FINAL REPORT TO THE

CALIFORNIA AIR RESOURCES BOARD

UNDER AGREEMENT NO. A4-143-32

("Cloud and Precipitation Scavenging Processes
in the South Coast Air Basin")

Prepared for California Air Resources Board

by

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ABSTRACT

In this report, the instrumentation package utilized aboard the University of Washington's C-131A research aircraft during the SCAQS program is documented. Calibration procedures and adjustments are also presented.

The responsibilities of the University of Washington's Cloud and Aerosol Research Group under Contract A4-143-32 with the California Air Resources Board (CARB) consisted of providing an aircraft from which to obtain airborne measurements of particles and trace gases during the 1987 Southern California Air Quality Study (SCAQS). These measurements included concentrations of SO_2, $SO_4^=$, SO_3^-, PAN, carbonyls, elemental carbon and HNO_3 by means of filter sampling. Canister samples for hydrocarbon speciation were also obtained. Analysis of these measurements is being undertaken by other CARB contractors. In addition, ancillary meteorological and selected continuous trace chemical measurements were obtained. The ancillary measurements have been screened for errors, calibrated and read onto computer tapes. These tapes have been sent to ERT for archiving.

An additional task under this contract was the provision of atmospheric particle size distributions measured aboard the aircraft during SCAQS. These average particle size distributions are presented and discussed in this Final Report.

A total of nine research flights was flown during the SCAQS project, five morning flights and four in the afternoon. Four sampling orbits were made on each flight at pre-determined locals.

1. INTRODUCTION

During the summer of 1987, the Southern California Air Quality Study (SCAQS) was conducted in the Los Angeles Basin. The Cloud and Aerosol Research (CAR) Group of the University of Washington (UW) participated in this study as the "orbiting aircraft". Our task was to obtain filter samples, for subsequent trace chemical species analysis, over four pre-selected sites in the Basin. After each flight, the filter samples were turned over to other SCAQS participants for chemical analysis. Sample volumes, or the data necessary to calculate such volumes, were also turned over to these participants.

Auxiliary to the above task, a number of variables (e.g., SO_2, NO_x, O_3, CO_2) were continuously monitored aboard the University of Washington aircraft. This data has been turned over to the designated SCAQS data manager (ERT Inc.) in the form of standard 9 track, 1600 bpi ASCII computer tapes.

Finally, as a supplementary study, the CAR Group has carried out a preliminary analysis of airborne particle size distribution measurements that were acquired concurrently with the measurements mentioned above.

Because only the last task alluded to above required any analysis by us, it is this topic to which the bulk of this report is devoted. However, some supporting details are also included with regard to the data tapes provided to ERT and the filter samples acquired for other SCAQS participants. The scientific analysis of the data described in this report will be undertaken by other CARB contractors.

2. DATA BASE AND DATA TAPES

2.1 Continuous measurements

The research aircraft used was the University of Washington's C-131A. The layout of the work stations and the major instrumentation units aboard this aircraft are shown in Figure 1. Details on the instrumentation are given in Table 1, where they are grouped under the following headings: navigational and flight characteristics, meteorological, cloud physics, aerosol, cloud and atmospheric chemistry, and data processing and display.

In collaboration with John Collins of ERT, we have selected a subset of the variables shown in Table 1 for inclusion in the data files on the magnetic tapes to be archived for the SCAQS community. These variables are listed in Table 2. The data included on the tapes are calibration corrected (i.e., calibration factors, see Section 3, have been applied). Where grounds exist for suspecting the data quality, the data have been flagged. The time resolution should meet the needs of all SCAQS participants.

Nine research flights were flown during the SCAQS study. These flights are listed in Table 3.

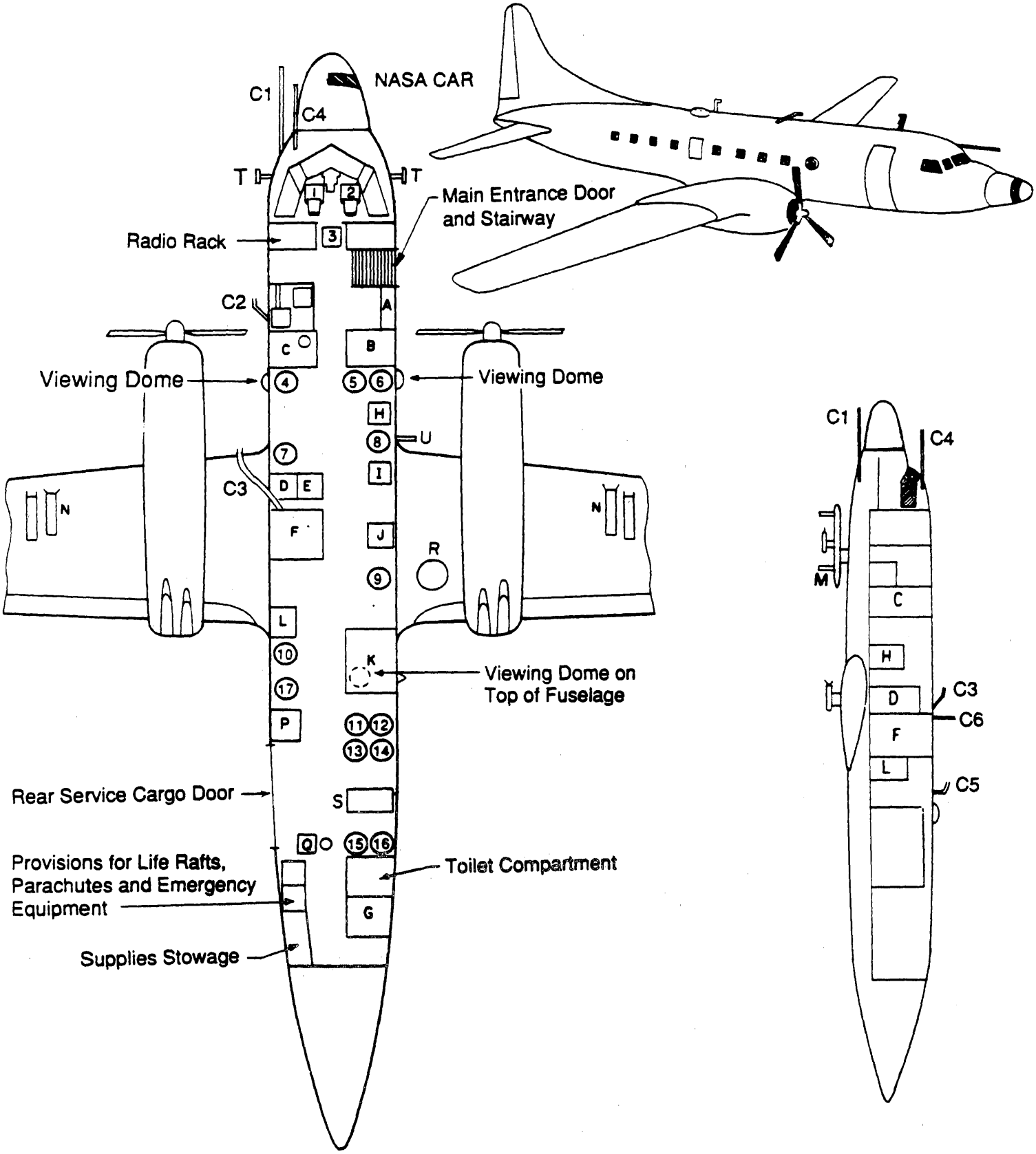

Figure 1. Layout of work stations and major research instrumentation units aboard the University of Washington's Convair C-131A research aircraft. (See following page for key to letters and numbers.)

KEY TO LETTERS AND NUMBERS IN FIGURE 1*

1. Pilot
2. Co-Pilot
3. Flight Scientist or Meteorologist
4. Aerosol Scientist
5. Flight Scientist or Meteorologist
6. Flight Scientist or Meteorologist
7. Chemist
8. Flight Engineer

Locations of Major Research Instrumentation Units

A. Inverters and power distribution.

B. Scientific situation display including digital and graphical monitors, analog and digital hard copies, radio and telecommunications.

C. Primary aerosol characterization system.

- C1. Inlet supplies the grab sampler.
- C2. Inlet supplies the heated plenum and Hi Vol sample ports.
- C3. Inlet supplies the 1.5 m^3 bag sampler and the trace gas detection system.
- C6. Inlet for cloud water sampler.

D. Trace gas system for NO, NO_2.

F. Enclosed 1.5 m^3 bag sampler and aerosol filter system.

G. Vacuum pump cabinet.

H. Data computer and recording system.

I. Controls for meteorological sensors.

M. Pod (located on aircraft belly under position 3) liquid water sensor (J-W) and PMS FSSP probe.

N. Under-wing mounts for 1 and 2-D PMS cloud and precipitation probes.

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* Only instruments used in SCAQS are listed.

TABLE 1. INSTRUMENTATION ABOARD THE UNIVERSITY OF WASHINGTON'S AIRCRAFT*

Parameter	Instrument Type	Manufacturer	Range (and error)
	(a) Navigational and Flight Characteristics		
Latitude and longitude, ground speed and horizontal winds	VLF: Omega navigator	Litton LTN-3000	0 to 300 m s^{-1} (± 1 m s^{-1} groundspeed and ± 1° drift angle)
True airspeed	Variable capacitance	Rosemount Model 831 BA	0 to 230 m s^{-1} (< 0.2%)
Heading	Gyrocompass	King KCS-55A	0 to 360° (± 0.5°)
Pressure altitude	Variable capacitance	Rosemount Model 830 BA	150 to 1060 mb (< 0.2%)
Altitude above terrain	Radar altimeter	AN/APN22	0 to 6 km (< 5%)
Aircraft position and course plotter	Works off DME and VOR (soon to be integrated with VLF Omega system)	In-house	180 km (1 km)
Angle of attack	Potentiometer	Rosemount Model 861	± 23° (< 0.5°)
Pitch angle	Gyroscope	Sperry M12	± 30°
Rate of climb	Variometer	Ball Engineering	± 12 m s^{-1}
	(b) Meteorological		
Total air temperature	Platinum wire resistance	Rosemount Model 102CY2CG + 414 L Bridge	-70 to 30°C (< 0.1°C)

(Continued)

* Only instruments used in SCAQS are listed

TABLE 1. (Continued)

Parameter	Instrument Type	Manufacturer	Range (and error)
	(b) Meteorological (Continued)		
Static air temperature	Computer value	In-house	-70 to 30°C (< 0.5°C)
Dew point	Dew condensation	Cambridge Systems Model TH73-244	-40 to 50°C (< 1°C)
	(c) Cloud Physics		
Liquid water content	Hot wire resistance	Johnson-Williams	0 to 2 and 0 to 6 g m^{-3}
Size spectrum cloud particles	Forward lightscattering	Particle Measuring Systems Model FSSP	2 to 47 μm*
Size spectrum cloud particles	Diode occultation	Particle Measuring Systems Model OAP-200X	20 to 30 μm*
Size spectrum cloud particles	Diode occultation	Particle Measuring Systems Model OAP-200X	20 to 300 μm*
Size spectrum of precipitation particles	Diode occultation	Particle Measuring Systems Model OAP-200Y	300 to 4500 μm*
	(d) Aerosol		
Number concentrations of particles	Light transmission	General Electric Model CNC II	10^2 to 10^6 cm^{-3} (particles > 0.005 μm)*

(Continued)

* All particle sizes refer to maximum particle dimensions.

TABLE 1. (Continued)

Parameter	Instrument Type	Manufacturer	Range (and error)
	(d) Aerosol (Continued)		
Size spectrum of particles	Electric aerosol analyzer	Thermal Systems, Inc. Model 3030	0.0032 to 1.0 μm*
Size spectrum of particles	90° lightscattering	Particle Measuring System (LAS-200)	0.5 to 11 μm*
Size spectrum of particles	Forward lightscattering	Royco 245 (In-house modified)	1.5 to 40 μm*
Size spectrum of particles	Diffusion battery	Thermal Systems, Inc. Model 3040 with in-house automatic valves and sequencing	0.01 to 0.2 μm*
Size spectrum of particles	35 - 120° lightscattering	Particle Measuring Systems Model ASASP-100X	0.09 to 3.0 μm (< 0.007 μm)*
Size spectrum of particles	Forward lightscattering	Particle Measuring Systems Model FSSP	2 to 47 μm*
Size-segregated concentrations of particles	Cascade impactor	Sierra Instruments Inc.	0.1 to 3 μm* (6 size fractions)
Light-scattering coefficient	Integrating nephelometer	Meteorology Research, Inc. Model 1567 (modified for increased stability and better response time)	1.0×10^{-6} m^{-1} to 2.5×10^{-3} m^{-1}

(Continued)

* All particle sizes refer to maximum particle dimensions.

TABLE 1. (Continued)

Parameter	Instrument Type	Manufacturer	Range (and error)
	(e) Cloud and Atmospheric Chemistry		
Cloud water samples	Impaction on slotted rods	In-house modification of ASRC sampler	Bulk cloud water collection efficiency ~ 40% based on analysis of in-house flight data
SO_2	Pulsed fluorescence	Teco SP43 (modified in-house)	1.0 ppb to 5 ppm
Ozone	Chemiluminescence (C_2H_4)	Monitor Labs Model 8410 A	0 to 5 ppm (< 7 ppb)
NO, NO_2, NO_x	Chemiluminescence (O_3)	Modified Monitor Labs Model 8840	0 to 5 ppm (~ 1 ppb)
	(f) Data Processing and Display		
Time	Time code generator	Systron Donner Model 8220	h, min, s ($1:10^5$)
Time	Radio UW	Gertsch RHF 1	min
Ground communication	FM transceiver	Motorola	200 km
Inflight data processing	Mini-computer	Computer Automation LSI-III	--
Inflight color	Micro-computer	Apple II	--
Recording (digital)	Micro-computer directed cartridge recorder	3M	--
Recording (digital)	Floppy disk	Calcomp Model 140C	--

(Continued)

TABLE 1. (Continued)

Parameter	Instrument Type	Manufacturer	Range (and error)
	(f) Data Processing and Display (Continued)		
Recording (analog voice transcription)	Cassette recorder	Radio Shack	--
Digital printout	Impact printer		
Analog strip charts	6-channel Hi-speed ink recorder	Brush Model 260	--

TABLE 2. PARAMETERS INCLUDED ON SCAQS DATA TAPES

Parameter	Units	Time Resolution
Time	hours, minutes, seconds	1 second
Dewpoint	° C	1 second
Total Temperature	° C	1 second
Static Temperature	° C	1 second
Static Pressure	mb	1 second
Liquid Water Content	g m^{-3}	1 second
Drop Rate	cm^{-3} s^{-1}	1 second
CN Concentration	cm^{-3}	1 second
b_{scat} = total light scattering	m^{-1}	1 second
b_{sp} = light scattering due to dried particles	m^{-1}	1 second
NO	ppb	1 second
NO_x	ppb	1 second
O_3	ppb	1 second
SO_2	ppb	1 second
Wind Direction	° magnetic	1 second
Wind Speed	m s^{-1}	1 second
Ultraviolet Light Intensity	millicalories cm^{-3} min^{-1}	1 second
True Air Speed	m s^{-1}	1 second
Latitude	° N	1 second
Longitude	° E	1 second
Ground Speed	m s^{-1}	1 second
LOR	° magnetic	1 second
DME 1	nautical miles	1 second
DME 2	nautical miles	1 second

TABLE 3. SCAQS DATA FLIGHTS BY THE UNIVERSITY OF WASHINGTON (UW) C-131A AIRCRAFT

UW Flight Number	Date (1987)	Sampling Time Period (PDT)
1290	19 June	1500 - 1830
1292	24 June	0440 - 0800
1293	25 June	0440 - 0800
1294	25 June	1340 - 1630
1302	13 June	0515 - 0800
1304	14 June	0450 - 0800
1305	14 June	1440 - 1715
1306	15 June	0450 - 0800
1307	15 June	1500 - 1730

2.2 Filter measurements

The various filter measurements taken aboard the C-131A during the SCAQS project are summarized in Table 4 together with the groups responsible for the filter analysis. All samples were taken from the high-volume bag sampler aboard the C-131A (see Fig. 1). This sampler has an ~10 cm I.D. sample intake line of stainless steel which fills an ~1.5 m^3 high density polyethylene bag from which all filter samples are drawn. The intake line is ~ 2 m in length and is capped by an isokinetic sampling head for particles in the submicron range. All sample lines between the bag and the various filters were teflon or high density polyethylene.

Associated with the filter measurements are, of course, uncertainties in the measurements. The portion of the uncertainty which can be characterized by the University of Washington is confined to the uncertainties in sample volumes measured through each filter. Both integrated flow meters (meters with totalizers) and non-integrating flow meters were employed. Flows, sample volumes and sampling time intervals have already been provided to STI and EMSI. The correction factors and uncertainties associated with this data are provided in this document.

For the non-integrating flow meters, both the flow rate and the time interval over which sampling occurred are important. Start and stop times are given to the nearest second; the uncertainty in these values is estimated at ± 2 sec. Therefore, the sampling time intervals have uncertainties of ±4 sec.

TABLE 4. Filter measurements taken during the SCAQS project aboard the C-131A.

Filter	Species Measured	Nominal Flow	Analysis Organization
Nylon Denuder (Denuder difference)	HNO_3	35 lpm	EMSI/ARB
Quartz	Carbon	50 lpm	ERT
Zefluor	Particulate	25 lpm	EMSI
K_2CO_3 Whatman	SO_2	25 lpm	EMSI
Nuclepore	Particulate mass	14 lpm	EMSI
Alkaline Whatman	PAN	25 lpm	Grojean & Assoc.
Teflo	Particulate Chemistry	35 lpm	EMSI
Oxalic Acid Whatman	NH_3	35 lpm	EMSI
Steel Canisters	Hydrocarbons	---	Oregon Graduate Center
DNPH Canisters	Carbonyls	2 lpm	EMSI

The uncertainties in the flow rates and/or integrated valued for the various University of Washington flow meters employed are given in Table 5. The correction factors for the Hastings and Matheson flow meters were derived by calibration of these devices against a secondary standard (a Hastings flowmeter recently calibrated against a positive displacement piston tube). The in-house calibration was performed on 19 May 1987 and checked on 3 June 1987. The two calibrations gave essentially the same results. The Sierra flow controllers were calibrated by Sierra against positive displacement piston tubes. Since SCAQS was the first project on which these instruments were used, the Sierra calibration has been accepted as correct.

3. SCAQS AUDIT AND INSTRUMENT CALIBRATIONS

The C-131A instrument package was audited three times during the SCAQS field deployment. The first two audits were performed by the Quality Assurance Section of the CARB. These audits took place on 23 and 26 June 1987. The third audit was performed

TABLE 5 Calibration corrections and measurements accuracies for the University of Washington's flowmeters used on the C-131A aircraft during SCAQS 1987. All flows are calibrated with air at 0°C and 760 torr.

Sample Filter	Flow Meter Type	Measurement	Correction Factor*	Accuracy
Nylon	Tylan	Flow rate	see note**	see note**
Quartz	Hastings	total volume	None required	± 1.5 %
Zefluor/Carbonate	Hastings	total volume	0.95	± 1.5 %
Nuclepore	Hastings	total volume	0.94	± 1.5 %
PAN	Sierra	Flow rate	None required	± 1 lpm
NH_3	Matheson	Flow rate	0.93	± 1 lpm
Carbonyl	Sierra	Flow rate	None required	± 0.3 lpm

* Multiply the apparent flow by this value to get the correct flow.
** Contact Jack Horrocks (CARB-LAB), Tel: (808) 575-6990, for information on these CARB flow controllers.

by Sonoma Technology Inc. on 27 July 1987. All three audits showed some consistent discrepancies between the output values of the NO_x, SO_2, O_3 analyzers and the standards utilized in the audits. The magnitudes of the discrepancies are illustrated in Figures 2 and 3, where the CAR Group values are plotted against the CARB standards. The quantitative relationships between the UW and CARB values (in ppb) are given by the following regression equations:

$$NO_2\ (UW) = 1.73\ NO_2\ (CARB) + 10.4$$

$$SO_2\ (UW) = 1.47\ SO_2\ (CARB) - 0.4$$

and

$$O_3\ (UW) = 1.97\ O_3\ (CARB) - 9.7$$

On the basis of these results, an extensive analysis and recalibration of the three analyzers in question was undertaken immediately after the SCAQS field deployment. The results of this analysis are described below.

Examination of the gravimetric data used to determine the permeation rate of the NO_x channel of the NO_x analyzer prior to SCAQS revealed an arithmetic error in the permeation rate calculation. After correcting for this error, much better agreement with the SCAQS audit was obtained. Furthermore, in order to ensure comparability, the instrument calibration was extended up into the range used by the SCAQS auditors. With this extension, the revised calibration produces agreement with the SCAQS audit values to

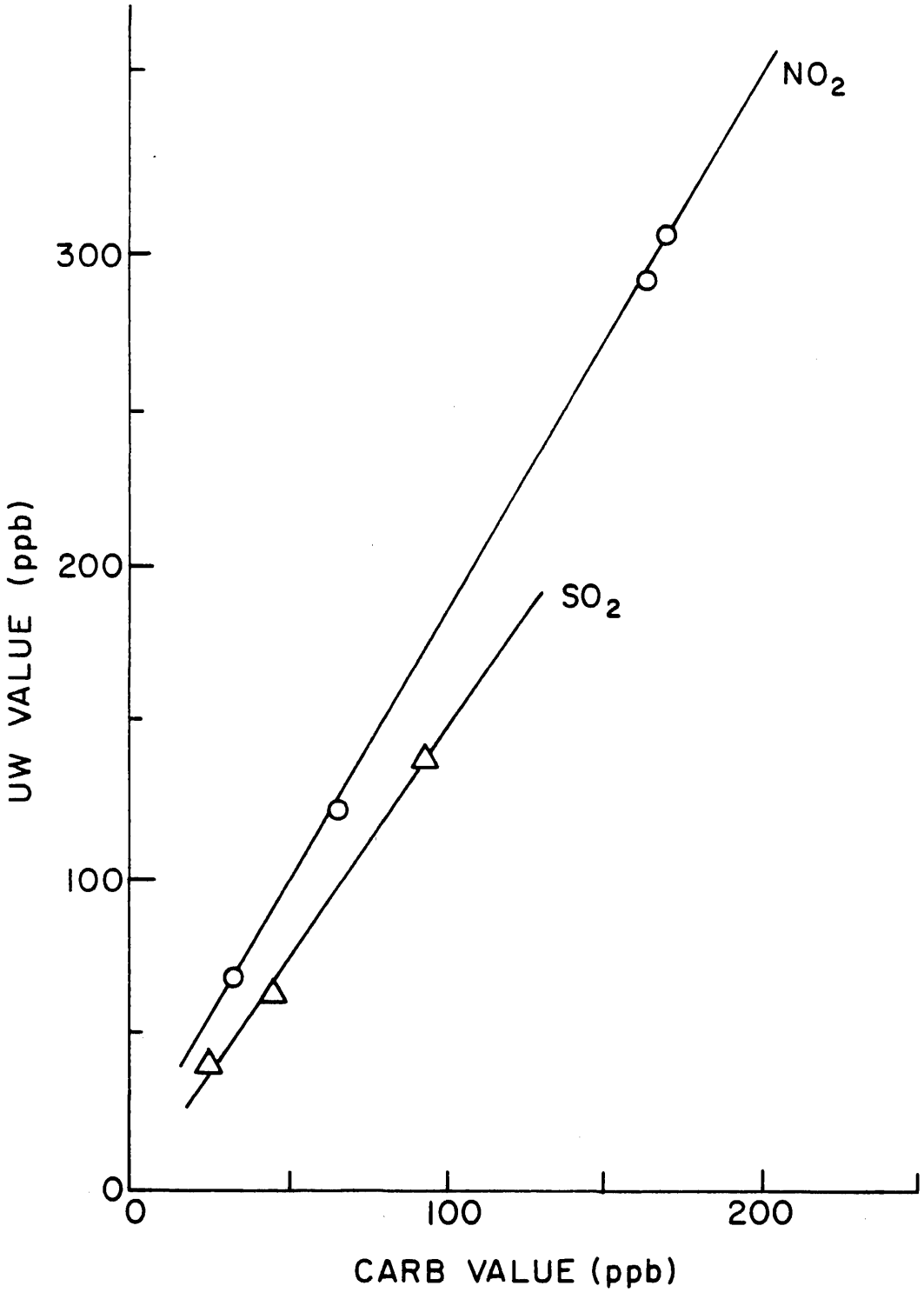


Figure 2 Comparison of UW and CARB audit values for NO_2 and SO_2. UW values shown here are based on calibrations done prior to SCAQS.

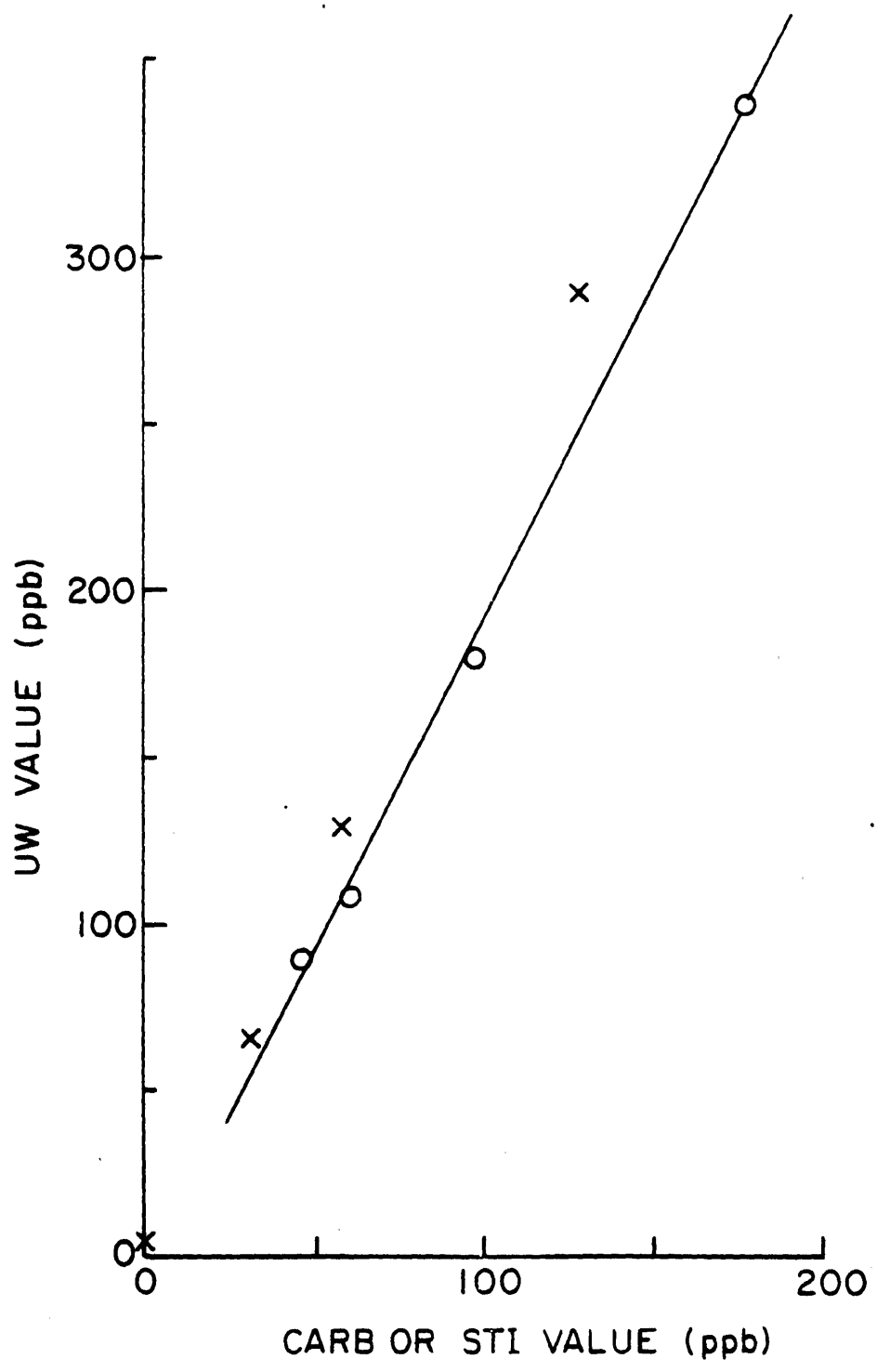


Figure 3 As for Figure 2 but for O_3. Circles are for CARB audit and crosses for STI audit.

better than 10% (see Figure 4). The regression relationship between the UW and CARB values (in ppb) is now given by the expression:

$$NO_2 \text{ (UW)} = 0.94\ NO_2 \text{ (CARB)} + 4.5$$

However, utilizing this calibration, the uncertainty in the NO_x concentration at low ambient levels is considerably enhanced and we can support an uncertainty no better than $\pm$ 5 ppb in place of our usual $\pm$ 1 ppb. Nevertheless, for the SCAQS data the new calibration is clearly preferable to the old, and we have therefore utilized it.

Reanalysis of the SO_2 calibration procedure revealed no obvious errors. However, gravimetric determination of the permeation rate from the tube used to calibrate our analyzer, made shortly after the SCAQS audit, revealed a permeation rate very different from that assumed on the basis of measurements made prior to SCAQS. Subsequent gravimetric monitoring of the permeation rate from this tube (over a period of 6 months) has shown that the permeation rate is highly erratic, varying by as much as a factor of 5. The reason for this abnormal behavior is not clear, either to us or the manufacturer. However, assuming that the permeation rate measured during the SCAQS program is the proper rate to employ, agreement to within ~ 12% of the SCAQS audit values is obtained. Therefore, it is this value that we have utilized on our SCAQS SO_2 data. With recalibration, the quantitative UW - CARB relationship is (for concentrations in ppb):

$$SO_2 \text{ (UW)} = 0.88\ SO_2 \text{ (CARB)} - 1.6.$$

The third discrepancy uncovered by the SCAQS audit concerned the O_3 monitor. Once again, analysis of the calibration procedure produced no obvious errors. We therefore checked the output of our calibration source (a Monitor Labs 8500 UV light source) against a secondary NBS standard calibrated by DOE. This standard, a Dasibi 1003-AH, revealed the calibrator was outputting O_3 at about one-half of the indicated values. After "re-calibration of our calibrator", our calibrated O_3 values are in agreement with the SCAQS audit to better than 10%. The quantitative relationship is now (for concentrations in ppb):

$$O_3 \text{ (UW)} = 0.96\ O_3 \text{ (CARB)} - 0.95$$

One final note on instrumentation, though not precisely on calibration, should be noted. The SO_2 analyzer displayed considerable zero drift during the SCAQS flights, particularly the first four flights. We attribute this to the very high cabin temperatures (> 100° F) encountered during these flights. After the airplane had been modified to adequately ventilate the cabin, this problem was greatly alleviated. However, good quality SO_2 data is sparse during the first four flights.

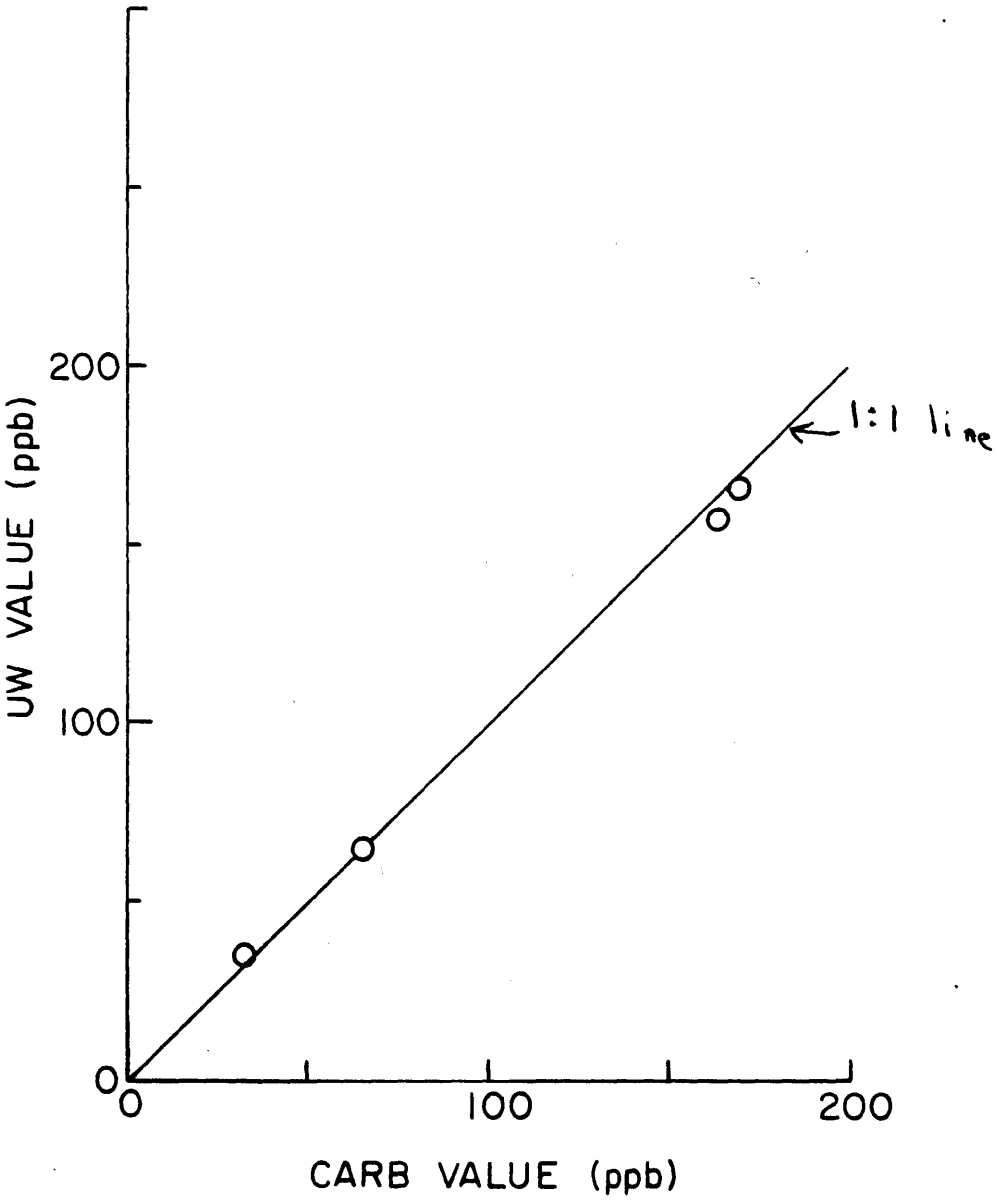


Figure 4 Final comparison of UW and CARB audit values for NO_2. UW values shown here are based on calibrations done after SCAQS.

4. AEROSOL SPECTRA

4.1 Introduction

While not part of the original SCAQS measurement suite, it was decided, subsequent to the SCAQS field program, that aerosol size distributions measurements were of sufficient interest to warrant inclusion of this data in this report. Before presenting this data, a brief description is given of the sampling system used to measure particle size distributions.

The sampling system used on the University of Washington's C-131A aircraft is a high-volume, isokinetic batch sampler. This system is shown schematically in Figure 5. The advantage of such a batch system is that the numerous individual sizing instruments employed, with their widely different time constants and sample volumes, can sample precisely the same air simultaneously. This allows unambiguous generation of a particle size spectrum covering a far wider range that would be the case with continuous samplers sampling independently. Another advantage of this system is that the overlap in instrument measurement ranges allows the consistency of the instruments with one another to be evaluated. Using this system, size spectra over the range 0.01 to 80 μm diameter can be reliably measured, both in clear air and interstitial to cloud droplets. Further discussion of this system can be found in Radke (1983).

The size measurements obtained with this system are interpreted in terms of log-normal particle spectra (Whitby, 1978) and are therefore presented as plots of dN (or dS or dV) /d(log D) vs. log D. Because the measurements are in terms of the number of particles per size interval, the dN/d (log D) plots are the most fundamental. However, differences in particle spectra are most clearly seen with dV/d (log D) plots, therefore, it will be these plots around which most of our discussion will center. There is a potential danger in such a procedure in that very slight shape changes in dN/d (log D) plots -- perhaps random noise -- can generate particle modes in dV/d (log D) plots. To avoid this pitfall, when modes appeared in the dV/d (log D) plots, the dN/d (log D) plots were examined to assess the reasonableness of the modal structure. Furthermore, modes that did not consistently appear in most of the individual samples at any given local were dismissed as spurious.

In the course of the sampling orbits at each of the four pre-selected locations, on the order of 10 individual spectra were obtained. To reduce the cumbersomeness of this large number of spectra, and to yield spectra that could be compared to the individual integrated samples obtained at a frequency of one per orbit, the individual spectra were averaged for each orbit. It is these average spectra on which the following discussion is based. There are, therefore, thirty-six dN, dS and dV plots, respectively, included in the report (see Appendix A).

The discussion of these plots, which follows, is intended to provide the prospective investigator with a brief overview of the complete data base. The plots themselves can be found in Appendix A, listed in chronological order.

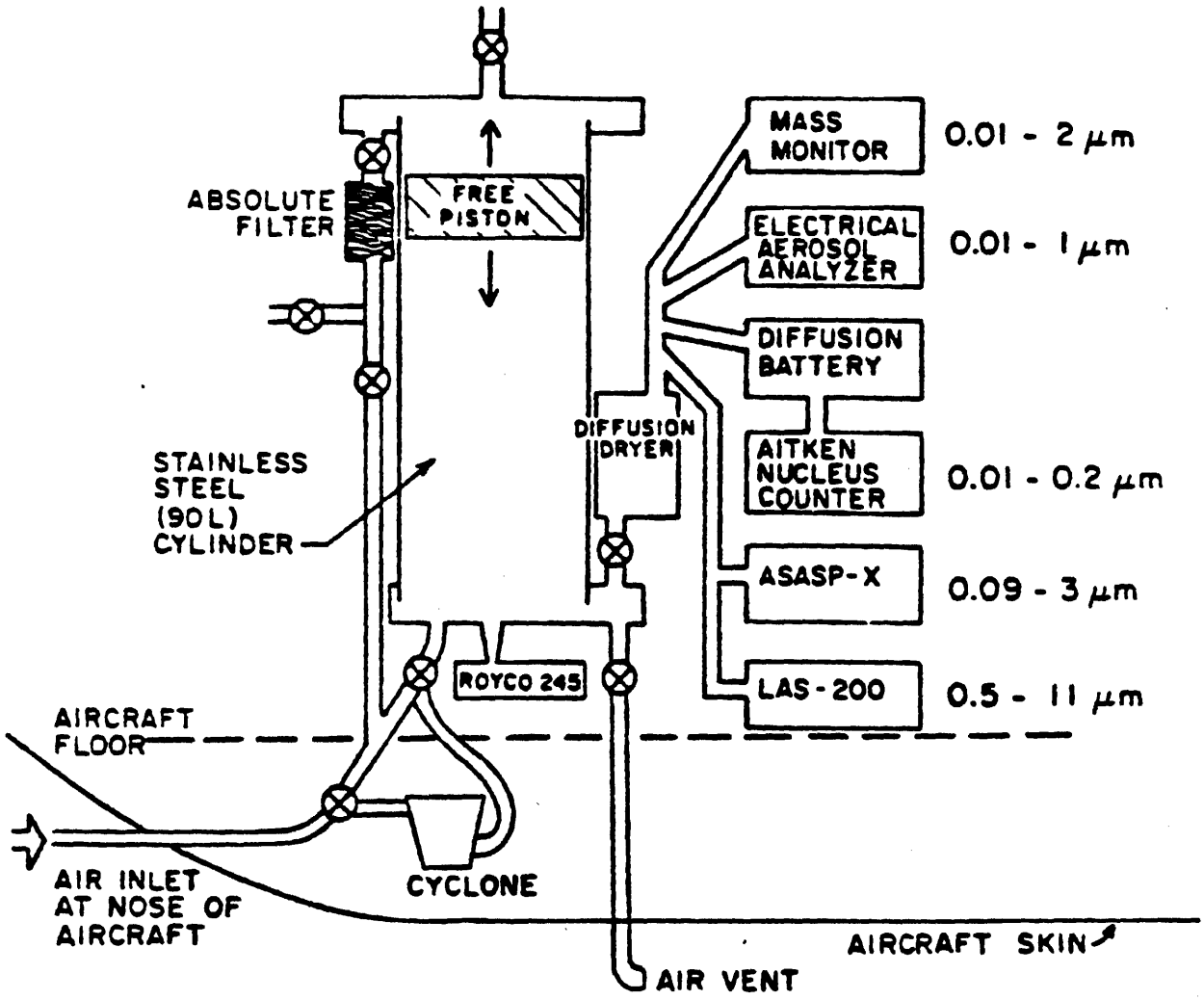


Figure 5 High volume, isokinetic batch sampler aboard the University of Washington's Convair C-131A research aircraft. This system is used to obtain the size distribution of aerosol in clear air and between cloud droplets.

4.2 Flight Tracks

As an aid in interpreting the aerosol particle data presented above, aircraft flight tracks, generated from the SCAQS data tapes now archived at ERT, are presented in Appendix B. These flight tracks show the aircraft trajectory on a latitude-longitude grid.

4.3 UW Flight 1290 (19 June 1987)

This afternoon flight commenced with a sample at the Amtra intersection (just northeast of LAX) followed by samples at Long Beach, Pomona and then Riverside. The Amtra sample showed the highest particle volume, followed by Pomona, Riverside and then Long Beach. The accumulation mode was bifurcated, a phenomenon most apparent in the Amtra sample. The first modal diameter was at ~ 0.2 μm and the second, less clear, modal diameter at ~ 0.3 - 0.4 μm. The course mode was only poorly developed with a modal diameter of ~ 10 μm in the Amtra sample.

4.4 Flight 1292 (24 June 1987)

For this morning flight, the standard order of sampling locations (Amtra, Long Beach, Doyle Intersection and then Paddr Intersection) was followed. Interestingly, for this case the Long Beach sample had the greatest particle volume, followed by Amtra and Paddr (roughly equal) and then Doyle. Once again, the main accumulation mode was at 0.2 μm with a second narrower, but generally higher, mode at ~ 0.3 - 0.4 μm. There was a more marked course particle mode for this flight than for UW flight 1290 with the mode located at ~ 10 μm. This mode was more obvious at Doyle and Paddr than at Amtra but it was most clearly defined at Long Beach. This rather surprising result is conceivably due to offshore flow during the night coupled with active sources in the Long Beach area.

4.5 UW Flight 1293 (25 June 1987)

This morning flight constitutes the first leg of a two-flight sampling scenario for this day. The sampling order was Amtra, Long Beach, Doyle and Paddr. While the modal structure and location of the accumulation mode was normal (i.e., the same as in the previous two flights), the coarse particle mode was virtually non-existent. For this flight, Amtra had the highest volume, followed by Paddr and then Long Beach and Doyle (the latter two are roughly equal).

4.6 UW Flight 1294 (25 June 1987)

This flight occurred on the afternoon of the day of the morning flight just described. The sampling order was Amtra, Long Beach, Pomona and Riverside. Particle modal diameters were normal, although the coarse particle mode was poorly defined. The coarse mode was most marked at Pomona, followed by Riverside and then Amtra - Long Beach (similar structure). For the accumulation mode the Amtra sample had the highest volume, followed by Long Beach and Pomona (about equal) and then Riverside. In comparison to the morning flight, all of the accumulation mode volumes were higher in the afternoon.

The greatest contrast, where direct comparison is possible, was at Long Beach where the afternoon value is more than twice that of the morning flight.

4.7 UW Flight 1302 (13 July 1987)

This morning flight follows a sampling order of Amtra, Long Beach, Doyle and Paddr. The particle volume spectra measured on this flight were much broader and lower than previously seen. The modal particle diameters were as previously observed for the accumulation mode, but the coarse particle mode, which was poorly defined, was at ~ 5 μm instead of the previously observed 10 μm. The spectra were quite different in character from the June spectra. With regard to the accumulation mode volume, the highest sample was over Amtra, followed by Long Beach, Riverside and Pomona. It is interesting to note that the accumulation mode volume over Riverside exceeded that over Pomona for the first time.

4.8 UW Flight 1304 (14 July 1987)

The sampling order of this morning flight (the first leg of another morning - afternoon pair) was Amtra, Long Beach, Doyle and Paddr. The particle spectra measured on this flight were very unusual. While the modal diameters were normal, the spectra showed very little volume in any mode. Indeed, Long Beach and Pomona have almost no volume; certainly, the lowest accumulation mode volumes for the entire series of flights. Also, Riverside had the highest relative accumulation mode value of the four sampling sites. The coarse mode, which was most marked at Amtra , was at a particle diameter of ~ 5μm.

4.9 UW Flight 1305 (14 July 1987)

This afternoon flight was the second leg of the am - pm pair of which UW Flight 1304 was the the first half. For this flight, the sample order was Long Beach, Amtra, Pomona and Riverside. All accumulation modal diameters were normal and the coarse particle mode appeared at ~ 5 μm diameter in all spectra. With the exception of Long Beach, all accumulation modes were quite substantial and even Long Beach had a mode many times that of the morning sample. It should be noted that the Amtra sample, which has an accumulation mode of about four times that of the morning value, has the highest accumulation mode value of the entire study. The accumulation volumes decreased in magnitude from Amtra to Pomona to Riverside to Long Beach.

4.10 UW Flight 1306 (15 July 1987)

Once again, this morning flight was the first part of a morning - afternoon pair. The modal diameters were all standard but the coarse mode was much more substantial than usual. Indeed, the coarse modal volumes are almost comparable to the accumulation mode volumes, particularly for the Long Beach and Paddr samples. Amtra, as usual, had the highest modal volumes followed by Long Beach, Paddr and Doyle.

4.11 UW Flight 1307 (15 July 1987)

The sampling order for this afternoon flight was Long Beach, Amtra, Pomona and Riverside. In comparison to the morning flight, while the coarse particle mode stayed about the same (except for some enhancement at Riverside), the accumulation modes were much enhanced in volume. The volume magnitudes were highest at Long Beach and Amtra (almost equal) closely followed by Riverside and Pomona. Modal diameters were all as usual. Clearly, it is the accumulation mode that evolves with the time of day, as expected. It is worth noting that the values observed on this flight were among the highest in the study. Indeed, the Long Beach and Riverside samples were the highest in the study for these sites.

4.12 Summary

Upon review of the entire spectral data base (36 volume spectra), several noteworthy features are apparent. Firstly, the location of the accumulation mode at 0.2 μm for the main mode and 0.3 - 0.4 μm for the secondary mode is, in general, in agreement with ground-based measurements obtained by Whitby et al. (1972) in Pasadena. While, the bifurcation of the accumulation mode into two distinct peaks was not separated in this earlier study, examination of the actual data peaks used shows this two peak structure. Whitby et al. simply chose to fit the data to a single log-normal distribution function in the accumulation size range and therefore speak of only one mode in this accumulation size range. It could be argued that this procedure should be followed with the current data set as well. However, we feel it worthwhile to point out the observed bifurcation since it is quite reproducible and definitely not an artifact.

Whitby et al. (1972) also cite evidence that the coarse particle mode in Los Angeles aerosol occurs at between 7 - 10 μm. Our measurements suggest the mode occurs between 5 - 10 μm, essentially the same location.

With regard to the relative characteristics of the spectra obtained at the four sampling locations, the Amtra spectra almost always showed the highest number and volume concentrations, as expected. The ordering of the other locations with respect to magnitude is much less clear, with inter-flight variability commonly exceeding the intra-flight variability of spectra.

A comparison of the three morning - afternoon flight pairs shows the strong effect of time of day on the particle accumulation mode. The afternoon spectra have accumulation modal volumes as much as a factor of 4 to 5 greater that the morning spectra at the corresponding locals. This change agrees with the previous ground-based measurements of Whitby et al. (1972). It is worth noting that the length of the flights, on the order of 4 hours, was sufficiently long that observed differences between sampling locations within a flight may be partially attributable to temporal trends at the individual sample sites.

Finally, the magnitudes of the particle spectra measure between ~ 0.6 - 1.0 km in this study are systematically lower than the magnitudes of the ground-based (~ 20 m above ground level) samples obtained by Whitby et al. (1972) during the Pasadena Smog Aerosol Experiment. The Amtra samples, perhaps the ones most comparable to the Whitby et al. data set, are around a factor of two (or greater) lower in particle volume than the Whitby et al. samples. A comparison of the airborne data presented here, with concurrent ground-based measurements during SCAQS will clearly be of interest.

5. LIQUID WATER SAMPLES

In the course of obtaining samples on several of the morning flights, stratus clouds were encountered offshore and at Long Beach. Bulk cloudwater samples were obtained and sent to W. Munger at the California Institute of Technology for chemical analysis. The results of these analyses are shown in Table 6. Also shown in this table are sample pH's taken immediately after sample collection aboard the aircraft and mass modal radii of the cloud droplet spectra, which were measured with PMS probes aboard the aircraft (see Table 1). Measurements of the pH of the cloud samples made aboard the aircraft with a pH meter are generally in reasonable agreement with the pH's estimated in the laboratory from the measured ion balance. This suggests the samples were not compromised in transit. It is noteworthy that the inverse correlation of mass modal droplet diameter and chemical concentration shows that a strong dilution effect was present.

Acknowledgments: We wish to acknowledge our own research flight crew and the STI field crew and, in particular, Jerry Anderson, for their aid during this project. This report was submitted in fulfillment of Contract Number A4-143-32 ("Cloud and Precipitation Scavenging Processes in the South Coast Air Basin") by the Cloud and Aerosol Research Group, Department of Atmospheric Sciences, University of Washington under the sponsorship of the California Air Resources Board. Analysis was completed as of May 1988.

REFERENCES

Radke, L. F. (1983): Preliminary Measurements of the Size Distribution of Cloud Interstitial Aerosol. In Precipitation Scavenging, Dry Deposition, and Resuspension. Elsevier Press, New York, 79-80.

Whitby, K. T. (1978): The Physical Characteristics of Sulfur Aerosols. Atmos. Environ., 12, 135-159.

Whitby, K. T., R. B. Husar and B. Y. H. Liu (1972): The Aerosol Size Distribution of the Los Angeles Smog. In Aerosols and Atmospheric Chemistry. Academic Press, New York, 237-264.

TABLE 6. CHEMICAL COMPOSITION OF BULK CLOUD WATER SAMPLES COLLECTED DURING THE SCAQS FIELD STUDY.

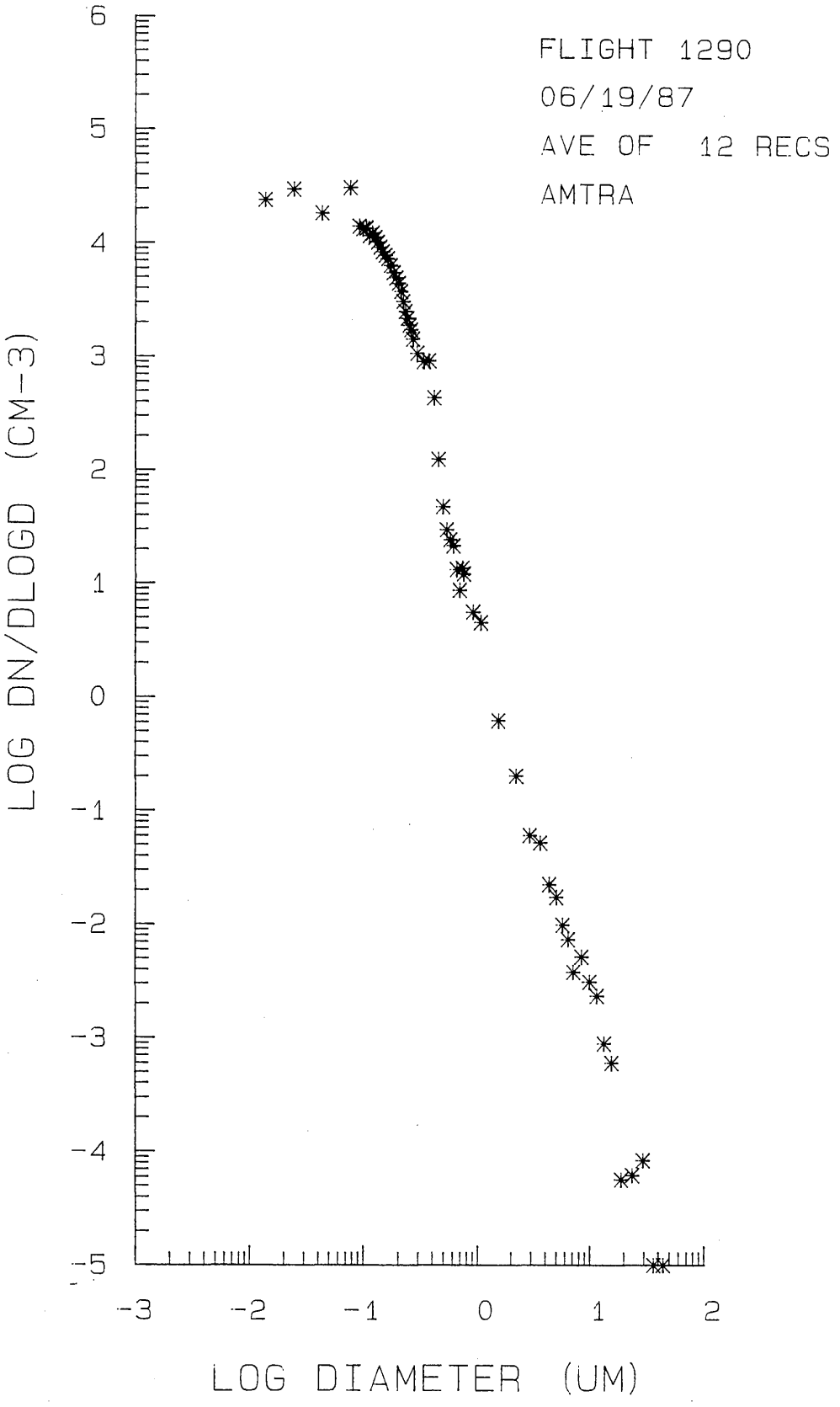
Date (1987)	Time	Flying Over	Altitudes (km, MSL)	pH (air)†	pH (lab)†	D (μm)*	Concentrations (μM)								
							Na^+	K^+	NH_4^+	CA^{+2}	Mg^{+2}	"Fo"§	Cl^-	NO_3^-	$SO_4^=$
25 June	0630-0643	Amtra	0.5	3.8	---	6	---	---	---	---	281	140	787	1469	613
25 June	0814-0820	Paddr	0.5	4.0	---	10	260	---	---	41	68	75	216	409	227
14 July	0616-0625	Long Beach	0.6	3.8	3.87	6	626	46	394	79	76	6	257	610	487
14 July	0725-0731	Doyle	0.6	4.0	3.77	10	160	26	71	36	40	5	194	148	162
15 July	0608-0612	Long Beach	0.6	3.6	3.60	8	78	8	296	20	21	0	71	359	246
15 July	0700-0706	Doyle	0.6	3.75	4.21	10	26	5	37	7	7	4	37	48	57

† See text
* Mass modal mean diameter of cloud droplet spectra
§ Formate (HCO_2^-)

APPENDIX A

PLOTS OF PARTICLE SIZE DISTRIBUTIONS

This appendix contains the number, surface and volume particle size distributions measured at each of four sample locations on the nine University of Washington SCAQS flights. The number of individual spectra use to synthesize the composite or average spectra displayed is shown on the individual plots. To facilitate comparison between sample sites, the dN, dS and dV spectra are grouped by type. Within types, the spectral plots are in chronological order.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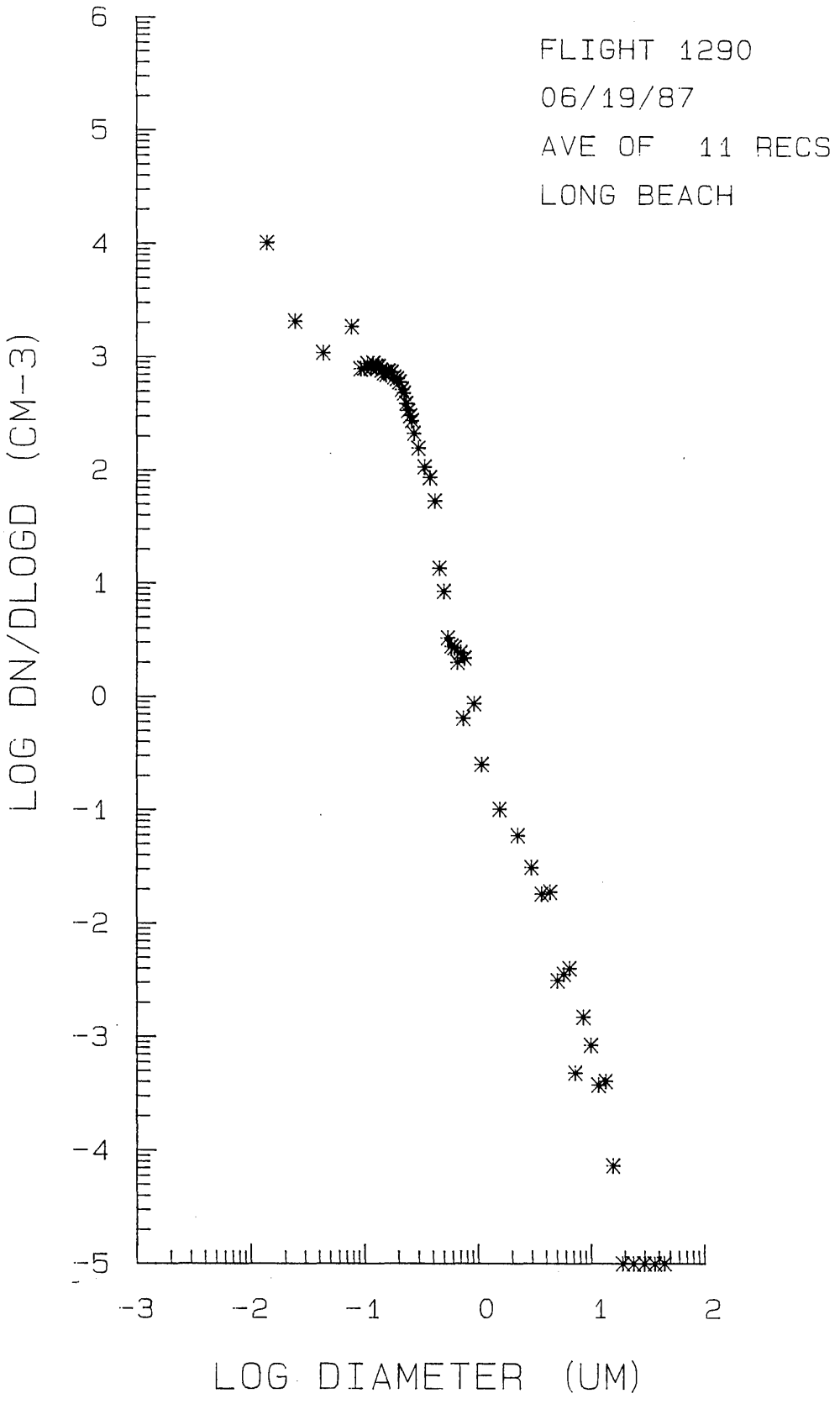
06/19/87
AVE OF 12 RECS
AMTRA
LOG DN/DLOGD (CM-3)
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-3
-2
-1
0
1
2
LOG DIAMETER (UM)


FLIGHT 1290
06/19/87
AVE OF 11 RECS
LONG BEACH
LOG DN/DLOGD (CM-3)
6
5
4
3
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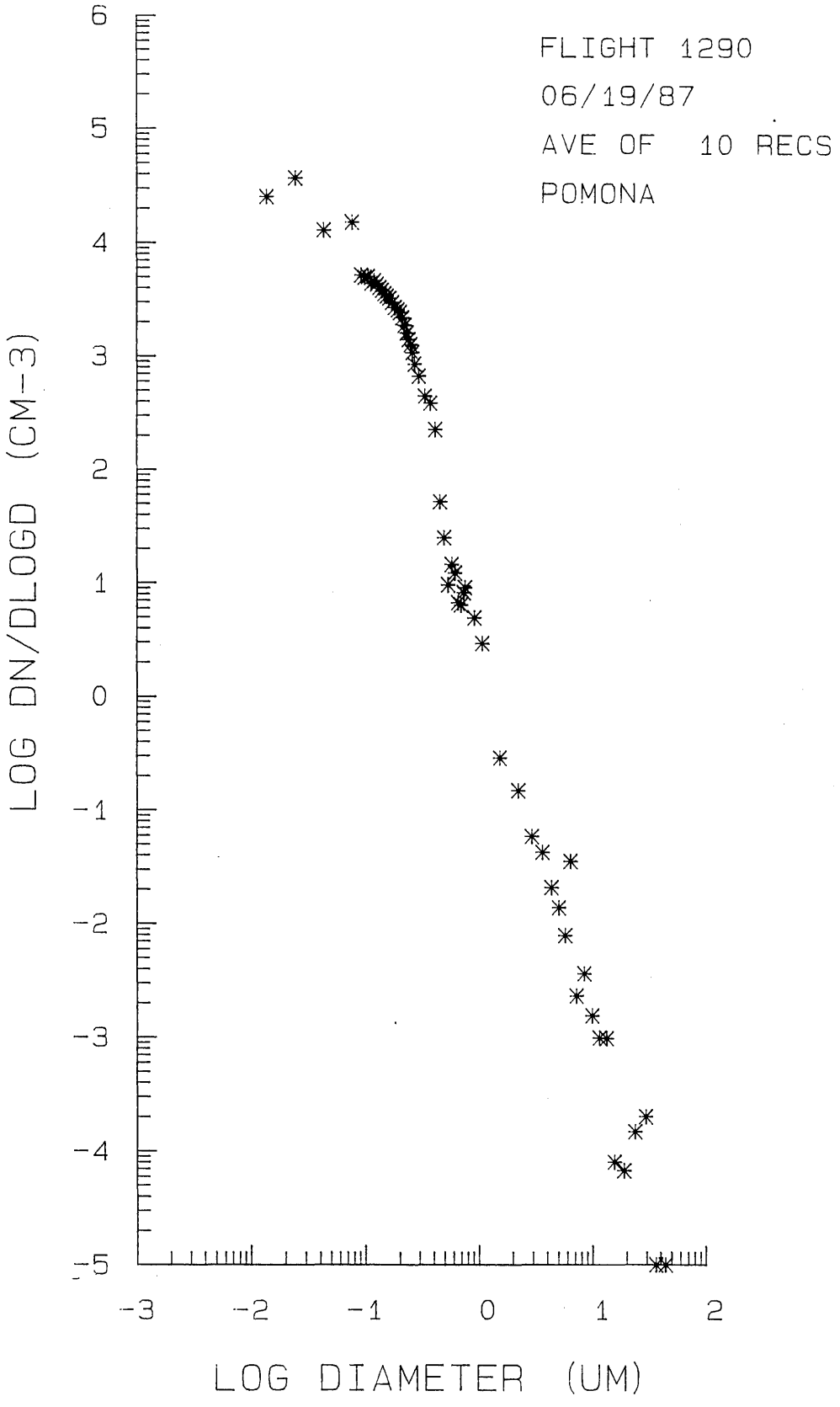
-1
-2
-3
-4
-5
-3
-2
-1
0
1
2
LOG DIAMETER (UM)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06/19/87
AVE OF 10 RECS
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LOG DN/DLOGD (CM-3)
6
5
4
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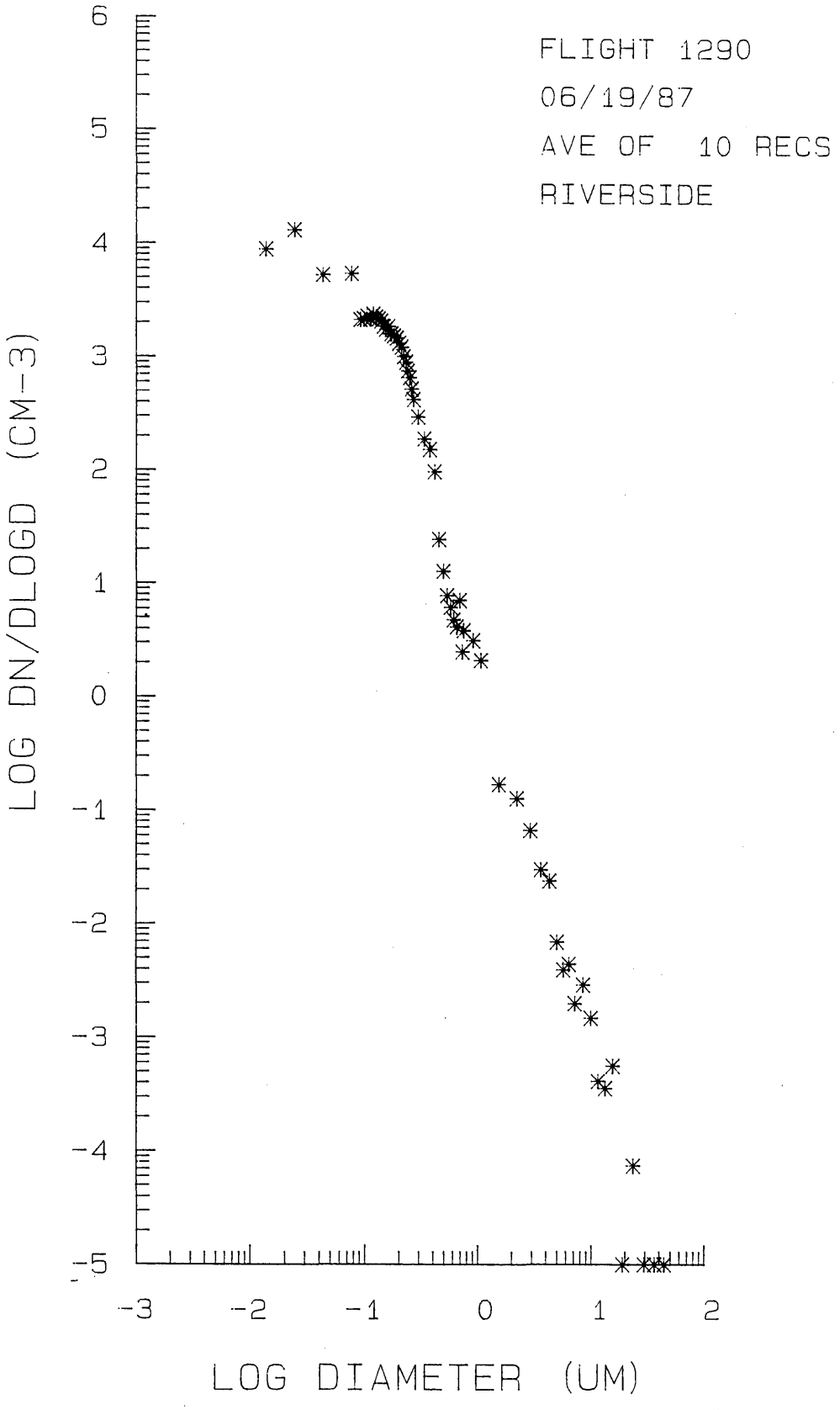
-2
-3
-4
-5
-3
-2
-1
0
1
2
LOG DIAMETER (UM)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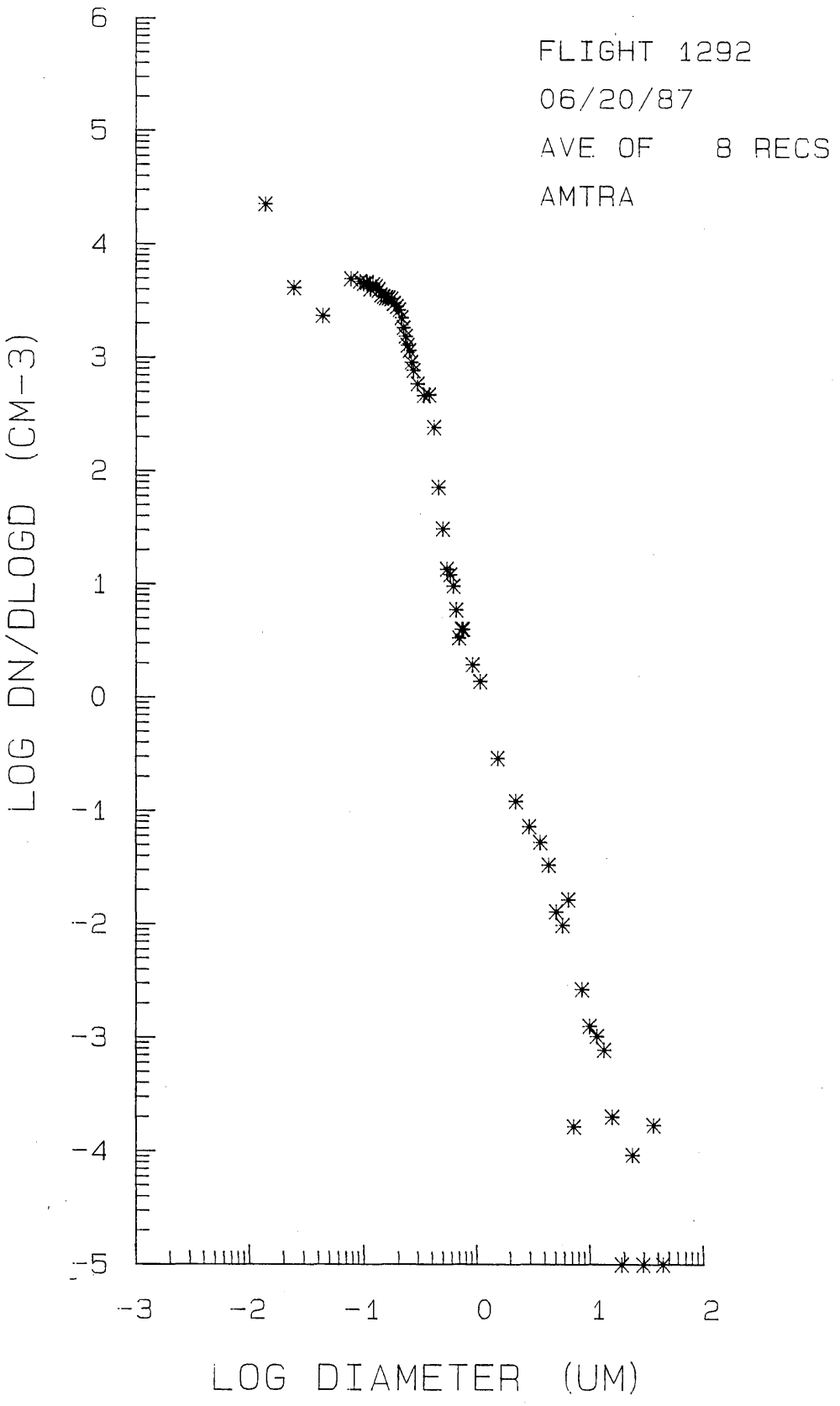
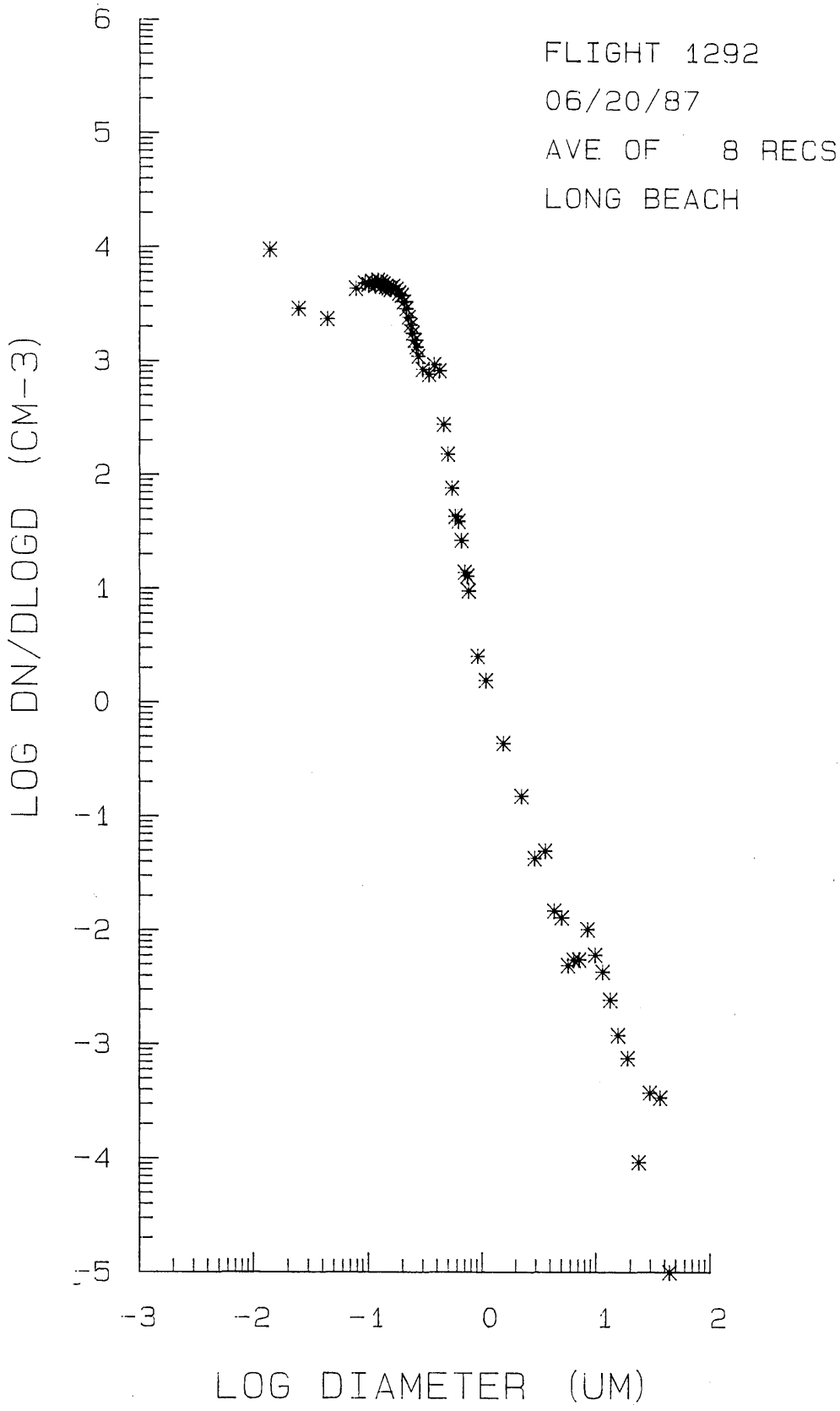
06/19/87
AVE OF 10 RECS
RIVERSIDE
LOG DN/DLOGD (CM-3)
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-3
-2
-1
0
1
2
LOG DIAMETER (UM)


FLIGHT 1292
06/20/87
AVE OF 8 RECS
AMTRA
LOG DN/DLOGD (CM-3)
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-3
-2
-1
0
1
2
LOG DIAMETER (UM)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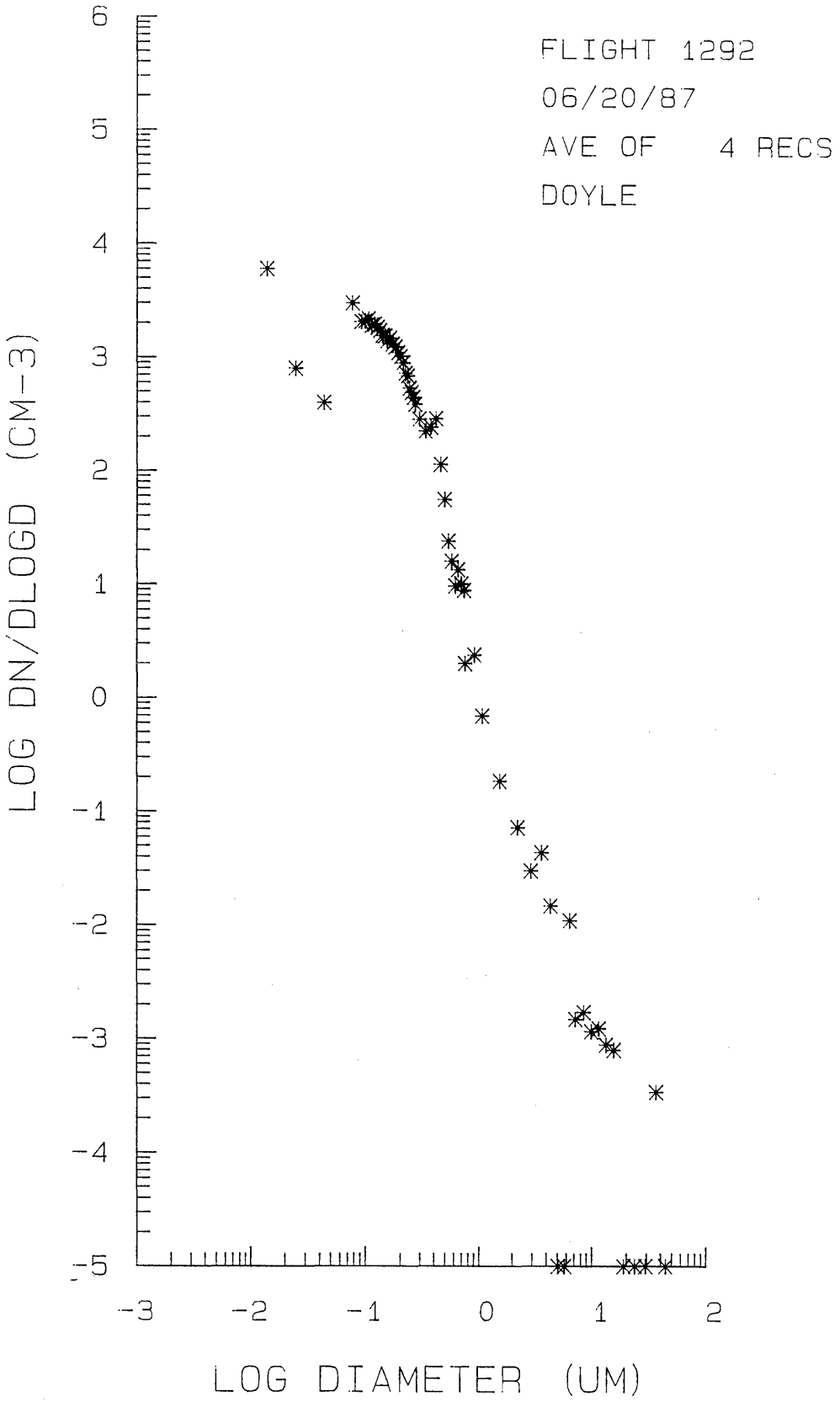
06/20/87
AVE OF 8 RECS
LONG BEACH
LOG DN/DLOGD (CM-3)
LOG DIAMETER (UM)
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-3
-2
-1
0
1
2


FLIGHT 1292
06/20/87
AVE OF 4 RECS
DOYLE
LOG DN/DLOGD (CM-3)
LOG DIAMETER (UM)
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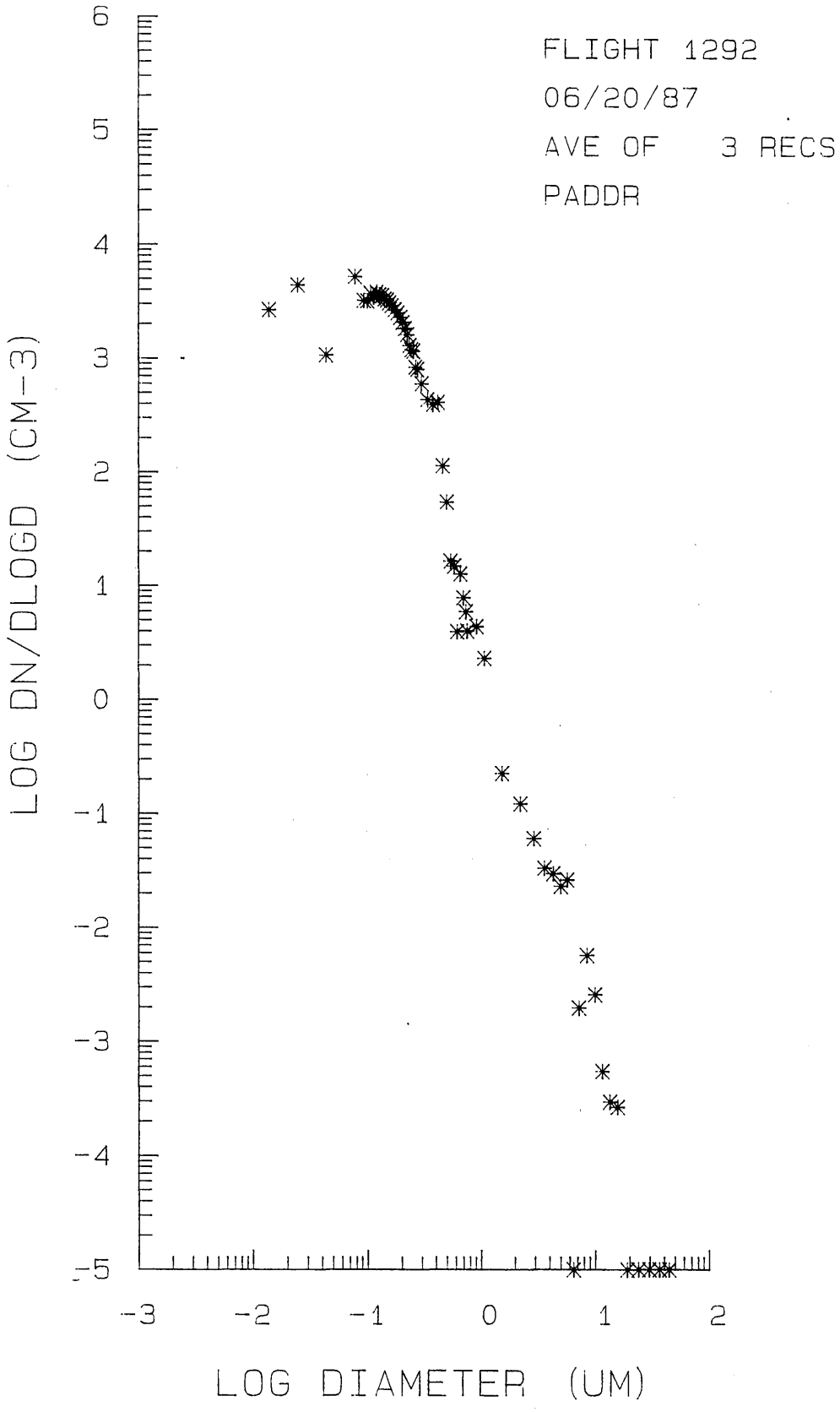
4
3
2
1
0
-1
-2
-3
-4
-5
-3
-2
-1
0
1
2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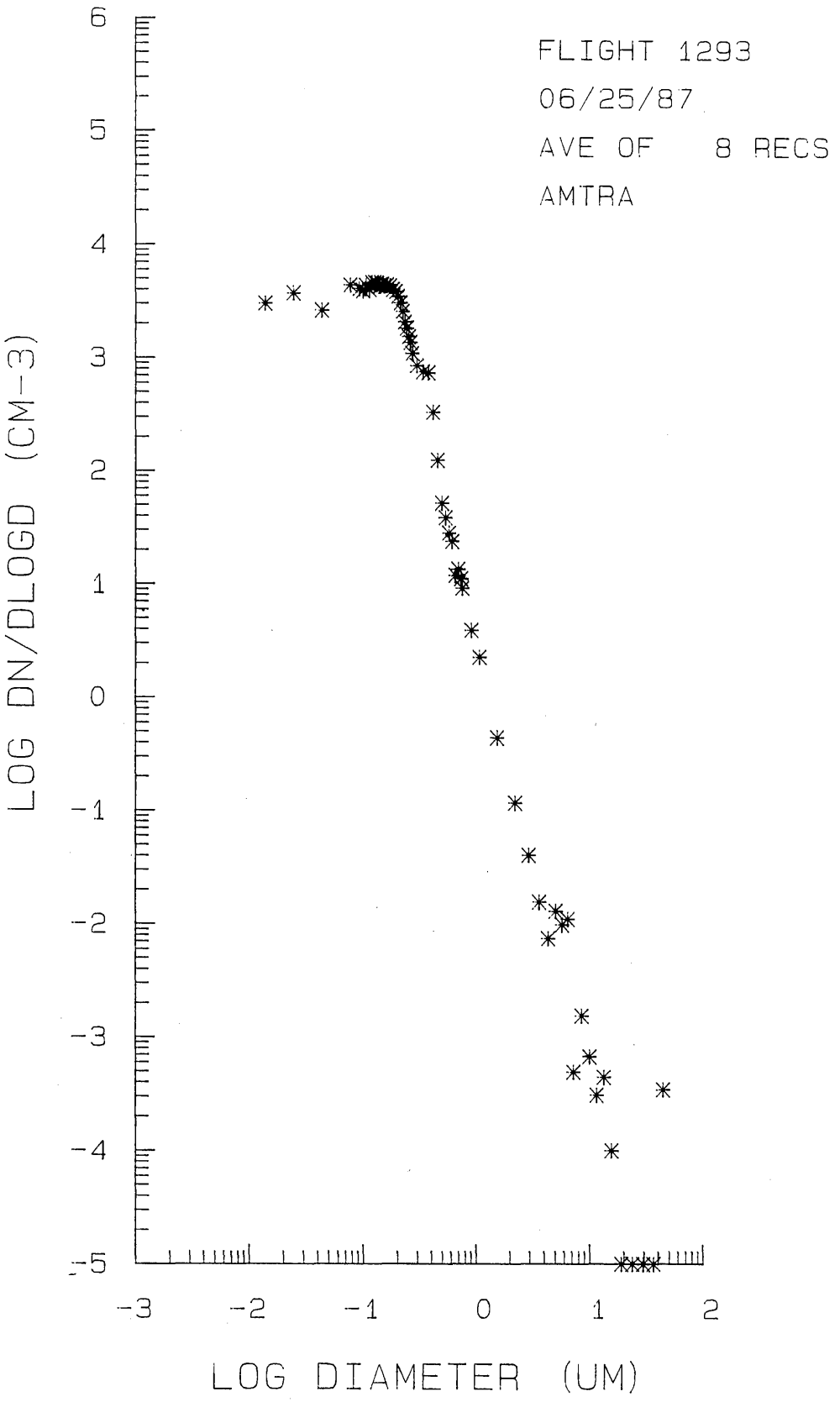
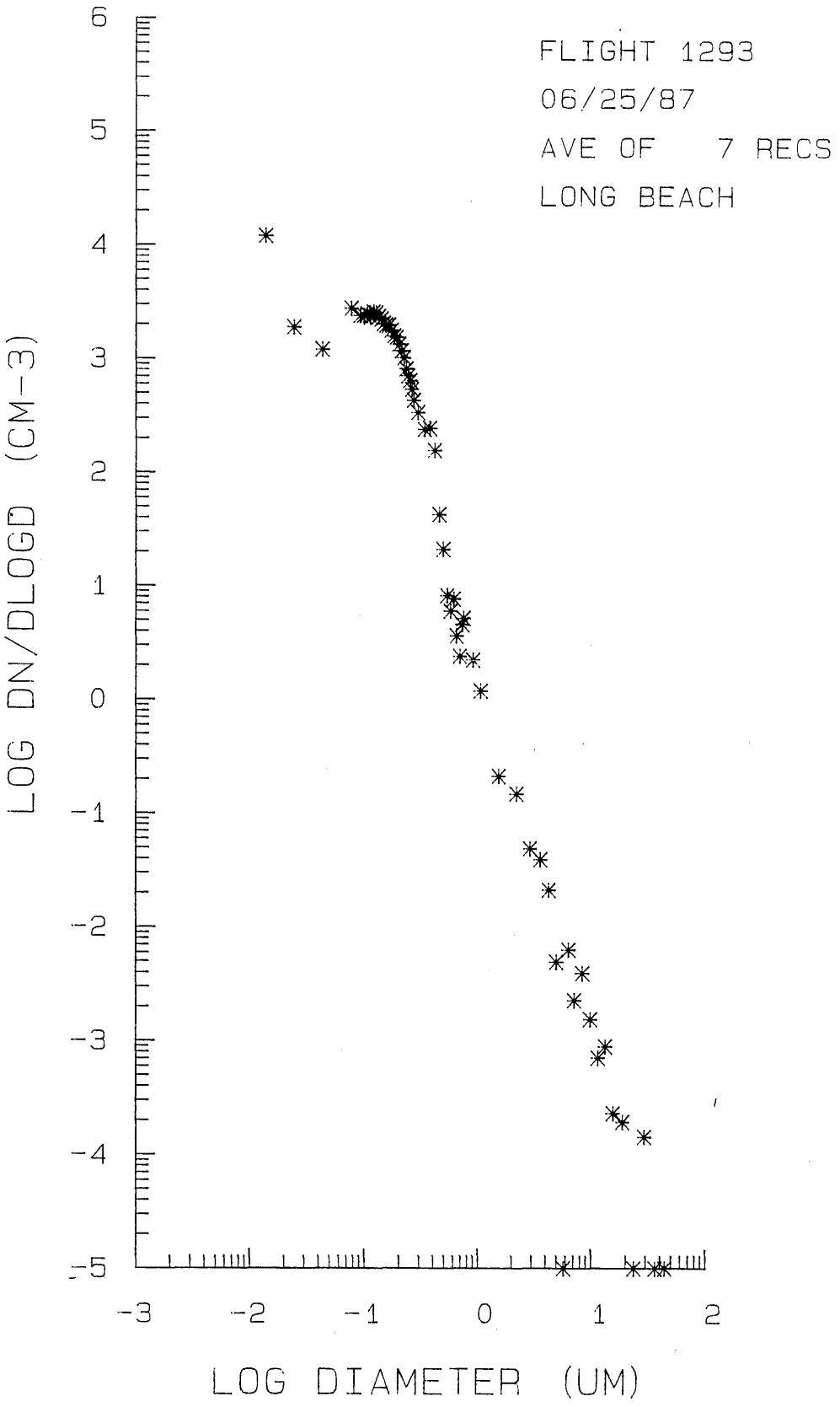
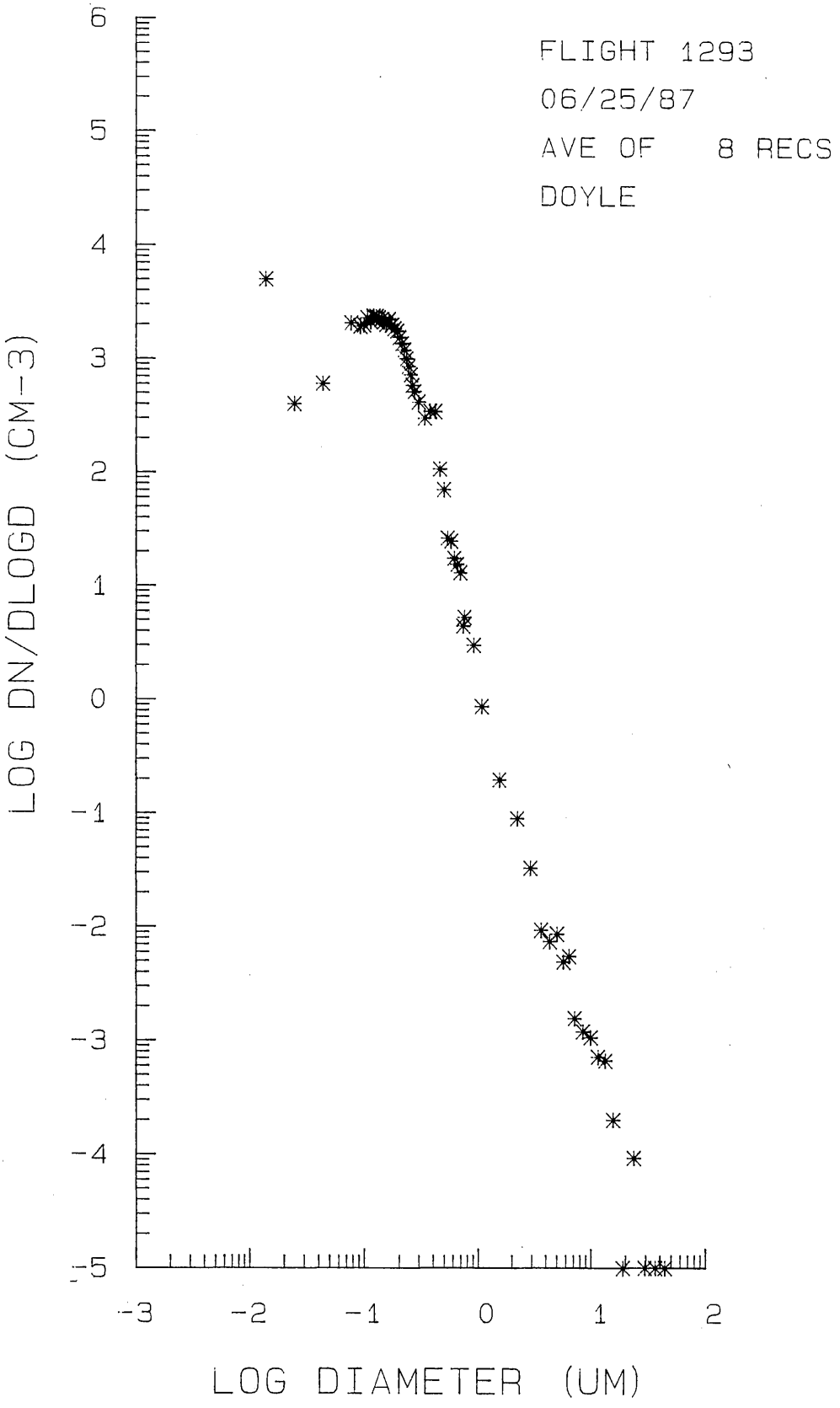
06/20/87
AVE OF 3 RECS
PADDR
LOG DN/DLOGD (CM-3)
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-3
-2
-1
0
1
2
LOG DIAMETER (UM)


FLIGHT 1293
06/25/87
AVE OF 8 RECS
AMTRA
LOG DN/DLOGD (CM-3)
LOG DIAMETER (UM)
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-3
-2
-1
0
1
2


FLIGHT 1293
06/25/87
AVE OF 7 RECS
LONG BEACH
LOG DN/DLOGD (CM-3)
LOG DIAMETER (UM)
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-3
-2
-1
0
1
2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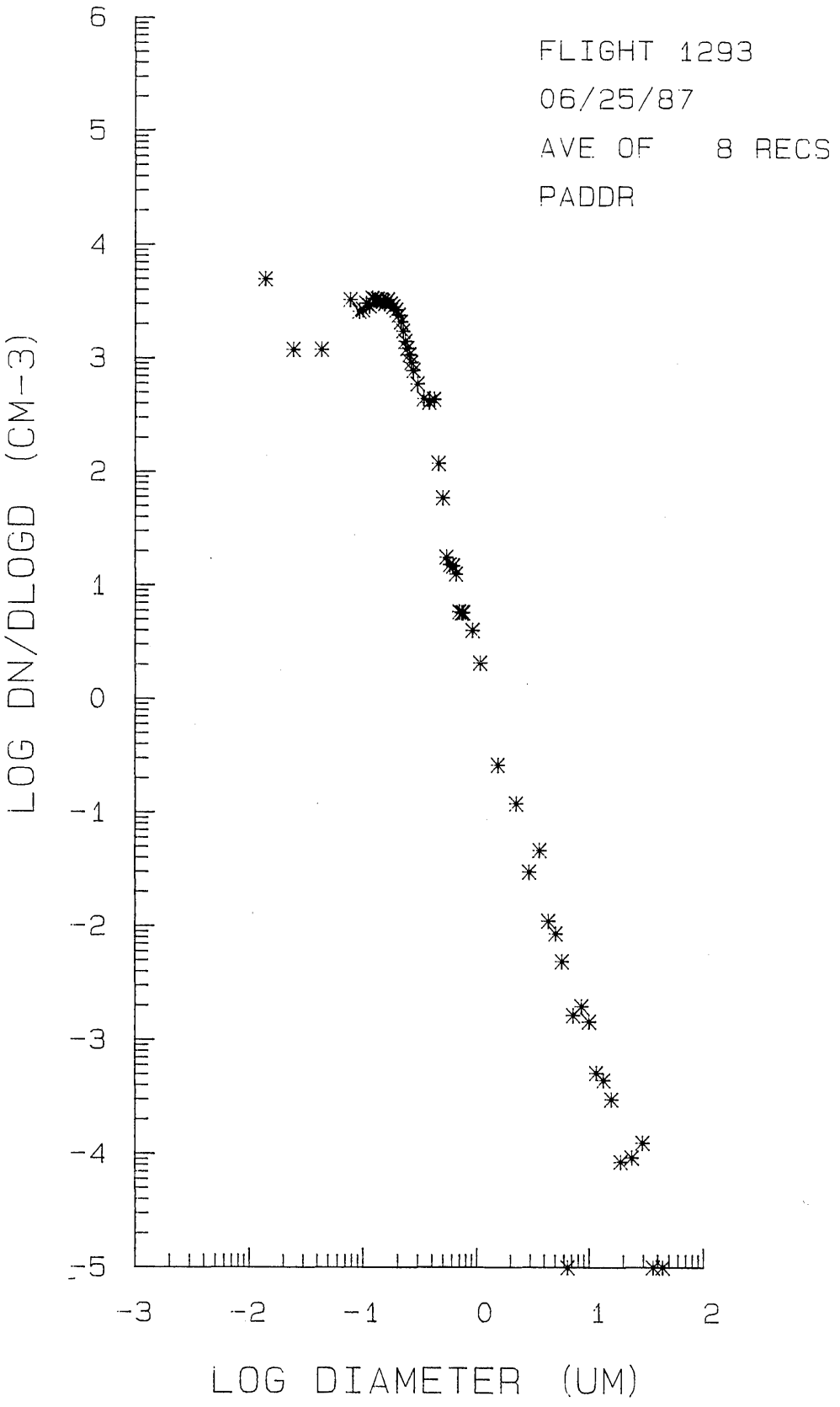
06/25/87
AVE OF 8 RECS
DOYLE
LOG DN/DLOGD (CM-3)
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-3
-2
-1
0
1
2
LOG DIAMETER (UM)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06/25/87
AVE OF 8 RECS
PADDR
LOG DN/DLOGD (CM-3)
LOG DIAMETER (UM)
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1
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-2
-3
-4
-5
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0
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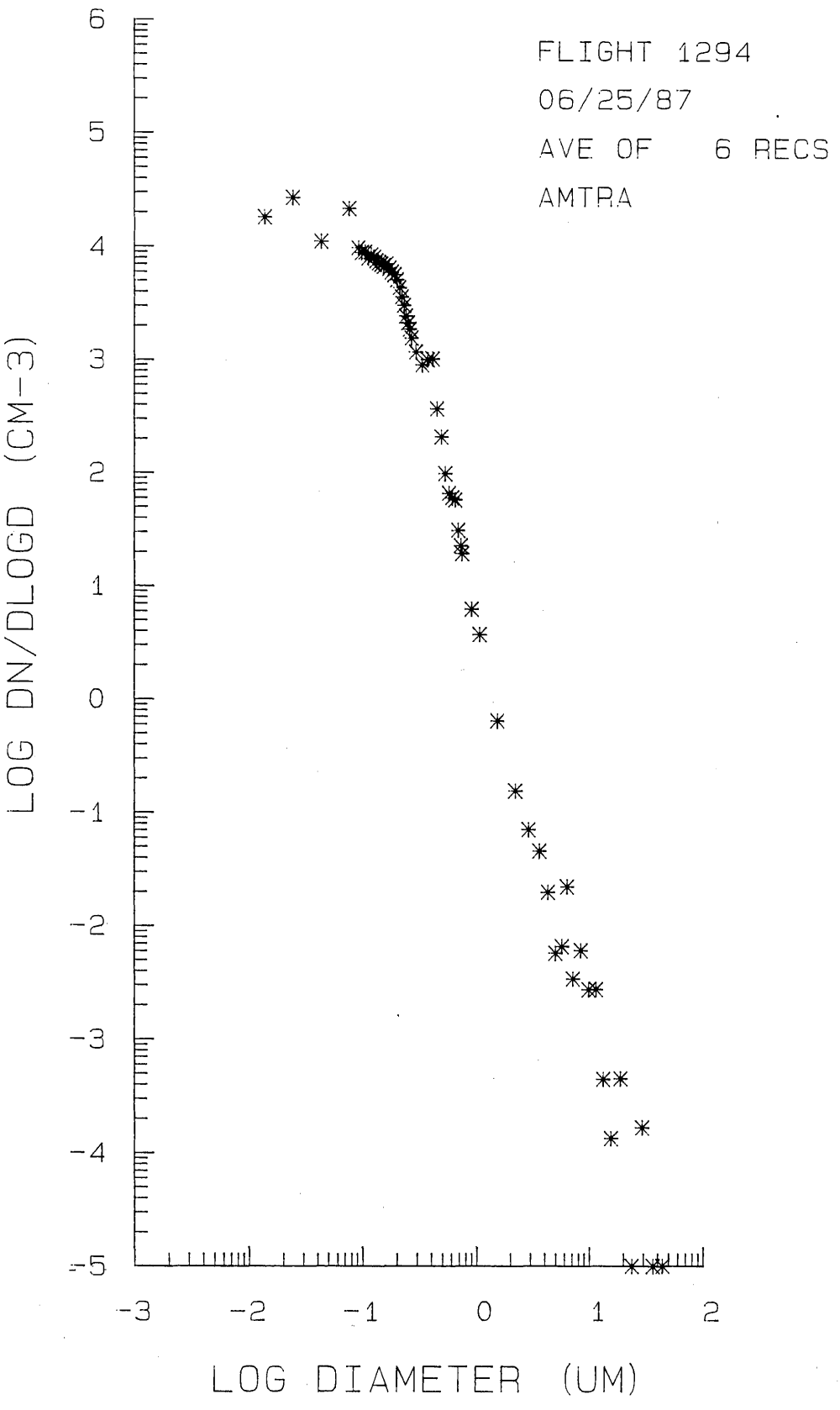
2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06/25/87
AVE OF 6 RECS
AMTRA
LOG DN/DLOGD (CM-3)
LOG DIAMETER (UM)
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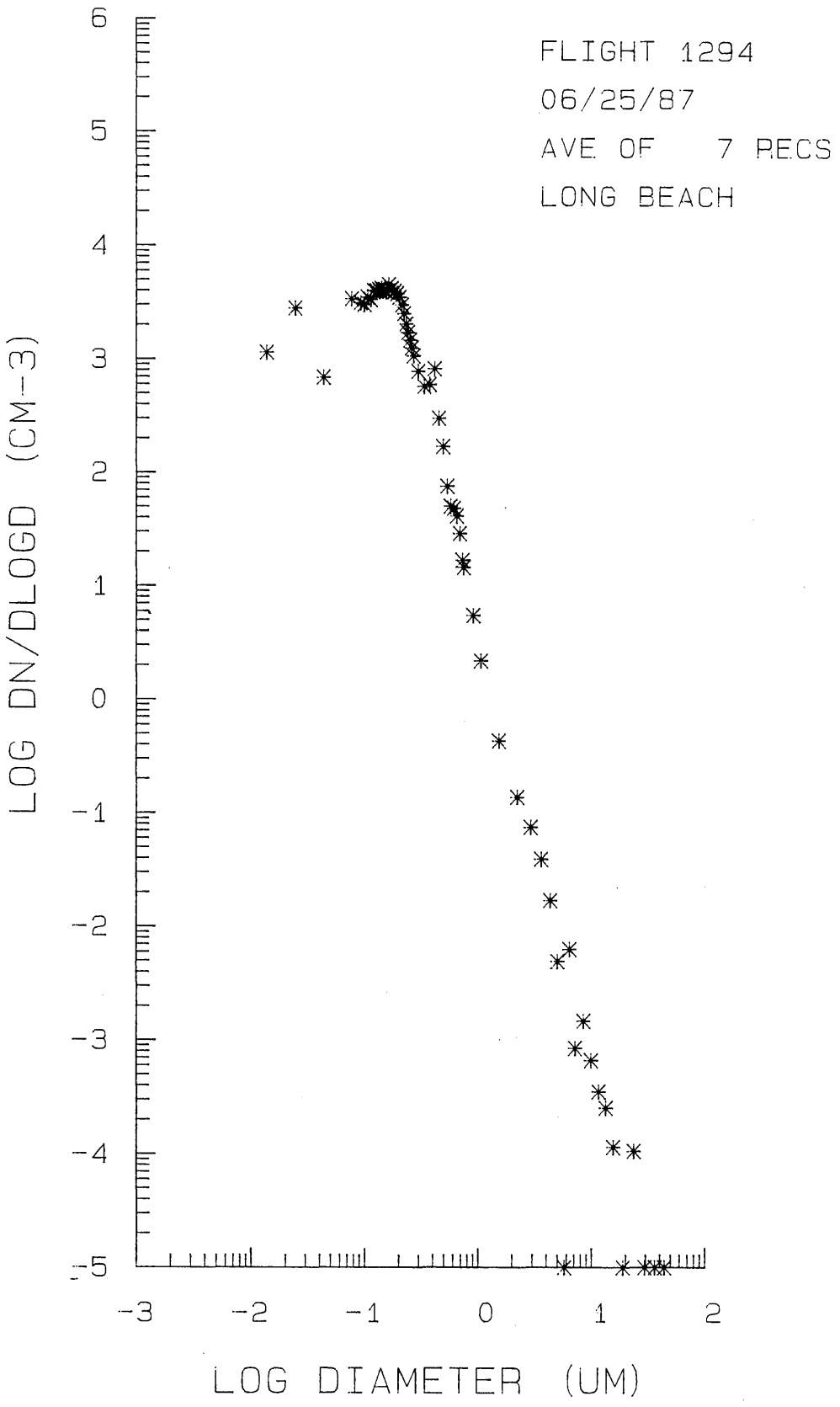
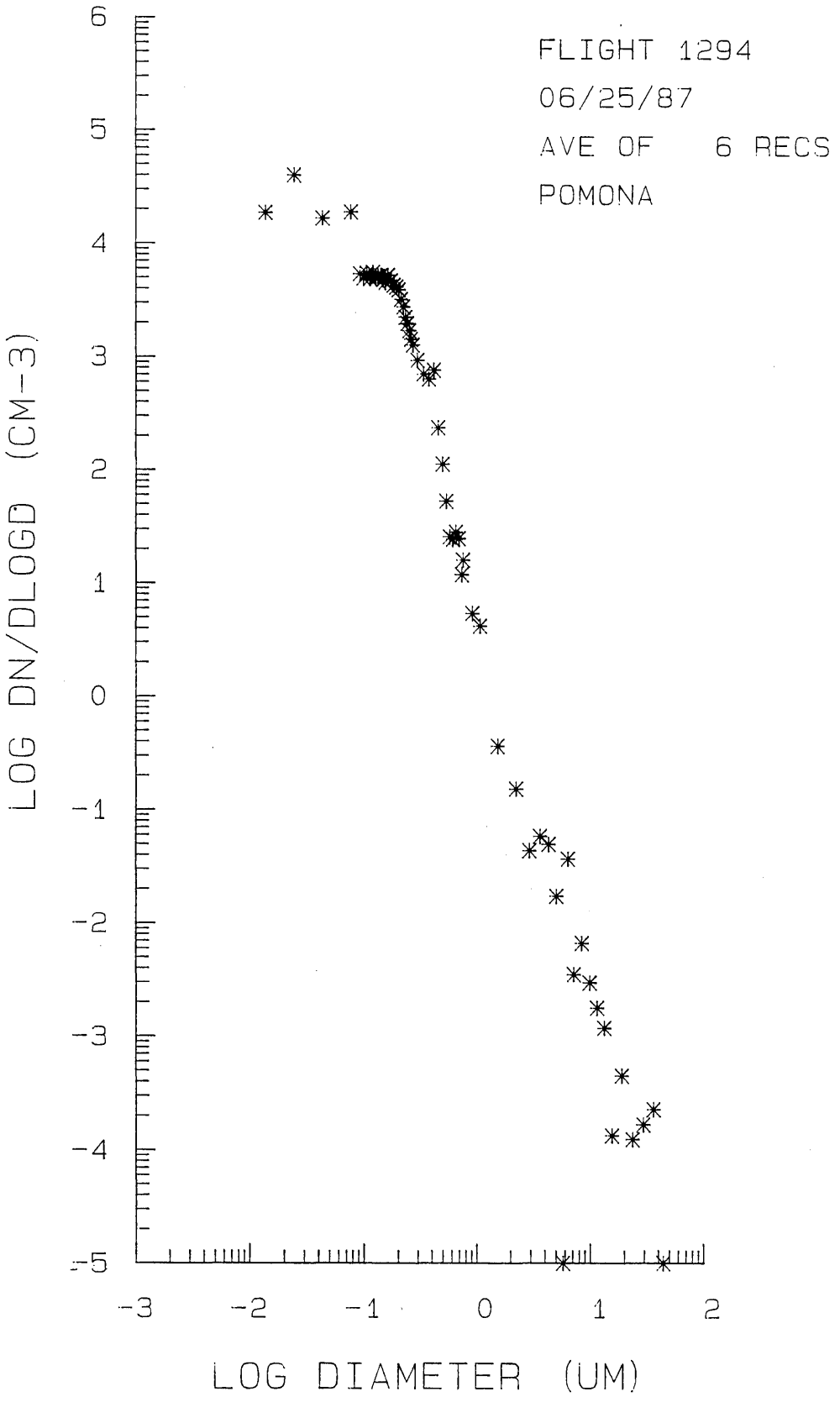
5
4
3
2
1
0
-1
-2
-3
-4
-5
-3
-2
-1
0
1
2


FLIGHT 1294
06/25/87
AVE OF 7 RECS
LONG BEACH
LOG DN/DLOGD (CM-3)
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-3
-2
-1
0
1
2
LOG DIAMETER (UM)


FLIGHT 1294
06/25/87
AVE OF 6 RECS
POMONA
LOG DN/DLOGD (CM-3)
6
5
4
3
2
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-1
-2
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-4
-5
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-1
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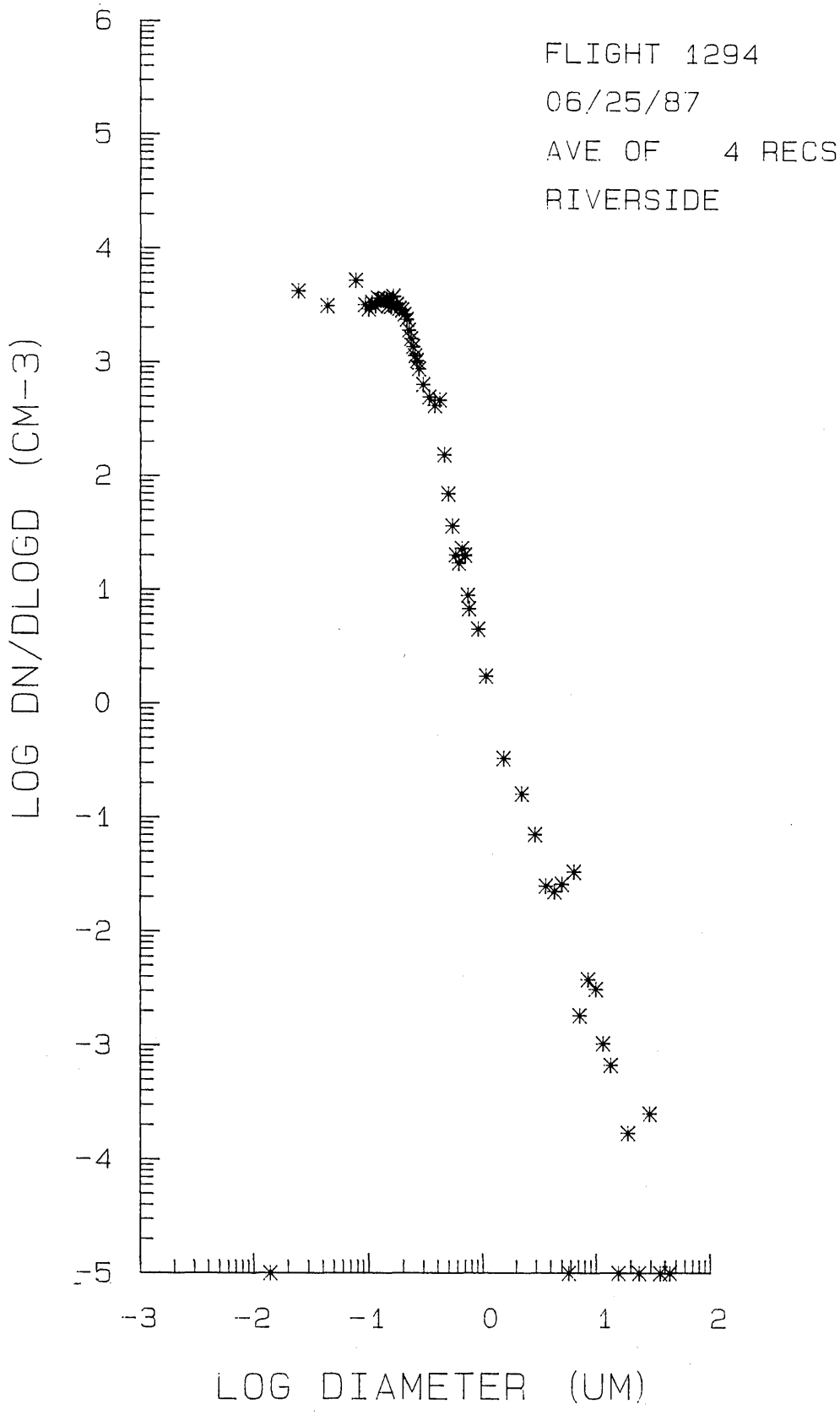
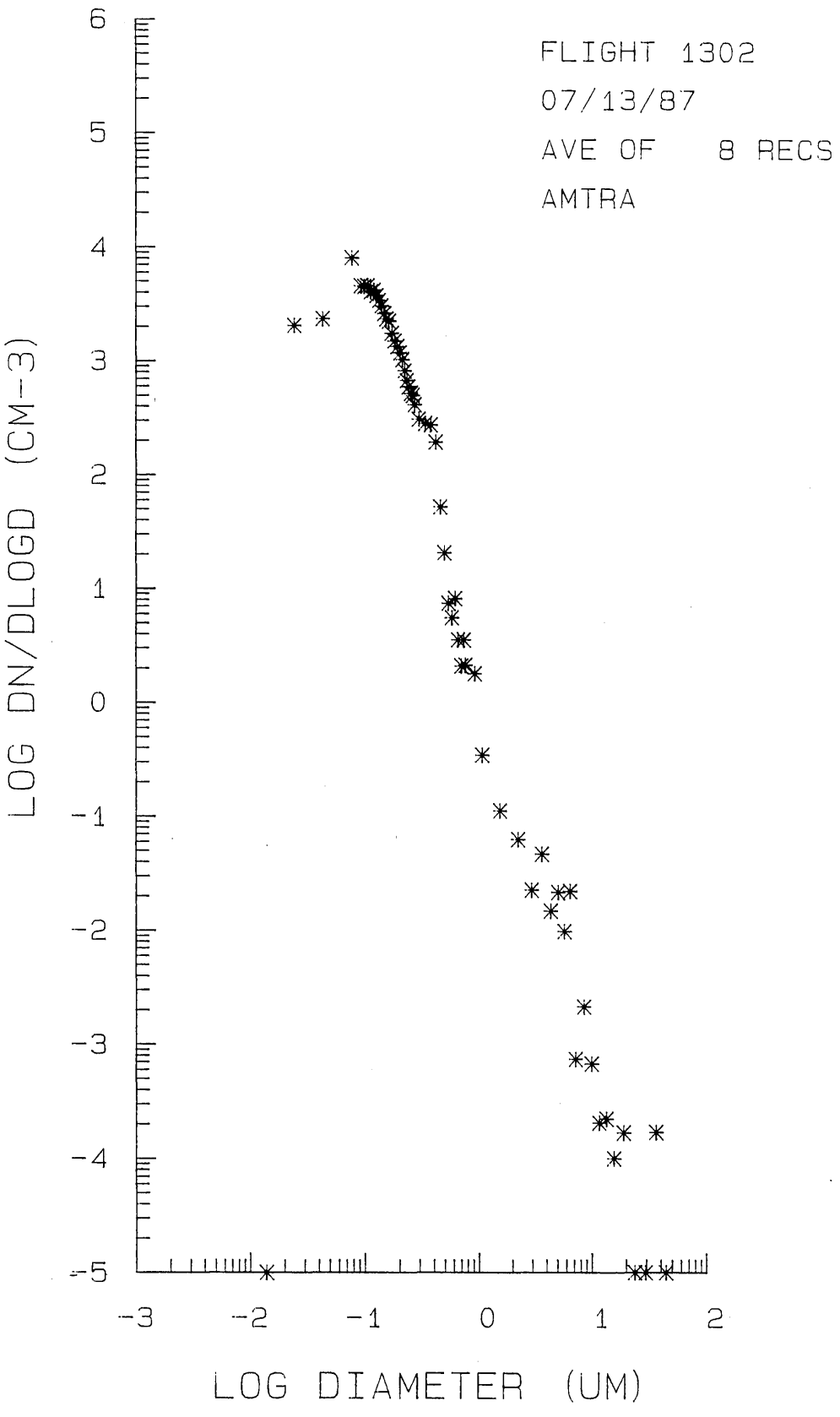
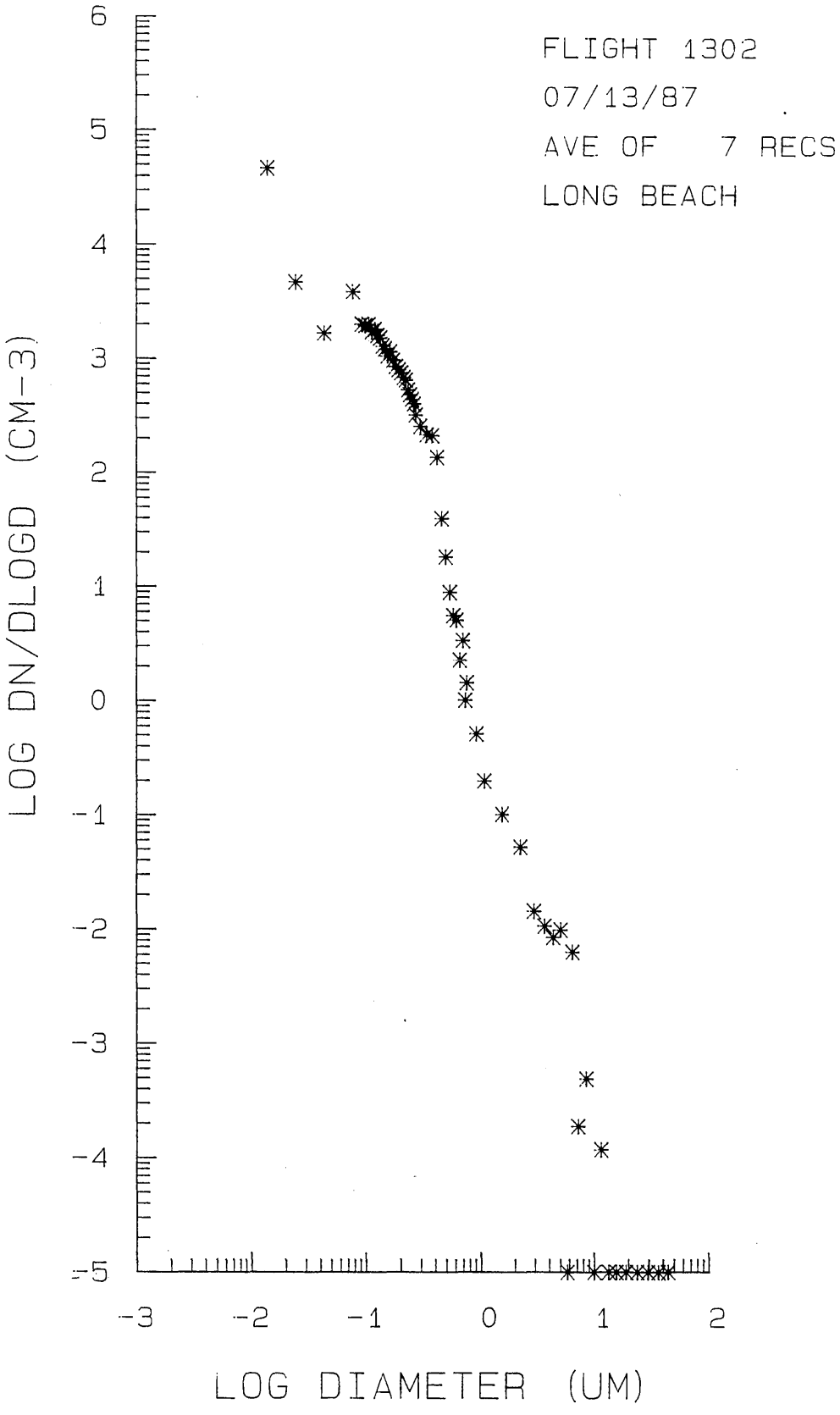
1
2
LOG DIAMETER (UM)


FLIGHT 1294
06/25/87
AVE OF 4 RECS
RIVERSIDE
LOG DN/DLOGD (CM-3)
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-3
-2
-1
0
1
2
LOG DIAMETER (UM)


FLIGHT 1302
07/13/87
AVE OF 8 RECS
AMTRA
LOG DN/DLOGD (CM-3)
LOG DIAMETER (UM)
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-3
-2
-1
0
1
2


FLIGHT 1302
07/13/87
AVE OF 7 RECS
LONG BEACH
LOG DN/DLOGD (CM-3)
6
5
4
3
2
1
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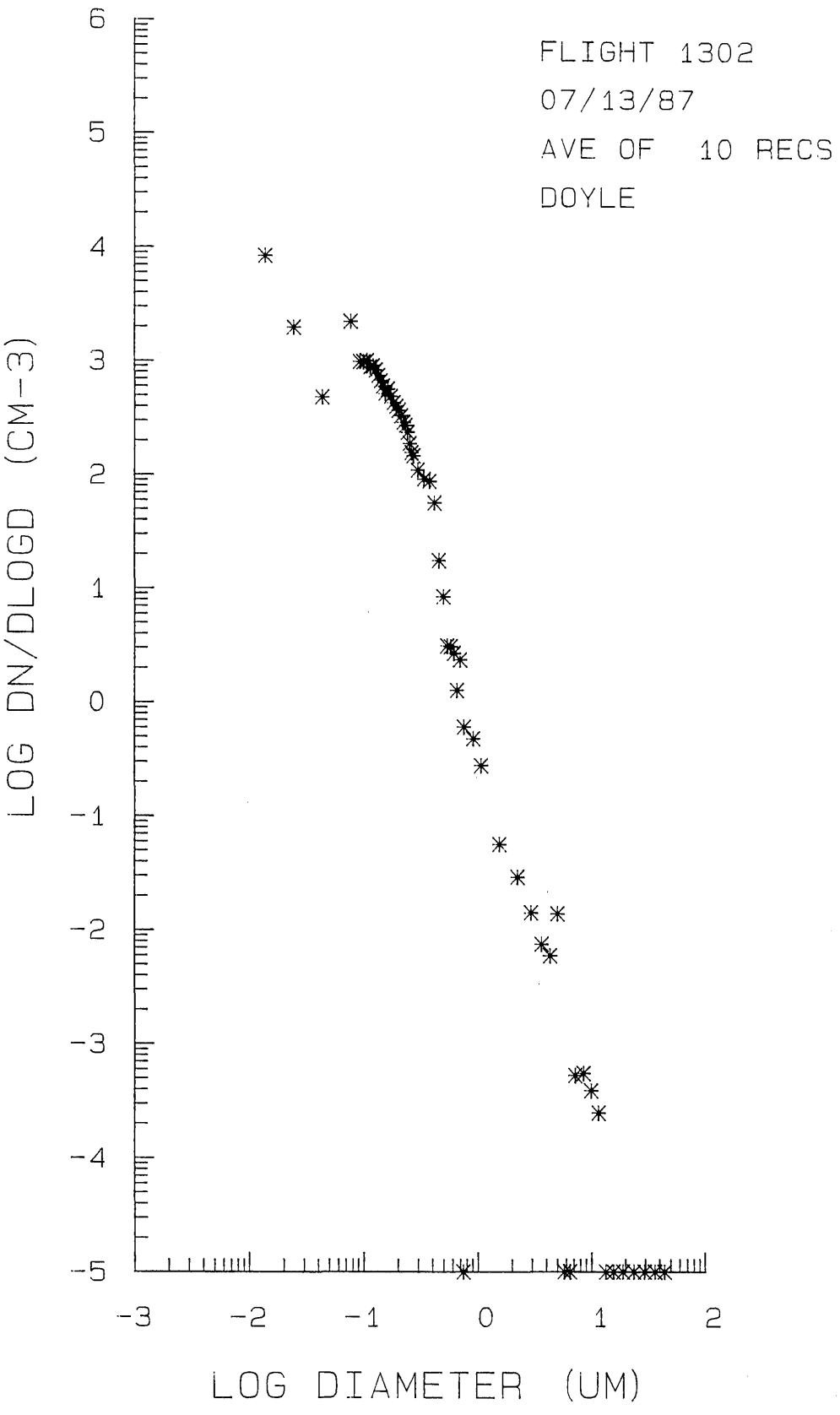
-1
-2
-3
-4
-5
-3
-2
-1
0
1
2
LOG DIAMETER (UM)


FLIGHT 1302
07/13/87
AVE OF 10 RECS
DOYLE
LOG DN/DLOGD (CM-3)
6
5
4
3
2
1
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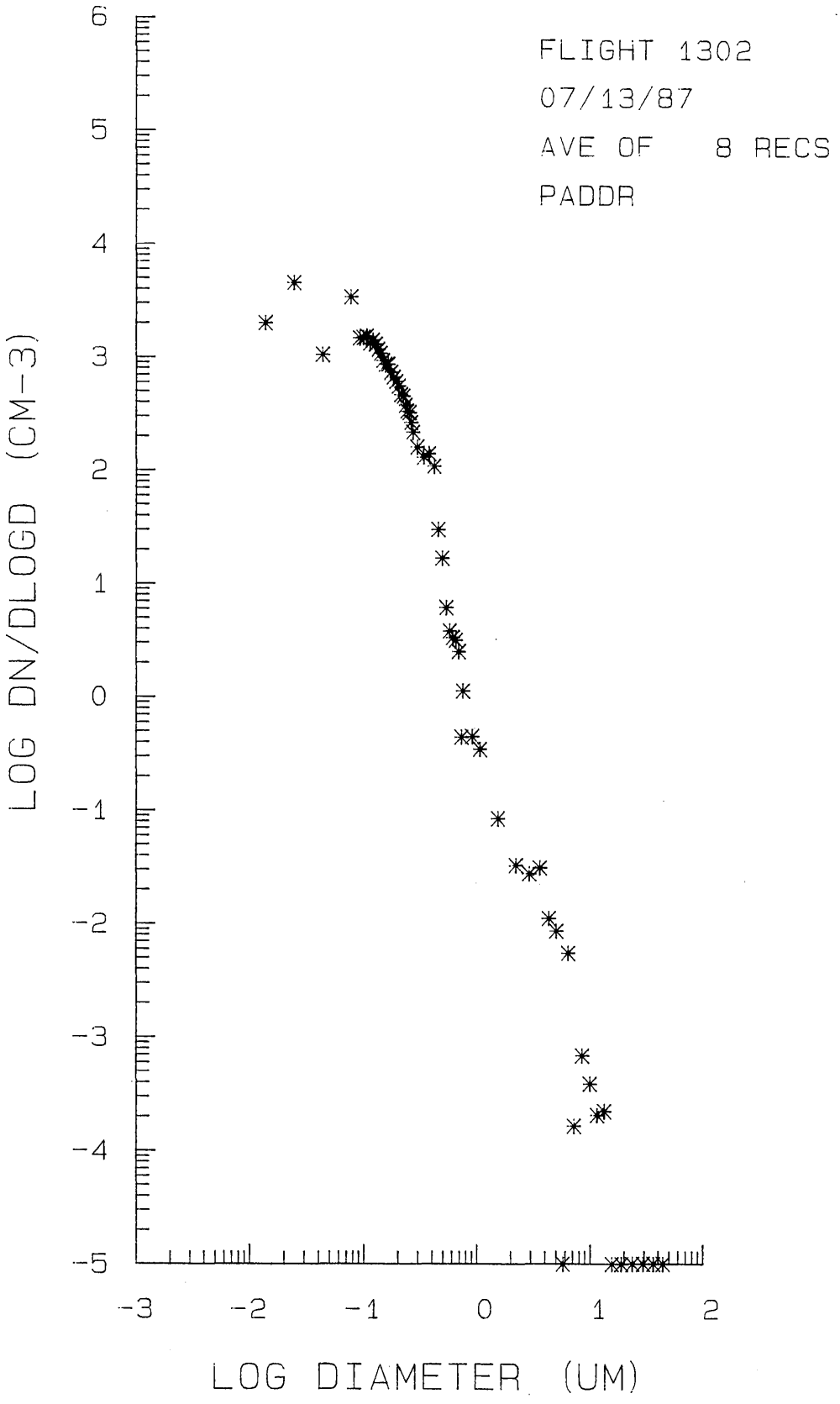
-1
-2
-3
-4
-5
-3
-2
-1
0
1
2
LOG DIAMETER (UM)


FLIGHT 1302
07/13/87
AVE OF 8 RECS
PADDR
LOG DN/DLOGD (CM-3)
6
5
4
3
2
1
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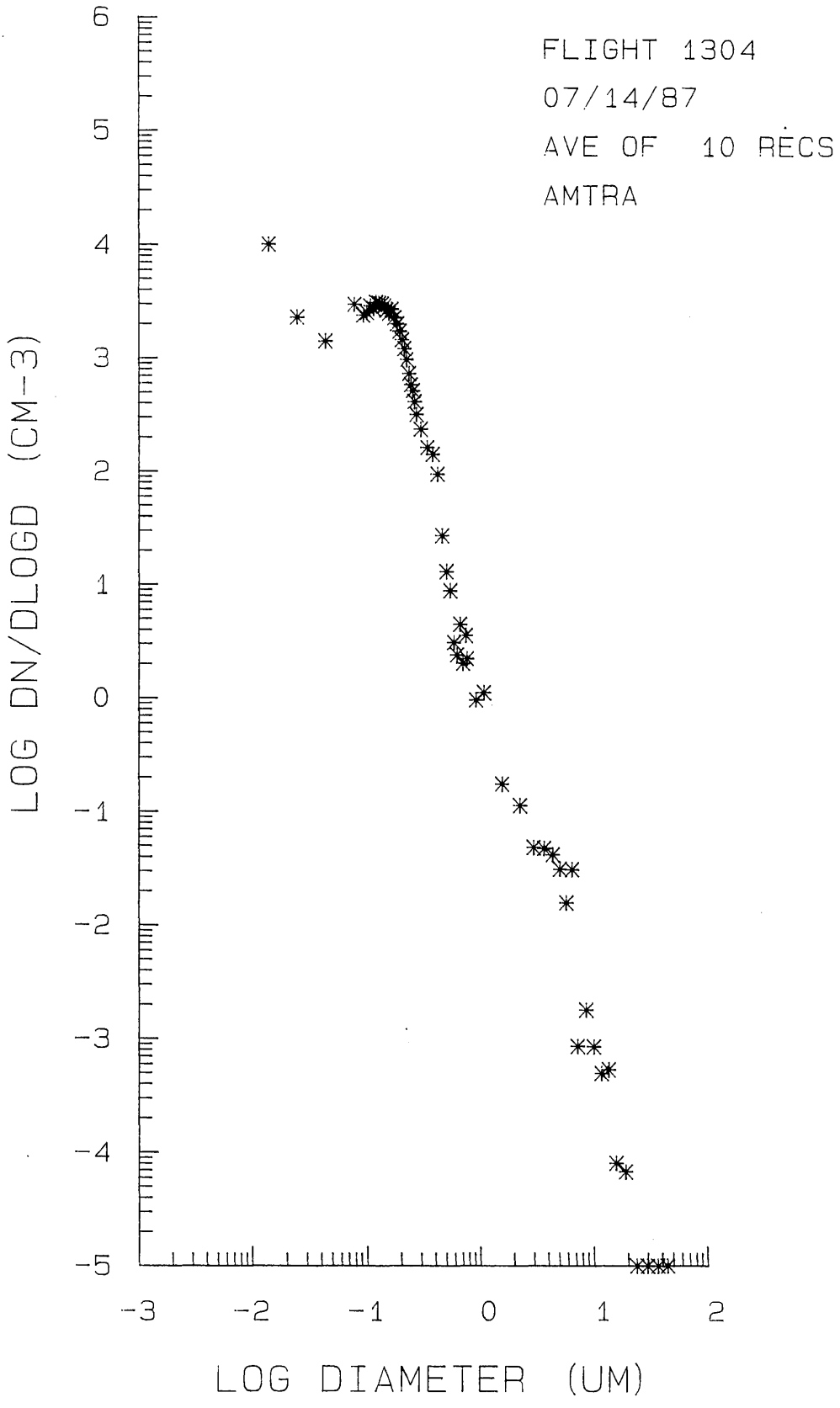
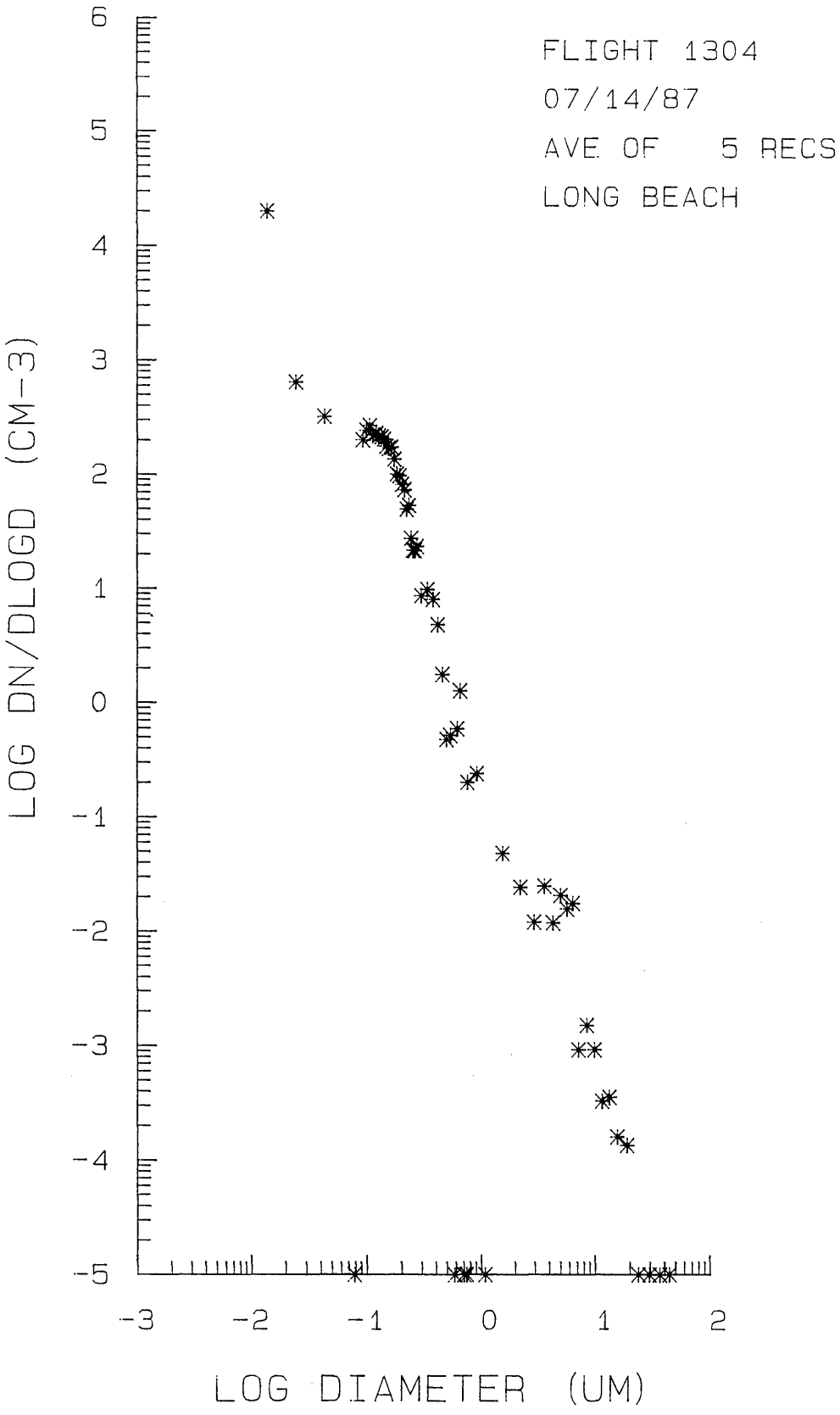
-2
-3
-4
-5
-3
-2
-1
0
1
2
LOG DIAMETER (UM)


FLIGHT 1304
07/14/87
AVE OF 10 RECS
AMTRA
LOG DN/DLOGD (CM-3)
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-3
-2
-1
0
1
2
LOG DIAMETER (UM)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07/14/87
AVE OF 5 RECS
LONG BEACH
LOG DN/DLOGD (CM-3)
LOG DIAMETER (UM)
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-2
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-4
-5
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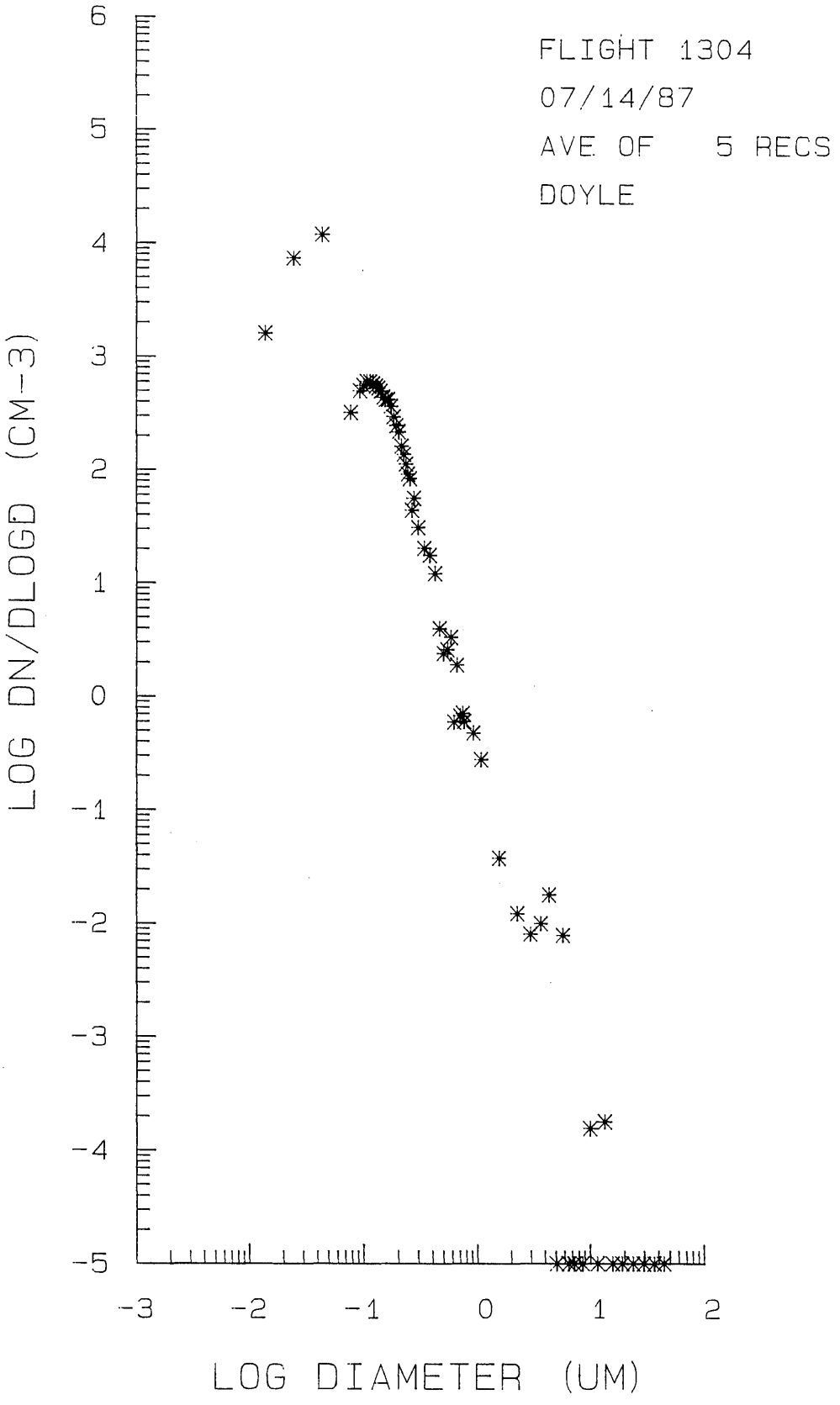
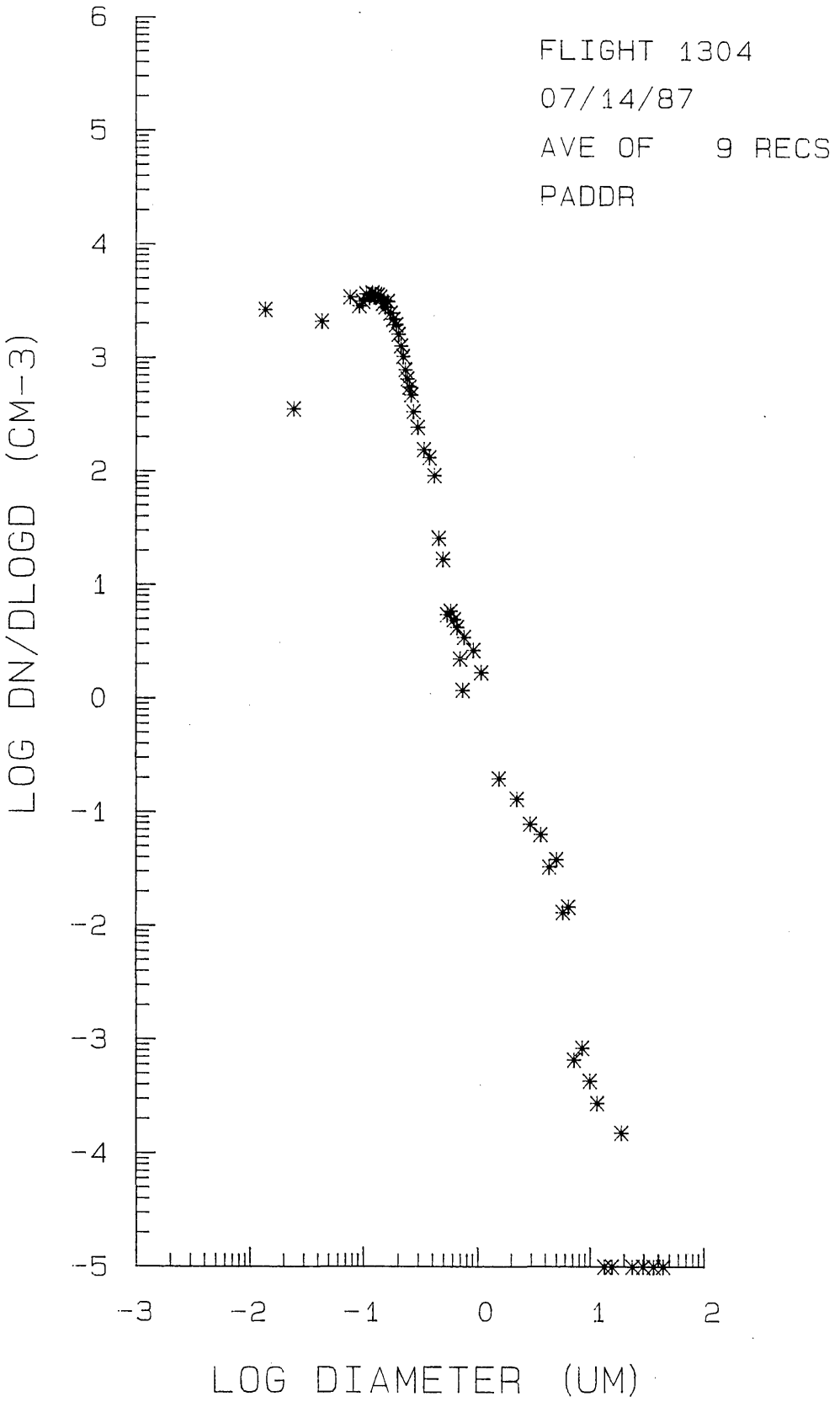
0
1
2


FLIGHT 1304
07/14/87
AVE OF 5 RECS
DOYLE
LOG DN/DLOGD (CM-3)
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-3
-2
-1
0
1
2
LOG DIAMETER (UM)


FLIGHT 1304
07/14/87
AVE OF 9 RECS
PADDR
LOG DN/DLOGD (CM-3)
LOG DIAMETER (UM)
6
5
4
3
2
1
0
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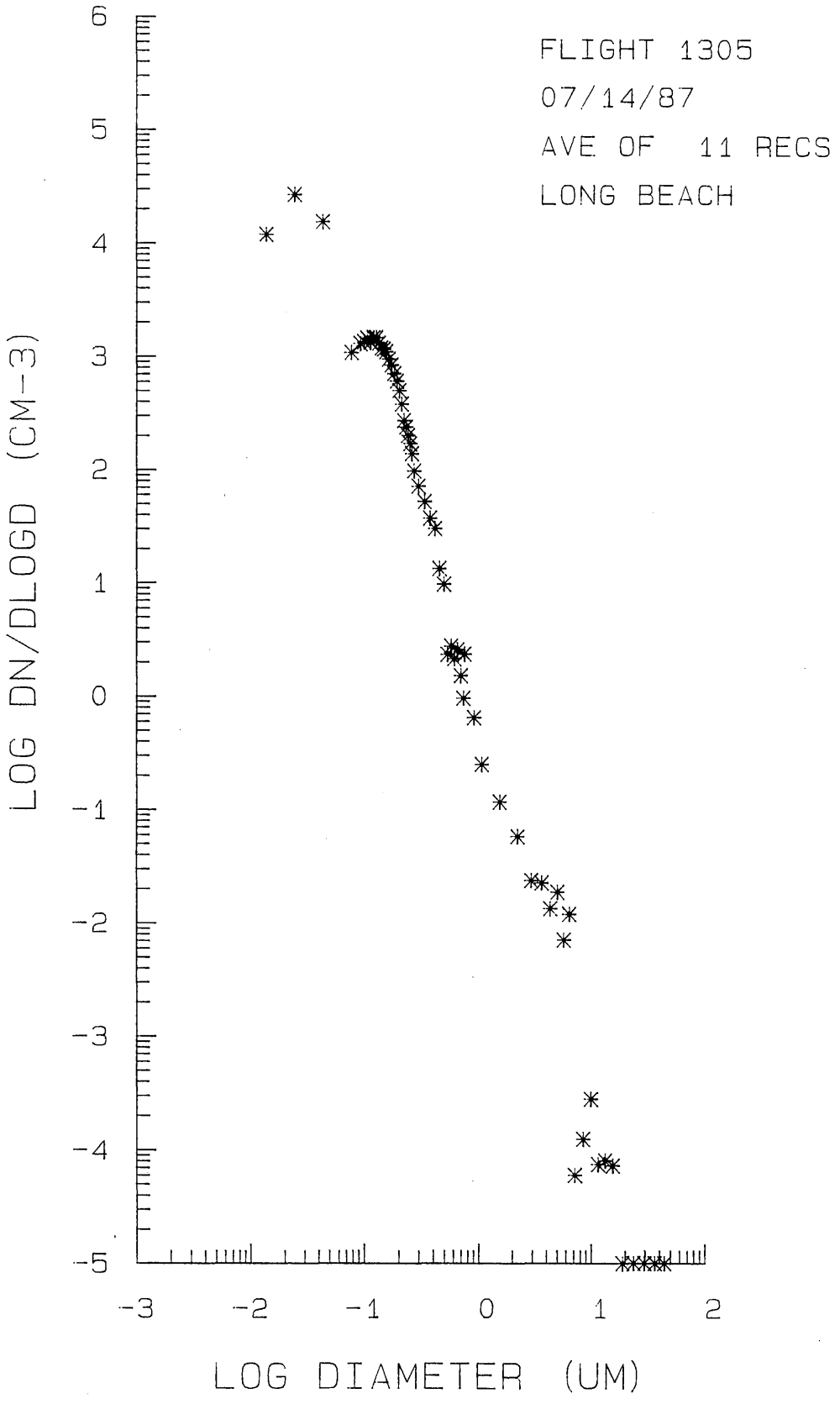
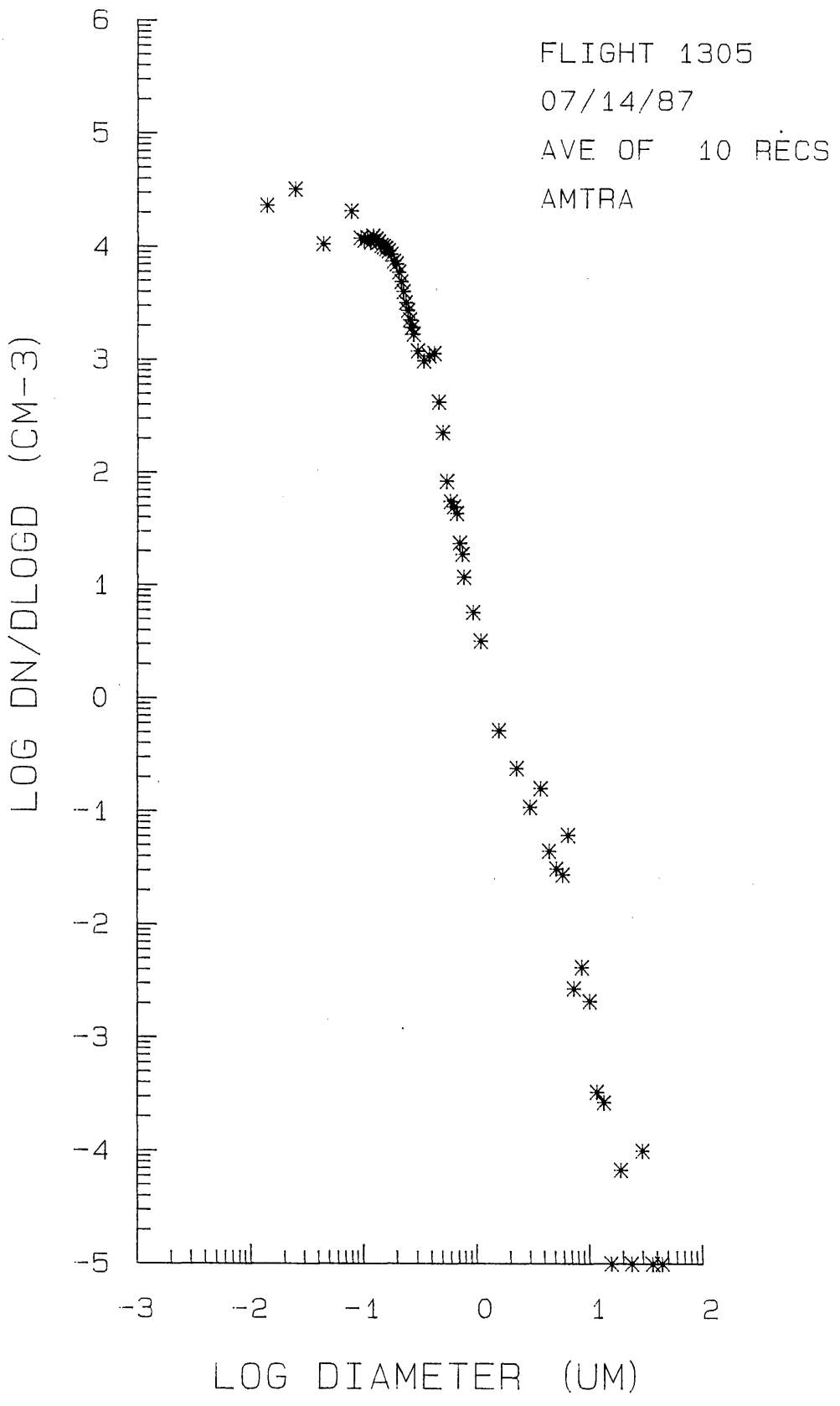
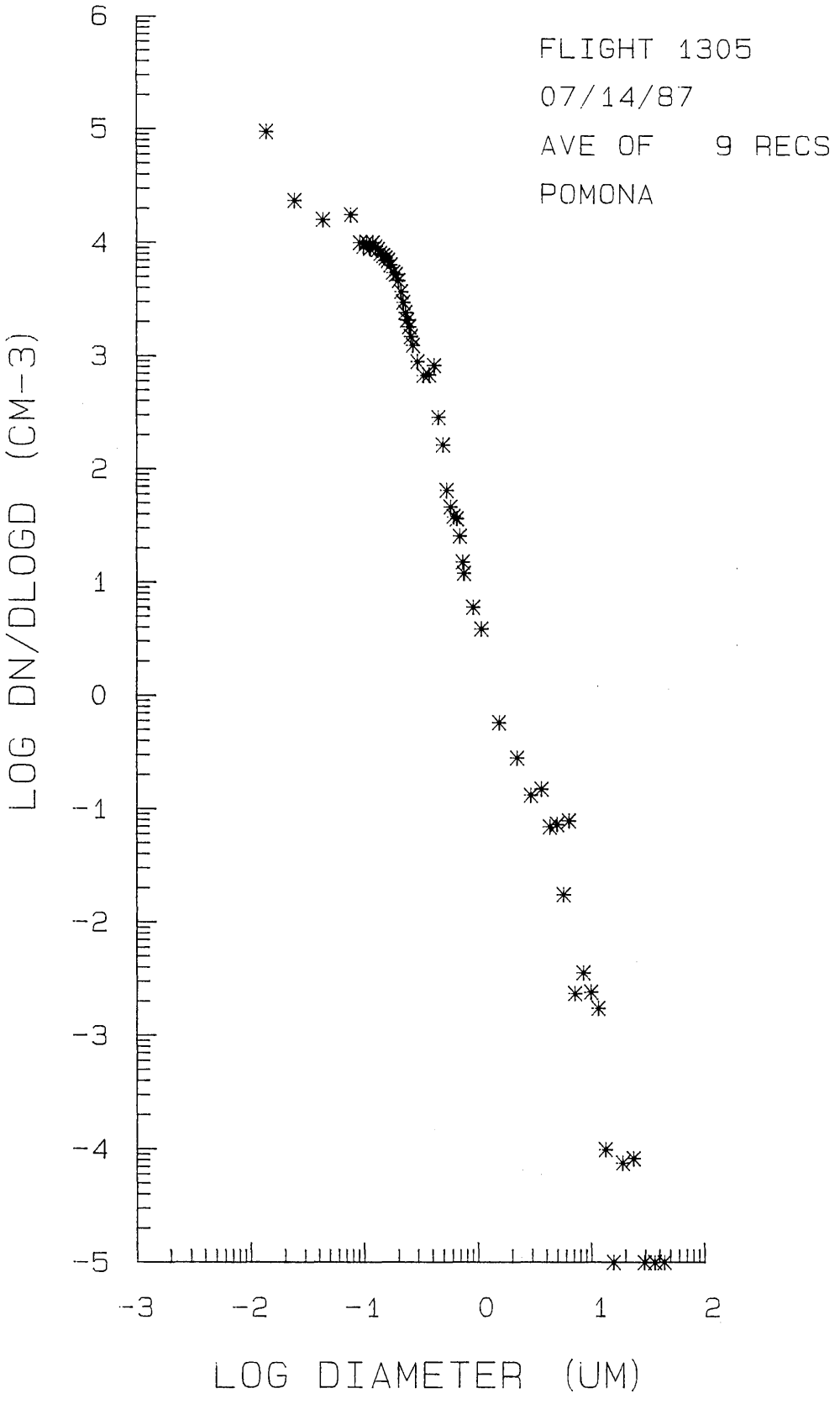
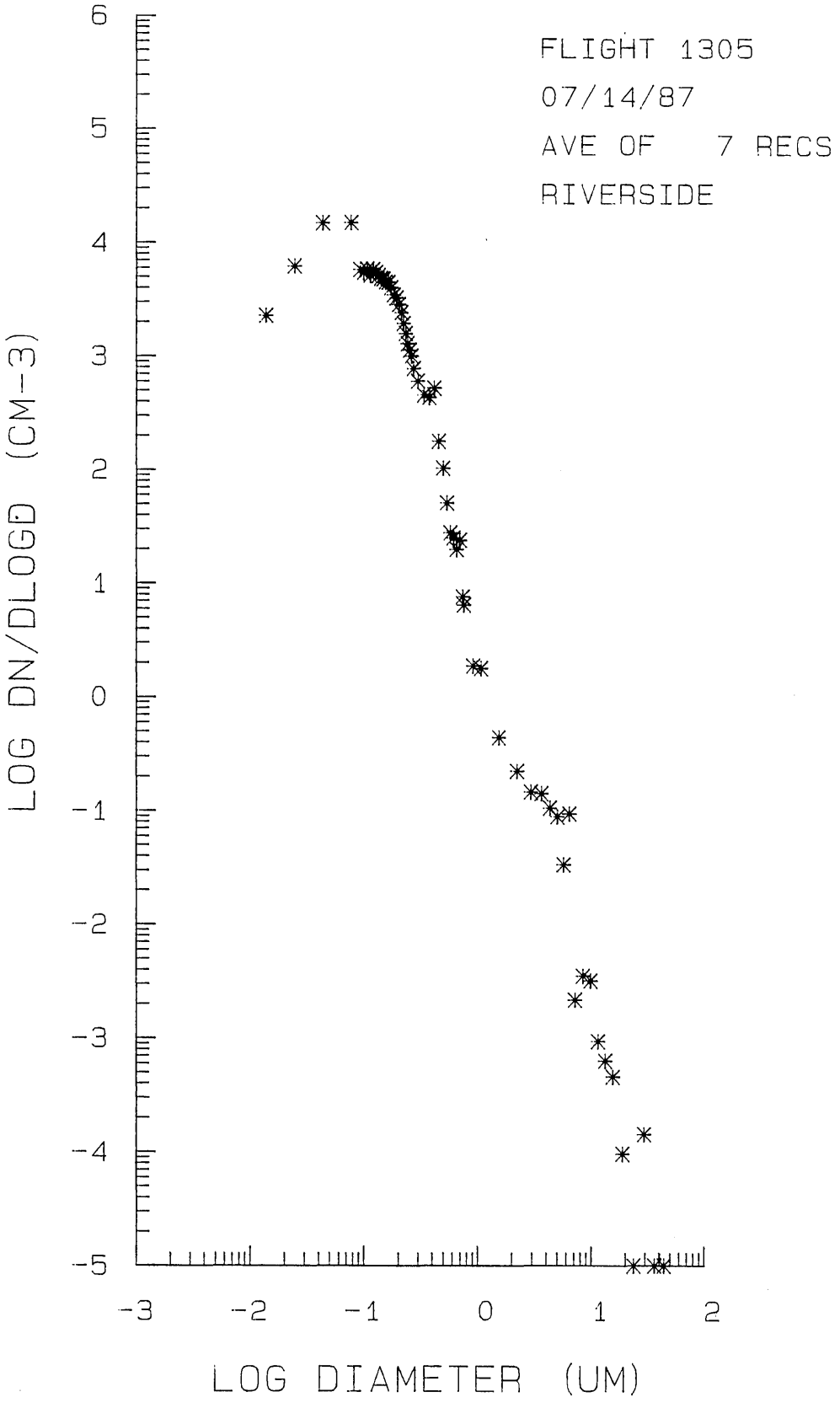
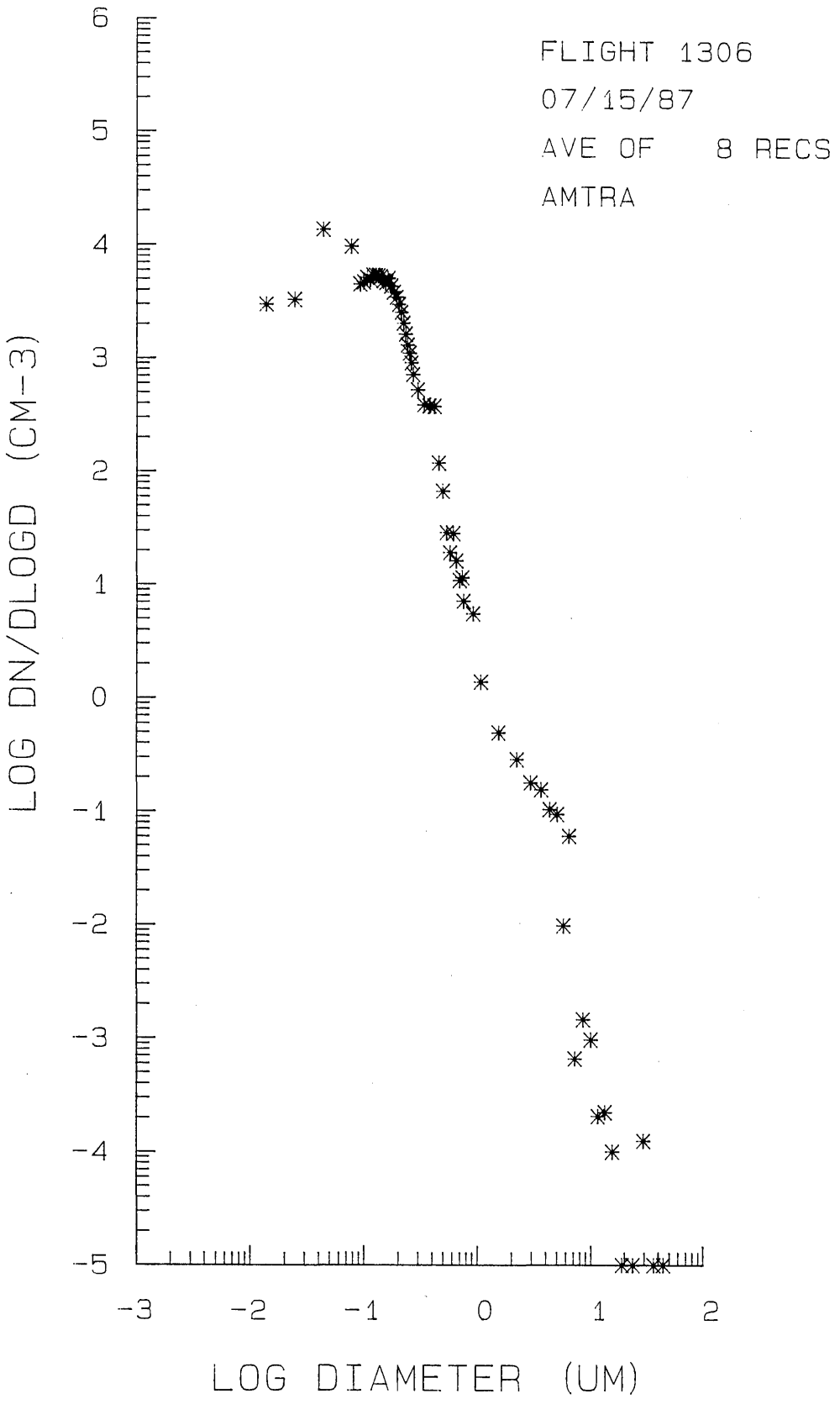
-2
-3
-4
-5
-3
-2
-1
0
1
2

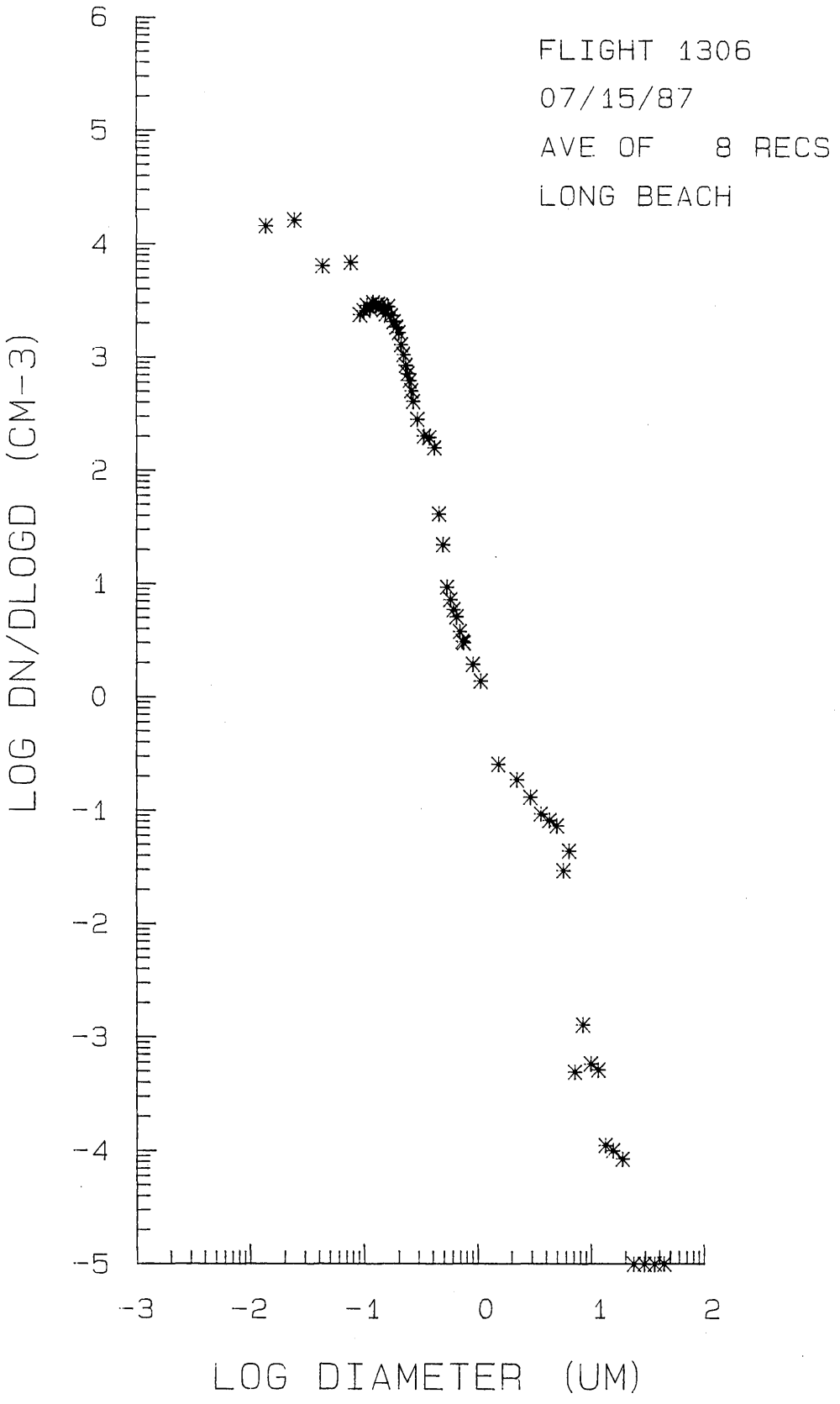

FLIGHT 1305
07/14/87
AVE OF 11 RECS
LONG BEACH
LOG DN/DLOGD (CM-3)
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-3
-2
-1
0
1
2
LOG DIAMETER (UM)

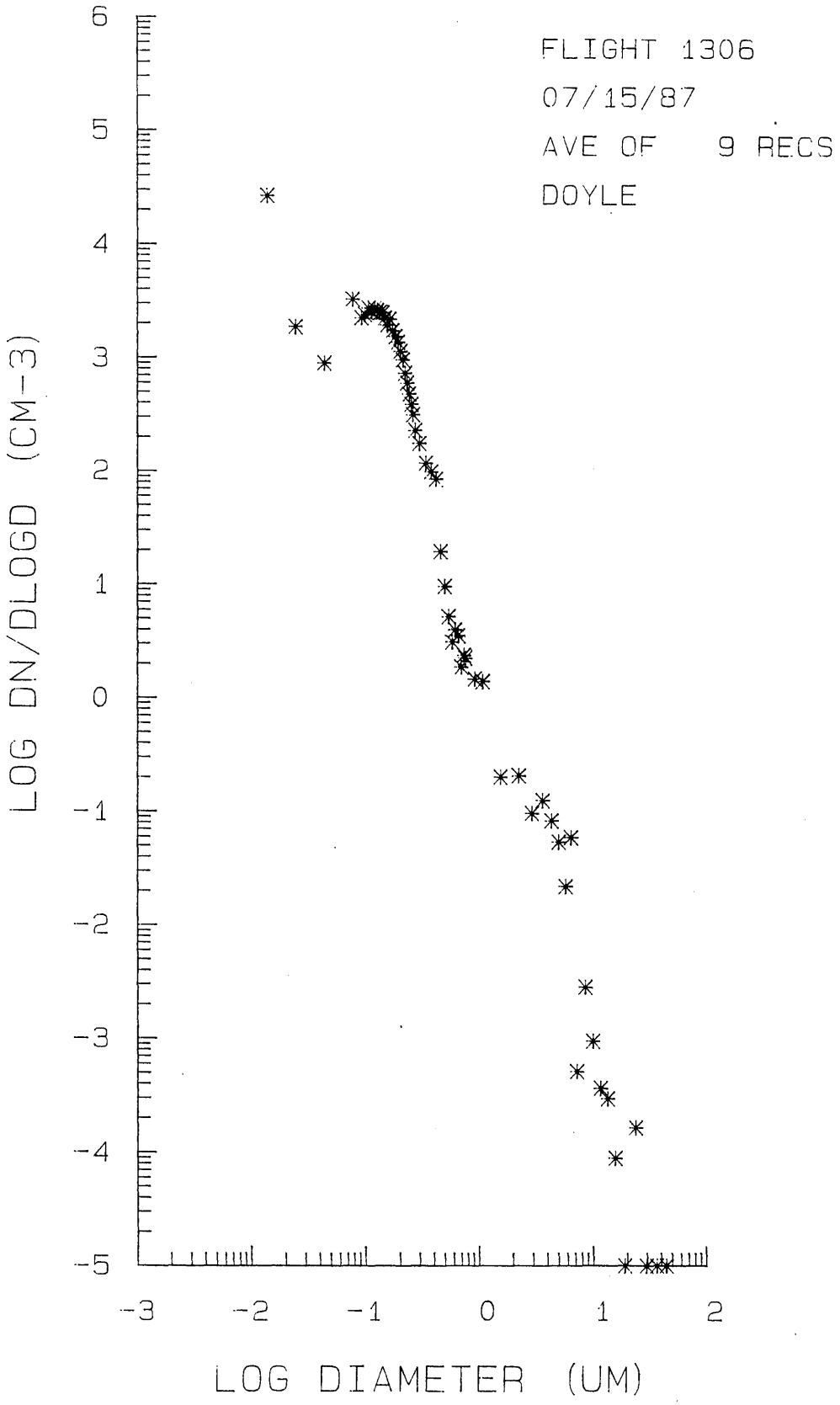

FLIGHT 1305
07/14/87
AVE OF 10 RECS
AMTRA
LOG DN/DLOGD (CM-3)
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-3
-2
-1
0
1
2
LOG DIAMETER (UM)

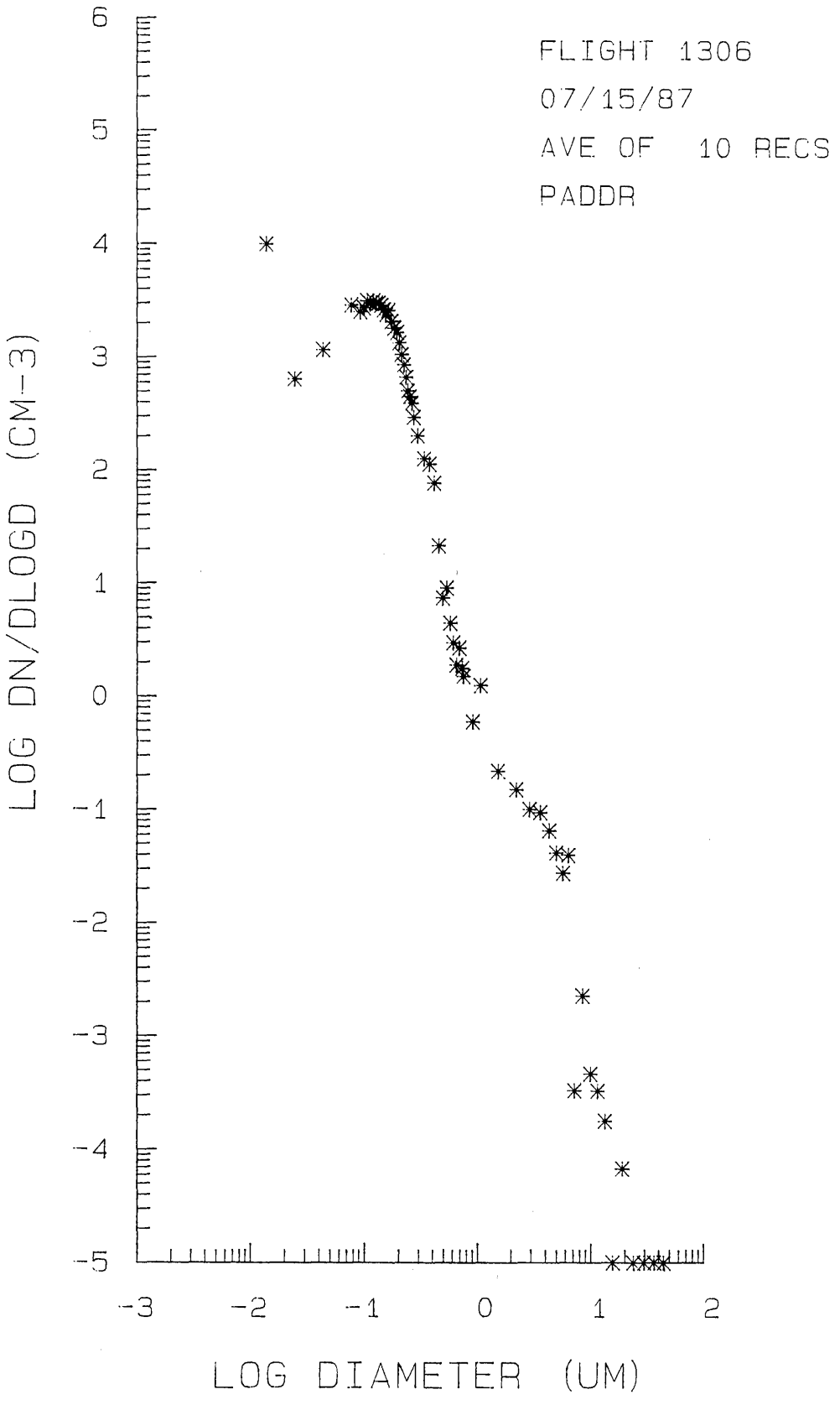

FLIGHT 1305
07/14/87
AVE OF 9 RECS
POMONA
LOG DN/DLOGD (CM-3)
LOG DIAMETER (UM)
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-3
-2
-1
0
1
2

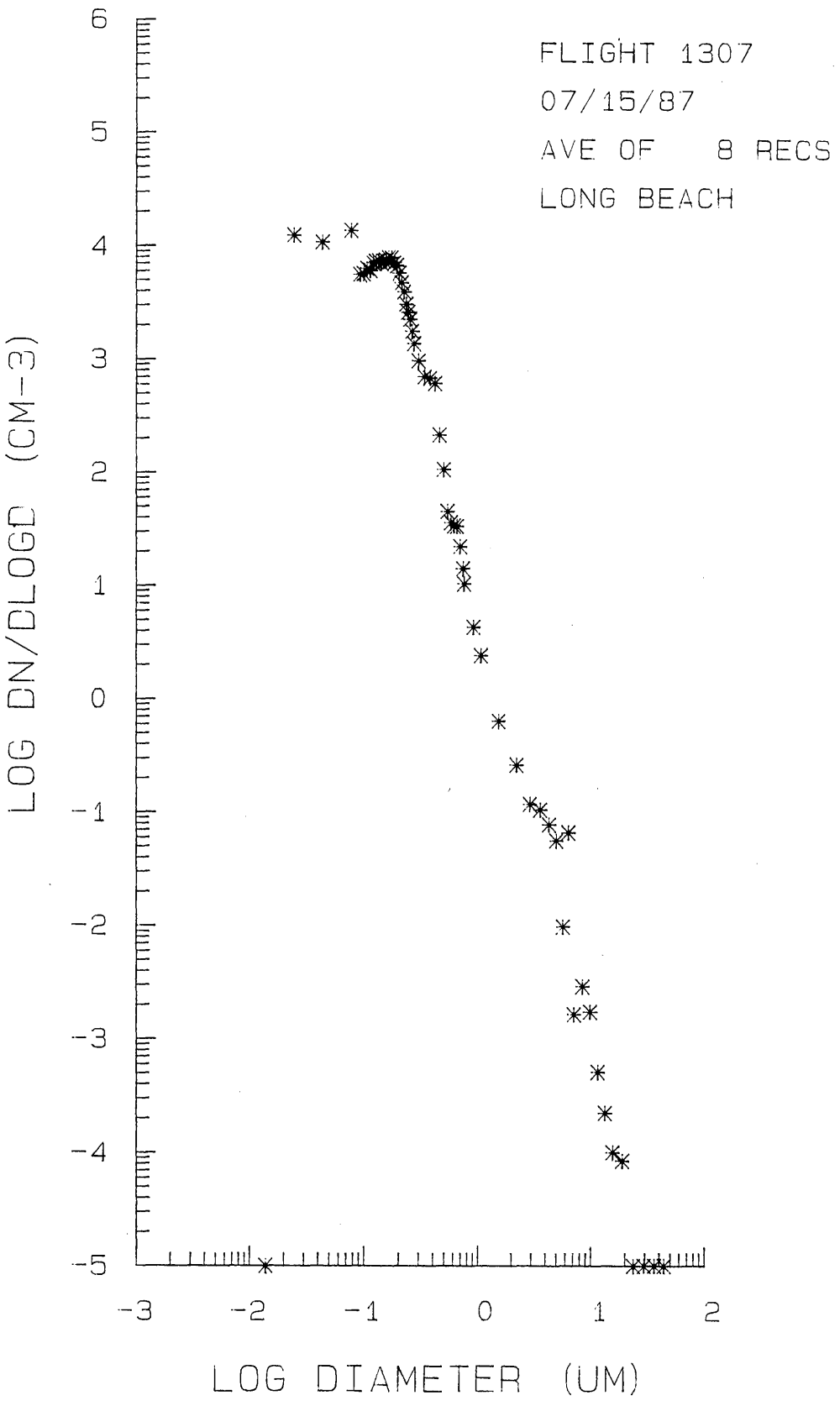

FLIGHT 1305
07/14/87
AVE OF 7 RECS
RIVERSIDE
LOG DN/DLOGD (CM-3)
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-3
-2
-1
0
1
2
LOG DIAMETER (UM)

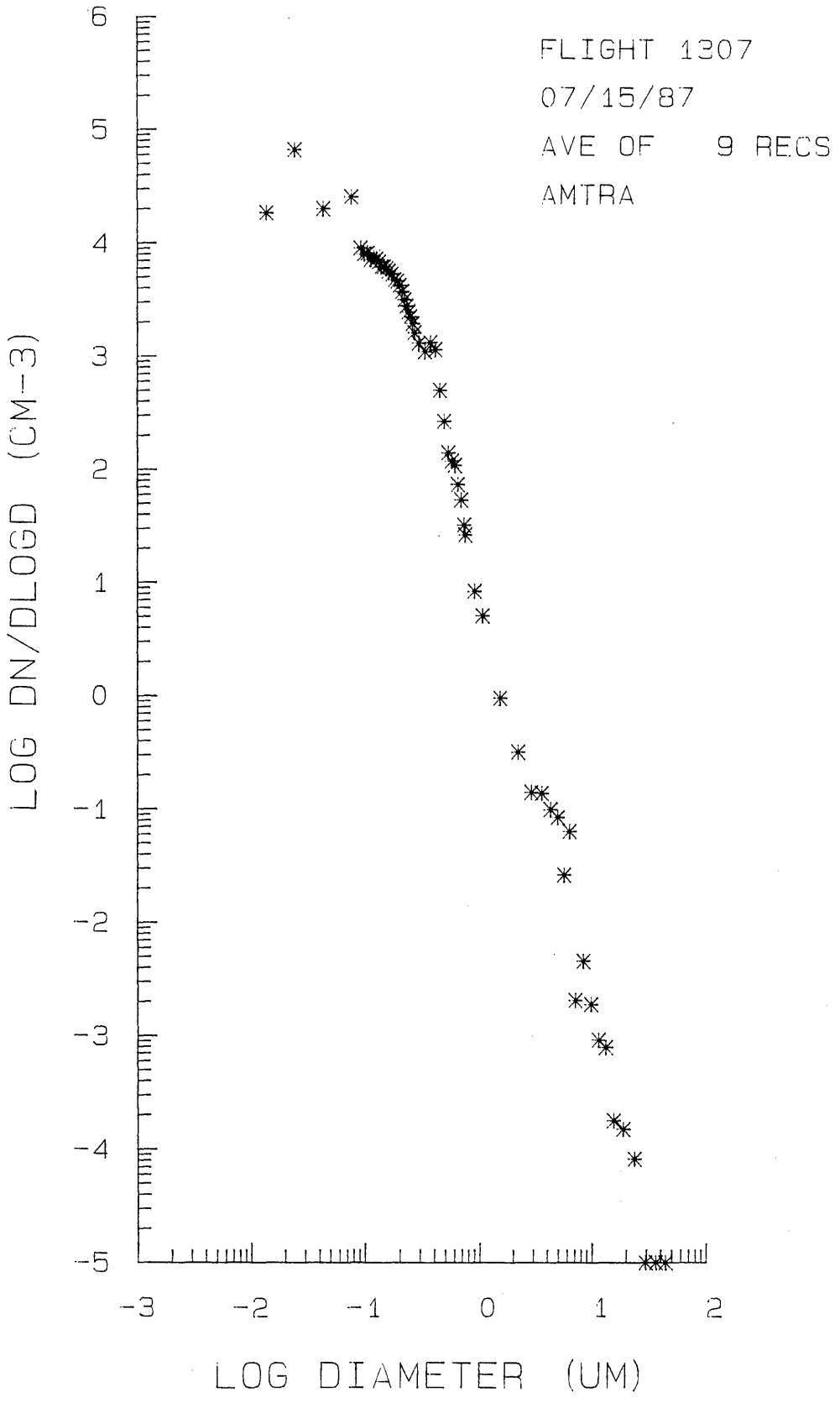

FLIGHT 1306
07/15/87
AVE OF 8 RECS
AMTRA
LOG DN/DLOGD (CM-3)
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-3
-2
-1
0
1
2
LOG DIAMETER (UM)

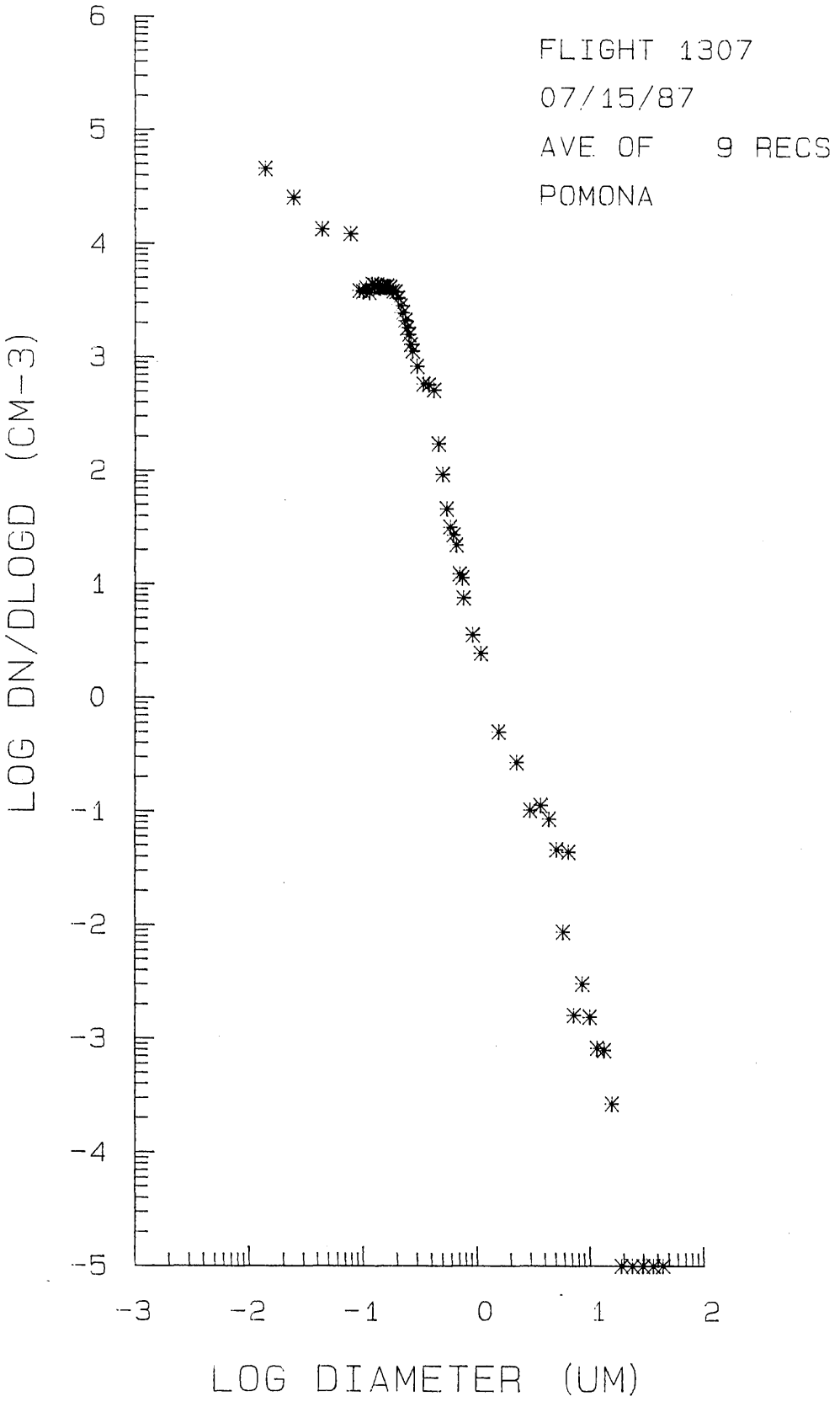

FLIGHT 1306
07/15/87
AVE OF 8 RECS
LONG BEACH
LOG DN/DLOGD (CM-3)
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-3
-2
-1
0
1
2
LOG DIAMETER (UM)

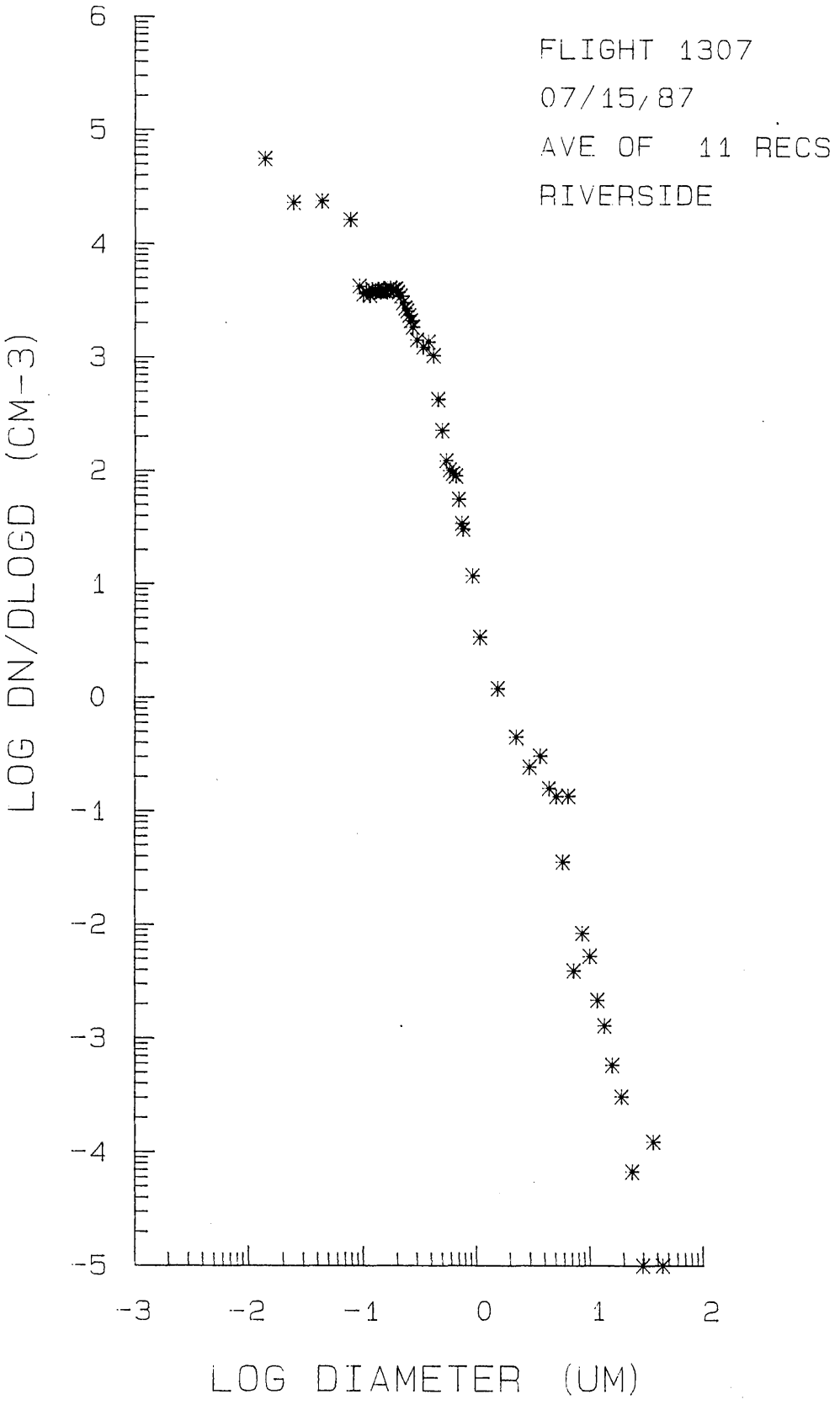

FLIGHT 1306
07/15/87
AVE OF 9 RECS
DOYLE
LOG DN/DLOGD (CM-3)
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-3
-2
-1
0
1
2
LOG DIAMETER (UM)

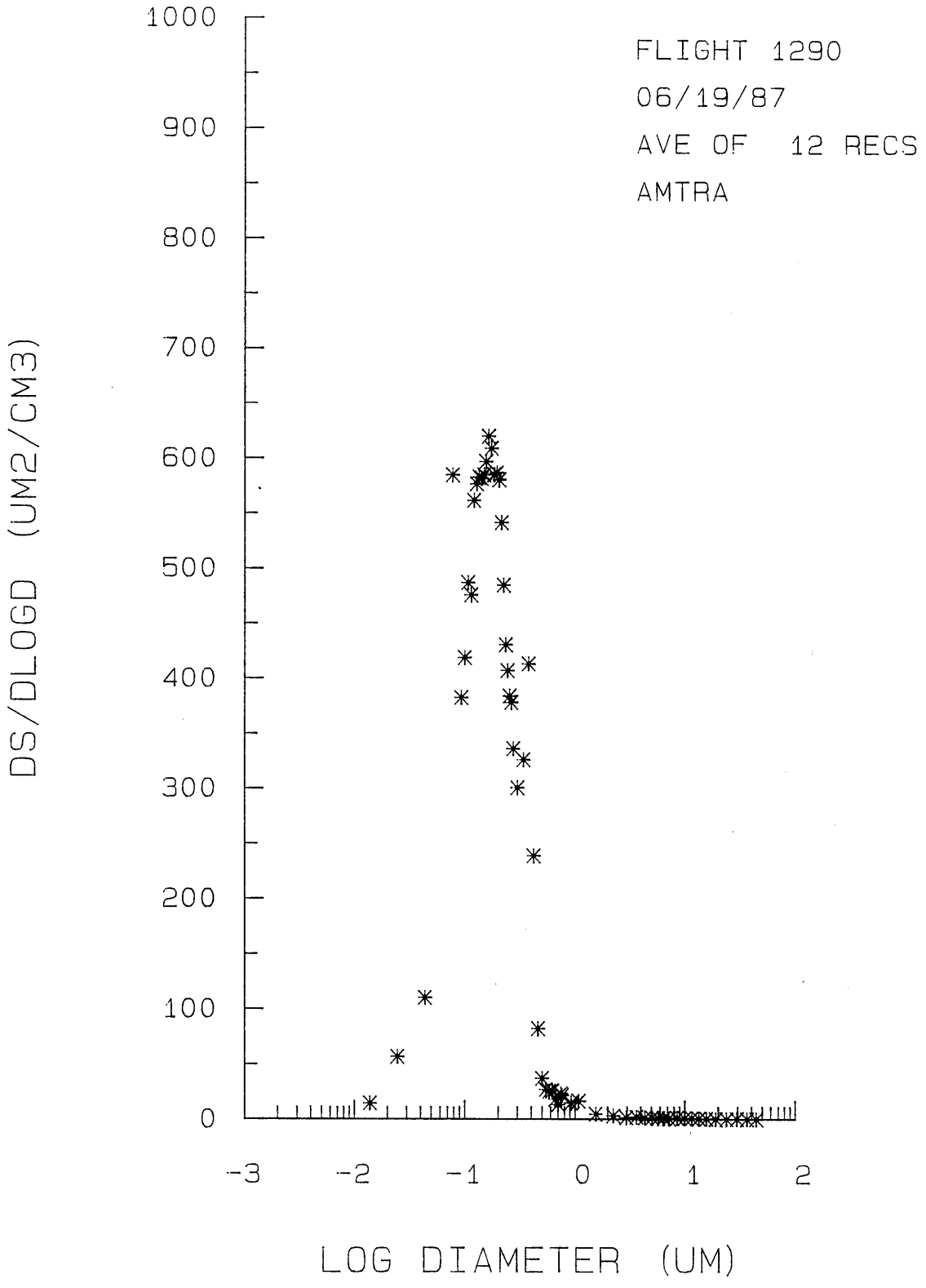

FLIGHT 1306
07/15/87
AVE OF 10 RECS
PADDR
LOG DN/DLOGD (CM-3)
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-3
-2
-1
0
1
2
LOG DIAMETER (UM)

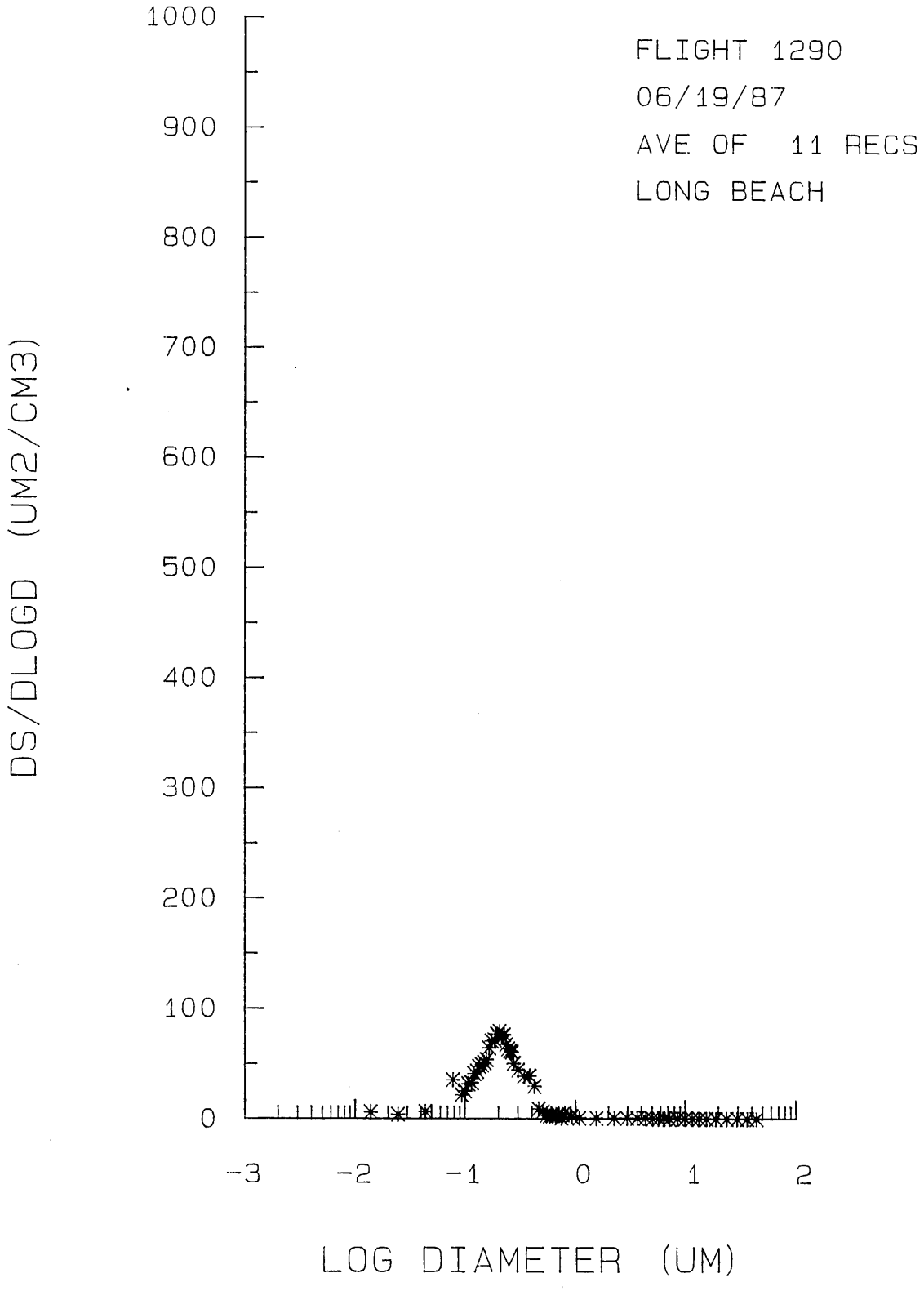

FLIGHT 1307
07/15/87
AVE OF 8 RECS
LONG BEACH
LOG DN/DLOGD (CM-3)
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-3
-2
-1
0
1
2
LOG DIAMETER (UM)

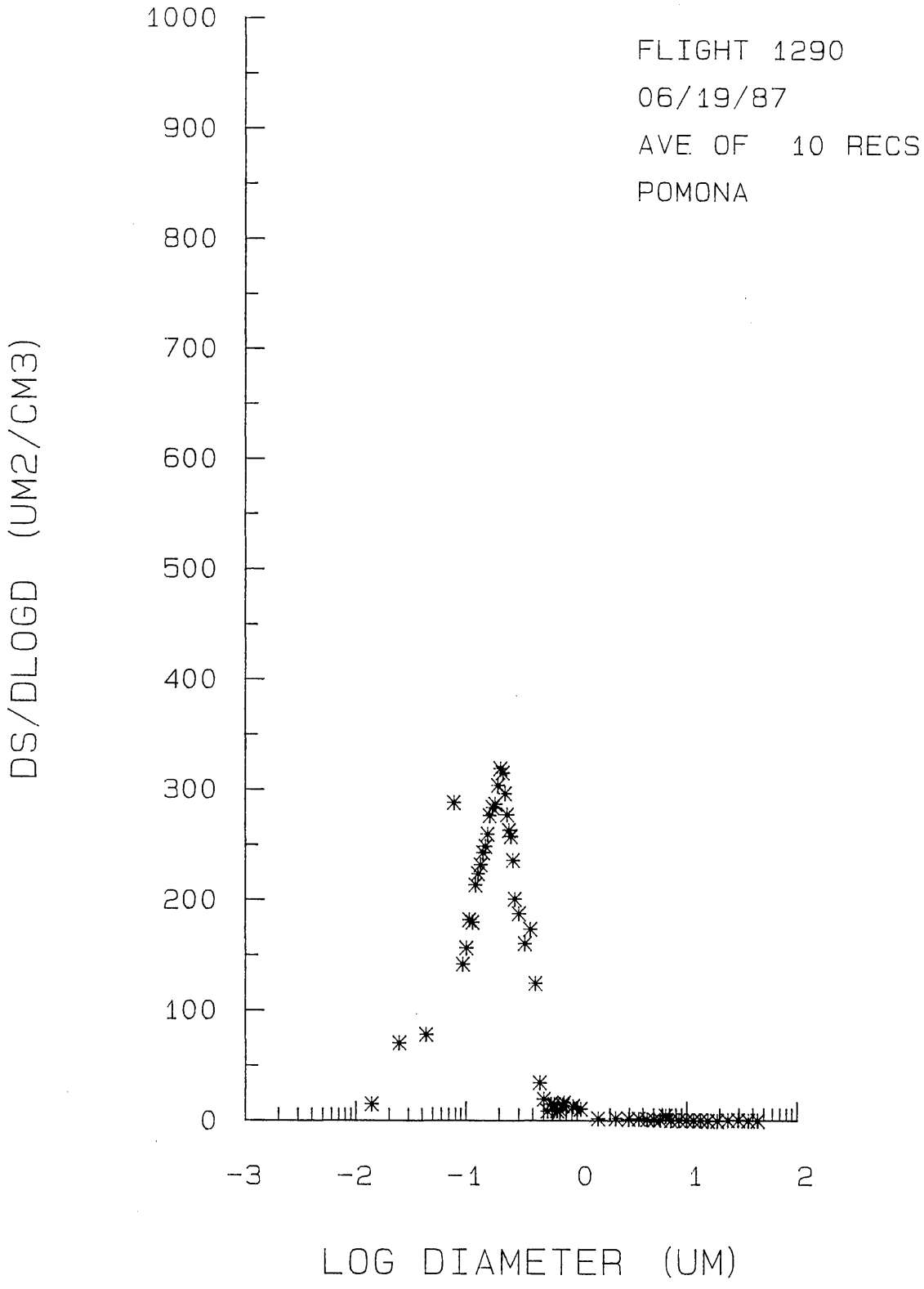

FLIGHT 1307
07/15/87
AVE OF 9 RECS
AMTRA
LOG DN/DLOGD (CM-3)
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-3
-2
-1
0
1
2
LOG DIAMETER (UM)

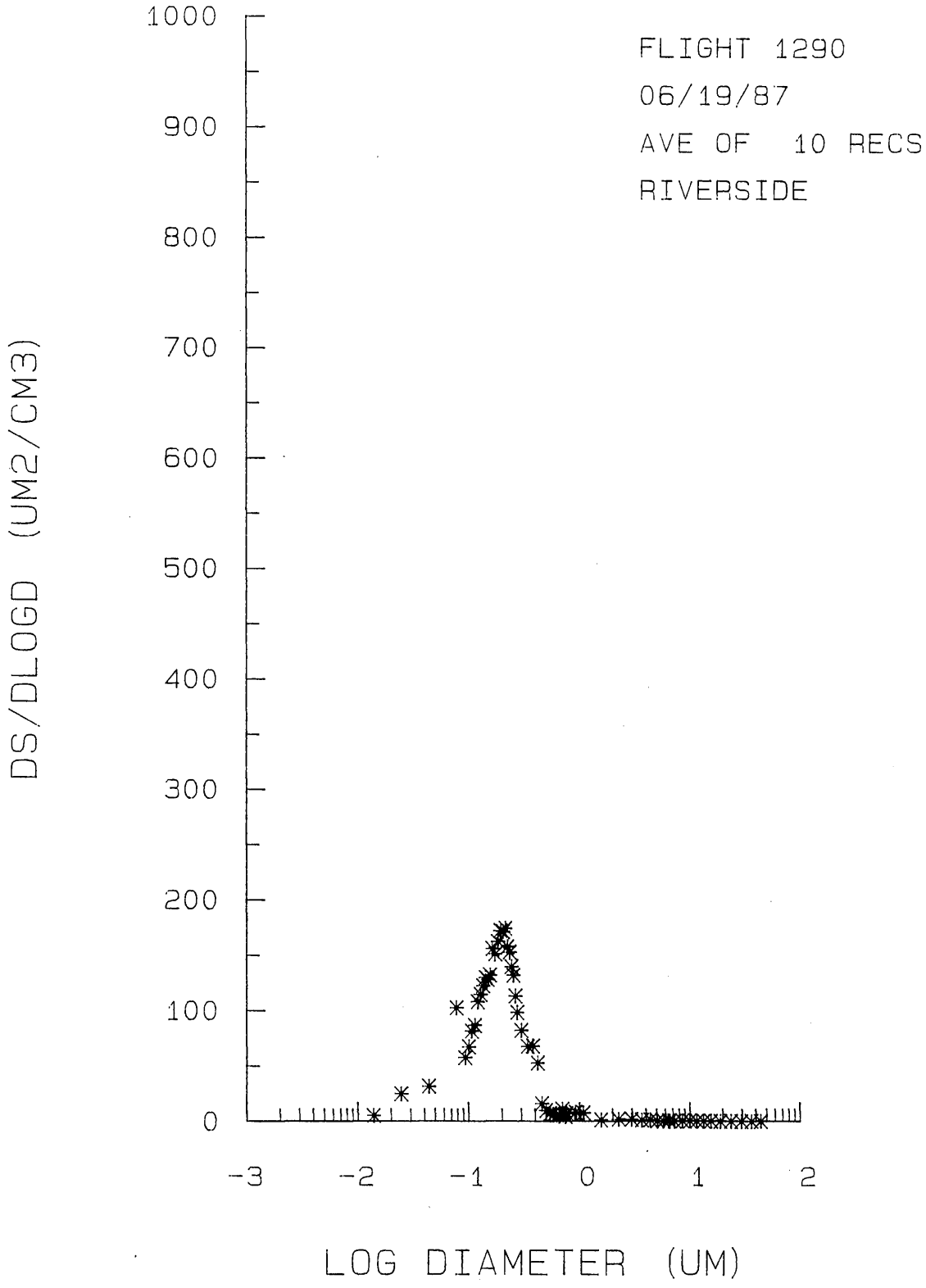

FLIGHT 1307
07/15/87
AVE OF 9 RECS
POMONA
LOG DN/DLOGD (CM-3)
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-3
-2
-1
0
1
2
LOG DIAMETER (UM)

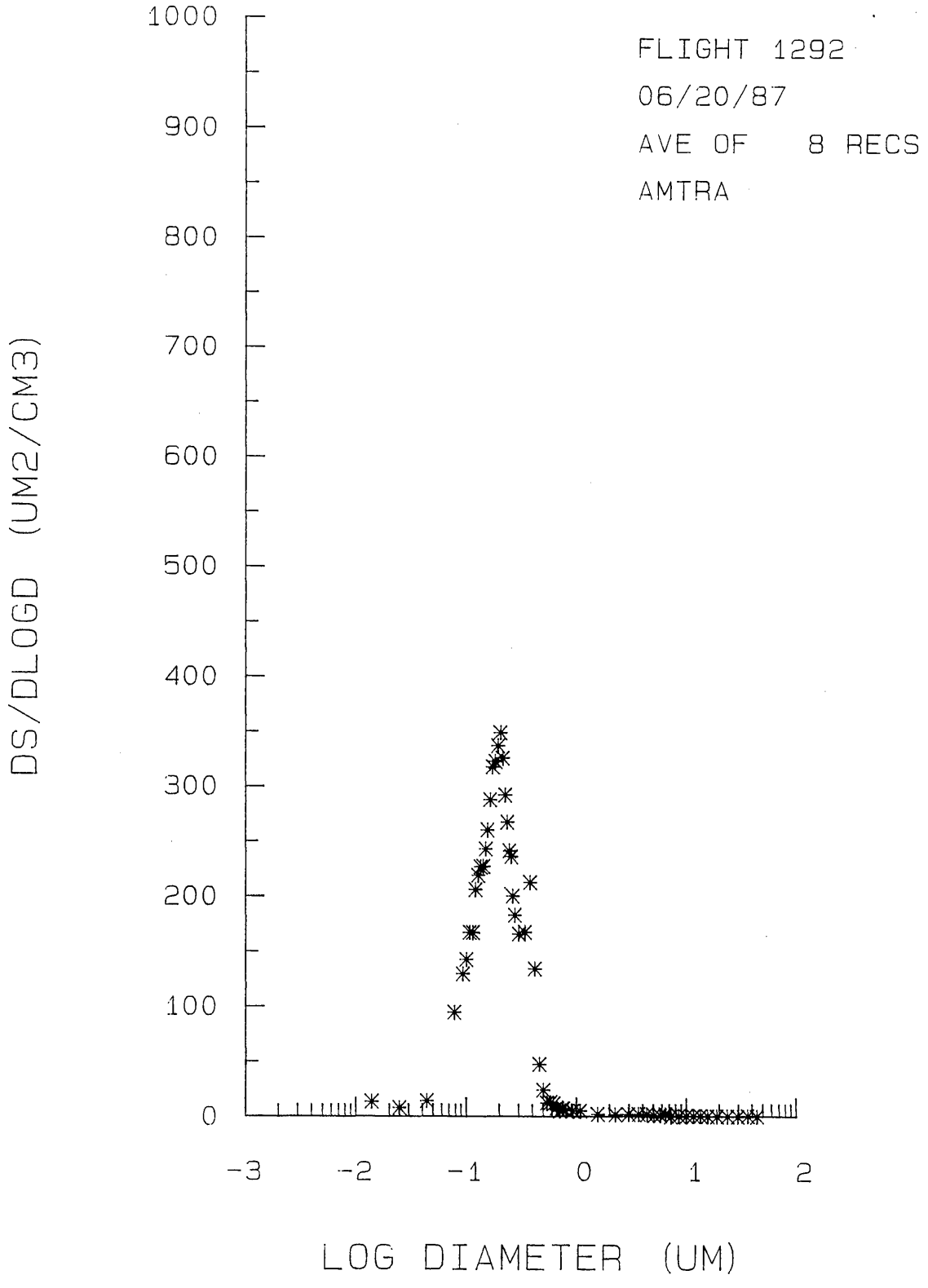

FLIGHT 1307
07/15/87
AVE OF 11 RECS
RIVERSIDE
LOG DN/DLOGD (CM-3)
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-3
-2
-1
0
1
2
LOG DIAMETER (UM)

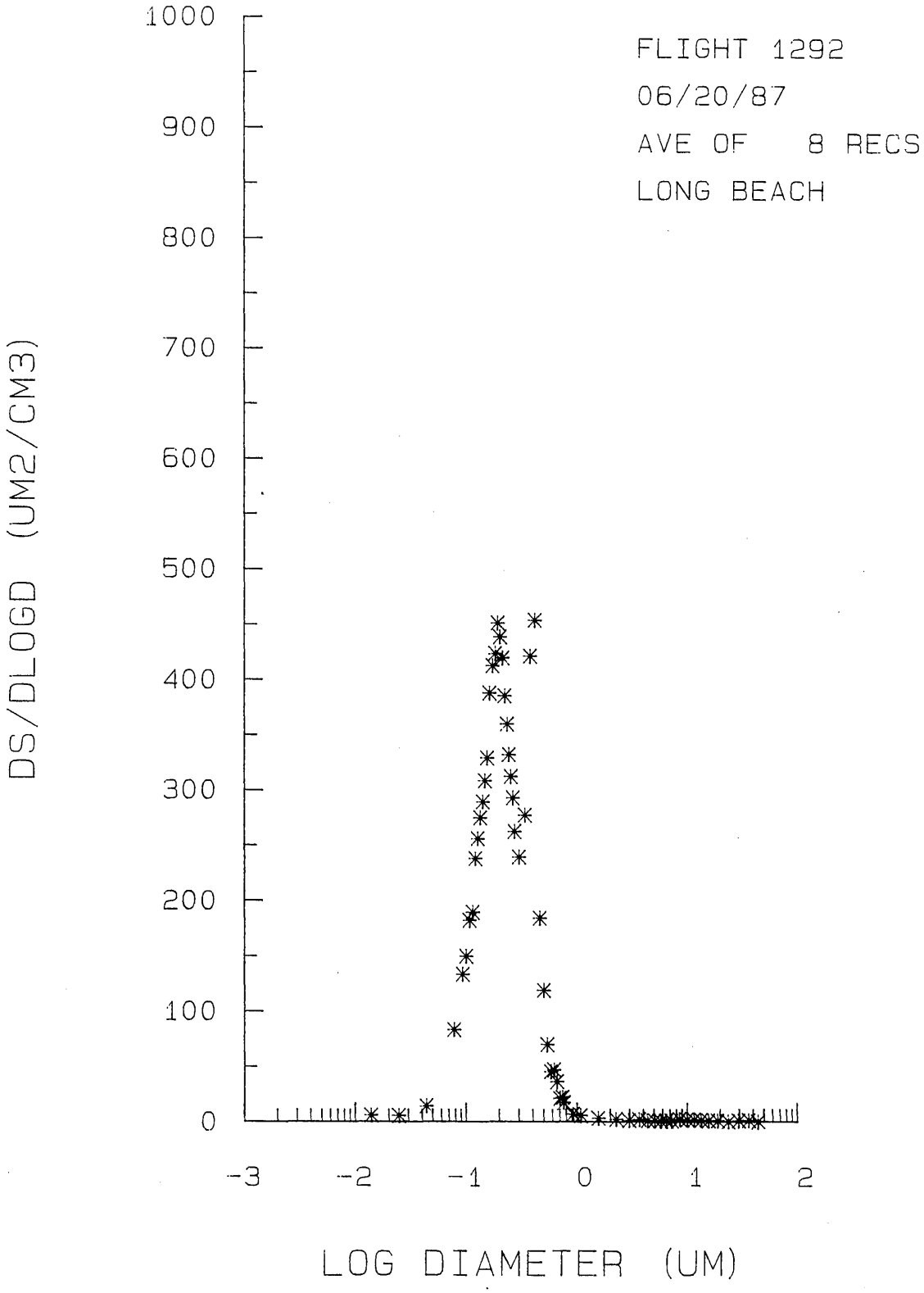

FLIGHT 1290
06/19/87
AVE OF 12 RECS
AMTRA
DS/DLOGD (UM2/CM3)
1000
900
800
700
600
500
400
300
200
100
0
-3
-2
-1
0
1
2
LOG DIAMETER (UM)

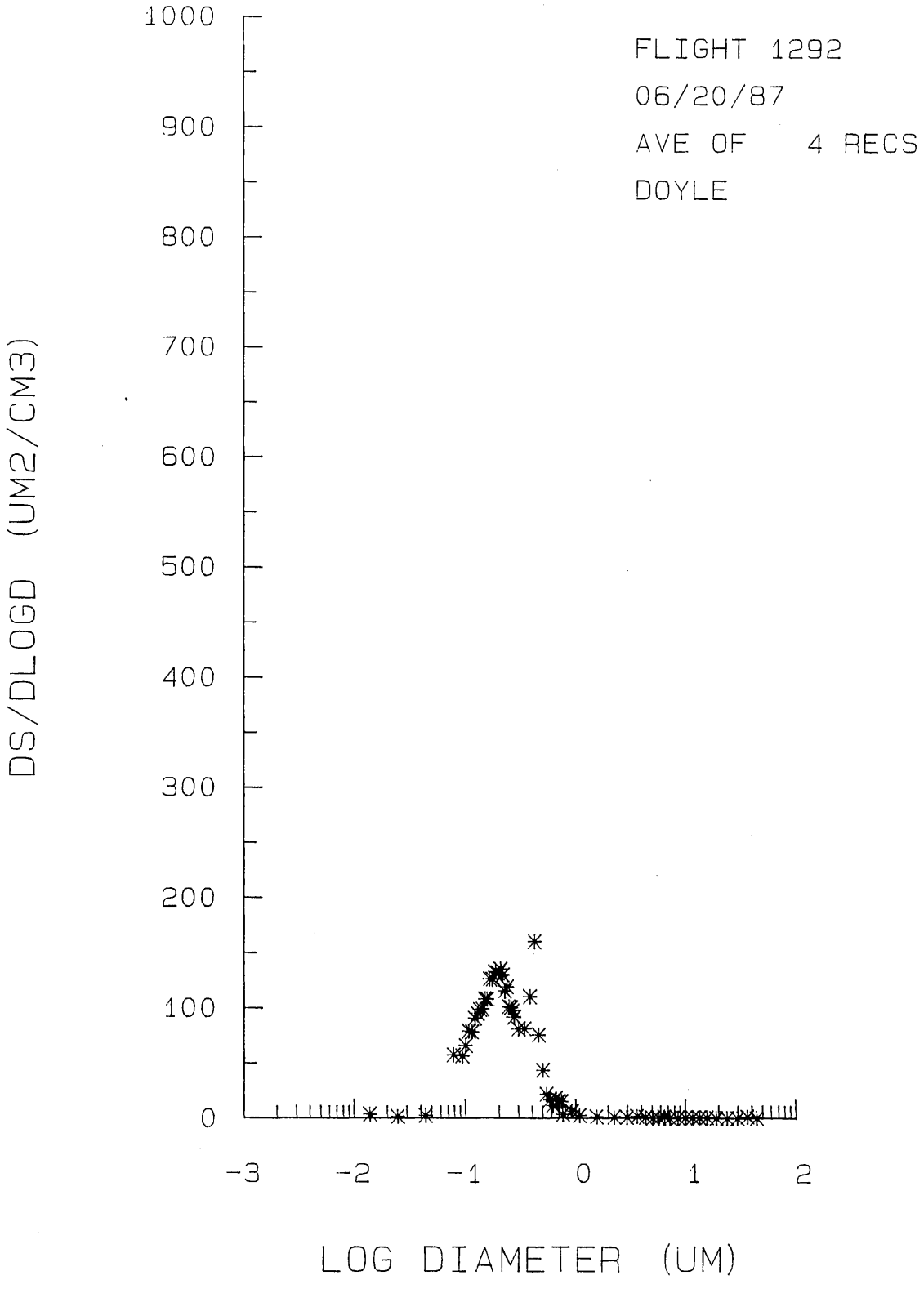

FLIGHT 1290
06/19/87
AVE OF 11 RECS
LONG BEACH
DS/DLOGD (UM2/CM3)
1000
900
800
700
600
500
400
300
200
100
0
-3
-2
-1
0
1
2
LOG DIAMETER (UM)

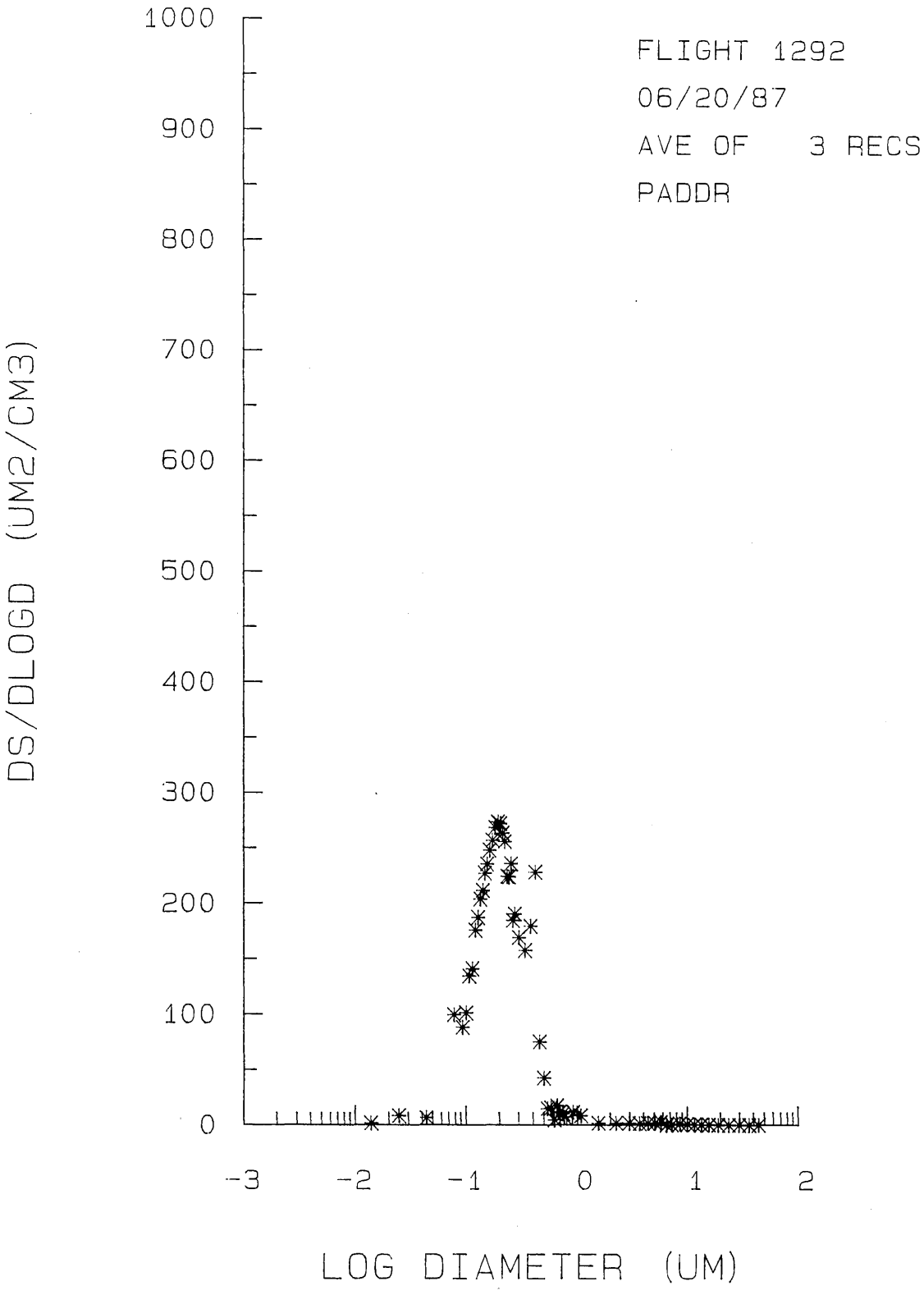

FLIGHT 1290
06/19/87
AVE OF 10 RECS
POMONA
DS/DLOGD (UM2/CM3)
1000
900
800
700
600
500
400
300
200
100
0
-3
-2
-1
0
1
2
LOG DIAMETER (UM)

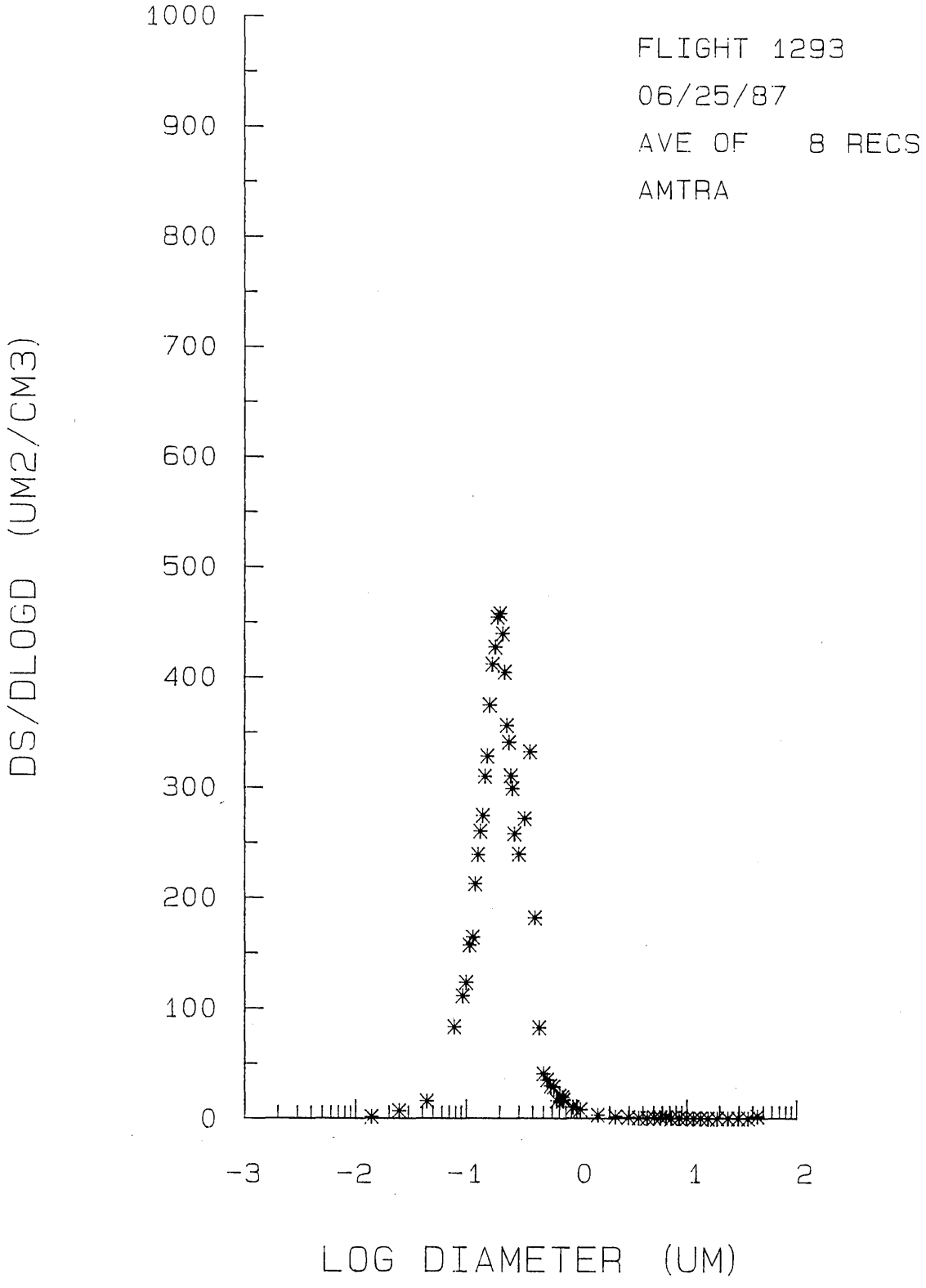

FLIGHT 1290
06/19/87
AVE OF 10 RECS
RIVERSIDE
DS/DLOGD (UM2/CM3)
1000
900
800
700
600
500
400
300
200
100
0
-3
-2
-1
0
1
2
LOG DIAMETER (UM)

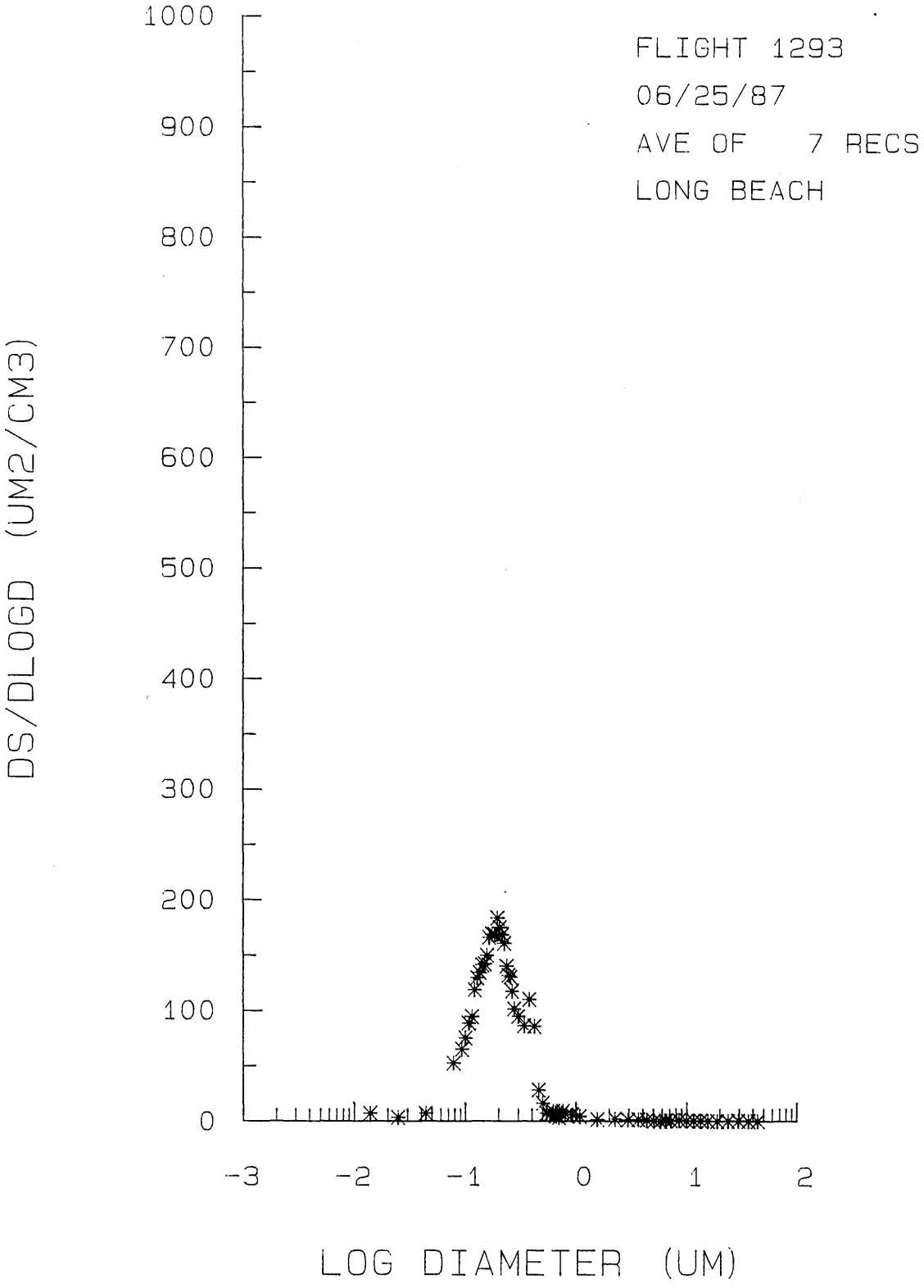

FLIGHT 1292
06/20/87
AVE OF 8 RECS
AMTRA
DS/DLOGD (UM2/CM3)
1000
900
800
700
600
500
400
300
200
100
0
-3
-2
-1
0
1
2
LOG DIAMETER (UM)

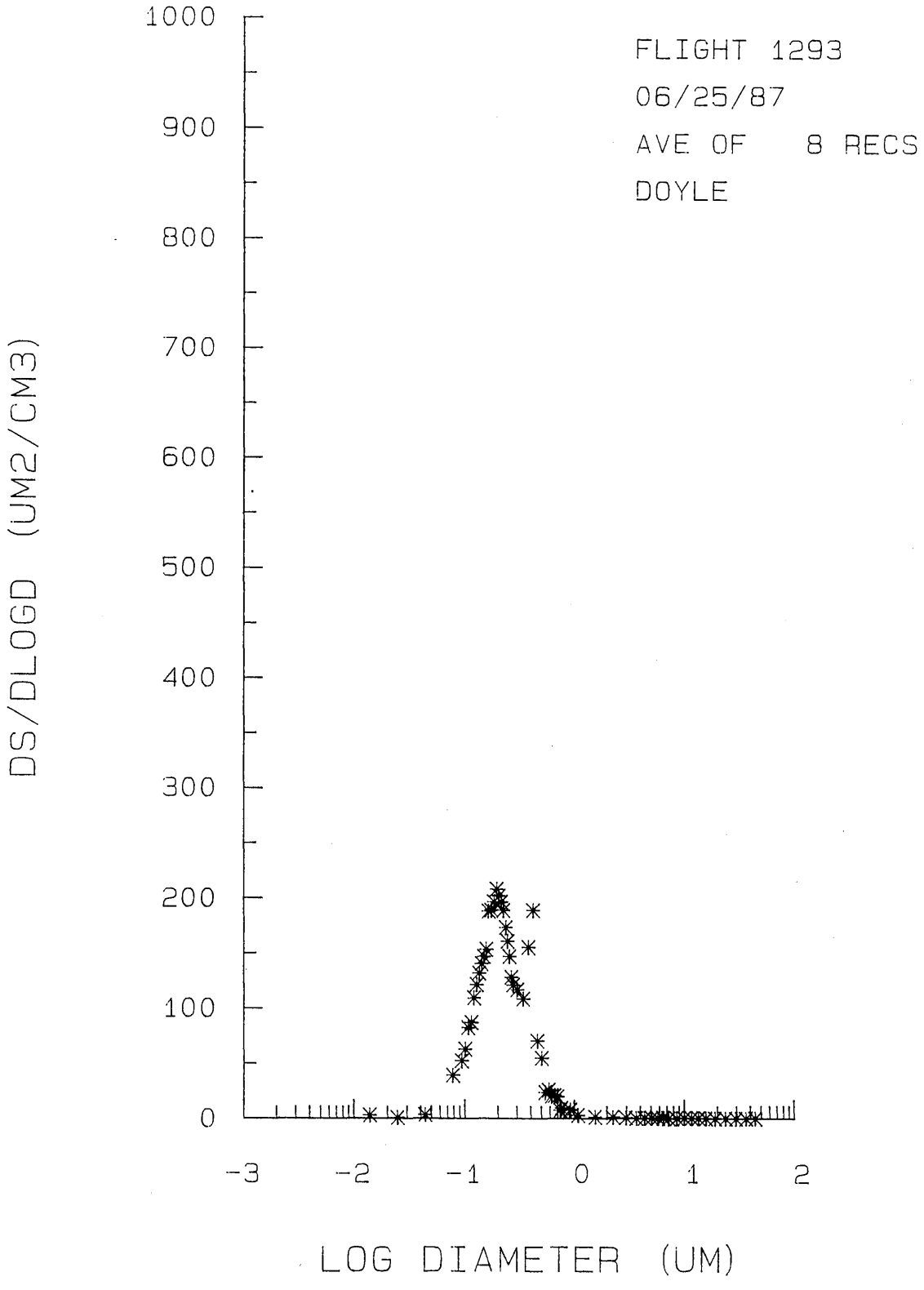

FLIGHT 1292
06/20/87
AVE OF 8 RECS
LONG BEACH
DS/DLOGD (UM2/CM3)
1000
900
800
700
600
500
400
300
200
100
0
-3
-2
-1
0
1
2
LOG DIAMETER (UM)

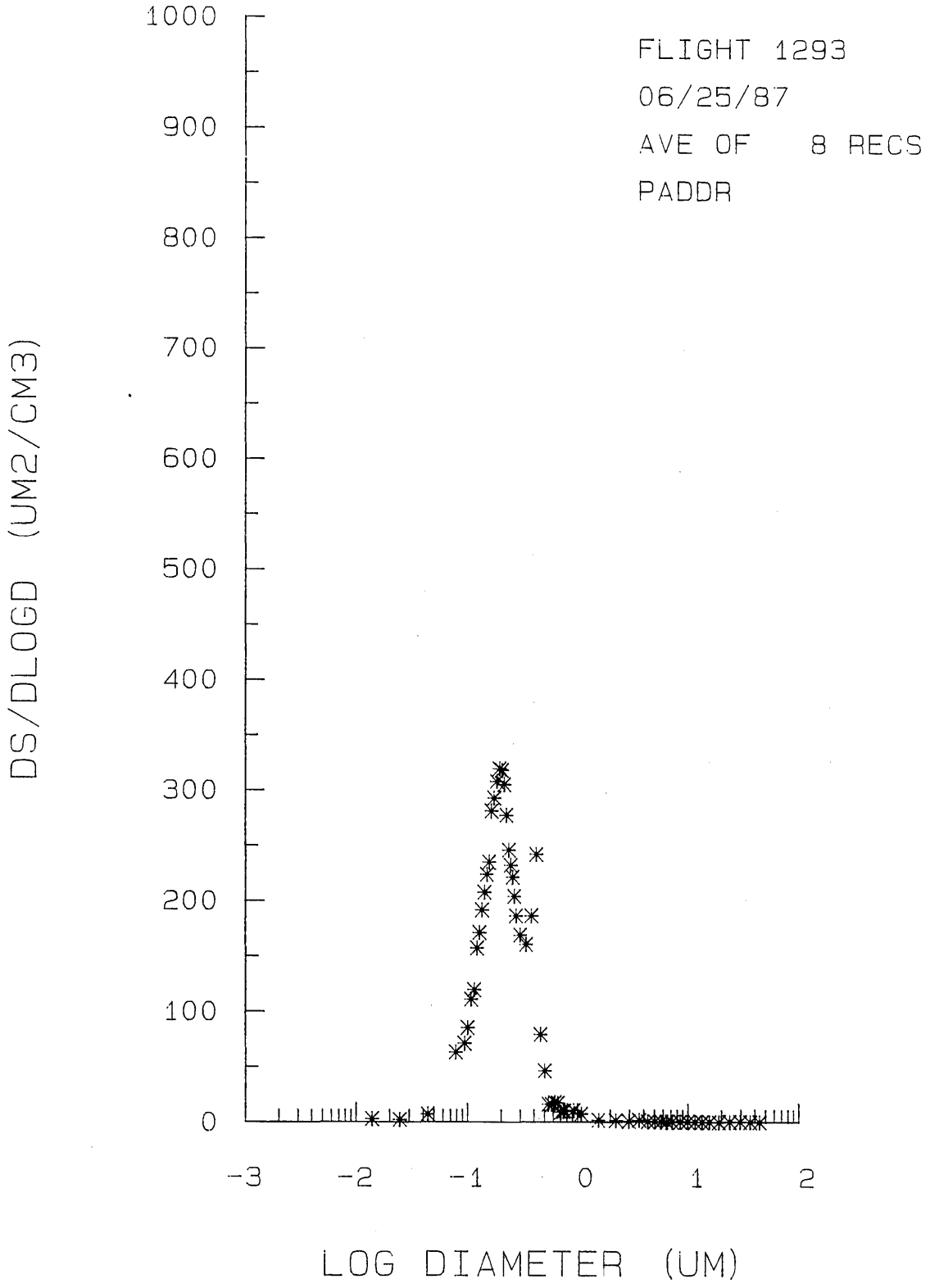

FLIGHT 1292
06/20/87
AVE OF 4 RECS
DOYLE
DS/DLOGD (UM2/CM3)
1000
900
800
700
600
500
400
300
200
100
0
-3
-2
-1
0
1
2
LOG DIAMETER (UM)

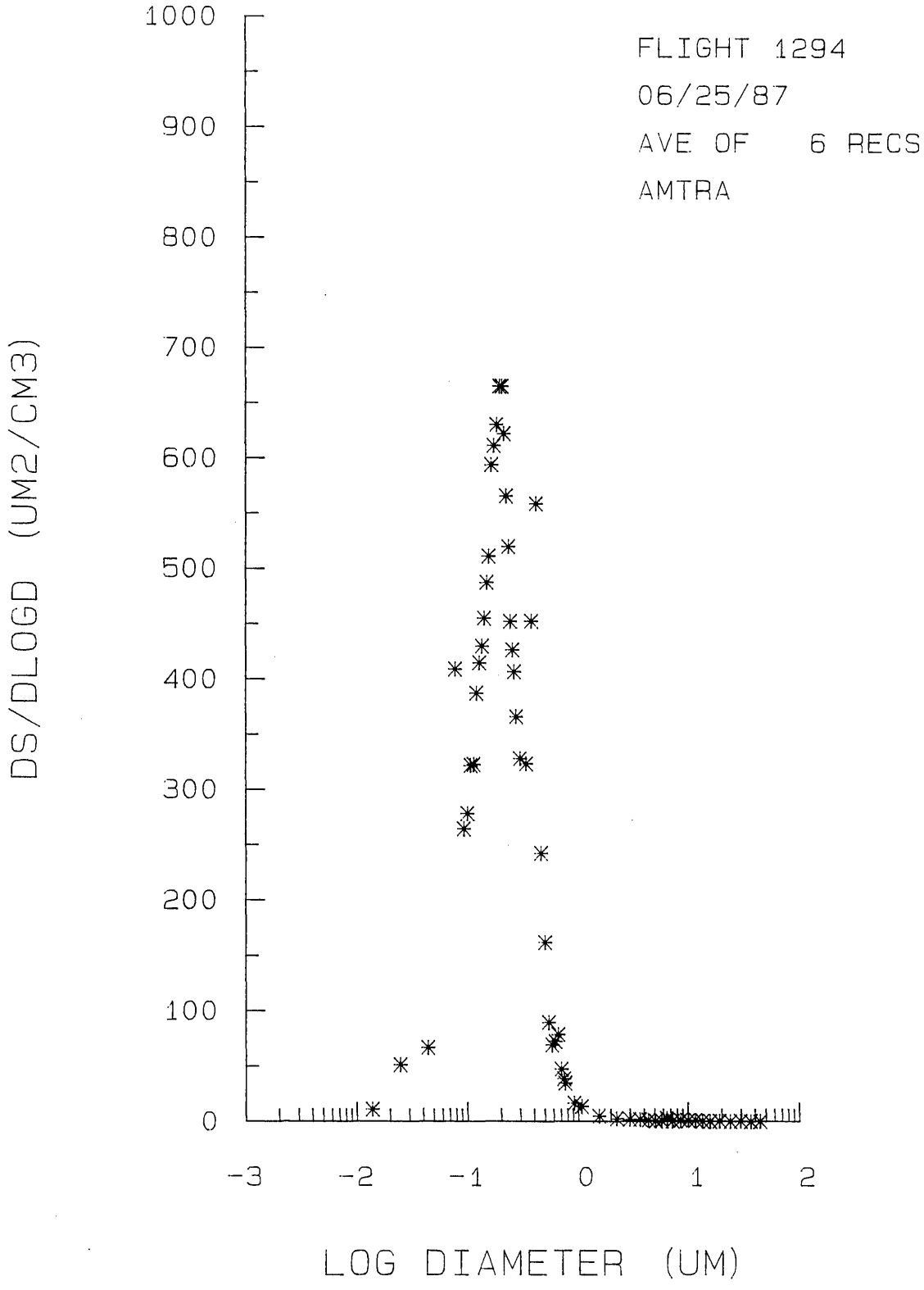

FLIGHT 1292
06/20/87
AVE OF 3 RECS
PADDR
DS/DLOGD (UM2/CM3)
1000
900
800
700
600
500
400
300
200
100
0
-3
-2
-1
0
1
2
LOG DIAMETER (UM)

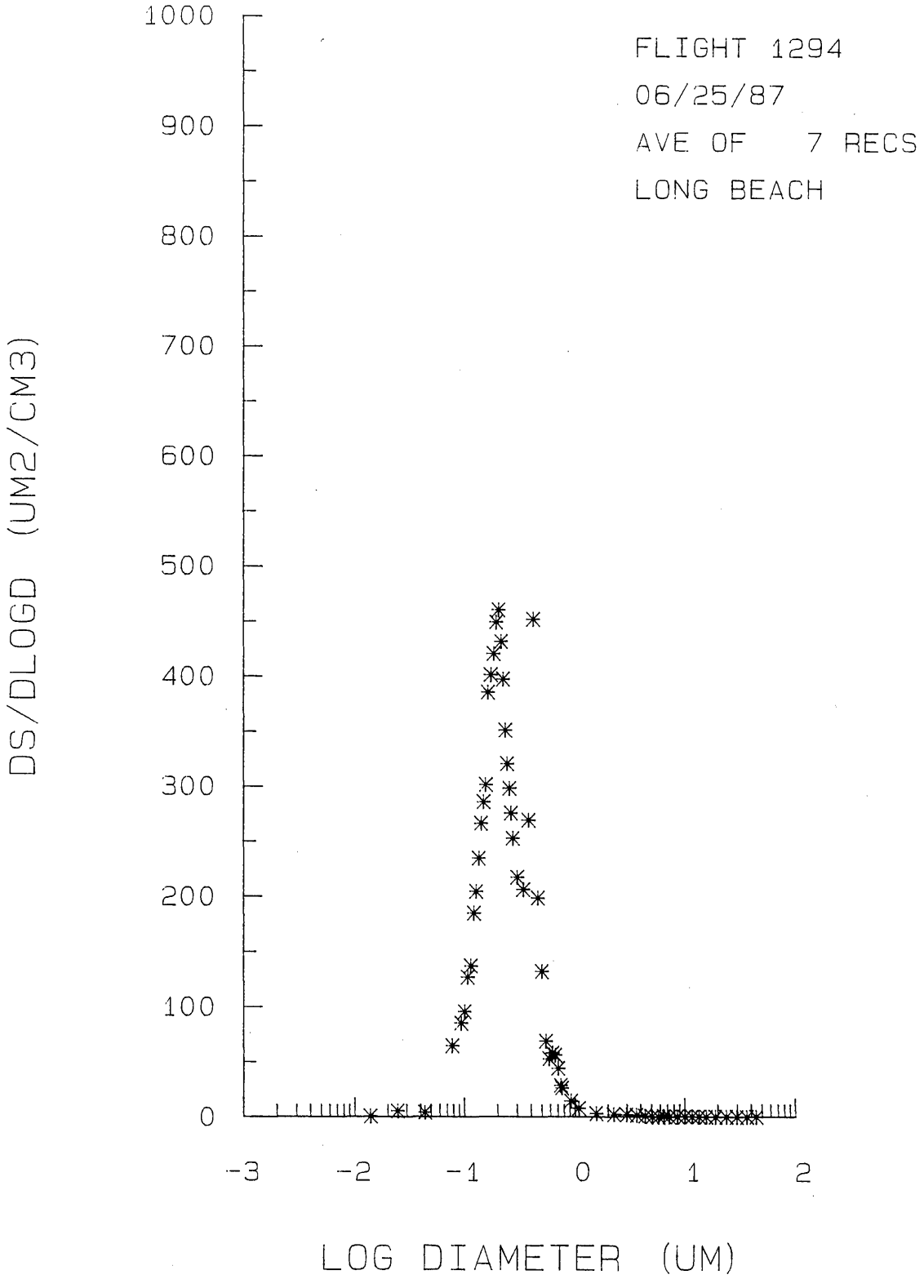

FLIGHT 1293
06/25/87
AVE OF 8 RECS
AMTRA
DS/DLOGD (UM2/CM3)
1000
900
800
700
600
500
400
300
200
100
0
-3
-2
-1
0
1
2
LOG DIAMETER (UM)

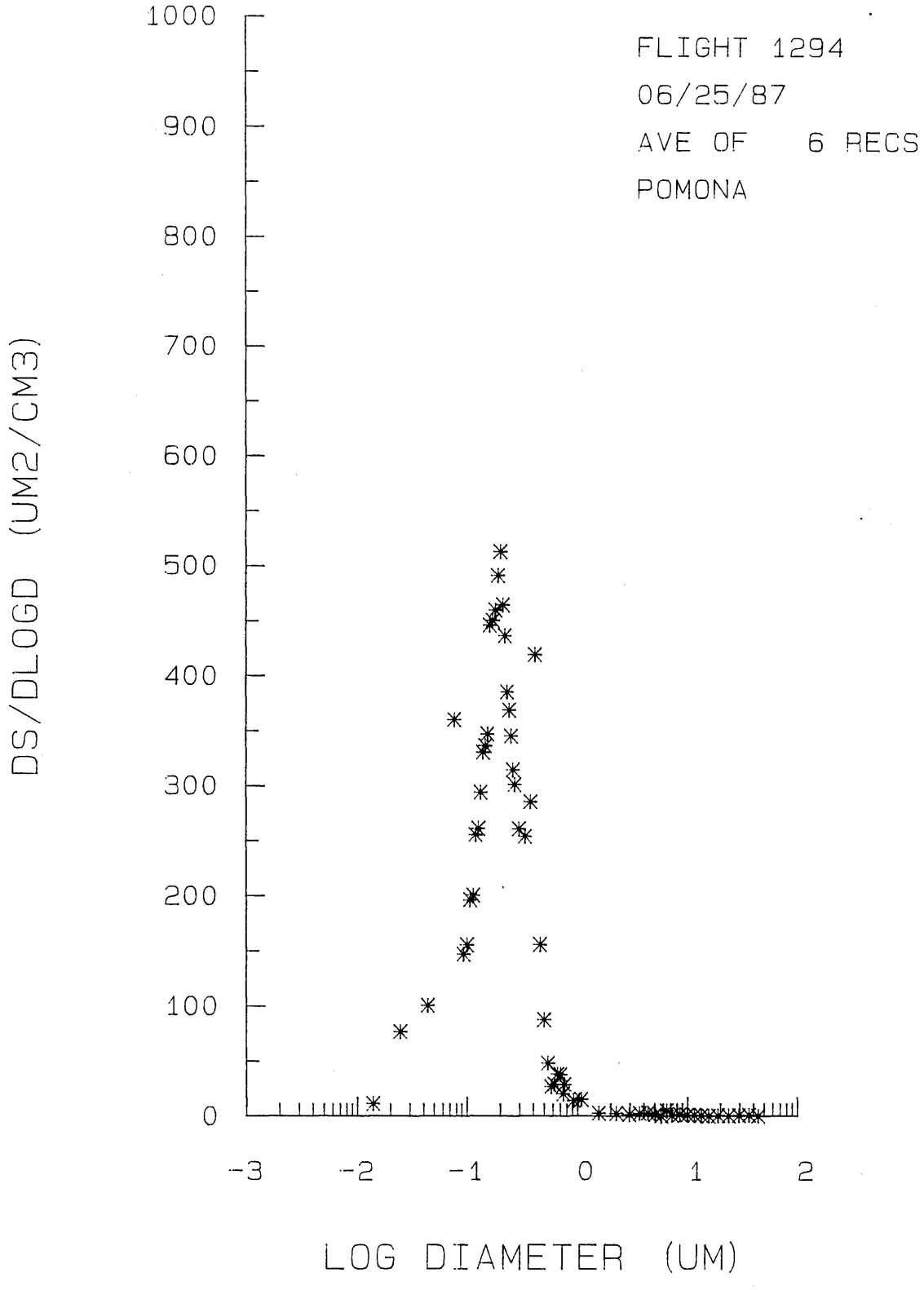

FLIGHT 1293
06/25/87
AVE OF 7 RECS
LONG BEACH
DS/DLOGD (UM2/CM3)
1000
900
800
700
600
500
400
300
200
100
0
-3
-2
-1
0
1
2
LOG DIAMETER (UM)

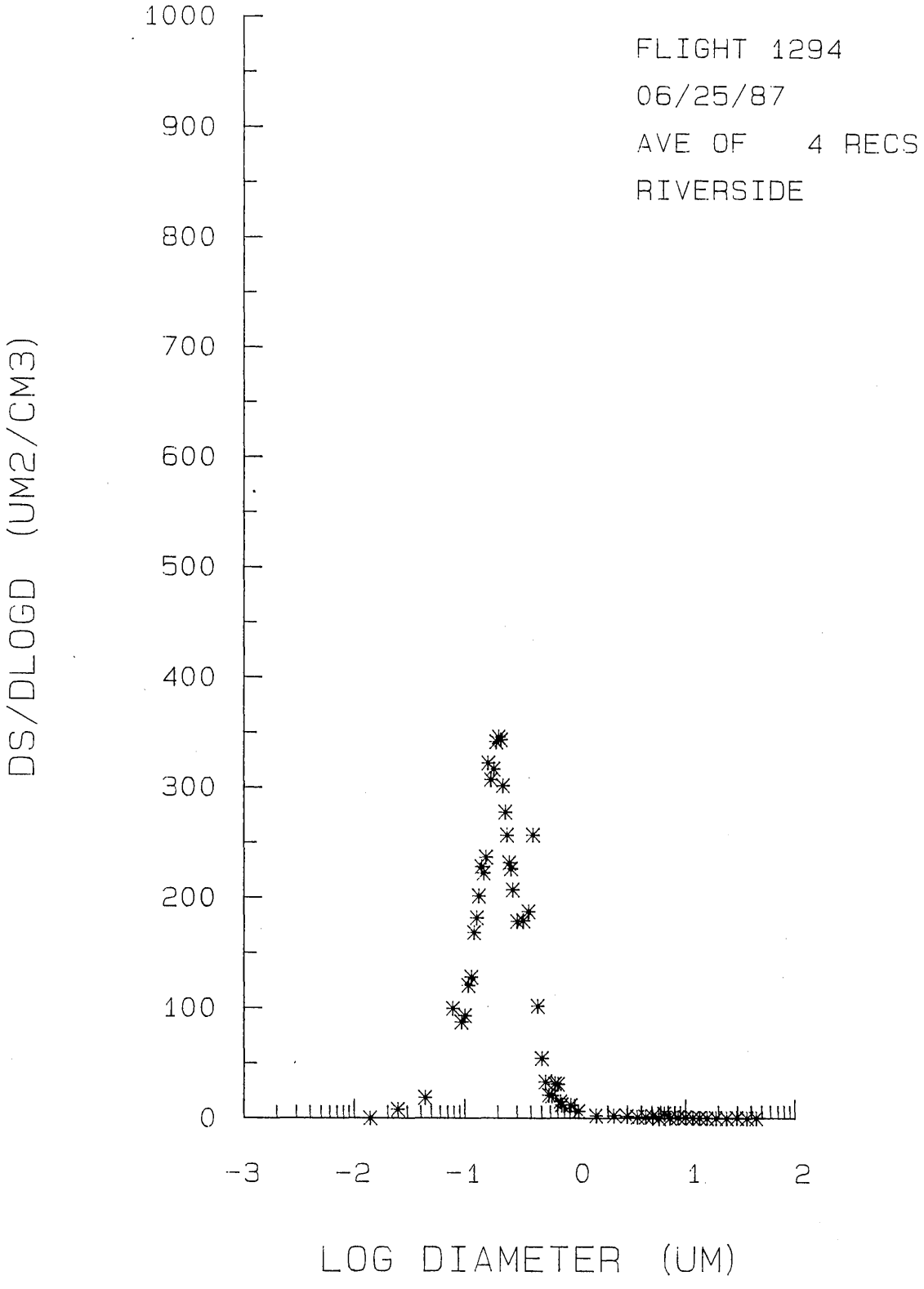

FLIGHT 1293
06/25/87
AVE OF 8 RECS
DOYLE
DS/DLOGD (UM2/CM3)
1000
900
800
700
600
500
400
300
200
100
0
-3
-2
-1
0
1
2
LOG DIAMETER (UM)

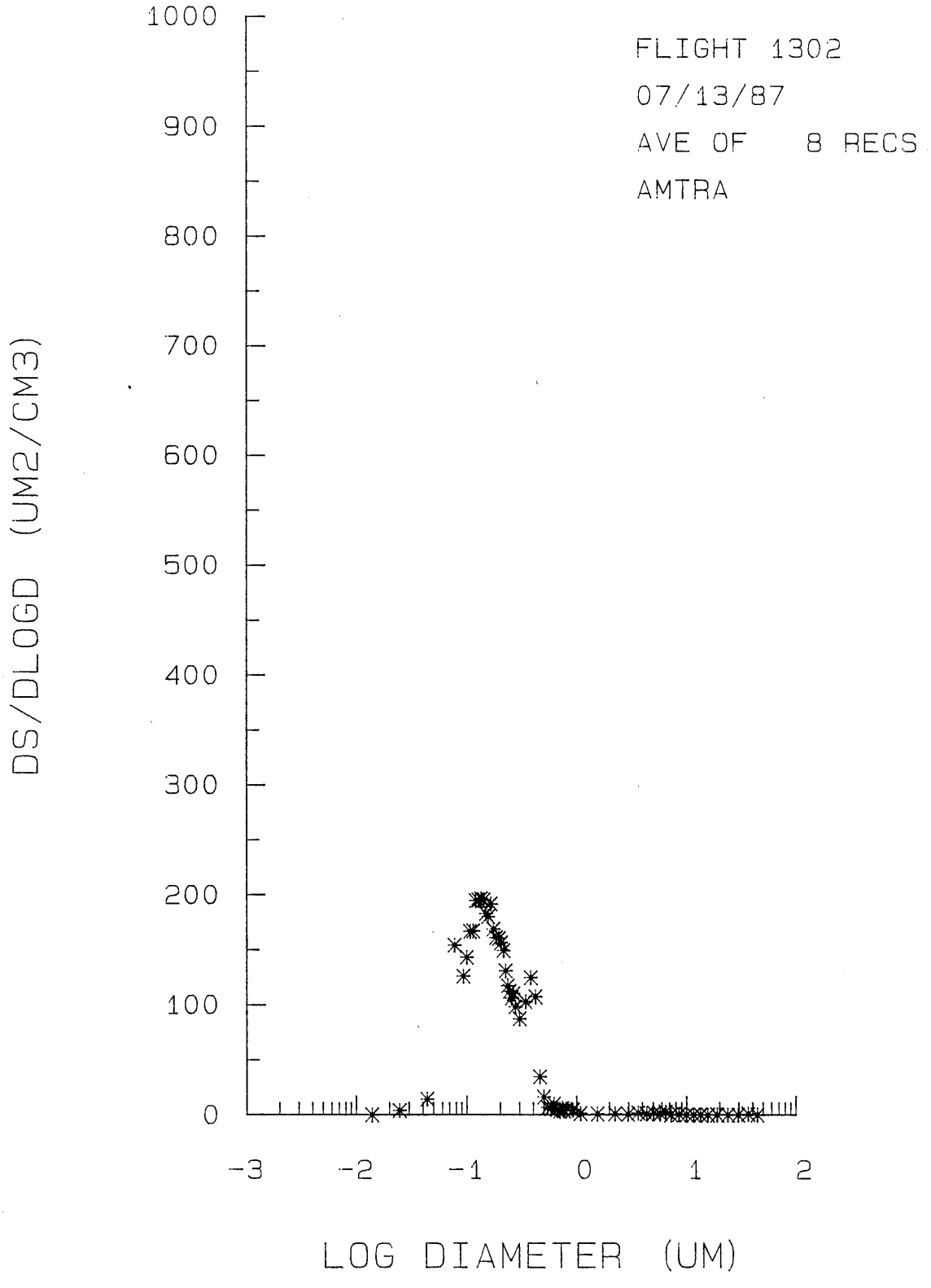

FLIGHT 1293
06/25/87
AVE OF 8 RECS
PADDR
DS/DLOGD (UM2/CM3)
1000
900
800
700
600
500
400
300
200
100
0
-3
-2
-1
0
1
2
LOG DIAMETER (UM)

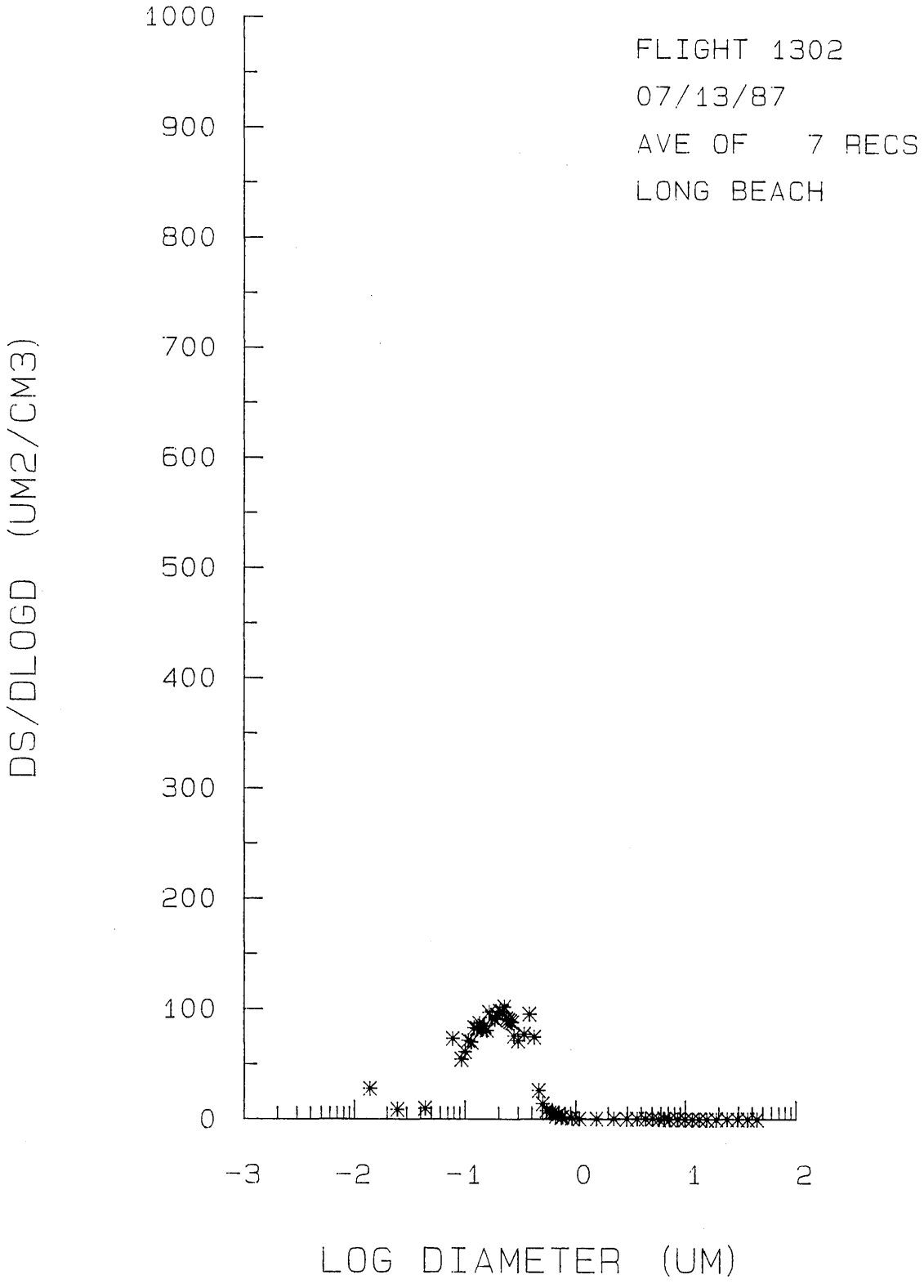

FLIGHT 1294
06/25/87
AVE OF 6 RECS
AMTRA
DS/DLOGD (UM2/CM3)
1000
900
800
700
600
500
400
300
200
100
0
-3
-2
-1
0
1
2
LOG DIAMETER (UM)

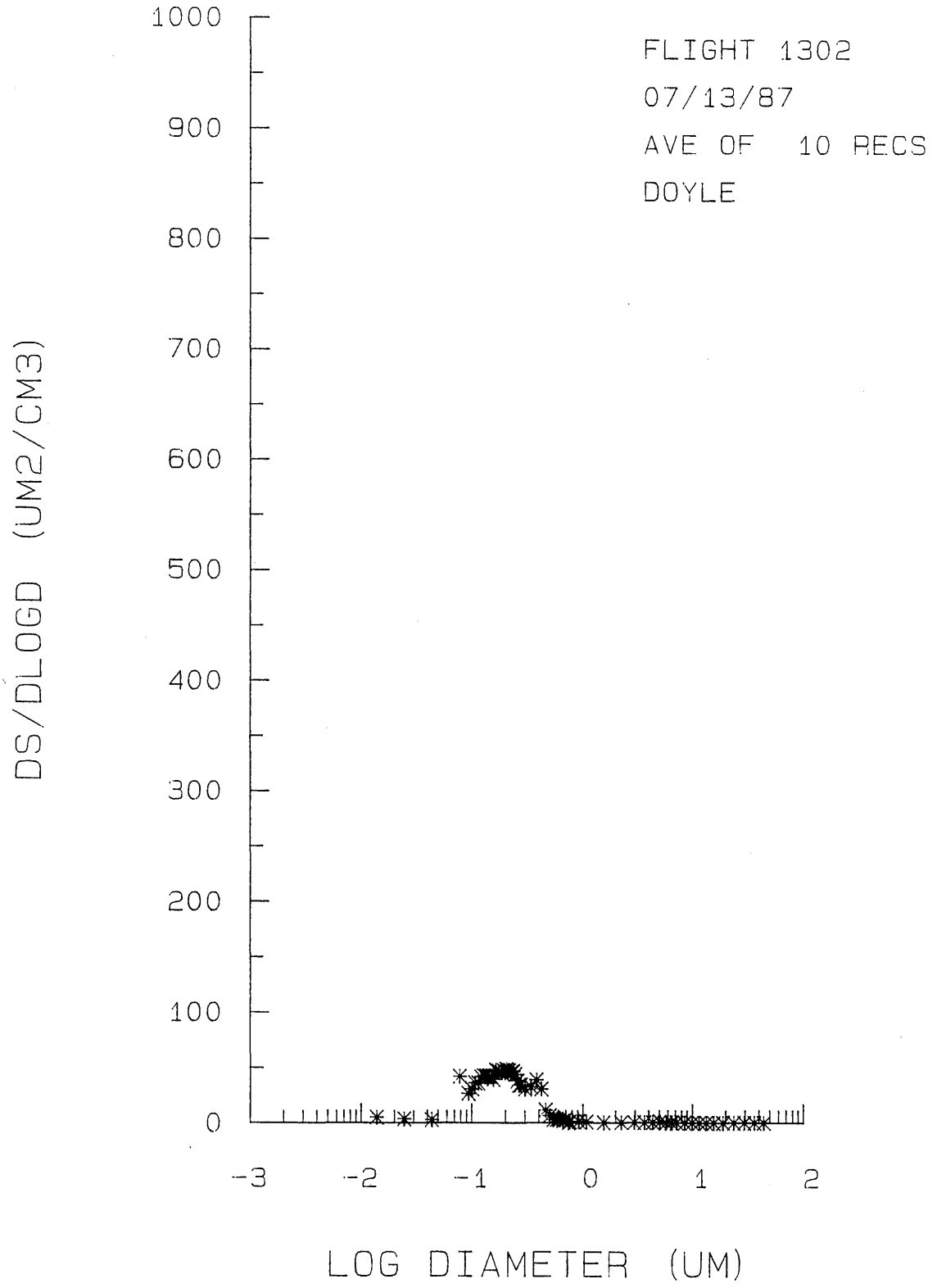

FLIGHT 1294
06/25/87
AVE OF 7 RECS
LONG BEACH
DS/DLOGD (UM2/CM3)
1000
900
800
700
600
500
400
300
200
100
0
-3
-2
-1
0
1
2
LOG DIAMETER (UM)

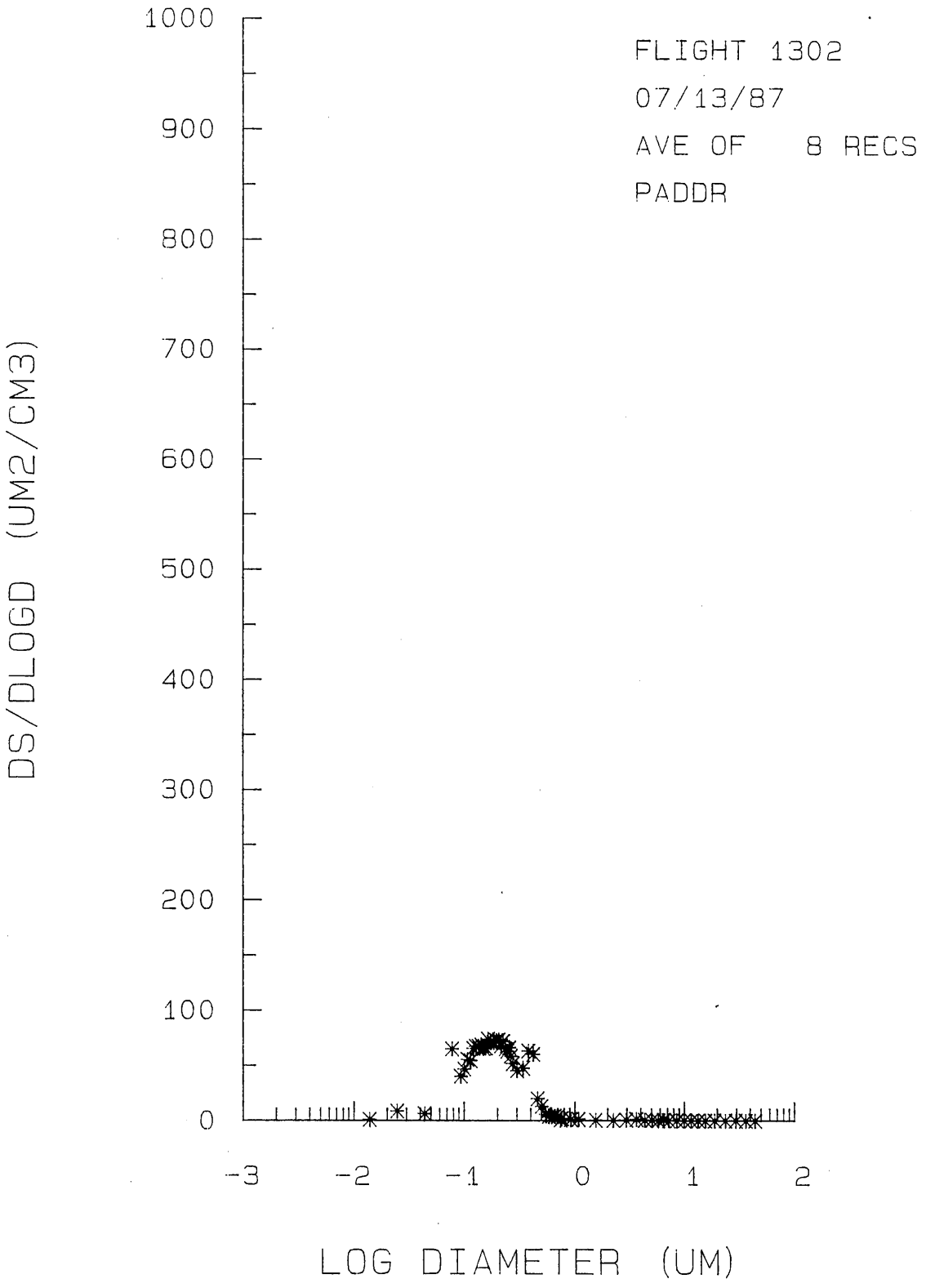

FLIGHT 1294
06/25/87
AVE OF 6 RECS
POMONA
DS/DLOGD (UM2/CM3)
1000
900
800
700
600
500
400
300
200
100
0
-3
-2
-1
0
1
2
LOG DIAMETER (UM)

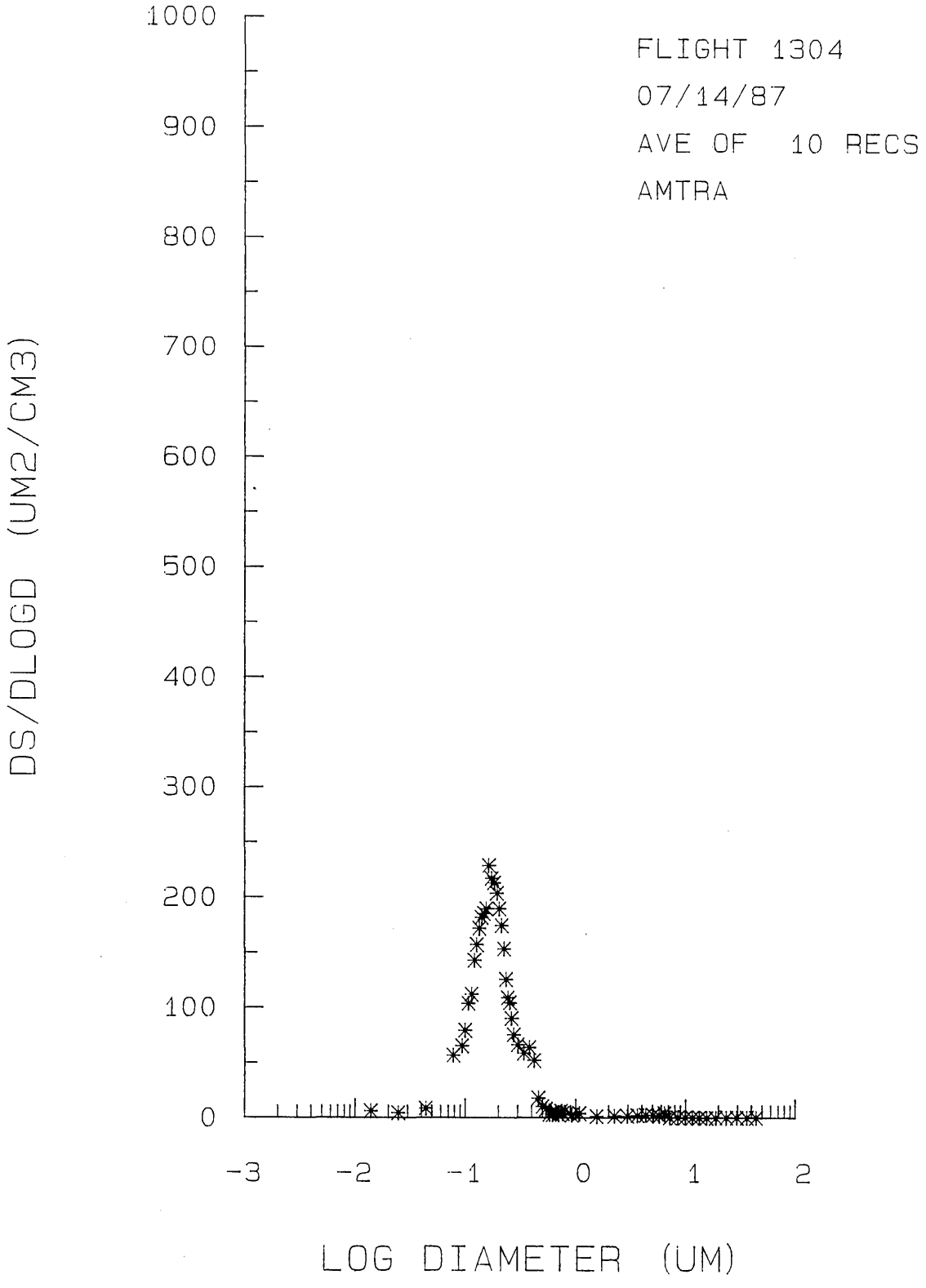

FLIGHT 1294
06/25/87
AVE OF 4 RECS
RIVERSIDE
DS/DLOGD (UM2/CM3)
1000
900
800
700
600
500
400
300
200
100
0
-3
-2
-1
0
1
2
LOG DIAMETER (UM)

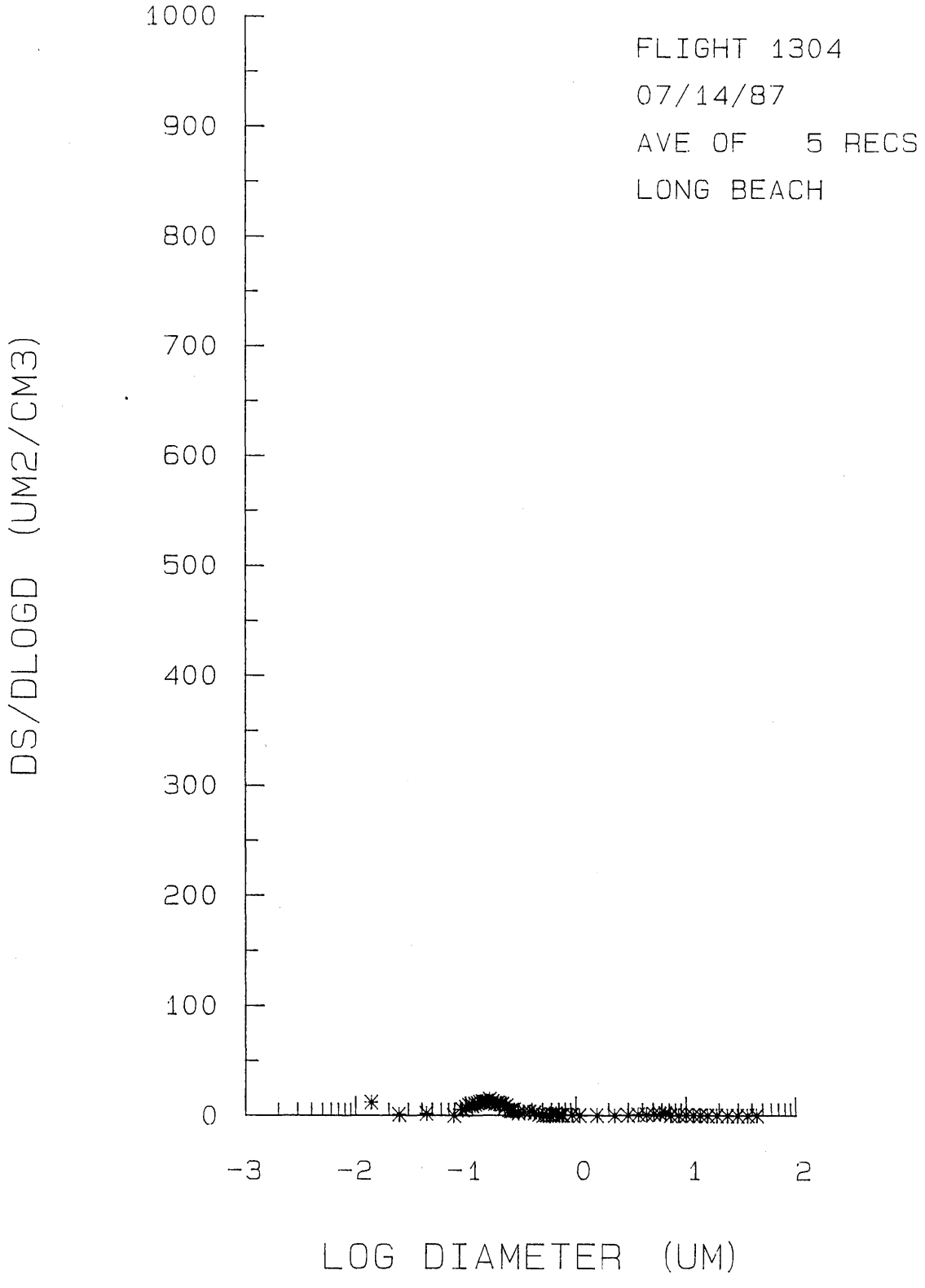

FLIGHT 1302
07/13/87
AVE OF 8 RECS
AMTRA
DS/DLOGD (UM2/CM3)
1000
900
800
700
600
500
400
300
200
100
0
-3
-2
-1
0
1
2
LOG DIAMETER (UM)

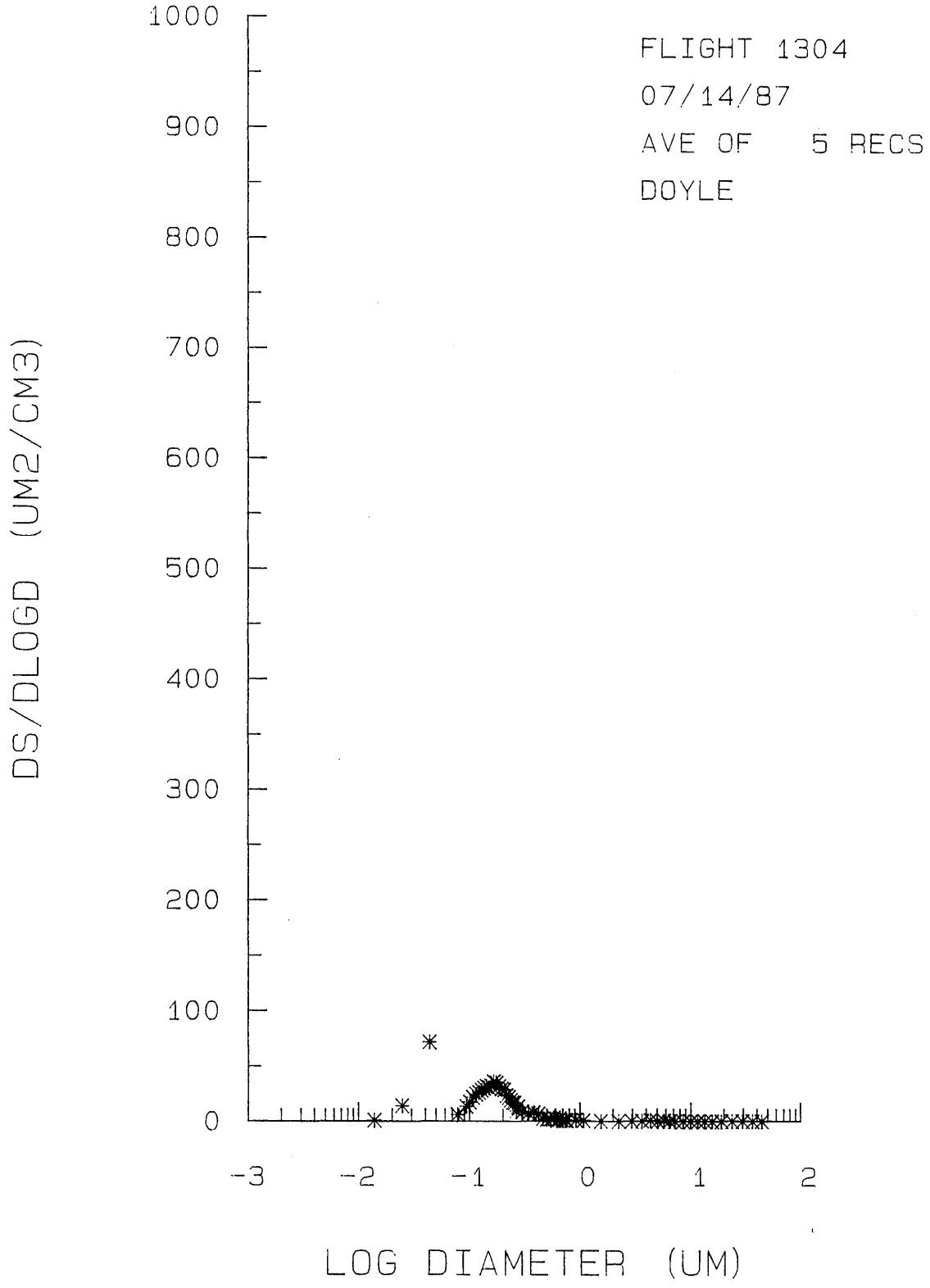

FLIGHT 1302
07/13/87
AVE OF 7 RECS
LONG BEACH
DS/DLOGD (UM2/CM3)
1000
900
800
700
600
500
400
300
200
100
0
-3
-2
-1
0
1
2
LOG DIAMETER (UM)

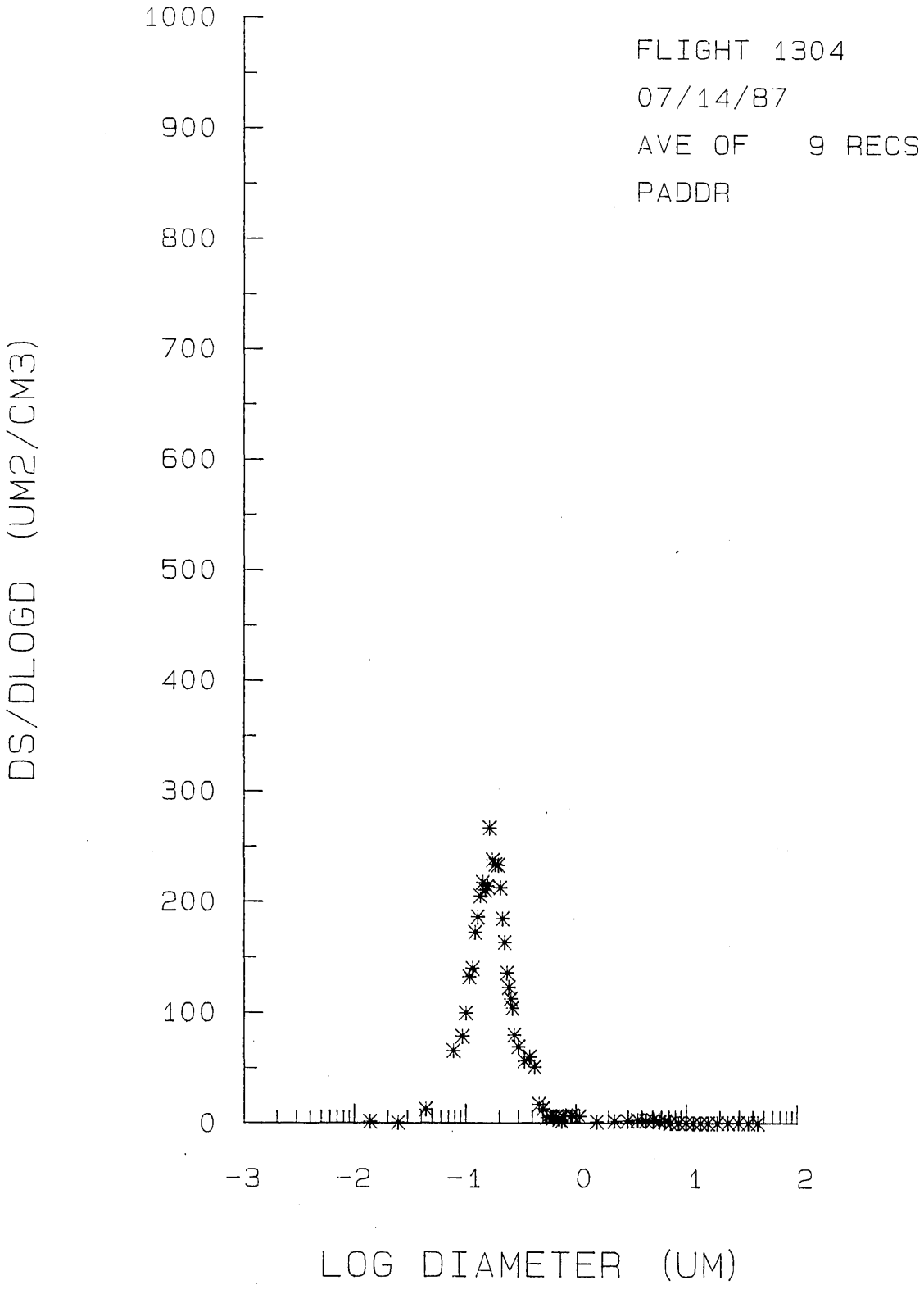

FLIGHT 1302
07/13/87
AVE OF 10 RECS
DOYLE
DS/DLOGD (UM2/CM3)
1000
900
800
700
600
500
400
300
200
100
0
-3
-2
-1
0
1
2
LOG DIAMETER (UM)

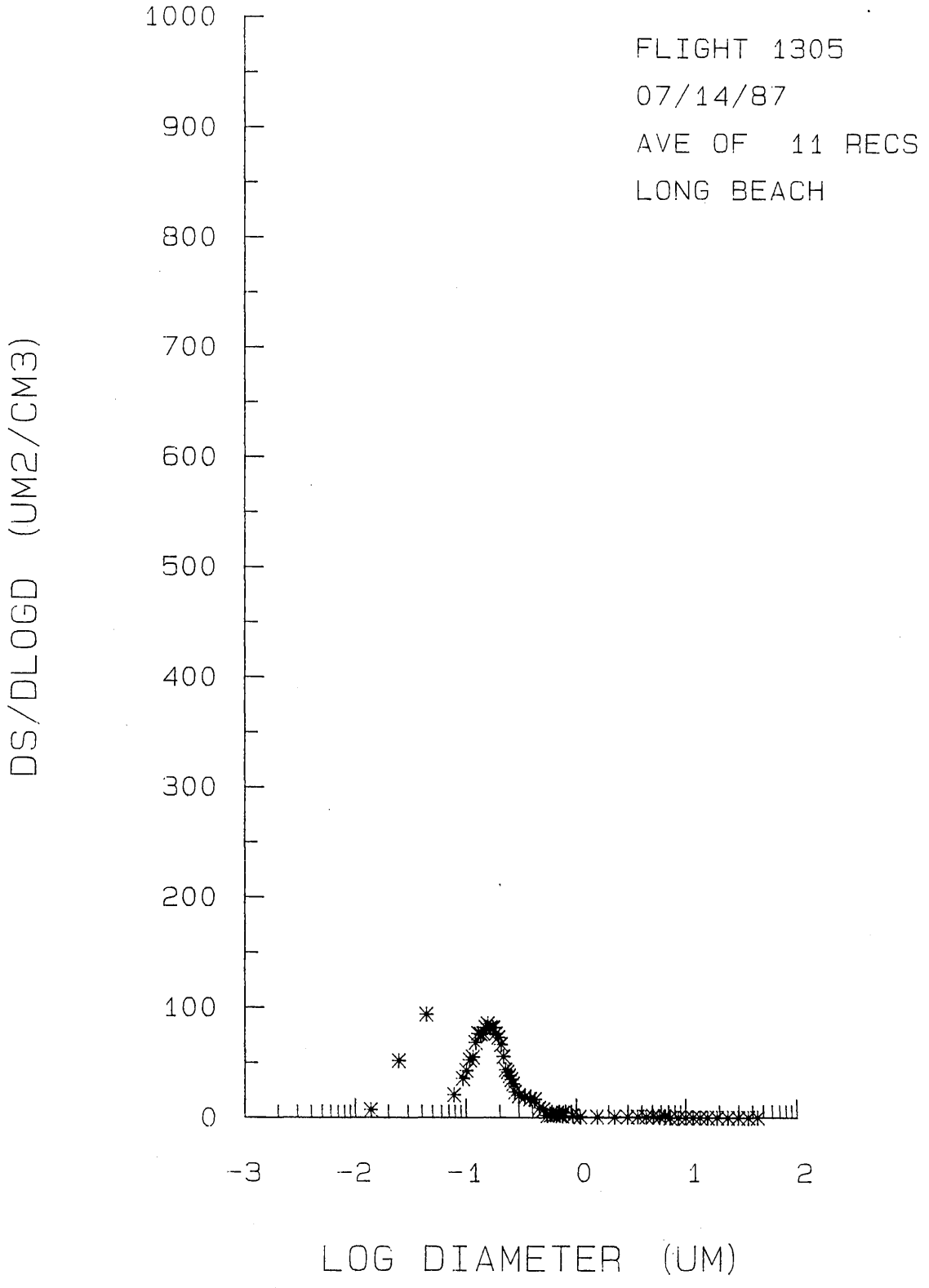

FLIGHT 1302
07/13/87
AVE OF 8 RECS
PADDR
DS/DLOGD (UM2/CM3)
1000
900
800
700
600
500
400
300
200
100
0
-3
-2
-1
0
1
2
LOG DIAMETER (UM)

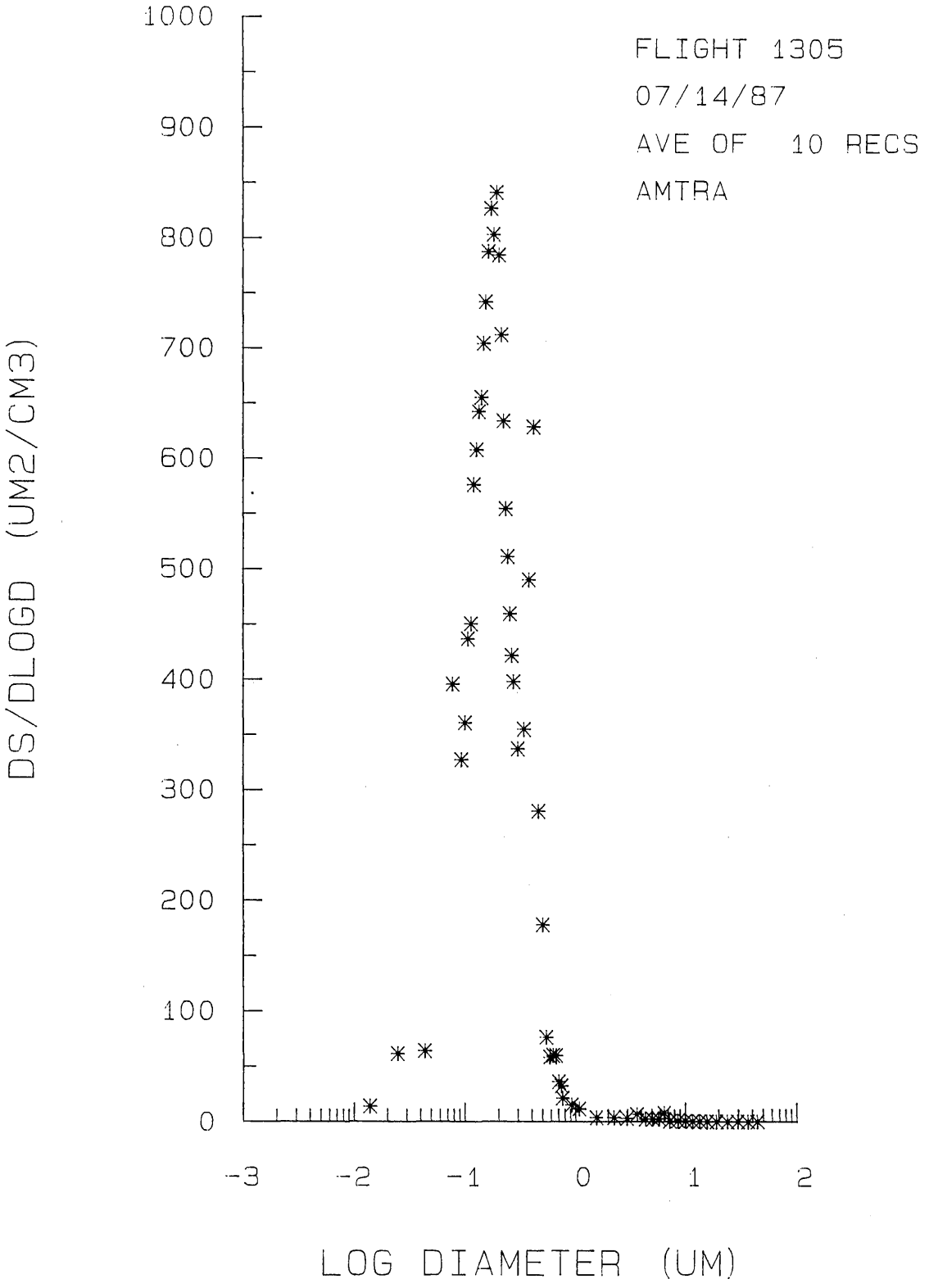

FLIGHT 1304
07/14/87
AVE OF 10 RECS
AMTRA
DS/DLOGD (UM2/CM3)
1000
900
800
700
600
500
400
300
200
100
0
-3
-2
-1
0
1
2
LOG DIAMETER (UM)

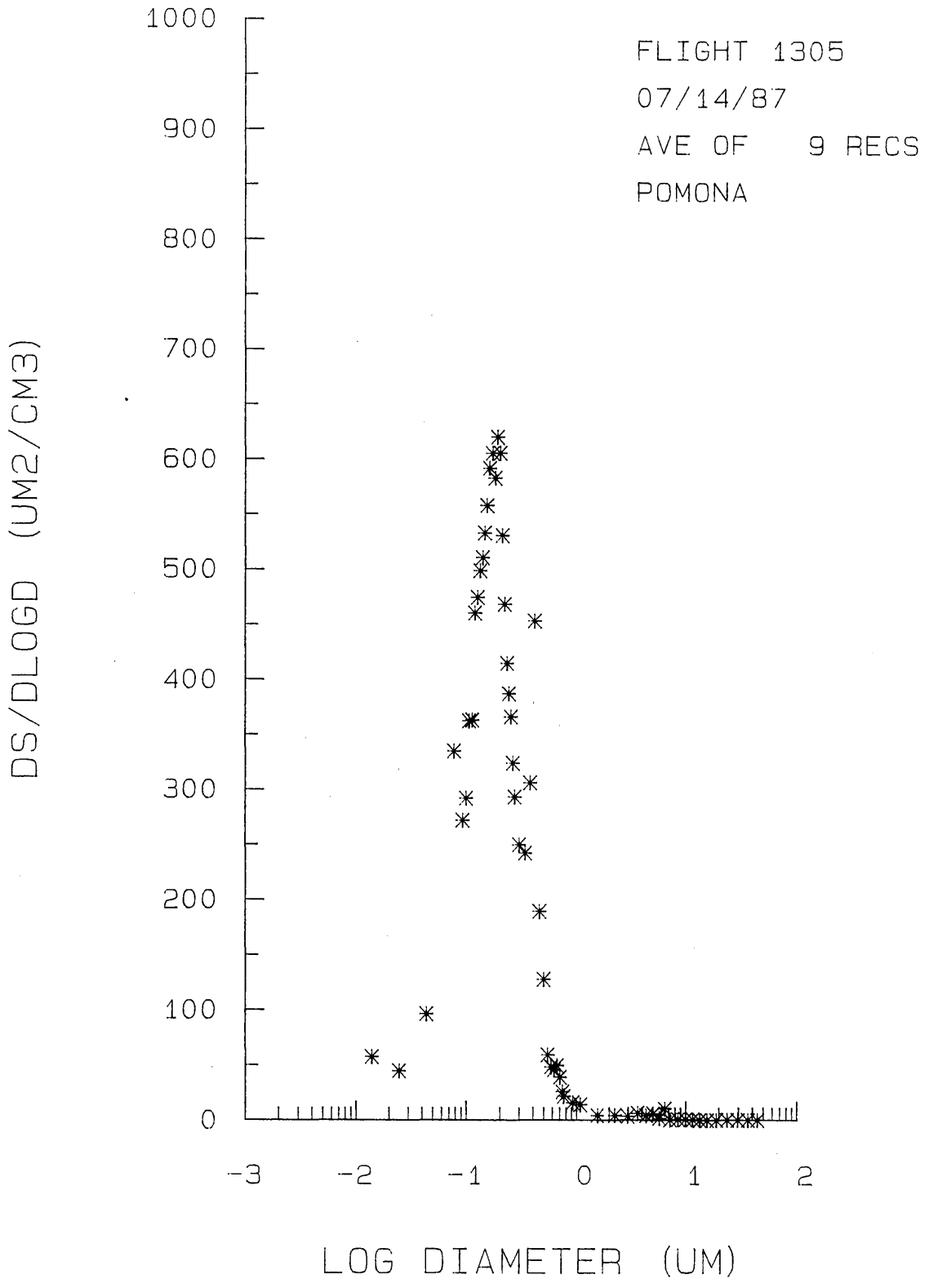

FLIGHT 1304
07/14/87
AVE OF 5 RECS
LONG BEACH
DS/DLOGD (UM2/CM3)
1000
900
800
700
600
500
400
300
200
100
0
-3
-2
-1
0
1
2
LOG DIAMETER (UM)

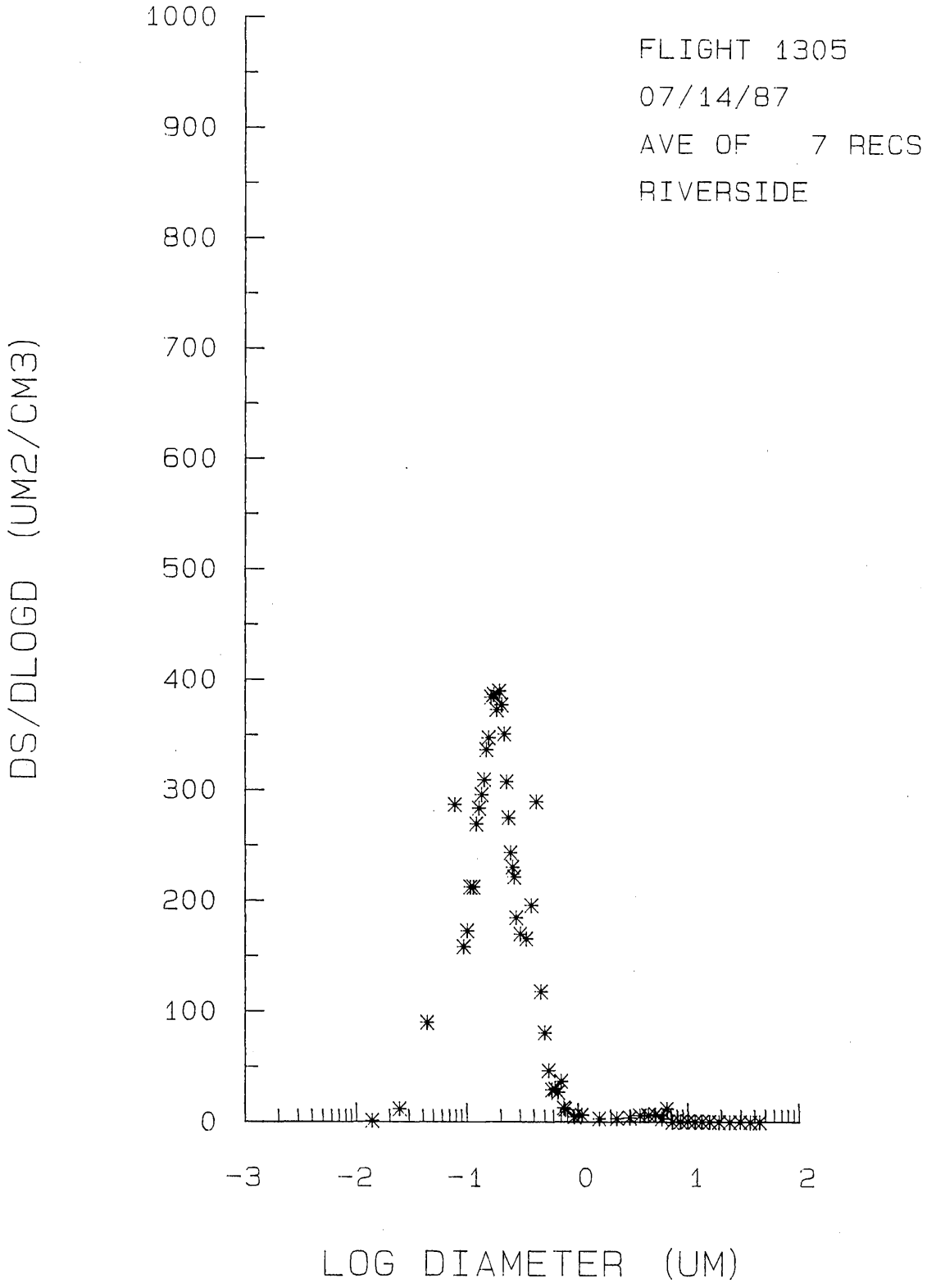

FLIGHT 1304
07/14/87
AVE OF 5 RECS
DOYLE
DS/DLOGD (UM2/CM3)
1000
900
800
700
600
500
400
300
200
100
0
-3
-2
-1
0
1
2
LOG DIAMETER (UM)

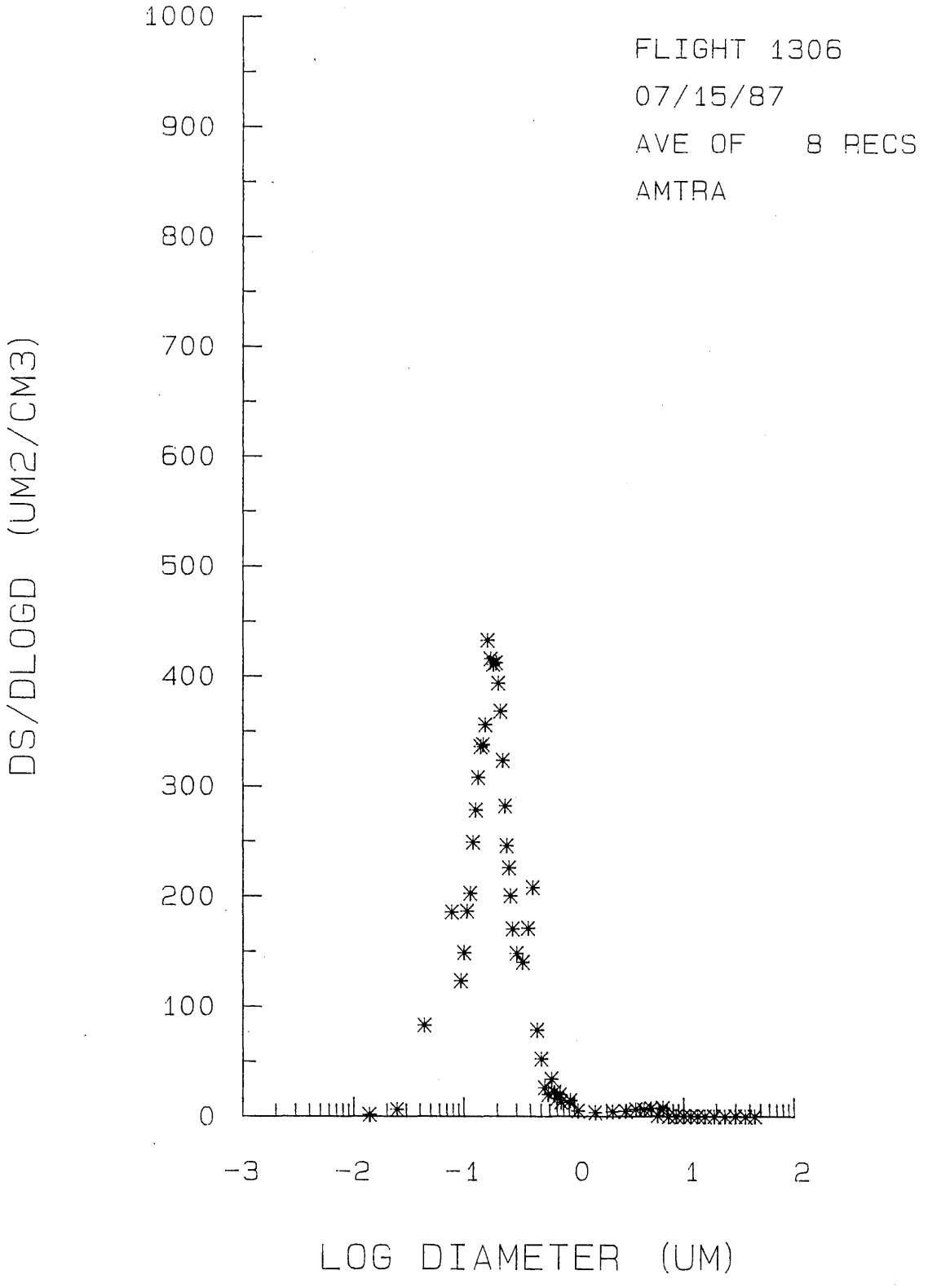

FLIGHT 1304
07/14/87
AVE OF 9 RECS
PADDR
DS/DLOGD (UM2/CM3)
1000
900
800
700
600
500
400
300
200
100
0
-3
-2
-1
0
1
2
LOG DIAMETER (UM)

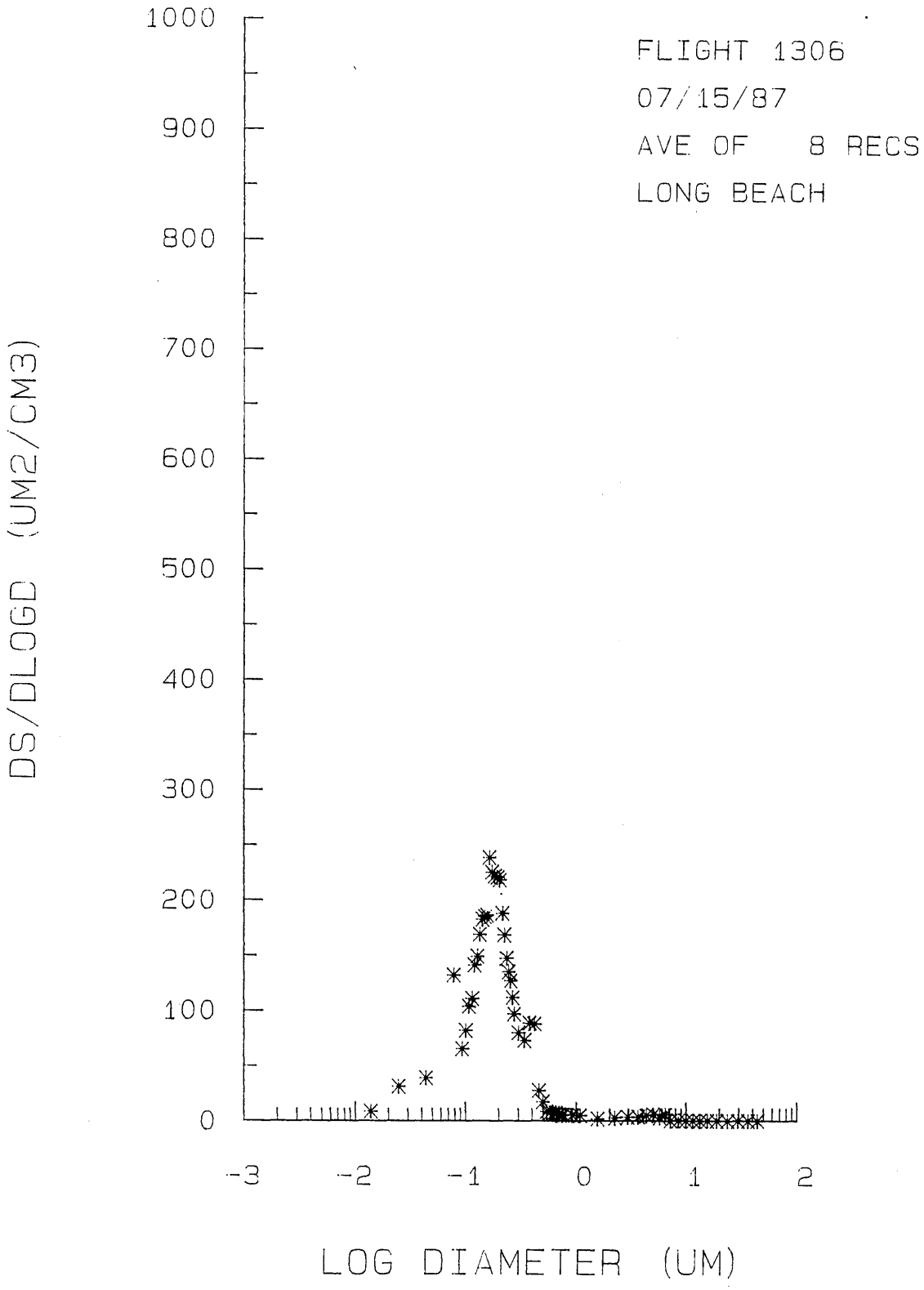

FLIGHT 1305
07/14/87
AVE OF 11 RECS
LONG BEACH
DS/DLOGD (UM2/CM3)
1000
900
800
700
600
500
400
300
200
100
0
-3
-2
-1
0
1
2
LOG DIAMETER (UM)

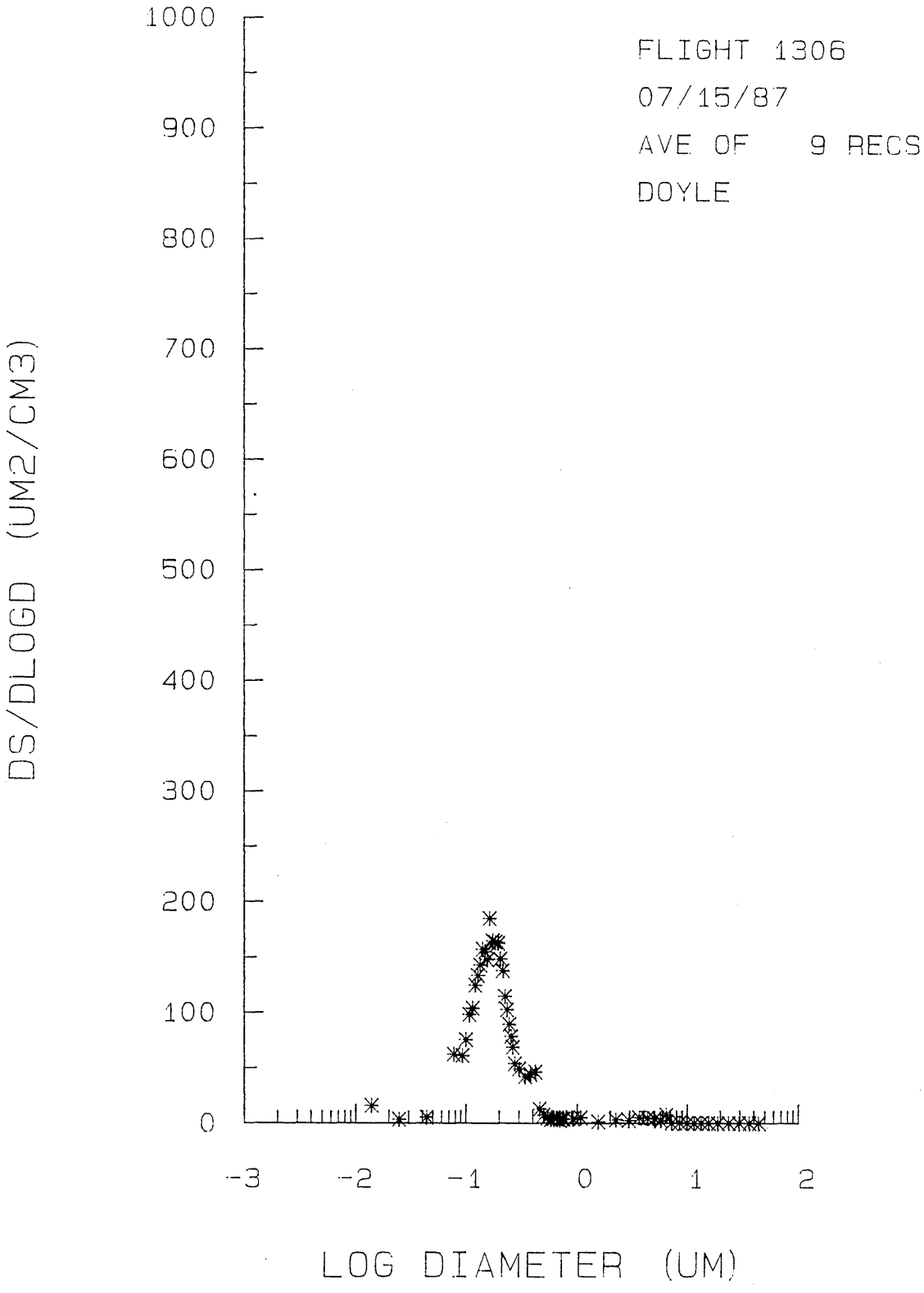

FLIGHT 1305
07/14/87
AVE OF 10 RECS
AMTRA
DS/DLOGD (UM2/CM3)
1000
900
800
700
600
500
400
300
200
100
0
-3
-2
-1
0
1
2
LOG DIAMETER (UM)

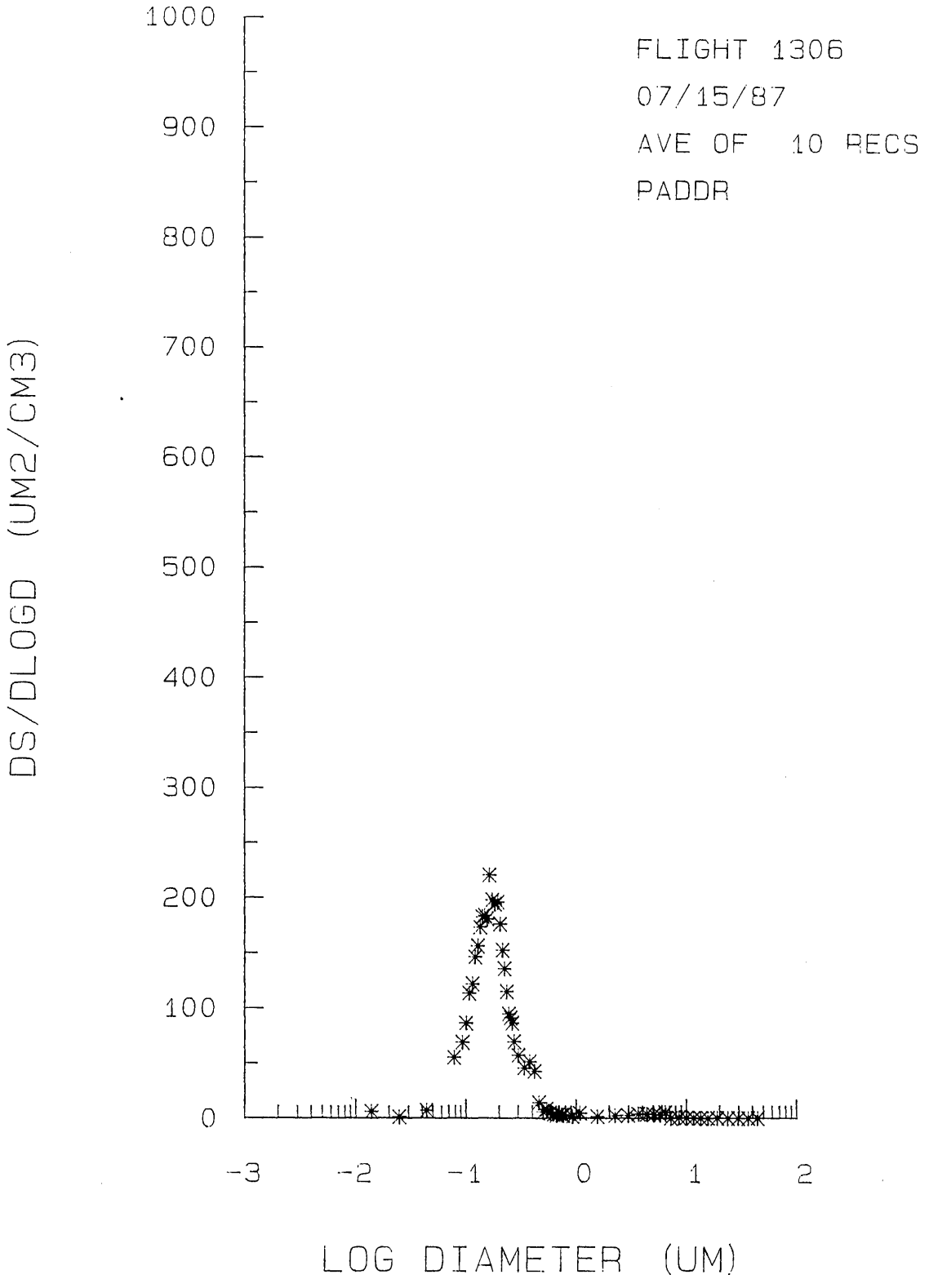

FLIGHT 1305
07/14/87
AVE OF 9 RECS
POMONA
DS/DLOGD (UM2/CM3)
1000
900
800
700
600
500
400
300
200
100
0
-3
-2
-1
0
1
2
LOG DIAMETER (UM)

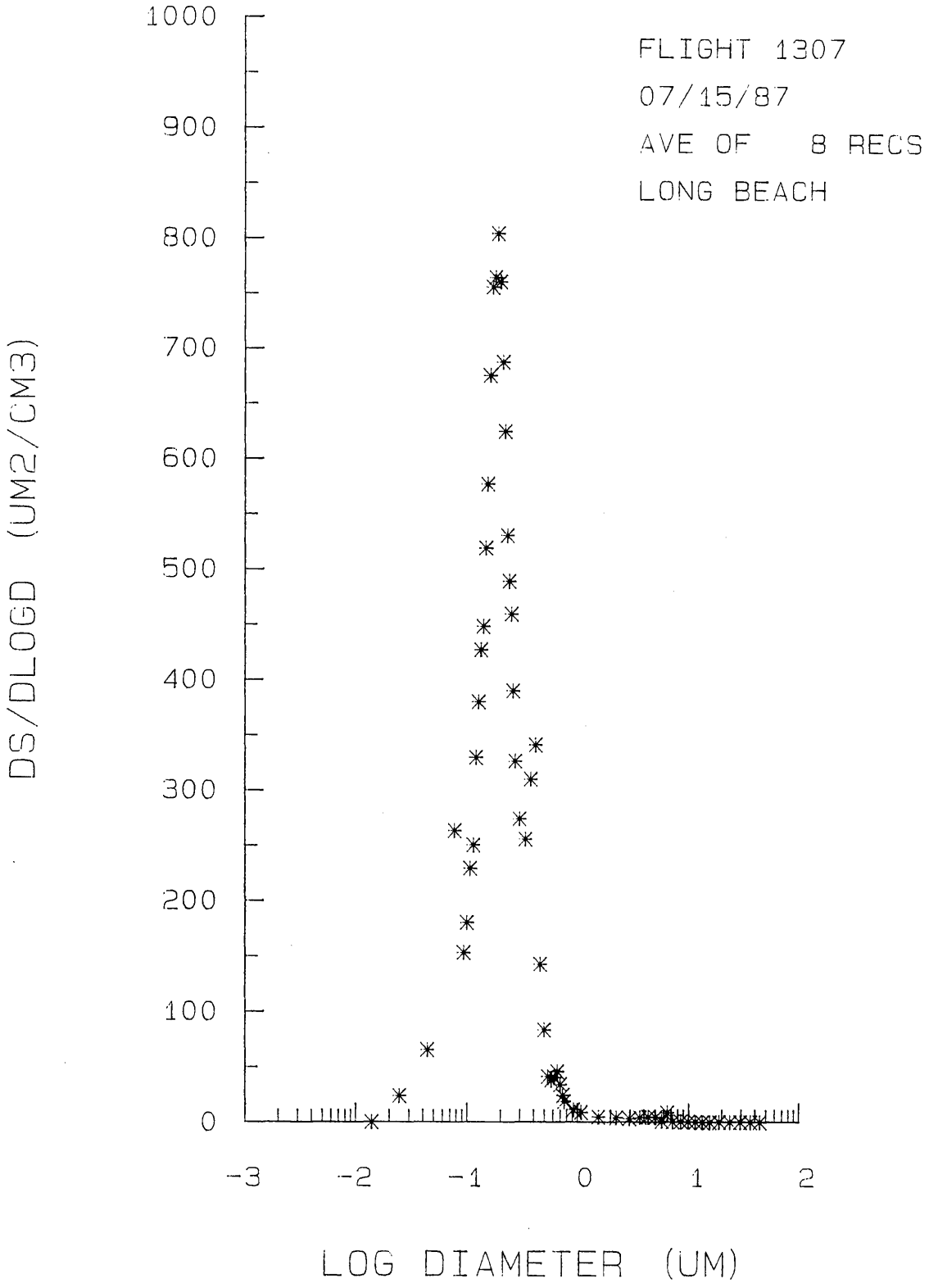

FLIGHT 1305
07/14/87
AVE OF 7 RECS
RIVERSIDE
DS/DLOGD (UM2/CM3)
1000
900
800
700
600
500
400
300
200
100
0
-3
-2
-1
0
1
2
LOG DIAMETER (UM)

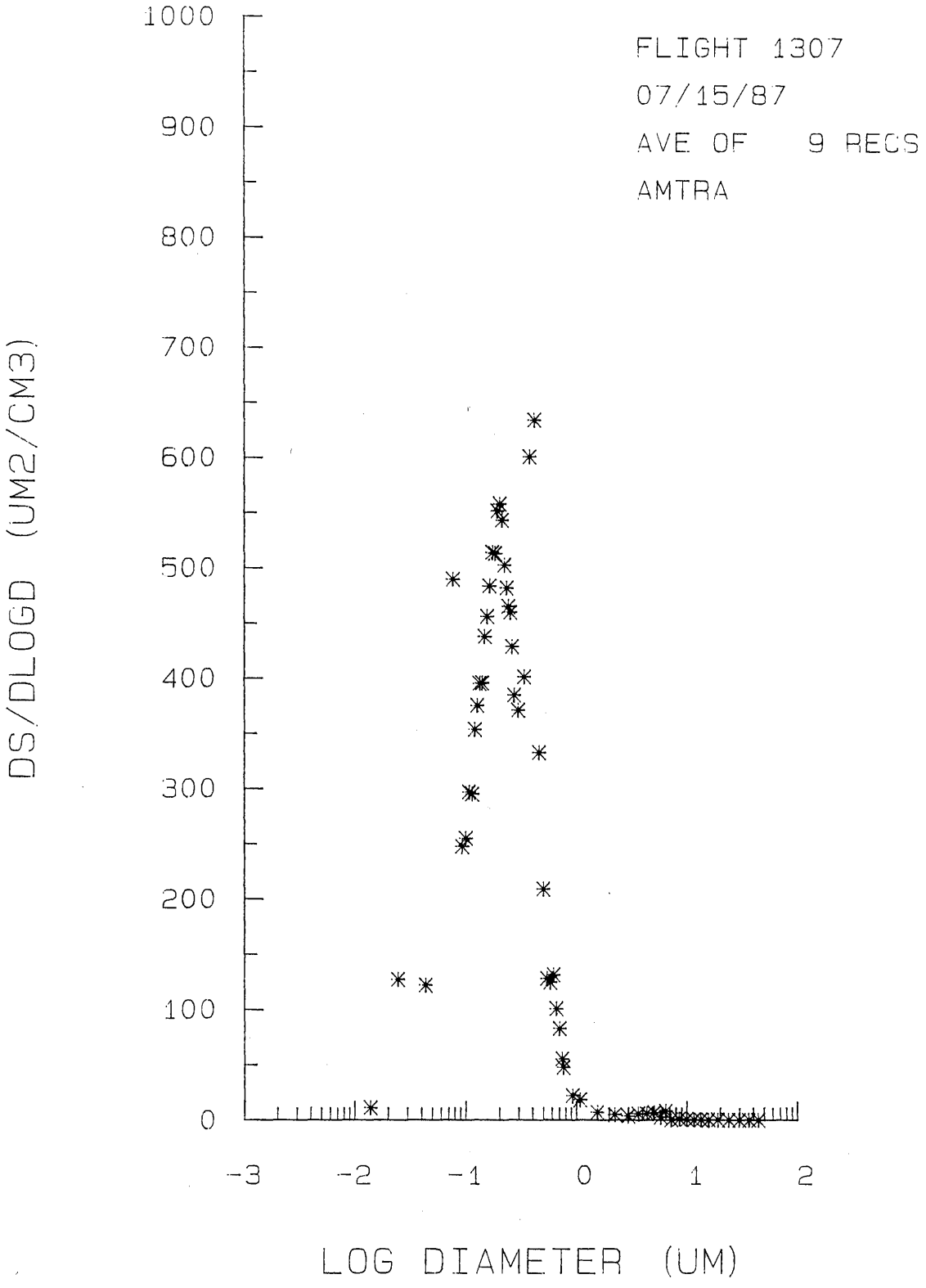

FLIGHT 1306
07/15/87
AVE OF 8 RECS
AMTRA
DS/DLOGD (UM2/CM3)
1000
900
800
700
600
500
400
300
200
100
0
-3
-2
-1
0
1
2
LOG DIAMETER (UM)

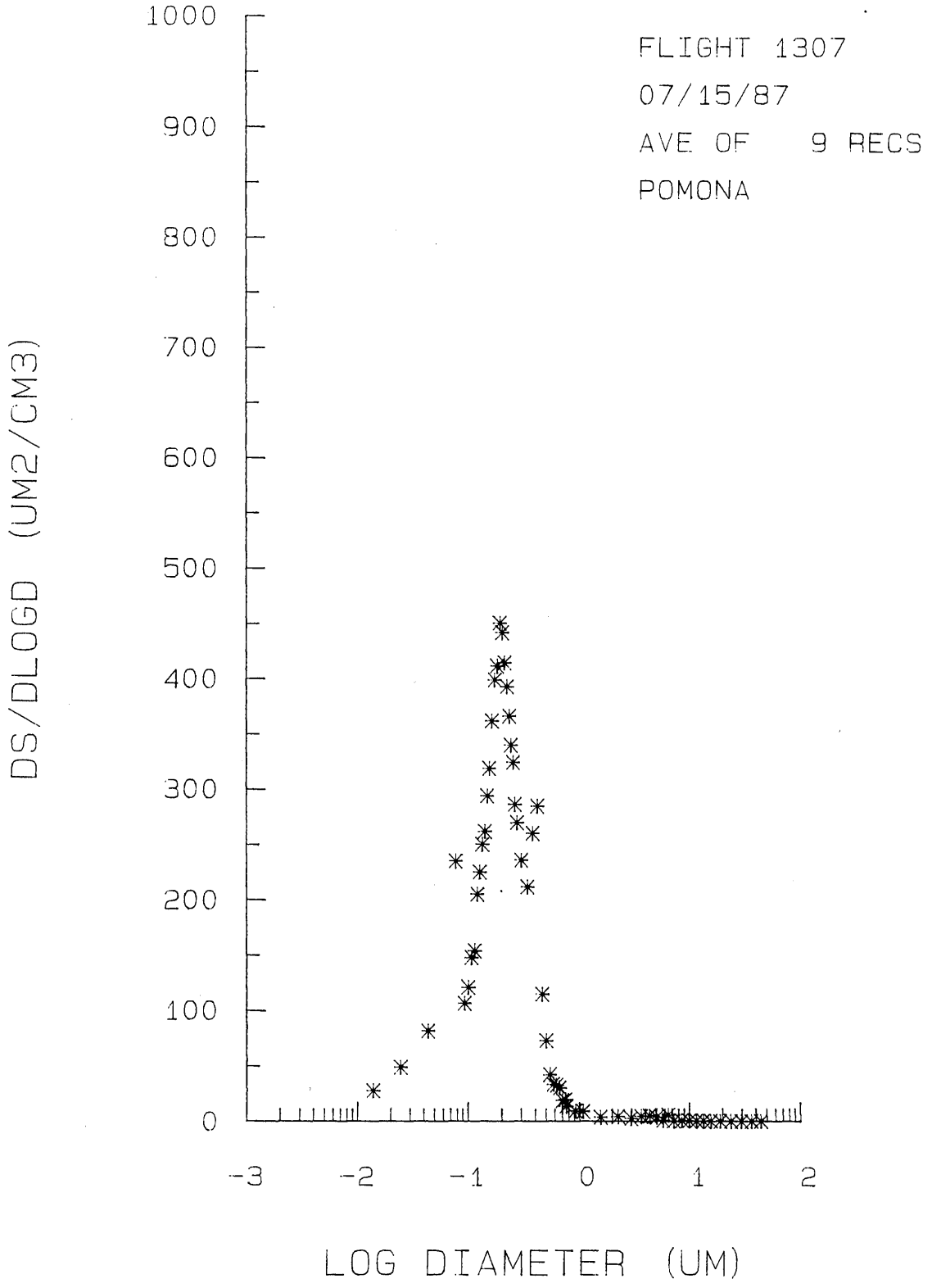

FLIGHT 1306
07/15/87
AVE OF 8 RECS
LONG BEACH
DS/DLOGD (UM2/CM3)
1000
900
800
700
600
500
400
300
200
100
0
-3
-2
-1
0
1
2
LOG DIAMETER (UM)

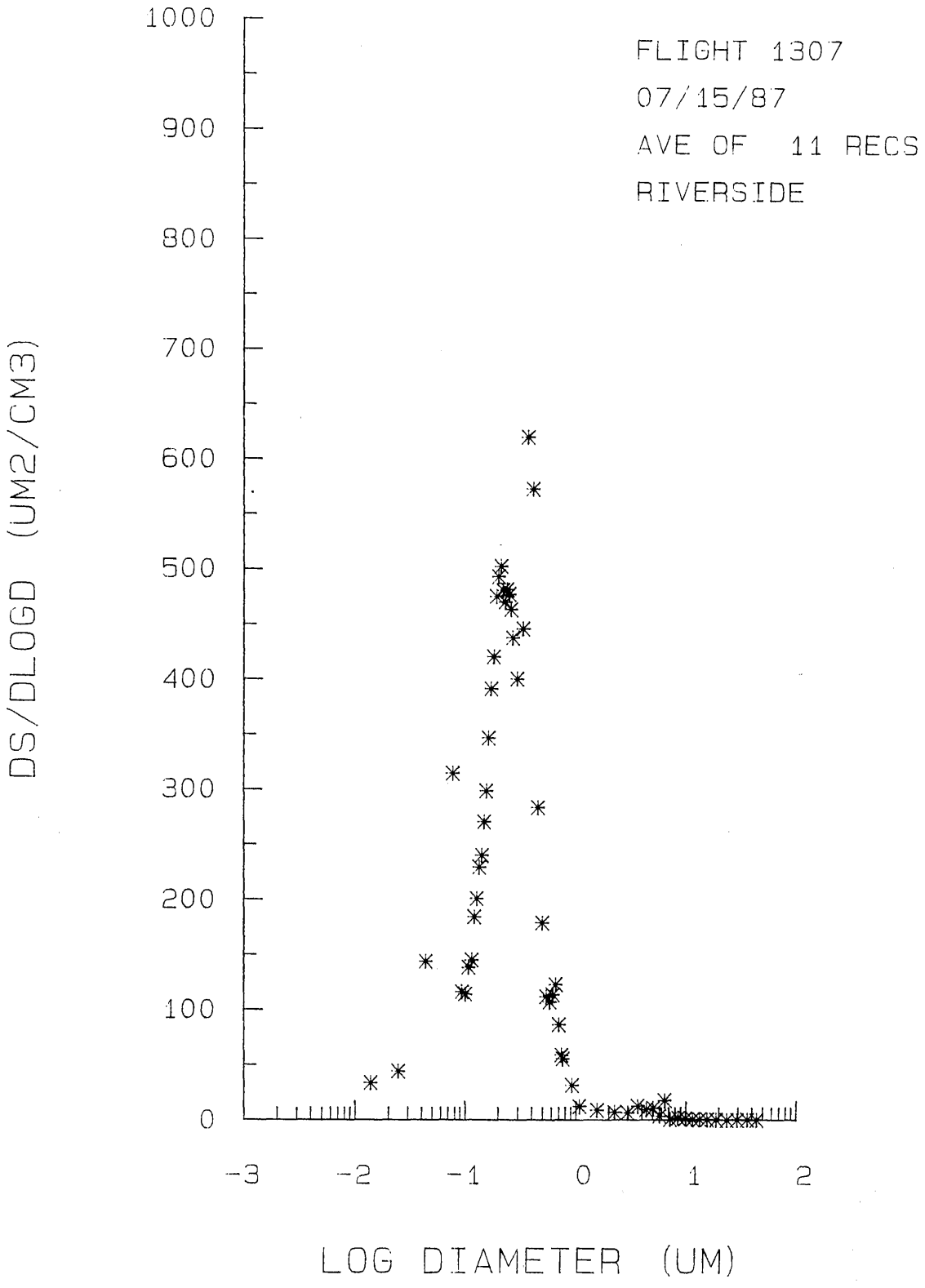

FLIGHT 1306
07/15/87
AVE OF 9 RECS
DOYLE
DS/DLOGD (UM2/CM3)
1000
900
800
700
600
500
400
300
200
100
0
-3
-2
-1
0
1
2
LOG DIAMETER (UM)

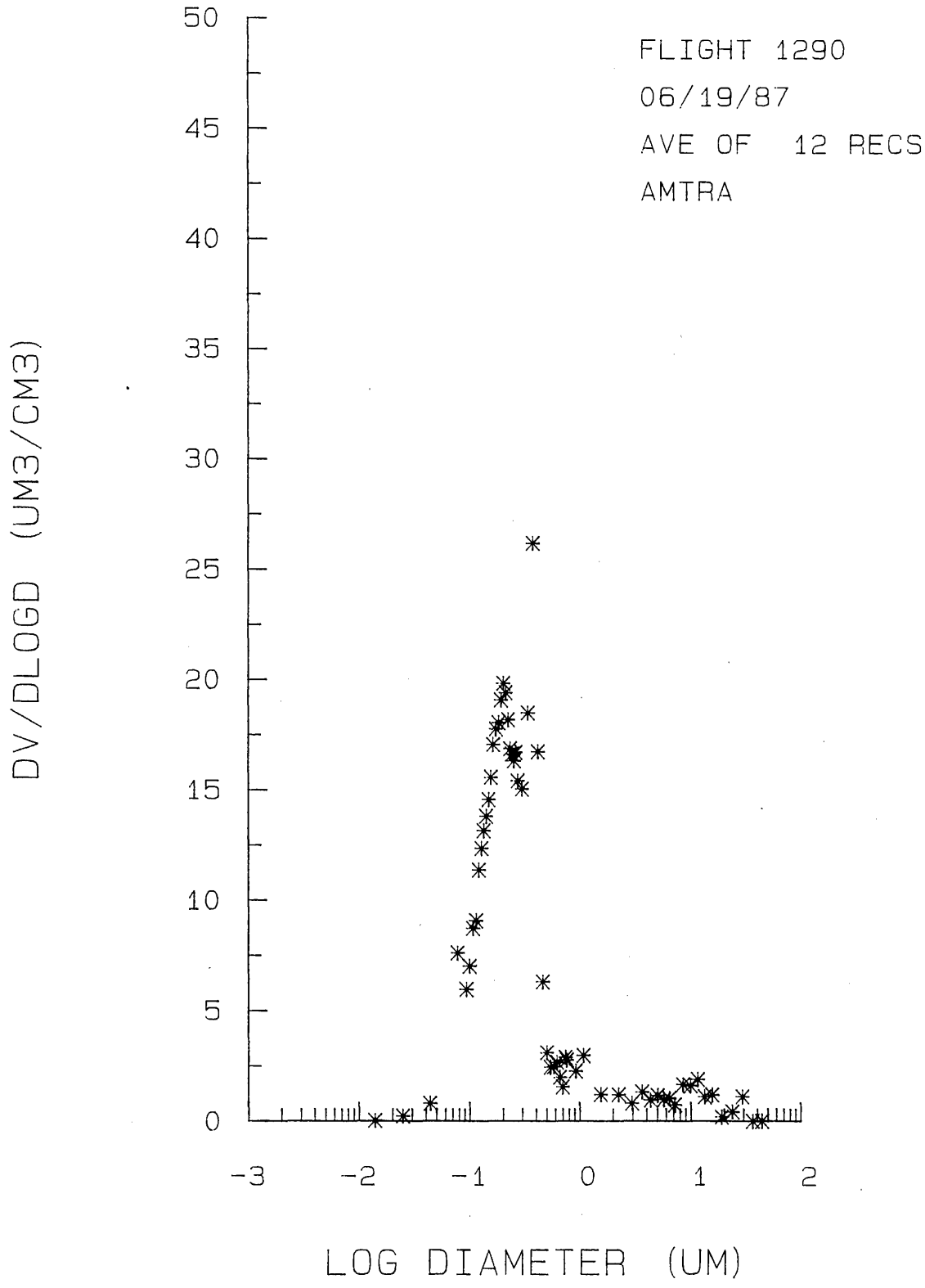

FLIGHT 1306
07/15/87
AVE OF 10 RECS
PADDR
DS/DLOGD (UM2/CM3)
1000
900
800
700
600
500
400
300
200
100
0
-3
-2
-1
0
1
2
LOG DIAMETER (UM)

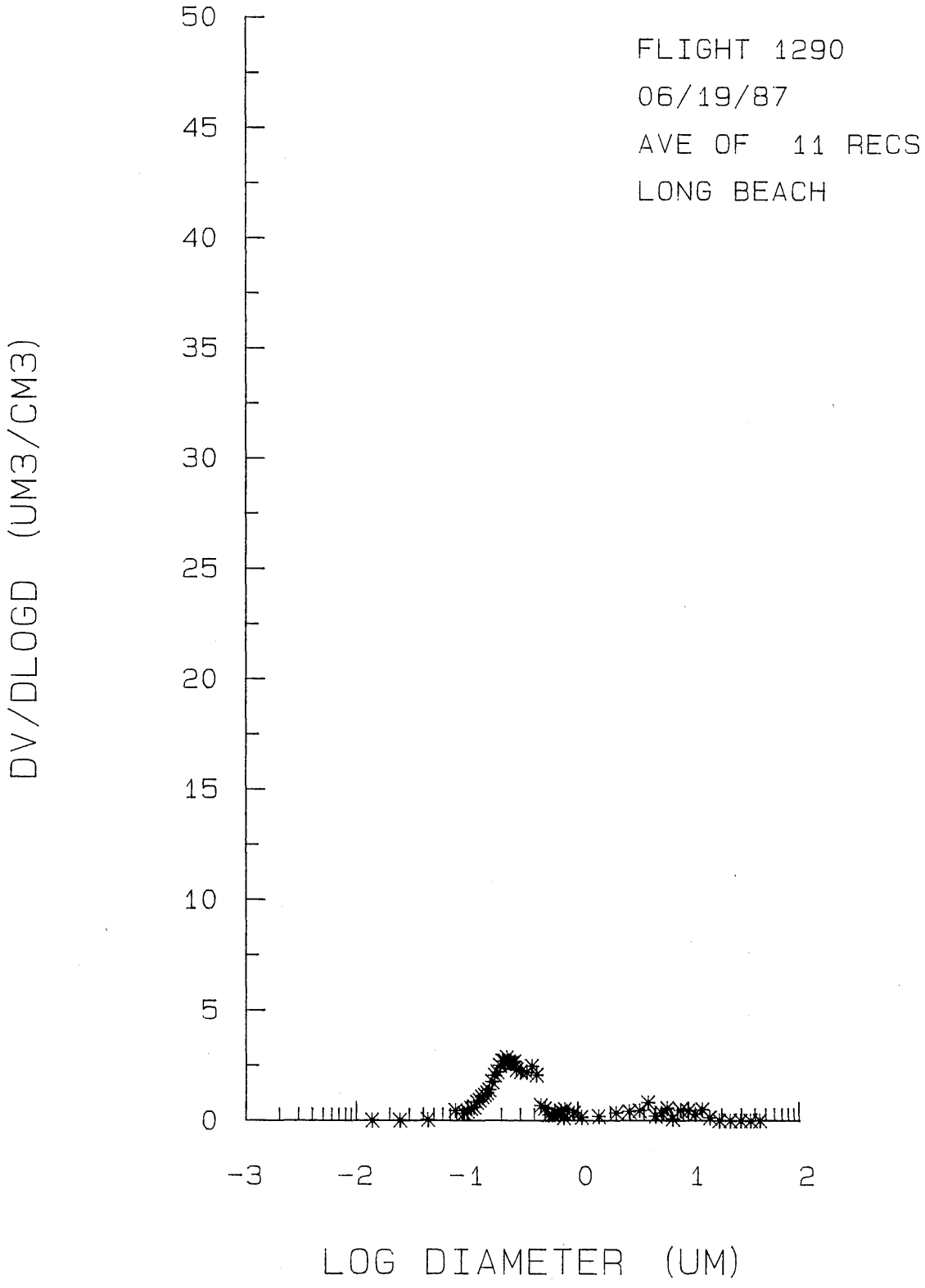

FLIGHT 1307
07/15/87
AVE OF 8 RECS
LONG BEACH
DS/DLOGD (UM2/CM3)
1000
900
800
700
600
500
400
300
200
100
0
-3
-2
-1
0
1
2
LOG DIAMETER (UM)

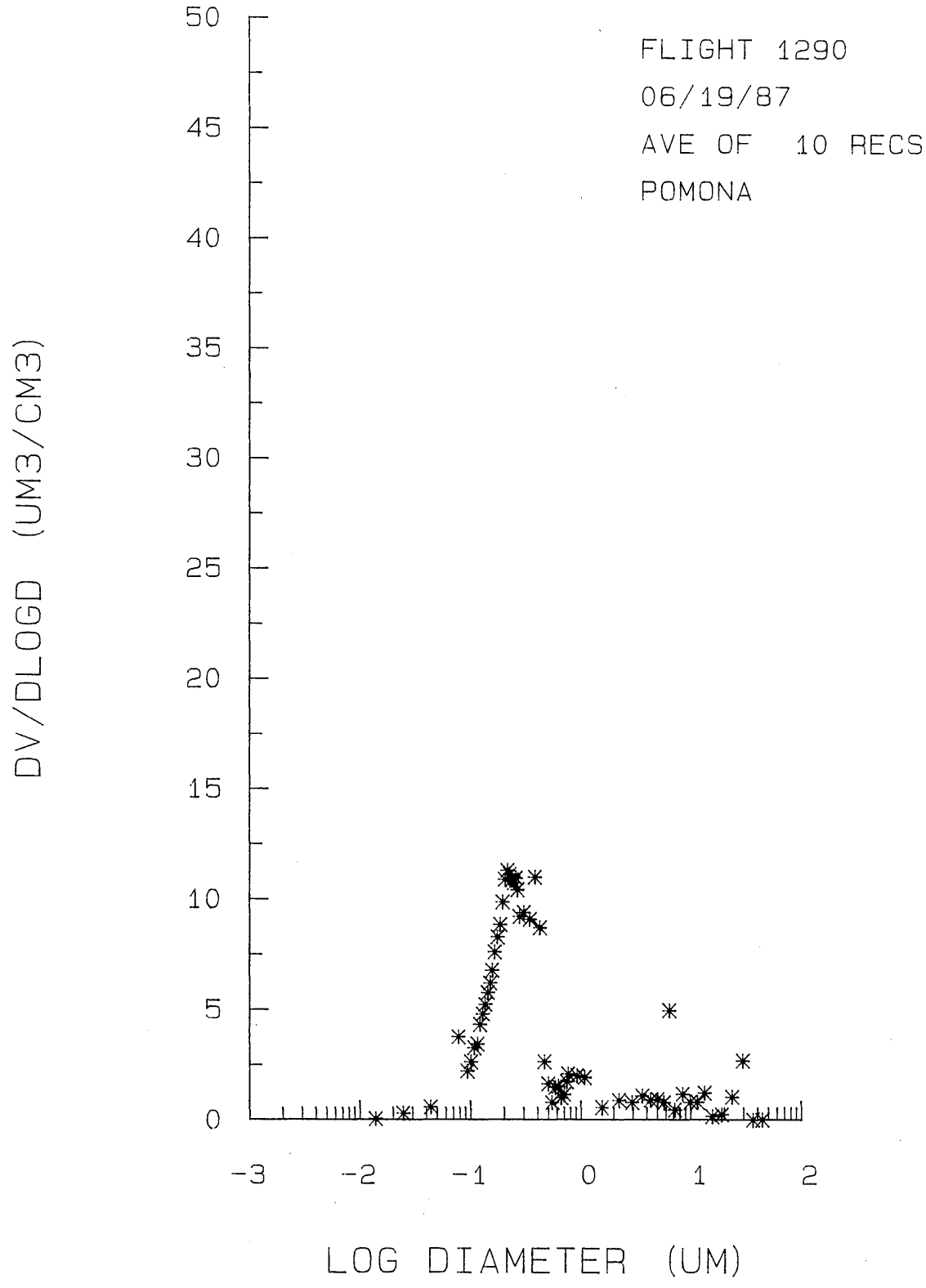

FLIGHT 1307
07/15/87
AVE OF 9 RECS
AMTRA
DS/DLOGD (UM2/CM3)
1000
900
800
700
600
500
400
300
200
100
0
-3
-2
-1
0
1
2
LOG DIAMETER (UM)

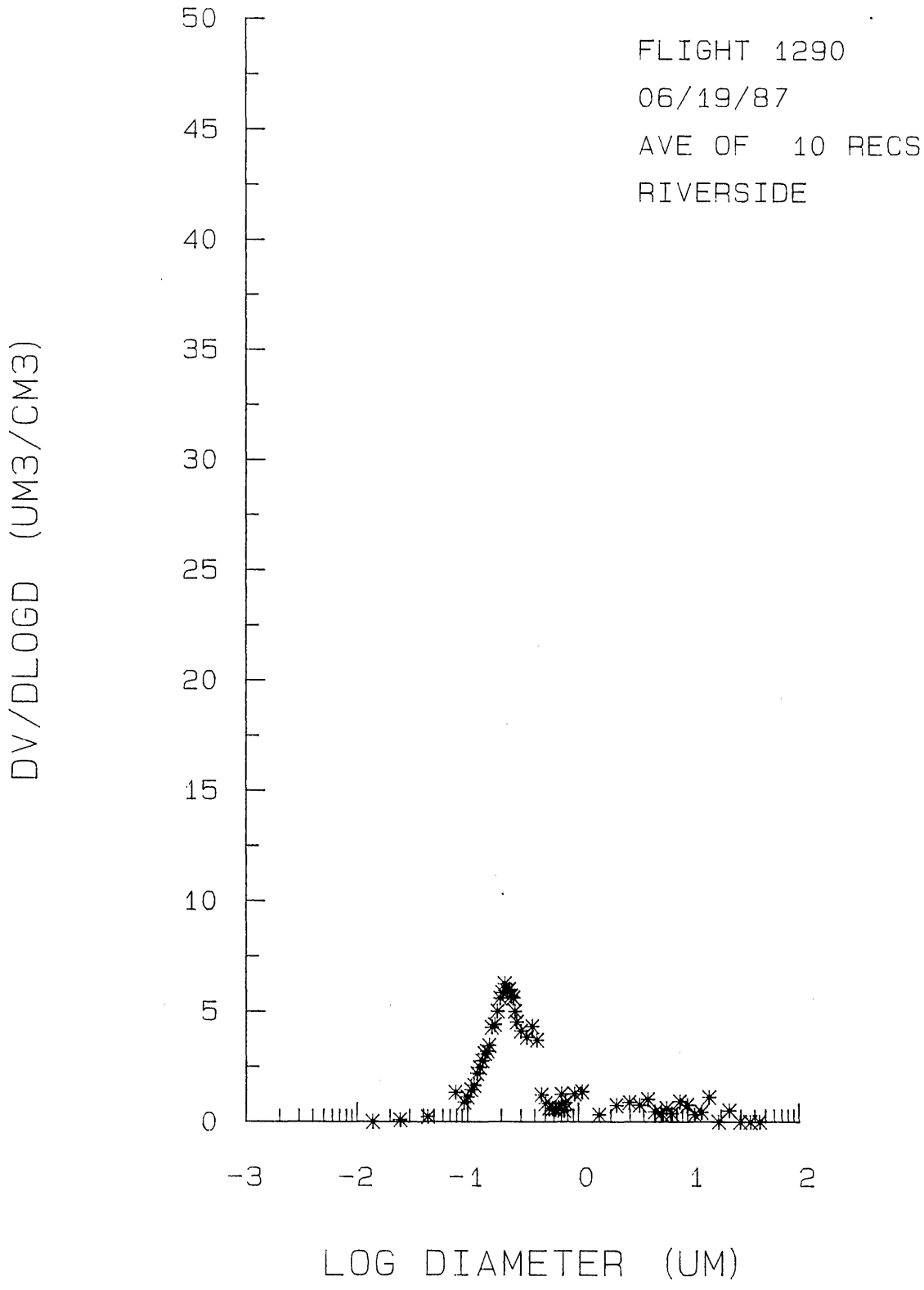

FLIGHT 1307
07/15/87
AVE OF 9 RECS
POMONA
DS/DLOGD (UM2/CM3)
1000
900
800
700
600
500
400
300
200
100
0
-3
-2
-1
0
1
2
LOG DIAMETER (UM)

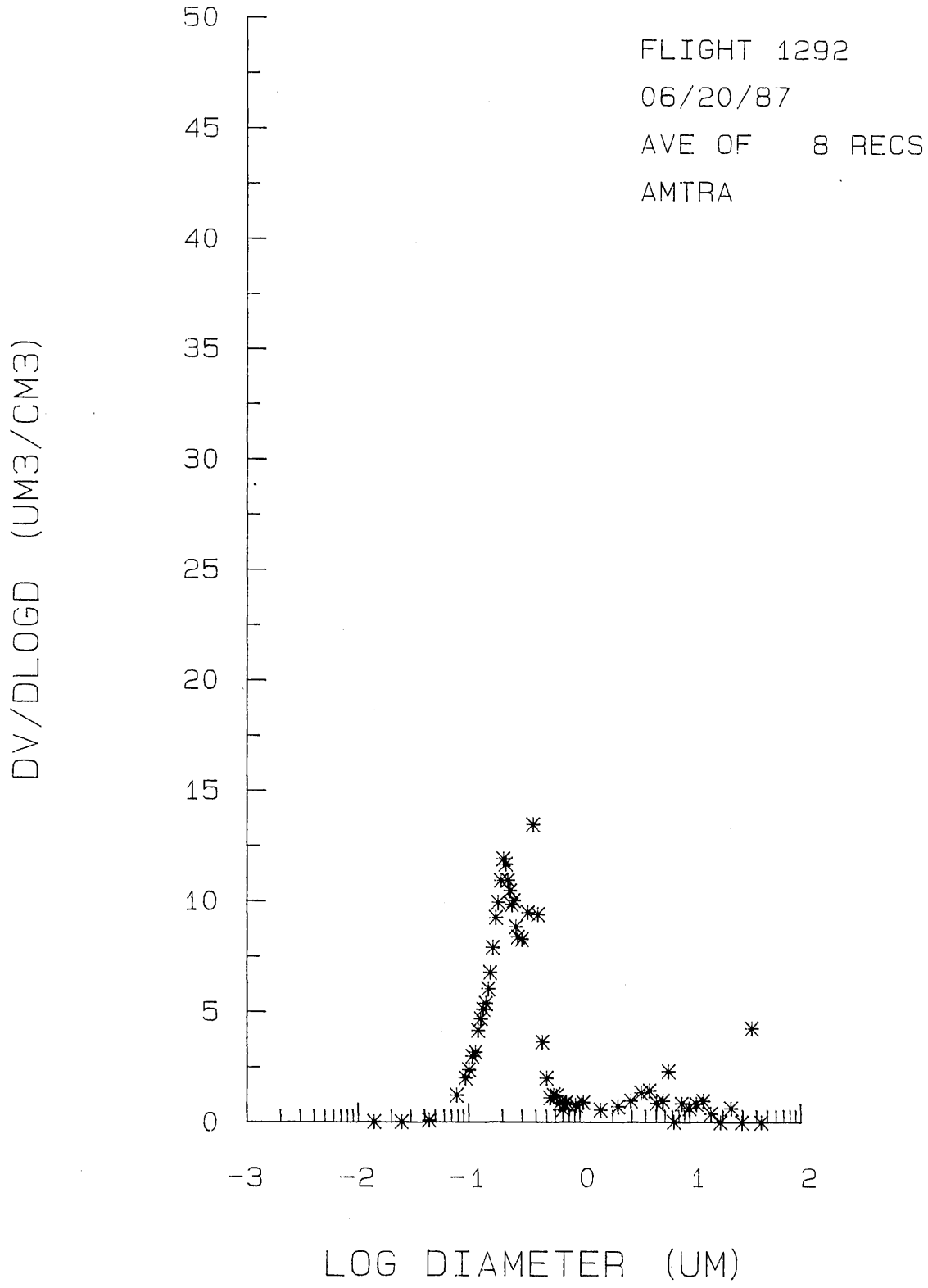

FLIGHT 1307
07/15/87
AVE OF 11 RECS
RIVERSIDE
DS/DLOGD (UM2/CM3)
1000
900
800
700
600
500
400
300
200
100
0
-3
-2
-1
0
1
2
LOG DIAMETER (UM)

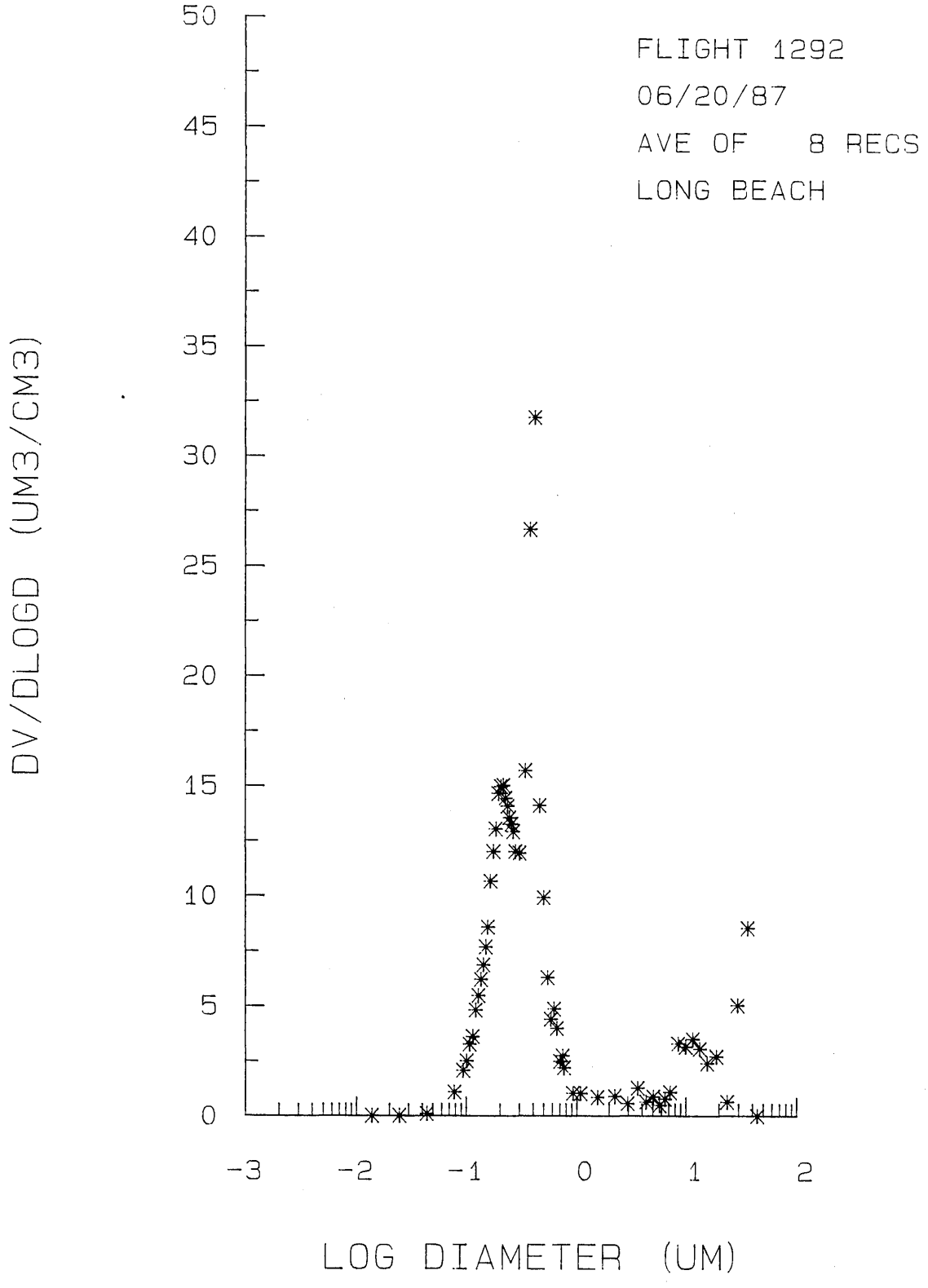

FLIGHT 1290
06/19/87
AVE OF 12 RECS
AMTRA
DV/DLOGD (UM3/CM3)
50
45
40
35
30
25
20
15
10
5
0
-3
-2
-1
0
1
2
LOG DIAMETER (UM)

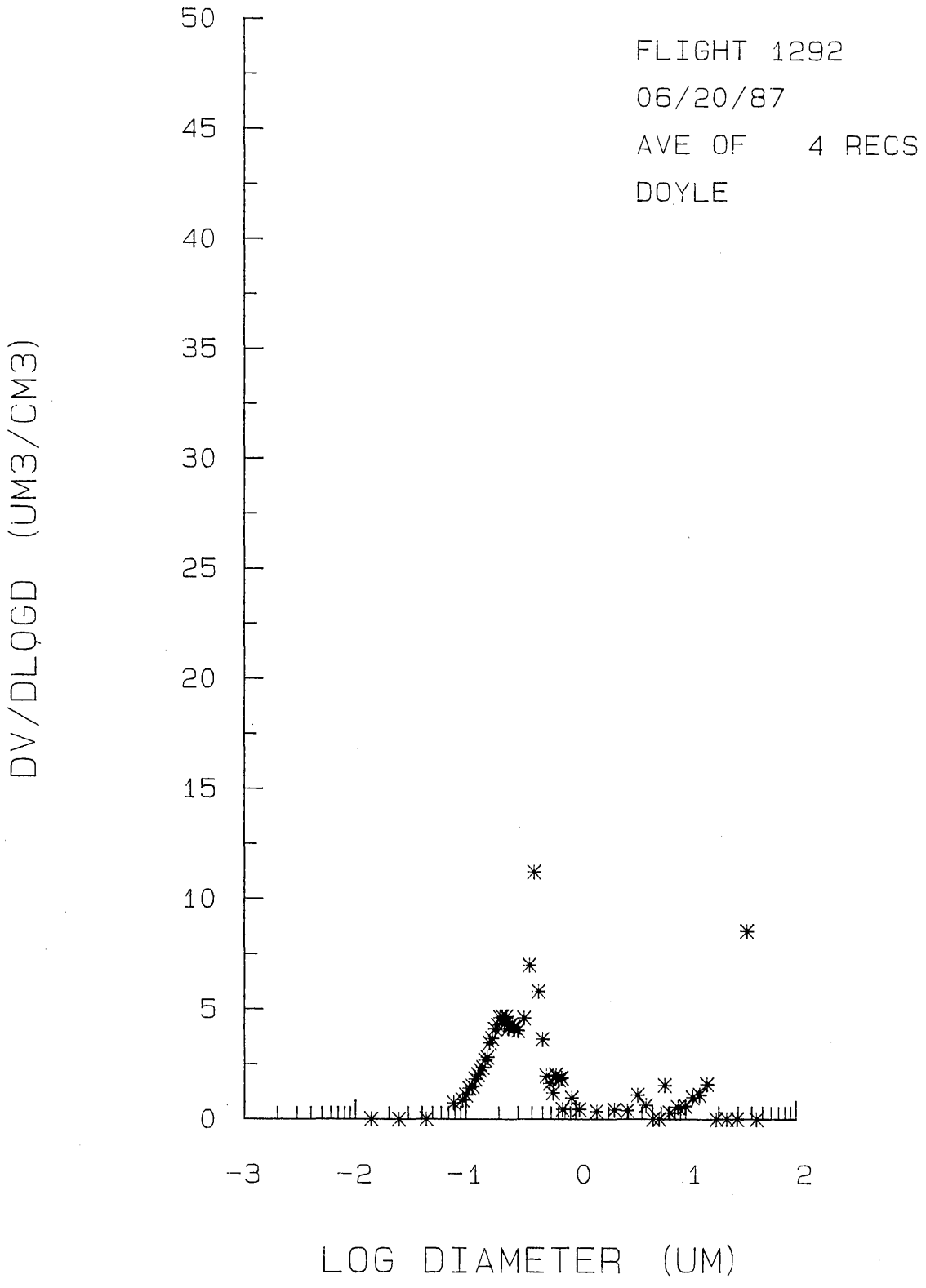

FLIGHT 1290
06/19/87
AVE OF 11 RECS
LONG BEACH
DV/DLOGD (UM3/CM3)
50
45
40
35
30
25
20
15
10
5
0
-3
-2
-1
0
1
2
LOG DIAMETER (UM)

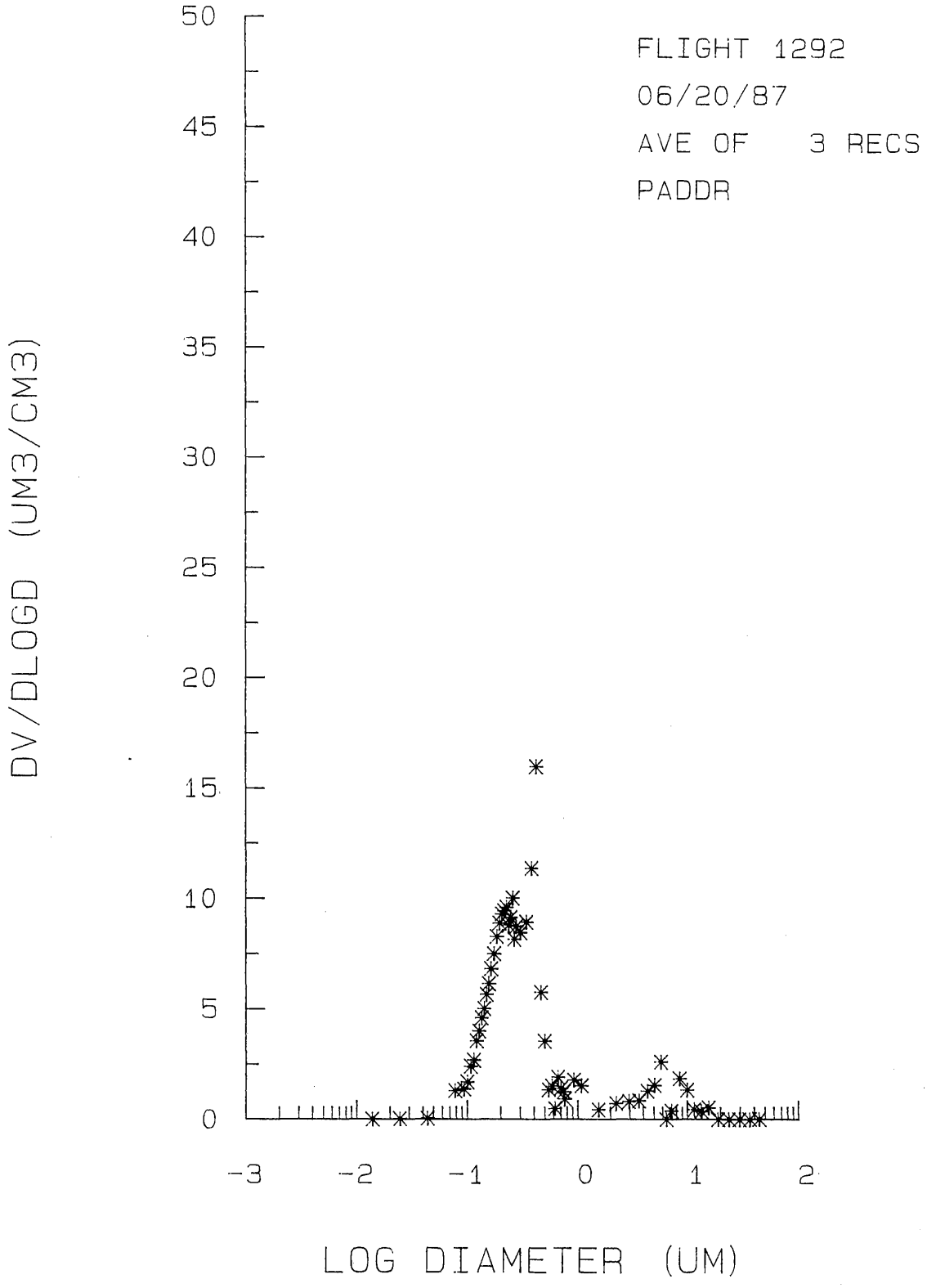

FLIGHT 1290
06/19/87
AVE OF 10 RECS
POMONA
DV/DLOGD (UM3/CM3)
50
45
40
35
30
25
20
15
10
5
0
-3
-2
-1
0
1
2
LOG DIAMETER (UM)

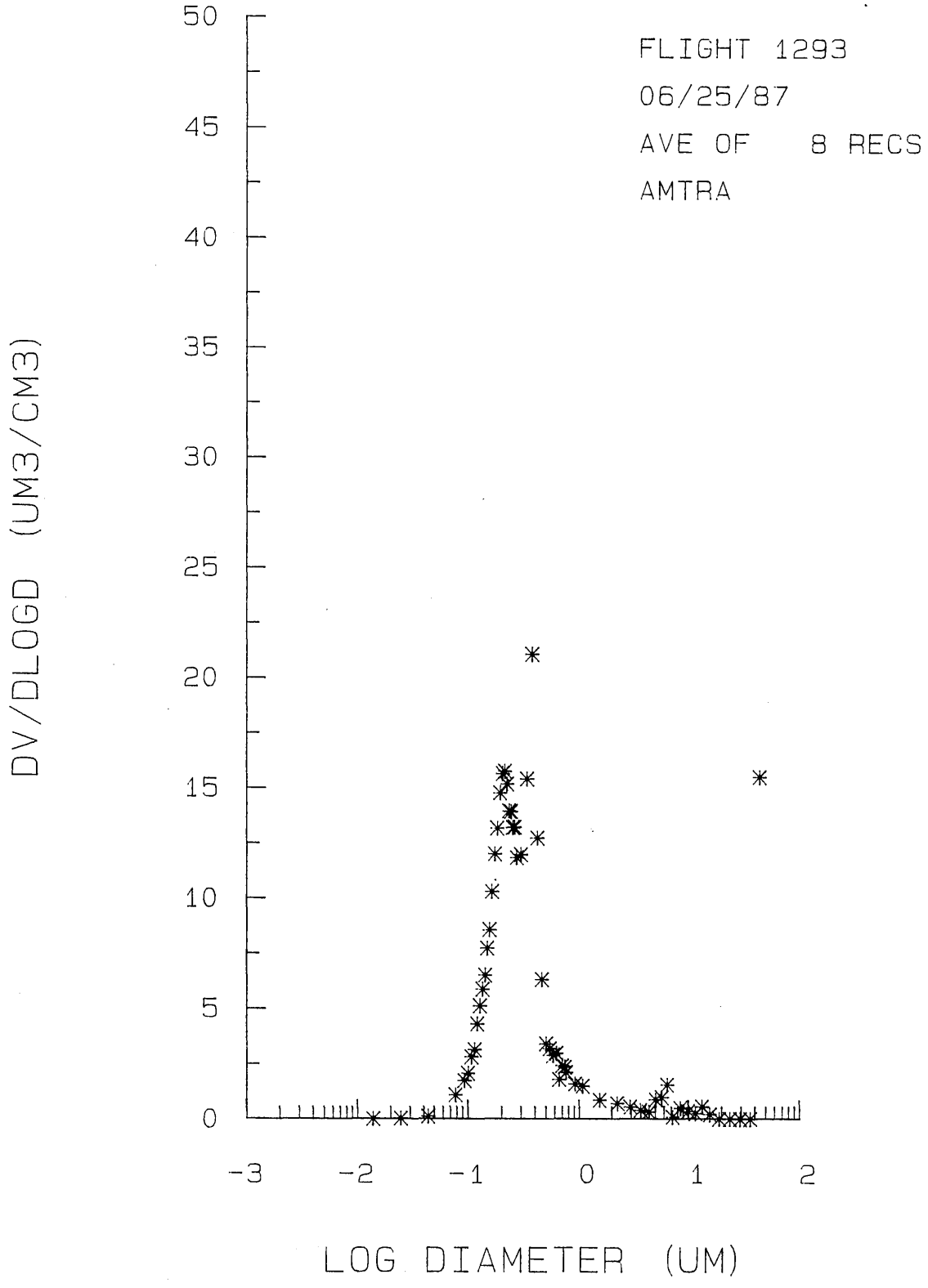

FLIGHT 1290
06/19/87
AVE OF 10 RECS
RIVERSIDE
DV/DLOGD (UM3/CM3)
50
45
40
35
30
25
20
15
10
5
0
-3
-2
-1
0
1
2
LOG DIAMETER (UM)

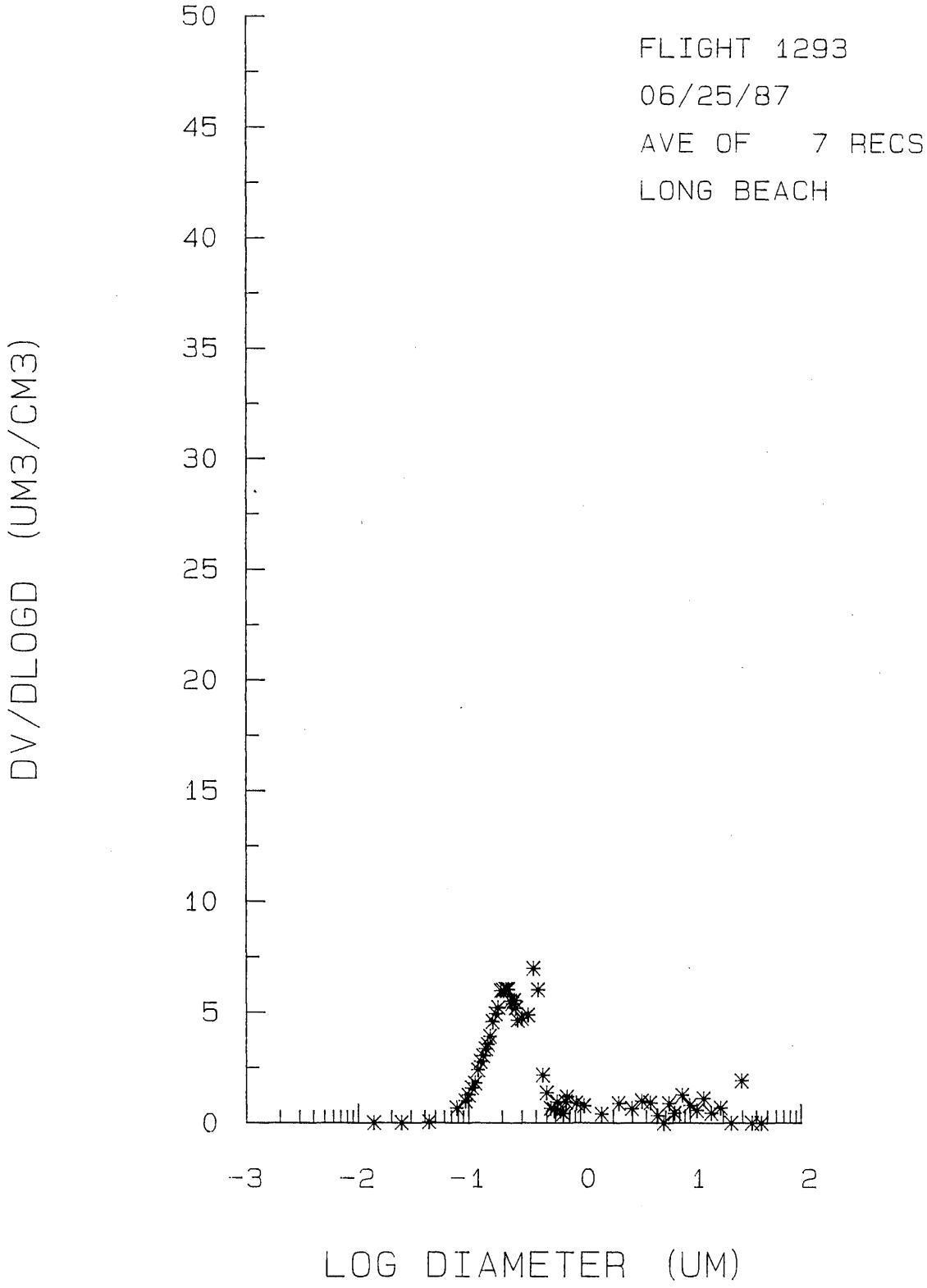

FLIGHT 1292
06/20/87
AVE OF 8 RECS
AMTRA
DV/DLOGD (UM3/CM3)
50
45
40
35
30
25
20
15
10
5
0
-3
-2
-1
0
1
2
LOG DIAMETER (UM)

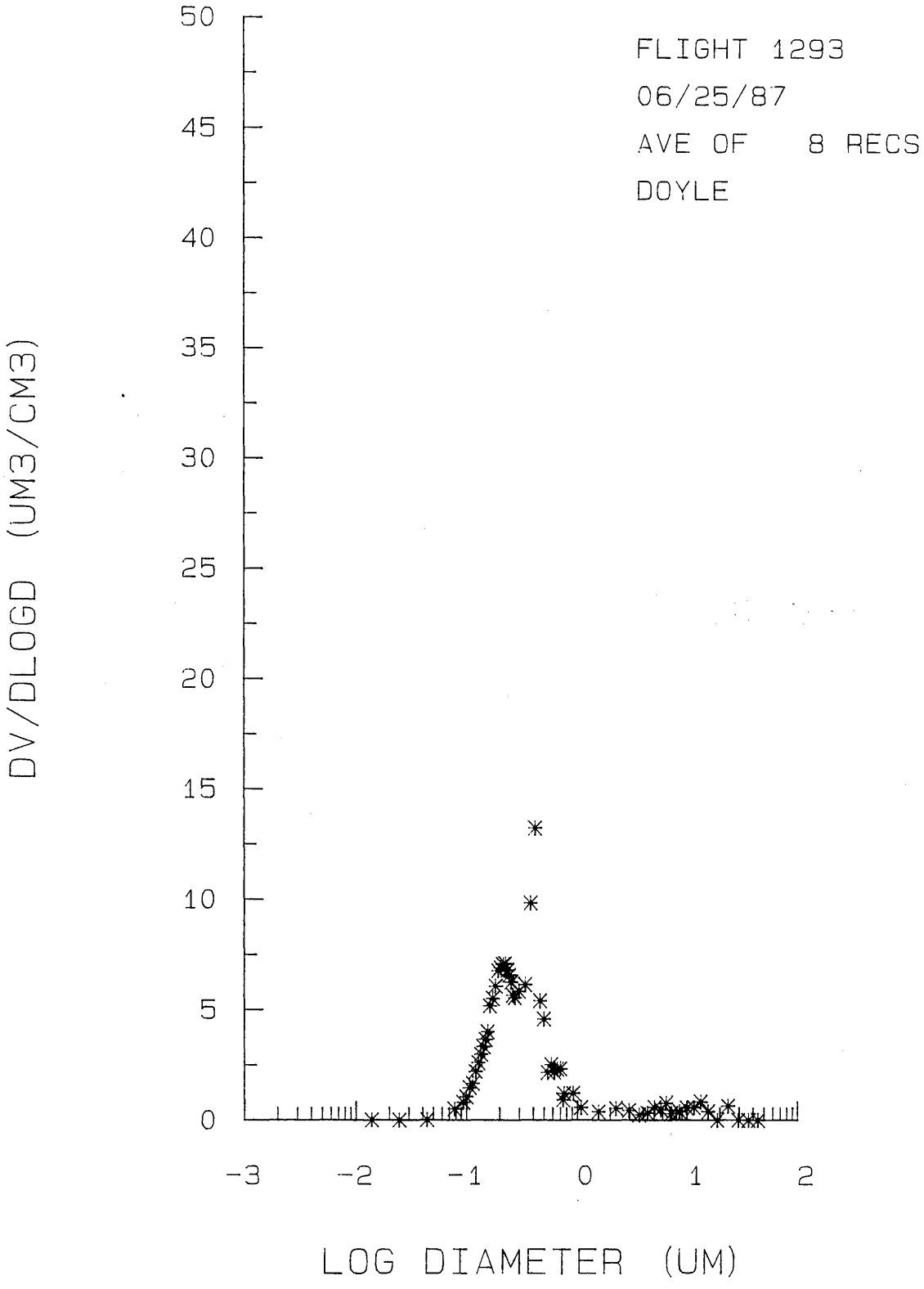

FLIGHT 1292
06/20/87
AVE OF 8 RECS
LONG BEACH
DV/DLOGD (UM3/CM3)
50
45
40
35
30
25
20
15
10
5
0
-3
-2
-1
0
1
2
LOG DIAMETER (UM)

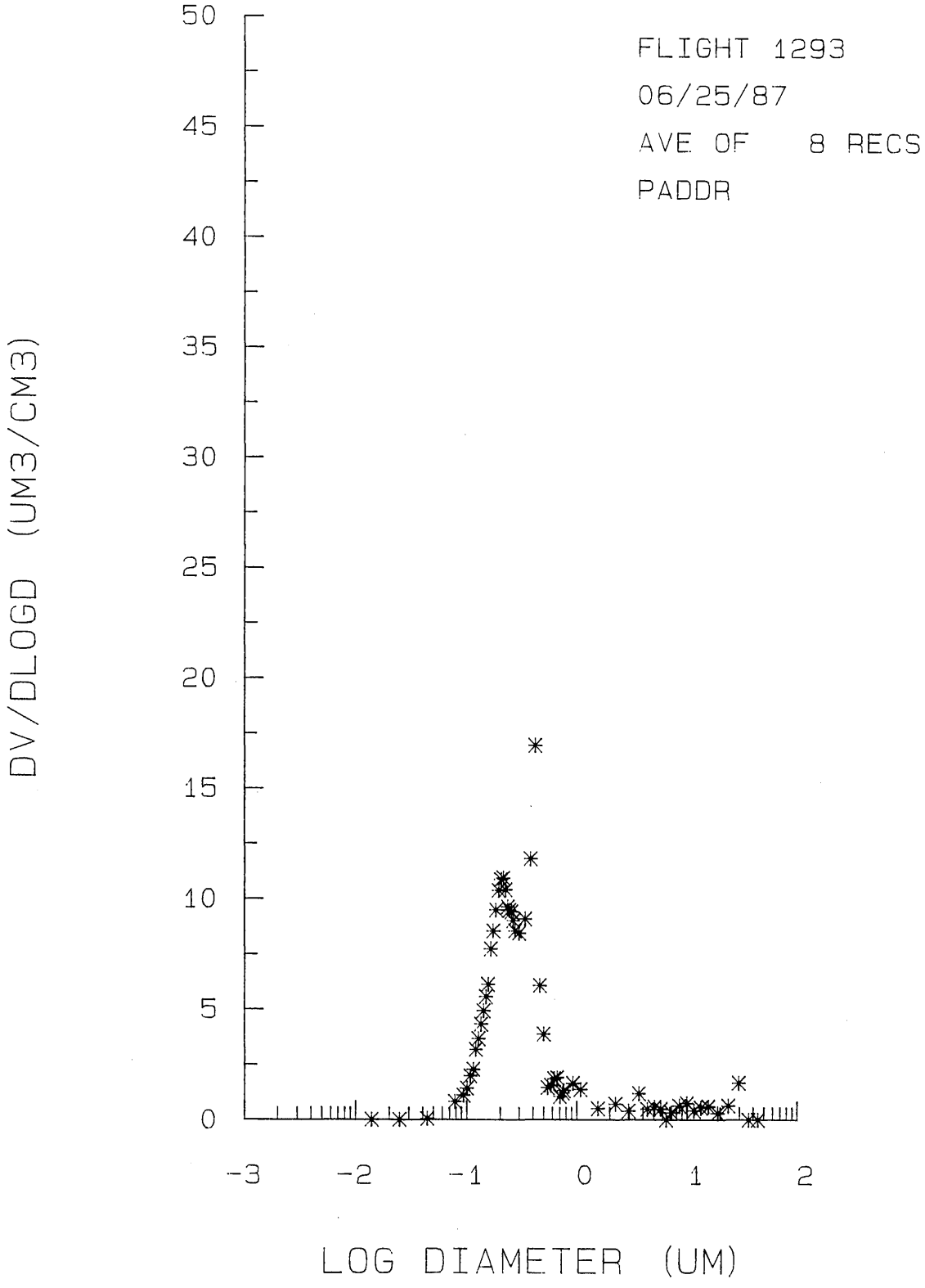

FLIGHT 1292
06/20/87
AVE OF 4 RECS
DOYLE
DV/DLOGD (UM3/CM3)
50
45
40
35
30
25
20
15
10
5
0
-3
-2
-1
0
1
2
LOG DIAMETER (UM)

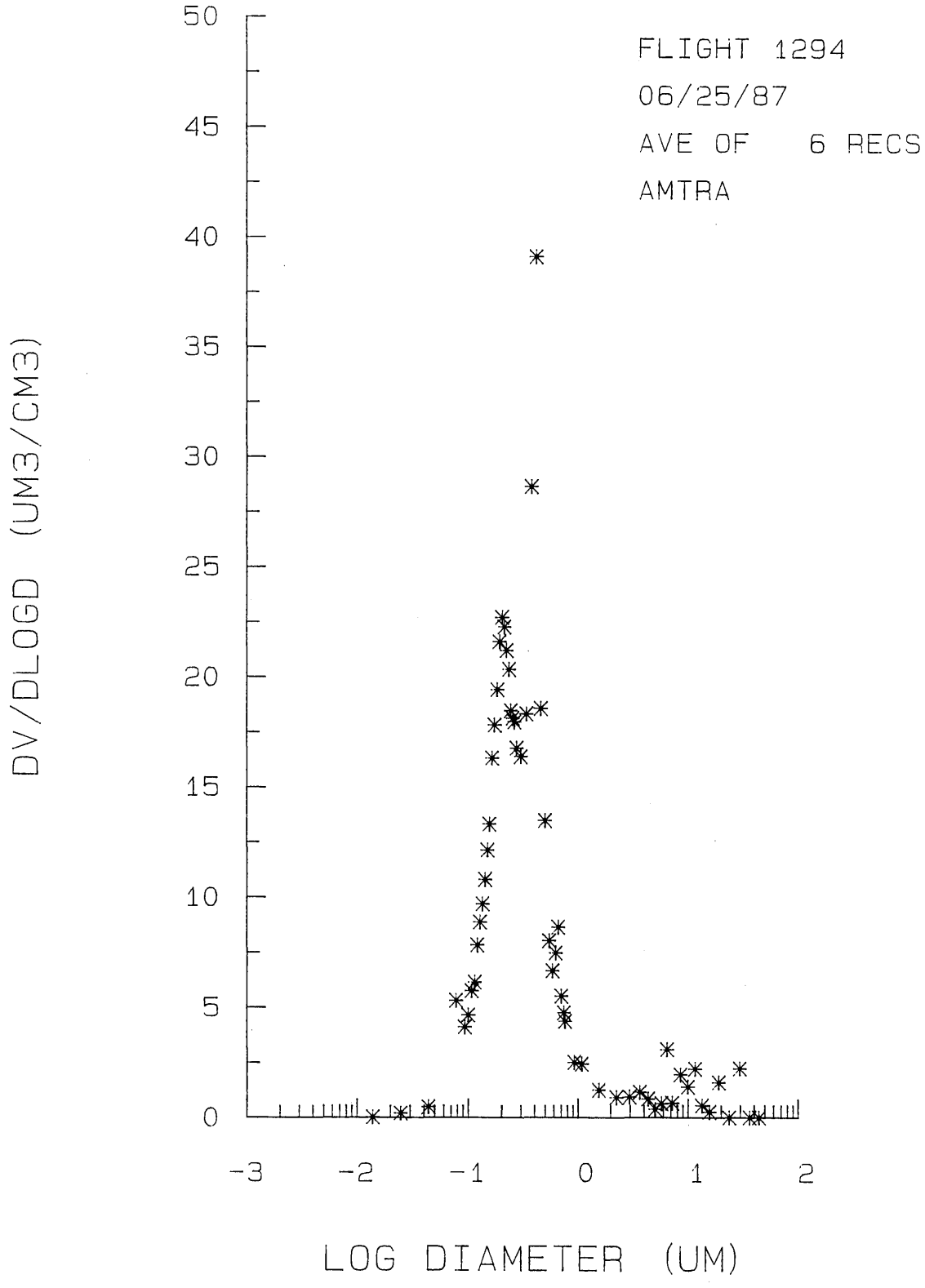

FLIGHT 1292
06/20/87
AVE OF 3 RECS
PADDR
DV/DLOGD (UM3/CM3)
50
45
40
35
30
25
20
15
10
5
0
-3
-2
-1
0
1
2
LOG DIAMETER (UM)

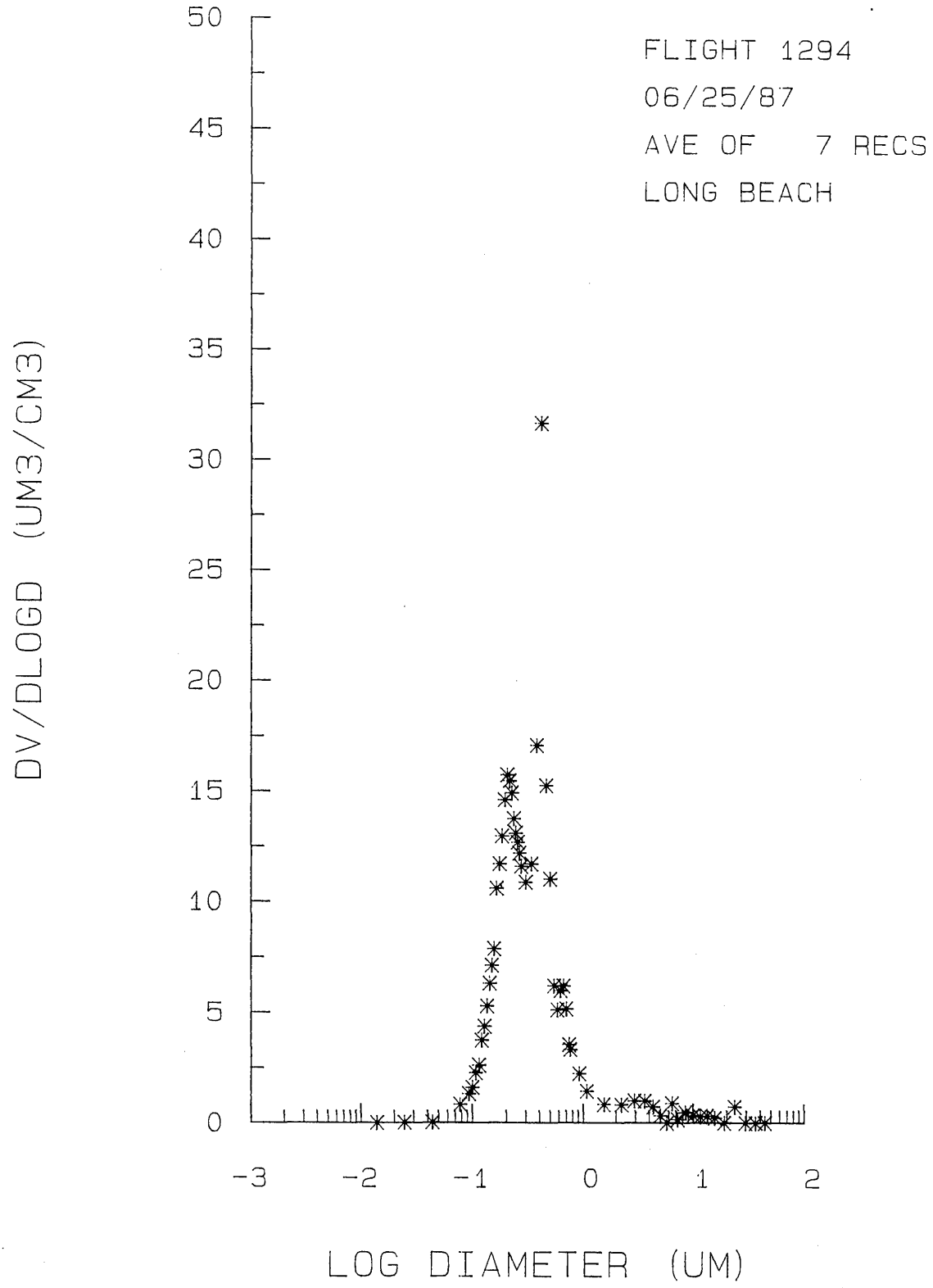

FLIGHT 1293
06/25/87
AVE OF 8 RECS
AMTRA
DV/DLOGD (UM3/CM3)
50
45
40
35
30
25
20
15
10
5
0
-3
-2
-1
0
1
2
LOG DIAMETER (UM)

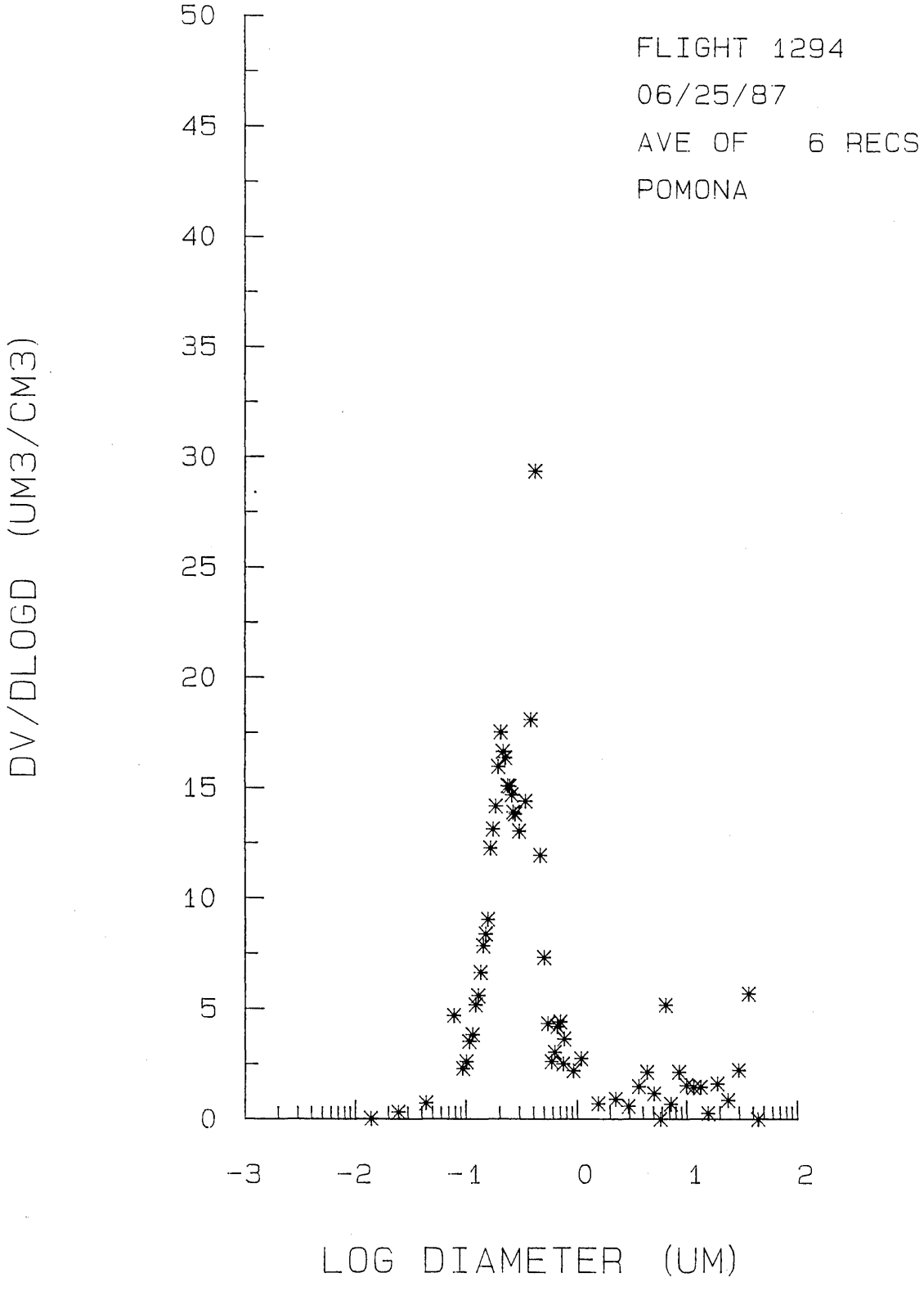

FLIGHT 1293
06/25/87
AVE OF 7 RECS
LONG BEACH
DV/DLOGD (UM3/CM3)
50
45
40
35
30
25
20
15
10
5
0
-3
-2
-1
0
1
2
LOG DIAMETER (UM)

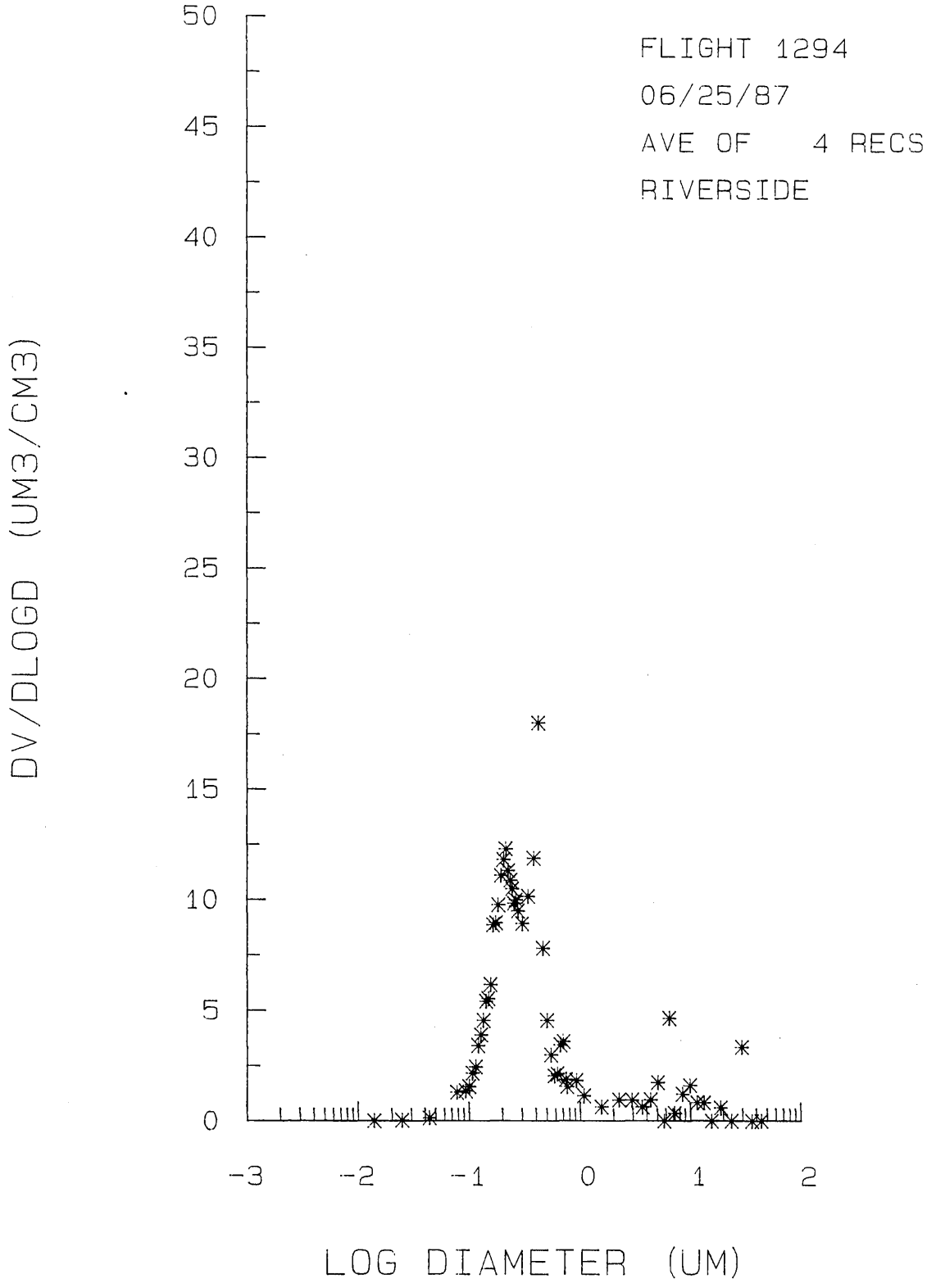

FLIGHT 1293
06/25/87
AVE OF 8 RECS
DOYLE
DV/DLOGD (UM3/CM3)
50
45
40
35
30
25
20
15
10
5
0
-3
-2
-1
0
1
2
LOG DIAMETER (UM)

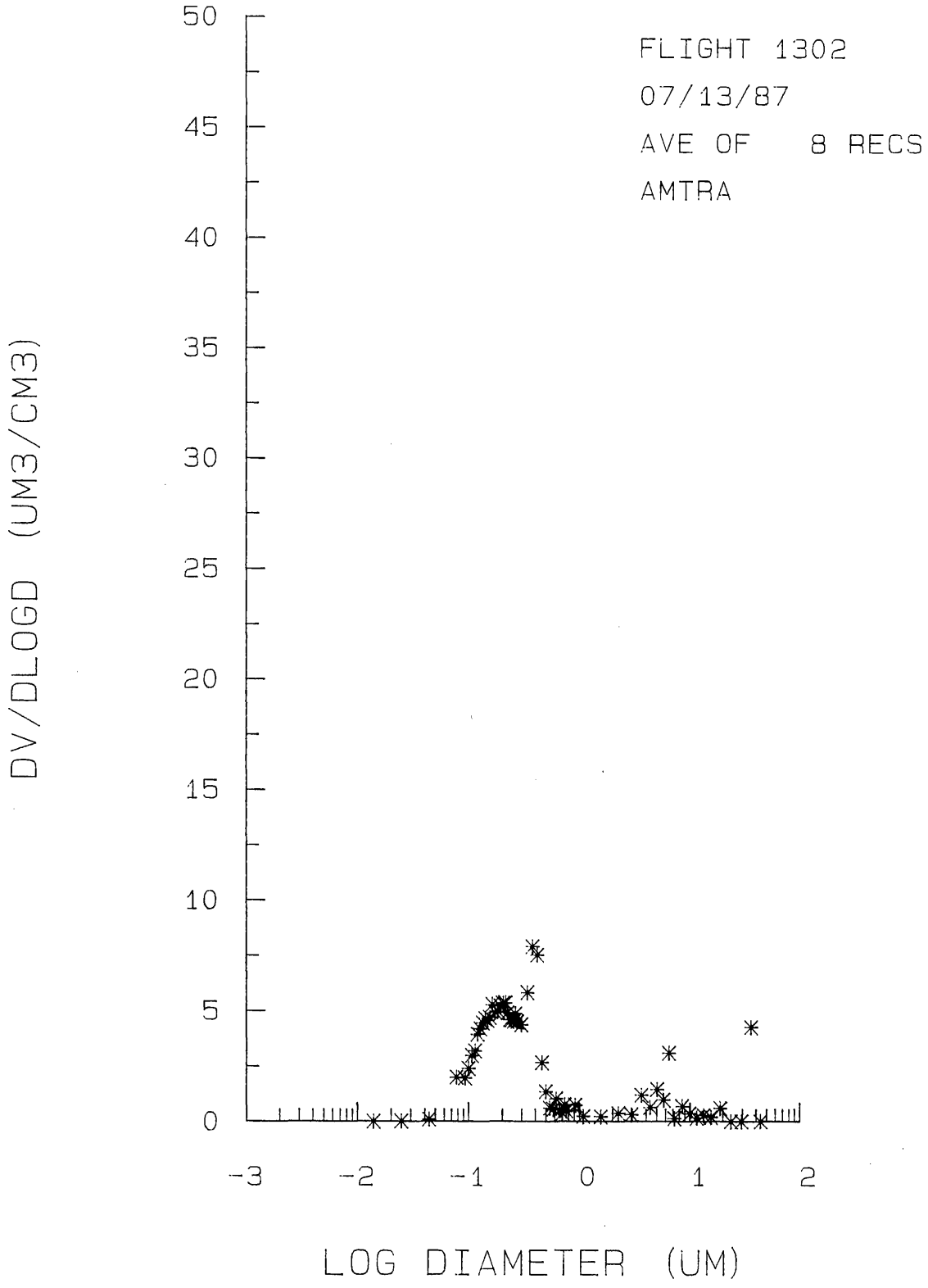

FLIGHT 1293
06/25/87
AVE OF 8 RECS
PADDR
DV/DLOGD (UM3/CM3)
50
45
40
35
30
25
20
15
10
5
0
-3
-2
-1
0
1
2
LOG DIAMETER (UM)

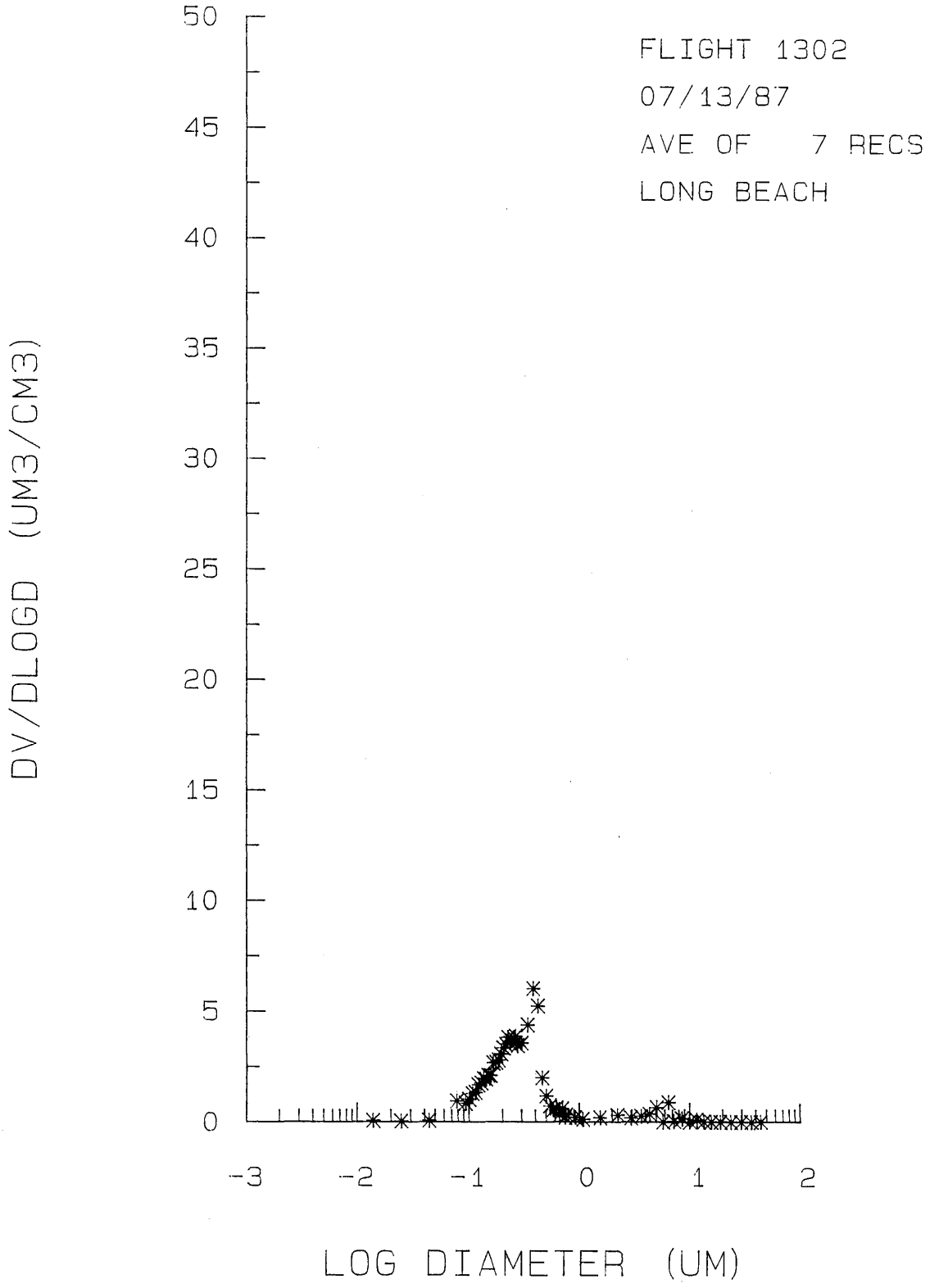

FLIGHT 1294
06/25/87
AVE OF 6 RECS
AMTRA
DV/DLOGD (UM3/CM3)
LOG DIAMETER (UM)
50
45
40
35
30
25
20
15
10
5
0
-3
-2
-1
0
1
2

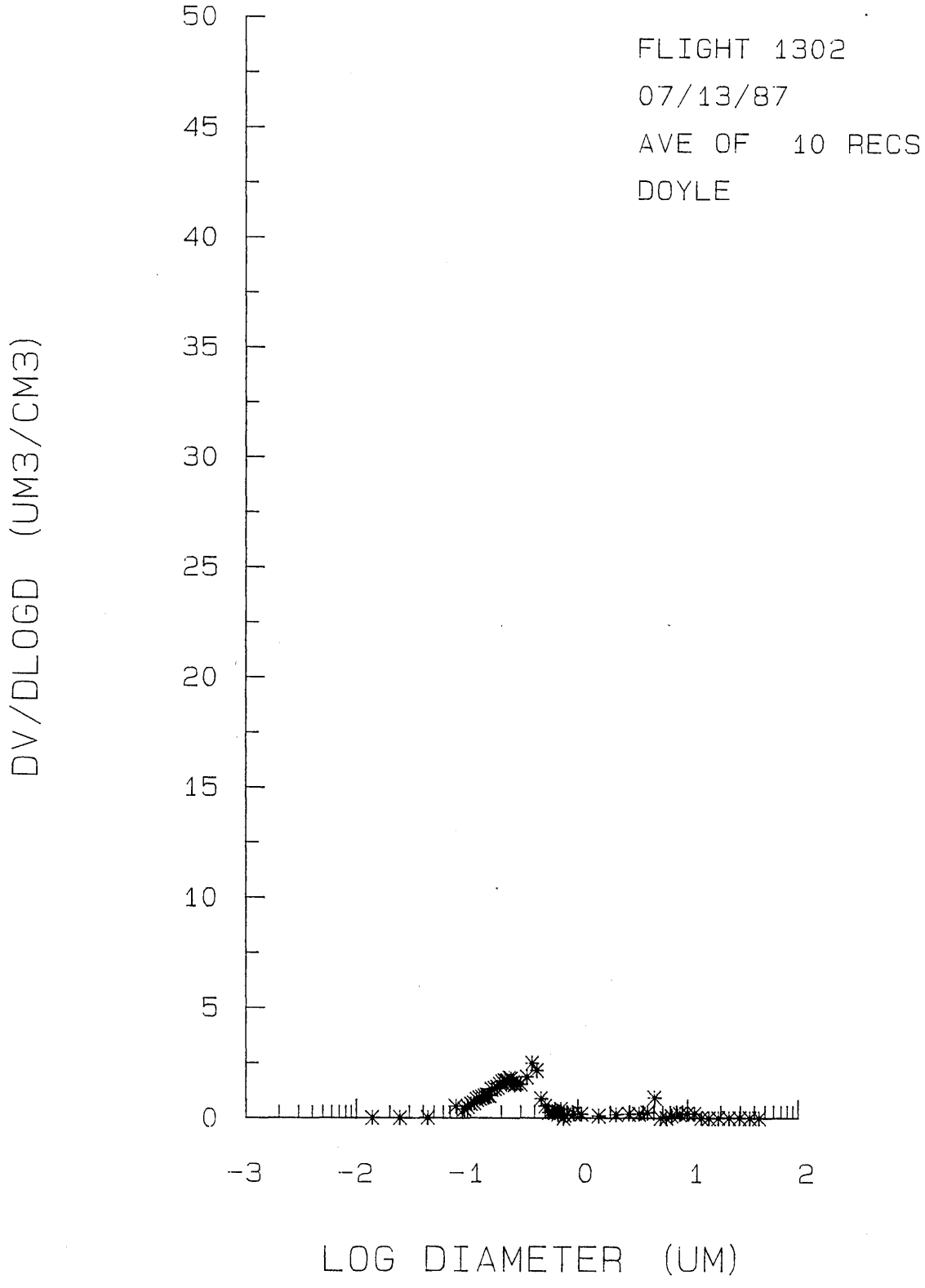

FLIGHT 1294
06/25/87
AVE OF 7 RECS
LONG BEACH
DV/DLOGD (UM3/CM3)
50
45
40
35
30
25
20
15
10
5
0
-3
-2
-1
0
1
2
LOG DIAMETER (UM)

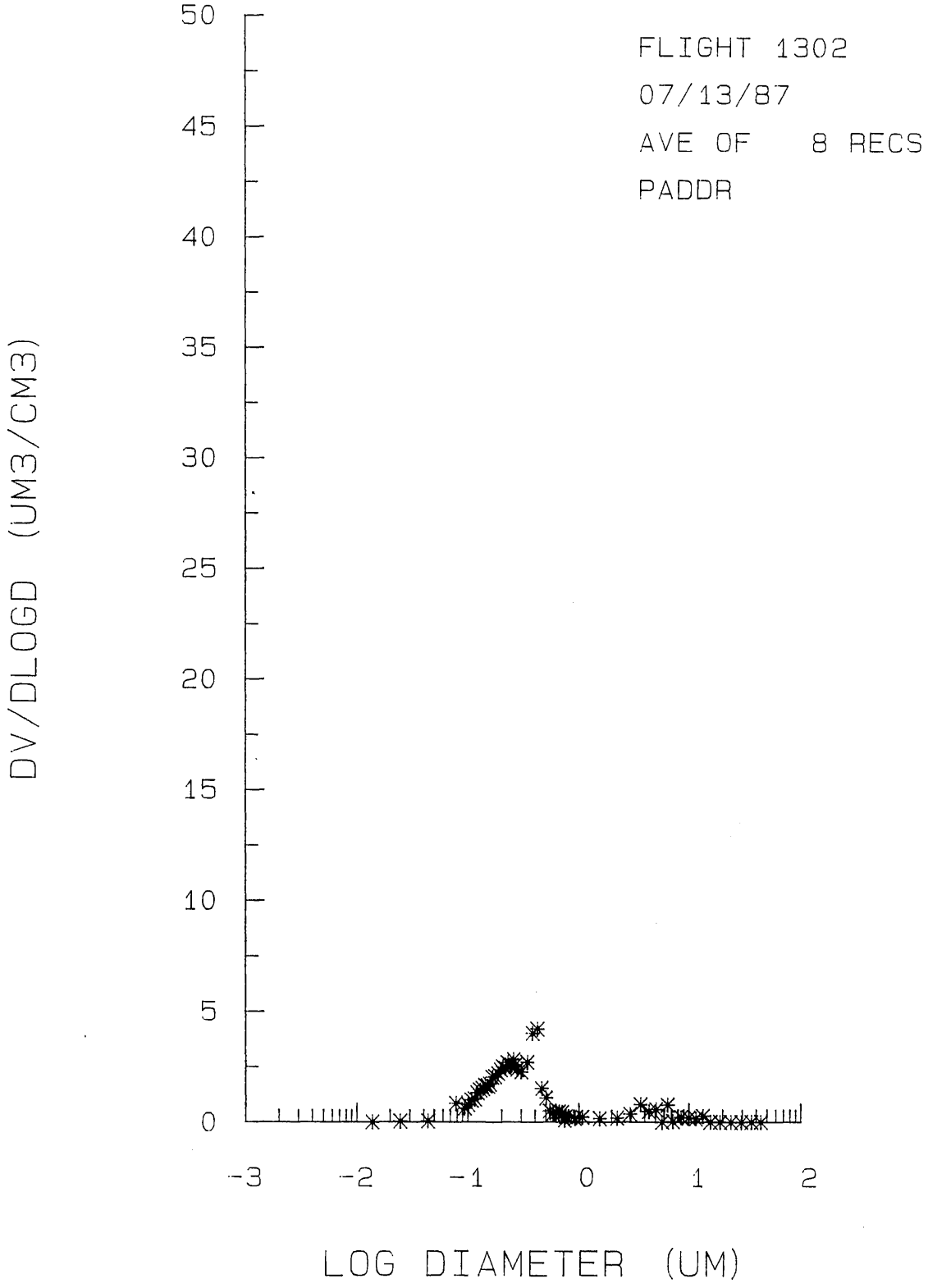

FLIGHT 1294
06/25/87
AVE OF 6 RECS
POMONA
DV/DLOGD (UM3/CM3)
LOG DIAMETER (UM)
50
45
40
35
30
25
20
15
10
5
0
-3
-2
-1
0
1
2

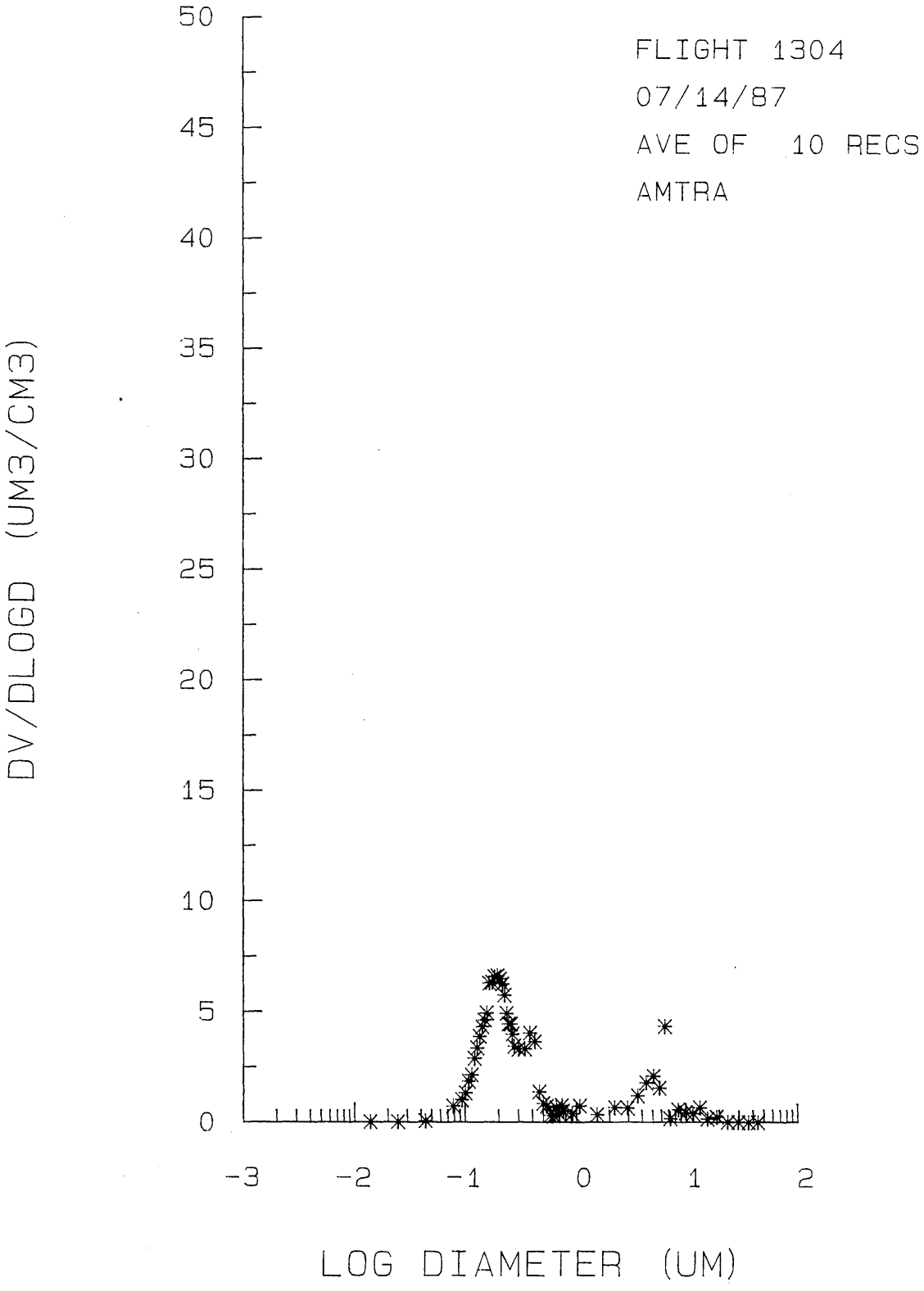

FLIGHT 1294
06/25/87
AVE OF 4 RECS
RIVERSIDE
DV/DLOGD (UM3/CM3)
50
45
40
35
30
25
20
15
10
5
0
-3
-2
-1
0
1
2
LOG DIAMETER (UM)

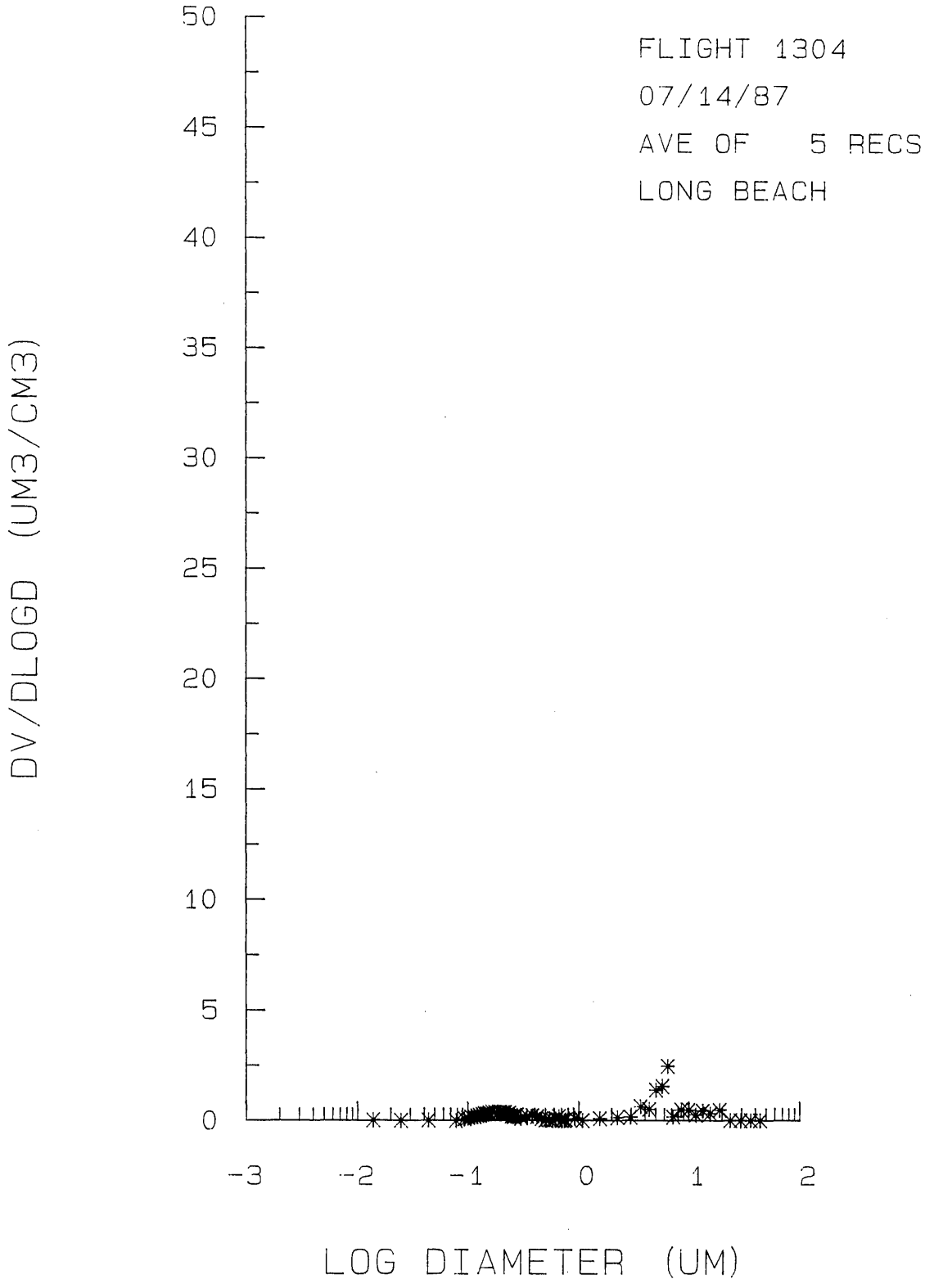

FLIGHT 1302
07/13/87
AVE OF 8 RECS
AMTRA
DV/DLOGD (UM3/CM3)
50
45
40
35
30
25
20
15
10
5
0
-3
-2
-1
0
1
2
LOG DIAMETER (UM)

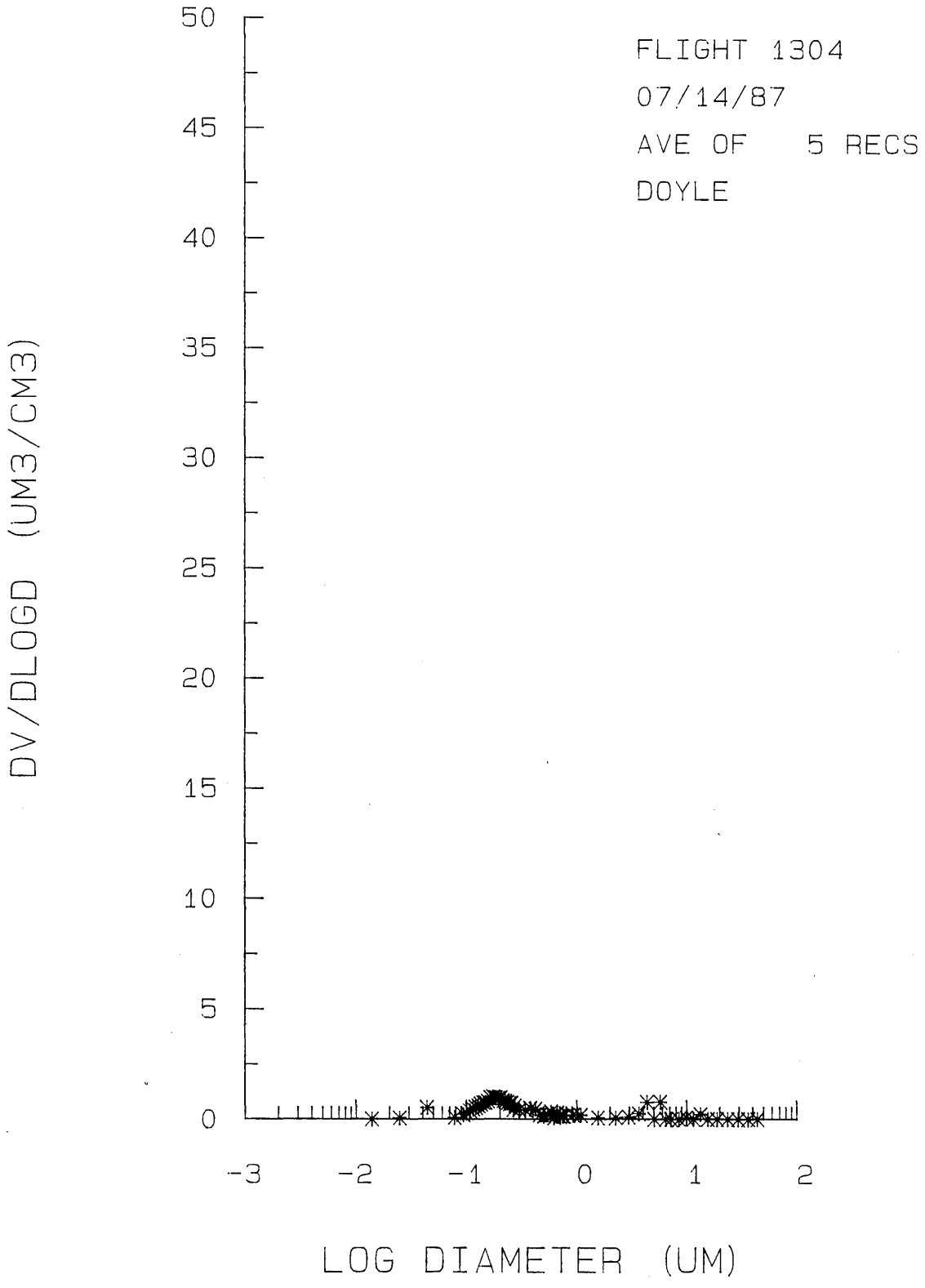

FLIGHT 1302
07/13/87
AVE OF 7 RECS
LONG BEACH
DV/DLOGD (UM3/CM3)
50
45
40
35
30
25
20
15
10
5
0
-3
-2
-1
0
1
2
LOG DIAMETER (UM)

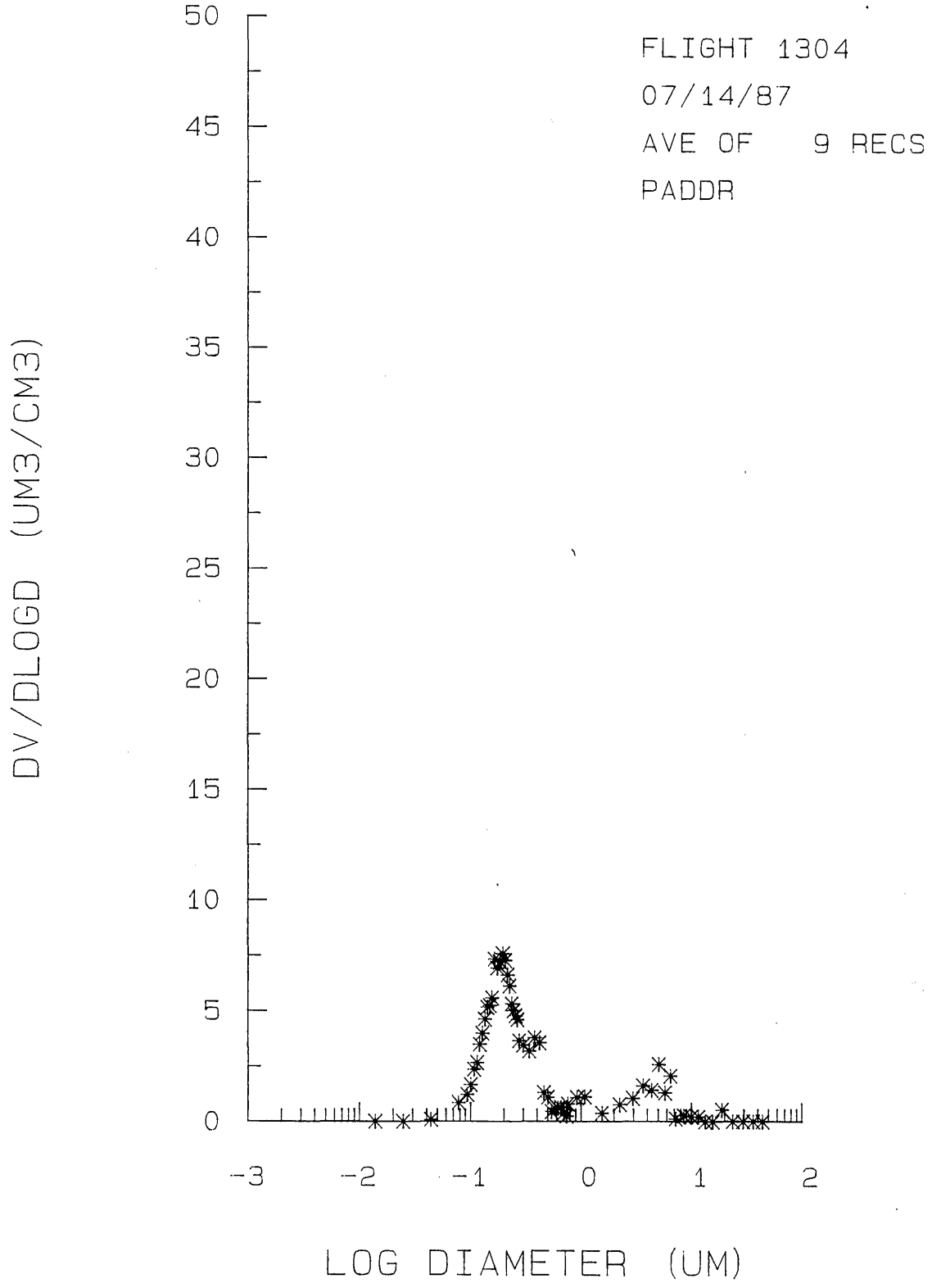

FLIGHT 1302
07/13/87
AVE OF 10 RECS
DOYLE
DV/DLOGD (UM3/CM3)
50
45
40
35
30
25
20
15
10
5
0
-3
-2
-1
0
1
2
LOG DIAMETER (UM)

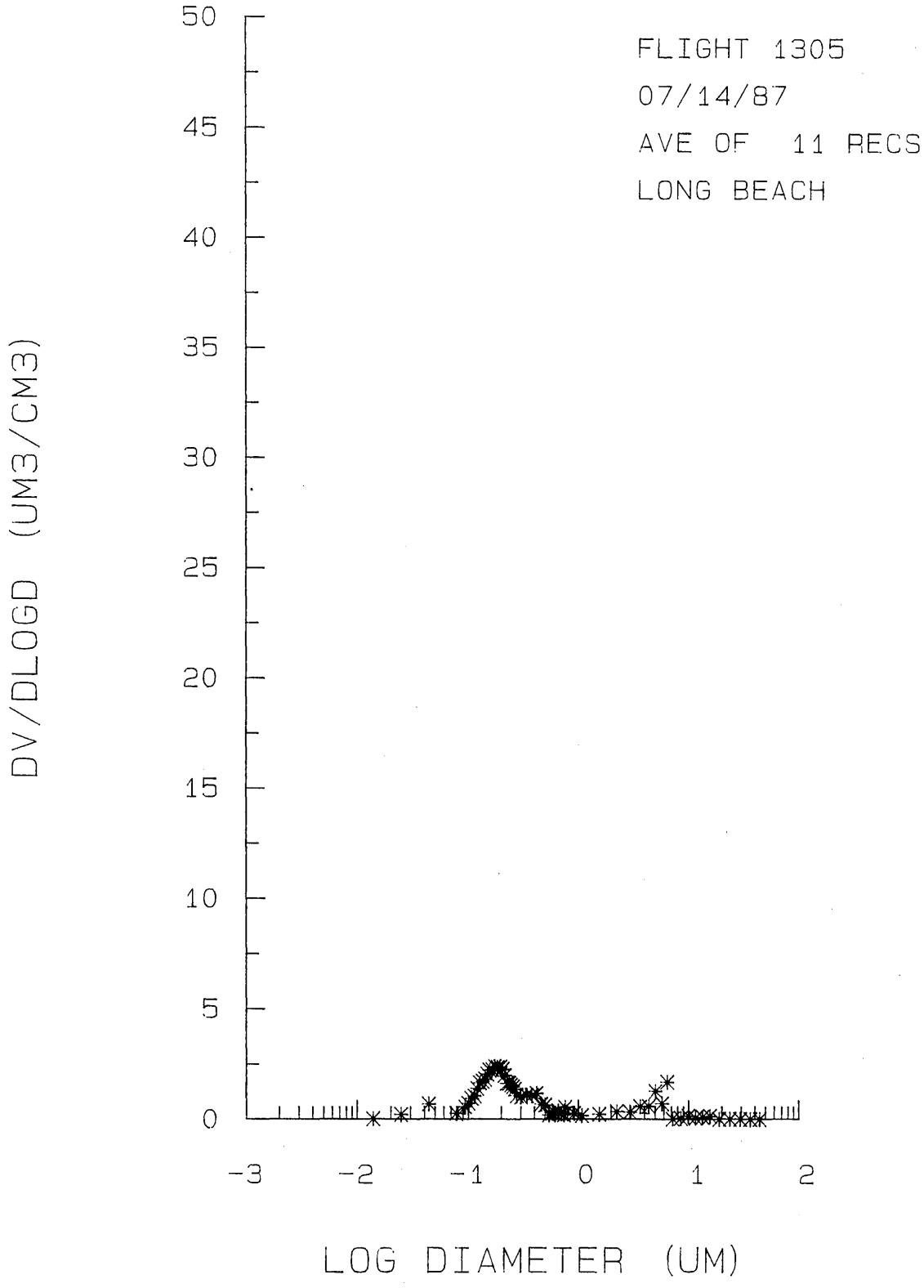

FLIGHT 1302
07/13/87
AVE OF 8 RECS
PADDR
DV/DLOGD (UM3/CM3)
50
45
40
35
30
25
20
15
10
5
0
-3
-2
-1
0
1
2
LOG DIAMETER (UM)

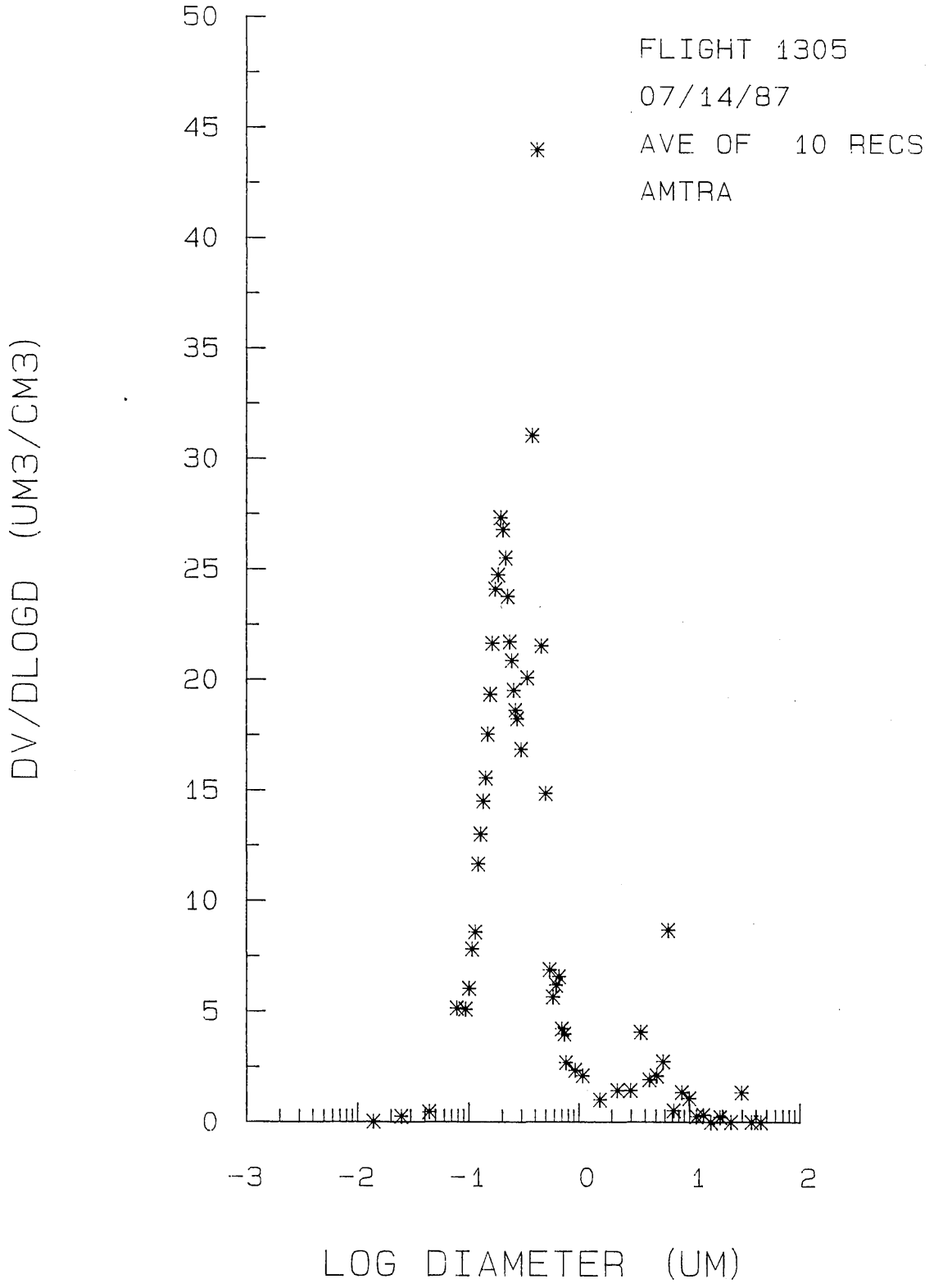

FLIGHT 1304
07/14/87
AVE OF 10 RECS
AMTRA
DV/DLOGD (UM3/CM3)
50
45
40
35
30
25
20
15
10
5
0
-3
-2
-1
0
1
2
LOG DIAMETER (UM)

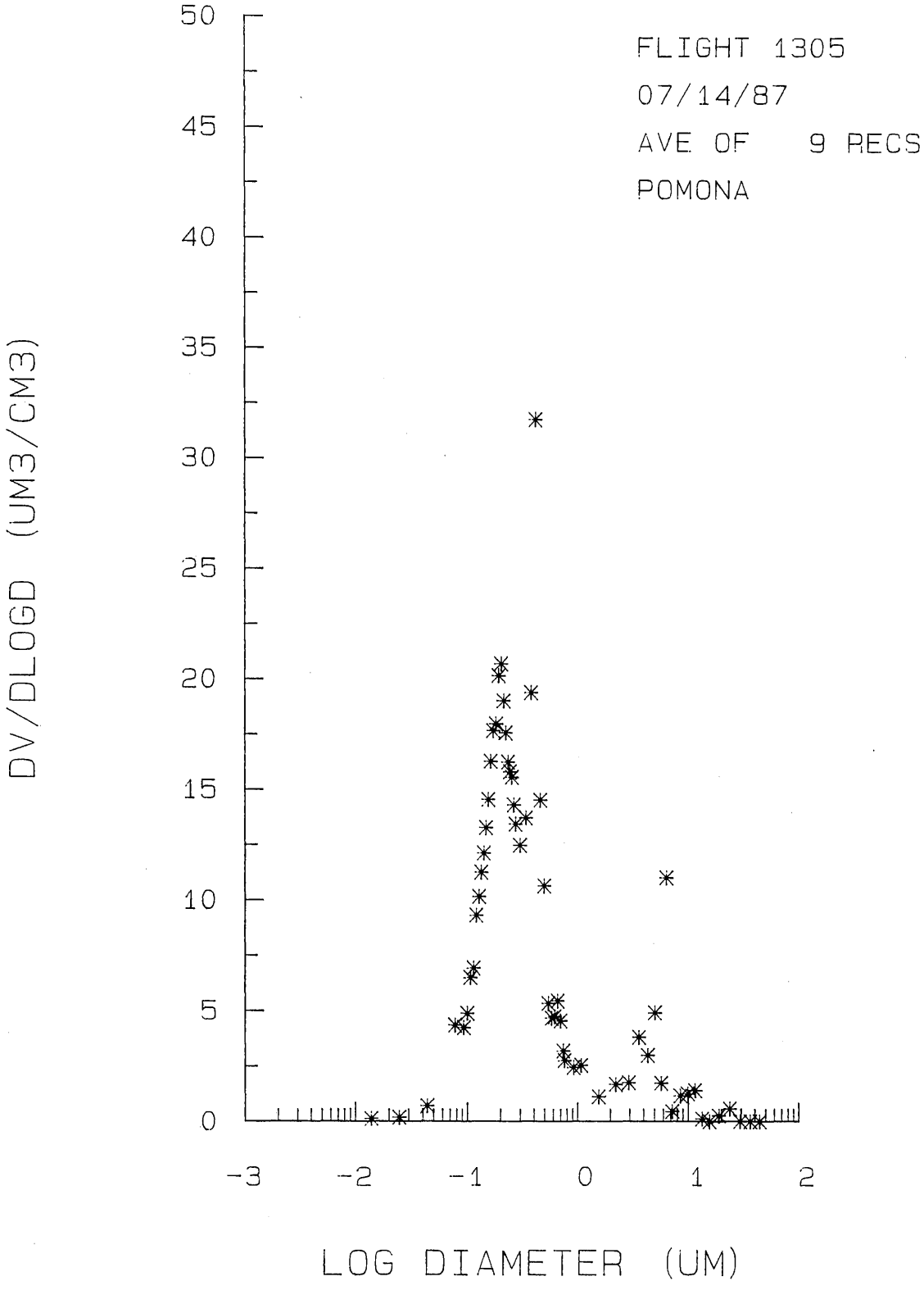

FLIGHT 1304
07/14/87
AVE OF 5 RECS
LONG BEACH
DV/DLOGD (UM3/CM3)
50
45
40
35
30
25
20
15
10
5
0
-3
-2
-1
0
1
2
LOG DIAMETER (UM)

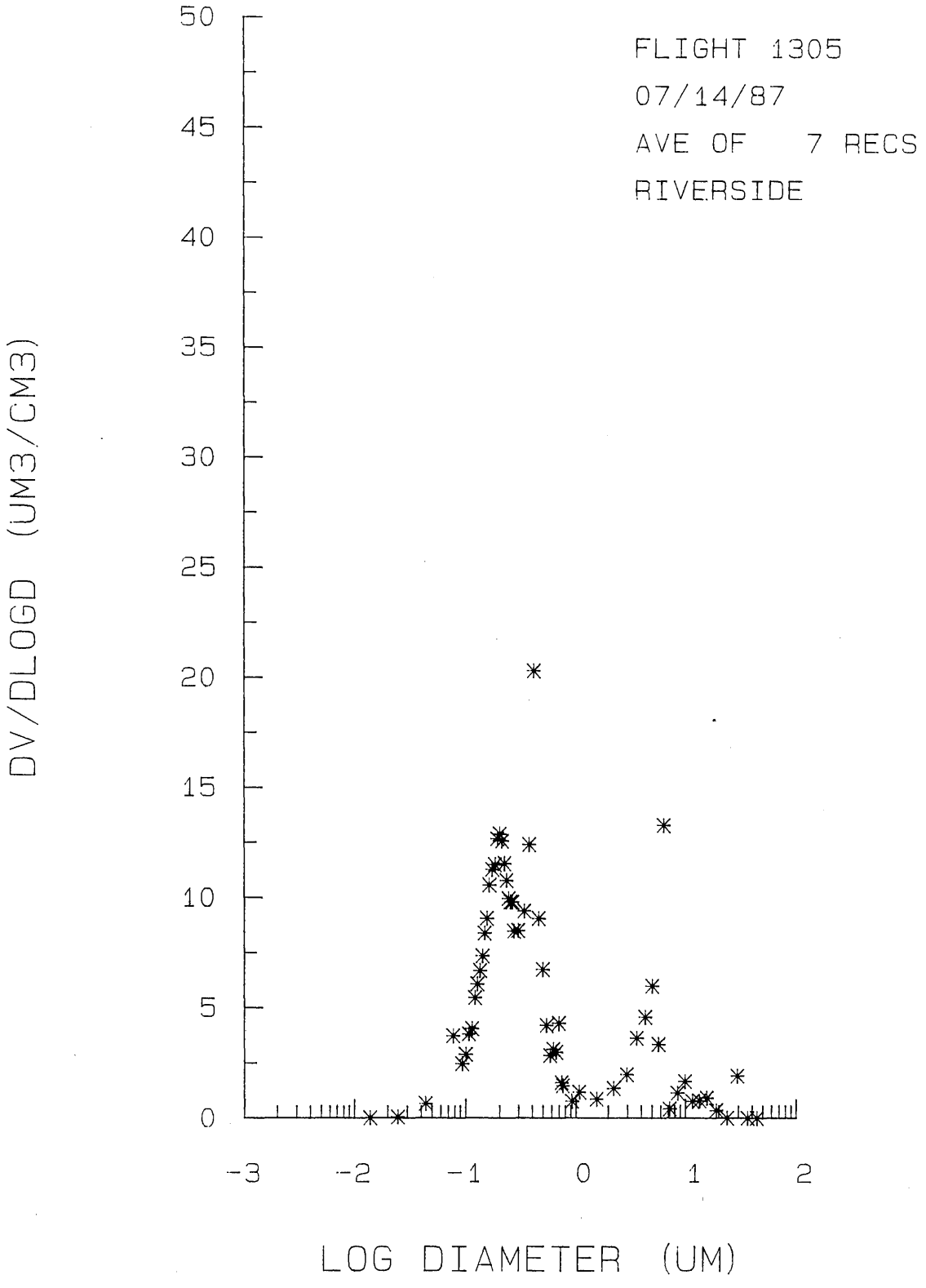

FLIGHT 1304
07/14/87
AVE OF 5 RECS
DOYLE
DV/DLOGD (UM3/CM3)
50
45
40
35
30
25
20
15
10
5
0
-3
-2
-1
0
1
2
LOG DIAMETER (UM)

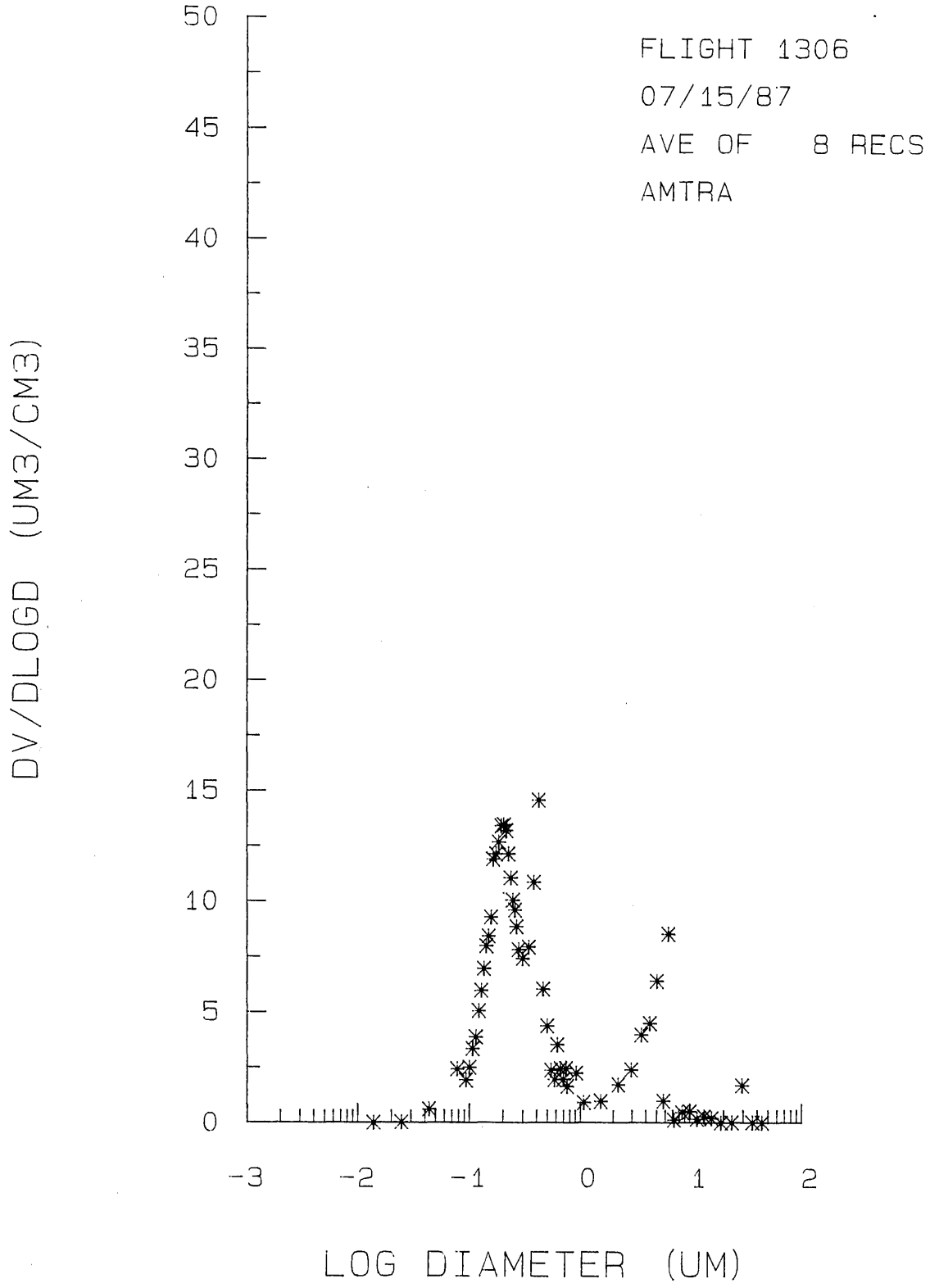

FLIGHT 1304
07/14/87
AVE OF 9 RECS
PADDR
DV/DLOGD (UM3/CM3)
50
45
40
35
30
25
20
15
10
5
0
-3
-2
-1
0
1
2
LOG DIAMETER (UM)

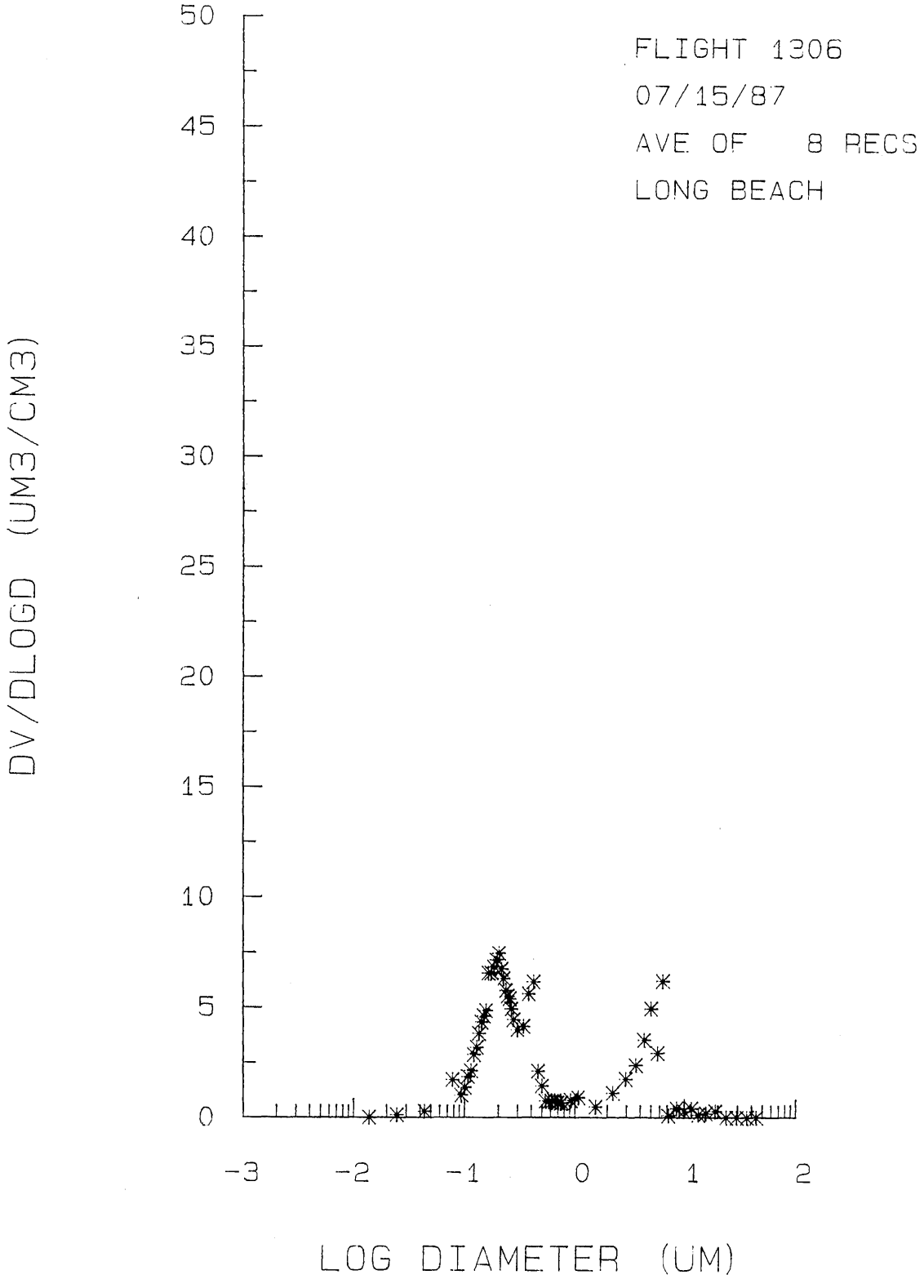

FLIGHT 1305
07/14/87
AVE OF 11 RECS
LONG BEACH
DV/DLOGD (UM3/CM3)
50
45
40
35
30
25
20
15
10
5
0
-3
-2
-1
0
1
2
LOG DIAMETER (UM)

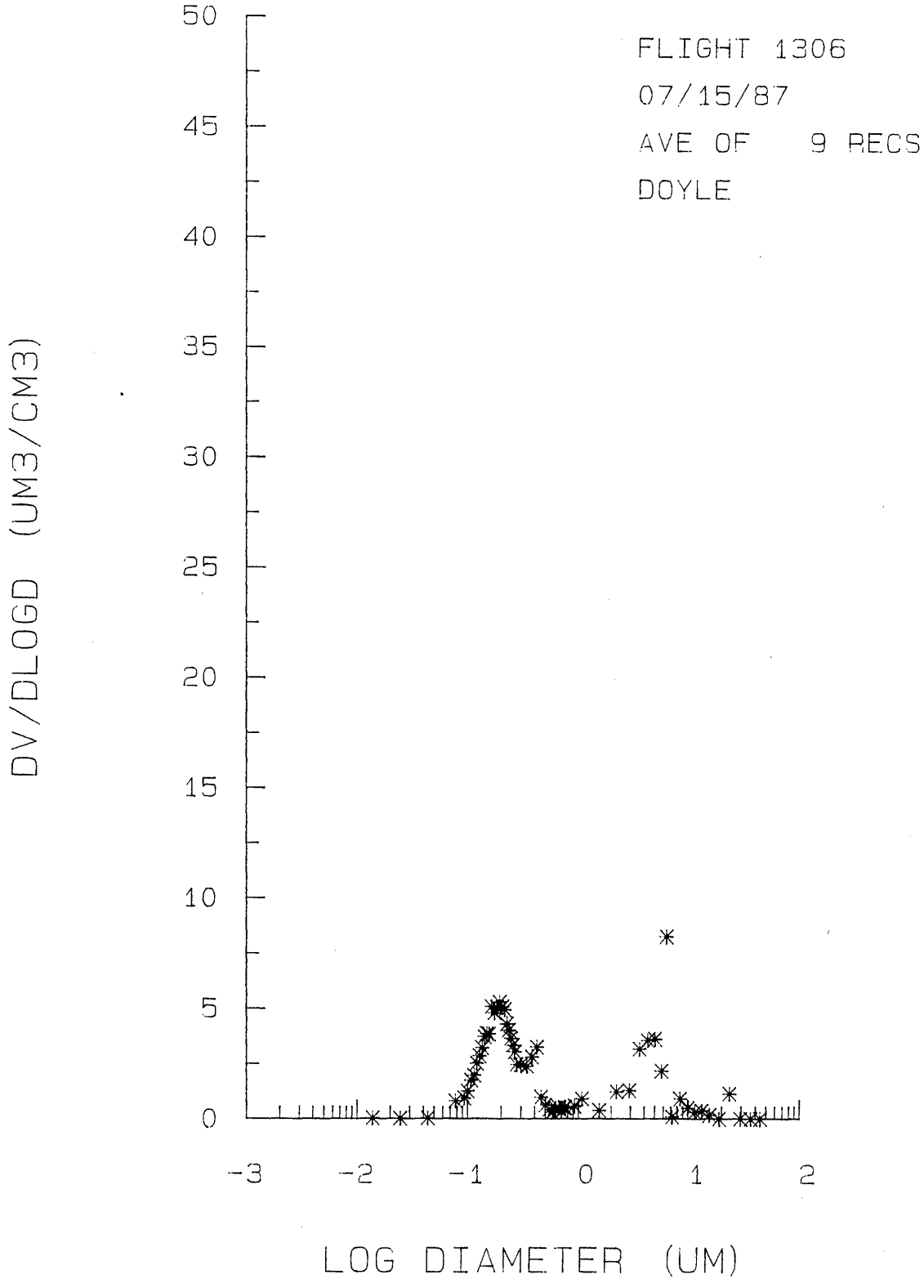

FLIGHT 1305
07/14/87
AVE OF 10 RECS
AMTRA
DV/DLOGD (UM3/CM3)
50
45
40
35
30
25
20
15
10
5
0
-3
-2
-1
0
1
2
LOG DIAMETER (UM)

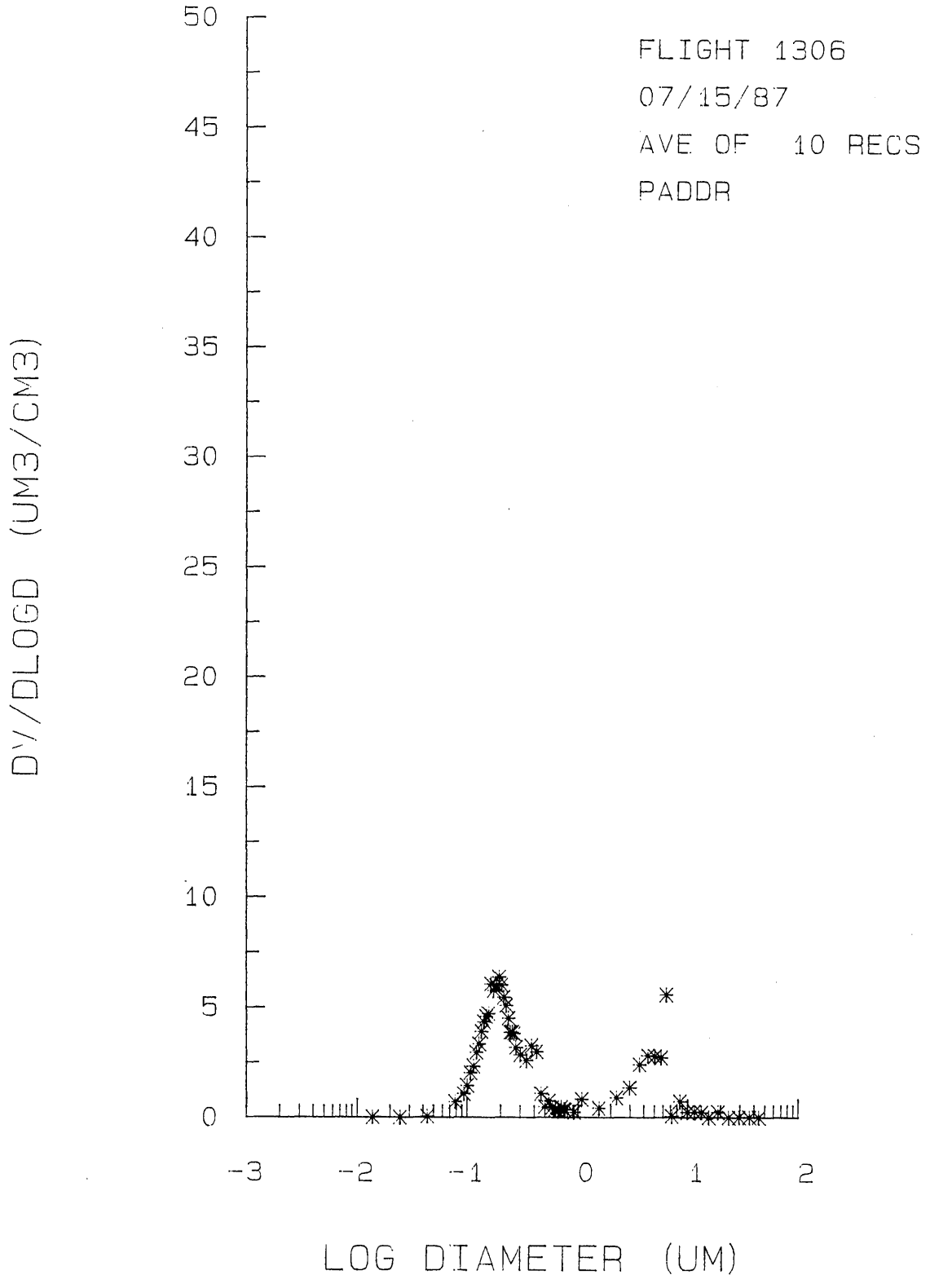

FLIGHT 1305
07/14/87
AVE OF 9 RECS
POMONA
DV/DLOGD (UM3/CM3)
LOG DIAMETER (UM)
50
45
40
35
30
25
20
15
10
5
0
-3
-2
-1
0
1
2

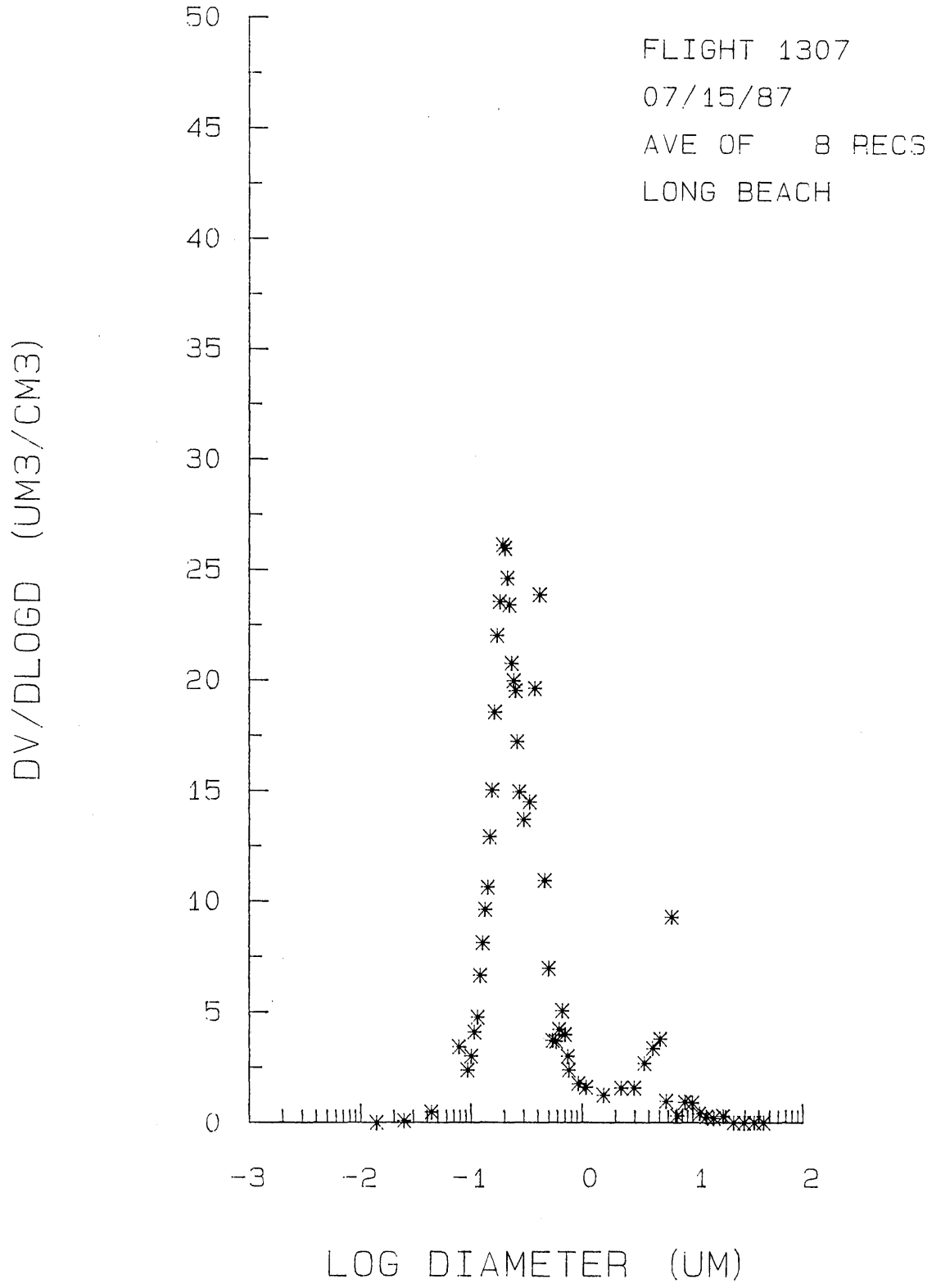

FLIGHT 1305
07/14/87
AVE OF 7 RECS
RIVERSIDE
DV/DLOGD (UM3/CM3)
50
45
40
35
30
25
20
15
10
5
0
-3
-2
-1
0
1
2
LOG DIAMETER (UM)

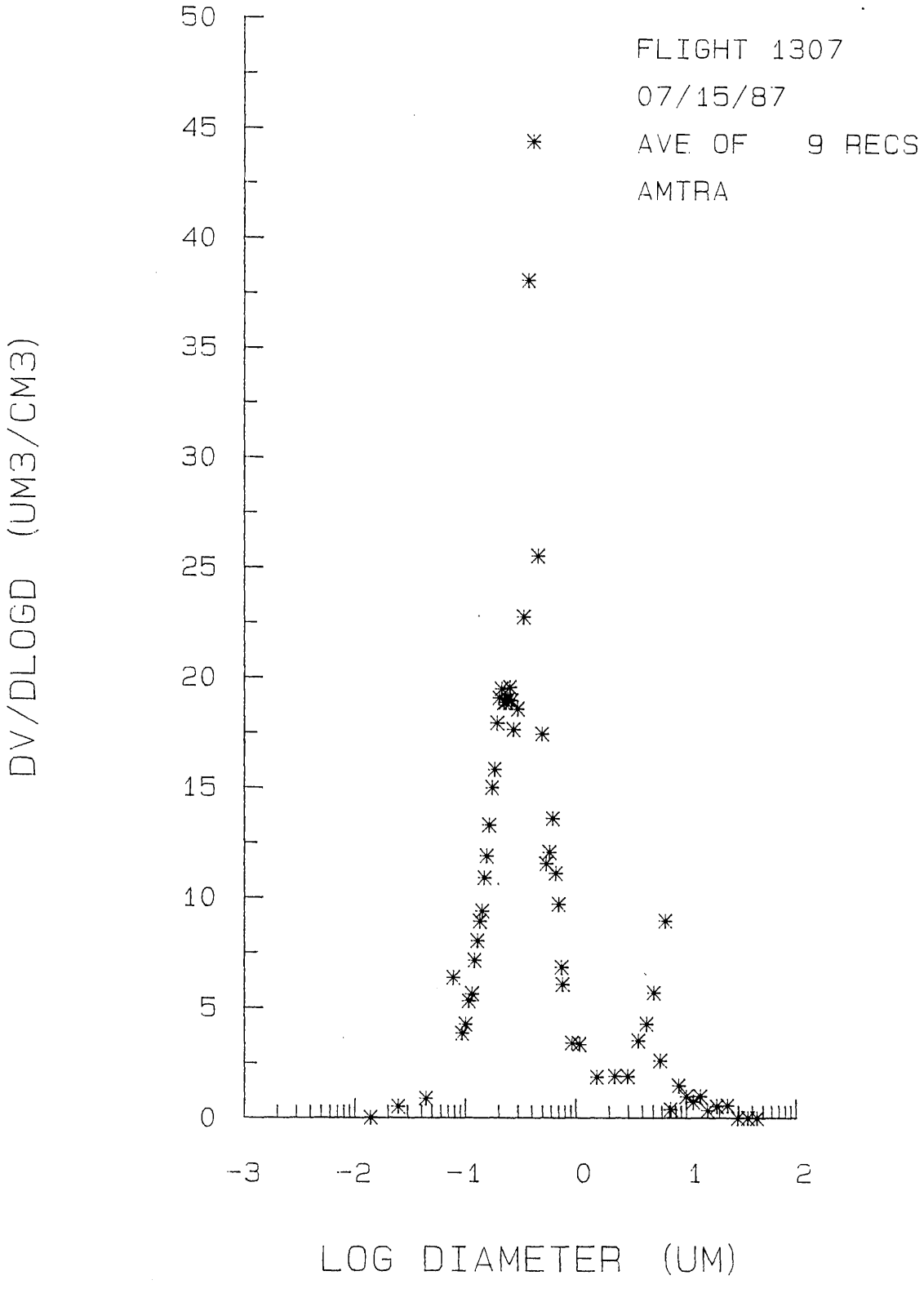

FLIGHT 1306
07/15/87
AVE OF 8 RECS
AMTRA
DV/DLOGD (UM3/CM3)
50
45
40
35
30
25
20
15
10
5
0
-3
-2
-1
0
1
2
LOG DIAMETER (UM)

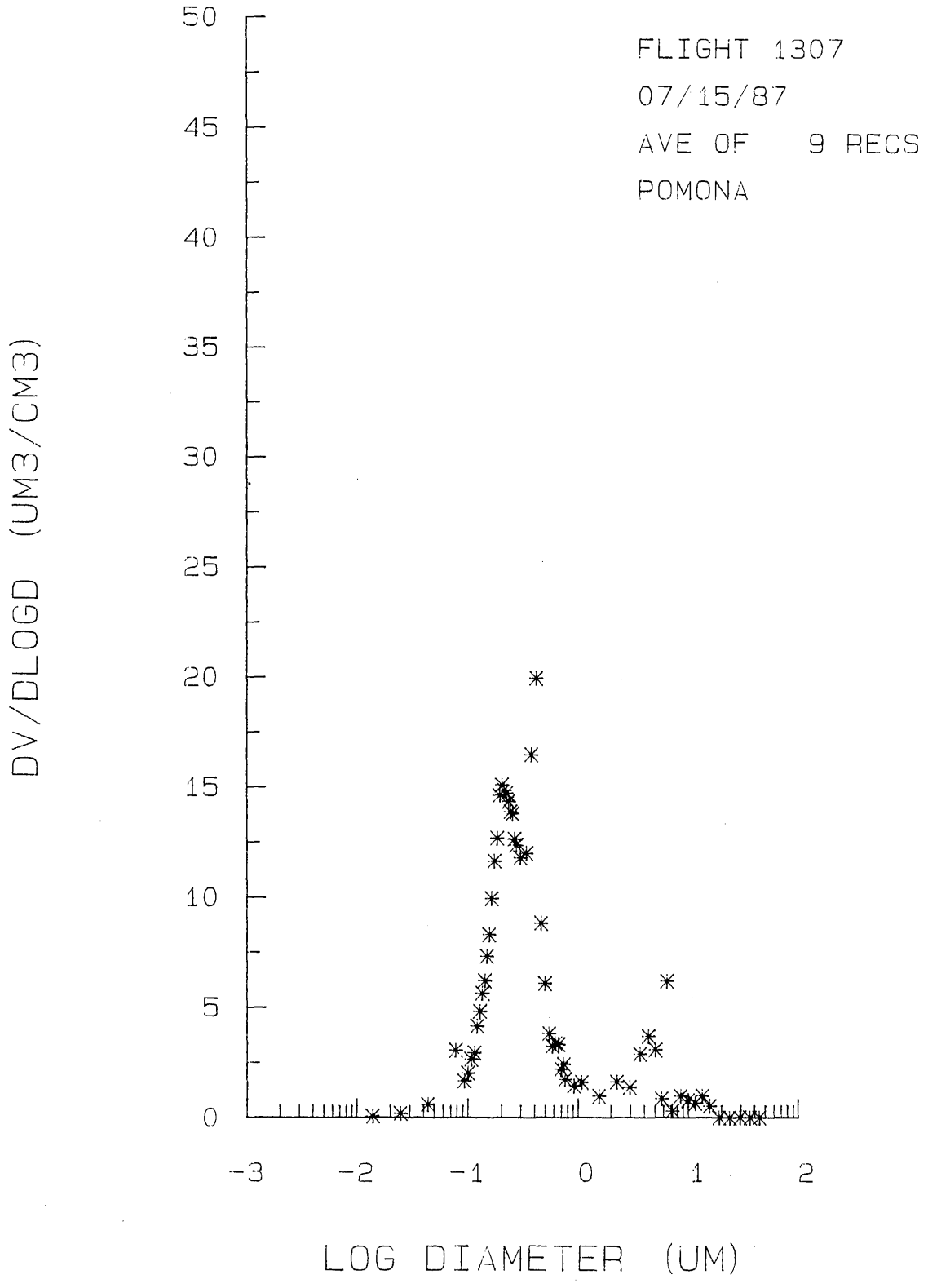

FLIGHT 1306
07/15/87
AVE OF 8 RECS
LONG BEACH
DV/DLOGD (UM3/CM3)
50
45
40
35
30
25
20
15
10
5
0
-3
-2
-1
0
1
2
LOG DIAMETER (UM)

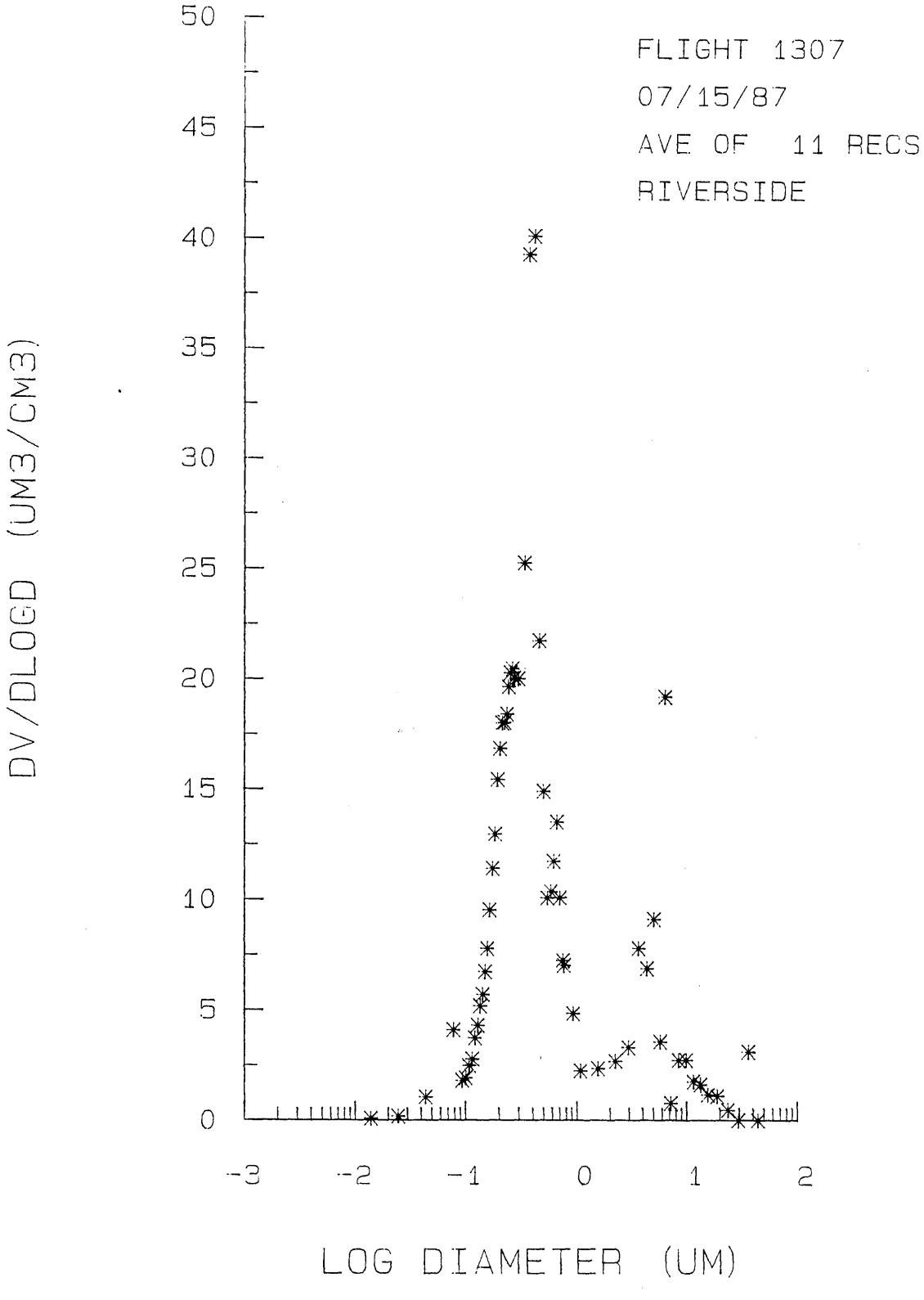

FLIGHT 1306
07/15/87
AVE OF 9 RECS
DOYLE
DV/DLOGD (UM3/CM3)
50
45
40
35
30
25
20
15
10
5
0
-3
-2
-1
0
1
2
LOG DIAMETER (UM)


FLIGHT 1306
07/15/87
AVE OF 10 RECS
PADDR
DV/DLOGD (UM3/CM3)
50
45
40
35
30
25
20
15
10
5
0
-3
-2
-1
0
1
2
LOG DIAMETER (UM)


FLIGHT 1307
07/15/87
AVE OF 8 RECS
LONG BEACH
DV/DLOGD (UM3/CM3)
50
45
40
35
30
25
20
15
10
5
0
-3
-2
-1
0
1
2
LOG DIAMETER (UM)


FLIGHT 1307
07/15/87
AVE OF 9 RECS
AMTRA
DV/DLOGD (UM3/CM3)
50
45
40
35
30
25
20
15
10
5
0
-3
-2
-1
0
1
2
LOG DIAMETER (UM)

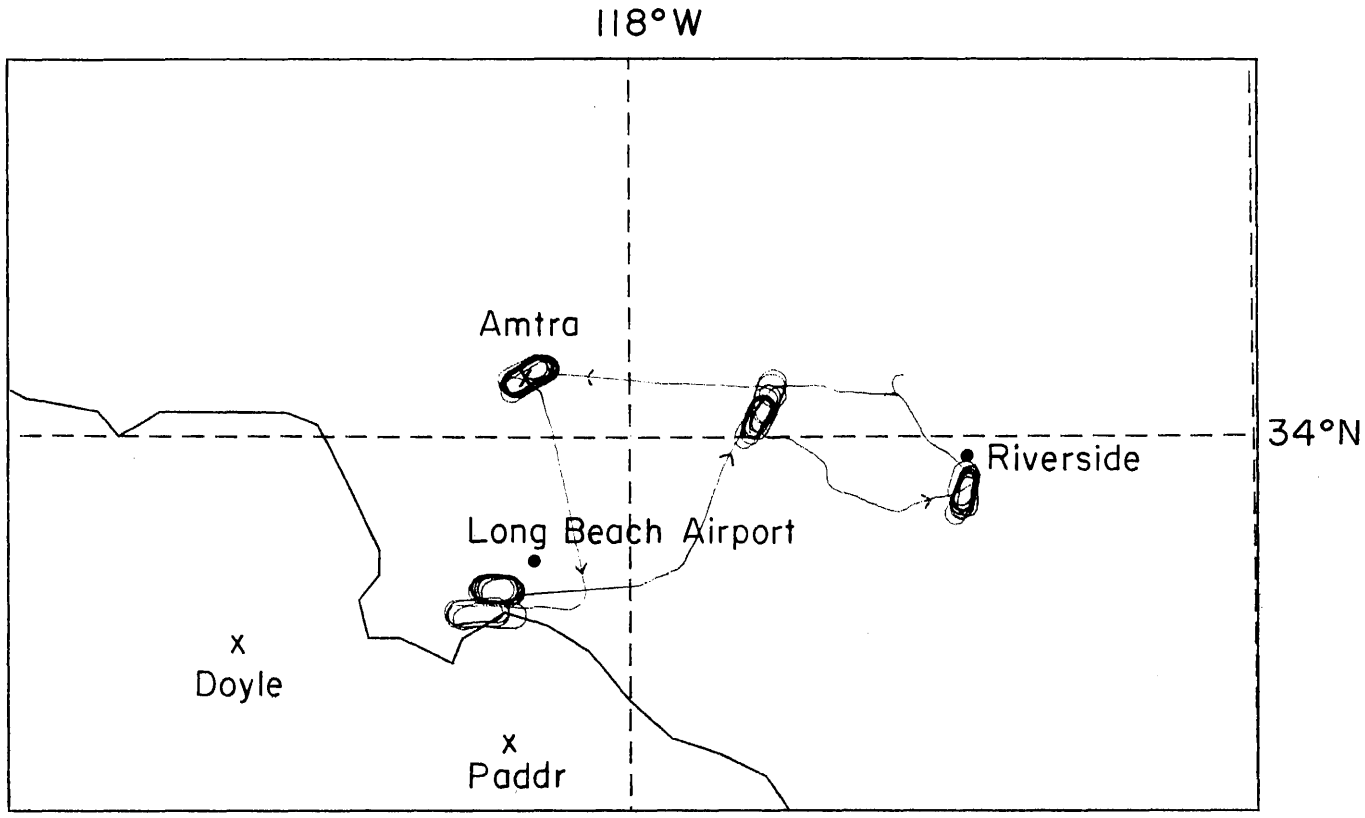

FLIGHT 1307
07/15/87
AVE OF 9 RECS
POMONA
DV/DLOGD (UM3/CM3)
50
45
40
35
30
25
20
15
10
5
0
-3
-2
-1
0
1
2
LOG DIAMETER (UM)


FLIGHT 1307
07/15/87
AVE OF 11 RECS
RIVERSIDE
DV/DLOGD (UM3/CM3)
50
45
40
35
30
25
20
15
10
5
0
-3
-2
-1
0
1
2
LOG DIAMETER (UM)

APPENDIX B

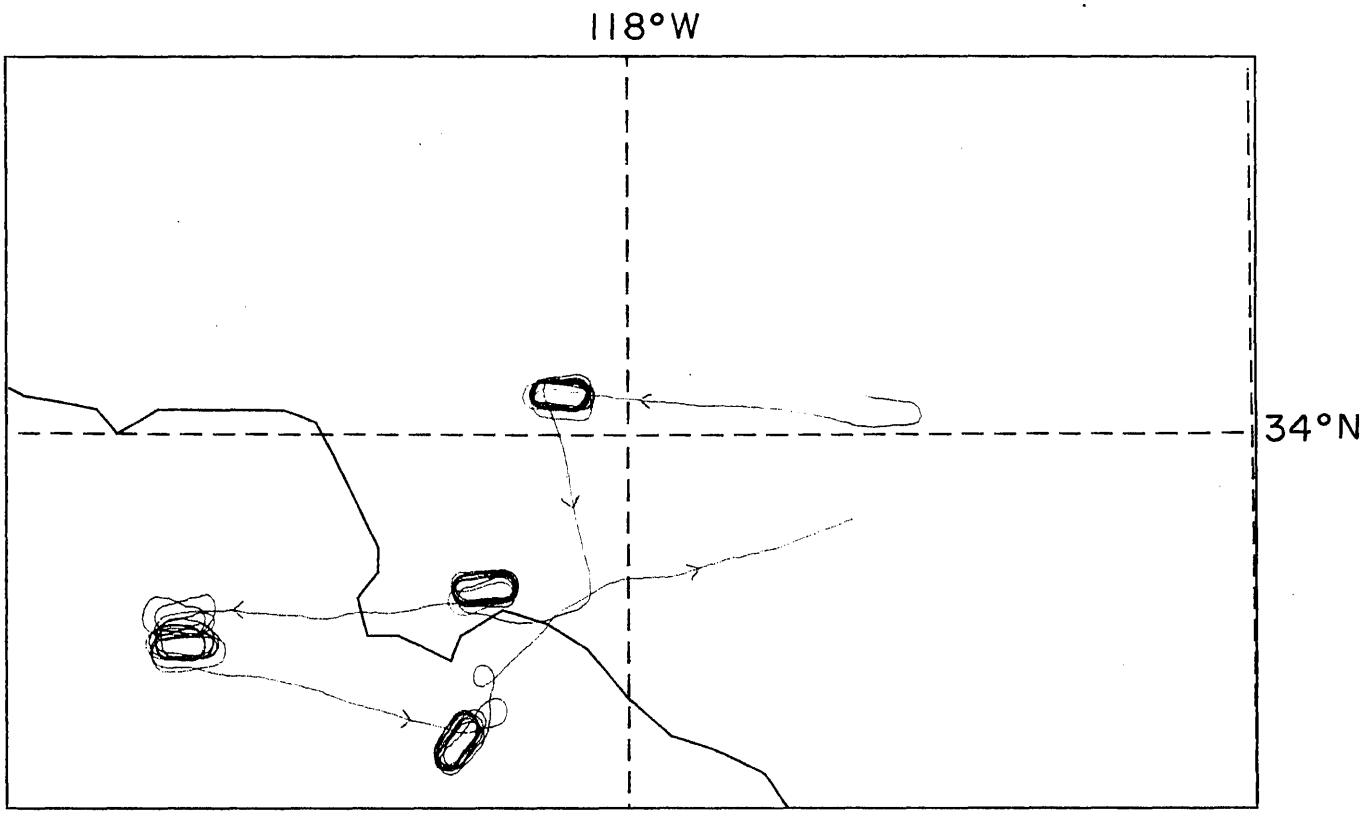
AIRCRAFT FLIGHT TRACKS

This appendix contains computer plots of the aircraft position during each of the nine SCAQS research flights. The plots are derived from the VOR/DME volumes recorded on the SCAQS data tapes archived at ERT. The plots are intended as a rough guide to prospective data users rather than a precise indication of aircraft position relative to the ground sampling network



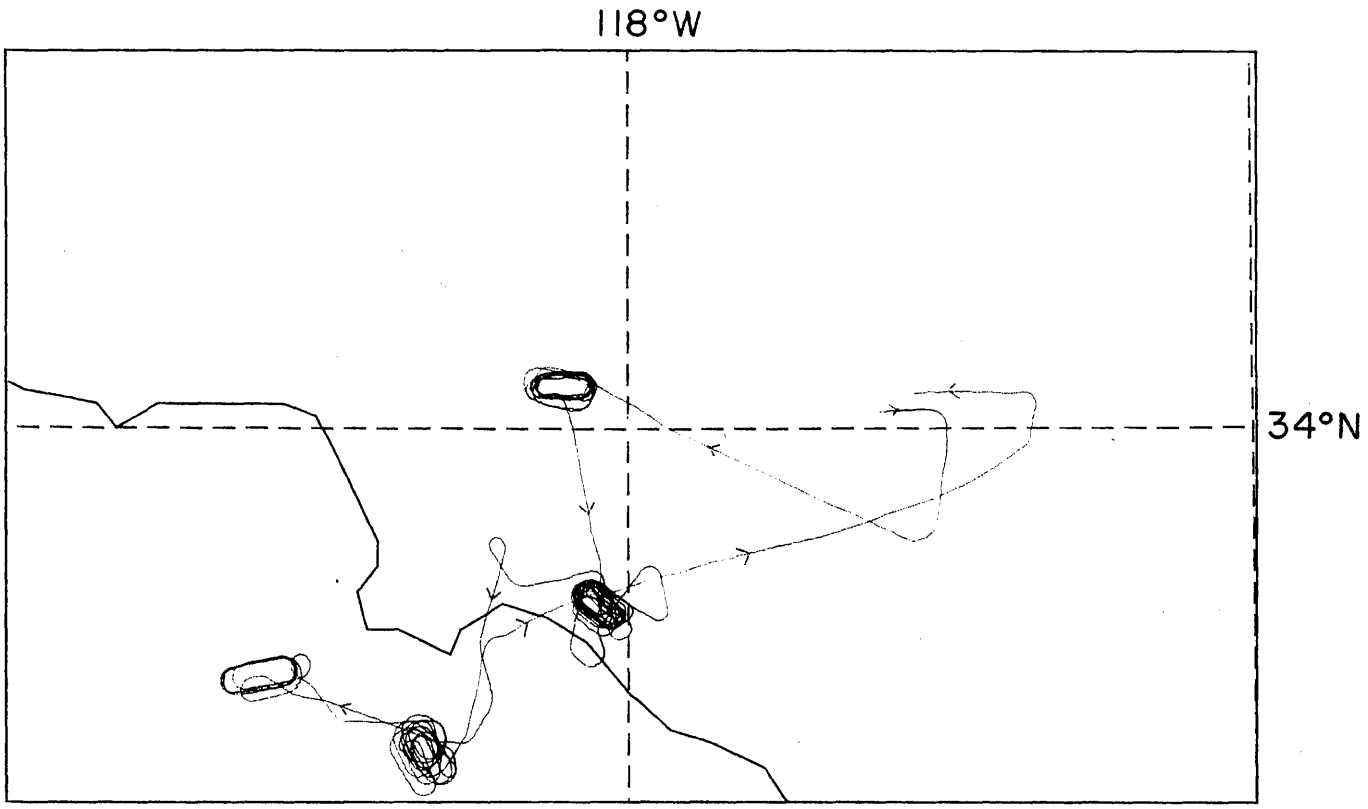
6/19/87 14: 30 - 18. 40

1 INCH = 15 NM

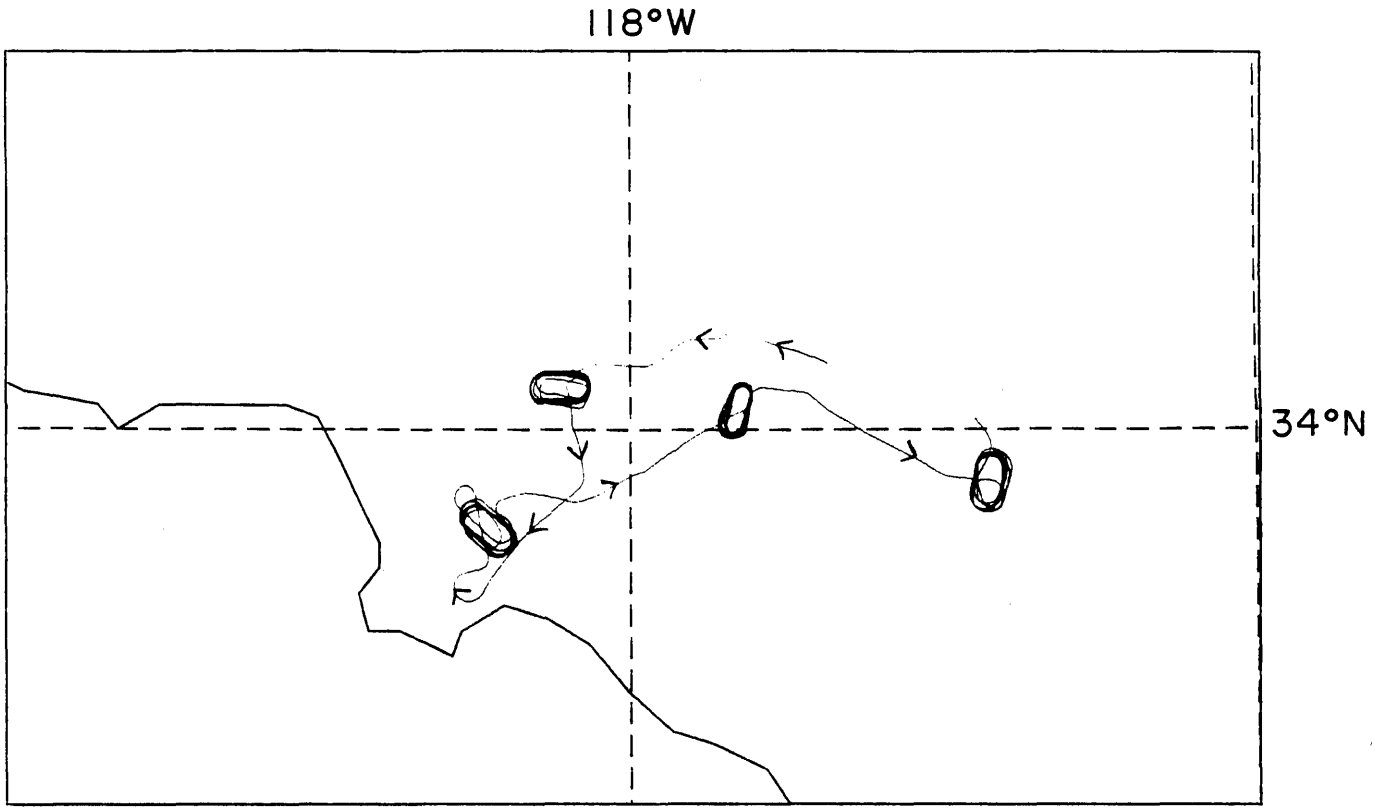


6/24/87 4:50 - 8:20

1 INCH = 15 NM

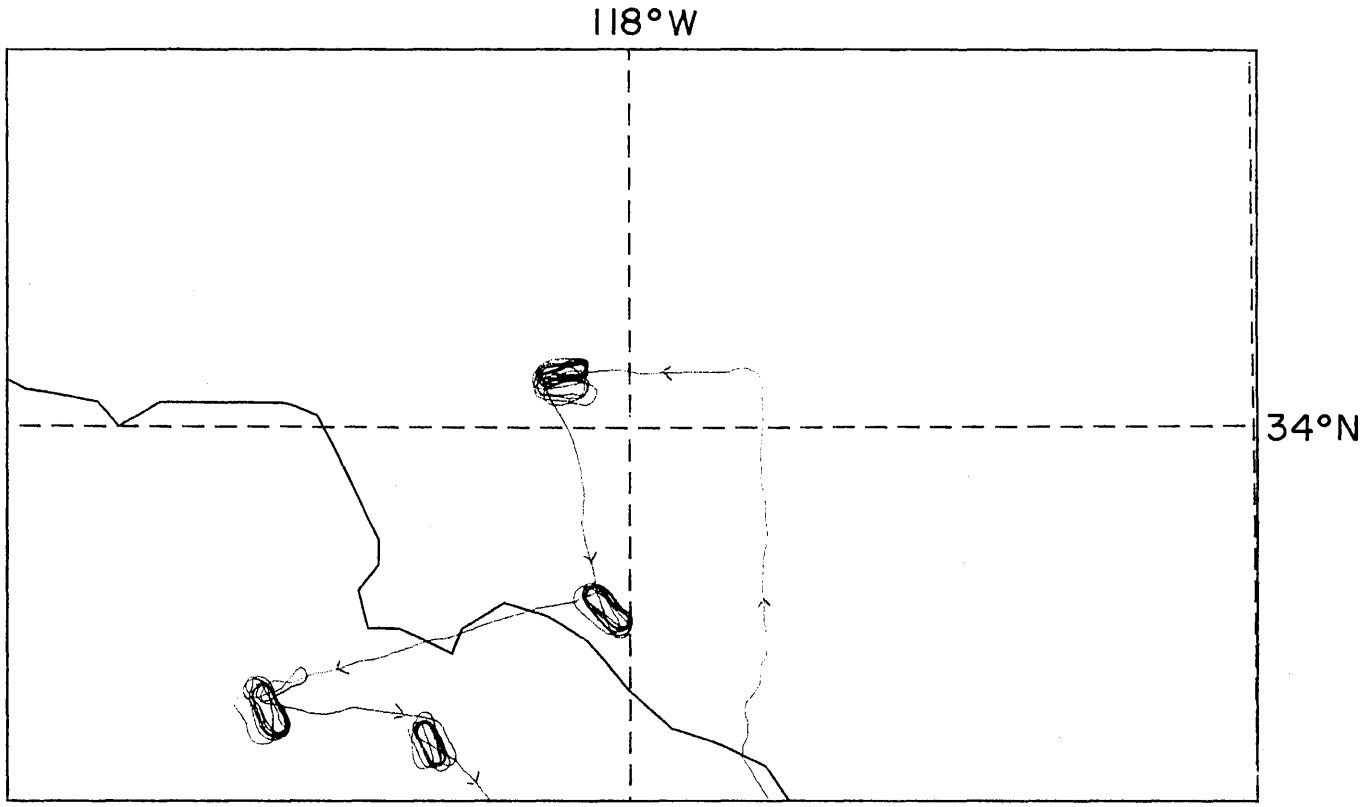


6/25/87 4. 30 - 8. 50 1 INCH = 15 NM

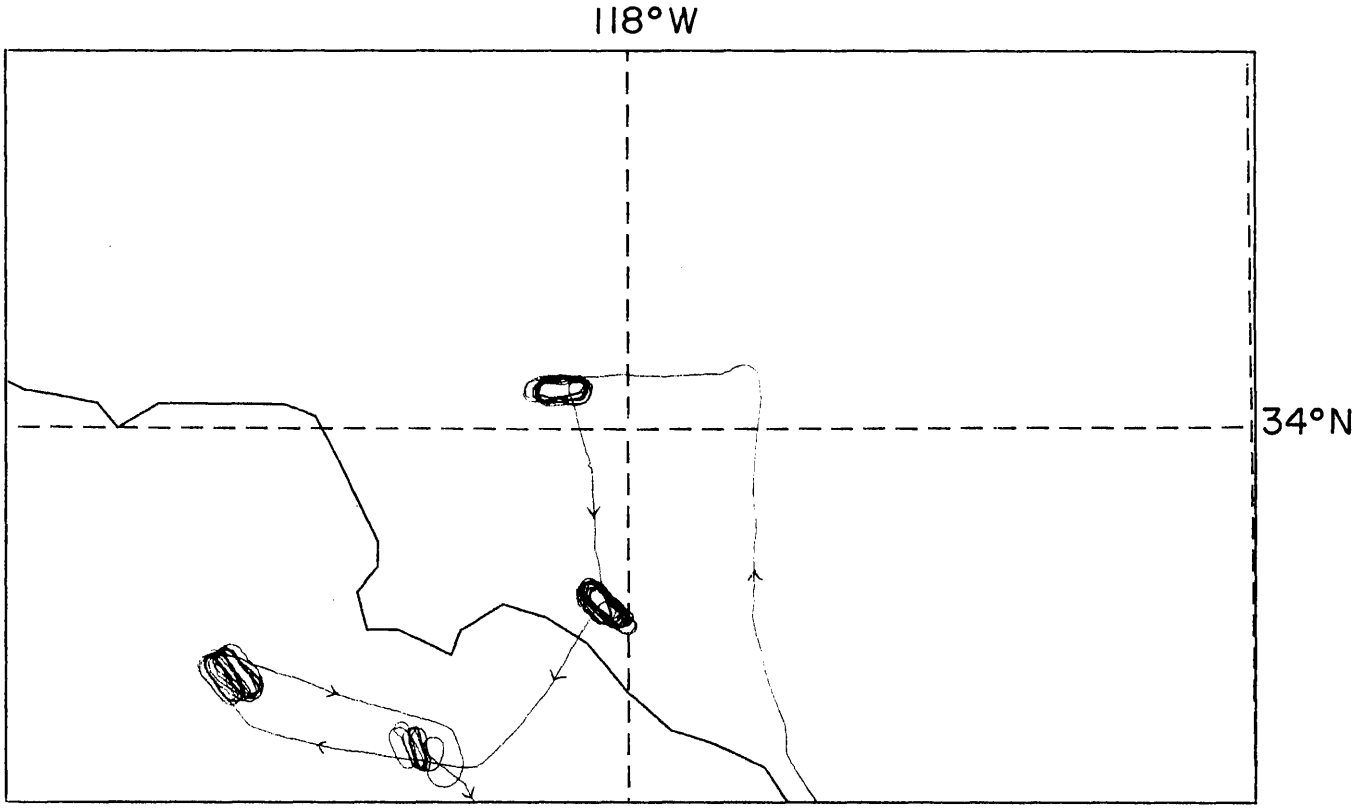


6/25/87 13.20 - 16.30

1 INCH = 15 NM

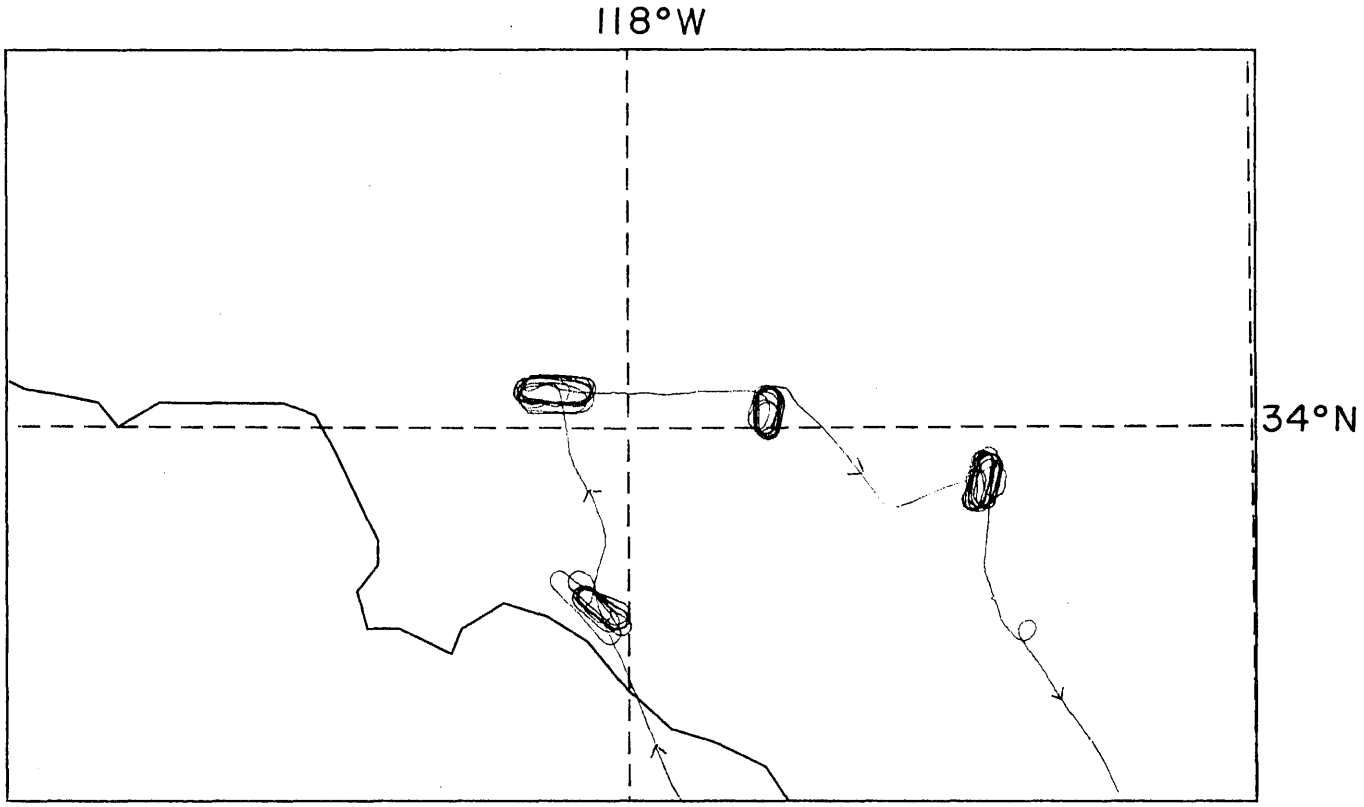


7/13/87 4:45 - 8:05 1 INCH = 15 NM



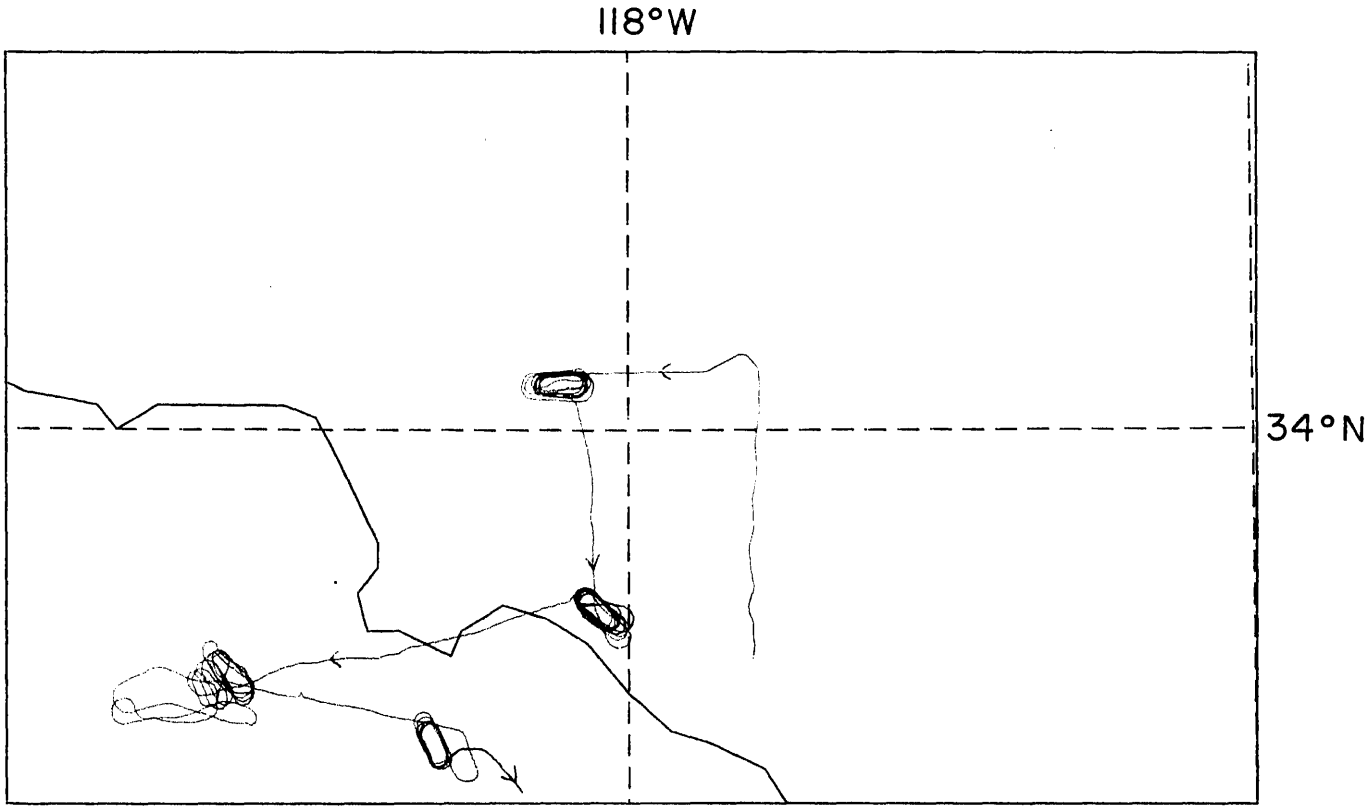
7/14/87 4:30 - 8:15

1 INCH = 15 NM



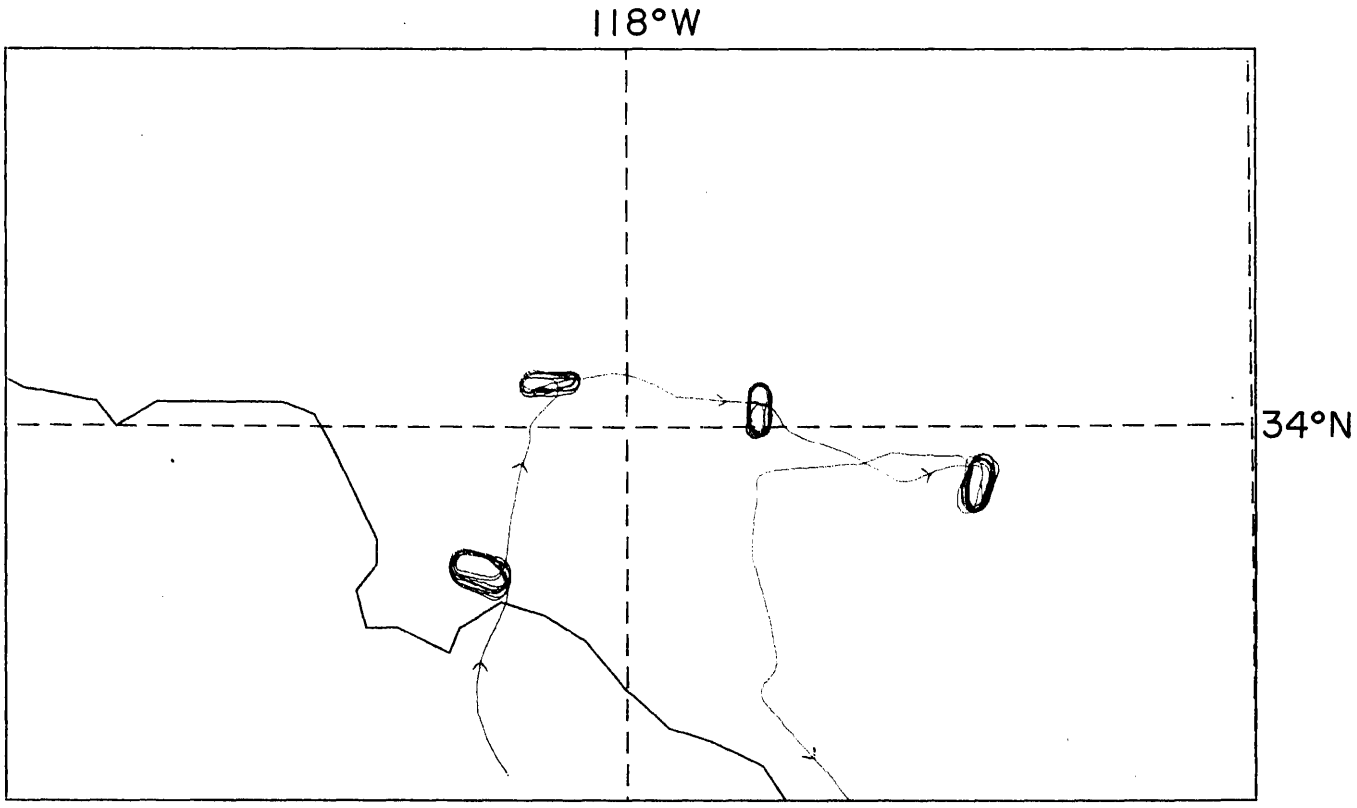
7/14/87 14.30 - 17.35

1 INCH = 15 NM



7/15/87 4:30 - 7:50

1 INCH = 15 NM



7/15/87 14:55 - 17:55

1 INCH = 15 NM