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# FOEHN RESEARCH IN THE RHINE VALLEY DURING MAP: OBJECTIVES, CONCEPTS SAND FIRST RESULTS

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## 1. Introduction

For the observation of foehn-related phenomena during MAP, the Rhine Valley between the Julier Pass and Lake of Constance was specially instrumented. The philosophy followed for setting up the complex observing network that comprised a wide variety of in-situ and remote sensing instruments is described, and the individual instruments briefly listed. The roles of the Coordination Center COC and the MAP Data Center MDC are briefly described, and the overall performance of the observing system is assessed. Finally, some results obtained from the observations are described.

## 2. Selection of the Target Areas

In the Mesoscale Alpine Programme MAP, three primary meteorological phenomena were studied: (i) deep convection and the resulting heavy precipitation, (ii) foehn, and (iii) clear air turbulence (Binder and Schär 1995). For the investigation of the different objectives, so-called Target Areas were defined and instrumented (Bougeault et al. 1998). For objective (ii), the study of foehn, the Rhine Valley was chosen after careful considerations taking into account climatological data, existing instrumentation, accessibility, infrastructure etc. However, because of its rather complex topography, the Rhine Valley was not suitable for studying gap winds, consequently, the Brenner cross section was chosen and instrumented for studying this phenomenon. For an overview of the entire MAP activities and preliminary achievements see Bougeault et al. (2001).

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### *2.1 The Brenner Cross Section*

Objectives of activities in this area were:

(i) to determine the relative importance of gap width versus terrain flow through realistic topography;

(ii) to determine the relationship between the gap flow and the flow above mountain-top level; in particular, to investigate whether the gap flow is reinforced by flow aloft along the axis of the gap or by a mean-state critical level which caps the low-level cross-mountain flow;

(iii) to study the vertical and cross-gap distribution of wind speed and thermodynamic properties.

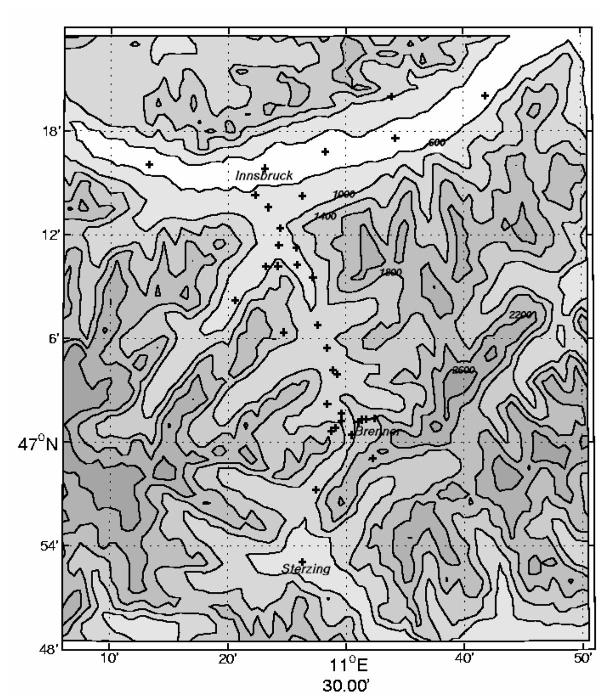


Figure 1: Location of ground-based additional GAP-instrumentation (+) superimposed on topography.

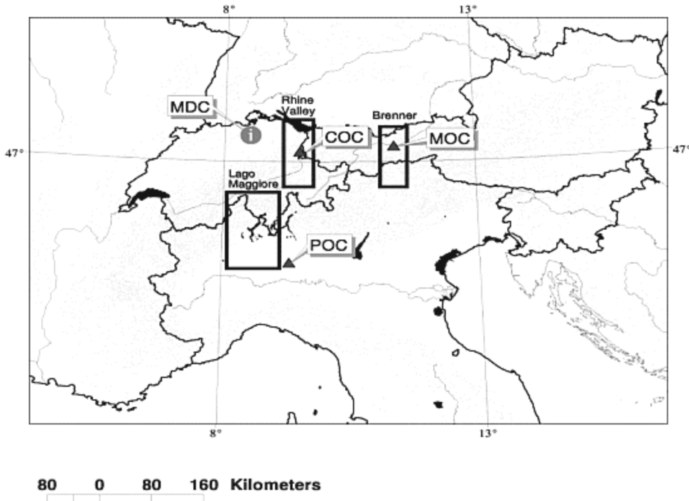


Figure 2. Map showing the Alpine region with the Control Centers and the locations of the different Target Areas, in particular the complementary Rhine Valley and Brenner Target Areas. Note that the Lago Maggiore Target Area is not dealt with in this paper.

In addition to the dense surface network (Fig. 1), ground-based lidar, sodar, radisondes were operated and more than a dozen aircraft mission were flown across the pass.

In this overview, the instrumentation of and the activities along the Brenner cross section are touched only briefly. A more elaborate treatment can be found in papers 13.6, 13.7, 14.1 through 14.5, and P3.6 through P3.11 in this volume.

### *2.2 The Rhine Valley Target Area*

The objectives for the activities in the Rhine Valley -- the complementary Target Area for studying foehn-related events to the Brenner Cross Section -- are

(i) How is the cold pool removed by the foehn wind? Is it by turbulent erosion at the internal boundary between the stagnant cold pool and the fast moving foehn, is it by convective processes, or is it a simple static displacement?

(ii) What is the role of the winds from side valleys? When do these air masses simply merge with the foehn in the main valley, when do they keep their identity and move as independent airflow?

(iii) Which factors determine whether flow splitting occurs or not? When a valley branches, why does the foehn sometimes follow only one branch and why does it sometimes split?

## 3. Instrumentation philosophy in the Rhine Valley Target Area

After it was more or less clear which research groups would participate and what instruments would be available, an optimized observing system was designed such as to provide data for all the phenomena to be studied. The most important underlying principle of the design was to optimally combine the practically continuously observing remote sensing systems with only sporadically active, but usually more accurate in-situ observations.

Fig. 3 shows the distribution of the upper air and remote sensing stations. These included:

- 9 upper-air sounding stations (one not shown);
- 2 windprofiling radars (one equipped with RASS for additional temperature sounding);
- 5 sodars (four operating in Doppler mode for wind profiling);
- 1 Raman backscatter lidar;
- 1 fully steerable Doppler lidar for wind measurements.

Please note in particular that the wind lidar was set up in the area where the Rhine Valley branches, so it could "look" along all three valley axes.

Fig. 4 shows the dense surface network put in place to monitor basic meteorological parameters with high spatial and temporal resolution. Some of the stations recorded data at 2 minute intervals.

Finally there was a selection of somewhat exotic observing systems. Among these were two scintillation anemometers measuring mean along-valley flow at two different height levels as well as the corresponding vertical winds; four continuously operating time-lapse cameras covering the entire region of the lower Rhine Valley; a large aperture stereo camera observing cloud developments; an instrument package mounted on a cable car near the Lake of Constance; three microbarographs for recording gravity waves with 1-second resolution; an instrumented automobile making traverses; an elaborated tracking system for constant density balloons allowing trans-Alpine trajectories of several hundred kilometers; a tethered balloon system with three instrument packages at different heights; and, last but not least, surface flux instrumentation.

Finally, aircraft played a very important role in the investigations. Unfortunately, large aircraft never flew dedicated missions, however, they did pass over the Rhine Valley occasionally on ferry flights. Merlin and Arat flew over a dozen missions during foehn events for studying synoptic to mesoscale phenomena. The small Dimona, a motor glider, flew nine missions. Its unique data collected in roller-coaster flights near the interface between foehn air and cold pool is as spectacular as the flight was itself.

On the Julier Pass, in the flow splitting region, and at the southern end of the Lake of Constance, several of these observing systems were clustered, producing complementary data sets.

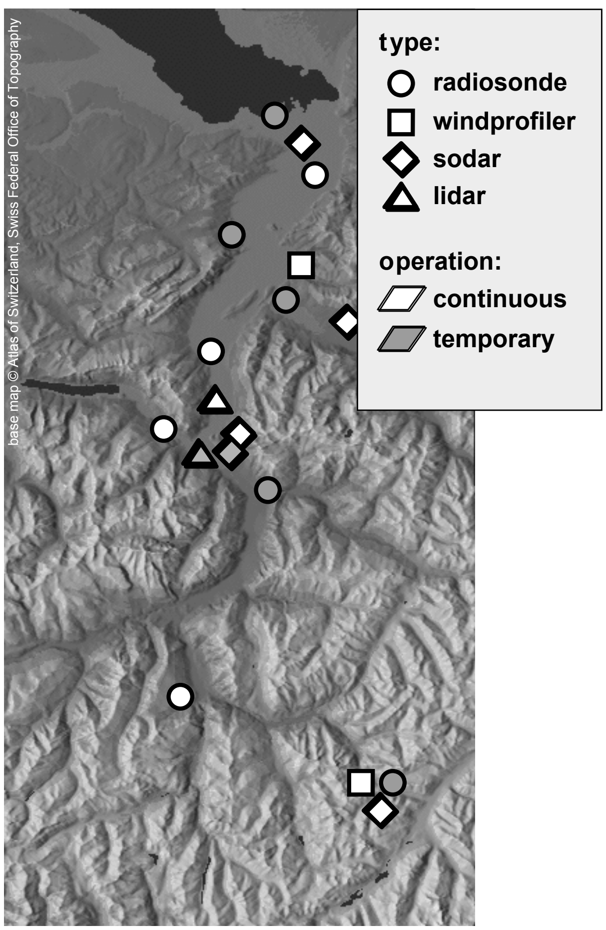


Figure 3: Upper-air and remote sensing stations deployed in the Rhine Valley Target Area; top is North. (Base map © Swiss Federal Office of Topography)

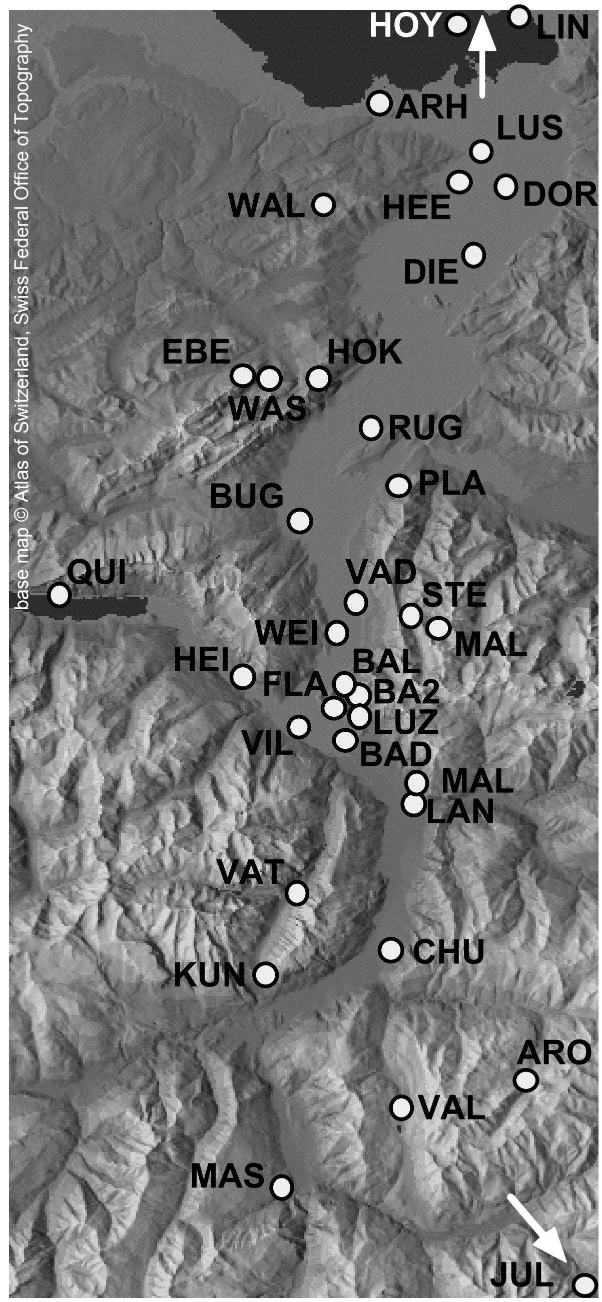


Figure 4: Surface stations in the main part of the Rhine Valley Target Area; top is North. Note the concentration of stations in the region of potential flow splitting. There were another 6 surface stations set up in the Brandner Valley. This valley lies east, just outside the frame and is more or less parallel to the Rhine Valley. (Base map © Swiss Federal Office of Topography)

All activities in the Target Area were monitored from the Coordination Center COC in Bad Ragaz. Data was immediately sent to the MAP Data

Center MDC where quick-look data sets were produced; some of the data was transmitted in real-time to the MAP Operation Center MOC for forecasting purposes and mission planing.

## 4. First Results

The vast amount of data gathered for any of the MAP objectives is far from being concludingly exploited. Nevertheless, there are already a number of results that illustrate the progress, that tell us something that was either not known or only suspected before the experiment. The topics listed below are an arbitrary, subjective, and incomplete selection of new insights.

### *4.1 Modeling foehn events*

A number of intercomparisons between numerical models and foehn events have been performed. The wind field representing the actual foehn flow (including waves) is quite well reproduced by the models. The interaction of the foehn air with the underlying cold pool that eventually leads to the removal of the stable air mass cannot be simulated yet in such a way as to include local features (see also papers 13.2 and 13.3).

Rather spectacular is the data collected by constant density balloons carrying radiosondes: Along 84 trajectories, temperature, humidity, and wind were measured. 39 trajectories crossed the Alpine ridge; the longest was about 400 km, the longest flight duration was over 11 hours. First validations of model data show that the synoptic-to-local-scale flow is quite well simulated by the mesoscale models used in MAP, however, that details in valleys are not yet adequately described.

### *4.2 Observations*

The rather dense surface and upper air network revealed that - contrary to previous assumptions by some foehn experts - the cold pool is not flushed out as an entity. Lens-shaped patches of cold air remain scattered on the valley floor; in addition, the depth of the cold pool can vary considerably (typically 100 m) across the valley.

Quite unexpectedly it was observed that in the Brandner Tal, a tributary valley far downstream of the main Alpine ridge, the foehn flow may locally be strongly decelerated because it moves towards higher pressure (see also poster P3.1).

The aircraft data gathered near the interface between foehn flow and cold pool allow for the first time to compute area averaged fluxes for this region. The heat flux is of the same magnitude as that on the surface; they are sufficiently high to make the cold pool disappear in about a day. Hence, the mechanism by which the cold pool is removed consists of a combination of convection from the ground, and a mixing with foehn air at the internal boundary.

Wind field analyses based on actual wind data as well as on conservative quantities (such as potential temperature) confirm that the flow in the main foehn valley can be significantly influenced by either flow from tributary valleys or by parallel flow over passes located lateral to the main valley.

An ozone study just south of Lake of Constance focused, among other objectives, on the effect of the foehn on the ozone distribution in the valley. Photochemical ozone production was negligible at the time of the experiment. Hence, the observed strong correlation between foehn air reaching the ozone-poor valley and the corresponding increase of the ozone concentrations demonstrated that ozone is a good tracer for foehn air.

## 5. Conclusions and outlook

The composite observing system deployed in the Rhine Valley produced an excellent data set describing the four-dimensional character of meteorological fields before, during, and after foehn events. Thanks to the numerous foehn cases during the roughly two-and-a-half months, a detailed data set is now available covering several different foehn situations. Once this data set is finalized and validated, it will help to identify and understand the physical processes related with trans-Alpine flow and, in particular, with flow over and in Alpine valleys. There is no doubt that, based on this knowledge, high resolution numerical model will be improved and the prediction of downslope storms and foehn events will become more reliable.

## 6. References


Binder, P. and Ch. Schär (eds.), 1995: *MAP Mesoscale Alpine Programme, Design proposal*. MAP Office, c/o MeteoSwiss, CH-8044 Zurich, 63 pp.

Bougeault, P., P. Binder, and J. Kuettner (eds.), 1998: *MAP Mesoscale Alpine Programme, Science Plan*. Chapter 3.4., Rhine Valley Target Area. MAP Office, c/o MeteoSwiss, CH-8044 Zurich, 44 - 48

For additional literature dealing with the preliminary results mentioned here, please consult: http://www.map.ethz.ch/form/publi/publi.html