12.1 PROGRESS IN THE ATMOSPHERIC SCIENCES DURING THE PAST TEN YEARS: WHAT DID *MAP* CONTRIBUTE ?

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1. INTRODUCTION

Ten years after the inception of the *Mesoscale Alpine Programme (MAP)* and five years after its special observing period (SOP) it is a natural question to ask about the progress which this initiative contributed to the overall development of the atmospheric sciences.

Progress implies some movement ahead, in every day life, in sport (*e.g.* the Olympic motto of *citius, altius, fortius*) as well as in philiosophy of science. According to Niiniluoto (2002) *progress* should be distinguished from neutral descriptive terms as *change* and *development.*

Before we can judge well what sort of progress was made within categories as *observational techniques*, *numerical simulation* or *physical understanding* regarding the complete atmospheric behaviour (or important processes) over a mountain range as the Alps, a thorough compilation of the numerous activities, which were carried our during the conduct of MAP, appears to be useful. Let us call the action the *harvest* of MAP, as this linguistic term denotes at the same time i) *the process of gathering a crop*, ii) *the amount of the crop gathered in a season*, and iii) *the result of an activity* (American Heritage, 2000). We note as an aside that *harvest* is closely related to *Herbst*, the German word for autumn; in 1999 the season of the MAP-SOP.

It must be kept in mind that this presentation can at best serve as a further ignition spark for the MAP harvest. All interested scientists are invited to contribute. The exercise is scheduled to last for another year and should terminate at the next international conference *ICAM/MAP-2005* to take place in Zadar, Croatia.

We begin with a brief sketch of the state-of-the-art of the MAP related atmospheric science topics in 1994 (section 2), mention at continuously compiled stocks of MAP information and results (section 3), and then point at mostly recent reviewed publication in the three mentioned categories (sections 4-6). The final section tentatively embeds the achievements made during the conduct of MAP into the century during which *weather predicition* changed from an art to a science and into the last five decades during which it became both *numerical* and *operational.*

2. MESOSCALE METEOROLOGY IN 1994

MAP can be seen as an inheritage of ALPEX, which had its field phase in spring 1982. More than a decade later *mesoscale* flow systems (space scales from 2 to 2000 km; time scale between 2 hours and 2 days) were regarded as central for the understanding of weather and climate details in mountains areas:

> *Mountains, and in particular **Alpine**-type orography, instigate or influence a rich range of **mesoscale** 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* (Binder and Schär, 1995).

At that time several meteorological services operated hydrostatic limited area models with a horizontal grid-size (Δx) of about 15 km (*e.g.* PERIDOT at Météo-France; DM/SM at DWD and MeteoSwiss; a version of the Unified Model at the MetOffice). Non-hydrostatic models with grid nesting facilities and the possibility to be driven by larger scale analyses were applied and developed mainly for research purposes (*e.g.* MM5 and COAMPS in USA, MC2 in Canada, Meso-NH in France).

All these tools now incorporate increasingly sophisticated micro-physical schemes to simu-

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late precipitation. Consequently the detailed study of orographically generated or modified precipitation (‘*wet MAP’*) was added to the originally more dynamically oriented research objectives (as breaking gravity waves, potential vorticity streamers and banners; *‘dry MAP’*) at a planning workshop in autumn 1994. This line was even extended in 1996 through the integration of the hydrological issue of flood forecasting. While a wealth of conventional and remotely sensed precipitation data were available for the Alpine region, a consistent international climatology and radar composite was lacking.

The hypothesis that narrow meridionally elongated troughs at tropopause-level, so-called *PV streamers,* constitute a significant dynamical precursor of sustained precipitation events on the Alpine southside linked wet- and dry-MAP issues. At lower levels *potential vorticity banners* were envisaged as dynamically important manifestations in the wake of the entire mountain block as well as of single massifs. Likewise it was felt necessary to investigate the role of clouds (through latent heat effects) on basic mechanisms of foehn flows or the life cycle of gravity waves (including their breaking). A better determination of the boundary layer structure in mountainous terrain constituted a further goal. Altogether 8 projects were defined to be pursued in an integrated field campaign of at least 2 months duration, which eventually took place between 7 Sept. and 15 Nov. 1999 with 15 intensive observation periods (IOP) covering 42 of the 70 days.

As one possible reference for the continuous increase of computing power for numerical weather prediction (NWP) we mention the progress in resolution of the operational ECMWF model (Txxx designates the highest horitontal wave-number in triangular truncation; Lyy the number of vertical layers; ECMWF, 2002):

IX 1991:	T213L31	$\Delta x \sim 95$ km
IV 1998:	T319L31	$\Delta x \sim 60$ km
III 1999:	T319L50	
X 1999:	T319L60	
XI 2000:	T511L60	$\Delta x \sim 40$ km

3. MAP DATA & INFORMATION SOURCES

Due to the inevitable lack of experiments in a laboratory field campaigns of increasingly complex scope accompany the development in atmospheric physics since at last 50 years (cf. Kuettner’s personal perspective in Taba, 1989). Of decisive importance for the overall success is a careful and user-friendly management of data and information. From the very beginning of MAP the international community profited much from the advance of computer links via the Internet. Well before the conduct of the MAP-SOP the *MAP data centre* (MDC) was established at the Institute for Atmospheric and Climate Science (IAC*ETH*) in Zurich. The web-address http://www.map.ethz.ch continues to be the gateway to the bulk of MAP data, in the categories *MAP database*, *SOP data* and *field catalog*, each of them with a detailed substructure. Additionally the MDC contains information about *MAP organization* (the people involved), *working groups*, *documents* and all 18 issues of the *MAP newsletter*, published by MeteoSwiss (Rossa et al. 1994-2003).

Overview articles and papers in the peer-reviewed scientific literature, sometimes collected in *special issues* of research journals, are the standard means to document the steps of scientific progress. The former type is collected in *part a)* of the *reference* section below together with the planning documents. After the completion of MAP-SOP Chong et al. (2000) reported on the real-time wind synthesis using several Doppler radars, Bougeault et al. (2001) provided sample results from all eight projects pursued, Benoit et al. (2002) documented the activities concerned with a dedicated numerical forecasting suite during the entire SOP, while Rotach et al. (2004) summarize the advances made with boundary layer studies in complex terrain. Bougeault (2003) posed the question *‘MAP: Where do we stand?’* to initiate the harvesting.

Coordinated collections of MAP related results are given in *part b)* of the *references,* here sorted in the sequence of publication: *i)* an overview and thirteen research papers regarding a better description of the atmospheric part of the hydrological cycle over the Alps from existing sources (final report of the EU funded project HERA; Volkert, 2000, **SI4**); *ii)* an editorial and 25 articles dealing with findings from MAP-SOP in all eight projects (Bougeault et al, 2003, **SI2**); *iii)* an editorial and ten papers dealing with the aspects of the coupling of atmospheric and hydrological models for flood forecasting including the real-time trial during MAP-SOP (final report of the EU-funded project RAPHAEL; Bacchi et al., 2003, **SI1**); and *iv)*, most recent, a number of presentations first delivered at ICAM/MAP-2003 in Brig, including mesoscale simulations initiated with the ECMWF re-analysis of MAP-SOP and an semi-automatted quality control scheme for conventional observations (Furger et al., 2004, **SI3**).

In the following three sections the contributions to these special issues and additional articles which appeared in the reviewed literature are sorted into the three broad categories mentioned in the *introduction* (all those references are listed in *part c)* below). A few sample figures are used to illustrate the close links between the categories.

4. OBSERVATIONAL TECHNIQUES

Traditionally the application of newly developed technology is an important driving force during the preparation of any field campaign. Here we briefly list remote sensing and *in-situ* methods successfully applied during MAP-SOP and meanwhile documented in publications.

Several precipitation radar networks were or became operational by European meteorological services during the 1990ies. An Alpine composite with six reflectivity ranges in a clear display in weather-map projection was set up during project HERA (cf. paper in **SI4**) and applied near-real time during the entire SOP with 30-min-intervals as exemplified in Fig. 1 for a snapshot during IOP 2a. Much more refined in scale are microphysical retrievals from a polarization radar near Lago maggiore (*e.g.* Fig. 1b) and ground-based or airborne Doppler-systems (cf. overview in Chong et al. 2000; papers in **SI2** and **SI4**; Bousquet and Smull 2003; Pradier et al. 2002), partly in combination with wind profiler data (Tabary and Petitdidier 2002). The combination of micro-physical retrievals with sophisticated lightning detection provided new insights into the electrification of strong storms (Soula et al. 2003, 2004).

A wealth of motion details for gap-flows and foehn currents were documented in unprecedented detail by a moving car (Mayr et al. 2002), by ground-based Doppler lidar (Fig. 3a; papers in **SI2**, Mayr et al. 2004), by airborne lidars (of backscatter and Doppler types) and light-weight dropsondes (Figure 4a from Jiang and Doyle 2005; Flamant et al. 2002, Smith et al 2002, papers in **SI2**) or a combination of techniques (Furger et al. 2001; Baumann-Stanzer and Piringer 2004; Weissmann et al. 2005). Turbulence characteristics above the surface were systematically determined from aircraft data (Lothon et al. 2003). A network of wind profilers was applied to obtain the synoptic scale flow with a better time resolution compare to radiosondes (Caccia et al. 2001).

Rapid scan METEOSAT images were used to track moving systems (Bolliger et al. 2004) or to highlight their stationarity (Smith et al. 2002; papers in **SI2**). Multi-channel NOAA images provided concise overviews about the co-existence of diverse cloud structures (Fig. 4b shows extended streets of wave generated lenticular clouds ahead of a front's cirrus shield). Automated methods for quality control and analysis of conventional surface data above complex terrain were developed and applied (Steinacker et al 2000; papers in **SI3**) as well as diagnostic methods for precipitation (Vrhovec et al. 2004; Žagar et al 2004).

The journal titles for the given quotations may be used as indicator whether the observational technique was the primary objective or rather comparisons with simulation. Inevitably there is much overlap with studies referred to in the next section. A formal task of the harvesting process should be to put this classification on better balanced grounds.

5. NUMERICAL SIMULATION

During the century since Bjerknes (1904) first claimed that weather forecasting should be possible on the grounds of theoretical physics the numerical simulation became more and more an integral link between observation, research and practical application. A particular strength of MAP lies in the close cooperation between operational model developers at meteorological services and their colleagues from research laboratories and universities.

Today a bulk of case studies is available for all IOPs. For *wet-MAP* sophisticated micro-physical schemes now treat convection and precipitation generation partly explicitly (Fig. 1c; Benoit et al. 2002; papers in **SI1-SI4**). The performance of operational NWP models is assessed in case studies (papers in **SI4**; Ahrens 2003; Ivančan-Picek et al. 2003).

Equally wide is the range of applications for the *dry-MAP* objectives PV streamers (papers in **SI2**, Hoinka and Zängl 2004), foehn flows and gravity waves (Smith et al. 2002; papers in **SI2;** Smith and Broad 2003; Beffrey et al. 2004; Gohm et al. 2004; Smith S.A. 2004; Jiang and Doyle 2005; Zängl et al. 2004a, 2004b), and PV banners (papers in **SI2**; Flamant et al 2004; Grubišić 2004).

The integration of hydrological aspects into MAP and combined precipitation and run-off modelling constitute a truly interdisciplinary effort. Prototype applications, partly in real time are reported in **SI1** and **SI2**. An illustrative example with observed and simulated precipitation and run-off is given in Figure 2 (daily updated results of the atmospheric model can now be accessed via http://www.cmirl.ge.infn.it/map/bolam/bolamin.htm).

An integral and global perspective of the combination of all additional SOP data is provided by the re-analysis of the complete 70-day-period in 1999 with the ECMWF data assimilation scheme of 2002 (Keil and Cardinali 2004). This exercise revealed subtle inconsistencies in the global assimilation scheme and provided standard observation and analysis datasets fur future investigations.

Also, technical improvements in mesoscale NWP models and idealized studies were motivated during the preparation phase before the SOP (Paper in SI4; Schär et al 2002; Sprenger and Schär 2001; Zängl 2003a, 2003b).

6. PHYSICAL UNDERSTANDING

Although an agreed improvement of physical understanding is the implicit motivation for most research initiatives, its clear detection remains a difficult task, especially when numerous processes act simultaneously. The following examples shall serve as a starting point for a more systematic collection during the harvesting.

The relevance of upper-level PV streamers for significant weather a day later and downstream was suggested early on (Massacand et al. 1998; paper in **SI4**). Now it became clear that PV streamers are ubiquitous features. The adequate description of the upper-level flow is a critical pre-requisite for a sufficiently correct meso-scale rainfall prediction (Fehlmann et al. 2000, Massacand et al 2001).

The complex interplay between advection routes of moist air from the Ligurian and Adriatic Seas with the convex south Alpine topography and synoptically determined structures in vertical stability was found as crucial for intense precipitation (Rotunno and Ferretti 2001; paper in **SI2**). Different convective regimes were explored in modelling studies (Gheusi and Stein 2003; Stein 2004).

The analysis of water vapor budgets over the Alps during IOP 2a indicated that the precipitation processes may be strongly scale dependent. While simple upslope models (Smith 2003; Smith and Barstad 2004) give reasonable precipitation predictions when heavily smoothed Alpine terrain us used, they give huge errors when small scales are included (with a 1 km terrain resolution the simplest upslope models predict a rainfall rate greater than the incoming water vapor flux – a physical impossibility). This finding has induced the construction of scale-dependent theories that capture the processes which limit precipitation. Three such processes are: water vapor depletion, limited penetration of vertical motion, and advection of condensed water to the lee slopes followed by evaporation (Smith R.B. 2004). With MAP data the predictability of precipitation started to be addressed over the Alps (Walser and Schär 2004; Walser et al. 2004).

For cross-mountain foehn flow the limitations of an approach with hydraulic analogues was investigated (paper in **SI2**; Beffrey et al. 2004). The relative roles of complex topography, clouds and stagnant surface layers for the life cycle of gravity waves start to become clearer (papers in **SI2**; Jiang and Doyle 2005).

The intricate links between the radiation budget at a sloping surface, boundary layer turbulence and exchange processes in Alpine valleys are being further unveiled (paper in **SI2;** Drobinski et al. 2002; Rotach et al. 2004).

7. Following V. BJERKNES and CRESSMAN

It appears attractive to place the MAP harvest into the long term progress of weather prediction: just as Bjerknes (1933) put his group's achievements in context or as the operational beginnings in the USA by Cressman and colleagues are recorded (Amer. Inst. Physics 2004).

The development of operational non-hydrostatic models with the explicit treatment of convection received a distinct push, notably in France (transformation of experiences with Meso-NH into the ongoing project AROME), in Italy (projects BOLAM and MOLOCH), and in Canada (routine coupling with hydrological models; realtime exercise with MC2 during SOP triggered ultrafine hurricane simulation on the Earth Simulator in Japan). At MeteoSwiss a multi meteorological service initiative started recently towards a MAP Forecast Demonstration Project as envisaged by WMO, whose general interest in MAP is already documented (Bougeault and Binder 2002, Little 2002).

The author hopes that the personal interest and determination for the MAP harvest remains high for numerous contributors (cf. snapshot in spring 2003; Fig. 5). This is especially necessary when as complete as possible list of MAP references is to be established together with a well balanced account of the overall achievements. Such a combined activity will eventually lead to a clever inspection of a well stocked harvest cart (symbolically depicted in Figure 6) and, thus, to a much better grounded answer to the question posed in the title.

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FIGURES:

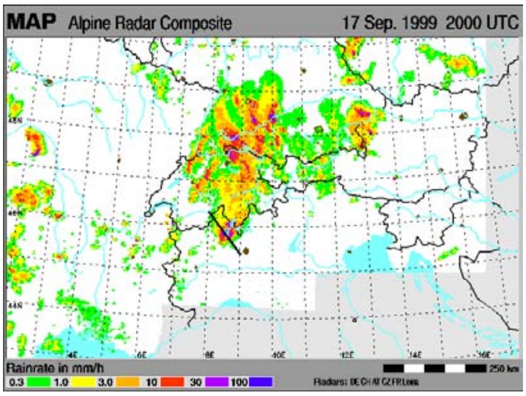


Fig. 1a: Precipitation above the central Alps (A, CH) and southern Germany on 17 Sept. 1999, 20 UT (IOP-2a; black line: base of Figs. 1b,c).

Courtesy of Martin Hagen

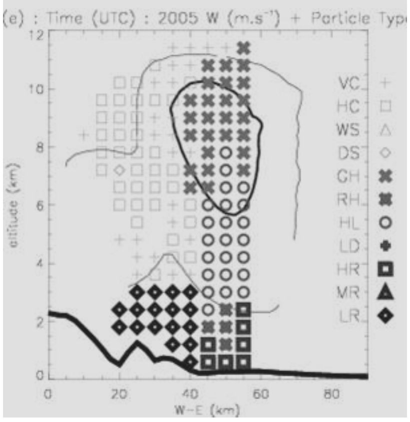


Fig. 1b: Radar based microphysical retrieval through deep precipitation cell at Alpine flank during IOP-2a; 11 categories including hail and graupel (**x**), large hail (**o**) heavy rain (**◘**) from polarimetric radars.

Courtesy of Pierre Tabary

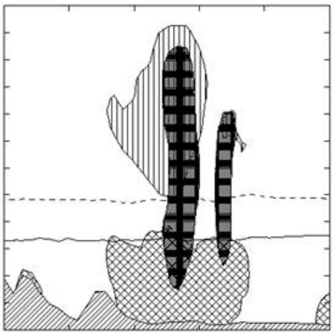


Fig 1c: Meso-NH simulated distribution of hydrometeors for IOP-2a, 20 UT along section of Fig. 1b: graupel (parallel lines), rain (crossing lines) and dark hail cores. *Courtesy of Evelyne Richard.*

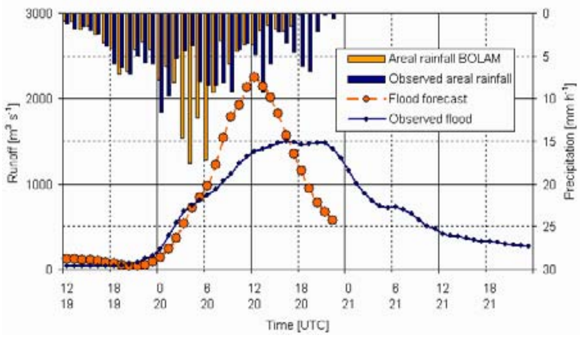


Fig. 2: Coupled hydro-meteorological simulation valid for Candoglia at the Toce river: observed vs. simulated precipitation (top; right axis) and run-off (bottom; left axis) over a 60 h period during IOP-2b.

Courtesy of Roberto Ranzi.

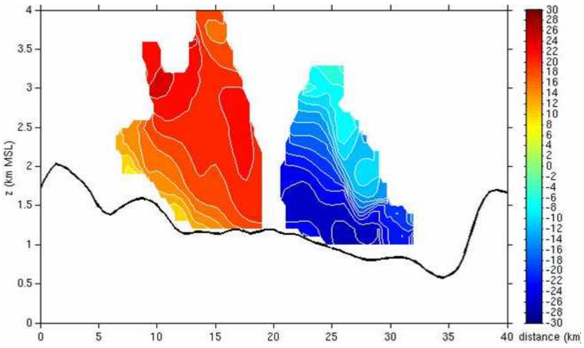


Fig. 3a: Lidar sensed radial velocity field along the Wipp valley (S: left; N: right) relative to the instrument site x = 20 km for 24 October 1999, 15 UT (IOP-10).

Courtesy of Alexander Gohm and Günther Zängl

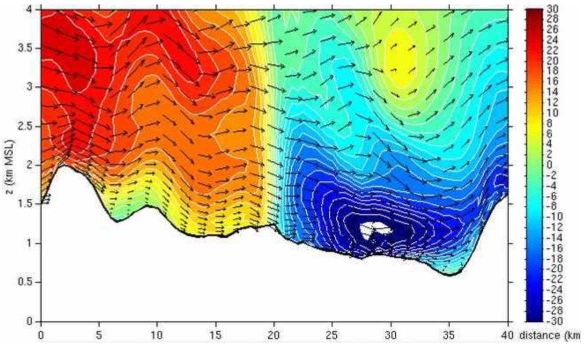
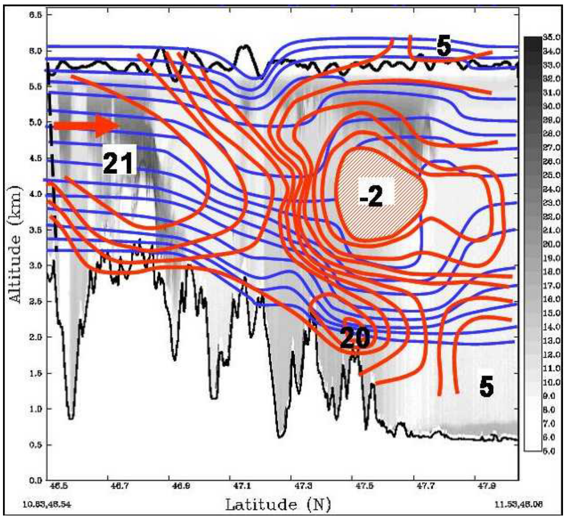


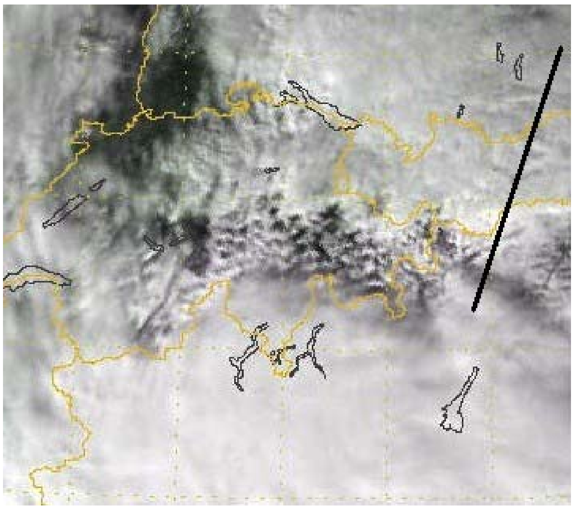
Fig. 3b: MM5 simulated flow section in lidar perspective (towards: red; away: blue) as in Fig. 3a.

Courtesy of Alexander Gohm and Günther Zängl



<u>Fig. 4a:</u> South-north section across northern half of central Alps during the foehn event of 21 Oct. 1999, 07 UT (IOP-8): laser observed aerosol and cloud layers (grey scale; SABL instrument) superimposed with along-section flow (red lines; increment: 2 m/s; local extrema indicated) and potential temperature (blue lines; increment: 1 K) analyzed from 7 deployed GPS dropwindsondes.

Courtesy of James Doyle and Qingfang Jiang



<u>Fig. 4b:</u> Complicated cloud structures including cirrus shields and elongated *altocumuli lenticulares* above the central Alps during the IOP-8 foehn event; multichannel composite from the NOAA-17 polar orbiting satellite on 21 Oct. 1999, 1327 UT. Black line: baseline of Fig. 4b; latitude/longitude grid (1° x 1°) and state borders are indicated in yellow.

Courtesy of Robert Meisner and Nikolai Dotzek

<u>Fig. 5:</u> Many of the MAP harvesting team assembled in an asymmetric triptych in Kühboden/Fiescheralp above Brig (CH) and close to the main Alpine crest on 21 May 2003. *Photos: Brigitta Klingler*

<u>Fig. 6:</u>

Idyllic depiction of a harvest cart under dry-MAP autumn conditions and leisurely inspected by a curious and notoriously clever observer.

Courtesy of Google picture search