14.2 INVESTIGATING THE IMPACT OF CHANGES IN TRAFFIC EMISSION STRCUTURES ON URBAN AIR POLLUTION WITH A NESTED MODEL SYSTEM

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1. INTRODUCTION

In relation to the health damage potential of atmospheric trace gases, air quality is one main indicator for quality of life in an industrial conurbation. In the last years, several administrative attempts were made to reduce the emissions of air pollutants, but these steps are opposed in part by an increasing demand for energy. In particular, reduction of ozone precursors (e.g. NO, NO_2 and VOC) is an important objective due to their potential of causing photochemical smog. An outstanding problem in this context is the individual traffic. According to a predicted increasing traffic volume, the environmental effects of motor vehicles intensify, in spite of improved, emission reducing automotive technology.

The spatially and temporally highly variable character of emissions, and the fact that many of the emitted species undergo chemical reaction processes during their transport through the atmosphere, inhibits an exclusively observational quantification of traffic emissions. For that reason the effect of air pollutants can more profitably be estimated by a combination of emission inventories, models of atmospheric dynamics and air chemistry.

Hence, to study the impact of traffic based emissions on urban air quality and the potential benefit of reduction strategies, a high resolution dynamic traffic model is applied, which is coupled with nested models of the atmospheric chemistry and transport.

2. THE CARLOS MODEL SYSTEM

For the simulation of pollution episodes in urban and industrial areas only local-scale information is not sufficient, since local air pollution is the result of temporally and spatially varying emissions as well as of meteorological and chemical processes on various scales. To take these circumstances into account the model system CARLOS (**C**hemical and **A**tmospheric transport in **R**egional and **LO**cal **S**cale; Brücher 2000) was developed at the IGMK which describes the complex relationship between release and transmission of gaseous pollutants in the atmosphere. This model system *(see figure 1)* has multiple-nesting capabilities which allow to account for large scale meteorological features and concentration patterns while simulating local scale structures in nested regions.

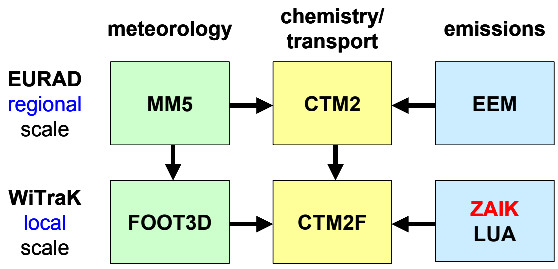

Figure 1: *Schematic chart of the CARLOS model system, including data flow. Additionally, each model can be nested in itself.*

On the regional scale, the EURAD system (**EUR**opean **A**ir Pollution **D**ispersion Model; Hass 1991, Jakobs 1995, Kessler et al. 2001) is applied to consider transport processes at different scales, making use of model nesting technique. The coarse model domain covers Central Europe with a horizontal resolution of 27km. Two subsequent nesting steps follow, from the first nest (Western Germany, 9km resolution) down to 3km resolution in the second nest domain, covering North-Rhine Westphalia. The output of the meteorological model MM5 is used as input to the chemistry transport model (CTM2). The emission inventories therefore required are provided by the emission module EEM, including information about the emitter groups traffic, house firing, industry and biogene emissions.

The results of these simulations serve as boundary conditions for the WiTraK system's (Brücher 1999) small scale high resolution models (FOOT3D/CTM2F), which are capable to simulate flow and pollution pattern e.g. on the scale of urban districts. On this local scale with a horizontal model resolution of presently 1km, a microscopic dynamic traffic simulator ('queuing model'; Eissfeldt 2002a) is employed at the Center for Applied Computer Science (ZAIK) to calculate highly resolved emission inventories for pollutants generated by traffic. Other emission data and air measurements were provided by the State Environmental Agency of North-Rhine Westphalia (LUA NRW).

By simulating individual routes for single vehicles in a road network, the ZAIK model takes into consideration e.g. interactions of the road users and even traffic jams (Gawron 1998). The design of this model also enables studying the impact of local administrative regulations, or municipal development planning on traffic flow and the related emissions. Due to its computational efficiency, it is suitable to

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calculate car emissions on the basis of individual vehicle units in a reasonable time, even for huge networks (about 10^6 cars).

3. APPLICATION TO THE COLOGNE AREA

Presently, on the local scale, special emphasis is given to nitric oxides (NO_x) and hydrocarbons (HC) emitted by vehicles in context with summertime ozone (O_3) production. Therefore, a period of August 1997 with high ozone mixing ratios in Central Europe and in the state North-Rhine Westphalia (Nest 2) was chosen and simulated with the EURAD model system on the regional scale *(for example see figure 2)*.

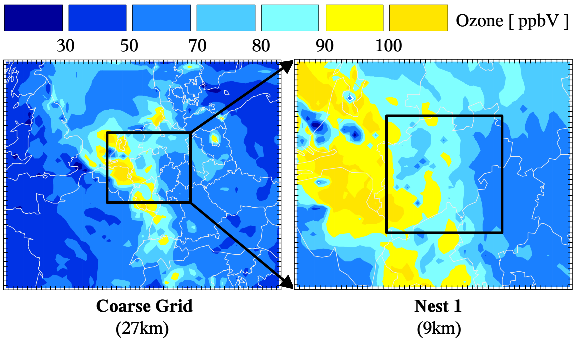

Figure 2: *Near surface mixing ratio of ozone [ppbV] in the coarse and in the first nest domain at 14 UTC, 13 August 1997 (EURAD CTM2 model output). The black rectangles refer to the nesting domains N1 and N2 respectively.*

The complete CARLOS model chain was first successfully applied to the city of Wuppertal in Germany (Brücher 2000). In this study, Cologne and its surroundings was chosen as an example for a Central European industrial conurbation. The complex, topographically structured terrain as well as the agglomeration of pollutant emitters makes this urban area an interesting domain for air quality modeling. Figure 3 shows the model domain for the local scale simulations (third nest). The Cologne area is characterized by channeling of the wind flow along the valley of the river Rhine (in the middle of the model domain) and the adjacent hills.

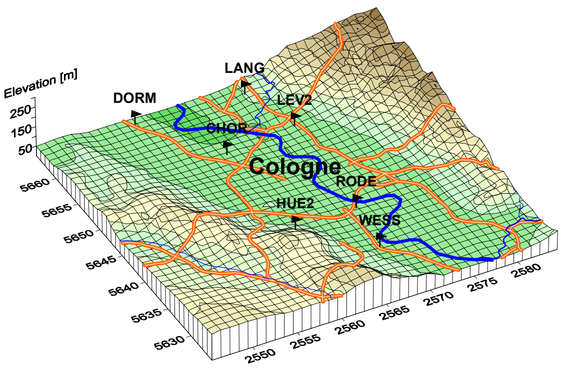

Figure 3: *Cologne Area. The local model domain covers an area of 40x40km^2 with a horizontal resolution of 1kmx1km. Orange lines mark the motorways around Cologne, rivers are in blue and the measurement sites of the LUA NRW are also displayed.*

The regional part of the CARLOS model system is appropriate for providing regional flow and pollution patterns required for local scale simulations. In general, model results e.g. for near surface ozone compare reasonably well with the measured data (see figure 4 for Cologne Chorweiler). However, during nighttime the model and particularly the coarse grid simulation overestimates ozone mixing ratios. The reasons for this deviation probably rely on insufficient grid resolution in comparison to the area represented by point measurements and inaccurate emission data. At Saturday (9.8.1997) in contrast, maximum values of ozone are clearly underestimated by the regional model system EURAD.

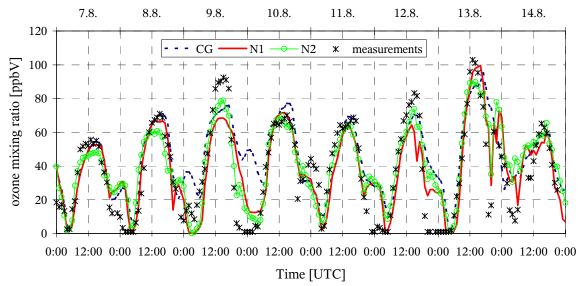

Figure 4: *Comparison between the near surface mixing ratios of ozone [ppbV] in the coarse, first and second nest domain (EURAD CTM2 model output) during the selected episode of August 1997 and the measurements at the site Cologne Chorweiler (CHOR, see figure 3).*

To enhance model resolution and accuracy the local part of CARLOS is applied to the Cologne area. In this third nest domain, the temporally and spatially high resolution traffic emission inventory of the ZAIK model for the city area *(see figure 5)* is used. The missing areas of the dynamic model are filled with traffic emission data from the LUA NRW.

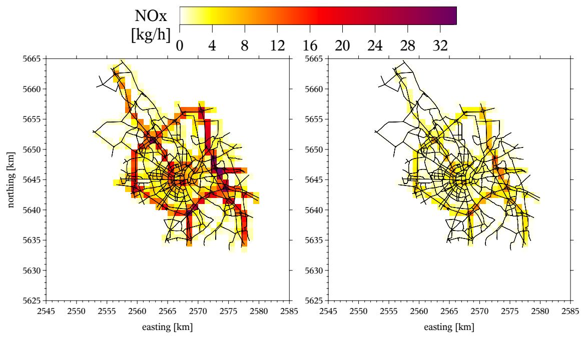

Figure 5: *Computed spatiotemporal amount of NO_x per 1km^2 grid box, emitted by street traffic on a typical workday around the city of Cologne at two different daytimes. The black lines represent the road network used for the ZAIK traffic simulations.*

Figure 6 shows an example of the chemistry transport calculations in the second and the third nest domain for 14 UTC, 13 August 1997. The local scale simulation includes the emissions calculated by the dynamic traffic model. High pressure over Eastern Europe and week easterly winds were dominating during this ozone episode. Therefore, the result for nest 3 shows a detailed, structured ozone pattern with comparable low values along the motorways and the inner city. This effect is caused by the local dumping of fresh NO-emissions by vehicles and the subsequent titration effect on ozone. There are also remarkably low ozone mixing ratios to the south of the site Cologne Rodenkirchen (RODE) along the loop of the Rhine, where many petrochemical industries (strong NO_x-emitters) are located.

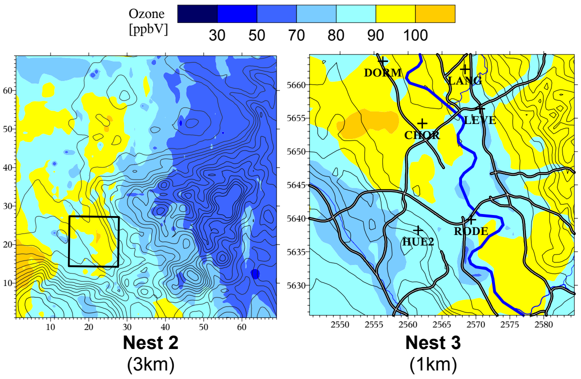

Figure 6: *Near surface mixing ratio of ozone [ppbV] in the second nest domain (EURAD CTM2, left) and in the Cologne area (CTM2F model output, right) at 14 UTC on 13 August 1997. The black rectangle on the left refers to the location of the local nest domain N3 to the right.*

The calculated traffic based emissions together with the other emitter groups provide a highly resolved data set which describes the present state of air pollution in the Cologne area. The specified *base case scenario* which is reproduced well by the model system acts as starting point for further investigations with fictitious but realistic traffic scenarios in the city of Cologne. One of these traffic scenarios simulates e.g. the impact of the intended motorway expansion around Cologne on the emission structure and possible consequences for air quality within the city. Two examples are presented in the following section.

4. SCENARIO SIMULATIONS

4.1 *Simulated Traffic Based Emission Data*

Starting from the base case simulation (scenario 0) with the traffic flow of a typical Monday, several scenarios are defined and calculated with the dynamic traffic model. Scenario 1 and 2 investigate the influence of traffic flow management on local emission exposure within the Cologne urban area. Two highly frequented bridges over the Rhine within the inner city are blocked for street traffic inside the dynamic model domain. Additionally, a speed limit reduction of 20km/h on all non-motorway roads is applied in scenario 1. The results of the emission calculation of the dynamic model for the different scenarios are presented in figure 7. The total emission of traffic based pollutants increases in both scenarios, because the model drivers have to go a long way round to get to their final destinations. Moreover, the results show that reduction strategies are only applicable on specified pollutants due to opposite effects on the related emissions caused by motor design, e.g. the reduced tempo limit leads to higher HC-emissions but only slightly increased NO_x-emissions in scenario 1.

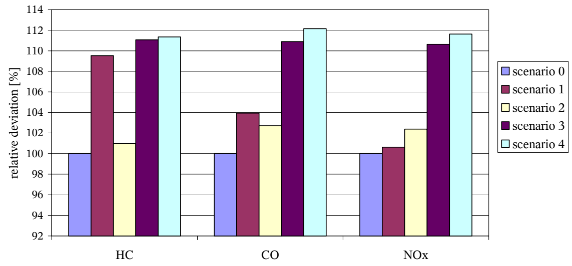

Figure 7: *Impact of different local administrative traffic regulations on the total emission amount of hydrocarbons (HC), carbon monoxide (CO) and nitrogen oxides (NO_x) within the dynamic model area. For scenario definition see text above.*

Scenario 3 and 4 simulate the effect of an increasing demand for individual traffic within Cologne about 15%. In scenario 4 the motorway ring around Cologne was expanded to three lanes, as it is actually planned by local authorities expecting a rise in traffic about this value during the next years. As a result of a rather undisturbed traffic flow the emissions should decrease but quite the contrary, emissions are increasing (see figure 7). Figure 8 shows that the expansion of the motorways induces additional traffic within the dynamic model. Due to the advanced flow conditions drivers can diminish their personal travel time on the expanded motorway and therefore accept a loop way to their destinations (Eissfeldt et al. 2002b).

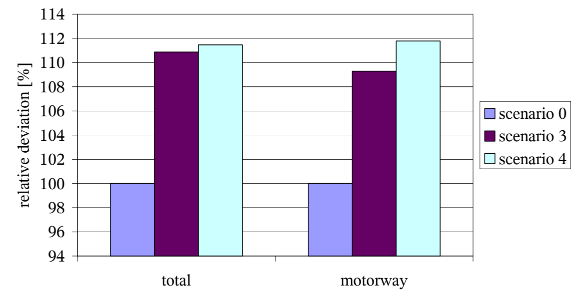

Figure 8: *Relative deviation of CO_2-emissions from the base case (scenario 0). For scenario definition see text above.*

4.2 *Local Scenario Simulations*

The above described traffic scenarios are used as input to the local scale air chemistry model CTM2F to investigate the impact of these traffic regulations on the formation especially of secondary air pollutants. As expected, the scenario results for primary emitted pollutants show the largest deviations to the base case simulation during rush-hours along the actually forced or preferred routes. Secondary pollutants like ozone show only slight differences to the base case during morning hours, though in the afternoon deviations along the alternative routes are increasing.

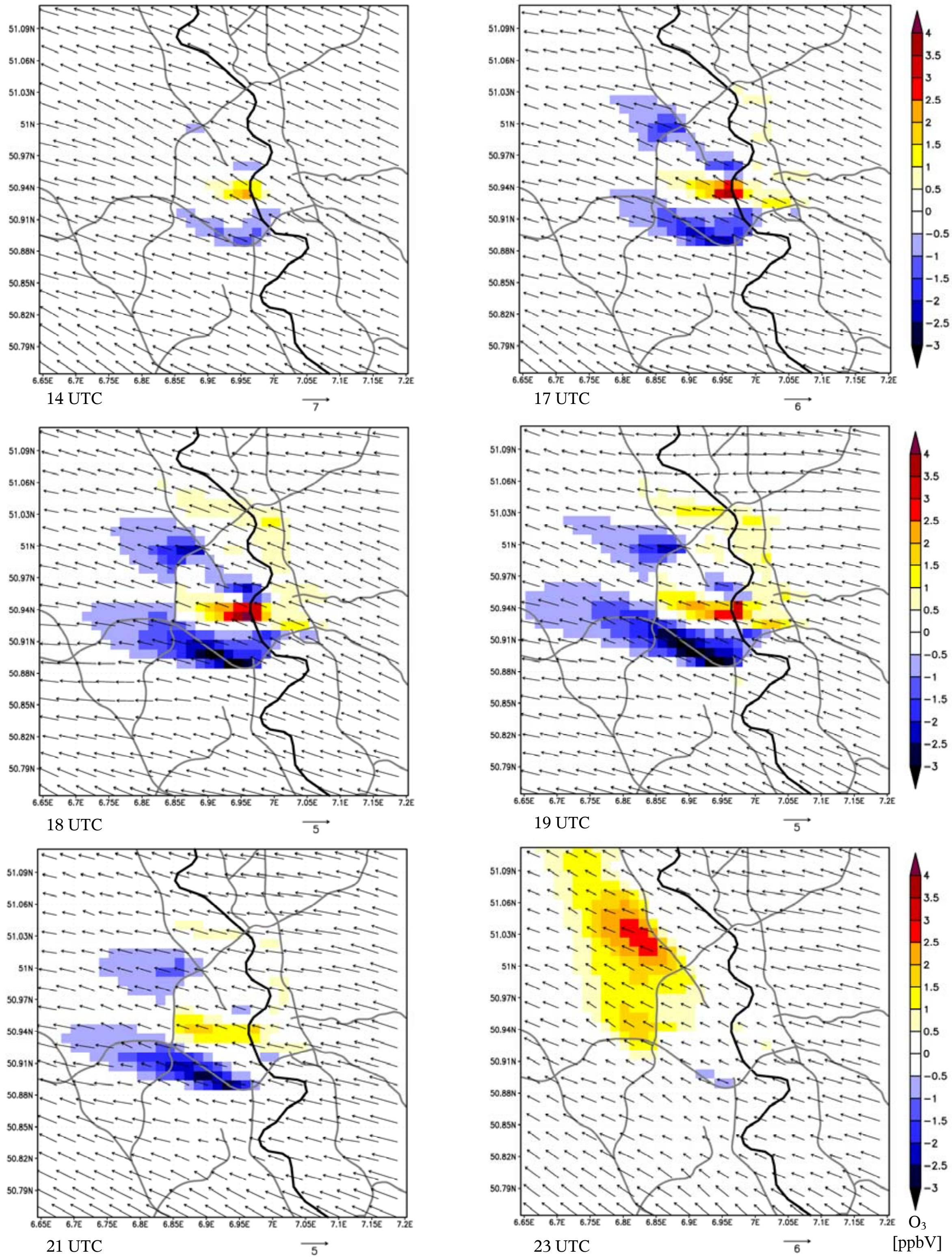

Figure 9: *Time series of horizontal wind and difference in ozone mixing ratio [ppbV] (scenario 1 – scenario 0) in the lowest model layer on 11 August 1997.*

These deviations are not limited to areas which are locally affected by changes in emission structure. On 11 August 1997, in scenario 1 the influence propagates with the wind flow in westerly directions and affects besides the close-up range of the inner city a wider area (see figure 9). In this figure, the location of the two closed bridges can be identified by higher ozone values in the afternoon near the Rhine. As a result of the blocking and the consequential detouring, the southern part of the motorway ring shows lower ozone values in scenario 1 in comparison to the base case (the same is valid for scenario 2, not shown). According to this, provisions like the example presented above probably not only do shift peak emission center but also lead to additional pollution by secondary pollutants in other regions. In the case of ozone in scenario 1, deviations to the base case in calculated values add up to –27% and +54% respectively.

In scenario 3 and 4 the increased traffic within the city area produces only small changes compared to the base run during the simulation (<-1% and –8% at low ozone levels). At rush hours the maximum difference in ozone mixing ratio between scenario 4 and base case amounts to –4ppbV (see figure 10). In the prevailing chemical regime the increasing of local traffic based emissions does not result in enhanced ozone formation due to a slight VOC-limitation of the air mass.

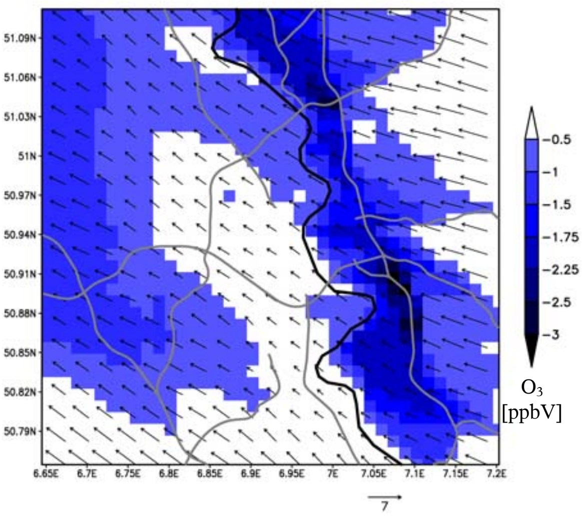

Figure 10: *Horizontal wind and difference in ozone mixing ratio [ppbV] (scenario 4 – scenario 0) in the lowest model layer at 05:30 UTC on 11 August 1997.*

The difference between scenario 3 and 4 is not highly pronounced. Like the calculated emissions, the simulated secondary pollutants show no advantage of the motorway expansion (maximum difference 1.5ppbV in the case of ozone). In scenario 4 the expanded motorway is preferred by drivers to inner city roads. In particular the southwestern part is more frequented which results in locally enhanced ozone depletion. Accordingly, at afternoon rush hour the city center shows smaller ozone values in the case of scenario 3 and higher levels along and leeward the motorway ring. Considering this result, the expansion of the road network seems not to be an appropriate means to improve air quality in metropolitan areas. However, the expansion of the motorway ring around Cologne is claimed by many local politicians under reference to positive environmental effects.

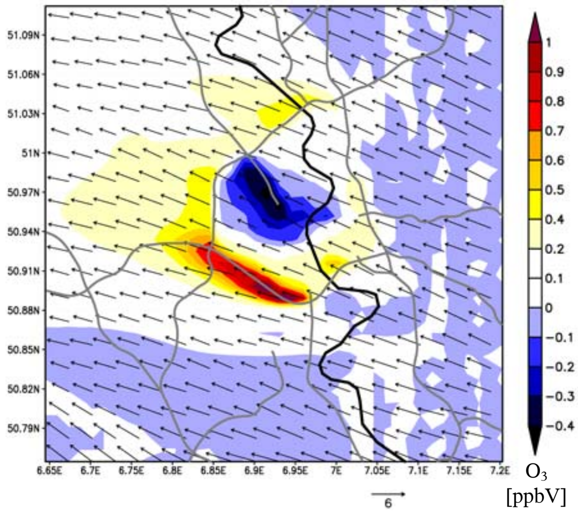

Figure 11: *Horizontal wind and difference in ozone mixing ratio [ppbV] (scenario 3 – scenario 4) in the lowest model layer at 17 UTC on 11 August 1997.*

Further investigations indicated that the effects of changes in the amount of traffic based emissions (such as increase or reduction scenarios) unlike changes in local emission structures cannot be considered exclusively on the local scale. The long-distance transport of air masses and pollutants is a dominant factor for air pollution modeling. Therefore, in an advanced study, additional scenarios were defined which combine local and regional changes of traffic based emissions.

5. CONCLUSION

The air quality model CARLOS, including a microscopic dynamic traffic model, shows the advantage of applying a complete hierarchy of models for local air pollution assessment. The presented model system provides the capability to describe meteorological and transport phenomena in a wide range of temporal and spatial scales.

The impact of changes in emission structures on air quality in the metropolitan area of Cologne was investigated by different scenarios for the urban area which describe various municipal plans or development potentialities. Basis simulations as well as scenario calculations reveal a high sensitivity of model results to emission variation. Local changes in traffic based emissions have an obvious impact on chemical production of secondary pollutants. The chemical regime in the Cologne area turns out to be slightly VOC-limited so that a reduction of traffic based emissions gives rise to increased ozone formation (Sentuc 2004). Provisions for an advanced traffic flow by the extension of the motorway ring around Cologne do not produce improved air quality. The effect of emission reduction caused by an undisturbed traffic flow is more than compensated by the induced traffic. The results of a detailed study show that local scenarios cannot be treated without taking into account the surrounding area due to the transport of air pollutants. The specification of concentrations at the boundaries significantly affects the processes within the inner model domain. As a result of the implemented nesting technique, the model system CARLOS is appropriate for the observance of these aspects of air chemistry on all scales that have to be considered while simulating the formation of secondary pollutants in the atmosphere.

Acknowledgments

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