P3.4 **ANALYSIS OF THE CONSTANT VOLUME BALLOON FLIGHTS ABOVE THE RHINE VALLEY DURING FOEHN EVENTS (MAP EXPERIMENT)**

Bruno Bénech[1] , Marie Lothon[1] , Heinz Berger[2]

[1]Laboratoire d'Aérologie, UMR 5560 CNRS/UPS, Toulouse; France
[2] Institut de Météorologie Suisse, Payerne ,Suisse

1. INTRODUCTION

During MAP (Mesoscale Alpine Program) experiment, 84 constant volume balloons (CVB) were launched from a side or from the other side of the Alps, operated by the "Laboratoire d'Aérologie" (LA), the "Centre National d'Etudes Spatiales" (CNES) and the Swiss Meteorological Institute (SMI). This study present the analysis of the measurements of the CVB which were launched during south foehn events, in the context of the FORM (FOehn in the Rhine valley during MAP) project. Thus the CVB are used here to study the foehn effect and the mountain wave characteristics, when a south flow blows over the Alps, and leads to foehn within the Rhine valley. A total of 48 balloons were launched in these conditions.

The aim of the CVB is to obtain a description of the flow properties over the Alps from 3000 to 6000 meters height and inside the valley. In south foehn cases, the balloons were usually launched from Ispra (upwind) and from Vilters (in the Rhine Valley). They were followed from Väisäla stations located in Ispra, Monte Lema and Hoher Kasten (see the location of these stations in Fig. 8). In this paper, we present, first, the mesoscale flow organization deduced from the CVBs flights, second, the analysis of the mountain wave characteristics and third, some eulerian and lagrangian comparison with numerical simulations, operated with the French non-hydrostatic mesoscale model Meso-nh.

2. MESOSCALE FLOW ORGANIZATION

The foehn in the Rhine Valley occurs when a southerly or south-westerly flow collides the Alps. This is usually the case when a low moves from west Europe toward the east. During the foehn events of MAP experiment, in function of the location of the low and of its activity and its shape, the upwind flow could be more or less intense and southerly orientated. Launched from Ispra, the CVB could cross the Alps if the south component of the flow was strong enough, or leave toward the west in the other cases. Figure 1 gives an example of IOP 8 foehn event of October 20 and 21 1999. Among the three CNES balloons launched from Ispra on the 21st, two of them crossed the Alps (C14 and C15) and the other (C16) flew along the crest and was lost because of the topography. Four SMI balloons were launched from the Rhine valley. No balloons was launched from Ispra on the 21st because of the rain upwind, in the blocking area.

Correspondig author address : Benech B., Laboratoire d'Aérologie, UMR 5560 CNRS/UPS, 31400 Toulouse; France; email: benb@aero.obs-mip.fr

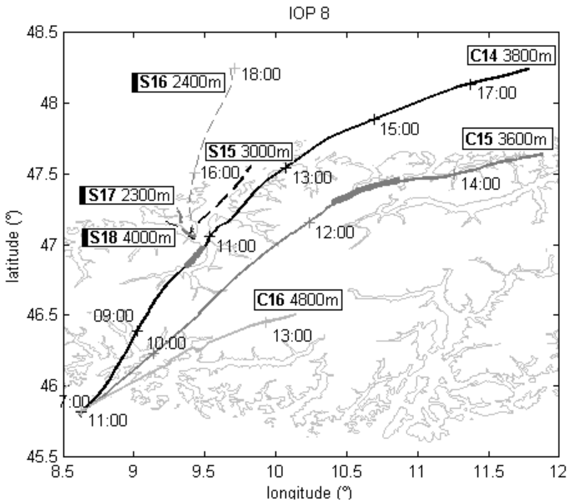

Figure 1: Trajectories of all the constant volume balloons which flew during IOP 8. The label indicates the balloon number and its level. S16, S17 and S18 flew on the 21st of October (thick black line on the left of the label frame). All other balloons flew on the 20th. The thick part line of C14 and C15 trajectories stands for the part of the flight when the mixing ratio and potential temperature significantly varied because of the foehn effect.

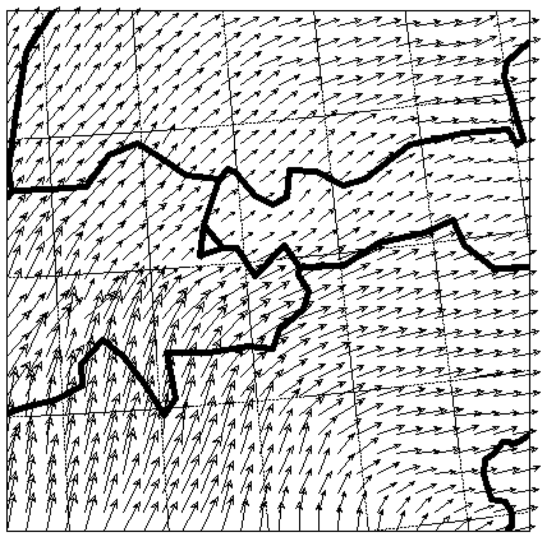

Figure 2 : Horizontal wind field at 3500 m the 20.10.99 at 1100 UTC, from a numerical simulation with Meso-nh model at 3 km resolution.

Figure 1 shows that the trajectories of the balloons which crossed the Alps deflect toward the east after the mountain crest. This can be explained by the fact that they are accelerated before and over the ridge and slowed down after, leading the Coriolis forces divert the balloons toward east above the crest. The horizontal wind field at the balloons level (about 3500 m) given by the numerical simulation with Meso-nh at 3 km horizontal resolution (Figure 2) shows this deflection at the crest.

3. MOUNTAIN LEE WAVE CHARACTERISTICS

Passing over the crest during foehn events, the balloons often measured an increase in potential temperature and a decrease in mixing ratio, which could be more or less sudden and distant from the ridge. As a typical example, Figure 3 shows the parameters measured by CNES 14 CVB. An increase of 4 K in potential temperature and a decrease of 1 $g.kg^{-1}$ were observed above the south Rhine Valley (see Figure 1 to locate the thermodynamical gaps on the trajectory). Note that in this case, the altitude of the balloon varied as well, what contributed to the increase of potential temperature and decrease of mixing ratio after the ridge. The descent observed upwind was due to condensation over the balloon surface, because the relative humidity of the air which was about 90% until 0840 UTC. Arriving after the crest in far dryer air, the balloon dryed as well and came back at its former flight level.

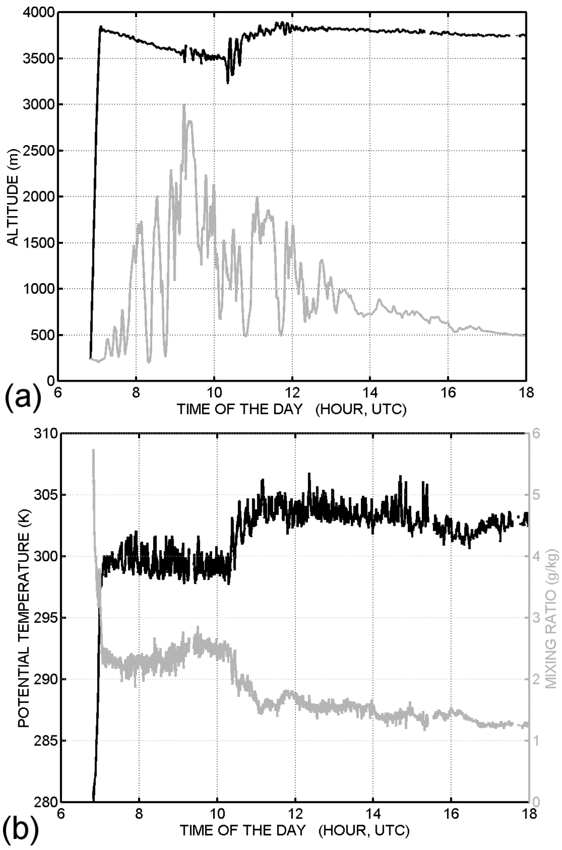

Figure 3 : Evolution of CNES 14 constant volume balloon parameters : (a) Altitude (black line) and topography (gray line) under its trajectory (cf. Fig. 1). (b) potential temperature (black line) and mixing ratio (gray line).

These characteristics of the mountain lee wave can be observed with numerical simulation in the north-south cross section of potential temperature and mixing ratio fields showed in Figure 4. The falling of the isentropes observed in Fig. 4a is characteristic of a flow passing over a mountain ridge, and leads to the so-called "foehn effect". The drying is also well marked, even if a more humid mass located at north, is observed. This humid air mass comes from north-east, and differs from the downslope dry and warm foehn air (Lothon et al, 2002).

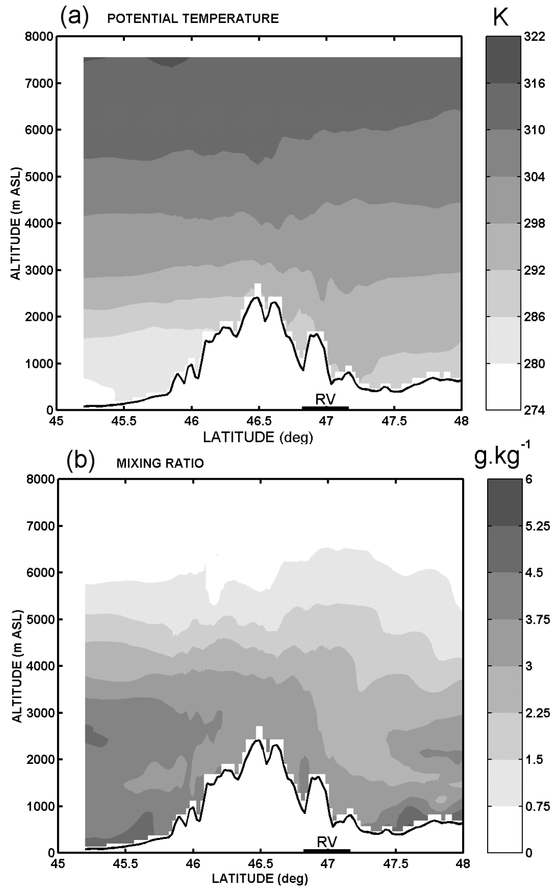

Figure 4 : (a) Potential temperature field and (b) mixing ratio field in a north-south cross section, from numerical simulation with Meso-nh at 3 km horizontal resolution. The latitude of the Rhine valley is indicated ("RV").

As the thermodynamic variation from upwind to the lee of the mountain which can be measured by the CVB seems to be a steering parameter, it has been evaluated from all the CVBs which crossed the Alps during MAP south foehn events. Thus, the increase in potential temperature and the decrease in mixing ratio along the trajectory of these CVBs have been evaluated. They are presented in table 1, with the corresponding time of these sudden variations, and the level of the balloon. The pressure difference between Lugano and Vaduz ground station (distant from 130 km) and the potential temperature between Vaduz and Lugano at the same time are also presented, because these parameters seem also to run the foehn event (Lothon et al, 2002).

The potential temperature increase has been put as function of the pressure gradient at the ground in Fig. 5. These two parameters are correlated in general, but some exceptions appear. For example, during IOP 12, three CVBs crossed the Alps, but their trajectory was not deflected at all over the ridge, and they did not measure any notable thermal variation. Though, the mean pressure gradient between Lugano and Vaduz was about 9 hPa during this IOP. This event presents a lot of atypical characteristics, as Dobrinski observed (Drobinsky et al, 2002). The only other event which presents a CVB with no thermal variation is the one of November 2, IOP 13. It is the weakest event during MAP, according to the analysis of Lothon et al (2002).

The CNES 17 CVB launched during IOP 9 observed a strong increase of the mixing ratio, because it entered in a very humid blocked air mass and kept flying north-eastward along an Alpine crest south-west/north-east orientated, between the Rhine valley and the Wipp valley.

IOP nb	BVC nb	Δmr g.kg^{-1}	$\Delta\theta$ K	ΔP_g hPa	$\Delta\theta_g$ K	date JJ.MM	time UTC	level m
2	C1	-1.2	+4	9	8.6	19.09	1130	4000
	C2	-0.9	+5.4	8.2	7.2	19.09	1420	3500
5	C9	-0.2	+3	7.7	6.4	02.10	1730	3250
8	C14	-1.0	+4.1	10.5	7.5	20.10	1030	3800
	C15	-0.6	+2.7	12.3	10.5	20.10	1245	3600
10	C20	-0.4	+4.2	11.4	9.2	24.10	1045	3400
12	C23 *	0	0	/	/	30.10	/	4350
	C25 *	0	0	/	/	30.10	/	3400
	C26 *	0	0	/	/	30.10	/	4000
13	C28	///	+1	8.5	7.2	02.11	1015	2300
	C29 *	0	0	/	/	02.11	/	4600
15	C31	-0.5	+1.5	5.8	3.0	05.11	1245	3800
9	C17	+1.9	0	12.6	11.5	22.10	2030	3300
	C18	-0.2	+1.5	11.7	10.0	22.10	1600	3800

Table 1 : All the balloons which were launched during a foehn event and which crossed the Alps from south to north are presented here. The corresponding potential temperature (Dq) and mixing ratio (Dmr) variation they measured along their trajectory and the time of this variation are indicated. In 5th and 6th columns, the pressure difference (-DPg) and the potential temperature difference (Dqg) between Vaduz and Lugano at the ground at the same time are indicated. The asterisked balloons didn't measure any change in potential temperature or mixing ratio. That is why the corresponding rows are incomplete.

Although the thermal variations could not be always so well marked along the CVB trajectories, because of their west component, of the complexity of the alpine topography, and of the originality of each foehn event, they remain a strong signature of the intensity of the foehn effect, that has to be assessed and analyzed. But, for the reasons developed beyond, it is often necessary to analyze in details what happened to each balloon during its flight, and to link it with the mesoscale and synoptic context.

4. COMPARISON WITH MESO-NH NUMERICAL SIMULATIONS

In order to determine whether the numerical simulation at 3 km horizontal resolution could reproduce the same phenomenology as the CVBs

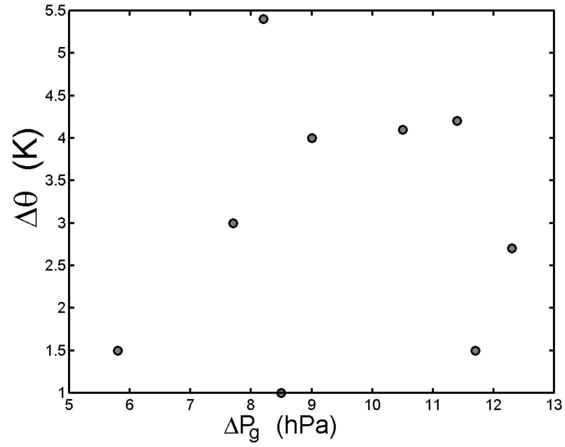

Figure 5: Potential temperature increase in function of pressure gradient between Lugano and Vaduz.

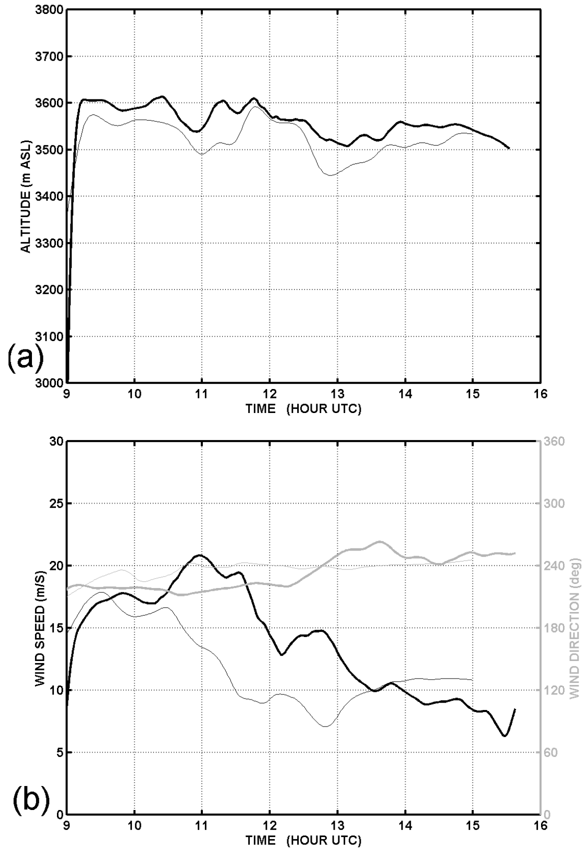

Figure 6 : Eulerian comparison between the measurements of CNES 15 constant volume balloon (thick line) and the numerical simulation with Meso-nh (thin line). (a) Altitude of the balloon. (b) Wind speed (black) and direction (gray).

observation, two different approaches have been carried out . The first one is Eulerian and consists in doing the comparison of the fields along the experimental balloon trajectory. The second one, Lagrangian, consists to run the equation of motion of the balloon within the Meso-nh model fields.

The first approach has been applied to the CVB CNES 14, 15 and 16 and to the CVB SMI 15.

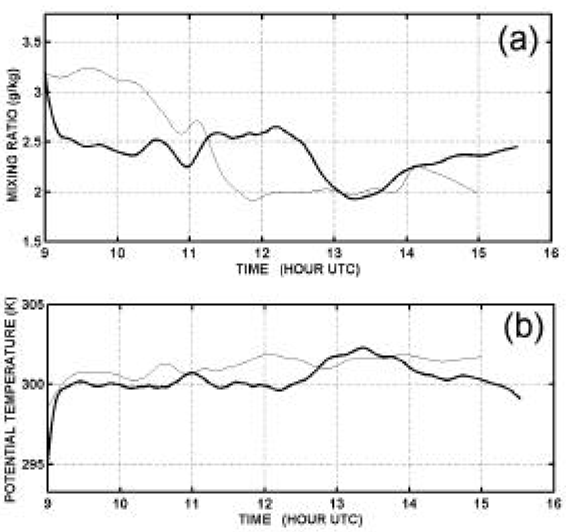

Figure 7 : Eulerian comparison between the measurements of CNES 15 constant volume balloon (thick line) and the numerical simulation with Meso-nh (thin line). (a) Mixing and (b) Potential temperature.

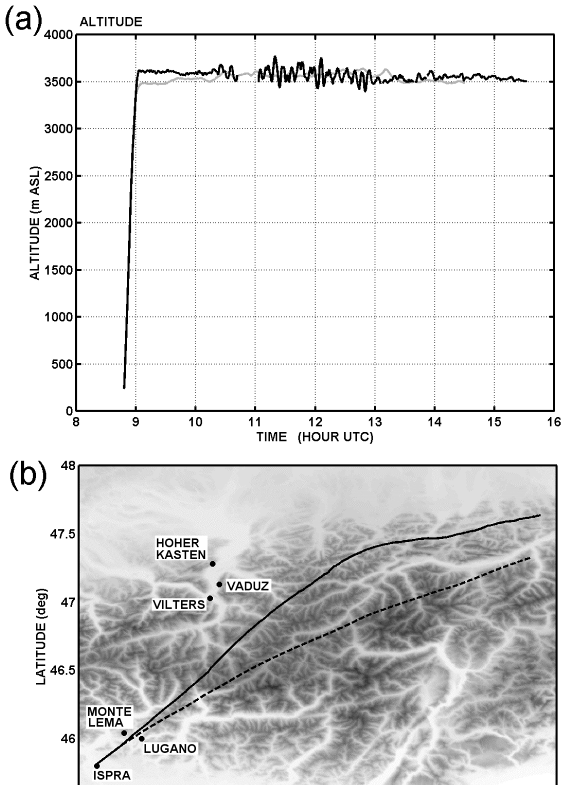

Figure 8 : Lagrangian comparison between the measurements of CNES 15 constant volume balloon and the numerical simulation with Meso-nh. (a) Altitude of the balloon (experimental data in black line, and numerical data in gray line). (b) Trajectory of the balloon (experimental data in solid line, and numerical simulation in dotted line).

The simulated field are supposed to be stationary for 1 hour duration. The results are presented figures 6 and 7.

The Eulerian comparison has been made by using the same coordinates of pressure, longitude and latitude. The experimental and simulated mean values for the dynamical and thermodynamic parameters are in good agreement. Some differences appears on the altitude (about 50 m in average). The wind intensity is underestimated in the simulation with a higher in the experimental data and a later decrease. The same remarks can be done about the mixing ratio for the decrease behind the mountain ridge (figure 7a). The comparisons made with the radiosoundings show in general a good agreement but some discrepancies appear indicating that the model follows the time evolution of the meteorological situation with a time lag.

The lagrangian comparison has been made using the equation of motion of the balloon (Koffi et al, 1999). A lagrangian comparison is presented figure 8 for the case of IOP 8 foehn event, which the CNES balloon 15. We note a divergence of the simulated trajectory compared with the experimental one despite the fact that the CVB altitude is correctly reproduce.

5. CONCLUSION

The CVB trajectories and the parameters measured along their flight axis bring some rich information about the deformation of the flow crossing the mountain range as the rotation above the mountain ridge, the acceleration of the wind, the heating and drying of the air mass well correlated with the pressure drag represented here by the differences of pressure between the south and the north of the Alps.

The fine comparison between the CVB data and the simulation remains a good procedure to validate the time evolution of the model response. The Eulerian and Lagrangian comparisons show clearly that the phenomenon is well reproduced with some differences with experimental data due to the smoothing effect taking into account in the simulations both spatially and temporally.

6. ACKNOWKEDGEMENTS

The authors acknowledge Dartiguelongues from CNES for operating the CVBs.

7. REFERENCES.

- Dobrinski P., C. Haeberli, E. Richard, M. Lothon, A.M. Dabas, P.H. Flamant, M. Furger, and R. Staneiker, 2002: Multiscale analysis of a south event in the Rhine valley: unstationary and inhomogeneity aspects, *submitted to Q. J. R. Metorol. Soc.*

- Koffi E., M. Georgelin, B. Benech and E. Richard, 2000: Trapped lee waves observed during PYREX by constant volume *balloons: comarison with mesoNH simulations,* J. Atmos. Sci., 57, 2007-2021.

- Lothon M., A. Druilhet, B.Benech, B. Campistron, S. Bernard and F. Saïd, 2002: Analysis of the turbulence in five MAP foehn events based on aircraft measurements and associated mesoscale features, *submitted to Q. J. R. Metorol. Soc.*