Major activities, year 3

In this report major activities in the third year of the project are presented, covering the period May 1, 2010 to April 30, 2011.

The prior reports on major activities are included at the end of this document

The major activities in the third year of the project included the following

- Study on characterizing the properties of microphysical parameterization and the related data assimilation problem using a 1D lagrangian cloud resolving model with MCMC (Markov Chain Monte Carlo) data assimilation algorithm.
- Developing a simplified tutorial program for MCMC method in Matlab
- PhD student academic training
- Presentations
- Publications

Specifically

a) The study on *Quantifcation of Cloud Microphysical Parameterization Uncertainty using Radar Reflectivity* involved performing numerous experiments with the MCMC algorithm in which different scenarios with the simulated observations and their error characteristics were explored. The experiments also included substantial effort on extracting properly the information on process activities in the cloud resolving model, as the model was not originally designed for this purpose. The computations were performed on the new PC , which was purchased at RSMAS/UM with the support from this NSF project.

b) The study results were summarized in a manuscript which has been recently submitted for publication in Monthly Weather Review : *Quantifcation of Cloud Microphysical Parameterization Uncertainty using Radar Reflectivity,* M. van Lier-Walqui, T. Vukicevic and D. Posselt.

c) The study results were presented at the 15-th Conference on Integrated Observing and Assimilation Systems for the Atmosphere, Oceans and Land Surface (IOAS-AOLS), at AMS Annual meeting, 2011. Graduate student, Marcus van Lier-Walqui, had poster presentation at the conference.

d) Marus van Lier-Walqui passed written PhD qualifying exam (“comps”) in fall 2010

e) Marcus also completed 4 graduate courses at RSMAS/UM and attended Advanced School on Data Assimilation in Bologna, Italy (June 7-11, 2010) . The summer school was co-directed by PI Vukicevic.

f) Van Lier-Walqui wrote a simplified tutorial Markov chain Monte Carlo program in Matlab to facilitate the investigation of basic characteristics of the MCMC algorithm as well as to serve as an instructional tool for MCMC methods. The code inverts parameters of a number of user-selectable functions, including a simple, static value inversion, damped harmonic oscillator, and one-dimensional non-linear advection. The code can be easily modified to use any function desired by the user. In addition, the code allows for a simple specification of observation types as well as observational error assumptions via an error covariance matrix. Currently, the code uses the Metropolis-Hastings algorithm to sample the posterior parameter distribution. Future modifications may include samplers such as the Gibbs sampler, slice sampler or advanced sampling techniques such as adaptive Metropolis, delayed rejection or nested sampling.

g) Vukicevic co-authored on study and manuscript with D. Posselt of University of Michigan, entitled "*Robust Characterization of Model Physics Uncertainty for Simulations of Deep Moist Convection*. ". Published in 2010: *Mon. Wea. Rev.*, **138**, 1513–1535. ; doi: 10.1175/2009MWR3094.1

Major activities in the second year of the project were in the following areas

1. Mesoscale model simulations, verification and sensitivity to modeling of radar reflectivity

2. Evaluating the data assimilation approach using MCMC with 1D cloud resolving model

3. Graduate student training

1. Model simulations and verification with radar reflectivity observations

In order to develop an optimal approach to correcting deficiencies in bulk explicit parameterizations of precipitation processes in mesoscale forecasting by radar data assimilation, it is necessary to first evaluate model performance relative to radar observations and to diagnose model errors and an optimal measure of distance from these observations to use in the data assimilation. The study so far includes model verification on examples of IHOP (International H2O Project). In the first year we performed simulations of a sequence of storms during June 13 2002 in Central Great Plains. The simulations were performed with Advanced Research WRF (ARW, Skamarock et al. 2005; Wicker and Skamarock 2002; Michalakes et al. 1998) community model with 4-km horizontal grid spacing and 51 vertical levels and three available microphysics options. The results of verification of these simulations with observations including radar reflectivities using diagnostics such as histograms and 3D contingency tables in the radar reflectivity space indicate that the model forecast has extremely low skill relative to radar observations at point-by-point bases. For example, the 3D contingency tables in the binned reflectivities for 3 different microphysical parameterizations, have shown that the model does not agree with the observations at more than 90% of the points in 3D domain only few hours into the forecast, despite almost perfect agreement at the initial time. The agreement at the initial time results from initialization with LAPS analysis which includes observed reflectivities. This initialization provides "hot start" to the forecast. The "hot start" initial model data include cloud and precipitation hydrometeor fields with adjusted wind, humidity and temperature fields. In contrast to the point-vise diagnostics which show low forecast skill, comparison of 2D reflectivity horizontal cross-sections between the model and LAPS analysis indicated that the model captures some general features of the observed evolution of the storm system. The results of this analysis were presented at the 19th Conference on Numerical Weather Prediction in June of 2009. These initial results indicated that the model resolution should be increased for better comparison with the reflectivity observations.

In the second year of the project analysis and model simulations of two IHOP events have been performed using higher spatial resolution. The events occurred during June the 13-14 and 16-17 of 2002. The three different microphysical schemes were used as before, including Lin, WSM6 and Schultz. The model simulations were compared to gridded radar reflecitivty analyses that were produced by LAPS at the same spatial resolution as the model grid. To test sensitivity of verification diagnostics to the modeling of reflectivity from the forecast model background fields, we employed three different reflectivity models. These are commonly used empirically-based synthetic reflectivity calculations referred to as 'Kessler' and 'RAMS' and physically based radar model which includes options for different hydrometeor distribution parameters and careful modeling of radar measurement's geometry, designated SynPolRad . This radar model was developed at the DLR-Institute of Atmospheric Physics, Oberpfaffenhofen, Germany, by M. Pfeifer and collaborators (Pfeifer et al. , 2008) for studies in radar meteorology and for mesoscale forecast model validation. We have acquired the model from the developers by contact through Prof. Katja Frierdich of department of Atmospheric and Oceanic Sciences at CU, Boulder .

2. Evaluating the data assimilation approach using MCMC with 1D cloud resolving model

In the second year of the project Vukicevic co-authored on study and manuscript with D. Posselt
of University of Michigan, entitled "Robust characterization of model physics uncertainty for simulations of deep moist convection (Posselt and Vukicevic, 2010. *J. Atmos. Sci, early on-line release*.). The study addresses properties of relationship between microphysics parameters and remote sensing observations in the context of data assimilation. The study abstract is as follows: *In this study, we seek to understand the functional relationship between model physics parameters and model output variables for*

the purpose of (1) characterizing the sensitivity of the simulation output to the model formulation and (2) understanding model uncertainty so that it can be properly accounted for in a data assimilation framework. We employ a Markov chain Monte Carlo algorithm to examine how changes in cloud microphysical parameters map to changes in output precipitation, liquid and ice water path, and radiative fluxes for an idealized deep convective squall line. Exploration of the joint PDF of parameters and model output state variables reveals a complex relationship between parameters and model output that changes dramatically as the system transitions from convective to stratiform. Persistent non-uniqueness in the parameter-state relationships is shown to be inherent in the construction of the cloud microphysical and radiation schemes, and cannot be mitigated by reducing observation uncertainty. The results reinforce the importance of including uncertainty in model configuration in ensemble prediction and in data assimilation, and indicate that data assimilation efforts that include parameter estimation would benefit from including additional constraints based on known physical relationships between model physics parameters in order to render a unique solution. Also the results suggest that using observations which are more directly sensitive to the microphysics such as radar observations should be beneficial to the results of data assimilation which include the effect of microphysics.

Consistency of the results in this study with the known relationships between the cloud microphysical processes and with the relationship between the properties of remote sensing types of observations with respect to these processes, suggest that the 1D-cloud resolving model that was used in the study is suitable for further analysis of data assimilation approach for purpose of improving the microphysical parameterizations. Specifically, because the 1D model is already imbedded within very accurate and fully nonlinear data assimilation algorithm (MCMC - Markov Chain Monte Carlo) the analysis of the data assimilation results using the radar reflectivity observations with this modeling system would provide comprehensive evaluation of properties of the data assimilation solution with respect to the parameterized microphysical processes. Such evaluation would be infeasible with a 4D modeling system but is needed in order to understand constraints under which a feasible data assimilation algorithm should be applied, such as 4DVAR. For example, understanding of the conditions that would render a posterior pdf (probability density function) unimodal is highly desirable. These conditions are driven by the modeled relationship between the parameterized microphysical processes and by the observations of radar reflectivity including temporal resolution, length of assimilation window and integrals used to define the cost function. The progression of the posterior pdf under variable conditions could be investigated only by analysis of the full pdf solutions as shown in Posselt and Vukicevic (210). Motivated by this approach, the new activity in the project in the second year involved implementation of the 1D model and MCMC algorithm at UM by graduate student van Lier-Walqui and diagnostic analysis of the microphysical processes in the model and simulation of the reflectivity from this model solution. The results are described in the summary of major findings.