Mobile measurements of the horizontal variation of fine particulate matter in the state of North Rhine Westphalia in Germany – a case study

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Abstract: - Fine particulate matter is well known for its adverse health effects for the population. It is still one of the major problems of air pollution in Germany. The limit values of fine particulate matter PM10 are often exceeded in bigger German cities. Therefore the level of fine particulate matter and other air pollutants are routinely monitored at single hot spots in the cities by measurement stations of the environmental state agencies. However, it is of high interest, what levels of concentrations of fine particulate matter are to be found in those areas, where no measurement stations are placed. Moreover, it is important to know, how strong exceedings of fine particulate matter concentrations can be influenced by meteorological conditions.

In this paper fine particulate matter concentrations are measured with a car, which was equipped with measurement systems for fine particulate matter and which was driving through industrial and rural areas of the state North Rhine Westphalia in Germany. By this means it was possible to measure coarse and fine fractions of particulate matter continuously during driving. In this way the horizontal variation of fine particulate matter could be investigated throughout the state. The measurements comprised dust concentrations of the fractions PM10 (coarse), PM2.5 (more fine) and PM1(very fine), which are addressed within the European environmental legislation. Moreover, every second during driving the full size distribution of particles between 250 nm and 32 µm diameter was measured. Therefore it could be investigated, at what places more bigger or more smaller particles were present under specific meteorological conditions.

The mobile car measurements were performed as a case study in a situation with a strong meteorological inversion layer. The mobile measurements of the horizontal variation of fine particulate matter in industrial and rural areas are compared with model prediction calculations. Moreover, using backward trajectories a source appointment of the fine particulate matter could be performed.

Key-Words: - air pollution, urban air pollution, PM10, PM2.5, PM1, fine particulate matter, horizontal variation of fine particulate matter, optical particle counters, OPC

1 Introduction

It is proven by several medical studies that fine particulate matter (fine dust) is adverse to human health. Long time exposure to fine particulate matter and even short time exposure can result in severe respiratory, cardiovascular and cardiopulmonary problems [1-4]. Therefore fine particulate matter is routinely monitored at fixed measurement stations by environmental authorities in Germany in order to detect exceedings of limit values for fine particulate matter [5]. However, concentrations of fine particulate matter at positions, where no measurement station is present, are not known and are therefore interpolated by simulation calculations. Especially at rural sites measurement stations are rare. Therefore in this paper mobile measurements of fine particulate matter are performed, using a car equipped with an optical particle counter (OPC) and a GPS-system. Mobile measurements of air pollutants are reported in the literature, but mostly are performed on a scale of a single city [7, 8, 9]. However, in this paper the variability of fine particulate matter on a scale of more than 100 km is investigated by mobile measurements in a special situation of a meteorological inversion situation with high concentrations of fine particulate matter.

2 Measurement Equipment

A Volkswagen Golf was used as a mobile platform for this study. The optical Particle counter (OPC) was installed within a box on the roof of the car. A special GRIMM SKY-OPC has been used for the measurements, which has a fast response time of 1 second and is otherwise used for aircraft measurements as well [10]. The function of this OPC is based on orthogonal scattering of a laser beam by the pollution particles and has a special measurement design with two parallel optical measurement cells in order to get a fast measurement response. The instrument is able to deliver online results for PM10 [1], PM2.5 and PM1 as well as the particle size distribution between 250 nm and 32 µm. More details of the principle function of the measurement system can be found in [11-13] The OPC was coupled with an isokinetic sampling device, in order to catch all fine particulate matter appropriately during the drive. Moreover, a special software had been developed in order to plot the measured concentrations in Google maps [14].

2 Measurement Drive

The measurements were taken during a drive with the measuring car starting in Düsseldorf, passing the cities of Wuppertal, Hagen and Dortmund and heading to the city of Münster (see Figure 1). The way back was slightly different passing the city of Herne. It is important to know, that the area around Düsseldorf is an industrialized area, whereas the area between Dortmund and Münster has a more rural character.

3 Results

Figure 1 shows the plot of the measurement drive between the city of Düsseldorf in the South (low lefthand site) and the city of Münster in the North (in the upper part of the picture). Most part of the drive took place on a motor highway. Additionally, the colors of the plot in Figure 1 visualize the measured dust concentrations PM10. As it can be seen, in the complete Rhine-Ruhr area extreme high concentrations of fine particulate matter could be found (partly above 150 µg/m3), whereas in the northern part of the state near Münster the

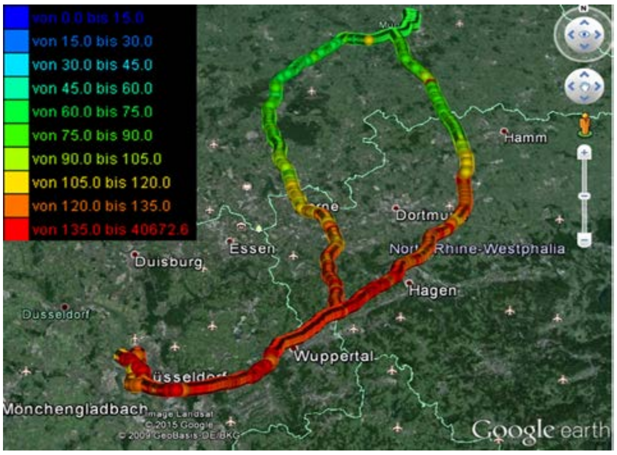

Figure 1: Plot of the mobile measurement in the state of North Rhine Westphalia in Germany between Düsseldorf and Münster (map taken from Google Maps) on 20 March 2015

concentrations were much lower (around 70 µg/m3). This can be seen even in more detail in Figure 2, where the concentrations of PM10, PM2.5 and PM1 are plotted over time during the mobile measurement. The measurement drive started in Düsseldorf, passed the city of Wuppertal on the highway and ended with a city drive in Münster and went back to Düsseldorf afterwards. It is important to note, that limit value for the daily mean is 50 µg/m3, which must not be exceeded more than 35 times per year [5]. So comparing the measured concentration values with the limit value it can be stated that the concentration of fine particulate matter was dramatically increased in North Rhine Westphalia during this meteorological inversion situation. Moreover it becomes clear from Figure 2 that within the industrial area around Düsseldorf

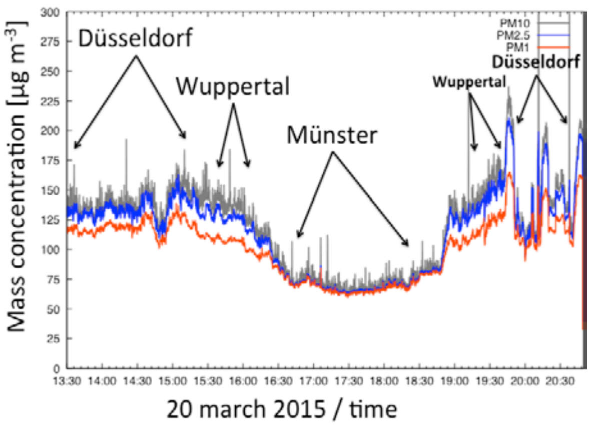

Figure 2: measured concentrations PM10, PM2.5, PM1 over time during the mobile measurement between Düsseldorf and Münster

[1] PM10 shall mean particulate matter which passes through a size-selective inlet as defined in the reference method for the sampling and measurement of PM10, EN12341, with a 50 % efficiency cut-off at 10 µm aerodynamic diameter [5]

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much more of the coarser PM10 particles compared with the smaller PM1 particles were present than in the rural area near Münster.

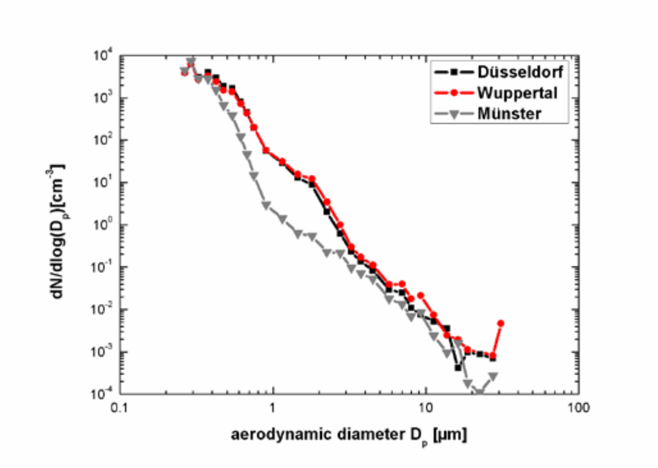

Figure 3: Size distribution of the measured dust particles in Düsseldorf at the beginning of the mobile measurement (black curve), near Wuppertal (red curve) and in Münster (gray lowest curve)

This becomes even more clear in Figure 3, where the size distributions of the particles measured in Düsseldorf, Wuppertal and in Münster are plotted. Figure 3 shows the normalized size distribution of the measured particles between 250 nm and 32 µm. It can be clearly seen in Figure 3 that the size distribution of the dust particles within the more industrialized area near Düsseldorf and Wuppertal is very similar. However, the size distribution of the fine particulate matter in the area near Münster is significantly different. It can be clearly seen in Figure 3 that particles around 1 µm in size have a significant lower concentration in the rural area near Münster than in the more industrialized area near Wuppertal and Düsseldorf.

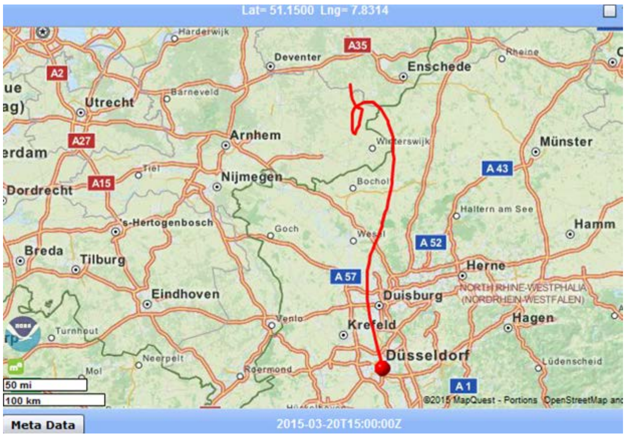

Figure 4: Backward trajectory calculated with NOAA HYSPLIT model [15] for Düsseldorf at 20 March 2015 3:00 pm UTC and 30 h backward calculation

In order to find the reason for the different size distributions and concentrations of dust particles in Düsseldorf and Münster backward trajectories were calculated with the open source calculation model NOAA HYSPLIT [15]. The backward trajectory (curve in in red in Figure 4) shows the travel path of the polluted air during a 30 hours run before it arrived in Düsseldorf on 30 March 2015 at 3:00 pm UTC. It turned out in this backward calculation that the polluted air came from the North near the Dutch border and might be influenced by industrial sites in the Netherlands.

In comparison to that backward trajectories were calculated with the NOAA HYSPLIT model for Münster on 20 March 2015 at 5:00 pm UTC. The result is shown in Figure 5. It can be clearly seen from the backward trajectory (red curve) in Figure 5 that the air, which arrived in Münster on 20 March 2015 at 5:00 pm UTC started from the North Sea 30 hours before.

Therefore the backward calculations proved that the air, which was measured in the area of Münster came from a cleaner atmospheric region than the air, which was measured in Düsseldorf. This might be an explanation for the fact that the mobile measurements of the fine particulate matter concentrations revealed higher concentrations for Düsseldorf, Wuppertal and the Rhine Ruhr area than for the area around Münster. Moreover, this can be an explanation for the different size distributions in the area of Münster and the areas of Düsseldorf and Wuppertal.

Figure 5: Backward trajectory calculated with NOAA HYSPLIT model [15] for Münster at 20 March 2015 5:00 pm UTC and 30 h backward calculation

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4 Comparison of the results of the mobile measurements with RIU model calculations

It is interesting to compare the results of the mobile measurements with model calculations for the dispersion and concentrations of PM10. The RIU-Institute (Rheinisches Institut für Umweltforschung), which is associated with the University of Cologne, is running the European Dispersion and Deposition Model EURAD. The results are stored in a database which is open to the public [6,16]

The RIU-Institute predicted high maximum and daily mean PM10 concentrations for 20 March 2015 for North Rhine Westphalia, with remarkable high concentrations in the Rhine Ruhr area and especially in an extended region around Düsseldorf [17].

The results of the mobile measurements are compared to the RIU model calculations in Figures 7 – 8.

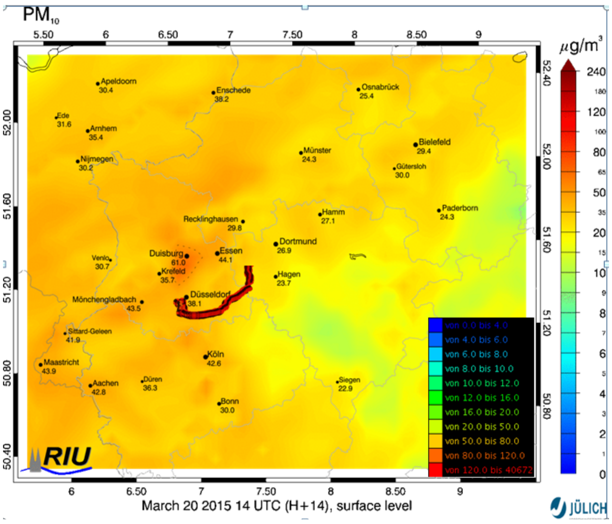

Figure 7: RIU model forecast for 1 hour mean value for PM10 for 20 March 2015 2:00 pm UTC [17] compared with the first part of the mobile measurement

In Figure 7 the first part of the mobile measurement track (red line in the middle of Figure 7) is shown in comparison with the predicted hourly mean PM10 concentrations for North Rhine Westphalia as forecasted by the EURAD model for 20 March 2015 2:00 PM. As a matter of fact the model predicted high PM10 fine particulate matter values in the Rhine Ruhr Area and especially around Düsseldorf. It forecasted slightly lower concentrations in the area of Münster for that time. However, the concentrations of fine particulate matter PM10, which were delivered by the real mobile measurements, were generally higher than the predicted model values.

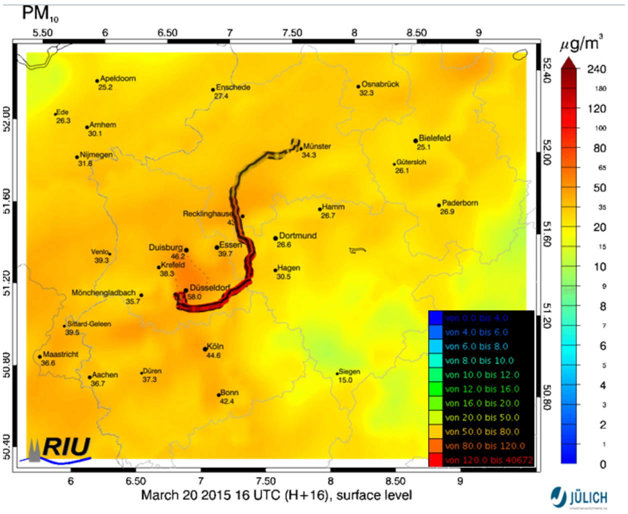

Figure 8: RIU model forecast for 1 hour mean value for PM10 for 20 March 2015 4:00 pm UTC [17] compared with the results of the mobile measurement between Düsseldorf and Münster.

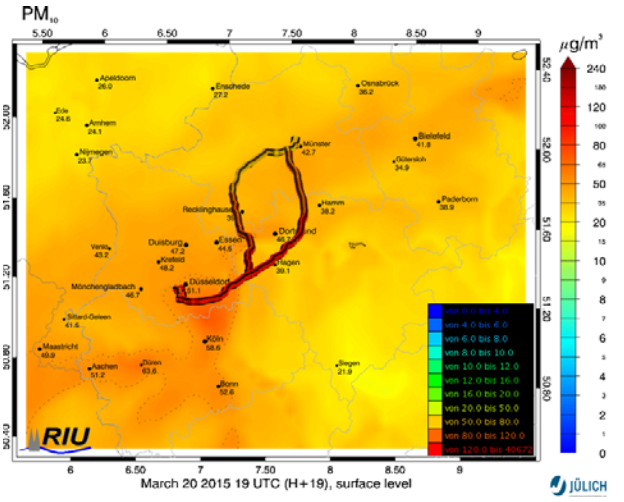

Figure 9: RIU model forecast for 1 hour mean value for PM10 for 20 March 2015 7:00 pm UTC [17] compared with the last part of the mobile measurement

In Figure 8 and 9 the model forecasts for fine particulate matter PM10 are shown for 4:00 pm UTC and 7:00 pm UTC together with the corresponding track and measured concentrations of the mobile measurements. Again the model predicts high concentrations of fine particulate matter in the area around Düsseldorf and lower concentrations in the area around Münster. This concentration gradient can be seen in the results of the mobile measurements as well. However, the mobile measurements show measured PM10 concentration on a higher level. As the optical particle counter was calibrated before the measurements, these mobile measurements can potentially be used to re-calibrate and adjust the model calculations.

5 Conclusion

Mobile measurements of fine particulate matter have been performed in the state of North Rhine Westphalia in Germany by using a car equipped with a fast optical particle counter. These mobile measurements have been executed as a case study especially in a meteorological situation, where a pronounced inversion layer was present over middle Europe. The mobile measurements could prove successfully that in this special situation the concentrations of fine particulate matter were lower in the rural area around the city of Münster than in the more industrial Rhine Ruhr area and especially in the area of Düsseldorf. Moreover, it could be successfully demonstrated within this case study by applying backward model calculations using NOAA HYSPLIT that the air masses in the area of Münster came from the relatively clean atmosphere above the North Sea, whereas the air in the region of Düsseldorf came from the more pre-polluted area near the Dutch border. Finally, the results of the mobile PM10 measurements have been compared with model calculations by the EURAD model, resulting principally in a similar general PM10 gradient over the area between Düsseldorf and Münster, but on a higher concentration level.

In general this case study could demonstrate successfully, that mobile measurements of air pollution can deliver valuable additional information to the pollution results of fixed stations or model predictions.

5 Acknowledgement

NOAA and RIU are greatly acknowledged for providing their open source models and results.

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