FOEHN AND STABLE AIR MASS IN THE RHINE VALLEY

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1. INTRODUCTION

The Intensive Observation Period 8 (20-22 october 1999) of the Mesoscale Alpine Program MAP experiment is a strong South foehn event on the northern side of the Alps. The event was documented during the campaign by a large set of instruments, and many high-resolution simulations have been run since then to study the onset of the foehn in the Rhine valley. Driven by synoptic scales, the meso and local behaviour of foehn depends on the topography, the strength of the incoming South flow and the stability of the original air-mass. After a brief description of the set of observation data available from the campaign and a presentation of the simulations, we present the general features of IOP8. Then, we focus on the junction of the Rhine and the Seez valley and the presence there of a cold pool.

2. DATA AND SIMULATIONS

The topography of the region under scrutiny is shown in Fig.1. From South to North, the Rhine valley first oriented South-West/North-East, turns around the Calanda ridge and split into two valleys, the Seez to the West towards Zurich, and the Rhine to the North towards the lake of Constance. Thanks to large number of instruments deployed in the Rhine valley during MAP, many data are available which document the whole foehn episode. Surface stations, radiosondes, sodar, instrumented aircrafts were operated. They give a first description of the flow and were used to validate high resolution simulations from the meso-scale atmospheric model Meso-NH.

Located at Vilters, where the Rhine and the Seez join, a Transportable Wind Lidar (TWL, location represented on Fig.1) gave three-dimensional descriptions of the radial velocity field during foehn onset. A raster scan was performed in the morning of the October 20. The raster scan consisted in sweeping the azimut of the Line Of Sight (LOS) at increasing elevation angles from 2 to 28 degrees. It was completed in about one hour. The radial resolution is 200m (see Drobinski et al. 2001 for more information) and first gate is 500m away from the instrument. The maximum range is dependant on the aerosol loading of the atmosphere. During foehn episodes, the air was rather clean, the range was limited to about 6km.

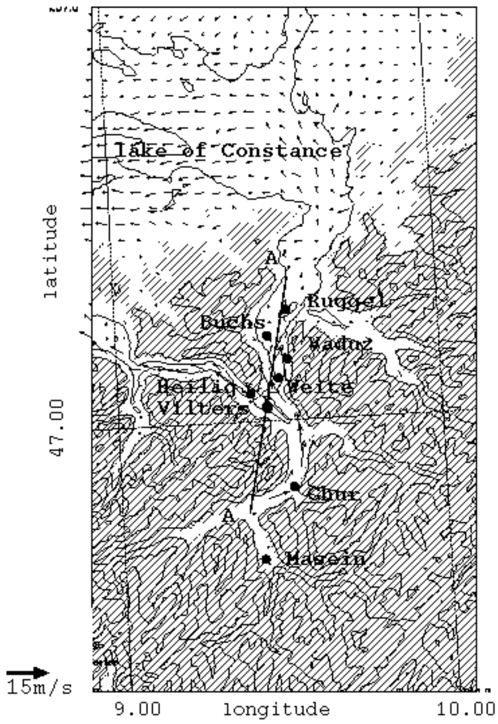

Fig. 1: Simulated wind at 800m ASL the 20 October at 09h30 UTC in the 0.625km model domain centered on the Rhine valley. AA': cross-section along the Rhine valley. Dashed area: topography higher than 800m ASL.

High resolutions simulations of the event were performed with the non-hydrostatic model Meso-NH (Lafore et al. 1998). The simulation combines three model runs on three nested grids. The grid nesting operates on a 2-way-interacting mode. The resolutions of the grid are 10, 2.5 and 0.625 kilometers. Model runs were forced by the analysis of the French operational model ARPEGE (same configuration that in Jaubert 2002). The 2.5km grid covers the alpine region, the North of Italy and of the Mediterranean sea. A three dimensional turbulent scheme is used for the third domain, centered on the high Rhine valley (this domain is represented on Fig.1). The

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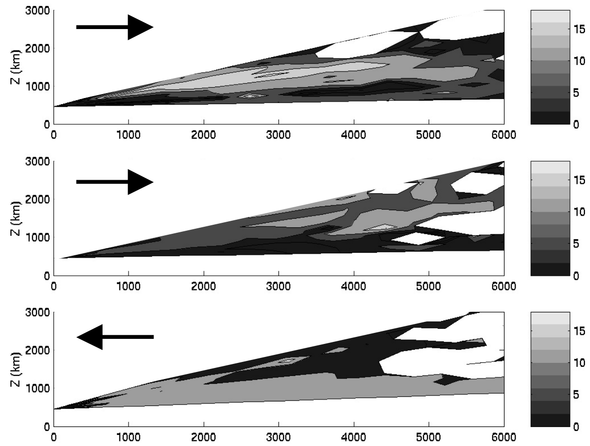


Fig. 2: TWL's radial wind velocity (m/s) on vertical cross-sections from the TWL toward the Seez valley (top), the lake of Constance (middle) and the upper Rhine valley (bottom), from the raster scan between 08h40 and 09h40 UTC. The arrows indicate the flow direction along the cross-sections

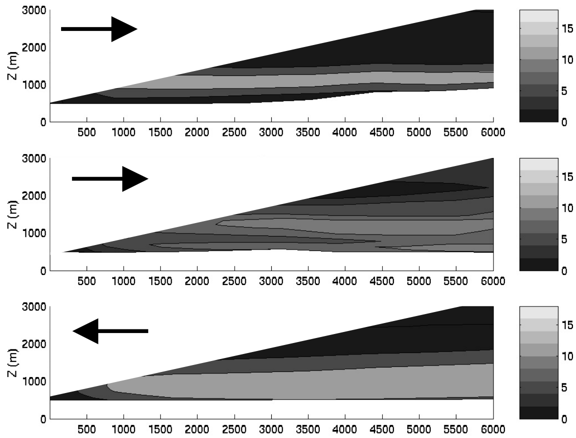


Fig. 3: same as Fig.2 but for the model's radial wind intensity (m/s) at 09h00 UTC.

three models simulation runned between 07h00 UTC and 09h30 UTC, as a raster scan from the TWL is available.

A simulation run limited to the 10km and 2.5km domains is also available which covers the entire day. To facilitate the comparison with observation data, radial velocities around the location of the TWL have been performed at each mass point of the grid of the inner model.

3. GENERAL FEATURES OF IOP08

The 20th October is characterized by a deep low approaching the West Mediterranean from the West. In the late afternoon it is centered over the North of the Iberian peninsula. It forces a South-Westerly flow towards the Alps, which turns to the North and accelerates during the day. The sea level pressure difference between Lugano in the Pô valley (South of the Alps) and Konstanz in Germany increased during the day, from 7 hPa at 09h00 UTC to 13 hPa at 18h00 UTC. The shallow foehn (Seibert, 1990) is replaced by a high reaching foehn, as the flow observed over the Pô valley becomes more southerly and strong, as revealed by the UHF profiler of Lonate. The low level flow in the Pô valley is blocked. Considering the inflow as the UHF measurement of the meridian wind between 1.5 and 4 km ASL and a mountain height of 2500m, the non-dimensional height is evaluated at 5.4 at 06h UTC, 3.2 at 12h UTC and 2.7 at 18h UTC (the Brund-Välsälä frequency is calculated from the radiosonde sounding of Milano).

The upstream flow from the model is consistent with these observations (not shown), except for the incident wind (meridian component) which increases too rapidly in the afternoon (at 4000m ASL, up to 16m/s at 16h UTC in the model and only at 20h UTC with the UHF data), allowing high level air to flow over the Alps and a high reaching foehn to develop too early in the North valleys.

North of the mountains, the low level flow is from East, due to the split around the whole alpine area. Thus, such a East flow, increasing during the day, can be observed North of the Rhine valley, over the lake of Constance (see Fig.1).

The well established foehn will then last all the IOP until a front arrives in the area during the night from the 21 to the 22 of October.

4. JUNCTION OF THE RHINE AND SEEZ VALLEYS

4.1 Comparisons: model and lidar data

As confirmed by the different radiosondes, the channelling of the flow during foehn periods is significant inside the valleys, which means that the radial velocities measured with the TWL can be in a good agreement with the real wind if the LOS is along the valley axis. Fig.2 and 3 represents these velocities on vertical cross-sections respectively measured by the TWL and simulated by Meso-NH. The raster scan presented here has been realized between 8h40 and 9h40 UTC. At the junction however, the interpretation is more difficult. The incoming flow seems to bump into the mountain and to split between the North part of the Seez valley and the West part of the Rhine valley.

As radisosonde data, the TWL data show that the incoming channeled flow, in the upper Rhine valley, appears just above the ground and up to about 2000m ASL with a maximum intensity under 1500m ASL (see Fig.2). Strong radial winds up to 15m/s can be observed by the TWL in the direction of the Seez valley (with a maximal intensity at about 1200m ASL), but not near the ground, as for the incoming flow. In the North part of the Rhine valley, the jet is less strong but concerned a larger layer between 1000 and 2500m ASL (Fig.2).

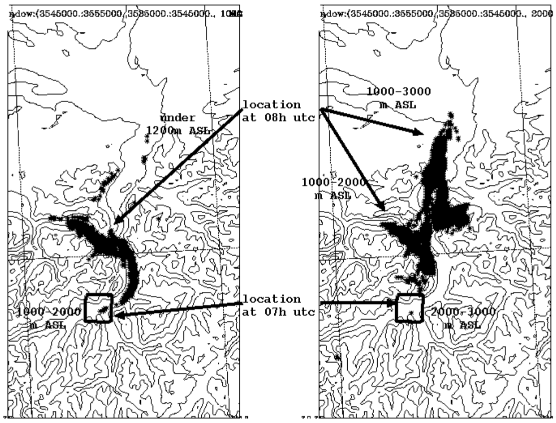


Fig. 4: Location at 08h UTC of the particules originated from the square area (between 1000 ans 2000m ASL on the left and between 2000 and 3000m ASL on the right) at 07h UTC

The model is able to simulate the radial velocity field and its behaviour at the junction. However, some little differences appear. Under 1200m ASL, both observations and simulations are in good agreement, but above, the channeling seems not to be sufficient enough in the model. The radial velocities are less strong than those from the TWL (Fig.3). The comparison with the Buchs-Grab radiosonde soundings confirms also this fact (Fig.5). This can perhaps be explained partly by the smoothing of the topography used.

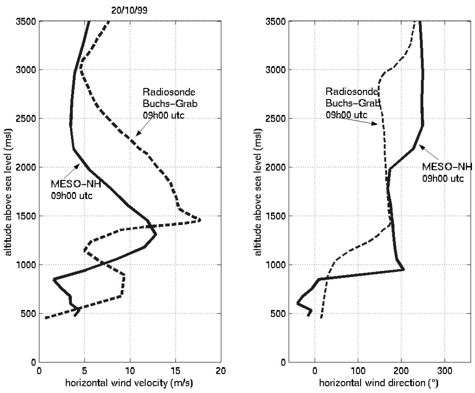
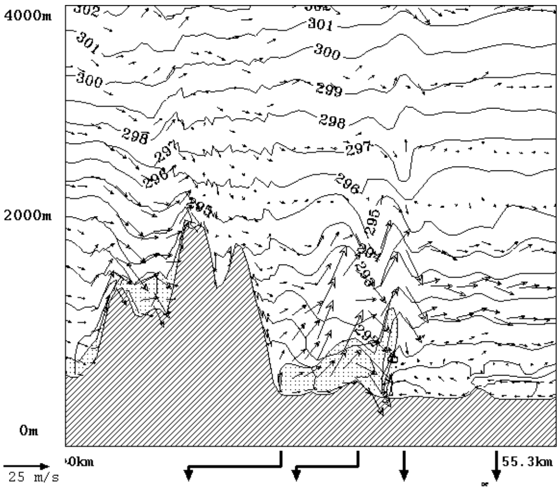


Fig. 5: Intensity (left) and direction (right) of the wind from the Buchs-Grab radiosonde sounding (dashed line) and from a vertical profile of Meso-NH (solid line) at 09h00 utc.

4.2 The flow at the junction

The foehn air that we can find in the North part of the Rhine valley and the one in the Seez valley didn't have the same way. In fact, the first one is warmer because of its falling behind the last ridge in a wave structure as approved by the isentrope surfaces hight. The second one comes essentially from the channelised flow from the high part of the Rhine valley. This can be seen looking at the simulated wind on a cross-section along the Rhine valley (Fig.7) and the wind at 800m ASL (Fig.1): we note the presence of a jet of the orthogonal wind (up to 10m/s) at the junction and under 1000m ASL, where the tangential wind is weaker. This is consistent with the radiosonde launched from the Seez valley (Heiligkreutz, not shown).

To improve this, it can be useful to study forward trajectories of air particules, derived from three Eulerian passive tracers (Gheusi and Stein, 2002). We first select a square area in the upper Rhine valley (see Fig.4) and look at the location of air particules originated from the selected area. The particules which were located between 1000m and 2000m ASL can be found in the upper Rhine valley under 1200m ASL after one hour (Fig.4 left). The other particules, which were first located at higher levels, can be partly found in the Rhine valley toward the lake of Constance above 1000m ASL (Fig.4 right), after they got over the last ridge (Calanda).



	Vilters	Weite	Vaduz	Ruggel
09h utc	T=13°c FF=2.5m/s DD=138°	T=9.5° FF=3m/s DD=20° RH=48%	T=7.5° FF=1m/s DD=340° RH=82%	T=8°c FF=1.1m/s DD=40° RH=77%
10h utc	T=14°c FF=4m/s DD=121°	T=11.3°c FF=3.9m/s DD=18° RH=64%	T=10.2°c FF=1.6m/s DD=340° RH=74%	T=10.5°c FF=1.7m/s DD=10° RH=65%
21h utc	T=14.5°c FF=7.6m/s DD=97.5°	T=16.9°c FF=13.4m/s DD=176.6° RH=38%	T=18°c FF=8m/s DD=173° RH=34.9%	T=16°c FF=4.7m/s DD=200° RH=24%

Fig. 6: Potential temperature and tangential wind along the Rhine valley (cross-section AA' on Fig.1) at 09h30 UTC. Dotted area: TKE greater than $0.8m^2/s^2$. Data of 4 ground stations (see location on Fig.1) are given at the bottom.

5. THE COLD POOL

As revealed by surface stations or radiosonde soundings, the foehn air is confronted a cold pool in the North part of the Rhine valley. This stable air mass is cooler and moister than the turbulent foehn air associated with strong South wind. Therefore, the interface between the two air-

masses is characterised by strong gradients of temperature and humidity, and by wind shear. A weak North wind breathes inside the cold pool.
The high resolution allow to simulate these features with good agreements. At a resolution of 2.5km, the cold pool exists but without the North component of the wind, and with a stability not strong enough. At a resolution of 625m however, the characteristic of the modelised cold pool are more consistent with the observations. The North component of the wind is simulated (see the wind field at 800m ASL on Fig.1, and cross-section on Fig.6 and 7). The thickness of the cold pool is about 500m (See for example the radiosonde sounding of Buchs-Grab on Fig.5). The foehn jet is located above the stable air mass: simulated between 1000 and 2000m ASL in the model, it locates between 1400 and 2500m ASL in the Buchs-grab radiosonde. The interface between the stable air-mass and the foehn has a hydraulic jump behaviour. The tangential wind and potential temperature field in a cross section along the valley axis revealed this structure (Fig.6 and 7). Unlike the cold pool, the foehn air is a high turbulent kinetic energy (TKE) area, essencially due to dynamical production of TKE.
The interface is localised at the time of the simulation between Vilters and Weite (see Fig.6 and location on Fig.1), a little bit more South that in the model. Note however that Weite is not exactly located along the cross-sections on Fig.6 but a little bit more East, and that the location of the interface correspond to the place where the valley width increases.

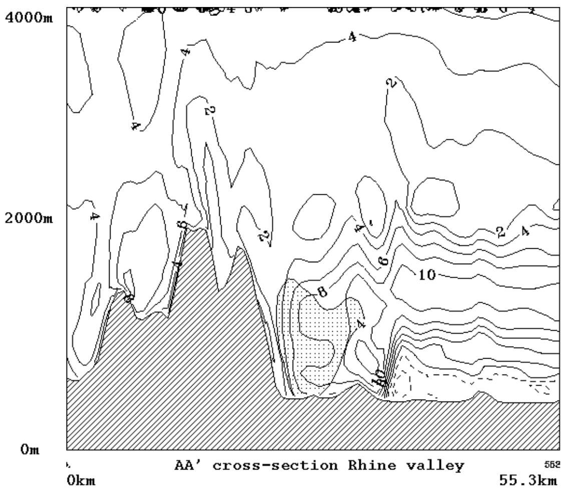


Fig. 7: As Fig.6 but for the tangentil wind component. Dotted area: orthogonal wind greater than 4 m/s.

The low level flow, from the East-North-East, in the lake of Constance area is responsible for the North weak wind that increases during the day in the cold pool of the Rhine valley. Before the onset of the high reaching foehn at the end of the afternoon, the foehn jet is rejected up to about 1800m ASL, above the North wind.
At the end of the day, the foehn suddently reaches the ground in all the cold pool area. The temperature and humidity evolution at ground stations in the cold pool during the day are consistent wih a diurnal cycle, and the onset of the high reaching foehn is particularly significant. The arrival of the foehn at Weite happens around 16h UTC and at about 20h UTC at Vaduz and Ruggel (Fig.6).
In the model, this onset happens a little bit too early during the afternoon probably due to the intensity of the inflow.

6. CONCLUSION

The first phase of the IOP8 foehn period has been described thanks to the data set available and to numerical high resolution simulations. The Meso-NH model is able to simulate the scale interactions and the interface between the foehn and the cold pool, that lead to the foehn evolution in the Rhine valley. The flow at the junction with the Seez valley is complex and divide between the incoming foehn air from the upper Rhine valley and the air falling from the last ridge in a wave mountain structure. The confrontation foehn/cold pool drives the foehn propagation to the ground in the North part of the Rhine valley. The physical parameters leading to the removal of the cold pool have to be study, in term of budget analysis for example.

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