1 General information (Allgemeine Angaben)

This is a renewal proposal within the framework of the priority program (PP) 1167 "Quantitative precipitation forecasting". The DFG code numbers of the preceding grant were BA 3464/1-2, CR 111/5-2, CR 245/1-1 and FI 435713-2. In the current proposal Dr. Axel Seifert (DWD) is now replacing Dr. Michael Baldauf (DWD; BA 3464/1-2) due to the stronger focus on parameterization development and testing in the last PP period.

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Nicole van Lipzig worked as QUEST project scientist from 1 July 2004 to 30 September 2005 until she got a position as Universitaetsdozent at the Catholic University Leuven, Belgium (KUL). She has successfully submitted a proposal (QUEST-B) to the Fund for Scientific Research - Flanders and funding is ensured for the 4-year period 2007-2010 (with S. Crewell and L. Delobbe from the Royal Meteorological Institute of Belgium as co-proposers). The recently started project will concentrate on spatial and temporal variability of precipitation in the Flanders region of gentle orography. Once a satisfactory agreement between model and measurements has been established, the effect of modelled precipitation on soil erosion processes in Belgium will be studied for different atmospheric circulation regimes. Close cooperation including the exchange of methods and data between both projects will be pursued.

1.2 Topic (Thema)

Quantitative evaluation of regional precipitation forecasts using multi-dimensional remote sensing observations (QUEST)

1.3 Scientific discipline and field of work (Fachgebiet und Arbeitsrichtung)

Meteorology, cloud microphysics, radiative transfer, radar and satellite remote sensing, numerical weather prediction.

1.4 Scheduled duration in total (Voraussichtliche Gesamtdauer)

The project is scheduled for 6 years in total corresponding to the total duration of the PP 1167. Funding by DFG started for the 1st PP period in April 2004 and the 2nd PP period in April 2006, respectively. Expenditures for personnel will probably last until summer/fall 2008 (IGMK: 30 September 2008; DLR: 31 March 2008; FUB: 31 April 2008). Expenses for consumables will probably last until March 2008. Funding from this grant should enable the project scientists to continue their work without interruptions.

1.5 Application period (Antragszeitraum)

24 months; 1 April 2008 until 31 March 2010

1.6 Summary (Zusammenfassung)

Because the amount of precipitation at the ground results from a complex process chain multiple parameters need to be investigated in order to identify and understand the mechanisms underlying the major deficits in quantitative precipitation forecasts. Therefore we make use of a variety of multi-dimensional remote sensing observations from radar, satellite and profiling stations to evaluate the model performance in predicting water cycle parameters. Focus is on high spatial resolution forecasts of DWDs COSMO-DE model. In the past phases of PP1167 QUEST has developed tools (e.g. forward operators) which are

needed to relate remote sensing observations with model forecasts. Their performance in a number of case studies and model test suites has been proven. In the third PP phase we will focus on the evaluation of the currently ongoing General Observation Period (GOP) 2007 and will generalize the findings by incorporating a systematic evaluation of the D-PHASE model ensemble. The systematic errors already identified for single variables will be cross-correlated and further related to certain regions and weather situations. The GOP observations allow an objective case study selection which will be used to improve microphysical, radiative and boundary layer parametrisations. Finally, the tools developed in the course of the priority program will be documented and made available for the general public.

2 State-of-the-art, preliminary work (Stand der Forschung, eigene Vorarbeiten)

2.1 State-of-the-art (Stand der Forschung)

In regional operational numerical weather prediction (NWP), **convection-resolving NWP** models have been introduced recently or are to be introduced in the near future. At MeteoFrance, the operational application of a 2-km high-resolution NWP model (AROME) is planned for 2008. In the U.S. the Weather Research and Forecasting (WRF) model has been developed by NCEP/NCAR for convection-resolving forecasting and has been applied typically with 4 km horizontal grid spacing. At the UK Met Office, a 1-km convection-resolving NWP model is planned for the near future. Since spring 2007 German Meteorological Service (DWD) runs operationally a convection-resolving version of the COSMO model (COSMO-DE, formerly called LMK, see Baldauf et al., [2006]). Such models are developed to improve the prediction of severe weather events related to deep moist convection (e.g. super- and multi-cell thunderstorms or squall lines) and to improve the representation of the fine scale topography leading to better forecasts of severe downslope winds or Foehn-storms. Many of those models take part in the currently ongoing Mesoscale Alpine Programs (MAP) Demonstration of Probabilistic Hydrological and Atmospheric Simulation of flood Events in the Alpine region (D-PHASE) project from June to November 2007.

Remote sensing observations cover the relevant scales of these mesoscale models and provide a wealth of information on atmospheric gases, aerosols, clouds and precipitation at high temporal and spatial resolutions. Therefore they are ideally suited for evaluating the new generation of high-resolution models though the ultimate goal is their use in data assimilation. However, due to the complex, non-linear relation between observed parameters and hydrometeors, typically only observations not affected by clouds are used. Exceptions are the ongoing developments at the European Centre for Medium Range Weather Forecast (ECMWF) concerning precipitation affected microwave radiances which first use a 1D-Var approach and then introduce model variables into the 4D-Var system [Bauer et al., 2006]. An extension to also use weather radar data is underway [Lopez and Bauer, 2007]. Moreover, first steps are taken to assimilate MODIS optical depth in the ECMWF model [Benedetti and Janiskova, 2007].

In respect to high-resolution NWP remote sensing observations are used for best member selection in ensemble prediction forecast systems. Here it is also advantageous not to retrieve geophysical variables (**observation-to-model**) and then compare them to model variables but rather to consider the so-called **model-to-observation** approach and perform the selection in observation space (Fig. 1). This optimally exploits the information content of the remote sensing measurements because retrieval algorithms often make implicit assumptions on the atmospheric state which might not correspond to those of a mesoscale model, e.g. drop size distributions. Sometimes even model analyses are used as background information in retrieval algorithms. Another important advantage of this approach is the independence from training data sets needed for the retrieval process which are known to lack representativeness. The development of the so-called “forward” model (operator) which converts model output to observation space is also an important step towards assimilation since they are a pre-requisite for variational assimilation techniques. These reasons have triggered several studies at (ECMWF) where radiances in the infrared and microwave range were simulated from ECMWF forecasts, for example Chevallier and Kelly [2002] and Chevallier and Bauer [2003].

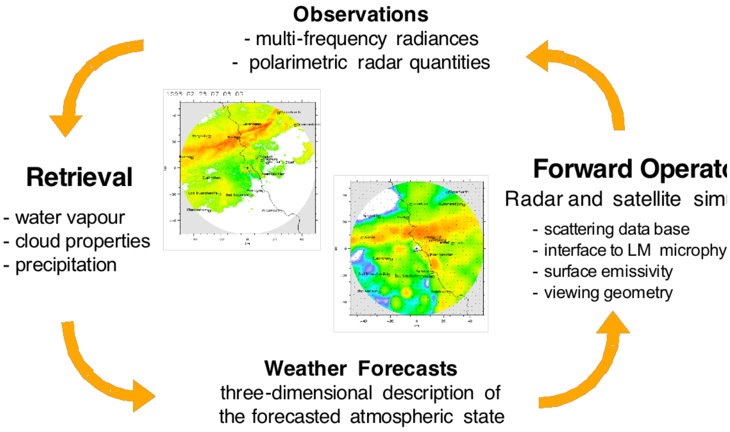

Figure 1. Illustration of the observation-to-model and the model-to-observation process.

The model-to-observation approach is a powerful tool for **model evaluations**. Especially the high temporal (15 min) and spatial (3-5 km) resolution of Meteosat Second Generation (MSG) observations have been extremely useful to investigate and improve cloud parametrisation (for example Chaboureau and Bechtold [2005], Chaboureau and Pinty [2006] and Keil et al. [2006]). However, it is currently becoming clear that new measures for assessing the forecast quality are needed when NWP models are using finer grids down to a few kilometres [Stoelinga et al., 2003; Ebert, 2007; Ament et al., 2007]. After all, clouds and precipitation are highly variable in time and space and therefore it cannot be expected that individual clouds will be represented in a mesoscale model forecast. Conventional verification scores might give the impression that high-resolution models perform worse than larger scale models, even though these high resolution models have a distinct added value for a forecaster. New evaluation measures include probability density distributions (pdfs) of cell intensity and size [Schröder et al., 2006] as well as the lifetime and the tracking of precipitating cells (see next section). In addition to MSG, further remote sensing observations like radar, microwave radiances from satellite, ceilometers, GPS, etc and the combination of ground-based sensors at super sites should be used since comprehensive cloud and precipitation information can only be gathered using sensor synergy [Rizzi et al., 2005].

An evaluation of models for a period of several months or years (**long-term evaluation**; LTE), is needed to identify systematic deficiencies in the models. Within the Cloudnet program [Illingsworth et al., 2007] cloud fraction, liquid and ice water contents derived from long-term radar, lidar, and microwave radiometer data are systematically compared to models. This study has revealed that there are many differences between the models in how well they represent boundary layer clouds, but that all models underestimate the amount of mid-level clouds. Less skill is found for the summer period, showing that modeling convective clouds is difficult. Also Atmospheric Radiation Measurement (ARM) program observations enable LTE. For example, Iacobellis and Somerville [2006] used these data to evaluate the performance of two types of autoconversion parametrisations. In this respect the deployment of ARM's Mobile (AMF) facility in the Murg Valley, Black Forest, from April to December 2007 and its participation in the General Observation Period (GOP; (http://gop.meteo.uni-koeln.de) provides a unique chance for QUEST. LTE is essential to verify if a modification in the model is an improvement in all situations and therefore LTE should go hand-in-hand with model improvements. Based on the ARM-dataset, Tselioudis and Kollias [2007] identified the simulation of multi-type cloud structures as the major source of the model cloud amount error. Multi-type cloud structures occur mostly in atmospheric regimes of large-scale uplift or weak large-scale forcing [Kollias et al., 2007], pointing to the relevance of regime-dependent model error analysis in an LTE framework.

The classical objective of verification is to assess the forecast quality from an end-user perspective [Murphy, 1993]. Therefore almost all verification methods are univariate [e.g. Murphy, 1987; Ebert et al., 2003], which means they are designed to evaluate a single forecast element (e.g. precipitation or temperature at 2 m height) only. However, analysing the joint probability distribution of model errors in various forecast elements by a **multivariate model evaluation** will allow conclusions on the origin of model deficits and be needed to enable model improvements. Although appropriate techniques of multivariate statistics like clustering, cross-correlations, conditioned probabilities or Bayesian statistics are well established, multivariate model evaluations are still rare. Recent research activities mainly concentrate on conditional verification by stratifying the evaluation according to an independent influencing factor, like e.g. a weather classification [Rossa et al., 2004].

A general problem in quantitative precipitation forecasts (QPF) is the representation of the **diurnal cycle of convection** leading to QPF errors both in magnitude and phase [Guichard et al., 2004]. Originally being reported for general cirulation models such deficiencies have also been found in the DWDs limited area model COSMO-EU with 7 km grid spacing where convection is parametrised using the Tiedtke scheme. Therefore the performance and improvement of the high-resolution **COSMO-DE** model with resolved deep convection on a horizontal grid spacing of 2.8 km is of particular interest. Since COSMO-DE resolves the bigger parts of convection explicitly, for convection parametrisation only shallow-convection is parametrized. For a better representation of the microphysics in explicitly simulated deep convection, the former 5-class microphysics scheme was extended by a new precipitation class "graupel" [Reinhardt and Seifert, 2006]. Rapidly updated radar data are assimilated by the latent heat nudging (LHN) method [Jones and MacPherson, 1997; Schraff et al., 2006]. When performing long-term model evaluation one always has to be aware of the changes in the model, which are always taking place in an operational context always has to take changes in the model into account. The most important changes in COSMO forecast models are listed in the Appendix.

The World Weather Research Program (WWRP) forecast demonstration experiment **D-PHASE** [Arpagaus, 2007], allows a broader perspective on today's ability to simulate the hydrological cycle: 30 NWP models (partly experimental and to become operational in near future) issue real-time precipitation alerts to a central warning platform (www.d-phase.info) and store their model output for evaluation purposes at the COPS/GOP/D-PHASE data archive in a unified format. The D-PHASE target domain covers the Alpine region including adjacent areas (like e.g. southern Germany) for a six month period. Participating models can be divided into three groups: deep convection resolving, deterministic models (Δx ~ 2 km), corresponding driving deterministic models (Δx ~ 10 km) and limited area ensemble prediction systems (EPS) with Δx = 2-27 km. The evaluation data set at the archive comprises pressure level fields, surface fields and vertically integrated quantities for all model types and additionally wind, pressure, temperature and humidity on model levels below 4 km for high-resolution models to allow detailed studies of the boundary layer.

The huge number of participating EPS reflects the trend that **probabilistic precipitation forecasts** will become standard. They can take into account the limited predictability of precipitation (e.g. Walser et al. [2004]), in particular at small scales. Future data assimilation might also strongly rely on the accuracy of EPS: The COSMO consortium has just decided to replace the nudging technique by the Local Ensemble Transform Kalman filter (LETKF, Hunt et al. [2007]) in 2011. However, a theoretical basis for the design of limited area ensembles is not well established; most systems are constructed pragmatically by combing multiple models (e.g. Quiby and Denhard [2003]). Therefore a thorough evaluation whether ensemble spread correlates with predictability (e.g. Scherrer et al. [2004]) is an important task.

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2.2 Preliminary work (Eigene Vorarbeiten)

The progress achieved within QUEST is described in detail in the Interim Report and the accompanying manuscripts. Therefore, only some highlights as well as the previous work by the new proposers (Felix Ament and Axel Seifert) is described in this section. It should be noted that a delay of several months occurred at IGMK when the project scientist Felix Ament (now a co-proposer) was replaced by Thorsten Reinhardt (formerly at DWD) who is an expert in cloud microphysical parametrisations [Reinhardt and Wacker, 2006; Reinhardt and Seifert, 2006]. At FUB Marc Schröder left the project due to the reduction to half a position but still keeps a strong cooperation. Anja Hünerbein [Hünerbein, 2006] temporary filled the gap until a suitable PhD student (Stefan Stapelberg) was found.

The **tool development (WP2)** has already been successfully completed. A microwave radiation simulator (**SynSatMic**) [Mech et al., 2007] was adapted to the COSMO model. Using microwave radiance simulations and observations a data base for mid-latitude precipitation cases could be created [Chaboureau et al., 2007]. SynSatMic was applied within case studies together with the polarimetric radar simulator (**SynPolRad**). [Pfeifer, 2007; Pfeifer et al., 2007a]. Several different microphysical schemes have been tested with SynPolRad sowing the strong influence of assumptions on frozen hydrometeors on thunderstorm representation [Gallus and Pfeifer, 2007; Pfeifer and Gallus, 2007]. In addition, SynPolRad is now able to also simulate cloud radar and micro rain radar geometry [Pfeifer et al., 2007b]. After a problem with the angular geometry in the synthetic satellite simulator (**SynSat**) [Keil et al., 2006] has been identified by QUEST the Meteosat radiances simulated by the updated code now agree well with explicit radiative transfer (RT) simulations by FUBs advanced RT code. Synthetic radiances are now used for COSMO evaluation within case studies and for long-term evaluation as part of the GOP [Crewell et al., 2008]. An algorithm to derive optical thickness from MSG observations has been developed, validated and implemented similar to other satellite derived variables like Integrated Water Vapor (IWV) [Albert et al., 2005] and cloud top pressure [Lindstrot et al., 2006]. The derived fields and time series data at anchor stations are routinely produced as part of the GOP.

For the **model evaluation (WP3)** case studies [van Lipzig et al., 2006; Pfeifer et al., 2006 and 2008; Reinhardt et al., 2007; Schröder et al., 2006] and test suites [Crewell et al., 2006] have been investigated in detail. To make full use of the high resolution information from MSG a patchiness parameter [Schröder et al., 2006] has been developed to describe clouds in models and observation. Tracking of cloud systems has been found to be a useful information in model evaluation (Fig. 2) providing information on phase shifts as well as amplitude errors. Tracking can also be applied for long-term studies [Schröder et al., 2007].

The evaluation of the COSMO-DE test suites of summer 2005 has revealed strong deficits in the representation of the boundary layer [Crewell et al., 2006] which was found too humid and too shallow. While cloud cover generally agreed well, the vertical extent of clouds was overestimated by the model. Furthermore, significant differences between the runs started at 0 and 12 UTC with the 12 UTC run being drier and having less skill in cloud cover prediction. This is further investigated using the **GOP** data whose use for the long-term evaluation of COSMO-DE [Crewell et al., 2008] is the central element of QUEST. Here we can exploit the fact that the COSMO-DE model is started every three hours for a forecast period of 21 h. Therefore 8 different forecasts are available for each given time. The near real-time comparison with the GPS network (front cover) has shown that the model started at 12, 15 and 18 UTC show a significant dry bias which can be pinned down to the fact that the radiosonde ingested into the assimilation run during daytime are affected by a dry bias.

We are currently investigating the relation between the different hydrological parameters. Similar analysis as for the GPS data have already been performed for the ceilometer network and shown strong diurnal tendencies in cloud base height [Crewell et al., 2008]. The same analysis is underway based on MSG observations. The relation to the precipitation rate is investigated together with the VERIPREG project. In the future we will further track the differences in respect to certain regions and weather regimes. Here we will also make use of the synoptic classification developed by the sister project QUEST-B [Demuzere et al., 2007].

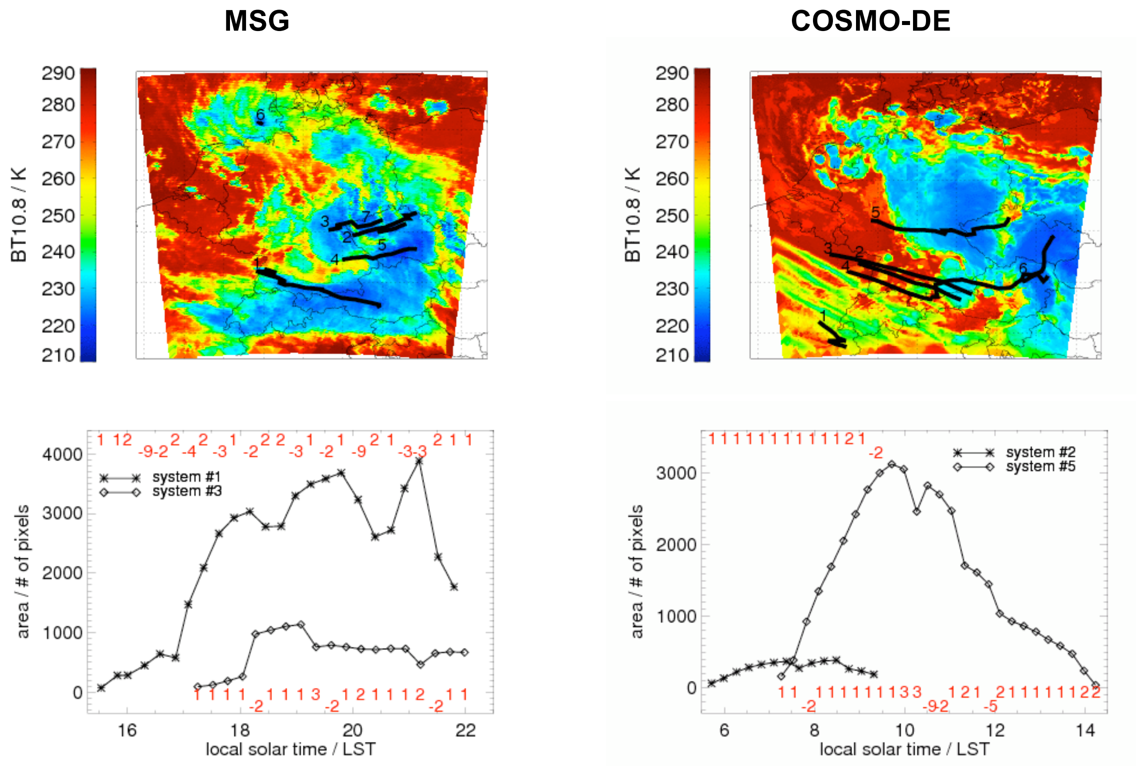

Figure 2. Top: Paths of convective systems with life times >3 hours and maximum area coverage >200 pixels observed by MSG (left) and simulated by COSMO-DE (right) on 28 August 2006 superimposed on BT at 10.8 μm at 19:00 UTC. Bottom: Area of systems which are represented similar in model and observation versus local solar time (MSG system 1 from15:32-22:04 LST compares to COSMO system 5 from 07:15-14:13 LST). Asterixed denote the MSG evolution and the routes the COSMO-DE evolution. A flag for merging (negative) and splitting (>1) events is provided. The difference in start and stop times between model and observations confirm a time shift in the temporal evolution in the model, with the majority of initiations in the morning hours in case of COSMO-DE. For further information see Pfeifer et al. [2008]. Note that this draft is added as an appendix.

In the past years, the QUEST scientists have contributed to **Model improvement (WP4).** Within the remaining part of the 2nd PP phase we will be investigating will further collaborate with the project by Bott (Bonn) to investigate the impact of their new convection scheme. Due to the difficulties experienced in the representation of the boundary layer DWD has performed several test suites including changes in the turbulent length scale (see also [Koller, 2007] and [Ament, 2006]). The thourough evaluation of these test suites will be a major work item within the next months.

- Microphysical Parametrisations: Since August 2006, important changes (see Appendix for a detailed description) have been made to the COSMO model at DWD partly under supervision of Axel Seifert. In particular he has lead the development of microphysical parametrisations for COSMO-DE and COSMO-EU. Most noticeable is the positive impact of the newly introduced scheme in COSMO-EU visible in the comparison with MSG (Fig. 3). Since the original MSG data are not available at DWD QUEST will further work on a more detailed attribution of the improvement to certain cloud features and further model variables.
- Improved representation of the land surface: While introducing the new multi-layer soil module TERRA-ML of the COSMO model, MeteoSwiss experienced serious soil dry-out problems in summer. Systematic evaluations of various enhancements [Ament, 2007] using a stand-alone version of TERRA-ML gave indications on promising modifications (e.g. revised bare soil evaporation, modified soil moisture transport). These potential improvements are currently tested with the full COSMO model system by analysing the impact on near surface parameters and on

precipitation forecasts. Furthermore, MeteoSwiss intends to resolve parts of the subgrid-scale variability of the land surface by using the mosaic/tile approach of Ament and Simmer [2006]. The implementation of this scheme is ongoing and first test suites will be available for evaluation in summer 2008.

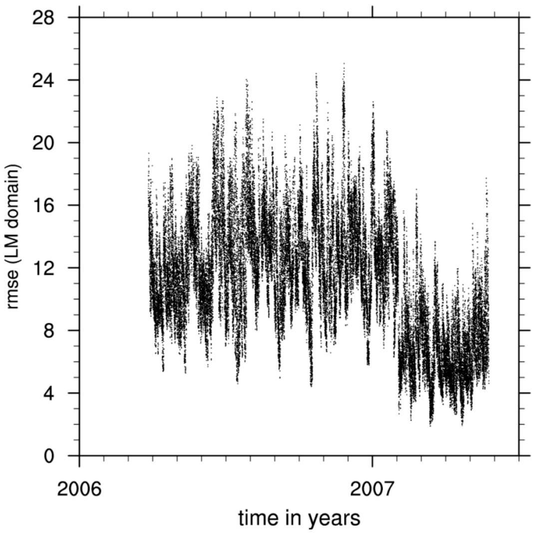

Figure 3. DWD's QUALISAT index describing the agreement between MSG TB and synthetic TB of the COSMO-EU model. Note, that MSG data are not available at DWD anymore.

- D-PHASE: MeteoSwiss coordinates all D-PHASE activities. Felix Ament was strongly involved in the organization of the demonstration period, the design of the unified D-PHASE GRIB format for archiving and is responsible to coordinate the alert generation by all atmospheric models. As a side effect of these duties, he established contact to all principle investigators of the D-PHASE modelling groups. His verification results of forecasted precipitation and issued alerts against radar data from the Swiss network (e.g. see Fig. 4) attracted a lot of attention and even triggered a model improvement in the microphysical schema of the Canadian CMC model.

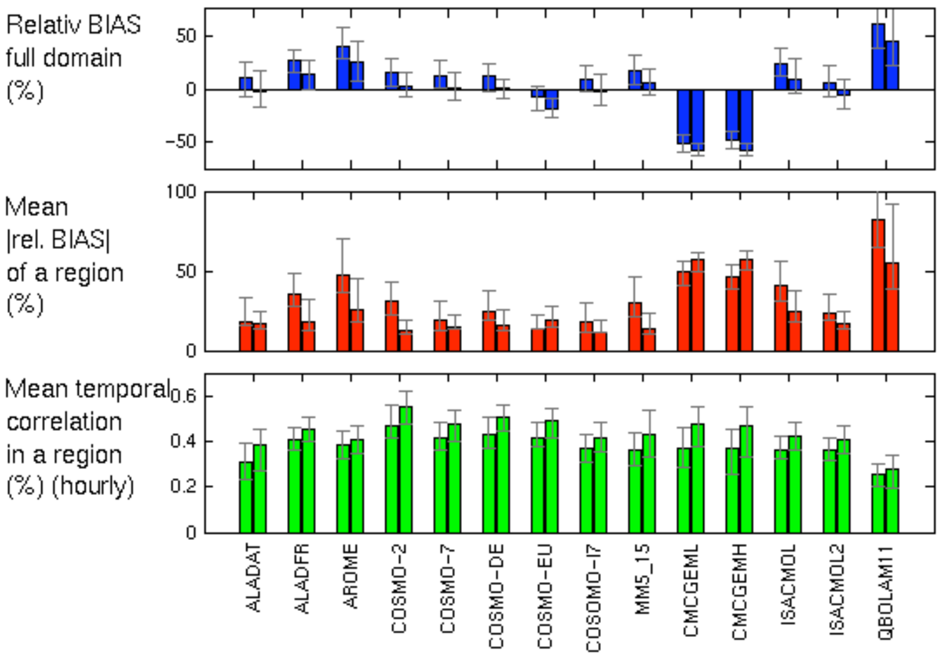

Figure. 4: QPF verification of D-PHASE models over Switzerland during summer (JJA) 2007. Reference: Swiss Radar composite (left bars) and radar data calibrated by daily gauge accumulations (right bar). Top: BIAS averaged over the whole period and domain. Center: Expected absolute value of a BIAS in a single warning region (Switzerland is decomposed into 18 warning regions). Bottom: Mean temporal correlation of hourly precipitation forecast in a warning region.

- COSMO-2: Since spring 2007, MeteoSwiss is integrating pre-operationally the deep convection resolving model COSMO-2 with a configuration closely related to the COSMO-DE model. Felix Ament is in charge to optimize the precipitation forecasts of this new model suite. The results of sensitivity studies to select model parameters and numerical formulations are summarized in [Ament, 2007a] and a supervised master thesis by Koller [2007].
- Radiation scheme: At the University of Bonn two adaptive schemes for reducing the computational speed of the radiation scheme were developed [Venema et al., 2007]

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3. Goals and work schedule (Ziele und Arbeitsprogramm)

3.1 Goals (Ziele)

The Priority Program (PP) 1167 “Quantitative Precipitation Forecasts (QPF)” states three main goals. QUEST activities are directly connected to the first two:

I. Identification of physical and chemical processes responsible for the deficiencies in quantitative precipitation forecast

II. Determination and use of the potentials of existing and new data and process descriptions to improve quantitative precipitation forecast

QUEST uses multi-dimensional remote sensing observations for evaluating model forecasts of DWDs COSMO models with focus on variables of the water cycle – specifically water vapour, cloud properties and precipitation. In order to identify model deficits a combination of detailed case study investigations and long-term model evaluations (LTE) focusing on the GOP is performed (Fig. 5). The LTE should point to systematic model deficits by averaging out stochastic errors arising from initial and/or boundary conditions. Furthermore, the long-term evaluation will reveal situations/cases with especially poor/high model performance (compare Fig.2 in the intermediate report. These situations can be analysed in detail by changing model physical parametrisations in order to attribute the errors to the treatment of specific processes: cloud microphysics, convection, radiation, turbulence, evaporation, etc. By using such refined methods, physical consistency is investigated and the model skill of a single variable is of lesser importance.

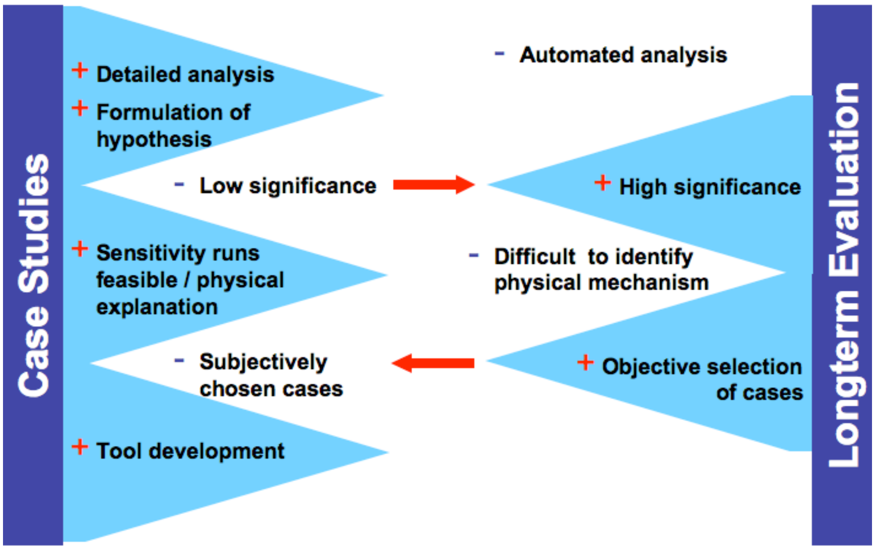

Figure 5. QUEST approach for identification of processes responsible for the deficiencies in quantitative precipitation forecast (PP goal I.)

Furthermore, QUEST contributes to PP goal II. by exploiting the potential of remote sensing data currently not used in routine model verification. A simple example are the cloud base heights derived from DWDs ceilometer network and available to QUEST since a few months which could already be used to show systematic discrepancies in the boundary layer. Their full potential will be exploited when combined with MSG and radar information (co-operation with coordination project by Hense, Bonn). Emerging data sources are polarimetric radar data which will become available within future radar networks as well as microwave radiance observed by several polar orbiting satellites. The potential of measured radiances in cloudy conditions is hardly explored and these data might become even more interesting if future satellites advance to higher frequencies (suggested CIWSIR and GOMAS missions). These measurements provide unique information about the different hydrometeor species (cloud water, cloud ice, rain, graupel, snow) of the cloud microphysical schemes.

The ultimate goals of QUEST are to study:

- the systematic errors in the precipitation forecasts of the COSMO and D-Phase models
- the typical conditions in which these systematic errors can be most clearly detected,
- the relation between correct water vapour, correct cloud and correct precipitation forecasts. Having found situations deficient QPFs, possible correlated errors in cloud and water vapour will be identified to study whether it is possible to trace the precipitation errors back through the water cycle,
- the improvement of cloud microphysical and radiative parametrisations and boundary layer representation, and
- the use of ensemble information to estimate model uncertainty

In this respect QUEST approaches the QPF problem from the statistical point while the COPS project (Wulfmeyer, Hohenheim) starts from individual observations with process studies. Consequently, the analysis of D-PHASE models will cover the D-PHASE domain and period to reach sufficient statistical confidence. QUEST has been planned to exist over the whole SPP. The 1st phase has included the development of a data base and analysis tools. The 2nd phase is mainly devoted to long-term evaluation based on COSMO operational forecasts and test suites as well as a first analysis of GOP data, whereas the 3rd phase will be devoted to a detailed analysis of specific problems (revealed by LTE of GOP) and possible improvements.

3.2 Work schedule (Arbeitsprogramm)

The work during the 3rd and last phase of the PP focuses on the exploitation of the GOP data for model evaluation and improvement. Work on model improvement (WP4) that has started in the second phase will be intensified. For this reason Axel Seifert, who works on the parametrisation development at DWD replaces Michael Baldauf as a project partner. The previous work package “Tool development” has been closed. These achievements shall be made available to the general public.The following paragraphs describe the WPs and their subtasks as well as the timing of each work package which are summarised in Table 1.

WP 1: Coordination

Since work package 1 ensures good communication between the QUEST partners, DWD and other projects within PP it covers the whole duration of the SPP. It includes the organisation of internal QUEST meetings as well as the **presentation of QUEST** within the PP and the scientific community. Furthermore, it coordinates the appearance of QUEST at international work shops and conferences and organizes the **dissemination of results** by pushing the writing of publications. The **project web site** (http://www.meteo.uni-koeln.de/crewell/doku.php/quest) plays a major role in the internal and external project communications. All reports, posters, talks and publications are available through this web site. This shall stimulate the immediate discussion of verification results with model PIs.

Furthermore, the tools developed in QUEST (forward operators like SynSatMic and analysis tools like cloud patchiness) shall be made available with detailed source code and documentation on the QUEST web site. In addition, a COPS/GOPS/D-PHASE testbed shall be established in cooperation with the COPS project where case studies (see already http://www.meteo.uni-koeln.de/crewell/doku.php/case_studies) like the intensive observation periods (IOP) 8b, 9c and 13a as well as periods with particular model problems will be documented. This shall give model PIs the opportunity to test possible model improvements. The close co-operation with VERIPREG (Wernli, Mainz) will be intensified by merging their precipitation analysis with our remote sensing analysis. WP 1 is the responsibility of IGMK.

WP 2: Model Evaluation

As outlined in section 3.1 we will use a combination of case studies, test suites and long-term evaluation to identify model deficits. For analysing the wealth of observations provided by the GOP automatic intercomparisons for “simpler” data sources like GPS, radiosondes, ceilometer and in situ precipitation has been set up and made available through the GOP website. For fully exploiting the more complex information from satellite and radar observations model output is stored during the GOP tailored to the observations in time and space and will be analysed with different aspects:

WP2.1 Representation of water vapour (FUB, IGMK)

Recently, comparisons of GPS and radiosonde data have shown the impact of observational problems on model forecasts [Crewell et al., 2008]. We will analyse contemplated effects in more detail by using additional information on water vapour from further instrumentations of supersites like AMF and Lindenberg. In particular we want to investigate whether the higher water vapour amounts seen in COSMO-DE compared to COSMO-EU result from enhanced surface evaporation or advective processes. With the help of satellite data we will study the temporal development and the spatial distribution of the humidity field as well as its relation to the clouds in COSMO. Satellite data will be used to study if the temporal development and the spatial distribution of the humidity field as well as its relation to the clouds in COSMO are consistently represented. If the COSMO models turn out to be inconsistent in the representation of clouds and humidity, meaning that clouds are formed in different situations than occurring in reality, this points to the direction in which model improvements are needed. Water vapour above land surfaces is detected with sufficient accuracy by the polar orbiting satellite instruments MODIS and MERIS. The use of MERIS and MODIS observations provides spatially highly resolved (0.25-0.30 km) products. The diurnal cycle will be studied with a less accurate water vapour product derived from the geostationary MSG SEVIRI. This analysis will be limited to cloud free conditions.

WP2.2 Development of clouds (FUB, IGMK)

The high temporal resolution of MSG allows to study the development of individual clouds using advanced tracking techniques. The tracking software extracts the location and extension of the analysed system for every 15 min. The tracking algorithm derives path, growth rate, life time, and origin of convective cells. It also counts the number of merging and splitting events. The tracking will be further refined in order to detect when and where large (> 10 km) cloud systems are formed. The same analysis will be performed for the model forecasts and a statistical comparison in terms of cloud origin and lifetime will be performed with respect to mean values and parameter velocity. Ultimately, we want to investigate how generation of convective systems determines the extent and the diurnal cycle of convective clouds. Low level clouds are also of interest even when they do not develop to a convective precipitation event: A correct prediction is required since they modulate surface radiation, heating and evaporation, thereby affecting the atmospheric branch of the hydrological cycle. This in turn will influence the QPF.

While the tracking is based on brightness temperatures the retrieved cloud top height gives information on the vertical cloud development especially on the rapid growth of deep convection. The tracking of individual clouds and cloud systems in comparison with the

COSMO cloud predictions enables us to estimate phase shifts and thus, whether COSMO predicts clouds and precipitation at the right place and the right time. The selected days of the COPS IOPs (see proposal by Wulfmeyer) will be studied in more detail, using the SEVIRI rapid scan data as well as by applying cloud tracking techniques. A focus will be put on the temporal and spatial development in response to topographical conditions. Deep convection will be investigated by combining the information on strong convective cells identified from AMSU observations with the temporal information its development by MSG.

The combination of cloud top from MSG and cloud base from the ceilometer network allows us to study the vertical cloud distribution and its development in time with respect to the COSMO simulations. A further step will be to add the precipitation products from VERIPREC. Herewith it is possible to connect the development of the cloud parameters to the precipitation rate. For special cases we intend to use additional information from supersite measurements (AMF) providing knowledge of multiple cloud levels.

WP2.3 Identification of regime related model deficits usting GOP data (IGMK, FUB, UHH)

The exploitation of the GOP data is a major effort of QUEST. Crewell et al. [2008] have already shown the year 2007 to be a rather variable year with very dry (April) and very wet periods [Crewell et al., 2008]. In order to identify model deficiencies in specific regions or during specific circulation regimes a regionalization (Fig. 6) has already been implemented. A statistical post-processing of model forecast and observations has already been prepared during GOP for these regions. For example, pdfs of all MSG brightness temperatures are available in high time resolution for the separate regions with similar model output and information on the general situation (stability, subsidence) including a “Wetterlagen-klassifikation” [Demuzere et al., 2007]. This database is currently build up as part of the GOP and within QUEST this will allow long-term evaluation in order to specify model deficiencies.

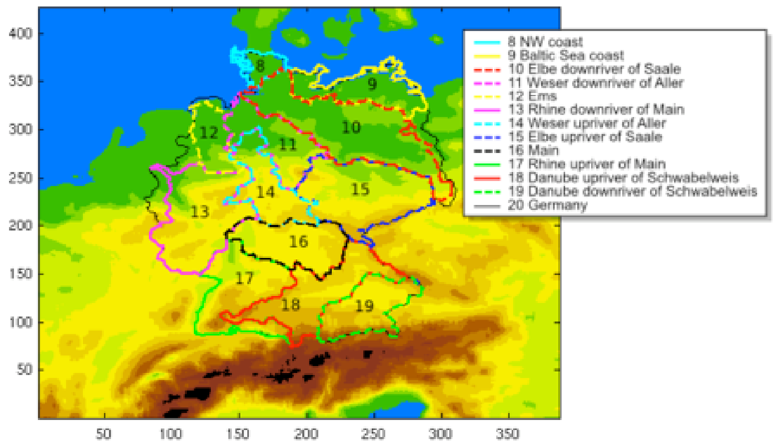

Figure 6. Water catchments which have been selected as specific regions for storing statistical information from model and observations (radar and satellite). In addition two the 13 catchments, seven geographic regions and six countries have been selected.

WP2.4 GOP generalization towards D-PHASE models (UHH)

Since the output of D-PHASE does not provide a full model state (i.e. all prognostic variables at all model levels), it is not possible to apply rigorously the model-to-observation approach as it has been performed for COSMO-EU and COSMO-DE during the GOP. We will apply an intermediate approach by selecting a set of “variables of interest” (VARI), which can be deduced both from D-PHASE data and observations, like e.g. boundary layer height or cloud cover at a specific location or averaged over a region. The adaptation of the QUEST tools to “model-to-vari” and “obs-to-vari” operators is a straightforward task. As an outcome, we will establish a database of “VARI” - time series for all D-PHASE models and observations. This database will be open to include verification results from other groups, in particular data from VERIPREG, as well as new model integrations (e.g. by potentially improved model versions or sensitivity tests.)

Based on this dataset it can be easily tested whether certain features of the COSMO LTE (e.g. dry bias effect for runs starting after 12 UTC or to thin boundary layers) are also revealed by other models. This analysis will help to detect potential model improvements by inspecting the different model formulations between D-PHASE models exhibiting a particular problem and those performing well. We will be in close contact with the D-PHASE model PIs to discuss the verification results in this direction.

WP2.5 Detecting error structures in the hydrological cycle

In order to assess the representation of the full hydrological cycle the forecasts will be analysed by a multivariate approach. This includes the error correlations among different key variables and joint probability functions to be calculated. Based on the experiences of WP2.3 the conditional verification shall reveal the specific processes in the hydrological cycle with exceptionally poor/good performance. This work package aims both at establishing methods for multivariate variation which can be transferred to operational practice and secondly at identifying crucial points for model improvements. Finally, we will investigate temporally lagged correlations to answer the question: can we forecast the QPF performance within the next few hours by analysing the errors now? This analysis will be done in close cooperation with the best member selection activities of the DAQUA project.

WP 3: Model improvement

The model improvement within QUEST is mainly performed in close collaboration with model developers at DWD and other PP groups by testing parametrisations and recommending further directions of improvement. An exception are cloud microphysical parametrisations which will be explicitly be development (WP 3.2).

WP3.1 Boundary layer evolution and the daily cycle (IGMK, DWD)

First analysis has already identified deficits in the representation of the planetary boundary layer (PBL) which is in general too humid with a too low vertical extent. Furthermore, the analysis of the lagged ensemble could show that the PBL moistens and mostly cools with time. These model deficiencies will be further investigated by inspecting the daily cycles of all variables in the atmospheric branch of the hydrological cycle, enabling a better understanding of the link between PBL evolution and precipitation. Statistical relations between different meteorological variables related to the PBL development will be investigated in the models and in nature. The model intercomparison will also address the question: How much variability is resolved by the models and how does this relate to precipitation? This directly addresses the issue of the turbulent length scale whose value has been found rather important for precipitation by DWD. To investigate the sensitivity of the diurnal cycle of convection to assumptions in the PBL scheme two test-suites have been performed at DWD for June und July 2007. The first test-suite uses a smaller asymoptotic mixing length in the classical Blackadar formulation while the second test suite uses, in addition, only the dry turbulence scheme. Both test suites are full re-forecasting experiments of COSMO-DE including data assimilation. And both modifications reveal a significant impact on the diurnal cycle of precipitation and the PBL. While the project by Kottmeier et al. (Karlsruhe) will investigate these using detailed COPS data QUEST will evaluate them in respect to the full model domain over long time scales using GPS water vapor, ceilometer network and MSG data which can well describe the built up of the PBL.

WP3.2 Cloud microphysics (DLR, IGMK)

Based on the model evaluation using SynPolRad [Pfeifer et al., 2007] we hypothise that deficiencies in QPF are related to deficiencies in the representation of the ice phase in the model. In particular the spatial distribution of snow vs. graupel is not correctly reproduced with a strong overprediction of graupel by the COSMO-DE model and an underestimation of snow and cloud ice contents by the (LMK version 3.x). In stratiform conditions often reflectivities in snow were underestimated in comparison to rain (gradient of reflectivity snow /rain too large) while in convective situations the reflectivities in graupel/convective cells were underestimated. Such information might add more insight into the problem of an overestimation of the lifetime of convective clouds in COSMO-DE. Because in convection, no ice hydrometeors reached the ground before melting this might have implications for redistribution of latent heat and therefore the life cycle of the convection which lived too long in the model in the cases examined.

These results suggest that the size distribution and perhaps density of the ice phase hydrometeors is incorrect (too many small and/or less dense particles). In order to verify or extend these conclusions the full suite of QUEST products (including the microwave radiances measured by AMSU and SSM/I being also sensitive to frozen hydrometeors and cloud radar) will be used for a wider range of weather conditions and model sensitivity will be test conducted. Case studies from COPS IOPs will be analysed in collaboration with the project by Blahak, Karlsruhe, who work with COSMO-DEs 2-moment scheme. Consistent with the earlier results, we would focus on the ice phase, and in particular the density and size distribution function.

WP3.3 Cloud radiation interaction

QUEST pursues the physical consistency of model forecasts. In this respect an inconsistency in the radiation parametrisation of the COSMO shall be tackled. Since the introduction of the prognostic precipitation scheme in April 2004 the mixing ratios of the precipitating hydrometeors (rain, snow, graupel) predicted by the model are not passed to the radiation parameterization routine. With the current model version and the possibilities of horizontal transport of precipitation, e.g. situations are possible where in a vertical column snow exists, but no cloud water or cloud ice because snow is generated in upper model levels somewhere else and then transported by horizontal advection. In such situations the radiation scheme does not “see” this snow cloud, and the model is physically inconsistent. We want to investigate whether the physically consistency (and therefore also potential forecast skill) of the COSMO model might be improved by a more accurate consideration of cloud and especially precipitation quantities in the radiation parametrisation. Additional motivation arises from the study by Jaeger et al. [2008][2] who find a significant bias in shortwave downward radiation for the Climate Local Model (CLM) which employs the same parametrisation as the COSMO models.

Supported by a PhD theses at IGMK (K. Ebell) we want to update and test the radiation scheme using the continuously measured surface radiative fluxes, detailed aerosol and cloud observations at the AMF supersite as well as Lindenberg and Cabauw. A very first approach would be (similar to Keil et al. [2006] for SynSat) to treat snow as it were cloud ice in the radiation scheme. We will study situations with observed ice in the atmosphere but no surface precipitation, since in situations with surface precipitation the retrieval of atmospheric ice profiles is hardly possible. These situations will be considered for case studies for comparison of output form operational model configuration, a single column version of the radiation scheme and with model output from model versions with improved cloud-radiation consistency. Measured surface radiative fluxes will be compared with model model output of a control run and different alternative model formulations.

WP3.4 Evaluation of ensembles (UHH)

Using the wealth of D-PHASE models, it is possible to extract / construct various types of ensembles: a) multi-model ensembles by combining all models b) a “single model - various configuration” ensemble by combing the COSMO models and c) the COSMO-LEPS as a downscaled global EPS. In a first step, we will analyse the performance of these ensemble systems by investigating the spread skill relation of all VARI quantities (see WP 2.4). This exercise will describe the accuracy of diagonal elements of the model error background covariance being vital for future ensemble data assimilation like the COSMO LETKF. The off-diagonal elements can be verified by comparing predicted covariances between VARI quantities with corresponding observed covariances. Finally, it will be possible to give advice which technique to design a limited area EPS ist most promising. Half of this workpackage is devoted for third year beyond the PP, which will be requested separately.

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[2] Jaeger, E.B., I. Anders, D. Lüthi, B. Rockel, C. Schär, and S. I. Seneviratne, 2008: Analysis of ERA40-driven CLM simulations for Europe*, Meteorol. Z.*, submitted.

Table 1. Summary and time table of work packages of QUEST during the 3rd phase of the SPP.

WP	Tasks	I	II	III	IV	I	II	III	IV
1	**Coordination**								
	Project meetings (all)	x			x			x	
	Implementation: Testbed and tools (IGMK)								
2	**Model Evaluation**								
	Representation of water vapour (FUB, IGMK)								
	Development of clouds (FUB, IGMK)								
	Regime related deficits (IGMK,KUL, DWD)								
	D-Phase generalization (UHH) + third year								
	Error structures hydrological cycle (IGMK,UHH)								
3	**Model Improvement**								
	Boundary layer evolution (IGMK, DWD)								
	Cloud microphysics (DLR, DWD)								
	Cloud radiative interaction (IGMK,DWD)								
	Ensemble evaluation (UHH) + third year								

3.3 Experiments with humans (Untersuchungen am Menschen)
not applicable

3.4 Experiments with animals (Tierversuche)
not applicable

3.5 Experiments with recombinant DNA (Gentechnologische Experimente)
not applicable

4. Funds requested (Beantragte Mittel)

4.1 Staff (Personalbedarf)
Funding for the following employees is requested from DFG for the whole duration of the project:

Institute	**Personnel**	**Tasks**
IGMK(a)	1 scientist TVL- 13 for two years	WP1, WP2., WP3
DLR(b)	0.5 scientist TVL-13 for two years	WP3.2
FUB(c)	0.5 scientist TVL-13 for two years	WP2, WP3.3
UHH(d)	0.5 scientist TVL-13 for two years	WP2, WP3.4

(a) Thorsten Reinhardt who took over the work from Felix Ament in November 2006 shall continue. Due to his previous work at DWD within the LMK group at DWD his detailed knowledge of the COSMO-DE model is of uttermost importance for all project partners. This is especially true for the planed work on microphysical parametrisations since he has a strong background here, e.g. he developed the graupel scheme for the COSMO-DE model.

(b) Monika Pfeifer who worked on QUEST since 1 April 2004 finished her PhD in spring 2007. She will be continuing with half of her time on QUEST. Specifically she will work on the implementation of changes in the microphysical parametrisations on the basis of results suggested by SynPolRad studies, e.g. sedimentation rates for graupel etc.

(c) Stefan Stapelberg started his PhD on long-term model evaluation using satellite data in November 2007. Funding for the final two years of his theses is requested.

(d) A new PhD student will start to work on the extension of the QUEST methodology towards D-PHASE as member of a new emerging young scientist group with the focus on the interface between models and observations. Funding for the third year, which is devoted to probabilistic evaluation and finalizing the thesis, will be requested from DFG during the second year in the framework of the “Individual Grants Programme”. An excellent candidate to fill this position is Friederike Koch, who has already gather experience in radar data as student worker at IGMK and will finish her diploma in spring 2008.

4.2 Scientific equipment (Wissenschaftliche Geräte)

The data archiving at DKRZ Hamburg as part of the joint COPS/GOP project of phase 2 includes only final products for observations and model runs. For detailed analysis of test suites and GOP data several raw and intermediate products are required/generated. Considering that the COSMO-DE output for one single month already amounts to about 2-3 TB storage space is requested for IGMK where the model output is generated and for FUB where work on raw satellite data (for example for tracking purposes) will be carried out. It should be noted that an extension of the GOP is envisioned (see coordination proposal by Hense) which will further increase the data volume.

IGMK	(2 Tbyte RAID system)		2.000,-
FUB	(2 Tbyte RAID system)		2.000,-
		total 4.2	**4.000,- EUR**

4.3 Consumables (Verbrauchsmaterial)

For each year and institute funding for archiving tapes, colour prints and copies, laser printer copies is requested with 500,- Euro.

total 4.3	**4.000,- EUR**

4.4 Travel expenses (Reisen)

National travel: Project meetings between the QUEST partners, DWD and other PP groups (VERIPREG, COPS) have been found very fruitful in the course of the project. This will lead to additional meetings between the different project scientists. Each meeting is estimated with 150 Euro per person.

International travel: QUEST results were presented at several international conferences (European Geophysical Society (EGS); European Conf. on Radar Meteorology and Hydrology 2004 & 2006; WMO Workshop on Nowcasting; AMS Conf. on Radar Meteorology; GEWEX conference 2005, 2nd Int. Symp. Quantitative Precipitation Forecasting and Hydrology 2006) and we expect even more results of general interest in the 3nd phase. Therefore for each group one international conference per year is foreseen with an average cost of 1.000,- Euro[3]. Appropriate conferences are the EGS Symposium in April 2009 and 2010, the European Conference on Radar Meteorology and Hydrology 2008 & 2010, 15th International Conference on Clouds and Precipitation 2008, the PAN-GCSS GEWEX Cloud System Study Meeting 2008, the Fall meeting of the American Meteorological Society (AMS) or a more specialised conference in this period which has not been announced yet.

National travel:

IGMK (T. Reinhardt, S. Crewell)	500,-
DLR (M. Pfeifer, either G. Craig or M. Hagen)	500,-
FUB (S. Stapelberg, J. Fischer)	500,-
DWD (A. Seifert)	500,-
UHH (F. Ament)	500,-

International travel:

IGMK (T. Reinhardt)	2.000,-
DLR (M. Pfeifer)	2.000,-

[3] This is based on average costs in the past for one European (400,-Eu) and one international (1600,- Eu) conference

FUB (S. Stapelberg)	2.000,-
DWD (A. Seifert)	1.000,-
UHH (F. Ament)	2.000,-
total 4.4	**11.500,- EUR**

4.5 Publication costs (Publikationskosten)

Two refereed publications [van Lipzig et al., 2006; Schröder et al., 2006] have already been published, one is submitted and another one in preparation. Several more are expected for the last phase of the SPP. Therefore 750,- EUR per year (x2) are requested by each institute (x4):

total 4.5 **6.000,- EUR**

4.6 Other cost (Sonstige Kosten) - none

5. Preconditions for carrying out the project (Voraussetzungen für die Durchführung des Vorhabens)

5.1 Your team (Zusammensetzung der Arbeitsgruppe)

IGMK

Prof. Dr. Susanne Crewell	Professor for Meteorology
Dr. Ulrich Löhnert	Assistant professor, ground-based remote sensor synergy
Thorsten Reinhardt	Project scientist for the evaluation/improvement of the Lokal-Modell; funding for his position is requested from DFG
Kerstin Ebell	PhD student; cloud-radiation interactions
Veronika Breininger	Diploma student; evaluation of COSMO precipitation forecasts
Christoph Selbach	Diploma student, evaluation of COSMO using GPS data

UHH

Dr. Felix Ament	Appointed to become "Juniorprofessor" for experimental meteorology; currently at MeteoSwiss (MAP D-PHASE)
Friederike Koch	PhD student for the evaluation of D-PHASE models, third year will be requested in a separate DFG proposal

DLR

Dr. George Craig	Head of the department "Cloud physics and traffic meteorology"
Dr. Martin Hagen	Head of the radar group
Dr. Monika Pfeifer	Project scientist for the polarimetric radar simulator; funding for half of her position is requested from DFG.
Dr. Hartmut Höller	Scientist in the radar group
Dr. Christian Keil	Scientist for COSMO-DE simulations

FUB

Prof. Dr. Jürgen Fischer	Head of the Institute for Space Science
Dr. Rene Preusker	Assistant professor, solar and thermal radiative transfer
Dr. Anja Hünerbein	Postdoc, former project scientist
Stefan Stapelberg	Project scientist for the use of satellite data, the last two years of his PhD is requested from DFG.

K.U.Leuven

Prof. Dr. Nicole van Lipzig	Head of the meteorology and climate group
Kwinten vande Weverberg	PhD student, modelling of precipitation in Belgium, soil erosion

DWD

Dr. Axel Seifert	parametrisation development for the COSMO models

5.2 Co-operation with other scientists (Zusammenarbeit mit anderen Wissenschaftlern)

Collaboration was established with other verification projects within the priority program namely VERIPREG (**Wernli**, Mainz) and STAMPF (**Reimer**, Berlin). VERIPREG surface precipitation analysis will be combined with further QUEST observables. Strong bonds with the coordination project by **Hense** (Bonn) will be kept in respect to the continuation of the GOP. Close co-operation on model improvement will be kept with the cloud microphysics project (**Blahak**, Karlsruhe), the development of a new convection scheme by **Bott (Bonn),** the boundary layer project based on COPS data (**Kottmeyer et al**., Karlsruhe) and the data assimilation project (DAQUA coordinated by **Simmer**, Bonn) in respect to best member selection. In addition, we will cooperate with the COPS/D-Phase analysis project by **Wulfmeyer** (Hohenheim) in putting the results achieved for the COPS region into perspective to other regions and seasons.

5.3 Foreign contacts and co-operations (Arbeiten im Ausland und Kooperation mit ausländischen Partnern)

Beside the co-operation with leading international groups on the individual observing techniques collaborations concerning the model evaluation and improvement exist:

Satellite and Radar Observations:

- Peter Bauer (radiance assimilation; ECMWF)
- V.N. Bringi and V. Chandrasekar (T-matrix code; both at CSU, Ft. Collins)
- Paul Menzel and Ralf Bennartz (MODIS; University of Wisconsin, USA)
- Peter Regner and Philippe Goryl (MERIS, ESA / ESRIN)
- Richard Santer (radiative transfer simulations; Universite du Littoral, France).

Model evaluation/improvement:

- Jean-Pierre Chaboureau (use of satellite data for parameterization improvement; Laboratoire d'Aérologie (LA), France)
- Evelyne Richard (Meso-NH parameterizations and runs; LA, France)
- Erik van Meijgaard (regional climate modlling; KNMI)
- Anthony Illingworth (Cloudnet model evaluation; UReading)

D-PHASE:

- Mathias Rotach (Head of MAP D-PHASE science steering committee, MeteoSwiss Switzerland)
- Marco Arpagaus (Coordinator of MAP D-PHASE , MeteoSwiss Switzerland)
- Manfred Dorninger (Chair of MAP D-PHASE WG “Verification”, Vienna, Austria)
- Andrea Montani (Chair of MAP D-PHASE WG “Data interface”, Bologna, Italy)

5.4 Scientific equipment available (Apparative Ausstattung) - not applicable

5.5 Your institution’s general contribution (Laufende Mittel für Sachausgaben)

All institutes contribute by providing computers, office space, staff and minor expenses.

5.6 Conflict of Interest (Interessenkonflikt) - not applicable

5.7 Other requirements (Sonstige Voraussetzungen) - not applicable

6. Declarations (Erklärungen)

A request for funding this project has not been submitted to any other address. In case we submit such a request we will inform the Deutsche Forschungsgemeinschaft immediately. The Vertrauensdozenten of the University of Cologne (Prof. Dr. Nauman) and the Free University of Berlin (Prof. Dr. Bohnsack), and the Programme Directorate and Executive Board of DLR. have been informed.

7. Signatures (Unterschriften)

Köln, 29.10.2007

(S. Crewell)

Zürich, 29.10.2007

(F. Ament

Berlin, 29.10.2007

(J. Fischer)

Oberpfaffenhofen, 29.10.2007

(G. Craig) (M. Hagen)

Offenbach, 29.10.2007

(A. Seifert)

Leuwen, 29.10.2007

(N. van Lipzig)

8. List of Appendices (Verzeichnis der Anlagen)

- Appendix 1: Proposal information in German
  - Thema (1.2)
  - Zusammenfassung (1.6)
  - Beantragte Mittel (4)

- Appendix 2: Information on COSMO model chnges

- DFG form 10.03 of project scientists not already available to DFG
  - Thorsten Reinhardt
  - Stefan Stapelberg

- QUEST Interim Report, 10 pages

- Two relevant QUEST publications which will be submitted by the end of 2007

  Crewell, S., S., V. Breininger, M. Mech, T. Reinhardt, C. Selbach, H.-D. Betz, E. O'Connor, G. Dick, J. Fischer, T. Hanisch, T. Hauf,, A. Hünerbein, A. Mathes, G. Peters, H. Wernli, 2008: General Observation Period 2007: Concept and first results. *Meteorol. Z.*, to be submitted.

  Pfeifer, M., W. Yen, M. Hagen, G. Craig, T. Reinhardt, M. Mech, S. Crewell, A. Hünerbein, J. Fischer, M. Schröder, and M. Baldauf, 2008: Validating precipitation forecasts using sensor synergy: The case study approach, to be submitted until the end of 2007.

Appendix 1: Antragsinformation in deutsch

1.2 Thema

Quantitative Evaluierung regionaler Niederschlagsvorhersagen durch Nutzung mehrdimensionaler Fernerkundungsdaten (QUEST)

1.6 Zusammenfassung

Die Niederschlagsmenge am Boden resultiert aus einer komplexen Prozesskette, weshalb multiple Parameter zur Identifikation von Defiziten in der quantitativen Niederschlagsvorhersage berücksichtigt werden. Wir verwenden daher mehrdimensionale Fernerkundungsbeobachtungen von Radar, Satelliten und Profilstationen zur Evaluierung der Vorhersagegüte verschiedener Variablen des Wasserkreislaufs mit Fokus auf den räumlich hochaufgelösten Vorhersagen des DWD COSMO-DE Modells. In den ersten Phasen des SPP1167 wurden Werkzeuge (i.W. Vorwärtsoperatoren) zur Verbindung von Fernerkundungsbeobachtungen und Modellvariablen entwickelt, deren Funktion in einer Reihe von Fallstudien und Testsuiten getestet wurde. In der dritten SPP Phase liegt der Schwerpunkt auf der derzeit laufenden *General Observation Period* (GOP) 2007. Die dabei erzielten Ergebnisse sollen mit einer systematischen Evaluierung des MAP D-PHASE Ensembles verallgemeinert und entsprechend Wettersituationen und Gebieten entschlüsselt werden. Mittels multi-variater Analyse sollen die Fehler der verschiedenen Variablen bestimmten Prozesen zugeordnet werden. Letztendlich sollen dabei mikrophysikalische, Strahlungs- und Grenzschicht-Parametrisierungen verbessert werden. Zudem sollen die in QUEST entwickelten Werkzeuge dokumentiert und der Allgemeinheit zur Verfügung gestellt werden.

4. Beantragte Mittel

4.1 Personalbedarf

Die Finanzierung der folgenden Mitarbeiter wird für die Dauer des Projektes bei der DFG beantragt:

Institut	Personal	Aufgaben
IGMK(a)	1 Wissenschaftler TVL-13 für zwei Jahre	WP1, WP2, WP3
DLR(b)	0.5 Wissenschaftler TVL-13 für zwei Jahre	WP3.2
FUB(c)	0.5 Wissenschaftler TVL-13 für zwei Jahre	WP2, WP3.3
UHH(d)	0.5 Wissenschaftler TVL-13 für zwei Jahre	WP2, WP3.4

(a) Thorsten Reinhardt, der die Arbeit von Felix Ament im November 2006 übernommen hat, soll seine Arbeiten fortführen. Durch seine vorherige Tätigkeit beim DWD in der COSMO-DE-Entwicklergruppe hat er detaillierte Kenntnisse des COSMO-Modells, was äußerst wichtig und nützlich für alle Projektpartner ist. Dies gilt insbesondere für die geplanten Arbeiten zur Wolkenmikrophysik und zur Strahlungs-Wolken-Wechselwirkung, da er beim DWD u.a. das Graupel-Wolkenmikrophysikschema für COSMO-DE entwickelte.

(b) Monika Pfeifer, die seit 1.4.2004 für QUEST arbeitet, schloss ihre Promotion im Frühjahr 2007 ab. Sie soll mit der Hälfte ihrer Arbeitszeit für QUEST weiterarbeiten. Sie wird insbesondere an der Implementierung von Änderungen in der Wolkenmikrophysik-Parametrisierung (z.B. der Sedimentationseigenschaften von Graupel) arbeiten, die sich aus bisherigen Ergebnisssen ihrer Arbeit mit SynPolRad ergeben haben.

(c) Stefan Stapelberg beginnt im November 2007 an der FUB als Doktorand mit Arbeiten zur Langzeitevaluierung von Modelldaten unter Nutzung von Satellitenbeobachtungen. Die Finanzierung der letzten zwei Jahre seiner Promotionsarbeit (ab 1.11.2008) wird beantragt.

(d) Ein(e) neue(r) Doktorand(in) soll in der Nachwuchswissenschaftlergruppe an der Universität Hamburg beginnen mit Arbeiten zur Erweiterung der QUEST-Methoden mit dem

Schwerpunkt auf der Verbindung von Modellen und Beobachtungen. Für die Finanzierung des dritten Jahres seiner/ihrer Promotionsarbeit, in dem er/sie an probabilistischer Modellevaluierung und der Fertigstellung der Dissertation arbeiten soll, wird bei der DFG ein Einzelantrag gestellt werden. Eine hervorragende Kanditatin für diese Stelle ist Friederike Koch, die bereits als studentische Hilfskraft Erfahrung mit Radardaten gesammelt hat und ihr Diplomstudium in Meteorologie am IGMK im Frühjahr 2008 abschließen wird.

4.2 Wissenschaftliche Geräte

Das Datenarchiv am DKRZ Hamburg als Teil des gemeinsamen COPS/GOP-Projektes der zweiten Phase des SPP enthält nur Endprodukte der Beobachtungen und Modellläufe. Bei der detaillierten Analyse der GOP-Daten (einschließlich Modellausgaben) werden Zwischenprodukte erzeugt, für die Speicherplatz benötigt wird. Unter Berücksichtigung, dass das Datenvolumen eines einzelnen Monats COSMO-DE-Modellausgabe sich auf etwa 2-3 TB beläuft, wird Speicherplatz für das IGMK, wo die Modelldaten verarbeitet werden, und für die FUB, wo die Satellitendaten (z.B. für Tracking-Analysen) verarbeitet werden, beantragt..

IGMK	(2 Tbyte RAID-System)		2.000,-
FUB	(2 Tbyte RAID-System)		2.000,-
		gesamt 4.2	**4.000,- EUR**

4.3 Verbrauchsmaterial

Pro Jahr und Institution werden für Archivmaterial, Farbdrucke und –kopien sowie Poster 500,- Euro beantragt.

gesamt 4.3 **4.000,- EUR**

4.4 Reisen

Inlandsreisen:

Projektreffen zwischen den QUEST-Partnern, DWD-Wissenschaftlern und anderen Gruppen im SPP (VERIPREG, COPS) haben sich im bisherigen Projektverlauf als äußerst fruchtbar erwiesen. Es ist abzusehen, dass die Zusammenarbeit mit anderen SPP-Gruppen intensiviert wird (2-Momenten-Mikrophysik (Beheng, Karsruhe), Konvektions-parametrisierung (Bott, Bonn), spektrale Mikrophysik (Knoth, Leipzig), DAQUA (Simmer, Bonn) sowie weitere). Dies wird zu zusätzlichen Arbeitstreffen von Wissenschaftlern aus verschiedenen Projekten führen. Die Kosten jeder Reise werden auf 150 Euro pro Person angesetzt.

Auslandsreisen:

QUEST-Ergebnisse wurden bereits auf verschiedenen internationalen Tagungen vorgestellt (European Geophysical Society (EGS); European Conf. on Radar Meteorology and Hydrology 2004 & 2006; WMO Workshop on Nowcasting; AMS Conf. on Radar Meteorology; GEWEX conference 2005, 2nd Int. Symp. Quantitative Precipitation Forecasting and Hydrology 2006). Wir erwarten für die dritte Phase eher noch mehr international vorzeigbare Ergebnisse und sehen daher pro Gruppe und Jahr eine internationale Konferenz mit durchschnittlichen Kosten von 1000 Euro[4] vor. Passende Konferenzen sind das EGS Symposium im April 2009 und 2010, die European Conference on Radar Meteorology and Hydrology 2008 & 2010, die 15th International Conference on Clouds and Precipitation 2008, das PAN-GCSS GEWEX Cloud System Study Meeting 2008, das Fall Meeting der American Meteorological Society (AMS) sowie spezialisiertere Konferenzen, die kurzfristig angekündigt werden.

Inlandsreisen:

IGMK (T. Reinhardt, S. Crewell)	500,-
DLR (M. Pfeifer, G. Craig oder M. Hagen)	500,-

[4] Die Durchschnittskosten basieren auf Erfahrungswerten für jeweils eine Konferenz in Europa (400,- Euro) und eine Konferenz auf einem anderen Kontinent (1600,- Euro).

FUB (S. Stapelberg, J. Fischer)	500,-
DWD (A. Seifert)	500,-
UHH (F. Ament)	500,-

Auslandsreisen:

IGMK (T. Reinhardt)	2.000,-
DLR (M. Pfeifer)	2.000,-
FUB (S. Stapelberg)	2.000,-
DWD (A. Seifert)	1.000,-
UHH (F. Ament)	2.000,-

gesamt 4.4 **11.500,- EUR**

4.4 Publikationskosten

Zwei begutachtete Publikationen [van Lipzig et al., 2006; Schröder et al., 2006] sind bereits veröffentlicht, eine ist eingereicht und eine weitere in Vorbereitung. Mehrere weitere begutachtete Veröffentlichungen sind in der dritten Phase des SPP zu erwarten. Daher werden Publikationskosten in Höhe von 750,- Euro pro Jahr (x2) und Institution (x4) beantragt:

gesamt 4.5 **6.000,- EUR**

4.5 Sonstige Kosten

keine

Appendix 2: Information on COSMO model changes

On August 14th, 2006 the pre-operational test of the COSMO-DE (at that time still called formerly) started and operational usage began on April 16th, 2007. 21-hour COSMO-DE forecasts are started every three hours from a continuous data assimilation cycle. Therefore a “lagged ensemble” of up to eight forecasts is available for each target time. The most important changes in the operation of that model are listed below:

- From Dec. 19th, 2006 to April 4th, 2007 latent heat nudging (LHN) [Jones and MacPherson, 1997; Schraff et al, 2006] was switched off. The reason was that on the one hand due to bright-band effects in winter unrealistically high precipitation rates were assimilated, deteriorating the model performance. Note that in winter the positive the impact of LHN on forecast skill is much smaller than in summer.
- On Jan. 31st, 2007 changes in the cloud microphysics in COSMO-EU were introduced to tackle the problems of a positive frequency bias of low precipitation amounts and of an overestimation of orographic effects on precipitation. Properties and assumptions about the snow particles were modified, e.g. leading to a lower particle sedimentation velocity. Moreover, the formulation of the autoconversion rates from cloud water to rain water was improved. Besides their impact on surface precipitation, these changes also increased the atmospheric amounts of cloud water, cloud ice, and snow.
- On Feb. 6th, 2007 the COSMO-DE microphysics scheme including the graupel [Reinhardt and Seifert, 2006] was switched off and replaced by the improved cloud microphysics scheme of COSMO-EU. The reason for this change was that the increased hydrometeor mixing ratios in COSMO-EU turned out to be inconsistent with COSMO-DE’s model physics and caused unrealistically high precipitation amounts in COSMO-DE’s boundary zone.
- On April 4th, 2007, the COSMO-DE microphysics scheme including graupel was switched on again, but with implementation of the changes in the snow microphysics and the cloud-water autoconversion introduced in COSMO-EU on Feb, 4th. Also the treatment of hydrometeors in the boundary-relaxation scheme of COSMO-DE was improved.
- On May, 24th, 2007 the method for composite generation of radar-derived precipitation rates changed leading to a systematic reduction of precipitation that is used in the LHN of COSMO-DE. Therefore, precipitation in COSMO-DE’s assimilation cycle is systematically reduced.
- On July 26th, 2007 improvements in the identification and specification of appropriate latent heating profiles in the COSMO-DE LHN scheme were introduced reducing significantly the systematic overestimation of precipitation in the COSMO-DE assimilation cycle.
- On Oct 10th, 2007 the reference precipitation flux used in the LHN scheme has been modified to achieve a further reduction of the systematic overestimation of precipitation in the assimilation cycle.

Jones, C.D., and B. MacPherson, 1997: A Latent heat Nudging Scheme for the Assimilation of Precipitation Data into an Operational Mesoscale Model, *Meteorol. Appl.* , 4, 269-277.

Reinhardt, T., and A. Seifert, 2006: A three-category ice scheme for LMK. *COSMO Newsl.*, 6, 115- 120.

Schraff, C., K. Stephan, and S. Klink, 2006: Revised Latent Heat Nudging to cope with Prognostic Precipitation. *COSMO-Newsl.*, 6, 31-37.