## 3.1 General information about the project D5

### 3.1.1 Title:

A high-resolution multi-scale space-time precipitation model from direct measurements and remote sensing

Ein hoch aufgelöstes multiskaliges Raumzeitmodell des Niederschlags aus direkten Messungen und Fernerkundung

### 3.1.2 Research areas:

Applied mathematics, radar meteorology

### 3.1.3 Principal investigator(s):

1. Battaglia, Alessandro, Hochschulassistent, Dr., 02.04.1972

Meteorologisches Institut, Rheinische Friedrich-Wilhelms-Universität Bonn,
Auf dem Hügel 20, 53121 Bonn

Tel.: 0228/73-5790

Fax: 0228/73-5188

E-mail: batta@uni-bonn.de

Does the principal investigator hold a permanent position?

☐ Yes ☒ No, limited until Oktober 2007

☒ Further employment is planned until September 2010

2. Thomas Gerstner, Dr., 19.01.1971

Institut für Numerische Simulation, Rheinische Friedrich-Wilhelms-Universität Bonn,
53115 Bonn

Tel.: 0228/733430

Fax: 0228/737527

E-mail: gerstner@ins.uni-bonn.de

Does the principal investigator hold a permanent position?

☐ Yes ☒ No, limited until March 2009

☐ Further employment is planned until ____________

3. Griebel, Michael Univ.-Prof. Dr., 13.01.1960

Institut für Numerische Simulation, Rheinische Friedrich-Wilhelms-Universität Bonn,
53115 Bonn

Tel.: 0228/733437

Fax: 0228/737527

E-mail: griebel@ins.uni-bonn.de

Does the principal investigator hold a permanent position?

☒ Yes ☐ No, limited until ________________

4. Simmer, Clemens, Univ.-Prof. Dr.,
Meteorologisches Institut, Rheinische Friedrich-Wilhelms-Universität Bonn,
Auf dem Hügel 20, 53121 Bonn
Tel.: 0228/73-5181
Fax: 0228/73-5188
E-mail:csimmer@uni-bonn.de

Does the principal investigator hold a permanent position?

☒ Yes ☐ No, limited until

### 3.1.4 The project includes:

- research on human subjects ☐ Yes ☒ No
  A copy of the required approval of the responsible ethics committee is included with the project proposal ☐ Yes ☒ No
- clinical studies in somatic gene therapy ☐ Yes ☒ No
- experiments involving animals ☐ Yes ☒ No
- experiments involving recombinant DNA ☐ Yes ☒ No
- research with human embryonic stem cells ☐ Yes ☒ No
  Legal authorisation has been obtained ☐ Yes ☒ No

### 3.1.5 Requested Funding

| Financial year | Funding for staff | Funding for direct costs | Funding for instrumentation | Total |
|---|---|---|---|---|
| **2007** | 112.2 | 1.0 | 230.0 | 343.2 |
| **2008** | 112.2 | 1.0 | 200.0 | 313.2 |
| **2009** | 112.2 | 1.0 | 0.0 | 113.2 |
| **2010** | 112.2 | 1.0 | 0.0 | 113.2 |

The proposed project section is currently not funded.

(Figures in thousands of euros)

## 3.2 Summary

*The project section will detect and monitor structures of rain fields covering spatial scales from tens of metres to hundreds of kilometres and temporal scales from minutes to months Up- and down-scaling space-time models will be developed, which are constrained by observed surface precipitation information, and which will explicitly account for spatial and temporal structures of precipitation events. The model will assimilate uncertain and sparse surface precipitation estimates reaching from an X-band Doppler radar with polarisation diversity to conventional rain gauges.*

The general space-time data-based precipitation model will allow for a variety of error structures, spatial and temporal resolutions associated with the different data sources. The numerical solution of the associated data assimilation problem will be performed by efficient multilevel and multigrid methods. The model will be applied to an area covering at least the Rur and Erft catchment. Backbone data source of the model will be the Bonn Doppler-X-band radar, which will be upgraded within the project by polarisation diversity. A dense network of cell-phone links will provide quantitative constraints to the radar estimates, i.e. mean rain intensity along the line paths of the communication network. The bordering C-band Doppler radars (Essen, Frankfurt, Neuheilenbach) of the German Weather Service (DWD) will be used to improve the radar estimate especially in the more Western and Northern regions of the catchments. Different measurements (rain gauges, mini radars, micro rain radar, microwave links, weather radar) and existing precipitation data sets (e.g. REGNIE) will be merged in the model and high temporal resolution precipitation models on the point scale will resolve the smallest scales. It is expected that such a data set will be beneficial for both better understanding the precipitation processes and for hydro-meteorological modelling.

Scientific problems on the meteorological and remote sensing side include:

- How can the spatial and temporal structure of precipitation events be quantitatively described on different scales?
- Which exploitable relations exist between larger scale atmospheric conditions and the spatial and temporal structure of precipitation events, and how can these relations be used for spatial and temporal inter- and extrapolation of precipitation data?
- How can different data sources be optimally combined taking into account the information about spatial and temporal structure?
- Are polarization diversity radars more effective in capturing the spatial and temporal structure of precipitation by identifying its underlying drop size distribution variability?
- Can cell-phone link attenuation measurements improve radar based rainfall estimates?

Scientific problems on the numerical side to be addressed include:

- How can the large linear matrix equations which arise from general data assimilation problems be solved efficiently?
- Which functionals have to be minimized in space-time data assimilation problems and to what type of matrix equations do they lead?
- How can nonlinear projectors and problem functionals be constructed such that prescribed structures in the result are respected?
- How can good scale transfers operators to both coarser and finer scales be designed and how are they numerically realized?

### 3.3 Starting point

Precipitation is the main driver of terrestrial hydrological processes and thus the key input for hydro-meteorological modelling. The importance of precipitation stands, however, in contrast to our knowledge of its spatial and temporal structure, which itself influences almost any process in the soil. Being the result of a chain of processes covering all scales in the atmosphere, surface precipitation varies on almost all scales and thus inhibits the determination of spatio-temporal structures of precipitation fields from point measurements (e.g. rain gauges). Ground based active microwave measurements (precipitation radars) are considered to be suitable for estimating precipitation rates and distributions on a wider range of scales, but the absolute quality of radar based rain estimates suffers from large uncertainties related to the physical relation between radar signal and near surface rain rate.

### 3.3.1 State of the art

**Scaling structure properties of precipitation field from observations.** Many atmospheric fields are characterized by scaling or scale invariance, which manifests itself as log-log linearity of the power spectrum in space or time. Evidence of scaling power spectra for rain fields can be found in numerous studies (Lovejoy and Schertzer, 1995, Lilley et al, 2006 and reference therein). Although these results are mainly empirical, arguments suggest that the scaling of observed scalars such as rainwater is linked to the scaling observed in turbulence (Tessier et al., 1993). Methodologies to evaluate the multi-scale statistical properties of a rain field (like Fourier generalized structure and moment-scale analysis) are well described in Harris et al., 2001. Multi-fractal behaviour of rain fields has been characterized in terms of universal exponents on various precipitation time series ranging from seconds to centuries as well as for spatial scales from few hundred meters to planetary scales (e.g. Tessier et al., 1993). In general different storm conditions result in different structures; few studies tried to connect the scaling exponents to changes in atmospheric stability and differences in the local orographic environment (e.g. Perica and Foufoula-Georgiou, 1996, Purdy et al., 2001).

**Combined space-time variability:** Only few multifractal analyses of the combined space-time variability have been carried out (e.g. Over and Gupta, 1996). Space-time modelling requires the identification of the space/time relation; Venugopal et al. (1999a) identified dynamic scaling in space-time rainfall and developed a space-time downscaling model (Venugopal et al., 1999b). Only few studies try to classify the spatio-temporal structure of precipitation events as a function of the atmospheric state (e.g. Rosenfeld et al., 1995) and, up to now, there is no general space-time model of precipitation available, which allows for the assimilation of diverse information on precipitation.

**Scaling structure properties of drop size distribution and reflectivity:** Many authors have investigated the dependence of the drop size distribution (DSD) variability at different scales (climatological, day to day, within a day, between physical processes, and within a physical process) and its effects on rainfall intensity estimation from radar reflectivity (Steiner and Smith, 2004). This is particularly relevant when evaluating the effects of the DSD variability on the rain rate estimation from radar reflectivity Z (Lee and Zawadzki, 2005).

**Multilevel Data Assimilation:** From the mathematical point of view, we encounter a data assimilation problem, where we have to extract and assimilate information from observation data into a model. The observation data are usually not uniformly distributed, noisy, and often sparse rendering the data assimilation problem underdetermined. Hence, in order to reduce the impact of the noise one needs to weight the observations against a predefined set of model parameters. To this end, typically some sort of statistical interpolation of the observation data is applied with many variants such as nudging, kriging (e.g. Cassiraga et al., 2002), optimal interpolation (Todini, 2001), statistical objective analysis (SOA) (Pereira Fo and Crawford, 1999), Kalman filter (Houtekamer and Mitchell, 2001), 3D-Var, 4D-Var including their dual versions PSAS (Daley, 1991). These methods minimize a quadratic functional (Aarnes, 2005) and differ in the type of functional to be minimized. In general, the minimization leads to a large linear coupled matrix equation whose unknowns are the interpolation weights $w$ and the increments $x_o$-$x_a$ between observed and analyzed data, respectively. Under simplifying assumptions, (uncorrelated and unbiased observation errors) the system decouples, which leaves a small linear system in the unknowns $w$ to be solved from whose solution the remaining large part of the unknowns $x_o$-$x_a$ are gained by backward substitution.

In more realistic settings, however, the system does not decouple and a very large and full linear matrix equation has to be solved. The size of this system is given by the number of observation points, which usually inhibits direct solution methods. For the numerical solution of large systems besides classical iterative solvers there exist in principle various multigrid and domain decomposition methods. Relevant experiences exist in atmospheric (Brandt and Zaslavsky, 1997), oceanographic (Aarnes, 2005), and image data analysis (Henn and Witsch, 2002; Zou and Ganem, 2004). For creating a high-resolution precipitation model from discrete measurements, these efficient techniques have not been adopted or applied. The data assimilation problem becomes more difficult, if further assumptions are violated. Then, the functional to be minimized becomes more complicated, involving, e.g., anisotropies and general structure functions. The resulting system can even become nonlinear. For the efficient numerical solution of such systems, nonlinear multigrid methods such as FAS (Brandt 1984; Hackbusch 1985) can in principle be employed. Nonlinear multigrid methods have not been used so far for the solution of data assimilation problems for high-resolution precipitation models.

**Multilevel Up- and Downscaling.** Multilevel constructions (Daubechies, 1992) are a natural tool for multiscale analysis of multidimensional data. The various techniques differ mainly in the type of multilevel basis used, such as wavelets, interpolets, hierarchical finite elements, frames or generating systems. Starting from such a hierarchical multilevel representation of the data, the different scales are typically obtained by a thresholding of the basis coefficients. Here, special goal-oriented error estimators which describe a problem-dependent functional to guide the adaptive refinement (Bangerth and Rannacher, 2003; Giles and Süli, 2002) or explicit coarse-level constraints such as topological consistency (Gerstner and Pajarola 2000) can be used. But in the context of atmospheric data analysis, these approaches have not been used so far. Furthermore, (multigrid) homogenization or asymptotic expansions are used to derive coarse-scale models. Here, also nonlinear approaches have been studied which were up to now mainly applied in the context of porous media flow (Allaire 1992, Oleinik 1994, Lions et al. 1978). These techniques are not directly suitable for atmospheric data, but might provide a source of inspiration for the derivation of new methods.

Several stochastic models for rainfall downscaling have been proposed. Following Ferraris et al., 2003 (and reference therein) disaggregation models can be grouped in three main categories: 1) multifractal cascades; 2) nonlinearly filtered autoregressive processes, and 3) point processes based on the random positioning of a given number of rainfall. All these models are characterized by an extremely fast numerical implementation and by a low number of free parameters. The rainfall downscaling is particularly ticklish when dealing with mountain regions because of orographic effects. Analyses of scaling parameters dependence on orography have been carried out by Purdy et al., 2001 and simple solutions have been recently proposed by Badas et al. (2005). The effects of the circulation on the mesoscale precipitation field have been considered as well (e.g. Salathe 2003).

**Polarisation diversity with X-band radars.** In order to improve radar-based precipitation estimates and to overcome single polarization radar limitations (e.g. large errors in the reflectivity to rainfall intensity relation - the Z-R-relation - , attenuation, calibration, contamination by ground returns) polarisation diversity radars have been proposed, which have the potential to retrieve both droplet size distributions (DSD) and hydrometeor types (e.g. Bringi and Chandrasekar 2001, Gorgucci et al. 2001,2002, Meischner et al. 2003). This advantage has been demonstrated mostly for S and C band (near 10 and 5 cm, respectively), and many Weather Services are upgrading their radar networks accordingly (Zrnic and Ryzhkov, 1999). Attention has shifted now towards X-band (3 cm) polarimetric radars which suffer more from attenuation problems but offer finer spatial resolution, higher mobility because of size, reduced ground clutter problems, and increased sensitivity for weaker targets due to the much larger specific differential phase KDP: X-band KDP-based polarimetric techniques are applicable to rainfall rates as low as about 2.5-3 mm/h while the S-band KDP-based estimates are generally unavailable for rainfall rates less than about 8-10 mm/h. Moreover X-band differential reflectivity (ZDR) is larger than S-band differential reflectivity for drop sizes above 2 mm thus potentially providing a better differentiation for larger drop sizes. The attenuation of reflectivity measures can be corrected by using the integrated differential propagation phase as a constraint (Matrosov et al., 2002; Anagnostou et al., 2004; Gorgucci et al., 2005; Park et al., 2005a-b, Matrosov et al., 2005). By so doing X-band rainfall polarimetric estimators have been demonstrated to perform better than conventional Z-R relations when compared to rain gauges/disdrometers for rain rates higher than 3 mm/h (Matrosov et al., 2002, Anagnostou et al., 2004; Park et al., 2005b). Thus a polarisation diversity X-band radar is an ideal tool for monitoring moderately sized complex terrain watersheds and urban basins.

**The use of mobile-phone links.** Messer et al. (2006) showed that it is possible to gauge rainfall by analysing the signal fluctuations of mobile-phone base stations. There is almost a linear relationship between rainfall and attenuation at frequency around 30 GHz; in effect, base stations automatically compensate for such attenuations as the atmospheric conditions change. Using recordings of signal-strength fluctuations between base stations, mean surface rain rates along the link paths can be estimated. Microwave links can be used to correct for the attenuation of the X-band radar as described by Rahimi et al. 2006.

**Existing precipitation products:** Daily 1 km resolution precipitation products for Germany are available the German Weather Service (DWD) based on station data (REGNIE, Regionalisierung räumlicher Niederschlagsverteilungen) since 1931. The development of integrated precipitation products from different measurements is a matter of ongoing research: RADOLAN (RADar OnLine ANeichung, DWD) is a real time precipitation product based on radar data locally calibrated with rain-gauges (Weigl, 2001); MUSIC (Multi-Sensor Precipitation Measurements Integration, Calibration and Flood Forecasting, EU/FP5) develops techniques for improving weather radar, weather satellite and rain gauge derived precipitation data for flood forecasting systems; VOLTAIRE (Validation of multisensors precipitation fields and numerical modeling in Mediterranean test sides, EU/FP5) aims at improving radar-derived precipitation fields in Mediterranean test sites using in situ measurements and adjustment techniques; Rubel et al. (2004) derived a 3 hourly, 0.2 degree precipitation product for Oct. 1999 - Dec. 2000 from CERAD (Central European Radar Network) and BALTRAD (Baltic Radar Network) where the data is adjusted by a precipitation gauge data set consisting of approximately 21600 rain gauges.

Aarnes, J. (2005): Iterative methods for data assimilation and an application to ocean state modeling, report, SINTEF, Oslo.

Anagnostou, E.N.; Marios N. Anagnostou; Witold F. Krajewski; Anton Kruger; Miriovsky B.J. (2004): High-Resolution Rainfall Estimation from X-Band Polarimetric Radar Measurements. J. of Hydromet., 5 (1), 110-128.

Allaire, G. (1992): Homogenization of the unsteady Stokes equations in porous media, in C. Bandle et al. (eds.) Progress in Partial Differential Equations: Calculus of Variations, Applications, Pitman Research Notes in Mathematics 267, 109-123.

Badas M. G.; Deidda R.; Piga E. (2005): Orographic influences in rainfall downscaling, Advances in Geosciences, 285-292.

Bangerth, W.; Rannacher R. (2003): Adaptive Finite Element Methods for Differential Equations, Lectures in Mathematics, Birkhäuser, Basel.

Brandt, A. (1984): Multigrid Techniques, GMD-Studien, St. Augustin.

Brandt, A. ; Zaslavsky L.Y. (1997): Multiscale algorithm for atmospheric data assimilation. SIAM J. Sci. Comput. Vol. 18, No.3, pp. 949-956.

Bringi, V. N.; Chandrasekar V. (2001), Polarimetric Doppler Weather Radar, Principles and applications, Cambridge University Press, 636 pp.

Cassiraga, E. F.; Guardiola-Albert, C.; Gómez-Hernández, J.J. (2002). Automatic Modeling of crosscovariances for rainfall estimation using raingage and radar data. geoENV II. Kluwer Academic Publishers, Barcelona, SPAIN.

Candes, E.; Romberg J.; Tao T. (2005): Stable Signal Recovery from Incomplete and Inaccurate Measurements, Comm. Pure Appl. Math, to appear.

Daley, R. (1991): Atmospheric Data Assimilation, Cambridge University Press.

Daubechies, I. (1992): Ten Lectures on Wavelets, SIAM, Philadelphia.

Ferraris, L.; Gabellani S.; Rebora N.; Provenzale A. (2003), A comparison of stochastic models for spatial rainfall downscaling, Water Resources Research, 39, 10.1029/2003WR002504

Giles, M.; Süli E. (2002): Adjoint methods for PDEs: a posteriori error analysis and postprocessing by duality, Acta Numerica 11, 145-236, Cambridge Universiy Press.

Gorgucci, E.; Scarchilli G.; Chandrasekar V.; Bringi V.N. (2001): Rainfall estimation form polarimetric radar measurements: composite algorithms immune to variability in raindrop shape-size relation. J. Atmos. Ocean. Technol., 18, 1773-1786.

Gorgucci, E.; Chandrasekar V.; Bringi V. N.; Scarchilli G. (2002): Estimation of Raindrop Size Distribution Parameters from Polarimetric Radar Measurements. J. Atmos. Sc.: 59 (15), 2373-2384.

Gorgucci, E.; Chandrasekar V. (2005): Evaluation of Attenuation Correction Methodology for Dual-Polarization Radars: Application to X-Band Systems. J. Atmos. Ocean. Technol., 22 (8), 1195-1206.

Hackbusch, W. (1985): Multi-Grid Methods and Applications, Springer.

Harris, D.; Foufoula-Georgiou, E.; Droegemeier, K.; Levit, J.J. (2001): Multiscale statistical properties of a high-resolution precipitation forecast. J. Hydromet., 2, 406-418.

Henn, S.; Witsch K. (2002): Iterative multigrid regularization techniques for image matching, SIAM Journal on Scientific Computing 23(4), 1077-1093.

Houtekamer, P. L.; Mitchell, H. L. (2001): A sequential ensemble Kalman Filter for atmospheric data assimilation. Mon. Wea. Rev., 129, 123-137.

Kunoth, A. (2002): Fast Iterative Solution of Saddle Point Problems in Optimal Control Based on Wavelets, Comput. Optim. Appl. 22, 2002, 225-259.

Lee G.; Zawadzki I. (2005): Variability of Drop Size Distributions: Time-Scale Dependence of the Variability and Its Effects on Rain Estimation. Journal of Applied Meteorology: Vol. 44, No. 2, pp. 241-255.

Lilley, M.; Lovejoy S.; Desaulniers-Soucy N.; Schertzer D. (2006): Multifractal large N limit in Rain, J. of Hydrol, in press.

Lions, J.; Benoussan A.; G. Papanicolau (1978): Asymptotic Analysis for Periodic Structures, North Holland Publishers.

Lovejoy, S.; Schertzer D. (1995): Multifractals and rain, in New Uncertainty Concepts in Hydrology and Water Resources, edited by A. W. Kundzewicz, pp. 61-103, Cambridge Univ. press, New York,.

Matrosov, S.Y.; Clark K.A.; Martner B.E.; Tokay A. (2002): X-Band Polarimetric Radar Measurements of Rainfall. Journal of Applied Meteorology, 41 (9), 941-952.

Matrosov, S. Y.; Kingsmill D.E.; Martner B.E.; Ralph F.M. (2005): The Utility of X-Band Polarimetric Radar for Quantitative Estimates of Rainfall Parameters. J. Hydromet., 6 (3), 248-262.

Meischner, P. [ed.] (2003): Weather Radar: Principles and Advanced Applications. Springer monograph series "Physics of Earth and Space Environment", 337 p.

Messer, H.; Zinevich A.; Alpert P. (2006), Environmental Monitoring by Wireless Communication Network, Science, 312, 713.

Oh, S.; Milstein A.B.; Bouman C.A.; Webb K.J. (2005): A General Framework for Nonlinear Multigrid Inversion, IEEE Transactions on Image Processing, 14(1), 125-140.

Oleinik, O. (1994): Homogenization of Differential Operators and Integral Functionals, Springer.

Over, T.; Gupta V. K. (1996): A space-time theory of mesoscale rainfall using random cascades. J. Geophys. Res., 101 (D21), 26319-26331

Over, T.; Gupta V. K., (1994): Statistical Analysis of Mesoscale Rainfall Dependence of a Random Cascade Generator on Large-Scale Forcing. Journal of Applied Meteorology: Vol. 33, No. 12, pp. 1526-1542.

Park, S.-G.; Bringi V. N.; Chandrasekar V.; Maki M.; Iwanami K. (2005a): Correction of Radar Reflectivity and Differential Reflectivity for Rain Attenuation at X Band. Part I: Theoretical and Empirical Basis. J. Atmos. Ocean. Technol., 22 (11), 1621-1632.

Park, S.-G.; Maki M.; Iwanami K.; Bringi V. N.; Chandrasekar V. (2005b): Correction of Radar Reflectivity and Differential Reflectivity for Rain Attenuation at X Band. Part II: Evaluation and Application. J. Atmos. Ocean. Technol., 22 (11), 1633-1655.

Pereira Fo, A.J.; Crawford, K.C. (1999): Mesoscale precipitation fields. Part I: Statistical analysis and hydrologic response.- Journal of Applied Meteorology (38): 82-101.

Perica, S.; Foufoula-Georgiou, E. (1996). Linkage of Scaling and Thermodynamic Parameters of Rainfall: Results From Midlatitude Mesoscale Convective Systems. Journal of Geophysical Research 101(D3): doi: 10.1029/95JD02372. issn: 0148-0227.

Purdy, J. C.; Harris, D. ; Austin, G. L. ; Seed, A. W. ; Gray, W. (2001) A case study of orographic rainfall processes incorporating multiscaling characterization techniques J. Geophys. Res. Vol. 106 , No. D8 , p. 7837-7845.

Rahimi, A. R.; Holt, A. R.; Upton, J. G.; Krämer, S.; Redder A.; Verworn, H.R. (2006): Attenuation Calibration of an X-Band Weather Radar Using a Microwave Link. J. Atmos. Ocean. Technol.: Vol. 23, No. 3, pp. 395-405.

Rosenfeld, D.; Amitai, E.; Wolf, D.B. (1995). Classification of rain regimes by the three-dimensional properties of reflectivity fields. J. Appl. Meteor. 34, 198–211.

Rubel, F.; Brugger, K.; Skomorowski, P.; Kottek, M. (2004): Quantitative precipitation estimates from CERAD, BALTRAD and gauges.- Proceedings of ERAD (2004): 1–4

Salathe', E.P. (2003): Comparison of various precipitation downscaling methods for the simulation of streamflow in a rainshadow river basin, Int. J. of Climatology, 23, 887-901.

Steiner, M.; Smith, J.A. (2004): Scale Dependence of Radar-Rainfall Rates - An Assessment based on Raindrop Spectra.- J. Hydromet.,5: 1171-1180.

Tessier, Y.; Lovejoy S.; Schertzer D. (1993): Universal Multifractals: Theory and Observations for Rain and Clouds. J. Appl. Meteorology: Vol. 32, No. 2, pp. 223-250.

Todini, E. (2001): A Bayesian technique for conditioning radar precipitation estimates to rain-gauge measurements.- Hydrology and Earth System Sciences 5 (2): 187 – 199.

Venugopal, V.; Foufoula-Georgiou, E.; Sapozhnikov, V. (1999a). Evidence of dynamic scaling in space-time rainfall. J. Geophys. Res., 104(D24):31,599-610

Venugopal, V.; Foufoula-Georgiou, E.; Sapozhnikov, V. (1999b). A space-time downscaling model for rainfall. J. Geophys. Res., 104(D16):19,705-721

Weigl, E. (2001). Real-Time Adjustment Scheme of Radar Precipitation Data at DWD, 30th International AMS Conference on Radar Meteorology, 19-24 July 2001, Munich, Germany, poster presentation; http://www.dwd.de/de/wir/Geschaeftsfelder/ Hydrometeorologie/ a_href_pages/ RADOLAN/index.htm

Zou, Y.; Ganem R. (2004): A Multiscale Data Assimilation with the Ensemble Kalman Filter, Journal on Multiscale Modeling and Simulation, 3(1), 131-150.

Zrnic, D.S; Ryzhkov A.V. (1999): Polarimetry for weather surveillance radar, Bull. Amer. Meteor. Soc., 80, 389-406

## 3.3.2 Preliminary work by the research groups

### 3.3.2.1 Institute for Numerical Simulation, University of Bonn

In the last years multi-scale methods for analysis and archiving of three-dimensional, time dependent data were an intensive research subject at the Institute for Numerical Simulation (INS). In this framework, the construction of orthogonal wavelets with correct treatment of the boundary (Koster 2002) as well as bi-orthogonal wavelets and hierarchical bases (Gerstner 1998) were investigated. In Koster et al. (1998) different wavelet constructions (orthogonal and pre-wavelets on global and local tensor product grids) for the scale analysis of turbulent flow fields are applied and compared. Furthermore, multi-grid homogenization methods for diffusion problems with varying coefficient functions were developed in Knapek (1999). Robust multigrid solvers were developed in Griebel et al. (2003, 2006). The parallelization of multigrid methods was investigated in Griebel and Zumbusch (1999, 2000) and Griebel et al. (2006). The application of multigrid methods to geoscientific problems was shown in Gerstner et al. (2003). Efficient space-time discretizations based on sparse grids (Bungartz and Griebel 2004) were developed in Griebel et al. (2005) and Oeltz (2006). Hierarchical basis constructions on adaptive tetrahedral grids for interactive processing of three-dimensional volume data sets were investigated by Gerstner et al. (2000), Gerstner and Pajarola (2000) and Gerstner (2002). Within various studies approaches to analyse, compress and visualize measurements of the X-band radar Bonn and precipitation simulated by a numerical weather prediction model were performed with encouraging results (Gerstner et al., 2002; Gerstner et. al. 2003). In addition, an efficient technique for nonlinear data regression based on regularization networks was developed in Garcke et al. (2001), Garcke &Griebel (2001, 2002, 2005) which is in the spirit of data assimilation problems.

### 3.3.2.2 Meteorological Institute, University of Bonn

Precipitation analysis using the X–band radar Bonn is an ongoing research focus at the Meteorological Institute. Within several Diploma and PhD theses, methods were developed to account for clutter, attenuation, and beam shading. Recently, Heuel (2004) developed a complete processing chain to derive high-quality precipitation rates from the radar and rain gauge data using a variational approach. Current projects focus on operational now-casting of floods connecting radar precipitation estimates to hydrological models in the nearby Erft- and Agger catchment (Meetschen et al., 2005), and on the development of methods to simulate and understand the complex, polarisation-dependent scattering and transport processes in microwave radiation transfer (Battaglia et al., 2001, 2003, 2005; Battaglia and Mantovani, 2005, Czekala and Simmer, 2002, Czekala et al., 2001, Meetschen et al., 2000). Radar meteorology and precipitation was a key issue of the two international Baltic Bridge Campaigns coordinated by the group members (e.g. Crewell et al., 2004, Rose et al., 2004).

In the framework of the BMBF/AFO2000 project 4DClouds Venema et al. (2004, 2006a/b) developed an Iterative Amplitude Adapted Fourier Transform (IAAFT) algorithm, which is able to reconstruct 2- and 3-dimensional geophysical fields from very limited measurements while preserving both the power spectrum and the amplitude distribution. A variant of this algorithm is able to generate high-resolution fields from a coarse field and its spectrum extrapolated to small scales (Venema and Simmer, 2005). The smallest (time/space) scales of precipitation were modelled based on rain gauges (Steinhorst et al., 2003) and an array of Micro Rain Radars (Simmer et al., 2004). The aspect of probability density distributions of precipitation and its extremes is covered by a project funded by the Nordrhein-Westfälische Akademie der Wissenschaften (Zolina et al., 2004, 2005a, b).

## 3.3.3 List of relevant publications

### **3.3.3.1** Institute for Numerical Simulation, University of Bonn

### I. Peer-reviewed publications

a) in scientific journals

Bungartz, H.J.; Griebel, M. (2004): Sparse Grids, *Acta Numerica,* **13**, 1-123.

Garcke, J.; Griebel, M. (2002): Classification with sparse grids using simplicial basis functions, *Intelligent Data Analysis,* **6(6)**, 483-502.

Garcke, J.; Griebel M.; Thess, M. (2001): Data mining using sparse grids. *Computing*, **67(3),** 225-253.

Gerstner, T.; Rumpf M.; Weikard, U. (2000): Error indicators for multilevel visualization and computing on nested grids. *Computers & Graphics*, **24 (3),** 363-373.

Gerstner, T. (2002): Multiresolution extraction and rendering of transparent isosurfaces, *Computers & Graphics*, **26**, 219-228.

Griebel, M.; Metsch, B.; Oeltz, D.; Schweitzer, M. (2006): Coarse grid classification: A parallel coarsening scheme for algebraic multigrid methods, *Num. Lin. Alg. Appl.*, to appear.

Griebel, M.; Oeltz D.; Schweitzer, M. (2003): An Algebraic Multigrid Method for Linear Elasticity, *SIAM J. Sci. Comp.* **25(2)**, 385-407.

Griebel, M.; Oeltz D.; Vassilevski, P. (2005): Space-time approximation with sparse grids, *SIAM J. Sci. Comp.*, to appear.

Griebel, M.; Zumbusch, G. (2000): Parallel adaptive subspace correction schemes with applications to elasticity, *Comp. Meth. Appl. Mech. Eng.,* **184**, 303-332.

Griebel, M.; Zumbusch, G. (1999): Parallel multigrid in an adaptive PDE solver based on hashing and space-filling curces, *Parallel Computing,* **25**, 827-843.

Knapek, S. (1999): Matrix-dependent multigrid homogenization for diffusion problems. *SIAM J. Sci. Comp.,* **20(2):**515-533.

b) at major scientific conferences

Gerstner, T.; Meetschen, D.; Crewell, S.; Griebel, M.; Simmer, C. (2002): A case study on multiresolution visualization of local rainfall from weather radar measurements, In H. Pfister and M. Bailey (eds.), *Proc. IEEE Visualization 2002*, IEEE Computer Society Press, 533-536.

Garcke, J.; Griebel, M. (2001): Data mining with sparse grids using simplicial basis functions. In: *Proc. Seventh ACM SIGKDD International Conference on Knowledge Discovery and Data Mining*, 87-96.

Garcke, J.; Griebel, M. (2005): Semi-supervised learning with sparse grids, in Proc. 22th International Conference on Machine Learning, 2005.

Gerstner, T.; Pajarola, R. (2000): Topology preserving and controlled topology simplifying multiresolution isosurface extraction. In Proc. *IEEE Visualization* 2000, IEEE Computer Society Press, 259-266

Griebel, M.; Oswald, P.; Schweitzer, M. (2005): A particle-partition of unity method – Part IV: A p-robust multilevel solver, in M. Griebel and M.A. Schweitzer (editors) Meshfree Methods for Partial Differential Equations II, volume 43 of Lecture Notes in Computational Science and Engineering, Springer, 71-92.

Koster, F.; Griebel, M.; Kevlahan, N.; Farge, M.; Schneider, K. (1998): Towards an adaptive wavelet-based 3D Navier-Stokes solver. In: Hirschel, E.H. (ed.), *Notes on Numerical Fluid Mechanics*, Vieweg.

c) in monographs

Gerstner, T. (1998): Adaptive hierarchical methods for landscape representation and analysis. In: S. Hergarten and H.-J. Neugebauer (eds.): Process modelling and landform evolution, *Lecture Notes in Earth Sciences*, Springer, 75-92.

**II. Non peer-reviewed publications**

a) in scientific journals

b) at major scientific conferences

c) in monographs

Gerstner, T.; Helfrich, H.-P.; Kunoth, A. (2003): Wavelet analysis of geoscientific data, In Dynamics of Multiscale Earth Systems, H.-J. Neugebauer and C. Simmer (Eds.), Lecture Notes in Earth Sciences 97, Springer, 69-88.

Gerstner, T.; Kiefer, F.; Kunoth, A. (2003): Wavelet and Multigrid Methods for Convection-Diffusion Equations, In Dynamics of Multiscale Earth Systems, H.-J. Neugebauer and C. Simmer (Eds.), *Lecture Notes in Earth Sciences* 97, Springer, 123-134.

Koster, F. (2002): Multiskalen-basierte Finite Differenzen Verfahren auf adaptiven dünnen Gittern, Dissertation, Institut für Angewandte Mathematik, Universität Bonn.

Oeltz, D. (2006): Ein Raum-Zeit Dünngitter-Verfahren zur Diskretisierung parabolischer Differentialgleichungen, Dissertation, Institut für Angewandte Mathematik, Universität Bonn.

### 3.3.3.2 Meteorological Institute, University of Bonn

**I. Peer-reviewed publications**

a) in scientific journals

Battaglia, A.; Prodi, F.; Sturniolo O. (2001): Radar multi-parameter analysis for ice cloud. Atm. Res., 59-60, 231-250

Battaglia, A.; Kummerow, C.; Shin, D.-B.; Williams, C. (2003): Toward characterizing the effect of radar bright bands on microwave brightness temperatures.- J. Atmospheric and Oceanic Technology, Vol. 20, No. 6: 856-871.

Battaglia, A.; Ajewole M.O.; C. Simmer (2005): Multiple scattering effects due to hydrometeors on precipitation radar systems. *Geophysical Research Letters*, **32**, L19801, doi:10.1029/2005GL023810,2

Battaglia, A.; Mantovani, S. (2005): Forward Montecarlo computations of fully polarized microwave radiation in non isotropic media.- J. Quantitative Spectroscopy & Radiative Transfer, 95, 285-308.

Crewell, S.; Simmer, C.; Ament, F.; Löhnert, U.; Venema, V.; Feijt, A.; van Meijgaard, E.; van Lammeren, A.; Bloemink, H.; Jolivet, D.; Wendisch, M.; Jäkel, E.; Schmidt, S.; Schröder, M.; Ruhtz, T.; Fischer, J.; Willen, U.; Jones, C.; Quante, M.; Meywerk, J.; Nagel, D.; Krasnov, O.A.; Trautmann, T.; Garcia, S.; Macke, A.; Pfeilsticker, K.; Scholl, T.; Berger, F.; Barfuss, K. (2004): The BALTEX Bridge Campaign - An integrated approach for a better understanding of clouds. Bulletin of the American Meteorological Society, 85(10), 1565-1584, doi: 10.1175/BAMS-85-10-1565.

Czekala, H.; Simmer, C. (2002): On precipitation induced polarization of microwave radiation measured from space. Meteorologische Zeitschrift, 11, 49-60.

Czekala, H.; Crewell, S.; Simmer, C.; Thiele, A.; Hornbostel, A.; Schroth, A. (2001): Interpretation of polarization features in ground based microwave observations as caused by horizontally aligned oblate rain drops. Journal of Applied Meteorology, 40, 1918-1932.

Rose, T.; Crewell, S.; Simmer, C. (2004): A network suitable microwave radiometer for operational monitoring of the cloudy atmosphere. Atmospheric Research 75 (3), 183-200.

Venema, V.; Ament, F.; Simmer, C. (2006a): A Stochastic Iterative Amplitude Adapted Fourier Transform Algorithm with improved accuracy. Accepted in Nonlinear Processes in Geophysics

Venema, V.; Meyer, S.; García, S.G.; Kniffka, A.; Simmer, C.; Crewell, S.; Löhnert, U.; Trautmann, T.; Macke, A. (2006b): Surrogate cloud fields generated with the Iterative Amplitude Adapted Fourier Transform algorithm. Tellus 58A, no 1, pp. 104-120.

Zolina, O.; Simmer, C.; Kapala, A.; Gulev S. (2005): On the robustness of the estimates of centennial-scale variability in heavy precipitation. *Geophysical Research Letters*, 32, L14707, doi:10.1029/2005GL023231

Zolina, O.; Kapala, A.; Simmer, C.; Gulev S. (2004): Analysis of extreme precipitation over Europe from different reanalysis: a comparative assessment. Global and Planetary Change, 44, 129-161.

b) at major scientific conferences

Meetschen, D.; Crewell, S.; Gross, P.; Haase, G.; Simmer, C.; van Lammeren, A. (2000): Simulation of weather radar products from a mesoscale model. Phys. Chem. Earth (B), 25, 1257-1261.

c) in monographs

Heuel, E.-M. (2004): Quantitative Niederschlagsbestimmung aus Radardaten - ein Vergleich von unterschiedlichen Verfahren unter Einbeziehung der statistischen objektiven Analyse. Disseration am Meteorologischen Institut der Universität Bonn.

### II. Non peer-reviewed publications

a) in scientific journals

Zolina, O.; Simmer, C.; Kapala, A.; Gulev S. (2005): Use of indices in characterizing precipitation extremes: a Europen example. *GEWEX Newsletter*, May 2005, 5-6

b) at major scientific conferences

Ament, F.; Crewell, S.; Simmer, C.(2004): Impact of horizontal model resolution on cloud parameters forecasted by a non-hydrostatic mesoscale model. Proceedings of the 14th International Conf. on Clouds and Precipitation, Bologna, 19-23 July, 2004, 1883-1886.

Meetschen, D.; Simmer, C.; Scheuer L. (2005): Warnung vor Starkniederschlägen mittels Niederschlagsradar. Entscheidungsunterstützung in der Wasserwirtschaft - Von der Theorie zum Anwendungsfall, Beiträge zum Tag der Hydrologie 2005, 22./23. März, 2005, Aachen, Forum für Hydrologie und Wasserbewirtschaftung, Heft 10.05 (ISSN 3-937758-68-2), 209-216.

Simmer, C.; Venema, V.; Diederich, M.; Crewell, S.; Schröder, M.; Feijt, A.; Brenguier, J.L. (2004): The BALTEX Bridge Campaigns – a Quest for Continental Cloud Structures. Proceedings of the 14th International Conference on Clouds and Precipitation, Bologna, 19-23 July, 2004, 1742-1745.

Venema, V.; Meyer, S.; Garcia, S.G.; Simmer, C.; Crewell, S.; Löhnert, U.; Trautmann, T. (2004): Ilterative amplitude adapted Fourier transform surrogate cloud fields. Proceedings

of the 14th International Conference on Clouds and Precipitation, Bologna, 19-23 July, 2004, 1761-1764.

Venema, V.; Simmer C. (2005): 3-dimensional surrogate cloud fields with measured structures. EGU General Assembly, Vienna, Austria, 24 - 29 April, no. EGU05-A-08502.

c) in monographs

Battaglia A.; Simmer, C.; Crewell, S.; Czekala, H.; Emde, C.; Marzano, F.; Mishchenko, M.; Pardo, J.; Prigent, C. (2005): Emission and scattering by clouds and precipitation. Chapter in the book "Thermal Microwave Radiation - Applications for Remote Sensing", IEE Electromagnetic Waves Series, London, UK, 2006, edited by C. Mätzler, P.W. Rosenkranz, A. Battaglia and J.P. Wigneron

Battaglia A.; Prodi F.; Porcu F.; Shin, D.-B. (2005): 3D effects in MW radiative transport inside precipitating clouds: modeling and applications. Chapter in the book “Measuring Precipitation from Space: EURAINSAT and the future”, edited by V. Levizzani, P. Bauer and F. J. Turk, Eds., Springer, 113-126, in press

Neugebauer, H.; Simmer, C. (Eds.) (2003): Dynamics of Multiscale Earth Systems. Lecture Notes in Earth Sciences, Springer Verlag, 357p, 2003.

Steinhorst, H., C. Simmer, and H.-D. Schilling (2003): A statistical-dynamic analysis of precipitation data with high temporal resolution. In: Neugebauer and Simmer (Eds.), Dynamics of Multiscale Earth Systems. Lecture Notes in Earth Sciences, Springer Verlag, 337-350.

## 3.4 Project description (goals, methods, work programme)

**Overall goal:**

A general space-time data-based model for precipitation for arbitrary spatial (tens of meters to hundreds of kilometres) and temporal (minutes to months) scales will be developed and validated. The model will allow for the assimilation of a range of observed precipitation information from different data sources with a variety of spatial and temporal resolutions and arbitrary sampling characteristics. The novelty of the tool will be the extension of advanced geostatistical variational data assimilation approaches to correlated and biased input data and its combination with void-filling and structure-preserving features. The model will preserve the temporal correlation structure at subgrid spatial scales. This temporal persistence in rainfall is of crucial importance when using coupled atmospheric-hydrological models, which are affected by spatial variability of accumulated local quantities (e.g. soil moisture storage and runoff production).

The model will be applied to an area covering at least the Rur and Erft catchment starting with the first radar observations in the nineties. Backbone data source of the model will be the Bonn Doppler-X-band radar, which will be extended within the project section by polarisation-diversity. The surrounding DWD C-band Doppler radars (Essen, Frankfurt, Neuheilenbach) will be used to upgrade the radar estimate especially in the more Western and Northern regions of the Rur catchment. Different measurements (rain gauges, micro rain radar, weather radar, satellite measurements) and existing data sets (e.g. REGNIE) will be assimilated in the model by taking the spatial and temporal variability of precipitation explicitly into account. High temporal resolution precipitation models on the point scale will model the smallest scales. The main evaluation period will start in 2008, when the Bonn X-Band radar has been extended to polarisation diversity and also the very high resolution mini radars in the sub-catchments are installed and running. Thanks to the variety of data sources and the much higher quality including its possibility of ad-hoc scans, high spatial and temporal resolution short range observations the radar will provide a perfect data set to perform the data assimilation tasks, to create a multiscale precipitation model from it.

The first phase encompasses (a) the extension of the Bonn X-Band Radar with polarisation diversity including the pertinent algorithms and their evaluation, (b) the speed-up and adaptation to a suit of observation types of an advanced geostatistical variational assimilation tool including biased and correlated observations errors, (c) the adaptation of the surrogate technique for downscaling and void-filling, and (d) a concept to merge the (b) and (c) in a mathematically consistent scheme.

In the next phases the combined scheme will be implemented and the variational part of the scheme further generalized into a nonlinear data assimilation tool employing nonlinear multigrid methods as a numerical solver. The latter allows for the exploration of nonlinearity of the structure functions. Furthermore, new nonlinear sampling and reconstruction theories (Candes et al., 2005) suggest that it is possible to go below the Shannon rate. It would be interesting to further advance these techniques to be able to transfer and apply them to atmospheric data assimilation problems. The downscaling part will be further developed to finer time and space scales. E.g. time-series models like in Steinhorst et al. (2003) will be linked to the spatial surrogates as constraints to guaranty the correct combined spatio-temporal behaviour even on the plot scale. We expect, that transmission monitoring of cell phone links is in place at that time on a large scale, which will allow us to integrate this new information into the assimilation chain. Improvement in the radar rainfall estimates will be achieved by providing physical constraints (e.g. rain/no rain identification) coming form high spatial/temporal satellite observations (mainly Meteosat Second Generation).

The third phase will see the extension of the model to include terrain elevation and possibly all morphological factors which affect the local probability distribution of rainfall (e.g. slope and shape of the relieves, exposition with respect to the direction of perturbation) and to include structures in the droplet size distributions via the disdrometer and micro rain radar measurements enforcing also the inclusion of the vertical variability within rainfall. Besides better characterizing rainfall concerning its impact on soil and vegetation, this will also lead to an improved understanding of the rainfall process and its effect on indirect measurements like radar. Finally, the better characterization of the rainfall pattern will be assessed for different applications in which non-linear processes are relevant (like in a coupled atmospheric-hydrological model or in the evaluation of the beam-filling effect on microwave remote sensing measurements).

**First period:**

- Generation of preliminary precipitation fields (12 months, INS)

A first set of precipitation fields will be generated from available data by composing the measurements of the C-Band radars Essen, Neuheilenbach and Frankfurt of the German Weather service (DWD) and merging them - using standard geostatistical methods (SOA or Kriging) - with the REGNI data set of daily precipitation estimates from rain gauges. This will result in a preliminary product with a temporal resolution of 15 minutes and a spatial resolution of approximately 1 km. The product will be made available for the project sections requiring rainfall data as input.

- Improvement of the SOA precipitation analysis method (6 months, INS)

The SOA method is a geostatistical method which can combine point and areal precipitation measurements (having individual associated errors) such that the error variance is minimized. The currently existing SOA algorithm is relatively slow and its applicability is restricted due to various underlying statistical assumptions which are not fulfilled in practice. Nevertheless, in order to guarantee a first simple model for the experimental data, in the first step, the efficiency of the current SOA algorithm will be improved using a parallel direct solver for the matrix equation. Access to a parallel cluster computer at INS is available.

- Development of a multilevel SOA method (12 months, INS)

A multilevel SOA (MLSOA) method will be developed which allows for correlated and biased observation errors. Using general quadratic functionals, this leads to a linear matrix equation. This matrix equation no longer decouples and thus the system cannot be solved using a backward-substition like in the original SOA approach. Since the system can get very large, standard linear solvers also cannot be applied due to complexity reasons. To solve the matrix equation all-in-one multigrid methods will be employed. To this end, suitable prolongation, restriction and smoothing operators for the matrix equation have to be developed. This way, the computational framework for the application of the MLSOA algorithm will have optimal complexity. The computing times will be comparable to the SOA approach, however, with improved results since the original restrictions are alleviated. Time-dependent behaviour will be integrated into MLSOA in a similar way as in 4D-Var. In addition, the MLSOA method will include more than one areal precipitation field, which is necessary to incorporate measurements obtained by neighbouring operational radars and mini radars.

- Development of a multilevel upscaling method (12 months, INS)

Finally, a multilevel data upscaling method will be developed in which coarse-scale structure functions can be prescribed. To this end, existing adaptive hierarchical finite element and adaptive wavelet methods will be extended and adapted to facilitate upscaling operators which allows to evaluate precipitation fields on arbitrary given coarse scales.

- Upgrade of the Bonn Doppler-X-band radar to polarisation diversity and rainfall algorithm set-up (12 month, MIUB)

The upgrade of the radar to polarisation diversity will be performed by the proposers of MIUB and permanent staff at MIUB together with the provider of the upgrade for the radar. Up-to date polarimetric rainfall algorithms will be implemented and performances of the rainfall estimations will be evaluated.

- Temporal and spatial structure of precipitation (24 months, MIUB)

The spatio-temporal structure of precipitation will be analysed and quantified using a combination of point-like measurements (rain gauges, disdrometers, micro rain radars), high resolution mini rain radars, and the upgraded high resolution Bonn X-Band Doppler radar with polarisation diversity. The structure of rain events will be classified according to typical indices (e.g. generalized fractal dimension, structure functions, power spectra, spatial autocorrelation) and related to weather patterns based on variables of atmospheric state derived from meteorological reanalysis data e.g. large scale rain rates (Over and Gupta, 1994) or CAPE values (Perica and Foufola-Georgiou 1996). This analysis will produce the driving information needed (a) to downscale coarse products to higher resolutions or (b) to fill the usually frequent data gaps caused e.g. by system failures. For both objectives the surrogate method will be applied (see next work package), which enables to reconstruct fields from statistical information of the expected rain fields taking account also of constraints imposed by alternative sparse observations like micro-links or rain gauges.

- Generation and validation of a high resolution precipitation product (12 months, MIUB)

Different data sources will be combined using an interpolation and extrapolation algorithm, which uses ideas from the IAAFT method in preserving spatial and temporal structures on any given scale. We will start with the preliminary product derived by INS in the beginning of the project. Our iterative IAAFT downscaling algorithm will generate a high resolution field that possesses the coarse grained means of the preliminary product and high-resolution power spectrum. This power spectrum can be derived by a fractal extrapolation to small scales of the preliminary field or calculated from high resolution measurements of mini radars. The increment distribution (related to the structure functions used in multifractal statistics) can be computed in the same two ways and will increase the realism of the small scale structures. The inclusion of this statistics will make the algorithm computationally more expensive. Thus, we will study if the improvement justifies its inclusion. On the smallest scale, point measurements can be directly inserted and line integrated values from micro links can serve as additional constraints. Mini radars will provide high resolution fields crucial to validate the downscaling procedure. Data gaps will be filled using structural information based on the atmospheric state for interpolation.

- Development of a concept for merging multilevel SOA with structure-preserving interpolation (6 months INS)

Usual geostatistical methods are generally not able to create structures in data void areas. The surrogate technique to be developed further in the previous step, has this ability. It is highly desirable to develop a consistent pathway to merge both approaches instead of using them sequentially, because only in a holistic approach can optimally exploit the strength of both methods and rule out the possibility of contradictory assumptions. Thus the final endeavour of the first phase is to conceive a mathematically sound concept which combines the downscaling and void-filling properties from IAAFT with the optimizing and upscaling potential from MLSOA within a joint multilevel precipitation analysis tool which can be used on a whole variety of scales.

## 3.5 Role within the Transregional Collaborative Research Centre

This project section is linked to the other project sections that use arbitrarily resolved spatially and temporally distributed precipitation data as a model input (e.g. the project sections in Clusters B, C, and D) on the field to regional scale. The hydrological effect of the derived precipitation fields will be compared with precipitation data using standard interpolation (C2). Synergetic effects do exist with Project Section C3 because the scale analysis of the precipitation structure will be necessary for both project sections. Methodological liwnks exist with D3 on structure assimilation issues

## 3.6 Demarcation from other funded projects of the principal investigator(s)

Institut für Numerische Simulation, Universität Bonn

AQUARadar (DFG GR 1144/15-1) tries to improve quantitative precipitation estimation from radar measurements by exploiting the 3D radar reflectivity data under the assumption that volume integrals give a better quantitative relation with surface rainfall than just taking the measured reflectivity above the observation point. A major point is the reduction of ground-clutter and other non-atmospheric signals from the raw radar data, and the development of methods to deal with large data sets by efficient storage, compression and visualisation techniques. These techniques will be very helpful for the work planned in the TR32, but do not overlap with the geostatistical two-dimensional methods, which will be developed here.

SFB 611 (TP C1) which deals with wavelet methods for PDE-controled optimization problems and SFB 611 (TP C2) which is concerned with robust multigrid methods for PDEs are related but have no direct association with multilevel data assimilation problems.

Projects in the special programs DFG SPP 1145, DFG SPP 1165 and the BMBF focus program mathematics deal with numerical methods in quantum chemistry, nanotechnology and finance, respectively, and are thus mainly unrelated to this project.

Meteorologisches Institut, Universität Bonn

AQUARadar (DFG SI 606/8-1) tries to improve quantitative precipitation estimation from radar measurements by exploiting the 3D radar reflectivity data under the assumption, that volume integrals give a better quantitative relation with surface rainfall than just taking the measured reflectivity above the observation point. Results from the project, which will operate on C-Band radar Karlsruhe, can eventually be used, e.g. to constrain the high-resolution estimates intended in TR32.

SMASS (DFG SI 606/9-1) exploits together with ECMWF the potential of future L-band passive microwave observations from satellites for data assimilation in order to improve soil moisture initialisation in the ECMWF medium range weather forecast model.

DAQUA (DFG SI 606/7-1) develops a method (so-called physical initialisation) to assimilate radar derived precipitation and satellite observations of cloud cover and cloud top-height in order to improve precipitation forecasts from nowcasting to 24 hours.

Graduiertenkolleg 437/3 (DFG) is addressing the relation between rainfall, orography, and river runoff in a region of moderate orography (Sieg catchment) by extending the LM weather prediction model with a routing scheme.

IMPETUS (BMBF-GLOWA 07 GWK 02) concentrates on the combination of information from different satellites over West Africa with the goal to derive a reliable precipitation climatology and to derive a nowcasting scheme for Benin.

AMMA (EU-FP6) executes atmospheric measurements during the West African monsoon in order to validate atmospheric models. The satellite methods derived in IMPETUS are applied also in a comparison project with other partners.

GEOLAND (EU-FP6) retrieves soil moisture estimates from current satellites with passive microwave sensors and compares it with other partners.

SfP 981044 (NATO) analyses the driving forces and the effects of the Atlantic on the generation of extreme precipitation events over Europa and the USA.

HOWISErft (Erftverband, Land NRW) develops a flood warning system based on radar measurements by feeding a commercial hydrological model with the radar data and developing a nowcasting tool based on the radar data.

There is no significant overlap of any of the listed projects with this project section. We want to mention, however, the fruitful cooperation of the project section partners within AQUARadar. It can, however, be expected that results and techniques developed in AQUARadar (also by other groups within AQUARadar) will be beneficial and used. This will especially concern the approach used by the DLR group (Martin Hagen) for the DLR polarized C-band radar.

### 3.7 Auxiliary support for the project

| | 2007 | | | 2008 | | | 2009 | | | 2010 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Funding for staff** | **Salary scale** | **No.** | **Sum €** | **Salary scale** | **No.** | **Sum €** | **Salary scale** | **No.** | **Sum €** | **Salary scale** | **No.** | **Sum €** |
| | IIa | 1 | 58800 | **IIa** | 1 | 58800 | IIa | 1 | 58800 | IIa | 1 | 58800 |
| | IIa/2 | 1 | 29400 | IIa/2 | 1 | 29400 | IIa/2 | 1 | 29400 | IIa/2 | 1 | 29400 |
| | Stud. Ass. | 2 | 24000 | Stud. Ass. | 2 | 24000 | Stud. Ass. | 2 | 24000 | Stud. Ass. | 2 | 24000 |
| | **total:** | **4** | **112200** | **total:** | **4** | **112200** | **total:** | **4** | **112200** | **total:** | **4** | **112200** |
| **Funding for direct costs** | **1000** | | | **1000** | | | **1000** | | | **1000** | | |
| **Small equipment (up to € 10,000)** | | | | | | | | | | | | |
| **Consumables** | 1000 | | | 1000 | | | 1000 | | | 1000 | | |
| **Laboratory animals** | - | | | - | | | - | | | - | | |
| **Travel** | | | | | | | | | | | | |
| **Other** | | | | | | | | | | | | |
| **Fundung for instrumentation (instruments exceeding € 10,000 gross)** | **230000** | | | **200000** | | | | | | | | |

### 3.7.1 Staffing of the project

| | **Name, acad. Title, position** | **Field of research** | **Department of the university or non-university institution** | **Work performed in the project in hours/week (consultancy: C)** | **Salary scale** |
|---|---|---|---|---|---|
| ***Core support*** | | | | | |
| **3.7.1.1 Research assistants (incl.student assistants)** | 1. Battaglia, A., Dr., | Meteorology | Meteorological Institute | 10 | |
| | 2. Gerstner, Th., Dr., | Numerical Simulation | Institute for Numerical Simulation | 3 | |
| | 3. Griebel, M., Prof. Dr., | Numerical Simulation | Institute for Numerical Simulation | 5 | |
| | 4. Simmer, C., Prof. Dr., | Meteorology | Meteorological Institute | 5 | |
| | 5. N.N. (stud. Assist.) | Remote sensing | Meteorological Institute | 8 | |
| | 6. Meetschen, D., Dipl.-Met. | Radar Meteorology | Meteorological Institute | C | |
| | 7. Venema, V., Dr. | Pattern analysis | Meteorological Institute | C | |
| **3.7.1.2 Non-scientific assistants** | 8. Schneider, A. Dr. | | Meteorological Institute | 30 | |
| ***Auxiliary support*** | | | | | |
| **3.7.1.3 Research assistants (incl. Student assistants)** | 1. Adelsberger, Dipl.-Math. | Numerical Simuation | Institute for Numerical Simulation | 41 | IIa |
| | 2. Hartmann, cand. Dipl-Met. | Meteorology | Meteorological Institute | 20.5 | IIa/2 |
| | 3. N.N. | Numerical Simulation | Institute for Numerical Simulation | 15 | SHK |
| | 4. N.N. | Meteorology | Meteorological Institute | 15 | SHK |
| **3.7.1.4 Non-scientific assistants** | | | | | |

**Job description of staff paid from core support for the funding period requested**

1. Battaglia, Dr. A. (MIUB)

Principal investigator and expert in polarimetric radars, microwave radiative transfer, rainfall remote sensing

2. Gerstner, Dr. Th. (INS)

Principal investigator and expertise and support in all questions related to multilevel methods, hierarchical interpolation, visualization and data structures

3. Griebel, Prof. Dr. M. (INS)

Principal investigator and expertise in numerical analysis, multigrid methods, multilevel mlgorithms, data mining and sparse grids

4. Simmer, Prof. Dr. C. (MIUB)

Principal investigator and expertise in remote sensing, precipitation statistics, and mesoscale modelling

5. N.N. (MIUB)

Monitoring the quasi-operational rain monitoring systems including mini radar, micro rain radar, disdrometer and rain gauges operated by MIUB within the SFB/TR

6. Meetschen, Dipl.-Met., D. (MIUB)

Expertise on radarmeteorology and radar data processing.

7. Venema, Dr. V. (MIUB)

Expertise on pattern analysis.

8. Schneider, Dr. A. (MIUB)

Coordination and execution of all technical aspects of the operation of the direct and remote sensing instruments including the extension of the X-Band radar to polarization diversity

**Job description of staff paid from auxiliary support for the funding period requested**

1. Dipl.-Math. Jutta Adelsberger (BAT IIa, INS)

The PhD student will develop the MLSOA algorithm and associated numerical methods for its implementation. She will also combine the developed MLSOA method with the IAAFT technique and implement an efficient multilevel-algorithm. These tasks are very challenging and for their successful realization advanced knowledge and experience in multiresolution analysis and multiscale methods as well as scientific computing are required.

Jutta Adelsberger is currently finishing her diploma thesis at the INS on global weather simulation and has excellent skills in the necessary research fields. Therefore she is the ideal candidate. In order to hold her at the university or to hire a similarly qualified assistant, a full BAT IIa position is required.

2. cand. Dipl.-Met. Peter Hartmann (BAT IIa/2, MIUB)

The PhD-student will investigate the structure of precipitation at the different spatial and temporal scale by the multi-sensor observations. He will adapt the IAAFT methodology to the available datasets (including all possible constraints provided by the rain monitoring systems), evaluate the performances of the downscaling scheme with independent measurements, and compare with other downscaling stochastic methodologies.

Peter Hartmann is currently finishing his master thesis on the evaluation on MicroRainRadar measurements with disdrometer data. He has been working in the US for three month on this topic and is very qualified to perform a PhD study in the framework or precipitation structures.

3. N.N. (SHK, INS)

A substantial amount of programming work, software validation, and post-processing of data for visualization will be accomplished by a student assistant. Furthermore, the will be part of the work of the student assistant.

4. N.N. (SHK, MIUB)

Support by a student assistant is required in the radar data management and in the post-processing of the polarimetric variables needed for radar-based rainfall estimations. He/she will also investigate the potentiality of cell-phone microwave link data by assessing the feasibility of extracting useful point-to-point constraints for the rain fields.

### 3.7.2 Distribution and justification of funding for direct costs (excl. salaries and instrumentation) (by financial year)

| | 2007 | 2008 | 2009 | 2010 |
|---|---|---|---|---|
| **Estimated core support available for direct costs** | 4000 | 4000 | 4000 | 4000 |
| | | | | |
| **Requested funding for direct costs** | 1000 | 1000 | 1000 | 1000 |

(All figures in euros)

**Justification for auxiliary support for direct costs (as above)**

Small Equipment: - none -

**Consumables:** For operating the mini radar and the MicroRainRadar in the field sites annual costs for power and minor repairs of EUR 1000 are requested.

**Other Costs** - none -

### 3.7.3 Instrumentation (instruments exceeding € 10,000 gross and vehicles)

| | Requested for financial year | | | |
|---|---|---|---|---|
| | 2007 | 2008 | 2009 | 2010 |
| **Total** | 230 | 200 | 0 | 0 |

(All prices in thousands of euros incl. VAT and transportation costs, etc.)

**Justification for auxiliary support for instrumentation**

The Bonn X-Band Doppler Radar will be extended to polarisation diversity to allow for improved quantitative precipitation estimation as detailed in the work plan. According to proposals by the leading manuifacturers/sellers (GEMATRONIK/Neuss and GAMIC/Aachen) the total prize will be EUR 400000,- The extension will start in 2007 and finalisation is expected in 2008, thus the cost are splitted between both years. A mini x-band radar to be operated on the field site of FZ Jülich will be bought in 2007 from METEK/Hamurg (EUR 30000) in order to study the small scale precipitation patterns for the down scaling to the 100 m scale.