Chapter 10: Conclusions

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10.1 Achievements of SATURN

The major scientific achievement of SATURN is its contribution to a better understanding of physical processes occurring in the urban atmosphere. Such processes are nowadays evident in most numerical simulation models and an extensive database of laboratory experiments exists within which these processes are present. In particular, research in SATURN led to an improved scientific knowledge of the spatial and temporal characteristics of urban air pollution in Europe. The associated investigations led to the identification of critical meteorological conditions responsible for severe air pollution episodes in conjunction with the specification of the regions where these episodes occur. Emphasis was put on the study of circulations that are associated with low wind conditions and thermal effects. Towards this aim, high-quality experiments were performed and modelling tools were improved and developed, including novel multi-scale model cascades.

Concerning air pollutant emissions, a harmonised method for compiling urban emission inventories was developed in SATURN. Guidelines developed include the methodology requirements on data resolution and emission factors. A protocol for qualitative and quantitative comparisons of emission inventories was also established. Individual studies confirmed that suitable combinations of NO_x and VOC emission reductions are needed for an effect-oriented and cost-effective strategy aiming at the reduction of ozone. For this reason, special emphasis was put on assessing the effectiveness of ozone precursor emission reductions at the local and regional scales.

Field experiments led to a better insight into the characteristics of polluted urban air. There was special focus on the particulate pollution, including:

- the assessment of contributions from various pollution sources due to human activities (e.g. traffic, industry) and biogenic emissions (e.g. sea salt aerosols);

- a better understanding of the particulate matter characteristics (size distribution, chemical composition, transport properties etc); and
- an improved knowledge on important processes such as the suspension of particles from deposited road dust.

Specifically, it was found that the PM_{10} mass and most of the analysed species are dominated by the fine fraction. Traffic is the dominating source of ultra-fine particles in busy streets, while also having a significant contribution to PM_{10}.The application of averaged PM data, collected continuously, in combination with routine monitoring data and manually counted traffic rates, was found to be a powerful tool to determine the contribution and emission factors of particles from diesel and petrol vehicles from the actual car fleet under normal driving conditions. The method may prove useful for demonstrating the effect of air pollution abatement measures.

Other experiments concentrated on photochemical pollution especially in South Europe revealing pathways that lead to secondary particle generation. Regarding the chemical composition, the coarse mode (composed of sea salts and nitrates) is most important at the beginning of the event, but decreases strongly when the pollution increases, to become much lower than the accumulation mode. The latter mode is totally dominated by sulphates and ammonium and the smaller particles of this mode become progressively more important during the event. The focus of other experiments was the investigation of the thermal characteristics of the urban atmosphere and their effects on the boundary layer flows and structure.

Improvement of receptor modelling techniques within SATURN has led to the more accurate estimation of source-receptor relationships for various pollution sources in urban areas and their surroundings. A better knowledge on the relative contribution of individual sources is a prerequisite for cost-effective control strategies.

Urban scale dispersion models were refined in the framework of SATURN. Efficient interfaces were developed for linking such models to suitable regional scale models. In addition, improved parameterisation methods were developed and numerical techniques were refined. Work included evaluating the aerosol behaviour in urban areas using detailed chemical and aerosol dynamical models. In addition, transport-chemistry models for the evaluation of emission reduction strategies, for providing information to the public, and as the central part of models for forecasting episodes and for the calculation of human exposure were developed. SATURN has shown a special interest in the issue of air pollution exposure, providing measurements and modelling systems that can be used in traffic and urban planning, in environmental management and in analysing the health effects of air pollution.

Both the concept and the application range of local scale models progressed significantly within the framework of SATURN. Applications included simulations of the air motion, turbulent field and heat fluxes close to building walls, as well as their effect on pollutant dispersion. The investigations of several SATURN groups on the effects of buildings on the developed airflow within the street have shown the essential role of the street and building geometry on the ventilation and air pollution dispersion from the street. Vehicle induced turbulence within the street corresponds to an important influence of traffic on the dispersion characteristics. The numerical results show the importance of the measuring position when models are to be evaluated thus suggesting the significance of an adequate siting of urban monitoring stations. Computational Fluid Dynamical (CFD) modelling may prove useful for recommendations regarding suitable monitoring sites.

SATURN led to significant progress of the state-of-the-art with regard to model quality assurance. A straightforward procedure for evaluating local scale models has been formulated based on discussions between numerical model developers and experimentalists. It is characteristic of the urban canopy layer that the velocity and concentration fluctuations are larger than the corresponding mean values causing a large inherent uncertainty in the data, and this needs to be quantified before the data can be used for validation purposes. A methodology for the quantification was developed and applied. On the other hand, wind-tunnel experiments have been carried out to quantify how numerical model results depend on domain size and geometrical resolution. Furthermore, valuable new knowledge regarding quality assurance of urban scale models resulted from intercomparison and validation activities, an example for the latter category being ESCOMPTE_INT, an exercise based on the ESCOMPTE pre-campaign data sets.

Work performed in SATURN elucidates the great potential of remote sensing with regard to urban air quality management. Apart from the demonstration of monitoring approaches based on remote sensing, it was shown that interferometry may contribute to the better representation of terrain elevation and land use and the provision of reliable information on roughness and building configurations.

Knowledge and tools acquired in the framework of SATURN were integrated in order to make them directly suitable for applications related to environmental policy and to support urban air quality management. Gradually, the integrated tools for modelling and predicting air pollution improve in quality and efficiency, while novel telematics techniques are being applied for informing the public on air pollution. Moreover, methods for the air quality forecasting have been developed and improved with special emphasis to those concerning ozone forecast.

The policy relevance of the above scientific achievements is obvious, given their direct influence on the formulation of improved tools for urban air quality assessments. Hence, in the last few years new methods to determine the contributions of various sources to air pollution in conurbations were developed and existing ones were improved. Such methods may be utilised by urban authorities wishing to have insight into the possibilities of reducing air pollution levels or in controlling anticipated increases of those levels. Furthermore, methods were refined for the prediction of the effect of long-term emission changes. Such methods may considerably help formulating and evaluating air pollution abatement strategies.

10.2 Remaining gaps of knowledge

Despite the scientific progress achieved in SATURN, several issues related to urban air pollution have not yet been fully explored. Examples are photochemical air pollution in South European cities and particulate matter in conurbations. Moreover, more effort is needed to arrive at reliable hotspot assessments. This refers to both local scale emission estimates and appropriate multi-scale dispersion modelling approaches. In particular, the following appear to be the remaining gaps of knowledge:

- Pollutant emissions due to real traffic behaviour. Much more detailed information is required for delivering appropriate emission estimates for local scale problems, typically investigations of traffic flows between crossings, traffic signals, etc. Research should focus on the description of the actual vehicle fleet, a better knowledge on the engine working conditions and obtaining access to instantaneous emission data.
- Sources of PM_{10} and $PM_{2.5}$ affecting the urban atmosphere. Knowledge of local emissions and regional transport of PM_{10} and $PM_{2.5}$ is limited and associated emission inventories are at an early stage of development. The formation and regional transport of secondary particles are so far only poorly understood. Such mechanisms are inadequately treated in present modules and the few models that include the description of particle formation and transport were not yet properly evaluated and tested.
- Physico-chemical properties of urban aerosol. More knowledge is needed regarding the chemical and physical properties of the particles (EC, OC, PAH, metals etc.), e.g. surface properties, volatility, hygroscopicity, morphology. For this purpose it is necessary to apply advanced analytical techniques. Also the process of nano-particle formation has not been unambiguously determined. In this context it is recommended to establish a systematic urban network in Europe for the monitoring of fine particles (including their size distribution and chemical composition) in order to achieve a more detailed and region-depending picture of the origin and potential risks associated with particles.
- Assessing the impact of urban sources vs. long-range transport with regard to urban air quality. Dispersion and transformation processes at the local scale differ considerably from those at the urban and regional scales. Future research should concentrate on novel simulation methods based on nested domains with different models in order to accurately predict to what extent air quality in various city parts is affected by sources within the city boundary or can be attributed to long-range transport.
- Prediction of pollutant concentrations at hotspot locations. Further research is needed for understanding processes taking place during the residence of pollutants in the urban canopy. Furthermore, more effort is necessary for better simulating local phenomena observed in the vicinity of buildings, such as thermal

convection due to the heating of the ground and walls and traffic induced influences.

- Disparity between sophisticated models and tools needed for legislative purposes. Obtaining reliable predictions of concentration fields inside the urban canopy layer is not straightforward. The more sophisticated CFD codes available for that purpose are still relatively new and mostly in their development phase. The fitness for purpose of these models was demonstrated at the example of rather idealised cases only. The prediction of concentration levels for detecting exceedances of limit values is hardly possible at the temporal and spatial resolution required by the existing air quality legislation. The simple models, on the other hand, lack sufficient physical foundation. Targeted efforts are needed to close the gap, primarily towards adapting scientific models to regulatory needs.

- Quantitative level of confidence of model predictions. The widespread use of urban scale models in various countries in Europe requires a comparable increase of co-ordinated international initiatives aiming at the verification of model quality, model evaluation and setting standards on their performance. A standardised quality assurance procedure would give clear guidance to developers and users of urban air quality models as to how to properly assure the quality of their models and results. In this respect, activities towards model intercomparison and validation may prove extremely helpful.

- Need of data in support of model quality assurance work. SATURN started to provide suitable and quality-approved data for model validation purposes in a convenient and generally accessible form. In general, however, such data refer to rather idealised cases with simple geometries. In parallel to the increasing potential of numerical models, more and higher quality data will be required for meeting the needs of complete evaluation procedures.

- Integrated assessment framework. A robust methodological framework for integrated assessment at the local and urban scales is still lacking. Specifically, the linking between traffic modelling, emissions modelling, dispersion modelling and personal or community exposure modelling could be regarded as weak. Also the combined and fully integrated use of measuring and modelling for assessing air quality is still in its infancy. The associated disciplines tend so far to act independently.