P3.3

MASS BUDGETS IN THE RHINE VALLEY DURING A FOEHN EVENT

Geneviève Jaubert and Joël Stein

Centre National de Recherches Météorologiques (CNRS and Météo-France), Toulouse, France

1. INTRODUCTION

During strong Foehn events, the downslope wind organizes in a low level jet in and at the outlet of some major valleys in the lee side of the mountains. This phenomena has been observed during the IOP2 of the MAP experiment in the Rhine valley, north of the Alps. Measurements and high resolution simulations allow us to describe how this phenomena occurs for a real case over a complex orography.

2. NUMERICAL SETUP

The numerical simulations are performed with the non-hydrostatic model Meso-NH (Lafore *et al.* 1998), using three nested domains (10, 2.5 and 0.625 km meshes), with 2 way interactive grid nesting and cold microphysics. The 2.5 km domain (500 x 500 km^2) includes North-Italy and Switzerland. The simulation starts at 00 UTC September 19th and is forced by the ARPEGE large scale operational analyses. The third nested model centered on the Rhine valley was activated during the flight of the research aircraft Merlin IV (99/09/19 1200 to 1400 UTC)(Figure 1).

The Rhine valley represent a very deep cut in the Alpine topography. Its shape is typical of the glacial erosion, with a horizontal valley floor close to 500 m ASL and steep sides. Its width varies between 1 and 5 km. It is surrounded by mountains higher than 2000 m ASL.

We focus on the higher resolution simulation, at 14 UTC. The southerly wind speed is 12 ms^{-1}, corresponding to a nondimensional mountain height close to 2.3 (see Jaubert and Stein 2002 for an overview of the mesoscale flow). The drag force value, approximated by the Mean Sea Level Pressure difference between Lugano (south of the Alps, altitude 275 m) and Vaduz, in the Rhine valley (altitude 463 m), is 8 hPa.

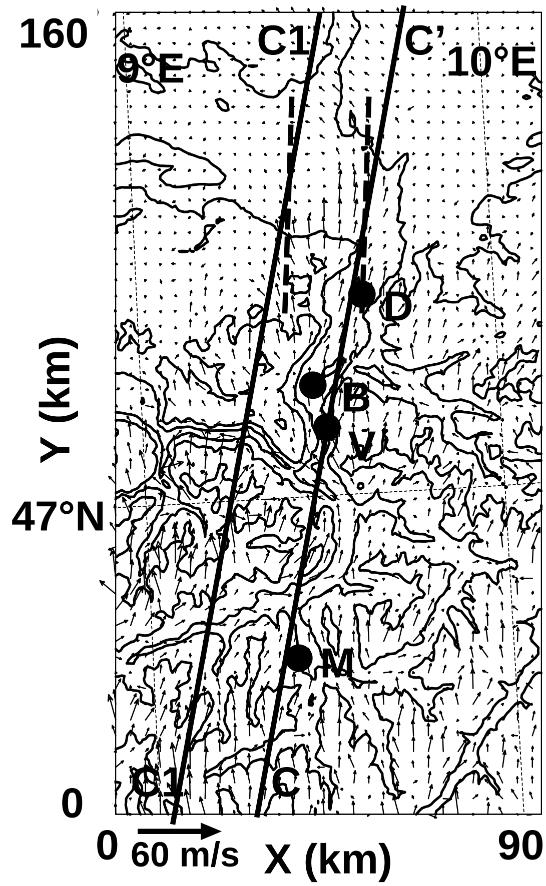

Figure 1. *Simulated ground wind the 19 September 14 UTC in the 0.625 km model domain. The elevation isolines are 500 m, 1000 m and 2000 m. Radiosounding locations (Masein:(M), Buchs-Grabs:(B), Diepolsau:(D)) and surface station (Vaduz:(V)) are plotted. C-C': Rhine valley cross-section, C1-C1': mountain cross-section.*

3. THE FOEHN NEAR THE RHINE VALLEY

Radiosounding measurements launched in the Rhine valley (Fig.2 and Fig.1), show an inversion at 4 km ASL. This is close to the highest summits of the Alps crest. Above this inversion, a mixed region exists for the three soundings, but at different levels, corresponding to a breaking wave. The ver-

[1] *Corresponding author address*: Geneviève Jaubert, CNRM, 42 av. Coriolis, 31057 Toulouse Cedex, France. e-mail:genevieve.jaubert@meteo.fr

tical profile of the Foehn jet evolves when the air flows from the upper Rhine valley (Masein), to its lower part. The air warms by 3 K below the inversion between Masein and Buchs-Grabs, and the wind speed increases. The Foehn jet is organized at Buchs-Grabs, with a maximum speed of 22 m/s at 3 km ASL. Close to the valley outlet, at Diepolsau, the low level jet is less strong (18 m/s at 2km ASL) and the air below the inversion is a little warmer.

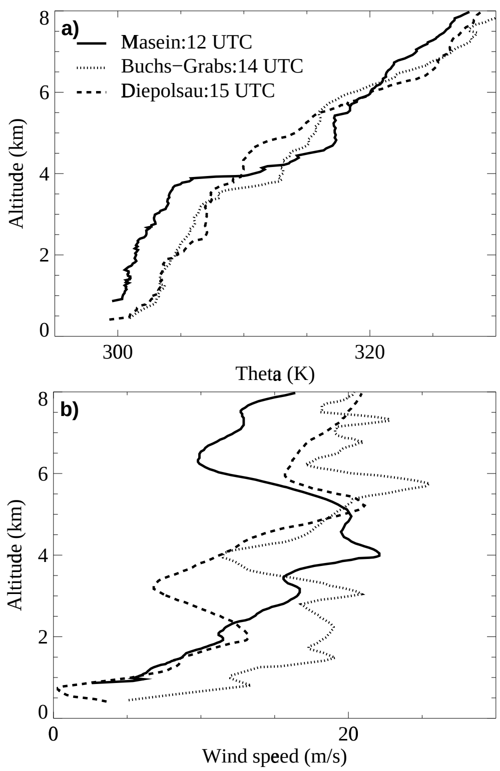

Figure 2.*Rhine valley soundings. a) Potential temperature , b) Wind speed.*

These features are recovered by the simulation, in a cross-section along the Rhine valley (C-C', Figure 3). At low levels, the downslope wind due to the mountain wave over the Calandas mixes with the air coming from the upper Rhine valley (Figure 1), producing a large turbulent kinetic energy and a warming of the low levels. This air organized in a low level jet in the Rhine valley, and gently goes up after the outlet of the valley. Wave breaking appears at the lee side of the Calandas between 5 and 6km height, in a narrow region (10 km).

The East-West extension of the jet (30 km) over the lake of Konstanz (Fig.1) is recovered by the simulation, in accordance with the Merlin aircraft measurements (Jaubert *et al.* 2001).

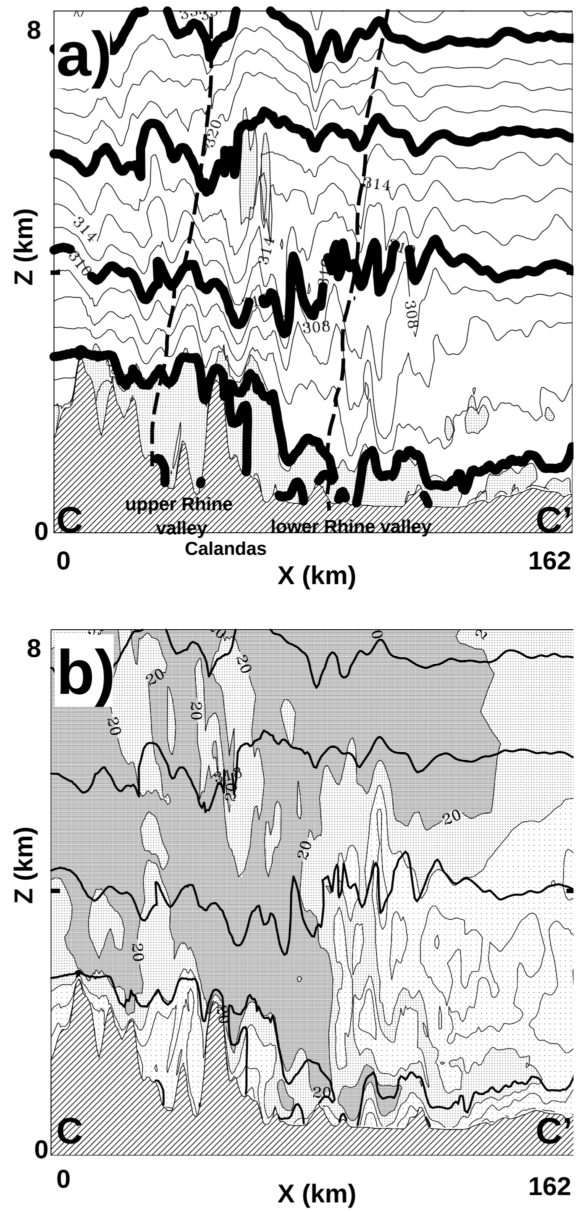

Figure 3.*Potential temperature and Turbulent kinetic energy (a), wind speed (b) along the Rhine valley (cross-section C-C' on Fig.1) the 19 September 14 UTC from the high resolution model. Turbulent kinetic energy greater than* $0.5m^2s^{-2}$ *is hashed in (a). The contour interval is 2 K for* θ, $5ms^{-1}$ *for the wind speed.* θ *heavy isolines every 8 K is heaviest. dashed lines in (a): trajectories of the radiosoundings launched from Masein and Buchs-Grabs.*

The air trajectory is not the same outside the Rhine valley. A cross section 16 km to the west of this valley (Fig.1) indicates the mountain wave is stronger, producing a larger region of wave breaking, but the downslope wind does not extend so much in the lee of the Alps, due to the quickly return at higher altitude. This creates a stationnary lee jump when the warm air reaches the stagnant air close to the lake of Konstanz (Fig.5), at the contrary of the Rhine valley where the Foehn air returns slowly to a higher altitude (Fig.6).

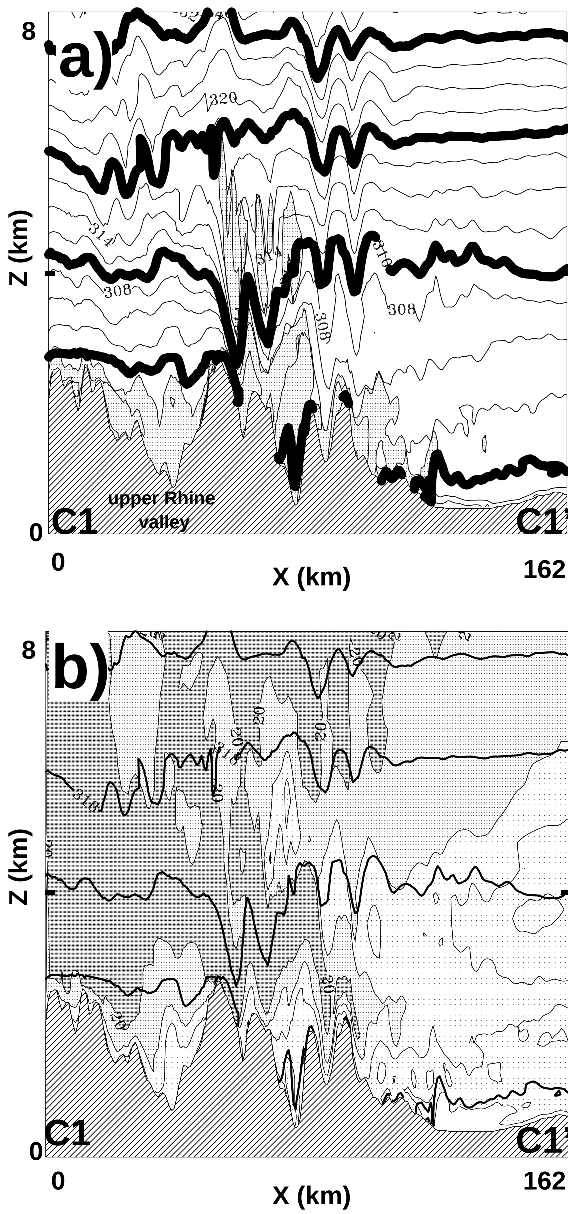

Figure 4. *Same as Fig.3 but for the mountain cross-section (C1-C1' on Fig.1)*

4. MASS BUDGET

The mass budget is computed in a box of 75 km x 112 km, centered over the Rhine valley (Table 1, domain on Fig.7). For a box between the ground and 4000 m ASL, the contribution of the flux across the top is small, compared to the lateral fluxes. The comparison between the boxes with tops at 2 km and 4 km ASL indicates that in the 2 km box most of the air comes through that height in the box and goes out by the North side. This is no more the case for the 4 km box, where we find most of the flow enters the box by its South side and goes out by the North one. This global budget has been completed by more local ones (Fig.7). It shows that the feeding of the low level air by warm air coming from higher levels is not uniformely distributed: the most intense vertical flux is found in the lee of the last massif of the Alpine chain where the air flows downstreams of the Alpine crest. This maximum value decreases from 303 $10^6 kg\ s^{-1}$ West of the Rhine valley to 77 at the East. It should be noted that the return to higher altitudes is more gradual in the Rhine valley and this is proved by the still high value of the flux (430) at the northernest side at the outlet of the valley compared to their neighbours (223 and 177).

Another interesting point is the minor importance of the W-E fluxes to feed the Foehn air in the Rhine valley (i.e. the air coming from adjacent valleys) compared to the N-S flux and the top flux.

Top Alt	South 75km	North 75km	West 112km	East 112km	Top
2000m	+62	-830	+92	-99	+729
4000m	+2023	-2102	+1152	-1335	+246

Table 1. *Mass budget for the whole domain(75 * 112 km) of Fig.7 between the ground and an altitude of 2000 m ASL and 4000 m ASL. Incoming fluxes ($10^6 kg\ s^{-1}$) for the 5 sides of the box.*

5. CONCLUSION

The simulation of this very strong Foehn event at high resolution has been validated and allows us to approach the complexity of the phenomena involves in a real case, where mountain waves are strong, inducing wave breakings and hydraulic jump. A mass budget analysis of the air near the Rhine valley shows the unhomogeneity of the feeding of the Foehn and the minor part of the adjacent valleys.

References

[1] G. Jaubert, Asencio N., and J. Stein. Relation between the Rhine valley Foehn intensity and the mesoscale regime based on IOP2 Foehn event and idealized numerical simulations. *MAP Newsletter*, 15, 2001.

[2] G. Jaubert and J. Stein. Multiscale and unsteady aspects of a deep foehn event during map. *submitted to Quart. J. Roy. Meteor. Soc.*, 2002.

[3] J.P. Lafore, J. Stein, N. Asencio, P. Bougeault, V. Ducrocq, J. Duron, C. Fischer, P. Héreil, P. Mascart, J.L. Redelsperger, E. Richard, and J. Vilà-Guerau de Arellano. The Meso-NH atmospheric simulation system. Part I : Adiabatic formulation and control simulations. *Annales Geophysicae*, 16:90–109, 1998.

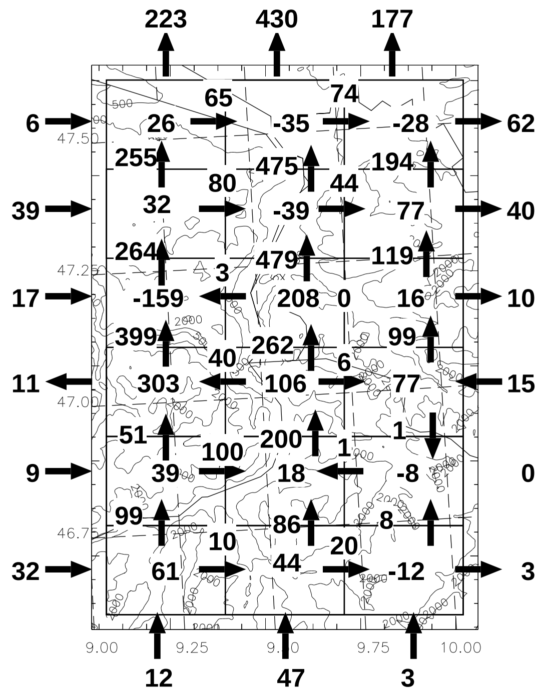

Figure 7.*Mass fluxes near the Rhine valley between the ground and 2000 m ASL. The number in the center of each rectangle is the downward flux* ($10^6 kg\ s^{-1}$). *Size of the boxes: 25 km x 18.75 km.*

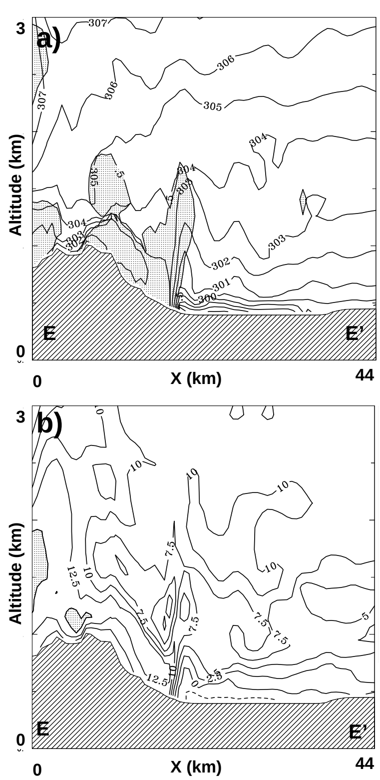

Figure 5.*Potential temperature (a) and wind parallel to the cross-section close to the lake of Konstanz (dashed cross-section in Fig.1 near C1-C1') Wind contour interval is 2.5 m/s, speed greater than 15 m/s is dashed in b. The turbulent kinetic energy higher than 0.5* $m^2\ s^{-1}$ *is dashed in a.*

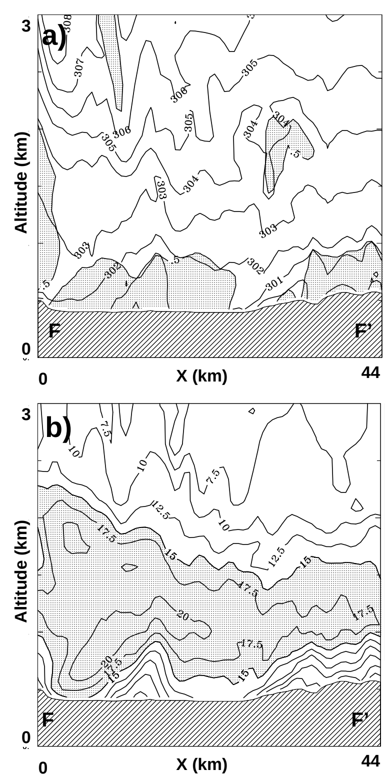

Figure 6.*Same as Fig.5 but near the outlet of the Rhine valley (dashed cross-section in Fig.1 near C-C')*