THE BENEFITS OF LIDAR FOR METEOROLOGICAL RESEARCH: THE CONVECTIVE AND OROGRAPHICALLY-INDUCED PRECIPITATION STUDY (COPS)

Andreas Behrendt[(1)], Volker Wulfmeyer[(1)], Christoph Kottmeier[(2)], Ulrich Corsmeier[(2)]

[(1)]*Institute of Physics and Meteorology, University of Hohenheim, D-70593 Stuttgart, Germany, behrendt@uni-hohenheim.de*

[(2)] *Institute for Meteorology and Climate Research (IMK), University of Karlsruhe/Forschungszentrum Karlsruhe, Karlsruhe, Germany*

ABSTRACT

How can lidar serve to improve today's numerical weather forecast? Which benefits does lidar offer compared with other techniques? Which measured parameters, which resolution and accuracy, which platforms and measurement strategies are needed? Using the next generation of high-resolution models, a refined model representation of atmospheric processes is currently in development. Besides higher resolution, the refinements comprise improved parameterizations, new model physics – including, e.g., the effects of aerosols – and assimilation of additional data. As example to discuss the role lidar can play in this context we introduce the Convective and Orographically-induced Precipitation Study (COPS). The motivation of COPS is the fact that even with today's most advanced research models, the forecast skills are especially low for convective precipitation in complex terrain. COPS will be conducted in Southern-Western Germany and North-Eastern France in summer 2007. During COPS a large suite of state-of-the-art remote sensing systems, ground-based and airborne, partly scanning and employed for the first time, shall be combined with in-situ instruments. The measurement strategies which involve state-of-the-art lidar systems will be discussed and an outlook on the perspectives of lidar in future meteorology will be given.

1. INTRODUCTION

Precipitation is the end product of a complex chain of inter-coupled processes. As non-linear effects are involved, the correct forecast of precipitation depends critically on both accurate initial fields and an adequate model representation of the relevant physical processes.

A comprehensive field experiment aimed at the improvement of numerical weather prediction demands a previously unachieved set of high-quality data that cannot be obtained by routine observations. In order to identify and distinguish between different kinds of model deficits and to improve initial conditions and process understanding, high-resolution data sets covering especially the entire evolution of convective precipitation events are needed. This can only be achieved by a combination of sensors reflecting the most advanced results of instrumental development within an intensive observations period.

Such a field experiment is the Convective and Orographically-induced Precipitation Study (COPS, http://www.uni-hohenheim.de/spp-iop/) which takes place in summer 2007 in a low-mountain range in Southern-Western Germany and North-Eastern France. This area is characterized by high summer thunderstorm activity and particularly low skill of numerical weather prediction models. COPS is part of the German Priority Program "Praecipitationis Quantitativae Predictio" (PQP, http://www.meteo.uni-bonn.de/projekte/-SPPMeteo/) and has been endorsed as World Weather Research Program (WWRP) Research and Development Project (Fig. 1).

It is the overarching objective of COPS to identify the physical and chemical processes responsible for the deficiencies in quantitative precipitation forecast (QPF) over low-mountain regions and 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.

An important tool to achieve this goal is the assimilation of additional data – especially from state-of-the-art lidar systems. Data assimilation allows too separate models errors due to errors in the initial fields and errors in the models' approximations of the relevant physical processes (parameterizations). Furthermore, re-analyses testing the assimilation of different data, allow to investigate the sensitivity of the models.

COPS builds on a series of previous international measurement campaigns focusing on quantitative precipitation forecast like the Mesoscale Alpine Program (MAP), 1999, the International H_2O Project (IHOP_2002), 2002, and the Convective Storm Initiation Project (CSIP), 2005.

2. THE INITIATION OF CONVECTION

Mesoscale studies in flat terrain during IHOP_2002 demonstrated the potential of high-resolution model runs for process studies [1, 2] and of ensemble forecasts for sensitivity studies [3]. As characterization of the water vapor field was the key component of IHOP_2002, the performance of water vapor lidar systems was investigated [4, 5] and the impact of high-resolution lidar observations for improving the prediction of convection was highlighted by assimilation of airborne water vapor DIAL measurements [6].

In low-mountain regions, which cover the majority of the Earth's land surface, the relevant processes leading to convective precipitation are still hardly understood. This is especially unsatisfactory as many severe weather events are related to convective precipitation.

Open questions are related to the relative influence of

- the convergence and updrafts created by forced lifting on the windward side and to thermally-forced anabatic flow,
- the wind shear profile in the region of the ridges,
- 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,
- the presence of gravity waves impinging on the ridges,
- aerosol load in the pre-convective environment influencing the diurnal cycle of boundary variables.

The latter topic demonstrates the importance of the interaction between the initiation of convection and microphysical processes, i.e., the role of aerosols acting as cloud condensation nuclei.

Consequently, it is important to perform 4D thermodynamic measurements of atmospheric variables in the troposphere in regions where initiation of convection 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 synergy of ground-based scanning, airborne, and space borne remote sensing systems.

3. THE ROLE OF LIDAR IN COPS AND SYSTEM SYNERGIES

Lidar systems are key components within COPS to investigate the initial clear-air fields of temperature, humidity and wind before the initiation of convection and to detect and characterize aerosols.

The ground-based instruments of COPS shall be concentrated in supersites in order to make optimum use of possible instrument synergies (Fig. 2). Each supersite shall be equipped with different types of state-of-the-art remote sensing instruments (different types of lidars, cloud radars, and radiometers), which shall be combined with in-situ sensors.

Four supersites form an east-west transect of the COPS area. Supersite 1 will be arranged around the mountain crest of a low mountain range in the Northern Black Forest, where the novel 3D scanning water vapor differential absorption lidar (DIAL) of University of Hohenheim (UHOH), Stuttgart, Germany, shall be applied. This instrument will be able to perform 2D water vapor measurements within one minute and will be collocated with the scanning rotational Raman lidar of UHOH [7]. The synergy of these systems provides water vapor and temperature measurement from close to the ground up to a range of several km. In the boundary layer, turbulence and convection can be resolved. A scanning Doppler lidar will be placed properly to get coincident water vapor and wind measurements to calculate vertical turbulent water vapor fluxes, and to localize the initiation and timing of convection onset.

The corresponding atmospheric fields expected at this location during a pre-convective phase are shown in Fig. 3.

A scanning cloud radar will be operated at supersite 1 to monitor the transition from dry convection to cloud formation and to get information on cloud particles. A transect of micro-rain radars is used to measure the raindrop size distribution; one micro rain-radar is placed on the mountain top to obtain the initiation of precipitation and vertical profiles of rain rate. To derive the mass, heat and moisture transport by thermally and terrain driven wind regimes, sodars, as well as in situ turbulence stations are installed on the slopes. Energy balance stations on top of the mountains and a setup of soil moisture sensors provide information on the importance of soil moisture, evapotranspiration and sensible heat fluxes for the surface induced convection.

As part of the instrumental cluster of supersite 1, the ARM mobile facility (AMF) will be operated during COPS in a valley. The AMF consists of a suite of instruments, among others, various radiometers for the detection of both infrared and microwave radiation, a ceilometer, a micro-pulse lidar, a cloud radar, a precipitation radar, a radar wind profiler, and a radiosonde station. For characterizing aerosols and for analyzing cloud microphysical properties at the cloud base, a multi-wavelength Raman lidar, a scanning Doppler lidar, both of the Institute for Tropospheric Research, Leipzig, Germany, and a scanning multi-channel microwave profiler will be added to the AMF.

Operation of Supersite 2 is planned for the lowlands of the Rhine valley. In contrast to Supersite 1, on top of the Hornisgrinde, the highest peak of the northern Black Forest, this location is characteristic for rather flat surfaces, the only landscape differences arising from land use differences. Supersite 3 will be placed in the east of the Black Forest, a region where lightning data prove that the probability of occurrence of mature convective cells which were formed over the Black Forest is high. Supersite 4 in the Vosges Mountains will complement the line of supersites to the west in order to characterize the inflow to the region and allow comparisons between two low-mountain ranges.

The supersites are the preferred locations of overpasses with the Falcon aircraft of the German Aerospace Center (DLR) which will carry during COPS two lidar systems: a four-wavelength water vapor DIAL and a Doppler lidar. While the beam of the water vapor DIAL is fixed, the Doppler lidar performs conical scans which will allow to measure the 3D wind field.

4. SUMMARY

In low-mountain regions, which cover the majority of the Earth's land surface, the relevant processes leading to convective precipitation are still hardly understood. This is especially unsatisfactory as many severe weather events are related to convective precipitation. The Convective and Orographically-Induced Precipitation Study (COPS) is a international field campaign planned for summer 2007 in Central Europe to tackle this problem. During COPS, a large suite of different types of lidar systems will be employed in order to investigate clear-air fields of meteorological key parameters, namely, water vapor, temperature, wind, and aerosol characteristics. In combination with other state-of-the-art remote sensing systems, ground-based and airborne, partly scanning and employed for the first time, the measurement strategies include the use of system synergies and the assimilation of new data to mesoscale models in order to separate errors in the initial fields from errors due to inadequate parameterizations. COPS serves as example for the benefits of lidar for improving our understanding of meteorological processes and assessing their relevance for numerical weather forecast.

REFERENCES

1,2. Xue, M., and W.J. Martin, *Mon. Wea. Rev.*, *Monthly Weather Review*, 134, 1, 2006 a,b.

3. Martin, W.J., and M. Xue, *Monthly Weather Review*, 134, 1, 2006.

4,5. Behrendt, A., et al., *J. Atmos. Oceanic Technol.*, accepted, 2006 a,b.

6. Wulfmeyer, V., et al., *Monthly Weather Review*, 134, 1, 209-230, 2006.

7. Radlach, M., et al., this conference.

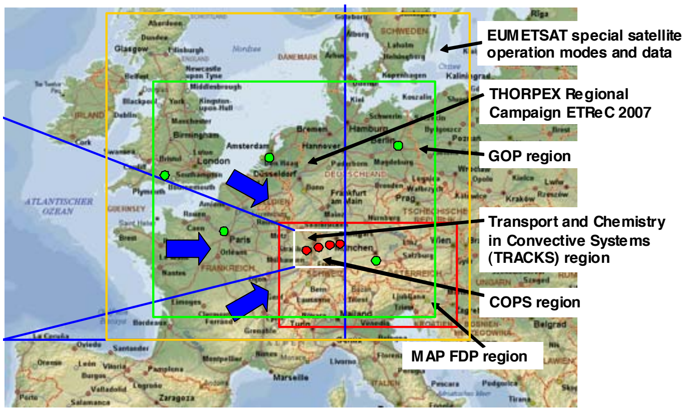

Fig. 1. Location of the COPS region in central Europe and coverage of meteorological programs in summer 2007 demonstrating the excellent overlap between their domains. The circles indicate COPS supersites where different types of lidar systems will be combined with cloud radars and radiometers to allow synergetic measurements.

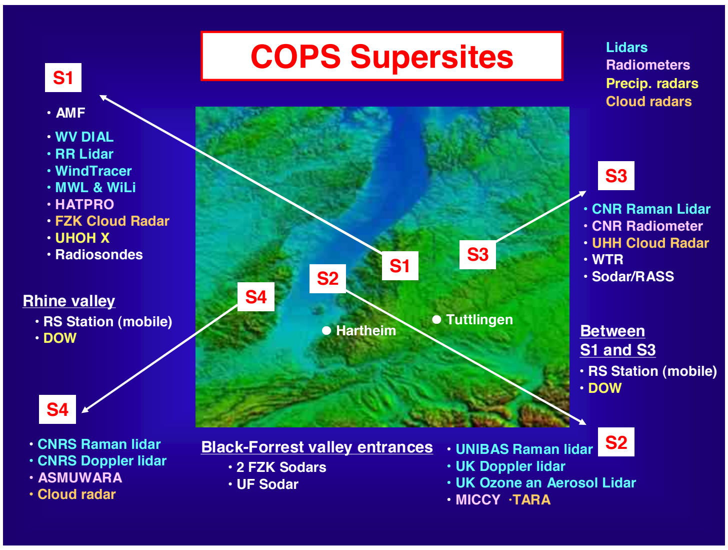

Fig. 2. Set up of COPS supersites (S1 to S4) with instrumentation and orography. S1 is located in the northern Black Forest, S2 in the Rhine Valley, S3 is in the typical lee of the mountain ranges, S4 in the Vosges Mountains. The optimum distribution of instruments is still under discussion and will be refined in the next months.

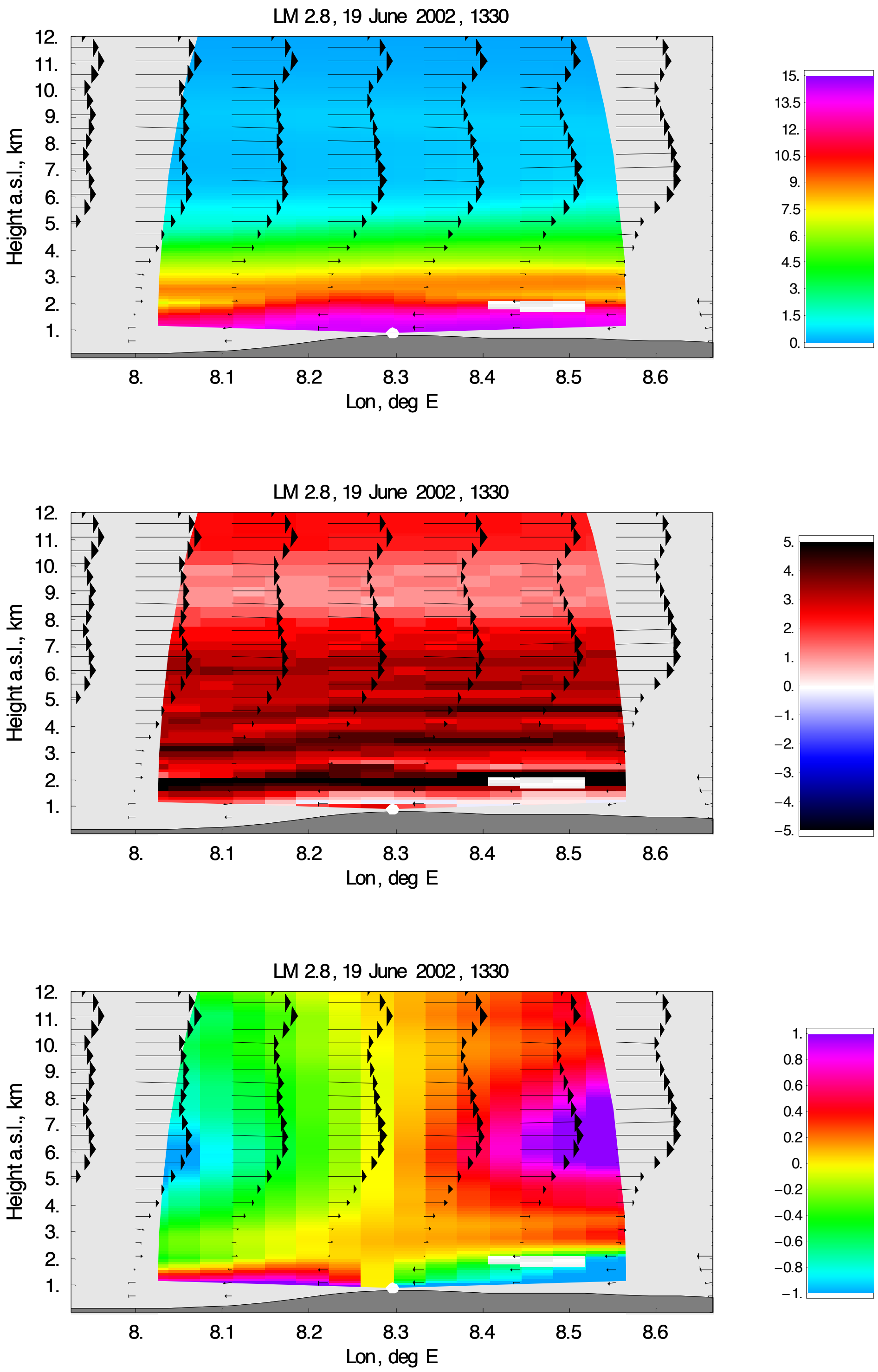

Fig. 3. Clear air fields of meteorological key parameters at Hornisgrinde, the highest peak (1160 m above sea level) of the northern Black Forest, Germany, like seen in a research version of the local model of the German Weather Service with 2.8 km horizontal resolution in the pre-phase of a convective precipitation event (13:30 UTC, 19 June 2002, east-west direction, data are by courtesy of Christian Bartlott, Research Center Karlsruhe). At Hornisgrinde, 3 scanning lidar systems shall be located during COPS. **Top:** water vapor mixing ratio in g/kg.
Middle: temperature gradient + 9.81 K/km. **Bottom:** line-of-sight wind component in m/s. In addition to the fields of the parameters shown in contours, also clouds (white) and the zonal wind component is plotted (arrows).