THE CONVECTIVE AND OROGRAPHICALLY INDUCED PRECIPITATION STUDY

A Research and Development Project of the World Weather Research Program for Improving Quantitative Precipitation Forecasting in Low-Mountain Regions

by Volker Wulfmeyer, Andreas Behrendt, Hans-Stefan Bauer, Christoph Kottmeier, Ulrich Corsmeier, Alan Blyth, George Craig, Ulrich Schumann, Martin Hagen, Susanne Crewell, Paolo Di Girolamo, Cyrille Flamant, Mark Miller, Andrea Montani, Stephen Mobbs, Evelyne Richard, Mathias W. Rotach, Marco Arpagaus, Herman Russchenberg, Peter Schlüssel, Marianne König, Volker Gärtner, Reinhold Steinacker, Manfred Dorninger, David D. Turner, Tammy Weckwerth, Andreas Hense, and Clemens Simmer

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Quantitative precipitation forecasting (QPF) in low-mountain regions is a great challenge for the atmospheric sciences community. On the one hand, orographic enhancement of precipitation in these regions can result in severe flash-flood events. On the other hand, the relative importance of forcing mechanisms leading to convection initiation (CI) is neither well understood nor adequately reproduced by weather forecast models. This results in poor QPF skill, both in terms of the spatial distribution of precipitation and its temporal evolution.

Two prominent systematic errors of state-of-the-art mesoscale models are identified. Figure 1 shows the difference between a 1-month average of 24-h integrated precipitation forecasted with the Consortium for Small-Scale Modeling (COSMO)-EU Model (formerly known as Lokalmodell) of the German Meteorological Service (DWD) and the corresponding observational data. Shown on this figure is the Black Forest low-mountain region in southwestern Germany. Strong systematic errors are found on both the windward and the lee sides. On the windward side, the model strongly overestimates precipitation, whereas on the lee side it is underestimated, which we call the "windward/lee effect." To our knowledge, this error is found in all mesoscale models for both weather prediction and climate simulations, which require convection parameterization, such as in COSMOCH7 of Meteo Swiss, ARPEGE and ALADIN of Meteo France, as well as in the mesoscale models MM5 and ETA. Although we show a summertime example here, Baldauf and Schulz previously demonstrated that this error structure exists during all seasons.

Another key problem is the inadequate simulation

of the diurnal cycle of atmospheric variables. Although this is a well-known and long-standing problem of weather and climate simulation models, no significant improvement has been made to date. Thorough validation efforts of weather forecast centers confirm that not only is the diurnal cycle of precipitation incorrectly predicted, but the cycles of boundary layer variables such as temperature, water vapor, and wind are incorrect as well. Generally, weather forecast models are simulating initiation of convection several hours too early so that precipitation is simulated several hours in advance.

Both the windward/lee effect and the diurnal cycle problem strongly limit the application of mesoscale models for many decision makers and end users alike (e.g., hydrologists generally refrain from using QPF results to extend the lead time for flash flood warnings). Furthermore, these deficiencies also limit the use of regional climate models for decision makers. Consequently, improving QPF is a key crosscutting issue for both the World Weather Research Program (WWRP) and the World Climate Research Program (WCRP).

In order to address these challenges, the German Research Foundation (DFG) established the Priority Program 1167, "Quantitative Precipitation Forecast PQP (Praecipitationis Quantitativae Predictio)," in April 2004 with 23 QPF-related research projects (see also www.meteo.uni-bonn.de/projekte/SPPMeteo).

From the beginning of this priority program, the initiators considered it essential to provide extensive observation programs for validating mesoscale models and improving the representation of key processes. PQP originated two specific programs to cover these points: the General Observing Period (GOP, see http://gop.meteo.uni-koeln.de) and the Convective and Orographically Induced Precipitation Study (COPS, see www.uni-hohenheim.de/cops).

COPS is part of a series of experiments for improving QPF in different weather regimes, including the Mesoscale Alpine Programme (MAP), the International Water Vapor Project (IHOP_2002), and the Convective Storm Initiation Project (CSIP).

The aim of MAP, the first WWRP Research and Development Project (RDP), whose field phase took
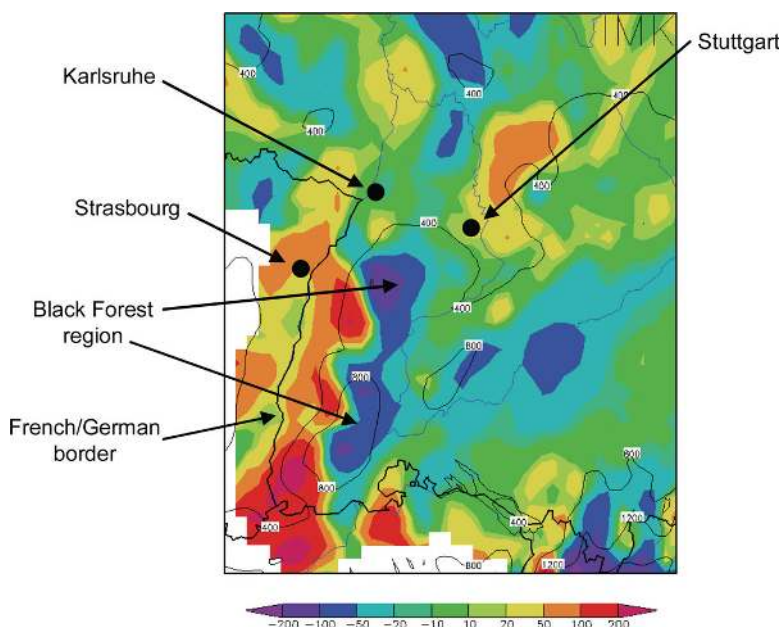

FIG. 1. Difference (mm) between predicted and observed precipitation in the Black Forest region for August 2004 using the COSMO model of the DWD with a grid resolution of 7 km, confirming the windward/lee problem. The thin black lines indicate the topography. The mean prevailing wind is from the west. The locations of major cities and the French/German and German/Swiss borders are also shown. (Courtesy of L. Gantner, IMK, Karlsruhe, Germany.)

place in 1999, was to understand precipitation over the Alps and to determine three-dimensional circulation patterns in the vicinity of high mountains. IHOP_2002 was performed in the southern Great Plains of the United States, which is flat terrain but has large mesoscale variations in dynamics and moisture (e.g., strong moisture gradients along the dryline). The CSIP experiment was conducted over the southern United Kingdom in 2005. The high latitude of this marine environment makes sea-breeze effects in combination with transient synoptic forcing by fronts, troughs, and potential vorticity anomalies important for the understanding and prediction of convective initiation. There is a gradual transition toward more complex terrain from IHOP_2002 and CSIP to COPS. The diurnal cycle is also different in these three regimes. The COPS region is more maritime than the IHOP_2002 region but more continental than the CSIP domain. In the low-mountain region of COPS, we expected convection initiation to be determined by a subtle balance between forcing mechanisms due to land-surface

processes and orography, as well as to mesoscale and large-scale conditions. Together these experiments are striving to improve our understanding of convection initiation and QPF over a broad-flow regime.

COPS OVERVIEW. In the region selected for COPS (Fig. 2), severe thunderstorm activity is present in summer but the skill of numerical weather prediction (NWP) models is particularly low. This "natural convection laboratory" hosted the international field campaign from 1 June to 31 August 2007.

The overarching goal of COPS is to *advance the quality of forecasts of oro-graphically induced convective precipitation by four-dimensional observations and modeling of its life cycle* for identifying the physical and chemical processes responsible for deficiencies in QPF over low-mountain regions. Within a strong collaboration between atmospheric scientists, modelers, and instrument principal investigators (PIs) at various universities and research and weather forecast centers, a list of fundamental hypotheses has been developed:

- 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 featuring a resolution of a few kilometers.
- Location and timing of the initiation of convection critically depends 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 subgrid-scale processes in complex terrain can be improved.
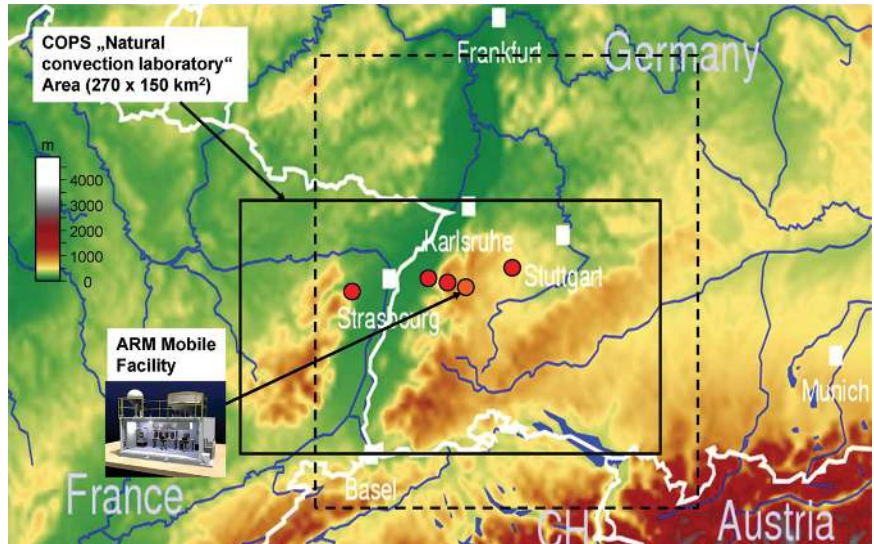

FIG. 2. Solid black line: the **COPS region**. Dashed black line: **validation box shown in Fig. 1**. Red/orange circles: locations of five Supersites where a synergy of remote-sensing systems was deployed. The orange circle represents the Atmospheric Radiation Measurement Program Mobile Facility (AMF).

- Real-time, mesoscale data assimilation of key prognostic variables such as water vapor and dynamics is routinely possible and leads to a significantly better short-range QPF.

In order to address these hypotheses, observations of the full life cycle of convective precipitation—from the preconvective environment, to the initiation of convection, to the initiation and development of clouds and precipitation—are essential.

LINKS BETWEEN COPS AND OTHER INTERNATIONAL PROGRAMS. Convection initiation, cloud development, and precipitation in low-mountain regions are controlled by land-surface processes, orography, and the mesoscale and synoptic-scale settings simultaneously. The relative importance of these forcing mechanisms will be evaluated, separated, and quantified. This requires both observations of the large-scale environment and small-scale observations in the COPS domain.

COPS is an extensive collaboration between research institutions from eight countries and with international research programs. This interaction includes a strong coordination of the measurement efforts as well as a strong link between instrument PIs and modelers at weather forecast centers and research institutes. This successful interaction was one aspect that led to the

endorsement of COPS as a Research and Development Project (RDP) of WWRP.

The observations coordinated with COPS included the following activities:

- ETReC07, the first summertime European THORPEX Regional Campaign in 2007 of THORPEX (www.wmo.int/thorpex), a Global Atmospheric Research Program of the WWRP. This campaign was conducted from 1 July to 1 August 2007. By targeting efforts using denser or additional observations within ETReC07, the representation of the large-scale conditions in the COPS area will be improved. The impact of targeting can be validated and the interaction of large-scale and small-scale processes will be studied in detail in the COPS region.

- TRACKS (Transport and Chemical Conversion in Convective Systems), an initiative of the German Helmholtz Centers (www-fzk.imk.uni-karlsruhe. de/english/417.php), executed from 16 July to 2 August 2007. This project provided additional airborne observing systems for observing the chemical conversion and transport of pollutants by convective systems.

- GOP, a 1-year General Observations Period in Europe. The collection of routine observations during the full year of 2007 enabled relating the COPS observations to a larger context and comparing these with results from other regions.

- AMF, the deployment of the US Atmospheric Radiation Measurement (ARM, see www.arm.gov) Mobile Facility (AMF, www.arm.gov/sites/amf/blackforest) from 1 April to 31 December 2007 in the COPS region. This unique combination of instruments alone, the operation of which was funded by the ARM program, will provide for a previously unachieved dataset on initiation of convection, as well as cloud and precipitation microphysical properties in a low-mountain region.

- EUMETSAT (European Organisation for the Exploitation of Meteorological Satellites) provided
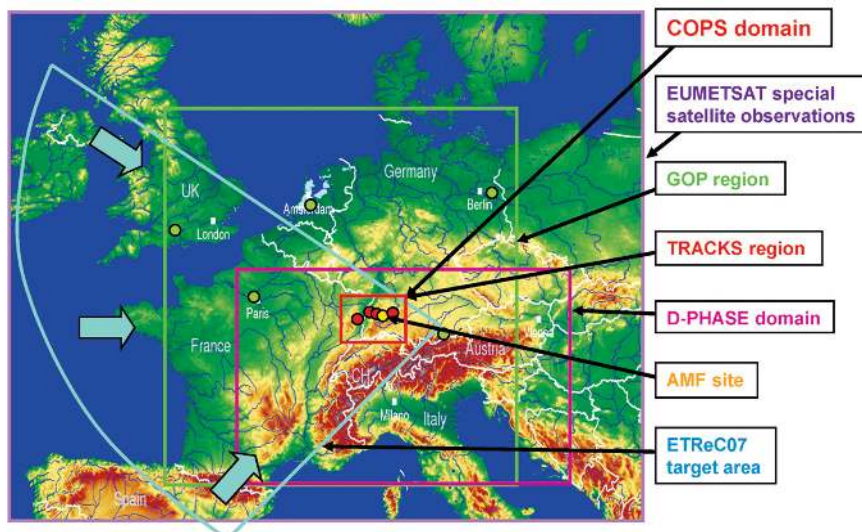

FIG. 3. International collaboration within COPS during summer 2007. The green circles show the locations of major observatories, where data are stored within the GOP. The red circles indicate the COPS supersites (see also Fig. 4), one of which one is the AMF (yellow circle). The blue arrows indicate the mean flow.

special satellite observations and products. These included special observation modes such as Meteosat Second Generation (MSG) rapid scans and data from new satellite remote-sensing systems such as the METOP platform.

The intense interaction with modeling efforts includes the following activities:

- D-PHASE, Demonstration of Probabilistic Hydrological and Atmospheric Simulation of flood Events in the Alpine region (see www.map.meteoswiss.ch/map-doc/dphase/dphase_info.htm, a WWRP Forecast Demonstration Project (FDP). This cooperation ensures the application and investigation of the newest generation of research and operational, high-resolution deterministic and ensemble prediction mesoscale models optimized for application in complex terrain.

- Real-time data assimilation by research institutes and weather forecast centers using COPS observations such as additional radiosonde launches from the AMF and other sites as well as Global Positioning System slant path and zenith path delays.

The overlap between the core regions of these projects coordinated with COPS is depicted in Fig. 3.

Fɪɢ. 4. COPS observing strategy. The operational networks have been densified in the COPS domain (e.g., with automated weather stations, additional GPS receivers, and radiosonde stations). A transect of five Supersites has been set up (V: Vosges mountains, R: Rhine valley, H: Hornisgrinde Mountain, M: Murg valley, S: Stuttgart) with synergetic remote sensing instruments. The weather radar coverage has been extended with POLDIRAD (DLR C-band polarization radar), a new operational French polarization radar at Montancy, two mobile DOWs (NCAR Doppler-On-Wheels X-band radars), and scanning C-band radars at Forschungszentrum Karlsruhe and the Vosges supersite. Mobile drop-up sonde teams were moved and operated in regions of interest. Regional observations between Supersites were performed with a suite of low-flying aircraft, whereas large-scale mesoscale observations including targeting were executed with fast aircraft flying in the lower to upper troposphere.
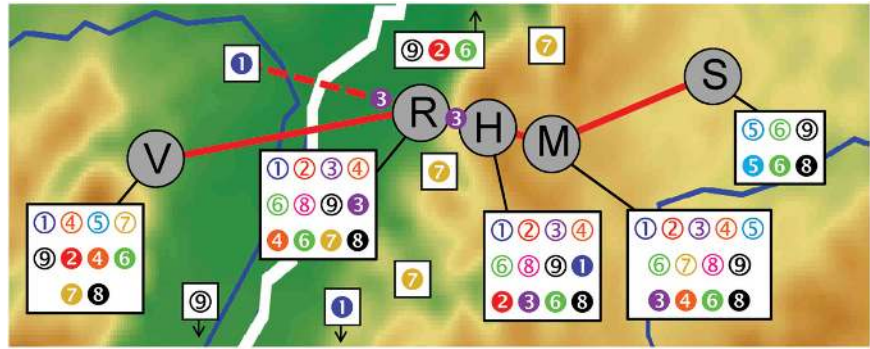
Airborne lidar platforms: DLR Falcon (① ③) and SAFIRE Falcon (①)
2 mobile Doppler-On-Wheels (❷ ❷)

Legend:
① Water Vapor Lidar   ❶ C-Band Polarization Radar
② Temperature Lidar   ❷ Precipitation Radar (other)
③ Wind Lidar   ❸ Micro-Rain-Radar
④ Aerosol Raman Lidar ❹ Wind Profiler
⑤ Ceilometer   ❺ Wind-Temperature-Radar
⑥ Microwave Radiometer ❻ Energy balance station
⑦ FTIR Radiometer   ❼ Sodar
⑧ Cloud Radar   ❽ GPS receiver
⑨ Radiosonde station

D-PHASE and COPS investigators agreed to use the same data structure, the GRIB1 format, for all D-PHASE model outputs. The corresponding set of variables, domains, and model output levels was summarized in the so-called TIGGE+ table, which is considered as a precursor of the THORPEX Interaction Grand Global Ensemble (TIGGE)–Limited Area Model (LAM) output dataset, currently in preparation within WWRP. We also designed this dataset to serve potential process studies (e.g., on convection initiation) and to use the results for COPS mission planning. Model outputs were stored with different levels of details in two predefined domains, the D-PHASE domain and the COPS domain, at the World Data Center for Climate (WDCC) in Hamburg, Germany (http://cera-www.dkrz.de/WDCC/ui/BrowseExperiments.jsp). Simultaneously, the Institute of Physics and Meteorology (IPM) of the University of Hohenheim developed an automated procedure based on the GrADS software to produce plots of model results which were useful for mission planning in both domains. Details can be found in the D-PHASE Implementation Plan, which can be downloaded from the D-PHASE Web site.

Key information about the huge set of models operated during COPS and D-PHASE is summarized in Table 1. We identified three distinct classes of models, which were all useful for COPS mission planning, performance, and guiding: Ensemble prediction systems (EPSs) with large forecast range, LAMs with coarse-grid resolution requiring convection parameterization (LAMCP) but large forecast range, and high-resolution LAMs without convection parameterization (LAMnoCP) but with shorter forecast range. We envisioned the use of EPSs and LAMCPs for aircraft mission planning, as this requires decisions about two days ahead, which cannot yet be covered with LAMnoCPs. Particularly interesting was the capability of the LAMnoCPs to predict the timing and location of CI and the distribution of clouds and precipitation. LAMnoCPs, with their shorter forecast range but improved capability to predict CI more accurately, were useful to mission refinement and same-day guidance.

This collaboration led to a win-win situation. On the one hand, the D-PHASE results were used for COPS mission planning. On the other hand, informa-

	Model name on data archive	Model[1] (ensemble size)	Mesh-size [km, (degrees)]	Number of grid points (S-N, W-E)	Number of vertical levels	Position of rotated Npole (lat, lon); 'none' for unrotated grid	Position of lower left corner [rlat, rlon]; italic for unrotated grid	Forecast range (h)	Initial time(s) (UTC)	Data available [h after initial time(s)]	Institutions
Limited-area ensemble prediction systems (EPS)	CLEPS	COSMO-LEPS (16)	10 (0.09)	258, 306	40	40, -170	-16, -12.5	132	12	13	ARPA Emilia-Romagna
	INMSREPS	SREPS (20)	27 (0.25)	164, 384	40	*none*	*24, -65*	72	00, 12	8	INM
	CSREPS	COSMO-SREPS (16)	10 (0.09)	258, 306	40	40, -170	-16, -12.5	72	12	19	ARPA Emilia-Romagna
	LAMEPSAT	ALADIN-LAEF (17)	18 (0.15)	49, 105	37	42.59, 2.95	42.95, 2.35	48	00, 12	10	ZAMG
	PEPS	PEPS	7 (0.0625)	560, 960	—	*none*	*35, -30*	42	00, 06, 12, 18	6	EUMETNET SRNWP
	MPEPS	Micro-PEPS	2 (0.02)	500, 650	—	*none*	*40, 4*	18	00, 03, 06, 09, 12, 15, 18, 21	1.5	DWD
High-resolution deterministic, limited-area models with convection parameterization (LAMCP) and with explicit simulation of deep convection (LAMnoCP).	COSMOCH7 **COSMOCH2**	COSMO-7 COSMO-2	7 (0.0625) 2.2 (0.02)	325, 385 350, 520	45 60	43.0, -170 43.0, -170	-9.75, -16 -4, -5.7	72 24	00, 12 00, 03, 09, 12, 18	4.0 2.5	MeteoSwiss
	LMEURO **LMITA**	COSMO-ME COSMO-IT	7 (0.0625) 2.8 (0.025)	641, 401 604, 542	50	32.5, -170 32.5, -170	-27.5, -16 -23, -5	72 30	00, 12 00	5 8.5	CNMCA
	LAMI7 **LAMI28**	COSMO-I7 COSMO-I2	7 (0.0625) 2.8 (0.025)	319, 299 532, 447	40 40	32.5, -170 32.5, -170	-25, -8.5 -21.925, -3.5	72 48	00, 12 00	5 7	ARPA Emilia-Romagna
	LME **LMK**	COSMO-EU COSMO-DE	7 (0.0625) 2.8 (0.025)	665, 657 461, 421	40 50	40, -170 40, -170	-20, -18 -5, -5	78 21	00, 06, 12, 18 00, 03, 06, 09, 12, 15, 18, 21	4-6 1	DWD
	ISACMOL **ISACMOL2**	MOLOCH MOLOCH	2.2 (0.02) 2.2 (0.02)	290, 340 290, 330	50 50	44.7, -171 32.5, -170	-1.84, -2.69 -14, -3.5	39 48	09 00	0 4	ISAC-CNR
	ARPALMOL	MOLOCH	2.2 (0.02)	194, 200	50	45, -171	-1.93, -1.99	36	12	9	ARPA Liguria
	QBOLAM33 QBOLAM11	QBOLAM QBOLAM	33 (0.3) 11 (0.1)	98, 162 210, 386	40 40	51.5, -167.5 51.5, -167.5	-13.2, -24.3 -9.9, -18.3	60 48	12 00	19[2] 7	APAT
	ALADFR **AROME**	ALADIN AROME[3]	(0.1) (0.04)	289, 289 160, 216	46 41	*none* *none*	*33.14, -11.84* *43.2, 5.3*	30 30	00 00	5 7	Météo-France
	MM5_2_CT **MM5_2_4D**	MM5 MM5	2 (0.02) 2 (0.02)	169, 184 169, 184	36 36	*none* *none*	47.02, 6.02	24 24	00 00	9.5 10.5	University of Hohenheim
	MM5_60 MM5_15 MM5_375	MM5 MM5 MM5	60 (0.56) 15 (0.14) 3.75 (0.04)	45, 55 73, 77 49, 57	26 26 26	*none* *none* *none*	*34.08, -7.02* *42.10, 2,72* *46.88, 10.18*	72 72 60	00, 12 00, 12 00, 12	10 10 10	FZK IMK-IFU
	ALADAT	ALADIN	9.6 (tdb)	270, 300	tbd	none	*(centered at 46.26, 17.0)*	48	00, 12	4	ZAMG
	CMCGEML **CMCGEMH**	GEM-LAM GEM-LAM	15 (0.188, 0.135) 2.5 (0.0327, 0.0225)	199, 174 413, 600	58 58	*none* *none*	*2.54, 3.5* *3.98, 0.2*	24 18	00 06	5 2	Environment Canada

tion about the performance of the D-PHASE models in the COPS domain was gathered in real time in the COPS Operations Center and detailed comparisons with the COPS dataset will be performed. A key question addressed during and after COPS is whether LAMnoCPs indeed better predict CI and reduce the windward/lee effect.

SETUP OF OBSERVATION SYSTEMS IN THE COPS REGION. The COPS observing strategy is depicted in Fig. 4. Land-surface exchange and boundary layer processes are being studied in

TABLE 1. D-PHASE atmospheric models participating in COPS separated in limited-area ensemble prediction systems and high-resolution deterministic models including various model specifications. Limited-area models without parameterization of deep convection (LAMnoCP) are indicated in bold face in column 2. ARPA: Agenzia Regionale Prevenzione E Ambiente, Italy; INM: Instituto National de Meteorologia, Spain; ZAMG: Zentrale Anstalt für Meteorologie und Geodynamik, Vienna, Austria; EUMETNET: Network of European Meteorological Services; SRNWP: Short-range numerical weather prediction; DWD: German Meteorological Service, Offenbach, Germany; Meteo-Swiss: Federal Office of Meteorology and Climatology, Zurich, Switzerland; CNMCA; Centro Nazionale di Meteorologia e Climatologia Aeronautica, Italy; ISAC-CNR: Institute of Atmospheric Sciences and Climate of the Italian National Research Council, Bologna, Italy; APAT: Agenzia Nazionale per la Protezione dell'Ambiente e per i servizi tecnici, Rome, Italy; FZK IMK: Forschungszentrum Karlsruhe, Institut für Meteorologie und Klimaforschung, Garmisch-Patenkirchen, Germany.

TABLE FOOTNOTES

[1] For the LAMnoCPs, which are indicated in bold face, the corresponding LAMCPs are generally the driving models.

[2] Mainly due to delay of 12 h in delivery of ECMWF analysis.

[3] AROME runs on a Lambert projected grid with a mesh size of 2.5 km with (309, 309) grid points centered at (46.39°N, 9.6°E). The specifications given in this table refer to the model output on a regular lat-lon grid.

detail by densifying the existing networks [e.g., using a mesonet, soil moisture sensors, and additional Global Positioning System (GPS) receivers]. Exchange processes and the flow in valleys are being investigated by additional turbulence and energy balance observing stations as well as sodars at the entrances and exits of valleys.

A transect of "supersites" was set up from the Vosges mountains, the Rhine valley, the Hornisgrinde Mountain, the Murg valley (where the AMF was operating), and on the lee side close to Stuttgart ("S" in Fig. 4). All of these supersites were equipped with soil moisture sensors, turbulence or energy balance and radiosonde stations, GPS, and surface meteorology instrumentation. The synergy of remote-sensing systems at each supersite can be considered as a particular highlight of COPS.

It consists of a unique combination of lidar systems for wind, temperature, and water-vapor profiling, and microwave and Fourier transform infrared radiometers and radars for extending the measurements into clouds, as well as radars for precipitation measurements, which also deliver the drop-size distribution.

In total, we deployed 13 lidar systems on 2 airborne and 11 ground-based platforms. These consisted of six water-vapor, four Doppler wind, and three temperature lidar systems. Four lidar systems were additionally equipped with aerosol Raman lidar channels. Furthermore, seven microwave radiometers, two Fourier transform infrared spectometers, three cloud radars, eight precipitation radars (in addition to the existing operational network of the national weather services), and five microrain radars were operated. Several of these systems have scanning capabilities, which were coordinated so that convection initiation could be observed by taking advantage of sensor synergy. The combination of this instrumentation was selected so that the observation of the full life cycle of convective precipitation, from the preconvective environment to the development of precipitation, was possible.

The observation strategy also considered the role of aerosol particles in cloud formation as well as cloud and precipitation microphysics. Details are provided in the COPS Field Report and the AMF Proposal available from the COPS Web site.

Specific observations in key regions where convection initiation was expected were performed by mobile teams launching a cluster of radiosondes, which can perform up to 30 measurements during rise and

descent, simultaneously, and can be recovered on the ground after launches (called "drop-up radiosondes"), and by two Doppler on Wheels mobile X-band radar systems.

A suite of airborne platforms performed large-scale observations as well as observations between supersites. The preconvective environment around the COPS region was mapped with two Falcon aircrafts: the DLR Falcon with a new four-wavelength water-vapor lidar combined with a 2-μm coherent Doppler lidar as well as dropsondes, and the SAFIRE (Service des Avions Français Instrumentés pour la Recherche en Environnement) Falcon 20 with water-vapor lidar and dropsondes. Within the COPS region, meteorological and turbulence measurements were provided by a DO 128 aircraft. Aerosol and cloud microphysical measurements were executed with the UK FAAM BAe 146, the SAFIRE ATR42, and the Partenavia aircraft. In particular, the BAe 146 aircraft flight legs were designed so that microphysical measurements in clouds were possible in conjunction with ground-based remote-sensing observations. Within TRACKS, a Lear jet performed tracer and transport measurements around and in the anvil of deep-convection outflow regimes. TRACKS provided three other aircraft: an ultralight and a DIMONA aircraft as well as a Zeppelin NT for meteorological and aerosol measurements in the boundary layer.

RESEARCH STRATEGY. The COPS science questions summarized in section 2 are addressed by four working groups that have been established during COPS workshops and endorsed by WWRP.

The Convection Initiation (CI) working group focuses on high-resolution, 3D observations and modeling of convection above orographic terrain. The group will develop dynamical and thermodynamic theories to understand the complex flow and the related moisture variability in order to comprehend the timing and location of the initiation of convection. For this purpose, COPS applied the unique combination of instruments to study the preconvective environment in four dimensions, including the upper tropospheric forcing and secondary forcing due to orography.

The Aerosol and Cloud Microphysics (ACM) working group explores the relationship between
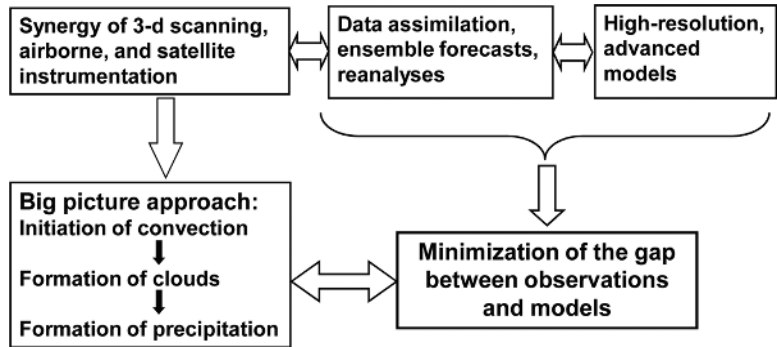

FIG. 5. The COPS approach and the relationship among its three research components. The combination of these components will enable the separation and quantification of QPF errors due to initial fields and parameterizations. After optimizing mesoscale ensemble prediction systems with respect to the representation of physical processes as well as to initial conditions, unique studies on the predictability of precipitation can be performed.

aerosol properties and cloud microphysics in a low-mountain region. One objective is to study whether subcloud aerosol variability affects convective precipitation. The group also addressed the relation between cloud turbulence and condensation, coalescence, aggregation, and thus precipitation. Furthermore, they will determine the correlation between measurable aerosol properties and ice formation.

The Precipitation Processes and Its Life Cycle (PPL) working group investigates the effect of orography on the development, organization, and decay of convective cells. A critical point is the distribution of the condensed water into the different hydrometeor categories (cloud water and ice, graupel, snow, rainwater) where there are large differences between mesoscale models. To study the development of graupel, hail, and drop-size distribution of precipitation, the working group will use a combination of data from polarimetric radars, satellites, microrain radars, disdrometers, and lightning detection, as well as observations from the supersites to study the onset of full precipitation from drizzle conditions.

The Data Assimilation and Predictability (DAP) working group studies the impact of current and new observations on 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 COPS and GOP datasets. Therefore, data assimilation is an essential tool for process studies. Furthermore, using a variety of

mesoscale models in combination with ensemble forecasting, the group will study the predictability of convective precipitation.

We plan to merge this research infrastructure with the ongoing reorganization of WWRP. For example, COPS working groups will coordinate with the WWRP working groups on mesoscale forecasting (see www.wmo.ch/pages/prog/arep/wwrp/new/mesoscale.html), parameterization, and forecast verification. First results of COPS will be provided for the WWRP Strategic Plan 2008–2015, which is currently under preparation. Furthermore, the D-PHASE dataset can be considered as a model for the THORPEX TIGGE-LAM dataset under preparation.

In summary, COPS has three fundamental components:

1) synergy of unique in situ and remote-sensing instruments on different platforms;
2) advanced high-resolution models with data assimilation capabilities; and
3) data assimilation and ensemble prediction systems.

Figure 5 shows how these components interact to reach the goals of COPS. The scientific work with the COPS dataset was started at the 6th COPS workshop and will be continued during a series of upcoming workshops endorsed by WWRP. The next workshop will take place 27–29 October 2008 in Strasbourg, France. Further documentation can be downloaded from www.uni-hohenheim.de/cops.

If this approach is successful, a better understanding and prediction of precipitation, including extreme weather events, can be expected. This will have a large positive impact on society and economy both within and well beyond the COPS area.

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