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

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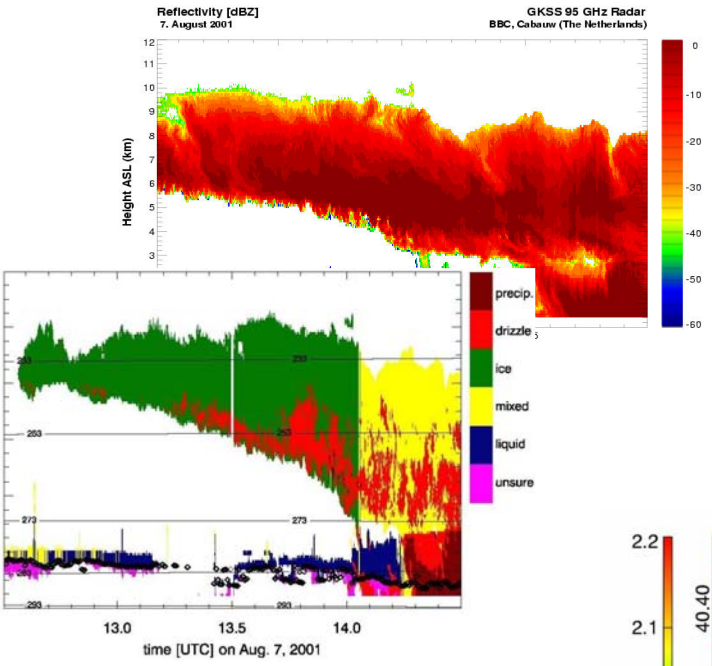

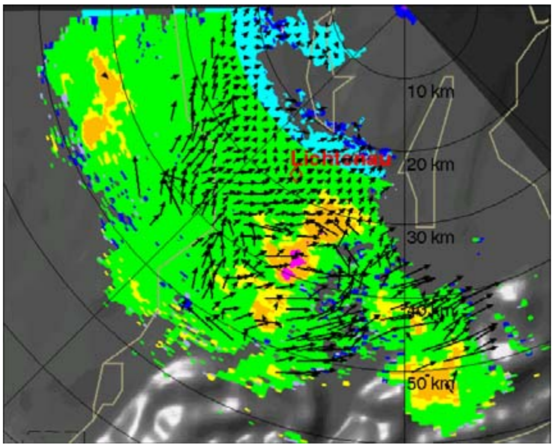

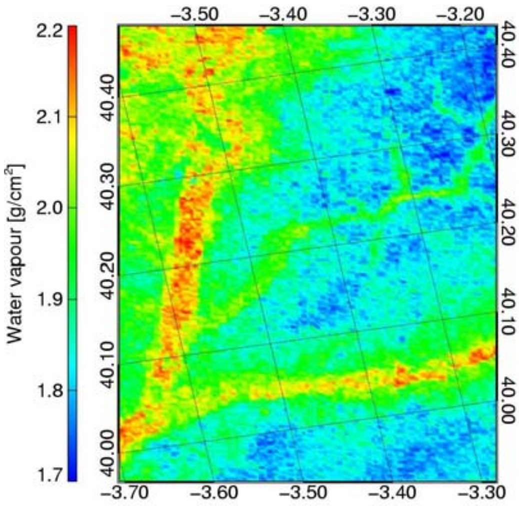

Application for a grant at the Deutsche Forschungsgemeinschaft

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Left: Time series of radar reflectivity profile with overlaid cloud classification based on doppler velocity, linear depolarisation, cloud base height (black dots), liquid water path and temperature profiles. This is a typical situation where seeding effects of an ice cloud lead to precipitation initiation.

Right: Observation of a thunderstorm (9 July 2002, 1608 UTC) by the polarimetric Doppler radar POLDIRAD at DLR Oberpfaffenhofen. Wind arrows are from the bistatic Doppler radar network using three remote bistatic receivers. Overlaid is the hydrometeor classification by polarimetric signatures: Blue – rain, green – ice, yellow – graupel, red – hail.

Bottom: Integrated water vapour over land derived from MERIS measurements with a nadir resolution of ~ 300 m. The image shows the confluence of Rio Jarama and Rio Tajuna in the vicinity of the Spanish city Aranjuez. The columnar water vapour increases with decreasing surface height.

1 General information (Allgemeine Angaben)

Proposal for granting specific funding: New proposal SPP 1167

(Antrag auf Gewährung einer Sachbeihilfe; Neuantrag im SPP 1167)

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[1] Dr. Crewell recently has accepted a professorship at the University of Munich and will change her affiliation to the Meteorological Institute Munich (MIM) before the start of the proposed project.

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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)

Work relying on DFG funding has not started yet. The project is outlined for the total duration (6 years) of the Schwerpunktprogramm (SPP). A detailed implementation plan for the first two (2) years is given for which funding is requested in this proposal.

1.6 Application period (Antragszeitraum)

1 April 2004 until 31 March 2006

1.7 First applications (Gewünschter Beginn der Förderung)

1 April 2004

1.8 Summary (Zusammenfassung)

Quantitative precipitation forecasts will be evaluated by considering the spatial-temporal structure of water in all its three phases using new remote sensing observations. By studying the whole process chain from the water vapour distribution through cloud processes to the amount of precipitation reaching the ground, weaknesses in the treatment of cloud processes in weather forecasting models will be identified. Improvements in predictions should be achieved by improving the assumptions about cloud and precipitation microphysics (e.g. conversion rates, drop size distributions, particle phase and shape) as well as the sub-grid variability.

Existing observational data sets will be used in both observation-to-model and model-to-observation approaches. The most important are: detailed observations of the vertical hydrometeor distribution available at observatories equipped with advanced ground-based remote sensors, three dimensional distributions of polarimetric radar parameters and simultaneous observations of the 3D wind field, and high spatial resolution water vapour fields, cloud parameters, and precipitation-relevant microwave radiances from satellite. The use of forward operators allows the full exploitation of the information content of the remote sensors and is an important step towards future data assimilation methods. The focus of the proposed research is on short-term predictions by the Lokal-Modell of the German Weather Service, however, the created tools will be transferable to other models.

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

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

To improve the quality of precipitation forecasts it is necessary to better parameterise the processes determining the amount of precipitation at the ground and to make optimal use of information concerning these processes in initialisation and assimilation schemes. Furthermore, it is recognized that due to the complexity of atmospheric processes it is of utmost importance to observe the atmospheric state as complete as possible. Both approaches require multi-dimensional remote sensing data since they are the only mean to observe the spatial-temporal distribution of water in all its phases. This is manifested in the SPP proposal (page 8) in the statement:

> “*Hierzu ist vorgesehen, die kleinräumigen bis turbulenten Wechselwirkungen zwischen Wasserdampf, Wolken und Niederschlag vierdimensional zu erfassen*“

The required observations – active and passive techniques both from the ground and from satellites – will be used in the proposed project to investigate the processes which determine the amount of precipitation at the ground. With observations covering vertical (at reference stations), horizontal (from satellite) and three-dimensional (from radar) distributions of water vapour, clouds and precipitation, hydrometeors and wind a solid data base for an in-depth understanding of the relevant atmospheric processes will be generated. By testing and rephrasing parametric assumptions used in the description of the relevant physical processes in the Lokal-Modell the proposed project will contribute to **area A** (Investigation and improvement of precipitation-relevant atmospheric processes).

Since data from all sources mentioned above already exist, the investigation of microphysical processes can start immediately. Furthermore, the data flow from the different sources is expected to continue over the next years. In particular the Global Precipitation

Measuring mission (GPM) consisting of nine satellites dedicated to the delivery of precipitation information will become available during the SPP. Therefore, the project will also contribute to **area B** (data basis and data provision) of the SPP by making data and derived products available to other SPP partners. Special emphasis will be put on the preparation of the General Observation Period (GOP) in 2007 which will be coordinated by Susanne Crewell. It is foreseen that the highest level quality controlled products (derived on the basis of the proposed work) will be made available for this time span which will also cover the planned field experiment. The proposed evaluation will also point at the most suitable observation modes (e.g. scanning techniques, sampling times) and thus contribute to **area E** (preparation of the field experiment).

In contrast to the observations currently used in the operationally environment for the routine forecast verification and data assimilation, remote sensing observations often have multi-dimensional information but are less directly connected to the model variables. Therefore, it is indispensable for the successful physically based assimilation of remote sensing observations that the atmospheric model is able to consistently represent all parameters which determine the remote sensing signal. Hence, a thorough evaluation of the model variables and model physics is needed prior to assimilation experiments. On one hand, the synergy of multi-wavelength (active/passive) observations can be combined to derive the atmospheric variables using existing or newly developed algorithms (observation-to-model approach). For evaluation of model forecasts these variables will be the prognostic model parameters; for development of parameterisations an even more complete set of variables will be necessary to formulate and test parametric assumptions. On the other hand, it can be helpful to convert the model output to the direct observables (model-to-observation approach) and perform comparison in terms of observables. 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 need to extent this approach has also been highlighted by the Atmospheric Radiation Measurement (ARM) cloud parameterisation and modelling working group[1]. 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, including variational methods. In this context it is important to specify the uncertainties of observables and the forward operator as well as the representativeness of the observation for a model grid box. These points which will gain weight in the course of the project are connected to **area C** (data assimilation, validation).

Observations

Advanced ground-based remote sensing measurements by cloud radar, wind profiler, lidar and radiometers in different spectral ranges, together with in situ measurements are routinely performed at European observatories (e.g. Cabauw, Chilbolton, Lindenberg, and Palaiseau). By combining the different sensors via synergetic algorithms (Löhnert et al., 2001 and 2003) **vertical profiles** of temperature, humidity, liquid water content (LWC) and ice water content (IWC) can be derived with high temporal resolution. Even information on hydrometeor size can be provided to a limited degree (Shupe et al., 2001). The **horizontal distribution** of water

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[1] The ARM vision 2000 document is available at the ARM website.

vapour, cloud properties and precipitation is observed by satellite sensors which have significantly been improved in recent years in terms of spatial, temporal and spectral resolution. The **three dimensional** distribution of precipitating hydrometeors can be measured by conventional weather radars performing volume scans. Information on horizontal winds and falling behaviour can be extracted from the Doppler signal. Since the shape and orientation of hydrometeors leads to polarimetric signatures, measurements by the Polarimetric Doppler Weather Radar (POLDIRAD) provide information on the distribution of the different type of hydrometeors, including the degree of melting of ice particles, or identification of the size category of particles (Höller et al., 1994; Vivekanandan et al., 1999). The bistatic radar network connected to POLDIRAD can simultaneously provide the three-dimensional wind field (Friedrich et al., 2000; see plate 2 on title page).

Ground-based remote sensing instruments at well equipped stations (Southern Great Plains, North Slope of Alaska, Tropical Western Pacific) form the backbone of the ARM program which aims at a better understanding of the cloud-radiation-climate problem. ARM has established quality control procedures and value added products. ARM data are used by a wide community for model evaluation and improvement of cloud and radiation parameterisations. In Europe advanced atmospheric observatories with similar instrumentation exist at Lindenberg, Cabauw, Chilbolton, Sodankylä, L'Aquila, and 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 during specific field campaigns. The data from three of these stations are used within the European CloudNET project (http://www.met.rdg.ac.uk/radar/cloudnet/) to study ice clouds and their representation in atmospheric models. Radar/lidar algorithms are applied to derive ice water content and effective radius profiles. The onset of precipitation can be observed well (see plate 1 on title page), however, the information about large scale advection is missing.

Large areas up to 400 km diameter with a horizontal resolution of about 1 km are observed by weather radar systems. The vertical extent of precipitation systems can be investigated by performing horizontal scans at different elevation angles. Today many national weather services combine the observations of their individual radar systems (16 for Germany) to produce national composites of the reflectivity factor. This allows for a monitoring of precipitation in a domain approximately 1000 × 1000 km^2 in size. Furthermore radar data are exchanged between European weather services, and radar composites on a European scale can be generated (e.g. the DWD generates a radar composite using German, French, Austrian, Dutch, Belgian, Danish, and Czech radars). For the Special Observation Period (SOP) of the Mesoscale Alpine Programme (MAP) an Alpine radar composite was generated (Hagen, 1999). Unfortunately, the quality of the radar derived precipitation is still insufficient[1]. In particular when the three-dimensional structure over larger areas composed of several radars is concerned, the inhomogeneity and other typical problems (e.g. clutter, anomalous propagation, and attenuation) cause significant problems. One suggestion to derive improved precipitation rates is the use of polarimetric radar. Although it is anticipated that the next generation of DWD radars will have polarimetric features today only POLDIRAD can observe polarimetric quantities such as differential reflectivity (ZDR), the linear depolarisation ratio (LDR) and specific differential phase on forward scatter, and the cross-correlation factor, which reflect all the

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[1] A detailed argumentation is given in the AQUAradar proposal which includes several approaches to improve the quantitative precipitation estimation by radar.

microphysical properties within the radar volume. Unfortunately, weather radars have a lower sensitivity than cloud radars so that only already precipitating particles can be detected.

Currently, three independent satellite systems allow the remote sensing of atmospheric water vapour and cloud properties on an operational basis. The Medium Resolution Imaging Spectrometer MERIS onboard Envisat, the Moderate Resolution Imaging Spectroradiometer MODIS onboard the TERRA and AQUA satellites and the SEVIRI instrument onboard Meteosat Second Generation (MSG) satellite. MERIS and MODIS provide measurements of total integrated columnar water vapour from backscattered solar radiation in cloud free areas (Bennartz and Fischer, 2001). In cloudy areas, measurements of the integrated water vapour from top of the atmosphere down to the highest cloud level are possible and can be combined with cloud top height measurements from the same sensors (Albert et al., 2001). Products derived from MERIS include a cloud mask, cloud optical thickness and height. Additionally, MODIS provides IR measurements, also allowing the retrieval of several cloud products during day and night (see Tab. 1 for details).

The water vapour and cloud property measurement from the polar orbiting satellites is perfectly complemented by the geostationary SEVIRI measurements which cover the full disk with the very high temporal resolution of 15 minutes. SEVIRI is equipped with different IR channels sensitive to cloud properties and atmospheric water vapour. This allows measurements of total columnar water vapour in cloud free areas as well as measurements of water vapour content in three different atmospheric layers (low, medium and high) during day- and night time as well as the determination of several cloud properties. This multi-sensor, multi-channel approach allows for a well validated, reliable long-term dataset of water vapour measurements as well as the thorough investigation of certain observation periods. The high spatial resolution of the MERIS measurements in combination with the high temporal resolution of the SEVIRI measurements allow the investigation of the dynamic evolution of the water vapour and cloud fields, leading to a better understanding of the underlying physical processes.

Table 1 Satellite instruments and products for water vapour and cloud properties

Instrument	**Platform**	**Resolution**		**Product**[*]	
		Spatial (km)	Temporal	Day	Night
SEVIRI	MSG	4	15 min	1, 2, 3, 4, 5, 6	1, 3, 6
MERIS	Envisat	0,25	1 day	1, 2, 3, 6	none
MODIS	TERRA, AQUA	1	2-3 day, 2-3 night	1, 2, 3, 4, 5, 6	1, 3,

[*] Product codes: 1 = cloud mask, 2 = cloud optical thickness, 3 = cloud top pressure, 4 = cloud droplet effective radius, 5 = liquid water path, 6 = vertical integrated water vapour under cloud free conditions.

Precipitation rate estimate from satellite is a long-standing application. In 1987 the Special Sensor Microwave/Imager (SSM/I) became operational on the DMSP satellite series, which still provide the basic source of satellite-based precipitation observation data outside the tropics. The Tropical Rainfall Measuring Mission (TRMM) has assessed the feasibility of retrieving rather accurate precipitation information from space, also fostering the development of a large amount of cloud and precipitation modelling as well as retrieval algorithms, and showing the impact of assimilating precipitation data in global numerical weather prediction (NWP) models.

This system will be followed by the Global Precipitation Measurement (GPM) mission that consists of a core satellite equipped with passive and active microwave instrumentation and a constellation of further eight satellites equipped with passive microwave sensors which will result in a 3 hourly sampling optimal for global NWP but also important for regional forecast models like the Lokal-Modell. This configuration is partly achieved today with two missions specifically focusing on precipitation. The Japanese Advanced Microwave Scanning Radiometer (AMSR) has been launched on the EOS AQUA and the ADEOS-II satellites in 2002. This instrument provides spatial resolutions that match global NWP models at low frequencies and mesoscale forecast models at high frequencies. It is noteworthy that one AMSR and one MODIS instrument are on the same platform which will allow for cloud classification for passive microwave brightness temperature scenes. Compared to surface based radar data the coverage of the forecast model domain with almost horizontally homogeneous data quality is one of the big advantages in using satellite data for precipitation analysis.

Forward modelling

Because radiometers and radars do not directly measure atmospheric constituents represented by model variables two approaches coexist for the comparison of model and remote sensing data namely the model-to-observation and the observation-to-model approach (Chevallier and Bauer, 2003). Both possibilities are influenced by different spatial and temporal sampling as well as model resolutions. The observations are mostly determined by the emission and scattering of electromagnetic radiation by the surface and atmospheric constituents and therefore represent an integration of information from different sources. For a model evaluation discrepancies between the model and the derived parameter may be difficult to interpret because the relationship between the observable and the parameter may not be unique. It has often been noted that retrieval errors especially for precipitation are difficult to characterize (e.g. Morcrette, 1991; Shah and Rind, 1995). Before assimilation of rain-affected radiances can begin, it must be verified that the model clouds can realistically represent observable radiances using grid-averaged cloud geometry and microphysical properties (Chevallier and Bauer, 2003).

Radar simulation has been used in several studies to address problems of radar meteorology. Chandrasekar and Bringi (1987) studied the influence of varying rain drop-size distributions (DSD) on the relation between radar reflectivity and the surface rain rate. In later studies by Chandrasekar the work was extended to multi-parameter radar, particularly the error structure of differential reflectivity, X-band attenuation, and specific differential phase. In these studies prescribed drop size distributions (DSD) were the basis for the simulations. The simulation of three-dimensional radar reflectivity for realistic rainfall events using a stochastic space-time model and a statistically generated DSD was performed by Anagnostou and Krajewski (1997). The output fields of a mesoscale model are used by the radar simulator model (RSM) of Haase and Crewell (2000) which includes the realistic propagation and attenuation of a radar beam within the model domain. The application of RSM revealed a large deviation between the “observed” radar reflectivity and the model surface rain rate derived with a conventional relationship. Since these deviations are mainly due to the radar measurement process and the vertical variability of the different hydrometeor types it strongly supports the model-to-observation approach for model evaluation. Originally developed for the Lokal-Modell, the RSM has also been adapted to the High Resolution Limited Area Model (HIRLAM) to be used in routine model evaluation.

The computation of model-equivalent radiances at solar, infrared, and microwave wavelengths for several satellite instruments is realized in the RTTOV model developed by EUMETSAT's Satellite Application Facility on Numerical Weather Prediction. Since, RTTOV is a fast radiative transfer model used within global model assimilation cycles it does not consider scattering processes which are essential for the determination of radiances in this proposal. A more complex simulation tool for Meteosat-7 radiances was developed by Ringer et al. (2003) for the Met Office Unified Model. Although such a model may not be fast enough for applications as data assimilation it can serve as a standard against simpler (parameterised) codes. For the simulation of passive microwave satellite radiances usually two-stream Eddington approximation models assuming plane-parallel conditions are employed (e.g. Bauer at al. 1998, Bauer 2002, Moreau et al., 2002) which compare rather well (1-2 K model uncertainty) with Monte Carlo models. Hydrometeor optical properties are provided from pre-computed Mie tables for liquid water, cloud ice, rain, and precipitating ice. Weaknesses of current models are the poor knowledge of ice particle size distributions which are extremely important over land surfaces because the brightness temperature depression at higher frequencies depends strongly on the cloud ice amount. For a given surface rain rate the resulting variability in the amount of microwave scattering can range over a factor of 6-7 (Bennartz and Petty, 2001). Additionally, measured polarisation features of clouds with cold tops at microwave channels are successfully simulated only if oriented spheriodical particles are taken into account (Prigent et al, 2001). The determination of land surface emissivities is rather complex in the microwave and depends on surface composition (soil, vegetation, snow, wetness, etc.) and geometry (soil roughness, geometry of the vegetation canopy, topography, etc.). Satellite measurements of surface emissivity are restricted to the SSM/I frequencies and are of good quality only at lower frequencies.. However, land emissivity models have been developed for frequencies up to 100 GHz by Weng et al (2001).

Model evaluation

The operational verification of quantitative precipitation forecasts from mesoscale models is mostly based on comparisons of the model output averaged over a day and measurements from rain gauge networks that have varying station density. The advantage of using gauges is that they deliver a "true" value but the disadvantages are that gauge data may be not representative of model grid box values. Most observations are made only once a day, and verification results may be biased towards regions with high gauge density. But eventually the most important point is that operational verification does not include the verification of moisture and cloud fields from which precipitation is diagnosed[1].

In current NWP models clouds are characterised by their liquid and ice water content. Beside these two quantities larger scale models sometimes employ cloud fraction as a prognostic variable. Recently, Tompkins (2002) proposed a scheme which caries the variance and the skewness of the total water content (vapour and condensed phases) as prognostic variables. If

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[1] Precipitation will become a prognostic variable in the Lokal-Modell during the SPP which enhance the necessity for validating the conversion of cloud liquid and ice water into precipitation.

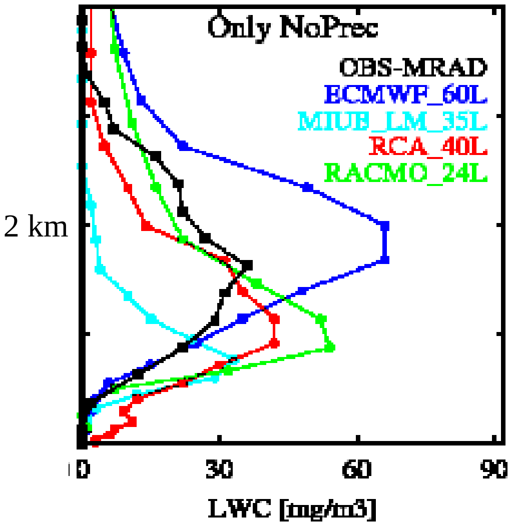

Figure 1: Mean profiles of liquid water content (LWC) averaged over non precipitating conditions during the BBC campaign when the method of Löhnert al. (2003) could be applied (courtesy of E. van Meijgaard, KNMI).

a microphysical scheme involves five „bulk“ hydrometeor quantities (for example snow, rain, graupel, cloud water and ice) this results in more than 30 conversion terms between the different categories (Petch et al., 1997), with many involved parameters not known to within a factor of two. Hence, one challenge in model evaluation is to interpret the raw remote sensing measurements that the instruments make into something useful like average particle size and cloud water content. Another problem is the mismatch between the spatial and temporal scales of models and observations. Furthermore, the evaluation is often hampered by the limitations of the observation to certain conditions. Therefore intense communication is needed between the observation and modelling communities to match the information content of the observations with the model variables, to reveal biases and deficiencies in the observations, and to improve observation strategies.

To improve the treatment of liquid water clouds in NWP and climate models the BALTEX Cloud Liquid Water Network: CLIWA-NET (Crewell et al., 2002) was initiated. During a total of six months of observation an extensive data set was gathered which was used to thoroughly evaluate the short-term forecasts of four European models. From the observations a quality controlled data set of vertically integrated liquid water path (LWP) and information on the cloud vertical structure (base height, temperature and LWC for selected sites) was compiled. Although the focus was on cloud-radiation interaction it was also found that all models overpredict frequency and duration of precipitation. On average, models provide a reasonable representation of the LWC vertical distribution (Fig. 1), but variations among the models in amount and height of the maximum value are huge. For the Rossby Centres model (RCA) the difference might be attributed to a tendency to convert liquid water content into precipitation at a low threshold value. Within CLIWA-NET the evaluation revealed more model deficits and physical inconsistencies (see enclosed CLIWA-NET final report; several publications for a special issue in Atmospheric Research are currently in preparation).

While water clouds were the main target for CLIWA-NET another Framework Programme 5 project, CloudNET, focuses more on ice clouds. A network of three cloud remote sensing stations is operated for a two year period to evaluate the representation of clouds in four major European weather forecast models. Studies include the investigation of sub-grid structure, like average range of variability within a model grid box and the overlap characteristics of these fluctuations (Hogan and Illingworth, 2003).

Model evaluation in CLIWA-NET, CloudNET and also with the ARM data has been performed on a statistical basis and even many more validation studies were performed on a case study base. In order to better identify the weaknesses of current parameterisation schemes it might be appropriate to use long-term data sets and distinguish different regimes (C. Jakob 2003, personal communication).

Recently, also satellite measurements were used to assess global distributions and spatial variability. To avoid some of the inherent uncertainties which occur when model quantities are retrieved from satellite observations, radiances (brightness temperatures) were simulated from ECMWF output for infrared radiances from polar orbiters (Chevallier et al., 2001), Meteosat (Chevallier and Kelly, 2002) and SSM/I (Chevallier and Bauer, 2003). The availability of a sophisticated global operational model with simulation scales of the same order as satellite observations provided a unique tool to evaluate the model cloud physics over all synoptic regimes. As the spatial resolutions of passive microwave sensors have been dramatically improved (AMSR) it seems now possible to transfer these approaches also to regional forecast models. The work of Chevallier and Kelly (2002) is a very good example of how satellite measurements can be used to validate the scales of spatial structures that are resolved in the model simulation by estimating the variability of satellite data and model output. As a result they obtained that spatial structures in the ECMWF model are three to four times larger than in the corresponding Meteosat images where the horizontal resolution for their analysis was 35 km.

The question of the resolved horizontal scales is of special importance for the German Weather Services Lokal-Modell, because the very high spatial and temporal variability of water in its three phases is only partly resolved in the 7 km operational resolution. At the ECMWF seminar on *Key Sub-grid parameterisation issues in NWP*, 3-8 September 2001, the issue of sub-grid cloud variability was identified as the major difficulty needing attention if forecasts are to be improved. Using high resolution satellite data one might be able to understand the variety of subgrid-scale probability density functions (PDF) or cloud properties under different environmental conditions (regimes) and find ways to parameterise their shapes and widths.

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2.2 Preliminary work (Eigene Vorarbeiten)

All groups involved in the proposed projects have a long experience in the scientific topics covered by QUEST, e.g. remote sensing observations from ground, air- and satellite-borne platforms (measurement and algorithm development), and their use for model evaluation and assimilation.

Observations

Remote sensing of water vapour, clouds and precipitation is one of the key topics at MIUB/MIM (Crewell, 2003). For this purpose a ground-based multi-sensor system consisting of lidar ceilometer, infrared radiometer, multi-channel microwave radiometer and X-Band radar has been set up (Crewell et al., 1999). A main focus is on passive microwave radiometry with research ranging from the theory of radiative transfer (Czekala and Simmer, 1998) to experimental work with a "state-of-the-art" microwave spectrometer especially designed for the remote sensing of clouds (Crewell et al, 2001). To fully exploit the information content of the observations retrieval methods using a synergetic sensor approach were developed (Crewell and Löhnert, 2003, Löhnert et al., 2001). The algorithms range from purely statistical ones (Löhnert and Crewell, 2003) to an optimal estimation approach including explicit radiative transfer to simultaneously retrieve physically consistent temperature, humidity and cloud liquid water profiles together with their error characteristics (Löhnert et al., 2003). Within the EU-project CLIWA-NET Susanne Crewell was responsible for the measurements within a ground based network consisting of about 10 stations (Crewell et al., 2000 and 2002) and the corresponding data base including quality control. To investigate the potential of space borne cloud profiling by lidar and radar of the Earth Explorer Mission EARTHCARE statistical analysis of hydrometeor profiles was performed based on advanced remote sensing measurements at the ARM sites and at Cabauw.

Retrieval algorithms for the MERIS and MODIS (Albert et al., 2001, Bennartz and Fischer, 2001) instrument were developed, tested and validated at FUB. MODIS measurements over central Europe with a nadir resolution of 1 km are available from FUB in near-real-time based on MODIS level1b data obtained from the DLR-DFD in Oberpfaffenhofen. Currently, up to 4 daytime overpasses are processed automatically within 90 minutes of the satellite overpass and the results are displayed on the Internet (http://wew.fu-berlin.de/nrt). MERIS and MODIS derived integrated water vapour (IWV) was validated at FUB using radiosonde measurements and microwave radiometer derived values at the ARM-Southern Great Plains site in Oklahoma / USA. The root mean square deviation for all comparisons was around 0.2 g cm^{-2}, with a bias well below 0.01 g cm^{-2} (Albert et al., 2003).

The cloud physics group at the Institut für Physik der Atmosphäre has operated the polarimetric Doppler weather radar - POLDIRAD (Schroth et al., 1988) since 1986. This radar was the first polarimetric C-band radar in Europe and is still one of the few C-band weather radar systems which can transmit and receive waves at any polarisation base. Comprehensive observations of thunderstorms and squall-lines using POLDIRAD have considerably improved the understanding of the mechanisms for hail formation (Meischner et al., 1991; Höller et al., 1994, Haase-Straub et al., 1997, Höller et al., 1998). Detailed observations and theoretical considerations led to the development of a classification scheme for hydrometeors based on polarimetric radar observations (Höller et al., 1994). Additionally, the identification of ice particles and the quantification of the degree of riming of snow aggregates has been evaluated (Meischner et al., 1992; Vivekanandan et al., 1994). Co-ordinated measurements with radar and in situ observations from aircraft were used to validate this parameterisation. Recently, the radar was complemented by a bistatic Doppler network (Friedrich et al., 2000). With this system the complete 3-dimensional wind vector can be retrieved within precipitation systems in an area of about 50 x 50 $(km)^2$ southwest of Oberpfaffenhofen. Both systems (POLDIRAD and the bistatic Doppler network) are now capable of retrieving the complete dynamical and microphysical structure of precipitation systems

Forward modelling

For forward calculations of radiances measured by satellites MIUB has a wide experience in radiative transfer modelling (Drusch and Crewell, 2003) covering solar, infrared, and microwave wavelengths. Infrared models have been used to estimate radiative properties of ice clouds (Schulz, 1998) and for forward simulation of GOES channels to constrain the surface temperature in soil moisture retrieval schemes. The microwave models include the consideration of surface emissivity of land surfaces (Drusch, 2001) and were used for assessing the potential for improved soil moisture initial conditions in NWP models by assimilation of screen-level parameters and 1.4 GHz radiances (Seuffert et al., 2003). More directly related to precipitation, the effect of nonspherical particle shapes on simulated radiances and polarisation was investigated by Czekala and Simmer (1998) and Czekala et al. (1999). Passive microwave and radar satellite observations from TRMM and SSM/I were used to develop an advanced technique for the determination of surface rainfall from the combination of active and passive measurements (Bauer et al., 2002; Schulz et al., 2002). These techniques are used within the German Global Change in the Hydrological Cycle project IMPETUS (www.impetus.uni-koeln.de) for the monitoring of precipitation over Africa and the statistical evaluation of atmospheric circulation models including the Lokal-Modell in climate mode. The monitoring system and QUEST will benefit from the principal investigator status of Jörg Schulz for the AMSR instrument at the National Space Development Agency of Japan (NASDA).

To simulate radar reflectivities from forecasts of the mesoscale Lokal-Modells of DWD the RSM model was developed (Haase und Crewell 2000; Meetschen et al. 2000) at MIUB, which currently is employed for operational validation at the German (DWD) and the Finnish Weather Service (FMI). For a better interpretation of polarimetric radar observations detailed scattering simulations of melting ice particles were performed by Dölling (1997) using the T-matrix approach. The calculations showed the sensitivity of the simulated polarimetric radar parameters on the mixing ratio and the falling behaviour of the hydrometeors.

Model evaluation and assimilation

The CLIWA-NET project (Crewell et al., 2003), which aimed at an improved understanding of cloud processes was jointly initiated by KNMI and MIUB. Within the model evaluation activities MIUB focussed on the Lokal-Modell – the only non-hydrostatic model considered in CLIWA-NET. Numerical experiments were conducted to examine the sensitivity of cloud and precipitation parameters on the horizontal resolution in the range of 10 to 1 km. The treatment of convection is especially difficult since convection is still not fully resolved but most parameterisations were not developed for this scale and therefore need to be adapted or newly developed. Model runs (not using the convection scheme) showed that the size distribution of model resolved convective cells depends strongly on the employed horizontal resolution. The dominant spatial scale corresponds to a number of grid cells rather than a model-independent physical scale. At the smallest grid spacing (2.2 and 1 km) a resolution independent distribution starts to develop. There are indications that the application of fully parameterised turbulence without horizontal exchange between grid boxes is no longer adequate in this range of grid spacing. For detailed description of the CLIWA-NET results see the attached Final report.

The difficulties in testing microphysical parameterisations using remote sensing observations are in part due to the parameterisation schemes themselves. An example of this was found by Petch et al. (1997), who showed that radiative transfer calculations can be significantly influenced by the small ice crystals that are typically ignored by parameterisation schemes since they contain a negligible fraction of the cloud mass and play little role in precipitation formation. Experience at DLR has shown that information from new remote sensing technologies, notably polarised radar can be usefully inverted to classify observed hydrometeor distributions into categories similar to those used in bulk microphysical parameterisations (Höller 1995). This raises the hope that forward models that predict these observed parameters will place stronger constraints on the behaviour of the parameterisation than have been available from observations in the past.

In the framework of the BALTIMOS project within the German Climate Research Programme (DEKLIM), MODIS IWV and cloud fraction derived by FUB have recently been used for validation of the regional climate model (REMO) of the Max-Planck-Institute of Meteorology, Hamburg on a statistical basis. The area under investigation was the Baltic Sea catchment. Within the European CLOUDMAP-2 project MODIS IWV measurements including their error characteristics were used within the 3D-Var assimilation scheme of the numerical weather prediction model HIRLAM of the Swedish Weather Service SMHI.

Assimilation activities at MIUB include – together with DWD – a method to initialize the Lokal-Modell with radar data (Haase et al. 2000, Haase 2002). Radar data were also assimilated together with METEOSAT data into the soil module of the Lokal-Modell (as part of SFB 350) to determine regional evaporation (Braun et al. 2001). Furthermore, the Lokal-Modell was coupled with the hydrological model TOPLATS to study the sensitivity of the weather forecast towards a more accurate soil moisture distribution (Seuffert et al., 2002).

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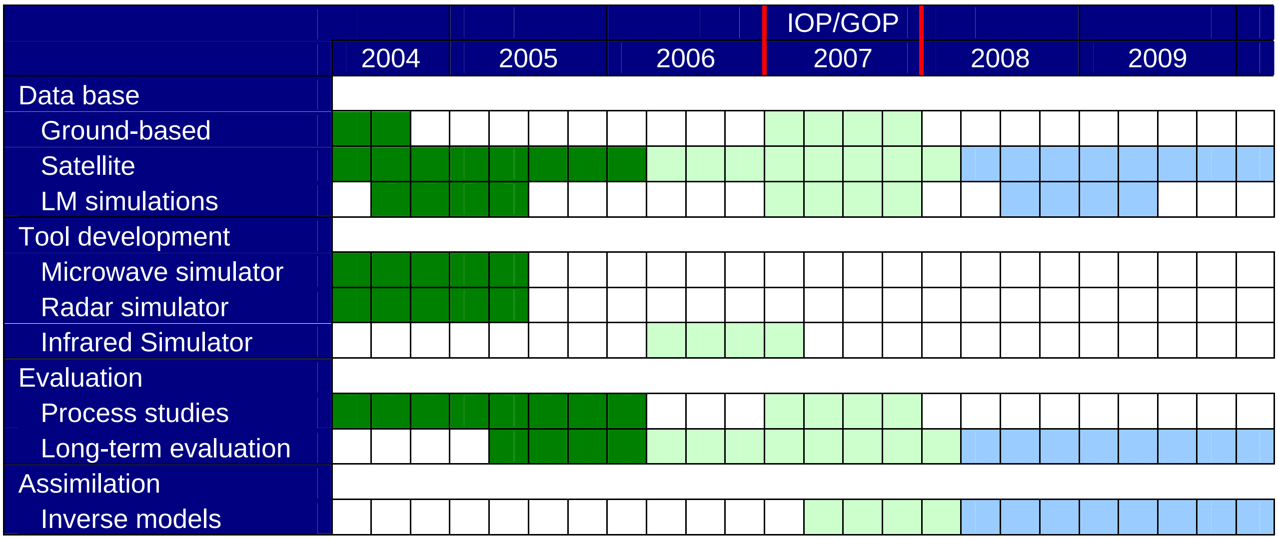
3 Goals and work schedule (Ziele und Arbeitsprogramm)

3.1 Goals (Ziele)

The main aim of this project is 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. These data are the only source to provide observations of the spatial-temporal variability of water in all its three phases. However, due to the nature of the observations new strategies to judge forecast improvements in this framework need to be developed. The quantitative evaluation has the goal of guiding the improvement of parameterisations of the processes that determine the amount of precipitation at the ground. The tools developed within this project should provide to the community an independent test bed for all new parameterisations that may emerge from other projects within the SPP. If parameterisations are verified to realistically represent observables from different observing systems, the developed tools will be used for data assimilation purposes. With respect to the General and Intensive Observing periods a central goal will be an optimal utilisation and provision of data emerging from all relevant observing systems including high quality ground-based and the many satellite platforms dedicated to water vapour, cloud properties, and precipitation measurements.

QUEST is planned to exist over the whole SPP and Table 2 shows the outline over six years subdivided into three periods of two years length. One central objective throughout the lifetime of the project is the development of a data base that guarantees quick access to high quality remote sensing data sets including both derived model variables and direct observables. Also included in this data base will be all relevant Lokal-Modell simulations matched to the observations in space and time. The development of forward modelling tools will provide the link between evaluation of forecast models and the opportunity of the assimilation of observables to improve the forecast. The tools will be developed in three steps starting with the microwave and radar simulator in the first phase, the infrared simulator in the second phase and eventually inverse models in the third phase of the SPP. The evaluation task is also an activity which will last over the whole SPP because improved parameterisations and model configurations will be subsequently evaluated in full 3D integrations in forecast setting, to

Table 2: **Outline implementation plan for QUEST during the SPP lifetime. Three different colours are used to highlight the threeSPP phases. The first phase (dark green) is described in detail below.**



													IOP/GOP											
	2004				2005				2006				2007				2008				2009			
Data base																								
Ground-based	🟩	🟩																						
Satellite	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	▧	▧	▧	▧	▧	▧	▧	▧	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
LM simulations		🟩	🟩	🟩	🟩							▧	▧	▧	▧			🟦	🟦	🟦	🟦			
Tool development																								
Microwave simulator	🟩	🟩	🟩	🟩	🟩																			
Radar simulator	🟩	🟩	🟩	🟩	🟩																			
Infrared Simulator									▧	▧	▧	▧												
Evaluation																								
Process studies	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩				▧	▧	▧	▧									
Long-term evaluation					🟩	🟩	🟩	🟩	▧	▧	▧	▧	▧	▧	▧	▧	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
Assimilation																								
Inverse models													▧	▧	▧	▧	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦

gauge the level of improvement in the full 3D model representation of the important cloud and rain processes. Until their eventual maturity for data assimilation there will be several iterations to improve the parameterisations employing the evaluation framework. The specific objectives of QUEST in the first two years are described below.

Specific objectives

In the first phase of the SPP QUEST will try to identify the reasons for deficits in current precipitation forecasts by using existing data sets and develop tools to better exploit the information content of the multi-dimensional remote sensing data. In particular QUEST will:

- Establish a data base of quality controlled ground-based and satellite remote sensing observations matched with Lokal-Modell simulations. Data starting from 1 January 2004 onwards will be considered.
- Develop a set of forward modelling tools to describe as well as possible the multi-dimensional observations. Work within this task will investigate
    - whether the combination of observing systems now available provide sufficient information about the phase, habit and spectral properties of hydrometeors to constrain all the degrees of freedom in a bulk microphysical scheme.
    - whether the microphysical scheme in the Lokal-Modell provides sufficient information to drive forward models for the available remote sensing instruments.
- Use data of field experiments (VERTIKATOR, CLIWA-NET and BBC2) to investigate
    - the initiation of precipitation and occurrence of drizzle (cloud overlap).
    - the subgrid variability of water vapour, clouds, and precipitation.
    - the development of convective precipitation systems.
    - the process chain from water vapour to precipitation at the ground.
- Compile one year data set (2004) of operational Lokal-Modell forecasts with special output which takes into account the nature (e.g. asynoptic, resolution) of remote sensing data.
- Perform a long-term comparison of forecasts with remote sensing data in the observation-to-model as well as in the model-to-observation mode.

3.2 Work schedule (Arbeitsprogramm)

The work during the first phase is stratified into four different tasks which are the overall coordination, the organisation of the needed data, the tool development, and the evaluation. The tool development and evaluation tasks are each divided into two work packages. Figure 3 shows how the responsibilities for the work packages are distributed among the partners. The following paragraphs describe the subtasks and the timing of each work package which are summarised in Table 3.

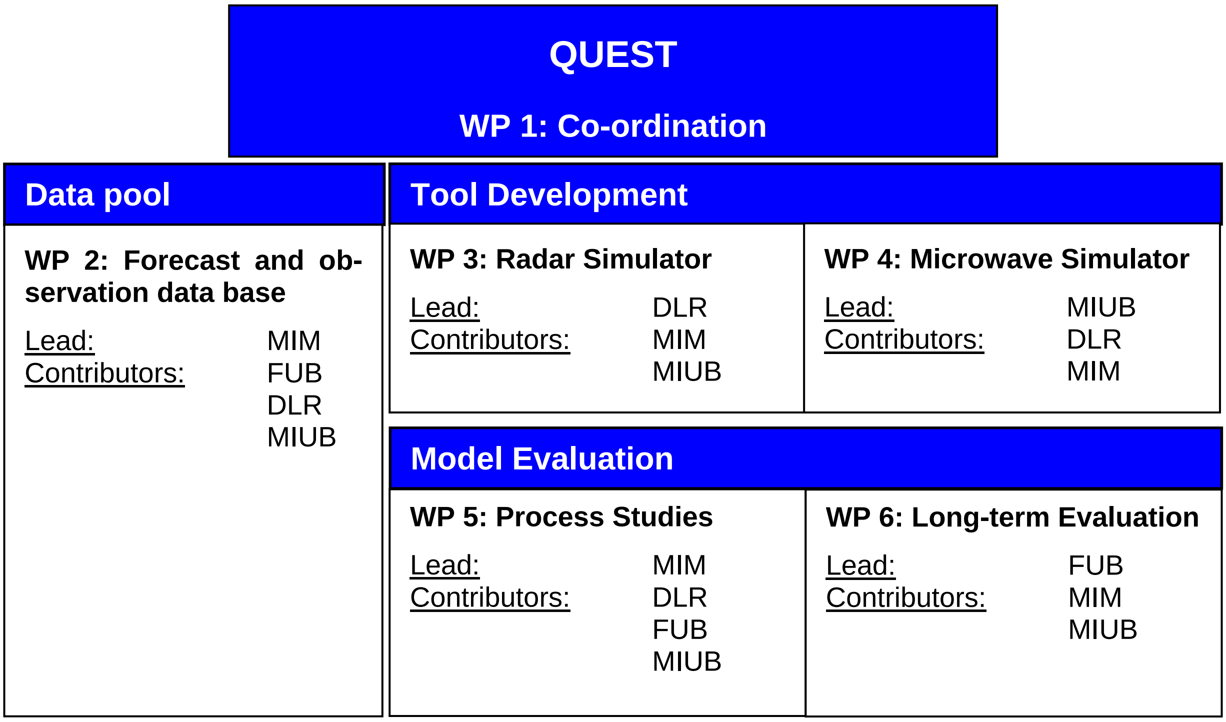


Figure 2: Work package structure and teaming within QUEST.

WP 1: Coordination

Since work package 1 ensures good communication between the QUEST partners, DWD and other projects within SPP 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 SPP. Tools which are already available by some partners will be distributed among the other partners. Examples are a scheme to diagnose 3D-precipitation from LM operational forecasts and a single column LM radiative transfer version.

A project web site will be created. Here, the simulation tools developed in WP3 and WP4 will also be made available on the internet for the access of all SPP partners. For the long-term evaluation in WP6 it is necessary to define the model output for the foreseen evaluation approaches. This means that besides the model variables which can be retrieved from the satellite measurements also those necessary for the application of the forward operators need to be stored at the times of the satellite overpasses. For model evaluation at the ground-based references sites the same output strategies as used in the CLIWA-NET project can be used. At the end of the first phase of SPP recommendations for a validation environment making use of advanced remote sensing observations will be given. WP 1 is the responsibility of MIM.

WP 2 Forecast and observation data base

The data base will include ground-based and satellite remote sensing data as well as model forecasts. A distributed data base will be **set up** meaning that the data is physically kept at the responsible partners but access will be through a joint portal. This is necessary since a data volume of 20 Tbyte is expected within the first two SPP years. In this work package also the exact definition of comparison periods, case studies and available products will take place.

a) Ground-based data

Ground-based remote sensing data from campaigns intended for the process studies will be made available by DLR for the VERTIKATOR campaigns and by MIM for CLIWA-NET (http://www.knmi.nl/samenw/cliwa-net/) and the second BALTEX Bridge Campaigns (http://www.knmi.nl/samenw/bbc2/) within the first half year of QUEST. In preparation of the GOP it is envisaged to provide a continuous data flow from the reference sites. For the GOP also the use of volume scans routinely performed within the German Radar Network is of high interest. However, these data haven't been archived by DWD in the past. For the process studies within QUEST three-dimensional data from research radars and the Dutch radar network are available. For the long-term evaluation an effort will be made in coordination with other SPP partners to get and archive quality controlled data from the German Radar Network.

b) Satellite data

A main ingredient is the combination of the geostationary SEVIRI observations and the MERIS / MODIS / AMSR measurements from polar orbiting satellites with the purpose of using the synergy of all sensors: gaining maximum profit from the different system's advantages for quantitative precipitation forecasts, i.e.

- the high temporal resolution of SEVIRI
- the very high spatial resolution of MERIS
- the high spatial resolution and high spectral coverage of MODIS
- the more direct information on precipitation by AMSR

Therefore **retrieval** algorithms for the remote sensing of atmospheric water vapour (column; three layers: low, middle, high) and cloud properties (cloud fraction, cloud optical thickness, cloud top height, cloud top temperature, cloud top phase, liquid water content) from SEVIRI / MSG measurements will be developed by FUB. Validation of the above algorithms using independent satellite and ground-based measurements will lead to a description of **error characteristics** for future assimilation experiments. AMSR brightness temperatures will be used for the comparison with the output of the microwave simulator. Several quality checks on the brightness temperatures will be applied and bad data scans will be flagged. For comparison of rain occurrence rain identification will be introduced in brightness temperature space.

To ensure highest data quality over the course of the SPP and especially the General Observing Period (2007) **quality control** schemes will be developed which allow the automatic processing of the satellite data and generation of quality flagged products.

c) Lokal-Modell forecasts

First, Lokal-Modell forecasts for the selected **case studies** will be performed (or made available if already existing) by MIUB for the BBC campaigns and by DLR for VERTIKATOR events. In parallel **analysis tools** for the model output will be developed and/or refined to better match observations and model. In order to allow a long-term evaluation we decided to investigate the precipitation forecasts of the Lokal-Modell over the period of one whole year, e.g. 2004, in order to include a large variety of atmospheric situations. The **forecast run** which will include short-term (up to +36 h) predictions will naturally be made in 2005 and therefore be available for the second year of the project. In order to save computation time only forecasts for days with precipitation (either in the model or in reality) will be made. MIM will be responsible for this task. It is envisaged that the runs will be made in co-ordination with DWD on their supercomputer. The feasibility of such runs on this computer has already been shown for the two month period of the BBC campaign.

WP 3 Microwave radiation simulator

The main goal of this work package is the simulation of radiances for space- and ground-based radiometers ranging from the infrared to the microwave spectral range. During the first phase (2004 – 2006) of the project the focus will be on microwave radiative transfer in the model atmosphere as simulated by the Lokal-Modell. During the second phase (2006 – 2008) this will be enhanced by forward operators for infrared sensors, especially in the geostationary orbit to allow also for the analysis of temporal variability of precipitation systems. During the General Observing Period (2007) and the planned field experiment this forward tool can be used to deliver a full set of observables that can be compared to the space- and ground-based measurements. It is also foreseen to adapt and use algorithms to derive precipitation from satellite data to quantify existing biases in model variables. Under the assumption that the microphysical and precipitation parameterizations have been improved under the course of the project for the last phase (2008 – 2010) it is planned to employ the forward simulation tool for variational data assimilation purposes.

In an **orientation and planning phase** at the beginning the project scientist will get acquainted with satellite passive microwave instruments and radiative transfer modelling. In close co-operation with WP 4 the interaction of the microphysical properties as given by the Lokal-Modell and the radiative transfer will be studied. All assumptions made in the Lokal-Modell and those which have to be added for the radiation transport calculations need to be well understood. Additionally, it is necessary to understand the different viewing constellations of the considered platforms and their implications on the results that will be achieved. This phase will be completed by a detailed model development plan.

It is planned that the forward simulation tool will be constructed to work for several satellite sensors currently in space which are the AMSR, SSM/I, and the Advanced Microwave Sounding Unit (AMSU) as well as instruments launched in the future like the Special Sensor Microwave Imager/Sounder (SSMIS), the passive microwave radiometer of the European contribution to the GPM mission (EGPM), the GPM Microwave Imager (GMI), and the Conical Microwave Imager/Sounder (CMIS). Additionally, the simulation of ground-based instruments like MICCY will be possible. Special focus will be put on the simulation of the 89 GHz channel of AMSR because the resolution of this channel (3.6 km × 6.3 km) coincidences quite well with the spatial resolution of today’s operational mesoscale forecasts and will be also useful for future higher resolution versions of those models. Because the rain signal at 89 GHz is characterised by a depression through scattering by large ice particles this requires a thorough treatment of the scattering caused by different hydrometeors. In close co-operation with WP-4 a **data base for scattering parameters** interfaced to the microphysical assumptions of the Lokal-Modell will be developed. The signal of low frequency microwave channels is dominated by emission but this information can only be used over sea surfaces because of the high and heterogeneous emissivity of land surfaces. However, more than 40% of the surface in the Lokal-Modell area is covered by oceans so that the consideration of the emission channels will be beneficial for the model evaluation. The emission channels (~19 GHz) have the advantage of being less sensitive to cloud geometry and model generated snow, thus providing a more unique relationship between rain water and brightness temperature.

For computations over land surfaces an improved **surface emissivity model** will be integrated into the existing microwave radiation transport model to calculate microwave emissivities from the surface parameters of the Lokal-Modell. For the ocean surface the widely used FASTEM-2 model developed at the U.K. Met Office will be implemented.

The next step is the **interfacing of the Lokal-Modell microphysical output to the radiative transfer scheme**. The optical properties needed within the radiative transfer scheme will be tabulated after particle spectra and particle properties have been defined. Although it is only important for low frequencies over ocean surfaces also optical properties of melting particles will be included in these tables using available models for the melting process. The tables will be stratified after frequency, particle type, temperature and water content to allow a quick diagnose of optical properties from the liquid and ice water contents as well as other information on particle type extracted from the Lokal-Modell.

A major point during the development will be the implementation of the **viewing geometries of the different sensors**. The radiative transfer simulation will be quasi three-dimensional along the slant paths through the model atmosphere. The approximation of three-dimensional radiation paths by the first-order slant paths for the downwelling, reflected, and upwelling radiances has been found to give an accurate counterpart of real three-dimensional simulation employing Monte Carlo type models. Therefore the vertical profiles of the Lokal-Modell have to be redistributed according to the zenith and azimuth angles of the considered instrument. Consequently, the microphysical properties associated with each profile have to be taken along the slant path[1]. Software to realise this redistribution has already been written for other cloud resolving models used within the derivation of retrieval schemes.

Some **sensitivity studies** concerning the different assumptions will be performed to find the optimal trade-off between needed accuracy and computing time. Because the surface emissivity model will dominate the error budget of the simulated brightness temperatures, the first important test will be the sensitivity of the results on the surface parameters used to drive the land surface emissivity scheme. The sensitivities will be examined as a function of the surface rain rate produced by the Lokal-Modell. Other sensitivities to be explored are those on particle size spectra and particle shape assumptions.

WP 4 Polarimetric radar simulator

The aim of this work package is the simulation of polarimetric radar parameters from the output of Lokal-Modell simulations. In an **orientation and planning phase** the microphysical parameterisation of the Lokal-Modell, the polarimetric radar simulator tool provided by V.N. Bringi (Colorado State University, Ft. Collins, USA), the RSM tool and their possible interaction will be studied. The assumptions implicitly considered in the microphysical parameterisations about particle size distribution and falling behaviour need to be well understood.

A special point is the treatment of the melting layer. The melting layer is of great importance for radar simulations, since melting ice particles show enhanced signatures at the reflectivity factor and polarimetric radar parameters. Because the melting layer is not explicitly treated in the Lokal-Modell, assumptions about the melting of ice particles have to be made. The RSM already includes a crude approximation of this effect by converting snow to rain as

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[1] The treatment of AMSU measurements in this way might be critical because AMSU is a cross track scanner with a decreasing horizontal resolution away from the nadir view. It is foreseen to start with the implementation of the AMSU geometry when the other sensors are successfully installed.

a function of temperature. Improved methods will be considered during the orientation phase in close co-operation with WP 3.

The basic tool for the polarimetric radar simulator is the RSM (Haase and Crewell, 2000) which uses Lokal-Modell output to simulate the radar reflectivity factor as it would be observed by radar. It explicitly includes radar beam propagation and attenuation. Because the Lokal-Modell provides only bulk microphysical properties (e.g. liquid water content) the RSM uses assumptions on particle size distribution. For detailed polarimetric radar simulations specific particle properties (size distribution, shape, phase, density and falling behaviour) are required. Those have to be defined according to the microphysical scheme of the Lokal-Modell. Additionally, common approaches taken from the literature will be used to make the required assumptions. In order to realistically simulate the polarimetric quantities the scattering characteristics of non-spherical particle need to be considered. For this purpose a **scattering data base** will be generated in close co-operation with WP 3. The T-matrix program provided by Bringi will be used to simulate polarimetric radar parameters axial symmetric particles.

To **integrate the Bringi polarimetric radar simulator into the RSM** the LM hydrometeor classes need to be mapped according to the hydrometeor classes as defined in the Bringi model. The definitions are based on typical radar signatures, and the classes are cloud droplets, rain, ice needles, snow, graupel, dry hail, wet hail. Again co-operation with WP3 will be beneficial. In addition, numerical interfaces between LM, RSM, and the polarimetric radar simulator have to be defined. The current version of RSM has to be **adapted to handle differential propagation** of polarimetric radar parameters. In addition, the radial Doppler velocity will be simulated from the LM dynamic wind field.

Finally, **sensitivity studies** concerning the different assumptions will be performed. For example, most particles are smaller than the wavelength of POLDIRAD (5.45 cm), i.e. scattering processes can be approximated using the Rayleigh assumption. This assumption may be also important considering the exact shape and falling behaviour of ice particles. The sensitivity studies need to address the natural variability of mixed particles to identify how far details (shape or phase of mixed particles) need to be simulated.

WP 5 Process studies

The field campaigns (integrated into the data base in WP2) will be used to investigate the **precipitation initiation.** For this purpose a proper knowledge about the information content of the diverse ground-based remote sensing instruments describing the vertical structure in detail is needed (orientation phase). One example is 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 data from the BBC2 campaign in May 2002 will be extremely useful in relating the processes in the atmospheric column to the precipitation at the ground since additional instruments to observe rainfall (4 micro rain radars, disdrometer and several rain gauges) were distributed around the Cabauw site. In addition, the measurements by three uplooking polarimetric cloud radars measuring at different frequencies and the volume scans of the Dutch weather radar can be simulated by the radar simulator developed in WP 4, thus providing a thorough check of the brightband treatment.

Furthermore, the observed temporal evolution of cloud vertical structure will be used to study evaporation rates below clouds. Very often drizzle is present in low level water clouds which mostly does not reach the ground. This is well observed by the combination of cloud radar (sensitive to particle diameter to the sixth) and lidar (sensitive to particle diameter squared). In the case of precipitation generation by seeding (see plate 1 on title page) the mid-troposphere is moistened by the evaporation of precipitating ice particles until the particles can finally reach a lower water cloud where the Bergeron-Findeisen process triggers precipitation and its intensity.

While the reference sites only provide the temporal evolution at one point the large scale development is observed by satellite measurements (from FUB) and 3-D weather radar (from KNMI). The high temporal resolution of SEVIRI will be exploited during these cases to investigate how the cloud life cycle is related to these precipitation events (formation, development, extent, decay and disappearance) and how this is represented within the model. The proposed studies will immediately feed back into WP2 since it might be useful to perform additional forecast runs, for example with different horizontal resolution. Furthermore, it is likely that these studies will reveal additional model variables which should be stored in the one year forecast run.

One possible cause for deficiencies in quantitative precipitation forecast is the insufficient description of **sub-grid variability**. Here, sub-grid-scale variability will be defined in terms of cloud fraction, and the first and second moments of the cloud optical thickness distribution. Water vapour fluctuations can also be observed, but can only easily be interpreted over flat terrain (e.g. The Netherlands). The high horizontal resolution of SEVIRI (~4 km) and MERIS (~300 m) will enable us to investigate the sub-grid variability as a function of grid size. Therefore the information is not only beneficial for the operational Lokal-Modell (7 km grid), but important for all other models. Statistical parameterisations of cloud fraction (e.g. Tompkins, 2002) employ probability density functions derived from high-resolution cloud models. The satellite information, eventually distinguished for different regimes, are suited to constrain these assumptions. The MERIS measurements can also identify sub-grid scale clouds and the respective sub-grid scale LWP for LM runs with higher resolution (down to 1 km). The question which amount of convection might be resolved by a certain model resolution can be addressed. For concurrent SEVIRI and MERIS measurements the impact of sub-grid variability within the SEVIRI pixels will be investigated. The focus will be on the question whether convective precipitation events can properly be observed by SEVIRI and how well they are reproduced within the LM. Convective precipitation is mostly connected to small-scale precipitation, where sub-grid-scale effects are most likely to affect grid-sized observations. Since during the selected cases information on **water vapour, clouds and precipitation** and their variability is available we will try to follow the whole chain from water vapour convergence to the precipitation on the ground as well in the model as in reality.

In this work package the polarimetric radar simulation tool (WP 4) will be applied to LM simulations. The aim of this work package is the simulation of case studies which can be used to evaluate the simulator and the microphysical parameterisation of the LM. The case studies will be selected from the field campaigns EULINOX (1998) and VERTIKATOR (2002) which provide comprehensive radar, aircraft, and surface observations in the Alpine foreland close to Oberpfaffenhofen. The observations allow for a detailed description of the dynamical and microphysical structure of **convective events**. LM simulations will be provided by partners within DLR (C. Keil, T. Fehr) with 7 km and 2.8 km resolution for the relevant cases. The polarimetric radar simulator will simulate polarimetric radar parameters which are compatible to the radar observations with POLDIRAD.

The simulated radar measurements will be compared to observed radar data. The following questions will be studied: (1) how does LM simulate the observed features of deep convection; (2) what effects have a variation of assumptions in the LM microphysics parameterisation on simulated radar observables; (3) how to optimise the microphysical parameterisation in respect to the simulation of polarimetric radar parameters; (4) how to optimise the polarimetric radar simulation tool. Points (1), (2), and (3) require slight **modifications of the parameters of the microphysics parameterisation** of LM in order to receive a variation of the radar parameters without affecting the general results of the simulation. A variational approach will be used to test the effects on the simulated radar parameters. Point (4) requires a refinement of the assumptions made for the particle properties like shape, phase, ice-water mixing-ratio, and falling behaviour. As deep convective events are the easiest one to identify in passive microwave measurements around 89 GHz, the VERTIKATOR data are also crucial to answer the question wheather the microphysical scheme in the Lokal-Modell provides sufficient information to reproduce the AMSR measurements, and if the microwave simulator is able to convert the microphysical information provided by experimental data into the satellite measurement. It will be investigated whether the changes in the microphysical parameterisation under (3) are also beneficial for the simulation of satellite signals.

WP 6 Long-term evaluation

The long-term satellite observations of water vapour, cloud fraction, liquid water content, cloud top height, phase and temperature will be used to validate the model forecast 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 power spectra. Care has to be taken to closely match model and observation, e.g. water vapour is derived only for cloud free scenes. The comparison will benefit from the experience gained in WP 5.

In order to better identify the weaknesses of model precipitation forecasts we plan to distinguish between different regimes, for example by “Großwetterlagen”, 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.

Furthermore, model evaluation will be performed in terms of the **model-to-observation approach.** For this purpose the microwave simulator tool developed in WP 3 will be applied to the Lokal-Modell forecasts of corresponding AMSR and SSM/I overpasses (WP 2). In a test phase measurements and simulations of both instruments will be analysed over ocean. Under these conditions the brightness temperatures simulated with the ECMWF model showed a positive bias compared to SSM/I measurements at 19 and 37 GHz. The higher resolution of both AMSR and Lokal-Modell can then be exploited to quantify the role of sampling for these comparisons. Through the comparison of brightness temperature histograms it will be possible to make statements on biases in rain intensity. In particular the comparison of PDFs at 89 GHz can give indications of an excess or deficit production of ice water in the model or an inadequate ice fall out scheme.

The new simulator will allow for the first time the comparison of brightness temperatures over land surfaces. As we expect, problems will occur over regions with pronounced topography and those need to be excluded from the comparison. Since only the scattering information at 89 GHz will be useful over land surfaces here mostly the brightness temperature depression in the model and the AMSR data will be compared. At least the comparisons will reveal information on the extension of cloud and rain systems by applying identical brightness temperature thresholds to satellite and model data.

We realise that the proposed research is quite ambitious and the interpretation of results from the model-to-observation approach is challenging. However, this work package will significantly increase our experience on this topic and help us to recommend a validation environment for the second phase of the SPP.

Table 3: Summary and time table of work packages of QUEST during the first phase of the SPP.

WP	Tasks	I	II	III	IV	I	II	III	IV
1	Coordination	░	░	░	░	░	░	░	░
	Project meetings (all)	x			x			x	
	Recommendation for validation environment (all)								█
2	Forecast and observation data base	░	░	░	░	░	░	░	░
	Setup & selection of case studies (MIM)	█							
	Ground-based remote sensing data (MIM, DLR)	█	█						
	Satellites: retrieval & error assessment (FUB, MIUB)	█	█	█					
	Satellites: quality control (FUB)				█	█	█	█	█
	LM: - Case study forecast data set (DLR, MIUB)		█	█					
	LM: - Analysis tools (MIUB, DLR, MIM)		█	█					
	LM: - 2004 forecast run (DLR, MIM, MIUB)				█				
3	Microwave Simulator	░	░	░	░	░			
	Orientation and planning phase (MIUB)	█							
	Land surface emissivity model (MIUB)		█						
	Scattering data base (MIUB, DLR)		█	█					
	Viewing geometry for different sensors (MIUB)		█	█					
	Interface microphysics/radiative transfer (MIUB, MIM)				█				
	Sensitivity studies (MIUB)				█	█			
4	Polarimetric radar simulator	░	░	░	░	░			
	Orientation and planning phase (DLR)	█							
	Scattering data base (DLR, MIUB)		█	█					
	Integration Bringi and RSM model (DLR, MIM)			█	█				
	Adaptation of differential phase (DLR)				█				
	Sensitivity studies (DLR)				█	█			
5	Process Studies	░	░	░	░	░	░	░	░
	Precipitation initiation (MIM)	█	█	█	█				
	Sub-grid variability (MIM, FUB)			█	█				
	Water vapour-cloud-precipitation (FUB, MIM)				█	█			
	Convective precipitation events (DLR, MIUB)					█	█		
	Parameterisation tuning (DLR)							█	█
6	Long-term evaluation					░	░	░	░
	Observation-to-model (MIM, FUB)					█	█	█	█
	Model-to-observation (MIM,MIUB)							█	█

3.3 Experiments with humans (Untersuchungen am Menschen)

not applicable

3.4 Experiments with animals (Tierversuche)

not applicable

3.5 Experiments with recombinant DNA (Gentechn. Exp.)

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 for two years, BAT IIa W	WP1, WP2, WP5, WP6
	1 student research assistant, without diploma for two years with 40 h/month	WP2, WP6
DLR(b)	0.5 scientist for two years BAT IIa W	WP2, WP3, WP5
FUB(c)	1 scientist for two years, BAT IIa W	WP2, WP5, WP6
	1 student research assistant, without diploma for two years with 40 h/month	WP2, WP5, WP6
MIUB	0.5 scientist for two years, BAT IIa W	WP2, WP4, WP5, WP6
	1 student research assistant, without diploma for two years with 40 h/month	WP2, WP4

(a) MIM plans to fill the position with Dr. Birgit Heese who has a long experience in remote sensing of different atmospheric quantities using active and passive instruments. She is cooperating with FUB on the derivation of cloud top properties from aircraft measurements for validation of satellite algorithms.

(b) Dipl.-Met. Monika Pfeifer will work as a PhD candidate on the polarimetric radar simulator at DLR. She recently joint the radar group working on the retrieval of microphysical properties from polarimetric radar measurements.

(c) It is foreseen to fill the scientist's position with Peter Albert, who is currently finishing his Ph.D. thesis at FUB. In his work he is focusing on the development and validation of algorithms for the satellite based remote sensing of atmospheric water vapour and the assimilation of these measurements in a numerical weather prediction model. He has developed the water vapour retrieval algorithms for MERIS and MODIS to be used within this project. Because of his long experience in this research field he is very well suited for this position.

4.2 Scientific equipment (Wissenschaftliche Geräte)

To establish the data base (WP2) sufficient storage capacity is needed. The standard forecast output of the Lokal-Modell accounts to about 50 GByte per month, e.g 0.6 Tbyte per year. Taking into account the additional output variables needed for the satellite evaluation a RAID system with 1 Tbyte capacity is needed at MIM. The satellite data flow is estimated to be:

AMSR	2 GByte / day
SEVIRI	8 GByte / day
MERIS	2 GByte / day
MODIS	4 GByte / day
total	14 GByte / day

At FUB, satellite data from four instruments will be stored: SEVIRI on MSG, MERIS on ENVISAT and MODIS on TERRA and AQUA. This will allow access to raw data and possible reprocessing of atmospheric parameters with refined algorithms. Since FUB builts its own storage systems a request for 10.000,- EURO is expected to be sufficient assuming a future decrease in disc storage costs. AMSR data will be stored at MIUB. The following list estimates the daily data amount

MIM	(1 Tbyte RAID system)		3.500,-
FUB	(10 Tbyte hard disk capacity)		10.000,-
MIUB	(1 Tbyte RAID system)		3.500,-
		total 4.2	**17.000,- 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: The SPP kick-off meeting and the joint DWD/SPP meeting will be connected with internal QUEST consultations. A few months before the end of Phase 1 an additional QUEST meeting is planned to accomplish an optimal dissimination of results and to compile a set of recommendations on model evaluation for the next SPP phase. Each meeting is estimated with 200 Euro per person. The travel cost for B. Ritter (DWD) for two meetings is included at MIM.

International travel: It is expected that towards the end of the first SPP phase results suitable for presentation at international conferences will be achived. Therefore for each group one international conference is foreseen with an average cost of 1.500,- Euro. Appropriate conferences are the Symposium of the European Geophysical Society (EGS) in April 2005, the Fall meeting of the American Meteorological Society (AMS) in January 2006 or a more specialised conference in this period which has not been announced yet.

National travel:

MIM (project scientist, B. Ritter, S. Crewell)	1.600,-
DLR (project scientist, either G. Craig or M. Hagen)	1.200,-
FUB (project scientist, J. Fischer)	1.200,-
MIUB (project scientist, J. Schulz)	1.200,-

International travel:

MIM (project scientist)	1.500,-
DLR (project scientist)	1.500,-
FUB (project scientist)	1.500,-
MIUB (project scientist)	1.500,-
total 4.4	**11.200,- EUR**

4.5 Publication costs (Publikationskosten)

For publication costs 750,- EURO per year are requested by each institute:

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)

MIM

PD Dr. Susanne Crewell	currently Head of the working group “Ground-based remote sensing“ at MIUB; Full professor at MIM starting February 2004
Dr. Ulrich Löhnert	currently scientist at MIUB; assistant professor at MIM starting April 2004.
Dr. Birgit Heese	Project scientist for the evaluation of the Lokal-Modell; funding for her position is requested from DFG.

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. Katja Friedrich	Scientist in the radar group
Dr. Thorsten Fehr	Scientist for LM simulations
Dr. Christian Keil	Scientist for LM simulations

FUB

Prof. Dr. Jürgen Fischer	Head of the Institute for Space Science
Dr. Rene Preusker	Scientist
Peter Albert	Project scientist for the use of satellite data in the evaluation; funding for his position is requested from DFG.

MIUB

Dr. Jörg. Schulz	Senior Scientist
Dipl. Met. Felix Ament	Ph.D. Student for LM simulations
N. N.	Project scientist for the development of the microwave simulator; funding for this position is requested from DFG.

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

The contact to the DWD will be through Dr. **Bodo Ritter** who will also particpate during the QUEST meetings. This will allow intense communication and interaction with respect to parameterisations employed in the DWD model. Furthermore, the possible implementation of tool developed in QUEST into the operational environment can be discussed.

Co-operation exists with Prof. Dr. **Madhu** Chandra, DLR-Institut für Hochfrequenz und Radarsysteme (HR) and Universität Chemnitz. POLDIRAD, was developed together with DLR-HR. Continuos co-operation concerning the operation of the radar, simulation of radar scattering, and the interpretation of polarimetric radar measurements. Concerning 3D-radiative transfer in the sub-millimetre range co-operation with Dr. **Stefan Bühler,** IUP Bremen**,** exists.

The data base and the validation tools developed in QUEST should be used by other SPP patrners. Examples are the development of a non-local hybrid cumulus convection parameterisation scheme (Prof. Dr. **Andreas Bott,** MIUB) and the assimilation bundle (DAQUA) coordinated by Prof. Dr. **Clemens Simmer,** MIUB. The storage and pre-processing of SSM/I data was developed and done in close co-operation with Dr. **Christian Klepp,** Max-Planck-Institute for Meteorology, Hamburg. Work on the evaluation of those data with respect to precipitation over sea will be continued in the SPP proposal High Impact Weather Early Warning System (Dr. Christian Klepp, MPI). For the preparation of the General Observation Period and the field experiment close contact will be kept with Prof. Dr. **Volker Wulfmeyer**, Uni Hohenheim.

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

Concerning radar observations and simulation close collaboration exists with **Günther Haase** and **Daniel Michelson** (both at SMHI, Sweden). Furthermore, 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), **Anthony Illingworth** (University of Reading), **Jaques Testud** (CETP-CNRS) and **Eugenio Gorgucci** (CNR).

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** (Uiversity 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).

Jörg Schulz is a member of the International Precipitation Working Group (**IPWG**, with the objective of an improved use of satellite data for remote sensing of precipitation) founded by WMO and is active in the sub-group research mostly concerned with the development of parametric rainfall algorithms from passive microwave satellite sensors and data assimilation into NWP models. Herein the collaboration with **Peter Bauer** (ECMWF) and **Ralf Bennartz** (University of Wisconsin) is especially fruitful on the construction on forward operators for satellite sensors. In respect to the Global Precipitation Mission (GPM) and the 3d-submm radiative transfer with focus on precipitation co-operation with **Bizzaro Bizzari** and **Alberto Mugnai** (both at ISAC-CNR) exist.

Concerning the model evaluation the very close co-operation established in CLIWA-NET will be continued with **Erik van Meijgaard** (KNMI) and with **Colin Jones** and **Ulrika Willen** (both at SMHI). The latter are especially interested in the use of ground-based remote sensing data for cloud overlap assumptions and the cloud radiation interaction. Contact to the model evaluation activities in CloudNET is guaranteed due to the good co-operation with **Anthony Illingworth**.

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

- operational Doppler-X-band radar Bonn (MIUB);
- two Micro Rain Radar (MRR) from METEK (MIUB);
- polarimetric Doppler radar POLDIRAD (DLR);
- bistatic Doppler radar network (DLR);
- multispectral Microwave radiometer MICCY (MIUB, MIM);
- MSG receiving dish including a PC and disc storage system.

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

All institutes contribute to QUEST by providing computing power, 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 will be made available by MIUB/MIM. SEVIRI data is routinely received at FUB, the water vapour retrieval algorithms are currently developed. The MODIS data is received by DLR-DFD and transferred for further processing via ftp to FUB within the CLOUDMAP2 EU-project until January 2004. Further agreement between DLR-DFD and FUB with regard to further data delivery has to be confirmed. Data from the passive microwave radiometer SSM/I are available through the joint SSM/I data base at the Max-Planck-Institute for Meteorology in Hamburg. AMSR data are available through the Principal Investigator status of Dr. Jörg Schulz and are regularly delivered to the University of Bonn.

6 Declarations (Erklärungen)

A request for funding this project has not been submitted to any other address. In case we submit such a request I will inform the Deutsche Forschungsgemeinschaft immediately. The Vertrauensdozent of the Rheinische-Friedrich Wilhelm University, Dr. S. Penselin, has been notified of this proposal.

7 Signatures (Unterschriften)

Bonn, 29.09.2003 ________________________ ________________________

(S. Crewell) (J. Schulz)

Berlin, 29.09.2003 ________________________ ________________________

(J. Fischer) (P. Albert)

Oberpfaffenhofen, 29.09.2003 ________________________ ________________________

(G. Craig) (M. Hagen)

8 List of appendages (Verzeichnis der Anlagen)

CV of PD Dr. Susanne Crewell

CV of Dr. George Craig

CV of Dr. Martin Hagen

CV of Prof. Dr. Jürgen Fischer

CV of Dr. Jörg Schulz

Financial plan in German

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