UNSTATIONARY ASPECTS OF FÖHN IN A LARGE VALLEY

Reinhold Steinacker [1] and the members of the FORM group [2]

[1] University of Vienna, Department of Meteorology and Geophysics, Althanstr. 14, UZAII, A-1090 Vienna
[2] MAP-FORM group: see http://www.map.ethz.ch/form
E-mail: reinhold.steinacker@univie.ac.at

Abstract: After an outline of the scientific questions within FORM (Foehn study in the Rhine valley during MAP) some results are being discussed, which allow a deeper insight into the unstationary behavior of foehn in a complex Alpine valley. Due to an extremely dense and sophisticated instrumentation of in situ and remote sensing platforms the themodynamic and dynamic structure could be nicely investigated. It was clearly seen that the static stability within valleys may be quite complex, leading often to a three rather than two layer configuration. Simulations with different very high resolution models allow to derive the critical factors which determine the usefulness of the model with respect to local foehn prediction. Of special importance is the correct treatment of the shallow cold air pool. Considering the scientific results so far obtained of the different types of foehn events during MAP-SOP (MAP Special Observing Period, 7 September – 15 November 1999) the FORM initiative can be seen as a very successful part of MAP.

Keywords - *MAP, Foehn, Alps, complex topography, Cold air pool, flow splitting, very high resolution modeling*

1. INTRODUCTION

The MAP Project P5 "unstationary aspects of foehn in a large valley" focused its investigations to the Swiss-Austrian Alpine Rhine valley. This target was chosen due to some unique phenomena which occur in this area. In the region of Sargans two branches of the valley direct to the Alpine forelands allowing the flow to split. In contrast to other popular foehn valleys like the Reuss- or the Wipp-valley, the Rhine valley consists of segments with different orientations, forcing the flow to change direction. The southern tributaries of the Rhine valley have their origin in several passes along the main crest of the Alps, which allow significant cold air advection from the blocked region South of the Alps during foehn. Northern Alpine West-East oriented mountain ridges perpendicular to the flow lead to secondary foehn phenomena. Last not least the broad estuary segment of the Rhine valley is typically characterized by a tough cold air pool which is only sporadically removed. The local prediction of the foehn penetration in that area is of high practical importance e. g. for aeronautics and for air pollution and imposes a challenge to forecasters.

To understand the diversity of small scale foehn phenomena in the Rhine valley a large number of additional in situ and remote sensing platforms were installed in the target area, including sophisticated instruments like scanning Lidars, RASS-systems and Scintillometers, see Richner et al, 2005 . Due to the above normal frequency of foehn during the MAP-SOP a unique data set could be gained which allows to follow the four dimensional structure of the atmosphere and a validation of the simulations with very high resolution numerical prediction models. In the following chapter some findings based on data analyses and simulations are shown and discussed.

2. SELECTED RESULTS

New insight into the small scale structure of the foehn flow in a complex valley system like the Rhine valley including its tributaries has been obtained with respect to the role of the passes in the main crest of the Alps. Considerable amounts of cool air from the blocked windward side can flow through the gaps into the main Rhine valley (see Fig. 1). This can be seen clearly in the temperature profiles of the array of radio soundings which were operated in the Rhine valley (see Fig. 3). Most of the time in the Southern part of the valley a three layer structure becomes evident: a shallow channeled cold air layer representing the cold air originating south of the Alps below crest height. The intermediate cool layer with a southerly flow direction is confined at the upper level by a typical inversion somewhat above the crest of the mountains (Steinacker, 2005). Above that layer the (potential) warm air of the free air follows, typically separated also by a significant change in flow direction. A tricky phenomenon occurs at the beginning of a foehn event. The establishment of the single layers is not synchronous. This may lead to a situation that the lowest layer is still strongly influenced by diabatic effects (e. g. nocturnal radiative cooling). Then the distinction and transition between the valley wind system and the low level channeled foehn flow becomes difficult. For some time even a flow reversal within the valley may be observed ("sandwhich foehn", Drobinski, 2001).

In the wide Northern part of the Rhine valley the layers are different. The lowest layer there is represented by a cold air pool which is extending from the Alpine forelands and typically even colder than the low level air in the valley. This is impressively shown by a cross section of potential temperature (see Fig. 3). The second layer over the Northern part of the valley is similar to the Southern part, the upper level being mostly lower there and the wind speed less. The free atmosphere layer does not show a significant difference between both valley segments.

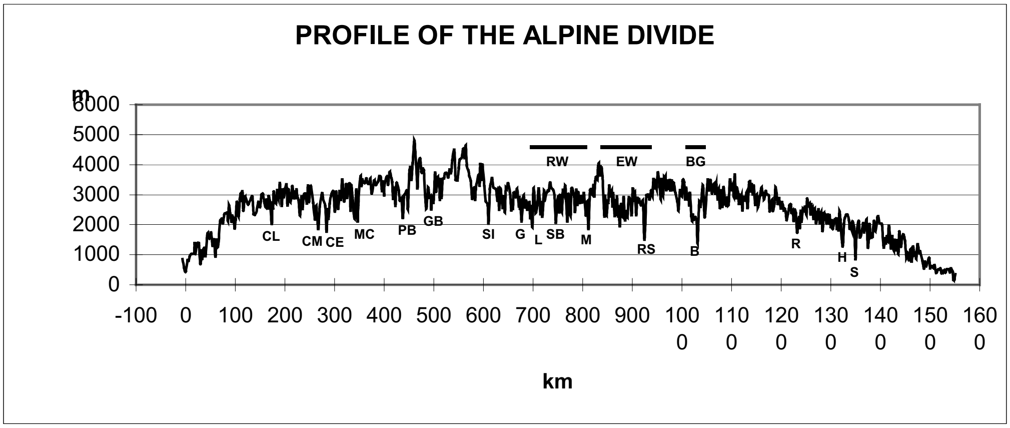

Figure 1: Height profile of the Alps along the main crest between the maritime Alps (left) to Vienna (right). The abbreviations indicate the main passes: CL…Col de Larche, CM…Col de Montgenevre, CE…Col de l´Echelle, MC…Mont Cenis, PB…Petit St. Bernhard, GB…Grande St. Berhard, SI…Simplon, G…St. Gotthard, L…Lukmanier, SB…San Berardino, M…Maloja, RS…Reschen, B…Brenner, R…Radstätter Tauern, H…Hoher Tauern, S…Schoberpaß. Significant series of low passes are the Rhine valley window (RW), the Engadin window (EW) and the Brenner gap (BG).

Depending on the stability of the air in the valley, the flow splitting may be well understood by applying hydraulic theory (Drobinski, 2001). The varying depth of the low level cold air can be nicely followed by the pressure field. The pressure in the Rhine valley which was observed by a very dense automatic surface network gives some interesting details (Chimani, 2002). At the bending of the Valley North of Chur a pressure maximum can be observed which is caused by the impinging flow. The piling up of the cold low level air creates this high pressure hydrostatically and helps the air being accelerated downvalley towards West. Another area of interest is the area of the flow splitting. Due to the part flowing into the Seez valley towards West only a minor part flows down the Rhine valley, leading to a concentrated pressure gradient and corresponding wind acceleration. In this region the Szintillometer prove the strong vertical motions. A further interesting detail was encountered. In a tributary valley (Brandner valley) north of a secondary ridge perpendicular to the flow a strong wave like pressure distribution was commonly observed which fits perfectly to the wave pattern modelled by a high resolution simulation.

This feature has some interesting consequences: Around the location of the pressure wave a village (Brand) is located. The upper (Southern) part of the valley experiences very often strong foehn winds

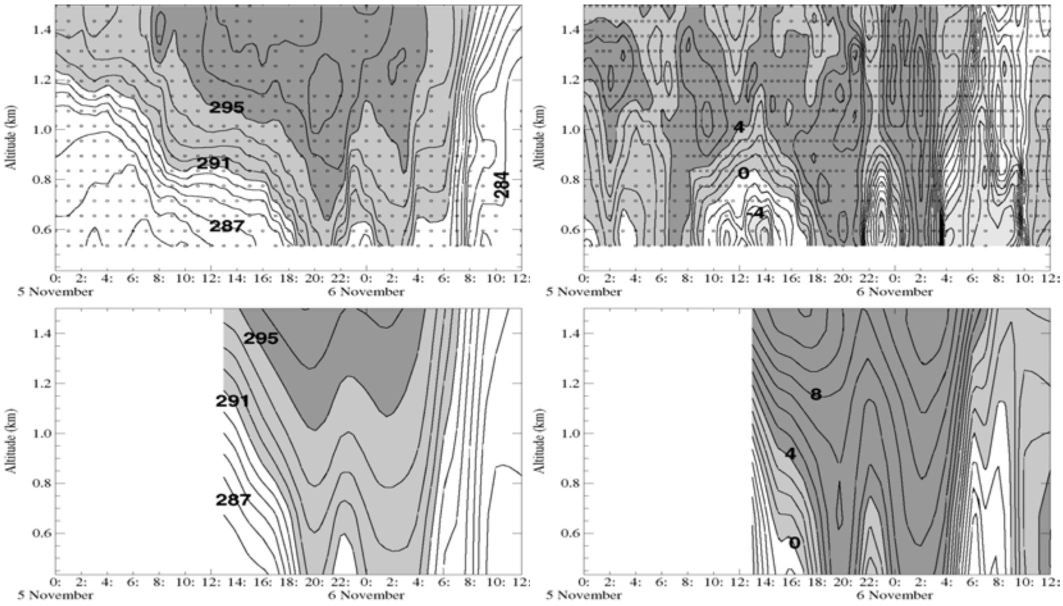

Figure 2: Comparison of time-hight cross sections based on RASS observations (top) and modelled with Meso-NH (bottom). On the left side the potential temperature with a 1 K spacing (grey shading means high value), on the right side the meridional component of the wind with 1 m/s isoline spacing (grey shading is representing south wind, white is north wind), after Vogt and Jaubert, 2004.

whereas the lower part , where the pressure increases in the flow direction and hence decelerates the flow, strong foehn winds are rarely observed (Steinacker, 2003).

A crucial role for the foehn penetration plays the cold air pool. Some interesting results have been gained with this respect. The cold air pool is not a passive layer of air, being turbulently eroded by the foehn flow aloft but has its own dynamics governed by the large reservoir over the Alpine forelands. Wave like processes lead to an intermittent penetration of the foehn to the surface. Due to the dense surface network it could be observed, that the foehn penetration does not take place frontlike, but isolated islands of cold air may remain in some parts of the valley, depending on local topography. An important result was obtained by the simulation experiments with very high resolution numerical prediction models (Zängl et al, 2003). If the initial condition with respect to the cold air pool are sufficiently accurate, the models give very satisfying results. Pure nesting techniques from large scale models, where the cold air pools are not represented correctly, did not lead to useful results. This is an indication, that future operational very high resolution forecasts need a sufficient data coverage in the area of cold air pools.

An important result concerning data interpretation was yielded by using the array of radiosoundings along the Rhine valley. Radiosondes are typically used as vertical profiles through the atmosphere, e. g. the static stability of the atmosphere is directly derived. Due to the small scale features and high winds during foehn, this may lead to considerable errors. Only taking into account the drift of the balloons gives reasonable wave structures and static stability profiles during foehn (see Fig. 3).

3. CONCLUSION

Several new findings were achieved in the FORM project. First, a three layer structure of foehn was found typical in the valley as well as over the Alpine forelands. The significant difference in potential temperature of the layers allows the successful application of shallow water or hydraulic theory, especially with shallow foehn. Second, the change of the channeled flow due to a changing orientation of

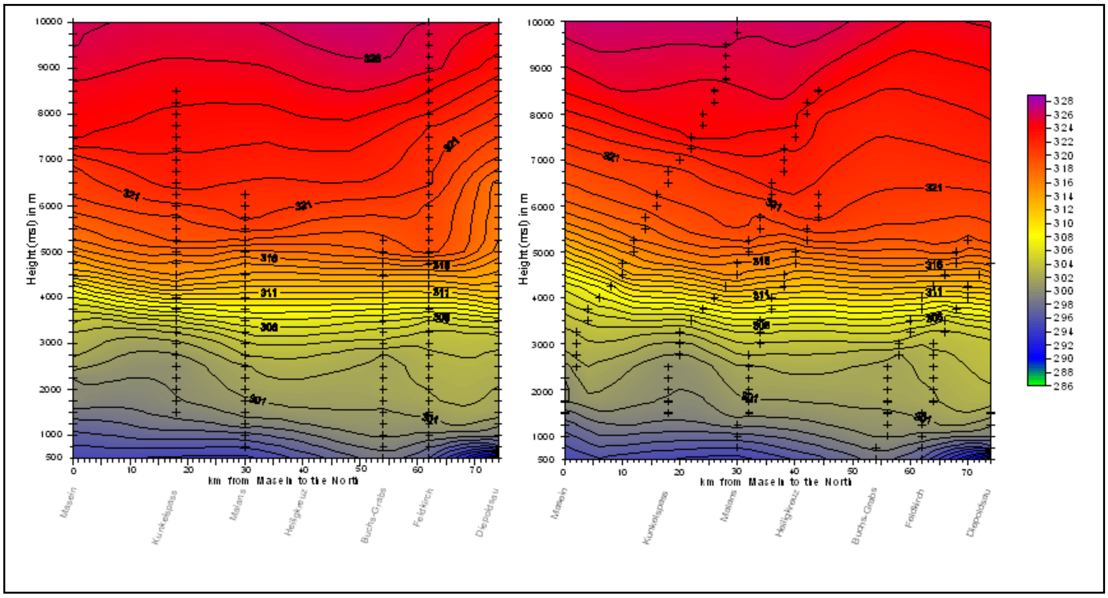

Figure 3: Comparison of objective cross section analyses of potential temperature with 1 K interval spacing neglecting (left) and considering (right) the drift of the 7 radiosonde balloons in the Rhine valley from Masein (South, left) to Diepoldsau 74 km farther North (right), after Tschannett, 2003. The blue color indicates the cold shallow layer in the valley (left side of figures) and the cold air pool of the forelands (right side of figures), the green-yellow indicates the middle layer, red the free atmosphere aloft.

the valley and the flow splitting is guided basically by different depth of the low level cold air the corresponding pressure field. Third the cold air pool is not passive but has its own dynamics in conjunction to the basins of the Alpine forelands. Thus, the turbulent erosion of the cold air is not the determinant mechanism for the foehn penetration. Fourth, the air in the cold air pool is usually heavily polluted due to the lack of vertical exchange so that the foehn penetration gives a sudden relief of pollution. Fifth, the foehn penetration and retreat is not taking place front-like but allows isolated cold air pools and "warm islands". Sixth, the wave motion of the medium and upper level flow shows a significant "footprint" at low levels and has a strong impact on the channeled flow, especially during deep foehn episodes. Seventh, the prediction of local foehn behavior by very high resolution numerical models is successful, if the correct initial condition with respect to the cold air pools is available. This points toward the importance of an operational high resolution obverving network in foehn areas. A comprehensive discussion of the scientific results of FORM may be found in Steinacker et al, 2005.

The FORM data set is far from being completely exploited. The unique density and quality of observational data will certainly serve also in the future to investigate foehn related phenomena and to validate numerical models.

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