Draft Feb. 2009: Modified August, 2009 (WAP)

A GPM-DOE Midlatitude Continental Convective Clouds Experiment (MC^{3}E)

Walter A. Petersen[1], Steven A. Rutledge[2], Mathew R. Schwaller[3]

[1]NASA GPM Ground Validation Science Manager, NASA-MSFC
[2]GPM GV Science Panel member, Colorado State University
[3]NASA GPM Ground Validation Project Manager, NASA GSFC

With contributions from:
PMM Science Team MC3E Working Group

1. INTRODUCTION

To improve the fidelity of radiometer-based rainfall estimates over land at short temporal and spatial scales, the Global Precipitation Measurement mission (GPM) requires development of physically-based passive microwave (PMW) precipitation retrieval algorithms anchored by dual-frequency precipitation radar (DPR) drop size distribution (DSD), hydrometeor profile and rain rate retrievals. Emphasizing this need, the 2nd GPM Ground Validation White Paper (Kummerow and Petersen, 2006; hereafter GVWP) outlined the many significant challenges involved with the development and validation of these algorithms. To broadly paraphrase the GVWP, PMW algorithm development/validation over land requires not only an improved understanding of cloud and precipitation microphysics (particularly in the ice and mixed phases), but an improved representation of microphysical processes/properties (at the bulk and particle scales) in relevant cloud and/or empirical models- to include improved formulation of the radiative transfer occurring in a variable background of land-surface emissivity. Considering that 1) precipitation estimates made by the GPM satellite constellation will rely most heavily on PMW and combined DPR/PMW retrieval algorithms; 2) there are currently no robust physically-based PMW precipitation retrieval algorithms available for use over land[1]; and 3) GPM objectives ascribe considerable importance to making accurate measurements over land where people live, water resources are managed, and flooding occurs; the ability to accurately retrieve precipitation over land using combined DPR/PMW and or PMW-only algorithms, especially those areas not covered by radar and/or rain gauge networks, is critical to the overall success of GPM. The proposed GPM GV effort thus devotes significant effort and resources to improving the basic understanding required for developing and validating physically based PMW algorithms over land.

One key component to the successful validation of PMW precipitation retrieval algorithms will be the coincident "calibrating" measurements provided by the GPM core satellite Ka/Ku band Dual-frequency Precipitation Radar (DPR).. However, while a physically-based rainfall retrieval algorithm currently exists for the single frequency (Ku) Precipitation Radar on TRMM, new rainfall and attenuation correction algorithm development will need to be completed to take full advantage of the multi-frequency

[1] Here we distinguish between predominantly empirical algorithms currently in use, and "robust" implies fully developed and validated.

DPR capabilities. Hence development and validation of DPR precipitation retrievals also directly influences the successful refinement and validation of PMW retrieval algorithms.

As an important component of PMW and DPR algorithm development, the GVWP also acknowledges the fundamental role that cloud-resolving models (CRMs) play in the development and testing of such algorithms. Via creation of realistic synthetic datasets CRMs provide a virtual testbed by which to examine difficult-to-observe quantities and perform sensitivity studies critical to PMW measurement of precipitation (e.g., the presence and relative fractions of cloud, rain and ice water) and other parameters such as precipitation vertical profile, and associated latent heating rates. However, it is also understood that CRMs have weaknesses. For example, to adequately simulate clouds of a given environment CRMs require well-constructed, quality forcing datasets. Even given a perfect "forcing" dataset, model physics are not perfect and hence prior to using model-simulated microphysical fields for testing microwave precipitation retrievals, the CRMs require robust observational validation of microphysical and kinematic quantities for each simulation. Here empirical datasets derived from coincident airborne sampling become another key input to the development of both the CRMs and robust DPR and PMW algorithms. The airborne datasets will provide high resolution details to advance physics in the algorithms but also provide an important source of microphysical process truth to the models such that the models should also improve. Collectively, this feedback loop should provide a more useful satellite simulation tool for testing the algorithms.

Put succinctly: *GPM GV activities must vigorously address the issue of physically-based PMW, DPR, and combined PMW-DPR precipitation retrievals along with validation of CRMs, with special emphasis placed on over-land retrievals, and must do so early in the pre GPM-launch phase.* By extension, this activity requires 1) the collection of new observational datasets that extend and improve current microphysical descriptions of the 3-D distribution and character (e.g., sizes, phases, precipitation rates etc.) of both cloud and precipitation particles; and 2) observational datasets suitable to initialize/force our best CRMs and to provide robust statistical verification of the simulated clouds and precipitation. Arguably, these activities should also culminate in the clear establishment, early-on, of the capability/fidelity/limitation of CRMs to support precipitation retrieval algorithm development. Herein we propose to accomplish the aforementioned requirements via joint research collaboration between NASA GPM and the DOE ARM program in the form of an intensive field campaign, the Mid-latitude Convective Clouds Experiment (MC^{3}E). We propose to conduct MC^{3}E during the late spring/early summer of 2011 within the ARM Southern Great Plains (SGP) site in south-central Oklahoma (near the center of the CASA X-band radar network 60 km southwest of Norman). Importantly, this site is within the field of view of *both* the TRMM PR/TMI[2] and CloudSat platforms. Extensive analysis of data collected in MC^{3}E will follow the observational campaign.

2. SUMMARY OF DOE ARM INTERESTS AND SCIENCE QUESTIONS

[2] Assuming TRMM and CloudSat are both still operational in 2011- which current projections suggest.

The primary goal of the ARM Program is to improve the treatment of cloud and radiation physics in global climate models in order to improve the climate simulation capabilities of these models. Specifically, the ARM science component addresses the question: How do radiative processes interact with dynamical and microphysical processes to produce cloud feedbacks that regulate and/or force climate change? The ARM program cannot fully address this question without considering the role that convective clouds and convective parameterization play within global climate models (GCMs). As an important part of this consideration GCMs must adequately represent the role that precipitation plays as a sink of total water in the atmospheric column; a contributor to the energy balance through latent heating effects, and a feedback on the local environment impacting the subsequent formation of clouds. Accordingly, CRMs verified against observational datasets, are the main approach of the GEWEX (Global Energy and Water-Cycle Experiment) Cloud System Study (GCSS) in its quest to study the large-scale role of clouds.

To this end, DOE-ARM is proposing to conduct the MC^{3}E during the late spring/early summer of 2011 in order to collect a comprehensive dataset on clouds, precipitation and other environmental parameters. The goal is to provide new and meaningful information on the physical processes that act in continental convective cloud systems through an integrated data analysis approach. The dataset from (MC^{3}E) will be applied in a comprehensive comparison with a host of CRM simulations in an effort to evaluate continental convective parameterization in large-scale models and to improve these parameterizations.

DOE-ARM has identified eight specific elements of convective parameterization that are targeted for improved understanding and quantification: 1) Pre-convective environment, 2) Convective Initiation, 3) Updraft/Downdraft Dynamics, 4) Condensate Transport/Detrainment, 5) Precipitation/ Cloud microphysics, 6) Influence on environment, 7) Influence on Radiation and 8) Large-scale forcing. Related to these elements, five ARM science objectives are identified for MC^{3}E (many these are clearly synergistic with GPM interests):

(1) Improve the parameterization of convective cloud systems and precipitation physics in numerical models.

(2) Validate cloud-resolving model simulations using unprecedented remote sensing observations of convective cloud systems.

(3) Observe 3-D cloud and precipitation microphysics and kinematics in deep convective cloud systems and their associated anvil clouds.

(4) Determine radiative and latent heating rate profiles in precipitating cloud systems

(5) Evaluate the performance of state-of-the-art radar systems for future ARM use.

3. PROPOSED GPM MC^{3}E SCIENCE OBJECTIVES

The GPM and ARM interests discussed in Sections 1 and 2 provide motivation for the design of a synergistic, multi-agency, process-oriented field project that addresses issues related to observations over land of cloud and precipitation processes (including latent heating), cloud modeling, and the construction of both PMW and DPR precipitation retrieval algorithms. The field campaign observations will provide both the DOE-ARM and NASA-GPM communities a means to further establish linkages between macro and microphysical characteristics of precipitating clouds and their associated radiative characteristics as sensed by passive and active microwave instruments deployed on the ground by ARM, on current orbiting NASA satellite platforms such as TRMM and CloudSat, and on the NASA GPM core and constellation satellites. Relative to GPM ground validation implementation, this field project will also provide a framework to directly test the logistics, instruments and methods applied for GV design. Specific to GPM, but synergistic with DOE-ARM MC^{3}E goals, GPM objectives for the MC^{3}E field campaign include:

(1) Collection of cloud microstructures (cloud water, cloud ice, liquid, mixed and solid precipitation phases), particle sizes and shapes with size distributions, high resolution melting layer characteristics, rainfall rates, and aerosol characteristics (e.g., CCN and IN concentrations to the extent possible) in a mid-latitude land environment during the varying "regimes" of the boreal spring and summer transition under the TRMM and CloudSat fields of view.
(2) Evaluation of the core complement of GPM GV instrumentation (aircraft, radars, profilers, disdrometers etc.) to specifically include sampling/measurement methodologies and assessment of associated error characteristics as applied to mid-latitude temperate-climate precipitation measurements.
(3) Quantification of surface radiative (multi-channel microwave), sensible and latent heat fluxes (including soil moisture) to support coupled LSM/CRM modeling.
(4) Construction of accurate large-scale forcing environments for CRM simulations (i.e., remove the issue of quality forcing datasets as an issue for the accuracy of the CRM)
(5) Testing of CRM simulation fidelity via intensive statistical comparisons of simulated to observed cloud properties and latent heating fields (e.g., using radar and ARM-SGP sounding array data) in a variety of case types (leveraging seasonal transition in regimes over Oklahoma).
(6) Further establishment of CRM space-time integrating capability for quantitative precipitation estimation.
(7) Supported by (1-6) development and refinement of a physically-based GPM passive microwave retrieval algorithm for use over land (this objective could also test empirical approaches).
(8) Supported by (1-6) and use of ground-based (GPM-GV) and airborne (HIWRAP or APR2) Ku-Ka band radars with other available radar frequencies (S, X, W etc.) and CRM simulations, further develop/refine GPM DPR attenuation correction and precipitation retrieval algorithm.

4. PROPOSED MC^{3}E FUNDING AND FIELD OBSERVING FACILITIES (GPM, DOE)

ARM-DOE proposes to allocate significant ground-based field deployment funds for MC^3E (i.e., independent of airborne expenditures). Currently the NASA GPM GV Project Office (Dr. M. Schwaller) will support NASA ground (e.g., fine-scale disdrometer network, radar deployments) and/or airborne observational infrastructure during MC^3E in FY2011, and limited additional support for follow-on quality control and data analysis in FY2012. Critical additional support for NASA participation will be requested through NASA Precipitation Sciences (Dr. Ramesh Kakar). These resources will be used in MC^3E primarily to cover remaining costs associated with the NASA GPM aircraft component (and associated instrumentation). Funds for analysis of related datasets could be competed as part of the selection of the NASA Precipitation Measurement Science Team.

Relative to *both* DOE and GPM science objectives deployment of the following instrumentation[3] is highly desirable [funding source in brackets]:

Ground-Based:

1. Radar Systems:
    a. Scanning multi-Doppler, dual-polarimetric Ka-Ku (possibly W) bands (NASA GPM GV Ka/Ku pair or like platform) [NASA]
    b. CASA IP1 X-band network [DOE-ARM]. Note, this assumes that the scanning strategy can be modified to suit MC3E objectives.
    c. Ka/W band scanning/vertically pointing radars [DOE-ARM][3]
    d. N-POL S-band dual-polarimetric Doppler radar [NASA]; KOUN-or other C/X-band scanning radars possible.
2. 5-7 Station radiosonde (8/day launch) and enhanced surface network for model forcing [DOE-ARM]
3. High resolution video/optical disdrometer and rain gauge network observations: Deployment of a D-scale disdrometer network (18-36 disdrometers total) capable of resolving variations in rain rate type, intensity, and size distributions (e.g., D_0) on scales 1 - 5 km (order of the GPM footprint) within an area of ~25 km^2, within the CASA network, and under optimal coverage of ground multi-parameter radars [NASA + UCLM].
4. Two 915 MHz profilers currently being deployed within CASA coverage [DOE-ARM].
5. NOAA-ESRL S-band profiler [NASA]
6. Surface Energy Flux/Eddy Correlation Flux, Surface Bowen Ratio (tower currently located in domain) [DOE-ARM][3].

Airborne (2-Aircraft):

1. In-situ microphysics: 1-D, 2-D PMS particle suite plus IN counter and aerosol probes (UND Citation). [NASA].

---

[3] It is likely that DOE-ARM will provide even more surface and radar instrumentation, but this is still TBD.

2. High altitude satellite simulator (NASA ER-2) with Ka/Ku Radar (HIWRAP or modified APR-2), PMW radiometers (10-183 GHz; AMPR + CoSMIR). [NASA]

Spaceborne (multi-satellite target of opportunity):

1. Tropical Rainfall Measurement Mission Satellite (TRMM): The TRMM satellite is currently still forecast to be operational at the time of MC3E. As such, PR, TMI, VIRS and LIS data will be available over the proposed location of the field campaign (which will be south of 36ºN).
2. NASA A-Train (CloudSat, Calipso, Aqua etc.): Combined cloud-radar, passive microwave and lidar.
3. NOAA Polar Orbiters (AMSU-A/B, MHS) and SSM/I: Passive microwave remote sensing extending to 183+ GHz.
4. GOES VIS/IR
5. GPM integrated water vapor

The field campaign will leverage all other TBD instrumentation in the vicinity where it is possible and makes sense to do so via collaboration with other investigators/activities in Oklahoma (ARS, NSSL, OU). Initial contact has been made with the Norman groups via GPM GV and DOE. More input/work is needed to identify and solidify these collaborations. Regardless of external funding, it is expected that the KOUN dual-polarimetric NEXRAD will be operational and scanning during MC3E.