

## **4 Further Data Exploitation Plans**

### **4.1 Numerical Weather Prediction Developments Related to MAP**

#### **4.1.1 The Challenge of NWP for MAP**

In the Alpine region, at least five limited area NWP models operationally provide short range forecasts with a spatial resolution approaching 10km. These models have demonstrated their capability to reasonably model and predict the meso-alpha and meso-beta scale features of the Alpine meteorology (lee cyclogenesis, hydrostatic mountain wave and related phenomena, ...). However, despite the recent progress and increased resolution of regional models, the forecast of the heavy precipitation events leading to damaging flash-floods, the fine scale structure of the Foehn, the occurrence and location of gravity wave breaking are not yet accurate enough to prevent the risks inherent to these potentially dangerous meteorological events. Several arguments indicate that a much higher resolution is actually needed than the current 10-20km range.

The real challenge for MAP is to obtain accurate forecasts or hindcasts of:

1. the hourly rainfall distribution over a 1000km<sup>2</sup> watershed,
2. the onset and time duration of Foehn within a given valley,
3. the occurrence and location of gravity wave breaking.

While this may become feasible during the SOP thanks to the enhanced density of measurements, this will require much work on higher resolution models, coupling techniques, and data assimilation.

#### **4.1.2 A New Generation of Models**

Over rough and steep mountainous areas such as the Alps, individual mountain elements possess intrinsic scales of less than one kilometre. However, only relatively large massifs and valleys can be captured by the current operational models in which the orographic forcing remains truncated due to the lack of resolution. It is also well recognized that heavy precipitation occurs mainly in vertical atmospheric motions concentrated in regions of less than a hundred meters in which take place complex dynamical, thermodynamical, and microphysical interactions involving liquid and solid water particles. Such motions are obviously not resolved by operational models that have to resort to parametrizations for which no consensus has been achieved yet.

In recent years, a new generation of very high resolution NWP models has emerged. These models are based on the full non-hydrostatic system of equations and can be used over a very large range of scales ranging from a few thousands of km to a few hundreds of meters. Moreover, these models have the capability of being self nested. It has become possible to have several models with differences in resolution of a factor of 5 to 10 running simultaneously and interacting smoothly on their boundaries. One can therefore integrate "state of the art" cloud microphysics and turbulence developments in the innermost nested model and then use it in a NWP context.

These new tools will be extensively used during all MAP phases. During phase I, they presently help to fine-tune the design and observational strategy of the field phase. During Phase II, some of them will be used in real time to support mission planning.

During Phase III, they will be further validated and improved thanks to the special observations.

A special effort has already been done to provide, via the MDC, high resolution physiographic information on the inner MAP domain. This will be continued as better products become progressively available.

#### **4.1.3 Data Assimilation**

The optimal use of these regional models strongly depends on the availability and/or utilization by the models of high resolution upper air observations, that will allow to perform data assimilation and model validation at a scale consistent with the model's resolution. Without such data the mesoscale model results consist mostly of a redistribution to smaller-scales of field properties predicted at the synoptic scale: this is often called dynamical adaptation to higher resolution terrain features alone. At the meso-scale, data assimilation is a challenging research topic in itself and various methods with various levels of complexity (from observation nudging up to the 4 dimensional variational data assimilation) are and will continue to be investigated after the MAP field phase. Presently, a substantial increase of the space-time resolution of the upper air network can only be envisioned during the course of a field campaign such as MAP.

Required measurements in that respect are mainly increased time and space radiosondes (ground based and/or drop sondes) and an improved activation (less missing reports) and more timely data transmission of the present (already dense) surface network. Continuously operating ground based microbarographs and wind profilers will bring additional useful information and allow to further explore their potential benefits for operational use.

The availability of Doppler radar measurements, either ground-based or airborne, will stimulate on-going work on the assimilation of such data in NWP models. One may speculate that in some cases, accurate numerical simulation of the rainfall distribution will only be possible with initial states containing some information on the storm-scale circulation or moisture distribution, which could only be derived from radar measurements.

Especially noted should also be the need for improved soil moisture observations and assimilation techniques in order to achieve the NWP objectives of MAP.

It is anticipated that several NWP centres will produce, shortly after the field phase, a full reanalysis of the interesting periods, using the most recent assimilation systems. These products will be used by the numerical modelling groups of MAP to run hindcasts of the IOPs.

#### **4.1.4 Real-time Effort**

During the MAP SOP, a special effort will be made to provide high-resolution forecasts to support the experiment (e.g. aircraft mission planning). This will be achieved by nesting the MC2 Canadian fully non-hydrostatic model in the Swiss operational model (SM) with special products made available for the MAP operation centre. The distributed-memory parallel version of MC2 will allow to cover an exceptionally broad area of order of 1000km x 800km with a resolution of 2km, including therefore most of the Alpine massif. Possibly experimental forecasts at the same scale will be provided by the German Lokal Modell (DWD) running with a mesh size of 2.5 km.

NCEP also plans to run a nested version of the Eta model in support of the MAP SOP. The nested Eta will be driven by the boundary conditions provided by the "Middle East" operational run of the Eta, expected to start being executed once a day in the second half of 1998. The domain and resolution of the nested Eta will be determined depending on the model efficiency on the next NCEP computer, to be delivered in 1998. Previous nested eta runs were done on domains of about 2000km x 2000km, and using 10km/60 layers resolution.

## 4.2 Climatology

The special field observations and the numerical modelling effort of MAP are supported by an extensive program of statistical analysis of longer term observations (for brevity, this will be called climatology in the remainder of the text).

The primary questions of the MAP climatological programme are the following:

1. establish and refine empirical knowledge of Alpine heavy precipitation and topographic flow phenomena;
2. develop physical-dynamical hypotheses from empirical knowledge of the phenomena;
3. test the climatological significance of previous and newly developed process insights
4. provide information for an optimal planning of the field phase (location of special observing instruments and period of intense observations);
5. establish data-sets and methodologies for a systematic validation of numerical forecasting models.

The statistical study of the weather is the main research topic in the field of the alpine climatology. These studies are focused on the statistical analysis of precipitation occurrence and regimes, time trends and frequency of occurrence of the relevant meteorological events.

In particular, regarding precipitation and temperature climatology, typical products useful for the MAP purposes are: annual, seasonal and monthly precipitation amounts; annual, seasonal and monthly frequency of days with precipitation over certain thresholds; indices of climatic risk (e.g.: return periods, time intervals between such excessive precipitation events); frequency of severe thunderstorms and hailstorms north and south of the Alps; location of flood events in the MAP high-resolution data domain. annual, seasonal and monthly mean temperatures and thermal indices (number of frost days, number of days above or below particular thresholds; indices of climatic risk in the different periods of the year);

As a second type of study, the statistical analysis must be extended also to the knowledge of the large-scale and mesoscale physical processes that determine the observed local climate in the Alpine region. Emphasis must be given to the statistical behaviour of: - mesoscale processes linked to the Alpine chain that determine and enhance orographic precipitation and trigger deep convection over the northern and southern side of the Alps; - the occurrence of convective systems with leading line-trailing stratiform organization, which are on average the largest systems and show the largest damage potential compared to other types of organization; - gravity wave breaking and the onset of Foehn events; - low level PV features induced by orography; - cold frontal deformations due to the Alpine chain and the thermally and dynamically driven circulations; - structure and modification of the PBL;

Finally, climatological results take on an important role with respect to a systematic validation of numerical models. The availability of long time series of data are essential for the validation of climatic simulations of global and regional numerical models.

A full “physical” understanding of the climate of the Alpine region can be obtained by studying, in an objective way, the physical links existing between different meteorological weather types (Grosswetterlagen) and the local weather of the Alpine area.

### **Data Requirements**

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). These data have 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. Under the “umbrella” of the MAP programme, the collaboration between operational services and science institutes is an important chance for the establishment of valuable datasets.

Time series of surface parameters are not sufficient for the definition of a “dynamic climatology”. As regards the Weather Types definition, time series of objective analyses of surface and upper air fields are essential (500hPa Geopotential, Mean sea level pressure, 850hPa Temperature). Time series of thermodynamical indices, characterizing global scale phenomena are also necessary, as also numerical indices giving an objective signature of relevant synoptic patterns (Blocking events, cyclone occurrence etc).

Climatological studies regarding mesoscale processes can be carried out by using, where available, a good “local” data base, as also by means of time series of mesoscale objective analyses of low level parameters as mean sea level pressure and 850hPa wind. Satellite data are also important to define a detailed cloud climatology. Finally, time series of radar data and images are essential to achieve a good climatological knowledge of severe weather occurrence on limited domains, such as hailstorms.

Some mesoscale processes are inaccessible to long-term climatological monitoring. In particular, this holds for upper air features such as gravity waves, wave breaking, low-level PV banners, and orographical modifications of static stability. These features are not observed by the coarse network of routine radiosoundings in the Alpine area. It is therefore necessary to evaluate existing time-series of high-resolution analyses and short-term forecasts of NWP models. It is furthermore advisable to use dynamical or statistical-dynamical downscaling procedures to evaluate the links between large-scale patterns and upper-air mesoscale processes.

### **4.3 Budget Studies over the Alps**

Any study of heavy alpine precipitation would be incomplete without an investigation of the heat, energy and momentum (or vorticity) budgets associated with precipitation events. The relatively high density of radiosonde stations in the Alps and the relatively high density raingauges makes the region especially suitable for such investigations.

The methodology for such a study is well known and goes back to the pioneering work of Yanai et al. (1973). The idea is to calculate the vertical distributions of apparent heating (Q1), apparent moistening (Q2) and the apparent potential vorticity source (see e.g. Hell and Smith, 1998) over a given region as functions of time. The structure of Q1

and Q2 provide information about the general character of cloud systems producing rainfall over the region in question (see e.g. Yanai and Tomita, 1997). These characteristics can be compared with the precipitation structure of cloud systems to be provided by the MAP radars. Modifications to the budget calculations are required when applied over mountainous terrain as described by Johnson and Bresch (1991).



**LIST OF ACRONYMS**

ANETZ	Swiss network of automatic meteorological stations
CIG	Coordination and Implementation Group
CAT	Clear air turbulence
CETP	Centre d'Étude Terrestres et Planétaires
CLB	Constant level baloon
CNES	Centre National d'Étude Spatiale
CNR	Consiglio Nazionale delle Ricerche
CNRM	Centre National de Recherches Météorologiques
CNRS	Centre National de Recherche Scientifique
COAMPS	Coupled Ocean and Atmosphere Prediction System, US Navy
DFG	Deutsche Forschungsgemeinschaft
DIAL	Differential absorption lidar
DLR	Deutsches Zentrum für Luft und Raumfahrt
DWD	Deutscher Wetterdienst
ECMWF	European Centre for Medium-Range Weather Forecasts
EC-RPN	Environment Canada, Recherche en Prevision Numerique
ENEL	Ente Nazionale Energia Elettrica
ETH	Swiss Federal Institute of Technology
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
ELDORA	airborne Doppler radar system
FISBAT-CNR	Istituto per lo Studio dei Fenomeni Fisici e Chimici della Bassa e Alta Atmosfera, Bologna
GIETH	Institute of Geography, ETH
GOES	Geostationary Operational Environmental Satellite
GOP	General Observing Period
GPS	Global Positioning System
GTS	Global Telecommunication System
ICG-CNR	Istituto di Cosmo-Geofisica, CNR, Torino
IFA-CNR	Istituto di Fisica dell'Atmosfera, CNR, Roma

IGP	International Governing Panel
IMK	Institut für Meteorologie und Klimaforschung (joint institute of University and Forschungszentrum Karlsruhe)
INDOEX	Indian Ocean Experiment
INSU	Institut National des Sciences de l'Univers
IOP	Intensive Observational Period
IPA-DLR	Institut für Physik der Atmosphäre, DLR-Oberpfaffenhofen
IROE-CNR	Istituto di Ricerca sulle Onde Elettromagnetiche, Firenze
ISIATA-CNR	Istituto per lo Studio dell'Inquinamento Atmosferico e l'Agrometeorologia, CNR, Lecce
JRC	Joint Research Centre, Ispra
LA	Laboratoire d'Aerologie
LAMP	Laboratoire de Météorologie Physique
LAPETH	Institute for Atmospheric Sciences, ETH
LMD	Laboratoire de Météorologie Dynamique
LSEET	Laboratoire de Sondage Electromagnétique de l'Environnement Terrestre
MADD	Module d'Acquisition De Données (automatic weather station, supplied by solar cells)
MAP	Mesoscale Alpine Programme
MDC	MAP Data Centre
METAIR	Swiss private company
METEOSAT	Meteorological Satellite, EUMETSAT
MF	Météo France
MOC	MAP Operation Centre
NASA	U. S. National Aeronautics and Space Administration
NCAR	U. S. National Center for Atmospheric Research
NOAA	U. S. National Oceanic and Atmospheric Administration
NRL	Naval Research Laboratory
NSSL	National Severe Storm Laboratory
NWP	Numerical Weather Prediction
PBL	Planetary Boundary Layer

PO	Programme Office
POC	Project Operation Centre
PV	Potential Vorticity
RASS	Radio Acoustic Sounding System
RONCARD	French Doppler radar
SABL	Scanning Aerosol Backscatter Lidar
SMI	Swiss Meteorological Institute
SMI-AER	Aerological and remote sensing section, SMI
SMI-ENV	Environmental meteorology section, SMI
SOP	Special Observing Period
SSC	Scientific Steering Committee
SYNOP	report of a surface observation of a land station
UKMO	United Kingdom Meteorological Office
ULF	Upper Level Feature
WIND	Wind Infrared Doppler Lidar
WMO	World Meteorological Organization
WP	Wind Profiler
ZAMG	Zentralanstalt für Meteorologie und Geodynamik, Austria



## REFERENCES

- Aebischer, U., and C. Schär, 1998: Low-level potential vorticity and cyclogenesis to the lee of the Alps. *J. Atmos. Sci.*, **55**, 186-207.
- Altese, E., O. Bolognani, M. Mancini and P. A. Troch, 1996: Retrieving soil moisture over bare soil from ERS 1 synthetic aperture radar data: sensitivity analysis based on a theoretical surface scattering model and field data. *Water Resour. Res.*, **32(3)**, 653-661.
- Appenzeller, C., and H. C. Davies, 1992: Structure of stratospheric intrusions into the troposphere. *Nature*, **358**, 570 - 72.
- Appenzeller, C., H. C. Davies, and W.A. Norton, 1996: Fragmentation of stratospheric intrusions. *J. Geophys. Res.*, **101**, 1435 - 1456.
- Arakawa, S, 1968: A proposed mechanism of fall winds and Dashikaze. *Papers in Met. Geophys.*, **19**, 69-99.
- Armi, L., 1986: The hydraulics of two flowing layers with different densities. *J. Fluid Mech.*, **163**, 27-58.
- Armi, L., and R. Williams, 1993: The hydraulics of stratified fluid flowing through a contraction. *J. Fluid Mech.*, **251**, 355-375.
- Bacmeister, J. T., and M. R. Schoeberl, 1989: Breakdown of vertically propagating two-dimensional gravity waves forced by orography. *J. Atmos. Sci.*, **46**, 2109-2134.
- Banta, R. M., 1990: The role of mountain flows in making clouds, in "Atmospheric Processes over Complex Terrains". *Meteor. Monogr.*, **45**, 173-228.
- Banta R. M., L. D. Olivier, W. D. Neff, D. H. Levinson, and D. Ruffieux, 1995: Influence of canyon-induced flows on flow and dispersion over adjacent plains. *Theor. Appl. Climatol.*, **52**, 27-42.
- Bessemoulin, P., P. Bougeault, A. Genoves, A. Jansa Clar, and D. Puech, 1993: Mountain pressure drag during PYREX. *Beitr. Phys. Atmosph.*, **66**, 305-325.
- Caccia, J. L., and J. P. Cammas, 1998: VHF-ST radar observations of an upper-level front using vertical and oblique-beam CN2 measurements. *Mon. Wea. Rev.*, **126**, 483-501.
- Cotton, W. R., and R. A. Anthes, 1989: The influence of mountains on airflow, clouds, and precipitation, in "Storm and Cloud Dynamics", Academic Press, 788-870.
- Dörnbrack, A., M. Leutbecher, H. Volkert, and M. Wirth, 1998: Mesoscale forecasts of stratospheric mountain waves. *Meteorol. Appl.*, **5**, June Issue.
- Fliri, F., 1983: Die Niederschlagsverteilung in den Alpen an Tagen mit starkem Südföhn in Innsbruck und in Altdorf. *Wetter und Leben*, **35**, 154-162.
- Frei, C., and C. Schär, 1998: A precipitation climatology of the Alps from high-resolution rain-gauge observations. *Int. J. Climatol.*, **18**, in press.
- Frey, K., 1984: Der "Jahrhundertföhn" vom 8. November 1982. Eine synoptische Betrachtung. *Meteor. Rdsch.*, **37**, 209-220.
- Georgakakos, K. P. and E. Foufoula-Georgiou, 1991: Real time coupling of hydrological and meteorological models for flood forecasting. In: D. S. Bowles and P. E. O'Connell (Eds.), *Recent advances in the modelling of hydrologic systems*, D. Reidel Publishing Company, Boston, Mass.
- Heimann, D., 1992: Potential and equivalent-potential temperature pattern at cold fronts with pre-frontal Foehn. *Meteor. Atmos. Phys.*, **48**, 165-171.
- Hell, R. M., and R. K. Smith, 1997: A monsoon depression over northwestern Australia. Part I: A case study. *Aust. Met. Mag.* (in press).
- Hoinka, K. P., 1990: Untersuchung der alpinen Gebirgsüberströmung bei Südföhn. *Forsch. Ber. DLR, IPA 186pp*, Oberpfaffenhofen.
- Holopainen, E. O., and L. Rontu, 1981: On shear lines in the upper troposphere over Europe. *Tellus*, **33**, 351 - 359.
- Houze, R. A. Jr., 1993: Orographic Clouds, in "Cloud Dynamics", Academic Press, 502-538.
- Jackson, R. L., and D. G. Steyn, 1994: Gap winds in a fjord. Part I: Observations and numerical simulation. *Mon. Wea. Rev.*, **122**, 2645-2665. Part II: Hydraulic Analog. *Mon. Wea. Rev.*, **122**, 2666-2676.
- Johnson, R. H., and J. F. Bresch, 1991: Diagnosed characteristics of precipitation systems over Taiwan during the May-June 1987 TAMEX. *Mon. Wea. Rev.*, **119**, 2540-2557.
- Levinson, D. H., and R. M. Banta, 1995: Observations of a terrain-forced mesoscale vortex and canyon drainage flows along the front range of Colorado. *Mon. Wea. Rev.*, **123**, 2029-2050.

- Kuhn, M., 1989: Föhnstudien. Wiss. Buchges., 494 pp, Darmstadt.
- Massacand, A. C, H. Wernli, and H. C. Davies, 1998: Heavy precipitation on the Alpine southside: An upper-level precursor. *Geophys. Res. Lett.*, **25**, 1435-1438.
- MAP Design Proposal, 1996 (P. Binder and C. Schär, editors).
- Obled, Ch., J. Wardling and K. Beven, 1994: The sensitivity of hydrological models to spatial rainfall patterns: an evaluation using observed data. *J. of Hydrol.*, **159**, 305-333.
- Olafsson, H, and P. Bougeault, 1996: Non-linear flow past an elliptic mountain ridge. *J. Atmos. Sci.*, **53**, 2465-2489.
- Pampaloni, P., L. Chiarantini, P. Coppo, G. Luzi and S. Paloscia, 1990: Sampling depth of soil moisture content by radiometric measurements at 21 cm wavelength: some experimental results. *Int. J. of Remote Sensing*, **11**, 1085-1092.
- Schär, C., and D. R. Durran, 1997: Vortex formation and vortex shedding in continuously stratified flows past isolated topography. *J. Atmos. Sci.*, **54**, 535-554.
- Schär, C., and R. B. Smith, 1993: Shallow-water flow past isolated topography. Part I: Vorticity production and wake formation. *J. Atmos. Sci.*, **50**, 1373-1400.
- Scorer, R. S., 1952: Mountain-gap winds; a study of surface wind at Gibraltar. *Quart. J. Roy. Met. Soc.*, **78**, 53-61.
- Seibert, P., 1990: South Foehn studies since the ALPEx Experiment. *Meteor. Atmos. Phys.*, **43**, 91-103.
- Seibert, P., 1993: Der Föhn in den Alpen – ein aktueller Ueberblick. *Geogr. Rdsch.*, **45**, 116-123.
- Sénési, S., P. Bougeault, J. L. Cheze, P. Cosentino, and R. M. Thépenier, 1996: The Vaison-la-Romaine Flash Flood: Meso-Scale Analysis and Predictability Issues, *Weather and Forecasting*, **11**, 417-442.
- Smith, R. B., 1985: On severe downslope winds. *J. Atmos. Sci.*, **42**, 2597-2603
- Smith, R. B., 1989: Hydrostatic flow over mountains. *Advances in Geophysics*, **Vol. 31**, Academic Press, 1-41.
- Smith, R. B., A. C. Gleason, P. A. Gluhosky, and V. Grubisic, 1997: The wake of St. Vincent. *J. Atmos. Sci.*, **54**, 606-623.
- Smolarkiewicz, P. K. and R. Rotunno, 1989: Low froude number flow past three dimensional obstacles. Part I: Baroclinically generated lee vortices. *J. Atmos. Sci.*, **46**, 1154-1164.
- Ulaby, F. T., R. K. Moore and A. K. Fung, 1986: *Microwave remote sensing: active and passive*, **Vol. 3**, Artech House, Norwood, Mass.
- Wirth, V., C. Appenzeller, and M. Juckes, 1997: Signatures of induced vertical air motion accompanying quasi-horizontal roll-up of stratospheric intrusions. *Mon. Wea. Rev.*, **125**, 2504 - 2519.
- Yanai, M., S. Esbensen, and J. H. Chu, 1973: Determination of bulk properties of tropical cloud clusters from large-scale heat and moisture budgets. *J. Atmos. Sci.*, **30**, 611-627.
- Yanai, M., and T. Tomita, 1997: Seasonal and interannual variability of atmospheric heat sources and moisture sinks as determined from NCEP/NCAR reanalysis. *J. Climate*, (in press).