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ANALYSIS AND MODELING OF SUMMERTIME CONVECTIVE CLOUD AND PRECIPITATION STRUCTURE OVER THE SOUTHEASTERN UNITED STATES

Report for the period 15 September to 14 June 1989

NASA Grant NAG8-654

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1. Introduction

This report describes work completed under NASA Grant NAG8-654 for the period 15 September 1988 through 14 June 1989. This work involves primarily data analysis and numerical modeling efforts that are related to the 1986 Satellite Precipitation and Cloud Experiment (SPACE). Progress during this period includes the following:

1) further testing and development of the the RAMS numerical modeling system on the Alabama CRAY X-MP/24;

2) a continuation of the observational analysis of the 13 July 1986 mesoscale convective system (MCS);

3) an initial investigation of a small MCS that formed over the COHMEX region on 15 July 1986.

Details under each of these individual tasks are given in the following sections.

2. RAMS Testing and Development

The Regional Atmospheric Modeling System, developed at Colorado State University, was previously installed on both the Johnson Research Center VAX 11/785 and the Alabama CRAY X-MP/24 supercomputer in May 1988. Further testing and code development has been completed since 15 September 1988. Some effort was required to develop an efficient communication protocol between the CRAY and VAX, such that model activities can be efficiently submitted, monitored and returned to the VAX without direct login access to the Cray. All model computations will be conducted on the CRAY, while limited model development and analysis of simulations will be completed on the VAX. Since model output can be voluminous (up to 300 Mbyte per run), an efficient data management and storage scheme will be required.

Because the RAMS does not contain perturbation techniques to efficiently initiate cloud-scale circulations, some effort was required to develop realistic, yet economical ways of producing convective clouds. Two options have been developed so far. The first is a moisture perturbation which is designed to simulate the time-integrated effects of low-level convergence, as well as the initial cloud. In this method, a cylindrical perturbation of specified radius and height (input by the user) contains a moisture perturbation whose core contains a constant water vapor mixing ratio from the surface up to a maximum height. Any supersaturated value above cloud base is forced to remain at saturation, with the excess converted to cloud liquid water. From the edge of the core (at half radius) to the maximum radius of the cylinder, the mixing ratio is assumed to decrease linearly to environmental values.

The second method utilizes a scheme developed by McNider and Kopp (1989), in which the horizontal dimension of temperature perturbations within the ABL are scaled according to the ABL depth. Thus, this technique incorporates realistic constraints in the size of initial thermal circulations. The technique requires input of two parameters, surface heat flux and boundary layer depth. This algorithm has be encoded into RAMS and is currently undergoing final testing.

A number of modeling applications are planned using the RAMS. For the 13 July MCS event, both mesoscale and cloud-scale modeling activities are planned. Initial work will utilize a 2-D version of the model to examine the growth and mature structure of the 13 July case. Additional 3-D simulations will be conducted on the cloud scale in order to further understand specific cloud-scale processes and the interaction with the mesoscale.

3. 13 July 1986 COHMEX Analysis Work

Several goals have been defined for this case, including (1) a general description of the growth and structure (kinematic and precipitation) of the MCS observed on this day; (2) a definition of the relationship between the cloud and mesoscale flows, with a focus on variability of deep convection, and the impact of deep convection on the MCS. These two objectives require considerable analysis of both cloud-scale flows (using multiple Doppler radar) and mesoscale flows. The following subsections summarize work conducted on both scales.

a) Conceptual model

A number of data sources are being analyzed in detail in order to describe the structure of the 13 July MCS. Data examined to date include RADAP, surface data, Doppler radar data, GOES data and rawinsonde data. One applied research goal of this work is to relate the results of a comprehensive analysis to existing and future satellite measurements of cloud structure and precipitation. Such measurements require detailed knowledge of precipitation characteristics, including type, concentration and distribution. A conceptual model illustrating the developing and mature phase structures of the 13 July MCS presented in Fig. 1 incorporates all data sets mentioned above. During the developing stage (2.5 h after first echo) a broad spectrum of deep convective clouds were observed, exhibiting a range of cloud tops (8-16 km), associated updraft/downdraft vigor and precipitation intensity. Only the more vigorous clouds developed significant cold low-level outflow pools, which independently and interactively triggered secondary deep convection, and thereby promoted horizontal expansion of the system. Three hours later during the mature MCS phase, a uniform mesoscale anvil had formed, and much less vigorous deep convection was confined to the leading (south) edge of the system. Radar analyses described in more detail below measured the vertical and horizontal flow magnitudes and precipitation distribution shown in Fig 1b.

It is interesting to note that at the mature stage the highest (coldest) cloud tops were not generally colocated with the deep convection, but occurred in some portions of the MCS over the mesoscale anvil ~50 km to the rear of the convective line. Such patterns appear to be common within MCSs entering their mature stage (e.g., the 10-11 June Pre-STORM squall line; Zipser, personal communication). Additional analyses of the 13 July MCS should provide further insight on this relation. At this point, it appears that the cold cloud tops over the mesoscale anvil represent the location of both previously intense convection and continued mesoscale ascent within the anvil.

b) VAD analyses

The movement of the MCS directly over the Doppler radar network allowed for determination of mesoscale flows using VAD analyses with the CP-4 radar. A number of such analyses have been completed during the mature to dissipating stages of the MCS. Figure 2 shows results within the stratiform region for a 40 km radius at 2334 UTC. The following features represent the important structural aspects: (1) a bright-band signature appears in the reflectivity profile (Fig. 2a); (2) a jet appears just below the bright band peak (Fig. 2b); (3) the flow is convergent at middle levels (4-8 km), divergent below 4 km and weakly divergent above 8 km (Fig. 2d); (4) the divergence profile thus produces weak mesoscale ascent peaking at ~10 cm/s above 6 km and descent of ~30 cm/s near 4.5 km. Such patterns are similar to VAD measurements of both tropical and midlatitude squall lines.

At the VAD analysis time of Fig. 2, GOES IR temperatures were exhibiting a warming trend. Thus, the anvil cloud top was sinking while ascent was occurring within the anvil below. This relationship will be examined in greater detail with additional analyses, and with the numerical model. Such comparisons between trends in cloud-top temperature and mesoscale vertical motions within the cloud below should provide greater insight on physical properties of mesoscale anvils.

c) Multiple Doppler analyses

The general objective of this work is to define the kinematic and precipitation characteristics of deep precipitating convection existing within low-shear, subtropical (continental) environments. The work on deep convection involves both observational (primarily Doppler radar) and associated numerical modeling components. Several cloud systems occurring within and in advance of the 13 July MCS have been examined in some detail. A summary of this work is presented in Appendix A.

One objective is to define the specific relationships between cloud-scale flows and mesoscale flows, within evolving mesoscale convective systems. This has been, and will continue to be, an important but unanswered problem. In particular, the following questions will be addressed:

(1) What are the instantaneous and time-integrated convective transports (including entrainment and detrainment) in relation to mesoscale flows within a MCS?

(2) What are the structural and evolutionary details of the kinematic and precipitation structures of clouds existing within low-shear, moist environments? Work under this category will include the development of new conceptual models and/or refinement of existing models.

(3) In relation to both items above, how do clouds dissipate, i.e., what are the characteristics of updrafts, downdrafts and precipitation once the cloud becomes decoupled from low levels?

d) Miscellaneous precipitation analyses

Radar measurement of precipitation is fundamental in the observational analyses. The C-band CP-4 radar was the primary source of surveillance scans (acquired every 6 min) during COHMEX. However, attenuation can be significant at C-band wavelengths in heavy rain. Therefore, some effort to partially correct for attenuation has been expended. The method used applies an attenuation correction factor to the raw data prior to interpolation to Cartesian coordinates. This method has been thoroughly tested on the 13 July data and appears to provide a much improved estimate of C-band attenuation. Such corrected values will be used for both precipitation estimation and compositing techniques discussed in previous reports under this grant.

4. Preliminary analysis of the 15 July MCS

The 15 July MCS exhibited appreciable differences in structure and evolution from the 13 July system. It developed during the early morning hours (~0800 UTC) and dissipated by midafternoon (~2000 UTC), a cycle which is completely opposite of normal for the summer months in the Southeast. Such a behavior suggests that synoptic-scale forcing was appreciable in this case. As shown in Fig. 3, this MCS at maturity was quasi-circular in shape and approximately 100 km in diameter. In contrast to the 13 July case, deep convection was less intense, was more randomly distributed and occupied a smaller fraction of the total precipitation area. Thus the relative contribution from stratiform precipitation was greater. The stratiform region displayed an echo top of ~10 km, as well as a significant bright band. An inflow jet (~5 m/s relative speed) centered near a height of 3 km entered the system from the northwest. The initial inspection of kinematic structural features indicates weak mesoscale updrafts and downdrafts within the stratiform region.

A complete analysis of this system is underway and should be completed (in publication draft form) by late 1989. Three general objectives have been defined:

(1) Define the kinematic and precipitation structure of this MCS, using all available data sets, and develop a conceptual model of its structure.

(2) Define the relationship of this MCS to its ambient environment.

(3) Define and infer the precipitation characteristics within the system (both in convective and stratiform regions), and compare with similar results from the 13 July case.

5. Future research efforts

Planned work for the latter half of 1989 includes the following:

(1) Complete the descriptive analysis of the 13 July MCS and submit the manuscript to Monthly Weather Review.

(2) Complete the analyses of the 15 July MCS and put together a journal manuscript. Three students are currently conducting analyses of this case.

(3) Begin numerical modeling efforts for the 13 July case, including modeling of cloud-scale modeling activities and mesoscale modeling activities. This work will be carried out by a graduate student (C.L. Wu).

(4) Begin a detailed analysis of precipitation characteristics within a variety of precipitation systems, including the 28 June, 13 July and 15 July cases. This work is conditional upon the anticipated arrival of a post-doc (Y. Golestani) with expertise in multi-parameter radar analysis.

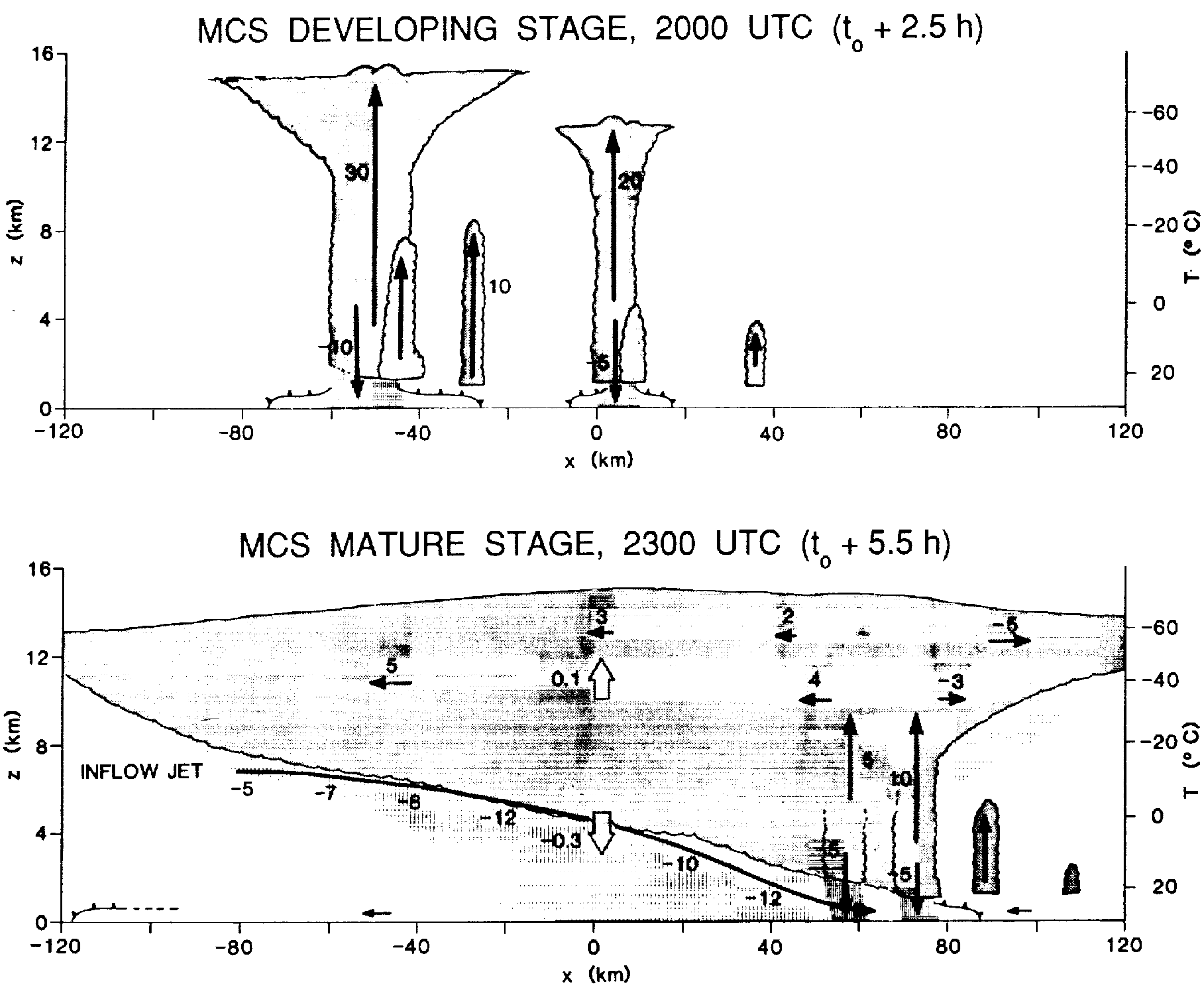
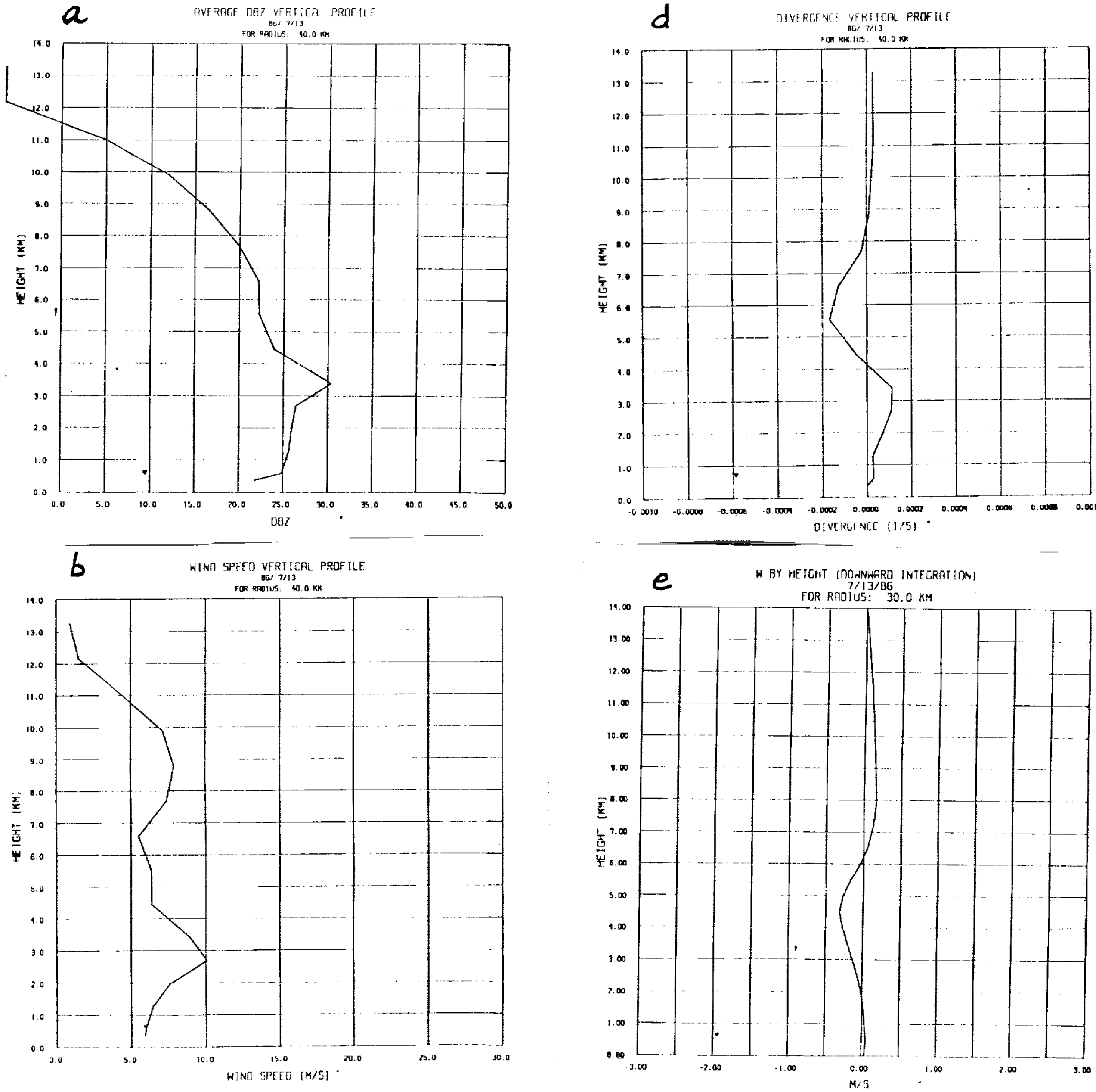


Figure 1. Schematic illustrating the observed cloud-scale and mesoscale features within the 13 July MCS during(a) the developing stage, 2.5 h after first echo; and (b) the mature stage, 5.5 h after first echo. Arrows denote flow magnitudes in m/s, and vertical hatching represents precipitation.



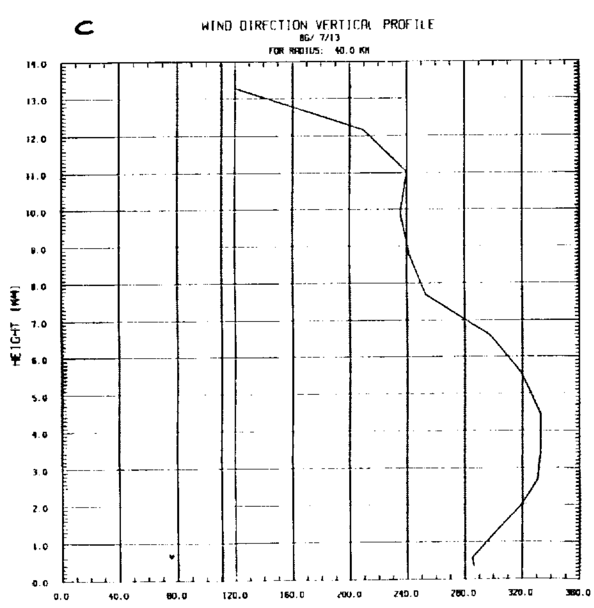


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Figure 2. Results from a CP-4 VAD analysis (40 km radius) at 2334 UTC 13 July 1986 showing profiles of (a) reflectivity factor averaged around the circle; (b) mesoscale horizontal wind speed; (c) wind direction; (d) divergence and (e) vertical motion.

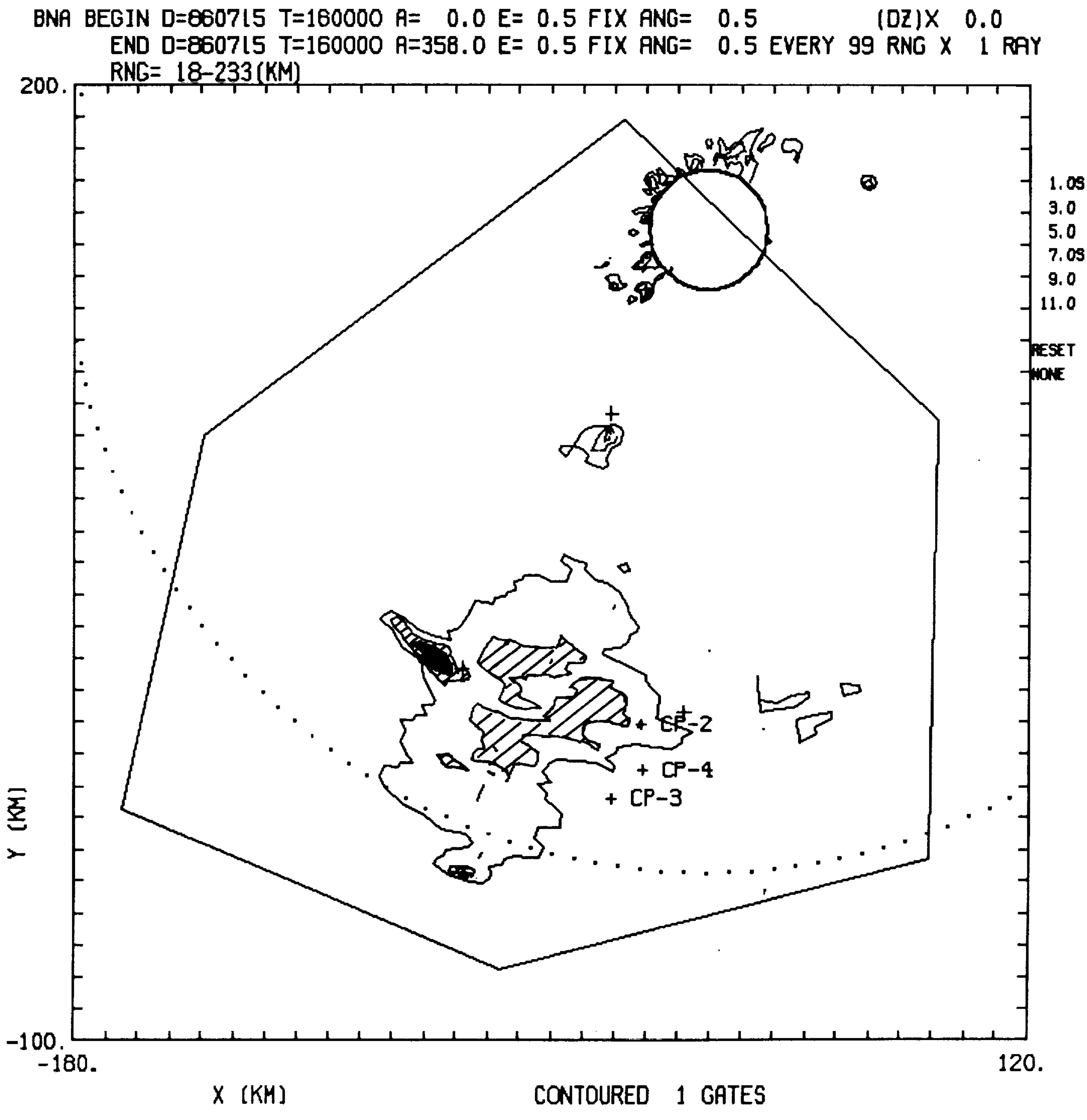

Figure 3. Contour analysis of RADAP data from the Nashville WSR-57 radar, located at the center of the small circle at the upper right. Contours correspond to 18, 30 and 43 dBZ. Values greater than 30 and 43 dBZ are hatched and blackened, respectively.

Appendix A.
Reprint of paper from the 24th Conference on Radar Meteorology