Title: Vertical Structure of Precipitation Retrieved from Multi-Frequency Profiling Radars for Validating Satellite-based Precipitation Products

Type of Report: Year 2 Progress Report

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Overall Project Objective
Analyze vertically-pointing profiler and polarimetric scanning radar observations to quantify the vertical and spatial structure of raindrop size distributions (DSDs).

Overall Project Methodology
To meet the overall project objective, this project was divided into two themes:

Theme #1: Retrieving DSDs from Vertically Pointing Profiling Radars
Analyze multiple years of profiler observations from Darwin, Australia, and California to produce a data base with tens-of-thousands of vertical air motion and raindrop size distribution (DSD) profiles in Tropical and mid-latitude rain regimes.

Theme #2: Retrieving DSDs Parameters using Polarimetric X-band Scanning Radars
Analyze multiple years of X-band polarimetric radar observations from the Hydrometeorological Testbed (HMT) campaigns to study the spatial and temporal variability of DSD parameters around the vertically-pointing profilers.

Accomplishments for Year 2
The progress for this project is divided into its two themes.

Theme #1: Retrieving DSDs from Vertically Pointing Profiling Radars

The 50-MHz and 920-MHz profiler spectra from approximately 30 rain events from 2005 and 2006 have been processed to produce data files containing DSD estimates and vertical air motion estimates. An ensemble of DSD models were used to estimate the DSD so that each retrieval contains the best estimate plus an uncertainty (Williams and Gage, 2009).

The ensemble DSD estimates were made available to PMM scientists Drs. V.N. Bringi, Ana Barros, and Ziad Haddad for their NASA sponsored research. After getting their feedback, selected data files will be made available to the general public through the NOAA HMT web page and all of these data files are being made available to all PMM scientists through a NASA PMM web page. The details of the distribution are still being configured, but should be finalized by the end of this year's reporting period.

NOAA HMT web pages: One reason for putting data on the NOAA HMT web page is that part of the funding for this project came from the NOAA USWRP program through the HMT program. Since the HMT web page is a public web page that provides data and images to all visitors without secure access, images of all data products will be made available but only selected ASCII data products will be placed in the public domain. Data files will be made available to the general scientific community on a case-by-case basis.

NASA PMM web pages: I'm in contact with NASA to determine which of two web sites would be the best place to host these data products. The two options are the PMM GV web page (http://gpm.gsfc.nasa.gov/groundvalidation.html) or the PMM Science Team web page (http://pmm.gsfc.nasa.gov/New2_index.html). I'm leaning toward the PMM GV web page because these retrievals are part of the GV data sets needed to help validate and improve models and algorithms.

Other activities during this second year included: Working with Dr. Olivier Prat and Prof. Ana Barros at Duke University, we used vertically pointing profiler DSD retrievals to verify Dr. Prat's model describing raindrop break-up and coalescence processes in stratiform rain. Working with Dr. Thymios Nikolopoulos at the University of Iowa, we combined profiler observations with surface disdrometer and rain gauge observations to study the temporal variability of precipitation and Z-R relationships.

Theme #2: Retrieving DSDs Parameters using Polarimetric X-band Scanning Radars

Working with Dr. Peter May at the Australian Bureau of Meteorology, we used the DSD retrievals from this project and scanning polarimetric scanning C-band radar (C-POL) differential reflectivity to investigate the uncertainties of C-POL retrieved median raindrop diameter (Dm) estimates. This work appeared in Williams and May (2008).

The X-POL differential reflectivity (Zdr) data collected from the NOAA HMT during the 2005-2006 and 2006-2007 winter seasons were corrected for differential attenuation. Surface disdrometer observations were used to adjust a power-law relationship relating Zdr to median mass raindrop diameter (Dm). Then, horizontal grid maps of Dm were generated for each low-elevation scan with a 250 meter by 250 meter resolution. In year three of this project, the spatial variability of these Dm estimates will be investigated.

PMM Working Groups

In addition to performing the duties outlined in the proposed work plan, the PI also participated in three PMM Working Groups: the DSD Working Group, the Canadian CloudSat and Calypso Validation Project (C3VP) Working Group, and the GPM Ground Validation (GV) Working Group.

Publications

During this second year of this project, the following manuscripts were published:

Nikolopoulos, E. I., A. Kruger, W. F. Krajewski, **C. R. Williams**, and K. S. Gage, 2008: Compariative scaling analysis from two vertically pointing radars, an optical disdrometer and a rain gauge. *Nonlinear Processes in Geophysics*, 15, 987-997.

Prat, O. P., A. P. Barros, and **C. R. Williams**, 2008: An intercomparison of model simulations and VPR estimates of the vertical structure of warm stratiform rainfall during TWP-ICE, *J. Appl. Meteor. Climatol.*, 47, 2797-2815.

Williams, C.R. and P.T. May, 2008: Uncertainties in profiler and polarimetric DSD estimates and their relation to rainfall uncertainties. *J. Atmos. Oceanic Technol.*, 25, 1881–1887.

Williams, C. R., and K. S. Gage, 2009: Raindrop size distribution variability estimated using ensemble statistics. *Ann. Geophys., 27, 555-567, www.ann-geophys.net/27/55/2009/.*

Newman, A. J., P. A. Kucera, **C. R. Williams**, L. F. Bliven, 2009: Snowflake size spectra retrieved from a UHF vertical profiler. *J. Atmos. and Oceanic Technol.*, 26, 180-199.

The following manuscripts were accepted for publication:

Bringi, V. N., **C. R. Williams**, M. Thurai, and P. T. May, 2009: Using dual-polarized radar and dual-frequency profiler for DSD characterization: A case study from Darwin, Australia. *J. Atmos. and Oceanic Technol.*, accepted.

Kim, D.-K, K.R. Knupp, and **C.R. Williams**, 2009: Airflow and precipitation properties within the stratiform region of Tropical storm Gabrielle during landfall. *Mon. Wea. Rev.*, accepted.

Tokay, A., P. Hartmann, A. Battaglia, K.S. Gage, W.L. Clark, and **C.R. Williams**, 2008: A field study of reflectivity and Z-R relations using vertically pointing radars and disdrometers. *J. Atmos. and Oceanic Technol.*, accepted.

The following manuscript was submitted for publication:

Lerach, D. G., S. A. Rutledge, **C. R. Williams**, and R. Cifelli, 2009: Vertical structure of convective systems during NAME 2004. *Mon. Wea. Rev.*, submitted.

Budget Information

This project receives support from NASA and from NOAA. Therefore, the budget is broken into two columns for each year.

	Year 1		**Year 2**		**Year 3**	
	NASA	NOAA	NASA	NOAA	NASA	NOAA
Salary/Fringe/Computer Support						
C.R. Williams, 6 months	$63k		$67k		$71k	
C.R. Williams, 2 months				$22k		$22k
S. Matrosov, 2 months		$28k				
Travel – Domestic	$ 3k	$ 4k	$ 2k	$ 8k	$ 4k	$ 4k
Travel – Foreign	$ 0k	$ 4k	$ 5k	$ 8k	$10k	$ 0k
Other Direct Costs	$10k	$ 6k	$ 3k	$14k	$ 8k	$ 6k
Total Direct Costs	$76k	$42k	$77k	$52k	$93k	$32k
Indirect Costs (CIRES Overhead)	$20k	$10k	$20k	$10k	$24k	$ 6k
Indirect Costs (NOAA Overhead)						$10k
Total per Agency	$96k	$52k	$97k	$62k	$117k	$48k

Potential Contribution to NASA PMM Announcement of Opportunity (ROSES)

In response to the NASA PMM announcement of opportunity (ROSES), I intend to request funding to participate in the Midlatitude Continental Convective Cloud Experiment (MC^3E) that is scheduled to be held in Oklahoma in April through May 2011. This two month NASA PMM and DOE ARM experiment will use aircraft, scanning radars and surface instruments to sample the life cycle of convective systems and will include: cloud initiation, updraft and downdraft structure, hydrometeor evolution with time and location within the updraft, and partition of condensate into precipitation and outflow (anvil cloud).

I would like to deploy a dual frequency vertically pointing profiler system with one profiler operating at S-band (2.8 GHz) and the other operating at UHF (449 MHz). The 449-MHz profiler will enable retrieving the vertical air motion and the 2.8-GHz profiler will enable retrieving the DSD. These profilers will be deployed at a DOE ARM site that will have 915-MHz, 9.4-GHz, and 94-GHz vertically pointing radars.

Initial conversations with NASA PMM Ground Validation (GV) program and with NOAA ESRL suggest that leveraging of funds is possible. While further discussions are necessary, estimated costs and possible funding sources are:

- 2.8-GHz profiler – $75k – supported by NASA PMM GV
- 449-MHz profiler – $100k – supported by NOAA (USWRP)
- Analysis – $100k/year – supported by NASA ROSES