EPA Report ____
November 1984

AIRBORNE LIDAR MONITORING OF FLUORESCENT DYE PARTICLES AS A TRACER TO CHARACTERIZE TRANSPORT AND DISPERSION: A FEASIBILITY STUDY

Final Report

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Contract No. 68-02-3791

SRI Project 5782

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NOTICE

The information in this document has been funded wholly or in part by the United States Environmental Protection Agency under Contract NO. 68-02-3791 to SRI International. It has been subject to the Agency's peer and administrative review, and it has been approved for publication as an EPA document.

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ABSTRACT

During October 1983, SRI International (SRI) conducted a field experiment to study the feasibility of using airborne lidar to remotely monitor and map the long-distance transport and dispersion characteristics of a cloud of nontoxic fluorescent dye particles (FDP) in various release scenarios. The ALPHA-1 (Airborne Lidar Plume and Haze Analyzer) system installed in SRI's Beechcraft Queen Air aircraft was used in the study. Laser energy was transmitted vertically downward at wavelengths of 0.53 μm and 1.06 μm, simultaneously, and the ALPHA-1 two-wavelength receiver system was used to detect range-resolved FDP fluorescent scattering at 0.60 μm and aerosol scattering at 1.06 μm. The ALPHA-1 system was made available for this program by the Electric Power Research Institute (EPRI).

The ALPHA-1/FDP feasibility experiment was conducted within the same time period as the Cross Appalachian Tracer Experiment (CAPTEX '83). The lidar aircraft operated out of Akron-Canton airport, Ohio. FDP tracer releases were made by a commercial cropduster. Successful lidar mapping of FDP releases occurred on six separate days during the period 14 through 21 October.

The system proved capable of providing detailed range resolution of both a cloud of FDP particles and the background aerosol distribution, the latter for obtaining concurrent information on atmospheric stratification and convective structure. On one occasion, an FDP cloud was released above the mixed layer and subsequently tracked over a total distance of 327 km. The 3-dimensional tracer-cloud trajectory showed detailed characteristics that differed from the trajectory calculations which utilized twice-daily soundings from the synoptic-scale network. On another occasion, an initially-released circular cloud reached an 8-to-1 (16-to-2 km) length-to-width ratio two hours after release, and a 12-to-1 (30-to-2.5 km) length-to-width ratio about four hours after release. ALPHA-1/FDP tests also were made in connection with a power plant plume, convective cumulus clouds, and a tracer trajectory across Lake Ontario.

The study successfully demonstrated that airborne lidar observations of FDP tracer clouds released in the mixed and free tropospheric layers can

identify local and regional processes of horizontal and vertical transport and dispersion, can provide the precise verification data required to test and validate model trajectory calculation schemes, and can provide input to studies of cloud venting.

CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

ACKNOWLEDGMENTS

This research has been funded as part of the National Acid Precipitation Assessment Program by the Meteorology and Assessment Division, Environmental Sciences Research Laboratory, Office of Research and Development, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina.

The authors express their appreciation to Dr. Jason K.S. Ching, EPA Project Monitor, for his continued interest and technical guidance during the field experiment and the data analysis phases of the project.

We also acknowledge the contribution made by Mr. Tom Freitas, pilot of the lidar aircraft, whose interest and dedication made it possible to successfully complete all scheduled research flights.

Mr. Norman Nielsen, SRI Field engineer, participated in the modification, field preparation, and initial testing of the ALPHA-1/FDP system.

The EPRI ALPHA-1 airborne lidar was made available for the feasibility study by Dr. Glenn Hilst of EPRI.

SECTION 1

INTRODUCTION AND OBJECTIVES

Anthropogenic pollutants, such as acidic precursors, oxidants, and particulates, can arrive above a convective mixed layer by penetrative convective cloud activity (venting) or by air mass convergence. These pollutants are then displaced along paths that are not necessarily horizontal, and can subsequently re-enter the mixed layer by either entrainment, subsidence, or in precipitating systems. The development of improved long-range transport models will require consideration of the transport and dispersion processes in both the mixed and free tropospheric layers.

These processes in the free troposphere are not adequately documented or understood, and are generally ignored in current trajectory calculation schemes and source-to-receptor models. This, of course, is primarily due to the unavailability of adequate measurement techniques or air parcel tracking technology for this application. For example, tetroons are set to drift along constant density surfaces; however, free tropospheric transport is more likely to occur along isentropic surfaces. The use of chemical tracers requires in situ sampling by aircraft, but logistical requirements make Lagrangian tracking extremely difficult on long-range transport scales. Thus, adequate and precise verification data to test and validate model trajectory calculation schemes (that use twice daily routine soundings from the synoptic-scale network) are still unavailable.

To address this problem, a technique to track free tropospheric pollutant transport was recently developed as part of the National Acid Precipitation and Analysis Program (NAPAP). The airborne two-wavelength ALPHA-1 lidar system (Uthe et al., 1980) was modified to track the movement, and to characterize the dispersion, of a cloud of nontoxic fluorescent dye particles (FDP) in various release scenarios. This system is capable of making range-resolved measurements of both a cloud of FDP particles and aerosol distributions. The latter obtains concurrent information on atmospheric stratification and convective structure. Initial field tests were conducted in conjunction with the Cross Appalachian Tracer Experiment (CAPTEX '83) tracer study.

The ALPHA-1/FDP feasibility study was carried out by SRI for the U.S. Environmental Protection Agency under Contract No. 68-02-3791. The ALPHA-1 airborne lidar was made available to SRI by the Electric Power Research Institute (EPRI). This report presents the highlights of an analysis and interpretation of ALPHA-1 observations of FDP tracer clouds released on six separate occasions in the general CAPTEX area. On each occasion, a specific scenario which related to atmospheric transport and dispersion was emphasized.

SECTION 2
BACKGROUND

FLUORESCENT DYE PARTICLE (FDP) LIDAR TECHNIQUE

Studies of atmospheric transport and dispersion have used lidar techniques to map the downwind structure of aerosol tracers or plumes emitted into the atmosphere by local and regional sources. These lidar observations, however, can be used along the downwind transport trajectory only as long as the backscatter signal received from the tracer or plume remains above that of the background aerosols. When the backscatter signal from the tracer or plume equals that of the background aerosols, the tracer can no longer be distinguished. This restriction can severely affect the useful application of backscatter-type lidar observations to long-range transport studies.

Rowland and Konrad (1979) have demonstrated a different technique that uses a lidar system to excite fluorescent particles released into the atmosphere, and to monitor the emitted fluorescent light. When the lidar receiver is spectrally filtered, the fluorescent light can be detected separately from the radiation which is elastically backscattered by background aerosols at the wavelength of the incident laser light. Thus, this technique allows the fluorescent particles to be remotely detected in the presence of an atmospheric aerosol background, even in low concentrations.

The objective of the study described in this report was to field test the fluorescent dye particle (FDP) lidar technique using the ALPHA-1 airborne lidar system for long-range transport and diffusion observations.

ALPHA-1 LIDAR SYSTEM

The ALPHA-1 (Airborne Lidar Plume and Haze Analyzer) was designed and constructed for the Electric Power Research Institute (Uthe et al., 1980). It is a downward-looking lidar flown aboard a twin-engine Beechcraft Queen Air aircraft with specialized navigational instrumentation and facilities for lidar applications. Figure 1 shows a view of the research aircraft, and an interior view of the lidar operation.

(a) IN FLIGHT

(b) INTERIOR VIEW SHOWING ALPHA–1 ELECTRONICS, DISPLAY UNIT, AND OPERATORS

FIGURE 1 ALPHA-1 AIRCRAFT USED IN FLUORESCENT DYE PARTICLE (FDP) TRACER EXPERIMENT

The ALPHA-1 was constructed using an Nd:YAG laser transmitter emitting pulses at a wavelength of 1.06 µm. By placing a frequency-doubling crystal in the beam path, laser pulses can be simultaneously transmitted at the primary wavelength of 1.06 µm, and at the frequency-doubled wavelength of 0.53 µm. Elastic backscatter at the near infrared wavelength (1.06 µm) is sensitive to subvisible particulate pollution because of the larger ratio of aerosol-to-molecular scattering at longer-than-visible wavelengths. Elastic backscatter measurements at the frequency-doubled wavelength (0.53 µm) allow a two-wavelength analysis of backscatter signatures in terms of aerosol extinction and concentration (Uthe et al., 1982). Also, the short wavelength data can be used to derive visibility information because 0.53 µm is at the peak of the human visual response-function curve.

The ALPHA-1 data system uses dual microprocessors to record data at high collection rates, and to process lidar backscatter signatures in terms of height/distance facsimile displays of atmospheric and terrain features in real time. The lidar can be operated at pulse rates up to 10 s^{-1} for a horizontal resolution of about 6 m. The backscatter signature at each wavelength resulting from each pulse transmission was digitized to provide 1000 values with vertical resolution as small as 1.5 m. The fine vertical and horizontal resolution data are plotted in pictorial form, and are available in real time for directing the data collection. The signatures are also recorded on nine-track magnetic tape for later analysis of atmospheric behavior and aerosol physical and optical properties. Other details of the ALPHA-1 lidar system are documented elsewhere (Uthe et al., 1980).

Figure 2 shows an example of a steam plume and background aerosol distributions which were observed with the 1.06 µm wavelength of ALPHA-1 at the Geysers geothermal area of northern California. The top of the boundary layer and elevated aerosol layers indicate terrain-induced air motion. At the source, the steam plume is clearly detected in the aerosol background. However, as the plume is transported downwind, its density can rapidly decrease to the point where it becomes difficult to distinguish the plume structure from background aerosol concentrations.

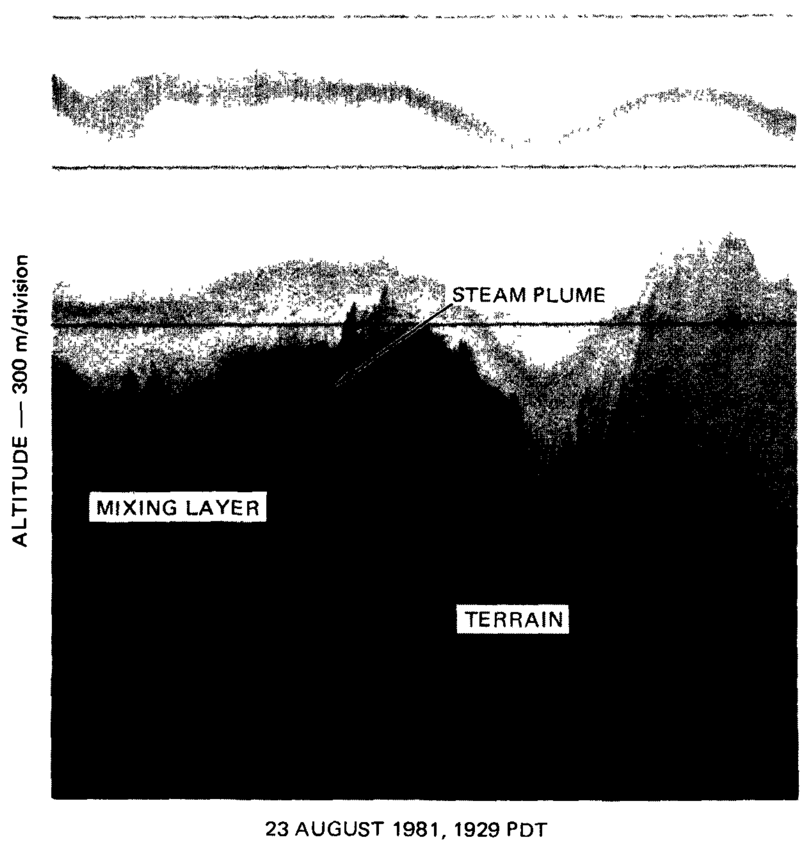

FIGURE 2 EXAMPLE OF STEAM PLUME AND BACKGROUND AEROSOL DISTRIBUTIONS OBSERVED BY ALPHA-1 IN THE GEYSERS GEOTHERMAL AREA OF NORTHERN CALIFORNIA (UTHE, 1983)

FLUORESCENT PARTICLE CHARACTERISTICS

The fluorescent particles used in the FDP-tracer experiment were transparent organic resin particles containing a dye with a fluorescent orange color. The orange color (dominant wavelength of 0.61 μm) is produced by converting energy absorbed at the green wavelength (0.53 μm) of ALPHA-1. During daytime, fluorescence can be excited by solar energy as well as by laser light. However, because of the large energy density of the laser pulse, the laser-induced fluorescent light is larger than that induced by the sun.

The fluorescent dye particles (FDP) have an average diameter of 3.5-4.0 μm and a density of 1.36 g cm^{-3}. Measurements at SRI indicated a mean particle diameter of 2 μm. Using Stokes' Law, the fall velocity of these particles in air near the top of the boundary layer is about 0.6 mm sec^{-1}.

FDP for the lidar experiment were obtained in 50-lb bags from the Day-Glo Color Corporation, Cleveland, Ohio. (The color is designated as "Fire Orange" by Day-Glo).

ALPHA-1 MODIFICATION FOR FDP TECHNIQUE

The ALPHA-1 has two independent receivers that measure the elastically backscattered radiation at 1.06 μm and 0.53 μm. For application to the fluorescent particle technique, the interference filter of the 0.53 μm receiver was replaced with a filter that blocked 1.06 μm and 0.53 μm backscattered radiation but transmitted 0.61 μm fluorescent (orange) light.

Because the fluorescent spectrum is relatively wide, a wide bandwidth filter was needed to pass the fluorescent signal. The wide bandpass filter, however, also passes a large amount of background (solar reflected) light. On the basis of ground tests, two interference filters were considered. One filter used a bandwidth of about 500 Å bandpass, but also passed a small percentage of the elastic backscatter at 0.53 μm and/or 1.06 μm. The second filter had a 1500 Å bandpass and had more blocking at 0.53 μm, but the increased background radiation resulted in a lower overall signal-to-noise ratio during daylight hours. Therefore, most of the data was collected with the 500 Å filter. The 1500 Å filter was used only on a convective cloud experiment where greater receiver rejection of the primary radiation at 0.53 μm and 1.06 μm was needed.

SECTION 3
PRELIMINARY TESTS

GROUND TESTING

During July 1983, preliminary ground tests were conducted at SRI's Menlo Park facility. During these tests, the ALPHA-1 lidar system was used in its surface-based configuration to observe FDP releases from a tall stack. The objectives were to optimize transmitter and receiver components to best observe the FDP-release, and to evaluate capabilities and limitations of the ALPHA-1/FDP technique, before the system was committed to aircraft operations.

The ground tests demonstrated the feasibility of the ALPHA-1/FDP technique. Three receiver filters were evaluated, and two were chosen for future tests. It was shown that the FDP fluorescent backscatter cross section was only about four times greater than the particle elastic backscatter cross section, so that relatively large FDP quantities would be needed for long-range transport studies. However, because the FDP receiver is filtered so as not to observe lidar elastic backscatter, the technique would be particularly useful in hazy atmospheric conditions. Several techniques were investigated for releasing large quantities of FDP from aircraft platforms. Release of about 100-lbs in a few minutes could only be accomplished economically by use of a cropduster aircraft.

LOCAL AIRBORNE TESTING

During August/September 1983, the ALPHA-1 lidar was installed within the SRI Queen Air aircraft for observing FDP releases from the tall stack and from a second aircraft platform. The objectives of these tests were to demonstrate the ALPHA-1/FDP technique using an aircraft-mounted sensor and FDP release system, and to gain experience with tracking the generated FDP clouds.

The local airborne testing demonstrated that FDP could be released in large quantities from a cropduster aircraft, and that the FDP release could be observed with the ALPHA-1 for at least several hours. It was determined that lidar detectability of FDP is proportional to inverse distance squared and, therefore, is best observed at shorter distances. Moreover, because of laser eye-safety considerations, the ALPHA-1/FDP technique is best suited for higher altitude FDP releases.

Increased 0.53 μm wavelength laser emission was needed to obtain greater signal from generated FDP clouds. An extensive evaluation was conducted of various harmonic crystals used to generate 0.53 μm wavelength energy from the primary 1.06 μm laser emissions. High-efficiency crystals were found to be unreliable -- sometimes lasting for only one hour of operation. A compromise crystal was finally decided upon that provided adequate output energy and appeared to have sufficient reliability to be used during a two-week field program.

SECTION 4

SUMMARY DESCRIPTION OF FIELD PROGRAM AND DATA COLLECTION

The ALPHA-1/FDP feasibility study was conducted within the same time period as the Cross Appalachian Tracer Experiment (CAPTEX '83) with the expectation to take advantage of additional meteorological observations to evaluate the study results. The Akron/Canton airport, about 200 km (125 miles) northeast of Dayton, Ohio, was selected as the base of operations for the ALPHA-1 lidar aircraft since this location was expected to be downwind of the CAPTEX tracer releases made from Dayton. The commercial cropduster aircraft, used for FDP releases, was stationed 43 km (27 miles) to the southwest at the Wayne County (Wooster) airport. FDP tracer material (50-lb bags) was brought in from Cleveland.

Based on considerations of laser eye-safety, the ALPHA-1 operated at flight levels between 2100 m and 2900 m (7000 ft and 9500 ft) ASL. On the average, FDP releases were made by the cropduster at altitudes 450 to 600 m (1500 to 2000 ft) below the ALPHA-1 flight level. Figure 3 shows the loading of the cropduster, and an FDP release in the form of a doughnut-shaped cloud of 3/4 km diameter and a thickness of about 50 m. Typically, 100-lbs of FDP (at a cost of about $500) was released for each test.

Figure 4 shows an example of lidar data displayed on a gray-scale facsimile record. The darker areas represent greater backscatter on a logarithmic scale. The data present two cross-wind traverses (2032-2036 EDT and 2036-2040 EDT) of an elongated FDP tracer plume observed in eastern Ohio by the ALPHA-1 from a flight altitude of 2900 m ASL, during the evening of 16 October. The upper part of the gray-scale presentation represents elastic backscatter data at 1.06 μm. It shows terrain contours, the ground-based aerosol (haze) layer (about 1500 m thick), and the infrared backscatter from the FDP cloud in a vertical plane perpendicular to the transport direction. The lower part shows terrain contours,* and the fluorescent backscatter at 0.6 μm received from the FDP after illumination by 0.53 μm laser radiation.

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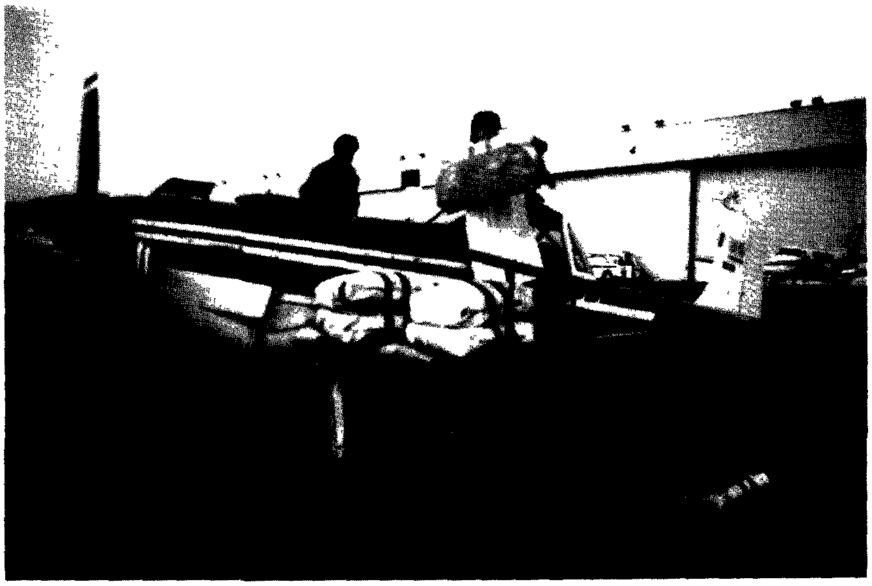
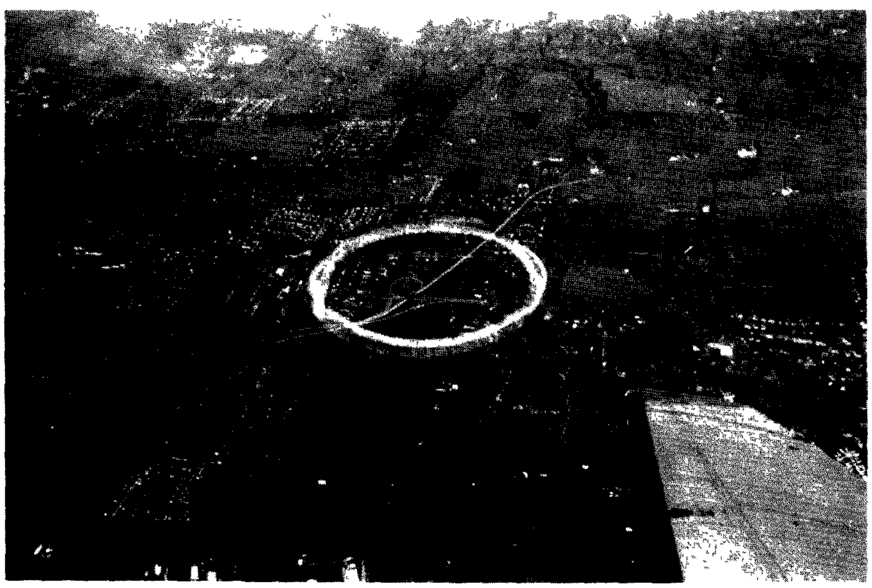
* Terrain contours are shown in the fluorescent channel because of filter leakage of strong 0.53 μm lidar backscatter signals from ground surfaces (Section 2.4).



FDP LOADING OF COMMERCIAL CROPDUSTER



FDP RELEASE BY CROPDUSTER BELOW ALPHA-1 LIDAR AIRCRAFT

FIGURE 3 LOADING AND RELEASE OF FDP TRACERS BY CROPDUSTER AIRCRAFT

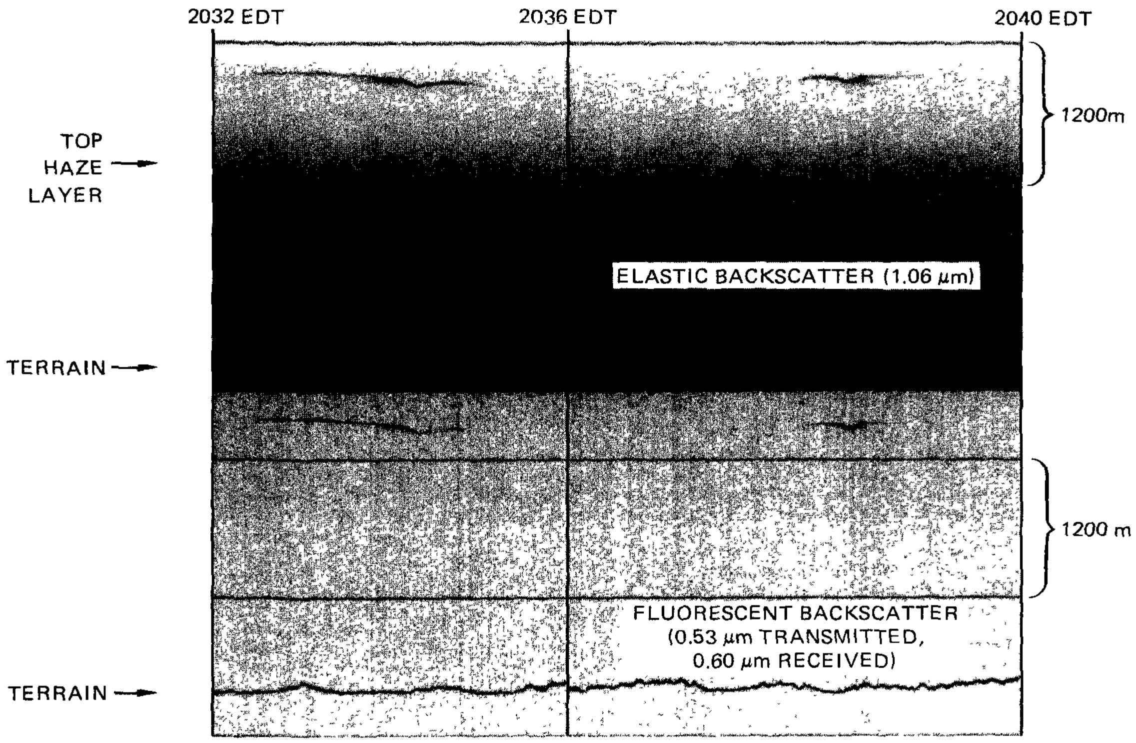


FIGURE 4 EXAMPLE OF GRAY-SCALE FACSIMILE RECORD SHOWING TWO LIDAR CROSS SECTIONS OBTAINED BY ALPHA-1 WHILE TRAVERSING A FDP TRACER PLUME.

Upper part represents aerosol background and plume cross sections from elastic backscatter. Lower part shows fluorescent tracer plume. 16 October 1983, eastern Ohio, 2032-2040 EDT. Lidar aircraft altitude: 2900 m ASL.

No elastic backscatter from the atmospheric aerosol background is detected at this wavelength. The lidar observations of Figure 4 clearly demonstrate that the FDP cloud is detected above the near-surface haze layer, and that its height above the terrain, and its shape and size, can be accurately determined by remote measurements. This figure also shows that the FDP cloud can be observed with the 1.06 µm lidar receiver as well as the 0.6 µm receiver, provided interfering atmospheric background aerosol concentrations are sufficiently low at the FDP-cloud location.

Table 1 lists the significant experiments carried out during the field program period of 10 October through 21 October 1983. During this period, only one CAPTEX experiment from Dayton took place on 14 October. The experiments that are encircled in Table 1 represent those that provided significant ALPHA-1/FDP feasibility data for various scenarios. Case studies for these six experiments are described in detail later in this report.

Figure 5 shows the geographic locations where the six FDP tracer releases were made, and the distances and general areas over which the tracer clouds were tracked by the ALPHA-1. The arrowhead at the end of each track indicates the general transport direction. Tracks 1 and 2 cover long distances of 327 km and 236 km, respectively. In these two cases, tracers were released under cloud-free conditions above the mixing layer. Case 3 represents an FDP release made in connection with the plume of the Conesville power plant north of Zanesville, Ohio. The behavior of FDP tracer clouds released from a point north of Columbus, Ohio, at two different altitudes above ground level was investigated in Case 4. Case 5 followed a low-altitude tracer release from a point north of Buffalo, New York, across Lake Ontario. During the afternoon of the same day, another experiment (Case 6) involved convective cumulus clouds, and was carried out near Johnstown, Pennsylvania. Except for Cases 5 and 6, all releases were made in Ohio.

TABLE 1

QUEEN AIR AIRCRAFT FLIGHT LOG

ALPHA-1 FDP DEMONSTRATION/CAPTEX EXPERIMENTS

DATE (1983)	DATA TIMES (EDT)	FLIGHT HOURS	FDP RELEASE TIME (EDT)	FDP RELEASE ALTITUDE (FT)	FDP RELEASE LOCATION	REMARKS
Aug-Oct		17.0				Local FDP demonstrations
8-9 Oct		12.6				Ferry to Akron, Ohio
10 Oct	1400-1420	3.6	1405	5500	40°53'N/81°52'W	Lidar test/Flight to Dayton
11 Oct		4.9				Tetroon location exp./lidar problem
12 Oct	2010-2200	3.7	2012	6500	Wayne Co. Airport	FDP to 18 nmi
(14) Oct	1800-2400	9.6	1800	7000		CAPTEX/FDP to 150 nmi (2230 EDT)
15 Oct	1100-1230	1.8				Washington, D.C. to Akron (0.53/1.06 μm)
(16) Oct	1630-0100	9.2	1650	8000	40°17'N/83°8.3'W (Delaware Airport)	Akron to Columbus (0.53/1.06 μm)/ FDP to 130 nmi/Return to Akron (0.53/1.06 μm)
(17) Oct	2000-2400	6.2	2010	plume height	Conesville Power Plant (40°11'N/ 80°53'W)	FDP to 16 nmi (2330 EDT)
(19) Oct	0900-1300	10.6	0920	8000 and 6000	40°50'N/81°55'W	Two cloud experiment: Bottom to 70 nmi/Top to 50 nmi/Lost clouds after refueling
20 Oct	1630-1700	1.3				Akron to Buffalo (0.53/1.06 μm)
(21) Oct	0700-1000	4.3	0710	1500	43°18'N/78°31'W (east of Buffalo)	FDP to 50 nmi (across Lake Ontario)
(21) Oct	1330-1530	5.0	1340-1500	cloud height	50 nmi SE of Pittsburgh	Convective cloud studies/ 6 FDP releases
23/24 Oct		12.7				Ferry to San Jose, CA

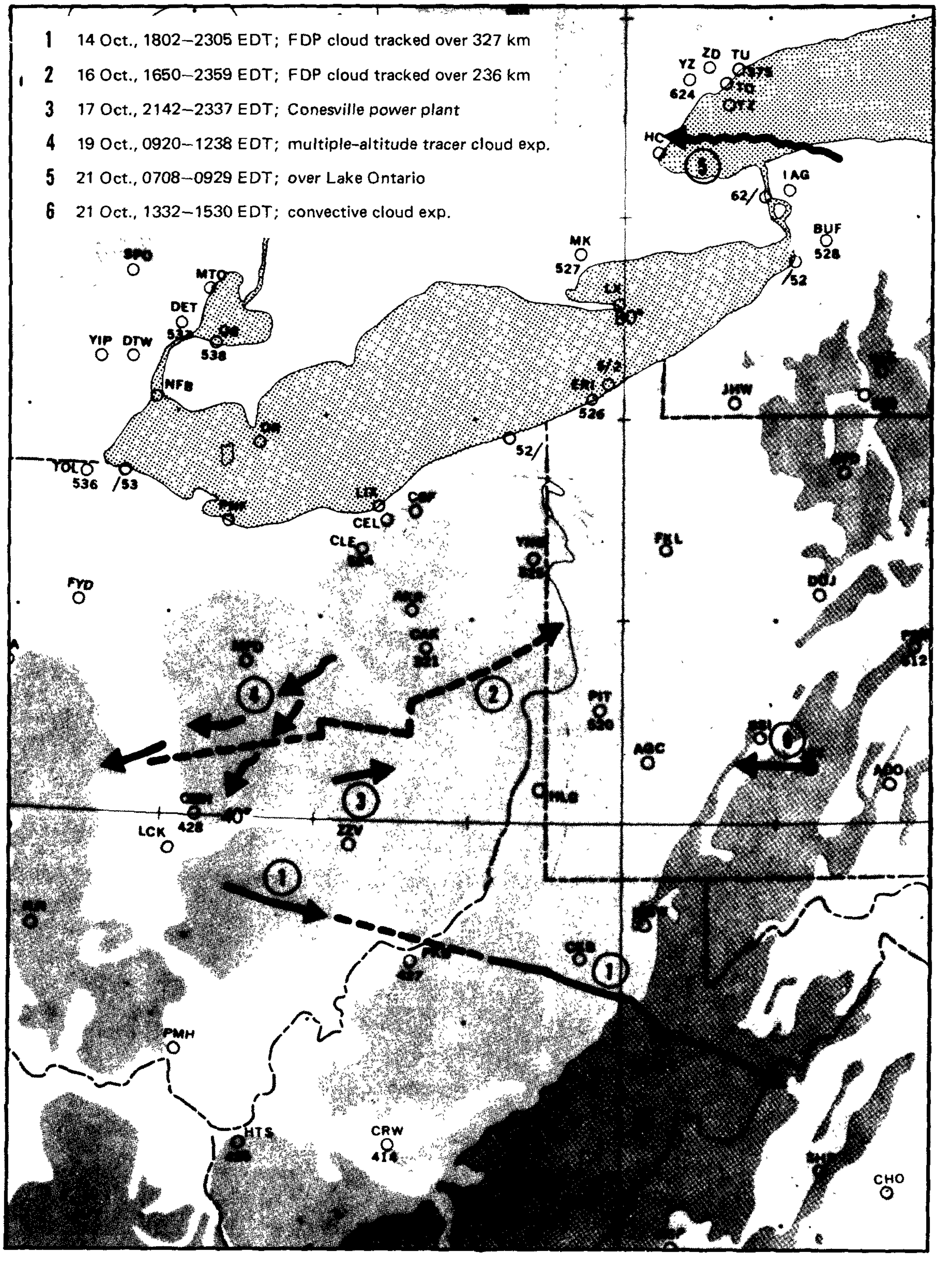


FIGURE 5 GEOGRAPHIC LOCATIONS AND HORIZONTAL FDP-TRANSPORT TRAJECTORIES ASSOCIATED WITH SIX ALPHA-1/FDP EXPERIMENTS CONDUCTED IN THE CAPTEX AREA DURING OCTOBER 1983

SECTION 5

ANALYSIS AND INTERPRETATION OF LIDAR TRANSPORT OBSERVATIONS

CASE I: LONG-RANGE TRACKING OF FDP-CLOUD 3-D TRAJECTORY

Scenario

The ALPHA-1/FDP experiment conducted on 14 October 1983, 1802-2305 EDT, demonstrated the feasibility of determining the long-range 3-dimensional transport trajectory of an FDP tracer cloud with high spatial and temporal resolution. The data analyses are described in the following paragraphs.

FDP-Cloud Track

On 14 October, a donut-shaped cloud of fluorescent dye particles about 3/4-km in diameter, was released from Lancaster, Ohio (45 km SE of Columbus), at 1750 EDT. Meteorological conditions were controlled by a high pressure system. Release height was 2290 m ASL, nearly 900 m above the mixing layer, and above a subsidence inversion in relatively dry air. The ALPHA-1 tracked the FDP cloud over a total distance of 327 km from Lancaster southeastward through West Virginia (Clarksburg) to just across the Shenandoah Mountains. At this point, the cloud became fragmented, and was lost by the tracking aircraft. The cloud trajectory (A-B and C-D) is shown in Figures 6 and 7. The lidar aircraft was refueled at point B, and contact with the FDP cloud was reestablished at C. FDP-cloud altitude decreased from 2290 m ASL upon release (A), to 1570 m ASL in the lee of the mountains (D).

Lidar Data

Figure 8 shows a gray-scale facsimile record of lidar data of three consecutive traverses across the FDP cloud at 2151, 2154, and 2157 EDT, obtained over a 25-km horizontal distance.* These data are at a location

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* In Figure 8, and in all other vertical cross-sections of lidar data presented in this project report, time increases from left to right -- i.e., the lidar aircraft crosses the underlying terrain from left to right.

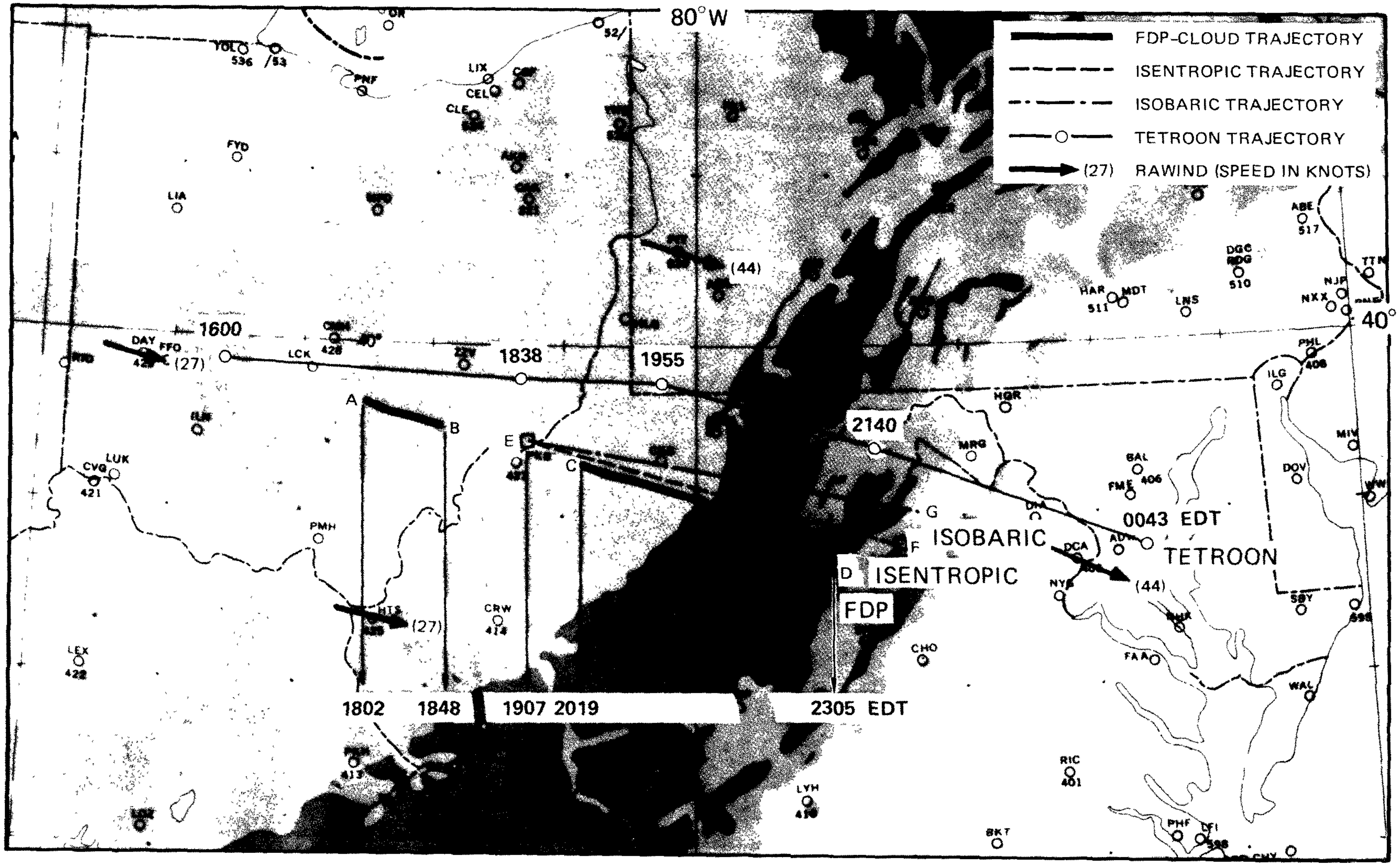

FIGURE 6 OBSERVED FDP-CLOUD TRAJECTORY (A-B AND C-D), COMPARED WITH COMPUTED ISENTROPIC AIR TRAJECTORY (E-F), AND ISOBARIC TRAJECTORY (E-G).

Tetroon trajectory is indicated by a solid line.

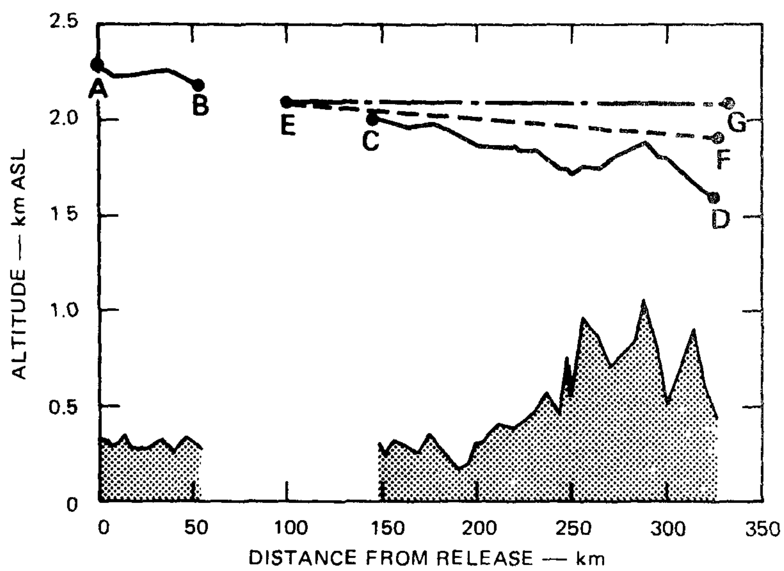

FIGURE 7 VERTICAL PLANE OF OBSERVED FDP-CLOUD TRAJECTORY (A-B) AND C-D) WITH UNDERLYING TERRAIN CONTOUR. E-F AND E-G REPRESENT COMPUTED AIR-PARCEL TRAJECTORY ON THE ISENTROPIC AND ISOBARIC SURFACE, RESPECTIVELY, STARTING ON THE FDP-CLOUD TRACK AT POINT E (14 October 1983, 1802-2305 EDT).

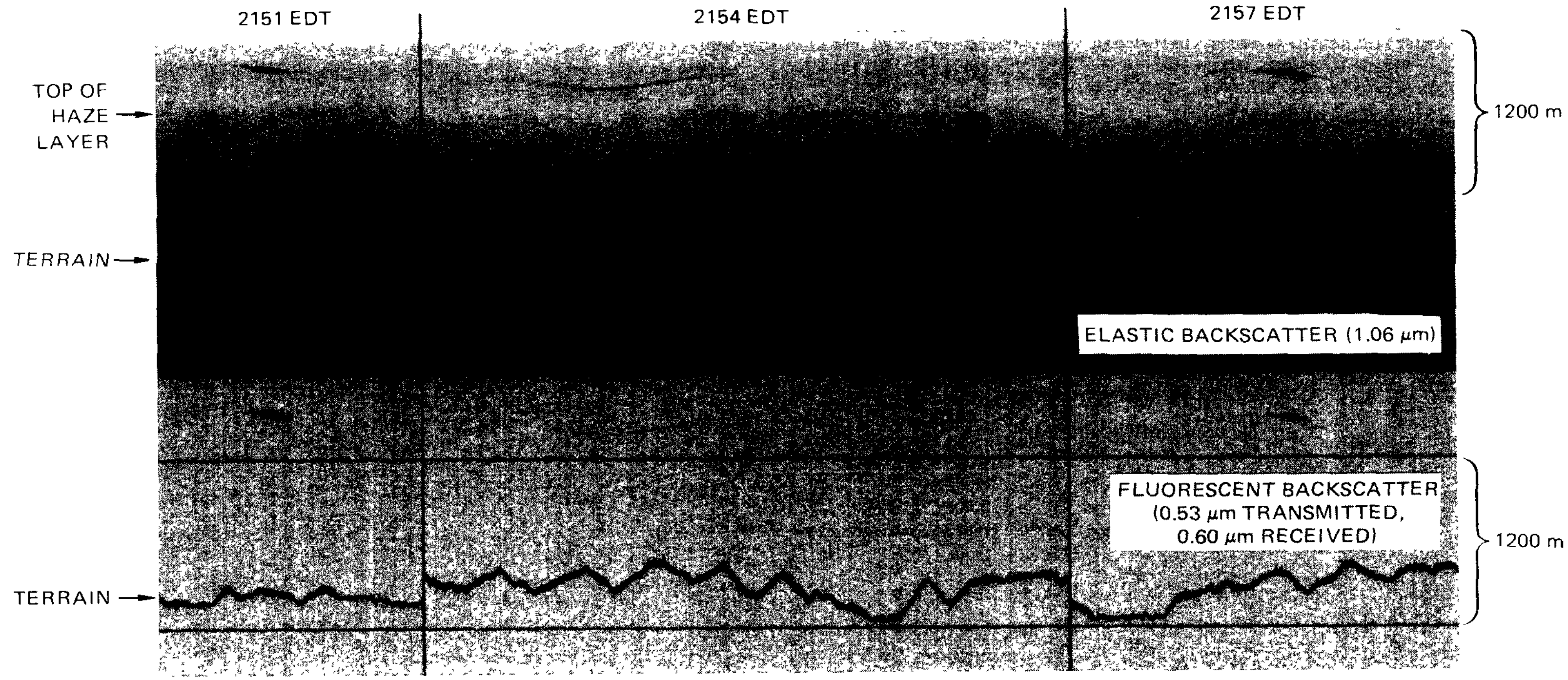

FIGURE 8 FACSIMILE RECORD OF LIDAR DATA SHOWING FDP CLOUD ABOVE THE MIXING LAYER AT THREE DIFFERENT TIMES

14 October 1983, 2144-2201 EDT. Lidar aircraft altitude: 2300 m ASL.

approximately 230 km downwind from the FDP-release point (just before the high-elevation mountains shown in Figure 7). The upper part of the figure presents elastic backscatter data at 1.06 μm. It shows terrain contours, the near-surface haze layer (about 900-1000 m thick), and the infrared backscatter from the FDP cloud.* The lower part shows terrain contours and the fluorescent backscatter at 0.6 μm. No elastic backscatter from the atmospheric aerosol layers is received at this wavelength.

Meteorological Data

Figure 9 presents the surface weather map (surface weather reports, isobars, and fronts) at 14 October 1983, 08:00 EDT. At this time, West Virginia and Ohio (outlined) were located between a high-pressure system centered in Tennessee and a low-pressure area north of the Great Lakes. This situation persisted throughout the day, so that westerly winds prevailed in the area of the ALPHA-1/FDP experiment.

Further meteorological analyses for the area of the FDP cloud were made using rawinsonde data from the synoptic-scale network stations of Pittsburgh, Pennsylvania (PIT), Dayton, Ohio (DAY), Huntington, West Virginia (HTS), and Washington, D.C. (DCA) at the standard radiosonde release time of 1900 EDT (2300 GMT).** The upper-air observations near the average altitude of the cloud (2000 m ASL) were made at about 1907 EDT. This time is the same as that associated with the location of the FDP cloud at the point E indicated in Figures 6 and 7.

The temperature, pressure, and wind at point E were determined by linear interpolation of the 1900 EDT rawinsonde data from PIT and HTS. Thus, these

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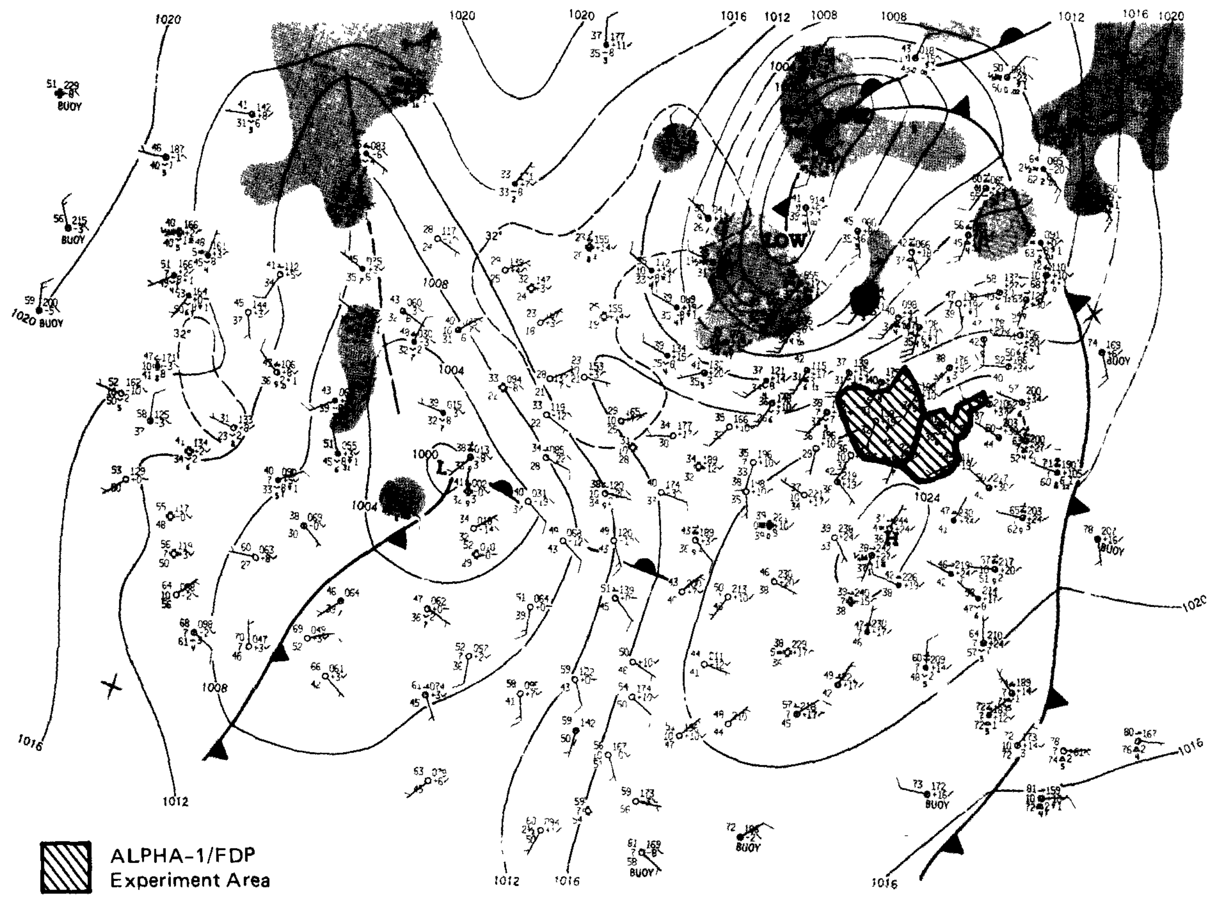
* The top of the ground-based haze layer is an indicator of the mixing depth only during convective periods.

** A CAPTEX experiment was conducted on 14 October, but the CAPTEX sampling aircraft flight paths and the cooperative rawinsonde ascents were to the north of the West Virginia area of the lidar/FDP track.



SOURCE *Daily Weather Maps, Weekly Series, NOAA, NES, Data and Information Service.*

FIGURE 9 SURFACE WEATHER CHART (SURFACE WEATHER REPORTS, ISOBARS, AND FRONTS) 14 OCTOBER 1983, 0800 EDT.

Area where ALPHA-1/FDP experiment took place (Ohio and West Virginia) is located to the north of the high-pressure system in a region of westerly winds.

quantities characterize an air parcel at the location of the FDP-cloud at 1907 EDT. The trajectory of this air parcel was computed both on the isentropic surface (constant potential temperature) corresponding to the potential temperature at E (θ = 295^{o} K) and on the isobaric surface (constant pressure) corresponding to the pressure at E (P = 794 mb).

Air Parcel Trajectories

Using the 1900 EDT (2300 GMT) rawinsonde data of PIT, DAY, HTS, and DCA, the field of the Montgomery streamfunction for $\theta = 295^{o}$ was analyzed for the area of the FDP experiment. The isentropic trajectory starting at point E was constructed assuming steady state conditions -- i.e. the Montgomery streamfunction field was held constant and the air parcel at E was moved with the interpolated winds parallel to the streamfunction isolines for the nearly 4-hour time period extending from 1907 EDT until 2305 EDT (the end time of the FDP-cloud track at D). In a similar manner, an isobaric trajectory was calculated on the isobaric surface of P = 794 mb, assuming steady state conditions for the 4-hour transport period.

Figure 6 shows the trajectory comparison in the horizontal plane. The dashed line E-F represents the computed isentropic air trajectory. It terminates at F about 52 km northeast of the FDP track endpoint D. The average transport speed along the isentropic trajectory is 36 knots. The dash-dot line E-G represents the isobaric trajectory. It terminates at the point G which is 24 km north of F. The average velocity along the isobaric trajectory is 36 knots. Its general direction (279^{o}) is more westerly than that of the isentropic path (284^{o}). The isentropic air trajectory agrees quite favorably with the FDP track, except during the second half of the time period when the FDP track veers about 10^{o} toward the south. This could be interpreted as a curvature induced by the mountains, the effect of diabatic processes such as radiative cooling on the air parcel transport, or inaccuracy in the simplified isentropic trajectory calculation. The lines connected by open circles indicate the path of a tetroon released at Dayton, Ohio, at 1500 EDT. The various times of the tetroon position are shown along its track.

Figure 7 shows the trajectory comparison in the vertical plane, together with the underlying terrain topography. The general descent of the FDP cloud is evident as well as its up-and-down transport across the mountains. The calculated isentropic trajectory shows a gradual descent; the isobaric trajectory does not show any descending motion.

Using the average diameter of the fluorescent dye particles (3.5 to 4.0 μm), and a value for specific gravity of 1.36 g cm^{-3}, the fall velocity (settling rate) computed from Stokes' Law equals 0.6 mm sec^{-1}. The possible clustering of individual dye particles during an FDP-cloud release could increase the mean diameter by a factor of 3 (for example, 9 particles clustering together). Such effect would increase the fall velocity by a factor of 9 to 5.4 mm sec^{-1} or 0.54 cm sec^{-1}. Even this worst-case fall velocity would not explain the lidar-observed 4.3 cm sec^{-1} downward motion of the FDP tracer cloud.

The altitude of the tetroon trajectory, located 75 km north of the FDP experiment area, decreased from 2149 m ASL at 1600 EDT to 1785 m ASL at 2140 EDT (see data listing in Appendix). When it is assumed that this descent is entirely due to atmospheric motion, the tetroon data suggest an average downward motion along the tetroon trajectory equal to 1.8 cm sec^{-1}.

From their common location at E, the lidar-observed and calculated transport trajectories diverge in both the vertical and horizontal plane. The observed small-scale features of the FDP trajectory in comparison with the computed synoptic-scale air-parcel trajectories are most evident in Figure 7. The overall trajectory characteristics are summarized in Table 2.

TABLE 2

TRAJECTORY CHARACTERISTICS
(14 October 1983, 1802-2305 EDT)

Trajectory	Mean Direction (degrees)	Horizontal Transport Velocity (knots)	Mean Vertical Transport Velocity* ($cm\ sec^{-1}$)
Tetroon (1600-2140 EDT)	279	41	-1.8
FDP	290	35	-4.3
Isentropic	284	36	-1.0
Isobaric	279	36	0

*Negative represents descending motion.

CASE II: LONG-RANGE TRACKING OF FDP-CLOUD SHAPE AND SIZE

Scenario

The ALPHA-1/FDP experiment conducted on 16 October 1983, 1650-2359 EDT, established the feasibility of evaluating FDP-cloud height, shape, and size with high spatial resolution. These data can be used to determine dispersion rate along, and transverse to, the transport direction, and to identify small-scale features in the transport circulation. These experimental results are described in the following paragraphs.

ALPHA-1/FDP Track

On 16 October, an FDP cloud was released from Delaware, Ohio (about 40 km north of Columbus), at 1650 EDT. A high pressure system prevailed in the area. Release height was 2300 m ASL at about 500 to 800 m above the mixing layer. Relative humidity at the release level was 10-20%. The cloud was tracked by the ALPHA-1 over a total distance of 236 km through eastern Ohio to a point between Youngstown, Ohio, and New Castle, Pennsylvania. Underlying terrain was relatively flat, varying in elevation between 274 and 305 m (900-1000 ft ASL). The ALPHA-1/FDP track is shown in Figure 10 together with the streamlines of the wind near the average altitude of the tracer cloud (2250 m AGL). Two aircraft runs were made to map the shape or structure of the FDP cloud by flying the ALPHA-1 back-and-forth within the tracer cloud in a stationary north-to-south vertical plane while the FDP cloud moved through this plane from west to east. The locations of the structure runs indicated in Figure 10 at 1908 EDT and 2105 EDT are based on data from the aircraft navigational system.

Lidar Data

Figure 11 shows 4 cross-sectional ALPHA-1 observations of the tracer cloud centered at the indicated times at a location between the two "structure" runs. These lidar data are in a vertical plane perpendicular to the transport direction of the FDP cloud. The cross-sectional cloud shape and size are identified by both the elastic backscatter return at 1.06 μm (upper part of the figure), and the fluorescent signal at 0.6 μm (lower part of figure). The background aerosol at 1.06 μm clearly identifies a 1500-m deep surface-based haze layer, the top of which is below the transport level of the tracer cloud. The top of this layer normally indicates the maximum mixing depth attained on this day.

Using lidar data of the type illustrated in Figure 11, the height of the FDP cloud above the underlying terrain was determined along the entire 236-km transport distance. Figure 12 presents these height data. The downwind distances at which the structure of the tracer cloud was determined are indicated at 95 km (first run) and at 151 km (second run). After the second structure run was completed, contact with the FDP cloud was reestablished with some difficulty. Subsequent lidar observations indicate that the cloud became diffuse and disorganized.

Up to 150 km downwind distance, the height of the tracer observations suggests a non-horizontal FDP cloud at a mean altitude of 2250 m AGL. A linear regression fit to all lidar-determined height points including those of

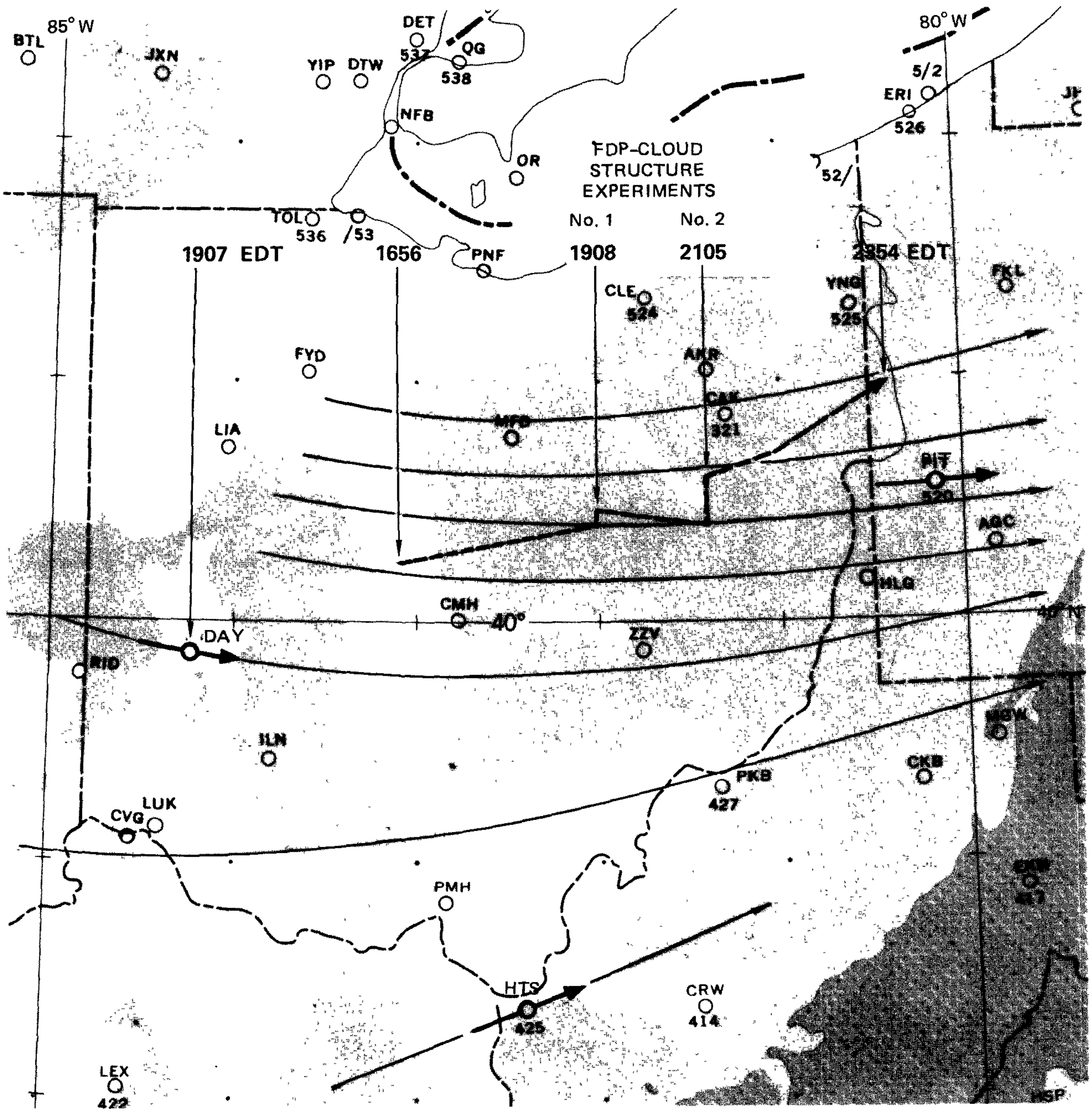


FIGURE 10 LOCATION OF FDP TRACER CLOUD WITH STREAMLINES OF THE WIND AT 2250 m ABOVE TERRAIN.

Cloud structure runs by the ALPHA-1 were made at 1908 EDT and 2105 EDT. Streamlines are based on wind observations from standard radiosonde network.

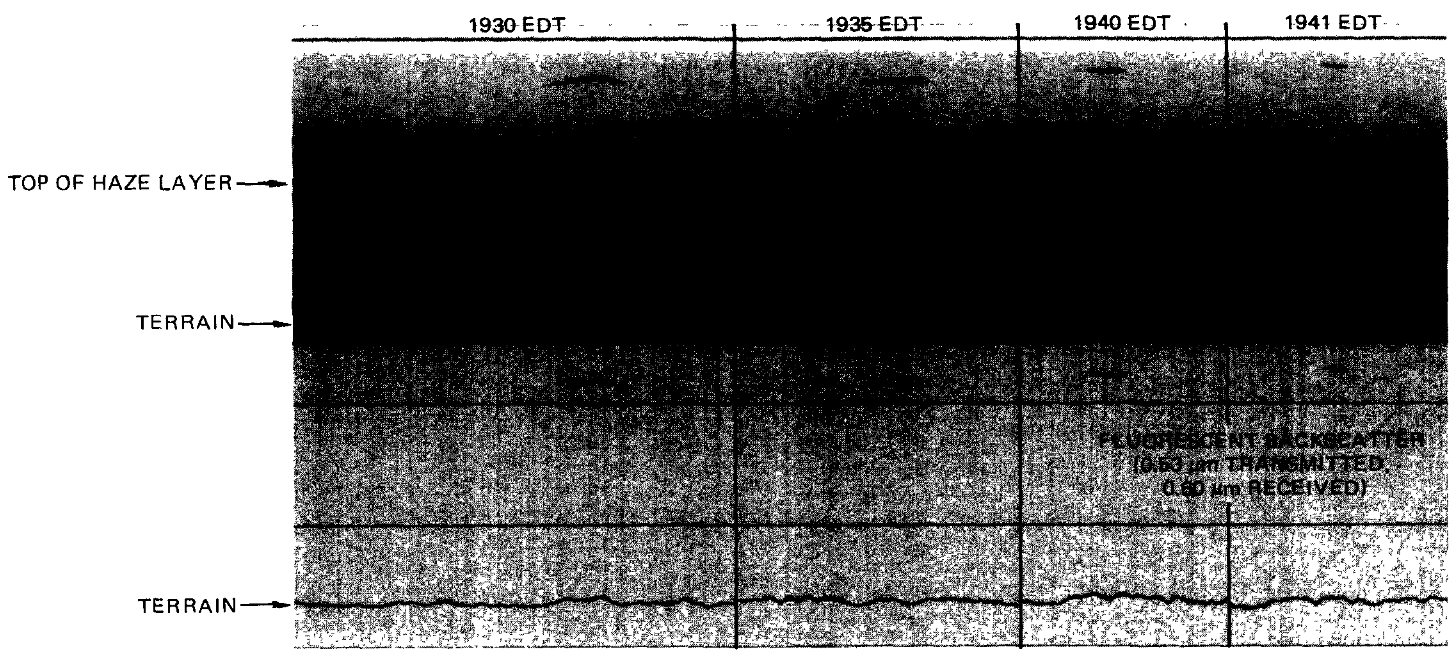


FIGURE 11 FACSIMILE RECORD OF LIDAR DATA SHOWING FDP TRACER CLOUD ABOVE THE MIXING LAYER AT FOUR DIFFERENT TIMES

Lidar observations are in a vertical plane perpendicular to the transport direction. 16 October 1983, eastern Ohio. Lidar aircraft altitude: 2900 m ASL.

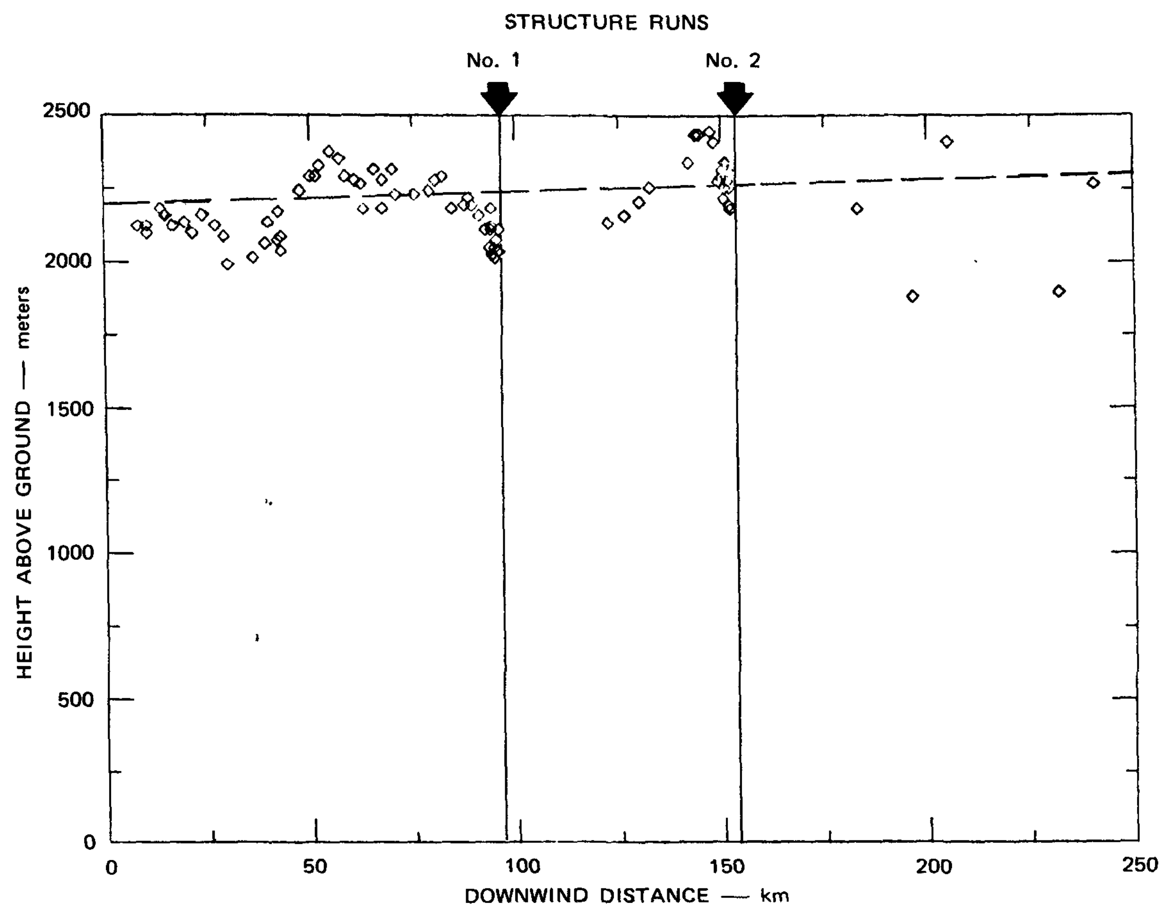


FIGURE 12 HEIGHT ABOVE GROUND LEVEL OF FDP TRACER CLOUD DETERMINED BY AIRBORNE LIDAR FROM TRACER RELEASE POINT TO END OF ALPHA-1/FDP EXPERIMENT (236 km DOWNWIND DISTANCE)

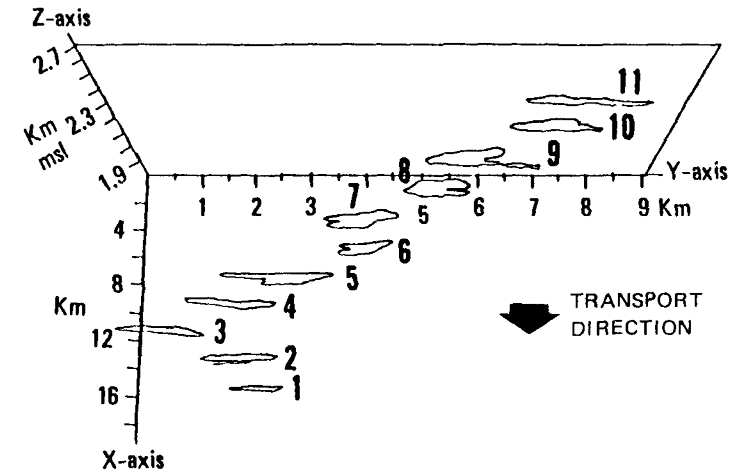
Note evidence of non-horizontal motion along transport trajectory; location of the structure runs; and linear regression indicating mean ascending motion of 0.47 cm s^{-1}.

the two structure runs, indicates a mean ascending motion of the FDP cloud equal to 0.47 cm sec^{-1}.

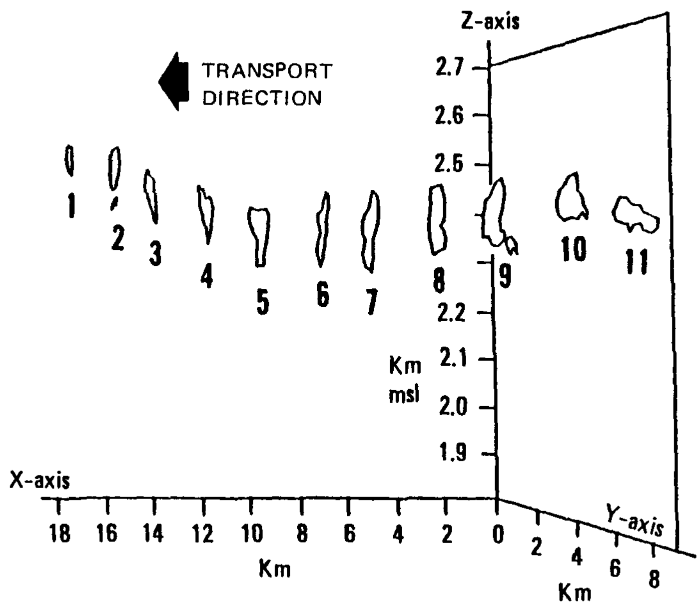
Rate of Change of Cloud Shape and Size

Figure 13 shows the shape of the FDP tracer cloud obtained from the first structure run made at 95 km downwind (2-hour travel time) from the release point. The data are obtained from the vertical lidar cross sections recorded along a fixed flight-path perpendicular to the transport direction while the tracer plume moved below the flight path. Figure 13(a) presents a computer-generated view of the FDP cloud cross-sections from a position above the front of the tracer cloud. Figure 13(b) shows a view from a position off to the side. The FDP-cloud cross section #1 represents the front, and cross section #11 represents the tail end of the FDP cloud. Figure 14 shows a data presentation similar to that of Figure 13, but constructed from lidar observations of cross cloud structure recorded at a downwind distance of 151 km (about 4 hours of travel time) from release. Several features of interest are evident from these unique observations:

- Two hours from release time, the tracer cloud is about 16 km long and 2 km wide (distance along the X-axis is evaluated from mean cloud speed).
- Four hours after release, the cloud is about 30 km long and shows variable width of 1 to 5 km which indicates continued elongation along the transport direction. However, the variation in cross-sectional area along the length of the FDP tracer cloud may indicate that the tracer ribbon is beginning to break up into separate elements.
- At both times during which structure runs were made, the FDP cloud showed wave structure along the mean transport direction.
- Considering that the FDP release was in the form of a circular cloud of 3/4 km diameter and 50 m thickness (see Figure 3), the lidar observations demonstrate a rapid and continued elongation of the tracer material along the transport-wind direction into a narrow ribbon-type shape.
- The top views of Figure 13(a) and Figure 14(a) show a tendency for the tracer ribbon to develop a V-shape in the horizontal (X-Y) plane. A suggestion as to the cause will be presented below in connection with the discussion of the meteorological analysis.
- The lidar observations contain all information necessary to compute the volume and the growth rate of the tracer cloud.



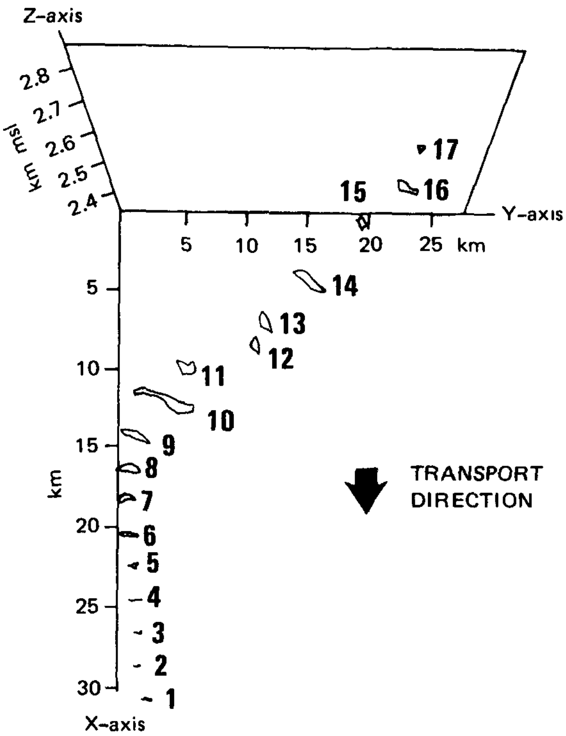
(a) VIEW FROM ABOVE (INDIVIDUAL LIDAR CROSS SECTIONS NUMBERED)



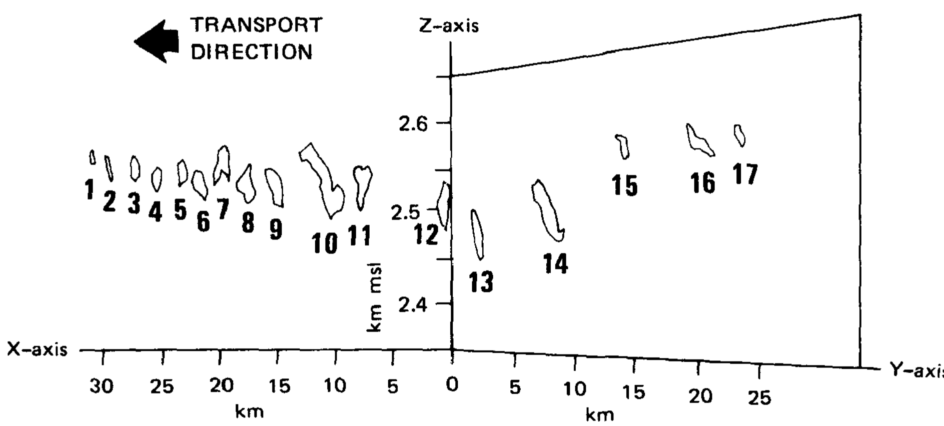
(b) VIEW FROM SIDE

FIGURE 13 FDP-CLOUD STRUCTURE OBSERVED BY ALPH-1 TWO HOURS AFTER RELEASE ON 16 OCTOBER 1983, 1845 TO 1908 EDT

(a) is top view of lidar data along entire FDP-cloud length (No. 1 through No. 11). (b) is side view of lidar cross sections. Transport direction is along the X-axis.



(a) VIEW FROM ABOVE



(b) VIEW FROM SIDE

FIGURE 14 FDP-CLOUD STRUCTURE OBSERVED BY ALPHA-1 FOUR HOURS AFTER RELEASE ON 16 OCTOBER 1983, 2009 TO 2105 EDT.
(a) Top view of vertical lidar cross sections along the entire FDP-cloud length (No. 1 through No. 17).
(b) Side view of lidar cross sections.
Transport direction is along the X-axis.

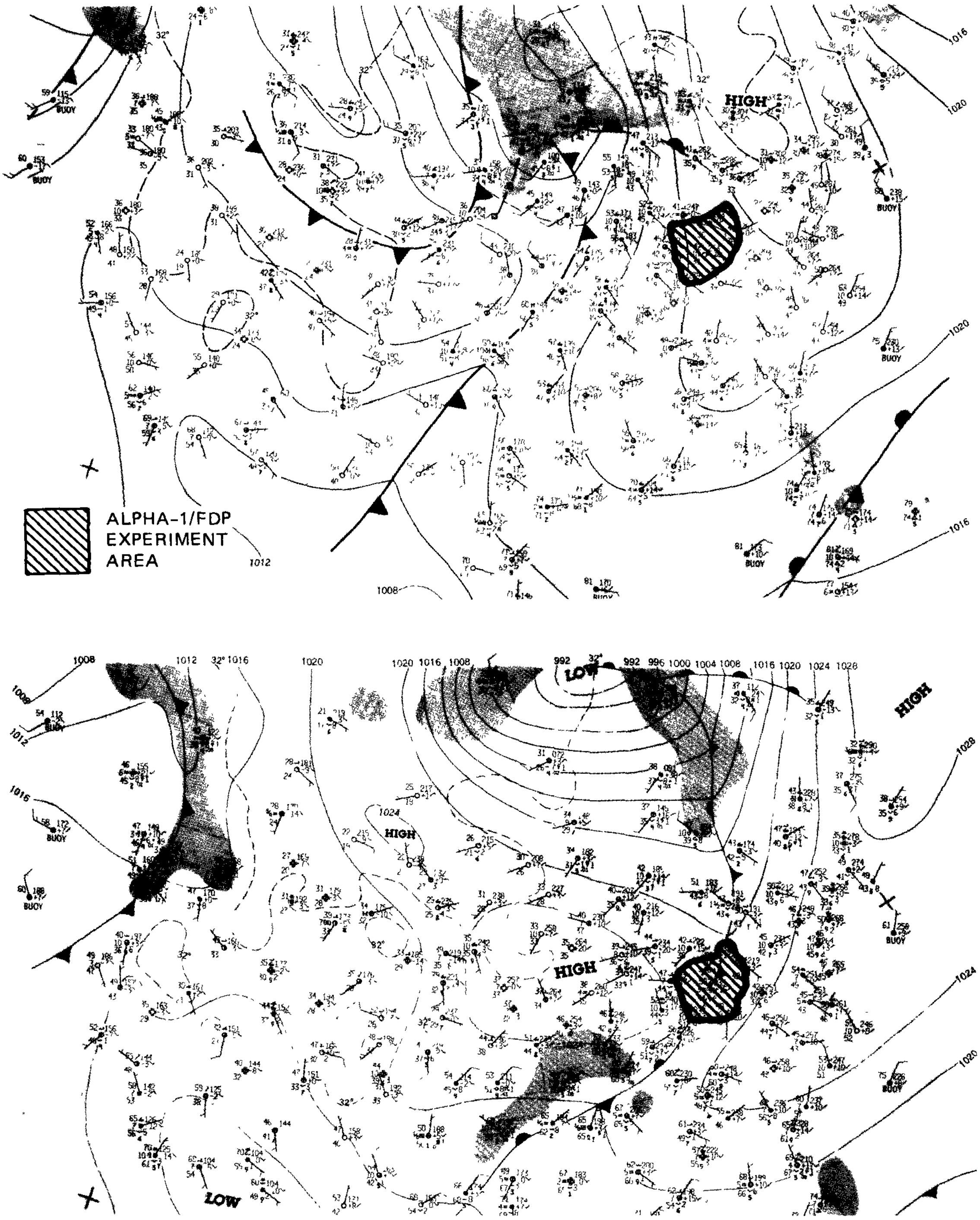
Meteorological Analysis

Figure 15 presents two available surface weather charts for 16 October, 0800 EDT, and 17 October, 0800 EDT. It is evident from these charts that during the period of the ALPHA-1/FDP experiment, a cold front approached Ohio from the west, and that the high pressure system which prevailed over Ohio during the daytime hours was moving toward the East Coast.

Further meteorological analyses were made using the standard (synoptic-scale) rawinsonde data of 1900 EDT (rawinsonde launch time) for Dayton, Ohio (DAY), Huntington, West Virginia (HTS), Pittsburgh, Pennsylvania (PIT), and Buffalo, New York (BUF).

Figure 16 shows vertical profiles of the horizontal wind for DAY and PIT for 16 October 1983, 1900 EDT. The height interval within which the FDP tracer cloud was transported, is indicated. Winds in this altitude range were obtained at about 1907 EDT -- i.e. 7 minutes after the rawinsonde launch. Referring back to Figure 10 which shows the FDP track, it is seen that the first structure run occurred near 1907 EDT about halfway between DAY and PIT. The rawinds of Figure 16 show vertical directional shear in the FDP-cloud layer, and suggest a trough in the wind field. The trough line was analyzed at the position of the first structure run and, therefore, the bend in the tracer cloud seen in Figure 13(a) may have been directly on the wind trough. Furthermore, the increased V-shape of the FDP cloud evident in the lidar observations of 2 hours later, Figure 14(a), suggests that the FDP cloud was transported through the wind trough between 1908 EDT and 2105 EDT (i.e., the tracer cloud moved faster than the trough).

Figure 17 shows vertical profiles of relative humidity for DAY and PIT. Relative humidities at the altitude of the FDP cloud are 10-20%. Thus, the transport observations were made during dry, cloud-free conditions.



SOURCE: Daily Weather Maps, Weekly Series, NOAA, NES, Data and Information Service.

FIGURE 15 SURFACE WEATHER CHARTS (SURFACE WEATHER REPORTS, ISOBARS, AND FRONTS) VALID AT 16 OCTOBER 1983, 0800 EDT (UPPER CHART) AND AT 17 OCTOBER 1983, 0800 EDT (LOWER CHART).

Area (Ohio) where ALPHA-1/FDP experiment took place is outlined. During period of experiment, Ohio was under the influence of a high-pressure system with a cold front approaching from the west.

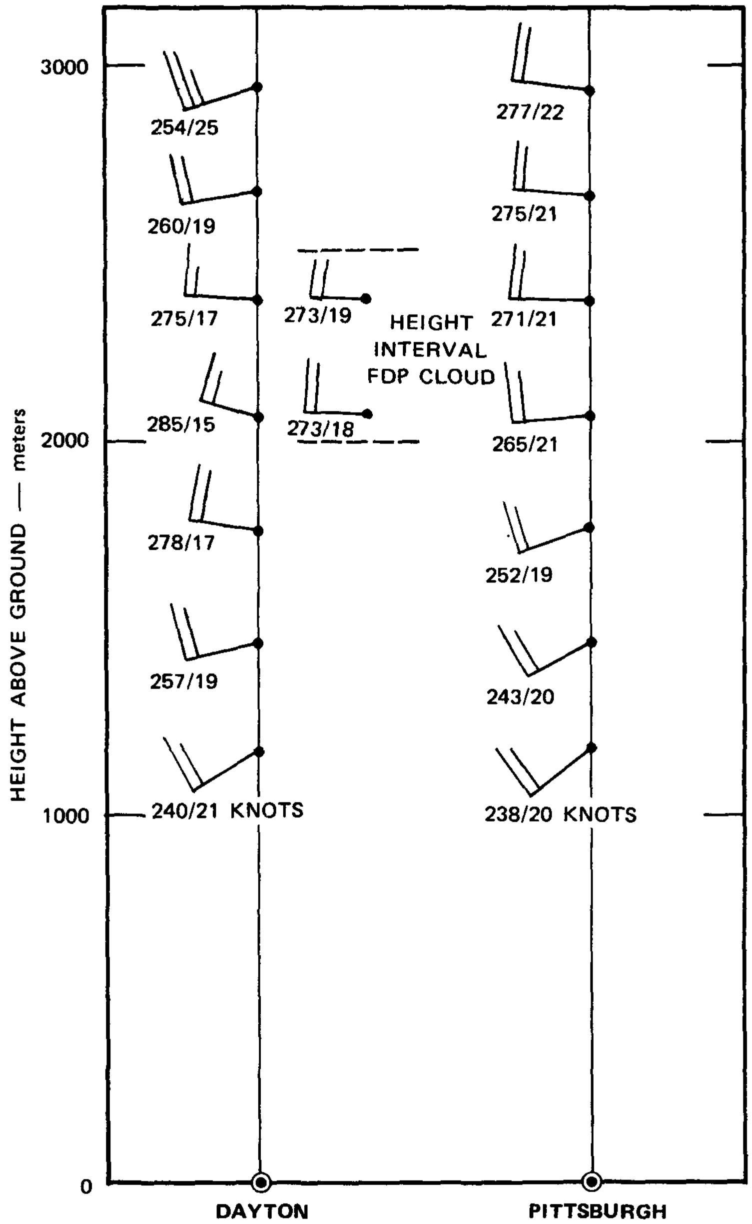


FIGURE 16 WIND DIRECTION AND SPEED (KNOTS) FOR EACH MINUTE OF RADIOSONDE ASCENT AT DAYTON, OHIO (DAY) AND PITTSBURGH, PENNSYLVANIA (PIT) ON 16 OCTOBER 1983, 1900 EDT (2300 GMT). Altitude interval of FDP tracer cloud is indicated by dashed lines together with interpolated winds at halfway points between DAY and PIT. FDP cloud was located at halfway point at 1907 EDT.

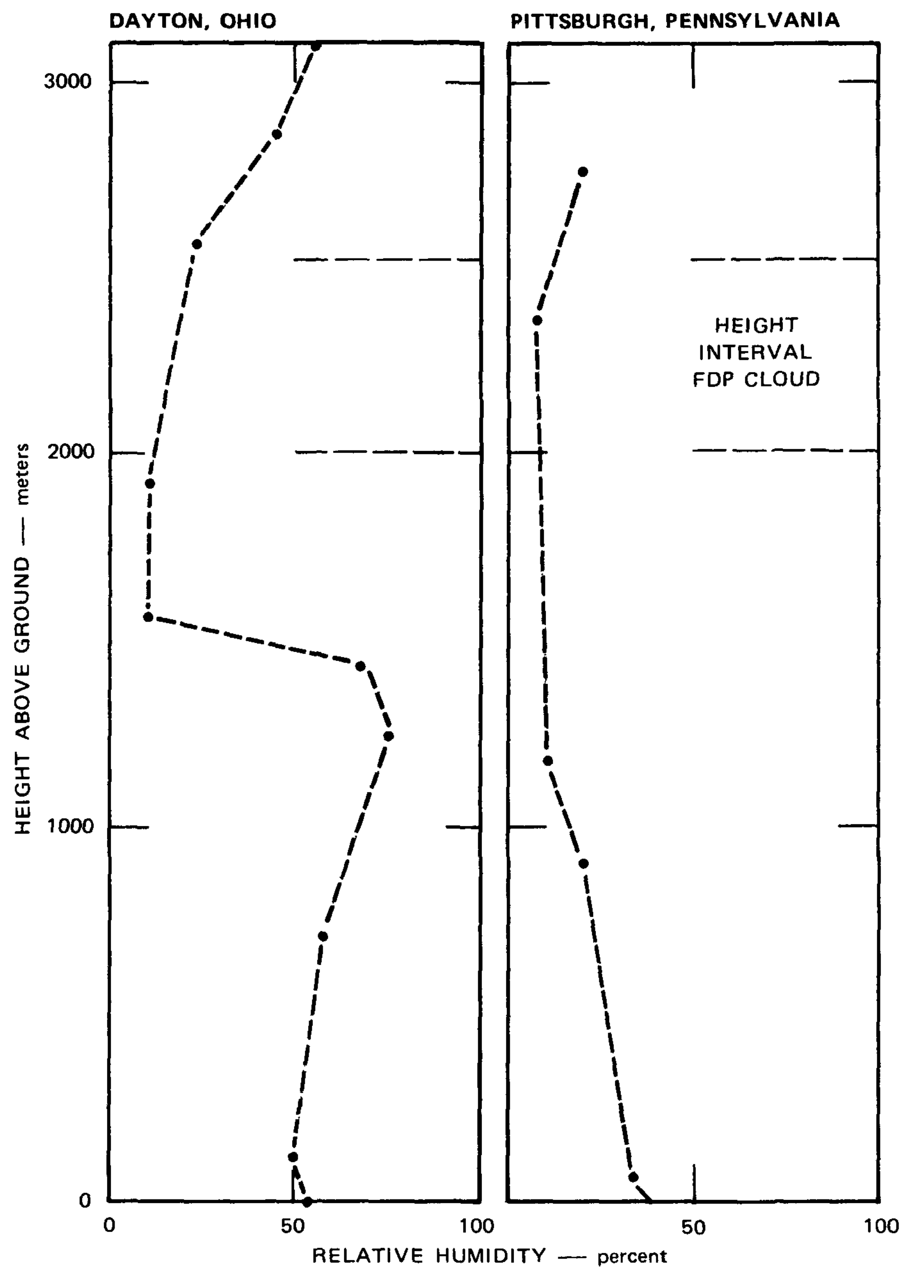


FIGURE 17 VERTICAL PROFILES OF RELATIVE HUMIDITY FOR DAYTON, OHIO AND PITTSBURGH, PENNSYLVANIA NEAR THE TIME THAT THE FIRST FDP-CLOUD STRUCTURE WAS OBSERVED BY THE ALPHA-1. Data are from the standard radiosonde ascent of 16 October 1983, 1900 EDT (2300 GMT).

CASE III: FDP-PUFF RELEASE NEAR POWER PLANT PLUME

Scenario

The ALPHA-1/FDP experiment conducted on the evening of 17 October 1983, 2142-2338 EDT, investigated the feasibility of tracking an FDP tracer-puff released near a power plant plume at 500-600 m above ground level. The power plant plume and the tracer cloud were observed by ALPHA-1 for nearly 2 hours. The lidar observations were made to show the diffusion of the plume and tracer puff transverse to the transport wind direction. In addition, the FDP tracer can provide information on "puff" dimensions in the downwind direction.

FDP-Cloud Track

On 17 October, 2142 EDT, an FDP tracer-puff was released on top of the plume of the Conesville Power Plant located about 80 km (50 miles) east of Columbus, Ohio. The release height was 600 m above ground level which corresponded to the top of the haze layer, as indicated by the lidar data. Lidar cross-sections of the power plant plume and of the released tracer puff were recorded along the west-to-east distance shown in Figure 5 (Section 4.0). Winds were southwesterly in advance of a cold front approaching from the west. The experiment took place during darkness, and little or no visual contact was made with either the plume, or the tracer cloud. Using the lidar backscatter signals as guidance, the lidar aircraft was directed along flight paths transverse to the power plant plume, -- i.e., transverse to the transport wind.

Lidar Data

Figure 18(a) shows lidar data of the power plant plume before FDP release about 1.5 km downwind from the power plant. The lidar observations are in a vertical plane transverse to the transport wind. The plume lies on top of the haze layer, and no fluorescent light from the plume or background aerosols is evident on the fluorescent channel. Figure 18(b) shows the puff of fluorescent tracer shortly after it was released on top of the plume near 2142

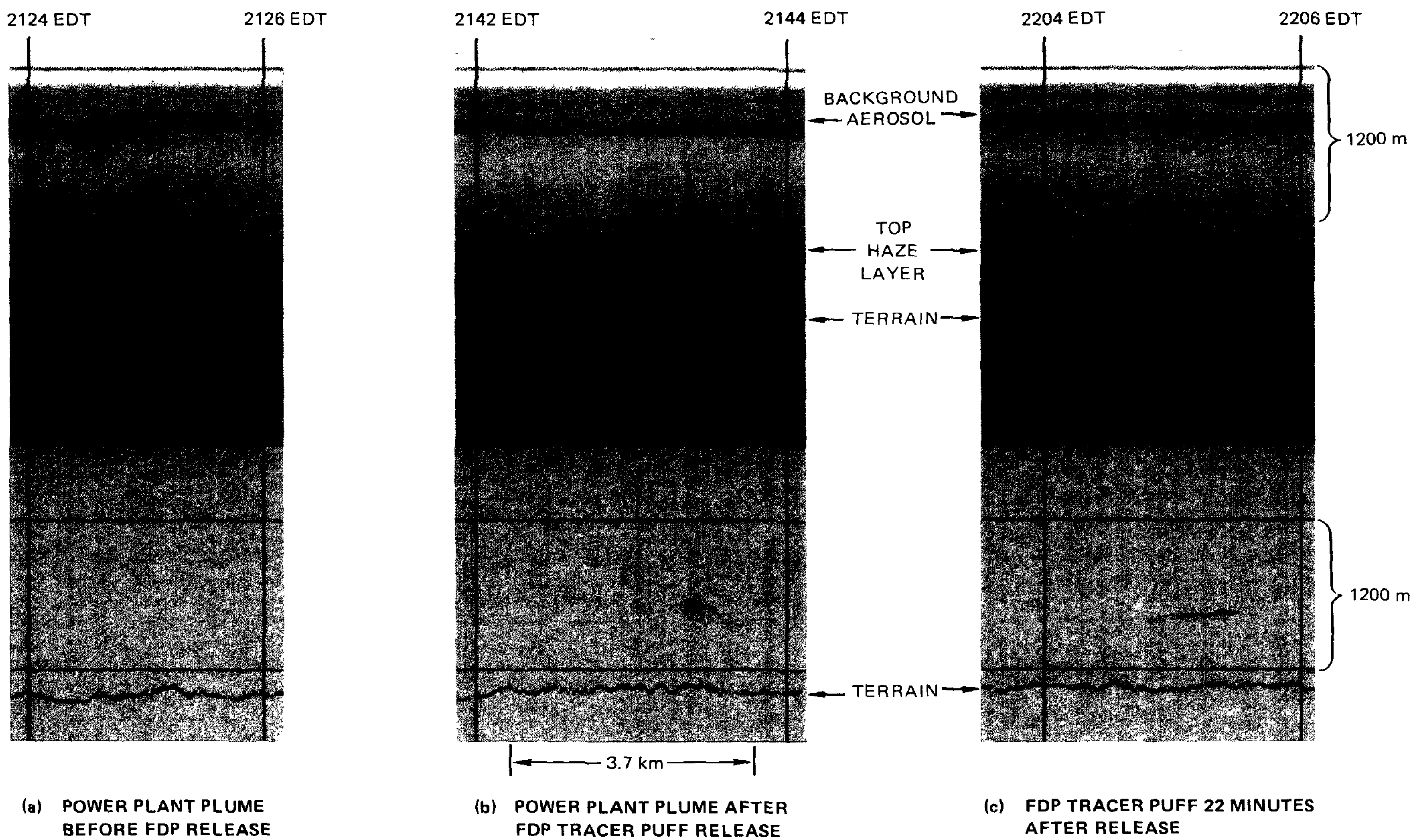


FIGURE 18 SAMPLES OF LIDAR DATA TRANSVERSE TO A POWER PLANT PLUME RECORDED DURING THE ALPHA-1/FDP EXPERIMENT AT THE CONESVILLE POWER PLANT EAST OF COLUMBUS, OHIO ON 17 OCTOBER 1983.

Upper part: elastic backscatter at 10.6 μm showing powerplant plume, FDP puff and background aerosol.
Lower part: fluorescent backscatter; 0.53 μm transmitted, 0.60 μm received. Aircraft altitude: 2300 ASL.

EDT. At the backscatter wavelength of 1.06 μm [upper part of Figure 18(b)], the tracer puff is difficult to locate in the plume background. The fluorescent channel, however, identifies the location and shape of the tracer puff [lower part of Figure 18(b)] without interference by the plume and the background aerosol. The plume is about 3.7 km wide, and the FDP puff is about 300 m wide at 1.6 km downwind from the power plant, assuming the aircraft traverse is truly perpendicular to the transport direction. At 2205 EDT (7.7 km downwind), the tracer puff has grown in the transverse direction to 1300 m as shown by the fluorescent channel data in Figure 18(c). Observations of the type presented in Figure 18 were recorded by the ALPHA-1 over a 2-hour period.

Diffusion of FDP-Tracer Puff

Table 3 lists the size of the tracer cloud in a direction transverse to the power plant plume as a function of travel time (time after release) to a distance of about 29 km downwind from the release point. Since no visual contact with the tracer cloud was possible because of darkness, it is unknown whether or not the transverse direction of lidar observation was perpendicular to the longitudinal plume axis. At 1 hour and 16 minutes after release (20 km downwind), the length of the FDP-tracer cloud was between 2 and 3 km estimated from lidar observations made along a fixed transverse direction while the tracer cloud passed by below the aircraft flight level. Table 3 does not suggest that the tracer puff diffused into a "ribbon" along the direction of the power plant plume as in Case Study II. The radiosonde ascents at Dayton and Pittsburgh for 1900 EDT showed west-south-west winds at 8-10 knots (4-5 $msec^{-1}$) near the height of the Conesville plume. Toward the end of the observation period, clouds began to move in at 1500 m above ground level, and prevented a continuation of the experiment.

CASE IV: FDP-CLOUD RELEASES AT DIFFERENT ALTITUDES

Scenario

On 19 October 1983, 0920-1238 EDT, FDP clouds were released at two different altitudes in a northeast-to-southwest wind flow regime. By tracking the top (2200 m AGL) and the bottom (1500 m AGL) tracer clouds, the ALPHA-1 observed large directional wind shear between these altitudes. Individual FDP cloud observations also showed wind shear effects and descending motion during the 3-hour lidar-tracking period. Cloud location was lost after an extended refueling stop.

Table 3

DIFFUSION CHARACTERISTICS OF FDP TRACER PUFF
OBTAINED FROM ALPHA-1 OBSERVATIONS

Time After Release	FDP Size Transverse to Plume	FDP Length (km)	Distance Downwind From Powerplant (km)
0	0.3	0.3	1.6
11 min	0.6	--	4.2
16 min	0.9	--	6.0
22 min	1.3	--	7.7
1 hr 16 min	--	2.0-3.0	20.5
1 hr 21 min	3.7	--	21.2
1 hr 51 min	3.9	--	28.6

FDP-Cloud Track

On 19 October 1983, 0920 EDT, two FDP tracer clouds were released, one at 2200 m AGL, and the other at 1600 m AGL. The transport and dispersion of these two clouds were observed by the ALPHA-1 flying near an altitude of 2700-2800 m AGL for nearly 3 hours over a distance of 132 km downwind of the release point. Figure 19 shows the release and tracking area between Columbus and Mansfield, Ohio. The tracer releases took place at nearly the same

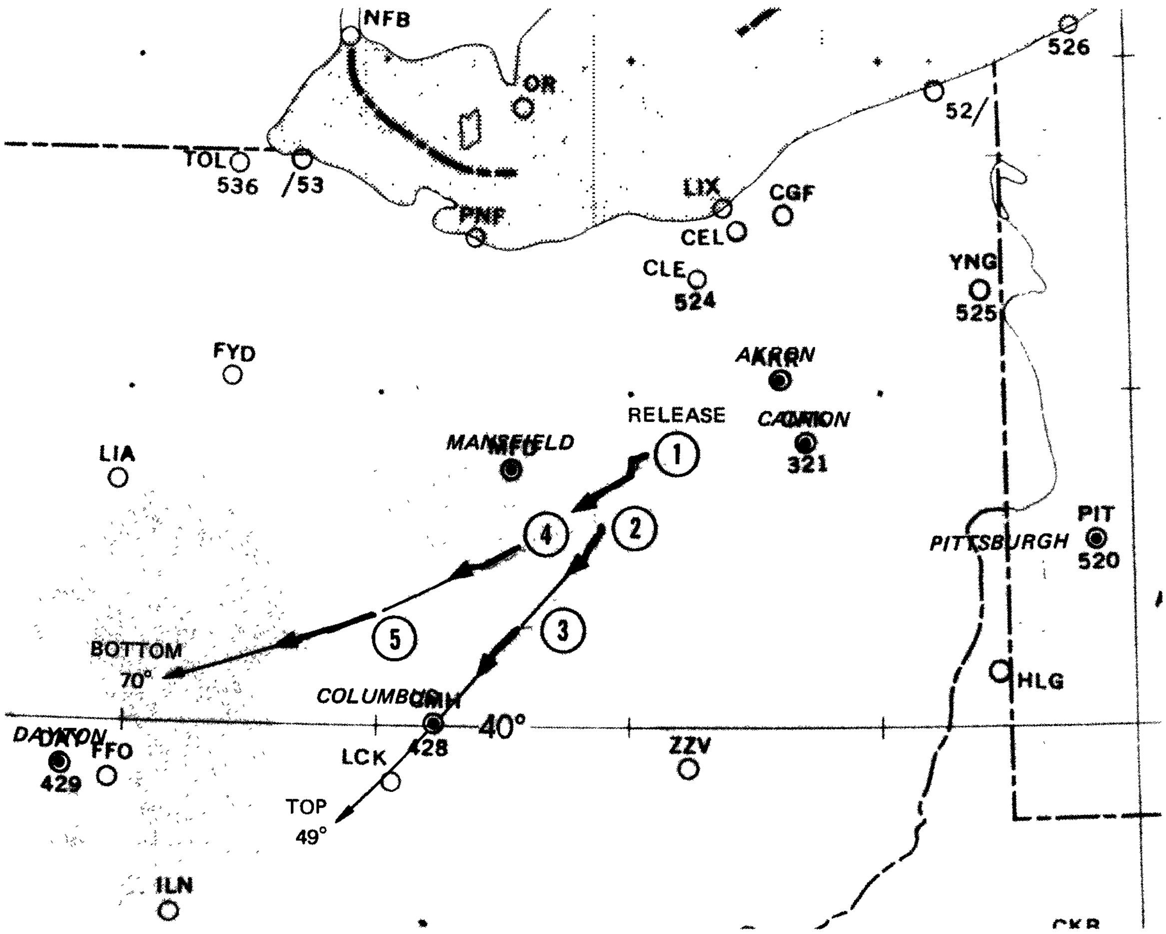


FIGURE 19 AREA OF ALPHA-1/FDP STUDY OF TRACER CLOUDS RELEASED AT TWO DIFFERENT ALTITUDES BELOW THE LIDAR AIRCRAFT ON 19 OCTOBER 1983, 0920-1238 EDT.

1: Release location
2 and 3: Trajectory of top FDP cloud
4 and 5: Trajectory of bottom FDP cloud

Thin lines with arrow represent mean trajectories with direction in degrees.

location (location #1 in Figure 19). About 35 minutes after release, the horizontal trajectories of the top and bottom FDP-clouds were observed to separate. The top cloud followed the tracks indicated by #2 and #3, while the bottom cloud followed the trajectory indicated by #4 and #5. This separation with altitude identified a vertical directional shear of the horizontal wind equal to 21 degrees (4.2 degrees per 100 m).

Lidar Data

Figure 20 shows a time series of lidar observations over a period of about 3 hours. Both the top and bottom cloud undergo a strong shearing effect with parts of the cloud sheared off in a horizontal direction. This effect is especially evident in the lidar observations of the top cloud by comparing the period 0947-0953 EDT [Figure 20(b)] with the period 1132-1134 EDT [Figure 20(c)]. Shearing effects on the bottom cloud are seen in Figure 20(d). It is also seen that both tracer clouds descend in altitude.

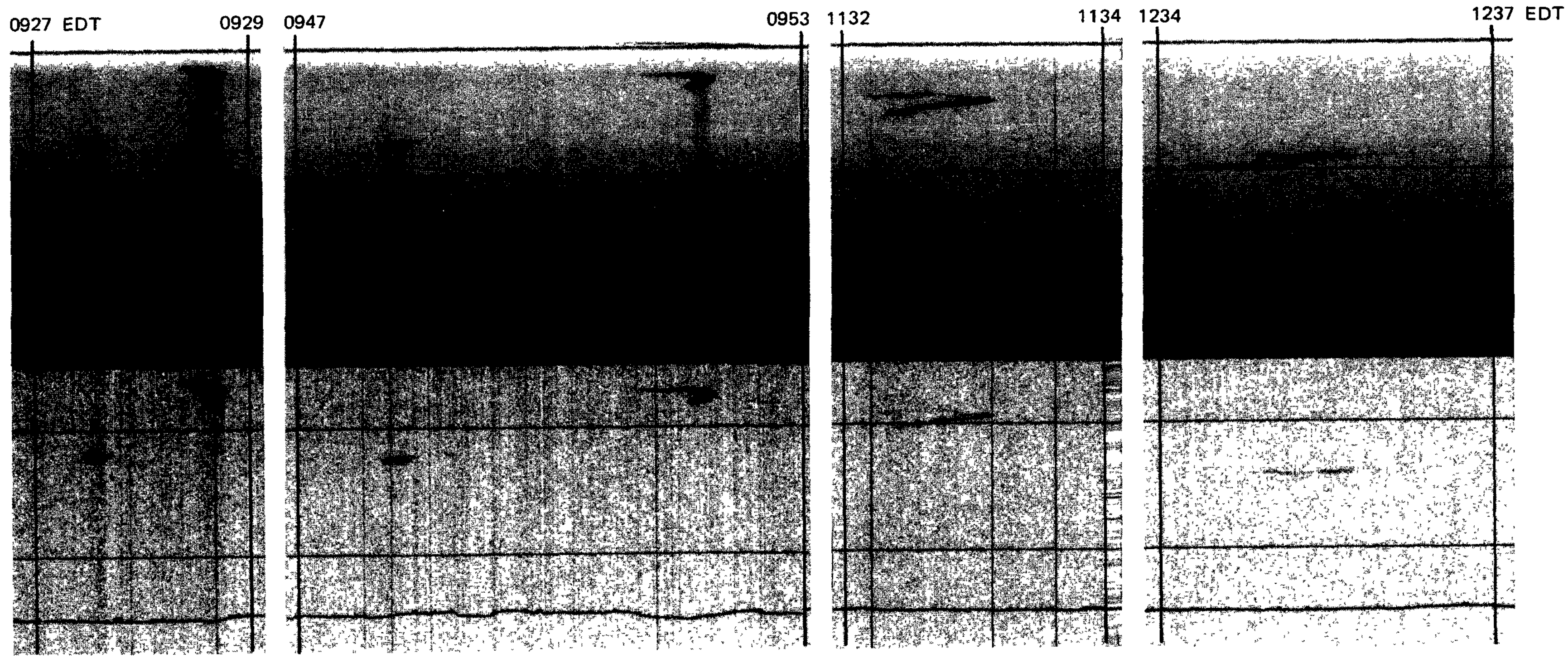
Figure 21 shows the lidar-observed height above ground level of the top and bottom tracer clouds during the nearly 3-hour period of observations. Linear regression fits to the data points indicate a mean descending motion of 1.6 cm sec^{-1} for the bottom cloud and 4.1 cm sec^{-1} for the top cloud. These numbers suggest that the downward motion decreases toward the top of the haze layer where, most likely, it approaches zero.

Unique information such as shown in Figures 19 through 21 can be applied to validate and develop sub-synoptic scale transport models.

CASE V: FDP TRACKING ACROSS LAKE ONTARIO

Scenario

On 21 October 1983, 0708-0929 EDT, a low-altitude FDP tracer cloud was released north of Buffalo, New York, on the east shore of Lake Ontario during easterly wind flow. The tracer cloud was transported across the lake, and its dispersion characteristics were observed by the ALPHA-1 for over 2 hours. Subsidence was observed over the lake, and a strong rising motion was observed



(a) TOP AND BOTTOM FDP TRACER CLOUD 7 MINUTES AFTER RELEASE

(b) TOP AND BOTTOM FDP TRACER CLOUDS ABOUT 30 MINUTES AFTER RELEASE

(c) TOP FDP TRACER CLOUD ABOUT 2 HOURS AND 10 MINUTES AFTER RELEASE

(d) BOTTOM FDP TRACER CLOUD ABOUT 3 HOURS AND 10 MINUTES AFTER RELEASE

FIGURE 20 TIME SERIES OF TOP AND BOTTOM FDP TRACER CLOUDS OBSERVED BY ALPHA-1 IN AN AREA OF NORTHEAST-TO-SOUTHWEST WIND FLOW, 93 km NORTH OF COLUMBUS, OHIO ON 19 OCTOBER 1983.

Upper part: elastic backscatter at 1.06 μm showing FDP clouds, background aerosol, and underlying terrain. Lower part: fluorescent backscatter; 0.53 μm transmitted, 0.6 μm received. Lidar aircraft altitude; 2740 m ASL.

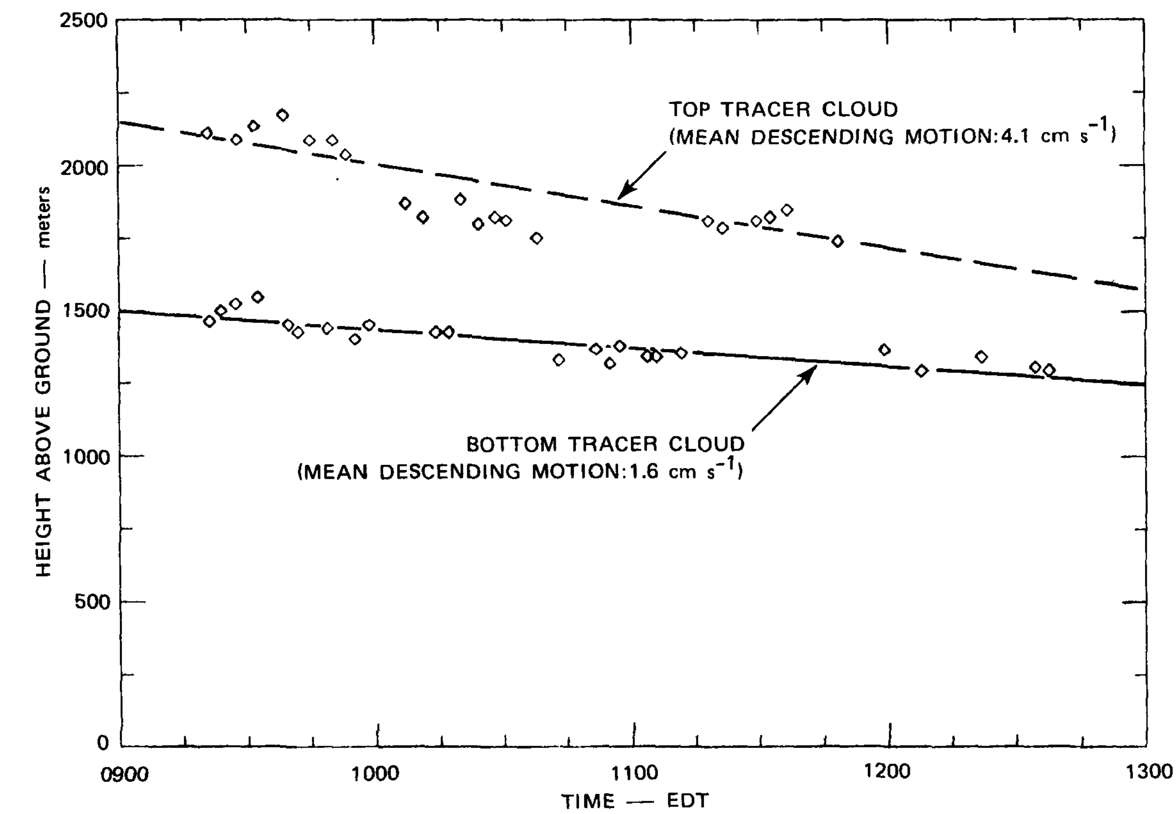


FIGURE 21 LIDAR OBSERVATIONS OF THE HEIGHT ABOVE GROUND LEVEL FOR THE TOP AND BOTTOM FDP TRACER CLOUDS DURING THE 3-HOUR PERIOD AFTER THE TRACER-CLOUD RELEASE ON 19 OCTOBER, 0920 EDT NORTH OF COLUMBUS, OHIO. Note mean descending motion of the tracer clouds indicated by linear regression fits to the data points.

when the tracer cloud approached the west shore in an area of cumulus clouds during onshore wind flow.

FDP-Cloud Track

On 21 October, 0708 EDT, an FDP cloud was released on the east shore of Lake Ontario north of Buffalo, New York. The release was made before sunrise at an altitude of 360 m above ground level. Figure 22 shows the tracer cloud trajectory across the lake from the U.S. to the Canadian shore over a distance of about 95 km (2.3 hours of travel time).

Figure 23 represents the surface weather map at 0800 EDT -- i.e., about one hour after release of the FDP cloud. Lake Ontario is located in an area of predominantly easterly wind flow, on the southern side of a high-pressure system. These surface winds cause off-shore flow on the eastern (U.S.) shore, and on-shore flow along the western (Canadian) shoreline.

Lidar Data

Figure 24 shows a time series of lidar data. The location of these backscatter data correspond to the location of the heavy dots along the FDP cloud trajectory of Figure 22. Shortly after release [Figure 24(a)], the FDP cloud is observed to be about 800 m wide across the east-to-west transport direction. Two hours later, when the cloud is in the proximity of the west shore, the width is close to 3 km [Figure 24(d)]. The cross-sectional structure of the tracer cloud is clearly identified in the lidar observations.

The height of the tracer cloud as observed by the ALPHA-1 along the cloud trajectory is shown in Figure 25. Observed cloud height is presented as a function of distance downwind from the release point. From the release point to the east shore, a slight increase in cloud height (ascending motion) is evident. A distinct mean descending cloud motion (1.5 cm sec^{-1}) is observed along the over-water trajectory. Upon approaching the west shore, a strong upward motion (10 cm sec^{-1}) of the tracer cloud occurs which continues to the west shoreline. Cumulus clouds were present in this area, and were, most likely, associated with the on-shore flow and solar heating of the land surface 2 hours after sunrise.

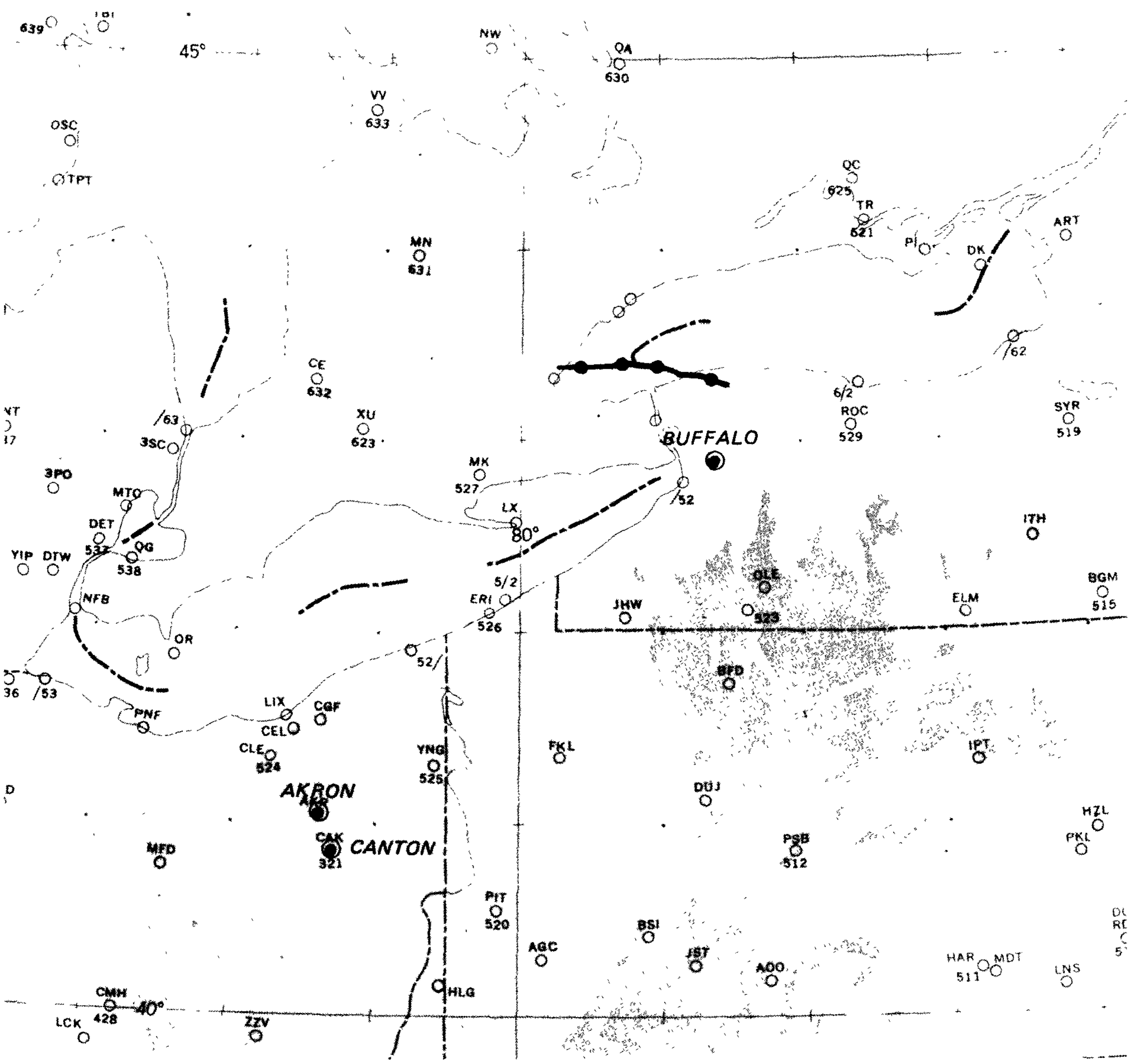
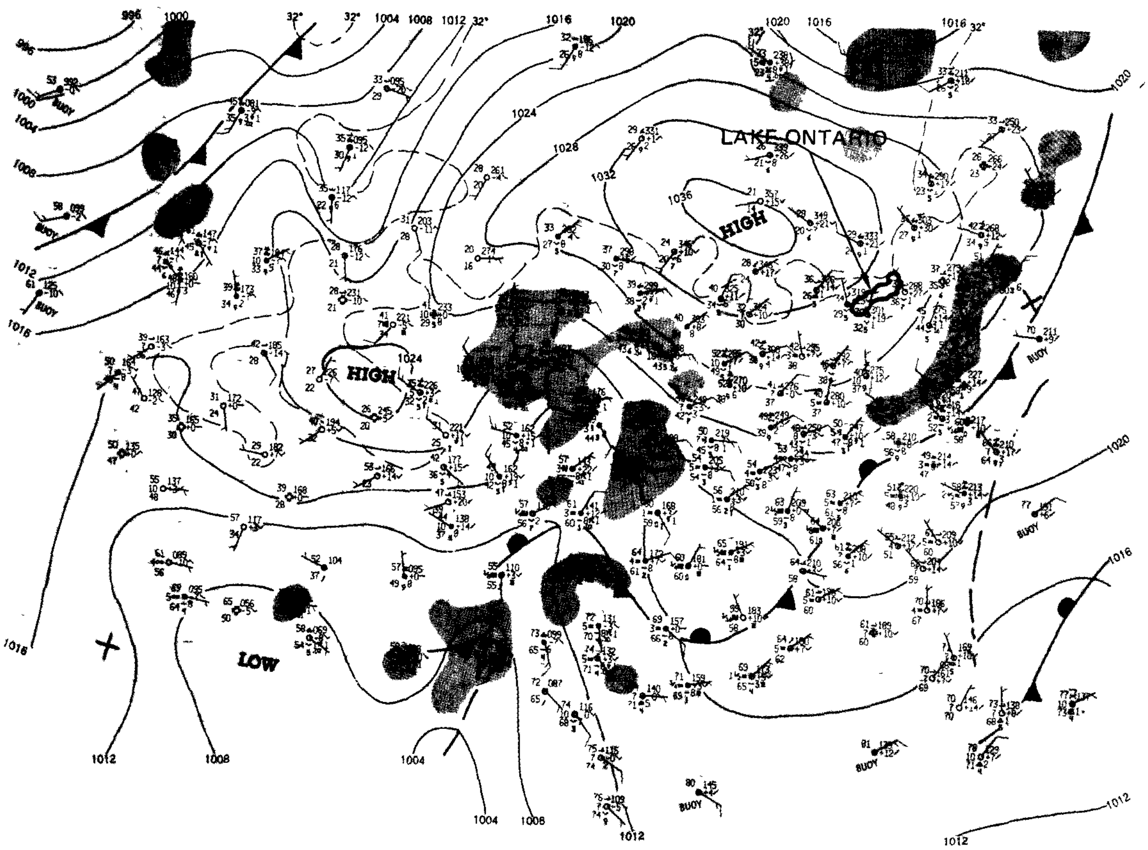


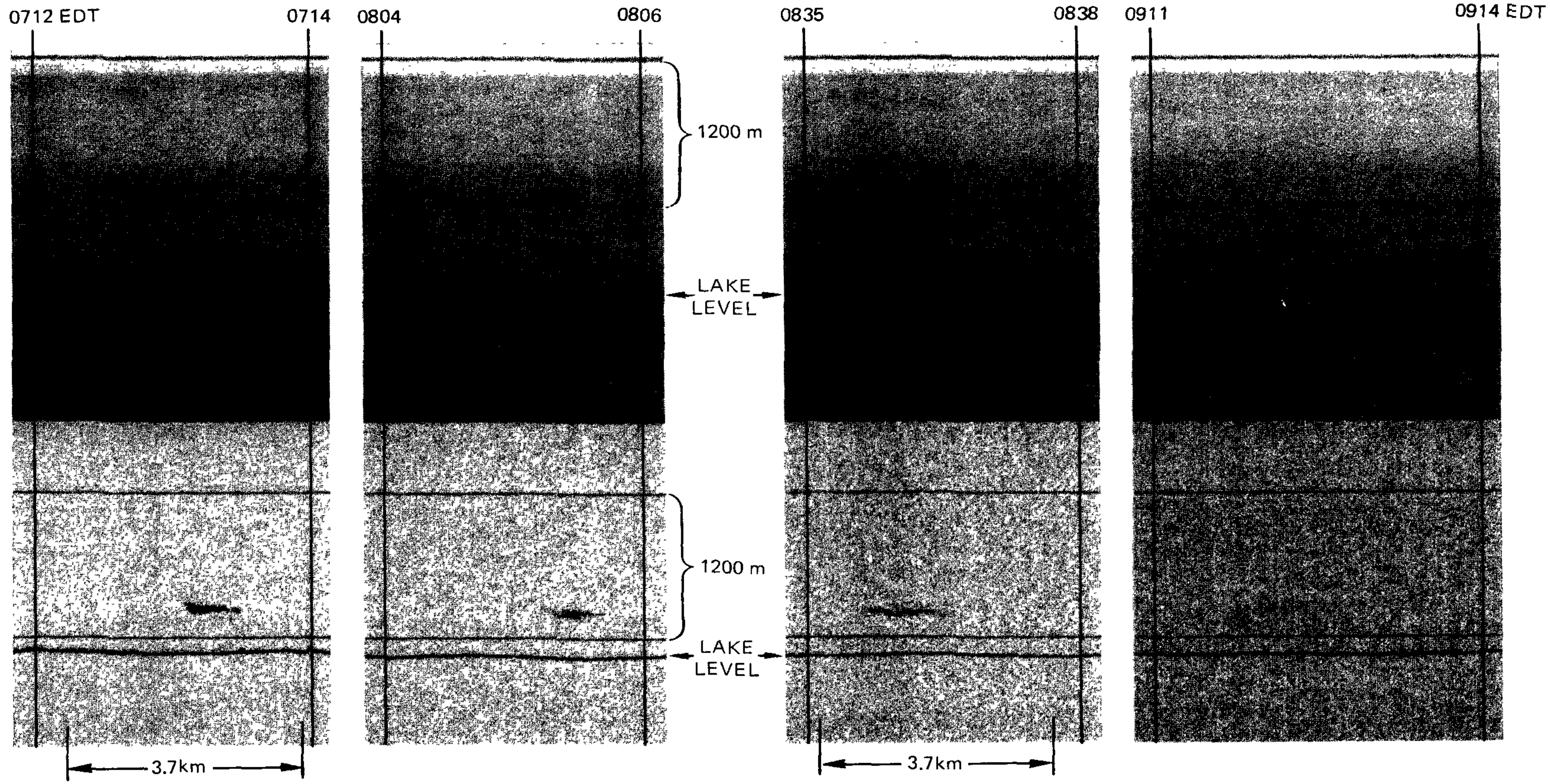
FIGURE 22 TRACK OF FDP TRACER CLOUD ACROSS LAKE ONTARIO AFTER ITS RELEASE FROM LOCATION NORTH OF BUFFALO, NEW YORK.

Heavy dots along the FDP cloud trajectory correspond to the location of the lidar backscatter data displayed in Figure 24. 21 October 1983.



SOURCE: Daily Weather Maps, Weekly Series, NOAA, NES, Data and Information Service.

FIGURE 23 SURFACE WEATHER CHART (SURFACE WEATHER REPORTS, ISOBARS, AND FRONTS) SHOWING LOCATION OF ALPHA-1/FDP EXPERIMENT ACROSS LAKE ONTARIO IN AN AREA OF EASTERLY WINDS ON THE SOUTHERN SIDE OF A HIGH PRESSURE SYSTEM. WEATHER CHART IS VALID AT 21 OCTOBER 1983, 0800 EDT ABOUT ONE HOUR AFTER RELEASE OF FDP CLOUD NORTH OF BUFFALO, NEW YORK.



(a) FDP CLOUD OVER EAST SHORE OF LAKE ONTARIO ABOUT 5 MINUTES AFTER RELEASE

(b) FDP CLOUD OVER LAKE ONTARIO ABOUT 1 HOUR AFTER RELEASE

(c) FDP CLOUD MIDWAY ACROSS LAKE ONTARIO ABOUT 1.5 HOURS AFTER RELEASE

(d) FDP CLOUD UPON ENTERING WEST SHORE OF LAKE ONTARIO ABOUT 2 HOURS AFTER RELEASE

FIGURE 24 TIME SERIES OF FDP TRACER CLOUD ALONG ITS TRAJECTORY ACROSS LAKE ONTARIO, ON 21 OCTOBER 1983, 0712-0914 EDT. NOTE DISPERSION OF CLOUD IN HORIZONTAL PLANE ABOVE THE LAKE LEVEL.

Upper part: elastic backscatter at 1.06 μm showing FDP cloud, background aerosol, and underlying terrain/lake level.
Lower part: fluorescent backscatter; 0.53 μm transmitted, 0.60 μm received. Lidar aircraft altitude: 2100 m ASL.

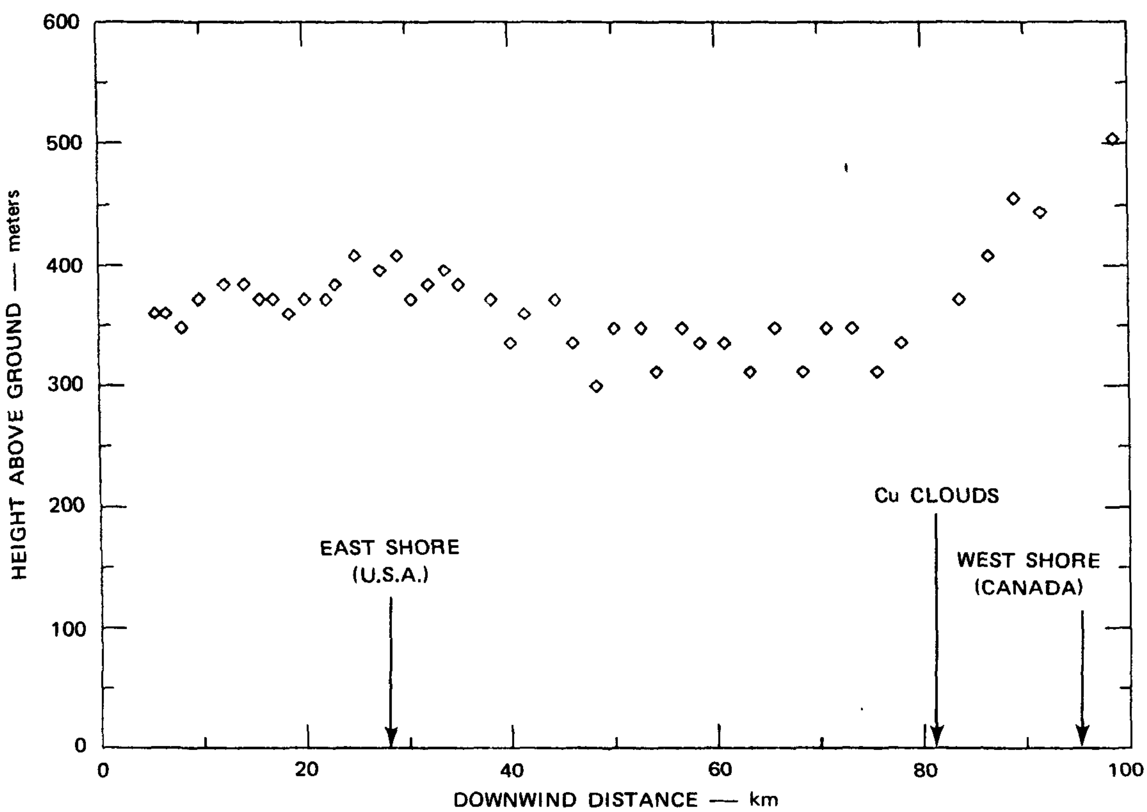


FIGURE 25 ALTITUDE ABOVE GROUND LEVEL OF FDP TRACER CLOUD OBSERVED BY THE ALPHA-1 DURING THE ALPHA-1/FDP EXPERIMENT ACROSS LAKE ONTARIO ON 21 OCTOBER 1983, 0708 TO 0929 EDT. Note descending motion over lake surface and strong ascending motion of FDP cloud as it approaches the west shore during on-shore wind flow conditions.

Diffusion of FDP Cloud

The growth rate of the FDP cloud observed by the ALPHA-1 in a general direction transverse to the east-to-west transport wind is illustrated in Figure 26. The growth rate is large along the over-water trajectory. By fitting a linear regression to the 15 data points over the lake surface, a mean growth rate of 27 m min^{-1} is obtained.

CASE VI: FDP EXPERIMENT NEAR CONVECTIVE CUMULUS CLOUDS

Scenario

During the afternoon of 21 October 1983, 1332-1538 EDT, FDP tracers were released at various positions with respect to convective cumulus clouds near Johnstown, Pennsylvania. An FDP cloud released in the mixing layer in a clear area halfway between the base and tops of surrounding convective cumulus clouds rapidly disappeared by turbulent mixing after about 4 minutes. When an FDP release was made near the base of cumulus clouds, the lidar aircraft flying above the clouds could not monitor the tracer cloud because of a continually obstructed line-of-sight. However, the FDP was visually observed to rapidly disperse within the boundary layer. FDP releases above the top of cumulus clouds tended to descend downward across the cloud layer to become mixed within the turbulent boundary layer.

FDP-Cloud Track and Lidar Data

During the afternoon of 21 October, FDP releases were made around convective cumulus clouds near Johnstown, Pennsylvania (about 120 km east-south-east of Pittsburgh). Johnstown is located on the western slope of the Allegheny Mountains at an elevation of 2282 ft. ASL. According to the radiosonde ascents made at Pittsburgh, the winds in the FDP experiment area were southeasterly at 20-25 knots. Thus, Johnstown was located on the lee side of the mountains. Cloud bases were 500 m and cloud tops were 800 to 1000m above ground level.

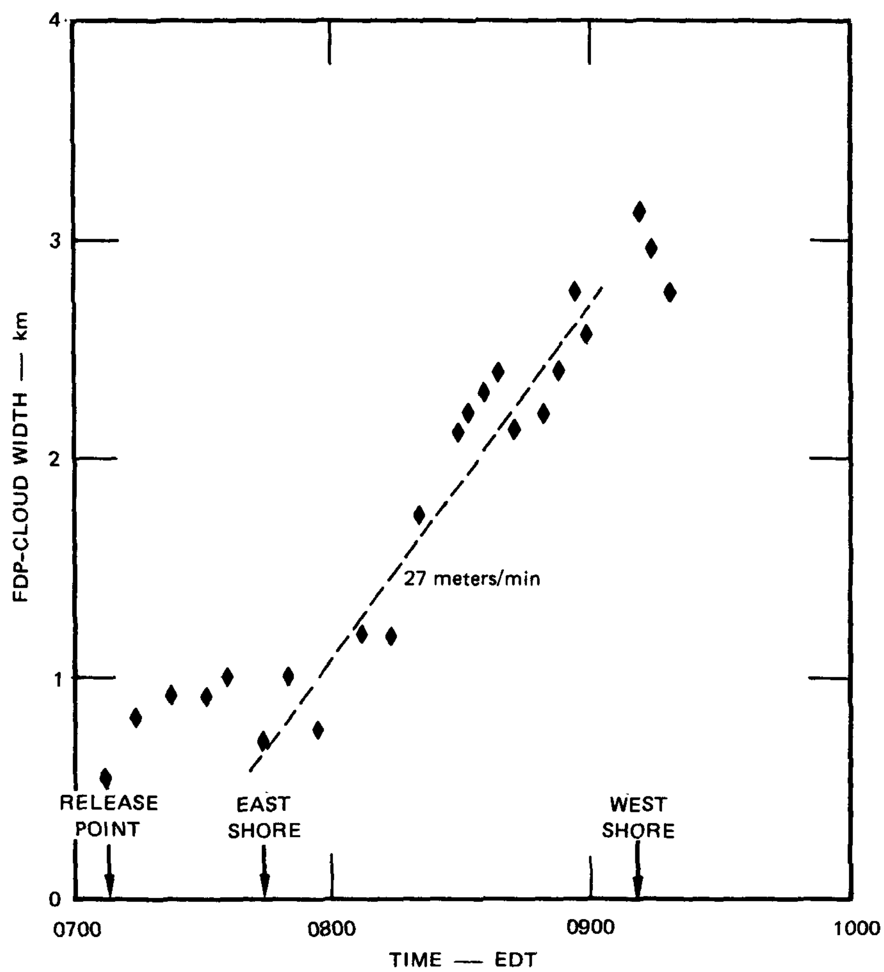


FIGURE 26 SIZE OF FDP TRACER CLOUD TRANSVERSE TO TRANSPORT DIRECTION OBSERVED BY THE LIDAR AS A FUNCTION OF TIME DURING THE ALPHA-1/ FDP EXPERIMENT ACROSS LAKE ONTARIO ON 21 OCTOBER 1983, 0708 TO 0929 EDT

Figure 27 shows cross sections of lidar data at two times after FDP tracers were released in the mixing layer at a height of 600 to 700 m AGL between the base and tops of the cumulus clouds. In both cross sections, time increases from left to right -- i.e., the lidar aircraft proceeds from left to right. The left-hand cross-section shows the FDP cloud and surrounding cumulus at 1412 EDT. The fluorescent channel separates the FDP cloud from the surrounding cumulus and aerosols. The FDP tracer cloud is 500 to 600 m above the terrain. Four minutes later, at 1416 EDT, the tracer cloud has moved downwind, and is 200 m above the terrain and dispersing rapidly. Surrounding cumulus clouds dissipated in the descending wind flow on the lee side of the mountains. The strong subsiding motion is evident from the lidar observations. In this case, strong mixing processes are observed in the boundary layer.

At 1449 EDT, an FDP release was made near the base of the cumulus clouds. This release, however, could not be observed with the ALPHA-1 because of obstructed line-of-sight and the very rapid dilution of the FDP tracer cloud within the boundary layer.

At 1509 EDT, an FDP release was made above the cumulus clouds. Figure 28 shows vertical cross-sections of lidar data at three different times during a 30-minute period when the release was observed by the ALPHA-1. The FDP tracer cloud is seen above the cloud tops in Figure 28(a). At 1529 EDT [Figure 28(b)], the tracer cloud has moved downwind to an area without clouds, and is located on top of the mixing layer. Cumulus clouds had dissipated in the descending air flow on the lee side of the mountains. The shape of the tracer cloud about 30 minutes after release is shown in Figure 28(c). In the vertical plane of the lidar observations, the tracer cloud covers a horizontal distance of nearly 5 km. The tracer cloud, however, is clearly identifiable in contrast to the earlier tracer release (Figure 27) which took place within the mixing layer, and which showed that the FDP disappeared in about 4 minutes.

Another FDP release above cumulus cloud tops was monitored by the ALPHA-1 lidar during a 6-minute time period as shown in Figure 29. After release at about 600 m above the underlying terrain at 1410 EDT, the tracer cloud follows

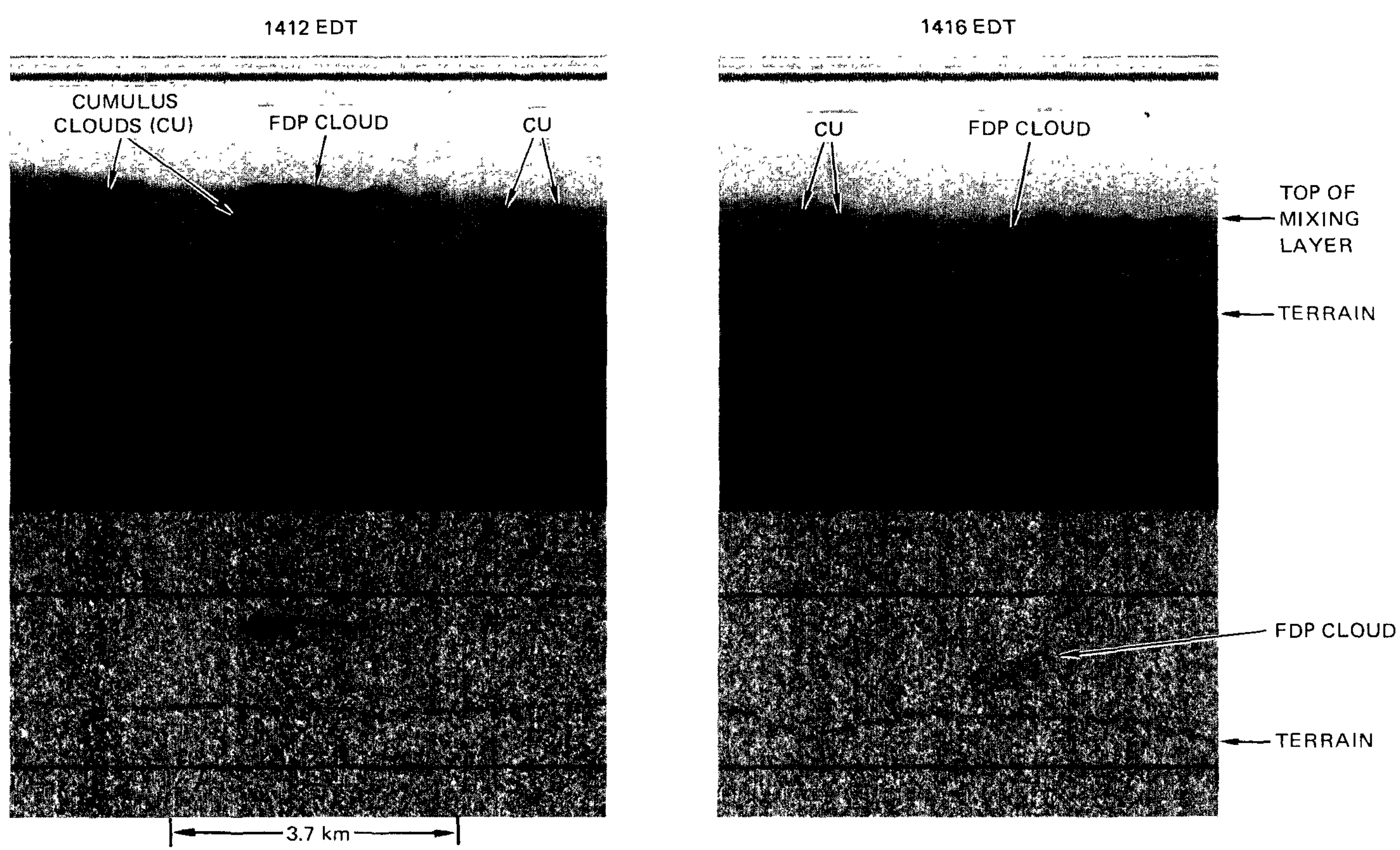
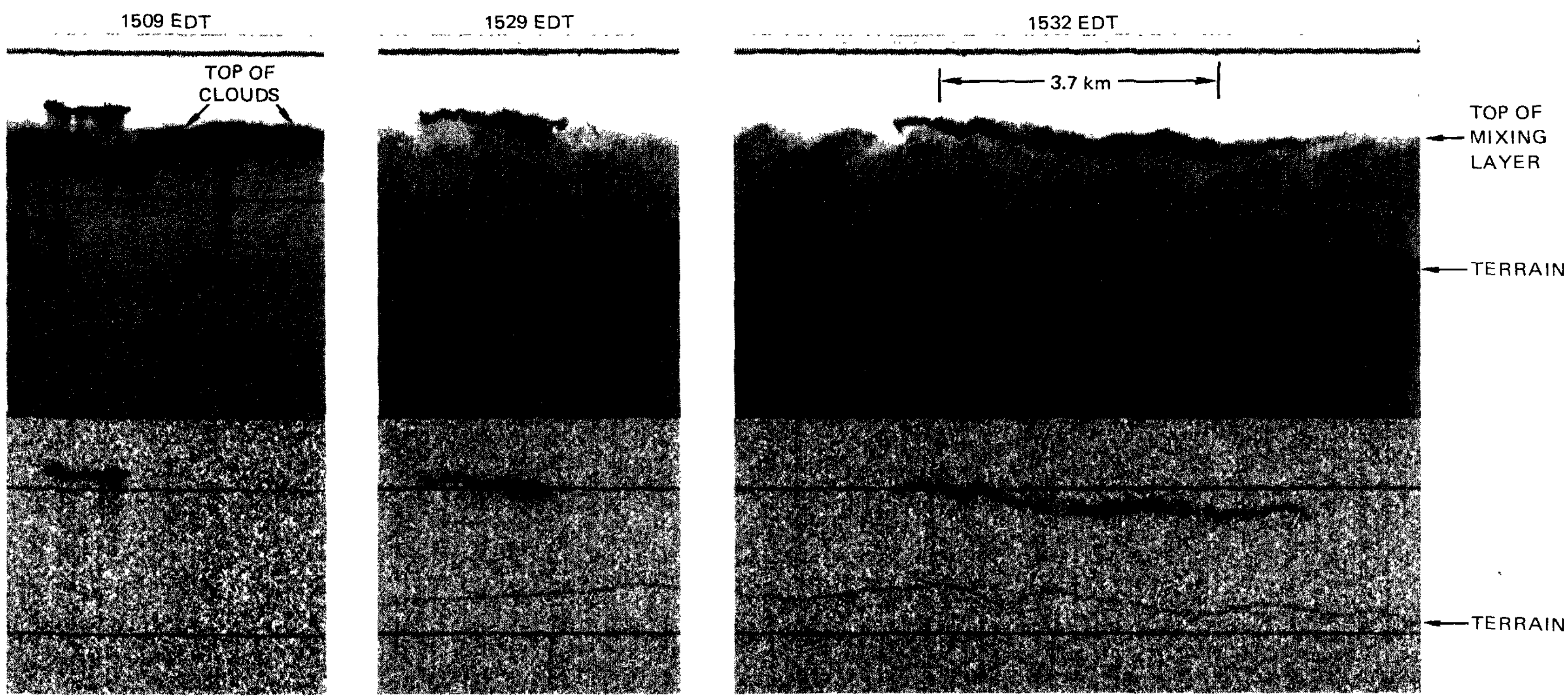


FIGURE 27 SAMPLE OF LIDAR DATA, 4 MINUTES APART, AFTER FDP TRACER CLOUD RELEASE IN THE MIXING LAYER AT A LOCATION BETWEEN CUMULUS CLOUDS.

Note that tracer cloud is transported to a location with no cumulus while dispersing rapidly (21 October 1983, Johnstown, Pennsylvania). Upper part: elastic backscatter at 1.06 μm showing mixing layer, convective cumulus clouds, FDP tracer cloud, and terrain. Lower part: fluorescent backscatter showing rapid dispersion of FDP tracer cloud during 4-minute period. Lidar aircraft altitude: 2300 m ASL;



(a) **FDP RELEASE ABOVE CLOUD TOPS (ABOVE MIXING LAYER)**

(b) **FDP TRACER 20 MINUTES AFTER RELEASE. NO CLOUDS PRESENT**

(c) **FDP TRACER 23 MINUTES AFTER RELEASE ON TOP OF MIXING LAYER**

FIGURE 28 TIME SERIES OF LIDAR DATA DURING ALPHA-1/FDP EXPERIMENT IN AREA OF CONVECTIVE CUMULUS CLOUDS NEAR JOHNSTOWN, PENNSYLVANIA ON 21 OCTOBER 1983, 1332-1538 EDT.

Note how tracer cloud is transported along the top of the mjxing layer. Upper part: elastic backscatter at 1.06 μm showing FDP tracer cloud, mixing layer with cumulus clouds, and terrain. Lower part: fluorescent backscatter showing subsiding tracer cloud without aerosol background. Lidar aircraft altitude: 2100 m ASL.

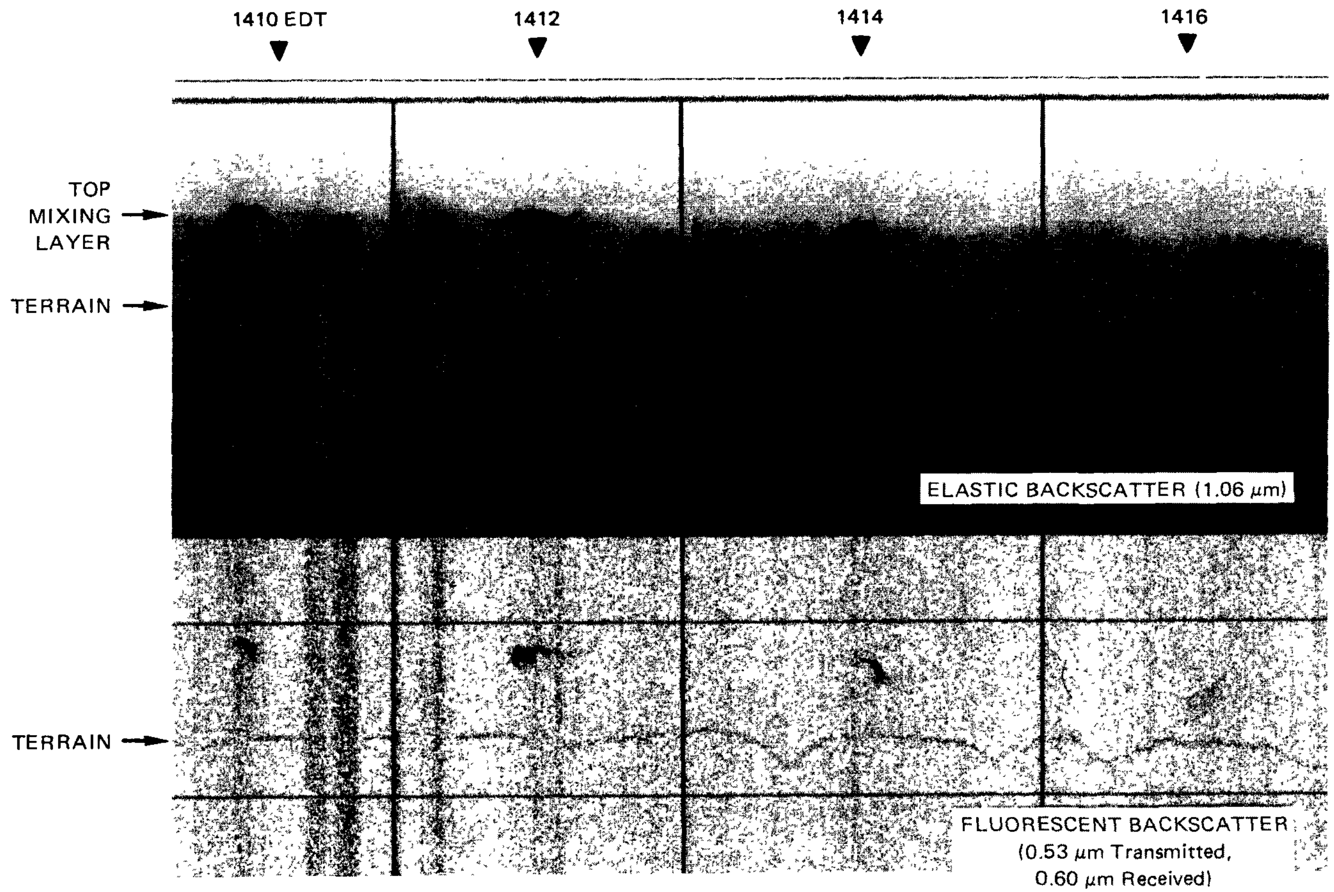


FIGURE 29 SIX-MINUTE TIME SERIES OF LIDAR DATA SHOWING RELEASE OF FDP NEAR TOP OF CUMULUS CLOUDS (1410 EDT) AND RAPID DISPERSION IN THE BOUNDARY LAYER AT 200 m TO 300 m ABOVE GROUND LEVEL (1416 EDT)

(Convective Cloud Experiment, 21 October 1983) a descending trajectory into the turbulent boundary layer where it is rapidly diluted 6 minutes later at an altitude of 200 m to 300 m above ground level.

Although the ALPHA-1/FDP experiment in the area of convective cumulus clouds was relatively difficult because it was located on the lee side of the mountains, it provided some interesting observational data on the effect of the transport wind on FDP tracers compared to the effect on the cumulus clouds. The lidar observations emphasized the large turbulent flow in the mixing layer compared to the laminar-type flow in the free troposphere above.

SECTION 6

QUALITY CONTROL EVALUATION ACCOUNT

SUMMARY

The Quality Assurance (QA) and Quality Control (QC) activities associated with the experimental data collection were primarily concerned with performance of the ALPHA-1 lidar, and with verifying that data recording was proceeding in a proper manner. Although no standard QA/QC activities have been defined for lidar, the following control activities were performed:

1. Laser transmitted energy levels were determined both before and after the field program. The green wavelength energy had decreased from 15 mj to 7 mj.

2. Data tapes were periodically checked to assure that data were being recorded. All data were found to be recorded on tape. Subsequent data processing verified all data were recorded.

3. Data tapes were periodically played back to assure that stored data provided results identical to the real-time records. In all cases, recorded data matched the real-time records.

4. Linearity of the lidar detector/log amplifier was calibrated. Linearity was found to be within $\pm$ 1 dB over a 30 dB range.

5. Aircraft location instrumentation (LORAN-C) was periodically checked with map values. RNAV values were checked with airport locations. These data indicate position accuracies of about 0.3 nmi. However, because of lag time of the RNAV computer, larger errors can occur following aircraft turns.

6. All accessible optics were cleaned at the start of each aircraft data collection mission.

7. The aircraft was kept in a hangar during non-flight times to reduce environmental effects on lidar performance. Previous studies have shown that excessive heat can result in condensation of water on optical surfaces as the aircraft altitude is increased.

8. FDP was stored in air-tight bags to prevent moisture problems that could cause the particles to stick together.

9. The Biomation digitizers were calibrated at the manufacturers to provide correct range resolutions of 7.5 m.

10. Almost daily communications were made with the EPA Technical Monitor to make sure the ALPHA-1/FDP experiments best followed EPA objectives.

11. All lidar supplies and data tapes were stored in a specially-rented, environmentally-controlled, secure area. No equipment or data were lost.

QA/QC Problems

The major QA/QC problem was the performance of the non-linear crystal used to generate 0.53 µm laser energy. Backup units were available, but it was difficult to determine crystal performance in the field environment. This problem was solved with limited success by making 0.53 µm (FDP) wavelength lidar measurements before the receiver was tuned to the 0.60 µm (FDP fluorescence) wavelength region. A receiver optical filter was used that passed a small amount of the 0.53 µm energy, thereby giving a surface return as a constant indicator of crystal performance.

One lidar failure resulted because a lens came loose, and went out of alignment. This problem was diagnosed by conversations with available technicians at SRI, and was repaired in the field without loss of data.

QA/QC Evaluations

The quality of the recorded data was evaluated during the data analysis program. All data were recorded in the expected format. All data tapes could be read by the computer system.

QA/QC Deliverables

Generated facsimile records from recorded data (magnetic tapes) provide information on data quality. Several of these facsimile records were presented and discussed in this report. All facsimile records are evaluated at SRI. No major data recording problems or data quality problems were encountered.

SECTION 7

CONCLUSIONS AND RECOMMENDATIONS

The feasibility of using airborne lidar to observe the three-dimensional distribution of fluorescent dye particle (FDP) tracers in long-range atmospheric transport and dispersion studies has been successfully demonstrated on the basis of field experiments conducted in the CAPTEX '83 area during October 1983. FDP tracers were released in or above the mixing layer on six separate occasions under various conditions of atmospheric wind and temperature. The following results and conclusions were obtained:

- The three-dimensional trajectory of an FDP tracer cloud released in the free troposphere above the mixing layer was tracked by the lidar during a 5-hour period (327 km distance) over relatively complex terrain. The observed trajectory showed features not available from calculations of air-parcel trajectories that are based on upper-air data from the standard radiosonde network. This tracer experiment provides adequate and precise verification data to further develop and validate model trajectory calculation schemes.

- A circular FDP tracer cloud released in the free troposphere during westerly wind flow was observed to develop a high rate of stretching along its transport direction. Two hours after release (95 km downwind), the tracer cloud was 16 km long but only 2 km wide. Four hours after release (151 km downwind), the tracer cloud had elongated further to a length of 30 km and a width variable from 1 to 5 km. These tracer observations provide input to studies of longitudinal versus transverse atmospheric dispersion as a function of transport travel time.

- An FDP tracer puff released on top of a power plant plume under relatively light wind conditions showed large diffusion transverse to the transport direction but did not exhibit disproportionate stretching in the longitudinal direction.

- Vertical directional wind shear and differential vertical motion were observed during an event when tracers were released at different altitudes above the mixing layer. Also, tracer clouds released during convective cloud activity clearly showed the presence of strong turbulent flow in the convective mixing layer versus the more laminar flow above the mixing layer. FDP tracers released above cumulus cloud tops were transported downward across the convective cloud layer and were mixed within the turbulent boundary layer close to ground level. These data provide insight into the transport processes that affect particulates and anthropogenic pollutants that arrive in the free troposphere above the convective clouds.

- By observing the vertical motion of a low-level FDP tracer cloud along its transport trajectory across Lake Ontario shortly after sunrise, the large difference in boundary-layer stability between the water of the interior lake surface and the shoreline became apparent. Upward motion of 10 cm sec^{-1} was calculated from the lidar observations when the tracer cloud approached the on-shore wind side of the lake.

This study demonstrated that the airborne lidar/FDP technique represents a powerful tool for supporting research programs related to isentropic transport, cloud venting, boundary layer and free tropospheric transport and dispersion, and complex terrain effects. However, before the technique can be implemented to its fullest capability, more information is needed on the characteristics of an FDP cloud: for example, particle growth in a high humidity environment and sunlight-induced flourescence. Also, evaluation of the minimum detectable FDP concentration is needed to determine release amounts for a given test objective. Improved lidar signals should be possible by better matching receiver optical filters with the fluorescent spectrum.

During the field experiment, the tracer cloud was lost about 50% of the time after aircraft refueling, limiting the tracking period. Improved real-time aircraft navigation equipment is recommended, as well as a reserve pilot to extend the aircraft tracking periods.

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Rowland, J.R., and T.G. Konrad, 1979: "A New Technique for the Study of Power Plant Plume Behavior Using Fluorescent Dye as Tracers and Lidar as the Remote Sensor", Applied Physics Laboratory, Johns Hopkins University, Technical Report SIR79U-003.

Uthe, E.E., W.L. Jimison, and N.B. Nielsen 1980: "Development of an Airborne Lidar for Characterizing Particle Distribution in the Atmosphere", EPRI EA-1538, RP 1308-2, Final Report (September) Paperbound, from Electric Power Research Institute, Palo Alto, CA 94304.

Uthe, E.E., B.M. Morley, and N.B. Nielsen, 1982: "Airborne Lidar Measurements of Smoke Plume Distribution, Vertical Transmission, and Particle Size", Applied Optics, 21, 3, 460-463.

Uthe, E.E., 1983: "ALPHA-1/ALARM Airborne Lidar Systems and Measurements", Reprint Volume of Extended Abstracts, Ninth Conference on Aerospace and Aeronautical Meteorology, June 6-9, Omaha, Nebraska. Published by the American Meteorological Society, Boston, Mass.

APPENDIX
DATA TABULATIONS AND PLOTS

This appendix contains numerical tablulations and graphical representations of the positions of the FDP tracer clouds in space and time for each case study for which lidar observations are analyzed. In the numerical listings, observation time is given from the release time or the first time of lidar observation, to the time of the last lidar observation. The geographical positions of the tracer clouds are tabulated in terms of latitude and longitude. Distance represents the distance downwind from the release point. Altitude is height above the terrain (AGL). The numerical data listing for each case is followed by several graphical data presentations.

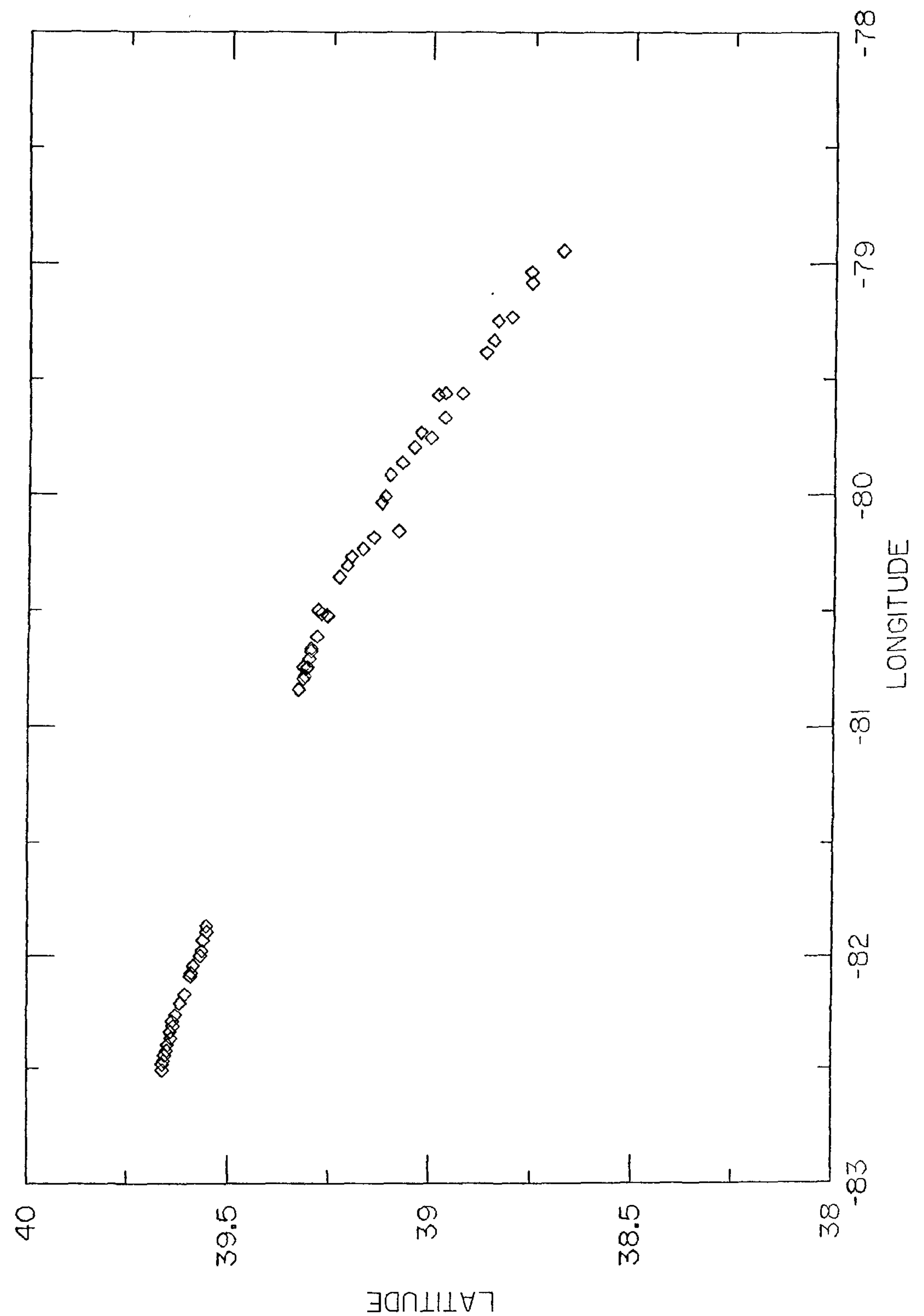
Case I: 14 OCTOBER 1983, 1802-2305 EDT

- - - - - R E L E A S E - - - - -

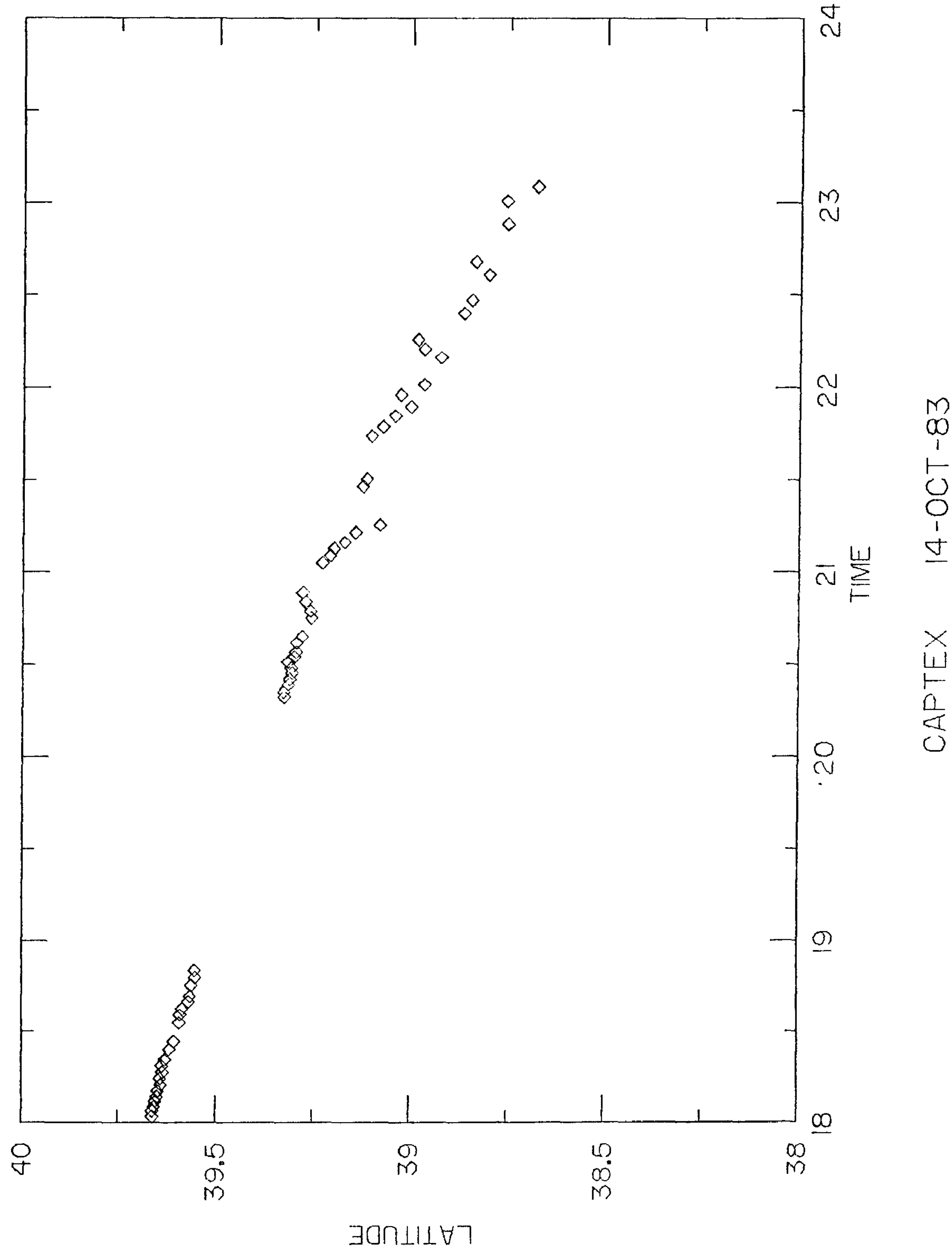
Date	Time	Position
10-14-83	17:50: 0	39.667N 82.500W

Observation Time	Observation Lat-Lons		Distance (Km)	Altitude (meters)	Delta-t (hours)	--RNAV-- Dist.	Theta
18: 1:52	39.662N	82.508W	0.904	2016.	0.198	61.90	68.60
18: 3:36	39.662N	82.483W	1.531	1884.	0.227	4.08	290.70
18: 4:52	39.658N	82.467W	3.000	1860.	0.248	4.82	299.40
18: 6:41	39.655N	82.442W	5.160	1872.	0.278	6.12	290.50
18: 8:16	39.650N	82.420W	7.096	1956.	0.304	7.23	289.00
18:10:15	39.648N	82.395W	9.218	1944.	0.338	10.75	286.60
18:12:13	39.640N	82.367W	11.795	1836.	0.370	11.49	289.40
18:14:19	39.642N	82.338W	14.119	1788.	0.405	16.49	289.20
18:16:22	39.635N	82.313W	16.368	1884.	0.439	16.12	285.90
18:18:34	39.637N	82.290W	18.289	1956.	0.476	19.27	287.60
18:20:29	39.628N	82.263W	20.711	1968.	0.508	19.27	284.70
18:23:52	39.618N	82.210W	25.414	1932.	0.564	27.43	290.70
18:26:36	39.607N	82.172W	28.908	1884.	0.610	28.72	289.90
18:32:43	39.592N	82.092W	35.969	1884.	0.712	37.43	289.90
18:35:20	39.590N	82.077W	37.263	1968.	0.756	37.43	291.00
18:37:18	39.585N	82.045W	40.035	1992.	0.788	40.40	290.90
18:39:34	39.568N	82.000W	44.230	1872.	0.826	46.33	292.10
18:41:26	39.565N	81.978W	46.124	1848.	0.857	46.52	292.70
18:45: 6	39.562N	81.932W	50.099	1932.	0.918	51.70	290.70
18:47:45	39.552N	81.897W	53.284	1884.	0.962	54.48	291.70
18:50: 7	39.553N	81.870W	55.462	1908.	1.002	56.71	290.20
20: 2:35	0.000N	0.000W	0.000	1560.	2.210	137.51	294.50
20: 4:36	0.000N	0.000W	0.000	1500.	2.243	138.62	293.60
20: 7:51	0.000N	0.000W	0.000	1692.	2.297	139.92	291.70
20: 9:47	0.000N	0.000W	0.000	1644.	2.330	140.10	292.20
20:19:11	39.327N	80.843W	147.425	1692.	2.486	149.55	290.70
20:20:50	39.328N	80.843W	147.374	1716.	2.514	145.66	293.70
20:23:13	39.317N	80.797W	151.609	1752.	2.554	153.07	291.10
20:24:58	39.313N	80.785W	152.681	1692.	2.583	113.23	167.90
20:27: 0	39.307N	80.745W	156.211	1668.	2.617	157.15	291.90
20:28:40	39.308N	80.750W	155.745	1680.	2.644	155.11	292.90
20:30:34	39.317N	80.743W	156.048	1692.	2.676	152.89	290.10
20:32: 9	39.300N	80.707W	159.604	1656.	2.703	2.97	265.10
20:33:51	39.297N	80.675W	162.340	1656.	2.731	6.49	274.30
20:36:48	39.297N	80.665W	163.173	1644.	2.780	7.04	235.90
20:38:51	39.282N	80.613W	167.930	1728.	2.814	11.12	282.90
20:44:58	39.257N	80.525W	176.050	1608.	2.916	18.53	286.30
20:47:13	39.260N	80.520W	176.363	1644.	2.954	17.98	281.30
20:50:12	39.272N	80.512W	176.702	1668.	3.003	20.94	287.50
20:53:16	39.280N	80.497W	177.707	1668.	3.054	21.87	283.00
21: 2:56	39.230N	80.353W	191.165	1740.	3.216	35.40	290.50
21: 5:23	39.210N	80.305W	195.811	1692.	3.256	38.92	290.90
21: 7:40	39.200N	80.268W	199.177	1560.	3.294	42.44	291.70
21: 9:39	39.172N	80.235W	202.860	1548.	3.327	45.22	294.90
21:12:50	39.145N	80.185W	207.892	1464.	3.381	51.33	296.40

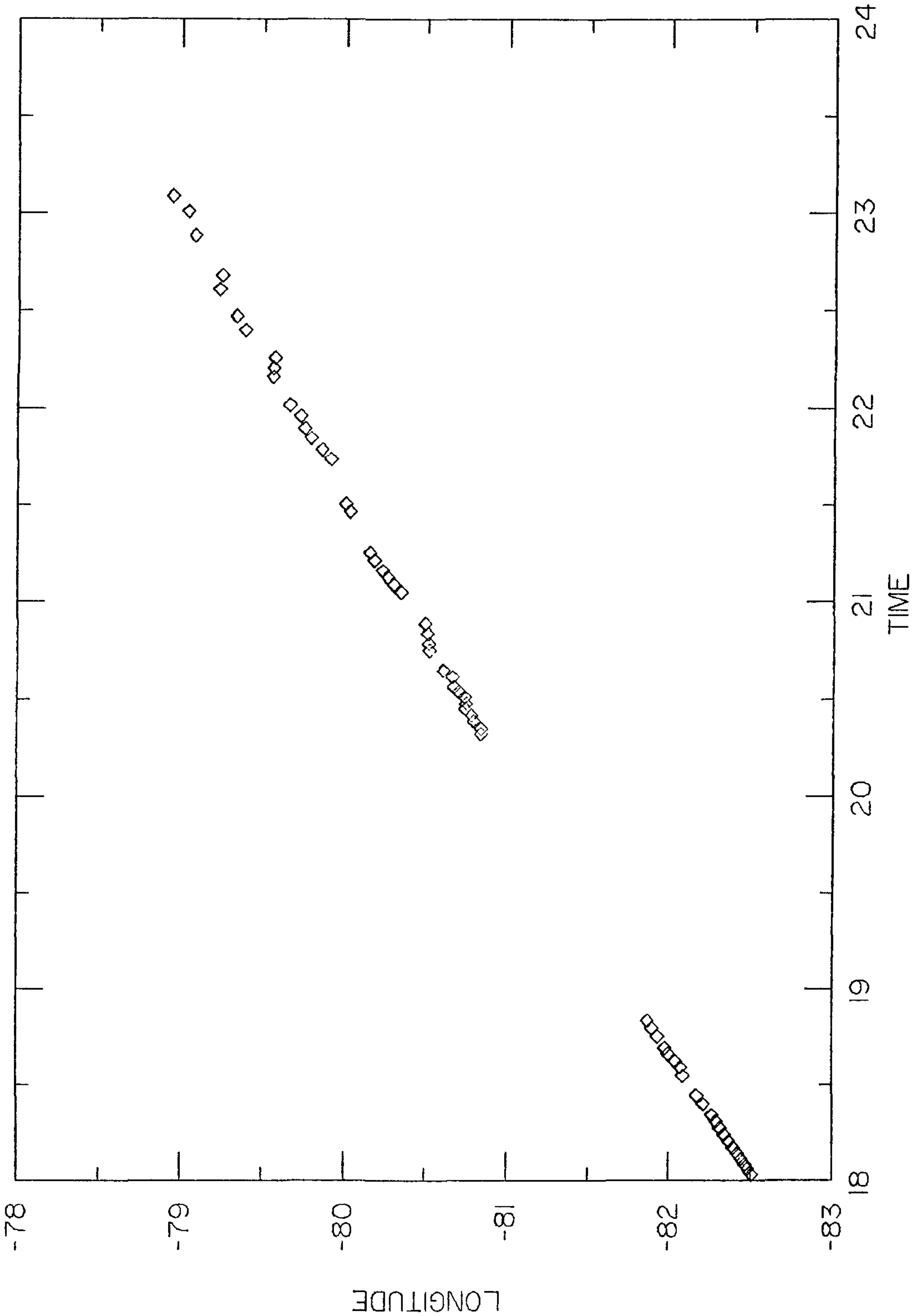
21:15:22	39.082N	80.157W	212.463	1440.	3.423	56.89	302.90
21:28: 2	39.125N	80.035W	220.997	1452.	3.634	64.86	294.10
21:30:20	39.115N	80.008W	223.543	1440.	3.672	68.20	294.50
21:44:21	39.103N	79.915W	231.680	1380.	3.906	74.68	293.70
21:47:18	39.073N	79.863W	236.975	1200.	3.955	80.43	295.20
21:50:52	39.043N	79.795W	243.670	1260.	4.014	86.92	295.70
21:53:47	39.002N	79.757W	248.319	972.	4.063	91.36	298.20
21:57:42	39.028N	79.732W	249.436	1152.	4.128	93.40	295.00
22: 1: 0	38.968N	79.668W	256.822	780.	4.183	101.00	298.20
22: 9:36	38.925N	79.563W	267.086	852.	4.327	110.45	298.50
22:12:15	38.968N	79.563W	265.490	936.	4.371	107.67	296.00
22:15:29	38.985N	79.570W	264.344	1080.	4.425	107.30	295.60
22:23:56	38.867N	79.388W	283.701	1008.	4.566	127.69	298.40
22:28:17	38.847N	79.335W	288.857	828.	4.638	131.58	298.90
22:36:28	38.803N	79.233W	298.901	996.	4.774	145.66	300.30
22:40:41	38.837N	79.248W	296.370	1272.	4.845	139.55	297.80
22:53: 0	38.755N	79.082W	313.264	768.	5.050	154.93	300.10
23: 0:27	38.757N	79.037W	316.893	960.	5.174	159.75	298.50
23: 5:14	38.678N	78.945W	327.575	1140.	5.254	166.42	303.00



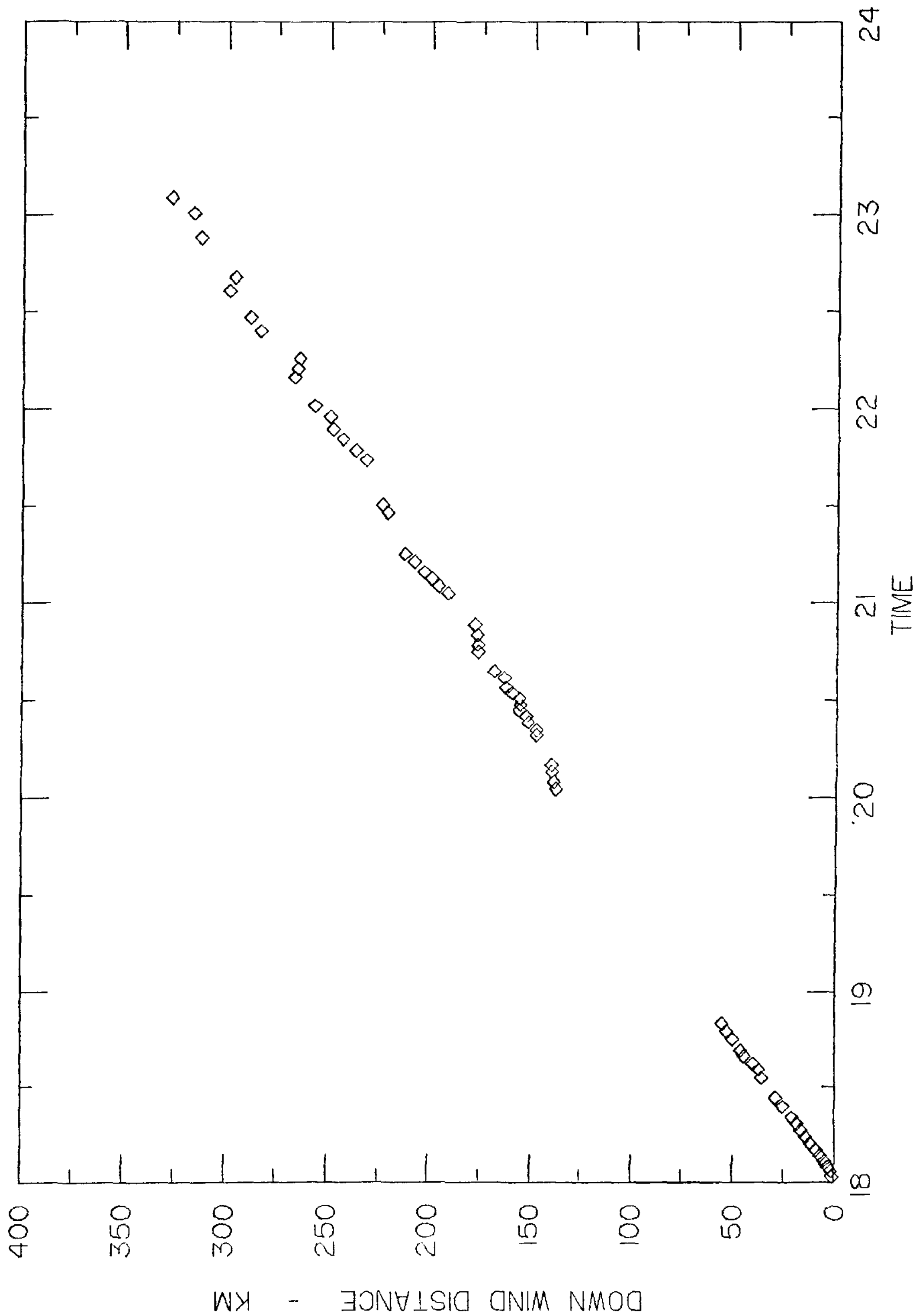
CAPTEX 14-OCT-83



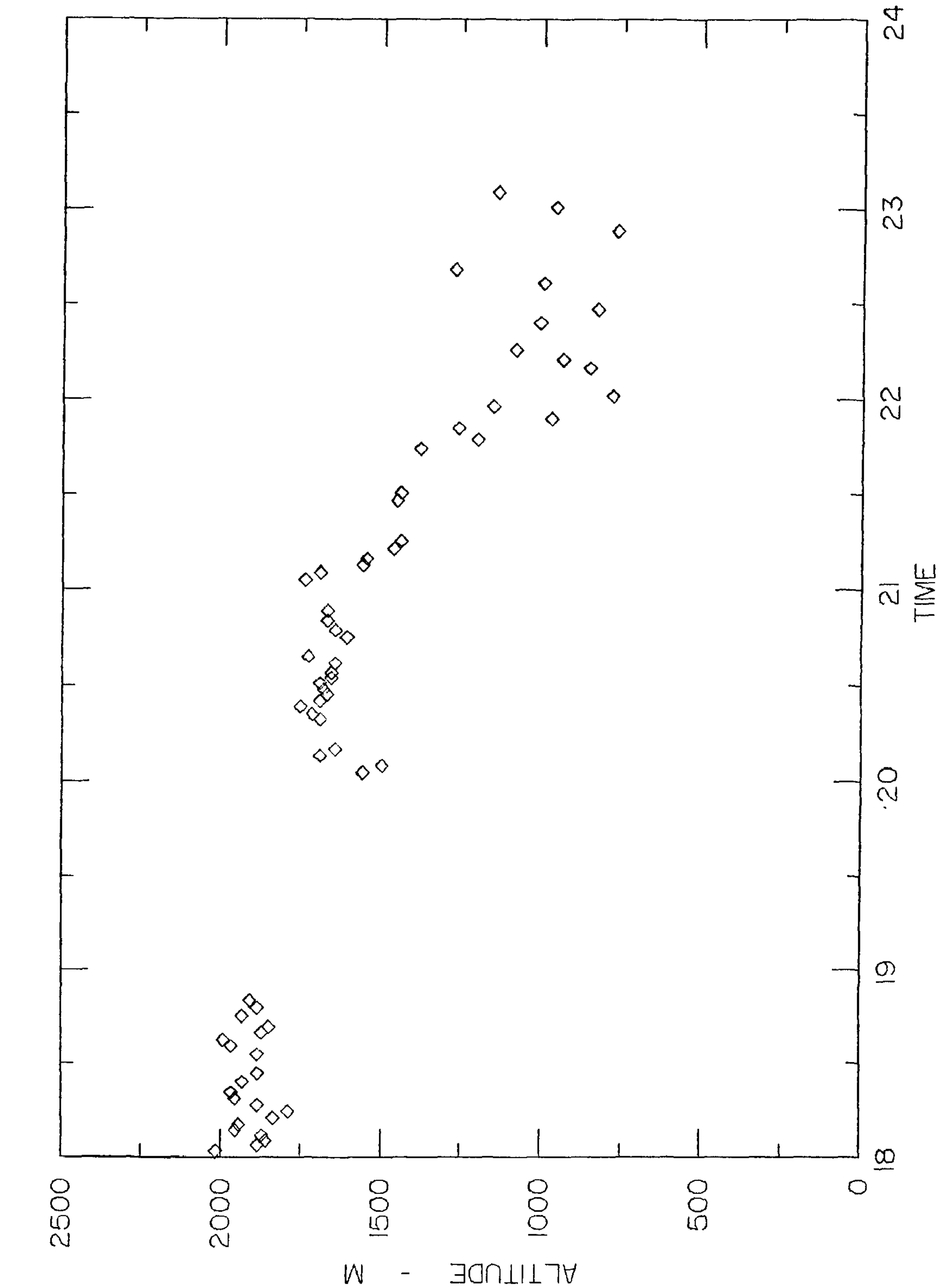
LATITUDE
40
39.5
39
38.5
38
TIME
18
19
20
21
22
23
24
CAPTEX 14-OCT-83



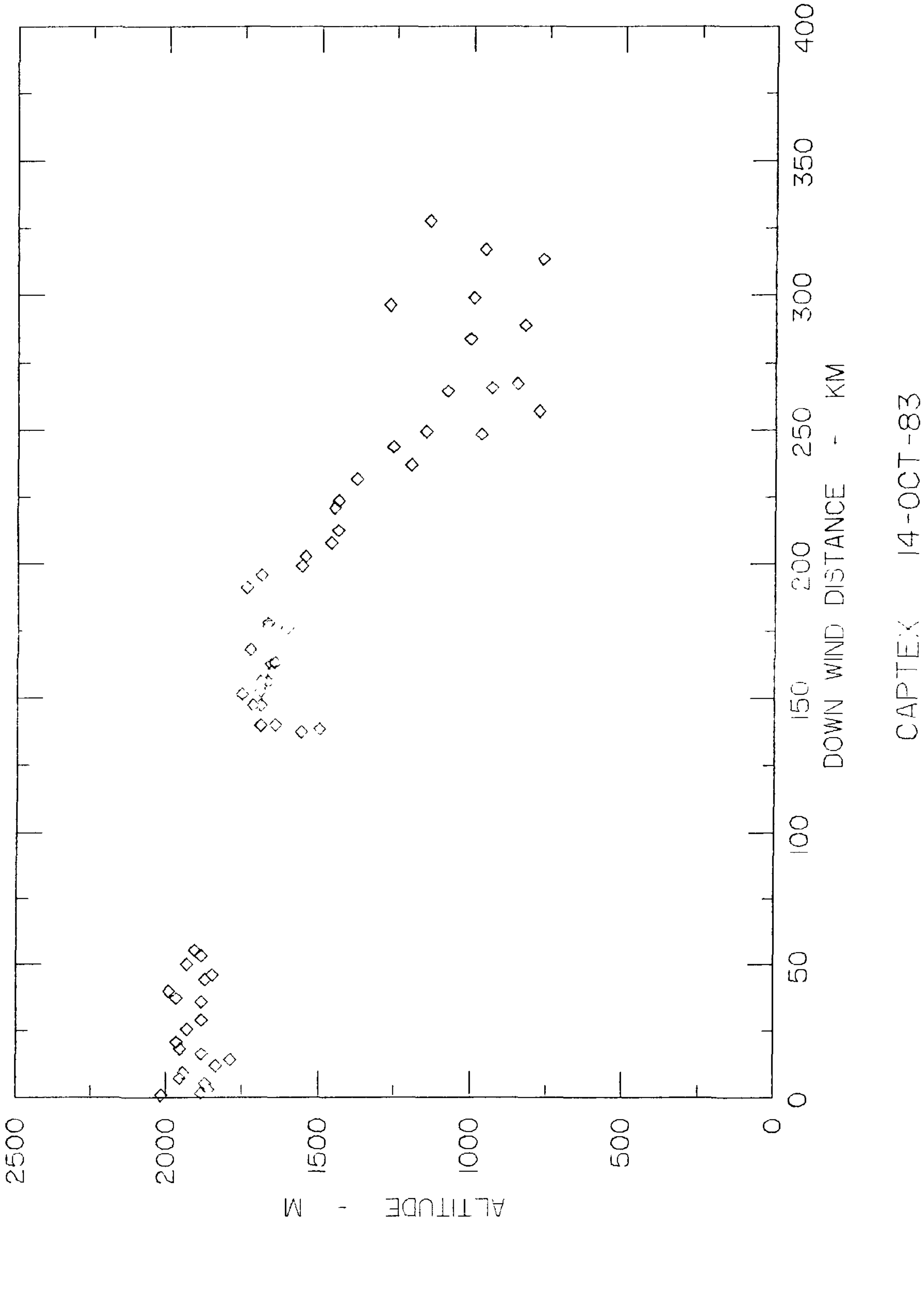
CAPTEX 14-OCT-83



CAPTEX 14-OCT-83



CAPTEX 14-OCT-83


ALTITUDE - M
2500
2000
1500
1000
500
0
0
50
100
150
200
250
300
350
400
DOWN WIND DISTANCE - KM
CAPTEX 14-OCT-83

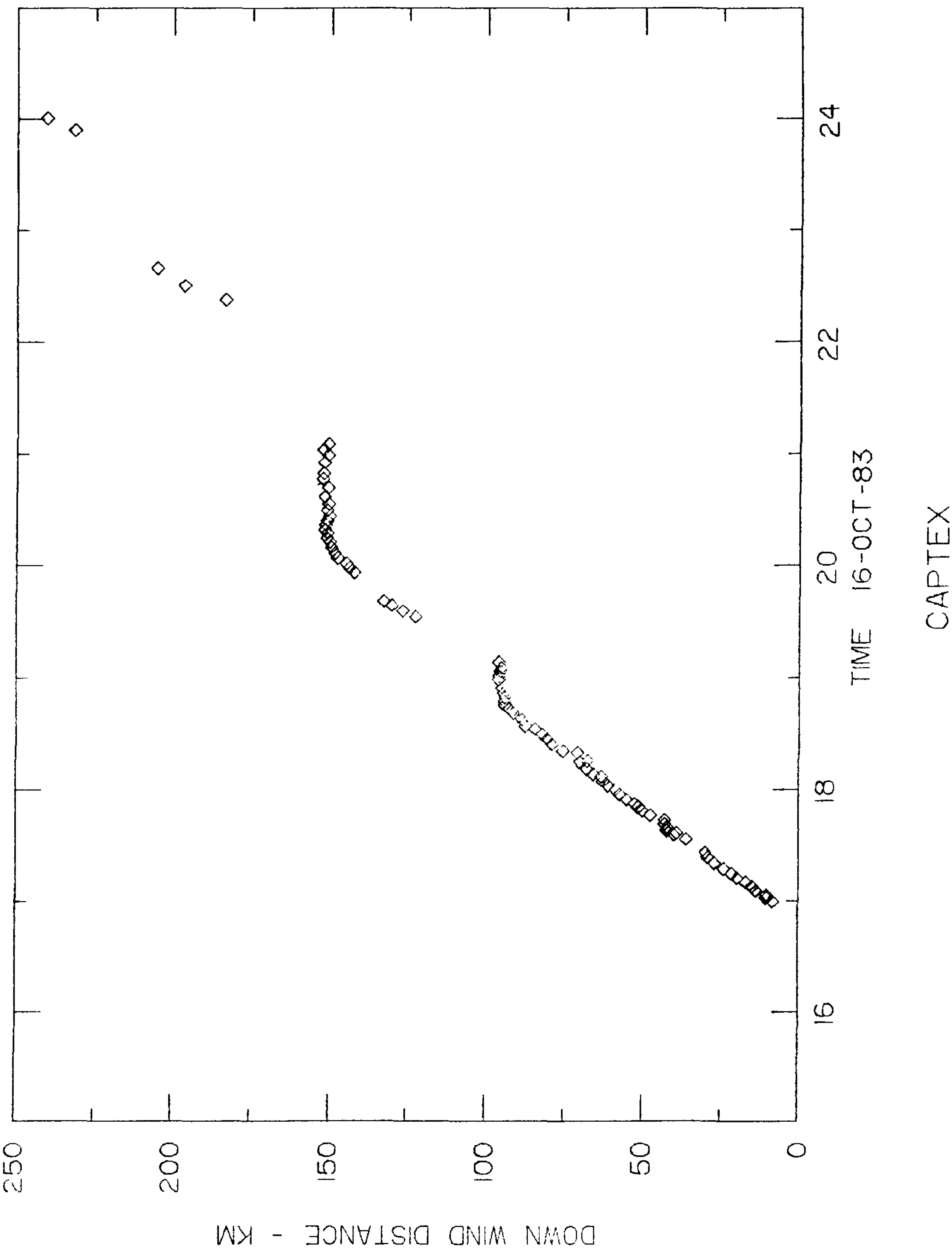
Case II: 16 OCTOBER 1983, 1650-2359 EDT

- - - - - R E L E A S E - - - - -

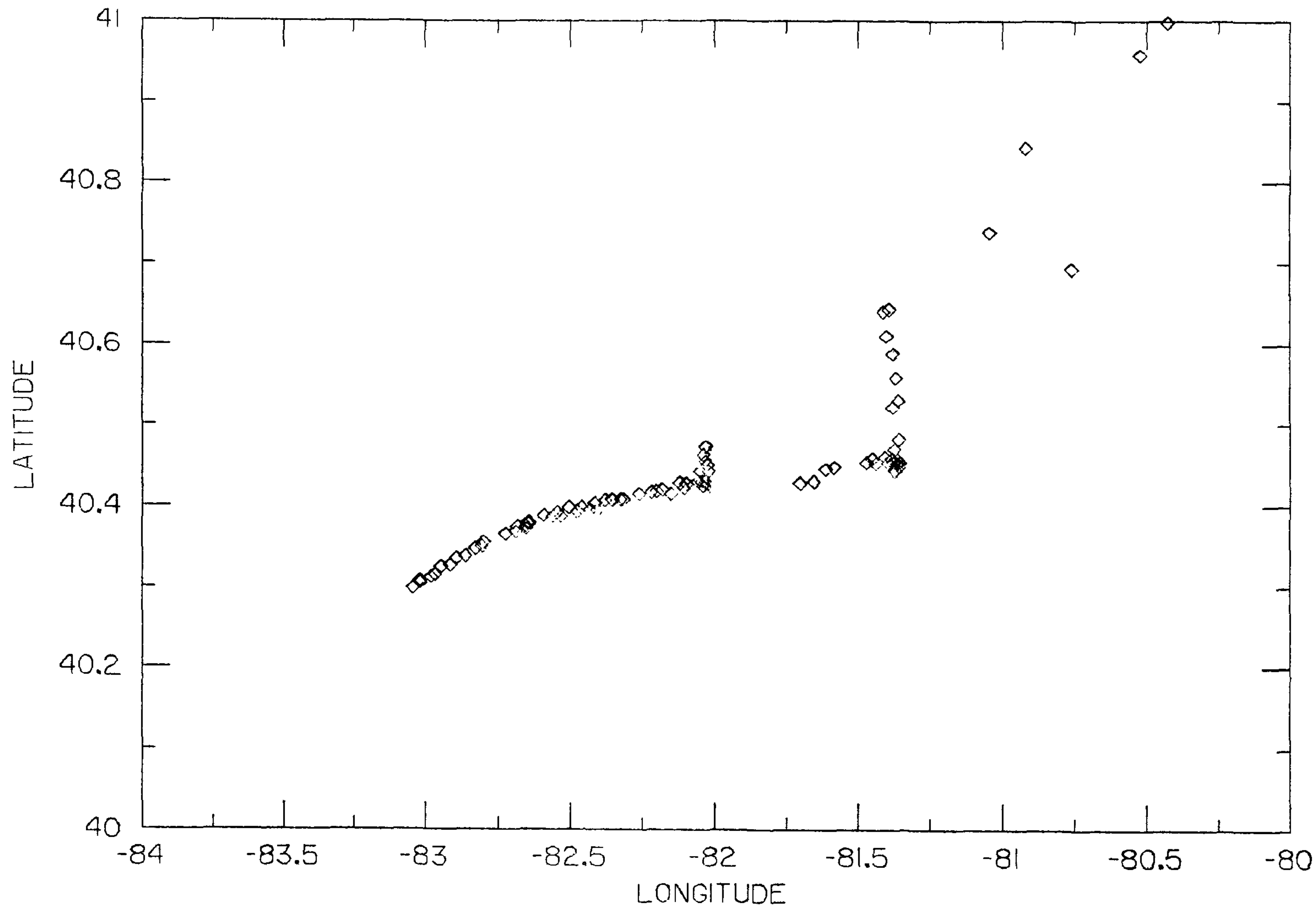
Date	Time	Position
10-16-83	16:50: 0	40.290N 83.138W

Observation Time	Observation Lat-Lons		Distance (Km)	Altitude (meters)	Delta-t (hours)	--RNAV-- Dist.	Theta
16:56:14	40.285N	83.078W	5.120	2124.	0.104	82.47	81.70
16:59:38	40.298N	83.043W	8.110	2124.	0.161	6.30	257.90
17: 1:38	40.305N	83.018W	10.312	2100.	0.194	8.90	247.10
17: 3:14	40.307N	83.018W	10.343	2124.	0.221	9.45	254.70
17: 5:23	40.312N	82.980W	13.639	2184.	0.256	11.68	248.60
17: 7:47	40.315N	82.967W	14.818	2160.	0.296	13.71	256.40
17:10: 2	40.325N	82.945W	16.845	2124.	0.334	15.57	258.00
17:12:16	40.327N	82.913W	19.505	2136.	0.371	17.79	254.80
17:14:48	40.335N	82.893W	21.361	2100.	0.413	19.64	256.10
17:17:18	40.338N	82.863W	23.919	2160.	0.455	22.61	249.40
17:20:16	40.347N	82.828W	27.016	2124.	0.504	25.02	254.90
17:23:22	40.350N	82.805W	29.024	2088.	0.556	27.98	257.30
17:25:50	40.355N	82.797W	29.839	1992.	0.597	27.61	255.10
17:33: 5	40.365N	82.723W	36.135	2016.	0.718	34.47	257.10
17:35:16	40.375N	82.682W	39.822	2136.	0.754	38.55	256.10
17:36:22	40.368N	82.688W	39.106	2064.	0.773	37.43	259.10
17:37:39	40.375N	82.652W	42.295	2172.	0.794	40.21	256.30
17:39:29	40.372N	82.653W	42.078	2076.	0.825	39.47	258.90
17:41:19	40.378N	82.645W	42.927	2088.	0.855	40.96	256.30
17:43:25	40.380N	82.645W	42.969	2040.	0.890	40.96	258.10
17:45:59	40.388N	82.592W	47.572	2244.	0.933	47.07	258.40
17:48:26	40.387N	82.560W	50.148	2292.	0.974	48.18	259.50
17:50:12	40.392N	82.547W	51.367	2292.	1.003	50.22	258.60
17:52:17	40.387N	82.533W	52.356	2328.	1.038	50.59	260.60
17:54:27	40.398N	82.505W	54.967	2376.	1.074	53.74	258.80
17:57:10	40.393N	82.477W	57.200	2352.	1.119	55.23	260.50
17:59:47	40.398N	82.462W	58.553	2292.	1.163	57.08	259.70
18: 2: 4	40.395N	82.433W	60.833	2280.	1.201	58.75	261.20
18: 4:22	40.403N	82.417W	62.392	2268.	1.239	60.78	259.90
18: 6:43	40.395N	82.408W	62.912	2184.	1.279	60.60	261.80
18: 8: 4	40.407N	82.380W	65.505	2316.	1.301	63.75	259.80
18:10:42	40.407N	82.355W	67.581	2280.	1.345	65.79	261.40
18:14:26	40.408N	82.327W	69.970	2316.	1.407	68.20	261.80
18:15: 6	40.408N	82.357W	67.477	2184.	1.418	65.60	261.20
18:19:27	40.408N	82.317W	70.802	2232.	1.491	68.94	261.50
18:20: 9	40.415N	82.263W	75.369	2232.	1.503	72.65	261.60
18:23:57	40.417N	82.220W	79.009	2244.	1.566	75.05	261.90
18:26:37	40.418N	82.202W	80.567	2280.	1.610	78.21	262.70
18:29:11	40.420N	82.182W	82.265	2292.	1.653	79.50	262.60
18:32:12	40.415N	82.153W	84.540	2184.	1.703	81.36	263.10
18:33:42	40.428N	82.120W	87.556	2196.	1.728	84.51	262.20
18:37:17	40.422N	82.107W	88.550	2220.	1.788	85.99	263.50
18:39: 1	40.427N	82.097W	89.471	2196.	1.817	88.21	262.70
18:40:50	40.425N	82.075W	91.251	2160.	1.847	89.32	263.90
18:43:11	40.430N	82.058W	92.727	2112.	1.886	90.81	263.20
18:45: 7	40.430N	82.042W	94.119	2184.	1.919	92.47	263.90
18:47: 3	40.425N	82.040W	94.174	2124.	1.951	92.29	263.50

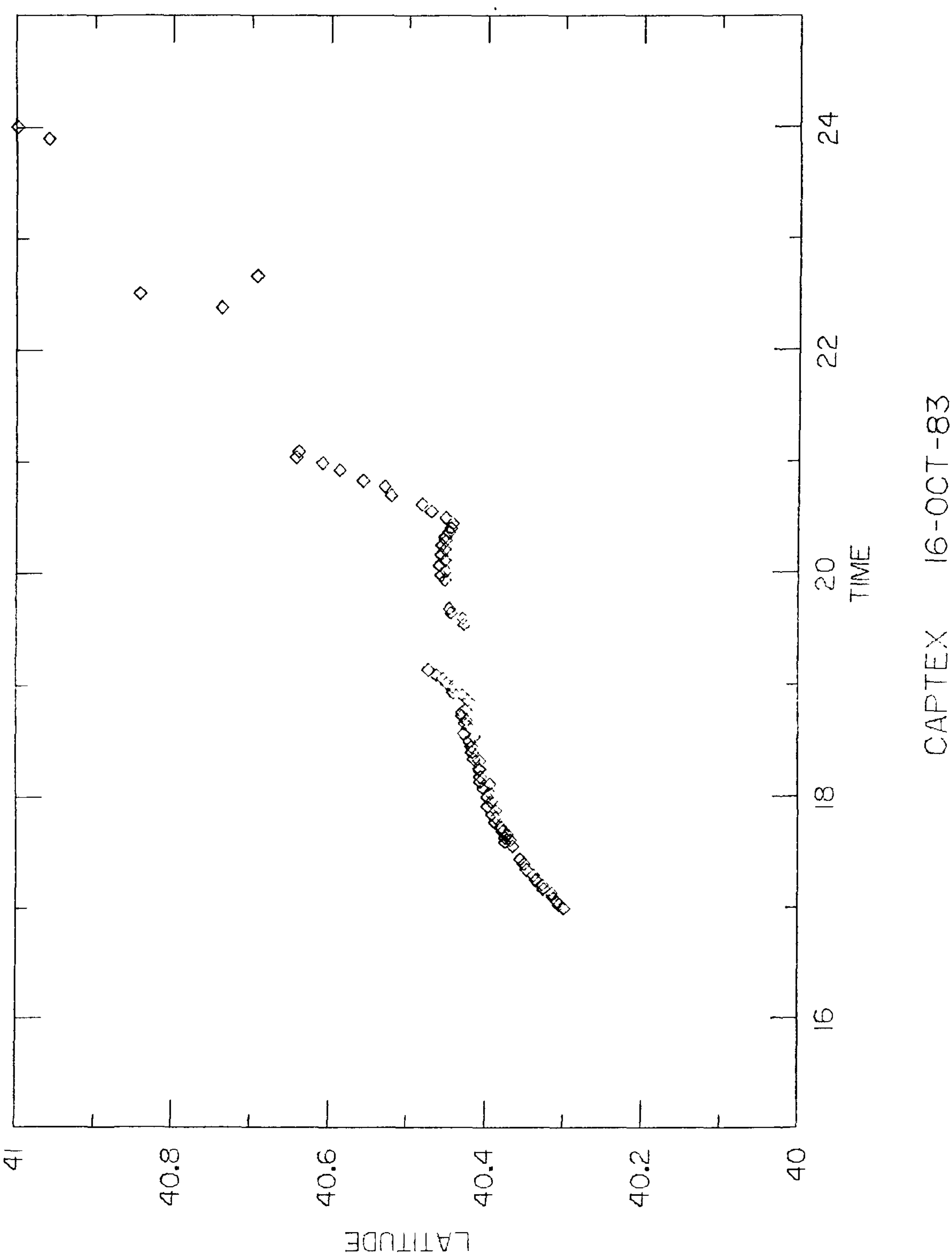
18:49:22	40.417N	82.040W	94.042	2112.	1.989	92.10	264.40
18:51:36	40.423N	82.037W	94.426	2028.	2.027	92.10	263.40
18:54:19	40.430N	82.032W	94.953	2016.	2.072	92.85	263.40
18:55:43	40.442N	82.048W	93.771	2052.	2.095	92.85	262.20
18:59: 3	40.442N	82.020W	96.131	2040.	2.151	94.33	262.80
19: 0:44	40.450N	82.025W	95.870	2040.	2.179	93.77	261.50
19: 3:12	40.455N	82.032W	95.414	2076.	2.220	93.77	261.70
19: 5:14	40.463N	82.038W	95.033	2052.	2.254	93.22	260.70
19: 8: 3	40.473N	82.030W	95.940	2112.	2.301	93.77	260.40
19:32:33	40.428N	81.703W	122.432	2136.	2.709	119.72	265.90
19:35:43	40.430N	81.655W	126.511	2160.	2.762	124.16	266.10
19:38:39	40.445N	81.613W	130.193	2208.	2.811	128.43	265.60
19:40:48	40.447N	81.583W	132.731	2256.	2.847	130.47	265.90
19:56:17	40.453N	81.472W	142.183	2340.	3.105	139.55	266.20
19:58:47	40.458N	81.452W	143.922	2436.	3.146	141.58	265.90
20: 1: 3	40.452N	81.440W	144.821	2436.	3.184	142.14	266.40
20: 4: 1	40.460N	81.408W	147.578	2448.	3.234	145.48	264.30
20: 6:52	40.453N	81.397W	148.479	2412.	3.281	145.66	266.60
20: 9:57	40.458N	81.385W	149.516	2280.	3.332	146.77	266.80
20:12:53	40.453N	81.378W	150.018	2292.	3.381	147.51	266.80
20:15: 1	40.457N	81.367W	151.036	2328.	3.417	148.63	266.30
20:17:25	40.452N	81.367W	150.980	2304.	3.457	148.44	267.00
20:19:29	40.453N	81.358W	151.699	2280.	3.491	149.00	266.40
20:21:58	40.448N	81.362W	151.364	2340.	3.533	148.63	267.10
20:24:15	40.445N	81.367W	150.908	2340.	3.571	148.07	266.90
20:26:39	40.443N	81.375W	150.190	2316.	3.611	147.51	267.00
20:29:38	40.452N	81.367W	150.980	2256.	3.661	148.44	267.00
20:33:18	40.470N	81.377W	150.357	2316.	3.722	147.33	266.00
20:37:11	40.482N	81.362W	151.766	2280.	3.786	149.00	266.30
20:41:51	40.522N	81.382W	150.700	2220.	3.864	148.07	263.40
20:46:41	40.530N	81.363W	152.368	2184.	3.945	150.29	261.90
20:49:49	40.558N	81.372W	152.199	2196.	3.997	149.18	262.20
20:55:35	40.588N	81.383W	151.861	2316.	4.093	149.37	260.70
20:59:15	40.610N	81.405W	150.581	2316.	4.154	148.81	259.90
21: 2:26	40.643N	81.397W	152.108	2256.	4.207	150.48	258.20
21: 5:20	40.640N	81.415W	150.525	2292.	4.256	148.44	258.40
22:22:40	40.738N	81.045W	183.275	2184.	5.544	181.98	257.60
22:30:19	40.843N	80.920W	196.483	1884.	5.672	195.51	255.30
22:39:45	40.693N	80.762W	205.329	2412.	5.829	203.85	261.60
23:53:56	40.958N	80.525W	231.687	1896.	7.066	231.28	255.00
0: 0:21	40.998N	80.430W	240.545	2268.	7.173	239.99	254.20



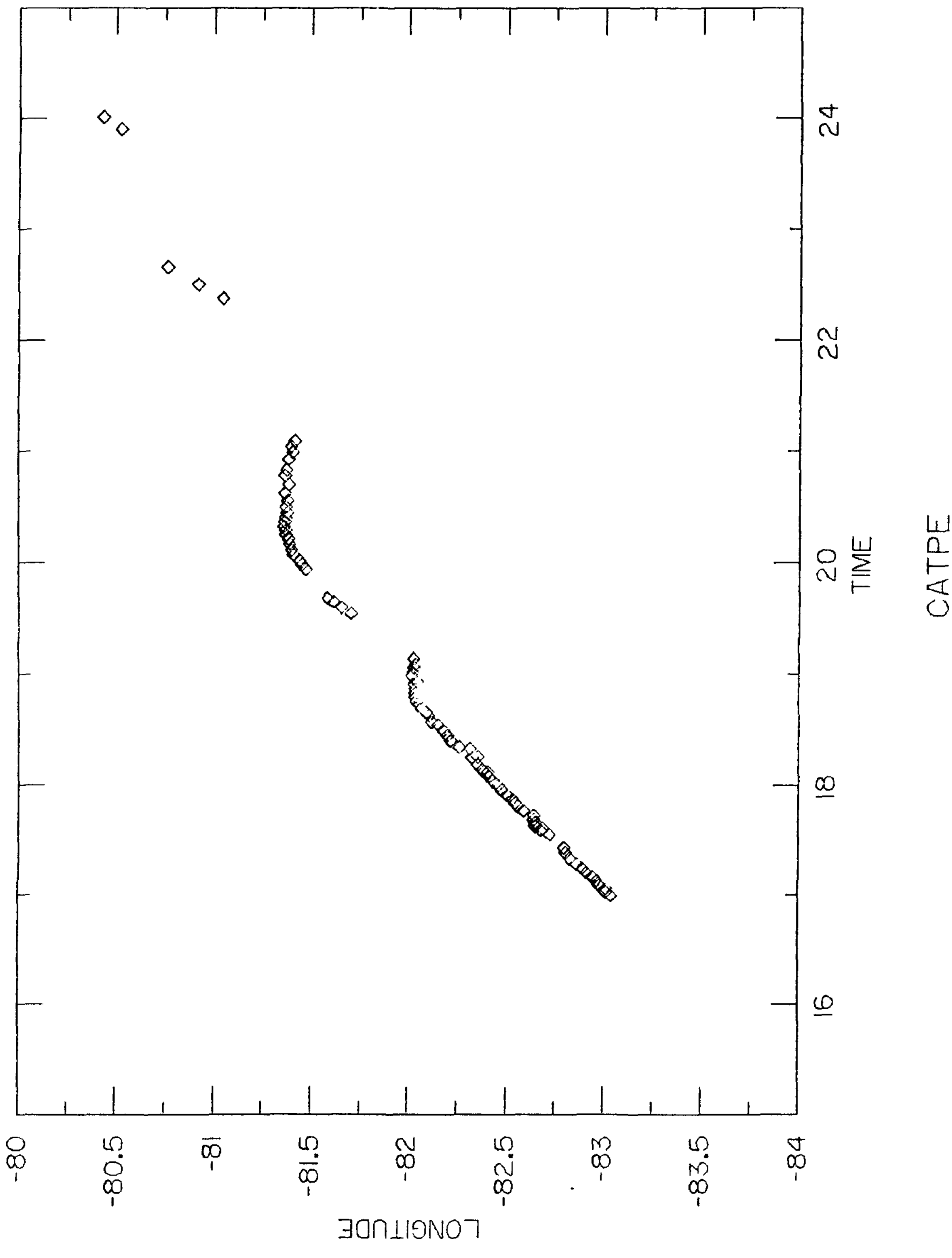
DOWN WIND DISTANCE - KM
250
200
150
100
50
0
16
18
20
22
24
TIME 16-OCT-83
CAPTEX



CAPTEX 16-OCT-84



CAPTEX 16-OCT-83
TIME
16
18
20
22
24
LATITUDE
40
40.2
40.4
40.6
40.8
41


-80
-80.5
-81
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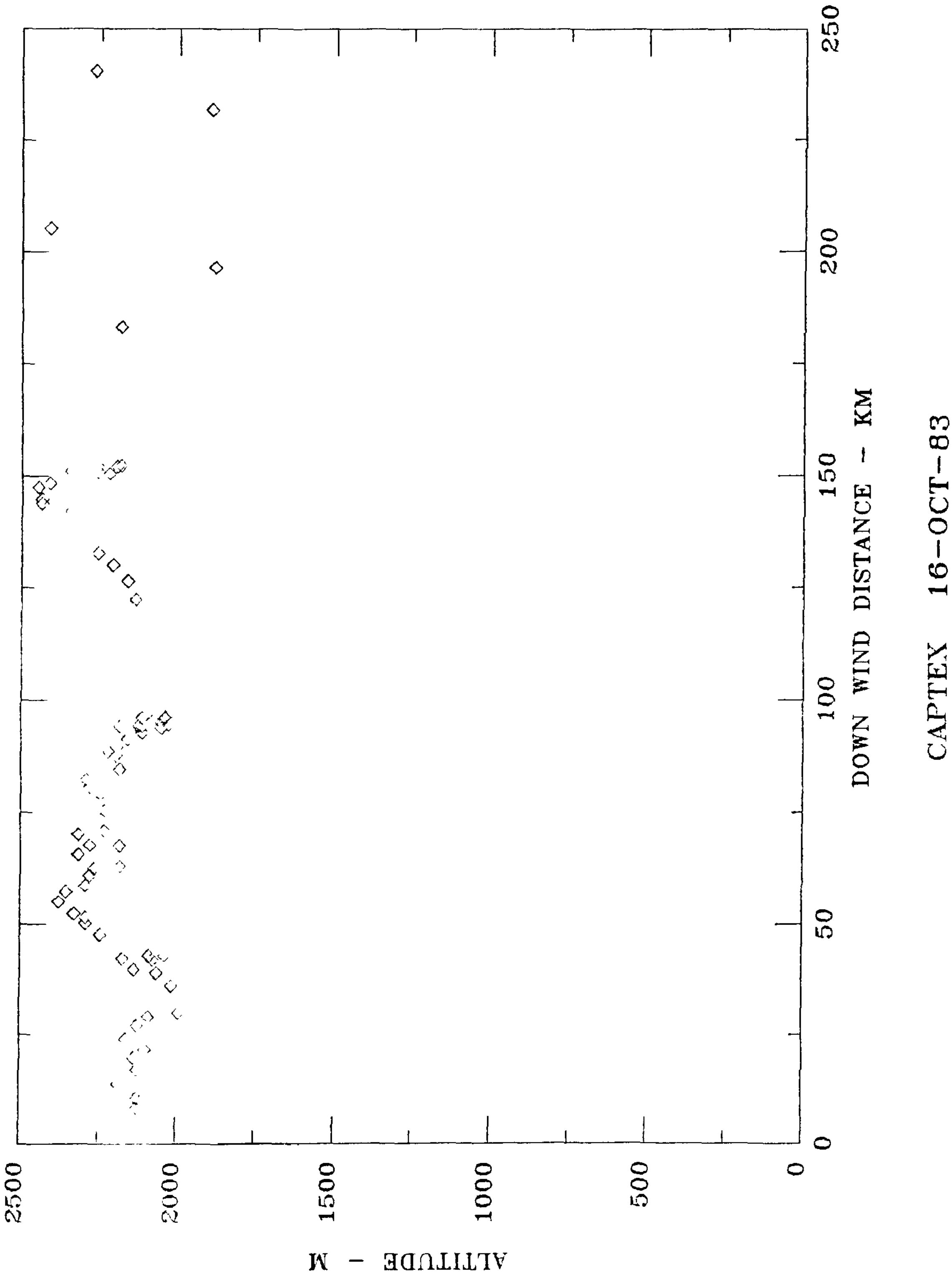
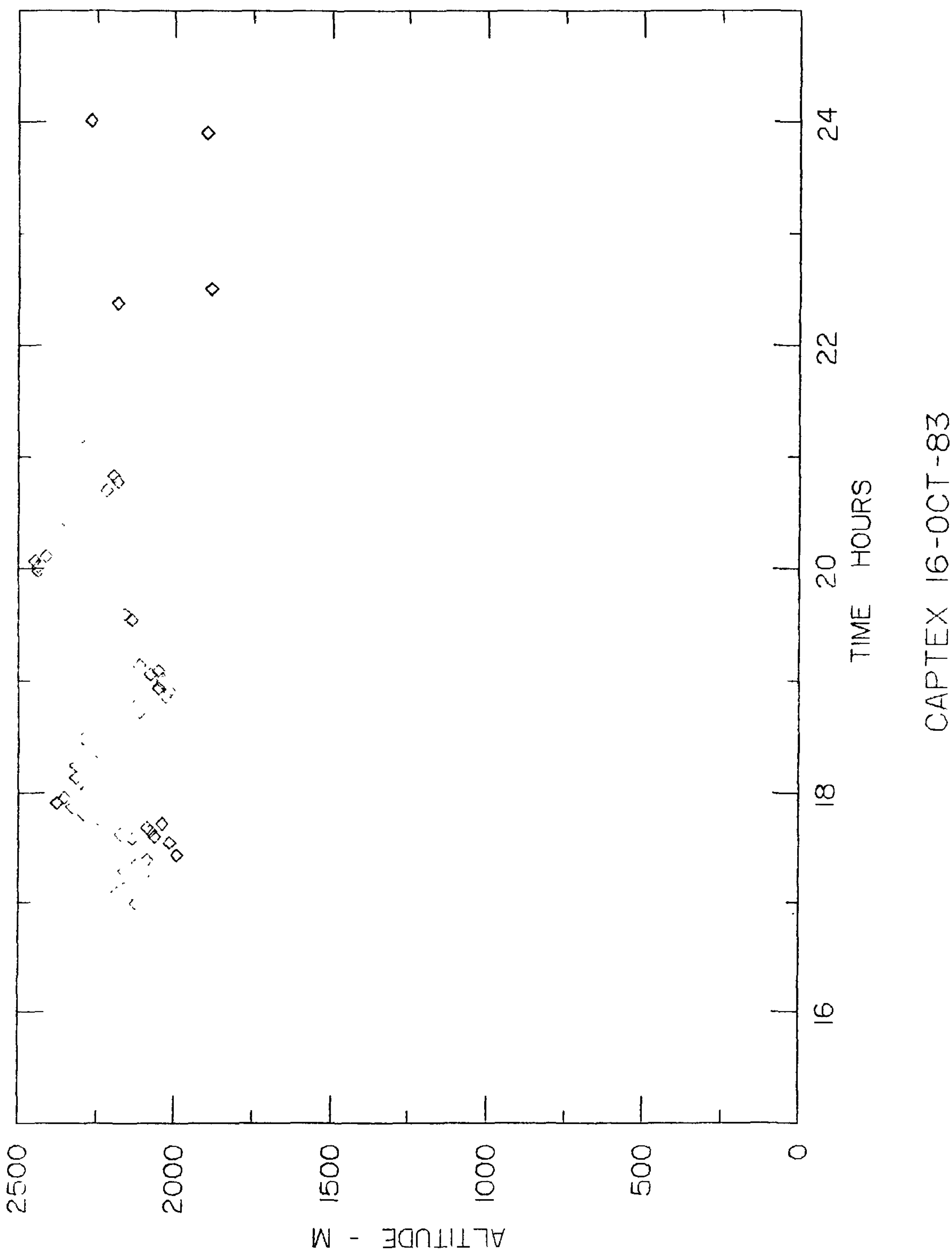
-84
LONGITUDE
16
18
20
22
24
TIME
CATPE



ALTITUDE - M
2500
2000
1500
1000
500
0
0
50
100
150
200
250
DOWN WIND DISTANCE - KM
CAPTEX 16-OCT-83



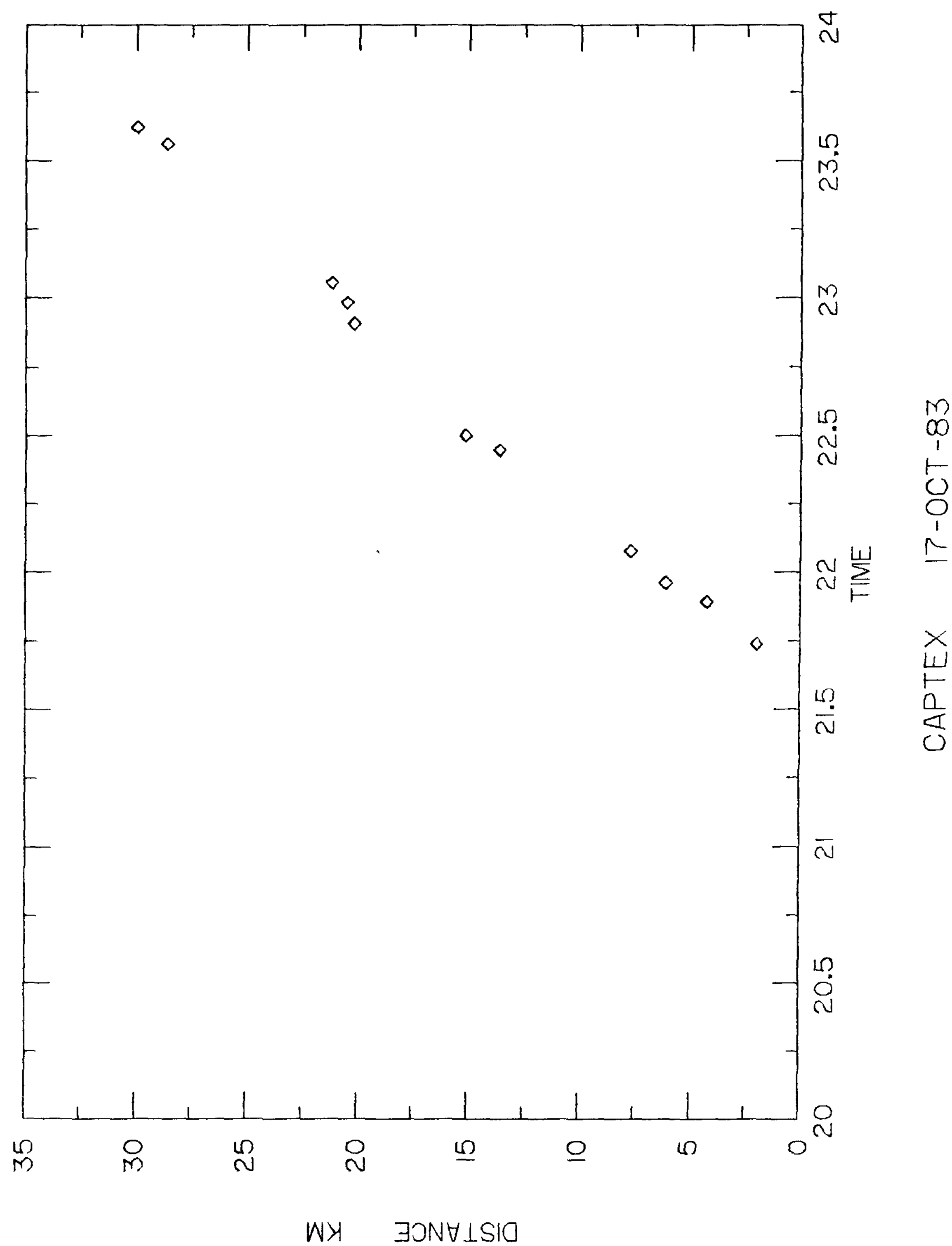
ALTITUDE - M
0
500
1000
1500
2000
2500
16
18
20
22
24
TIME HOURS
CAPTEX 16-OCT-83

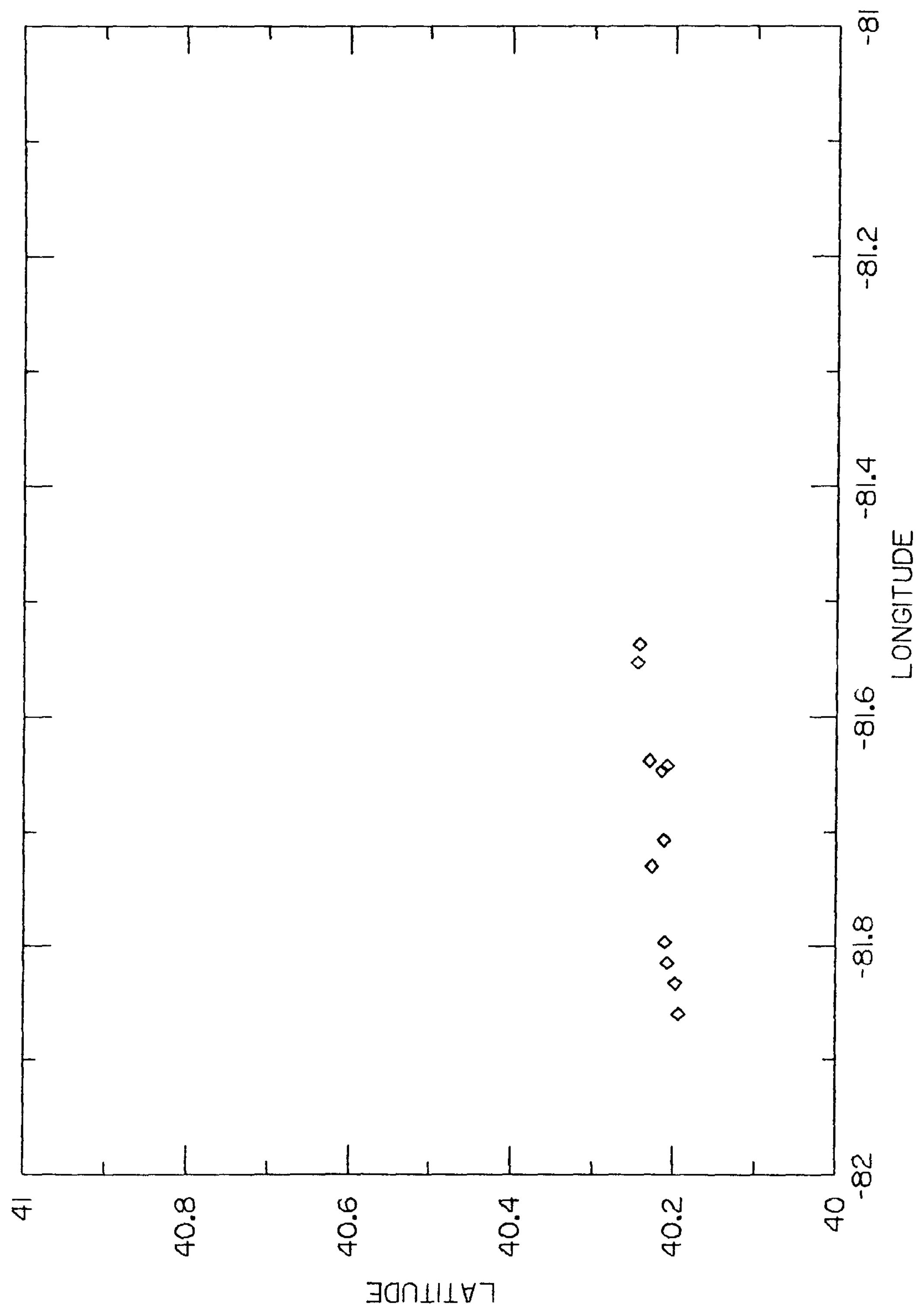
Case III: 17 OCTOBER 1983, 2142-2338 EDT

- - - - - R E L E A S E - - - - -

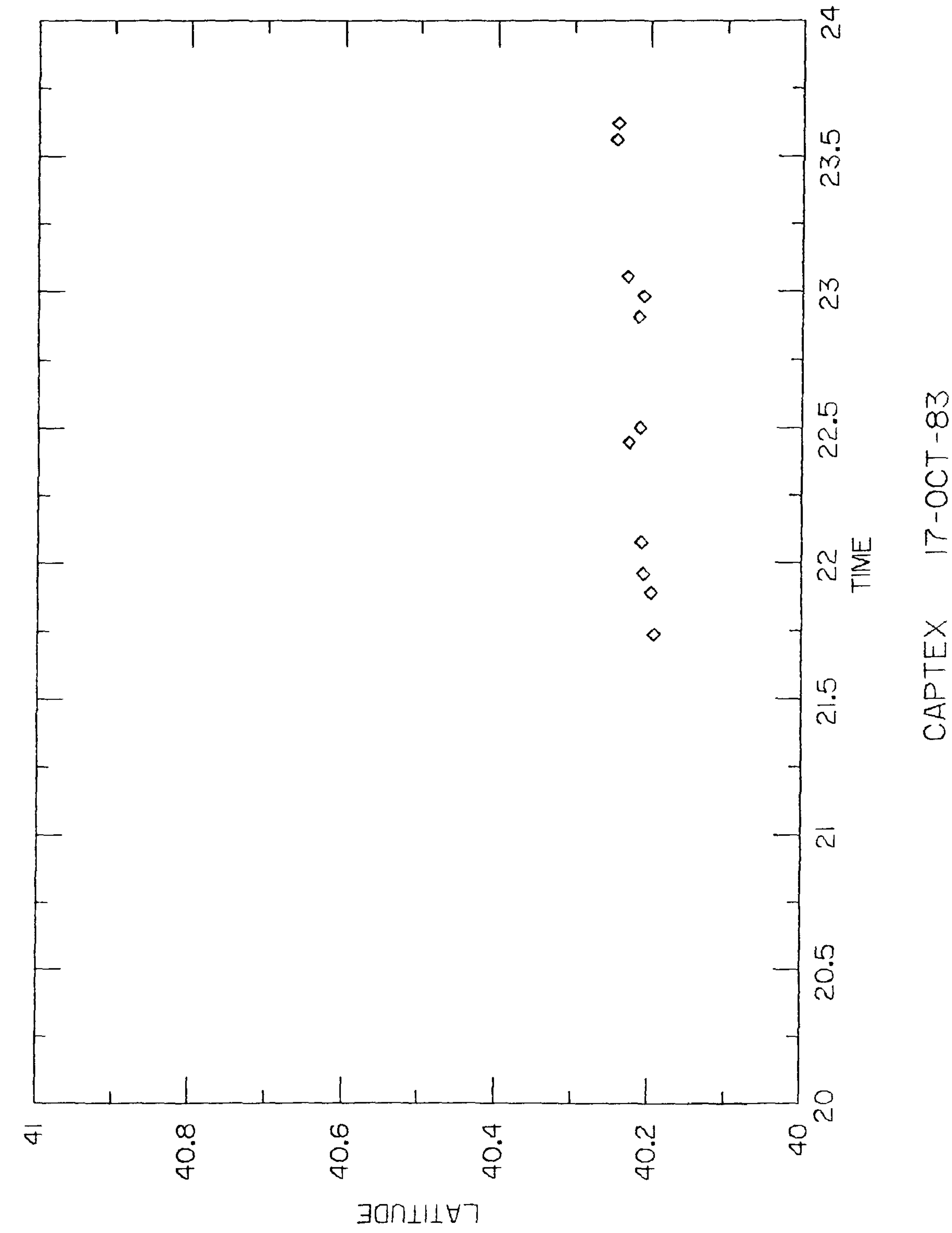
Date	Time	Position
10-27-83	20: 0: 0	40.187N 81.882W

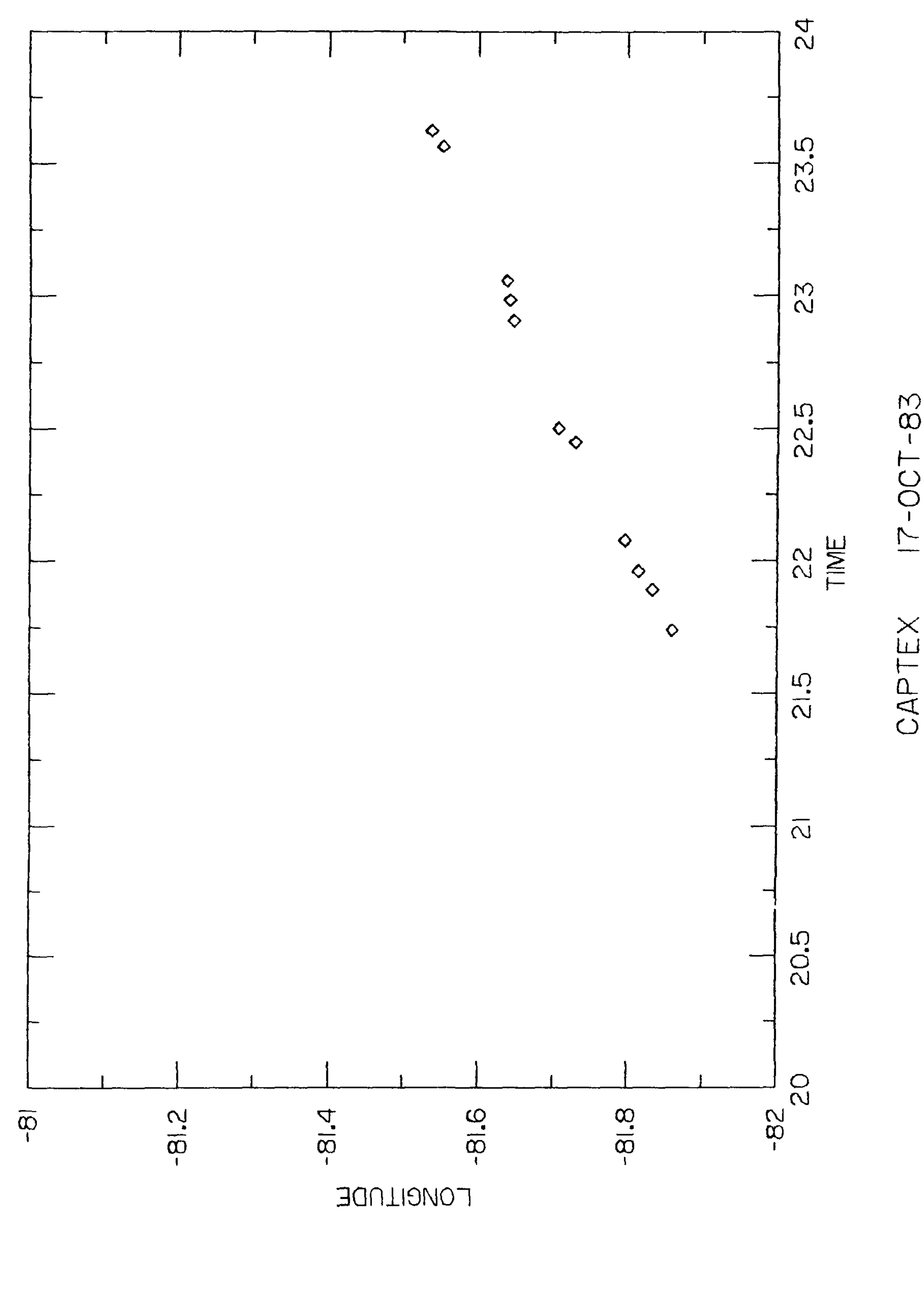
Observation Time	Observation Lat-Long		Distance (km)	Altitude (meters)	Delta-t (hours)	--RNAV-- Dist.	Theta
21:42:46	40.188N	81.863W	1.568	1332.	1.713	27.24	192.90
21:44:14	40.193N	81.860W	1.964	1440.	1.737	29.10	194.00
21:53:27	40.197N	81.833W	4.253	1368.	1.891	29.10	197.50
21:57:42	40.207N	81.815W	6.082	1416.	1.962	30.21	201.60
22: 4:39	40.210N	81.797W	7.670	1476.	2.077	30.95	204.40
22:26:47	40.227N	81.730W	13.622	1548.	2.446	15.57	263.50
22:29:58	40.212N	81.707W	15.118	1560.	2.499	16.49	269.20
22:54:18	40.215N	81.647W	20.201	1476.	2.905	21.50	271.90
22:58:55	40.208N	81.642W	20.522	1536.	2.982	22.24	274.30
23: 3:16	40.230N	81.638W	21.211	1524.	3.054	22.61	265.50
23:33:39	40.245N	81.553W	28.611	1140.	3.561	30.58	267.70
23:37:18	40.243N	81.537W	29.952	1044.	3.622	31.13	266.80

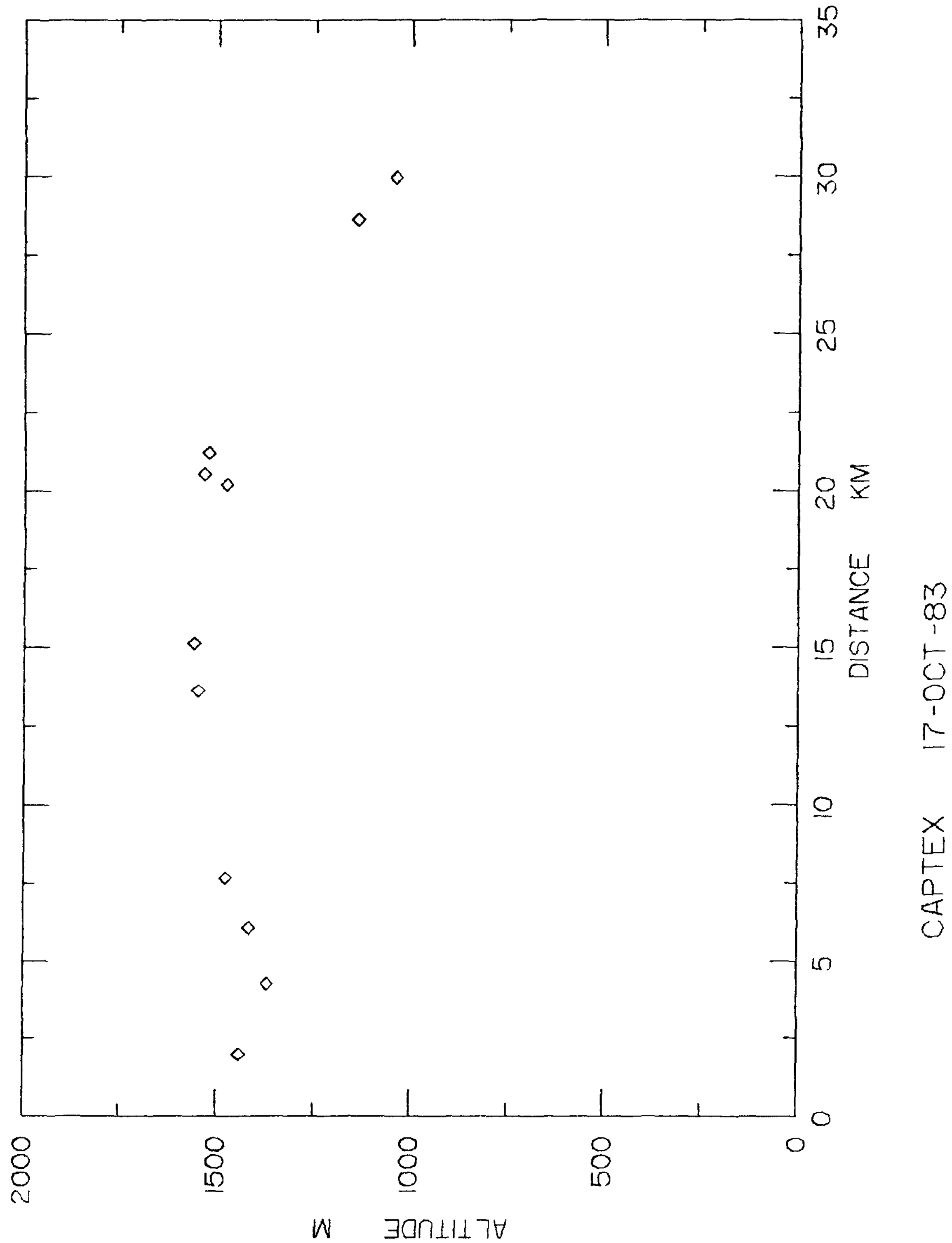

DISTANCE KM
TIME
CAPTEX 17-OCT-83



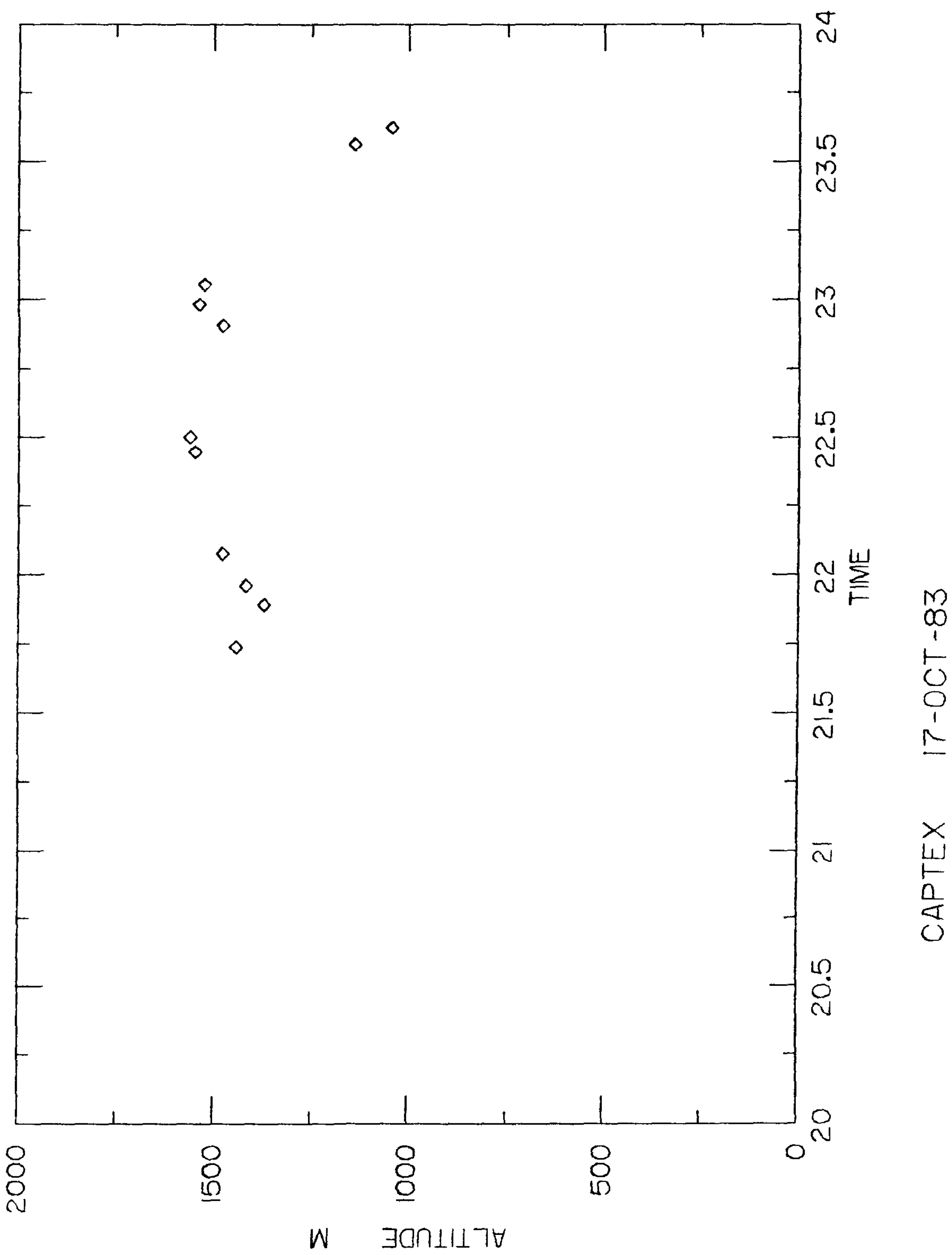
CAPTEX 17-OCT-83


LATITUDE
41
40.8
40.6
40.4
40.2
40
TIME
20
20.5
21
21.5
22
22.5
23
23.5
24
CAPTEX 17-OCT-83


LONGITUDE
-81
-81.2
-81.4
-81.6
-81.8
-82
20
20.5
21
21.5
22
22.5
23
23.5
24
TIME
CAPTEX 17-OCT-83



ALTITUDE M
0
500
1000
1500
2000
DISTANCE KM
0
5
10
15
20
25
30
35
CAPTEX 17-OCT-83

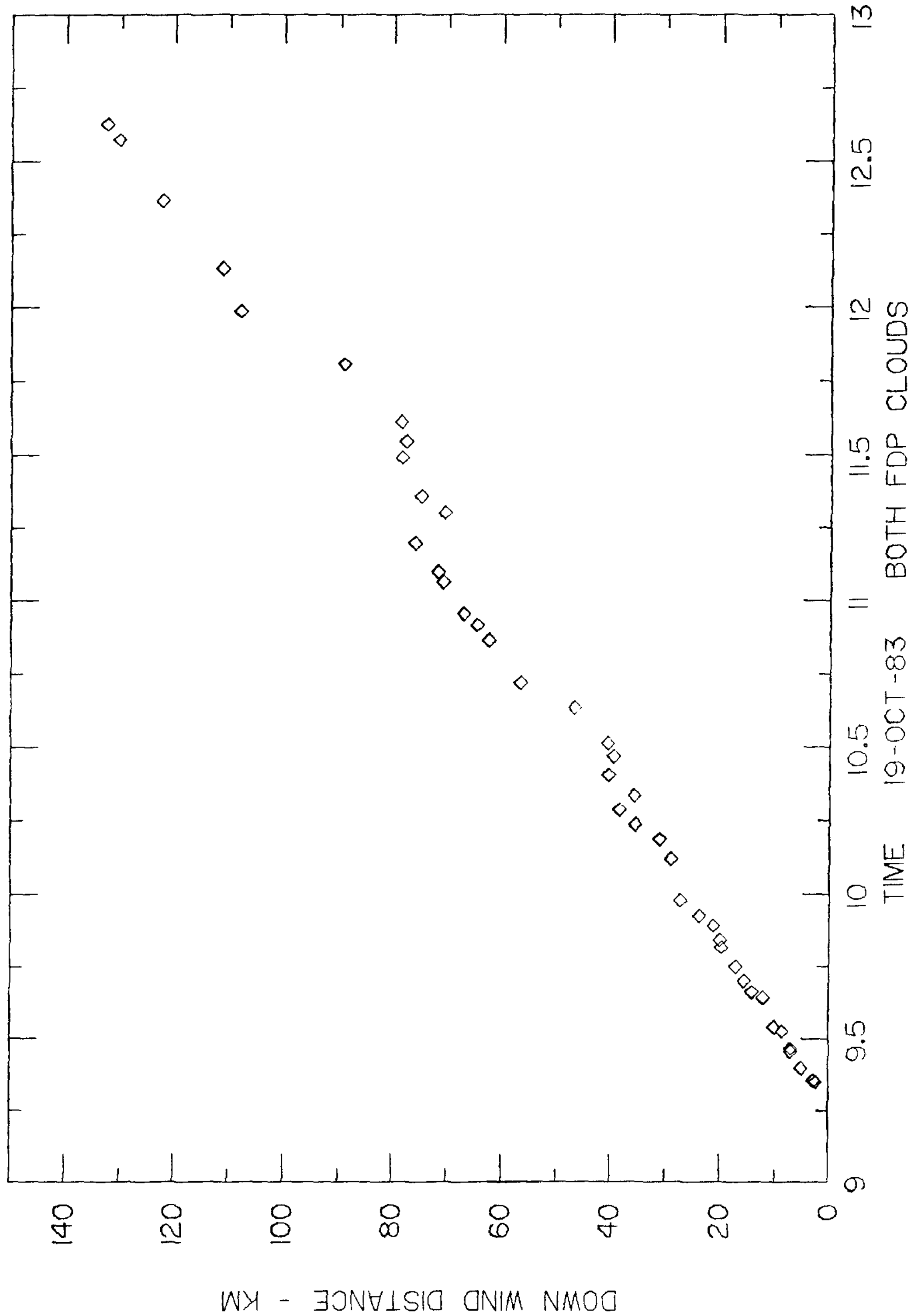

ALTITUDE M
2000
1500
1000
500
0
20
20.5
21
21.5
22
22.5
23
23.5
24
TIME
CAPTEX 17-OCT-83

Case IV: 19 OCTOBER 1983, 0920-1238 EDT

- - - - - R E L E A S E - - - - -

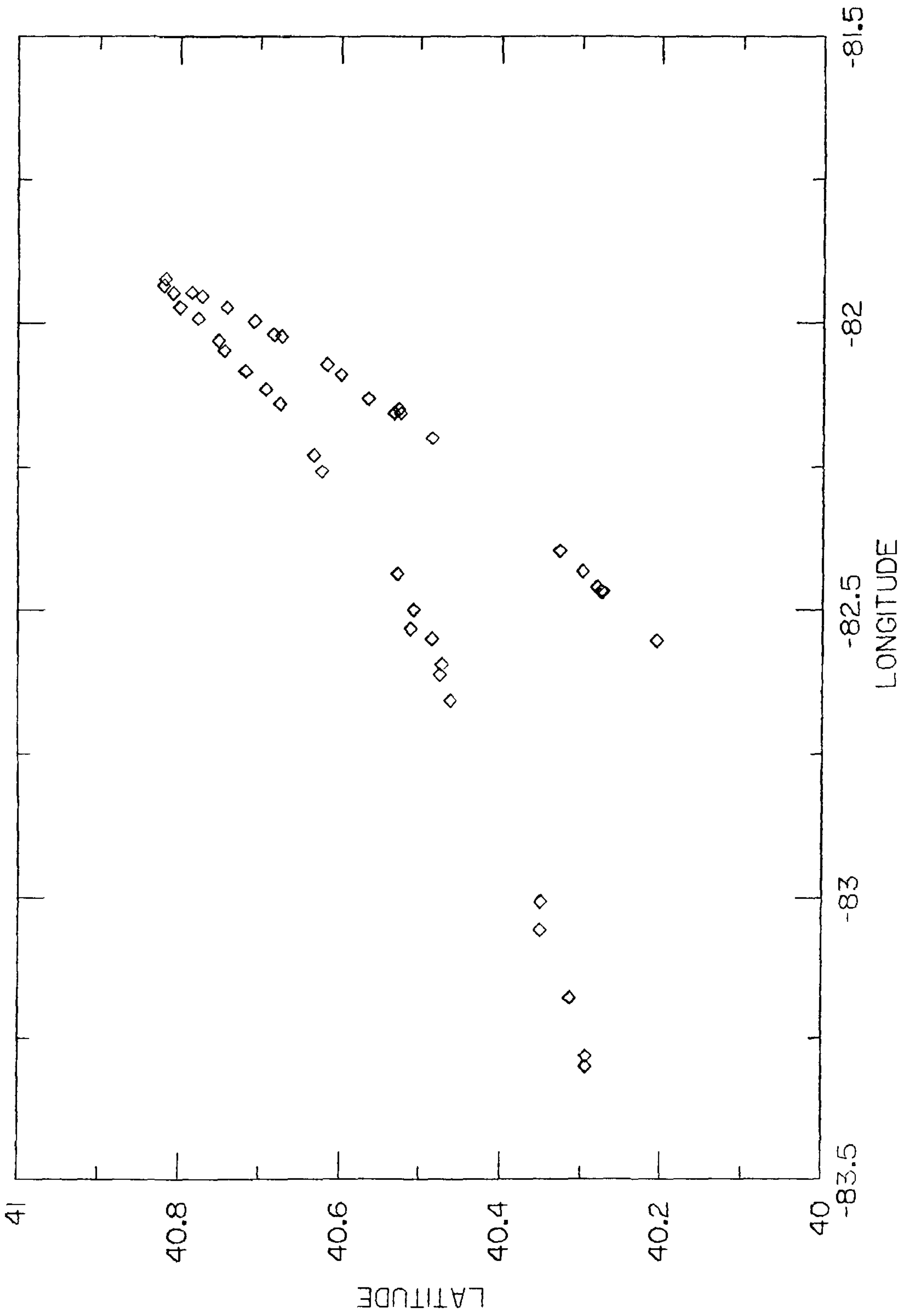
Date	Time	Position
10-19-83	9:15: 0	40.833N 81.917W

Observation Time	Observation Lat-Lons		Distance (Km)	Altitude (meters)	Delta-t (hours)	--RNAV-- Dist.	Theta
9:20: 0	40.828N	81.917W	0.556	2064.	0.083	2.04	343.70
9:20:57	40.818N	81.923W	1.760	2112.	0.099	2.41	6.90
9:21:12	40.820N	81.935W	2.140	1464.	0.103	2.78	30.30
9:23:46	40.808N	81.948W	3.851	1500.	0.146	5.00	28.40
9:27:18	40.800N	81.972W	5.930	1524.	0.205	7.04	48.70
9:27:52	40.785N	81.947W	5.938	2088.	0.214	7.04	24.30
9:31:42	40.772N	81.953W	7.520	2136.	0.278	8.52	25.00
9:32:33	40.777N	81.992W	8.921	1548.	0.292	10.01	46.70
9:38:33	40.742N	81.973W	11.255	2172.	0.392	12.05	31.70
9:39:44	40.752N	82.030W	13.175	1452.	0.412	14.06	49.30
9:42: 5	40.745N	82.048W	14.816	1428.	0.451	15.57	49.00
9:45: 2	40.707N	81.997W	15.615	2088.	0.501	17.05	25.70
9:48:54	40.718N	82.083W	18.995	1440.	0.565	19.64	52.00
9:50:25	40.683N	82.020W	18.817	2058.	0.590	20.01	30.50
9:53:26	40.673N	82.023W	19.936	2040.	0.641	21.13	29.00
9:55:29	40.693N	82.115W	22.846	1404.	0.675	23.72	50.40
9:58:35	40.675N	82.140W	25.781	1452.	0.726	27.24	49.60
10: 7: 8	40.617N	82.072W	27.415	1872.	0.869	28.91	32.90
10:11:10	40.600N	82.090W	29.787	1824.	0.936	30.95	32.60
10:14:12	40.633N	82.230W	34.549	1428.	0.987	35.40	53.70
10:17:15	40.623N	82.258W	37.104	1428.	1.038	38.36	55.40
10:20: 2	40.565N	82.132W	34.929	1884.	1.054	35.58	35.10
10:24:13	40.527N	82.150W	39.391	1800.	1.154	40.40	34.20
10:28: 6	40.533N	82.157W	39.040	1824.	1.218	39.47	36.20
10:30:41	40.525N	82.157W	39.836	1812.	1.261	40.59	34.50
10:38: 0	40.485N	82.200W	45.545	1752.	1.383	46.70	36.60
10:43: 4	40.528N	82.437W	55.512	1332.	1.468	56.52	56.40
10:51:45	40.508N	82.500W	61.139	1368.	1.613	62.27	57.90
10:54:56	40.512N	82.533W	63.221	1320.	1.666	64.49	60.30
10:57:16	40.485N	82.550W	66.099	1380.	1.704	66.90	57.50
11: 3:41	40.473N	82.595W	69.961	1344.	1.811	70.79	59.30
11: 5:47	40.475N	82.612W	71.016	1344.	1.846	71.72	60.70
11:11:42	40.462N	82.657W	75.015	1356.	1.945	75.98	61.30
11:18: 4	40.327N	82.397W	69.495	1812.	2.051	70.42	39.70
11:21:29	40.298N	82.433W	73.883	1788.	2.108	74.87	40.60
11:29:21	40.275N	82.467W	77.661	1812.	2.239	78.39	41.40
11:32:33	40.280N	82.460W	76.875	1824.	2.293	77.65	41.20
11:36:37	40.273N	82.468W	77.895	1848.	2.360	78.58	41.30
11:48:20	40.205N	82.553W	88.343	1740.	2.556	88.95	42.20
11:59:15	40.350N	83.008W	106.987	1368.	2.737	107.86	63.80
12: 7:54	40.350N	83.057W	110.547	1296.	2.882	111.19	65.10
12:21:58	40.313N	83.178W	121.599	1344.	3.116	122.31	65.90
12:34:22	40.293N	83.282W	130.413	1308.	3.323	130.28	67.60
12:37:30	40.293N	83.300W	131.795	1296.	3.375	132.50	67.30

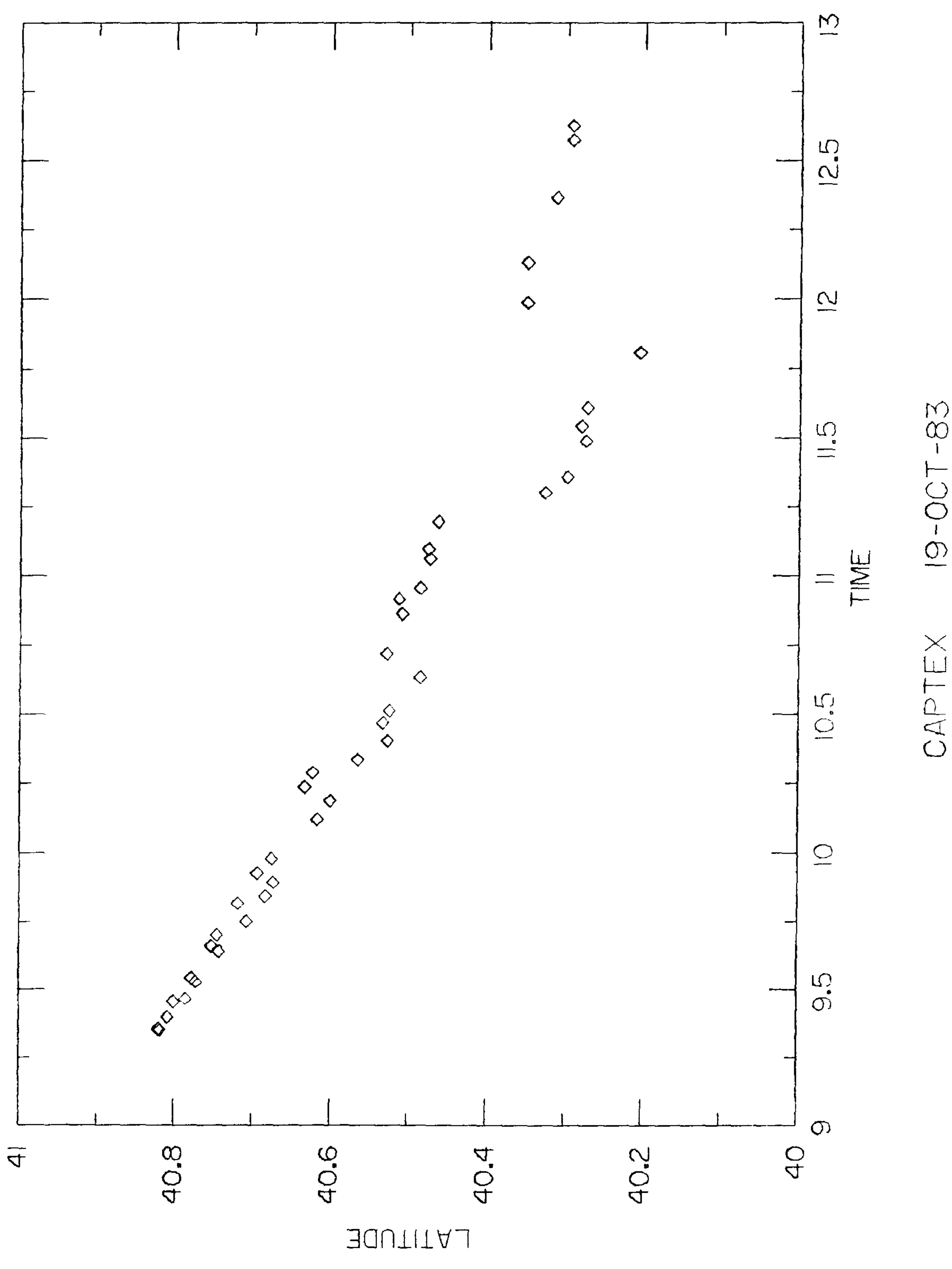


DOWN WIND DISTANCE - KM
0
20
40
60
80
100
120
140
9
9.5
10
10.5
11
11.5
12
12.5
13
TIME 19-OCT-83 BOTH FDP CLOUDS

CAPTEX



CAPTEX 19-OCT-83


LATITUDE
41
40.8
40.6
40.4
40.2
40
TIME
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9.5
10
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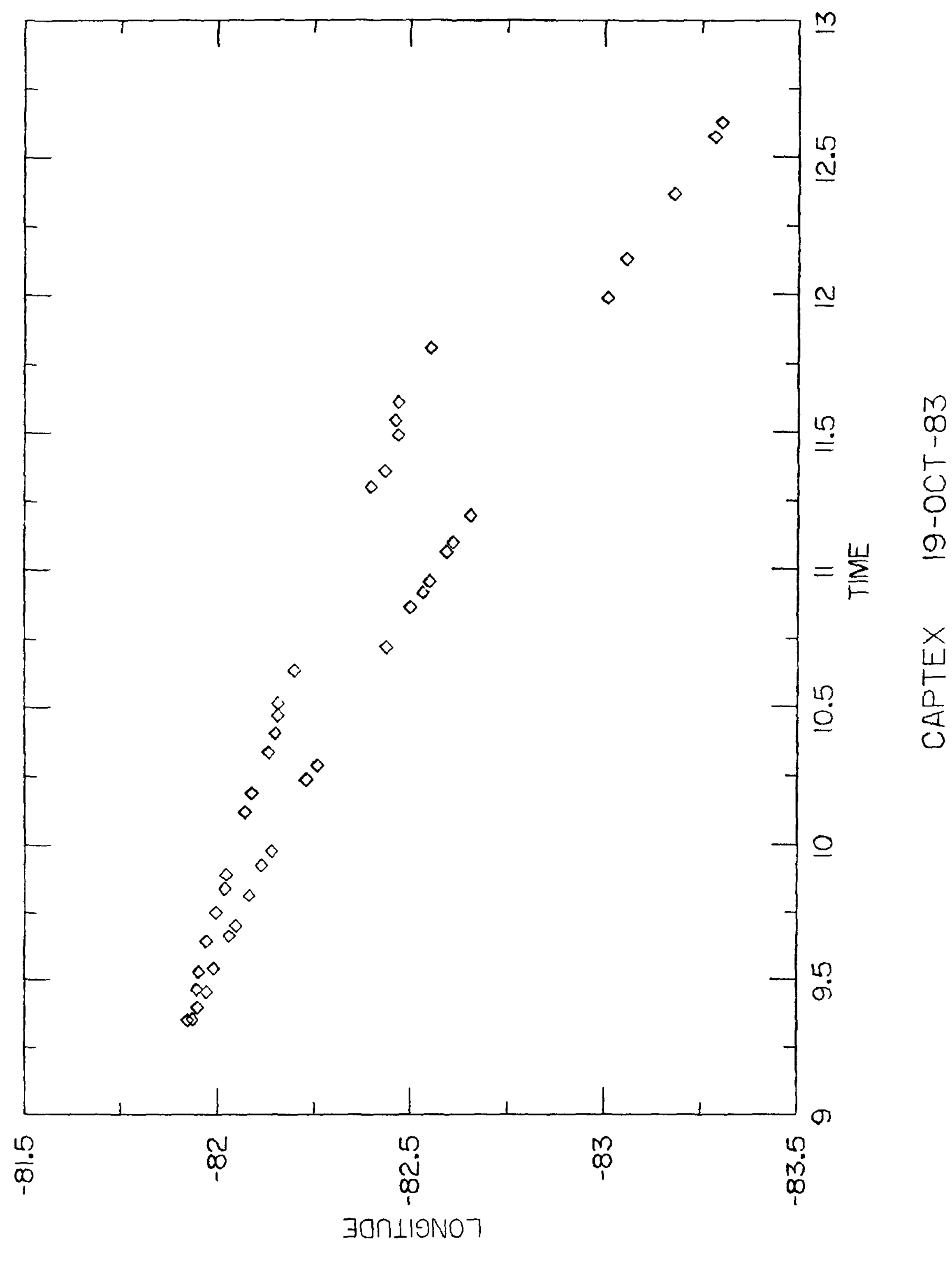
11
11.5
12
12.5
13
CAPTEX 19-OCT-83


LONGITUDE
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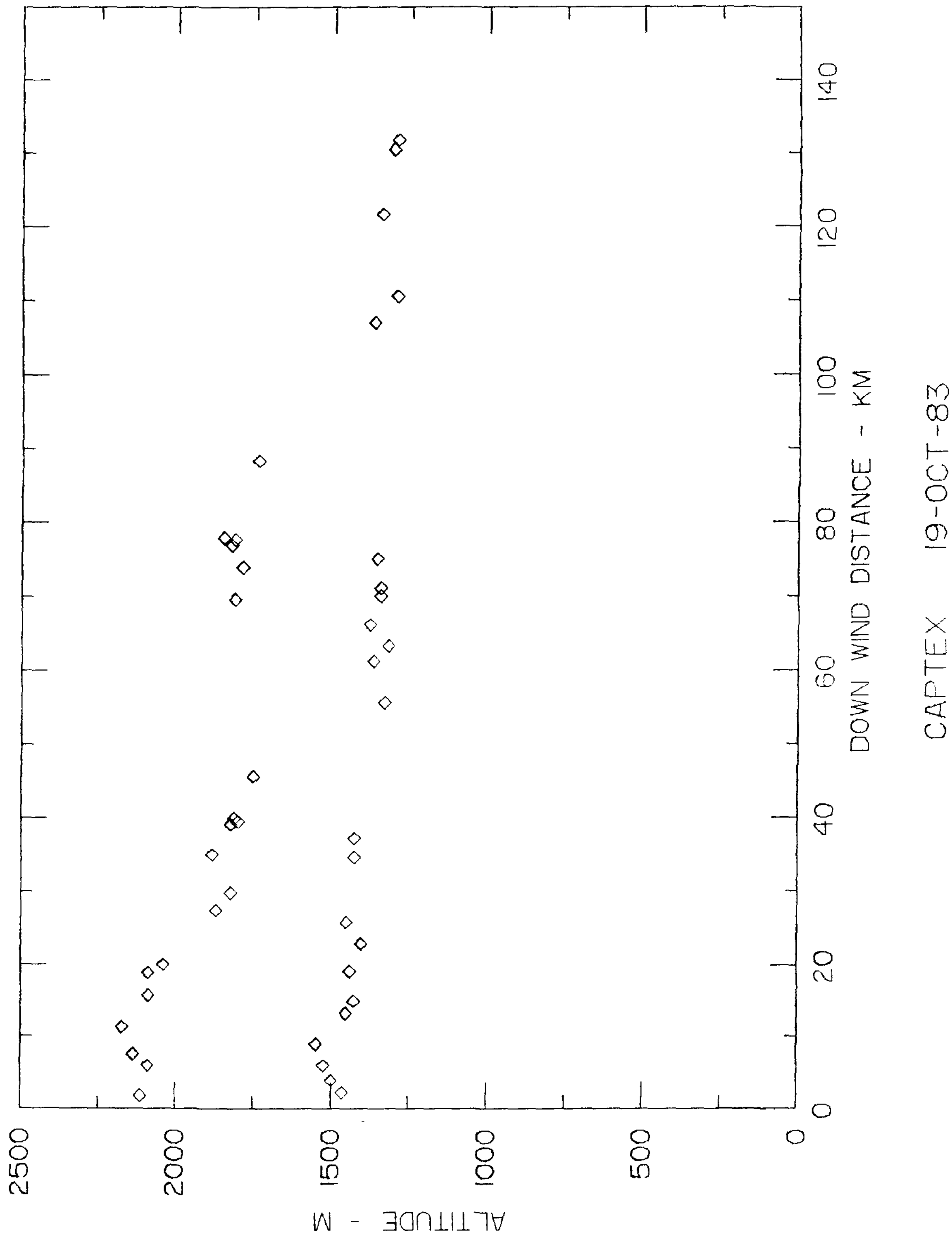
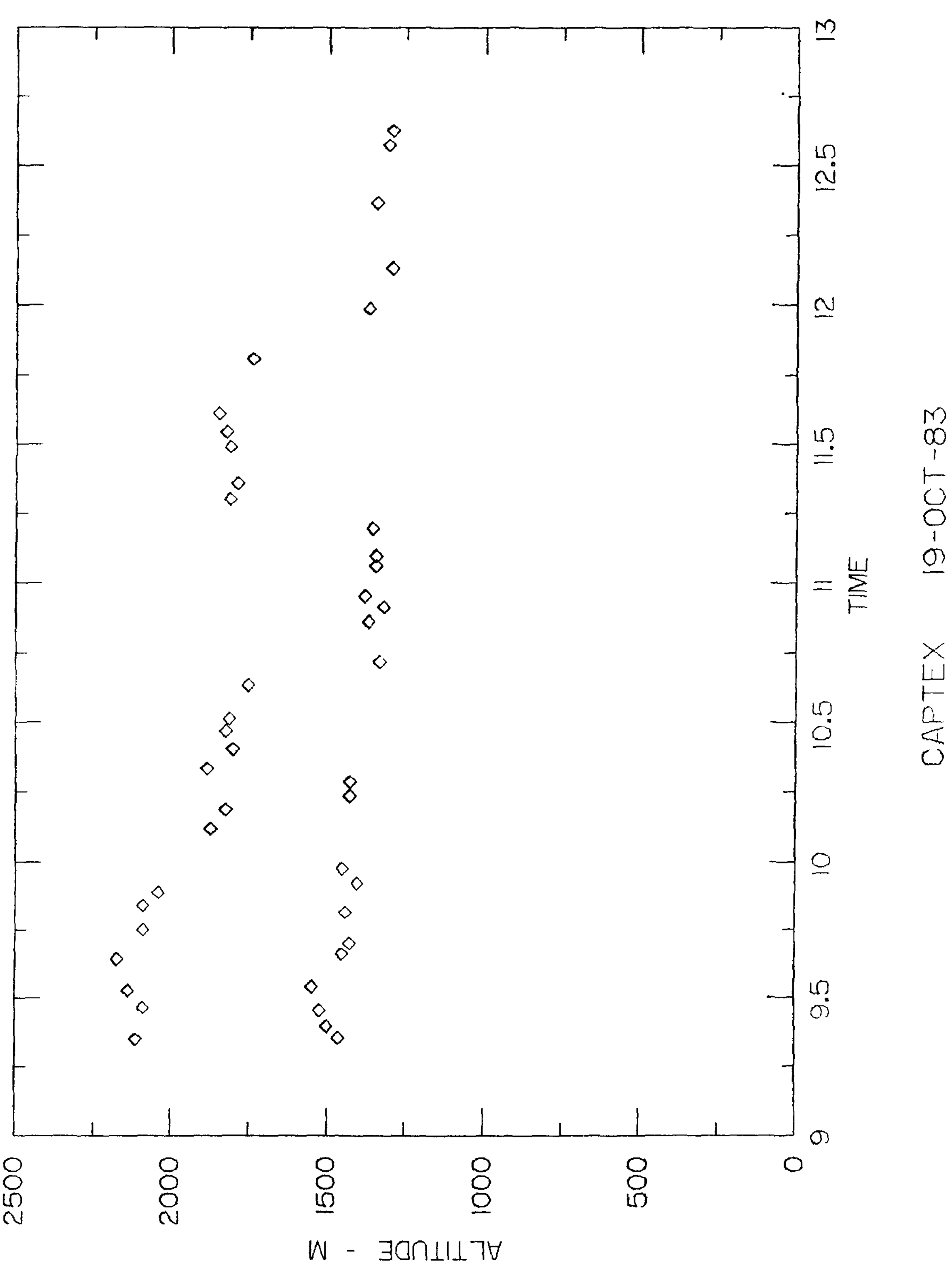
-82.5
-83
-83.5
TIME
9
9.5
10
10.5
11
11.5
12
12.5
13
CAPTEX 19-OCT-83



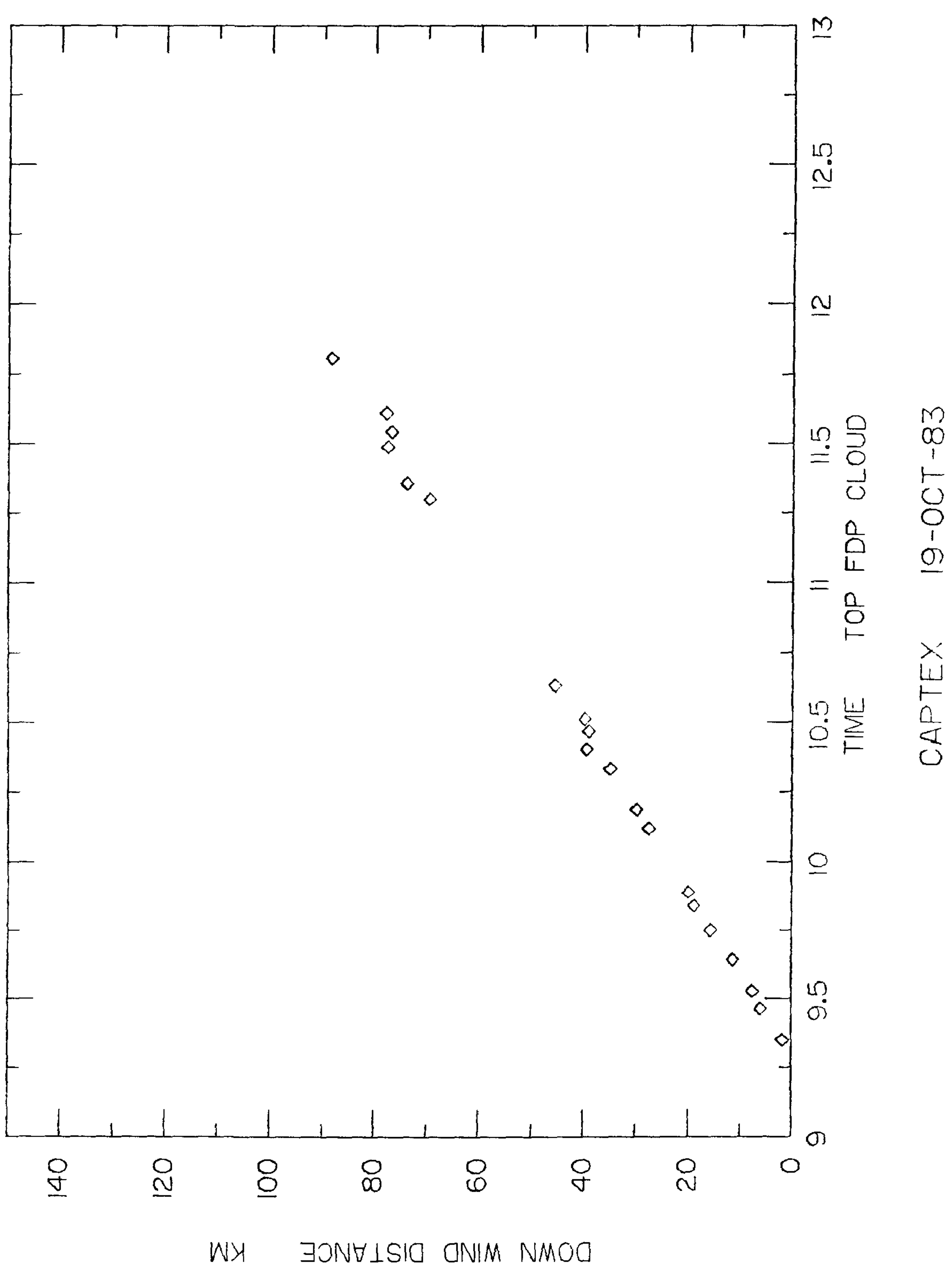
ALTITUDE - M
0
500
1000
1500
2000
2500
DOWN WIND DISTANCE - KM
0
20
40
60
80
100
120
140
CAPTEX 19-OCT-83


ALTITUDE - M
0
500
1000
1500
2000
2500
TIME
9
9.5
10
10.5
11
11.5
12
12.5
13
CAPTEX 19-OCT-83

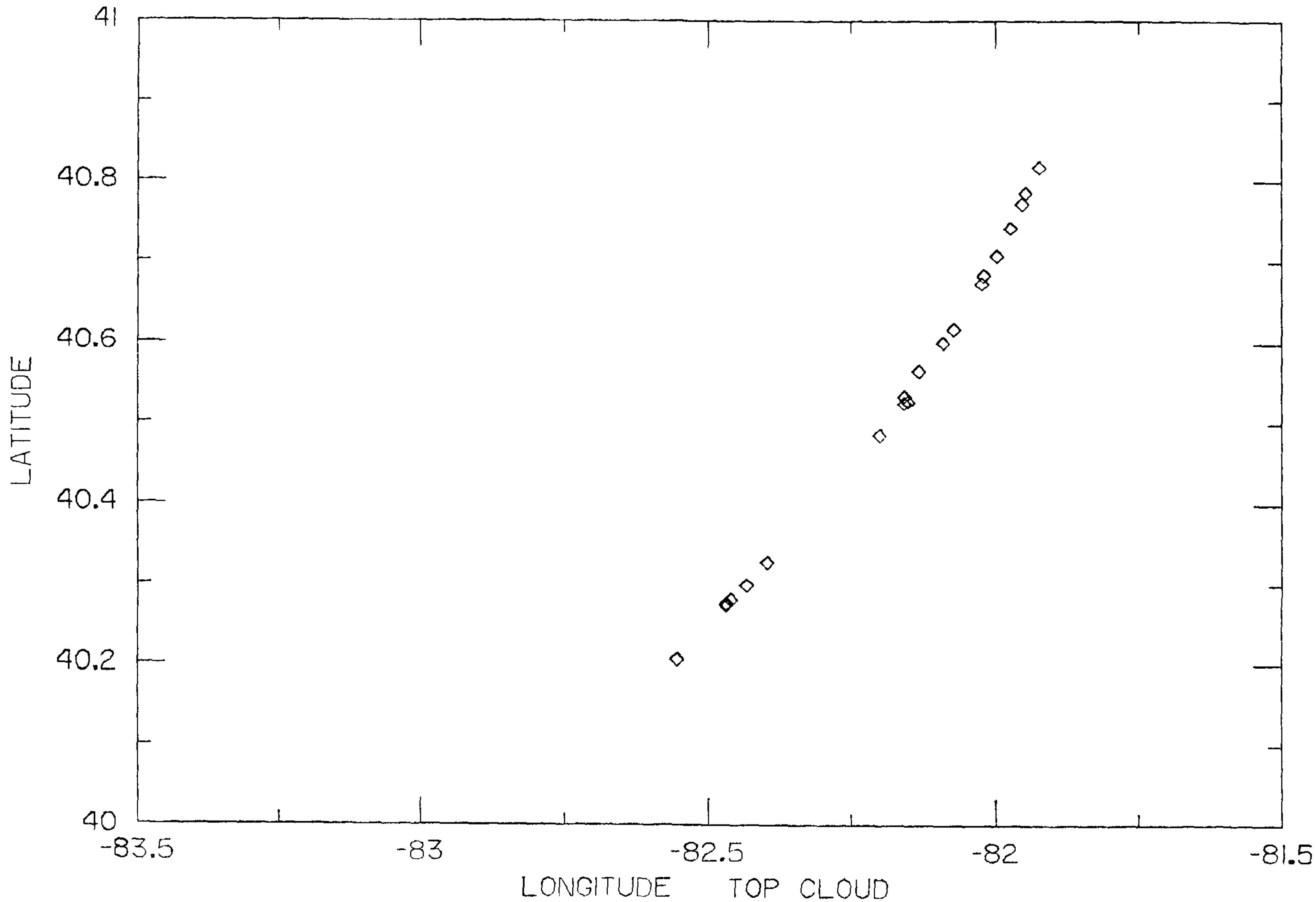
- - - - - R E L E A S E - - - - -

Date	Time	Position
10-19-85	9:15: 0	40.833N 81.917W

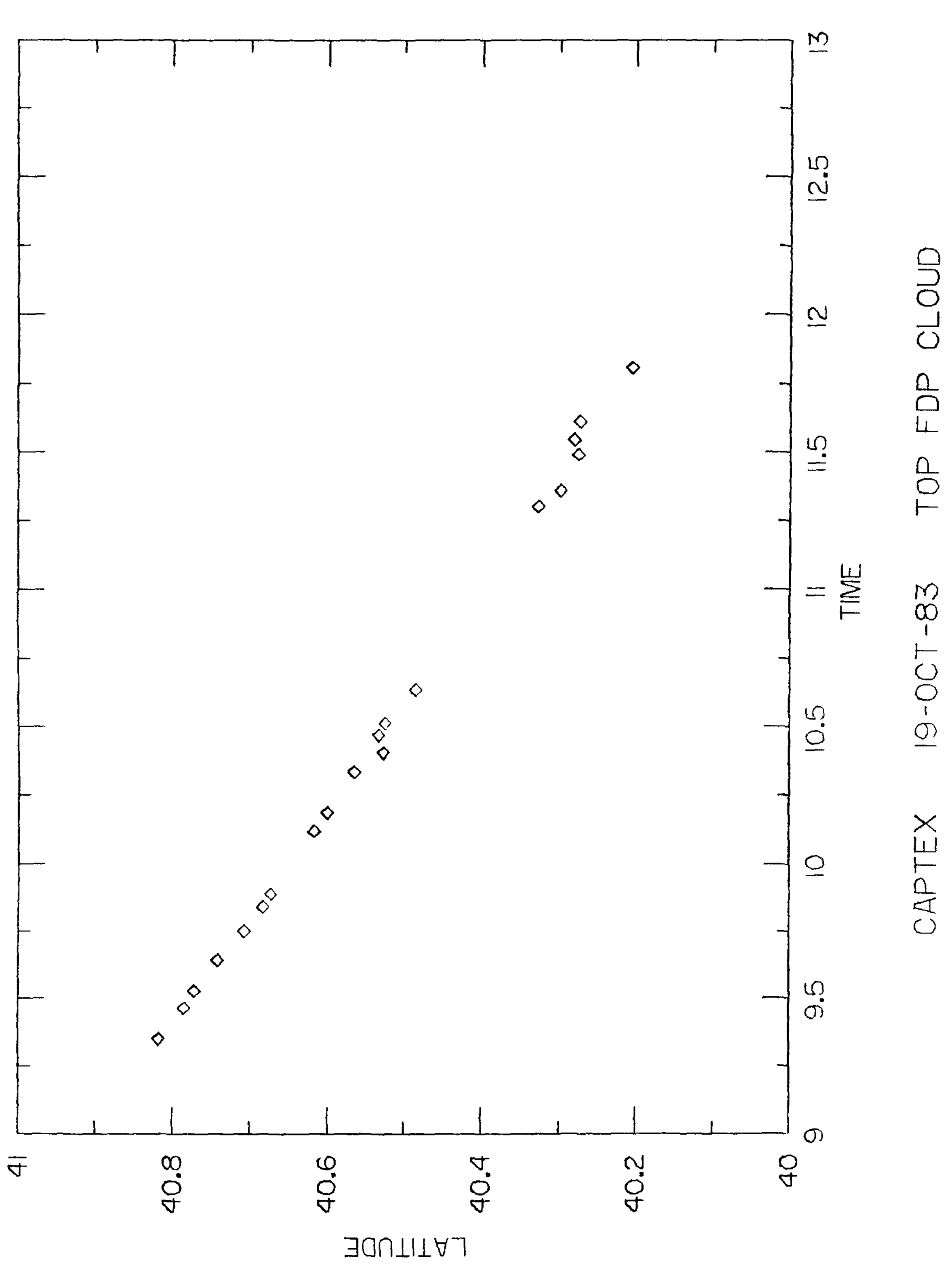
Observation Time	Observation Lat-Long		Distance (Km)	Altitude (meters)	Delta-t (hours)	--RNAV-- Dist.	Theta
9:20: 0	40.828N	81.917W	0.556	2064.	0.083	2.04	343.70
9:20:57	40.818N	81.923W	1.760	2112.	0.099	2.41	6.90
9:27:52	40.785N	81.947W	5.938	2088.	0.214	7.04	24.30
9:31:42	40.772N	81.953W	7.520	2136.	0.278	8.52	25.00
9:38:33	40.742N	81.973W	11.255	2172.	0.392	12.05	31.70
9:45: 2	40.707N	81.997W	15.615	2088.	0.501	17.05	25.70
9:50:25	40.683N	82.020W	18.817	2088.	0.590	20.01	30.50
9:53:26	40.673N	82.023W	19.936	2040.	0.641	21.13	29.00
10: 7: 8	40.617N	82.072W	27.415	1872.	0.869	28.91	32.90
10:11:10	40.600N	82.090W	29.787	1824.	0.936	30.95	32.60
10:20: 2	40.565N	82.132W	34.929	1884.	1.084	35.58	35.10
10:24:13	40.527N	82.150W	39.391	1800.	1.154	40.40	34.20
10:28: 6	40.533N	82.157W	39.040	1824.	1.218	39.47	36.20
10:30:41	40.525N	82.157W	39.836	1812.	1.261	40.59	34.50
10:38: 0	40.485N	82.200W	45.545	1752.	1.383	46.70	36.60
11:18: 4	40.327N	82.397W	69.495	1812.	2.051	70.42	39.70
11:21:29	40.298N	82.433W	73.883	1738.	2.108	74.87	40.60
11:29:21	40.275N	82.467W	77.661	1812.	2.239	78.39	41.40
11:32:33	40.280N	82.460W	76.675	1824.	2.293	77.65	41.20
11:36:37	40.273N	82.468W	77.895	1848.	2.360	78.58	41.30
11:48:20	40.205N	82.553W	88.343	1740.	2.556	88.95	42.20

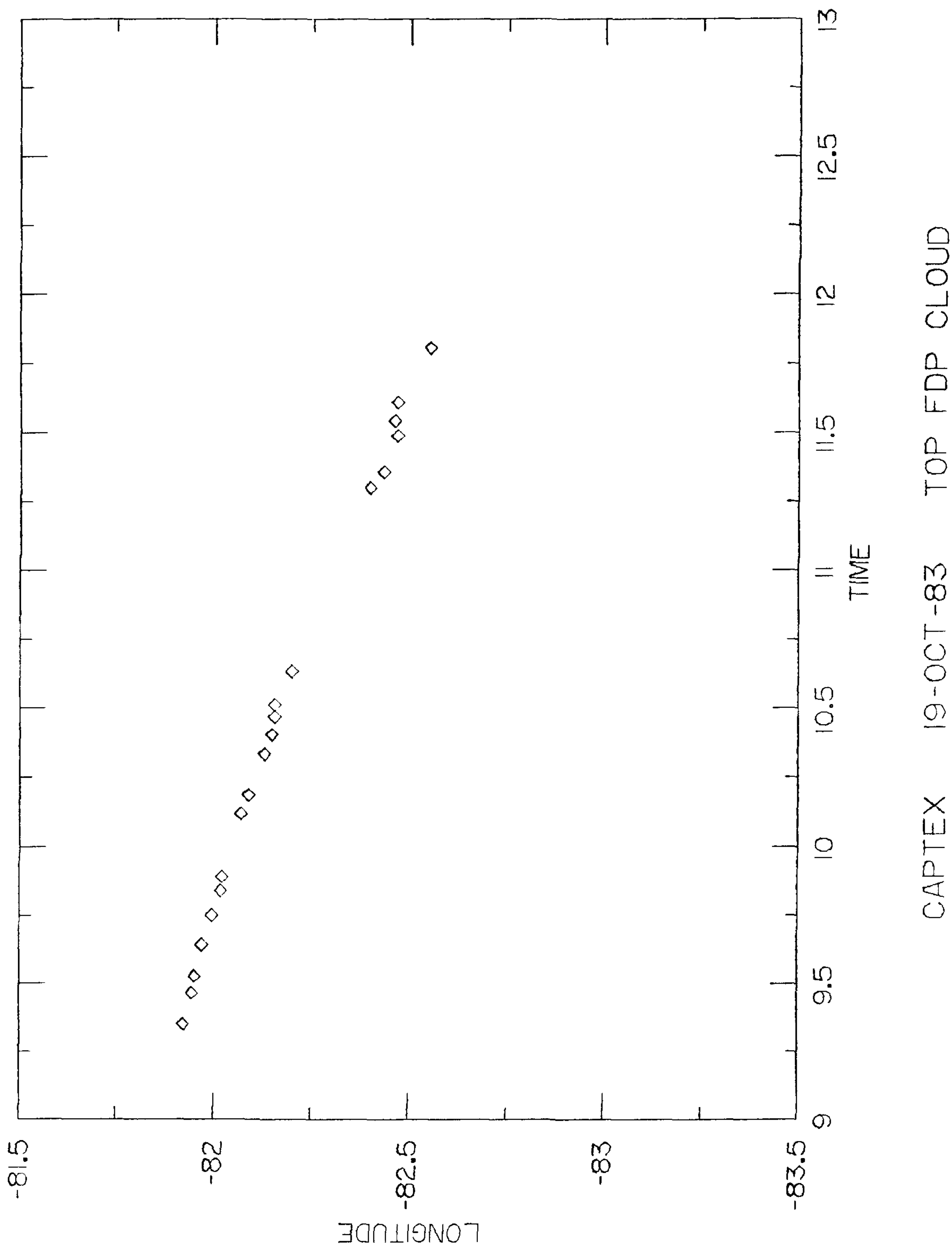


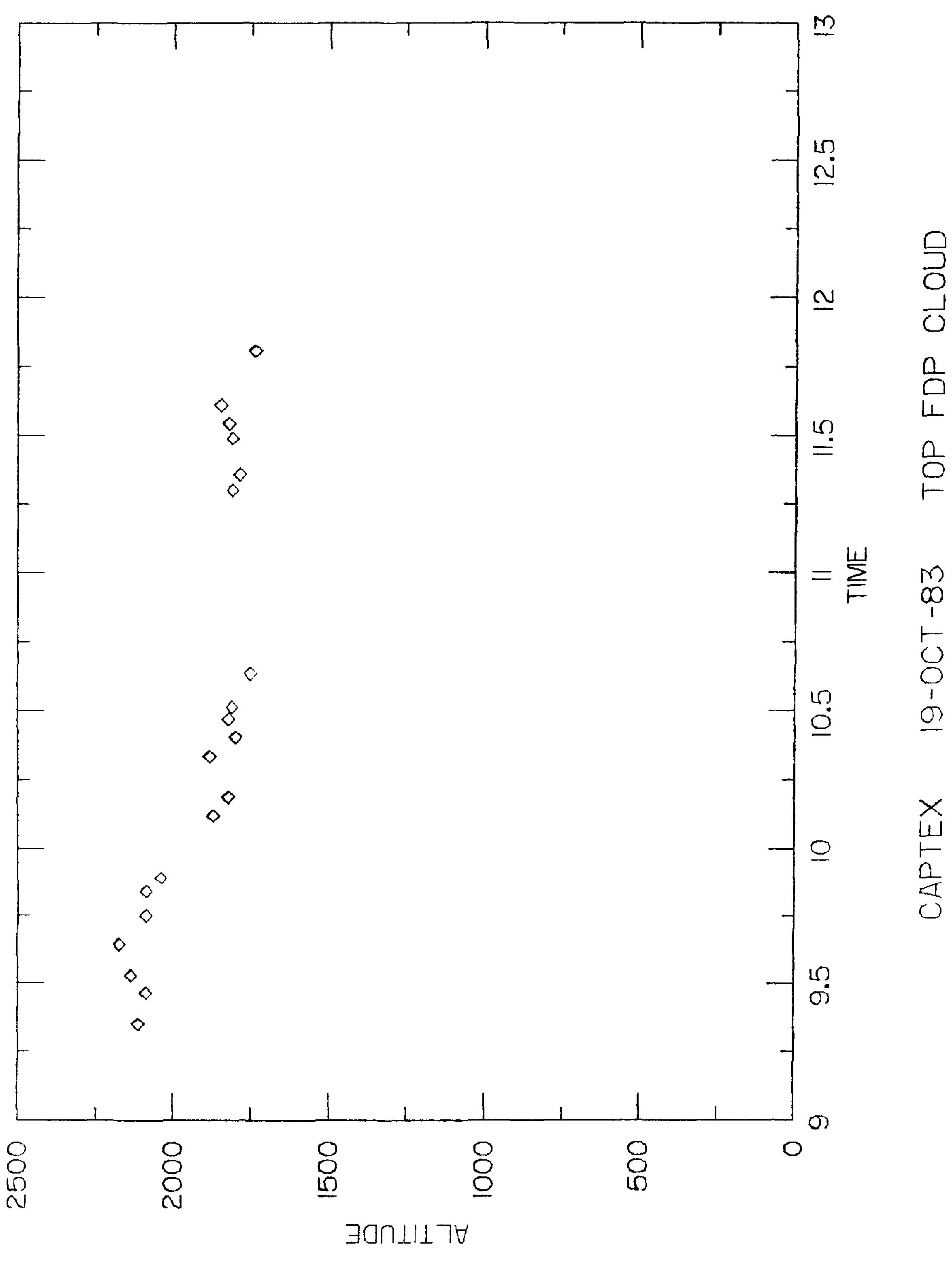
DOWN WIND DISTANCE KM
0
20
40
60
80
100
120
140
9
9.5
10
10.5
11
11.5
12
12.5
13
TIME TOP FDP CLOUD
CAPTEX 19-OCT-83

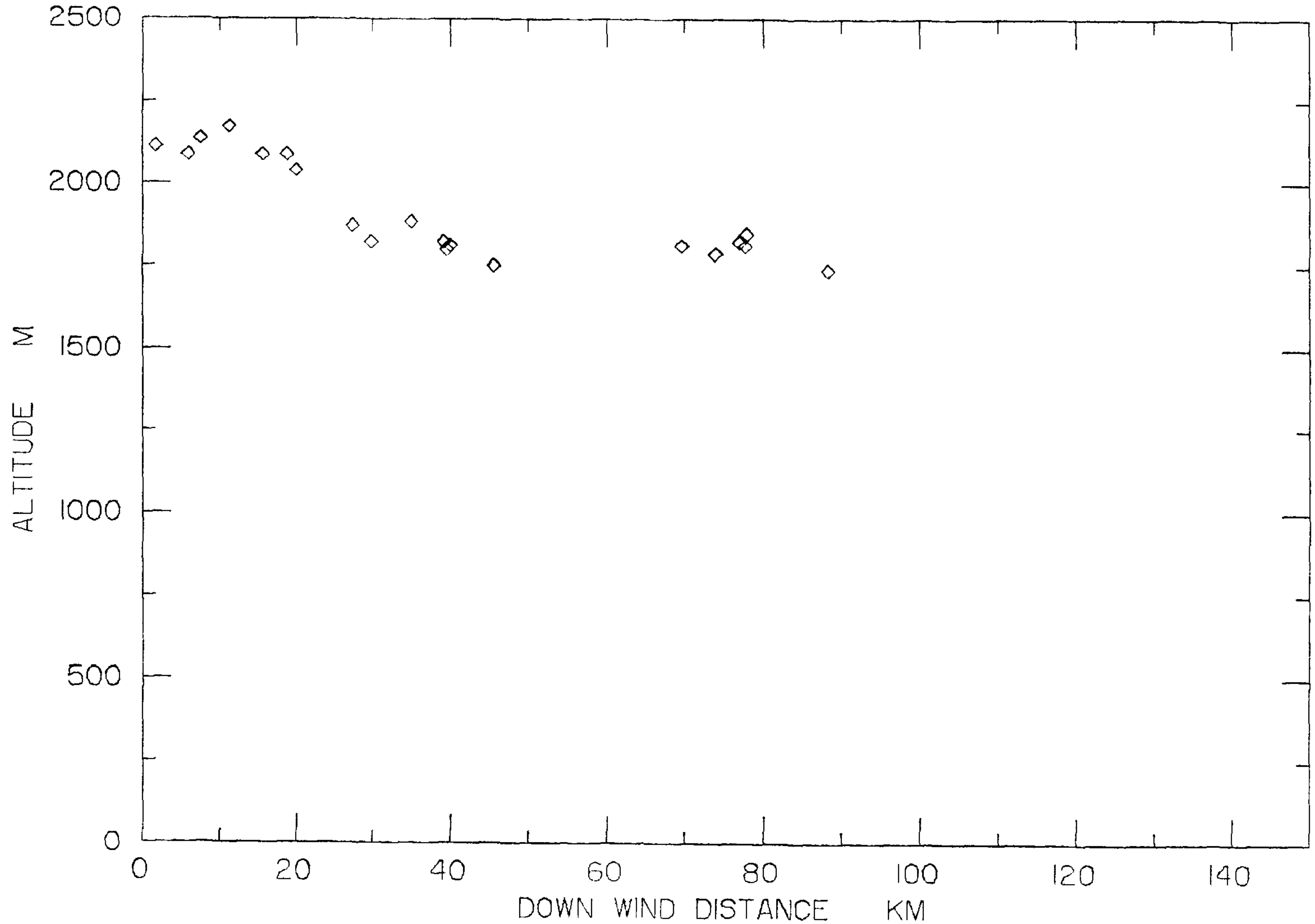


CAPTEX 19-OCT-83


CAPTEX 19-OCT-83 TOP FDP CLOUD
TIME
LATITUDE
9
9.5
10
10.5
11
11.5
12
12.5
13
40
40.2
40.4
40.6
40.8
41


CAPTEX 19-OCT-83 TOP FDP CLOUD
TIME
LONGITUDE
9
9.5
10
10.5
11
11.5
12
12.5
13
-81.5
-82
-82.5
-83
-83.5


CAPTEX 19-OCT-83 TOP FDP CLOUD
ALTITUDE
TIME
0
500
1000
1500
2000
2500
9
9.5
10
10.5
11
11.5
12
12.5
13

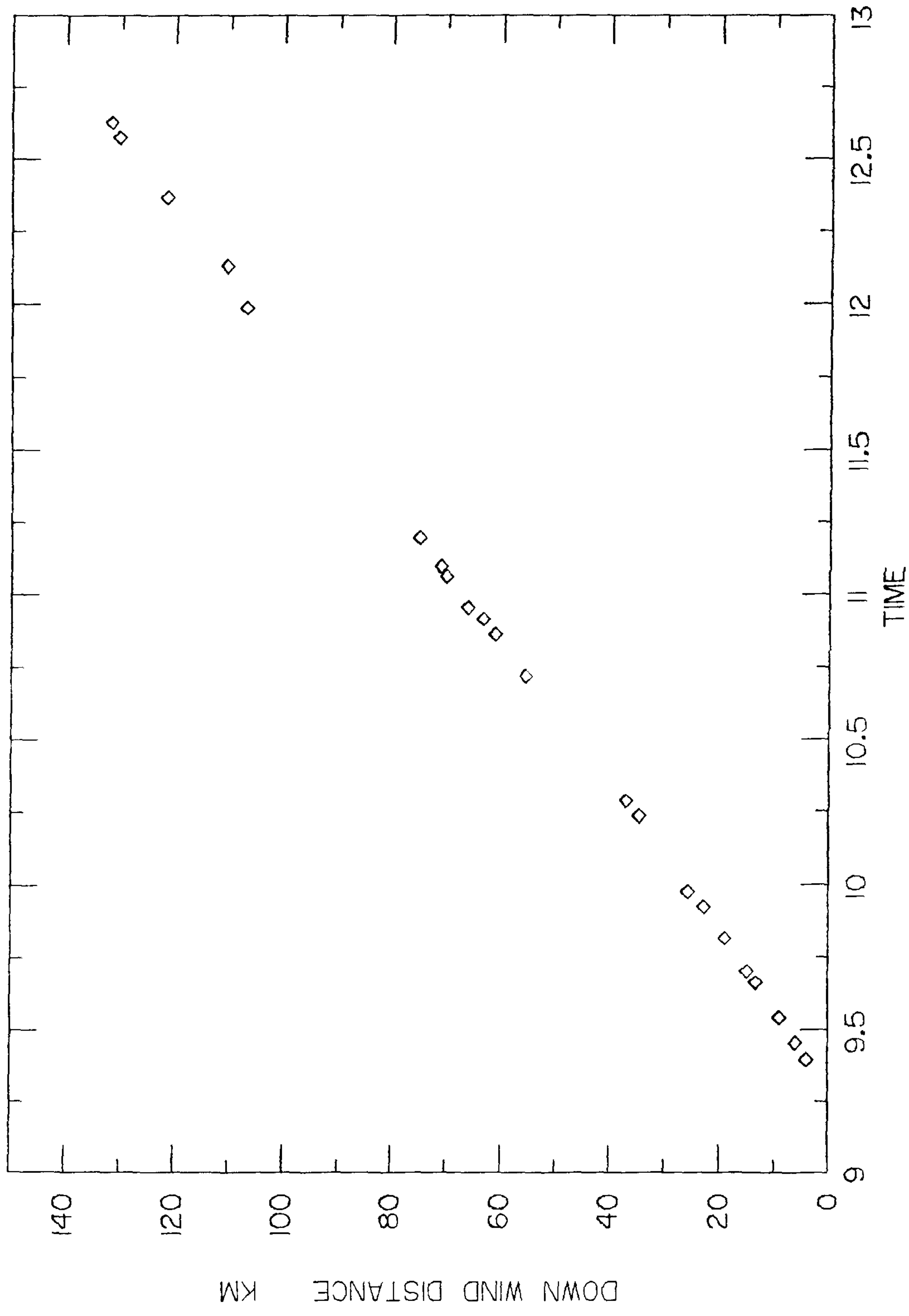


CAPTEX 19-OCT-83 TOP FDP CLOUD

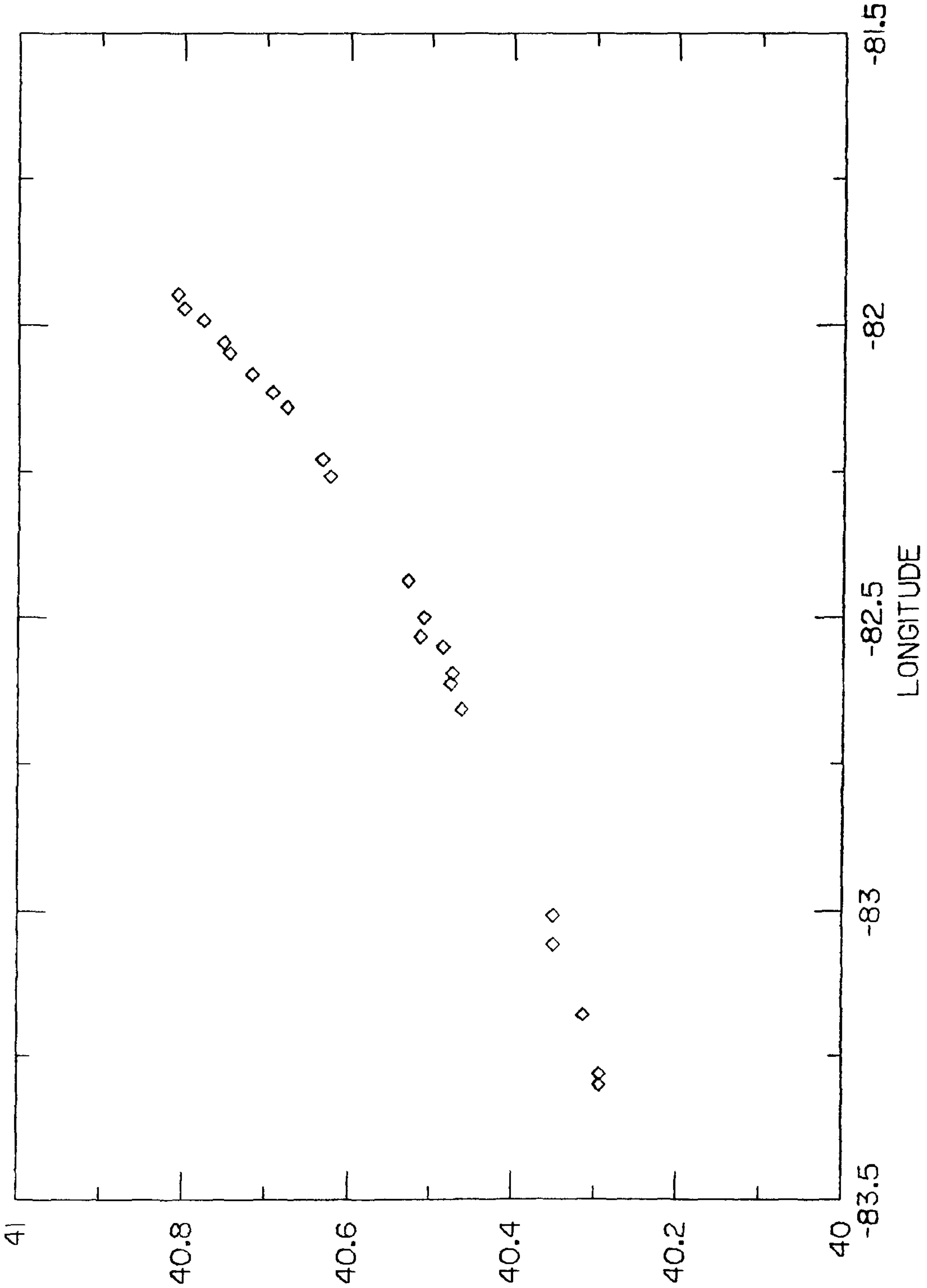
- - - - - R E L E A S E - - - - -

Date	Time	Position
10-19-83	9:15: 0	40.833N 81.917W

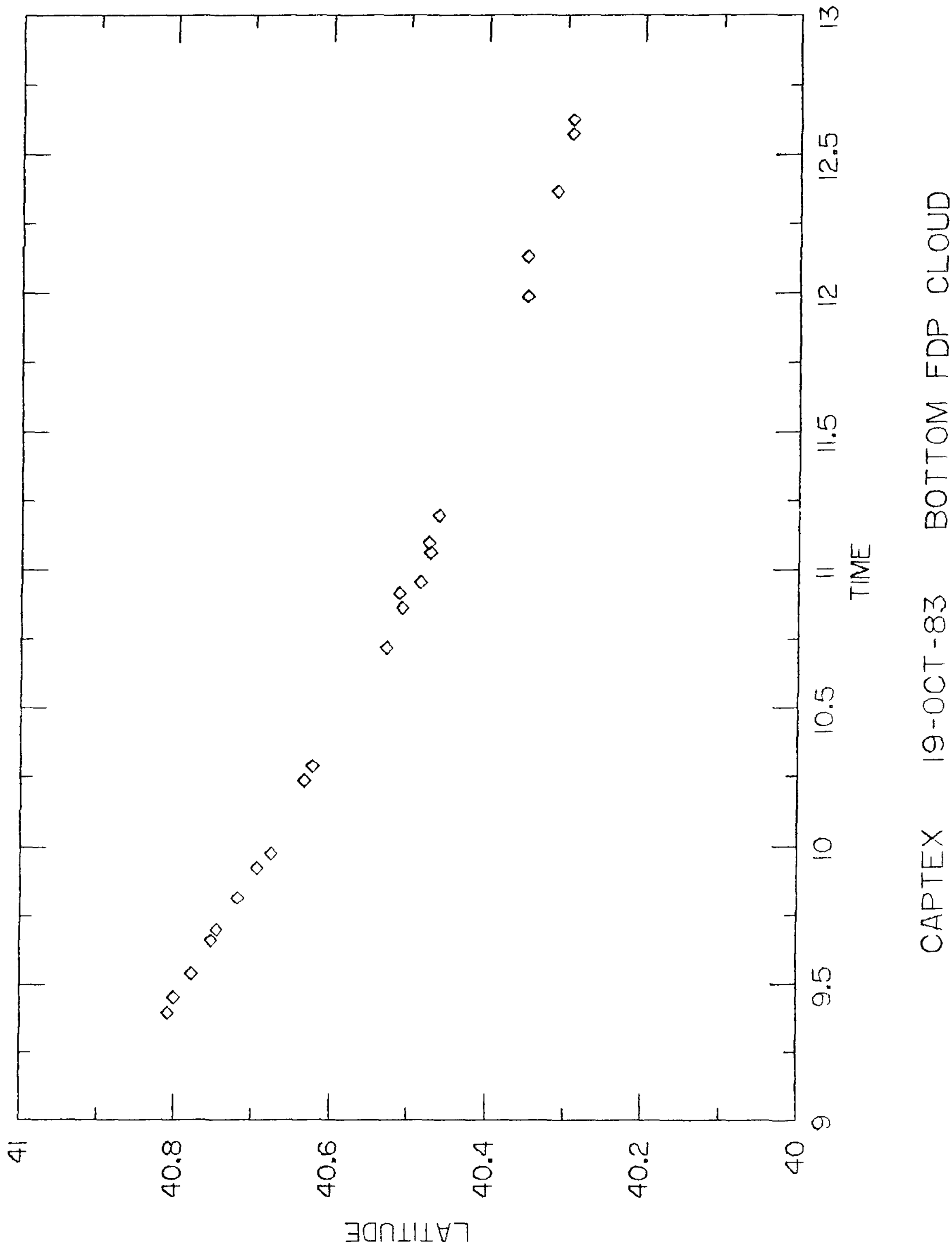
Observation Time	Observation Lat-Long		Distance (km)	Altitude (meters)	Delta-t (hours)	--RNAV-- Dist.	Theta
9:21:12	40.820N	81.935W	2.140	1464.	0.103	2.78	30.30
9:23:46	40.808N	81.948W	3.851	1500.	0.146	5.00	28.40
9:27:18	40.800N	81.972W	5.930	1524.	0.205	7.04	48.70
9:32:33	40.777N	81.992W	8.921	1548.	0.292	10.01	46.70
9:39:44	40.752N	82.030W	13.175	1452.	0.412	14.08	49.30
9:42: 5	40.745N	82.048W	14.816	1428.	0.451	15.57	49.00
9:48:54	40.718N	82.083W	18.995	1440.	0.565	19.64	52.00
9:55:29	40.693N	82.115W	22.846	1404.	0.675	23.72	50.40
9:58:35	40.675N	82.140W	25.781	1452.	0.726	27.24	49.60
10:14:12	40.633N	82.230W	34.549	1428.	0.987	35.40	53.70
10:17:15	40.623N	82.258W	37.104	1428.	1.038	38.36	55.40
10:43: 4	40.528N	82.437W	55.512	1332.	1.468	56.52	56.40
10:51:45	40.508N	82.500W	61.139	1368.	1.613	62.27	57.90
10:54:56	40.512N	82.533W	63.221	1320.	1.666	64.49	60.30
10:57:16	40.485N	82.550W	66.099	1380.	1.704	66.90	57.50
11: 3:41	40.473N	82.595W	69.961	1344.	1.811	70.79	59.30
11: 5:47	40.475N	82.612W	71.016	1344.	1.846	71.72	60.70
11:11:42	40.462N	82.657W	75.015	1356.	1.945	75.98	61.30
11:59:15	40.350N	83.008W	106.987	1368.	2.737	107.86	63.80
12: 7:54	40.350N	83.057W	110.547	1296.	2.882	111.19	65.10
12:21:58	40.313N	83.178W	121.599	1344.	3.116	122.31	65.90
12:34:22	40.293N	83.282W	130.413	1308.	3.323	130.28	67.60
12:37:30	40.293N	83.300W	131.795	1296.	3.375	132.50	67.30

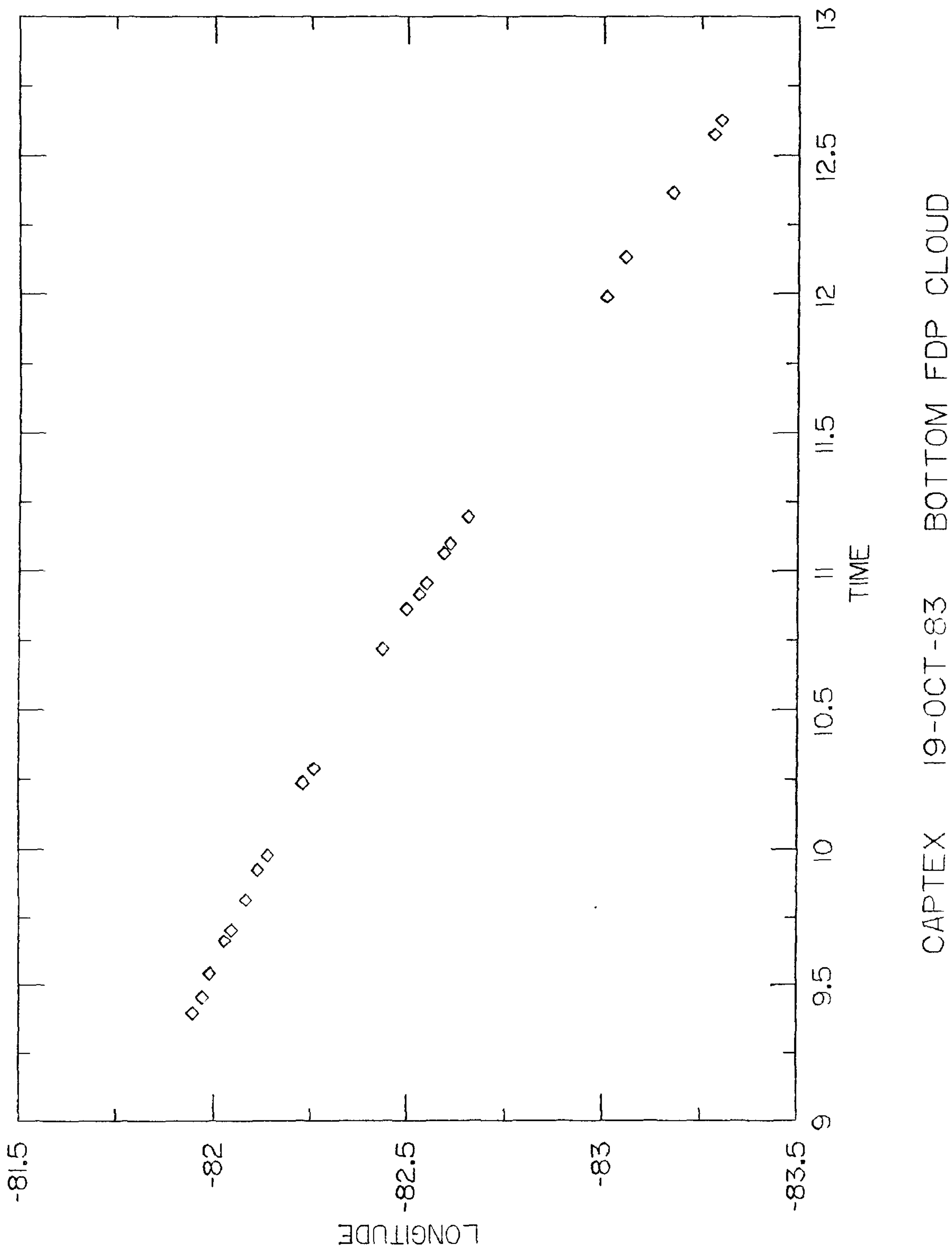


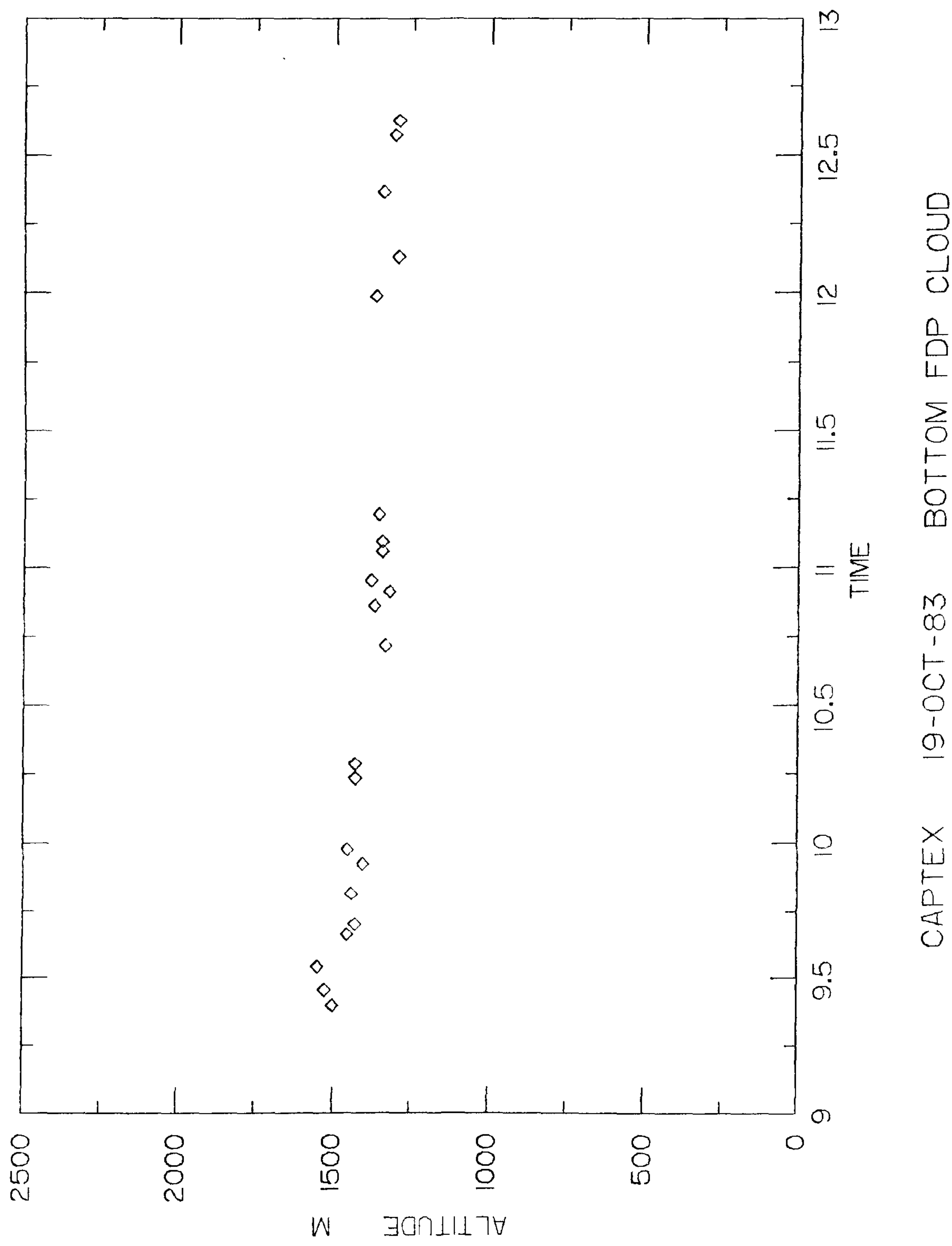
CAPTEX 19-OCT-83 BOTTOM FDP CLOUD

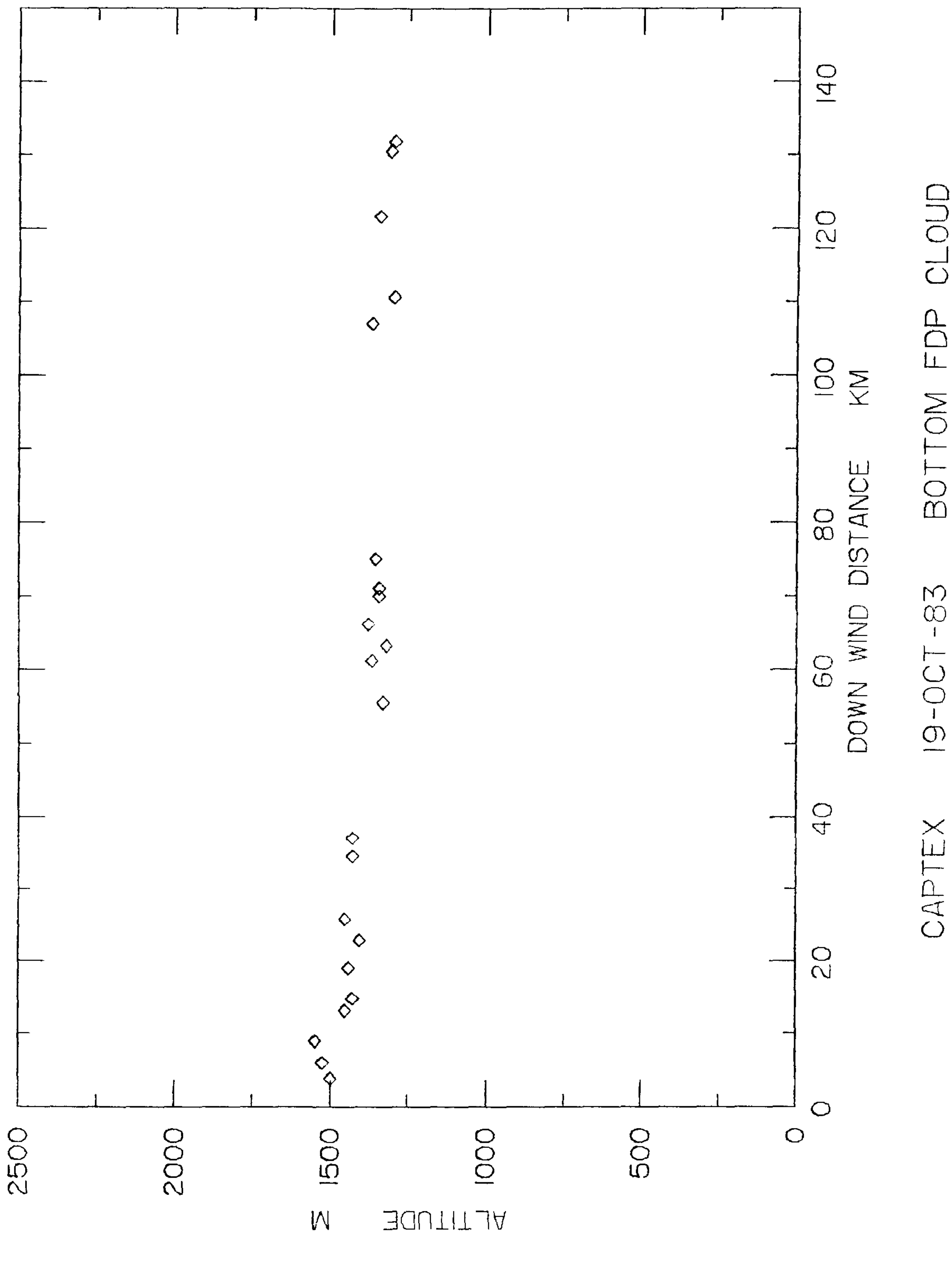


CAPTEX 19-OCT-83 BOTTOM FDP CLOUD


CAPTEX 19-OCT-83 BOTTOM FDP CLOUD
TIME
9
9.5
10
10.5
11
11.5
12
12.5
13
LATITUDE
40
40.2
40.4
40.6
40.8
41


CAPTEX 19-OCT-83 BOTTOM FDP CLOUD
TIME
LONGITUDE
9
9.5
10
10.5
11
11.5
12
12.5
13
-81.5
-82
-82.5
-83
-83.5


CAPTEX 19-OCT-83 BOTTOM FDP CLOUD
TIME
ALTITUDE M
9
9.5
10
10.5
11
11.5
12
12.5
13
0
500
1000
1500
2000
2500

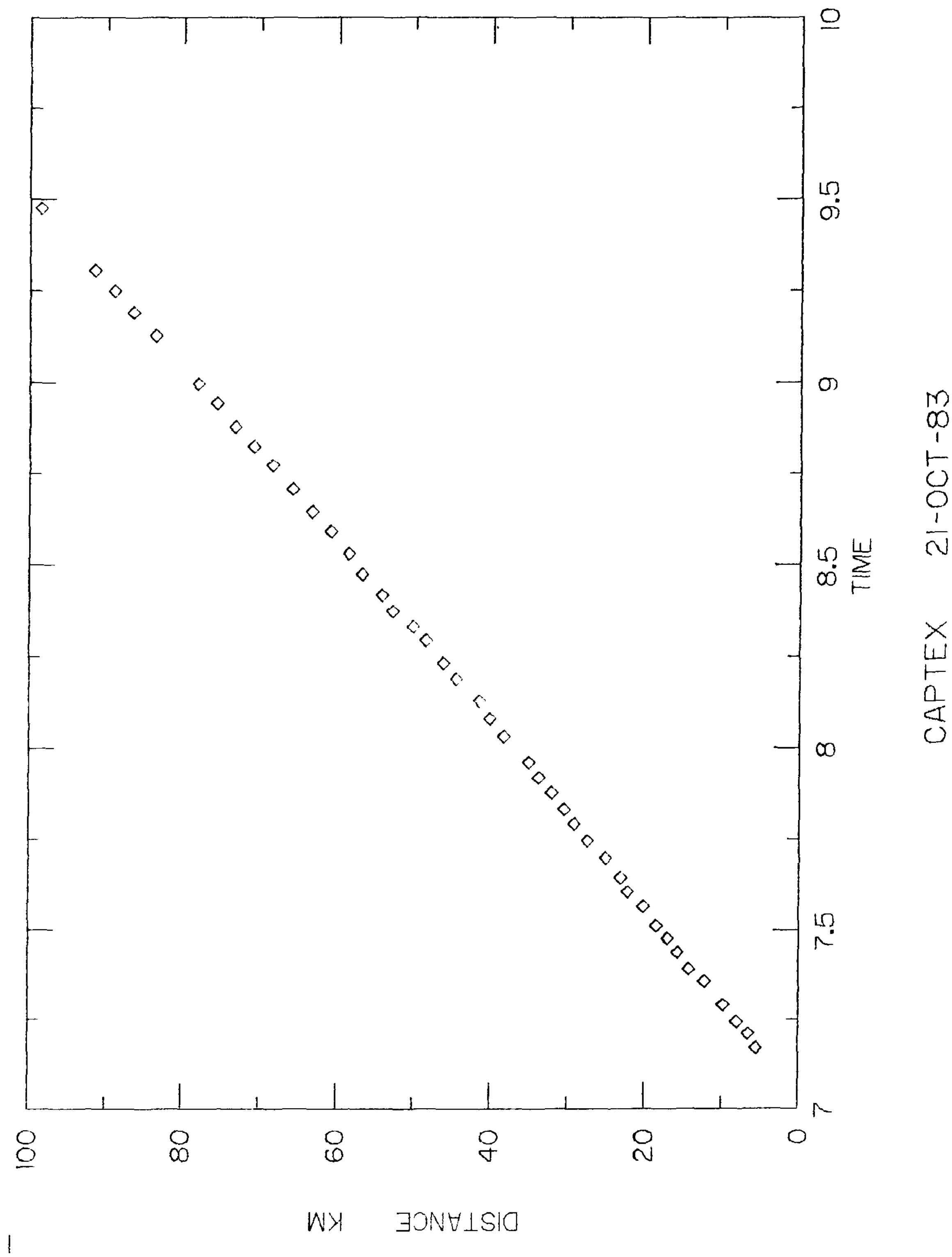

CAPTEX 19-OCT-83 BOTTOM FDP CLOUD
DOWN WIND DISTANCE KM
ALTITUDE M
0
20
40
60
80
100
120
140
0
500
1000
1500
2000
2500

Case V: 21 October 1983, 0708-0929 EDT

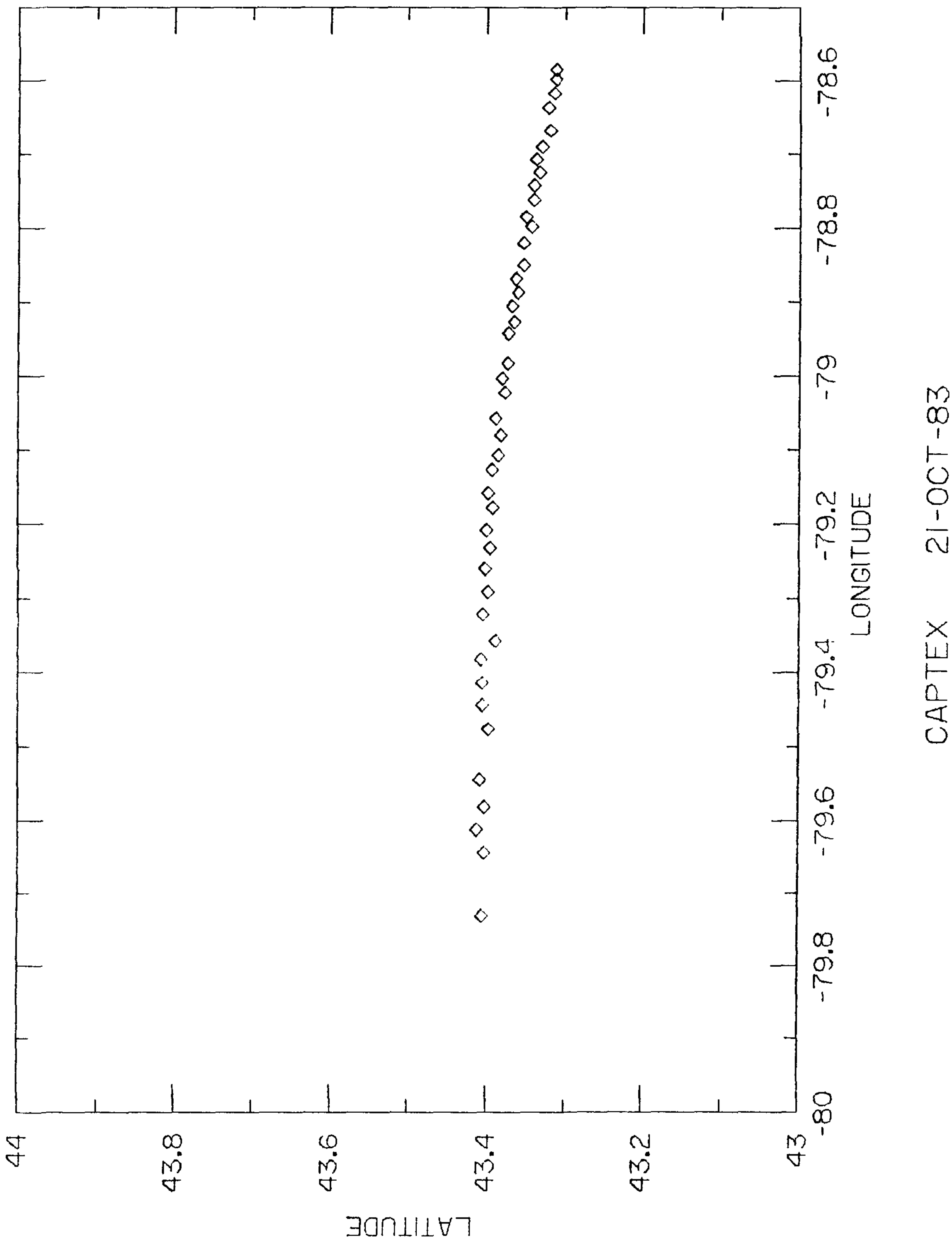
- - - - - R E L E A S E - - - - -

Date	Time	Position
10-21-83	7: 0: 0	43.298N 78.520W

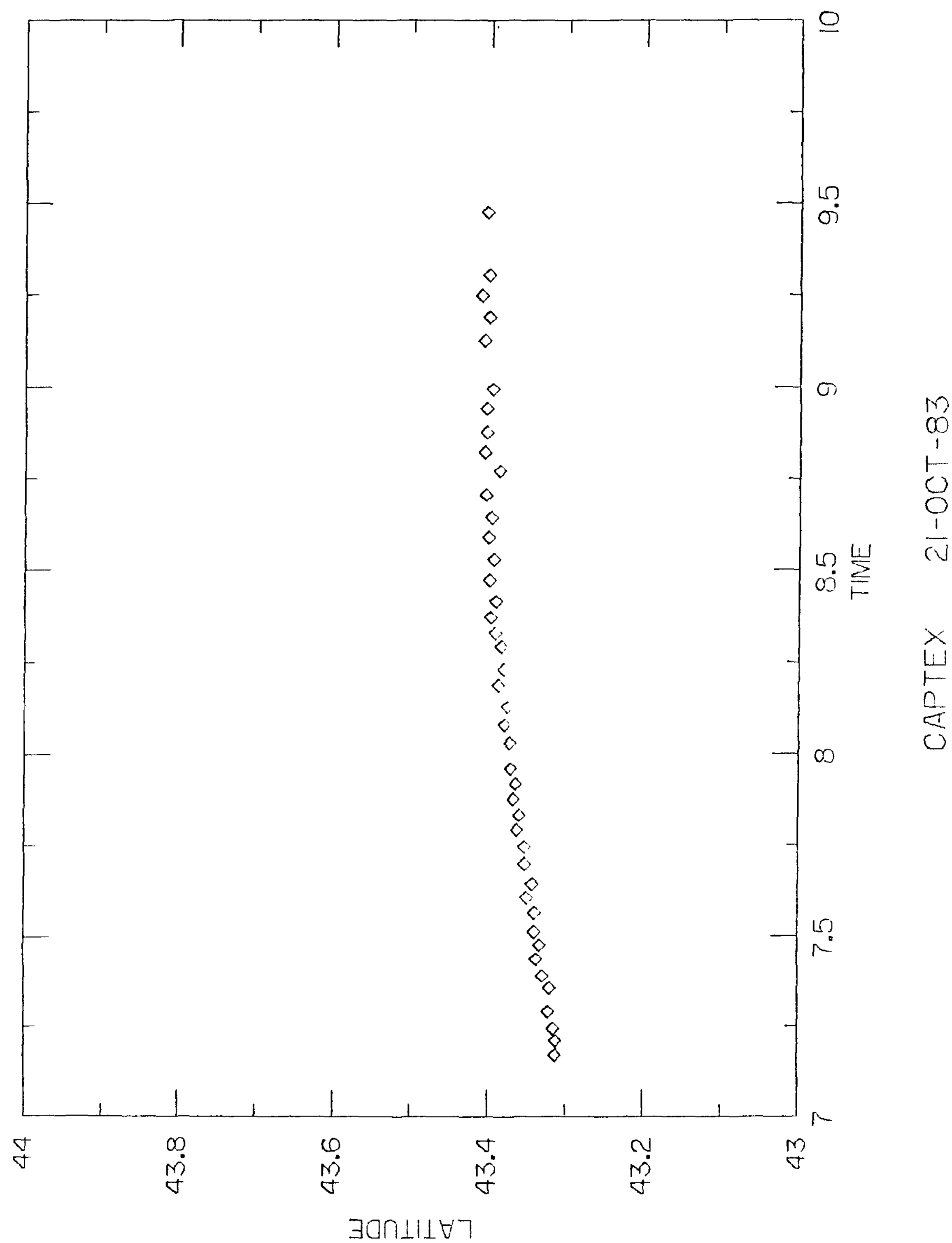
Observation Time	Observation Lat-Long		Distance (Km)	Altitude (meters)	Delta-t (hours)	--RNAV-- Dist.	Theta
7: 8: 9	43.303N	78.563W	3.550	372.	0.136	4.63	100.70
7:10:11	43.312N	78.585W	5.464	360.	0.170	8.15	108.80
7:12:36	43.312N	78.598W	6.509	360.	0.210	7.78	106.90
7:14:38	43.315N	78.617W	8.038	348.	0.244	10.19	103.30
7:17:25	43.322N	78.637W	9.786	372.	0.290	12.23	109.40
7:21:23	43.320N	78.668W	12.240	384.	0.356	11.86	108.20
7:23:23	43.330N	78.690W	14.194	384.	0.390	16.68	108.10
7:26: 9	43.337N	78.707W	15.687	372.	0.436	17.05	111.00
7:28:32	43.333N	78.725W	17.031	372.	0.476	18.72	106.20
7:30:46	43.340N	78.742W	18.516	360.	0.513	21.68	109.60
7:33:55	43.340N	78.762W	20.085	372.	0.565	22.61	106.40
7:36:18	43.350N	78.785W	22.184	372.	0.605	26.50	108.00
7:38:33	43.343N	78.798W	23.057	384.	0.642	24.28	107.40
7:41:50	43.353N	78.820W	25.015	408.	0.697	25.94	110.50
7:44:40	43.353N	78.850W	27.373	396.	0.744	28.35	109.00
7:47:27	43.363N	78.868W	29.072	408.	0.791	31.50	110.20
7:49:50	43.360N	78.887W	30.426	372.	0.831	30.95	109.50
7:52:31	43.368N	78.905W	32.079	384.	0.875	35.03	108.50
7:55: 3	43.365N	78.927W	33.699	396.	0.918	34.65	109.90
7:57:33	43.372N	78.942W	35.045	384.	0.959	37.81	108.70
8: 1:48	43.373N	78.982W	38.235	372.	1.030	39.47	109.20
8: 4:44	43.380N	79.003W	40.104	336.	1.079	42.44	108.30
8: 7:36	43.377N	79.022W	41.471	360.	1.127	42.81	105.90
8:11: 9	43.388N	79.057W	44.505	372.	1.186	46.70	108.80
8:13:47	43.382N	79.080W	46.196	336.	1.230	47.63	108.90
8:17:31	43.385N	79.107W	48.378	300.	1.292	49.48	108.90
8:19:45	43.393N	79.127W	50.143	348.	1.329	51.15	109.20
8:22:19	43.398N	79.158W	52.758	348.	1.372	54.48	108.60
8:24:55	43.392N	79.178W	54.198	312.	1.415	58.19	105.40
8:28:23	43.400N	79.206W	56.749	348.	1.473	58.19	108.80
8:31:45	43.395N	79.232W	58.497	336.	1.529	60.04	107.70
8:35:25	43.402N	79.260W	60.878	336.	1.590	62.22	107.70
8:38:38	43.398N	79.292W	63.329	312.	1.644	64.49	108.40
8:42:22	43.405N	79.322W	65.839	348.	1.706	67.46	107.60
8:46:18	43.388N	79.358W	68.477	312.	1.772	69.68	106.40
8:49:22	43.407N	79.383W	70.774	348.	1.823	73.94	105.50
8:52:35	43.405N	79.415W	73.268	348.	1.876	75.61	106.30
8:56:31	43.405N	79.445W	75.660	312.	1.942	78.39	105.20
8:59:44	43.397N	79.477W	78.064	336.	1.996	79.32	106.60
9: 7:37	43.408N	79.545W	83.697	372.	2.127	85.60	105.60
9:11:25	43.402N	79.582W	86.536	408.	2.190	88.95	104.80
9:14:56	43.412N	79.612W	89.075	456.	2.249	91.36	105.50
9:18:16	43.402N	79.645W	91.610	444.	2.304	93.77	104.50
9:28:31	43.405N	79.732W	98.599	504.	2.475	99.52	105.80



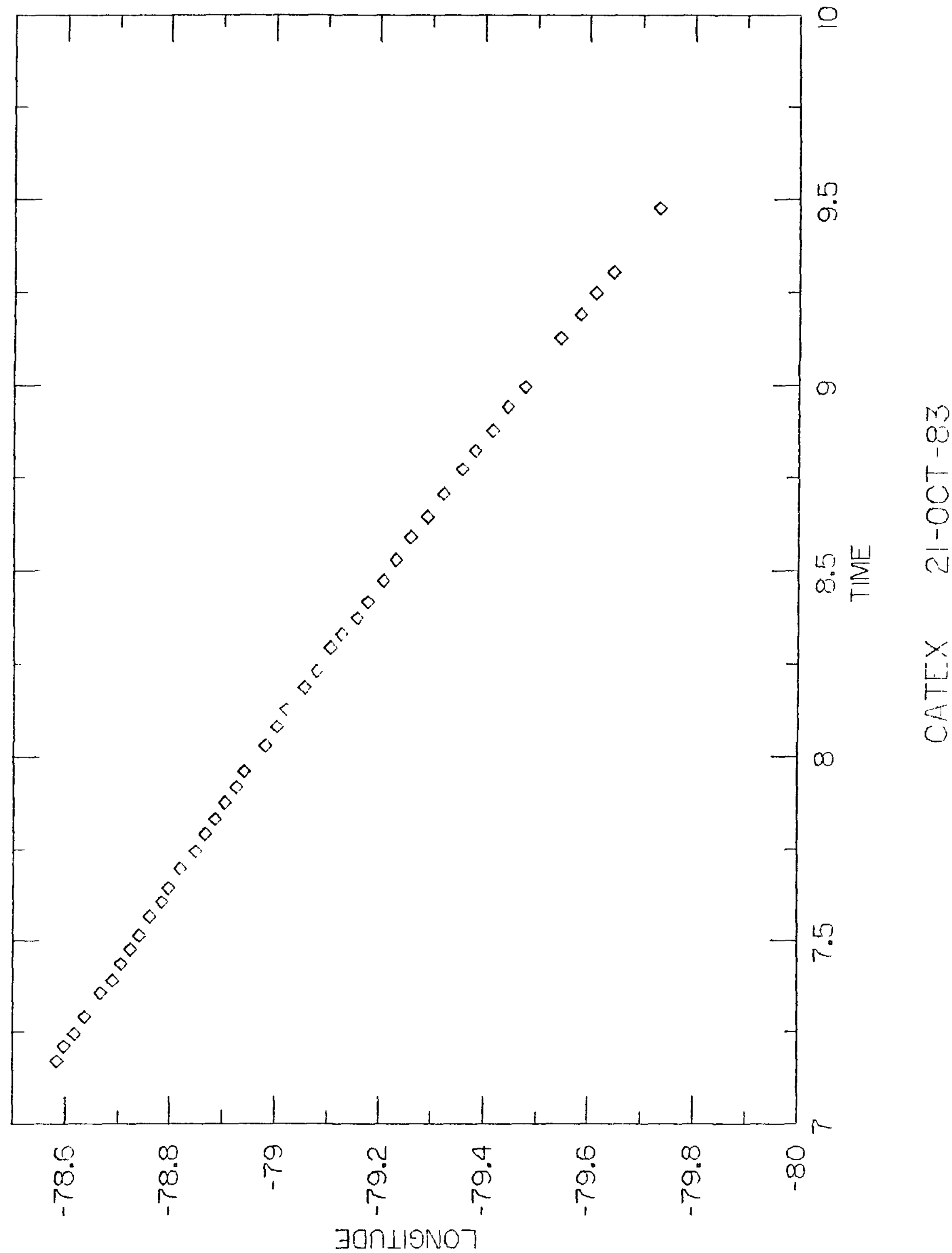
DISTANCE KM
100
80
60
40
20
0
7
7.5
8
8.5
9
9.5
10
TIME
CAPTEX 21-OCT-83

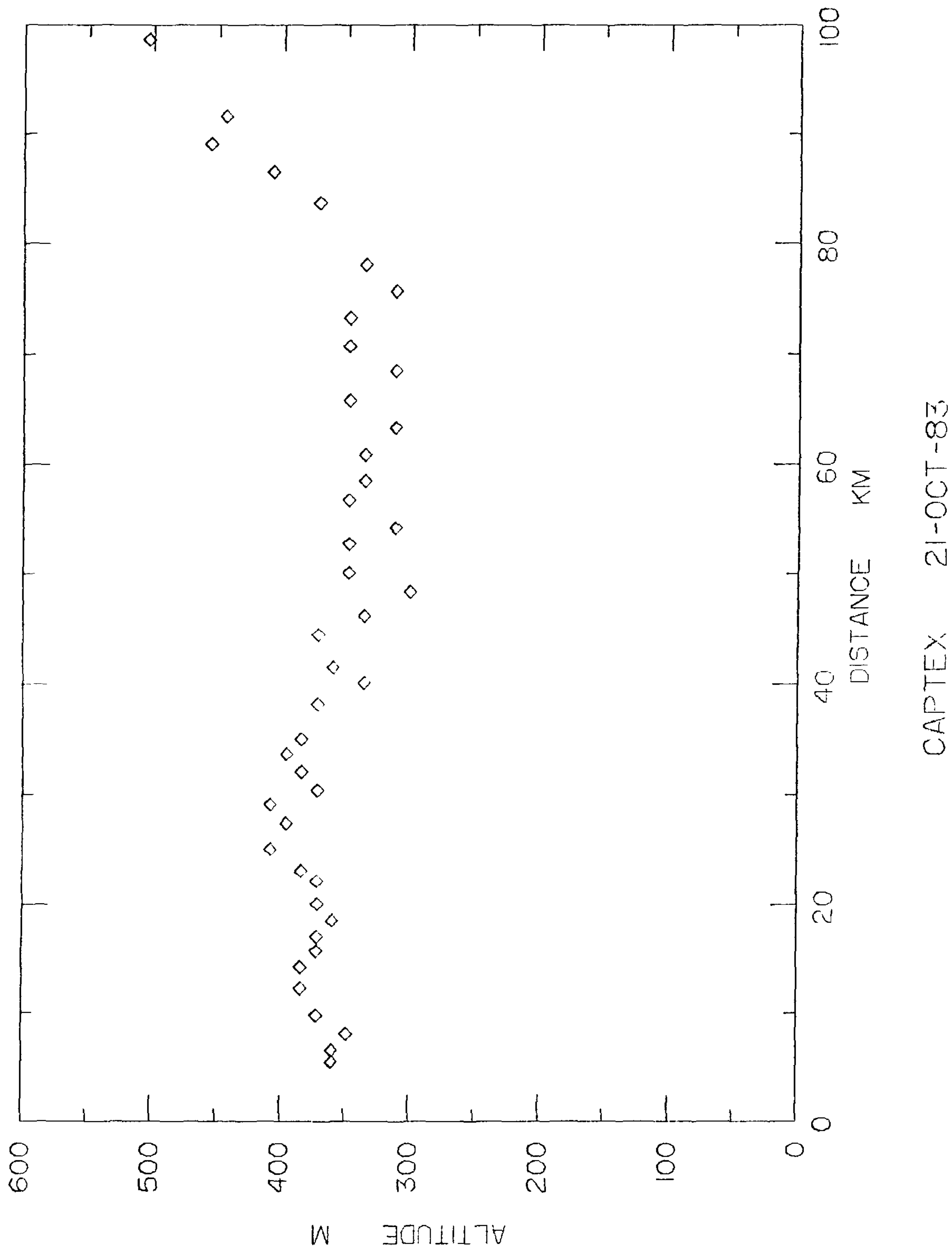


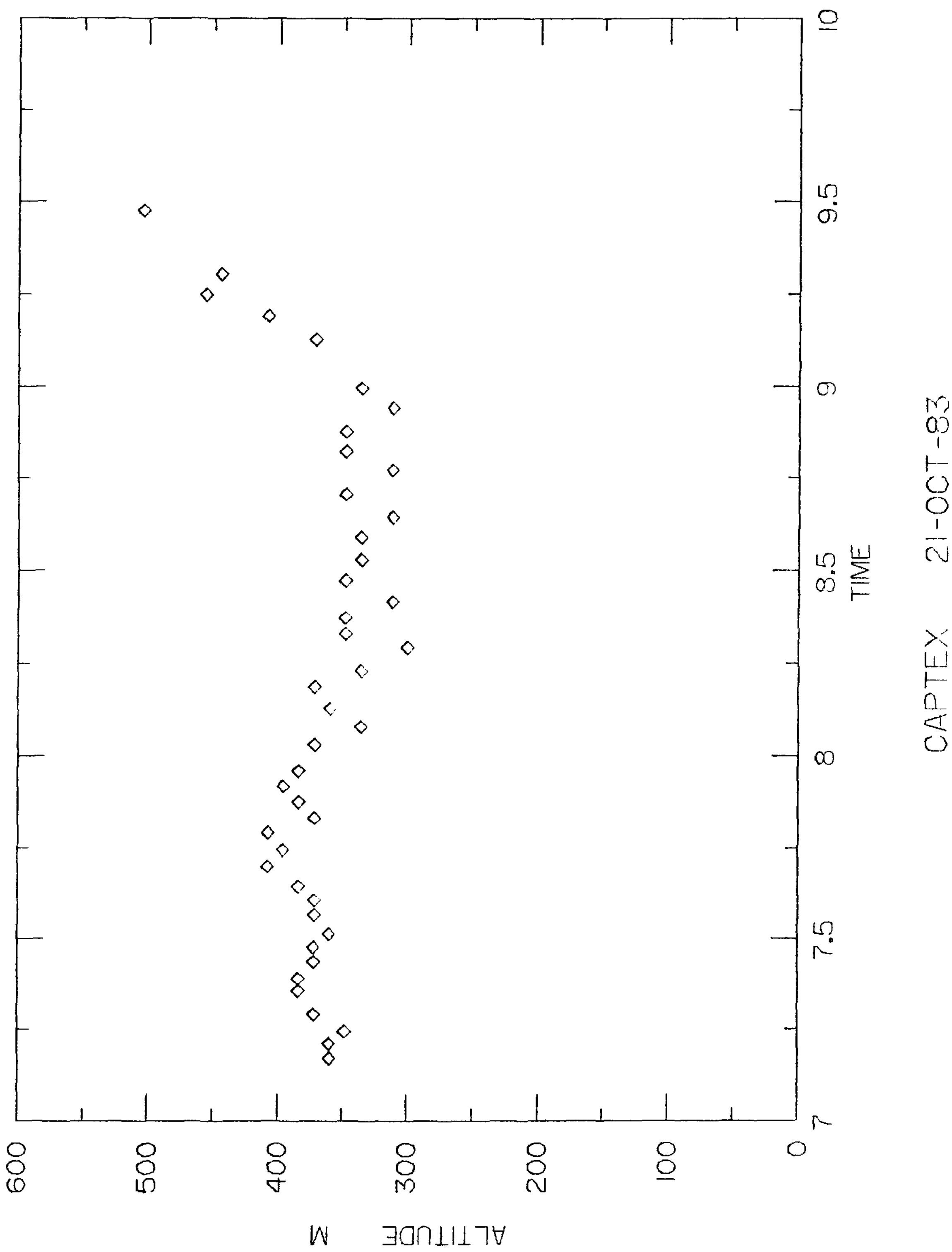
LATITUDE
44
43.8
43.6
43.4
43.2
43
LONGITUDE
-80
-79.8
-79.6
-79.4
-79.2
-79
-78.8
-78.6
CAPTEX 21-OCT-83



LATITUDE
44
43.8
43.6
43.4
43.2
43
TIME
7
7.5
8
8.5
9
9.5
10
CAPTEX 21-OCT-83


LONGITUDE
-78.6
-78.8
-79
-79.2
-79.4
-79.6
-79.8
-80
TIME
7
7.5
8
8.5
9
9.5
10
CATEX 21-OCT-83


ALTITUDE M
0
100
200
300
400
500
600
DISTANCE KM
0
20
40
60
80
100
CAPTEX 21-OCT-83



ALTITUDE M
TIME
0
100
200
300
400
500
600
7
7.5
8
8.5
9
9.5
10
CAPTEX 21-OCT-83

TETROON POSITION DATA, 14 OCTOBER 1983

DAYTON RELEASE AT 1200, 1330, 1500 EDT

Transponder 24
October 14, 1983

TIME	LAT	LON	MBAR	ALTITUDE (MSL) METERS	FEET
1600	395289*	833628	769.0	2149	7050
1838	394907	811961	768.0	2154	7068
1955	394790	801658	769.0	2149	7050
2140	392368	783782	811.0	1785	5854
0043	384815	763745	0.0	0	0

* 39^{o} 52.89'