U.S. DEPARTMENT OF ENERGY | Office of Science

DOE/SC-ARM-14-012

The Mid-latitude Continental Convective Clouds (MC3E) Experiment Final Campaign Report

M Jensen
S Giangrande
P Kollias

April 2014

ARM
CLIMATE RESEARCH FACILITY

DISCLAIMER

DOE/SC-ARM-14-012

The Mid-latitude Continental Convective Clouds Experiment (MC3E) Final Campaign Report

M Jensen P Kollias
S Giangrande

April 2014

Work supported by the U.S. Department of Energy,
Office of Science, Office of Biological and Environmental Research

Summary

The Mid-latitude Continental Convective Clouds Experiment (MC3E) took place from April 22 through June 6, 2011, centered at the ARM Southern Great Plains site (http://www.arm.gov/sites/sgp) in north-central Oklahoma. MC3E was a collaborative effort between the ARM Climate Research Facility and the National Aeronautics and Space Administration's (NASA's) Global Precipitation Measurement (GPM) mission Ground Validation (GV) program. The campaign leveraged the largest ground-based observing infrastructure available in the central United States, including recent upgrades through the American Recovery and Reinvestment Act of 2009, combined with an extensive sounding array, remote sensing and in situ aircraft observations, and additional radar and in situ precipitation instrumentation. The overarching goal of the campaign was to provide a three-dimensional characterization of convective clouds and precipitation for the purpose of improving the representation of convective lifecycle in atmospheric models and the reliability of satellite-based retrievals of precipitation.

Over the course of the campaign the ground-based observing network and aircraft platforms captured a variety of convective cloud systems. These cases included strong convective lines with large trailing stratiform regions, organized mesoscale convective systems, scattered thunderstorms, elevated nighttime convection, some severe weather, and other convective cloud types. Several cases included coordinated aircraft flights providing both airborne remote sensing and in situ observations.

There are a number of current and ongoing research projects using the MC3E data set and it is anticipated that this data set will be used for years to come, not only toward the original campaign science goals, but also for many additional topics. A few of the current and anticipated research activities are:

- testing of column-based and scanning weather radar vertical velocity, drop size distribution and rainfall retrievals
- cloud-aerosol interactions in deep convection model intercomparison study
- cold pools and convective re-development
- satellite-based precipitation retrieval algorithm development
- melting layer precipitation microphysics studies
- multi-frequency, spectra-based retrievals of cloud and precipitation
- variability in derived large-scale forcing data sets.

Acronyms and Abbreviations

ABRFC	Arkansas Red River Basin Forecast Center
ARM	Atmospheric Radiation Measurement
BNL	Brookhaven National Laboratory
CF	Central Facility
CIP	Cloud Imaging Probe
CoSMIR	Conical Scanning Millimeter-Wave Imaging Radiometer
CPC	Condensation Particle Counter
GPM	Global Precipitation Measurement
GV	Ground Validation
HIWRAP	High-Altitude Imaging Wind and Rain Airborne Profiler
IOP	Intensive Operational Period
KAZR	Ka-band ARM Zenith-pointing Radar
LWC	Liquid Water Content
MCS	Mesoscale Convective System
MFRSR	Multi-Filter Rotating Shadowband Radiometer
NASA	National Aeronautics and Space Administration
NEXRAD	Next-Generation Radar
RWP	Radar Wind Profiler
SACR	Scanning ARM Cloud Radar
SGP	Southern Great Plains

Contents

Figures

Tables

1.0 Introduction

The Mid-latitude Continental Convective Clouds Experiment (MC3E) took place from April 22 through June 6, 2011, centered at the ARM Southern Great Plains site (http://www.arm.gov/sites/sgp) in north-central Oklahoma. MC3E was a collaborative effort between the ARM Climate Research Facility and the National Aeronautics and Space Administration's (NASA's) Global Precipitation Measurement (GPM) mission Ground Validation (GV) program. The campaign leveraged the largest ground-based observing infrastructure available in the central United States, including recent upgrades through the American Recovery and Reinvestment Act of 2009, combined with an extensive sounding array, remote sensing and in situ aircraft observations, and additional radar and in situ precipitation instrumentation. The overarching goal of the campaign was to provide a three-dimensional characterization of convective clouds and precipitation for the purpose of improving the representation of convective lifecycle in atmospheric models and the reliability of satellite-based retrievals of precipitation.

2.0 MC3E Campaign Highlights

Over the course of MC3E, coordinated ground-based and airborne instruments sampled a wide variety of convective clouds.

Table 1. A summary of campaign "golden events."

Description	# days sampled	Days
Convective lines/cells	9	April 22, 25, 26; May 11, 18, 20, 23, 24, 31
Widespread Stratiform Rain	3	April 27; May 1, 10
Elevated Weak (Overnight) Convection	2	April 23, 24
Boundary Layer Clouds	9	May 5, 13-15, 19, 27-29; June 1
Mid- or Upper-level Clouds	7	May 2, 3, 8, 9, 25, 26; June 2
Clear	14	

April 25, 2011 – Mid- to upper-level ascent associated with the passage of an upper-level trough aided the development of thunderstorms across the northern part of Oklahoma along an elevated frontal boundary. These nighttime convective cells were relatively shallow in depth, with elevated bases removed from the surface boundary layer forcing features, which were responsible for convective activity in southern Oklahoma.

May 20, 2011 – After 0900 UTC, a line of convective cells that originated along a dry line in west Texas propagated into the ARM scanning radar domain. These cells continued to propagate up and along the northward tilting trough axis. These cells clustered to form a classical north-to-south squall line as well as a larger mesoscale convective system over the Southern Great Plains (SGP) Central Facility (CF) by 1000 UTC. Extended stratiform precipitation with pronounced radar bright band signatures continued over the CF until approximately 1500 UTC.

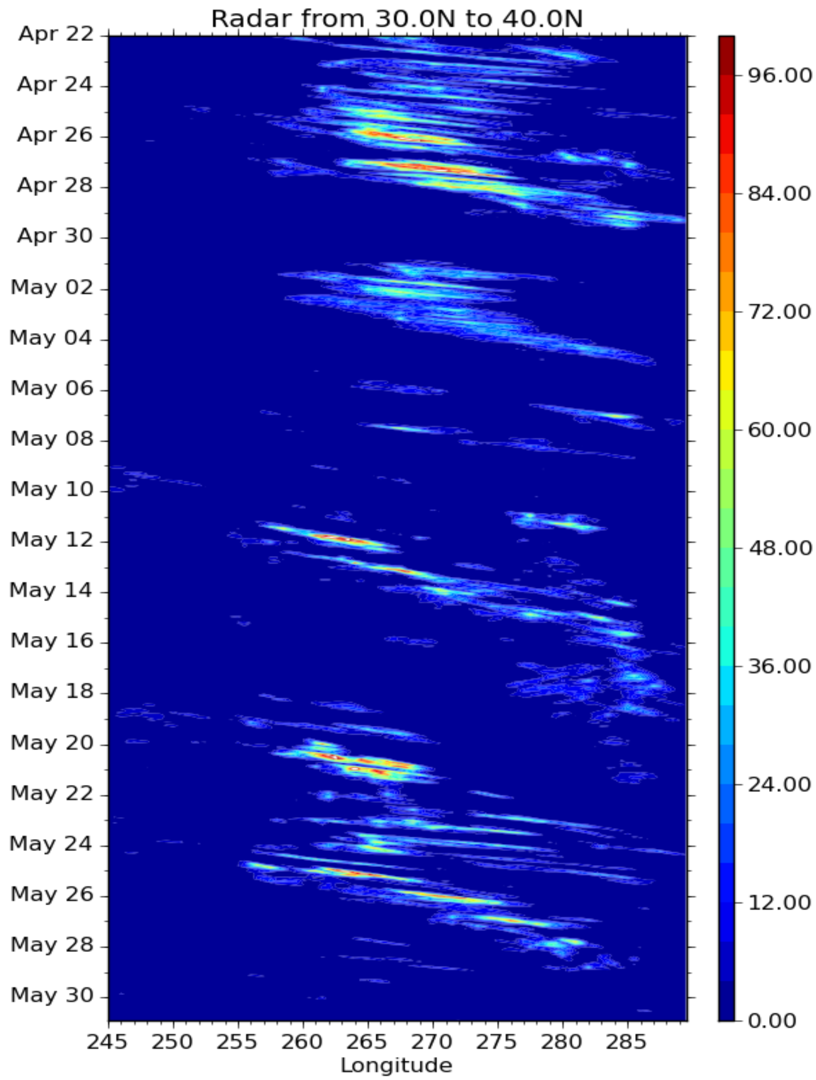

Figure 1. Hovmoller diagram of Next-Generation Radar (NEXRAD) radar reflectivity averaged over 30-40°N latitude. The vertical line indicates the location of the SGP CF.

May 23, 2011 – Late afternoon convection formed along surface boundaries associated with a surface low-pressure system centered over the Texas panhandle. This dynamical forcing coupled with significant daytime heating led to thermal instability in combination with a deep wind shear layer leading to the eventual development of strong, discrete supercell thunderstorms. The severity of these conditions prompted the National Oceanic and Atmospheric Administration (NOAA) Storm Prediction Center to issue this as a "moderate risk" event for regions including the MC3E campaign facilities. The storms developed ahead of a surface dry line in western Oklahoma and propagated eastward through the MC3E domain by 2100 UTC.

3.0 Instruments

3.1 Sounding Network

A major component of MC3E was the deployment of an enhanced radiosonde array of six sites that performed launches at a 3-6 hour sampling interval. Over the course of the six-week campaign, 1348 launches were completed. During post-processing of these soundings, several data quality issues were identified and corrected (when possible). A total of 15 soundings contained data quality issues (e.g., very early termination, unrealistic temperature/humidity variation) that were not correctable. Three of the sites (S03, S04, and S05) had errors in the recorded surface elevation that propagated through the depth of the sounding. One site (S02) had an error in the reported surface pressure. These fixes for these errors are included in a soon-to-be-released (March 24, 2014) data set. The Vaisala RS-92 radiosondes also suffer from a set of well-documented biases. To account for these biases, the algorithm used for the SONDEADJUST algorithm (Troyan 2012) was applied. In addition, the CF soundings were scaled to the integrated water vapor measurement from the ARM microwave radiometer (A similar scaling is being prepared using the Brookhaven National Laboratory (BNL) microwave radiometer at S05). There remains an unresolved issue with the launch times at site S04, where the indicated launch times are consistently one half hour later than the other sites.

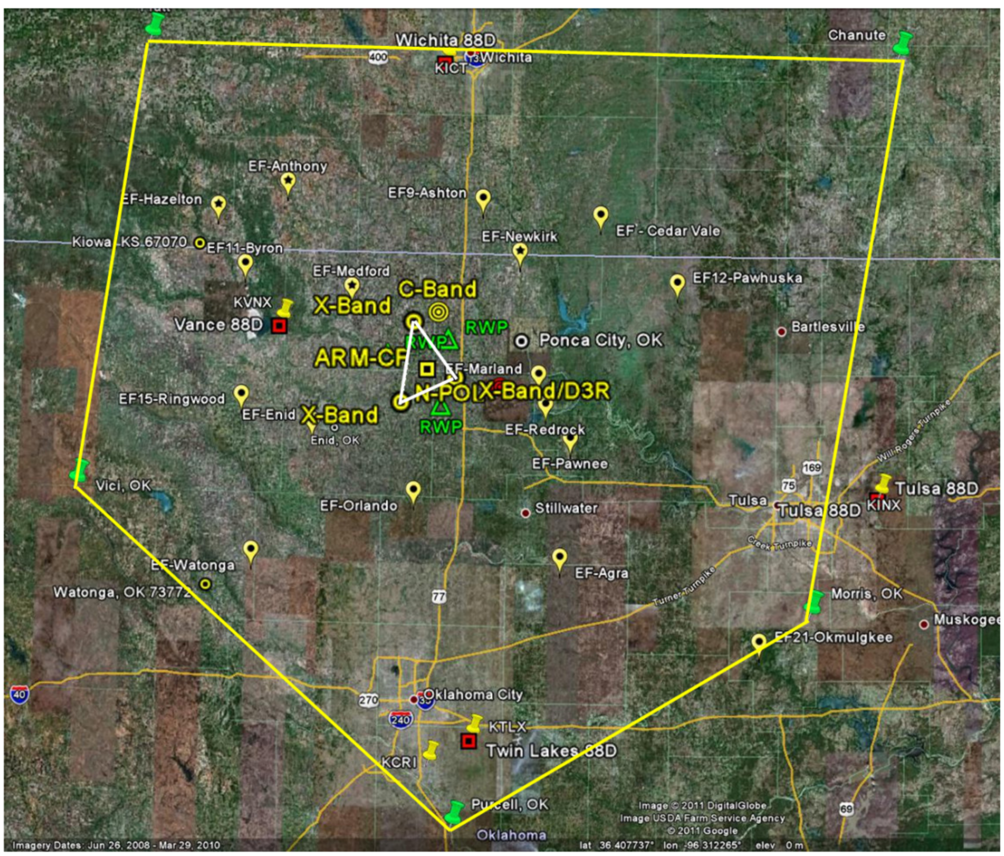

Figure 2. Map of the MC3E ground-based observing domain including the outer sounding domain: CF (C1 Lamont, Oklahoma (OK) 36,695° latitude, -97.485° longitude) S1 Pratt, Kansas (KS) (37.7, -98.75); S2 Chanute, KS (37.674, -95.488), S3 Vici, OK (36.071, -99.204); S4 Morris, OK (35.687, -95.856); and S5 Purcell, OK (34.985, -97.522).

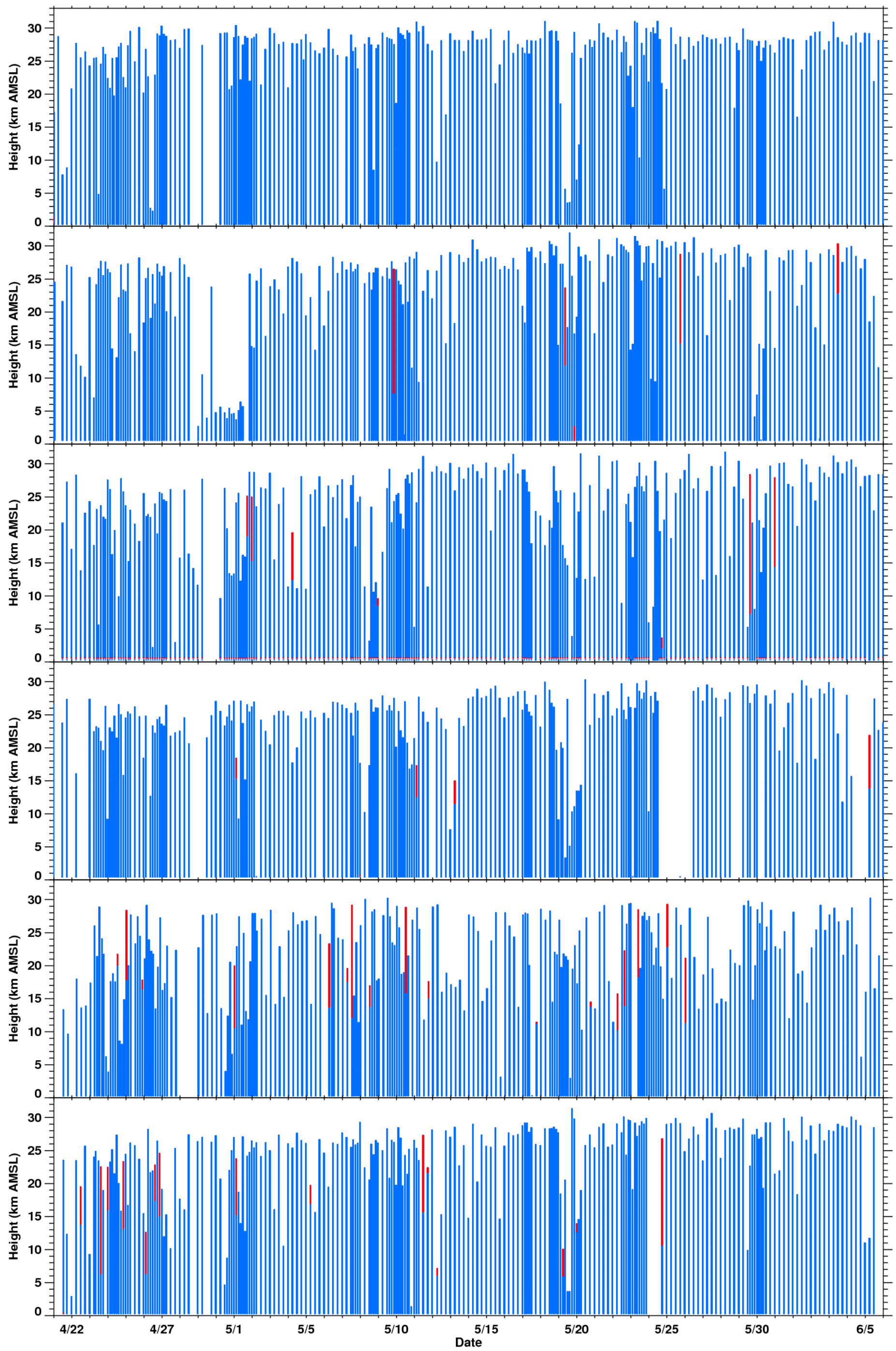

Figure 3. Sonde inventory summarizing the time of each launch and maximum height attained by each sonde for C1 (top), S1 , S2, S3, S4, S5 (bottom). Each bar is color coded to represent nominal data quality (blue = good, red = indeterminate or bad)

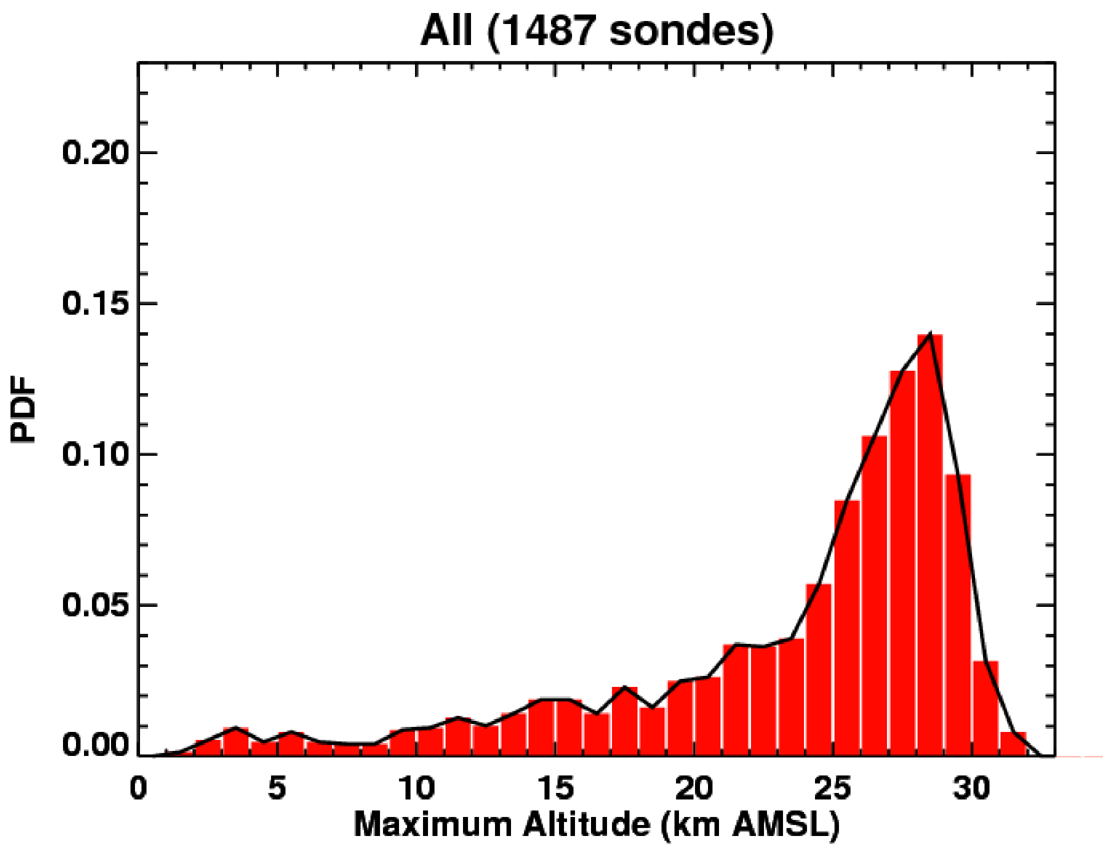

Figure 4. Histogram of the maximum height obtained by MC3E soundings.

3.2 C-SAPR

The C-band Scanning ARM Precipitation Radar (C-SAPR) was installed February 18, 2011, at the SGP I7 (Nardin, OK) site within 30 km north of the CF. The first data available from the ARM Data Archive is from March 25, 2011, a month before the start of MC3E campaign. During MC3E, the C-SAPR system provided general surveillance and precipitation system morphology and evolution. It also provided quantitative precipitation estimates and dual polarization radar insights into precipitation microphysics. Over the course of the MC3E campaign, approximately 50 hours of usable C-SAPR data was obtained during light (~1 mm/hour) to heavier (>100 mm/hour) precipitation. Radar data quality was within reasonable bounds, although lower than expected as a consequence of the limited operational uptime for these systems (e.g., need for improved clutter mitigation methods; campaign standard deviation of phase measurement was relatively high for research quality instrument). The observations demonstrated only minor radar miscalibration bias (the reflectivity factor Z was usually within 2 dBz compared to independent disdrometer and radar measurements). Mechanical failures were the major limitation for C-SAPR usefulness and resulted in loss of capture for significant precipitation events on May 10 and 11. Significant attenuation in rain at C-band was also problematic when considering the presence of heavier precipitating cores. During one event (May 20), complete extinction was observed for several sectors along the stronger squall line.

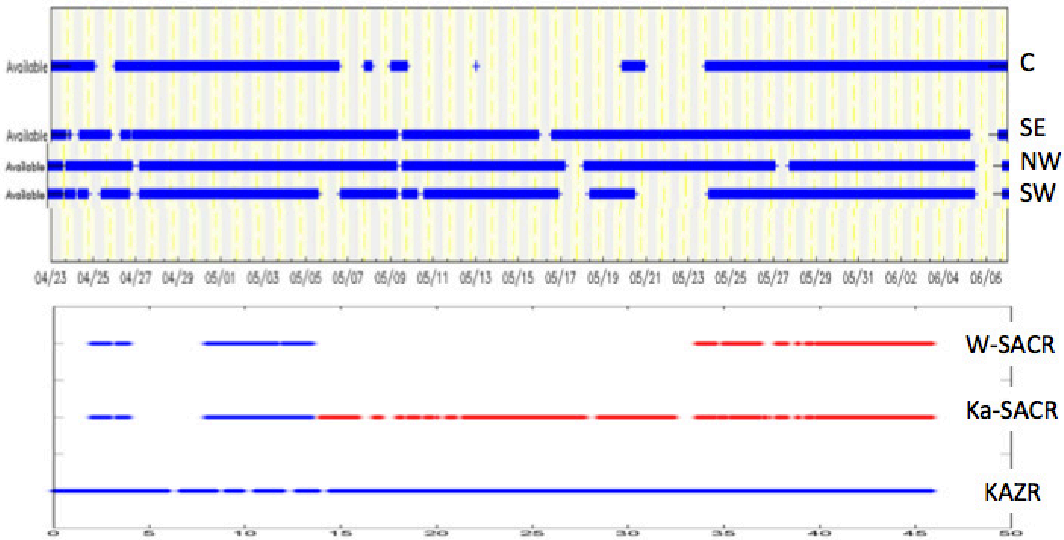

Figure 5. ARM radar system operation uptime (blue/red) for the precipitation radar systems (top, C-band, SE/NW/SW X-band) and the cloud radar systems (W/KA-Scanning ARM Cloud Radar (SACR), Ka-band ARM Zenith-pointing Radar (KAZR)). For the SACR systems, blue represents operation in vertically pointing mode while red indicated operation in scanning mode. This plot does not represent quality of observations during operation.

3.3 X-SAPRs

Three X-band Scanning ARM Precipitation Radars (X-SAPRs) were deployed in the vicinity of the CF during MC3E. The Southeast X-band scanning ARM precipitation radar (X-SAPR) (I4 -Billings, OK) was installed on December 10, 2010, with first available data on December 14, 2010. The SW (I5 – Garber, OK) and NW (I6 – Lamont, OK) X-SAPRs were installed with data available on April 20, 2011, just before the start of the MC3E campaign. The primary function of the X-SAPR systems was the use of multi-Doppler techniques for the retrieval of storm-relative winds including vertical velocity of deep convective cores. The SE and SW X-SAPR systems operated well for the majority of the campaign (see Figure 4) collecting a data set that includes roughly 30 hours of data obtained during significant (> 1 mm/hour) precipitation. The NW X-SAPR system had a pointing error during the entire campaign, but data sets may be salvageable with appropriate adjustments. Data quality during the campaign was below research-level standards for quantitative precipitation estimation purposes (e.g., relatively higher errors in observed X-band differential phase measurements). However, Doppler velocity measurements were of reasonable quality for velocity dealiasing, gridding, and hence the stated multi-Doppler retrieval purposes. Significant attenuation in rain was observed for many campaign events. While this was expected, complete extinction during several events contributed to a limited usefulness of the X-SAPRs for redundant or complementary radar measurements (e.g., Z, ZDR) despite available correction methodologies.

3.4 N-Pol

The NASA GPM-GV S-band transportable dual-Polarimetric Radar (N-POL) operated continuously from April 22 through June 2, with the exception of a four-day down period from May 19 to 23. Overall, the N-POL operation was considered a success, collecting a rich data set including tornadic supercells and mesoscale convective systems. The system was predominantly operating in slower-scanning range height indicator modes directed over the CF and should provide a higher-resolution reference for detailed column-based retrieval efforts over the facility.

3.5 Ka/W Scanning ARM Cloud Radar

The Ka/W-SACR was installed at the ARM SGP CF in February 2011, and ingested data begins April 30, 2011 (a few days after the start of the MC3E campaign). There were issues with the SACR scanning pedestal, so scanning data was only collected from May 24 through June 6. There was some vertically pointing data collected prior to this time period. The W-band system suffered from a lack of sensitivity and is likely not useful for many scientific applications.

3.6 Ka-band ARM Zenith-pointing Radar (KAZR)

The KAZR was first installed at the ARM SGP CF in December 2010 and first began collecting data on January 18, 2011. The system operated with two distinct long pulse modes during MC3E: 12-μs long pulse: January 18, 2011, to May 3, 2011; and 4 μs long pulse: May 3, 2011 to present. Calibration was likely stable within these modes, but raw system data was apparently biased low on the order of 10 dBz.

3.7 915 MHz Radar Wind Profiler (RWP) Systems

Four RWP systems operated during the course of the MC3E campaign at sites I8 – Tonkawa, OK, I9 – Billing, OK, I10 – Lamont, OK, and the CF. These systems operated in dedicated vertically pointing modes for the purposes of collecting precipitation and vertical velocity observations (Tridon et al. 2013; Giangrande et al. 2013). The data quality, calibration stability, and overall data availability indicate these systems as among the most reliable during the entire campaign. There were some select issues with individual profiler operations during major power losses (e.g., events wherein backup systems apparently failed after nearby lightning strikes had temporarily knocked out power to various SGP profilers). These issues were primarily limited to the satellite profiler systems located in the dual-Doppler lobes of the X-SAPR systems, as the CF profiler recorded no significant data loss during the campaign.

3.8 NASA ER-2 Flights

The NASA ER-2 serves as a GPM core satellite simulator operating at a nominal altitude of 20 km with a payload including a dual-frequency, dual-beam, nadir-pointing Ka-Ku band Doppler radar (High-Altitude Imaging Wind and Rain Airborne Profiler (HIWRAP)) and two multi-frequency passive microwave radiometers (the airborne Conical Scanning Millimeter-Wave Imaging Radiometer (CoSMIR); and the Advanced Microwave Precipitation Radiometer (AMPR)).

Table 2. The ER-2 flew a total of 14 science flights totaling more than 73 flight hours from Offutt Air Force Base in Bellevue, NE.

Flight Date	Flight Times	Conditions	Instrument Status
4/22	1919–0113 UTC	Transit - Supercell	
4/25	0712–1230 UTC	MCS convection and stratiform rain, Land surface	
4/27	0457–1139 UTC	Widespread stratiform	HIWRAP, CoSMIR down
5/7	1807–2308 UTC	Gulf Calibration Flight	
5/8	1759–2109 UTC	Land Surface Flight	
5/11	1505–1923 UTC	Land surface flight, MCS stratiform precipitation	
5/18	0512–0955 UTC	Small multi-cell system convection	CoSMIR down
5/20	1313–1856 UTC	MCS Convection and Stratiform precipitation	
5/23	2055–0233 UTC	Supercell and anvil	AMPR data not collected
5/24	1855–2325 UTC	CHILL coordination, also MCS convection, stratiform over SGP	
5/29	1753–2353 UTC	Land surface and Gulf calibration	
6/1		MCS convection off-site	

3.9 University of North Dakota Citation Flights

The University of North Dakota Citation provided in situ observations of cloud, precipitation, aerosol, and atmospheric state.

Table 3. The Citation flew 15 data missions totaling 42.6 flight hours.

Flight Date	Flight Times	Conditions	Instrument Status
4/22	2234–0057 UTC	Supercell	CIP/2DC intermittent, Edgetech bad
4/25	0921–1222 UTC	MCS convection and stratiform rain	Nevzorov liquid water content (LWC) inoperable, no CPC
4/27	0754–1139 UTC	Widespread stratiform	Nevzorov LWC inoperable, no CPC
5/1	1629–1842 UTC	Baroclinic Widespread Stratiform	CIP noisy, no CPC, anti-ice off early
5/10	2150–0011 UTC	Baroclinic Widespread Stratifrom	CIP/2DC noisy, 2DC good for second half of flight

Table 3. (contd)			
Flight Date	**Flight Times**	**Conditions**	**Instrument Status**
5/11	1602–1927 UTC	MCS stratiform precipitation	CIP noisy, some 2DC problems
5/18	0720–0922 UTC	Anvil	No Ultra-High Sensitivity Aerosol Spectrometer (UHSAS) at end of flight
5/20	1255–1702 UTC	MCS Convection and Stratiform precipitation	No UHSAS
5/23	2123–0042 UTC	Supercell and anvil	CIP/2DC intermittent, airspeed issues late in flight
5/24	2011–2229 UTC	Anvil	CIP issues, a few gaps in imaging probes, airspeed issue
5/30	1722–2102 UTC	Cumuliform non-precipitating	King LWC inoperable, tunable diode laser bad
6/1	1630–1744 UTC 1907–2203 UTC	Cumuliform non-precipitating	No CIP
6/2	1441–1819 UTC	Cumuliform non-precipitating	No CIP, No Applanix (winds)

4.0 Ongoing or Future Research Opportunities

There are a number of current and ongoing research projects using the MC3E data set, and it is anticipated that this data set will be used for years to come, not only toward the original campaign science goals, but also for many additional topics. A few of the current and anticipated research activities are:

- testing of column-based and scanning weather radar vertical velocity, drop size distribution, and rainfall retrievals
- cloud-aerosol interactions in a deep convection model intercomparison study
- cold pools and convective re-development
- satellite-based precipitation retrieval algorithm development
- melting layer precipitation microphysics studies
- multi-frequency, spectra-based retrievals of cloud and precipitation
- variability in derived large-scale forcing data sets.

5.0 MC3E Data Access

As a joint field campaign at an ARM fixed site, MC3E data are stored in different places depending on the funding agency (DOE, NASA), measurement status (routine, long-term, intensive operational period (IOP)), and data product type (ingest, evaluation, value-added product). This section summarizes the location of these data products.

5.1 ARM Standard Datastreams

http://www.archive.arm.gov

All standard ARM observations at the SGP, including radar, lidar, radiation, surface meteorology, etc., are available from the ARM Data Archive. Access to the ARM Data Archive requires a freely available user account. Highlights include:

915 MHz RWP	Aerosol Observing System	C-SAPR
Cimel Sun Photometer	JW Disdrometer (CF)	Doppler Lidar
Infrared Thermometer (CF, EFs)	Ka-SACR	KAZR
KAZR Spectra	Surface Meteo (CF, EFs)	MFRSR (CF, EFs)
Micropulse lidar	Solar/IR Radiation (CF/EFs)	
Radiosonde (CF)	SWATS (CF, EFs)	Total Sky Imager
Ceilometer	W-SACR	X-SAPR

5.2 ARM MC3E IOP Data

http://iop.archive.arm.gov/arm-iop/2011/sgp/mc3e

Data sets collected only during the MC3E data set under ARM funding, or as part of ARM supplementary MC3E IOPs, are available in the ARM IOP archive. Access to this archive requires a freely available user account, which is the same as the standard ARM Data Archive account.

- Video disdrometer CF
- Radiosondes (S1-S5, no CF)
- BNL Microwave Radiometer (S5)
- High Volume Precipitation Spectrometer (Citation)
- Ultra-High Sensitivity Aerosol Spectrometer (Citation)
- Single Column Model Forcing
- Vertically Pointing S-band radar (CF)

- 449 MHz Profiler (CF)
- Parsivel Disdrometer (CF)
- Surface Meteorology (CF)
- Vertical Air Motion (CF).

5.3 NASA MC3E IOP Data

ftp://gpm.nsstc.nasa.gov/gpm_validation/mc3e

- Agricultural Research Service land surface
- Citation Navigation Data
- ER-2 Navigation Data
- NEXRAD (KGLD, KICT, KINX, KTLX, KTWX, KVNX)
- NASA Polarimetric Radar (N-POL)
- OU Mesonet Data
- NASA Goddard Weather Research and Forecasting (WRF) Output
- Advanced Microwave Precipitation Radiometer (AMPR) (ER-2)
- In situ cloud microphysics (Citation)
- CoSMIR (ER-2)
- NASA Disdrometer and Rain Gauge Network
- Flight Tracks
- HIWRAP (ER-2)
- 449 MHz (Ultra-High Frequency) Wind Profiler
- Reports (Forecasts, Instrument, Mission Scientist, Plan of the Day)

5.4 ARM Value-Added Products

http://www.arm.gov/data/vaps

- AERI Noise Filter (AERINF)
- AERI Profiles of Water Vapor and Temperature (AERIPROF)
- Aerosol Best Estimate (AEROSOLBE)
- Aerosol Intensive Properties (AIP)
- Aerosol Optical Depth from MFRSR/NIMFR (AOD)
- ARM Best Estimate Data Products (ARMBE)

- Best Estimate Fluxes from Energy Balance Bowen Ratio (EBBR) Measurements and Bulk Aerodynamic Calculations (BAEBBR)
- Best Estimate Radiative Flux (BEFLUX)
- Microwave Radiometer Scaled Sonde Profile (LSSONDE)
- Cloud Properties from MFRSR Using Min algorithm (MFRSRCLDOD)
- Cloud Mask from MicroPulse Lidar (MPLCMASK)
- MWR LWP/PW Retrievals (MWRRET)
- Planetary Boundary Layer Height (PBLHT)
- Data Quality Assessment for ARM Radiation Data (QCRAD)
- Raman Lidar Vertical Profiles (RLPROF)
- Surface Spectral Albedo (SURFSPECALB)
- Tower Water Vapor Mixing Ratio (TWRMR)

5.5 Evaluation Phase Value-Added Products

Variational Analysis (VARANAL)	Entire campaign
KAZR Active Remote Sensing of Clouds (ARSCL)	Entire campaign
Mapped Moments to a Cartesian Grid (MMCG) C-SAPR	4/24, 25, 27
	5/1, 20, 23-26, 31
Convective Vertical Velocity (CONVV)	4/25, 5/20, 23
Interpolated Sounding (INTERPSONDE) CF	Entire campaign
Merged Sounding V2 CF	Entire campaign
Microbase-KAZR CF	Entire campaign
MFRSR – Column Intensive Properties (MFRSRCIP)	Entire campaign
Best Estimate Land Surface Properties (ARMBELAND)	Entire campaign
Quantitative Precipitation Estimates (QPE)	Entire campaign

5.6 Relevant External Data Sets from the ARM Data Archive

- SuomiNet Global Positioning System (many sites)
- Arkansas Red River Basin Forecast Center (ABRFC) Precipitation

- ECMWF Diagnostic Analyses
- Geostationary Operational Environmental Satellites (GOES)
- NASA Langley visible infrared solar-infrared split-window technique (VISST) Cloud and Radiation Properties from GOES.

6.0 References

Giangrande, SE, S Collis, J Straka, A Protat, C Wiliams, and S Krueger. 2013. "A summary of convective-core vertical velocity properties using ARM UHF wind profilers in Oklahoma." *Journal of Applied Meteorology and Climatology* 52:2278-2295 doi:10.1175/JAMC-D-12-0185.1.

Heymsfield, GM, L Tian, L Li, M McLinden, and JI Cervantes. 2013. "Airborne radar observations of severe hailstorms: Implications for future spaceborne radar." *Journal of Applied Meteorology and Climatology* 52:1851-1867. doi:10.1175/JAMC-D-12-0144.1.

Iguchi, T, T Matsui, A Tokay, P Kollias, and W-K Tao. 2012. "Two distinct modes in a one-day rainfall event during MC3E field campaign: Analyses of disdrometer observations and WRF-SBM simulation." *Geophysical Research Letters* 39(24). doi:10.1029/2012GL053329.

Matsui, T, T Iguchi, X Li, M Han, W-K. Tao, WA Petersen, T L'Ecuyer, R Meneghini, W Olson, CD Kummerow, AY Hou, MR Schwaller, EF Stocker, and J Kwaitkowski. 2013. "GPM satellite simulator over ground validation sites." *Bulletin of the American Meteorological Society* 94:1653-1660. doi:10.1175/BAMS-D-12-00160.1.

Tao, WK, D Wu, T Matsui, C Peters-Lidard, S Lang, A Hou, M Rienecker, WA Petersen, and MP Jensen. 2013. "Precipitation intensity and variation during MC3E: A numerical modeling study." *Journal of Geophysical Research* 118:7199-7218. doi:10.1002/jgrd.50410.

Tridon, F, A Bataglia, P Kollias, EP Luke, and CR Williams. 2013. "Signal processing and reflectivity calibration of the Atmospheric Radiation Measurement Program 915 MHz wind profilers." *Journal of Atmospheric and Oceanic Technology* 30:1038-1054. doi:10.1175/JTECH-D-12-00146.1.