AEROSOL MEASUREMENTS IN THE RHINE VALLEY DURING FOEHN – ANOTHER FORM PERSPECTIVE

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Abstract: While the main focus of the MAP subproject FORM (Foehn in the Rhine Valley during MAP) was on atmospheric dynamics, numerous measurements of chemical constituents of the atmosphere have been performed with various instruments on different platforms. Aerosol measurements have been obtained with routinely operated conventional surface stations, in-situ airborne particle counters and a backscatter lidar. For the MAP SOP it was found that near-surface aerosol concentrations are reduced by the foehn, i.e. they are lowest at the day after the foehn event, especially in the late fall when the valley inversion becomes stronger. A case study for 2 Oct 1999 (IOP 5) reveals considerable spatial variability in aerosol concentrations and shows interactions of the aerosols with the humidity field.

Keywords - *FORM, MAP, foehn, aerosol, aircraft measurements, lidar, air quality, Rhine valley*

1. INTRODUCTION

It is well known that foehn in the alpine valleys has a significant influence on air quality issues, e.g. an increased visibility or elevated ozone concentrations (Seibert et al. 2000). During the FORM (Foehn in the Rhine Valley during MAP) project, ozone profile measurements have been obtained in the northern part of the valley and discussed by Baumann et al. (2001). In contrast, aerosol measurements have been made in the southern part of the Rhine valley with a lidar system (Frioud et al. 2003), but these measurements have mainly been used for dynamical studies. More aerosol data is available from ground stations and aircraft sensors for analysis of foehn effects on suspended matter in a valley atmosphere. This study presents some characteristics of aerosol measurements during foehn.

The FORM experiment (Richner et al. 2005) has provided new insight into a couple of phenomena related to foehn flow in alpine valleys. Relevant for aerosol concentrations are two recurring features. The first and more important one is the often observed two-layer structure of the foehn flow, with the foehn air flowing on top of a pool of cold air in the valley. This dynamically stable cold air pool is often a trap for high pollution concentrations due to restricted vertical exchange of pollutants. If this stable layer is removed during the day, pollution levels at the surface stations should decrease. The second feature of foehn flow is that it can transport aerosols and trace gases across the Alps (Seibert et al. 2000). Depending on the source area, foehn air can be substantially polluted and contribute to the local pollution in the valley.

2. INSTRUMENTATION

MetAir's Dimona aircraft was equipped with two optical particle counters (MetOne laser particle counter) that measured the number concentration of the aerosol particles with optical diameters exceeding 0.3 and 0.5 m. Output was given in counts per cm^3 with a time resolution of 0.1 s, which was subsequently integrated to 1-min integrals. Due to the logarithmic decay of the size distribution towards larger particles, the counts can be approximately considered as particle concentration in a size bin just above the size cut. Measurements were obtained along the flight paths of the aircraft, which varied from mission to mission.

Surface data was available from several stations of the local air pollution authorities. Due to their air quality monitoring background, these stations are equipped with standard aerosol or particle collectors, generally not distinguishing between particle size distributions, but rather collecting the larger particles (TSP - total suspended matter; PM10 - particulate matter of size > 10 µm). Furthermore, these stations also collected the dust for longer periods, e.g. 24 h, and can thus not fully resolve the dynamics of foehn events. Nevertheless, due to their continuous operation, they should provide some insight into the effects of foehn on near-surface concentrations of aerosols.

A vertically-pointing backscatter lidar was operated in Trübbach by the Observatoire de Neuchâtel. This instrument provided time-height cross-sections of aerosol backscatter with a very high resolution.

3. OBSERVATIONS AND DISCUSSION

This study concentrates on two aspects. A more 'climatological' approach seeks to work out typical variations of aerosol concentrations during foehn periods compared to normal days. A case study sheds light on the three-dimensional distribution of aerosols during one foehn event in early October 1999.

3.1. Surface station dust measurements and foehn

Air quality monitoring stations provide longer-term aerosol measurements that were obtained under quality-controlled conditions, but often with reduced temporal resolution, e.g. daily sums. Therefore, using a foehn calendar that characterizes a day as foehn or non-foehn day will allow for a first analysis. The daily values of PM10 are shown in Fig. 1. The time series shows two different aerosol behaviors for foehn. In the first half of the SOP PM10 values were rather low and seemingly independent of foehn. In the second half of the SOP, i.e. later in fall, foehn always started with rather high PM10 values that dropped by half on the next day. This indicates that in the second phase the thermal stability of the valley atmosphere (cold air pool) played a crucial role by trapping air pollutants until the pool was removed either by the foehn flow or by the foehn-terminating cold front.

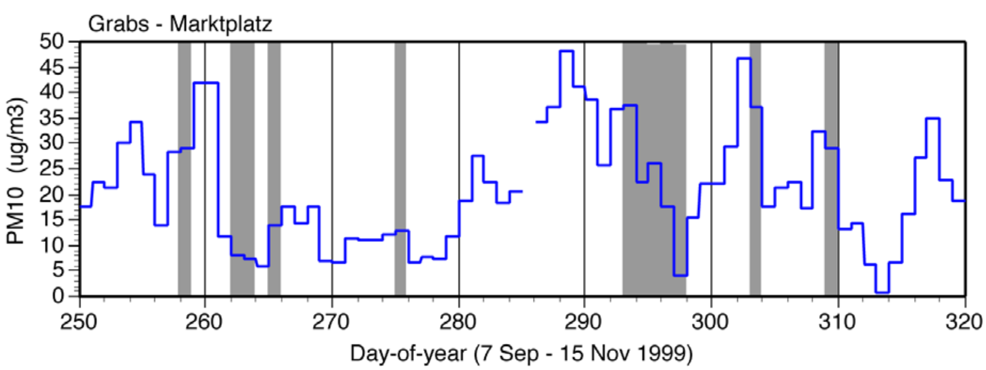

Figure 1. PM10 (particulate matter of size > 10 μm) measurements at Grabs-Marktplatz during the MAP-SOP. Grey shaded areas indicate foehn at the station Weite, some 12 km further south (upstream), according to (Richner et al. 2005).

3.2. Aircraft and lidar measurements: Case study of 2 October 1999

On 2 October 1999 foehn set in around sunrise and increased in strength during the day, with only a short decrease in intensity in the early afternoon. Two MetAir Dimona flights took place, one from 0651-0953 UTC (morning flight), the other from 1200-1700 UTC (afternoon flight). Fig. 2 shows the vertical distribution of aerosols. The profiles show a general decrease in aerosol number concentration from the surface to 4000 m asl, with a significant step at 3000 m asl indicating the top of the foehn air. Within the foehn air, aerosol concentrations increase during the day and with increasing wind speed. As the aerosol concentration near the ground does not decrease at the same time, this is an indication for aerosol transport from farther upwind, e.g. from south of the Alpine crest, or from the Rhine valley between Sargans and Chur. Signs of such a transport can be seen already in the morning profile between 2000 and 3000 m asl in the Sargans area where concentrations reached 30 counts cm^{-3}. Farther north only 20 counts cm^{-3} and less were measured.

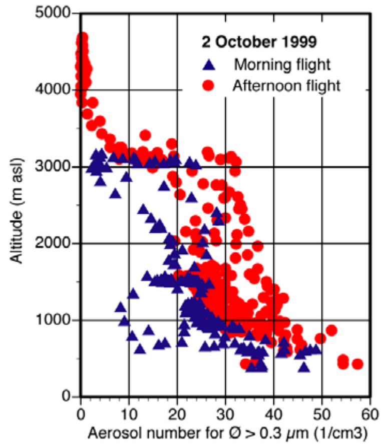

Figure 2. Synthetic profiles of aerosol number concentrations for particles > 0.3 μm during the morning and afternoon flights of MetAir's Dimona aircraft. All measurements during each flight are included in the diagram, irrespective of their sampling location within the Rhine valley.

Although optical particle counters do not reveal significant details about the composition or the size distribution of the aerosol particles, the ratio of the two aerosol measurements may tell us something about the relative amount of large particles. A large ratio indicates that relatively more large particles are present than smaller ones. Aerosol particle size depends on the source area, the composition, the aging processes and the relative humidity. In a foehn situation descending air is adiabatically heated which leads to evaporation of water and semi-volatile material of mainly smaller aerosols, thereby decreasing the particle diameter. Hence, an increase in the aerosol number concentration ratio could indicate descending air. On the other hand, an increase in relative humidity would spawn particle growth, with smaller particles growing faster than larger ones, and thus the ratio would decrease. The ratio itself does not indicate whether the air is rather clean or heavily polluted, because it is only a relative measure. The observed ratios are plotted in Fig. 3. The morning flight shows an increase of the ratio with height from 0.15 near the surface to 0.2 at 3000 m asl. The afternoon flight shows a constant ratio of 0.15 for all heights up to 3000 m asl (the ratio increases rapidly for heights above 3500 m asl). We interpret this as a sign of advection of moist air and subsequent particle growth mainly of the smaller particles. Evidence for moist air advection comes from the humidity gradient observed with the aircraft (higher relative humidity in the south, not shown here).

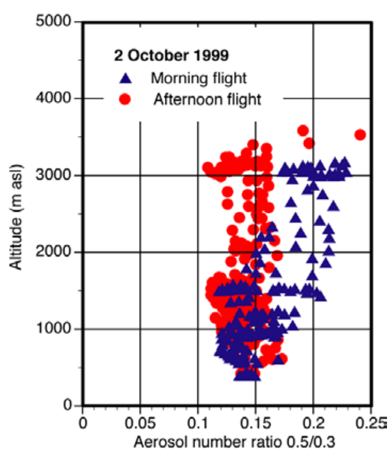

Figure 3. Profiles of aerosol number concentration ratios (number concentration for particles > 0.5 μm divided by number concentration for particles > 0.3 μm) during the morning and afternoon flights of MetAir's Dimona aircraft. All measurements during each flight are included in the diagram, irrespective of their sampling location within the Rhine valley.

The foehn air is also visible in the lidar measurements in Trübbach (Fig. 4). The backscatter signal starts to become quite uniform up to 3000 m in the morning of 2 Oct 1999 (orange and red color), which could be interpreted as the effect of turbulent mixing at the cold pool top. In the afternoon the backscatter signal decreases throughout the lower atmosphere (green color). This indicates a reduced number or size of aerosol particles, which may be the result of subsidence (drying) or of advection of less polluted air from a different (more elevated) source region. Our measurements do not allow for a complete explanation, but MC2 model calculations indicate a rather narrow area of descending and thus drier air in the southern Rhine valley close to the lidar. The aircraft profiles show data of the whole valley between Sargans and the Lake of Constance and thus exhibit significantly larger scatter and a generally more humid environment.

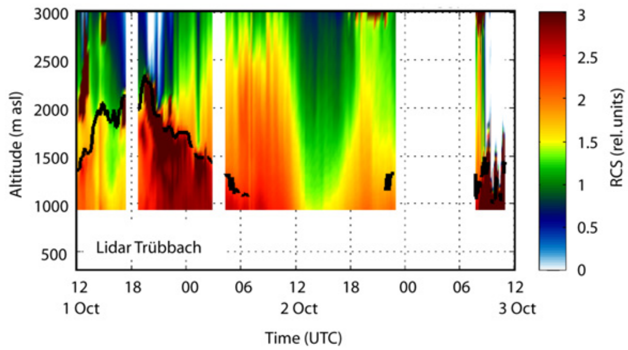

Figure 4. Time-height cross-section of aerosol backscatter (RCS = range-corrected signal) above Trübbach, Switzerland, for 1-3 October 1999. The black line indicates the top of the cold pool in the Rhine valley.

4. CONCLUSION

Aerosols have been studied within MAP mainly from a remote sensing perspective as a tracer for air mass dynamics. This study puts more emphasis on air pollution aspects in foehn-prone valleys and hence used alternative aerosol measurements from aircraft and ground stations. We found that the thermal stratification of the valley atmosphere plays a crucial role for the observed aerosol concentrations. Furthermore, advection and subsidence also alter the aerosol characteristics.

Our study analysed available aerosol data measured at the surface and in vertical profiles, and thus developed only a preliminary image of aerosol characteristics during foehn. More sophisticated instrumentation would be needed to determine physical and chemical characteristics of aerosols for a more quantitative analysis.

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