wind speed and a nearly parallel wind direction. The performance of GRAL varies less in terms of the wind speed and direction; the model better simulates cases with low wind speed and wind direction nearly parallel to the road, as compared with the CAR-FMI model.

4.2.3 Nantes ’99

The Nantes ’99 experimental campaign took place in Nantes, France, with the aim to investigate the mechanisms of air pollution dispersion in a typical street canyon. The experiment provided a unique detailed database to street scale modellers for assessing their models.

The project was funded by the French Ministry of Environment within the inter-organism programme for air quality PRIMEQUAL-PREDIT. The experiment was driven as a cooperation between the Laboratory of Fluid Mechanics (CNRS - Ecole Centrale de Nantes), the Service Aerodynamics & Climatic Environment (CSTB), the CERMA Laboratory (CNRS - Ecole d’Architecture de Nantes), the regional air quality survey network Air Pays de la Loire, and the Service of Urban Environment of the city of Nantes. In addition two British scientists (Richard Griffiths, UMIST and Chris Jones, DERA Porton Down) measured very short distance tracer dispersion and transfer times.

Major scientific issues investigated (Nantes ’99)

The experimental campaign Nantes ’99 was conceived as a first stage of the project URBCAP whose main aim was to determine the chemical and physical processes taking place within an urban canopy and affecting the local air pollution. Nantes’99 had four main objectives, namely the study of the wind field in the street, the determination of the production of turbulent kinetic energy induced by the motion of vehicles, the quantification of the influence of the distribution of street surface temperatures on the structure of the flow and consequently on the pollutant dispersion within the street, and the validation of several models developed by the teams participating in the campaign.

Relevance to SATURN aims (Nantes ’99)

One of the primary aims of the experiment was explicitly to provide data allowing to evaluate numerical simulations codes used for studying the dynamic and thermodynamic structure of the urban canopy layer, and to validate novel (sub-) models. More specifically, three models were tested: SOLENE for the radiation-heat transfer and energy budget at the street surfaces (walls and ground), CHENSI and PHOENICS for the flow and turbulent diffusion field and for the transport-diffusion of pollutant tracers. The experiment aimed especially at investigating the level of turbulence generated by the traffic motion within the street. In addition, the intention of the experiment was to provide a reference data base for the further validation of street scale air quality models.

Experimental set-up (Nantes '99)

The Nantes '99 experiment took place in June-July '99 in the centre of the city of Nantes (France). The "rue de Strasbourg" is a street canyon with approximately North-South orientation (332° from North). It is a high traffic one-way street, with three lanes, and a great homogeneity in buildings construction. The width of the street is 15 m and the mean height of the buildings is 22 m (H/W = 1.4). The street is 800 m long and the experimental section is located midway between two crossroads which are 60 m apart.

The wind field and the vehicle induced turbulence were measured with sonic, 3D propeller and hot wire anemometers at three levels on each side of the street. Air temperature and the temperature of the walls were measured using thermocouples at the same levels as the anemometers. Carbon monoxide (CO) was chosen as the pollutant emissions tracer and it was also measured at three levels. Reference wind, CO concentration and temperature were measured on a small mast at 7 m over the roof. Radiation budget components (global, diffuse, and Infra-Red) were continuously measured over the roof. They were also measured at pedestrian level during one day, at several locations (on the sunny side, in the shadow). Traffic was measured by vehicle counters at eight different places within the street and within the lateral streets. Finally, the wind was measured at a height of 3 m, alternately in each of the transverse streets, with a light 3D bivane propeller anemometer.

During the experiment, a mobile laboratory was stationed 250 m South from the measurement section, measuring CO, NO_x, SO_2, dust and O_3 at 3.5 m from the ground, temperature and relative humidity at 5 m, and wind speed and direction at 10 m. CO and NO_x were also measured by a permanent station of the air quality monitoring network 150 m North of the study section at 4 m from the ground.

At several occasions clusters of non-buoyant Helium-filled balloons were released at pedestrian level: their times of residence were measured and their trajectories were recorded with a video camera.

The experiment emphasis being on the low wind conditions that are the most favourable for pollutant accumulation, the Intense Observation Periods (IOP) were defined as the days when wind speed was less than 3 m s^{-1} at the reference level (30 m above the ground), with intense solar radiation, and dense traffic. These conditions were chosen in order to correspond to high pollution episodes and the most effective thermal situations. During these IOP's, all the sensors were kept operational, otherwise, the sensors of the lowest levels were removed.

The Nantes ’99 experiment was complemented by a smaller experiment in September 2000, at the same site, mainly to document the momentum and heat transfer to the building walls with arrays of thermocouples and hot wire anemometers.

Main results (Nantes ’99)

A data base comprising the measurements taken during the experiment Nantes’99 was constructed with Microsoft® Access. It includes only the IOP's. Two parts were defined within this data base: one data set called “Nantes’99” and another one called “Trafic’99” (Vachon et al. 1999, 2000a, b).

Each table of the “Nantes’99” data set corresponds to one full day of measurements (0:00 to 24:00 local time) with a time step of 15 minutes. It contains the measurements of wind direction, wind speed, fluctuations of the three wind components, temperature, and CO concentration at the different levels within the street, the measurements of pollution at the surrounding stations and the radiation components. The data base also includes wind measurements within the lateral streets with a bi-vane 3D propeller anemometer. In addition, the meteorological data obtained with the mobile laboratory are also included.

Each table of “Trafic’99” corresponds to a full day of measurements with a time step of 15 minutes for each traffic sensor. The flux of vehicles per lane, the total flux of vehicles and, according to the type of the counter, the mean velocity of the vehicles or the number of light and heavy-duty vehicles are included in the tables.

The data base is openly available on request for model validation, on one CD.

A detailed numerical model of the quarter buildings has been generated for the morphological analysis, for the numerical simulations and to build a physical model at the 1/20 scale. This model was thoroughly studied in the atmospheric wind tunnel of the University of Karlsruhe, for simulating the flow above and within the street and its neighbourhoods and it was equipped with mobile devices to simulate the generation of turbulence by the traffic.

The nine internal reports prepared contain among other the results on the local street-scale meteorology comparison to the regional meteorological survey, the evaluation of pollutant transfer times within the street from tracer balloon trajectories, a survey of alternate wind speed measurements obtained in the lateral streets around the experimental section, and the analysis of the flow simulations in the Karlsruhe wind tunnel.

Most of the major results obtained to date concern the validation of numerical models or sub-models. Interesting conclusions could be drawn from the comparison of the radiation and temperature measurements to the simulations with the model SOLENE. In particular, the surface temperature time evolution was found to be correctly modelled in conditions of radiation trapping, while it is being underestimated at sunshine periods due to a high sensitivity of the model to the surface albedo and to the convective heat transfer coefficient (Vachon 2001). Regarding the flow within the street in the presence of an important differential wall heating, it appeared that the thermal turbulent boundary layer at the wall is much thinner than expected, leading to an overestimation of the heat transfer at the wall by the numerical model (Louka et al. 2002). On the other hand, the investigation of the generation of turbulence by the traffic motion showed its influence on the pollutant dispersion and demonstrated its importance during low wind conditions, while novel modules were drafted and included in the model CHENSI and in the operational street canyon model OSPM (Vachon et al. 2002; Berkowicz et al. 2002). Finally, it could be quantified to what extent thermal conditions and traffic induced turbulence affect the distribution of pollutant concentrations within the street as a function of time and meteorology, while it was demonstrated that it is important to properly position sensors for monitoring hotspot pollutant concentrations (Vachon 2001; Vachon et al. 2000a; Berkowicz et al. 2001).

4.2.4 Klagenfurt

Field measurements were undertaken in Klagenfurt in order to investigate pollution dispersion near tunnel portals. These measurements covered gaseous pollutants and meteorology over four months and a couple of tracer gas tests over a period of two days. The field experiments were supposed to provide data for model development and application.

Major scientific issues investigated (Klagenfurt)

Road tunnels and covered roadways are becoming more and more part of a functioning urban road network. Policy is now to separate between traffic calming zones and a highly effective main street network. This leads to a shift of the pollution due to exhaust gases towards the two portal regions. For a big part of the whole region the air quality will be improved, but for those two areas, it will definitely become worse. In order to estimate the pollution concentration at the portal locations during the planning phase it is necessary to use appropriate dispersion models. Simple operational dispersion models are not designed to treat complex situations like junctions and tunnel portals. On the other hand complex models, which are capable to consider all the necessary details (buoyancy effects, exit velocity, building structures), can be operated only for single situations. They are not able to calculate concentration statistics, e.g., annual means, percentiles. A gap still exists between simple – but operational - street models, and complex CFD models, which cannot be used in an operational way.

Field experiments were undertaken in order to investigate the special dispersion conditions in the vicinity of tunnel portals, and to develop and validate a new model for operational use. The field campaign included seven SF_6 tracer experiments over a time span of half an hour at a highway portal in flat terrain. During the SF_6 tests anticyclonic conditions prevailed. This allowed local wind systems to be developed. For most of the tests a large fraction of the wind speeds, recorded with the sonic anemometer, were below 0.8 m s^{-1}.

Relevance to SATURN aims (Klagenfurt)

The main aim of the experiment was to provide a dataset for the evaluation of dispersion models for tunnel portals. The dispersion patterns show the distinct features of the jet and its interaction with the ambient air flow. The dataset was used in order to test different model types, which included simple empirical models up to numerical models. Finally an operational dispersion model was developed on the basis of a Lagrangian particle concept. The whole study led to a better understanding of urban air pollution in the vicinity of tunnel portals. Reliable source-receptor relationships can be established now near these vast emission sources.

Experimental set-up (Klagenfurt)

Meteorological data: Meteorological measurements were performed for monitoring the dispersion situations. As the region of the test site is well known for the frequent calm wind situations, the usage of sonic anemometers was imperative, as otherwise no reliable meteorological information would have been obtained. In addition to the sonic anemometers a standard cup anemometer was mounted on a 10m mast. The location of the meteorological equipment can be found in Fig. 4.5.

Tracer gas experiments were undertaken for investigating the behaviour of the tunnel air exhaust jet stream. SF_6 was used as tracer gas in order to obtain the parameters for short term exposure. 27 bag samplers were posted for getting a clear picture of the exhaust jet of the tunnel portal. While one grab sampler per bore was installed inside the tunnel, the remaining 25 were positioned depending on the meteorological conditions. The analysis of the SF_6 samples was made with an FTIR system using a White cell with a path length of 10 m. The detection limit was 3 ppb with an accuracy of ± 5%. Individual pumps with 0.3 l/min each were employed for the grab samplers. 10 l bags allowed a measurement time of 30 minutes. The 30 minutes period was chosen in order to have the same time intervals as the standard meteorological data. Fig. 4.5 shows the location of the sampling points for the experiments 1 to 4. The tracer gas was released some 1 km inside the tunnel for ensuring a well-mixed exhaust air jet when exiting the tunnel. A mass flow controller was employed to control the SF_6 release.

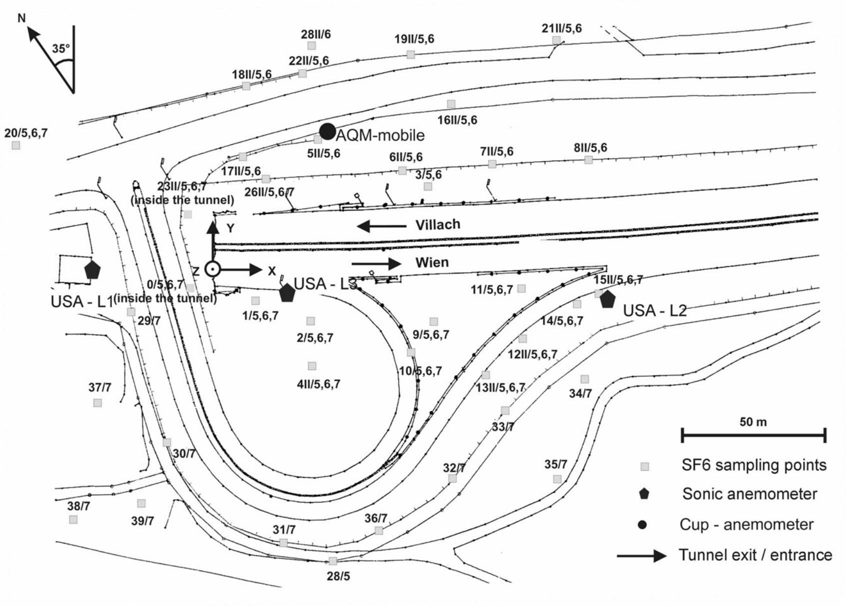


Fig. 4.5. Location of the meteorological equipment and the SF_6 sampling points

Main results (Klagenfurt)

The dispersion of pollutants from a roadway tunnel portal is largely determined by the interaction between the ambient wind and the jet stream leaving the tunnel portal. Due to the fact that the wind direction changed frequently it was possible to cover a broad variety of dispersion situations. The drawback of these varying winds was that the grab samplers were not always positioned at the most representative locations. In one case the wind direction changed by almost 180° shortly after the start of a test. This resulted in a number of zero samples. During the second test day the wind direction varied only by 90° which reduced the zero samples enormously. Only a few dispersion models appear in literature, which are designed to be used for regulatory purposes. These models are either empirical models, which may not be applicable for many different sites, or do not account for important physical effects like buoyancy phenomena. Here, a rather simple model has been developed, which takes into account most of the important physics playing a role in the dispersion process in the vicinity of tunnel portals. These are the jet stream, buoyancy, influence of ambient wind direction fluctuations on the position of the jet stream, and traffic induced turbulence.

Momentum of the exhaust jet (exit velocity): The exit velocity is a simple function of the piston effect of the traffic inside the tunnel, mechanical ventilation by fans, and the pressure gradient between the two portals. The velocity can be calculated according to the traffic piston equation.

Buoyancy: A temperature difference between the ambient and the tunnel air is caused by warming of the latter by the combustion process of the vehicles and a warming or cooling by heat transfer at the tunnel wall. Both will lead in most cases to a warmer tunnel air compared to the ambient one (except on summer days). Hence, a model not taking into account buoyancy will overestimate in most cases concentrations in the vicinity of roadway tunnel portals. Temperature differences typically can lie between 0 and 7 K.

Traffic induced turbulence: Especially heavy duty vehicles disturb the jet stream of a roadway tunnel and cause the jet stream to be orientated rather along the road compared to a “free” jet stream. The latter changes its direction more quickly towards the ambient wind direction.

Interaction of the ambient wind with the exhaust jet stream: The jet stream will change its direction more or less quickly according to the ambient wind direction. Because the ambient wind direction is changing over the considered time interval (in most cases 30 minutes), the position of the jet stream will also vary. Thus, concentrations will be overestimated by a model which computes the interaction between the jet stream and the mean ambient wind without considering the wind direction fluctuations,.

The meteorological conditions recorded and used for subsequent simulations can be seen in Table 4.1 where U_A is the ambient wind speed, DD the observed direction, u* the friction velocity, L the Monin-Obukhov length, σ_u the standard deviation of the along-wind and σ_v of the cross-wind, U_{pS} the tunnel air exit velocity, and $\theta_{S0} - \theta_A$ the temperature difference between tunnel and ambient air.

In most cases the mean wind speeds were quite low, which causes the ambient wind to meander (e.g., Etling 1990). In other words, the wind direction fluctuations are quite high in such conditions and the effect will not be negligible. The different wind directions during the experiments allow for a critical testing of the models’ capability to simulate the position of the jet stream centreline correctly. In most cases the atmospheric stability was unstable, except for test case 4, where it was stable.

Table 4.1. Meteorological conditions during the field tests.

#	U_A (m s^{-1})	DD (deg)	u_* (m s^{-1})	L (m)	σ_u (m s^{-1})	σ_v (m s^{-1})	U_{pS} (m s^{-1})	$\theta_{S0} - \theta_A$ (K)
1	1.21	252	0.258	-33.4	0.59	0.59	3.0	5.0
2	1.07	204	0.242	-10.8	0.60	0.54	3.2	2.8
3	1.55	101	0.130	-8.2	0.36	0.45	4.0	2.5
4	0.62	25	0.108	19.3	0.26	0.44	4.3	5.5
5	0.65	237	0.213	-19.2	0.46	0.47	4.6	5.0
6	0.56	248	0.187	-10.1	0.57	0.79	6.2	1.0
7	1.10	314	0.051	-11.2	0.29	0.46	6.2	5.0

4.2.5 Podbielski St.

The prevention of air pollution in traffic-loaded areas and the execution of the EU Directives ask for suitable tools for predicting pollutant concentrations. Different procedures and methods are operationally used to achieve that aim. Quality assurance asks to aspire to comparable procedures for concentration prediction. Ring tests comparable to tests with monitoring devices can essentially contribute to these comparisons. The Podbielski Strasse Exercise was used as a first attempt into this direction. The entire chain of the prediction process was checked, from the input parameters over the modelling of the dispersion to the predicted concentrations (Lohmeyer et al. 2002). The goal was to show the possible spread of the resulting concentrations predicted by different organisations/persons and/or different procedures if all users had the same input parameters at their disposal.

The meteorological parameters recorded were the wind direction and speed at the station HRSW, on the flat roof of the service building of the Lower Saxony State Agency for Ecology (NLÖ) in Göttinger Strasse in Hanover (see below), approximately 4 km off from Podbielski Strasse, 42 m above ground, 10 m of height over roof. Measurements of pollutant concentrations at the station HRSW were provided as hint for the background concentration (benzene, soot, NO_2, NO and CO as well as the 98-percentiles for NO_2, NO and CO). Traffic data were available (number of vehicles) between 06.30 and 18.30, providing mean traffic time series over the day, on weekdays, on Saturdays and on Sundays.

For benzene, a mean value was taken for ten months (April 1999 to January 2000) with 5 $\mu g/m^3$. The measured mean annual soot concentration was 3.1 $\mu g/m^3$. The measured annual mean for NO_2 was 50 $\mu g/m^3$ and for NO_x 95 $\mu g/m^3$. The 98-percentiles amounted to 88 $\mu g/m^3$ for NO_2 and 247 $\mu g/m^3$ for NO_x. Based on these results and the meteorological input several models were applied and validated.

4.2.6 Göttinger St.

The EU Air Quality Directives foresee the use of air pollutant dispersion models as instruments of environmental policy. The quality of these models has to be checked. One part of that procedure is the validation, i.e. the comparison of the results of the models with specially designed and acquired reference data sets from field and wind tunnel measurements.

A data set for validation of microscale numerical dispersion models was compiled in the framework of the AFO 2000 project VALIUM (Development and validation of tools for the implementation of European air quality policy in Germany).

Within an urban quarter around the “Göttinger Strasse” in Hanover, Germany, air pollutants and meteorological parameters were measured continuously at different sites by stations in the frame of the State Environmental Agency of Lower

Saxony Monitoring System LÜN operating a permanent monitoring station. Apart from those long term measurements three intensive measurement campaigns with additional tracer experiments are performed. During the tracer experiments, a line source of approx. 96 m long operates along the median strip of the Göttinger Strasse. The width of the canyon was 25 m and buildings on both sides of the street were ca. 20 m high. It was a four-lane street canyon with a traffic load of ca. 30000 vehicles/day.

In August 2001, a pre-test was executed to check the experimental conception and set up. Samples of air were collected in bags at 12 locations within the street canyon and at the roofs of the buildings, and analysed later. This first test of the experimental layout was, with minor reservations, successful. The results allow drawing useful conclusions on the distribution of the concentration in the street area.

4.2.7 London

The London campaign investigated the variability of road-users (cyclists, bus and cars users) exposure to fine particulate matter ($PM_{2.5}$) for different routes, with its results having main application to Air Quality Management Systems (AQMSs).

The project was funded by the UK Engineering & Physical Science Research Council, under their Inland Surface Transport programme, with additional support from Go-Ahead Group p.l.c. and other transport operators, and collaboration with CERC Ltd.

Major scientific issues investigated (London)

The campaign was designed to answer the following questions, with reference specifically to $PM_{2.5}$:

- To what extent does monitored or modelled fixed-point urban background or roadside air quality represent the level of air pollution people are exposed to while travelling on urban roads?
- How variable is road-user exposure to air pollution in Central London at the individual level, at the between-vehicle level, between different modes of transport (bus, car, bicycle), diurnally, from day to day, seasonally, and between different routes?
- What are the determinants of exposure?
- Is it possible for air quality management decision support software to include a facility to examine road-user exposure to air pollution, using existing Gaussian-type and street canyon dispersion modelling methodology?
- What would the implications for urban air quality management be if more attention was paid to road-user exposure instead of the current exclusive focus on fixed-point background or sometimes roadside concentration?

Relevance to SATURN aims (London)

The aims of SATURN extend as far as the application of AQMS decision support software tools to assess population exposure to air pollution, usually by simple multiplication of modelled concentration by number of people living or working in each part of a city. The London exposure measurements go beyond SATURN's stated aims by considering exposure of moving receptors in the on-street microenvironment. This is an important contribution to the development of AQMS capability in this area, by allowing the appropriateness and accuracy of the simpler modelling techniques to be assessed. Insofar dispersion modelling might be capable of considering road-user exposure, the London results should also be incorporated into future AQMS development, if it is deemed to be useful to be able to consider such detail. Such AQMS development is one of the key integrating aims of SATURN (see Chapter 9).

Experimental set-up (London)

Road user exposure to $PM_{2.5}$ fine particulate air pollution was measured using high-volume personal sampling equipment (Adams et al. 2001a) along 3 fixed routes within Central London during a 3-week summer 1999 and 3-week winter 2000 campaign, for the three modes of transport bicycle, bus and car. An additional summer 1999 cyclist exposure measurement campaign was made on variable routes corresponding to the volunteer cyclists' normal commuting journeys (Adams et al. 2001b). Each sample was analysed in the laboratory for total mass of particulate matter collected (including correction for humidity and pressure effects) and for blackness as a calibrated measure of the contribution of carbon principally from diesel exhaust (Adams et al. 2002). Simultaneous daily samples during the summer 1999 measurement period were taken from a fixed urban background monitoring site and analysed for major anions and cations by ion chromatography to quantify the contribution of long-range and regional transport of principally nitrate, sulphate and ammonium aerosol.

Main results (London)

The data set collected is significantly larger than most, if not all, previous road-user exposure measurement data sets. After quality control, the number of valid samples from the fixed-route summer campaign was cyclist: 40, bus: 36, car: 42; for the fixed-route winter campaign cyclist: 56, bus: 32, car: 12, plus 120 variable-route summer cyclist samples.

Time-series of modelled or measured roadside or urban background air quality correlate well with road-user exposure. The road-user exposure, however, is more variable than roadside concentration and twofold the urban background concentration.

A large fraction of the exposure variability is at the individual and between-vehicle level, with day-to-day and between route variability also being very important. For example, the difference in exposure between two cyclists travelling on the same route at the same time is similar to the difference in exposure of one of those cyclists on two different routes or two different days. Above the noise of the other sources of variability however, it was not possible to detect any systematic difference between the average exposure of several cyclists and the average exposure of several car or bus users on the same route and the same day. Most of the exposure variability at individual level and between routes is attributable to the black carbon fraction of the $PM_{2.5}$, while the non-carbon fraction was more important in the day-to-day variability. For the black carbon part of $PM_{2.5}$, it was also possible to detect almost a factor of two differences between modes of transport, with car drivers having greater exposure than cyclists.

Regression modelling (Adams et al. 2001c) shows that the main determinants of exposure are wind speed and route. Detailed information about instantaneous position on road was not available to be included in the regression modelling, so the possibility that this is a cause for the unexplained individual-level variability is left as a plausible hypothesis to be tested by further research.

The ADMS-Urban dispersion modelling system is capable of reproducing the dependence of exposure on wind speed and route, including the day-to-day variability where sufficient information about imported secondary transboundary $PM_{2.5}$ is available for inclusion in the model input. It is not, however, currently capable of accounting for the individual-level variability in exposure, nor all the enhancement of road-user exposure relative to roadside air quality. The average measured exposure is similar to the modelled concentration at the most polluted part of the route, not the average along the route assuming steady movement at constant speed.

One insight gained by our approach to modelling road-user exposure is the large difference between the most polluted 10% of a route and the less polluted 90%. Action to tackle the hotspots is likely to result in the most effective improvement of the quality of the urban environment, including such simple measures as decreasing delays to cyclists and bus users at congested locations and physical separation of non-polluting road-users from polluting vehicles. The source apportionment of $PM_{2.5}$ at the exposure hotspots is also quite different to that along the rest of the route. At the hotspot, emissions from the nearest road dominates. Along the rest of the route, the contribution of imported secondary transboundary particulate matter is the same order of magnitude as that of the local emissions. Local authorities, who are often the main end users of the AQMSs that SATURN is developing, therefore have more control over the hotspots and exposure than they do over general urban air quality. This research continues and will be integrated with street canyon intersection modelling and wind tunnel studies. Major on-street measurement campaigns are planned for Spring 2003 and 2004 at the junction of Marylebone Road with Gloucester Place.

4.3 Urban scale campaigns

4.3.1 LisbEx – Experimental studies in the Portuguese Atlantic coast

The Great Lisbon Area is, due to its industrial and urban importance, an example of a region with high emission levels and photochemical air pollution. On the other hand, it is located on a coastal zone with a complex coastline associated to significant terrain features and sea/land breezes circulation, which result in a complex airflow circulation. Two summer campaigns, in 1996 and 1997, were dedicated to the investigation of the effects of flow circulation on pollutants transport and the model evaluation.

Major scientific issues investigated (LisbEx)

The knowledge and characterisation of mesoscale airflow patterns as well as its effect on the dispersion of atmospheric pollutants in coastal areas is fundamental. The objectives of the Lisbon campaigns were the characterisation of meteorology and air quality situation during summer and focused on the study of the breeze circulation in coastal zone, vertical structure of atmospheric boundary layer, formation and transport of photochemical pollution, and model evaluation. The application of numerical modelling as a complementary tool to experimental fieldwork was essential for this study.

Relevance to SATURN aims (LisbEx)

The LisbEx databases are fundamental for model development particularly applied to coastal zones, and its validation contributing to a better performance of models. The Lisbon campaigns also represented an effort on monitoring the Great Lisbon Area air quality showing the need of improvement of the air quality network in terms of spatial coverage.

Experimental set-up (LisbEx)

Two field studies (meteorology and air quality) were carried out in Lisbon coastal area from 8 to 18 July 1996 and 1997 (LisbEx 96 and 97), searching for typical synoptic summer situations.

The Lisbon campaigns were structured in order to integrate all monitoring stations (public or private) located in the study domain (area about 200 km × 200 km). Mobile monitoring stations with locations based on numerical simulation were also used. Generally, temperature, relative humidity, wind speed and direction were measured at every meteorological station. O_3, CO, NO_x and SO_2 concentrations were measured at air quality stations (Fig. 4.6). In addition to ground-based information, radiosondes and tether-balloon soundings were performed. The tether-balloon soundings system includes both meteorological data acquisition and O_3 sensor. In addition, satellite images, forecast maps, etc were available from the Portuguese Meteorological Institute (Borrego et al. 1998).

In the summer ’97 campaign, the vertical structure of the atmospheric boundary layer was also studied with aircraft measurements in the frame of the STAAARTE Programme (Scientific Training and Access to Aircraft for Atmospheric Research Throughout Europe). The flights performed with the instrumented aircraft had “in situ” monitoring of atmospheric pollutants.

According to the mean sea-level pressure analysis based on the 12:00 UTC synoptic charts from the Portuguese Meteorological Institute, the synoptic situation during LisbEx 96 was dominated by the presence of the Azores anticyclone centred over the Northwest of Iberian Peninsula. Two prominent synoptic meteorological patterns were identified. The first pattern, from 8 to 15 July, was characterised by an eastern wind, with hot and dry air, transported in the Azores anticyclone flow that extended in ridge to Northeast. In the second pattern, during 16 and 17 July, the synoptic situation was influenced by the joint action of an anticyclone centred over Scotland and an under-pressure valley over Iberian Peninsula that generated a Western flow over Portugal. During LisbEx 97, the meteorology was conditioned by the presence of the Azores anticyclone that was either centred over the Azores islands or at the West or Northwest extending in ridge to France. Also, the presence of depressions on the Iberian Peninsula and British islands resulted in atmospheric instability, associated with the observation of the approximation and transit of a cold front with a subsequent thunderstorm and showers.

Main results (LisbEx)

Based on their locations, the stations were divided in coastal, inland and urban stations. In the LisbEx 96 period, the mean temperature at coastal stations (Cabo da Malha, Cabo Carvoeiro and Sines) was 20ºC, the maximum being observed at Cabo da Malha (32.8ºC) whilst for the urban stations (Lisbon, Barreiro, Setúbal and Tires) the maximum was registered at Tires (38ºC). The mean temperature of 25ºC was found for all urban locations except Setúbal (21ºC). The air temperature was generally higher for the inland stations with a maximum of 39ºC observed at Pego. At the different monitoring sites the same pattern for the wind speed variations was observed, but it was generally lower at inland sites. The average wind speed at the coastal stations was about 4 m s^{-1} while at others it was about 3 m s^{-1}.

The air temperature during LisbEx 97 was generally lower than in the LisbEx 96 campaign with the maximum observed at inland sites (Évora and Beja - 33ºC). The maximum wind speed at the coastal stations varied between 5 and 12 m s^{-1} while at others stations it varied between 4 and 8 m s^{-1} (Borrego et al. 1999).

The vertical structure of the atmosphere was studied up to 8000 m by analysing vertical profiles of pressure, temperature and wind speed and direction obtained from radiosondes realised at the Lisbon station. Fig. 4.7 presents the vertical profiles for 10 July 1996. This day was characterised by a synoptic forcing from N-NE with moderate wind speeds at the surface. The predominant flow from N-NE over Portugal is representative for a typical summer situation.

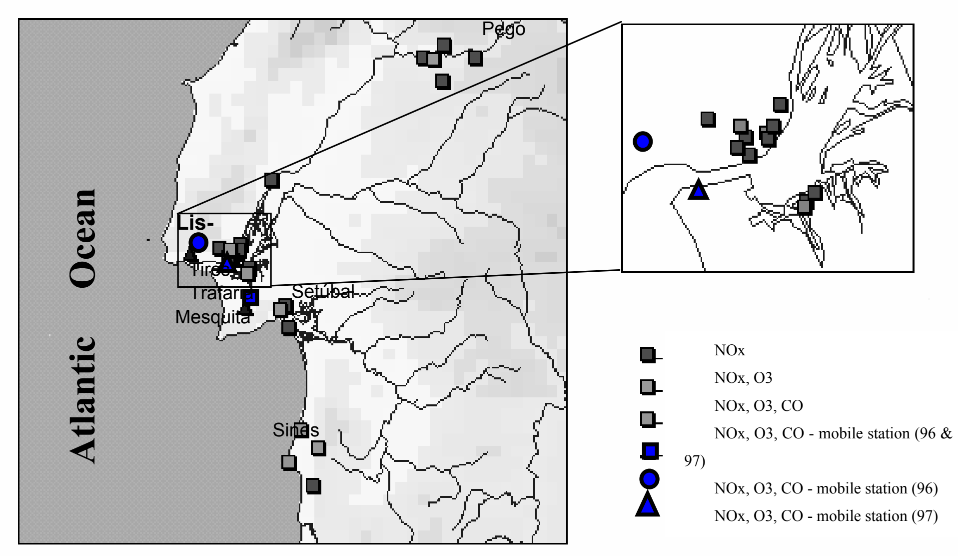


Fig. 4.6. Location of air quality stations and pollutants measured at Great Lisbon Area during LisbEx

Table 4.2. Mean, maximum, minimum and 98th percentile of hourly average O_3 concentration ($\mu g\ m^{-3}$) during the LisbEx field campaigns

	Mean		Max.		Min.		98th percentile	
	96	97	96	97	96	97	96	97
Pego	84	78	173	107	19	7	199	98
Rua do Século	38	32	61	77	27	2	52	65
Entrecampos	8	18	23	50	2	0	19	43
Tires	72		168		2		155	
Trafaria		63		108		15		104
Hospital Velho	39	67	192	143	20	14	182	112
Monte Chãos	49	72	192	218	18	16	160	193
Monte Velho	107	69	155	116	65	16	145	110

During the Lisbon field campaigns O_3 was measured at nine stations (Fig. 4.6). In Table 4.2 the mean, maximum, minimum and 98th percentile of hourly average O_3 concentration obtained at the various stations are presented. It is evident that the highest O_3 concentrations were observed at the stations located far from the urban centres (Pego, Monte Velho and Monte Chãos). This situation was expected as O_3 is depleted by high concentrations of NO_x caused by emission of heavy traffic in the urban centres (Borrego et al. 1999).

The diurnal O_3 concentrations at the nine measuring stations in the Greater Lisbon Area generally showed the typical pattern of photochemical smog formation, namely, a steep rise in O_3 concentrations in the first morning hours at 8:00 to 9:00 UTC with a maximum in the first afternoon hours around 14:00 UTC.

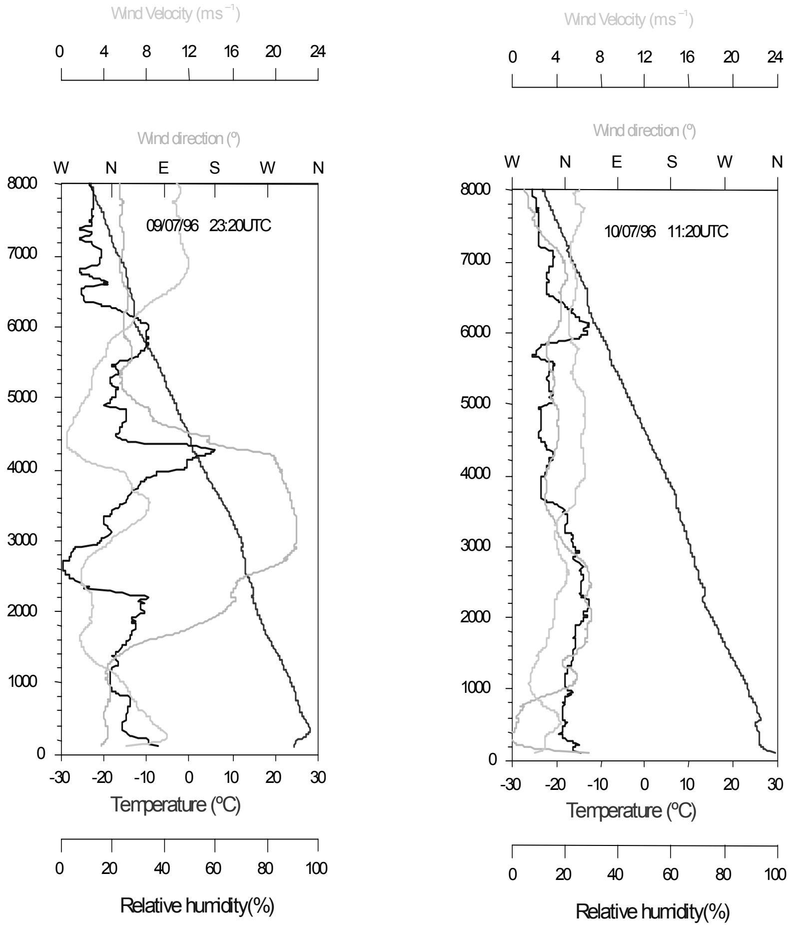


Fig. 4.7. Radiosondes realised at Lisbon station during LisbEx on 10 July 1996

4.3.2 Graz

The air quality investigation in the city of Graz included two major measurement campaigns in winter 98/99 and summer 99. Two episodes were investigated during high pressure periods over Central Europe under which local wind systems could develop. It was shown that air quality is affected by the location of the city in the southeast of the Alps in a basin surrounded by mountains. The existence of a counter-current over the city area was investigated together with its dependence on stable atmospheric conditions frequently occurring during night and morning hours. The implications to pollution dispersion were illustrated.

Major scientific issues investigated (Graz)

The research project DATE Graz (Dispersion of Atmospheric Trace Elements taking the city of Graz as an example) aimed at the investigation of mesoscale dispersion of pollutants emitted in a city over complex terrain in a pre-alpine region South of the Alps. Two episodes were investigated which were characterised by anticyclonic fair weather conditions. Main objective of the measurement campaigns was to analyse the influence of local wind systems and strong temperature inversions on air quality; to study the vertical structure of the boundary layer and its temporal development; to compare point measurements against open path air quality measurements; and to validate models developed by the teams participating in the project.

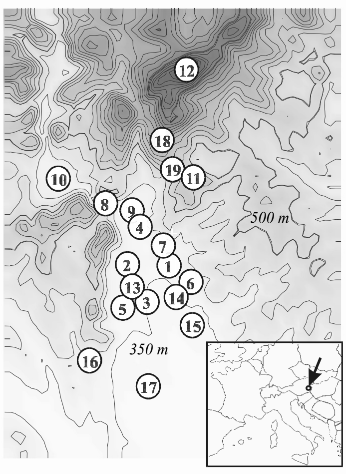
Relevance to SATURN aims (Graz)

The measurement campaign in the city of Graz was designed to investigate the dispersion conditions of cities situated in valleys and basins in pre-alpine regions during anticyclonic weather conditions. Graz is well suited for such an investigation as it is situated in the Southeast of the Alps in the transition area of mountainous to flat land. The city itself is located in the valley of the river Mur, which forms a basin surrounded by small mountains. The development of local wind systems which interact with larger circulation patterns has a strong influence on the air quality of Graz. The local wind systems consist of the katabatic flows from the small tributary valleys in the East of the city and the frequent development of stable low wind situations in the basin. These local systems are overlapped and interact with the mountain-valley wind system of the valley of the river Mur. This valley enters the basin from Northwest and origins from some 190 km Northwest in the Alps. It produces a distinct valley wind at two to three hours after sunset. Nevertheless it is not able to enter the basin down to its ground due to strong temperature inversions in the basin. The measurements show a counter-flow from South going underneath the valley wind from Northwest. Numerical investigations show that this is very probably a Froude-number dependent flow circulation around the small mountain ridge in the West of the city. The relevance to SATURN was to show the influence of the mountainous topography on the air quality of cities. Although Graz is a rather small European city, the air quality during the described conditions is poor. The measurement campaign aimed at the investigation of the different influences on air quality and resulted in two measurement data sets.

Source-receptor relationships in Graz during the winter episode were studied with a mesoscale dispersion model. Input for the simulation was the emission inventory and extensive meteorological measurement data. Results of the simulation reflect the distinct patterns of daily variations of air quality levels measured. The influence of meteorology, emission patterns and chemical reactions is evident and can be qualitatively and partly quantitatively simulated by the model. A validation attempt was made using air quality data from the monitoring network. Several papers describe the measured phenomena also in comparison to the model results.

Experimental set-up (Graz)

The area investigated is characterized by a continuous transition from the Alps to flatlands. The major part of the city is located in a basin surrounded by small mountains to the West and North (Fig. 4.8). From the East, tributary valleys enter the city basin coming from a small North-South oriented ridge, which forms a barrier approximately 10 km to the East. To the South the oval basin (25 km S-N and 15 km W-E) is surrounded by small hills. The river Mur enters the basin in the Northwest through a narrow gap, and leaves it in the South. The contour lines indicate the altitude in 50 m intervals. The highest elevation is at a height of 1450 m a.s.l.. The position of the area within Europe is indicated in the small square in the lower part of Fig. 4.8. The Alps are located Northwest of this area. The measured quantities are shown in Table 4.3.



DATE Graz: Winter measurement campaign
10 - 13 January 1998, Area 26 x 34 km
Height: 350 m - 1450 m (50 m isopleths)
Orography and measurement sites

		Met	AQ	Special Equip.
1	Graz Mitte	x	x	DOAS, FTIR
2	Graz West	x	x	
3	Graz Sued	x	x	
4	Graz Nord	x	x	
5	Graz Suedwest	x	x	
6	Graz Ost	x	x	
7	Graz Schlossberg	x		O_3
8	Weinzoettl	x		
9	Wasserwerk			T-B
10	Gratkorn	x	x	T-B, SODAR
11	Platte	x		O_3
12	Schoeckl	x		
13	Kaertnerstrasse	x		
14	Umspannwerk	x		T-B, O_3-Profile
15	Eurostar	x		Eddy-Corr.
16	Dobl	x		Tower 160m
17	Airport	x		SODAR
18	Kalkleiten	x		
19	Annengraben			T-B

Fig. 4.8. The location of the Graz campaign

Table 4.3. The measured quantities in Graz experimental campaign

Met.:	*Meteorological standard devices (wind speed, wind direction, temperature)*
AQ:	Air quality monitoring sites (NO, NO_2, SO_2, TSP, CO)
DOAS:	Differential optical absorption spectroscopy
FTIR:	Fourier transformed infrared spectroscopy
T-B:	Tethered balloon measurements (hourly)
O_3-Profile:	Hourly vertical O_3-profiles
Eddy-Corr.:	Eddy correlation measurement by sonic anemometer
Tower:	Meteorological tower with met. standard devices at 10 m, 30 m 160 m

The winter measurement campaign was designed to study a typical winter smog situation. The first anticyclonic weather episode during that winter started on 9 January. The anticyclone in the 500 hPa ridge was very intense and prevented fog by the downdraft of dry air even at ground level in the area under investigation. The episode ended with the advection of ground fog in the late evening of 12 January. The measurements started at 6 p.m. of 9 January and ended after 82 hours in the morning of 13 January. During the three days of the field experiment, hourly vertical profiles of wind speed and direction, temperature and humidity were measured at four locations (indicated by T-B in Fig. 4.8) in the chosen area. In addition, one meteorological tower, two SODARs, one eddy correlation measurement device and at least 15 meteorological standard devices on the ground were in operation. At the same time 1 DOAS system and 7 air quality stations for the measurement of standard pollutants were in operation.

Main results (Graz)

Three typical local wind systems can be distinguished for the city of Graz (Almbauer et al. 1995, Lazar and Podesser 1999): (a) Mountain-valley wind system; (b) Drainage flows from the tributary valleys East of Graz; (c) Cold air from the southerly basin.

Measurements of the winter campaign showed the expected local wind systems. The mountain valley wind system of the river Mur is clearly documented in the observed vertical wind profiles South (Fig. 4.9) and North (Fig. 4.10) of the city centre. The arrows in the diagrammes show the hourly measured horizontal wind direction and wind speed up to a height of 500 m above ground level. Approximately two hours after sunset at 18:00 LST (Local Standard Time) the mountain wind entered the basin of Graz. It reached ground level on 10 and 11 January in the North of the city centre at site 9. South of the city centre southerly wind directions remained even at the beginning of the valley wind. During the night the southerly flow developed and increased in depth up to a height of approximately 100 m - as can be seen in Figs 4.9 and 4.10. Above, the low level jet of the mountain wind with velocities up to 8 m s^{-1} remained during the night and ended in the late morning. The centre of the low level jet moved to higher altitudes during both

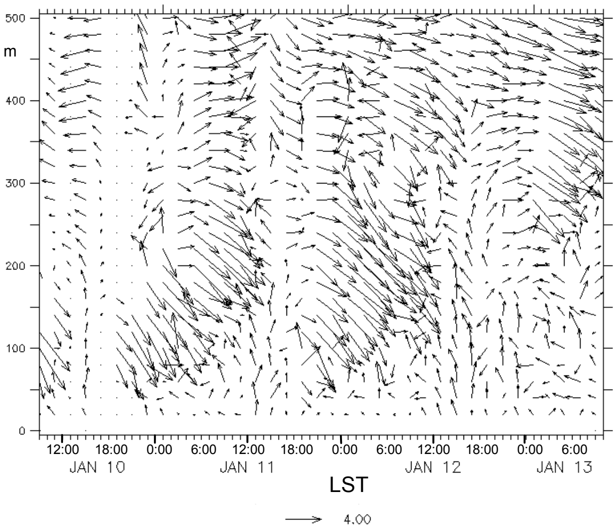


Fig. 4.9. Measured vertical wind profile south of the city

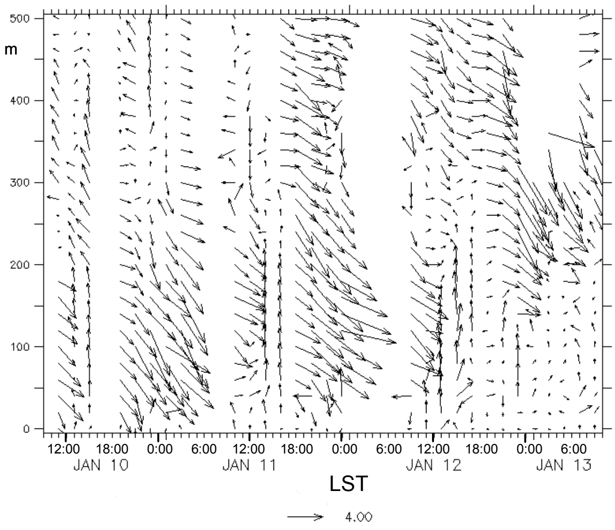


Fig. 4.10. Measured vertical wind profile North of the city

nights. During the day a weak valley wind from the South developed. The depth of the valley wind correlated well with the depth of the isothermal layer.

The measured time height diagram of O_3 (Fig. 4.11) and temperature (Fig. 4.12) at site 14 indicate the build up of a well-mixed layer during all three days (10 – 12 January) between 11:00 and 15:00 LST. During the night an inversion layer with a growing height was measured. Differences between the situations North and South of the city are explained in detail in Piringer and Baumann (1999). Differences are accounted for by the influence of the increased roughness length in the city on the mountain wind.

Air quality results are presented for NO and NO_2 as they are the pollutants which are closest to exceeding present threshold values. NO concentrations are influenced by: (a) the daily and hourly variation of emission rates depending on traffic and industry activity; (b) the complex flow field determined by the local wind system; (c) chemical reactions with importance for the conversion of NO to NO_2.

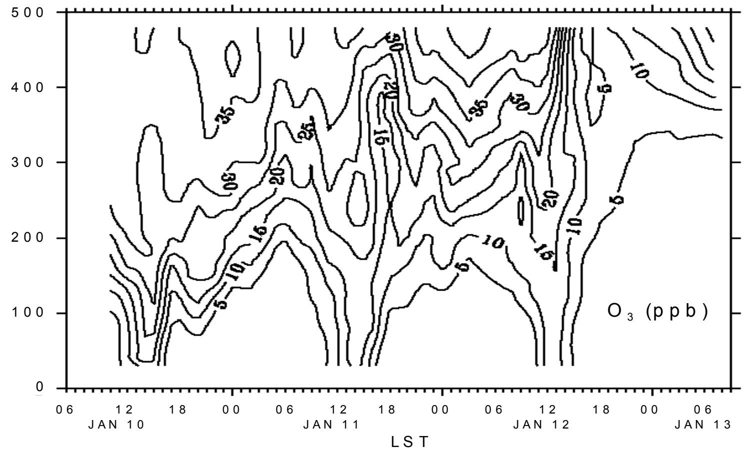


Fig. 4.11. Measured O_3 at site 14

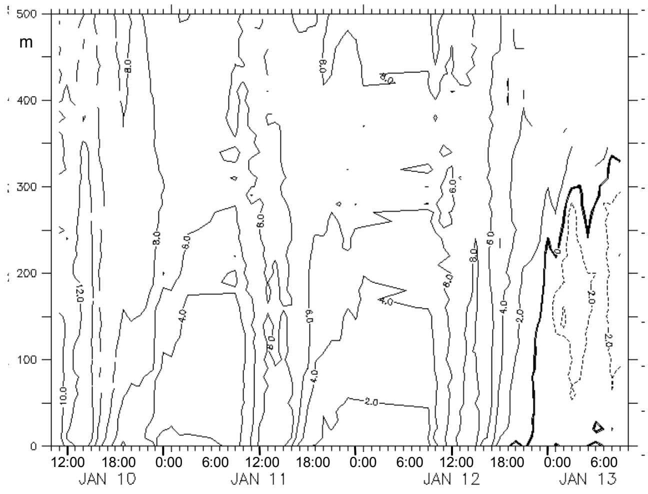


Fig. 4.12. Measured temperature at site 14

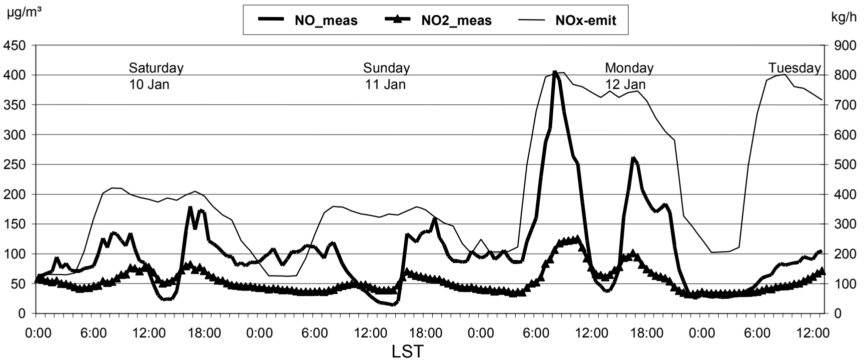


Fig. 4.13. Measured concentrations of NO, NO_2 and NO_x emissions

In order to explain in general the daily variations of NO_2-concentrations, the mean NO and NO_2-concentrations for the whole city were calculated from sites 1, 2, 3, 5 and the DOAS records (Fig. 4.13). NO concentrations during both nights from 10 to 11 January and from 11 to 12 January are on a level of approximately 100 µg/m³. NO_2 concentrations decrease from approximately 75 µg/m³ in the evening to 40 µg/m³ in the early morning. On Monday a strong increase over time, up to daily maximum of more than 400 µg/m³ at about 8:00 LST was recorded. NO_2 concentrations rise slowly after sunrise with a Monday-maximum of more than 120 µg/m³, three hours after the NO maximum at about 11:00 LST. The fast conversion of NO to NO_2 is caused by the down-mixing of O_3 from higher altitudes (Fig. 4.11). The O_3 concentration during all three days in the residual layer above the inversion is about 30–40 ppb. All three days show a distinct minimum NO concentration at noon with values less than 40 µg/m³. NO_2 decreases more slowly to values between 40 to 60 µg/m³. During all three days NO-concentrations increase shortly after the breakdown of the well-mixed layer at 15:00 LST. On Saturday and Sunday the maxima in the afternoon are higher as a result of increased traffic. On Monday the second NO maximum is lower. NO_2-concentrations show the same behaviour as NO for their maxima on all three days. The sum of NO and NO_2 concentration decreases after 19:00 LST in line with the normal reduction in emissions. The NO-concentration shows a good coincidence with predicted emission rates. Vertical soundings of O_3 for the three days confirmed the assumption of O_3 down-mixing (Fig. 4.11). During the first two days, the O_3 values in the lowest 150 to 200 m increase with a rate of about 5 ppb per hour between 11:00 and 15:00 LST. The maximum values reach up to 20 ppb. During the rest of the days the O_3 concentrations were at a level less than 1.5 ppb near ground. Daily mean values of O_3 concentrations at the monitoring stations 2, 4 (at the city ground level) and 11, at a height of 210 m a.g.l. show a strong vertical stratification. The temperature inversion and weak winds prevented an exchange of air masses.

The mesoscale dispersion model GRAMM was applied for the simulation of air quality during the winter episode. Instead of using a nesting procedure initial and boundary conditions were directly obtained from the numerous observations within the model domain by objective analysis.

A prerequisite for predicting air quality is to simulate the complex flow fields correctly. The dominant mountain-valley wind system of the Mur valley with its characteristic diurnal change in wind direction from northwesterly winds in the night to daytime southerly winds is reproduced well in the simulation. Simulated wind speeds of the up-valley flow agree well with observations. On the contrary, the local drainage flows on the eastern side of Graz were not reproduced by the mesoscale model. The modelled temperature agreed well with observations during night-time hours, where an inversion layer with a temperature increase of 6 K within the first 250 m above ground level developed. During the day the inversion broke up and an isothermal stratification was observed. The warming of the air after sunrise and also the cooling in the afternoon is somewhat slower in the simulation.

Concerning the simulated NO and NO_2 concentrations, the strong increase during the morning rush hours on Saturday and Monday is well reproduced by the model. In particular, results in terms of the NO_2 levels agree fairly well with the measurements. The agreement is less satisfactory regarding individual peaks for Saturday morning and evening and the Monday morning rush hour. Results for the other sites show a similar behaviour. At most sites NO concentrations are underestimated. The reason for this might be either too low emission rates or wrong dispersion conditions.

4.3.3 Milan

The urban areas in Northern Italy are characterised by significant photochemical pollution associated with the geographical, meteorological and emission systems complexity. Urban experimental campaigns in the Lombardia region were designed and managed in order to improve knowledge of the urban dispersive and photochemical properties. Pollutant levels were investigated, with emphasis on photochemical pollution and particulate matter.

Major scientific issues investigated (Milan)

The experimental campaigns in Milan aimed at characterising the chemical regimes near and inside the city plume, improving the knowledge of the urban dispersive and photochemical properties during the cold season, improving the vertical chemical characterisation, characterising the organic and inorganic mass composition of PM_{10}, and determining the urban aerosol mass closure and the relation between secondary aerosol formation and photochemical properties.

Relevance to SATURN aims (Milan)

The experimental campaigns in Lombardia region aimed at measuring meteorological parameters and chemical compounds in order to provide data for model validation, as well as to develop emission inventories necessary for model application in the frame of different EUROTRAC-2 subprojects, while a “Milan focal point” task force was established in summer ’98.

Experimental set-up (Milan)

Seven experimental campaigns were performed in the years 1997 – 2001 aimed at measuring meteorological parameters and chemical compounds at ground level and in the vertical. The research institutes involved in the campaigns were CESI, ENI Tecnologie and Università di Torino.

Two summer experimental campaigns were organised in 1997. During June-July, the measurements in rural and suburban areas of Milan were performed in order to characterise chemical regimes near and inside the city plume. From July until September the data were collected in Turin using sonic anemometer and SODAR.

During spring 1998 measurements were performed in several places: Milan (Piazza Carbonari, Viale Marche, Segrate and Turbigo Bresso suburban site); Bresso airport and Turbigo (ENEL thermal power plant); and Redecesio (suburban site – East Milan). The Doppler SODAR and RASS sonic anemometers, hydrometers and fast ozonometers were used during the campaign.

During the winter 1999 experimental campaign in the Milan area, ground level and vertical profile measurements of meteorological and chemical variables were performed. Part of the winter campaign took place in particular, from 1 February to 25 March 1999, at Carbonari Square, in the northern part of Milan urban area, near the main railway station. It was mainly devoted to improve knowledge in urban dispersion and photochemistry properties during the cold season, and to extend and complete the data set started with the summer campaign (summer 1998). According to previous experiences, a relevant experimental effort was performed in order to improve the vertical chemical characterisation. Beyond a standard ground level meteorological and chemical characterisation, the winter campaign had, as a special focus, the measurement of vertical pollution structure related to meteorological conditions.

The experimental activity in July 2000 was mainly focused on urban aerosol chemical composition and aerodynamic distribution investigation. Aerosol analysis was combined with a complete characterisation of the primary and photochemical pollutants both at ground level and in the vertical structure. In January 2001 and in the period September-October of 2001 a mobile laboratory was used for measurements in Milan (Piazza Carbonari).

Main results (Milan)

An extensive experimental work was performed in Milan. The databases included:

- Meteorological parameters, i.e. conventional ground level meteorological measurements; vertical profiles of wind, turbulence and temperature in the Planetary Boundary Layer; sensible and turbulent heat fluxes and momentum at different levels.
- Chemical compounds, namely, NMHC C2-C9, HC, BTEX, CH_4, aldehydes, carbonyl compounds, PM_{10}, $PM_{2.5}$, CO, NO_x, O_3, H_2S, SO_2, HNO_3, HNO_2 at ground level; vertical profile of O_3 and aldehydes; aerosol composition (ammonium nitrate and sulfate, OC, EC, anions and cations) divided in different aerodynamic classes.

The experiments in Milan intercompared the instrumentation among different groups and improved the measurements quality control and assessment. The collected data were used for comparison with CALMET model prediction contributing to a critical review of methods for estimating mixing height, turbulence parameterisation and vertical diffusivities in urban areas. The results helped to understand deeper which chemical multi-phase modelling schemes should be implemented in the mesoscale models.

4.3.4 Marseille, the ESCOMPTE and UBL/CLU experiments

The ESCOMPTE programme (Experiment on Site to Constraint the Models of atmospheric Pollution and Transport of Emissions) aimed at improving the knowledge on the meteorological and chemical conditions prevailing during photochemical episodes. The ESCOMPTE programme included the (a) experimental campaign, (b) the construction of the detailed emission inventory over the whole region, (c) the construction of a comprehensive and extensive database to be placed at the disposal of the scientific community.

UBL/CLU-ESCOMPTE was an “associated project” of ESCOMPTE, with an additional experimental set-up to document the fine scale dynamics and thermodynamics of the urban atmosphere over the Marseille area, situated at the Mediterranean coast, and involving more than one million of inhabitants.

Major scientific issues investigated (ESCOMPTE and UBL/CLU)

City authorities generally desire to be able to take in advance decisions limiting the amplitude and the effects of photochemical episodes. For the pertinent space and time scales, efficient prediction tools are required for warning the public and for limiting the health impact, while deterministic simulation models would allow assessing the influence of the pollution reduction decisions by the public authorities. The simulations require four main modules: the evaluation at any time of the natural and anthropogenic emissions, the computation of the transport-diffusion in the atmosphere, the computation of the chemical transformations for the gases and particulates, the deposition of the oxidized species on surfaces and vegetation. The ESCOMPTE programme aimed at providing a reference data set allowing to validate these modules in detail.

The chosen method included on the one hand the construction of a detailed emission inventory of fixed and mobile sources, at the scale of 1km×1km×1h, and on the other hand to conduct a field experiment allowing to measure at the ground, at sea, and in altitude the chemical composition and the dynamic and thermodynamic characteristics of the atmosphere from the local scale to the regional scale. The aim of the experiment was to obtain all the data necessary to constraint and/or to qualify the above mentioned modules, at coherent space and time scales. The plan left room for side projects taking advantage of the general set up and also participating in the main objective.

The UBL/CLU-ESCOMPTE experiment aimed at documenting the four-dimensional structure of the Urban Boundary Layer in connection with the urban canopy thermodynamics during a 7 weeks summer period of low wind and breeze conditions. The objective was mainly to construct a database allowing to test urban energy exchange schemes and high resolution meteorological and chemistry-transport models.

The project took advantage of the large experimental set-up of the ESCOMPTE campaign over the Berre-Marseille area, especially as concerns remote sensing from ground, airborne measurements, and the intense documentation of the regional meteorology.

Relevance to SATURN aims (ESCOMPTE and UBL/CLU)

Both experiments are directly aiming at the validation of models that are required for understanding pollution episodes and predicting air quality. While ESCOMPTE focuses on the O_3-VOC photochemistry at the regional scale during several diurnal cycles for various sunny meteorological conditions, UBL/CLU-ESCOMPTE focuses on the urban atmosphere with highly inhomogeneous distributions of urban land use and pollutant sources. Both experiments document densely the atmospheric dynamics at the pertinent spatial and temporal scales, allowing to test and validate transport-diffusion models. UBL/CLU documents more extensively than ever the urban canopy thermodynamics, allowing to test and validate the urban energy models. ESCOMPTE documents more extensively than ever the gas and particulate concentration distributions and the photochemical transformations, allowing to test the tropospheric chemistry models. At the urban scale the documentation of pollutant concentrations was ensured by the permanent network of the air quality survey service AIRMARAIX.

The experimental set-up (ESCOMPTE and UBL/CLU)

The selected site for ESCOMPTE campaign is a domain of about 100 km by 100 km around the Marseille conurbation and the area of Fos-Berre. In this area the highest O_3 episodes of all the French territory have been registered. The pollutant sources are multiple, and include urban sources within the Marseille conurbation and industrial plants within the Fos-Berre complex. The geography is complex, with land-sea interactions through a twisted coast. This means that the modelling exercise following the experiment will be a demanding test for the models, but with quite well identified dynamic features (thermal contrasts and orography influence).

The ESCOMPTE set-up

The campaign ran from 4 June to 17 July 2001 and 5 Intense Observation Periods of 3 days average were selected for complete deployment of the sensors and flights of the instrumented aircrafts (see URL 4.1). The ground-based platforms, specifically deployed for the experiment, involve 20 stations, equipped for gas (O_3, NO_x, VOCs,) and/or particles measurements; among them, two were installed on ships, and two mobile stations were placed according to the plume locations. The surface energy budget was measured at 9 sites to cover the landscape variety in the area; among them, four were in the urbanised area of Marseille (see below); at some sites, fluxes of trace gases (O_3, NO_x) were also measured for emission/deposition velocities computation. The basic meteorological parameters (wind, temperature, moisture and radiation) were measured on the 9 above mentioned and on 5 complementary sites. Wind profile was continuously measured on 12 sites by 7 sodars, 4 UHF and 4 VHF radars. A scanning Doppler Lidar measured the 3D wind field over the Marseille agglomeration. 3 upward pointing, and 2 scanning O_3 lidars were set-up on a SW-NE axis (main breeze axis) through the domain. 4 radiosonde systems, 2 of them capable of O_3 profiling, were activated during the IOPs. The pollutant plumes were then tracked by 33 constant-volume balloons, launched in the boundary layer from the emission areas (Marseille city or Berre pond); they were equipped with radiosondes, some of them with an O_3 probe. 7 aircraft were flown during pollution episodes; 4 (DO 128 from IMK, Germany; Fokker 27 from INSU, France; Merlin 4 and Piper Aztec 23 from Météo-France) were able to in situ document dynamics and chemistry; a ULM from IFU (Germany) measured O_3, aerosol and UV radiation; the Falcon 20 from DLR (Germany) embarked the Doppler lidar WIND; and a Piper Aztec 28 embarked an IR camera for surface temperature characterisation over the Marseille area (Mestayer and Durand 2002).

The UBL/CLU set-up

The UBL/CLU instrumentation was mainly deployed at five sites along the North-South axis of the city, roughly parallel to the shoreline. Four urban sites were equipped with micro-meteorological masts raising some 12 to 20 m above the urban canopy level, where all the turbulent and radiation fluxes necessary to monitor the canopy surface energy budget were continuously measured. The turbulent fluxes were measured at 2 levels, except at the Observatory site at only one level at 12 m above ground. The central site (CAA) was located in the rather uniform, 19th century, dense part of the city centre. It was also equipped with an array of up to 19 IR radio-thermometers, either fixed to monitor the surface temperature of selected elementary surfaces, or hand-held to evaluate surface temperature distributions during some periods of intense observation. In this urban fragment thermometers also monitored the heat exchanges between building inside and outside during some periods. Two IR radio-thermometers were also operated at the North site located in a suburban area of mixed constructions to monitor the composite surface temperatures of the ensembles immediately North and South of the site.

The two sub-urban sites (GLM and St. Jerome) were equipped with mini-SODARs sounding the atmospheric surface layer while the fourth urban site (Observatory), close to the city centre was equipped with a wind profiler UHF radar and a tethered balloon occasionally measuring thermodynamic and O_3 profiles from 20 to 300 m. Two scintillometers were set to measure the integrated heat flux over the city centre, with 2.5 km optical paths oriented N-S and E-W. At the hilly northern border of the city, the site Vallon Dol hosted a 10 m high mast with a sonic anemometer, a RASS-SODAR vertical sounder, and two 3D scanning Lidars measuring O_3 concentration, particle concentration, and wind, over a range of about 10 km. They were operated in parallel to generate tomographic observations of the urban boundary layer. The permanent set-up also included an array of 20 T-RH continuous recorders at a 6 m height over the ground, while transect T-RH measurements were occasionally made from the “T-RH Clio” car.

As concerns pollutant distributions in the urban area the measurements were essentially those of the permanent network of the air quality survey service AIRMARAIX : 12 stations within Marseille measuring the concentrations of CO, NO, NO_2, PM_{10}, hydrocarbon, O_3, SO_2. In addition, aerosols were measured at pedestrian and roof levels in the city centre (see Chapter 5).

Main results (ESCOMPTE and UBL/CLU)

All the data obtained during the campaign are included in the unique ESCOMPTE data base, managed by MediasFrance (for access, contact crob@aero.obs-mip.fr). Most measurements were recorded continuously during the six weeks of the campaign, with the exception of the SODAR which were either shut up or operated at reduced power during nights and weekends. Two types of intensive observation periods (IOP) were more densely documented:

- 5 ESCOMPTE IOPs (for a total of 15 days), generally during breeze situations. During these periods several airplanes measuring the atmospheric composition, turbulence within or at the top of the boundary layer, or wind field transects flew over Marseille to document the urban boundary layer;
- 4 InfraRed days for which airplanes equipped with a thermal infrared mapping camera scanned the urban canopy at different times in the day. The influence of

spatial resolution and sensor orientation on the surface temperature measurement were documented by flying in 8 different directions with respect to the sun over the same 3 typical city quarters, especially the city centre around the CAA site monitored by the array of IR radio-thermometers; air temperature at 2 m level was also monitored with the "T-RH Clio" driven under the flight path.

The UBL/CLU database also includes a set of satellite images, i.e., about 170 images from the NOAA-AVHRR (4 images per day from 4 June to 16 July) obtained from the HRPT (Modena, Italy); 2 ASTER high resolution VNIR, SWIR and TIR images covering Marseille (19 June, 5 July) and one the Marignane area (5 June), from the NASA Jet Propulsion Laboratory; the multi-spectral and panchromatic spot images of 17 June.

Finally this data set includes the maps obtained with the specific analysis of data base BDTopo of the IGN (French national geographic institute) which includes such urban objects as buildings, constructions, vegetation, etc. These high resolution maps include urban land uses, roughness parameters, etc.

4.4 Other related urban experiments

4.4.1 Hamburg

Field measurements were carried out at a 300 m radio transmitter tower located at the edge of a large conurbation (Hamburg, Germany). Using modern instrumentation, high resolution time series of all 3 velocity components were recorded and subsequently analysed. Spectra and integral scales of turbulence were computed and compared with theoretical curves. The results reflect the effects of an about 30 km long urban fetch on the boundary layer formation. They give guidance for the set-up of small-scale boundary layers as they are utilised in physical model studies (Pascheke et al. 2001).

4.4.2 Copenhagen

The monitoring of NO_x/NO, CO, TSP, O_3 etc. has been carried out under the Danish air quality monitoring programme in a street canyon (Jagtvej in Copenhagen and other streets) and at urban background stations during SATURN project. In addition, special measurements of pollutants – especially from traffic - were carried out under the project. The measurements included benzene, toluene and xylenes. In addition, measurements of ultrafine particles were carried out by a Differential Mobility Analyser (DMA) at the street station Jagtvej in Copenhagen, the urban background station at H.C. Ørsted Institute and the street station Albanigade in Odense. The particles were separated in 29 size fractions from 0.01 μm to 0.7 μm. The particle measurements included also PM_{10} (see Chapter 5).

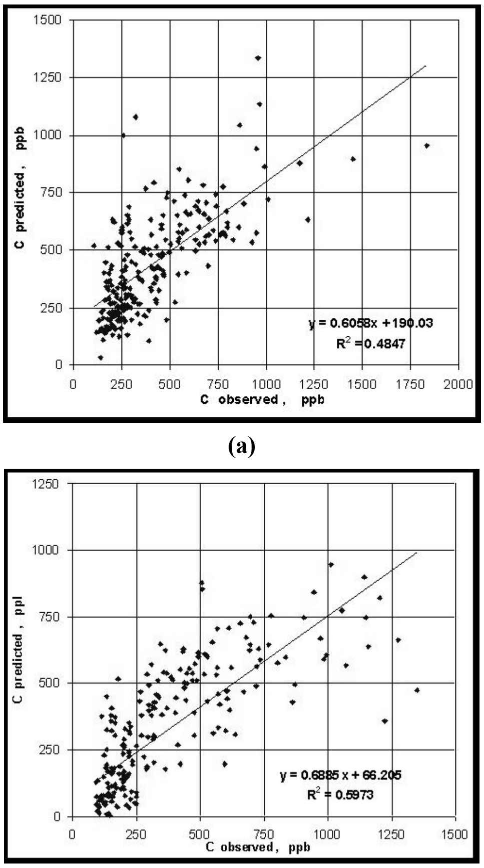
4.4.3 St. Petersburg

Since the end of 1998, two DOAS gas analysers were used to monitor continuously six pollutants, SO_2, NO, NO_2, O_3, benzene and toluene. Simultaneously, meteorological measurements were carried out on the meteorological mast installed on the roof of the building, which hosts the instruments. The monitoring site is located downtown in the street canyon of Pestelya Street with the traffic intensity up to 2000 vehicles per hour. The data collected during two years of observations with the use of DOAS instruments were processed to analyse the air pollution levels on one of the streets in the centre of St. Petersburg. These measurements show that concentrations of most of the species (except NO_2) are rather moderate and well inside the Russian ambient air quality standards. These data are directly logged into the municipal automatic system of air pollution monitoring and management, which is used by the city authorities in the decision-making on environmental issues. The results of monitoring and modelling were also used in preparation of the new version of the national guideline on dispersion modelling finalised in 2001.

4.4.4 Tel Aviv

The aim of the study was to develop and test the models for the short-term forecasting of air quality in terms of the NO_x concentration in the Tel Aviv urban area. Air quality observations were carried out within the urban area at three monitoring sites. Monitoring devices were situated on the roofs of buildings with the inlets for gas measurements at a height of about 15-20 m. The developed statistical models are based on the half-hour averaged measurements of NO_x from five new traffic monitoring stations of the Ministry of Environment located in the central area of the Tel Aviv conurbation, at the street level in proximity to the main arterial roads. The set of input meteorological data for the model development included standard ground-level meteorological parameters and data from diurnal (11:00 UTC) and nocturnal (23:00 UTC) radiosonde launches.

To forecast the morning and evening maximum NO_x concentrations, two multiple-linear regression models were developed and tested. Using an ordinary least squares method and stepwise regression, the set of predictor variables was obtained (previous day maximum concentration, wind, temperature, relative humidity, cloud cover, etc). The predictant is the maximum NO_x concentration during the morning or evening hours. Test results of one-year predictions (May 2000 – April 2001) versus observed values are presented in Fig. 4.14. The model predicted correctly 96% of the morning occurrences of the admissible NO_x concentrations (less the National Air Quality Standard level of 500 ppb) and 64% of exceeding of the limit level (> 500 ppb). The corresponding results of the evening prediction were 89% and 63%. Similar results were obtained for the period November 2001 – February 2002. Used in combination with the prognostic meteorological data, the developed regression models can be a useful tool for the urban air quality forecasting both in the morning and the evening.



(a)

(b)

Fig. 4.14. Maximum NO_x concentrations (May 2000-April 2001) **(a)** morning, **(b)** evening

4.5 Summary

During SATURN substantial effort was devoted to field campaigns in order to provide the scientific community with good quality experimental data for local and urban scale model evaluation. The field campaigns presented in the chapter are summarised in Table 4.5 emphasising the main objectives of the measurements, their duration, major parameters collected during the experiments and the data available for modellers.

Table 4.4. Short summary of field campaigns within SATURN

	Domain	Duration	Objectives	Data available
Local scale	Runeberg Str., Helsinki	1997	Model evaluation in low wind speed conditions; Studying the chemical transformation processes of NO_x and O_3	Hourly mean concentrations of CO, NO_x, NO_2, O_3 at street and roof levels; Wind speed, wind direction, air temperature, solar radiation
	Elimäki	1995	Model evaluation Studying the chemical transformation processes of nitrogen oxides and ozone	3 location, 3 heights on both sides of a road: concentrations of NO_x, NO_2, O_3; traffic densities, relevant meteorological parameters
	Nantes '99	June-July 1999	Production of turbulent kinetic energy induced by the motion of vehicles; Influence of street surface temperatures on the pollutant dispersion; Model validation used for studying the dynamic and thermodynamic structure of the urban canopy layer	Concentrations of CO, NO_x, SO_2, dust, O_3 with 15 minutes resolution at different levels, Radiation budget components, traffic counts, air temperature and temperature of walls, wind direction, wind speed, fluctuations of the three wind components
	Klagenfurt	4 month	Dispersion conditions near tunnel portals Model development and application	SF_6 with 30 minutes resolution, meteorological data.
	Podbielski Str.		Validation of microscale dispersion models	Wind speed and direction, traffic, benzene, soot, NO_2, NO, CO
	Göttinger Str.	August 2001	Validation of microscale dispersion models	Continuous measurements of air pollutants and meteorological parameters in 12 locations at street and roof levels
	London	Summer '99 Winter '00	Road user exposure to $PM_{2.5}$	Road user exposure to $PM_{2.5}$ for three modes of transport bicycle, bus and car
Urban scale	Lisbon Region-LisbEx (200×200 km^2)	July 1996, July 1997	Characterisation of meteorology and air quality during typical summer conditions; Breeze circulation in coastal zone; Atmospheric boundary layer vertical structure Model evaluation	Surface measurements of CO, NO_x, O_3, SO_2 ; temperature, relative humidity, wind speed and direction; Vertical structure up to 8000 m for pressure, temperature, wind speed, wind direction and O_3

Table 4.4. (cont.)

	Graz (26×34 km^2)	Winter 98/99, Summer 99	Dispersion conditions of cities in valleys; Influence of local wind system and strong temperature inversion on air quality; Vertical structure of the boundary layer; Model validation;	Concentrations of NO, NO_2, SO_2, TSP, CO, hourly vertical O_3 profiles; Meteorological parameters from monitoring stations; hourly vertical profiles of wind speed and direction, temperature, humidity at four locations
	Milan	7 campaigns during 1997-2001	Chemical regimes near and inside the city plume; Vertical chemical characterisation; Urban aerosol formation;	Ground level and vertical profiles (0-1000m) of wind, turbulence and temperature, Concentrations of NMHC, C2-C9, HC, BTEX, CH_4, aldehydes, carbonyl compounds, PM_{10}, $PM_{2.5}$, CO, NO_x, O_3, H_2S, SO_2, HNO_3, HNO_2; Vertical profile of O_3 and aldehydes
	Marseille ESCOMPTE, UBL/CLU (100×100 km^2)	June-July 2001	Meteorological and chemical conditions prevailing during photochemical episodes Four-dimensional structure of Urban Boundary Layer Database to test urban energy exchange and high resolution meteorological and chemistry-transport models	Concentrations of O_3, NO_x, VOCs, PM_{10}, SO_2; emission/deposition velocities of trace gases (O_3, NO_x), vertical thermodynamic and O_3 profiles, Meteorological basic parameters (wind, temperature, moisture and radiation), surface energy budget, turbulent and radiation fluxes at different heights within urban canopy level, heat exchanges between building inside and outside
Monitorring type	Hamburg		Provide guidance for the set-up of small-scale boundary layers used in physical models	3 wind velocity components at 300 m height
	Copenhagen		Air quality in street canyons	NO_x/NO, CO, TSP, O_3, benzene, toluene, xylenes, PM_{10}, ultrafine particles of 29 size fractions
	St. Petersburg	Since 1998	Guidance for the city authorities in decision making on environmental issues	SO_2, NO, NO_2, O_3, benzene, toluene; meteorological parameters
	Tel Aviv	1999-2002	Diurnal, weekly and season variation of pollutants, Short-term forecast	NO_x, NO_2, O_3