Date:	20 August 2003
NASA Grant #:	NAG5-9753
CU Project #:	1532925
Title of Grant:	Retrieval of hydrometeor drop size distributions from TRMM Field Campaign profiler Doppler velocity spectra observations
Type of Report:	Summary of Research
PI:	Christopher R. Williams
Organization:	University of Colorado at Boulder Office of Contracts and Grants East Campus Box 572 3100 Marine Street, Room 481 Boulder, CO 80309-0572
Co-I:	Kenneth S. Gage
Period Covered:	1 July 2000 to 30 June 2003

Executive Summary

Consistent with the original proposal and work plan, this project focused on estimating the raindrop size distributions (DSDs) retrieved from vertically pointing Doppler radar profilers and analyzing the relationship of the retrieved DSDs with the dynamics of the precipitation processes. The first phase of this project focused on developing the model to retrieve the DSD from the observed Doppler velocity spectra. The second phase used this model to perform DSD retrievals from the profiler observations made during the TRMM Ground Validation Field Campaigns of TEFLUN-B, TRMM-LBA, and KWAJEX. The third phase of this project established collaborations with scientists involved with each field campaign in order to validate the profiler DSD estimates and to enable the profiler retrievals to be used in their research. Through these collaborations, the retrieved DSDs were placed into context with the dynamical processes of the observed precipitating cloud systems.

Accomplishments

One way to measure the accomplishments of this project is to count the number of reviewed publications and conference presentations supported by this funding. Over a three year period, this grant partially supported:

* *12 Reviewed Publications* and
* *42 Professional Presentations.*

The reviewed publications are listed in Appendix A and the professional presentations are listed in Appendix B. These formal accomplishments can be divided into three main research themes:

* Estimating the raindrop size distribution (DSD),
* Analyzing the precipitation vertical structure, and
* Interpreting the dynamics of precipitating cloud systems.

Estimating the Raindrop Size Distribution (DSD)

Vertically pointing radar profilers are Doppler radars that record their observations with Doppler velocity spectra. This data collection procedure estimates the intensity of the returned signal over

a whide range of Doppler velocities. The first goal of this project was to convert these intensities at each Doppler velocity step into the appropriate number of raindrops at different raindrop diameters. This conversion translates the observed reflectivity Doppler spectra into a distribution of raindrops.

A model was developed that converts the observed Doppler velocity spectrum into a raindrop size spectrum and is described in detail in Williams (2002). This model uses the observed Doppler velocity spectrum as the input and produces an estimate of the raindrop size distribution (DSD) *as well as* the ambient air motion. The DSD retrieval model estimates the ambient air motion (or the updrafts or downdrafts) embedded in the precipitation. The results of the DSD retrieval model compared favorably with surface disdrometer observations during the TEFLUN-B Campaign (Williams et al., 2000). The modeling techniques are still being improved to remove the instrument effects on the observations. The Doppler velocity spectra are broadened by the horizontal winds advecting the particles across the broad beam widths of low frequency radars and new processing techniques were developed to correct for this smearing of the Doppler spectra (Schafer et al., 2002).

Analyzing the Precipitation Vertical Structure

The vertical pointing profilers with their high vertical resolution and fast temporal resolution are ideal for studying the vertical structure of precipitation. While scanning weather radars measure the reflectivity and the radial Doppler velocity (which is primarily a horizontal velocity) of the precipitation, vertically pointing radar profilers measure both the reflectivity and particle Doppler velocity (air motion plus terminal fall speed). Using cluster analysis techniques and the observed reflectivity and Doppler velocity moments, the precipitation observations can be separated from the clear-air observations (Williams et al., 2000). The vertical structure resolved by the profilers enables the different precipitation regimes to be identified ranging from the vigorous convective regime to the ice melting into raindrops stratiform regime and the low-altitude warm rain (no ice processes) regime. Identifying these regimes is important for scanning radar and space-based precipitation estimation and cloud dynamical processes. The vertical structure of reflectivity observed by the profiler during the KWAJEX Field Campaign verify the extrapolation of reflectivity below the lowest tilt angle used by the KWAJ scanning radar (Houze et al., 2003). The profiler observations were used to help characterize the effect the radar bright band intensity has on passive microwave observations measured from space during stratiform rain (Battaglia et al., 2003).

One feature demonstrated during this project is that the profilers used during the TRMM Field Campaigns had very stable calibration. The profilers were deployed with a surface Joss-Waldvogel disdrometer (Disdromet, Inc., Model Number RD-69) to measure the surface raindrop size distributions. The surface disdrometer reflectivity was used to calibrate the profilers. It was learned that once a calibration was set for the profiler, it remained within +/- 1 dBZ of that calibration for the whole campaign unless there was a catastrophic failure of the profiler equipment (Gage et al., 2002). The calibrated profiles of reflectivity can be used to compare with scanning radar observations and be used as a transfer standard to calibrate the scanning

radar to the surface disdrometer (Gage et al., 2000). Such a transfer standard compares scanning radar observations to vertically pointing radar observations which removes some of the uncertainties of disdrometer to scanning radar calibrations.

Interpreting the Dynamics of Precipitating Cloud Systems

While the DSD retrievals from the observed Doppler velocity spectra are interesting in themselves, placing these retrievals into their microphysical context is important for understanding the dynamical processes of the precipitation. In one storm that passed over the profiler site during the TRMM-LBA Field Campaign, the profiler provided observations of the warm updraft at the leading edge of the storm. This strong updraft lifted the smaller raindrops while the larger raindrops fell out of the storm because of their terminal fall speeds were greater than the updraft (Atlas and Williams, 2003a). The updraft acted as a mass spectrometer separating the small from the large raindrops. These smaller raindrops were lifted above the freezing level were they mixed with the previously frozen particles producing a heterogeneous mixed phase region above the 0°C level. The updrafts were strong enough to produce a balance level where there just as much mass moving upward as was downward. The balance level increases the residence time in the mixed phase region promoting the production of inductive charging by collisions between the descending hail and/or graupel and the ascending smaller ice crystals. Non-atmospheric signals (e.g., interference) were observed in the profiler records at the same altitudes as the balance level resulting from the lightning being produced at these levels and ducting through the profiler beam (Atlas and Williams, 2003b). The strong updrafts lift moisture above the freezing level and the subsequent fallout of the frozen particles can lead to downdrafts in the precipitation. A wet microburst was observed as 0.7 to 0.8 cm diameter hail fell through the 0°C level and evaporated before reaching the surface. The evaporation over a shallow depth produced enough cooling to produce a microburst detected in the surface annometer (Atlas et al., 2003).

Appendix A - 12 Peer Reviewed Publications (July 2000-June 2003)

Atlas, D., C.W. Ulbrich, and C.R. Williams, 2003: Physical origin of a wet microburst: Observations and theory, *J. Atmos. Sci.*, submitted.

Houze, R. Jr., Brodzik, S., Schumacher, C., S. Yuter, and C.R. Williams, 2003: The multiyear quantitative radar data set produced by the Kwajalein ground validation radar during TRMM. *J. Appl. Meteor.*, submitted.

Battaglia, A., C. Kummerow, D-B Shin, and C.R. Williams, 2003: Toward characterizing the effect of radar bright bands on microwave brightness temperatures. *J. Atmos. and Oceanic Technol.*, 20, 856-871.

Atlas, D., C.R. Williams, 2003b: Radar echoes from lightning and their microphysical environment. *Geophys. Res. Lett.*, 30, 10.1029/2002GL016521.

Atlas, D., and C.R. Williams, 2003a: The anatomy of a continental Tropical convective storm. *J. Atmos. Sci.*, 60, 3-15.

Schafer, R., S. Avery, P. May, D. Rajopadhyaya, and C. Williams, 2002: Estimation of drop size distributions from dual frequency wind profiler spectra using deconvolution and a nonlinear least squares fitting technique. *J. Atmos. and Oceanic Technol.*, 19, 864-874.

K. S. Gage, C. R. Williams, W. L. Clark, P. E. Johnston and D. A. Carter, 2002: Profiler contributions to Tropical Rainfall Measuring Mission (TRMM) Ground Validation Field Campaigns. *J. Atmos. Oceanic Tech.*,19, 843–863.

Williams, C.R., 2002: Simultaneous ambient air motion and raindrop size distribution retrieved from UHF vertical incident profiler observations. *Radio Science*, 37, 10.1029/2000RS002603.

Gage, K.S., C.R. Williams, P.E. Johnston, W.L. Ecklund, R. Cifelli, A. Tokay, and D.A. Carter, 2000: Doppler radar profilers as calibration tools for scanning radars. *J. Appl. Meteor.*, 39, 2209-2222.

VanZandt, T.E., W.L. Clark, K.S. Gage, C.R. Williams, and W.L. Ecklund, 2000: A dual-wavelength radar technique for measuring, ϵ, the turbulent energy dissipation rate. *Geophys. Res. Lett.*, 27, 2537-2540.

Williams, C.R., A. Kruger, K.S. Gage, A. Tokay, R. Cifelli, W.F. Krajewski, and C. Kummerow, 2000: Comparison of simultaneous rain drop size distributions estimated from two surface disdrometers and a UHF profiler. *Geophys. Res. Lett.*, 27, 1763-1766.

Williams, C.R., W.L. Ecklund, P.E. Johnston, and K.S. Gage, 2000: Cluster analysis techniques to separate air motion and hydrometeors in vertical incident profiler observations. *J. Atmos. and Oceanic Technol.*, 17, 949-962.

Appendix B - Total of 42 professional presentations (July 2000 - June 2003)

Williams, C.R., and K.S. Gage, Vertical structure of reflectivity retrieved from precipitation profilers, International Symposium on Tropospheric Profiling, 14-20 September 2003, Leipzig, Germany.

Williams, C.R., and P. Kollias, Vertical profiles of rain drop size distributions estimated with S-band and W-band profilers, 31st International Conference on Radar Meteorology, 6-12 August 2003, Seattle, WA.

Ellis, S.M., E.A. Brandes, C.R. Williams, and G. Zhang, Comparison of rain drop size distributions retrieved from polarization diversity radar and profiling radar using video disdrometer measurements, 31st International Conference on Radar Meteorology, 6-12 August 2003, Seattle, WA.

Kruger, A., B.J. Miriovsky, W.F. Krajewski, R. Goska, C.R. Williams, and K.S. Gage, Vertical variability of precipitation as seen by vertically pointing and scanning radars, 31st International Conference on Radar Meteorology, 6-12 August 2003, Seattle, WA.

Atlas, D., C.W. Ulbrich, and C.R. Williams, Physical origin of a microburst seen by radar profiler, 31st International Conference on Radar Meteorology, 6-12 August 2003, Seattle, WA.

Williams, C.R., P.E. Johnston, W.L. Clark, K.S. Gage, D.A. Carter, and P.A. Kucera, Vertically pointing profilers used to calibrate and monitor the reflectivity estimated by scanning radars, 31st International Conference on Radar Meteorology, 6-12 August 2003, Seattle, WA.

Gage, K.S., and C.R. Williams, Use of radar profilers as tools for the determination of space-time variability of precipitation parameters, 31st International Conference on Radar Meteorology, 6-12 August 2003, Seattle, WA.

Williams, C.R., and K.S. Gage, Vertical distribution of rain drop size distributions during convective and stratiform rain, International Union of Geodesy and Geophysics (IUGG 2003), 30 June-11 July 2003, Sapporo, Japan.

Gage, K.S., and C.R. Williams, On the application of radar profilers for the determination of space-time variability of precipitation parameters in precipitating cloud systems, International Union of Geodesy and Geophysics (IUGG 2003), 30 June-11 July 2003, Sapporo, Japan.

Williams, C.R., and K.S. Gage, Vertical structure of rain drop size distributions retrieved from profiler observations, 10th International Workshop on Technical and Scientific Aspects of MST Radar, 13-20 May 2003, Piura, Peru.

Clark, W.L., K.S. Gage, D.A. Carter, C.R. Williams, P.E. Johnston, and A. Tokay, Calibration issues using impact disdrometers for calibration of Doppler radar profilers, 12th Symposium on Meteorological Observations and Instrumentation, American Meteorological Society, 9-13 February 2003, Long Beach, CA.

Gage, K.S., W.L. Ecklund, W.L. Clark, D.A. Carter, C.R. Williams, and P.E. Johnston, A low-powered S-band precipitation profiler for hydrological applications, 12th Symposium on Meteorological Observations and Instrumentation, American Meteorological Society, 9-13 February 2003, Long Beach, CA.

Williams, C.R., P.E. Johnston, W.L. Clark, K.S. Gage, D.A. Carter, and P.A. Kucera, Calibration of scanning radars using vertically pointing profilers and surface disdrometers, 12th Symposium on Meteorological Observations and Instrumentation, American Meteorological Society, 9-13 February 2003, Long Beach, CA.

Gage, K.S, and C.R. Williams, Observations of diverse precipitating cloud systems utilizing ground-based Doppler radar profilers, Symposium on Observing and Understanding the Variability of Water in Weather and Climate, American Meteorological Society, 9-13 February 2003, Long Beach, CA.

Gage, K.S. and C.R. Williams, Recent developments in the use of Doppler radar profilers for the remote sensing of precipitating clouds, Remote Sensing of the Atmosphere, Ocean, Environment, and Space, The International Society for Optical Engineering, 23-27 October 2002, Hangzhou, China.

Atlas, D. and C.R. Williams, The anatomy of a continental tropical convective storm, TRMM International Science Conference, 22 - 26 July, 2002, Honolulu, HI.

Ahammad, P., C.R. Williams, T. Kasparis, and L. Jones, Estimating effects and significance of vertical velocity in precipitation measurements using disdrometer flux conservation model, TRMM International Science Conference, 22 - 26 July, 2002, Honolulu, HI.

Clark, W.L., K.S. Gage, C.R. Williams, P.E. Johnston, D.A. Carter, On reflectivity calibration of wind profiler radar using surface based disdrometers, TRMM International Science Conference, 22 - 26 July, 2002, Honolulu, HI.

Gage, K.S., C.R. Williams, W.L. Clark, P.E. Johnston, D.A. Carter, Profiler contributions to Tropical Rainfall Measuring Mission (TRMM) Ground Validation Field Campaigns, TRMM International Science Conference, 22 - 26 July, 2002, Honolulu, HI.

Ohno, Y., C.R. Williams, K.S. Gage, Statistical analysis of rain using UHF wind profilers in the Tropical Pacific and Asia for TRMM validations, TRMM International Science Conference, 22 - 26 July, 2002, Honolulu, HI.

Williams C.R. and K.S. Gage, Simultaneous ambient air motion and rain drop size distributions retrieved from UHF vertical incident profiler observations, TRMM International Science Conference, 22 - 26 July, 2002, Honolulu, HI.

Williams, C.R., C. Schumacher, R. Houze, and K.S. Gage, Vertical distribution of reflectivity at Kwajalein from profiler and scanning radar observations, TRMM International Science Conference, 22 - 26 July, 2002, Honolulu, HI.

Gage, K.S., W.L. Clark, A. Tokay, C.R. Williams, P.E. Johnston, and W.L. Ecklund, How well can a Doppler radar profiler be calibrated using disdrometers?, TRMM Science Team Meeting, 29 October - 2 November 2001, Fort Collins, CO.

Williams, C.R., and K.S. Gage, Ambient air motion and raindrop size distributions retrieved from UHF vertical incident profiler observations, TRMM Science Team Meeting, 29 October - 2 November 2001, Fort Collins, CO.

Williams, C.R., and K.S. Gage, Hydrometeor size distributions retrieved from UHF and S-band vertical pointing profilers during the TRMM Ground Validation Program, Specialist Meeting on Microwave Remote Sensing, 5-9 November 2001, Boulder, CO.

Gage, K.S., C.R. Williams, W. Clark, P.E. Johnston, W.L. Ecklund, and D.A. Carter, Profiler contributions to Tropical Rainfall Measuring Mission (TRMM) Ground Validation Field

Campaigns, Specialist Meeting on Microwave Remote Sensing, 5-9 November 2001, Boulder, CO.

Williams, C.R., and K.S. Gage, Ambient air motion and raindrop size distributions retrieved from UHF vertical incident profiler observations, 13th International Conference on Radar Meteorology, 19-25 July 2001, Munich, Germany.

Gage, K.S., G.N. Kiladis, L.M. Hartten, and C.R. Williams, Hadley circulation over the central equatorial Pacific observed by Trans-Pacific Profiler Network, 13th International Conference on Radar Meteorology, 19-25 July 2001, Munich, Germany.

Gage, K.S., D.A. Carter, W.L. Ecklund, C.R. Williams, P.E. Johnston, and A. Tokay, How well can a profiler be calibrated using a disdrometer, 13th International Conference on Radar Meteorology, 19-25 July 2001, Munich, Germany.

Williams, C.R., and K.S. Gage, Hydrometeor size distributions retrieved from vertical pointing profilers during the TRMM Ground Validation Program, 8th Scientific Assembly of International Association of Meteorology and Atmospheric Sciences (IAMAS), 10-18 July, 2001, Innsbruck, Austria.

Williams, C.R., W.L. Ecklund, and K.S. Gage, Vertical structure of precipitating clouds above the melting level using a S-band profiler over Manus Island, Papua New Guinea, 8th Scientific Assembly of International Association of Meteorology and Atmospheric Sciences (IAMAS), 10-18 July, 2001, Innsbruck, Austria.

Gage, K.S., G.N. Kiladis, L.M. Hartten, C.R. Williams, and P.E. Johnston, Highlights of tropical dynamics and climate research using the NOAA/CU Trans-Pacific Profiler Network, 8th Scientific Assembly of International Association of Meteorology and Atmospheric Sciences (IAMAS), 10-18 July, 2001, Innsbruck, Austria.

Hartten, L.M., D.A. Carter, K.S. Gage, P.E. Johnston, and C.R. Williams, Tropical wind-profiling radars: high-resolution, multi-purpose, and multi-scale observations, 5th Symposium on Integrated Sounding Systems, 14-19 January 2001, Albuquerque, New Mexico.

Williams, C.R., and K.S. Gage, Raindrop size distributions retrieved from UHF and S-band profilers using the Sans Air Motion (SAM) Model, American Geophysical Union Fall Meeting, 15-19 December 2000, San Francisco, California.

Gage, K.S., C.R. Williams D.A. Carter, W.L. Ecklund, P.E. Johnston, and A. Tokay, Calibration of Doppler radar profilers using disdrometers, American Geophysical Union Fall Meeting, 15-19 December 2000, San Francisco, California.

Williams, C.R., K.S. Gage, Comparison of raindrop size distributions retrieved from surface disdrometers and UHF and S-band profilers, 5th International Symposium on Tropospheric Profiling: Needs and Technology, 4-8 December 2000, Adelaide, Australia.

Gage, K.S., and C.R. Williams, Profiler Observations of Tropical Precipitating Cloud Systems during TRMM Ground Validation Field Campaigns, 5th International Symposium on Tropospheric Profiling: Needs and Technology, 4-8 December 2000, Adelaide, Australia.

Williams, C.R., P.E. Johnston, and J.A. Nystuen, Underwater acoustic rain gauge and collocated vertically pointing precipitation profiler, 10th International Symposium on Acoustic Remote Sensing (ISARS 2000), 27 November-1 December 2000 , Auckland, New Zealand.

Williams, C.R., and K.S. Gage, Raindrop size distributions retrieved from UHF and S-band profilers using the Sans Air Motion (SAM) Model, TRMM Science Team Meeting, 30 October-2 November 2000, Greenbelt, Maryland.

Gage, K.S., C.R. Williams D.A. Carter, W.L. Ecklund, P.E. Johnston, and A. Tokay, Calibration of Doppler radar profilers using disdrometers, TRMM Science Team Meeting, 30 October-2 November 2000, Greenbelt, Maryland.

Williams, C.R., and K.S. Gage, Hydrometeor size distributions retrieved from vertical pointing UHF and S-band profilers during the TRMM ground validation program, Society of Photo-Optical Instrumentation Engineers (SPIE) 2nd International Asia-Pacific Symposium on Remote Sensing of the Atmosphere, Environment, and Space, 9-12 October 2000, Sendai, Japan.

Williams, C.R., W.L. Ecklund, and K.S. Gage, Statistical properties of precipitating clouds using UHF and S-band profilers on Manus Island, Papua New Guinea, 13th International Conference on Clouds and Precipitation (ICCP), 14-18 August 2000, Reno, Nevada.