2.4 FIELD MEASUREMENTS OF VERTICAL POLLUTION TRANSPORT IN A HIGH ALPINE VALLEY IN SOUTHERN SWITZERLAND

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1. INTRODUCTION

Vertical transport of NO_x and VOC polluted boundary layer air to the free troposphere (FT) can enhance the ozone production efficiency ($P_{(O3)}$), which is the number of ozone molecules produced by each NO_x molecule consumed (Lin et al. 1988). Once the air mass has left the atmospheric boundary layer (ABL), dry deposition of NO_x and O_3 ceases and leads to increased lifetime of these species (Crutzen 1995). Both effects can contribute to a higher background concentration of ozone in the FT. Re-entrainment into the ABL can prolong photosmog episodes and reduce effects of local emission controls.

Vertical transport through convective and frontal systems (cloud venting) has been investigated in recent years (Cotton et al. 1995). Their influence on ozone production has been estimated for different convective systems (Pickering et al. 1992) and the global troposphere (Lelieveld and Crutzen 1994). However, little is known about the effect on $P_{(O3)}$ of vertical exchange over high mountainous terrain (mountain venting). Some estimates for orographically induced vertical mass transport exist (Kossmann et al. 1999). Furger et al. (2000) showed that five times the volume of the Mesolcina valley in southern Switzerland was exported to the lower free troposphere (LFT) during one upwind phase under clear sky conditions.

About 4% of all traffic related NO_x emissions in Switzerland occur within high Alpine valleys in or approaching the transalpine Gotthard route. An upper limit of ozone production enhancement may be calculated by considering the complete transport of these pollutants to the LFT. If $P_{(O3)}$ is increased by a factor of 10 this would lead to the conclusion that transalpine traffic via the Gotthard route is subsequently responsible for 30% of the total Swiss ozone production.

In recent studies (Furger et al. 2000, Carnuth and Trickl 2000) a so-called injection layer was observed under clear sky and high-pressure conditions with weak synoptic flow above the European Alps. A closed valley circulation was not observed but rather the injections of polluted ABL air into the LFT. Figure 1 shows a schematic plot of the airflow.

To quantify the air mass exchange and to investigate the enhanced ozone production in the LFT above an alpine valley the CHAPOP (characterization of high alpine pollution plumes) measurement campaign took place in the summer of 2001. The Leventina valley containing a major traffic route south of the Gotthard tunnel was chosen as investigation area.

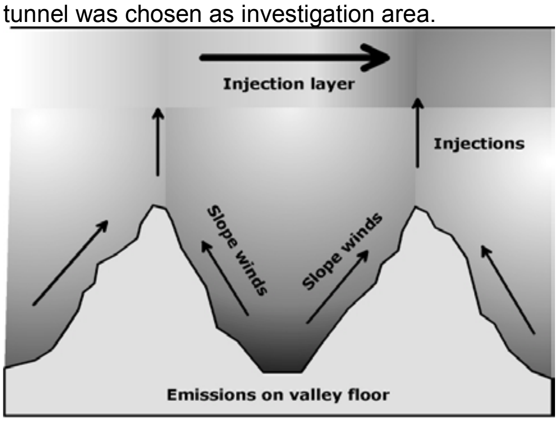

Figure 1: Injection layer airflow pattern

2. FIELD CAMPAIGN

The activities in the Leventina valley are summarized in Figure 2. On three flight days the MetAir DIMONA motor glider acquired meteorological, chemical and aerosol parameters by flying cross sections within the valley (thick solid lines). The MERLIN (Meteo France) flew a box grid pattern within the injection layer, 3 – 4 km asl, measuring parameters similar to the DIMONA.

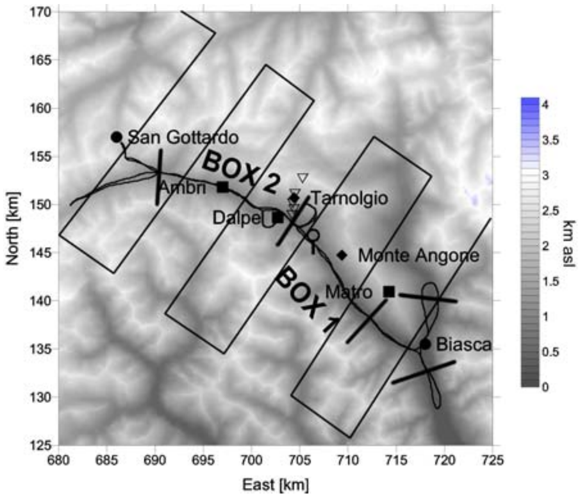

Figure 2: CHAPOP Measurement setup, for details refer to text.

The FALCON (DLR) carried a nadir-pointing aerosol LIDAR at a height of 8 km asl that supplied information about boundary layer development and aerosol distribution. Both MERLIN and FALCON flew patterns similar to that in Figure 2 (solid line). The PSI

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mobile laboratory MOSQUITA measured gases and aerosols along the valley floor and at the slopes (thin solid line). Vertical profiles of the valley atmosphere were taken at a balloon sounding station (open circle). Continuous measurements of standard chemical and meteorological parameters were conducted during five weeks at three sites (squares), including formaldehyde and detailed VOC analysis in Dalpe. The station Matro, at 2.2 km asl, measured within the injection layer. Wind profiles up to 1 km agl were also acquired at this site. Meteorological data was gathered at two additional sites (diamonds) at the valley's south-orientated slope and with temperature sensors (triangles) distributed in a vertical profile up to 2.5 km asl.

3. DYNAMIC RESULTS

The first and third days of flight (26./28. August) are analysed here. A northwest to northerly flow prevailed at 3 to 4 km height with a wind speed of 3 to 5 ms^{-1}. The days were cloudless except for shallow cumulus convection above the mountain crests. Within the valley a valley wind built up in the early morning hours below 2.6 and 1.9 km asl, respectively, and persisted until late afternoon.

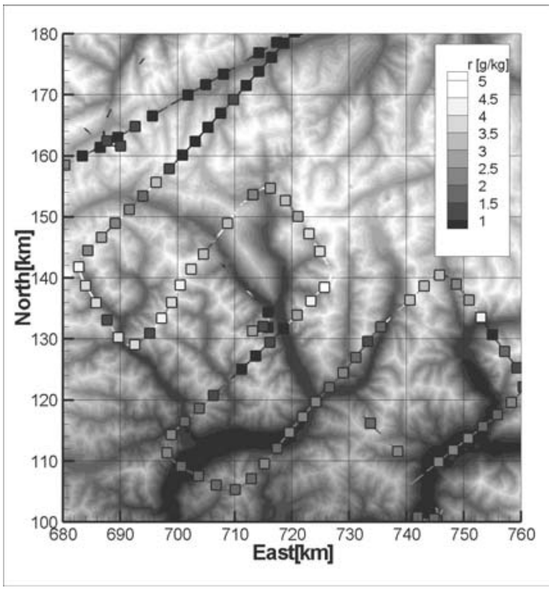

Figure 3: Water vapor mixing ratio at 4 km asl

A mass flux budget was calculated by assuming a simple model of the valley with only two horizontal fluxes streaming into and out of a valley box, and a vertical mass flux which is mainly the net flux of slope wind outflow and compensating subsidence. The horizontal parts were estimated using the data recorded by the motor glider within the cross sections shown in Figure 2. For the two boxes referring to the Leventina valley a total vertical mass flux of 5.7E8 kg/h and 3.6E8 kg/h was computed for the southern (box 1) and the northern (box 2) part of the valley, respectively. These flows correspond to 66% and 36% of the valley mass being transported out of the valley per hour. Considering an upwind phase of about 8 hours this leads to the conclusion that the whole valley mass is exchanged 5 and 3 times per day, respectively. The higher value for box 1 might be explained by the bent structure of the southern part where air is driven out of the valley dynamically.

MERLIN in-situ and FALCON remote measurements on August 28 both reveal details of the discussed injection layer. Pollutant concentrations and height of the injection layer show a maximum south of the alpine main ridge and above the investigated area. The water vapor mixing ratio, a good tracer for ABL air, is shown in figure 3 for the MERLIN flight at 4 km asl. A longitudinal belt containing areas with strong vertical transport is associated with lighter squares and extends from 155 to 130 km, Swiss coordinates.

4. FUTURE WORK

Detailed VOC and NO_x information at different height levels within the valley and in the injection layer will be used in a further analysis with a steady state and a Lagrangian chemical model. This will provide insight in the processes that influence the ozone production efficiency. Embedding the findings into meteorological models will help to quantify the total effect of thermal induced mountain venting on the ozone concentrations in the LFT on a European scale.

6. ACKNOWLEDGEMENT

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