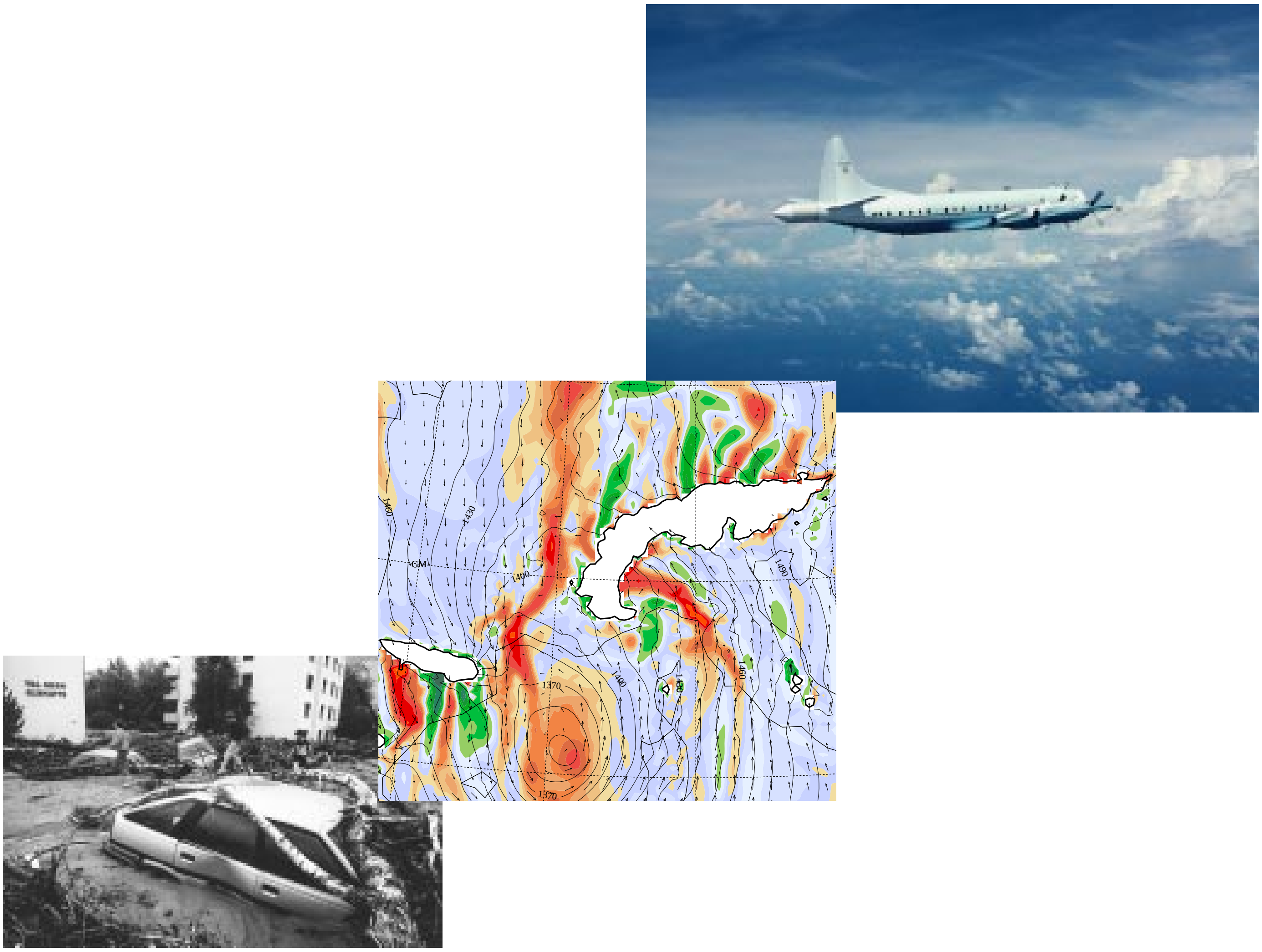
MAP

Mesoscale Alpine Programme



Design Proposal

December 1996

FRONT COVER:

Panel in the middle: The colour coding shows the distribution of potential vorticity (PV) on the 850 hPa surface at 06UTC on 24 September 1993, 42 hours into a high-resolution hydrostatic numerical simulation. Geopotential height and the wind vectors are shown on this pressure surface as well. Red and green areas refer to anomalously high (>0.8 pvu) and low (<0 pvu) values of potential vorticity, respectively. Note the PV bands downstream of the Alps and the Pyrenees (From Aebischer and Schär 1994).

The upper left panel shows the NCAR Electra research aircraft with its tail-mounted Doppler radar ELDORA. (courtesy of P. Hildebrand, NCAR)

Lower left panel shows a car buried in mud after the devastating flash flood of the river Saltina in the town of Brig, Switzerland on 24 September 1993. (Photo: Coffrini / Sonntags Zeitung of 26 Sept. 1993)

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The following individuals contributed to the present document:

Editors:

Peter Binder
Christoph Schär

Authors:

Peter Binder
Philippe Bougeault
Andrea Buzzi
Huw C. Davies
Guy Delrieu
Isabelle Desurosne
Dietrich Heimann
Klaus-Peter Hoinka
Anja Klebelsberg
Joachim P. Kuettner
Nick Kouwen
Herbert Lang
Detlev Majewski
Georg Mayr
Stefano Orlandini
Roberto Ranzi
Hans Richner
Mathias Rotach
Bruno Schädler
Christoph Schär
Ronald B. Smith
Reinhold Steinacker
Hans Volkert
C. David Whiteman

FOREWORD

The MAP Design Proposal is the basic planning document of a new research initiative in mountain meteorology, termed the *Mesoscale Alpine Programme*. This programme is designed as a cooperative international undertaking and aims at resolving some of the most outstanding scientific and practical problems in the realm of weather and climate in mountainous regions. To this end MAP includes numerous activities, ranging from high-resolution numerical modelling to a major field campaign in the Alpine area.

In this document an outline is given of the motivation for the initiation of this undertaking, and the principal objectives to be addressed are specified. Furthermore a tentative schedule for, and the organizational structure of, the programme are presented.

The first edition of the MAP Design Proposal was based on the broad consensus that emerged from an international workshop held in Zurich, Switzerland, on 12-14 September 1994. Seventy-seven participants from 42 institutions in 13 countries, among them 12 national weather services, WMO and ECMWF, took part in this workshop. Following the workshop, a team of authors contributed to the preparation of this document. In addition all workshop participants had the opportunity to critically review an earlier version of the Design Proposal, and the resulting comments have helped to significantly improve the document. The document was approved by the Scientific Steering Committee of MAP (MAP-SSC) at its first mXSeeting on 28 June 1995 in Bad Tölz, Germany.

During the spin-up phase of the *Mesoscale Alpine Programme* it has become evident that atmospheric and hydrological sciences would greatly benefit from common efforts within the framework of the overall programme. At its second meeting early in 1996 the MAP-SSC has thus decided to invite hydrologists to a workshop in order to examine their potential interest and define fields of cooperation within MAP. Consequently the first MAP hydrology workshop was held in Zurich on 26 April 1996. Hydrologists from 5 Alpine countries and Canada took part. The very positive mutual response led to the decision to complement MAP by hydrological aspects. This fact is reflected by this second edition of the MAP Design Proposal. The procedure to update the document was analogous to the former.

We are deeply indebted to the atmospheric scientists and hydrologists who shared their knowledge and contributed enthusiastically to produce this document. The editorial assistance of Andrea Rossa is gratefully acknowledged.

This MAP Design Proposal represents the platform for the newly initiated and constitutes the framework for the specification of individual projects within the overall programme.

We wish MAP to become a successful research programme.

January 1995 (first edition)	Peter Binder and Christoph Schär
December 1996 (second edition)	Editors

EXECUTIVE SUMMARY

Mountains, and in particular Alpine-type orography, instigate or influence a rich range of mesoscale[1] phenomena. These phenomena and their associated processes are intricate in character, interact with larger and smaller scale flow, and are responsible for much of day-to-day mountain weather and for many of the extreme weather events. Moreover their composite effect contributes significantly to determining the climatic features of mountainous regions.

These facets of orographic-related mesoscale phenomena combine to make their adequate observation, basic understanding, and successful prediction both difficult and desirable enterprises. The challenge has been highlighted by various developments in the last decade: pertinent field studies helped establish the importance of orographic effects and pinpointed gaps in our information and knowledge base; new high resolution numerical models revealed various deficiencies (e.g. the representation of mesoscale moist processes and orographic effects), the lack of suitable observational data for the inter-related purposes of diagnostic analyses and the initialization and validation of forecasts; and the emergence of novel observing systems (e.g. profilers, lightweight dropsondes, airborne Doppler radar and lidar) can contribute substantially to remedying the shortcomings.

The Mesoscale Alpine Programme (MAP) is a measured response of the international atmospheric and hydrologic scientific community to the foregoing challenges and developments. It is conceived as a coordinated and integrated programme of basic research that has direct practical applications in the realm of numerical weather prediction and river runoff forecasting. The programme's coupled overall aims is to further our basic understanding and forecasting capabilities of the physical and dynamical processes that

- govern precipitation over major complex topography, including hydrological aspects, and
- determine three-dimensional circulation patterns in the vicinity of large mountain ranges,

and the strategy is to focus on key orographic-related mesoscale effects that are exemplified in the Alpine region.

One of the two core MAP topics relates to the study of orographically-influenced events of deep convection and frontal precipitation to ascertain their scale-interaction, internal structure and microphysical characteristics. Intimately linked to these atmospheric processes is the hydrological response of Alpine watersheds. The second relates to the consideration of the phenomena and processes that give rise to Alpine drag effects with particular regard to the role of three-dimensionality, transience, the boundary layer, cloud processes and the Coriolis effect. These core activities will be supported and complemented by related climatological and dynamical studies linked to Alpine aspects of climate and stratosphere-troposphere exchange.

The MAP is designed as a multi-year programme structured in three phases – an extended ~3 year preparatory period, a 13-month field phase including a shorter intensive special observing period of 3 months, followed by an evaluation period. In Phase I activity will centre on: the climatology of Alpine mesoscale weather systems, numerical experimentation and the detailed systematic evaluation of the performance of current forecast models, the testing of new observing systems. This information base will serve

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1) Mesoscale flow systems are those that posses space scales of 2 to 2000 km and time scales between 2 hours and 2 days.

to refine scientific hypotheses on the pertinent phenomena and processes. It will concomitantly help to fine-tune the design and observational strategy for the field experiments of Phase II, which will be undertaken with a state-of-the-art range of instrumentation, and will involve the acquisition of specific and detailed data sets. Integral feature of Phase III will be the assembly and analysis of the observational field data, the testing of hypotheses, and the application of the results in the context of operational forecast models.

Central to the establishment of MAP has been the identification and dovetailing of fundamental research issues and practical forecasting needs. It is this combination that has guided the programme's design, will stimulate its execution, and aid the incorporation of the accrued knowledge into the operational forecasting environment. The MAP is geared to the successful completion of this process and thereby to benefiting the public at large.

1 Motivation

The complex topography of the earth's continents acts as a strong and permanent modifier of atmospheric circulations on a wide variety of scales. Certain mountain ranges such as the Alps exert a particularly large impact on the weather and climate of their environment.

The Alps have a length of ~800 km, a width of ~100 km, and are characterized by numerous different valley systems (Fig. 1-1). Maximum peak height reaches up to ~4800 m. Atmospheric research in the Alpine countries has always focused on the effects of the orography on the ambient weather and climate. In recent years, additional motivation has been provided by the following developments:

- Operational weather forecasting with high-resolution numerical models has reached a stage where the Alpine circulations can be resolved adequately, and their effect on the key parameters such as precipitation has become directly amenable to numerical simulation. Until recently, atmospheric models were restricted to the so called meso-α scale[2], but are now approaching the meso-β scale[3], which is the scale of the topographic forcing and of some precipitation mechanisms. Current mesoscale numerical models have a horizontal resolution around 10 km. Present

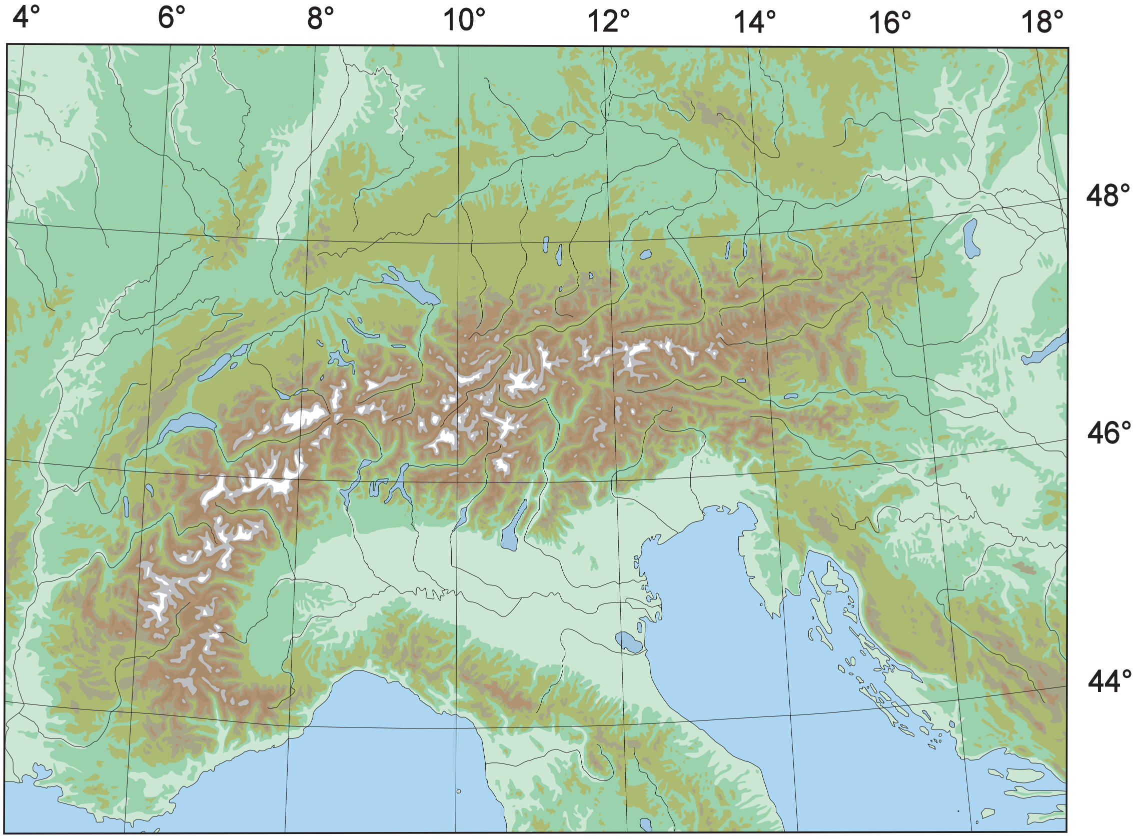

FIGURE 1-1. The Alps. Grey-scale changes at 200, 500, 1000, 1500, 2000, 2500 and 3000 m altitude. Terrain above 3000 m in white.

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[2] This encompasses flow-features with horizontal scales in the range of ~200 to ~2000 km, e.g. fronts and cyclones. See Orlanski (1975).

[3] Flow-features with horizontal scales in the range of ~20 to ~200 km, e.g. Foehn and other orographically induced circulations.

day routine observational data sets are, in comparison, too coarse, and inadequate for validation of such high-resolution models.

- It has been realized that many, if not most, of the natural disasters in the Alpine region are linked to strong precipitation events – landslides (e.g. Valtellina 1987), flash floods (e.g. Vaison-la-Romaine 1992, Brig 1993, Piedmont 1994, cf. Fig. 1-2), hail storms (e.g. Munich 1984) and large avalanches (e.g. St. Anton / Arlberg 1988). The enhancement of the forecasting capabilities for such extreme events features at the top of the research agenda of several European national meteorological services. Improved prediction and earlier warning could significantly help to avoid loss of life and reduce damage.
- Anthropogenic emissions of greenhouse gases and aerosols are expected to lead within the next century to significant changes of the global climate (Houghton et al. 1990, 1996). The assessment of the resulting impacts upon the Alpine environment is at a preliminary stage. Of particular interest are changes in the distribution and frequency of precipitation, and changes in the water-storage of Alpine glaciers and in snow-cover. These issues are not only of central importance to the Alpine countries themselves, but they are of significance for fresh-water management in much of central Europe via any putative changes in the Alpine streamflows associated with the Rhone, the Rhine and the Danube.
- Mountains are being recognized as one of the key factors which determine the geographical distribution of climate zones. Sound estimates regarding global change necessitate improved parametrization schemes for mountain induced mesoscale processes like gravity wave propagation in three spatial dimensions, gravity wave breaking and flow splitting.
- Circulation systems in mountainous regions also create distinct planetary boundary layer features, and thus strongly influence environmental conditions, e.g. the level of air pollution. Advances in the understanding of the complex structure and

FIGURE 1-2. Car buried in mud after the devastating flash flood of the river Saltina in the town of Brig, Switzerland on 24 September 1993. (Photo: Coffrini / Sonntags Zeitung of 26 Sept. 1993)

evolution of the Alpine planetary boundary layer are needed, in particular with regard to the representation of the associated dynamical and physical processes in numerical prediction models.

The scientific problems pertinent to these issues are not only important in the Alpine region, but they are of general interest for many other mountainous regions of the earth, and furthermore relate to aspects of the general circulation of the atmosphere.

1.1 General Aims and Tools

The Mesoscale Alpine Programme is to be undertaken as a concerted, international and interdisciplinary effort to further the basic understanding and the forecasting capabilities of the physical and dynamical processes which

- *govern precipitation and runoff over complex topography*, and
- *determine the three-dimensional circulations in the vicinity of large mountain ranges.*

These themes are intimately interrelated, and the insights gained will be mutually beneficial.

The envisioned programme includes a multi-year preparatory phase, followed by a 13-month observing period with a 3-month intensive field campaign, and will be concluded with a two-year evaluation phase.

Systematic use of operational numerical weather prediction (NWP) and research models will represent one of the key activities within MAP. The acquisition of high-resolution data sets with emphasis on moist processes and topographic circulations will help the validation of these models, and this feature is decisive for further development. These data sets will also be geared towards better understanding of the underlying physical and dynamical processes.

In addition to the operational networks, several advanced observing systems will be dedicated to the MAP Special Observing Period (SOP) with a tentative duration of 3 months. MAP will make intensive use of recent technological developments, e.g. surface based wind profilers, radar networks, airborne radar and lidar systems, lightweight sondes dropped from aircraft, and satellite products. Some of these new technologies (e.g. wind profilers) will become operationally available within the Alpine region in the next years, and will be used in conjunction with existing systems for the monitoring of longer periods (i.e. complete annual cycles) in the General Observing Period (GOP) which is tentatively scheduled to have a duration of 13 months.

The establishment of climatologies of mesoscale systems from existing archives, and the application of the most recent numerical models to data sets from previous campaigns (e.g. ALPEX and PYREX) constitutes an integral part of MAP. These activities will start well ahead of the MAP field phase, and will help the planning and fine-tuning of the observational campaign.

The Alps are very well suited for the envisioned programme, since they are very rich in topographically controlled flow features, and since they are already equipped with very dense operational networks for atmospheric observation. This includes one of the densest radiosonde networks (operated by the national weather services), as well as a precipitation network of several thousand rain gauges (operated by the region’s hydrological and meteorological services).

1.2 Weather Prediction Aspects

Most national weather services in Europe utilize numerical models which include the Alpine region in their daily forecast practice. The horizontal resolution of these models ranges from ~80 km to 14 km (e.g. at the German and the Swiss Weather Services, see Majewski and Schrodin 1994), but some higher resolutions have also been experimentally used either in the research mode or for specific forecasting purposes. The latter includes an experimental model suite with 3.6 km horizontal resolution operated by Météo France during the 1992 Olympic Winter Games in Albertville (see Bret and Bougeault 1992).

An example from the operational forecast for the flash flood case of Brig (23 September 1993; Fig. 1-3) highlights the high potential of modern numerical forecast models. Note the fairly realistic simulation of the very severe precipitation maximum near the southern border of Switzerland.

In general, however, snow and rainfall remain difficult quantities to forecast, especially if associated with deep convective activity and thunderstorms. Forecast failures in the Alpine region occur also as a result of the limited ability to simulate orographic circulations and their interaction with the synoptic-scale flows. For instance, while there have been significant advances in the understanding of two-dimensional flow past topogra-

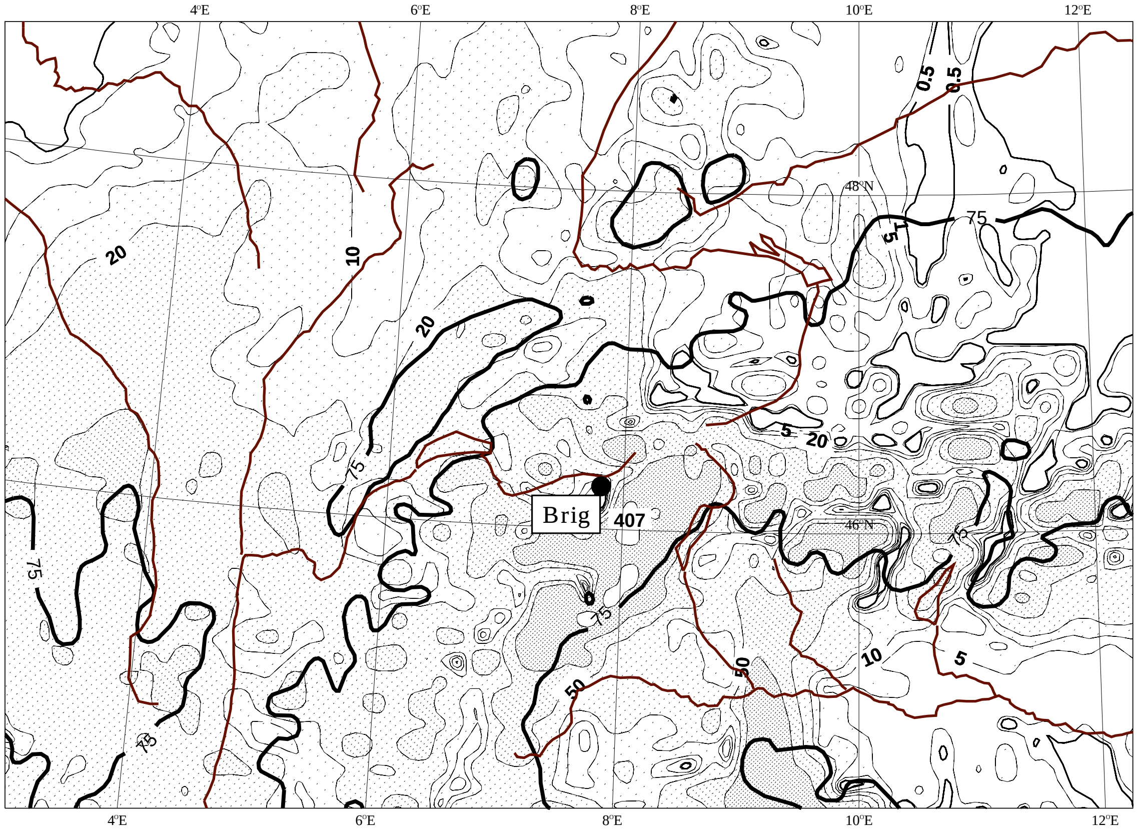


FIGURE 1-3. 24 h accumulated precipitation between 23 and 24 September 1993, 18 UTC, as predicted by the operational Swiss Model. Isolines at 0.5, 1, 5, 10, 20, 50, 100 and 300 kg m^{-2}. The maximum of 407 kg m^{-2} is located over the catchment area of the river Saltina, which resulted in catastrophic flooding of the town of Brig, situated in the upper Rhone valley. The bold line depicts the 750 m contour of the orography. (Courtesy of Swiss Meteorological Institute)

phy (see the contributions in Blumen 1990), there is a large gap in our knowledge of fully three-dimensional, time-dependent and moist flows over and around complex mountain ranges.

Investigations with new numerical models is expected to increase in the next few years as operational nonhydrostatic models become available. These models with horizontal resolutions of a few kilometres are currently under development at several weather services (e.g. in Canada, France, Germany, Great Britain, USA) and are also increasingly being used in a research mode (see for instance Grell and Grell 1994; Benoit et al. 1995). These new tools will enable the explicit resolution of convection, thunderstorms, and trapped orographic lee-wave features that with the present generation of forecast models are parametrized or not even represented.

With an increase in the spatial resolution of model forecasts, additional efforts will have to be undertaken to cross-validate model results and observations (Hollingsworth 1994). This calls for new developments to generate high-resolution data sets of critical atmospheric processes. It is imperative that such a data set be compiled in the context of a cost-effective international effort. Such data sets can

- be utilized in order to improve the initial conditions,
- aid in the validation of numerical model runs, and
- be analysed with the aim of improving the understanding of relevant dynamical and physical processes.

1.3 Flood Prediction Aspects

The flood that affected the Piedmont Region in Italy in the first days of November 1994 was one of the most damaging events that occurred in the Alpine area in this century. The heaviest rain fell in the period 4-6 November following a generally wet spell. Several stations recorded cumulated values in excess of $300\,\mathrm{mm}(36\,\mathrm{h})^{-1}$ (Lionetti 1996). Two main areas and periods of precipitation can be distinguished. The first (see Fig. 1-4), characterized also by embedded convective activity (with very high peak rainfall intensities up to $50\,\mathrm{mm\,h}^{-1}$), affected the area between the Maritime Alps / Ligurian Apennines and the Langhe hills on November 4-5. For the Tanaro river, a major right-side tributary of the river Po, the peak flow at the Montecastello gauge ($7985\,\mathrm{km}^2$) has been estimated in the range 3500 to $4800\,\mathrm{m}^3\mathrm{s}^{-1}$ with a corresponding return period of 70 to 1300 years (Brath and Maione 1996). The second rainfall maximum occurred over the eastern flank of the western Alps, north of Turin, on 5-6 November. It affected the basins of several tributaries of the Po river with less severe effects. Numerical experiments have demonstrated the essential role played by the orography in determining the amount and distribution of precipitation (see for example Buzzi and Tartaglione 1995).

As a consequence of the Piedmont flood, 70 people died, and 2000 had to be evacuated. Damages to properties were extensive and estimated to exceed 20'000 billion liras (~10 billion ecu), about one third of which in public works and agriculture. For example, 150 bridges collapsed or were seriously damaged, and more than 5000 heads of livestock were lost.

The Piedmont flood event cannot be properly classified as a flash flood, since the intense rainfall period lasted for more than 24 hours and affected several medium-sized river basins. Thus it seems to be an example in which a combination of accurate meteorological short range forecasting (12-48 h) by means of numerical weather prediction models, combined with multisensor (pluviometer networks, radars, satellites) real-time monitoring of precipitation and river state, and with hydrological forecasting models might have provided useful information and assistance for the public authorities. It is one primary aim of the MAP scientific community to set up and improve the basic tools needed to provide real-time flood forecasting and warning.

With respect to the mitigation of flood damages induced by heavy precipitation, a closer interaction between hydrologists and atmospheric scientists is desirable in order to define the forecast lead time and the accuracy of rainfall predictions needed to set up a useful flood forecasting, warning and response system (FFWRS) (Borga et al. 1991, Lang et al. 1996, Moore et al. 1993, Obled and Tourasse 1994). One of the most important variables influencing the adoption and success of FFWRS is the time available to issue and disseminate flood warnings and to take appropriate actions. Experience from events that occurred in the recent past suggests that, with rare exceptions, warnings cannot be really useful within a lead time of just a few hours, depending on many physical (structure of the drainage system, terrain properties, etc.) and social factors.

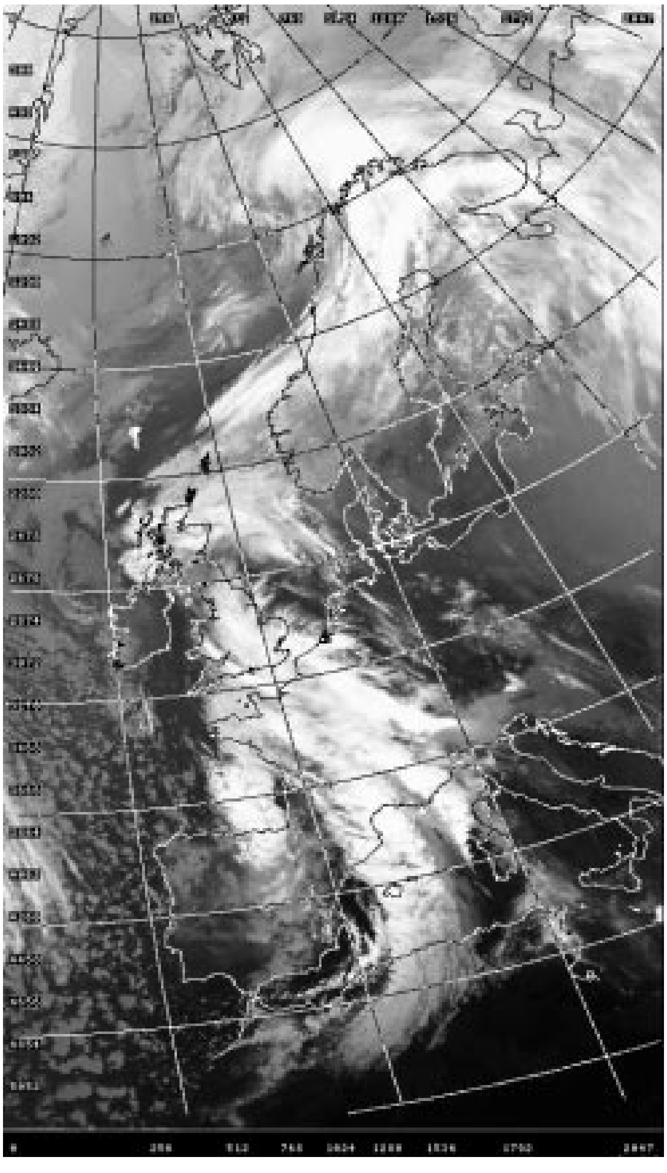


FIGURE 1-4. 1.3_1: NOAA IR (channel 5) satellite image of 5 November 1994, 9:34UTC, taken during phase I of the Piedmont flood (Dundee receiving station).

Particular attention in the theme of flood prediction has to be paid to the link between the spatial structure of the drainage systems and that of precipitation fields. The appropriate space-time resolution for coupling the meteorological models with a rainfall-runoff scheme has to be investigated, also in terms of precipitation forecast reliability and lead time availability. The general indication is that the larger the basin area, the longer the response time. For examples, in major river basins (>10’000 km^2), short term flood forecasting can mainly rely upon upstream measurements of the river discharge and runoff predictions based on rainfall monitoring (Todini and Wallis 1977). In contrast, for small-scale basins (<1000 km^2), only accurate rain forecasts can, in principle, allow to formulate useful FFWRS. It is an open problem to what extent numerical predictions of rainfall can be improved in the near future such as to allow for sufficient time-space accuracy as needed for reliable flash-flood warnings. On intermediate scale basins (1000-10’000 km^2) a combination of rainfall forecast, observations and hydrological modelling is likely to give the best results.

For mid-latitude complex orography like the Alps, accurate temperature forecasts are very important as well, since required for the distinction of snowfall from rainfall. The analysis of flood events (as for instance the Brig event and the Ticino flooding of 1993, and the Reuss valley event in 1987) clearly demonstrates that the altitude at which falling snow melts during heavy precipitation periods is decisive in many basins to discriminate between flood and no-flood conditions. Additional meltwater production during warm rainy periods may also contribute to flooding situations.

1.4 Climate Aspects

The research to be conducted within MAP is relevant to global change issues in two respects.

First, mountainous regions are very effective in extracting moisture from the ambient atmospheric flow via various orographic precipitation mechanisms. Such precipitation is important not only in the considered mountainous area itself, but is often highly relevant for the fresh-water management in large neighbouring regions. In the case of the Alps, more than 100 million people rely on the Alpine rivers Rhine, Rhone and Danube for their fresh-water supply. Climatological studies, attempts to downscale global change scenarios to mountainous region, and continental-scale studies of future fresh-water resources will clearly benefit from a better understanding of the pertinent mesoscale circulations and precipitation processes in mountainous regions.

Second, it has been recognized in recent years that mountains are one of the key factors in defining the geographical distribution of the climatic zones on the planetary scale. An illustrative example from a general circulation experiment is reproduced in Fig. 1-5. It shows the results of a pair of global climate simulations. In both the experiments, the geographical distribution of land and sea is prescribed, while the topography has been removed for the simulation shown in the right-hand panels. The bottom panels depict the simulated geographical distribution of wet and dry climatic zones on the northern hemisphere. The local effects of topography (such as in the Alpine precipitation anomaly) are clearly visible, but there are remarkable effects remote from mountains. For instance, large parts of Siberia are classified as dry in the topography run (in agreement with the observed climatology), but would experience substantially larger rainfall amounts in the absence of topography.

From the top panels in Fig. 1-5 it can be inferred that the control exerted by topography is through planetary-scale standing wave patterns and their embedded storm tracks and a variety of the mesoscale processes contribute to determining the precise position and amplitude of these waves. The study of these mesoscale processes is one major objective of MAP and these processes include both upper-level gravity wave drag (e.g. Palmer et al. 1986) as well as low-level drag effects (e.g. Lott 1995). These processes are subgrid-scale in current general circulation models and must be parametrized. Current schemes are not adequate, and a better understanding of three-dimensional gravity wave propagation, gravity wave breaking and flow splitting, which is anticipated by MAP, will help to improve these parametrizations.

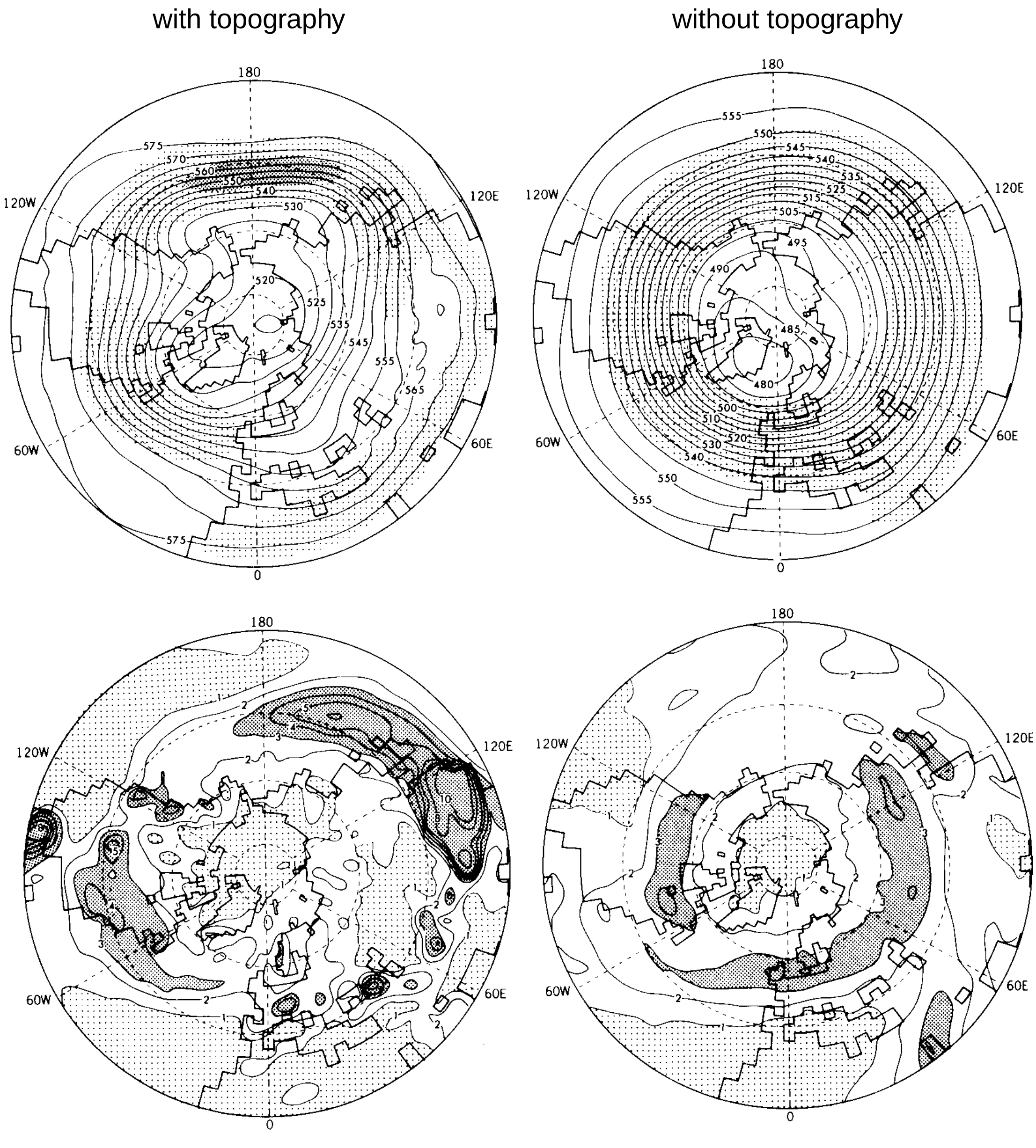


FIGURE 1-5. Mean spring circulation and precipitation patterns from global numerical simulations with (left) and without (right) mountain topography. The top panels show the 500 hPa geopotential height (dm) and wind speed; light and dense stippling indicates winds > 12 m s^{-1} and > 24 m s^{-1}, respectively. The bottom panels show precipitation rates (mm d^{-1}); contours are given at 1, 2, 3, 4, 5, 6, 8, 10, 15, 20 and 30 mm d^{-1}; light stippling indicates dry regions with precipitation < 1 mm d^{-1}; dense stippling indicates wet regions with precipitation > 3 mm d^{-1}. Taken from Broccoli and Manabe (1992).

1.5 Links to Past and Present Research Initiatives

MAP is not the first research initiative in the atmospheric sciences to focus on the Alpine region. The Alpine Experiment (ALPEX) took place 1981-82 as the last large campaign of the Global Atmospheric Research Programme with a special observing period of two months in spring 1982. The emphasis lay on general circulation aspects and on weather systems down to the meso-α scales (Gutermann and Wanner 1982; Kuettner 1986; GARP 1986). Also the modification of fronts as they approach the Alps was intensively probed during the Front Experiment 1987 (cf. Hoinka and Volkert 1992; Fronts and Orography 1992). Momentum budgets and regional wind systems over and around the simpler shaped, neighbouring range of the Pyrenees have been thoroughly investigated during PYREX in autumn 1990 (Bougeault et al. 1993). Related experiments were conducted in other mountainous regions, as for instance the Hawaiian Rainband Project (see e.g. Smith and Grubisic 1993; Rasmussen and Smolarkiewicz 1993).

Though significant advances have been made through these previous initiatives, the complexity of Alpine meteorological phenomena and the requirement for improved understanding and enhanced forecasting capabilities necessitate another concerted effort specifically addressing meso-β and smaller scale phenomena, and making use of the most recent observational and numerical tools.

It is foreseen that results from MAP will contribute to continuing research programmes. A better understanding of the dynamical effects of upper-level flow features near the tropopause will be beneficial to the interpretation of measurements obtained during the Second European Stratospheric Arctic and Mid-Latitude Experiment (SESAME), which is sponsored by the European Union. A better understanding of mountain effects in the Alpine region will also help to better assess some air-quality, transport and boundary layer problems, as for instance those addressed under the umbrella of the ALPTRAC (see EUROTRAC 1993), or POLLUMET programmes (POLLUMET 1990). The study of upper-level gravity wave breaking will touch also on aspects of interest to stratosphere-troposphere exchange studied within SPARC (1993).

All aspects regarding improved mesoscale numerical forecasts are in accord with the Short Range Weather Prediction Programme of the World Meteorological Organisation (WMO). Research tasks focusing on orographic processes influencing the regional or global climate are of high interest to the World Climate Research Programme of WMO. Therefore MAP has already been accepted as a WMO-sponsored project.

Detailed investigations concerning the generation and efficiency of convection, precipitation and hydrological processes over the Alps are of relevance to the Global Energy and Water Cycle Experiment (GEWEX). Following the presentation of MAP at the second session of the GEWEX Hydrometeorology Panel (GHP) in Toronto in August 1996, it was noted that GEWEX and especially GHP recognize the contribution of MAP activities towards improving the prediction of moist processes over and in the vicinity of complex topography, including interactions with land-surface processes. Ongoing interactions with MAP were encouraged, including cross-representation at respective working group sessions, workshops and Scientific Steering Group meetings as appropriate. This arrangement will provide for MAP to be conducted in liaison with GHP.

Finally, environmental issues are becoming more and more pressing for the Alpine ecosystem as a whole (Alpine Convention 1993) to secure with the help of protocols for various fields (e.g. agriculture, traffic, tourism) this unique homeland of 11 million people and sojourn of many more visitors. Through the Mesoscale Alpine Programme, atmospheric scientists from within Europe and abroad will be able to provide more detailed background information about the weather and climate over the Alps and its impact on other components of the entire eco-system.

2 Scientific Objectives

The scientific objectives of the Mesoscale Alpine Programme were defined during the first MAP Workshop which was held on September 12-14, 1994, in Zurich. This workshop was attended by 77 participants representing 42 institutions from 13 countries. Scientists from 12 national weather services (Austria, Croatia, France, Germany, Great Britain, Hungary, Italy, Slovakia, Slovenia, Spain, Switzerland, USA) as well as from WMO and ECMWF were present. Hydrological components were integrated following a dedicated workshop on April 26, 1996, in Zurich, which was attended by about 30 scientists, among them hydrologists from Austria, Canada, France, Germany, Italy and Switzerland. A careful evaluation procedure resulted in the formulation of the following *primary scientific objectives*:

1a *To improve the understanding of orographically influenced precipitation events and related flooding episodes involving deep convection, frontal precipitation and runoff.*

1b *To improve the numerical prediction of moist processes over and in the vicinity of complex topography, including interactions with land-surface processes.*

2a *To improve the understanding and forecasting of the life cycle of Foehn-related phenomena, including their three-dimensional structure and associated boundary layer processes.*

2b *To improve the understanding of three-dimensional gravity wave breaking and associated wave drag in order to improve the parametrization of gravity wave drag effects in numerical weather prediction and climate models.*

3 *To provide data sets for the validation and improvement of high-resolution numerical weather prediction, hydrological and coupled models in mountainous terrain.*

In addition to these primary scientific objectives, MAP supports other research activities. In particular, it supports efforts to establish a climatology of mesoscale weather systems in the Alpine region, and to facilitate the collection and exchange of so-called non-GTS data not operationally distributed through WMO channels. It is also expected that several research groups will contribute, and thus make optimal use of the instrumental set-up deployed for the foregoing primary scientific objectives. Activities related to boundary layer research and flow features at the tropopause level are particularly encouraged, since these will also provide important support on aspects of basic interest to the primary scientific objectives.

2.1 Topographically Influenced Precipitation and Related Land-surface Processes

2.1.1 Atmospheric Aspects

The effect of the Alps on the precipitation distribution is well attested and evident in all seasons (see for instance Fig. 2-1). In effect the orography creates specific patterns of ascending and descending air, which enhance or reduce precipitation. In the case of synoptic scale cyclonic activity, the orography enhances precipitation upstream, and in

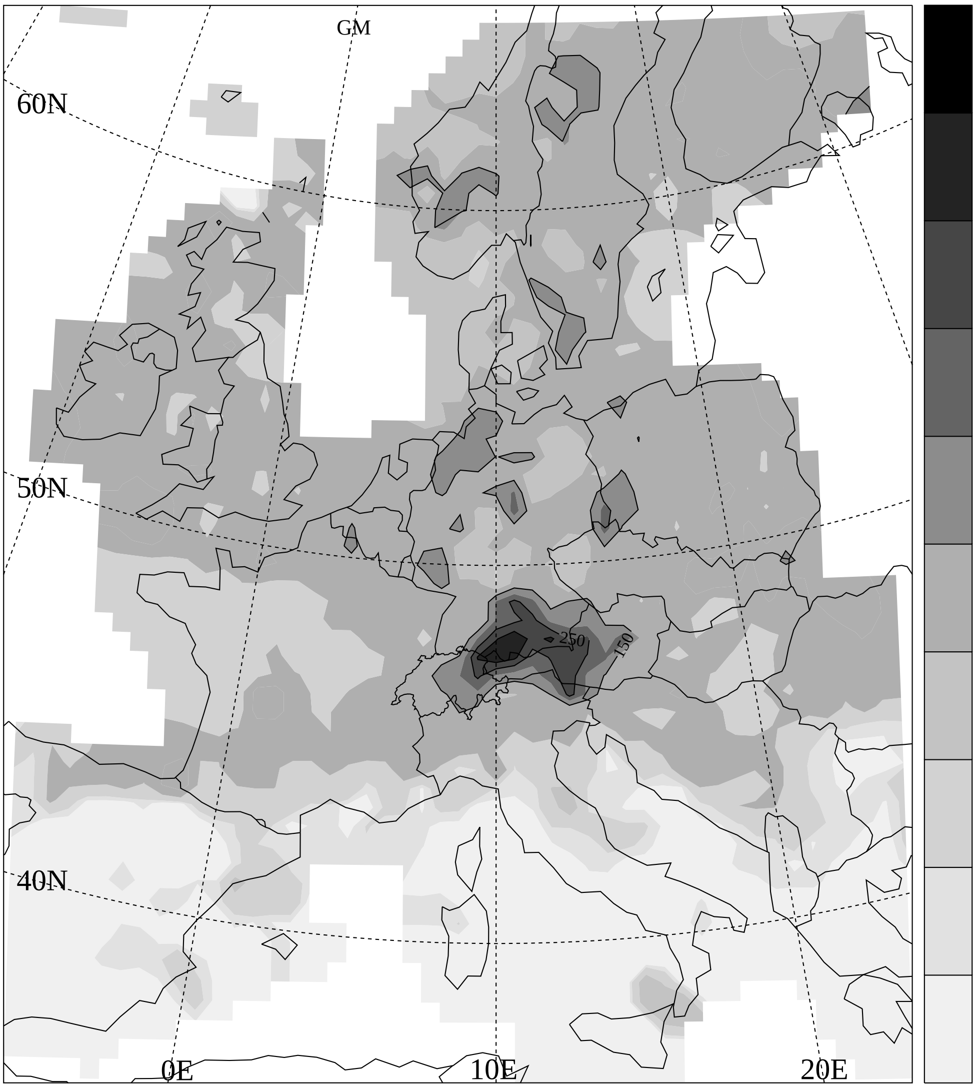


FIGURE 2-1. Monthly total precipitation for July 1993 (kgm^{-2}). Note the Alpine precipitation anomaly with values more than twice as large as in the rest of Europe. The analysis is based upon observations from around 1100 SYNOP stations. (Courtesy of Christoph Frei)

general induces a drying effect downstream. However, if conditions are favourable for convective developments, strong precipitation can occur even downstream. Convection in the Alps is quite common in situations of weak synoptic activity, as for example during the summer season when convection becomes the main source of precipitation. It is usually triggered via thermal circulations or other orographic effects, or may be prompted by upper-air anomalies advected into the area, but this mechanism is not so well understood.

Beside forming one of the most important aspects of the local climate, Alpine precipitation is also the source of specific natural hazards of significant economic importance. The majority of damages by natural disasters in the Alpine region is precipitation related. Severe flooding, hail streaks, land slides and avalanches cause loss of human lives and substantial material damage. Recent examples are provided by the severe

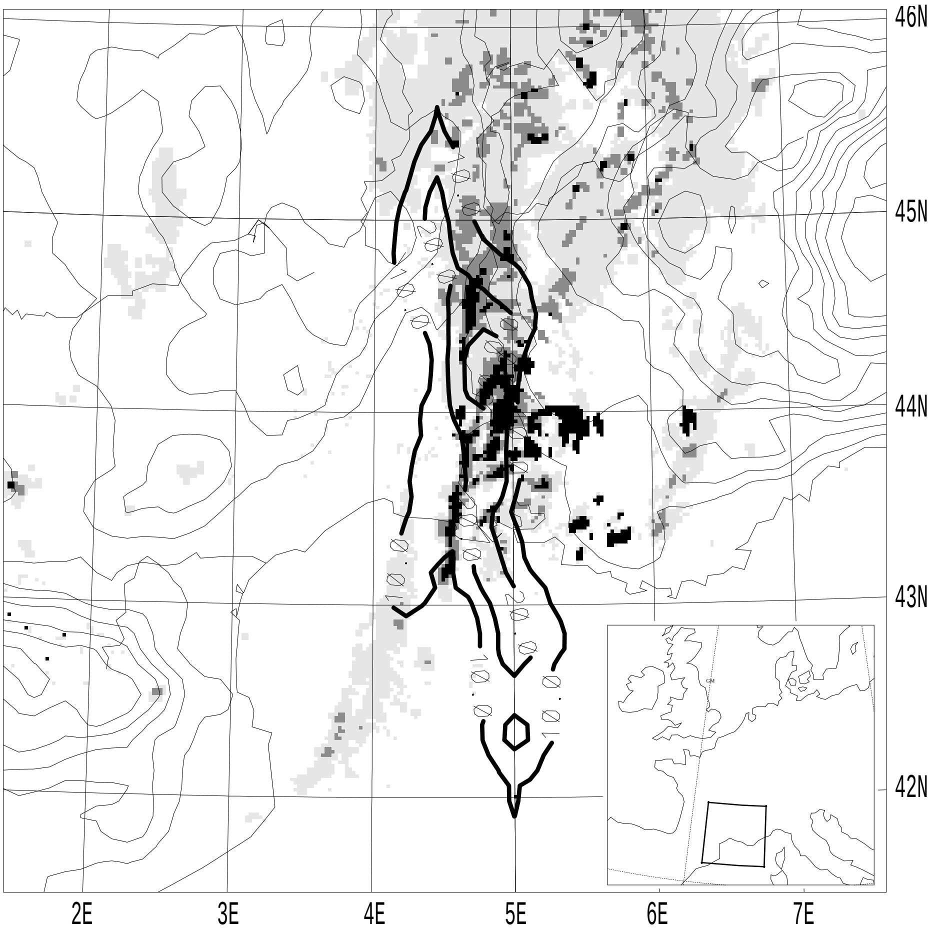


FIGURE 2-2. A comparison between observed and simulated rainfall on 23 September 1992 (Vaison-la-Romaine flash flood). The radar echo of 1130UTC has been converted into instantaneous rainfall rates ($kg\,m^{-2}\,h^{-1}$) using the data of all available raingauges as calibration (grey-scale steps at 4 and $24\,kg\,m^{-2}\,h^{-1}$). Superposed is the predicted rainfall of a research version of the Météo-France Péridot Model (isolines), run here at 10 km resolution, and accumulated for 1 hour (1100 to 1200UTC). This is the best forecast obtained during subsequent studies on this case, yet it is not precise enough to assess the extent of the damage in the area. (Courtesy of Météo France)

flood episode of Piedmont (Italy, 5-7 November 1994), the flash floods of Brig (Switzerland, 23 September 1993), Vaison-la-Romaine (France, 23 September 1992, see Fig. 2-2), Valtellina (Italy, July 1987) and the so-called 'Papal front event' (southern Germany, 3 May 1987).

A primary objective of MAP is therefore to improve the understanding and short term numerical prediction of Alpine precipitation, and particularly of the forementioned heavy precipitation and flooding events. This objective requires a drastic improvement of our understanding of the flow dynamics at several scales. Indeed, it is known that the dynamical effects of the Alps take place on a broad range of scales. For short term numerical weather prediction, the relevant scales range from the meso-α scale (e.g. lee cyclogenesis and modification of upper level troughs, see Tibaldi et al. 1990), through meso-β scale (e.g. modification of fronts by orography, see Hoinka et al. 1990; Buzzi and Alberoni 1992) to the meso-γ scale (e.g. circulations in individual valleys, and inside individual clouds).

Although there exists some knowledge of the preferred synoptic-scale situations for severe precipitation in the Alpine region, little is known at present about the precise mechanisms that lead to the triggering, organisation, localisation, concentration and maintenance over many hours of these types of precipitating systems. Newly available observation systems (e.g. ground-based Doppler radars, and high-resolution numerical models) provide some evidence that episodes of strong precipitation are preceded by and/or associated with detectable mesoscale flow structures, such as upper-level short-wave troughs, convergence lines, shear lines, low-level jets, mesoscale vortices and thermally induced circulations. All these features become potentially more predictable as numerical models improve in resolution and accuracy, and incorporate more advanced representations of physical processes.

However, some basic knowledge is still missing on the precise structure of Alpine precipitating systems at the meso-β scale. Three issues need particular attention:

- The dynamical organization of convective systems: to what extent do the classical types of organization (multicellular, supercell, squall line, mesoscale convective complex, etc.) observed over comparatively flat terrain apply to the Alpine area, and how are they related to the larger-scale environment?
- The distribution of vertical velocity in the updrafts, and the associated distribution of instantaneous rain-rates: What is the relation between these elements and the larger scale via the moisture fluxes at lower levels, and the mass detrained into the environment at upper levels?
- The microphysical characteristics of these clouds including their cloud water loading, description of the condensates, and efficiency of the seeder-feeder mechanism need to be investigated.

With the advent of airborne Doppler radars, and stratosphere-troposphere (ST) wind profilers, the instrumental capacity now exists to conduct a major field study and thereby to significantly improve our knowledge.

Beside the dynamical effects of orography, soil and surface properties determine the heat and moisture budgets which in turn affect the hydrological cycle. There is increasing evidence that the correct specification of the surface moisture budget is a key aspect for the numerical prediction of the rain intensity. Thus, substantial effort is required to improve the representation of land-use, soil properties, soil moisture and snow cover in mesoscale models of the Alpine region.

The experimental task related to the Primary Objective 1 of MAP is therefore to collect precise measurements of the structure and dynamics of precipitating systems over the Alps, at the smallest possible scale, together with their meso-β-scale environment, and their surface forcing. Both frontal and convective systems will be sampled. The atmospheric flow settings for intensive studies are of three types:

- Convection resulting from the advection of warm and moist air masses from the Mediterranean into the Alpine area (especially during fall),
- Fronts crossing the Alpine area, usually from the north-west (all seasons), and
- Convection generated locally (especially in the summer season).

The resulting new and detailed observational data will serve to validate numerical models at the finest achievable scale. It is foreseen that both meso-β-scale and meso-γ-scale models will be used for extensive case studies using the observations acquired during the field phase.

This intensive experimental and numerical effort will be complemented by a similar effort in the treatment of existing radar measurements, with the aim of producing quality controlled maps of precipitation at small spatial (<5 km) and temporal (<3 hours) scales.

Finally, the analysis of mesoscale dynamical features, and the diagnosis of momentum, heat and moisture budgets will greatly benefit from this effort, resulting in much improved conceptual models of the orographic influence on precipitation.

The MAP Primary Objective 1 builds upon the experience acquired in several European groups in the study of convective and frontal systems in the Alpine foreland. Examples include MATREP (Buzzi et al. 1991), the Front Experiment (Hoinka and Volkert 1992), CLEOPATRA (Haase-Straub et al. 1994), SETEX (Peristeri 1994), Grossversuch IV (Federer et al. 1986; Houze et al. 1993), as well as individual case studies (e.g. Meischner et al. 1991; Volkert et al. 1991; Senesi et al. 1994).

2.1.2 Hydrological Aspects

On the mesoscale the atmosphere and the underlying land surfaces represent a heavily coupled system (Eagleson 1978; Brubaker and Entekhabi 1995). On one hand, the moisture content and other soil properties determine the runoff production in response to atmospheric precipitation. On the other hand, the land surface provides fluxes of moisture, heat and momentum into the atmosphere that affect the atmospheric circulation. Both these factors are highly relevant to regional weather and flood forecasting and are substantially affected by complex topography. The task of coupling of hydrological models and numerical weather prediction models opens the possibility of connecting all the water fluxes in the land-atmosphere system. Within MAP pursuance of this highly desirable goal will directly contribute to the further development of flood forecasting systems and water-resource modelling, and also improve the assessment of the local and regional components of the latent and sensible heat input from land surfaces into the atmosphere, and thereby improve the basis for precipitation forecasting in the Alps.

Research areas in this field which require particular attention are (a) the integration of high-resolution radar and satellite data with classical rain gauge observations for precipitation measurements, (b) the improvement of the methodologies for the estimation of return periods of heavy precipitation events in ungauged sites where orographic effects are dominant, (c) the adaptation of soil-vegetation-atmosphere transfer schemes and surface-layer formulations to mountainous terrain, and (d) the integration of advanced hydrological and atmospheric numerical models to provide "coupled" runoff predictions. Further aspects related to these research areas are discussed in turn below.

A. Retrieval of rainfall estimates from radar data

Owing to the short response times (typically one to a few hours) of potentially dangerous watersheds located in mountainous regions, real-time monitoring of rainfall is highly essential, both for the assessment of the risks related to heavy precipitation events and for driving real-time hydrological models. The use of weather radar could substantially contribute to hydrological forecasting although the topography acts as a troubling factor (Joss and Waldvogel 1990, Andrieu et al. 1996). Considerable operational effort has been paid in recent years for the installation of modern radar systems in the Alps. Studies have been performed to better understand specific error sources. Newly developed correction algorithms were tested either against a few cases (e.g. Creutin et al. 1996, Bacchi et al. 1996) or in an operational context (e.g. Joss and Lee 1995). The results obtained are encouraging. Valuable quantitative information can be obtained from radar data (see Fig. 2-3) provided certain conditions are met. These are related to the choice of the radar site and the implementation of a high-rate volume scan strategy with the two-fold objective of maximizing the detection domain and characterizing the vertical structure of the atmosphere. In addition, refined physically-based processing methods are required to identify and eliminate ground clutter (here Doppler systems provide a base for significant advances), correct for partial beam blockage, and account for the vertical profile of reflectivity in order to obtain best estimates of quantitative precipitation at the ground.

Several additional problems need special consideration in the future: First, it is now recognized that the stability of the radar hardware components is essential and that an adjustment procedure based on rain gauge data may be used to compensate for an eventual absolute calibration error. Second, relevant relations between radar measurements (e.g. reflectivity, attenuation) and the rainrate are needed for radar data processing. Hence, the use of in-situ sensors (rain gauges, drop size distribution sensors) is necessary. Third, the merging of data from radar measurements at different altitudes and/or at different wavelengths, and the quantitative assessment of newly available radar parameters (e.g. differential reflectivity, Doppler velocity) are scientific tasks with promising potential.

B. Precipitation distribution

For the implementation of effective flood hazards control policies and the design of civil structures, an accurate knowledge of the probability of occurrence of extreme rainfall events with respect to their duration and spatial extent is required. For this purpose

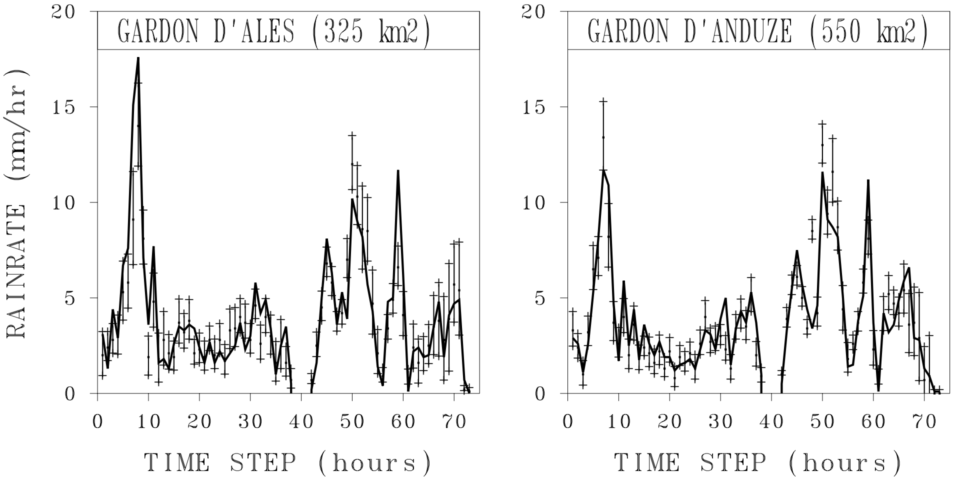


FIGURE 2-3. Autumn precipitation in the Cevennes region (France). The figure presents time series of hourly hyetographs for two potentially dangerous regions, namely the Gardon d'Ales (325 km^2) and the Gardon d'Anduze (550 km^2) watersheds. Radar estimates (solid lines) are derived from 10 cm radar reflectivity. The data is corrected for the typical sources of error in mountainous areas such as ground clutter, beam blockage, and vertical profile of reflectivity. For calibration a single radar-raingauge adjustment factor for the whole event is used. The points and the vertical bars represent the corresponding raingauge network estimates and their 80% confidence intervals obtained through a geostatistical approach. The good agreement between the two time series is encouraging so as to the possibility of obtaining valuable quantitative information from weather radar. Such information could be used both for the validation of rainfall estimates provided by atmospheric models and as input into hydrological models. (Courtesy of H. Andrieu)

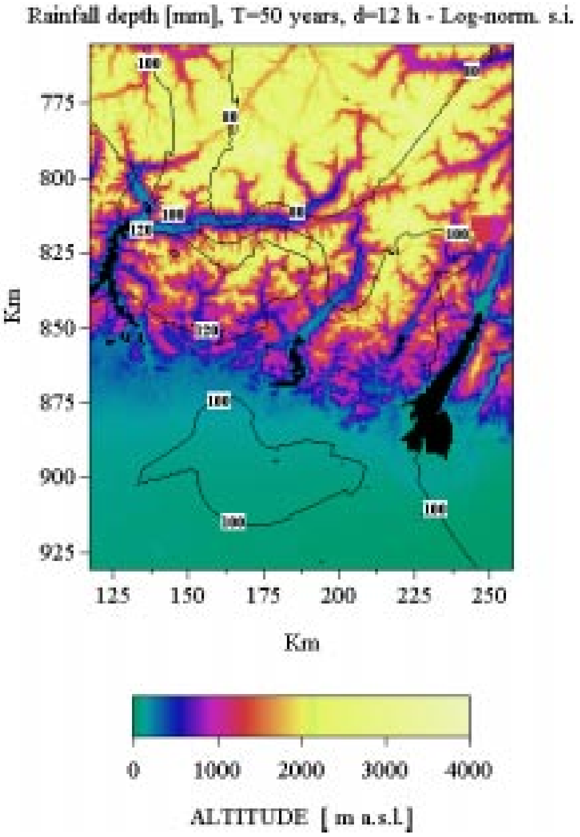


FIGURE 2-4. The rainfall depth with a duration of 12 hours and a return period of 50 years as estimated from more than fifty stations over the Central Italian Alps using a log-normal scale-invariant statistical model. The contours of the rainfall depth are superimposed on a digital elevation model.
The central part of the Figure covers the Upper Adda watershed (Valtellina), where a catastrophic flood occurred in July 1987. It exhibits a clear minimum that is induced by the orographic shadowing of the Bernina and the Orobie massifs, which are located, respectively, to the North and the South of the valley. Hourly average rainfall depths decrease with altitude in the investigated area since intense short-duration convective events are a dominant meteorological feature in the lowland areas. However, the increase of rainfall depths with duration is more pronounced in mountainous areas, probably as a result of extended orography-induced precipitation events related to the passage of frontal systems. (Courtesy of B. Bacchi and R. Ranzi)

depth-area-duration relationships have been estimated (Grebner 1995, Lang et al. 1996) and different statistical models were applied in the Alps (Jensen 1986, Villi et al. 1987, Margoum et al. 1995, Watzinger 1996). Particular attention has been devoted to the statistics of extreme rainfall depths with a duration ranging from 1 to 24 hours, consistent with the response time of catchments with sizes ranging from some tens to some thousands square kilometres. Despite the numerous investigations, the spatial distribution of extreme precipitation in mountainous areas is still not very well known. Factors contributing to this gap are the bias in the distribution of rain gauge locations to the bottom of valleys, and the lack of sufficiently representative data records. The latter is particularly pertinent for short duration representative of the response time of small upstream basins. Physical considerations can be used to improve the understanding of orographic effects. For instance in the western part of the Alps, recent analyses show that micro-scale climatic effects are of increasing importance as time step increases from one hour to one day, while meso-scale climatic effects are more important as the time step decreases (Desurosne et al. 1995). This appears to be related to pronounced shielding effects induced by the Alpine barrier, as for instance in the upper Durance and Maurienne valleys in France, or in the Italian Alps (see Figure 2-4). Such effects are also relevant for the precision of the underlying measurements, and associated microclimatic effects related to altitude, wind regime and exposure of the rain-gauge stations have been investigated in the Swiss Alps (Kirchhofer and Sevruk 1992).

Of scientific and practical importance is also the investigation of the scaling properties exhibited by precipitation fields in the space-time domain (Schertzer and Lovejoy 1987, Gupta and Waymire 1993) and in the statistics of their extremes (Burlando and Rosso

1996). How these properties are linked to thermodynamic variables (Pertica and Foufoula-Georgiou 1996) and to the rainfall-generating mechanisms in regions of complex topography is an issue worth to be explored.

C. Surface-Atmosphere Exchange Processes

As a result of both the Global Energy and Water cycle Experiment (GEWEX) and the Biospheric Aspects of the Hydrological Cycle (BAHC) research projects, it is now recognized that the correct formulation of soil-vegetation-atmosphere processes plays a key role in affecting both short-term meteorological forecasts and longer-term climatic projections (Betts et al. 1996). However, intercomparison projects of land-surface models (e.g. PILPS-GEWEX) show that the agreement between different formulations is sometimes small (Love and Henderson-Sellers 1994, PILPS 1994).

In high mountainous areas, the exchange of moisture and heat with the atmosphere is, in addition, highly influenced by the presence of snow cover. Radiation models that take into account the effect of topography (Dozier 1980, Ranzi and Rosso 1995) could be implemented to account for the distribution of radiative fluxes and albedo. Energy and moisture fluxes between the snow surface and the atmosphere (Lang 1981, Olyphant and Isard 1988) can be simulated with distributed models (Ranzi and Rosso 1991, Bloeschl et al. 1991), whereas snow-covered areas can be monitored by means of ground networks and remote sensing (Rosenthal and Dozier 1996).

Another key factor for the determination of the turbulent fluxes of sensible heat, latent heat and momentum is the efficiency of exchange processes between the surface (bare soil or rock, vegetated surface and snow fields) and the atmosphere. This efficiency is essentially determined through the turbulence structure of the lowest atmospheric layers and depends upon the nature of the underlying surface. Presently, the theoretical understanding of these processes is restricted to flat and horizontally homogeneous terrain for which the Monin-Obukhov similarity theory can be used (e.g. Kaimal and Finnigan 1994). In recent years, extensions to this theory have been proposed for either gently rolling terrain (e.g. Carruthers and Hunt 1990) or again idealized settings of inhomogeneity such as step changes in some surface property. Similarly, the turbulent exchange over tall vegetation (forests, crop fields) and within their canopy has been investigated (e.g. Kaimal and Finnigan 1994). However, relatively little is known at present about the turbulence structure over mountainous terrain and hence about the nature and efficiency of exchange processes. In this context, the following aspects require special attention: First, complex topography can induce a mean pressure gradient such that classical scaling variables may loose their physical significance. Second, the rough nature of the surface over the Alps leads to the formation of a roughness sublayer of non-negligible vertical extent (Raupach et al. 1991). Third, the horizontal inhomogeneity of the surface at scales smaller than that of mesoscale atmospheric models makes it very difficult to explicitly determine representative surface fluxes from a limited number of field observations or from the available parameters in a numerical model (e.g. Schmid and Buenzli 1995).

The above issues, and the fact that all these aspects of non-ideality occur at the same time and with still unknown relative importance, will have to influence the design of suitable experimental strategies and numerical experiments in order to proceed towards a better understanding of turbulent exchange processes over mountainous surfaces.

D. Hydrological processes and modelling

Mountainous terrain causes strong spatial variations in the hydrological processes and parameters, which pose particular problems to the assessment and modelling of the hydrological cycle and water balance. The knowledge about the spatial and temporal variability of precipitation, evapotranspiration and soil water storage is still poor, in particular in the higher Alpine regions. For example, recent research reveals vertical evaporation gradients quite different from what has been assumed up to now (Gurtz et al. 1996, Konzelman et al. 1996). More basic research and model development in the field of mountain climatology and hydrology needs to be activated with particular consideration of the scale problem (Lang and Schulla 1996).

The interaction of the gravitational field with the rough (geologically young) topography of the Alps produces complex patterns in the structure of the surface drainage system. Considerable efforts have been undertaken by the developers of lumped schemes to search for general laws that allow the synthesis of associated system variability and process nonlinearity (Dooge 1959, Rodriguez-Iturbe and Valdes 1979, Valdes et al. 1979, Tarboton et al. 1988, La Barbera and Rosso 1989, Rinaldo et al. 1991, 1995). In comparison relatively little such work has been devoted to distributed modelling schemes. The aim is to improve the description of processes at the elemental scale on the one hand (see Beven 1989), and to reduce the computational costs of running distributed models for mid- and large-scale catchments on the other hand. The hydraulic effects related to the locally-varying channel shape in complex drainage networks should also be addressed. Recent results (Orlandini and Rosso 1996) motivate further experimental and theoretical work with the goal to develop efficient parametrization schemes that describe the impact of the stream channel geometry in distributed catchment models.

Physically-based distributed models (Fig. 2-5) of runoff dynamics (Kite and Kouwen 1993, Wigmosta et al. 1994, 1996, Orlandini et al. 1996) offer some advantages and seem to be a potentially useful tool for the current project, since they make use of the full information content of spatially distributed data, and since they can be coupled with reasonable efforts with atmospheric models. Extended experience is available for a north Alpine river basin. With the support of GIS information about the land-surface characteristics, it was possible to determine all water flux processes for the Thur basin (1700 km^2). The models are grid based, either using the concept of aggregation into representative unit areas, or using regular grid cells with resolutions between 50 metres

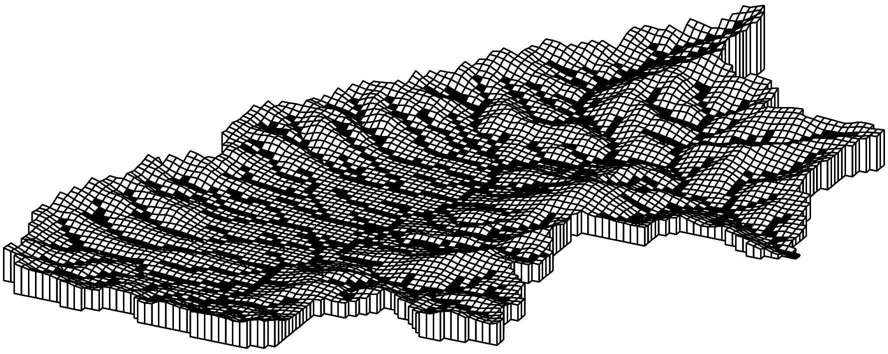


FIGURE 2-5. : Example of a numerically resolved catchment (Sieve catchment with an area of about 840 km^2). The resolution is 400x400 m, and shading shows cells with overland flow (white) and channel flow (black). (Courtesy of Stefano Orlandini)

and some kilometres (Gurtz et al. 1996). Another successful example of distributed modelling is the recent work of Kouwen et al. (1995) in the 50’000 km^2 Columbia River watershed in British Columbia. Weather data generated by a simple boundary layer model or alternatively by a numerical weather prediction model were used as input to a gridded hydrological model (Kouwen et al. 1993). The hydrological model was designed to make maximum use of remotely sensed data, including detailed land-cover (see e.g. Donald et al. 1995) and meteorological data. The numerical weather prediction model used was the MC2 model (see Benoit et al. 1995), and the investigated periods included periods of intense precipitation. The experience gained in this study shows that the use of numerical weather prediction models to provide the necessary data for flood forecasting is a viable and promising approach.

2.2 Gravity Waves and Foehn

The understanding of stratified airflow past high topography has advanced considerably over the last 25 years. This progress has occurred due to the contributions from four areas of research: (1) theoretical studies, (2) numerical (and laboratory) simulation, (3) case-studies based on operational data, and (4) specially designed field programmes. The frontier of knowledge concerning mountain airflow and weather is related to the processes which have so far been omitted by the theoreticians and modellers, and by the spatial and temporal coverage and the accuracy not yet achieved with observations. Several of these poorly understood aspects are listed below:

Three-dimensionality: There is a broad body of literature on theoretical and observational studies of two-dimensional aspects of flow past topography (cf. Fig. 2-6). However, real mountain flow is highly three-dimensional (cf. Fig. 2-7). Though a theme of observational and theoretical studies for a long time (e.g. Lammert 1920, Vergeiner 1978, Smith 1979), it is only in the last five years that a concerted effort has started to systematically investigate such flows. Well established results for two-dimensional geometry may require major modifications when a third dimension is added:

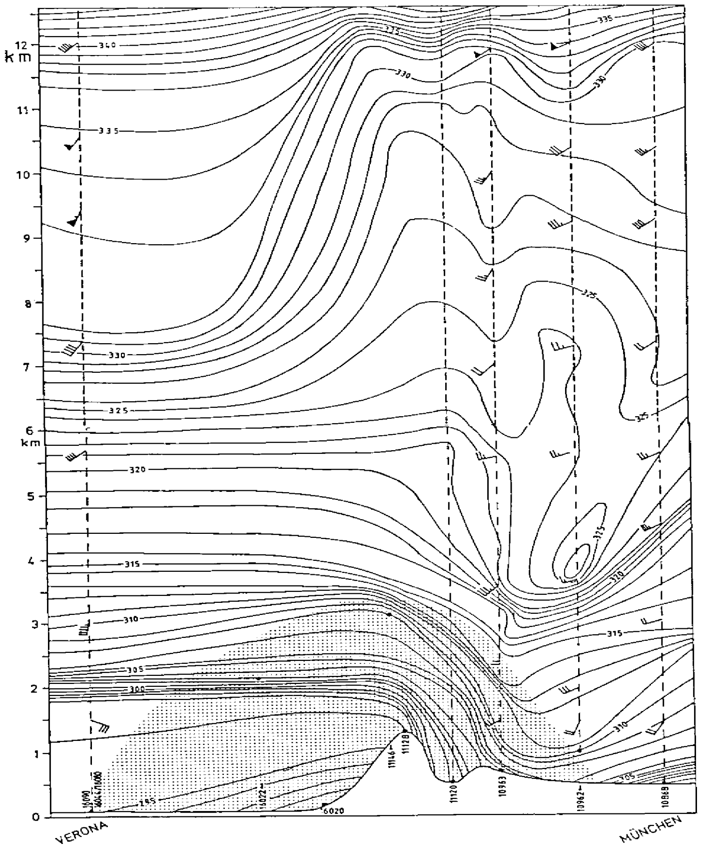
- A significant fraction of Foehn cases in the Alpine region is classified as shallow (Seibert 1990), when strong cross-Alpine flow is essentially confined to valley transects. In addition, most deep Foehns are superimposed on shallow and cold air which is channelled through mountain passes. It is unknown to what extent the two-dimensional concepts of downslope windstorms (cf. Clark and Peltier 1977; Smith 1985; Durran and Klemp 1987; Bacmeister and Pierrehumbert 1988), apply in such a situation. Some aspects of shallow Foehn might rather be interpreted as a result of wind channelling effects (cf. Wippermann 1984).
- Foehn occurs for both southward and northward flow across the Alps, although only the latter has been investigated in some detail. Little is known about the dynamic differences and similarities between these two phenomena, which are influenced by three-dimensionality as well as baroclinicity.
- In three dimensions, upper-level gravity wave breaking and lower-level flow splitting may lead to the generation of flow-anomalies of potential vorticity (cf. Smith 1989) which can – unlike gravity wave features – be advected off the topography. Potential vorticity streamers (see front cover for an example) originating at the edges of topography or from localised upper-level dissipation have been studied in ideal-

ised settings (Schär and Smith 1993a, b; Smith and Smith 1995) and can also be found in recent operational high-resolution NWP models (Aebischer and Schär 1994), but observational confirmation of these 'banners' is only available at low resolution (Thorpe et al. 1993). The detailed structure of the streamers, as well as the relative contribution of various hypothesized generation mechanisms (cf. Smolarkiewicz and Rotunno 1989; Schär and Smith 1993a; Thorpe et al. 1993) remains largely unknown.

A better understanding of these three-dimensional aspects is important for a number of reasons:

- Low-level topographic flow anomalies downstream of the Alps manifest themselves as shearlines and mesoscale vortices. As such, they are important for operational forecasting purposes that range from the prediction of low-level convergence (and thus moist convection) to that of lee cyclogenesis. Several case studies of Genoa cyclones have for instance revealed the presence of low-level anomalies of potential vorticity downstream of the Alps (e.g. Tafferner 1990; Pichler et al. 1993).
- The potential vorticity associated with the generated flow anomalies represents conceptually an intermediary between the mesoscale and the resulting feed-backs onto the larger-scale balanced flow (cf. Hoskins et al. 1985). This contrasts with current parametrizations of gravity wave drag (see for instance Palmer et al. 1986) which are essentially based on two-dimensional theory.

FIGURE 2-6. Cross-section of equivalent potential temperature from Verona to Munich (Brenner section) during the Foehn of 8 November 1982, 1200 UTC. The analysis is based on radiosoundings (dashed lines), synoptic stations, and upper-level aircraft measurements. The ground level refers to a section along the valley floors, while the shaded area marks the height of the surrounding mountains. (Adapted from Seibert 1990)



- A highly structured, three-dimensional topography can instigate a wide spectrum of gravity waves. The interaction and lateral dispersion of these components, as well as their modulation by the ambient atmospheric profiles, will determine the total wave momentum flux deposited in the upper troposphere and higher atmosphere (Bacmeister 1993; Bacmeister et al. 1994; Broad 1995; Shutts 1995). This in turn is important for the parametrization of mountain wave effects in large scale models.

Boundary-layer effects: Several studies have demonstrated that the planetary boundary layer significantly affects flow past topography, including the penetration of Foehn into valleys (Hoinkes 1950, Hoinka and Rösler 1987), the generation of low-level vortices (Thorpe et al. 1993), the stabilization of wakes (Grubisic et al. 1994), and the generation of surface gusts (Richard et al. 1989; Miller and Durran 1991). It has also been recognised that some of these processes are important on a planetary scale, and attempts are underway to parametrize low-level effects of subgrid-scale topography in large-scale and mesoscale numerical models (Mason 1991; Georgelin et al. 1994; Lott and Miller 1997). Some of these boundary layer issues are further addressed in Section 2.4.2.

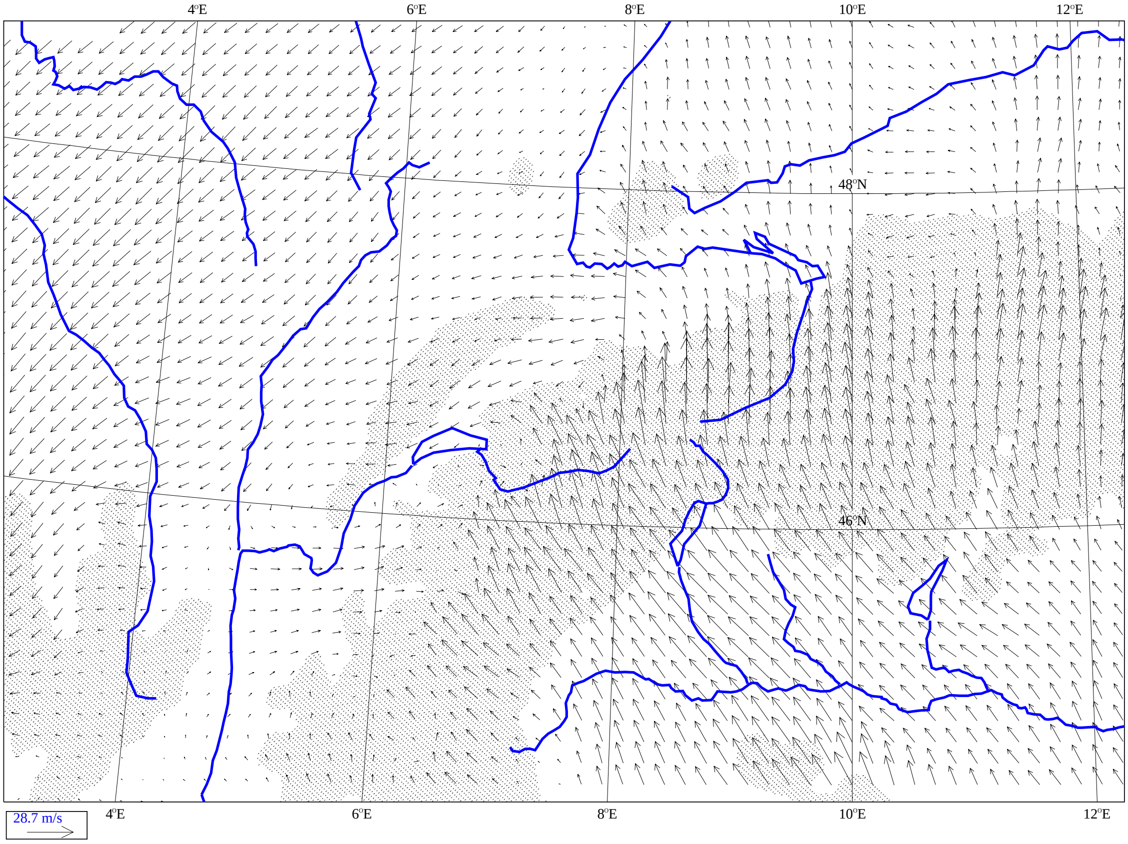


FIGURE 2-7. Wind field about 600 m to 700 m above ground (on a terrain-following model level) of the operational forecast of 23 September 1993 12 UTC +24 h by the Swiss Model (mesh width about 14 km). Note that the wind field has a rich structure: Over the Alps and in the north-eastern part of Switzerland the Foehn flow prevails, whereas in the western part of the Swiss Plateau between the Alps and the Jura mountains the wind turns to a north-easterly direction („Bise“). These features are consistent with the available observations. A vortex and other details can also be recognized in the French Rhone valley. The maximum wind speed on the plot is 30 m s^{-1}. The stippled area denotes terrain elevations above 750 m. (Courtesy of Swiss Meteorological Institute)

Nonhydrostatic effects: The process of gravity wave breaking, the trapping of gravity waves by stable layers, as well as moist upslope convection are intrinsically nonhydrostatic. While several research models nowadays capture the effect of vertical acceleration airflow dynamics, we do not understand how this effect modifies the airflow separation from sharp terrain features, the horizontal distribution of momentum flux (cf. Keller 1994; Durran 1995) and the structure and location of wave breaking. The current programme comes at a time when the nonhydrostatic models are reaching an appropriate resolution to tackle these problems in a realistic and three-dimensional manner. In order to validate and improve these models, guidance from observations is imperative.

Non-stationarity: Until now, the assumption of stationarity has widely been used in order to gain understanding of the fundamental dynamical characteristics of gravity waves and Foehn-related phenomena. These phenomena are, however, intrinsically time-dependent, and new investigations will be required to improve our understanding of their evolution. The onset and especially the cessation of gravity waves and Foehn are poorly understood, and they are closely linked with the evolution of the synoptic-scale flow such as the progression of frontal systems past the Alps (cf. Egger and Hoinka 1992). Foehn can strengthen or weaken fronts (Heimann 1992a, b), and is usually terminated by the arrival of fronts. This interaction is poorly understood, and it represents one common forecasting problem in the Alpine countries.

Clouds and moisture: While the effect of water condensation has been included in simple two-dimensional airflow models (e.g. Smith and Lin 1982) and numerical simulations (e.g. Durran and Klemp 1982), and while some attempts have been made to document orographic clouds and precipitation (cf. Fliri 1983; Reinking and Boatman 1986; Lee 1986; Banta 1990), we are far from an adequate understanding of the interaction of clouds, precipitation and Foehn-like flows. Whether upstream precipitation enhances or weakens Foehn is unclear (Lilly and Durran 1983; Davies and Schär 1986). The relative contributions of moist ascent and net descent to Foehn warmth and dryness have not been determined climatologically although their importance is disputed (see Seibert 1990). Also, the role of windward evaporative cooling on airflow blocking and splitting is largely unknown. These issues are closely linked with the MAP scientific objectives relating to topographically influenced precipitation (see Section 2.1).

Coriolis cut-off: It has been known theoretically for some time that for scales of motion larger than 100 kilometres or so, the influence of the Coriolis force is to inhibit gravity wave phenomena (Queney 1948; see also Smith 1979; Durran 1990). Thus, airflow on the scale of the entire Alps is non-wavelike whereas airflows on the scale of individual peaks and valleys are wavelike. The role of this wave cut-off and the propagation of inertia gravity waves is significant for momentum transport and for flow over three-dimensional mountains (cf. Trüb and Davies 1994), but little is known about its role on Foehn, airflow splitting, clear air turbulence and wave momentum flux.

Approach

The Mesoscale Alpine Programme has been organised and designed to advance the boundaries of our knowledge and the forecasting capability in mesoscale mountain meteorology. With respect to airflow studies, the Alps are a suitable research area for this programme, because of rather than in spite of their complexity. They have already been well studied using earlier generations of models and instruments. Furthermore, the Alps are – already at current operational level – equipped with one of the densest networks of conventional surface and upper-air observing systems. The deployment of new techniques in the field phase in conjunction with the use of numerical models of the next generation, will enable the *analysis* of three-dimensional flow past topography, *advance* our knowledge of mesoscale dynamical processes in mountainous terrain, *improve* the forecasting of flow features in the Alpine region, and *contribute* to the understanding and simulation of global climate through improved representations of mountains in general circulation models.

2.3 Validation and Improvement of Models

2.3.1 Atmospheric Models

In the context of numerical models in meteorology, the term *validation* is used in the sense of determining the conformity of numerical model simulations with the available observational data and knowledge. This in turn defines the fitness or suitability for the intended model application. According to Hollingsworth (1994) an elaborate process of cross-validation of model forecasts, data analyses, routine observations and field data is necessary to improve the forecast model's performance. The pressing need to validate high-resolution mesoscale models in a systematic fashion is acknowledged (Chouinard et al. 1994, Kuo 1993), but only a few detailed studies are available for regional limited area models with horizontal mesh size below 100 km (e.g. Anthes et al. 1989).

In the early nineties, meso-β-scale numerical models covering the Alpine area became operational at several meteorological services. These high-resolution models aim explicitly at *weather* prediction (i.e. a correct spatio-temporal specification of cloud cover, rain areas, daily temperature extrema, etc.) rather than merely *flow* prediction (i.e. height and pressure patterns, wind fields; cf. Wergen 1994). Thus in addition to standard techniques (e.g. as compiled in Stanski et al. 1989) mesoscale model validation has to focus also on a detailed examination of physical parametrizations, as was claimed by Hollingsworth (1994) and exemplified for a gravity wave drag parametrization scheme by Bougeault et al. (1992).

Thus, important MAP tasks are: to systematically *validate* the performance of high-resolution models, to *assess* the quality of the regional forecasts in the Alps, and to *stimulate* model improvements.

Table 2-1 provides an overview of the typical mesh size and data storage interval of current operational models, along with typical station spacing and sampling intervals of different observational networks. Estimated values are included for the nonhydrostatic models that are currently under development and are expected to become operational during or shortly before the course of MAP. The spatio-temporal resolution of upper-air and surface observations lags significantly behind that of model data. Precipitation measurements have a high spatial resolution for daily sums, yet the data collection is organised nationally and not included in the GTS-network (see Section 2.4.1). Areal precipitation derived from the radar network is still not integrated into systematic validation schemes. Wind soundings with high temporal resolution from radar wind profilers are foreseen as providing important new information, even if only installed as isolated systems in the coming years.

The gap between the density of observed and forecasted data will significantly increase when the new generation of meso-γ models with ten times smaller mesh size becomes available.

MAP will serve to ameliorate the current situation in two ways:

- by extending the operational validation procedures of NWP models, and
- by establishing special data sets during the field phase, which will allow evaluation of model parametrizations through process studies.

The first item necessitates the systematic collection of all routinely available data from within and outside the meteorological services, and the development of a validation strategy, which is intermediate between studies of single cases (e.g. Volkert et al. 1992; Pichler et al. 1993) and the operational calculation of skill scores for extended regions and periods of time (e.g. Majewski and Schrodin 1994). These tasks are to be started right at the beginning of MAP. Before the field phase data become available, diagnostic tools could be applied for the validation of thermodynamic processes during strong precipitation events (cf. Dorninger et al. 1992). The second item is to be tackled after the field phase of MAP. However, the processes to be evaluated (gravity wave parametrizations, dry and moist planetary boundary layer processes, cumulus parametrization schemes) have to be precisely defined early on in the programme so that sufficient parameters (e.g. heat and moisture fluxes) are observed during the special observing period of the field phase. It is foreseen that the observations from the field phase will serve in particular to validate the first meso-γ-scale model performances in simulating Foehn and lee waves, breaking waves, intense convection and precipitation.

The data sets with enhanced resolution and a wider selection of parameters are important for both initialisation and evaluation of the numerical models. The Special Observing Period of MAP ought to be long enough and cover a sufficiently large area to serve both purposes.

	d (km)	t (h)
Operational NWP models	15	1
Upper-air network	250	6 or 12
SYNOP stations	30	1 or 3
Rain gauges (climatological and hydrol. networks)	15	12 or 24
Radar network (quantitative precipitation)	5	0.25
Wind profiler	–	0.25
nonhydrostatic models (under development)	1	–

TABLE 2-1. Typical spatial (horizontal direction; km) and temporal (h) resolution of current and planned operational NWP models and various observing systems.

2.3.2 Hydrological Models

Hydrological river basin models are used in several ways: (1) to derive a quantitative understanding of the different time-dependent processes in a river basin, and to determine the variations of the transfer and state variables; (2) to forecast important hydrological variables (runoff, soil moisture, snowpack, etc.) based on either observed and forecasted meteorological variables; (3) to assimilate observations from different sources into a spatially consistent time-dependent framework.

In order to run hydrological models, observed or predicted meteorological variables (i.e. precipitation, temperature, water vapour pressure, wind speed and radiation) are used as input. The spatial scale of most Alpine river basins is however such that in the past the resolution of both operational NWP models and/or observed meteorological data was often too low and thus incompatible with the needs of operational hydrological models. One particularly important objective of MAP is to improve the resolution and functionality of the models and thereby to allow for either one-way or fully interactive coupling of the meteorological and hydrological models. Data from the MAP General Observing Period (GOP) will be highly useful for the development, improvement and validation of relevant model components. Emerging "model chains" could efficiently be used for operational runoff and flood prediction purposes on the scale of individual river basins.

The combined use of high-resolution meteorological and hydrological models offers attractive advantages since it closes the water budget on the scale of individual valleys. For instance, precipitation is the most important input parameter for hydrological models, yet it is also very difficult to predict by atmospheric models, and also to observe in a spatially consistent manner. On the other hand, runoff can be measured quite accurately and may be used to validate model-derived rainfall amounts and precipitation-interpolation procedures. Such data could be used in two ways: First, coupled meteorological / hydrological model chains can directly be validated in terms of runoff predictions over selected river basins. Second, simulated precipitation of atmospheric models can be compared with rainfall amounts as derived over extended periods from the water balance in selected catchments. Since the water balance in the Alpine region is dominated by precipitation and runoff, the evapotranspiration term in the water balance can be estimated with sufficient accuracy.

Similar validation methodologies are recommended at larger scale by the WMO WCRP-Water project "Grid estimation of runoff data" (WMO 1994) which aims towards the preparation of monthly central European runoff data over a 30-year period with a grid resolution of 0.5 degree. The approach has also been used in the GEWEX Continental-scale International Project (GCIP) in the Mississippi River basin, the Baltic Sea Experiment (BALTEX 1995), and in the Columbia River Study (Kouwen et al. 1995). Essentially the same methodology has also been pioneered to validate surface-flux measurements in the Boreas Ecosystem-Atmosphere Study (BOREAS, see Sellers et al. 1994).

If hydrological models are driven by observed meteorological parameters, point observations must be interpolated into a high-resolution grid. This procedure is not an easy task in Alpine environment, in particular not for precipitation data. When calibrating hydrological models, interpolation errors may thus lead to distorted model parameters. Results from high resolution meteorological models together with information collected by radar and conventional observing systems during the MAP general observing period (GOP) could help to advance the understanding of the spatial distribution of precipitation in mountainous regions and hence to improve interpolation and calibration procedures for hydrological models.

MAP will therefore provide an ideal opportunity to carry out research on:

- the interpolation of point rainfall measurements in river basins,
- the validation and intercomparison of individual sub-processes (such as evaporation and transpiration),
- the validation of NWP simulated rainfall amounts over selected river basins,
- the overall validation of coupled atmospheric / hydrological models in terms of runoff, and
- the improvement of model components, on the basis of the results obtained from the validation experiments.

The choice of suitable river basins has to be done very carefully. Relevant criteria are:

- Size: it should be compatible with the resolution of the NWP-models in order to include several grid-points. For 15 km grid size the area should be at least 1000 km^2. For special studies, such as for instance on atmosphere-soil interaction or snow cover modelling, the size can be substantially smaller.

- Geology: it should be well defined, so that the control volumes and the respective water fluxes can be modelled with a sufficient degree of accuracy.
- Data: runoff, precipitation and other necessary data should be available for several years for calibration and validation purposes of the hydrological models.
- Anthropogenic influences: no major diversions and reservoirs should be present or data should be available.

2.4 Supporting Objectives

2.4.1 Establishment of a Mesoscale Alpine Climatology

The climate or climatic state of a region is defined as the mean state of the atmosphere which is the average behaviour of the regional-scale land-atmosphere system over relatively long periods (Landsberg 1967). This mean state is described by the statistics of

1. local-scale weather (meteorological parameters),
2. mesoscale weather (Foehn, fronts, etc.) and
3. synoptic-scale weather (‘Grosswetterlagen’ etc.).

A complete regional climatology contains statistics of all three types itself, as well as statistics which describe the link between the different scales, from the local scale up to the synoptic scale. These statistics are derived by aid of methods of synoptic climatology (Barry and Perry 1973; Yarnal 1993).

Early work on Alpine climatology was published more than a century ago (for an overview see Fliri 1975). So far, conventional Alpine climatology – statistics of type 1 – consists of long-term time series of meteorological parameters at single stations and corresponding spatial distributions (e.g. Fliri 1975; Volkert 1985; Frei and Schär 1997). Recent examples of work on statistics of type 2 (e.g. Foehn) can be found in Seibert (1985), and on statistics of type 3 (e.g. synoptic-scale weather pattern, ‘Grosswetterlagen’) in Hess and Brezowsky (1969). Further work deals with the statistical relation between synoptic-scale weather and meteorological parameters measured locally (Fliri 1984; Gerstengarbe et al. 1993, Cacciamani et al. 1995).

Nevertheless, at present a climatology of the Alpine region is far from being complete. Therefore, one MAP objective is to *establish an Alpine climatology* which contains a set of statistics describing the climatic states of the following mesoscale processes and features that are prominent in the Alpine region:

- orographic influence on precipitation,
- convective activity over and in the vicinity of the Alps,
- upper-level features (e.g. potential vorticity anomalies, trans-tropopause exchange),
- low-level thermally and dynamically driven wind systems,
- surface forcing (e.g. surface heat and moisture budget, roughness), and
- orographically induced or modified line structures (e.g. convergence/shear lines, potential vorticity streamers, fronts).

This regional Alpine climatology should contain statistics on the mesoscale atmospheric flow structures and their relation to both, smaller-scale local weather and larger-scale synoptic forcing. The statistics should describe the space-time variability, correlation and scale interacting characteristics of parameters and patterns on all scales relevant for the Alpine atmosphere.

The compilation of such a climatology should seek to optimize the use of existing observational data, beyond that transmitted operationally by WMO through the Global Telecommunication System (GTS). Currently all the Alpine countries operate dense non-GTS climatological networks (e.g. for precipitation). This data has been exploited with respect to the specific questions of the individual countries, but their use for the study of atmospheric processes over the whole of the Alps has suffered from the lack of an international, Alpine-scale database. By combining the various national data sets, a valuable archive of Alpine data could be compiled. Such an undertaking is time-consuming (see Hulme 1994), but is more readily attained within the frame of an international programme. MAP will aid the establishment of fruitful contacts with and between the various data supplying institutions, which in turn would accelerate the administrative procedures. Some effort should also be considered for homogenization of available routine and climatological data collected in various Alpine and close-Alpine countries.

It is also necessary to build up an integrated physiographical data set containing climatological information on soil and surface properties of the entire Alpine region including their daily, seasonal and annual variability. Satellite data (LANDSAT, NOAA etc.) would be very helpful in order to derive terrain height, vegetation and land-use data (Albertz 1991).

Clouds play an important role in the hydrological cycle. At present, the cloud distribution above the Alpine region is not well documented in its climatological variability. Remote sensing methods are a powerful tool for providing a climatology of clouds above the entire Alpine region in their monthly and seasonal variability (cf. Kästner and Kriebel 1994).

Additional effort is required to support the development of regionalization methods, i.e. upscaling and downscaling procedures. Firstly, scaling methods that can to a measure identify mesoscale processes from finer-scale observations would be of great utility (e.g. the regional generalization of very local rain-gauge measurements). At present, there is an obvious lack of methods presenting the point-to-region scale linkage, in particular for precipitation measurements. Secondly, downscaling procedures are required in order to obtain statistics of regional phenomena from long-term synoptic-scale analyses, e.g. the development of convection depending on larger-scale flow types. Finally, it is desirable to obtain a climatology of numerical forecasts of particular mesoscale situations, e.g. events favourable to wave breaking. This latter method should provide climatological information on phenomena which at present are not detectable by routine observational networks.

In summary, the desired set of statistics and the methods to be developed are a valuable contribution to climatology in general. Moreover, such an undertaking describes the present-day state of the climate of the Alpine region, and it is therefore fundamental for the estimate of potential future changes of the Alpine regional climate and their socio-economic impact (e.g. Kane et al. 1992). Moreover, this set of statistics does help the planning of the MAP field phase by supplying information for the selection of the location, timing and duration of the Special Observing Period.

2.4.2 The Alpine Planetary Boundary Layer

The overall aim of this task is to investigate the structure and evolution of the planetary boundary layer (PBL) and its effect on Alpine weather systems.

The usual concept of a PBL comes from ideas developed over flat or homogeneous terrain, in which the layer is considered to be relatively uniform horizontally, but is evolving with time. The effects of turbulence, radiative flux divergence, advective effects, and cloudy convection are addressed in this context with various boundary layer theories (Stull 1988). In areas of complex terrain such as the Alps, further complications to PBL structure and evolution arise because of additional physical processes and special topographic effects (see Blumen 1990). The development of heated or cooled boundary layers on slopes instigates motion up or down the inclination, and in complex terrain it produces interacting slope, valley, and mountain-plain wind circulations. Terrain irregularities and variations in surface cover and ground moisture play a role in modifying the circulations at individual locations, as do mechanically driven circulations produced by interactions between the mountains and the prevailing flow. Because of these complications the Alpine boundary layer is poorly understood quantitatively, and its parametrization in existing numerical models, now based largely on flat terrain concepts, is expected to be a key area where advances in understanding can pay important dividends in improving forecasts of Alpine weather.

The PBL plays an important role in Alpine weather. It supplies the heat and moisture that generate clouds and precipitation (Banta 1990); it affects the development and penetration of the Foehn and other severe windstorms (Hoinkes 1950; Hoinka and Rösler 1987; Richard et al. 1989); it develops inversions that decouple airmasses within the topography from the winds aloft, allowing moisture, clouds, fogs and pollutants to build up within basins and valleys (Petkovsek 1992); and it generates the thermally driven wind systems (cf. Vergeiner and Dreiseitl 1987) that transport and disperse pollutants (ASCOT Investigators 1989; Whiteman 1990).

A research programme which combines field experimentation, numerical modelling, and theory is therefore envisioned to improve our understanding of the structure and evolution of the Alpine boundary layer and its representation in operational forecast models. This research programme will benefit from new research-grade numerical models that are able to treat Alpine topography on a scale heretofore unrealized, and new and improved observational technologies including atmospheric remote sensors (Neff 1990), air motion tracers, and airborne lidars and turbulence instrumentation.

Specific research topics that should be addressed in this topical area include:

- contribution of boundary layer processes to the development of deep cumulus convection and precipitation events over the Alps (see also Section 2.1),
- influence of boundary layer processes on the development and structure of the Foehn and of other regional wind systems such as Bora, Mistral, and Bise that develop on the periphery of the Alps (see also Section 2.2 and Section 2.4.4),
- determination of the spatial and temporal evolution of mass, momentum, heat and moisture fluxes in and above the Alpine topography, and the role of surface cover and soil properties on boundary layer development, and
- development and testing of new parametrizations of the PBL, and different approaches for incorporating more highly resolved topography in numerical models.

These research topics will also be useful in addressing questions relating to thermally-driven wind systems within the Alpine topography (slope, valley, and mountain-plain wind systems), and effects of boundary layer processes on air pollution transport and dispersion within and across the Alpine region. For instance, several Alpine countries suffer from enhanced levels of pollutants during the summer and autumn season (cf. the period of the field campaign).

The research on the boundary layer topics will also benefit from the special observational and modelling resources of the MAP, and from the collaboration of research institutes and operational weather service components from many countries.

2.4.3 Upper-Level Features

The Alpine region hosts a wide range of mesoscale flow phenomena that are essentially confined to the troposphere (see Section 2.1 and Section 2.2). In addition there are systems that are centred at tropopause elevations (e.g. tropopause folds). These upper-level features (ULFs) advect toward the region as deep (~4 km), slender (~200 km) and elongated (~1500 km) intrusions of stratospheric air into the troposphere (cf. Danielsen 1968). Relative to the ambient atmosphere these bands are characterised by high values of potential vorticity and ozone and low values of humidity (Danielsen et al. 1987). Another key factor is that they are associated with, and accompanied by, a flow signal that although it decays with distance downward remains significant (~5-10 ms^{-1}) at low-levels, and thus the bands are an integral and important component of mid-latitude synoptic activity (see for instance Hoskins et al. 1985; Davis and Emanuel 1991). Furthermore they are the seat for significant stratosphere-to-troposphere exchange of atmospheric constituents (Danielsen 1968; Ebel et al. 1991; Hoerling et al. 1993; Lamarque and Hess 1994) and thereby they serve to modify key atmospheric radiative and chemical processes.

The occurrence of these ULFs over central and southern Europe is sufficiently prevalent for the potential vorticity imprint to be discernible in the monthly mean climatology at tropopause-level (Lau et al. 1981). In the Alpine region itself the low-level signal of the incoming ULFs is modified in two ways. Firstly, observational evidence (Appenzeller and Davies 1992) indicates that during their passage toward the Alps the bands often acquire a rich mesoscale structure as they break-up into a train of vortex-like disturbances, and secondly Alpine orography constitutes a potentially major perturbing effect. The bands often accompany the Alpine passage of surface fronts (Davies 1989) and there is considerable evidence linking ULFs to lee-cyclogenesis events (see for instance Bleck and Mattocks 1984; Lanzinger et al. 1990). There are also case study examples (Tafferner, personal communication) and some statistical-climatological information linking ULFs with isolated events of deep convection. There is also some evidence linking ULFs to incidences of anomalous high values of ozone at low elevations (Buzzi et al. 1984, 1985; Davies and Schüpbach 1994).

The general aims of this subprogramme are to obtain a better understanding of the structure and dynamics of the ULFs and to examine their influence upon atmospheric processes and weather systems in the Alpine region (cf. Fig. 2-8). The specific objectives are:

- to *derive* a synoptic-climatology of the ULFs (see also Section 2.4.1),
- to *undertake* a field measurement programme to better ascertain their three-dimensional structure and their modification by orography,
- to *investigate* their relationship to surface weather developments,
- to *perform* model simulation experiments to study their significance for NWP,
- to *examine* their contribution to trans-tropopause exchange.

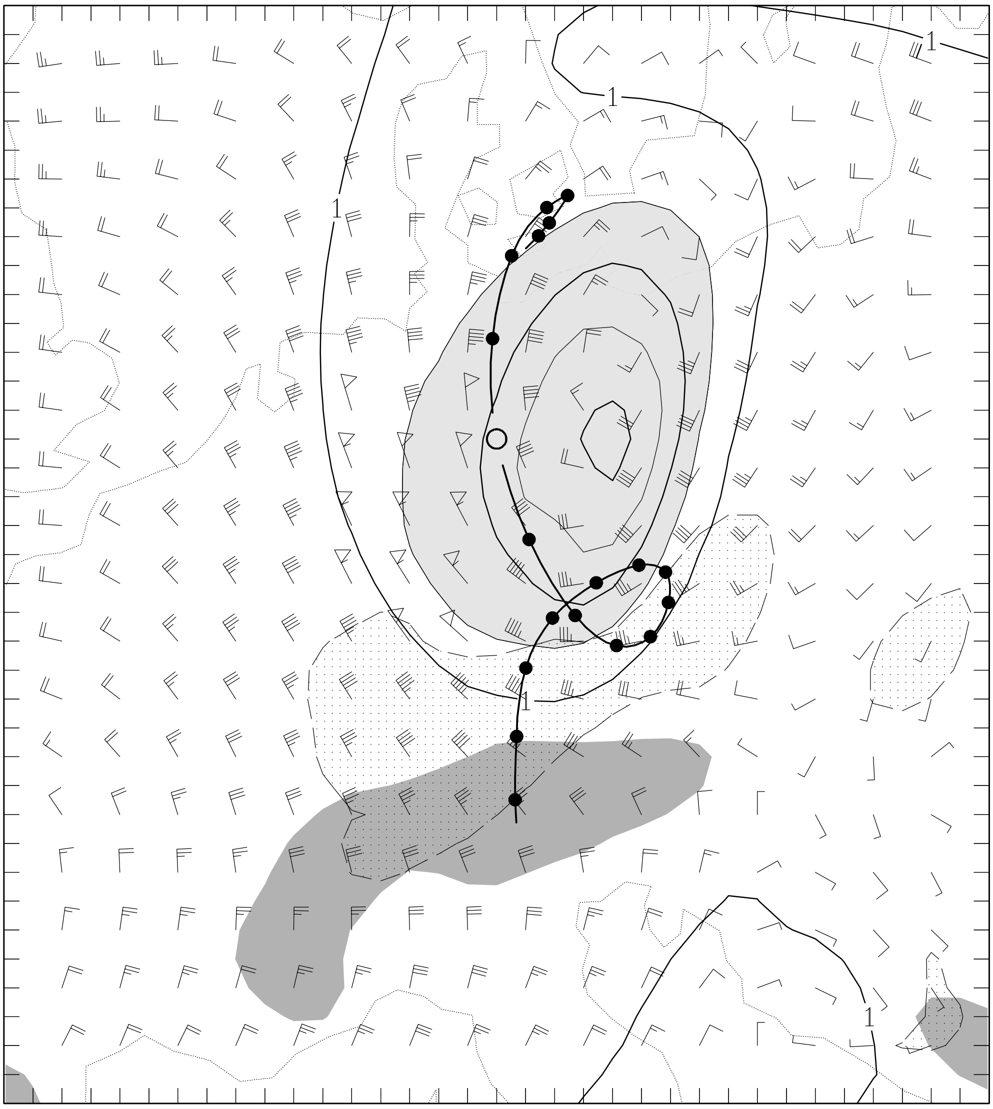


FIGURE 2-8. The figure illustrates the flow situation in the upper troposphere on the 300K isentropic surface at 5 January 1990 12UTC. Shown are simulated fields after 12 hours of forecast using an isentropic coordinate model (horizontal resolution 45km; model design due to Bleck, Mattocks, Han, Tafferner). Potential vorticity ($10^{-6}\,m^2 s^{-1} K kg^{-1}$; solid lines, region above 2pvu light grey), wind (knots; conventional notation), vertical velocity (only values greater than $4\,cm\,s^{-1}$; dotted areas). Regions of orographic heights greater than 1200m are marked dark grey. The thick solid curve is a trajectory calculated kinematically from half-hourly model output. It starts at 5 January 00UTC over Lolland in the Baltic Sea and ends at 6 January 12UTC over the eastern Alps after 36 hours of forecast. Dots mark 2-hourly positions of the parcel. The open circle indicates its position after 12 hours.
As indicated by the wind field the mesoscale PV-maximum features an upper-level cyclone which was advected from the Baltic Sea towards the Alps within 24 hours. The uplift ahead of the PV-maximum (dotted area) caused unexpected snow fall of about 20cm in the Alpine forelands and the Alps. The mesoscale dynamic structure of this PV anomaly could not properly be represented by the operational models at that time (cf. Berliner Wetterkarte of 5 January 1990). The trajectory indicates the fine mesoscale flow structure at upper levels. Note the spiral cyclonic path of the parcel over the Baltic Sea and southern Germany when it circles around the centre of the cyclone. (Courtesy of Tafferner and Eisert)

These objectives are closely tied to, and would serve as a means for testing, the following hypotheses regarding ULFs:

1. their dynamics instigate weather-bearing systems in the Alpine region and / or influence significantly pre-existing systems,
2. their accurate specification in the initial analysis of NWP models is a key factor for successful forecasts,
3. the trans-tropopause exchange accomplished by the bands is modified appreciably in the vicinity of the Alps.

2.4.4 Other Low-Level Wind Systems

In addition to the Foehn, the Alps also induce a number of well known regional winds, such as the Bora (see Smith 1987; Jurcec 1989; Glasnovic and Jurcec 1990; Bajic 1991; Vucetic 1991), the Mistral (see Pettre 1982; Blondin and Bret 1986), the Bise in the Swiss Alpine foreland (cf. Wanner and Furger 1990), as well as an easterly low-level jet over the Po valley (see Tampieri et al. 1984; Buzzi and Alberoni 1992). The occurrence, intensity, and horizontal extension of these wind systems are all related to influence of orography. They merit further study in order to improve their practical forecasting and their representation in numerical models. Also, the total pressure drag of the Alps may be dominated by effects associated with one single regional wind system during certain episodes (Tutis and Ivancan-Picek 1991).

The studies of local wind systems will clearly benefit from a synergy with the primary objectives of MAP, as the basic physical mechanisms leading to their formation are comparable. In turn, these local wind systems contribute to the mesoscale environment, and must often be included in the forecasting of other features such as precipitation, convection and Alpine lee cyclogenesis.

3 Programme Strategy

The Mesoscale Alpine Programme is structured in three phases (see Fig. 3-1). Phase I of the programme is dedicated to modelling activities, theoretical studies, improvement of existing Alpine climatologies, and to the preparation of the field phase. A distinctive feature of the programme is that a number of these activities will continue throughout its duration. Phase II is the field phase referred to as *General Observing Period* (GOP). It is a 13 months period where the MAP Data Centre devotes maximum effort to collect data in near real-time without additional measurements. For most of its duration, it will be primarily based on operational observing systems, but during a 3-month *Special Observing Period* (SOP), dedicated observing systems such as research aircraft and temporarily installed observational platforms will be deployed, and activated during a number of *Intensive Observing Periods* (IOPs). In Phase III of the programme the field phase results will be analysed and used for modelling studies. This scheme assures that

- optimal use is made of existing data sets, and numerical models in the preparation of the observational programme, and
- that expertise and manpower is available for a thorough and careful analysis of the field campaign data set.

In the following subsections further information is provided on the studies and activities to be undertaken in the respective phases of MAP.

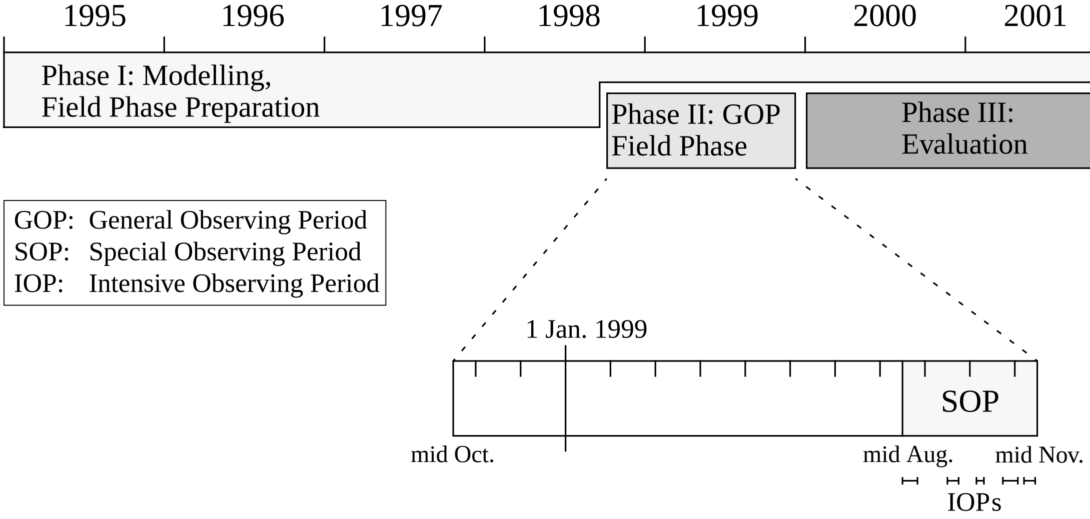


FIGURE 3-1. Timing of the phases of MAP.

3.1 Phase I

3.1.1 Numerical Experimentation

The last decade has seen the development of many high-resolution numerical weather prediction models (see overview in Wergen and Majewski 1993, du Vachat 1994). Presently, at least four centres in Europe provide operational NWP models for the Alpine region resolving the meso-β scale with mesh sizes between 15 and 35 km (i.e. Deutscher Wetterdienst, Météo France, Regional Meteorological Service Bologna and Swiss Meteorological Institute). Moreover research models with even much higher resolutions are now being tested.

The MAP goals for the numerical experimentation during Phase I are the following:

- To serve as an international focal point for all groups working in the field of NWP for the Alpine region;
- to systematically evaluate the predictive skill and the limitations of NWP models in simulating heavy precipitation events and orographically-induced flow systems in the Alpine area;
- to improve mesoscale data assimilation procedures, with particular emphasis on humidity and water variables and to include the utilization of non-GTS data and data from new observing systems (e.g. radar, wind profilers);
- to aid in the design of the field experiment, especially in defining specific areas for high-density observational networks.

To achieve these goals, the following steps are planned:

- Systematic forecast evaluation:

  Evaluate daily forecasts for the period 1994 through 1997 using existing meso-β-scale NWP models for the proposed months of the field phase (i.e. August through November). Special emphasis to be placed on the comparison of predicted lower tropospheric flow and 24 h accumulated precipitation with the available observations. The comparison will be based on plotted forecast maps of precipitation (+6 h up to +30 h) and +12 h (+24 h) mean sea level pressure and 10 m winds.

  Such systematic studies will help to identify model deficiencies and point out specific needs for improvement in the predictive skill of the NWP models in different weather situations. Furthermore they will help to locate the preferred regions of heavy precipitation and of strong low-level flow. As of now, the four forementioned NWP centres have agreed to provide such results.
- ‘Climate-mode’ simulations:

  Run the high-resolution models in a ‘climate’ mode (e.g. for a period of 1 month) driven by observed lateral boundary conditions (e.g. analyses) and compare the predicted mean flow to observed mean conditions (e.g. Giorgi et al. 1990; Cress et al. 1995). The comparison will point out systematic errors of the NWP models which might not be seen in the usual short range forecasts and it will be of value in determining the best locations for measurements.
- Case studies:

  Perform detailed numerical experiments for a number of relevant cases, e.g. the heavy rain events of Brig on 23 September 1993, the Vaison-la-Romaine flash flood (23 September 1992, see Senesi et al. 1994) and Foehn cases like the PYREX SOP 3 case of 15 October 1990 (which is the second case study in the COMPARE project; for PYREX see Bougeault et al. 1993; for COMPARE see Chouinard et al. 1994). These simulations will be run by a variety of mesoscale models having mesh sizes between 500 m and 50 km. The comparisons will include various aspects of the models including the numerical representation of mountains (e.g. terrain-following vs. step-mountain coordinates (Mesinger et al. 1995), mean vs. envelope orography) and the parametrizations of physical processes (e.g. various cumulus parametrization schemes vs. explicitly resolved convection and various implementations of cloud physical parametrizations). Sensitivity studies with respect to initial and boundary conditions as well as the physical parametrizations needs to be conducted in order to evaluate the skill of the models in predicting heavy rain and orographically induced flow systems, like the Foehn. Examination of model output for several Foehn cases will also help in determining optimum positioning of wind profilers and special observing networks.

- Mesoscale data assimilation:

  The current operational data assimilation systems are to a large extent unable to retrieve mesoscale information from the data since the temporal resolution of the analyses (usually 6 h) and the spatial resolution of the OI (optimum interpolation) structure functions are too coarse to capture mesoscale flow structures. Thus at present mesoscale phenomena enter the analyses only via the first guess fields provided by the high-resolution model itself. For a better definition of the initial state several approaches should be tested:

  - increase the temporal resolution of the analysis,
  - use of non-GTS data, and
  - development of procedures capable of continuously inserting data into the model.

- Observing system simulation experiments (OSSEs):

  Experiments of this type can make valuable contributions to the design of the observing networks to be installed for the MAP field phase, e.g. the positioning of wind profilers.

As a prerequisite for high-resolution numerical modelling, a high-resolution (~1 km) physiographical data set including orography, land-sea mask, soil parameters, albedo, and preferably some description of vegetation covering the entire Alpine region need to be available for all groups involved in MAP. MAP seeks to coordinate and facilitate the use of such data for numerical experimentation. As a first step, the participating groups should make available their own high-resolution topographical data sets covering different parts of the Alps. These data can then be combined to derive a unified data set for the whole region to be used by all groups. A data set including topography and land-sea mask at a resolution of 1 km and covering the whole Alpine region exists at the UK Met. Office.

Satellite observations can be used to determine some of the additional external parameter fields (vegetation, snow cover, etc.) required for the specification of the lower boundary condition in numerical models.

The MAP Data Centre (see Section 4) will be responsible for the collection of the data sets and making them available to the MAP community.

3.1.2 Hydrological Modelling

To meet the hydrological requirements of MAP several research groups will have to take up coordinated efforts in model experiments and development. It is suggested to delineate the hydrological parts of the modelling in a first step to the river basins in the southern and central Alps. The participating research groups will apply their models each to particular basins as parts of the whole region.

In order to establish and improve the coupling of hydrological and atmospheric models and to provide hydrological model components for the adequate representation of the land surface and sub-surface water processes the following steps have to be taken in Phase I:

- Collection of spatial data concerning the orography, vegetation and snow cover, soil properties and water table depth in the selected basins must be undertaken.

- Model simulations for selected catchments and periods will be carried out. Thereby, periods of dry weather, flood events, snow cover accumulation and snow melting periods have to be considered.
- Where existing networks are insufficient to validate the simulation experiments, the installation of additional measurement networks shall be initiated for exploitation during Phase II. The collection and exploration of satellite information will also be undertaken as a valuable complement to surface observations.
- In view of successful flood forecasting the assessment of the required temporal and spatial resolution of rain intensities is of particular importance. Model experiments including radar information will provide insight. They allow to explore the sensitivities of the hydrological systems taking into account the various spatial scales in the catchment areas and their specific response characteristics. Statistical information about the structures of the precipitation fields will also be useful in this context.
- The significance of the hydraulic properties of the river basins must be evaluated to determine the duration of flood events.
- The role of landuse, vegetation cover and snow cover needs particular attention with respect to the seasonal variation of these parameters.
- The model experiments will be conducted in a range of spatial scales to show up the variation of model efficiency with spatial resolution. This is a necessary step towards coupling hydrological models to atmospheric models.

The present composition of hydrological research groups contributing to MAP has expertise in distributed catchment modelling of small to large river basins, flood forecasting, modelling of soil, snow-cover and vegetation effects, and experience with various remote sensing techniques.

3.1.3 Climatology

In Phase I of MAP a climatological survey is needed for the detailed planning of the field phase. The survey will aid the definition of location, time and duration of the Special Observing Period. This task requires statistics of the frequency of occurrence, duration and spatial extension of the mesoscale features relevant for the programme, and should provide average values and variability on a monthly base. Typical examples of statistics (e.g. for cold fronts) compiled in advance of a field phase are published by Monk (1986, ‘FRONTS 87’) and Hoinka (1985, ‘German Fronts Experiment 1987’).

Furthermore, statistics of meteorological parameters are required in order to describe the variability, intensity and other important characteristics of the phenomena under consideration. A desirable objective is to identify within the sample of available parameters, those key parameters that play a dominant role in the relevant mesoscale process.

In addition there is a need for statistics that describe the link between different scales, from the small scale up to the synoptic scale. Numerical models can help to supply a climatology of particular mesoscale situations, e.g. events favourable to wave breaking. The resulting statistics can describe the link between the synoptic scale situation and the smaller-scale phenomenon and can be very helpful in guiding the planning of intense measurements during the field phase.This is particularly true for phenomena which are not currently detectable with the routine observational networks. Wave breaking is a striking example of such a flow feature. Numerical simulations (Scinocca and Peltier 1989), observations (Smith 1987) and measurements (Neiman et al. 1988) have demonstrated the importance of wave breaking. Indeed lack of routine observations implies that climatological statistics are required of their temporal and spatial occurrence.

3.1.4 Testing of New Observing Systems

Several mesoscale features such as gravity wave breaking and shear lines elude detection by the conventional observing network. During Phase I, numerical simulations should be used to establish preferred regions in the Alps where these phenomena can be found in order to guide the installation of wind profilers or other remote sensing systems.

For the first time, the inner-Alpine atmosphere will be probed regularly with the new radiosonde station in Innsbruck. Data from wind profilers and the new radiosonde should be evaluated in Phase I to aid in

- verifying numerical models,
- refining hypotheses, and
- devising an observational strategy for the field phase.

The testing of new airborne remote sensing systems over the Alps should be encouraged during Phase I. The results of such tests will be useful in planning the field phase.

3.1.5 Involvement of Operational Forecasters

A working group of operational forecasters of all Alpine countries has been initiated in order to prepare them as specialists of MAP-related subjects. Interaction of MAP research scientists with operational forecasters will be of mutual benefit. It will serve to pinpoint the key forecasting issues, facilitate the introduction of better forecasting methods, and help establish decision trees for the forecasting issues of the field phase. The fruitful way to initiate contacts is the distribution of a questionnaire on specific difficulties of analysis and / or prognosis of Alpine events such as fronts, deep convection, Foehn events (see e.g. Hoinka and Smith 1986). A similar action has been taken by MAP. To maintain contacts and to train a group of motivated forecasters for the field phase activities it is possible to organize regular workshops where case studies of typical MAP events can be investigated and discussed. Those forecasters who develop special links to the project should ideally be freed of other operational duties during the field phase to enable them to focus on MAP-related forecasting tasks and to interact with the research scientists.

3.2 Phase II: Field Phase

3.2.1 Field Experiment: Time, Duration and Location

The MAP field experiment will take place during a 13-month period, (the so-called General Observing Period, GOP) during which the normal station network will be upgraded and mesoscale forecasting efforts will be intensified. This period encompasses an entire annual cycle in which the seasonal variability of Alpine weather systems can be investigated and includes an extra month at the beginning of the period to solve operational problems and assure that all routine data collection systems are fully operational.

Within the GOP, the 3-month period from mid August to mid November is designated as the Special Observing Period (SOP) for which the time and space resolution of the routine observational networks will be enhanced. This 3-month period appears climatologically to be the most suitable for measurements documenting the phenomena related to the primary objectives of the programme, i.e. convection, gravity waves and Foehn. The early part of this period usually has deep convection events over the northern and central Alps, and is followed by a period with typically a number of Foehn events, along with significant convection and upslope precipitation events on the southern side of the Alps (cf. the cases cited in Section 2.1). Specific climatological analyses will be carried out during Phase I of MAP to determine the final dates of the SOP.

Within the SOP a number of Intensive Observing Periods IOPs, say 10 to 15 each of 1 to 3 days duration, will be defined. During these IOPs, whose selection depend on the actual meteorological situation, all available measuring platforms, including research aircraft will be deployed.

Phase I studies will help to define the optimal experimental target areas and to refine suitable observational strategies. It is anticipated that the main study area for precipitation and convection will be located on the southern side and slope of the Alps, whereas gravity wave and Foehn phenomena will be investigated on the northern side of the Alps. For ground-based observing systems fixed target areas on both sides of the Alps as well as a number of Alpine transects are envisaged. The missions of aircraft and mobile ground-based measuring platforms will be designed to complement the fixed installations. Nevertheless, aircraft and mobile stations offer the opportunity to significantly extend the domain of action.

3.2.2 Observational Strategy

For the field experiment MAP aims at an observational strategy that makes optimal use of an efficient and economical combination of operationally-available measurements and a set of special equipment. The complete observing system constitutes in essence a composite system of three components:

- Operationally-available networks and stations form the backbone of the observing system. These networks will be improved somewhat, for instance by increasing the quality of the operational observations, by including additional parameters in the bulletins (e.g. unreduced station pressure at all synoptic stations), by increasing the number of observations (e.g. radio soundings every 6 h instead of 12 h), and by adding supplementary stations to the existing networks (e.g. operating additional aerological stations in the Alps).
- New, continuously operating networks will have to be created, e.g. arrays of microbarographs, automated surface stations (mesonetworks), wind profiling radars.

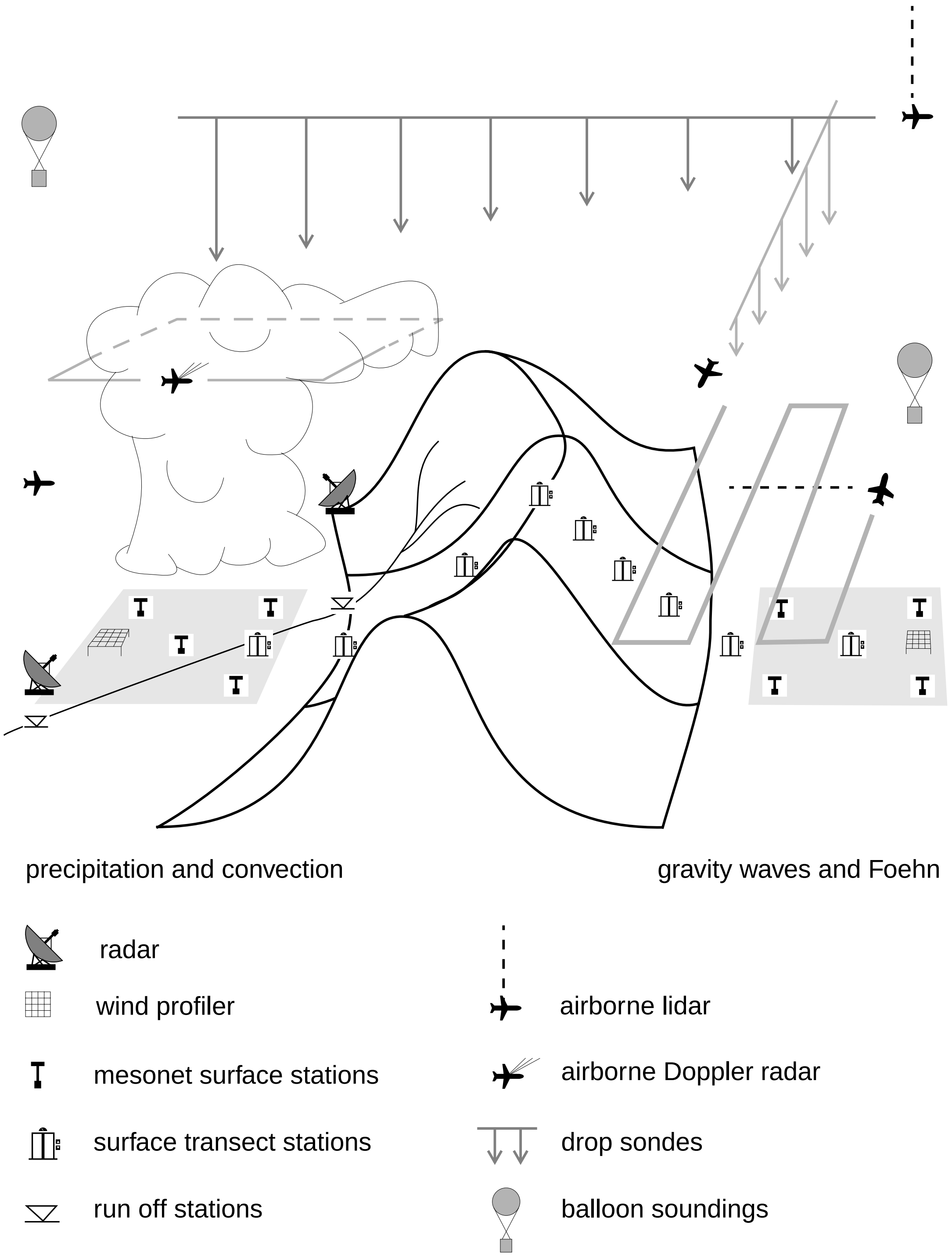


FIGURE 3-2. Schematic view of the composite observing systems during the Special Observing Period (SOP).

- Special observation platforms will be activated in association with the occurrence of particular phenomena. This category of observing systems includes aircraft and all other special equipment (constant level balloons, etc.).

A sketch of this composite observing system is provided in Fig. 3-2 where an imaginary north-south cross-section perpendicular to the Alpine chain is depicted. Convection on the southern side of the Alps is probed by aircraft equipped with Doppler radar (box-pattern flight track), ground-based radar, radiosoundings and light-weight dropsondes. Prior to the major convective event, the low-level meso-β-scale and upstream environment will have been observed by mesonetworks including Doppler sodar, radiosondes, wind profilers and low-flying aircraft. River runoff measurements provide integral and filtered information on the precipitation input into the hydrological catchment.

Lee-side flow characteristics are investigated by aircraft at lower levels (zig-zag pattern), mesonets, wind profilers, Doppler sodars and curtains of light-weight dropsondes released from high-flying aircraft. Gravity waves are observed by ST-radars, aircraft and Doppler lidar mounted on aircraft at upper-level. This is just a rough guide of the major systems and more detailed account is given in the following sections.

The finer details of the observing system depends upon several factors: decisions by the participating nations; competing field projects; funding situations; technological developments; and a refinement of the project requirements. However, already at this point in time it appears reasonable to have a station layout comprising of both several transects and chain-like set-ups parallel to the main Alpine ridge. Carefully selected areas will have to be especially heavily instrumented in order to yield the data necessary for tackling the objectives.

3.2.3 Observational Requirements

A. Mesoscale Environment

In comparison to the other major mountain ranges of the earth, the Alpine area is covered with a relatively dense routine meteorological observational network. Figure 3-3 shows the operational radiosonde and weather radar network. Recently the upper-air network has been complemented by the radiosonde station at Innsbruck.

Nevertheless, the present density of these networks is far from adequate to describe the meso-β-scale environment above and around the Alps (in contrast to the operational meso-β-scale numerical weather prediction models!). For this purpose substantial temporary enhancements of the upper-air network will have to be realized during the field phase. As an example of such an exercise the set-up of a forerunner field experiment ‘MiniMAP’ is shown (see detail in Fig. 3-3, Richner 1994). All supplementary upper-air observations will be fed into the GTS in order to enable their utilization in real-time numerical modelling, in particular in the assimilation cycle of ECMWF.

In addition, there exists a dense network of automatic surface stations reporting a rich set of meteorological parameters at 10 minute intervals (Fig. 3-4).

B. Orographically Influenced Precipitation

Precipitation measured operationally by surface rain gauges is the meteorological quantity which is observed with the highest spatial resolution in the Alpine area (Fig. 3-7). However, the high-resolution measurements are only available as daily precipitation sums. Furthermore, these observations are usually not readily accessible be-

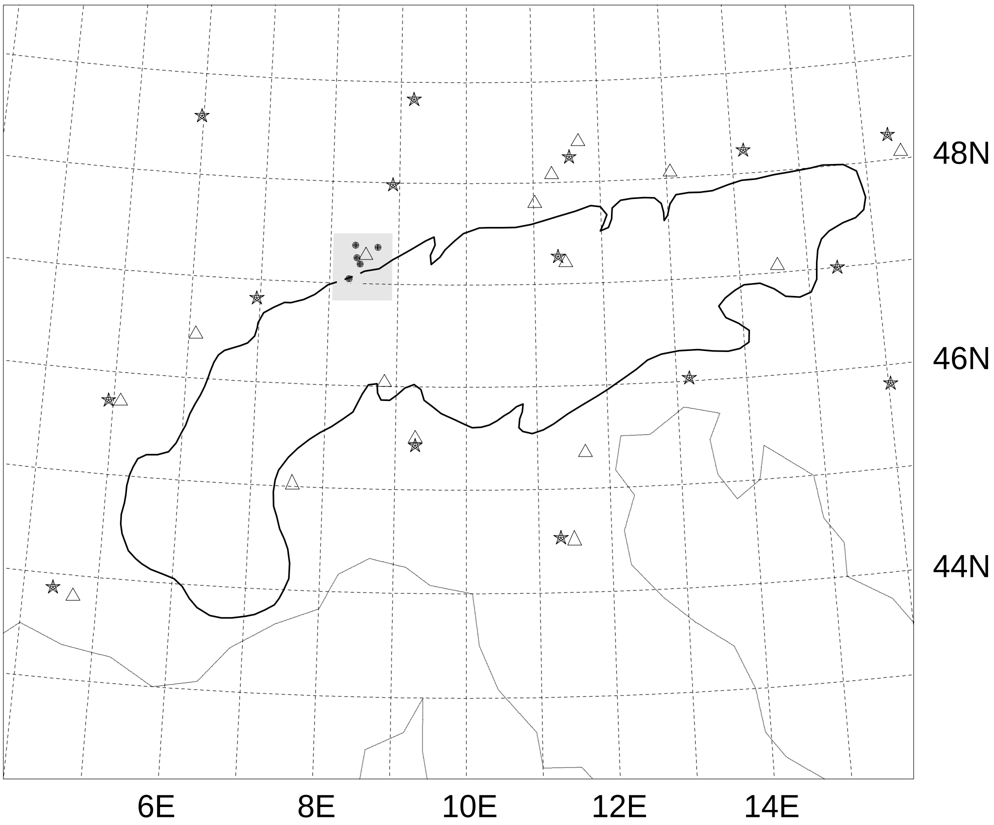


FIGURE 3-3. Networks of radiosonde (stars) and weather radar stations (open triangles) in the Alpine region. The shaded area depicts the mesoscale array of sounding stations (filled circles) operated during MiniMAP (Richner 1994).

yond the boundaries of the individual Alpine countries or even provinces, and certainly not in real time. In addition to the surface rain gauge network there also exists a number of ground-based weather radar stations (some of them with Doppler capabilities). However they do not constitute a real network, because the data exchange and integration has yet to be fully realized.

Modern operational mesoscale numerical prediction models with a horizontal resolution on the order of 10 km call for a comparable spacing of observations for verification purposes (Binder 1992). Furthermore, process studies of orographic precipitation enhancement need observational data on a similar or even more refined scale. Adequate temporal resolution is on the order of an hour to a few hours.

For the field phase (GOP) it is essential to integrate the existing precipitation observing networks, gauges and weather radar, that include numerous non-GTS surface stations. Recognizing the inability of covering the entire Alpine region with a surface network of the required resolution, it is necessary to select target areas for the installation of mesonets. For the investigation of extreme gradients of orographically influenced precipitation (altitude dependency, shielding effects) it is appropriate to establish a small number of densely instrumented Alpine transects. Radar complements the high-quality surface point measurements from rain gauges by providing area-covering observations with high spatial and temporal resolution. However use of radar data requires consideration of shielding by orography, ground clutter effects as well as the height-dependency of the radar reflectivity profile (Joss and Waldvogel 1990; Joss and Pittini 1991).

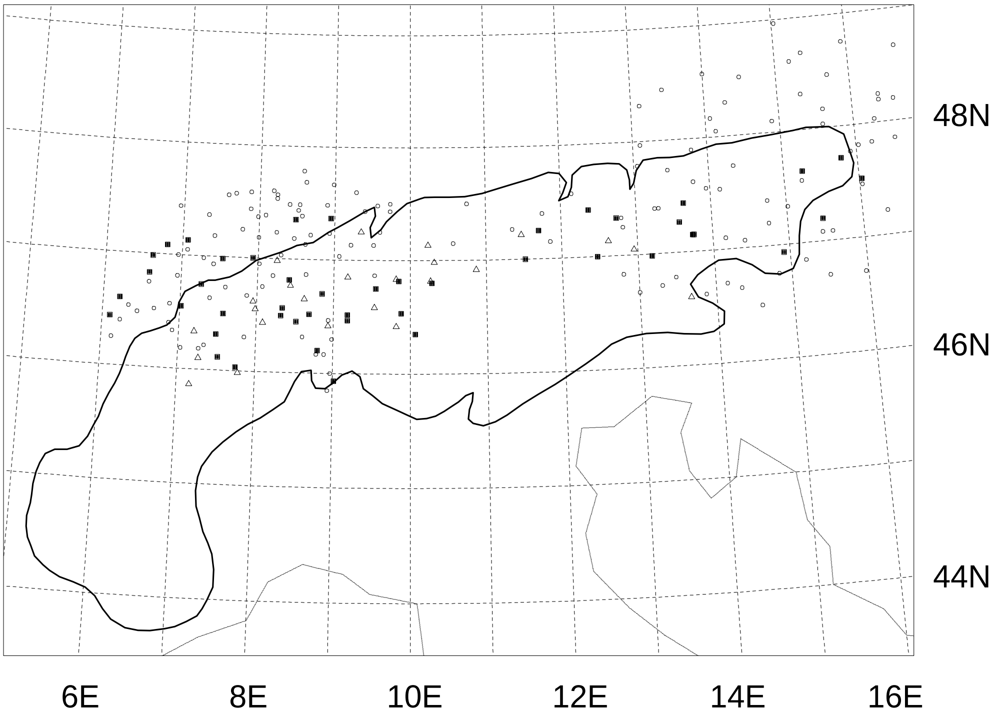


FIGURE 3-4. Network of automatic surface stations in Austria and Switzerland. Other Alpine countries also operate automatic surface networks. Open circle: station height below 1000 m; filled quadrangle: station height between 1000 m and 2000 m; open triangle: station height above 2000 m.

C. SOP Observing Systems for Objective 1 (Convection)

The MAP proposes to investigate several aspects related to convection and these pose different observational requirements. The bulk effect of convection involves a transition from the pre- to the post-convective atmospheric state (vertical thermodynamic, humidity and wind profiles). There are indications that these atmospheric characteristics depend to some extent on environmental conditions such as the surface texture and state, latitude and the terrain geometry (e.g. Binder 1990). Determination of the atmospheric state can be achieved by radiosonde ascents, dropsondes and wind profilers.

A careful description of the planetary boundary layer prior to convective activity is needed to contribute to the identification of the trigger mechanisms for convection. Better knowledge of these mechanisms would help to improve their description in numerical prediction models. At present the representation of the initiation of convection originating in the boundary layer is quite crudely and schematically described, although model predictions prove to be sensitive to these processes (Kain and Fritsch 1991). To this end, surface mesonets, clear-air measurements with Doppler radar and wind profilers, arrays of Doppler sodar and low-level research flights can all yield useful observational data. With the exception of low-flying aircraft these facilities are also appropriate for observing the progression of gust fronts and downdraft outflows of convective systems.

Valuable information on the development and propagation of convective systems is provided by Doppler radar devices. The airborne instrument ELDORA is a particularly notable observation system. Remote sensing techniques, both airborne and ground-

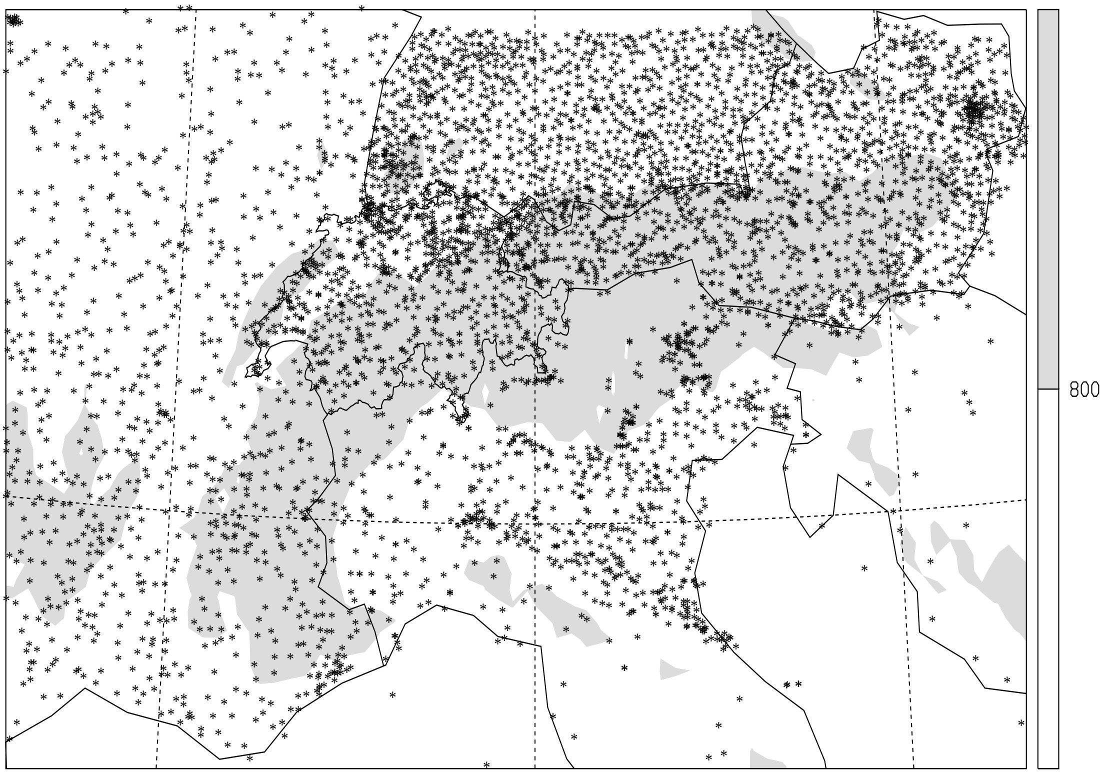


FIGURE 3-5. Rain gauge network in the Alpine region. Dots indicate locations of stations with regular reports of daily precipitation. The display currently comprises a total of about 5000 observing stations from various national institutions. Contacts to additional institutions are underway to further improve the data coverage. The topography is shown at an altitude of 800 m. The precipitation data will become available to MAP scientists for selected periods through the MAP data center. (Courtesy of Christoph Frei, Atmospheric Science ETH)

based, can contribute to the determination of the heat, moisture and momentum budgets of convective systems as well as to the detection of convective-scale structures, e.g. low-level convergence, high-level divergence, up- and downdrafts, and mesocyclones associated with supercell storms.

In-situ measurements by research aircraft are required to elucidate the microphysical and electrical processes associated with convective clouds. The armoured T28 aircraft of the South Dakota School of Mines and Technology operated in Switzerland in 1982 / 83 (Waldvogel et al. 1987), and its use enables the acquisition of in-situ measurements even in the core of deep convective clouds.

For studies of deep convection there is a need to explore the potential of combined measuring systems early on in the preparatory phase of MAP. Examples of field programmes of deep convection include the CLEOPATRA experiment (carried out in southern Germany in summer 1992, Meischner et al. 1993) and the SETEX experiment (initiated in 1994 in southern Germany and northern Switzerland). Both programmes led to a close cooperation of German and Swiss scientists (Haase-Straub et al. 1994). These and similar field experiments can be viewed as preparatory activities for the intense observing periods of MAP.

D. SOP Observing Systems for Objective 2 (Gravity Waves and Foehn)

To observe the characteristics of Foehn flow in vertical cross-sections, upper-level aircraft traverses will be utilized. The aircraft should be equipped with a light-weight dropsonde system in order to construct sections from dropsonde curtains. Also an upward pointing lidar device will be of particular value in detecting patches of gravity wave breaking above flight levels. Across- and along-barrier flight tracks at different heights are needed to describe the three-dimensional structure of these phenomena (Fig. 3-6).

To observe the characteristics of Foehn flow at lower levels and its interaction with the planetary boundary layer, suitable instrumentation are wind profilers (1000 MHz; 400 MHz), preferably equipped with radio acoustic sounding systems (RASS), and Doppler sodar instruments. In addition, a cross-Alpine transect of surface stations, including microbarographs, has to be established. Experience from earlier projects (cf. Davies and Phillips 1985; Richner 1987; Bessemoulin et al. 1993) will facilitate the design of such a network.

The three-dimensional structure of the lower-level wake-flow (shear lines, convergence lines, turbulence characteristics) can be probed by zig-zag research aircraft patterns, much like the strategy followed in the wake-subprogramme of the Hawaiian Rainband Project (Smith and Grubisic 1993). In addition to in situ registered quantities, remote sensing techniques like sideward pointing lidar devices open new perspectives.

Upstream and downstream conditions of cross-barrier flow are to be sampled by an enhanced network of radiosonde stations, as described in sub-section *A* above.

E. Other Observing Systems

In addition to the observing systems immediately related to the main objectives of MAP, it is planned to install further systems that will be deployed by individual participating groups. In this section a list is provided of such possibilities.

Research aircraft can measure profiles of mean and turbulent fluxes of mass, momentum, and heat above the Alpine topography and thereby support observational and modelling studies of the evolving Alpine boundary layer. Aircraft with differential Global Positioning System (GPS) capabilities are now thought to provide suitable positioning accuracy to make direct measurements of the horizontal pressure gradients that are responsible for driving synoptic and inner-Alpine wind systems, including even the thermally-driven wind systems.

Lidar-equipped aircraft could be used to support the evaluation of hypotheses regarding the vertical transport and diffusion of aerosols, water vapour and ozone in the Alpine atmosphere. Hypotheses regarding the transport and diffusion of air pollutants within and across the Alpine chain can be evaluated also using regional and local scale air motion tracers (perfluorocarbons and sulfurhexafluoride).

Other networks of instruments can be helpful in meeting the objectives of the planetary boundary layer task including Doppler sodar networks, radar profiler / RASS networks within and surrounding the Alps, mesonets, surface flux stations, slope profiles, and tethered, pilot, and manned balloon sounding systems.

Frequent (3 h), narrowly spaced (~50 km) ground-released radiosonde ascents and dropsonde curtains from aircraft as well as aircraft flying at about tropopause height level are best suited for observing upper-level features.

For the study of additional low level features such as Bora, Mistral, etc., the special equipment of different research institutions should be combined in order to meet the high space-time density required for detailed observation. Appropriate observing means

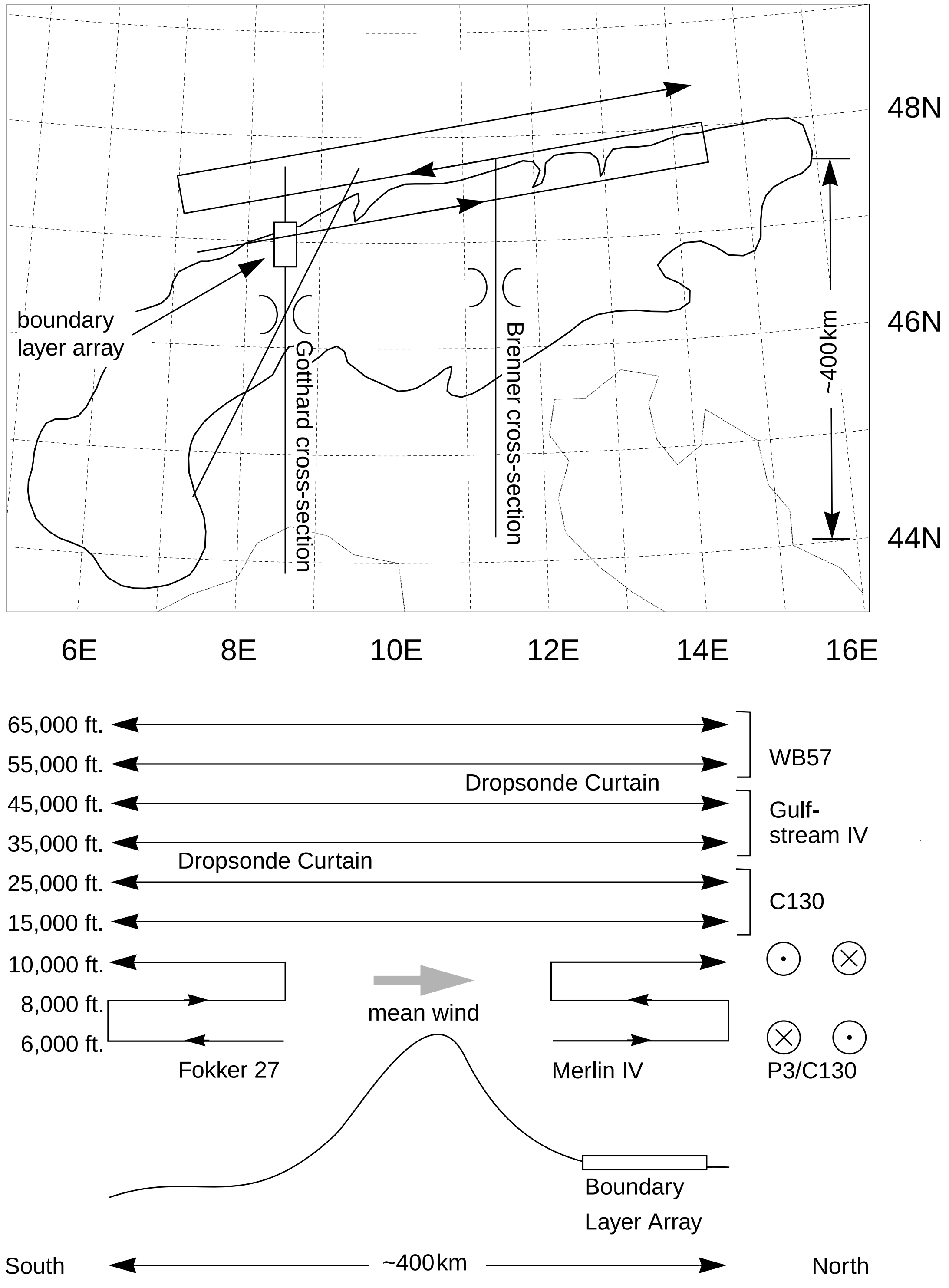


FIGURE 3-6. Schematic of tentative cross-Alpine and along-barrier multi-level flight tracks serving i) the study of Foehn, gravity waves (including wave breaking) and boundary layer processes, and ii) the study of the lower-level wake-flow features. Top: Plan view. Note that cross-barrier flight tracks can be rotated in azimuth and shifted in east-west direction to best match wind fields. Bottom: Vertical cross-sections of flight tracks indicated in the top panel. The displayed aircraft and flight level assignments are merely indicative rather than definitive (cf. Table 3-2).

comprise surface mesonetworks, minisondes, pilot balloons, tethered balloons, constant level balloons, sodars, boundary-layer wind profilers, etc.

F. Targeted Major Observing Systems

The following tables, one for ground-based and aerological systems (Table 3-1) and one for aircraft (Table 3-2), summarize the key-observing systems for the SOP of MAP. These tables do not list operational devices and are not complete in the sense that all systems which will be deployed during the field phase are listed. Emphasis is placed on sophisticated systems with special capabilities of non-operational nature which are particularly suited and desirable for the purposes of MAP. During the ongoing planning process specifications will be formulated in more detail.

Observing System	Δt	Δx	Δz	remarks
mesonets	10 min	10 km	–	target areas; transects
microbarographs	10 min	10 km	–	abs. pressure: 0.3 hPa
Doppler sodar	1 min	10 km	10 m to 40 m	typical height range: 500 m
Doppler radar	10 min	–	1 km	
Doppler lidar	30 min	–	–	horizontal and vertical range very dependent on atmospheric conditions, up to 20 km
wind profiler / RASS				height range of profiler (associated RASS)
VHF (50 MHz)	10 min	–	375 m	3 km to 30 km (7 km)
low UHF (400 MHz)	10 min	–	150 m	1 km to 16 km (3 km)
UHF (1200 MHz)	1 min	–	75 m	150 m to 4 km (1 km)
additional radiosondes	3 h	50 km	50 m	some mobile
light-weight dropsondes	curtains	25 km	50 m	see aircraft

TABLE 3-1. Potential ground-based and aerological systems.

G. Observing Systems for Hydrology

Data sets used in hydrological modelling are precipitation, meteorological parameters such as 10 m wind, surface and 2 m temperature, dew point temperature, snow cover, runoff, evapotranspiration, soil water content and ground water levels. Precipitation, meteorological parameters and snow cover are observed by the dense network of the meteorological surface stations (Fig. 3-4) and by the rain gauge network (Fig. 3-5). The discharge in diversions and the volume of water stored in the major reservoirs must also be monitored.

For hydrological purposes, areal precipitation has to be calculated with suitable methods from point measurements. As an example, Cemagref in Lyon is ready to supply precipitation fields for single events based on rainfall measured on the ground. This information would be provided with a high spatio-temporal resolution for the northern part of the Alps: The one dimensional network from Lyon to the Belledonne massif in the French Alps, called the "TPG" (Transect of Pluviographs for analysis and modelling

Aircraft	Agency	Endurance / Range	Ceiling	Special Instruments
A. High Altitude (above 10000 m)				
Falcon-20	DLR	3h / 2000km	12000m	lidar (DIAL); Doppler lidar$^{\#}$ light-weight dropsondes$^{\#}$ aerosol and droplet spectrometers
Gulfstream IV	NOAA	9h / 7500km	13500m	light-weight dropsondes Doppler radar
WB57	NCAR	7h / 5000km	20000m	light-weight dropsondes; lidar; atmos. chemistry
B. Medium Altitude (5000 m - 10000 m)				
C130	NCAR	10h / 5500 km	9000m	light-weight dropsondes; Doppler radar (ELDORA); lidar; atmos. chemistry
C130	UKMO	10h / 5500km	10000m	light-weight dropsondes; microphysics
P3	NOAA	10h / 55000km	7500m	light-weight dropsondes; Doppler radar
Merlin IV	Météo France	4h	8000m	microphysics; turbulence
Fokker 27 ARAT	CNES, MF, CNRS, IGN	3h	7000m	microphysics; turbulence; lidar
Dornier-228	DLR	8h / 2600km	8000m	atmos. chemistry (trace gases) droplet spectrometer$^{\#}$
C. Low Altitude (below 5000 m)				
Stemme S10	MetAir	8h / 1500km	5000m	differential GPS for mesoscale pressure field; atm. chemistry incl. NMHC

TABLE 3-2. Targeted research aircraft. All aircraft will have basic research instrumentation, such as state parameters etc. „Special“ instruments refers to unique equipment of interest to MAP. Systems marked by $^{\#}$ are still under development.

of rainfall Gradients), exists since 1987 and consists in three important assembly lines crossing the mountain ranges with increasing elevations: 1000 m, 2000 m and 3000 m (Desurosne et al. 1994). The network density is about one gauge per 2.3 km^2.

For the estimation of areal precipitation in hydrological basins the network of weather radar will be an important complement to the traditional rain gauge network (Joss and Waldvogel 1990). In particular in high Alpine regions, where the ground based rain gauge network is less dense, radar provides improved resolution of rainfall measurements both in space and time. Radar data will help for the better understanding of the variability of the precipitation-elevation gradients in a mountainous environment

Evaporation is either measured by agrometeorological stations in class-A-pans, or by other instruments that give not the real evaporation data but rather some kind of evap-

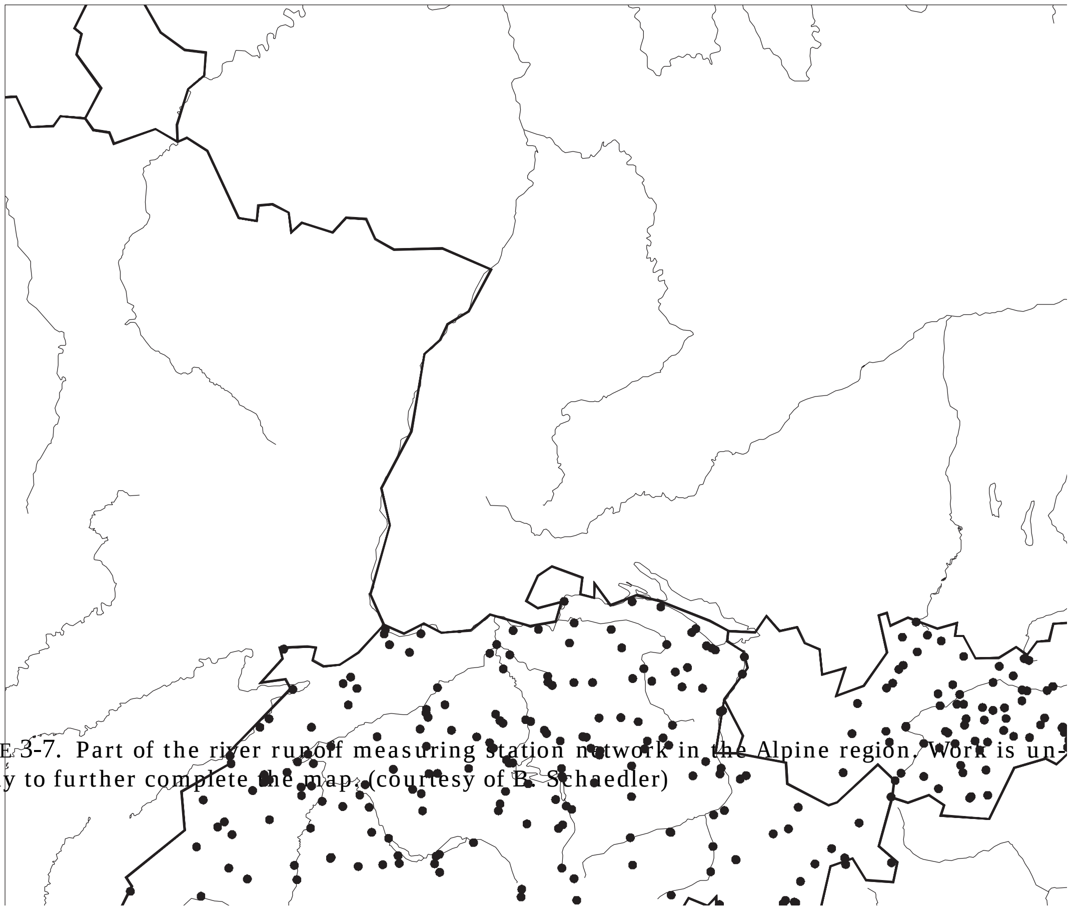


FIGURE 3-7. Part of the river runoff measuring station network in the Alpine region. Work is underway to further complete the map. (courtesy of B. Schaedler)

oration index. Reliable evapotranspiration measurements are available from weighing lysimeters. Only a few instruments are in operational use, by some agrometeorological stations or in research projects (Arbeitsgruppe Lysimeter 1989). To observe soil water content suitable instruments are weighing lysimeters, Time-Domain-Reflectometry (TDR) instruments or neutron probes. These point measurements are frequently not very representative - especially in an alpine environment - due to the high variability of soil types and vegetation cover.

Snow cover, which is important not only for hydrological purposes but also for energy balance considerations, is observed by different networks. Snow depth is usually observed daily, snow water equivalent is measured periodically by hand or monitored by automatic equipment. In addition, snow cover extension may be monitored by remote sensing techniques (Baumgartner and Rango 1991).

Runoff is measured by dense networks (Fig. 3-7) operated by different state hydrological services as well as by private companies (e.g. hydropower companies) and sometimes also by research institutes. Basin size varies between some hectares and several thousand square-kilometres. The stations are spread all over the Alps and can be found at very different altitudes. The time resolution of these data records is usually very high (some minutes). Unfortunately many of these runoff observations are distorted by anthropogenic effects: Diversions of water from one basin into another, artificial reservoirs (dams), drinking water supply etc. Therefore suitable basins have to be carefully selected.

International networks and data bases have been established in the framework of the International Hydrological Programme (IHP) of UNESCO: One is AMHY the "Alpine Mediterranean HYdrology" programme (Lama 1994), a subproject of the project FRIEND the "Flow Regimes from International Experimental and Network Data" (Roald et al. 1994). Another programme is ERB, the "Euromediterranean network of experimental and Representative Basins" (Barbet 1993).

In France discharge information is available from some small adjacent basins (ten or so) to the "TPG"-region and from fitted-together watersheds (about five) of the Guiers river (north- western part of the Isère department). This information together with the rainfall information is suitable to be taken into account in rainfall / runoff modelling.

Other important data for hydrological purposes are parameters describing basin characteristics such as topographic, morphologic, geologic, pedologic and land-use parameters. Such data can be found or assembled in Geographic Information Systems (GIS). Parameters for the ERB-basins can be found in the ICARE-database, the "Inventory of the CAtchments for Research in Europe" (Barbet et al. 1995). For the Swiss research basins they are published in Aschwanden (1996) and HADES (1992).

3.3 Phase III: Evaluation

After the concerted observational effort of the field phase two major tasks need to be tackled as an integral part of MAP: Field data have to be assembled and analysed and the scientific hypotheses set up in Phase I need to be tested.

As outlined in Section 3.2 observational data from the field phase will originate from a variety of measuring platforms. Individual data sets may need completion, calibration and correction. Intercomparison and intercalibration studies (e.g. Richner 1985, for aircraft data) will be necessary in order to ensure and to increase the quality and consistency of the overall MAP field phase data. The creation of reference data sets, cf. the ALPEX level-IIB and ALPEX level-IIIB data sets in the past, will greatly increase the value of the data collected for subsequent studies.

Experience from ALPEX has shown that re-examination and analysis of observational data can be a tedious and long-lasting process. For instance, a documentation of errors for ALPEX level-IIB SYNOP and radiosonde data was not published until 5 years after the field experiment (Steinacker et al. 1987). The generation of the ALPEX level-IIIB data set is still in progress (Paul 1994). Thus, learning from this experience, it seems necessary that such initiatives form an integral part of MAP.

Ultimately, field observations will serve to meet the scientific objectives of MAP:

It is planned to make observational data available in real time. Such an effort will enable real-time evaluation of the collected data in the data assimilation cycle of ECMWF, and other prediction centres. It will be of special interest to monitor the impact of the extra data on the forecast quality.

The unique density and variety of measurements will render feasible the testing and improvement of objective mesoscale analysis techniques (in particular on the meso-β scale). The influence can be investigated of the individual kinds of data on the specification of the initial conditions for high-resolution numerical prediction models. Results from such studies will feedback on the design and equipment of future observing networks.

The assembled – and analysed – field data will be of particular value for case studies. They will help in the assessment of the quality of model forecasts in intercomparison studies and contribute to ascertaining the most effective version of an individual model. It is already proposed to include a future MAP case (or cases) in the catalogue of events to be studied within the frame of the COMPARE project (COMPARE Newsletter No. 6, 1995). Forecast verification is most important in view of further improvement of high-resolution numerical weather prediction models. It is well recognized, that present day observing networks do not meet the requirements of a serious verification on the meso-β scale in several respects. The MAP data set will improve this situation considerably.

The MAP data set, unique with respect to spatial and temporal resolution and to the selection of observed parameters, will help also in the validation of individual model components such as the parameterization schemes for cloud physics, convection and turbulence. Thus, new developments can be expected from the insights gained by consideration of the observations. Such considerations will relate to numerical, theoretical and conceptual studies.

Experience in utilizing field data to test the scientific hypotheses and to validate numerical models will help to improve the quality of the final data set. Data post-processing efforts and scientific investigation will benefit optimally, if they are closely tied together in Phase III.

The strength of MAP is that both scientific issues and practical applications will benefit. The MAP data set will be made available to interested institutions beyond those directly involved in the programme to enable a broad use of the data. It is believed, that a careful preparation of the data base will guarantee that the MAP data set becomes a long-term reference for studies in mountain meteorology.

4 Data Management

All data gathered in or used by MAP will be stored and made available by the MAP Data Centre (MDC). The MDC is responsible to the MAP Programme Office, and is physically located at ETH Zurich. Access is through the Internet at address

http://www.map.ethz.ch.

Build-up of the MDC has started in 1995. It is funded by financial contributions of the European Weather Services through an official EUMETNET project, that grants funding until the end of 1999. In the meantime, the MDC has become operational, both on a technical and administrative level. Registration to users is open since 1 August 1996. At the time of this writing, a wide range of data is already available. Further data will be included as it becomes available from the numerous data providers.

Access to data stored at the MDC is regulated by the MAP Data Access Policy (see Schär and Binder 1996). The Intergovernmental Panel of MAP and all major data providers have approved the MAP Data Access Policy on 22 May 1996. Access to the MDC is open to all scientists upon registration, regardless of whether they are project participants or not. The registration procedure requires to sign a brief statement that specifies the conditions under which the data may be accessed and used. This simple procedure applies for all the field phase and case study data. For a few other data categories (such as long-term climatological series), additional conditions are implied by the providing agencies.

4.1 Tasks

The tasks of the MDC are primarily to

- collect and make available:
  existing data sets
  operational data
  special data
  supporting data
  field phase data
  ‘secondary’ data
  data catalogues
- operate a bulletin board
- compile a data catalogue
- issue a Data User’s Manual
- document data
- quality control data

Existing data sets are required for climatological studies and analyses. *Operational data* relates to GTS-type data whose collection should start at a very early stage of the programme. *Special data* refers to data either measured or produced in special pre-field experiment activities in so-called warm-up activities. *Supporting data* includes physiographical data, digital maps, address lists, bibliographies, etc. As its name suggests, *field phase data* are data collected in the field experiment. *Secondary data*, finally, refers to results of simulations, model output, etc.

The location of and access to data which is relevant for MAP, but is already stored elsewhere (e.g. in the InfoClima system) is facilitated by including the respective *data catalogues* in the MDC.

An electronic *bulletin board* provides the latest information on the status of observing systems, experimental activities, and other news of interest to the MAP community.

The MDC is responsible for the compilation and continuous updating of a *data catalogue*, listing the information available from MDC, and providing instructions on how to retrieve data in a *Data User's Manual*.

It is the MDC's responsibility to ensure that poorly or only partly documented data sets are properly described. This must be done in co-operation with the data producer or, in simple cases, by the MDC alone.

Data arriving at the MDC must be *formally quality controlled* by the MDC. Depending on the available manpower, the MDC might also run quality control programmes. However, quality control is basically in the responsibility of the data producer. Additional independent projects related to data quality control are encouraged.

4.2 Archiving Philosophy

The MDC will have a modular structure: A Central MAP Data Bank (CMDB) to which all requests for data are made, is connected with a number of Special MAP Data Banks (SMDB). Each data bank has its own Data Bank Manager(s) who is (are) responsible for the tasks listed in Section 4.1 (of course, this applies only with respect to the data archived in the data bank in question).

Data are to be submitted to the data banks in form of sequential files. Archiving of the data is either *file structured* or for certain data categories in *relational data bases*. The transfer of the data submitted as sequential files into the relational data base is the responsibility of the data bank manager. While relational data bases are very user friendly, not all data types are suitable for archiving in this way. In addition, the transfer is quite demanding on manpower. Consequently, the extent to which relational data bases will be established, will depend on feasibility and available resources.

4.3 Security

Access to the CMDB and later on to any SMDB is only possible through a *Guard and Logging Facility*. Here all data traffic is monitored, users may be identified, passwords may be requested, etc. Two main security problems exist:

1. Data retrieval by unauthorised persons must be prevented. The distribution of some data is subject to restrictions by the data supplying institution. Field campaign and case study data is available to all scientists upon registration.
2. It is fully recognized that data produced by weather services have a substantial commercial value. Hence if such data are used in studies other than pure research, it is mandatory that this use (and payment) be ratified by the appropriate agency.

4.4 Network

The different data banks making up the MDC will be connected via Internet. Efficient and user friendly transfer protocols are used. However, it should be born in mind that on many Internet connections traffic is quite heavy. For the transfer of data files larger than, say, 10Mbytes, line capacity will most likely be a problem. Consequently, the exchange of large amounts of data (e.g. radar and satellite images), is realized by alternate means such as compact disks.

4.5 Data Format

In order to allow data in BUFR and GRIB format to be included in the data banks, binary as well as text formats are supported. For a given data type (e.g. aircraft data, profiler data, surface data, etc.) as few different formats as possible are used, formats allowing for quality flags are preferred. Apart from transferring file-structured data to a relational data base, it is *not* the responsibility of the data bank managers to re-code data to a different format!

4.6 Personnel

The Central MAP Data Bank Manager carries the responsibility for the operation of the MDC as a whole. The manager is not connected with a specific MAP research programme but is funded from central services through EUMETNET. The Special MAP Data Bank Managers will, as a rule, be experts involved in and funded via the particular project that gathers the data in question (e.g. aircraft and radar data, etc.).

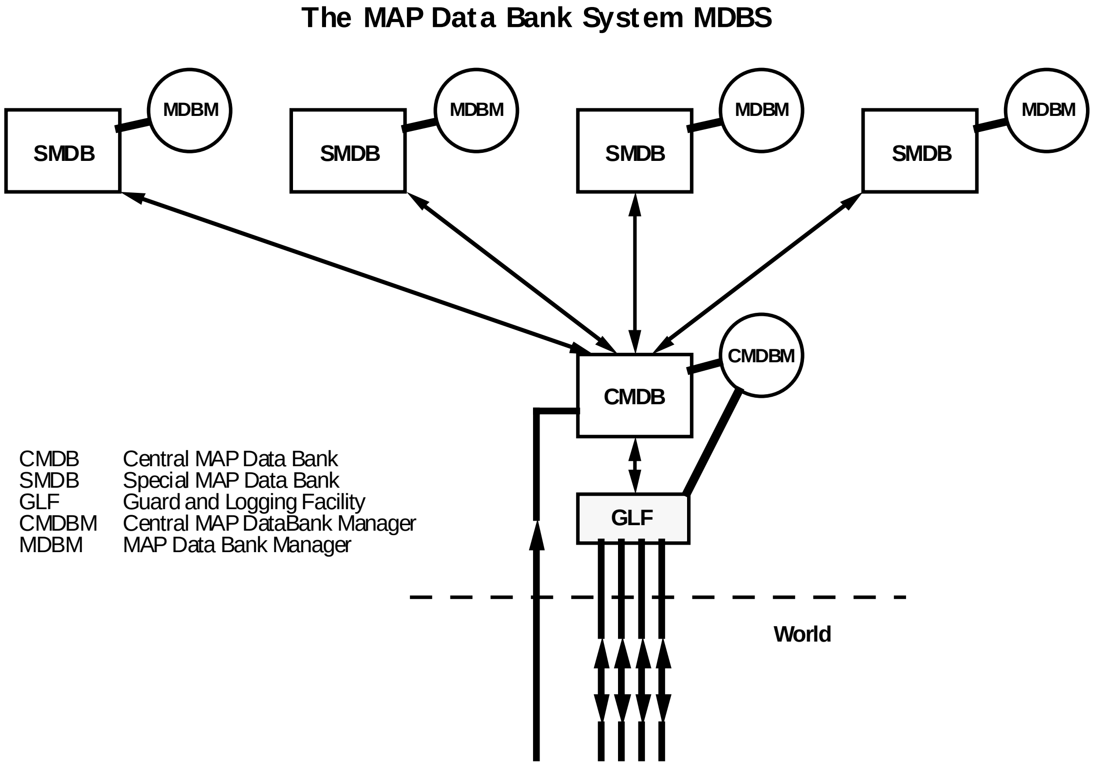


FIGURE 4-1. Structure of the MAP Data Centre.

5 Organization and Overall Schedule

5.1 Organizational Structure of MAP

The organizational structure of MAP comprises three official bodies whose duties are specified in their respective terms of reference:

A. The *International Governing Panel (IGP*)
B. The *Scientific Steering Committee (SSC)*
C. The *Coordination and Implementation Group (CIG)*

In addition a Programme Office (PO) is created to serve as focal point for the MAP activities. The MAP Data Centre, an essential component of the programme, is described in Section 4.

A. International Governing Panel

The IGP consists of representatives of the national meteorological services and of the science funding agencies. The IGP carries the final responsibility for the implementation of the overall Mesoscale Alpine Programme. It approves the recommendation on the structure and implementation of MAP, particularly with respect to the necessary financial and technical support.

Dr. Philippe Bougeault, Météo France CNRM, Toulouse, F
Dr. Daniel Cadet, CNRS - INSU, Paris, F
Dr. Frederic Delsol, WMO AREP, Genève, CH
Dr. Thomas Gutermann, Swiss Meteorological Institute, Zurich, CH *(chairman)*
Dr. Joachim P. Kuettner, NCAR, Boulder, USA
Prof. Gianpiero Maracchi, University of Florence, Firenze, I
Dr. Fedor Mesinger, NOAA Science Centre, Camp Springs, USA
Prof. Eberhard Müller, Deutscher Wetterdienst, Offenbach, D
Dr. Roberto Sorani, Servizio Meteorologico dell' Aeronautica, Roma, I *(vice-chairman)*
Prof. Peter Steinhauser, Zentralanstalt für Meteorologie und Geodynamik, Wien, A
Dr. John M. Stone, Environnement Canada, Dorval, CAN

B. Scientific Steering Committee

The SSC consists of leading atmospheric scientists and technologists. It is responsible for the formulation of well defined objectives and of a coherent scientific programme for MAP. The SSC will ensure the scientific integrity and coherency of the scientific objectives of MAP.

The following individuals have agreed to serve as members of the SSC:

Dr. Reinhard Böhm, Zentralanstalt für Meteorologie und Geodynamik, Vienna, A
Dr. Philippe Bougeault, Météo France, Toulouse, F *(chairman)*
Dr. Andrea Buzzi, FISBAT–CNR, Bologna, I
Prof. Huw C. Davies, Atmospheric Science ETH, Zurich, CH
Prof. Josef Egger, Universität München, Munich, D
Dr. Klaus P. Hoinka, Institut für Physik der Atmosphäre, DLR, Oberpfaffenhofen, D

Prof. Robert A. Houze, University of Washington, Seattle, USA
Dr. Joachim P. Kuettner, NCAR, Boulder, USA
Dr. Martin J. Miller, European Centre for Medium Weather Forecasts, Reading, UK
Prof. Hans Richner, Atmospheric Science ETH, Zurich, CH
Prof. Roger K. Smith, Universität München, Munich, D
Prof. Ronald B. Smith, Yale University, New Haven, USA
Prof. Reinhold Steinacker, Universität Wien, Vienna, A

C. Coordination and Implementation Group

The responsibilities of the CIG are the general planning and coordination of MAP in accordance with the scientific and technical goals set forth in the MAP Design Proposal document and in accordance with the decisions of the SSC and IGP. At present, the members of the CIG are:

Dr. Robert Benoit, Environnement Canada, Dorval, CAN
Dr. Peter Binder, Swiss Meteorological Institute, Zurich, CH *(chairman)*
Dr. Carlo Cacciamani, Servizio Meteorologico Regionale, Bologna, I
Dr. Massimo Crespi, Centro Sperimentale per l'Idrologia e Meteorologia, Teolo, I
Dr. Richard Dirks, UCAR, Boulder, USA
Dr. Georg Mayr, Universität Innsbruck, Innsbruck, A
Dr. Evelyne Richard, Laboratoire d'Aéorologie CNRS, Toulouse, F
Dr. Hans Richner, Atmospheric Science ETH, Zurich, CH
Prof. Christoph Schär, Atmospheric Science ETH, Zurich, CH
Prof. Reinhold Steinacker, Universität Wien, Vienna, A
Dr. Jürgen Steppeler, Deutscher Wetterdienst, Offenbach, D
Dr. Hans Volkert, Institut für Physik der Atmosphäre, DLR, Oberpfaffenhofen, D

D. Programme Office

A permanent MAP Programme Office staffed by one full-time scientist with secretarial support is funded by and located at the Swiss Meteorological Institute. It commenced operating on 1 January 1995. The PO forms the internal administrative focus of MAP and is the interface of MAP to outside bodies. It is charged to meet the administrative needs of the SSC and CIG. Furthermore, in close collaboration with the CIG, it supports the organization of scientific meetings and the periodic publication of the MAP Newsletter.

E. MAP Liaison to WMO

WMO within the CAS / AREP Programme on Very Short- and Short-Range Weather Prediction Research will co-sponsor MAP. This does not entail a financial contribution.

In addition, further steps have been undertaken to establish a connection with the World Climate Research Programme (WCRP), since the MAP objectives are of interest to a range of its activities within GEWEX. The GEWEX Hydrological Panel has decided to establish regular interactions with the MAP community by cross-representation at respective working group sessions, workshops and Scientific Steering Group meetings. This arrangement will provide for MAP to be conducted in liaison with GHP.

5.2 Overall Schedule

Here only a brief summary is given of the programme strategy elaborated in Section 3. In particular reference is made to Fig. 3-1 on page 39 for the timing and the (tentative) dates of the programme.

MAP is designed as a programme in three phases.

Phase I (1995-1999): Essential activities during the first phase are refinement of hypotheses, numerical experimentation, establishment of climatologies of mesoscale features in the Alpine area from existing data and testing of new observing systems. The results of these studies will help in the devising of the detailed observational strategy for the field experiment.

The field phase preparation work will in time be succeeded by the field experiment itself, but other activities, in particular numerical experimentation and climatological studies, will continue throughout the whole time span of MAP.

Phase II (1999): The MAP field experiment as a coordinated campaign will take place during a 13-month period, called the MAP General Observing Period (GOP), encompassing a full annual cycle with an extra month for spin-up at the beginning. Within the MAP General Observing Period, a 3-month period will be designated as a MAP Special Observing Period (SOP) during which the time and space resolution of the routine observational networks will be enhanced. Climatological evidence suggests that a 3-month period lasting from mid August to mid November appears to be the most suitable for the measurements to document the phenomena related to the primary objectives of the programme. Within the SOP a number of Intensive Observing Periods (IOPs), say 10 to 15 each of 1 to 3 days duration, will be defined. During these IOPs, chosen in connection with the actual meteorological situation, all available measuring platforms, and in particular research aircraft, suited to observe the respective phenomena will be deployed.

To avoid conflict in the booking of certain measuring platforms and other essential resources, the timing of the year for the field experiment has to be chosen in coordination with other experiments which are currently under preparation. Other boundary conditions could necessitate a shift of the field experiment to 1999 and thus, the proposed schedule is tentative.

Phase III (2000-2001): The tasks of the third phase are to assemble and analyse field data, as well as to evaluate the data in order to test the hypotheses set up in Phase I. These efforts have to be an integral part of MAP in order to guarantee optimum interaction between data post-processing and research activities.

APPENDIX

List of Acronyms

ALPEX	Alpine Experiment of the Global Atmosphere Research Programme
ALPTRAC	High-Alpine Aerosol and Snow Chemistry Study
AREP	Atmospheric Research and Environment Programme
BUFR	Binary Universal Form for Data Representation (code)
CAS	Commission of Atmospheric Sciences
CIG	Coordination and Implementation Group
CLEOPATRA	Cloud Experiment Oberpfaffenhofen and Transports
CMDB	Central MAP Data Bank
CNES	Centre National d‘Etude Spatiale
CNRS	Centre National de Recherche Scientifique
COMPARE	Comparison of Mesoscale Prediction and Research Experiments
DFG	Deutsche Forschungsgemeinschaft
DLR	Deutsche Forschungsanstalt für Luft und Raumfahrt e.V.
DWD	Deutscher Wetterdienst
ECMWF	European Centre for Medium-Range Weather Forecasts
EUROTRAC	European Experiment on the Transport and Transformation of Environmentally Relevant Trace Constituents in the Troposphere over Europe
ELDORA	airborne Doppler radar system
FRONTS 87	British / French Fronts Experiment 1987
FTP	File Transfer Protocol
GARP	Global Atmospheric Research Programme
GCM	Global Circulation Model
GEWEX	Global Energy and Water Cycle Experiment
GOP	General Observing Period
GPS	Global Positioning System
GRIB	Gridded Binary (code)
GTS	Global Telecommunication System
IGN	Institut National de Géographie
IGP	Intergovernmental Panel

IOP	Intensive Observational Period
MAP	Mesoscale Alpine Programme
MATREP	Monitoraggio dell’Attività Temporalesca nella Regione Padana
MDC	MAP Data Centre
MF	Météo France
NASA	U. S. National Aeronautics and Space Administration
NCAR	U. S. National Center for Atmospheric Research
NOAA	U. S. National Oceanic and Atmospheric Administration
NWP	Numerical Weather Prediction
OI	Optimum Interpolation
OSSE	Observing System Simulation Experiment
PBL	Planetary Boundary Layer
PO	Programme Office
POLLUMET	Pollution and Meteorology
PV	Potential Vorticity
PYREX	Pyrenean Experiment
RASS	Radio Acoustic Sounding System
SESAME	Second European Stratospheric Arctic and Mid-Latitude Experiment
SETEX	Severe Thunderstorm Experiment
SMDB	Special MAP Data Bank
SMI	Swiss Meteorological Institute
SOP	Special Observing Period
SPARC	Stratospheric Processes and their Role in Climate
SSC	Scientific Steering Committee
ST-Radar	Stratosphere-Troposphere-Radar
SYNOP	report of a surface observation of a land station
UKMO	United Kingdom Meteorological Office
ULF	Upper Level Feature
WCRP	World Climate Research Programme
WMO	World Meteorological Organization

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