MEASUREMENTS OF THE VORTEX WAKE CHARACTERISTICS OF THE BOEING 747, LOCKHEED C5A, AND OTHER AIRCRAFT (PERIOD FEBRUARY 18-21, 1970)

C. R. Dickson
G. E. Start
Air Resources Laboratory
Environmental Sciences Services Administration
Idaho Falls, Idaho

Data Report
Project No. 177-621-03X
Contract No. DOT FA70NA-AP-73

Test and Evaluation Division
Aircraft Branch

April 1970

79 pp.

DATA REPORT

Project No. 177-621-03X

(SPECIAL TASK)

MEASUREMENTS OF THE VORTEX WAKE CHARACTERISTICS OF THE BOEING 747, LOCKHEED C5A, AND OTHER AIRCRAFT (PERIOD FEBRUARY 18-21, 1970)

TEST AND EVALUATION DIVISION

Aircraft Branch

APRIL 1970

DATA REPORT

PROJECT NO. 177-621-03X
(SPECIAL TASK)

MEASUREMENTS OF THE VORTEX WAKE CHARACTERISTICS OF THE BOEING 747, LOCKHEED C-5A, AND OTHER AIRCRAFT
(PERIOD FEBRUARY 18 - 21, 1970)

Test and Evaluation Division
Aircraft Branch
April 1970

NOTICE

As noted by the title, this is a Data Report. It is advised that a data report is a report which transmits data only to keep the requestor informed of pertinent results on a timely basis. Caution must be exercised in the utilization of the data enclosed herein due to the vulnerability of unanalyzed data being submitted and various premature judgements and/or actions being taken based thereon.

It is also advised that the data film coverage, 16 mm colored motion pictures acquired on each aircraft tower fly-by in support of this project, is an integral part of the overall data acquired and can be as significant as the time-history vortex velocity data enclosed herein. Unfortunately, due to the sheer volume of data motion picture coverage attained and associated cost of insertion in a report, the data film coverage is not included. It will be collocated in the NAFEC Photographic Laboratory on an identical test time basis with the time-history vortex velocity data and the two sets of data analyzed. The results of this analysis will form the basis of a final formal report.

Objective

A high priority program was initiated by the Director, Flight Standards Service, FS-1, on February 11, 1970, to investigate as soon as possible the vortex wake turbulence characteristics of the Boeing 747, Lockheed C-5A aircraft, and other jet transport-type aircraft. The program was divided into three phases, all of which were conducted concurrently, and into three geographical areas.

The first phase involved the Western Region, WE, the National Aeronautics and Space Administration, NASA, Flight Research Center, Edwards, California, and the U.S. Air Force, Edwards Flight Test Center, California. These flight tests were conducted in the Edwards area. Primarily, the tests performed by the above group were inflight penetrations of the vortices of the Lockheed C-5A airplane by an instrumented Convair 990 airplane at Edwards and participation with the latter aircraft in the second phase of the program.

The second phase was conducted by the Boeing Company in the Seattle, Washington, area. In these tests, the above mentioned Convair 990, a Boeing 737, and a North American F86 aircraft penetrated the vortex systems of the Boeing 747 and 707-300 series aircraft.

The objective of the third phase of this Wake Turbulence Program, and which phase is covered in this data report, was for the National Aviation Facilities Experimental Center (NAFEC) to conduct flight tests in the Southeastern Idaho area to gather quantitative data on the vortex wake turbulence characteristics of large, medium and small jet transport aircraft by low altitude tower fly-by techniques. These aircraft were the Boeing 747, 707-320C, and 727-100, the Douglas DC-8-63F, DC-8-33, and DC-9-10, the Lockheed C-5A and the Learjet 24.

Discussion

Test Site: The flight test site used for this effort was provided by the Atomic Energy Commission (AEC) and the Environmental Science Services Administration (ESSA) Air Resources Laboratory Field Research Office (ARLFRO) which is located at and is a tenant activity of the AEC Nuclear Reactor Test Station (NRTS) at Idaho Falls, Idaho. A general layout of the AEC NRTS is shown in Figure 1-1. The site is approximately 5000 feet above sea level. It is a very flat and level area, extending approximately 10 miles in all directions from the tower used for these tests, thereby minimizing possible distortion of the trailing aircraft vortex flow by strong vertical motions of air due to adverse terrain features. In addition, these flat terrain features reduce pilot workload with regard to obstruction avoidance, minimize the ground-air collision risk factor associated with very low altitude flight paths, and permit the pilot to devote the majority of his attention to maintaining aircraft course, speed, and altitude, particularly on the final leg which passes abreast of the test tower.

Test Instrumentation and Tower: The tower used for the tests was the ESSA 200-foot Grid III Research Tower. This tower is located approximately 1 mile northeast of the TRA Facility on the National Reactor Testing Station and is about 46 miles west of Idaho Falls as shown in Figure 1-1. Two faces of the tower parallel a line along 235° and 055° true and two faces parallel 145° and 325° true, Figure 2-3. The tower is 200 feet high with its base at 4915 feet above sea level (Figures 2-1a and 2-1c) and located 1.5 miles from the nearest nuclear reactor facility. The tower is a rectangular upright scaffold of a kind especially designed for meteorological research and presents extremely low blockage to air currents from any direction and, accordingly, causes very little interference with airflow measurement as can be seen in Figure 2-1b.

The tower was instrumented by ESSA and NAFEC personnel in 3 days with hot-wire and hot-film anemometers to measure vortex airflow velocity and direction and with colored smoke dispensers, the smoke of which would become entrained in the passing vortex system thus producing a visual indication of its movement and structure as shown in Figure 2-6. Airflow sensor and smoke grenade installation levels are shown in Figure 2-1c.

Test Instrumentation: The meteorological instruments mounted on the tower and used during the tests were divided into two groups. Group one consisted of high frequency hot wire and film anemometers which were used to measure the vortex velocities (Figures 2-2a, 2-2b, and 2-2d). Group two consisted of standard meteorological instruments used for measuring the low frequency atmospheric components such as horizontal and vertical wind direction, wind velocity, air temperature and humidity (Figure 2-2c). Meteorological sensors were mounted at the tower corners as shown in Figure 2-3. The four tower corners can conveniently be called North, East, South, and West corners. All hot wire probes were mounted at the north corner. Aspirated and shielded thermocouples were located at the west corner. Bivanes and cup anemometers were on 12-foot booms projecting southeastward from the south corner (smoke grenades were mounted on the southeast tower face). The height locations of meteorological sensors are listed in Table 2-1. Detailed descriptions of the individual hot wire orientations are provided in Appendix B, Figures 2-7 through 2-12.

Hot-Wire/Hot-Film Anemometers: The high frequency hot-wire or film anemometers used in this series of tests were of three kinds differing in the number of sensoring elements used, sensor design and manufacturer. The sources of the anemometers were Thermo-Systems, Inc.[1]

---

[1] A product of Thermo-Systems, Inc., St. Paul, Minnesota.

(TSI), Flow Corporation[2] (ESSA), and Biggs' System[3] (BGS). The former system used a hot film sensor whereas the latter two used hot wires. Basically, all of these systems utilize the "constant resistance" mode of operation (Hinze, 1959)[4] in which the current is a measure of the cooling effect of the wind. The TSI and ESSA systems output voltages, or currents since currents are proportional to volts, are in the range of 4 to 14 volts. The BGS system output is in the -0.5 to 1.0 volt range.

Hot Wire Arrays: Since the cooling that a hot wire experiences is a measure of the component of the wind velocity that is normal to the wire, arrays of hot wires can be used to determine the magnitude of the total velocity vector $|V|$ and its components at a point in space. An orthogonal array of three hot wires allows the determination of $|V|$ and the magnitudes of the velocity components u, v, and w with linear equations in the squares of the components. The TSI system and, for some of the tests, the ESSA and BGS systems were aligned with respect to an orthogonal coordinate system.

In order to determine the signs of the individual components, a nonorthogonal array has to be used. Theoretically, four wires can be arrayed to determine component magnitudes and signs within an octant and five wires can be used to resolve component magnitudes and signs within a hemisphere. However, the use of nonorthogonal arrays entails the simultaneous solution of nonlinear equations by iteration.

Hot Wire Geometry During Tests: The anemometers were installed in 25-foot increments starting at the 50-foot level and continuing to the 200-foot level, (Figure 2-1c). The TSI hot film probes contain three orthogonally situated wires on each probe arm (Figure 2-2a), therefore, the wires were oriented such that one paralleled the expected aircraft flight path (145 - 325°T) and one was perpendicular to the ground. This wire orientation permits the direct determination of the vortex tangential velocity component from the wire oriented nearly parallel to the actual aircraft flight path (126°T). The difference in bearing of 19° between the wire orientation and the aircraft heading will produce only slight ($<5\%$) errors. The other two wires can be used as indicators of the vortex radial and axial velocity components. A diagram showing this hot wire geometry and the equations for each wire velocity and for $|V|$ are shown in Figure 2-7. The convention for velocity components in the equations is u in the alongwind direction, v in the horizontal crosswind direction and w in the vertical crosswind direction. Since the probe orientation was fixed in space throughout the entire test series, the velocity components are only approximations to the conventional ones. The orthogonal TSI sets were located at the 100-, 125- and 175-foot levels of the tower during the tests.

---

[2] System developed by Flow Corporation for the Air Resources Laboratory Field Research Office, Environmental Science Services Administration at Idaho Falls, Idaho.

[3] System specially developed by Dr. W. Gale Biggs, Iowa State University, Ames, Iowa, for airflow research.

[4] Hinze, J.A., 1959, Turbulence, McGraw-Hill, New York, pp. 75-121.

ESSA hot wire arrays were located at the 150- and 200-foot levels of the tower. Each array consisted of three probe arms, two with two orthogonal wires and one with a single wire (Figure 2-2d). This arrangement permitted several possible arrays. On February 18, a nonorthogonal, five-wire array was used in an effort to determine signed components within the hemisphere (semi-cylinder). Solution of the set of nonlinear simultaneous equations was not found to be feasible within the time limitation imposed on this project. On the other test days, skewed orthogonal arrays were used. The hot wire geometry and orientation for each test day along with the equations for each wire velocity are shown in Figures 2-8, 2-9, and 2-10. The wire velocities selected for plotting on each day are also shown in the figures. The plotted wire values were selected because the major portion of the velocity seen by a wire is due to the cylindrical coordinate component (V_{TAN}, V_{RAD}, V_{AXIAL}) of the vortex but cannot necessarily be interpreted as a measure of the component.

The BGS hot wire arrays were located at the 50- and 75-foot levels of the tower and consisted of two sets of two orthogonally oriented wires at each level (Figure 2-2b). On February 18, the four wires at each level were arranged in a nonorthogonal array (Figure 2-11). On the other test days, the arrays were orthogonal, with one redundant wire, and oriented in the same directions as the TSI systems (Figure 2-12). The same comments on wire orientation with respect to the aircraft vortex that were made for the TSI and ESSA systems apply to the BGS system.

<u>Calibration and Zero Checks:</u> All high frequency anemometers including their associated cables and electronics were calibrated prior to and after completion of the flight tests. Calibration was accomplished by use of a laminar flow, low velocity wind tunnel at ESSA test site (Figure 2-4). Sufficient test points were taken to define the calibration curves on all sensors. The wind tunnel velocity was varied from near 4 to 34 fps in five steps, carefully checking the zero value before and after the calibration. These calibration points were then fitted by the method of least squares to the relationship (King's law)

$$C^{1/2} = A' + B'E^2$$

for each wire. The fitted values of A' and B' were then used to compute velocities from voltages recorded during the tests. For the TSI and ESSA systems, the output voltages E were used directly. For the BGS system, the output voltages were converted by use of the formula $E = 4(E' + 1.5)$ because E' is a biased and attenuated voltage.

Checks of the voltage setting for zero velocity were made before and after each aircraft series of fly-bys. Generally, the drift of the voltage setting was very small.

Atmospheric Measurement: Meteorological supporting measurements of the ambient atmosphere were made by ESSA personnel using sensors positioned mostly on the 200-foot Grid III research tower.

Slow Response Instrumentation and Recording:

Sensors - Wind and temperature sensors were located at the 50-, 100- and 200-foot levels of the tower. Beckman and Whitley K 100A cup anemometers were used to measure wind speed. NRTS annular finned bivanes were used to measure horizontal and vertical wind direction, Figure 2-2c. Temperature was measured by copper-constantan thermocouples in Climet aspirator shields with a 150°C Pace reference junction.

Data Acquisition - A Hewlett-Packard 2012B Digital System recorded the atmospheric data digitally on magnetic tape. Each sensor output was sampled sequentially every 1.1 seconds during the entire duration of an aircraft series. The cup anemometer outputs were also recorded on mechanical counters.

Data Reduction - The mean and standard deviation of wind speed, horizontal wind direction and vertical wind direction were computed for each aircraft series with an IBM 360-75 computer. In addition, 15-second averages of each of these parameters were computed for a 3-minute period following each T_0 for aircraft passes. The counter outputs were converted to wind speeds through use of calibration curves of wind speed versus count rate.

The general mean meteorological conditions of wind speed and direction, temperature, pressure, and relative humidity are listed in nine tables, Tables 2-2 to 2-10, one table for each aircraft fly-by series. The standard deviation of wind speed, horizontal wind direction, and temperature are included as an indication of their changeability during the aircraft test series.

The following meteorological data are unavailable for these reasons. TSI hot-film wire #4 and Biggs hot-wire #5 were broken before beginning flight testing. ESSA annular fin bivane data are missing for February 18 (747 and C-5A #1) due to electrical cable shorting. ESSA hot-wire #6 was broken and inoperative all day of February 18. TSI hot-film wire #9 and ESSA hot wires #1 and #9 were out for the first few passes of the 747 due to open electrical circuits between the hot wires and the hot wire electronics units. Biggs hot-wire #8 data were missing because its electronic circuit was inadvertently put in calibration mode.

On February 19 (707 morning and DC8-63F afternoon), all TSI probes were covered for calibration until early in the second 707 aircraft pass. All Biggs hot wire data are affected by an analog tape recorder malfunction. The Biggs data were distorted by a gradual development of a slowdown in the tape drive speed (since voltage is being recorded as a FM frequency shift from a known reference). Data runs #1 through #5 should be used cautiously and data runs #6 through #12 are omitted. For the afternoon of February 19, all systems were operative except TSI hot-film wire #4 and Biggs hot-wire #3 which were broken. For February 20 and 21, all systems were operative except TSI hot-film wire #4 and Biggs hot wires #1 and #2, all of which were broken and not able to be repaired before the end of the test program.

In addition to the high and low frequency meteorological sensors on the tower, smoke grenades, dispensing four different colors of smoke, were installed at eight different tower levels (Figure 2-1c). All levels were fired simultaneously by electrical means. There were sufficient smoke grenades installed to allow 12 separate aircraft passes per flight test period. Burn time was approximately 60 seconds for the green smoke grenades and 90 seconds for the red, yellow, and violet ones. The smoke was used for visual observation of the vortex penetration into and past the tower (Figure 2-6).

Fast Response Instrumentation and Recording:

Data Recording and Reduction - Signals from all of the hot wire, hot film and thermocouple sensors installed on the tower were recorded on magnetic tape recorders that were located in an instrumentation trailer located near the base of the tower, Figures 2-5a and 2-5b, and operated by Special Instrumentation Group, Idaho Nuclear Corporation. The incoming signals from the anemometers were conditioned to a voltage level compatible to the magnetic tape recorder (Figures 2-5c and 2-5e). In order to record all of the signals from the TSI, ESSA, and BGS and thermocouples sensors, three 14 track analog magnetic tape recorders were utilized (Figure 2-5d). All tape recordings were in the frequency modulation (FM) mode so that all frequencies between 0 and 5000 Hz could be recorded. Maximum recorded frequencies were not limited by the tape recorder.

A marker channel was used on each tape to serve as a data recording reference related to each aircraft fly-by. To limit and identify the desired analog data strings, the marker channel voltage was switched between 0 and 10 volts to indicate the beginning and stopping points of hot wire data during a fly-by.

During the tests, a strip chart recorder was utilized for real time output in order to monitor the data (Figure 2-5f).

Digitization of Analog Tapes - The analog tapes were digitized at a rate of either 80/sec with 1/160 sec filtering or 10/sec with 1/20 sec filtering on a Minneapolis-Honeywell DDP-124 analog-to-digital converter and transferred to magnetic digital tape. The number of channels containing data varied with the number of inputs produced by the sensors at specific tower levels. The digital tape produced by each data set contains separate strings of data from each channel.

Digital Computer Processing Programs on IBM 360-75 Computer:

Channel Merge and Data Conversion - This program merges the data so that the data from each channel acquired at the same time are placed together on the tape. During this merging process, the data are converted from scaled units to voltages using scaling factors and from voltages to either velocities or temperatures. The procedure used to convert voltages to velocities was accomplished by using the A' and B' values obtained from the hot wire calibrations in the wind tunnel and solving the equation $C = (A' + B'E^2)^2$ to obtain the cooling velocity. Then the cooling velocity was converted to a wind velocity by applying the density and viscosity correction factors based on the mean temperature during each aircraft series of fly-bys. The thermocouple output voltages were converted to temperature units through use of the appropriate standard copper-constantan equation for the reference junction. A merged digital tape containing data in velocity and temperature units and the digitized contents of the marker channel is the output from this program.

Plot Program - This program provides the final display of airflow speed data contained in Appendix G of this report. The wire speeds most nearly representing the tangential velocity VTAN, the radial velocity VRAD and the axial velocity VAXL with respect to the aircraft vortex are plotted. Also, at the bottom of each plot, the computed magnitude of the total velocity vector $|V|$, when possible, is plotted. Each set of four-time series plots represents one level during one fly-by. The event marker appears as a vertical line at the appropriate time on the abscissa of the graph. Zero time denotes when the aircraft was abreast of the tower and, therefore, wing-tip vortex shedding time.

The speed values are plotted every 0.1 second. Eight values of data extracted at 80/sec were averaged to provide appropriate data for plotting at 0.1-second intervals.

Photography: This is considered a mandatory requirement for this aircraft vortex measurement technique. Photography combined with vortex flow visualization provides a means of determining if and when either or both wing vortex systems intercept the tower. In addition, it was the intent to attempt to determine the core diameter of vortex systems outlined by colored smoke.

Four camera positions were selected around the instrumented tower for motion picture data acquisition. Each was positioned approximately 600 feet northwest, southwest, southeast and northeast, magnetic, from the tower. The terrain dictated the camera position at each site thus making the positions approximate. Time did not permit each position to be determined accurately. A plan view schematic of camera positions is shown in Figure 6-1. Two of the cameras were positioned along the test aircraft's flight path facing the tower so as to try to obtain coverage of the tangential flow and core diameter. The third camera was positioned upwind of and facing perpendicular to the flight path so as to obtain coverage of the vortex axial flow.

Bell and Howell 16mm Motion Picture Cameras with 400-foot magazines and synchronous motors were used. Fifteen millimeter focal length lenses were selected. Twenty-four frames per second was used. Kodachrome II Film was selected to give the maximum color saturation of the four colors of smoke.

Three of the four sites, each side and the upwind position, were manned for all data collection runs. One hundred and fifteen V.A.C. commercial power was made available at the four sites. A time code generator providing 10 pulses per second was positioned near each camera. These timing blips were recorded on the film's edge for providing accurate frame rates. An event mark was initiated by a team member at a specified and recorded time following the ignition of the smoke grenades indicating a time "zero." This event mark was recorded on the tape systems, it interrupted the time base on each camera and on the later tests fired a flash bulb which was in the field of view of all cameras and thus recorded on film.

Test Techniques: The tower fly-by technique as shown in Figures 2 and 4 was used and basically consists of flying the test aircraft perpendicular to the ambient surface wind as measured at the 200-foot tower level at an appropriate distance vertically and upwind laterally from the tower under low ambient wind conditions so as to have the trailing aircraft vortex system drift laterally into the instrumented tower. By proper vertical and lateral positioning of the test aircraft, the "age" of the vortex system can be varied. By miscalculating the wind and/or mispositioning the airplane, one can easily have the vortex system float over the tower or settle prematurely into ground effect.

Concurrently, the vortex settling rate was also important to know beforehand and for the same reasons sited above. However, since classical theory on vortex settling rates may be suspect, particularly in close proximity to the ground, and because of possible atmospheric stability and buoyancy effects on the vortex system's vertical motion, a combination of theory, monitoring of vertical intercept of the tower with a vortex on previous fly-bys, and professional judgement was used.

In addition, marking of the rolled up wing vortex sheet helped immeasurably for the Boeing 747 and 707-320C aircraft tests. This marking was the result of injecting CORVUS-type oil into the exhaust systems of the outboard engines of these respective aircraft with a resultant dense, white smoke as noted in Figures 2 and 3 which became entrained in and adequately marked the rolled up vortex system, particularly its vertical and lateral movement. The C-5A engine exhaust smoke, Figure 4, aided somewhat that aircraft's vortex flow visualization.

Atmospheric Conditions: The early morning period immediately following sunrise was found to be most conducive to providing the type of flight conditions required for this type of flight testing; namely, low ambient, steady wind conditions of approximately 3 to 5 knots and a stable atmosphere with little, if any, thermal activity.

A knowledge of the vertical temperature profile above the ground surface is extremely important for predicting the type of atmospheric stability, wind direction and velocity for flight test purposes. Inversion conditions were noted during this test period and, in fact, based on comprehensive studies conducted by ESSA, an inversion formation can be expected at this site, on the average, almost every day of the year (96.2 percent of the time). The average time of inversion formation and dissipation during this time of the year is 1800 and 0900, respectively. This type of atmospheric phenomena plus possible thermal activity would have an effect on the descent velocity of vortex systems.

The prevailing wind at this site for this time of the year is from either the northeast or the southwest. Unpredictable wind shifts and velocities occurred during the course of certain test periods, necessitating last minute course changes from the project manager to the test aircraft commander to insure a reasonable vortex trajectory toward the tower. Concurrently, wind sheers and 180° wind shifts were noticed in the vertical span of the tower when the colored smoke grenades were ignited. For example, at the tower base, the ambient surface wind at one time was from the southwest whereas, 200 feet up from the base at the tower top, the wind was from the northeast! As characteristic of the atmosphere, the boundary layer effect on the atmosphere; i.e., a vertical variation of wind direction, speeds, and turbulence, due to earth surface was also noticeable for the vertical span of the tower by the tower meteorological instrumentation and continued further up into the atmosphere as evidenced by the higher wind velocities reported by the C-5A aircraft which had an inertial guidance system on board and a computer from which the crew determined and reported the wind direction and velocities affecting their aircraft at their altitude which was higher than the top of the tower.

Test Aircraft: Eight different model jet transport-type aircraft were used in this phase of this test program. These aircraft were the Boeing 747, Boeing 707-320C, Boeing 727-100, Douglas DC8-63F, Douglas DC8-33, Douglas DC9-11, Lockheed C-5A, and Learjet 24. For these aircraft, geometric, gross weight, and performance data, as applicable to vortex theoretical calculations, are listed in Figures 4-1 through 4-8 and Table 4-1.

It was the intent to have the test aircraft arrive at the site at maximum permissible gross take-off weight minus fuel consumed enroute from point of departure to the test site so as to insure generating the highest circulation Γ and tangential velocities, V_{TAN}. However, in view of the recent temporary restriction on maximum take-off weight for the C-5A aircraft, the aircraft arrived at the site at a much lower gross weight than desired, never exceeding 481,000 pounds.

Flight Tests: The flight tests were conducted during the period February 18 - 21, 1970, during daylight hours. Nine consecutive flight test periods were scheduled and flown with the above model aircraft. Each aircraft was scheduled for one period "on station" with each test period lasting approximately 2 hours. The time interval between passes for flying the rectangular tract was about 10 minutes. The C-5A aircraft was scheduled for a repeat period because of very few vortex "hits" on the data acquisition tower during its first scheduled period on station. The rectangular test pattern tract was established so as to avoid all nuclear reactor and other ESSA/AEC facilities and is shown in Figures 1-1 and 1-2.

The final leg which went past the tower was on a course of 108° 42 minutes magnetic, 126° 42 minutes true. The maximum lateral deviation authorized to the southwest of the tower, while on this tract, was 600 feet. There was no lateral distance limitation, within reason, to the northeast of the tower.

Initially planned was a test altitude of 500 feet above the ground per direction of the AEC. However, to increase the probability of intercepting the tower, particularly when flying to the southwest of the tower with relatively high ambient winds and due to the relatively low tower height for this type work, lower flight altitudes were requested and granted with due considerations for flight safety. The flight tests required that the aircraft be in stabilized flight (speed and altitude) when passing abreast of the tower. All flights past the tower were controlled by the "Range" Safety Officer who was also the Project Manager. His position was at the base of the tower at a ground-air VHF radio command control vehicle. Last second ambient wind velocity and direction signals were provided the project manager by ESSA from signals telemetered from the 200-foot tower level

meteorological sensors. Aircraft configurations and vertical and lateral positioning were dictated by the project manager. Directions to data central and the photographers were provided by the project manager by sound-powered phone.

One or two familiarization runs were scheduled for each period to insure compliance with previously established AEC flight path pattern and altitude requirements. All flights required an FAA project pilot on board the aircraft as well as an official from the AEC.

Final aircraft lineup for the track past the tower was provided by three strobe lights of the type shown in Figure 1-3 positioned along the desired tract and an AEC Security Police Station Wagon which had a rotating red beacon on the roof top. Communication to driver of this vehicle for positioning purposed was provided by walkie-talkie radio. Flight test data sheets for the nine test periods are listed in Tables 5-1 through 5-9. The configurations flown, number of familiarization runs, data runs, vortex captures, etc. are listed in a Summary Table 5-10.

Test Results

Only limited significant quantitative data and test results on the test aircraft involved are considered for analysis at this time owing to the extreme urgency of promulgating a data report as soon as possible to interested recipients so that they, in turn, will be aware of the tests, test techniques, results, preliminary conclusions and recommendations and may have available for their possible review, interpretation and analysis, if they so desire, of the vortex time-history and other data enclosed herein.

All significant recorded vortex time-history data for the eight test aircraft and the nine test periods are listed sequentially in the order of testing in Appendix G. Data acquisition was attempted for each familiarization flight and data run for each test period, and from each sensor location level on the tower. Where time-history data are lacking for a particular aircraft at a certain tower probe level, it is due to the fact that the data are either insignificant or not recorded because of an inoperable sensor, probe, or recorder as discussed earlier.

The data points are plotted in the form of vortex induced velocity versus vortex "age" - the latter simply meaning the elapsed time between the data point and time zero, which is defined as the time at which the test aircraft is abreast of the instrumented tower - a valid reference point for this type of investigation.

Accuracy of Data: In the data analysis several assumptions were made to expedite the calculations. Each of these assumptions introduces a small error or uncertainty in the final results. The assumptions were:

1. The hot wires respond only to the component of the wind velocity that is normal to the wire. If the actual airflow is nearly parallel to the wire ($< 20^{o}$) convection from the wire leads to an overestimate of the normal component, depending upon the magnitude of the speed.

2. The hot wires were calibrated to wind speeds less than 34 fps in the ESSA wind tunnel and the calibration was assumed to follow King's law for higher velocities. A partial calibration of the hot wires at high speeds supported a continuation of the calibration curve slope found at low speeds (in agreement with King's law).

3. Corrections of hot wire velocities for temperature were based on mean temperatures for each aircraft series. Variation in temperature either on a trend basis or on a turbulent fluctuation basis can lead to uncertainties of a few percent.

4. The drift in voltage at zero velocity from the beginning of an aircraft series to the end was ignored. This source of error leads to an underestimate of the velocity because the voltage drift is downward.

When all of these effects and assumptions are pooled together, the following cumulative result is produced. The overestimation of flow speed resulting from air movement with a component parallel to a wire axis is partly opposed by an underestimation of the magnitude of the flow due to a time drift of the zero flow reference point. The temperature variations and the individual wire response deviations from their least squares fit of their individual calibration point values basically cancel out individually; i.e., each approaches a zero mean deviation. The hot wire wind speeds in the time series plots, as a consequence of these assumptions and effects, deviate less than ± 20 percent from the plotted values. This data accuracy lies within the limits verbally requested for the study. Each assumption, each individual piece of data handling and recording equipment could have been improved upon using the best states of the art available. The cumulative data uncertainty could theoretically be reduced to 1/2 to 1/4 of the 20 percent quoted above. However, under the priority demand for information in very limited time, the only choice available was to adopt those assumptions enumerated above and employ that equipment readily available which still would yield acceptable accuracies and allow timely data presentation.

The limited analysis pertains to the most significant data on the test aircraft. Of primary concern and attention were the data from the Boeing 747, Boeing 707-320C and Lockheed C-5A aircraft, the reasoning being to quickly compare the vortex wake characteristics of the newer and larget jet transport B-747 and C-5A aircraft with the currently operational and relatively large B-707 aircraft.

A comparison of the three sets of data shows that the vortex velocities induced by the B-747 and C-5A trailing vortex systems, as far as they were determined from the limited data available on the aircraft, do not significantly exceed those generated by the B-707. Maximum tangential velocities on the order of 130 - 140 ft/sec were recorded for the former two aircraft and 120 - 130 ft/sec for the B-707. These high velocities were noted for the "clean," holding configurations of the respective aircraft. The peak tangential velocities are approximately double those velocities predicted by certain theory (which assumes elliptical lift distribution) which are in the order of 70 - 80 ft/sec. However, this particular theory assumes that the core diameter is

$$r_c = .155\ b/2$$

If this theory is questionable, as is believed by some, and the r_c is smaller, then the tangentially velocity would be higher since it varies inversely as the core radius. From visual observations of the tubular-type vortex system and during which the highest vortex tangential velocities were recorded, the core radius as outlined by the tower smoke appeared to be smaller, at most, approximately 5 - 6 feet in radius. Suitable anemometer spacing closer than 25 feet, if the anemometers were available, would have helped clarify this particular vortex characteristic. It is concurrently believed, again based on visual observation of the vortex systems and limited 16mm film review, that the above theory may hold for vortex systems generated from the wing with the aircraft in the dirty configuration since larger diameter vortex flow fields were noted.

It was observed that for the "clean" configuration and small flap deflections, the vortex systems of all the aircraft were of tubular form, relatively small diameter, as stated earlier, very clearly structured and very persistent as can be seen in some representative samples shown in Appendix G, Figures 7-1 through 7-4. As the flap deflection increased, the aircraft vortices of tubular form were much less evident and when maximum flap deflections were employed finally disappeared, the vortex wake appearing much larger in diameter but more closely resembling random turbulence. This is very clearly substantiated by our 16mm photographic coverage and somewhat by our time-history data in Appendix G.

Such random turbulence would dissipate rapidly compared with a well structured vortex system, and as a general observation, one would say that the "dirtier" the airplane configuration is for a given weight and airspeed, the less dangerous its wake turbulence should be at large distances (3 miles and more) downstream of the airplane. Analytical consideration tend to support this contention for these reasons:

1. The vortex appearing downstream and parallel to the aircraft flight path is a direct consequence of the generation of lift. For a constant configuration and altitude, its strength varies as airplane gross weight divided by airspeed. This vortex represents the aggregate of all the vorticity shed along the wing trailing edge. This trailing edge vorticity wraps up into two large vortices at a distance downstream dependent on airplane span, aspect ratio, gross weight, altitude and airspeed.

2. The above-mentioned vorticity first appearing at the trailing edge is locally either right or left handed in rotation, depending on whether the local lift is increasing or decreasing toward the tip. Irregularities in lift distribution, such as are caused by large flap deflections, produce alternately left and right hand rotation, whereas a smoothly varying lift distribution associated with small or zero flap settings produces a constant direction of rotation along the wing. The former result leads to a far less well-defined vortex structure, with resulting more rapid decay, even though a dirty configuration generates more wake energy initially.

Very few data points were obtained for the DC8-63 aircraft primarily due to either very large atmospheric buoyancy effect on the aircraft's descending vortex system or to the aircraft commander flying his aircraft at an attitude higher than that requested by the project manager. The latter is suspected based on visual observation from the ground of the aircraft's altitude and could be due to either a faulty radio altimeter or the pilot's reluctance to fly low abreast of the tower. Lack of aircraft installed vortex marking system and "clean" engines precluded observation of trailing vortex system's movement.

As aircraft size and wing loading diminished, so did recorded vortex velocities and visually sighted core diameters down to the point where with the smallest aircraft tested, the Learjet 24, no "hits" were recorded either visually or on the tower anemometers. The trailing vortices either did not descend to the vicinity of the tower due to low descent velocity or were of such small diameter and tangential velocity as to pass between sensors and smoke emitters on the tower.

Of particular note in this investigation was an attempt to determine vortex axial flow phenomena by the colored smoke visualization technique. When tubular-type vortex systems passed through the tower,

it was clearly noted that the entrained smoke as picked up from the tower smoke generators spontaneously moved within the vortex system along its axis in both directions; i.e., up flight path and down flight path. This is clearly noted in Figure 7-4 and the 16mm coverage. The vortex system, particularly the tubular-type which looks like a tornado or water spout, has a low pressure area within its cylindrical wall similar to a tornado or water spout and once this wall is penetrated, as by the instrumented tower upon tower passage, there is an immediate injection of relatively higher pressure ambient air and associated colored smoke if in the vicinity of the smoke generator which spreads rapidly in both axial directions in an attempt at pressure equalization. Thus, it is hypothesized that axial flow solely in the direction of aircraft flight path either does not exist or is so small as to be negligible for the vortex age time-histories under discussion; i.e., 1 to 2 minutes. Previous vortex investigations conducted at NAFEC using the tower fly-by technique indicated an axial flow in the direction of aircraft flight path and at approximately the aircraft's airspeed. However, these were relatively short age vortex systems on the order of 20 seconds and may have been due to wing profile drag.

CONCLUSIONS

Based upon analysis of the results of these tests, it is concluded that:

1. For "clean" and low flap setting configurations of the Boeing 747, C-5A and 707 aircraft, the maximum velocities of the respective aircraft trailing vortex systems are similar in magnitude, approximately 140 feet/sec, under the existing environmental flight test conditions.

2. More persistent, clearly defined "tubular-type" vortex systems are generated as the flap setting is decreased on an aircraft.

3. "Tubular-type" vortex systems are very persistent, up to approximately 2 minutes in age, as sighted visually and recorded photographically, in close proximity to the ground; i.e., not exceeding tower height.

4. For "dirty," full flap configurations, the short-age (up to 40 seconds) vortex systems of the Boeing 747 aircraft exhibited higher velocities, on the order of 100 per second, as compared to the Boeing 707 vortex velocities, which were on the order of 60 feet per second.

5. The trailing vortex system of the Boeing 747 full flap configuration aircraft breaks up very rapidly from "ordered" flow to turbulent-type flow as noted by visual observation and photographic coverage.

6. As the trailing vortex system approaches the "tubular-type" structure, the tangential velocities increase whereas the vortex diameter; i.e., the field of influence as sensed by the anemometers and seen visually in the 16mm motion picture coverage, decreases. Conversely, as the trailing vortex system deviates from a tubular-type structure, the tangential velocities decrease and the vortex diameter increases. This type of flow is characteristic of the classical free vortex flow.

7. Axial flow either does not exist or is insignificant for relatively long-age vortex systems.

8. Test towers should be higher than 200 feet for the tower fly-by technique except for vortex investigations in ground effect.

9. More airflow sensors and decreased sensor spacing, down to at least 5 feet, are required.

10. Tower smoke is mandatory for flow visualization and data correlation.

11. Vortex marking on test aircraft is mandatory to minimize misses and test time.

12. A minimum of two towers is required for vortex decay rate determination.

13. An airborne airflow measurement system is mandatory for longer time-history data out of ground effect and out of atmospheric boundary layer.

14. Only relatively short time-history vortex data $<$ 2 minutes could efficiently be gathered with the tower fly-by technique with a 200-foot tower. The vortex age and data acquisition efficiency would increase with tower height subject to consideration of the conclusions herein on instrumentation and flow visualization.

15. An automatic data processing capability is mandatory for short turn-around time between flight test and data output in usable form; i.e., three-dimensional velocity time histories as listed herein in Appendix G.

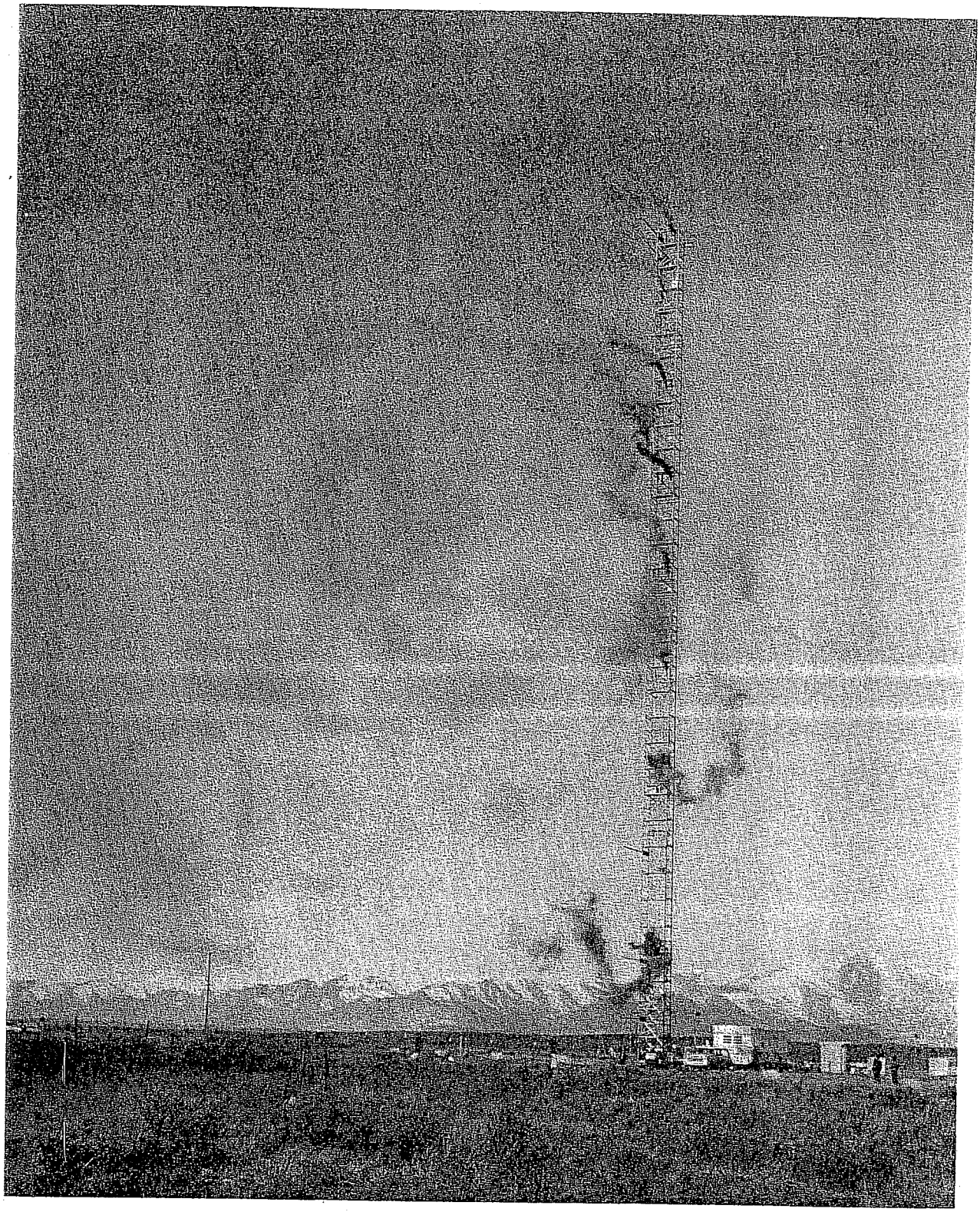


FIG. 1 AIRCRAFT VORTEX FLOW VISUALIZATION

FIG. 2 BOEING 747 FLYING ABREAST OF INSTRUMENTED TOWER FOR VORTEX DATA ACQUISITION

FIG. 3 BOEING 747 VORTEX MARKING BY INJECTION CORVUS-TYPE OIL INTO EXHAUST SYSTEM OF OUTBOARD ENGINE

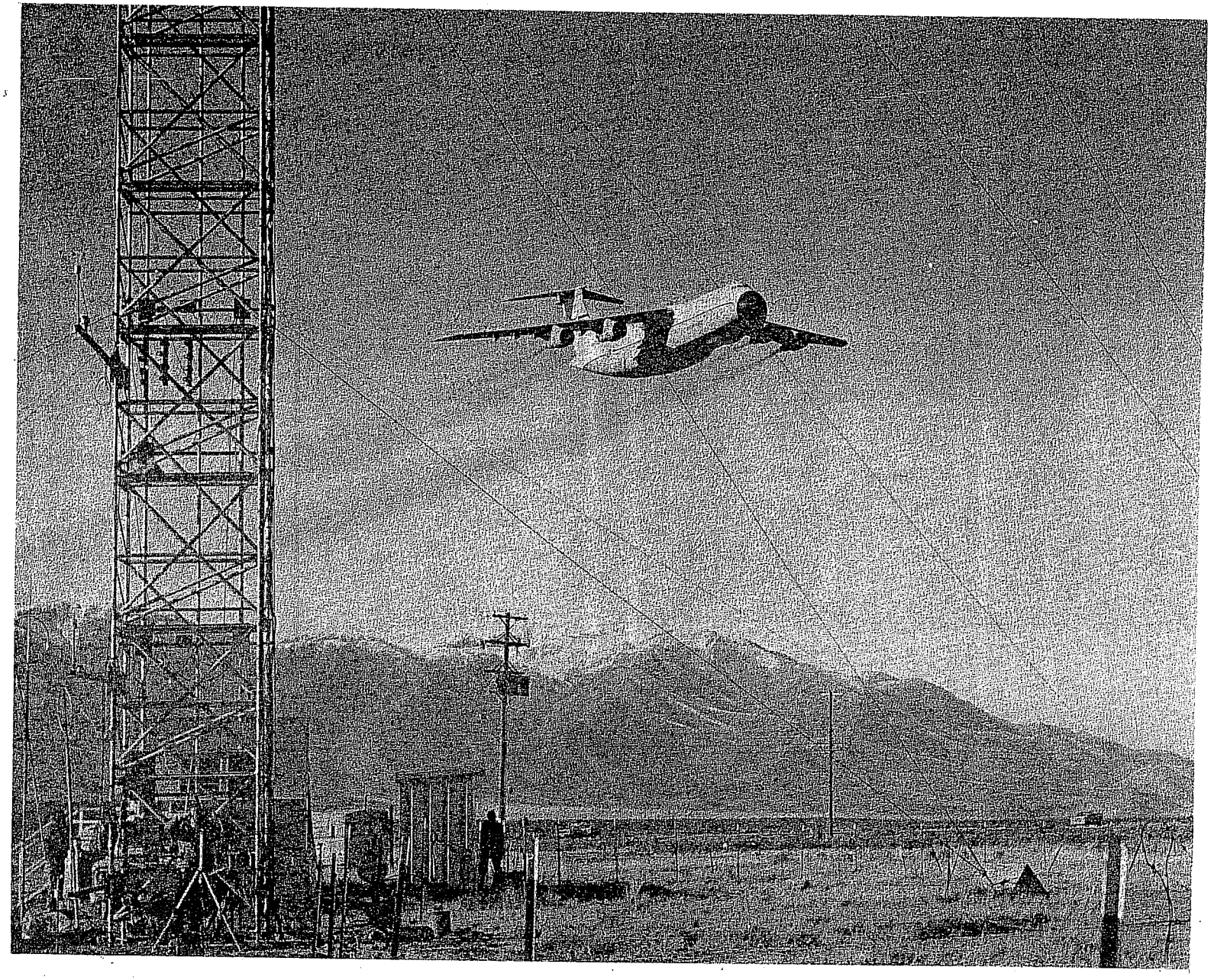


FIG. 4 LOCKHEED C5A APPROACHING INSTRUMENTED TOWER FOR VORTEX DATA ACQUISITION

Prepared by:

Leo J. Garodz
Project Manager

Approved by:

Wayne O. Howell
Chief, Instruments and Flight
Test Section

APPENDIX A

TEST SITE

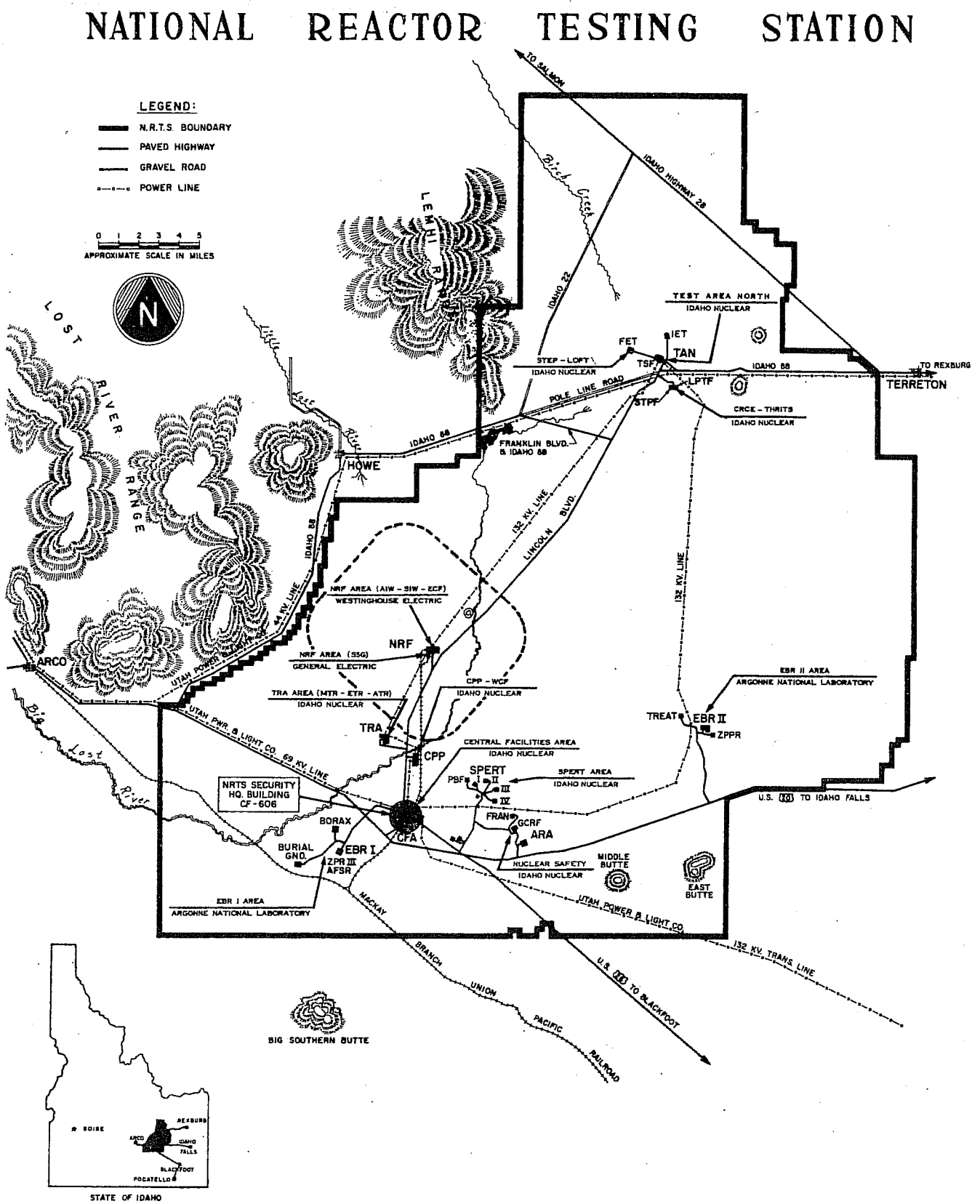


FIG. 1-1 GENERAL LAYOUT OF THE NRTS, IDAHO FALLS, IDAHO

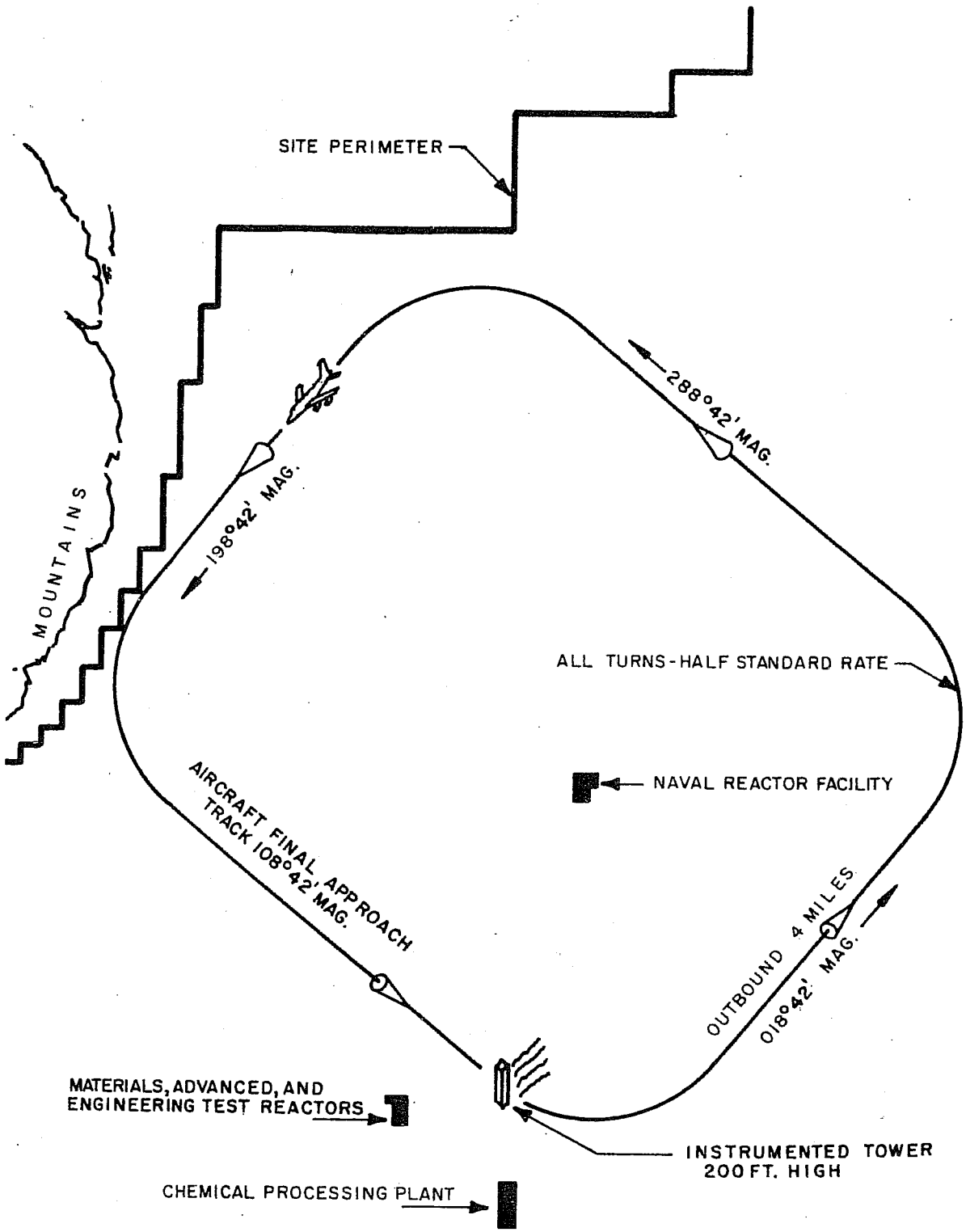


FIG. 1-2 VORTEX MEASUREMENT FLIGHT TEST TRACK

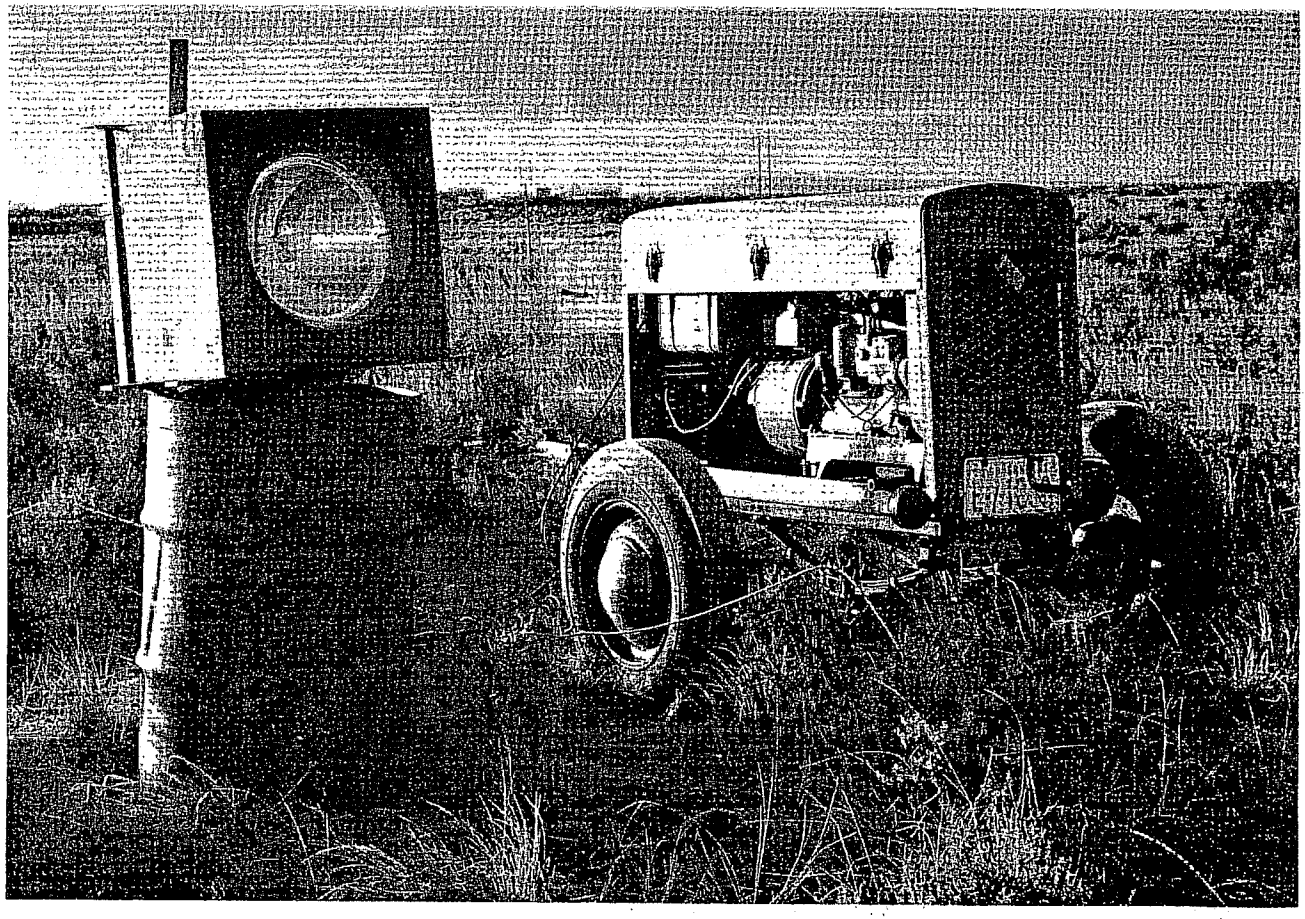
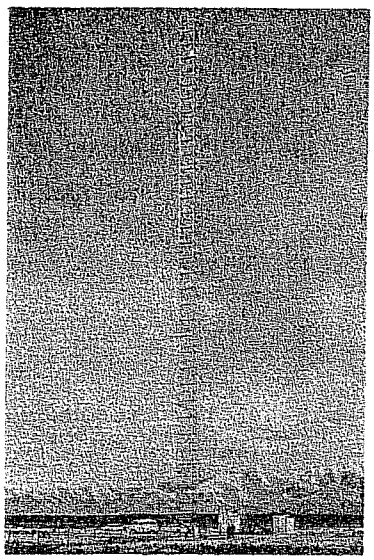


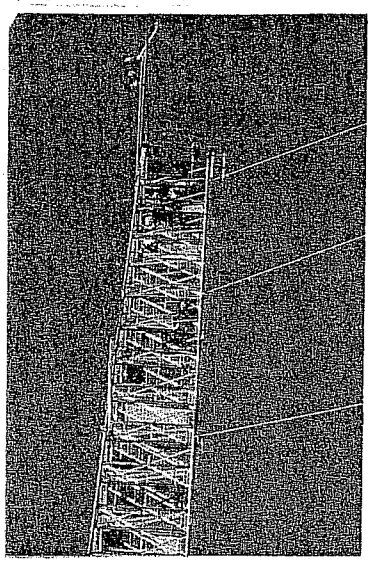
FIG. 1-3 STROBE LIGHT USED FOR TEST AIRCRAFT ALIGNMENT ON FINAL

APPENDIX B

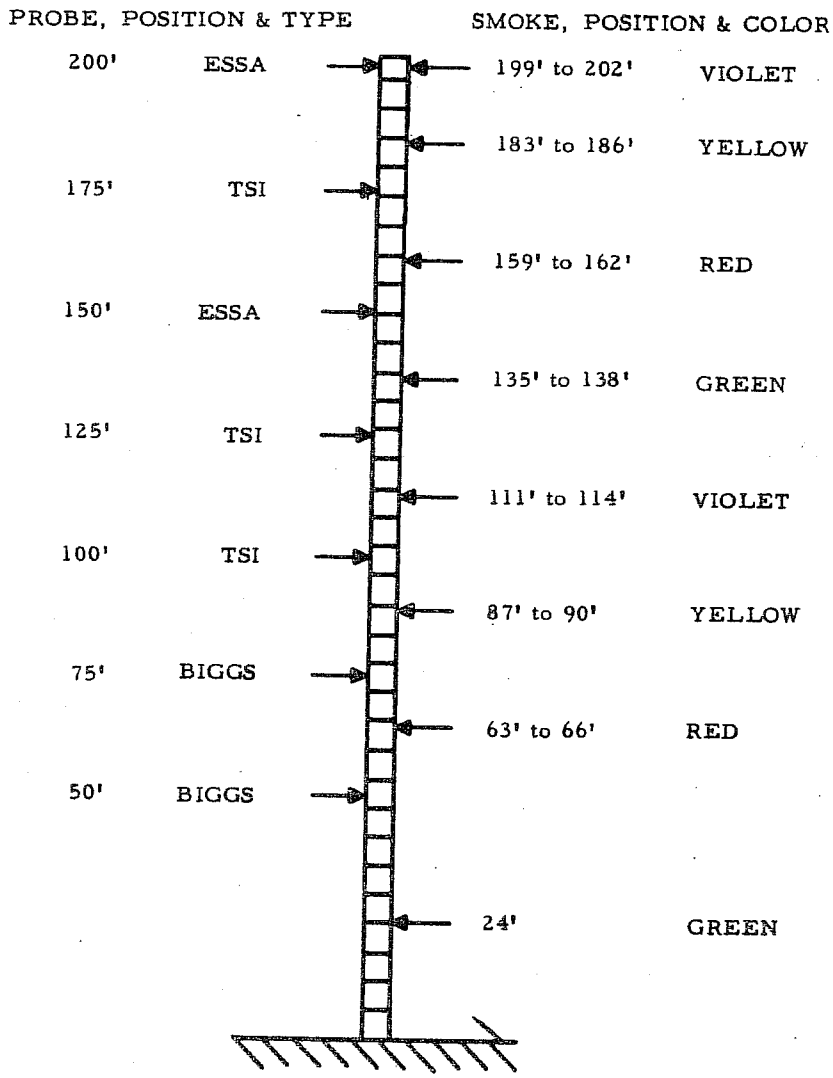
INSTRUMENTATION



(a) Tower (Full view)

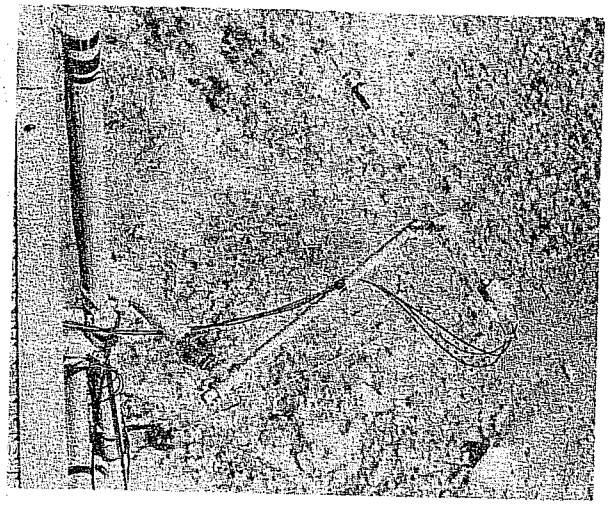


(b) Tower (Close-up)

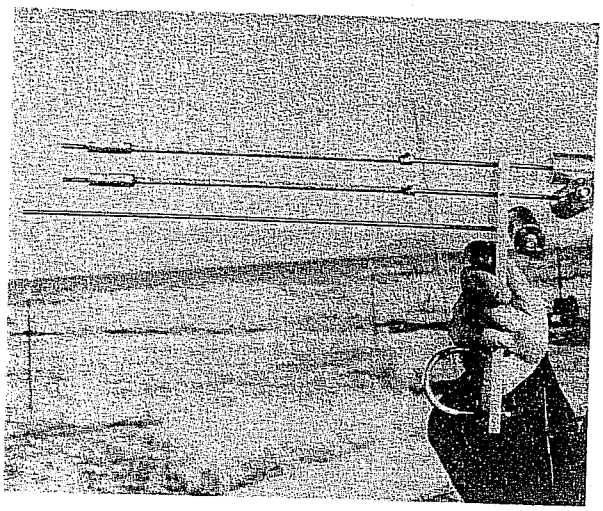


(c) Tower (Schematic)

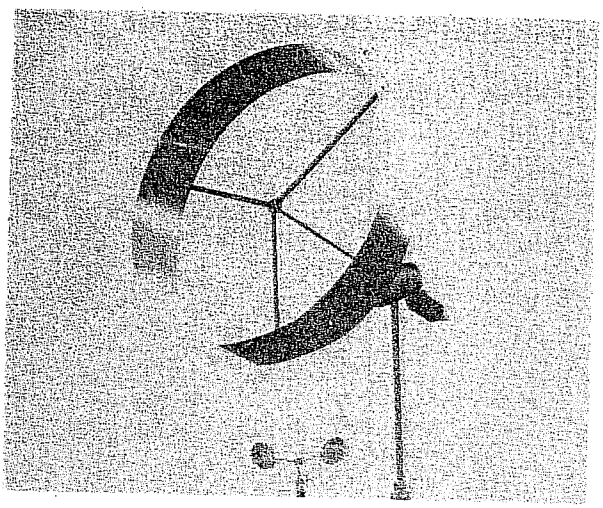
FIG. 2-1 INSTRUMENTED ESSA TOWER USED FOR AIRCRAFT VORTEX WAKE TURBULENCE MEASUREMENTS



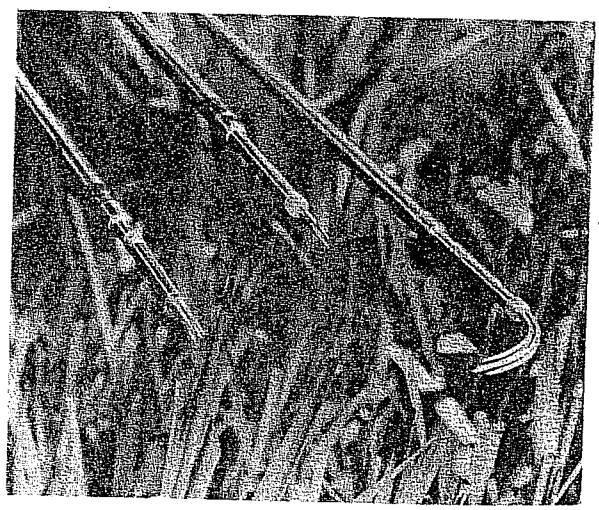
(a) TSI Hot-Film Sensor



(b) BIGGS Hot-Wire Sensor



(c) Cup Anenometer/Bi-Directional Vane



(d) Flow Corp (Essa) Hot-Wire Sensor

FIG. 2-2 AIRFLOW MEASUREMENT SENSORS USED AT TEST SITE

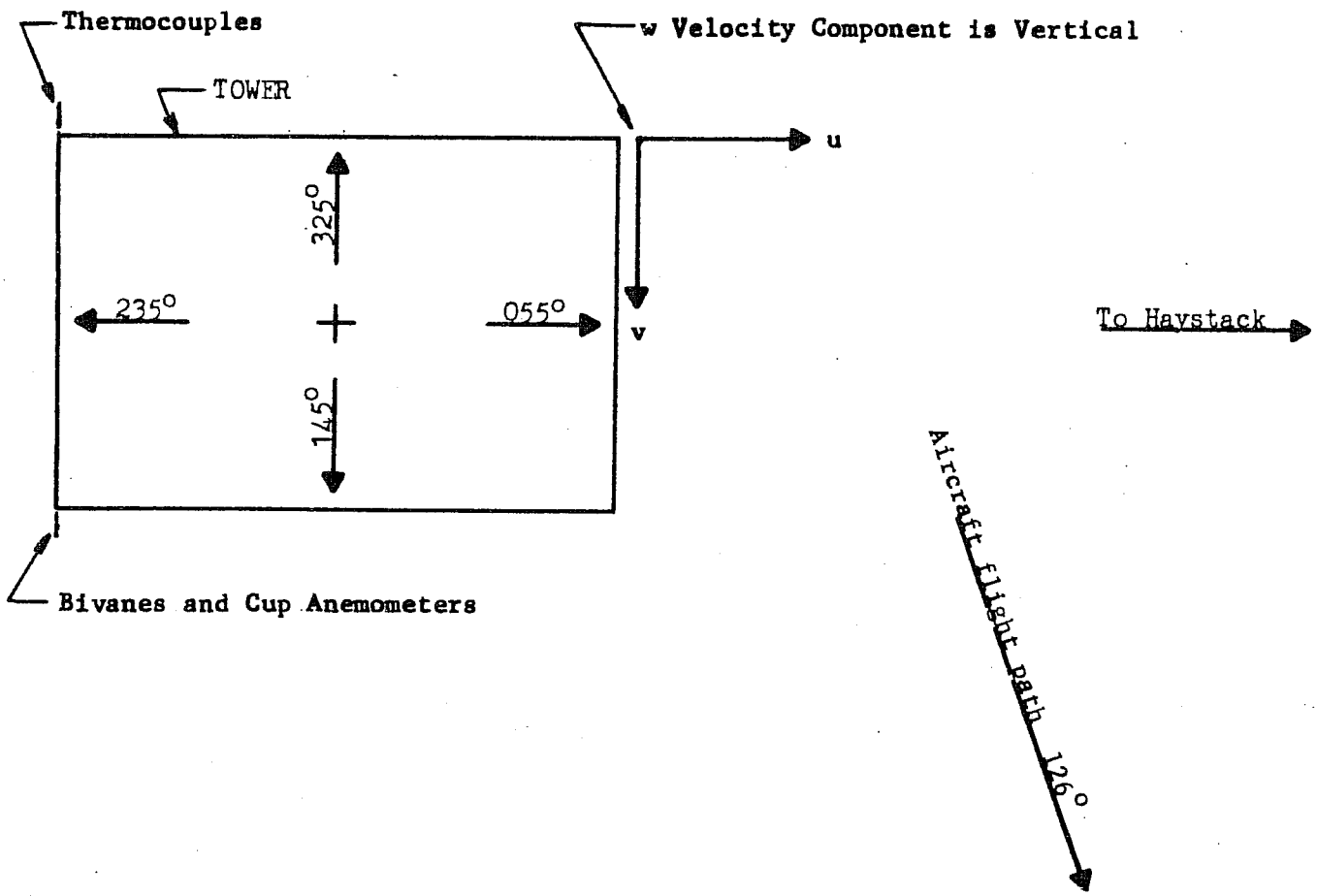


FIG. 2-3 ESSA TOWER, FLIGHT PATH, METEOROLOGICAL SENSOR, AND ANEMOMETER ORIENTATION AEC SITE, IDAHO FALLS, IDAHO

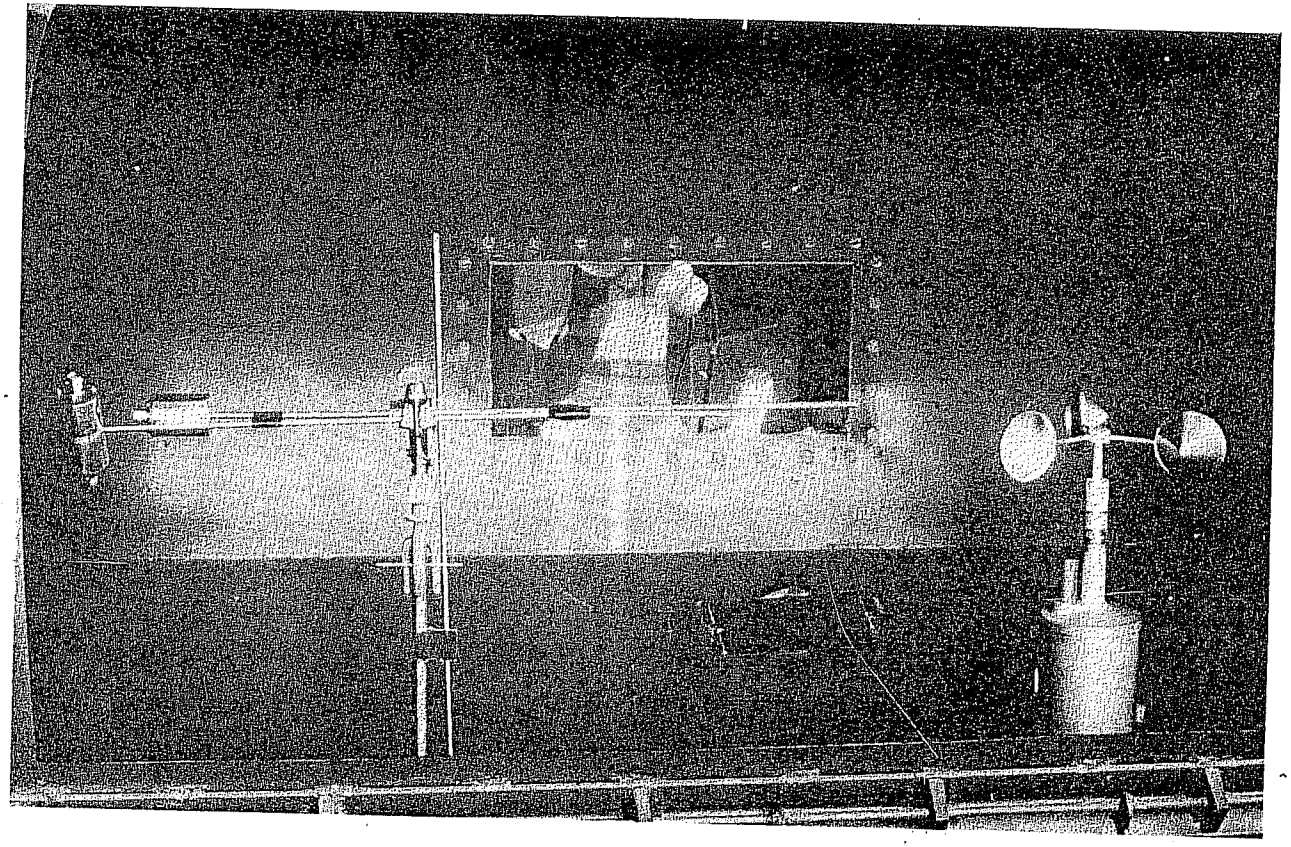
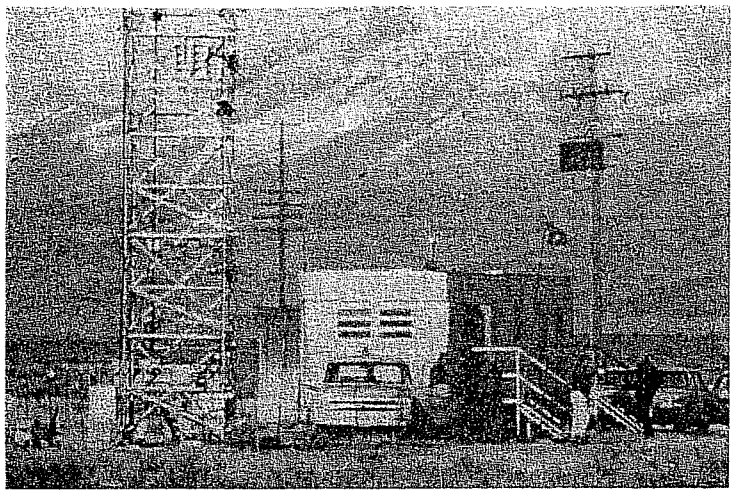
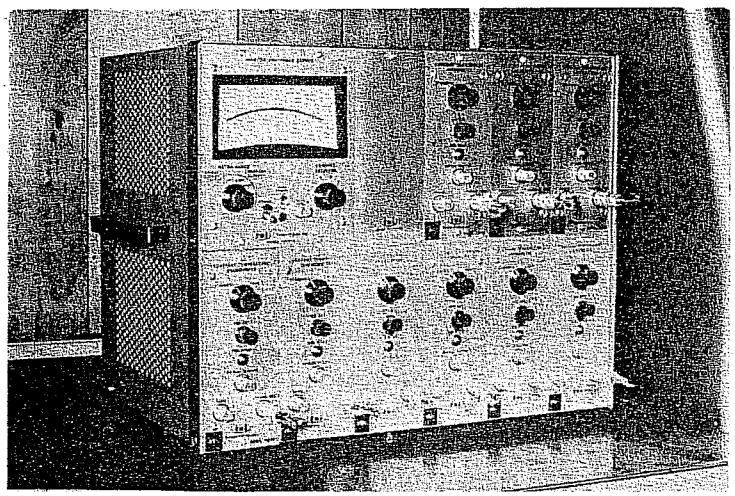


FIG. 2-4 WIND TUNNEL FOR AIRFLOW SENSOR CALIBRATION



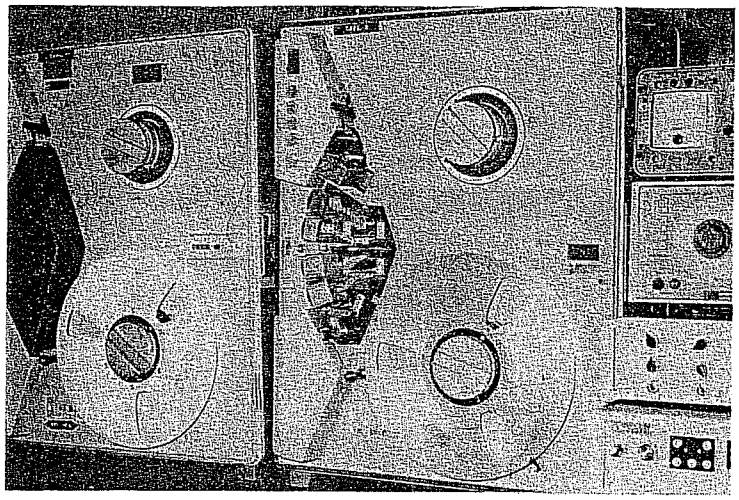
(a) Instrumentation Trailer (exterior)

(b) Instrumentation Trailer (interior)

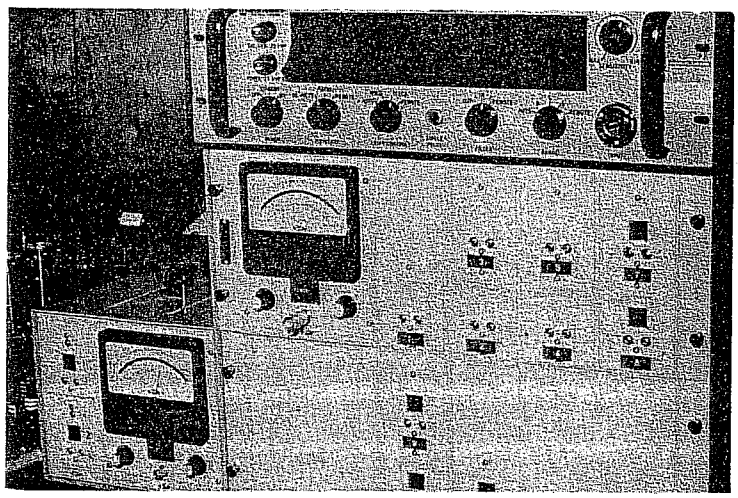


(c) TSI Signal Conditioning Equipment

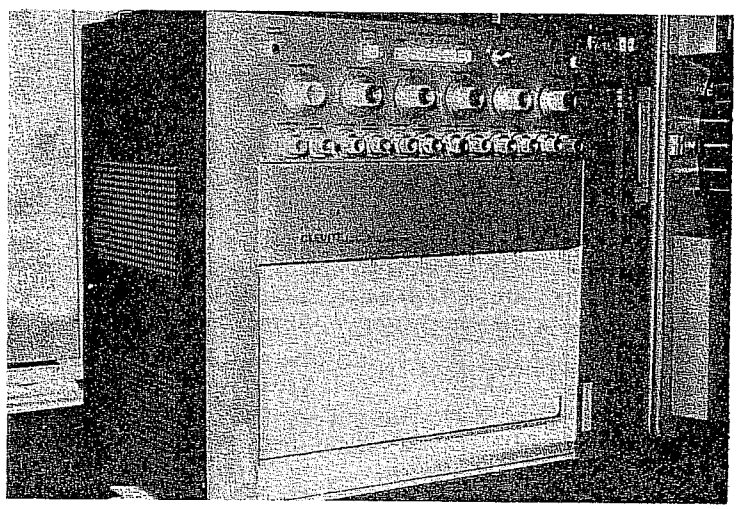
FIG. 2-5 INSTRUMENTATION TRAILER, RECORDING AND SIGNAL CONDITIONING EQUIPMENT



(d) Recording Equipment (Tape)



(e) ESSA Signal Conditioning Equipment



(f) Recording Equipment - Analog Type

FIG. 2-5 (CONTINUED) INSTRUMENTATION TRAILER, RECORDING AND SIGNAL CONDITIONING EQUIPMENT

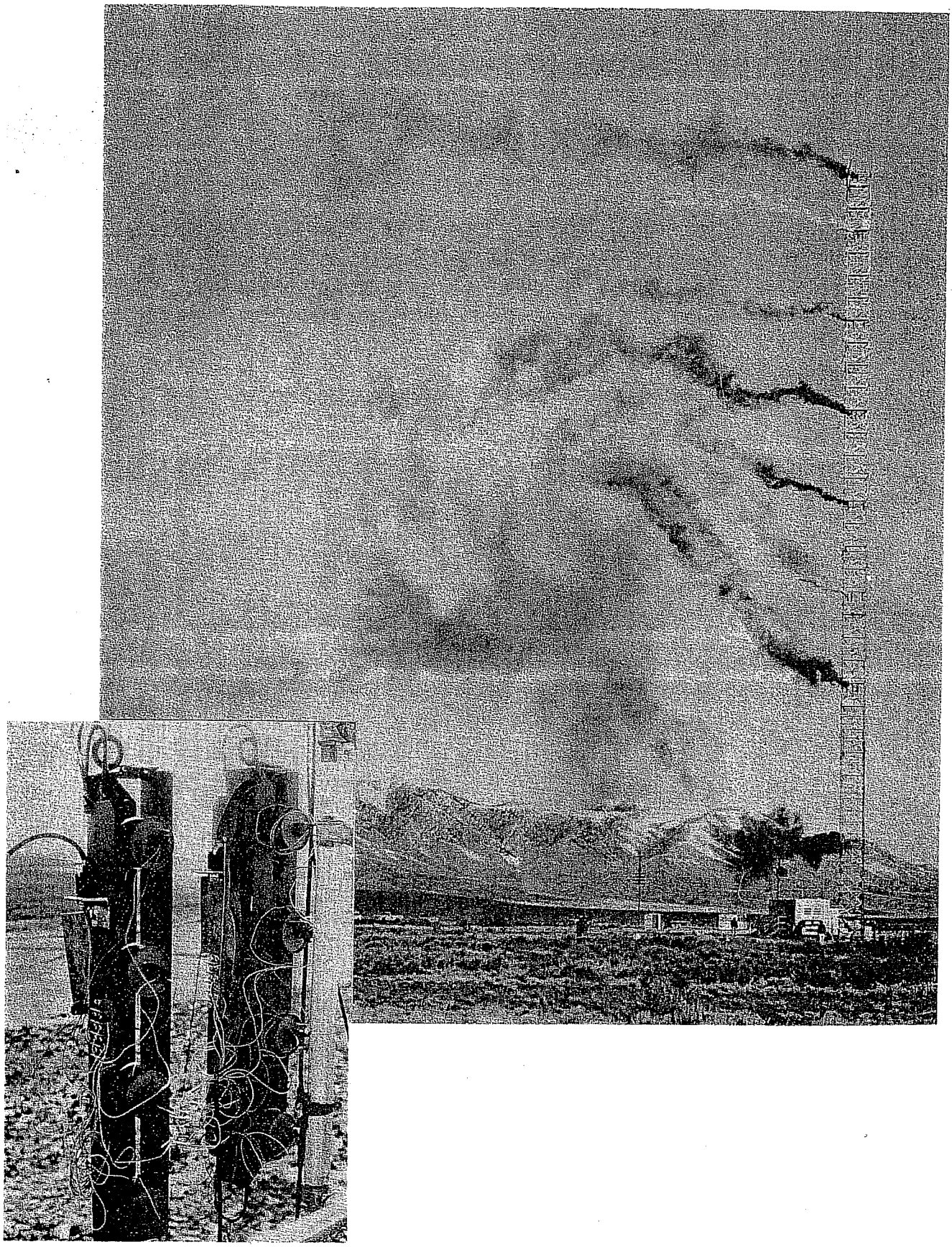
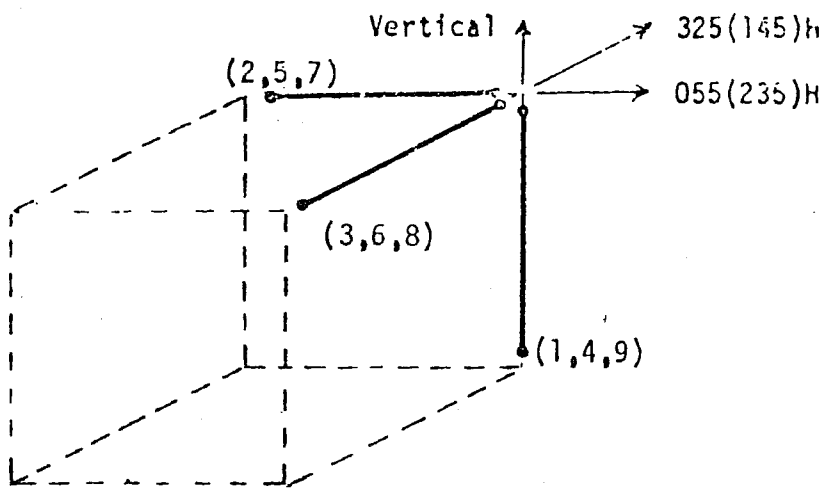


FIG. 2-6 M18 COLORED SMOKE GRENADE INSTALLATION AND VORTEX FLOW VISUALIZATION

Schematic of Wire Array



Wire Orientation

Wire Number	Orien-tation	Level (ft)
1	Vert	
2	055H	125
3	145H	
5	055H	175
6	145H	
7	055H	
8	145H	100
9	Vert	

Wire Equations

$$u^2_{Vert} = u^2 + v^2$$

$$u^2_{055H} = v^2 + w^2$$

$$u^2_{145H} = u^2 + w^2$$

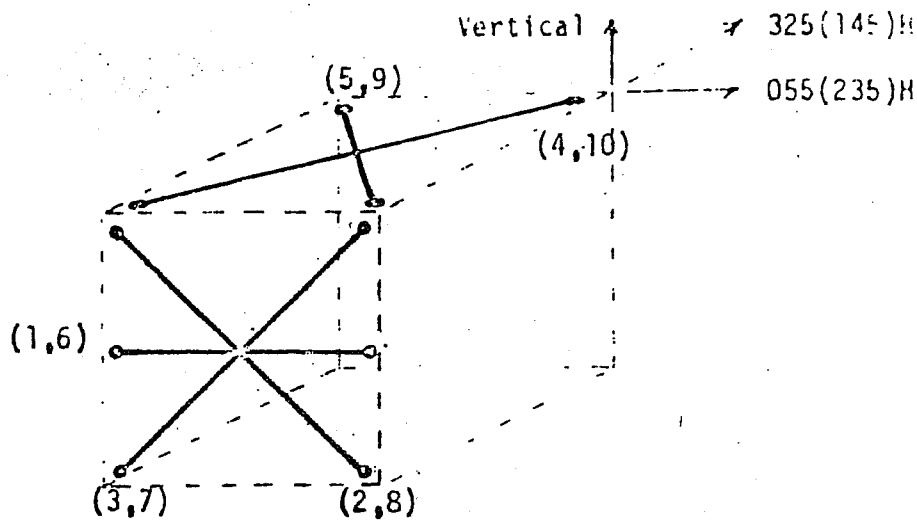
$$|V|^2 = \frac{1}{2}\left(u^2_{Vert} + u^2_{055H} + u^2_{145H}\right)$$

Wires Used in Plots

Hgt(ft)	VTAN	VRAD	VAXL
100	8	9	7
125	3	1	2
175	6	-	5

FIG. 2-7 TSI HOT-WIRE GEOMETRY, EQUATIONS AND WIRES USED FOR PLOTTING

Schematic of Wire Array



Wire Orientation

Wire Number	Orientation	Level (ft)
1	055H	
2	055D	
3	055U	150
4	010H	
5	100H	
6	055H	
7	055U	
8	055D	200
9	100H	
10	010H	

Wire Equations

$$u^2_{100H} = \frac{1}{2}(u - v)^2 + w^2$$
$$u^2_{010H} = \frac{1}{2}(u + v)^2 + w^2$$
$$u^2_{055D} = \frac{1}{2}(u + w)^2 + v^2$$
$$u^2_{055U} = \frac{1}{2}(u - w)^2 + v^2$$
$$u^2_{055H} = v^2 + w^2$$

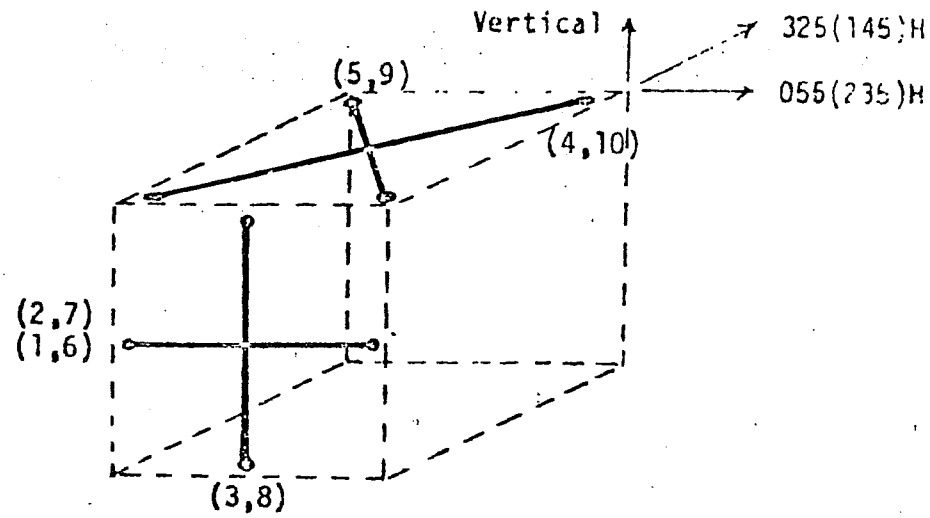
$$|V|^2 = \frac{1}{2}(u^2_{100H} + u^2_{010H} + u^2_{055D} + u^2_{055U} - u^2_{055H})$$

Wires Used in Plots

Hgt(ft)	VTAN	VRAD	VAXL
150	5	2	4
200	9	8	10

FIG. 2-8 ESSA HOT-WIRE GEOMETRY, EQUATIONS AND WIRES USED FOR PLOTTING ON FEBRUARY 18, 1970

Schematic of Wire Array



Wire Orientation

Wire Number	Orien-tation	Level (ft)
1	055H	
2	055H	
3	Vert	150
4	010H	
5	100H	
6	055H	
7	055H	
8	Vert	200
9	100H	
10	010H	

Wire Equations

$$u^2_{100H} = \frac{1}{2}(u - v)^2 + w^2$$

$$u^2_{010H} = \frac{1}{2}(u + v)^2 + w^2$$

$$u^2_{Vert} = u^2 + v^2$$

$$u^2_{055H} = v^2 + w^2$$

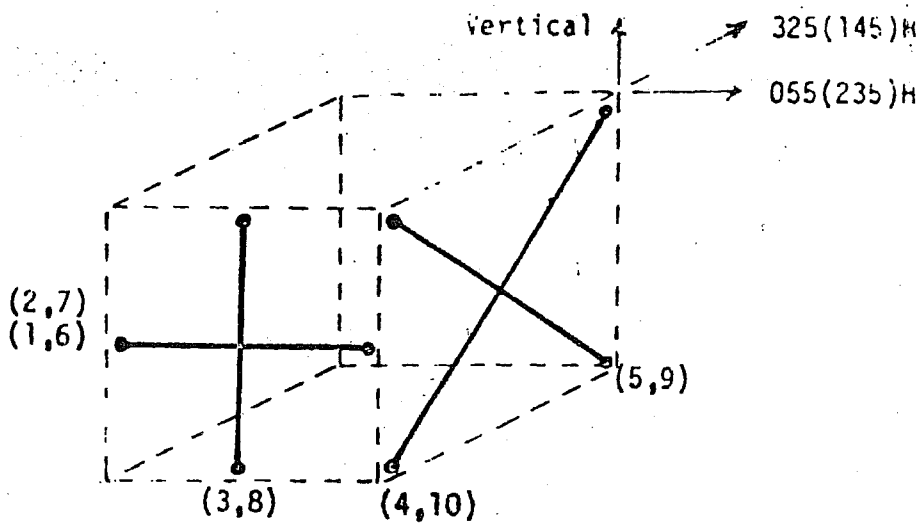
$$|V|^2 = \frac{1}{2}(u^2_{100H} + u^2_{010H} + u^2_{Vert})$$

Wires Used in Plots

Hgt(ft)	VTAN	VRAD	VAXL
150	5	3	4
200	9	8	10

FIG. 2-9 ESSA HOT-WIRE GEOMETRY, EQUATIONS AND WIRES USED FOR PLOTTING ON FEBRUARY 19 AND 21, 1970

Schematic of Wire Array



Wire Orientation

Wire Number	Orientation	Level (ft)
1	055H	
2	055H	
3	Vert	150
4	145D	
5	145U	
6	055H	
7	055H	
8	Vert	200
9	145U	
10	145D	

Wire Equations

$$u^2_{145U} = \frac{1}{2}(v - w)^2 + u^2$$

$$u^2_{145D} = \frac{1}{2}(v + w)^2 + u^2$$

$$u^2_{Vert} = u^2 + v^2$$

$$u^2_{055H} = v^2 + w^2$$

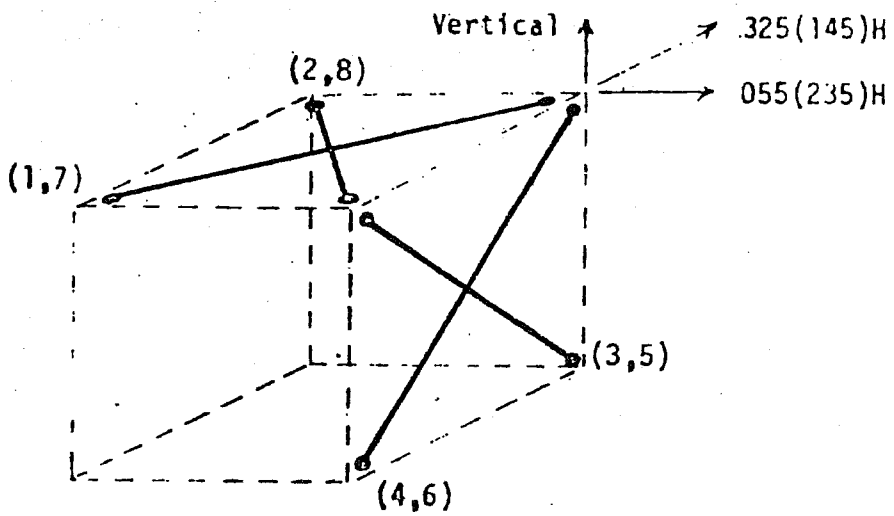
$$|V|^2 = \frac{1}{2}(u^2_{145U} + u^2_{145D} + u^2_{Vert})$$

Wires Used in Plots

Hgt(ft)	VTAN	VRAD	VAXL
150	5	3	2
200	9	8	7

FIG. 2-10 ESSA HOT-WIRE GEOMETRY, EQUATIONS AND WIRES USED FOR PLOTTING ON FEBRUARY 20, 1970

Schematic of Wire Array



Wire Orientation

Wire Number	Orientation	Level (ft)
1	010H	
2	100H	50
3	145U	
4	145D	
5	145U	
6	145D	75
7	010H	
8	100H	

Wire Equations

$$u^2_{010H} = \frac{1}{2}(u + v)^2 + w^2$$

$$u^2_{100H} = \frac{1}{2}(u - v)^2 + w^2$$

$$u^2_{145U} = \frac{1}{2}(v - w)^2 + u^2$$

$$u^2_{145D} = \frac{1}{2}(v + w)^2 + u^2$$

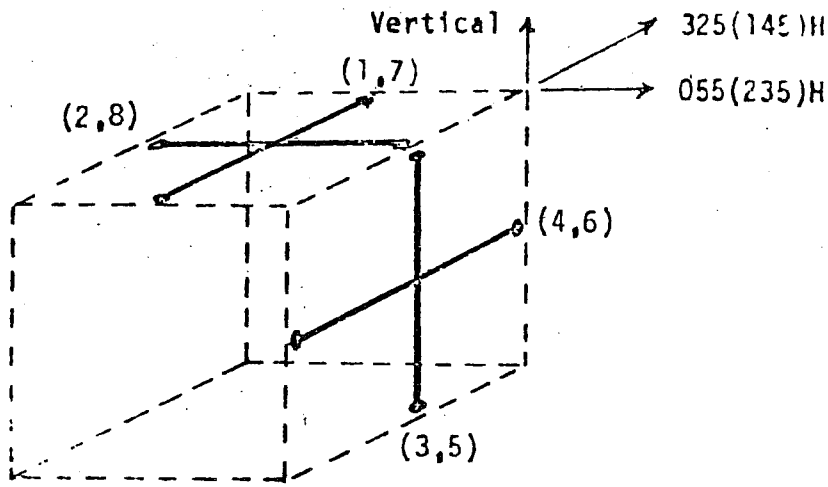
$|V|$ - none can be computed

Wires Used in Plots

Hgt(ft)	VTAN	VRAD	VAXL
50	2	3	1
75	8	6	7

FIG. 2-11 BIGGS HOT-WIRE GEOMETRY, EQUATIONS AND WIRES USED FOR PLOTTING ON FEBRUARY 18, 1970

Schematic of Wire Array



Wire Orientation

Wire Number	Orien-tation	Level (ft)
1	145H	
2	055H	50
3	Vert	
4	145H	
5	Vert	
6	145H	75
7	145H	
8	055H	

Wire Equations

$$u^2_{145H} = u^2 + w^2$$

$$u^2_{055H} = v^2 + w^2$$

$$u^2_{Vert} = u^2 + v^2$$

$$|V|^2 = \frac{1}{2}\left(u^2_{145H} + u^2_{055H} + u^2_{Vert}\right)$$

Wires Used in Plots

Hgt(ft)	VTAN	VRAD	VAXL
50	1	3	2
75	7	5	8

FIG. 2-12 BIGGS HOT-WIRE GEOMETRY, EQUATIONS AND WIRES USED FOR PLOTTING ON FEBRUARY 19 - 21, 1970

TABLE 2-1. HEIGHT LOCATIONS OF METEOROLOGICAL SENSORS ON THE 200-FOOT TOWER

		Sensor Type			
Height	Hotwires	ESSA Bivanes	Cup Anemometers	Aspirated and Shielded Thermocouples	Non-Aspirated Non-Shielded Thermocouples
200'	ESSA#6-10	1	1	1	1
175'	TSI#4-6				
150'	ESSA #1-5				1
125	TSI#1-3				1
100'	TSI#7-9	1	1	1	
75'	BIGGS#5-8				1
50'	BIGGS#1-4	1	1	1	1

TABLE 2-2. METEOROLOGICAL CONDITIONS AND INSTRUMENTATION STATUS DURING FLIGHT TESTS OF 747, FEBRUARY 18, 1970

747 ACFT SERIES 09:33:25--11:37:25 MST

FEBRUARY 18 1970

HEIGHT METERS	HEIGHT FEET	DIRECTION (°True) MEAN	DIRECTION (°True) ST. DEV.	SPEED (MPH) MEAN	SPEED (MPH) ST.DEV.	TEMPERATURE MEAN °F	TEMPERATURE ST.DEV.
61	200	-	-	9.8	4.5	27.8	1.6
32	100	-	-	11.3	5.9	28.7	1.0
16	50	-	-	9.7	4.8	28.9	1.5

PRESSURE 25.22 INCHES HG.

REL. HUMIDITY 29%

INSTRUMENTATION STATUS

HOTWIRES

HEIGHT	TYPE	REMARKS
200'	ESSA	#9 out until DATA 3, #6 out during all runs
175'	TSI	#4 out during all runs
150'	ESSA	#1 out until FAM 2
125'	TSI	All operative
100'	TSI	#9 out until DATA 4
75'	BIGGS	#5 & #8 out during all runs
50'	BIGGS	All operative

PROFILE

CUP ANEMOMETERS*	(FEET/SEC)
61 m	22.2
32 m	23.5
16 m	22.3

*Based on period 10:17:25 to 11:37:25 during which wind speeds were greater.

TABLE 2-3. METEOROLOGICAL CONDITIONS AND INSTRUMENTATION STATUS DURING FLIGHT TESTS OF C5A, FEBRUARY 18, 1970

C5A #1 ACFT SERIES 13:57:30 - 15:51:30 MST

FEBRUARY 18 1970

HEIGHT METERS	HEIGHT FEET	DIRECTION (°True) MEAN	DIRECTION (°True) ST. DEV.	SPEED (MPH) MEAN	SPEED (MPH) ST. DEV.	TEMPERATURE MEAN °F	TEMPERATURE ST. DEV.
61	200	-	-	11.8	3.3	32.0	1.8
32	100	-	-	12.8	3.8	32.8	1.1
16	50	-	-	9.8	2.8	33.0	1.2

PRESSURE 25.26 INCHES HG.

REL. HUMIDITY 29%

INSTRUMENTATION STATUS

HOTWIRES

HEIGHT	TYPE	REMARKS
200'	ESSA	#6 out for all runs
175'	TSI	#4 out for all runs
150'	ESSA	All operative
125'	TSI	All operative
100'	TSI	All operative
75'	BIGGS	#5 out for all runs
50'	BIGGS	All operative

PROFILE CUP ANEMOMETERS (FT/SEC)

61 m	16.4
32 m	16.1
16 m	13.6

TABLE 2-4. METEOROLOGICAL CONDITIONS AND INSTRUMENTATION STATUS DURING FLIGHT TESTS OF 707-320, FEBRUARY 19, 1970

[illegible] ACFT SERIES 07:52:47 - 09:54:47 MST

FEBRUARY 19 1970

HEIGHT METERS	HEIGHT FEET	DIRECTION (°True) MEAN	DIRECTION (°True) ST. DEV.	SPEED (MPH) MEAN	SPEED (MPH) ST.DEV.	TEMPERATURE MEAN °F	TEMPERATURE ST.DEV.
61	200	229	15	10.0	2.2	19.3	2.1
32	100	228	17	9.7	3.0	19.0	2.9
16	50	233	19	7.7	1.9	18.5	3.6

PRESSURE 25.45 INCHES HG.

REL. HUMIDITY 50%

INSTRUMENTATION STATUS

HOTWIRES

HEIGHT	TYPE	REMARKS
200'	ESSA	All operative
175'	TSI	All out until DATA 2, #4 out all runs
150'	ESSA	All operative
125'	TSI	All out until DATA 2
100'	TSI	All out until DATA 3
75'	BIGGS	SERIOUS ANALOG RECORDER SLOWDOWN DATA 6-12 MISSING
50'	BIGGS	" " " " DATA 6-12 MISSING

PROFILE

CUP ANEMOMETERS	(FT/SEC)
61 m	13.2
32 m	11.9
16 m	10.6

TABLE 2-5. METEOROLOGICAL CONDITIONS AND INSTRUMENTATION STATUS DURING FLIGHT TESTS OF DC-8-63, FEBRUARY 19, 1970

DC8-63F ACFT SERIES 13:05:30 - 15:05:30 MST

FEBRUARY 19 1970

HEIGHT METERS	HEIGHT FEET	DIRECTION (°True) MEAN	DIRECTION (°True) ST. DEV.	SPEED (MPH) MEAN	SPEED (MPH) ST.DEV.	TEMPERATURE MEAN °F	TEMPERATURE ST.DEV.
61	200	355	84	5.9	2.0	30.9	1.0
32	100	353	89	5.7	2.5	31.9	0.5
16	50	351	93	5.4	2.0	32.1	0.6

PRESSURE

25.43 INCHES HG.

REL. HUMIDITY

32%

INSTRUMENTATION STATUS

HOTWIRES

HEIGHT	TYPE	REMARKS
200'	ESSA	All operative
175'	TSI	#4 out for all runs
150'	ESSA	All operative
125'	TSI	All operative
100'	TSI	All operative
75'	BIGGS	All operative
50'	BIGGS	#3 out for all runs

PROFILE

CUP ANEMOMETERS (FT/SEC)

61 m	7.5
32 m	7.3
16 m	7.0

TABLE 2-6. METEOROLOGICAL CONDITIONS AND INSTRUMENTATION STATUS DURING FLIGHT TESTS OF DC-8-33, FEBRUARY 20, 1970

DC8-33 ACFT SERIES 08:02:30 - 10:02:30 MST

FEBRUARY 20 1970

HEIGHT METERS	HEIGHT FEET	DIRECTION (°True) MEAN	DIRECTION (°True) ST. DEV.	SPEED (MPH) MEAN	SPEED (MPH) ST.DEV.	TEMPERATURE MEAN °F	TEMPERATURE ST.DEV.
61	200	51	7	11.9	2.1	16.4	3.0
32	100	44	10	10.4	2.7	16.6	3.6
16	50	45	11	9.8	2.8	16.7	3.5

PRESSURE 25.46 INCHES HG.

REL. HUMIDITY 52%

INSTRUMENTATION STATUS

HOTWIRES

HEIGHT	TYPE	REMARKS
200'	ESSA	All operative
175'	TSI	#4 out for all runs
150'	ESSA	All operative
125'	TSI	All operative
100'	TSI	All operative
75'	BIGGS	All operative
50'	BIGGS	#1 & #2 out for all runs

PROFILE

CUP ANEMOMETERS	(FT/SEC)
61 m	16.8
32 m	14.8
16 m	13.8

TABLE 2-7. METEOROLOGICAL CONDITIONS AND INSTRUMENTATION STATUS DURING FLIGHT TESTS OF C5A, FEBRUARY 20, 1970

C5A #2 ACFT SERIES 13:55:20 - 15:55:20 MST

FEBRUARY 20 1970

HEIGHT METERS	HEIGHT FEET	DIRECTION (°True) MEAN	DIRECTION (°True) ST. DEV.	SPEED (MPH) MEAN	SPEED (MPH) ST.DEV.	TEMPERATURE MEAN °F	TEMPERATURE ST.DEV.	PRESSURE
61	200	64	28	8.6	2.4	35.4	1.9	25.38 INCHES HG.
32	100	61	20	8.0	2.0	36.3	1.1	REL. HUMIDITY
16	50	62	24	7.7	2.5	36.6	1.1	31%

INSTRUMENTATION STATUS

HOTWIRES

HEIGHT	TYPE	REMARKS
200'	ESSA	All operative
175'	TSI	#4 out for all runs
150'	ESSA	All operative
125'	TSI	All operative
100'	TSI	All operative
75'	BIGGS	All operative
50'	BIGGS	#1 & #2 out for all runs

PROFILE
CUP ANEMOMETERS (FT/SEC)

61 m	12.0
32 m	11.5
16 m	10.9

TABLE 2-8. METEOROLOGICAL CONDITIONS AND INSTRUMENTATION STATUS DURING FLIGHT TESTS OF 727-100, FEBRUARY 21, 1970

727 ACFT SERIES 07:36:37 - 09:36:37 MST

FEBRUARY 21 1970

HEIGHT METERS	HEIGHT FEET	DIRECTION (°True) MEAN	DIRECTION (°True) ST. DEV.	SPEED (MPH) MEAN	SPEED (MPH) ST.DEV.	TEMPERATURE MEAN °F	TEMPERATURE ST.DEV.
61	200	57	7	9.6	1.8	-	-
32	100	54	14	7.3	2.6	18.2	2.2
16	50	51	21	6.0	1.9	16.8	3.0

PRESSURE 25.30 INCHES HG.

REL. HUMIDITY 54%

INSTRUMENTATION STATUS

HOTWIRES

HEIGHT	TYPE	REMARKS
200'	ESSA	All operative
175'	TSI	#4 out for all runs
150'	ESSA	All operative
125'	TSI	All operative (all wires rotated 45° clockwise about probe axis)
100'	TSI	All operative
75'	BIGGS	All operative
50'	BIGGS	#1 & #2 out for all runs

PROFILE

CUP ANEMOMETERS (FT/SEC)

61 m	13.3
32 m	10.5
16 m	8.4

TABLE 2-9. METEOROLOGICAL CONDITIONS AND INSTRUMENTATION STATUS DURING FLIGHT TESTS ON DC-9-10, FEBRUARY 21, 1970

DC9 ACFT SERIES 10:40:00 - 12:30:00 MST

FEBRUARY 21 1970

HEIGHT METERS	HEIGHT FEET	DIRECTION (°True) MEAN	DIRECTION (°True) ST. DEV.	SPEED (MPH) MEAN	SPEED (MPH) ST. DEV.	TEMPERATURE MEAN °F	TEMPERATURE ST. DEV.	PRESSURE
61	200	043	13	9.2	1.4	32.6	3.0	25.29 INCHES HG.
32	100	041	14	8.6	1.6	33.6	2.8	REL. HUMIDITY
16	50	045	16	8.4	1.6	33.7	2.9	31%

INSTRUMENTATION STATUS

HOTWIRES

HEIGHT	TYPE	REMARKS
200'	ESSA	All operative
175'	TSI	#4 out for all runs
150'	ESSA	All operative
125'	TSI	All operative
100'	TSI	All operative
75'	BIGGS	All operative
50'	BIGGS	#1 & #2 out for all runs

PROFILE
CUP ANEMOMETERS (FT/SEC)

61 m	12.7
32 m	12.3
16 m	11.7

TABLE 2-10. METEOROLOGICAL CONDITIONS AND INSTRUMENTATION STATUS DURING FLIGHT TESTS OF LEAR JET 24, FEBRUARY 21, 1970

LEAR JET ACFT SERIES 13:54:00 - 15:08:00 MST

FEBRUARY 21 1970

HEIGHT METERS	HEIGHT FEET	DIRECTION (°True) MEAN	DIRECTION (°True) ST. DEV.	SPEED (MPH) MEAN	SPEED (MPH) ST.DEV.	TEMPERATURE MEAN °F	TEMPERATURE ST.DEV.
61	200	073	50	5.8	1.8	40.0	1.1
32	100	060	64	5.1	1.8	41.0	0.7
16	50	048	87	4.9	1.7	41.3	0.8

PRESSURE 25.24 INCHES HG.

REL. HUMIDITY 23%

INSTRUMENTATION STATUS

HOTWIRES

HEIGHT	TYPE	REMARKS
200'	ESSA	All operative
175'	TSI	#4 out for all runs
150'	ESSA	All operative
125'	TSI	All operative
100'	TSI	All operative
75'	BIGGS	All operative
50'	BIGGS	#1 & #2 out for all runs

PROFILE
CUP ANEMOMETERS (FT/SEC)

61 m	8.9
32 m	8.4
16 m	7.8

APPENDIX C

DATA PROCESSING

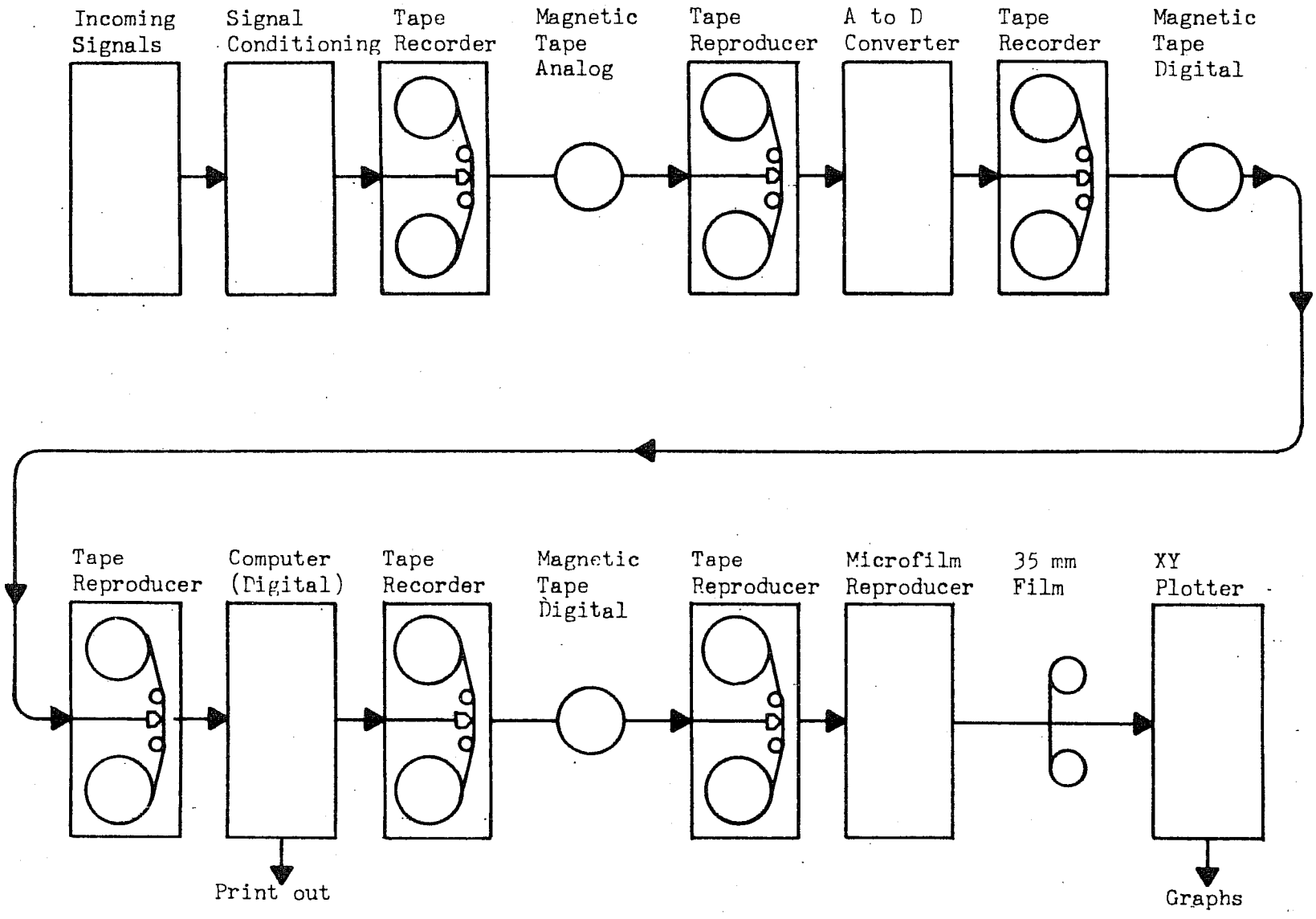


FIG. 3-1 DATA PROCESSING FLOW CHART

APPENDIX D

FLIGHT TEST AIRCRAFT

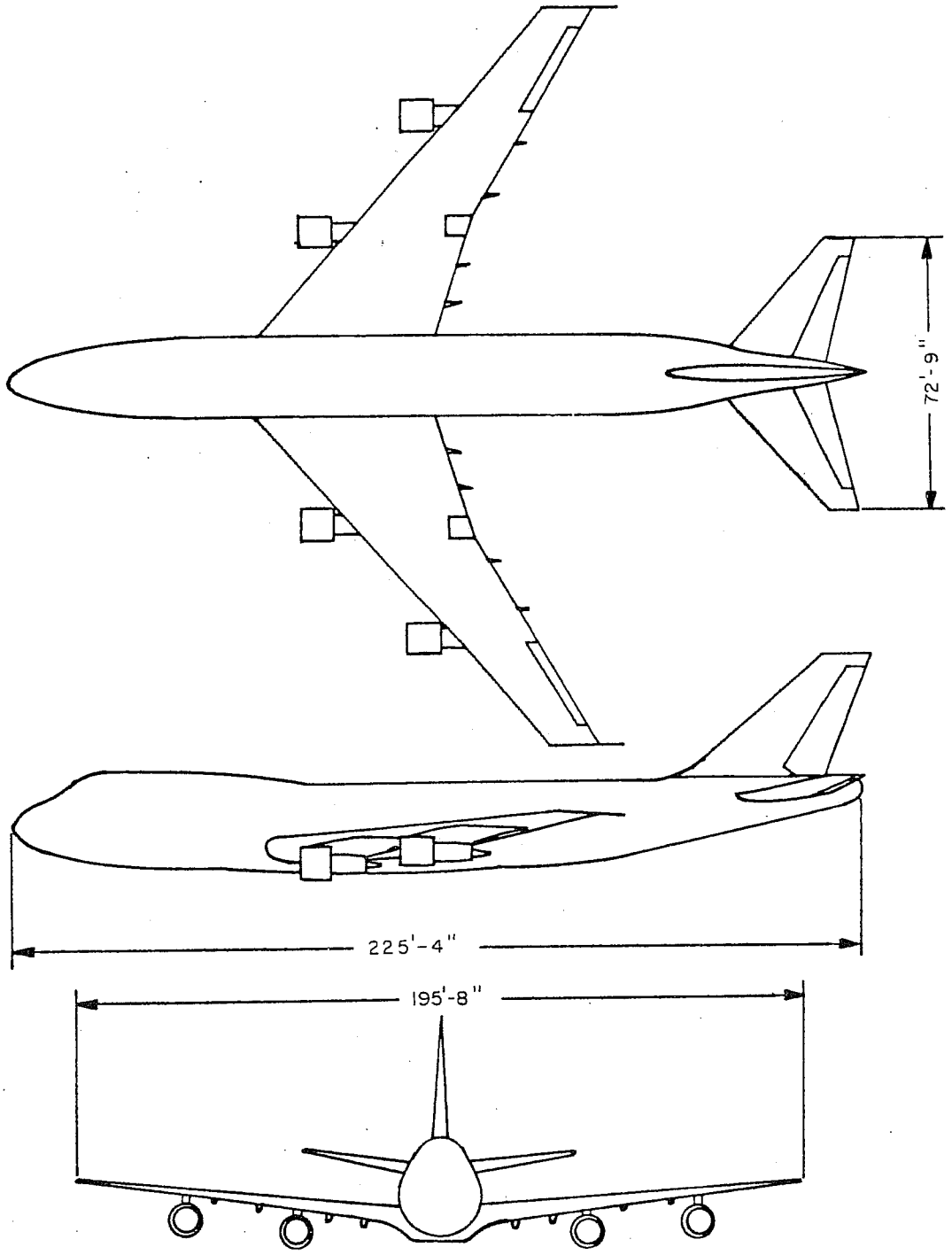


FIG. 4-1 BOEING 747

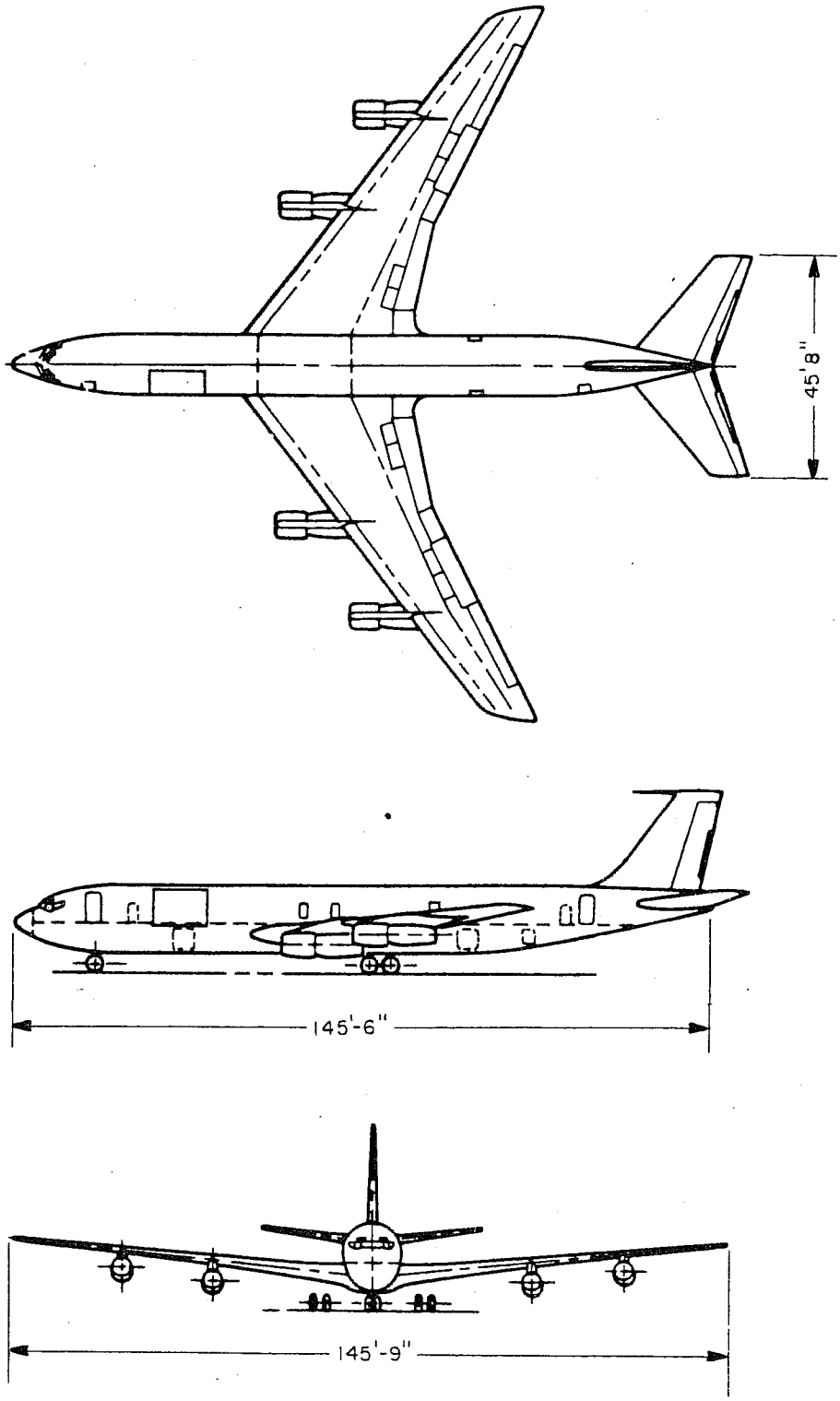


FIG. 4-2 BOEING 707-320C

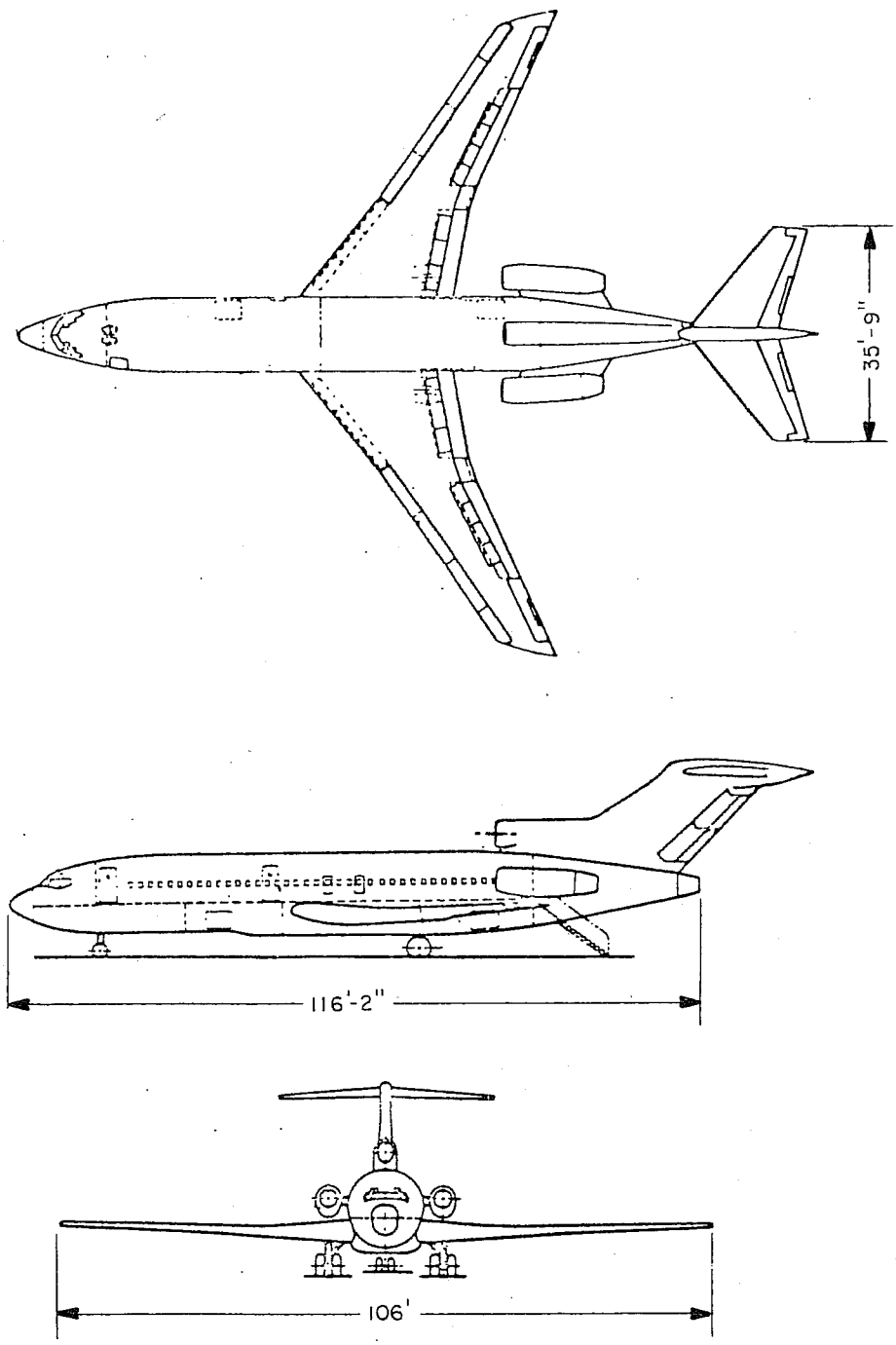


FIG. 4-3 BOEING 727-100

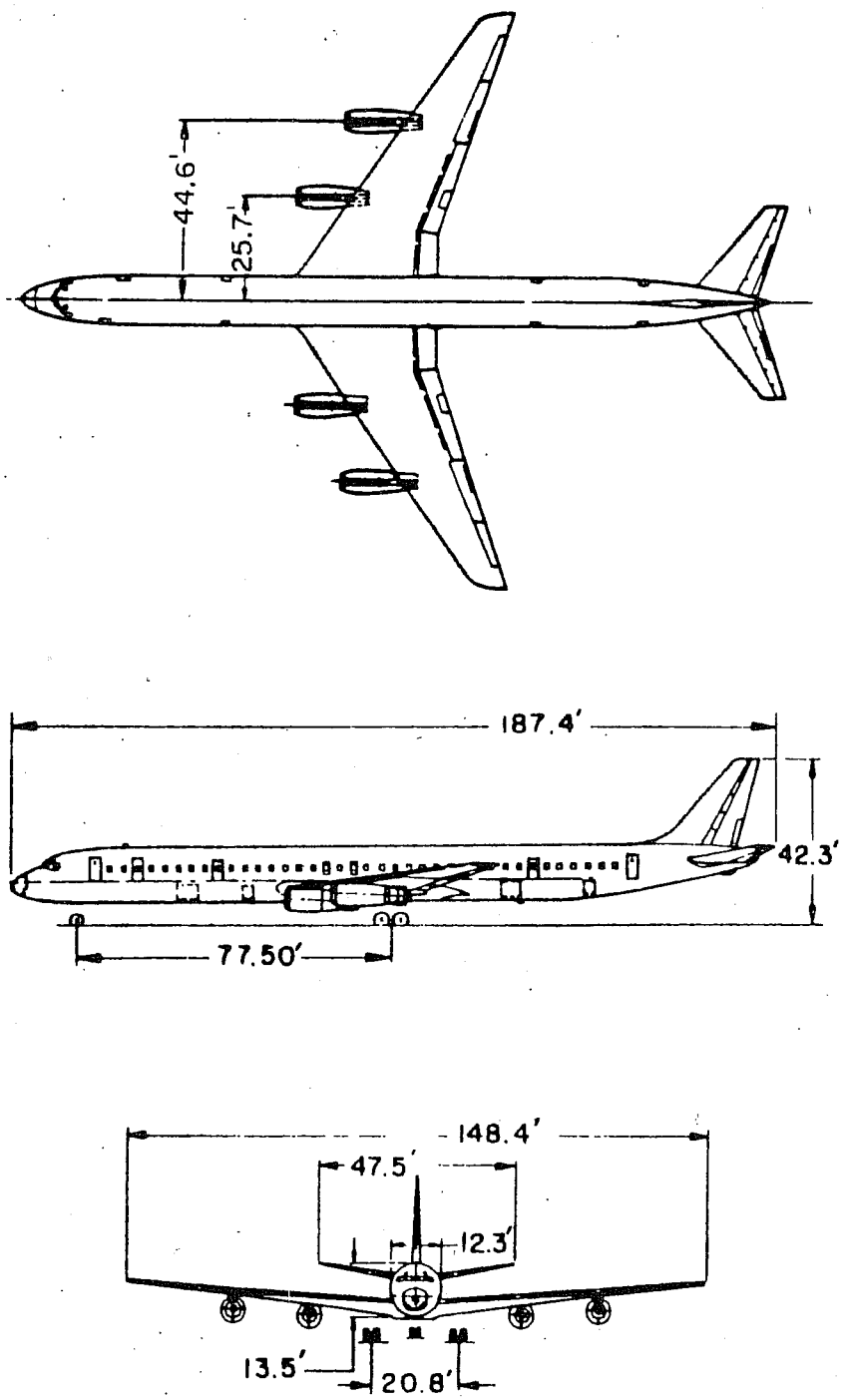


FIG. 4-4 DOUGLAS DC-8-63F

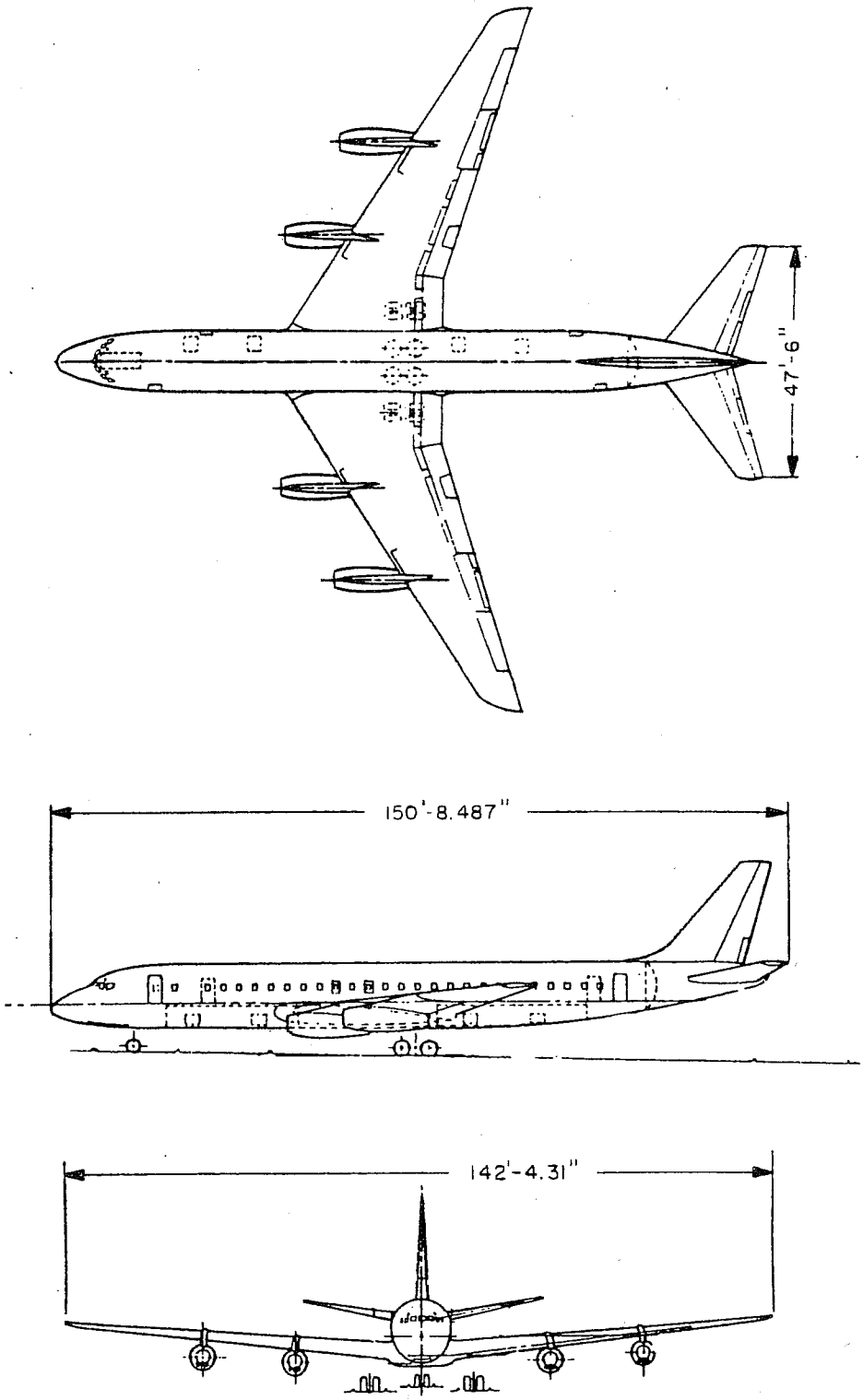


FIG. 4-5 DOUGLAS DC-8-33

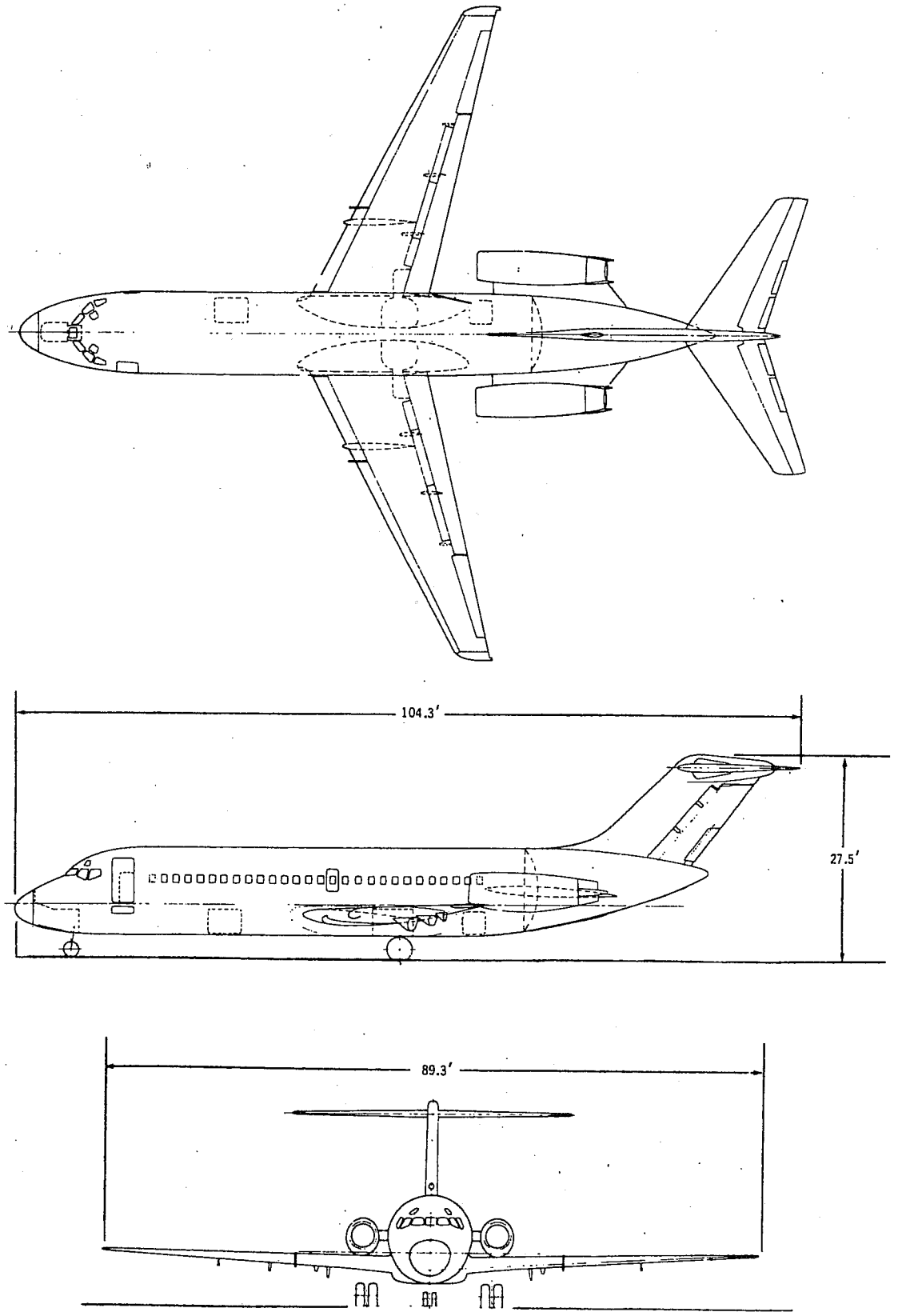


FIG. 4-6 DOUGLAS DC-9-10

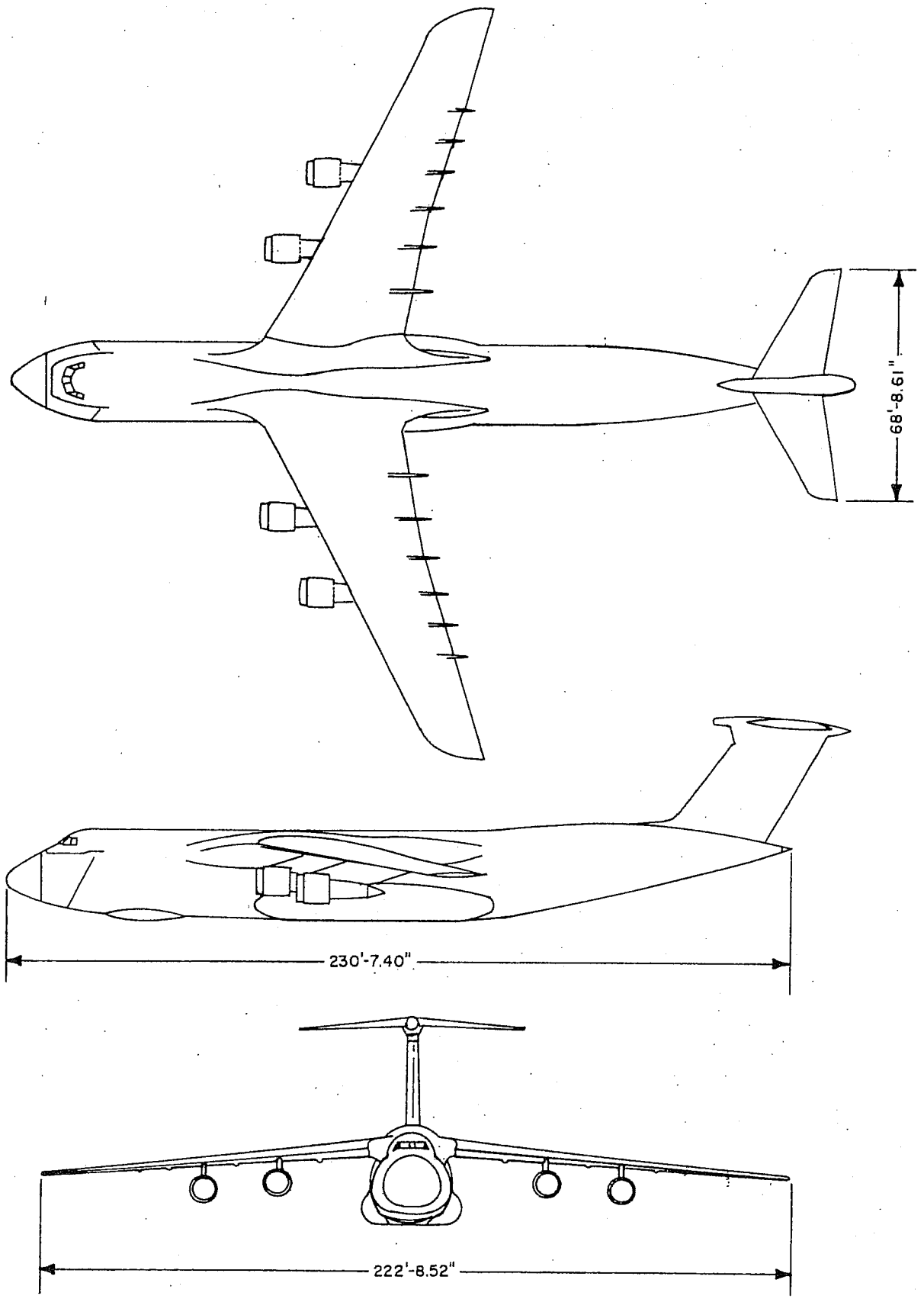


FIG. 4-7 LOCKHEED C5A

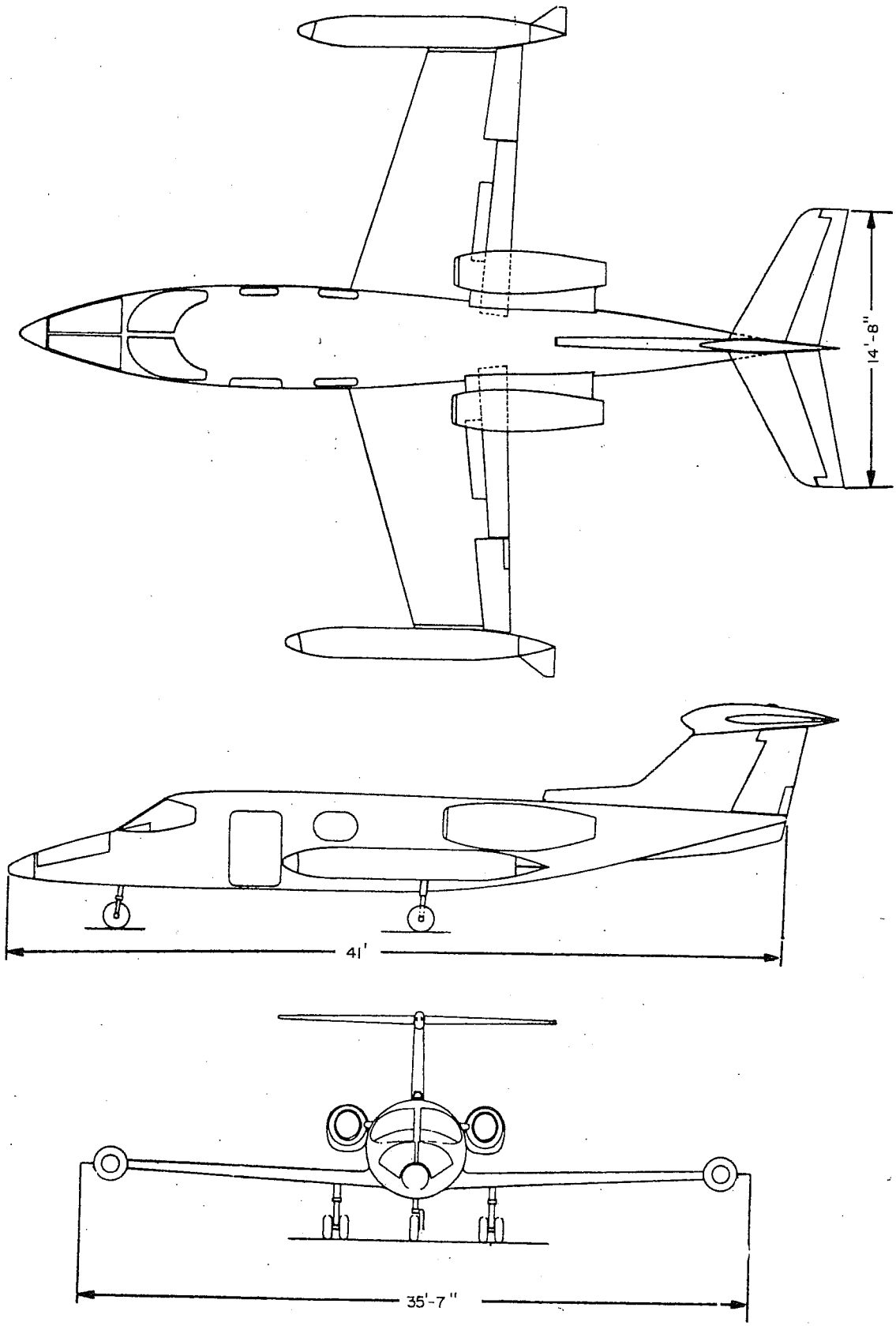


FIG. 4-8 LEAR JET - 24

TABLE 4-1. PERTINENT PHYSICAL AND PERFORMANCE CHARACTERISTICS OF TEST AIRCRAFT

	Boeing 747	Boeing 707-320C	Boeing 727-100	Douglas DC-8-63F	Douglas DC-8-33	Douglas DC-9-10	Lockheed C-5A	Learjet Mod 24
Wing Span (ft)	195.67	145.75	108.00	148.42	142.42	89.30	222.71	35.58
Wing Area (ft^2)	5500	2892	1650	2927	2884	934	6200	232
Aspect Ratio	6.95	7.36	7.67	7.52	7.03	7.40	7.20	5.02
Mean Aerodynamic Chord (in)	327.8	272.3	180.0	272.8	275.9	141.5	370.5	84.5
Takeoff Weight (max) (lbs)	710,000	336,000	160,000	355,000	315,000	90,700	728,000	13,000
Takeoff Speed (kts)	170	170	138	163	162	144	140	132
Flap Setting	1°	14°	25°	23°	25°	20°	10°	20°
Landing Weight (max) (lbs)	564,000	247,000	142,500	275,000	207,000	81,700	635,850	11,880
Landing Speed (kts)	142	137	133	150	133	134	131	127
Flap Setting	40°	50°	40°	50°	50°	50°	41°	40°

APPENDIX E

FLIGHT TEST DATA SHEETS

TABLE 5-1. BOEING 747, FEBRUARY 18, 1970 (AM)

FLIGHT TEST DATA SHEET - VORTEX INVESTIGATION

DATE 2/18/7 AIRCRAFT BOEING 747 COMPANY PAN AMERICAN REGISTRATION RA 002

AIRCRAFT COMMANDER LOU WALLICK FIELD ELEVATION 4915 FEET TURBULENCE LEVEL NR

Run number	Fam 1	Fam 2	1	2	3	4	5	6	7	8	9	10	11	12
Time (Zulu)	1520	1529	1540	1550	1558	1607	1615	1632	1641	1650	1659	1708	1717	1736
Aircraft position (Note 1)	600'S	600'S	300'S	300'S	300'P	125'P	100'P	200'P	250'P	300'P	350'P	600'P	800'P	900'P
Pressure altitude H_p (Feet)	5330	5320	5330	5320	5320	5320	5420	5320	5300	5320	5360	5350	5360	5300
Radar altitude (Feet)	340	350	340	340	330	330	350	350	310	330	350	350	390	320
Total outside air temp. (°C)	NR →													
Wind dir. 200' level (° True)	220	220	220	220	040	020	020	020	027	010	025	026	000	010
Wind vel. 200' level (MPH)	4	4	0-2	0-2	4	2	4	7	9	7	14	10	11	14
Equivalent airspeed (Knots)	170	168	175	175	175	165	250	240	180	182	142	141	139	142
A/C Gross weight (Lbs x 1000)	606	598	593	586	581	579	576	573	569	569	559	554	550	543
Gear (Up or down)	D	D	D	D	D	D	U	U	U	U	D	D	D	D
A/C configuration (Note 2)	TO	TO	TO	TO	TO	TO	VMAX	VMAX	HLDG	HLDG	LDG	LDG	LDG	LDG
Flap setting (Degrees)	10	10	10	10	10	10	0	0	5	5	30	30	30	30
Engine pressure ratio	NR	NR	1.8	1.8	1.8	1.8	1.5	1.5	1.15	1.15	1.2	1.25	1.25	1.25
Engine RPM (%)	NR	NR	70	70	72	71	65	65	63	62	65	80	80	80
Fuel flow/engine (Lbs/hr.)	NR	NR	6000	6200	6400	6200	8000	8000	5600	5500	7000	9000	10,000	10,000
Vortex age at tower. Starboard	NR →													
Seconds approximate. Port	NR →													
Remarks	NOTES: (1) WIND SHIFTED FROM SW TO NE BETWEEN RUNS 2 & 3. (2) RISING SUN BOTHERED PILOT ON FINAL.													

Note 1: Lateral offset(feet) from tower. Note 2: TO = Takeoff, V max = 250 knots, Hldg = Holding, Ldg = Landing
Note 3: NR = Not Required/Recorded.

TABLE 5-2. LOCKHEED C5A, FEBRUARY 18, 1970 (PM)

FLIGHT TEST DATA SHEET - VORTEX INVESTIGATION

DATE 2/18/70 AIRCRAFT LOCKHEED C5A COMPANY U.S. AIR FORCE REGISTRATION AF 70168

AIRCRAFT COMMANDER MAJOR GORDEN FARNEL FIELD ELEVATION 4915 FEET TURBULENCE LEVEL NR

Run number	Fam 1	Fam 2	1	2	3	4	5	6	7	8	9	10	11	12
Time (Zulu)	NR	NR	2109	2118	2127	2134	2152	2201	2208	2216	2223	2231	2247	NR
Aircraft position (Note 1)	1000'P	NR	600P	600P	300P	1000P	800P	800P	1000P	1000P	1100P	1100P	1000P	NR
Pressure altitude H_p (Feet)	NR	NR	5000	5070	5090	5070	5010	5000	5000	5000	4980	5000	4990	NR
Radar altitude (Feet)	NR	NR	280	350	350	350	300	300	300	300	300	320	300	NR
Total outside air temp. (°C)	NR	NR	1	1	1	1	1	1	1	1	1	1	1	NR
Wind dir. 200' level (° True)	040	NR	040	040	040	040	010	025	020	050	030	050	025	NR
Wind vel. 200' level (MPH)	5	NR	5	8	11	8	8	8	10	13	15	5	8	NR
Equivalent airspeed (Knots)	133	NR	138	142	135	142	127	122	198	203	193	129	127	NR
A/C Gross weight (Lbs x 1000)	458.5	NR	457.0	455.5	453.8	451.2	446.0	442.6	438.0	435.8	432.0	431.0	428.0	NR
Gear (Up or down)	D	NR	D	D	D	D	D	D	U	U	U	U	U	NR
A/C configuration (Note 2)	LDG	NR	TO	TO	TO	TO	LDG	LDG	HLDG	HLDG	HLDG	LDG	LDG	NR
Flap setting (Degrees)	NR	NR	TO	TO	TO	TO	LDG	LDG	O	O	O	LDG	LDG	NR
Engine pressure ratio	NR	NR	2.70	2.70	2.71	2.71	2.90	2.90	2.91	2.94	2.94	2.92	2.92	NR
Engine RPM (%)	NR	NR	82	81	82	81	85	85	80	80	80	82	84	NR
Fuel flow/engine (Lbs/hr.)	NR	NR	6000	5900	6000	5900	6500	5700	4800	4700	4750	5600	4800	NR
Vortex age at tower. Starboard	NR	NR	NR	NR	NR	1:30	1:00	NR	NR	NR	1:00	1:20	0:50	NR
Seconds approximate. Port	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
Remarks														

NOTES: (1) RUN 12 NOT PERFORMED DUE TO A/C BEING LOW ON GAS
(2) FOR FLAP SETTING, PILOT LISTED CONFIGURATION VICE ° FLAPS
(3) AIRCRAFT VERY LIGHT DURING THIS TEST PERIOD
(4) AFTER 4TH PASS, LOWER ALTITUDE TO 300' AGL REQUESTED & GRANTED BY AEC.

Note 1: Lateral offset(feet) from tower. Note 2: TO = Takeoff, V max = 250 knots, Hldg = Holding, Ldg = Landing
Note 3: NR = Not Required/Recorded.

TABLE 5-3. BOEING 707-320C, FEBRUARY 19, 1970 (AM)

FLIGHT TEST DATA SHEET - VORTEX INVESTIGATION

DATE 2/19/70 AIRCRAFT BOEING 707-320C COMPANY UNITED ARAB REPUBLIC REGISTRATION N 4094B

AIRCRAFT COMMANDER L. WALLICK FIELD ELEVATION 4915 FEET TURBULENCE LEVEL NR

Run number	Fam 1	Fam 2	1	2	3	4	5	6	7	8	9	10	11	12
Time (Zulu)	NR	NR	1400	1408	1417	1427	1435	1442	1450	1458	1507	1515	1525	1534
Aircraft position (Note 1)	600'S	NR	600'S	500'S	500'S	600'S	600'S	600'S	600'S	600'S	600'S	600'S	600'S	600'S
Pressure altitude H_p (Feet)	NR	NR	5200	5200	5180	5200	5170	5200	5220	5175	5245	5245	5260	5250
Radar altitude (Feet)	280	NR	280	280	270	280	250	270	300	260	325	225	240	230
Total outside air temp. (°C)	NR	NR	2	2	2	5	4	4	4	4	4	4	4	4
Wind dir. 200' level (° True)	210	NR	220	230	235	230	230	235	280	220	215	210	205	200
Wind vel. 200' level (MPH)	6	NR	5	4	12	9	5	7	8	5	7	9	7	7
Equivalent airspeed (Knots)	170	NR	160	169	158	162	260	260	222	228	152	145	140	148
A/C Gross weight (Lbs x 1000)	267.5	NR	267.0	265.5	264	262	259.5	257.5	256	255	253.5	251.5	249.5	247.0
Gear (Up or down)	D	NR	D	D	D	D	U	U	U	U	D	D	D	D
A/C configuration (Note 2)	APP	NR	APP	APP	APP	APP	VMAX	VMAX	HLDG	HLDG	LDG	LDG	LDG	LDG
Flap setting (Degrees)	14	NR	14	14	14	14	0	0	0	0	50	50	50	50
Engine pressure ratio	NR	NR	1.20	1.25	1.25	1.28	1.25	1.20	1.50	1.50	1.50	1.50	1.45	1.40
Engine RPM (%)	NR	NR	75	78	76	76	80	90	70	64	89	59	58	NR
Fuel flow/engine (Lbs/hr.)	NR	NR	1500	1800	1800	1800	1800	1400	1700	1300	2800	2800	2500	NR
Vortex age at tower. Starboard	NR	NR	30	25	20	38	70	60	60	50	45	1:30	0:55	0:60
Seconds approximate. Port	NR	NR					65	NR	NR	45	NR	1:00	0:45	0:50
Remarks														

Note 1: Lateral offset(feet) from tower. Note 2: TO = Takeoff, V max = 250 knots, Hldg = Holding, Ldg = Landing

Note 3: NR = Not Required/Recorded.

TABLE 5-4. DOUGLAS DC-8-63F, FEBRUARY 19, 1970 (PM)

FLIGHT TEST DATA SHEET - VORTEX INVESTIGATION

DATE 2/19/70 AIRCRAFT DOUGLAS DC-8-63F COMPANY FLYING TIGERS REGISTRATION 7957

AIRCRAFT COMMANDER CAPT W. KORTH FIELD ELEVATION 4915 FEET TURBULENCE LEVEL CONVECTIVE INSTABILITY

Run number	Fam 1	Fam 2	1	2	3	4	5	6	7	8	9	10	11	12
Time (Zulu)	NR	NR	2025	2034	2044	2052	2100	2109	2119	2129	2138	2147	2155	2204
Aircraft position (Note 1)	600'	NR	600'S	600'P	400'P	600'P	600'P	300'S	500'P	300'P	50'P	300'P	300'P	20'P
Pressure altitude H_p (Feet)	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
Radar altitude (Feet)	NR	NR	350	350	280	250	250	300	300	290	300	300	280	300
Total outside air temp. (°C)	NR	NR	-1	-1	0	0	0	-1	0	0	0	0	0	0
Wind dir. 200' level (° True)	NR	NR	110	090	—	065	080	—	075	010	—	035	—	—
Wind vel. 200' level (MPH)	NR	NR	5	5	CALM	3	4	CALM	5	3	CALM	4	CALM	CALM
Equivalent airspeed (Knots)	NR	NR	176	176	175	205	205	205	148	147	147	168	168	174
A/C Gross weight (Lbs x 1000)	NR	NR	282.0	279.0	275.0	273.0	271.6	270.5	267.2	264.0	261.0	258.1	255.6	252.8
Gear (Up or down)	NR	NR	D	D	D	U	U	U	D	D	D	D	D	D
A/C configuration (Note 2)	NR	NR	TO	TO	TO	HLDG	HLDG	HLDG	LDG	LDG	LDG	APP	APP	APP
Flap setting (Degrees)	NR	NR	23	23	23	0	0	0	50	50	50	23	23	23
Engine pressure ratio	NR	NR	1.2	1.3	1.4	1.2	1.2	1.2	1.3	1.4	1.5	1.3	1.3	1.4
Engine RPM (%)	NR	NR	83	84	91	88	87	87	NR	93	93	87	90	92
Fuel flow/engine (Lbs/hr.)	NR	NR	5200	4200	4800	NR	3400	3200	NR	5000	6000	4000	3900	3900
Vortex age at tower. Starboard	NR	NR	NR	NR	NR	1:00	NR	NR	1:00	0:45	NR	0:30	NR	NR
Seconds approximate. Port	NR	NR	NR	NR	NR	NR	NR	NR	2:00	NR	NR	NR	NR	NR
Remarks	NOTES: (1) FAM HITS DUE TO PILOT FLYING HIGH (IN SPITE OF RADAR ALTIMETER INDICATION LISTED ABOVE) & VARIABLE TO CALM WIND CONDITIONS MAKING IT DIFFICULT TO POSITION A/C PROPERLY. POSSIBILITY OF THERMALS ALSO EXISTED.													

Note 1: Lateral offset(feet) from tower. Note 2: TO = Takeoff, V max = 250 knots, Hldg = Holding, Ldg = Landing
Note 3: NR = Not Required/Recorded.

TABLE 5-5. DOUGLAS DC-8-33. FEBRUARY 20. 1970 (AM)

FLIGHT TEST DATA SHEET - VORTEX INVESTIGATION

DATE 2/20/70 AIRCRAFT DOUGLAS DC-8-33 COMPANY UNITED AIR LINES REGISTRATION N-8207U

AIRCRAFT COMMANDER CAPTAIN C. BECK FIELD ELEVATION 4915 FEET TURBULENCE LEVEL NR

Run number	Fam 1	Fam 2	1	2	3	4	5	6	7	8	9	10	11	12
Time (Zulu)	NR	NR	1516	1524	1535	1545	1553	1602	1611	1620	1629	1636	1646	1655
Aircraft position (Note 1)	600'P	NR	350'P	800'P	600'P	700'P	700'P	800'P	800'P	700'P	700'P	800'P	800'P	800'P
Pressure altitude H_p (Feet)	4600	NR	4600	4600	4600	4600	4600	4600	4600	4600	4600	4600	4600	4600
Radar altitude (Feet)	NR	NR	330	360	220	340	280	290	300	300	300	290	290	240
Total outside air temp (°C)	-11	NR	-11	-11	-10	-10	-9	-9	-9	-9	-9	-9	-9	-8
Wind dir. 200' level (° True)	070	NR	025	073	065	065	025	073	068	073	065	070	078	068
Wind vel. 200' level (MPH)	10	NR	9	7	4	8	7	9	11	8	10	8	11	11
Equivalent airspeed (Knots)	150	NR	141	142	143	141	140	142	130	130	130	200	200	200
A/C Gross weight (Lbs x 1000)	198.5	NR	198.0	196.0	193.0	191.0	188.0	185.0	182.0	179.0	176.5	175.0	174.0	172.5
Gear (Up or down)	D	NR	D	D	D	D	D	D	D	D	D	U	U	U
A/C configuration (Note 2)	TO	NR	TO	TO	TO	TO	TO	TO	LDG	LDG	LDG	HLDG	HLDG	HLDG
Flap setting (Degrees)	25	NR	25	25	25	25	25	25	50	50	50	0	0	0
Engine pressure ratio	NR	NR	NR	1.45	1.70	1.68	1.69	1.70	1.87	1.89	1.80	1.25	1.27	1.30
Engine RPM (%)	NR	NR	NR	83	84	84	85	86	88	87	86	78	78	78
Fuel flow/engine (Lbs/hr.)	NR	NR	3800	4500	4700	4900	4700	4800	5000	5000	5100	2200	2900	3000
Vortex age at tower. Starboard	NR	NR	NR	45	0:50	NR	40	NR	NR	0:35	45	0:50	0:45	0:45
Seconds approximate. Port	NR	NR	NR		1:15	NR		0:45	0:50	0:40		1:00	0:50	0:50

Remarks

NOTE: (5) CLEAN CONFIGURATION VORTICES WERE PERSISTENT TUBES.

NOTES: (1) RUNS SUN BATHED PILOT ON FINAL
(2) 20 MINUTE BLACK SMOKE BOMB FOR PILOT TRACK ROLLED PHOTOGRAPHY & WAS REMOVED
(3) PARTIAL FLAP VORTICES DISINTEGRATE MORE RAPIDLY THAN CLEAN.
(4) FULL FLAP VORTICES DISINTEGRATE MORE RAPIDLY THAN PARTIAL FLAP CONFIG

Note 1: Lateral offset(feet) from tower. Note 2: TO = Takeoff, V max = 250 knots, Hldg = Holding, Ldg = Landing
Note 3: NR = Not Required/Recorded.

TABLE 5-6. LOCKHEED C5A, FEBRUARY 20, 1970 (PM)

FLIGHT TEST DATA SHEET - VORTEX INVESTIGATION

DATE 2/20/70 AIRCRAFT LOCKHEED C5A COMPANY U.S. AIR FORCE REGISTRATION 67-0168

AIRCRAFT COMMANDER MAJOR G. TONNI FIELD ELEVATION 4915 FEET TURBULENCE LEVEL NR

Run number	Fam 1	Fam 2	1	2	3	4	5	6	7	8	9	10	11	12
Time (Zulu)	NR	NR	2006	2014	2023	2034	2043	2055	2106	2115	2124	2132	2141	2148
Aircraft position (Note 1)	700'P	NR	800'P	800'P	700'P	700'P	700'P	700'P	700'P	700'P	700'P	700'P	700'P	700'P
Pressure altitude H_p (Feet)	NR	NR	5270	5280	5290	5290	5290	5290	5240	5245	5240	5260	5260	5250
Radar altitude (Feet)	300	NR	240	250	200	210	200	200	205	210	200	220	220	220
Total outside air temp. (°C)	NR	NR	10	9	9	8	7	6	7	7	7	7	7	7
Wind dir. 200' level (° True)	070	NR	075	106	086	065	065	085	095	083	088	068	080	—
Wind vel. 200' level (MPH)	8	NR	6	5	7	7	7	6	7	3	5	3	5	CALM
Equivalent airspeed (Knots)	205	NR	208	213	205	128	128	125	122	122	122	202	204	205
A/C Gross weight (Lbs x 1000)	481.6	NR	480.6	479.4	478.3	472.3	471.7	462.3	462.0	459.2	457.0	455.4	454.5	452.8
Gear (Up or down)	U	NR	U	U	U	U	U	U	U	U	U	U	U	U
A/C configuration (Note 2)	Hldg	NR	Hldg	Hldg	Hldg	APP	APP	APP	Ldg	Ldg	Ldg	Hldg	Hldg	Hldg
Flap setting (Degrees)	0	NR	0	0	0	25	25	25	41	41	41	0	0	0
Engine pressure ratio	NR	NR	2.04	2.00	1.86	2.50	2.84	2.84	3.10	3.10	3.10	2.2	2.2	2.2
Engine RPM (%)	NR	NR	NR	85	80	90	90	80	85	85	85	80	80	80
Fuel flow/engine (Lbs/hr.)	NR	NR	3200	3200	3000	4500	4800	4600	5800	5800	5800	3200	3200	3200
Vortex age at tower. Starboard	50	NR	0:55	1:05	0:55	0:45	0:45	0:40	0:45	70	90	90	60	2:00
Seconds approximate. Port		NR	1:05	1:20	1:10	1:00	2:10	NR	NR					
Remarks														

NOTE: (1) LDG GEAR WAS UP ON ALL PASSES DUE TO GEAR PROBLEMS

Note 1: Lateral offset(feet) from tower. Note 2: TO = Takeoff, V max = 250 knots, Hldg = Holding, Ldg = Landing
Note 3: NR = Not Required/Recorded.

TABLE 5-7. BOEING 727-100, FEBRUARY 21, 1970 (AM)

FLIGHT TEST DATA SHEET - VORTEX INVESTIGATION

DATE 2/21/70 AIRCRAFT BOEING 727-100 COMPANY FEDERAL AVIATION ADMINISTRATION REGISTRATION N-127

AIRCRAFT COMMANDER MR ROY MOUNT FIELD ELEVATION 4915 FEET TURBULENCE LEVEL NR

Run number	Fam 1	Fam 2	1	2	3	4	5	6	7	8	9	10	11	12
Time (Zulu)	1529	1542	1552	1601	1610	1619	1627	1635	1644	1651	1659	1708	1717	1727
Aircraft position (Note 1)	600'P	600'P	600'P	650'P	650'P	650'P	650'P	550'P	675'P	675'P	625'P	600'P	500'P	500'P
Pressure altitude H_p (Feet)	4600	4600	4600	4600	4600	4600	4600	4600	4600	4600	4600	4600	4600	4600
Radar altitude (Feet)	300	305	295	300	300	280	255	250	270	230	260	250	250	240
Total outside air temp (°C)	0	0	-2	0	-2	1	2	0	1	1	-4	-3	-3	-2
Wind dir. 200' level (° True)	060	065	078	078	076	079	076	078	078	082	077	051	077	064
Wind vel. 200' level (MPH)	8	9	9	7	7	7	7	5	5	5	6	5	6	5
Equivalent airspeed (Knots)	NR	NR	140	140	140	200	200	200	200	200	126	125	124	132
A/C Gross weight (Lbs x 1000)	137.4	135.7	134.6	133.8	132.0	130.6	129.4	128.6	127.6	126.5	125.8	124.1	122.7	124.1
Gear (Up or down)	D	D	D	D	D	U	U	U	U	U	D	D	D	D
A/C configuration (Note 2)	TO	TO	TO	TO	TO	Hldg	Hldg	Hldg	Hldg	Hldg	Ldg	Ldg	Ldg	T.O.
Flap setting (Degrees)	25	25	25	25	25	0	0	0	0	0	40	40	40	25
Engine pressure ratio	1.4	1.5	1.5	1.5	1.5	1.1	1.1	1.2	1.1	1.2	1.6	1.6	1.6	1.4
Engine RPM (%)	82	84	84	84	84	67	68	74	76	78	88	87	87	85
Fuel flow/engine (Lbs/hr.)	3500	4000	4000	3900	4000	1100	1200	1400	2500	1500	5300	4800	4900	3700
Vortex age at tower. Starboard	NR	45	35	45	45	50	55	90	50	NR	60	55	45	NR
Seconds approximate. Port	NR	NR	45				65	45	60	NR	NR	65	60	NR
Remarks														

Note 1: Lateral offset(feet) from tower. Note 2: TO = Takeoff, V max = 250 knots, Hldg = Holding, Ldg = Landing
Note 3: NR = Not Required/Recorded.

TABLE 5-8. DOUGLAS DC-9-10, FEBRUARY 21, 1970 (AM)

FLIGHT TEST DATA SHEET - VORTEX INVESTIGATION

DATE 2/21/70 AIRCRAFT DOUGLAS DC-9-10 COMPANY FEDERAL AVIATION ADMINISTRATION REGISTRATION N-119

AIRCRAFT COMMANDER MR FERRELL FIELD ELEVATION 4915 FEET TURBULENCE LEVEL VERY, VERY LIGHT

Run number	Fam 1	Fam 2	1	2	3	4	5	6	7	8	9	10	11	12
Time (Zulu)	NR	NR	1750	1800	1810	1816	1826	1834	1844	1848	1850	1904	1913	1921
Aircraft position (Note 1)	600'P	NR	600'P	600'P	600'P	600'P	600'P	600'P	600'P	450'P	450'P	450'P	450'P	450'P
Pressure altitude H_p (Feet)	4440	NR	4440	4440	4440	4440	4440	4440	4440	4440	4440	4440	4440	4440
Radar altitude (Feet)	280	NR	250	280	250	250	270	250	250	250	250	300	300	275
Total outside air temp. (°C)	7	NR	7	7	7	7	7	7	7	10	10	10	10	10
Wind dir. 200' level (° True)	050	NR	057	048	055	069	057	065	050	078	062	080	062	076
Wind vel. 200' level (MPH)	6	NR	5	8	7	6	7	5	6	5	8	7	7	7
Equivalent airspeed (Knots)	140	NR	140	140	140	200	200	205	200	200	130	130	130	133
A/C Gross weight (Lbs x 1000)	77.0	NR	76.0	75.0	74.0	73.0	72.5	72.0	71.5	70.5	70.0	69.5	68.5	67.5
Gear (Up or down)	D	NR	D	D	D	U	U	U	U	U	D	D	D	D
A/C configuration (Note 2)	TO	NR	TO	TO	TO	Hldg	Hldg	Hldg	Hldg	Hldg	Ldg	Ldg	Ldg	Ldg
Flap setting (Degrees)	20	NR	20	20	20	0	0	0	0	0	50	50	50	50
Engine pressure ratio	NR	NR	1.36	1.36	1.34	1.20	1.80	1.20	1.15	1.15	1.60	1.60	1.60	1.55
Engine RPM (%)	NR	NR	82	82	82	78	78	78	78	78	88	87	88	87
Fuel flow/engine (Lbs/hr.)	NR	NR	3000	2900	2700	2000	2000	2000	2000	2000	4400	4300	4300	4200
Vortex age at tower. Starboard	45	NR	35	35	40	35	NR	50	NR	NR	35	25	NR	20
Seconds approximate. Port		NR		45		50	NR		60	NR		35	NR	NR
Remarks														

Note 1: Lateral offset(feet) from tower. Note 2: TO = Takeoff, V max = 250 knots, Hldg = Holding, Ldg = Landing
Note 3: NR = Not Required/Recorded.

TABLE 5-9. LEARJET 24, FEBRUARY 21, 1970 (PM)

FLIGHT TEST DATA SHEET - VORTEX INVESTIGATION

DATE 2/21/70 AIRCRAFT LEARJET 24 COMPANY FEDERAL AVIATION ADMINISTRATION REGISTRATION 674LJ

AIRCRAFT COMMANDER CAPT E. REDDOUT FIELD ELEVATION 4915 FEET TURBULENCE LEVEL

Run number	Fam 1	Fam 2	1	2	3	4	5	6	7	8	9	10	11	12
Time (Zulu)	NR	NR	2000	2009	2020	2030	2038	2046	2053	2106	NR	NR	NR	NR
Aircraft position (Note 1)			500'P	400'P	400'P	300'P	200'P	0'	0'	0'				
Pressure altitude H_p (Feet)			NR											
Radar altitude (Feet)			300	260	250	250	250	325	280	300				
Total outside air temp. (°C)			12	12	12	12	12	12	12	12				
Wind dir. 200' level (° True)			105	098	100	093	085	180	—	—				
Wind vel. 200' level (MPH)			2	6	5	2	9	2	Calm	Calm				
Equivalent airspeed (Knots)			136	150	136	140	129	132	190	180				
A/C Gross weight (Lbs x 1000)			12.0	12.8	12.6	12.3	12.0	11.9	11.5	11.0				
Gear (Up or down)			D	D	D	D	D	D	D	U				
A/C configuration (Note 2)			TO	TO	LDG	LDG	LDG	LDG	LDG	HLDG				
Flap setting (Degrees)			20	20	40	40	40	40	40	0				
Engine pressure ratio			1.4	1.4	1.2	1.2	1.2	1.2	1.5	1.3				
Engine RPM (%)			83	88	89	89	88	89	88	80				
Fuel flow/engine (Lbs/hr.)			1000	1000	1250	1250	1250	1250	1150	NR				
Vortex age at tower. Starboard			NR											
Seconds approximate. Port			NR											
Remarks														

NOTE: (1) NO HITS VISUALLY

(2) FLIGHT TESTING TERMINATED AFTER RUN # 8 DUE TO INABILITY TO HIT TOWER WITH A/C VORTEX

(3) RUN # 4 WAS A PULL-UP AT 1½ G'S ABREAST OF TOWER TO INCREASE WING LOADING

Note 1: Lateral offset(feet) from tower. Note 2: TO = Takeoff, V max = 250 knots, Hldg = Holding, Ldg = Landing

Note 3: NR = Not Required/Recorded.

TABLE 5-10. FLIGHT TEST SUMMARY

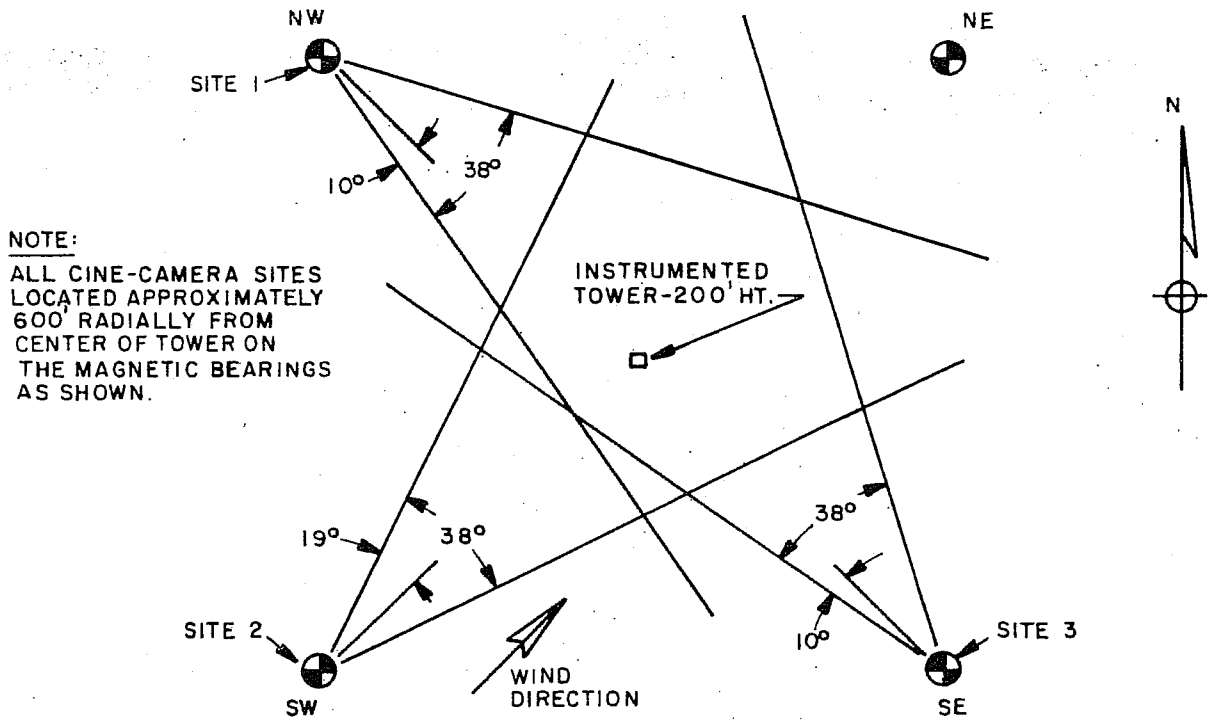
AIRCRAFT USED IN VORTEX WAKE INVESTIGATIONS AT IDAHO FALLS, IDAHO

DATE	AIRCRAFT TESTED	AIRCRAFT TEST WEIGHT RANGE (LBS x 1000)	TEST SITE FAM.	A/C CONFIGURATION T.O. H/M TOT.	LDG. H/M TOT.	HLDG H/M TOT.	Vmax H/M TOT.	VISUAL HITS	TOTAL PASSES	REMARKS
2/13/70	Boeing 727-100 FAA	NA	3	NA	NA	NA	NA	NA	3	Project pilot checkout of test area.
2/15/70	Boeing 727-100 FAA	NA	7	NA	NA	NA	NA	NA	7	Demo. flight for AEC to demo. flight safety aspects of south west passes
2/18/70	Boeing 747 Pan Am	606.0 - 543.0	1/1 2	4/0 4	4/0 4	1/1 2	0/2 2	10	14	Good data was obtained on second Fam. pass in take-off configuration.
2/18/70	Lockheed C5A Air Force	457.0 - 428.0	1	1/3 4	3/1 4	2/1 3		6	12	
2/19/70	Boeing 707-320C United Arab Airlines	267.0 - 247.0	1	4/0 4	4/0 4	2/0 2	2/0 2	12	13	
2/19/70	Douglas DC8-63F Flying Tigers	282.0 - 252.8	1	2/4 6	2/1 3	1/2 3		5	13	
2/20/70	Douglas DC8-33 United Airlines	198.0 - 172.5	1	4/2 6	3/0 3	3/0 3		10	13	
2/20/70	Lockheed C5A Air Force	480.6 - 452.8	1	3/0 3	3/0 3	4/2 6		10	13	
2/21/70	Boeing 727-100 FAA	137.4 - 124.1	2	3/1 4	2/1 3	4/1 5		9	14	
2/21/70	Douglas DC9-10 FAA	76.0 - 67.5	1	2/1 3	1/3 4	1/4 5		4	13	
2/21/70	Learjet-24 FAA	13.0 - 11.0	1	0/2 2	0/5 5	0/1 1		0	9	Only flight test aircraft on which vortex data could not be obtained.
Totals			21	36	33	30	4	66	124	

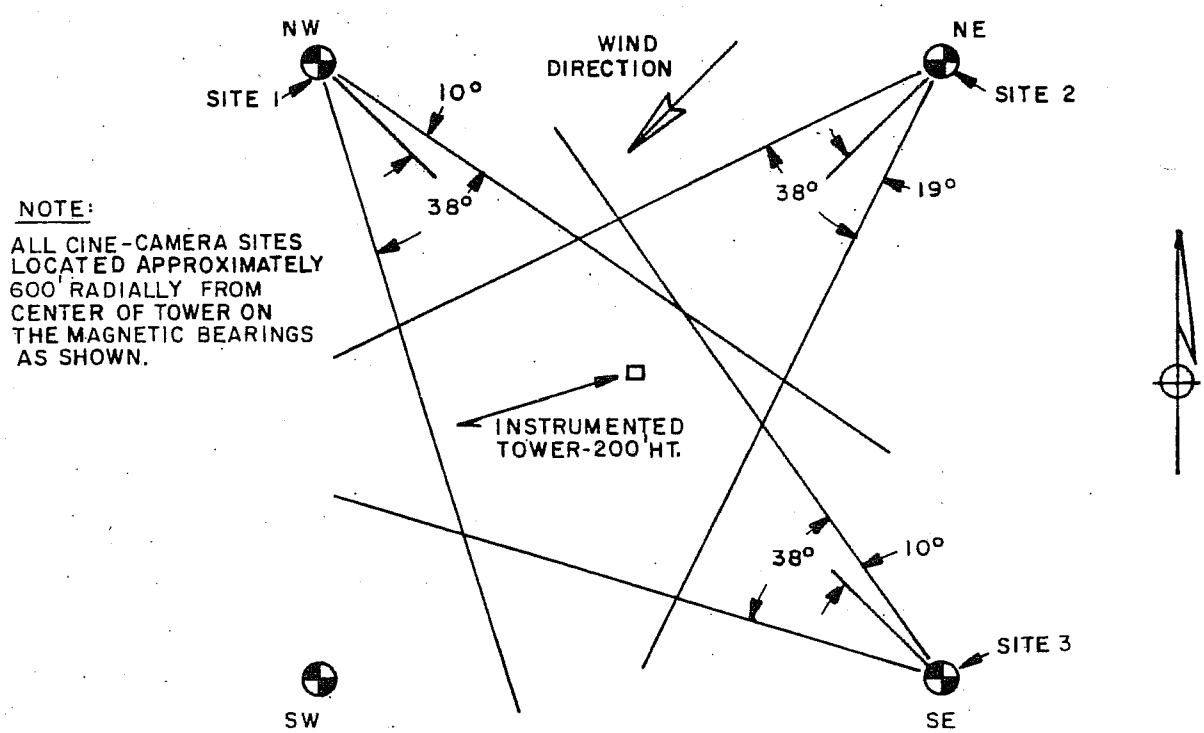
Code: NA=Not available. H=Vortex system hit tower instrumentation. M=Missed tower instrumentation.

APPENDIX F

PHOTOGRAPHY



(a) DATA-CAMERA SITE LOCATIONS FOR SOUTHWEST WIND CONDITION.



(b) DATA-CAMERA SITE LOCATIONS FOR NORTHEAST WIND CONDITION

FIG. 6-1. PLAN VIEW OF 16MM DATA MOTION PICUTRE CAMERA SITES

APPENDIX G

VORTEX VELOCITY PHOTOGRAPHIC AND TIME-HISTORY DATA

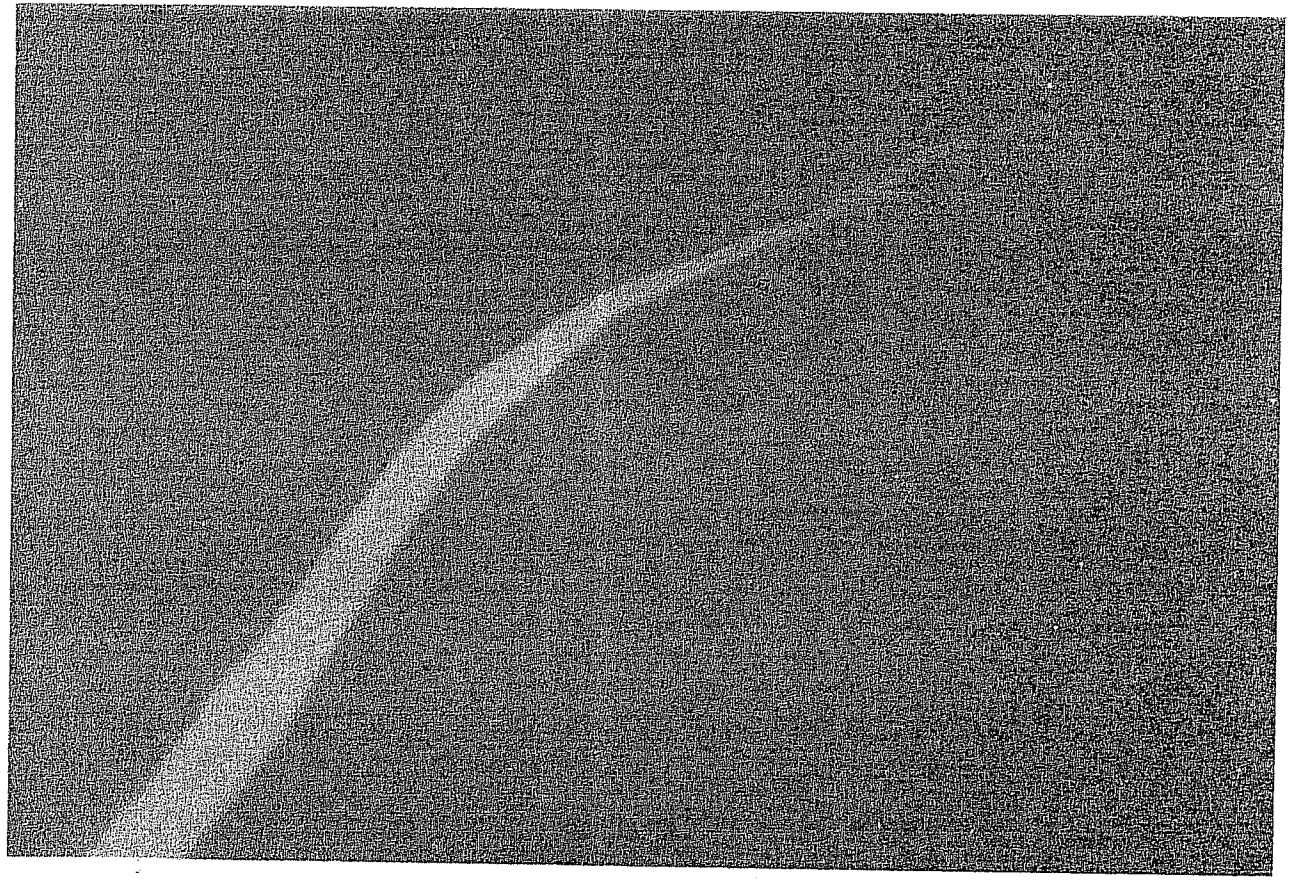


FIG. 7-1. TUBULAR TYPE VORTEX SYSTEM

FIG. 7-2. TUBULAR TYPE VORTEX SYSTEM

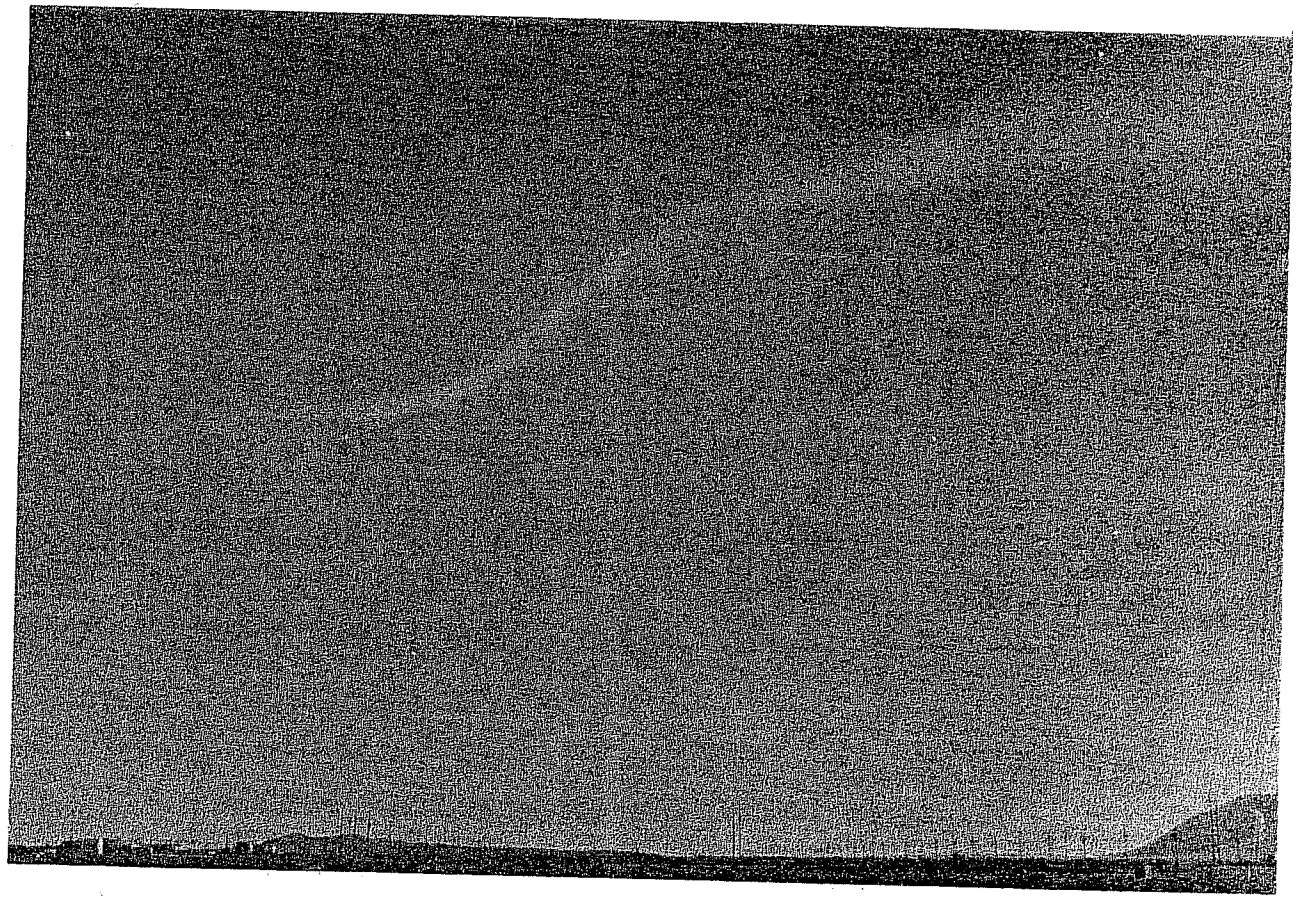


FIG. 7-3. TUBULAR TYPE VORTEX SYSTEM

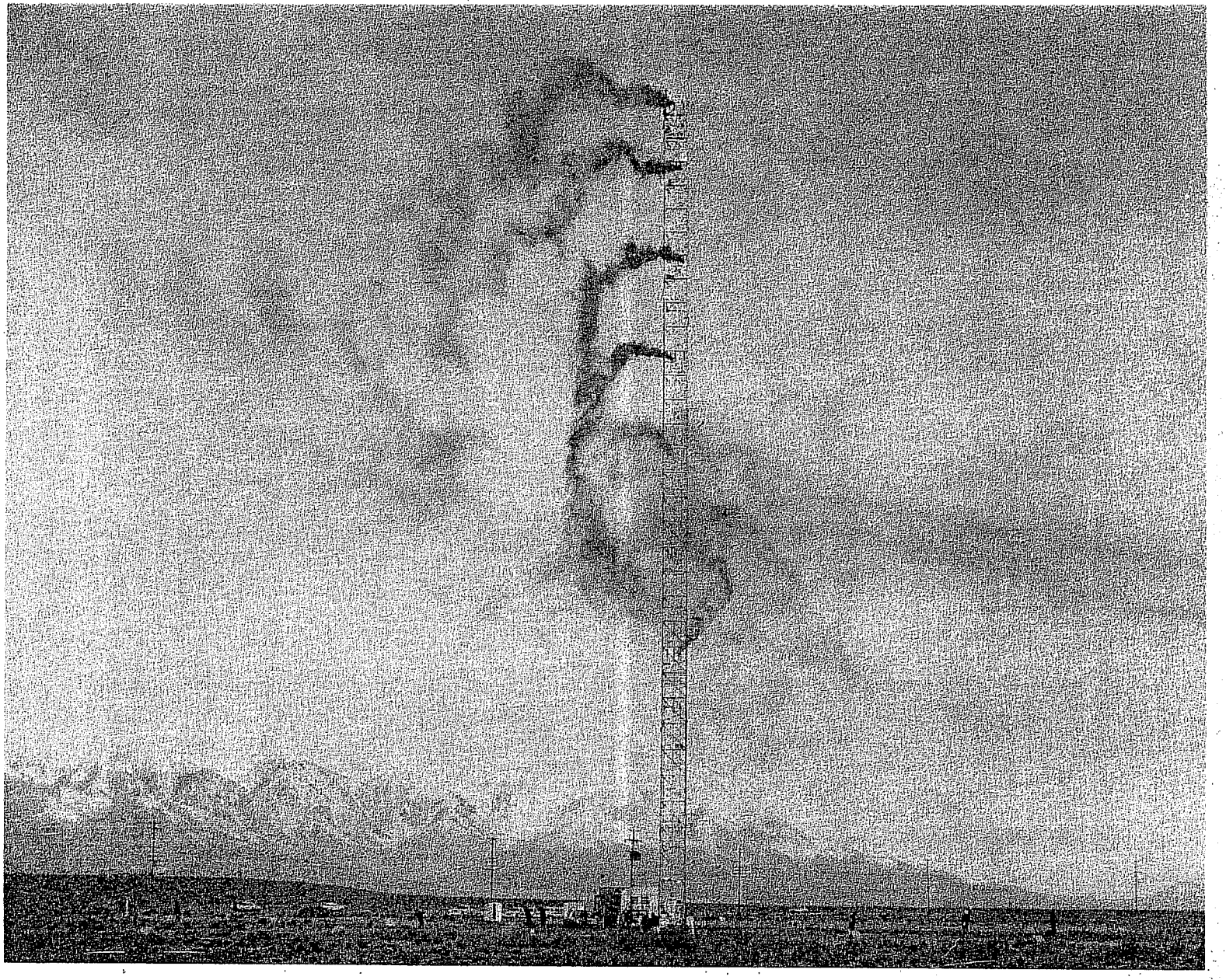


FIG. 7-4. TUBULAR TYPE VORTEX SYSTEM

DATA REPORT

Project No. 177-621-03X

(SPECIAL TASK)

MEASUREMENTS OF THE VORTEX WAKE CHARACTERISTICS OF THE BOEING 747, LOCKHEED C5A, AND OTHER AIRCRAFT (PERIOD FEBRUARY 18-21, 1970)

APPENDIX G
CONTINUED
(7-5 TO 7-195)

TEST AND EVALUATION DIVISION

Aircraft Branch

APRIL 1970

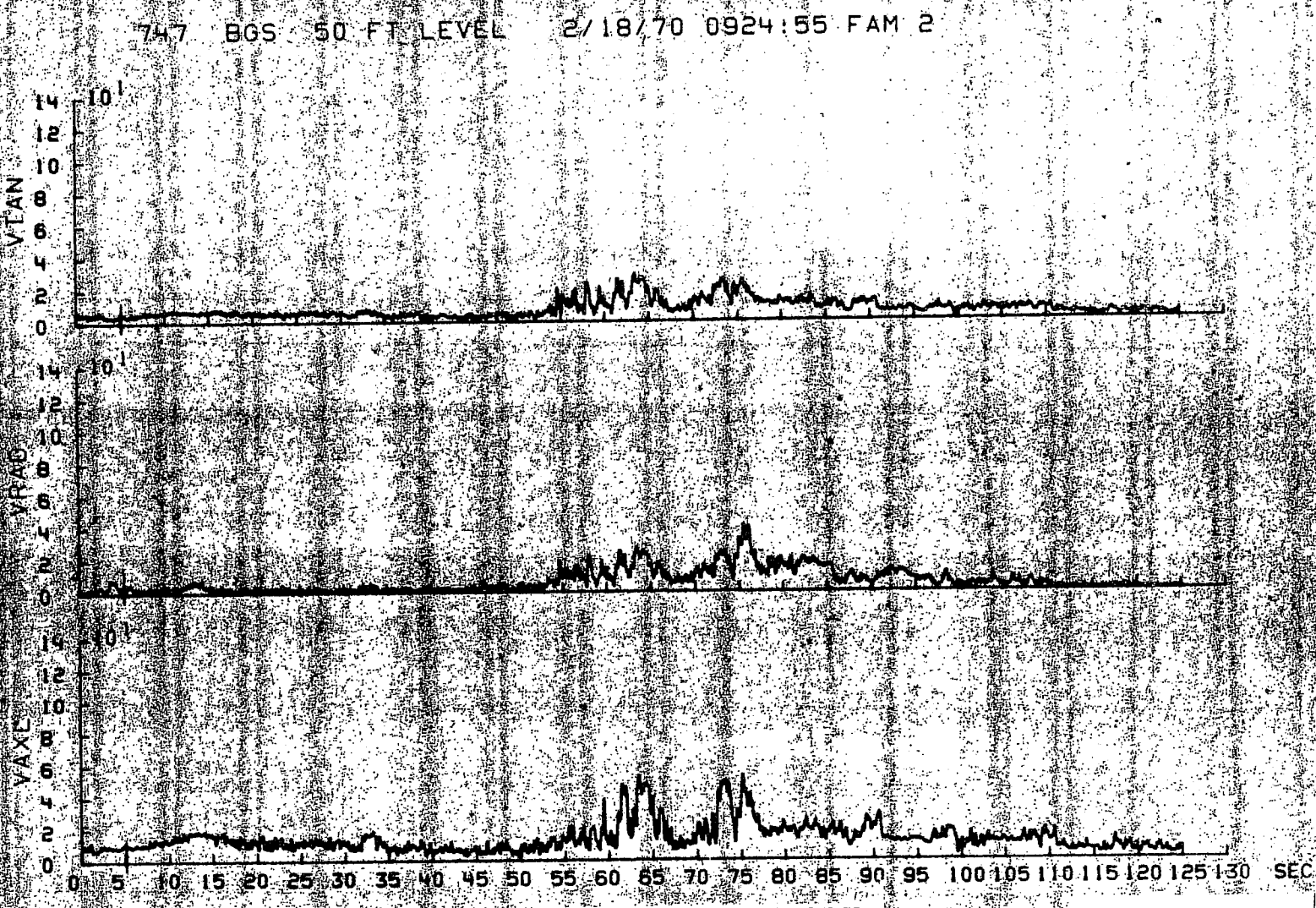


FIG. 7-5 TIME HISTORY

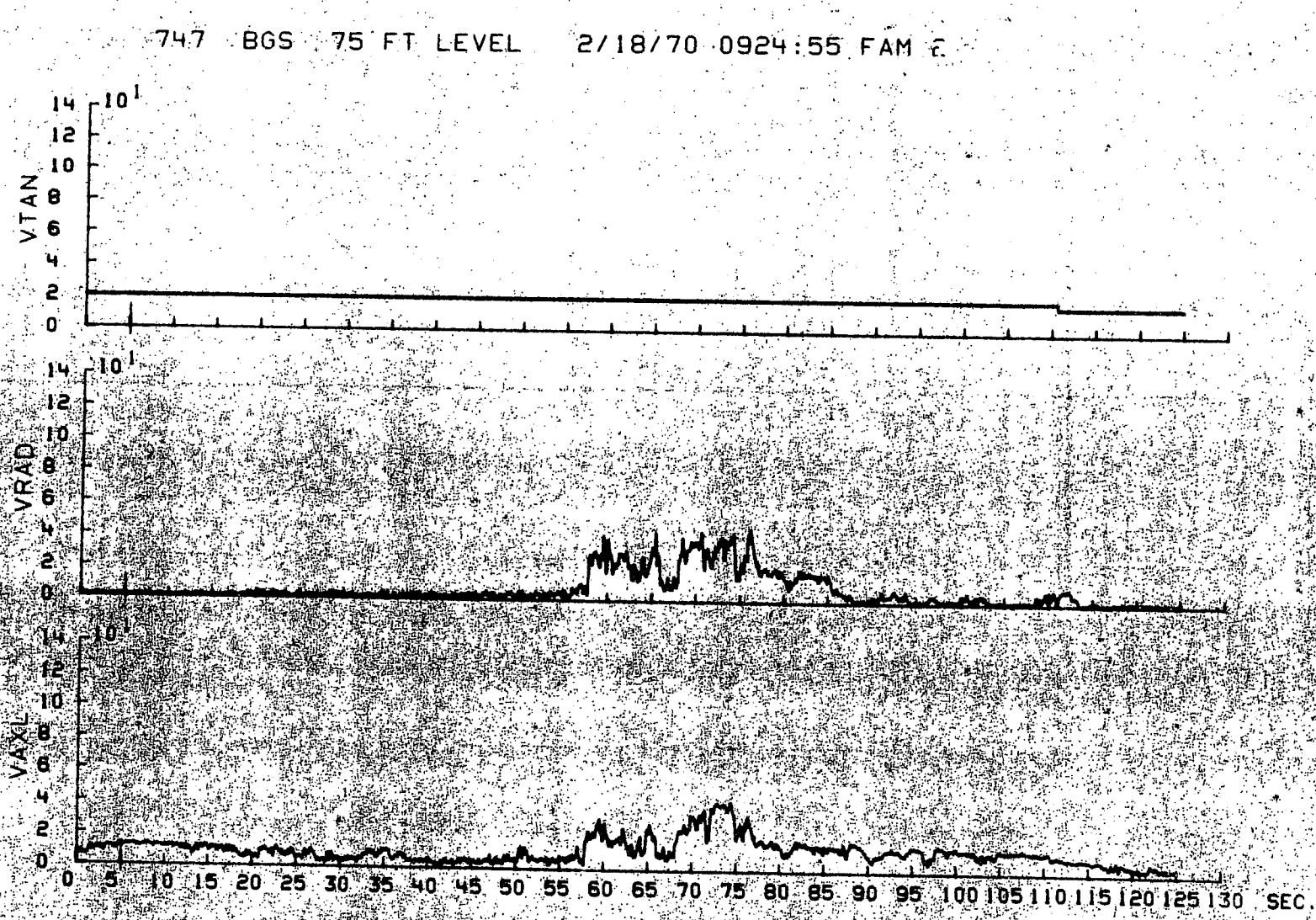


FIG. 7-6 TIME HISTORY

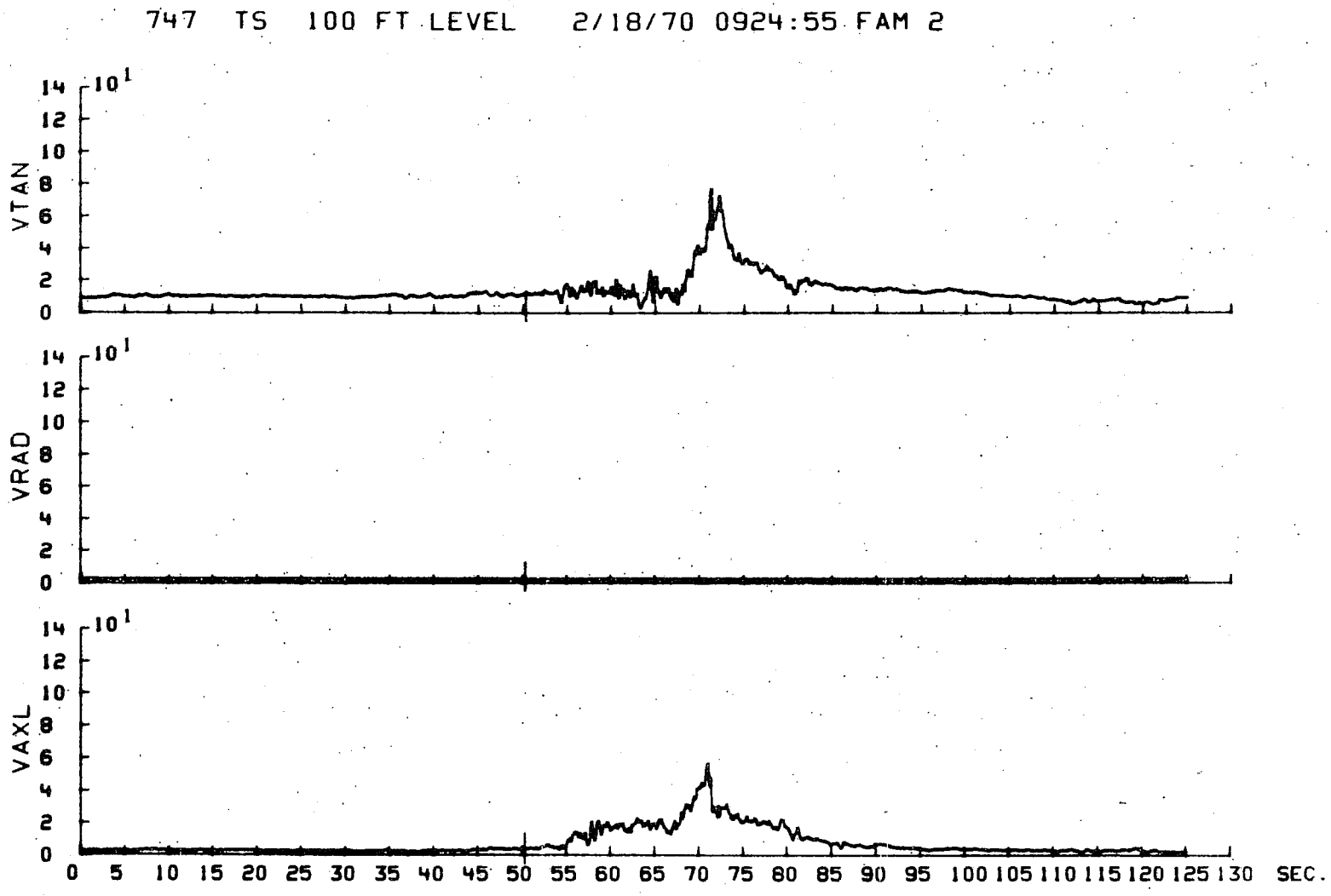


FIG. 7-7 TIME HISTORY

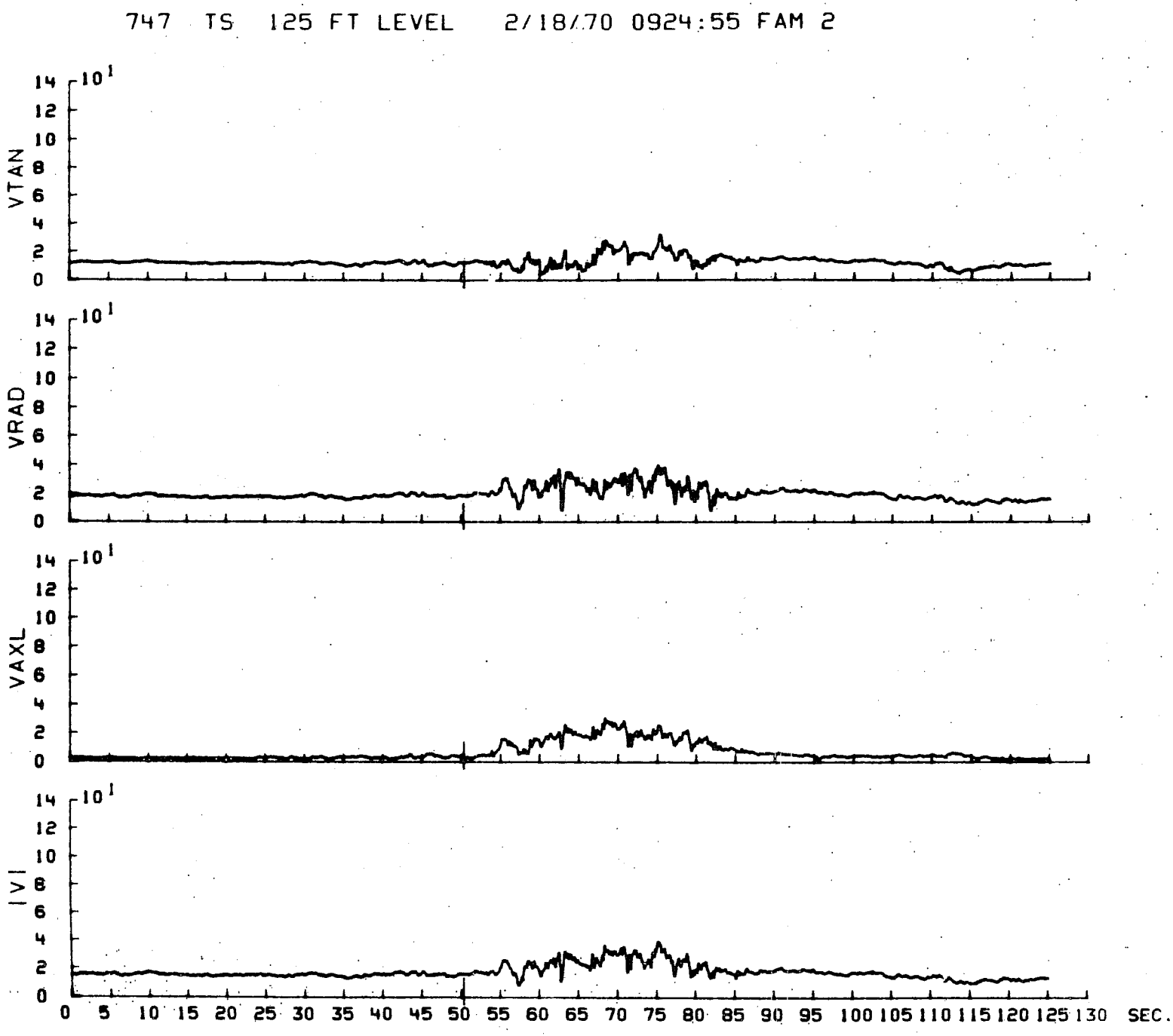


FIG. 7-8 TIME HISTORY

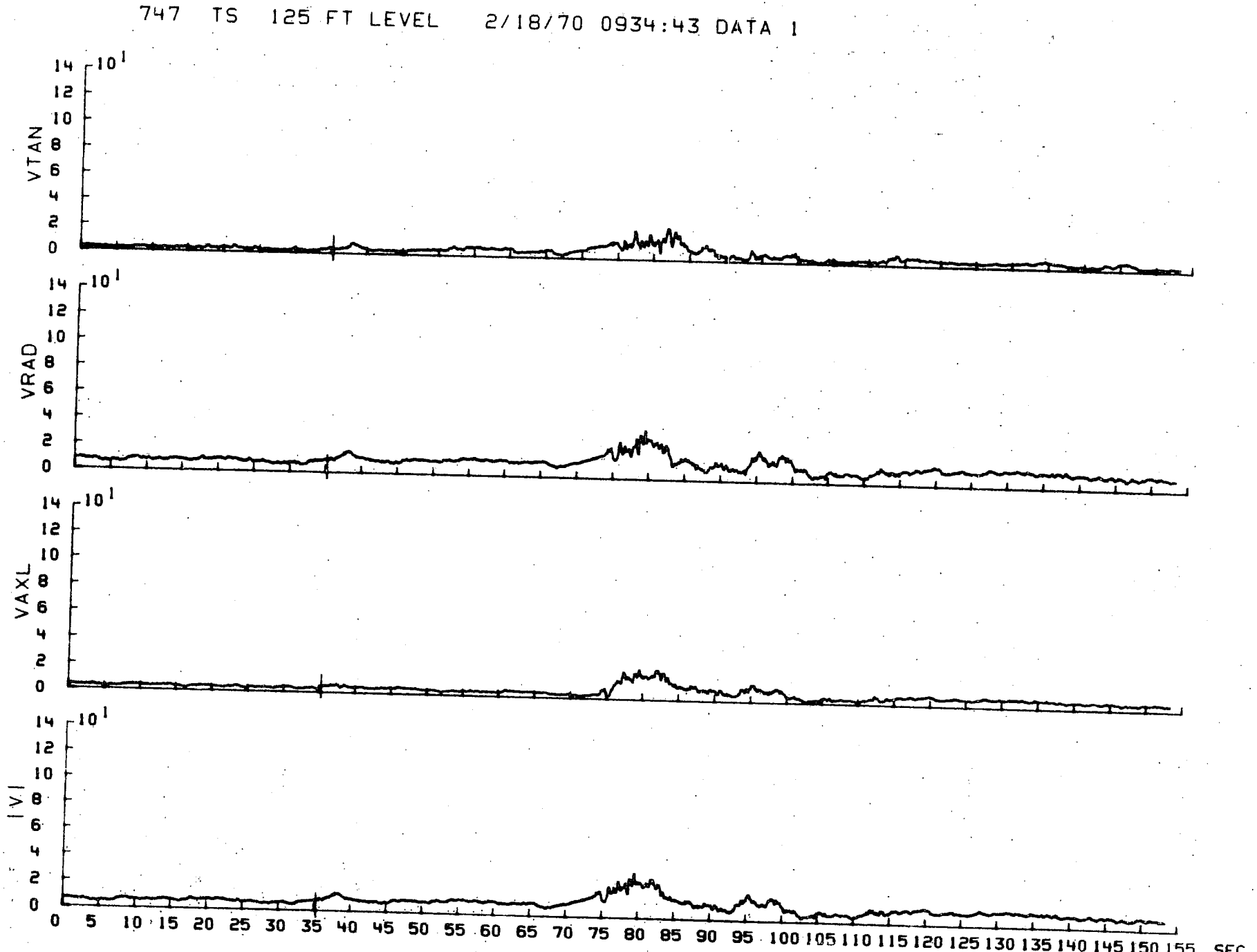


FIG. 7-9 TIME HISTORY

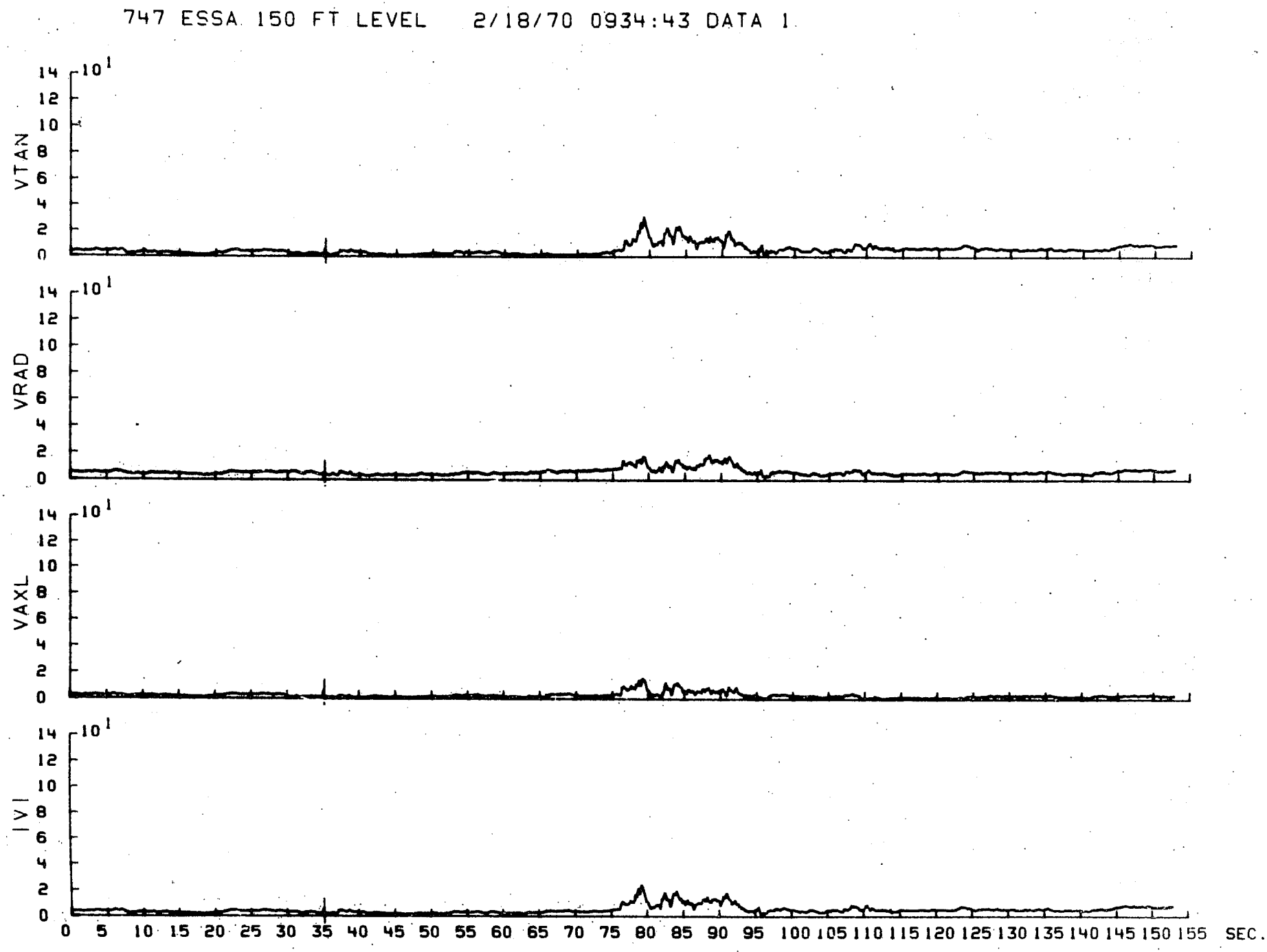


FIG. 7-10 TIME HISTORY

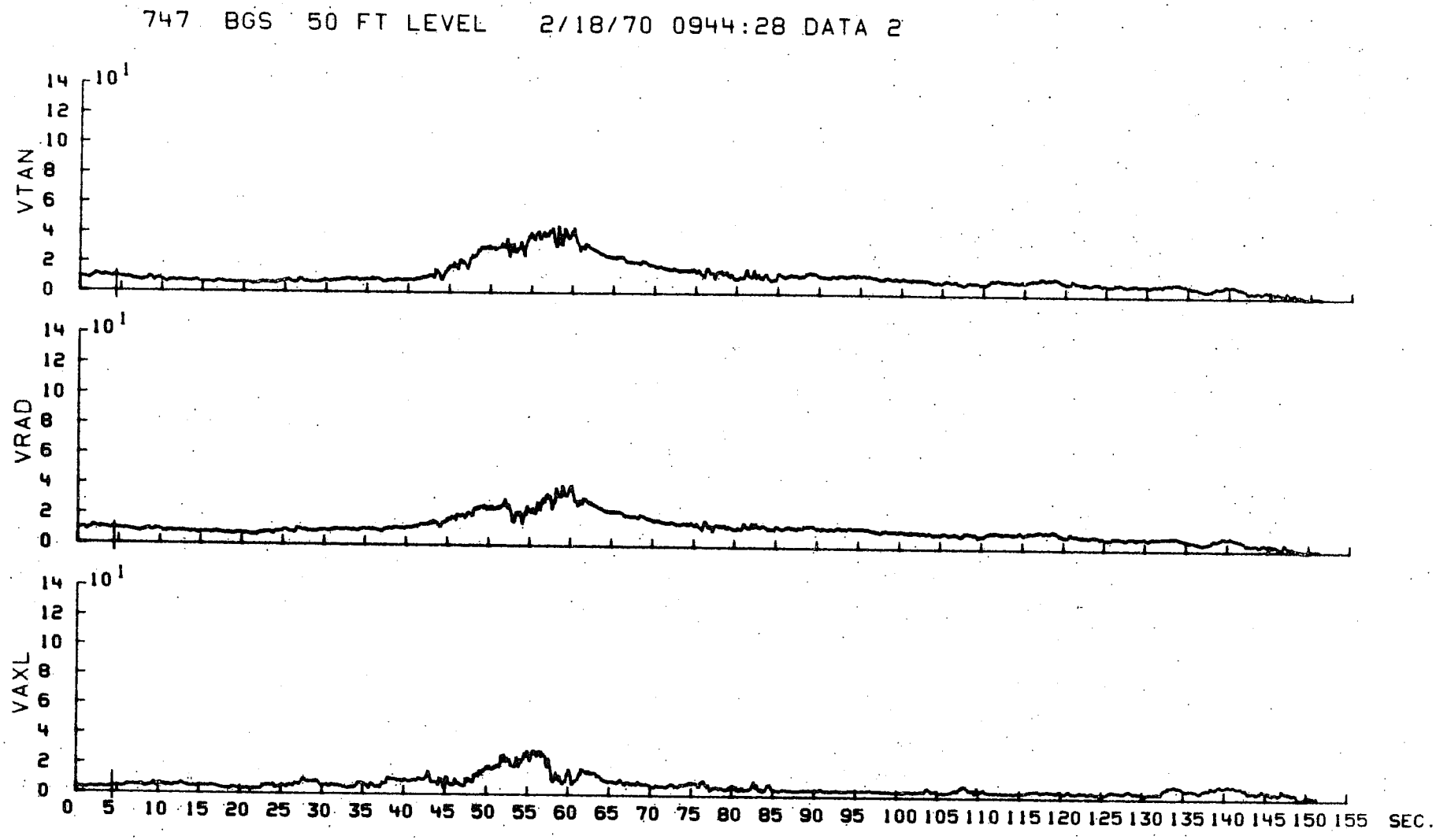


FIG. 7-11 TIME HISTORY

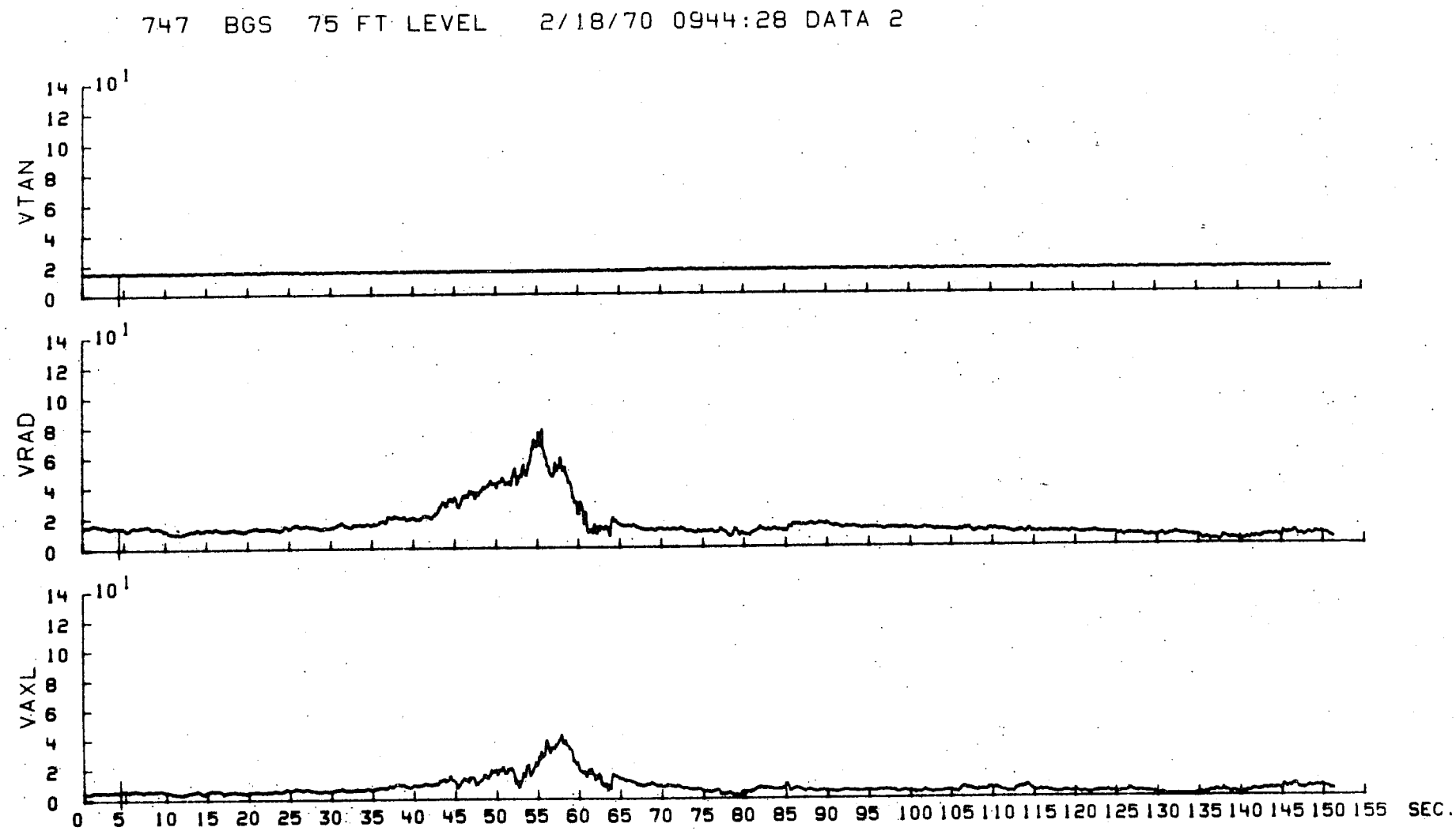


FIG. 7-12 TIME HISTORY

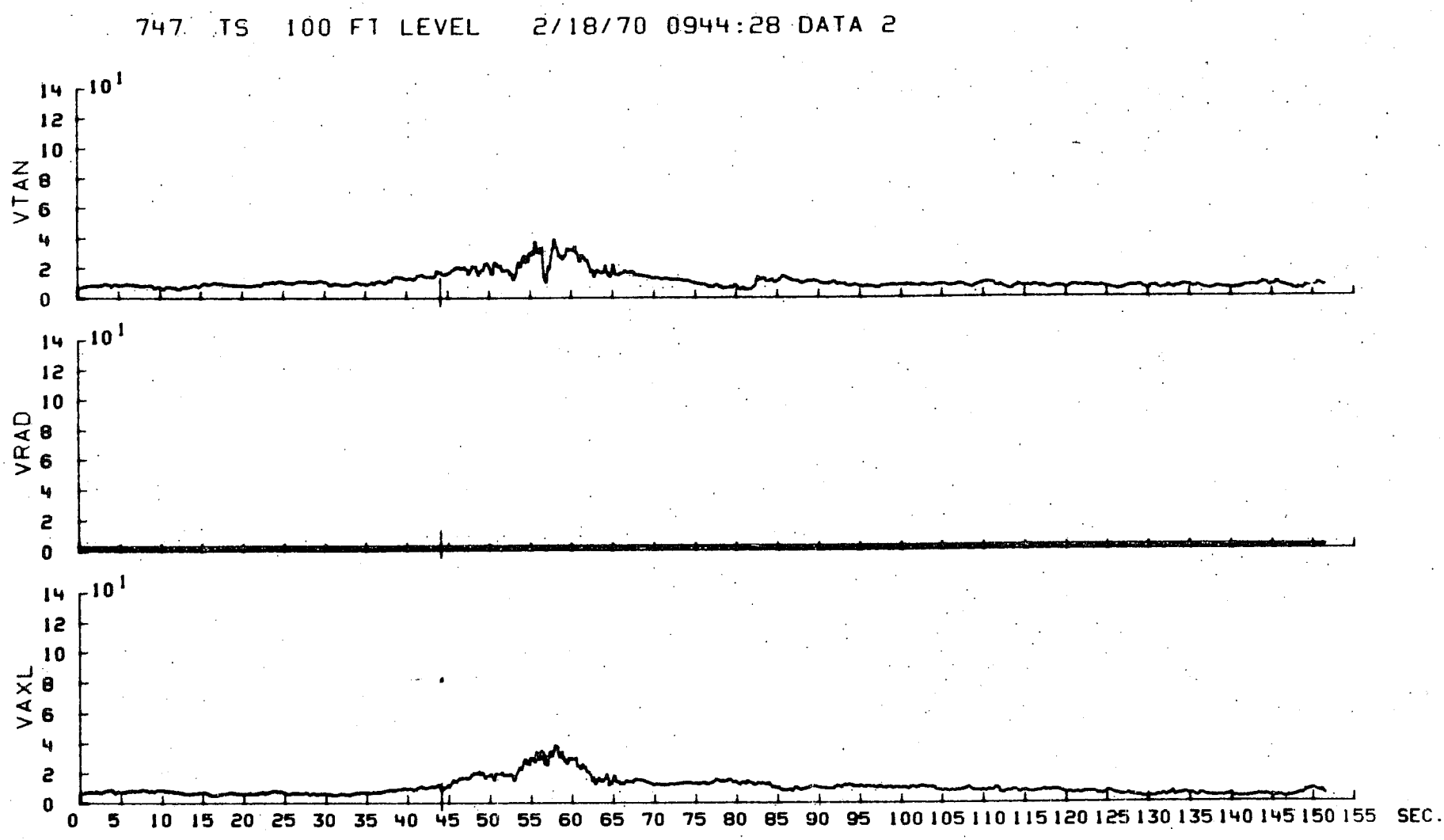


FIG. 7-13 TIME HISTORY

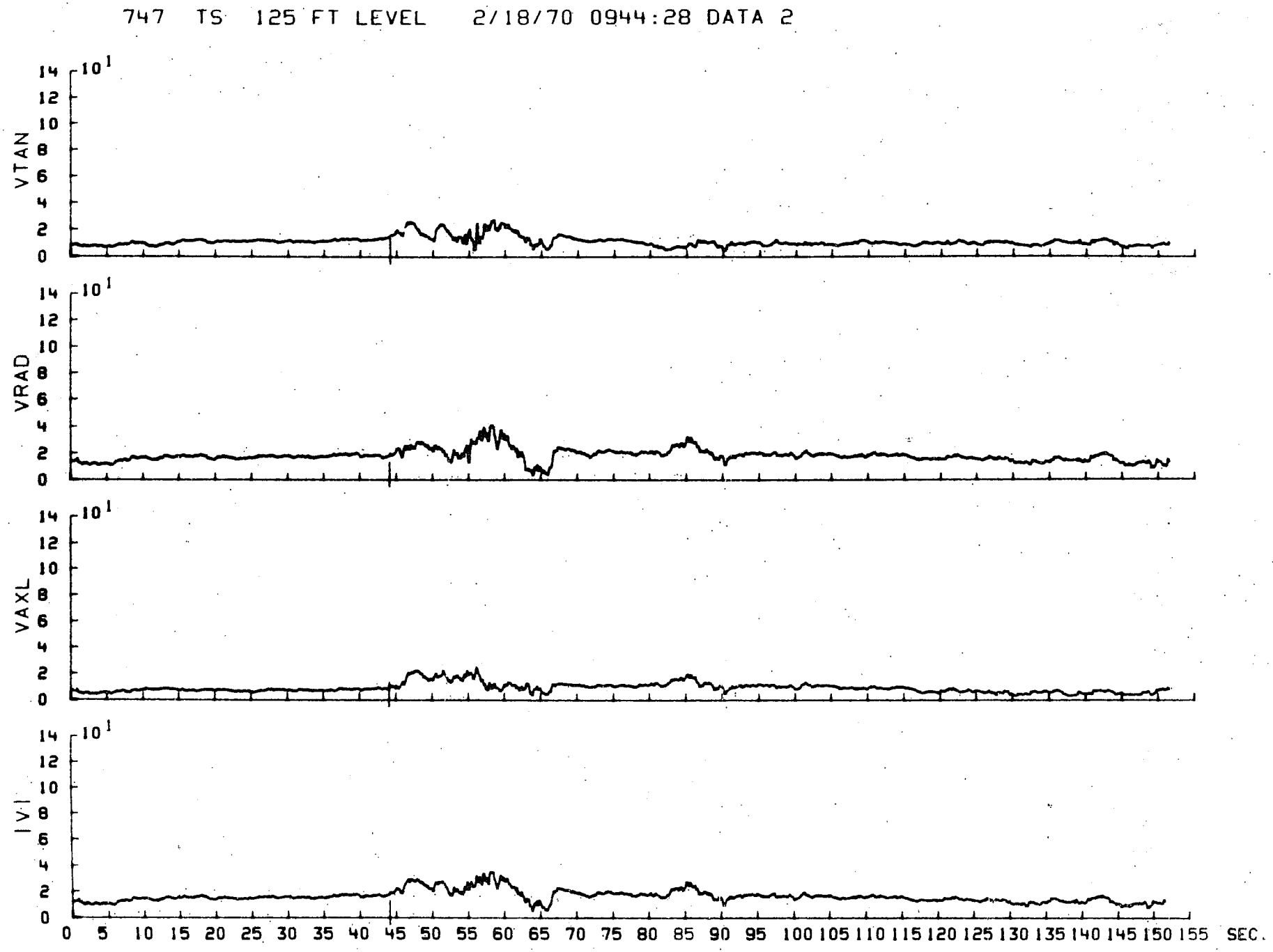


FIG. 7-14 TIME HISTORY

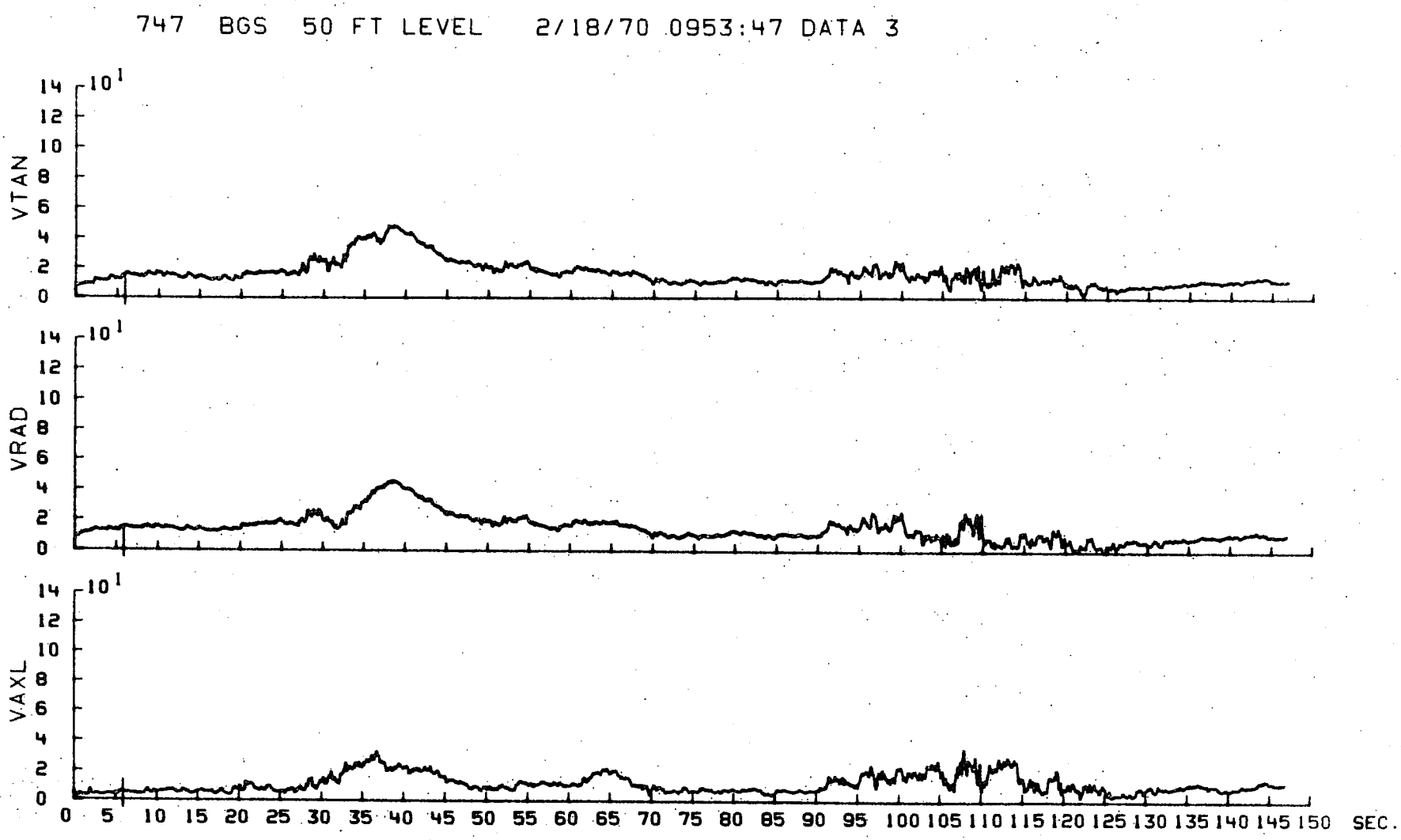


FIG. 7-15 TIME HISTORY

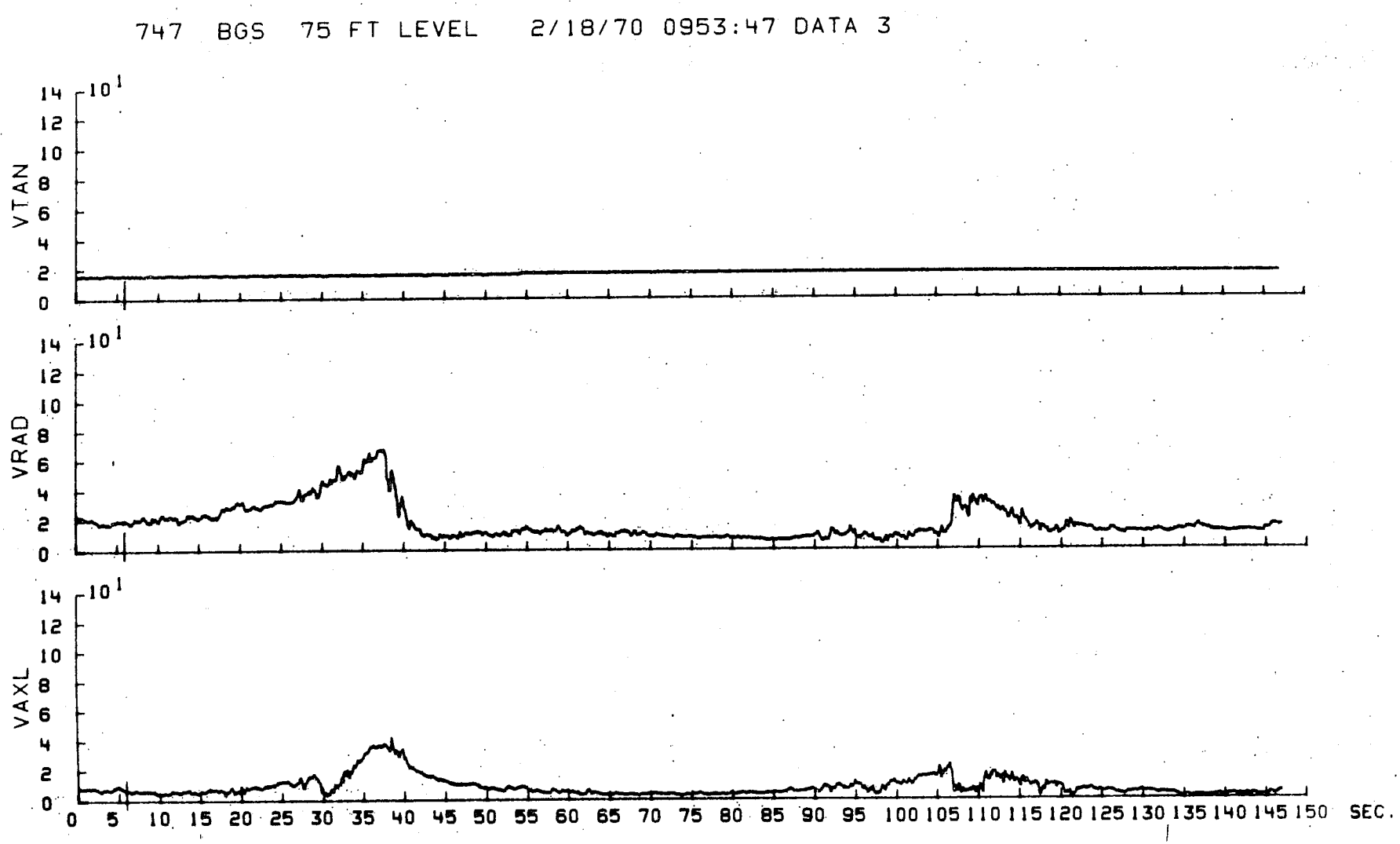


FIG. 7-16 TIME HISTORY

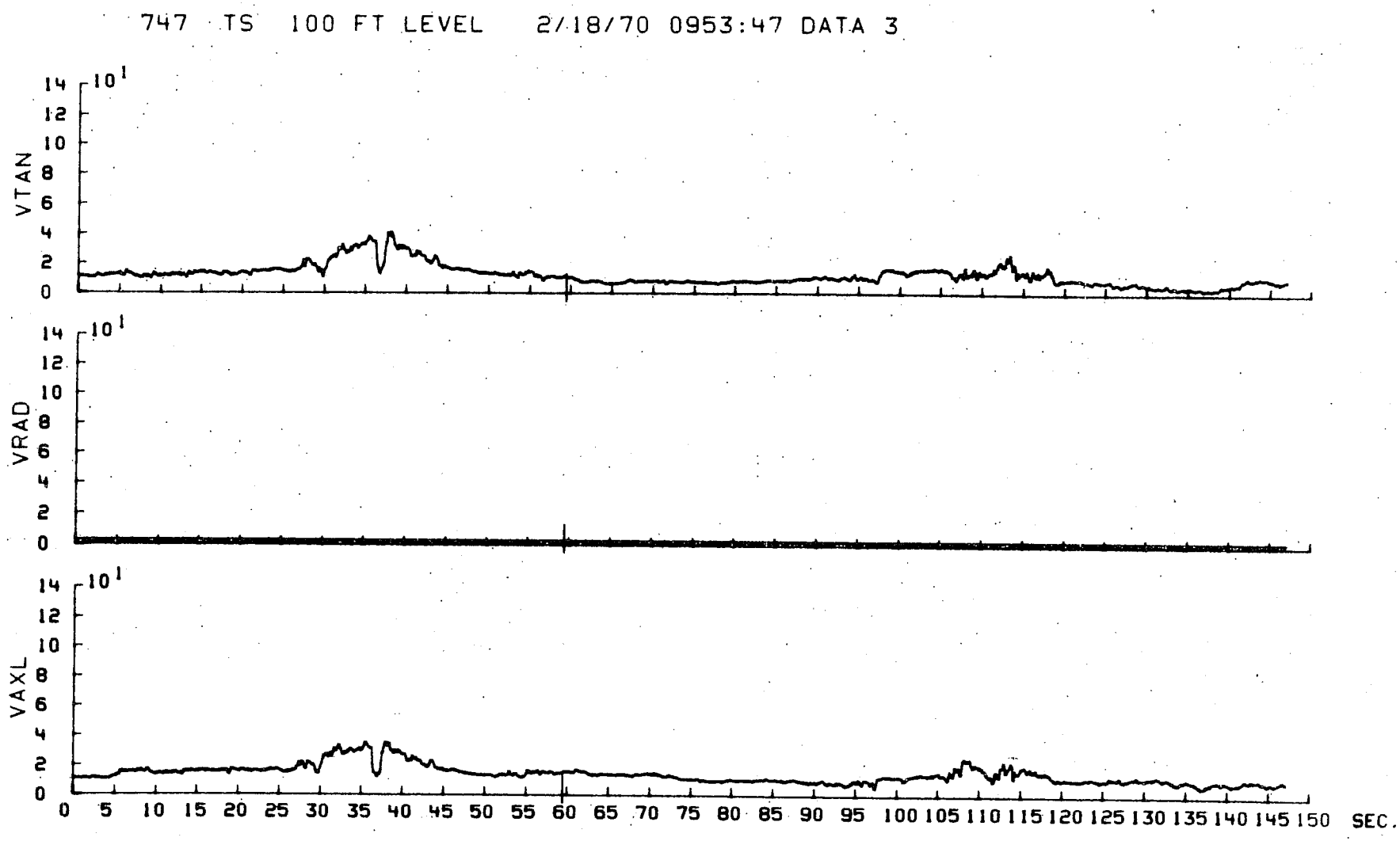


FIG. 7-17 TIME HISTORY

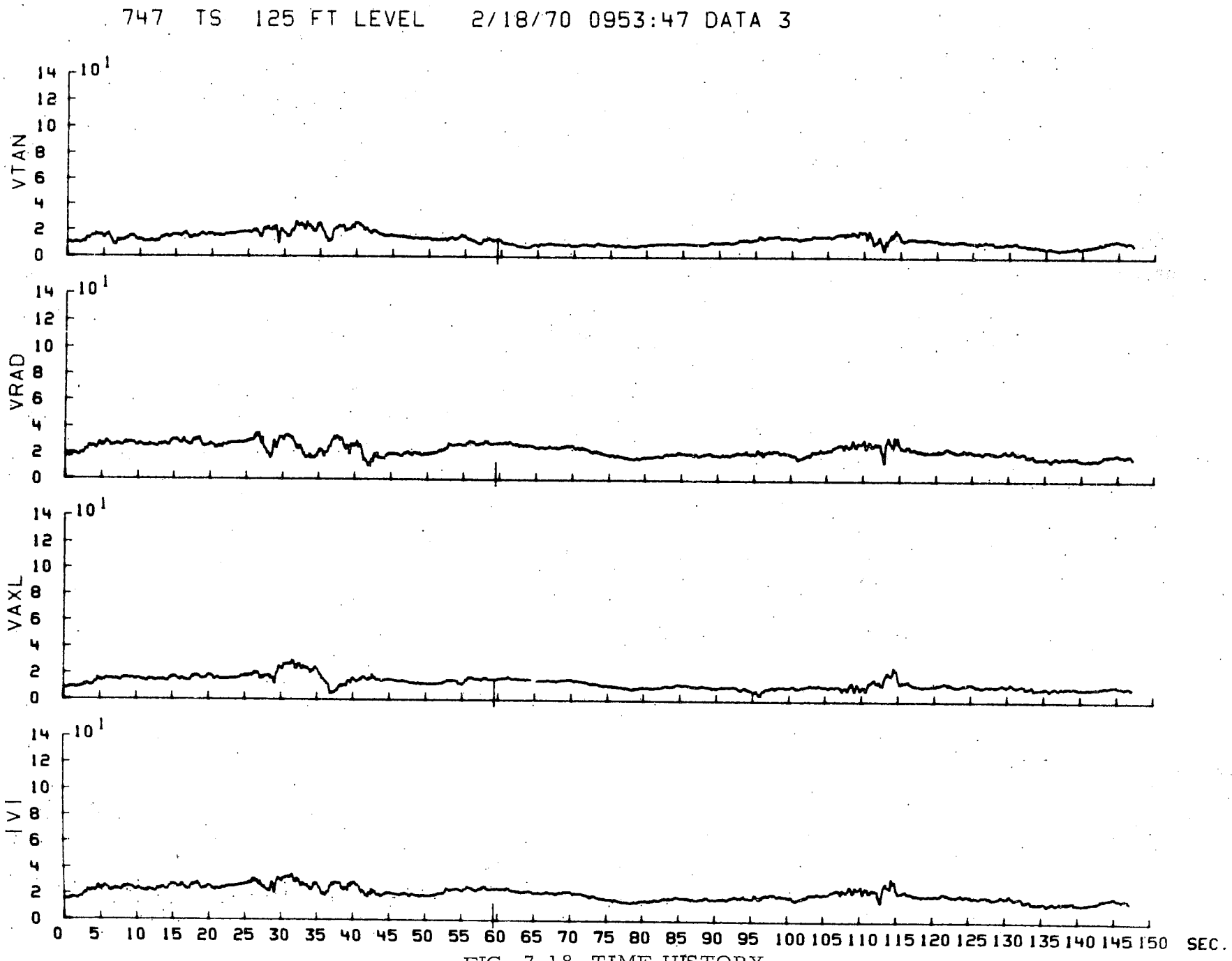


FIG. 7-18 TIME HISTORY

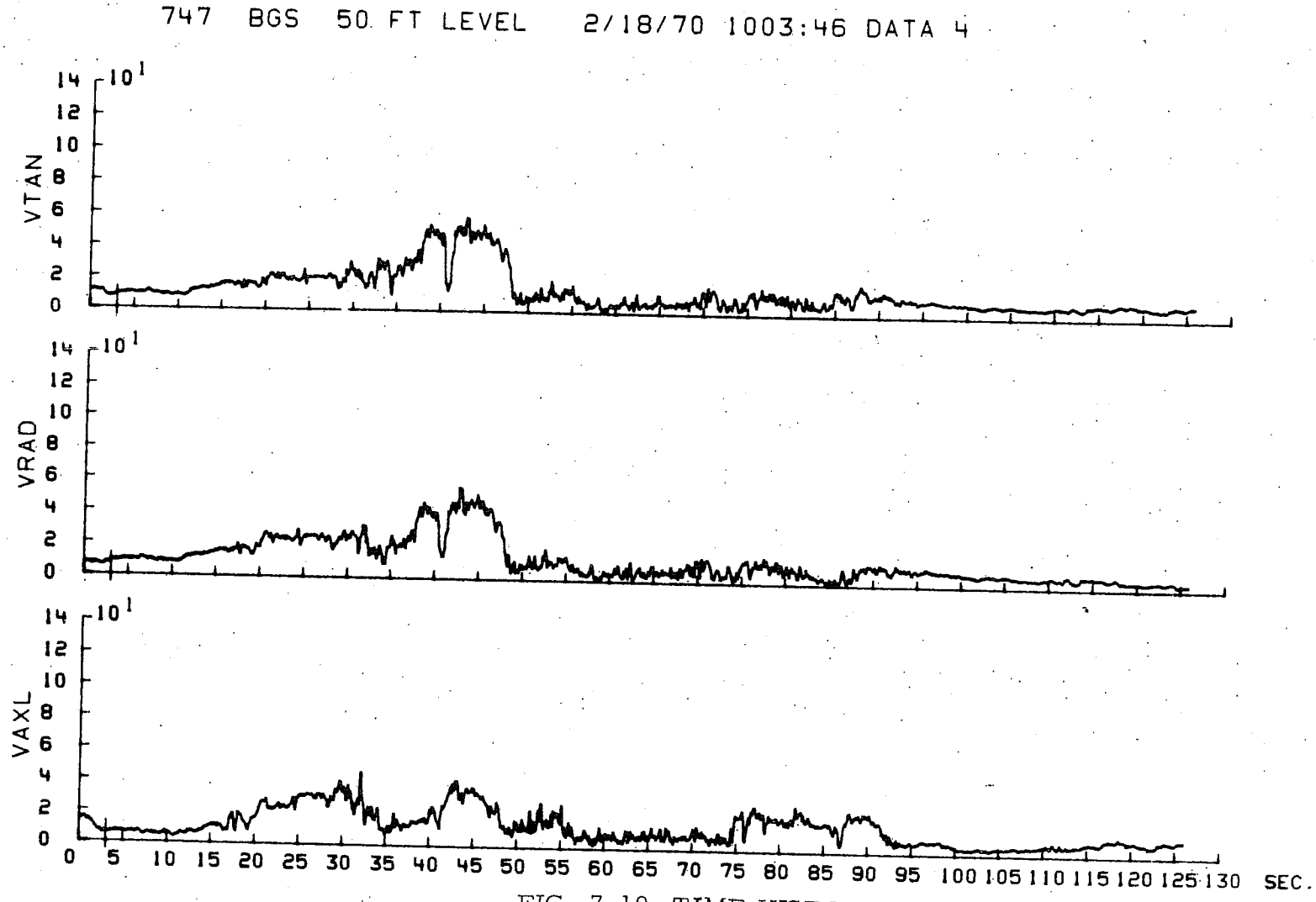


FIG. 7-19 TIME HISTORY

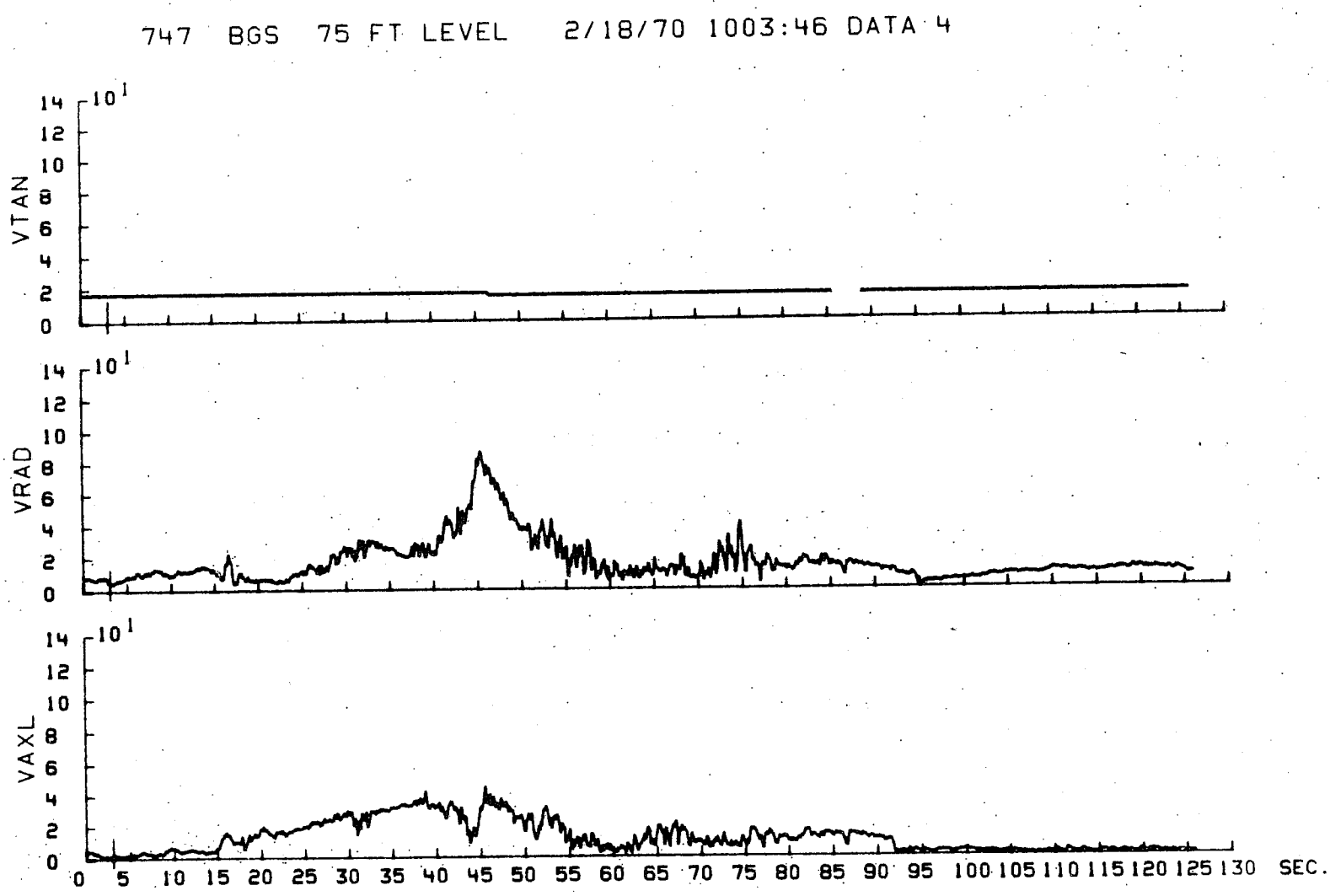


FIG. 7-20 TIME HISTORY

747 TS 100 FT LEVEL 2/18/70 1003:46 DATA 4

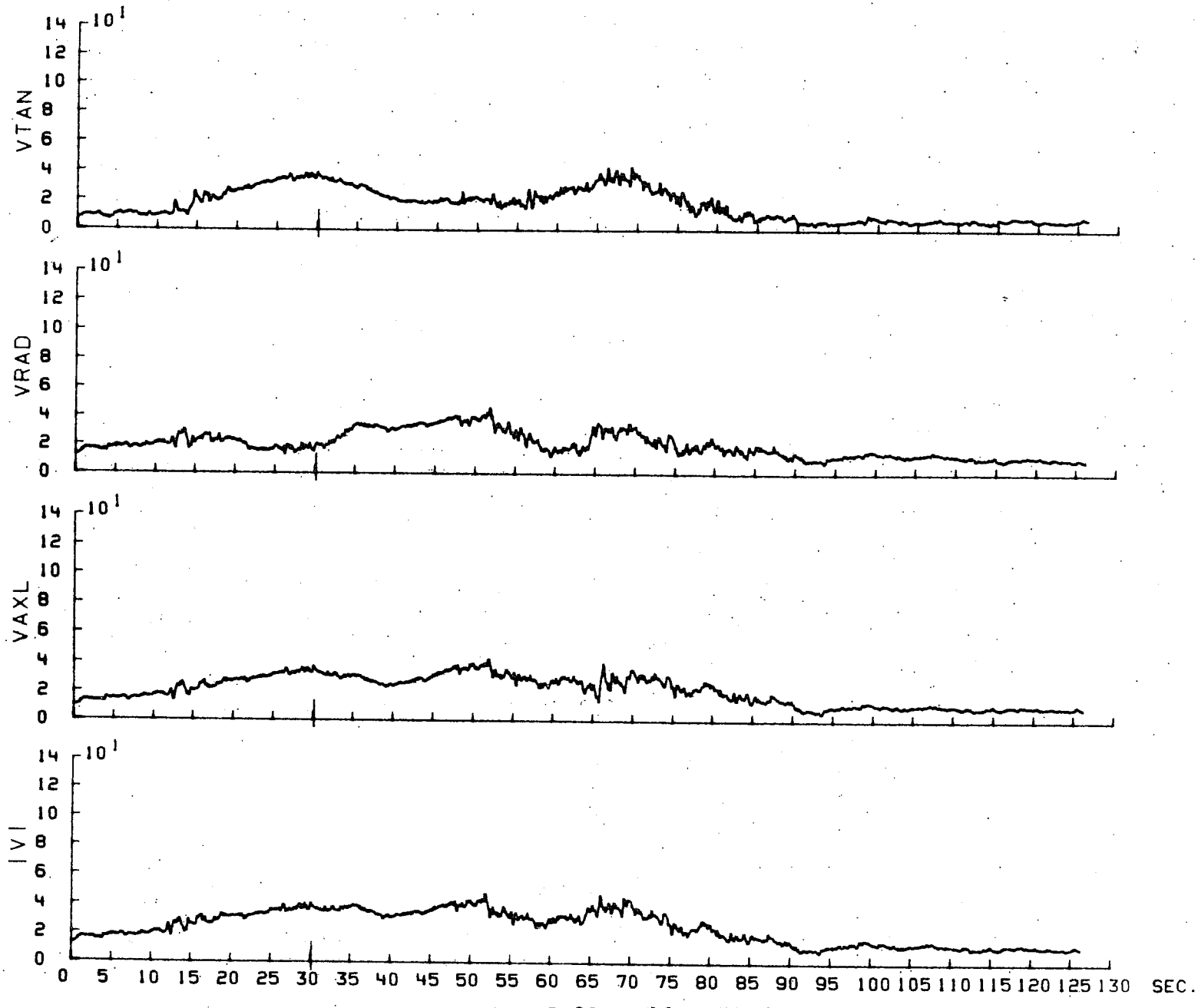


FIG. 7-21 TIME HISTORY

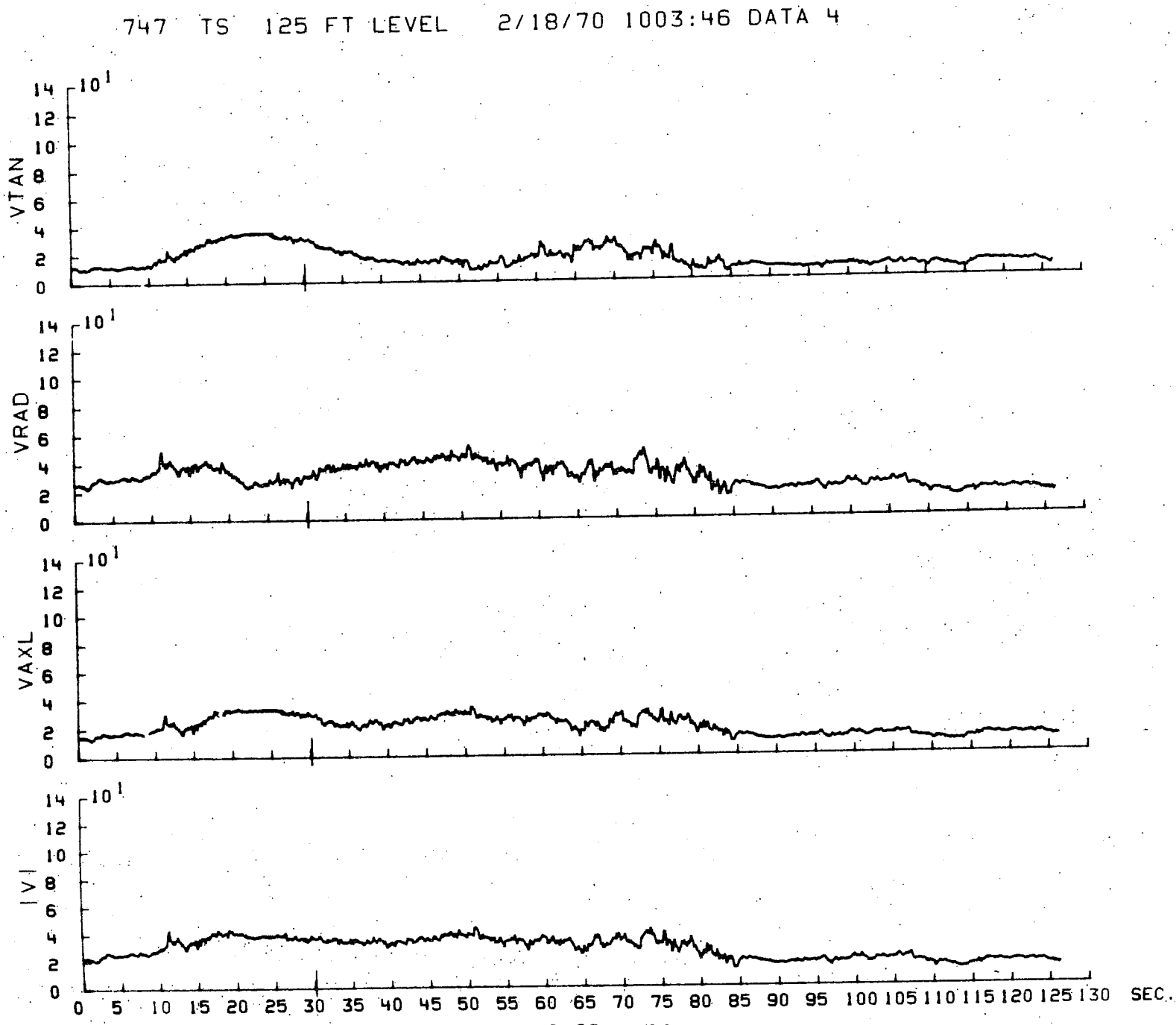


FIG. 7-22 TIME HISTORY

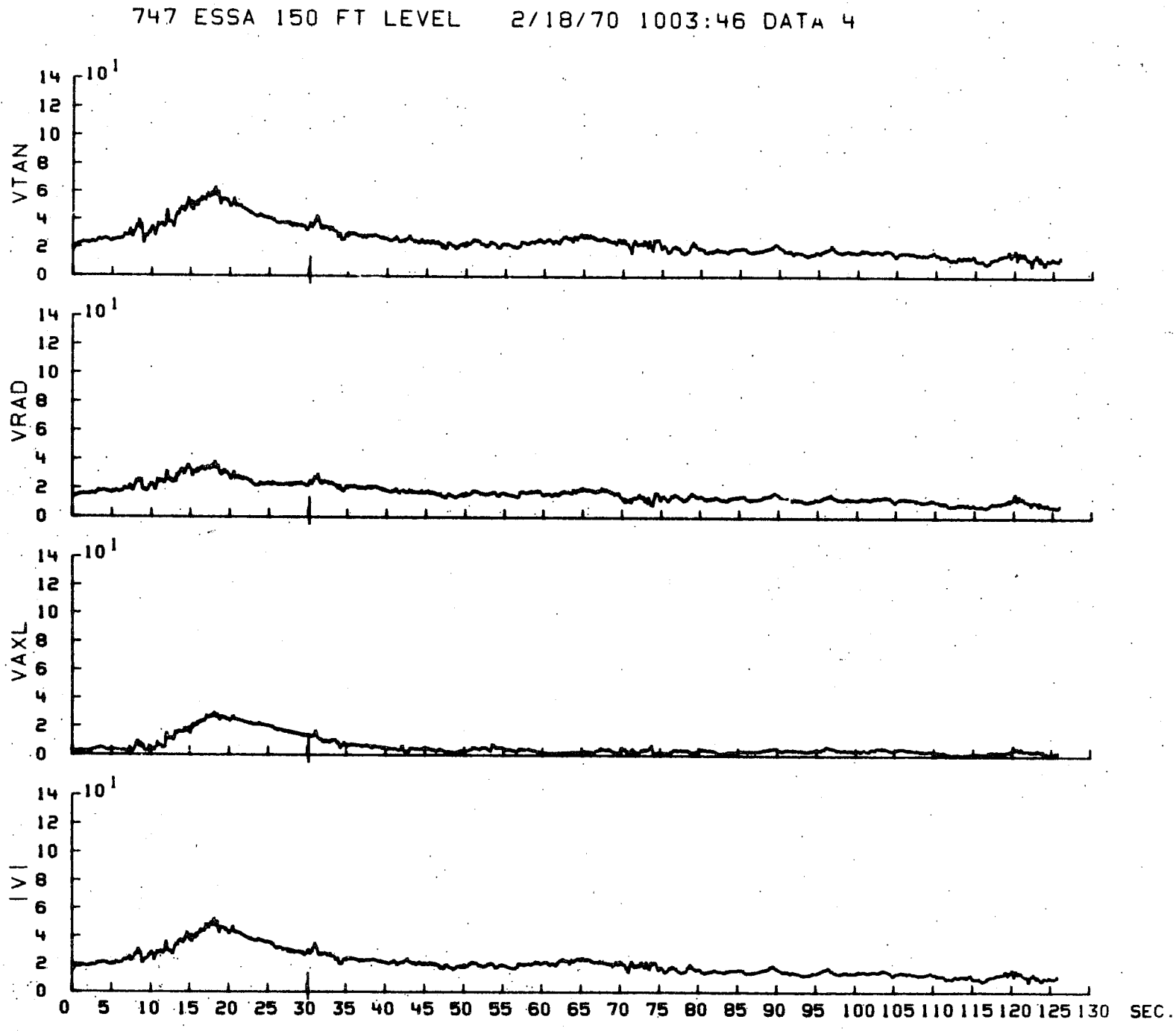


FIG. 7-23 TIME HISTORY

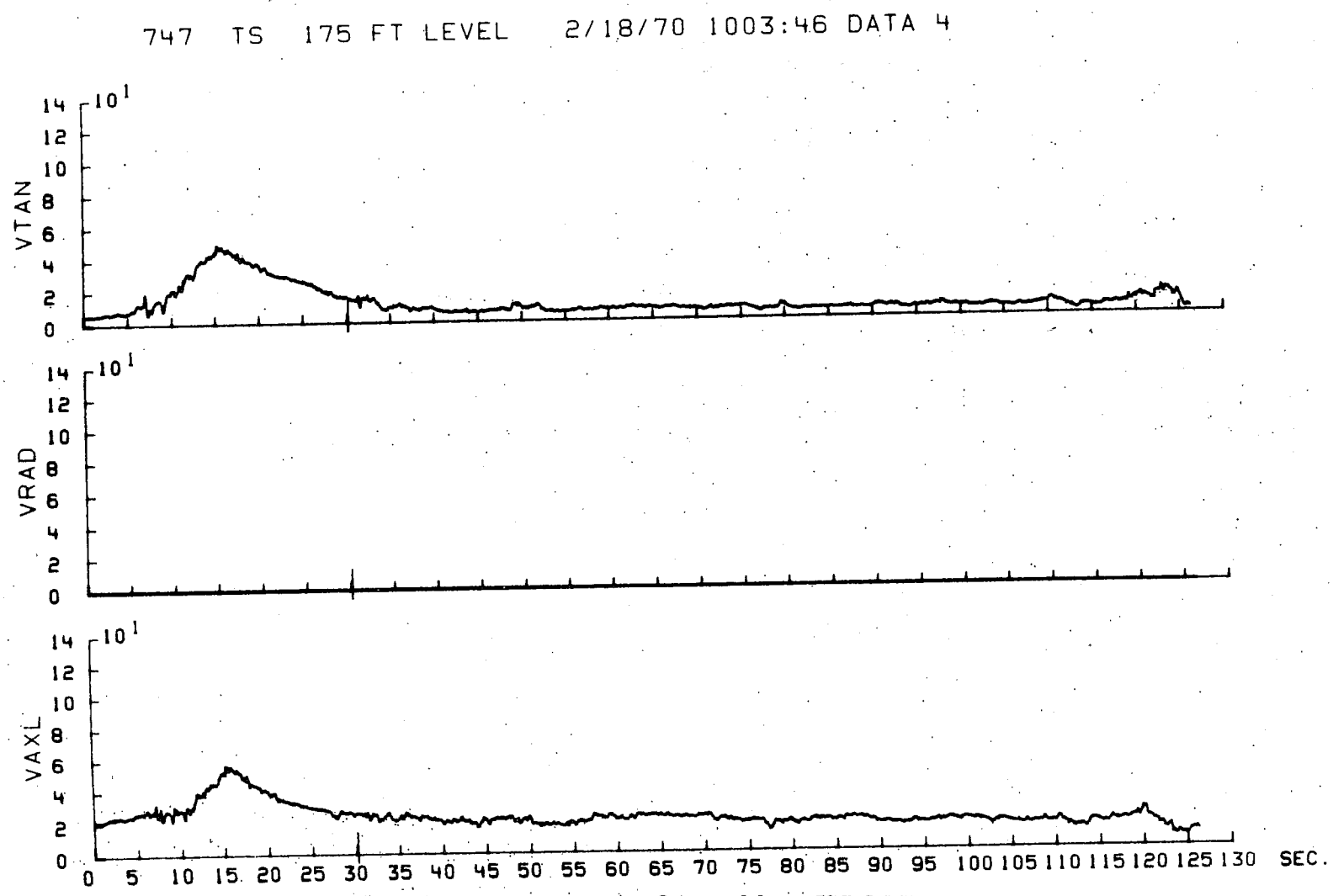


FIG. 7-24 TIME HISTORY

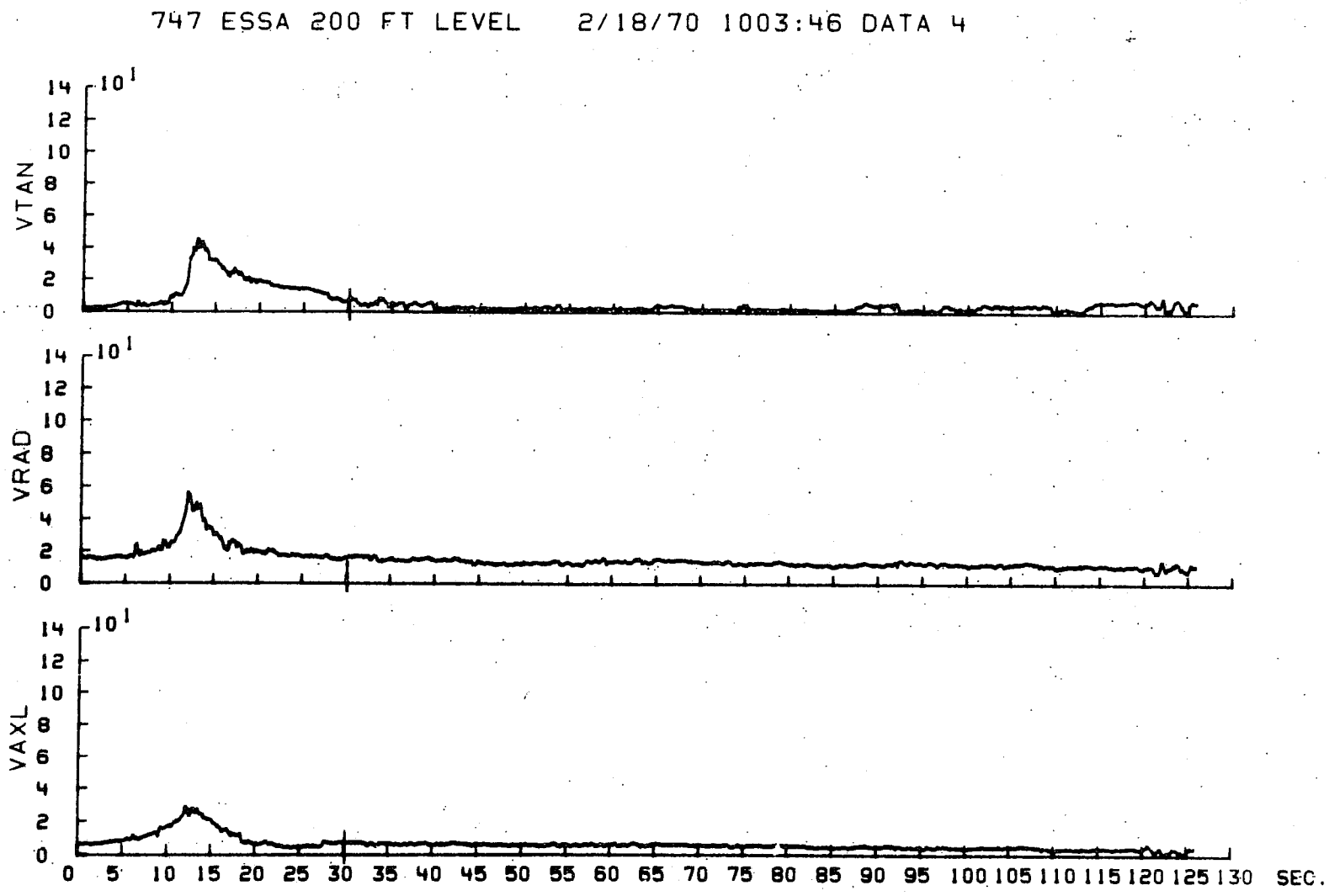


FIG. 7-25 TIME HISTORY

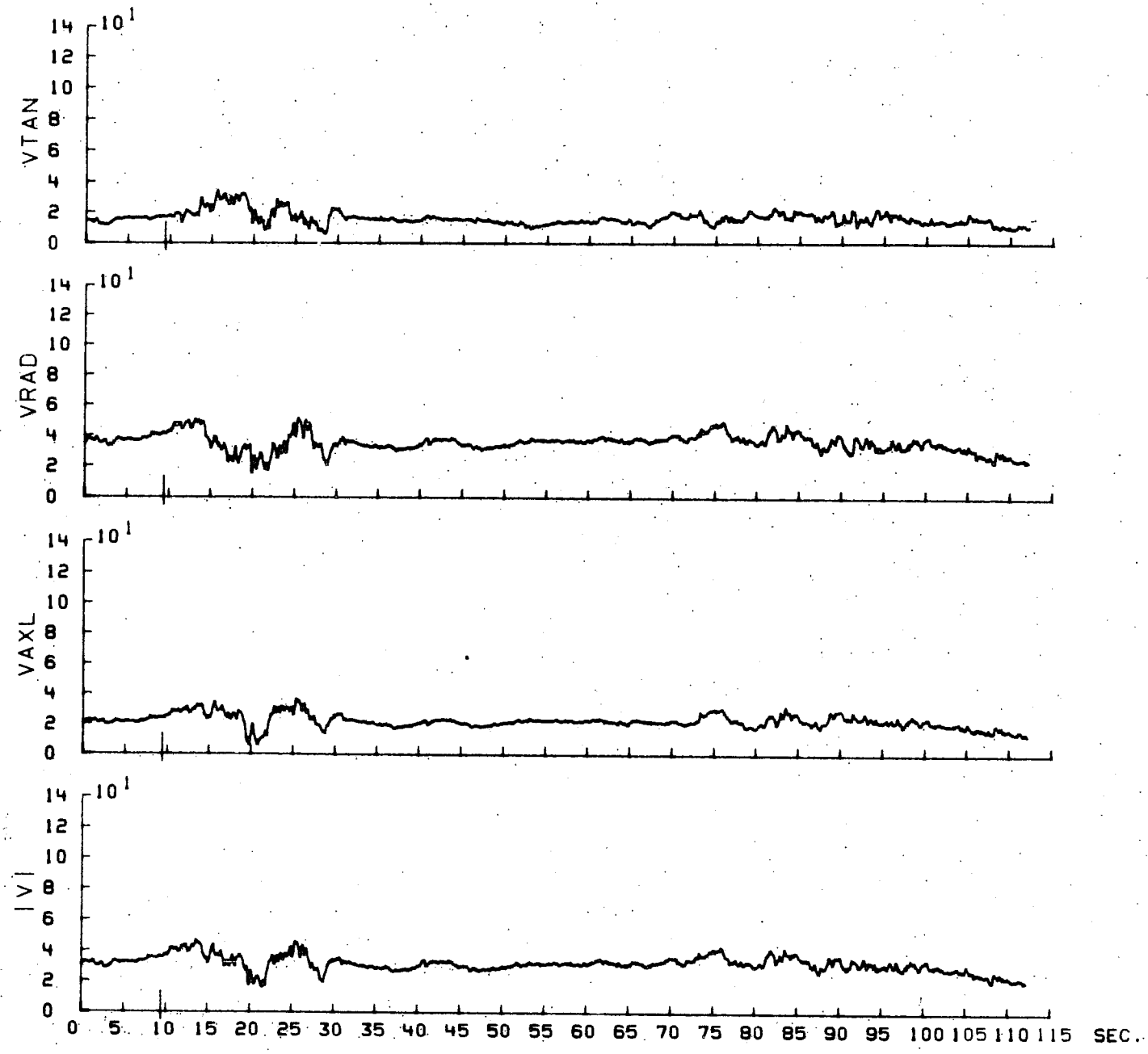


FIG. 7-26 TIME HISTORY

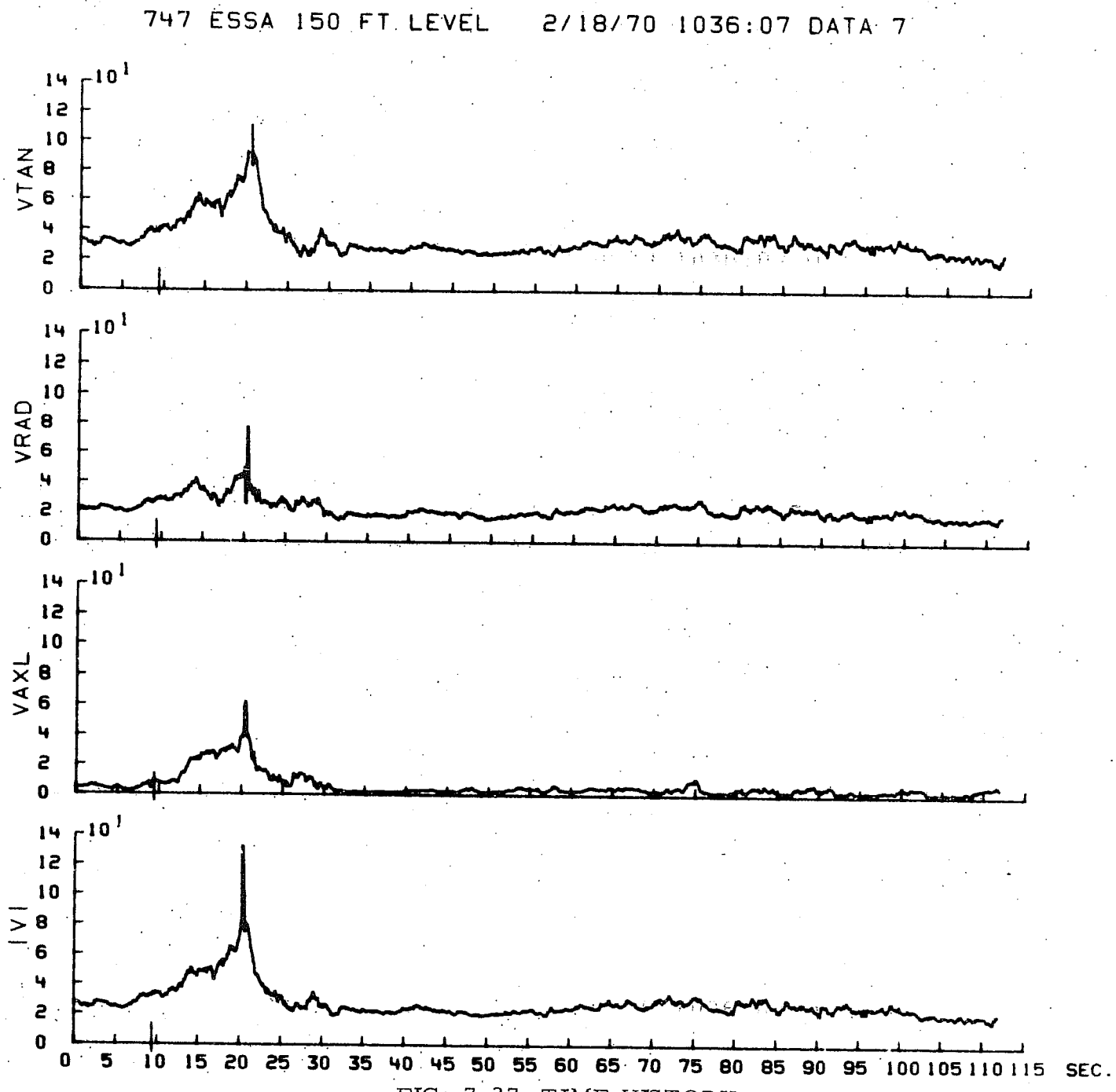


FIG. 7-27 TIME HISTORY

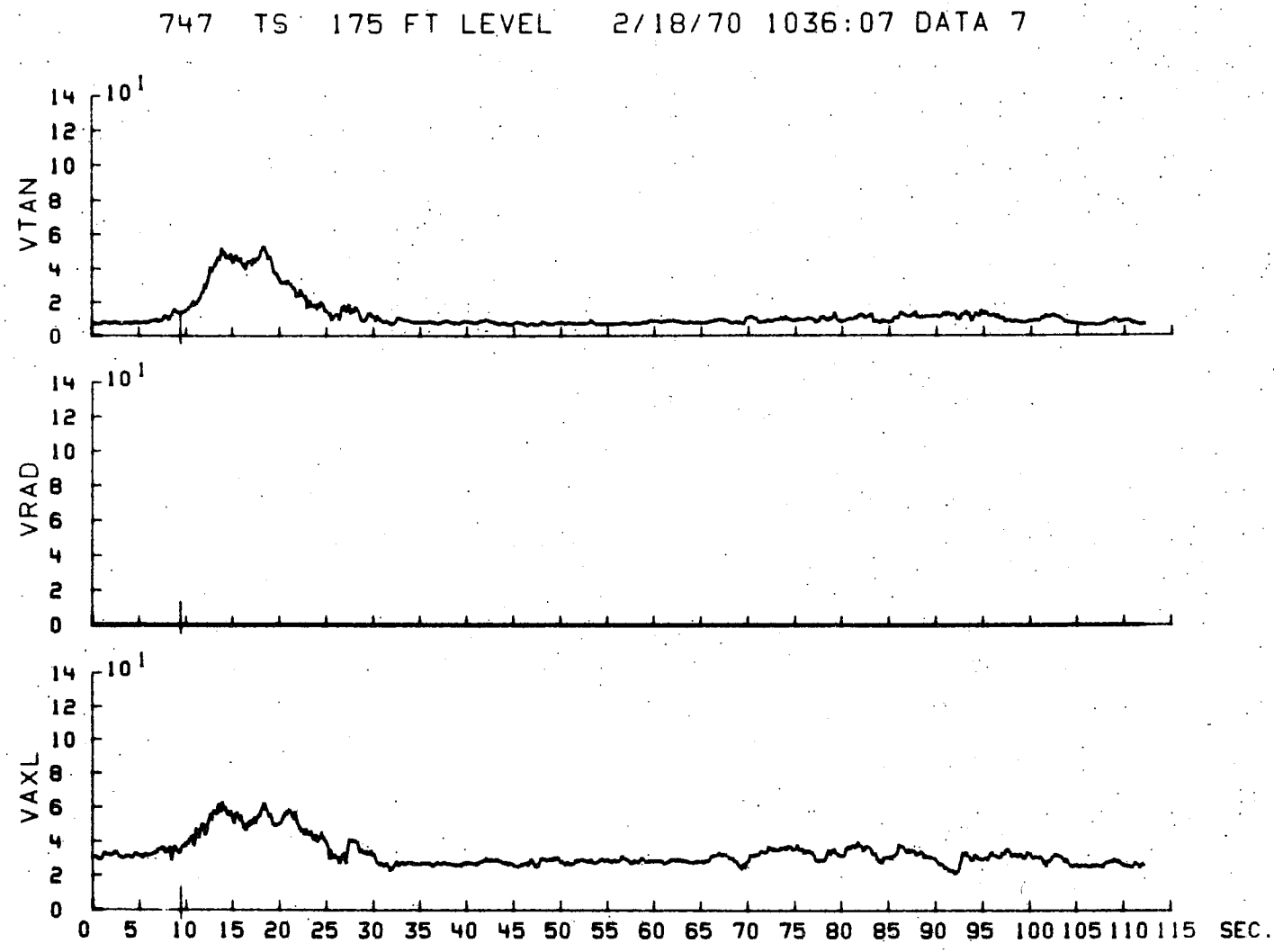


FIG. 7-28. TIME HISTORY

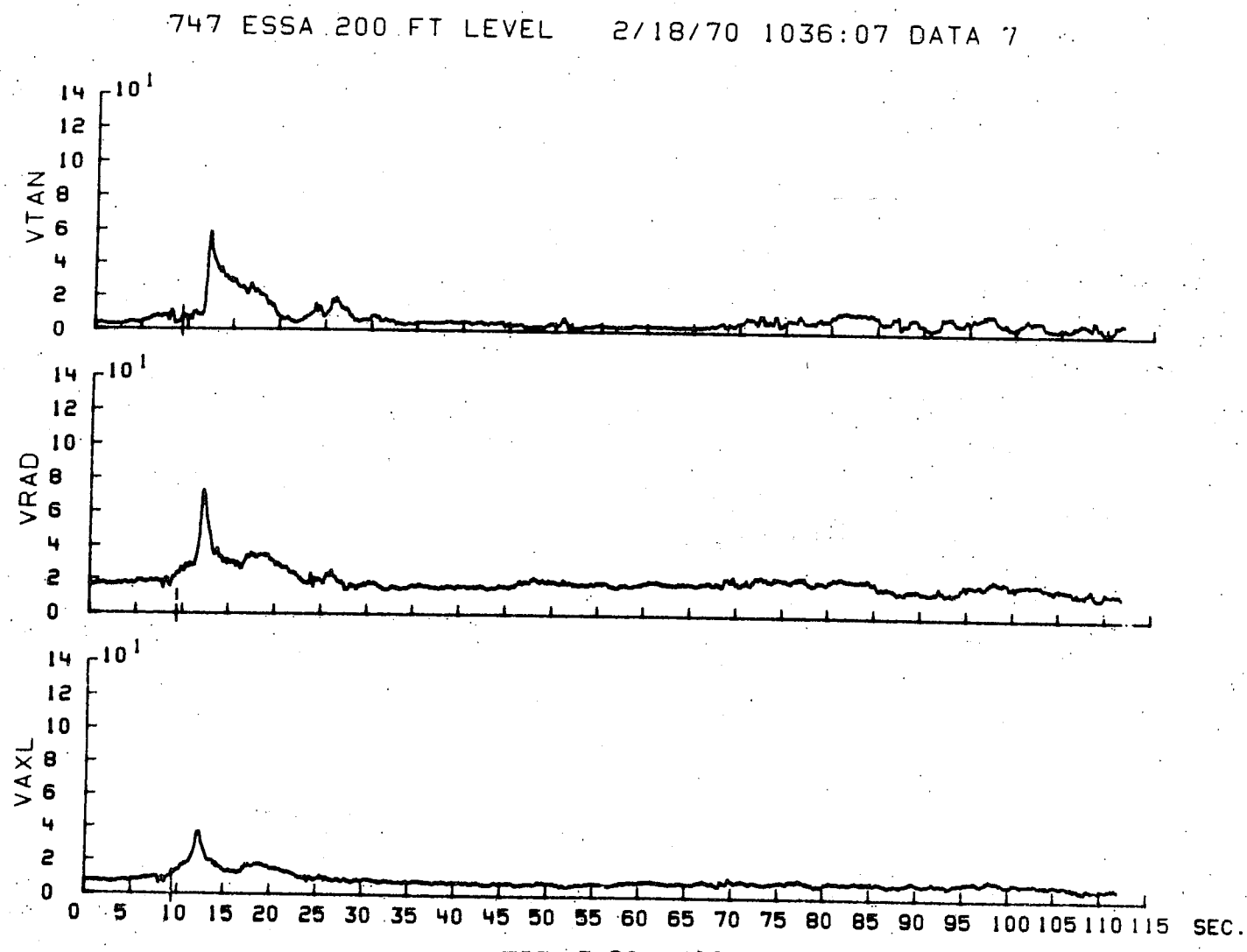


FIG. 7-29 TIME HISTORY

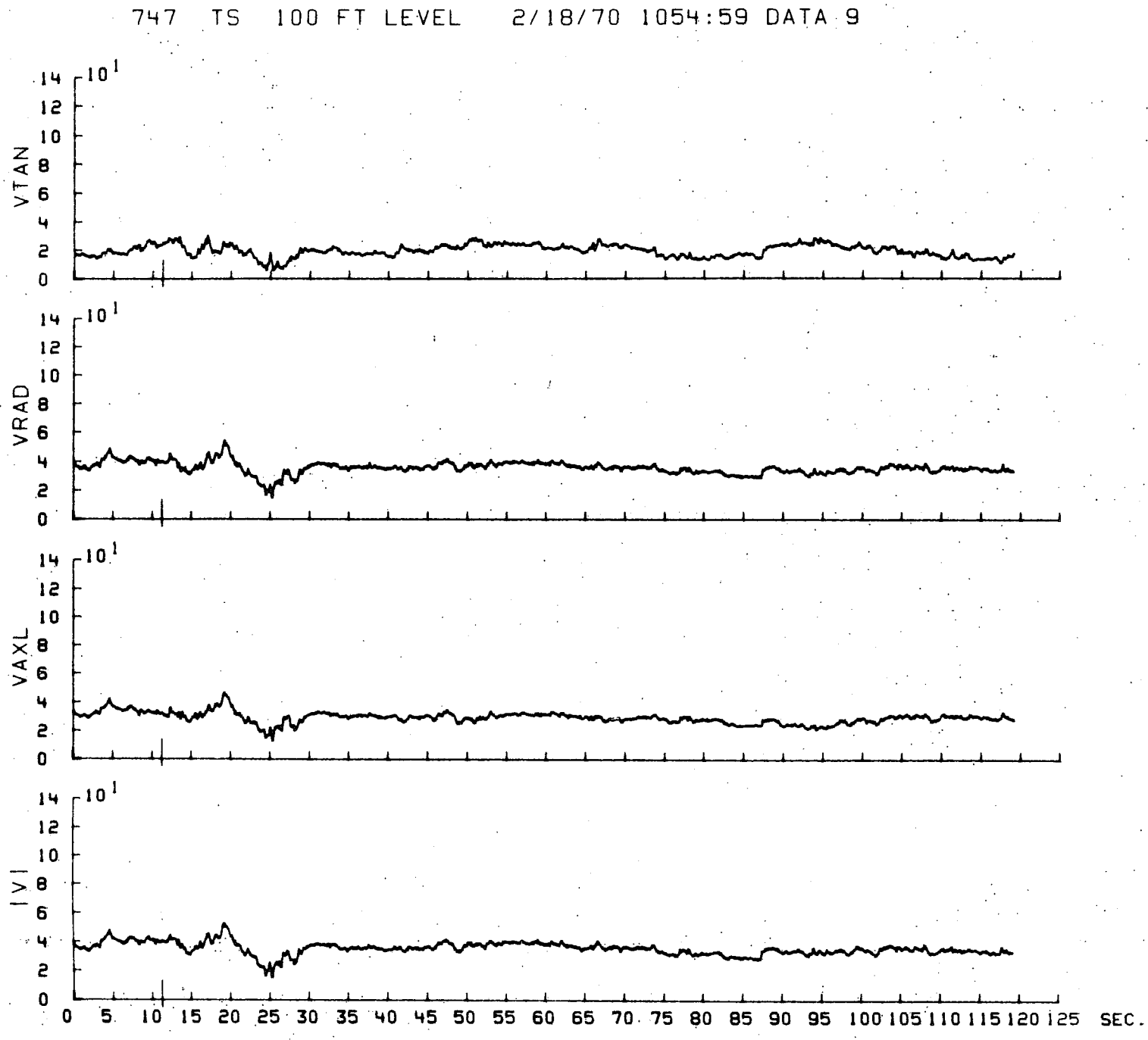


FIG. 7-30 TIME HISTORY

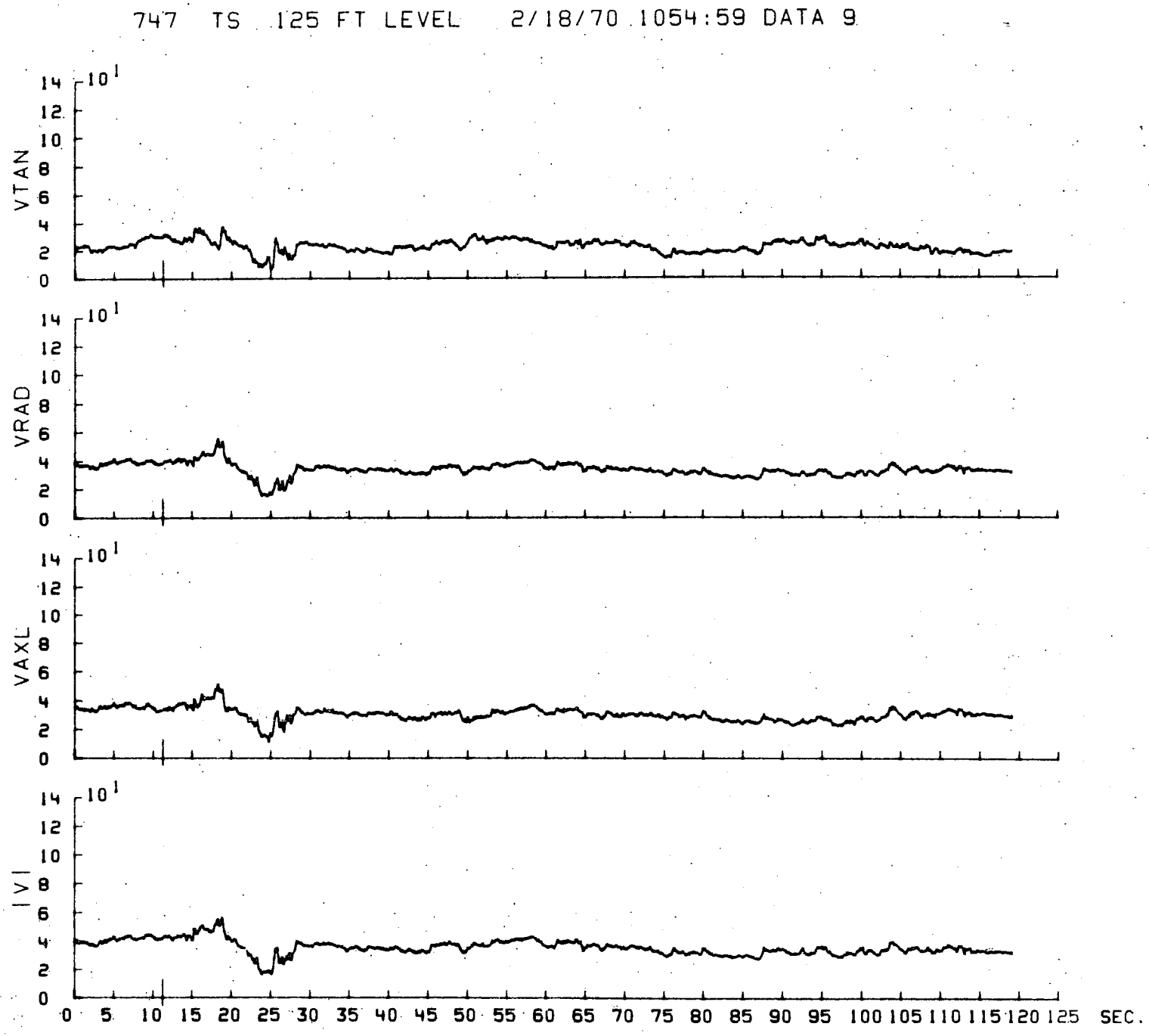


FIG. 7-31 TIME HISTORY

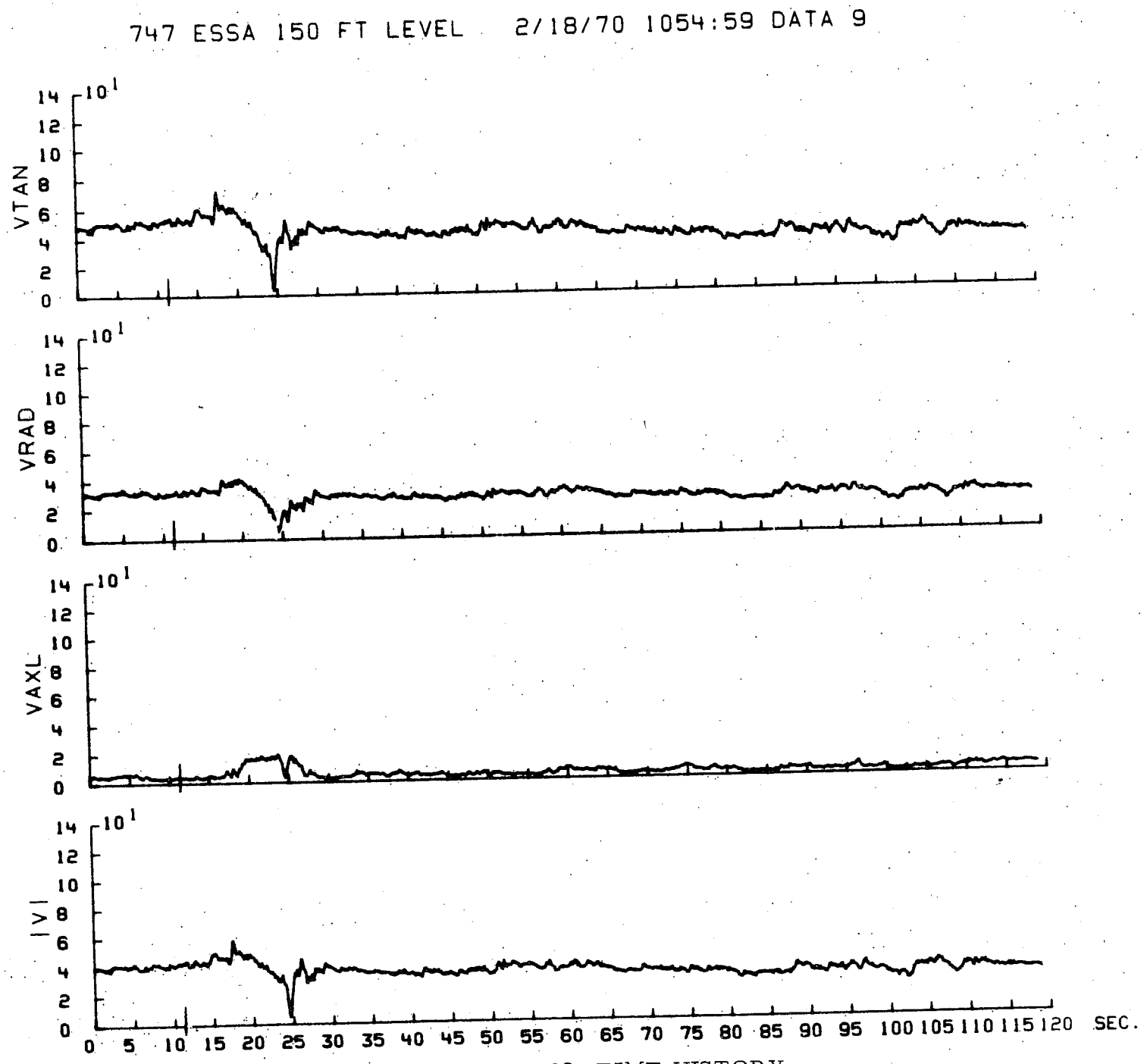


FIG. 7-32 TIME HISTORY

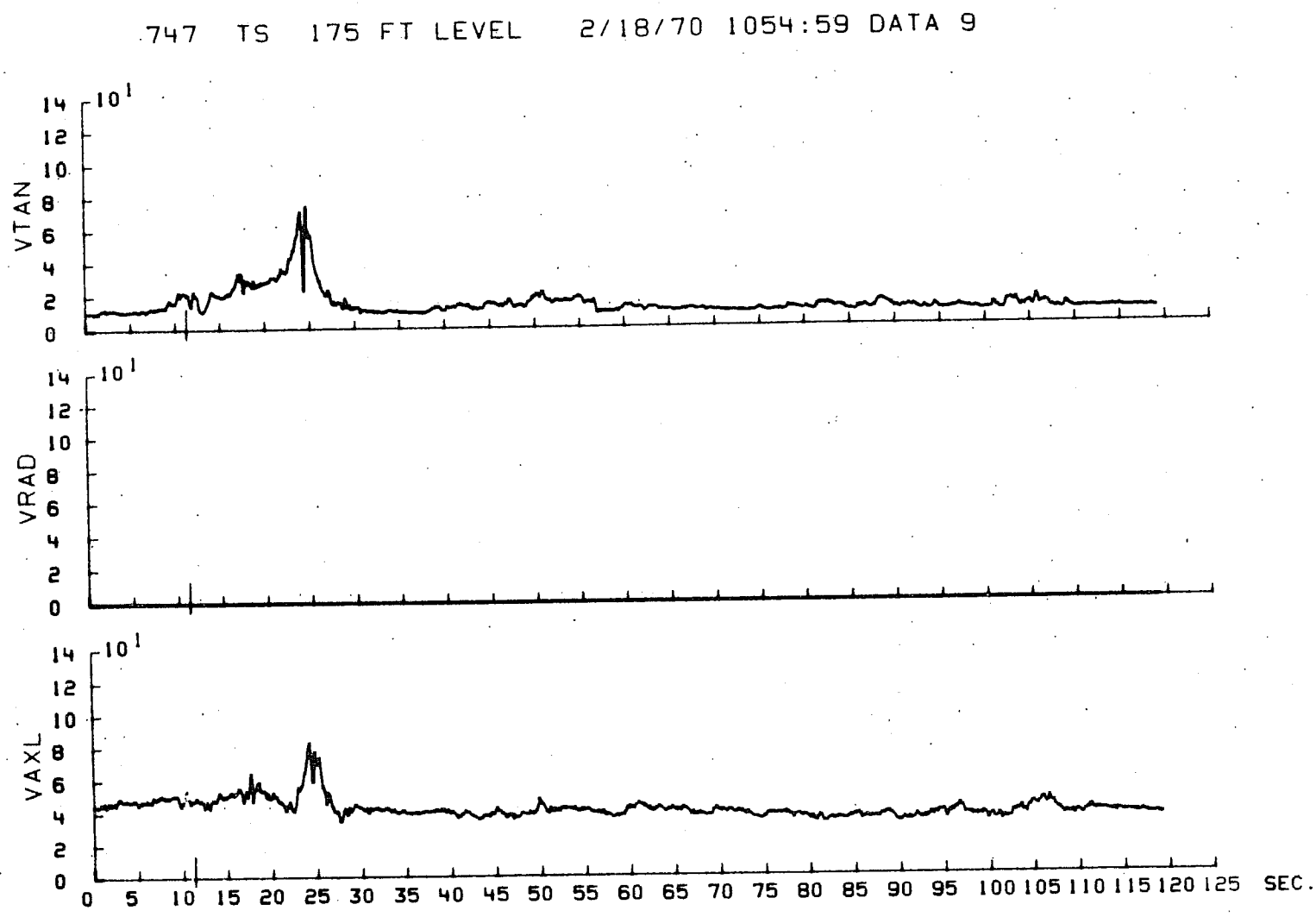


FIG. 7-33 TIME HISTORY

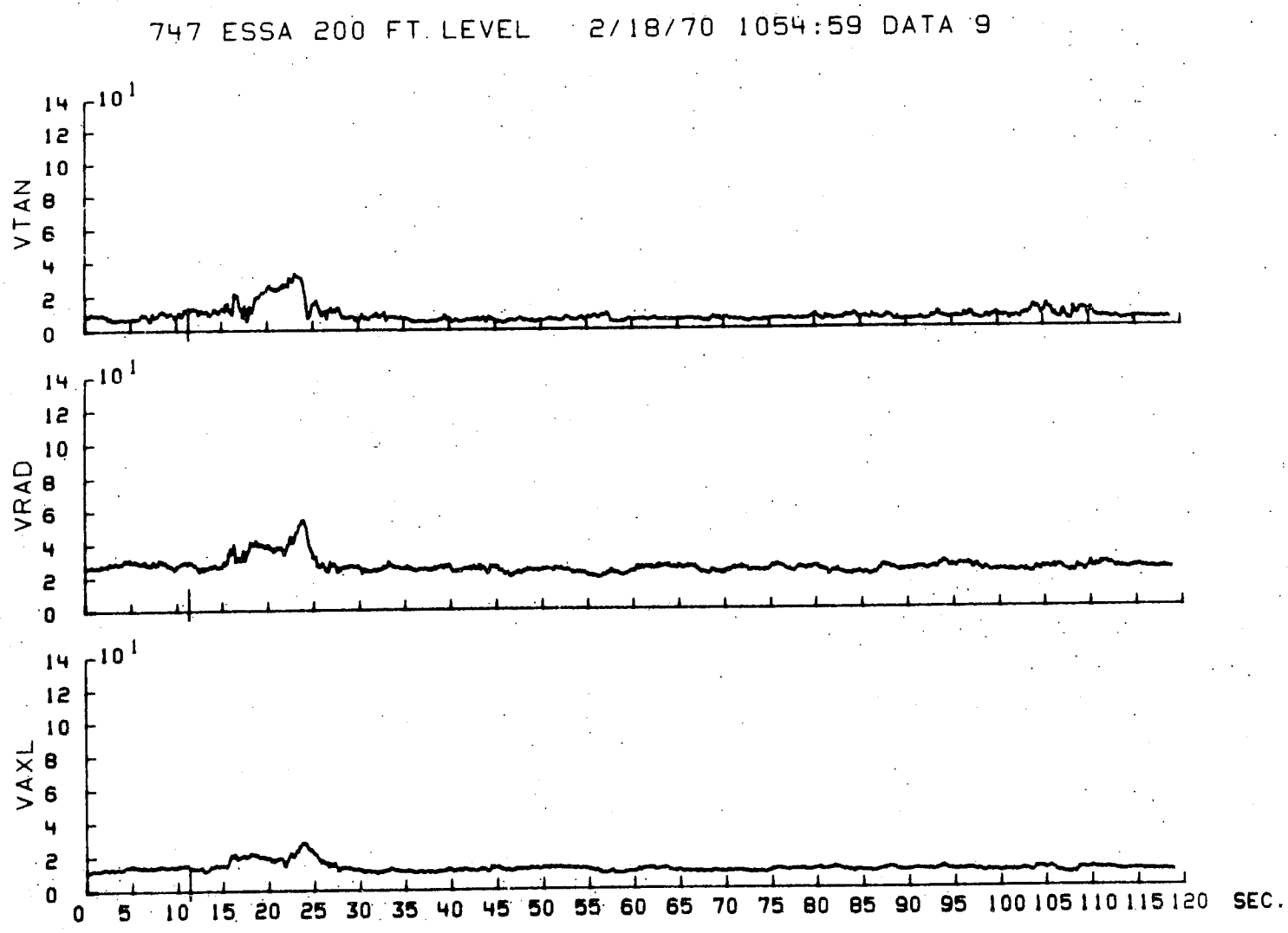


FIG. 7-34 TIME HISTORY

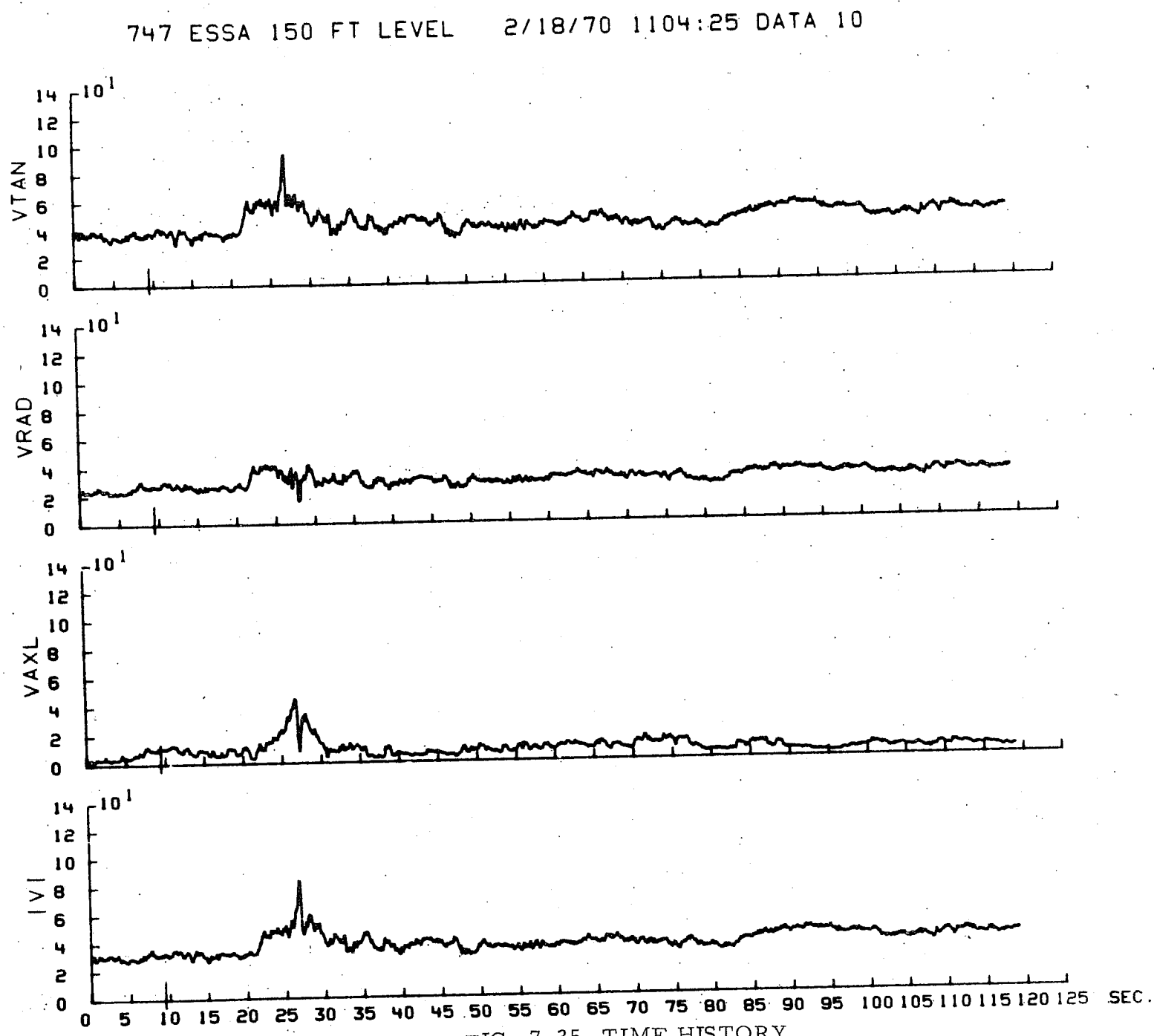


FIG. 7-35 TIME HISTORY

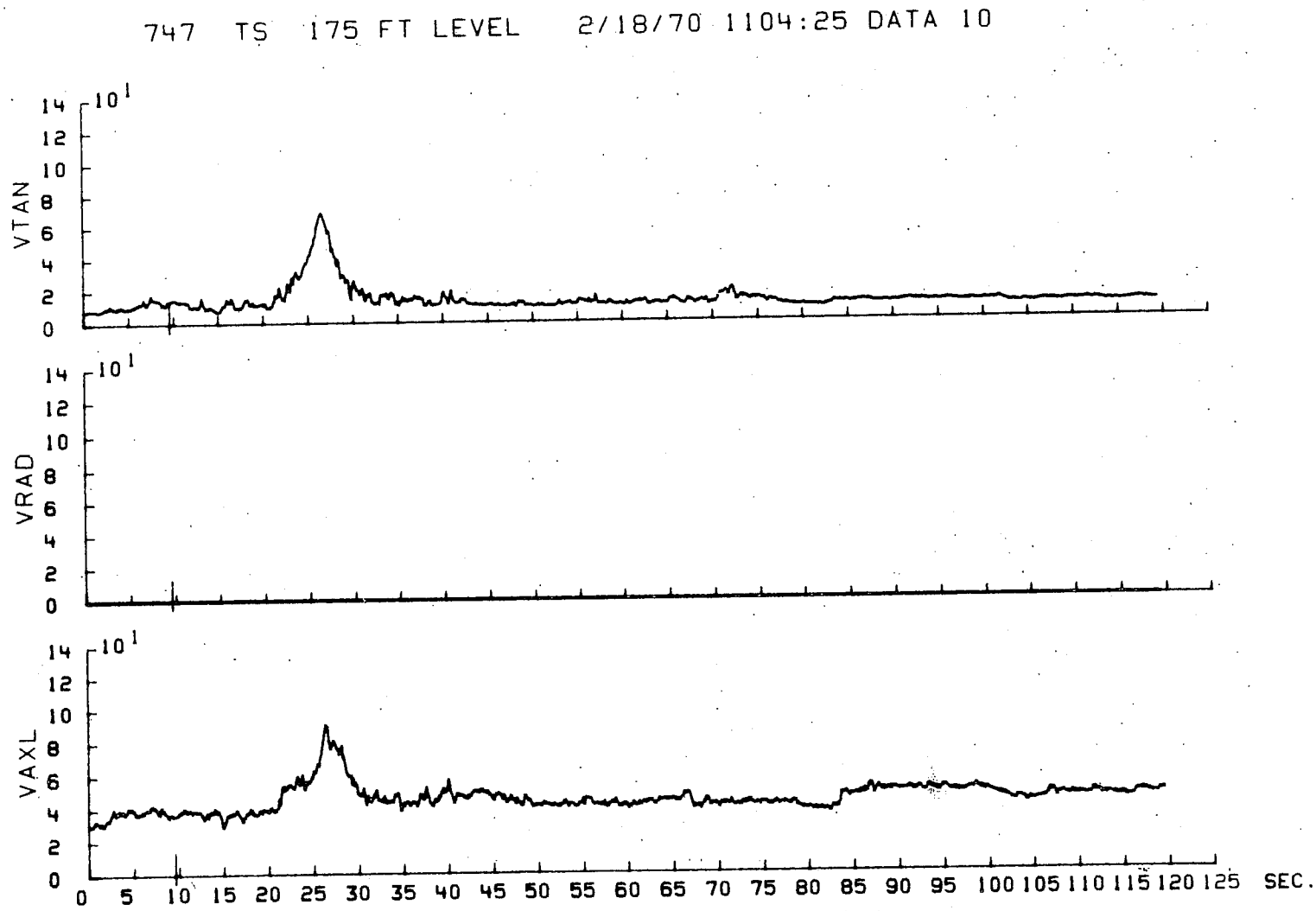


FIG. 7-36 TIME HISTORY

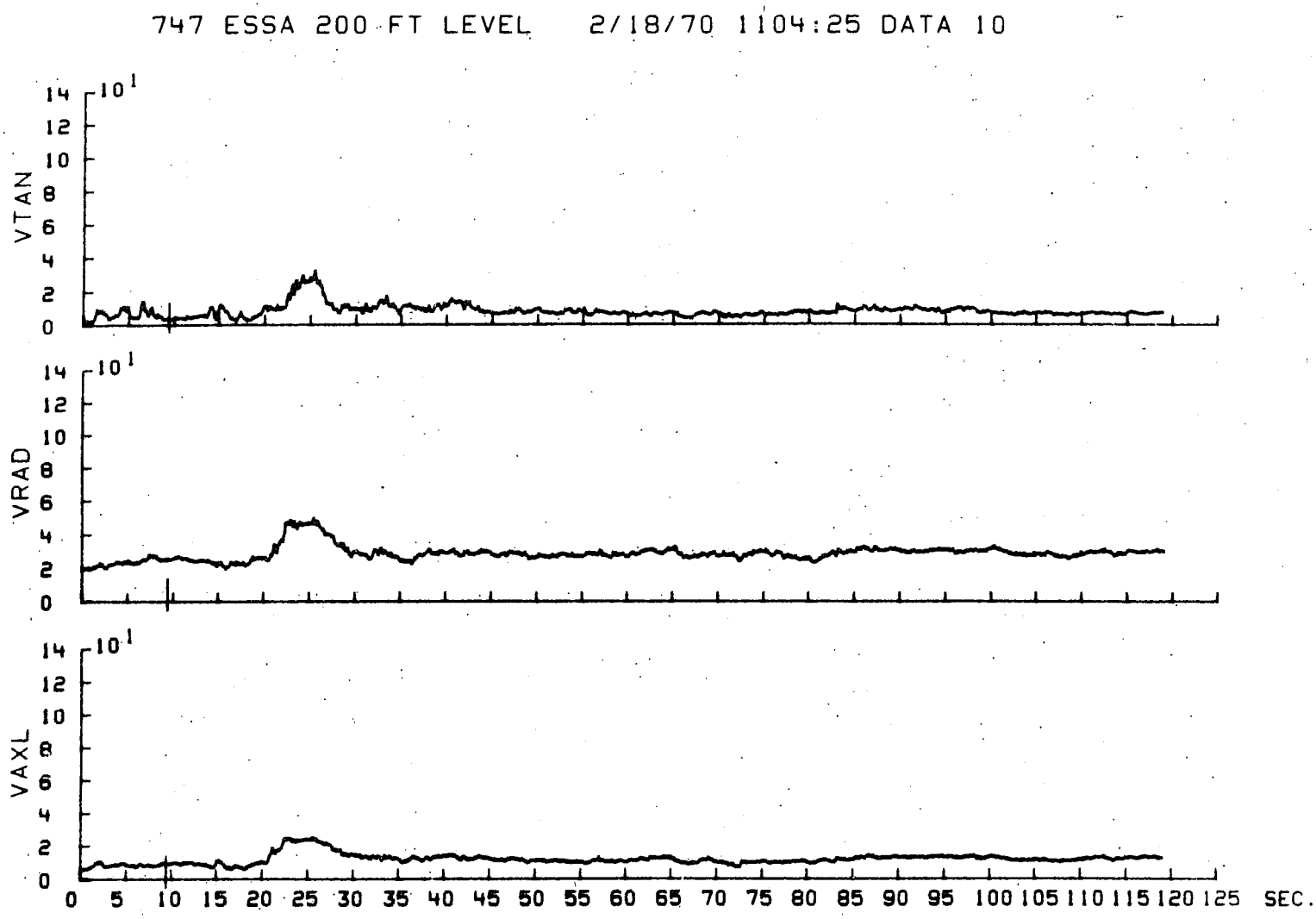


FIG. 7-37 TIME HISTORY

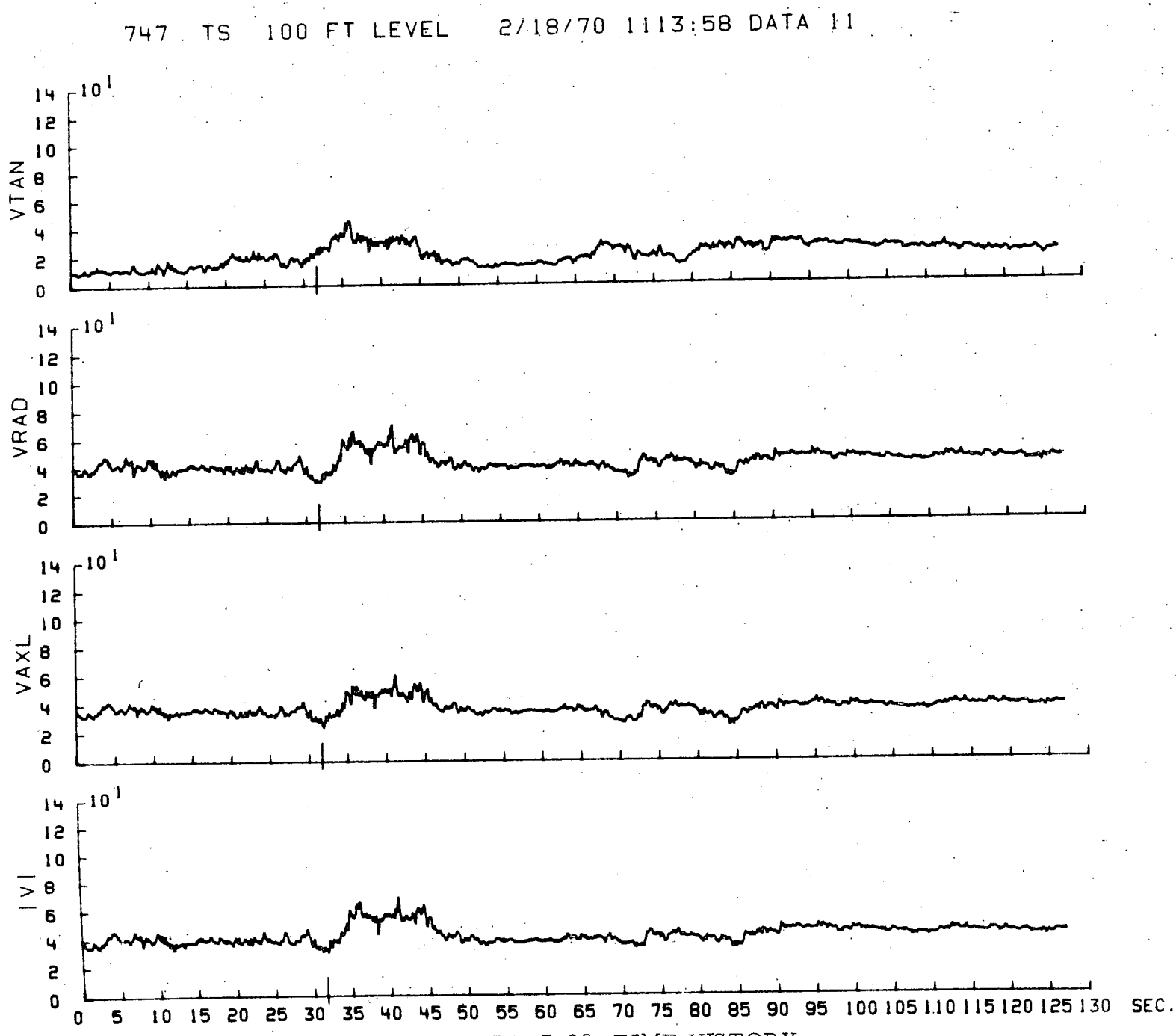


FIG. 7-38 TIME HISTORY

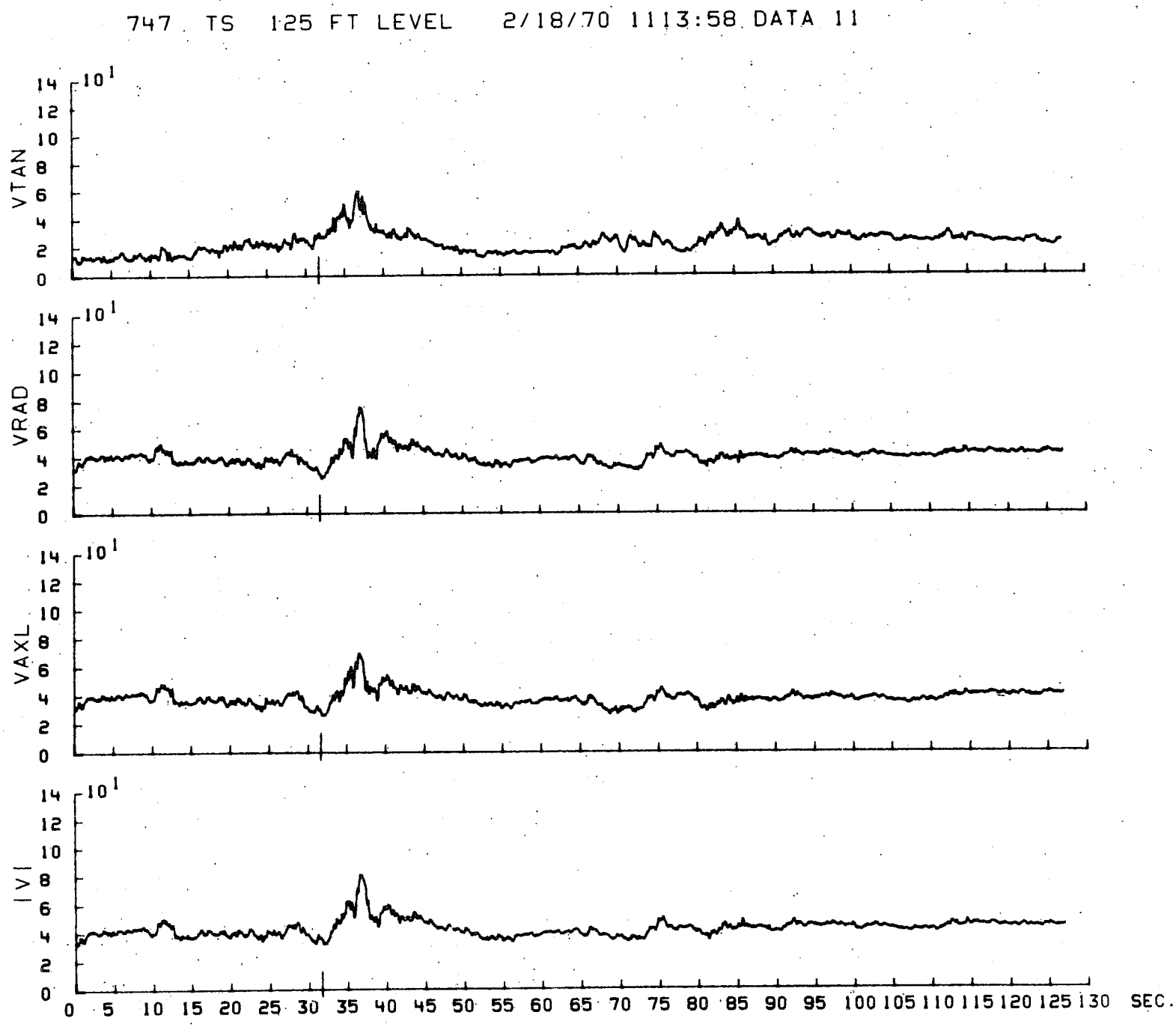


FIG. 7-39 TIME HISTORY

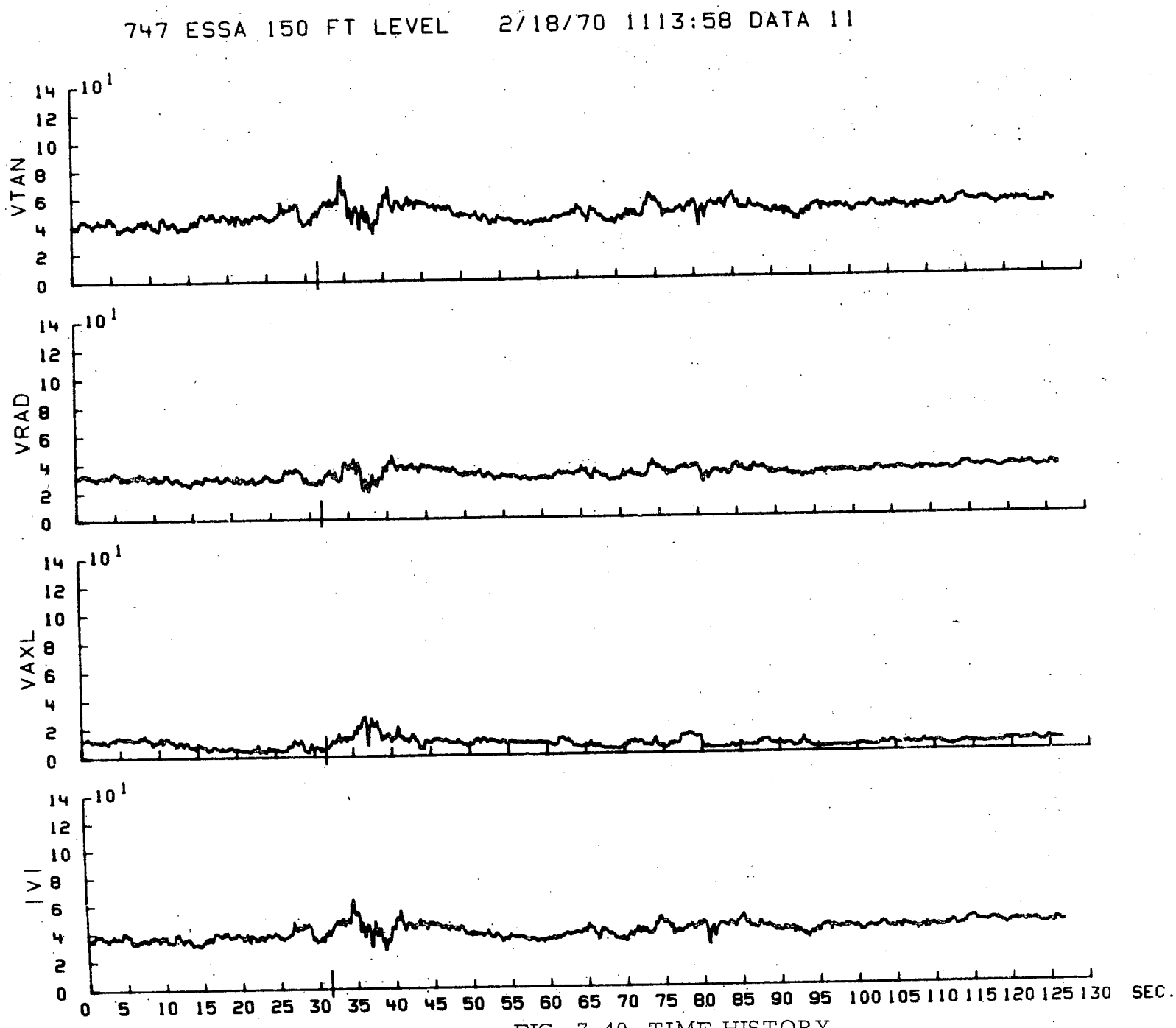


FIG. 7-40 TIME HISTORY

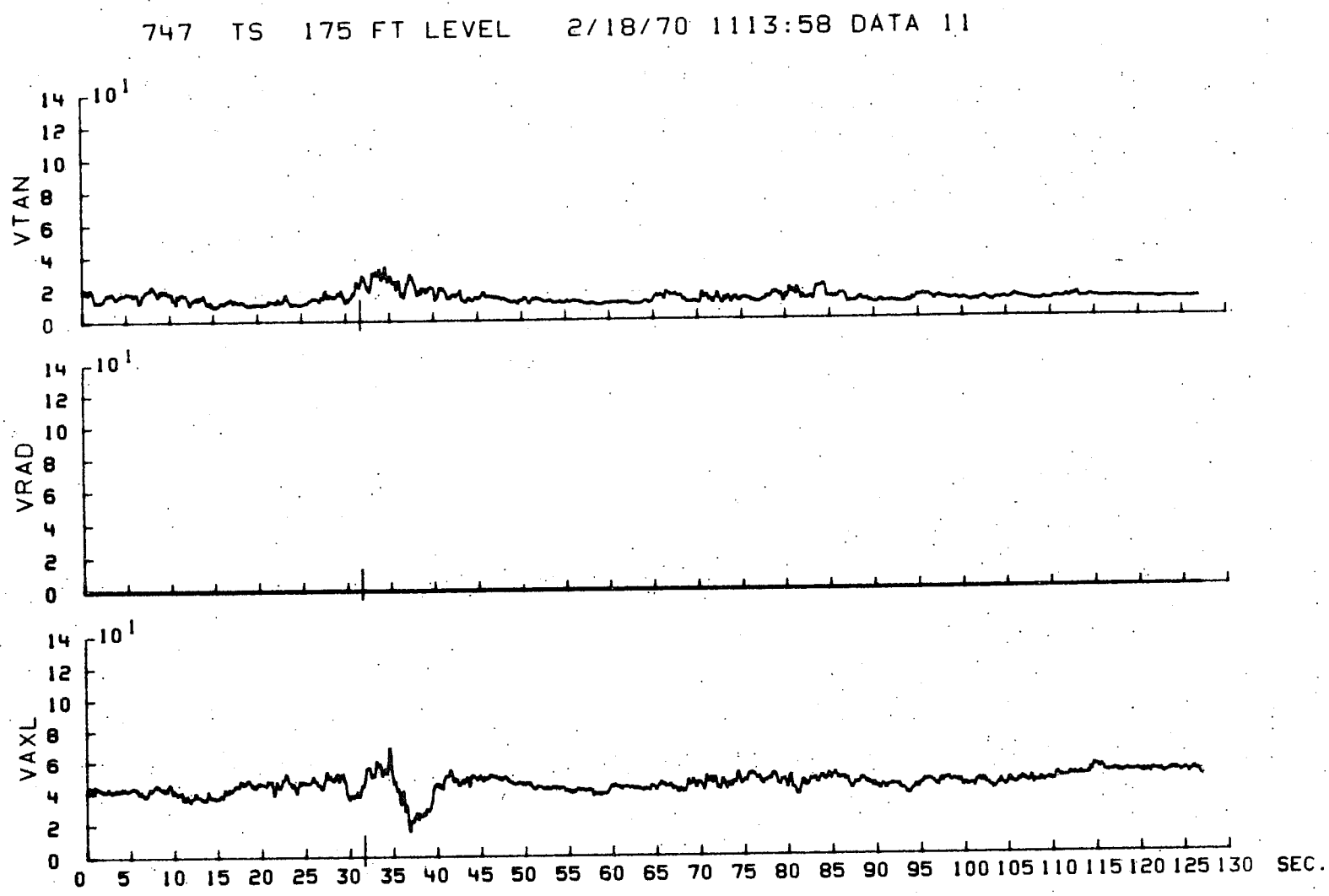


FIG. 7-41 TIME HISTORY

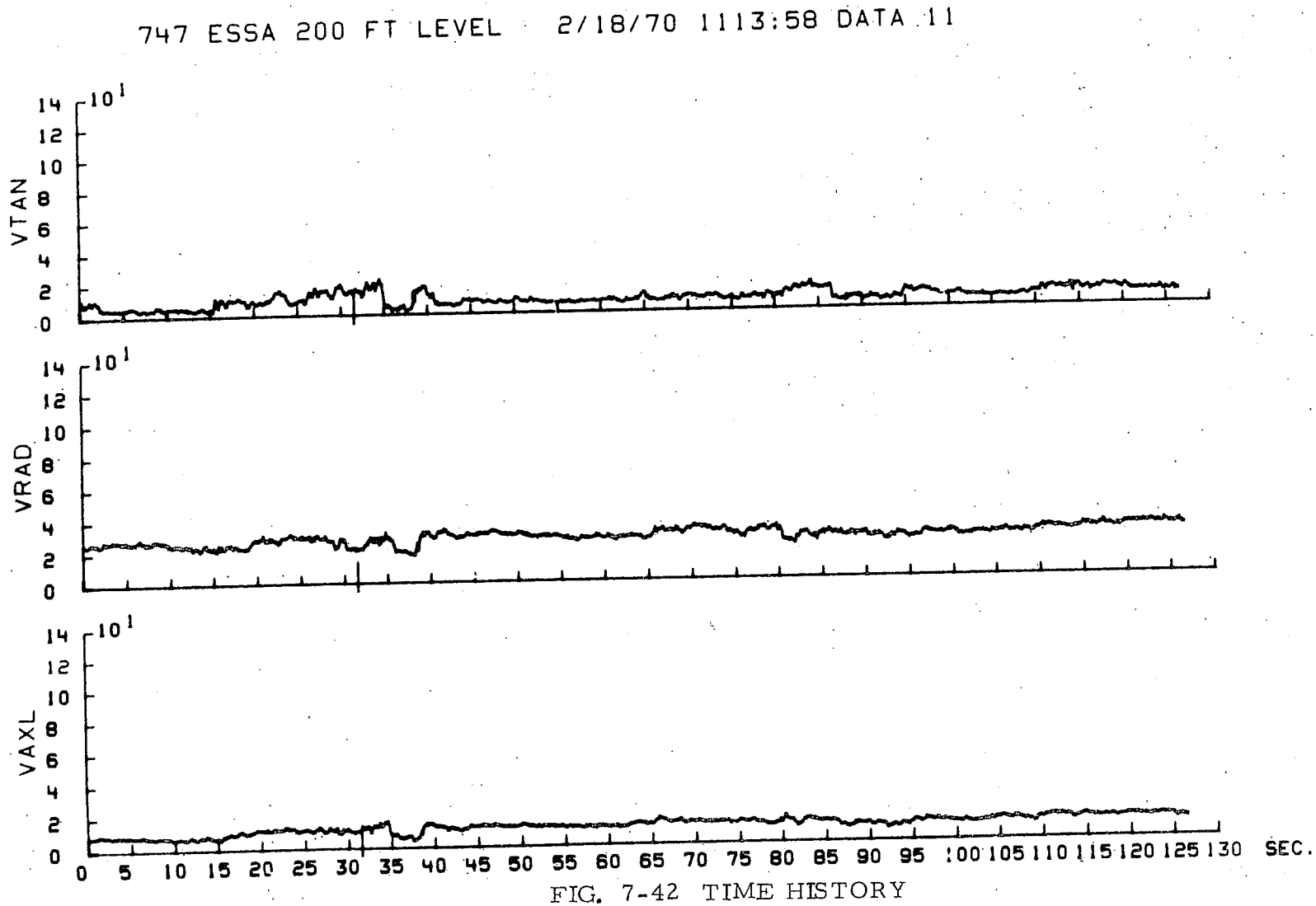


FIG. 7-42 TIME HISTORY

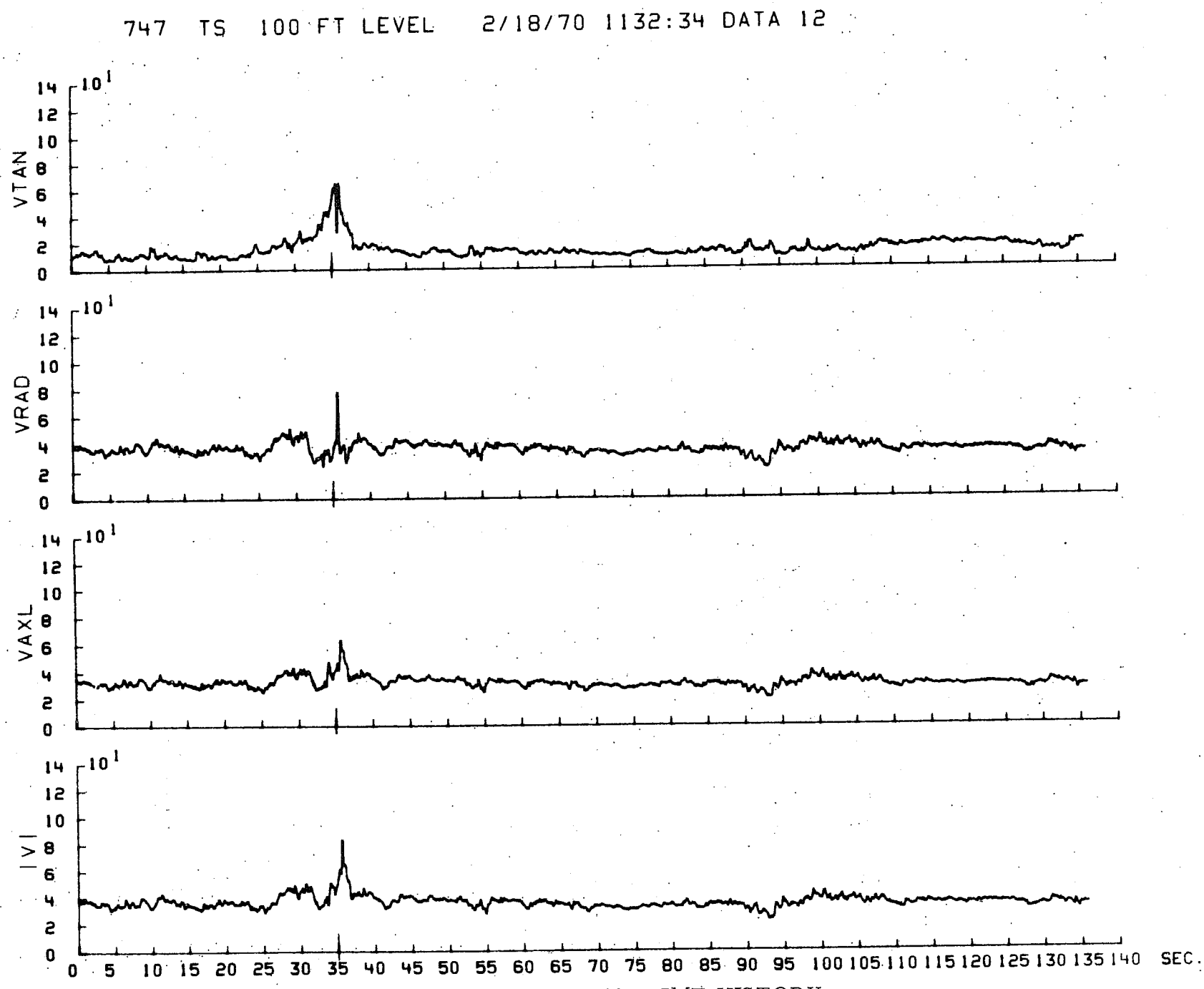


FIG. 7-43 TIME HISTORY

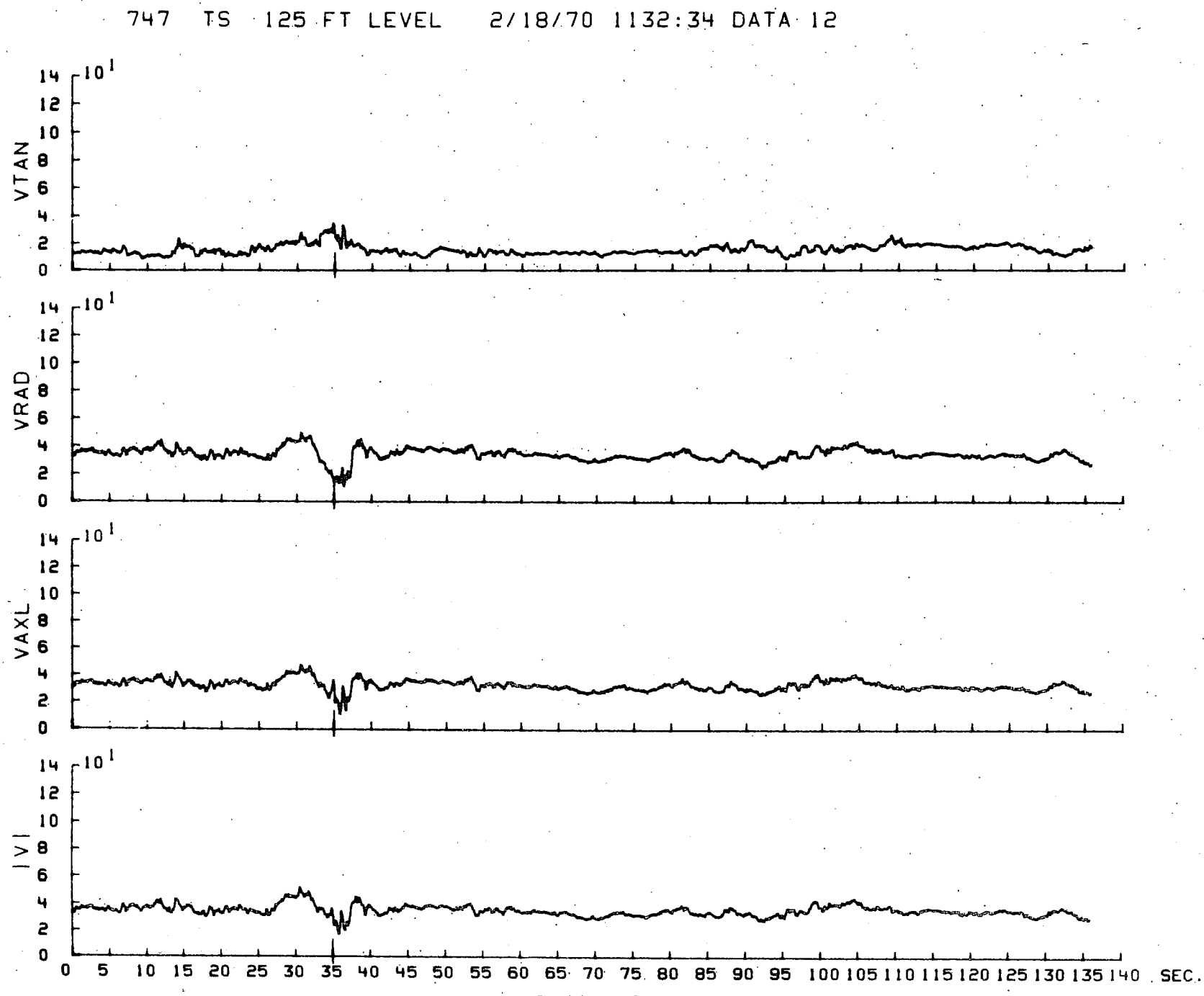


FIG. 7-44 TIME HISTORY

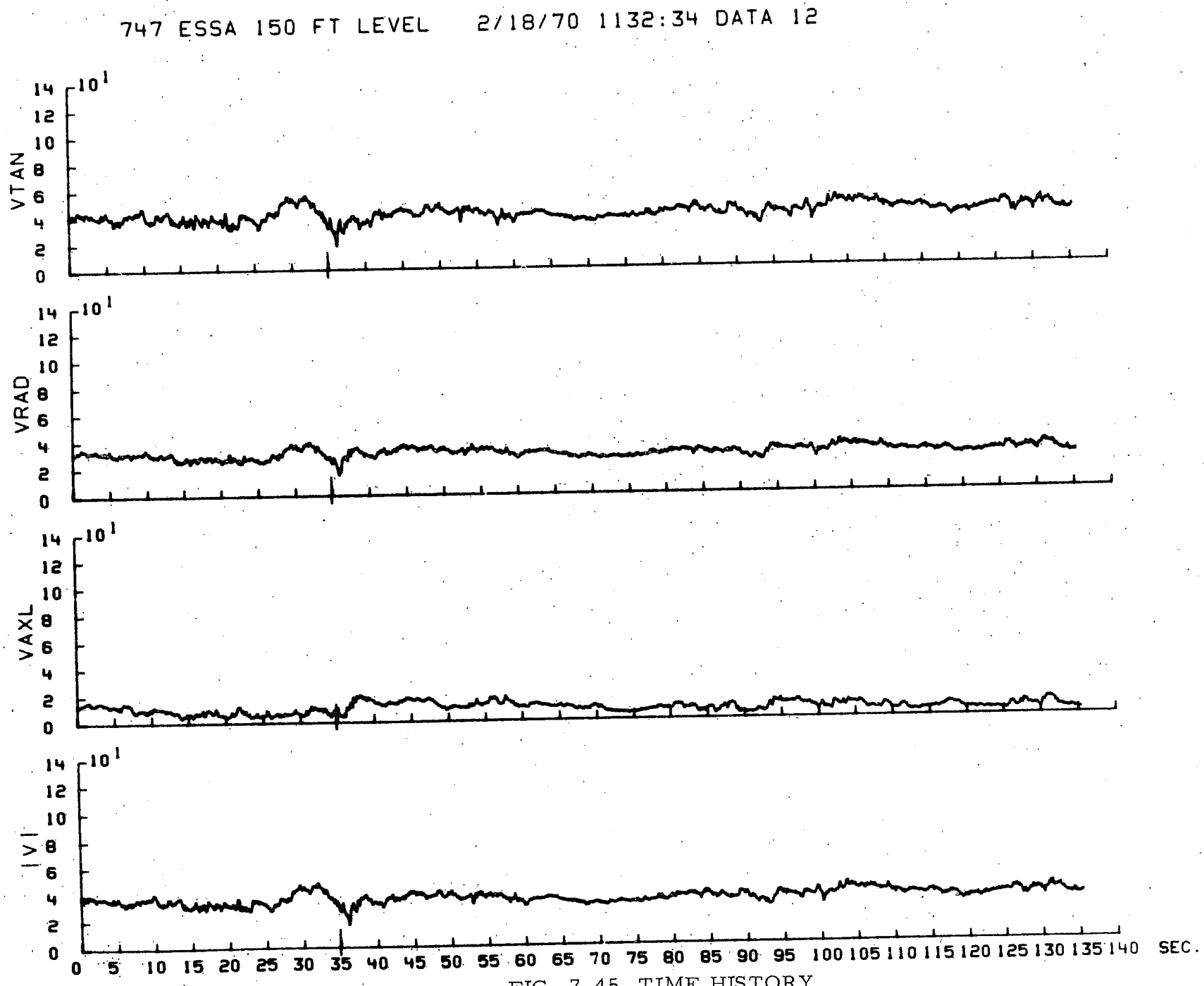


FIG. 7-45 TIME HISTORY

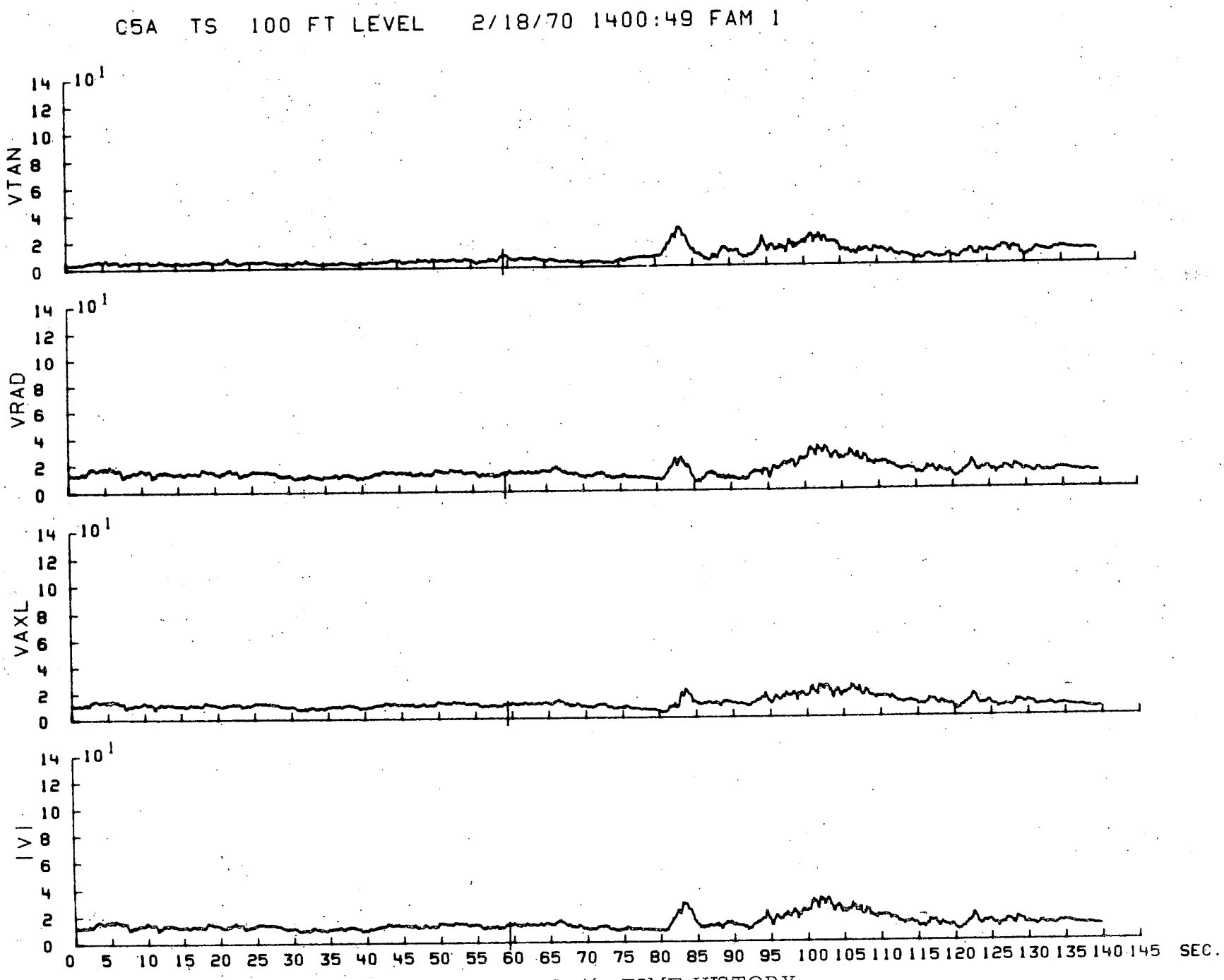


FIG. 7-46 TIME HISTORY

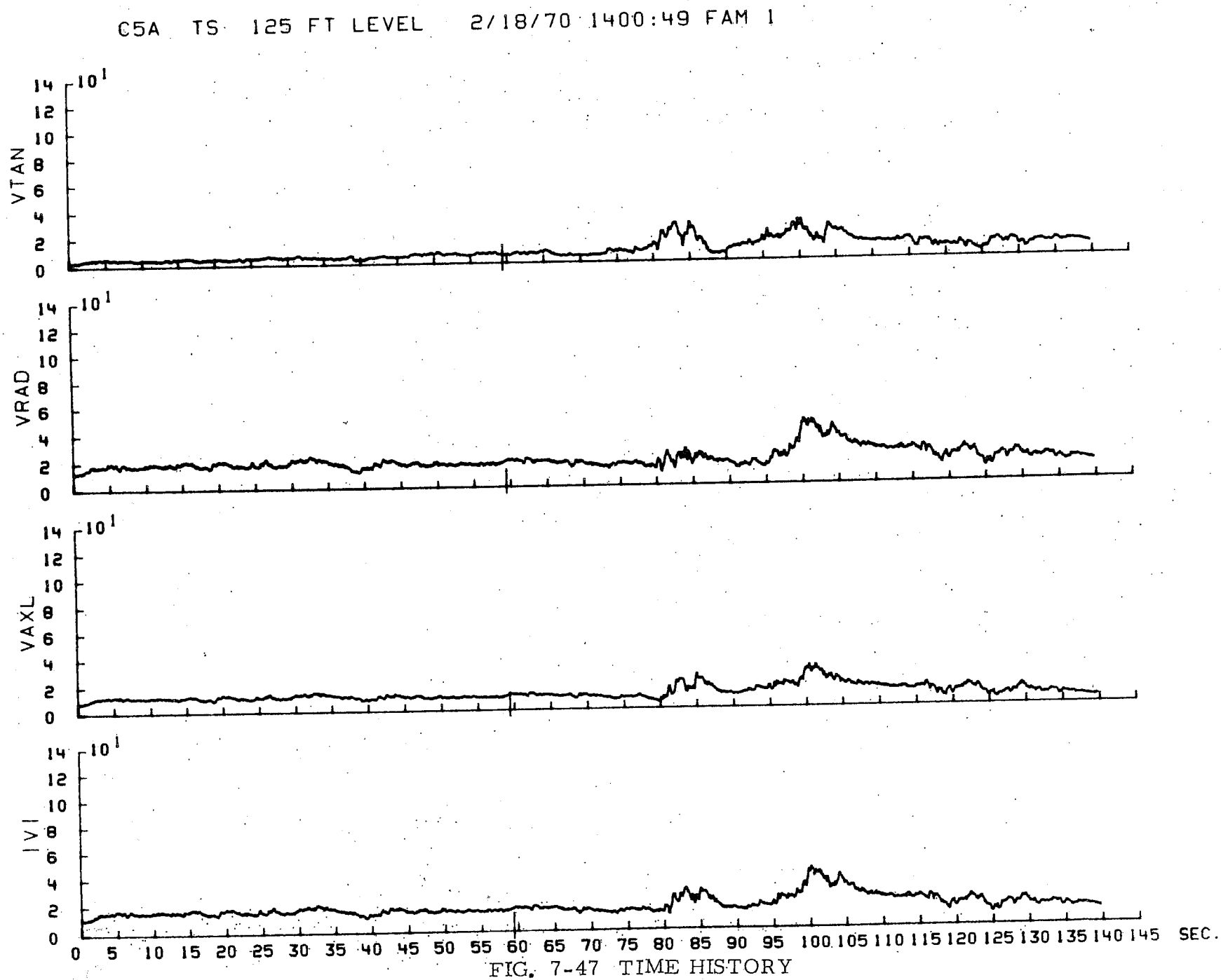


FIG. 7-47 TIME HISTORY

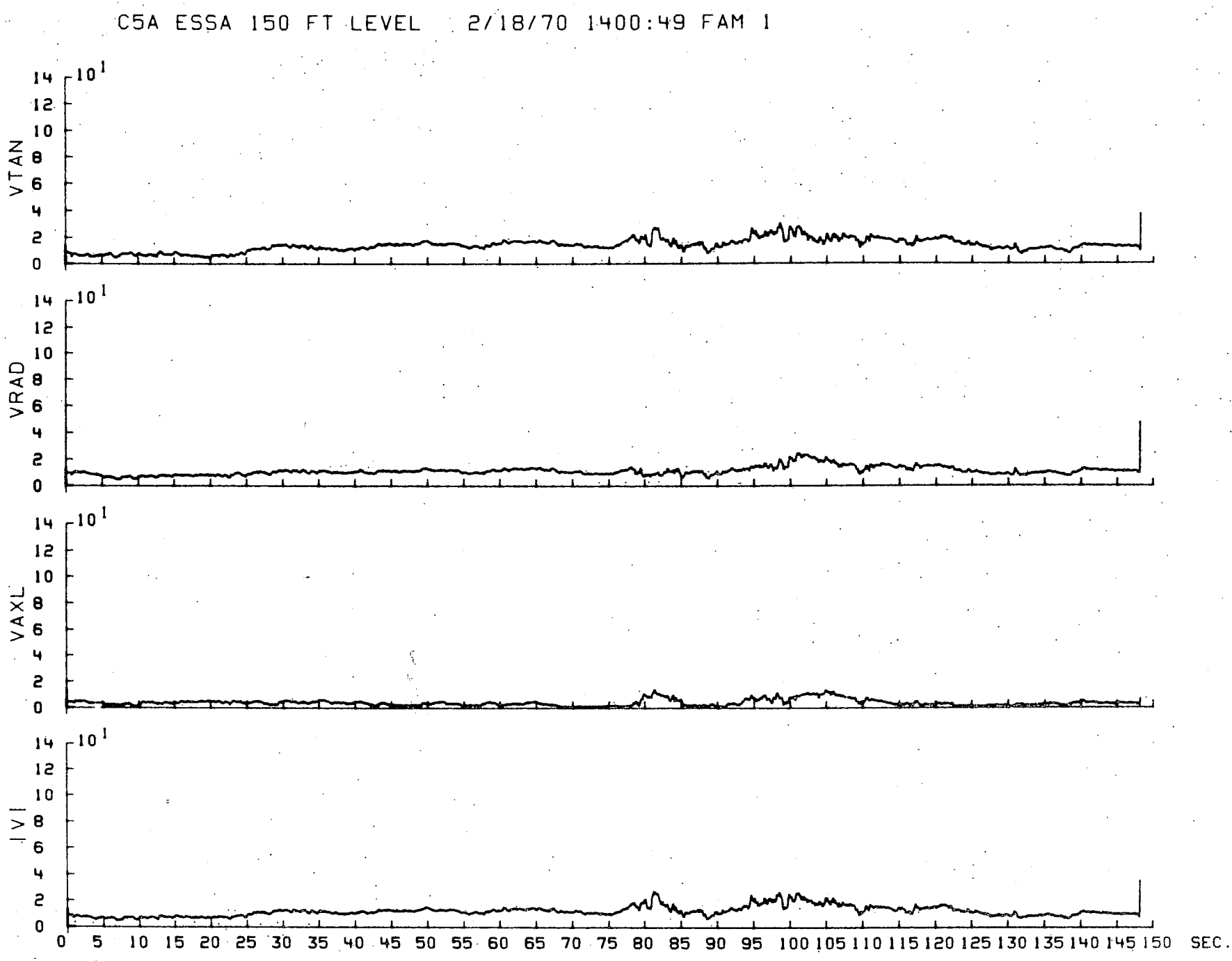


FIG. 7-48 TIME HISTORY

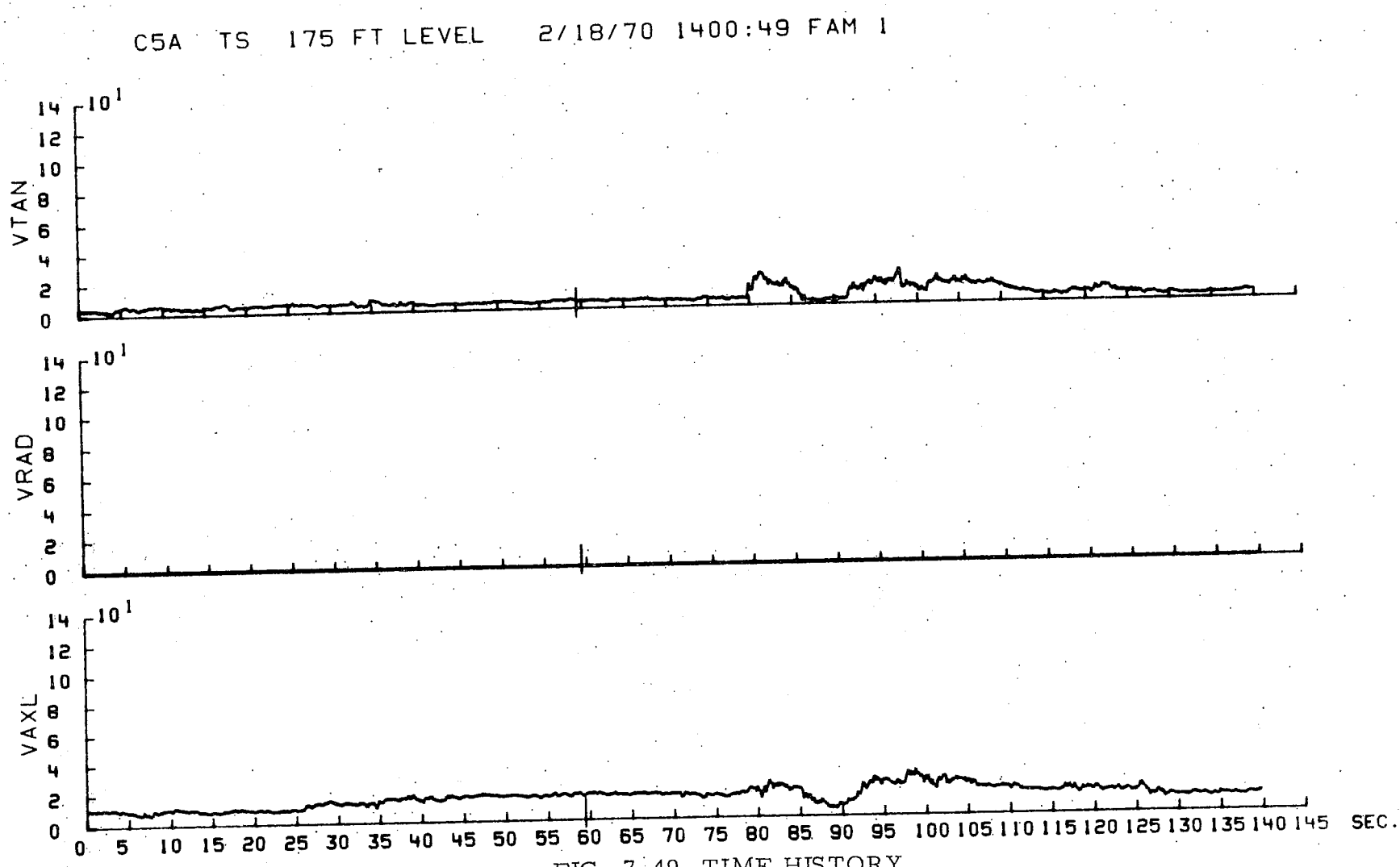


FIG. 7-49 TIME HISTORY

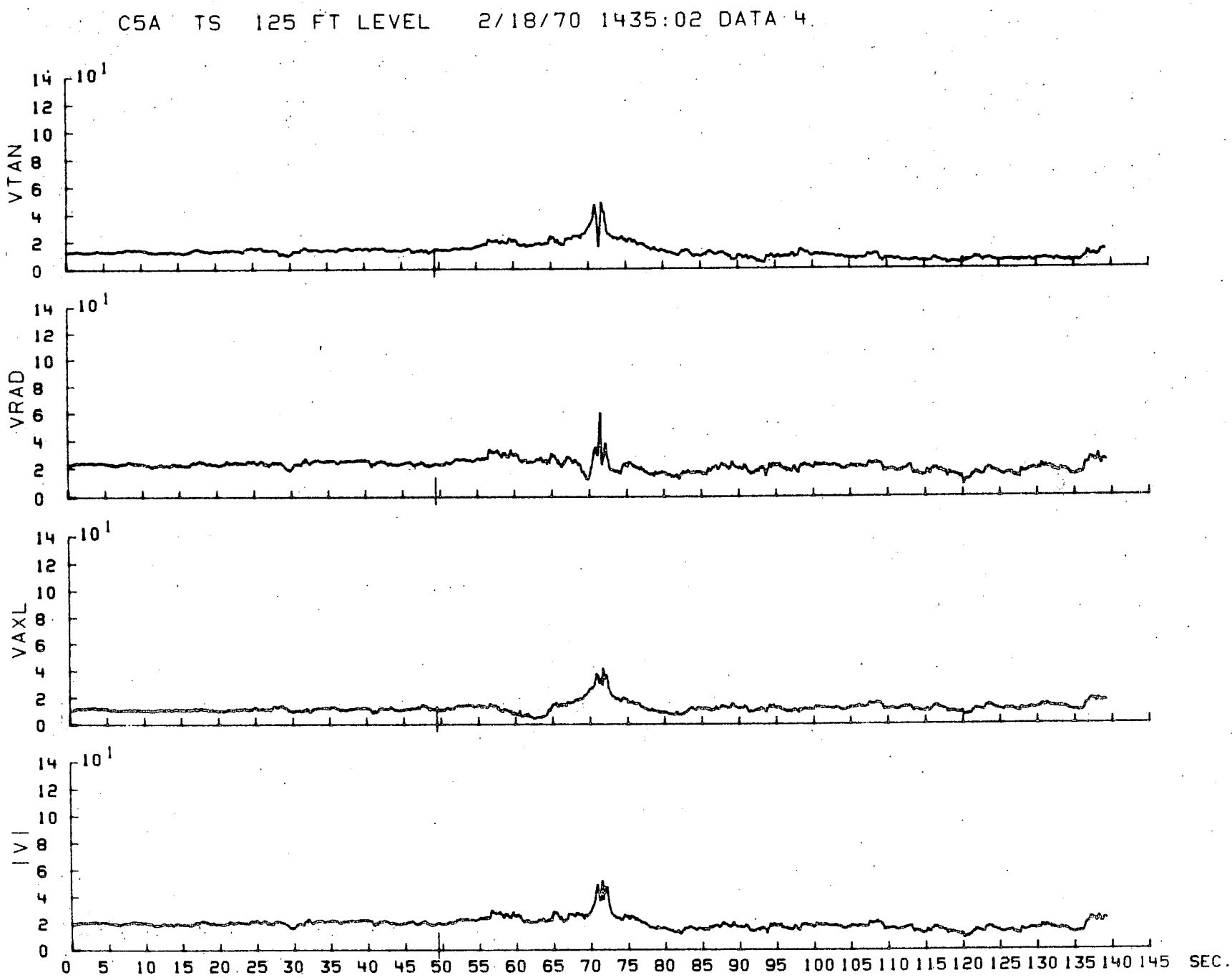


FIG. 7-50 TIME HISTORY

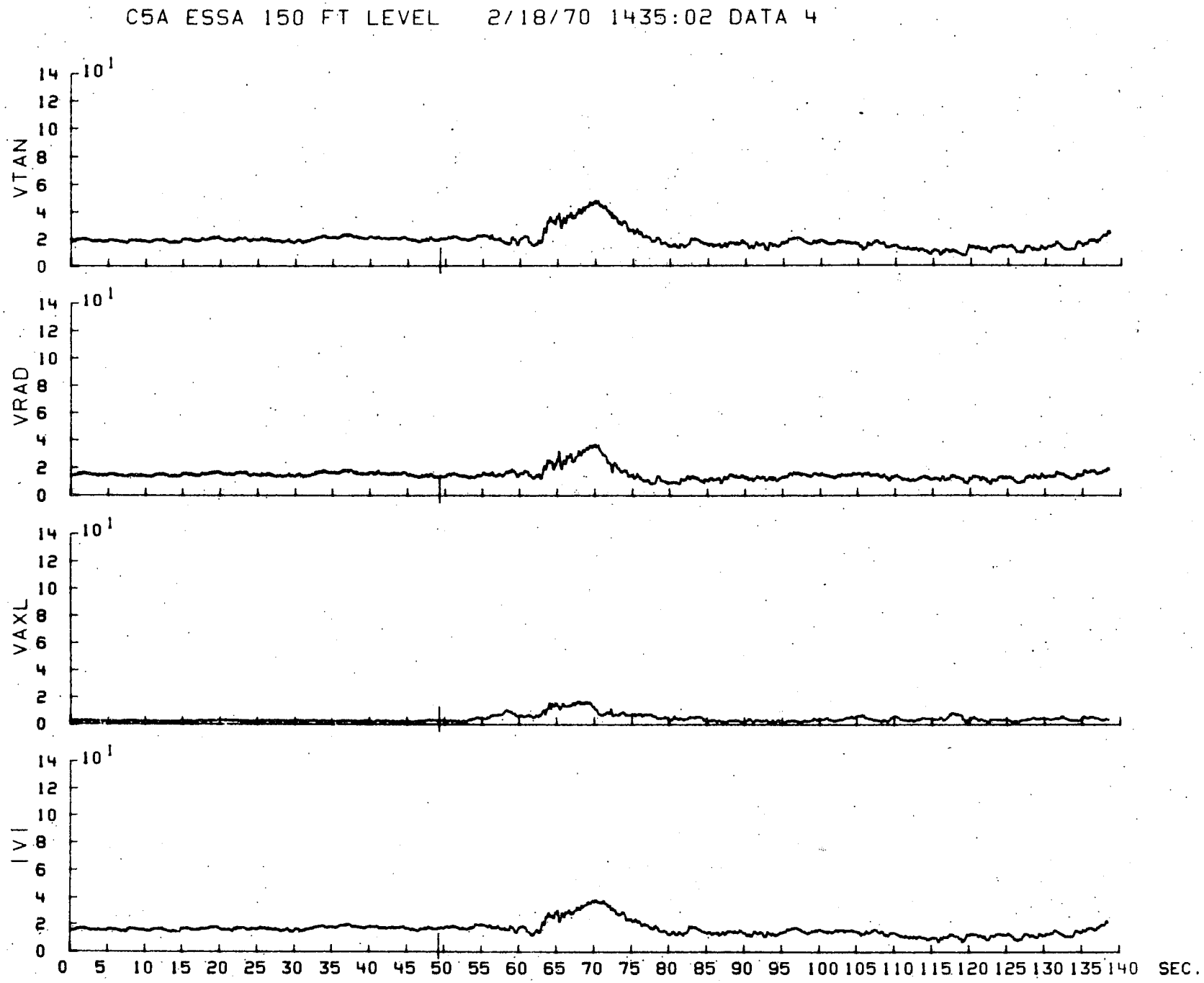


FIG. 7-51 TIME HISTORY

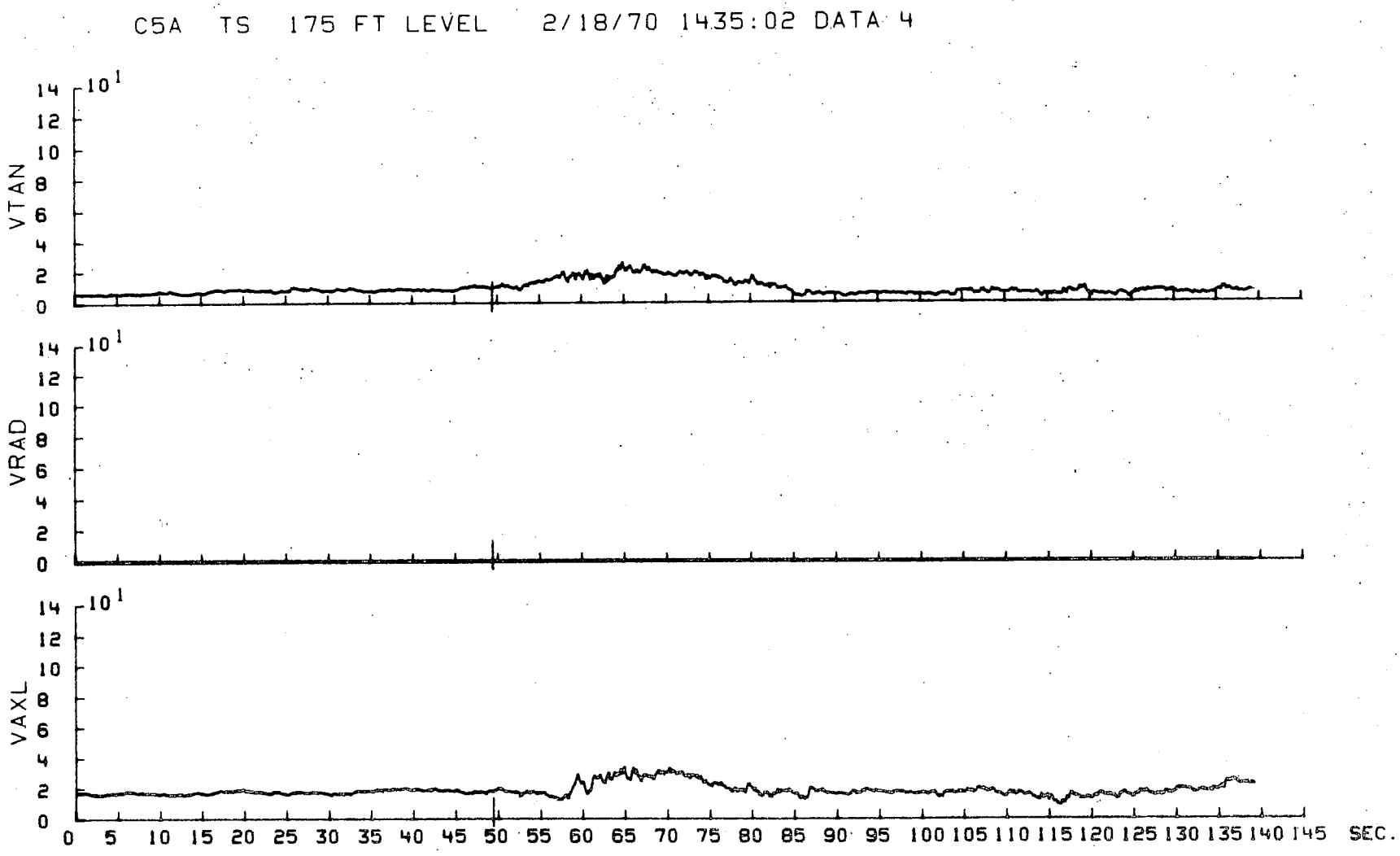


FIG. 7-52 TIME HISTORY

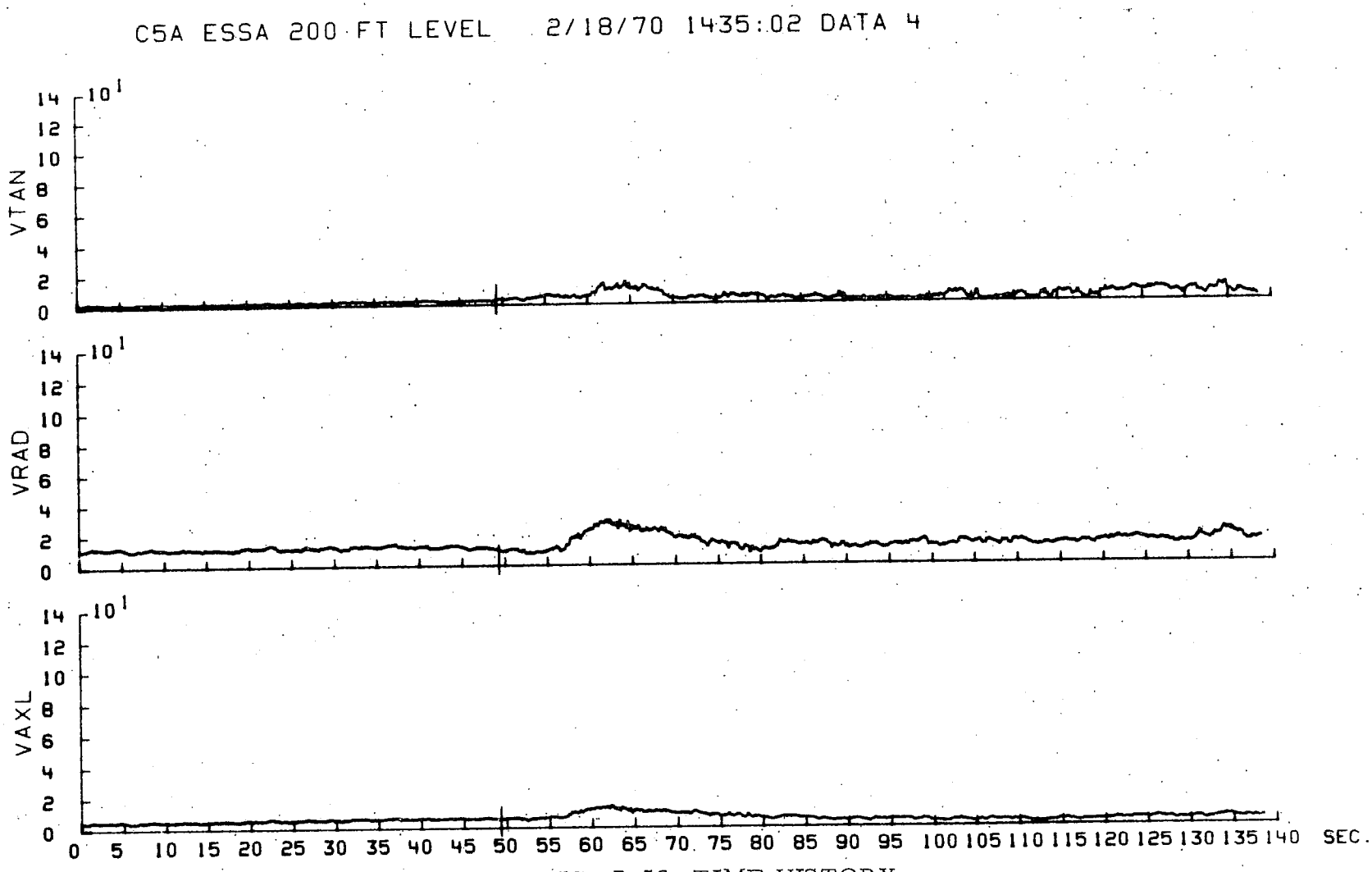


FIG. 7-53 TIME HISTORY

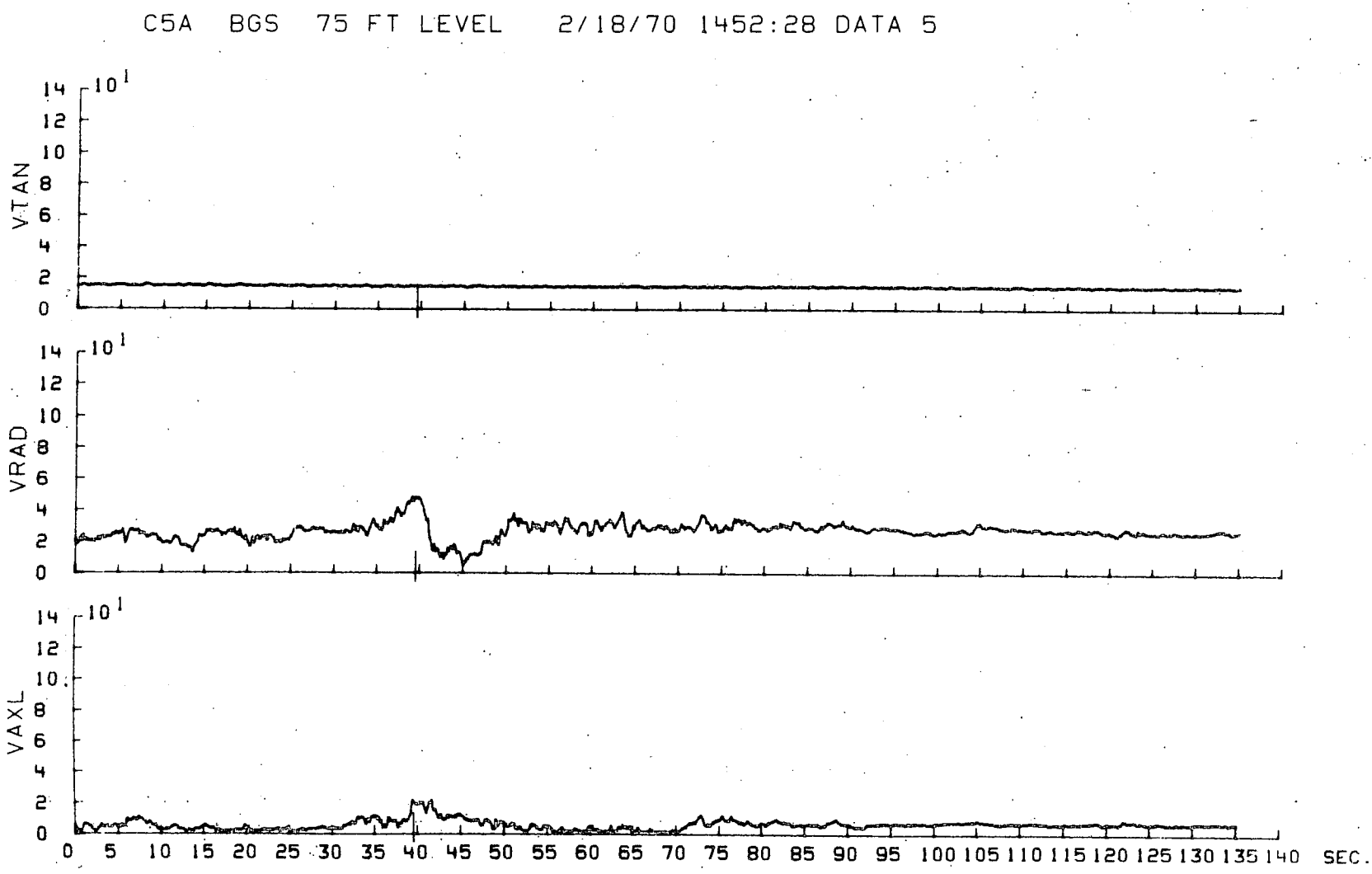


FIG. 7-54 TIME HISTORY

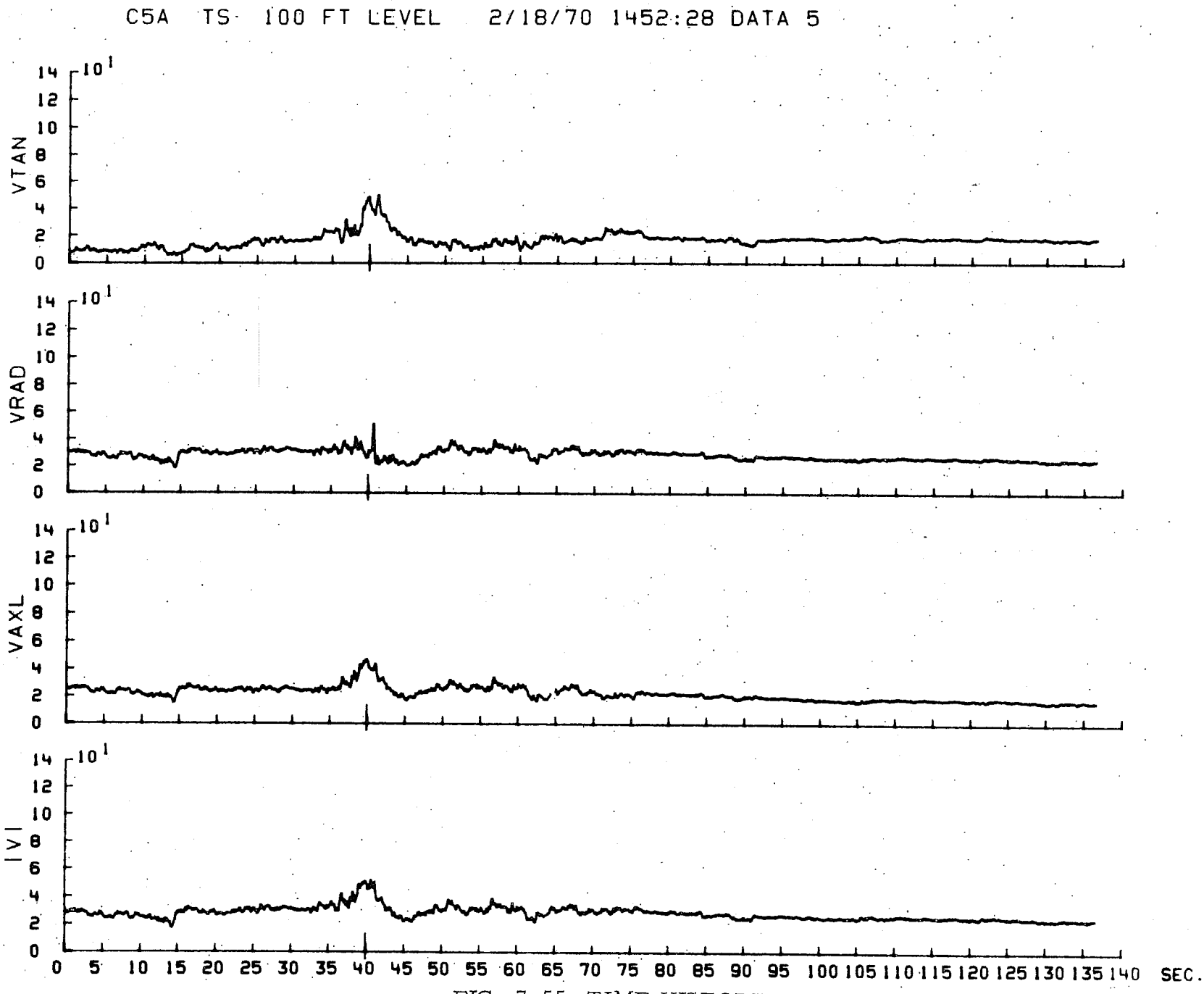


FIG. 7-55 TIME HISTORY

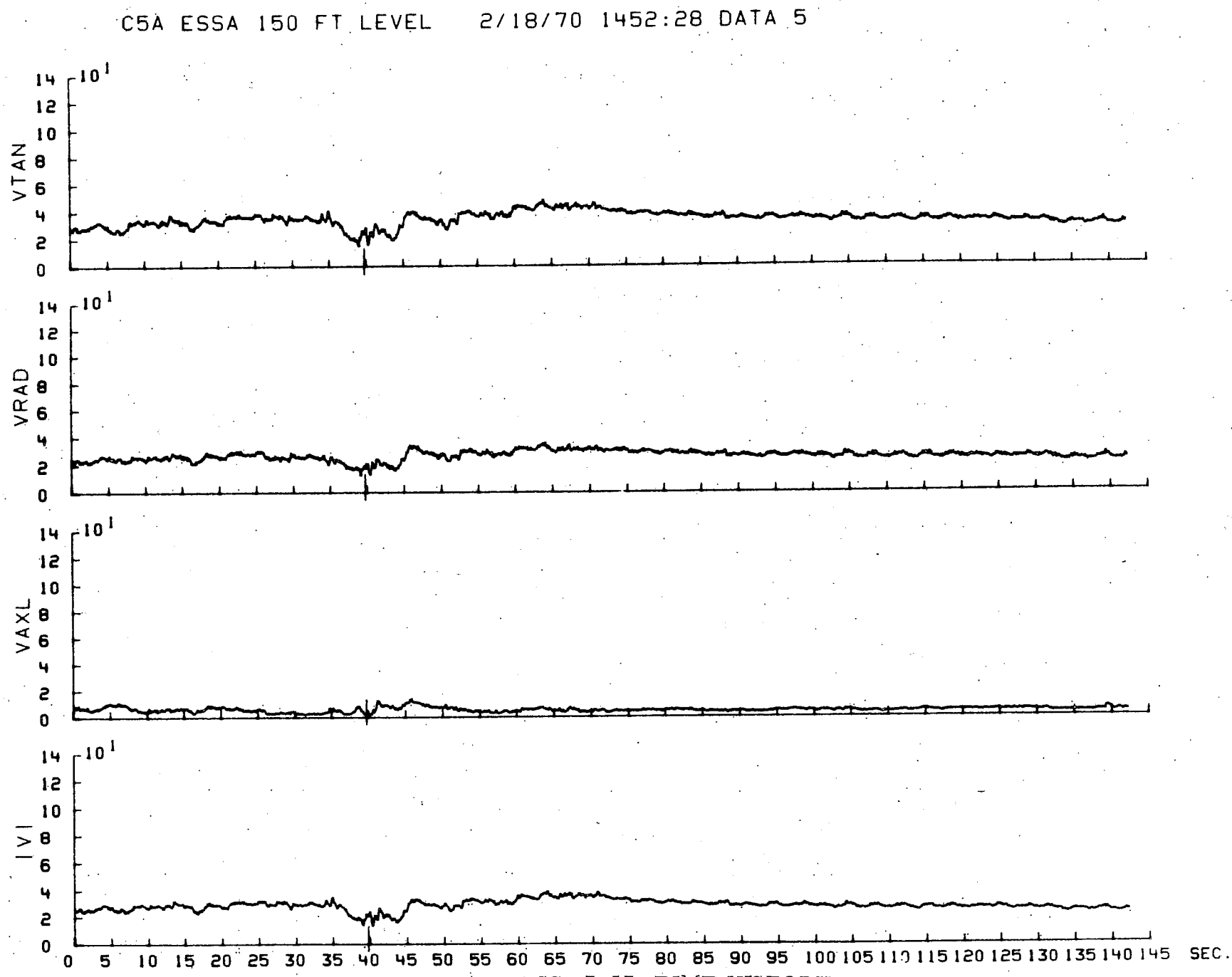


FIG. 7-57 TIME HISTORY

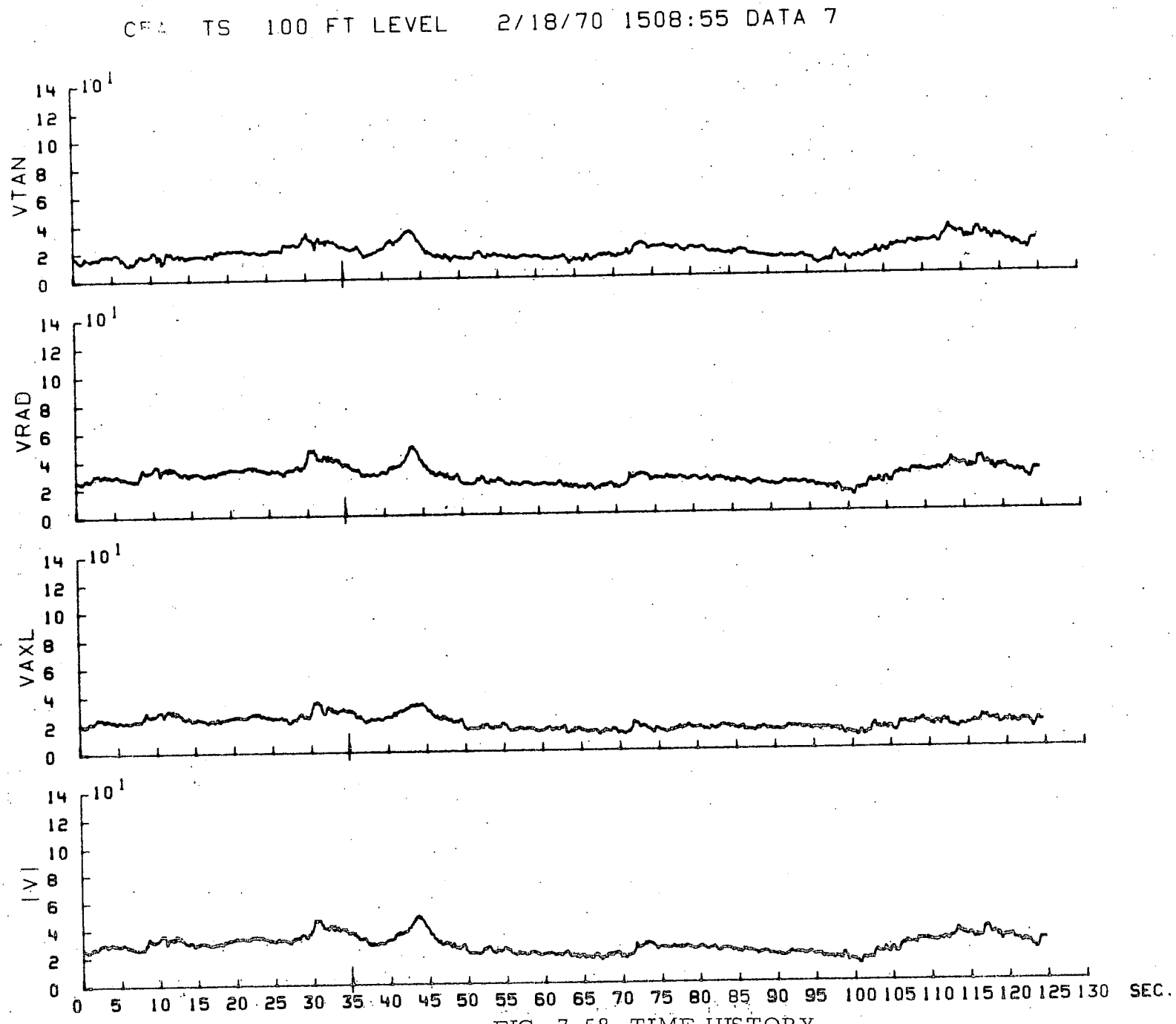


FIG. 7-58 TIME HISTORY

C5A TS 125 FT LEVEL 2/18/70 1508:55 DATA 7

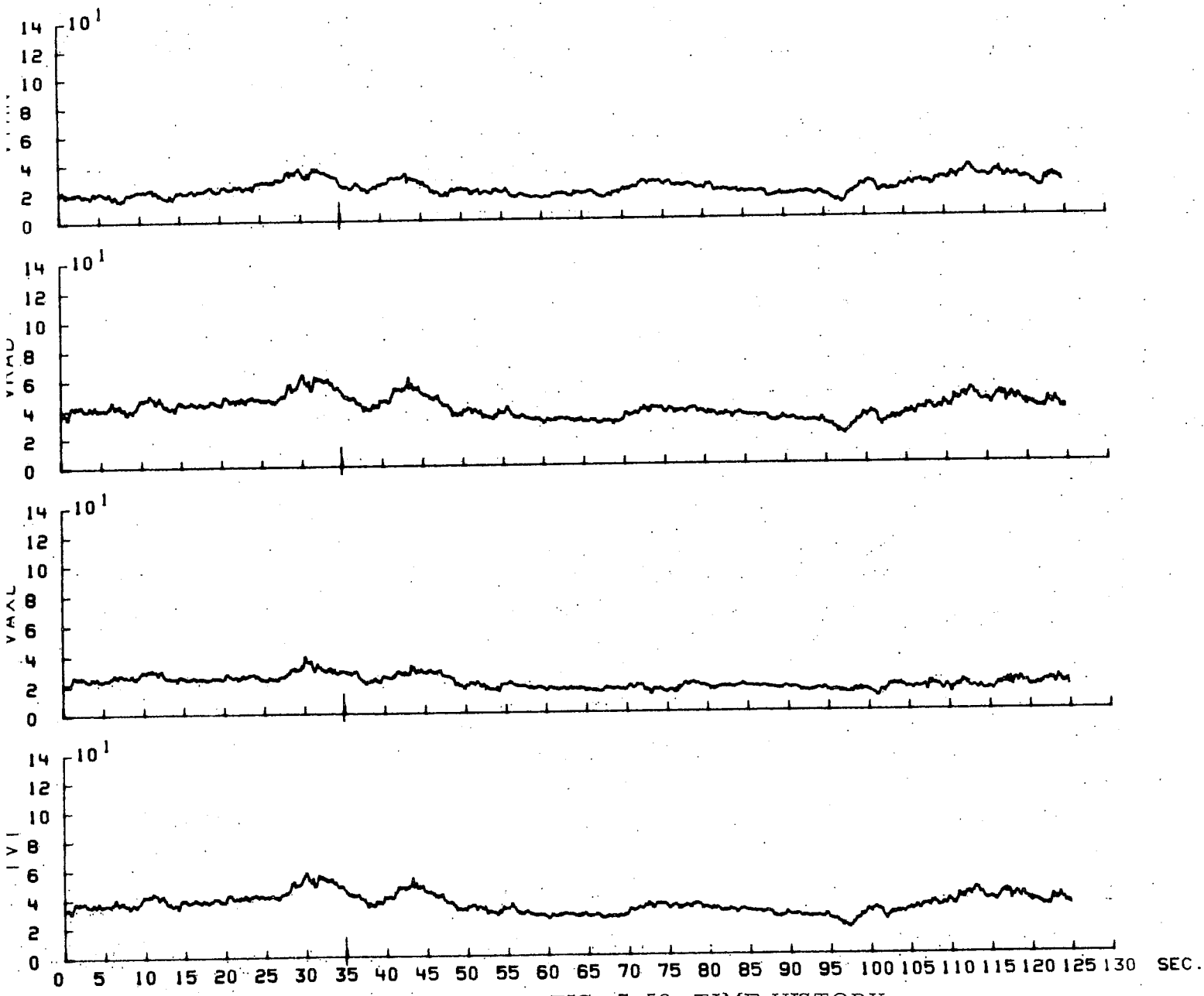


FIG. 7-59 TIME HISTORY

C5A ESSA 150 FT LEVEL 2/18/70 1508:55 DATA 7

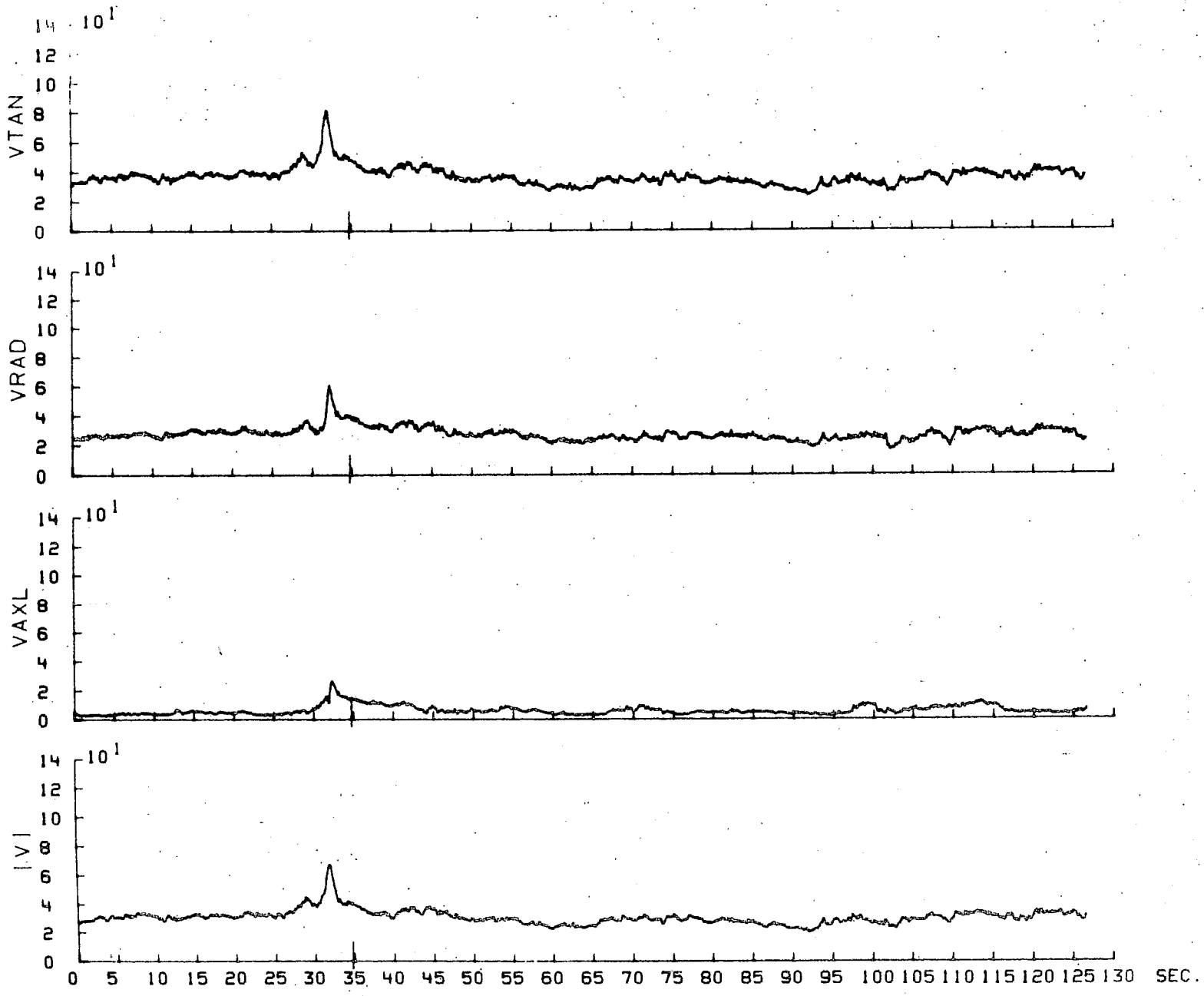


FIG. 7-60 TIME HISTORY

C5A TS 100 FT LEVEL 2/18/70 1523:35 DATA 9

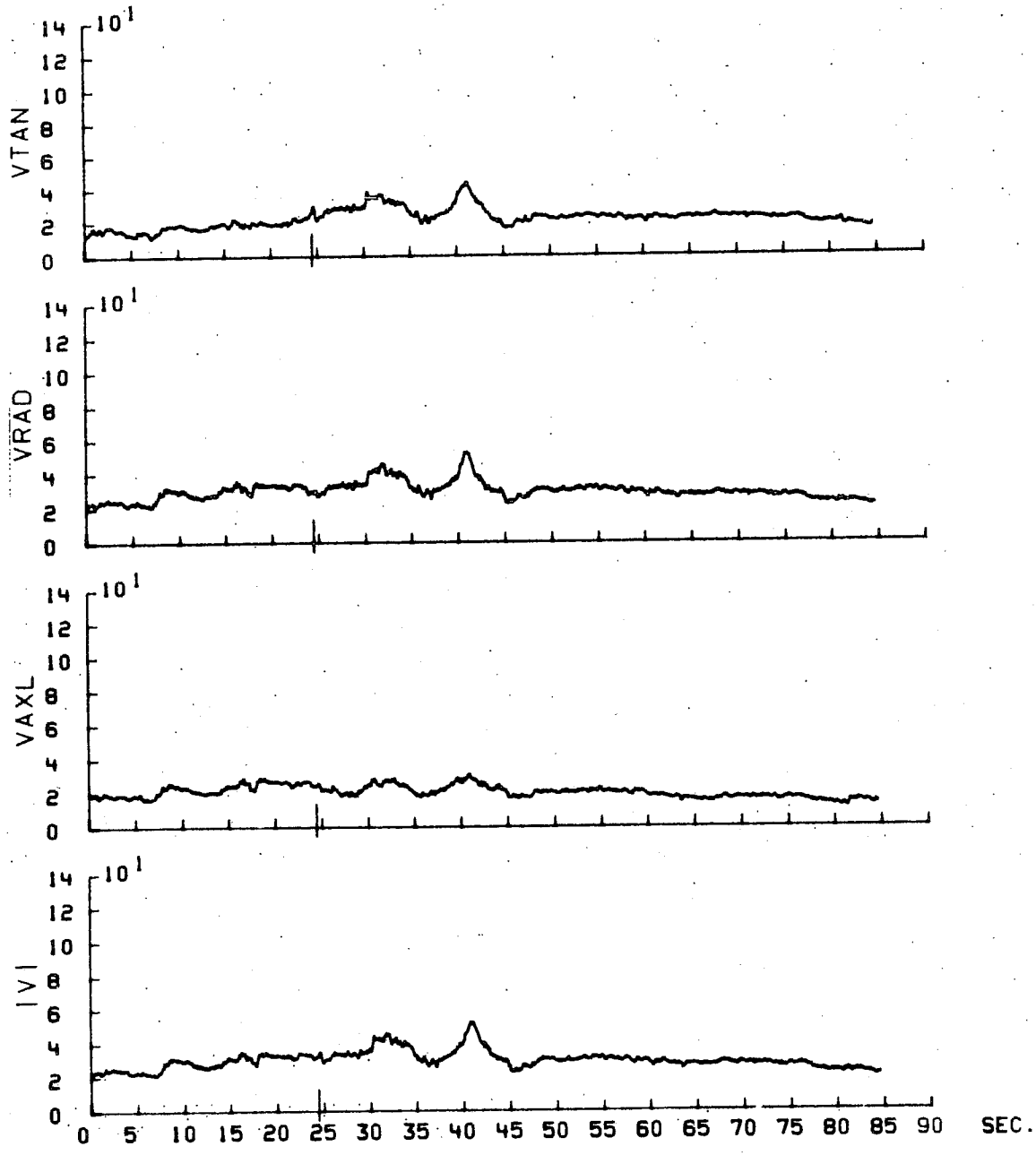


FIG. 7-61 TIME HISTORY

C5A TS 125 FT LEVEL 2/18/70 1523:35 DATA 9

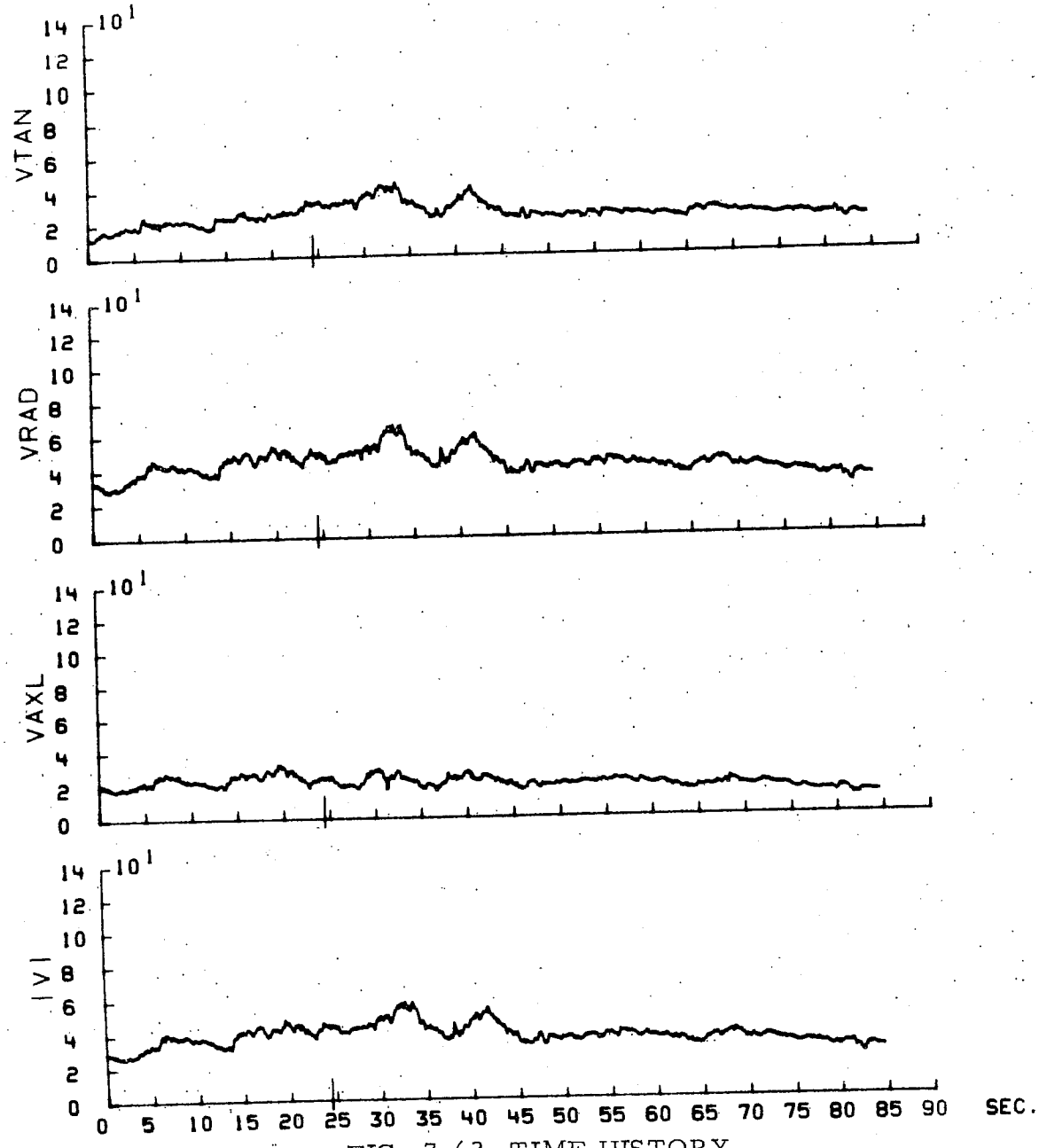


FIG. 7-62 TIME HISTORY

C5A ESSA 150 FT LEVEL 2/18/70 1523:35 DATA 9

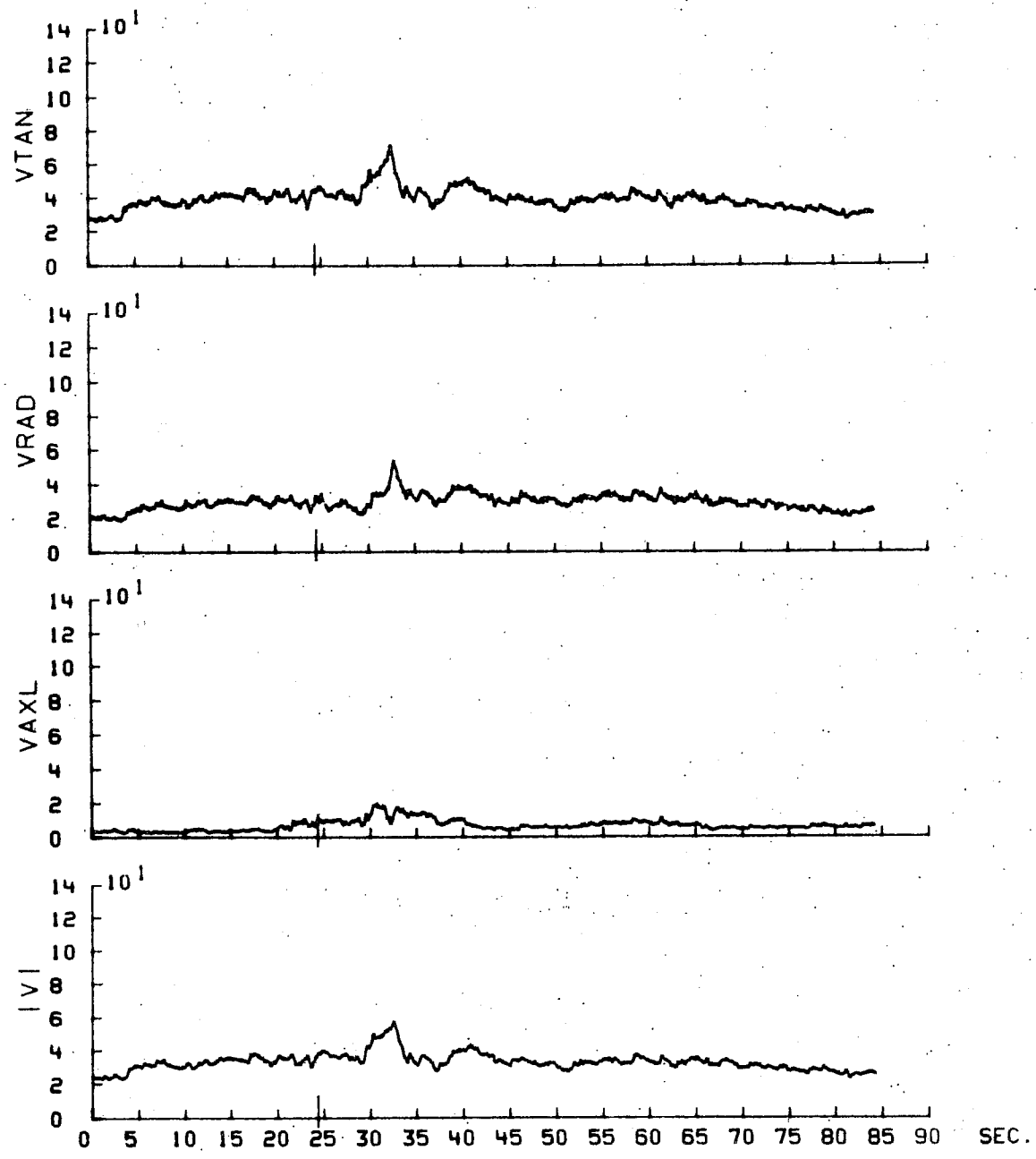


FIG. 7-63 TIME HISTORY

C5A TS 175 FT LEVEL 2/18/70 1523:35 DATA 9

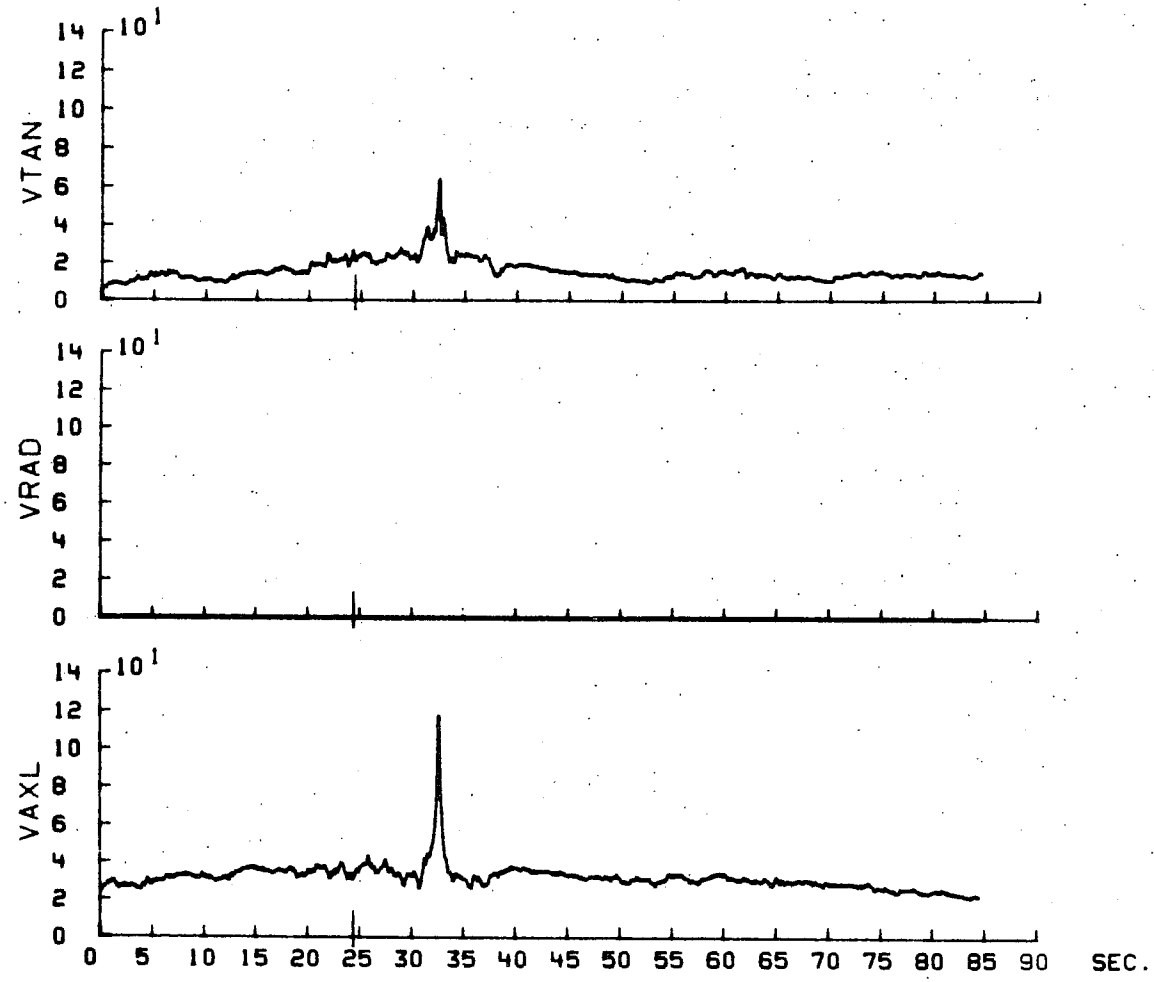


FIG. 7-64 TIME HISTORY

C5A TS 125 FT LEVEL 2/18/70 1548:07 DATA 11

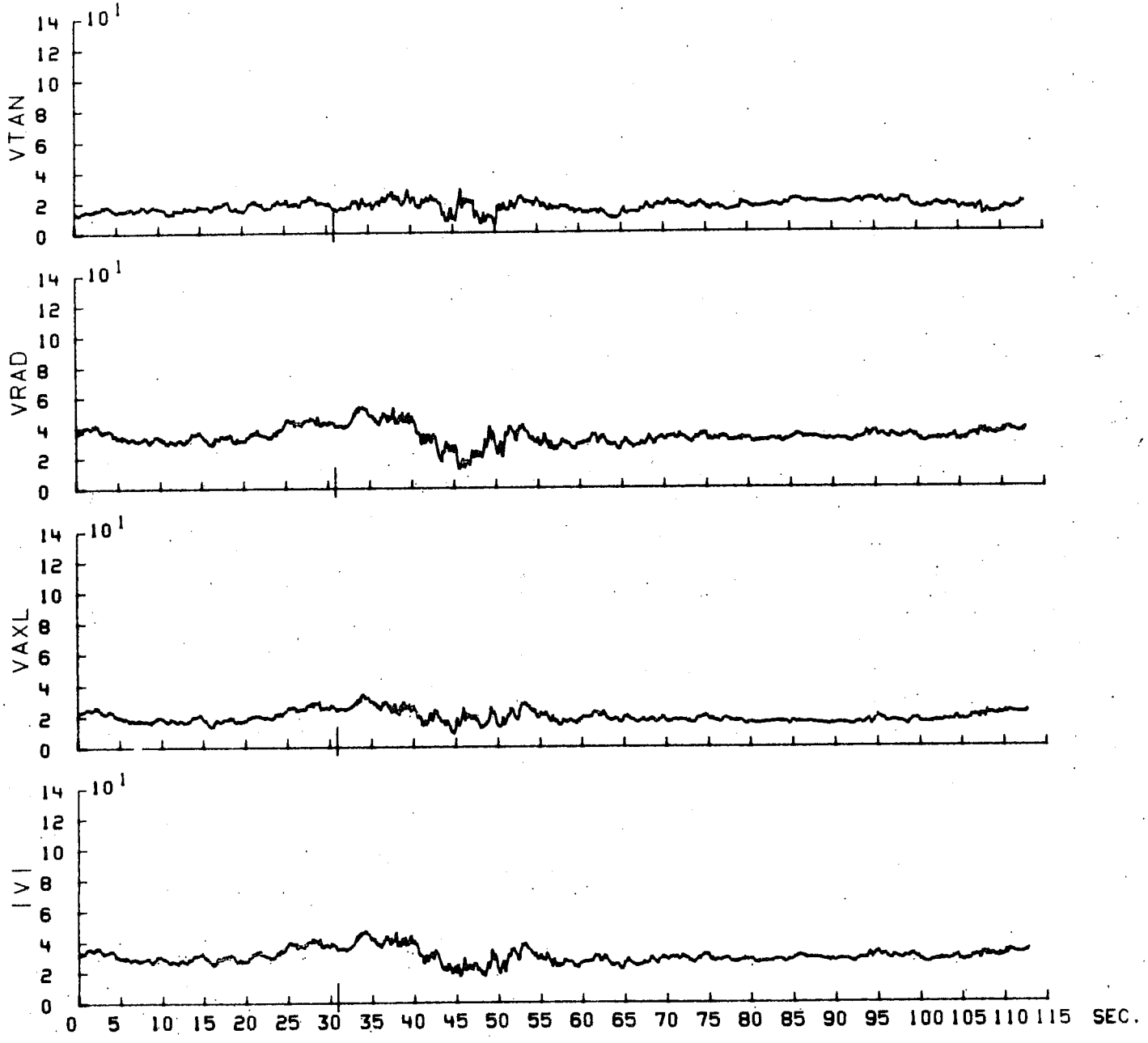


FIG. 7-65 TIME HISTORY

707 ESSA 150 FT LEVEL 2/19/70 0808:17 DATA 2

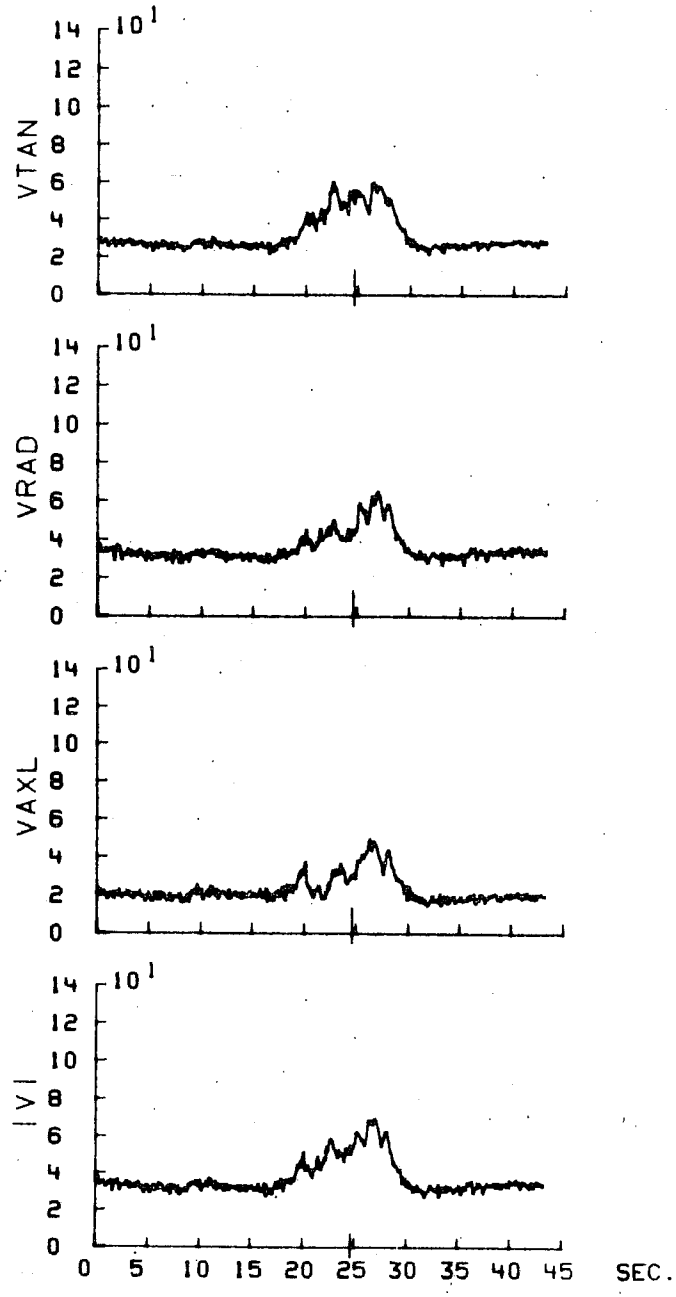


FIG. 7-69 TIME HISTORY

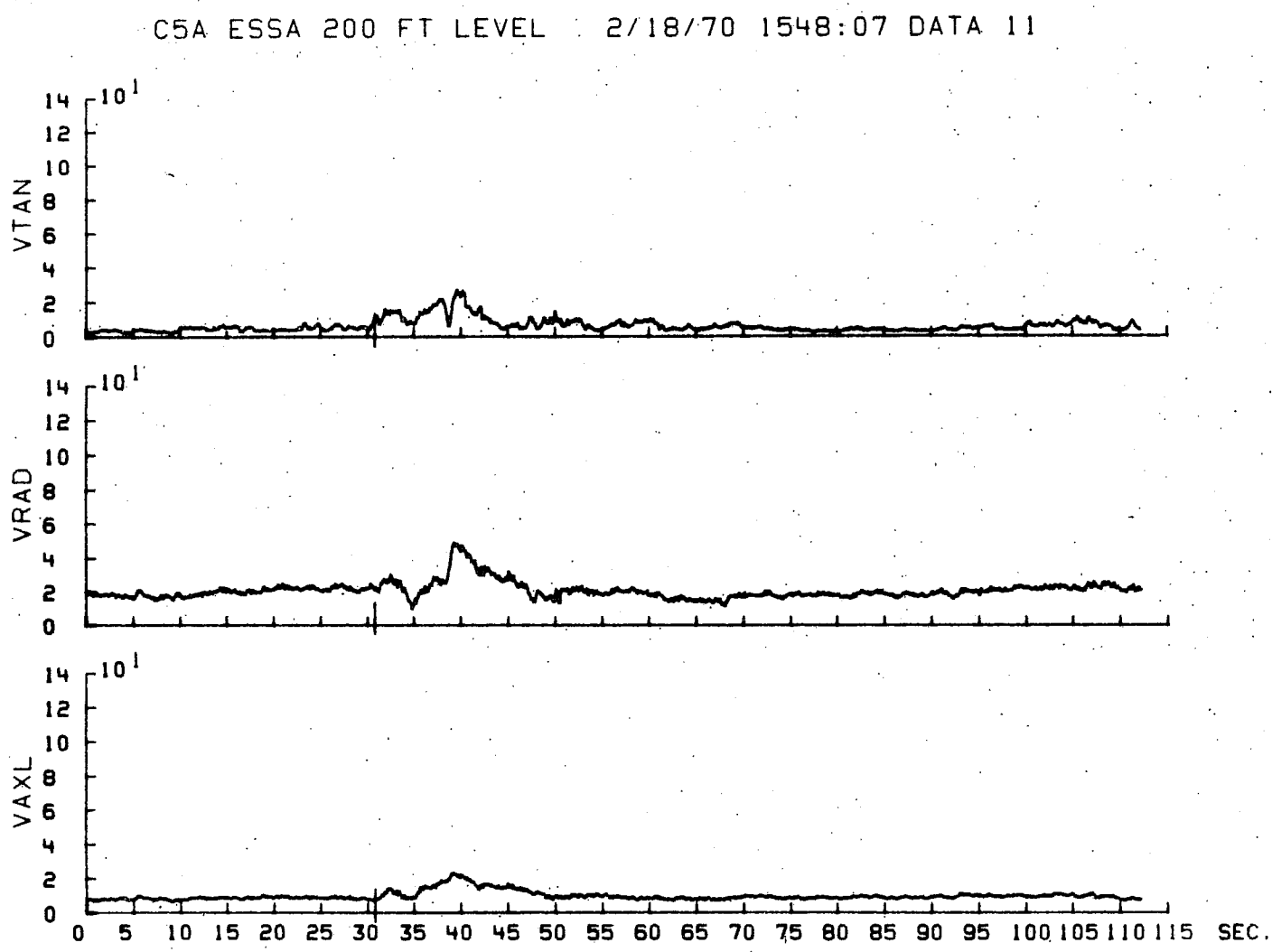


FIG. 7-68 TIME HISTORY

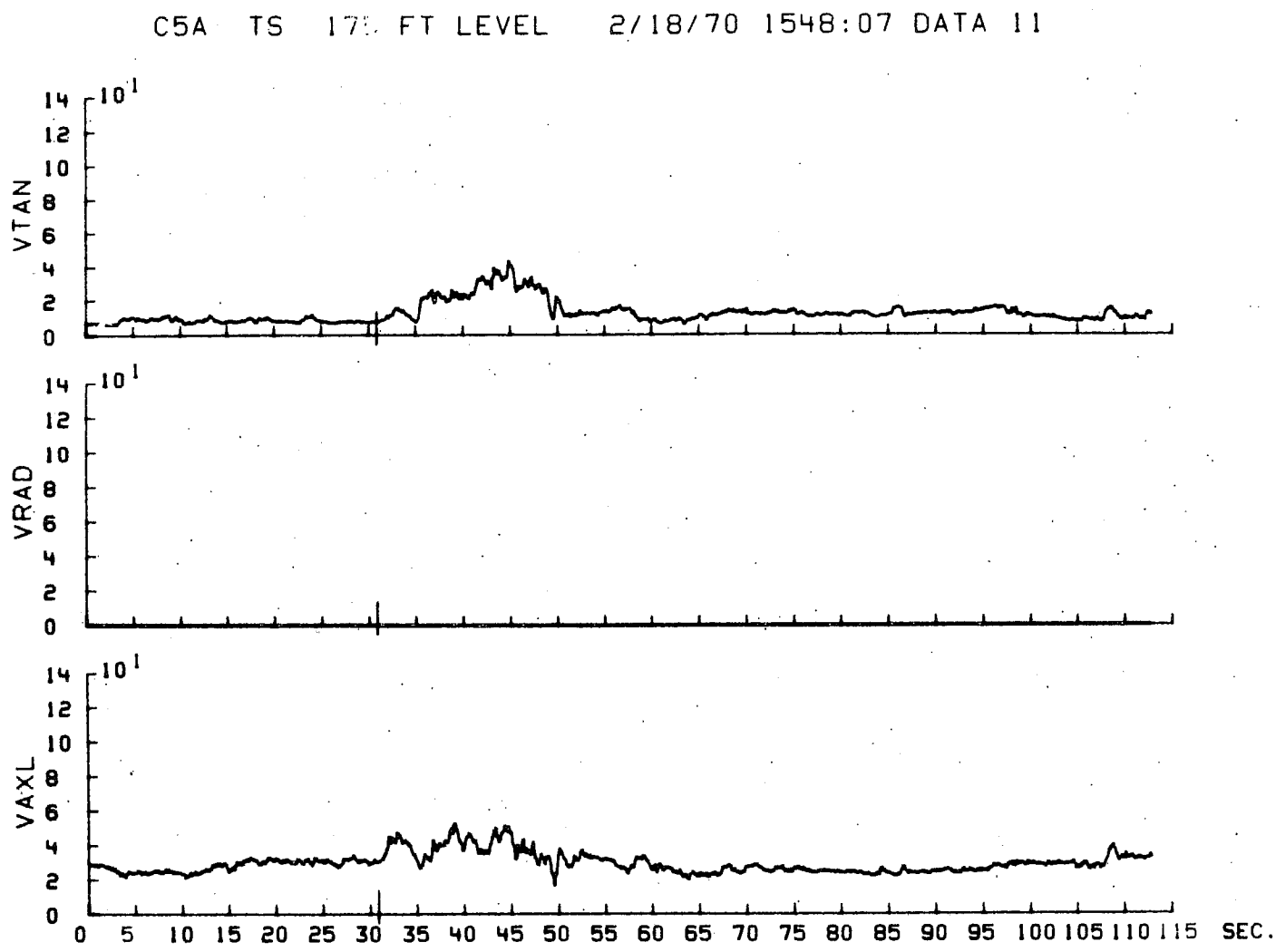


FIG. 7-67 TIME HISTORY

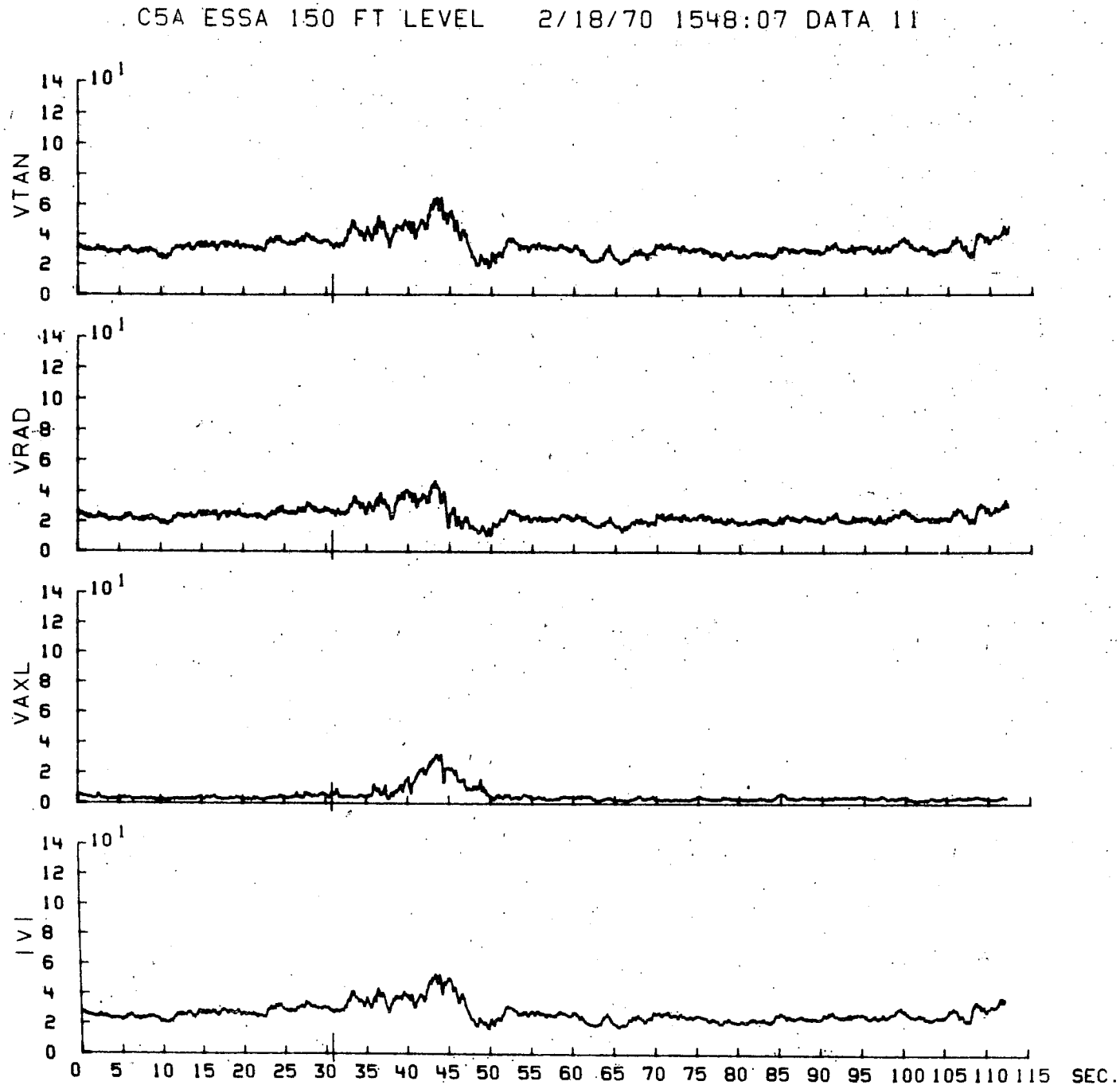


FIG. 7-66 TIME HISTORY

707 TS 175 FT LEVEL 2/19/70 0808:17 DATA 2

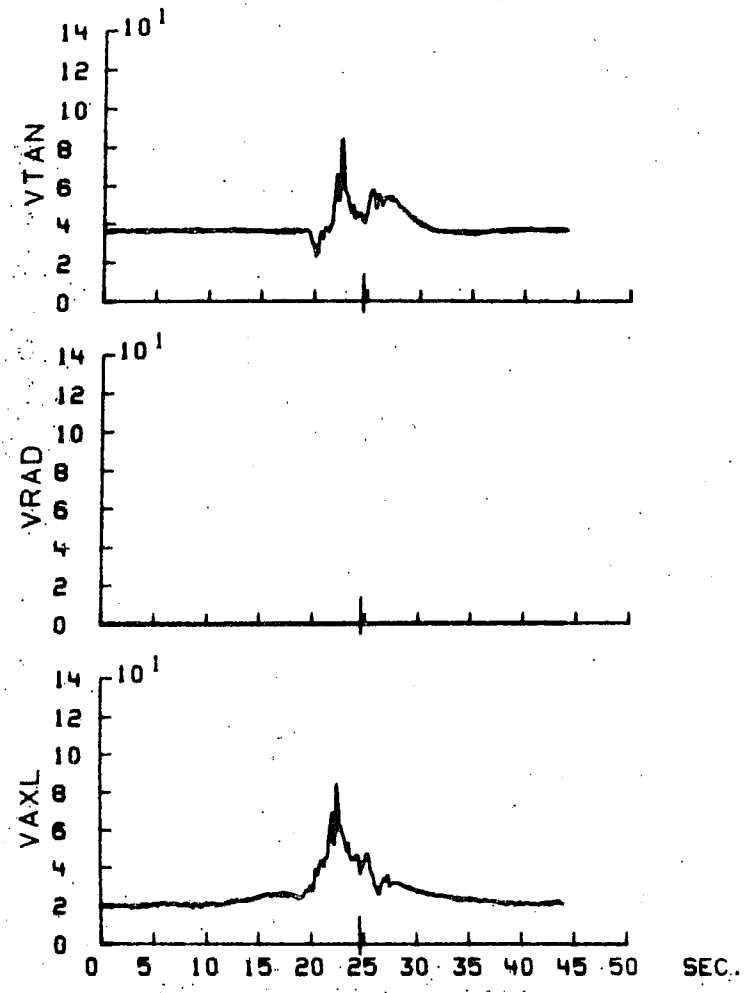


FIG. 7-70 TIME HISTORY

707 ESSA 200 FT LEVEL 2/19/70 0808:17 DATA 2

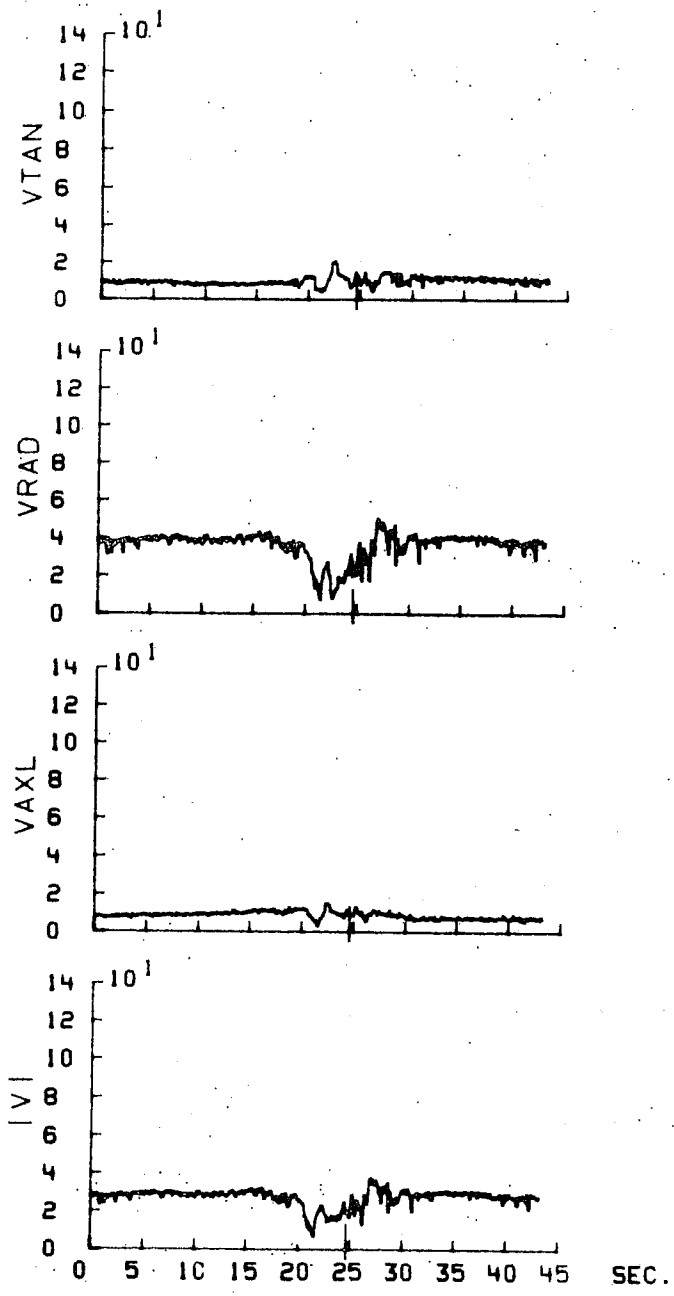


FIG. 7-71 TIME HISTORY

707 BGS 50 FT LEVEL 2/19/70 0817:26 DATA 3

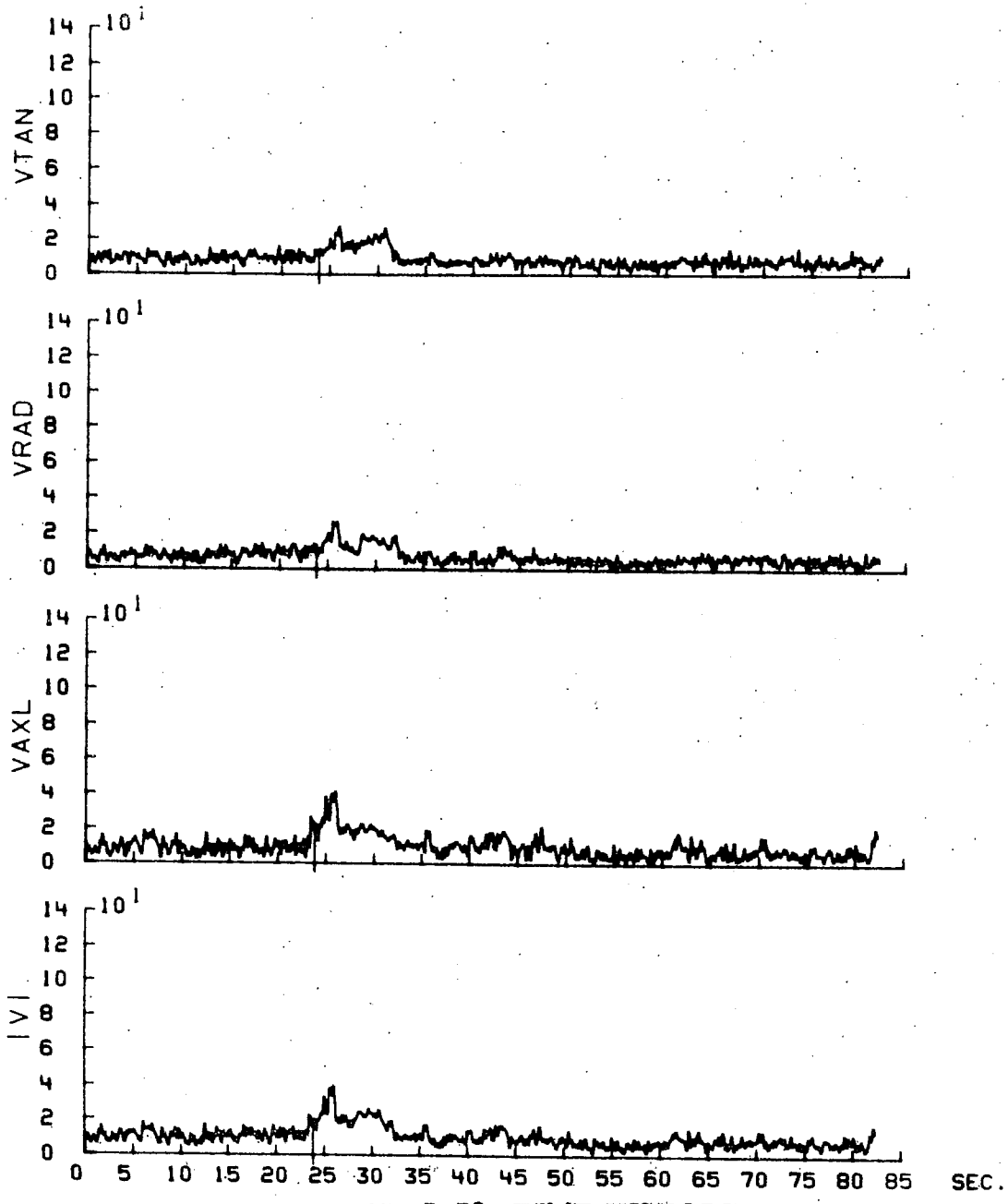


FIG. 7-72 TIME HISTORY

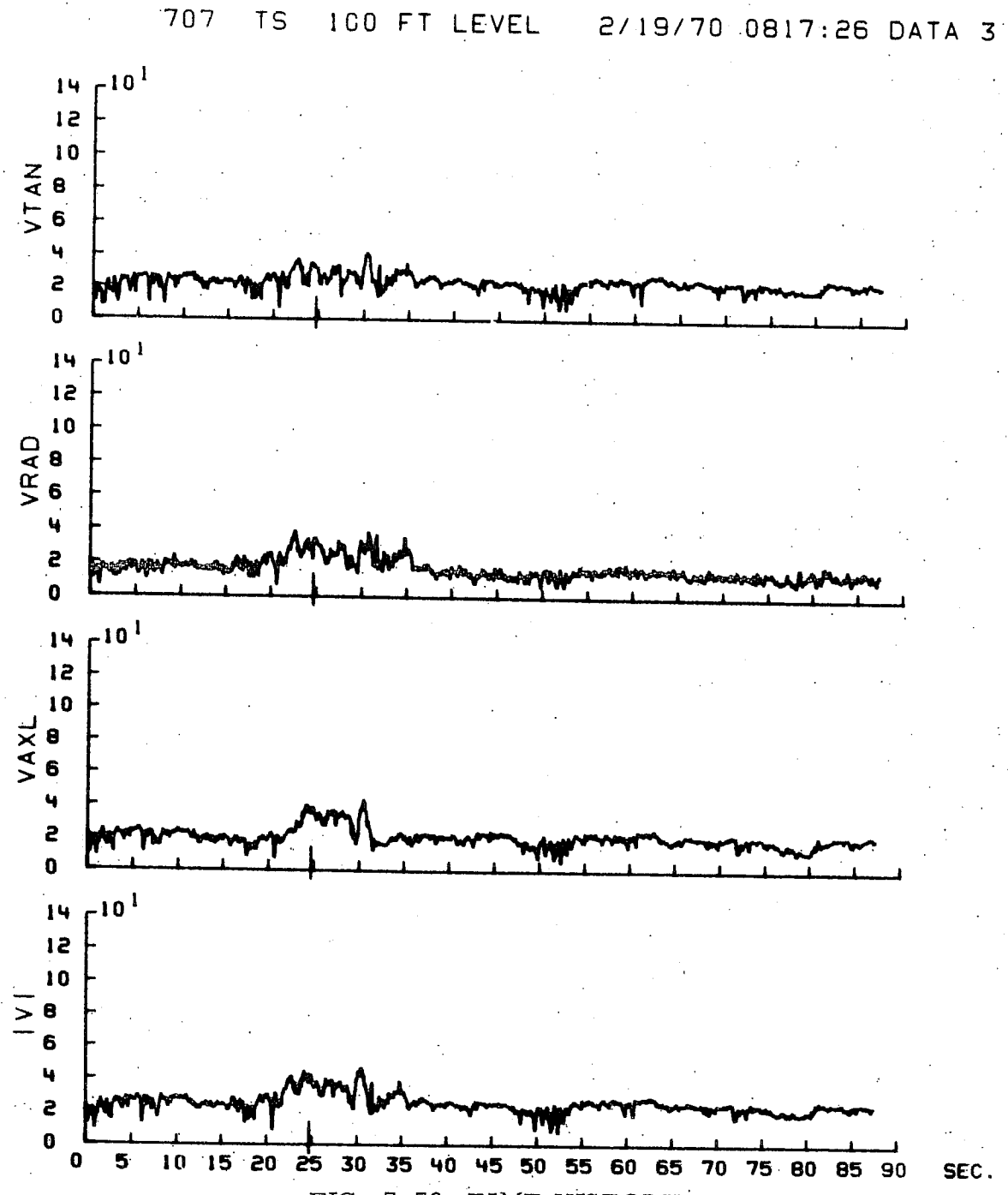


FIG. 7-73 TIME HISTORY

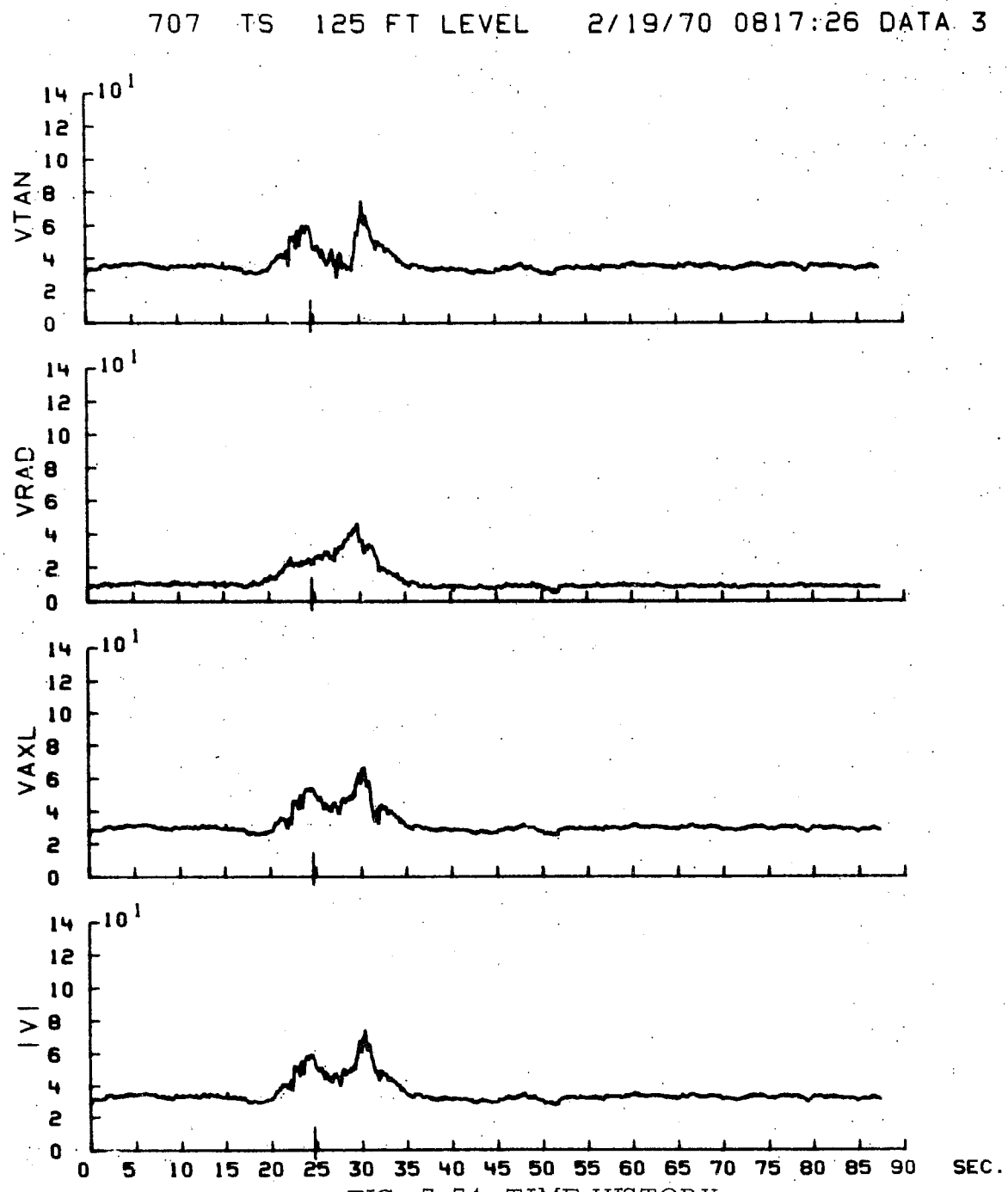


FIG. 7-74 TIME HISTORY

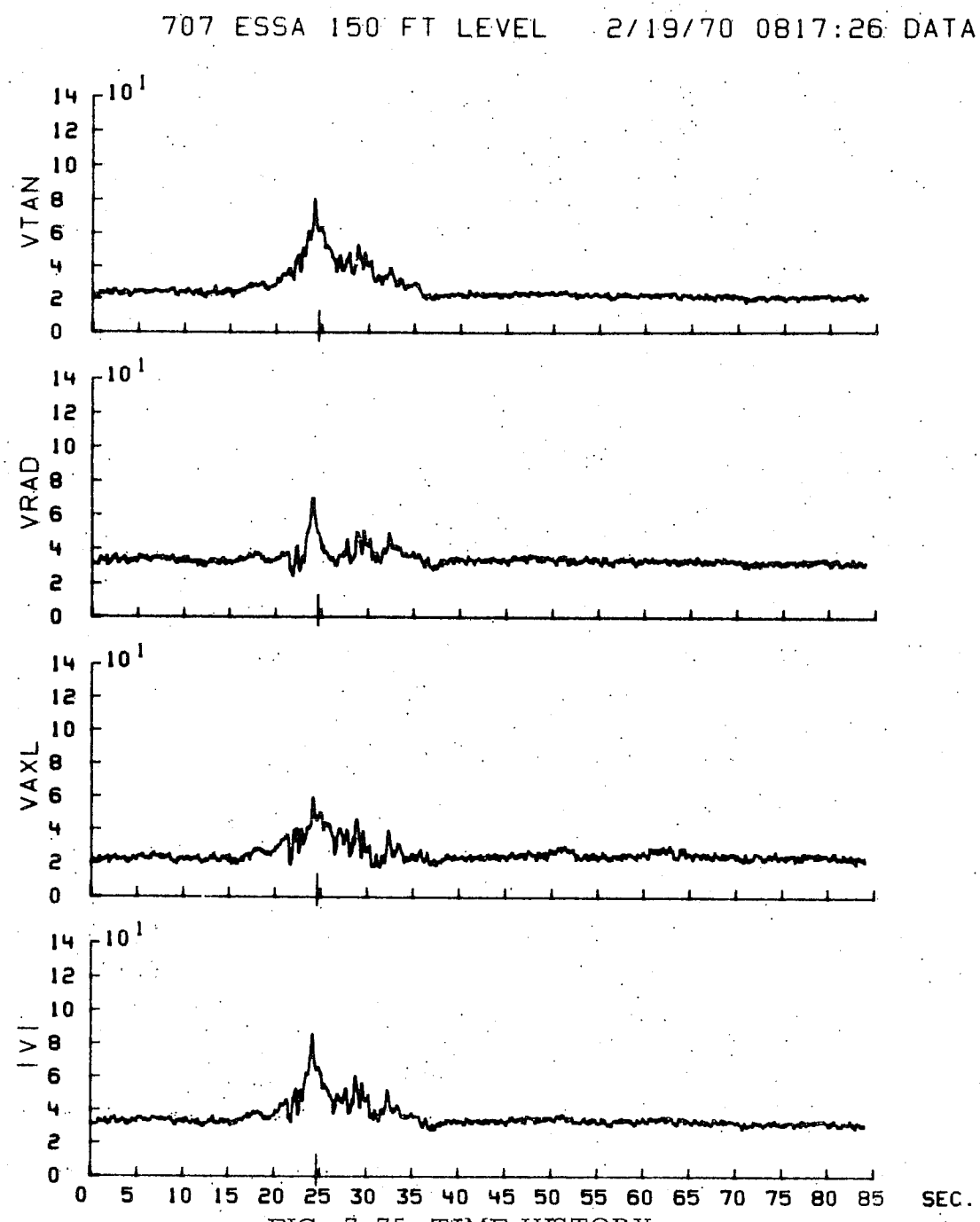


FIG. 7-75 TIME HISTORY

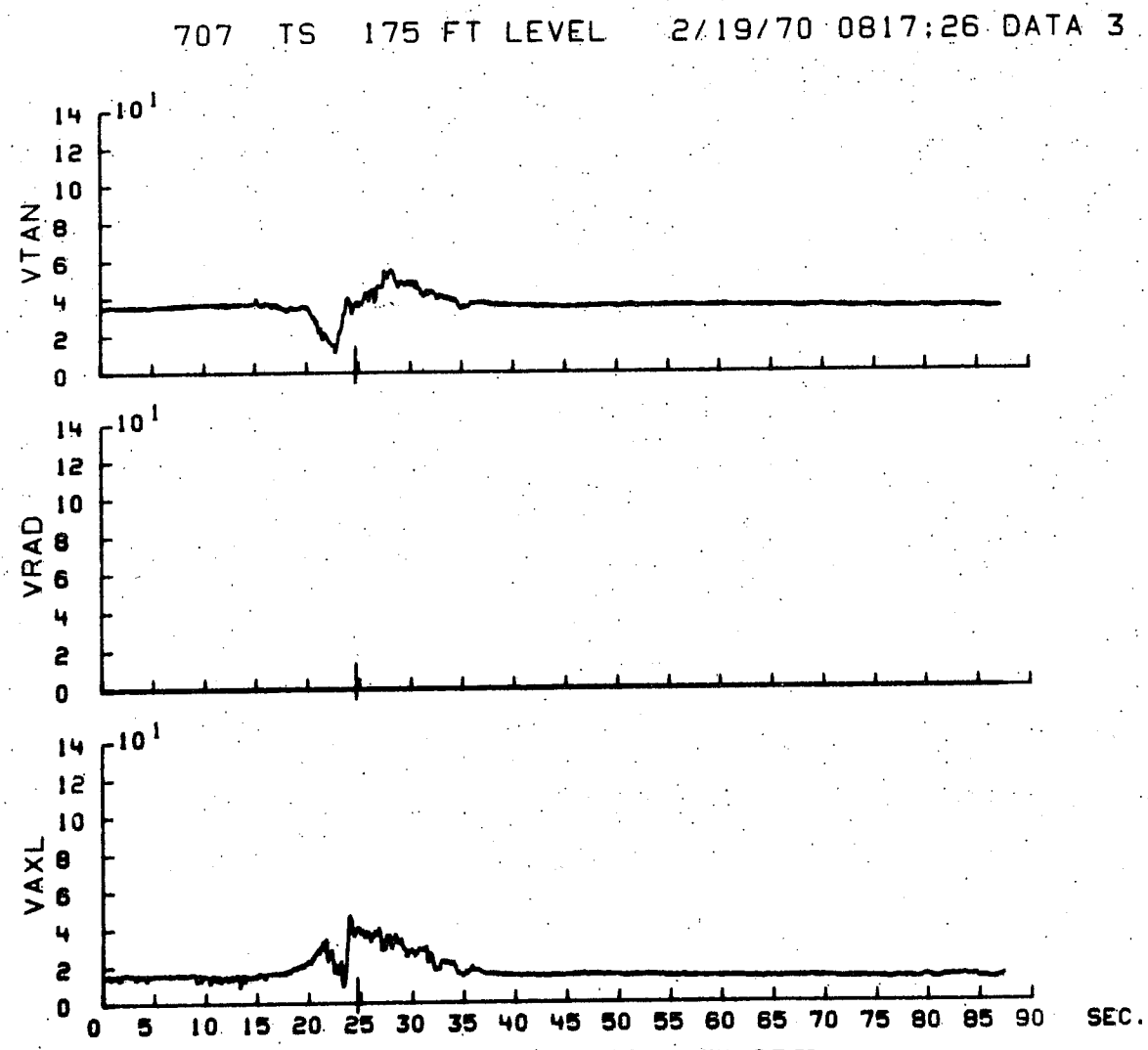


FIG. 7-76 TIME HISTORY

707 ESSA 200 FT LEVEL 2/19/70 0817:26 DATA 3

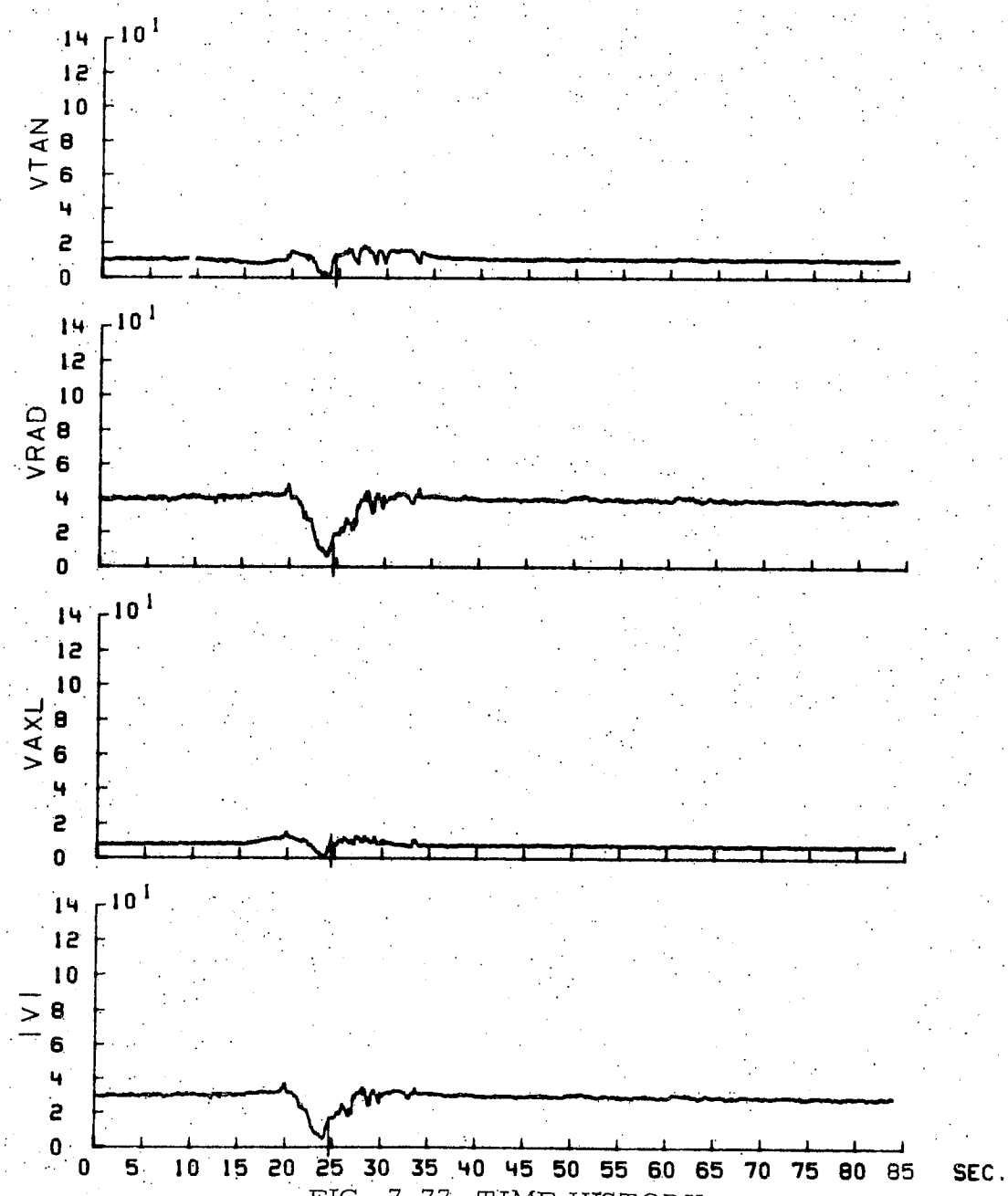


FIG. 7-77 TIME HISTORY

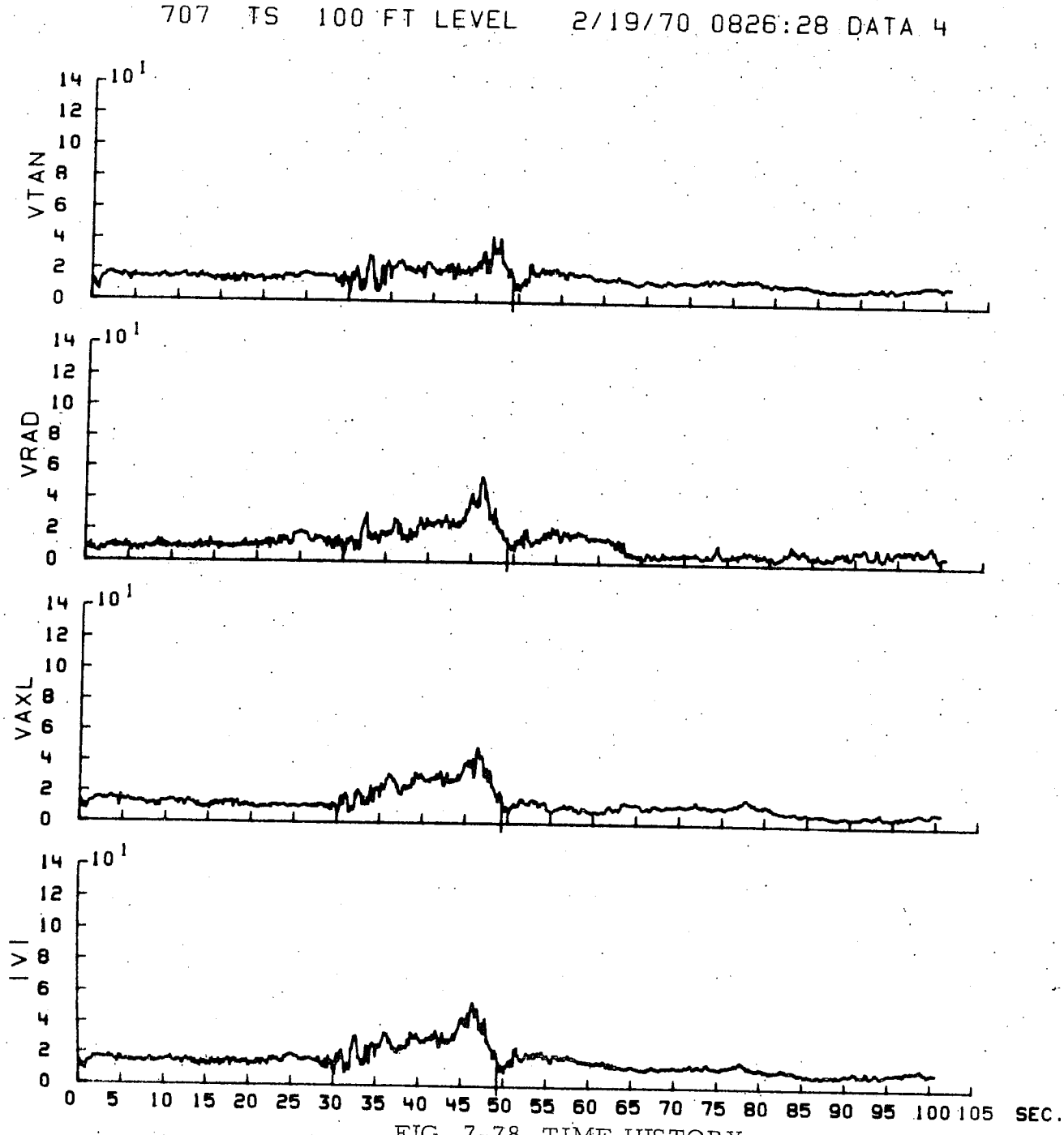


FIG. 7-78 TIME HISTORY

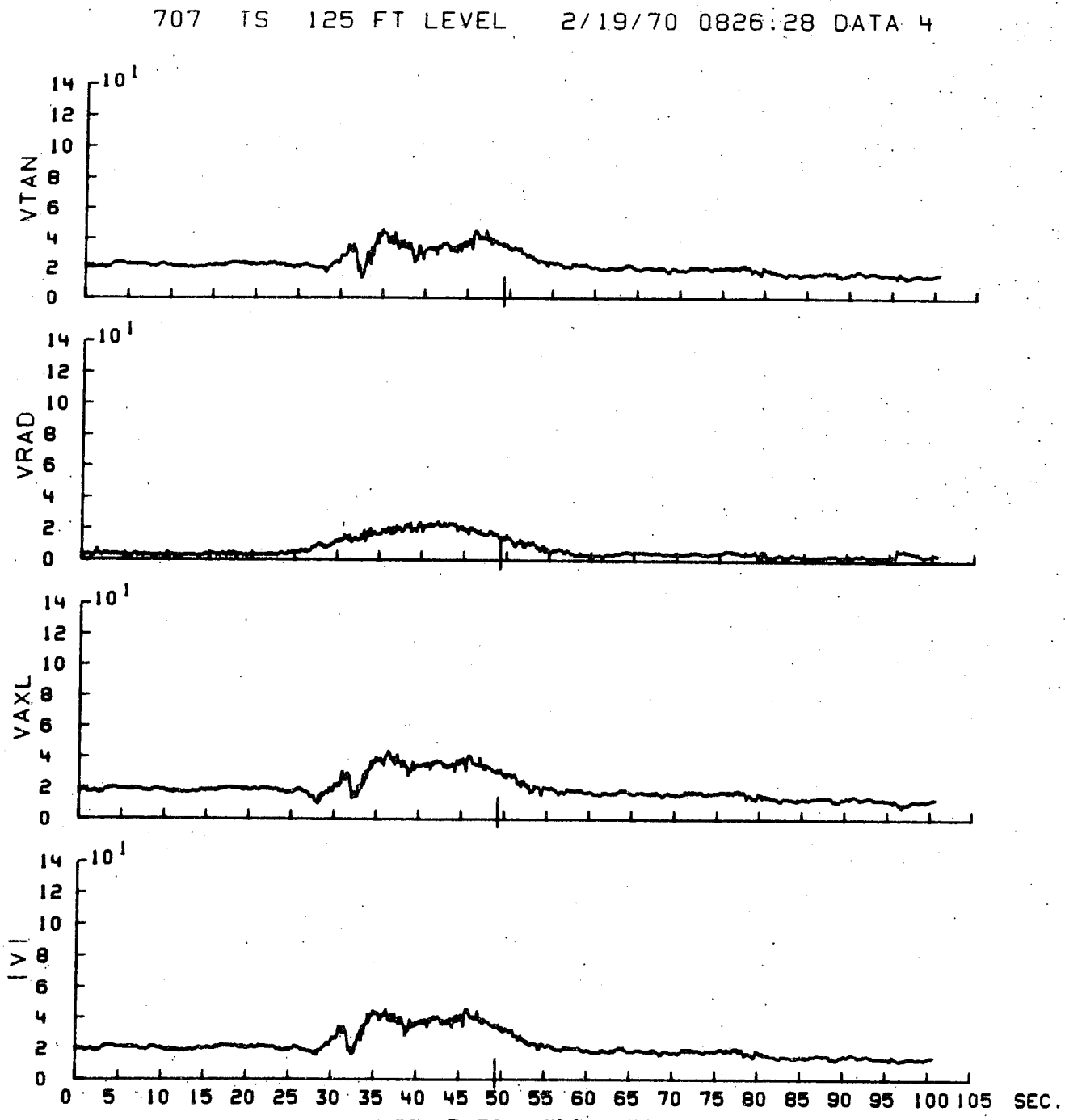


FIG. 7-79 TIME HISTORY

707 ESSA 150 FT LEVEL 2/19/70 0826:28 DATA 4

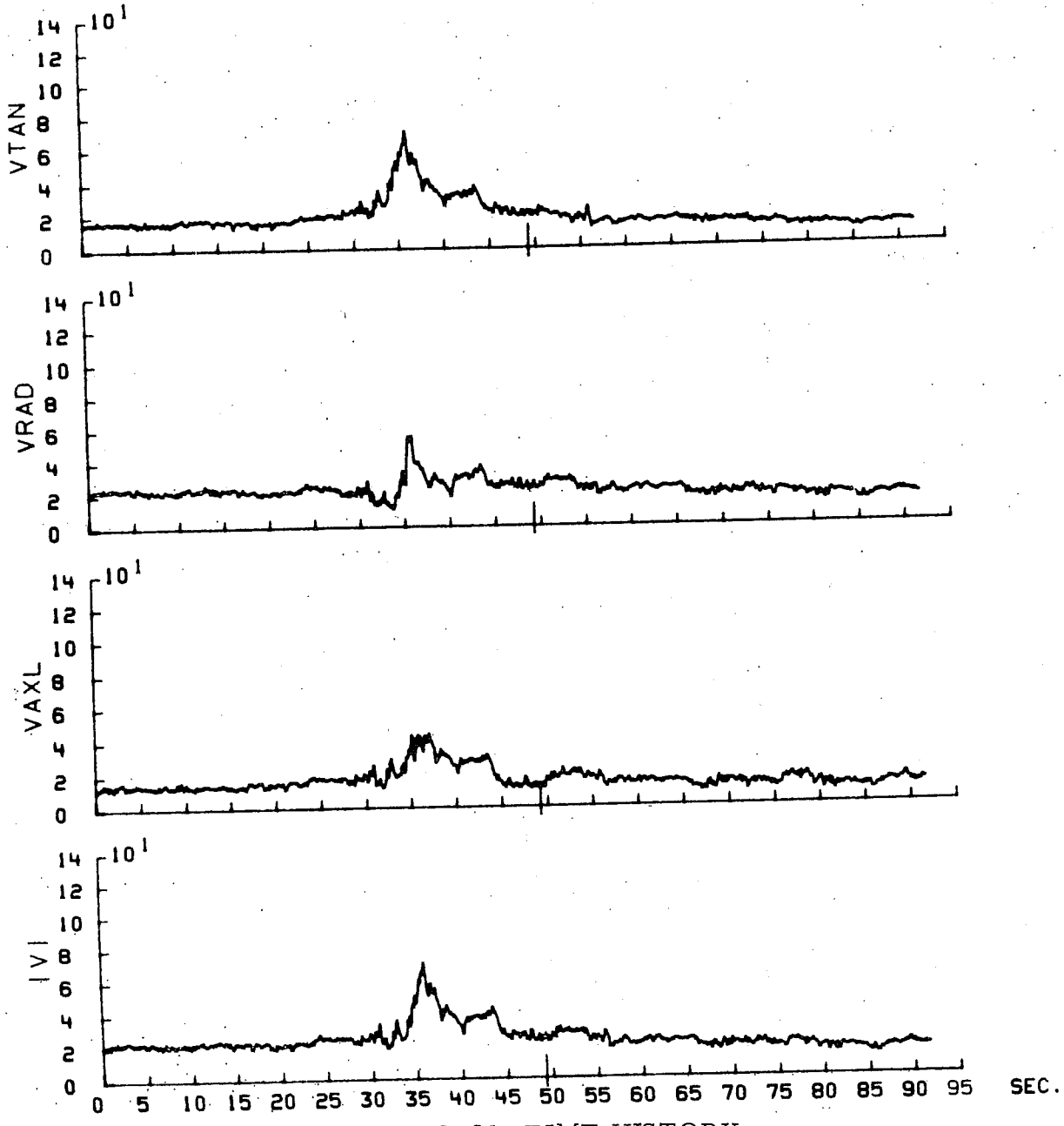


FIG. 7-80 TIME HISTORY

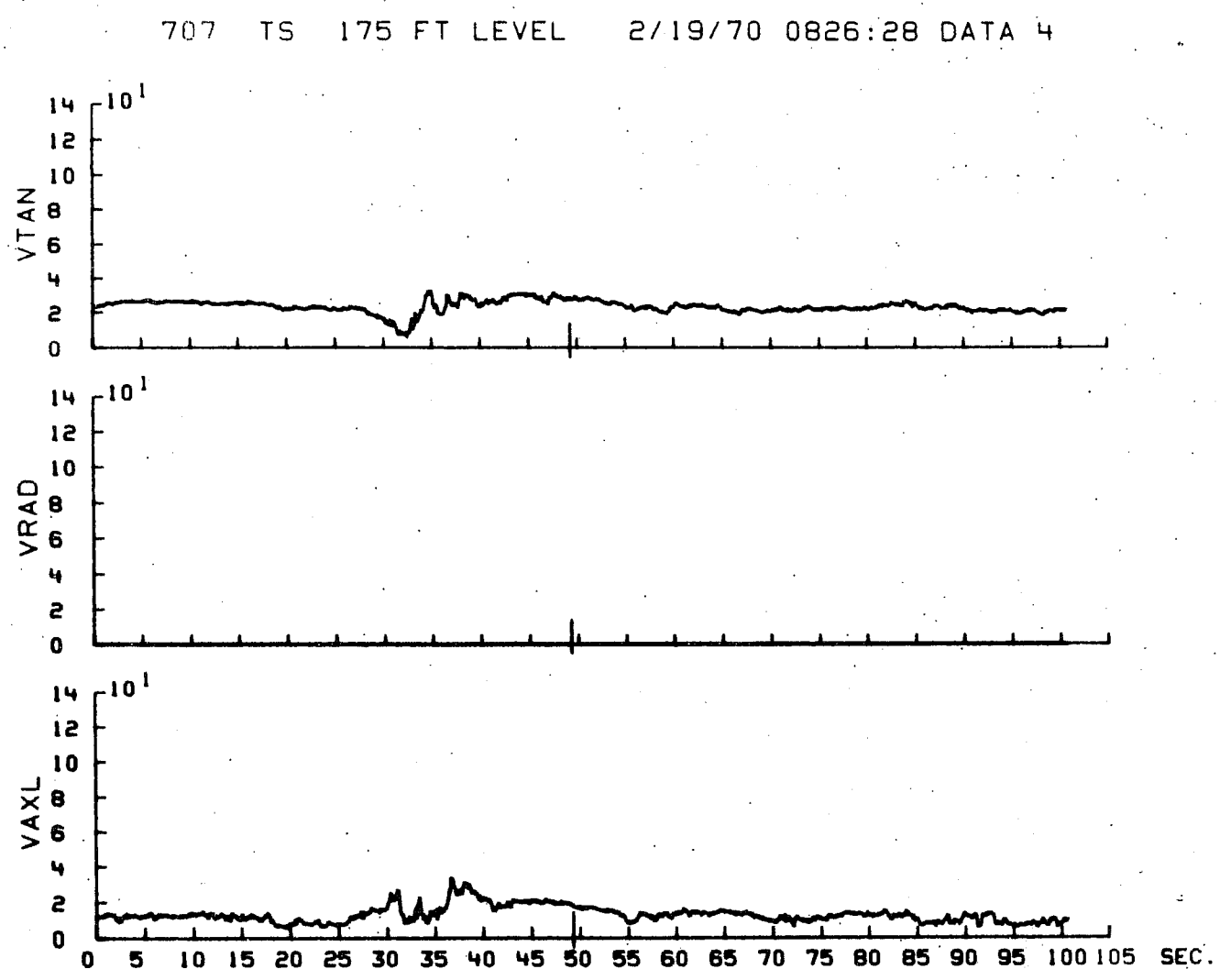


FIG. 7-81 TIME HISTORY

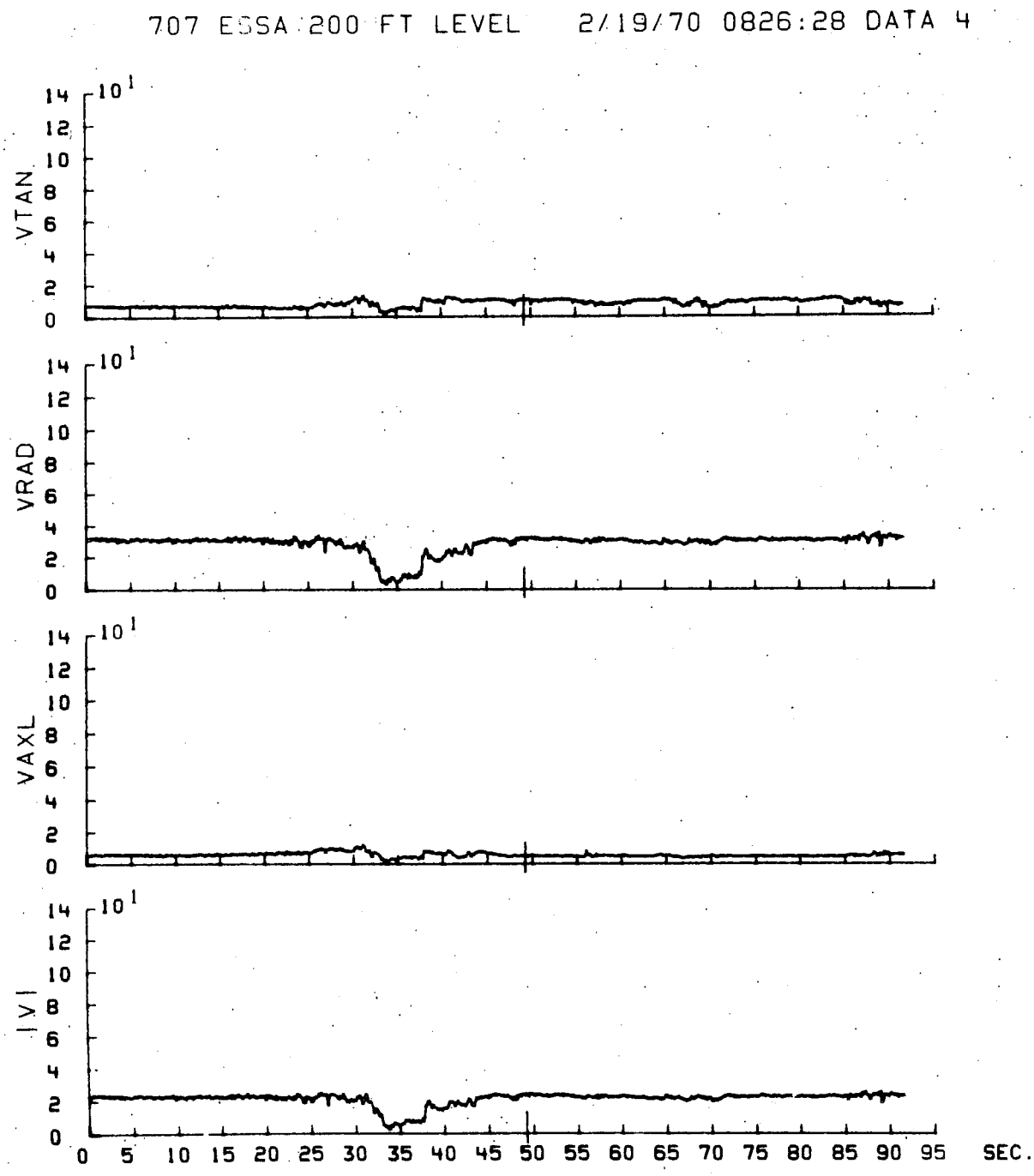


FIG. 7-82 TIME HISTORY

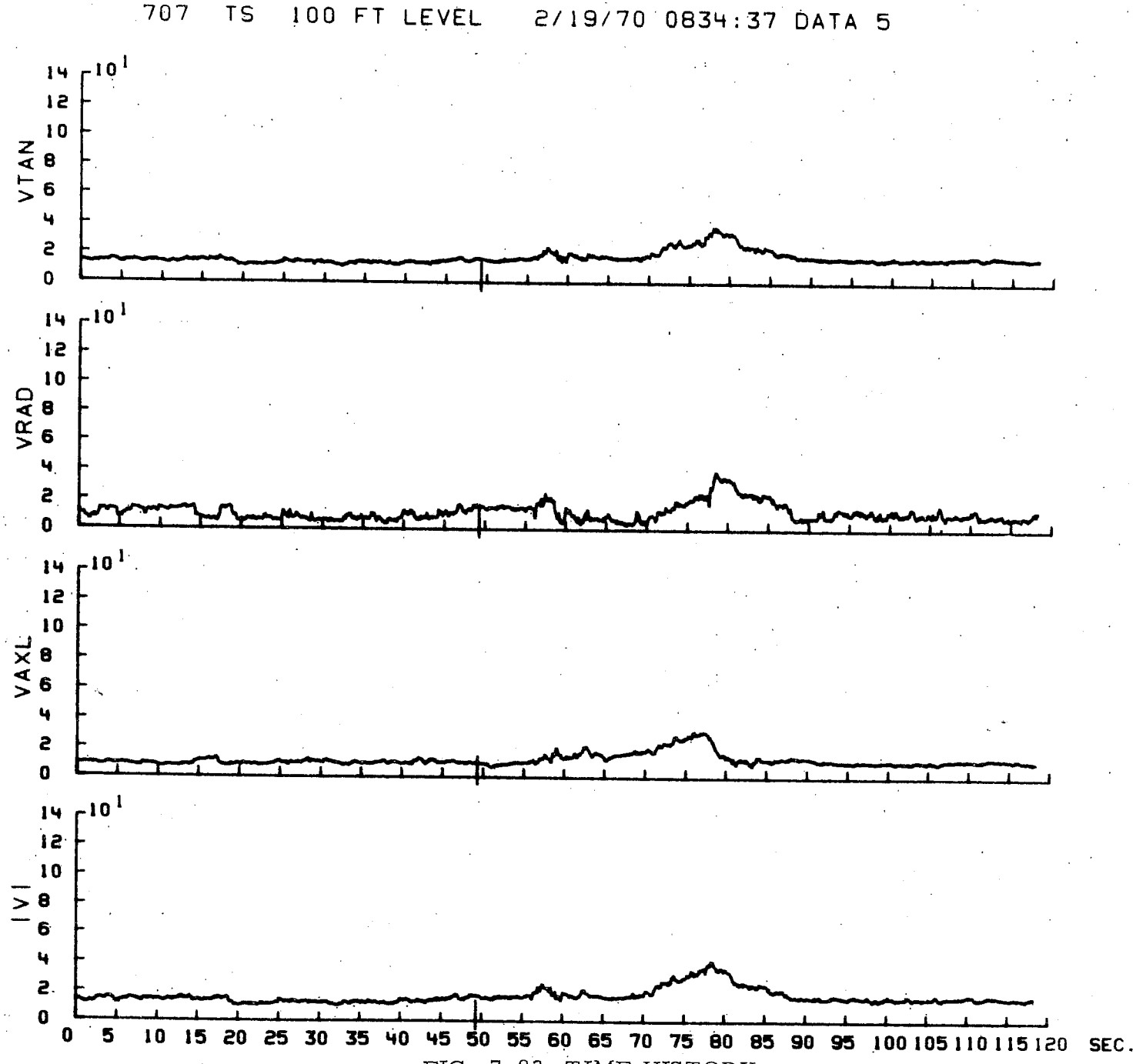


FIG. 7-83 TIME HISTORY

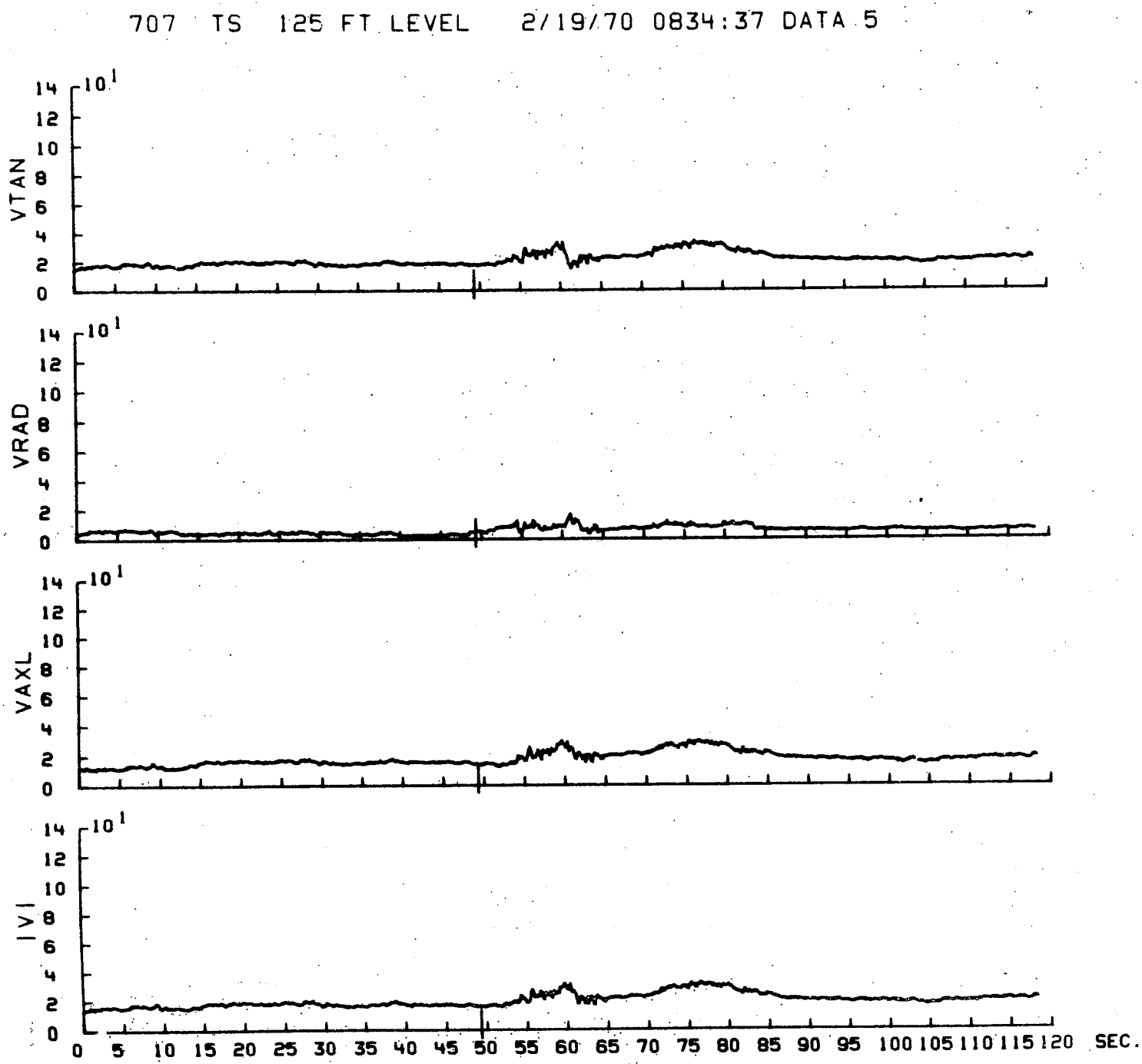


FIG. 7-84 TIME HISTORY

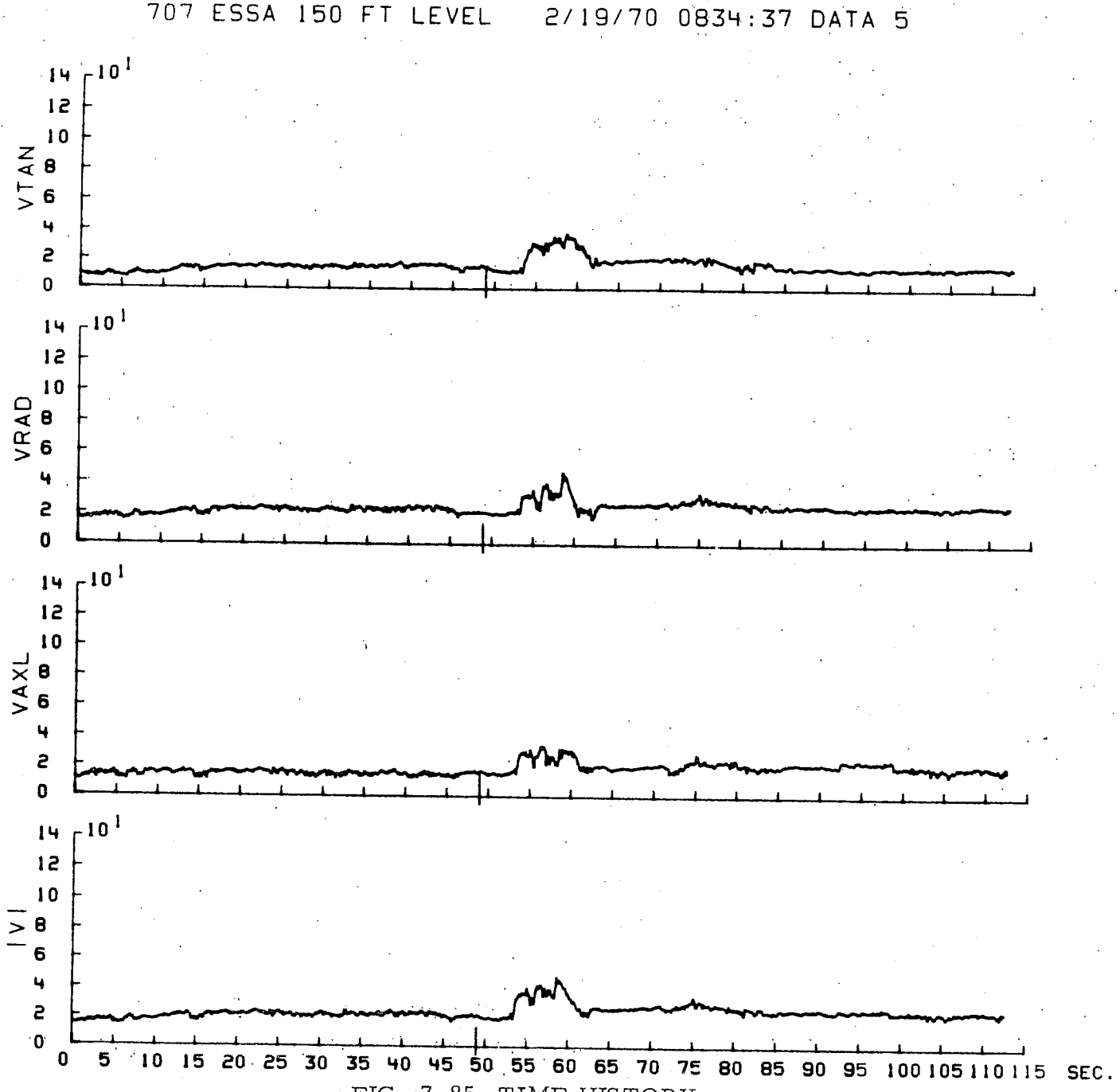


FIG. 7-85 TIME HISTORY

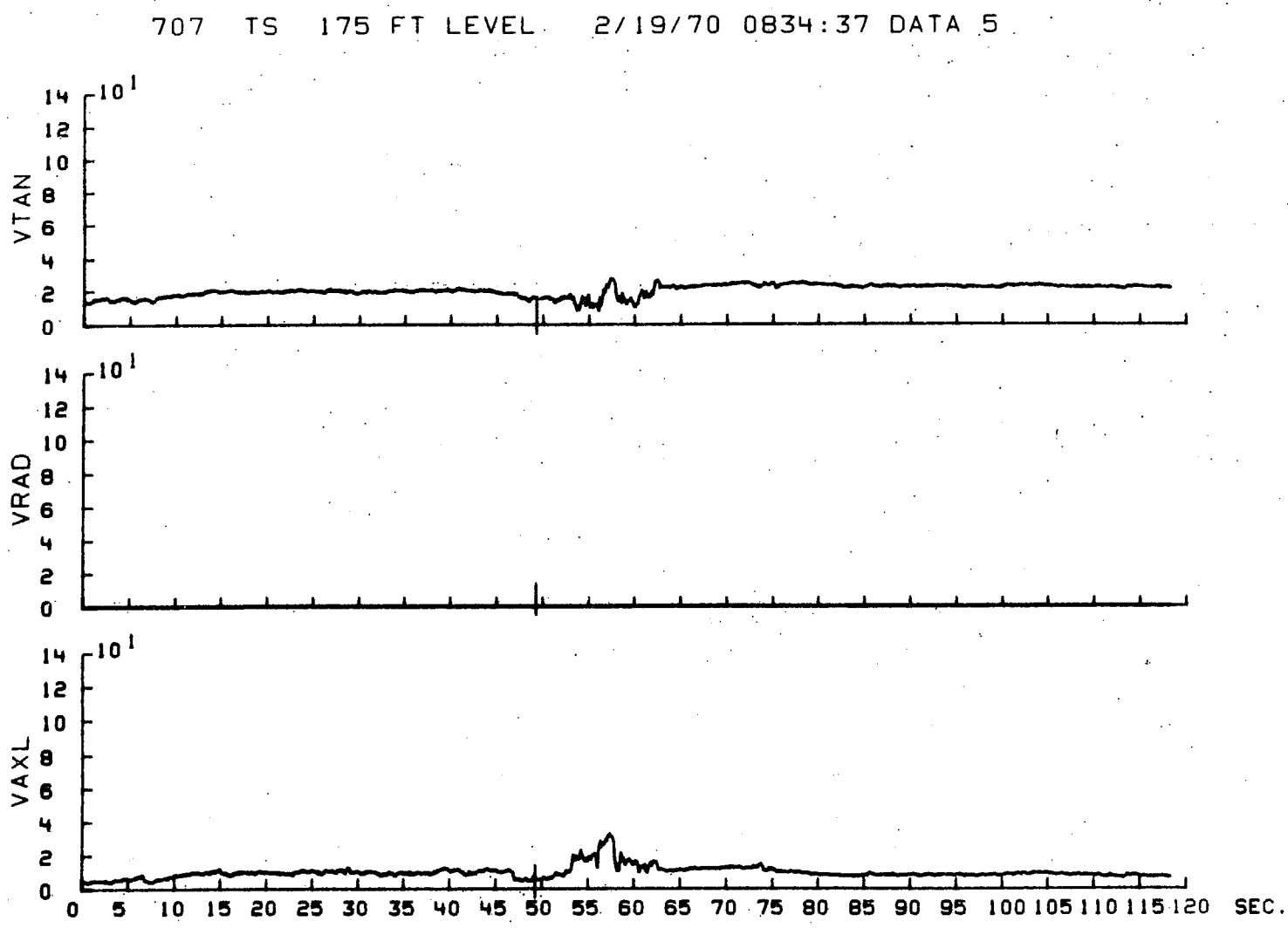


FIG. 7-86 TIME HISTORY

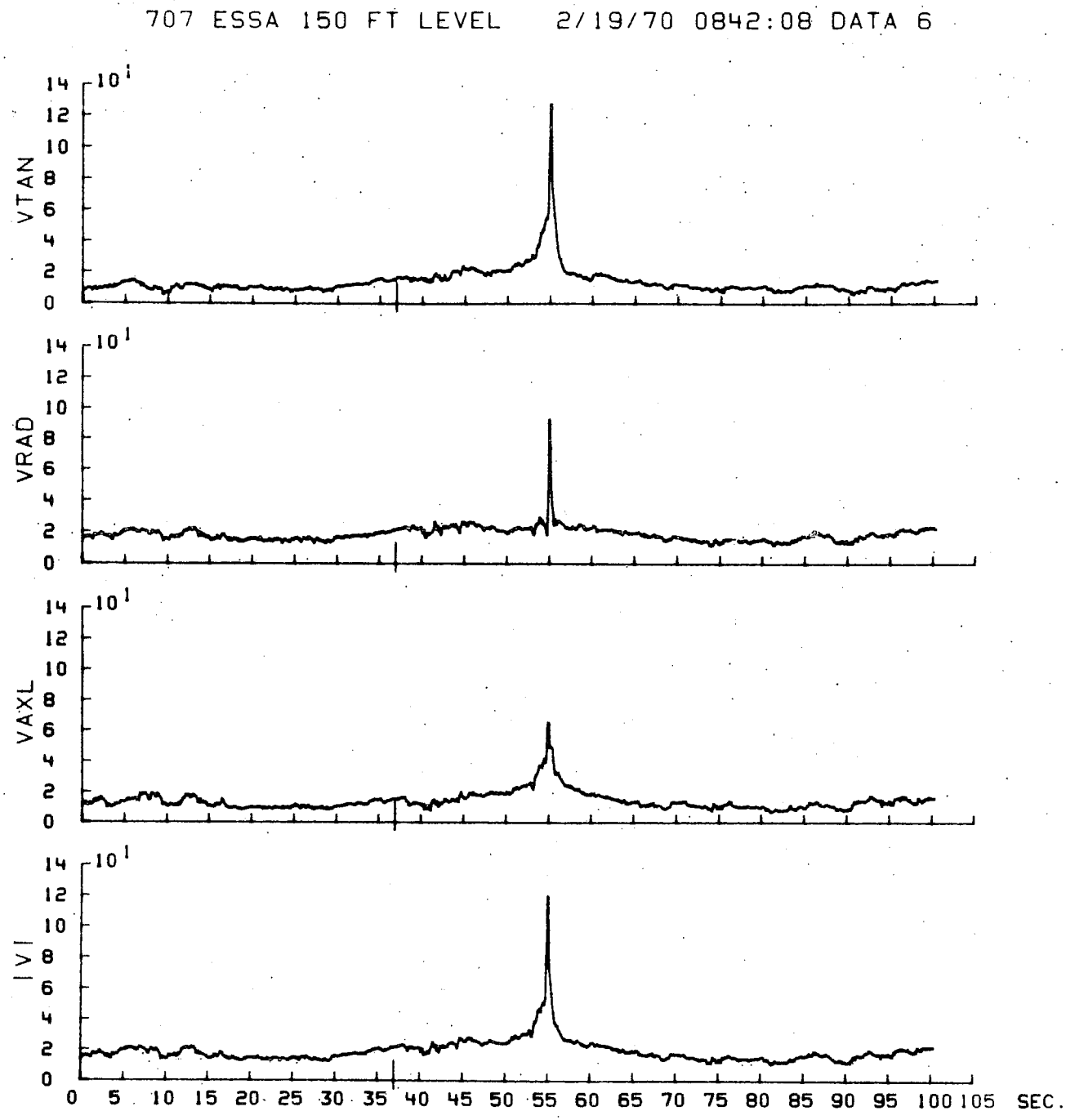


FIG. 7-87 TIME HISTORY

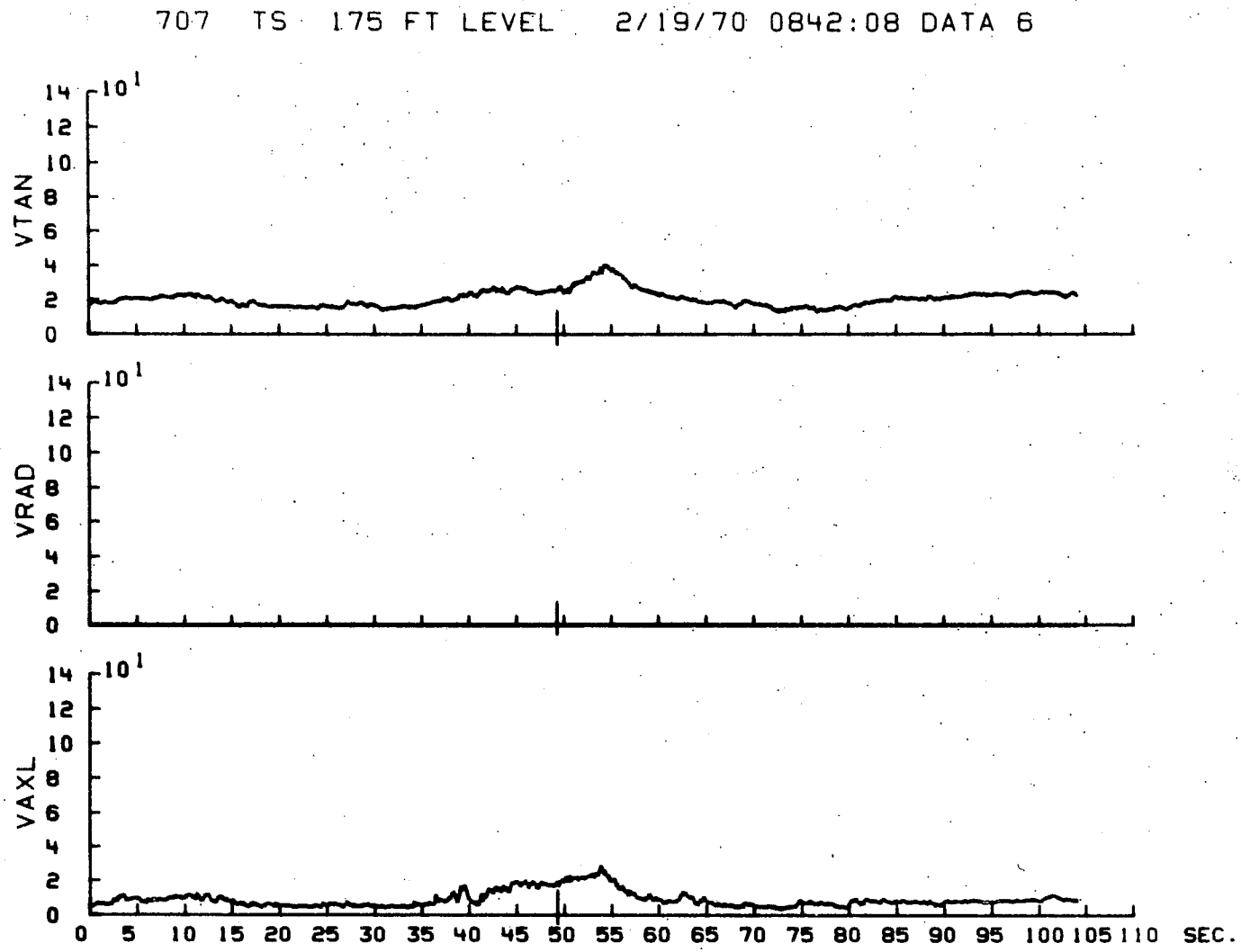


FIG. 7-88 TIME HISTORY

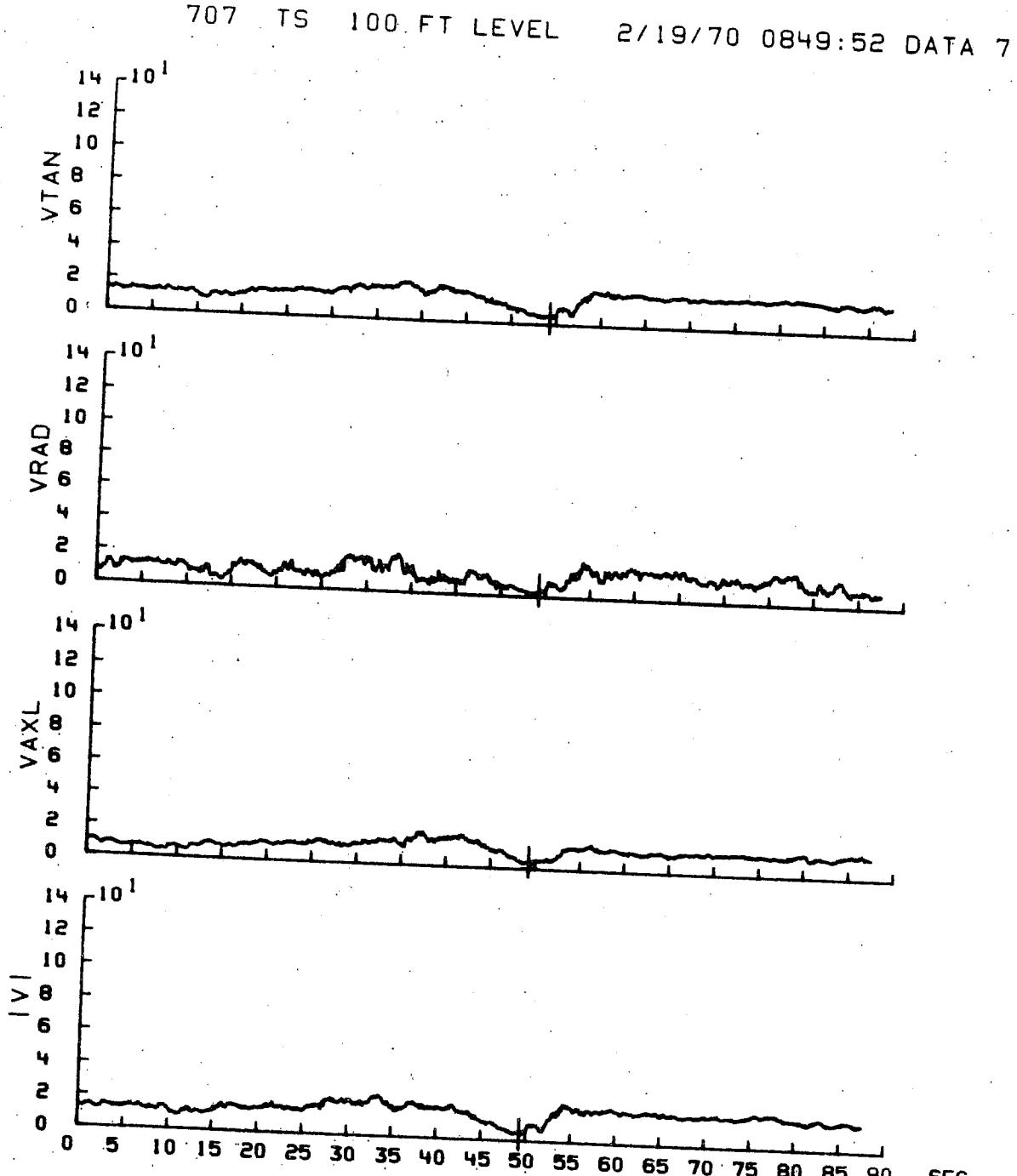


FIG. 7-89 TIME HISTORY

707 TS 125 FT LEVEL 2/19/70 0849:52 DATA 7

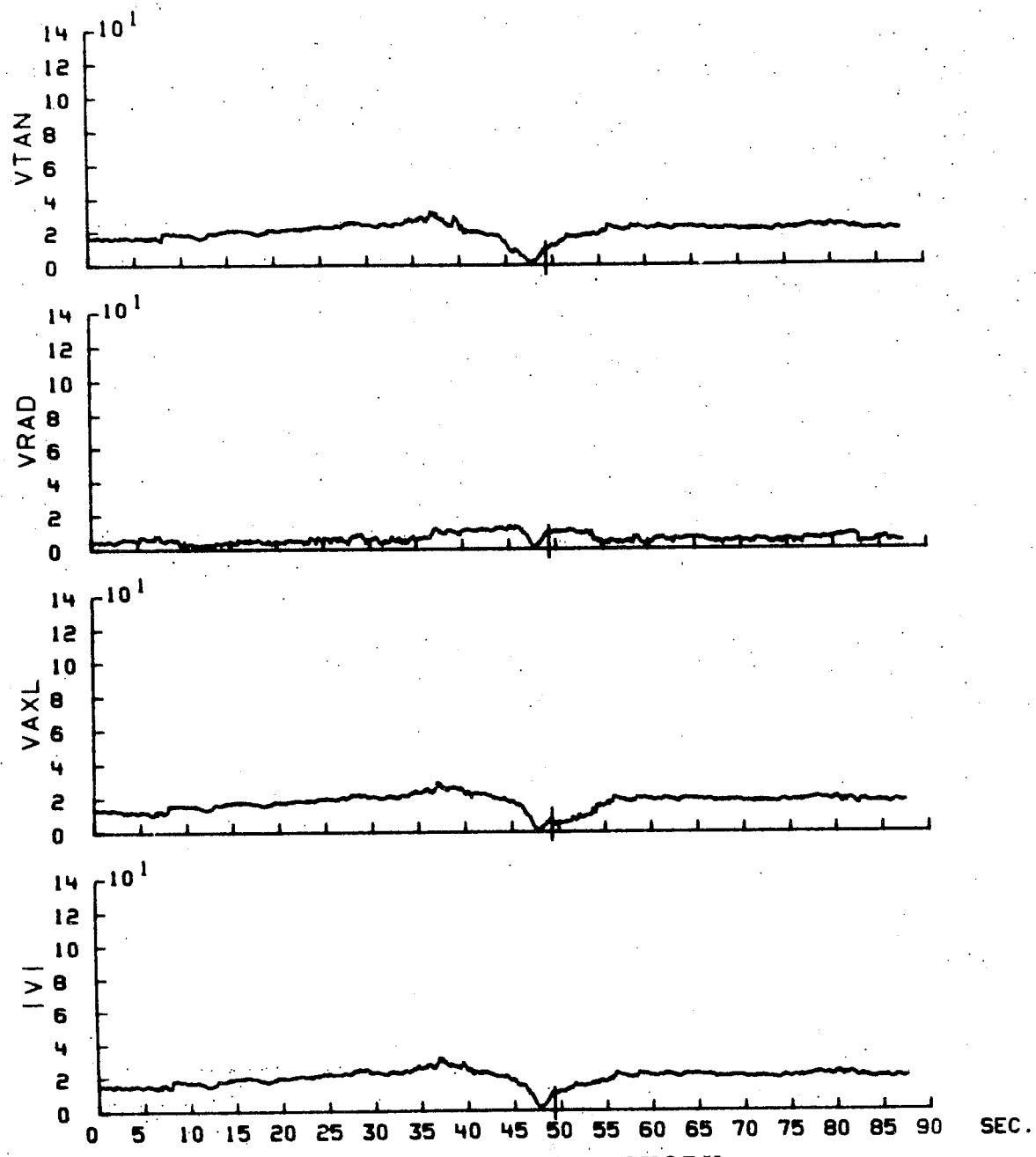


FIG. 7-90 TIME HISTORY

707 ESSA 150 FT LEVEL 2/19/70 0849:52 DATA 7

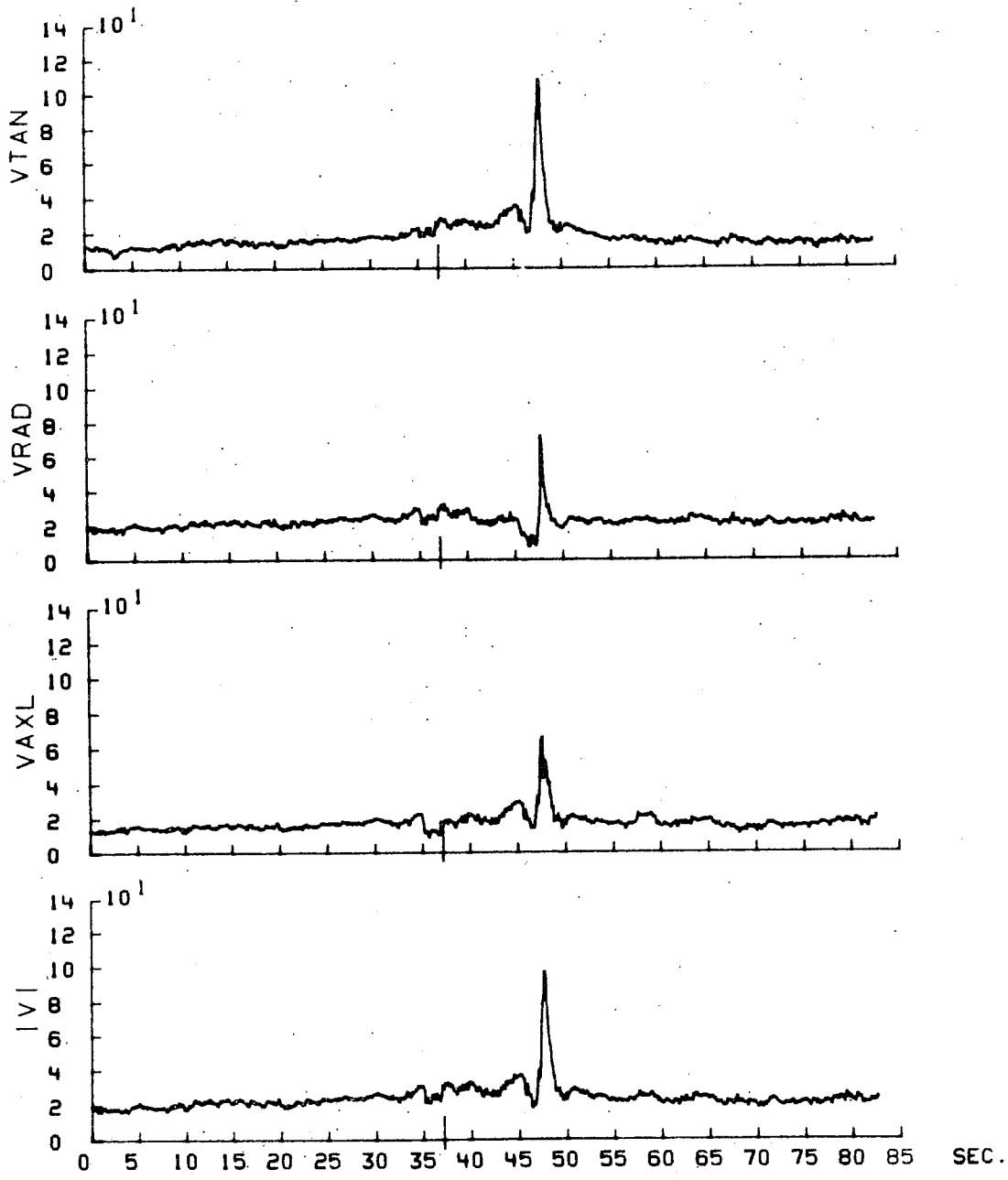


FIG. 7-91 TIME HISTORY

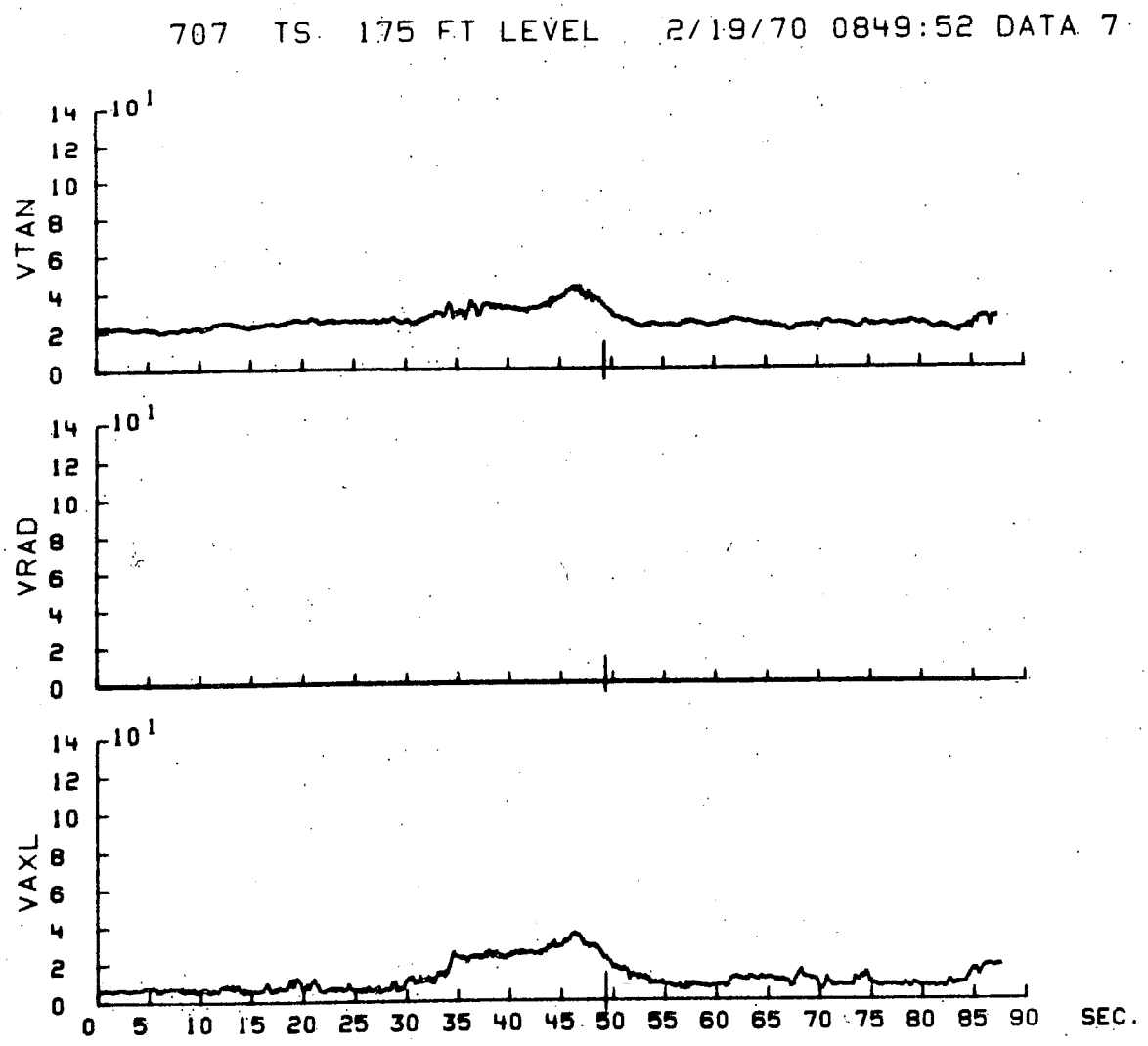


FIG. 7-92 TIME HISTORY

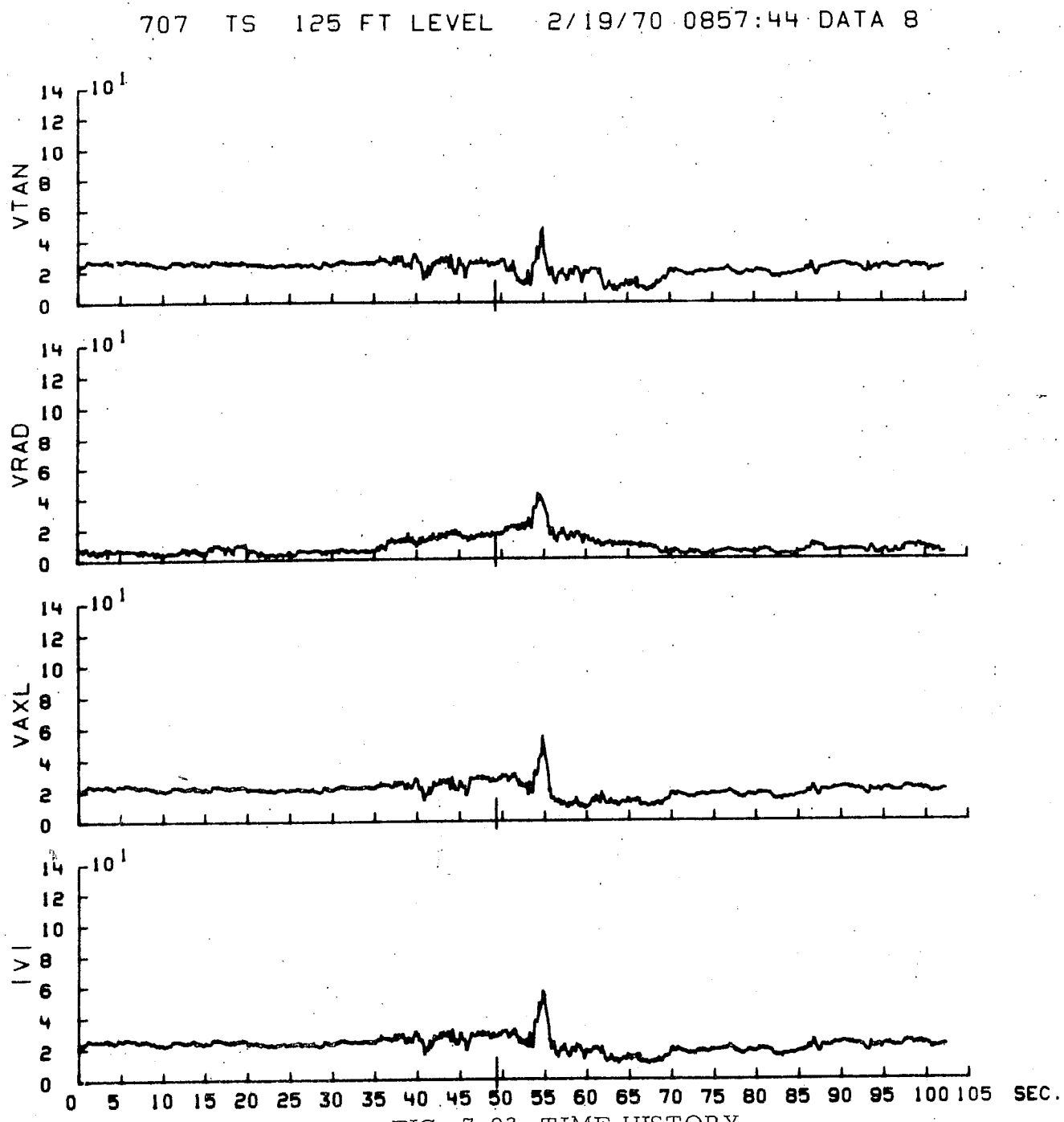


FIG. 7-93 TIME HISTORY

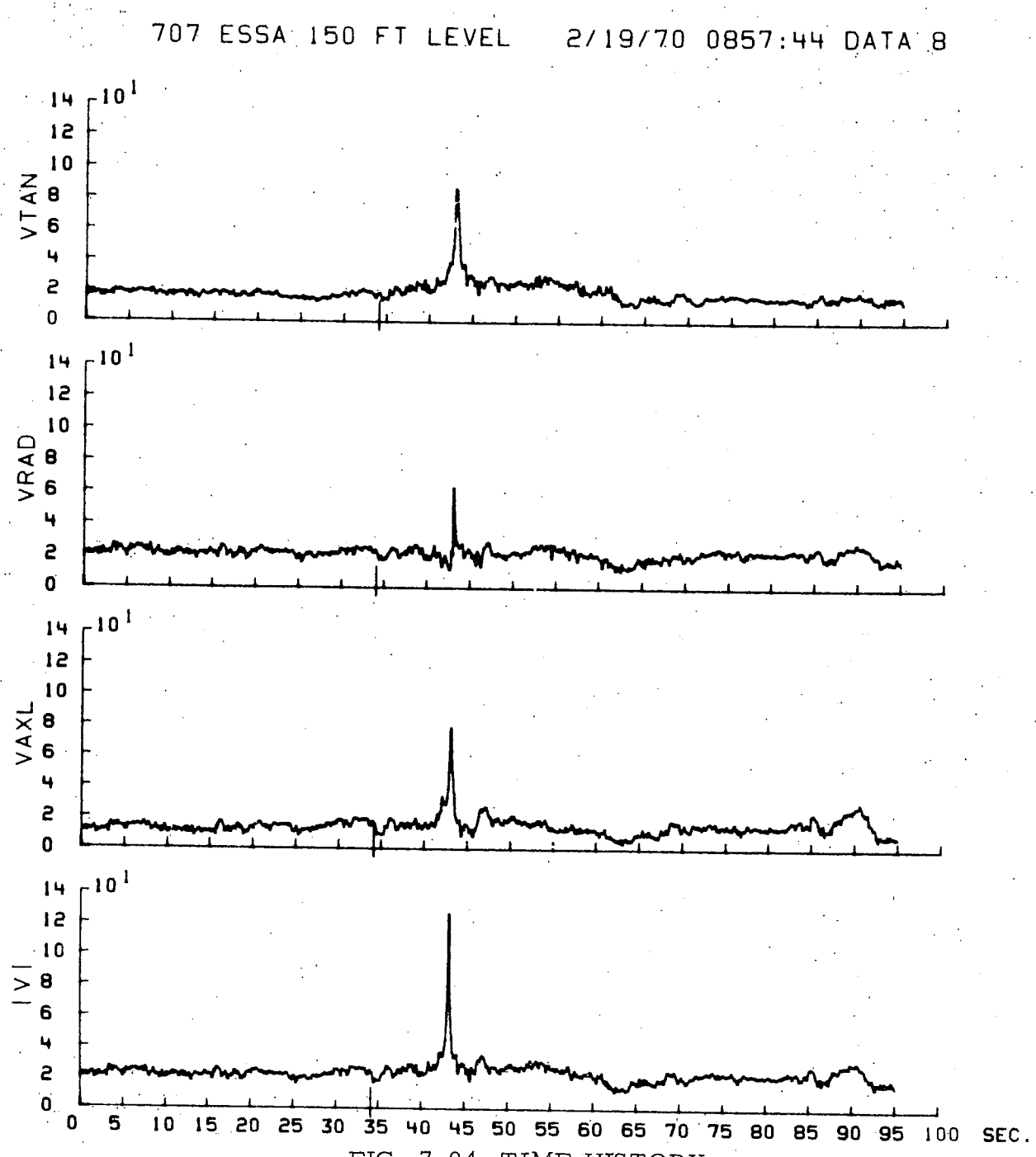


FIG. 7-94 TIME HISTORY

707 TS 175 FT LEVEL 2/19/70 0946:42 DATA 9

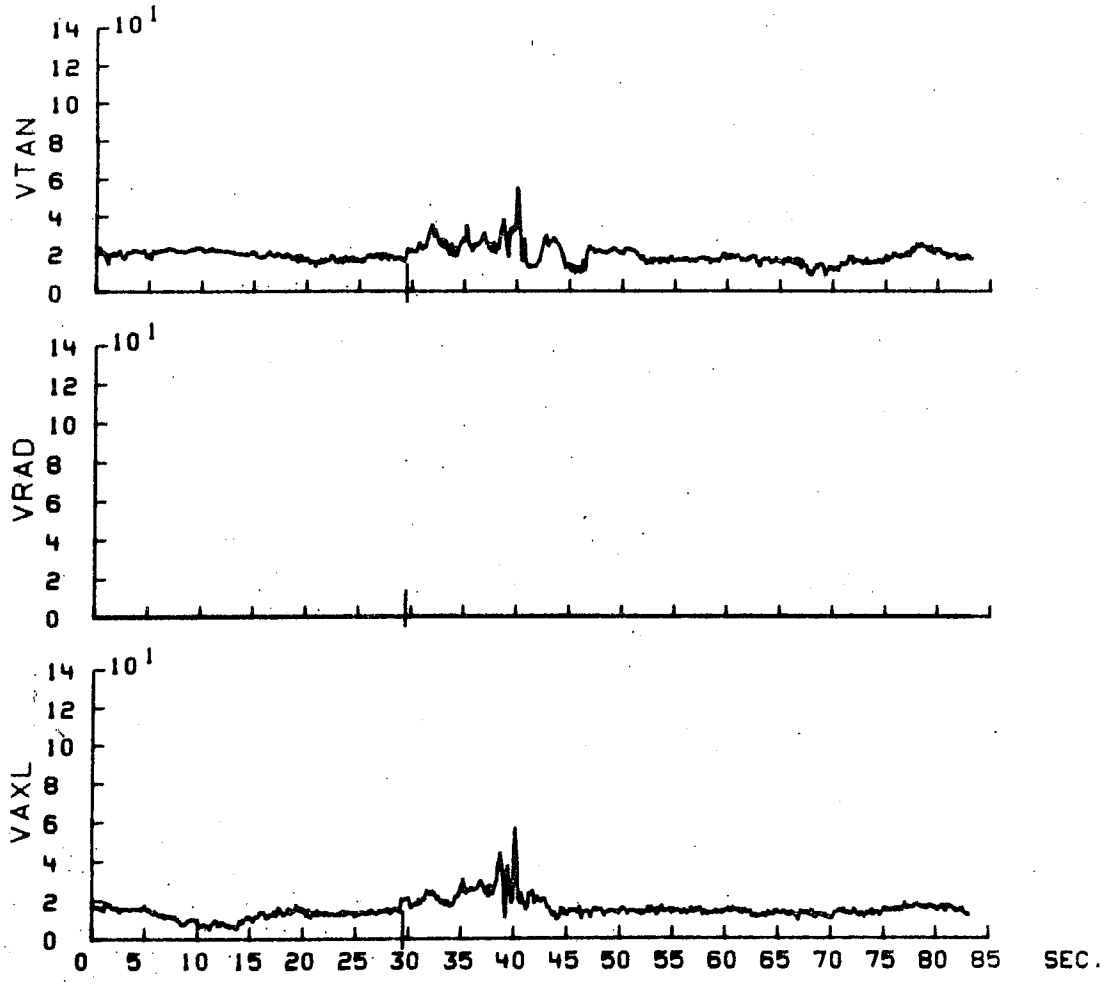


FIG. 7-95 TIME HISTORY

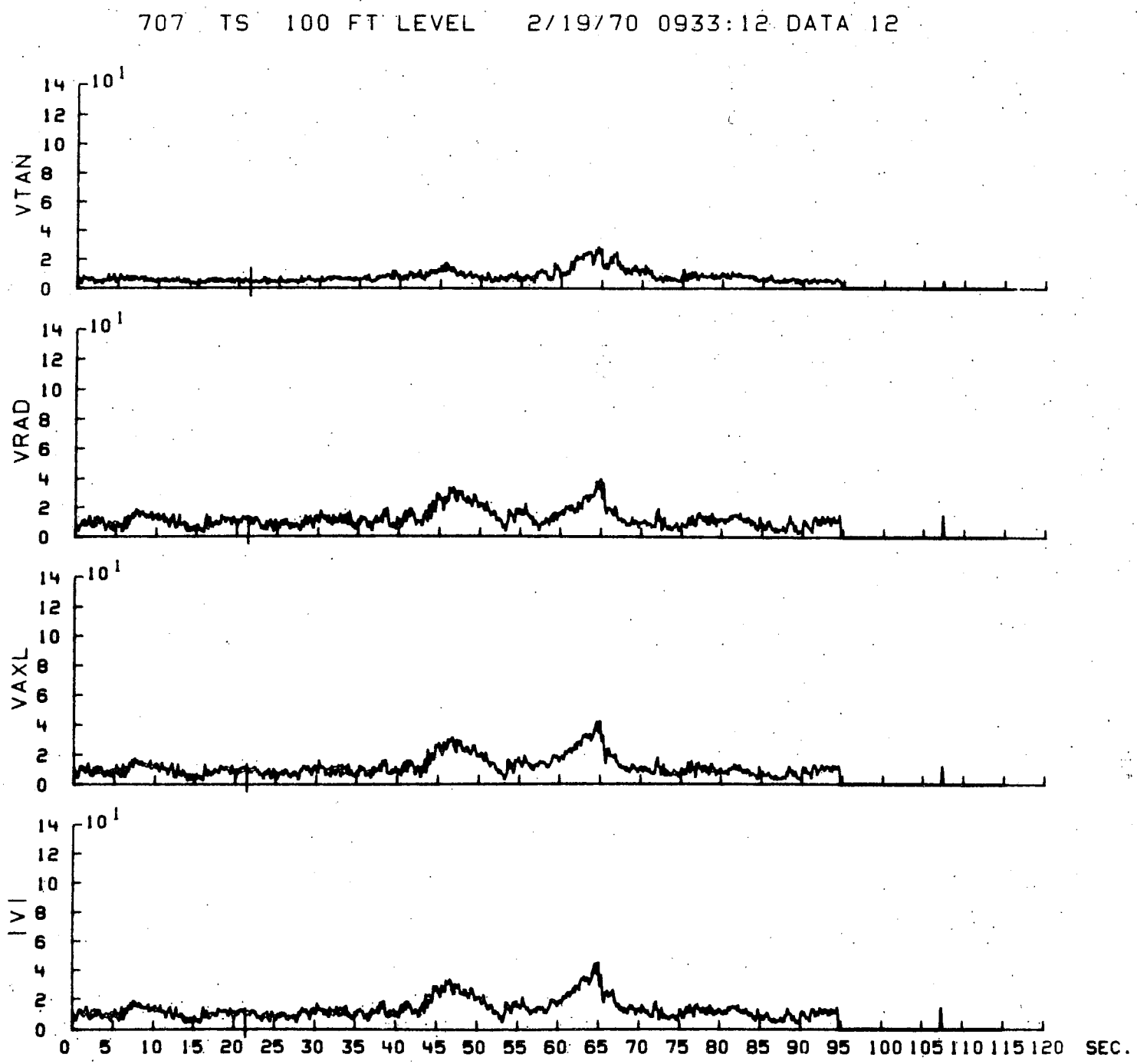


FIG. 7-96 TIME HISTORY

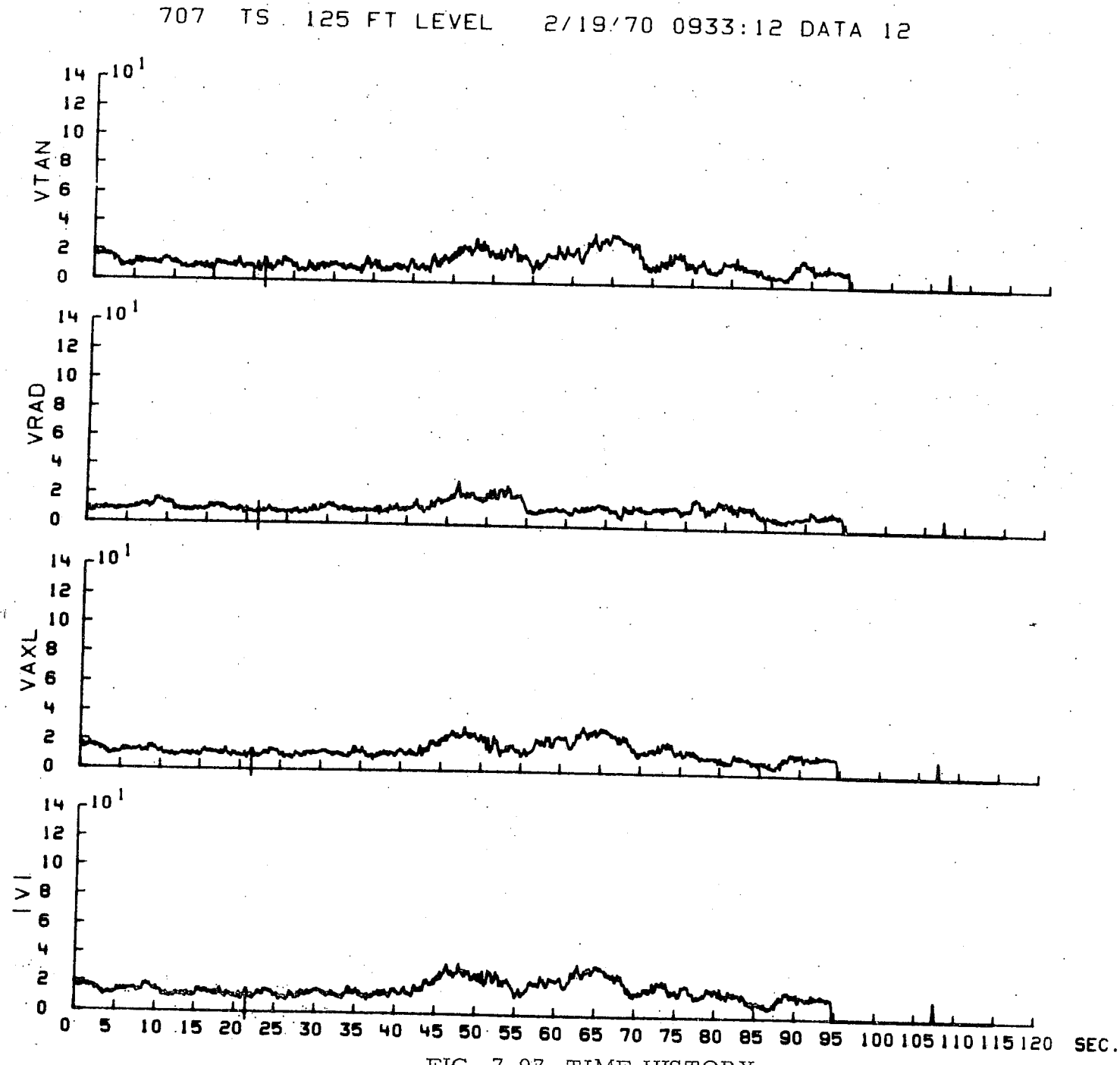


FIG. 7-97 TIME HISTORY

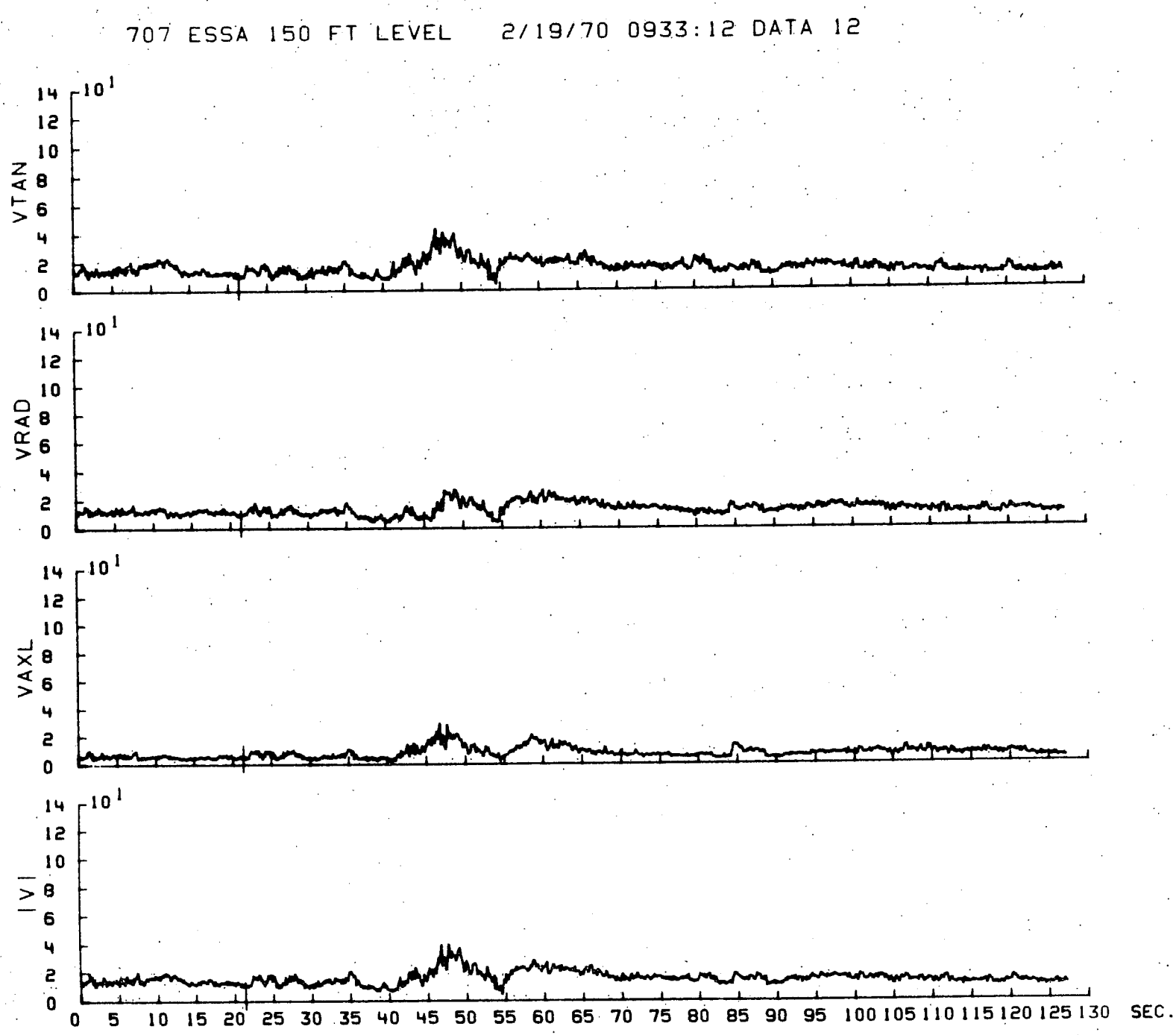


FIG. 7-98 TIME HISTORY

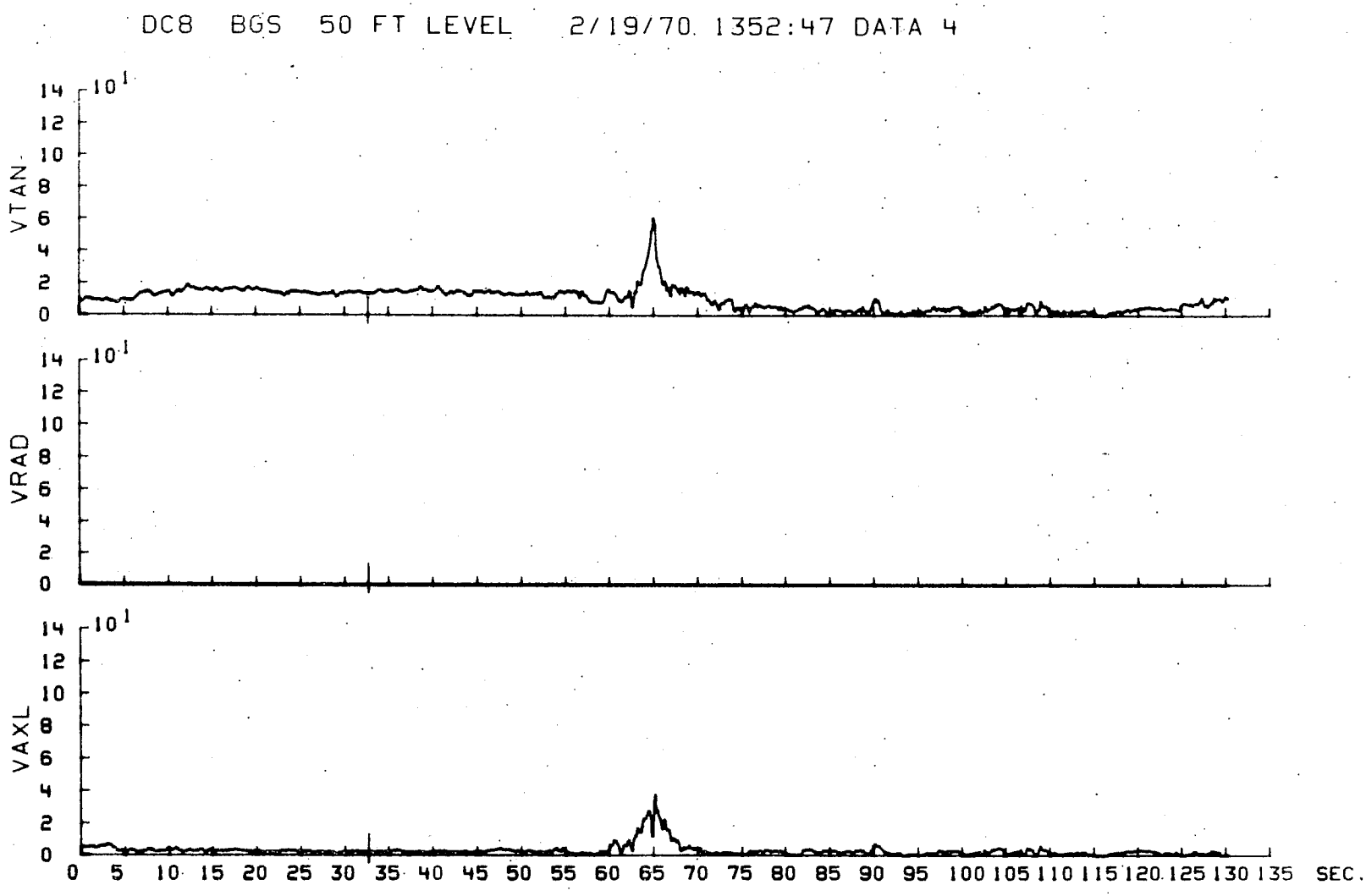


FIG. 7-99 TIME HISTORY

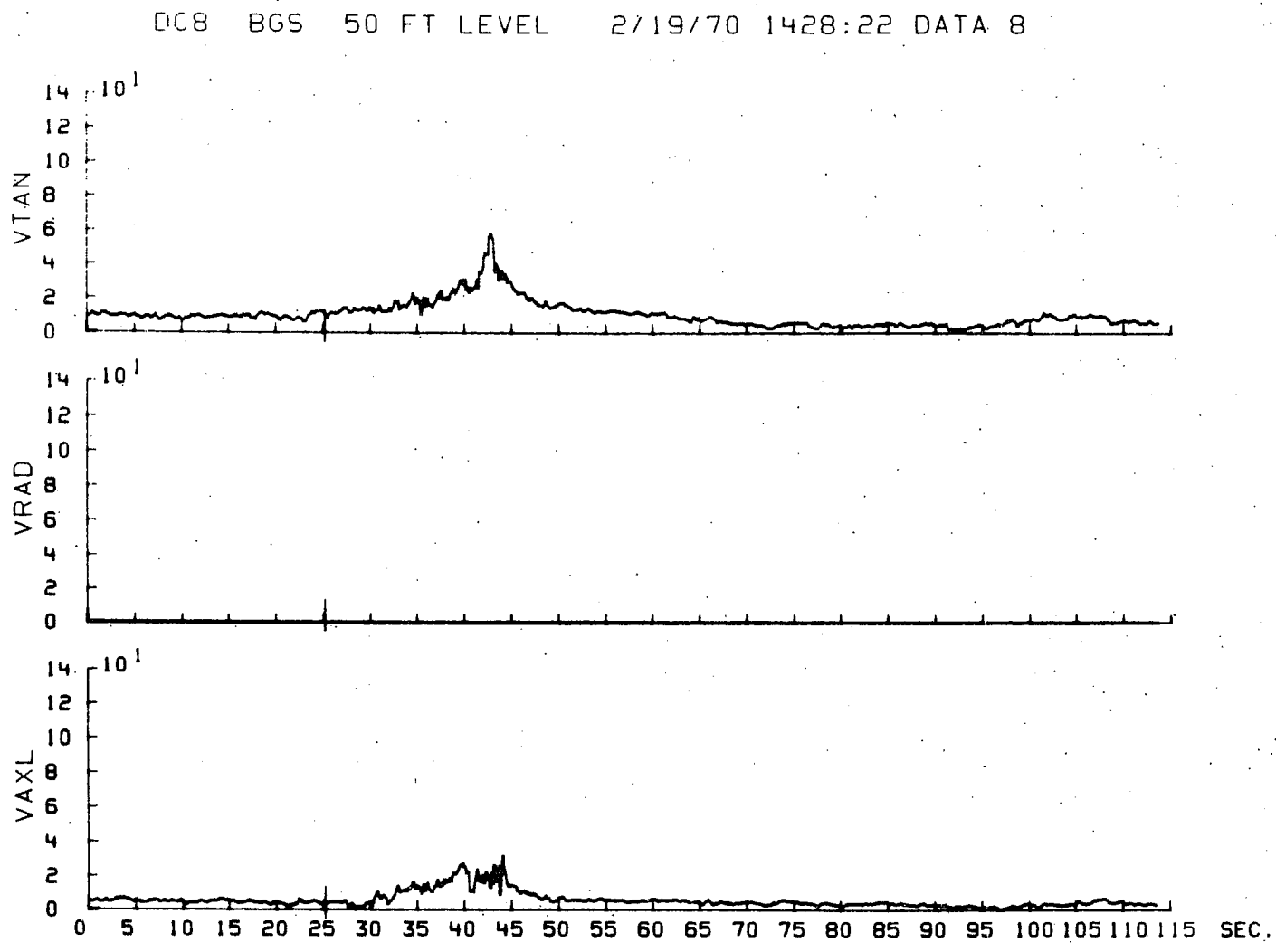


FIG. 7-100 TIME HISTORY

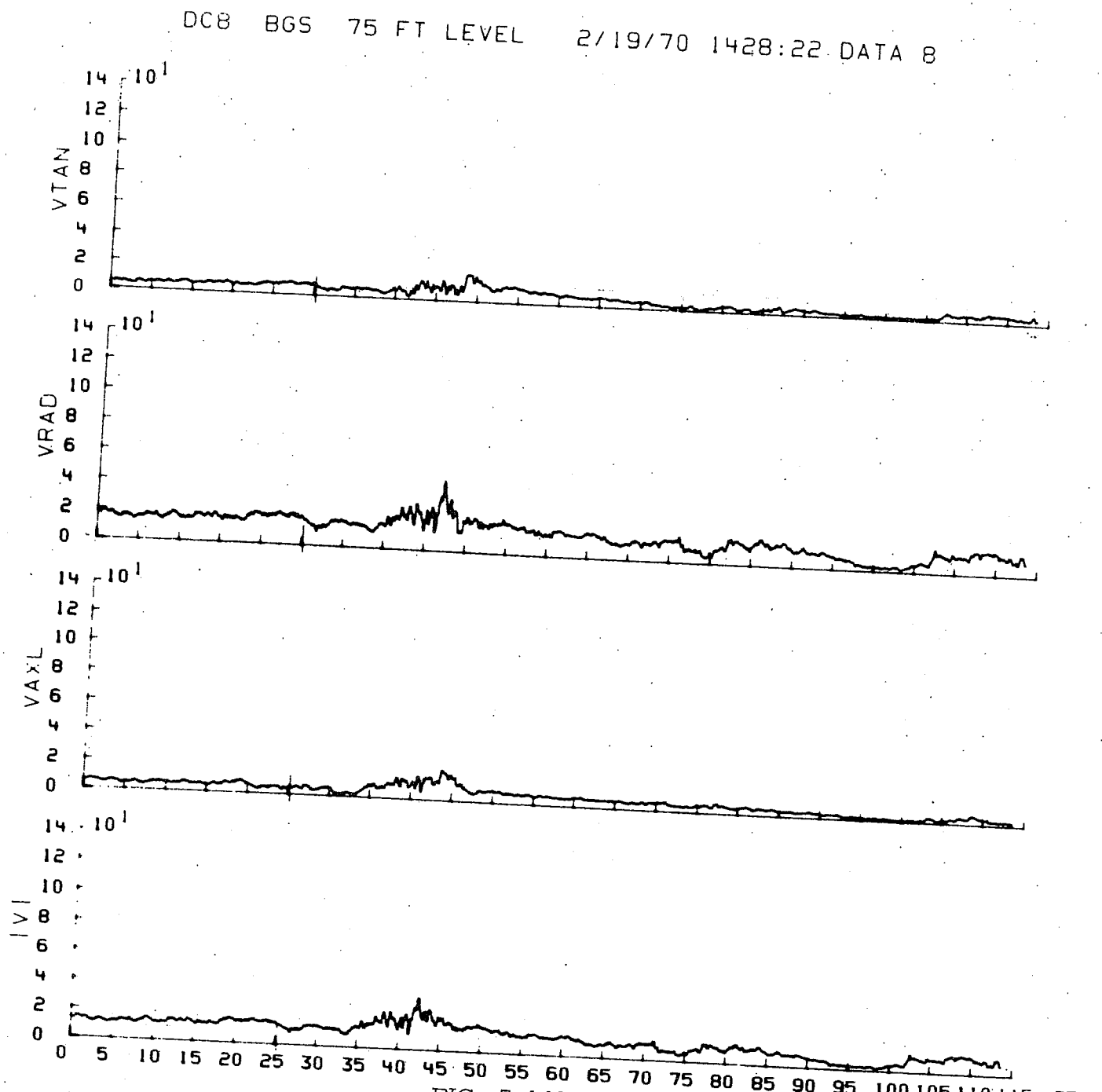


FIG. 7-101 TIME HISTORY

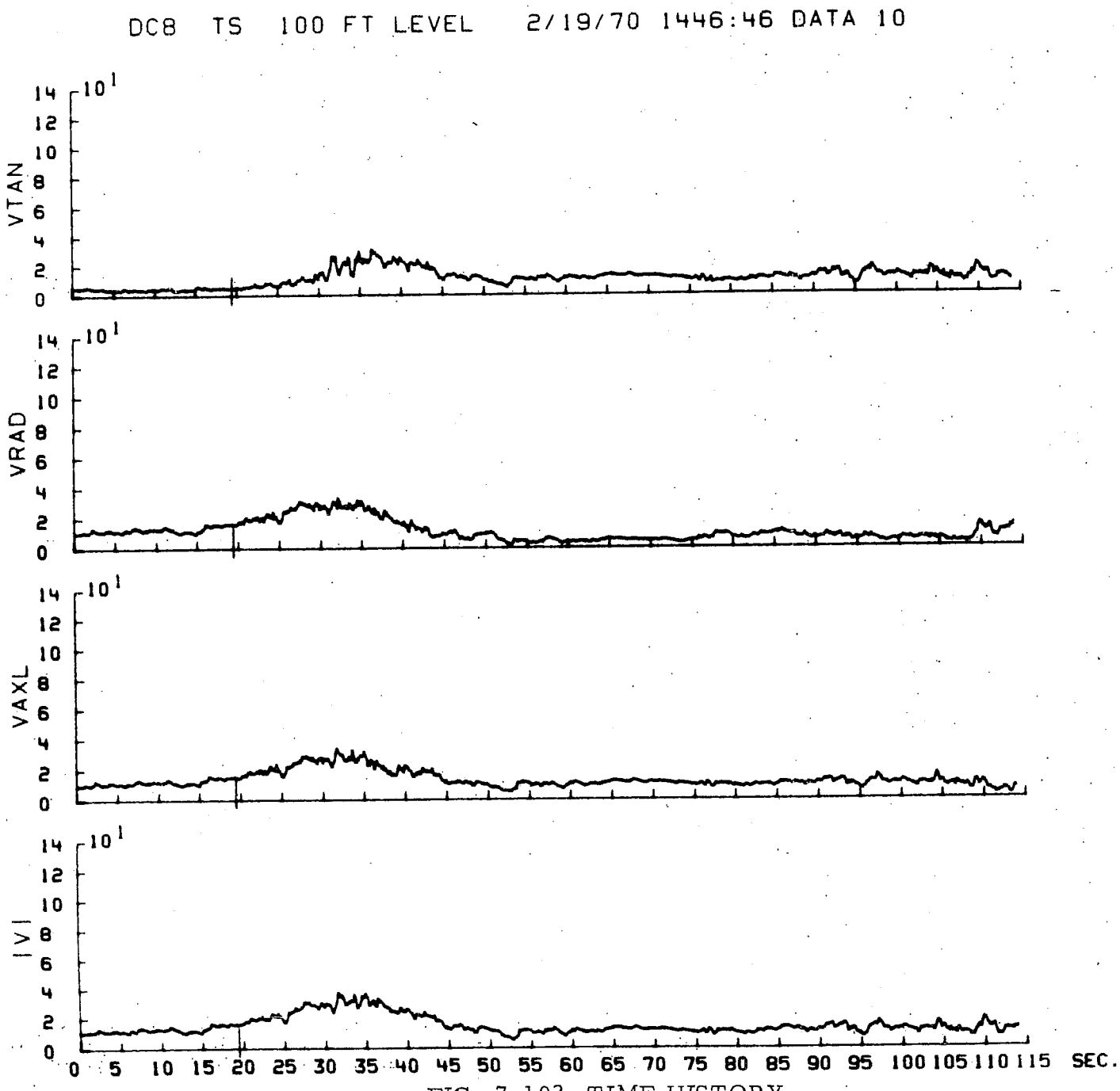


FIG. 7-102 TIME HISTORY

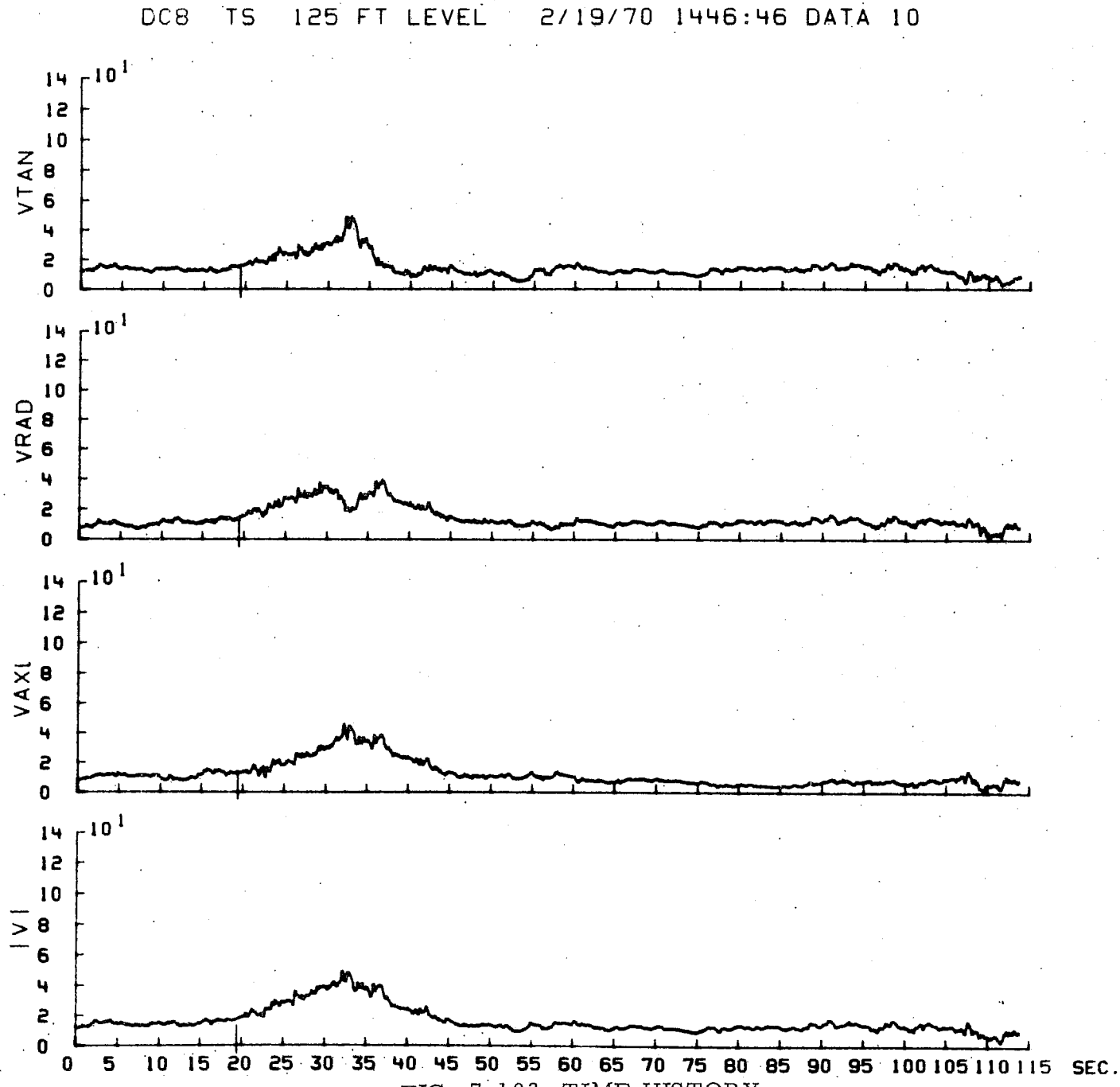


FIG. 7-103 TIME HISTORY

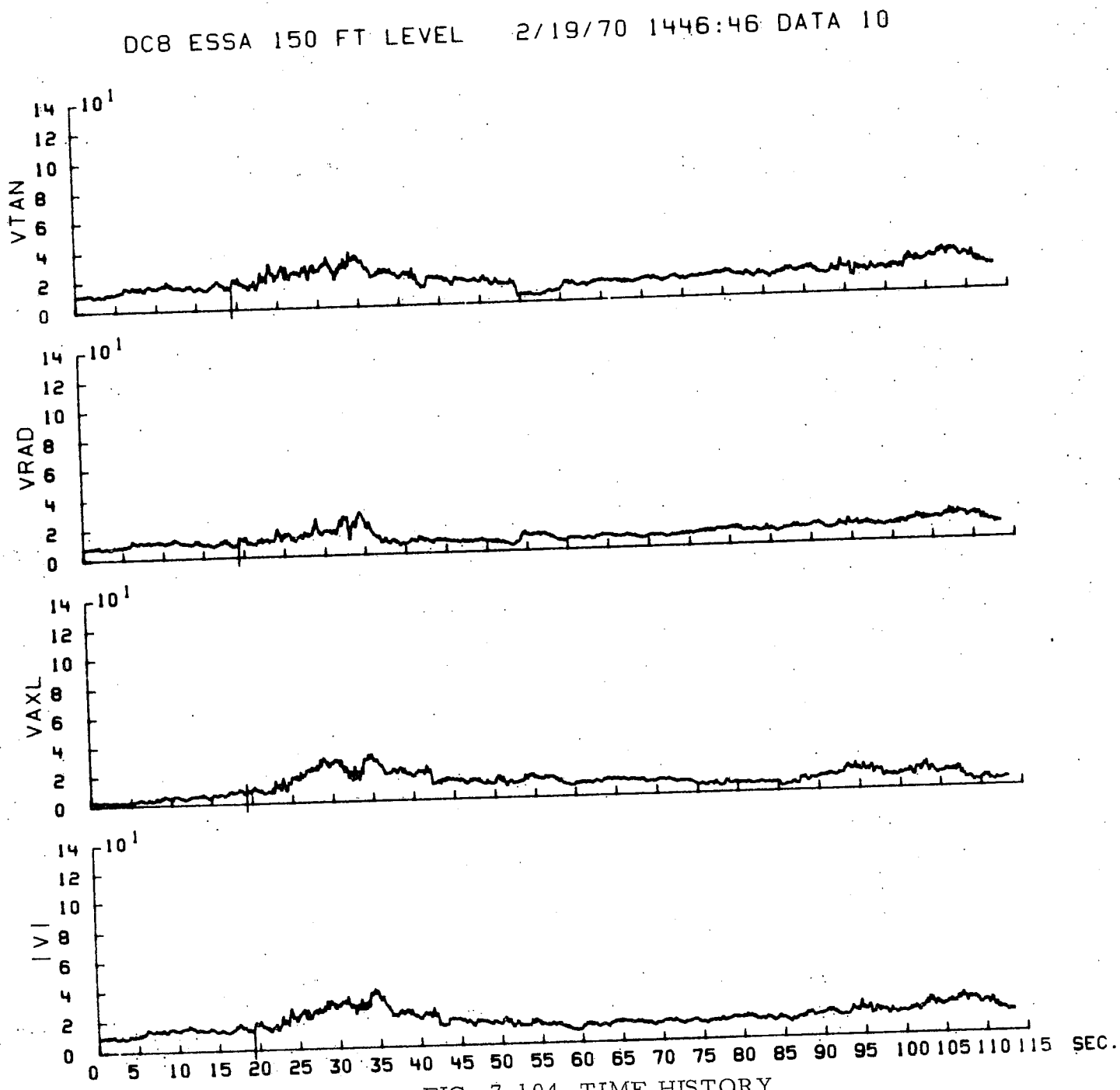


FIG. 7-104 TIME HISTORY

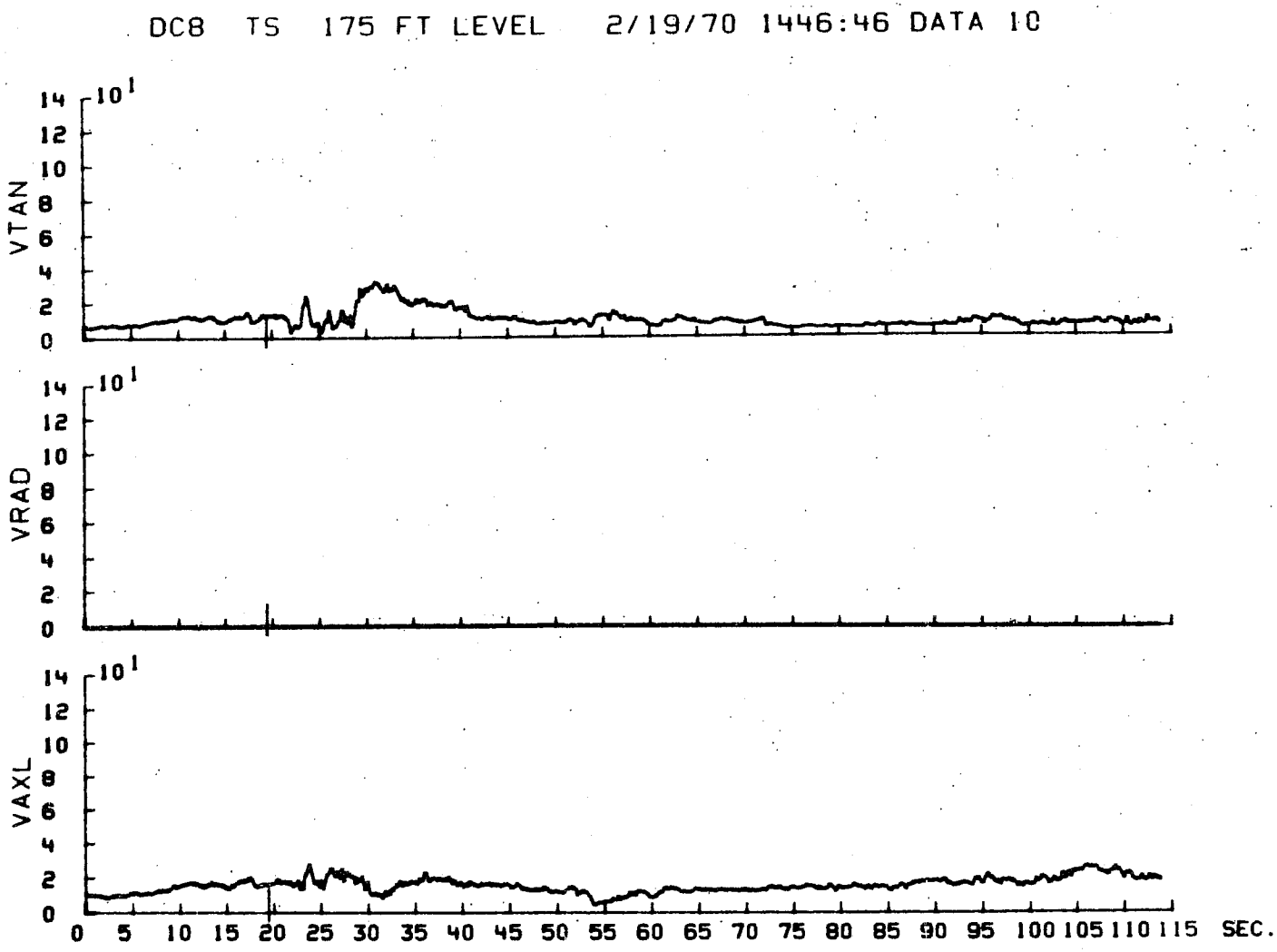


FIG. 7-105 TIME HISTORY

DC8 TS 100 FT LEVEL 2/20/70 0825:16 DATA 2

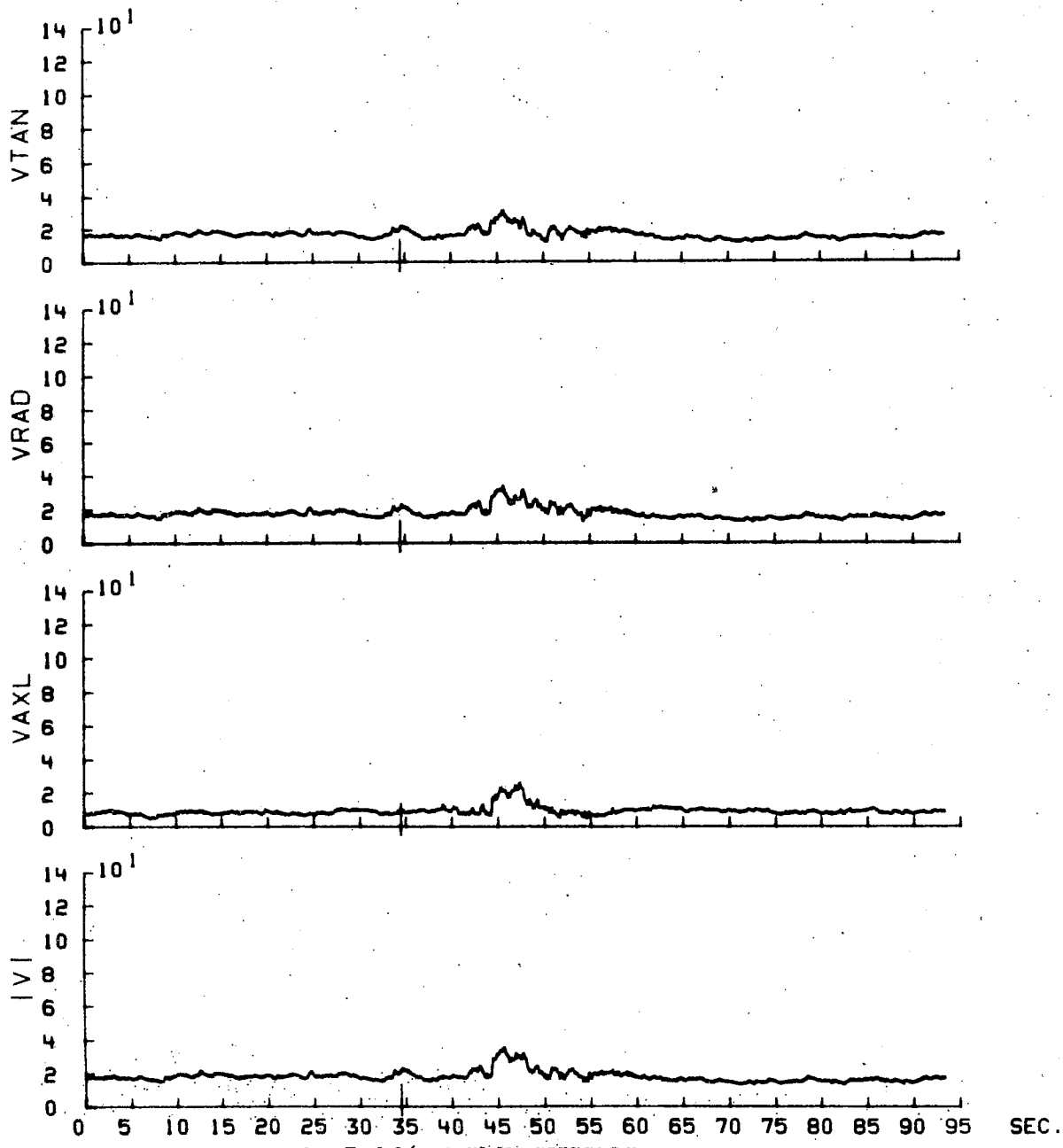


FIG. 7-106 TIME HISTORY

DC8 TS 125 FT LEVEL 2/20/70 0825:16 DATA 2

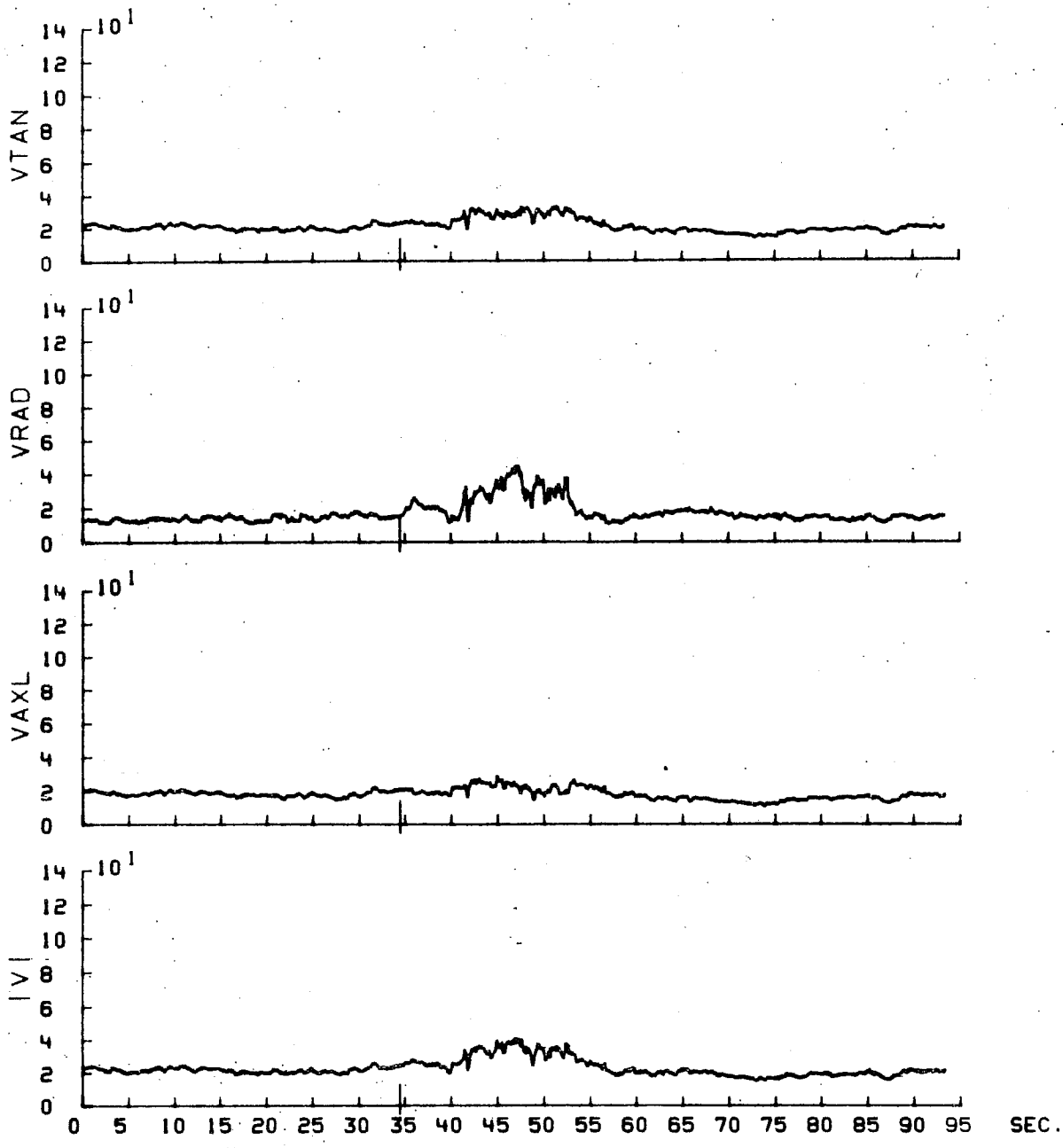


FIG. 7-107 TIME HISTORY

DC8 ESSA 150 FT LEVEL 2/20/70 0825:16 DATA 2

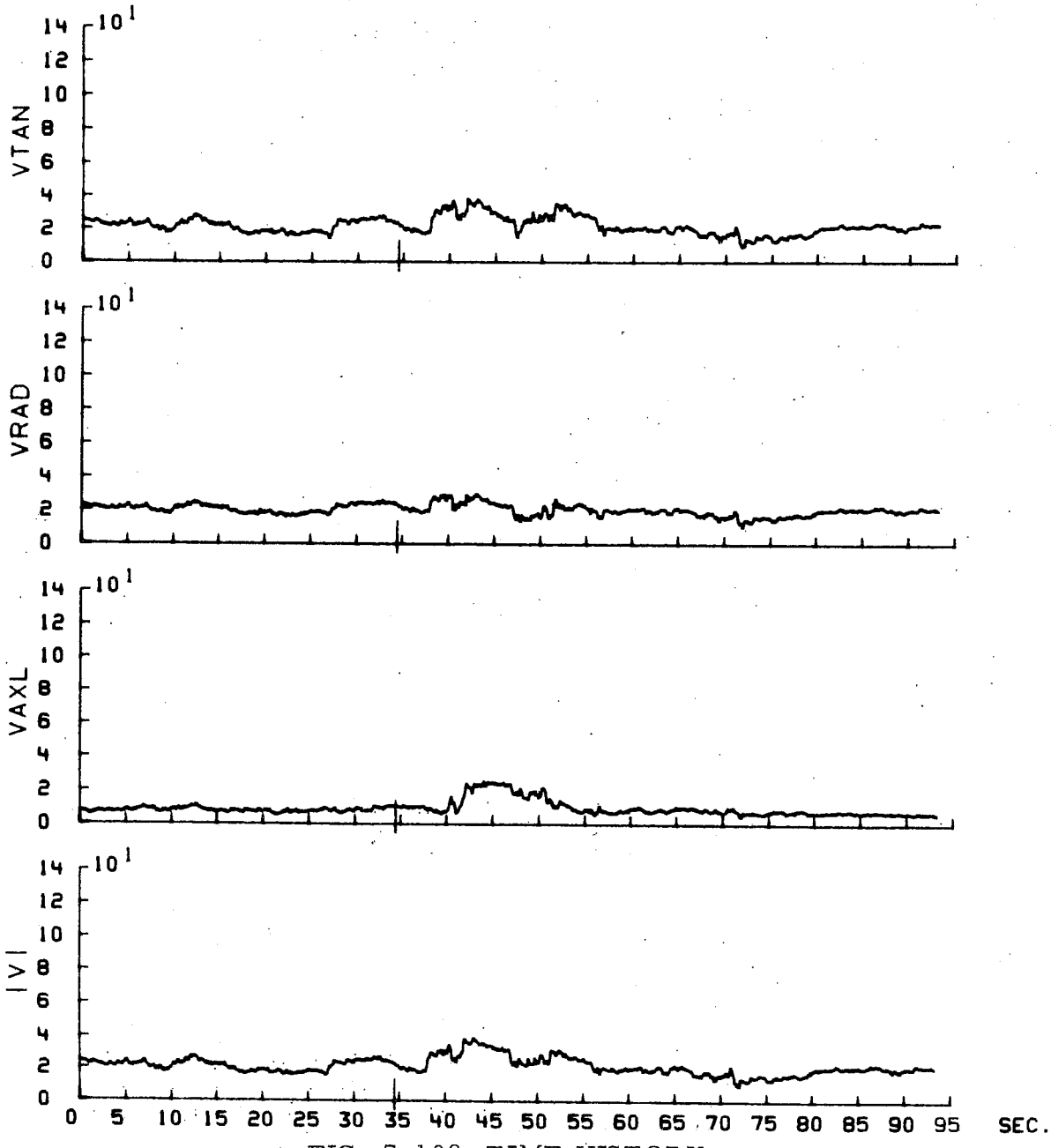


FIG. 7-108 TIME HISTORY

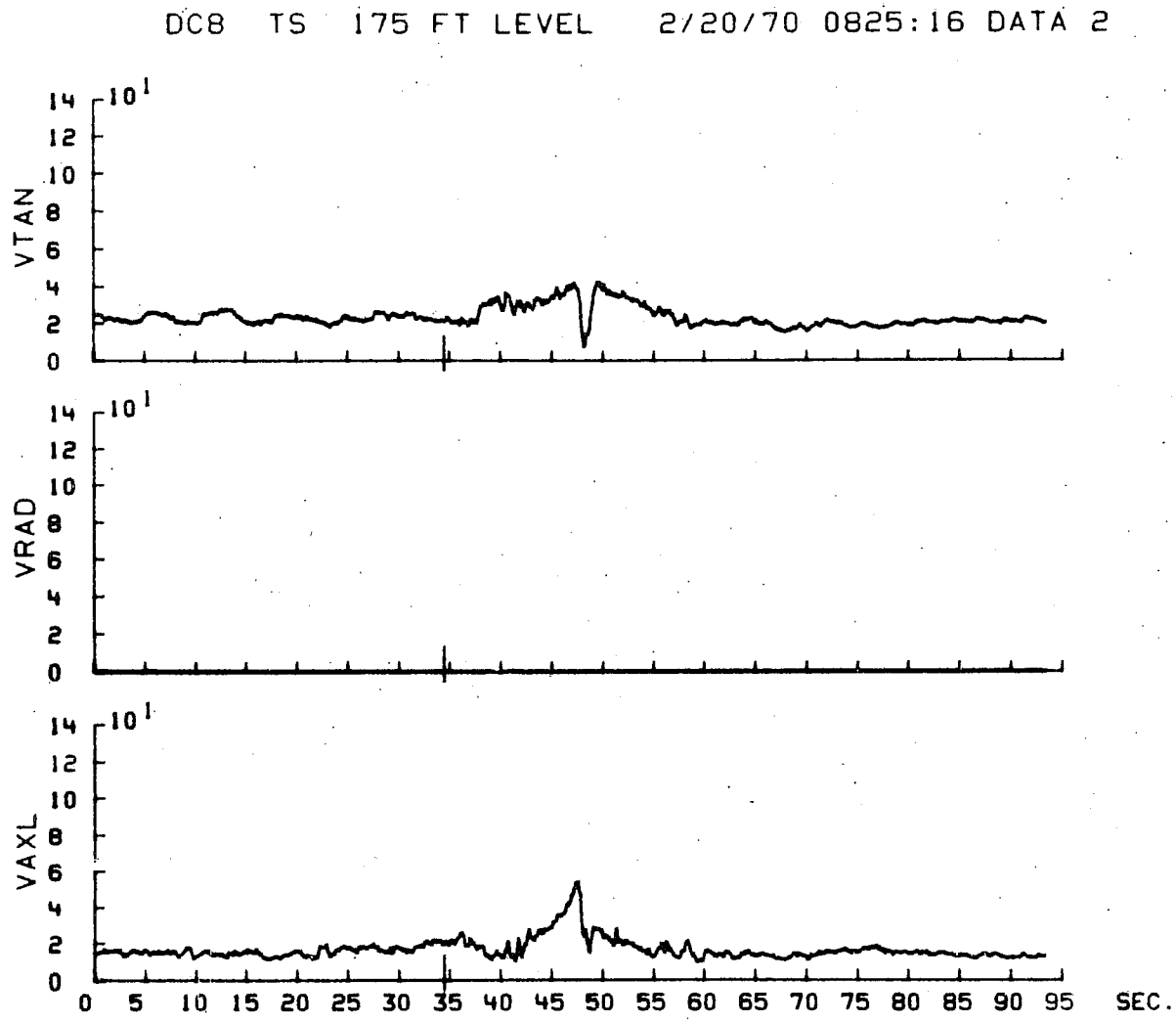


FIG. 7-109 TIME HISTORY

DC8 ESSA 200 FT LEVEL 2/20/70 0825:16 DATA 2

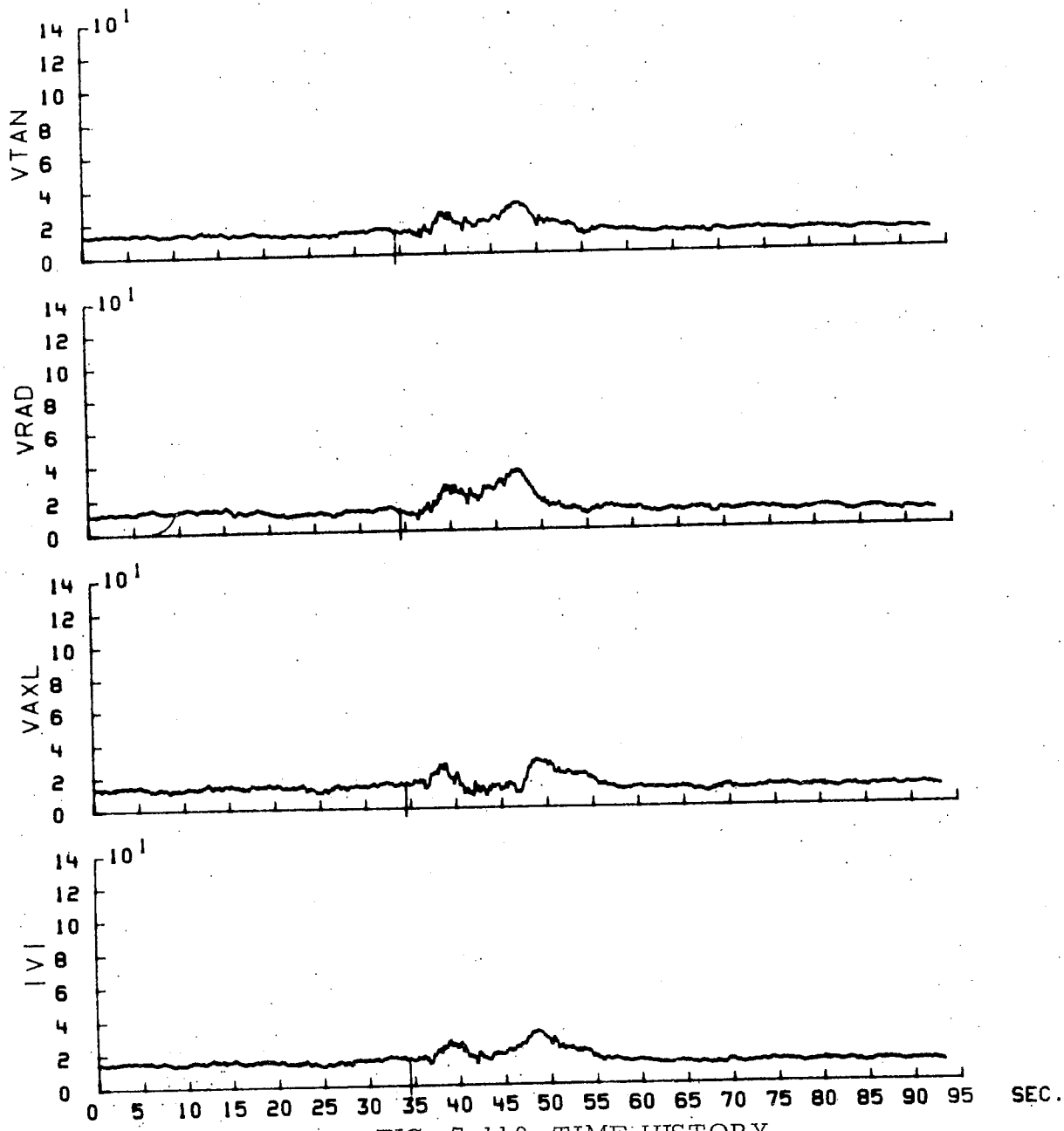


FIG. 7-110 TIME HISTORY

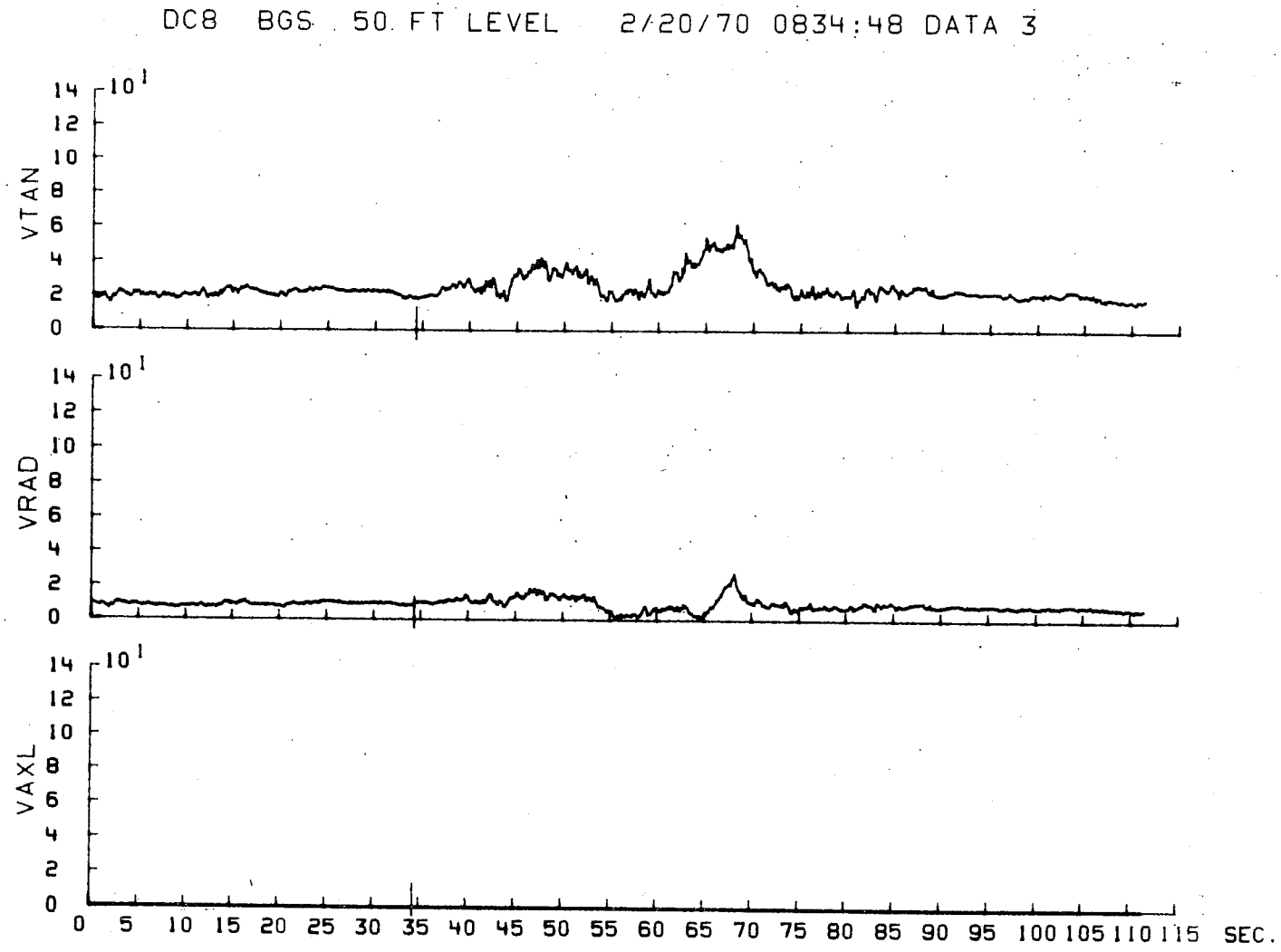


FIG. 7-111 TIME HISTORY

DC8 BGS 75 FT LEVEL 2/20/70 0834:48 DATA 3

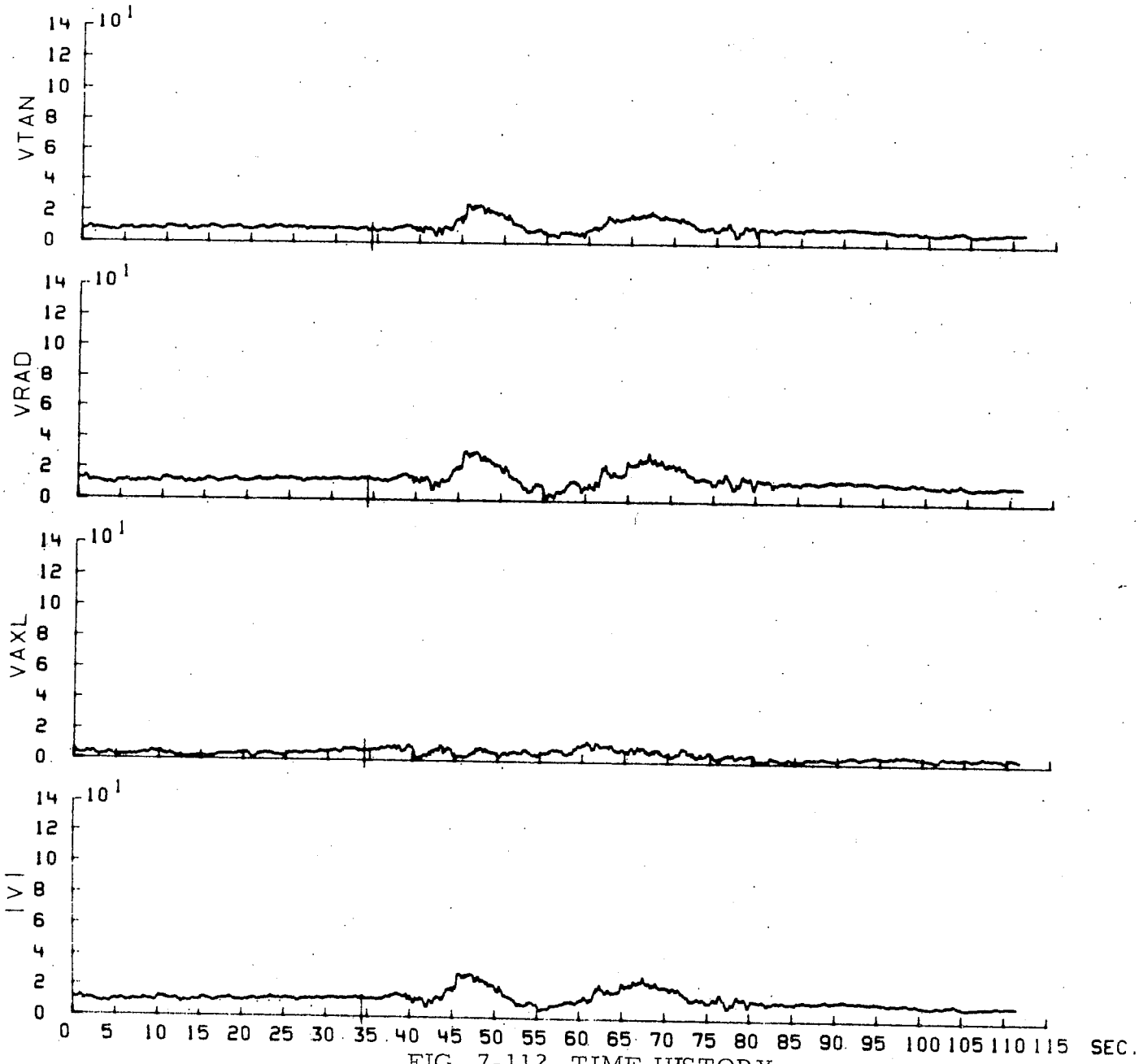


FIG. 7-112 TIME HISTORY

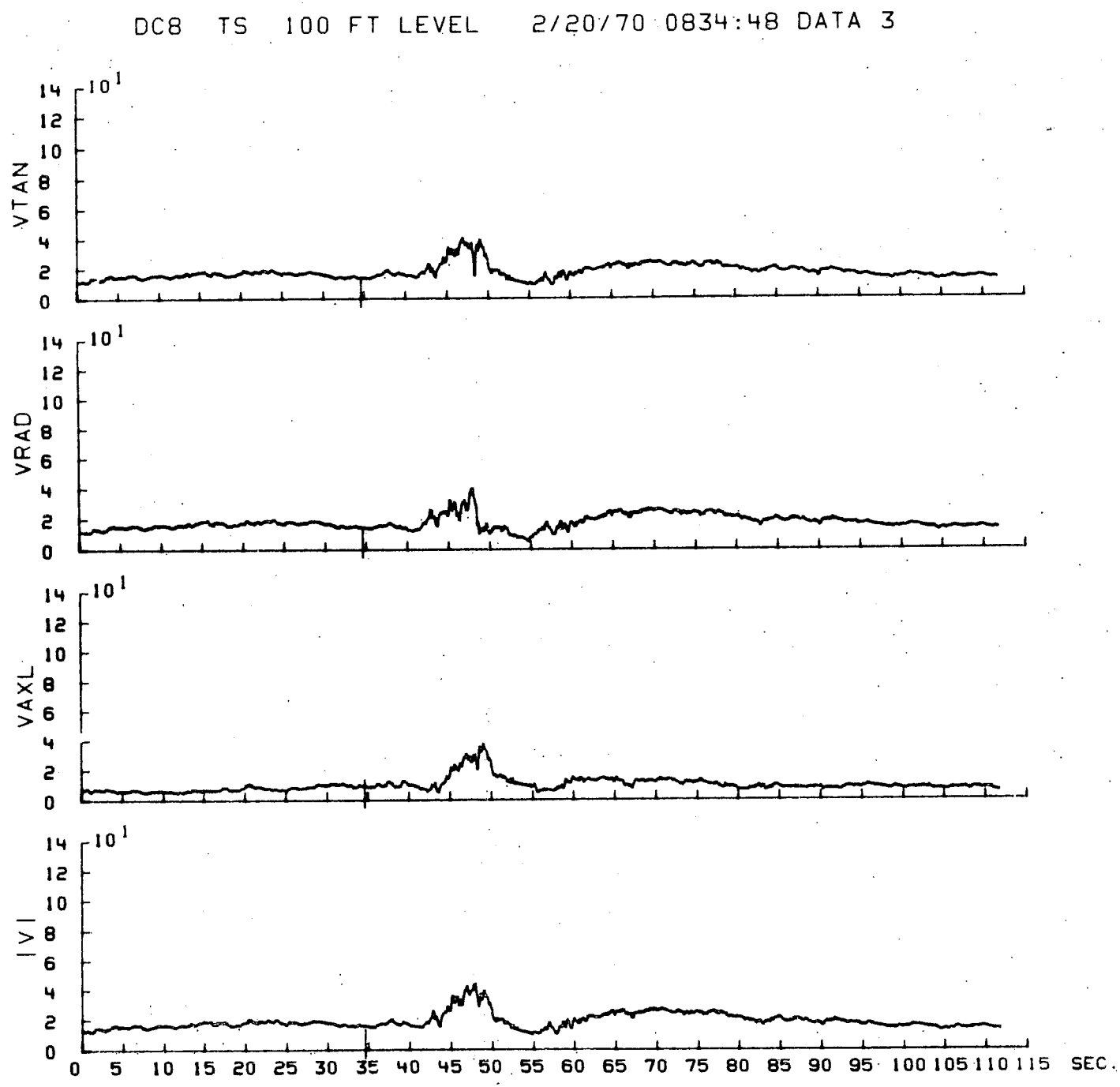


FIG. 7-113 TIME HISTORY

DC8 TS 125 FT LEVEL 2/20/70 0834:48 DATA 3

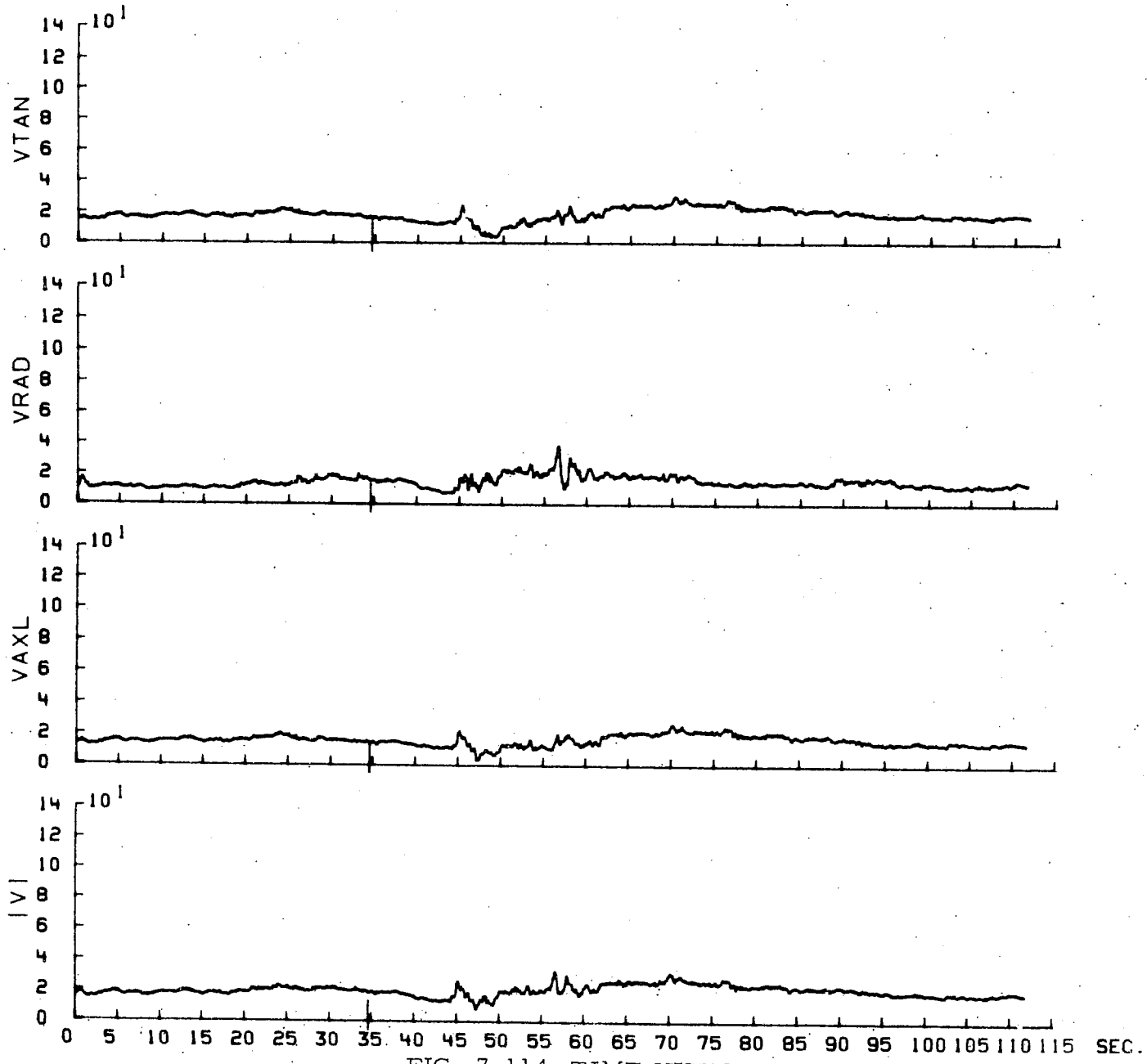


FIG. 7-114 TIME HISTORY

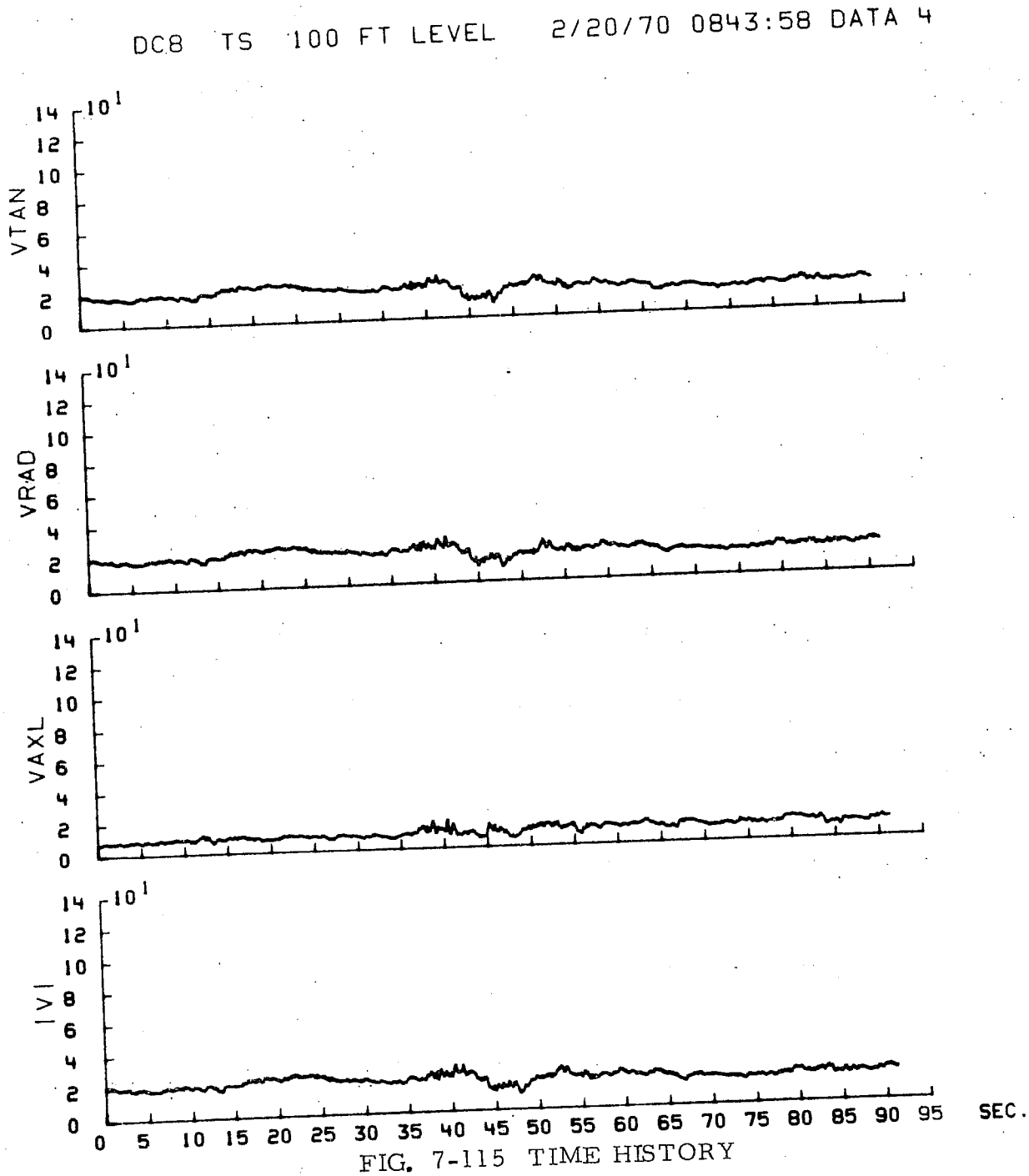


FIG. 7-115 TIME HISTORY

DC8 TS 125 FT LEVEL 2/20/70 0843:58 DATA 4

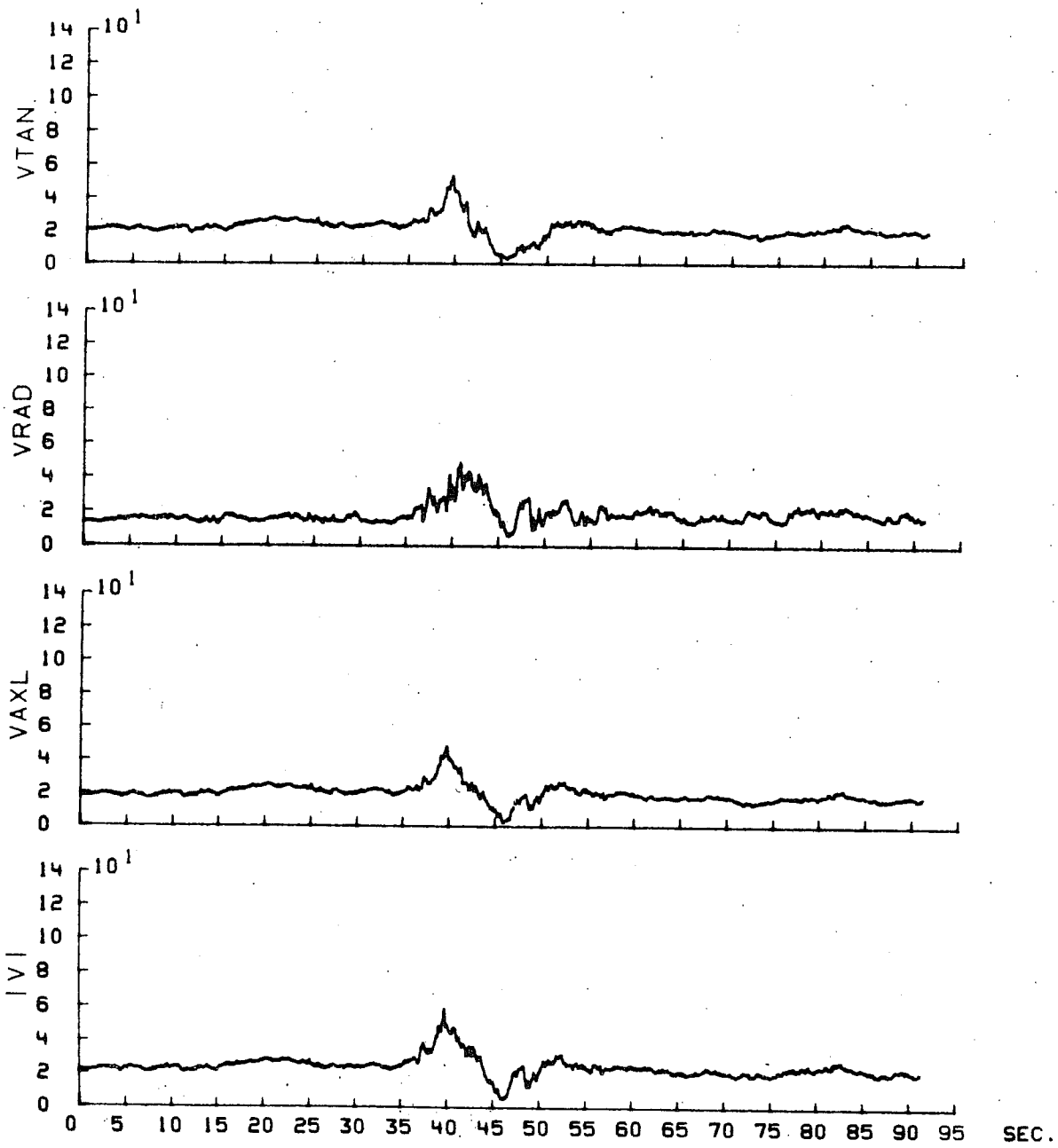


FIG. 7-116 TIME HISTORY

DC8 ESSA 150 FT LEVEL 2/20/70 0843:58 DATA 4

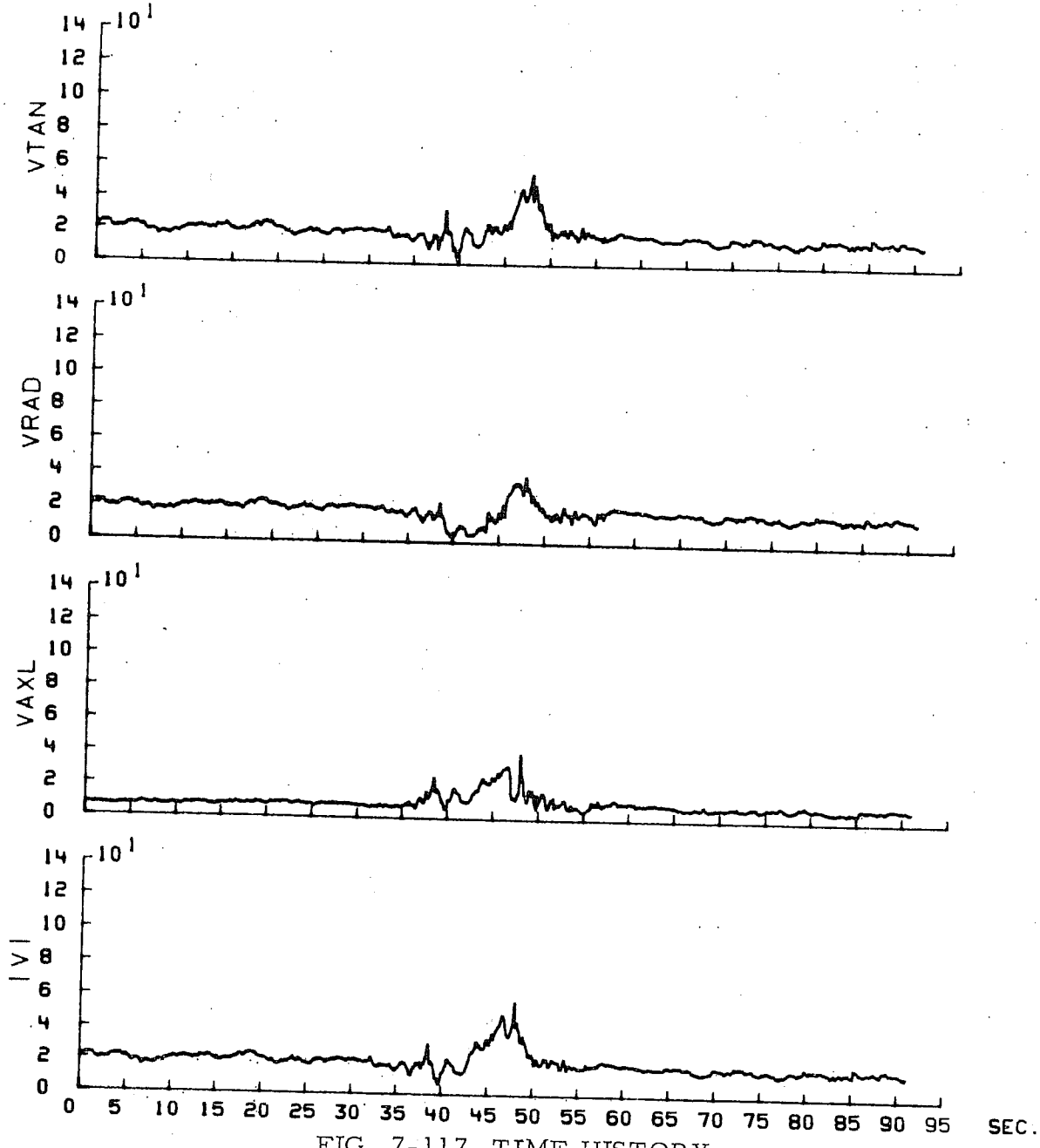


FIG. 7-117 TIME HISTORY

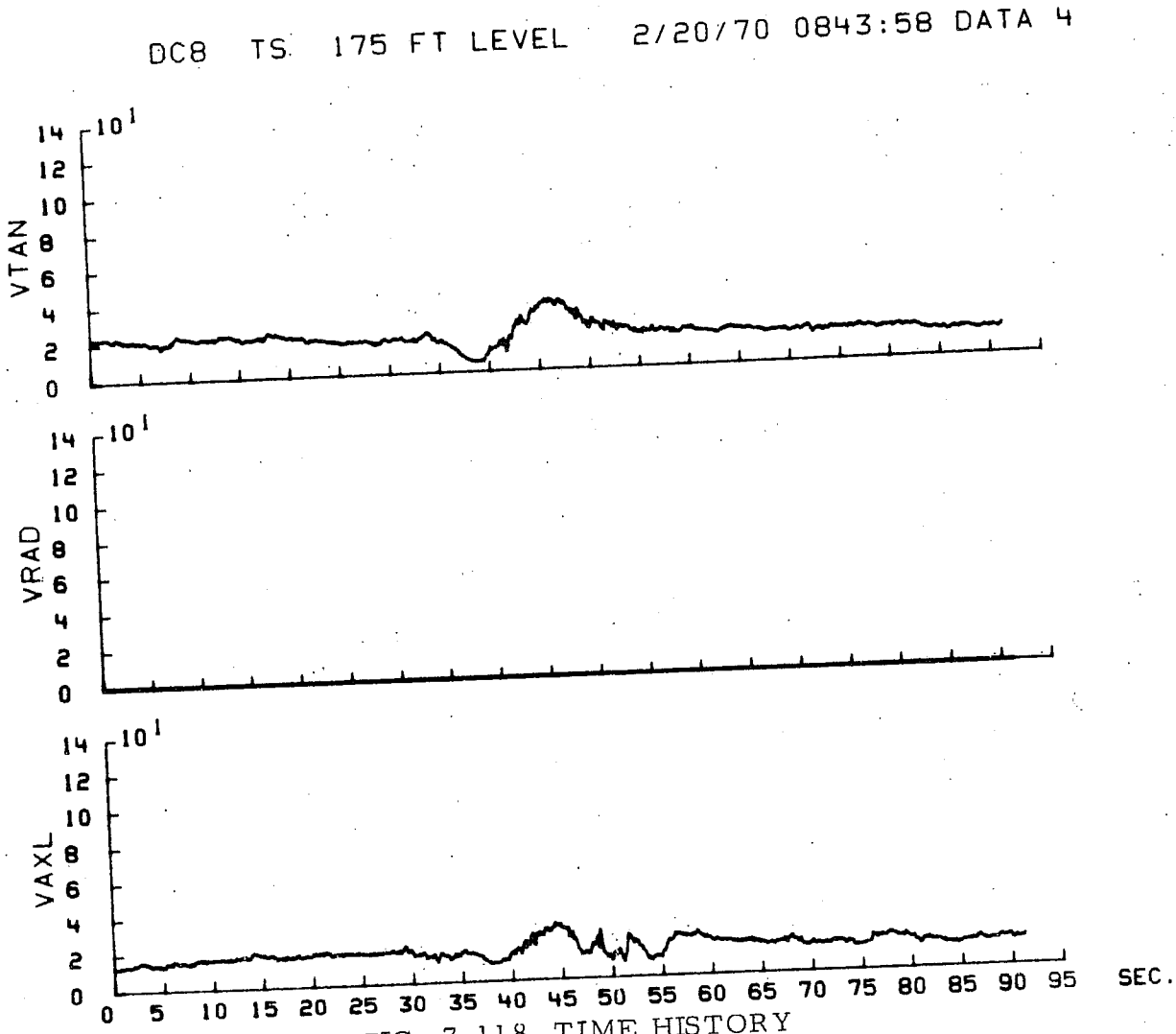


FIG. 7-118 TIME HISTORY

DC8 ESSA 200 FT LEVEL 2/20/70 0843:58 DATA 4

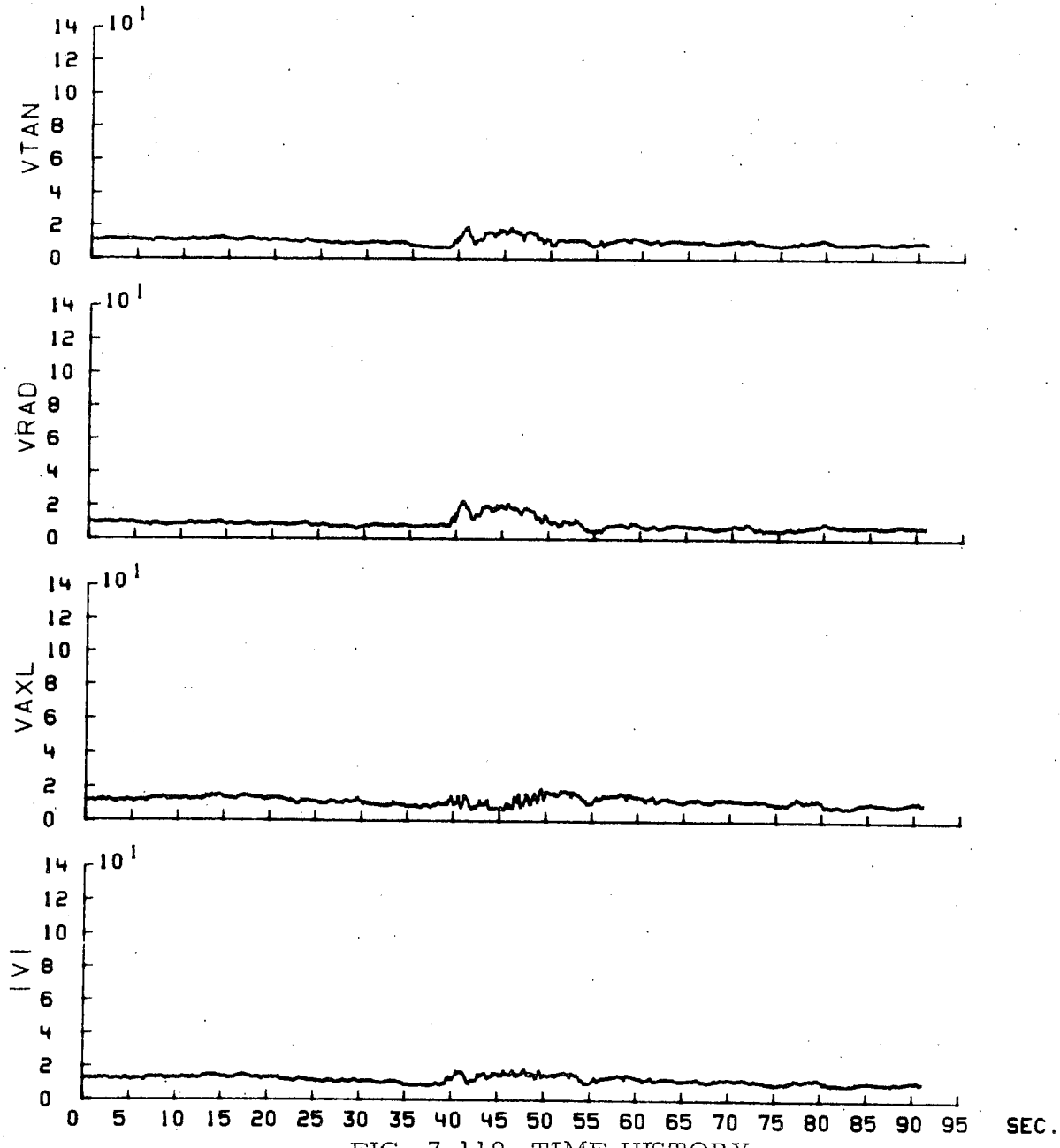


FIG. 7-119 TIME HISTORY

DC8 TS 125 FT LEVEL 2/20/70 0852:57 DATA 5

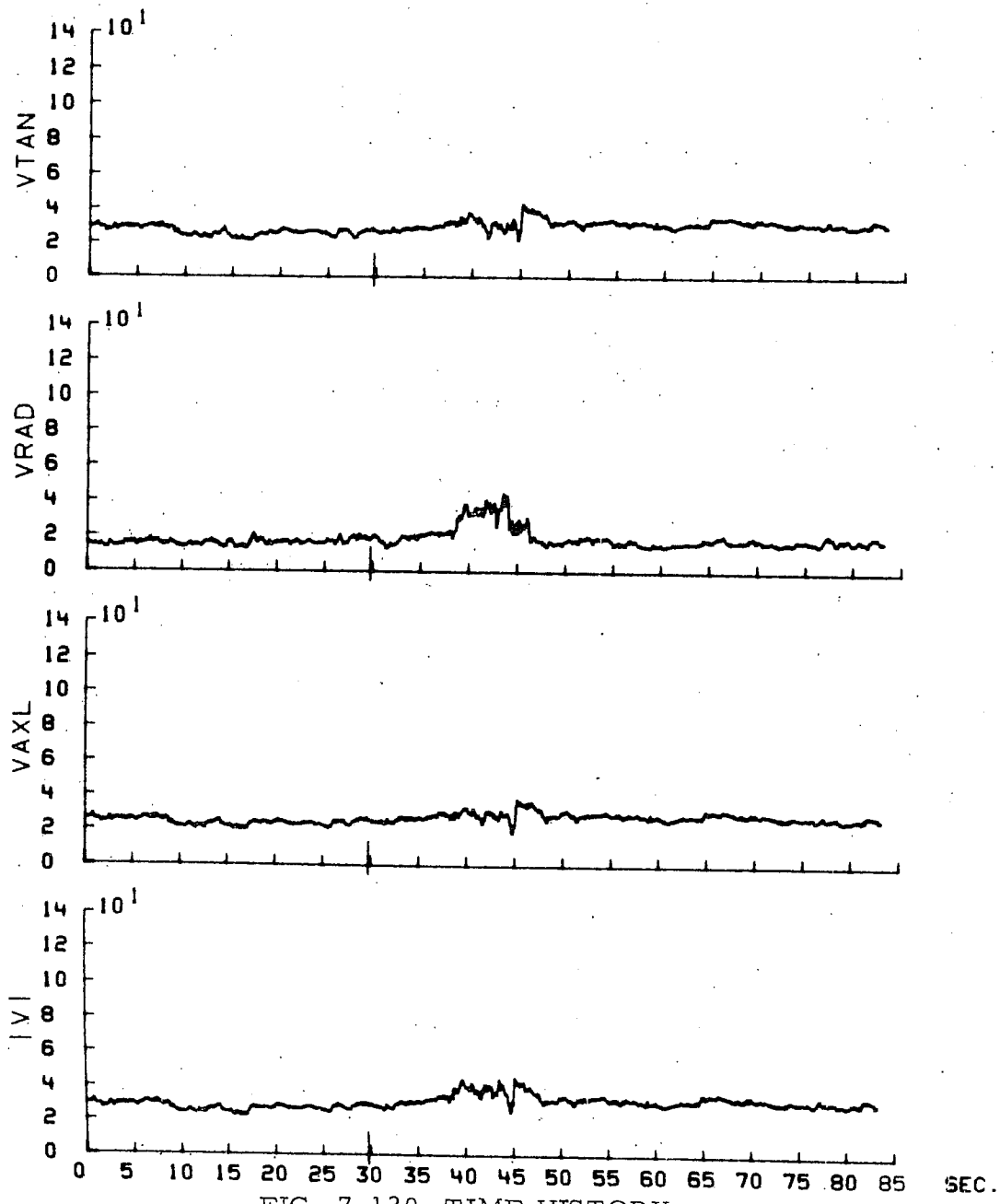


FIG. 7-120 TIME HISTORY

DC8 ESSA 150 FT LEVEL 2/20/70 0852:57 DATA 5

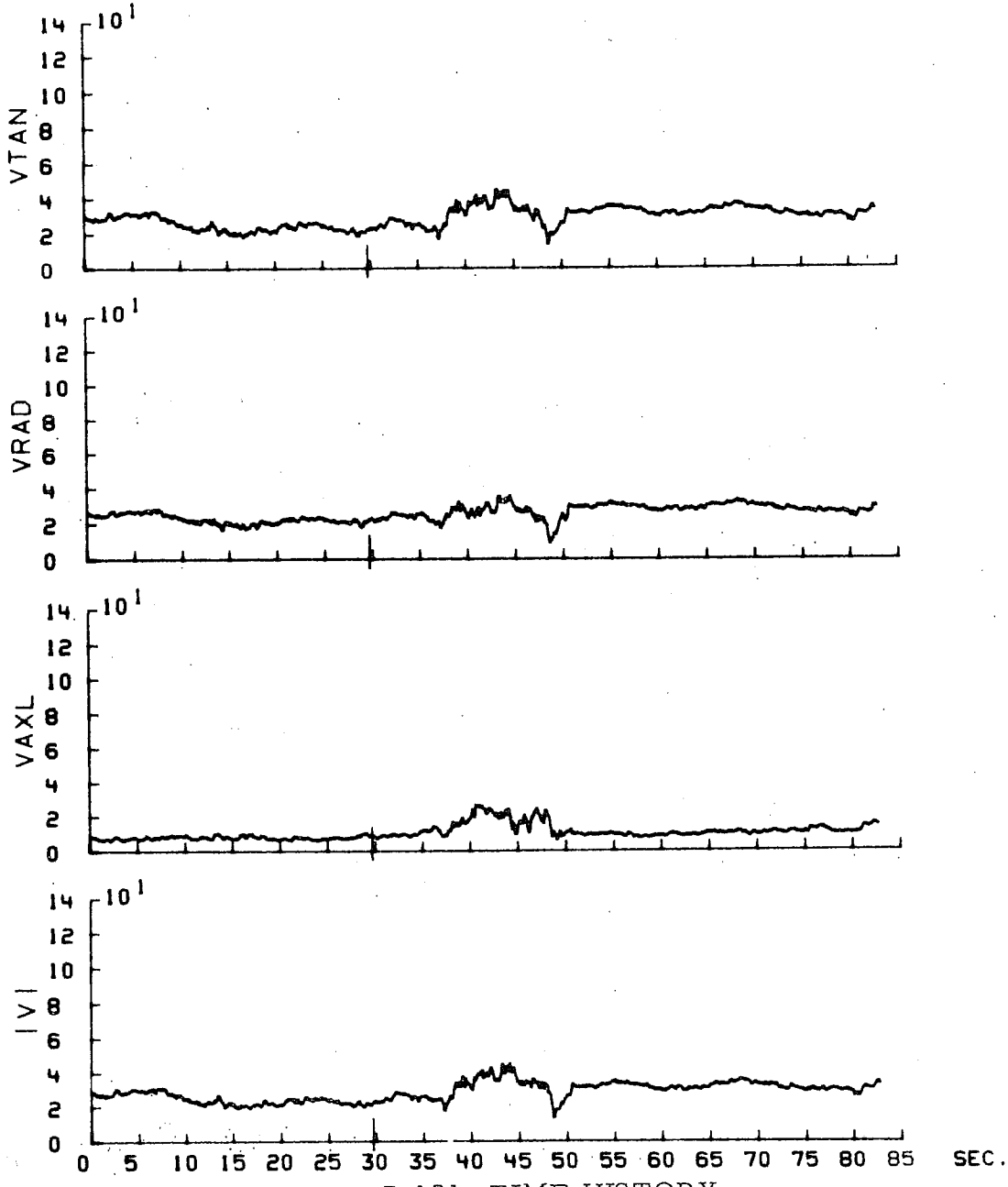


FIG. 7-121 TIME HISTORY

707 ESSA 150 FT LEVEL 2/19/70 0808:17 DATA 2

DC8 TS 175 FT LEVEL 2/20/70 0852:57 DATA 5

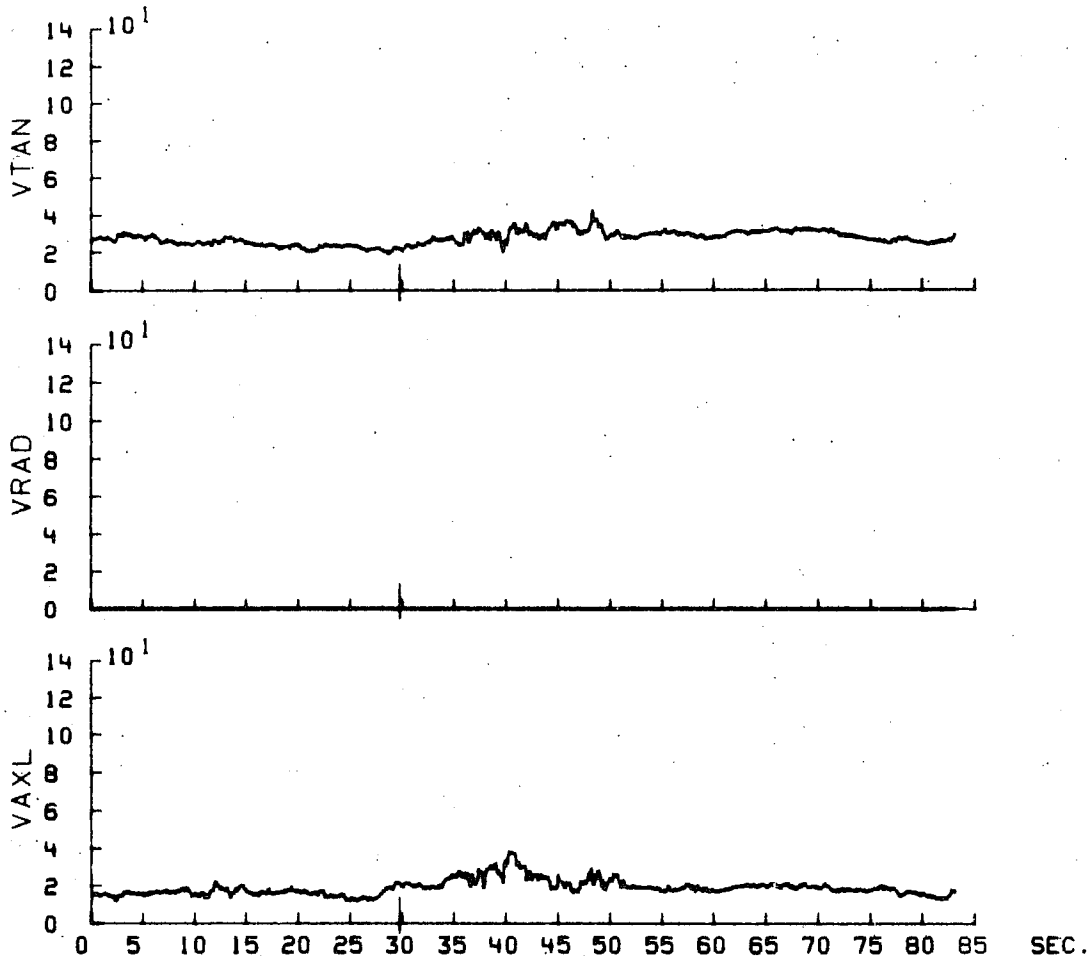


FIG. 7-122 TIME HISTORY

DC8 ESSA 200 FT LEVEL 2/20/70 0852:57 DATA 5

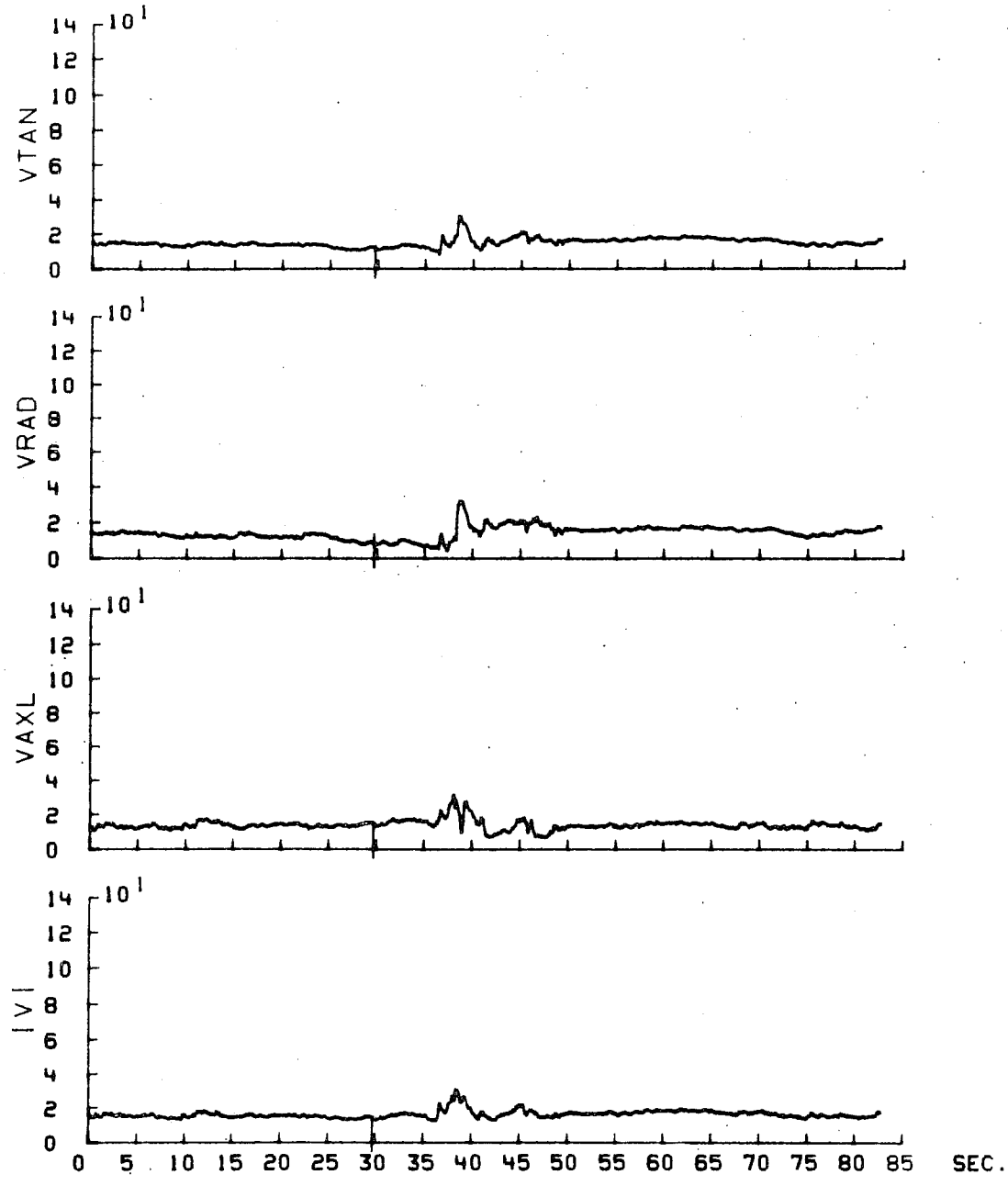


FIG. 7-123 TIME HISTORY

DC8 BGS 75 FT LEVEL 2/20/70 0901:43 DATA 6

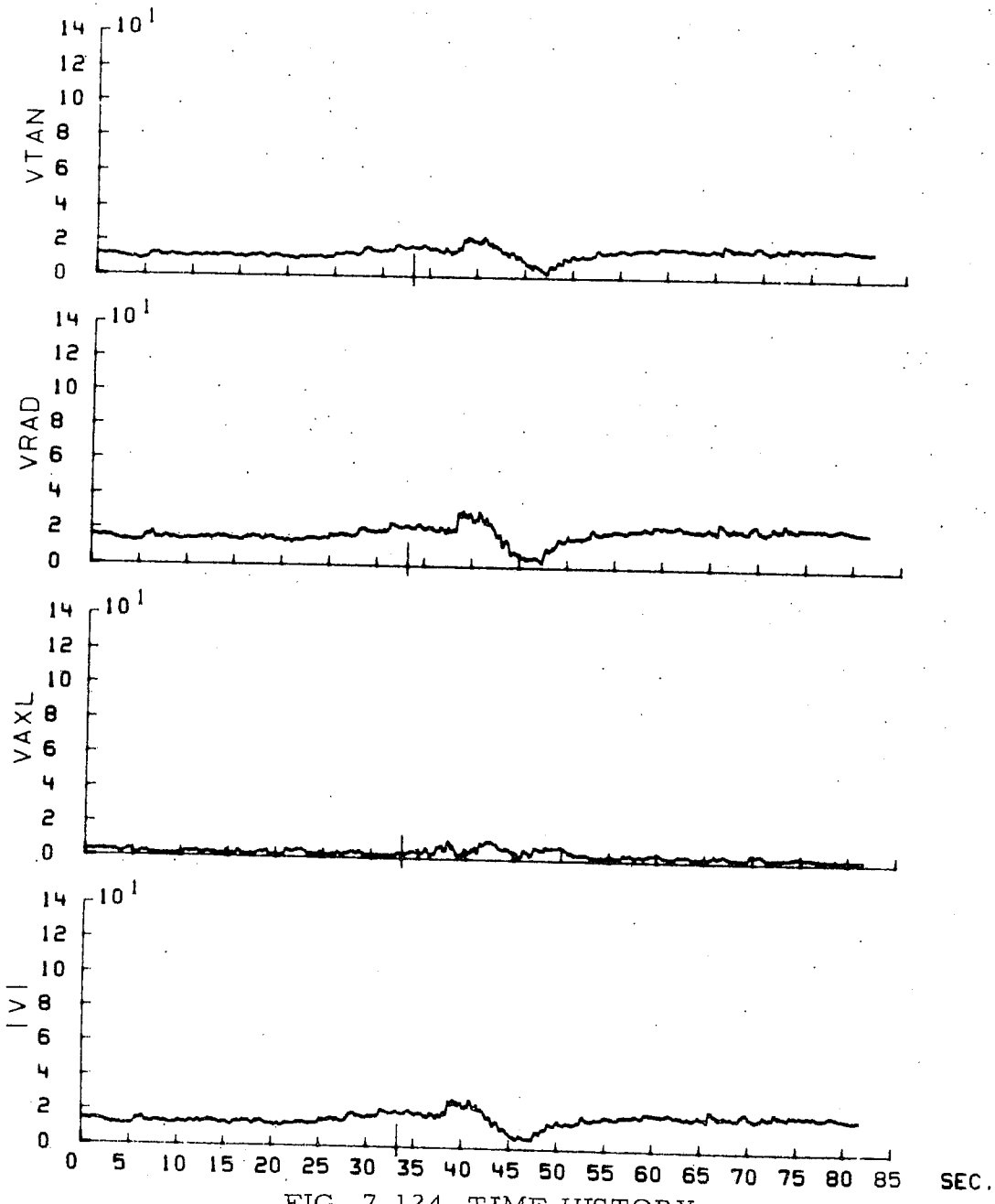


FIG. 7-124 TIME HISTORY

DC8 TS 100 FT LEVEL 2/20/70 0901:43 DATA 6

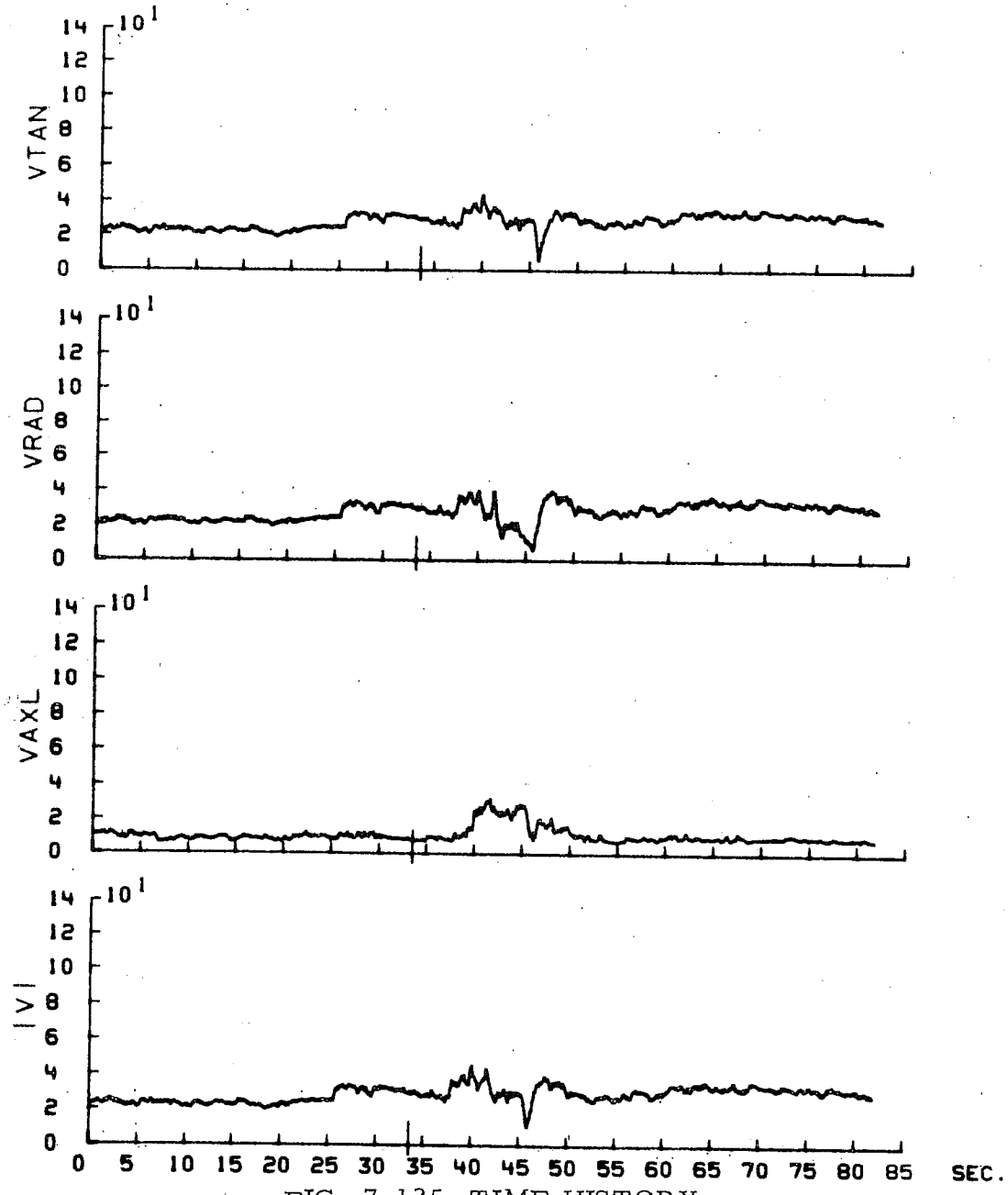


FIG. 7-125 TIME HISTORY

DC8 TS 125 FT LEVEL 2/20/70 0901:43 DATA 6

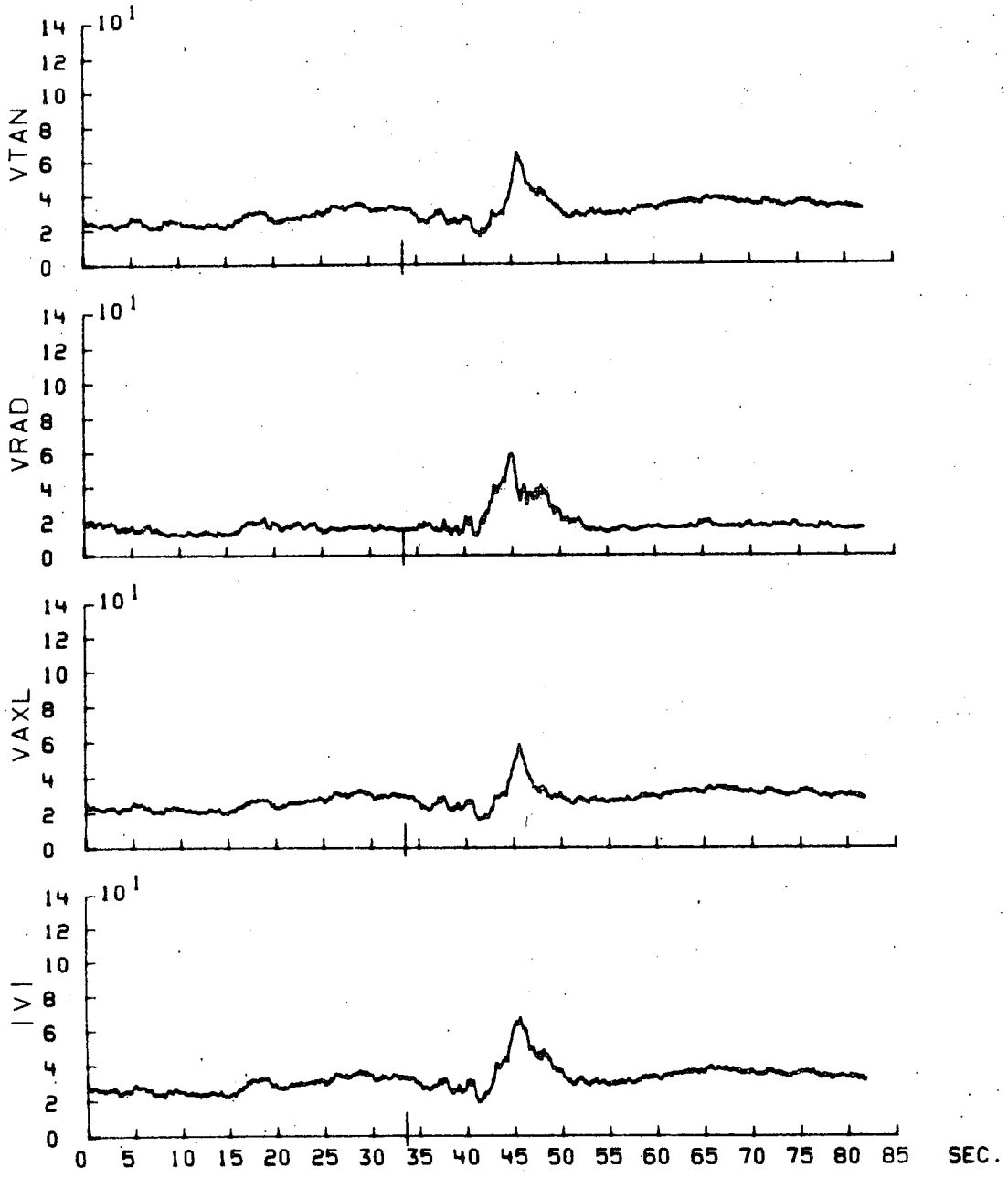


FIG. 7-126 TIME HISTORY

DC8 ESSA 150 FT LEVEL 2/20/70 0901:43 DATA 6

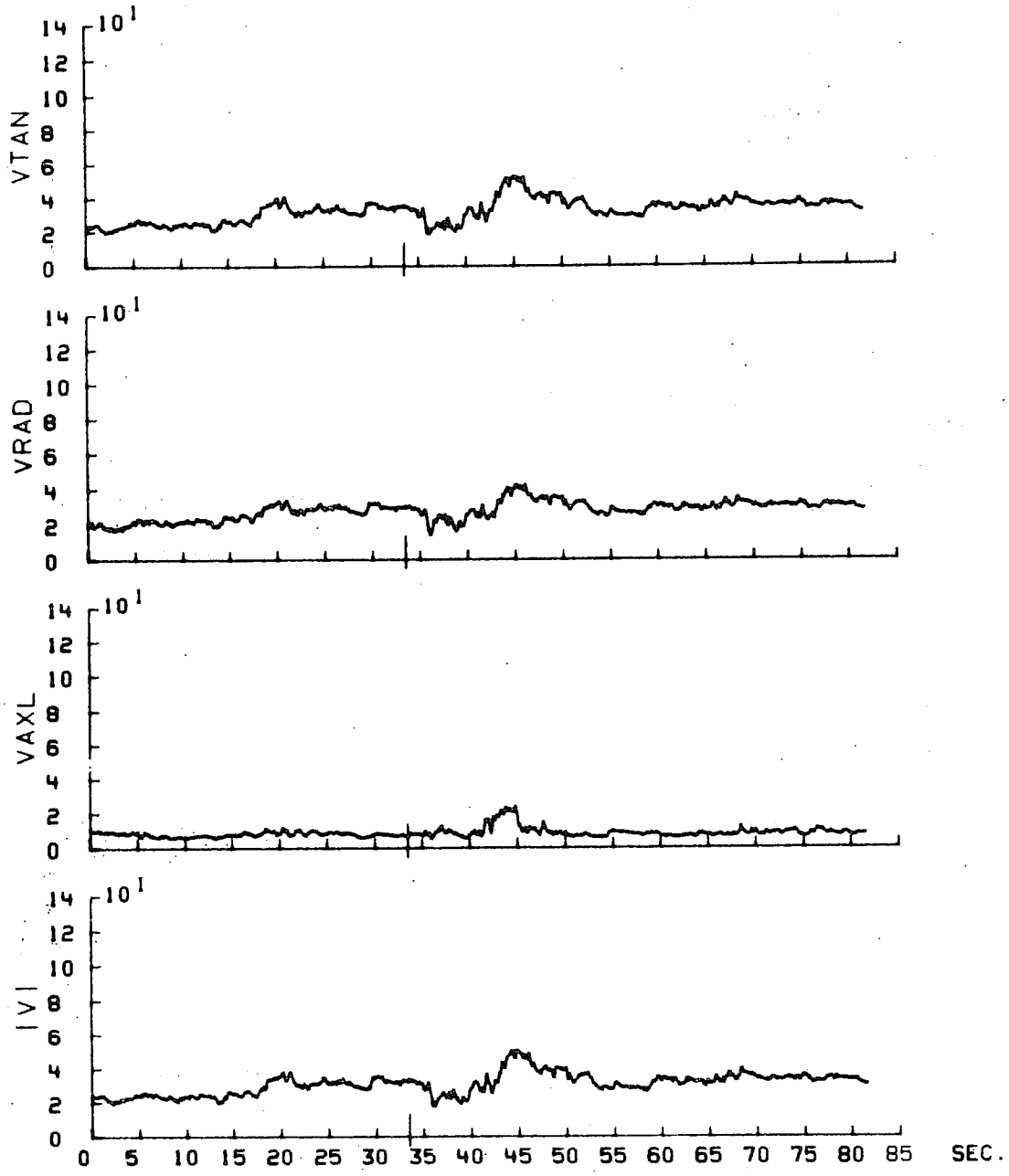


FIG. 7-127 TIME HISTORY

DC8 TS 100 FT LEVEL 2/20/70 0910:58 DATA 7

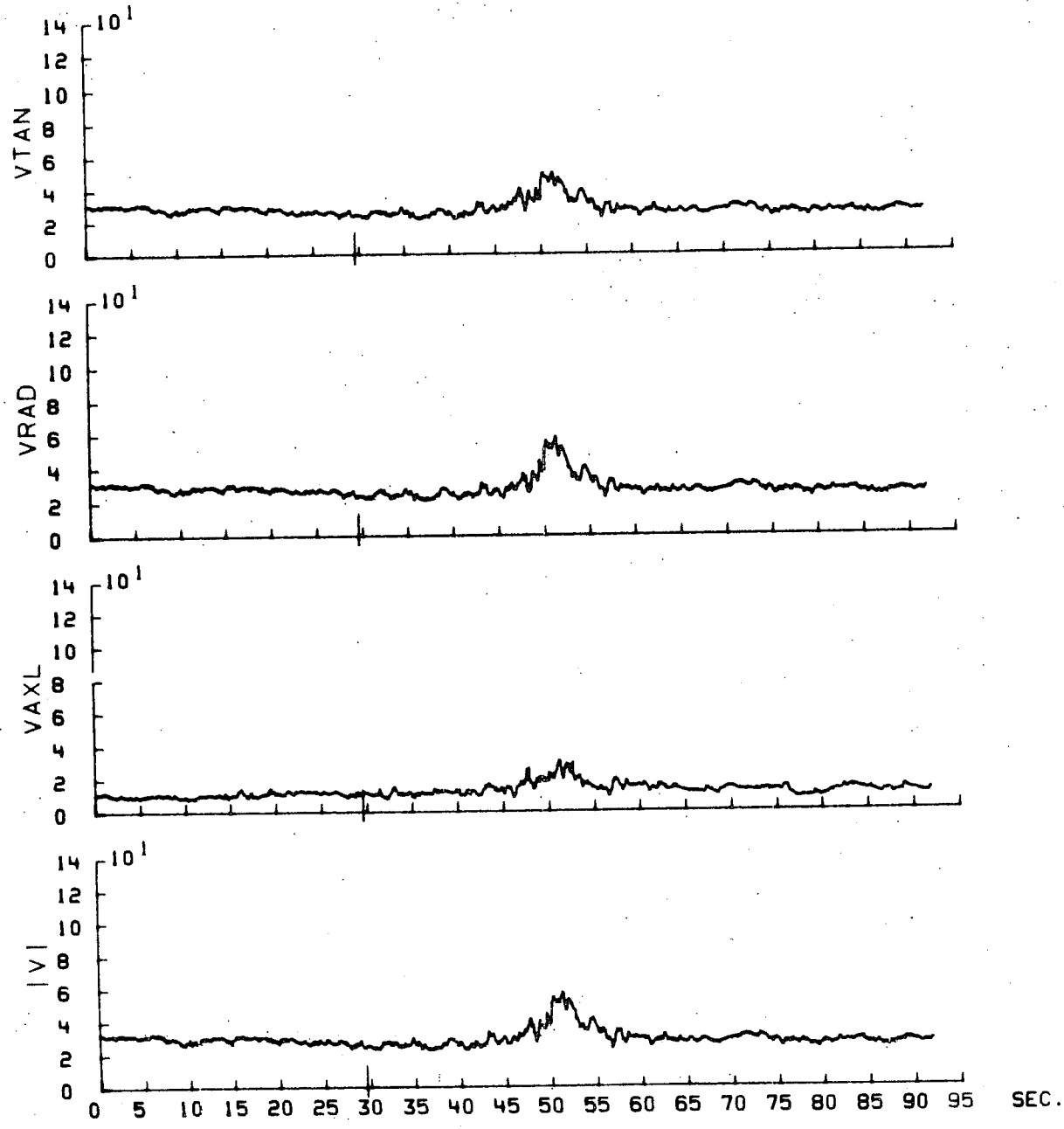


FIG. 7-128 TIME HISTORY

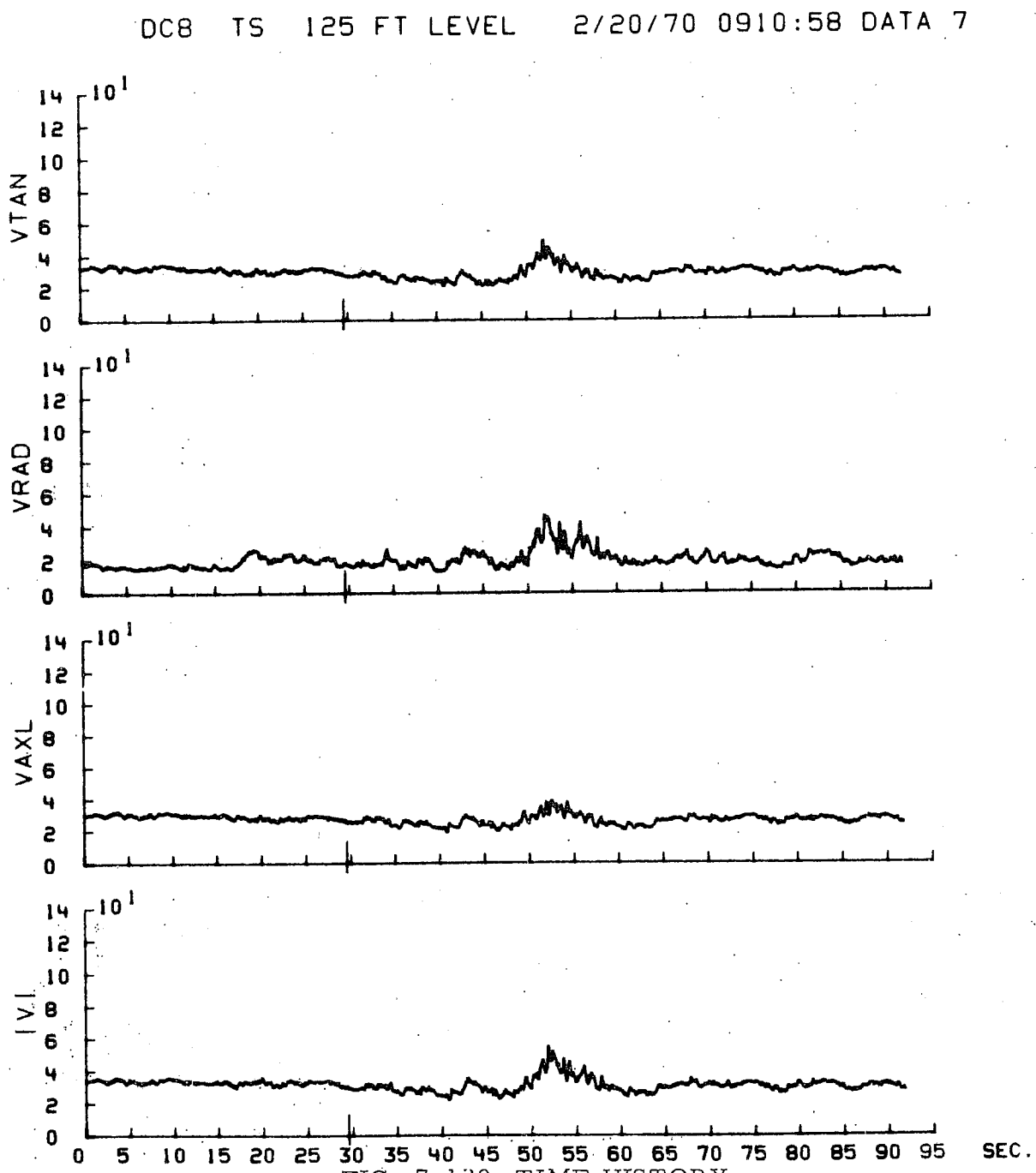


FIG. 7-129 TIME HISTORY

DC8 TS 100 FT LEVEL 2/20/70 0919:55 DATA 8

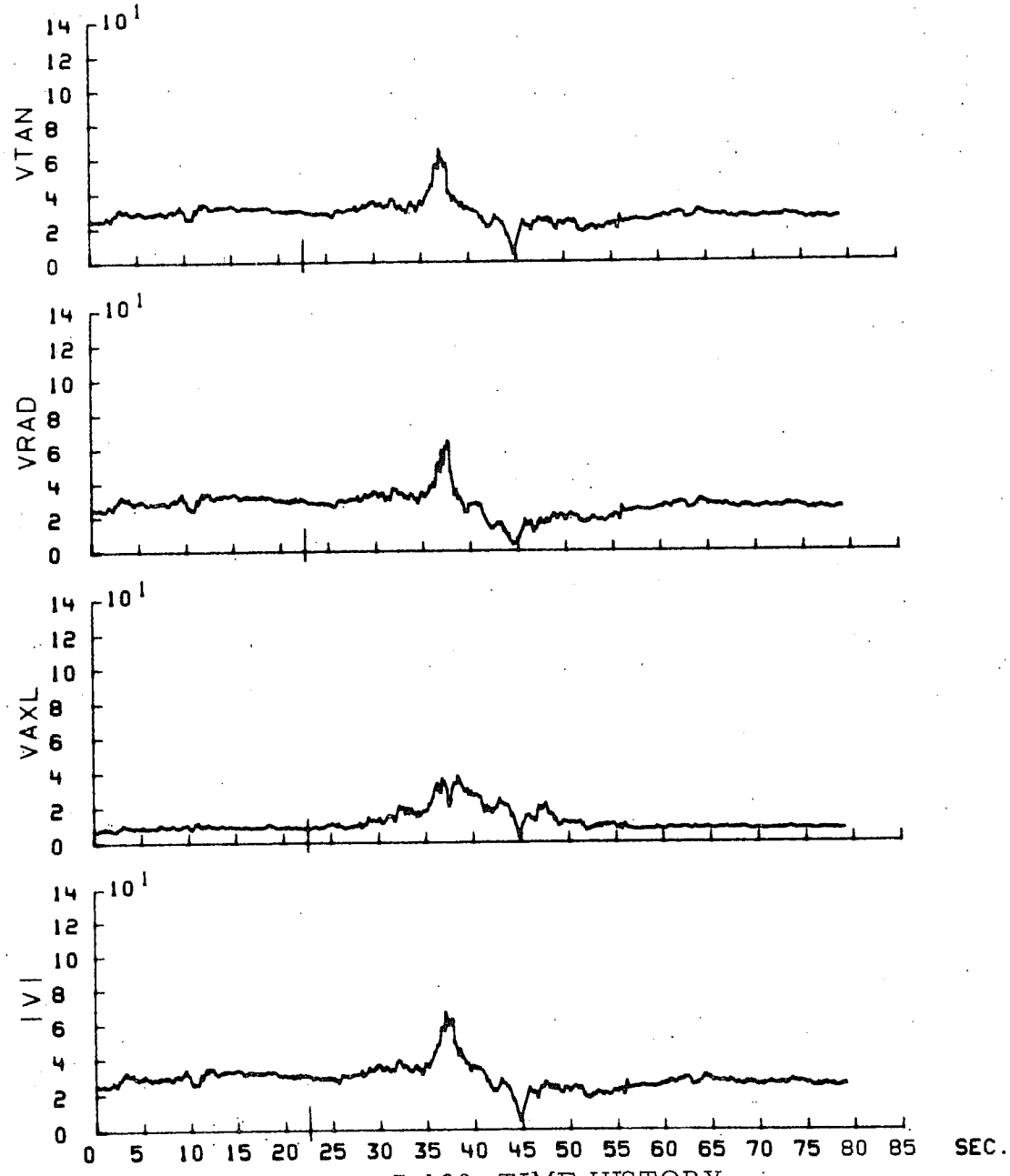


FIG. 7-130 TIME HISTORY

DC8 TS 125 FT LEVEL 2/20/70 0919:55 DATA 8

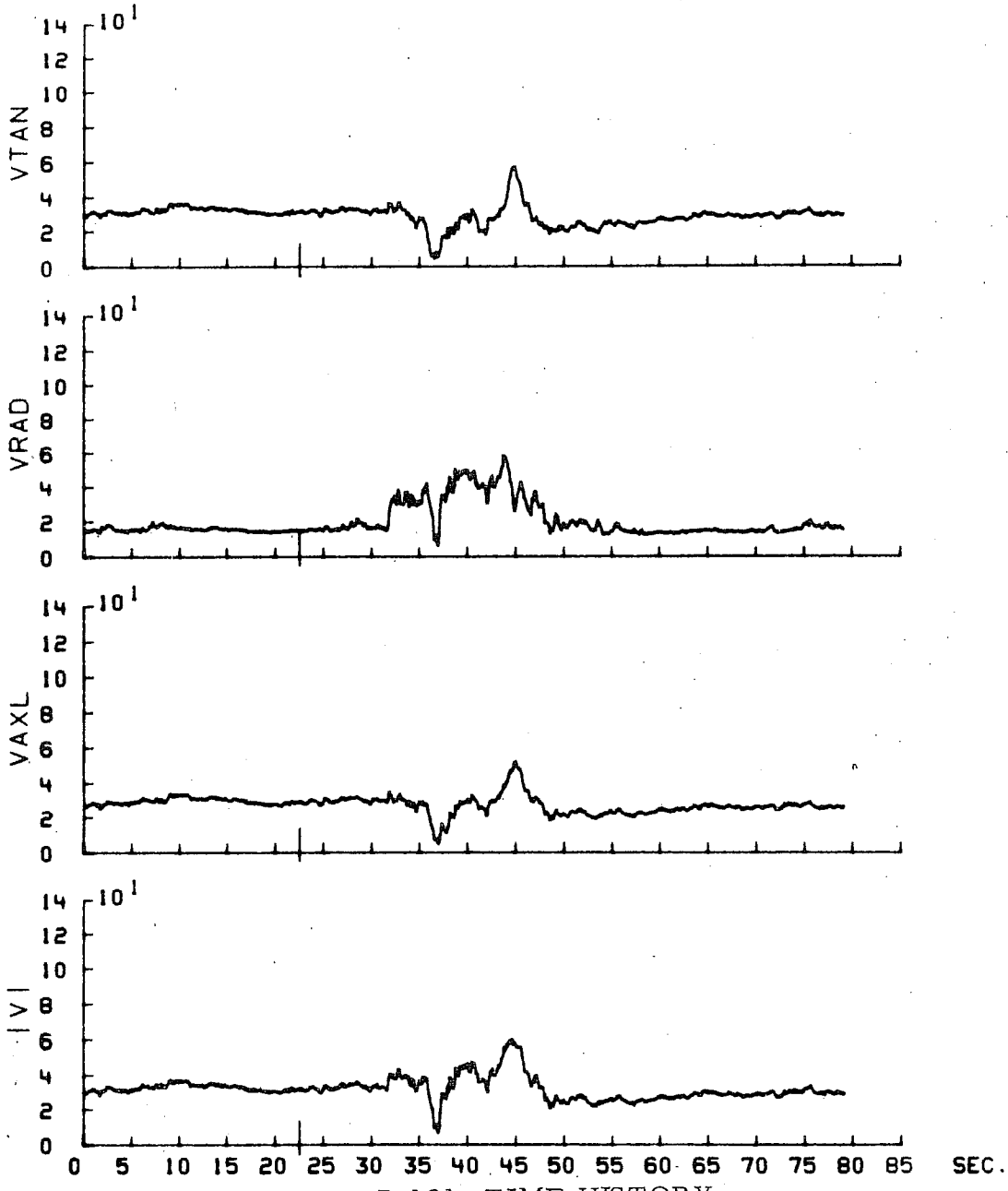


FIG. 7-131 TIME HISTORY

DC8 ESSA 150 FT LEVEL 2/20/70 0919:55 DATA 8

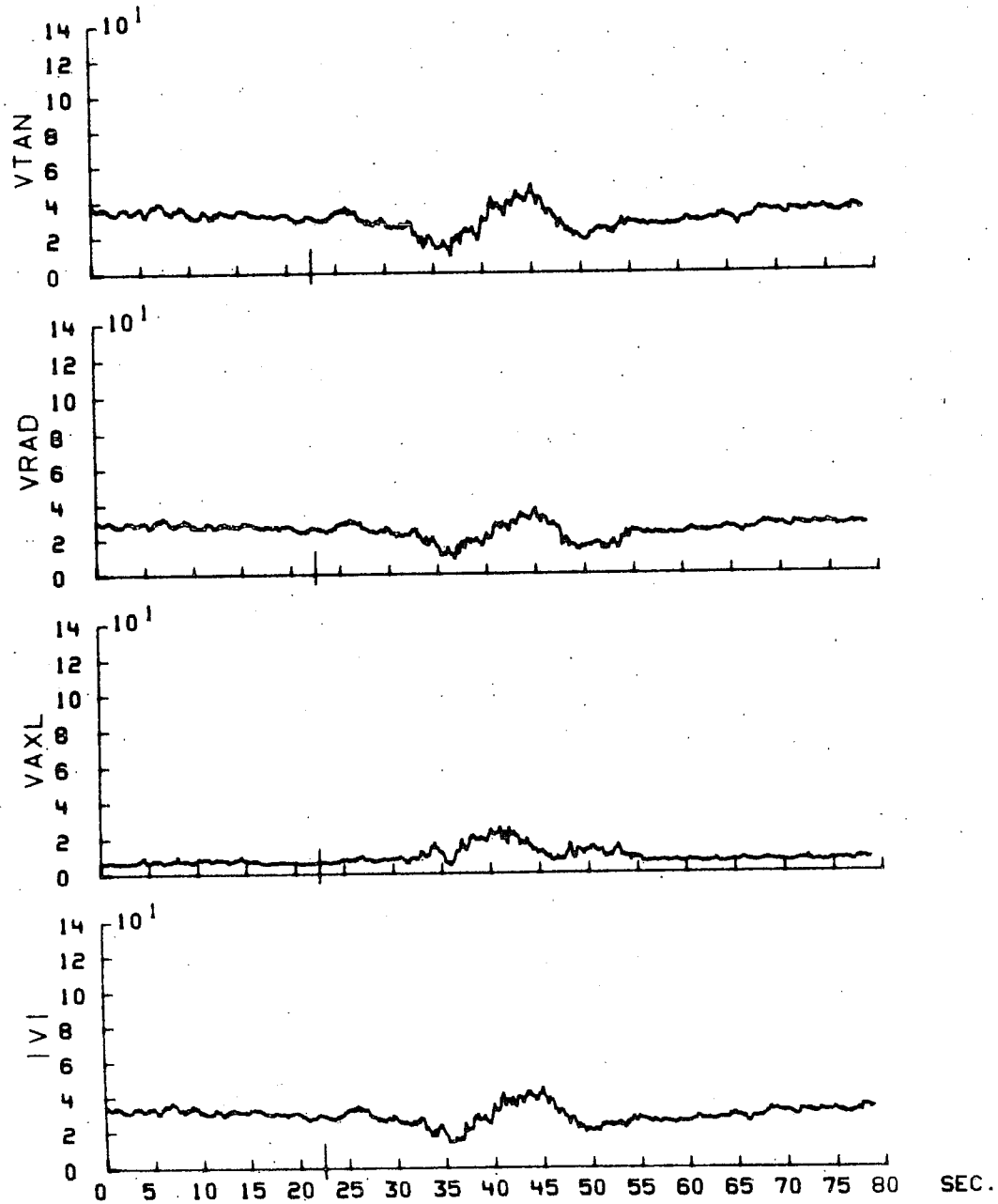


FIG. 7-132 TIME HISTORY

DC8 TS 100 FT LEVEL 2/20/70 0936:28 DATA 10

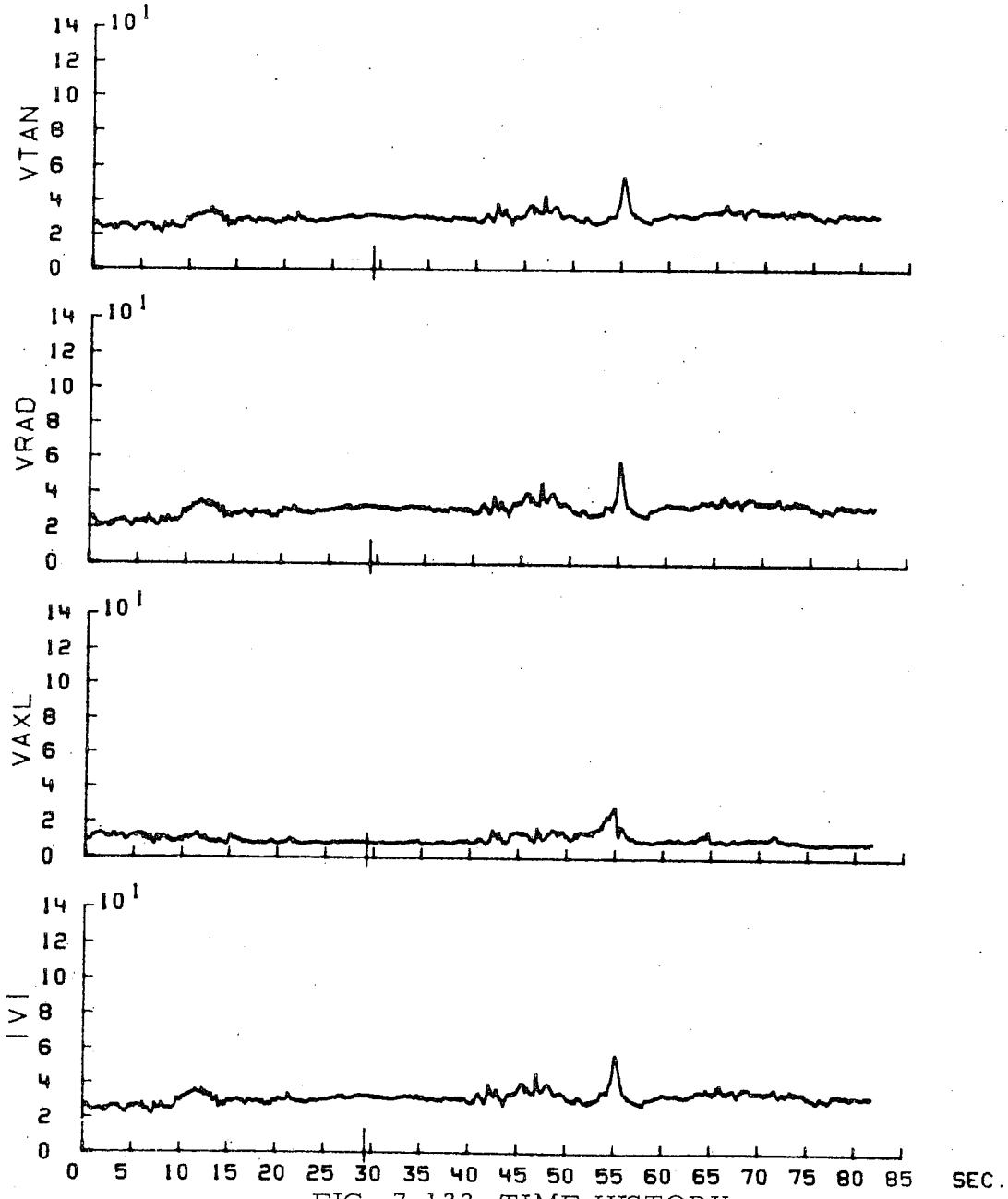


FIG. 7-133 TIME HISTORY

DC8 TS 125 FT LEVEL 2/20/70 0936:28 DATA 10

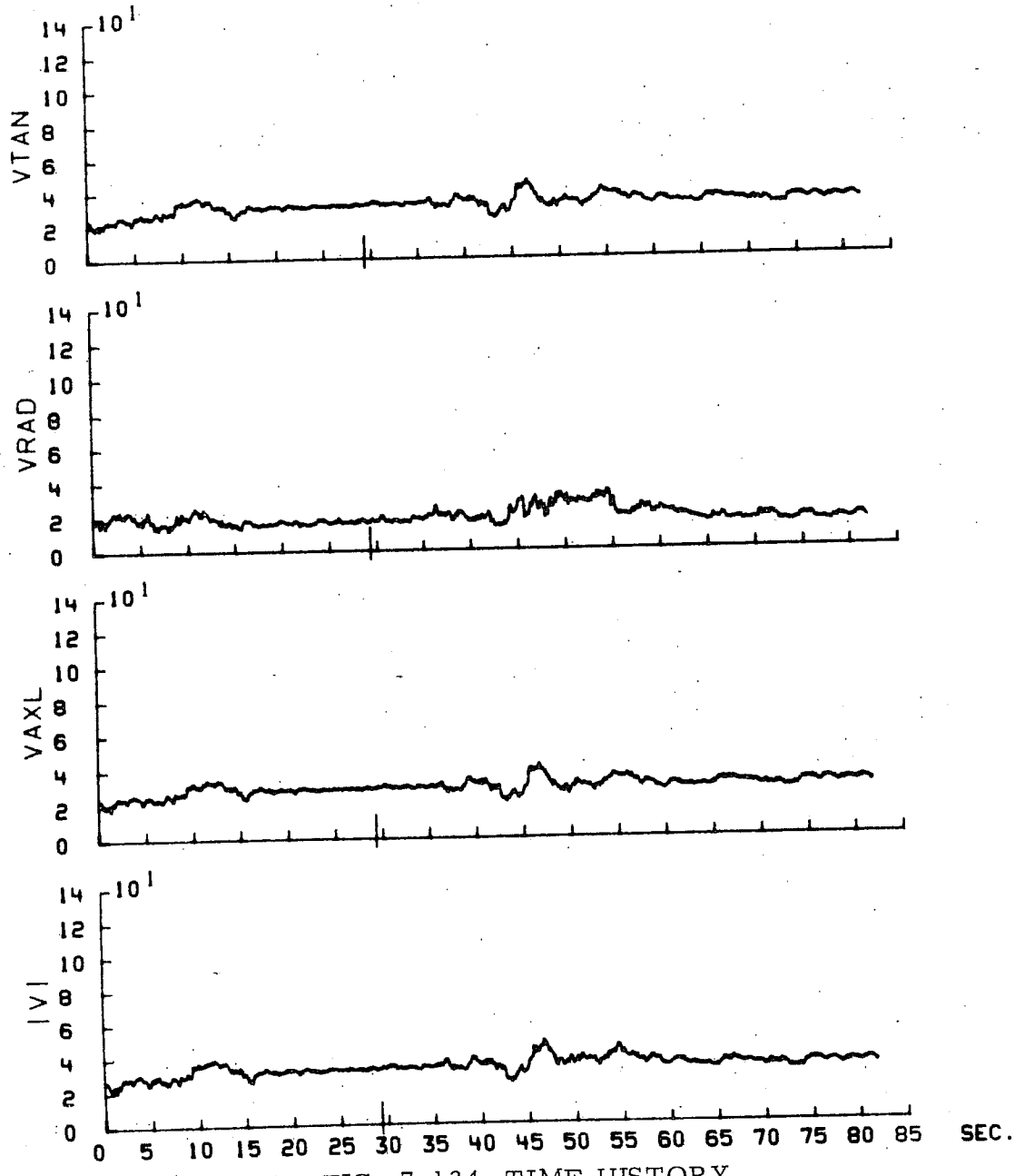


FIG. 7-134 TIME HISTORY

DC8 ESSA 150 FT LEVEL 2/20/70 0936:28 DATA 10

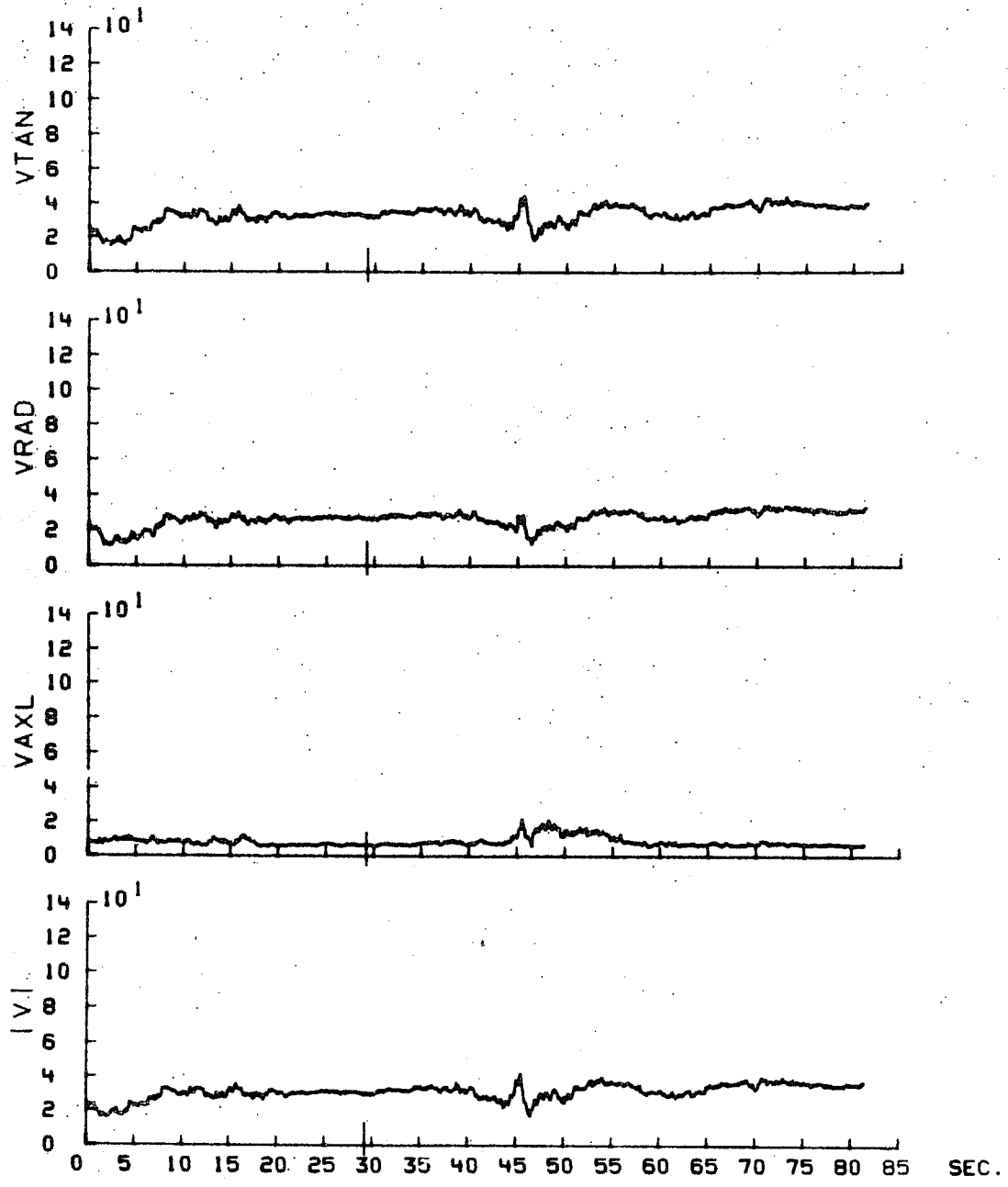


FIG. 7-135 TIME HISTORY

DC8 TS 100 FT LEVEL 2/20/70 0943:17 DATA 11

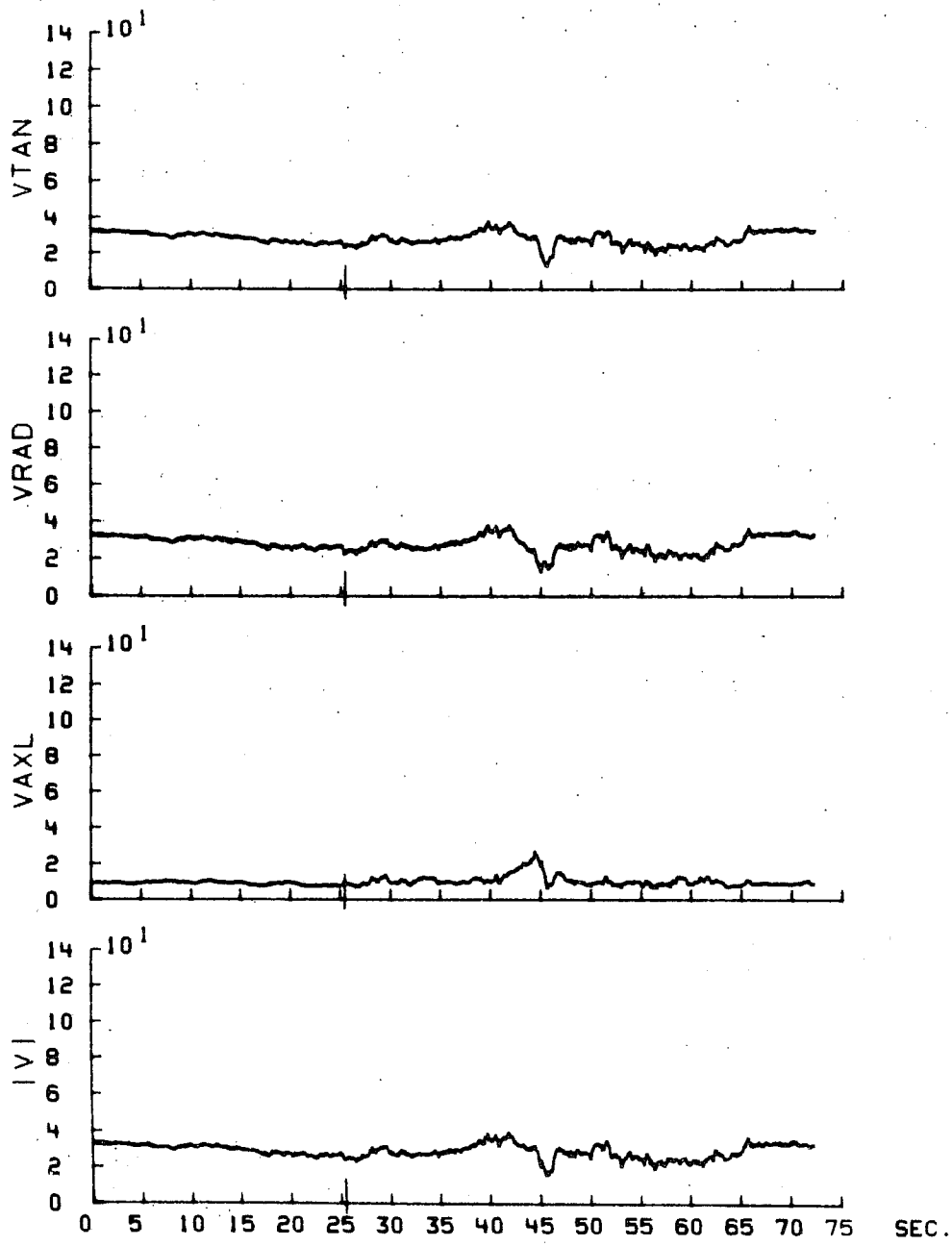


FIG. 7-136 TIME HISTORY

DC8 TS 125 FT LEVEL 2/20/70 0943:17 DATA 11

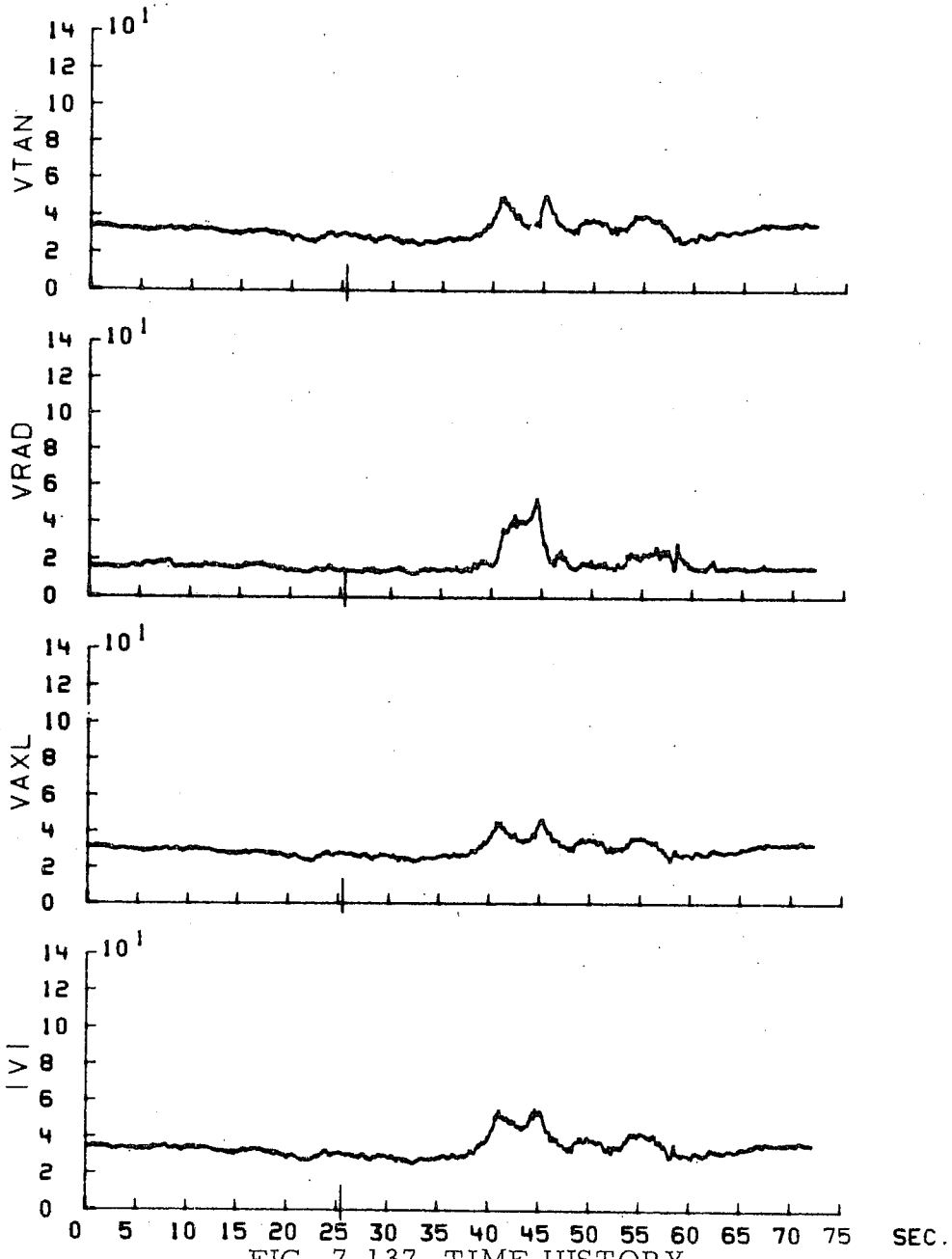


FIG. 7-137 TIME HISTORY

DC8 TS 100 FT LEVEL 2/20/70 0950:17 DATA 12

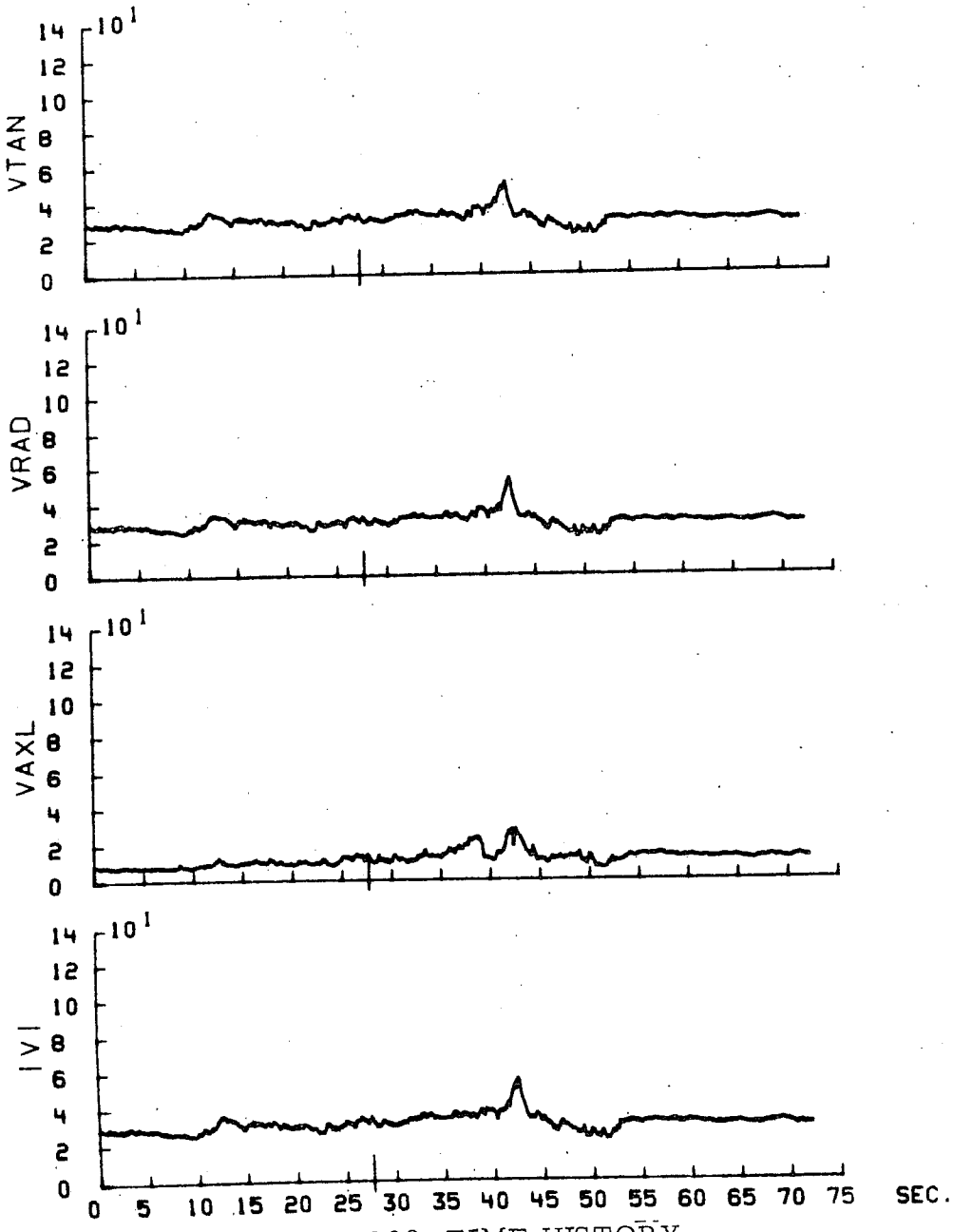


FIG. 7-138 TIME HISTORY

DC8 TS 125 FT LEVEL 2/20/70 0950:17 DATA 12

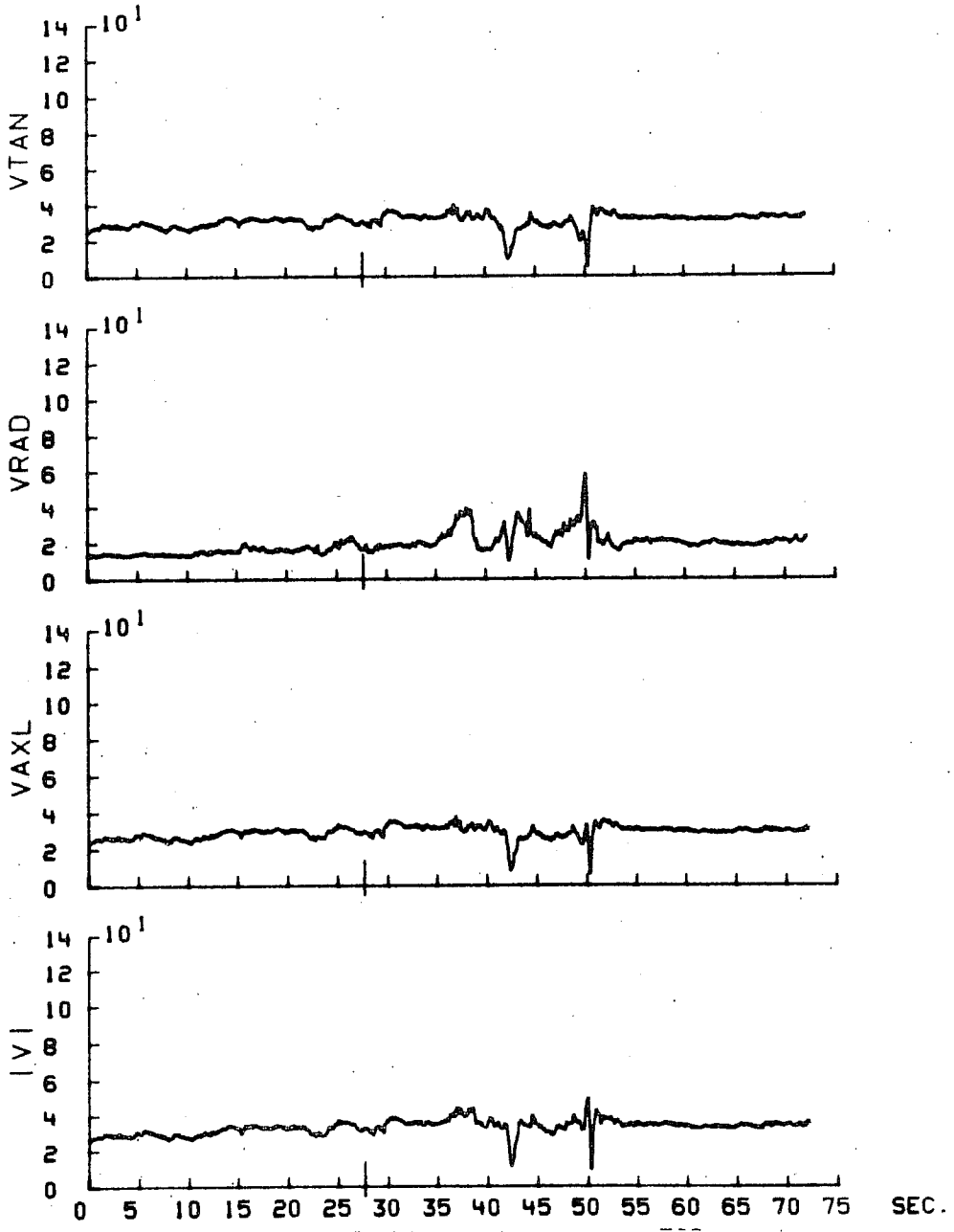


FIG. 7-139 TIME HISTORY

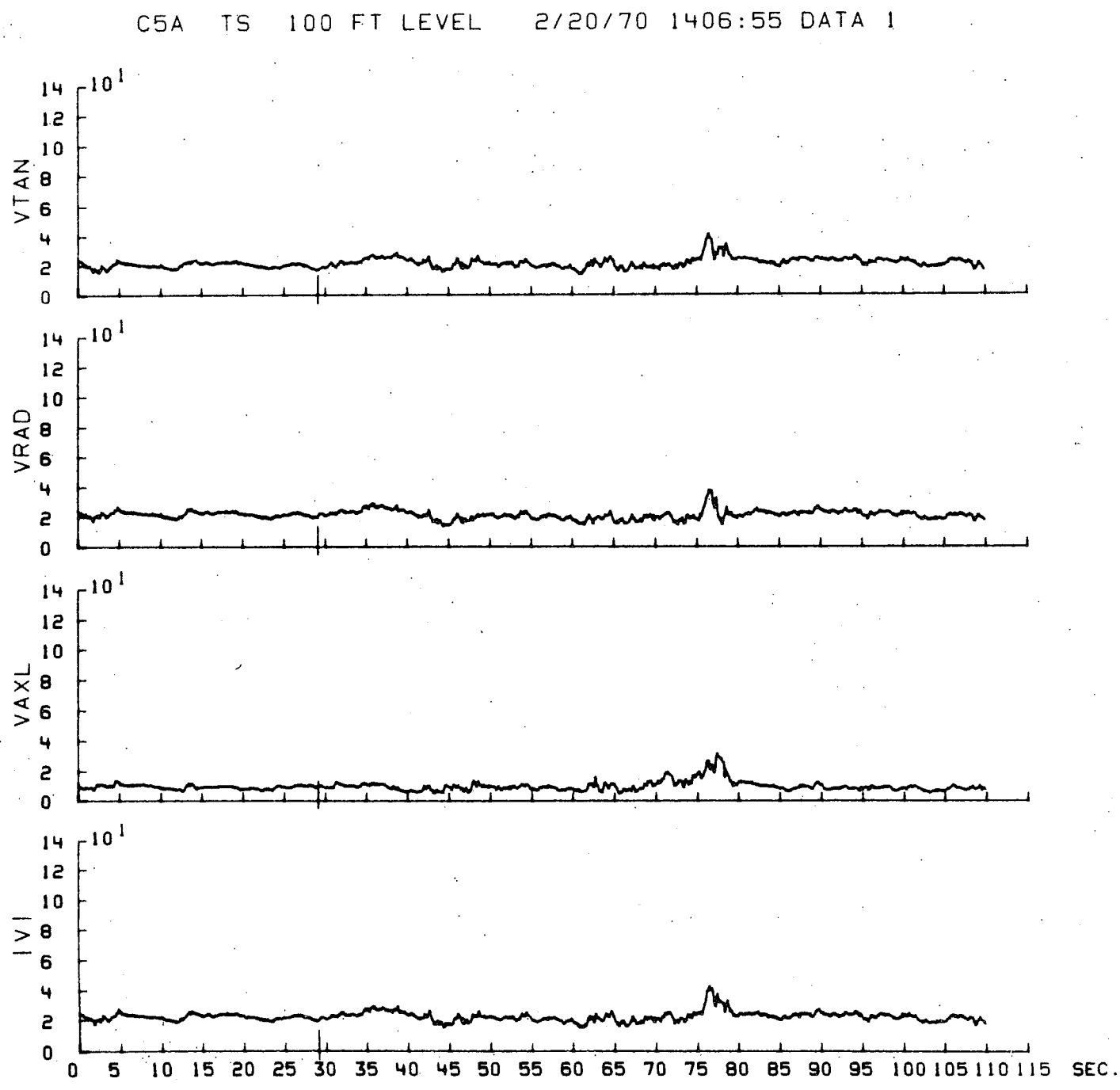


FIG. 7-140 TIME HISTORY

C5A TS 125 FT LEVEL 2/20/70 1406:55 DATA 1

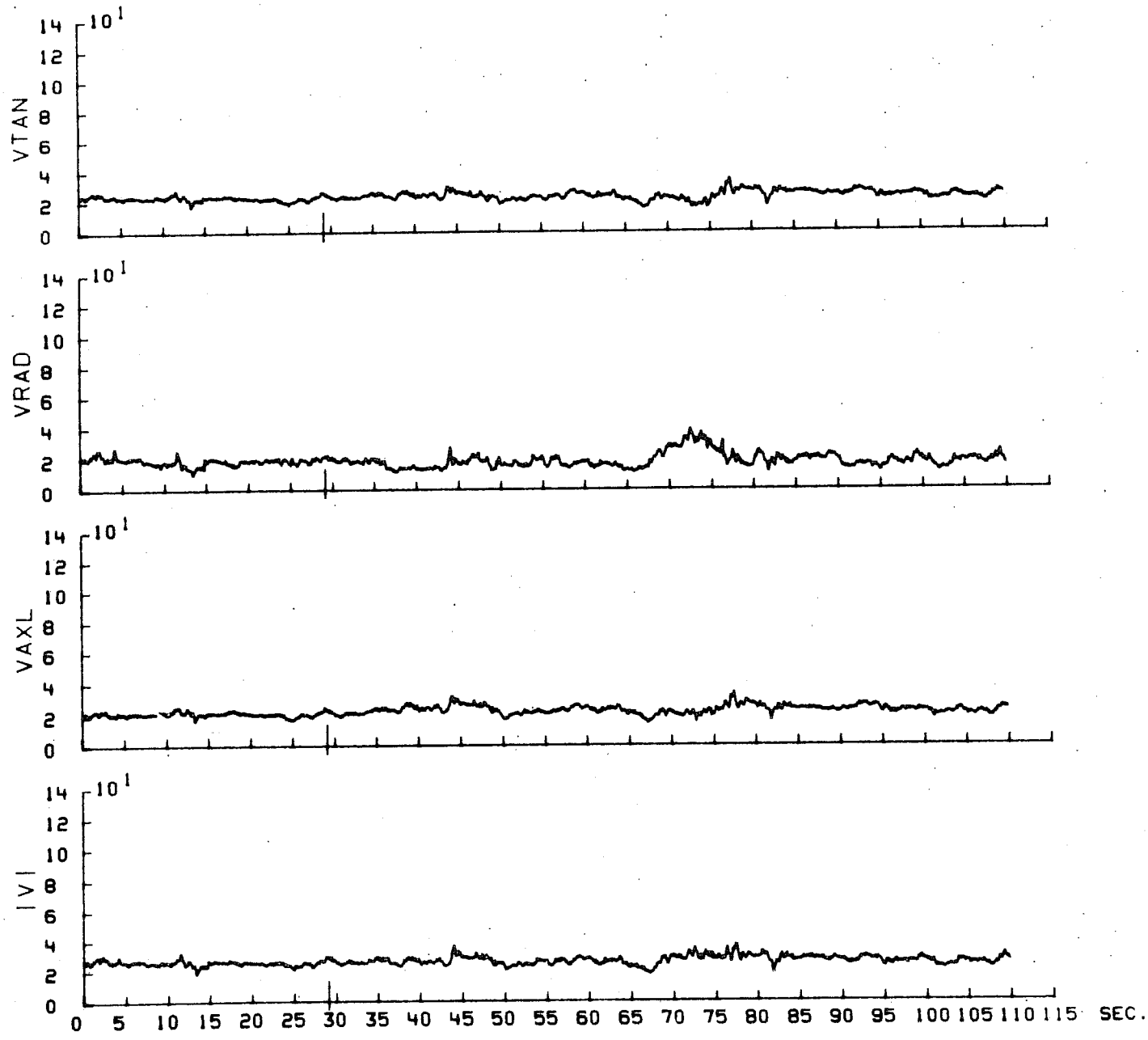


FIG. 7-141 TIME HISTORY

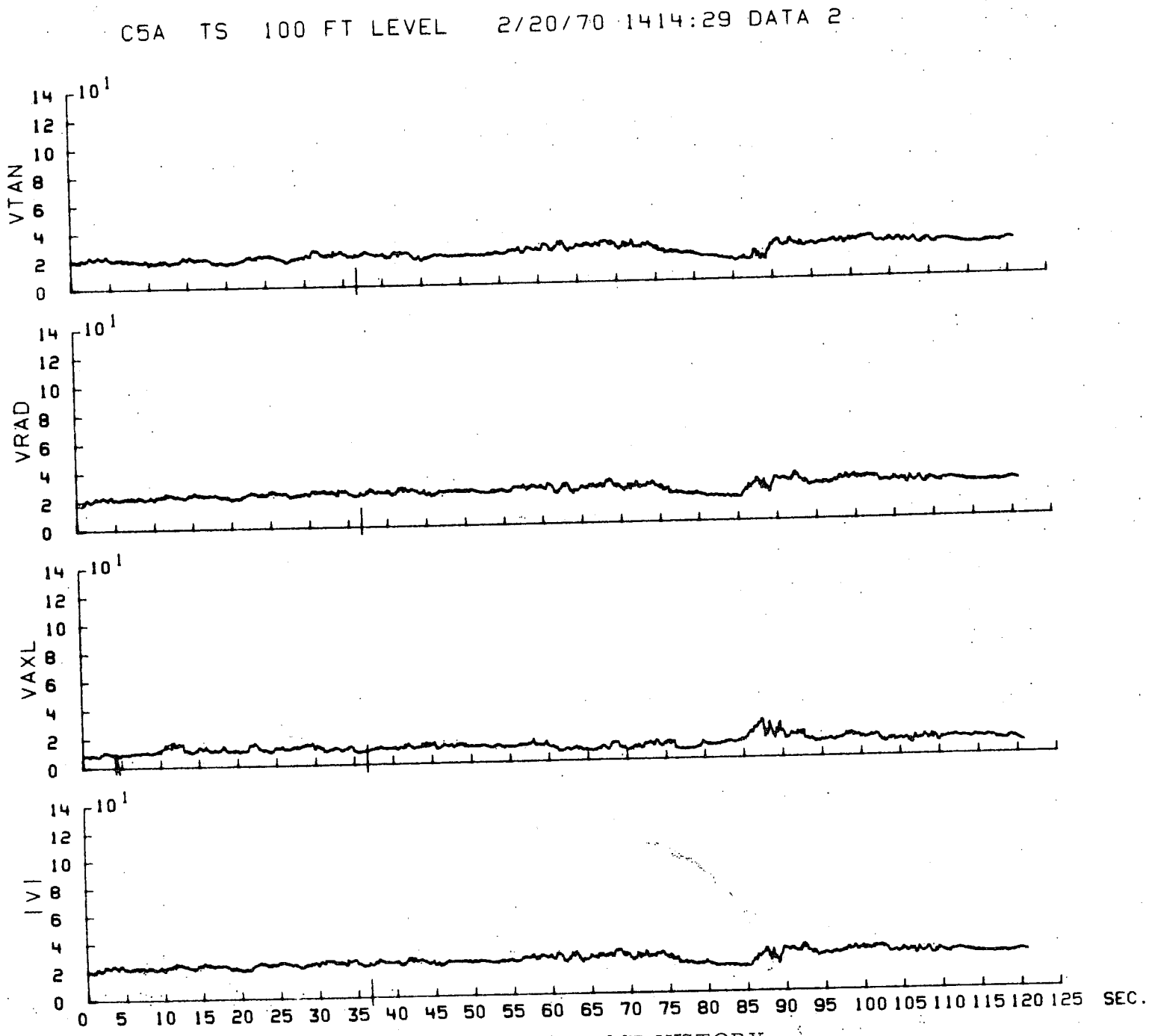


FIG. 7-142 TIME HISTORY

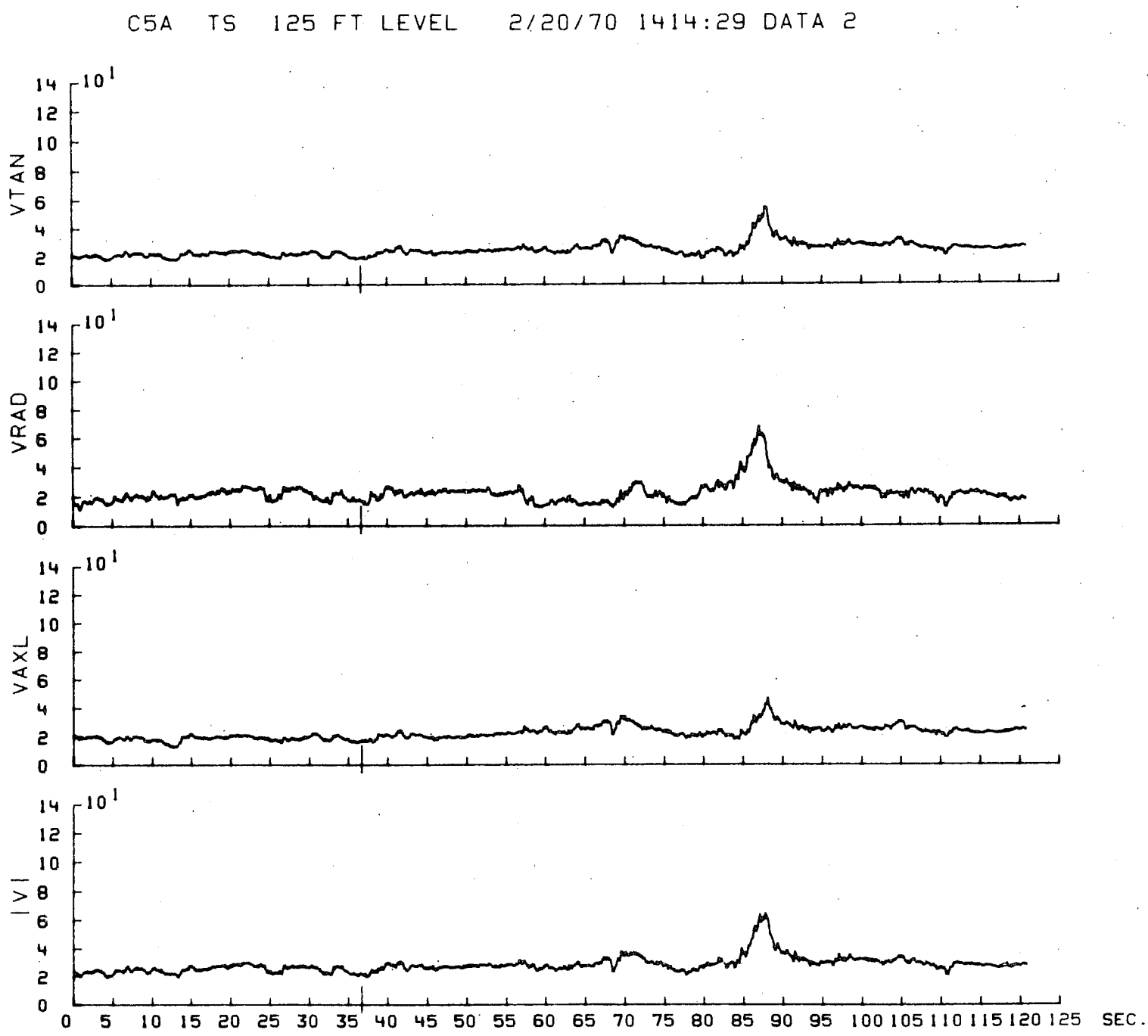


FIG. 7-143 TIME HISTORY

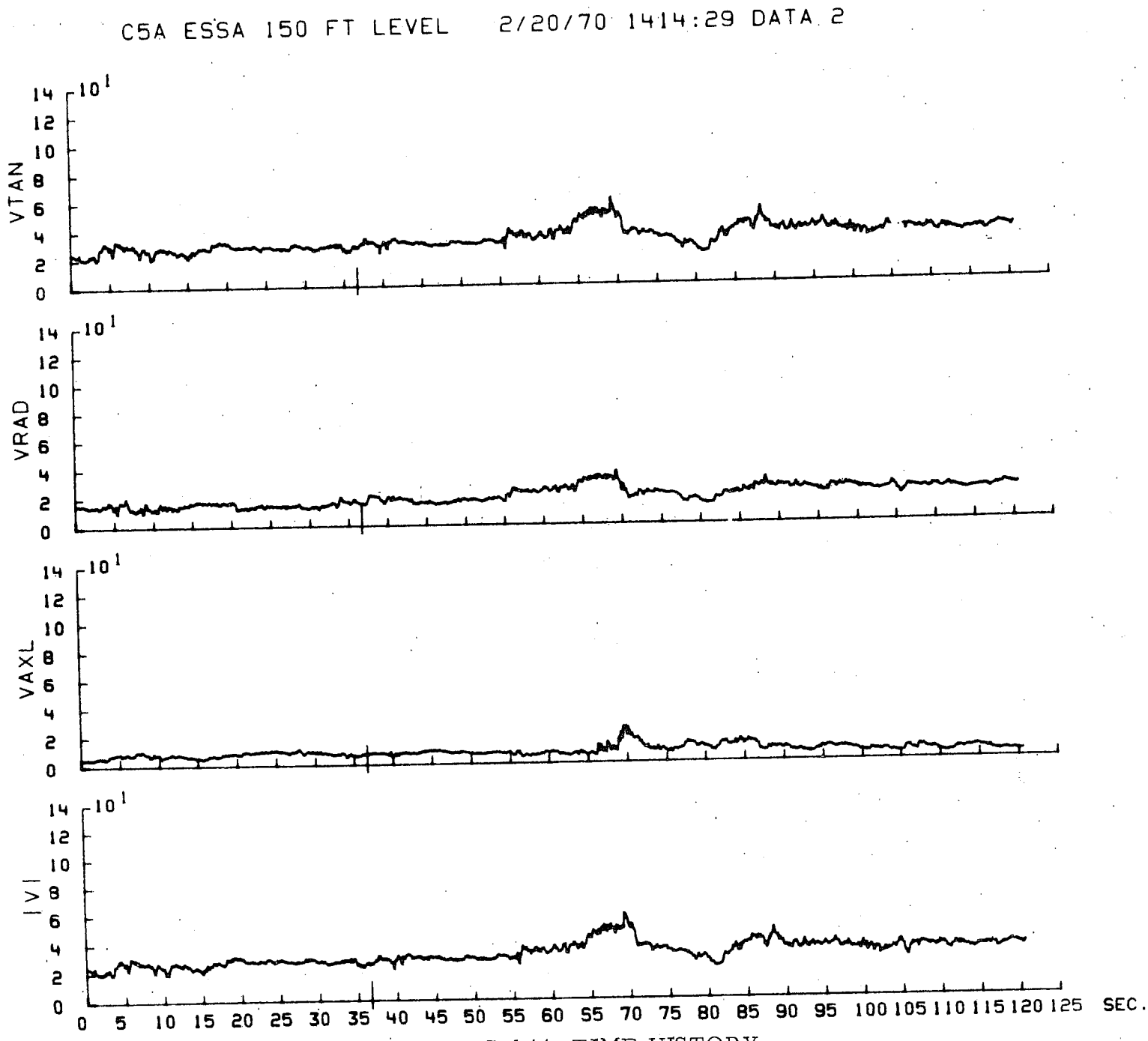


FIG. 7-144 TIME HISTORY

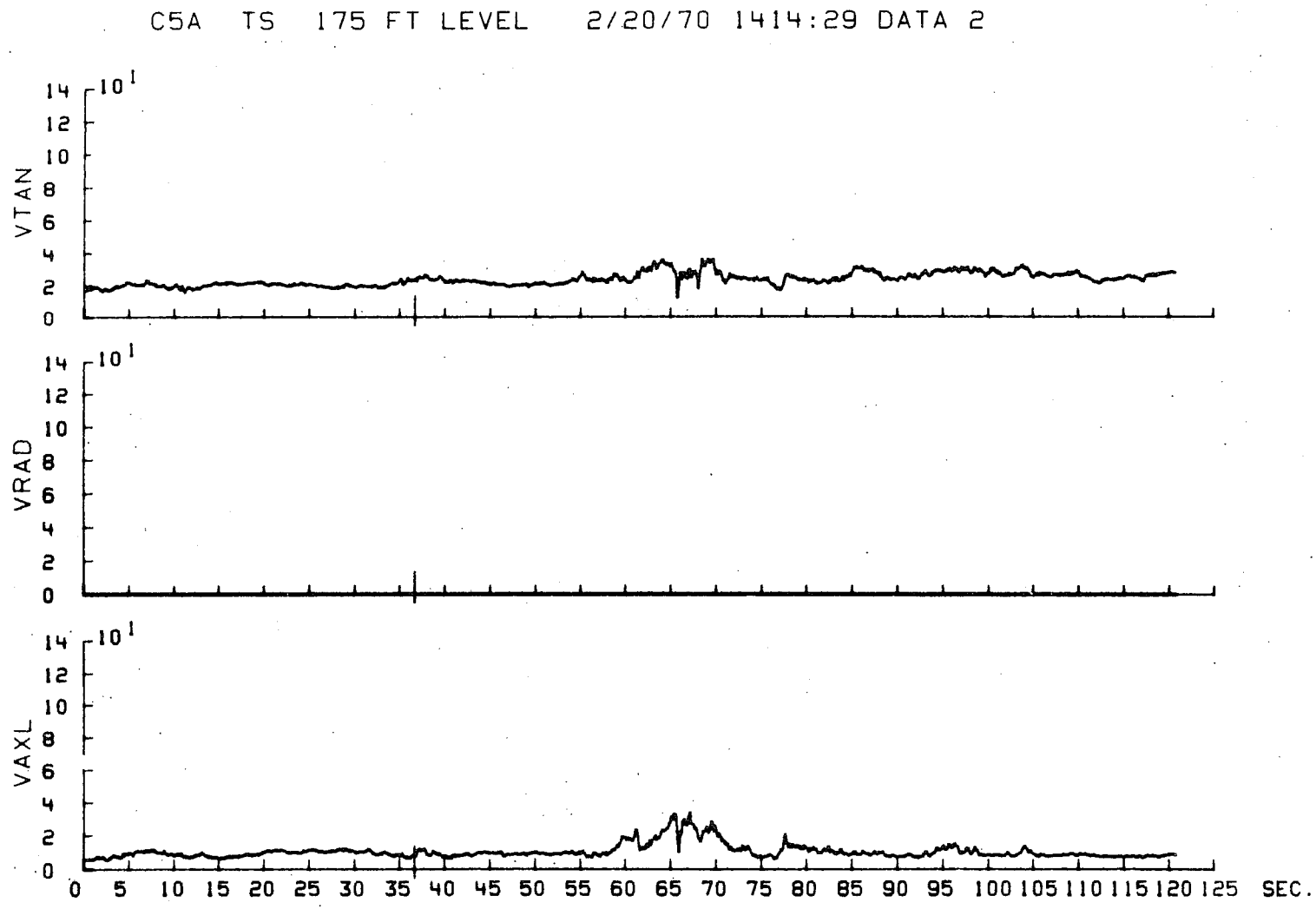


FIG. 7-145 TIME HISTORY

C5A TS 125 FT LEVEL 2/20/70 1421:52 DATA 3

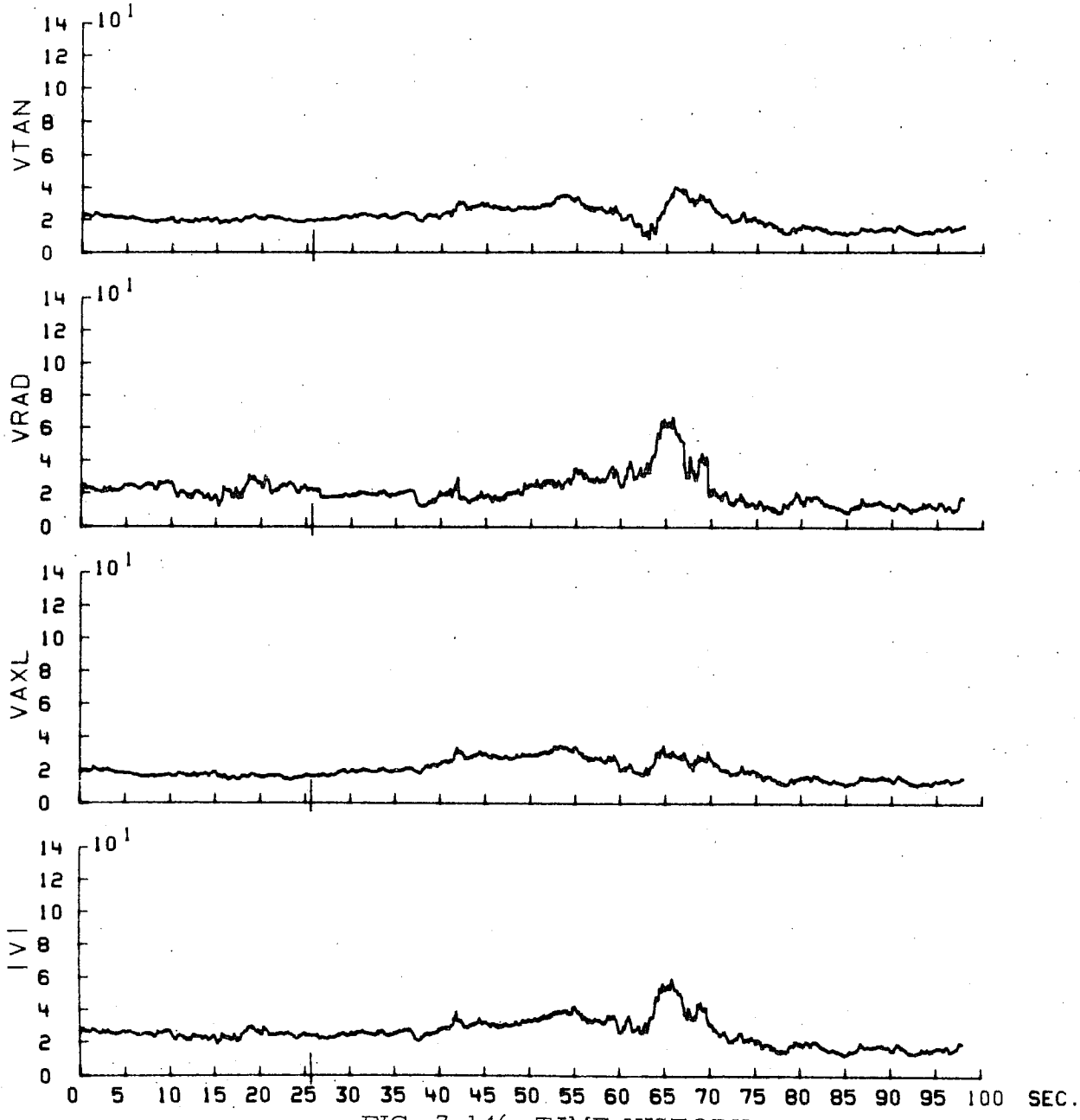


FIG. 7-146 TIME HISTORY

C5A ESSA 150 FT LEVEL 2/20/70 1421:52 DATA 3

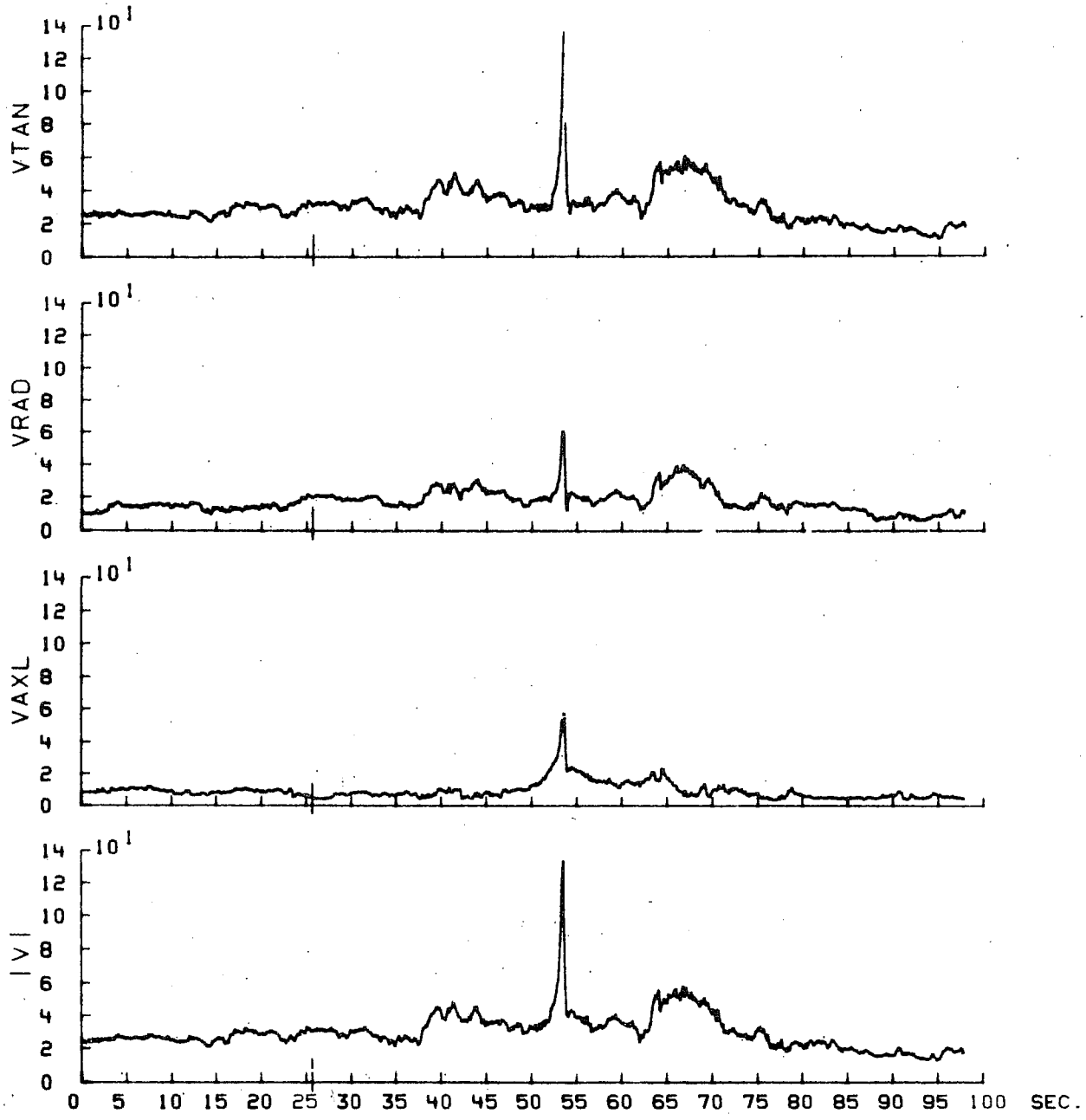


FIG. 7-147 TIME HISTORY

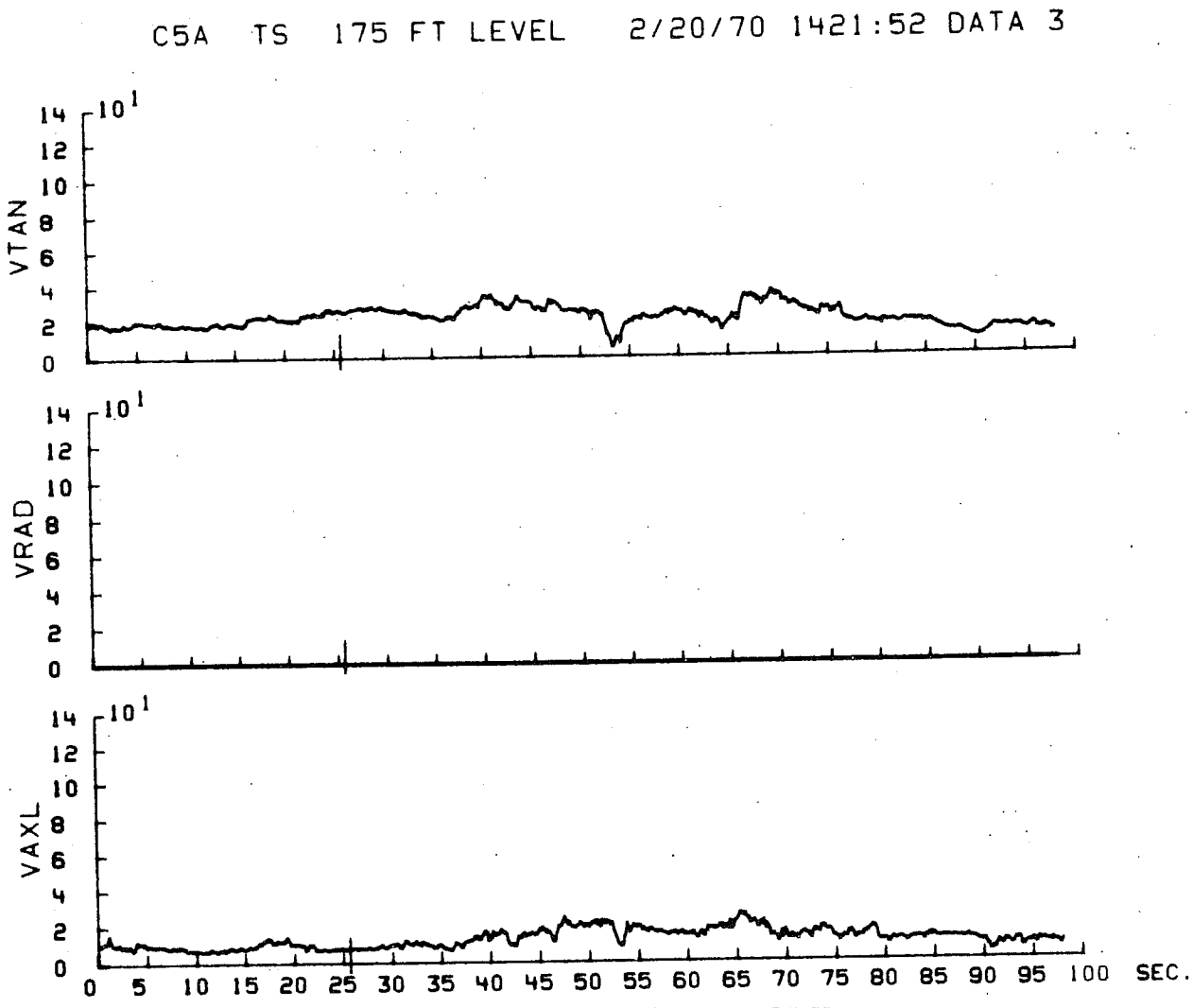


FIG. 7-148 TIME HISTORY

C5A TS 100 FT LEVEL 2/20/70 1432:59 DATA 4

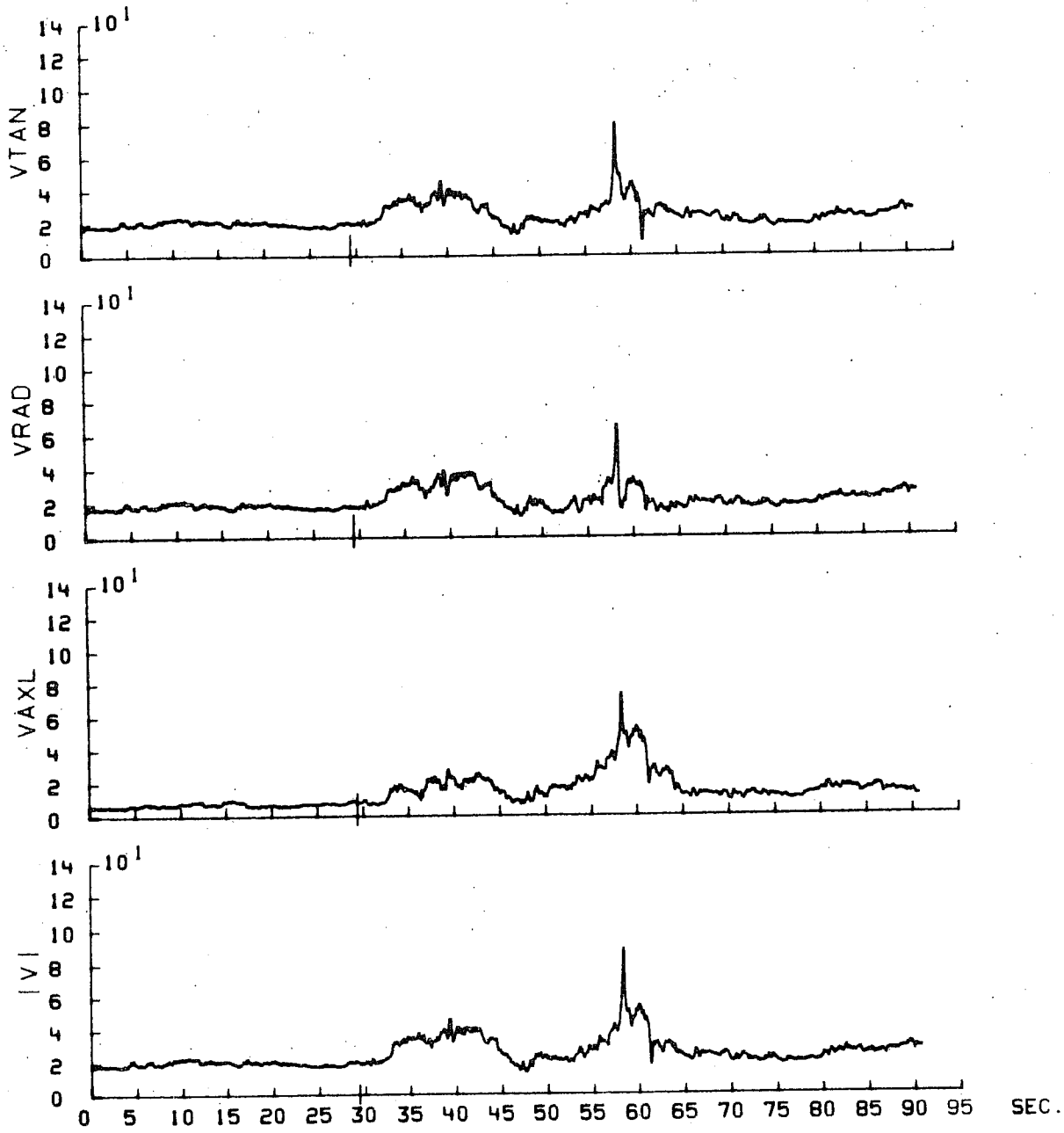


FIG. 7-149 TIME HISTORY

C5A TS 125 FT LEVEL 2/20/70 1432:59 DATA 4

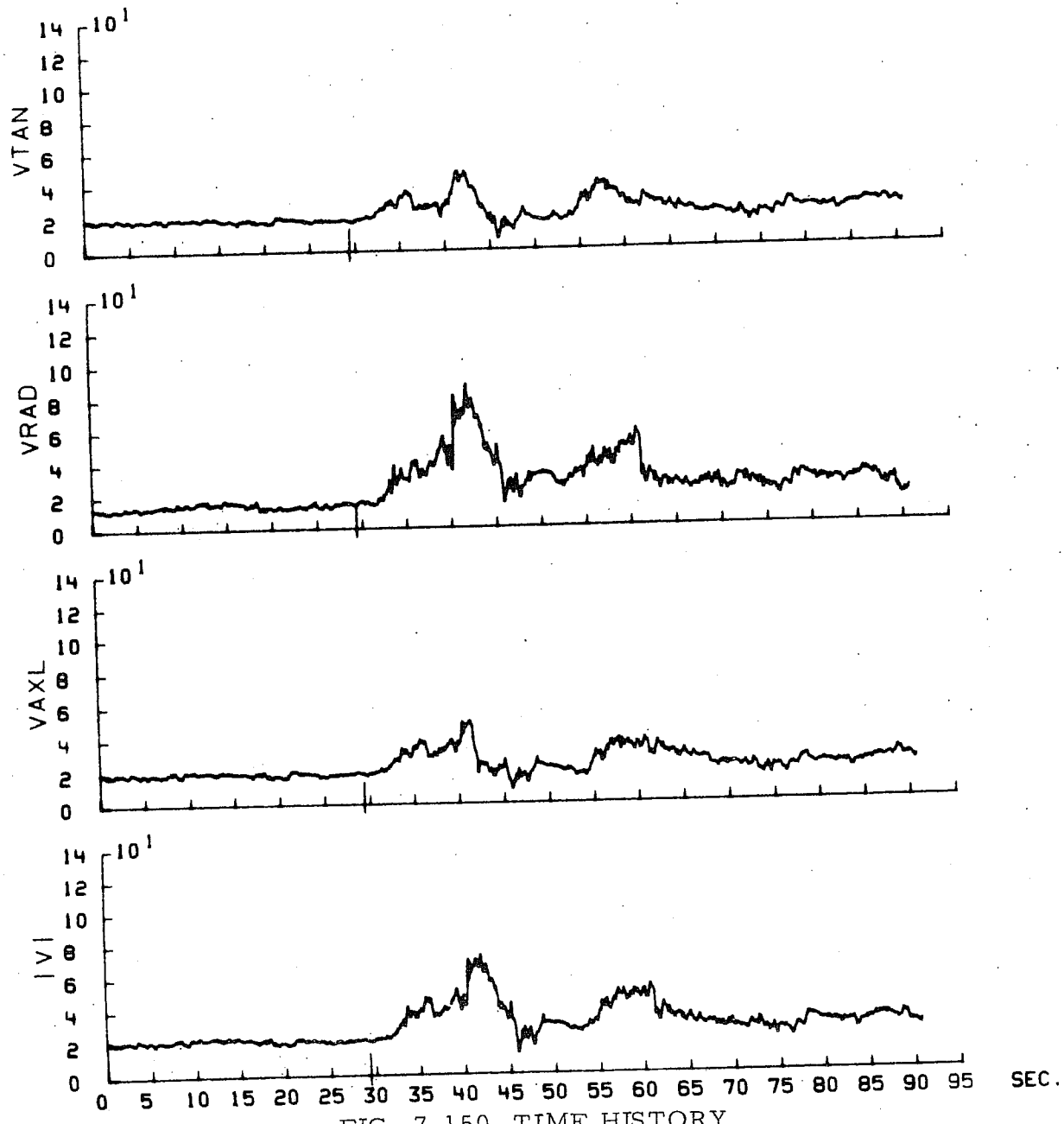


FIG. 7-150 TIME HISTORY

C5A ESSA 150 FT LEVEL 2/20/70 1432:59 DATA 4

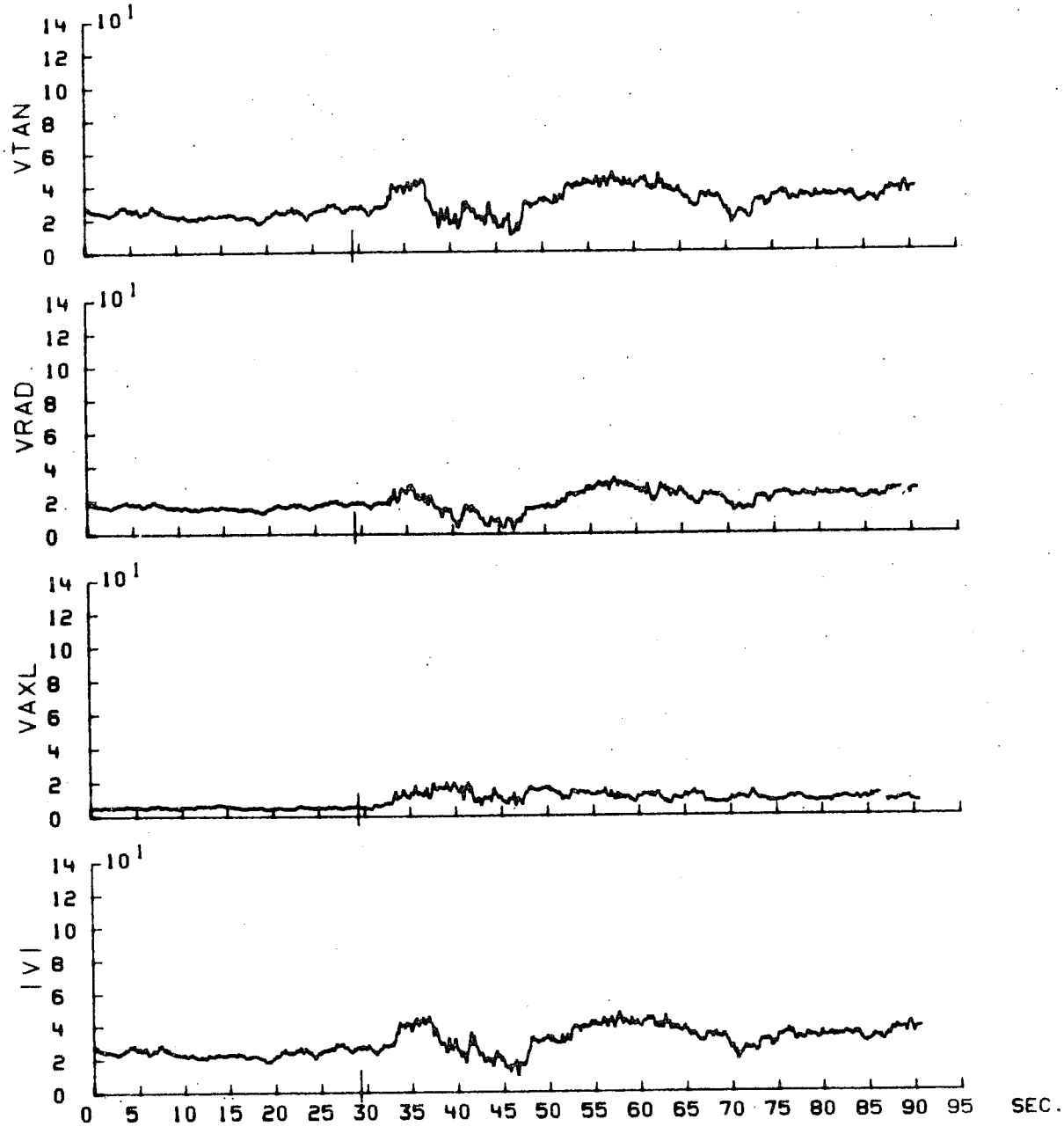


FIG. 7-151 TIME HISTORY

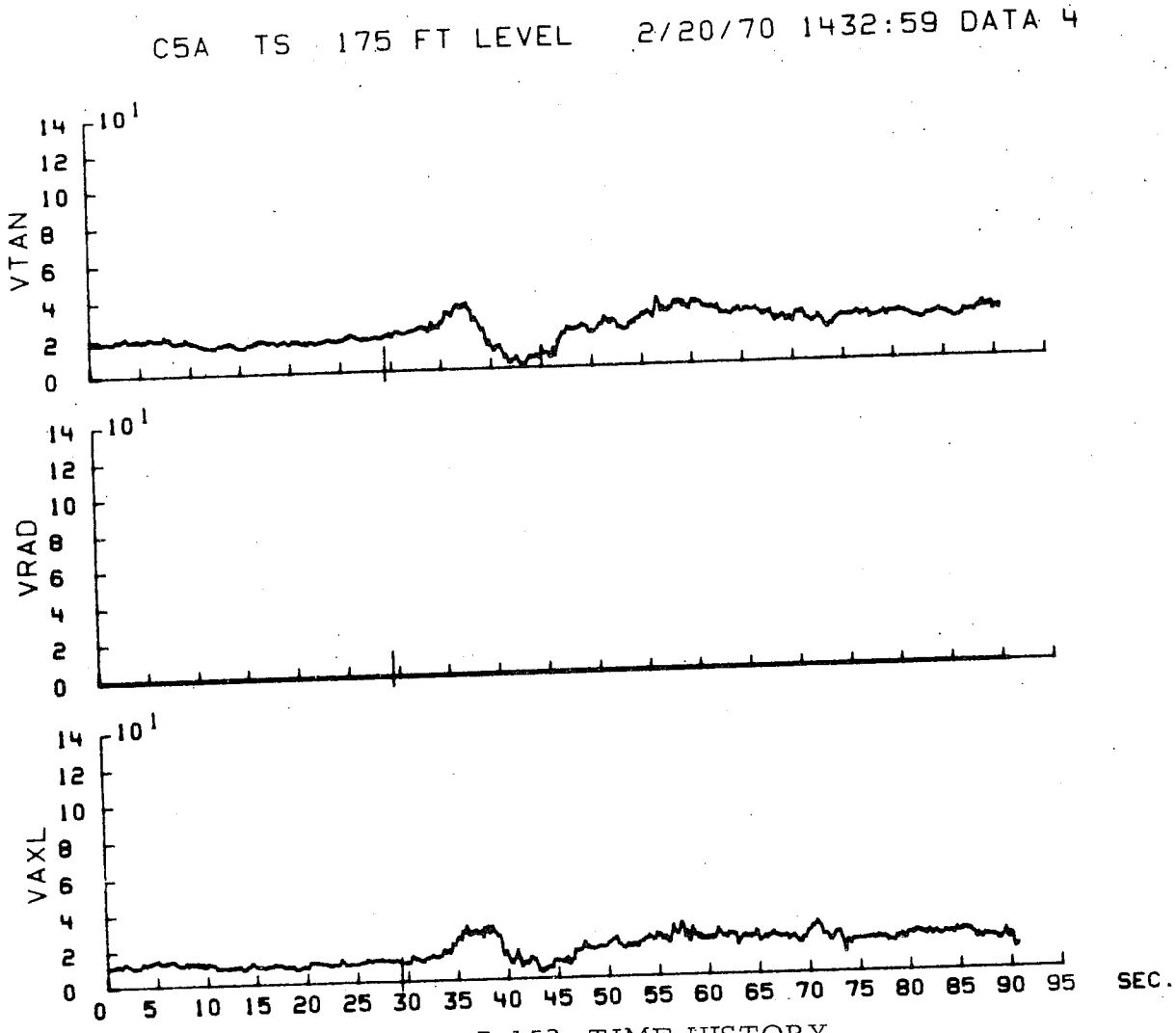


FIG. 7-152 TIME HISTORY

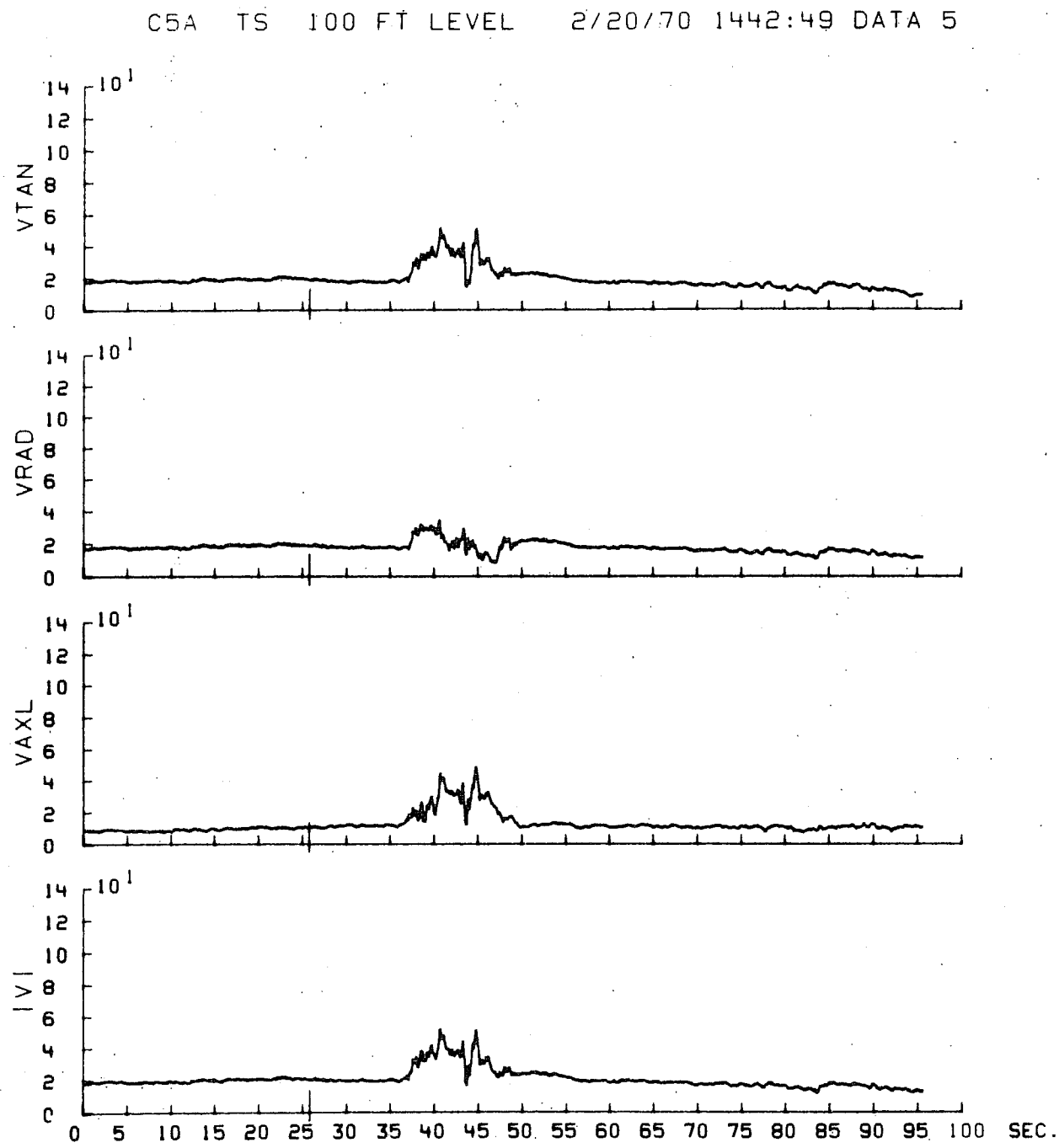


FIG. 7-153 TIME HISTORY

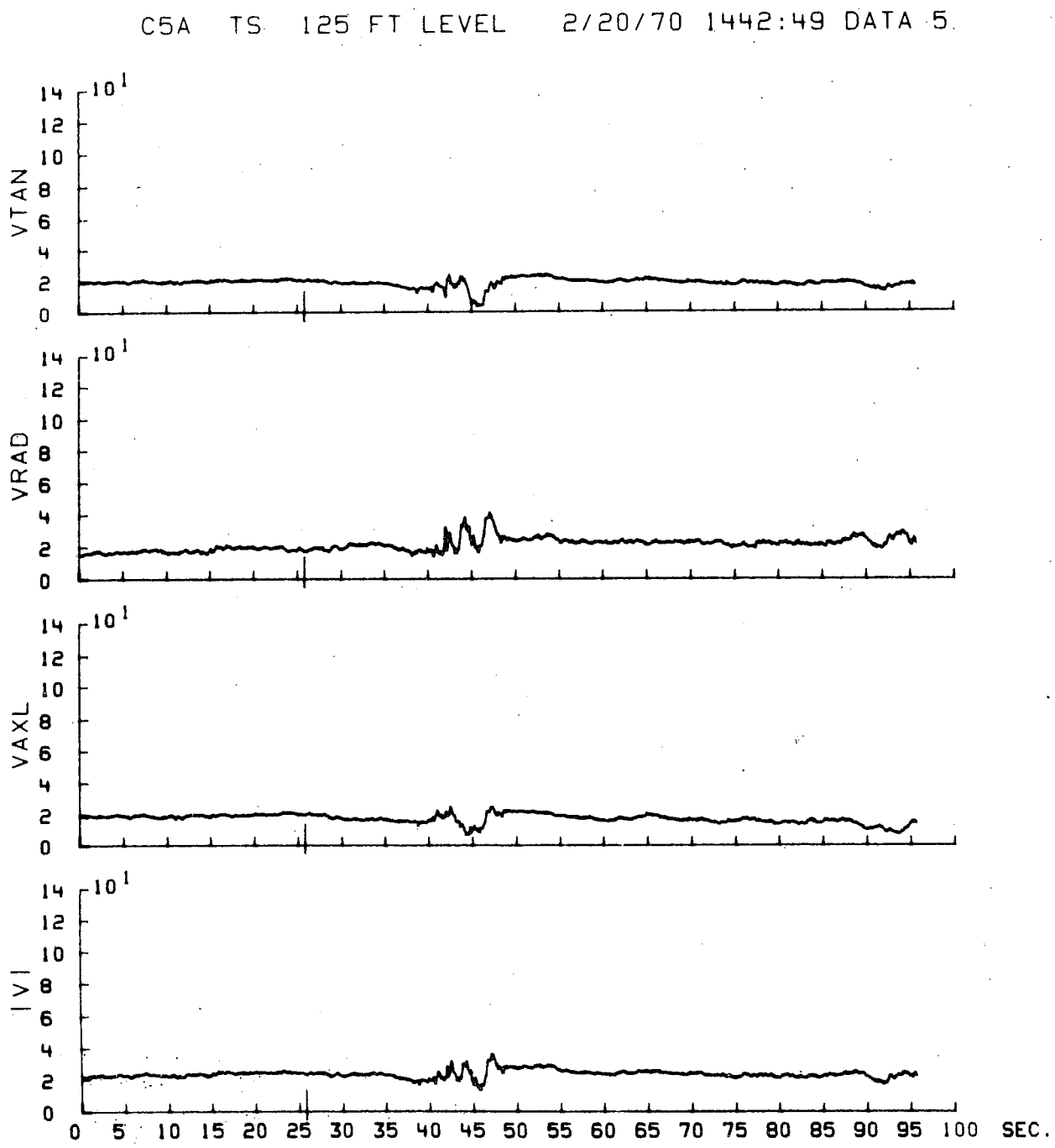


FIG. 7-154 TIME HISTORY

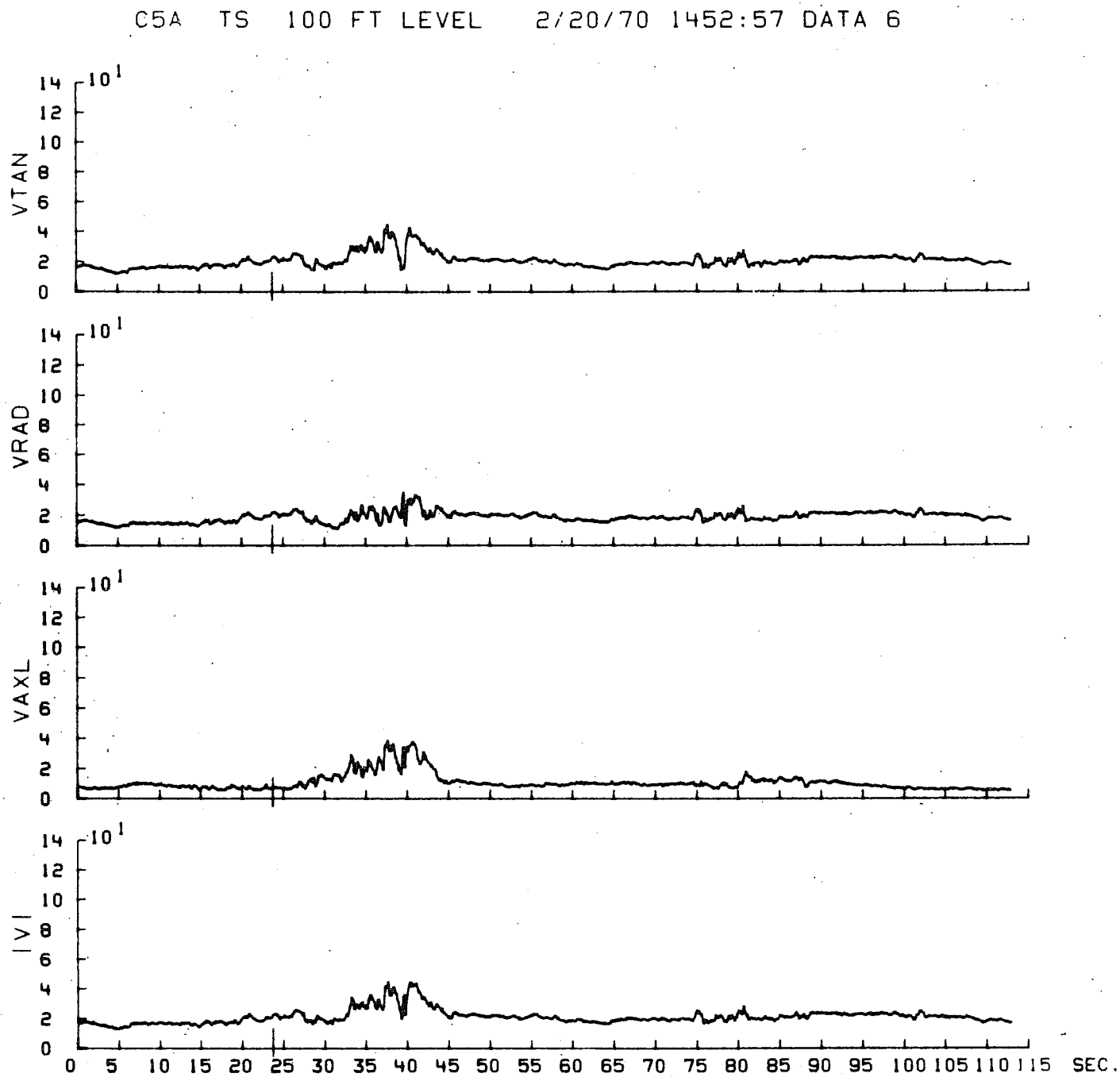


FIG. 7-155 TIME HISTORY

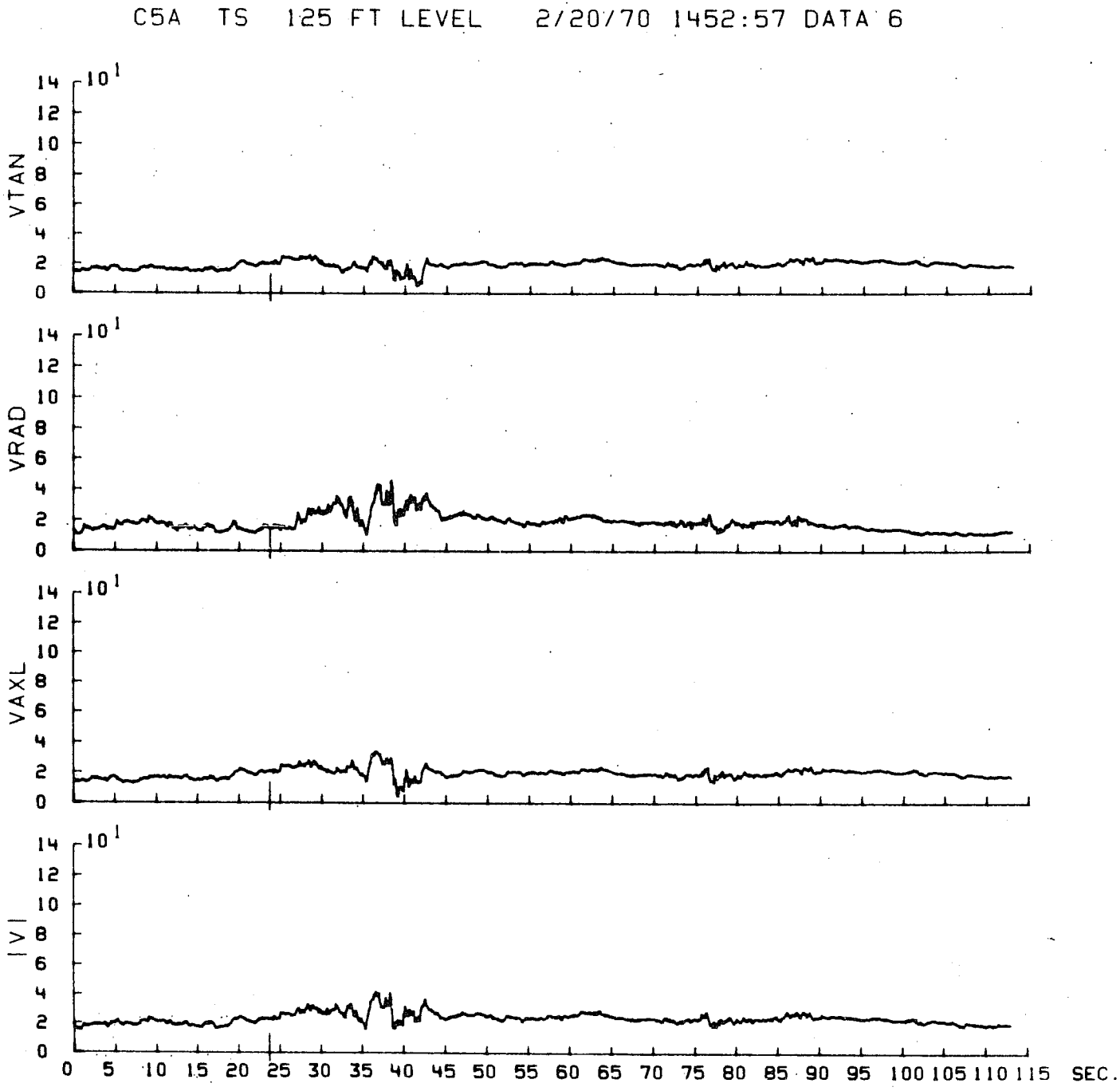


FIG. 7-156 TIME HISTORY

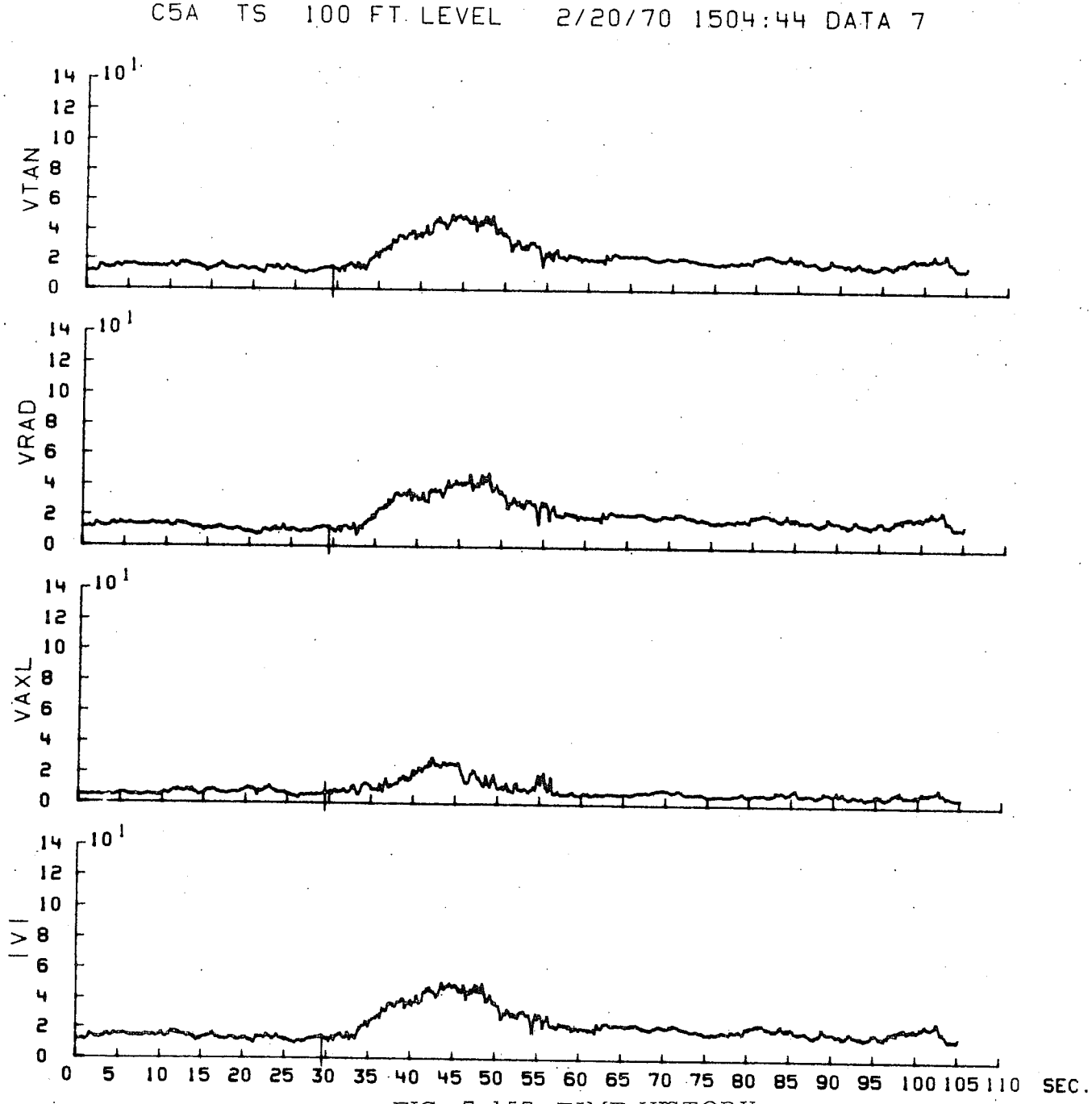


FIG. 7-157 TIME HISTORY

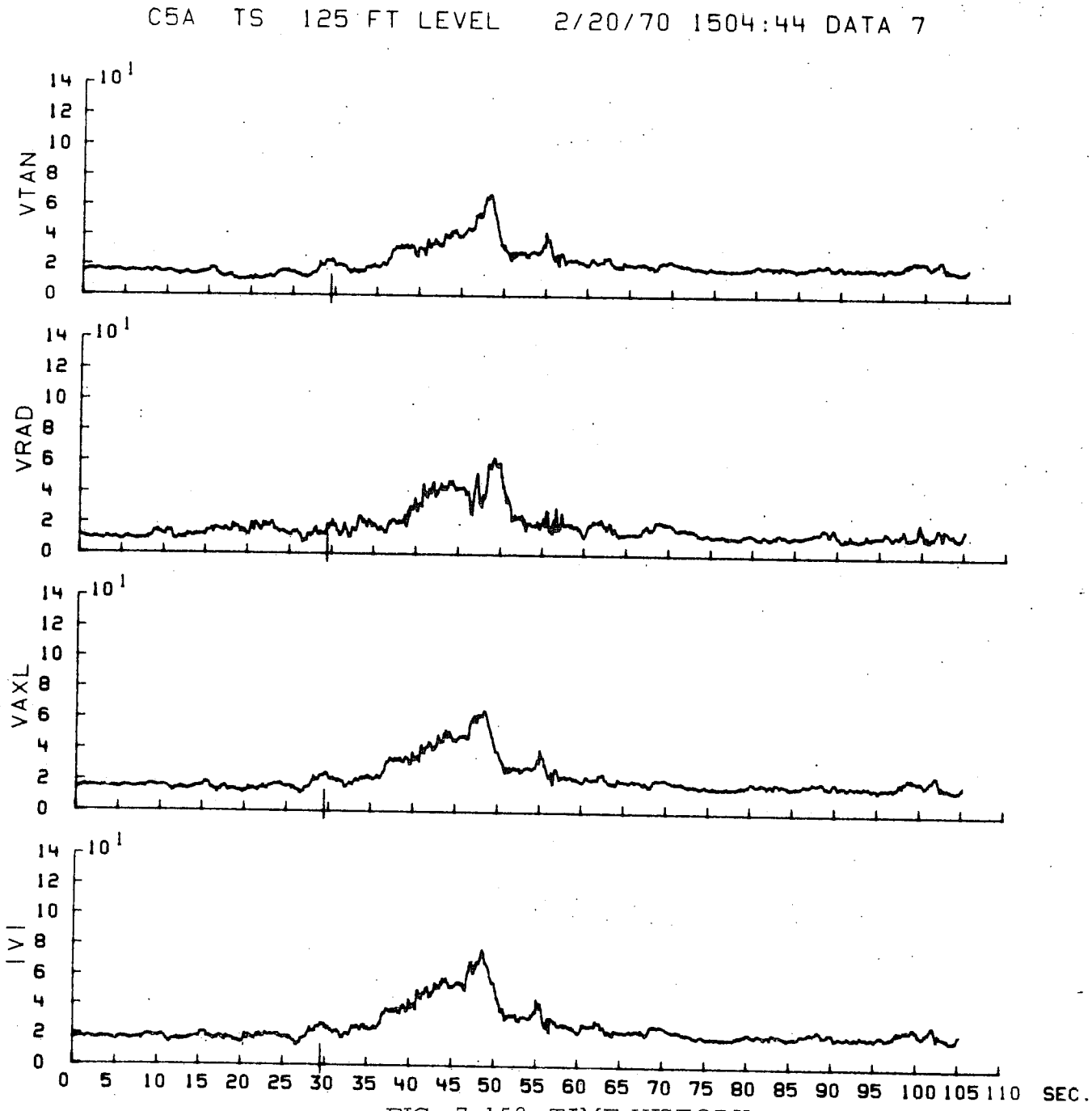


FIG. 7-158 TIME HISTORY

C5A ESSA 150 FT LEVEL 2/20/70 1504:44 DATA 7

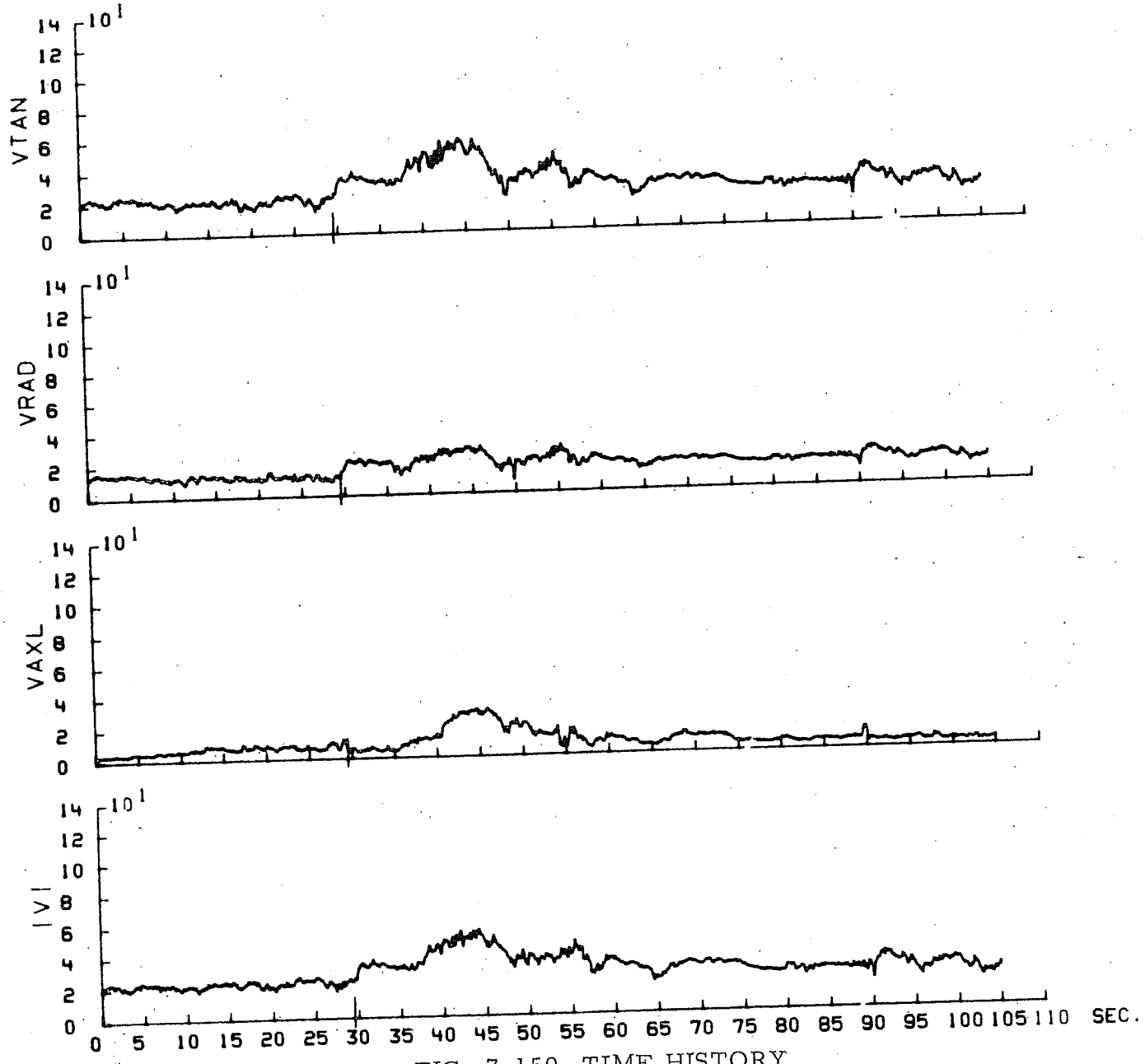


FIG. 7-159 TIME HISTORY

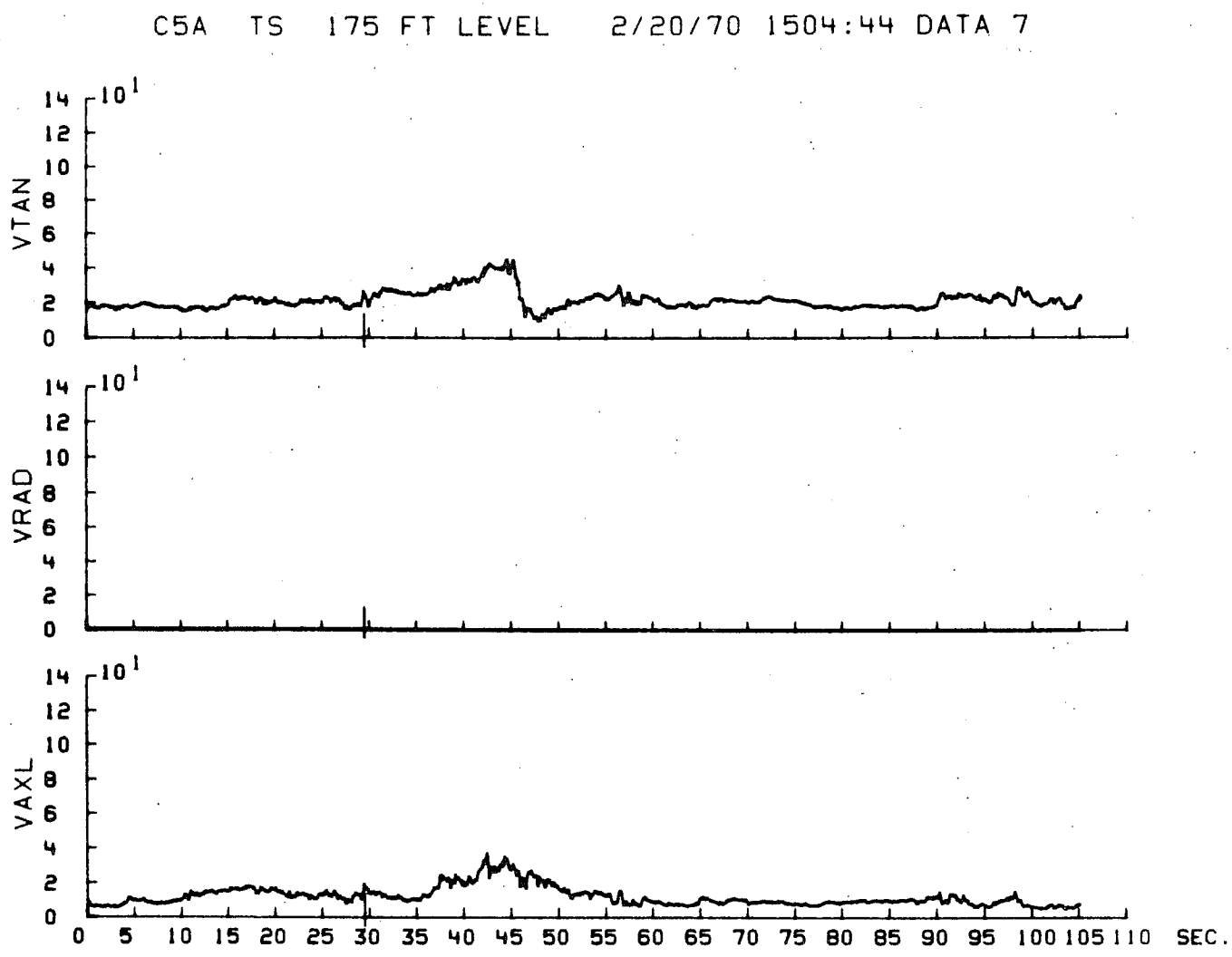


FIG. 7-160 TIME HISTORY

C5A TS 100 FT LEVEL 2/20/70 1514:33 DATA 8

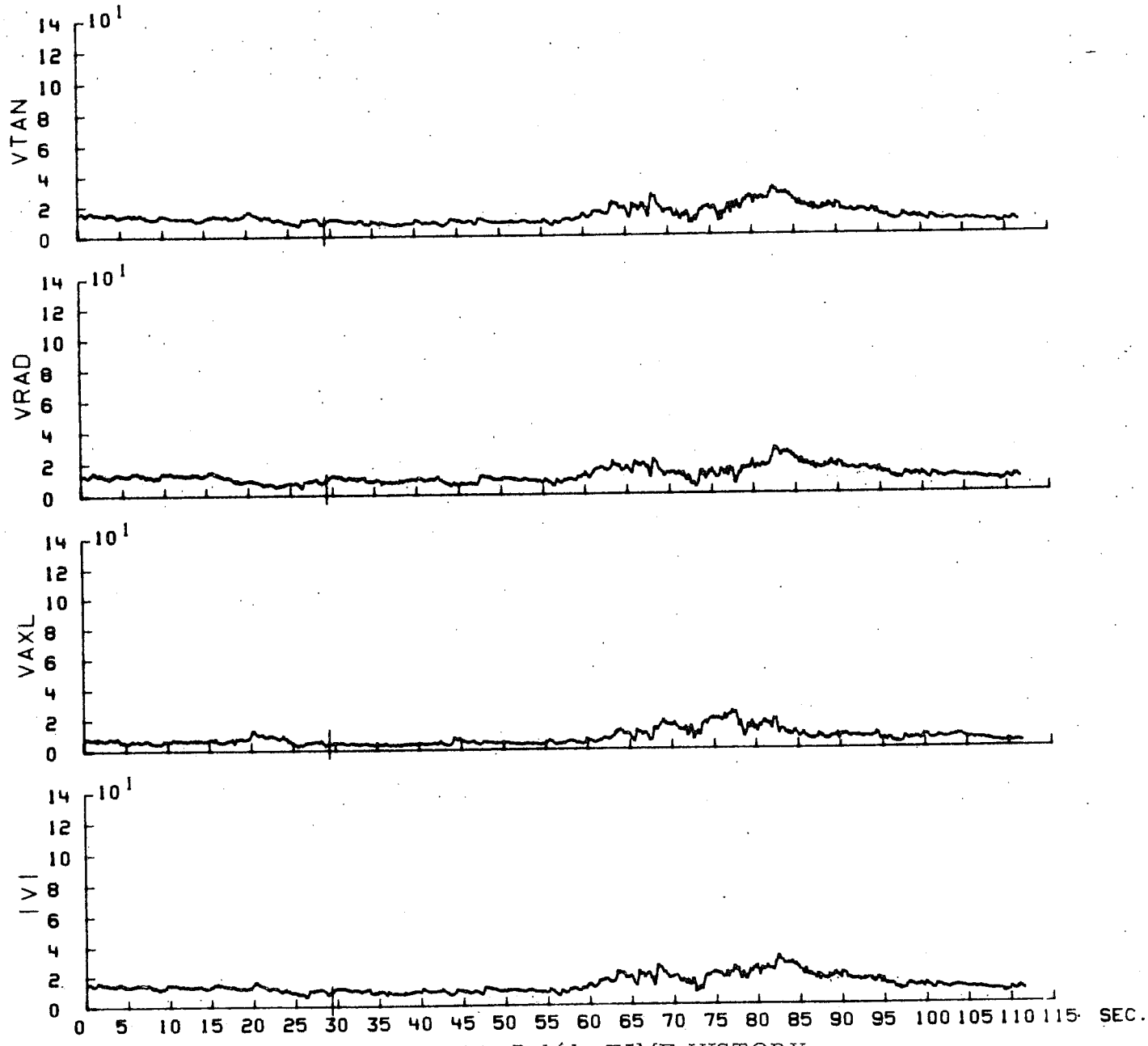


FIG. 7-161 TIME HISTORY

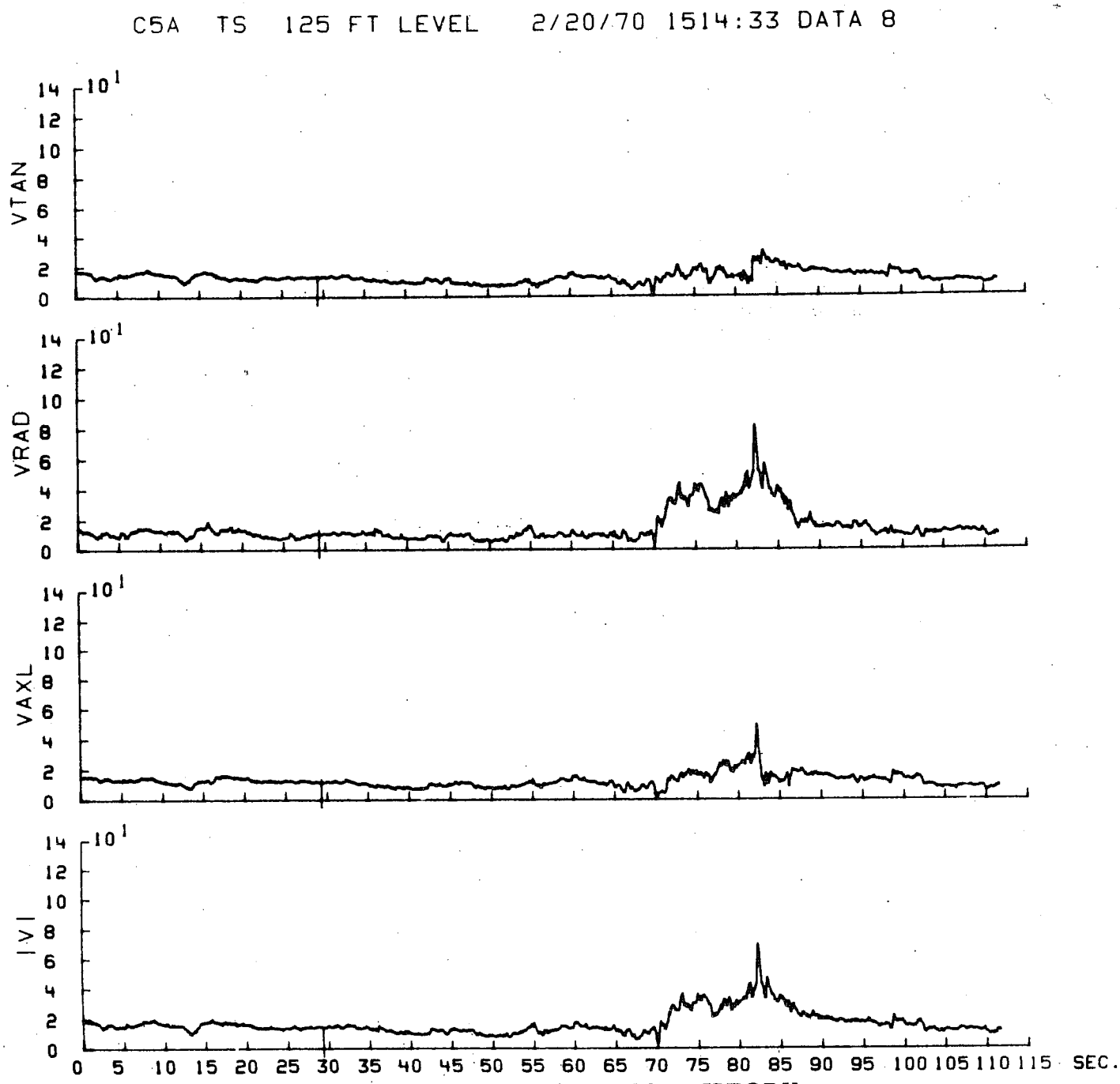


FIG. 7-162 TIME HISTORY

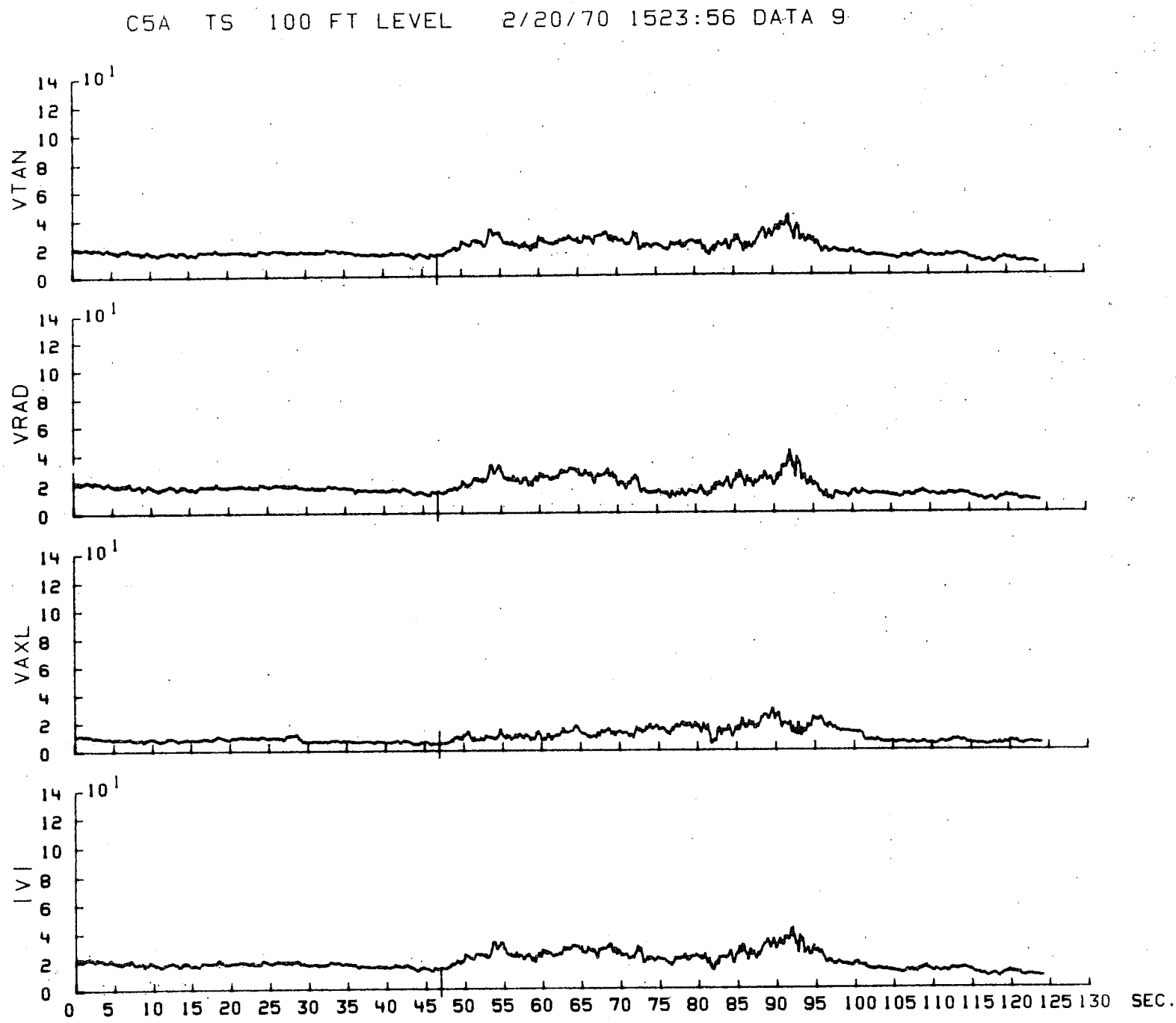


FIG. 7-163 TIME HISTORY

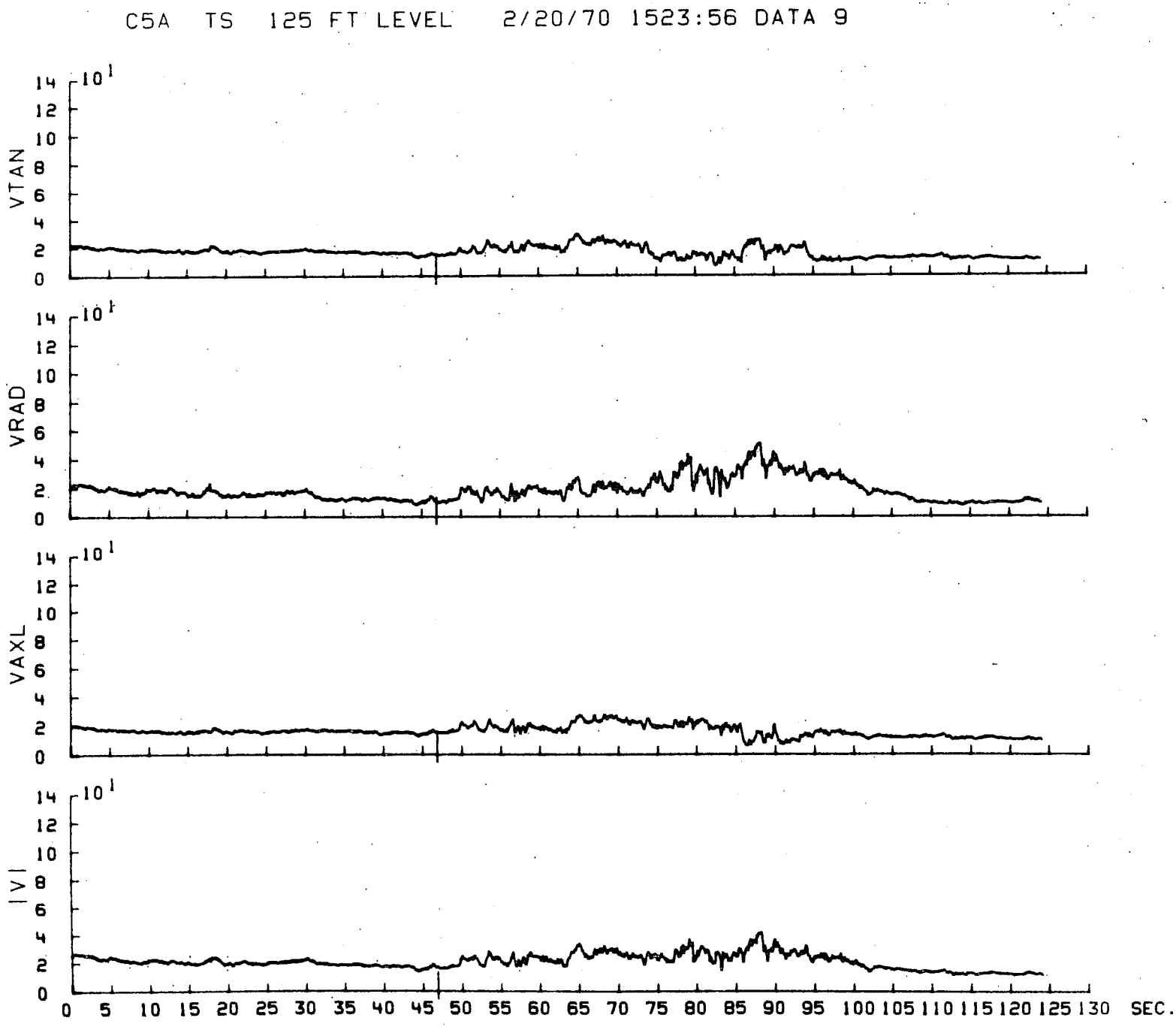


FIG. 7-164 TIME HISTORY

C5A TS 125 FT LEVEL 2/20/70 1539:31 DATA 11

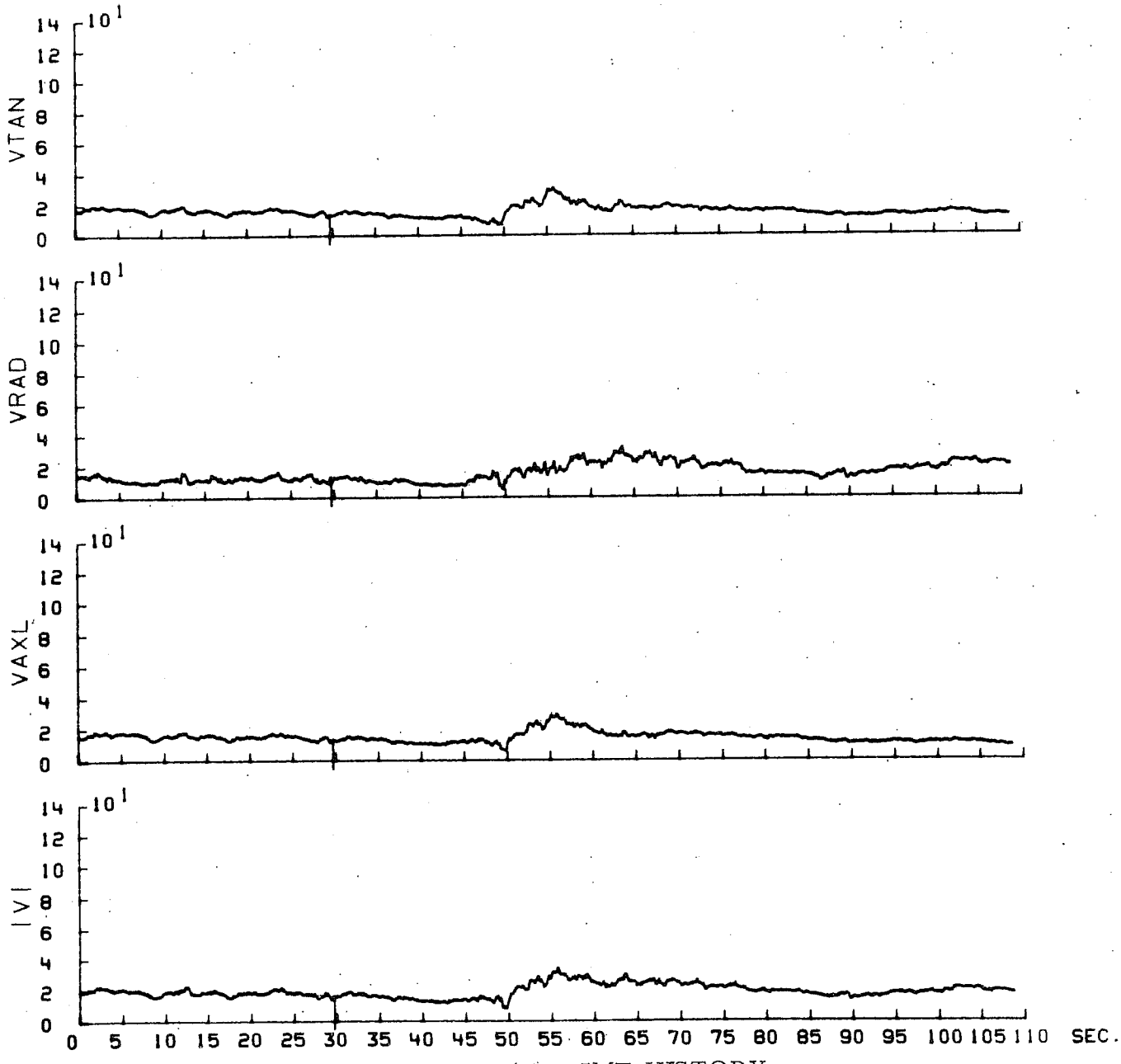


FIG. 7-165 TIME HISTORY

C5A ESSA 150 FT LEVEL 2/20/70 1539:31 DATA 11

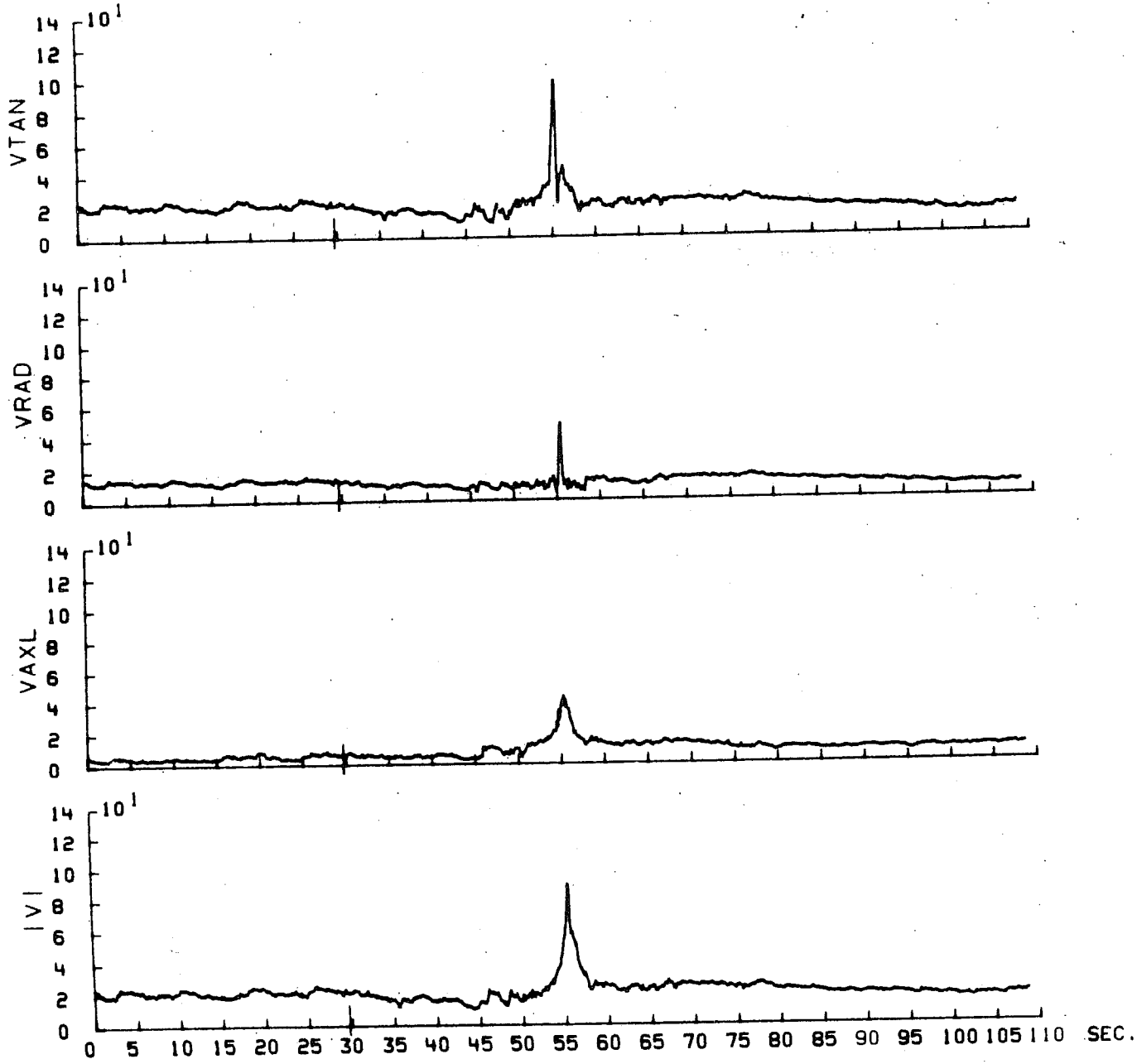


FIG. 7-166 TIME HISTORY

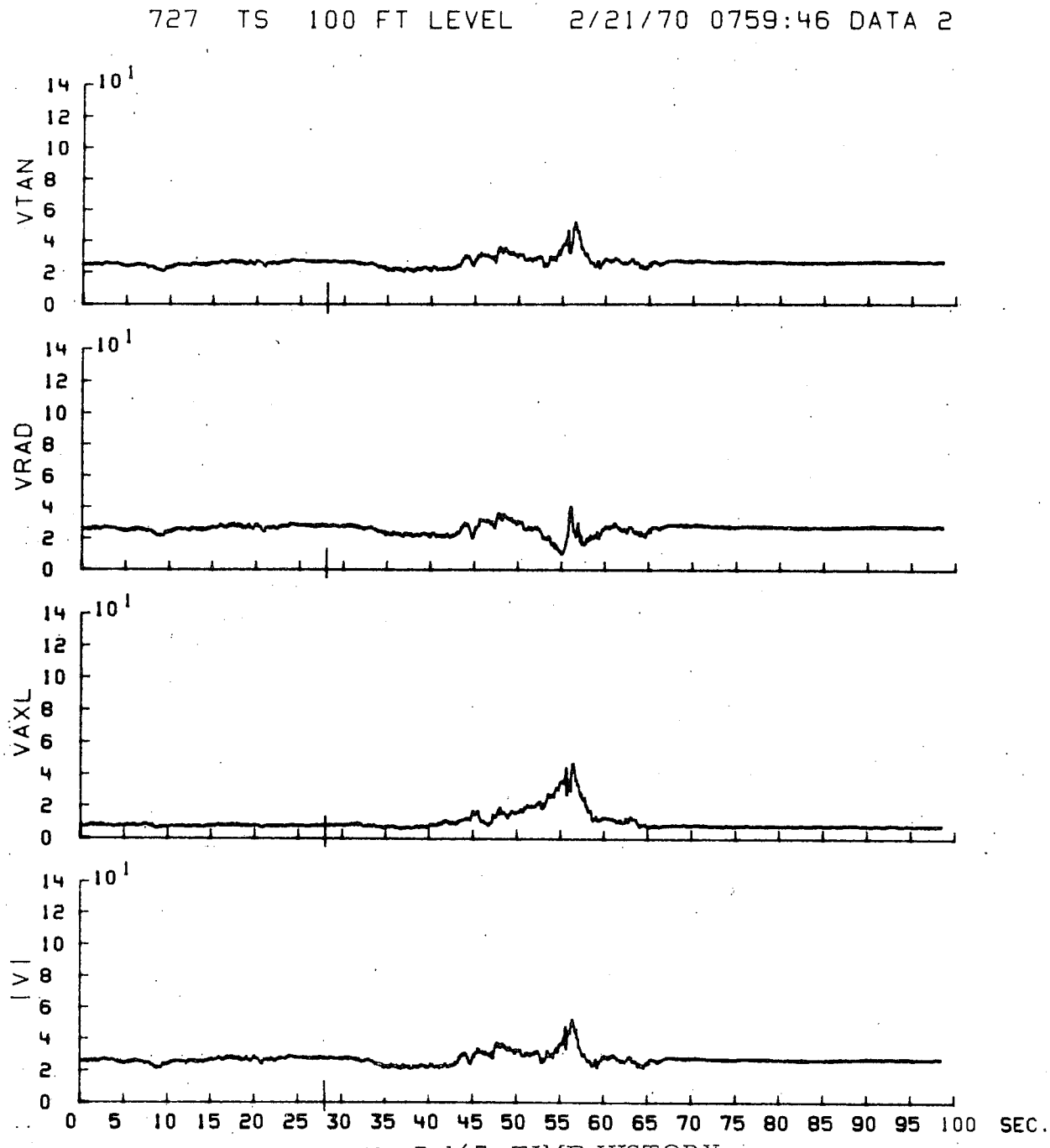


FIG. 7-167 TIME HISTORY

727 TS 125 FT LEVEL 2/21/70 0759:46 DATA 2

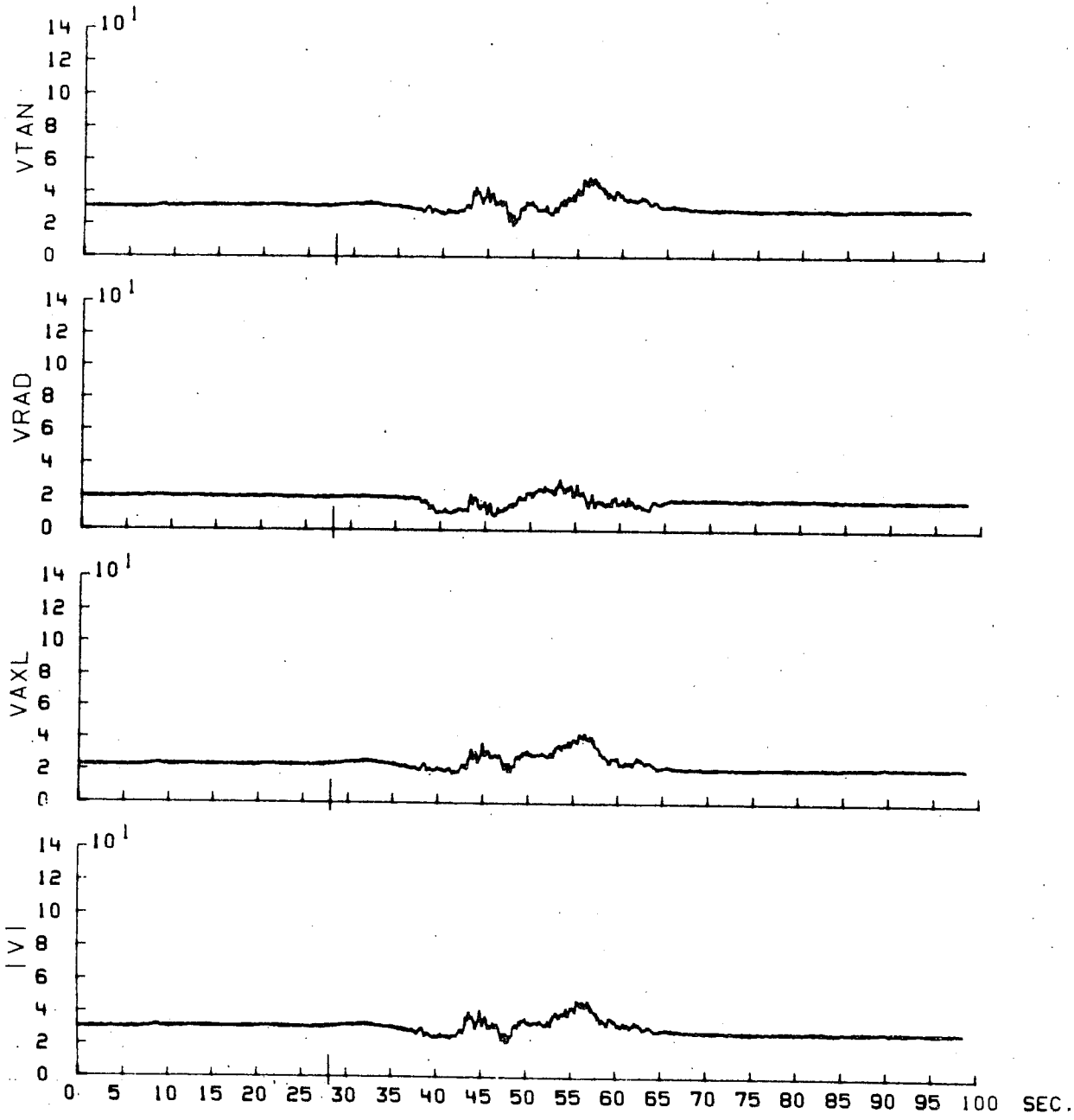


FIG. 7-168 TIME HISTORY

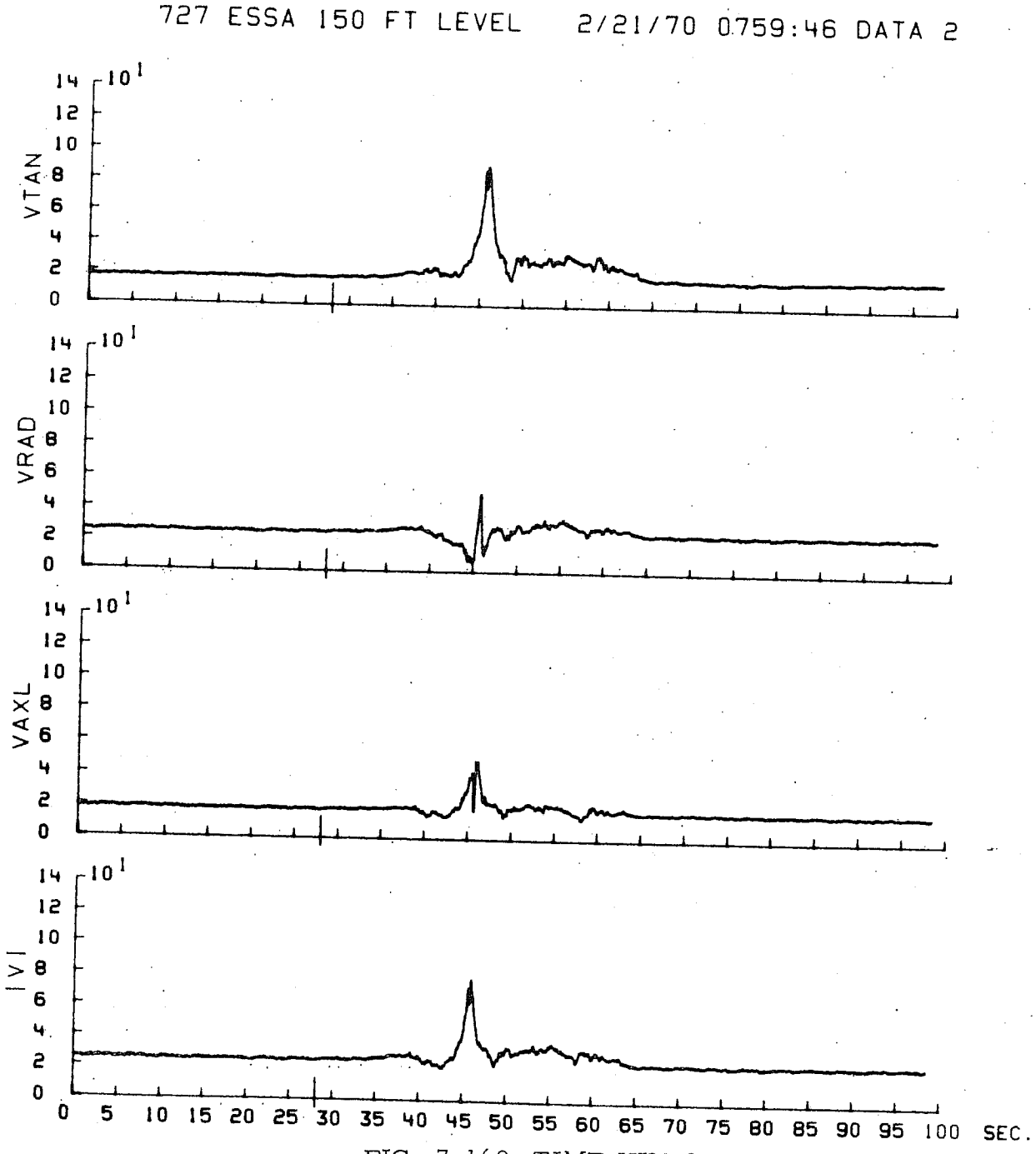


FIG. 7-169 TIME HISTORY

727 TS 125 FT LEVEL 2/21/70 0809:13 DATA 3

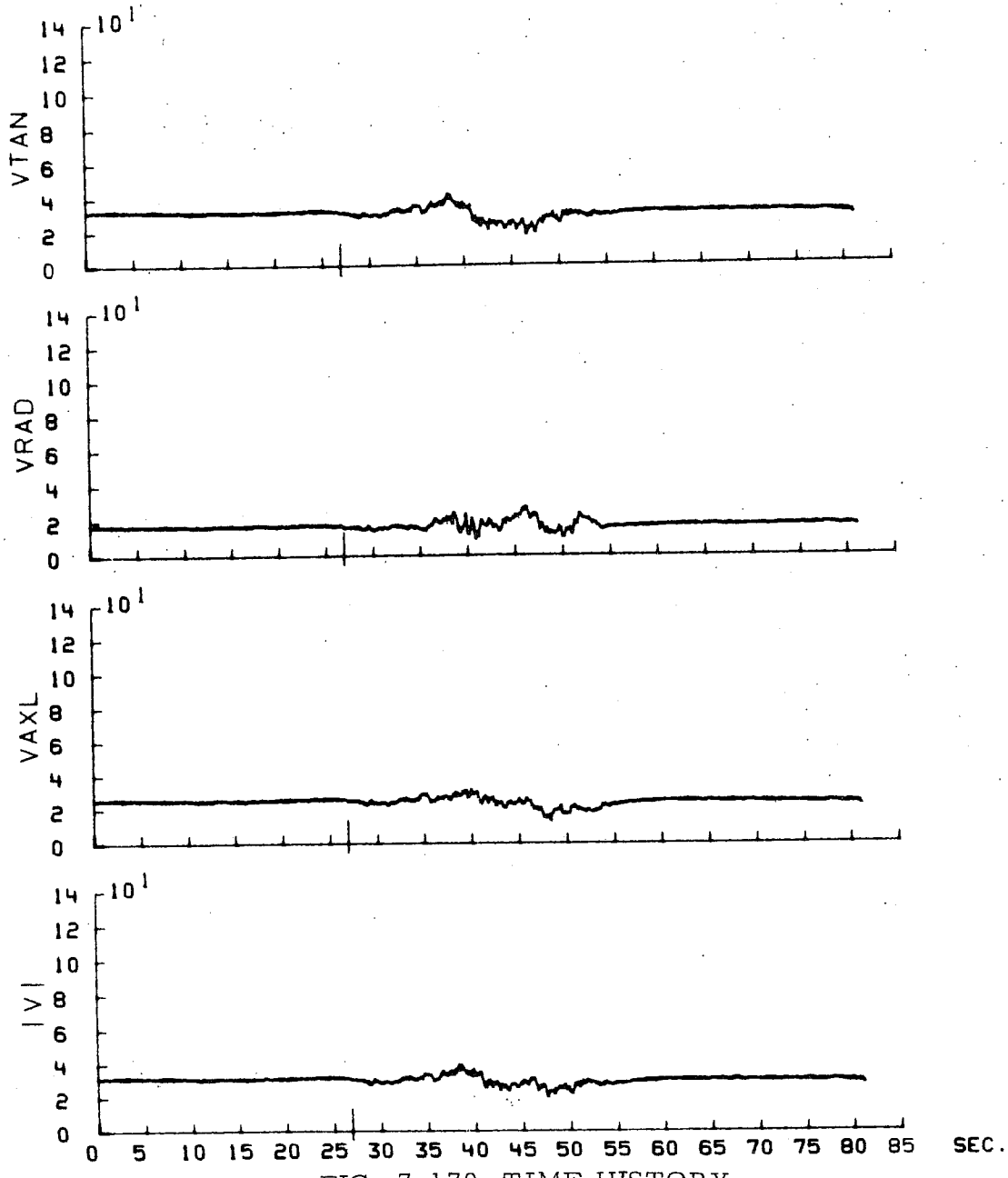


FIG. 7-170 TIME HISTORY

727 ESSA 150 FT LEVEL 2/21/70 0809:13 DATA 3

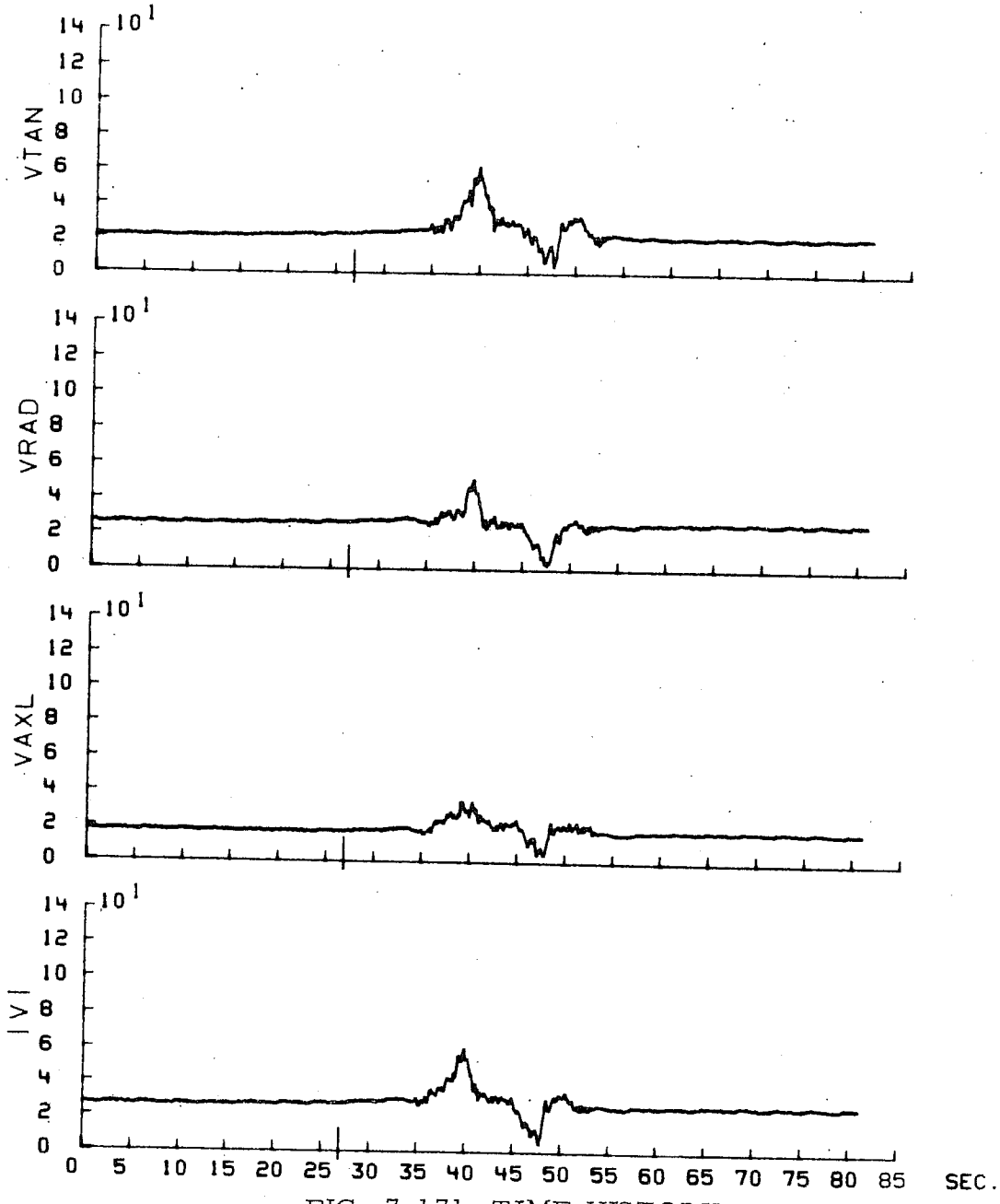


FIG. 7-171 TIME HISTORY

727 TS 175 FT LEVEL 2/21/70 0809:13 DATA 3

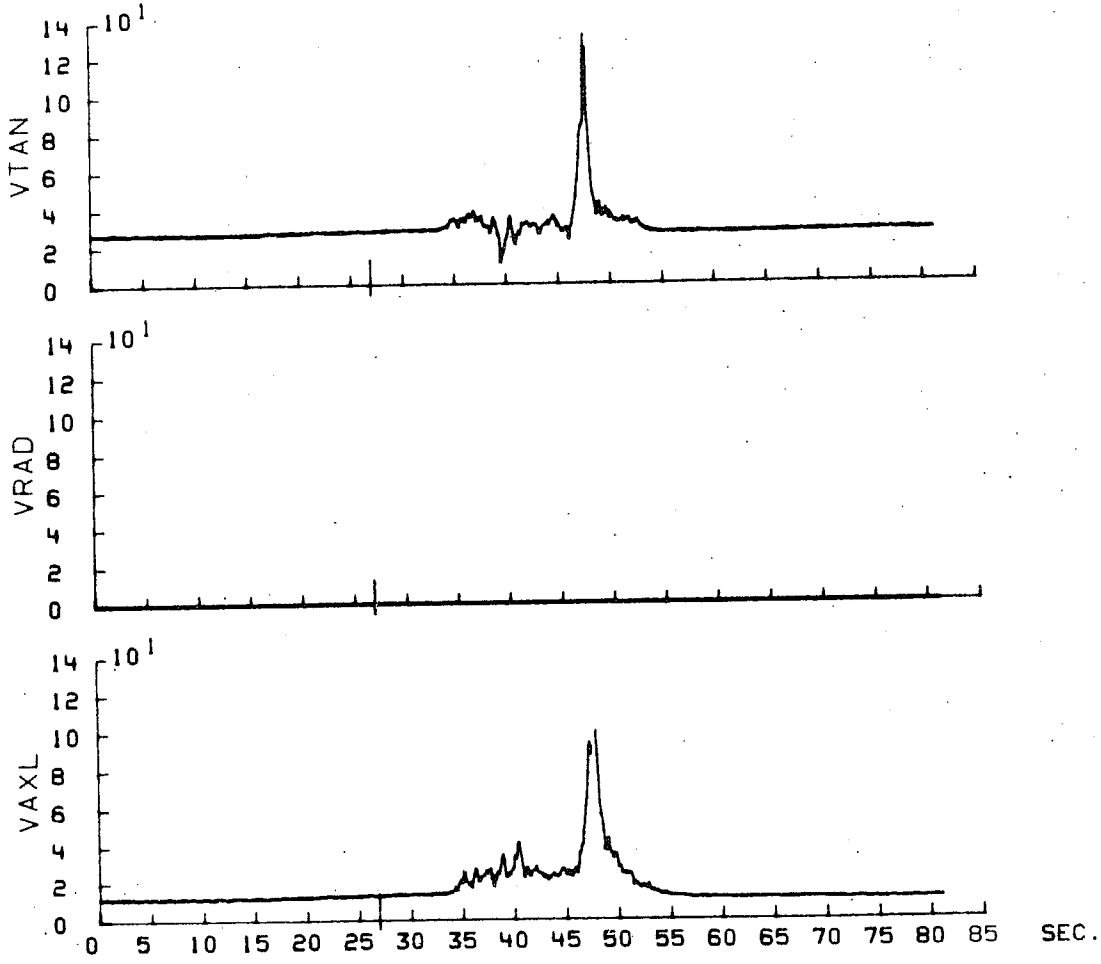


FIG. 7-172 TIME HISTORY

727 ESSA 200 FT LEVEL 2/21/70 0809:13 DATA 3

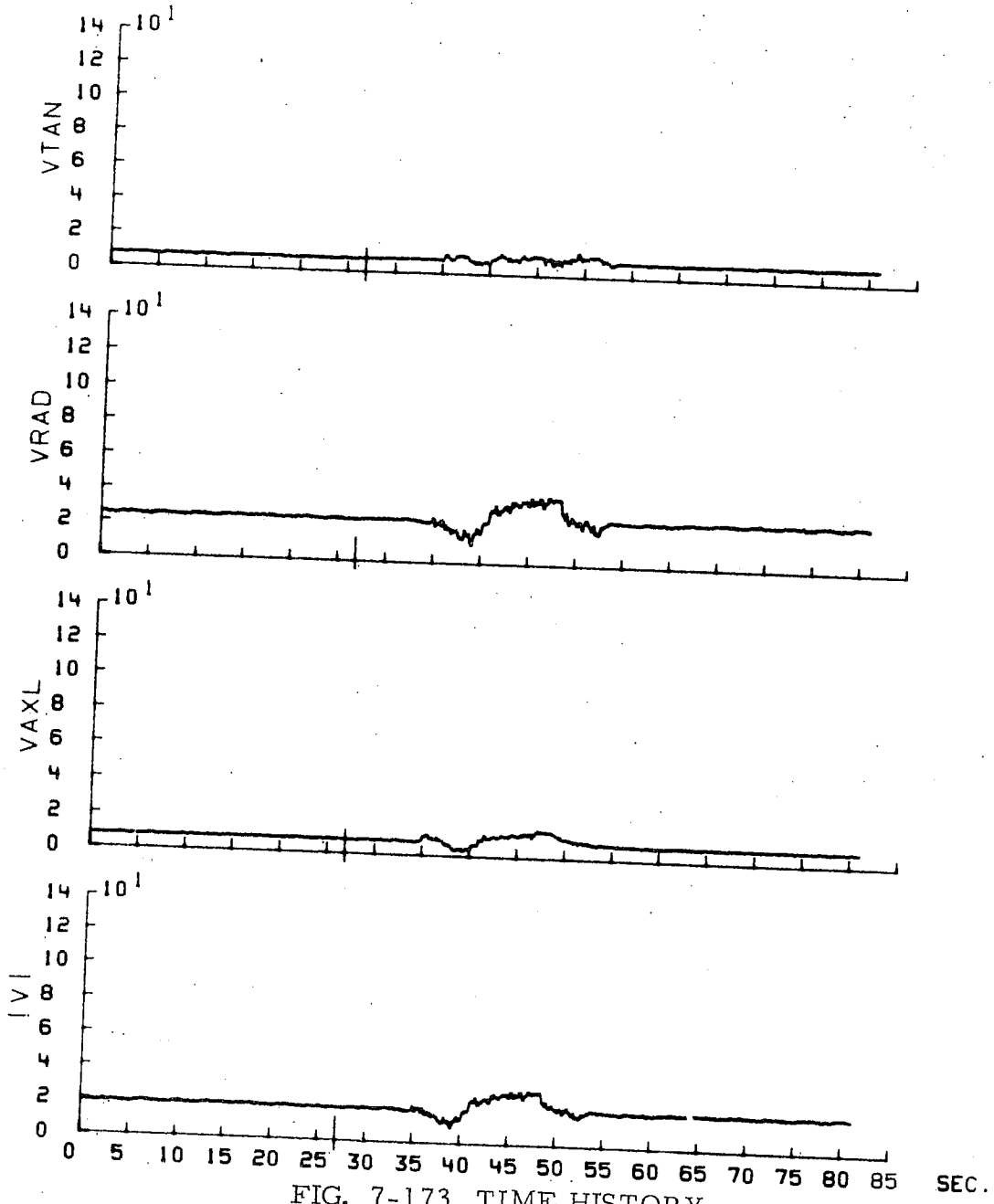


FIG. 7-173 TIME HISTORY

727 BGS 75 FT LEVEL 2/21/70 0817:47 DATA 4

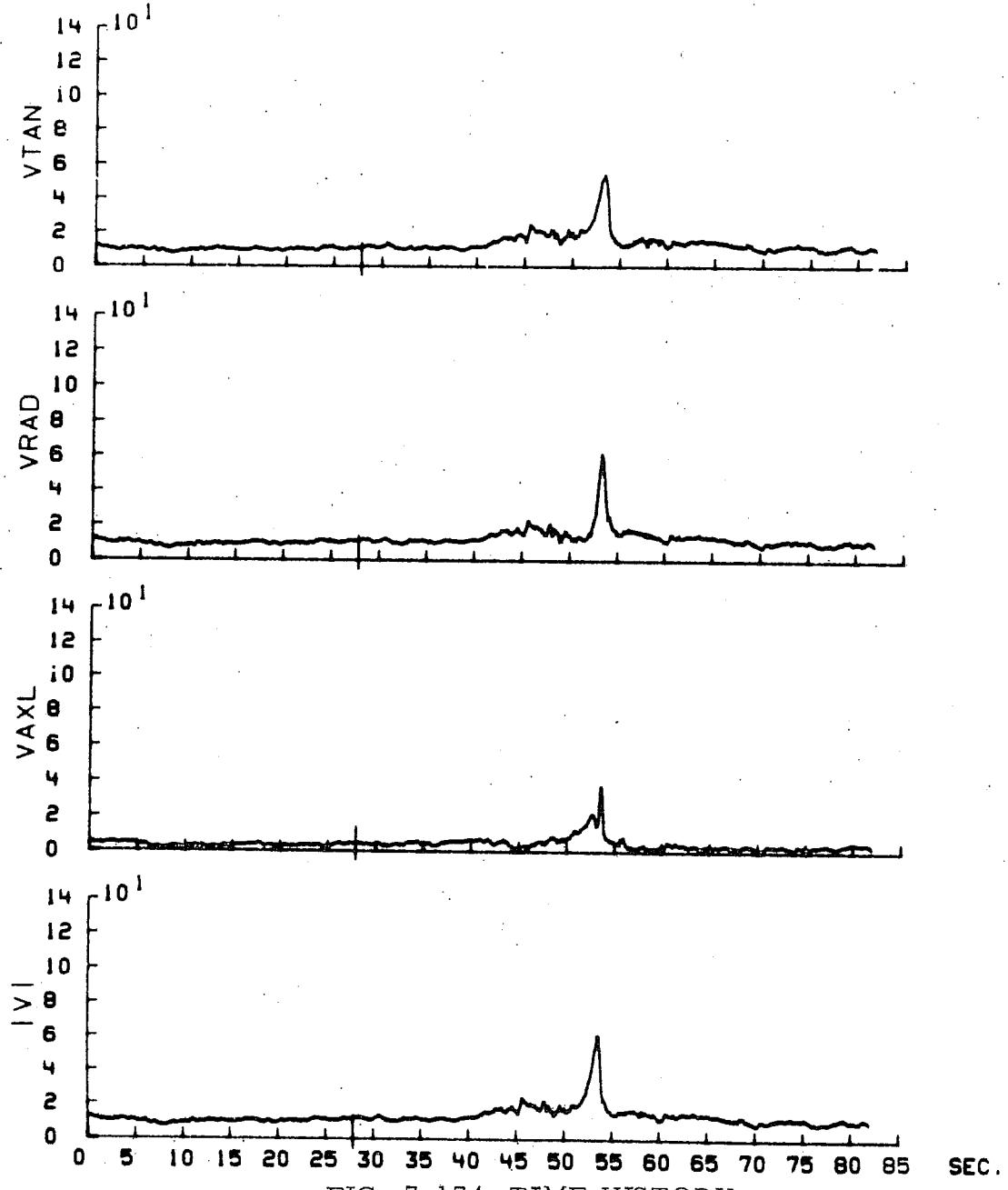


FIG. 7-174 TIME HISTORY

727 TS 100 FT LEVEL 2/21/70 0817:47 DATA 4

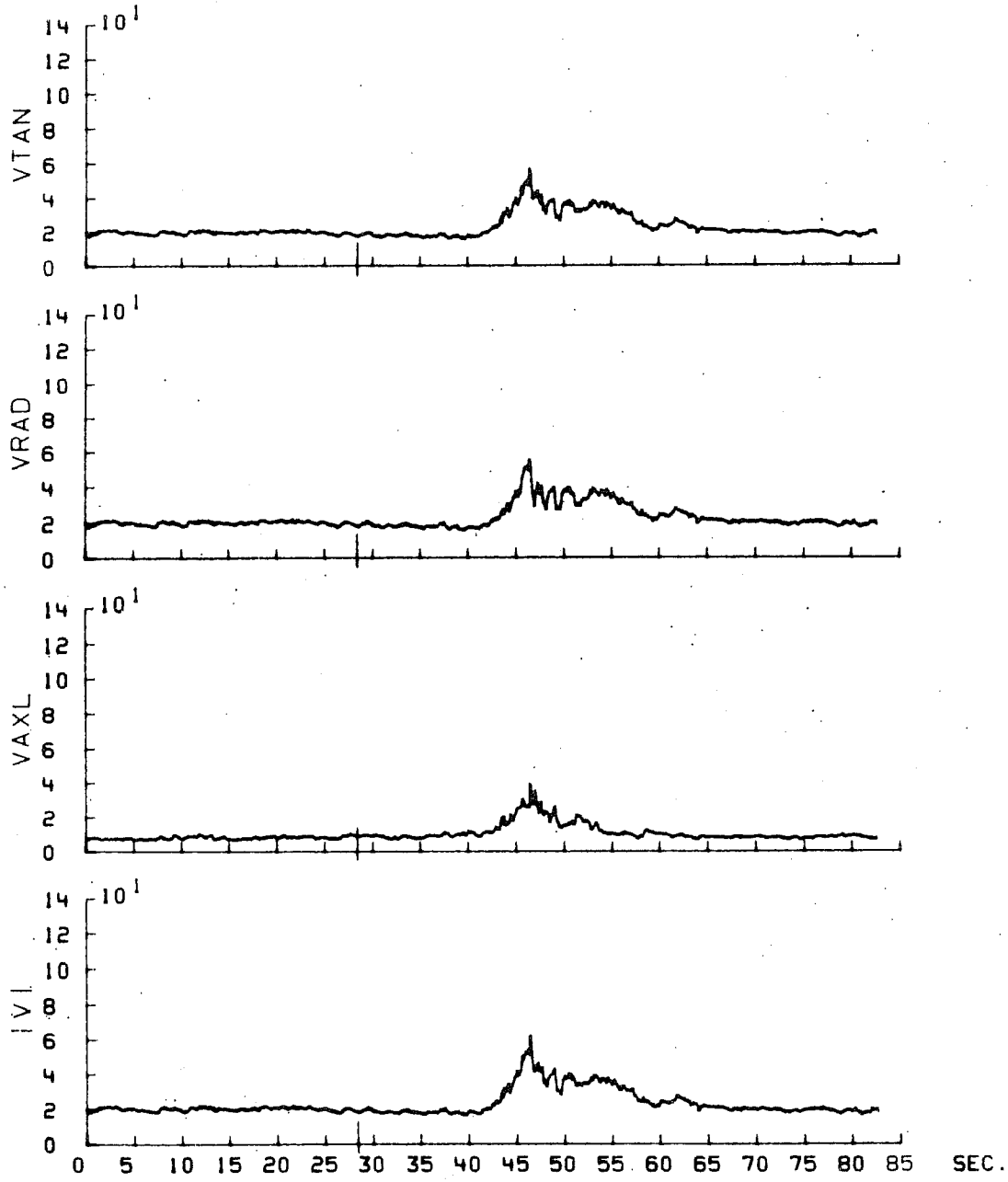


FIG. 7-175 TIME HISTORY

727 TS 125 FT LEVEL 2/21/70 0817:47 DATA 4

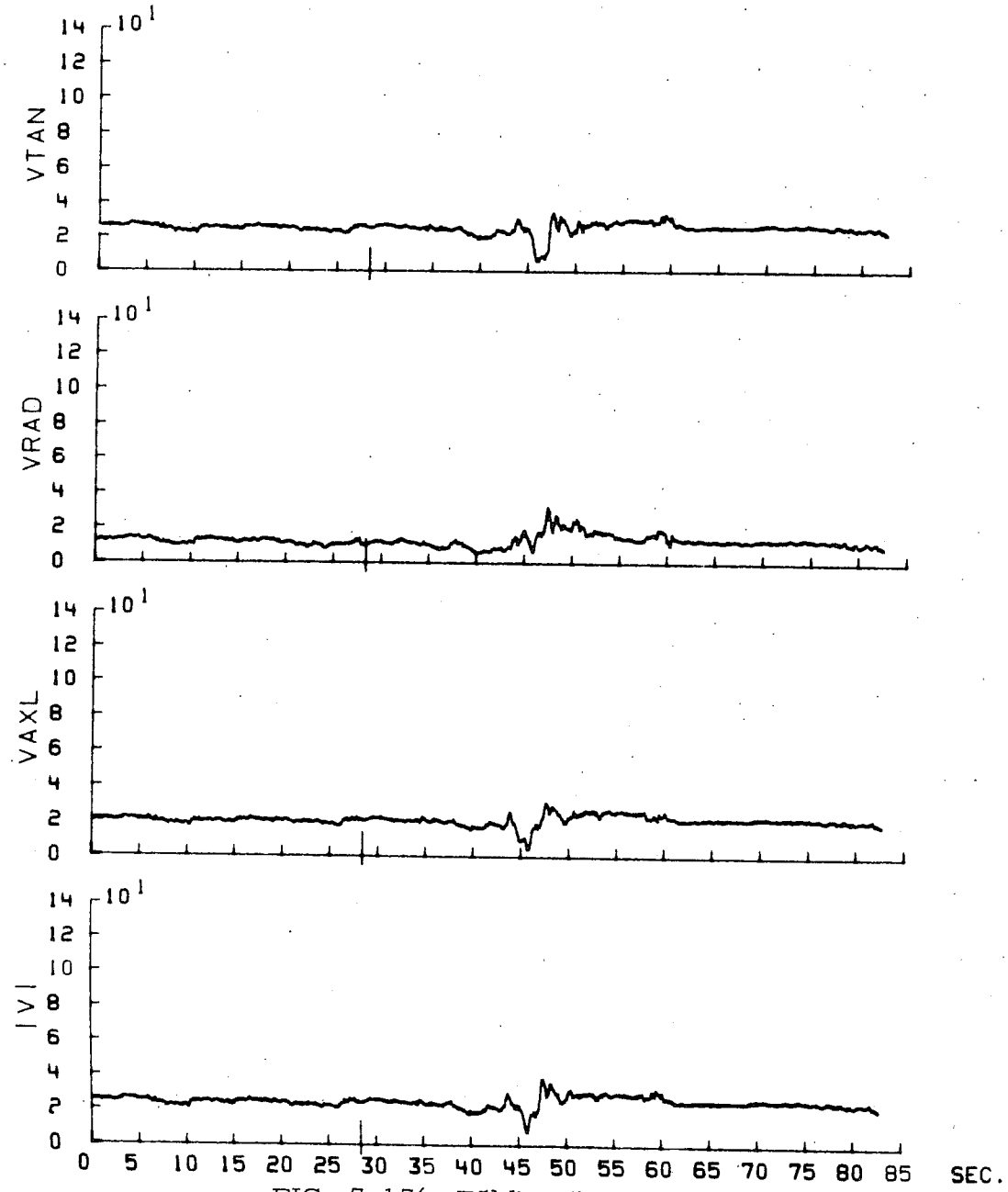


FIG. 7-176 TIME HISTORY

727 TS 100 FT LEVEL 2/21/70 0826:04 DATA 5

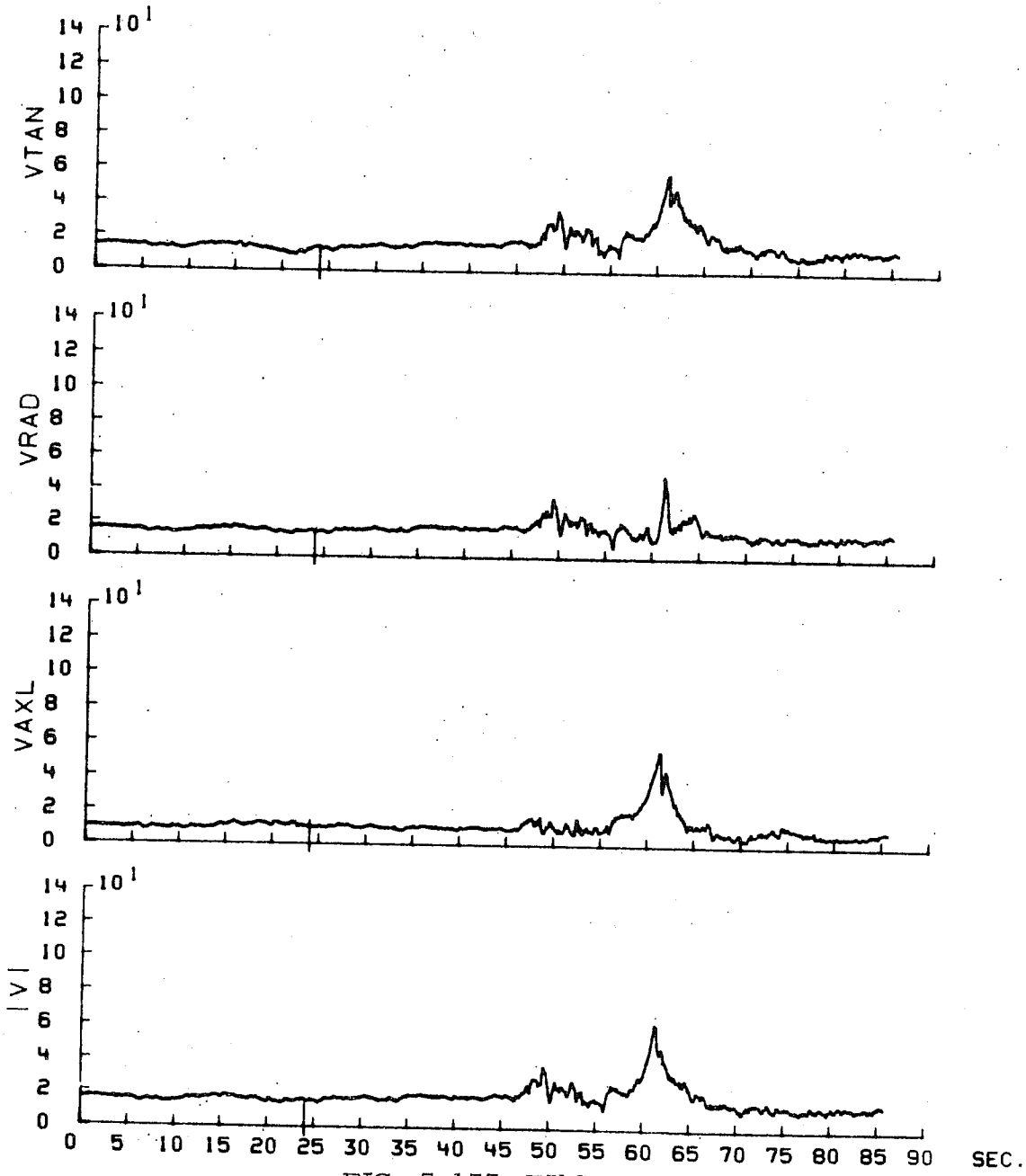


FIG. 7-177 TIME HISTORY

727 TS 125 FT LEVEL 2/21/70 0826:04 DATA 5

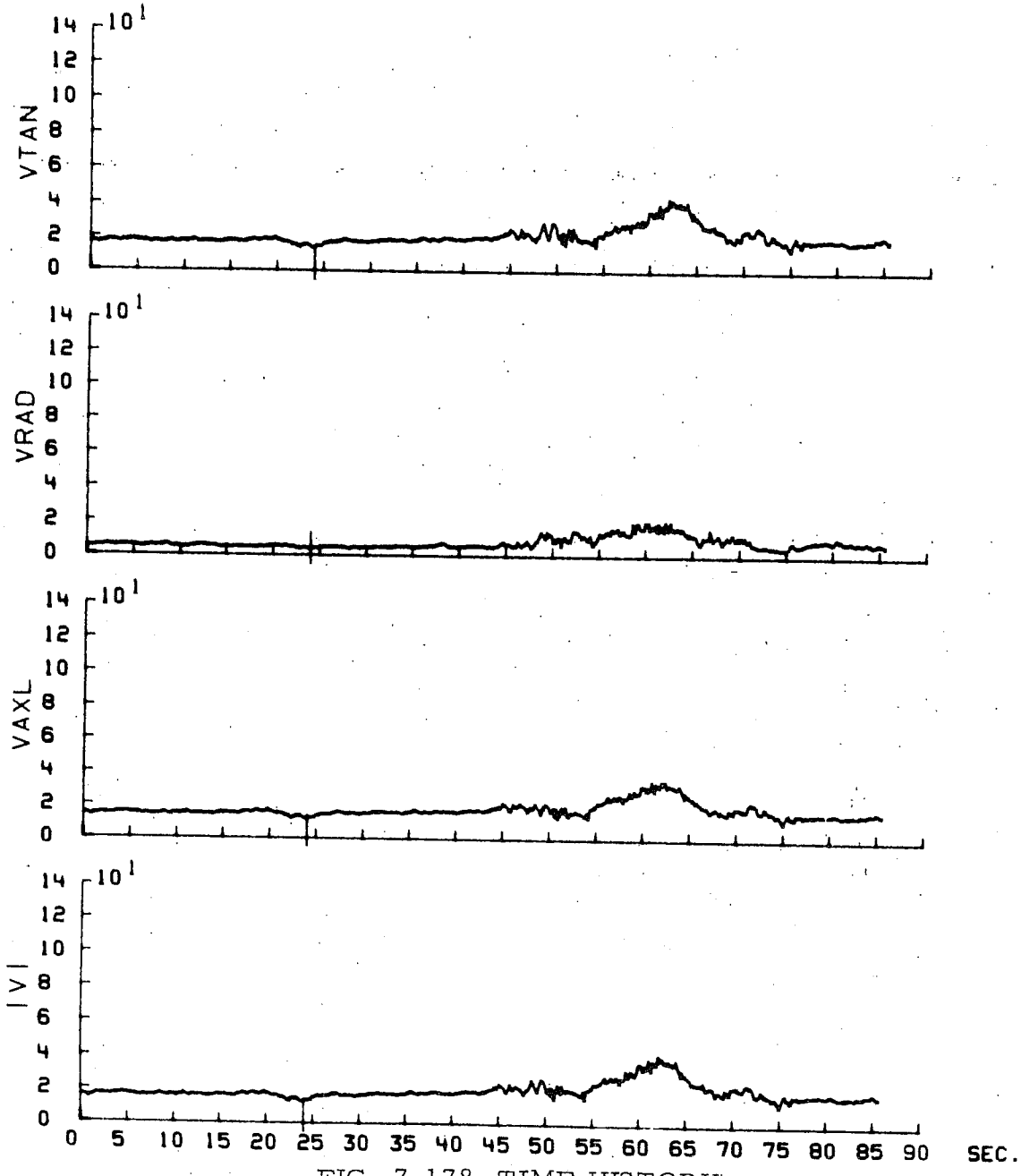


FIG. 7-178 TIME HISTORY

727 TS 125 FT LEVEL 2/21/70 0834:04 DATA 6

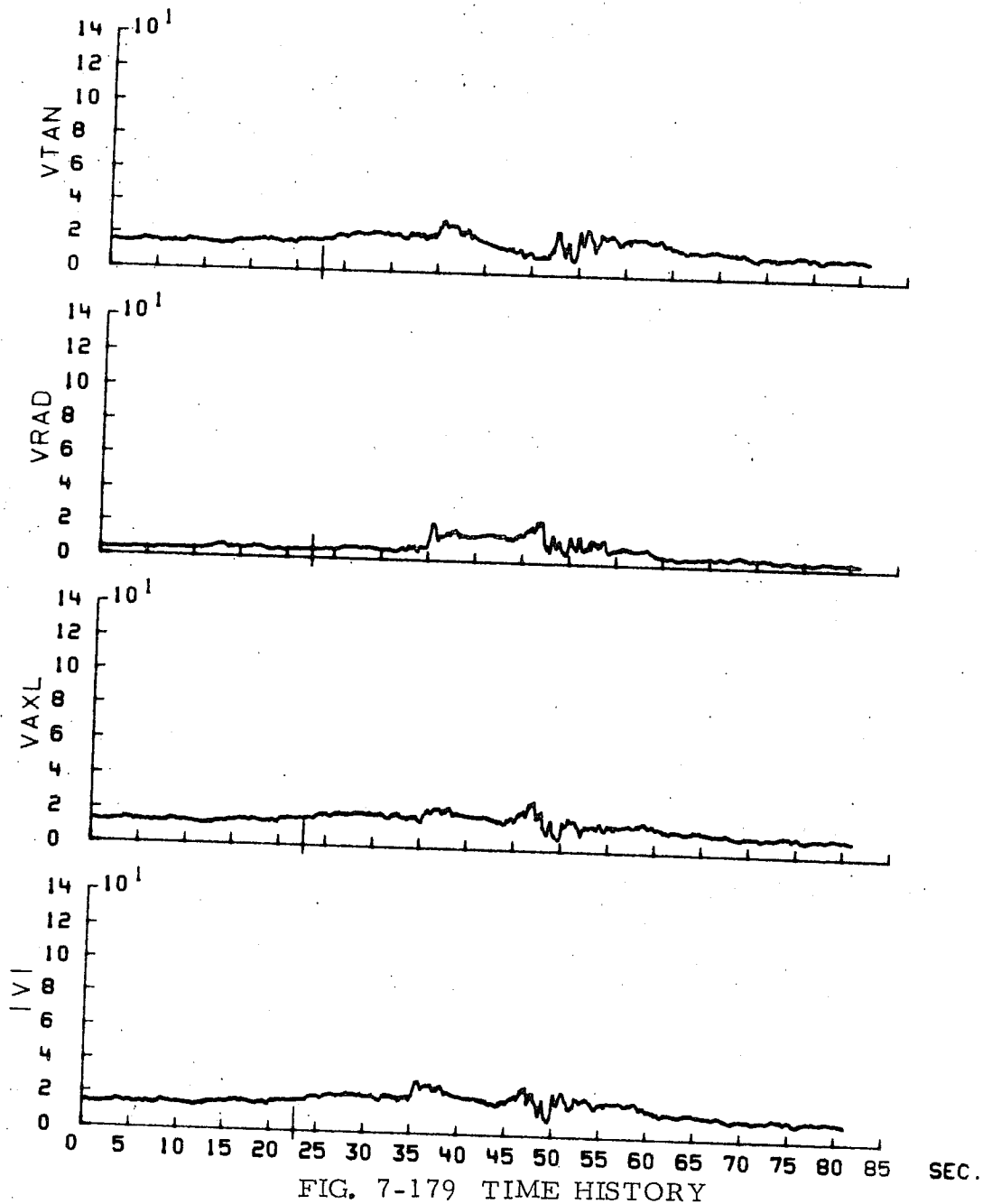


FIG. 7-179 TIME HISTORY

727 ESSA 150 FT LEVEL 2/21/70 0834:04 DATA 6

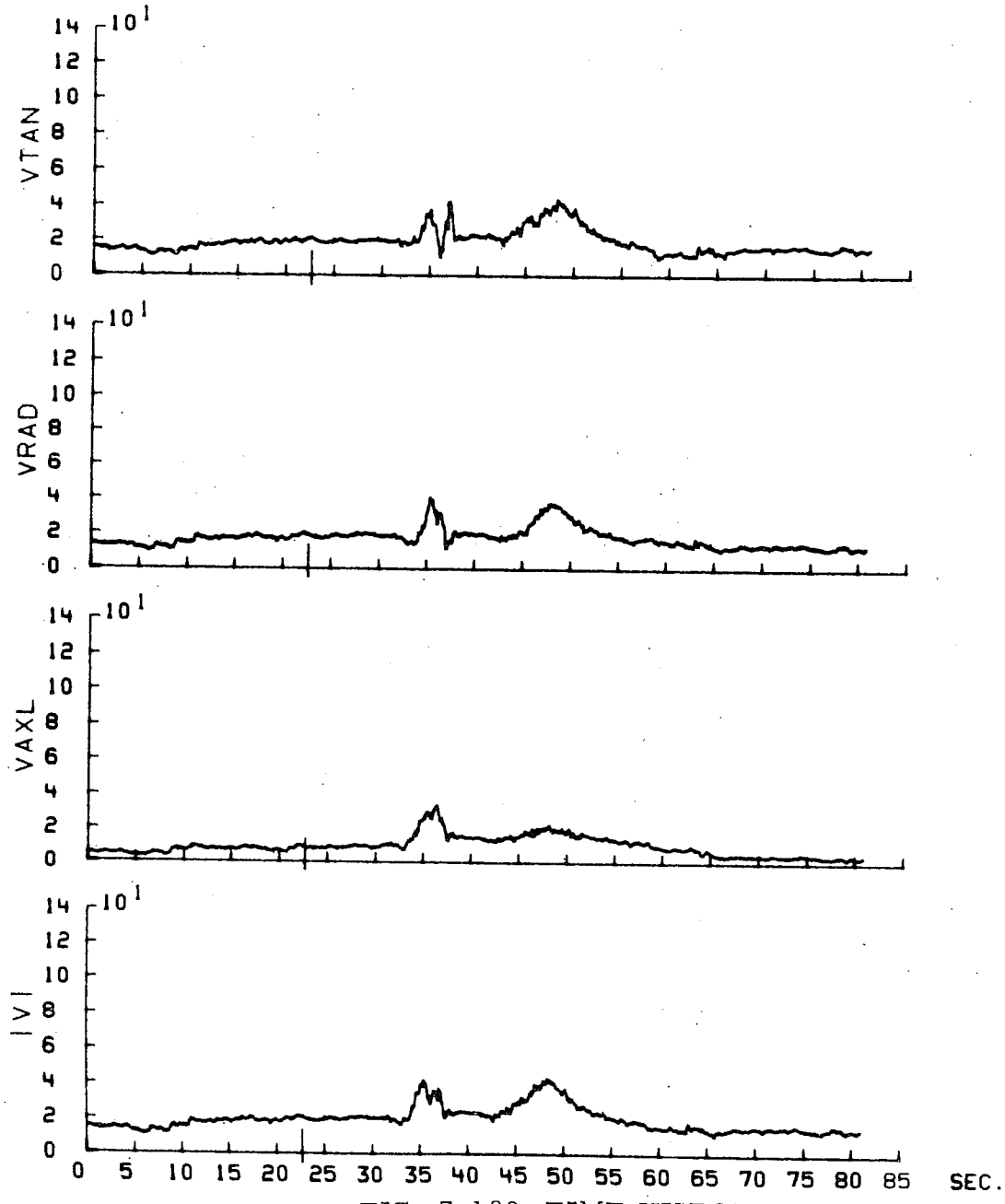


FIG. 7-180 TIME HISTORY

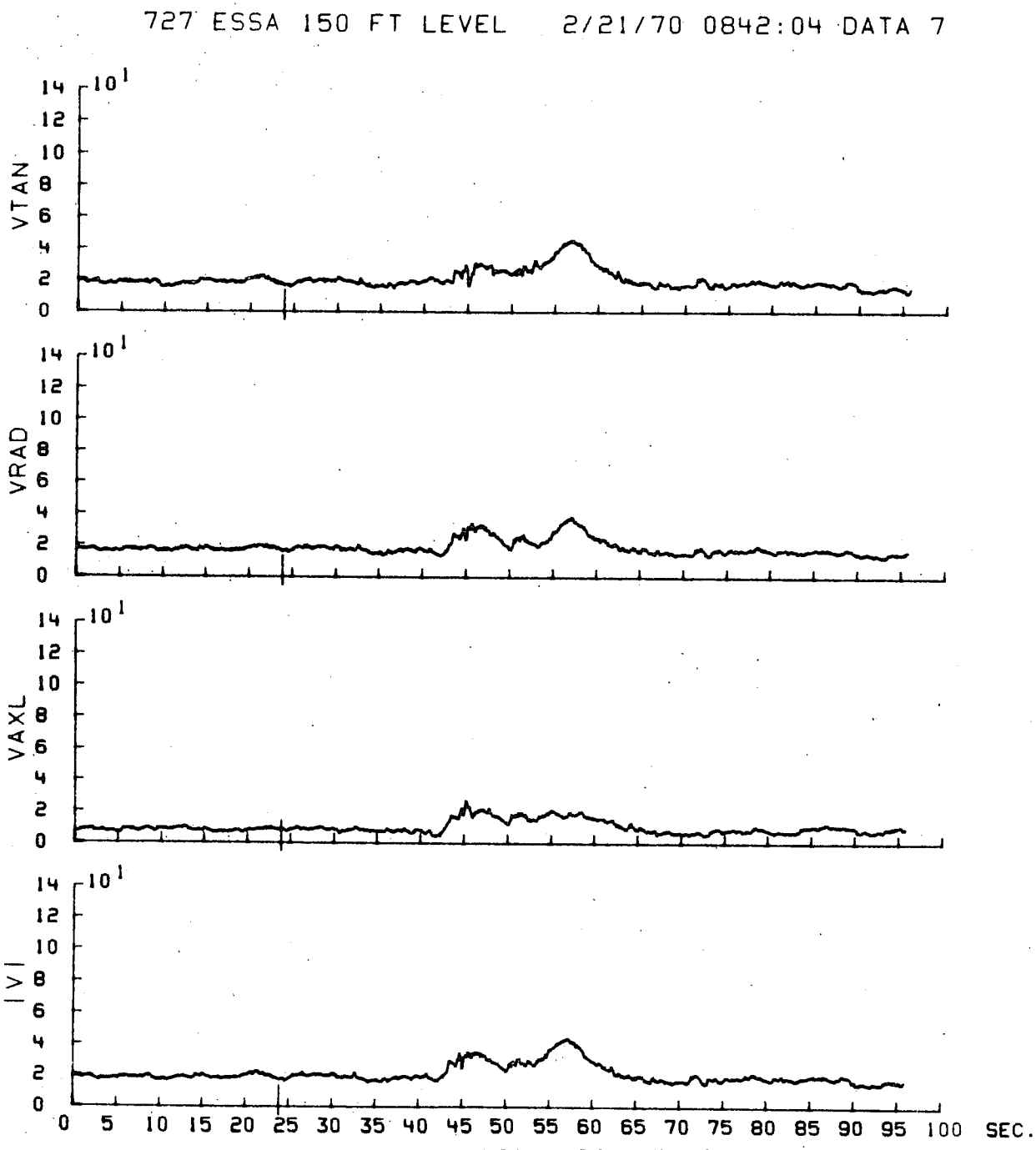


FIG. 7-181 TIME HISTORY

727 TS 175 FT LEVEL 2/21/70 0842:04 DATA 7

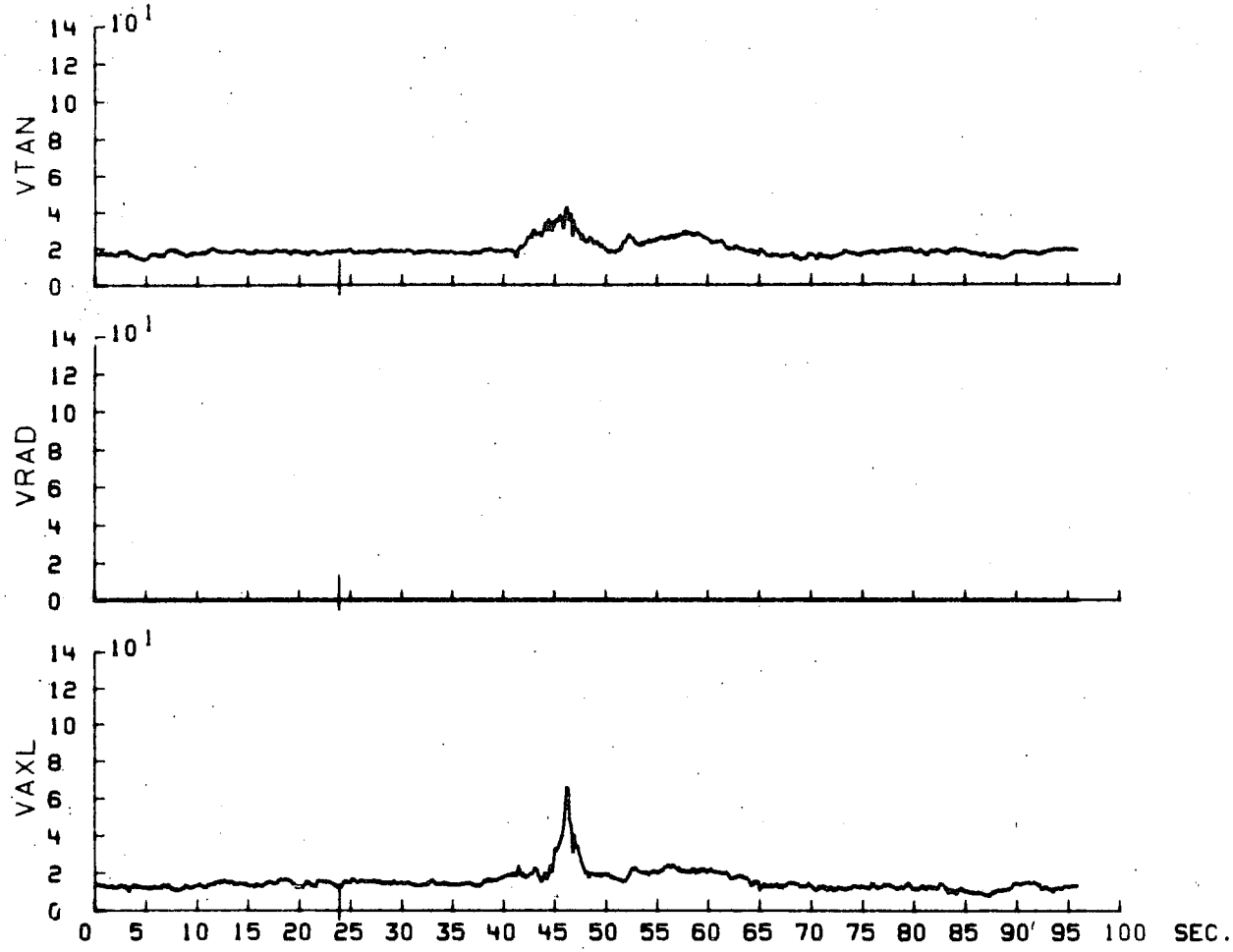


FIG. 7-182 TIME HISTORY

727 TS 100 FT LEVEL 2/21/70 0849:23 DATA 8

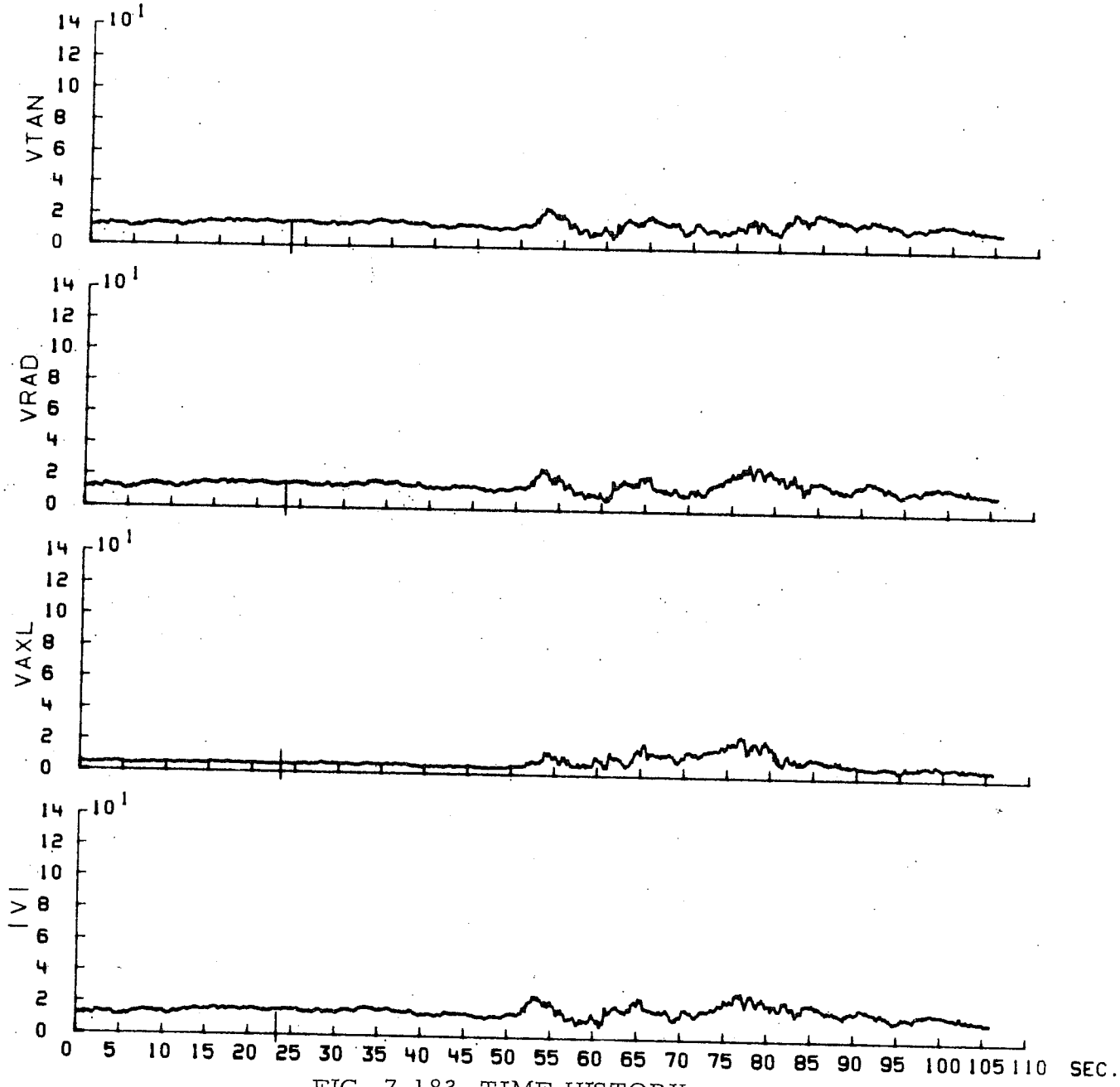


FIG. 7-183 TIME HISTORY

727 TS 125 FT LEVEL 2/21/70 0849:23 DATA 8

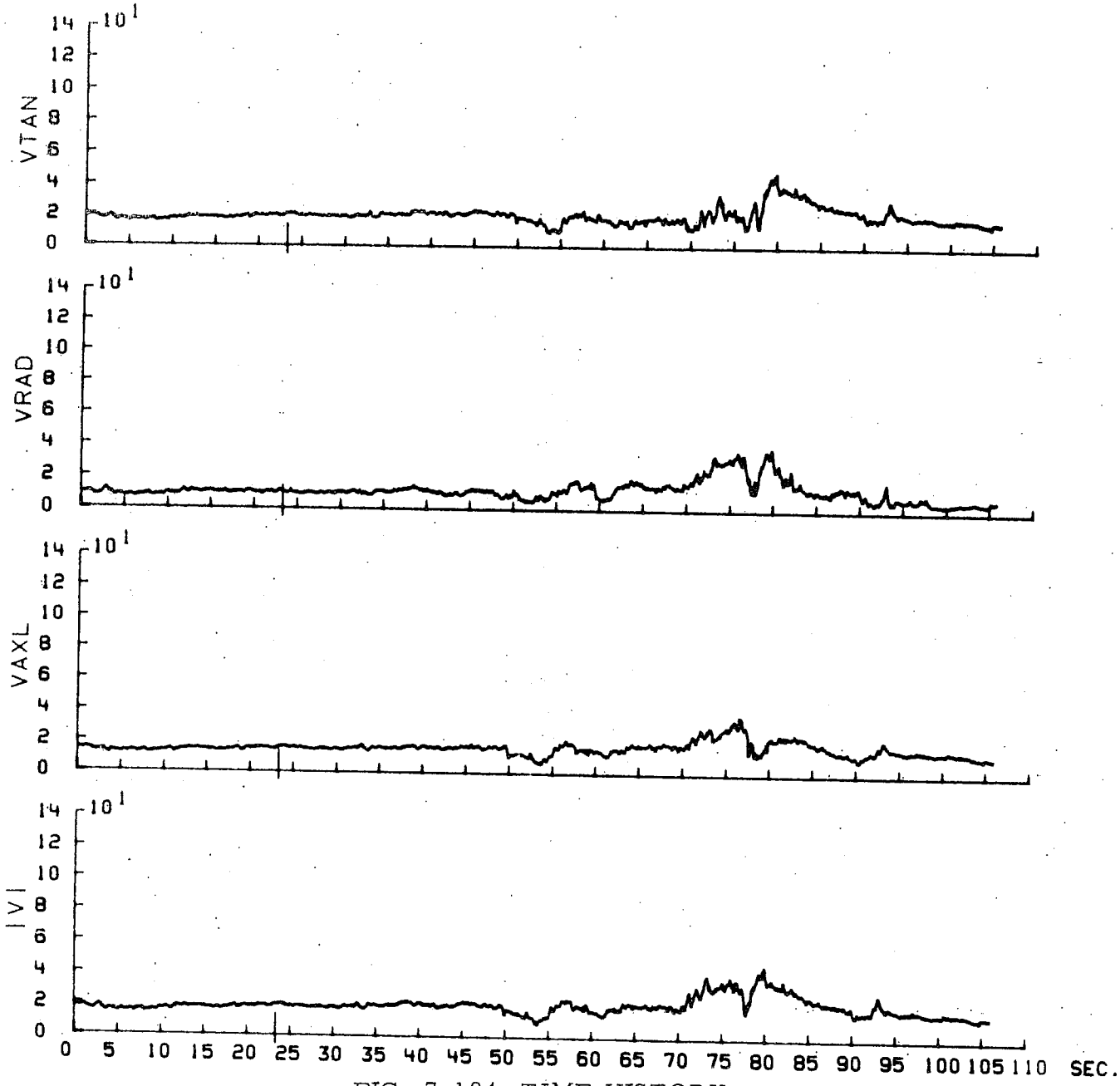


FIG. 7-184 TIME HISTORY

727 ESSA 150 FT LEVEL 2/21/70 0849:23 DATA 8

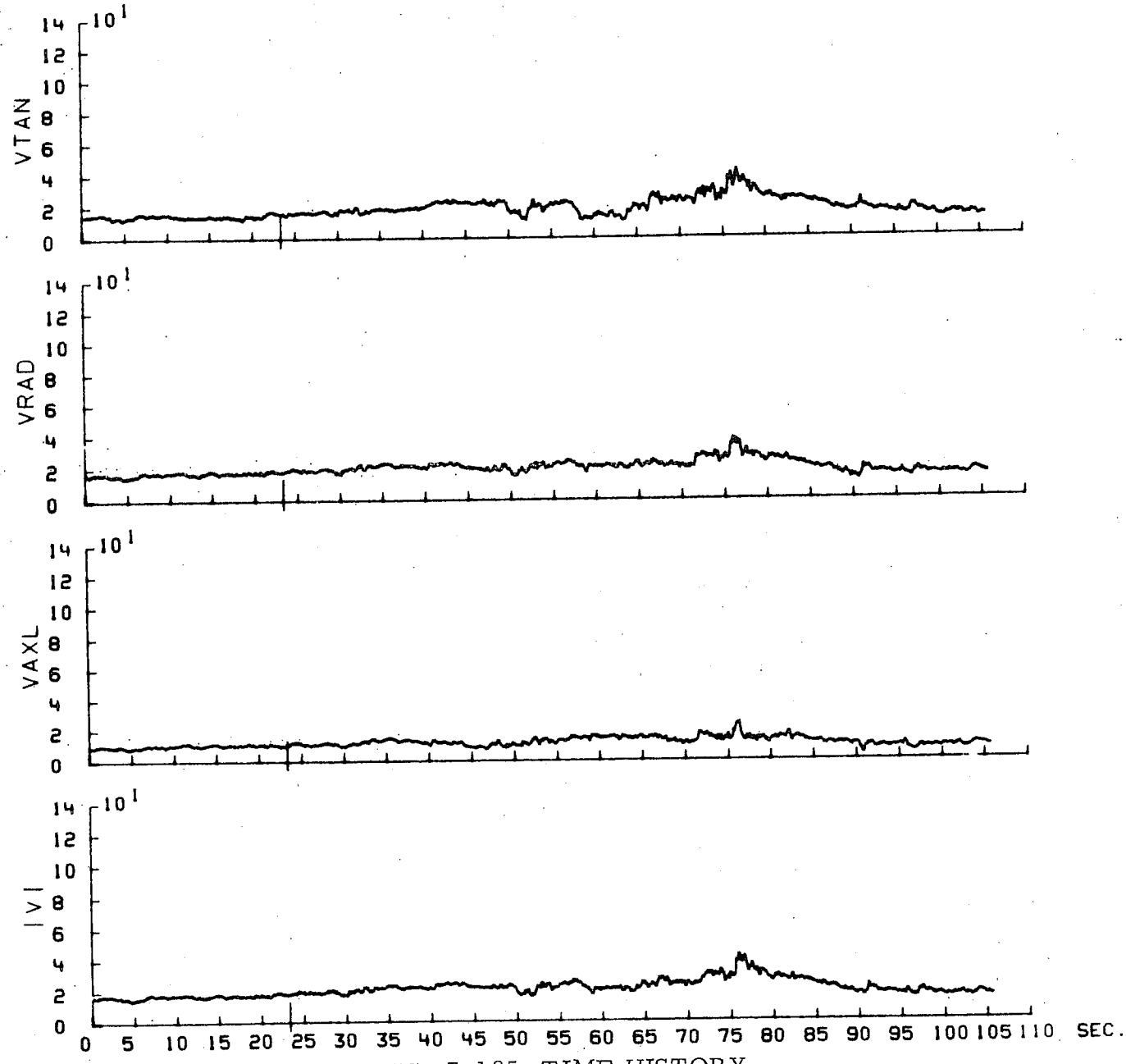


FIG. 7-185 TIME HISTORY

727 TS 100 FT LEVEL 2/21/70 0907:53 DATA 10

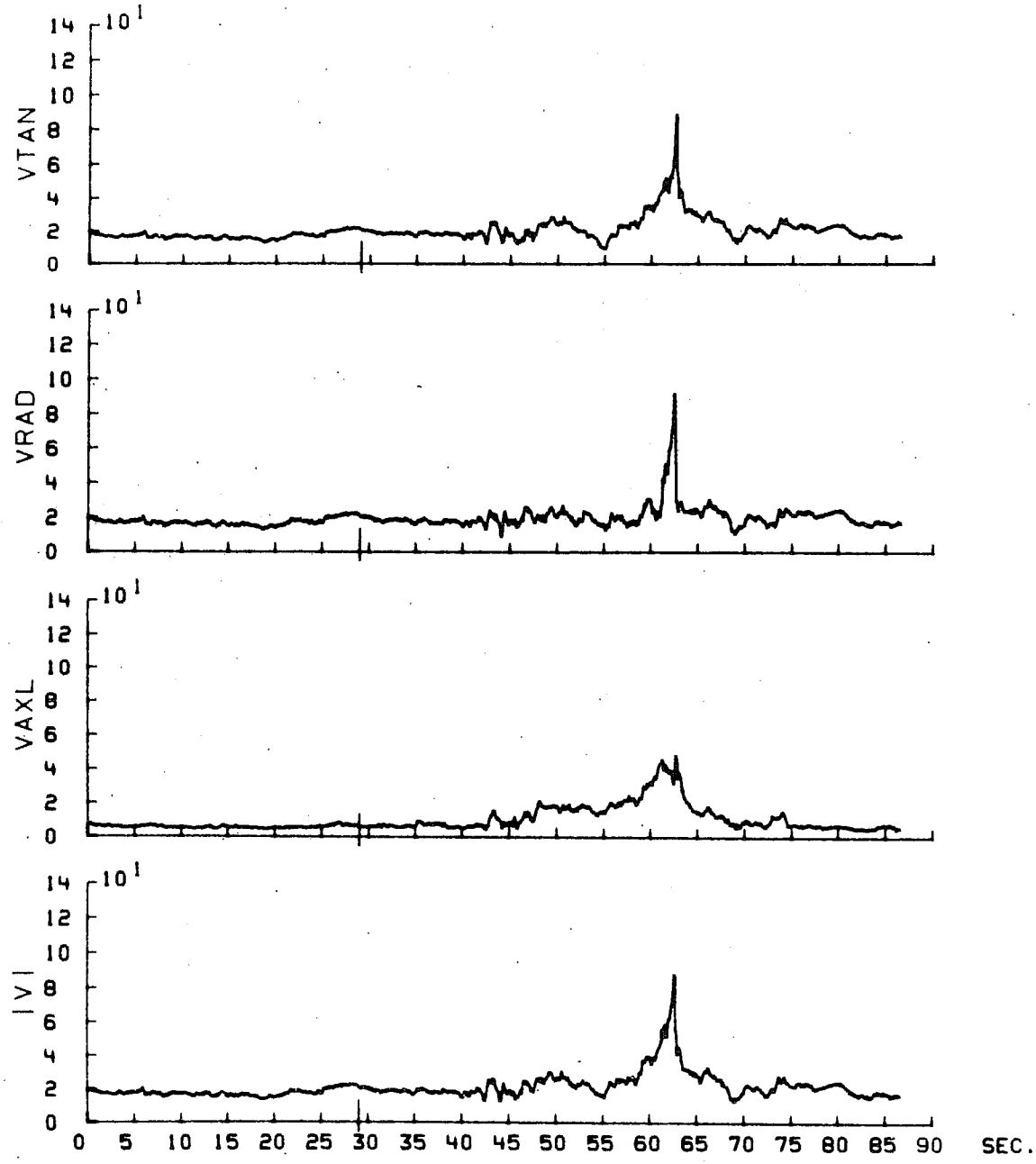


FIG. 7-186 TIME HISTORY

727 BGS 50 FT LEVEL 2/21/70 0916:48 DATA 11

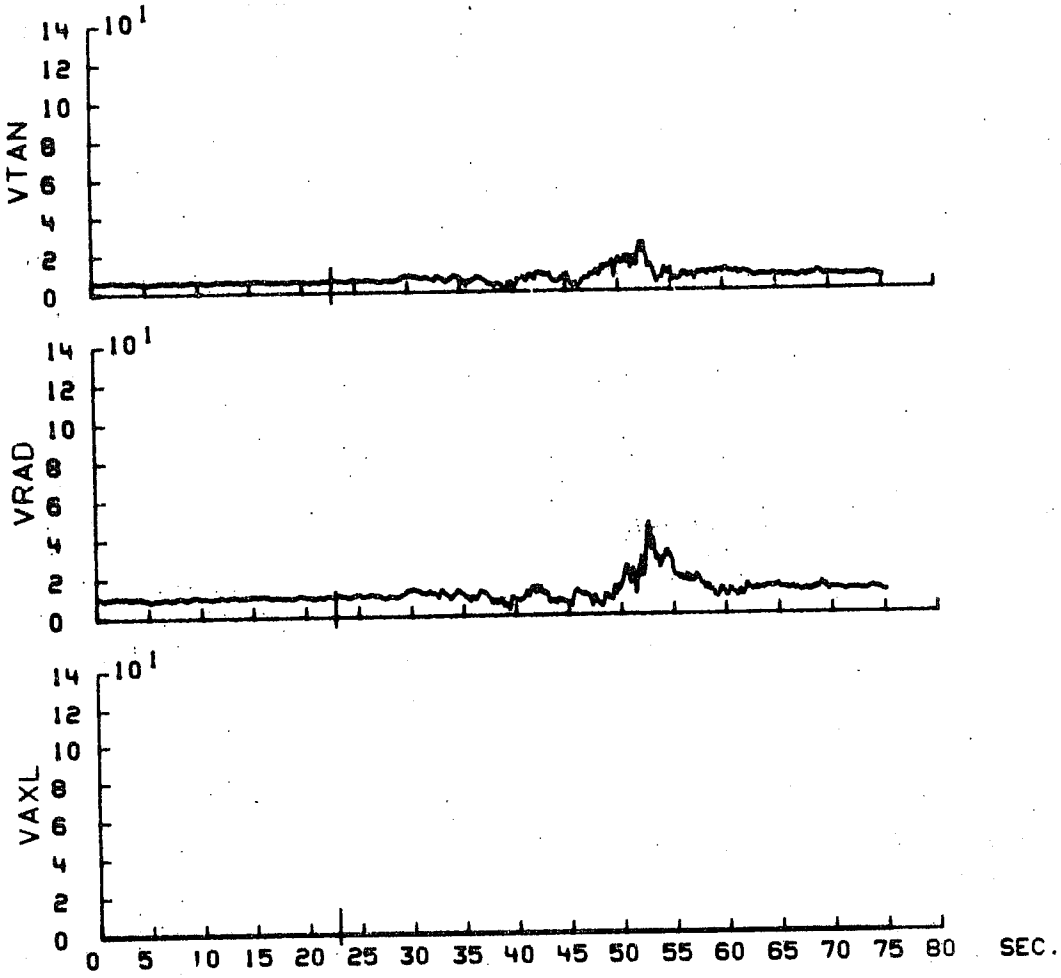


FIG. 7-187 TIME HISTORY

727 TS 100 FT LEVEL 2/21/70 0926:01 DATA 12

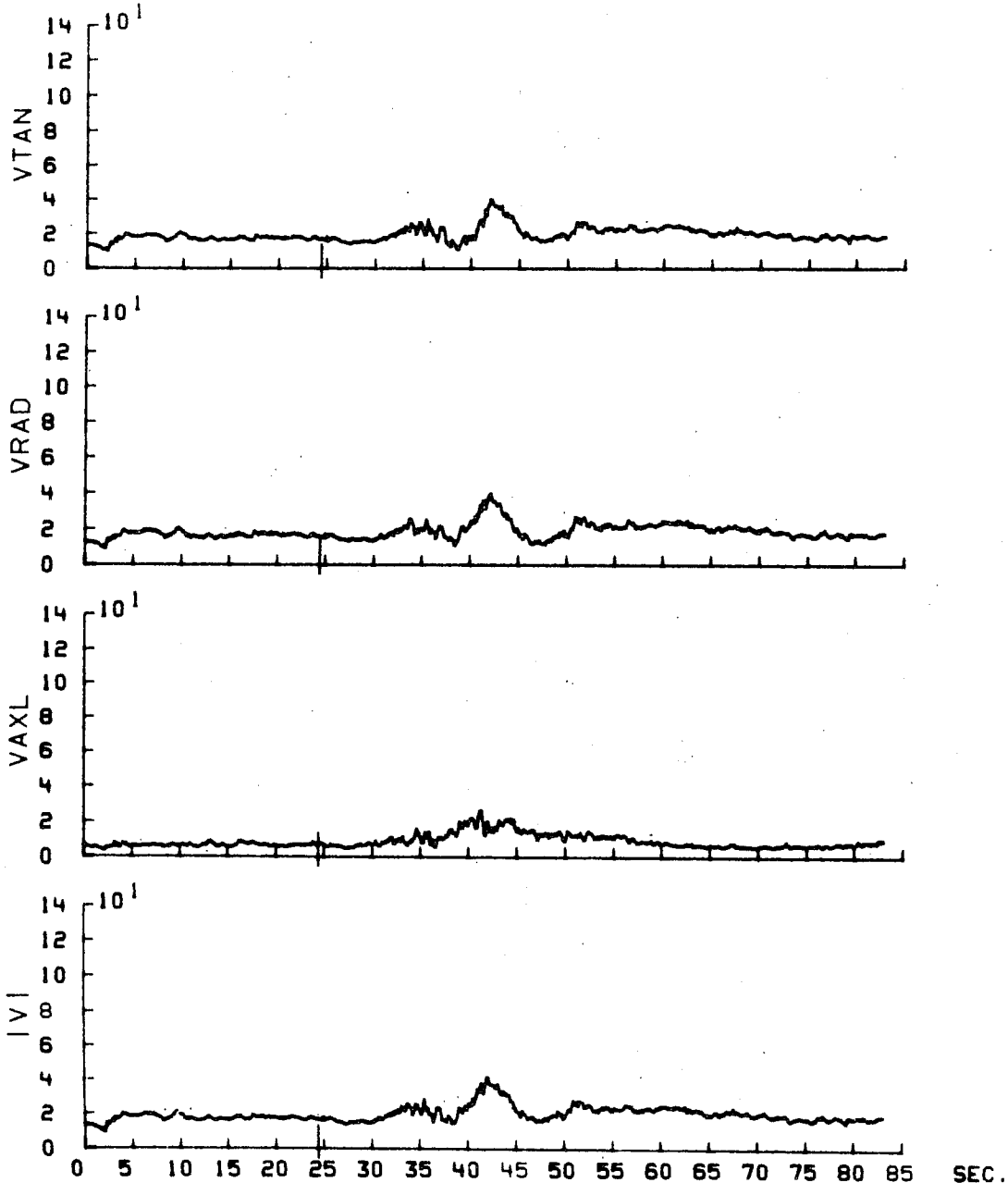


FIG. 7-188 TIME HISTORY

727 TS 125 FT LEVEL 2/21/70 0926:01 DATA 12

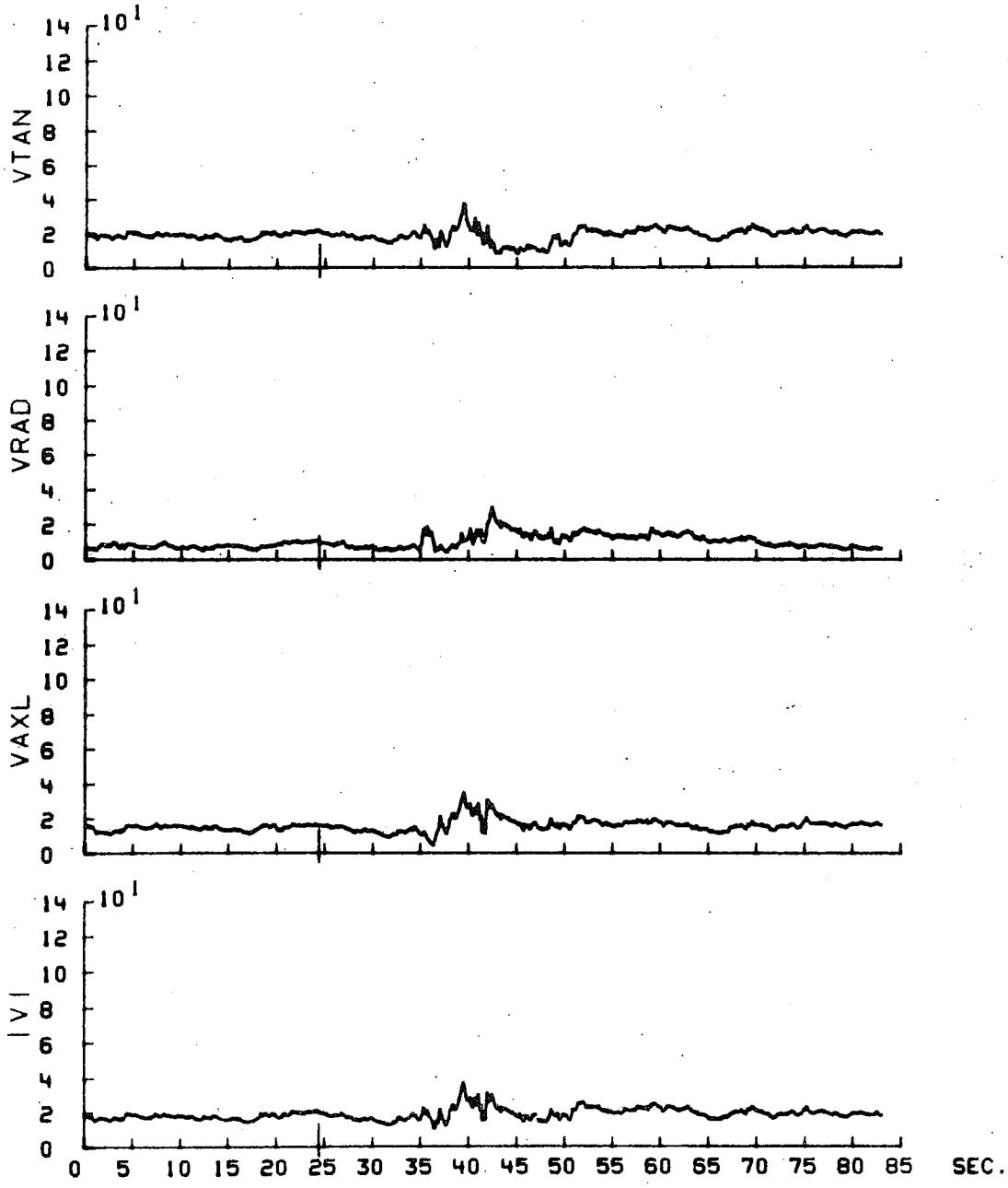


FIG. 7-189 TIME HISTORY

DC9 TS 125 FT LEVEL 2/21/70 1053:20 DATA 1

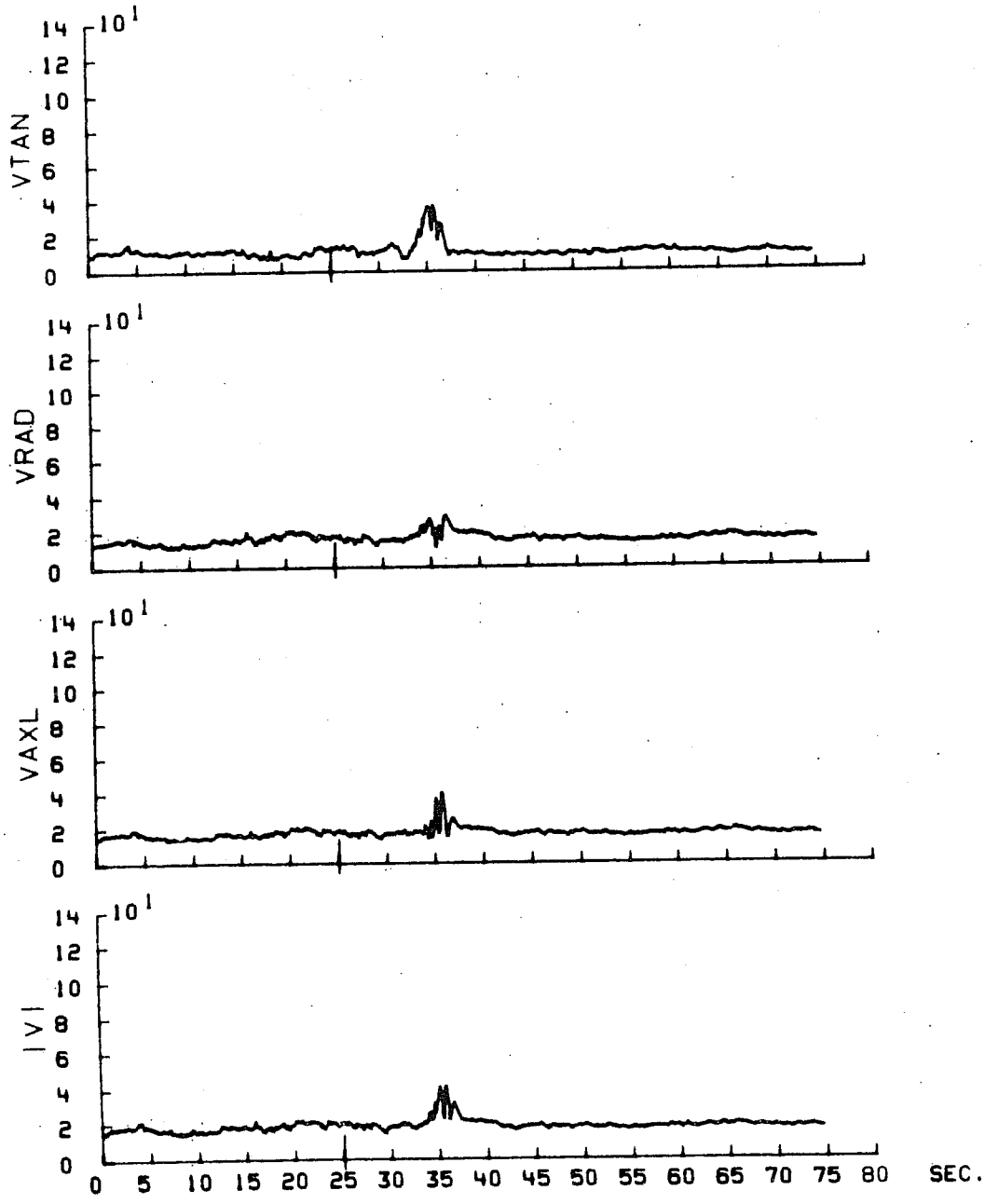


FIG. 7-190 TIME HISTORY

DC9 ESSA 150 FT LEVEL 2/21/70 1053:20 DATA 1

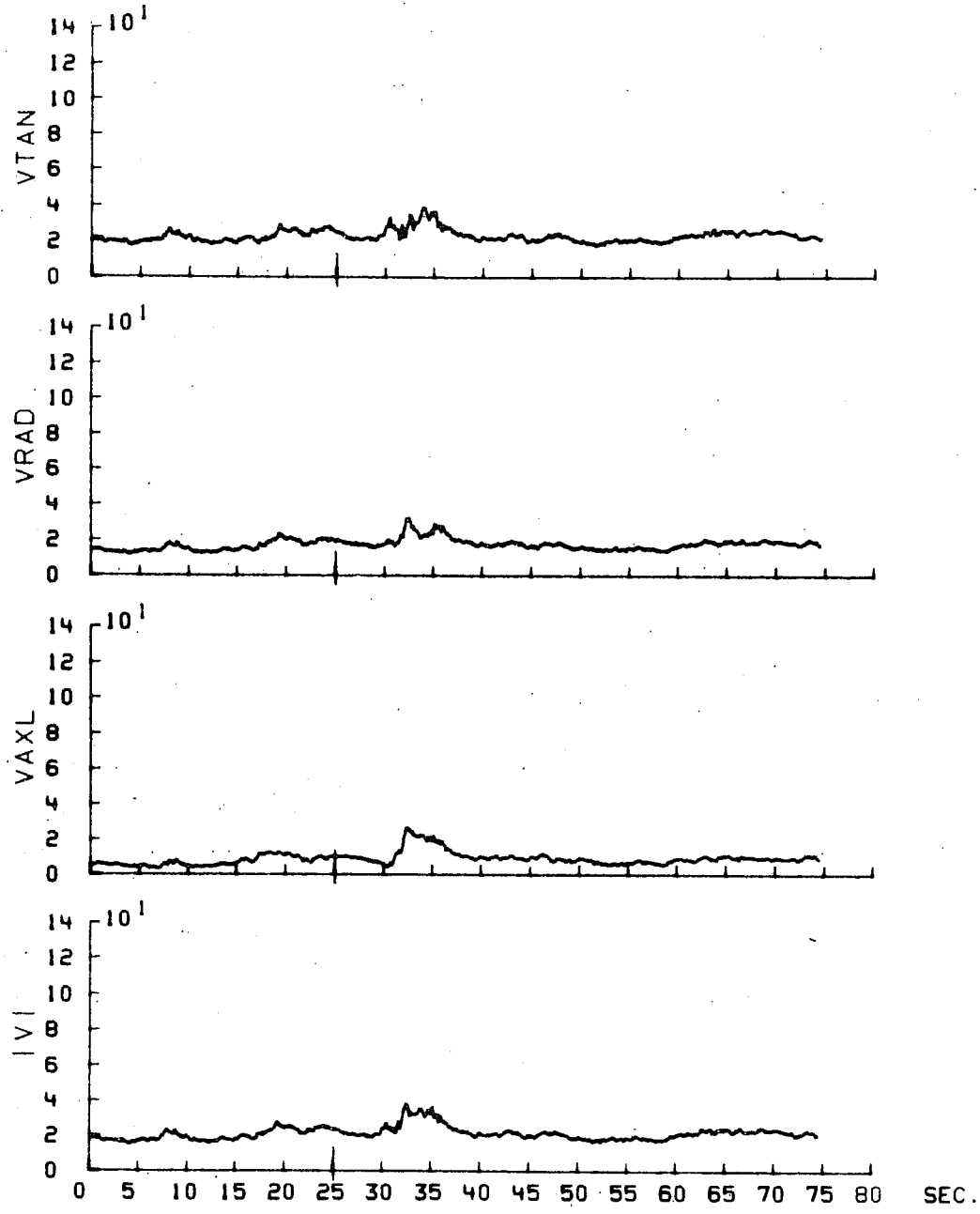


FIG. 7-191 TIME HISTORY

DC9 TS 175 FT LEVEL 2/21/70 1053:20 DATA 1

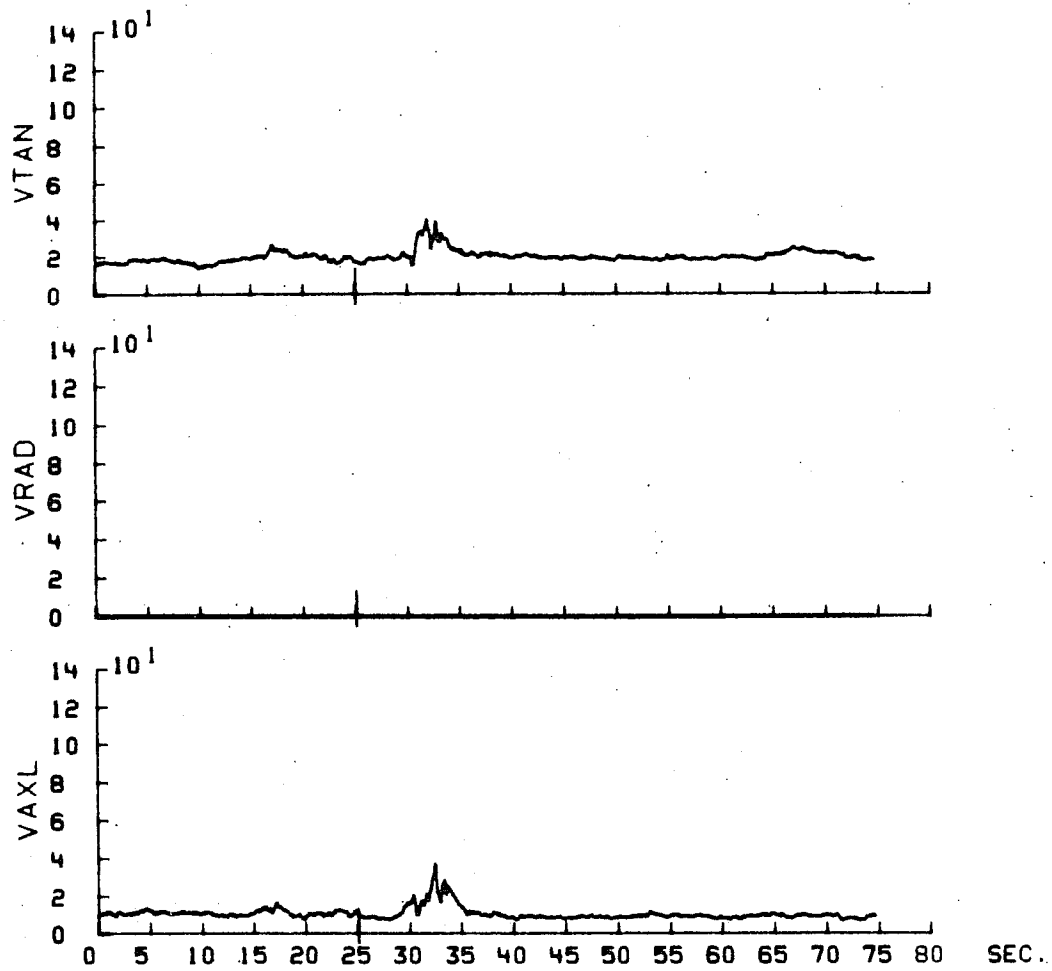


FIG. 7-192 TIME HISTORY

DC9 TS 100 FT LEVEL 2/21/70 1102:56 DATA 2

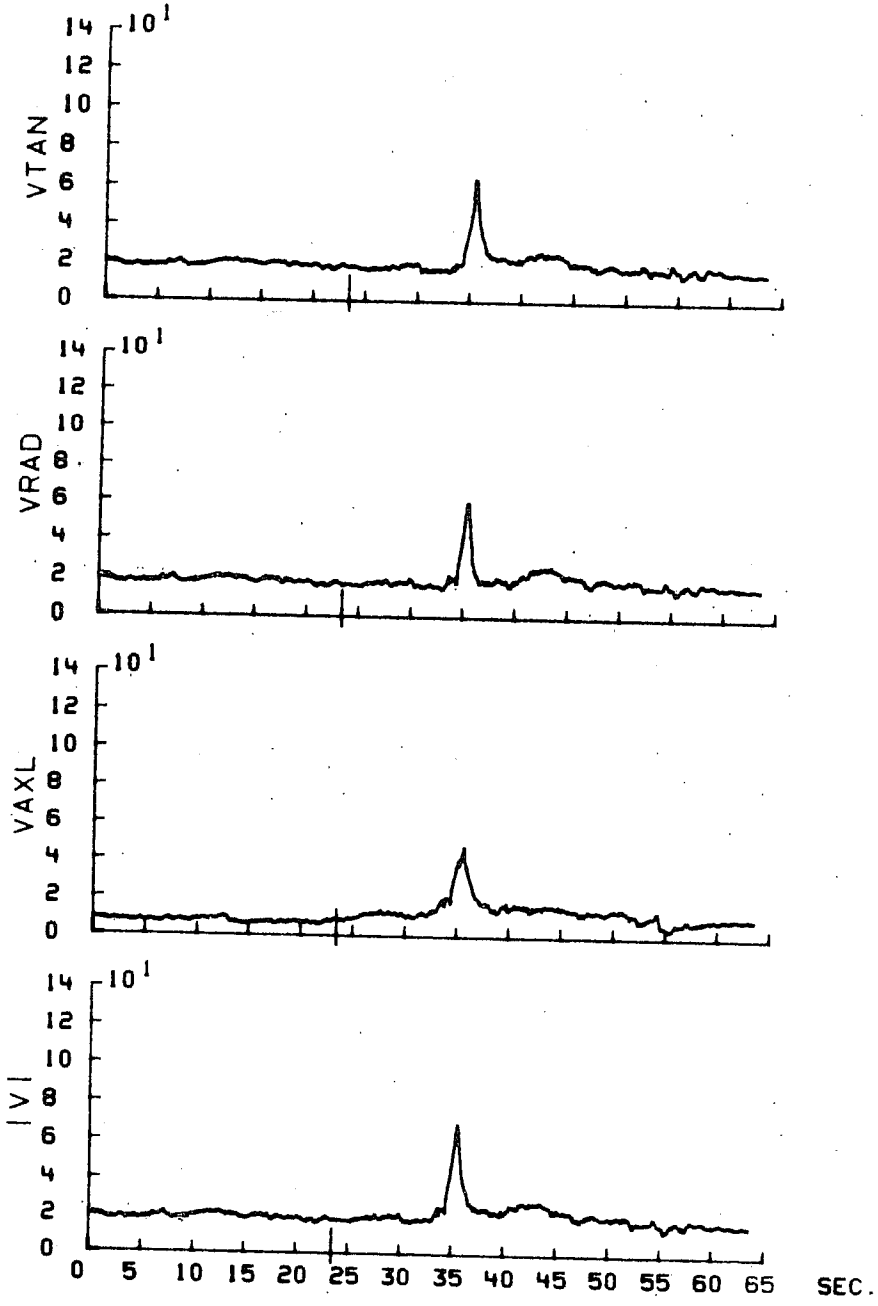


FIG. 7-193 TIME HISTORY

DC9 BGS 50 FT LEVEL 2/21/70 1120:12 DATA 4

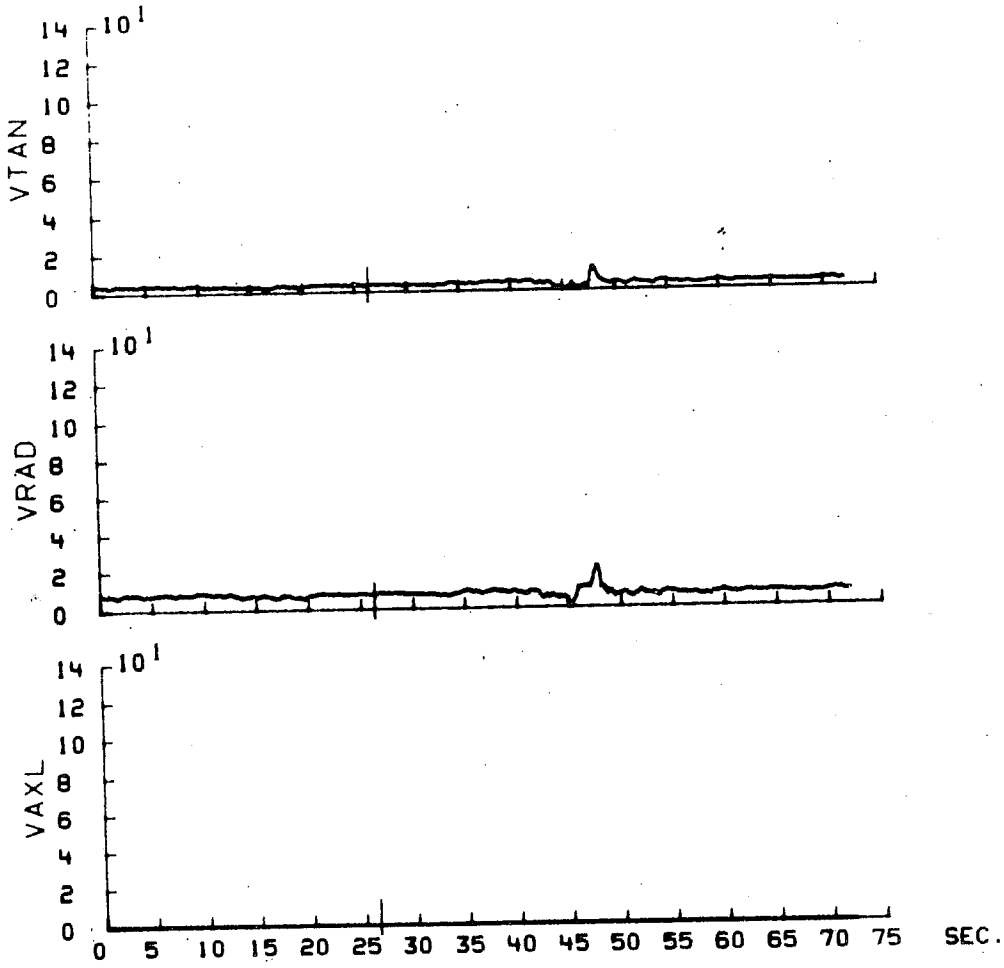


FIG. 7-194 TIME HISTORY

DC9 TS 100 FT LEVEL 2/21/70 1120:12 DATA 4

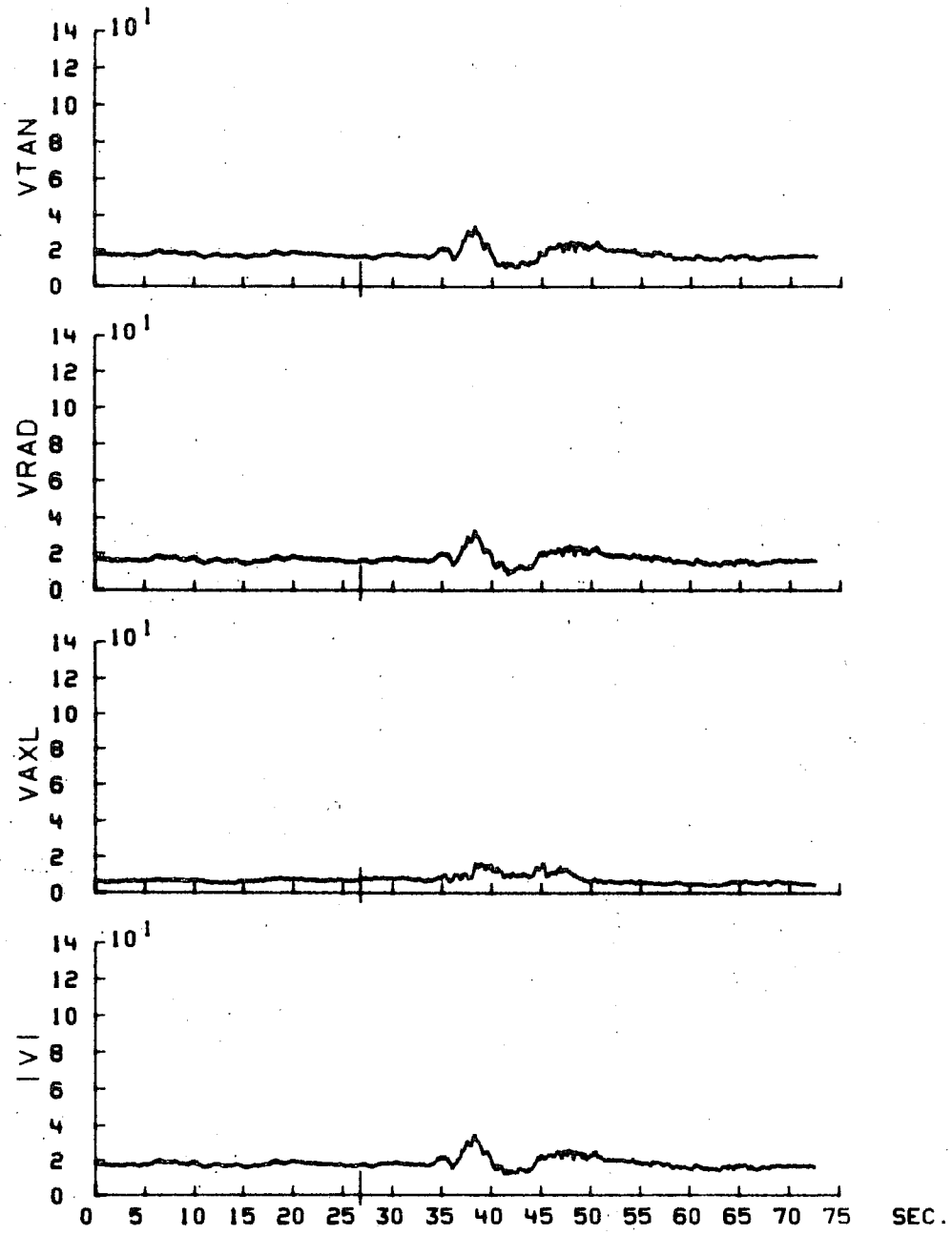


FIG. 7-195 TIME HISTORY

DC9 TS 125 FT LEVEL 2/21/70 1206:41 DATA 10

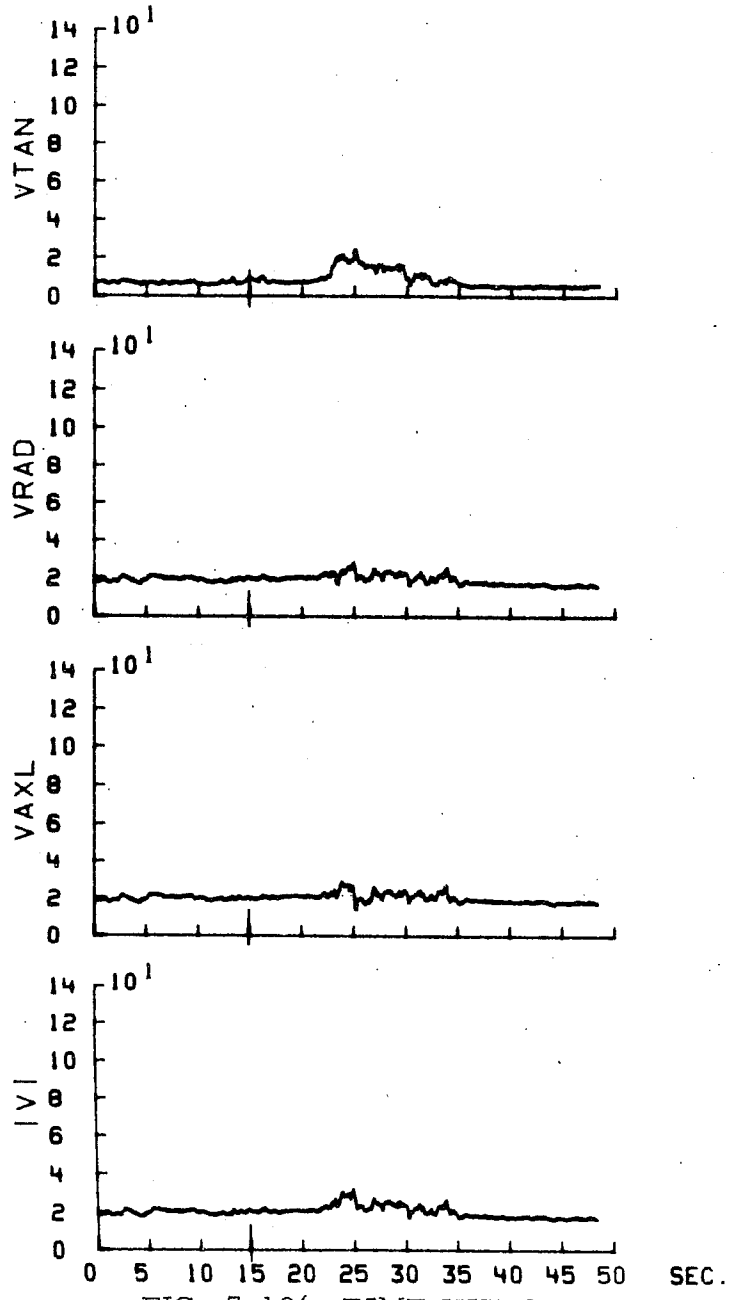


FIG. 7-196 TIME HISTORY

DC9 ESSA 150 FT LEVEL 2/21/70 1206:41 DATA 10

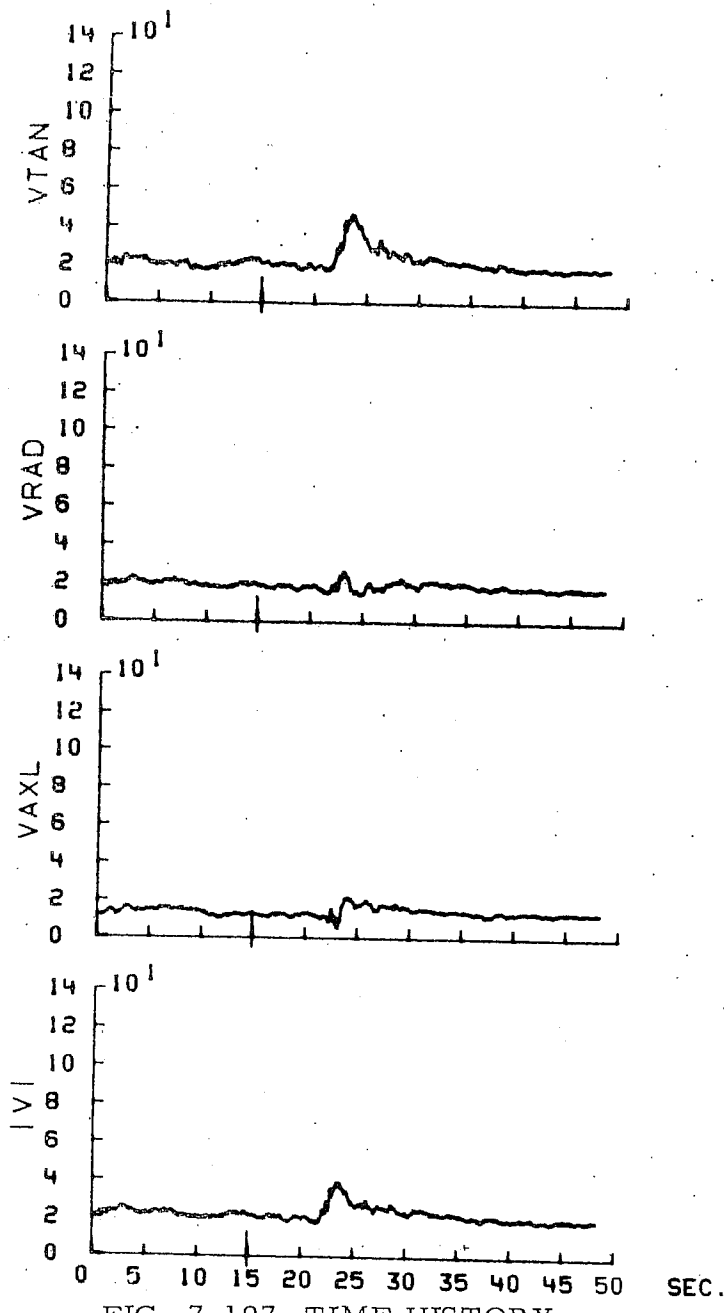


FIG. 7-197 TIME HISTORY