

Origin and influence of PM₁₀ in urban and in rural environments

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Abstract. The paper presents an estimate of emission source influence on PM₁₀ concentrations in Berlin. Particulate matter less than 10 μm in aerodynamic diameter (PM₁₀) is a conglomerate of different chemical components related to distinct sources and physico-chemical processes in the atmosphere and lithosphere. Emission reduction thus has temporally and spatially varying effects on different scales. Urban PM₁₀ concentrations are heavily influenced by long range transport (up to 70%) from remote source areas, whereas rural air pollution is strongly determined by urban emissions. By means of emission reduction scenario simulations with a chemistry-transport-model it has been found that on average two third of the urban background concentrations in Berlin are due to Berlin-specific emissions. This percentage varies strongly considering primary and secondary components: only about 5% of secondary PM₁₀ concentrations are related to local emissions, while approximately 70% of primary concentrations stem from the urban sources. City related emissions influence homogenously the rural air-pollution concentrations, but with different ranges of influence.

1 Introduction

In order to derive effective PM₁₀ concentration reduction strategies the sources of these concentrations have to be known and associated. PM₁₀ is composed of different species of primary as well as secondary origin. Thus, composition and concentration are strongly varying temporally as well as spatially. Different techniques based on either measurements or computer simulations have been proposed to assign PM₁₀ concentrations to distinct emission sources. Lentschow et al. (2001) have analysed simultaneous measurement results in order to associate different PM₁₀ components concentrations to monitoring site representative emissions. They have shown that for instance kerbside PM₁₀ concentrations on a yearly average can be explained by roughly 30% long range transport, 30% urban increment and 30% traffic related emissions. Reimer et al. (2004) have analysed air mass back-trajectories relating high local concentrations to surface contact points of the air parcels. This analysis has shown high spatial correlation between high sulphate concentrations in Berlin and south-eastern regions while primary PM₁₀ pollutions are related more to local sources exhibiting no clear

preferential pathways toward the city of Berlin. Chemistry transport models have been applied in estimating the contribution of individual countries to other countries' air pollution (van Loon et al., 2007). On the local scale, Thunis et al. (2007) applied the same technique to different European cities. In this study, we analysed the influence of urban emission sources on the local as well as on the remote PM₁₀ concentrations in the Berlin-Brandenburg region.

2 Method

The Chemistry Transport Model REM_Calgrid (Stern et al., 2003, Beekmann et al., 2007) has been used to simulate the PM₁₀ concentration in the Berlin-Brandenburg region for the whole year 2002 with a horizontal resolution of ca. 4 km. This region is a nested domain of a Europe-wide application of the same model taking its boundary conditions from the coarser resolved run. The horizontal extension of approximately 300×300 km has been considered sufficient to allow considerations concerning origin and fate of PM₁₀-concentrations. The vertical extension was 3000 m with a resolution of 4 mixing-height-following levels and one surface layer of 20 m height. This ground level height is representative of the particle concentration at ground. Emissions were provided by local authorities of Berlin and



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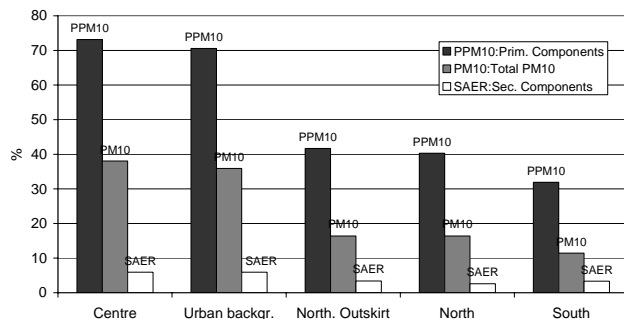


Figure 1. Relative maximum contribution of Berlin Emission to Primary PM₁₀ (PPM₁₀), to Total PM₁₀ (PM₁₀) and to Secondary (PM₁₀) concentrations in city-centre (centre) areas, in central residential areas (Urban backgr.), in northern urban suburbs (North. Outskirt), in northern residential areas (North) and in southern residential areas (South).

neighbouring Länder. In order to estimate the maximum local influence on local as well as on remote PM₁₀ concentrations, a scenario run with no Berlin emissions has been made without altering the background boundary conditions. Ranges of influence have been determined considering radial air pollution concentration reduction potentials. In order to obtain also an estimate of the preferential wind direction for distinct PM₁₀ components, species fluxes towards to and from Berlin have been analysed. Thus, the in- and outgoing mass-exchanges through rectangular boundaries around Berlin and therefore around the main emission sources have been recorded on an hourly basis, integrated over the whole simulation time period. Transport processes only have been analysed. Chemical transformations, emission and deposition processes which all contribute to an overall mass conservation balance are not discussed explicitly.

3 Results

Simulating Berlin PM₁₀ concentration levels with and without Berlin emissions gives an extreme estimate of the Berlin maximum potential contribution to the Berlin air pollution situations. Figure 1 shows the relative contribution of Berlin emission sources to Berlin PM₁₀ air pollution concentrations, subdivided into primary, total and secondary PM₁₀ components and analysed at different representative areas inside the urban agglomeration. REM_Calgrid considers elemental carbon and primary organic carbon, emitted by combustion processes, and mineral particles stemming from soils as primary PM₁₀ components, while secondary components comprise inorganic (sulphate, nitrate, ammonium, sodium and chloride) and organic aerosols. Both fractions form Total PM₁₀. Primary PM₁₀ in the city centre and in the central residential areas amount to more than 70% from Berlin emission sources, while in the outskirts only approximately 40% can be related to local emissions. Within ca. 25 km (city cen-

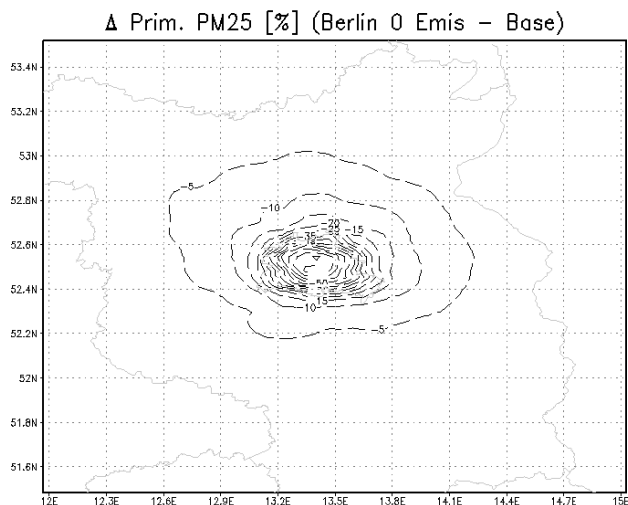


Figure 2. Primary PM_{2.5} concentration reduction due to total Berlin emission reduction. Isolines in %, contour levels in 5% intervals. Light gray lines indicate political borders of Berlin and surrounding Länder and countries.

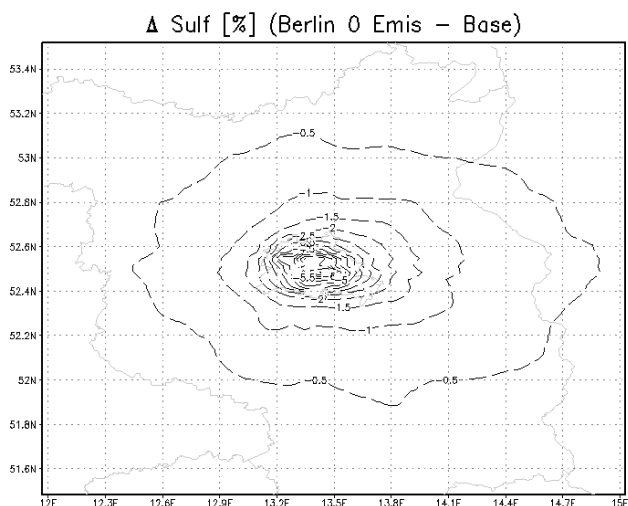


Figure 3. Secondary Sulphate aerosol concentration reduction due to total Berlin emission reduction. Isolines in %, contour levels in 0.5% intervals. Light gray lines indicate political borders of Berlin and surrounding Länder and countries.

tre to outskirts) the influence of local PM₁₀-sources to local PM₁₀ concentrations is reduced by a factor of 1.75. The same gradient is evident in the total PM₁₀ concentration reduction, although the relative contribution of local emissions to local concentrations is only half of that of primary PM₁₀ concentrations. Nevertheless, this is a strong indication, that total PM₁₀ reduction spatial distribution is dominated by that of primary PM₁₀ components. Furthermore, it is evident that total PM₁₀ concentrations, even in the inner circle of the city, are related only by approximately 40% by local emissions,

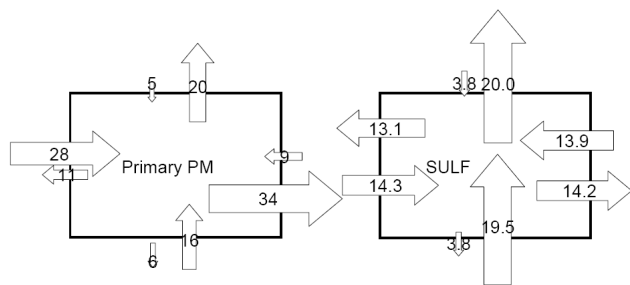


Figure 4. Absolute contribution of primary PM and Sulphate aerosols (SULF) to Berlin PM₁₀ concentrations due to horizontal advective processes through fictitious walls (arrows toward the rectangle indicate accumulation processes, arrows from rectangle indicate loss processes) in kilo-tons per year.

while ca. 60% are due to transport processes from outside the city. The local influence on secondary aerosol concentrations is all over Berlin only ca. 5%. Figure 2 shows contour isolines of primary PM_{2.5} (modelled inert aerosols smaller than 2.5 μm) reductions due to a total Berlin emission reduction. Longer ranges of influence are simulated towards north. The 10% reduction isline due to Berlin emissions is approximately between 50 km in the west and 60 km in the east of the city centre. Thus, Brandenburg's primary PM_{2.5} (comprising elemental carbon, primary organic carbon and mineral dusts smaller than 2.5 μm) concentrations inside of a roughly 20 km belt around Berlin can be ascribed for 10% only to Berlin Emissions. Considering the main secondary aerosol component sulphate (see Fig. 3) there is almost no contribution of Berlin emission sources to sulphate concentrations. Also inside Berlin, only approximately 5% can be attributed to Berlin emissions. Fluxes toward and from the city of Berlin are also component specific (Fig. 4.). While primary PM₁₀ come predominantly from the west and leave the city mainly towards the east, sulphate aerosols enter the urban agglomerate mainly from the south and are exported toward the north. This indicates different sources for these different components, being the first in the west or local and the second in the south to south-east.

4 Discussion and conclusions

We simulated with a chemistry transport model the growth and loss of secondary pollutions considering non-linear effects of different variables such as emissions, atmospheric conditions and solar insolation. Primary particles do not undergo any chemical processes in the model. Emission, deposition and transport are the only processes contributing to the primary particle concentrations. Secondary aerosols, however, undergo chemical transformations from gaseous to solid phases and are thus highly non-linear in their formation, thus altering the amount of one species alters the whole chemistry chain. Emission scenarios varying the amount of individual precursor species by different percent-

ages, however, have shown, that reductions of 50% NO_x Berlin emissions lead to a comparable amount of reduced secondary aerosol concentrations. The overall reduction of maximum 5% is not compromised by the non-linear effects of aerosol chemistry. The local extension of Berlin is too small to influence the long-term character of secondary aerosols. In conclusion, it has been shown that local sources are responsible for local PM₁₀ concentrations only by approximately 40% in the Berlin residential areas. Primary particles have their origin and their fate in the city being related mainly to traffic- and industry-related combustion processes. Moreover, a strong contributor to local primary PM₁₀ accumulations is wind-blown dust in form of minerals in the atmosphere. The re-suspended material from roads due to traffic-induced turbulences is another important PM₁₀ source in cities which cannot be reduced but with traffic reduction. Estimates of these turbulence related emissions, whoever, are even more uncertain than direct emissions. Nevertheless, they are responsible for a considerable part of PM₁₀-concentrations in urban environments. Secondary aerosols have their origin in remote areas, mainly in the south or south-east of Berlin. The contribution of local emission sources to local secondary aerosol concentrations is very limited.

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