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ANALYSIS OF T-28 DATA FROM THE 1978 CSD FIELD SEASON IN COLORADO

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ABSTRACT

This report describes the analysis of T-28 data gathered during the Convective Storms Division field season in 1978. The characteristics of the vertical velocity regions encountered are presented, as well as the implications these characteristics have toward the precipitation mechanism occurring in northeast Colorado convective clouds prior to the time they reach the cumulonimbus stage of development.

The primary characteristics investigated were vertical velocity strengths, cloud liquid water concentrations, equivalent potential temperature, and ice hydrometeors. The principal finding was the frequent observation of sub-adiabatic liquid water concentrations in both strong updrafts and downdrafts. The number concentrations of ice crystals in these observations were usually very low, and some of the hydrometeors were of the order of several millimeters in their maximum dimension.

The presence of strong vertical velocity regions with very low concentrations of precipitation-sized hydrometeors suggests that a penetrative downdraft mechanism was active in these clouds.

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1. INTRODUCTION

This is a report of analysis performed on T-28 data gathered during the Convective Storms Division (CSD) 1978 field season under Contract No. S9008.

The purpose of the research was to examine cloud physical processes occurring in selected regions of the T-28 penetrations in order to help gain a better understanding of the precipitation mechanisms occurring in northeast Colorado storms.

Originally the primary research emphasis was to arrange data from various T-28 penetrations with respect to first radar echo formation, followed by an investigation of how certain variables were related to first echo formation. However, the unavailability of FAA flight track information for much of the season precluded the use of much of the data for establishing first echo locations. Most of the remaining first echo cases occurred before the T-28 penetrations, which made the study of precipitation formation very difficult by this method. Simultaneously another study was underway, which was to describe the character of the vertical velocity regions encountered by the T-28 and how those characteristics were related to the precipitation mechanism. The results of this latter investigation form the basis for this report.

2. BACKGROUND

One of the most bewildering aspects of cloud physics research is the extreme variability of the parameters being observed. Such items as vertical velocity, liquid water concentration, and ice crystal habits and concentrations show such extreme variability that the task of making sense from the data is almost overwhelming. This makes studies of the precipitation mechanisms of storms extremely difficult. Thus, the 1978 CSD field season was designed to investigate the formation of precipitation in smaller storms earlier in their development, presumably when the precipitation process might be simpler and easier to observe and understand.

Even though it has been shown that the ice process plays a dominant role in the precipitation mechanism of High Plains thunderstorms (Dye *et al.*, 1974), the details of that process are not well understood. Questions persist about where the ice crystals form, as well as their trajectories, and the lack of knowledge concerning the growth environments of these particles. Liquid water concentrations which supply the fuel for the growth of the hydrometeors are apparently governed by processes that are not well understood. Further down the road are implications of these questions for weather modification processes.

Vertical motions in convective clouds are intrinsically tied to the precipitation mechanism. Therefore, a detailed knowledge of the characteristics of the vertical velocity regions is extremely important to any precipitation study. This study was undertaken to examine the character of the vertical velocity regions encountered during certain T-28 penetrations during the 1978 field season.

2.1 The 1978 Field Season

The 1978 CSD field experiment emphasized the gathering of data from convective clouds early in their development, near the time of first radar echo formation. The experiment was a coordinated one involving three aircraft assigned to the in-cloud data-gathering task. The T-28's role was to penetrate the mid-altitude region of the cloud, while the high-altitude aircraft was a NOAA/NCAR sailplane, and the low-altitude aircraft was the University of Wyoming Queen Air. The latter aircraft was assigned the additional task of selecting the cloud, as well as coordinating the penetrations. The main task was to gather information from inside the clouds in as nearly simultaneous fashion as possible. No attempt was made to include data from the sailplane and Queen Air in this study because of analysis time limitations.

The area of operations was within about a 100-km radius of Grover, Colorado, which includes portions of southeast Wyoming, southwest Nebraska, and northeast Colorado.

3. T-28 SYSTEM

The T-28 has been modified to make intentional penetrations of thunderstorms and hailstorms (Johnson and Smith, 1980). It has been armored to withstand hailstones up to about 7.5 cm[*] and is equipped with an elaborate instrumentation system which emphasizes observations of the cloud microphysics, but also provides measurements of temperature, vertical air motion, turbulence, and other quantities of interest.

The instrumentation used during the 1978 field season is summarized in Table 1. The main feature of the data acquisition system is that it has the capability of sampling over virtually the entire hydrometeor spectrum, as well as making a distinction between the liquid and solid phases of water.

The primary recording system carried on the T-28 consists of a Precision Instruments Model 1387 computer-compatible magnetic tape recorder and a Monitor Labs Model 9100 multiplexer unit. This system is capable of recording 30 BCD digits of information plus 24 channels of analog data converted to digital form. The basic recording interval is once per second, although some of the variables are sampled twice during each 1-sec cycle to provide higher frequency response. In addition, a Pertec digital recorder is used to record the particle size information from the Particle Measuring Systems (PMS) probes and also serves as a back-up recorder. It records all digital and some of the analog data that are recorded on the primary system.

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[*] All sizes of hydrometeors are expressed as diameter unless otherwise noted.

TABLE 1

T-28 Instrumentation Complement

Variable	Instrument	Range of Measurement
State:		
Static Pressure (Altitude)	Rosemount 1301-A-4-B Ball Engineering EX-210-B	0 to 15 PSI 0 to 27,000 ft (8.2 km) MSL
Total Temperature	Rosemount 102AU2AP, platinum wire NCAR Reverse Flow, diode	-25 to +25°C -25 to +25°C
Hydrometeors:		
Cloud droplets	Johnson-Williams LWC	<50 µm dia (liquid only); 0 to 6 g m^{-3}
	Particle Measuring Systems FSSP	3 to 45 µm dia; adjustable
Rain, graupel, snow	Williamson Foil Impactor	1 to 20 mm dia
	Particle Measuring Systems OAP-2D	31 to 1000 µm
	Cannon Particle Camera (alternates with hail spectrometer)	Approx. 50 µm up
Hail	IAS Laser Hail Spectrometer (alternates with Cannon camera)	4.5 to 50+ mm dia
Aircraft Navigation & Performance:		
Attitude	Servomechanisms TR541 angle-of-attack vane	-15 to +15°
	Pitch (Humphrey vertically-stabilized accelerometer)	-50 to +50°
	Roll (Humphrey vertically-stabilized accelerometer)	-50 to +50°
Navigation	IAS Heading indicator	0 to 360° magnetic
	NARCO UDI-2ARD DME	0 to 100 n mi
	CESSNA 400 DME	0 to 100 n mi
	NARCO MK12 VOR (2 units)	0 to 360° from
	NARCO NAV-122 VOR	0 to 360° from
Performance	Ball Engineering 101A variometer (rate-of-climb)	-6000 to +6000 ft min^{-1} (-30 to +30 m s^{-1})
	Rosemount 1301-D-1-B dynamic pressure (ind. airspeed)	-3 to +3 PSI
	NCAR True Airspeed Computer	0 to 250 knots (128 m s^{-1})
	Humphrey SA09-D0101-1 vertically-stabilized accelerometer	-1 to +3 g's
	Giannini 45218YE manifold pressure	0 to 50+ in Hg

4. SUMMARY OF DATA

4.1 General Comments

During the 1978 field season, the T-28 accomplished 63 cloud penetrations during 9 research flights (Prodan *et al.*, 1978). Of these, two flights early in the season were not used in this analysis because of known coordination and operational problems. A third flight later in the season was also removed from the data sample because it was in a mature storm and made specifically to test modifications made to the hail sensor. It was not carried on any of the other flights during the 1978 field season. The data from the remaining six flights were screened, primarily to remove penetrations with known problems that would adversely affect the vertical motion measurements. For instance, a small number of penetrations were eliminated when the aircraft was known to be climbing intentionally during a penetration while enroute to a rendevous point with the other aircraft, or when the aircraft was known to be in a rather well developed storm which essentially was mature and hence did not fit the criteria set down for the 1978 field season. A small number of penetrations were added to the data sample when penetrations were known to have passed through two clouds, a situation which showed up as one penetration in the recorded T-28 data. The screening left a total of 49 penetrations, the distribution of which is given in Table 2. Also shown are nominal altitudes and temperatures for each flight, as well as estimates of cloud bases and tops.

TABLE 2

T-28 Flight Summary - 1978 CSD Program

Date	Flt.	Pens.	Avg Alt [km MSL]	Avg T [°C]	Est Cloud Base [°C]	Est Radar Top [km MSL]
11 Jul 78	228	7	5.9	-8.1	+1	9.3
13 Jul 78	229	9	6.1	-9.7	+3	11.6
18 Jul 78	231	9	6.1	-10.3	+3	9.6
19 Jul 78	232	5	6.3	-10.0	+5	9.5
30 Jul 78	237	10	6.3	-13.4	+2	8.9
30 Jul 78	238	9	5.7	-8.6	-2	8.4

Because of aircraft positioning problems during the 1978 field season, it is difficult to say how many different clouds the 49 penetrations represent, but according to the pilot's voice comments and changes in target points during each flight, there are about 18 different clouds in the data sample at various stages of development ranging from towering cumulus to near cumulonimbus. Because there was not a dedicated cloud base aircraft for most of the cases in this study, cloud base was estimated from an appropriate radiosonde using a 50-mb mixed layer in the lowest level. Cloud tops were estimated from CP-2 radar data (5-dBz threshold). Since some of the cases never developed an echo, some tops had to be estimated using radar data from a neighboring cloud. Most of the clouds in this study were turrets that developed near a pre-existing cloud, which was often in a mature stage of development. Without a dedicated tracking system and especially with the failure of the post season FAA tracking data on 11 July and 30 July (both flights), it was virtually impossible to determine exactly where the T-28 was actually penetrating in a cloud in all cases.

The horizontal dimensions of the clouds penetrated can be seen in Fig. 1, which shows a frequency distribution of penetration lengths for the clouds penetrated during flights shown in Table 2. The penetrations ranged in length from 30-224 sec, which is equivalent to distances of about 3-22 km based on a nominal penetration speed of about 100 m s^{-1}. The average length was 96 sec with a standard deviation of 47, suggesting that many of the clouds penetrated during the 1978 field season were too large for studying initial precipitation formation. Only about 20% of the cases are in a size category between 3-5 km, which probably would be more suitable for precipitation formation studies. Many of the clouds also had weak radar echoes at the time of penetration.

4.2 Vertical Velocity Distribution

Arbitrary criteria were used to select the vertical velocity data used in this analysis. The draft region had to exist continuously for at least 5 sec (thus having a horizontal extent of about 0.5 km or more) and had to have a peak value greater than 2 m s^{-1} for the updrafts or less than -2 m s^{-1} for downdrafts in order to qualify for the data sample. This is felt to be within the accuracy of the vertical velocity calculation used in the T-28 analysis. Regions of the penetrations which did not fit the criteria for selection were classed as neutral and were not used in the analysis. The complete breakdown showing various parameters for each draft region is discussed in Appendix A.

Figure 2 shows the frequency distribution for peak updrafts and downdrafts collected in the manner described above. There were often several drafts per penetration and 60% of them were downdrafts. This is due to the fact that on many penetrations, the vertical velocity field consisted of an updraft with downdrafts on either side. Many

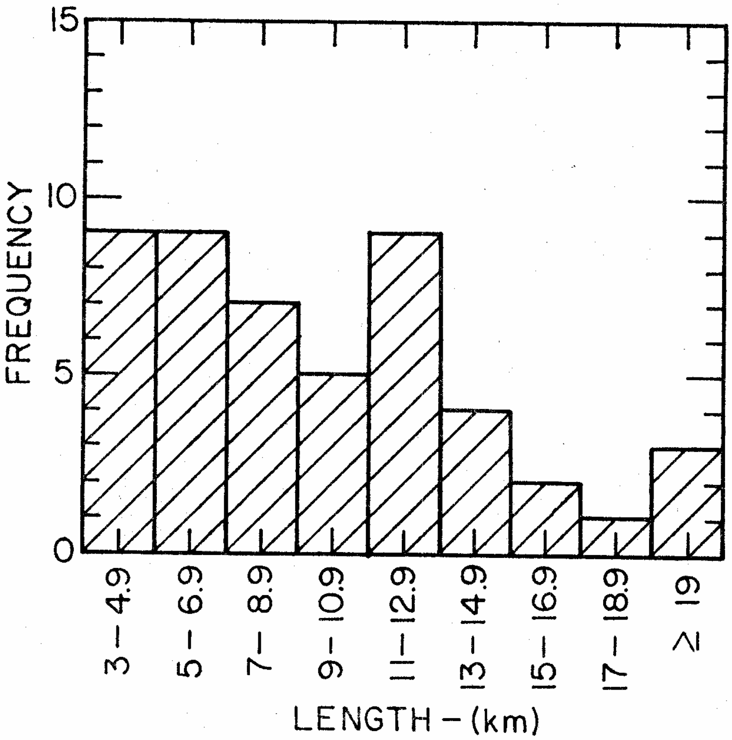

Fig. 1: Frequency distribution of penetration lengths for clouds penetrated by T-28 during 1978 field season.

penetrations had multiple draft regions. The modes and medians for the updraft and downdraft regions occur in the first category in either case, which corresponds to weak drafts of about ±5 m s^{-1}. The drafts were sometimes very strong, again suggesting that some of these storms may have been too large or too well organized for studying precipitation formation. Although stronger updrafts have been observed by the T-28 in more intense thunderstorms, the maximum downdraft of -26 m s^{-1} is the strongest observed up to 1978.

The size of the vertical velocity regions is illustrated in Fig. 3. There is no way of knowing whether these measurements represent the maximum dimensions of the draft regions encountered because there is no way of knowing for certain which parts of the regions the aircraft actually penetrated. However, there are striking similarities between these observations and those observed by the T-28 during previous field seasons in the National Hail Research Experiment (Musil et al., 1977). About one-half of the draft observations in each study are between 1-2 km wide and about 80% between 1-4 km, even though the observations described here typically were from much smaller and less organized clouds, which usually had no precipitation reaching the ground.

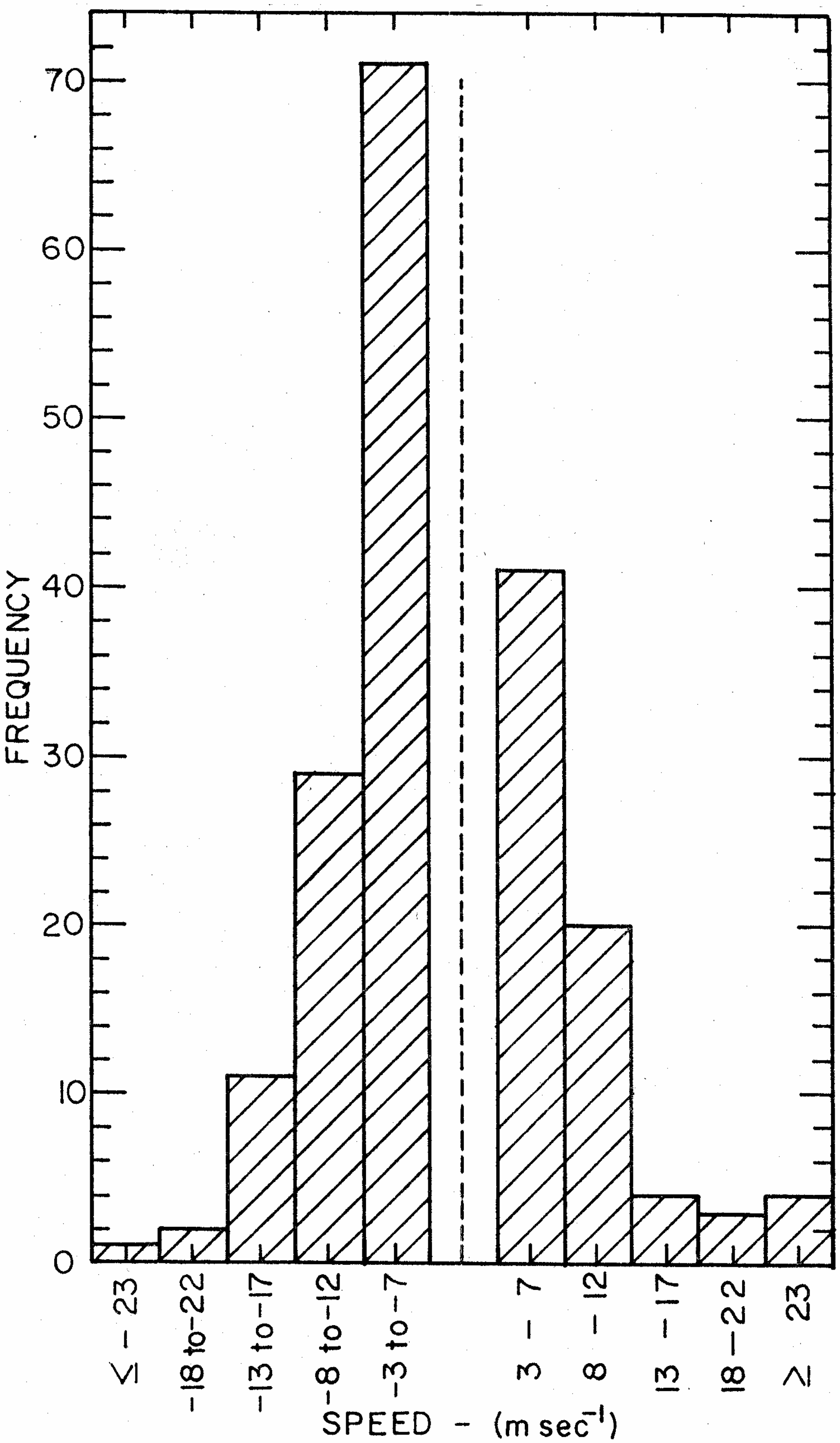

Fig. 2: Frequency distributions for peak updrafts and downdrafts encountered by T-28.

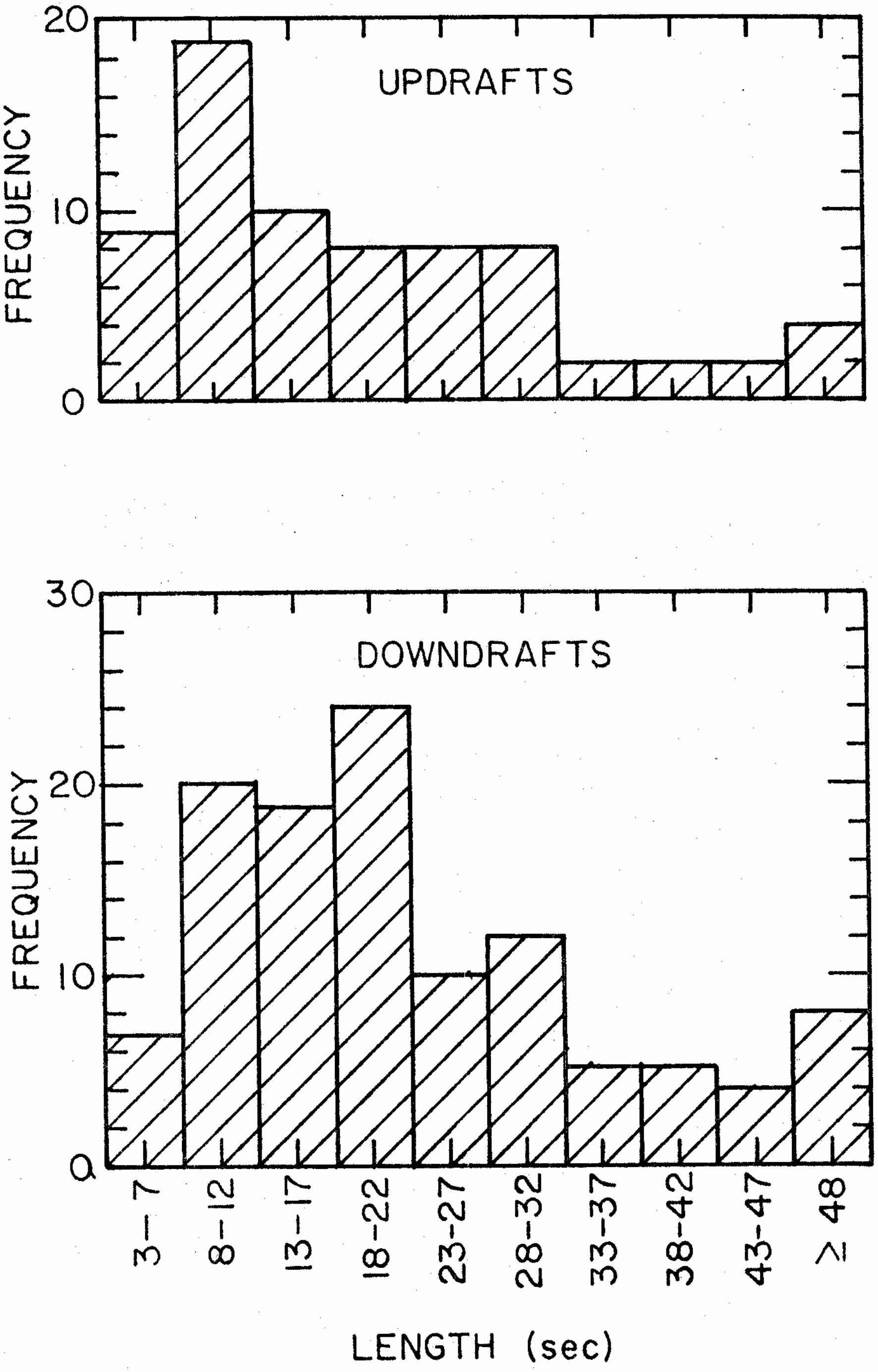

Fig. 3: Frequency distribution for sizes of updrafts and downdrafts encountered by T-28.

4.3 Cloud Liquid Observations

A Forward Scattering Spectrometer Probe (FSSP) was used to calculate the liquid water concentration (LWC) in this study. The FSSP sorts cloud droplets into 15 size categories between 0-45 μm. The distributions are available once s^{-1} and the LWC values are obtained by converting each size category to its equivalent mass and summing over each category.

The FSSP data were examined carefully for any evidence of false detection of ice crystals and for coincidence errors. An examination of the FSSP data almost always shows the droplet spectra to be quite narrow, a situation typical of Colorado convective clouds (Fig. 4).

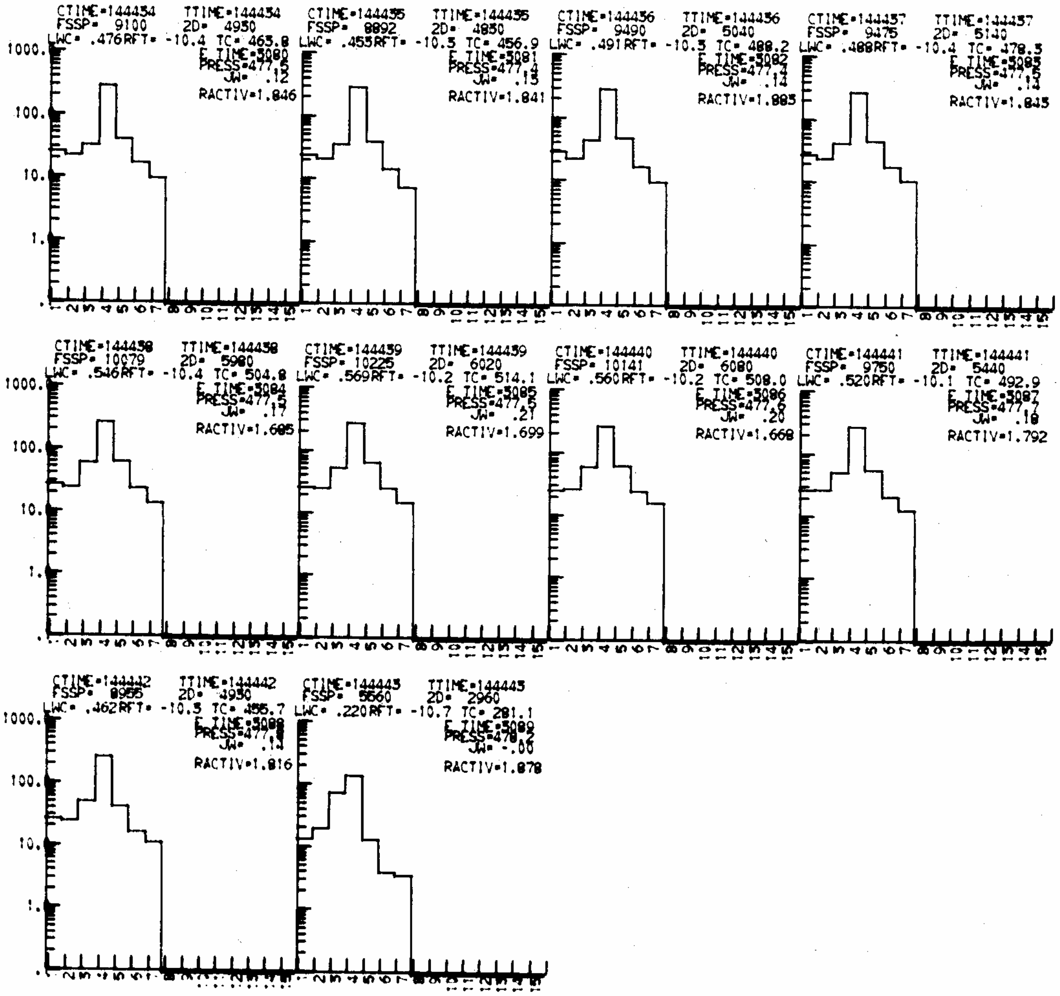

Fig. 4: Sample cloud droplet spectra measured by FSSP device on 11 July 1978.

Thus, there are practically no cloud droplets larger than about 20 μm, indicating that the FSSP probably was not detecting any significant numbers of ice crystals. These have occasionally appeared in size categories larger than 20 μm in the past. A few larger particles were detected on the flights of 30 July when the LWC values were generally higher than at any other time during the field season. However, there is no reason to suspect that these larger particles are ice when they occur in conjunction with smaller particles. In any event, the large particles were so infrequent in these data that even if they were ice, they would have had very little effect on the LWC observations.

The FSSP has occasionally experienced coincidence error problems in the past. This is recognized by a dip or minimum in size categories near where the mode is usually expected (∿10 μm in Colorado observations), indicating that some categories may have been saturated and, hence, all particles were not counted. The examination of the FSSP data showed that the spectra were quite variable. This normal situation leads to typical distribution forms similar to those shown in Fig. 4, which have no known coincidence problems. Furthermore, total FSSP counts were similar to past observations. All indications were that the FSSP worked properly during these penetrations. Therefore, the cloud liquid data obtained from the FSSP are felt to be representative of the actual conditions in the clouds where the T-28 penetrated.

The distribution of peak liquid water concentration in the vertical velocity regions is shown in Fig. 5. The LWC values showed extreme variations, ranging between 0-2 g m^{-3}. The most notable features are that the amounts of cloud liquid are quite low and there are great similarities in cloud liquid amounts between downdraft and updraft regions. In other words, the cloud liquid is generally spread throughout the cloud. The median occurs in the range of about 0.5-1.0 g m^{-3} in both updrafts and downdrafts. The mode tends to be higher in the updrafts (about 0.5-1.0 g m^{-3}) than in the downdrafts, where it is about 0.1-0.5 g m^{-3}. Although there is some tendency for LWC to be higher in the updrafts than in the downdrafts, the LWC values appear to have little relationship to peak vertical velocity strengths. An analysis of stronger, more organized storms (Musil _et al._, 1977) showed a fairly good direct relationship between peak cloud liquids and peak vertical velocities. The presence of rather high cloud liquid amounts in the downdrafts is in agreement with observations by Hobbs _et al._ (1980) in small eastern Montana clouds.

The distribution of the cloud liquid across the vertical velocity regions is shown in Fig. 6, which shows frequency distributions of the ratio of continuous LWC length to length of the vertical velocity region. Whenever the ratios are greater than 1, it indicates that the LWC regions are larger than the corresponding vertical velocity regions.

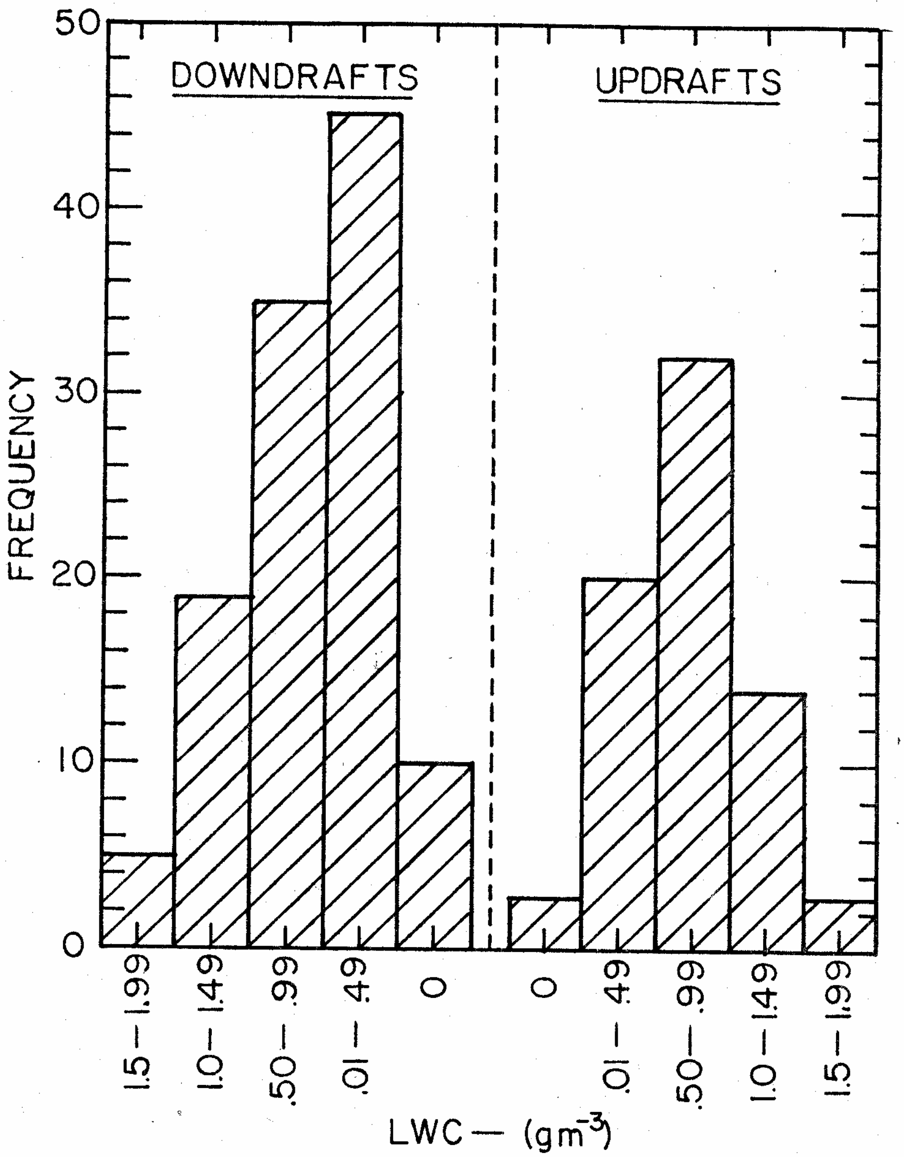

Fig. 5: Frequency distributions for peak cloud liquid water concentration in updrafts and downdrafts as measured by FSSP device.

The ratios exceeded 1 about 75% of the time in the case of the updrafts and about 65% of the time for the downdrafts. This means that the LWC regions are spread beyond the edges of the respective draft regions. In other words, most draft regions are completely filled with cloud water, although there is a tendency for the higher values to be in the updrafts when the updrafts and downdrafts are adjacent. A greater percentage of the updrafts are completely filled with cloud liquid than are the downdrafts; however, about two-thirds of the downdrafts are completely filled with cloud liquid.

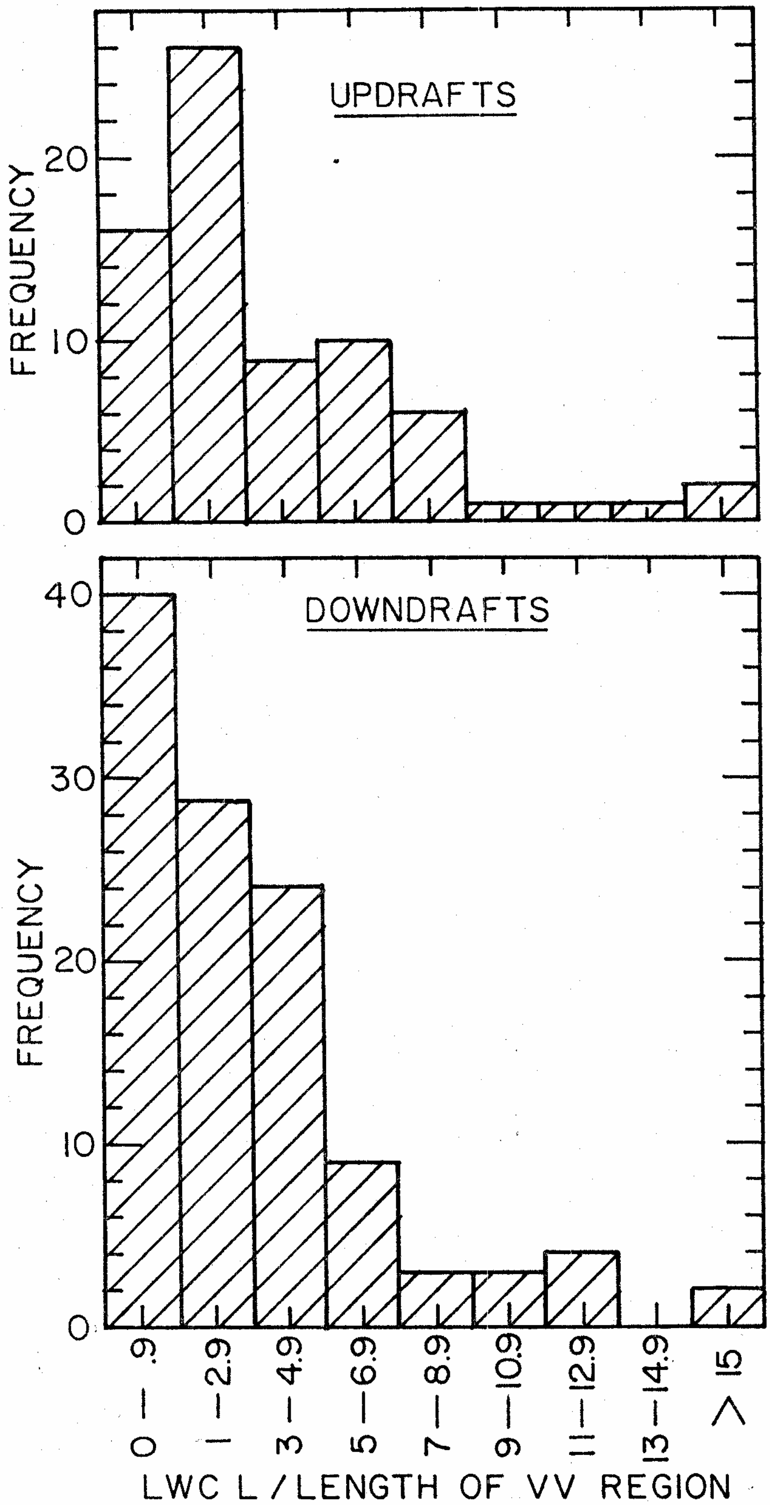

Fig. 6: Frequency distributions for ratio of continuous cloud liquid water concentration lengths to length of vertical velocity regions.

Since vertical velocity calculations from aircraft data have certain inherent errors, it is possible that this could lead to some sort of misrepresentation of the LWC values in the vertical velocity regions. Although the method used relies on the differentiation of high resolution altitude data, this could only cause problems where the vertical velocity values are very weak, so that at times we might not be able to detect whether the air was actually an updraft or a downdraft. In fact, high values of cloud liquid are nearly as common in the more well organized, strong downdrafts as in the small vertical velocity regions. Therefore, any inherent errors in the vertical velocity calculations are probably not large enough to cause any appreciable problems with data interpretation.

The ratio of peak LWC to the appropriate adiabatic value (w/w_a) for each vertical velocity region is shown in Fig. 7. Peak LWC from each draft region encountered was compared with the appropriate adiabatic value to form the ratio. Since little or no cloud base information was available for these cases, 50 mb of moisture was mixed on an appropriate sounding selected for each flight, in order to determine the adiabatic cloud water value for each case.

The frequency distribution shows a mode around 30% for updraft and downdraft regions. No values exceeded adiabatic. In fact, most of the higher values in the entire data sample came on the last two flights which happened to occur on the same day. In any event, there is very little difference in w/w_a between updrafts and downdrafts and the concentrations are well below adiabatic.

4.4 Equivalent Potential Temperature

The distribution of equivalent potential temperature (θ_e) in these penetrations also exhibited wide variations. The average values of θ_e in the updrafts and downdrafts for each flight are shown in Table 3, and Appendix A has average values for each draft region. Also shown in Table 3 are the appropriate adiabatic values of θ_e for each flight as determined from an appropriate sounding on each day. On the average, θ_e was sub-adiabatic in both the updrafts and downdrafts, but there often were small regions in both the updrafts and downdrafts that were near adiabatic values, and a few times when adiabatic was exceeded. The average values of θ_e in the updrafts were greater than those in the downdrafts, but the average differences are only of the order of 1° or less. In some cases, θ_e peaks in the downdraft exceeded those found in an associated updraft.

4.5 Hydrometeors

Three devices were used for the determination of ice crystal habits, sizes, and concentrations in this study. These were a 2-D Optical Array Probe (2D-C), a foil impactor, and a particle camera. The most vital

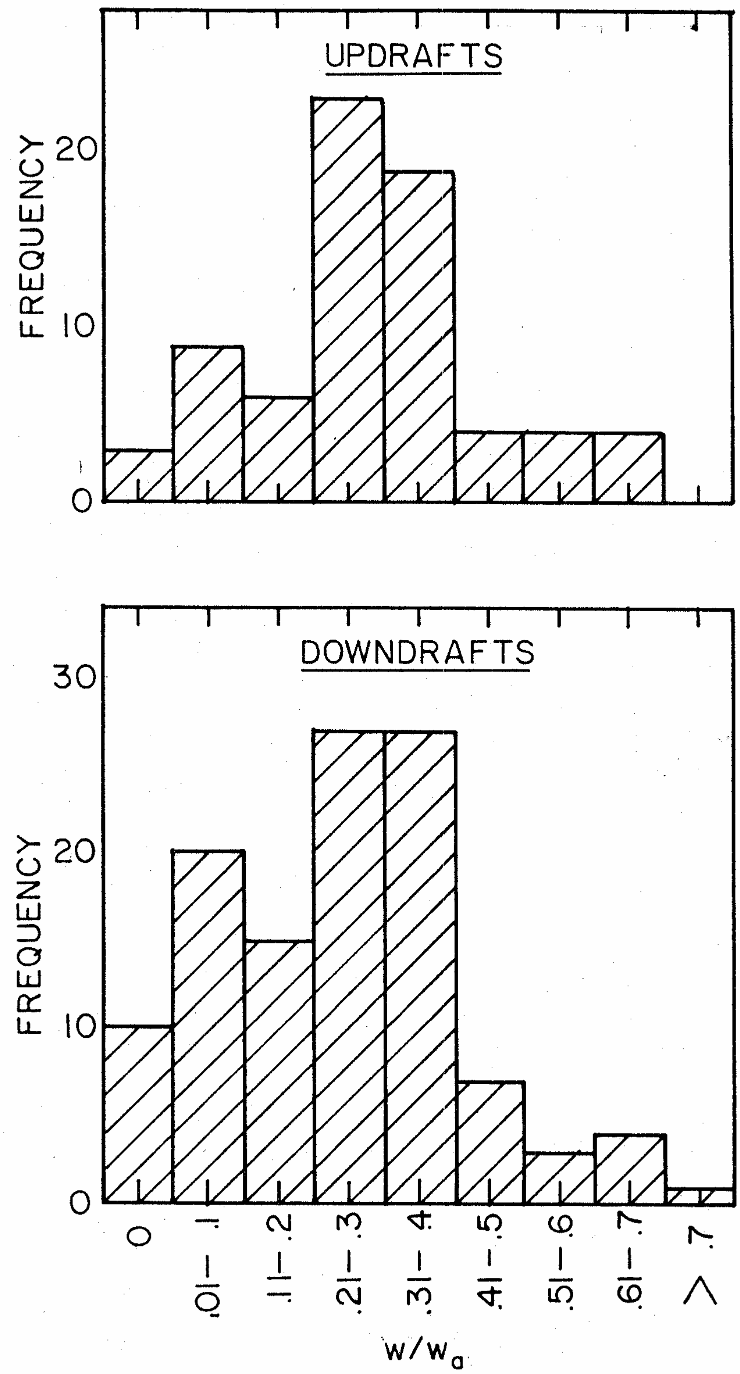

Fig. 7: Frequency distributions for ratio of actual peak cloud liquid water concentration to adiabatic value for each vertical velocity region.

TABLE 3

Equivalent Potential Temperatures

	Adiabatic	Updrafts		Downdrafts	
July	θ_e	θ_e	s	θ_e	s
11	341	337.1	1.0	336.4	1.2
13	341	337.3	1.5	336.3	1.7
18	338	335.9	2.0	334.8	1.5
19	345	338.7	1.5	338.0	1.4
30 (1)	334	331.8	1.1	331.5	1.0
30 (2)	334	333.7	1.5	332.7	1.1
		335.8		335.0	

instrument was the 2D-C. Unfortunately, it malfunctioned during parts of the 1978 field season so that precise ice measurements were precluded during segments of the penetrations. The reasons for the problem with the 2D-C are unknown, but may have been due to loose optics, or in some cases due to shedding of particles from the tips of the probe. Nevertheless, the 2D-C provided hydrometeor information in the size range 25 μm to about 1 mm, although extrapolations are used if the particle is partially outside the array to obtain data for particles > 1 mm (Heymsfield and Parrish, 1979).

The foil data were analyzed for each of the penetrations to obtain an estimate of hydrometeors > 1 mm. Even though smaller particles were observed on the foil, only those larger than 1 mm are acceptable because of sampling problems (Knight *et al.*, 1976).

A preliminary analysis of the particle camera data performed by CSD personnel showed graupel on the 18th, 19th, and the first flight on 30 July, while on the 11th, 13th, and the second flight on 30 July, there were combinations of graupel and aggregates. There were numerous artifacts on the film on all the flights, which are likely a result of static discharges, dirt, fogging, etc. The phases of the particles were almost exclusively ice, with the possibility of a few liquid particles on the second flight on 30 July.

The characteristics of the hydrometeor observations are given in terms of maximum dimension and average concentrations of the total number of particles (N_T), number larger than 0.5 mm (N_5), and number larger than 1 mm (N_{10}) for each draft region used in the study. These values are given in Appendix A. Only the 2D-C and the foil impactor data were used because the massive manual reduction required for the camera data precluded its use for determination of detailed concentrations.

The number concentrations of ice crystals in these observations were generally very low, except for some of the later penetrations on 13 July. The mass concentrations due to the ice in these observations were no greater than about 0.1 g m^{-3}. Therefore, the total water concentration during these penetrations is still well below that which would be expected from adiabatic considerations, at the levels of T-28 penetrations. Quite large hydrometeors were present on some of the penetrations, but in very low concentrations of only a few m^{-3}. This can be contrasted with larger storms where observations of the order of 10^2-10^3 m^{-3} are often made with the T-28 system.

An attempt was made to identify the primary ice crystal habit using the 2D-C data. In most cases, no single ice crystal habit could be identified as predominant because the habits were usually mixtures. Furthermore, particles < 200 μm or so cannot be identified with respect to habit because of resolution limitations in the 2D-C device. Nevertheless, graupel was observed on all flights, but aggregates were common in many regions. The largest hydrometeors were of the order of several mm in their maximum dimension and the habits of the largest particles were usually in the form of aggregates or snowflakes, with some that appeared to be graupel.

4.6 Data Samples

Figures 8-10 show examples of the types of draft regions that were encountered during the 1978 field season. The figures show vertical velocity, LWC, and θ_e from portions of three different penetrations on three different days.

Figure 8 shows a situation where the LWC and the increase in θ_e were well confined within the updraft, with virtually no overlap into the downdraft regions. On the other hand, Figure 9 illustrates a case where the LWC does overlap into the downdraft region, near an interface region between the updraft and downdraft. Figure 10 is a case with quite high LWC throughout the entire draft region. Also shown in this case is a high θ_e value (higher than in the updraft) directly in a fairly strong downdraft region.

These cases are only illustrations of the variety of conditions which existed in the various draft regions. Also the reader is referred to Appendix A for indications of corresponding hydrometeor information.

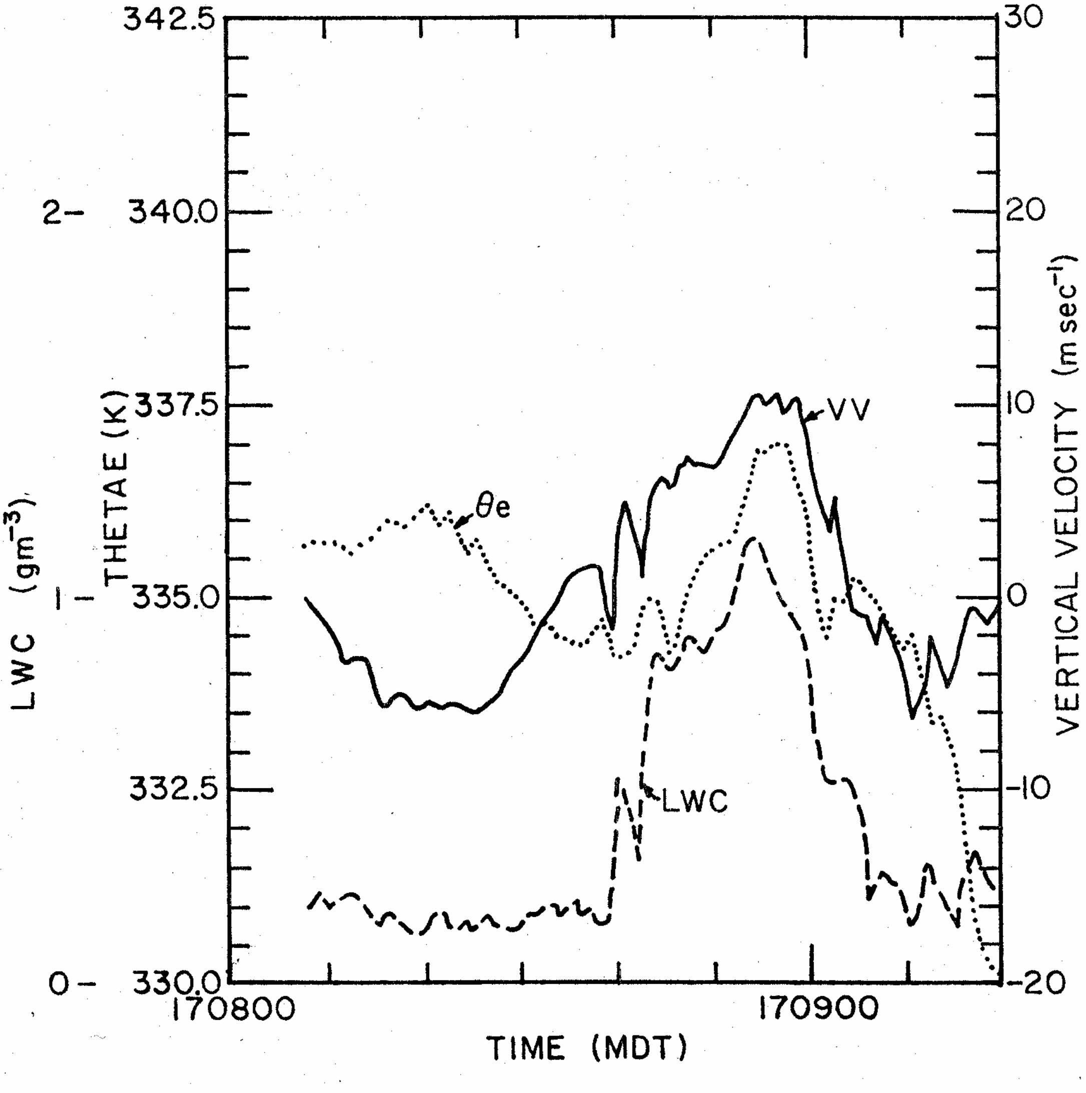

Fig. 8: Sample of data encountered by T-28 on 30 July 1978.

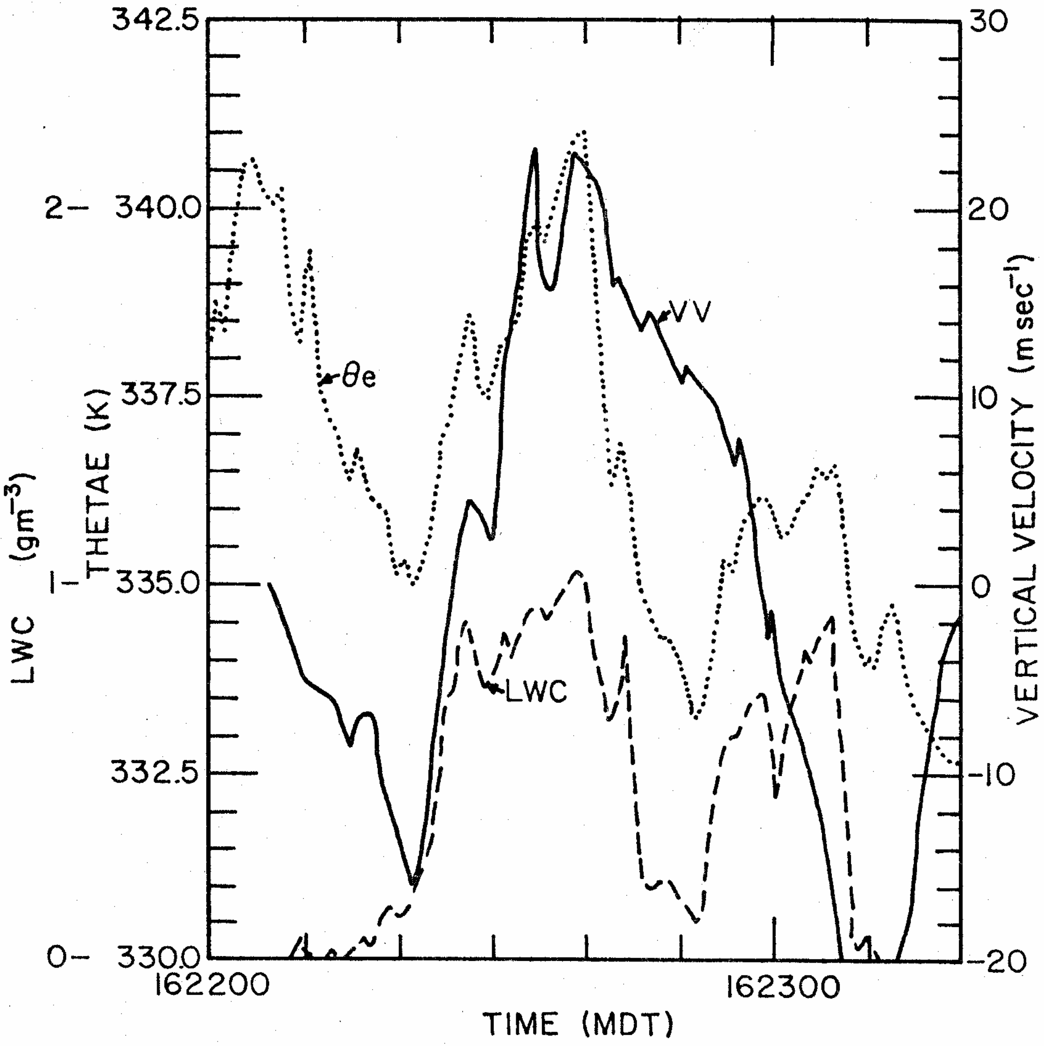

Fig. 9: Sample of data encountered by T-28 on 18 July 1978.

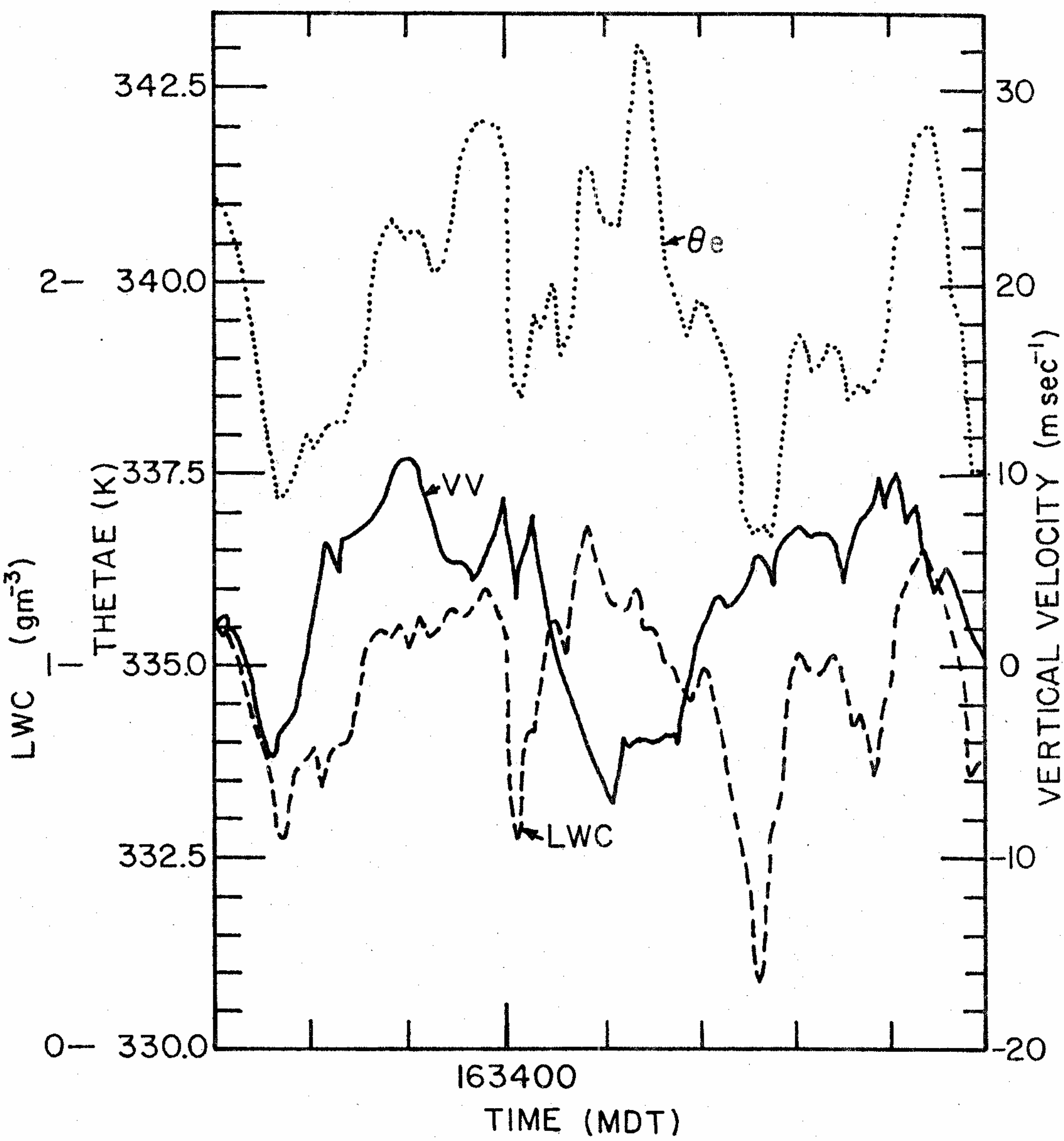

Fig. 10: Sample of data encountered by T-28 on 19 July 1978.

5. DISCUSSION

5.1 Mixing and Entrainment

The sub-adiabatic LWC observations require that some sort of mixing between cloud and environment be invoked in order to explain the observations. A mixing process, by whatever mechanism, should tend to dilute the LWC observations. In this regard, the T-28 observations of LWC in this study are essentially in good agreement with observations by others, as well as with past T-28 observations.

Past observations of cloud liquid by other investigators, especially in small cumulus clouds, not only show the ratio of cloud liquid to adiabatic liquid (w/w_a) to be < 1, but also indicate a rapid decrease with height (Warner, 1977). Although observations of near adiabatic and even super-adiabatic values of cloud water in small clouds have been reported, they tend to occur over very small time and space scales. There have been reports of near adiabatic values in some larger, more organized storms (Heymsfield _et al._, 1978).

The more typical observations in convective clouds at all stages of development have been for LWC to be much less than adiabatic. Warner (1977) found the ratios of w/w_a in small clouds to be about .43 and .46 using data sets from two different years. No adiabatic values were found in their observations. Although observations in large clouds are generally more scarce, the observations of cloud liquid are still low, usually much less than 1 g m^{-3}. Observations from penetrations of hailstorms (Musil _et al._, 1977) showed the ratio in the updrafts to be about .41 with just a couple of the observations barely exceeding adiabatic. Thus, the observations indicate that cloud liquids less than adiabatic are common to cumulus clouds at all stages of development, including the observations in this report.

The time variation of cloud liquid near a given altitude was studied by Sax and Keller (1980) in cumulus clouds in Florida. Their results from successive penetrations in the same cloud showed a rapid LWC decrease with time. Similar observations have been made in Project HIPLEX in southeastern Montana.[†] The observations suggest that if adiabatic cores exist, they would likely occur very early in cumulus development. Most T-28 observations are made later in the cumulus life cycle and show sub-adiabatic LWC values, much like the later observations of Sax and Keller. Of course, T-28 penetrations are usually in clouds that are so large that the lengths of the penetrations lead to time resolution that could not resolve the phenomena observed in Florida and Montana in smaller clouds, because it happens on the order of a few minutes.

[†] J. R. Miller, Jr., personal communication.

The T-28 observations in hailstorms in Colorado (Musil et al., 1977), in mature thunderstorms in Florida (Smith and Musil, 1980), and in the towering cumulus clouds in this study all show remarkable similarities with other investigations with regard to cloud liquid, which is almost always much below adiabatic.

The low LWC values observed at all stages of cumulus development by the T-28 and other groups raises questions about the necessity of adiabatic cores in convective clouds and the development of precipitation in them. While they may occur, the data suggest that the precipitation mechanism gets along with sub-adiabatic values. Furthermore, simple models show they are not necessary for typical hailstone growth (Dennis and Musil, 1973). Unknown organization factors may be more important so that the cloud can process air and water vapor more efficiently. There is a need to know more details about the variation of cloud liquid with time and height in cumulus clouds and in a more coordinated fashion than has been accomplished in the past.

The sub-adiabatic values of LWC could also mean that some of the cloud water was converted to ice or larger precipitation-sized hydrometeors, items that could not be observed by the FSSP. Furthermore, higher values might be located in unobserved regions of the cloud. Although observations of ice and larger particles were somewhat sporadic due to the previously mentioned equipment problems with the 2D-C device in 1978, concentrations were generally low anyway, leaving total water concentration well below adiabatic at levels of the T-28 penetrations. Fallout could not have been much of a factor in removing mass from the system because most of the clouds penetrated were non-precipitating, although some of the clouds merged and precipitated after the penetrations.

5.2 θ_e Variations

Generally, values of equivalent potential temperature were less than would be expected due to adiabatic considerations in both updraft and downdraft regions, suggesting that mixing was having a dilution effect. However, there were high values in both regions that were close to, or even exceeded, adiabatic.

The high values of θ_e found in the downdrafts in this study can be explained by assuming that the entrained air in these storms is coming from near cloud top. Since θ_e reaches a minimum between 6-8 km, once the cloud top exceeds that level, the entrainment process could mix in cooler, drier air from outside the cloud which has θ_e values similar to, or even higher than, those near the surface. Although there is no way of telling for sure whether entrained air came from above in these data, a penetrative downdraft mechanism (Squires, 1958; Paluch, 1979) could lead to mixing and dilution of the liquid water concentrations, while allowing θ_e to remain relatively high at times.

In the updrafts, mixing is undoubtedly having a dilution effect, too, because sub-adiabatic values of θ_e and LWC are the rule rather than the exception. High θ_e values do exist, but these can be expected from adiabatic considerations, if it is assumed that they result from relatively unmixed air which has been carried up from near the surface. It is possible that the high θ_e values in the updrafts could also be a result of mixed air from above, if one considers the evolution of a convective cloud. The entrainment of dry environmental air through the sides of an updraft or from below could lead to reduced LWC values, while leaving θ_e at relatively high values, but less than adiabatic because θ_e does decrease with height in the lower levels of the atmosphere. Regions of near-adiabatic θ_e are usually smaller than the updrafts in which they occur, suggesting mixing of entrained air from the sides is occurring.

The process is obviously complicated and there appears to be room for an infinite variety of conditions. Although the ideas given here are somewhat speculative, the line of reasoning does fit the general features of the T-28 observations quite well. The importance of mixing at all stages of cumulus development cannot be overestimated.

5.3 Precipitation Mechanism

Downdrafts in large convective storms in the High Plains contain large numbers of ice hydrometeors (Musil *et al.*, 1978). In the clouds studied here, ice was present but it was usually very small and in quite low concentrations. The dynamics appeared to dominate these developing convective clouds without any apparent assistance from the ice. Therefore, such things as updraft loading (Orville *et al.*, 1975) and LWC depletion (Musil *et al.*, 1978) by the ice hydrometeors have to be negligible, simply because there is too little ice present to accomplish them. Two-dimensional cloud models[‡] also show evidence of internal circulations (updrafts and downdrafts) around rising bubbles in a developing model cloud prior to the time of precipitation development.

The presence of strong vertical velocity regions with very low concentrations of precipitation-sized hydrometeors supports the idea that a penetrative downdraft mechanism (Squires, 1958) is active in the clouds studied here.

The exact origin of the air being entrained from above cannot be determined from these data, but a best guess would be near cloud top because this is a region where observations suggest strong mixing

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[‡] H. D. Orville, personal communication.

(McPherson and Isaac, 1977) is taking place. Visually, strong mixing and overturning is obvious near the tops of convective clouds. It is interesting that McPherson and Isaac observe sharp downdrafts near cloud tops along with the updrafts, lending support to the penetrative downdraft theory.

6. CONCLUSIONS

This report has presented an analysis of data gathered by the T-28 during the 1978 CSD field season. The principal finding in the study was the frequent observation of strong updrafts and downdrafts, each with sub-adiabatic liquid water concentrations. In fact, there was very little difference in the LWC distributions between the updrafts and downdrafts. Although the data set is from a single level, it provides insights into mechanisms occurring in convective clouds in a stage of development between towering cumulus and cumulonimbus.

The updrafts observed in this study were expected because the clouds usually grew very rapidly visually. For that reason, the strong downdrafts were not expected. Nevertheless, the vertical velocities observed in these clouds were similar to those found in moderate thunderstorms and hailstorms by the T-28 in previous field seasons. Work by other investigators has shown that comparable updrafts and downdrafts are also observed in small cumulus clouds at the same time, which suggests that this type of arrangement is an integral part of convective clouds at all scales.

The details of the precipitation mechanism in these clouds remain obscured, but the observations of well developed downdrafts in convective clouds at times when there has been very little precipitation development suggest that some sort of penetrative downdraft mechanism was active in these clouds. Concentrations of ice hydrometeors were generally very low so that the strong downdrafts could not be related to a loading phenomenon. Initiation of the downdrafts could not be assessed in this study, but is probably related to evaporative cooling in the region of strong mixing occurring near cloud top. The relationship between the draft regions and the development of precipitation could not be studied as thoroughly as desired because the observations generally were made too late in the life cycle of the storms to study precipitation formation. Because of this, there are several operational considerations in dealing with future field programs of this type.

It is necessary to have the aircraft arrive earlier at the clouds being investigated. These clouds were generally well past the precipitation formation stage; in fact, many already had existing radar echoes greater than 15 dBz at the time of the penetrations. Once the aircraft are on the scene, a scheme should be devised to make penetrations at an earlier stage of development. In other words, it is not possible to wait for clouds to be taller than all levels at which the aircraft wish to penetrate or the initial precipitation formation likely will be missed. The techniques used in the 1981 Cooperative Convective Precipitation Experiment in Montana were good in this regard.

It is essential to have better aircraft positioning on a real time basis. In 1978, there were instances when the aircraft penetrated different clouds even though coordination appeared to be adequate at the time. Unfortunately, the real time aircraft positioning was not adequate to recognize the problem. Accurate positioning after-the-fact is just as important in order to be able to study and describe the precipitation mechanism. In 1978, the loss of most of the FAA aircraft positions for the T-28 necessitated the use of VOR/DME positions, which have inherent inaccuracies so large that they are not usable when high spatial and temporal resolution is required.

It would be useful to obtain data from cloud penetrations encompassing the full life cycle of a thunderstorm, in order to study the differences in the precipitation mechanism between small and large clouds. Although some observations here were similar to those made in larger clouds, many were not. The vertical velocity regions appear to be of similar size, but the number concentrations and sizes of hydrometeors are larger in the bigger storms. Small clouds tend to have a rather even distribution of LWC throughout the cloud, while in larger clouds LWC are much lower or nonexistent in the downdrafts. Why this happens is unknown. There are suggestions that with more hydrometeors, depletion or loading may be having an effect, or with more organization, there is more dilution in the downdrafts. Of course, the larger complexes and more organized systems will ultimately be more important in producing precipitation at the ground, so these are the ones in which it will be important to study and understand the precipitation mechanism and the possible modifications of it.

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APPENDIX A

Table A-1 summarizes the pertinent information for each draft region used in this study. The vertical velocities and liquid water concentrations are the maxima observed in each draft region. The hydrometeor data are summarized in terms of maximum observed dimension, predominant habit, and concentrations of the total number of particles (N_T), those greater than 500 μm (N_5), and those larger than 1 mm (N_{10}). The identification of habits used the following key:

P - plates

G - graupel

RA - rimed aggregates

UA - unrimed aggregates

UD - unrimed dendrites

RD - rimed dendrites

The identification of particles less than about 200 μm as plates is arbitrary because the resolution of the 2D-C probe is not sufficient to make this distinction. The column labeled 2-D gives a subjective indication of how well the 2D-C probe was working. Those draft regions labeled OK allow more confidence in the given hydrometeor information, because the device appeared to work properly at those times. Those labeled S indicate shedding was occurring from the probe tips, while those labeled M indicate the probe was malfunctioning for unknown reasons. The appearance of a minus sign in conjunction with M or S indicates that the problem was quite minor and that most of the 2D-C data were usable. There were varying degrees of shedding and malfunctioning; however, there were no cases where at least some data were not available for analysis purposes.

TABLE A-1: Summary of Vertical Velocity Regions

BEGIN	END	V V	LWC	W/W_A	$\bar{\theta}_e$	$\bar{T}$	2-D	D_m	Habit	N_T	N_5	N_{10}
[MDT]	[MDT]	[m s^{-1}]	[g m^{-3}]		[°K]	[°C]		[mm]		-----[Avg Conc - ℓ^{-1}]----		
780711 - FLT 228:												
143842	143913	-5	.40	.14	336.9	-7.4	S	--	--			
143913	143919	4	.42	.21	336.1	-7.7	S	0.1	P	.133		
143919	144001	-4	.28	.14	334.6	-8.7	OK	0.2	P	<.001		
144004	114029	-3	.38	.19	335.8	-8.0	S	0.2	P	<.001		
144029	144056	18	.32	.16	336.9	-9.0	OK	0.5	G	.003	.001	
144056	144115	-8	.04	.02	335.2	-9.9	OK	0.3	P	.003		
144340	144402	-4	.23	.10	334.8	-9.9	OK	0.1	P	.001		
144404	144435	12	.50	.22	336.6	-9.5	S	2.5	RA	.035	.009	<.010
144435	144501	-11	.57	.25	336.0	-10.2	OK	2.5	UA	.412	.086	.010
144526	144544	9	.62	.27	337.3	-9.5	OK	.2	P	.016		
145238	145247	4	0	0	336.5	-6.8	OK					
145247	145307	-7	.12	.06	336.2	-6.9	OK					
145312	145357	-5	.20	.10	336.2	-7.0	OK					
145357	145409	4	0	0	337.0	-6.7	OK					
145409	145419	-3	.47	.24	337.2	-6.9	OK					
145419	145426	3	.42	.21	337.0	-7.1	OK					
145426	145433	-3	.26	.13	336.6	-7.5	OK					
145433	145447	5	.60	.30	337.8	-7.1	OK	.9	G	1.150	.109	
145520	145534	-7	.32	.17	337.5	-7.1	OK	.6	UD	.009	.001	
145535	145549	-4	.36	.19	339.2	-6.3	OK	.4	UD	.007	.001	
145549	145602	4	.51	.27	339.2	-6.5	OK	1.1	RD	.884	.016	<.010
145607	145641	6	.50	.26	336.7	-8.2	S,M	2.5	G	1.831	.043	.010
145641	145650	-3	0	0	336.1	-8.6	OK	2.5	G	2.986	.185	.080
150244	150320	-7	.31	.17	335.8	-7.0	OK	2.5	G	1.484	.035	.010
150320	150407	9	.60	.33	338.6	-6.7	S	1.1	G	.792	.033	<.010
150446	150531	-6	.14	.07	335.6	-8.5	OK	1.8	G	.914	.051	.010
150531	150550	5	.24	.11	336.1	-8.1	OK					
150550	150605	-4	0	0	335.8	-8.6	OK					
152239	152259	-4	.58	.31	338.6	-6.8	M,S	3.5	G	4.439	.106	.040
152259	152322	9	.62	.33	337.8	-7.3	M	2.5	G	3.004	.184	<.010
152322	152346	-4	.62	.33	337.6	-7.6	M	4.5	G	15.769	.420	.040
152400	152447	-7	.46	.24	336.2	-8.0	M	2.5	G	15.134	.293	.090
152458	152509	3	.20	.11	336.0	-8.1	M	3.5	G	56.230	.325	.130
780713 - FLT 229:												
170052	170111	-7	.47	.36	338.8	-3.5	OK	1.8	G	.030	.001	<.001
170111	170211	9	.53	.41	338.4	-6.0	S,M	.3	P	.056	<.001	<.001
170214	170220	6	.36	.28	334.7	-8.2	S	.1	P	.001		
170220	170230	-9	.43	.53	334.5	-8.2	OK	.1	P	.004		
170533	170552	-7	.32	.23	335.2	-6.3	M	2.5	G	.341	<.001	<.001
170552	170618	21	.26	.19	335.4	-6.8	M	1.1	G	5.990	.152	.020
170624	170659	8	.49	.35	336.4	-7.4	S	4.5	G	1.366	.024	.010
170659	170707	-4	.52	.37	340.3	-6.4	S	.2	P	.037	.001	<.010
171242	171253	3	.62	.34	339.0	-5.8	S	1.1	G	.053	<.001	<.001
171253	171315	-7	.60	.33	335.6	-5.9	S	1.1	G	.236	.015	<.010
171315	171403	15	.65	.36	336.8	-7.8	S	2.5	G	1.834	.112	.020
171406	171436	-6	.15	.08	332.8	-10.6	OK	4.5	G	4.773	.197	.050
172201	172213	-8	.55	.37	336.5	-7.8	OK					
172215	172221	-4	.58	.39	337.7	-7.0	OK	.7	G	.030	.005	
172221	172247	7	.59	.39	338.6	-7.1	M	.6	G	.279	.021	
172247	172317	-11	.37	.25	336.4	-8.0	OK	.6	RA	.001	<.001	
173518	173526	-3	0	0	336.2	-7.7	OK					
173540	173547	3	.40	.29	338.0	-7.1	S					
173552	173616	10	.69	.45	339.8	-7.0	S	1.1	RD,RA	.584	.038	.010
173616	173626	-6	.38	.27	335.6	-9.4	S	.6	G	.299	.004	
173835	173905	-7	.42	.21	333.9	-10.5	OK	1.8	G	.001	<.001	<.001
173935	174043	14	.71	.37	336.4	-10.5	M,S	3.5	G	6.833	.057	.010
174047	174054	4	.69	.36	338.0	-11.3	S	1.8	RD	1.092	.018	<.010
174054	174109	-14	.68	.36	337.2	-12.0	S	1.8	G	1.581	.038	<.010
174510	174527	-11	.73	.33	337.8	-13.0	S					
174531	174545	6	.73	.33	338.6	-12.6	S	2.5	G	.319	.016	.010
174545	174603	-13	.71	.32	338.0	-12.8	OK	2.5	RD	1.261	.035	.010
174603	174633	28	.63	.29	337.4	-14.0	M	2.5	RD	1.303	.014	.010
174637	174650	-11	.63	.29	337.4	-14.8	M	3.5	G	86.940	1.765	.090
174650	174705	7	.64	.29	335.2	-16.0	M	.5	G	7.238	.234	
174705	174716	-6	0	0	336.0	-14.9	OK	.5	UD	4.629	.009	
175044	175202	-7	.29	.13	335.4	-14.4	M	2.5	G	41.83	1.037	.110
175214	175236	-12	.61	.28	335.5	-14.0	OK	3.5	G	765.500	15.091	1.460
175236	175255	3	.48	.22	336.6	-13.6	OK	2.5	G	283.100	9.300	1.250
175255	175305	-5	.20	.09	336.1	-13.9	OK	2.5	RD	163.545	4.364	.410
175318	175327	-5	.50	.23	335.8	-13.9	M	3.5	G	19.132	.488	.130
175327	175349	12	.65	.30	337.5	-13.9	OK	1.8	G	3.285	.038	.020

TABLE A-1 (continued)

BEGIN	END	V V	LWC	W/W_A	$\overline{\theta}_e$	$\overline{T}$	2-D	D_m	Habit	N_T	N_5	N_{10}
[MDT]	[MDT]	[m s^{-1}]	[g m^{-3}]		[°K]	[°C]		[mm]		-----[Avg Conc - ℓ^{-1}]----		
780718 - FLT 231:												
161708	161720	-6	.68	.23	335.2	-8.7	OK	1.8	G	1.287	.016	.010
161720	161747	17	.89	.30	337.5	-8.3	S	1.8	RD	.385	.005	<.010
161747	161802	-5	.64	.21	335.6	-10.0	OK	1.8	G	.208	.017	.010
161814	161825	-6	0	0	336.9	-9.2	S	.6	RA	.083	<.001	
162155	162207	4	.23	.08	338.4	-7.7	S					
162207	162227	-16	.92	.31	337.6	-7.9	S	.1	P	.112		
162227	162259	23	1.05	.35	337.1	-8.8	S	1.1	RD,RA	.940	.025	<.010
162259	162331	-26	.95	.32	334.4	-10.5	OK	4.5	G	2.538	.103	.030
162602	162625	-6	.70	.22	334.2	-10.2	OK	1.8	G	.517	.014	.010
162628	162657	-6	.92	.29	334.8	-10.2	M,S	4.5	G	4.499	.106	.030
162657	162726	24	1.01	.32	336.2	-10.0	OK	1.8	RD	1.689	.061	.010
162726	162753	-20	.95	.30	335.4	-11.1	S	.8	UD	.085	.002	
163828	163837	3	.02	.01	333.4	-9.2	OK					
163841	163921	7	.04	.01	335.9	-8.8	OK					
163921	163943	-15	.47	.16	336.6	-9.2	OK	.2	P	.001		
163948	164028	-7	.80	.27	335.2	-9.1	OK	.6	RA	.025	.002	
164440	164449	-5	.22	.08	335.6	-6.9	OK					
164449	164508	11	1.02	.36	337.4	-6.6	OK					
164532	164553	10	.64	.21	336.4	-6.7	OK					
164555	164608	-4	.40	.13	335.2	-7.7	OK					
164620	164642	-6	.15	.05	334.4	-7.7	OK					
170948	171020	-4	.51	.15	332.9	-12.9	OK	.6	RD	.186	.002	
171103	171120	-4	.61	.17	333.2	-12.5	S	.2	P	.006	<.001	
171120	171148	8	.81	.23	334.2	-12.6	S	.9	RA	.070	.004	
171338	171408	-7	.15	.04	332.2	-14.0	S	1.1	G	.186	.016	<.010
171408	171424	10	.55	.15	332.4	-14.3	S	.7	G	1.151	.063	
171427	171442	-5	.50	.14	332.8	-13.7	OK	.8	RD	.566	.030	
780719 - FLT 232:												
162747	162826	-9	1.07	.33	339.6	-9.0	S	1.1	RA	.309	.008	<.010
162828	162834	6	.87	.27	341.2	-7.8	S	1.1	RA	.326	.021	<.010
162834	162840	-6	.73	.23	338.9	-8.9	S	.6	RA	.260	.009	
162840	162845	10	.78	.24	338.5	-9.2	S	.4	P	.151		
162845	162937	-11	.84	.26	336.6	-9.6	S	1.8	G	.332	.007	<.010
163230	163328	-14	1.08	.35	338.6	-7.2	S	2.5	RD	.540	.031	<.010
163333	163339	-4	1.12	.36	338.6	-7.1	S	.7	G	.953	.024	
163339	163406	11	1.21	.39	340.0	-7.4	S	1.1	G	.975	.061	<.010
163406	163419	-6	1.38	.45	341.1	-7.5	S	1.8	RA	2.549	.173	.040
163419	163450	10	1.30	.42	339.4	-9.2	M	1.8	RA	5.110	.628	.050
163450	163513	-15	1.15	.37	338.0	-10.7	S	1.1	G	1.143	.143	.020
163513	163523	3	.18	.06	336.9	-10.5	S	1.1	G	.178	.013	<.010
163523	163557	-11	.72	.23	335.5	-11.1	S	.9	G	.364	.017	
164000	164007	-7	1.02	.31	338.4	-10.0	S					
164009	164025	-10	.95	.29	336.8	-10.3	S					
164025	164033	4	1.08	.33	336.6	-10.5	S					
164035	164047	-12	1.11	.34	338.0	-10.0	S	2.5	G	2.212	.154	.060
164050	164058	5	.95	.29	337.8	-9.7	M,S	2.5	RD	4.293	.403	.157
164058	164134	-12	1.04	.32	336.0	-10.2	S	1.8	RA	5.716	.169	.040
164134	164214	17	1.25	.38	340.3	-9.8	M,S	3.5	G	4.806	.340	.080
164214	164235	-13	1.08	.33	336.6	-12.5	S	2.5	G	2.261	.130	.010
171215	171224	6	.08	.02	337.9	-10.1	OK	.2	P	.006	.001	
171235	171254	-6	.92	.28	338.0	-10.7	OK	1.8	RD	.670	.033	.010
171301	171319	-12	.71	.22	338.0	-10.3	OK	.7	RD	.182	.023	
172535	172634	-14	1.08	.35	337.9	-10.0	OK	2.5	RA	1.105	.066	<.010
172640	172648	-5	1.02	.33	338.8	-9.2	M	.7	RA	.302	.017	
172648	172700	3	1.23	.40	339.6	-8.8	M	3.5	RA	3.301	.053	.010
172700	172718	-8	1.24	.40	338.9	-8.7	M	2.5	RA	2.312	.071	.010
172718	172728	11	.64	.21	337.7	-9.8	S,M	.6	G	.384	.033	
780730 - FLT 237:												
131023	131053	-11	1.28	.47	330.5	-14.6	S,M	1.1	G	2.064	.181	.040
131053	131101	3	1.22	.45	331.2	-14.1	M	1.1	G	4.771	.051	.030
131101	131121	-8	1.70	.63	332.2	-13.2	M	2.5	G	13.680	.335	.090
131129	131147	-9	.08	.03	332.0	-13.3	M	3.5	G	12.066	.066	.030
131410	131434	-7	.05	.02	333.6	-12.2	M	3.5	G	14.926	.105	.040
131438	131456	-4	.98	.39	331.1	-13.5	M	2.5	G	19.988	.410	.150
131456	131511	4	.59	.24	332.4	-12.9	M	1.8	G	9.370	.288	.040
131511	131531	-6	1.20	.48	333.2	-12.7	M	.8	RD	1.178	.024	
131826	131836	-10	1.85	.69	331.1	-13.4	OK	1.0	G	15.855	.194	.020
131840	131902	10	1.58	.59	331.2	-14.0	M					

TABLE A-1 (continued)

BEGIN	END	V V	LWC	W/W_A	$\overline{\theta}_e$	$\overline{T}$	2-D	D_m	Habit	N_T	N_5	N_{10}
[MDT]	[MDT]	[m s^{-1}]	[g m^{-3}]		[°K]	[°C]		[mm]		-----[Avg	Conc -	ℓ^{-1}]----
131902	131947	-6	1.20	.44	329.7	-15.0	M	1.8	G	.249	.012	<.010
132255	132348	-6	.08	.03	331.6	-13.9	M	3.5	G	25.099	.472	.240
132353	132426	-9	.20	.07	329.9	-14.5	M	3.5	G	21.816	.392	.130
132426	132450	6	1.00	.37	330.6	-14.2	M	2.5	G	42.478	.766	.160
132450	132508	-11	1.28	.47	331.2	-14.3	M	1.8	G	15.792	1.356	.010
133147	133216	-14	.65	.24	332.3	-14.1	M	.9	RD	14.340	.153	
133436	133507	-8	.04	.02	331.8	-13.0	M	1.8	G	33.725	.771	.130
133834	133903	-3	1.63	.60	330.8	-14.5	OK					
133905	133920	-9	1.63	.60	331.4	-14.0	S	1.0	RA	.576	.049	.020
133920	133928	4	.98	.36	329.7	-14.9	S	.4	G	.350		
134626	134641	-7	0	0	331.0	-11.8	S					
134641	134723	20	1.84	.68	332.8	-12.2	S,M	1.1	UA	.960	.120	.020
134844	134855	-9	1.65	.66	333.2	-11.2	M	1.0	RA	3.330	.210	.020
134855	134923	24	1.70	.68	333.1	-12.1	M	1.1	G	1.090	.070	.010
134923	134932	-5	.18	.07	329.8	-14.5	OK					
135131	135213	-8	1.23	.49	330.1	-11.9	OK	2.5	G	2.790	.130	.010
135213	135228	6	1.35	.54	331.8	-11.4	M,S	1.8	RA	.710	.230	<.010
780730 - FLT 238:												
161310	161323	-6	.91	.61	332.4	-7.6	S	.7	RA	.020	<.010	
161323	161332	4	.11	.07	334.9	-6.3	S	.4	P	.110		
161332	161340	-14	0	0	334.4	-6.8	S	.04	P	.060		
161503	161512	3	.08	.05	336.6	-7.0	S					
161514	161611	-19	.48	.32	333.8	-6.2	S					
161611	161618	6	.08	.05	332.0	-6.5	S					
161618	161656	-7	1.08	.72	332.2	-6.2	S	.7	G	.060	<.010	
161703	161710	-5	0	0	335.0	-4.9	S	.9	UD	.030	.010	
162657	162716	9	.97	.61	333.2	-7.8	S					
162716	162732	-8	.42	.26	331.7	-8.5	S					
162921	163019	-13	.71	.44	333.1	-6.7	S	.7	G	.130	.010	
163019	163030	5	1.03	.64	334.5	-5.8	S	.6	G	.020	.010	
163326	163333	3	.58	.34	332.6	-7.9	S	.6	G	.020	<.010	
163333	163408	-11	.63	.37	332.8	-7.8	S	.9	UD	.920	.050	
165149	165200	-3	0	0	331.4	-10.0	OK	2.5	G	5.670	.260	.130
165217	165229	-3	.08	.04	331.9	-10.1	M	3.5	G	21.470	1.020	.190
165234	165248	6	.52	.26	333.8	-9.4	M					
165248	165305	-6	.42	.21	332.0	-9.9	M					
165312	165337	-7	.48	.24	330.2	-10.8	M	3.5	G	9.510	.030	.020
165345	165358	7	.50	.25	332.4	-10.0	M	2.5	G	2.420	.060	.020
165653	165713	-5	.10	.05	332.4	-9.7	OK					
165713	165722	4	.07	.04	333.0	-9.3	OK					
165722	165738	-4	.51	.27	332.1	-10.6	OK					
170709	170727	-3	0	0	334.5	-10.0	M	3.5	UD	4.920	.240	.080
170727	170737	3	0	0	332.4	-11.2	M	3.5	UD	15.500	1.240	.350
170753	170808	6	.24	.12	336.2	-9.8	M					
170808	170835	-6	.23	.12	335.3	-9.9	M					
170835	170904	11	1.16	.58	335.6	-10.2	M	1.1	RD	.010	.010	.010
170904	170919	-6	.40	.20	332.7	-11.5	M					
170926	171016	-6	.13	.07	331.7	-12.4	M	1.1	RD	1.380	.030	.030
171031	171050	-3	.05	.03	331.0	-12.2	M	4.5	G	18.890	.310	.200
171415	171503	9	1.00	.53	333.8	-9.8	M	2.5	G	5.020	.090	.010
171503	171527	-10	1.08	.57	334.1	-9.3	M	1.1	G	5.220	.050	<.010