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UNSTATIONARY AND INHOMOGENEITY ASPECTS OF THE MAP IOP 12 SOUTH FOEHN EVENT IN THE RHINE VALLEY

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1*. INTRODUCTION

This paper examines the three-dimensional structure and dynamics of a south foehn flow in the Rhine valley during its entire life-cycle from 29 October until 31 October 1999. The south foehn event was documented in the framework of the Mesoscale Alpine Programme (MAP) (Bougeault et al. 2001). This study investigates the forcing sources at synoptic scale, the dynamical processes driving the circulation of the foehn flow in the complex network of tributaries of the Rhine valley, and the degree of inhomogeneity at the scale of the FORM ("FOehn in the Rhine valley during MAP" program) target area (Fig. 1).

In this atypical foehn case, the "classical" shallow foehn phase, as defined by Seibert (1990) is replaced by a nocturnal katabatic drainage flow phase with similar charateristics with weaker intensity. This paper shows that the deflection mechanism of the westerly basic-state flow in the longitudinal (i.e. south-north oriented) valleys is the same in the shallow foehn and katabatic drainage cases. The channelling efficiency of the main longitudinal tributaries of the Rhine valley (e.g. Domleschg) is higher during the foehn phase when the south-westerly upper-level flow, experiencing mountain wave induced downward motion, penetrates in these tributaries than during the katabatic drainage phase when the upper-level wind blows from the west.

At local scale (Fig. 1b), the structure of the foehn flow varies at a kilometer horizontal length scale and the time evolution of the respective location of the cold air pool and the warm foehn air is investigated in details. Also flow splitting between the Rhine and Seez occurs during the entire foehn life-cycle, but its vertical extension is maximum during the katabatic drainage phase, when lower- and upper-level flows are fully decoupled. During the mature foehn phase on 30 October 1999, air masses advected from the south-west penetrates in the Rhine and Seez valleys and thus squeeze the flow layer that splits between the two valleys (Drobinski et al. 2001).

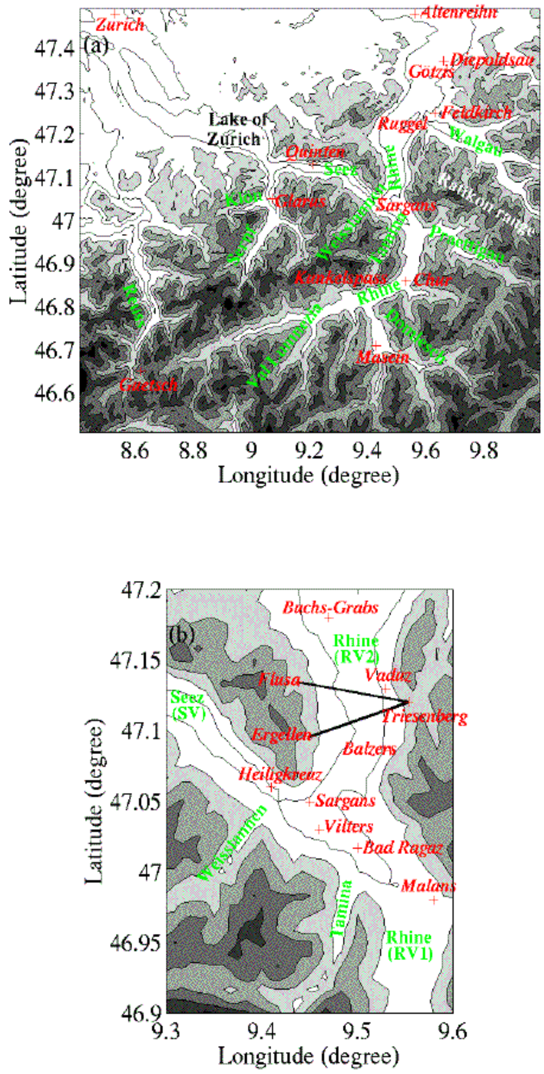

Figure 1: FORM target area (a) with a zoom (b) on the region of interest at local scale. Red italic (green) writing indicates names of cities (valleys). The straight lines indicate the scintillometer light beams.

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2. SYNOPTIC SCALE CONDITIONS

The foehn case of IOP 12 (30 October - 31 October 1999) is also known as the `Sahara dust-foehn' of the MAP-SOP. Ahead of a trough west of the Iberian peninsula on 29 October 1999, very warm air from north-western Africa was advected to southern France (Pau reported 29°C). A branch of this warm air also reached the regions north of the Alps. In Geneva (southwestern Switzerland) large amounts of dust from the Sahara were registered on 29 October 1999 during the day. Also at the MAP operations centre in Innsbruck a probe of Sahara dust was collected. Temperature maxima in the FORM target area reached remarkable 20°C. The Iberian trough moved northeastward and joined the strong westerly jet over the northeast Atlantic.

The surface pressure field was initially dominated by a large anticyclone with its centre over eastern Europe. This anticyclone moved further to the south-east. This movement together with the trough moving towards the European continent caused the large scale mid-troposhperic flow to back from west on 29 October in the afternoon to south-west during the evening. In the same time interval, the cross-Alpine pressure difference increased to about 6 hPa within 6 hours. The situation did not change much during the second half of the night. Until noon on 30 October 1999 the mid tropospheric flow reinforced and the cross-Alpine pressure difference increased to 8.5 hPa around 1200 UTC. At about the same time foehn started. It ended when the cold front associated with the Iberian trough reached the target area shortly after midnight of 30/31 October 1999.

Precipitation during the whole episode was weak and spatially inhomogeneous. Very light precipitation in the northern parts of the target area started after the passage of the cold front after midnight of 30/31 October 1999. First rain observations are from Diepoldsau and Heiligkreuz at 0100 UTC.

3. DEVELOPMENT OF THE FOEHN FLOW IN THE RHINE VALLEY AND ITS NEARBY TRIBUTARIES

3.1. *Phase I: Pre-Foehn Drainage*

The increasing cross-Alpine pressure gradient supported the katabatic flow in the Rhine valley and its tributaries during the night from 29 October 1999 to 30 October 1999. The southerly flow in the valley started between 1730 and 1830 UTC. At the same time the cross-Alpine pressure gradient had its strongest increase of this phase when it jumped from 1 to 2.5 hPa within 1 hour. This katabatic flow had many charateristics in common with a foehn flow like elevated temperature, low humidities and high windspeed (Drobinski et al. 2002, see Fig. 2).

The area where this flow touched the ground, reached until Vaduz in RV2 and further than Quinten in SV although there the temperature increase was less than in RV2. At Vaduz, the temperature of this katabatic flow was 5-6 K higher than in the cold air pool covering the part of RV2 north of Vaduz (Fig. 3, the Altenrhein station being in the cold air pool).

The relative humidity decreased from 70 % on 29 October 1999 at 1900 UTC to 55 % at the end of the episode at 0330 UTC on 30 October 1999 compared to almost saturation in the cold air pool to the north. During this episode a strong horizontal temperature gradients existed, e.g. 6 K per 9 km between Vaduz and Buchs-Grabs (Fig. 3). The wind speed at Vaduz was between 3 and 4 m s^{-1} throughout this phase (Fig. 2).

This katabatic flow was stably stratified (not shown). Above Buchs-Grabs, the temperature increase was 7.3 K in the first 1000 m of the sounding. This cold air pool in the northern RV2 was fed by the tributaries and the side walls during the rest of the night. From the wind measurements at the surface stations between Sargans and Vaduz we assume that in this area the production of cold air by radiative cooling was very effective supported by at least partly clear sky. This is confirmed by the cloud observations at Heiligkreuz where 4 octas of total clouds were observed during a few hours. All other stations in the target area reported permanently overcast sky. The thickness of the cold air pool above Buchs-Grabs grew from less than 40 m at 1800 UTC on October 29 1999 to 60 m at 2100 UTC and 0000 UTC, to 110 m at 0300 UTC and 300 m at 0600 UTC on October 30 1999.

Due to the higher windspeed caused by channelling in the narrower SV no distinct cold air pool developed in this valley at least as far as the available observations indicate (Fig. 3).

Between the valley flow described above and the large scale synoptic south-westerly flow a shallow layer with southerly flow established during this phase. This layer was more pronounced in the south and central part of RV2 than in any other part of the target area. Above Buchs-Grabs it stretched from 1000 m – 1800 m ASL at 1800 UTC on 29 October 1999, was squeezed to 900 m – 1500 m ASL with increasing wind speed (10 m s^{-1} at 1200 m) at 2100 UTC, 0000 UTC and 0300 UTC and weakened again but stretched from 800 m to 3100 m at 0600 UTC on 30 October 1999.

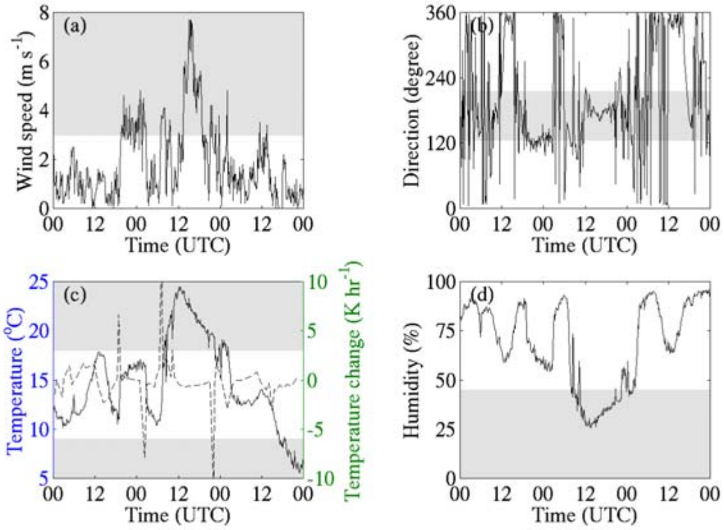

Figure 2: Surface wind speed (a) and direction (b), temperature (panel c, solid line) and temperature growth (panel c, dashed line), and relative humidity (d) measured at Vaduz. The shaded area show the domains when foehn occurs at Vaduz. These criteria must be met simultaneously.

3.2. *Phase II: Cold Air Pool Covers RV2*

The regime described in the previous section lasted until 0400 UTC on 30 October 1999. During phase I, the mesoscale pressure minimum was situated in the northern part of RV2 or even north of it. Between noon on 29 October 1999 and midnight, pressure decreased by 1-2 hPa in the south of the target area but 4 hPa in its northern parts. Starting at 0300 UTC, the pressure field established during phase I was disturbed. A small zone of higher pressure established in the very northern parts of the Rhine valley. Due to the steadily falling pressure the pressure minimum in RV2 moved to the area between Vaduz and Sargans, in the southern parts of RV2. This caused a flow reverseal in the upper parts of RV2, and allows the cold air pool to pour into the region where we had katabatic flow during phase I (Figs. 2 and 3). The wind in this area turned to northerly directions. The moisture content in the cold air pool was near to saturation but Diepoldsau was the only station which reported fog at 0700 UTC on 30 October 1999. Phase II lasted until 0700 UTC when the temperature started to increase rapidly. At most stations in the southern part of RV2 the same katabatic flow as in phase I established for a short time and later the temperature further increased.

3.3. *Phase III: Foehn Flow and Breakdown*

The main reason for the intensification of the foehn flow in RV and SV was the increasing cross-Alpine pressure difference which augmented from 6 hPa at 0600 UTC to 8.5 hPa at 1200 UTC on 30 October 1999 and the rotation of the upper-level flow from west to south-west. Thus, the main effect until about 1200 UTC of the foehn flow was the enhancement of the diurnal cycle, i.e. the temperature increase during the morning hours was steeper than the previous day. The first temperature maximum was reached about 1 hour earlier and was 1-2 K higher than during the previous day. The cold air pool had almost completely disappeared by 0900 UTC in RV1 and by 1200 UTC in SV and RV2. Almost all stations between Masein in a the southern tributary of RV1 until Ruggell in RV2 and Heiligkreuz in SV show a clear positive jump of the temperature and a negative jump of the humidity between 1100 UTC and 1400 UTC on 30 October 1999. This is a clear indication that the foehn flow touched the surface. The distribution of potential temperature shows a well established foehn flow at 1500 UTC. This led to a short-term small-scale pressure fall in the basin of Buchs-Grabs. The pressure minimum in RV2 was situated in this area for about 2 hours. As a consequence the cold air pool situated in the northern parts of RV2 oscillated back to the south into the basin of Buchs-Grabs and the temperature gradient between the foehn air and the cold air pool increased. At 1800 UTC, the border between the foehn flow and the cold air pool was again further to the north and at 1900 UTC the foehn touched the surface at Diepoldsau. During the following hour, the foehn flow at the surface was confined to the western valley wall due to the katabatic flow coming from the Walgau east of Feldkirch. It was not before 2200 UTC that the foehn touched also the surface at Feldkirch. The cold air flow out of the Walgau was stronger and cut the foehn flow into a southern patch (until Balzers to Buchs) and a northern part (Diepoldsau-Goetzis) before the foehn completely stopped by the approaching cold front at 0200 UTC.

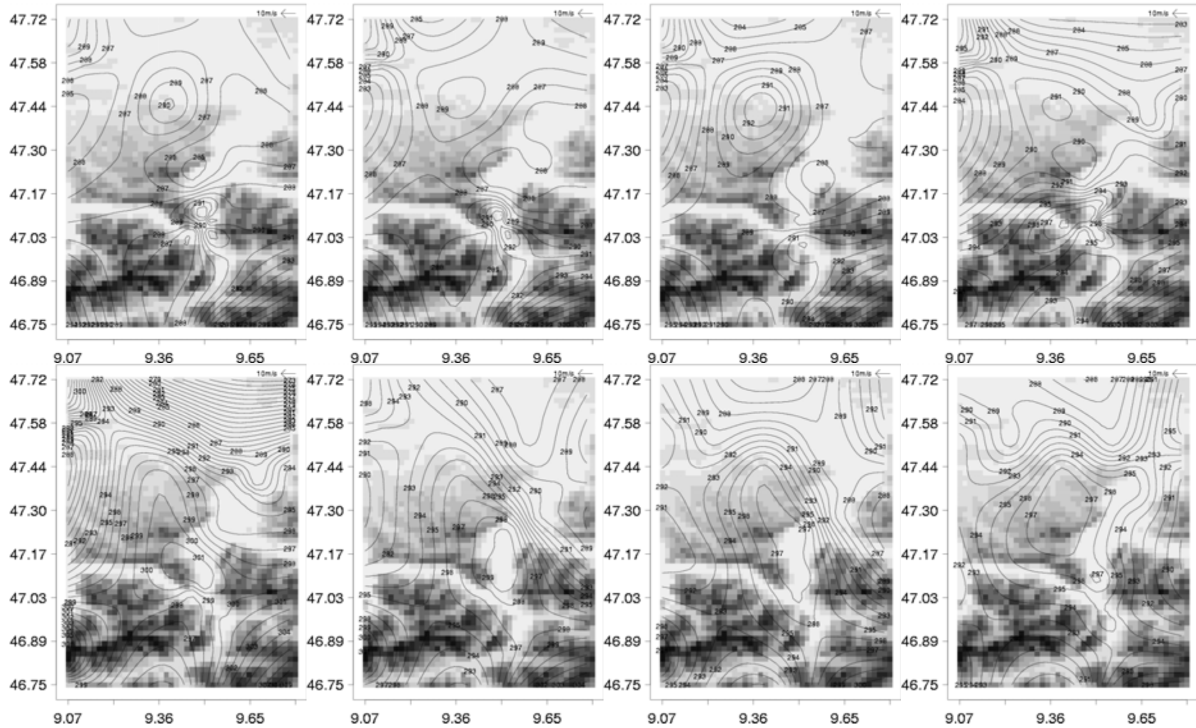

Figure 3: Surface potential temperature and wind speed analyses in the FORM target area using VERA algorithm. The analyses are shown form left to right on 29 October 1999 at 2100 UTC, on 30 October 1999 at 0300 UTC (phase I), 0600 UTC (phase II), 0900 UTC, 1200 UTC, 1500 UTC, 1800 UTC and 2100 UTC (phase III).

5. REFERENCES

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