PBL elevation to 3.5 km agl over Rhine Valley: Backscatter lidar observation in FORM

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INTRODUCTION

The aerosol structure in the PBL has been studied extensively by backscatter lidar above horizontally homogeneous terrain and sea surface (Crum et al, 1987; Melfi et al., 1985; Dupont et al., 1994 and the references there). Above a complex terrain a few lidar observations have been reported, all by airborne lidars performing a spatial scanning (Hoff et al., 1997; Flamant and Pelon, 1997; Nyeki et al, 2000; Hägeli et al, 2000]. The PBL measurements reported here are done with a ground based lidar following the diurnal development above one measurement site. The lidar was installed in the village of Trübbach in the Rhine Valley (9°28'E, 47°04'N) and operated during the Special Observation Period (SOP) of the campaign Foehn in the Rhine Valley – FORM [Bougeault et al, 2001].

LIDAR AND METHOD

The backscatter lidar operates with the second harmonic of a Nd:YAG laser (Quanta System H102] with pulse energy of 10-15mJ at pulse repetition rate of 20 pps. The receiver has diameter of 15cm. The detection and data acquisition are performed by PMT EMI 9829QB and two 8 bit oscilloscopes LeCroy 9310 and 9314. The altitude and temporal resolution of the measurements was 3m and 50s-150s. For the data processing the resolution was degraded to decrease the statistical error.

Using the gradient of the range-corrected signal, we may identify two types of aerosol layers: One is a layer with a constant or gradually decreasing aerosol altitude distribution with a step-wise drop on the top. Such layer is of a "mixed-like layer" type (in consistency with the Convective PBL presentation, see [Flamant C et al, 1997; Melfi et al., 1985; Hägeli et al, 2000] and is referred further as type (i). The second type is "accumulation-like" layer, i.e., a layer with a "bump-like" altitude distribution, referred further as type (ii). Layers of the type (ii) may appear beneath a temperature inversions and above intrusions of slope winds from the mountain slopes. The lidar signal gradient of layers type (i) demonstrate one negative peak. The altitude of this peak defines the top of this (mixed) layer. The gradient of the lidar signal from layers of type (ii) show one positive and one negative peak with altitudes in succession and the altitude of type (ii) layer is defined as the mean of these two altitudes. Indeed changes in the range corrected lidar signal and its gradient are caused by the changes in the aerosol backscatter coefficient and such may be caused not only by the changes of the number density of the particles, but also by the humidity variation.

SYNOPTIC CONDITIONS AT THE BEGINNING OF SEPTEMBER 1999

The synoptic conditions in the Alpine region around the lidar site for the days 8-14 September show a radiation-dominated weather situations, favourable for convection and accumulation layers.

Table 1 presents the meteorological parameters measured in stations around the lidar site. The values show high pressure, between 1011hPa and 1023hPa, high value for the Solar radiation (mean value 19,5 MJ/m²) with a max at 12:30 MET of more than 700W/m², high mean daily temperatures, high daily maximum of the relative humidity. The topographic temperature gradient is presented in Fig. 1 for two pairs of sites: Sänits - Vaduz with 2000m altitude difference and Fraxern - Feldkirch with 400m altitude difference. Presented are values for the morning (7:00 MET) and for the afternoon (14:00 MET). The temperature gradient for Fraxern – Feldkirch (see Werner 1988) shows a stable inversion above the ground. The temperature gradient for Sänits – Vaduz is between -5,07 and - 3,79 °/km, i.e., approximately 50% of the wet adiabatic gradient (-6,50 °/km), i.e., a situation consistent with temperature inversions leading to aerosol accumulation layers.

Table 1. Measurements from stations Dornbirn and Lustenau (without suffix for daily mean, suffixes „x“ for maximum, suffix „n“ for minimum); DAY is for day of September 1999.

DAY	PP	PPx	PPn	GR	GRx	TT	TTx	TTn	UU	UUx	UUn
8/9	1019	1021	1017	20,0	730	17,8	24,4	10,7	74	99	42
9/9	1022	1025	1020	20,0	720	16,9	23,9	9,5	78	99	43
10/9	1023	1026	1021	20,0	730	17,9	25,9	9,4	74	100	44
11/9	1021	1023	1018	19,0	710	17,5	25,0	9,2	78	99	47
12/9	1017	1020	1013	19,5	720	18,9	26,5	11,1	73	99	41
13/9	1011	1015	1008	19,0	720	18,6	25,9	10,2	76	100	50
14/9	1012	1013	1010	18,5	690	19,0	26,2	9,5	72	99	41
unit	hPa	hPa	hPa	MJ/m2	W/m2	°C	°C	°C	%	%	%

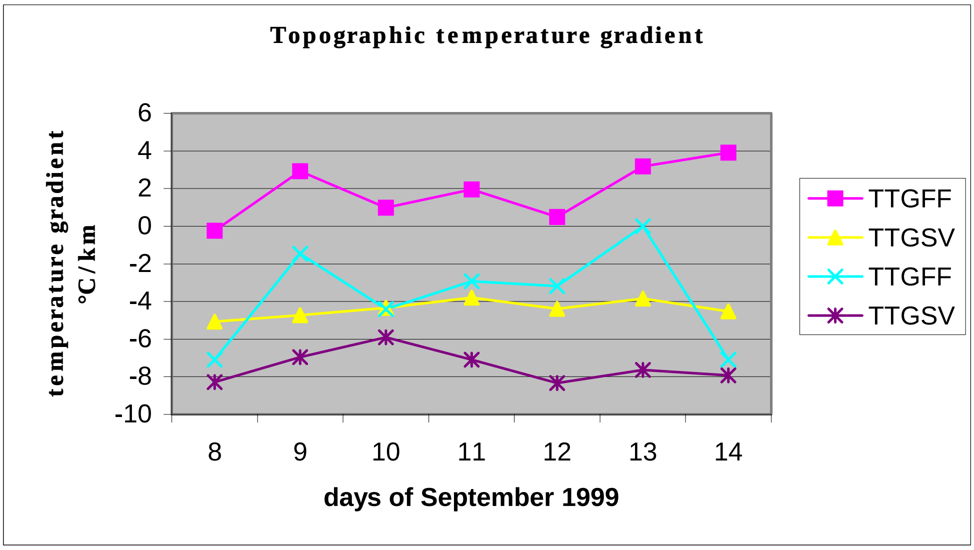

Figure 1. Topographic temperature gradient (TTG) at the beginning of September 1999: TTGFF - for Fraxern-Feldkirch, TTGSV :Säntis-Vaduz; pink and yellow :morning; blue and violet: afternoon.

ELEVATED PBL CASES AT THE BEGINNING OF SEPTEMBER 1999

Elevated PBL structure cases were observed by the lidar between 7 and 14 September 1999. One such example is presented in Figs. 2 where the measurement is from approx. 08:00UTC on 9 September till 14:00h on 10 September. The horizontal axis gives the time of measurements in UTC, the vertical axis presents the altitude above ground level (agl), the magnitude of the range-corrected lidar signal is presented by the colour scale. The altitude of the top of layers type (i) is marked by “o” while the altitude of layers type (ii) is marked by “x”. The succession in altitude of the various layers is shown by the different colours of the marks. The measurements show a diurnal variation of a complex layered structure of types both types. The layers of type (i) are 4 where the top of the highest varies between 4-5km agl. This highest layer shows a negligible diurnal variation. At noon-afternoon hours another one appears at low altitudes, like emerging from a layer of type (ii). Layers of types (i) are also observed to go into type (ii).

Table 2 presents the meteorological parameters corresponding to the period 29 Sept-1 Oct 1999. Fig. 3 presents a lidar measurement from 1 October 1999 for six. The marking of the various layers follow the marking in Fig. 2, with the white spots presenting clouds, i.e. regions with a high number of water droplets. There are some notable differences compared to the case in Fig.2: a) The structure contains no layers of type (ii) and less of type (i); b) The highest layer at 4-5km agl in Fig. 2 is missing in Fig.3; c) The top altitudes of the layers of type (i) are lower by several hundred meters compared to the case in Fig.2; These differences my be explained with the conditions, favouring the convection and venting, and temperature inversions, under which the measurements presented in Fig. 2 were done.

Table 2. Similar as table 1, for the period 29 September to 1 October 1999

DAY	PP	PPx	PPn	GR	GRx	TT	TTx	TTn	UU	UUx	UUn
29/9	1012	1016	1006	7,0	450	13,0	18,3	10,9	88	99	51
30/9	1004	1008	1000	6,0	460	13,2	18,9	10,9	88	98	65
1/10	1013	1015	1008	9,0	550	12,9	18,1	10,2	80	95	44
unit	hPa	hPa	hPa	MJ/m2	W/m2	°C	°C	°C	%	%	%

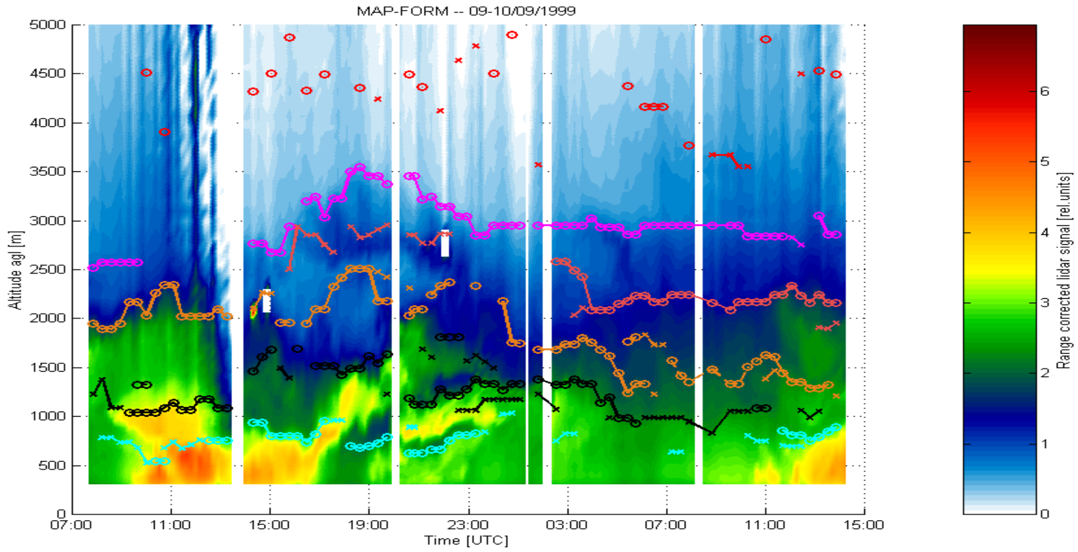

Figure 2. Variation of the aerosol stratification for 9-10 September 1999.

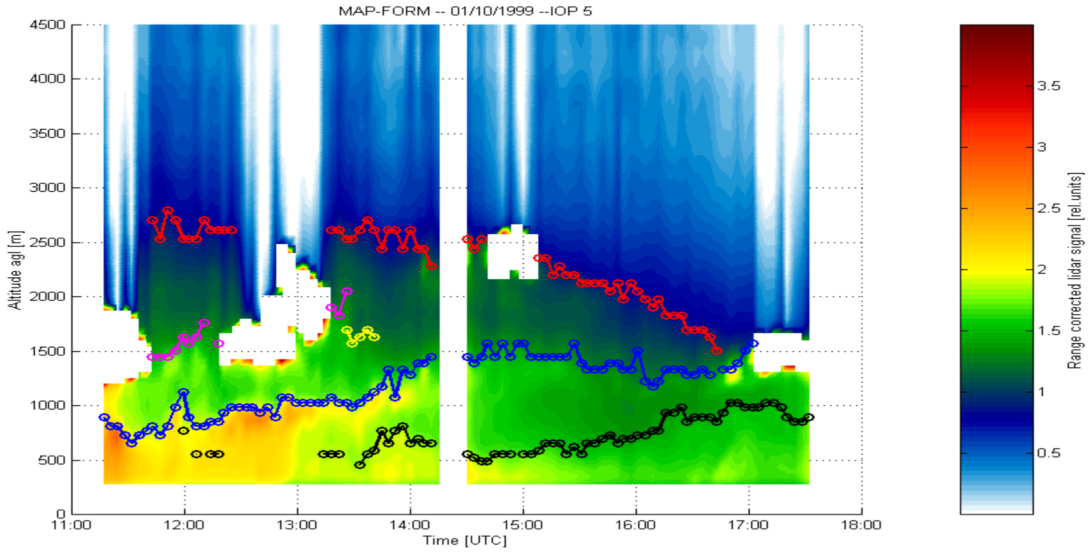

Figure 3. Variation of the aerosol stratification for 1 October 1999; white spots show cloud.

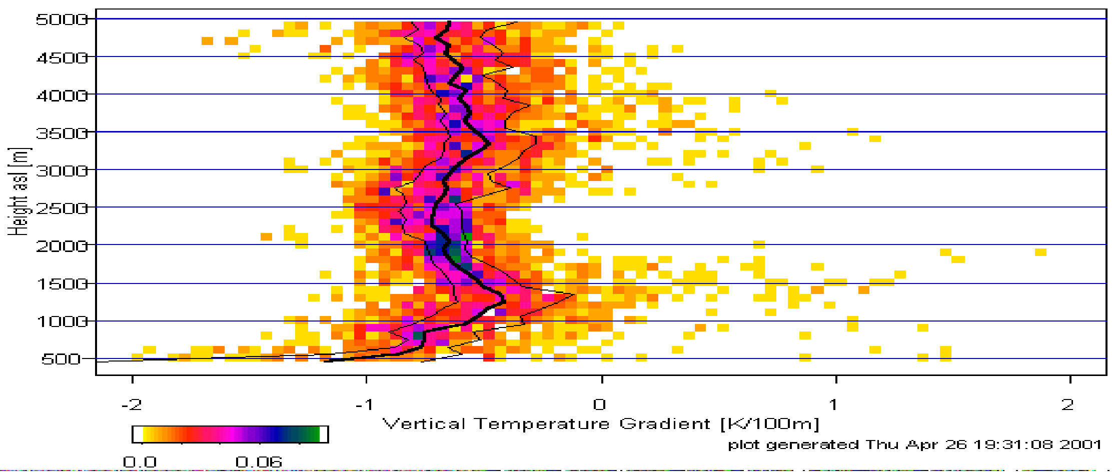

Figure 4. Vertical temperature gradient, 55 days in Sept. –Nov. 1999, outside Foehn periods; station Heiligkreuz; colour bar:relative frequencies with respect to all cases.

DISCUSSION

Profiles of meteorological parameters profiles were taken in high temporal and spatial resolution during the SOP from sites around the lidar site: Heiligkreuz, Buchs-Grabs, Malans (Häberli et al. 2001]. This provides give an opportunity to evaluate the average temperature gradient and to determine its turning points. Fig. 4 presents a statistical evaluation of the temperature gradient all daytime (09:00, 12:00 and 15:00 UTC) radiosonde ascents taken at Heiligkreuz. The presented figure combines measurements during 55 days with no Foehn during the SOP. It is seen that turning points of the gradient correlates well with the altitudes of the layers type (i) determined from the lidar measurements. This correlation is consistent with the assumption that the vertical structure of the PBL above the Valley under most of the meteorological conditions is composed by a number of successive mixed layers. Probably the aerosol in the first and the second mixed layers originates basically from Valley emissions while higher layers are likely a product of combined emission, advection and mixing from a larger scale area.

During strong convection combined with advection, there is an up-lifting of the this layered structure up to 3.5km agl at 4km asl, what is consistent with the observations reported in [Nyeki et al, 2000]. The highest layer of type (i) at 4-5km agl, i.e., at 4.5-5.5 km asl, is observed under strong convective conditions and the appearance of elevated layers type (ii), and possibly reveal handover processes and mixing with the free troposphere [Kossmann et al, 1999]. For measurements on 1 October, when the aerosol structure is lower and highest layer does not appear the synoptic conditions were quite different, see Table 2.

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