SUPPLEMENT

RAIN IN SHALLOW CUMULUS OVER THE OCEAN

The RICO Campaign

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This document is a supplement to "Rain in Shallow Cumulus over the Ocean—the RICO Campaign," by Robert M. Rauber, Bjorn Stevens, Harry T. Ochs III, Charles Knight, B. A. Albrecht, A. M. Blyth, C. W. Fairall, J. B. Jensen, S. G. Lasher-Trapp, O. L. Mayol-Bracero, G. Vali, J. R. Anderson, B. A. Baker, A. R. Bandy, E. Burnet, J.-L. Brenguier, W. A. Brewer, P. R. A. Brown, P. Chuang, W. R. Cotton, L. Di Girolamo, B. Geerts, H. Gerber, S. Göke, L. Gomes, B. G. Heikes, H. G. Hudson, P. Kollias, R. P. Lawson, S. K. Krueger, D. H. Lenschow, L. Nuijens, D. W. O'Sullivan, R. A. Rilling, D. C. Rogers, A. P. Siebesma, E. Snodgrass, J. L. Stith, D. C. Thornton, S. Tucker, C. H. Twohy, and P. Zuidema (*Bull. Amer. Meteor. Soc.*, **88,** 1912–1928) • ©2007 American Meteorological Society • Corresponding author: Robert M. Rauber, Department of Atmospheric Sciences, University of Illinois at Urbana–Champaign, 105 South Gregory St., Urbana, IL 61801 • E-mail: rauber@atmos.uiuc.edu • DOI:10.1175/BAMS-88-12-Rauber.

In this supplement we provide a tabular overview of the full array of instrumentation deployed during the Rain in Cumulus over the Ocean (RICO) study. In addition to the instruments listed in the Tables 1–6, RICO investigators made use of a wide array of routine data (measurements of opportunity), such as those provided by satellite overpasses or nearby sounding stations. An overview of these data is provided on the project archive.

Below we also outline some of the major instrumental issues that might influence the use of the data. Further details and a more exhaustive treatment of instrument issues are available in the Web-based documentation for the project in association with the project data archive, or from the investigator responsible for a particular measurement. The information below is provided mostly by way of overview.

DATA ISSUES. Both the *W*-band radars encountered difficulty. The shipboard *W*-band radar failed on 12 January and was unavailable for the remainder of the deployment. The King Air *W*-band radar had to have its transmitter replaced just weeks before the experiment began, and operated at reduced sensitivity throughout the experiment; on some flights some antennas did not provide useful Doppler data. The K_a-band radar component of the National Center for Atmospheric Research (NCAR) polarized S- and k-band radar (SPolKa) was never left to operate unattended and was not operated at all on 14, 15, 26, and 27 December. The K_a operation experienced other problems as well (sensitivity issues, attenuation, beam blockage), and while its data often appear reasonable they should be treated with care. On the aircraft familiar problems of probe salinification and wetting

Table 1. SPolKa and Barbuda-based instrumentation.	
Instrument and variables	**Reference/comment**
S-band, 2.809-GHz radar	Scanning instrument measures reflectivity (horizontal, copolar) Doppler velocity and spectrum width, differential reflectivity, linear depolarization ratio (Keeler et al. 2000).
Ka-band, 34.8-GHz radar	Scanning instrument measures reflectivity (horizontal, copolar), reflectivity (vertical, copolar), Doppler spectrum width (Farquharson et al. 2005).
Digital camera	Antenna-mounted system takes sky images following a radar scan during daylight hours (Rilling and VanAndel 2006).
Integrated Surface Flux Facility (ISFF)	Measurements of 10-m winds, 2-m temperatures and humidities, surface pressure, and downward visible and IR radiation at Spanish Point.
Sounding system	GPS Advanced Upper-Air Sounding System (GAUS) with RS92 sondes launched from ISFF site on Spanish Point.

Table 2. Dian Point (Antigua) instrumentation. Unless otherwise noted the chief contact for measurements at this site is Olga Mayol-Bracero [University of Puerto Rico-Río Piedras (UPR-RP)].	
Instrument and variables	**Instrument scientist**
Dekati low pressure impactor (DLPI)	Size-segregated particles on 13 stages ($0.03 < D_p < 10\ \mu$m), for chemical characterization.
Stacked-filter units (SFUs)	Measures fine ($D_p \leq 1\mu$m) and coarse ($D_p \geq 1\mu$m) particles for chemical characterization.
Weather station	Surface winds, temperature, and relative humidity.
Condensation particle counter (model 3010, TSI)	Total particle number concentration, $D_p > 10$ nm (Laurent Gomes, Meteo-France).
University of Wyoming CCN counter	CCN at selected supersaturations between 0.2% and 2% (Laurent Gomes, Meteo-France).
Scanning mobility particle sizer (SMPS-TSI)	Particle size distribution 10 $nm < D_p < 700$ nm (Laurent Gomes, Meteo-France).
Ground-based volatility system with Availability Stats and Performance Extension	Size-differentiated chemical information based on volatility following Brooks et al. (2002) (Justin Lingard, J. H. Smith, and J. McQuaid, University of Leeds).
Passive Cavity Aerosol Spectrometer Probe (PCASP-X)	Particle size distribution($0.1 < D_p < 10\ \mu$m; Justin Lingard, J. H. Smith and J. McQuaid, University of Leeds).
Väisälä ceilometer	Cloud base and vertical distribution of aerosol loading in lower 1–2 km (Elz Grzeszczak, Warsaw University; Piotr Flatau, Scripps Institution of Oceanography).
Whole-sky camera	1-min, whole-sky images (Ela Grzeszczak, Warsaw University; Piotr Flatau, Scripps Institution of Oceanography).
Filter system	Collection of particles for surface analysis by scanning electron microscope (James Anderson, Arizona State University).

affected the temperature measurements; and droplet shattering, stuck bits, and the slow time response affected the performance of the two-dimensional cloud (2DC) and precipitation (2DP) imaging probes. Data from the forward-scattering spectrometer probes also require scrutiny, particularly in the presence of rain (e.g., Fig. 8 of cloud water and droplet concentrations in the main article), where drop shattering can dominate the measurements. Cloud condensation nuclei (CCN) measurements for flights 1–5 on the C130 may have suffered from inlet contamination and should be treated with caution. After research flight 05 the CCN inlet was repositioned and inlet contaminations appears not to be an issue. The carbon monoxide (CO) instrument on the C130 failed on 17 January and was unavailable for the rest of the project, dimethyl sulfide (DMS) measurements proved excessively noisy and may be difficult to use, and the cloud water peroxide measurements failed owing to their reactive loss on the stainless steel surfaces of the CVI.

Table 3. National Science Foundation (NSF)/NCAR C130 measurements. Unless otherwise specified, Al Schanot of NCAR is the contact person for these measurements.

Class of measurements	Description
Aircraft state	Honeywell Inertial and Trimble GPS Navigation Systems providing aircraft position, ground speed, and orientation (heading, pitch, and roll). Rosemount flow angle sensor providing angle of attack and sideslip measurements. Rosemount icing rate detector (NCAR/RAF Bulletin 24, available online at www.eol.ucar.edu/raf/Bulletins/bulletin24.html) measures water accretion measurements. Radar altimeters and pressure altimetry for measuring aircraft height.
Video	Forward-looking digital video imagery (Seeward Beaton, NCAR).
Velocities	Estimated using navigation information and pressure differences measured with a five-hole system on the aircraft radome.
Pressure	Rosemount and Ruska oscillation frequency instruments for static pressure and a Rosemount variable-capacitance instrument for carbon static pressure and dynamic pressure.
Temperature	Rosemount platinum resistance thermometers measuring total air temperature (deiced and nondeiced) and an Ophir infrared thermometer providing open-path measurements of ambient air temperature.
Humidity	Water vapor density from open-path tunable diode laser measurements (Teresa Campos NCAR), fast-response water vapor density from an NCAR cross-flow Lyman-α absorption measurement. Dewpoint temperatures measured by a thermoelectric hydrometer.
Radiation	Eppley pyrgeometer measurements of infrared radiation (upward and downward); Eppley pyranometer measurements of visible radiation; photometer measurements of ultraviolet radiation; and surface and sky temperatures from Heimann infrared bolometric radiometers.
Integrated cloud water	Hot-wire King probes (NCAR/RAF Bulletin 24) and the Gerber Particulate Volume Monitor-100 (Gerber 1994).
Hydrometeors	NCAR FSPP-100, a PMS Forward Scattering Spectrometer Probe (FSSP) with modified electronics, which measures particle diameters between 2 and 47 μm, French fast FSSP (Brenguier et al. 1998), phase Doppler instrument (Patrick Chuang, University of California, Santa Cruz), and 2D optical array stereo probe (SPEC 2DS; Lawson et al. 2006); NCAR 1D optical array Probe (260X) with 60 channels between 40 and 600 μm, NCAR 2DC (cloud) optical array probe measuring between 25 and 800 μm, NCAR 2DP optical array probe measuring between 0.2 and 6.4 mm; SPEC cloud particle imager (Lawson and Cormack 1995). A cloud integrating nephelometer for cloud-droplet scattering coefficients (Gerber et al. 2000). The NCAR instruments are described in the NCAR/RAF Bulletin 24, available online).
Aerosol	Butanol expansion instrument for condensation nuclei (CN) measurements between 0.01 and 3 μm and an ultrafine counter (concentrations between 0.003 and 3 μm; Dave Rogers, NCAR); size-discriminated CCN measurements (Hudson 1989); counterflow virtual impactor measurements (Twohy et al. 1997) and electron microscopy for aerosol composition (James Anderson, Arizona State University); small aerosol size distributions from the NCAR radial differential mobility analyzer (Dave Rogers, NCAR); aerosol size and composition from the analysis of slides taken with the NCAR giant aerosol impactor (Jorgen Jensen, NCAR; Colón-Robles et al. 2006); wet/dry nephelometers for measuring aerosol light scattering extinction coefficients (Dave Rogers, NCAR).
Chemistry	Fast-response NO_2 chemiluminescence and slow-response UV absorbance measurements of ozone, as well as UV resonance fluorescence measurements of CO (Teresa Campos, NCAR); DMS and SO_2 from fast-response ionization mass spectroscopy measurements (Donald Thorton, Drexel University); peroxides were also measured using in situ aqueous reaction measurements (Brian Heikes, University of Rhode Island).
Lidar backscatter profiles	Up- and downward two channel backscatter lidar measurements at 1064 and 532 nm (Bruce Morely, NCAR).
Vertical soundings	GPS dropsondes providing measurements of temperature, pressure, humidity, and horizontal winds as a function of GPS height (Kate Young, NCAR).

Table 4. University of Wyoming King Air Measurements. Unless otherwise specified, Perry Wechsler is the contact person for these measurements.	
Class of measurements	**Description**
Aircraft state	Honeywell Inertial and Trimble GPS Navigation Systems providing aircraft position, ground speed, and orientation (heading, pitch, and roll); Rosemount flow angle sensor provides angle of attack and sideslip measurements; rosemount icing rate detector measures water accretion measurements.
Video	Forward- and downward-looking analog video.
Velocities	Estimated using navigation information and pressure differences measured with a five-hole system using the Rosemount 858 gust probe.
Pressure	Rosemount (1201) variable capacitance and Rosemount High Accuracy Digital Sensing oscillation frequency instrument for cabin static pressure.
Temperature	Platinum resistance thermometers measuring deiced (Rosemount 102) and nondeiced (Minco) total temperatures.
Humidity	LICOR instrument for measuring water vapor; Cambridge 137C3 chilled-mirror hygrometer for dewpoint temperature.
Radiation	Eppley pyrgeometer measurements of infrared radiation; Eppley pyranometer measurements of visible radiation; surface and sky temperatures from Heimann infrared bolometric radiometers.
Integrated cloud water	Hot-wire King probe (DMT LWC-100) and the Gerber PVM-100 (Gerber 1994).
Hydrometeors	FSSP-100, a forward-scattering spectrometer probe that measures the cloud droplet spectrum; 1D optical array probe (200X), 2DC (cloud) optical array probe, and 2DP (precipitation) optical array probe.
Aerosol	Butanol expansion instrument (TSI 3010) for aerosol condensation nuclei and a static diffusion changer measurement of cloud condensation nuclei.
Chemistry	Carbon dioxide from a LICOR instrument.
Cloud radar	Three antenna (up, down, side) W-band (94.92 GHz) Doppler radar (Samuel Haimov, University of Wyoming).

Velocity measurements from a five-hole system on the aircraft radome showed attenuation at high frequencies for both the lateral and vertical components, with the former being more affected. The BAE-146 measurements appear to be less attenuated at a high frequency, but suffer from an obvious "spike" at about 3 Hz, which is presumed to result from aliasing a signal from above the 16-Hz Nyquist frequency of the data, possibly an acoustic resonance. The scanning aerosol backscattering lidar (SABL) was down from the period between 13 and 15 January while replacement parts were being ordered and installed. Additionally, the Research Vessel *Seward Johnson* turned out to be a poor ship platform choice because it was so responsive to wave and wind forcing. The ship motion exceeded the parameters considered in the design of the lidar motion-compensation hardware, requiring further postexperiment processing.

Despite the limitations listed above, some of which (like in-cloud temperature and drop-size distribution measurements) are familiar and long-standing problems, a wide variety of redundant instrumentation helped mitigate data loses associated with the limited performance of particular instruments. For instance, the infrared measurements of in-cloud temperatures by the Ophir, Inc., radiometric temperature instrument (Beaton 2006) were more reliable than usual and helped mitigate limitations resulting from wetting of the standard probes; although, a faster time response would have been desirable. The new two-dimensional stereo (2DS) probe (Lawson et al. 2006) addresses the well-known effects of the limited sample volume and slow time response of the standard 2D probes. It appeared to function well during RICO, and we look to its measurements to greatly enhance the characterization of the drop spectra as well as help constrain the performance of the standard drop (2DC/2DP) probes. In addition, a new phase Doppler instrument became operational toward the end of the experiment and provided useful measurements of the drop-size spectrum for the last few flights, especially in the critical range of drop sizes (40–100-μm diameter) that tend to be poorly measured by both the for-

Table 5. FAAM BAE-146 measurements. Unless otherwise specified, Phil Brown of the Met Office is the contact person for these instruments.	
Class of measurements	**Description**
Aircraft state	Inertial and GPS navigation systems providing aircraft position, ground speed, and orientation (heading, pitch, roll); flow angle sensor providing angle of attack and sideslip measurements.
Video	Analog recordings (Joos Kent, Met Office).
Velocities	Estimated using navigation information and pressure differences measured with a gust probe.
Pressure	Reversed Vertical Separation Minimum air data system measurements of pitot-static pressures and pressure altitude and indicated air speed (Steve Devereau, FAAM).
Temperature	Platinum resistance thermometers measuring deiced and nondeiced total temperatures.
Humidity	GE 1011 hydrometer (Strom et al. 1994), total water content following Nicholls et al. (1990).
Radiation	Pyrgeometer measurements of infrared radiation (4–50 μm), and pyranometer measurements of visible radiation [one making hemispheric measurements at 0.3–3 μm, the other operating between 0.7 and 3 μm (Foot 1986)]; downward-facing radiometer for surface brightness temperature measurements (between 8 and 14 μm; Steven Devereau, FAAM).
Integrated cloud water	Johnson–Williams hot-wire probe (Strapp and Schemenauer 1982).
Hydrometeors	FSPP-100, a forward scattering spectrometer probe measures for cloud droplets (1–23.5 μm) using measurement principles developed by Brenguier et al. (1998); 2DC (cloud, 25–800 μm) optical array probe and 2DP (precipitation 0.2–6.4 mm) optical array probe (Korolev et al. 1998); spherical equivalent small ice equivalent measurements (1–50 μm) following Hirst et al. (2001).
The aerosol	Optical probe for aerosol size spectrum (between 0.1 and 3 μm); condensation particles measured with a TSI 3025 condensation particle counter (Steve Devereau, FAAM) and a nephelometer (Maureen Smith, FAAM) measuring total scattering and hemispheric backscattering at 450, 550, and 700 nm; aerosol characterization measured by milipore 47- and 90-mm membrane filters, and black carbon from a particle soot absorption photometer; particle residuals measured with a counterflow virtual impactor (Noone et al. 1988) and Rosemount "pair inlet" measurements of condensation nuclei and volatile aerosol concentrations and composition (Jim McQuaid, University of Leeds).
Chemistry	Carbon monoxide (AL5002; Steve Devereau, FAAM); trace gas analyzer for sulfur dioxide (Ruth Purvis, FAAM); TECO 49UV photometric measurements of ozone (Ruth Purvis, FAAM); NO, NO_2, and NO_x measurements by a TECO 42 chemiluminescence instrument. Whole-air sample bottles were also collected and analyzed by Jim Hopkins (University of York).

Table 6. R/V Seward Johnson instrumentation.	
Instrument	**Description**
Ka-band, 35-GHz radar	Scanning dual-polarization instrument measures reflectivity and Doppler velocity (Martner et al. 2002); the radar is unstabilized but Earth referenced and has an approximately 15-km range.
X-band, 9.4-GHz radar	Vertically pointing instrument measures reflectivity, Doppler velocity (Bruce Albrecht, University of Miami).
W-band, 94-GHz radar	Vertically pointing instrument measures reflectivity and Doppler velocity; it was unstabilized, and operated through 12 January only (Kollias et al. 2001).
915-MHz, Doppler wind profiler	Stabilized instrument measures horizontal winds and reflectivity (Ecklund et al. 1988).
Air–sea flux system	Measures radiative and turbulent heat fluxes, surface winds, near-surface air and sea state, rain rates, and CO_2 fluxes (Fairall et al. 1997).
Microwave radiometer	Two-channel "mailbox," vertical pointing radiometer measures cloud-base height and reflectivities (Zuidema et al. 2005).
PMS Lasair-II	Aerosol size spectrum in six size bins $D_p > 0.1$ μm operated after 16 January only.
Väisälä rawinsonde system	Provides temperature, relative humidity, and horizontal winds versus height using RS-92 sondes launched 4–6 times per day.

ward-scattering and the direct-imaging probes. The X-band ship radar performed very well and provided images of cloud structure that were expected from the *W*-band measurements, and the scanning shipboard K_a-band measurements might help offset the loss of data from the ground-based K-band instrument. And, although the Doppler lidar had been deployed once before, the addition of ship motion–compensation hardware and new data-processing procedures helped provide exciting new measurements of circulations in the subcloud layer [see the sidebar in Rauber et al. (2007) titled "High-resolution cloud and boundary layer measurements on the high seas"].

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