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

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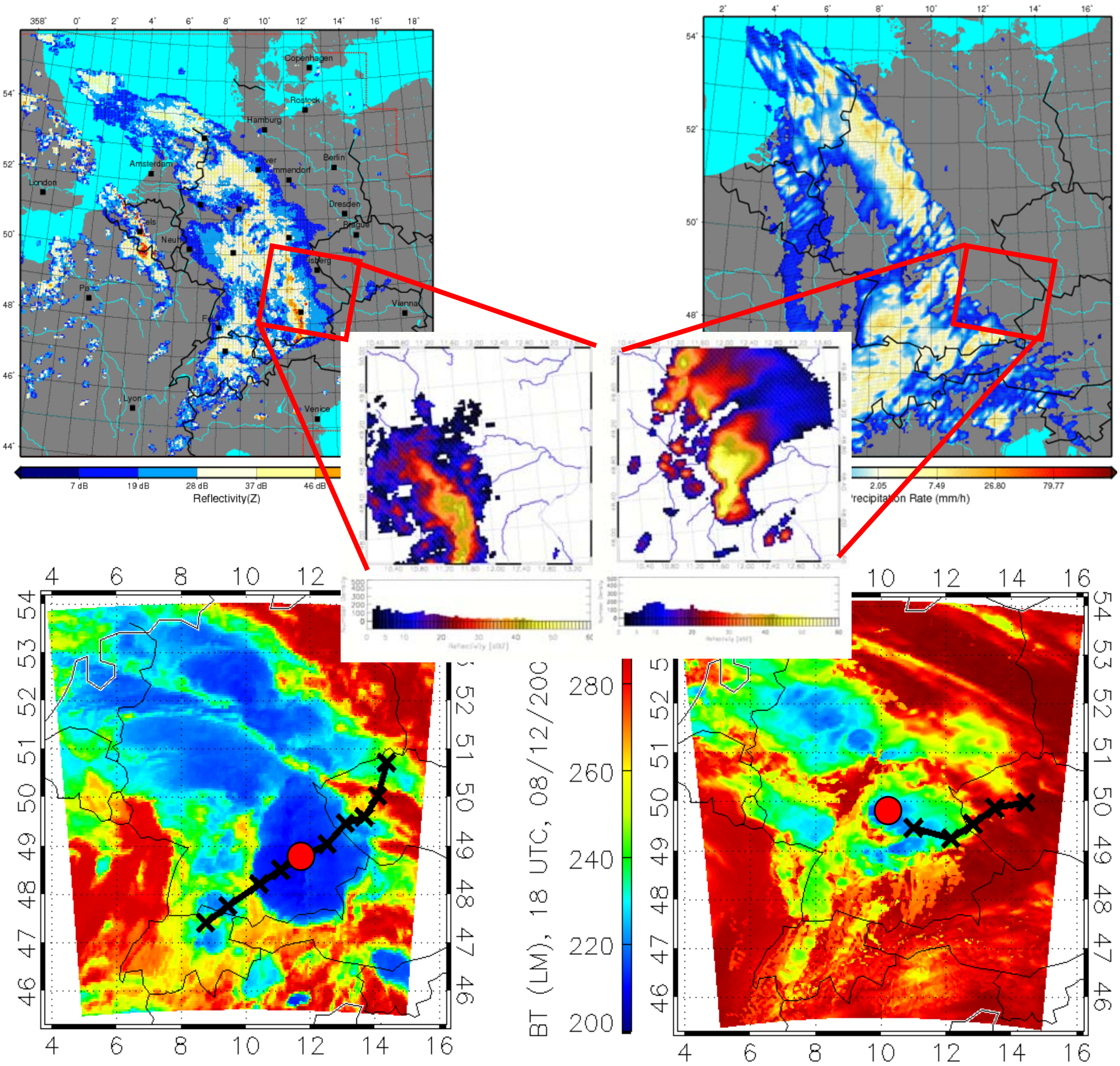

Application for a grant at the Deutsche Forschungsgemeinschaft

October 31, 2005

Top row: Radar reflectivity (*Z*) composite (left) of the frontal system moving over Germany on 12 August 2004 at 18 UTC and corresponding LM precipitation (*R*) forecast (right). The forecast was started at 12 UTC on the previous day using a grid spacing of 2.8 km. Colour schemes are matched to represent standard *Z*-*R* relation.

Middle row: Polarimetric radar observations by POLDIRAD (left) in southern Germany and the radar simulation from **SynPolRad** based on LM forecast (right) both on 12 August 2004 at 18 UTC. The reflectivity histogram is plotted at the bottom.

Bottom row. Brightness temperature at 10.8 μm observed by Meteosat Second Generation (left) and calculated by **SynSat** from LM forecast (right) both on 12 August 2004 at 18 UTC. The black line shows the track of the most intense (coldest) part of the precipitation system from 14 to 23 UTC (left). The track in the left panel starts later in the evening (19 UTC). The red dots indicate the current position at 18 UTC.

Model problem I: As can be seen on the top row, the strong thunderstorm in the region of Munich is not represented by the LM using the full model domain over Germany. Sensitivity tests were performed using a smaller domain and it was found that the thunderstorm is better represented, when a small domain over the Munich area excluding the Alps was chosen (second row left panel). This sensitivity run indicates that during this day the foehn effect in the high-resolution domain is overestimated when the Alps are included.

Model problem II: The largest cell within the SynSat simulations is located in the North-West of the domain while in reality the majority of cells occurs in southern Germany. Furthermore the modelled cells are smaller in size and last for a few hours only. An exception in terms of size is the cell whose track is plotted in the right panel. However, it becomes active too late in the evening, and the cell exhibits less intensity in terms of area of cold cloud tops relative to the observation.

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 Cr 111/5-1, Cr 245/1-1 and Fi 435712-1.

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1.2 Topic (Thema)

Quantitative evaluation of regional precipitation forecasts using multi-dimensional remote sensing observations.

1.3 Code name (Kennwort)

QUEST

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

Meteorology, cloud physics, radiative transfer modelling, radar and satellite remote sensing.

1.5 Scheduled duration in total (Voraussichtliche Gesamtdauer)

The project is scheduled for 6 years in total corresponding to the total duration of the PP. Funding by DFG started for the 1st PP 1167 period in April 2004.

1.6 Application period (Antragszeitraum)

24 months; 1 April 2006 until 31 March 2008

1.7 First applications (Gewünschter Beginn der Förderung)

The previous grant (CR-111/5-1) is from 1 April 2004 to 31 March 2006. Expenditures for personnel will probably last until spring/summer 2006 (MIM: 30 June 2006; DLR: 31 March 2006; FUB: 31 May 2006). Expenses for consumables will probably last until March 2006. Funding from this grant should enable the project scientists to continue their work without interruptions.

1.8 Summary (Zusammenfassung)

Clouds and precipitation are highly variable in time and space, which hampers their treatment in atmospheric models. Attempts have been made to improve their representation by decreasing the horizontal grid spacing (Δx). In-depth analysis of model deficiencies, using adapted evaluation techniques, is absolutely necessary to check whether an improved resolution leads to an improvement in the forecast. We will use multi-dimensional remote sensing data from radar, satellite and profiling stations to develop new tools to judge the performance of the Lokal-Modell Kürzestfrist (LMK) of DWD with $\Delta x = 2.8$ km. Because the amount of precipitation at the ground results from a complex process chain we will consider a number of atmospheric parameters and their cross correlation in the model and in reality. In order to cover all relevant precipitation types we will apply the evaluation tools developed in the first project phase to the long-term data set gathered during the General Observation Period (GOP) 2007. This includes the use of radar and satellite observations in both observation-to-model and model-to-observation approaches. The statistical analysis of this data set will a) identify systematic model weaknesses and b) help us select case studies which give especially poor/good model performance. Consequently, we will work on the model improvement by investigating the treatment of cloud microphysics, turbulence, land surface treatment and/or the radiation scheme.

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

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

Remote sensing observations cover the relevant scales of mesoscale models and provide a wealth of observation about atmospheric gases, aerosols, clouds and precipitation at high temporal and spatial resolutions. However, the observed signal is not directly connected to the model variables. In the retrieval of geophysical variables (**observation-to-model**) algorithms often make implicit assumptions on the atmospheric state which might not correspond to those of a mesoscale model; for example drop size distributions. Sometimes even model analyses are used as background information in retrieval algorithms. Therefore we will also consider the so-called **model-to-observation** approach (Fig. 1) in order to optimally exploit the information content of the remote sensing measurements. This approach avoids uncertainties due to the retrieval process because the so-called "forward" model (operator) can be described much more accurately than the inversion process, which always involves certain assumptions to compensate for the ambiguities of the problem. Another important advantage is the independence from training data sets needed for the retrieval process which are known to lack representativeness. The development of operators which convert model output to observation space is also an important step towards assimilation since they are a pre-requisite for modern assimilation techniques. These reasons have triggered several studies at the European Centre for Medium Range Weather Forecast (ECMWF) where radiances in the infrared and microwave range were simulated from ECMWF forecasts [for example Chevallier and Kelly, 2002; Chevallier and Bauer, 2003]. Another example for the model-to observation approach is a near real-time simulation of broad-band fluxes from the Met Office Unified Model for the comparisons with the Geostationary Earth Radiation Budget instrument´(GERB) instrument also onboard of Meteosat Second Generation (MSG) [Allan et al., 2004]. This exercise aims at an evaluation and improvement of the numerical weather forecast model (NWP) as well as the study of radiative processes involving clouds, water vapour, aerosols, etc.

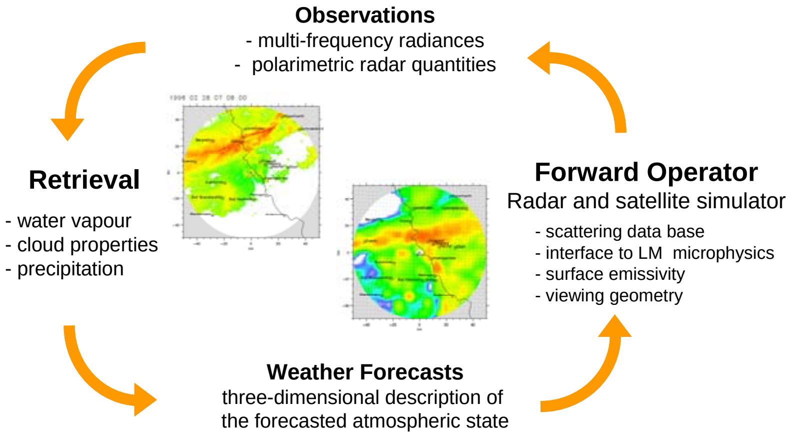

Figure 1. Illustration of the observation-to model and the model-to-observation process.

Within the numerical weather prediction (NWP) satellite application facility (SAF) the Radiative Transfer model for ATOVS calculations (RTTOV) [Saunders et al, 1999] is further developed to improve the interface between satellite data and NWP with special emphasis on assimilation. Currently, it is able to simulate about twenty different satellite instruments. Ongoing work concerns the simulation of microwave frequencies higher than about 80 GHz which are problematic due to the complex scattering characteristics of frozen or mixed phase hydrometeors. In a recent study [Wiedner et al., 2004] output from the Méso-NH model has been interfaced with a detailed microwave radiative transfer model taking the full scattering interactions into account. The resulting brightness temperature fields have shown very good agreement with Tropical Rainfall Measurement Mission Microwave Imager (TRMM/TMI) satellite observations up to 85 GHz, in two convective situations. The agreement obtained at 85 GHz is especially remarkable, given the high sensitivity of these frequencies to particle characteristics, especially in the ice phase. Studying several mid-latitude precipitation cases a very good correlation between microwave radiances and the different hydrometeor types (e.g. graupel and snow) was revealed (Fig. 2) suggesting the high potential of microwave observations (for example by the Advanced Microwave Sounding Unit AMSU-B) to better evaluate cloud microphysical parametrisations.

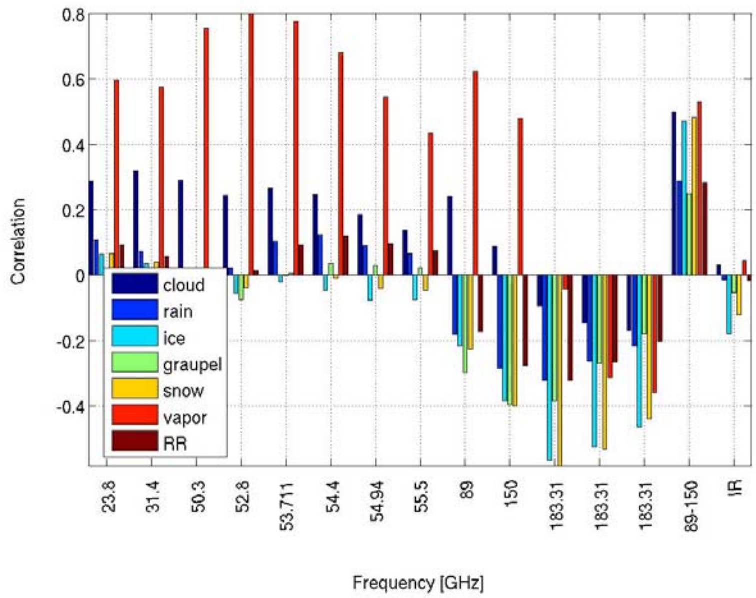

Fig. 2. Correlation of microwave brightness temperatures at the different AMSU frequencies with the integrated hydrometeor amounts of cloud water, cloud ice, graupel, snow and rainwater as well as the surface rain rate RR and the integrated water vapor. The data base includes 10 different cases ranging from winter storms to summertime precipitation (Elbe flood) Courtesy of C. Prigent (LERMA, Paris).

Ground-based remote sensing instruments at well equipped stations (Southern Great Plains, North Slope of Alaska, Tropical Western Pacific) form the backbone of the Atmospheric Radiation Mission (ARM) program which aims at a better understanding of the cloud-radiation-climate problem. ARM data are used by a wide community for model evaluation and improvement of cloud and radiation parametrisations. For example data from the ARM Clouds And Radiation Testbed (CART) domain, located in the Southern Great Plains in the United States of America, have been used to evaluate different type of models (cloud resolving models, large eddy simulations, single-column models, numerical weather prediction models and global climate models; e.g. Williamson et al. 2005). In Europe advanced atmospheric observatories with similar instrumentation exist at Lindenberg, Cabauw, Chilbolton, Palaiseau, and first attempts have been made to build a network of European reference stations. Here, detailed information about the vertical structure of the atmosphere can be gained and value added products have been derived for example for Chilbolton [Hogan et al., 2001] or from Cabauw observations using the Integrated Profiling Technique (IPT) [Löhnert et al., 2004]. The observations from these stations are used within the European Cloudnet project (http://www.cloud-net.org) to study clouds and their representation in atmospheric models. Different algorithms (for example radar/lidar) are applied to derive model variables with a focus on ice clouds. These observations are used to evaluate atmospheric models and to test and improve certain model parametrisations. Within the COST 720 initiative "Integrated Profiling" algorithms developed in Cloudnet, CLIWA-NET [Crewell et al., 2002] and other projects are currently combined in order to achieve a **best estimate of the vertical hydrometeor distributions** together with temperature and humidity including their error bars which will provide a data set well suitable for model evaluation and improvement.

Model evaluation techniques will need to be altered when numerical weather prediction (NWP) models are using finer grids down to a few kilometres. Clouds and precipitation are highly variable in time and space and therefore it can not be expected that individual clouds will be represented in a mesoscale model forecast. Therefore, conventional verification scores might perform worse for high resolution models than for larger scale models and new measures for the forecast quality are needed [Stoelinga et al., 2003]. These might include probability density distributions (pdfs) of cell intensity and size as well as the lifetime and the track of precipitating cells.

In order to bring profiling observation at a specific site to the model output of a grid box, which represents a larger area, an **aggregation** time has been often used to relate measurements made (for example [van Meijgaard and Crewell, 2005]). But there are also other methods to consider, for example by interpreting model cloud predictions as **probabilistic forecasts** at the observation point [Jakob et al., 2004]. A detailed analysis (e.g. variance and autocorrelation) of modelled and measured time series at high temporal resolution might prove beneficial to fully exploit the information provided by profiling stations. First attempts to use autocorrelation measures [van Lipzig et al. 2006] for case studies have been found quite helpful to interpret cloud development in different models. To identify **systematic model errors**, long time series are needed. Recently, several studies have focussed on the vertical structure of clouds (e.g. Hogan et al. [2003] and Willén et al. [2005]). The latter found that in the regional climate model RCA underestimates the cloud base height for very low clouds while for clouds between 400 m to 2 km the cloud base is overestimated. Precipitation and cloud liquid water are coupled and models are found incapable of sustaining high amounts of liquid water without producing precipitation [van Meijgaard and Crewell, 2005]. In order to attribute model errors to **certain regimes** attempts are made to classifying weather regimes for example by vertical motion or atmospheric stability at different vertical levels (for example M. Brooks, Cloudnet Final Symposium 2005]. This procedure can point at processes where parametrisations need to improved but also provide the estimates of model errors in dependence of the actual situation which are needed if a data assimilation scheme is to be set up.

Dedicated field campaigns are well suited for process studies for a certain type of regime or region, which can be used for **model improvement**. For example an Intensive Observation Period at the ARM CART site identified the **autoconversion** rate as a critical component which widely differs within the different models [Xu et al., 2005] . Detailed observations of **cloud microphysical** parameters are seen as a promising tool to improve mesoscale models.

Currently, DWD and other weather services are working on an improved operational forecasting system using convection resolving forecast models. Finer grid spacing is combined with improved parametrisations of physical processes. The main difference between the currently used Lokal-Modell and the new **Lokal-Modell-Kürzestfrist (LMK)** with a horizontal resolution of 2.8 km is the abandoning of a deep convection parametrisation [Bryan et al., 2003]. Instead of this, the explicit simulation of the bigger parts of updrafts, downdrafts and their lifecycle is necessary. These new resolved processes induce the growth of bigger ice particles, which have to be considered in microphysics schemes. In LMK a new 6-class-(Graupel)-scheme was designed for this purpose. It is not yet clear if other additional particles with even higher sedimentation velocities (hail) are needed. Nevertheless a shallow convection scheme is needed to transport moisture and heat from the boundary layer into heights of about 2-3 km above ground, which reduces the low cloud coverage. The horizontal exchange of mass, momentum and energy is increased in convective cells, too, which is taken into account by a 3-dimensional turbulence scheme. The single column radiation transfer scheme will be called with a higher frequency at a nearly constant spatial resolution to keep a scale balance between temporal and spatial changes in the cloud coverage.

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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 attached publications – some highlights are given later in this section. In addition, activities in other projects helped us to acquire tools and experiences which will be beneficial for the QUEST project:

- Development of a satellite simulator for passive microwave observations (MIM)

The proposal for the 1st project phase of QUEST contained a proposal for the development of a satellite microwave forward simulator for LM which was declined. Through the Eumetsat project "Simulation Study of Precipitating Clouds from Geostationary Orbits with Passive Microwaves" (July 2004-July2005) MIM together with French partners successfully developed a microwave simulator based on forecasts of the Meso-NH model to investigate the potential of passive microwave observations from geostationary orbit for precipitation measurements. Its application to several case studies and the comparison with real observations could a) show the sensitivity of microwave observations (depending on frequency) to the different hydrometeor types (compare Fig. 2) and b) point at deficits (amount, density and/or size parametrisations) in model predicted hydrometeors (snow, graupel) [Crewell et al., 2005]. We will adapt this simulator to the Lokal-Modell and be able to use it in QUEST for comparisons with observations by AMSU.

- Modelling of land-surface interactions (ELDAS and MOSAIC approach) (MIM)

In October 2005 Felix Ament replaced Nicole van Lipzig as the MIM project scientist. His previous work has been concerned with the implementation of the European Land Data Assimilation Scheme (ELDAS) [Meetschen et al., 2004] and the development of a MOSAIC approach for the Lokal-Modell [Ament and Simmer, 2006]. The ELDAS approach assumes that the land surface model is perfect and errors in the modelling of the land-surface characteristics only arise from errors in the prediction of atmospheric input parameters. Therefore the input for the surface module (e.g. precipitation and radiation) is not taken from the NWP itself but rather from observed radar and satellite data. The MOSAIC approach is based on the fact that surface characteristics change at much smaller scales than the horizontal model resolution. Instead of the rather costly reduction of the full model grid size only the surface is broken down into a smaller grid on which the surface fluxes are calculated. These are averaged and fed back to the atmosphere at the coarse resolution. Therefore the surface heterogeneity with its non-linear processes is better taken into account. Both approaches will be available to QUEST.

- Satellite retrievals and validation (FUB)

SEVIRI/MSG, MODIS, and MERIS data are processed automatically to provide higher-order products at FUB. The output of the near real time (NRT) processor is displayed via internet: http://wew.met.fu-berlin.de/nrt and was mainly developed under EU funding. Retrieval algorithms for integrated water vapour and cloud top pressure for all three sensors were developed and validated at FUB [Albert et al., 2005; Lindstrot et al., 2005]. For MODIS, Schüller et al. [2003] developed and validated a retrieval scheme for cloud geometrical thickness and cloud droplet number concentration, applicable to marine boundary layer clouds, in the framwork of the European project PACE.

- Frontal/convective classification (FUB)

Within the German project BALTIMOS (Development and validation of a coupled model system in the Baltic region) as part of the BMBF project DEKLIM, Walther and Bennartz (2005) developed a new method to distinguish between frontal and convective precipitation within two-dimensional radar images. The algorithm is based on the analysis of textural and shape parameters of contiguous rain fields. The frontal/convective classification leads to the separation of precipitation characterized by a strong diurnal cycle and of those with only low diurnal variability. This approach is well suited for climatological studies, in particular for an analysis of phase shifts in the diurnal cycle, and is useful to classify long-term data sets into different weather regimes. The tool will be available to QUEST, and an adaption to MSG observations would be valuable for QUEST. Within the first phase of QUEST we developed a tracking algorithm whose exemplary applications are displayed on the front page. The tracking algorithm would also benefit from the frontal/convective classification.

- Highlights from the QUEST project

In the beginning of the project the focus was on the **tool development**, namely the polarimetric radar simulator **SynPolRad** [Pfeifer et al., 2004, Pfeifer, 2005] and new evaluation measures for satellite data [Schröder et al., 2005]. The latter included the simulation of model cloud optical thickness to compare with the most basic satellite product as well as the application of an RTTOV based simulator **SynSat** [Keil et al., 2005] to provide operationally IR brightness temperatures from LM output.

Simultaneously, work on specific **case studies** started to investigate the precipitation process in detail: Two cases – one stratiform and one convective – from the BALTEX BRIDGE Campaigns (BBC) [Crewell et al., 2004a] were defined for the WMO cloud modelling workshop [Crewell et al., 2004b; Grabowski, 2005] and analysed in detail [van Lipzig et al., 2006, Schröder et al., 2006]. This analysis included the LM as well as two other high resolution mesoscale models (Meso-NH and MM5) and two regional climate models (RACMO, RCA). Large deficits in the representation of clouds were identified including the inability of the models two distinguish stratiform and convective cloud fields between the different cases. The model performance was judged by comparing the model with observations of the vertical hydrometeor distribution at the atmospheric observatory Cabauw and satellite observations by MODIS. The evaluation of vertical hydrometeor distribution (Fig. 1. of the intermediate report), pointed to an underestimation of the lifetime of the clouds in the LM at the site Cabauw. This was also quantitatively reflected in a comparison between modelled and observed autocorrelation and standard deviation of the Liquid Water Path [van Lipzig et al., 2006].

The comparison of cloud optical thickness τ was found very useful to judge the performance of shallow convection schemes [Schröder et al., 2006] and to identify problems with the numerical diffusion. In particular it was found that τ is a parameter strongly reflecting certain model characteristics. While the satellite data strongly reflect the stratiform and convective nature of the two cases considered, the three different high resolution models do not show such a strong contrast between the two cases but rather reveal strong similarities (Fig. 3). From histograms based on MODIS and model cloud fields, it appears that for all models, the frequency of occurrence of small clouds and the patchiness is underestimated. For *frozen* clouds, an underestimation of the cloud size would lead to an underestimation of the lifetime of clouds at the site over which the cloud passes. The underestimation of the lifetime, which was found in LM, is therefore not due to advection of too small cloud systems; it is rather due to an overestimation of the variability in the vertical velocity. An overestimation of the horizontal wind speed up to 30% might also contribute.

In LM, a few convective cells reach too high levels on 23 September 2003. The concurrent underestimation of inversion strength points to the conclusion that the presence of a well-defined inversion is relevant to restrict the vertical extent of the boundary-layer clouds. Mixing of moisture to higher atmospheric levels is underestimated in LM, but also in all other models considered. This is reflected in an overestimation of the vertical gradient in the specific humidity. Since this bias occurs in all models, it is likely that the turbulent schemes are not active enough in transporting the moisture upwards during these shallow cloud conditions. The correspondence between modelled and measured specific humidity profiles slightly improves when shallow convection is parametrised, but still the specific humidity is overestimated near the surface and underestimated at higher atmospheric levels.

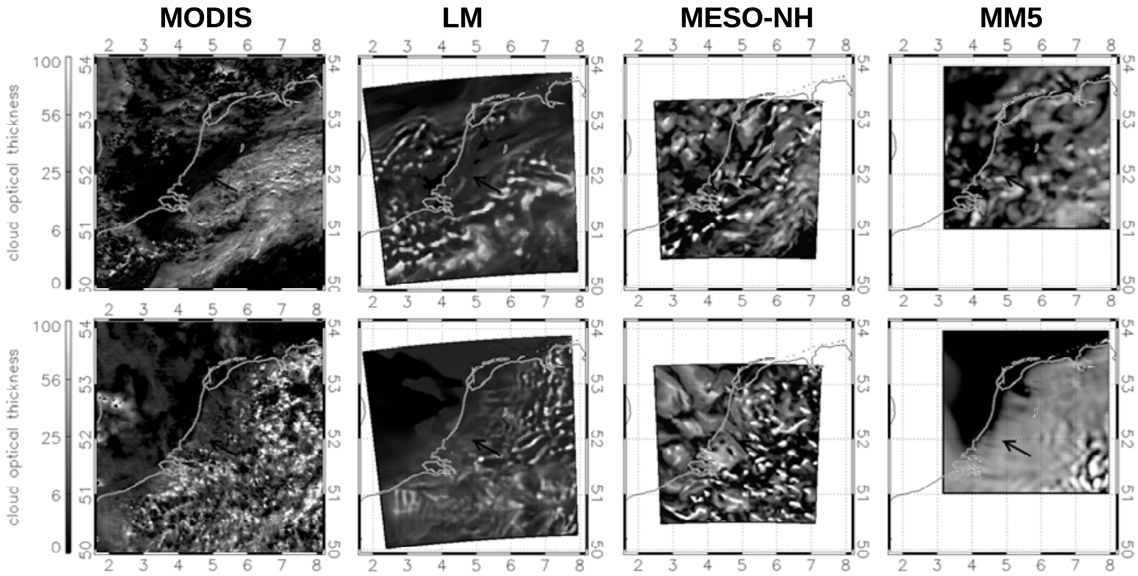

Figure 3. Cloud optical thickness for the 23 September 2001 (top row) and the 21 May 2003 (bottom row) observed by MODIS (left column) and three high resolution mesoscale models.

Another case study concerned a strong precipitating case (12 August 2004, see figure on front page) where the 3D structure of a thunderstorm in the Munich area was well characterized by observations with the polarimetric radar. It could be shown that the model only gives a realistic vertical structure if graupel is included as a prognostic parameter (see Fig. 4) – although some assumptions on graupel density need to be critically reviewed. On a larger scale the frontal rain band moving over whole Germany was analysed by DWD radar network and MSG data. Tracking of the system both in the model and reality showed that while the system movement was well described in northern Germany significant discrepancies in temporal and spatial development occurred in southern Germany (see front cover).

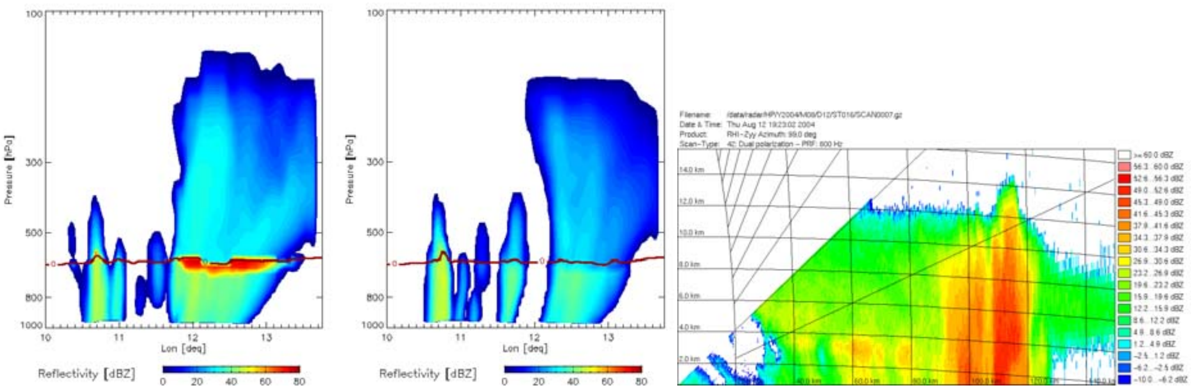

Figure 4. Simulation of the radar reflectivity distribution for a synthetic elevation scan deduced from the Lokal-Modell using a cloud water, cloud ice, rain water, snow water hydrometero scheme (left) and a scheme extended to cover graupel (centre) together with the observations.

QUEST is currently in the process of performing a **long-term evaluation** of several test suites done by the LMK group of DWD to complement their standard verification with remote sensing observations. As a first step the LMK testsuite for July 2004 was investigated using cloud cover retrieved from MSG observations and modelled in terms of an average over the LMK domain. Looking at the time series (Fig. 5, left panel), it can be seen, that the model represents the overall evolution of cloud cover quite well. Nevertheless, significant deviations occur at different temporal scales, which are partly not detectable by case studies. In general, the evaluation of the cloud cover reveals that the LMK tends to overestimate the cloud cover. This error is most pronounced during the morning (Fig. 5, right panel), but can be reduced by taking only the grid-scale clouds into account. This is an indication to reconsider the subgrid-scale cloud scheme, which was initially developed for coarse scale models with a resolution in the order of more than 10 km and might not be suitable for LMK anymore. Additionally, the analysis shows that reinitializing the model at 12 UTC (LMK12) results in a significant error reduction. Extending the LTE to a larger set of variables should give answers to such open questions.

A strong collaboration was established with other verification projects within the priority program resulting in a **joint verification report** on the performance of the Lokal-Modell [van Lipzig et al., 2005a] including the projects VERIPREG (Mainz), STAMPF (Berlin) and the preparation project for the field experiment (Hohenheim/Stuttgart). An update of this report together with a technical report on the verification methods will be generated at the end of the first phase of the PP.

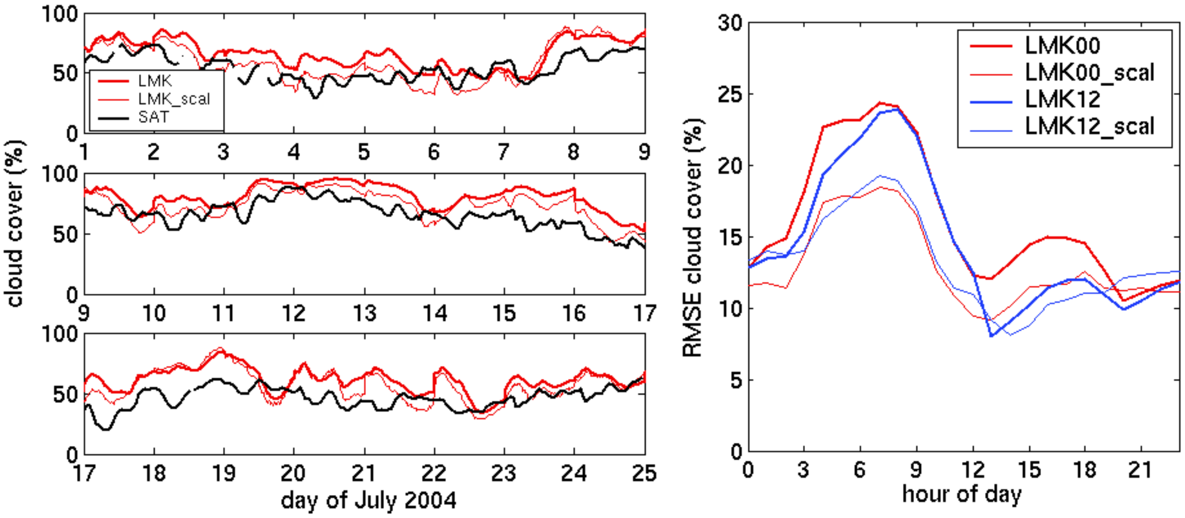

Figure 5. Left: Time series of mean cloud cover retrieved from MSG observations and modelled by LMK (24h forecast starting at 00UTC) averaged over the LMK domain. Right: Diurnal cycle of root mean square error in modelled domain mean cloud cover. Additionally, the results of the LMK forecasts starting at 12 UTC are displayed in blue. Thin, coloured lines indicate the modelled cloud cover if only grid scale clouds are taken into account.

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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:

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

   QUEST will identify these by evaluating model forecasts using multi-dimensional remote sensing observations with focus on variables of the water cycle – specifically water vapour, cloud properties and precipitation. A combination of detailed case study investigations and long-term model evaluations will be performed. The latter should point at 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. These situations can be analysed in detail by changing model physics in order to attribute the errors to the treatment of specific processes: cloud microphysics, convection, radiation, turbulence, evaporation, etc.

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

   QUEST uses remote sensing data which are currently not used in routine model verification. This encompasses (polarimetric) radar observations, several satellite products and profile information from ground-based observatories. Especially radar and satellite data have about the same resolution as the high resolution model forecasts by the Lokal-Modell Kürzestfrist (LMK, about 2.8 km) considered here and are therefore well suited to investigate the benefits of high resolution modelling. Special emphasis is on cloud microphysical processes. Here the new remote sensing techniques (polarimetric radar, millimetre wave radiometry) are able to provide unique information about the different hydrometeor species (cloud water, cloud ice, rain, graupel, snow) which are now prognostic model variables. Another approach is the analysis of the life cycle of clouds and precipitating cells from model and reality which can be studied by the high temporal and spatial resolution observations (MSG).

Already during its 1st phase QUEST has made large progress in achieving its primary goal "to establish a framework that allows for a physically based quantitative evaluation and improvement of global and regional weather forecasts employing as extensively as possible existing and upcoming remote sensing data". We decided to concentrate on the LMK as its horizontal resolution matches that of the remote sensing observations closely. However, the evaluation environment can in large parts be applied or adapted to an arbitrary model. Therefore a close collaboration with the LMK group was established (Michael Baldauf is now one of the proposers) during the 1st QUEST phase. We agreed to join the evaluation efforts for the LMK model[1] which will become operational in 2006. In preparation for that several LMK test suites are run for the previous summers. While DWD performs routine verification for these suites QUEST applies its advanced evaluation measures based on remote sensing data (compare Fig. 5 for a first result) both in observation-to-model and in model-to observation approach. This procedure also allows us to shift the focus of QUEST more on **model improvement** rather than

[1] This procedure is also most efficient in storage space as the cost for this was declined in the 1st phase proposal. One should note that for one month the standard LMK hourly model output amounts to about 270 GB. For exploiting the high temporal resolution information from remote sensing measurements – for example by applying tracking techniques – additional output is archived by DWD which amounts to 450 GB. Considering also that different model settings and schemes should be compared for two TestSuites we end up with a total of 2.6 TB

being a pure verification project. Performing changes in model settings/schemes within the test suites has the advantage that they are already tested in their operational environment and the full interactions between all the different model parametrisations are considered. To achieve the optimal results in terms of LMK improvement the specific QUEST goals for the 2nd phase are:

- **optimization and refinement of the existing evaluation tools**; examples are
  - update of polarimetric radar simulator SynPolRad to include cloud radar observations
  - adapt microwave satellite simulator including scattering to LMK SynSatMic
  - optimize the interface of the SynSat simulator to LMK cloud parameters, e.g sub-grid clouds
  - refine retrieval of cloud microphysical properties from SEVIRI observations

- **identification of systematic errors** in the precipitation, cloud and water vapour forecasts of the LMK; In order to answer the question

  "What are the typical conditions in which these systematic errors can be most clearly detected?"

  attempts will be made to attribute them to specific regions, times (diurnal cycle) and weather regimes (judged for example by vertical motion and stability)

- exploitation of the **complementary information of the different remote sensing observations**; e.g. investigate the performance in terms of different variables and their cross correlation and therefore looking at the models physical consistency. This should answer the question

  "How well do the models need to represent the clouds in order to get a good forecast of precipitation e.g. we have already seen problems related to patchy clouds [Schröder et al., 2006]; is it relevant to improve the correspondence between the modelled and observed clouds in order to get a good precipitation forecast?"

- use of the observations during the **General Observation Period (GOP) in 2007** to investigate the LMK performance for all seasons and make use of additional data on precipitation microphysics (for example micro rain radars; see COPS/GOP proposal)

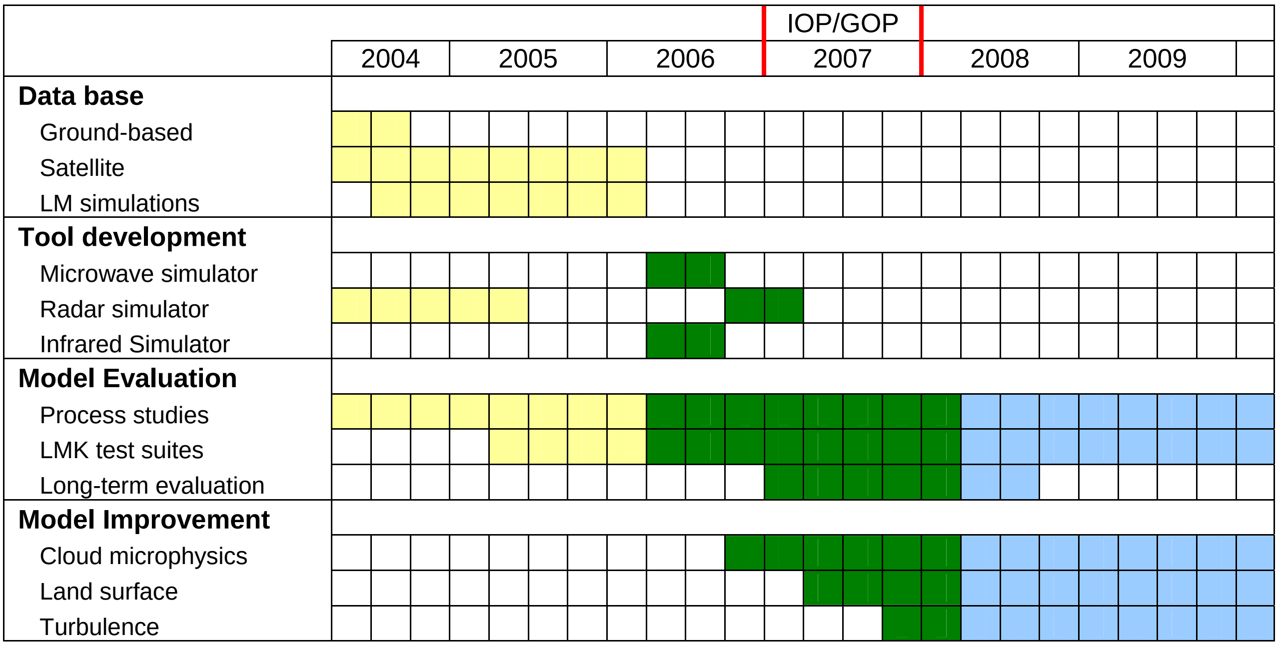
- provide an **independent test bed** for all new parametrisations that may emerge from other projects in the PP community. This is already foreseen for the cloud microphysics project (Beheng, Karlsruhe) and the new convection scheme (Bott and Gassmann, Bonn)

- **improve LMK performance** by changes in the treatment of cloud microphysics, turbulence, land surface etc ;

QUEST has acquired a set of observations (satellite data, data from field campaigns, radar data) during its 1st phase which are available to the PP partners via the PP meta data base form. In the 2nd phase the data base set up in the central COPS/GOP project will be used by QUEST. Data acquisition is not part of QUEST.

QUEST is planned to exist over the whole SPP, while this 2nd phase is mainly devoted to long-term evaluation based on LMK test suites and GOP data. The 3rd phase will be devoted to a detailed analysis of specific problems (revealed by LTE) using detailed observations from the field experiment COPS. A rough outline about the time schedule of QUEST is given in Table 1 and the detailed work plan in 3.2.

Table 1. Actualized implementation plan for QUEST during the PP lifetime adapted from the proposal for the 1st phase. Three different colours are used to highlight the three PP phases with dark green inicating the 2nd phase.



3.2 Work schedule (Arbeitsprogramm)

The work during the 2nd phase is stratified into four different tasks which are the overall co-ordination (WP 1), the tool development (WP 2), the model evaluation (WP 3) and the model improvement (WP4). In can not be expected that the WP 4 will be sufficiently finished in the next two years – rather it will be the focus of the 3rd PP phase. The following paragraphs describe the WPs and their subtasks as well as the timing of each work package which are summarised in Table 2.

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://server.meteo.physik.uni-muenchen.de/quest/) plays a major role in the internal and external project communications. All reports, posters, talks and publications will be available through this web site.

QUEST will also continue to coordinate (together with Heini Wernli) the **joint verification efforts** in the PP program which will regularly lead to internal reports on the current verification status as well as a description of the different verification methods used in the PP. The latter will help to distribute the tools (forward operators, cloud descriptors, tracking codes, etc) among the other PP partners. These reports will also combine the joint experience to give recommendations for a validation environment during GOP and COPS will be given. WP 1 is the responsibility of MIM.

WP 2 Tool development

WP 2.1 Microwave radiation simulator

The microwave simulator based on output of the French Meso-NH model will be adapted to LMK output. Besides matching the code to the LMK output all assumptions which are specific to Meso-NH specifications (hydrometeor drop size distributions and densities, surface wind over ocean, etc) need to be replaced with those of the LMK. The collaboration with DWD and the experiences with SynPolRad will help to quickly extract the relevant information which is often hidden within the code. Sensitivity tests and comparisons with Meso-NH will be performed to confirm the quality of the observations.

WP 2.2 Polarimetric radar simulator

Within the polarimetric radar simulator **SynPolRad** the interactions between the LM simulated bulk hydrometeor properties and the radar pulse are calculated in order to be as consistent as possible with LM physics (e.g., drop size distribution, density, etc). First applications of SynPolRad have revealed large discrepancies between different LM microphysics schemes (Fig. 4) which point at difficulties in the LM treatment of the frozen hydrometeors. For more detailed investigations of cloud microphysics SynPolRad will be extended to flexibly use input from **other microphysical schemes**:

- ongoing developments of LMK with likely extension to include hail as a further prognostic variable
- two-moment scheme by Seifert including prognostic cloud water, cloud ice, rain, graupel, snow (Seifert and Beheng, 2005) and possibly spectral microphysics LM version of Leipzig project
- integration of Reisner Schema (MM5) in LM
- the French research model Meso-NH. Selected QUEST cases will be provided by Evelyne Richard in order to compare them to LMK performance by means of radar and microwave simulator

Polarimetric **cloud radar** observations are routinely performed at the atmospheric observatories (Lindenberg, Cabauw, Chilboton; see 2.1) and continuously provide the vertical distribution of Z and LDR. Up to now little use is made of LDR except bright band studies. During the COPS experiment 2007 at least 2 cloud radars will be deployed in the black forest area. One of them will be performing azimuth and elevation scans to explore the 3 D structure of clouds. In order to optimally exploit the information content of the cloud radar data SynPolRad will be adapted to include typical cloud radar frequencies (e.g. 35 and 95 GHz). Due to the much stronger attenuation at these frequencies a much shorter range (about 20 km) can be covered. Therefore it will be useful to run SynPolRad on LMK simulations with 1 km horizontal resolution.

Currently, a **computing time** of about 3 hours is needed for one volume scan. In order to move from cases studies to a more systematic model evaluation the computing time needs to be reduced drastically. Therefore, besides programming exercises an analysis will be performed how computing time can be reduced by neglecting beam propagation effects, reducing bins in drop size distributions, developing parametrisations and other simplifications. This work should result in a version of SynPolRad which might be regularly applied to routine polarimetric radar observations. An example is the DWD research radar at Hohenpeissenberg which will perform regular ZDR observations for example during the AQUARadar experiment.

WP 2.3 SynSat adaptation

Within the 1st phase FUB and MIM started to archive LMK output, including radiation at SEVIRI channels conducted with the SynSat simulator. The comparison of observed and simulated radiances in the visible and thermal wavelength range (WP 3.2) will be supported by radiative transfer simulations of a more sophisticated radiative transfer models (Fell and Fischer, 2001; Rathke and Fischer, 2000) and will lead to suggestions for improvements to SynSat. Special focus will be on formulations which are consistent with respect to the physical package of LMK. Close collaboration is planned with Christian Keil from DLR (DAQUA) and Michael Baldauf from DWD.

WP 2.4 Refinement of satellite retrievals

Cloud microphysical properties retrieved from SEVIRI/MSG observations complement the evaluation of the representation of clouds in LMK carried out so far. FUB will refine and develop techniques to retrieve cloud optical thickness, the liquid water path, the size of the droplets and the phase from spectral measurements in the visible and near-infrared contain. There are two algorithms which both reflect on constrains of the cloud processes: 1) For continental and vertical expanded clouds the assumption of a homogeneous distribution of the cloud microphysical properties are assumed. A dedicated algorithm will be refined to estimate the effective radius of cloud droplets and the optical thickness and separate between water and ice clouds in SEVIRI measurements. The results will be validated against MODIS retrievals. 2) For marine boundary layer clouds with a maximum of 1 km of geometrical thickness the assumption of adiabatic droplet growth is found to be valid by in situ aircraft measurements. This enables to establish an algorithm for the estimation of cloud droplet number concentration and geometrical thickness of clouds. This procedure has been shown to be more sensitive with respect to air-mass or condensation nuclei and droplet size. We will identify the potential to adopt the procedure to MSG observations of stratiform clouds over land surfaces. A sensitivity analysis will be performed to study the influence of vertically structured clouds on the retrieval of microphysical properties.

WP 3 Model Evaluation

WP 3.1 Process Studies

The detailed investigation of cases has been found quite useful in a) optimizing the tools and procedures for longer term evaluation and b) identifying process most responsible for the poor model performance in this situation. Therefore this activity will continue throughout the project duration. Major emphasis will be on exploring the potential of the new forward operators for polarimetric radar and microwave satellite observations. First case studies will therefore be chosen by simultaneous observations of one **convective** and one **stratiform** case by POLDIRAD and AMSU. POLDIRAD will provide information on the occurrence of the different hydrometeor species while the microwave observations are more sensitive to integral quantities; e.g. the total water/ice content. We therefore expect important information on the cloud microphysics from the investigation of these cases.

Of special interest are the characteristic of the melting layer found below the 0° isotherme where precipitating ice crystals melt to rain drops. This transition zone is well depicted by radar observations (radar reflectivity factor, Doppler velocity, LDR), showing the prominent brightband characteristics. The thickness of the melting layer is best observed by the LDR. An increased thickness indicates more convective activity, which is also reflected in the fluctuations of the Doppler velocity above the brightband. It is expected, that the GOP data including a set of 10 **Micro Rain Radars** (MRR) distributed over Germany will be extremely useful in relating the processes in the atmospheric column to the precipitation rate at the ground.

Additional case studies will be performed in coordination with other PP groups to test new schemes and parametrisations (for example projects by Beheng, Bott and Gassmann, Schlünzen etc..).. By performing both evaluation approaches (**observation-to-model** and **model-to-observation**) within the case studies we will investigate the usefulness of using the model-to-observation for the long-term evaluation taking into account the higher computing time and more difficult interpretation.

Information from the radars operated by the Belgian meteorological institute, together with in-situ and satellite remote sensing measurements will be used to evaluate precipitation related processes. For this purpose, the model domain will be shifted over Belgium. The focus will be on the understanding of the spatial and temporal variability of precipitation in this 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 regimes. For this work, a co-proposal will be submitted in February to the Fund for Scientific Research - Flanders (Belgium).

WP 3.2 LMK Test suites

QUEST is currently in the process of performing the evaluation of several testsuites done by the LMK group of DWD. DWD applies a set of statistical methods for model verification (like root mean square error, bias, frequency bias, skill statistics like ETS) on measurements of daily means of precipitation from 3000-4000 stations, hourly measurements of precipitation from about 600 stations and other variables from about 170 synop stations, temperature from radiosondes two times a day and information from pilot balloons for their verification. However, there are several gaps in the current evaluation of LMK at DWD like the verification of 2D fields, which can be derived from satellite remote sensing instruments. Since QUEST is focussing on model-evaluation using ground-based and satellite remote sensing instruments, the work proposed here is **complementary to the standard evaluation done by the LMK-group**. A long-term evaluation is currently performed for two test suites for July and August 2004. Further test suites covering different months will be defined within the project. Testsuites with an improved physics-dynamics-coupling, 3-dimensional turbulence, alternative shallow convection formulations and an additional radar data assimilation procedure (latent heat nudging) will be delivered by the LMK group during the next months (until mid of 2006).

WP 3.3 Long-Term Evaluation using GOP data

The long-term evaluation (LTE) using satellite observations of water vapour, cloud fraction, liquid water content, cloud top height, phase and temperature as well as radar and profiling observations over the full year 2007 (**GOP**) is the central activity of QUEST. Besides their temporal and spatial resolution satellite observations have the advantage that they not only cover the area of interest but can also br used to investigate the large scale synoptic situation. In particular, satellites allow the observation of cloud systems in- and outside the GOP area. In particular, satellites allow the observation of cloud systems in- and outside the GOP area. Within this **observation-to-model approach** the quality of the LM forecasts will be assessed in terms of mean values, standard deviations, spatial and temporal correlations, correlation lengths and histograms. The long time series of high quality measurements during the GOP allow a statistically significant interpretation of our results. Care has to be taken to closely match model and observation, e.g. water vapour is derived only for cloud free scenes. The correlation between the water vapour in the clear sky vicinity of convective cells and the intensity of the cell will be analysed and accompanied by an analysis of allocated difference in rain rates. The comparison will benefit from the experience gained in WP 3.1 and 3.2. Similar methods will be used for WP3.2 and WP3.3:

The combination of **profiling information and high spatial resolution** satellite data should be powerful for understanding model deficiencies, for example the attribution of model deficits due to timing/advection errors in contrast to errors related to local development. Statistical analysis of the horizontal model fields (e.g. patchiness) can help to identify differences related to diffusion and the implemented turbulence scheme. Furthermore, the dependence of the evaluation parameters on the size of the area can be considered in order to better judge which scales can be realistically predicted by high-resolution models. This is important since the model grid size will always be coarser than the scale with which atmospheric parameters can be resolved.

In order to better identify the weaknesses of model precipitation forecasts we plan to **distinguish between different regimes**, for example by “Großwetterlagen”, atmospheric stability, large scale flow direction or by vertical velocities. Different classes of precipitation events can also be defined in terms of intensity and spatial dimension. During periods when the large scale synoptic forcing is weak the diurnal cycle of cloud occurrence will be investigated. The classification of the atmospheric state will benefit from an adaptation of the radar-based precipitation type analysis (stratiform/convective; see 2.2)to brightness temperature observations of SEVIRI. QUEST will make use of its multivariate data base: Cross correlating forecast errors in precipitation, cloud and humidity fields helps to identify the origin of model deficits. By combining very accurate measurements at supersites or target regions (Poldirad) with less accurate but area-wide satellite observations it is possible to assess the representativeness of results.

The LMK uses the radiation module SynSat at SEVIRI channels in the solar and thermal wavelength range. We will compare both data sets by means of standard statistical methods and refine the analysis by differentiating with respect to orography and time of the day. In addition, the tracking algorithm will allow the analysis of the size distribution of cloud cells with cold cloud tops in combination with their spatial distribution. It further reveals agreement or differences in histograms of life time and prominent regions of origin as well as typical paths of the cells. A cluster analysis in the phase room of cloud properties (WP 2.4) will help to separate deficits in the representation of clouds by LMK from deficits of SynSat.

The **timing of precipitation related to synoptic forcing** will be studied in more detail. From a study in the first phase of QUEST, it was already found that for 12 August 2004, the high pre-frontal clouds appeared too early, whereas the precipitation related to the front was slightly delayed in the model (see front cover). We will go into these processes in more detail i.e. comparing the surface values of pressure and precipitation with information derived from satellite remote sensing. When we have gathered information from different sources we will establish the relationship between the variables derived. For example, we will relate the optical thickness derived from cloud with the precipitation derived from the radar. Generally, the question how well clouds needs to be represented to get the correct precipitation forecast will be addressed.

WP 4 Model Improvement

WP 4.1 Microphysics

The microphysical parametrisations of state-of-the-art mesoscale models predict the evolution of the mixing ratio of the cloud droplets, the rain drops, the pristine ice crystals, the snowflakes, and graupel. Each broad particle category is characterized by intrinsic aerodynamical properties and encompasses the great variety of hydrometeors found in natural clouds. The temporal and spatial evolution of the microphysical fields result from many microphysical processes (aggregation, riming, vapour deposition, evaporation, fallout,..) which mostly depend on the particle size. Bulk quantities (which are the prognostic model variables) result from the integration over the size distributions of the particles.

Our first results regarding the evaluation of the representation of ice hydrometeors in the LMK show that the actual used microphysical component scheme is not able to represent these processes adequately (Fig. 4). While stratiform events already look quite realistic, convective precipitation will only be well represented both regarding dynamical aspects as well as microphysics if **graupel** and **hail** are implemented in a more realistic manner. Experiments with more sophisticated and realistic microphysical schemes will be carried out in close cooperation with DWD and IMK Karlsruhe to isolate critical model parameters. These studies will be the first step towards a better representation of microphysics in mesoscale models. Supplementary data from GOP and COPS will allow us the check our first results and furthermore adapt the existing microphysical schemes.

Another critical process in the chain described above is the **autoconversion** rate [Xu et al., 2005] which determines how much cloud water is converted into rain water. This parametrisation is assumed – at least partly – to be responsible for the fact that many model produce light precipitation too frequently. Also in nature clouds frequently drizzle but mostly the water evaporates (moistening and cooling the air) before reaching the ground. The detailed observations of vertical structure of different hydrometeor species including drizzle water flux at profiling stations will be used to “calibrate” formulations for the autoconversion rate taking the full model interactions into account.

WP 4.2 Land surface

Exchange processes between land surface and atmosphere have the potential to trigger convection. In particular the correct partitioning into sensible and latent heat flux turned out to be a key issue [e.g. Trier et al. 2004], which is largely determined by the representation of vegetation and by soil moisture. The current land surface of LM can only partly distinguish between different types of vegetation, neglects subgrid-scale variability at the surface and assumes a very simplistic annual cycle for the evolution of plants. Soil moisture is analysed by a variational method which corrects soil moisture according to errors in the prediction of 2 m temperature and humidity. Since rain observations are not assimilated, rain induced small scale structures cannot be represented realistically.

Based on LTE, cases of erroneous precipitation forecast, which are likely due to shortcomings in forcing from the surface, will be selected. As an intermediate step, sensitivity simulations with artificially modified surface parametrisation (e.g. systematic changes of soil moisture amount, shifts in the phase of surface fluxes, changes in net radiation …) will be conducted in order to identify key problems. There exist a great variety of enhancements of the existing land surface-scheme which are already implemented in the LM but not used operationally: For example, the MOSAIC-approach to consider subgrid-scale variability, vegetation type dependent plant parameters, satellite derived leaf area index and plant cover to capture the annual cycle (currently developed by DWD), an alternative measurement based soil moisture analysis scheme and various methods to predict the skin temperature. Guided by the findings of the sensitivity simulations and in close cooperation with DWD, appropriate enhancements will finally be tested and optimized in order to improve the skill of precipitation forecast.

WP 4.3 Turbulence and convection

The LMK treats prognostic cloud water with an all or nothing scheme. However it has been found necessary to include a description of subgrid-scale condensation for the radiation module. Furthermore a shallow convection scheme after Tiedke is used from which again a liquid water contribution for radiation is determined. Previous work has shown that the performance of the **shallow convection scheme** is not satisfactory – not surprising as it was developed for a grid spacing more than a factor larger than in LMK. Therefore alternative formulations in the initiation of shallow convection by turbulent fluxes (with a w*-scaling approach) instead of a pure moisture convergence were developed. DWD is planning to develop a more sophisticated scheme allowing determination of entrainment and detrainment as diagnostic quantities in terms of Convective Available Potential Energy (CAPE)) which will be supported by QUEST.

The use of spatial high-resolution satellite observations – especially of cloud optical thickness – together with appropriate measures for cloud patchiness has been found very useful to identify problems with numerical diffusion. With a grid resolution of about 2.8 km turbulence can not be considered as being just a vertical process – exchange processes between neighbouring grid cells need to be considered. Currently **3d turbulence** scheme is implemented in the LMK. We will use satellite data and structure related parameters from model and reality (compare Fig. 7b in the intermediate report) to optimize this scheme.

The validation approach mentioned above can also be used to investigate the impact of non-local turbulence closure. This will be done in cooperation with Dmitri Mironov (DWD) who is planning to incooperate turbulent potential energy as prognostic variable of the turbulence scheme.

Table 2. Summary and time table of work packages of QUEST during the 2nd phase of the SPP.

WP	Tasks	I	II	III	IV	I	II	III	IV
1	**Coordination**								
	Project meetings (all)	x			x			x	
	Recommendation for model improvements (all)								
2	**Microwave Simulator**								
	Microwave radiation simulator (MIM)								
	Polarimetric (cloud) radar simulator (DLR)								
	VIS/IR simulator (DLR, FUB, DWD)								
	Microphysical retrievals (FUB)								
3	**Model Evaluation**								
	Process studies (DLR, FUB MIM, KUL)								
	LMK Testsuites (DWD, FUB, MIM, KUL)								
	Long-term evaluation (DWD, FUB, MIM, KUL)								
4	**Model Improvement**								
	Cloud microphysics (DLR, DWD, MIM)								
	Land surface (DWD, MIM)								
	Turbulence (DWD, FUB, MIM)								

References

Fell, F., und J. Fischer, 2001: Numerical simulation of the light field in the atmosphere-ocean system using the matrix-operator method, *JQSRT,* **69**, 351-388.

Rathke, C., and J. Fischer, 2000: Retrieval of cloud microphysical properties from thermal infrared observations by a fast iterative radiance fitting method, *J. Atmos. Oceanic Technol.*, **17**, 1509-1524.

Seifert, A. and K. D. Beheng, 2005: A two-moment cloud microphysics parameterization for mixed phase clouds. Part 1: Model description, *Meteorol. Atmo. Phys.* (accepted)

Trier, S.B., F. Chen, K.W., Manning, 2004: A study of convection initiation in a mesoscale model using high-resolution land surface initial conditions, *Monthly Weather Review*, 132 (12), 2954-2976.

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
MIM(a)	1 scientist BAT IIa for two years	WP1, WP2., WP3, WP4
DLR(b)	0.5 scientist BAT IIa for year 1	WP2, WP3, WP4
	1.0 scientist BAT IIa for year 2	
FUB(c)	1 scientist BAT IIa for two years	WP2, WP3, WP4

(a) Felix Ament who took over the work from Nicole van Lipzig (1 July 2004 to 30 September 2005) in October 2005 shall continue the work. He will finish his PhD in the end of 2005

(b) Dipl.-Met. Monika Pfeifer who worked 1 April 2004 on QUEST will finish her PhD at the end of the third project year. Afterwards she shall continue as a Post-doc to work on the SynPolRad extension to cloud radars and the LTE with polarimetric radar observations.

(c) Dr. Marc Schröder who worked since 1 June 2004 on QUEST will continue his work on the satellite data for model evaluation

All three scientists have been very successful in their cooperation during the first phase of QUEST which is illustrated by the impressive number of publications (see 2.2) within a short time period. Therefore we expect a fruitful continuation in the 2nd phase.

4.2 Scientific equipment (Wissenschaftliche Geräte)

In the long-term evaluation remote sensing data and model output will be analysed together including the cross correlation of different atmospheric variables. As pointed out before the LMK output for one single month already amounts to about 2-3 TB. This does not include the observational data. Therefore, in order to perform the long-term evaluation – covering a full year – disk space is urgently needed to at least calculate evaluation measures on a monthly basis. Archiving of model forecasts and observational data will be done at DWD and DKRZ Hamburg (see joint COPS/GOP) proposal). An exception is the archiving of simulated VIS/IR radiances by SynSat which are not saved by DWD and are therefore processed at FUB.

MIM	(2 Tbyte RAID system)		2.000,-
FUB	(4 Tbyte RAID system)		4.000,-
		total 4.2	**5.000,- 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 **3.000,- 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. It is foreseen to intensify the collaboration with other PP groups (microphysics project by Beheng (Karlsruhe); convection parametrisation (Bott, Bonn); spectral microphysics (Knoth, Leipzig) and DAQUA (Simmer, Bonn) and possibly others). This will lead to additional meetings between the different project scientists. Each meeting is estimated with 150 Euro per person.

International travel: Already in the 1st PP phase QUEST results were presented at international conferences (European Geophysical Society (EGS); European Conf. on Radar Meteorology and Hydrology; WMO Workshop on Nowcasting; AMS Conf. on Radar Meteorology; GEWEX conference) and we expect even more results of general interest in the 2nd phase. Therefore for each group one international conference per year is foreseen with an average cost of 1.000,- Euro[1]. Appropriate conferences are the EGS Symposium in April 2006 and 2007, the European Conference on Radar Meteorology and Hydrology in September 2006, the Fall meeting of the American Meteorological Society (AMS) in January 2007 or a more specialised conference in this period which has not been announced yet.

Nicole van Lipzig worked as project scientist for MIM from 1 July 2004 to 30 September 2005 until she got a position as Universitaetsdozent at the Catholic University Leuven, Belgium (KUL). We will continue our joint work within QUEST and therefore request travel money for her participation in the QUEST and PP meetings (5 meetings each with 400,- EUR)

National travel:	
MIM (F. Ament, S. Crewell)	1.200,-
DLR (M. Pfeifer, either G. Craig or M. Hagen)	1.200,-
FUB (M. Schröder, J. Fischer)	1.200,-
DWD (M.Baldauf)	1.000,-
International travel:	
MIM (F. Ament)	2.000,-
DLR (M. Pfeifer)	2.000,-
FUB (M. Schröder)	2.000,-
N. van Lipzig	2.000,-
total 4.4	**12.800,- EUR**

4.5 Publication costs (Publikationskosten)

Two publications [van Lipzig et al., 2006; Schröder et al., 2006] are already in the review process. For publication costs 750,- EUR per year are requested by each institute:

total 4.5 **4.500,- 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)

MIM

Prof. Dr. Susanne Crewell	Professor for Experimental Meteorology at MIM
Dr. Ulrich Löhnert	Assistant professor, ground-based remote sensing, sensor synergy
Felix Ament	Project scientist for the evaluation/improvement of the Lokal-Modell; funding for his position is requested from DFG
Mario Mech	PhD student; microwave radiative transfer, satellite simulator
Wenchieh Yen	Diploma student working on the evaluation of LM using radar data

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

DLR

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

FUB

Prof. Dr. Jürgen Fischer	Head of the Institute for Space Science
Dr. Rene Preusker	Assistant professor, solar and thermal radiative transfer, satellite remote sensing
Dr. Marc Schröder	Project scientist for the use of satellite data in the evaluation; funding for his position is requested from DFG.

K.U.Leuven

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

DWD

Dr. Michael Baldauf	Head of LMK group

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

Collaboration was established with other verification projects within the priority program namely VERIPREG (**Heini Wernli, Mainz**) and STAMPF (**Eberhard Reimer, Berlin**). While VERIPREG generates improved hourly precipitation sums from a combination of radar and rain gage data to validate LM precipitation products QUEST focuses more on water vapour and cloud properties as well as the vertical hydrometeor structure. New precipitation scores to be developed in VERIPREG could be combined with the single cloud measures of QUEST. STAMPF archives and analyses high spatial resolution rain rates in the Berlin area. It is planned to investigate consistency between cloud classification (STAMPF) and tracking and to analyse the correlations between the rain observations and cloud properties from satellite observations to better understand the fine scale structure of rain events. The potential to increase the significance of the dynamical parameters by incorporating IWV and LWP will be analysed in STAMPF.

In its 2nd phase QUEST will focus on model improvement in cooperation with PP groups working on new model schemes and parametrisations. QUEST will apply its validation tools to test cases provided by the cloud microphysics project (**Klaus Beheng, Karlsruhe**), the new convection scheme by **Andreas Bott** and **Almut Gassmann** (**Bonn**) and others. The consistency of the scores of the verification tools of VERIPREG, STAMPF, and QUEST will be analysed on the basis of case studies which are performed in cooperation with the process study oriented projects (**Heinke Schlünzen, Hamburg**). Furthermore, the verification methods will also be used to asses the impact of data assimilation (DAQUA coordinated by **Clemens Simmer, Bonn)**. For the preparation of the field experiment COPS and the General Observation Period close contact will be kept with **Volker Wulfmeyer (Hohenheim)**.

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

Co-operation with leading international groups exits concerning the evaluation of polarimetric radar measurements including exchange of software, namely **V.N. Bringi** (T-matrix program to estimate the scattering properties of rain and other hydrometeors) and **V. Chandrasekar** (both at Colorado State University, Ft. Collins), **Jothiram Vivekanandan** (hydrometeor classification scheme) (NCAR, Boulder), **Jaques Testud** (CETP-CNRS, France) and **Eugenio Gorgucci** (CNR, Italy).

The microwave simulator was developed in a joint effort with **Cathrine Prigent** (LERMA, France) and support by **Jean-Pierre Chaboureau** (Laboratoire d'Aérologie, France). Close cooperation is ongoing to identify the reasons for the discrepancies between simulations and satellite data in strong convective precipitation events. Further collaboration with microwave simulations with **Peter Bauer** (ECMWF), **Ralf Bennartz** (University of Wisconsin) and **Bizzaro Bizzari** (ISAC-CNR) exists.

Concerning the data from the CLIWA-NET and the BBC2 campaign close contacts between the different partners are established. For the analysis of precipitation initiation and variability close co-operation with **Remko Uijlenhoet** (Wageningen University), **Herman Russchenberg** (TU Delft) and **Iwan Hollemann** (KNMI) are foreseen. Using long-term data sets at reference stations close contacts to several members of KNMI (for example **Arnout Feijt** and **Dave Donovan**), the Chilbolton site via the University of Reading (**Anthony Illingworth** and **Robin Hogan**) and to Lindenberg (**Dirk Engelbart** and **Jürgen Güldner**) exist.

Concerning satellite observations, close collaboration exists with **Peter Regner** and **Philippe Goryl** (ESA / ESRIN) with respect to MERIS data, with **Stephen Tjemkes** (EUMETSAT) with respect to SEVIRI and with **Paul Menzel** and **Ralf Bennartz** (University of Wisconsin, USA) with respect to MODIS. Close co-operation with the latter also exists in the field of radiative transfer simulations, complemented by collaboration with **Richard Santer** (Universite du Littoral, France). Concerning the cross-validation of satellite products and the validation with independent data, long-year co-operation exists with **Jan-Peter Muller** (University College London, UK).

The analysis of the BBC cases was performed in close co-operation with **Erik van Meijgaard** (KNMI), **Ulrika Willen** (SMHI), **Volker Matthias** (GKSS) and **Jean-Pierre Chaboureau**. Contact to the model evaluation activities in CloudNET is guaranteed due to the good co-operation with **Anthony Illingworth**. Cooperation with **Evelyne Richard** (Laboratoire d'Aérologie, France) in the evaluation of different microphysical schemes for the use with the polarimetric radar forward operator.

5.4 Scientific equipment available (Apparative Ausstattung)

Sufficient computing power in terms of PC, workstation networks and access to mainframe and high performance computer centers is available. Scientific instrumentation which has and will contribute to the data sets used in QUEST are

- polarimetric Doppler radar POLDIRAD (DLR);
- bistatic Doppler radar network (DLR);
- MSG receiving dish including a PC and disc storage system.

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

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

5.6 Other requirements: Data and programs (Sonstige Voraussetzungen: Daten und Programme)

Comprehensive data sets collected during EULINOX (1998) and VERTIKATOR (2002) from DLR Oberpfaffenhofen and the experiment partners will be provided by DLR. This includes POLDIRAD data, Doppler data from DWD radar at Hohenpeißenberg, aircraft data, lidar data and routine and additional surface data.

The data sets for the CLIWA-NET and BBC2 campaigns have been made available by tp the PP through the Meta data base. SEVIRI data is routinely received at FUB. The MODIS data was received by DLR-DFD and transferred for further processing via ftp to FUB within the CLOUDMAP2 EU-project until summer 2004. Data access is still given via internet but not on a near-real time basis. Global MERIS data is received from ESRIN, ESA/Kiruna, and DLR/Neustrelitz.

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 Ludwig-Maximilian-Universität (Prof. Dr. Picot) and the Free University of Berlin (Prof. Dr. Bohnsack), and the Programme Directorate and Executive Board of DLR. have been informed.

7 Signatures (Unterschriften)

München, 29.10.2005 ________________________

(S. Crewell)

Berlin, 29.10.20035 ________________________

(J. Fischer)

Oberpfaffenhofen, 30.10.2005 ________________________ ________________________

(G. Craig) (M. Hagen)

Offenbach, 29.10.2005 ________________________

(M. Baldauf)

Leuwen, 29.10.2005 ________________________

(N. van Lipzig)

8 List of appendages (Verzeichnis der Anlagen)

- Financial plan in German
- QUEST Interim Report, 20 pages
- CVs of project proposers; DFG form 10.04
  - Prof. Dr. Susanne Crewell
  - Dr. George Craig
  - Dr. Martin Hagen
  - Prof. Dr. Jürgen Fischer
  - Dr. Nicole van Lipzig
  - Dr. Michael Baldauf
- DFG form 10.03 of project scientists
  - Felix Ament
  - Monika Pfeifer
  - Marc Schröder
- Three relevant QUEST publications

Pfeifer, M., G. Craig, M. Hagen, and C. Keil: A polarimetric radar forward operator, Proc. Third European Conference on Radar in Meteorology and Hydrology (ERAD), Visby, Sweden, 494-498, 2004.

Schröder, M., N. P. M. van Lipzig, ,F. Ament., J.-P. Chaboureau, S. Crewell, J. Fischer, V. Matthias, E. van Meijgaard., A. Walther, and U. Willén., 2006: The representation of low-level clouds in atmospheric models: Part II: Spatial distribution from satellite remote sensing during the BALTEX Bridge Campaigns, *Atm. Res*., in Revision.

Van Lipzig, N.P.M., M. Schröder, S. Crewell, F. Ament, J.-P. Chaboureau, U. Löhnert, V. Matthias, E. van Meijgaard, M. Quante, U. Willén, W. Yen, W., 2006: Comparison of model predicted low-level cloud parameters with observations from the BALTEX-Bridge Campaign. *Atm. Res.*, in Revision.

4. Beantragte Mittel

4.1. Personalbedarf

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

Institut	Personal	Aufgaben
MIM(a)	1.0 Wissenschaftler BAT IIa für 2 Jahre	WP1, WP2., WP3, WP4
DLR(b)	0.5 Wissenschaftlerin BAT IIa für Jahr 1	WP2, WP3, WP4
	1.0 Wissenschaftlerin BAT IIa für Jahr 2	
FUB(c)	1.0 Wissenschaftler BAT IIa für 2 Jahre	WP2, WP3, WP4

(a) Felix Ament, der die Arbeit von Nicole van Lipzig im Oktober 2005 übernommen hat, soll seine Arbeiten insbesondere zur Langzeitevaluierung des LMK und Verbesserung der Bodenwechselwirkungen fortführen. Er wird seine Dissertation Ende 2005 beenden.

(b) Dipl-Met. Monika Pfeifer, die seit 1. 4. 2004 für QUEST arbeitet, wird ihre Dissertation Ende des dritten Projektjahres beenden. Danach wird sie als Post-Doc die Arbeit für QUEST fortsetzen, und den polarimetrischen Radaroperator SynPolRad für den Gebrauch mit Wolkenradar adaptieren und die Langzeitevaluierung des Modells im Vergleich mit polarimetrischen Radarmessungen durchführen.

(c) Dr. Marc Schröder, der seit 1. Juni 2004 für QUEST arbeitet, wird seine Arbeiten zur Modellevaluierung mittels Satellitenbeobachtungen weiterführen.

Alle drei Wissenschaftler waren in ihrer Kooperation während der 1. Projektphase von QUEST extrem erfolgreich, was auch durch die für die kurze Zeit doch hohe Anzahl der QUEST bezogenen Publikationen illustriert wird. Daher erwarten wir auch in der nächsten Phase eine fruchtbare Zusammenarbeit.

4.2. Wissenschaftliche Geräte

Im Rahmen der Langzeitevaluierung sollen Fernerkundungsdaten und Modellergebnisse gemeinsam analysiert werden. Dies soll auch eine Kreuzkorrelation verschiedener atmosphärischer Parameter beinhalten. Wie bereits dargestellt wurde, beläuft sich der Speicherbedarf der LMK Ausgabefelder für einen einzigen Monat bereits auf 2-3 TB. Dieser Speicherbedarf beinhaltet allerdings noch nicht den Bedarf für die Beobachtungsdaten. Um die Langzeitevaluierung über ein Jahr wenigstens auf Monatsbasis durchführen zu können, wird daher der oben genannt Speicherplatz benötigt. Modellvorhersagen und Beobachtungen werden beim DWD und beim DKRZ Hamburg gespeichert (vgl. auch COPS/GOP Antrag). Eine Ausnahme ist die Archivierung von simulierten VIS/IR Strahldichten von SynSat, die beim DWD nicht gespeichert werden und daher von der FUB prozessiert werden.

MIM	(2 Tbyte RAID System)		2.000,-
FUB	(4 Tbyte RAID System)		4.000,-
		total 4.2	**6.000,- EUR**

4.3. Verbrauchsmaterial

Pro Jahr und Institution werden für DVDs, CDs, Farbdrucke und Kopien, sowie Poster 500,- EUR beantragt.

total 4.3	**3.000,- EUR**

4.4. Reisen

Inlandsreisen: Projekttreffen von QUEST Partnern, DWD und anderen Gruppen innerhalb des Schwerpunktprogramms (z.B. VERIPREG, COPS) haben sich als extrem erfolgreich im Laufe des Projekts erwiesen. Es ist geplant die Zusammenarbeit mit anderen Projektgruppen weiter auszubauen. Dies wird zu mehr Reisen der verschiedenen Projektangestellten führen. Dabei wird jedes Treffen mit einer Summe von 150 Euro angesetzt.

Auslandsreisen: Bereits in der ersten Phase von QUEST konnten erste Resultate auf internationalen Konferenzen präsentiert werden (European Geophysical Society (EGS); European Conf. on Radar

Meteorology and Hydrology; WMO Workshop on Nowcasting; AMS Conf. on Radar Meteorology; GEWEX conference). Wir erwarten daher für die zweite Phase eher noch mehr international vorzeigbare Resultate und sehen daher pro Gruppe und Jahr eine internationale Konferenz mit durchschnittlichen Kosten von 1.000,- Euro[1] vor. Passende Konferenzen sind das EGS Symposium im April 2006 und 2007, die European Conference on Radar Meteorology and Hydrology im September 2006, das Fall Meeting of the American Meteorological Society (AMS) im January 2007 und spezialisierte Konferenzen, die kurzfristig angekündigt werden.

Nicole van Lipzig hat als Projektwissenschaftlerin am MIM von Juli 2004 bis 30 September 2005 gearbeitet bis sie eine Professur an der Katholischen Universität Leuven, Belgien (KUL) angetreten hat. Wir wollen unsere erfolgreiche Zusammenarbeit in QUEST fortführen und beantragen daher Gelder, die ihr die Teilnahme and den QUEST- und Schwerpunktstreffen ermöglicht (5 Treffen jeweils 400,- EUR)

Inlandsreisen:		
MIM (F. Ament, S. Crewell)		1.200,-
DLR (M. Pfeifer, either G. Craig or M. Hagen)		1.200,-
FUB (M. Schröder, J. Fischer)		1.200,-
DWD (M. Baldauf)		1.000,-
Auslandsreisen:		
MIM (F. Ament)		2.000,-
DLR (M. Pfeifer)		2.000,-
FUB (M. Schröder)		2.000,-
KUL (N. van Lipzig)		2.000,-
	total 4.4	**12.800,- EUR**

4.5. Publikationskosten

Es werden Publikationskosten in Höhe von 750,- EUR pro Jahr pro Gruppe beantragt:

	total 4.5	**4.500,- EUR**

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