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PRECIPITATION AUGMENTATION FOR CROPS EXPERIMENT: PHASE II, EXPLORATORY RESEARCH, YEAR 1

Prepared by

Stanley A. Changnon
David Brunkow
Robert Czys
Ali Durgunoglu
Philip Garcia
Steven Hollinger
Floyd Huff
Harry T. Ochs
Robert W. Scott
Nancy E. Westcott

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CHAPTER 1: INTRODUCTION

Stanley A. Changnon

This final report for project NOAA-NA86RAH05060 embraces the field activities and research on the project from 15 June 1986 through 14 August 1987. This project represents the first efforts in the second of the four major phases of PACE. This has been the first year in the Exploratory Phase, Phase 2, of PACE. PACE was planned as a 4-phase effort including: 1) a pre-experimental phase, 2) an exploratory phase, 3) a confirmatory phase, and 4) the interpretation and summarization phase.

Since its inception in 1978, PACE has been viewed as a long-term, step-by-step scientific project to address two fundamental questions: 1) can the precipitation in Illinois (and the Midwest) be altered through cloud seeding, and 2) can the altered weather produce benefits to Midwestern agriculture in a societal/environmental sound manner? The long-term goal of PACE is to learn whether agriculturally useful increases in rainfall can be produced in Illinois and elsewhere in the Midwest having similar precipitation climate. Past studies have shown that the concept of agricultural usefulness focuses the project on the study of potential rain modification during the agricultural water stress periods of summer (June-August).

In the original planning of PACE with representatives of four Midwestern universities, NOAA staff, and Water Survey staff in 1977-1979, PACE was envisioned as a four-phased project involving all six entities (and others as needed), and lasting from 10 to 15 years, depending on the rate of funding and the scientific findings. It had been planned to finish Phase I, the Pre-Experimental Phase, within 3 to 4 years, but it required 9 years because of intermittent and generally low federal funding. NOAA's involvement has been minor throughout the 10-year history of PACE, other than in 1977-1978, and research relating to PACE at the four state universities, and related to agricultural and hydrological issues has been limited due to the very limited funding to a few studies at Purdue University and the University of Illinois.

This particular 14-month project period has focused on five major task areas. These six task areas were:

1. The conduct of a 2-month field operational period to conduct trial seeding experiments and to gather cloud physics data by aircraft and radar.
2. To perform analyses of the a) cloud physics data, b) radar echo data, and c) forecasting and nowcasting data and techniques.
3. To conduct relevant agricultural and hydrologic research to define better the impacts of altered summer precipitation.
4. To integrate the results of prior years of research with those of 1986-1987 so as to redirect, if necessary, the general approach to research and the planning for future field operations and research.
5. To continue equipment development and the HOT radar.
6. To interact with NOAA and other agencies involved in the Federal-State Cooperative Weather Modification Program to maintain communications and cooperation in program planning and project operations.

It should be noted that in the conduct of the highly specialized field operations of 1986, and in the conduct of our subsequent research, an underlying but important concept has been the use of external expertise as needed. For example, for the 1986 field operations, crews from both aircraft involved were involved along with technicians and on-board flight experts who participated in the scientific and technical planning, and in discussions of the field operations (and who gave useful advice in the subsequent analysis efforts). We also had the full-time involvement of a meteorologist skilled in weather modification operations concerning convective clouds, Dr. William Woodley. During and subsequent to the field operations, we have utilized other expertise to provide guidance in the planning and conduct of the field operations and in the research. These persons have included Professor Ruben Gabriel of the University of Rochester, Professor Roscoe Braham of the University of Chicago, Dr. William Woodley of Woodley Associates, and Mr. Keith Brown of North American Weather Consultants. This approach has been proven to be very satisfactory, both for enhancing the field operations and the research.

Another important way to view the activities of this project is to realize that they are based in two broad areas: cloud and weather research relevant to weather modification, and agricultural and hydrologic impact studies.

Within the context of the past 14 months (the project period), the atmospheric efforts in the first three months were devoted to the conduct of the field operations in 1986, a major effort involving 15 staff members working seven days a week for two months, plus the intense project planning activities in late June 1986, followed by the immediate project dismantling activities of September 1986. This extensive field effort, although only three months of the total 14-month period, represented the utilization of about 3/4 of the project funds for support of the staffing and facilities required (radar, radiosonde, and two sophisticated weather aircraft). The second portion of the project, which began in October 1986 and ended with the termination of this project in August 1987, was largely focused on research which was devoted to the study of the 1986 field data.

Within the context of this twin effort, the hydrologic and agricultural research continued at a rather steady pace throughout the 14-month period. This has been an important project period for the agricultural economic modeling studies. In the final report for the project preceding this one (ending June 1986), the details of the comprehensive economic modeling were presented. In this project period of 1986-1987, research attention has been given to the interpretation of the modeling results which has led to the preparation of two scientific papers. Hence, a chapter devoted to this effort is not presented; we believe that the contents of these papers are sufficient to describe the final research phases of this part of PACE. The end of this project represents the end of the economic model development and its results. The hydrologic model development and basin simulation testing of the past two years has also been completed in this project year. The results, including the model development and the simulation testing on an Illinois basin, are sufficiently extensive and interesting to set them forth in a separate project report to be published. Thus, in this final report, only a brief description of this work is offered (in Chapter 3).

The impact area of PACE studies launched a new effort in 1987 based on a unique opportunity. This led to field trials involving irrigation of corn and soybeans in test plots to investigate the yield effects of various changes in summer rain, a subject described in Chapter 2. In summary, the 2-year efforts in hydrologic modeling and in agricultural economic modeling for PACE have been concluded in a timely fashion, during this research period. Furthermore, both study areas have provided the models and information desired to better assess the values and problems related to future rainfall modification in Illinois.

The specific objectives proposed for this 14-month project have been fulfilled. Four quarterly reports were prepared and submitted to NOAA, as required in the Cooperative Agreement. All other project milestones were reached, although radar equipment problems during the field operations reduced data collection as did the unusually dry weather. Delays on equipment delivery delayed completion of the HOT radar system into the next project period.

This report is composed of 11 chapters, including this introductory chapter. The chapters are arranged generally around the task areas of the project. Chapters 2 and 3 address the research related to the tasks concerning "impacts of altered precipitation;" chapters 4, 5, and 6 focus on the atmospheric research studies; chapter 7 focuses on the 1986 field operations and their assessment; chapter 8 relates to special efforts to develop a comprehensive weather modification library needed for the impact and atmospheric research and reacting to a unique opportunity; chapter 9 relates to equipment development, and the HOT radar specifically for PACE; and chapter 10 highlights principal program management and funding issues. The publications generated by the project and the scientific papers presented at conferences and workshops are presented in chapter 11.

CHAPTER 2: AGRICULTURAL IMPACT RESEARCH

Stanley A. Changnon and Steven E. Hollinger

Introduction

A major objective of PACE is the development of a technology in rainfall enhancement that would result in increased Illinois crop yields and a reduction in the year-to-year variations of crop yield. Much of what has been assessed about the value of added water on crop yields in Illinois and in turn to the state's economy has come from the use of crop yield-weather models based on historical records of yields and past weather conditions. To arrive at an estimate of the value of additional rainfall to the crop, the actual rainfall amounts have been used as inputs to regression type models and the predicted yields with the additional rainfall compared to the predicted yields with natural rainfall. The model results point to the importance of summer weather conditions, particularly the July and August rainfall.

All the models rely on a variety of assumptions that make their results less than reliable in applying them to real world situations. Therefore, actual field experiments are needed to evaluate the effects of differing amounts of additional rainfall on final crop yield. In the spring of 1987, specially constructed rain shelters became available in which field experiments could be conducted. These shelters are designed to be moved over the plot area during a rain event to exclude the natural rain from the plots. When there is no precipitation falling, the shelters are moved off the plots so the plants experience the same weather as the naturally growing crops in the region. An overhead sprinkler irrigation system is installed in the shelters so the time, amount, and quality of water applied to each plot can be controlled. This system allows the establishment of an experimental design to test the validity of the model results in an actual field situation.

Rainfall Assessment Project (RAP)

In the spring of 1987, a 2-year field experiment was established to determine the effects of simulated augmentation of natural rainfall through rain increases on crop yields. Two shelters, one movable and the other stationary, were used in the experiment. The stationary shelter was left open for natural rainfall could reach the crop and soil, and was fitted with an irrigation system that would allow the application of small amounts of water on each plot. The plots in the stationary shelter were treated with varying levels of water added to the daily rainfall. The treatments in the movable shelter were designed to simulate the effects of cloud seeding during a dry year, a normal rainfall year, and a wet year. The experiment in 1987 will be replicated during the 1988 growing season with the possible addition of other variables and tests based on the RAP87 results.

Stationary Shelter Equipment. Corn, a Mo17 x B73 Cross, and soybeans, Williams variety, were planted in the stationary shelter on May 28, 1987. Soybeans had been grown in the plots during the summer of 1984, 1985, and 1986. Prior to planting the corn, the 341 kg ha_{-1} of nitrogen, 94 ka ha_{-1} of potassium, and 94 kg ha_{-1} of phosphorus were applied.

The corn was planted using a field plot tractor and planter with a 0.76 m row spacing at a population of 64,220 plants ha^{-1} . the soybeans were planted with the same row spacing as the corn with a plant density of 430,400 plants ha^{-1}. The plots were situated on a Drummer silty clay loam sol (fine-silty mixed mesic Typic Haplaquolls) , a naturally poorly drained soil that has been artificially drained.

Ten different rainfall treatments were replicated three times. The ten treatments were:

1. Natural rainfall.
2. All daily rains increased by 10%.
3. All daily rains increased by 25%.
4. Ail daily rains increased by 40%.
5. All daily rains greater than 0.254 cm and less than 2.54 cm increased by 10%.
6. All daily rains greater than 0.254 cm and less than 2.54 cm increased by 25%.
7. All daily rains greater than 0.254 cm and less than 2.54 cm increased by 40%.
8. All daily rains greater than 2.54 cm increased by 10%.
9. All daily rains greater than 2.54 cm increased by 40%.
10. All daily rains less than 0.254 cm increased by 40%.

The additional rain increments were applied in the morning after determining the previous day's rainfall by a 7 a.m. reading. Water additions were started on 1 June 1987, and ended 31 August 1987.

Mobile Shelter Experiment. The mobile shelters with a sprinkler system installed allowed us to exclude all natural rainfall from the plots and construct the summer rain scenario within the shelter. These experiments studied the effects of altered rain levels on a typical average summer, a typical wet summer, and a typical dry summer on crop yields. The typical average, wet, and dry summer scenarios were based on historical climate values from Urbana, Illinois. Planting within the shelter was on the same day using the same cultural practices and cultivars as for the stationary shelter.

The typical seasons were designed using the long-term average values of precipitation for June, July, and August, and the statistical distribution of rain days for each month, and the temporal distribution of rain days for each month. The end result of the design of the rainfall treatments was a "summer rain model" for an "average" summer, a typical "wet" summer, and a typical "dry" summer. Wet and dry summers were defined by the wettest 20% of the 90 summers of the climatological series, and the driest 20% of the summers, respectively. The monthly values composing the wet and dry summers were based on the probability distributions of monthly rain values found in Changnon (1959).

The frequency distributions of rain days during summer dry periods were from Changnon and Huff (1971). Wet month values were determined by analysis of the wet months in the 1890-1980 Urbana climate record. Average values were obtained from the Urbana normals (ISWS, 1955). The average frequencies of rain days for the wet, average, and dry summers at Urbana are presented in Table 2-1.

The daily rain day distributions in Changnon (1959) for 0.254 mm increments were the basis for calculating the actual amounts for the average summer conditions. As shown in Table 2-1, an average summer in Urbana has 26 days of 0.254 mm or more of rain. The frequency distributions show that 40% of these days, or 10 rain days, are composed of values between 0.254 and 2.54 mm. In this category then, values were selected for use in the average model: 0.254, 0.508, 0.762, 1.27, 1.27, 1.778, 2.032, 2.286, 2.54, and 2.54 mm. The numbers were distributed, without consideration of their magnitudes, amongst the 3 months according to the magnitude of the 0.254 mm values (Table 2-1) such that 4 rain days in this category were assigned to June, 3 to July, and 3 to

Table 2-1. Rain day frequencies for Urbana, Illinois

Month	Days with Rainfall ≥ 2.54 mm Wet Summer	Average Summer	Dry Summer	Days with Rainfall ≥ 6.35 mm Wet Summer	Average Summer	Dry Summer
June	12	10	10	7	5	4
July	10	8	8	5	4	3
August	10	8	8	4	3	2

Month	Days with Rainfall ≥ 12.7 mm Wet Summer	Average Summer	Dry Summer	Days with Rainfall ≥25.4 mm Wet Summer	Average Summer	Dry Summer
June	5	3	2	2	1	1
July	3	2	1	2	1	0
August	3	2	1	1	1	1

August. The ten actual amounts were then distributed in keeping with the magnitude of the average monthly rainfall amounts, i.e., June averages 101.6 mm which is 36% of the summer total of 279.4 mm; July averages 86.36 mm which is 31%; and August averages 91.44 mm which is 33%. To distribute the 10 values, the sum of the 10 values was 15.24 mm. Application of the June percentage to this resulted in 5.588 mm. Four rainfall values from the 10 listed above were selected so that their sum equaled 5.588 mm. The selected values were 0.508, 0.762, 1.778, and 2.54 mm. This process was repeated for July and August. The resulting rain-day values appear in Table 2-2.

This process was repeated for each of the 2.54 mm rain categories. The 2.794 to 5.08 mm level represented 13% of all rain days and three rain days were assigned to this category for the summer (1 in June, 1 in July, and 1 in August). Three days (1 each month) were also assigned to the 5.334 to 76.2 mm category. The 2.54 mm categories above 7.62 mm up through 22.86 mm each averaged one rain day during the summer. The initial rain amount assigned to each of the rain categories was the middle of the range (i.e., 8.89 mm for the

7.874 to 10.16 mm range), and then adjusted slightly, if needed, so the monthly total rain amounts agreed with the long-term averages. The six values were distributed with 2 in June, 2 in July, and 2 in August. The distribution was such that each month received approximately 33.02 mm of total rainfall from these days. The final values selected were 15.494 and 17.78 mm for June; 8.89 and 22.86 mm for July; and 12.446 and 21.59 mm for August.

As shown in Table 2-1, the average summer has one rain day each with rainfall greater than 25.4 mm of rain assigned to each month. The magnitude in each month was established by summing all the other values already assigned and subtracting this total from the monthly average total. For example, in June, the 9 daily rain values less than 25.4 mm totaled 58.166 mm. The difference between this value and the monthly mean of 101.6 mm for June is 43.434 mm; therefore, the '25.4 mm' value used is 43.434 mm.

These rain days were then distributed throughout each month using information from Bark (1961) and Changnon (1959). A report by the NC-26 Committee (Bark, 1961) showed that 50% of all summer rain days in central Illinois are followed by another rain day, and that the likelihood of 3 days of rain in a sequence is extremely small. Therefore, the sum of the rain days were coupled so that there would be two rain days in a row. For example, half of the rain days in June (6 of the 10) were used to form 3 pairs of rain days. Arbitrarily, each pair consisted of a relatively high and a moderately low rain value.

The final temporal distribution of rain days throughout each month was based on studies of the probabilities of dry periods of 5-day durations for Urbana (Changnon, 1959). These provided information as to which parts of each summer month were more apt to be in wet periods. These periods include June 8 to 15, June 23 to 28, July 2 to 4, and August 10 to 19. The rain days were arbitrarily concentrated in these 'more likely' rain periods. For example, there are 10 days with 0.254 mm or more rain in an 'average' June; therefore, seven of these days were distributed within the two June 'wetter' periods. Two of the 8 rain days in an 'average' July were put in the 2 to 4 July dates, and 4 of the 8 measurable rain days in an 'average' August were distributed in the 9-day period of 10 to 18 August. The remaining rain days were randomly distributed amongst the other parts of each month such that no rainless period persisted for more than 7 days.

The modeled rain days for the 'average,' 'dry,' and 'wet' summers in Urbana are presented in Table 2-2. The rain day distribution for the dry and wet summers was the same as for the average summer. Thus the magnitude of rainfall oh a rain day was adjusted for the wet and dry summers but not the rain dates.

The amount of rain assigned to each rain day was found (1) determining the mean monthly rainfall in a wet and dry summer; and (2) the rain day frequencies in four levels in Table 2-1 were used to adjust the average summer daily values in Table 2-2.

The mean June, July, and August rainfalls in the wet and dry summers were obtained from frequency curves in Changnon (1959) that showed at the 20% frequency level, a dry June had 70% of the average rainfall, and a 20% level wet June had 137.5% of the average rainfall. The total rainfall values for months of June, July, and August for wet and dry summers is presented in Table 2-2.

The average of the rain day frequencies for the four rainfall levels shown in Table 2-1 were used to determine the daily rainfall values in Table 2-2.

Table 2-2. Modeled summer rainfall values at Urbana for average, dry, and wet summer conditions, mm.

Date	June			July			August		
	Average	Dry	Wet	Average	Dry	Wet	Average	Dry	Wet
1									
2						0.508	1.270	1.270	3.810
3	7.112	6.858	9.144				21.590	9.144	24.130
4	2.794	2.794	2.794	1.270	0.508	1.270			
5				39.878	20.320	46.736			
6									
7									
8	17.780	10.414	19.050						
9				8.890	2.032	10.160			
10						5.080	3.302	2.286	5.080
11	0.762	0.762	0.762						
12									
13							2.540	2.540	4.826
14	43.434	28.448	45.720	2.286		6.096	42.926	29.050	43.180
15	0.508	0.508	0.508						
16									
17									
18							12.446	5.080	12.446
19	9.398	4.318	9.398						0.254
20									
21				0.254	0.254	2.286			
22				22.860	10.922	39.730			
23	15.494	12.700	16.510						
24							2.032	2.032	2.032
25									13.208
26	2.540	2.540	26.924						
27	1.778	1.778	2.540	4.826	2.794	5.334			
28							5.334	4.318	5.334
29			0.254						
30			6.096	6.350	6.350	10.160			
31									
Total	101.60	71.12	139.70	86.36	43.18	127.00	91.44	45.72	114.30

For example, Table 2-1 shows that a July in a typical dry summer has one less rain day at the 2.54 mm level than the average. Therefore, one rain day had to be deleted; thus, a relative low rainfall value of 2.286 mm on 14 July was deleted. The rain day level frequencies in Table 2-1 reveal that the one day with more than 1 inch of rain does not occur in a dry July; hence the 39.878 mm rainfall assigned July 5 in an average summer was reduced to 20.320 mm. The number of days with rainfall of 12.7 mm or more (Table 2-1) is one for a dry summer compared to 2 for an average summer. Therefore, the next highest value in the average summer July rainfall, 22.86 mm on 22 July, was reduced to 10.922 mm. The 6.35 mm rainfall on 30 July was not altered as it was needed to match the frequency of rainfalls greater than or equal to 6.35 mm.

The sum of the 3 July rainfall values greater or equal to 6.35 mm was 37.592. Subtraction of this from the July rainfall target of 42.18 mm (Table 2-2) left 5.588 mm to be distributed among the remaining four rain days. These values were arbitrarily assigned as shown in Table 2-2.

The rainfall values for July in wet summers were constructed from the average values in a similar fashion. The goal was to ensure that the re-adjusted values equaled the means for the wet and dry summer frequencies shown in Table 2-1. Therefore, much of the adjustments of average daily rainfall occurred on the heavier rainfall amounts, particularly, those greater than 12.7 mm per day.

Finally, the rate of rainfall, the time of day that the rainfall occurred, and the duration of the rainfall event had to be specified. Irrigation system constraints prohibited variation of rain rates during a "rain period." Thus, the water application on a day with 8.128 mm rainfall would all be applied at a fixed rate, and the duration of the rain event would be long enough to apply the specified amount of rain. In the case of heavy rain events, to prevent the rain from running off a plot onto an adjacent plot with low rainfall, it was necessary to divide the event into several smaller events on the same day.

The time of day of the 'rain event' was determined from an analysis of the diurnal distribution of summer rains in the Urbana area (Huff, 1971). In general, these show that between the hours of 0900 LST and 1400, each hour received 3% of the rain, between 1400 and 2000 each hour receives approximately 4%, and between 2000 and 0900 each hour receives about 5% of the total rain. This reflects the nocturnal maximum and mid-day minimum.

Since RAP87 did not have the facilities or the personnel to distribute water at all times of the day on a fixed schedule, a schedule involving three different times of application distributed across a series of six rain days was used to emulate nature. The prescribed water amount was applied in the hours between 1500 and 2000, and beginning at 1500, on the first and third 'rain day' of a 6-day sequence. On the second, fourth, and fifth 'rain days,' the prescribed water was applied between 0600 and 0900. On the sixth 'rain day' in the sequence, water was applied between 0900 and 1500. This scheme puts 50% of the rain time in the nocturnal maximum, 33% in the late afternoon peak, and 17% in the mid-day minimum, a distribution that fits the climatology.

The rain day values in Table 2-2 apply only to the control cases of average, wet, and dry summer rainfall. For the simulation of the effects of increased rainfall due to seeding, the daily values in Table 2-2 are increased by 25% for the average, dry, and wet summers.

Yield Determination. Final yields will be determined by harvesting the center two rows of the plots, weighing the ears, adjusting the weight to 15.5% moisture and calculating the yield on a per hectare basis. At the time the corn plots are harvested, the number of plants in the harvest area, the number of ears harvested, the number of rows per ear, and the number of kernels per ear will be recorded. After the ears have been shelled, the average weight per kernel and ear will be calculated. The yield components of the soybean crop that will be recorded are: (1) number of plants harvested: (2) number of pods per plant; (3) number of pods with at least one seed greater than 5 mm in diameter; (4) number of seeds per plant; and (5) the average weight of each seed.

Preliminary Results

Since the corn and soybean crops are still growing at the end of August 1987, there are no yield comparisons to report. Therefore, this section will discuss the progress of the experiment and observations relative to the growing season.

Treatments (added rainfall) in the movable shelter were started on 5 June 1987. At the time the treatments were started, the corn and soybean crop had just emerged. During the vegetative stage of growth the weather was hot and dry. Some differences in heights of the plants in the different treatments were observed and a series of photographs were taken at intervals.

On 30 July the Urbana area experienced a once in 100-year storm when 114.3 mm of rain was received during a 4-hour period. At the time of the storm, the movable shelter was over the plots and no rain fell on the plots. However, due to the rapid rainfall rate and the lay of the land, the plots were exposed to surface runoff for approximately 3 hours. The soil moisture profiles of all the plots were recharged during this time. At the time of this storm the corn was silking and the soybeans were beginning to flower. Therefore, during the critical corn growth stage of flowering the dry plots were recovering from any stress they were exposed to. As a result of the storm, all water treatments planned for the 30 July to 9 August period were suspended. During this interval, all rain was excluded from the shelter.

These events provide a unique experiment relative to the effect of typical droughts during the vegetative stage of corn growth. Since the major portion of the drought was experienced during the early development of the ear, most of the yield variation should be reflected in the individual yield components, particularly the number of kernel rows on the ear. With a well watered condition during early seed set and grain fill, the effect of a reduced number of kernels per ear may be masked by a larger kernel weight.

Problems were also experienced in the stationary shelter in that a portion of the corn plots experienced severe lodging problems at the end of July. This problem was caused by a combination of factors. The 337 kg ha^{-1} of nitrogen, in addition to the residual nitrogen from three years of soybeans on the plots, plus the late May planting date and reduced light intensity caused by partial shading of the crop by the infrastructure of the stationary shelter, caused the corn plants to grow taller than normal without additional thickening of the stem. As a result, the plants were blown over by the downdrafts at the end of July. Results obtained from these corn plots will be limited. The soybean plots in the stationary shelter did not experience any problems, and the results from these plots should be usable.

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CHAPTER 3: HYDROLOGIC MODELING AND SIMULATION TESTING

Stanley A. Changnon

Results of this 2 1/2-year research and development effort were concluded at the end of this project period. The research was aimed at defining (for typical moderate sized basins (50 to 1000 sq mi) in Illinois) the effects of altered daily rainfall amounts on the hydrologic cycle. In other words, if a 0.25 inch rainfall occurred on July 15, 1987, what would be the fate of an additional 0.10 inch of rain presumably due to cloud seeding? In other words, what processes does additional rainfall (based on different estimated levels of weather modification) have on various portions of the hydrologic cycle?

To address these questions, it was apparent that existing multi-layer hydrologic models adequate to this task did not exist. Hence, an major portion of this research effort was to develop models, and to combine these with appropriate existing models, for the shallow soil layers and deeper levels in order to keep track, in time and space (over a basin), of the fate of rainfall generated during summer days.

The successful completion of this model, which occurred in this project period, allowed the input of simulated rainfall changes. Two historical 3-year periods, one in the 1950s containing a series of relatively dry years, and another in the 1970s being a series of wet years, were used in the study. Daily rainfall amounts during these years were selectively altered within the range of expected weather modification capabilities, 5% up to 40%, and these additions were used to ascertain the effects of this rainfall added to the natural regime.

The extent of the model development and the results generated were sufficiently great to lead to a decision to prepare a separate report documenting this work. This report will be submitted to NOAA as a separate report under this cooperative agreement.

CHAPTER 4. RADAR-ECHO STUDIES

Nancy Westcott

Introduction

During August 1986, a randomized seeding experiment was carried out in central Illinois as part of the exploratory phase of FACE (Precipitation Augmentation for Crops Experiment). The continuing goal of this program is to determine whether and under what conditions summer precipitation in Illinois can be enhanced by cloud seeding. The objective of this component of this program is to set up procedures to evaluate possible seeding effects on cloud growth through use of radar observations, and to make a preliminary evaluation of the data collected by the Illinois State Water Survey CHILL radar from the 1986 field effort.

Due to unusually dry weather conditions in August, only three successful randomized cloud seeding flights took place during the program, one on August 6 and two on August 26, 1986. On these two days, 30 treatment passes were made through a total of 20 clouds. A preliminary examination of the radar data associated with these 20 clouds has been made. Whether silver iodide treatment occurred during any of these three randomized flights has not yet been revealed, pending completion of the radar analysis. Thus, no statements can be made regarding a possible seeding effect, precluded in any event by the small sample size. However, the radar data from the two days provide an interesting contrast in convective conditions which can occur in this area of the country. This variability poses an intriguing challenge to identifying weather and cloud conditions suitable for seeding and also for determining a treatment effect.

Radar Data

The CHILL radar has been undergoing NSF funded refurbishment and testing for the last several years. At the time of the field program, 10-cm reflectivity data (1 ° beam) were collected at 512 range bins, each 300 m deep, out to a range of 150 km. The sensitivity of the radar had been improved such that reflectivities of 10 - 15 dBZ were obtained with confidence. The radar was operated in a 360° scan mode with the intent of topping all echoes in the area, completing a volume of 10 - 16 elevation steps within 3 - 5 minutes.

Data from these 2 days first were edited and reformated for use on the U. of Illinois CYBER 175 for an initial look at the data. Because of the expense and effort commonly encountered in processing radar data, a decision was made to adapt the radar analysis programs, and to transfer the radar data to the newly acquired Supercomputer now present on the U. of Illinois campus. To gain an overview of the storms occurring within 120 km of CMI, a program was run on each volume of data which compressed the data onto a 2-dimensional view of the maximum reflectivity, the height of the maximum reflectivity, and the maximum and minimum heights of reflectivities greater than or equal to 20 dBZ. This produced for each volume, grids of 121 x 121 points with 2 km resolution, i.e. a 242 X 242 km field with the radar located in the center. The approximate aircraft pass locations were then plotted on these grids. From this data, we were able to select smaller grids and time periods for interpolation of the echoes associated with the treated clouds.

Specific volumes were then interpolated using a bilinear interpolation scheme (8 closest radar bins to a particular grid location) onto 121 km x 61 km x 15 km cartesian grids, with 1 km resolution in each direction. The approximate aircraft pass locations were replotted onto these fields and the reflectivity history of the specific echo cores most likely associated with the treated clouds were tracked by hand, in time and height. The location of the echo associated with last two treatment passes on August 26 (cloud 8), could not be determined with any certainty and thus was omitted from the analysis.

A summary of characteristics for the 19 remaining treated echoes is presented in Tables 1-4. The first table presents the reflectivity and height information at the time the radar echo was first detected. As each volume spanned 3-5 minutes, some of the first detected echoes may be 3-5 minutes old and thus this data will only give an indication of the initial echo characteristics. The second table presents the echo conditions at about the time of treatment. Note that 5 passes were made at the time when one volume was ending and another beginning. The echo variables for these passes were averaged from the two volumes. The peak reflectivity values and the peak echo heights for the echoes associated with the cloud passes are presented in Table 3. The growth period of these echoes is defined by the height of the 20 dBZ contour. This information is presented in Table 4. Information relating to the beginning, ending and midtimes of the pertinent radar volumes from the 3 flights is found in Table 5.

Table 4-1. Echo Characteristics at Time of First Echo Detection.

Date	Cloud	Radar Volume	Volume Midtime (CDT)	Maximum Reflectivity (dBZ)	Height Max. dBZ (km)	Max.* Height (km)	Min.* Height (km)
8- 6-86	1	167	1619 08	22	1	3	1
FLIGHT 2	2	166	1615 01	17	1-3	5	1
	3	170	1631 18	25	3	5	1
	4	173	1643 41	57	2	5	1
	5	173	1643 41	15	4	4	2
8-26-86	3	38	0950 03	17	4	4	3
FLIGHT 1	4	46	1025 01	25	6	6	6
	6	50	1045 16	17	4	5	3
	7	55	1105 49	22	6	7	5
	8	55	1105 49	15	5	5	5
	9	57	1115 03	15	6	6	6
	10	58	1119 40	37	5-6	8	3
	11	59	1124 03	32	5	6	3
8-26-86	2	157	1551 20	25	4-5	6	3
FLIGHT 2	3	160	1601 52	22	4	7	3
	4	166	1620 23	22	3	4	2
	5	177	1702 40	20	2	4	1
	6	182	1724 29	32	4	4	4
	7	188	1748 36	30	4-5	6	4

* refers to height of the 15 dBZ reflectivity contour

Table 4-2. Echo Characteristics at Time at Treatment (First Cloud Pass).

Date	Cloud	Radar Volume	Volume Time	Time Since First Echo (min)	Peak Reflectivity at 6 km (dBZ)	Maximum Refl. (dBZ)	Height Maximum Refl. (km)	Max.** Ht. (km)	Min.** Ht. (km)
8-6-86	1	170	1631 18	12	27	55	2	7	1
FLIGHT 2	2	171	1635 26	20	50	57	3-4	8	1
	3	173	1643 41	12	22	35	1-2	7	1
	4	174	1647 48	4	17	57	2	6	1
	5	17 8	1704 18	21	25	43	2-3	7	1
8-26-86	3	40	0959 37	10	50	57	4	8	1
FLIGHT 1	4	46	1025 01	0	25	25	6	6	6
	6	51	1049 40	4	25	27	4-5	7	2
	7	*55.5	1108 01	2	32	32	5-7	8	4
	8	*56.5	1112 38	7	27	38	3-5	6	1
	9	57	1115 03	0	15	15	6	6	6
	10	58	1119 40	0	37	37	5-6	8	3
	11	61	1132 24	8	37	52	3-4	8	1
8-26-86	2	159	1558 21	7	42	47	5	8	1
FLIGHT 2	3	*161.5	1607 01	5	47	50	4-7	9	1
	4	169	1630 21	10	25	42	3	6	1
	5	179	1711 46	9	45	47	4-5	7	1
	6	*184.5	1734 14	10	42	50	2-5	7.5	1
	7	*190.5	1758 22	10	41	55	3-5	7.5	1

* Treatment occurred near the end of these volumes. Volume time in these cases reflects the end time of the volume rather than the midtime.

** Maximum and minimum heights refer to the height of the 15 dBZ reflectivity contour.

Table 4-3. Echo Characteristics at Time When First Reaching Peak Reflectivity and Peak Height.

Date	Cloud	Radar Volume Reach Peak Reflectivity	Volume Time	Time Since Treatment (min)	Peak Refl. (dBZ)	Radar Volume Reach Max. Ht. (min)	Volume Time	Time Since Treatment (min)	Max. Height (km.)
8- 6-86	1	170	1631 18	0	55	171	1635 26	4	7
FLIGHT 2	2	171	1635 26	0	57	173	1643 41	8	11
	3	175	1651 56	8	40	173	1643 41	0	6
	4	177	1700 11	12	60	177	1700 11	12	9
	5	179	1708 26	4	52	178	1704 18	0	6
8-26-86	3	41	1004 27	5	60	41	1004 27	5	9
FLIGHT 1	4	49	1040 45	16	52	49	1040 45	16	9
	6	54	1101 39	12	45	53	1057 54	8	7
	7	57	1115 03	7	57	59	1124 03	16	11
	8	59	1124 03	12	45	58	1119 40	7	7
	9	60	1128 14	13	45	58	1119 40	6	7
	10	60	1128 14	9	57	60	1128 14	9	11
	11	61	1132 24	0	52	62	1136 16	4	8
8-26-86	2	162	1608 53	11	57	164	1614 54	17	9
FLIGHT 2	3	162	1608 53	2	57	165	1617 38	11	12
	4	172	1641 58	12	55	173	1645 41	15	8
	5	180	1716 35	5	57	185	1736 19	16	13
	6	187	1744 22	10	52	190	1756 30	22	11
	7	190	1756 30	0	55	190	1756 30	0	8

Table 4-4. Growth of the 20 dBZ Reflectivity Contour.

Date	Cloud	Radar Volume at Detection	Midtime	Radar Volume Max. Ht. Reached	Midtime	Duration (min)	Initial Max. Ht.* (km)	Max. Ht. of 20 dBZ (km)	Change in Max. Height (km)
8- 6-86	1	167	1619 08	171	1635 26	14	2	7	5
FLIGHT 2	2	166	1615 01	173	1643 41	19	(3)	11	8
	3	170	1631 38	173	1643 41	12	4	6	2
	4	173	1643 41	177	1700 11	16	6	9	3
	5	173	1643 41	178	1704 18	20	(4)	6	2
8-26-86	3	38	0950 03	41	1004 27	14	(4)	9	5
FLIGHT 1	4	46	1025 01	49	1040 45	15	6	9	3
	6	50	1045 16	53	1057 54	13	(5)	7	2
		55	1105 49	59	1124 03	18	6	11	5
	8	55	1105 49	58	1119 40	14	(5)	7	2
	9	57	1115 03	58	1119 40	5	(6)	7	1
	10	58	1119 40	60	1128 14	9	8	11	3
	11	59	1124 03	62	1136 16	12	6	8	2
8-26-85	2	157	1551 20	164	1614 54	24	5	9	4
FLIGHT 2	3	160	1601 52	165	1617 38	16	6	12	6
	4	166	1620 23	173	1645 41	25	3	8	5
	5	177	1702 40	185	1736 19	34	2	13	11
	6	182	1724 29	190	1756 30	32	4	11	7
	7	188	1748 36	190	1756 30	8	6	8	2

* Refers to the 20 dBZ contour if present at time of initial detection.
( ) The peak reflectivity is < 20 dBZ at the time of initial detection.

Table 4-5. Timing information for pertinent radar volumes from the three flights.

8-6-86 Flight-2

vol	begtlme hhmm ss	endtlme hhmm ss	duration mm ss	midtime hhmm ss
166	1613 05	1616 58	3 53	1615 01
167	1617 12	1621 06	3 53	1619 08
168	1621 20	1625 14	3 54	1623 16
169	1625 28	1629 08	3 39	1627 17
170	1629 22	1633 15	3 53	1631 18
171	1633 30	1637 23	3 52	1635 26
172	1637 37	1641 31	3 54	1639 33
173	1641 45	1645 38	3 53	1643 41
174	1645 52	1649 46	3 53	1647 48
175	1650 00	1653 53	3 53	1651 56
176	1654 07	1658 01	3 53	1656 03
177	1658 15	1702 08	3 53	1700 11
178	1702 22	1706 16	3 53	1704 18
179	1706 30	1710 23	3 53	1708 26
180	1710 37	1714 31	3 53	1712 33
181	1714 45	1718 38	3 53	1716 41
182	1718 52	1722 46	3 53	1720 48

8-26-86 Flight-1

vol	begtlme hhmm ss	endtlme hhmm ss	duration mm ss	mldtlme hhmm ss
37	943 54	947 51	3 56	945 52
38	948 05	952 02	3 56	950 03
39	952 16	956 39	4 23	954 27
40	956 53	1002 22	5 29	959 37
41	1002 36	1006 19	3 42	1004 27
42	1006 33	1011 10	4 36	1008 51
43	1011 24	1016 13	4 49	1013 48
44	1016 27	1021 10	4 42	1018 48
45	1021 24	1021 48	0 23	1021 35
46	1021 52	1028 12	6 20	1025 01
47	1028 26	1033 15	4 49	1030 50
48	1033 29	1038 19	4 50	1035 53
49	1038 33	1042 58	4 24	1040 45
50	1043 12	1047 22	4 09	1045 16
51	1047 36	1051 46	4 09	1049 40
52	1052 00	1055 56	3 55	1053 57
53	1056 10	1059 40	3 30	1057 54
54	1059 55	1103 25	3 30	1101 39
55	1103 39	1108 01	4 22	1105 49
56	1108 16	1112 38	4 22	1110 26
57	1112 53	1117 15	4 22	1115 03
58	1117 29	1121 52	4 22	1119 40
59	1122 06	1126 02	3 55	1124 03
60	1126 17	1130 13	3 55	1128 14
62	1130 27	1134 23	3 56	1132 24
62	1134 25	1138 08	3 43	1136 16
63	1138 22	1142 05	3 43	1140 13
64	1142 19	1146 02	3 43	1144 10
65	1146 16	1150 13	3 56	1148 14

Table 4-5. continued

8-26-86 Flight-2

vol	begtime hhmm	ss	endtime hhmm	ss	duration mm	ss	midtime hhmm	ss
156	1546	13	1549	29	3	16	1547	50
157	1549	43	1552	59	3	15	1551	20
158	1553	13	1556	30	3	16	1554	51
159	1556	44	1600	00	3	16	1558	21
160	1600	14	1603	31	3	16	1601	52
161	1603	45	1607	01	3	15	1605	22
162	1607	15	1610	32	3	17	1608	53
163	1610	46	1613	22	2	35	1612	03
164	1613	37	1616	13	2	36	1614	54
165	1616	27	1618	51	2	23	1617	38
166	1619	05	1621	42	2	36	1620	23
167	1621	56	1624	33	2	37	1623	14
168	1624	47	1628	04	3	16	1626	25
169	1628	18	1632	26	4	07	1630	21
170	1632	41	1636	23	3	41	1634	31
171	1636	37	1640	07	3	30	1638	21
172	1640	21	1643	37	3	15	1641	58
173	1643	51	1647	33	3	42	1645	41
174	1647	48	1651	56	4	07	1649	51
175	1652	11	1656	19	4	07	1654	14
176	1656	33	1700	42	4	09	1658	37
177	1700	56	1704	26	3	29	1702	40
178	1704	40	1708	49	4	08	1706	44
179	1709	03	1714	31	5	27	1711	46
180	1714	45	1718	27	3	42	1716	35
181	1718	41	1722	24	3	42	1720	32
182	1722	38	1726	21	3	43	1724	29
183	1726	35	1730	18	3	42	1728	26
184	1730	31	1734	14	3	43	1732	22
185	1734	28	1738	11	3	43	1736	19
186	1738	30	1742	08	3	37	1740	18
187	1742	27	1746	18	3	51	1744	22
188	1746	45	1750	28	3	42	1748	36
189	1750	42	1754	25	3	42	1752	33
190	1754	39	1758	22	3	42	1756	30
191	1758	36	1802	33	3	56	1800	34
192	1802	47	1805	50	3	02	1804	18
193	1806	04	1809	47	3	43	1807	55
194	1810	01	1813	44	3	42	1811	52
195	1813	58	1817	28	3	30	1815	42
196	1817	42	1821	12	3	29	1819	26

Aircraft Data

The cloud seeding aircraft, a Cessna 421C Golden Eagle III, was operated under contract by Atmospheric Incorporated of Pasadena, Calif. Randomized cloud seedings operations were under the general direction of Dr. Bill Woodley. The experimental unit was based on synoptic weather events with more than one event possible on a given day. The seeding target area encompassed the region within 150 km of the base station located at the University of Illinois Willard Airport (CMI) in Savoy, Ill. However, all passes made were within 90 km of the radar. Cloud passes were made at the about the -10 C level. Silver iodide or placebo flares were released on a penetration whenever liquid water concentrations neared .5 g m^{-3} , as measured by a Johnson-Williams hot wire meter and updraft speeds of greater than about 2 m s^{-1} were found. Characteristics of the pyrotechnics used are presented in Table 6.

Table 4-6. Pyrotechnic Seeding Devices - Basic Characteristics (After Henderson, 1986)

Type: Electable (20 mm diameter)
Agl content: 20 gram
Burn time:
- a) first-fire Ignition: 5 seconds
- b) Agl output time: 30 seconds

Vertical fall distance:
- a) flrst-flre Ignition period: 500 ft.
- b) Agl output period: 3,000 ft.

Approximate efficiency (nuclei output)
- a) at -10°C: 2 x 10^{18} per gram Agl
- b) at -20°C: 4 x 10^{18} per gram Agl

Pyrotechnic composition:
- a) magnesium powder
- b) aluminum powder
- c) sliver lodate
- d) hexachlorobenzene
- e) epoxy binder

During the aircraft flights, the following were among an array of parameters were recorded at 6 second intervals on 8-6-86 and at one second intervals on 8-26-86:

aircraft position from LORAN C (latitude, longitude)
aircraft position from VOR/DME stations (degrees, nmi)
true air speed (m/s)
pressure altitude (feet msl)
temperature from a Rosemount Model 101 sensor (˚C)
cloud liquid water content from a Johnson-Williams Hot Wire meter (g/m^3)
aircraft vertical velocity from a Ball variometer (m/s)

Basic information relating to the location of each cloud pass is presented in Table 7. A cloud pass was defined in this study by the presence of cloud liquid water. The cloud pass length was determined by multipling the mean true air speed by the number of seconds within cloud. Information on the number of flares dropped, the mean and maximum cloud liquid water content, and on the mean and maximum updraft velocity found found for each pass are presented in Table 8. The first vertical motion presented for each pass was an instantaneous reading from the rate of climb meter (1VSI) made by the pilot, during the pass. On August 26 vertical motion data was available from the Ball variometer. The temperatures recorded by the AI system were about 2-3 °C colder than measured by the Peoria (P1A), Salem (SLO), or Champaign (CHI) rawinsondes and than reported by the pilot. Icing problems also troubled the Rosemount sensor, and thus these measurements were disregarded.

Table 7. Basic cloud pass time and location information derived from the Atmosphere Incorporated aircraft observations,

date	cloud	pass	begtim (hhmmss)	endtim (hhmmss)	duration (sec)	mean horiz. motion (m/s)	pass length (km)	num. data points	coordinates* -x-	-y-
8-6-86	1	1	163121	163139	30	78	2.3	4	-58	-36
	2	1	163503	163533	42	74	3.1	6	-59	-41
	2	2	164109	164121	24	79	1.9	3	-56	-40
	3	1	164451	164457	18	74	1.3	2	-59	-41
	4	1	164851	164903	24	71	1.3	3	-52	-42
	4	2	165133	165203	36	71	2.6	5	-52	-44
	4	3	165521	165557	48	73	3.5	7	-52	-41
	5	1	170357	170433	42	73	3.1	6	-52	-44
8-26-86	3	1	95819	95913	60	73	4.4	9	-14	-17
	4	1	102418	102515	58	73	4.2	37	46	-51
	4	2	103004	103018	16	74	1.2	13	50	-42
	4	3	103533	103559	28	79	2.2	24	55	-38
	6	1	104816	104844	30	76	2.3	25	58	-33
	7	1	110816	110909	54	85	4.6	38	63	-23
	8	1	111225	111247	24	84	2.0	20	59	-27
	9	1	111547	111610	25	81	2.0	21	56	-32
	10	1	111859	111948	50	76	3.8	42	51	-30
	11	1	113152	113241	50	77	3.9	43	72	-25
8-26-86	2	1	155811	155854	44	80	3.5	38	-74	62
	3	1	160639	160733	56	81	4.5	48	-75	45
	4	1	162954	163034	42	79	3.3	35	-31	18
	4	2	163519	163620	62	73	4.5	52	-27	13
	5	1	171136	171220	39	84	3.3	39	29	52
	5	2	171557	171642	51	79	4.0	39	36	52
	6	1	173336	173414	39	81	3.2	34	49	26
	6	2	174240	174312	33	7 8	2.6	33	58	24
	6	3	174643	174737	56	81	4.5	48	62	25
	7	1	175801	175854	47	82	3.9	47	60	28
	8	1	182323	182356	35	81	2.8	30	31	-53
	8	2	182643	182725	43	77	3.3	37	31	-53

* Approx. location v.r.t. radar from pilot report.
Duration —> 6 seconds added to pass duration for 6 second data.

Table 4-8. Basic cloud pass information on altitude, cloud liquid water, and estimated vertical motion. The first vertical motion esstimate was from an instantaneous reading of the IUSI. The later 5 parameters are from a Ball variometer.

date	cloud	pass	# flares	pre-pass altitude kft msl	max LWC	mean LWC	vert. vel (m/s)	vertical motion max+ (m/s)	max− (m/s)	mean+ (m/s)	mean− (m/s)	mean (m/s)
8- 6-86	1	1	7	17.72	0.74	0.57	2.5	-	-	-	-	-
	2	1	13	17.80	0.47	0.29	5.0	-	-	-	-	-
	2	2	4	17.78	0.18	0.14	2.5	-	-	-	-	-
	3	1	8	17.88	1.41	0.87	-	-	-	-	-	-
	4	1	9	17.87	1.04	0.52	-	-	-	-	-	-
	4	2	11	17.33	1.01	0.63	10.0	-	-	-	-	-
	4	3	8	17.75	0.32	0.12	7.5	-	-	-	-	-
	5	1	9	17.38	1.24	0.85	6.0	-	-	-	-	-
8-26-86	3	1	10	18.67	0.57	0.31	2.5	5.2	-6.5	1.9	-3.5	.1
	4	1	1	18.66	0.50	0.18	2.5	9.0	-10.0	4.0	-4.9	-.7
	4	2	4	18.66	0.78	0.36	2.5	4.0	-5.3	1.6	-3.9	-.1
	4	3	6	18.68	0.74	0.47	2.5	3.6	-5.2	2.3	-1.8	-.1
	6	1	6	18.61	0.96	0.56	2.5	2.4	-3.7	1.3	-1.8	-.4
	7	1	11	18.66	0.95	0.34	4.0	5.6	-7.0	2.4	-2.6	0
	8	1	4	18.67	0.86	0.40	-	4.4	-5.7	2.2	-2.9	-.9
	9	1	4	18.61	0.96	0.46	2.5	4.1	-2.0	1.9	-1.3	.6
	10	1	18	18.46	1.04	0.63	5.0	5.7	-9.3	3.9	-3.1	1.2
	11	1	3	18.58	0.49	0.31	1.5	3.0	-6.1	1.6	-2.5	-.3
8-26-86	2	1	3	18.91	1.00	0.43	1.5	4.0	-5.4	1.1	-1.9	-.4
	3	1	9	18.97	0.97	0.66	5.0	4.2	-3.7	2.0	-1.8	.4
	4	1	12	18.85	1.14	0.67	-	4.3	-5.1	1.3	-2.2	-1.4
	4	2	4	18.77	1.03	0.65	-	7.5	-6.9	2.4	-2.5	-.3
	5	1	16	18.89	1.10	0.63	6.0	7.8	-3.3	3.6	-1.5	2.3
	5	2	11	18.70	0.92	0.65	4.0	5.8	-6.7	3.1	-2.2	.5
	6	1	8	18.70	0.44	0.27	4.0	7.6	-4.5	2.9	-2.1	.8
	6	2	2	18.65	0.31	0.20	2.5	4.7	-2.7	2.2	-1.3	.3
	6	3	6	18.75	0.25	0.13	6.5	9.1	-4.6	4.3	-1.8	1.1
	7	1	6	18.73	0.42	0.15	3.5	5.3	-4.2	2.2	-1.7	.2
	8	1	3	18.59	0.89	0.38	-	2.1	-2.1	0.9	-1.0	-.5
	8	2	3	18.60	0.78	0.49	2.0	3.3	-5.6	1.6	-2.4	-1.7

The aircraft data was crucial for locating the echoes associated with each treated cloud. This unfortunately was a cumbersome task. A first comparison of the aircraft position from the LORAN C system and from the VOR/DME system revealed some discrepancies between the systems on both August 6 and August 26. Because it was unclear which instrument was more reliable at a given time, the following assumptions were applied in deciding the aircraft location:

1. The aircraft positions reported by the pilot to Dr. Woodley just prior to each cloud pass were correct.

2. The aircraft headings calculated from the LORAN C were correct.

3. The aircraft was located in an area where active convection was present and that a growing radar echo could be expected at the 6 km level (-10 °C) at or near the time of cloud treatment.

First, appropriate magnetic north corrections were made to the VOR/DME readings, and the fact that the VOR/DME station at CMI was located some small distance from the radar also was taken into account. In general the LORAN C appeared to align very closely the aircraft with the pilots report and also with the newly developing echoes on August 26. On this day, the LORAN C and VOR/DME readings drifted apart by as much as 20 km and thus the VOR/DME readings were ignored.

On August 6, the LORAN C and the VOR/DME readings more nearly matched (within about 0-5 km). However, a systematic jump would occur in the LORAN C readings which would offset the LORAN C from the VOR/DME such that it would be about 4 km to the west and 2 km to the north of the VOR/DME. At the time when this offset was apparent, the LORAN C locations closely coincided with the pilots report and with the newest echoes reaching 6 km. The uncorrected LORAN C and the VOR/DME often place the aircraft either out of echo or within the area of the more mature storm. These corrected LORAN C positions were used.

While this method of locating the echo pass is rather inexact, I am fairly confident that the appropriate echoes associated with cloud pass were selected. A strong recommendation for next summers field operations which will rely on the RATS system (radar aircraft tracking system) developed and tested during the 1987 North Dakota operations, is that the aircraft backup locating systems be monitored more closely.

August 6, 1986

Two flights occurred on August 6, 1986, a late morning flight (1142 - 1420 CDT) which found only weak convection in the target area, and a late afternoon flight (1556 - 1746 CDT) which was terminated after a tornado was sighted within the target area about 35 km from the treated cloud system. The surface analysis at 0700 CDT, showed a low pressure center located on the SE Iowa - Illinois border. At that time two troughs extended from the low, one stretching southwestward to south-central Kansas, and the other eastward to Rockford, Ill. and then southeastward to Terra Haute, Indiana. The low pressure center extended from the surface to 700 mb, overlain by a trough at 500 and 300 mb. As the surface low tracked eastward, the trough which extended to the southwest gradually strengthened. By 1800 CDT, it was analyzed as a cold front stretching from Chicago southward through east-central Illinois and then southwestward through the St. Louis area. The 1515 CDT CMI sounding indicated winds from the south at the surface at 8 m s^{-1}, veering to the west at 5 km and remaining westerly above to 15 km. Wind speeds were on the order of 15-20 m s^{-1} above 1 km.

The 1515 CDT CMI sounding was very stable and indicated the presence of an isothermal layer at 855-826 mb (1.3-1.7 km ms1). A moist layer extended from the surface to 600 mb (4.4 km ms1). The surface temperature at CMI at 1600 CDT was 25°C. An area of surface convergence as determined from the winds at NWS first order stations moved southward from northern Illinois between 1200 CDT and 1600 CDT, with values of -10^{-4} s^{-1} present in the target area at 1600 CDT. While scattered high-based and weak convective clouds had been observed in the area since late morning, only after 1500 CDT did this convection become suitable for treatment. Low-level convergence in the afternoon appeared sufficient to lift the air mass resulting in a convectively unstable conditions, and an enhancement of the convection moving into the area. Although dynamically and not thermodynamically driven, the convection as viewed by radar formed at or below the freezing level, 4 km. The cloud base temperature and height, as estimated by the lifted condensation level (LCL), the convective condensation level (CCL), and the cloud model calculations, were about 15.5-16.5 C at about .7-1.2 km msl. Visual observations from the aircraft indicated a cloud base of .8 km.

Eight treatment passes were made through 5 clouds between 1631 and 1703 CDT, some 65 km to the southwest of CMI. The eight passes were concentrated in a cloud cluster containing on the order of 6 reflectivity cores at the 1 km level during the treatment period. New growth was occurring on the WSW end of the storm. Scientists in the aircraft, flying at about -10°C (5.9 km msl), reported cells just reaching their level at 1600 CDT. At the time of each treatment pass, a radar echo was observed in the same approximate location, at 6 km. The major uncertainty in the location of the aircraft is whether it is on the edge or adjacent to the echo, or whether it is flying through the center main core of the echo. In all instances, however, treatment most likely occurred above an area of previously existing echo. In 4 of the 5 cases, the first treatment occurred more than 10 minutes after first echo detection.

A time-height plot of the peak reflectivity associated with each echo, followed by a series of CAFPls at 1, 4, and 6 km which encompass the time of the pass is presented in the following figures (1-12).

AUGUST 6, 1986   FLIGHT 2

ECHO 1 : This echo forms between and is connected to two existing echoes. As it matures it moves to the NW and dissipates on the NW edge of the echo cluster.

ECHO 2 and 4 : Echo 2 forms on the SW end of the echo cluster. It rapidly becomes attached to the line of thunderstorms, particularly with the growth of echo 1 to its NE. Later in its history, it forms an extension to the south which reaches reflectivities of greater than 55 dBZ.

Echo 4 develops on its western edge. It is not clear if echo 4 splits from echo 2, or if evidence of its growth is embedded in echo 2. At the time echo 4 is first distinguishable from echo 2, it already has reached reflectivities of 55 dBZ. It rapidly overtakes the southern extension of echo 2. Echoes 2 and 4 appear intricately related.

ECHO 3 : This echo also forms on the SW end of the echo cluster, and it also develops a southern extension. This core becomes joined with the main echo mass, but remains relatively distinct. It dissipates as echoes 4 and 5 on either side, are maturing.

ECHO 5 : This echo likewise develops on the SW end of the line. A new echo forms soon after the first detection of echo 5, between it and echo 3, resulting in the union of echo 5 with the main storm. Echo 5 remains more intense than the newer echo to its NE. It also develops a southern extension.

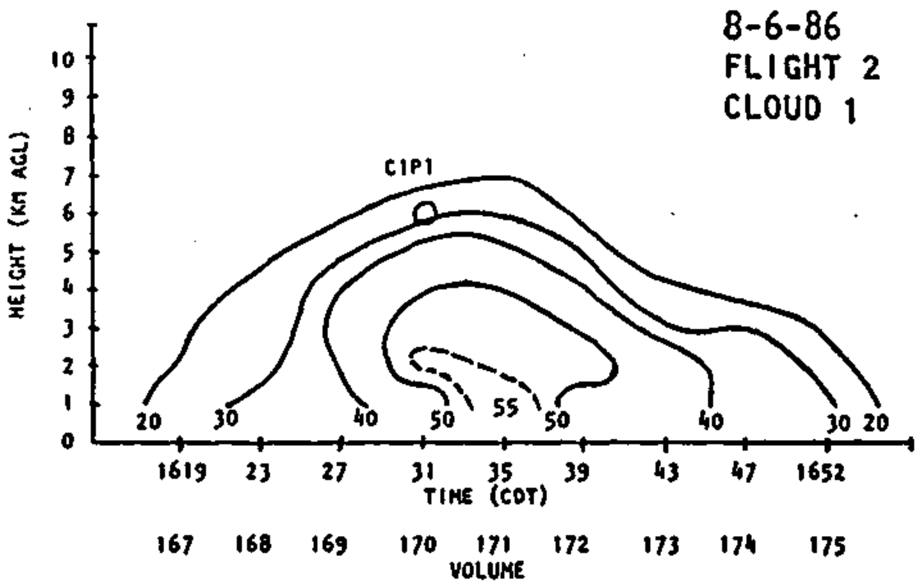


Fig. 4-1. Time-height history of the peak reflectivity found in echo 1. Treatment pass denoted by a circle at 6 km.

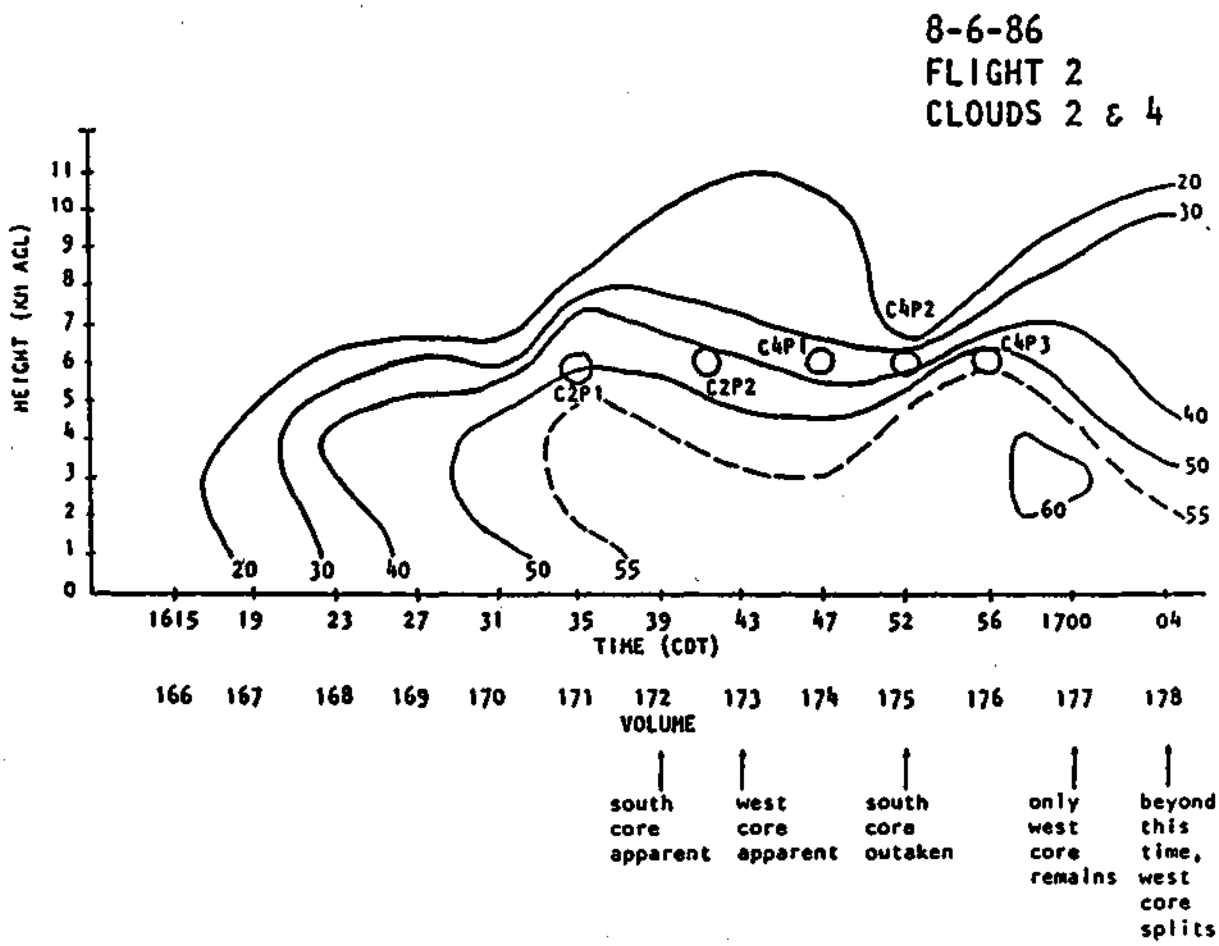


Fig. 4- 2. Time-height history of the peak reflectivity found in echoes 2 and 4. Treatment pass denoted by a circle at 6 km.

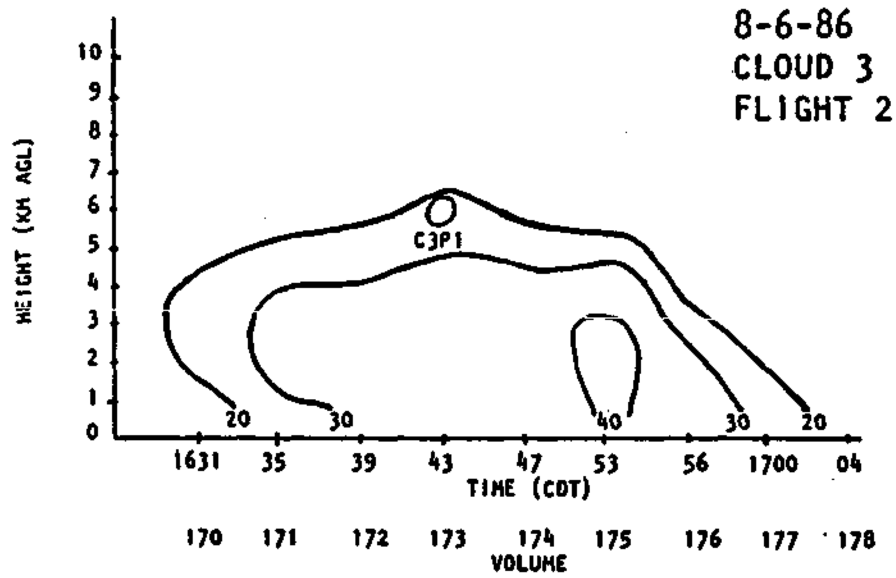


Fig. 4-3. Time-height history of the peak reflectivity found in echo 3. Treatment pass denoted by a circle at 6 km.

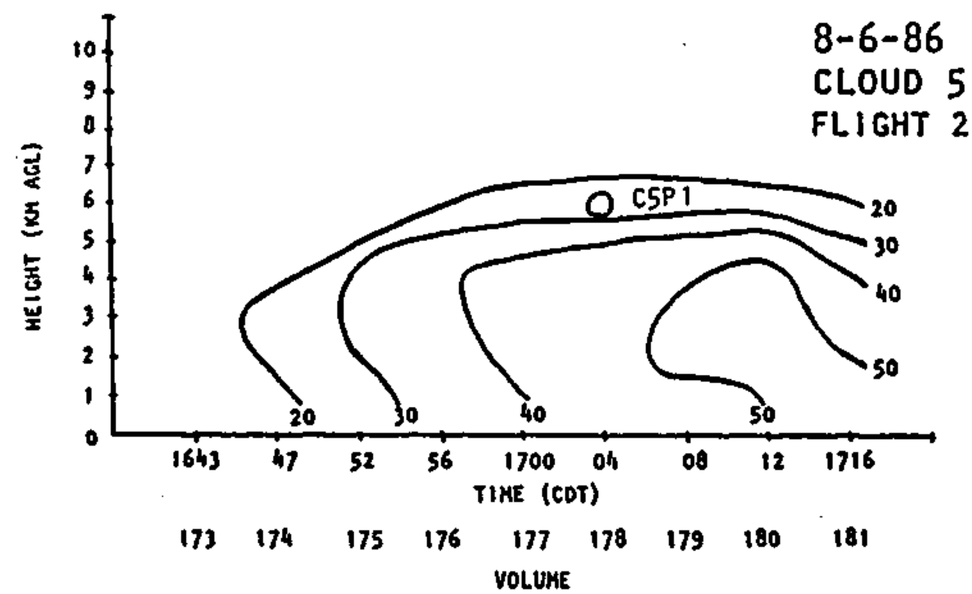
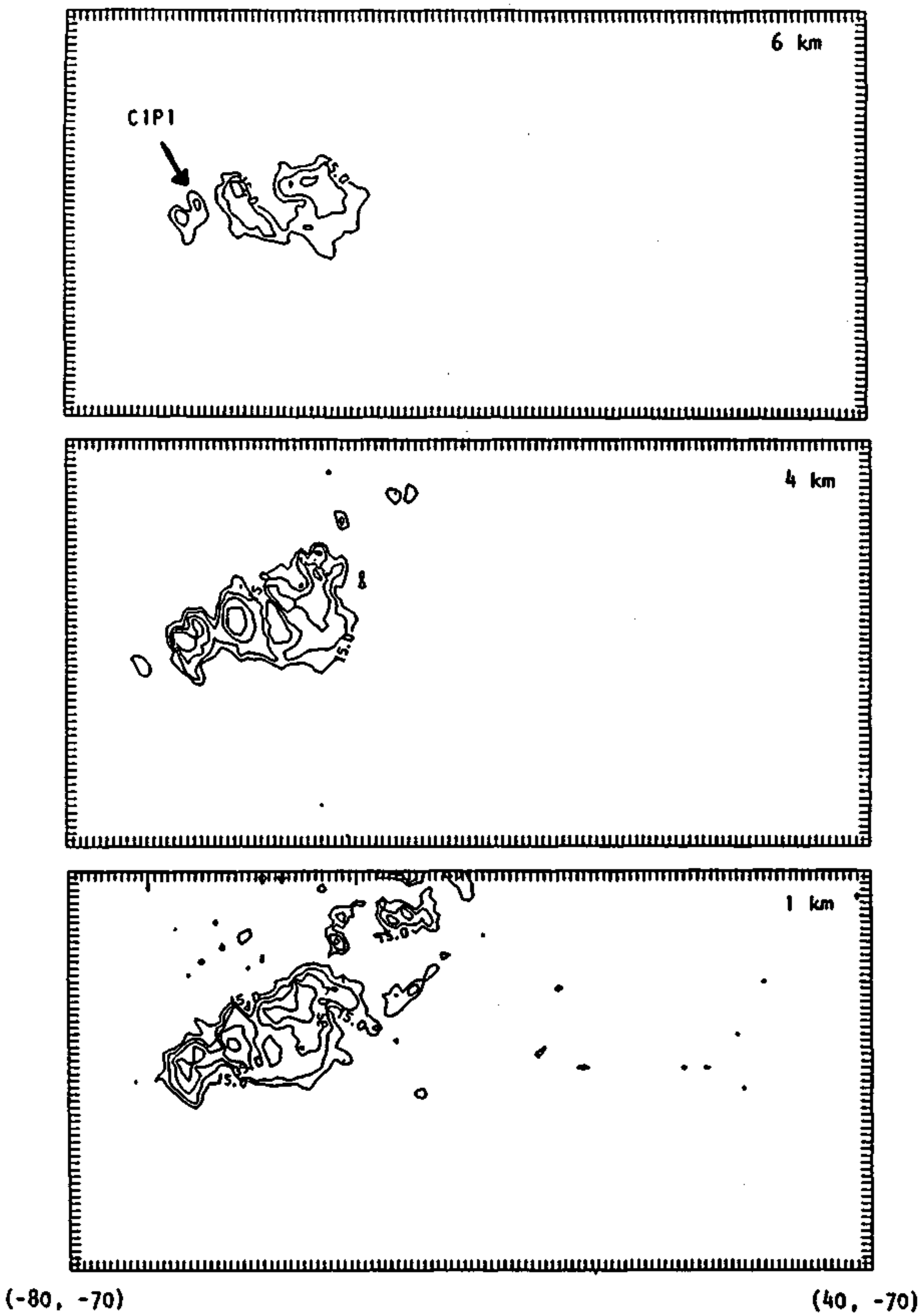
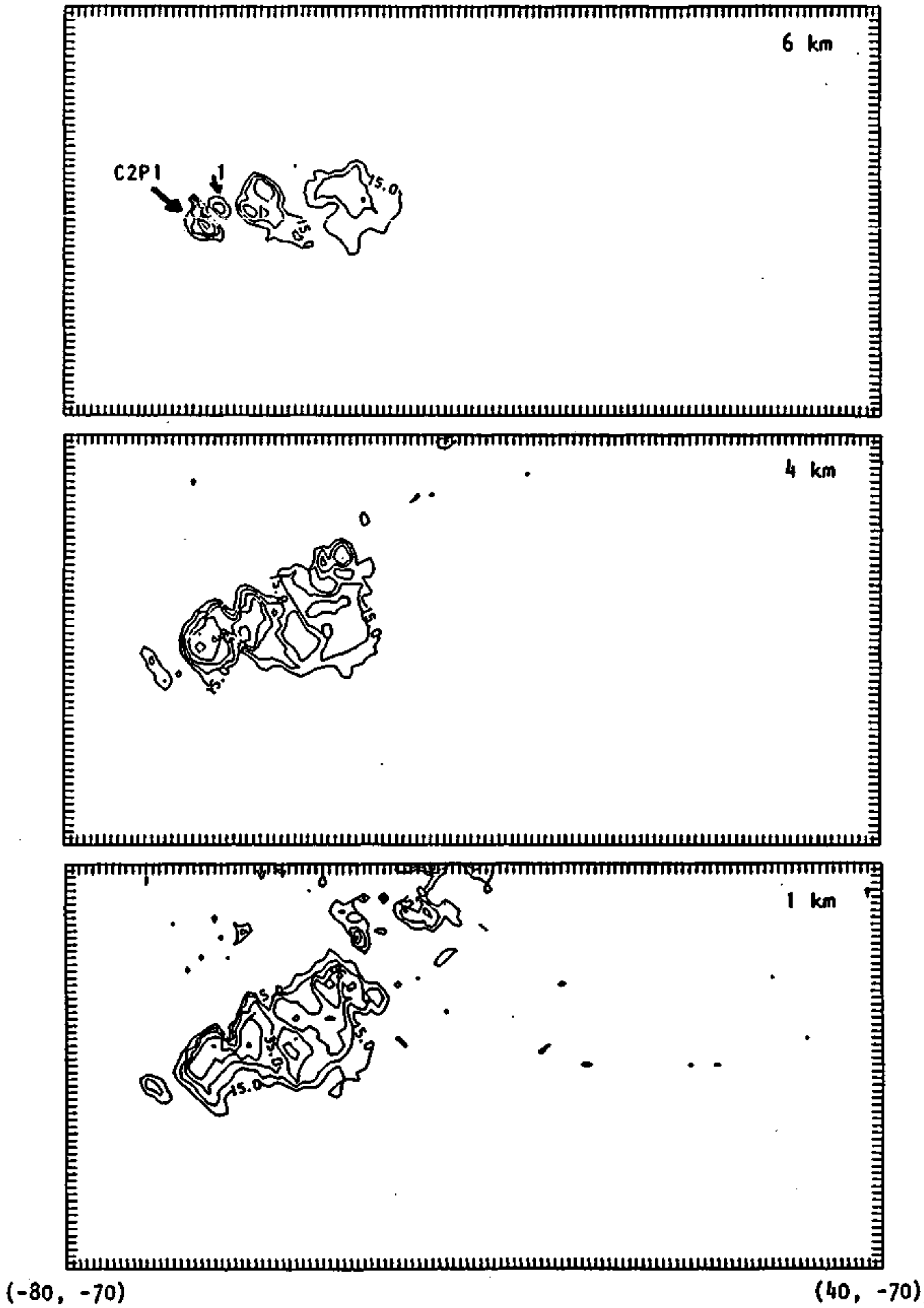


Fig. 4-4. Time-height history of the peak reflectivity found in echo 5. Treatment pass denoted by a circle at 6 km.



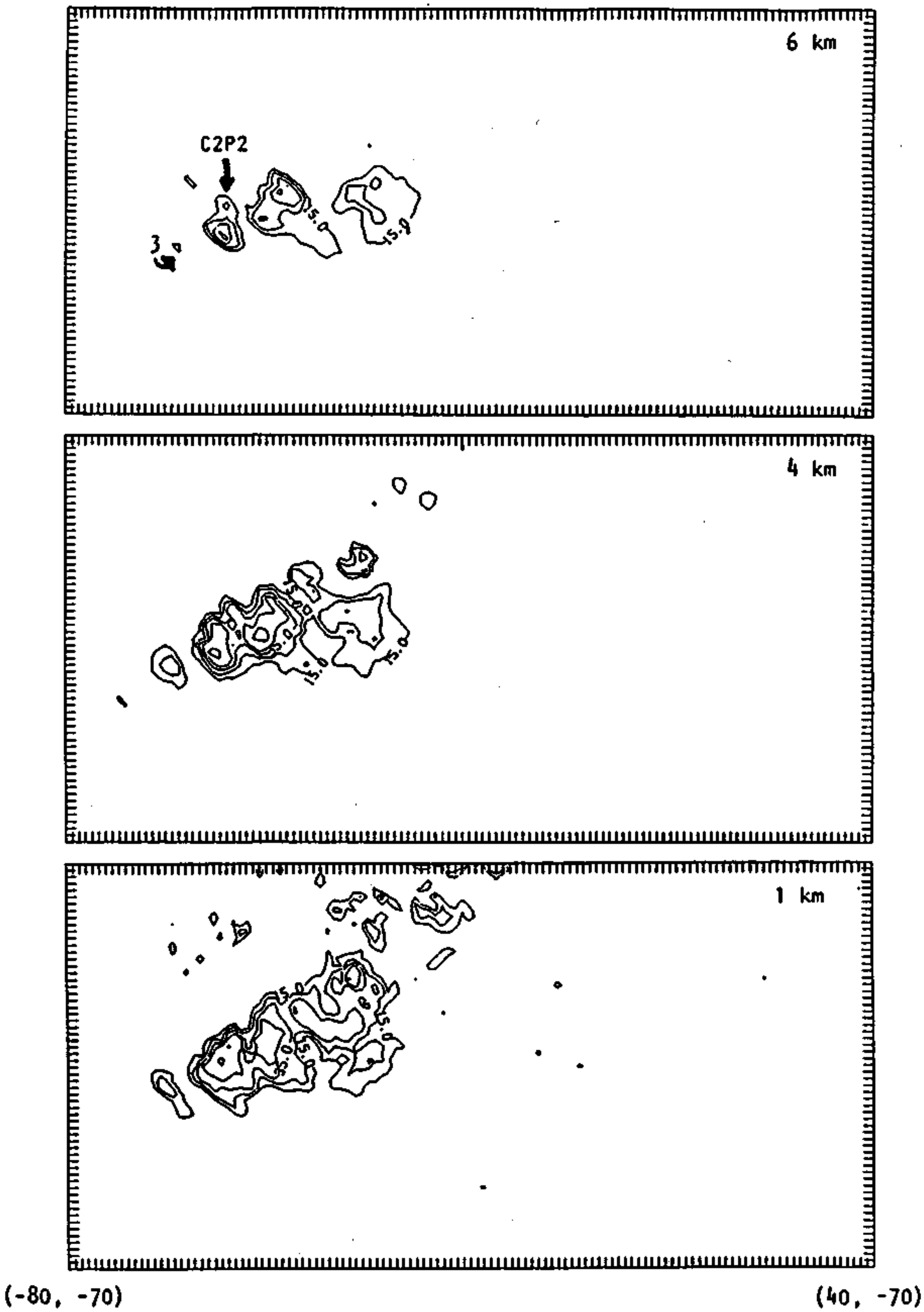
8-6-86 VOL 170 162922-163330 COT

Fig. 4-5. 1, 4, 6 km CAPPIs near time of cloud 1 pass 1. Reflectivity contoured in 10 dBZ intervals, beginning at 15 dBZ. Distance from radar noted in parentheses. Echo associated with cloud indicated by arrow at 6 km.



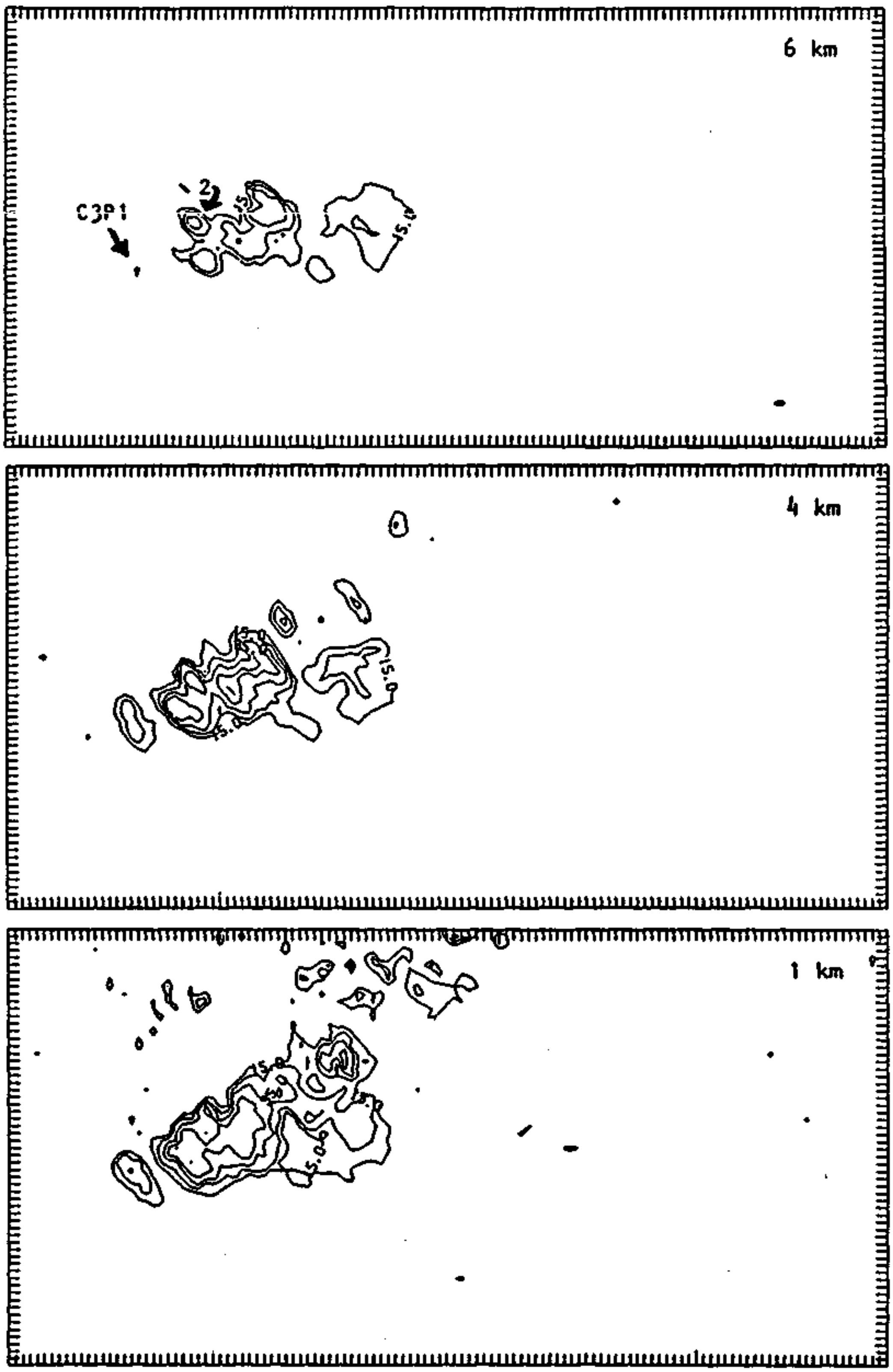
8-6-86 VOL 171 163330-163737 CDT

Fig. 4-6. CAFFis near time of cloud 2 pass 1; as in Fig. 5.



8-6-86 VOL 172 163737- 16145 CDT

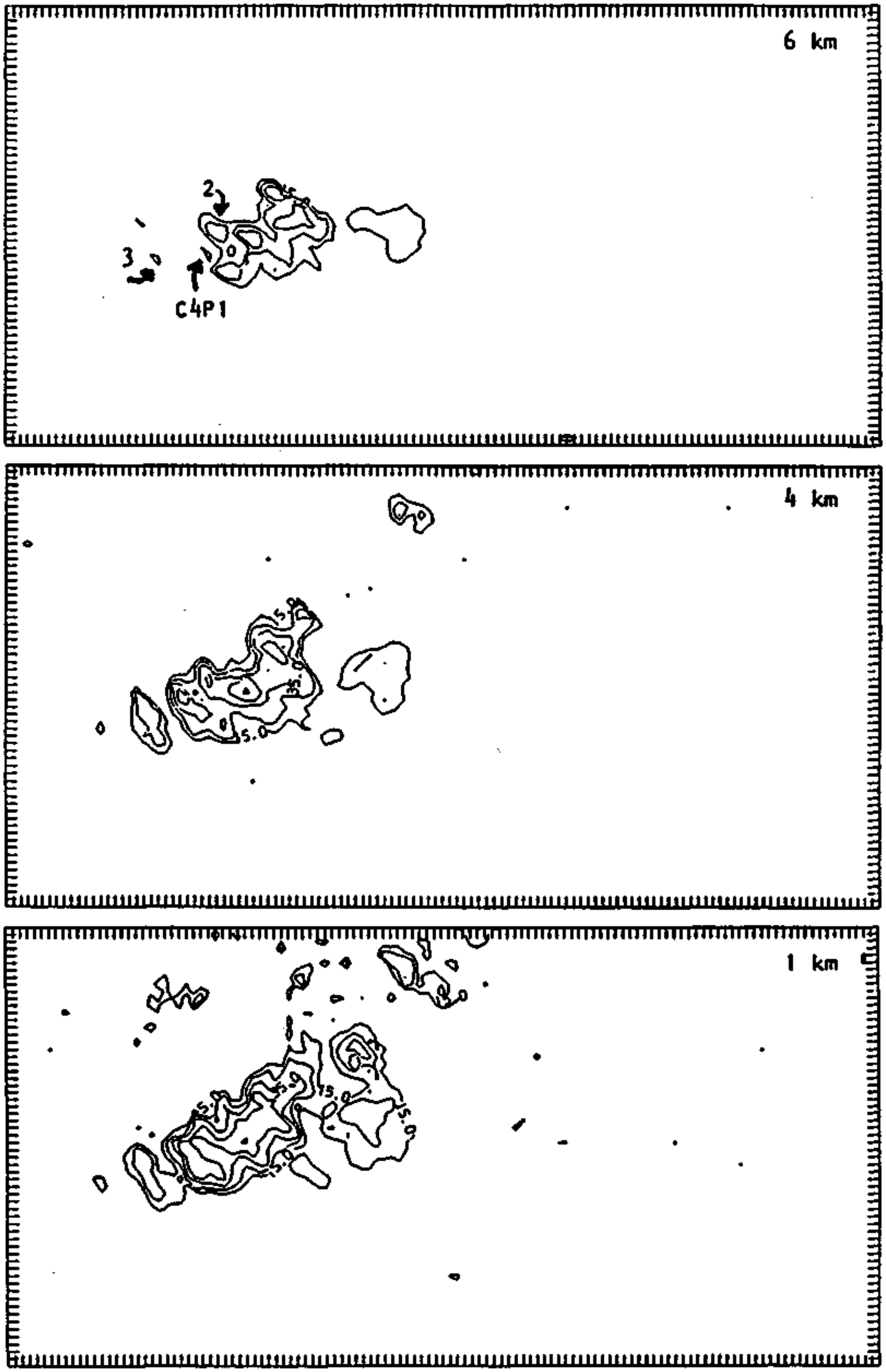
Fig. 4-7. CAPPIS near time of cloud 2 pass 2; as in Fig. 5.



(-80, -70) (40, -70)

8-6-86 VOL 173 164145-164552 CDT

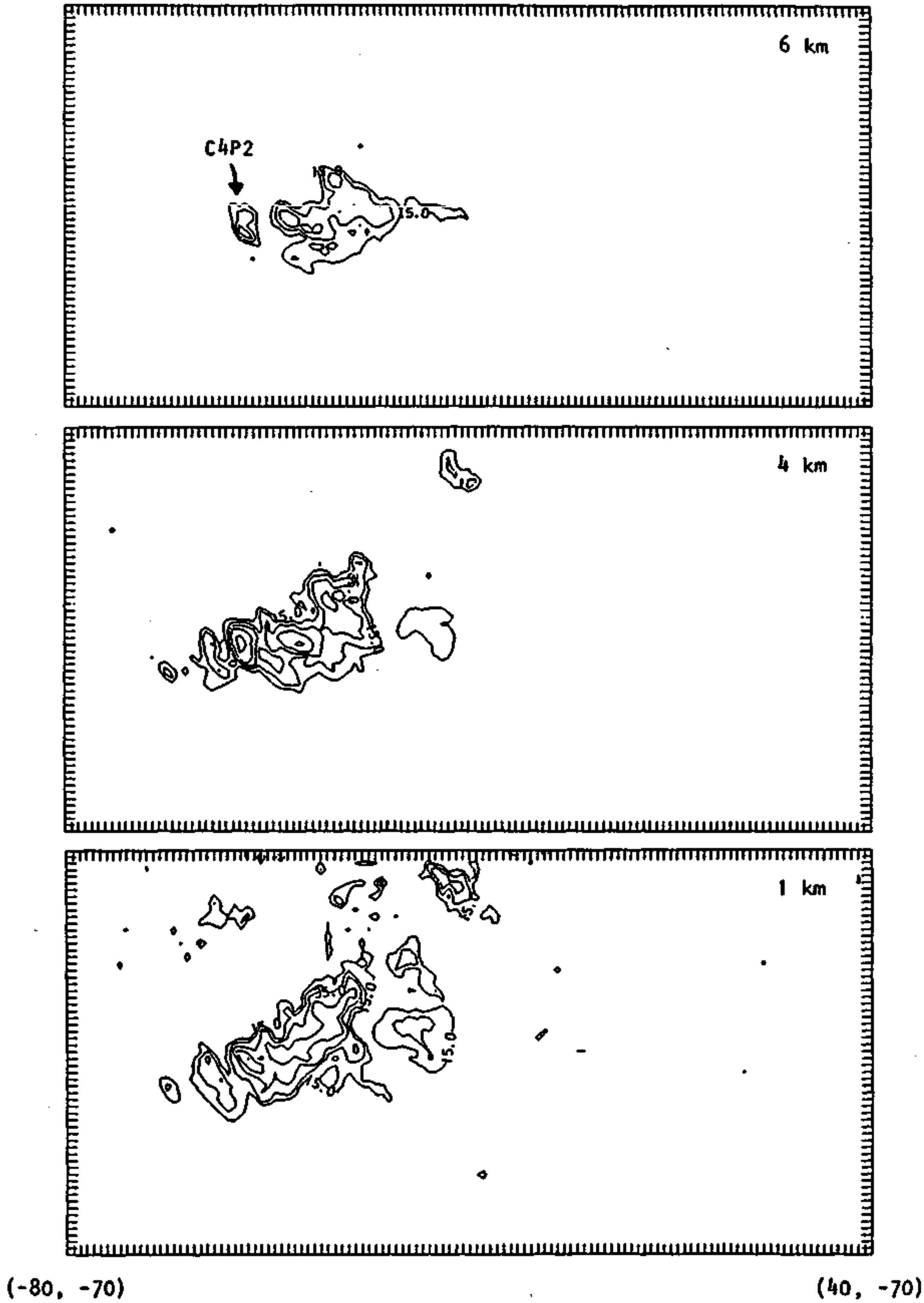
Fig. 4-8. CAPPIs near time of cloud 3 pass 1; as in Fig. 5.



(-80, -70) (40, -70)

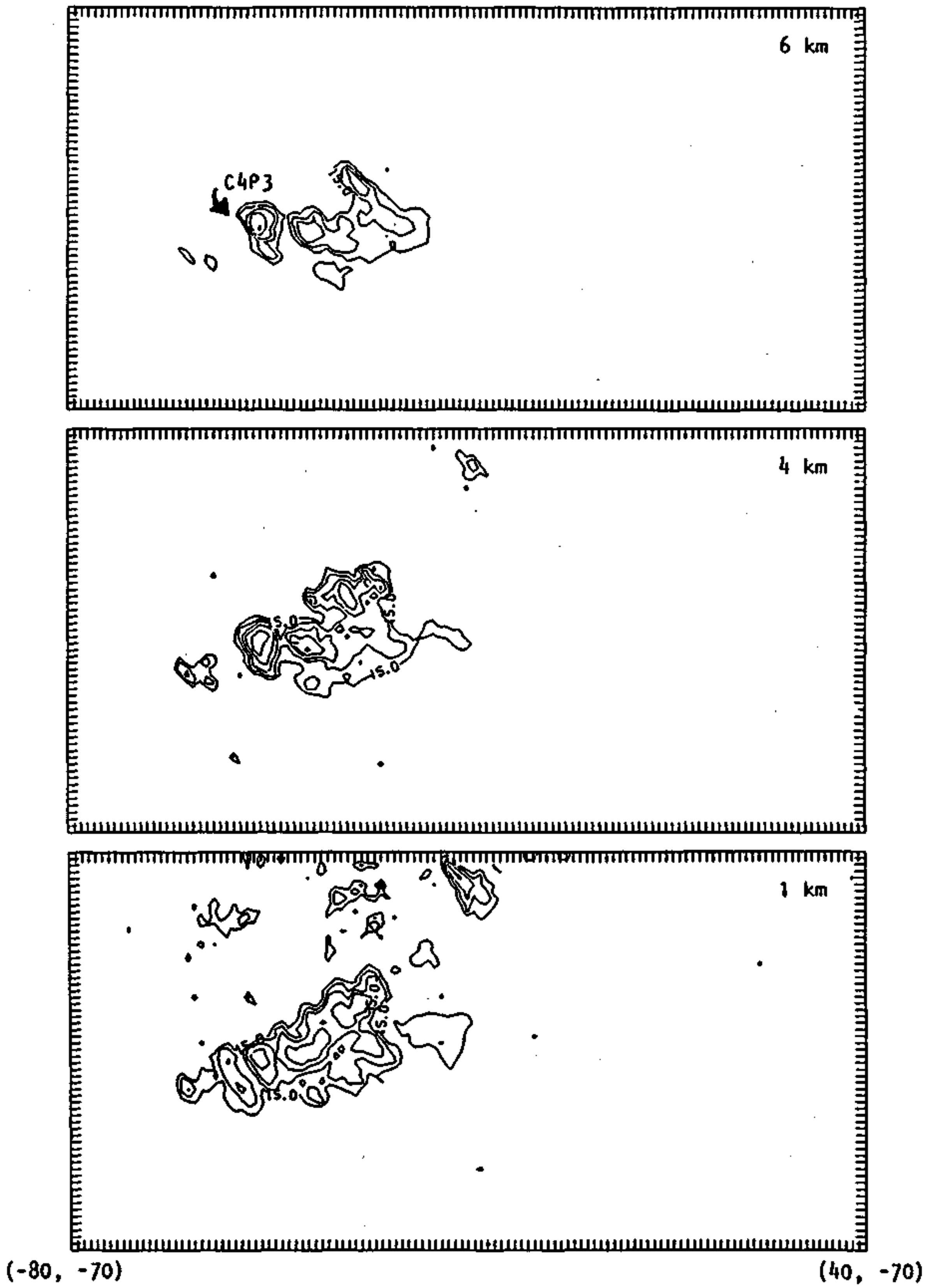
0-6-86 VOL 174 164552-165000 CDT

Fig. 4-9. CAPPIs near time of cloud 4 pass 1; as in Fig. 5.



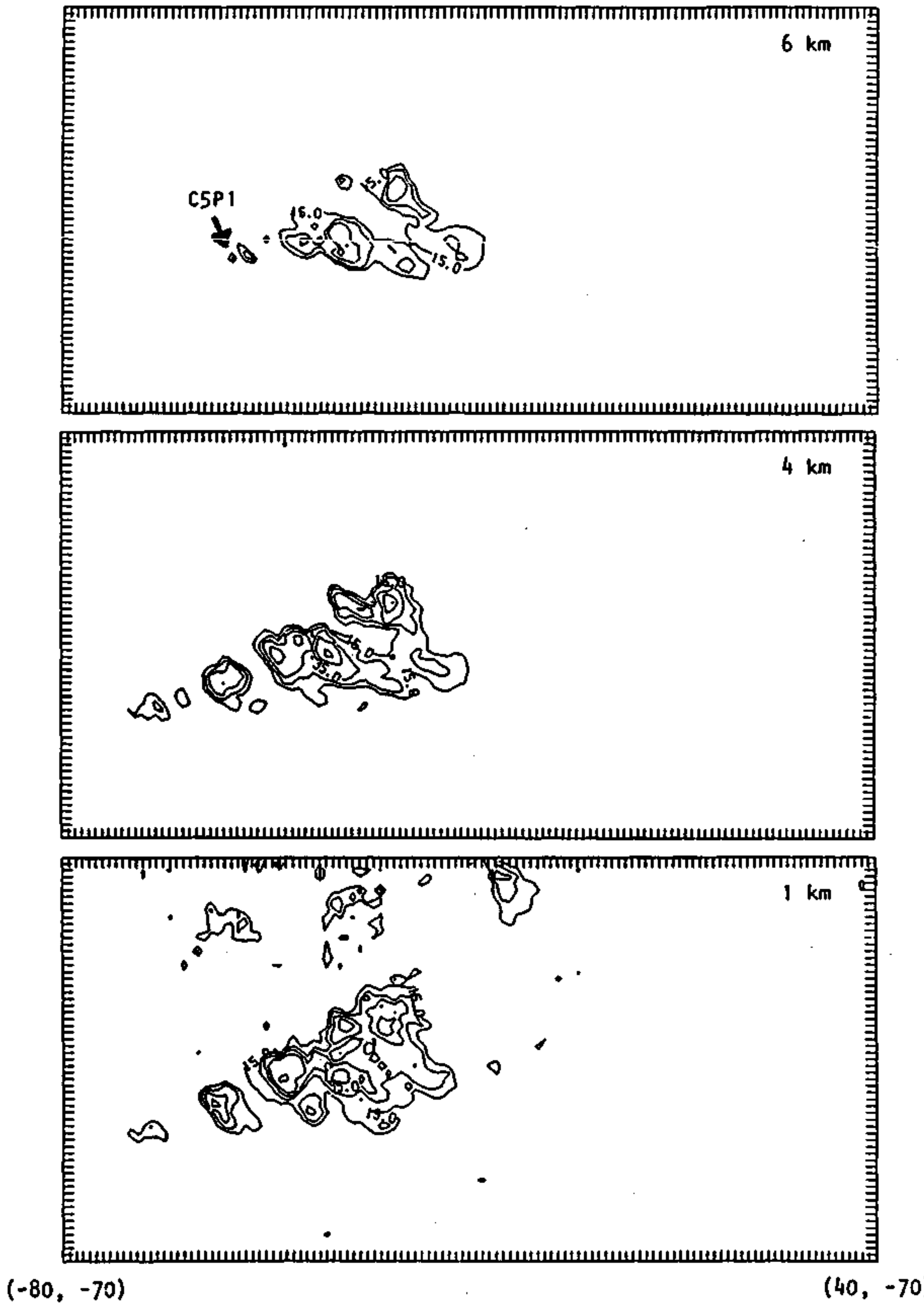
8-6-86 VOL 175 165000-16507 CDT

Fig. 4-10. CAPPIs near time of cloud 4 pass 2; as in Fig. 5.



8-6-86 VOL 176 165407-165815 CDT

Fig. 4-11. CAPPIs near time of cloud 4 pass 3; as in Fig. 5.



8-6-86 VOL 178 170222-170630 COT

Fig. 4-12. CAPPIs near time of cloud 5 pass 1; as in Pig. 5.

August 26. 1986 - Flight 1

The first treatment flight was from 0846 - 1202 CDT on this day, with thunderstorms forming about 250 km ahead of a strong, slowly moving cold front. Surface temperatures of 22 - 23°C were found at PIA and SLO, with a strong surface based inversion, reaching to about 930 mb. Cloud base temperatures estimates were on the order of 18-19˚C, at a height of about 1-1.5 km msl. Visual reports from the aircraft indicated a variable cloud base. The 0700 CDT FIA and SLO soundings showed very unstable conditions above the inversion, with substantial moisture up to 450 mb. A K Index of 42 and a Lifted Index of -5 were computed for SLO. Surface convergence values of -2×10^{-5} s^{-1} were present in the east-central Illinois area from 0900 - 1000 CDT. At 1100 CDT, this area of convergence had moved into west central Indiana. By 1145 CDT, the seeding aircraft was returning to home base, as convective activity was diminishing and moving rapidly eastward.

The echoes occurring during this flight had relatively uncomplicated histories, although often were a part of one of a number of small squall lines. Echo formation occurred at or above the freezing level (4.4 km msl), from 4 to 6 km. Ten treatment passes were made between 0958 and 1131 CDT, in a region 60 to 75 km to the SW and SE of the radar. On 5 of these passes, treatment occurred within about 5 minutes of first echo detection, and in the remaining 3 cases, within about 10 minutes. In 5 instances, treatment occurred in echoes (15 dBZ minimum reflectivity) which were separated from other echoes by at least 3 km. In the 3 other passes, new echo growth occurred adjacent to an existing echo. Again, time-height plots of peak reflectivity for the echoes most likely associated with the treated clouds are presented, followed by CAFFIs at 2, 4, and 6 km indicating the relevant echoes (Fig. 13-30).

AUGUST 26, 1987   FLIGHT 1

ECHO 3 : This echo forms on the SW end of a small line. Fifteen minutes after its first detection, this echo appears to merge with an echo core to its NE which had formed at about the same time and was of a similar size. Because of its close proximity to the radar which resulted in the presentation of a finer detailed structure, subsequent to the merger the echo history became difficult to track. It is planned to reinterpolated the data for this echo on a finer grid and to reevaluate its history.

ECHO 4 : This echo forms on the NE end of a small line of echoes. It is initially and through its lifetime joined with this line of echoes. However, it remains relatively distinct and eventually becomes the dominant reflectivity core of the small line.

ECHO 6 : Echo 6 forms to the N of echo 4, but remains separate from echo 4 at the 15 dBZ level. Several echoes form to its SE but are short-lived.

ECHO 7 : The echo associated with cloud 7 forms to the S of an echo which is ahead of a large line. Later in its life, echo 7 is over taken by this line. Echo 7 is joined almost immediately to the echo to the NE, but remains a distinguishable core.

ECHO 8 : This echo forms to the SW of echo 7 and is joined to but but distinct from echo 7.

ECHO 9 : This echo forms away from and to the WSW of echo 8. It remains isolated from echo 8, but is overtaken for a new SW / NE line which develops to its NW.

ECHO 10 : This echo develops initially as an isolated echo, but becomes a major element of the new SW / NE line mentioned previously.

ECHO 11 : This develops just to the NE of echo 10 and between echo 10 and another echo to its NE. Although at first it is joined to the NE echo, it soon is united with echo 10 as well.

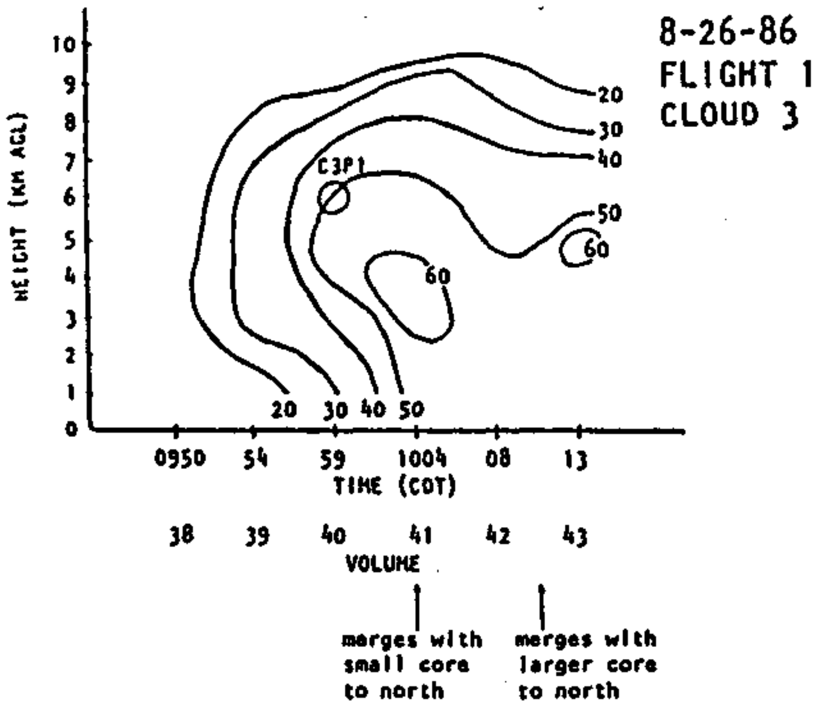


Fig 4-13. Time-height history of the peak reflectivity found in echo 3. Treatment pass denoted by a circle at 6 km.

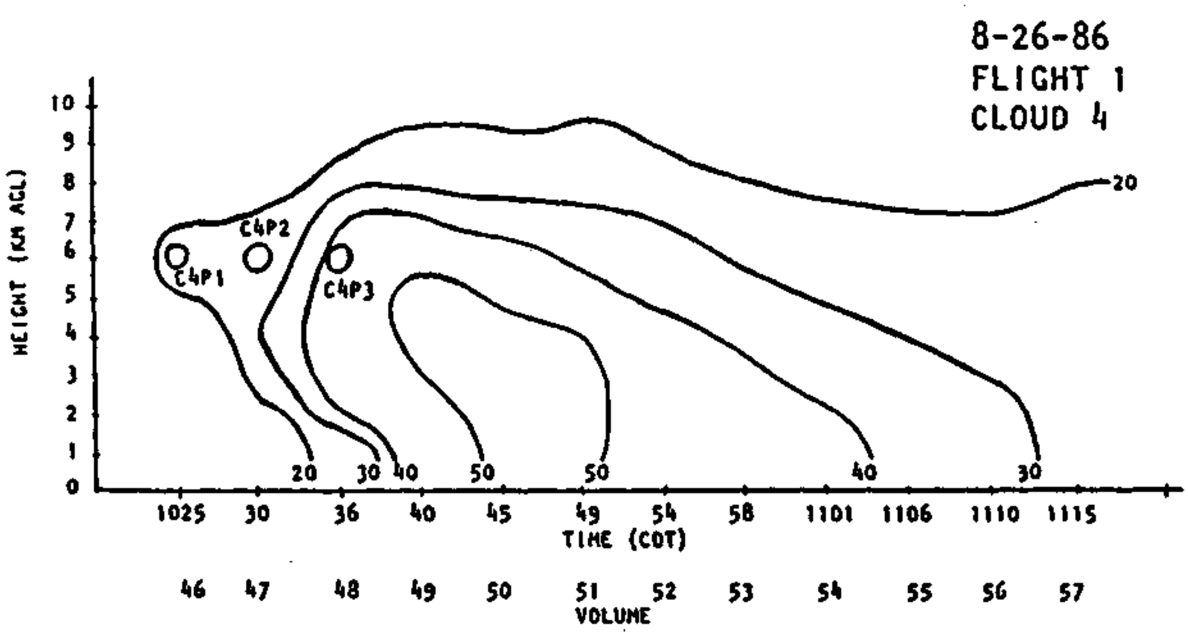


Fig. 444. Time-height history of the peak reflectivity found in echo 4. Treatment pass denoted by a circle at 6 km.

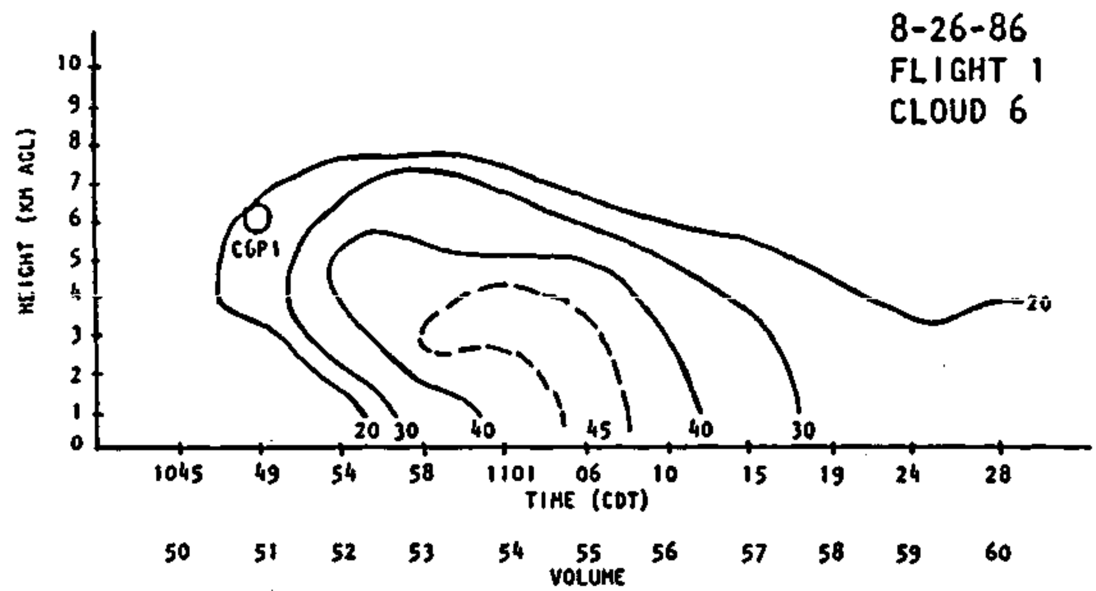


Fig. 4-15. Time-height history of the peak reflectivity found in echo 6. Treatment pass denoted by a circle at 6 km.

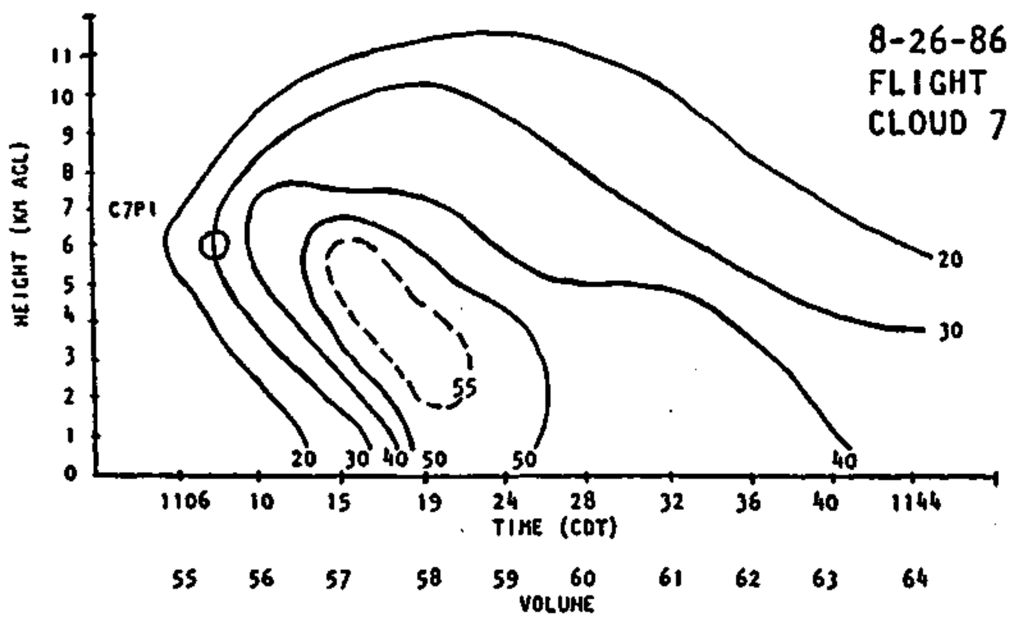


Fig. 4-16. Time-height history of the peak reflectivity found in echo 7. Treatment pass denoted by a circle at 6 km.

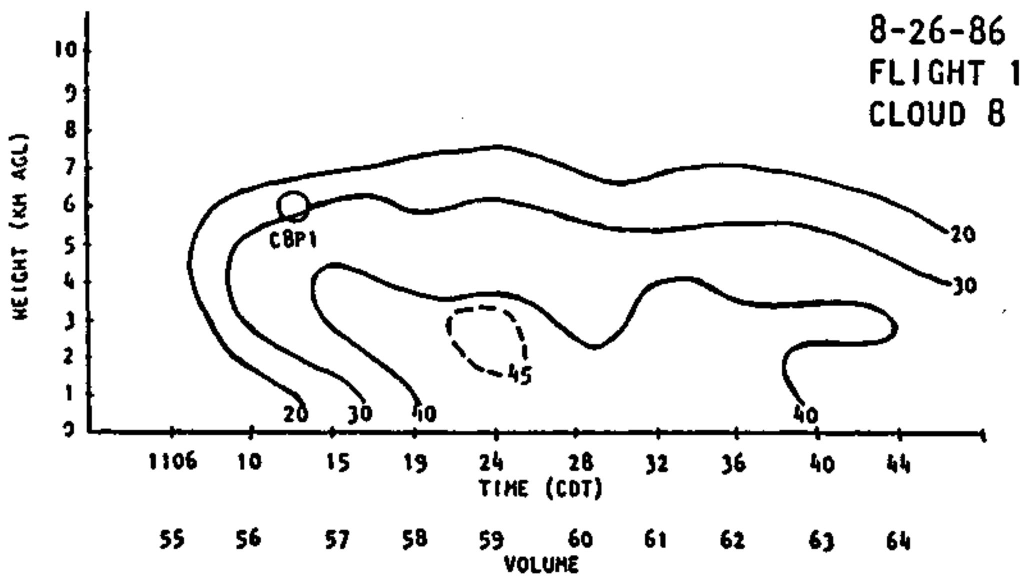


Fig. 4-17. Time-height history of the peak reflectivity found in echo 8. Treatment pass denoted by a circle at 6 km.

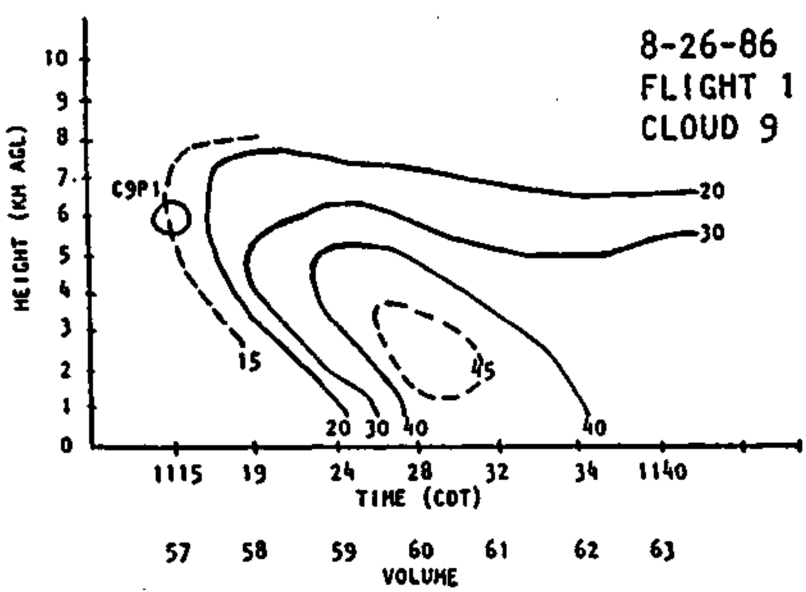


Fig. 4-18. Time-height history of the peak reflectivity found in echoes 9. Treatment pass denoted by a circle at 6 km.

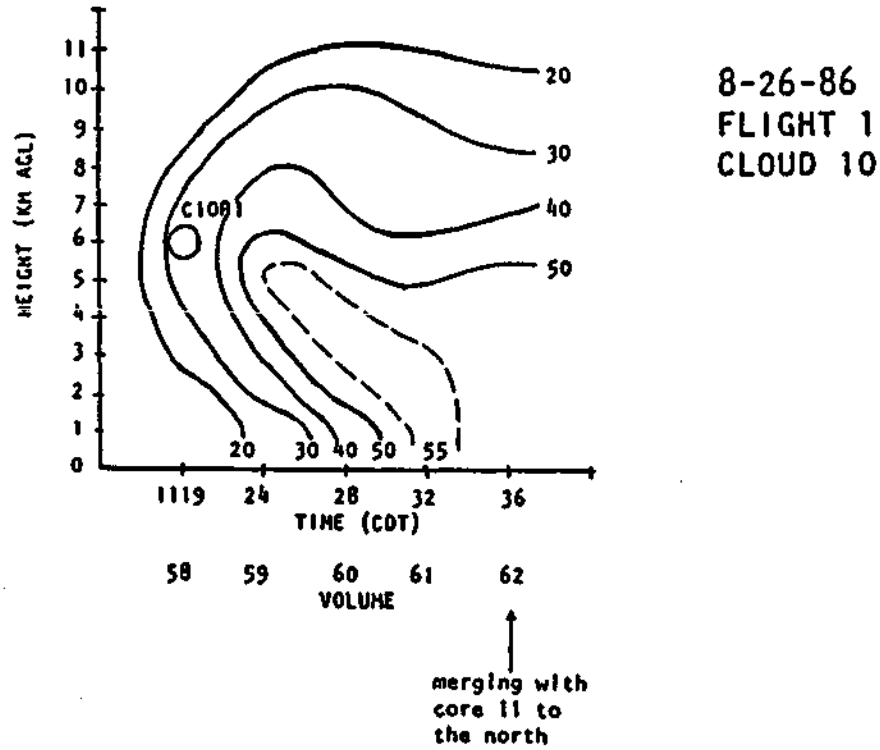


Fig. 4-19. Time-height history of the peak reflectivity found in echo 10. Treatment pass denoted by a circle at 6 km.

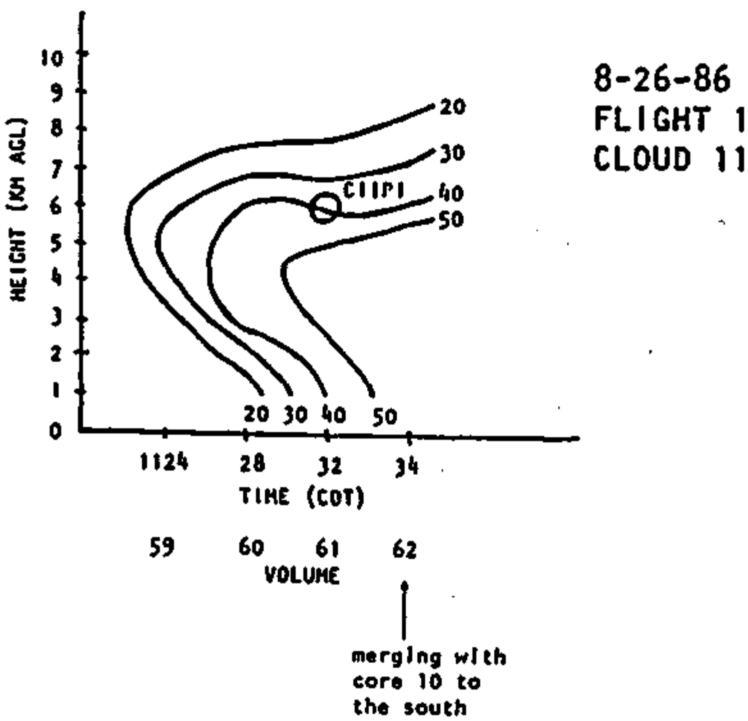


Fig. 4-20. Time-height history of the peak reflectivity found in echo 11. Treatment pass denoted by a circle at 6 km.

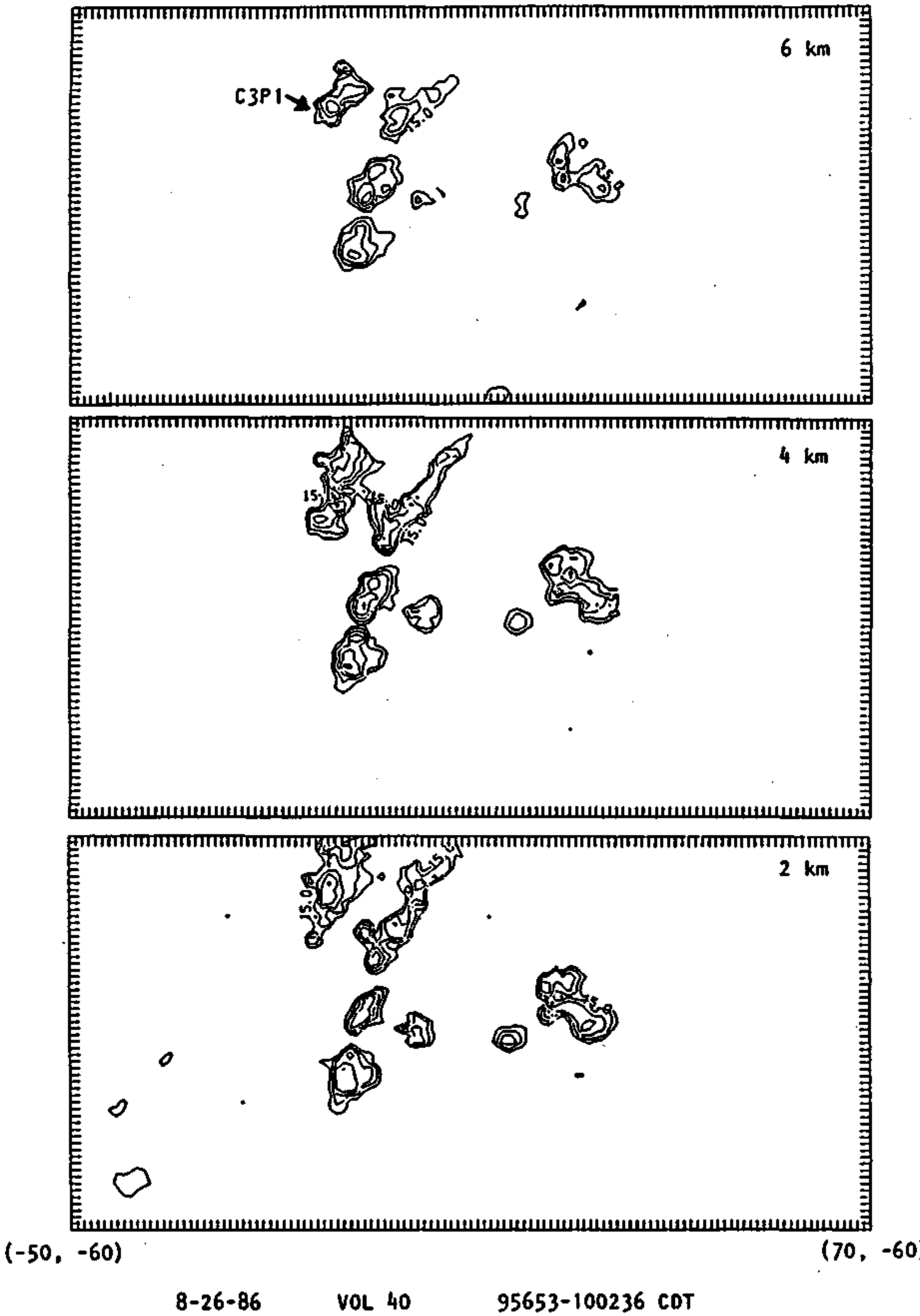


Fig. 4-21. CAPPIs near time of cloud 3 pass 1; as in Fig. 5.

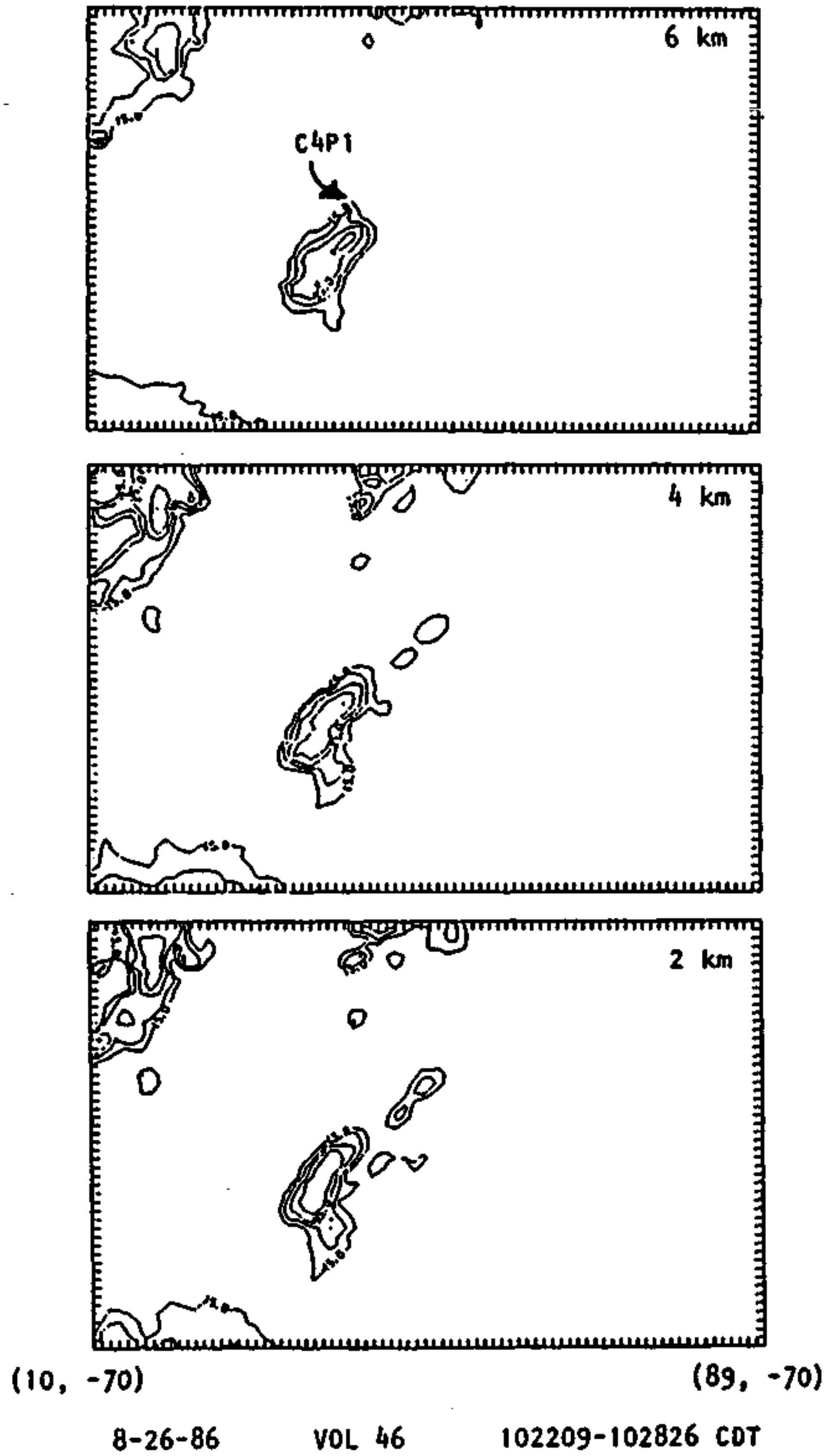


Fig. 4-22. CAPPIs near time of cloud 4 pass 1; as in Fig. 5.

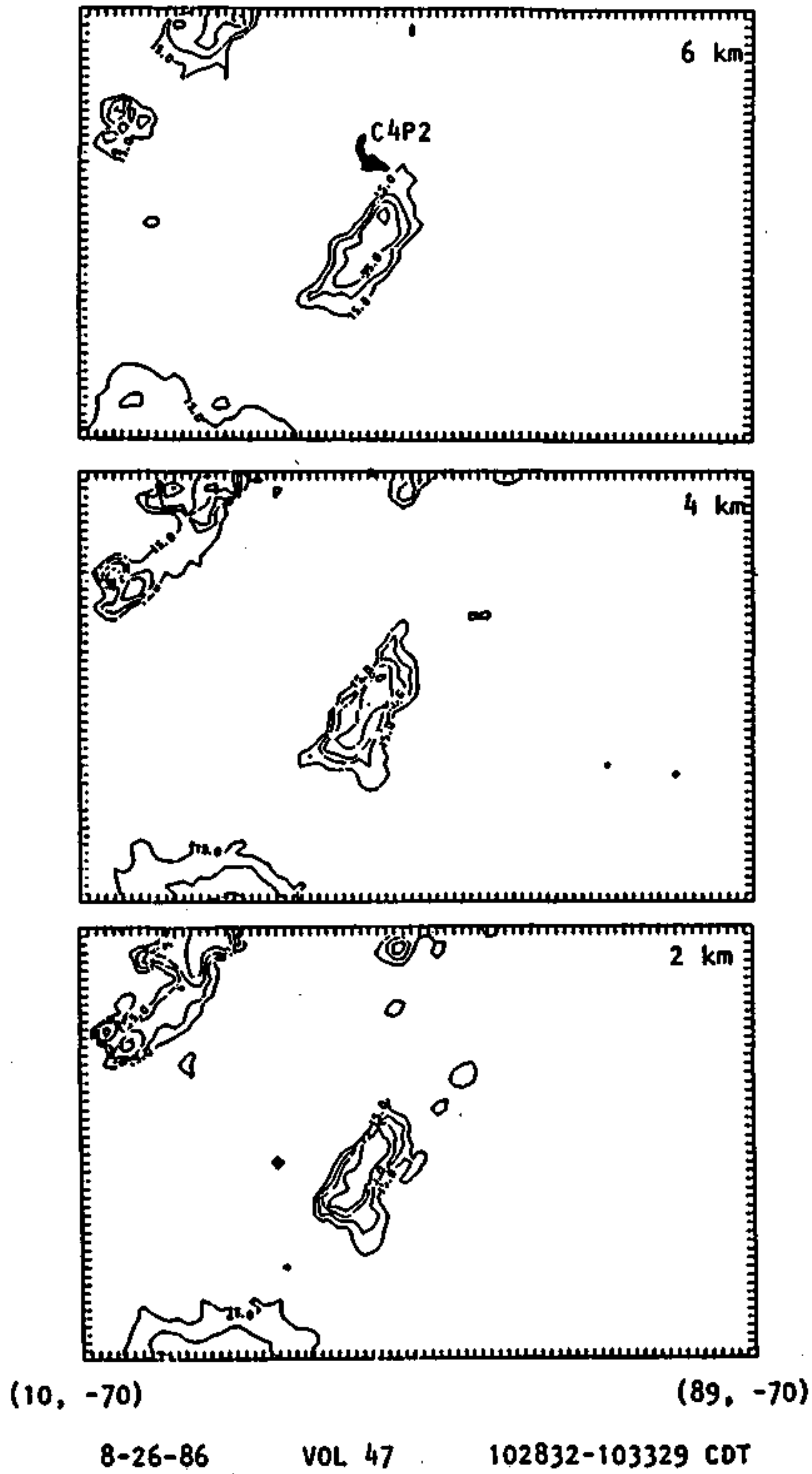


Fig. 4-23. CAPPIs near time of cloud 4 pass 2; as in Fig. 5.

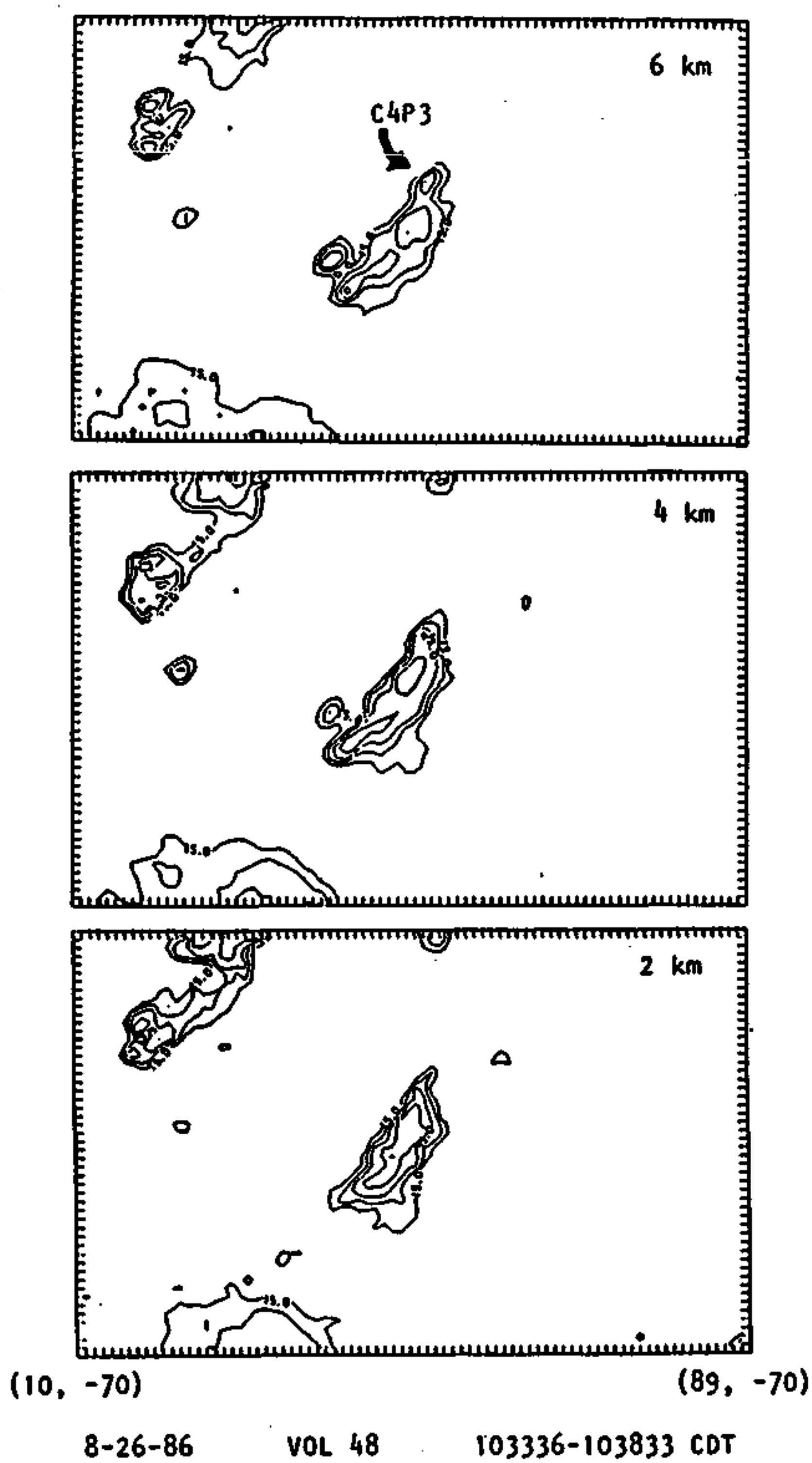
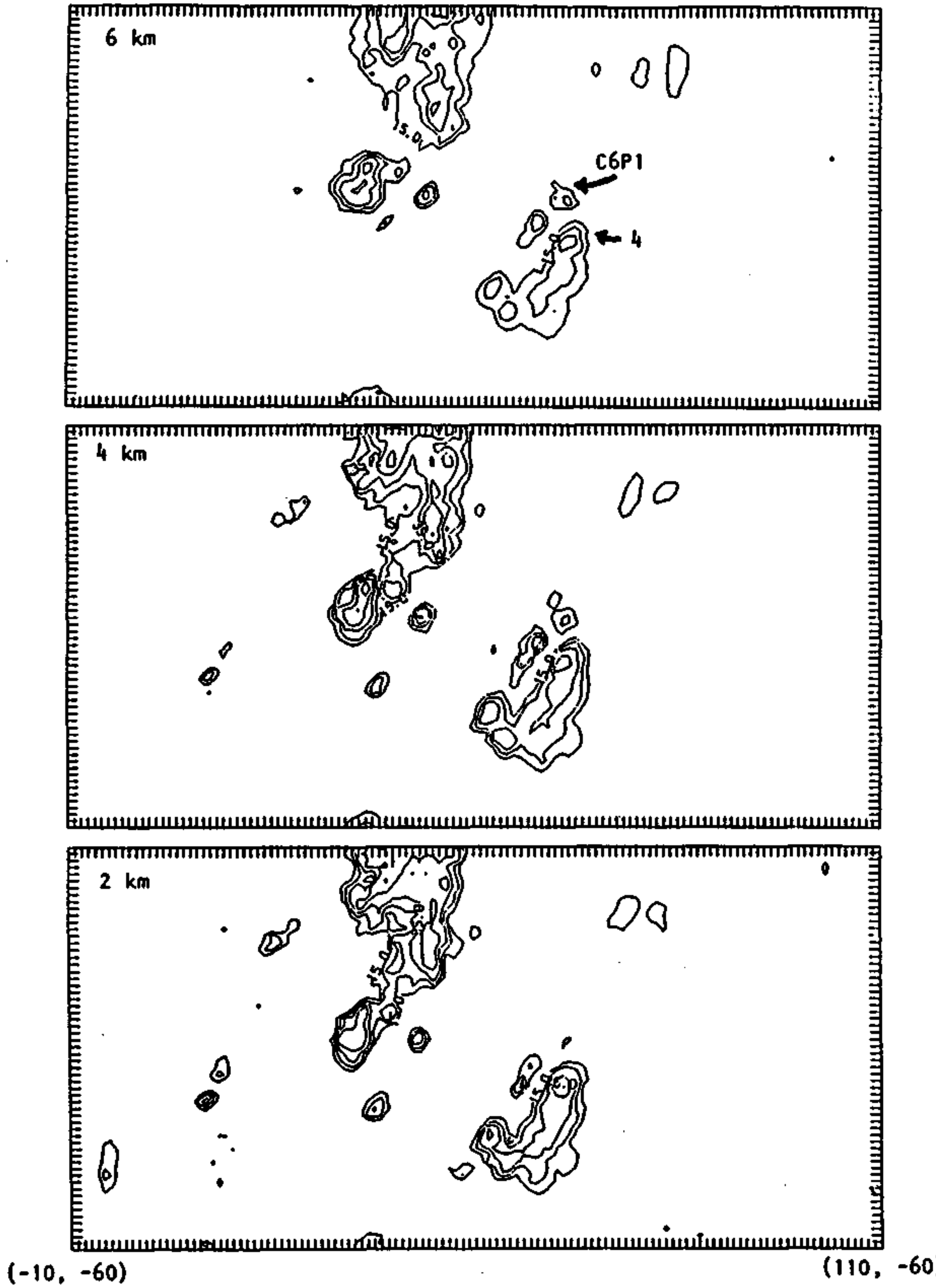
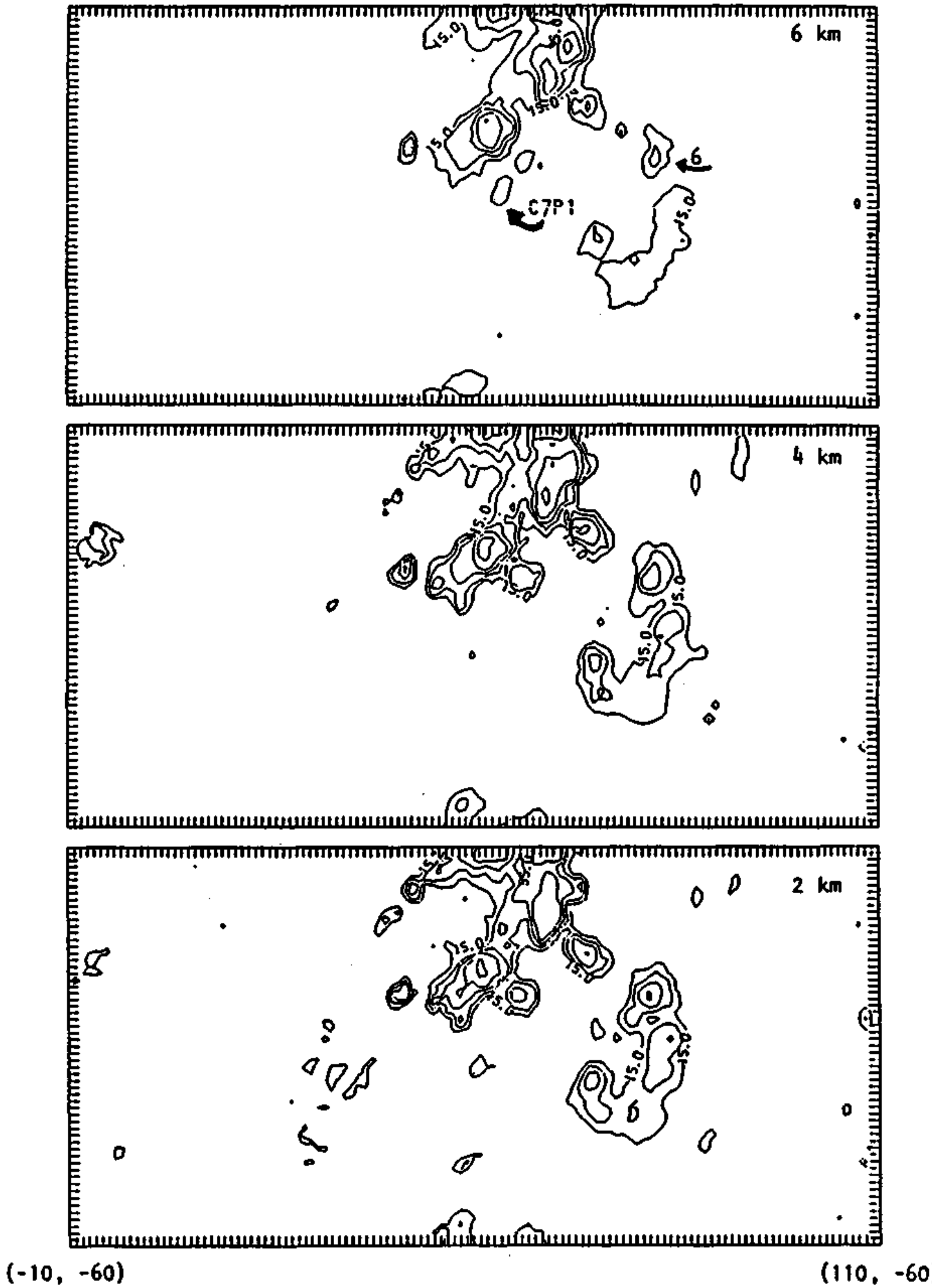


Fig. 4-24. CAPPIS near time of cloud 4 pass 3; as in Fig. 5.



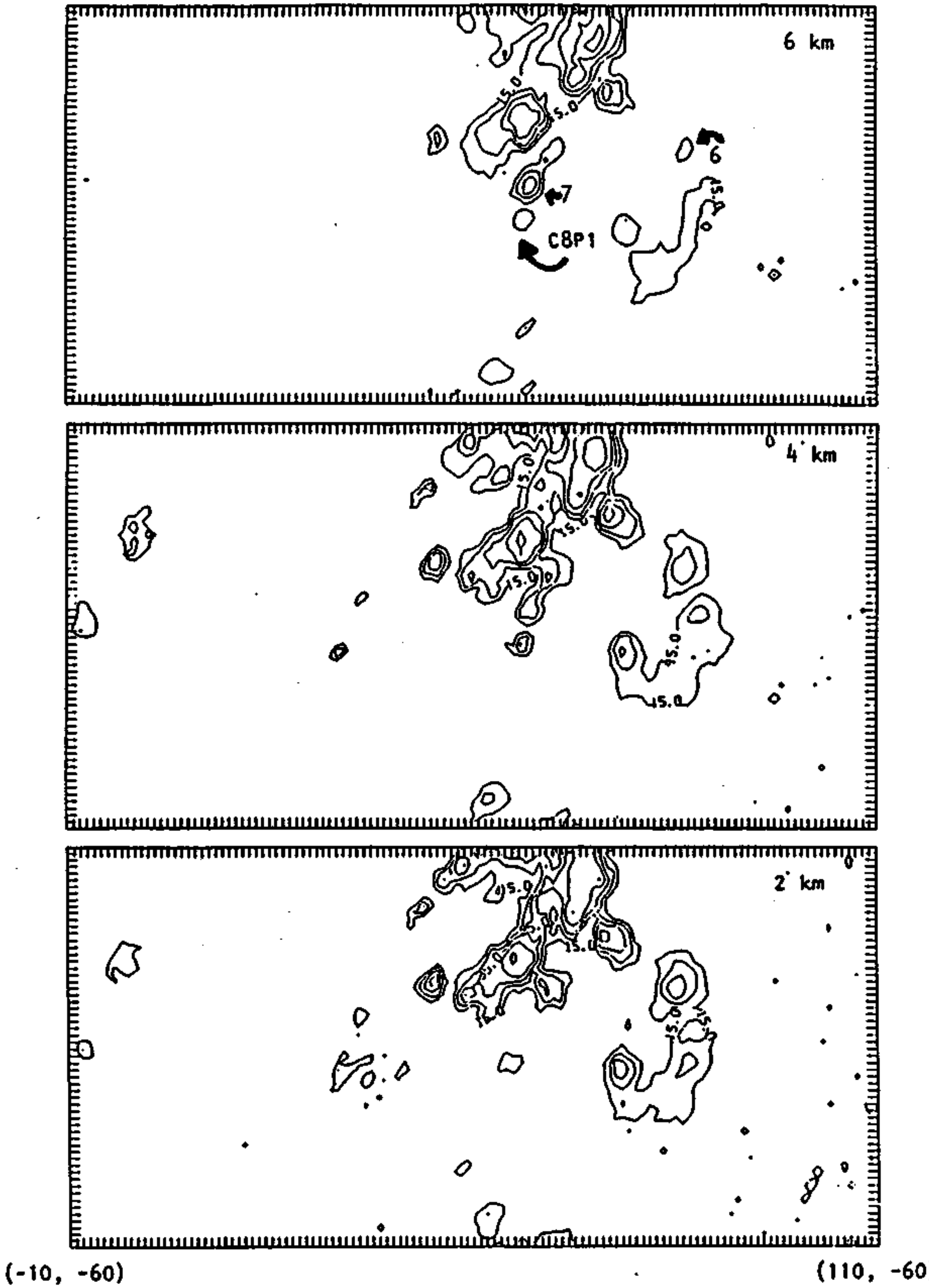
8-26-86 VOL 51 104740-105200 CDT

Fig. 4-25. CAPPIs near time of cloud 6 pass 1; as in Fig. 5.



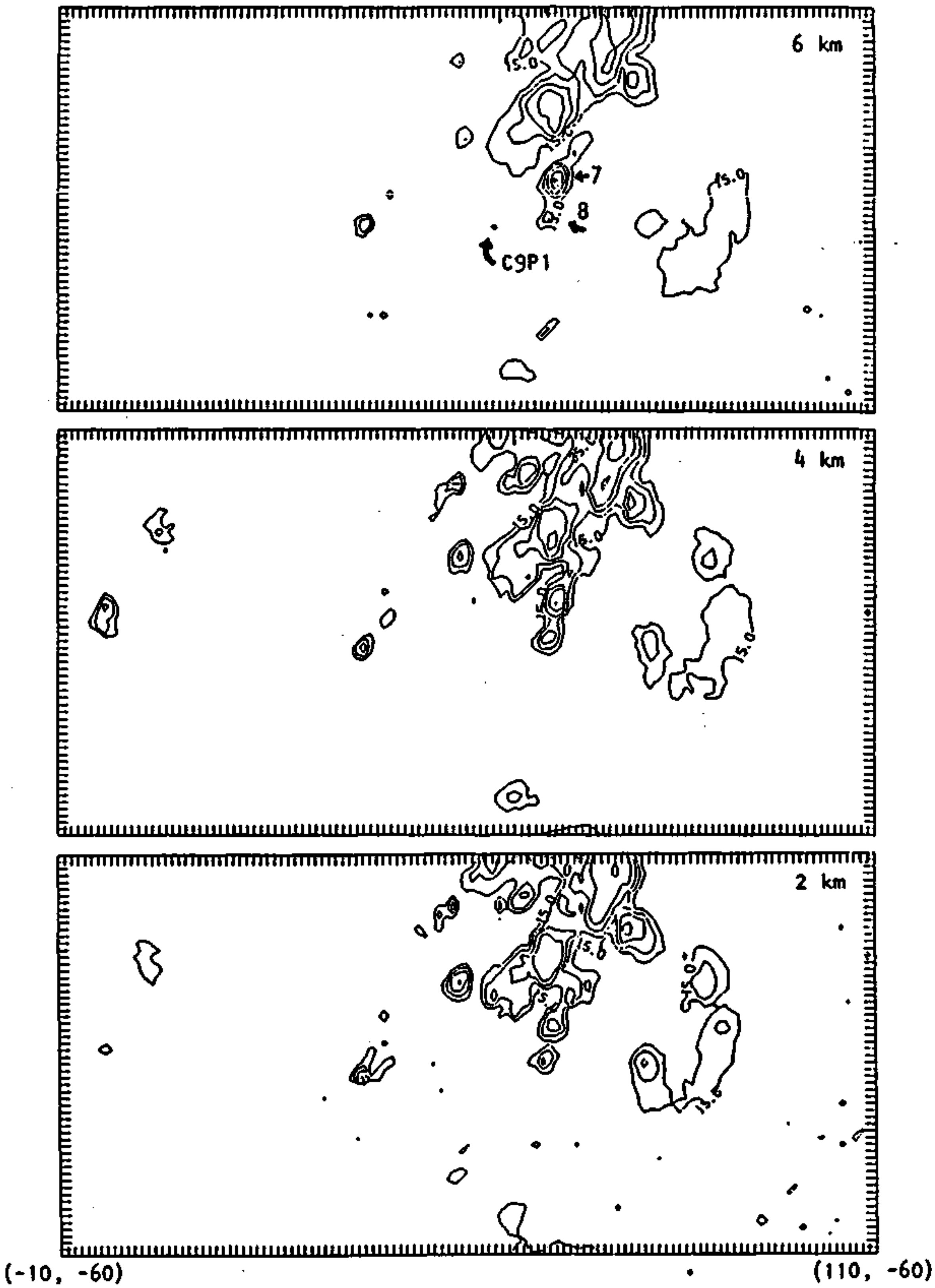
8-26-86 VOL 55 110343-110816 CDT

Fig. 4-26. CAPPIS near time of cloud 7 pass 1; as in Fig. 5.



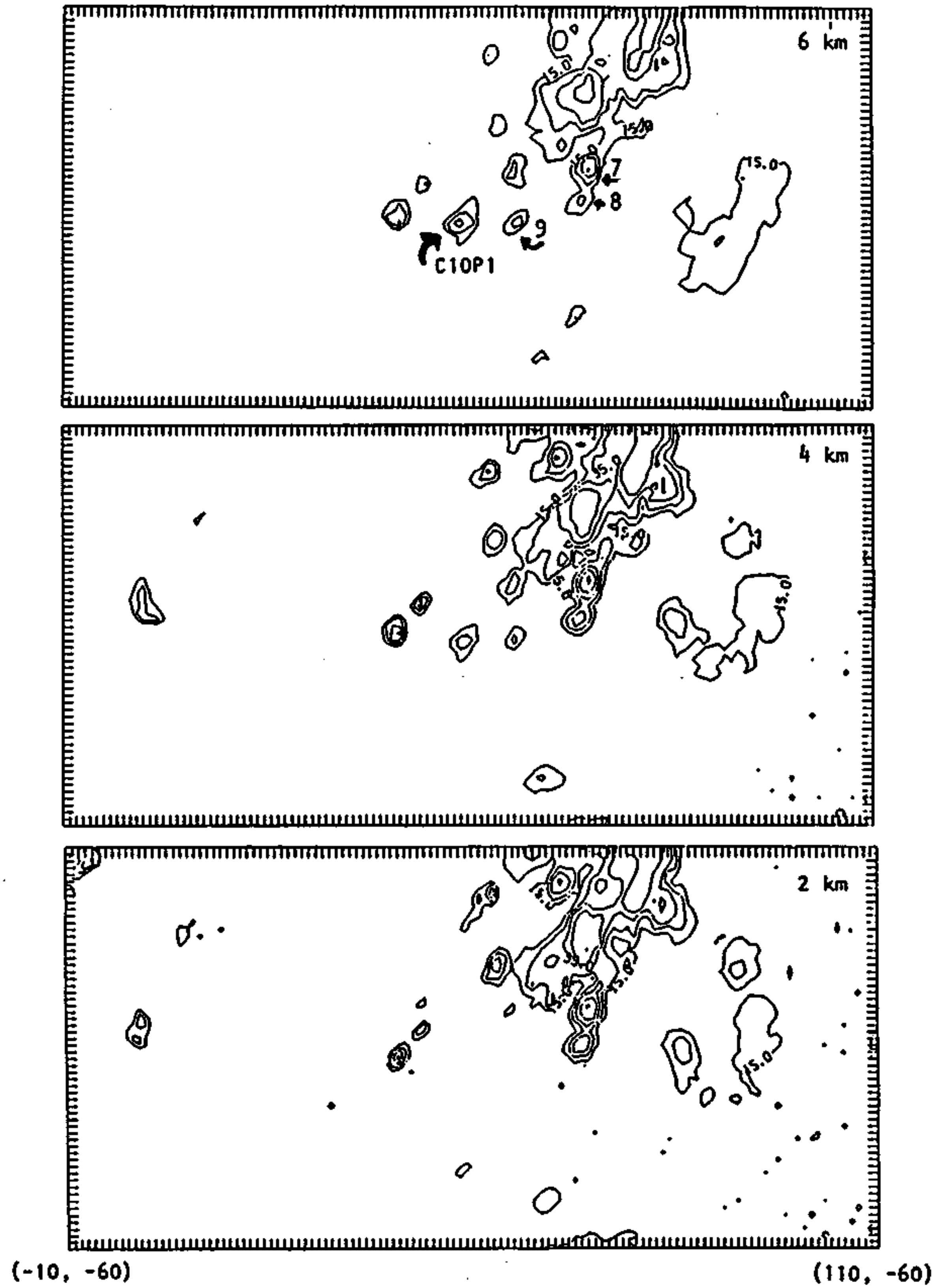
8-26-86 VOL 56 110820-111253 CDT

Fig. 4-27. CAPPIs near time of cloud 8 pass 1; as in Fig. 5.



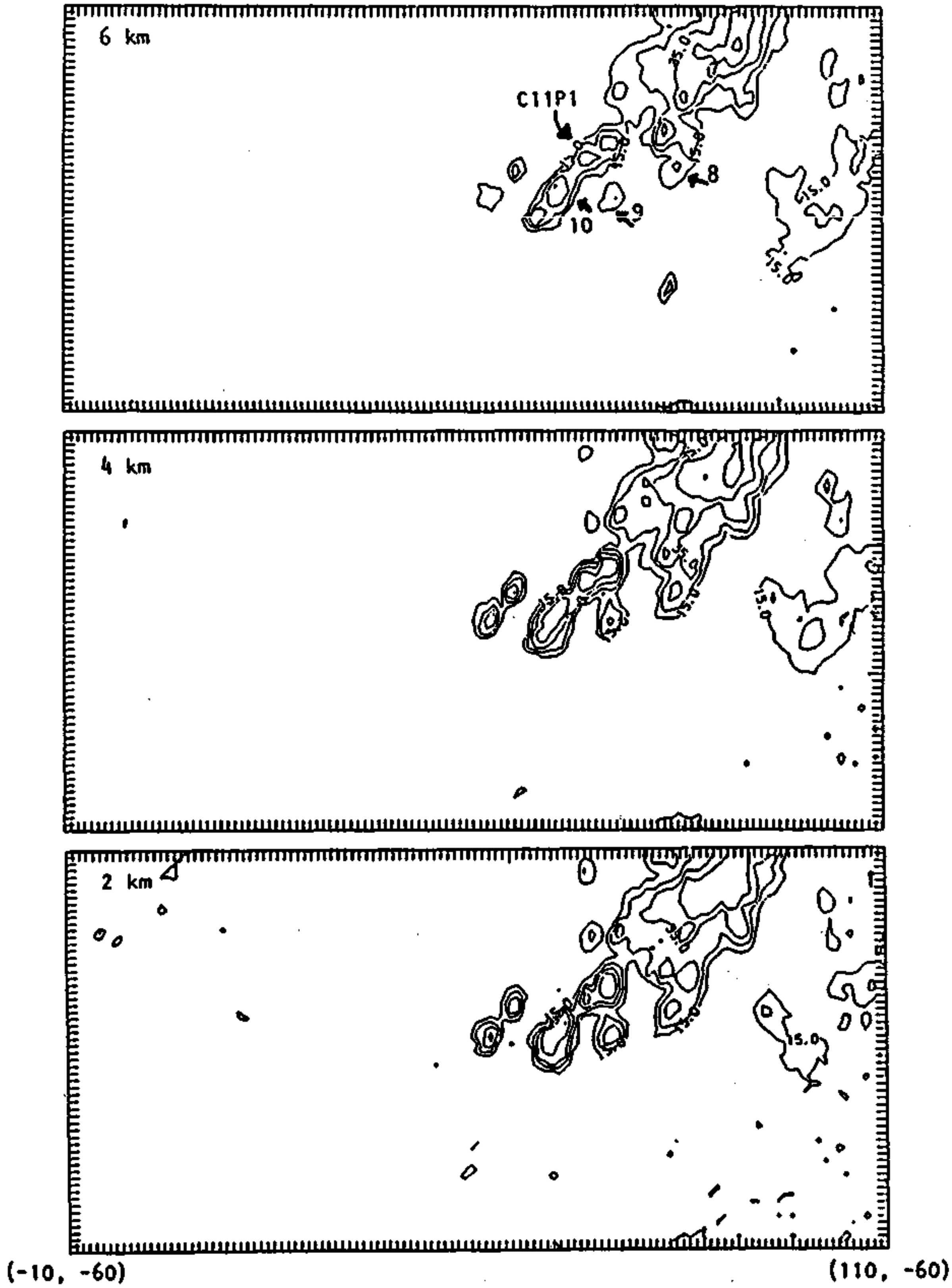
8-26-86 VOL 57 111257-111729 CDT

Fig. 4-28. CAPPIs near time of cloud 9 pass 1; as in Fig. 5.



8-26-86 VOL 58 111734-112206 CDT

Fig. 4-29. CAPPIs near time of cloud 10 pass 1; as in Fig. 5.



8-26-86 VOL 61 113031-113425 CDT

Fig. 4-30. CAPPIs near time of cloud 11 pass 1; as in Fig. 5.

August 26. 1986 - Flight 2

The second treatment flight was from 1507 - 1900 CDT on this day, with thunderstorms forming just ahead of the same strong, slowly moving cold front. Surface temperatures of greater than 30 °C were found ahead of the front. Cloud base temperatures estimated from the cloud model run of the 1417 CDT CMI rawinsonde and computations of the LCL and the CCL from this same sounding, varied from about 16 to 20 °C, at heights of 1.5-2.0 km msl. Visual observations from the aircraft indicated a cloud base of 2 km msl. Surface convergence values of greater than $-2 \times 10^{-5}\ s^{-1}$ were present in the east-central Illinois area during much of the afternoon. Frontal passage at CMI occurred at approximately 1800 CDT.

During this flight, the echoes appeared to form near the freezing level. The echoes were treated some 5-10 minutes after their first detection. At the time of treatment, these echoes contained somewhat stronger reflectivities at the 6 km level than typically found during the other two flights. These echoes were somewhat more diverse in character and the early histories of echoes 4, 6 and 7 were particularly difficult to track. While many of these echoes were connected to another cell, they were not a part of as large of storm cluster as found in August 6 case. The growth history of the echo associated with cloud 5 was unlike the other echoes examined on this day. This echo formed between two mature echoes and its initiation and subsequent growth was likely influenced by these two echoes. It appeared to form lowered in height, but grew to be the tallest echo of the FACE sample. The growth period for echoes 5 and 6 (as estimated from the height of the 20 dBZ reflectivity contour) was on the order of 30 minutes, 2-3 times that of all the other echoes sampled. The duration of the growth period of 4 out of the 6 echoes was greater than the echoes from the other two flights. The time-height plots and relevant CAPPIs are presented in Figures 31-46.

AUGUST 26, 1987   FLIGHT 2

ECHO 2 : This echo forms to the NW of a small thunderstorm of similar dimensions. Echo 2 becomes the more dominant of the two cores. Later, a core develops to its NW, but does not become as large in area as echo 2, nor its reflectivity as intense. Echo 2 eventually becomes joined with an E / W line to its SE.

ECHO 3 : This echo develops to the SW of echo 2. It is distinctly separate from echo 2 and all other echoes. Late in its history, a new reflectivity core develops to its N and is attached to it.

ECHO 4 : Echo 4 appears to contain multiple reflectivity cores through much of its life. It is more intricate in appearance than the other echoes, probably because of its closer proximity to the radar. This echo also will be reevaluated on a finer grid. A major core develops to its north later in its life. Because of its nearness to the radar, ground clutter returns at the lowest elevations are a problem.

ECHO 5 : This echo forms between 2 mature echoes and soon bridges them. These group of echoes is the S part of a large SW / NE line which is likewise filling in to the NE. The growth pattern of this echo is distinctly different from other echoes on this day.

ECHO 6 : This echo forms on the NE end of a small thunderstorm line. At its inception, it is connected to the other cores in the small cluster. It eventually becomes the dominant core of this echo group.

ECHO 7 : This echo forms in a similar manner to echo 6, but the other echo cores in the line remain active and are of like size and reflectivity as echo 7.

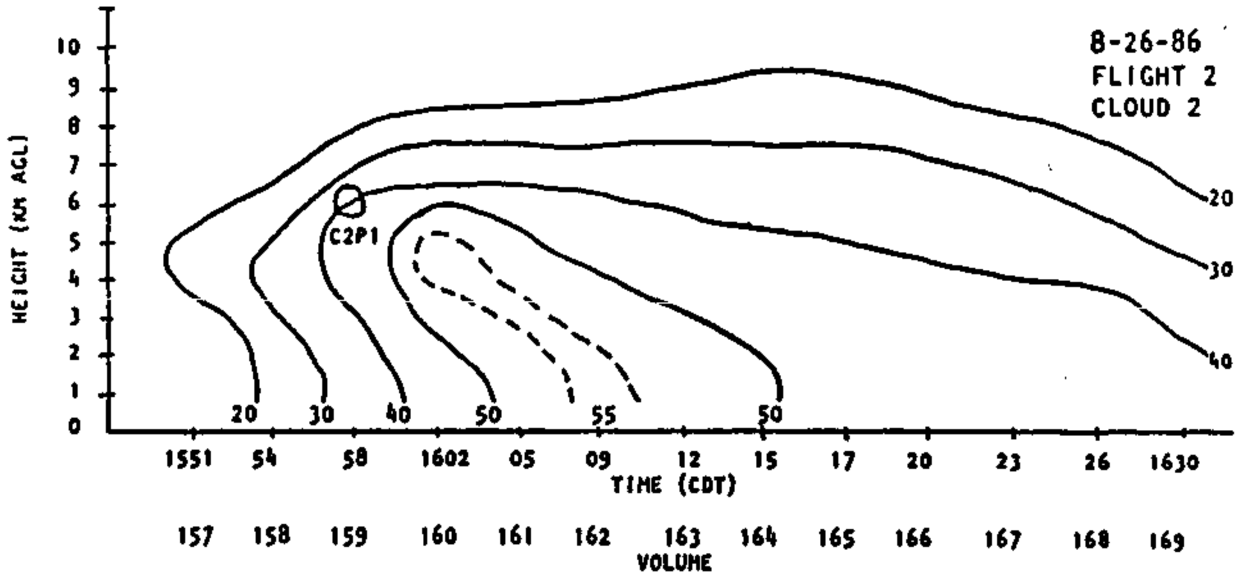


Fig. 4-31. Time-height history of the peak reflectivity found in echo 2. Treatment pass denoted by a circle at 6 km.

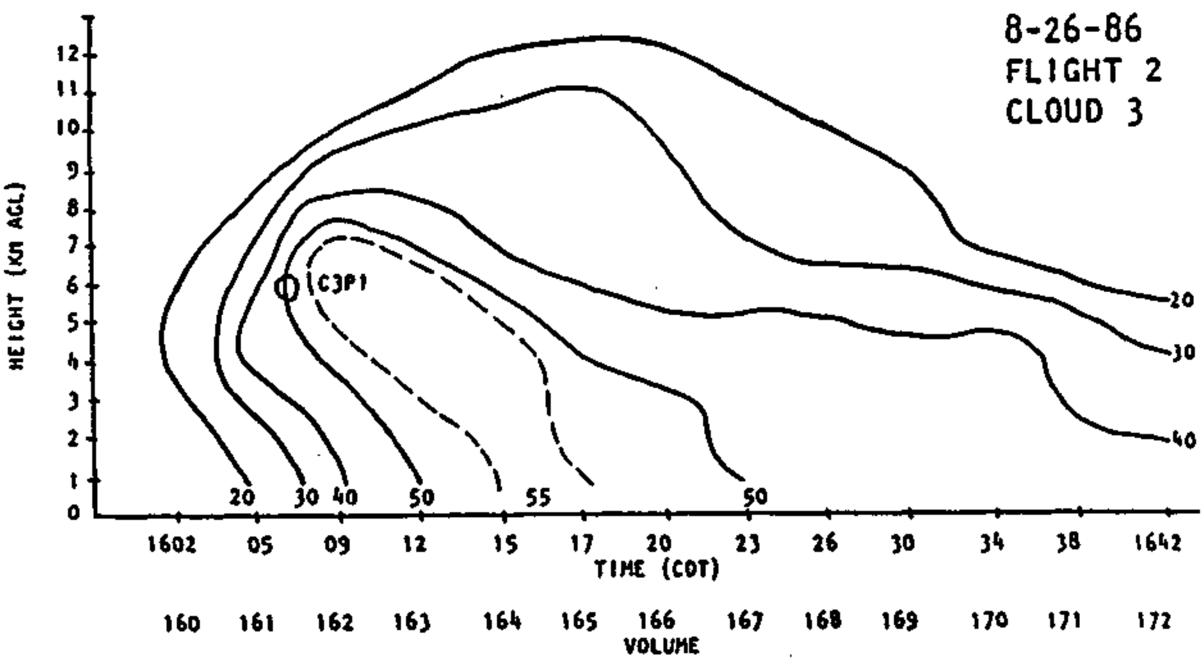


Fig. 4-32. Time-height history of the peak reflectivity found in echo 3. Treatment pass denoted by a circle at 6 km.

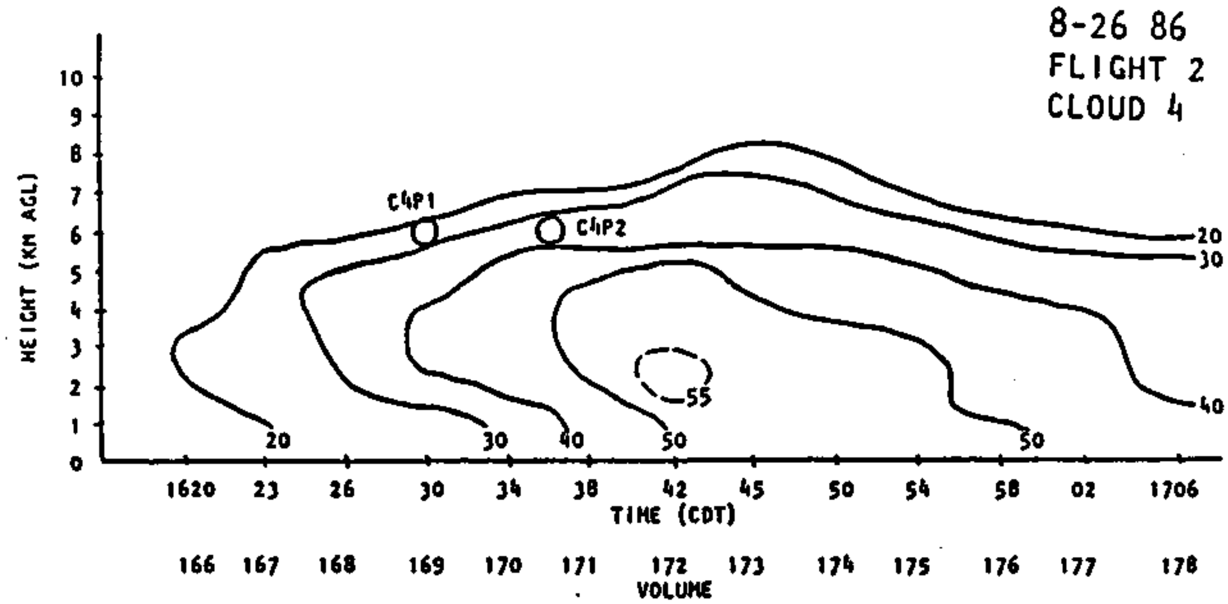


Fig. 4-33. Time-height history of the peak reflectivity found in echo 4. Treatment pass denoted by a circle at 6 km.

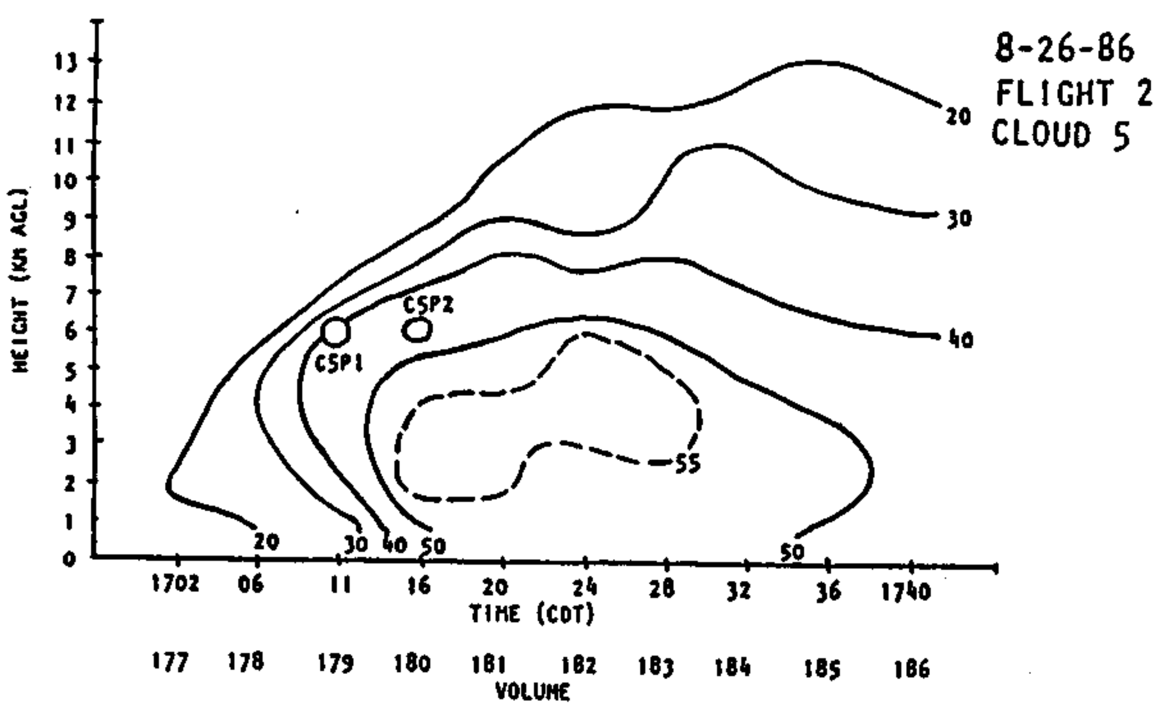


Fig. 4-34. Time-height history of the peak reflectivity found in echo 5. Treatment pass denoted by a circle at 6 km.

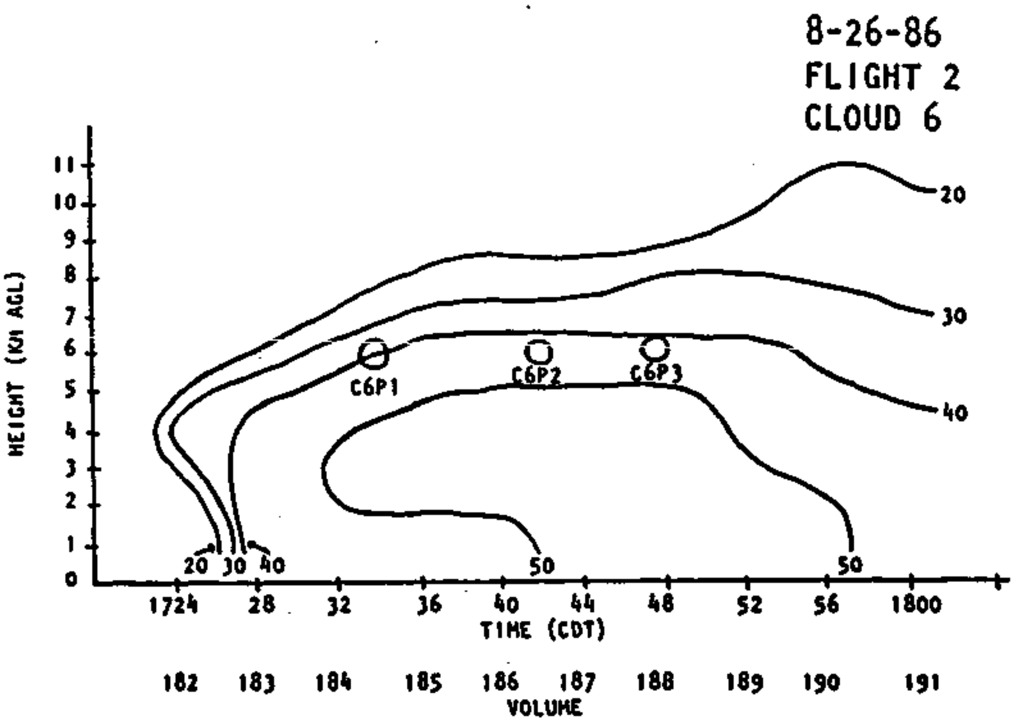


Fig. 4-35. Time-height history of the peak reflectivity found in echo 6. Treatment pass denoted by a circle at 6 km.

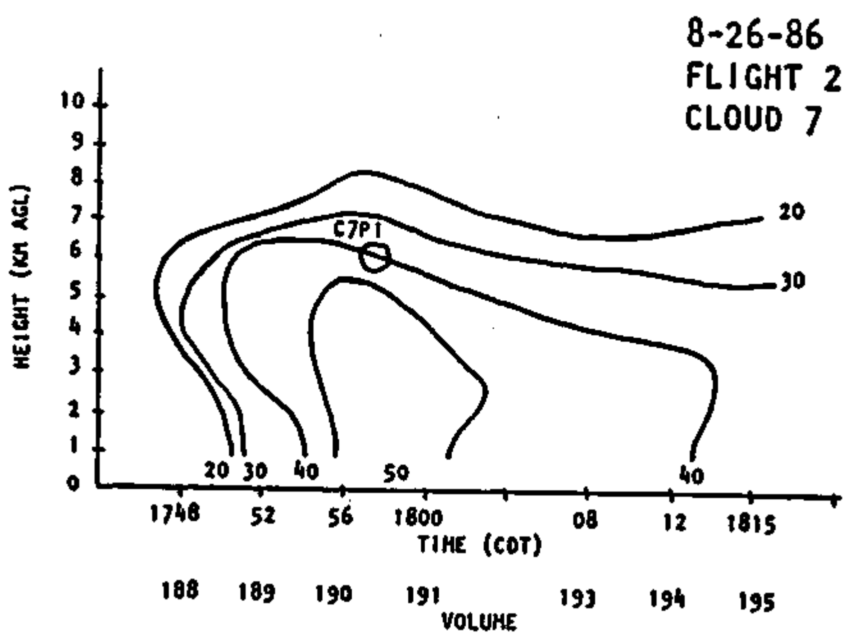
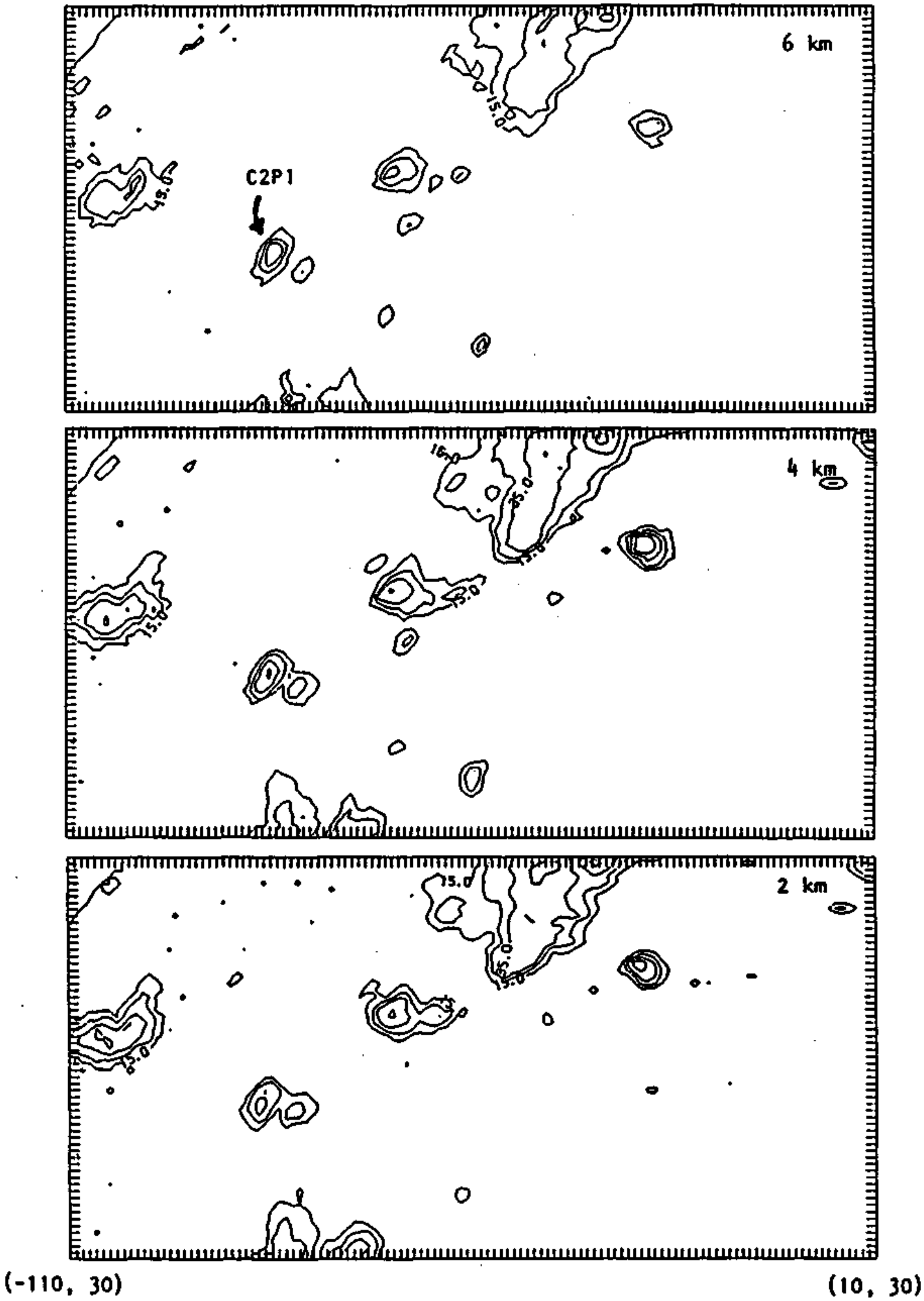


Fig. 4-36. Time-height history of the peak reflectivity found in echo 7. Treatment pass denoted by a circle at 6 km.



8-26-86 VOL 159 155648-160014 CDT

Fig. 4-37. CAPPIs near time of cloud 2 pass 1; as in Fig. 5.

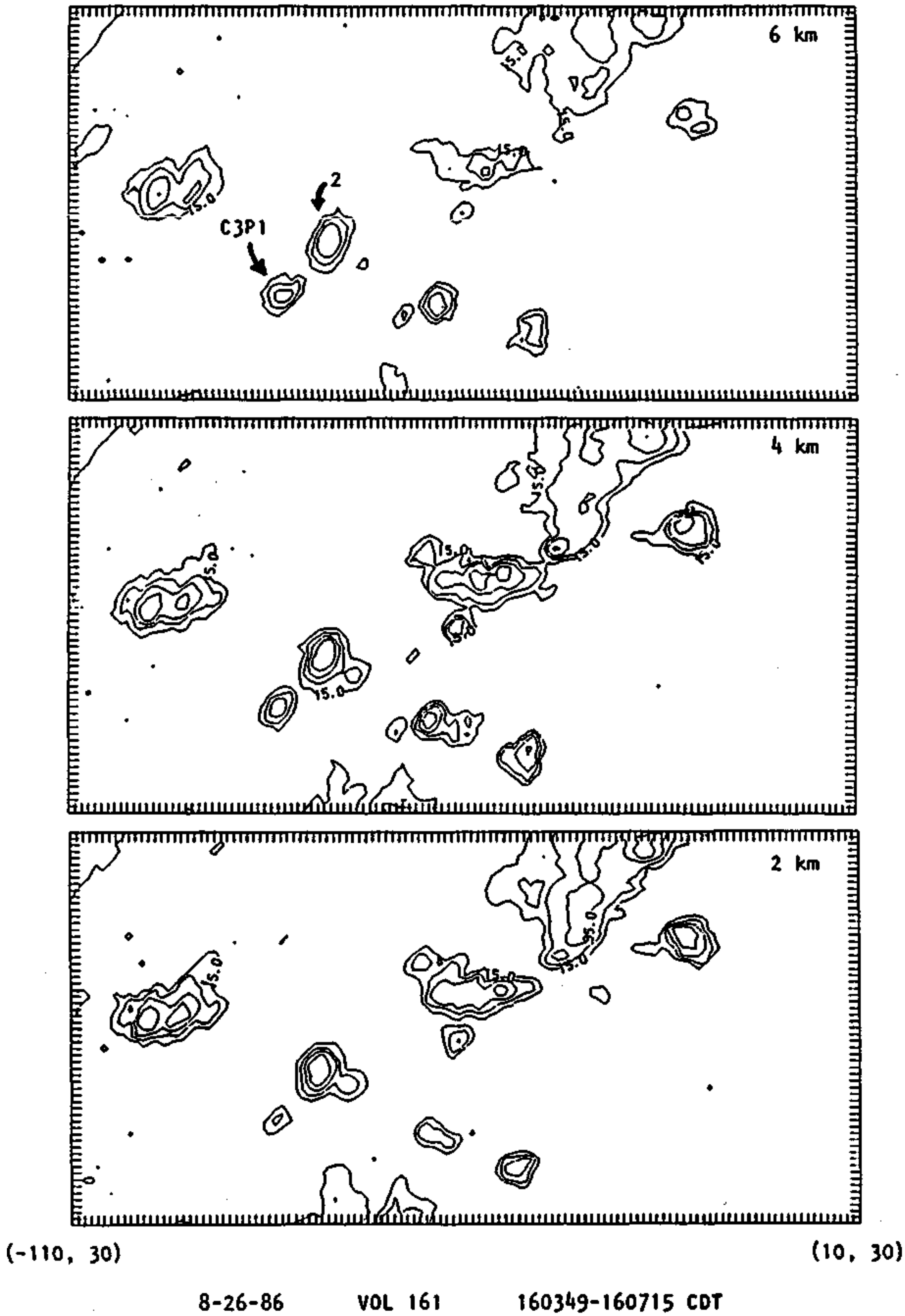
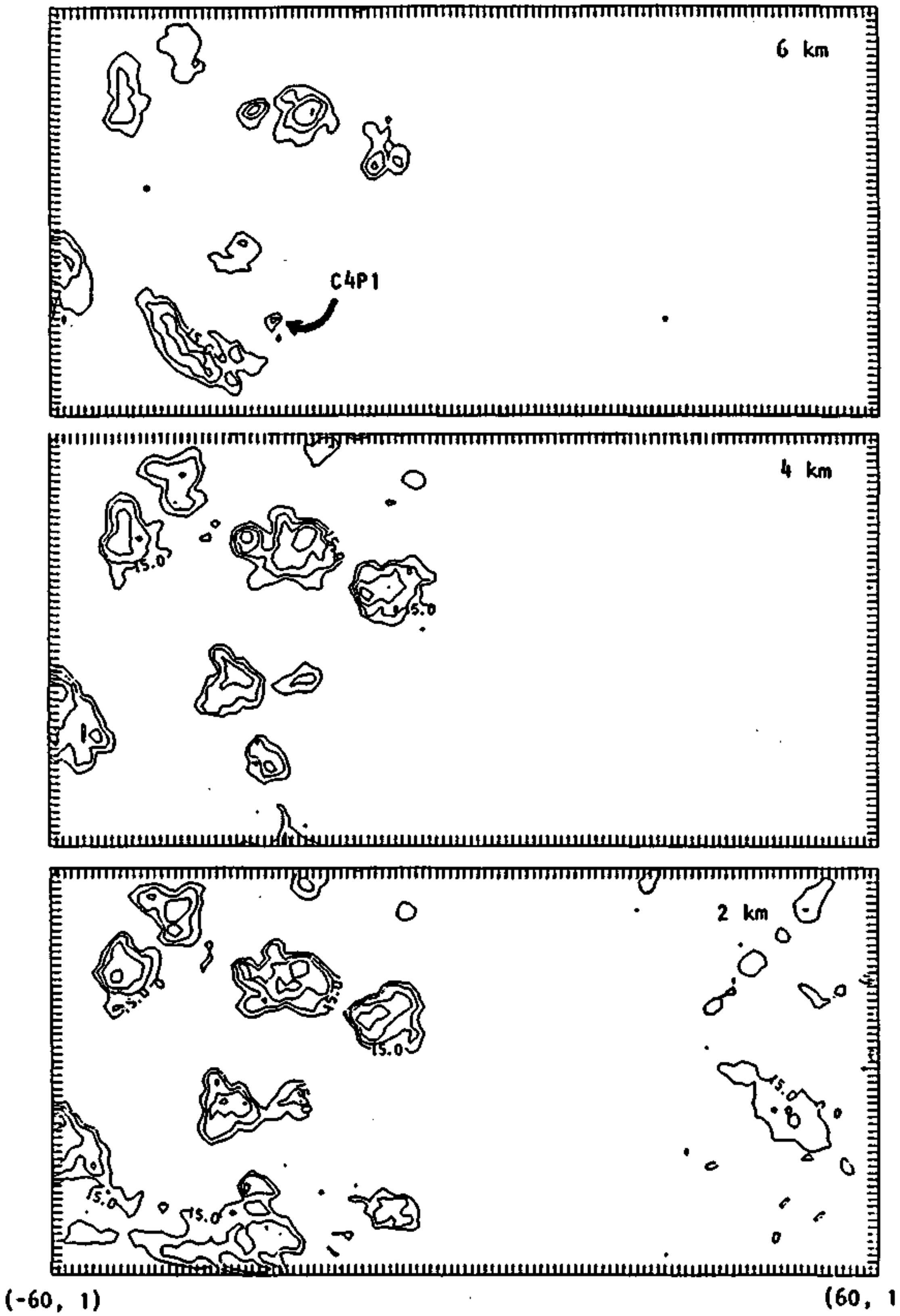
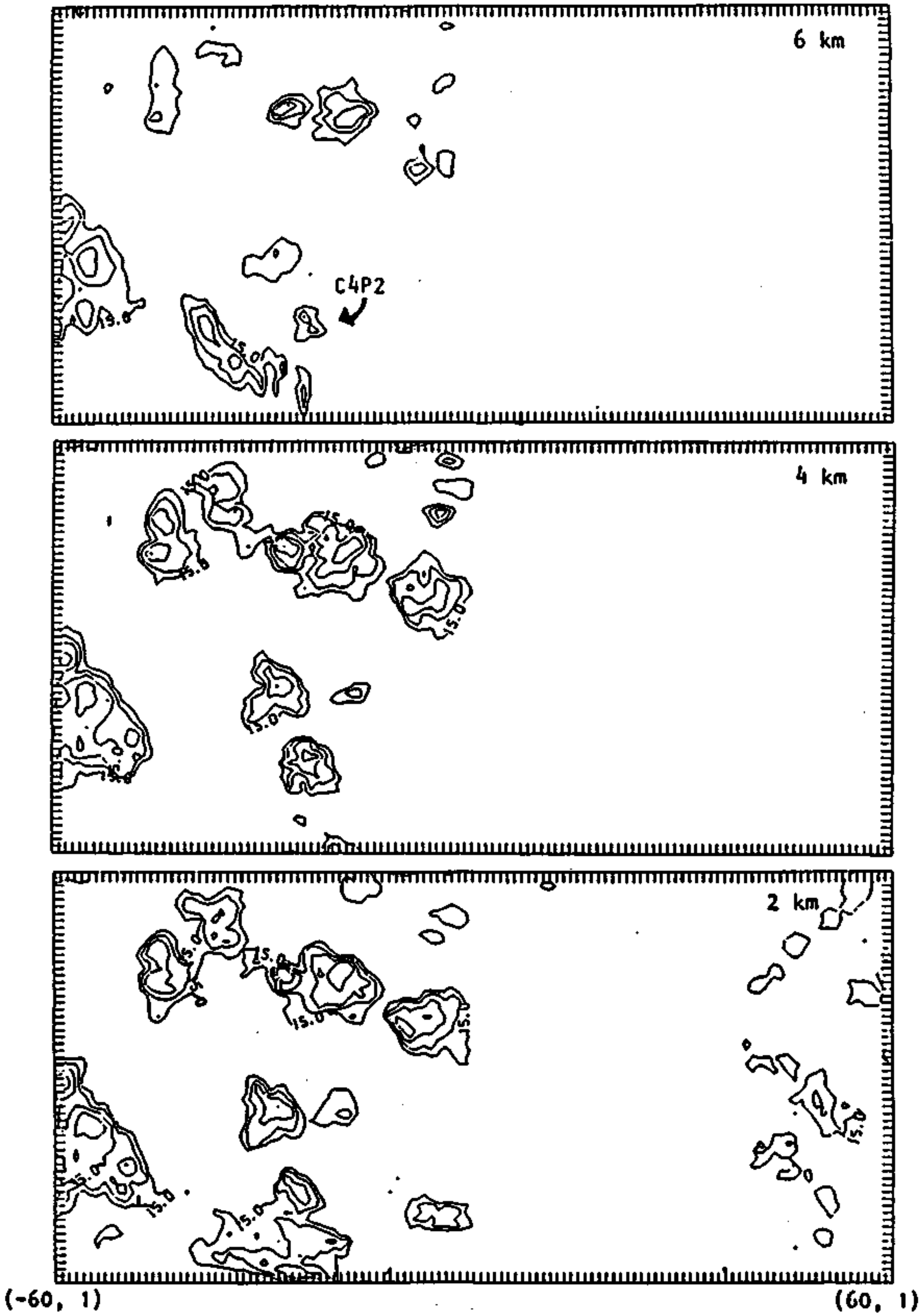


Fig. 4-38. CAPPIs near time of cloud 3 pass 1; as in Fig. 5.



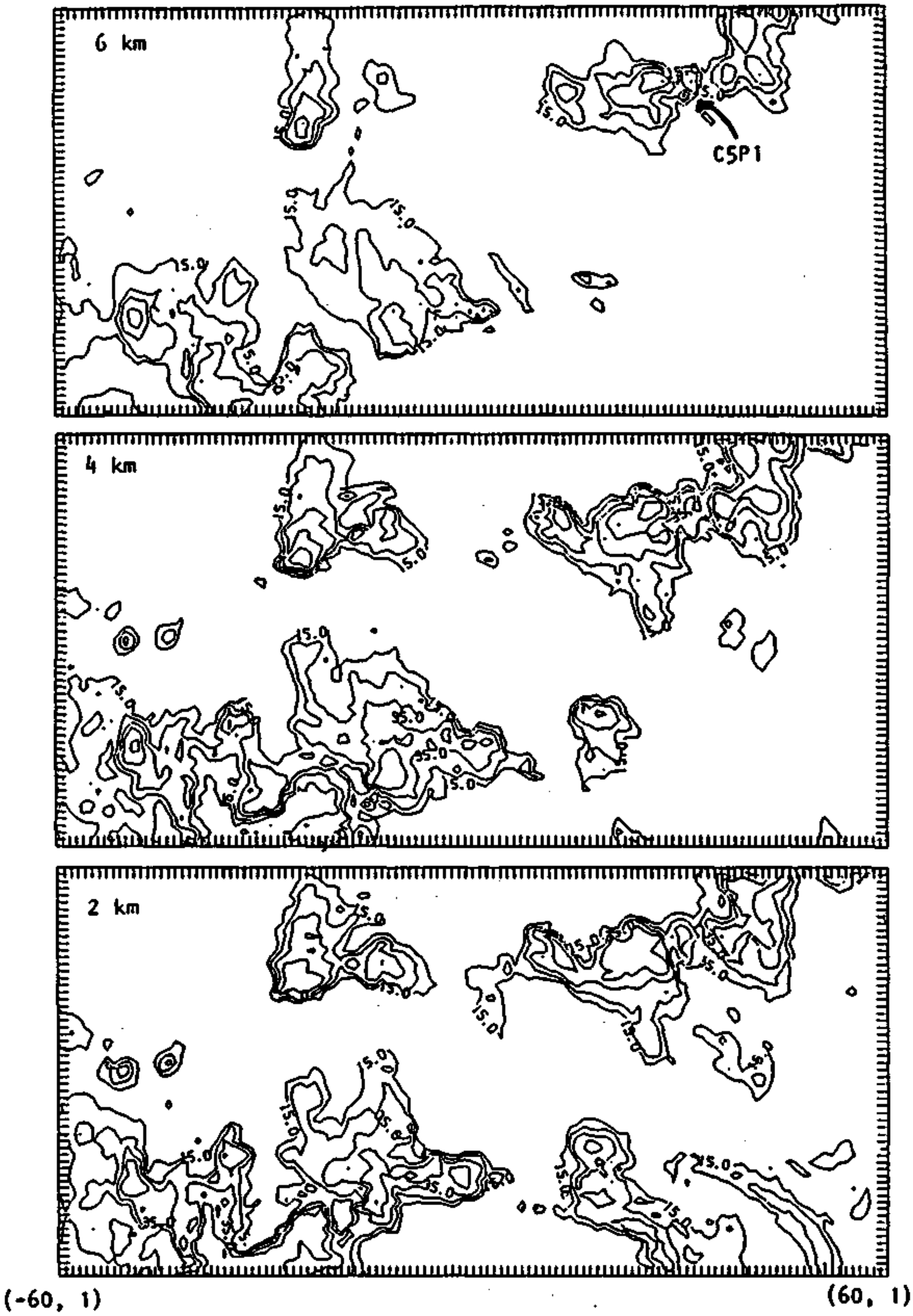
8-26-86 VOL 169 162822-163241 CDT

Fig. 4-39. CAPPls near time of cloud 4 pass 1; as in Fig. 5.



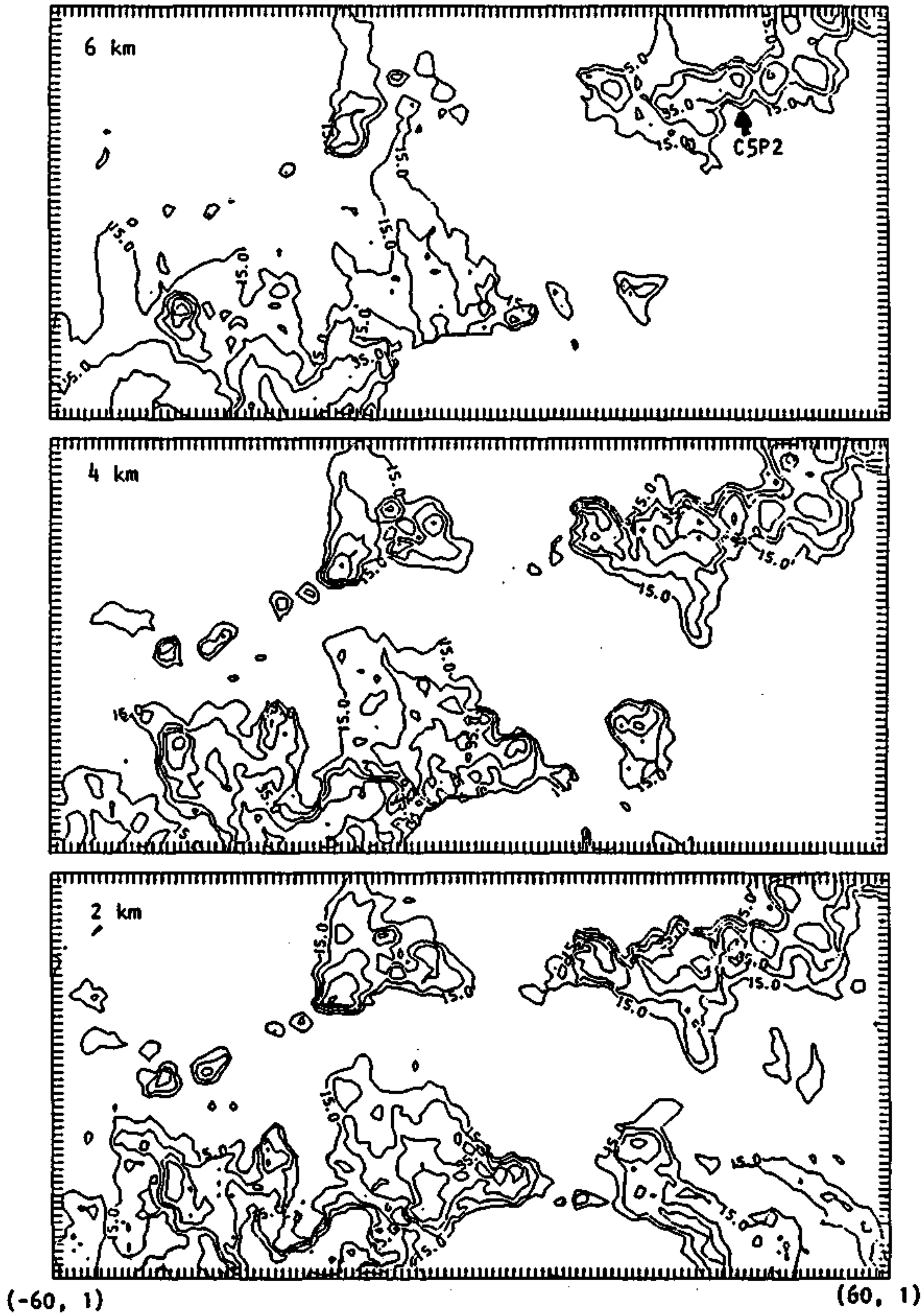
8-26-86 VOL 170 163245-163637 CDT

Fig. 4-40. CAFPIs near time of cloud 4 pass 2; as in Fig. 5.



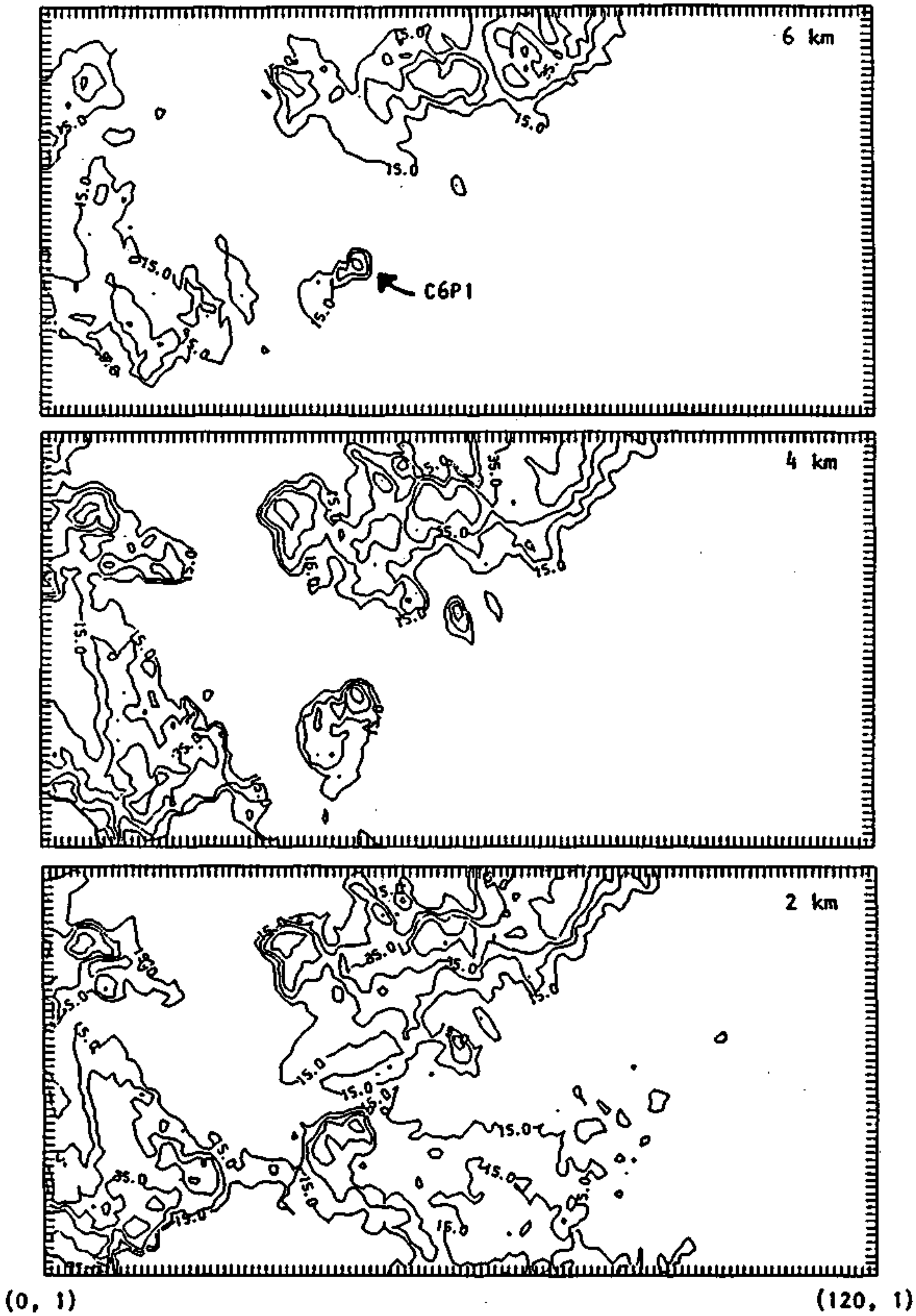
8-6-26 VOL 179 170907- 171445 CDT

Fig. 4-41. CAPPIS near time of cloud 5 pass 1; as in Fig. 5.



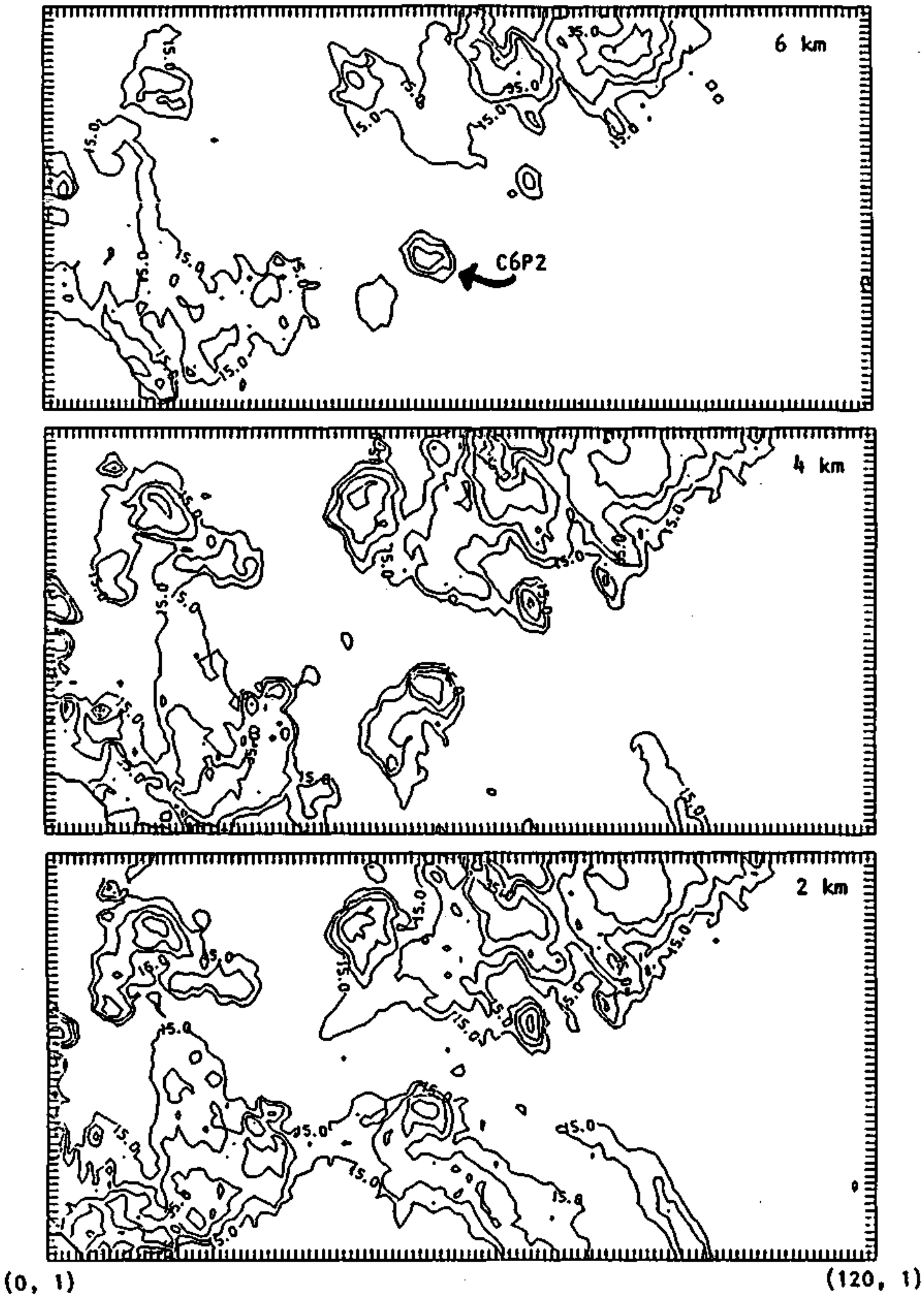
8-26-86 VOL 180 171449-171840 CDT

Fig. 4-42. CAPPIs near time of cloud 5 pass 2; as in Fig. 5.



8-26-86 VOL 184 173038-173428 CDT

Fig. 4-43. CAPPIe near time of cloud 6 pass 1; as in Fig. 5.



8-26-86 VOL 186 173832-174208 CDT

Fig. 4-44. CAPPIs near time of cloud 6 pass 2; as in Fig. 5.

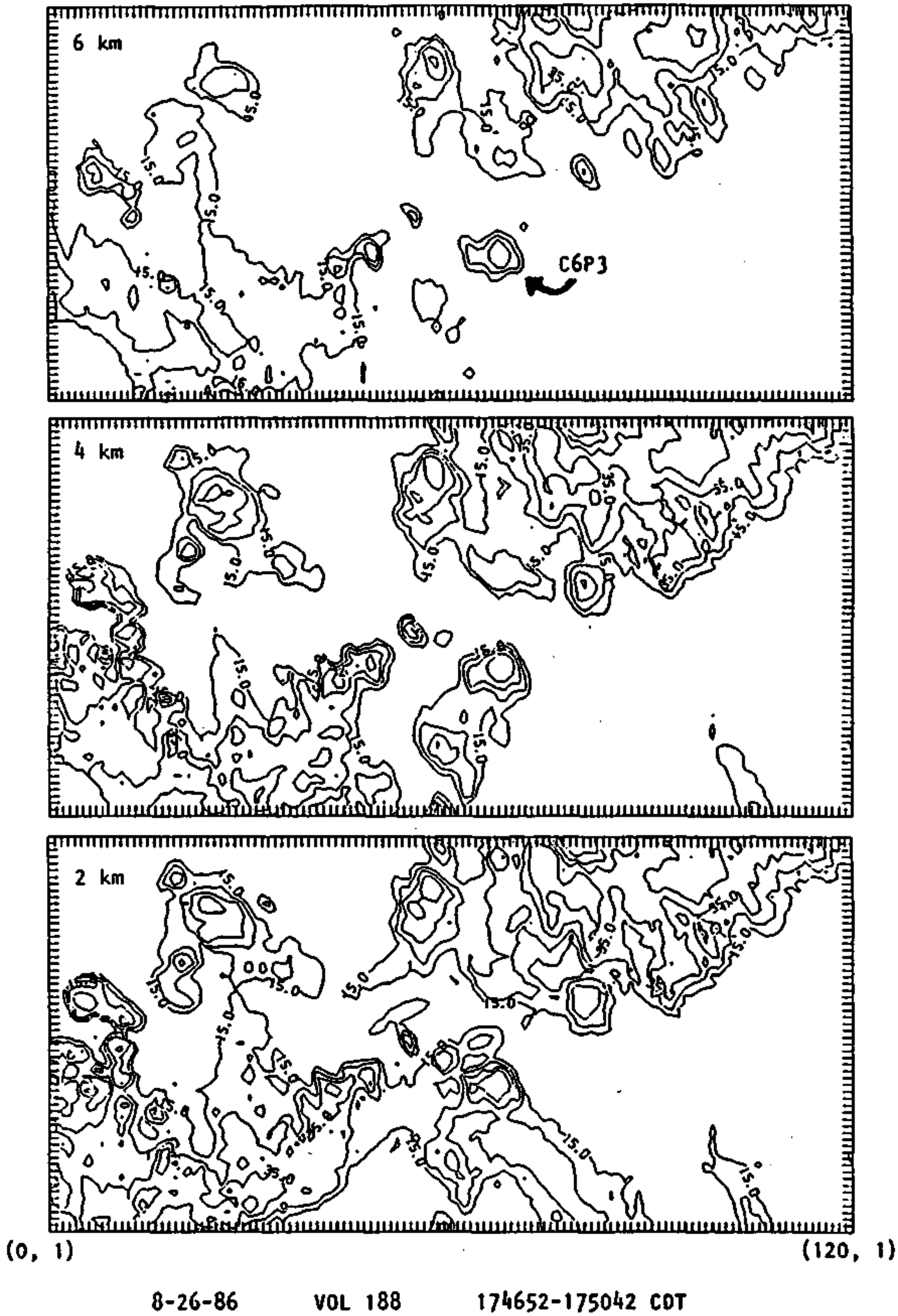


Fig. 4-45. CAPPIs near time of cloud 6 pass 3; as in Fig. 5.

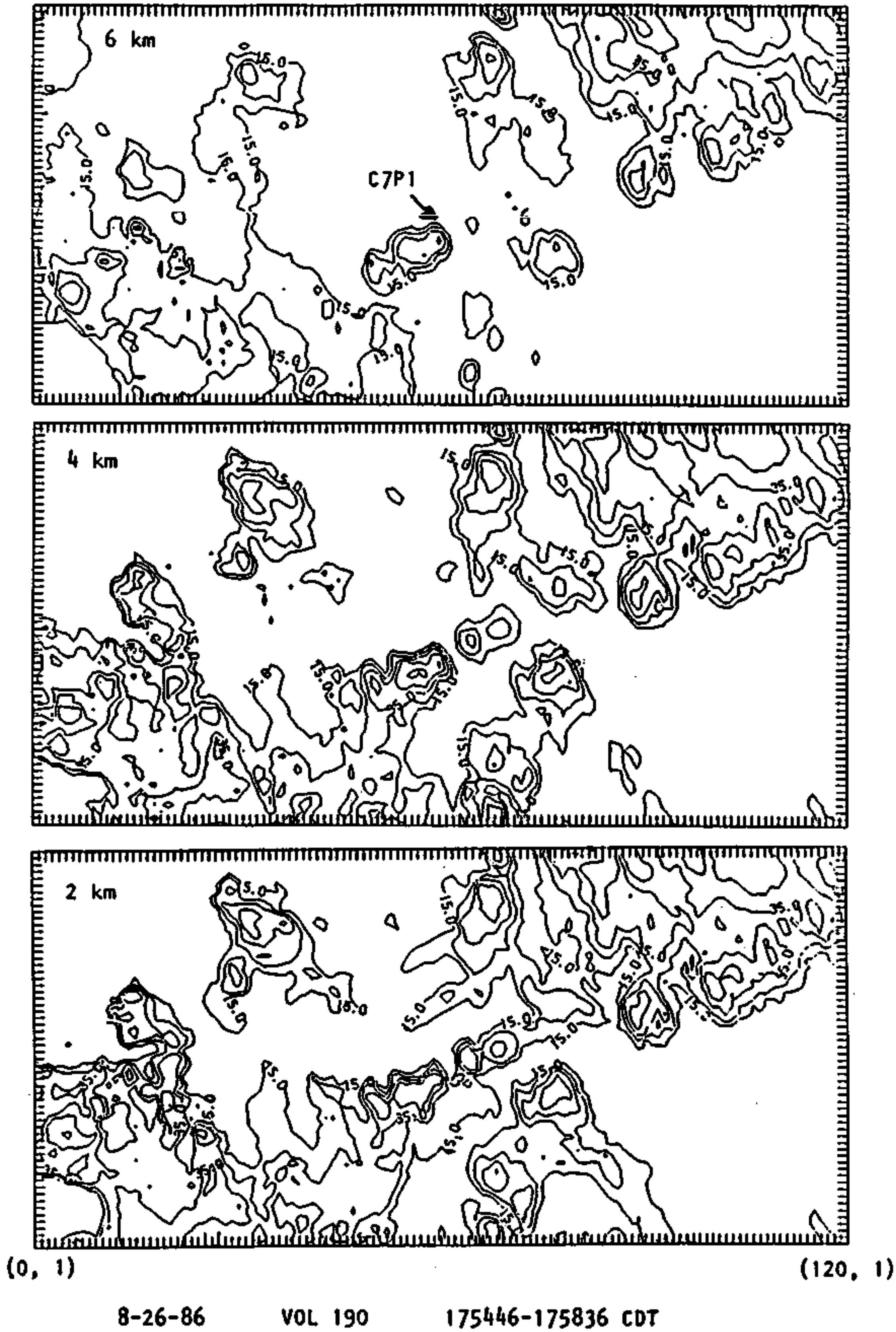


Fig. 4-46. CAPPIs near time of cloud 7 pass 1; as in Fig. 5.

Conclusion

This work will be extended in several directions. First, a closer examination of the echoes will be made. In the immediate future, it is planned that the area of these echoes be evaluated in a manner similar to the peak reflectivity histories. In addition, an effort will be made to quantize the relationship of these echoes to adjacent echoes. An evaluation of an equal number of untreated echoes occurring these 3 flights also is anticipated. Further programming work will involve experimentation with both the interpolation scheme and the echo tracking scheme.

REFERENCES

Henderson, T.J., 1986: PACE 1986: A Summary Report of Activities Conducted by Atmospherics Incorporated During the Period 1 July 1986 through 31 August 1986. Atmospherics Incorporated, Fresno, 33 p.

CHAPTER 5: CLOUD PHYSICS STUDIES

Robert Czys

Introduction

The cloud physics program carried out within PACE during the 1986 field operations had objectives to:

(1) to collect data (primarily near the -10C level) on the microphysical character of midwestern clouds under a variety of convective environments,

(2) to monitor the conversion of water to ice under natural and treated conditions,

(3) to investigate for differences between seeded and not-seeded clouds,

(4) to test certain parts of the theory of seeding for dynamic effects, and

(5) to provide microphysical observations for the interpretation of radar data.

Following the field operations analysis of cloud physics data initiated with measurements from natural clouds since most of the data collected pertained to these type of clouds and since an information base was needed to view cases in which clouds received treated. At the onset of analysis no facility existed to transform the raw aircraft data into a form suitable for interpretation. Thus a great deal of the effort has been spent during the past year to develop software for reduction of the raw aircraft data.

Analysis of aircraft data falls into two categories (1) standard fast analog data (temperature, pressure, cloud liquid water content, true air speed, altitude, vertical wind, etc) and (2) cloud hydrometeor data collected using 2-D imaging probes. Considerable progress has been made in this general area with most computer programs for the presentation of the analog data completed and routines to analyze the hydroneteor data nearly completed. In this chapter, a summary is presented of the cloud aicrophysical information gathered at the -10C level on 3 different days in July 1986 during moderately intense convection and a case study is presented of a mission in which the microphysical properties of the input clouds were measured and compared to the rain output just below cloud base.

Calendar

Table 5.1 summarizes the cloud physics operations for July 1986. Thirty hours of flight time were available for observation. The airplane arrived in Champaign, IL on July 1 and departed for Boulder, CO on August 1. A total of 9 missions were conducted on 8 different days with penetration of 45 cumulus congestus clouds which displaying visual characteristics similar to those defined by the selection criteria. The best data were collected on July 8th. The general lack of suitable clouds within the target area during July, due to unusually dry weather, limited the cloud treatment activities. Cloud treataent studies were conducted on 28 July and 31 July. The best day for microphysical data on cloud treatment was 28 July and the measurements that then should provide considerable insight for detecting in cloud reactions to silver iodide (AgI).

Table 5.1. Calendar of Cloud Physics Operations.

8 July 1986

Cloud microphysics observations at -10°C of moderately vigorous feeder cells into Cb anchored southeast of Indianapolis, IN. Nineteen feeders monitors with 25 passes, additional observation at 0 C and cloud base.

12 July 1986

Observations of raindrop size distributions, 3 showers ranging from light to moderate intensity.

21 July 1986

Microphysical study of a collapsing cumulus, step down through cumulus from 17k ft. to 7k ft. in 1k increments.

24 July 1986

Cloud microphysics observations at -10 C of moderately vigorous feeder cells into Cb system located NW of Saint Louis, MO; eleven feeders, one penetration each.

25 July 1986

Observations of vigorous feeders in to Cb line oriented NNE to SSW Just east of the Indiana-Illinois border; four warm temperature (0° to -4°C) passes in updrafts in excess of 2500 ft./min.

28 July 1986

Cloud treatment study of cumulus near Clinton, IL.; no DAS after feeder cell *2.

30 July 1986

Cloud microphysics study at -14, -12,-10 C of feeders into warm front Cb system located SSW of CMI; 6 feeders 1 pass each. Additional observations of rain showers 250 m below cloud base.

31 July 1986

A.M. Cloud treatment study of two embedded cumulus located SSW of SMI; 6 passes through Cu #1, 2 passes through Cu #2.

P.M. Cloud treatment study of single cumulus NW of CMI; 1 observation pass followed by 5 post treatment passes.

The observations collected during the cloud physics program of PACE form the first extensive, quality set of measurements of clouds at -10C in and around Illinois.

Aircraft and Instrumentation

The cloud physics airplane used was a Beechcraft Baron and is shown in Pig. 5.1. The performance characteristics of the Baron are listed in Table 5.2. The service ceiling is 25,000 ft. with a maximum rate of climb of 1500 ft/min. The -10C level over Illinois in July in 1986 was approximately 20,000 ft., thus 45 to 55 minutes were required to reach observation level. This permitted approximately 3 hours for observation.

Table 5.3 lists the instrument type, range, accuracy, sample rate and resolution that were on the aircraft. In addition to standard measurements of temperature, dew point and cloud liquid water, the airplane was equipped with particle spectrometer probes (FSSP, 2-D-C and 2-D-P). The FSSP measures the distribution of droplets with diameters ≤ 45 μm in 3 μm size categories. The 2-D-C measures the number and 2-dimensional shape of cloud particles of size between 25 μm. and 800 μm and 2-D-P of cloud particles between 200 and 6400 μm.

Vertical velocity was calculated using angle of attack, true air speed, pitch and vertical acceleration (Lawson, 1979). This method yields accurate vertical velocity only when the aircraft is in straight flight. Thus, some of the oscillation in vertical wind plots notable toward the end of many of the cloud penetrations is due to turning of the aircraft.

Fig. 5.1. Photograph of Cloud Physics Research Airplane.

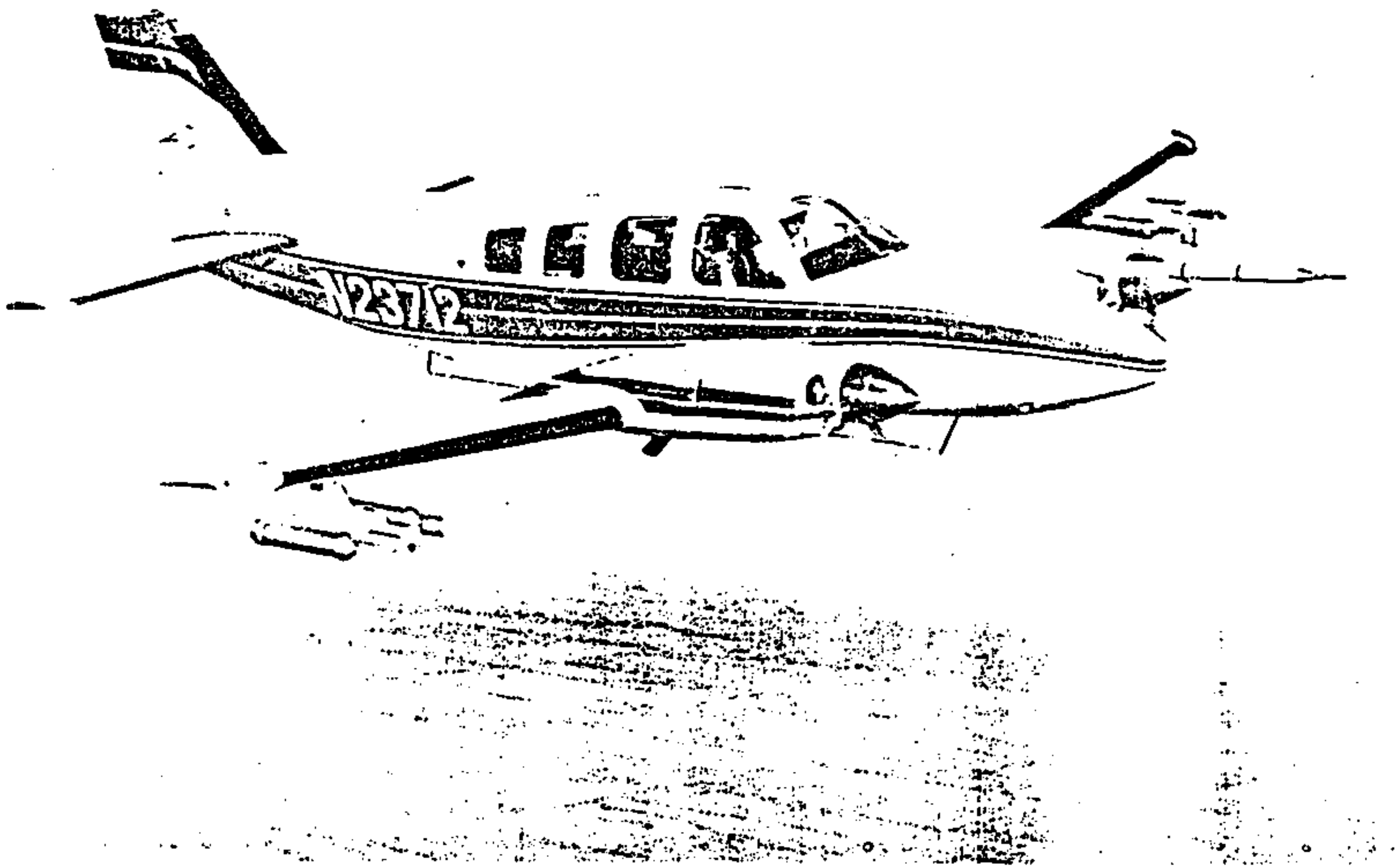


Table 5.2.

BEECHCRAFT BARON MODEL 58-TC, N23712

PERFORMANCE DATA

Power, each engine	310 hp
Maximum speed	235 kts.
Fuel capacity	175 gal
Service ceiling	25,000 ft
Single engine service ceiling	13,000 ft
Climb at gross wt	1500 ft/min
Maximum endurance	5 hrs
Maximum range	900 nm
Take-off distance	2100 ft
Landing distance	2500 ft
Gross weight	6100
Empty weight	4570
Seating (Restricted Category)	3 crew
Length	30 ft
Wing span	38 ft

Table 5.3.

Aircraft Instrumentation

Parameter Measured	Instrument Type	Manufactuerer and Model Number	Range	Accuracy	Time Constant	Sample Rate	Useable Resolution
			Combined Performance of Transducer, Signal Conditioning and Conversion				
Time	Crystal osc	PMS	12 mo	1s	N/A	0.1s	0.1s
Temperature	Platinum resistance, Deiced	Rosemount Eng. Co. 510BF9 Bridge Model 102 Probe	±50°C	0.5°C	1	1Hz	0.1°C
	Solid State reverse flow	NCAR - Probe AD 590 element	±50°C	0.5°C	1	10Hz	0.1°C
Dew Point	Peltier cooled mirror	Cambridge Systems Inc. Model 137-C3	±50°C	1°C	1-5 s	10Hz	0.3°
Liquid Water	Hot wire (Johnson-Williams)	Cloud Technology Model LWH	0-3 gm/m^3	0.2 gm/m^3	1	10Hz	0.01 gm/m^3
Cloud Particle Size Concentration	Optical Scattering	PMS FSSP	1-45µ .1-1500cm^{-3}	3µ 10%	Discrete Event	Continuous	1µ .1 cm^{-}
Cloud Size & Concentration	Optical array, imaging	PMS 2-d OAP	25-800µ 0.1-10,000L^{-1}		Discrete Event	Continuous	25µ 0.1L^{-1}
Cloud Precip. Size & Concentration	Optical array imaging	PMS 2-d OAP	200-6400µ 0.1-10,000L^{-1}		Discrete Event	Continuous	200µ 0.01L^{-1}
Vertical Velocity*	Computed						
Angle of Attack	Differential pressure	Rosemount Model 858 & 1201	±20°	0.25°	0.1	10Hz	0.1°

*Vertical velocity is computed using the angle of attack and true air speed measurements from a nose boom, pitch and integrated vertical acceleration of the airplane.

Table 5.3. cont.

Parameter Measured	Instrument Type	Manufactuerer and Model Number	Combined Performance of Transducer, Signal Conditioning and Conversion				
			Range	Accuracy	Time Constant	Sample Rate	Useable Resolution
Side Slip	Differential pressure	Rosemount Model 858 & 1201	±20°	0.25°	0.1	10Hz	0.1°
Pitch	3 axis Gyro	Lear Siegler	0-360°	0.5°	0.1	10Hz	0.01°
Vertical Acceleration (Airplane)	Pendulous mass	Sundstrand Corp.	±29	0.001g	0.01	10Hz	0.001g
Indicated Airspeed	Differential pressure	Rosemount Eng. Co. Model 1332B1	±2.5 psid	0.0025	0.1	10Hz	0.0025 psid
Heading	3 axis Gyro	Lear Siegler	0-360°	0.5°	0.1	10Hz	0.1°
Altitude	Total pressure	Rosemount Eng. Co. Model 1241	0-15 psia	0.015 psia	1	1Hz	0.007 psia
Position (azimuth)	VOR	King Radio	0-360°	±1°	0.1	10Hz	0.1°
(distance)	DME	King Radio	0-300km	0.2km	1	10Hz	0.1km
Position	Multi-DME CIC interface	King Radio Model KDM 7000	0-400km	0.07km	1	1Hz	0.02km
Position	Loran-C CIC interface	ARNAV R-21	0-9999nmi	0.5km	1	1Hz	0.01km
Events	Digital latch	PMS	4 events	1s	Discrete	Continuous	1s

Table 5.3. cont.

Parameter Measured	Instrument Type	Manufacturer and Model Number	Specifications
Photography	Video Camcorder (ISWS provided)		
Data Recording	Mag Tape	Pertec	9-track 1600 BPI Phase Encoded
Real Time Processing	Video	Kono	Cockpit Display of paramters updated every sec.
	Hardcopy Printer	MPI	Hardcopy updated every sec.
Floating Air Parcel Tracking			True airspeed, heading integration corrected for sideslip and angle of attack. Nominal accuracy is 0.5km for 20 min.

Other items of interest and use were an air parcel tracking algorithm for multiple penetration of the "same" cloudy air parcel. A video tape recorder was used to audibly document missions, photograph general sky conditions and record the response of the windshield to in-cloud conditions. This information has been used with the 2-D data to verify the times during which either supercooled water or ice was encountered. Finally, a ground playback system allowed monitoring of the instrumentation and allowed rudimentary analysis to provide real time guidance in planning future missions.

In all, the airplane and instruments operated satisfactorily over the course of the field program. However, several problems have been uncovered during the course 1986 analysis. One problem was identified in the output of the cooled mirror hygrometer which would oscillate with large amplitude under supercooled cloud conditions. Therefore have little useful in-cloud dew point data is available and buoyancy could not be computed using virtual temperature from measured parcel humidity. Another noteworthy problem was that the 2-D-P probe was poorly fitted with antiartifact guards at the laser tips. Thus a larger than desirable fraction of the 2-D-P images are streamers and artifacts. It has also been noticed in the 2-0 data that occasionally a larger than reasonable elapsed time since occurrence of last particle is recorded. This seems to be a problem inherent to 2-D probes and casts doubt on all the other values of timing words. In the analysis of 2-D data we have instituted the general practice of removing any timing word that would produce a total elapsed tine greater than the time allowed between image records. Thus particle concentrations for the 2-D probes given in this report should be viewed with this uncertainty in the sampling statistics.

Liquid water contents measured by hot-wire (JW) and calculated from the FSSP tended to be in good agreement when less than about 0.5 gr m^{-3}. The JW probe tended to give liquid water contents greater than that calculated from the FSSP above a value of 0.5 gr m^{-3}. The limitations of imaging devices have been discussed elsewhere (Heymsfield and Baumgardner, 1985; Vali et *al.*, 1981).

Microphysical Observations Near -10C

Table 5.4 gives a partial summary of the microphysical properties of natural clouds measured on three different days. On July 8, clouds feeding into an air mass thunderstorm positioned over the southeastern corner of Indianapolis, IN, were sampled. On July 24, data was obtained for 5 clouds feeding an air mass thunderstorm located northwest of St. Louis, MO. And, on July 30, data near -10C was gathered for a cloud feeding a warm front thunderstorm. More data is available at colder temperatures Each cloud is identified by the month, day, cloud number and penetration number. Missing data for clouds 708c2pl and 708c6pl was caused by momentary failure of the data acquisition system.

The clouds represented in Table 5.4 were mostly youthful, individual cumulus associated with a larger storm cloud. These were clouds which met the visual criteria for selection. They

Table 5.4. Summary of Cloud Properties.

Cloud ID	Penetraton Time (CDT)	Duration (sec)	Maturity*	Cloud Dia. (km)	Cloud Temp. (°C)	Thermal Buoy. (°C)	Peak Updraft (m/sec)	Mean/Max FWC (g/m³)	Mean/Max JWC (g/m³)	Mean Drop Dia. (μm)	Mean Conc. (cm⁻³)	S.P.D.**
708c1p1	151643	42	**	2.5	-8.6	0.4	12	0.4 0.6	0.4 0.7	13	190	Yes
708c2p1	157751	---	**	---	---	---	--	--- ---	--- ---	--	---	Yes
708c3p1	153237	94	****	5.5	-9.3	1.2	15	0.2 0.3	0.0 0.2	17	60	No
708c3p2	153933	43	*****	1.6	-8.0	---	10	0.3 0.5	0.4 0.6	13	140	Yes
708c4p1	153416	58	****	2.8	-9.5	---	7	0.2 0.3	0.2 0.4	14	80	No
708c4p2	153827	62	*****	3.9	-7.9	---	3	0.1 0.3	0.1 0.2	19	20	No
708c5p1	154417	89	**	4.5	-6.9	0.4	17	0.4 0.8	0.7 2.9	15	140	Yes
708c6p1	154552	--	****	---	---	---	--	--- ---	--- ---	--	---	No
708c7p1	155626	68	**	4.4	-10.6	0.3	14	0.2 0.4	0.1 0.3	15	70	Yes
708c8p1	155956	73	****	4.7	-10.1	0.6	15	0.0 0.1	0.0 0.0	22	10	No
708c9p1	161419	56	**	4.3	-9.7	-0.3	17	0.3 0.6	0.8 2.4	13	140	Yes
708c10p1	162623	41	**	3.2	-6.4	0.7	5	0.1 0.2	0.0 0.1	22	20	Yes
708c11p1	162716	26	**	2.1	-6.7	1.1	15	0.7 1.0	3.5 3.8	16	250	Yes
708c12p1	162920	82	**	3.2	-8.8	0.4	15	0.3 0.5	0.3 0.5	15	120	Yes
724c1p1	142420	110	****	8.6	-9.3	1.2	15	0.3 0.8	0.3 0.9	14	130	Yes
724c2p1	143016	133	**	10.9	-10.5	0.4	5	0.2 0.6	0.1 0.7	16	50	No
724c3p1	144550	54	**	4.0	-6.1	-1.0	3	0.4 0.8	0.5 1.5	13	170	Yes
724c4p1	144941	75	****	5.4	-7.7	2.6	8	0.4 0.7	0.8 2.3	14	200	Yes
724c5p1	145612	43	**	3.0	-6.1	-0.6	3	0.2 0.6	0.2 0.7	13	110	Yes
730c6p1	172639	67	****	2.2	-10.9	-0.6	12	0.4 0.5	0.5 1.2	13	220	No

* Maturity:	*	**	***	****	*****
Estimated height of cloud top above flight level	100-500'	500-1000'	1000-2500'	2500-5000'	>5000'

** S.P.D. = Supercooled Precipitation Drops showed a hard "blocky" appearance on approach. They had tops which were easily passing through the -10C level. The representative sounding for each day showed no evidence of either a shallow temperature inversion or a dry layer in raid-levels to restrict vertical cloud development. These were clouds at the very beginning of ice development. These clouds were mostly warm-based and had base temperatures and heights of: +16C and 6000', +15C and 6500', and +8C and 11000', for July 8, 24, and 30 respectively. The airplane radar often displayed an echo during cloud approach.

Cloud maturity for Table 5.4 was determined during cloud final approach by the flight scientist and pilot from the amount of cloud above flight level. All of the clouds were penetrated near dead center and cloud diameters were calculated from the duration of cloud penetration and true air speed.

In calculating cloud buoyancy three considerations must be made. The first is that moist air is more buoyant than dry air and therefore the virtual temperature should be used to make the calculation. Secondly buoyancy is greater affected by loading of the water mass. Thus for any given temperature difference between air parcel and environment a moist parcel with no liquid water will be more buoyant than one with liquid water. Since we have no reliable dew point measurements the "dry" buoyancy listed in Table 5.4 can be interpreted using the following considerations. If the environment air is assumed to be a 50% relative humidity and the cloud parcel at 100% relative humidity then 0.25C should be added to the buoyancy listed. This increase is offset by loading of the liquid water and the estimate for this is to subtract 0.25C for every .5 gr m^{-3} of water. Thus the buoyancy listed are a good first estimate if the parcel contains no drops greater in size than 45 μm. Clearly, since drops of precipitation were observed on a majority of the penetrations the buoyancy listed is an overestimation.

Buoyancy was calculated only when it was possible to get a good estimate of environmental air temperature. Clouds 3 and 4 on July 8 were very closely spaced and were consecutively penetrated and then repenetrated. Thus only the temperature of the environment air before cloud three was available for calculation. Of the 15 buoyancy, 7 are between 0 and +1C, 3 are slightly greater than +1C and 1 is nearly +3C. Four clouds were slightly negatively buoyant. Therefore, most clouds in this sample were probably slightly negatively buoyant at the -10C level if moisture and water loading are taken into account. Thus most of the updrafts in this sample were past the stage of acceleration.

Peak updrafts ranged from 3 to 17 m sec^{-1}, with determination of peak value limited to the portion of cloud over which the airplane was in nearly straight and level flight. The location of peak updraft did not necessary correspond to the location of maximum cloud liquid water, but does seem to be correlated with the location of supercooled precipitation-size drops.

Mean cloud liquid water content ranged from less than 0.05 for either probe, to 3.5 for the JW probe, and 0.7 gr m^{-3} from the FSSP. The liquid water contents observed in this sample were generally lower than expected when extrapolated from the micro-physical observations taken at warmer temperatures during 1978 (Ackerman *et al.,* 1979).

Table 5.4 gives mean concentrations of supercooled cloud droplets in the size range from 0 to 45 μm diameter as measured by the FSSP. Concentrations ranged from 20 to 250 drops per cm^3. These concentrations are lower than ones measured in Florida cumuli at similar temperature (Hallett *et al.,* 1980). Mean cloud droplet diameters ranged from 13 to 22 μm, were most frequently 13 μm and averaged 15.8 μm.

For the purposes of this report cloud 708fclpl has been selected for more detailed examination. Similar data for each of the other clouds listed in Table 5.4 is given in Appendix A.5.

A new technique for inspecting cloud droplet spectrum resulted from analysis of PACE microphysical data. The technique is based on sequential display of one second spectrum, and these are used to create a three-dimensional picture of droplet size and concentration with time. Previously, cloud droplet spectrum were integrated over an extended length of cloud penetration (e.g.. from 300 to more than 1000 m) by aircraft to obtain a single spectrum representative of the cloud for analysis. The three-dimensional diagrams reveal intricacies of the spectrum which have been heretofore overlooked as a comparison of the data presented in Appendix A.5 will show. This is an important develop-ment because the cloud droplet population form the foundation for almost every microphysical process important to the production of rain in cumuli and are important to the propagation of glaciation from the small to the large end of the size spectrum of super-cooled water.

Figure 5.2 shows six different perspectives of the cloud droplet spectra measured for cloud 708clpl. In practice, 20 different views of the spectra are generated for more detailed examination.

In Fig. 5.2, size-contours (those lines perpendicular to the drop-size-axis) correspond to the concentration of drops in each of the 15 size categories. Time-contours (those lines perpendicular to the time-axis) were drawn at 1 second intervals. FSSP concentrations have been smoothed slightly using a five point centered averaging scheme. The typical volume of air sampled in one second was 21 cm^3. The highest single droplet concentration was 55 droplets per cm^3 which occurred in the 3 to 6 μm size category. Concentration varies linearly in the vertical of Fig. 5.2.

The interesting feature of Fig. 5.2 is the bimodal and unimodal structure of the spectra. Bimodal structure has been observed in the upper parts of clouds before (Spyers-Duran, 1970; Warner, 1969) but never with a unimodal component. Figure 5.2 demonstrates that the structure of the cloud droplet spectra is more intricate than indicated by conventional 2-dimensional displays or by the output of numerical models of microphysical processes. Theoretical work has indicated that the injection of sub-micron size Agl will act to freeze the cloud droplet population first and these will go on to freeze larger supercooled

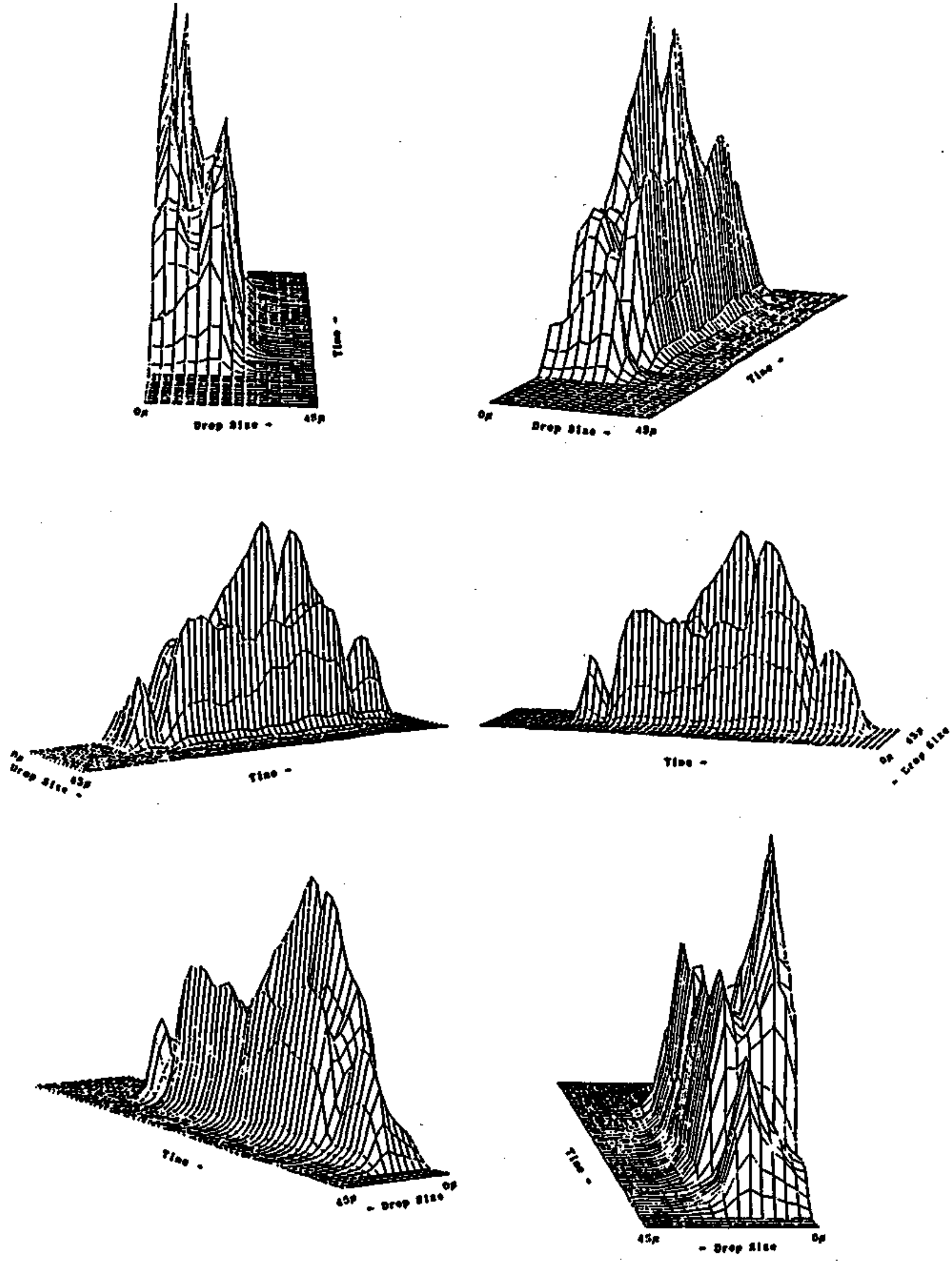


Fig. 5.2. Six different perspectives of the cloud droplet spectra of cloud 708fc1p1.

drops. Thus in this case a complicated process dependent on the shape of the cloud droplet spectrum and presence of supercooled drizzle and rain drops will dictate the course of imposed glaciation. Of course, Fig. 5.2 should be interpreted keeping the limitations of the FSSP in mind (Gardiner and Hallett, 1985; Dye and Baumgardner, 1984; Cerni, 1983).

Figure 5.3 shows the variation of vertical wind (VW), potential temperature (0) for cloud 708fclpl. Cloud liquid water calculated from the FSSP (FWC) and hot-wire probe (JWC) have been added to allow comparison to Fig. 5.2. The value of liquid water content in Fig. 5.3 can be determined using the potential temperature scale since each division of the potential temperature scale also corresponds to a 0.5 gr m^{-3} liquid water increment beginning with zero. The highest liquid waters in Fig. 5.3 are approximately 0.6 gr m^{-3}. The airplane began a 3° turn at about the time marked "a".

Figure 5.3 shows cloud 708clpl to be composed of a pocket of sinking air near the upwind edge, adjacent to a pocket of raising air, adjacent to a major updraft region. A general correspondence can be seen between the negatively and positively buoyant parts of the cloud and regions of falling and raising air. Liquid water contents show a tendency to increase from the region of negative buoyancy and sinking air to the region of slight positive buoyancy and strong updraft.

Table 5.4 indicates which clouds contained supercooled precipitation size drops. The existence of supercooled precipitation drops was noted during flight and verified from review of the

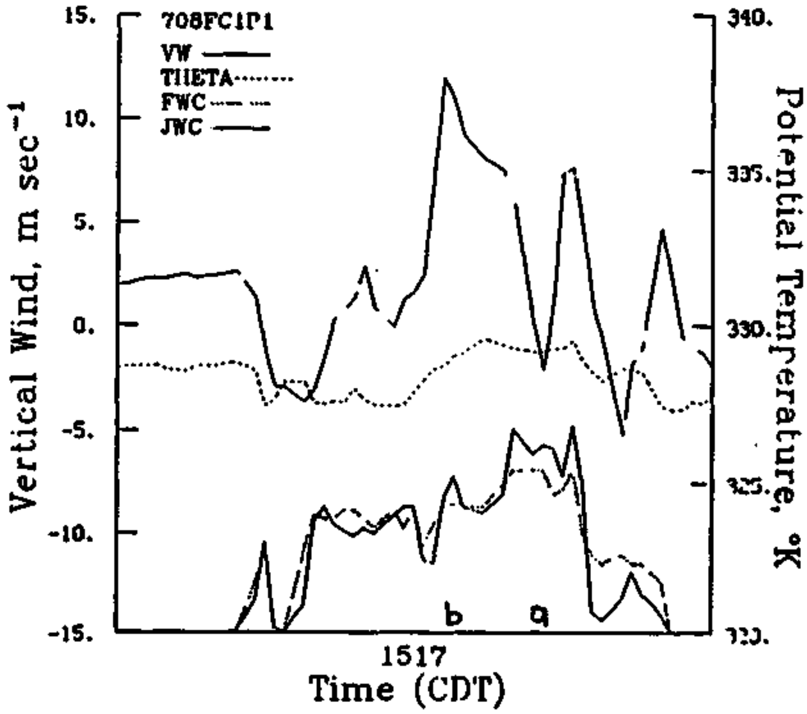


Fig. 5.3. Calculated vertical wind (VW), potential temperature (THETA), and cloud liquid water content (FWC and JWC) for cloud 708FC2P1.

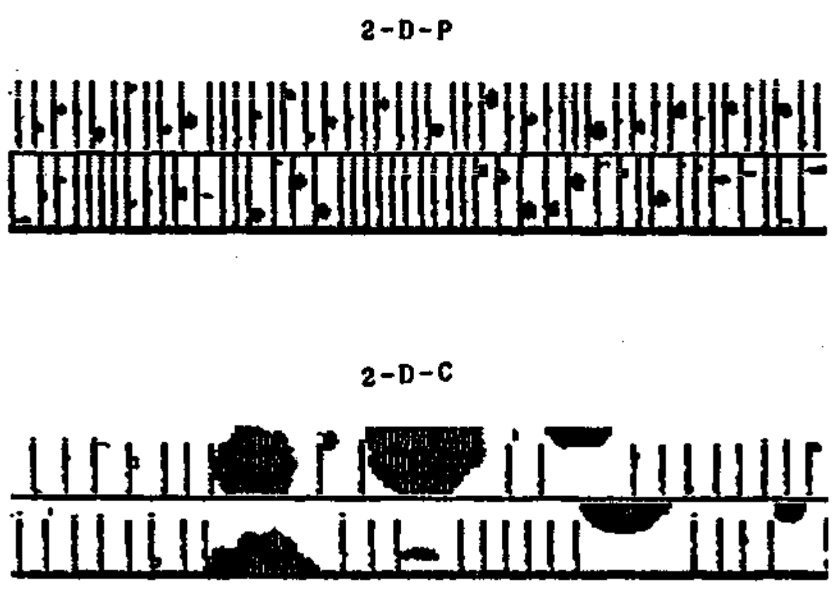


Fig. 5.4. Abridged 2-D-C and 2-D-P image record for cloud 708fclpl.

video recording. Playback of the video tape unquestionably shows the appearance of splashes on the windshield. Splash-size ranged from 3 mm to 3 cm. A "Yes" in Table 5.4 means splashing on the windshield occurred continuously for at least 2 seconds.

Precipitation-size drops were found in 13 of th 20 clouds sampled and were generally larger and more abundant on July 8 compared to July 24. No precipitation-size drops were observed in any of the cold-based clouds of July 30. In the case of cloud 708clpl, splashing began 26 seconds after entering the cloud and lasted for nearly 3 seconds (see "b" in Fig. 5.3).

Ice was generally presence in all of the clouds sampled. At the time of this report we are still in the process of estimating ice concentrations from the 2-D data.

Figure 5.4 is an example of the 2-D-C and 2-D-P image record of cloud 708clpl. The images are slightly distorted in the horizontal because of a mismatch between the frequency of the probe timing strobe and airplane velocity. This problem did not occur on any other flight. The maximum particle size for the 2-D-C is 800 μm and for the 2-D-P is 6400 μm. Most of the images appear to be caused from graupel; however a few are round enough to suspect that they were caused by a drop. In general on the rare occasion when an image appeared to be an ice crystal, the shape resembled either a stellar crystal, fragment or columnar crystal.

Summary for Observations near -10C

The major findings confirm characteristics that were deduced based on the limited data available at the end of the Planning

Phase of PACE. The deduced characteristics of cloud forming within a nesoscale setting were:

1. Cloud bases are usually at altitudes of 1 to 2 km and temperature between 16C.

2.. Vigorous, buoyant, updrafts usually with dimensions between 1.5 and 4-5 km increase in intensity with height from below cloud base to 6 or 7 km in deep clouds. Updrafts and thermal buoyancy tend to be larger in more extensive updrafts.

3. Cloud water content is close to adiabatic near cloud base, but tends toward a decreasing fraction of this theoretical value with height as it is converted into larger drops and depleted by entrainment. However, total water content remains substantial and at 5 to 6 km (0 to 10C) the total water content usually exceeds 1 g m^{-3} over significant fractions of the cloud diameter.

4. Large chloride non-hydrophobic aerosols are common at the cloud base and cloud droplet concentrations are moderately low, with daily averages of 300 to 600 cm^{-3}.

5. Large cloud particles (precipitation and drizzle drops) always occur in the upper reaches of cumulus congestus and cumulonimbus. Glaciation occurs, apparently as large water drops freeze into graupel particles, at temperatures of -5 to -10C within 10 to 15 minutes after these large particles occur and proceeds rapidly once initiated.

6. Radar will commonly detect coalescence echoes below freezing with day to day variations indicating the influence of

mesoscale, or larger, influences on cloud dynamic and microphysics.

Additional measurements of clouds at -10C under different mesoscale forcing are required to check for consistency of these data has they might apply to other clouds on other days. Furthermore, major questions still remain concerning the influence of the shape of the cloud droplet spectrum on the course of imposed glaciation and on the mechanism by which the invigorated updraft circulation entrains environment air to result in downward communication of the circulation to enhance convergence in the subcloud layer.

From this analysis the following refinements can be made to the deduced characteristics. The analysis show some similarity in buoyancy, liquid water content and presence of supercooled cloud and precipitation drops. From preliminary analysis of 2-0 images it is concluded that total liquid water contents can be far in excess of 1 g m^{-3} at the -10C level. Cloud liquid water were generally lower than expected. Cloud droplet distributions showed dramatic cloud-to-cloud and day-to-day variation. This expected variation has important implication for imposing glaciation by introduction of sub-micron aerosol.

The characteristics of clouds with warm bases that develop within a mesoscale setting were found to be consistent with the desire to improve rainfall by dynamic effects. Clouds of at least moderate updrafts possess abundant supplies of supercooled water for enhanced cloud vigor through the release of the latent heat of freezing. Preliminary analysi's of potential buoyancy enhancement for one cloud has indicated that about 0.25C increase in temperature is achievable from the freezing of 0.5 g m^{-3} of water in droplets with diameters less than 45 µm. Thus, greater increases are possible as drops with greater diameter begin to freeze.

Case Study 30 July 1986: Cloud Input and Rain Output

Toward the end of the cloud physics operations several hours of flight time were available to investigate the sicrophysical properties of a synoptic scale cloud system developing just beyond the southern reaches of the PACE target area. The cloud microphysics data collected on July 30, 1986 has been analyzed keeping the synoptic and mesoscale weather patterns in mind. In this section the case of July 30 is reported on and a comparison is given between the microphysical properties of the input clouds and the rainfall measured beneath cloud base.

Debriefing

At 2200Z (1700CDT), on July 30, 1986, a low pressure system was located in east-central Kansas. A warm front extended from the low through Missouri and into southern Illinois. The front separated a hot, dry air mass located to the southwest with temperatures around 100F and dew points in the 70's from a slightly cooler air mass located to the northeast with temperatures in the mid-80's and dew points around 70F.

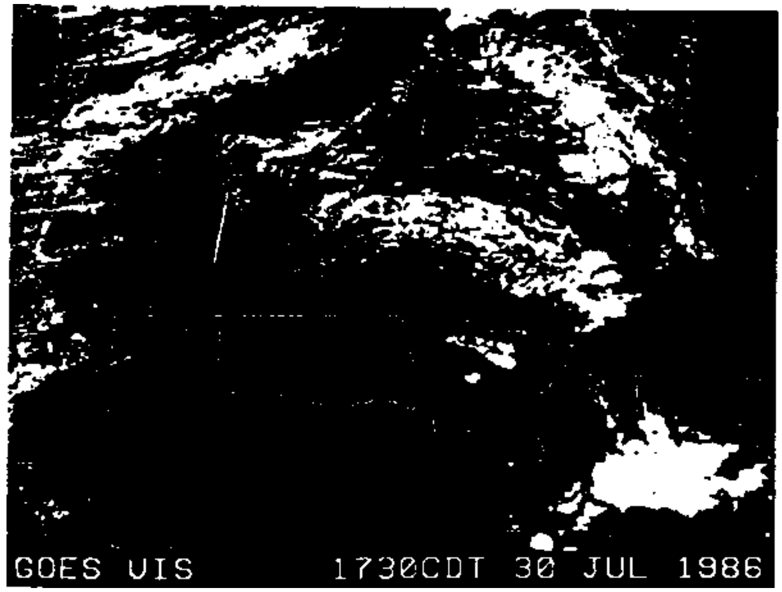
The airplane departed Champaign's Willard Airport (CMI) at 2123Z and headed toward the area of warm frontal convection in southern Illinois. By 2206Z the airplane was positioned about

100 nm south-southwest of CMI at an altitude of 22.5K ft. Two massive cunulonimbus clouds were visible on approach. Cloud top heights were estimated reaching 15K to 20K feet above flight level.

Figure 5.5 shows the GOES visible satellite image for 223GZ. The satellite image shows the cloudiness with embedded convection that was associated with the warm front. Other areas of cloudiness can be seen over north-central Arkansas, along the gulf coast and over Wisconsin and Lake Michigan.

Figure 5.6 shows the facsimile radar summary for 2235Z. The radar summary shows two areas of echo activity over southern Illinois. The first area, labeled "a" in Figure 5.6 is over south-central Illinois. The second area, labeled "b" in Figure 5.6 is over the extreme southern portion of Illinois. Microphysical observations were taken in the location corresponding to the southwest flank of area "a" (see arrow in Fig 5.6). As can be seen from Fig. 5.5 and 5.6 the northwestern half of area "a" was embedded within mid-level cloud.

Convective activity initiated at approximately 1930Z and persisted for **more** than 3 hours. By 2135Z the region of frontal clouds over Illinois were organizing into two distinct areas of echo. The echoes in area "b" had tops near 46K ft. and echo tops in area "a" were reaching their maximum, 43K ft. By 2235Z echo tops in area "a" had decreased to 33K ft., while tops in area "b" peaked at 50k ft. Beyond 2235Z, both storms gradually moved to the southeast and dissipated.



Pig. 5.5. GOES visible satellite image for 1730CDT, 30 July 1986

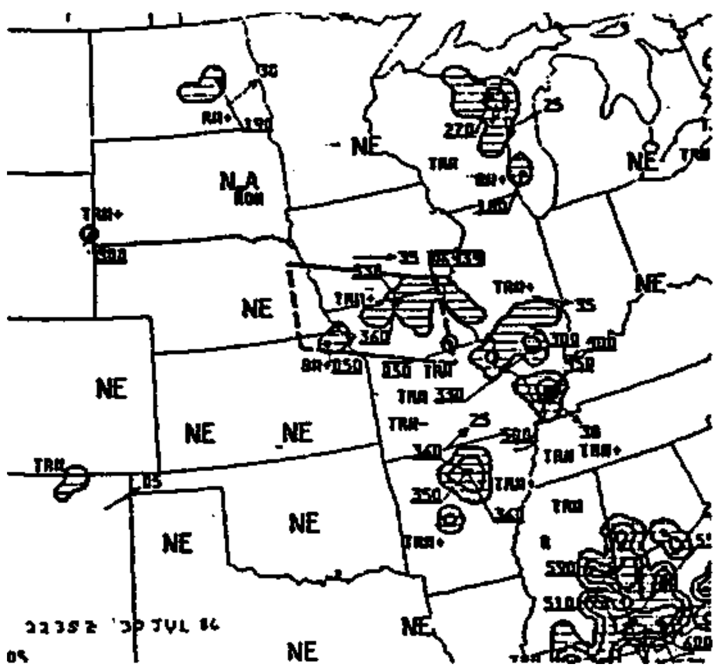


Fig. 5.6. NWS radar summary for 2235Z 30 July 1986

Penetration of cumulus began at approximately 2200Z. Six different clouds were penetrated. Three of the penetrations were made around the -11C level and one penetration was made near each of the following temperature levels; -12C, -13C and -15C, respectively. These were clouds that would have been considered for treatment had the cloud system been located in the target area.

By the time of the sixth penetration, the top of the mid-level cloud was intruding into flight level. This event brought the cold temperature microphysical studies to an end. Before returning to CNI, the airplane descended and flew at approximately 100 ft beneath cloud base through a rain shower.

Thermodynamic Structure

The sounding for Salem, IL, at 1200Z is shown in Fig. 5.7. The thermal structure of the sounding consists of: (1) an inversion between the surface and 950 mb, (2) a layer of conditional instability between 950 and 700 mb, (3) a dry adiabatic layer between 700 and 600 mb, (4) a shallow isothermal layer between 600 and 540 mb (5) a conditionally unstable layer between 540 and 280 mb, and (6) an absolutely stable layer from about 280 to 170 mb. The atmosphere is fairly dry through out the vertical with the exceptions of a shallow moist layer at 900 mb and one at 600 mb. The lack of moisture at upper levels reflects the fact that at the time of the sounding clouds were still well to the west-southwest of Salem.

Even though the sounding was taken 10 hours before the initiation of convection, it provides several indications

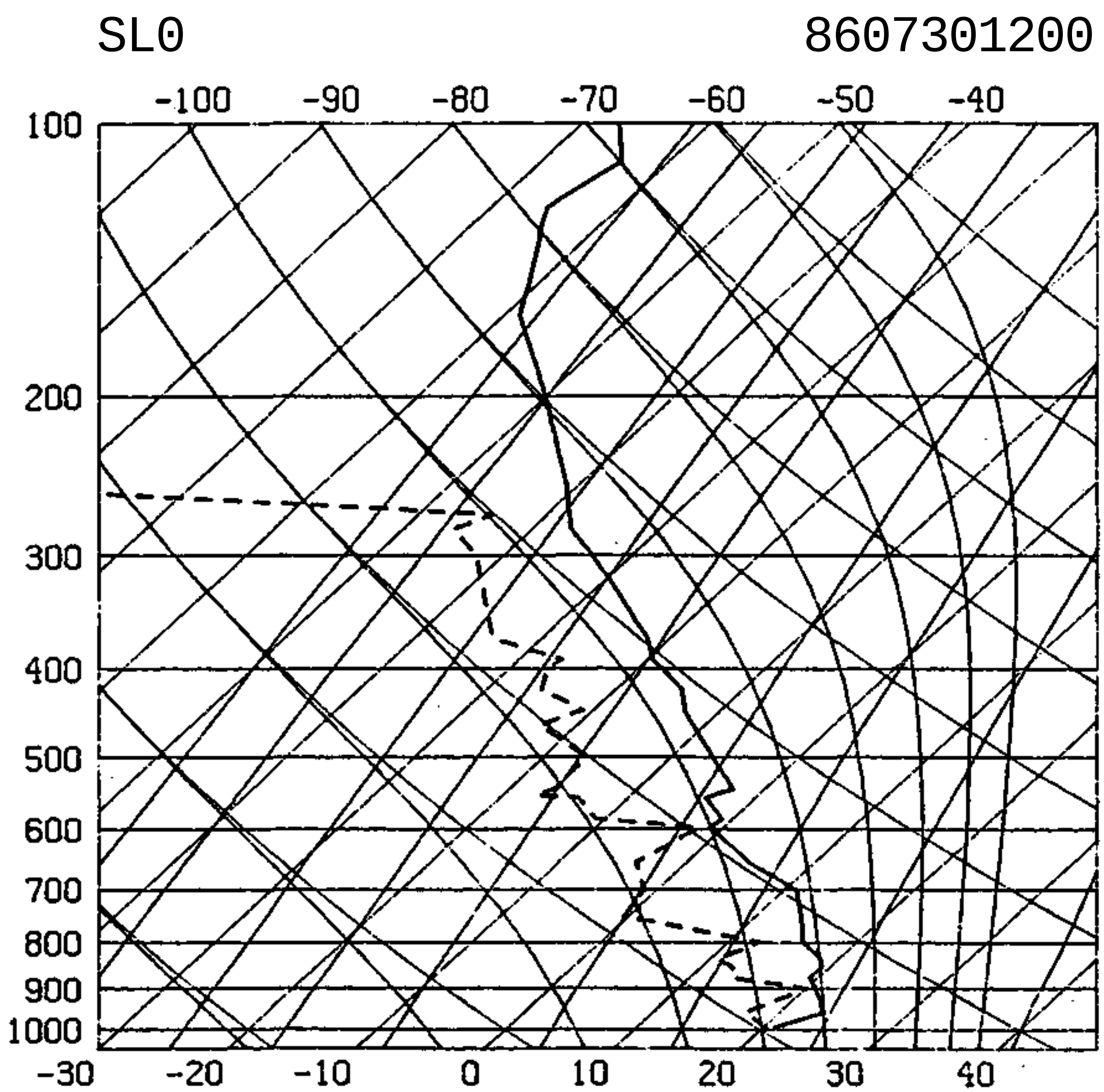


Fig. 5.7. Sounding for Salem (SLO) Ill., 1200Z, 30 July 1986.

consistent with the weather that occurred. First of all, the sounding indicated that conditions in the lowest levels were unfavorable for convection to develop from surface heating alone. Secondly, the most likely level for cloud bases should be near the level of free convection (670 mb and +8C). Finally, the sounding indicates that there are no shallow stable layers to inhibit vertical cloud growth. Thus cloud tops should be expected to reach at least 280 ab (or 33K feet).

Microphysical Observations

A summary of selected thermodynamic and microphysical features of the six clouds penetrated is presented in Table 5.6. Clouds have been identified by month, day, cloud number and penetration number. With the exception of cloud 730clpl the clouds where entered at their middle and cloud diameters were calculated from the length of tiae in cloud and true air speed.

The distance of cloud top above flight level was used to give the estimate of cloud maturity in Table 5.6. As indicated by Table 5.6, most of the observations were taken during the initial stages of cloud developaent.

Buoyancy was calculated for Table 5.6 by taking the difference between the maximum in-cloud and mean cloud environment temperature. Mean environment temperatures were calculated from measurements taken during approach at least 1 km away from cloud. Five of the six clouds sampled were negatively buoyant. Cloud 730clpl is somewhat anomalous in that it was the only cloud to be penetrated off-center, was the only to have a positive

Table 5.5. Summary of Cloud Properties.

Cloud ID	Penetration Time (CDT)	Duration (sec)	Maturity*	Cloud Dia. (km)	Cloud Temp. (°C)	Thermal Buoy. (°C)	Peak Updraft (m/sec)	Mean/Max FWC (g/m³)	Mean/Max JWC (g/m³)	Mean Drop Dia.	Mean Conc. (cm⁻³)	S.P.D.**
730c1p1	170907	14	***	1.2	-14.7	0.8	13	0.4 0.5	0.6 0.7	13	210	No
730c2p1	171517	48	**	2.2	-13.0	-0.3	7	0.4 0.5	0.3 0.6	14	200	No
730c3p1	171818	33	***	1.0	-12.1	-0.5	12	0.4 0.5	0.6 0.8	13	240	No
730c4p1	171953	28	***	1.9	-11.1	-0.3	4	0.5 0.7	1.0 1.6	13	280	No
730c5p1	172250	91	**	2.0	-11.3	-0.8	3	0.3 0.4	0.2 0.3	13	190	No
730c6p1	172639	67	****	2.2	-10.9	-0.6	12	0.4 0.5	0.5 1.2	13	220	No

* Maturity:	*	**	***	****	*****
Estimated height of cloud top above flight level	100-500'	500-1000'	1000-2500'	2500-5000'	>5000'

** S.P.D. = Supercooled Precipitation Drops with diameter > 1 mm calculated buoyancy and was the only to be distinguished with a pileus cap at the time of observation.

Mean liquid water contents ranged from 0.2 to 1.0 gr m^{-3}, measured by the hot-wire probe (JWC). Mean liquid water contents calculated from the FSSP showed less variability and varied from 0.3 to .5 gr m^{-3}. No relationship was found between peak updraft and either mean liquid water or maximum liquid water in this limited amount of data.

Cloud droplets were generally more abundant in these cold-base clouds than in the warmer based clouds observed on other days during PACE86. Mean concentrations of cloud droplets range from nearly 200 to nearly 300 cm^{-3}. Mean concentrations of cloud droplets measured on July 8 and July 24, rarely exceeded 200 cm^{-3}. Peak concentrations occurred for drops between 12 and 15 μm, diameter. Typically, the spectra were unimodal across the entire cloud traverse and had a steep slope.

The 2-D images were reviewed along with the video tape recording of the cloud penetrations, for evidence of the presence of precipitation-size drops. No evidence of the presence of precipitation-size drops was found.

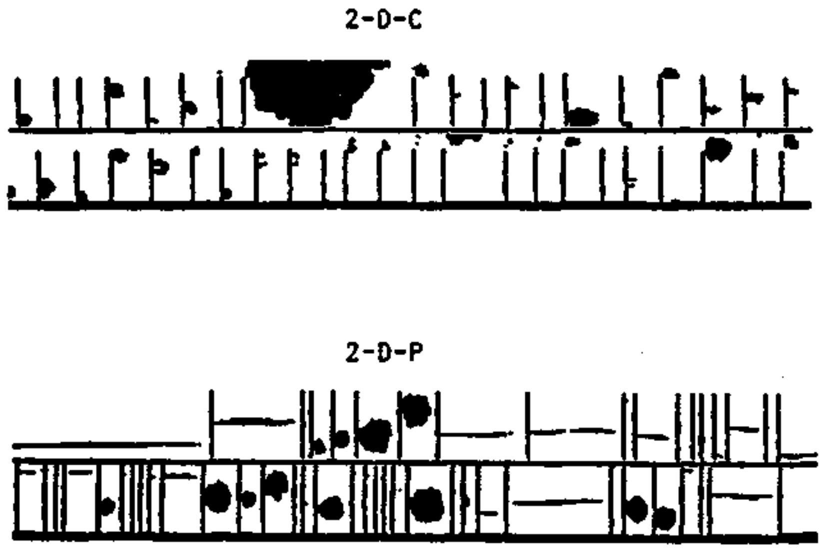
Figure 5.8 shows an example of the 2-D-C and 2-D-P images for cloud 730c6pl. The maximum vertical dimension for the 2-D-C is 800 μm and for the 2-D-P is 6400 μm. These images are fairly representative of the images from the other clouds observed on July 30. Many of the images in Fig. 5.8 are shaped like graupel. The problem we had with streamers and the 2-D-P probe is evident. We do not have independent observations to verify the elongated, sometimes hollow shapes in the 2-D-C record, but suspect that at least sone fraction of the total number of these images were caused by regular ice crystals. Analysis is currently underway to determine ice concentrations.

Rain Output

Figure 5.9 shows the size-distribution of raindrops and was composed from the 2-D-P image record using software developed as part of PACE funding. In addition to producing the output shown as Pig. 5.9 and calculating rainfall rate the interactive software also provides information about categories of images that were rejected as drops.

The 2-D-P record contained a total of 3273 images. Of this total, 422 images were determined to be artifacts. In our algorithm an artifacts is defined as an image that bears no similarity to either a drop, a streamer or a zero-area image. Of the total images, 840 were classified as streamers and 533 were zero-area images. Thus only 45% of the images were found to be valid drops.

The calculated rain fall rate for the distribution shown in Fig. 5.9 is about 2.5 mm hr^{-1}. This rate represents a lower limit given the brief exposure of the probe (approx. 2 min.) and the large number of images that were rejected as being drops. This light rainfall rate is consistent with what was reported during flight.



Pig. 5.8. Abridged 2-D-C and 2-D-P image record for cloud 730fc6p1.

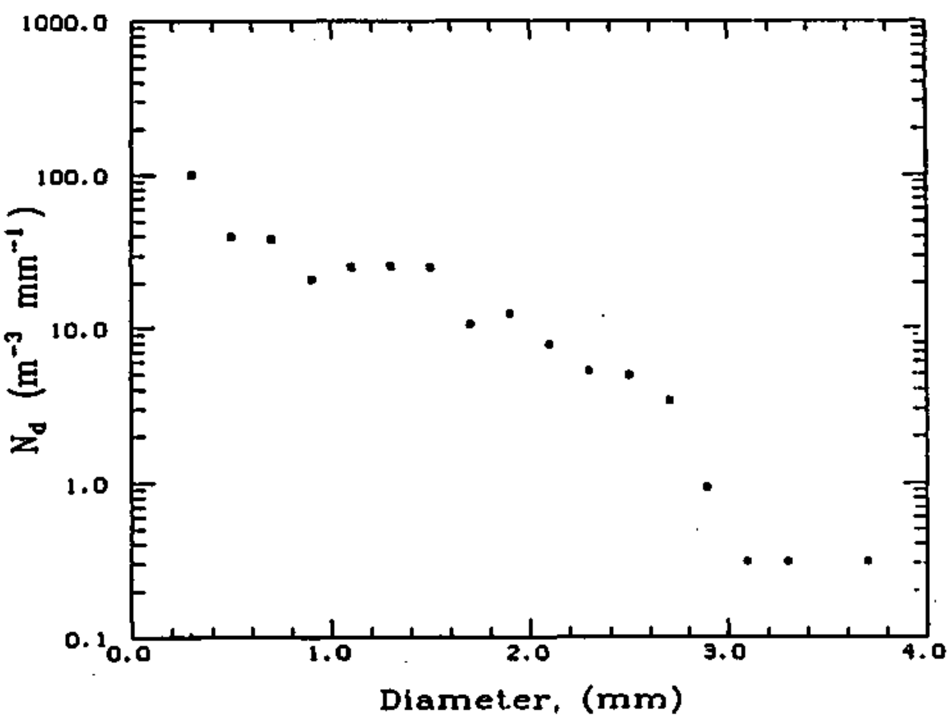


Fig. 5.9. Rain drop size distribution measured beneath cloud base on 30 July 1986.

SUmmary for 30 july 1986

The clouds of July 30 resemble in many ways clouds that have been reported on (e.g., Cooper, 1977; Hobbs *et al.,* 1978) for the high planes. The clouds investigated in this study had cold cloud bases, a fairly abundant supply of supercooled cloud droplets and lacked the presence of supercooled precipitation drops. These findings are consistent with what is expected for ware-frontal convection and demonstrate the dramatic difference between the microphysical properties of warm based convection associated with a mesoscale system and cold-base convection associated with synoptic scale feature. The precipitation mechanism for the clouds observed on 30 July seems to be based upon the growth of a few graupel by accretion of supercooled cloud droplets. The rainfall rate for the clouds investigated on this particular day was found to be light.

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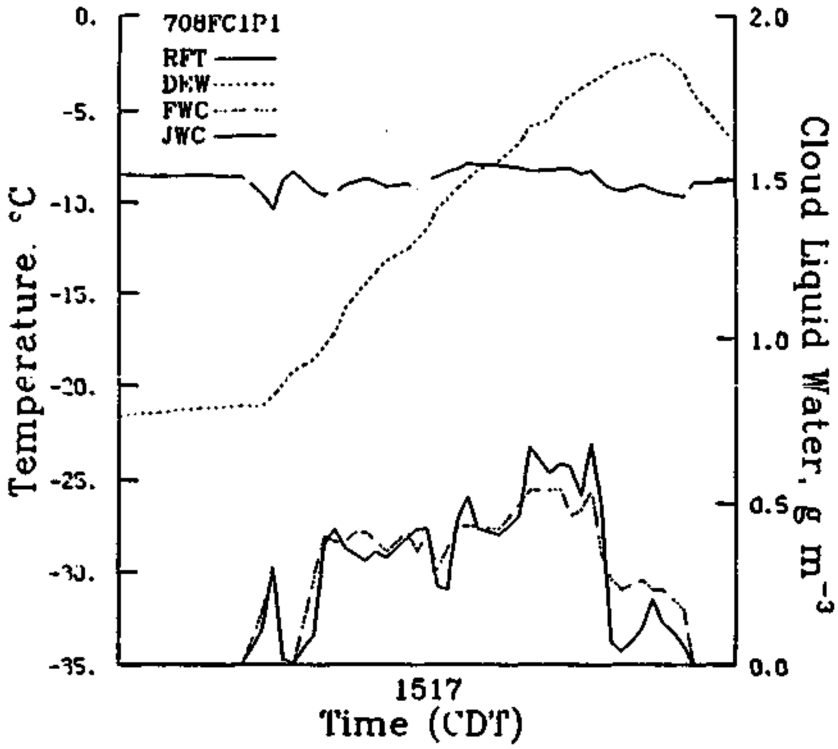
APPENDIX to CHAPTER 5

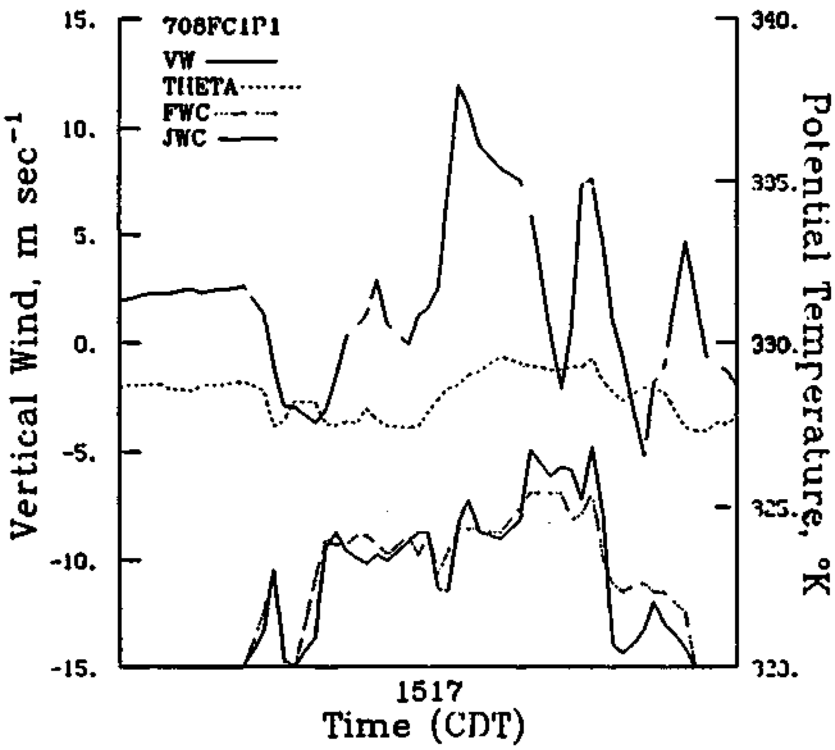
Selected

Thermodynamic and Microphysical Data

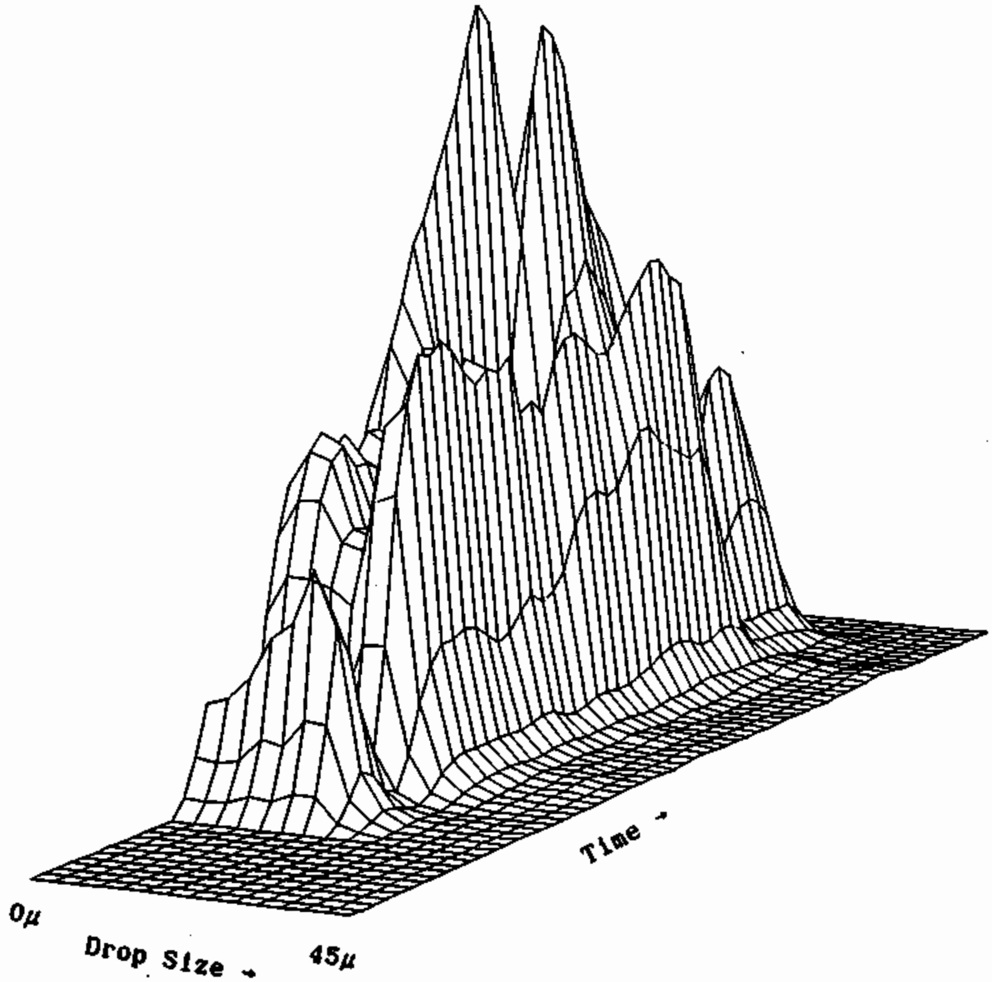
Obtained by the Cloud Physics Subprogram during

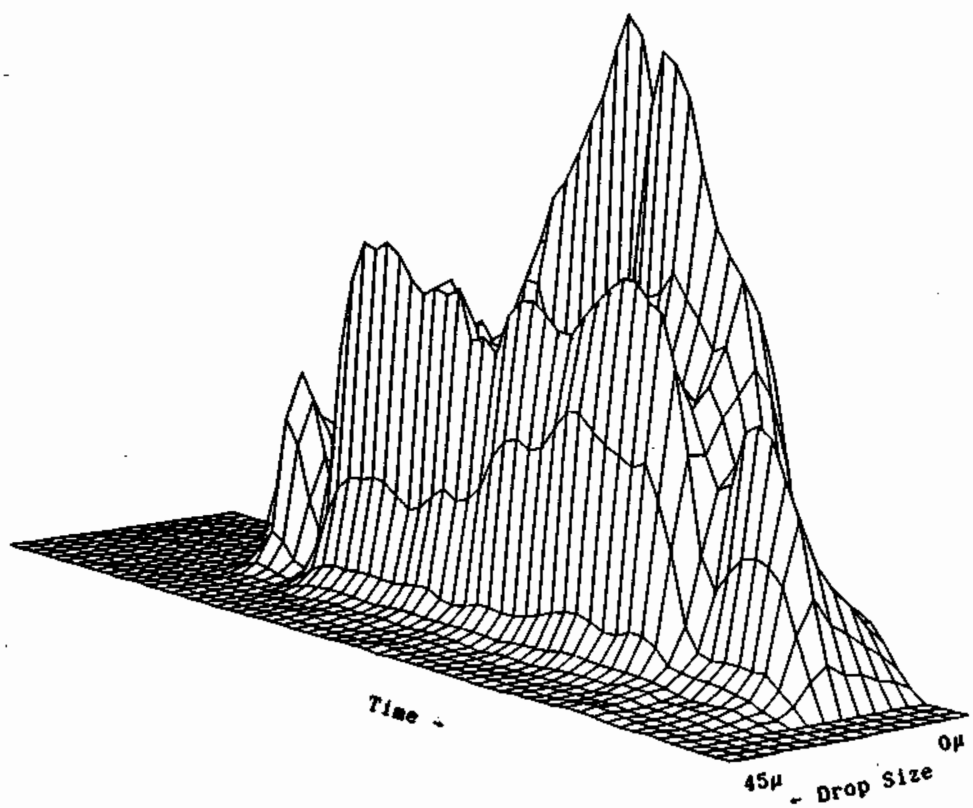
PACE86 Field Operations



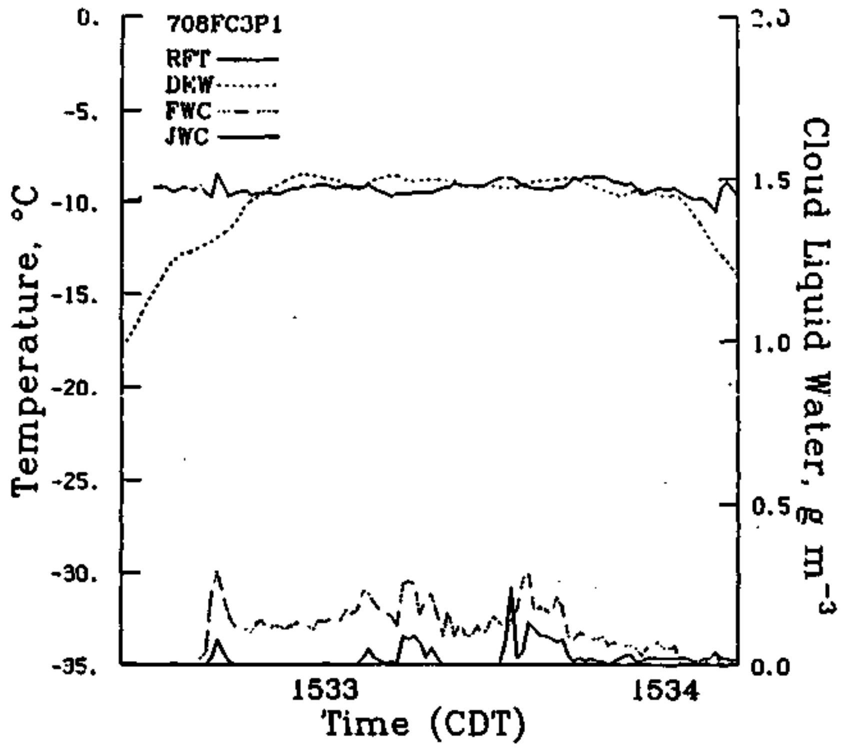


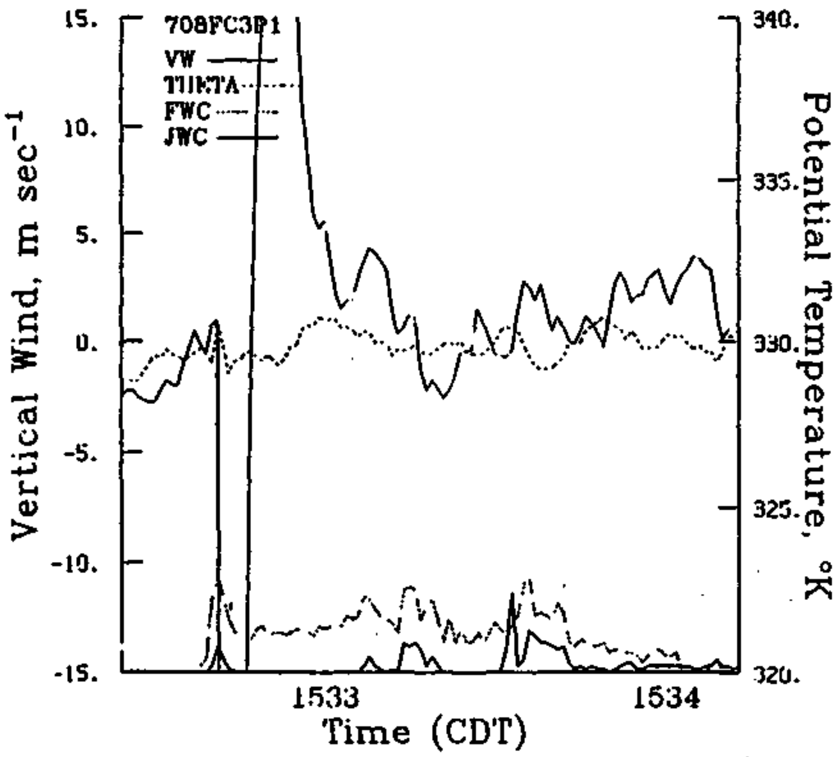
A.5-1 Cloud 708FC1P1



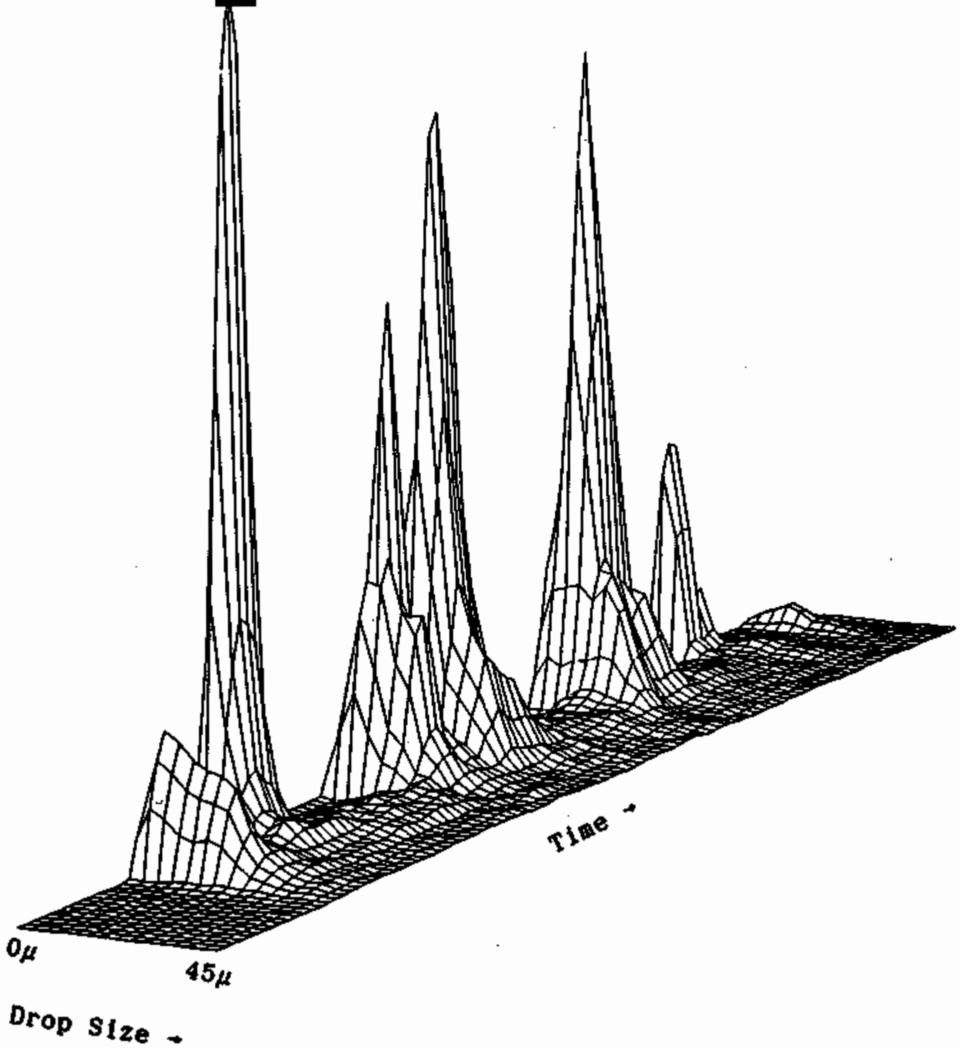


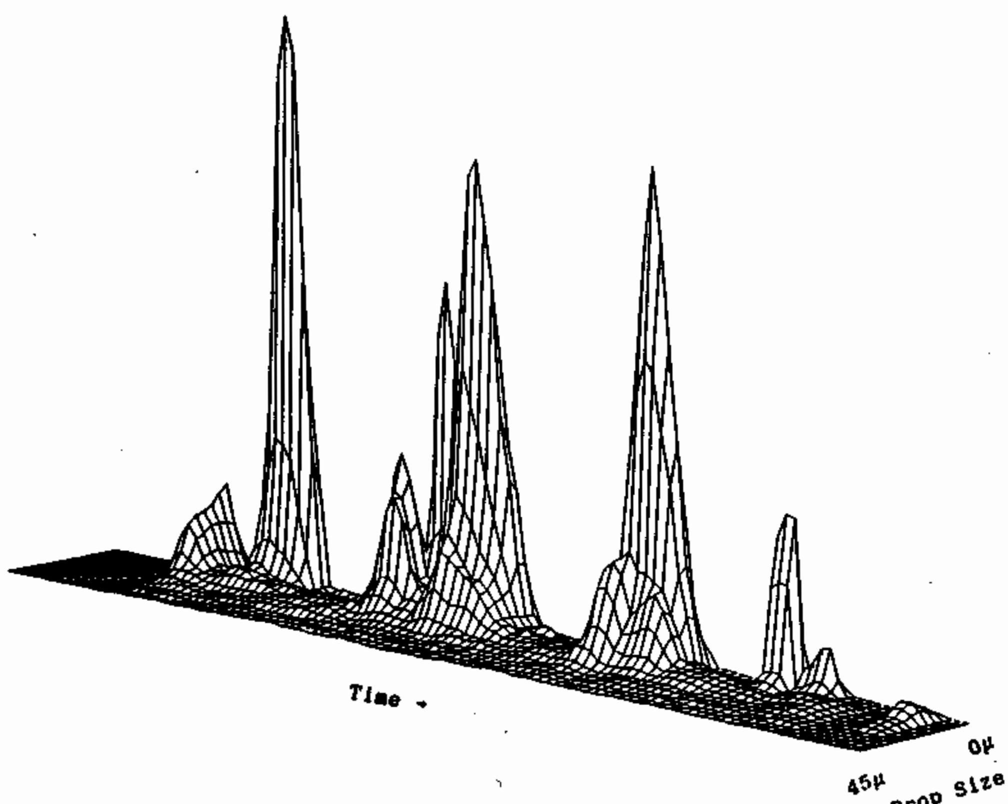
A.5-2 Cloud Droplet Spectrum 708FC1P1



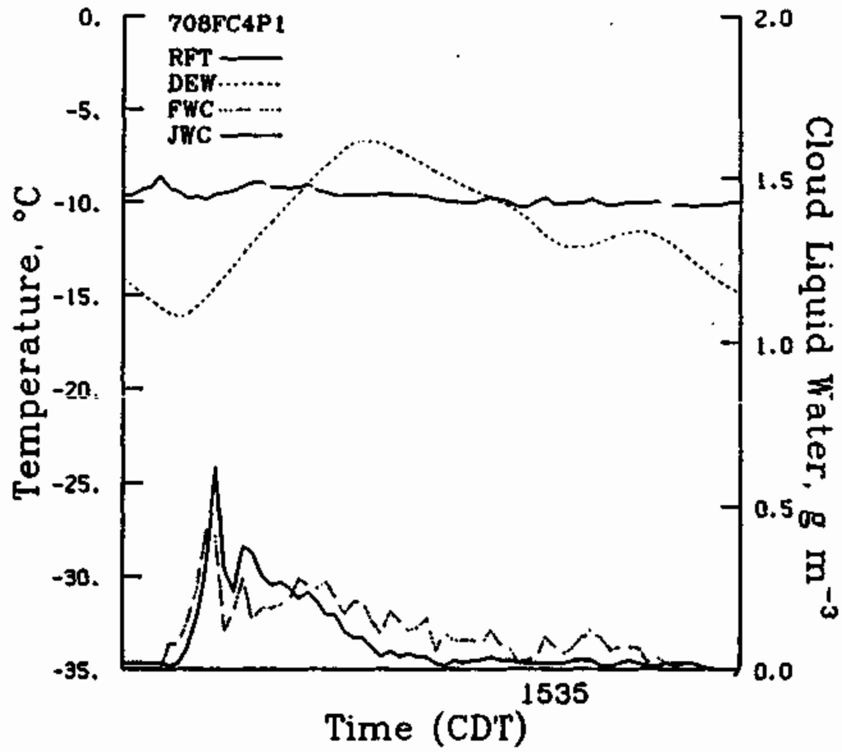


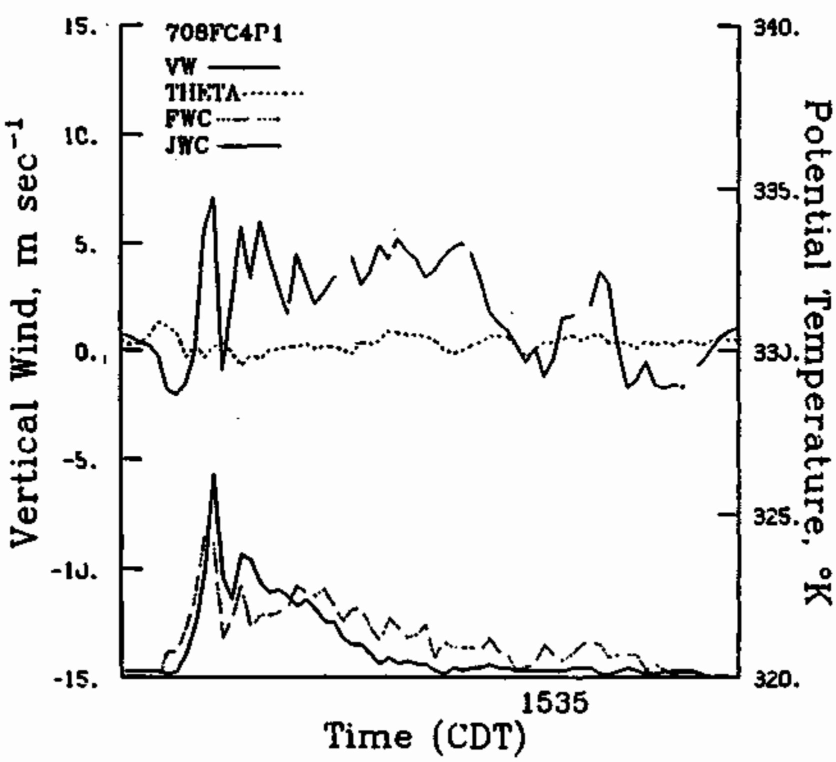
A.5-3 Cloud 708FC3P1



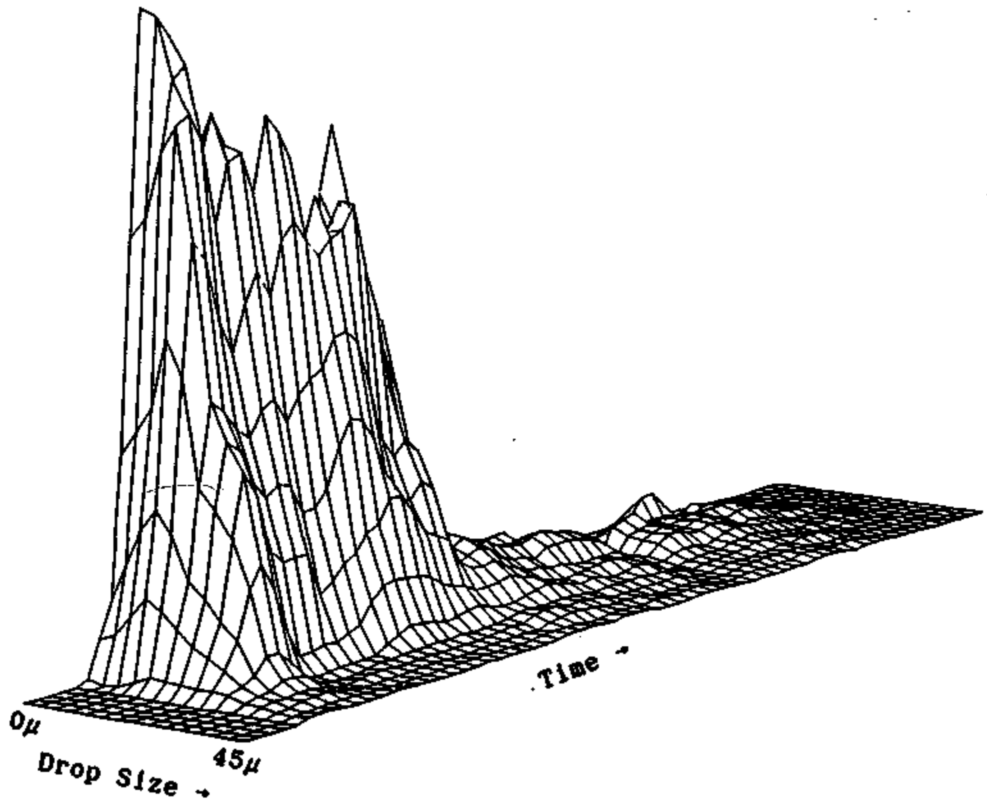


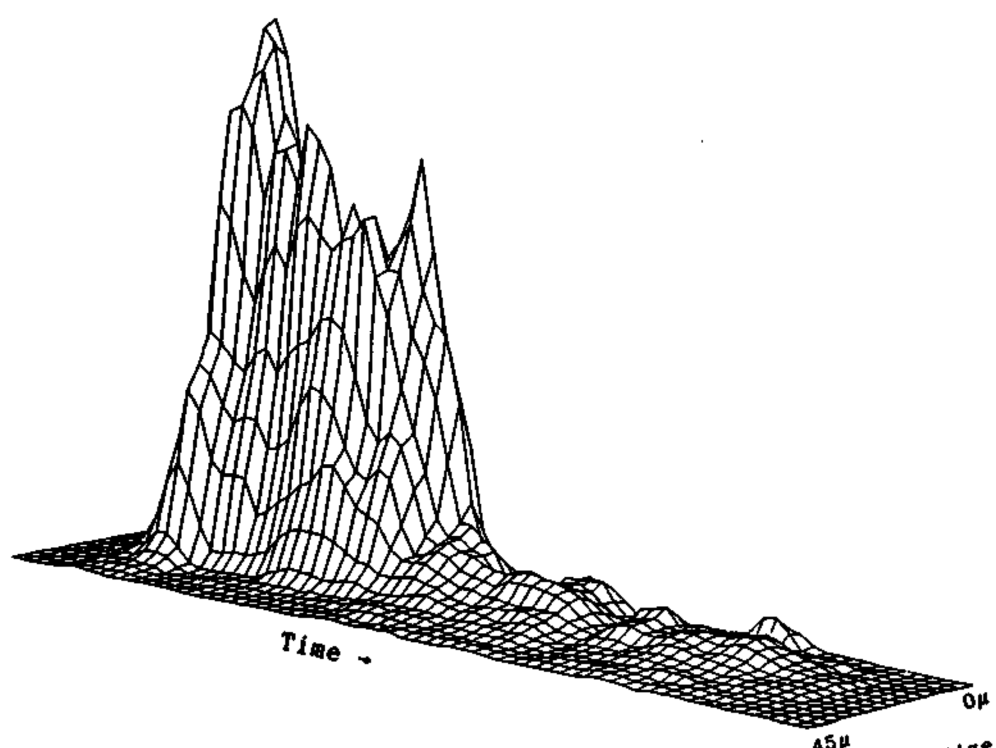
A.5-4 Cloud Droplet Spectrum 708FC3P1



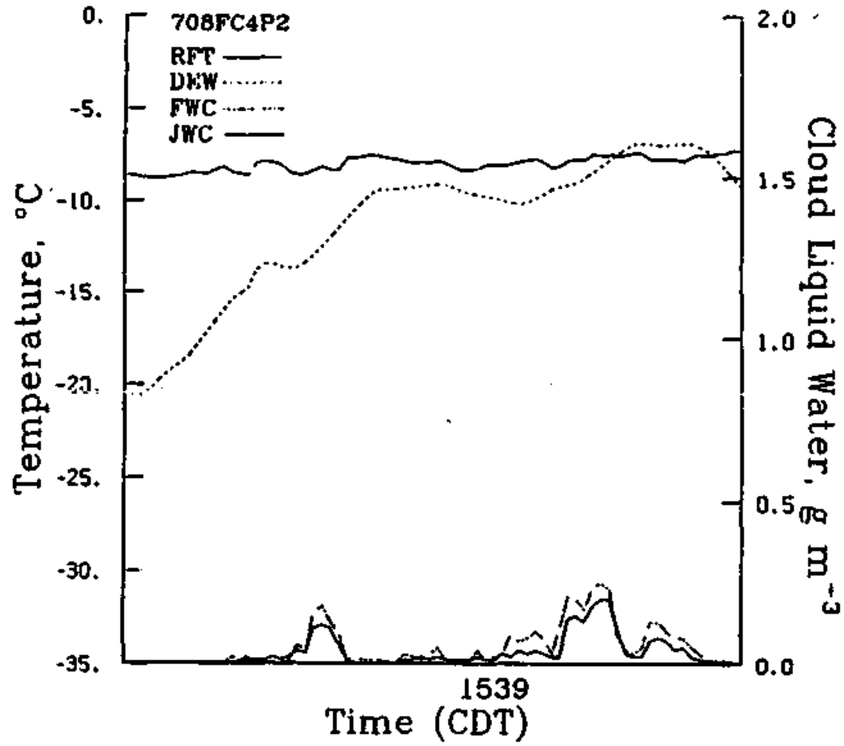


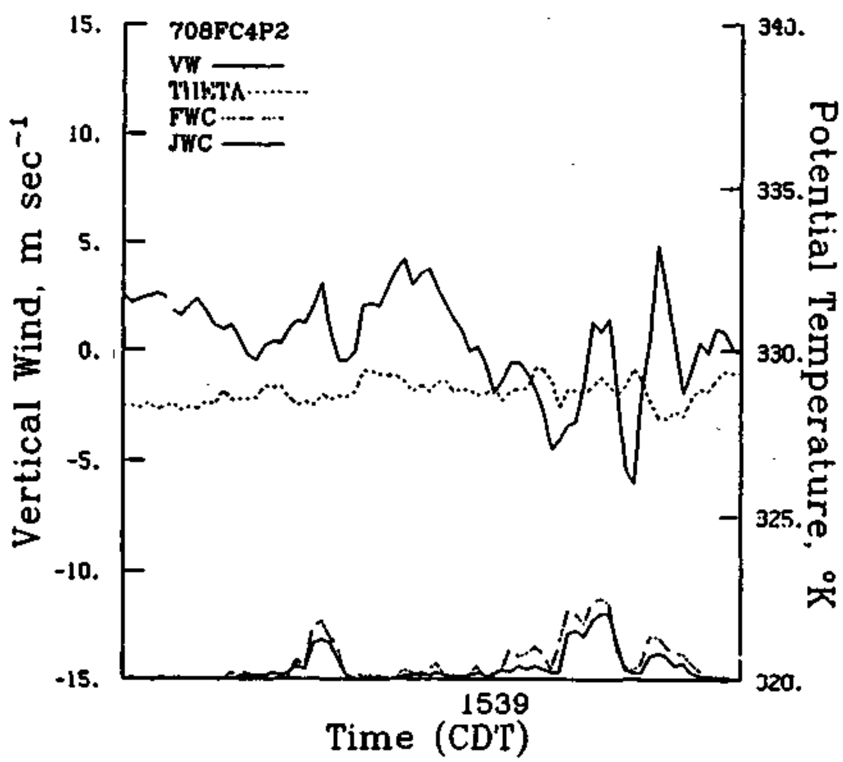
A.5-5 Cloud 708FC4P1



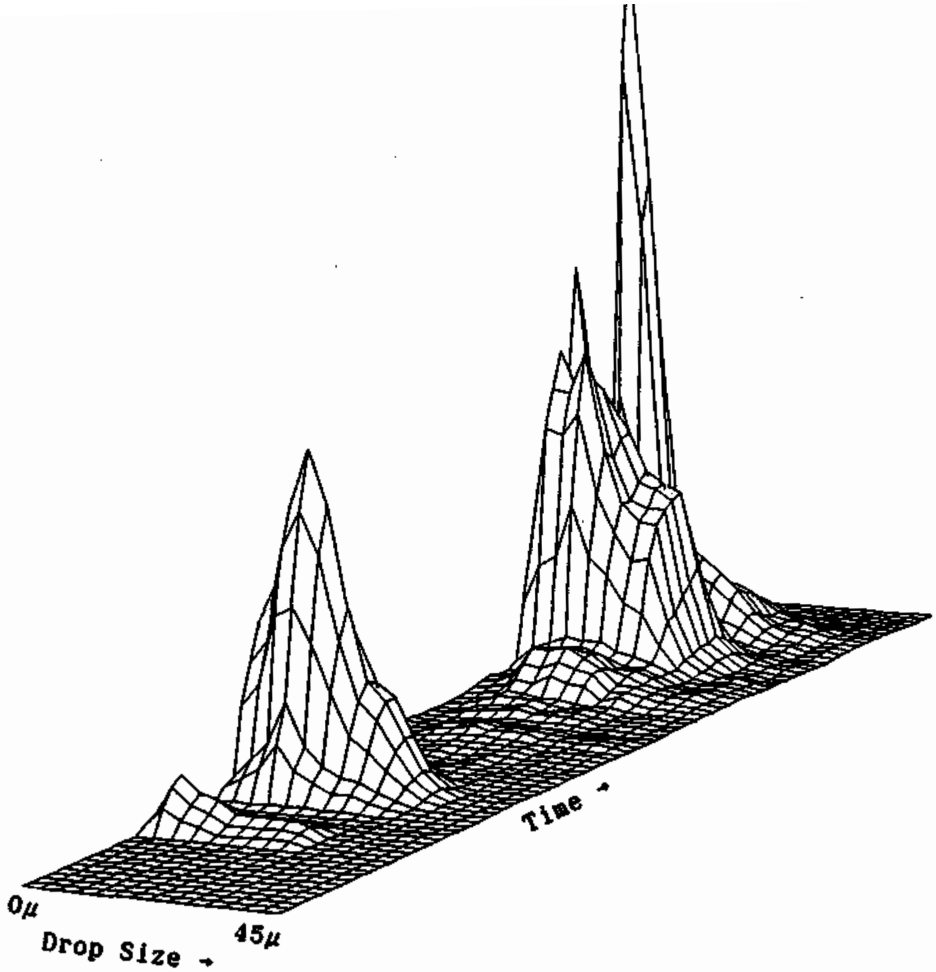


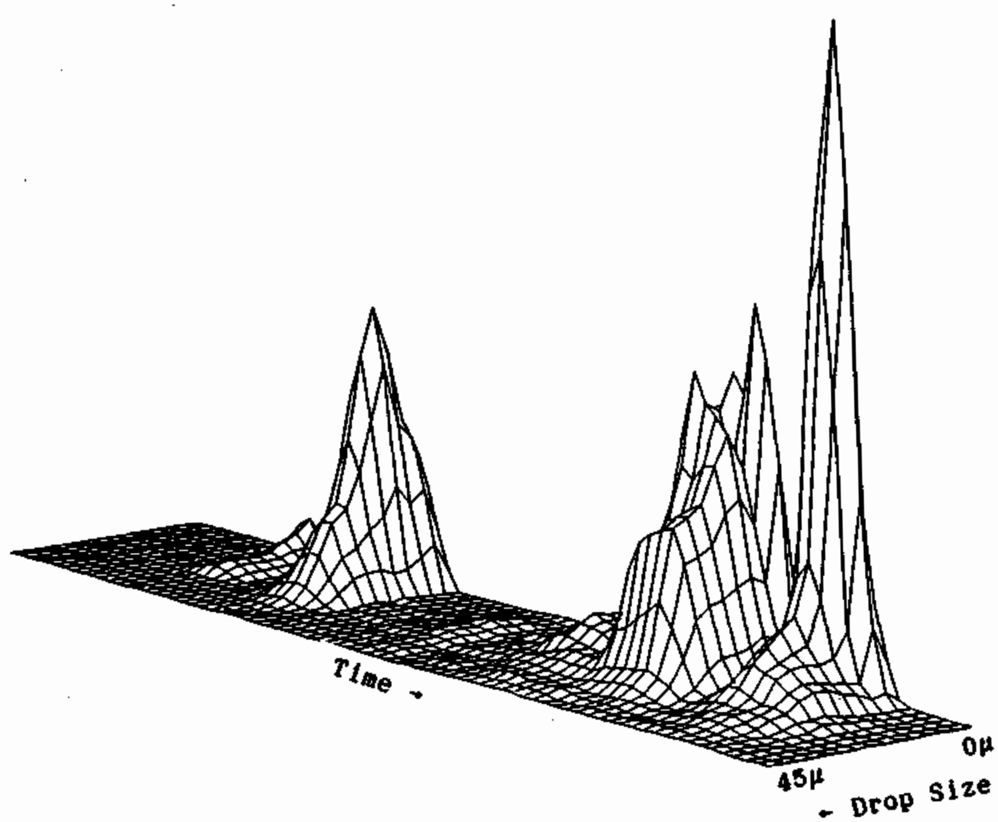
A.5-6 Cloud Droplet Spectrum 708FC4P1



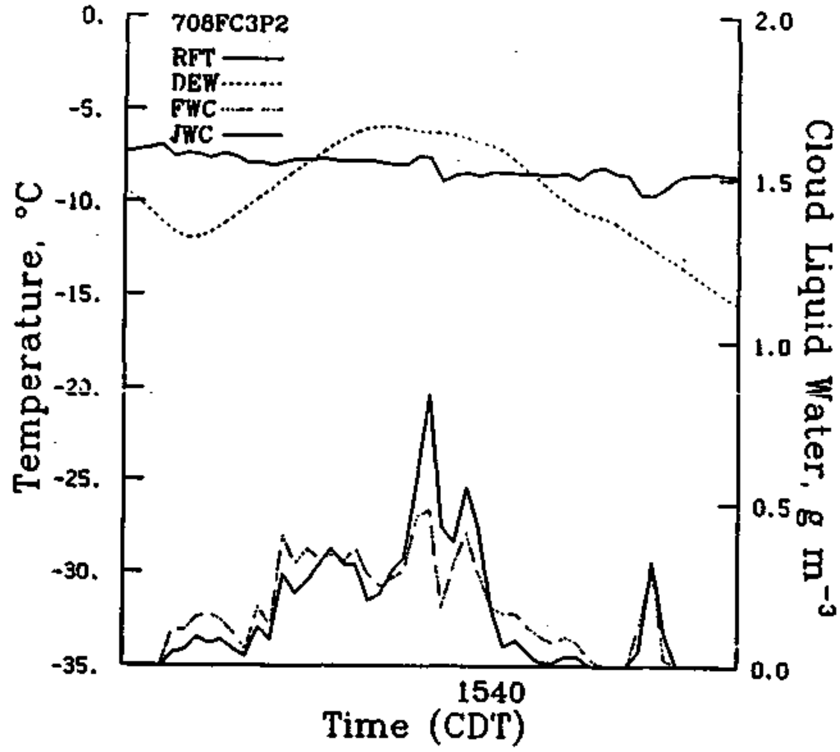


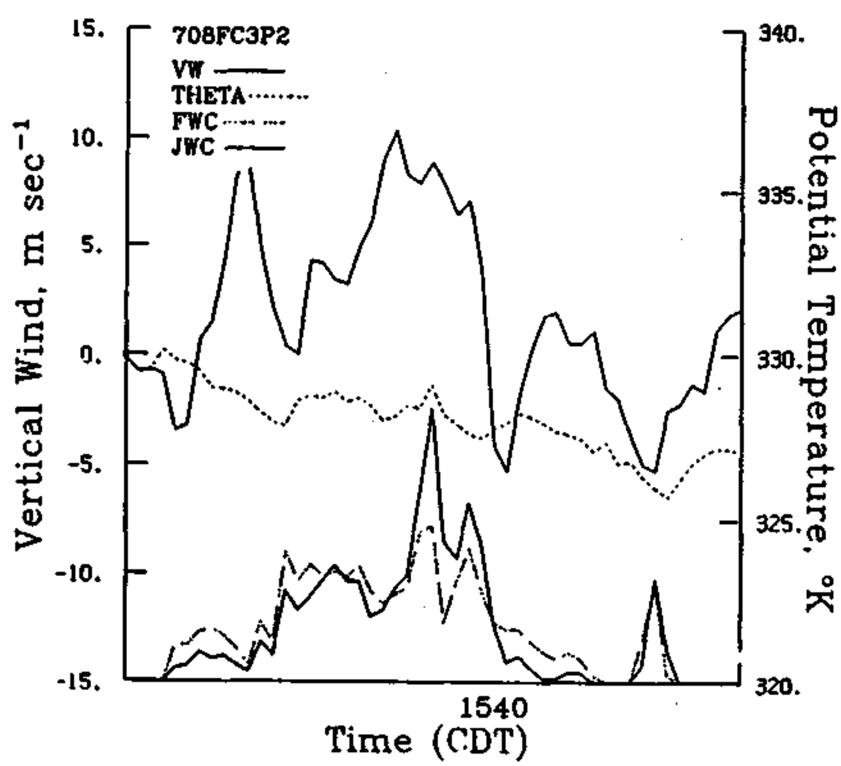
A.5-7 Cloud 708FC4P2



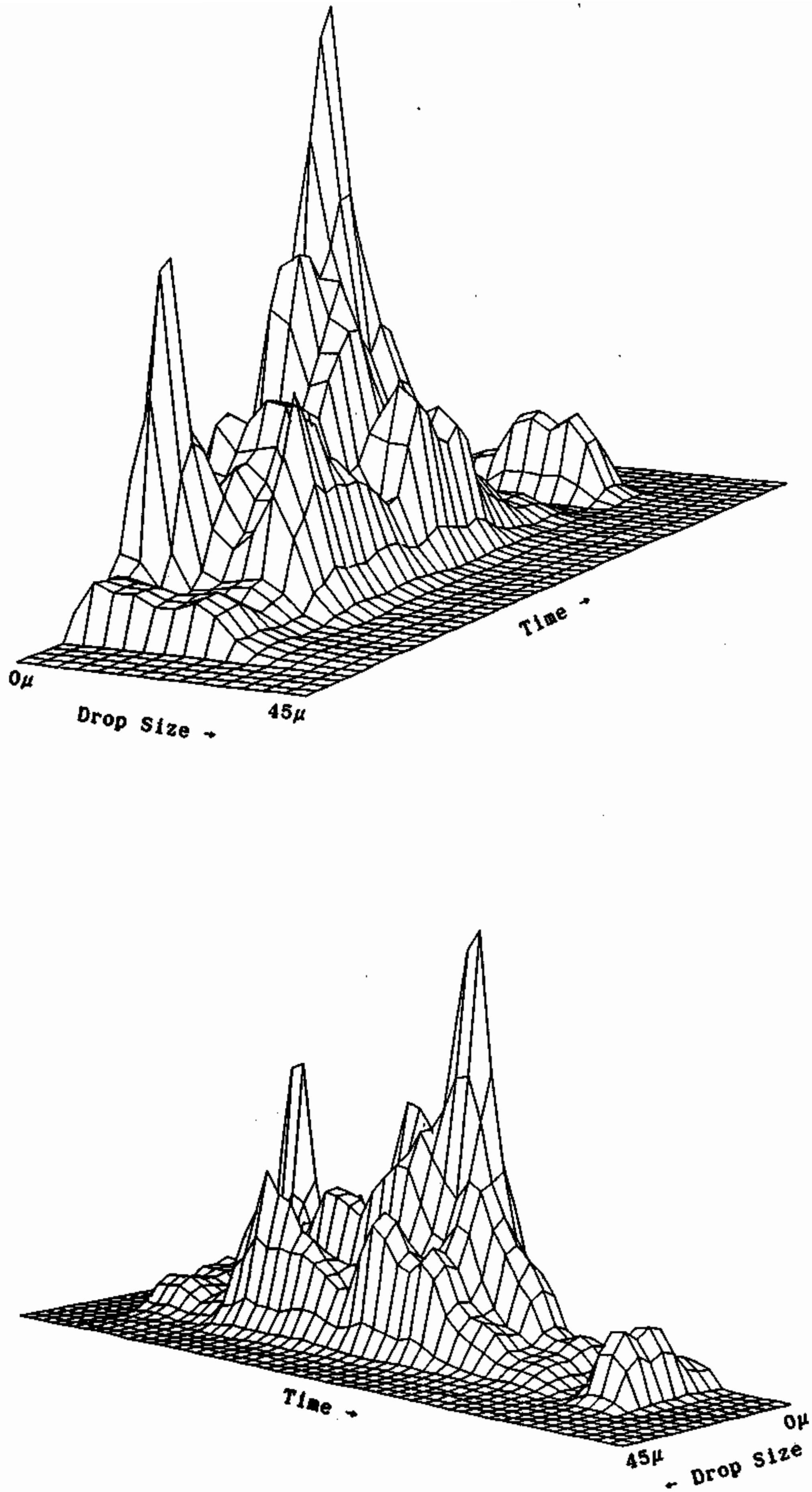


A.5-8 Cloud Droplet Spectrum 708FC4P2

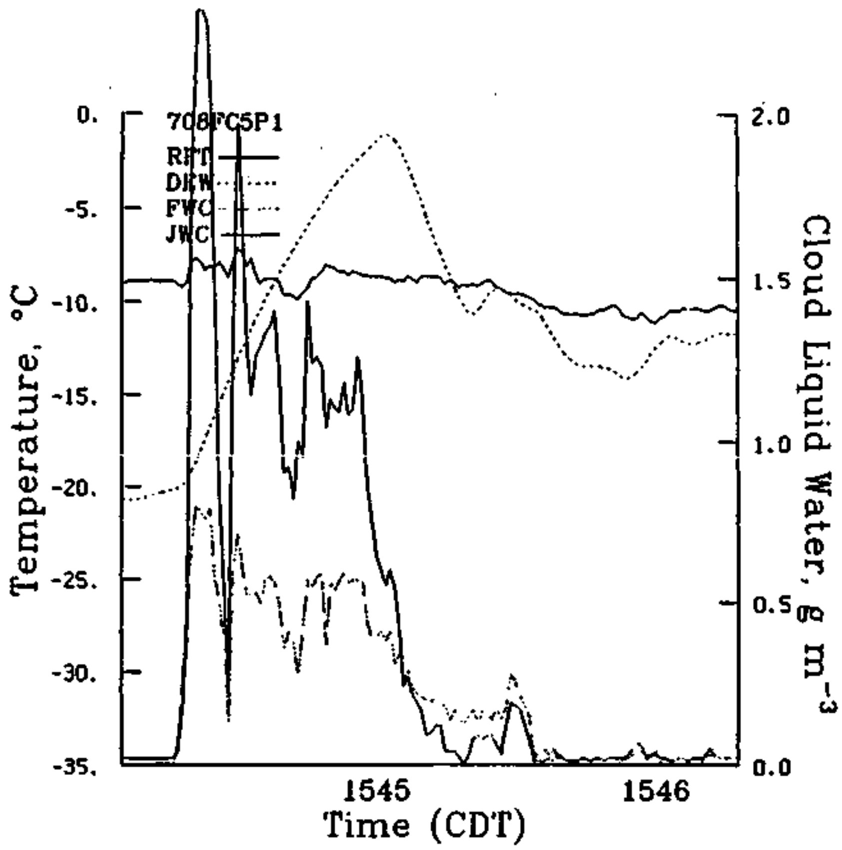


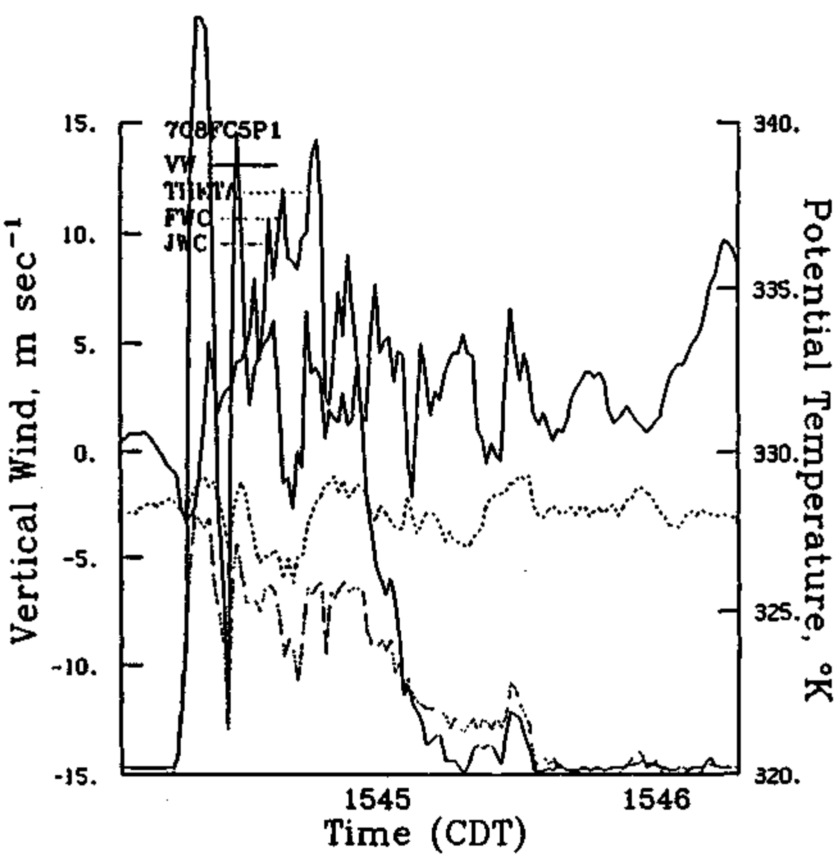


A.5-9 Cloud 708FC3P2

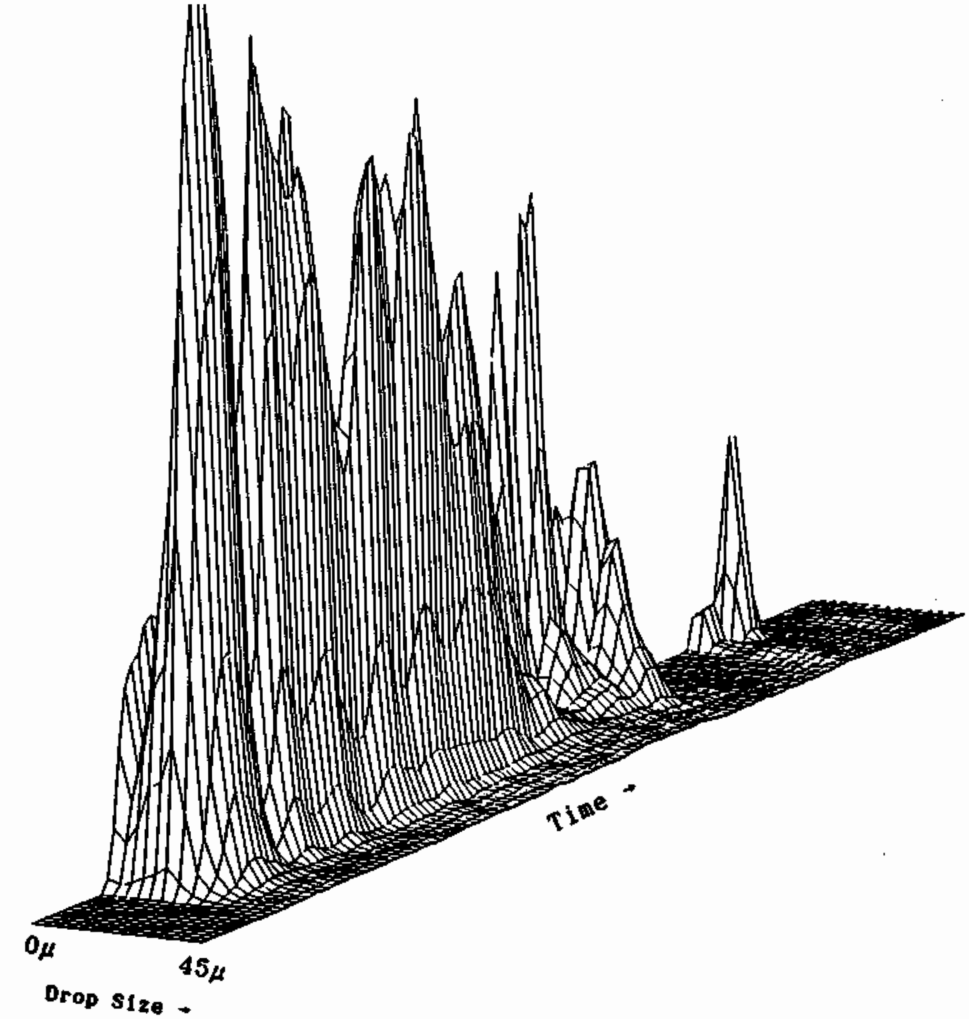


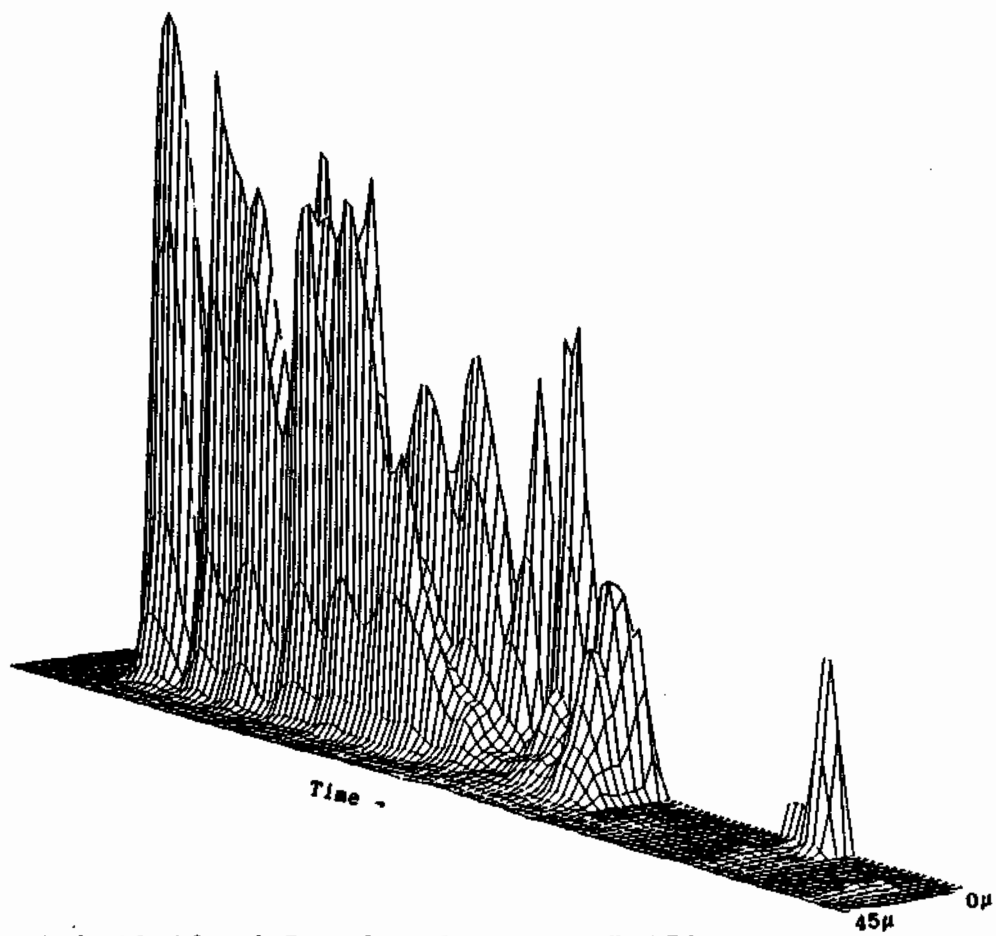
A.5-10 Cloud Droplet Spectrum 708FC3P2



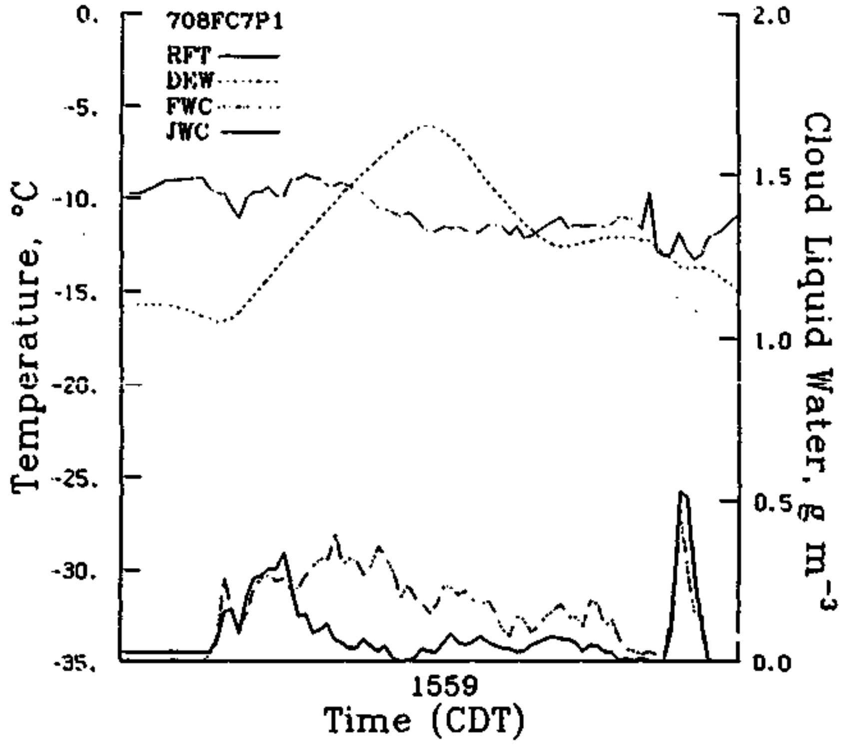


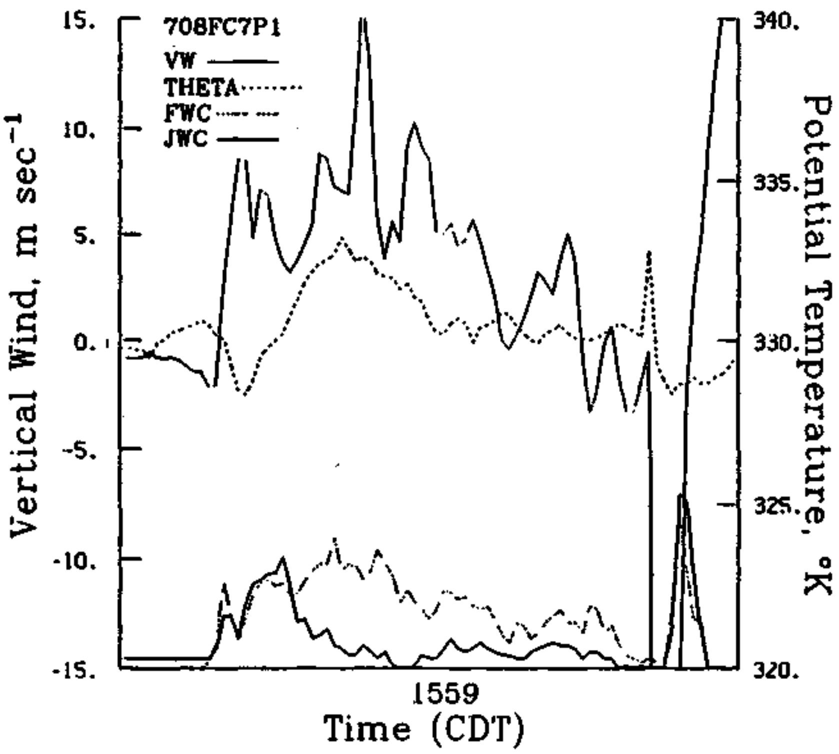
A.5-11 Cloud 708FC5P1



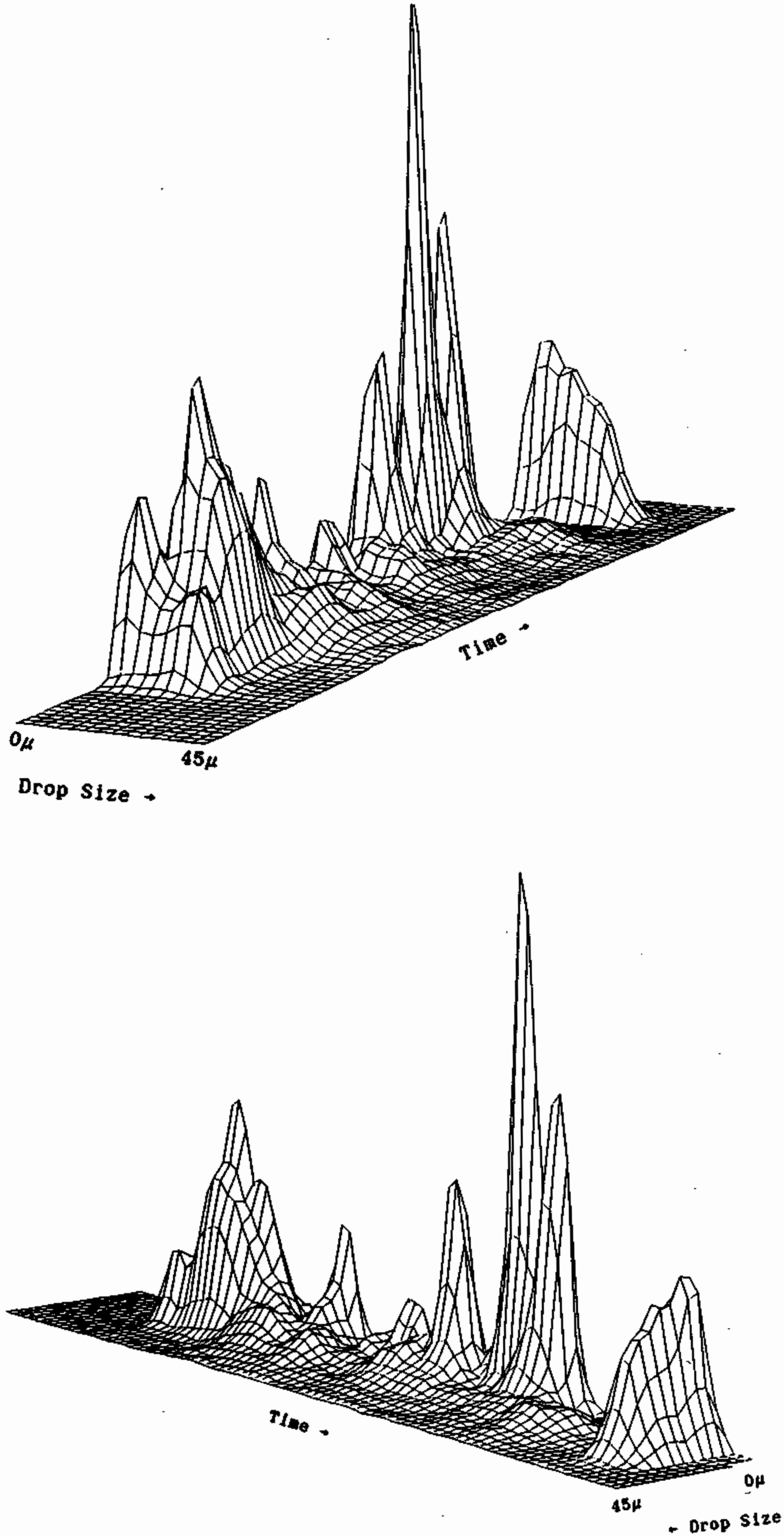


A.5-12 Cloud Droplet Spectrum 708FC5P1





A.5-13 Cloud 708FC7P1



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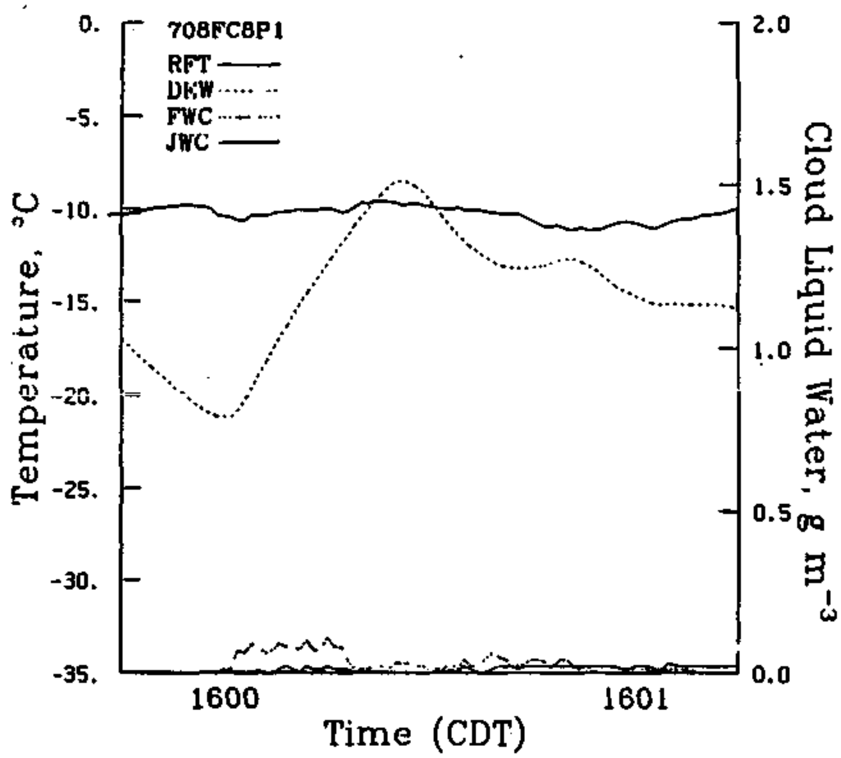
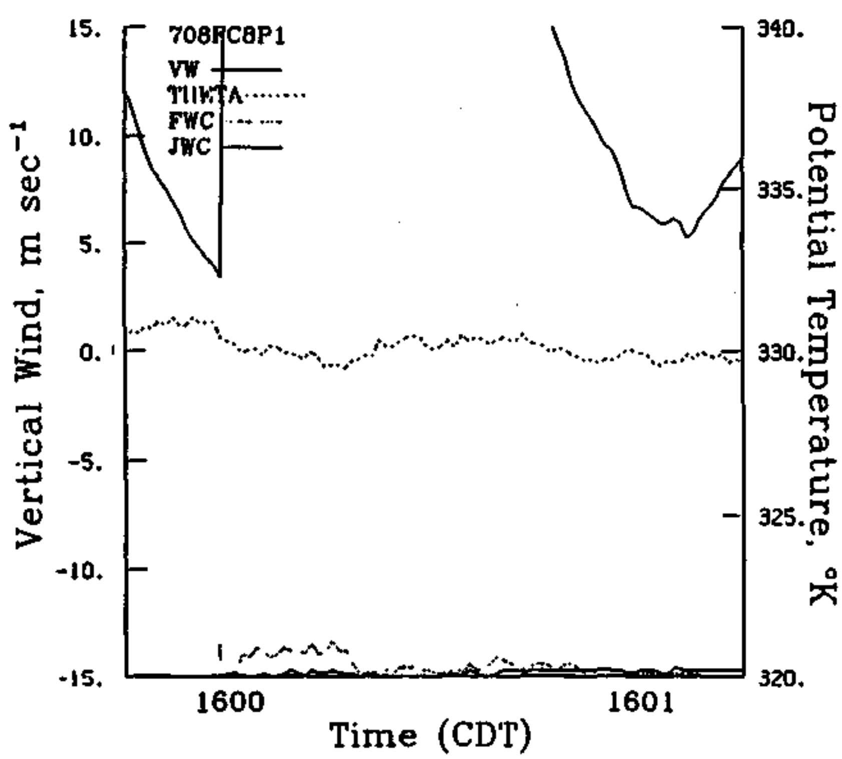
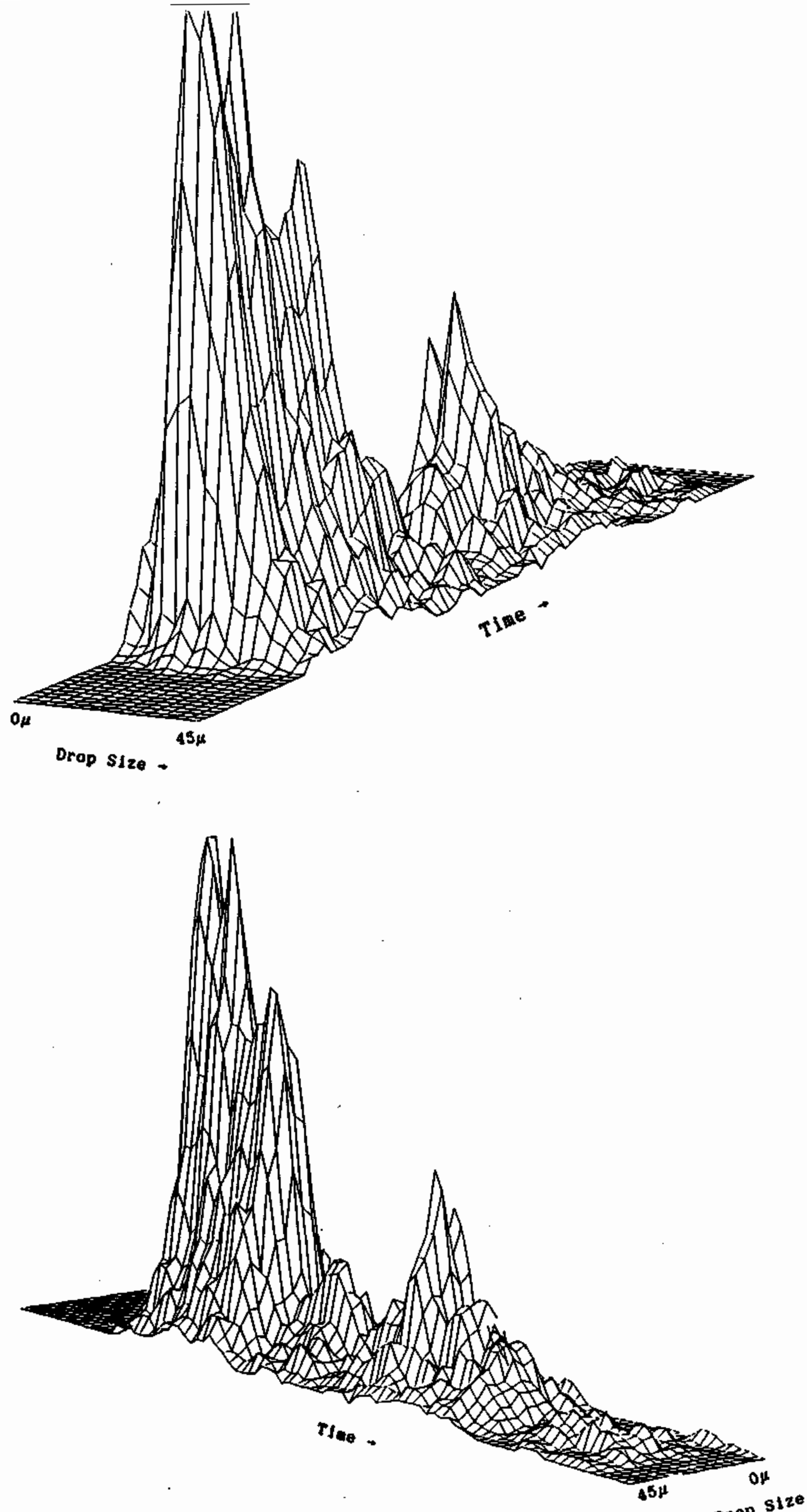
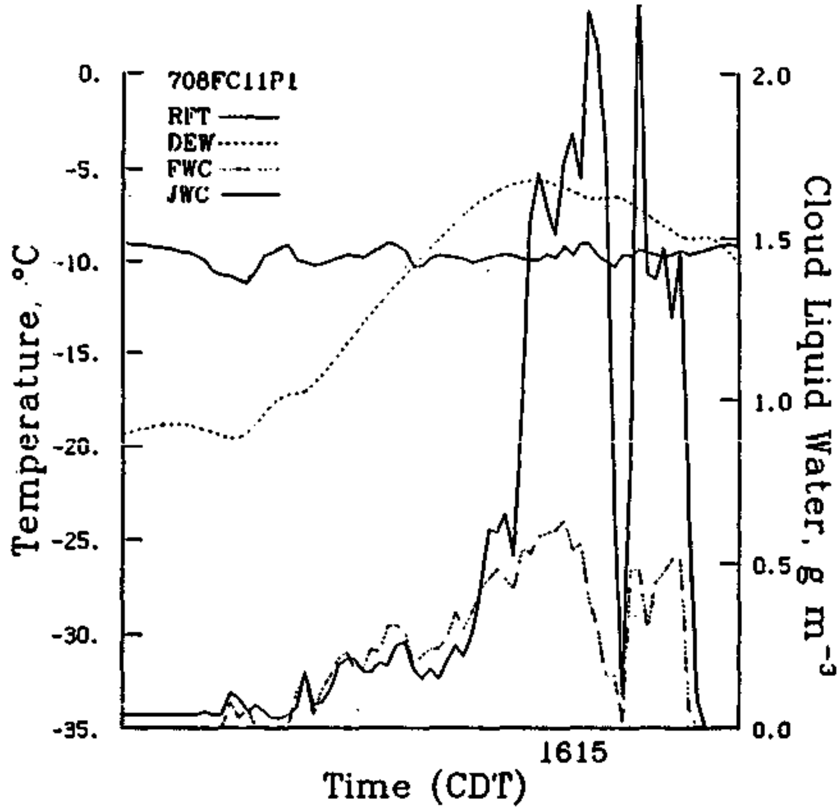


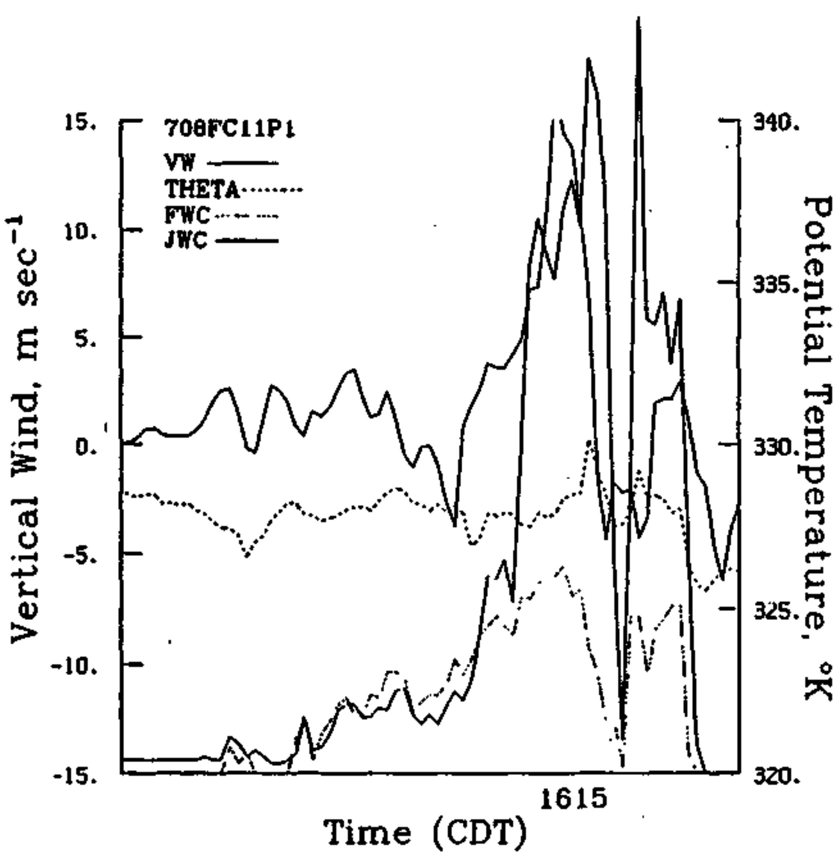


A. 5-15 Cloud 708FC8P1

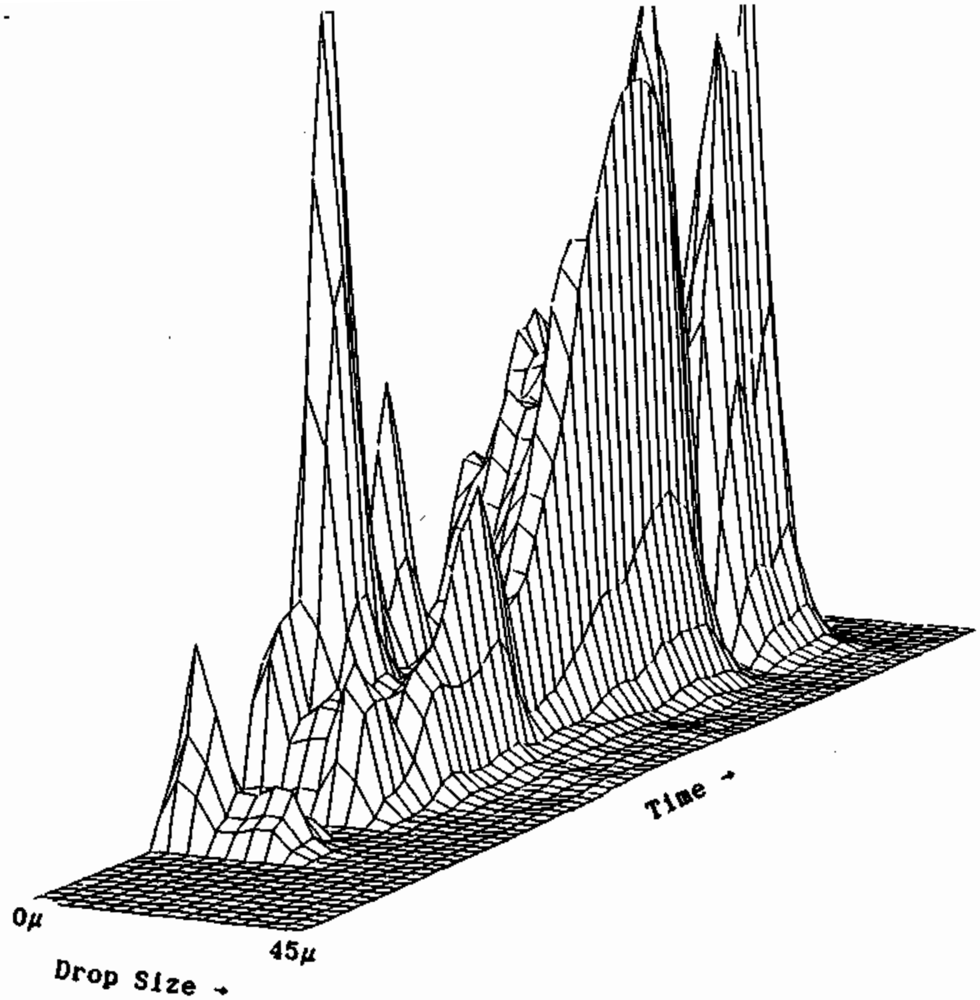


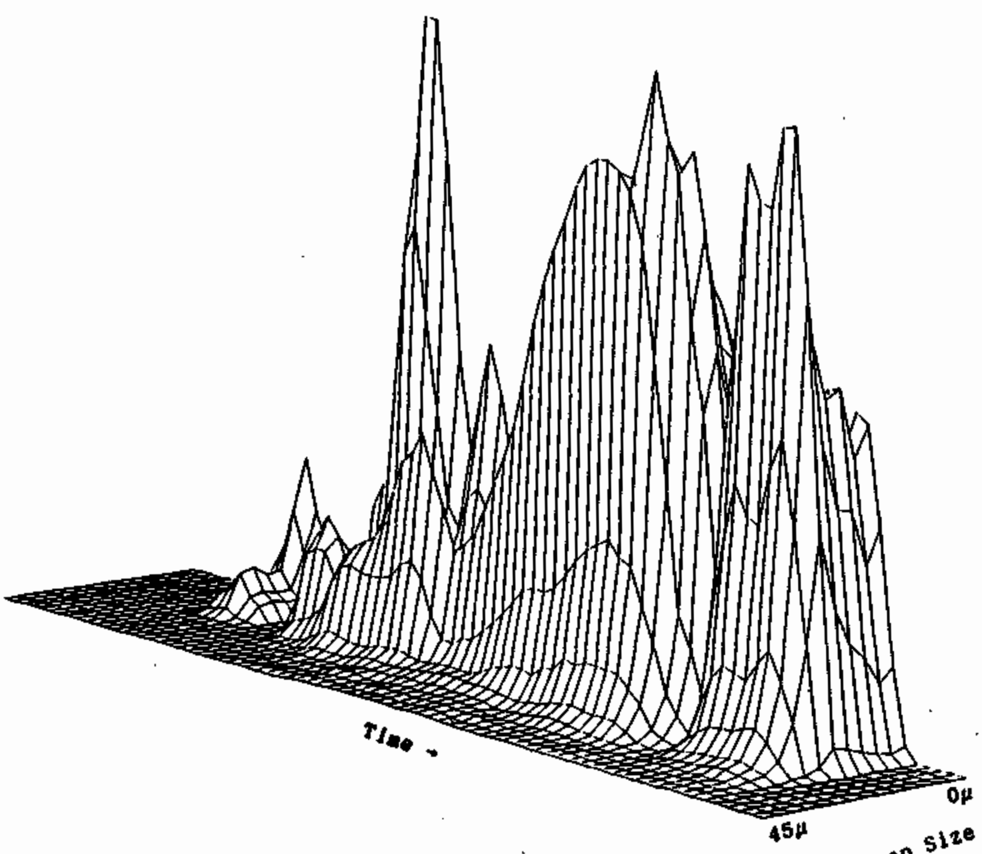
A.5-16 Cloud Droplet Spectrum 708FC8P1



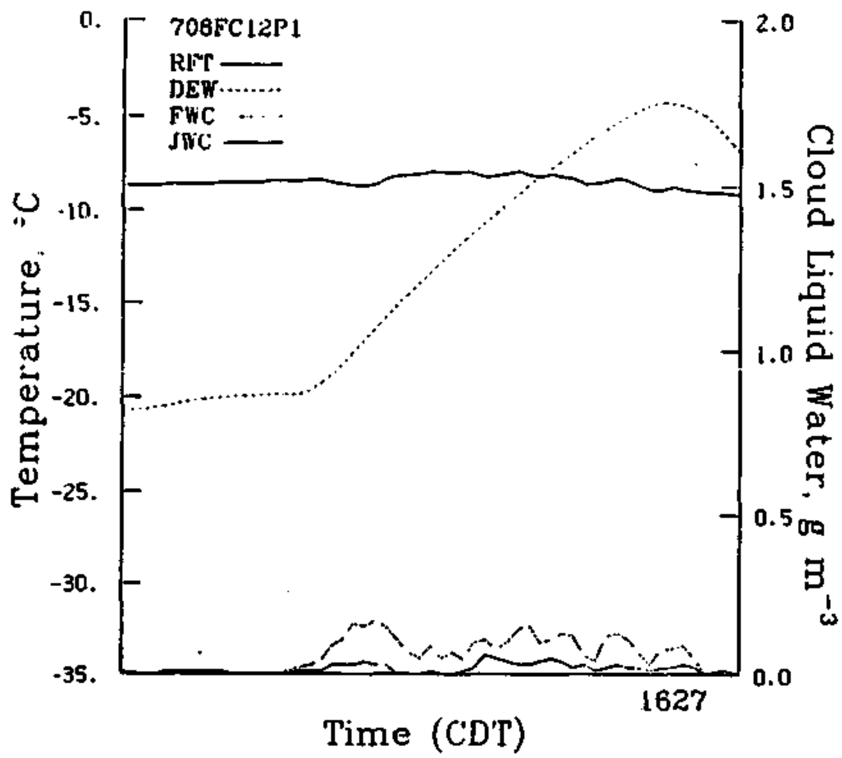


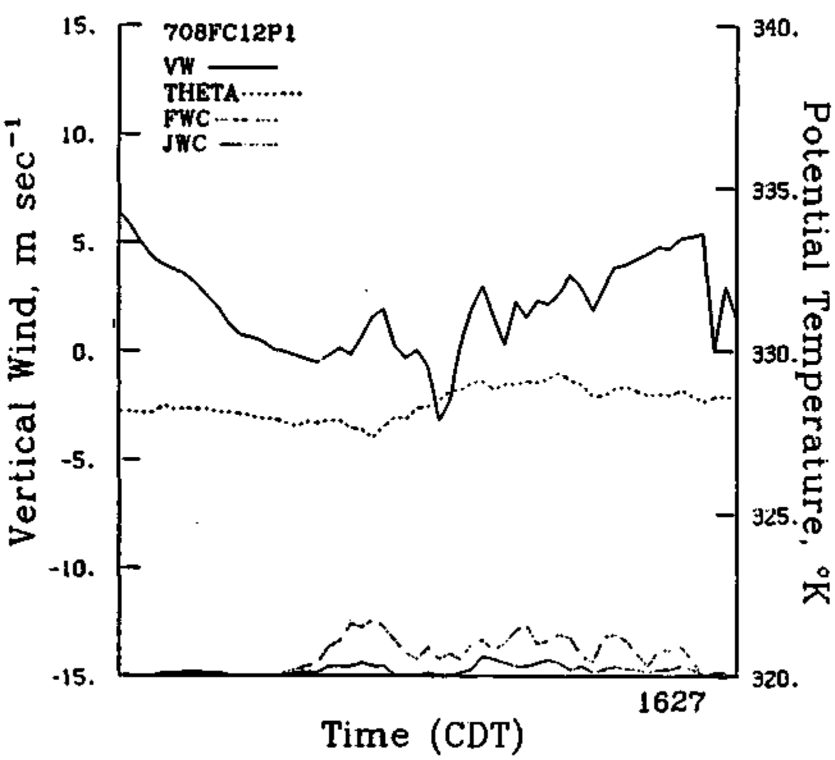
A. 5-17 Cloud 708PC11P1



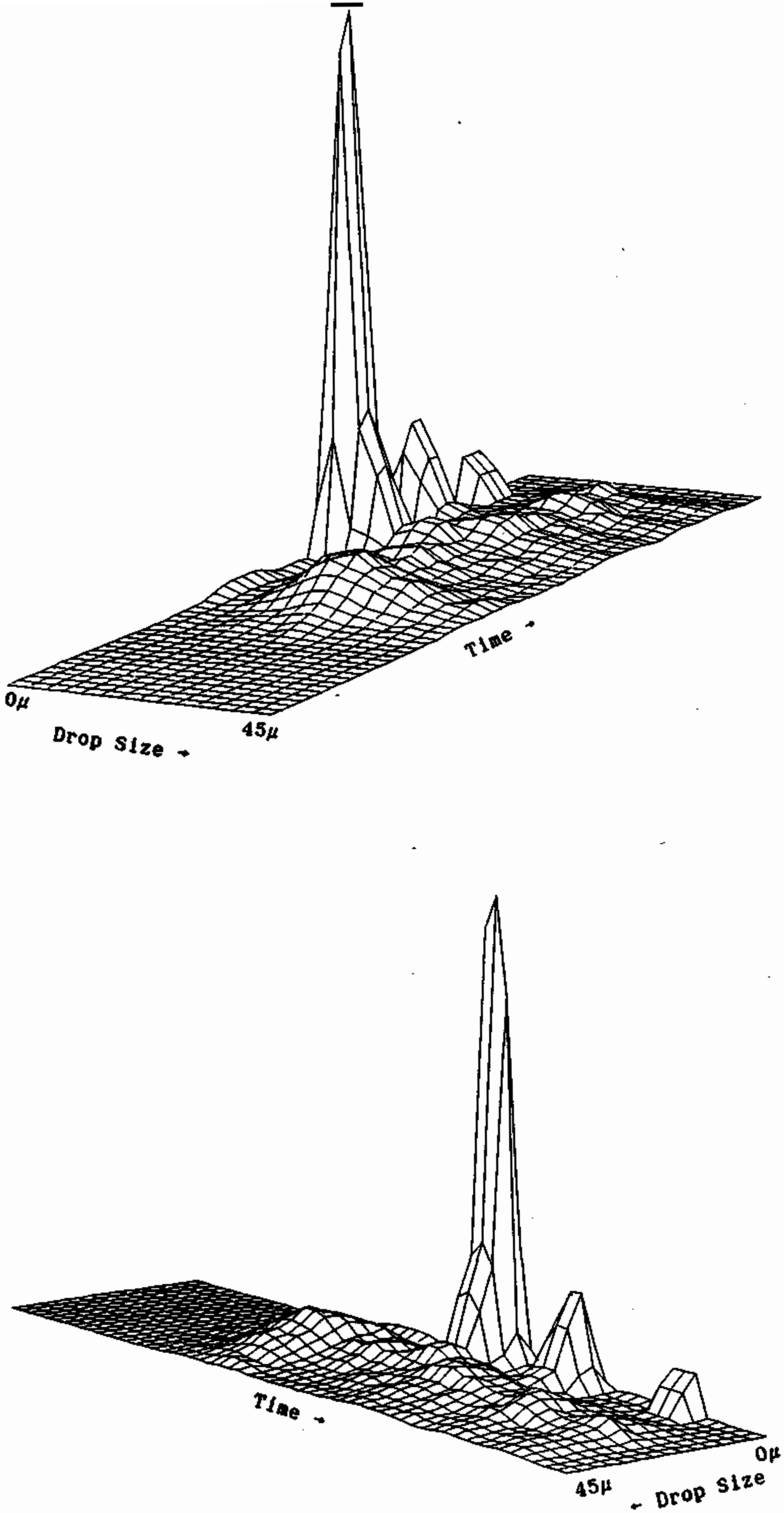


A.5-18 Cloud Droplet Spectrum 708FC11P1





A.5-19 Cloud 708FC12P1



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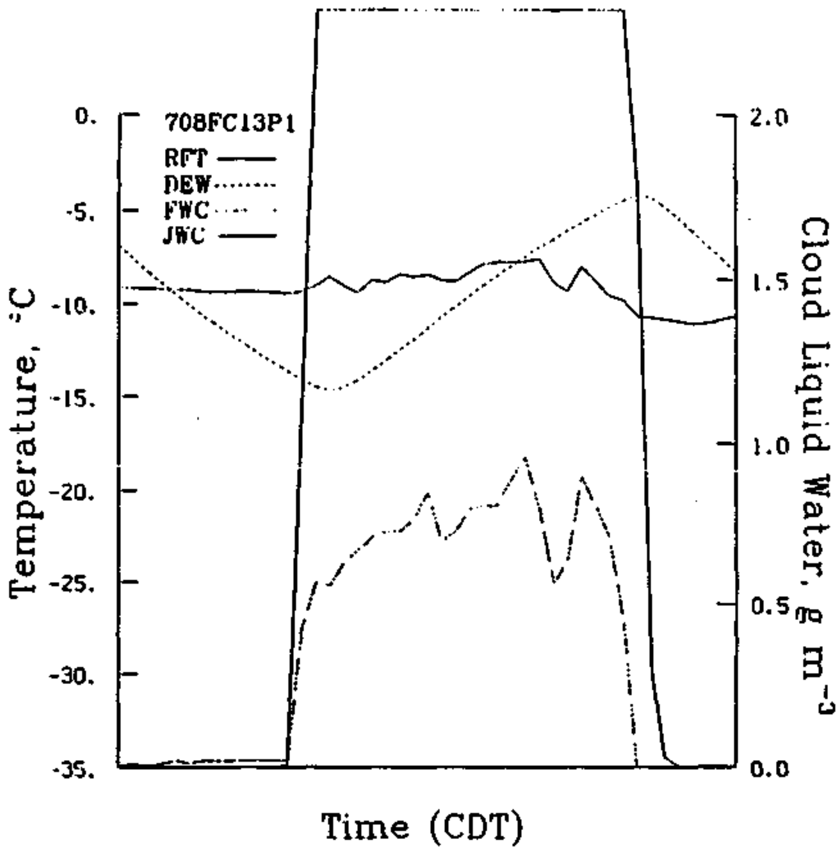
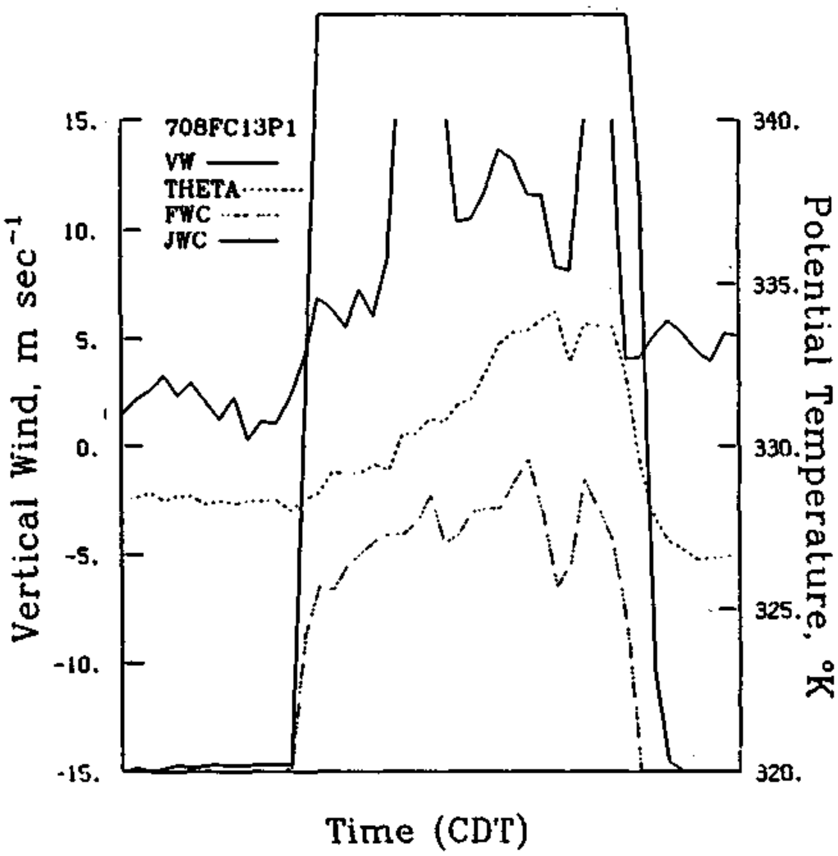
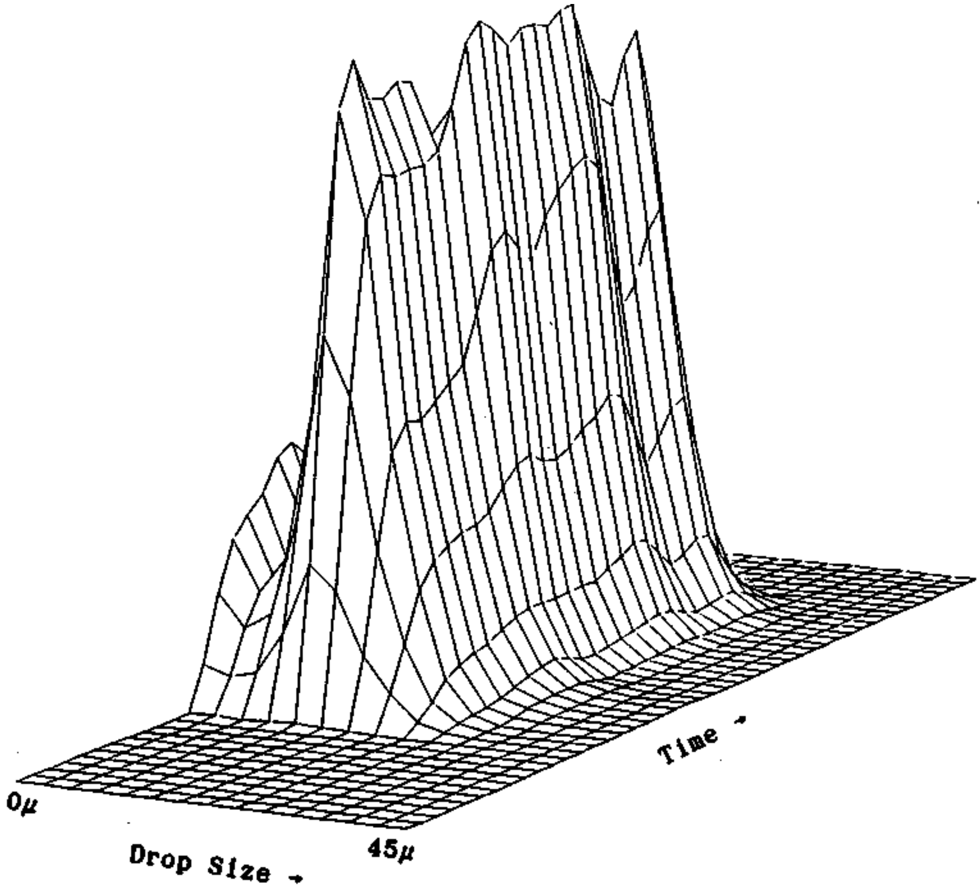
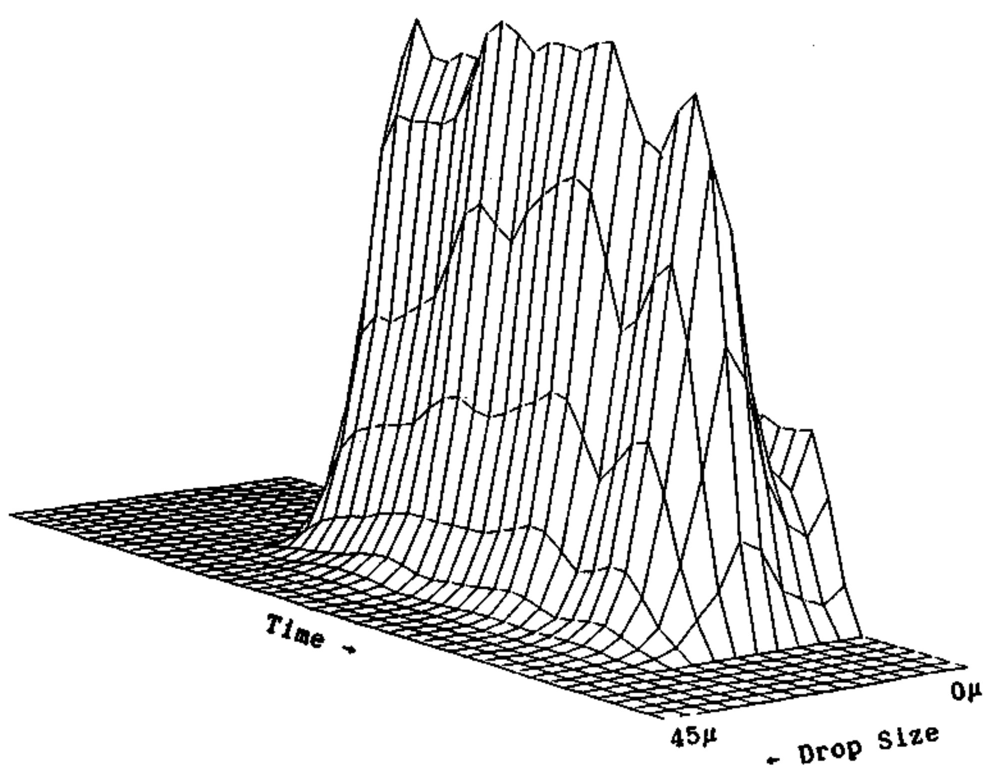




A.5–21 Cloud 708PC13P1





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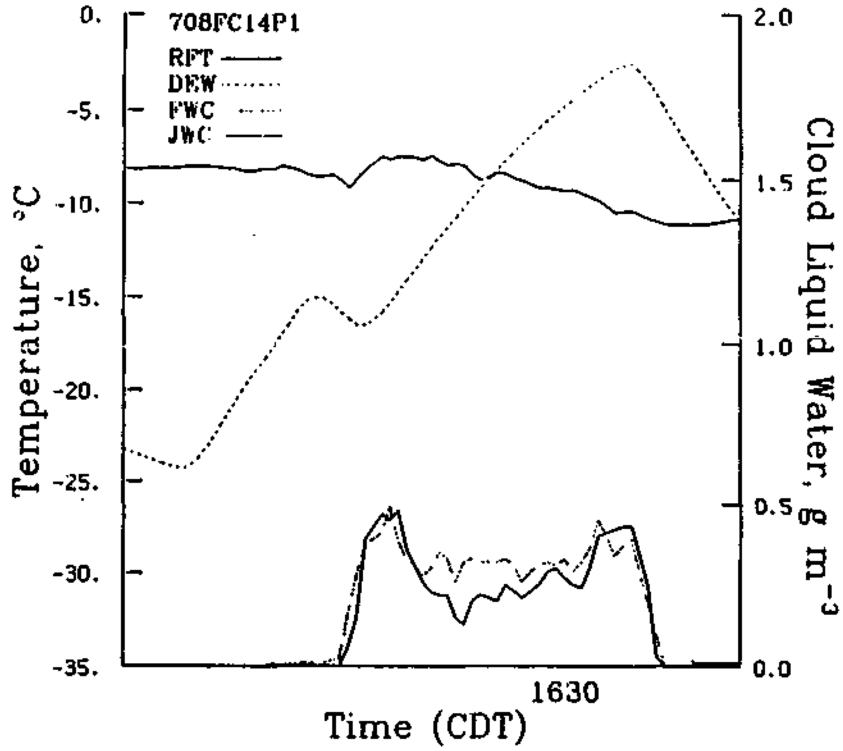

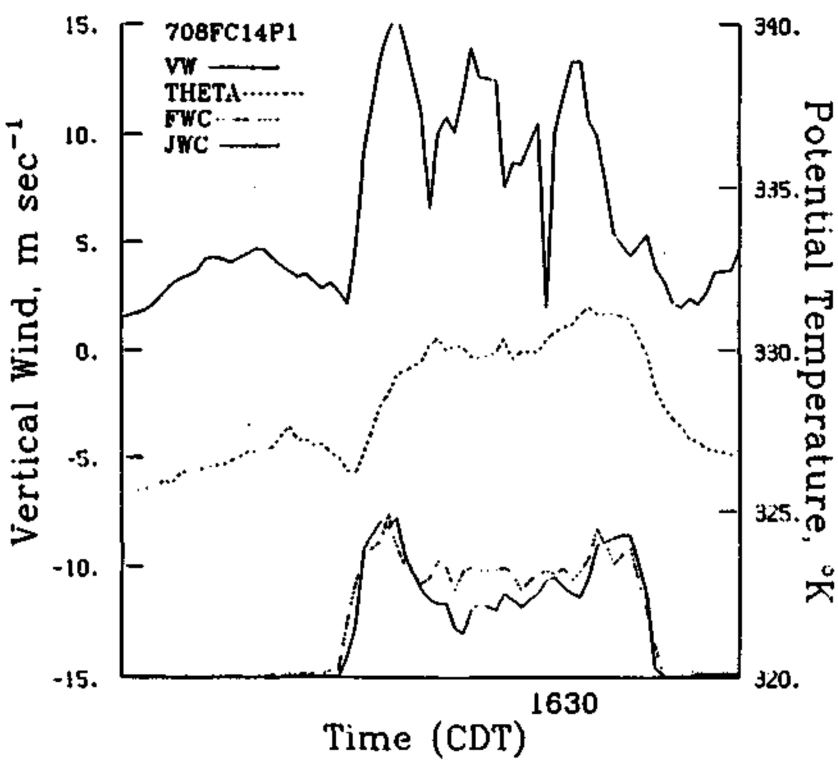

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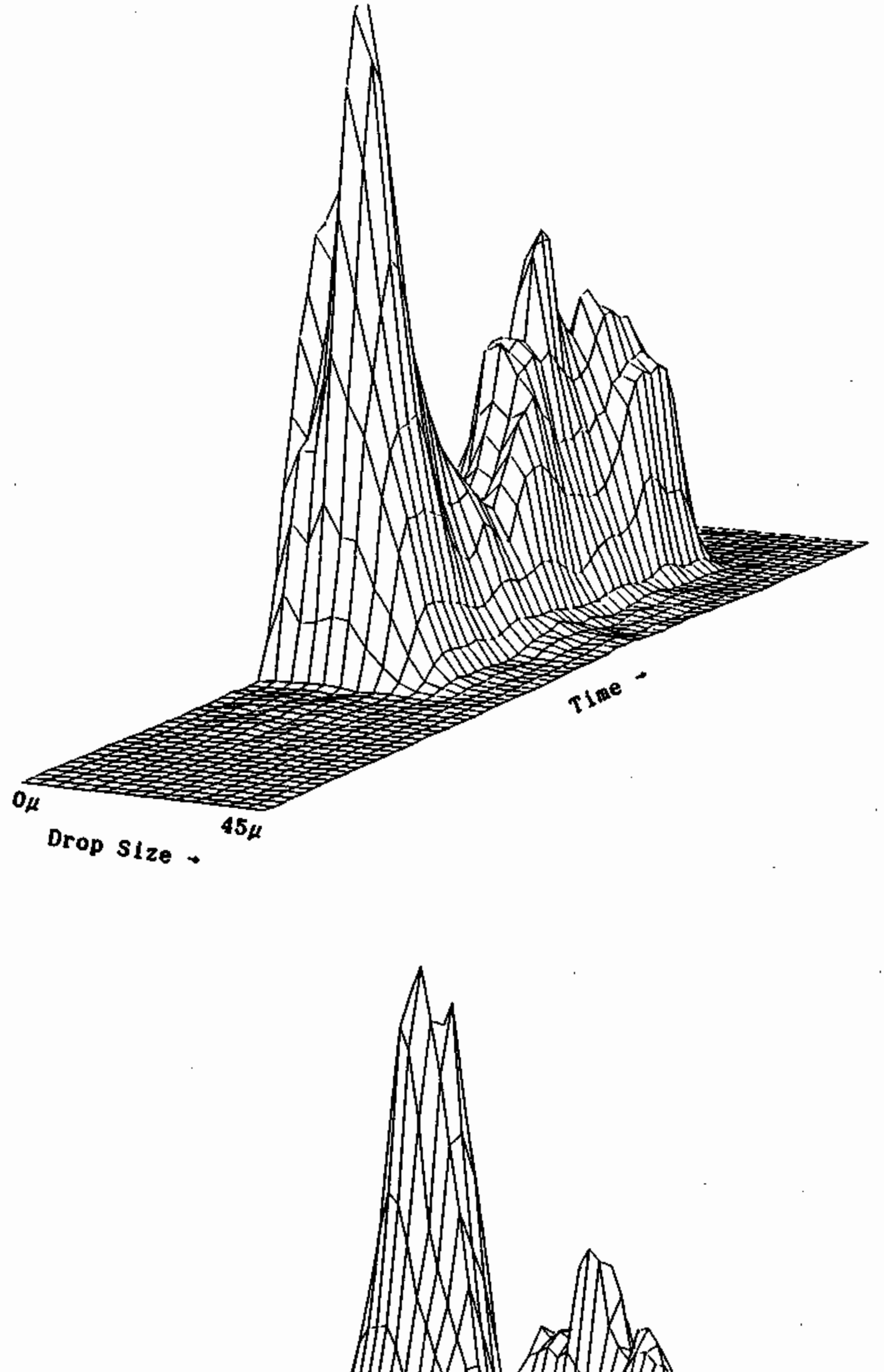

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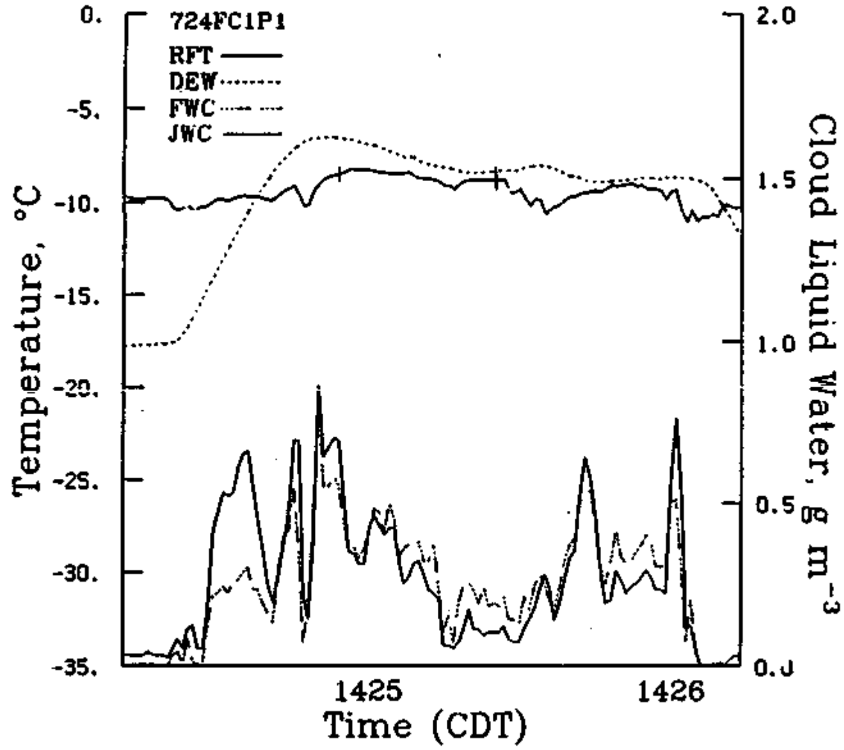
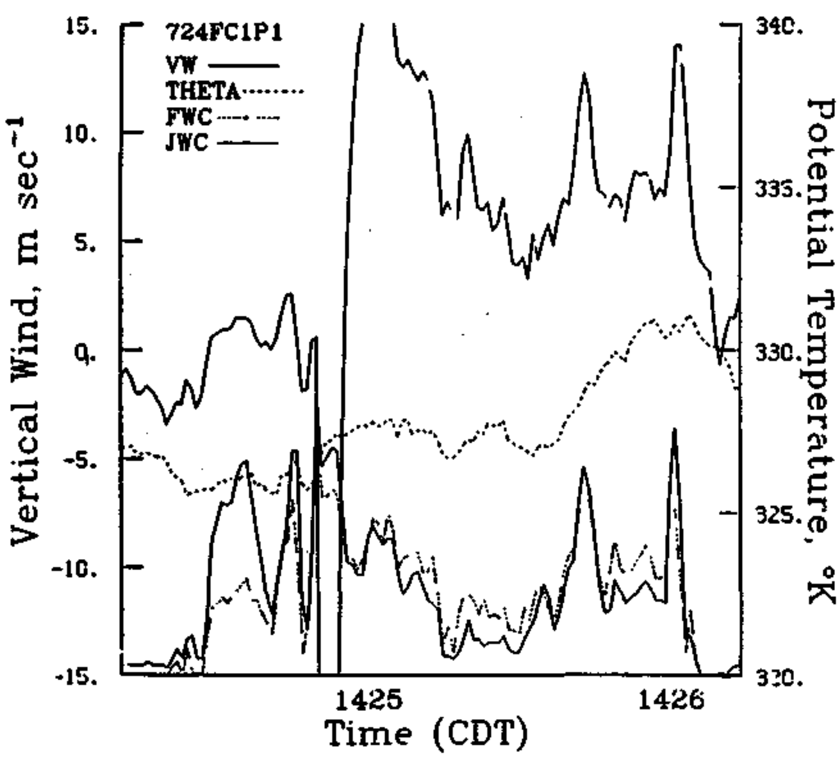
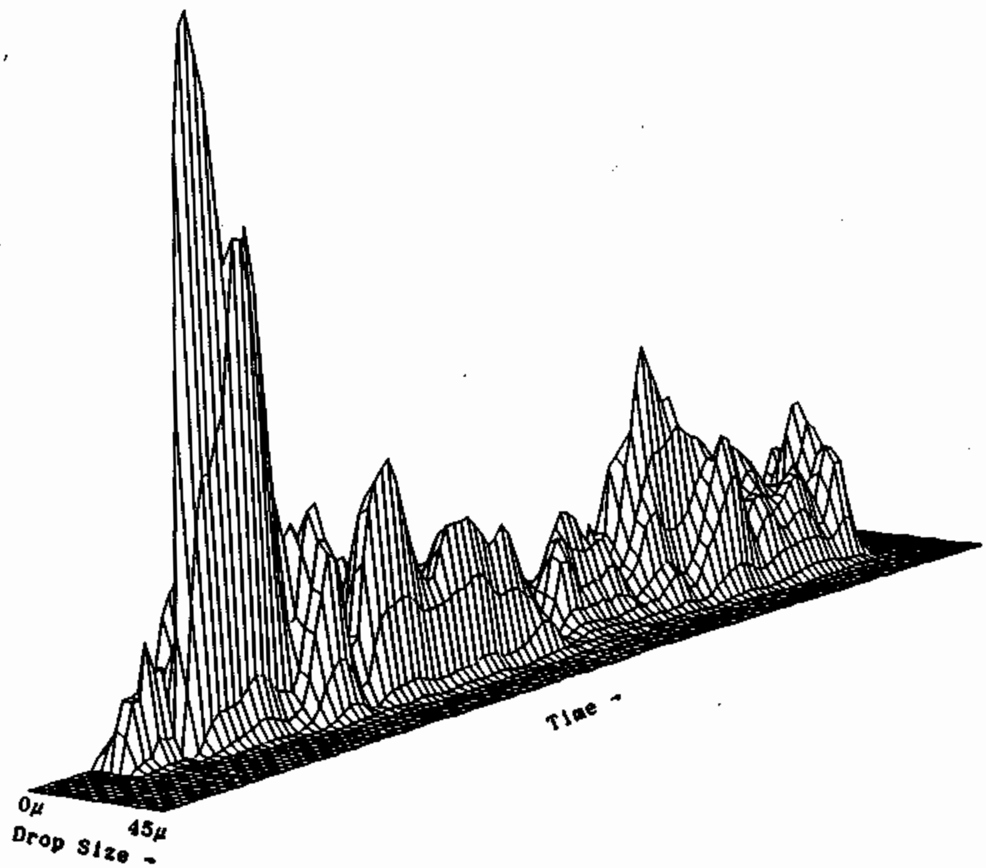
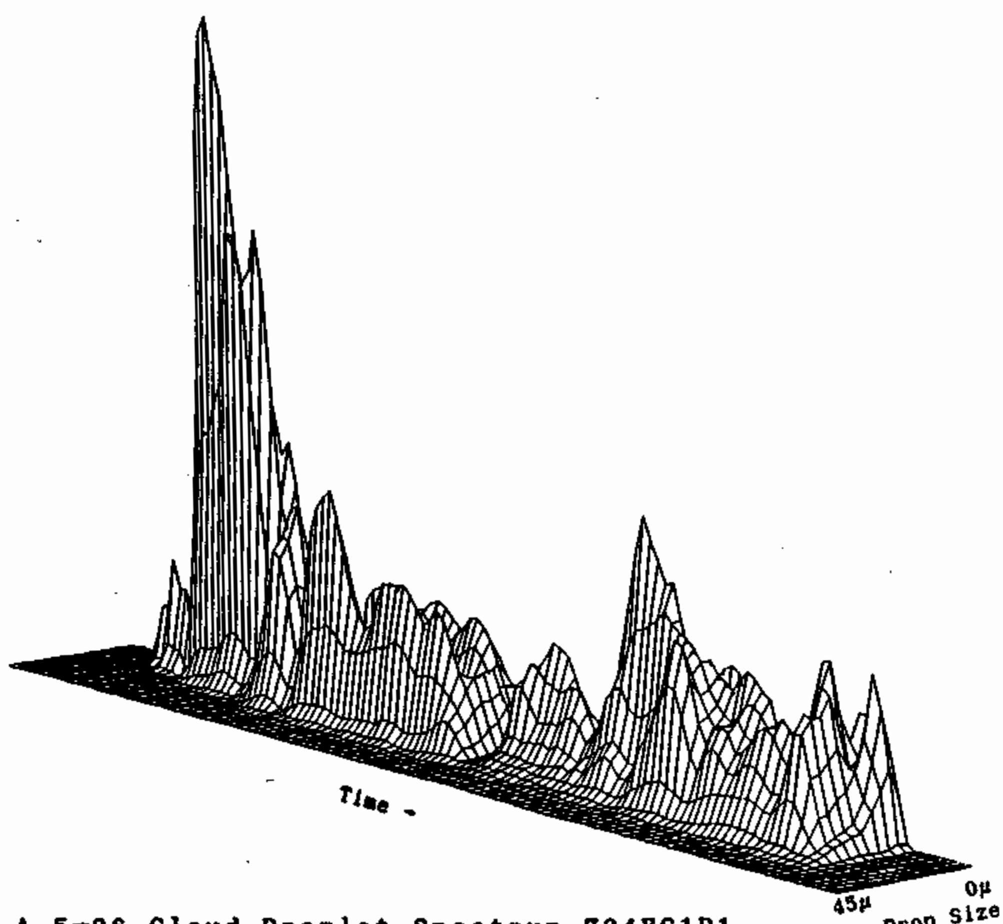




A.5-25 Cloud 724FC1P1





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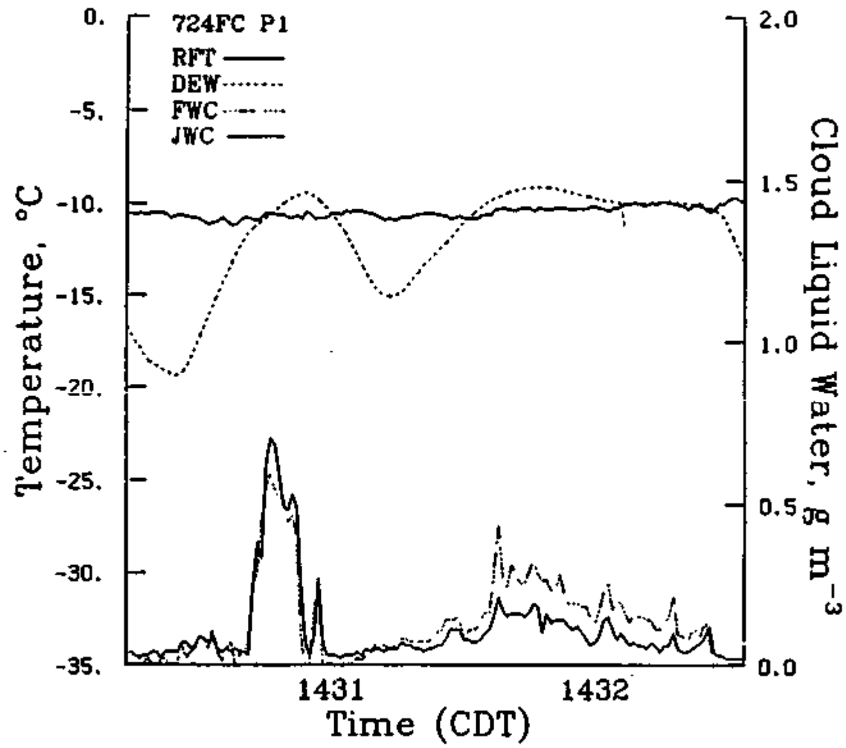
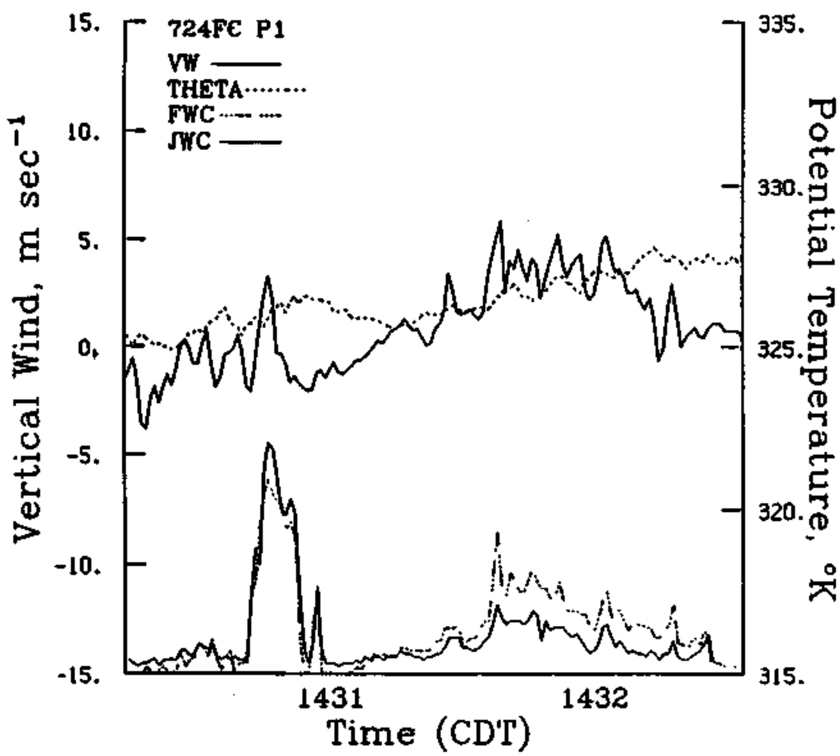
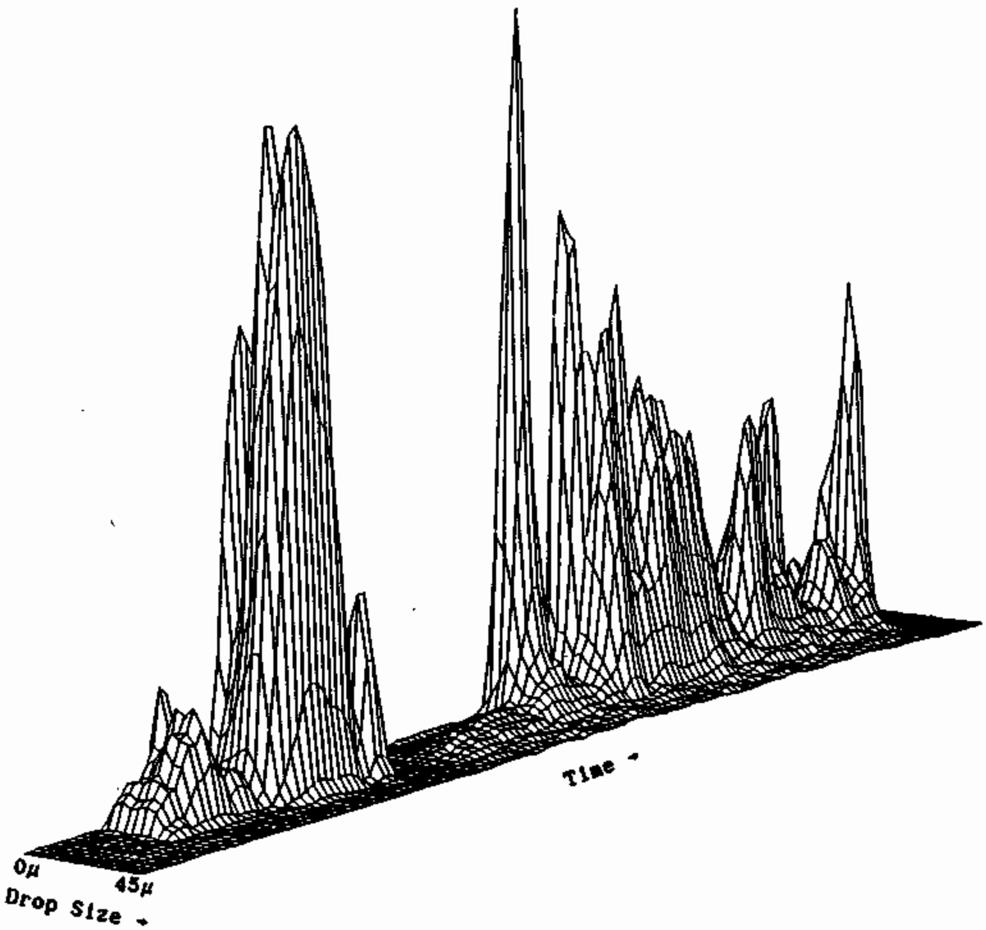
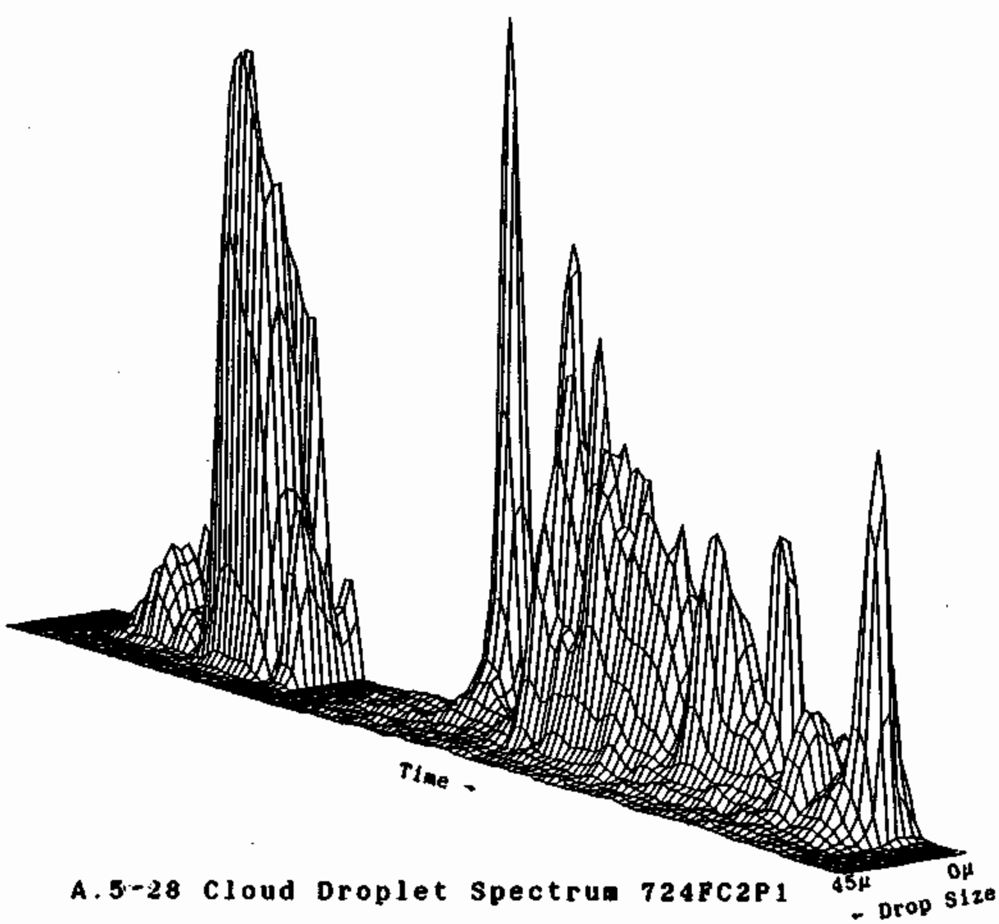




A. 5-27 Cloud 724FC2P1





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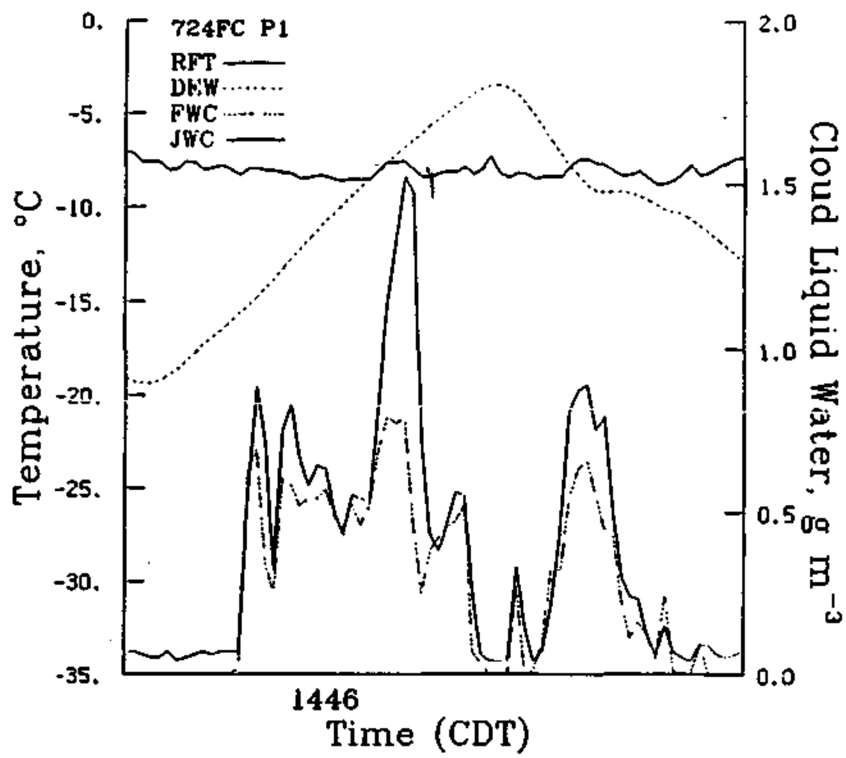
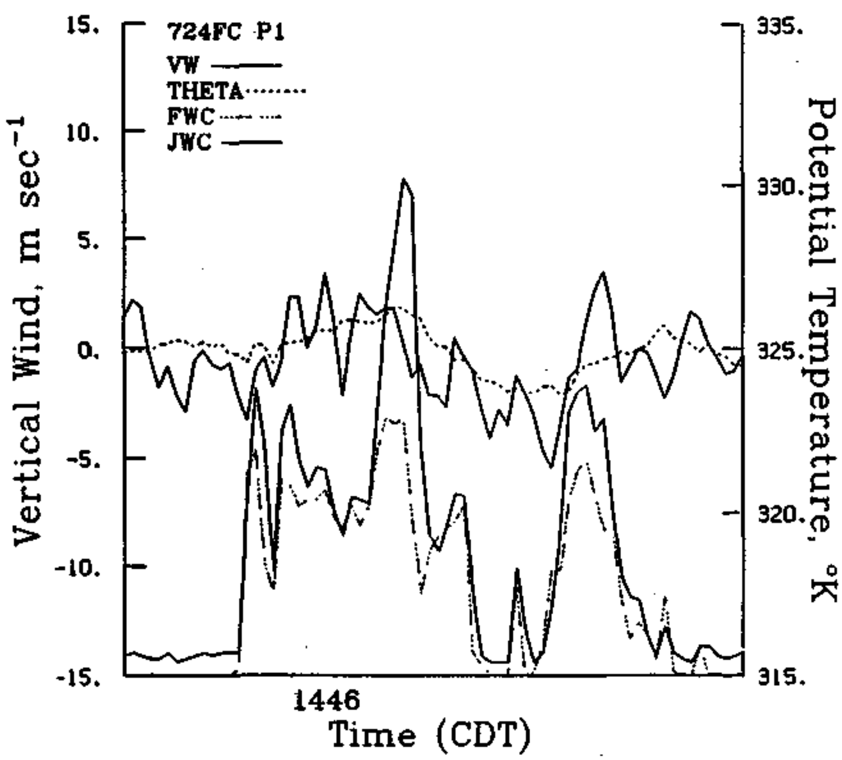
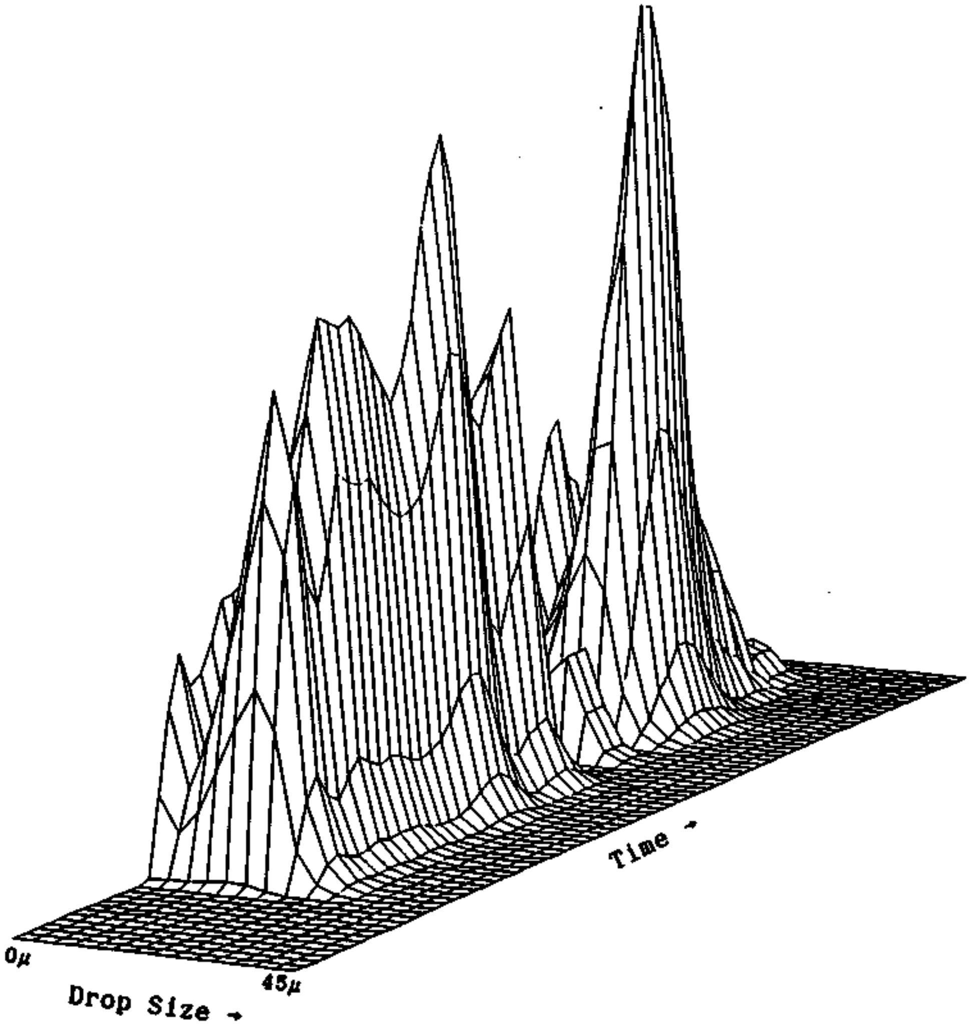
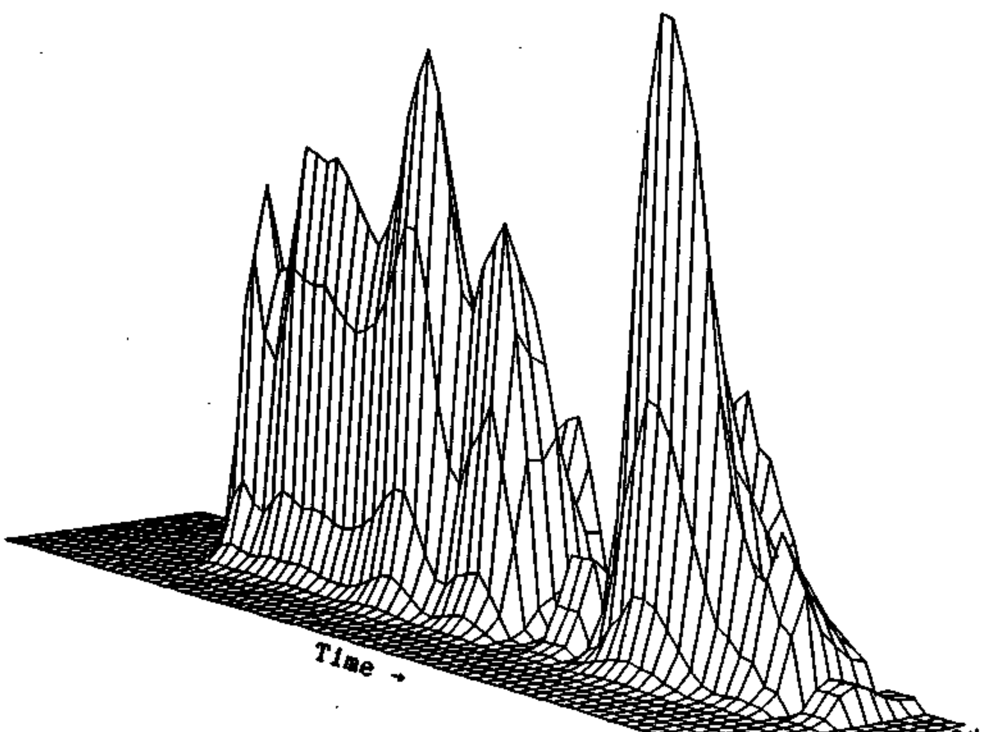


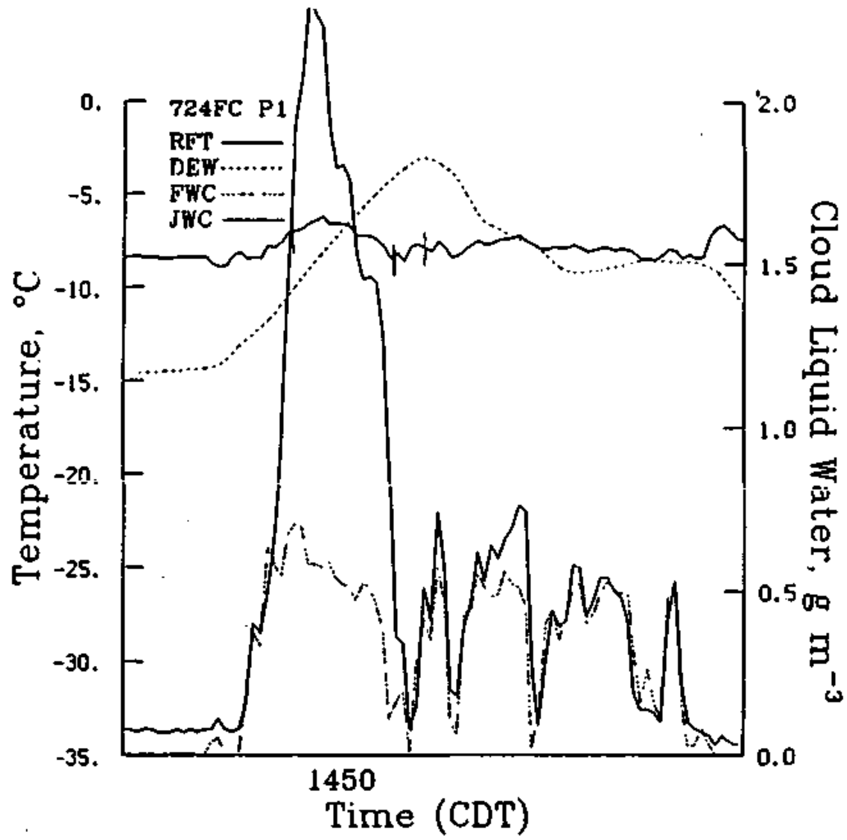


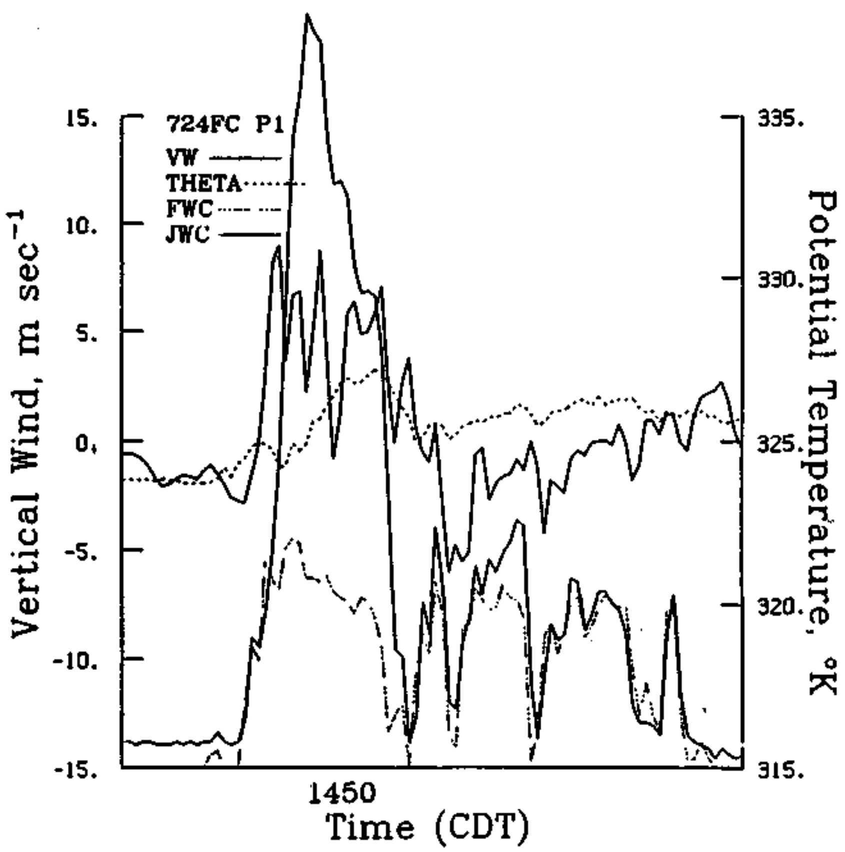
A. 5-29 Cloud 724FC3P1



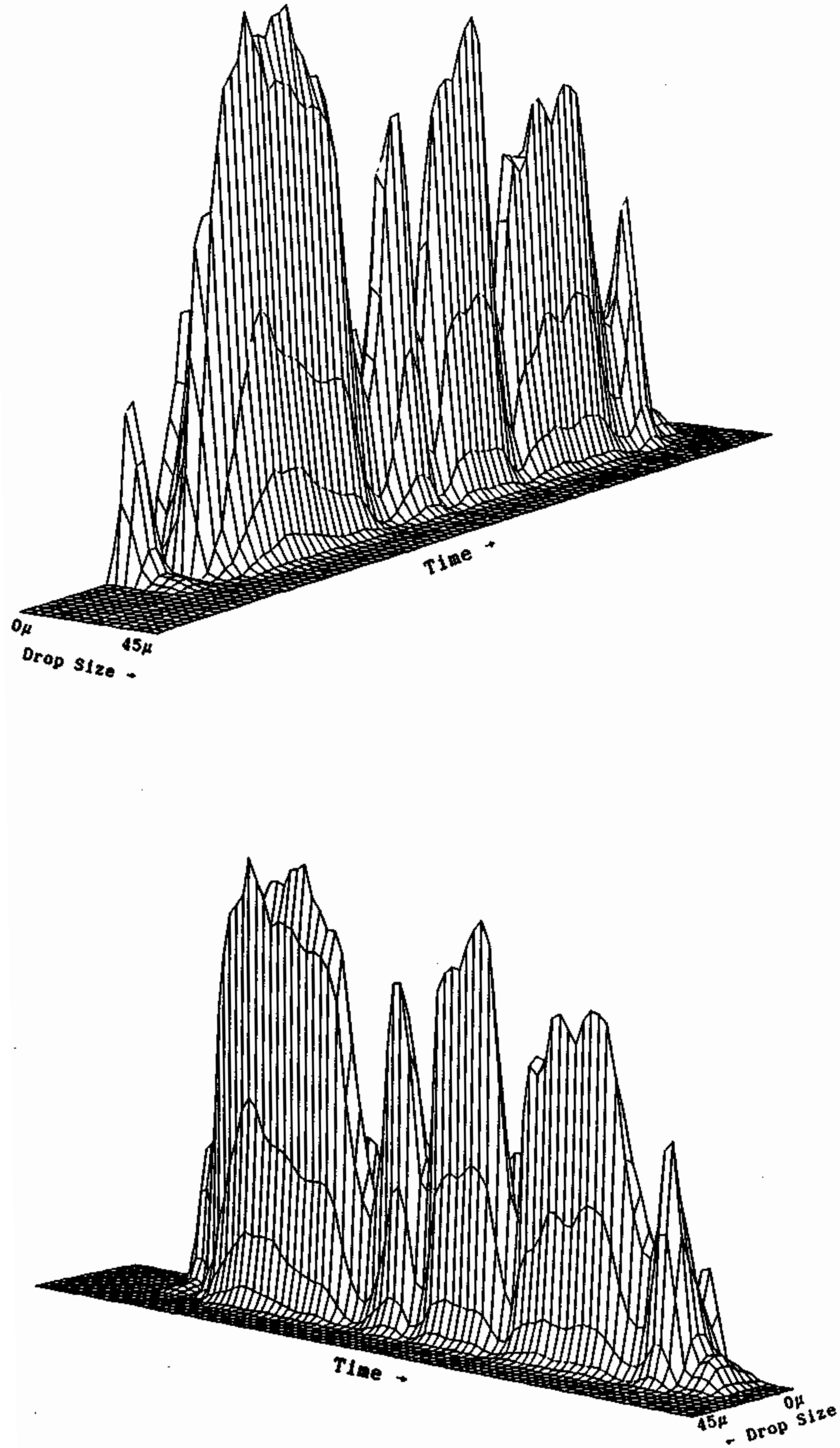


A.5-30 Cloud Droplet Spectrum 724FC3P1

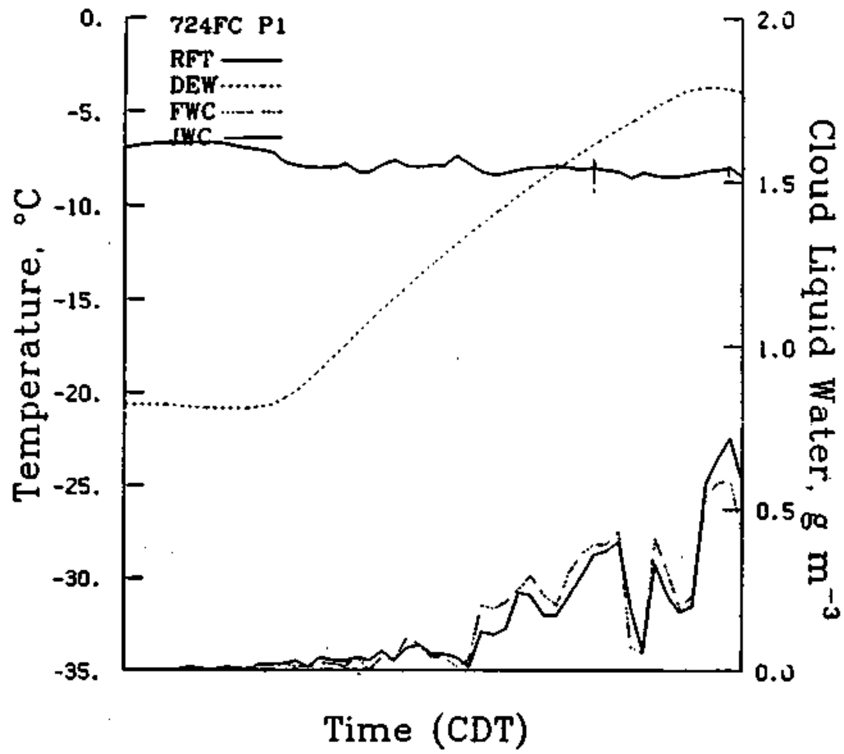


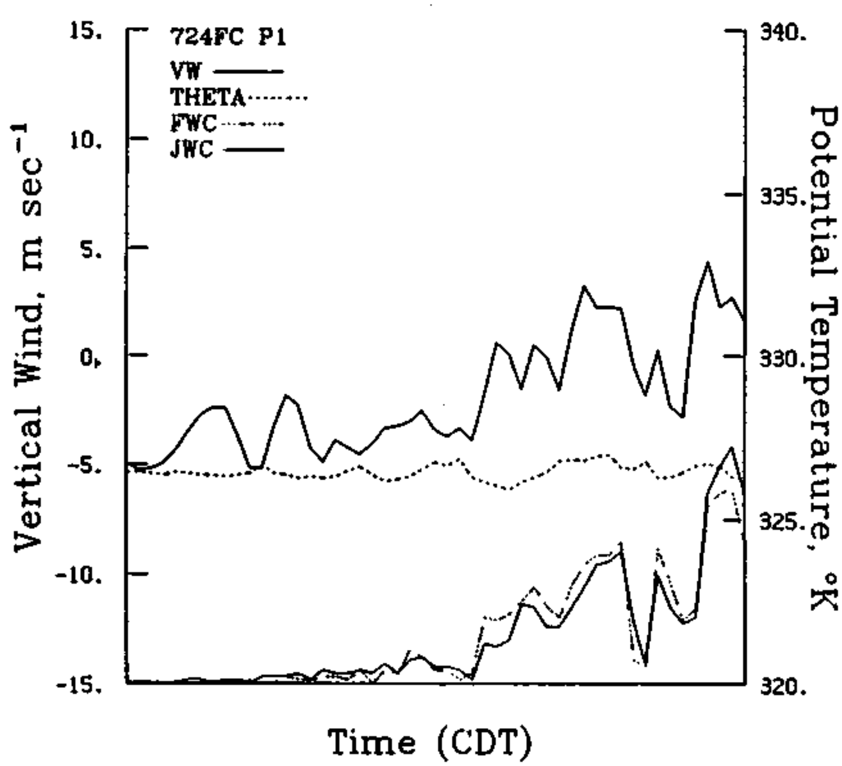


A.5-31 Cloud 724FC4P1

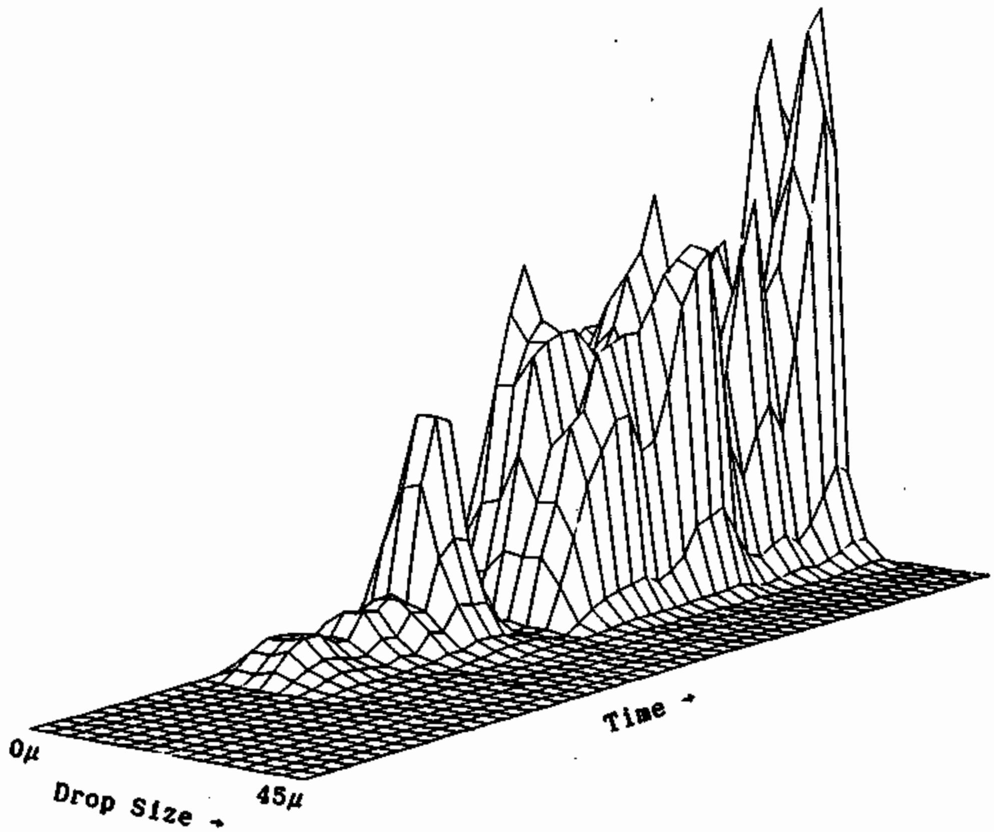


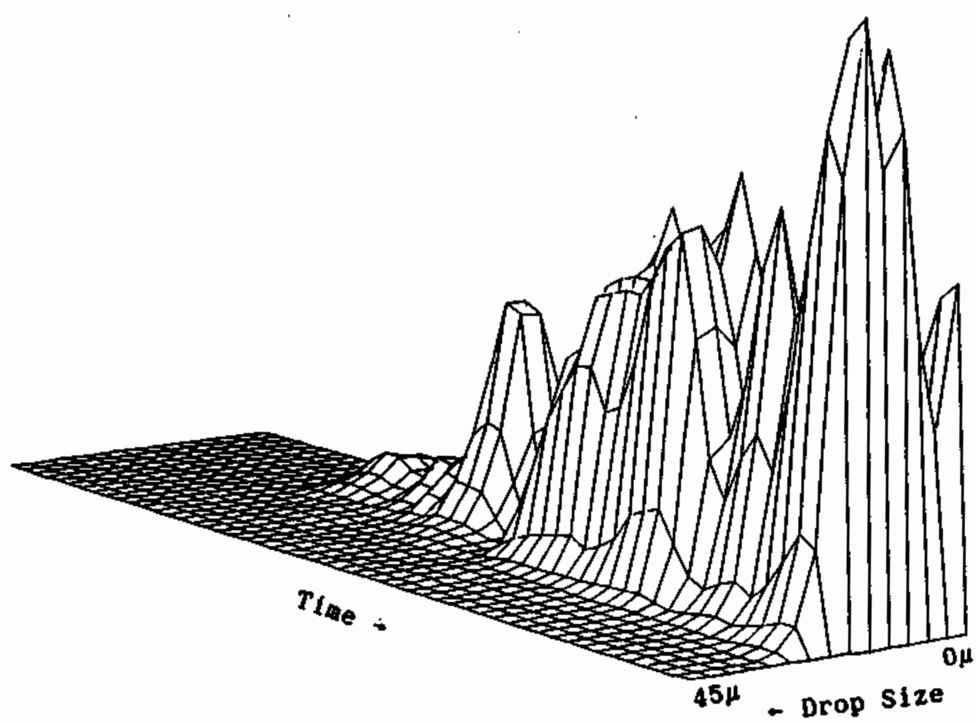
A.5-32 Cloud Droplet Spectrum 724FC4P1



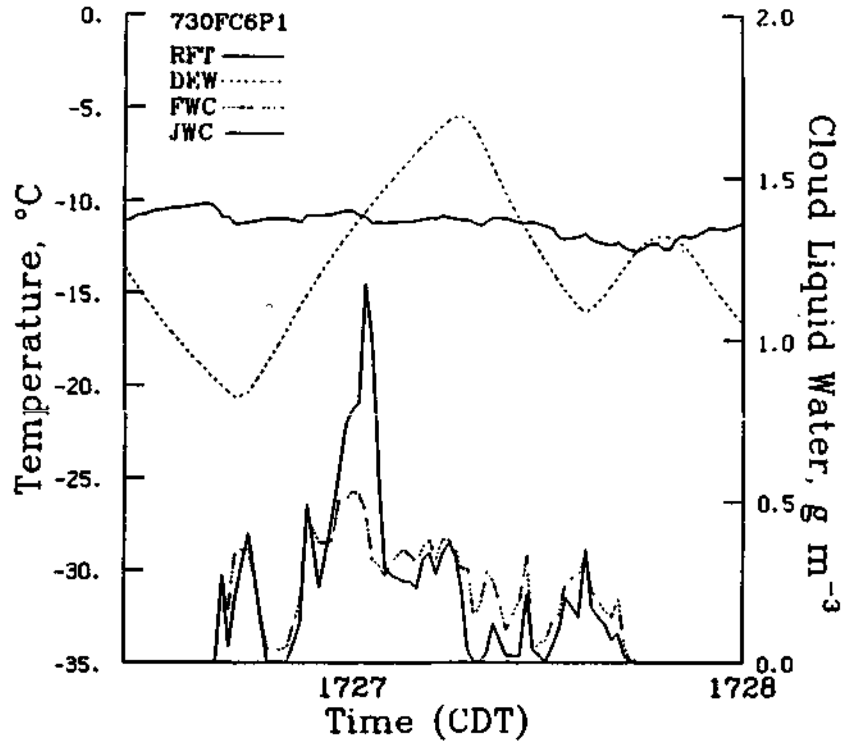


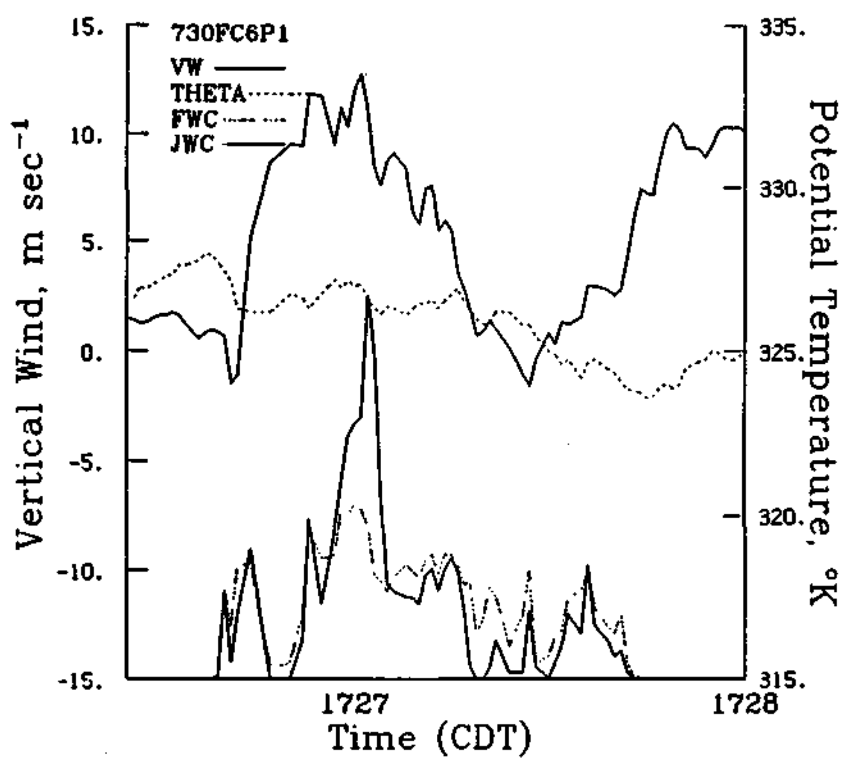
A.5-33 Cloud 724FC5P1



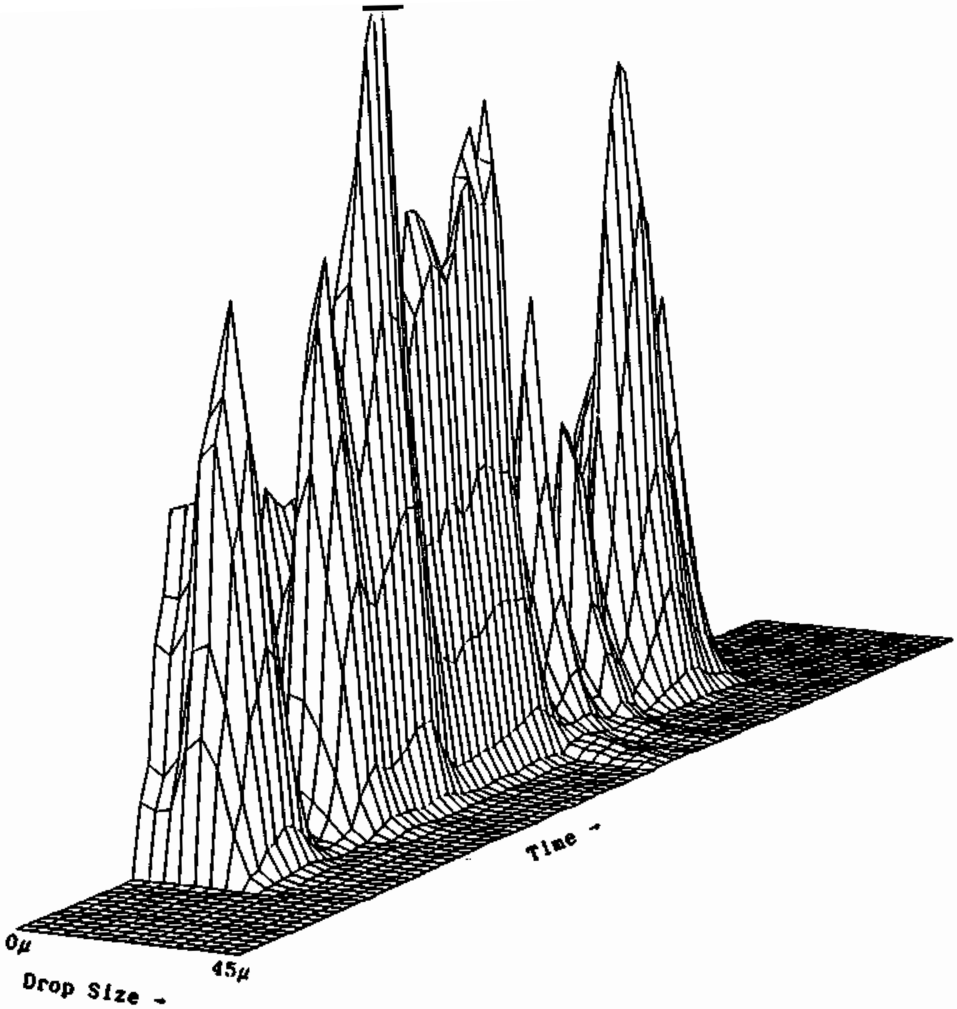


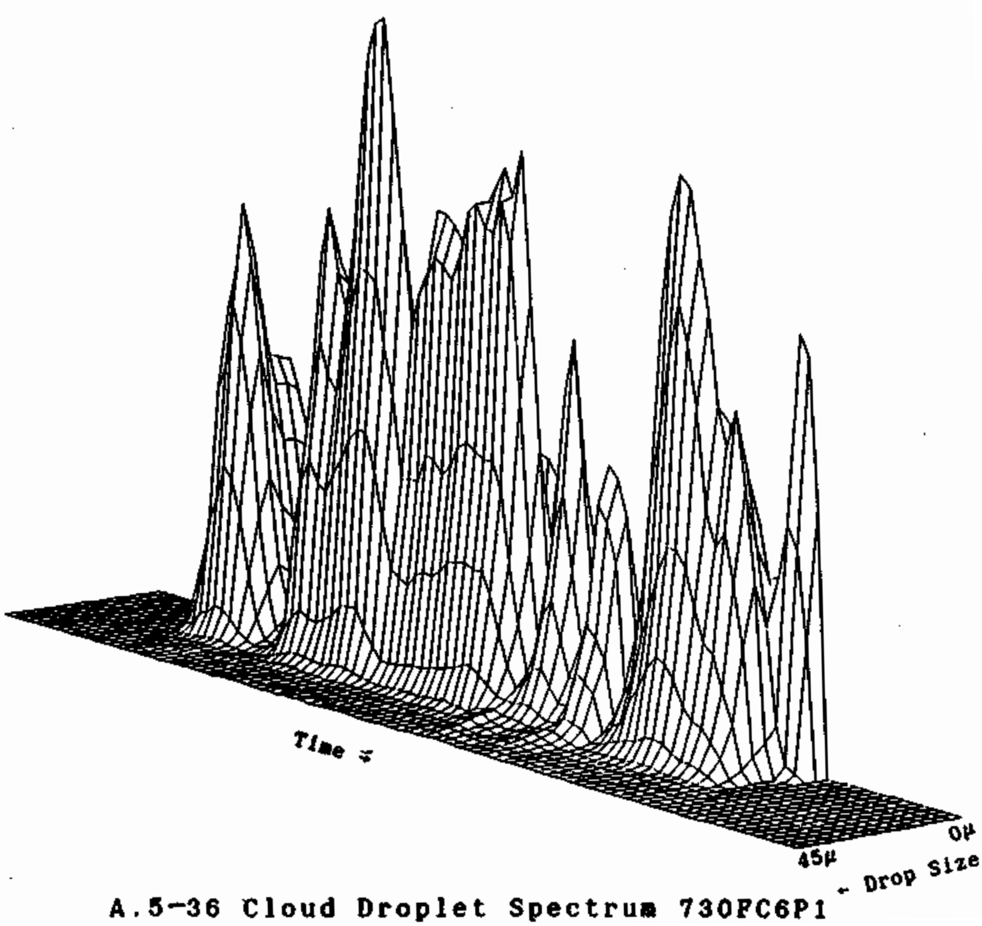
A.5-34 Cloud Droplet Spectrum 724FC5P1





A.5—35 Cloud 730FC6P1





A.5-36 Cloud Droplet Spectrum 730FC6P1

CHAPTER 6: ANALYSIS OF PACE-86 FORECASTING PROGRAM

Robert W. Scott and Floyd A. Huff

Introduction

Initial field experimentation under the Illinois weather modification program known as PACE (Precipitation Augmentation for Crops Experiment) was carried out during July-August 1986 in central Illinois. The field experiments were designed to operate during the period from 1200 to 2100 CDT on days when weather conditions met the seedability criteria established for convective cloud seeding in the Midwest (Changnon and Huff, 1987). Operations were carried out largely within a target area extending for a radius of 90 nautical miles (approximately 100 statute miles) from the project headquarters at Champaign (Fig. 6-1).

Randomized cloud treatments were made utilizing silver iodide and placebo flares discharged from an aircraft into convective clouds at or near the -10°C level, as prescribed by the seeding hypothesis (Changnon and Huff, 1987). Two types of subexperiments were performed. The first was a cloud physics experiment (CPS) in which various aircraft and radar measurements were made before, during, and following cloud treatment to acquire more knowledge on the physics and dynamics of midwestern clouds. The second subexperiment (ESX) was the initiation of limited rain enhancement operations with verification of treatment through measurement of pertinent radar echo parameters (Huff, 1987). Operational techniques in the 1986 field experiments were based primarily on findings in pre-experimental studies carried out during the 1980-1985 period. The 1986 field experimentation was designed to be conducted during July and August, because the agricultural needs for rain augmentation occur most frequently in Illinois and the Midwest during this period.

The Forecasting Problem

In general, the field operations required preparation of a forecast by 1100 CDT daily throughout July and August. This forecast had to specify whether suitable treatment conditions would occur within the 1200-2100 period. If so, the specific weather type during the operations had to be designated, the time and location within the target area of suitable treatment conditions indicated, and various atmospheric variables pertinent to the aircraft operations specified. Whenever, a "go-day" was predicted and operations undertaken, it then became necessary for the forecasting unit to provide a "nowcasting" service to the operational personnel. That is, weather conditions had to be periodically updated through use of available forecasting facilities, in order to adjust or abort operations if significant changes from the original prediction occurred. This was necessary both in the interest of optimizing the field experiment operations and for insuring safety of personnel and equipment.

Based on synoptic climatology studies, the 1986 experiment was grouped into treatment of four weather types for statistical evaluation (Changnon et al., 1986). Two basic blocking methods were considered. These included grouping by synoptic weather conditions or by classifications of weak, moderate, and strong convection. Although grouping by convection categories was considered best, the necessary information did not exist to specify the degrees of convection with a high degree of reliability for the 1986 operational forecasts. Therefore, the following four synoptic weather classifications were used for blocking, since these could be predicted with a high degree of accuracy and would provide a logical stratification of warm season precipitation-producing systems in the Midwest (an important scientific objective). The systems were:

1) Cold front cloud systems — those conditions (clouds) occurring within 130 nautical miles (150 statute miles) of a cold front at the surface.
2) Stationary front systems — those conditions within 130 nautical miles of a stationary surface frontal position.
3) Warm front systems — those clouds occurring within 65 nautical miles to the south (warm sector) and 130 nautical miles north of a surface warm front.
4) Air mass cloud systems — primarily cloud systems in the warm sector (warm air mass systems), plus those located over 150 statute miles to the rear of a front (cold air mass clouds).

Forecasting Facilities

A large variety of available products were used in the development of forecasting and nowcasting procedures for PACE. First, a select set of daily, meteorological charts prepared by the National Meteorological Center (NMC) were received on an Alden 18 facsimile recorder via the NAFAX line.

This included surface and upper air analyses, radar summaries, and outputs generated from computer forecast models run at NMC. The charts were used primarily in the forecasting mode of the experiment, being the main focus of the daily weather briefing, but were available to assist the nowcaster during operations, if desired.

Second, substantial digital and worded data transmitted over the FAA604 line were obtained and fed directly into the Water Survey's VAX 11/750 computer. From this vantage point, computer-generated atmospheric soundings, regionalized weather maps, and cloud models could be produced by both forecaster or nowcaster, depending on their individual need. In addition, the NOAA/NWS Public Products line was monitored whenever desired, but always during flight operations. This service provided important worded information to the experiment, such as current weather summaries, special weather statements, and severe weather watches and warnings across Illinois and adjacent states.

These data were supplied to the operational personnel via a Digital Decwriter II which provided a paper print-out of selected messages. The most important information triggered an alert bell for immediate notice. The data were simultaneously archived on the SWS computer. An intermediary company, Zephyr Weather Information Service, was the supplier for all of the above data via a satellite transmission.

Third, real-time GOES satellite images were obtained via a telephone-link to the Man-computer Interactive Data Access System (McIDAS). These were received in digital form, then reconstructed using an IBM PC/AT and displayed on an IBM Professional Graphics Display screen for use in directing aircraft to clouds of interest. Polaroid photographs were made of the images for cloud pattern continuity during operations. In addition, the digital data were archived on floppy disks. Visible images with a 1-km resolution were available every 30 minutes while 4-km resolution pictures were received every 2 hours.

Fourth, an advanced automatic atmospheric sounding capability was obtained for the experiment from the National Center for Atmospheric Research (NCAR). The system, called CLASS for Cross-chain Loran Atmospheric Sounding System, is a one-man, fully automated rawinsonde system which greatly reduces the human element in sounding operations. Tracking of the sonde is accomplished by loran navigation and the raw data is reduced via computer as the balloon ascends, allowing continuous real-time read-out of measured conditions. Data were collected at 10-sec intervals with 30-sec averages stored on disk. After each run, the average data were transferred to the Water Survey VAX computer and would then be available for further analysis.

Fifth, a mesometeorological model developed by Achtemeier (1979) was employed in conjunction with surface weather observations in and around the target area (Fig.6-1) to provide computer-generated patterns of sea-level pressure and divergence and streamline analyses on an hourly basis. These were computed primarily as a guide for the nowcaster on those days classified as operational or standby situations by the forecaster.

Daily Procedures

The daily forecasting procedure began with the sorting of overnight facsimile charts. The set received normally included: all 3"hour surface charts, the 0000 GMT upper air analyses, overnight radar summaries, the NGM, LFM, and man-machine forecast maps, and various other products. Surface charts were studied for the location of pressure centers and moist regions, plus the types of clouds observed. They were also checked for accuracy in the analysis of frontal positions and compared to each other for continuity and progression of the synoptic systems.

All upper air charts were perused as well, beginning with checks on height changes over the previous 24 hours at each level. Height contours at 10 m were added over the central Great Plains and Midwest to the standard 30-m analysis present on the 850-mb and 700-mb charts. In addition, the 5°C temperature analyses on these charts were enhanced to 2°C intervals. Coupled with the noting of moisture values at the individual rawinsonde sites, an improved picture of temperature and moisture advection resulted. At 500 mb, in addition to noting synoptic scale features, cooling over Illinois was considered significant in reducing stability. Jet locations and divergence over the state was likewise checked at 300 mb. Short-wave troughs were highlighted at all levels.

Computer products that were produced from data fed into the SWS computer included Log-P/Skew-T diagrams, 1-dimensional cloud models, and stability and thermodynamic parameters generated from the 1200 GMT soundings at Peoria (PIA) and Salem (SL0), Illinois (Fig. 6-1). Surface divergence and streamline analyses were normally produced. Also, a variety of extra meteorological parameters (e.g., vorticity, streamlines, etc.) could be added to more common analyses of height, temperature, and isotachs on computer-generated charts at 850, 700, 500, and 300 mb. Finally, a morning satellite image of the central United States was produced.

After the weather briefing, the nowcaster generally took over the operations. If a "standby" or "go" decision was made, a CLASS sounding was usually taken. All of the above equipment was then used in a nowcasting mode with the addition of the CHILL radar, a sophisticated 10-cm set with a 1° beam width and which employed Doppler and polarization features. Surface streamlines and divergence charts were produced on an hourly basis; new satellite images were obtained at half-hour intervals; and, the radar and Public Products line were monitored continuously. In addition, computer analysis of the CLASS sounding was done to compare with the morning soundings from PIA and SLO.

Verification of July-August Forecasts

During July and August, there were a total of 17 days predicted to be "go" days, 7 were classified "standby", and 36 were considered "no-go" situations. "Go" days were those on which minimal suitable convection occurred in or near the target (generally within 100 nautical miles of the project headquarters at Champaign). These included days on which cloud systems, in general, were too severe for penetration by aircraft or the convection was too imbedded for aircraft treatment and observations to be carried out safely and accurately. However, it is not uncommon on these days to find convective clouds flanking the intense storms cores that are suitable for treatment and for making the pre-treatment observations required by the project. Also included in the prediction of "go" days were some on which suitable convection occurred outside of the target area which could be usefully sampled in conjunction with the cloud physics sub-experiment, but were not expected to be cloud treatment opportunities. "Standby" days were those on which convective conditions were marginal, but suitable experimental conditions later in the day were considered possible. "No-go" days were obviously those on which no suitable convection was expected. Unless convection was ongoing or considered imminent, the operational personnel typically went on standby on all "go" or "standby" days, awaiting further information from the nowcaster on duty.

Verification of the July-August forecasts indicated that weak or no convection occurred on 2 of the 17 predicted "go" days. Three of the "standby" days eventually developed convection; four did not. Of the 36 predicted "no-go" days, some rainfall occurred in the target area on 5 days. However, only two of these were really "bad" forecasts. On one day, the convection was dying as it reached the target, and was, therefore, not suitable for the PACE experiments. Another day involved some very light post-frontal rainfall of short duration, probably not long enough for the aircraft to file a flight plan and fly. Furthermore, suitability of the clouds for the experiment was questionable. On a third missed day, the operational group was on standby, but decided not to fly because of the severity of the weather, and because both radar and satellite data were unavailable for guidance and observations. In retrospect, it appears that only two days were really missed opportunities, but the other three should have been predicted "standby" rather than "no-go". The two missed opportunities comprised only 10% of the possible treatment days; that is, there were 15 predicted go-days that verified, three standby days that produced convection, and two days when opportunities were missed.

Summary of Project Weather During July and August

Unfortunately for the objectives of the field experiment, the weather during the summer of 1986 was largely uncooperative. Precipitation fell inside the target during 1200-2100 CDT on 23 days, but only 9 of the days were judged by the subexperiment directors to have rainfall suitable for operations within ESX and 6 were considered suitable for CPS. On the remaining days, the convection that occurred was either too severe or too light, mechanical problems were encountered, or missed forecasts resulted in no operations.

Of the 6 possible days for flights in CPS, operations were conducted on 5 of them. The remaining day may have been a missed opportunity due to a forecasting error. In addition, one CPS flight was conducted in suitable clouds well outside the target, and two flights were made in warm clouds for the purpose of obtaining raindrop measurements.

Seven days were judged meteorologically suitable for ESX operations in July, but higher-priority CPS opportunities, aircraft problems, and the fact that no radar monitoring was available until 25 July prevented any ESX operations in July. In August, only two days were considered suitable, resulting in three ESX units. Flights were made on 5 other days with the hopes of finding suitable clouds but ended unsuccessfully. On 1 other day, unforecasted light convection existed within the target borders and, again, may have resulted in a missed opportunity.

As shown by Woodley (1986), the July weather regime was dominated by a surface and upper air ridge in southeast United States and a trough in western United States. Eight frontal passages occurred in the target area, consisting of 7 cold fronts and 1 warm front. Unfortunately, much of the July rainfall occurred outside of the 1200-2100 experimental period, although climatologically this is the period of most frequent convective rainfall in the target area during July.

In the August weather pattern, a trough replaced the ridge in eastern United States and a ridge dominated in western United States (Woodley, 1986). The frequency of convective activity in the target area was below normal in August, although fronts passed with a normal frequency of once every 3 to 4 days. Northwesterly flow of relatively dry air dominated in Illinois which resulted in the limited amount of convective activity.

Assessment of the Forecasting Effort

In many respects, the forecasting effort during PACE 1986 was substantially different than that of previous experiments operated by Water Survey personnel. The addition of facilities to rapidly analyze current digital weather data from 1200 GMT NWS rawinsondes plus the ability to view a real-time satellite image of the cloud patterns over the region aided greatly in the preparation of the forecast. This, in no way, lessened the importance of the basic facsimile charts; indeed, the project would have been severely hampered without the availability of these products in some form. Nevertheless, the additional information provided by the extra data sources was very beneficial.

The primary advantage of the new facilities was the capability for rapid data analysis via computer-generated products. For example, generation of mandatory-level charts was possible one-half to two hours ahead of their facsimile production. Not only did this provide an early "look" at height patterns but also allowed for production of additional contoured products, e.g., vorticity, 1000-500 mb thickness and relative humidity, dewpoint temperature or depression, isotachs, etc. These additional fields, not produced in the facsimile copies, greatly enhanced the analysis.

Another example was the generation of Skew-T/Log-P charts. In previous field studies, these diagrams were plotted by hand, often from data obtained in a daily telephone conversation with the rawinsonde operator at nearby sounding sites. Computer analysis of this product not only reduced the plotting time considerably and decreased the probability of human error, but allowed the forecaster extra time for additional analyses.

As the forecasting for PACE proceeded during the summer, a few parameters tended to be relied on more heavily. These included 850 mb and 700 mb charts, surface dewpoints and streamlines, the soundings at PIA and SLO, the morning satellite image, and calculations of stability indices. Enhanced height and temperature analyses in the lower troposphere greatly aided in defining locations of short waves not portrayed on the larger contour intervals of the synoptic charts. Moisture availability at the surface and potential triggering mechanisms in the wind field were also very important. The morning soundings were essential to indicate the depth of the moisture present and to provide information on favorable conditions, if any, in the thermal trace. The satellite image provided information on current activity, cloud types, and coverage.

Finally, calculation of several stability indices were useful in the prediction of precipitation occurrence. A total of seven measures were selected for evaluation on the basis of their prior performance in a similar study of nearly 40 parameters by Lamb and Peppier (1986). Those selected were the K, Modified K, Jefferson, Modified Showalter, and Sweat indices, plus the geometric heights of the LCL and CCL in meters. In addition, the Lifted Index was evaluated on the basis of its popularity in the forecasting community, although Lamb and Peppier rated it as one of their worst performers.

All of the parameters were calculated from the 0700 (1200 GMT) rawinsonde soundings at PIA and SLO, Illinois. Comparisons were made with precipitation occurrence (indicated from a variety of sources) within 100 run of CMI between 1200 and 2100. The time lag between the morning sounding and the verification period does not seem unreasonable in most cases. Although summertime precipitation in central Illinois is due largely to the approach and passage of frontal systems (Huff, 1981), the triggering mechanism for much of the actual rainfall depends, or at least is greatly enhanced by the surface and near-surface moisture and convergence fields. These, in turn, are driven by the local heating fields of the earth's surface.

In addition, from a climatological viewpoint, convective precipitation in central Illinois is at a minimum in the forenoon (Huff, 1971). Therefore, baring a mid-morning frontal passage or other process that would change the airmass type over the area, any precipitation potential found in the morning soundings often remains unchanged during the morning hours and can serve as a base on which afternoon heating and convergence fields are able to build.

From these comparisons, certain critical values were noted empirically that related many of the indices to afternoon and early evening precipitation. Interestingly, positive relationships were not found at each site individually but rather when the index values at both PIA and SLO crossed the same threshold. This implied that an indication of convection at both stations simultaneously represented a more generalized area of precipitation potential, whereas high index values at just one site could often be a reflection of other localized conditions.

Both PIA and SLO were on the edge of the target, PIA to the northwest and SLO to the south southwest (Fig.6-1). Due to this close proximity, allowing index values from these two stations to be representative of conditions in the target appears reasonable. In assessing the stability indices, any precipitation that occurred within a 100-nm radius of CMI during the 1200-2100 period qualified that day as a rain day, regardless of the convective or non-convective nature of the rainfall.

Table 6-1 shows the calculated values from PIA and SLO on each day of the PACE experiment. Starred items are those when both sites crossed over the critical value determined for each index. A summary of the performance of the five best indices is shown in Table 6-2.

All the indices performed well in forecasting precipitation occurrence. As shown in Table 6-2, from 62%-86% of the forecasted rain days actually verified with the Modified K-Index performing the best. Three additional days reported precipitation during the first two weeks of July when, unfortunately, soundings were available at only one site. However, all indices from the available site exceeded the threshold value on all three days, indicating the potential for even higher accuracies. On days when index values at one or both sites failed to reach the threshold point, accuracy rates were more uniform, 78%-86%.

Another relationship made with the stability indices is with the maximum daily radar echo top observed within the target during the operational period from local NWS radar sites. Table 6-3 shows stratified totals of the single highest radar top observed each day within 100 nm of Champaign between 1200-2100 CDT from any or all of the NWS radars located at St. Louis, M0, Marseilles, IL, or Evansville, IN. The daily tops are stratified by height categories and by the number of stability indices which exceeded precipitation thresholds at both PIA and SL0 on the day of the reported top. When two or more sites reported conflicting echo tops for the same cell, the top observed at site closest to the cell is used.

Results indicate that when all five indices suggested the occurrence of precipitation, it not only occurred but echo tops usually exceeded 30,000 ft. The most severe weather and embedded convection was observed on these days which generally are regions in which treatment would not be attempted. Frequently, however, less severe cells could be found away from the most intense echoes. On the one day that reported no echoes but had five positive indices, radar tops in excess of 50,000 ft. occurred just outside the target in extreme northwest Illinois.

Similarly, days on which no or just one index indicated precipitation, rainfall was predominantly nonexistent or tops were less than 20,000 ft., insufficient conditions for treatment. Interestingly, when just two or three indices gave positive indications for rainfall, tops were predominantly in the 20,000-30,000 ft. range. These were cells in which the atmospheric dynamics were weak and did not allow deep convection but where dynamic seeding may have had good testing opportunities.

At this time, data from these results should not be used in a forecasting mode other than an additional piece of information within the forecasting procedure. Analyses of several more summers of weather data yielding similar results may lead to a larger reliance of the indications given here. Future work in this area will be to incorporate cloud base calculations from the 1200 GMT sounding into previous results.

Weaknesses in the forecasting/nowcasting system were in two general areas, supporting equipment and sub-synoptic scale data. On the equipment side, the Public Products line was monitored through the VAX computer via a 300 baud modem on a dial-up telephone line. Monitoring was initiated by the user at the beginning of operations. With everything working properly this was an effective system, but there were instances when contact was lost with the VAX without any indication that this had occurred. This, of course, terminated the monitoring of the Public Products line, data essential to safe operations. A new system should be developed to forego the need for the user to constantly check the status of this line.

At the sub-synoptic scale, good quality computer-generated plots were obtained for the experiment on an HP7475A plotter via a 1200 baud error-correcting modem. However, the actual plotting time required to produce one streamline/divergence chart was about 12 minutes of each hour. A 9600 baud modem can perform the same task in less than 5 minutes.

A meteorological weakness resulted from the placement of NWS regular rawinsonde stations. The first stations to the west of the PIA and SLO sites in Illinois are in Omaha, Nebraska and Topeka, Kansas. Frequently, moist conditions were observed in the morning sounding at these two sites but not at PIA or SLO. It was not possible to estimate accurately the location of the largest gradients between these two different air masses. This information could be extremely useful in a forecast, especially under a favorable thermal lapse rate, upward synoptic-scale vertical motion, or some other triggering device for convection. In future project of this type in east-central Illinois, it is suggested that an extra RAOB site be considered in this data void region.

Summary and Conclusions

Overall, the performance of the forecasting unit with respect to both short-range forecasting and nowcasting met expectations. This is especially satisfying considering that the CHILL radar observations, one of the primary prediction tools, were not available to the forecaster and nowcaster during much of July. Continuous radar observations in and around the target area are particularly helpful in nowcasting for seeding operations.

An important finding from the 1986 field operations was that stability indices, such as the K-index and modified K-index, can be an excellent prediction guide if RAOB observations are available in or near the target area to provide accurate computations of the therodynamical characteristics of the region. The RAOB stations at PIA and SLO (Fig. 6-1) were quite adequate for this purpose in the 1986 Illinois program.

Satellite observations proved to be an excellent tool for recognizing convective activity in or approaching the target area. In combination with radar observations, satellite data, routinely accessed and displayed as done in the 1986 experiments, provide excellent guidance in recognizing the onset of seedable conditions, and in carrying out the required aircraft operations. These sources of information should be an integral part of all aircraft seeding programs. Limited use of mesoscale objective analysis techniques provided useful input to the forecasting activities, particularly in the nowcasting phase.

Some minor improvements in supporting equipment for future experiments were identified in the 1986 operations, but, in general, this phase of the design proved adequate. In the future, an assistant for the forecaster during the hectic forenoon hours would be helpful, especially if more precise forecasts of convective conditions are required in future experiments. Hopefully, better radar performance in future experiments will facilitate and further improve the forecasting and nowcasting.

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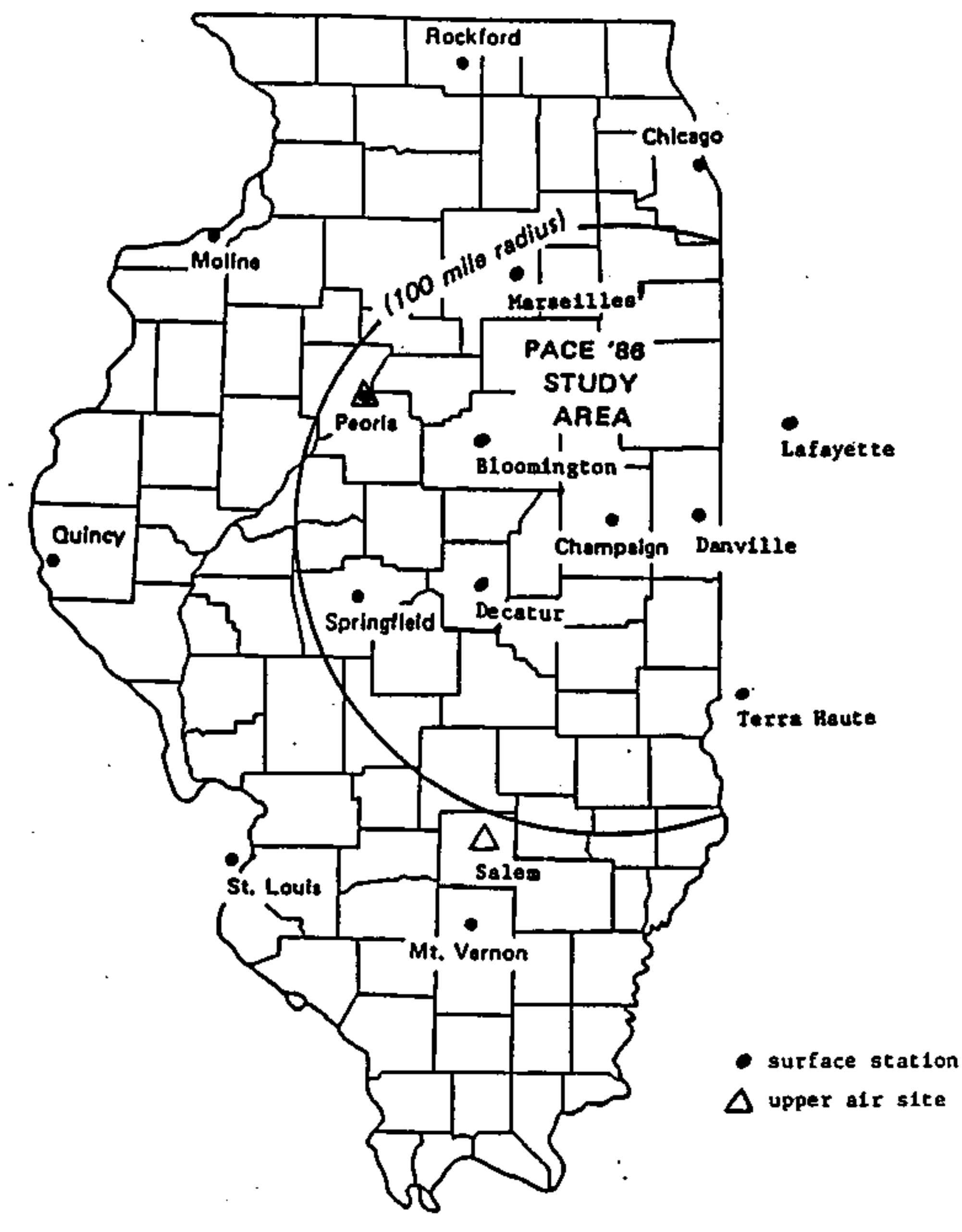

Fig. 6-1. Location of 1986 Field Experiment.

Table 6-1. Forecasting indices used during PACE 1986.

date	fcst	prec	fly	K-Index PIA	K-Index SLO	Mod K-I PIA	Mod K-I SLO	Jeffson PIA	Jeffson SLO	Mod Show PIA	Mod Show SLO	Sweat P1A	Sweat SLO
703	NG			-3	8	3	15	24	24	18	16	89	85
704	NG			27	37*	33	40*	30	35	8	10*	137	200
705	NG			34	7	40	12	32	32*	12	14	179	156
706	NG	EC,SC		24	M	30	M	34	M	10	M	155	K
707	SB	UP	T	23	26*	29	32*	35	35*	12	13	218	212*
708	GO	SC	CP	24	35*	30	41*	33	34*	10	10*	203	189*
709	GO	EC,SC	MP	33	39*	38	44*	33	34*	12	9*	222	231*
710	GO	EC	MP	39	37*	39	39*	36	35*	7	8*	240	233*
711	GO	EC,SC	MP	M	35	M	37	M	36	M	10	M	291
712	GO	UP	CP	31	M	37	M	34	M	10	M	214	M
713	NG			0	32	8	37	27	34	17	13	126	235
714	GO	OT	MP	38	36*	43	43*	33	36*	5	6*	180	254*
715	SB	OT		34	40*	38	45*	36	36*	10	5*	220	253*
716	NG			17	25	24	31	31	35*	13	9	164	196
717	NG			23	24*	28	31	32	32*	13	12	190	179*
718	NG			19	17	25	24	32	30	14	12	197	149
719	NG	OT	WW	23	27*	30	34*	31	31*	11	12*	192	174*
720	NG			17	31	24	36	29	36	12	11*	137	214
721	NG	UP	CP	3	1	9	7	30	28	14	17	146	136
722	NG			17	16	22	21	31	26	13	13	172	94
723	SB			22	17	29	25	25	24	15	14	78	81
724	GO		CP	37	7	42	22	38	21	4	11*	294	16
725	GO	SC	CP,MP	37	37*	41	41*	34	34*	6	8*	204	207*
726	NG			22	22	26	27	32	35*	14	13	194	221*
727	NG	EC		29	31*	33	38*	32	30	13	13	171	175*
728	GO	SC	CP,MP	28	39*	32	42*	35	33*	9	8*	193	226*
729	NG			22	27	29	35*	30	30	11	9*	132	154
730	SB	SC	CP,WW	23	26*	29	31*	31	32*	6	9*	59	180
731	GO	SC	CP,ES	37	43*	40	44*	32	37*	5	0*	164	326*
801	NG			4	33	12	36	25	35	16	10	82	200
802	NG	UK		29	21	37	29*	31	26	9	12*	78	55
803	NG			14	0	22	5	28	29	11	17	62	127
804	NG			11	8	16	13	28	28	15	14	85	84
805	GO	EC		26	27*	34	31*	27	28	8	10*	54	90
806	GO	SC	ES,WW	37	33*	43	37*	34	31*	8	9*	188	184*
807	SB	UP		-6	20	3	22	24	34	16	13	33	207
808	NG			0	6	6	12	27	32	15	15	92	180
809	NG			19	4	23	8	27	31	18	16	116	163
810	SB	AM		30	36*	37	42*	28	32	9	7*	145	294
811	NG			-7	-6	0	2	24	23	19	18	64	73
812	NG			-2	-3	8	5	22	21	13	17	17	18
813	NG			24	18	29	25	24	22	11	14	46	7
814	NG	AM		28	22	30	26	31	28	7	10*	136	90
815	GO	UP,OT	ES	32	34*	37	39*	35	32*	6	11*	204	172*
816	NG	AM	ES	12	36	21	41	28	33	16	6	117	194
817	GO	OT	ES	0	5	6	8	27	31	17	16	114	192
818	NG			29	29*	34	34*	29	31	13	15	106	178
819	NG	SC		14	17	17	20	32	34*	12	10*	135	155
820	SB	UP		1	33	6	39	29	33	14	10	101	131

821	NG			21	18	26	24	24	25	16	18	111	104
822	NG			2	4	3	6	29	29	15	17	160	179
823	GO	UP	ES	35	33*	41	38*	31	33*	8	15	184	225*
824	NG			-12	-13	-5	-5	20	19	19	18	19	22
825	GO	DP	ES	33	34*	32	33*	35	33*	11	11*	214	189*
826	GO	SC	ES	37	42*	42	48*	34	37*	8	5*	252	285*
827	NG			16	33	23	38	27	31	16	8	137	187
828	NG			-25	-9	-17	-2	13	14	25	25	42	51
829	NG			-5	-7	-1	-2	19	15	21	24	23	22
830	NG			19	-29	21	-17	25	16	11	12*	13	20
831	NG			17	9	21	12	22	27	14	15	9	88

prec - precipitation occurred in or near target (within 100 nm)
UP = unsuitable precipitation for operations (warm clouds, etc.)
SC = convection judged to be suitable for operations
EC = convection judged to be too embedded for operations
OT = precipitation just outside target
UK = light convection of unknown potential
AM = precipitation in or near target between 0700 - 1200

fly = flight made
T = test flight
CP = cloup physics flight
ES = treatment flight
MP = mechanical problems prevented or terminated flight
WW = flight limited or terminated due to severe weather warning

* = index at both sites exceeded threshold value for precipitation
K-Index ≥ 23 Modified K-Index ≥ 29
Jefferson Index ≥ 31 Modified Showalter ≤ 12
Sweat Index ≥ 170 or one ≥ 200 and one ≥ 160

Table 6-2. Performance of Selected Forecast Indices.

Index	Threshold Index Value	Rain Days	No Rain Days	Percent Correct Rain	Percent Correct No-Rain
K-Index	≥23	17	5	81	86
	< 23	4	31		
Modified K-Index	≥ 29	18	5	86	86
	< 29	3	31		
Jefferson Index	≥31	14	7	67	81
	< 31	7	29		
Modified Showalter	≥12	16	8	76	78
	< 12	5	28		
Sweat Index	*	13	5	62	86
	**	8	31		

* both sites ≥ 170, or one ≥ 200, and other ≥ 160

** failing above criteria

Table 6-3. Relationship between the single maximum daily radar echo top observed inside the PACE target by NWS radar during the 1200 - 2100 CDT operational period and the number of stability indices (K-index, modified K-index, Jefferson, modified Showalter, and Sweat index) in which calculated values from the 1200 GMT sounding at both PIA and SLO exceeded empirical threshold values for precipitation. Values in parentheses are those days on which soundings were available at just one site.

Radar echo tops (kft)	Number of indices exceeding threshold 0	1	2	3	4	5
no echoes	14	4	1	2	0	1
< 20	6	1	0	0	1	0
20-29	4	1	3	3	0	1
30-39	0	0	1	0	0	3
40-49	1	0	0	0	2	3(1)
> 50	0	0	0	0	0	5 (2)

CHAPTER 7: FIELD OPERATIONS

Staff

The field operations in July-August 1986 were extensive and well planned. A special planning document of more than 100 pages was prepared and copies provided to the NOAA Program Manager, Dr. Roger Reinking. This document with revisions made as needed during the operations represented an extensive effort by the project staff. The field project became known as "PACE-86." The use of this acronym in this chapter and elsewhere in this report relates to the July-August 1986 field operations of PACE.

The field operations involve the following Water Survey staff in these project functions:

1. Overall Director: Stanley Changnon
2. Operational Director: Stanley Kidder
3. Forecasters: Robert Scott (chief) and Gary Achtemeier (alternate)
4. Radar Operational Director: Nancy Westcott
5. Seeding Officer: Floyd Huff
6. Nowcasting System Monitor and in charge of Data Collection: Harry Ochs
7. Director of Cloud Physics Aircraft and Data Collection: Robert Czys
8. Assistant for Seeding Systems: Allen James
9. Radar Systems: Eugene Mueller
10. Electronics Engineer and Radio Systems: Donald Staggs
11. Radar Technician and Systems Maintenance: Darnell Oliver
12. Radar Systems Programming and Development: David Brunkow
13. Radar Technician and Operator: Art Sims

Those involved from other organizations included:

1. Mr. Tom Henderson, Atmospherics Incorporated, on-board flight observer
2. Mr. Jim Wood, Atmospherics Incorporated, pilot
3. Norm Ostranda, Colorado International, pilot
4. Don Stone, Colorado International, electronics technician
5. William T. Woodley, Woodley Weather Associates, Director of Seeding Flight Operations.

These 18 people were present, largely on a full-time basis, throughout the 61-day operations of PACE-86. The following text first describes the operations, and then assesses the conditions and the operations in the final portions.

Operations

Operations were conducted 5 July to 31 August 1986. Tables that follow itemize 1) the flights of the Cloud Physics Subprogram in July; 2) the flights of the seeding aircraft in July-August; 3) the Forecasts for all operational dates; and 4) the CHILL radar operations for July-August.

Further information on operations of two major subcontractors, Atmospherics Incorporated (seeding aircraft), and Woodley Weather Consultants (operational guidance) are attached as an Appendix.

The operations were conducted in two general modes:

1) the Cloud Physics Subexperiment (CPS, requiring the cloud physics aircraft of CIC and done on suitable weather periods in July); and
2) the Echo Subexperiment (ESX, involving the AI seeding aircraft and CHILL radar and done on suitable weather periods in August.

It should be noted that this was the first field operation for PACE; hence, the entire effort was viewed as a shakedown in order to get staff trained and equipment functioning to operate effectively and safely in complex cloud and rain conditions.

Due to the very poor (dry) weather conditions in July-August 1986 daytime periods, we gathered cloud physics data on 10 July days (4 were marginal, and treatment on only 3 flights); and only 2 ESX days in August.

Project visitors were numerous. They included 3 representatives from the Inspector General's (DOC) Office in Denver, the NOAA project manager, project consultant Dr. K. R. Gabriel, and interested citizens from several locales in Illinois.

Assessments

In general, most of the systems performed well, and the staff provided a strong team effort and generally did an outstanding job. Our major problem after July 7, when operations began, was an almost unbelievable lack of daytime precipitation systems within 80 nautical miles of Champaign. This lack of convective activity resulted in a serious lack of data, which will likely produce a second year of operations sometime in the summer of 1987 or 1988, to effectively collect the data desired for the summer of 1986.

1. System Assessments. The project utilized two aircraft, the Atmospherics Incorporated (AI) Cessna 421 which was the seeding aircraft and here from 1 July through 31 August, and the Beach Baron of Colorado International Corporation, which was the "cloud physics platform" and was here 1-31 July 1986. Except for very minor and infrequent problems, both aircraft and their on-board systems performed exceptionally well, particularly in relation to past performances here of the University of Wyoming aircraft and

NOAA aircraft used on PACE. There were no major operational failures. One operational event which was actually unsuccessful as available far as clouds, had to be ended because the pressurization failed on the AI aircraft. Thus, for the aircraft operations of PACE86, we have good computer-based data sets. The aircraft operations and interpretation of conditions was aided by the use of forward pointing video cameras on both aircraft, which with voice transmissions, give us an excellent record of the cloud conditions during operations.

The forecast system, which had been developed during the spring and early summer by Stan Kidder and Harry Ochs, operated flawlessly. The system which contains Zephyr products, the teletype, and the satellite pictures from Wisconsin, functioned well, both for the presentation of real-time products at the airport, and for the additional recording of the data on the VAX. Thus, we ended the project with an extensive data base on the "weather conditions" with much of it recorded on the VAX and the remainder on FAX maps. The forecast system never produced a glitch in our operations.

The CLASS portable radiosonde system obtained from NCAR and installed at the airport worked reasonably well. Certain early operational difficulties affected the real-time turn around of information, but we obtained all the data recorded in the VAX for all releases. The system was very easy to operation.

The CHILL radar performance was much less than desired. The refurbishing of the CHILL radar under the 4-year NSR agreement, called for test operations of the system during the May-August 1986 period. For various reasons these "test operations" had not begun prior to July 1. A variety of problems relating to getting the radar operational beset the system from 1 July until 24 July. This greatly affected the types of operations which could be pursued.

Fortunately, certain aspects of the cloud physics sub-experiment involving the two aircraft (one for seeding and the other for in-cloud evaluation) could be pursued to that not all was lost; however, in what was the "better cloud period" of the summer, we were without the radar which also affected direction of the aircraft as well as data collection desired. Furthermore, once the radar became operational, we only had reflectivity data; the highly desired differential reflectivity data were not collected because of problems with the polarization switch (unresolved as of August 25). Lack of this capability prevented pursuance of a key experiment particularly during July when the cloud physics aircraft was present and we had hoped to get in-cloud data on moisture and ice to compare with the ZDR signals.

The ratios for the project communication system were provided at no cost by AI. THe first radio systems provided functioned well but suffered a lot of other cross talk, so a second set of radios on a different frequency were installed. There were less than adequate for good plane-to-plane and plane-to-ground transmissions. A major lesson learned is that if at all possible, we need to purchase our own radios and seek a state-allotted frequency for future field operations involving aircraft.

In summary, if I were to give "grades" to the systems, I would give the AI aircraft an A, the CIC aircraft an A^+, the forecast system an A^+, the CLASS system a B, the radar a D, and the communications system a C. Considering the fact that this was the first field operation of the Water Survey since 1980 and that many of the staff and the visiting project types had never worked together or even in a field operation, everything went amazingly well.

2. Staff Assessments. A major objective of the PACE-86 effort was a shakedown and staff training to get experience in field operations. The staff

worked well together with excitement and a strong team spirit evolve.d Stan Kidder, assigned the job of "Nowcaster" and overseer for the operations, worked a tremendous number of hours and did a very effective job in directing operations and providing overall guidance to the staff.

Harry Ochs, who worked with Kidder to get the forecast system designed and operational was responsible for field data collection and inventorying. He helped on the CLASS system, worked effectively.

Nancy Westcott, who served as project radar meteorologist, also worked beyond the call of duty. She participated actively, seeking good operations, and was a very good team member.

Floyd Huff served as the Randomization Officer and took care of the handling of the flares, and did this in an efficient manner. He was always present and available when needed, which was a critical aspect of his task.

Bob Czys, who was responsible for planning operations and directing both aircraft during the July Cloud Physics Sub-experiment, and who was relatively new to such tasks, did an amazingly good job. He had much to learn and learned it quickly. He showed a real potential for leadership in a friendly, cooperative manner. He brought an enthusiasm to the effort.

Bob Scott was responsible for the daily forecasting and the operations of CLASS, as needed, throughout the summer, except for one week when he was replaced by Dr. Gary Achtemeier. Scott did an outstanding job of forecasting and worked very hard. He had the confidence of everyone. Gary Achtemeier made a significant contribution through gathering his modeling system up for operations, educating Bob Scott, and participating in the operations in an enthusiastic manner.

Gene Mueller and his staff of radar engineers and technicians worked exceptionally hard. Due to the poor radar behavior in July, they worked continuously over weekends, and often 10 to 12 hours a day. Failures of the radar system to function as desired could not be attributed to their lack of effort.

3. Selected Cloud Physics Assessments. Preliminary findings for moderate convection (i.e., feeder clouds rising easily through -10°C and reaching 25,000 to 30,000 ft) for observations at -10°C.

- The precipitation distribution was primarily composed of graupel/ice pellets and supercooled cloud drops.

  Pristine ice crystals appeared in the "quick look" 2DC and 2DP records. This suggests that ice crystals were not present, present in concentrations too low to be detected, or 2D probes can not detect these particles.
- Soft/slushy graupel was frequently observed. This may indicate that the "coalescence-frequency" rate is much larger than the rate of latent heat release.
- Findings above raise the issue of the overall impact of further latent heat release on cloud development via ice nucleation by AgI of supercooled cloud drops.

Preliminary findings for weak convection (i.e., cumulus towers struggling to reach 20,000 ft) at -10°C level.

- These cloud types appeared microphysically different from their more vigorous counterparts. Our deductions of the presence of larger supercooled cloud drops appears correct.

- Low concentrations of pristine ice crystals (columns ?) may have been detected by 2D probes.

4. Reports of the Contractors. As part of the contracts with Woodley Weather Associates, and with Atmospherics Incorporated, reports were provided from them about their operations and data collection. These reports are not included in this report but can be provided should they be of interest. In addition to these reports, Atmospherics Incorporated and Colorado International Corporation (who provided aircraft used in the project) both provided originals and/or copies of their on-board reporting data (in various formats) and video tapes of their forward-looking video cameras.

Table 7-1. PACE86: Cloud Physics Subprogram

Date	Flight	Description
7/05	8601	Rehearse aircraft manuvers in clear air for cloud treatment studies.
7/07	8602	Rehearse aircraft manuvers for cloud treatment studies in weak convection (tops approx. -9°C)
7/08	8603	Cloud treatment effort aborted due to problems with FM communications. Continue with cloud microphysics studies at -10°C of moderately vigorous convective feeders into Cb; 19 feeders 25 passes additional microphysical obs. taken at 0°C and cloud base.
7/09	8604	Flight to check out multiple DME.
7/12	8605	Observations of raindrop size distribution, 3 rain-showers ranging from light to moderate intensity.
7/14	8606	Cloud treatment study of weak convection NW of CMI ; mission aborted due to lack of Al aircraft pressurization and ATC restrictions.
7/19	8607	Test repaired multiple DME and debugged real time computer program.
7/21	8608	Step down through decaying cumulus; start at 17 k ft to 7 k in 1 k ft increments.
7/24	8609	Cloud microphysics study at -10°C of moderately vigorous feeders into Cb system; 11 feeders 1 pass each.
7/25	8610	Cloud microphysics study of vigorous feeders into Cb line oriented NNE to SSW just east of the IL-IN border. ATC restrictions permit only four warm temperature (0°C to -4°C) passes in updrafts approx. 2500 ft/min.
7/28	8611	Cloud treatment study of single cumulus. No DAS after feeder #2.
7/30	8612	Cloud microphysics study at -12°C of feeders into Cb system located SSW of CMI; 6 feeders 1 pass each. Additional observations of cloud base temperature and raindrop size distribution; 2 rainshowers of moderate intensity.
7/31	8613	Cloud treatment study in AM of embedded Cu, 2 cm cells, 6 passes thru Cu #1 2 passes thru Cu #2.
7/31	8614	Cloud treatment study in afternoon of small Cu cluster. 1 obs. pass followed by 5 past treatment passes. Last pass thru glaciated material.

Table 7-2. Seeding Aircraft Flight Summary

Date	Flt#	Start	Stop	Total	Purpose of Flight
7/02	1	1715	1752	0.6	Area familiarization
7/05	2	0840	0955	1.2	Area familiarization
7/06	TF	1105	1231	1.4	LORAN test
7/07	3	1355	1638	2.7	Al treatment - CPS
7/08	4	1400	1555	1.9	No treatment - CPS
7/14	5	1522	1630	1.1	Cabin pressure fault
7/15	TF	1135	1200	0.4	Test pressure system
7/22	TF	1830	1900	0.5	Test comp and pressure system
7/25	TF	1346	1434	0.8	Cabin pressure fault
7/28	6	1415	1713	3.0	Al treatment - CPS
7/31	7	0920	1121	2.0	Al treatment - CPS
7/31	8	1556	1718	1.4	Al treatment - CPS
8/0.6	9	1138	1422	2.8	No treatment
8/06	10	1553	1748	1.9	Al treatment
8/14	TF	1920	2019	1.0	Computer test
8/15	TF	0746	0813	0.5	Computer test
8/15	11	1404	1644	2.7	Cloud observation
8/16	12	1529	1728	2.0	Cloud observation
8/17	TF	0840	0928	0.8	Ball Variometer test
8/17	13	1412	1731	3.3	Cloud observation
8/18	TF	1350	1437	0.8	Test data package
8/22	TF	1418	1534	1.3	Test video and data
8/23	14	0830	0946	1.3	Cloud observation
8/25	15	1817	1942	1.4	Cloud observation
8/26	16	0.843	1202	3.3	Al treatment
8/26	17	1503	1903	4.0	Al treatment

TF = Test Flight

Table 7-3. Operations (PACE86 - forecasts, weather types, and aircraft operations in July-August 1986)

July	Forecast	Actual	Weather Type	Comments
7	GO	GO	Stationary front	Treatment, CP measurements
8	GO	GO	Stationary front	No treatment, CP measurements
9	GO	GO	Cold front	No treatment, CP measurements
10	GO	NO GO	Air mass	No suitable clouds
11	GO	NO GO	Cold front (S.L.)	No flights
12	GO	NO GO	Cold front (S.L.)	No flights
14	GO	GO	Stationary front	Al aborted flight (cabin pressure), - CP continued
15	STBY	NO GO	Stationary front	No suitable clouds
23	STBY	NO GO	Air mass	
2k	GO	GO	Air mass	No treatment, CP measurements
25	GO	GO	Cold front	Al aborted fit. (cabin pressure), CP continued
28	GO	GO	Cold front	Al treatment, CP measurements
30	STBY	NO GO	Air mass	No treatment, CP measurements
31	GO	GO	Cold front	Treatment (2 fits), CP measurements
August				
5	GO	NO GO	Air mass	No suitable clouds
6	GO	GO	Air mass	2 flights, 1st no treatment, 2nd treatment
7	STBY	NO GO	Cold front	No suitable clouds
10	STBY	NO GO	Cold front	No flights required
15	GO	NO GO	Air mass	Not seedable, no treatment
16	GO	NO GO	Air mass	Not seedable, no treatment
17	GO	NO GO	Cold front	Not seedable, no treatment
20	STBY	NO GO	—	No suitable clouds
23	GO	NO GO	Air mass	Not seedable, no treatment
25	GO	NO GO	Warm front	Not seedable, no treatment
26	GO	GO	Cold front	2 flights, both treated

Table 7-4. CHILL Radar Operations for PACE86

Date	Tape #	Radar ON - OFF	Recording Time, Hours
7/25	6IL001	1539-1730	2
7/28	6IL002	1535-1659	1.4 (Poor Data)
7/30	6IL003	1146-1626	4.7
	6IL004	1632-1853	2.3
7/31	6IL005	0700-1101	4.0
	6IL006	1550-1730	1.7
8/05	6IL006	0925-0930	0.1
8/06	6IL007	0907-1132	2.4
	6IL008	1132-1539	4.1
	6IL009	1539-2004	35 min gap in data due to 4.8h broken tach coupler
8/07	No Record		
8/10	No Record		
8/13	No Record		
8/14	No Record		
8/15	6IL010	1103-1242	1.7
		1420-1602	1.7
	6IL011	1602-1810	2.1
8/16	6IL012	1512-1700	1.8
8/17	6IL013	1406-1730	3.4
8/18	No Record		
8/21	No Record		
8/22	No Record		
8/23	6IL014	0732-1114	3.7
	6IL015	1114-1315	2.0
8/25	6IL016	1756-1915	1.3
8/26	6IL017	0745-1145	4.0
	6IL018	1145-1502	3.3
	6IL019	1502-1900	4.0
	6IL020	1900-2120	2.3 (58.8)

CHAPTER 8: HOT RADAR ACTIVITIES

David Brunkow

Work on the HOT radar system continued throughout this project period. The activities fell into three areas: work with the radar and the trailer housing its components; the work on the data system; and the siting of the radar.

The radar components are being installed in a 40-ft semi-trailer that has been under renovation for this purpose.

The walls and the ceiling of the trailer were insulated, covered with plywood and painted. A new door was installed on the side of the trailer to provide additional access to the operational area in the forward half of the trailer. A 4' by 4' porch was built adjacent to the new door, with steps leading up to it. Two air conditioners were acquired for installation in the front wall of the trailer. These are quite heavy and reinforcement of the front trailer wall is under way. The installation of the air conditioners is about 50% complete. The two FPS-18 radar cabinets, which comprise the bulk of the transmitter section, were fitted with shock mounts, painted, and installed in the rear of the trailer. A third 'control' chassis is being cut down in size. Several steel frames were welded together, painted, and installed. These will support 1) the motor-generator set which regulates power for the whole system, 2) the water-to-air heat exchanger which slides out the rear of the trailer on a track, and cools the transmitter during operations, and 3) the parts storage cabinets. Parts cabinets salvaged from an old system are being repaired.

The plans call for the installation of the antenna and radome on top of the existing radar tower adjacent to the Survey's building at the UI airport.

The trailer will be located between the tower and the building. To facilitate this, an older tower was removed. Extensive remodeling of the building was initiated by the State of Illinois. This will provide more desirable accommodations for radar displays, radios, and PACE operations and analysis. Components for the new solid-state frequency chain were also acquired.

The second area of activity related to the HOT radar's data system. Two double-bay cabinets were acquired to house the signal processor tape recorders, and the other computer system components. The SP-20 signal processor was delivered in September. The software required to operate the system was developed. Only minor changes are required to transfer other existing CHILL software to the HOT.

Siting of the radar system was a third area of considerable activity. After correlation with University of Illinois officials, four sites in and around the University Airport were assessed. Two sites were chosen and requests for permission to install were prepared and submitted to the UI officials (who subsequently approved both sites). These have been sent to the FAA for assessment. As soon as permission is obtained, antenna installation will begin.

CHAPTER 9: DEVELOPMENT OF A WEATHER MODIFICATION LIBRARY

Stanley A. Changnon

PACE and its antecedent weather modification research projects funded by the Bureau of Reclamation, NSF, and the State of Illinois now span a period of 18 years. A large number of publications have been generated in this period.

This same 18-year period has seen a proliferation of research, both atmospheric and impact-oriented relating to weather modification. Dimensions of the potentially useful reference materials are now so large to make access to information relevant to a particular question cumbersome at best. Furthermore, some useful reference material was not located within the Water Survey's main library and was in the sole possession of various staff scientists. Then, an opportunity to obtain a historical weather modification extensive set of reference materials occurred in 1987. An ex-federal official who had been involved in weather modification research and management for more than 20 years provided the Water Survey with his entire library.

A part-time librarian was employed to assess all existing references of our main library, private staff files, and the library gift into a single set of federal references. Annotation was done for these along with key words. This "weather modification library" allows for more meaningful research and rapid access of reference materials.

CHAPTER 10: PROGRAM MANAGEMENT AND FUNDING ISSUES

Stanley A. Changnon

Funding Issues

A primary funding problem related to the conduct of this project was the considerable delay in the receipt of funding needed for the PACE-86 field operations. The provision of funds, at a level reduced from that requested, finally occurred in August 1986, four months after the requested starting date. This created considerable problems, particularly due to the need to make commitments to contractors and purchases of supplies and services associated with the field project. Several letters and memoranda of complaint were provided to NOAA officials in Boulder and Washington, D.C. Funds had to be borrowed from the prior project ($25,000 set aside to pay for delayed equipment) and from the University of Illinois at a cost of reputation and credibility. Considerable extra efforts (and costs) were devoted to dealing with this issue throughout the initial months of this project.

Second, due to the actions in Congress to reduce federal expenditures, the amount requested for this year, $525,000, was reduced to $501,000. This reduction was realized in a reduction in the atmospheric research planned for this 14-month period.

Another funding-related issue concerned the delay in the delivery of a major radar system, the signal processor for the HOT radar expected to be delivered in the prior year project. A continuing delay in the delivery of this unique processor, which was to have been paid for by funds from the prior contract (1985-1986), existed. Because of the aforementioned delay in funding of this particular project, the funds set aside to pay for the processor from the prior cooperative agreement were utilized to meet essential operational costs in May-June 1986. That meant that the funds, approximately $25,000, for the processor had to be set aside out of this latest 14-month cooperative agreement to pay for the processor which was delivered in September 1987. The paperwork and communications involved in this action were also quite time consuming, involving NOAA, DOC, University of Illinois officials, and Water Survey staff.

Management Issues

Management of the project, the field efforts and the research efforts, proceeded relatively smoothly. An enormous field effort was conducted by a dedicated staff who worked 61 straight days without time off for vacations or weekends. Morale was high and remained high throughout the analyses of the data collected in PACE-86.

Management also included internal management of the allocation of funds, a time consuming task. Internal management included staff meetings to discuss operations and ensuing research plans. Planning also began for the PACE-88 field effort during this period, another time consuming management related activity.

Another administrative activity for PACE has related to in-state activities. Several radio and television programs focusing on PACE were conducted. Groups interested in weather modification, particularly in central Illinois, have been interested in and monitored the PACE activities closely. This involved two groups of visitors during PACE-86 and has subsequently involved subsequently two 1-day meetings with these groups.

The project leader during this period has been asked by the World Meteorological Organization to serve as a rapporteur for inadvertent weather modification. The federal government also asked the Principal Investigator to prepare the United States position on weather modification for the World Congress of WMO held during the fall of 1986. The continued state interest in PACE requires maintenance of interactions with other state agencies and with certain members of the state legislature who are particularly interested in or concerned about weather modification.

The project manager and principal investigator, also had to interact extensively with NOAA and Department of Commerce officials during the 14-month project. The interactions with the NOAA program manager involved a variety of expected interactions relating to the field operations and research activities. The NOAA program manager visited the project, and the PACE project director, visited with the program manager three times during the 14-month period in Boulder. Other PACE-related meetings were conducted at the International Weather Modification Session in Vancouver, Canada, in August 1987, and at the Weather Modification Association's Annual Meeting in Albuquerque, New Mexico, in April 1987. The meeting at the WMA conference also included the NOAA representative from Washington involved in weather modification reporting.

A management activity that was time consuming (during the 14-month project period) related to the activities of the Inspector General's Office of the Department of Commerce. Three representatives of this office visited the field project for three days in July 1987, reviewed the operations, and engaged the staff and the PACE project director in extensive discussions. This was part of an assessment of NOAA's activities relating to PACE and the 3 other projects involved in the Federal-State Cooperative Weather Modification Research Program. Following the visit of the Inspector General's team, a preliminary report was issued and comments were sought from us. A joint response to the Inspector General was prepared by the four states in the Program and extensive related communications with NOAA leadership, both written and by telephone, were conducted. Following this activity, a draft report of the DOC Inspector General was provided to us in March 1987. Its contents, calling for a shift of the Federal-State Program in NOAA to the Bureau of Reclamation, brought on further interactions with NOAA staff and others. The Illinois program leader, along with those of the other three states, met with NOAA representatives, and prepared and presented a 4-state position document to NOAA and to the Inspector General's office.

Another project management effort involving considerable time concerned the interactions with members of Congress and their staffs interested in PACE. For several years, PACE and the other state programs in the Federal-State Weather Modification Cooperative Research Program have been based on funds mandated by Congress to the NOAA budget. This situation required a level of communication with Congressional staff. Documents describing the project and its progress were prepared and provided to the Illinois Congressional Representatives and Senators during 1987.

An additional effort in program management related to the NOAA review of a laboratory program review held in Boulder during October 1986. The planning, preparation, and handling of this review were time consuming. Certain features of the planning were such that the PACE impact materials presented were seen as inappropriate by the review group. The NOAA handling of this activity was viewed inadequate.

CHAPTER 11: PUBLICATIONS AND SCIENTIFIC PRESENTATIONS

Staff

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