COPS

Convective and Orographically-induced Precipitation Study

Operations Plan, Draft 1.0

September 21, 2006

An observation program within the

Priority Program “Quantitative Precipitation Forecast (PQP)”

funded by the German Research Foundation

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Appendices:

1 The Priority Program “Quantitative Precipitation Forecast”

1.1 Objectives and Set up of the Priority Program

The deficiencies of QPF led to the initiation of the Priority Program (PP) 1167 “Quantitative Precipitation Forecast PQP” by the German Research Foundation (DFG) in 2003 (PQP stands for Praecipitationis Quantitativae Praedictio). This research program addresses the challenges identified by the user groups with respect to QPF. The program gathers atmospheric scientists at German and Swiss universities and research institutes to combine their knowledge for improving QPF. In close cooperation with the German Meteorological Service (DWD) their operational forecast systems are used and refined as a basic backbone for model development, testing, and validation. The structure of PQP is depicted in Fig. 1.1.

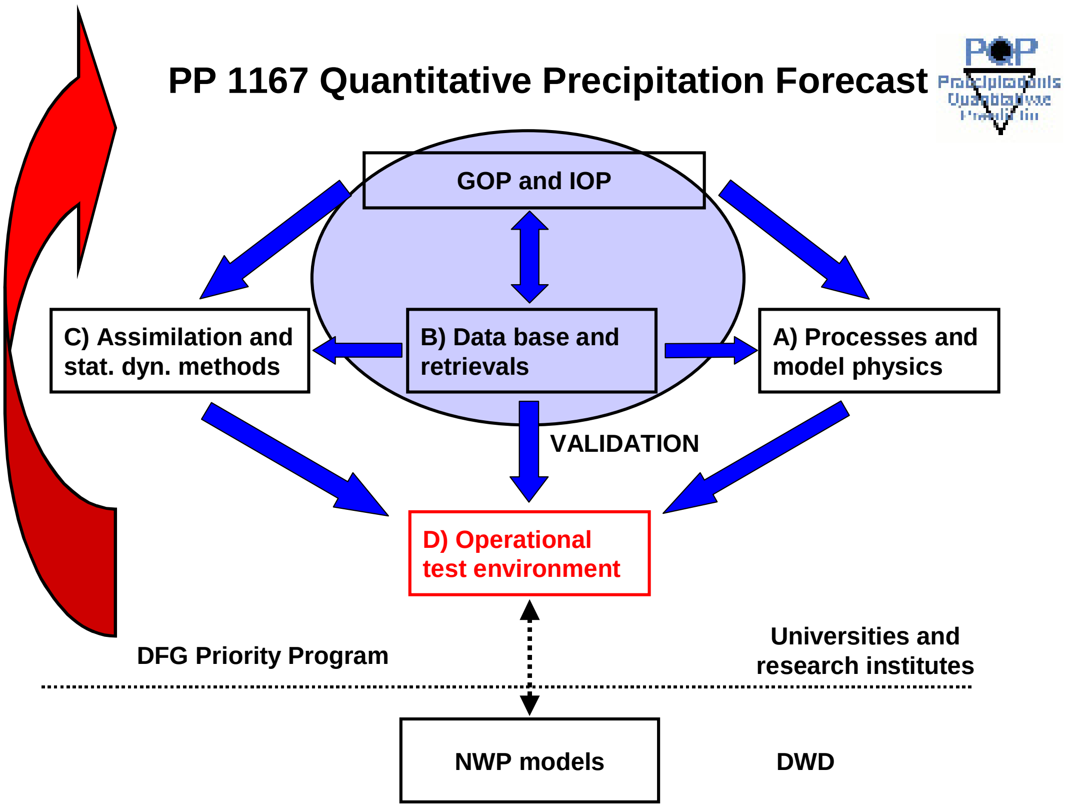


Fig. 1.1. *Structure of Priority Program 1167 Quantitative Precipitation Forecast - Praecipitationis Quantitativae Praedictio (PQP). GOP: General Observations Period, IOP: Intensive Observations Period = COPS*

The priority program focuses on reaching the following scientific objectives:

I. **Identification of processes responsible for deficiencies in QPF.**

II. **Determination and use of the potentials of existing and new data as well as new process descriptions to improve QPF.**

III. **Determination of the predictability of weather forecast models by combined statistical and dynamical analyses with respect to QPF.**

Presently, the main deficiencies of QPF are considered to be due to errors of the initial fields, suboptimal methods for the assimilation of observations, inadequate modeling of components of the water cycle, and fundamental problems in the interpretation of deterministic models.

The schedule of PQP is shown in Fig. 1.2. The program has been accepted in May 2003 and started in April 2004. The duration will be 6 years. The program is divided in three 2-year funding periods. More details are found on the PQP webpage (www.meteo.uni-bonn.de/projekte/SPPMeteo/).

	April 2004-2005	April 2005-2006	April 2006-2007	April 2007-2008	April 2008-2009	April 2009-2010
Year	1	2	3	4	5	6
	Period 1		Period 2		Period 3	
GOP				One year		
IOP	Phase 1: Preparation			Phase 2: Performance: Summer 2007	Phase 3: Data analysis	

Fig. 1.2. *Funding and timing of PQP. Exp: Experiment. GOP: General Observations Period, IOP: Intensive Observations Period (= COPS)*

23 research projects have been funded by the DFG after a review process, which took place in winter 2003/2004. These projects are related to surface-atmosphere exchange, convection, aerosol and cloud microphysics, data assimilation, remote sensing, numerics, and verification. More details are presented on the PQP web page. Strong collaboration between PQP PIs is fostered by the performance of joint workshops.

International collaboration is strongly supported. The field campaign, which is subject of this proposal, is an example.

Separately, funding has been requested for experiments, which shall be performed within the scope of the PQP. These experiments are imbedded in the center of the PQP program so that these activities can be coordinated with all PQP research projects. Furthermore, this permits to perform IOP projects and the corresponding data analysis within the duration of the PQP.

1.2 Experiments Within the Scope of PP 1167

The urgently required improvement of knowledge on the relevant processes as a basis of model optimization with respect to the currently blatant uncertainty of QPF can only be achieved when data are made available, which meet a far higher standard than the measurement values that are routinely recorded for weather forecast and climate investigation. It is therefore indispensable to extend the database by field experiments, where advanced sensors allow for the observation of decisive atmospheric variables. These include the atmospheric dynamics, the water vapor field, as well as cloud and precipitation parameters.

The experimental set up takes into account the huge temporal and spatial distribution of precipitation making the analysis of its statistics very difficult. The entire experiment shall comprise a large-area observation phase of one year **(General Observations Period, GOP)**, and a dedicated experiment regarding the precipitation process over several months **(Intensive Observations Period, IOP = COPS)**, providing high-resolution, four-dimensional measurements of atmospheric variables. This field campaign is the subject of this Science Overview Document (SOD).

During the GOP, all available observations routinely performed will be gathered (e.g., rain gauges, three-dimensional radar observations, satellite observations) in the GOP area covering the major part of Europe. Research institutes shall be supported for operating their "standard" instruments. Available instruments shall be redistributed within the GOP area to obtain information on the atmospheric state at certain sites as complete as possible. Strong cooperation with European Observatories (Cabauw, Chilbolton, Lindenberg, Palisieau) is planned. Additionally, at least one special long-term observation site shall be operated within the COPS area a critical location, which has been identified in the experiment preparation phase. The Atmospheric Radiation Measurement Program (ARM) Mobile Facility (AMF) has been requested for this purpose. This integration of operationally not employed data will result in the presently achievable optimum of information on the state of the atmosphere being supplied to a regional forecast system.

COPS shall be performed in summer 2007 in southwestern Germany and eastern France for 3 months. Precipitation processes will be observed in 4D by means of a synergy of a new generation of research remote sensing systems operated on ground, aircrafts and satellites. The whole life cycle of convective precipitation from the initiation of convection, to the formation and development of clouds, to the formation and development and decay of precipitation shall be observed in detail.

The combination of the GOP with COPS shall not only give rise to a far improved data set for assimilation and validation of models, but also to an improved in-depth process understanding. Evaluation of the data sets obtained under this priority program will lead to a better representation of relevant processes in models and, hence, to improved QPF.

2 COPS Science Goals and Hypotheses

It is the overarching objective of COPS to identify the physical and chemical processes responsible for the deficiencies in QPF over low-mountain regions with the target to improve their model representation. Correspondingly, the overarching goal of COPS is to

Advance the quality of forecasts of orographically-induced convective precipitation by 4D observations and modeling of its life cycle

The determination and use of the potentials of existing and new data sets and of better process descriptions are central issues to improve QPF in this context.

The COPS community developed the following fundamental hypotheses:

- Upper tropospheric features play a significant but not decisive role for convective-scale QPF in moderate orographic terrain.
- Accurate modeling of the orographic controls of convection is essential and only possible with advanced mesoscale models having a resolution of the order of a few kilometers.
- Location and timing of the initiation of convection depends critically on the structure of the humidity field in the planetary boundary layer.
- Continental and maritime aerosol type clouds develop differently over mountainous terrain leading to different intensities and distributions of precipitation.
- Novel instrumentation during COPS can be designed so that parameterizations of sub-grid scale processes in complex terrain can be improved.
- Real-time data assimilation of key prognostic variables such as water vapor and dynamics is routinely possible and leads to a significant better short-range QPF.

These hypotheses are the consequence of the gaps in our knowledge concerning QPF, which have been identified in chapter 1. Testing these hypotheses requires a combination of the most powerful remote sensing instruments with proven ground-based and airborne measurement techniques within COPS. Measurements must be arranged to obtain unachieved accuracy and resolution. Intensive collaboration with modelers and forecast centers providing deterministic and probabilistic forecasts is essential for model evaluation and testing these hypotheses. This requires a sophisticated scientific preparation and a careful coordination between the efforts of the institutions involved.

3 Key Research Components of COPS

The COPS science questions are addressed by four working groups (WGs), which have been established during the two recent COPS Workshop:

**WWRP or ARM proposal:

The **WG Initiation of Convection (CI)** is focusing on high-resolution, 4D observations and modeling of convection in orographic terrain. Dynamical and thermodynamic theories shall be developed to understand the complex flow and the related moisture variability in order to understand the timing and location of the initiation of convection. For this purpose, a unique combination of instruments will be applied to study the pre-convective environment in 3D including the upper tropospheric forcing and secondary forcing due to orography.

The **WG Aerosol and Cloud Microphysics (ACM**) is exploring the relationship between aerosol properties and cloud microphysics in a low-mountain region. For instance, they will study whether sub-cloud aerosol variability affect convective precipitation. The relation between cloud turbulence and condensation, coalescence, aggregation and thus precipitation is also addressed. Furthermore, the correlation between measurable aerosol properties and ice formation will be determined.

The **WG Precipitation Processes and its Life Cycle (PPL)** is investigating the role of orography for the development and organization of convective cells. A critical point is also the distribution of the condensed water into the different hydrometeor categories (cloud water and ice, graupel, snow, rain water) where large differences between mesoscale models have been noted. To study the development of graupel, hail and the drop size distribution of precipitation a combination of polarimetric radars, satellite observations, micro rain radars disdrometers will be used as well as observations supersites to study the onset of full precipitation from drizzle conditions.

The **WG Data Assimilation and Predictability (DAP)** is studying the impact of current and new observations for improving QPF. Data assimilation is the key to separate errors due to initial fields and parameterization, as the model can be forced to reduce forecast uncertainties due to initial fields by means of assimilation of the whole COPS and GOP data set. Therefore, data assimilation is an essential tool for process studies. Furthermore, using a variety of mesoscale models in combination with ensemble forecasting, studies on the predictability of convective precipitation shall be performed. A preliminary list of models to be applied within COPS is given in Appendix II.

3.1 Convection Initiation (CI)

Initiation of convection depends on various atmospheric and surface factors. They can be roughly attributed to differential surface heating, fronts (temperature fronts, differences in the wind/flow field such as gust fronts and gust convergence lines, moisture fronts), and upper tropospheric forcing related to large-scale advection of vorticity, upper level troughs, Rossby waves, and cold advection.

Mesoscale studies in flat terrain during IHOP_2002 demonstrated the potential of high-resolution model runs for process studies (Xue and Martin 2005a, 2005b) and of ensemble forecasts for sensitivity studies (Martin and Xue 2005). Furthermore, the potential of new high-resolution observations for improving the prediction of convection was highlighted (Wulfmeyer et al. 2005).

However, the relevant processes leading to CI in low-mountain regions are still hardly understood. Recent studies confirmed that coarse model resolution and non-representative parameterizations introduce significant biases for both modeled convective precipitation (Barthlott et al. 2005, Meißner et al. 2005) and frontal precipitation, e.g, during the Saxonian flood in 2002 (Zängl 2004a, 2004b) and in the Black Forest (Kunz and Kottmeier 2005a, 2005b). Open questions are related to the relative influence of

a) the convergence and updrafts created by forced lifting on the windward side and thermally-forced anabatic flow,

b) the wind shear profile in the region of the ridges,

c) variations in the depth of the convective boundary layer as well as in moisture, convective inhibition (CIN), and convective available potential energy (CAPE) across the mountain ridges,

d) the presence of gravity waves impinging on the ridges,

e) aerosol loading in the pre-convective environment influencing the diurnal cycle of boundary variables.

The latter topic demonstrates the importance of the interaction between CI and ACM processes.

Consequently, it is essential to perform 4D thermodynamic measurements of atmospheric variables in the troposphere in regions where CI is expected as well as throughout its depth within and upstream of the COPS region to assess its thermodynamic (CAPE, CIN) and dynamic state (sharpness and progression of fronts, vorticity, moisture, and temperature advection). This requires a new synergy of ground-based scanning, airborne, and space borne remote sensing systems.

3.2 Aerosol and Cloud Microphysics (ACM)

Although nothing is known about the global impact of aerosol particles on precipitation, evidence for the suppression of precipitation due to enhanced CCN concentrations have been found in clouds contaminated by ship tracks (Ferek et al. 2000), major industrial and urban emissions (Givati and Rosenfeld 2004, Rosenfeld 2000) and biomass burning smoke plumes from large forest fires (Andreae et al. 2004, Rosenfeld 1999).

Indirect aerosol effects on clouds have been investigated increasingly over the past five years both by modeling studies (cf. e.g., Lohmann and Feichter 2005, Seifert and Beheng, 2005) and field experiments (Feingold et al. 2003, Feingold et al. 2005a, Feingold et al. 2005b, Kaufman et al. 2005). In the latter approach, remote sensing systems such as lidars, radars, and microwave radiometers have been combined. For example, accurate observations of cloud liquid water content (LWC) and effective radius (r_e) are crucial (Feingold et al. 2005a) and can be improved by using new multi-channel microwave radiometers (Rose et al. 2005) in conjunction with advanced multi-instrument algorithms developed in the European Union (EU) projects CLOUDNET, Cloud Liquid Water Network (CLIWA-NET), and the European Cooperation in the Field of Science and Technology (COST) 720 “Integrated Profiling”. Furthermore, advanced cloud radar observations can provide the Doppler spectrum with high temporal resolution and allow a better detection of drizzle particles and updraft regions.

The EU project Baltic Sea Experiment (BALTEX) CLIWA-NET (Crewell et al. 2002) focused on a systematic observation and model evaluation of water clouds in Europe. The results revealed large model deficits (van Meijgaard and Crewell 2005) even in reproducing mean liquid water paths. The Baltex Bridge Cloud campaign (BBC) (Crewell et al. 2004) as part of CLIWA-NET emerged to a large experiment in August/September 2001 centered on the Cabauw station in the Netherlands. It was coordinated with the large-scale field experiment BRIDGE of BALTEX. A lesson from the BBC data analysis was the necessity to move from 1D to at least 2D observations to improve the representativeness of a model grid box (e.g., Willen et al. 2005). In this context it was found essential to get the atmospheric state as complete as possible at one site and therefore prefer less but well equipped sites to more sites with missing instrumentation.

In all these activities, the focus was on model evaluation with respect to cloud properties. Interaction of aerosol-cloud microphysics and their impact on precipitation was not considered. As it can be expected that aerosol-cloud microphysics has also an important impact on convective precipitation, a corresponding field study in a low mountain region is urgently required applying simultaneous observations of aerosol and cloud properties.

3.3 Precipitation Processes and their Life Cycle (PPL)

In Southern Germany, mesoscale convective systems, as well as super- or multi-cells, can live for several hours and propagate during that time for several hundreds of kilometers (e.g. Hagen et al. 1999, Hagen et al. 2000). This holds especially for large systems like squall lines. They are normally related to cold fronts, but develop well ahead of the front (50-200 km). Under these conditions, it is the prefrontal southwesterly flow with warm and humid air at low levels and prevailing cold air in upper levels, which destabilizes the prefrontal air mass and favors the development of organized deep convection (e.g., Meischner et al. 1991, Haase et al. 2000, Haase and Crewell 2000). If the wind field is influences by orography, convective cells will develop differently. The observations by Haase et al. (1997) showed a clear orographic influence on the development of a squall line. As shown above (see also

SOD, section 1.3), these systems are not predicted well enough in current mesoscale models.

Several studies demonstrated the importance of a detailed microphysical parameterization of the ice phase (e.g. Richard et al. 2003, Pfeifer et al. 2004) and the autoconversion rate between the particle classes (Xu et al. 2005) in NWP models. Verification of these processes can only be performed by polarimetric weather radar, which allows for retrieving 4D hydrometeor distributions and the flow within a thunderstorm cell. The potential also exists to perform these studies using operational radars (Friedrich and Hagen 2004). The development of hydrometeor classification schemes for polarimetric radars (Höller et al. 1994, Vivekanandan et al. 1999) gained new insight into the microphysical processes of graupel and hail formation. The retrieval of raindrop-size distribution from polarimetric radar observations (e.g. Seliga and Bringi 1976, Zhang et al. 2001) provided additional information on the underlying microphysics governing the initiation of precipitation. Recent progress in radar technology enabled to measure simultaneously surface layer refractivity fields as well as 3D cloud and precipitation fields (Weckwerth et al. 2005, Ellis et al. 2005). Convective systems can also be observed by space borne measurements of radiative temperatures of geostationary satellites.

Lightning detection techniques have been improved during the past few years. It is now possible to obtain a quasi 3D picture of flashes at Very Low Frequency / Low Frequency (VLF/LF) range and thus to discriminate between intra-cloud and cloud-to-ground lightning (Betz et al. 2004). These observations can be used for tracking of thunderstorms and attempts can be made to relate these data to cloud and precipitation microphysics like the simultaneous existence of solid and liquid particles (Fehr et al. 2005).

Within the WWRP, a global study on the lifetime of warm-season precipitation is ongoing. In the US it was found that convection, which was initiated in the Rocky Mountains, can have lifetimes of up to 60 h (Carbone et al. 2002). It was argued that this kind of mesoscale convection becomes correlated and reactivated by the diurnal cycle of boundary layer processes. A subsequent modeling study of this correlation failed to produce the observed lifetime and phase speeds of convective systems (Davies et al. 2003). In Europe, similar studies are ongoing but it seems that long-term coherence of convective systems is mainly present in the high-mountain regions such as the Alps. The organization and lifetime of convection is probably reduced in low-mountain regions. It is uncertain, which degree of coherence will remain. It is important to develop a general theory of the dependence of the lifetime and organization of convection in low-mountain regions on meteorological conditions. For this purpose, it is essential to perform field campaigns with 4D observations of thermodynamic, cloud, and precipitation properties.

3.4 Data Assimilation and Predictability (DAP)

As discussed previously (sections 2.1.1 and 2.1.3) the location and timing of convective precipitation depends on the synoptic or mesoscale flow, together with small-scale boundary-layer structures. For Alpine precipitation events, the small-scale flow is strongly constrained by the orography, and the greatest forecast sensitivity comes from the large-scale flow (Lascaux et al. 2004), while in other situations there is a strong sensitivity to perturbations in the model physics that primarily affect the local scales (Zängl 2004a, 2004b). To account for these various sources of uncertainty, regional ensemble forecasting systems have been constructed, using ensembles of global analyses and forecasts as boundary conditions to give variations in the larger scales (Molteni et al. 2001), and stochastic parameterizations or multimodel ensembles to give variations in the smaller scales (Bright and Mullen 2002, Quiby and Denhard 2003). In general it is difficult to know how accurately an ensemble forecast represents these various sources of uncertainty, because many of the significant structures are not well observed operationally, and model errors are poorly quantified. It is therefore essential that a measurement campaign considers both the large and small-scale factors controlling the precipitation in a given event, so that their roles can be identified and distinguished from model errors.

The operation of numerical weather prediction models at high resolution also provides the opportunity to reduce forecast uncertainty by assimilation of remote sensing data such as radar, lidar and passive instruments at full resolution and early results have shown great promise (Gao et al. 2004, Dowell et al. 2004, Wulfmeyer et al. 2005). There will be opportunities during the COPS measurement period, both for preliminary feedback on the performance of data assimilation systems, and to provide guidance for modifications to the observing strategy based on preliminary data impact studies.

4 Coordination with international activities

4.1 WWRP Research and Development Projects

COPS and MEDEX

4.2 THORPEX

THORPEX, a World Weather Research Programme, is a ten-year international research program under the auspices of the WMO Commission for Atmospheric Sciences to accelerate improvements in the accuracy of 1-day to 2-week high impact weather forecasts (Shapiro and Thorpe 2004). Research objectives are developed under four Sub-programs: Predictability and Dynamical Processes; Observing Systems; Data Assimilation and Observing Strategies; Societal and Economic Applications. THORPEX will address weather research and forecast challenges through international cooperation between academic institutions, operational forecast centers, and users of forecast products. A core research objective of THORPEX is to contribute to the design and demonstration of *interactive forecast systems* that allow information to flow interactively among forecast users, numerical forecast models, data-assimilation systems and observations to maximize forecast skill. Observation system test and targeting experiments are performed within so-called THORPEX Regional Campaigns (TreCs).

Research in connection with THORPEX is very interesting for COPS, as unique tools are developed and applied for QPF such as multi-ensemble prediction systems and targeting. In this connection, ECMWF is taking the lead to establish the THORPEX Interactive Grand Global Ensemble (TIGGE). Various research on ensemble prediction systems is performed such as studies of the role of observation and model errors on ensemble spread. The role COPS can play in connection with THORPEX goals includes the use of COPS observations as a validation network of targeted observations, performance tests of new in-situ and remote sensing systems, develop strategies for investigating predictability of convective precipitation, improvement of parameterizations, particularly of convection. **Therefore, it has been proposed to coordinate COPS with the first summertime European THORPEX Regional Campaign in 2007 (ETReC 2007). On the 2nd THORPEX ERC Meeting, Vienna,**

Austria, April 2005, this proposal was accepted by the THORPEX European Regional Committee.

4.3 WWRP Forecast Demonstration Project D-PHASE

As the first Research and Development Project of the World Weather Research Program (WWRP) of WMO, MAP has seen three phases so far: a *Development Phase* when the plans were made and the project was designed, the *Field Phase* with the SOP in fall 1999 and the *Analysis Phase* that is still ongoing and has brought a wealth of interesting results and insight in alpine meteorology (see Volkert 2004, Bougeault et al. 2001). Still, WWRP has encouraged the leading MAP scientists to consider a fourth or *Demonstration Phase,* namely the planning and organization of a Forecast Demonstration Project (FDP). FDPs form an essential part of the WWRP programs and are intended to confirm, by objective measures, the '*enhanced prediction capabilities* gained through improved understanding and/or the utilization of enabling technologies'.

The MAP Steering Committee has decided in early 2004 to establish a Working Group with the goal to explore the possibilities for, and define the details of a MAP FDP. In this working group, the national meteorological services of the Alpine (and some other) countries are represented as well as a number of university groups from atmospheric and hydrological sciences. The WWRP Science Steering Committee (SSC) just accepted the MAP FDP proposal.

The most relevant, high-impact, and best-studied aspect of weather with an international component in the Alps and during MAP is certainly heavy (orographic) precipitation and associated flooding. The main achievements of MAP in this respect can be summarized as follows:

- **Modeling**: The *operational use* of a high-resolution numerical model (i.e., the Canadian MC2) for decision-making purposes during the Special Observation Period, SOP (Benoit et al. 2002). Development of a new terrain-following coordinate for steep orography (Schär et al. 2002). Progress in hydrological modeling (Bacchi et al. 2003 and associated near-surface exchange processes (Rotach et al. 2004). Exploration of *ensemble prediction* of precipitation events in the Alps (e.g., Walser et al. 2004).

- **Observations**: The set-up of an alpine radar composite (e.g., Chong et al. 2000) and many related studies. High-quality Doppler lidar data and airborne data (e.g., Durran et al 2003). Small-scale soil moisture and near-surface hydrological observations (Zappa and Gurtz 2002).
- **Theory**: New insight in mechanisms of orographic precipitation (e.g., Medina and Houze 2003), PV banners and streamers (e.g., Schär et al. 2003).

Based on these achievements, *operationally forecasting flood events in the Alps* using high-resolution numerical modeling in connection with hydrological modeling has been decided to become the focus of the MAP FDP. Due to the foreseen emphasis on ensemble prediction techniques, the corresponding project is called **D-PHASE**: **D**emonstration of **P**robabilistic **H**ydrological and **A**tmospheric **S**imulation of flood **E**vents in the Alps. It will include the elements high-resolution atmospheric modeling (km-scale), ensemble prediction, data assimilation (e.g., radar composits), small-scale processes and hydrological modeling. The ultimate goal is to provide improved forecasts to the end users (civil protection authorities, water managers etc.).

Previously, a *demonstration phase* was foreseen for fall 2006, i.e. the season of the MAP SOP (September to November). **However, due to the unique opportunity to coordinate MAP FDP with COPS, this phase has been moved to the period of summer 2007 to winter 2008.** In connection with the modeling efforts, possibilities are being explored to make available some additional data during the very demonstration phase, to some extent thus mirroring the additional value of radar composites during the actual SOP. This might be achieved, for example, through collaborative efforts with EUCOS (EUMETNET Composite Observing System).

The relations of D-PHASE to COPS are apparent in as both projects deal with (heavy) precipitation, its observation and forecast, and both are tied to (more or less) complex terrain. The most pronounced difference between the two projects is the fact that D-PHASE is by definition a *forecast* demonstration project and hence heavily relies on modeling. COPS, on the other hand, has its focus on observations.

Clearly, the participants in COPS will be able to profit from the experience and outcomes of D-PHASE. The MAP experience with using high-resolution numerical modeling in the day-to-day mission planning during the SOP was indeed very fruitful and significantly contributed to the success of MAP.

The expected outcome of D-PHASE will consist of a strategy to forecast heavy precipitation events (a mixture between mid-range EPS forecast and short-range deterministic forecast combined with observations), demonstration of coupling capabilities between atmospheric and hydrological models and evaluation protocols and strategies in order to assess the value of all these forecasts to end users. Clearly, all these products will be available to the COPS community.

4.4 TRACKS

TRACKS "Transport and Chemical Conversion in Convective Systems (TRACKS)" has been planned by six Helmholtz-Centers to merge their expertise in initiating and organizing ambitious large-scale international experiments in atmospheric sciences, which are out of reach for university groups and smaller research institutes. Within the TRACKS project, the Helmholtz-Centers plan to study convective processes, which are of crucial importance to climate and environmental research. The present concept foresees three experimental regions (Tropics, Mid-Europe, Northern Europe), where measurement campaigns will be initiated and supported. The scientific focus of TRACKS is on (i) transport processes and precipitation formation in convective systems, (ii) influence of convection on the trace gas balance of the atmospheric boundary layer, and (iii) influence of deep convection on the budget of climatically active constituents in the upper troposphere. The paper describing TRACKS can be downloaded from the websites of participating Helmholtz-Centers, such as *http://www.imk.uni-karlsruhe.de/fi/fzk/imk/seite_417.php*.

Perfectly matching the objectives of the COPS, it is planned to measure in great detail transport processes of energy, momentum, and humidity as well as of cloud microphysical processes in various types of convection. These processes shall be investigated on the scales ranging from individual convection cells to convective systems like fronts and organized convection. Accordingly, measurements shall be performed in convective systems during various states of development. It is therefore timely and of mutual benefit for both PQP and TRACKS to focus the experimental efforts in Mid-Europe on COPS in 2007. Accordingly, **COPS has formally been accepted as a TRACKS experiment by both the TRACKS steering board and the COPS ISSC.**

Other TRACKS objectives regard the influence of convection on the trace gas balance of the Atmospheric Boundary Layer and of the upper troposphere. The atmospheric boundary layer is that part of the atmosphere, where most natural and anthropogenic emissions and the most intensive chemical conversion takes place. As habitat of man, fauna, and flora, the boundary layer and its air quality are of significant importance. Transport, transformations within the boundary layer, and exchange processes between the boundary layer and the free atmosphere determine the spatial distribution of trace gases and the hand-over of primary trace gases or secondary products to the free troposphere. Both shallow and deep convection are supposed to play a decisive role in these transport and exchange processes, in particular as far as the distribution of short-living substances is concerned.

It is planned to experimentally determine the effective convection-induced trace gas fluxes from the ground up into the free troposphere under various boundary conditions. Measurements will be sufficiently detailed to allow an improved model of vertical transport by convection to be derived. Convection provides rapid pathways for short-living primary substances, which couple short time scales to large space scales. The contributions from shallow convection and the frequency of redistribution by deep convection will be assessed. These interacting biological, air chemical, and meteorological processes are far from being understood or quantified completely. This especially applies to the feedback of turbulent transport processes of trace gases to HO_x chemistry, the associated conversion rates in the boundary layer, and further transport into the free troposphere.

Foreseeable contributions to the COPS-related experiment of TRACKS would be from Research Center Jülich (FZJ, ICG; gas phase chemical measurements from ground and from an instrumented air ship (ZNT)), Forschungszentrum Karlsruhe (FZK, IMK-TRO; air chemical and meteorological measurements from Do128 aircraft), Geoforschungszentrum Potsdam (GPS water vapor network from ground stations) and Deutsches Zentrum für Luft- und Raumfahrt (DLR, IPA; own contributions to Polarisation Radar, Falcon aircraft, lightning location network).

4.5 Atmospheric Radiation Measurement Program

**Set up and operation of the AMF.

4.6 Summary

During COPS, a large community will come together benefiting from previous collaboration within field campaigns and projects in atmospheric sciences. COPS is focusing on one of the most challenging but also on the most important topics in atmospheric sciences, QPF. Tools for advancing QPF shall be developed which can also be applied in other critical regions of the globe.

An ambitious experiment like COPS can only be successful, if it is linked with other international activities. Figure 8.1 demonstrates that this effort has already resulted in COPS being coordinated with the most important projects in meteorological sciences. The infrastructure of different leading research institutes will be combined and funding of different programs will be put together. This leads to a win-win situation not only for all participants but also for the funding agencies, as the output of this program will have a significantly higher impact on progress in atmospheric sciences. Due to the large international collaboration, which has been initiated in connection with COPS, it was reasonable to propose this experiment as WWRP RDP. **At the 8th Session of the WWRP SSC, this proposal was endorsed so that COPS became the first WWRP RDP initiated by German scientists.** Details of the ongoing collaboration are subject of COPS DFG Proposal such as coordination of D-PHASE model runs and ETReC07 activities with COPS. Furthermore, a very important topic is the organization of data archiving and data structure. It has been proposed that the group Models & Data at the Max Planck Institute for Meteorology (MPI) in Hamburg, Germany, will be the main data center using the same infrastructure for model data storage as TIGGE at ECMWF. Also all field data shall be stored at MPI with extensive quality control. Further details are discussed in section 10 of the SOD and sections 3.2 and 4 of the DFG proposal.

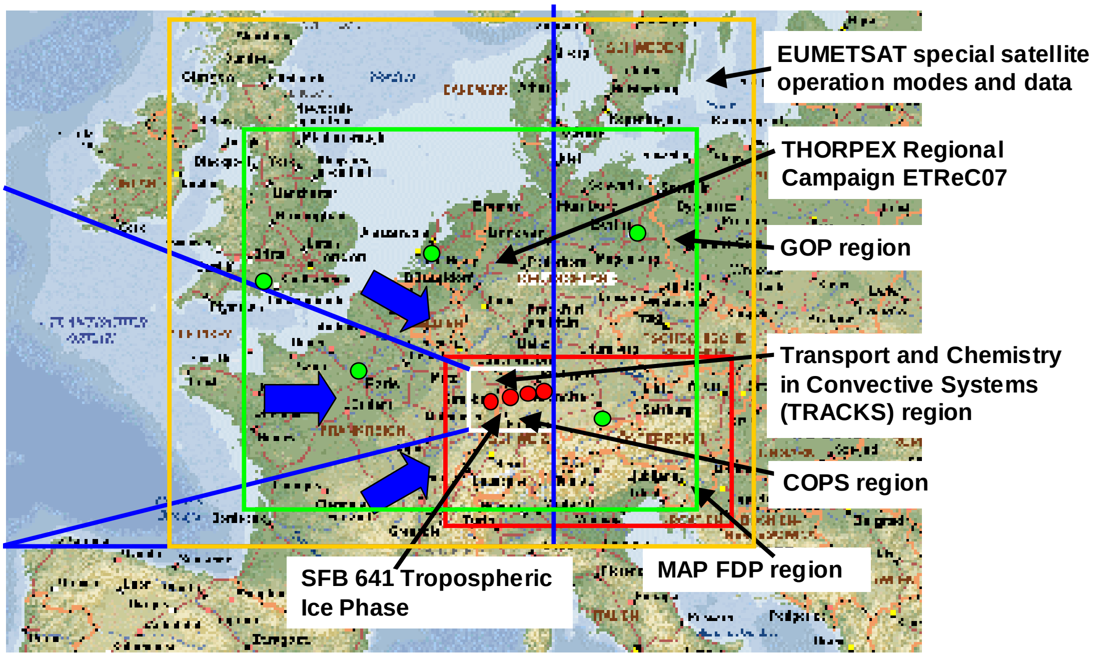
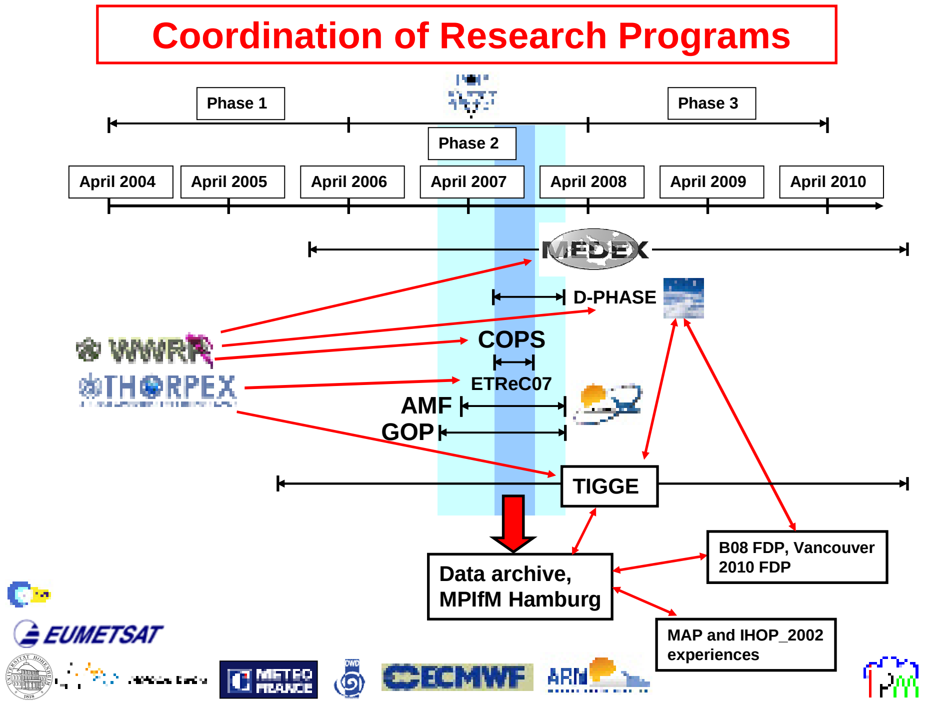


Fig. 8.1: Coordination of COPS measurements with other international activities.

5 Field schedule and duration in coordination with international programs



6 COPS Instrumentation

6.1 Ground-based operational networks

6.2 Ground-based research networks

6.3 Supersites

6.4 Aircrafts

6.5 Satellite observations

7 Measurement Strategy

7.1 General approach

7.1.1 Validation Efforts

Thorough control of the data quality is the fundamental basis of the success of any measurement. This is especially true for large campaigns in atmospheric science where the latest generation of state-of-the-art instruments and novel measurement techniques are employed in the field. In addition to internal quality control and standard calibration, the measurement data of the same quantity must also be compared with each other in order to ensure a consistent data set. Consequently, part of the operation time of the instrumentation will be allocated repeatedly during COPS for intercomparisons.

It is obvious that intercomparisons have to be as close in space and time as possible to minimize the effects of atmospheric variability. Thus stacked formation flights of the aircrafts carrying remote sensing instrumentation will be performed. These intercomparison flights need not be at the cost of employing the same instruments for the other meteorological aims of the campaign, e.g., they can be made on the ways to and from the central region of interest. In addition to such stacked formation flights also frequent overpasses over the ground-based supersites will be organized when the flight patterns are planned. Frequent overpasses are necessary to identify potential instrumental biases with good accuracy as the data of the remote sensing instruments are averaged in space and time and different air masses are sampled during these airborne/ground-based intercomparisons (Behrendt et al. 2005a,b). In extension to what was done in previous campaigns, all performed intercomparion cases will be listed in real-time to assure that there will be enough cases for statistical analysis of the data. Software tools for recording airplane-airplane meetings/stacked formation flights and supersite overpasses will be developed well in advance with information like instruments in operation at the same time, flags for good data quality, e.g., without thick clouds for lidar intercomparisons, day/night condition and different atmospheric conditions (clear air/cloudy, moist/dry, hot/cold, different aerosol content, different wind directions/velocities etc.).

Previous to the data comparison during COPS in the field, the potential instrumentation of COPS shall be validated as good as possible. In summer, 2005 there was one of such rare opportunities for intercomparisons during LAUNCH2005. A second campaign where some of the proposed German instruments are involved in, will be the field experiment within the virtual HGF institute COSI-TRACKS in summer 2006. In addition to data comparisons, also algorithm comparisons by the use of synthetic data are planned in advance of the COPS field phase for instruments using the same techniques.

7.1.2 Phases for observing the chain of key processes

According to the scientific considerations made in chapter 6 and to the analysis of existing instrumentation, we distinguish between four observation phases (see Fig.7.1) in order to observe the whole process chain from convective initiation over cloud microphysics to precipitation. Furthermore, we perform the measurements in three adaptive target areas as defined in section 6.1. Instruments will be deployed in several supersites in order to take advantage of sensor synergy as described in section 7.4.

Phase 1 is defined by the presence of a pre-convective situation. During this time, mainly three activities will take place. Within the ETReC07 (see Fig. 8.1), targeting will be performed for improving large-scale forecasts a few days ahead before CI is taking place. Mesoscale targeting for better characterization of the inflow in the COPS area will take place at suitable located surface stations as well as by airborne and satellite observations. Meanwhile, boundary layer processes will be characterized in great detail in the COPS domain.

During **Phase 2**, CI takes place. The operation mode of scanning remote sensing systems will be adapted to 3D observations of atmospheric key variables. Aerosol in-situ, scanning microwave radar and radiometer measurements will be added for extending the range of 3D observations into clouds and for investigation aerosol-cloud interaction.

During **Phase 3**, CI is continuing and precipitation is forming. Clear-air and cloud measurements will be continued to study the organization of convection, and precipitation radars will be added. Tracking of the convective system will be performed with ground-based mobile instrumentation, aircrafts, radar systems with large range, as well as satellite observations.

Phase 4 is defined by the maintenance and decay of the convective system, which will also be observed as continuous and detailed as possible. These observations will be surrounded by a preparatory phase based on mesoscale forecasts and an important accompanying activity, the real-time data assimilation of COPS and GOP observations.

Details of this strategy are worked out in the PP1167 COPS DFG proposal, as this depends on the type of instruments, which have been requested.

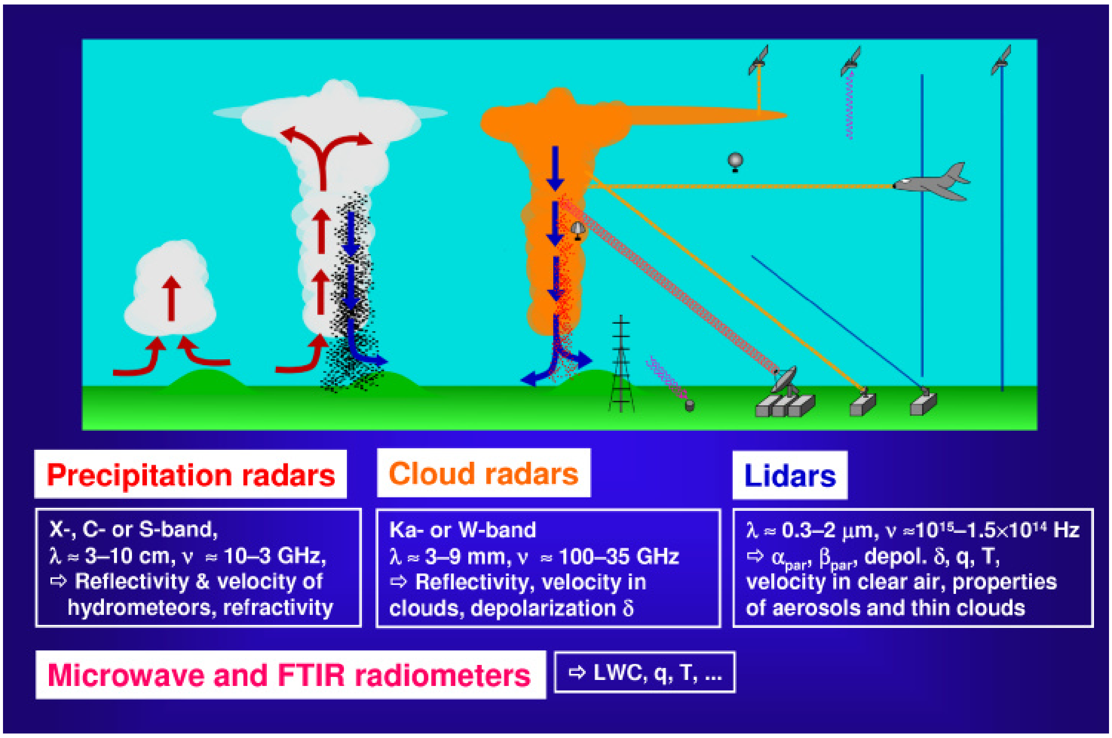


Fig.7.1. *Proposed sensor synergy for COPS for observing the life cycle of convective precipitation. Schematic of instrumentation at the three Supersites, whose locations are shown in Fig.4.1. The Supersites will consist of a synergy of in-situ sensors as well as passive and active remote sensing systems such as radiometers, precipitation radars, cloud radars, and different types of lidars. These instruments will be operated from mobile, ground-based, airborne and space-borne platforms. This way, convective processes will be studied in high spatial and temporal resolution and in both clear air and within clouds.*

7.2 Proposed Missions and their coordination

7.2.1 CI

7.2.2 ACM

7.2.3 PPL

7.2.4 DAP

7.2.5 Instrument intercomparison and validation

8 Mission selection

8.1 Functions and Communications Flow

8.2 MST Chairperson Responsibilities

8.3 Mission Scientist Responsibilities

8.4 Flight Scientist Responsibilities

8.5 Candidate Scientific Operations Personnel

8.6 The Mission Planning Process

8.6.1 Proposal Preparations

8.6.2 Daily Planning Meeting

8.6.3 Mission Plan

8.6.4 Optional Evening (or other) Update Meeting

9 Mission performance

9.1 Aircraft Coordination

9.2 Mobile Team Coordination

9.3 Coordination of Special Observations from Fixed Sites

9.4 Primary Operations Center Team Staff Responsibilities

9.4.1 Operations Director

9.4.2 Aircraft Coordinator

9.4.3 Ground System Coordinator

9.4.4 Status Coordinator

9.4.5 Field Documentation Coordinator

9.4.6 Communications Assistant

9.4.7 Forecasting/Nowcasting Coordinator

9.4.8 Logistics/Administrative Coordinator

9.4.9 OC Site Manager

9.4.10 Airport Site Coordinator

9.4.11 Hornisgrinde Site Coordinator

9.4.12 Operations Center Candidate Staff

9.5 Operations Center Logistics

9.5.1 OC Communications

9.5.2 OC Internet Access

9.5.3 OC Security

9.6 Team Descriptions: Missions and Personnel

9.6.1 Field Coordinator

9.6.2 Mobile Ballooning Laboratories

9.6.3 Photography

9.6.4 Coordination with Aircraft for CI, ACM, PPL, and DAP Missions

9.6.5 Base Locations of Ground-based Mobile Facilities

9.7 Communications

9.7.1 Phone Communication

9.7.2 Cellular Phones

9.7.3 Internet Communications

10 Instrument Descriptions

11 Aircraft Operations

12 Daily COPS Forecasting and Nowcasting Support

12.1 Introduction

12.2 Locations of Forecasting, Briefings and Nowcasting Support

12.3 Spatial and Temporal Domains of Interest for COPS Working Groups

12.4 Daily Operations Schedule

12.5 Forecast Products

12.5.1 Nowcasting

12.5.2 Day-1 Forecasts

12.5.3 Day-2 Forecasts

12.5.4 Day-3 Forecasts

12.5.5 Ensemble Forecasts

12.5.6 Forecast Dissemination

Appendix IV: Abbreviations

1D, 2D, 3D, 4D	1-Dimensional, 2-Dimensional, 3-Dimensional, 4-Dimensional
3DVAR	3 Dimensional Variational Assimilation
4DVAR	4 Dimensional Variational Assimilation
ACM	Aerosol and Cloud Microphysics, working group of COPS
ACTOS	Airborne Cloud Turbulence Observation System
AERI	Atmospheric Emitted Radiance Interferometer
AIRS	Atmospheric Infrared Sounder
aLMo	Alpine Model (based on LM)
AMF	ARM Mobile Facility
AQUA	Advances in Quantitative Areal Precipitation Estimation by Radar, DFG project
ARM	Atmospheric Radiation Measurement
Arôme	New French mesoscale forecast model
ARPA-SIM	Agenzia Regionale Prevenzione e Ambiente Dell’Emilla-Romagna – Servizio Idro Meteo
ARPS	Advanced Regional Prediction System
ATR 42	Avions de Transport Regional 42 (aircraft)
ATReC	Atlantic-THORPEX Regional Campaign
BAe 146	British Aerospace 146 (aircraft)
BALTEX	Baltic Sea Experiment
BUFR	Binary Universal Form for the Representation
CAPE	Convective Available Potential Energy
CAPS	Coupled Atmosphere–Plant–Soil (global model)
CART	Cloud and Radiation Testbed
CCN	Cloud Condensation Nuclei

CEOP	Coordinated Enhanced Observing Period
CI	Convection Initiation
CLEOPATRA	Cloud Experiment Oberpfaffenhofen And Transport (campaign 1991)
CLIWA-NET	Cloud Liquid Water Network
CloudNET	Research project supported by the European Comission
CLOUDSAT	NASA Earth System Pathfinder Satellite mission
CNRS	Centre Nationale de la Recherche Scientific
CODI	Compact DIAL
COPS	Convective and Orographically-induced Precipitation Study (= intensive observations period (IOP) of PQP)
COSI-TRACKS	Convective Storm Institute within TRACKS
COSMO-LEPS	Consortium On Small Scale MOdelling-Local Ensemble Prediction System
COST-720	European Cooperation in the Field of Science and Technology, Action 720: Integrated Ground-Based Remote Sensing Stations for Atmospheric Profiling
CrIS	Cross-Track Infrared Sounder
CSIP	Convective Storm Initiation Project (UK, summer 2005)
CVI	Counterflow Virtual Impactor
D-PHASE	Demonstration of Probabilistic Hydrological and Atmospheric Simulation of flood Events in the Alpine region; MAP Forecast Demonstration Project
DAP	Data Assimilation and Predictability, working group of COPS
DAQUA	Combined Data Assimilation with Radar and Satellite Retrievals and Ensemble Modelling fort he Improvement of Short Range Quantitative Precipitation, project within PQP
DFG	German Research Foundation, Deutsche Forschungsgemeinschaft
DIAL	Differential Absorption Lidar

DLR	Deutsches Zentrum für Luft- und Raumfahrt
DOE	Department of Energy
DOW	“Doppler-on-Wheels”, mobile radar system
DSD	Drop Size Distribution
DWD	Deutscher Wetterdienst, German Meteorological Service
EC	European Comission
ECHAM5	ECMWF model HAMburg version, release 5
ECMWF	European Centre for Medium-Range Weather Forecasts
EMETNET	The Network of European Meteorological Services
Envisat	Environmental Satellite
EOS	Earth Observing System
EPS	The Canadian ensemble prediction system
ESA	European Space Agency
ETReC07	European THORPEX Regional Campaign 2007
EU	European Union
EUCOS	EUMETNET Composite Observing System
EULINOX	European Lightning Nitrogen Oxides Project
EUMETSAT	European Organization for the Exploitation of Meteorological Satellites
FDDA	Four Dimensional Data Assimilation
FDP	Forecast Demonstration Project
FM-CW	Frequency Modulated Continuous Wave
FSL	Forecast Systems Laboratory
FTIR	Fourier Transformed Infrared
FZJ	Research Center Jülich
FZK/UKa	Forschungszentrum Karlsruhe, Universität Karlsruhe
GFZ	GeoForschungsZentrum Potsdam, Research Centre for Geosciences Potsdam

GME	Global Model of the DWD
GOES	Geostationary Satellite Server
GOP	General Observations Period of PQP
GPCP	Global Precipitation Climatology Project
GPS	Global Positioning System
GTS	Global Telecommunication System
GWA	Ground Water Atlas
HATPRO	Humidity and Temperature Profiler
HELIPOD	Helicopter-borne Turbulence Probe, University of Braunschweig
HGF	Helmholtz-Gemeinschaft Deutscher Forschungszentren
HODAR	Holographic Particle Recorder, University of Mainz
HRDL	High-Resolution Doppler Lidar
HTDMA	Humidified Tandem Differential Mobility Analyzer
IASI	Infrared Atmospheric Sounding Interferometer
ICG	Institut für Chemie der Geosphäre
IFS	Integrated Forecast System of ECMWF
IfT	Institute for Tropospheric Research
IHOP_2002	International Water Vapor Project 2002 (USA, 2002)
IMAA	Istituto di Metodologie per l’Analisi Ambientale
IMK	Institut für Meteorologie und Klimaforschung, Karlsruhe
IMPROVE	Improvement of Microphysical Prameterization through Observational Verification Experiment
INSU	Institut National des Sciences de l'Univers
INT	Interstitial Inlet
IOP	Intensive Observations Period = COPS
IPA	Institute of Atmospheric Physics
IPM	Institute of Physics and Meteorology, University of Hohenheim

IPT	Integrated Profiling Technique
IR	infrared
IRCTR	International Research Centre for Telecommunications-Transmission and Radar
ISSC	International Science Steering Committee
IWV	Integrated columnar Water Vapour
KAMM	Karlsruher Mesoscale Model
LaMMA	Laboratory for Meteorology and Environmental Modelling
LAUNCH2005	International Lindenberg campaign for assessment of humidity and cloud profiling systems and its impact on high-resolution modelling, Field experiment (Germany & Italy, 2005)
LINOX	Lightning produced NO_X (1996)
LM	Lokalmodell of DWD
LME	LM Europe
LMK	Lokal Modell Kürzestfrist
LWC	Liquid Water Content
LWP	Liquid Water Path
MAP	Mesoscale Alpine Programme
MC2	Modèle Mésoéchelle Compressibile Communautaire (Canada)
MERIS	Medium Resolution Imaging Spectrometer
Méso-NH	french mesoscale model
Met Office UK	British Weather Service
Meteo France	French Weather Service
MeteoSwiss	swiss Weather Service
METRAS	Mesoscale Transport and Fluid Model
MICCY	Microwave Radiometer for Cloud Cartography
MITRAS	Microscale Transport and Fluid Model
MM5	Mesoscale Model Release 5
MMM	Micro Meteorological Masts

MODIS	Moderate Resolution Imaging Spectroradiometer
MPI	Max-Planck-Institute
MPIfC	MPI for Chemistry
MPIfM	MPI for Meteorology
MRR	Micro rain radar
MSC	Meteorological Service of Canada
MSG	Meteosat Second Generation
MWL	Multi-Wavelength Raman Lidar of IfT
NASA	National Aeronautics and Space Administration
NCAR	National Center for Atmospheric Research
NCAR ATD	NCAR Atmospheric Technology Division
NCAR MMM	NCAR Mesoscale & Microscale Meteorology Division
NCAS	NERC Centres for Atmospheric Science
NCEP	National Centers for Environmental Prediction
NERC	Natural Environment Research Council
NINJO	Meteorological workstation of DWD
NIR	near infrared
NOAA	National Oceanic & Atmospheric Administration
NSF	National Science Foundation (USA)
NVaP	NASA Water Vapor Project
NWP	Numerical Weather Prediction
OC	Operations Center
OP	Operations Plan
PBL	Planetary Boundary Layer
PEPS	Poor Man’s EPS
PI	Principal Investigator
POLDIRAD	Polarization Diversity Doppler Radar, DLR Oberpfaffenhofen

PP	priority program (= SPP1167, Schwerpunktprogramm1167 = PQP)
PPL	Precipitation Processes and its Life Cycle, working group of COPS
PQP	Praecipitationis Quantitativae Praedictio (Latin for "quantitative precipitation forecast"), Priority Program 1167 of DFG
PrI	Precipitation Initiation
QPF	Quantitative Precipitation Forecast
RAMS	Regional Atmospheric Modeling System
RASL	Raman Airborne Spectroscopic Lidar
RASS	Radio Acoustic Sounding System
RDSD	Rain Drop Size Distribution
REAL	Raman-shifted Eye-save Aerosol Lidar
REKLIP	Regionales Klimaprojekt
RISH	Research Center for a Sustainable Humanosphere
RR	Rain Rate
RR	Rotational Raman
RS	Radiosonde
RV	Reduction of variance
S-POL	S-band Dual Polarization Doppler Radar
S-POL	S-Pol radar of NCAR
SAFIRE	Surveillance et Alerte Foudre par Interférometrie Radioélectrique; Blitz-Ortungssystem des Instituts für Meteorologie und Klimatologie, Universität Hannover
SETEX	Severe Thunderstorms Experiment
SEVIRI	Spinning Enhanced Visible and Infra-Red Imager
SFB	Sonderforschungsbereich
SGP	Southern Great Plains

SISOMOP	Simple Soil Moisture Probe
SMPS	Scanning Mobility Particle Spectrometer
SOD	Science Overview Documentation of COPS
Sodar	Sonic Detecting and Ranging
SOP	Special Observing Period
SRB	Surface Radiation Budget
SRL	Scanning Raman Lidar
SRQPF	Short-Range QPF, project within PQP
SSC	Science Steering Committee
SSM/I	Special Sensor Microwave Imager
SYNOP	Surface Synoptic Observations
TDR	Temperature Data Record
THORPEX	The ObservingSystem Research and Predictability Experiment
TIGGE	THORPEX Interactive Grand Global Ensemble
TIROS	Television Infrared Observation Satellite
TOVS	TIROS Operational Vertical Sounder
TRACKS	Transport and Chemical Conversion in Convective Systems; HGF project
TRACT	TRansport of Air pollutants over Complex Terrain
TreCs	THORPEX Regional Campaigns
UCAR	University Corporation for Atmospheric Research
UFAM	Universities' Facility for Atmospheric Measurement
UHF	Ultra High Frequency
UHOH	Universität Hohenheim, University of Hohenheim
UK	United Kingdom
UM-ELA	Unified Model – European Limited Area
UM-G	Unified Model - Global
UM-M	Unified Model - Mesoscale

US	United States
UTC	Coordinated Universal Time
UTMS	Urban Transportation Modeling System
UV	ultraviolet
UWKA	University of Wyoming King Air
VERTIKATOR	Vertikaler Transport und Orographie, Field experiment, see http://www.vertikator-afo2000.de/ (Germany, 2002)
VIS	visible
WCRP	World Climate Research Programme
WDCC	World Data Center for Climate
WG	Working Group of COPS
WiLi	Wind Lidar of IfT
WindTracer	Scanning Doppler Wind Lidar from IMK/FZK
WMO	World Meteorological Organization
WRF	Weather Research & Forecasting Model, mesoscale model
WRF-Chem	WRF with a chemistry module
WSR-88D	Weather Surveillance Radar 88 Doppler
WTR	Wind-Temperature Radar
WV	Water Vapour
WWRP	World Weather Research Programme
WWRP RDP	WWRP Research and Development Project