Assessment of benzene emissions and concentrations in the City of Antwerp using the urban air quality model AURORA

Contribution to subproject SATURN

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Summary

For the assessment of air quality in cities, we developed an *integrated modelling system*, named AURORA (**A**ir quality modelling in **U**rban **R**egions using an **O**ptimal **R**esolution **A**pproach). This air quality management system has been designed for urban and regional policy support and reflects the state-of-the-art in air quality modelling, using fast and advanced numerical techniques. Modules for meteorological input data, emissions, advection, diffusion and chemistry have been designed, tested and coupled by means of a user interface. The model system is implemented in the cities Antwerp and Hasselt (B) and is applied in two EU 5th framework projects (BUGS, DECADE).

The AURORA model has been used to compute benzene concentrations for a large number of streets in the City of Antwerp, Belgium. The results are compared with diffusive sampler measurements carried out in 101 street locations in Antwerp, during four periods of five days in 1998. Calculated benzene concentrations based on hourly emissions obtained for 1963 road segments in Antwerp show a very good agreement with the results of diffusive sampler measurements when averaged over periods of 5 days and over all streets. A streetwise comparison of measured and calculated benzene concentrations is needed to provide a more detailed comparison.

Aim of the research

The assessment of the air quality in urban regions, was the main the objective of our activities within SATURN. This included:

1) The evaluation of heat fluxes of the urban area based on satellite observations;
2) The estimation of atmospheric stability with satellite remote sensing data;
3) The development of an emission inventory for specific urban environments;
4) The development and refinement of existing modelling tools for these urban environments;
5) The provision of a case study data sets (emissions, meteorology and immissions).

Activities during the year

A methodology has been developed and presented (Mensink and De Ridder, 2000) which can be used to determine atmospheric stability parameters in urban and remote areas where ground based meteorological observations are not routinely available. The method resolves the surface energy balance by means of satellite remote sensing in an original way. Ground based data from the FIFE experiment are used to validate parts of the methodology.

An urban transport emission model has been developed for the City of Antwerp (Mensink et al., 2000). Hourly emissions of CO, NO_x, VOC, PM, SO_2 and Pb are provided for individual streets and road segments in the Antwerp area (20 km x 20 km). The hourly emissions are computed in function of road type, vehicle type, fuel type, traffic volume, vehicle age, trip length distribution and the actual ambient temperature. The traffic volumes are derived from an urban traffic flow model for the City of Antwerp, which contains a network with 1963 road segments. The emission factors used in the model are derived from the COPERT-II methodology. Cold start emissions and evaporation losses are included in the model. Recently (2001) the methodology has been updated to COPERT III standards and extended in such a way that it can be applied to other cities in Flanders and to the complete traffic network covering the whole of the Flanders region.

The urban transport emission model was integrated in the urban air quality management system AURORA (Mensink et al., 2001). It was coupled with a recently developed advection-diffusion scheme (Walcek, 2000), three (optional) chemistry modules (CB-IV, EMEP, RACM), a deposition module and a new analytical model for the evaluation of air pollution in street canyons (Mensink et al., 2002). A user-interface ensures the coupling of the modules and allows the user to define the characteristics of his simulations, to specify emission scenarios and to visualise the results.

A case study for benzene in the Antwerp area has been developed. It is based on a measurement campaign for benzene at 101 locations in the city over the period of 23-27 March 1998. A comprehensive data set is in construction. This data set will include emission data, nested meteorological data and measurement data.

Principal results

The AURORA model has been applied to calculate benzene concentrations in the City of Antwerp for four periods of five days in 1998. For these periods diffusive sampler measurements were carried out in 101 streets in Antwerp and at 4 regional background locations (Geyskens et al., 1999). The measurements were carried out in the framework of a European LIFE project (LIFE96ENV/IT/90) called MACBETH (Monitoring of Atmospheric Concentrations of Benzene in European Towns and Homes). The project included benzene measurements in 6 European cities (Antwerp, Copenhagen, Rouen, Murcia, Padova and Athens).

Emissions were calculated for 1963 road segments, using the urban transport emission model for the Antwerp area, described in detail by Mensink et al. (2000). This emission model computes hourly benzene (and other) emissions for individual streets in the Antwerp area (20 km x 20 km) in function of road type, vehicle type, fuel type, traffic volume, vehicle age, trip length distribution and the actual ambient temperature. Cold start emissions and evaporation losses are included in the model.

The benzene concentrations were calculated by the analytical street canyon model (Mensink et al., 2002), in which a uniform street concentration C (µg m^{-3}) is expressed by:

$$C - C_b = \frac{Q}{U_{\equiv} \cdot \left(\frac{H}{L}\right) \cdot W + (D + \ell U_{\perp}) \cdot \left(\frac{W}{H}\right)} \tag{1}$$

where Q is the emission source strength per unit length (µg m^{-1} s^{-1}), C_b the background concentration (µg m^{-3}), H is the height (m), W the width (m) and L the length (m) of the street.

In equation (1) the wind speed parallel to the street $U_{\circ}$ (m s^{-1}), is responsible for the "ventilation" of the street box, whereas wind speed perpendicular to the street $U_{\wedge}$ (m s^{-1}) is responsible for the vertical exchange of the pollutant over a characteristic length ℓ. This characteristic length ℓ can be associated with a typical mixing length caused by turbulent eddies shedding off at roof level. It is set to ℓ = 1 m. D is the diffusion coefficient (m² s^{-1}), which can play a role at low wind speeds as shown by Copalle (1999). He suggests a value of D = 1.5 m^2 s^{-1}.

In the calculations for the streets in Antwerp, an average street aspect ratio of 1 was assumed. The hourly values for wind speed and wind direction were obtained from two meteorological towers located in the city. Wind speed at roof level was calculated from a wind profile described by a power law, with the exponent derived from the wind speed measured at heights of 30 m and 153 m respectively. The measured averaged regional background benzene concentrations were used to estimate C_b. Figure 1 shows the calculated temporal evolution of benzene emissions and concentrations from Monday 23 March at 1h00 to Friday 27 March 24h00. Table 1 shows the measured and calculated benzene concentrations for four different periods of five days (Monday – Friday) in 1998.

Table 1: Averaged measured and calculated benzene concentrations for four different periods of five days (Monday – Friday) in 1998 (N is the number of sample locations)

Period	Measured back-ground concentr. (µg/m³)	Measured concentration in streets (µg/m³)	Measured Standard deviation (µg/m³)	Calculated concentration in streets (µg/m³)
	(N=4)	(N=101)	(N=101)	(N=1963)
19-23 January	1.8	3.3	± 0.9	3.26
23-27 March	1.8	3.1	± 0.8	3.11
25-29 May	1.3	2.6	± 1.0	2.53
28 Sep – 2 Oct	1.7	3.0	± 0.9	2.90

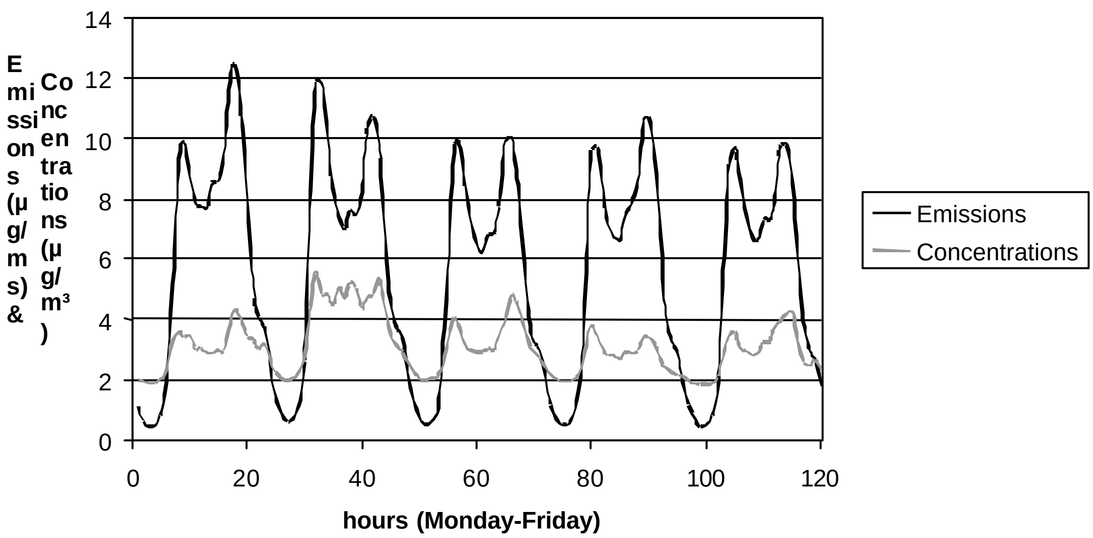

Figure 1: Benzene emissions (upper) and concentrations (lower) in Antwerp, 23 – 27 March 1998.

Main conclusions

AURORA is an integrated air quality modelling system that has been designed for urban and regional policy support, using fast and advanced numerical techniques. Modules for meteorological input data, emissions, advection, diffusion and chemistry have been designed, tested and coupled through a user interface. Calculated benzene concentrations based on hourly emissions obtained for 1963 road segments in Antwerp show a very good agreement with the results of diffusive sampler measurements when averaged over periods of 5 days and over all streets.

Aims for the coming year

Completing the case study for benzene in the Antwerp area, i.e. preparing a data set with the results of the measurement campaign for benzene at 101 locations in the city over the period 23-27 March 1998, the emission data and nested meteorological data (up to 1 km resolution). This data set is to be made available for other modelling groups.

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