4.1

An Overview of the Bow Echo and MCV Experiment (BAMEX)

Christopher A. Davis and M. L. Weisman
National Center for Atmospheric Research
Boulder, Colorado 80307

1. Introduction

The Bow Echo and Mesoscale Convective Vortex (MCV) Experiment (BAMEX) is a study of life cycles of mesoscale convective systems using three aircraft and multiple, mobile ground-based instruments. It represents a combination of two related programs to investigate (a) bow echoes (Fujita, 1978), principally those which produce damaging surface winds and last at least 4 hours and (b) larger convective systems which produce long lived mesoscale convective vortices (MCVs) (Bartels and Maddox, 1991). The project was conducted from 20 May to 6 July, 2003, based at MidAmerica Airport in Mascoutah, Illinois. A detailed overview of the project, including preliminary results appears in Davis et al. (2004). The reader wishing to view processed BAMEX data should visit http://www.joss.ucar.edu/bamex/catalog/.

To augment what is already published regarding BAMEX, we will herein discuss some preliminary, perhaps speculative, findings from the project. Broadly speaking, these fall into two categories: scientific results and lessons learned about the deployment of facilities or about the infrastructure of the project.

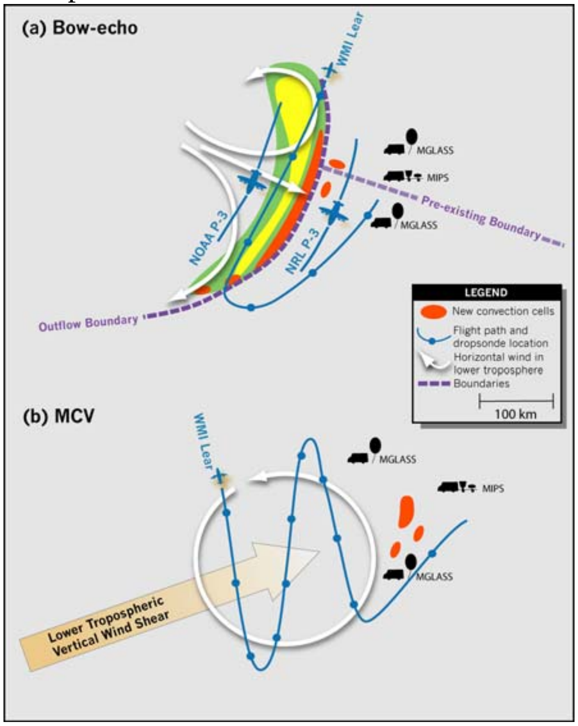
2. Facility Deployment

Three aircraft were used in BAMEX: one of the P-3s from the National Oceanic and Atmospheric Administration (NOAA), the Naval Research Laboratory (NRL) P-3 and a Lear jet leased from Weather Modification Inc. (WMI). Mobile Ground-based facilities included the Mobile Integrated Profiling System (MIPS) from the University of Alabama (Huntsville) and three Mobile GPS-Loran Atmospheric Sounding Systems (MGLASS) from NCAR. The MIPS and MGLASS were referred to as the ground based observing system (GBOS). The two P-3s were each equipped with tail Doppler radars, the Electra Doppler Radar (ELDORA) being on the NRL P-3. The WMI Lear jet deployed dropwinsondes from roughly 12 km AGL.

For MCSs, the objective was to sample mesoscale wind and temperature fields while obtaining high-resolution snapshots of convection structures, especially those linked to damaging surface winds. The ideal deployment (Fig. 1a) featured the Doppler aircraft on either side of the convective line with the Lear jet sampling environmental conditions ahead of the system as well as mesoscale circulation features. The NOAA P-3 was also equipped with cloud and particle imaging probes to quantify the microphysical composition of the stratiform region. The GBOS was focused on boundaries ahead of the MCS and measuring boundary evolution both ahead and within the MCS (i.e. measuring cold pool characteristics).

For mature MCVs, the lack of significant precipitation implied no need of the Doppler-equipped aircraft (except IOP 1). The Lear jet flew legs across the MCV (Fig. 1b) to cover the circulation of the MCV as well as some of the region outside the circulation. The MGLASS augmented sounding coverage, especially on the downshear side of the vortex.

The main challenge for BAMEX was complicated coordination of aircraft and ground teams near areas of hazardous weather. The ground teams were based near the location where convection was anticipated, hence they often had to drive 300-500 km in a single day to be in position. The aircraft were restricted to roughly an area of 600 km surrounding MidAmerica Airport near St. Louis, the base of the project.



Real-time aircraft communication (plane-to-plane and plane-to-ground) used internet chat room capability as well as satellite phones. This worked very well and overcame some of the complications related to intermittency of weather displays for the NRL P-3 and complex direction of the Lear jet, which had only weather-avoidance radar on board. Effective communication allowed extensive simultaneous Doppler measurements from each P-3, known as quad-Doppler, where four beams sample approximately the same volume of air. It also allowed the Lear jet to operate in the air above the NOAA P-3, a situation complicated by the rule that the two aircraft were required to be more than 25 nm apart when dropwinsondes were released.

Extensive communication and forecasting efforts led to accurate positioning of the GBOS in more than half of the intensive observing periods (IOPs). A team of both National Weather Service and university forecasters participated in BAMEX, with one forecaster and one to two nowcasters on duty each day. Forecasters and nowcasters each participated for at least one week. Primary forecast considerations were: (a) deployment of the GBOS; (b) setting take-off times for aircraft (24 h in advance). Primary nowcast considerations were (a) fine-tuning the GBOS position (1-6 hour forecast; (b) providing severe weather warnings for GBOS (0-30 minutes); (c) movement and organization of convection (0-1 h) and (d) weather hazards affecting aircraft return to MidAmerica Airport (0-3 h).

Forecasters were aided by a suite of numerical forecasts from operational models to “convection resolving” models such as WRF, RAMS and MM5. The performance of WRF is summarized in Done et al. (2004).

In all, there were 18 IOPs (Table 1), sampling 26 convective entities (including MCVs). Useful data was received from 437 or the 460 dropsondes deployed. The P-3s flew for about 120 research hours each, with roughly a third of that time used for ferrying to the systems of interest. Over 200 MGLASS soundings were also launched.

3. Lessons Learned

a. Facility deployment

We were able to successfully position the GBOS in nearly half the IOPs during BAMEX. This success rate was probably as high as anyone could have imagined prior to the experiment. However, the negative side was the incredible amount of driving (over 15,000 km per vehicle) during the experiment, coupled with frequent re-positioning. The latter meant that personnel seldom stayed in the same place on consecutive nights. In addition, the 4-5 hour drives coupled with 8-h data collection periods in a single day were common. Soundings often had to be launched in wind and rain. The enthusiasm of the scientists was able to overcome these difficulties, but fatigue was perhaps more of a factor that in other field efforts.

Aircraft takeoff times had to be set roughly 24 h in advance. Because of the duty cycle of flight crews, the takeoff time could be delayed, but it could never be advanced. This constraint led to an early bias in the timing of takeoffs. Delays often occurred, to the point where some missions were nearly cancelled due to a lack of sufficient convection organization. However, because the time period from

IOP	**Location**	**Non-bowed MCS**	**Mature MCV**	**Forming MCV**	**Bow Echo**
1: 24-25 May	OK, AR		X(2,3,4)		X(5)
2: 28-29 May	IL, IN	X(1,2,3,4)		X(3,4)	X(2,3,4,5)
3: 30-31 May	IL, IN	X(1,2,3,4,5)			
4: 2-3 June	KS, AR, MS		X(4)		X (1,2,3,4)
5: 5-6 June	TX, AR		X(1,3,4)		
6: 8 June	IN, OH	X(2,3,4)			
7: 9-10 June	NE, IA, MO, KY, TN	X(4)		X(3,4)	X (1,2,3,4,5)
8: 11 June	AR		X(4)		
9: 20-21 June	NE	X(2,3,4)			
10: 22 June	SD				X(1,2,3,4)
11: 23 June	NE, KS	X(1,2,3,4)			
12: 24 June	NE, IA				X(1,2,4,5)
13: 25-26 June	IL			X(3,4)	X(1,2,3,4)
14: 29 June	KS	X(1,2,3)			
15: 29-30 June	KS		X(1,3,4)		
16: 2-3 July	MN				X(1,2,3)
17: 4-5 July	IA, IL, IN	X(1,4)		X(3,4)	X(3,4,5)
18: 5-6 July	NE, IA	X(1,2,3,4)		X(3)	X(2,3,4,5)
Other Missions					
7-8 June	TX	X(1)			
10 June	MO, IL				X(5)

Table 1. Summary of phenomena sampled during BAMEX IOPs and other significant missions. X's indicate type of system. Red X's indicate MCVs within which new convection initiated. Blue X's indicate severe bow echoes with widespread damaging winds. Green X's indicate dissipating MCSs. Numbers in parentheses list observing platforms that sampled each case; 1 = GBOS; 2 = NRL P-3; 3 = NOAA P-3; 4 = Lear Jet with dropsondes; 5 = damage survey. For locations, AR=Arkansas, KY=Kentucky, IA=Iowa, IN=Indiana, IL=Illinois, KS=Kansas, MO=Missouri, MN=Minnesota, MS=Mississippi, NE=Nebraska, OH=Ohio, SD=South Dakota, TN=Tennessee, and TX=Texas.

the first signs of organization to the production of damaging wind was often only an hour or so, it was difficult to get to MCSs in their most severe phase, although we achieved this in several cases.

Flight tracks proceeded according to the general model in Fig. 1a, but with considerable improvisation. The lower fuselage radar of the NOAA P-3 was extremely valuable for determining flight tracks en route. The NRL P-3 relied on composite radar images uploaded through a satellite phone that experienced intermittent outages. Thus, there were times when the NRL P-3 could not remain close enough to the convection to obtain useful data. In general, tracks of the NRL P-3 required substantial real-time coordination from the operations center. Tracks of the Lear jet were entirely determined from the operations center. The large number of turns of the aircraft, the need to monitor the positions of the P-3s, the need to avoid dropsonde releases over heavily populated areas and the need to consider potential refueling airports (the plane did not have to return to Mid America to refuel) created a full-time job for two dropsonde coordinators.

In addition, we were reminded of the immense difficulty of switching from nighttime to daytime operations and back again. BAMEX was a project that was extremely demanding logistically and physically.

b. Science

Scientific results from the project are forthcoming as data analysis proceeds. However, a few noteworthy general results can be summarized.

Mesoscale rotational features were found in most convective systems and on a variety of scales. There was evidence for pulsation of some convective systems, with mesoscale vortex formation suggested with each pulse.

Damaging winds tended to not occur with the largest, mature MCSs, but rather, seemed more common in early stages of MCS and often occurred in fairly narrow swaths, suggesting processes on the scale of individual cells were important for wind production. This was true in IOPs 7, 12 and 18, as well as the 10 June St. Louis bow echo.

The two P-3s were able to coordinate in several instances to produce quad-Doppler measurements. A quad-Doppler analysis of the IOP 7 bow echo revealed an exceptionally strong elevated rear-inflow jet with relatively weak surface winds about two hours after damaging surface winds were reported. It is possible that the boundary layer began decoupling during the intervening time, but this did not happen in every case. In IOP 18, the greatest damage occurred just prior to midnight.

Some clues about downdrafts that may be related to damaging winds may come from detailed examination of in-situ cloud and precipitation measurements made on the NOAA P-3. These were often collected in the stratiform region near the leading line. In a few cases, data were collected in the reflectivity notch, a feature characteristic of bow echoes with damaging winds. In one case, frozen particles of modest size were observed at temperatures as high as 7^{o}C, perhaps suggesting the presence of strong downdrafts. One of the main compromises regarding microphysical measurements was the fact that slowly descending spirals were necessary for the best measurements, but these took up to 45 minutes to complete and during this time, the Doppler radar data were not useful.

Mature MCVs occurred in surprisingly varied environments. In IOP 1, the vector wind difference between 600 and 900 hPa was about 15 m s^{-1}, far exceeding that for typical MCV environments. The case of IOP 8 was a multi-day MCV embedded in exceptionally weak vertical shear.

One MCV featured continuous stratiform rainfall within its circulation for several hours after its formation (IOP 1, 24 May). Fortuitously, both P-3s were able to extensively sample the vortex owing to the fact that they were already in the air, heading toward what was supposed to be the continuing evolution of the bow echo that spawned the MCV. However, the bow echo decayed.

There were many more MCVs during BAMEX than could be sampled, due to resource limitations. Although convection re-triggered within the circulations of some of the MCVs, only one case (iop 8) was a true multi-day MCV. However, the MCV only initiated an MCS for one night (11 June, before we sampled it). After that, it began acquiring characteristics of an extratropical cyclone.

The MCVs of IOP 8 and IOP 15 clearly penetrated into the boundary layer. This behavior has significant bearing on tropical cyclogenesis dynamics. Anomalous potential vorticity was found at least down as far as the top of the daytime boundary layer.

c. Future Research Directions

The BAMEX scientists anticipate having a collection of papers ready for journal submission in the spring of 2005. In addition, we are beginning some of the modeling work that was originally proposed. By this time, we expect that approximately half the IOPs will have been analyzed in varying detail. There are a number of non-bow-echo cases with excellent data capturing a variety of MCS structures. It is important that these cases are examined as well (see Table 1).

The data in BAMEX offer unique opportunities to investigate predictability issues associated with MCSs and MCVs. From this perspective, we have essentially conducted a targeted observations experiment, focusing observations within and around convective systems. Given that soundings are relatively easy to assimilate, there are ample opportunities to assess whether and how concentrated data affect forecast skill.

The use of cloud-system-resolving models to support operations is not entirely new, but the success of these models, particularly WRF, during BAMEX, has spawned remarkable interest in performing similar real-time forecasting activities to examine prediction skill in both warm and cool seasons. This outgrowth was unexpected.

Finally, there are several lessons learned about logistics in BAMEX that may prove valuable to future field efforts such as VORTEX II. In particular, the use of dropsondes from a high-altitude aircraft is strongly recommended as a means of efficiently documenting environmental characteristics. Environments of multiple storms could be sampled in an attempt to understand those apparently subtle distinctions that differentiate one mode of convection from another.

References

Bartels, D. L., and R. A. Maddox, 1991: Midlevel cyclonic vortices generated by mesoscale convective systems. *Mon. Wea. Rev.*, **119**, 104--118.

Davis, C., N. Atkins, D.Bartels, L. Bosart, M. Coniglio, G. Bryan, W. Cotton, D. Dowell, B. Jewett, R. Johns, D. Jorgensen, J. Knievel, K. Knupp, W.-C. Lee, G. McFarquhar, J. Moore, R. Przybylinski, R. Rauber, B. Smull, J. Trapp, S. Trier, R. Wakimoto, M. Weisman, and C. Ziegler, 2004: The Bow-Echo And MCV Experiment (BAMEX): Observations and Opportunities, *Bull. Amer. Meteor. Soc.*, In Press: August Issue.

Done, J., C. Davis, and M. Weisman, 2004: The Next Generation of NWP: Explicit Forecasts of Convection Using the Weather Research and Forecasting (WRF) Model. *Atmos. Sci. Lett.*

Fujita, T. T., 1978: Manual of downburst identification for project NIMROD. Satellite and Mesometeorology Research Paper No. 156, Department of Geophysical Sciences, University of Chicago, 104 pp.