Hopkins 1971a

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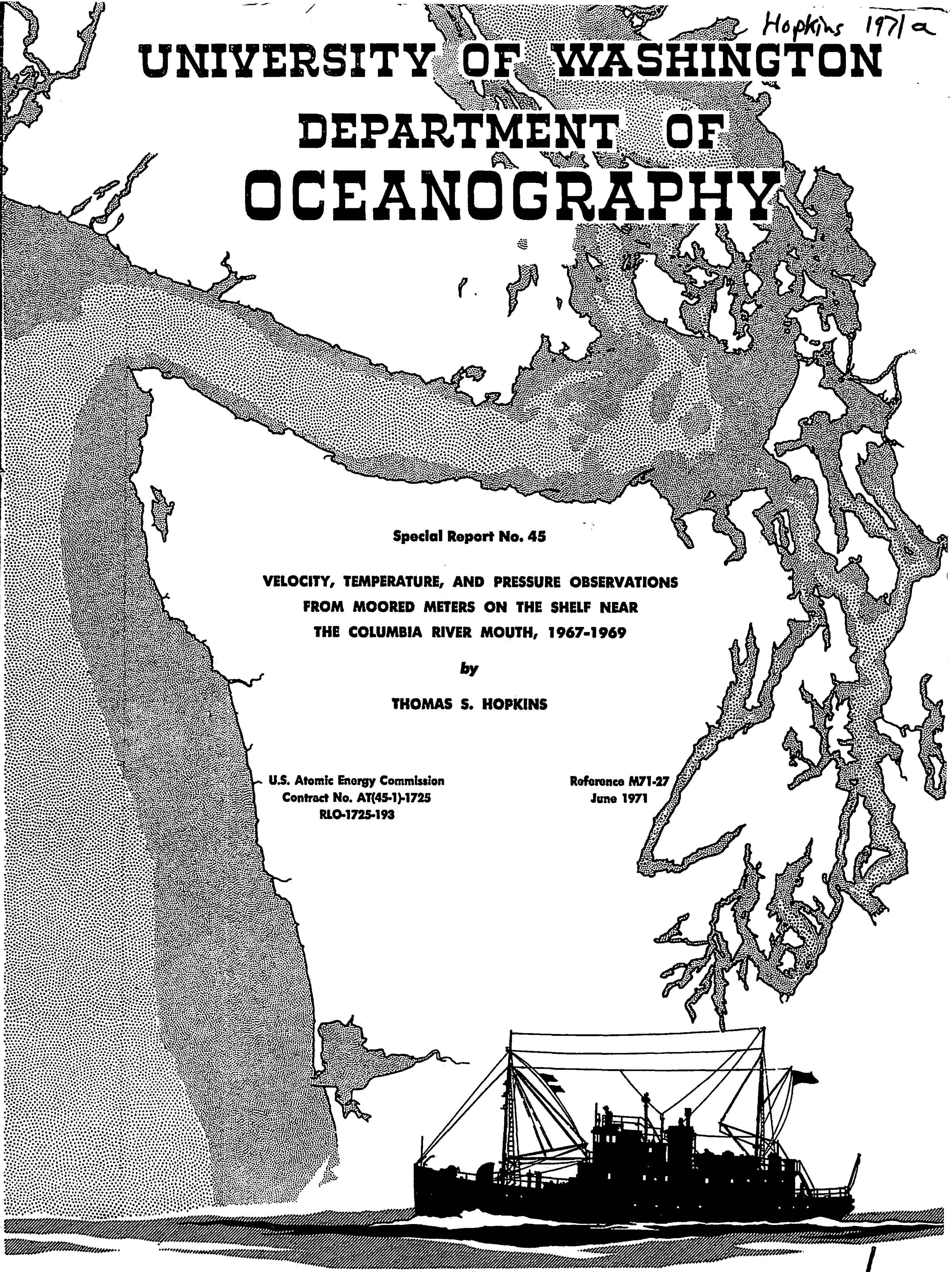

Special Report No. 45

VELOCITY, TEMPERATURE, AND PRESSURE OBSERVATIONS FROM MOORED METERS ON THE SHELF NEAR THE COLUMBIA RIVER MOUTH, 1967-1969

by

THOMAS S. HOPKINS

U.S. Atomic Energy Commission
Contract No. AT(45-1)-1725
RLO-1725-193

Reference M71-27
June 1971

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ABSTRACT

A description and the results of measurements taken from instruments moored off the Washington-Oregon coast are presented. Time series of horizontal velocity, temperature, and pressure fields were recorded intermittently between July 1967 and October 1969. The instruments were installed mostly near the bottom on taut wire moors located in the proximity of the Columbia River mouth.

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INTRODUCTION

The Department of Oceanography, University of Washington, with financial support from the United States Atomic Energy Commission, has conducted research to determine the distribution of Columbia River water in the Northeast Pacific Ocean. A part of this research, exploratory in nature, was designed to measure directly the current directions and magnitudes on the continental shelf off Washington using self-recording instruments installed on taut wire moorings. Although the general features of circulation on this shelf had been estimated from water mass properties and the movement of drifters, direct measurements by the proposed method were much needed. There was some question concerning the feasibility of making the needed measurements considering the limitations imposed by the rigorous environment, the local trawling activity, and a minimal amount of equipment. Nevertheless, considerable information has been obtained over the two-year period from June 1967 to October 1969. The purpose of this report is to describe the mechanical aspects of the program and to present a synopsis of the data in graphic and tabular form. Hopkins (1971) gives an interpretive analysis of the observations made and formulates a general model for the circulation.

The sampling program was subject to many compromises. In the time domain the constraints were those of weather, equipment, and ship availability. In regard to space, the vertical current measurements were restricted to more than 3 m above the bottom by mechanical limitations and to deeper than 20 m by wave action and instrument tilt. Restrictions on location in the horizontal were unexpectedly severe, because of Soviet and American trawl fishing. The only workable solution was to remain within the 12-mi limit and near a U. S. Coast Guard lighted sea buoy that provided some protection. The buoy site was chosen north of the Columbia River mouth and at midshelf on the basis of foreknowledge of mean movements of bottom drifters and sediment. The various locations at which measurements were made over the two-year period are shown in Fig. 1, and Table I in the appendix summarizes the observations.

INSTRUMENTATION

Current velocities were measured with Braincon type 316 and 381 histogram current meters. Both models record integrated sensor outputs on 16-mm film. The meters, described by Braincon (1965a), have the following operating characteristics (see also Mooers et al. 1966):

a) Current speed
  range: 0-5 kt or 2.5 kt
  threshold: 0.05 kt
  accuracy: ±3% full scale
b) Current direction reference to local magnetic north
  range: 0-360°
  accuracy: ±1%

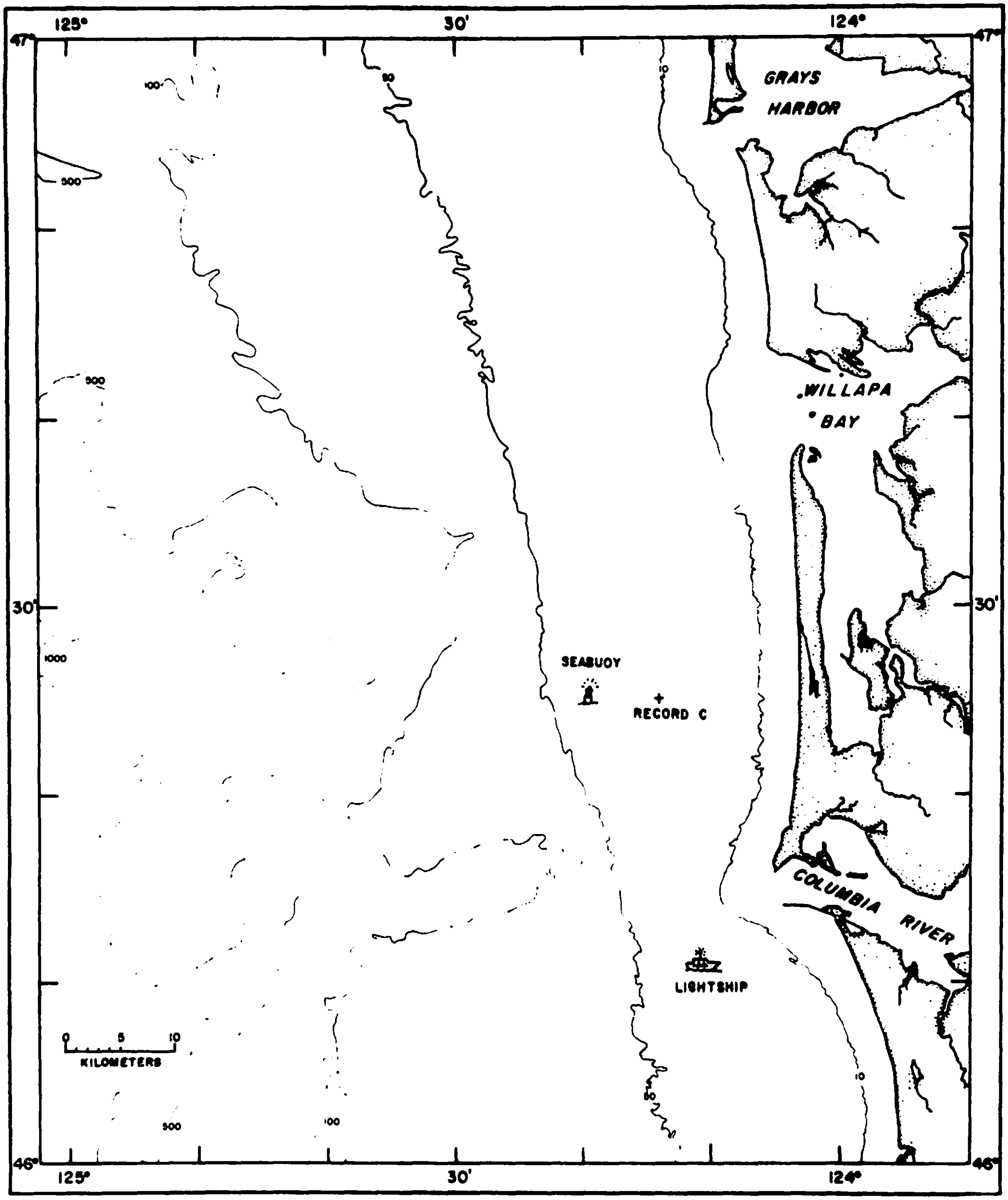

Fig. 1. Location of the various mooring installations

c) Tilt direction reference to direction vane
   range: 0-360°
   accuracy: ±10°
d) Tilt amplitude
   range: 0-30°
   accuracy: ±3°
e) Sampling time:
   one sample per 20 min., standard
   one sample per 5 min. to one sample per hour, optional
f) Number of samples:
   up to 3600 samples
g) Timing mechanism:
   316 - Solenoid-wound, spring-driven clock, ±10 sec day^{-1}, rate adjusted
   381 - Bulova Accutron timer

The above sensor characteristics are for optimal operating conditions that seldom occur in nature and hence give an erroneous impression of the quality of the data. Certain features of the meters limit the accuracy of the data to an undetermined extent. Some of these will be discussed.

The Savonius rotor has been much studied; for example, see Gaul, Snodgrass and Cretzler (1963), and Fofonoff and Ercan (1967). The rotor has no definite threshold speed as the impellor configuration gives it an asymmetrical torque distribution. Only as the rotor gains momentum does the speed become uniform. At low speeds fouling becomes important. Gaul et al. (1963) claim a thin coat of fouling caused a 40% reduction in rotor-operated efficiency at 0.25 kt; however, for lower speeds the fouled rotor operated more efficiently and had a lower threshold before cleaning than after. Biological fouling invariably occurred on meters left in Washington coastal waters for more than two weeks.

Chemical fouling on the bearing surfaces increases the bearing resistance, thus increasing the threshold and stall speeds. The deposition of magnesium sulfate on the bearings was found to slow and even stop the rotor. Fig. A-7 (Appendix) shows for Record M where the speed went to zero and remained there until the rotor was freed by stronger currents. The speed information for the last half of Record A was lost in this manner. Both Braincon models are equipped with sacrificial magnesium anodes purportedly designed to reduce galvanic effects associated with contact of the aluminum pressure case with other metals in sea water. The rotors are mounted on tungsten carbide pivot bearings housed in the pressure case. Coatings of silicon grease helped reduce chemical fouling. Eventually the magnesium anodes were removed, greatly reducing the bearing fouling and the pitting of the pressure case. Seabright and Fabian (1963) point out that ". . . in the case where magnesium and aluminum are in contact in sea water the higher solution potential of the magnesium (anode) causes current to flow in the direction which should electrolytically protect the aluminum (cathode). However, in this couple the strongly alkaline corrosion products caused by the rapidly corroding magnesium will severely attack the aluminum, thus causing both metals to corrode rapidly." Other anticorrosion precautions that have been taken were to insulate the bearings from the pressure case with PVC bushings and to replace all possible stainless steel hardware with nylon.

For intermediate and low frequency measurements, the speed integration feature of the Braincon meter is advantageous. The problem of aliasing inherent in discrete sampling meters is absent. Low speed sensing is improved by the mechanical advantage of, for example, the 20-min. sampling interval at a gear ratio of 3456:1, but the effects of fouling, in that they alter the calibration, are still present.

The rotor is magnetically coupled through a gear train to the luminous sensor indicator, which has a finite width. The speed integrations are performed over 19 min. (19½ for the 381) and the remainder of the 20-min. interval is spent advancing the film. Because the width of the speed sensor varied from meter to meter and often with the same meter, and because the beginning of the speed arc tended to be less well defined during high speeds, end-of-arc to end-of-arc measurements between adjacent film frames gave more reliable indications of the speed.

Finally there are some well-known limitations of the Savonius rotor pertinent to its use in coastal current programs. Whereas the rotor has a high degree of comparability between like units, local water turbulence and turbulence created by rotor housing and pressure case can alter its performance. Manufacturer's calibration curves were checked by the University of Washington in "still water" and with a dummy pressure case at the Division Hydraulic Laboratory of the Corps of Engineers, U. S. Army, Bonneville, Oregon. The agreement between calibrations is shown in Fig. 2. Gaul (1963) discussed the effect of tilt on the rotor, and the fact that tilt curves differ between tilts down and up from the mean flow. The Braincon meters have a tilt sensor. Tilt corrections were made, but rarely did the tilt exceed 10°. Exposure to tilt was minimized by the positive buoyancy in the mooring design, and by locating the meters in the lower water layers.

The Braincon current meter measurements are subject to contamination by surface wave action. The vane probably would not respond as it is ". . . detuned to eliminate sensitivity to 5- to 6-sec period surface wave excitation. . .," Braincon (1964). Also, large wave activity tends to coincide with high mean currents, reducing the possibility of vane reversal. However, the rotor is omnidirectional, is highly inertial, and has a poorer response to deceleration than to acceleration; consequently when subject to surface wave motion, its output is rectified, does not go to zero, and is distorted, respectively. The result is a spuriously augmented speed. Gaul (1963) summarizes the rotor response: "The 'time constant' (time for 63% response to a step change) is nominally 1 second for acceleration and 2.5 seconds for deceleration, both taken above 0.2 knots for a speed change about equal to the mean speed. The response is better at high speeds and deteriorates rapidly (longer time constant) as the current approaches zero." Collins (1967) concludes that the effect on the current meter (Braincon) did not seem to mask most variations in mean flow.

In the Washington coastal program, the meters were used cautiously at shallow depths. Only Record AA was taken near the surface and this in late summer when reduced wave activity was expected. Information about the near-surface water movements is so important that some contamination had to be risked.

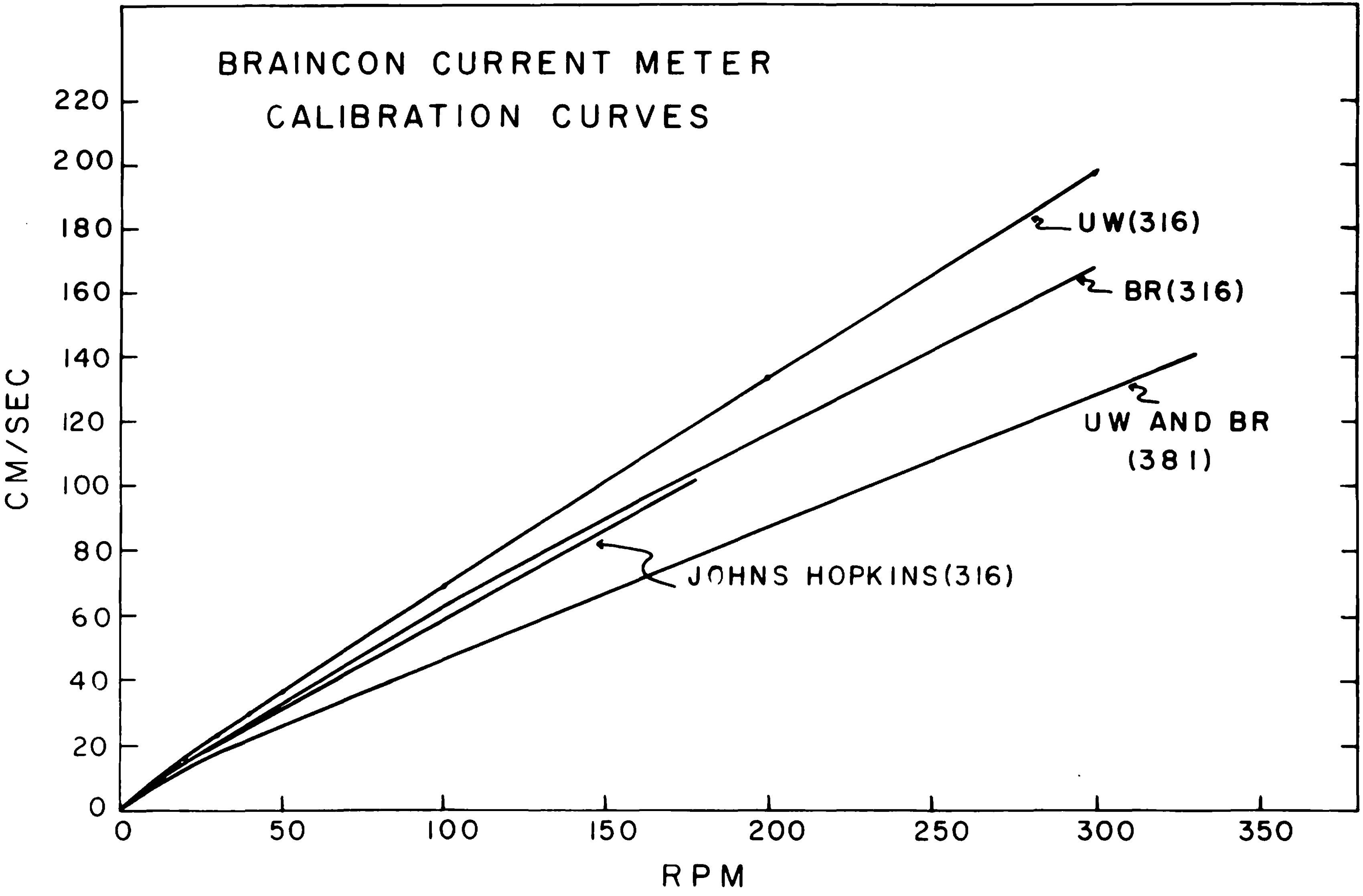

Fig. 2. Braincon current meter calibration curves

The speed sensor measures a mean quantity that is subject to reduction, fouling or augmentation by turbulence. The direction sensor, on the other hand, measures somewhere between mean direction and the most frequent direction. Reading the so-called direction arcs proved to be quite subjective, because they may be very dim, very long, bimodal, or highly skewed. Direction generally was taken from the most exposed part of the arc, or from the arc center when the exposure was uniform. When the current was variable or when the direction arc was dim, direction resolution was quite inadequate. Bimodal arcs, where the direction had to be taken from one or the other exposures or from the middle, caused some uncertainty. The expectation, similarly discussed by Mooers et al. (1966), is that the mean speed and interpreted direction combine to give a vector differing insignificantly from the mean velocity vector. No attempt has been made to investigate this further, primarily because of the variability encountered within a single record as well as between records of different meters. The effective accuracy of the direction sensor may vary from several degrees to ±180° in the extreme for a single measurement, but the effect of erratic directions is lessened with any smoothing or statistical treatment.

The timing mechanism of the type 316 current meter was generally accurate to the manufacturer's specification, meaning a loss of less than a frame per 50-day installation period. The period of clock life without maintenance is approximately 6 to 9 months. The type 381 timing mechanism worked unsatisfactorily 4 times out of 7, mostly because of behavior of the Accutron programmer when connected to the film advance mechanism. With both meters absolute timing, or even timing relative to another meter, has at best an uncertainty of one frame per installation period. Good start and end times (the 316 has a mercury switch and frame counter for this purpose) tend to keep the uncertainty low, whereas no end time, poor film exposure, uncertain start time, and frequent frame stuttering within a record increase it.

Water temperature and depth were recorded with a Braincon type 531 temperature-depth recorder. This instrument records temperature on 70-mm film as it passes between a phosphorescent light source and a mercury-in-glass thermometer. The thermometer ranges used were -2°C to +25°C and -2°C to +15°C. The accuracy is given as ±0.2°C, and the time constant for 95% of full value is less than 10 min.(Braincon, 1965b). The pressure sensor consists of a 4-inch Bourdon tube connected to an arm having a luminous point positioned to make a point exposure through a slit in the film cassette. The depth range is condensed to the width of the film. Much difficulty was experienced in reading the pressure records because of insufficient exposure. The accuracy of the depth range (0 to 200 psi and 0 to 15 psi were used) is given as ±0.5% of full depth range. The timing mechanism for the 531 temperature-depth recorder is the same as for the 381 current meter, and behaved similarly in use.

Acoustic release mechanisms used were the models 210E and 210B of Ocean Research Equipment, Inc. The ORE release system permits the release of an underwater load when commanded by an acoustic signal from a surface interrogator. The underwater unit amplifies signals from the acoustic hydrophone of the interrogator over the carrier frequency range of 7.8 KHz ± 300 Hz, detects any amplitude modulation by a resonant reed decoder, and operates a solenoid actuating circuit (210E) or fires a squib (210B) to release a pin that allows the release hook to open. The 210E is a shallow-water device designed to operate with tensile loads up to 1,500 lb and pressures up to 675 psi, vice 10,000 lb and 10,000 psi for the 210B. Of the three times the 210E model was used, it released prematurely twice and once the installation surfaced for an undetermined reason. The 210B worked satisfactorily each of 6 times. Firings apparently occurred always on the first attempt. These were made within 500-yd ranges to avoid risk of loss.

MOORINGS

Two basic types of moorage designs were employed. The type used from July 1967 up to April 1968 is shown in Fig. 3 and was closely patterned after that used by Oregon State University. The components were:

Subsurface floats: Navy surplus, steel, mine net floats, 350-lb positive buoyancy, specifically tested to depths in excess of 60 m were used to suspend the instrument string.

Vertical line: The instruments were hung on 3/16-inch galvanized wire rope. The vertical positions of instruments with reference to the bottom were accurate to ±0.5 m.

Main anchor: A rectangular concrete anchor, weighing about 1400 lb in air, with three 1-inch chain pad-eyes located at the middle and at each end. The 3/16-inch line was shackled in at one end and the ground line at the other end. Such a separation reduced the chances of fouling the current meters while lowering the main anchor with the ground line.

Ground line: 2500 ft of 1/4-inch galvanized wire rope was laid between the main anchor and the secondary anchor. Its purpose was to allow for grappling in the event the surface float was lost. It was usually laid along bottom countours.

Surface float anchor line: 9/16-inch, braided nylon rope with a cover and a core (10,500 lb breaking strength) was used to anchor the surface float to its anchor with a scope of 2:1. The nylon was shackled into 10 ft of 1/2-inch galvanized chain and a 5/8-inch swivel before being attached to the surface float, and connected to a 10-ft pendant with rings before being fastened to the anchor.

Surface float: A fiber glass, bulb-shaped float served as the main surface buoy. A 10-ft plastic tube (weighted on the inside) extended downward and a 10-ft mast surmounted by a radar reflector and a light projected upwards from the float.

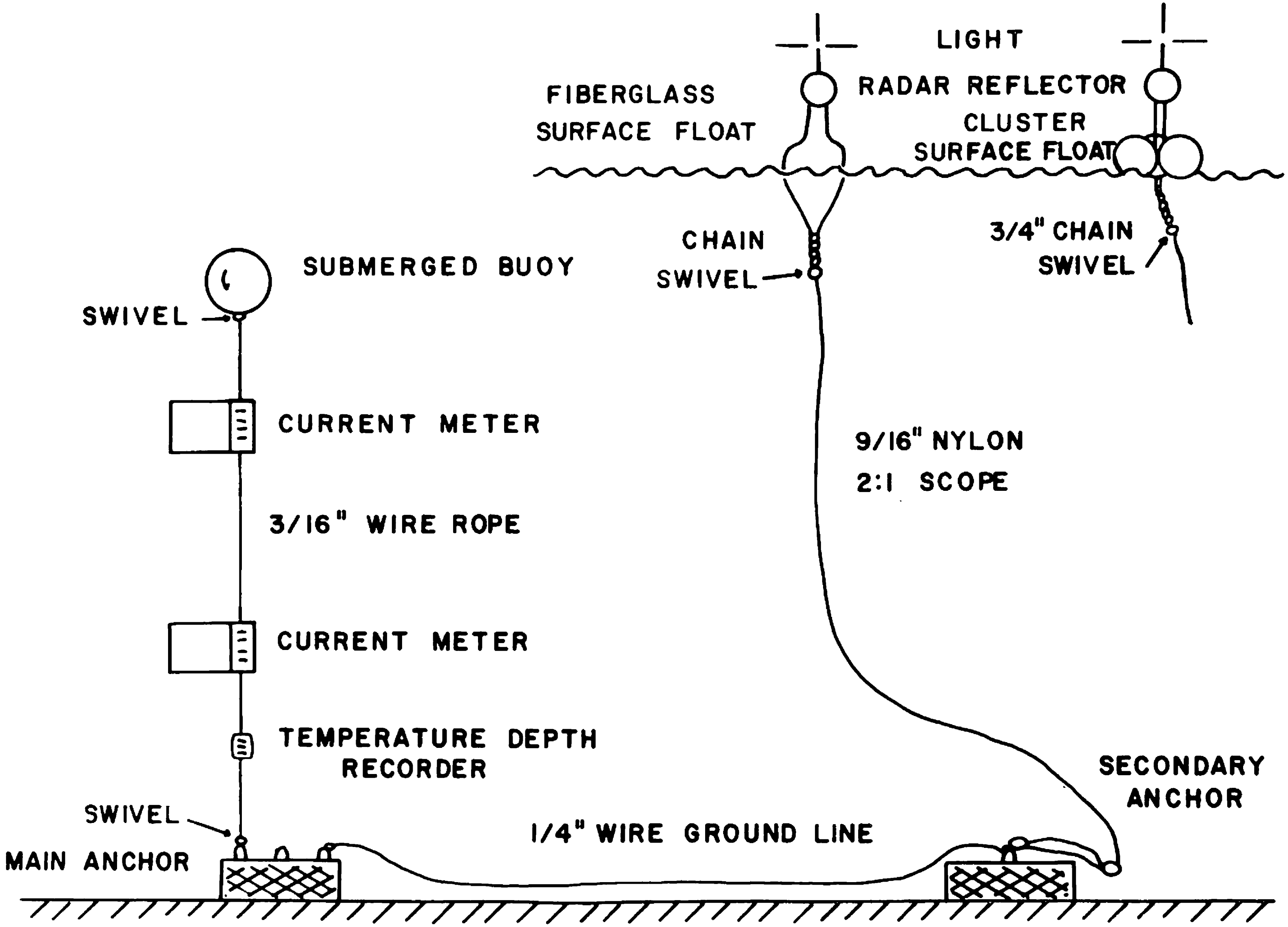

Fig. 3. Mooring design with surface marker and ground line

The radar reflector was an 18-inch diameter fiber glass sphere that slipped down over the mast and locked in place. The light, capping the mast top, was a high-intensity white light with a Fresnel lens, flashing every second.

Surface marker: A foot cube of polyurethane foam and a 10-ft weighted pipe extending 8 ft above the cube served as a surface marker over the instruments. A small aluminum radar reflector was placed on the mast. A 3/16-inch length of wire rope with a scope of 1.5:1 connected this marker to the underwater float. This surface marker allowed an accurate positioning of the primary anchor.

The method of installation involved:

1. stringing out subsurface floats and instrument string;
2. lowering main anchor with ground line on fixed course;
3. lowering secondary anchor with braided nylon;
4. casting off surface float.

Recovery was made in reverse order. Both installation and recovery took one to two hours depending on crew efficiency.

The second type of moorage design, used after April 1968, is shown in Fig. 4. It is a single string, taut wire, completely submerged system. Recovery is made by activating a release, generally acoustical. This design has several obvious advantages. Absence of surface floats prevented pilferage, the simpler design presented a smaller target to trawl fishing, and the mooring could be installed or recovered within a half hour.

CRUISES

Ship availability was a major problem in the continuing program. The actual ship requirements, such as a winch and a crane or boom facility for lifting 2000-lb anchors over the side and lowering to the bottom, were minimal. Much of the year, the weather in the area can build an unworkable sea within half a day. This makes the use of Seattle-based ships (day to day-and-a-half transit time) impractical. Furthermore it is difficult to schedule local vessels for reasons of pre-employment, weather, and sea conditions over the bar. During the first year U. S. Coast Guard ships were used frequently, and in the second year local fishing vessels were used. Because of their low freeboard and maneuverability, fishing craft proved superior to Coast Guard or larger oceanographic vessels for setting and retrieving mooring installations. The cruises are described in the appendix.

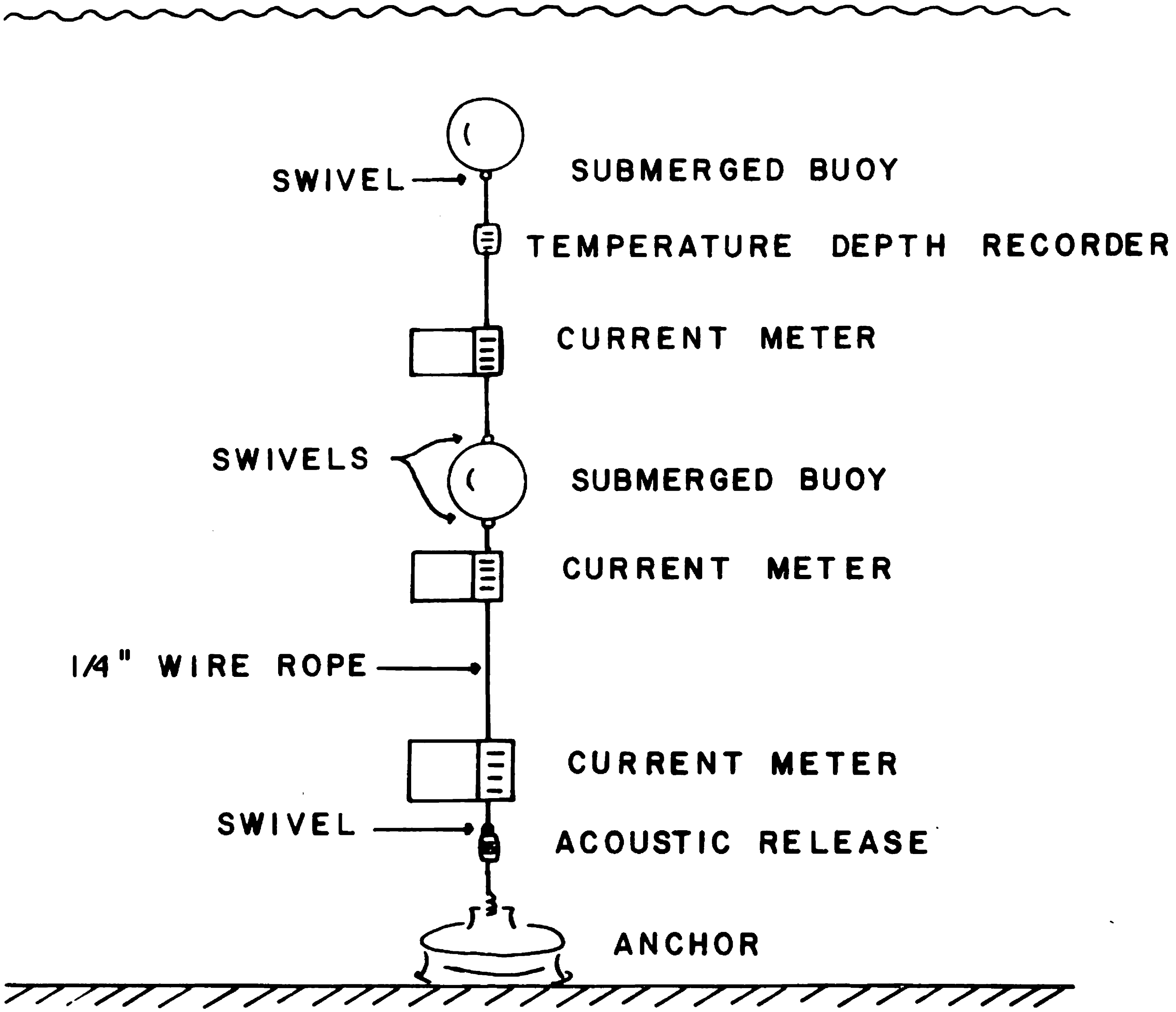

Fig. 4. Mooring design with acoustic release

DATA PROCESSING

The Braincon current meters record on 16-mm film. Commercial sources developed the films and printed high-contrast work prints. The films were numbered by frame, magnified fifteen times using a Richardson projector, and digitized onto magnetic tape utilizing a Benson-Lehner digital recording system. Readout involved recording the Cartesian coordinates of the six points exposed per frame (center dot, tilt, direction, beginning of speed arc, end of speed arc, and reference). A program, TOCARDS, then converted the tape to punched cards and to a listing, which was edited for digitizing and operator errors. Although the film reading rate was about 300 frames hr^{-1}, the rate from film numbering to final edited Cartesian coordinates on cards was only about 150 frames hr^{-1}.

Next a program, GBRAC, converted the Cartesian coordinates of the film information to a listing of the time and velocity. The velocity, in Cartesian and polar form, was compensated for tilt, magnetic variation, and calibration. The program also plotted the velocity components, and drew speed and direction histograms. Those frames for which a point was digitized out of reasonable bounds were noted. For example, frequently the direction arc could not be seen; the operator then "zeroed" the coordinates for the point that would have given the direction. Since such error frames were indicated in the listings, it was possible to consult the film or interpolate to determine reasonable values. For very poor sections of the film, the record had to be interrupted or discontinued. The corrected GBRAC output (cards) constitutes the archived form for the data and will be referred to as the original series.

A convenient method of presenting a vector time series is by means of progressive vector diagram, described by Webster (1964): "Each point of the diagram is determined by multiplying the corresponding velocity by the time elapsed since the previous point, and adding the resultant vector displacement to the sum of previous displacements." Interpretation is not meant to be that of a particle trajectory, except where the field of motion is spatially homogeneous. The progressive vector diagrams presented in the appendix were computed from every point in the original series.

The problem of poor direction resolution has been mentioned. Polar form is advantageous in that it separates the data from the two sensors, speed and direction, which have different responses. If processing were to be done in polar form, then poor quality of the direction data would not contaminate the speed information. A series in polar coordinates is more difficult to treat. For example, direction is difficult to smooth or average because of the discontinuity at 360°/0°. Smoothing was done on the components of the velocity vector, using a nine-point weighted polynomial filter. Fig. 5 shows the frequency response of the filter, that is, the ratio of the amplitude before and after filtering versus frequency. The cutoff frequency, where the response drops below 1%, is 6/10 of the Nyquist frequency, corresponding to a period of less than 1 hr. The filter was chosen as a compromise between eliminating the high frequency noise introduced mostly by poor direction resolution, and destroying some of the high frequency information.

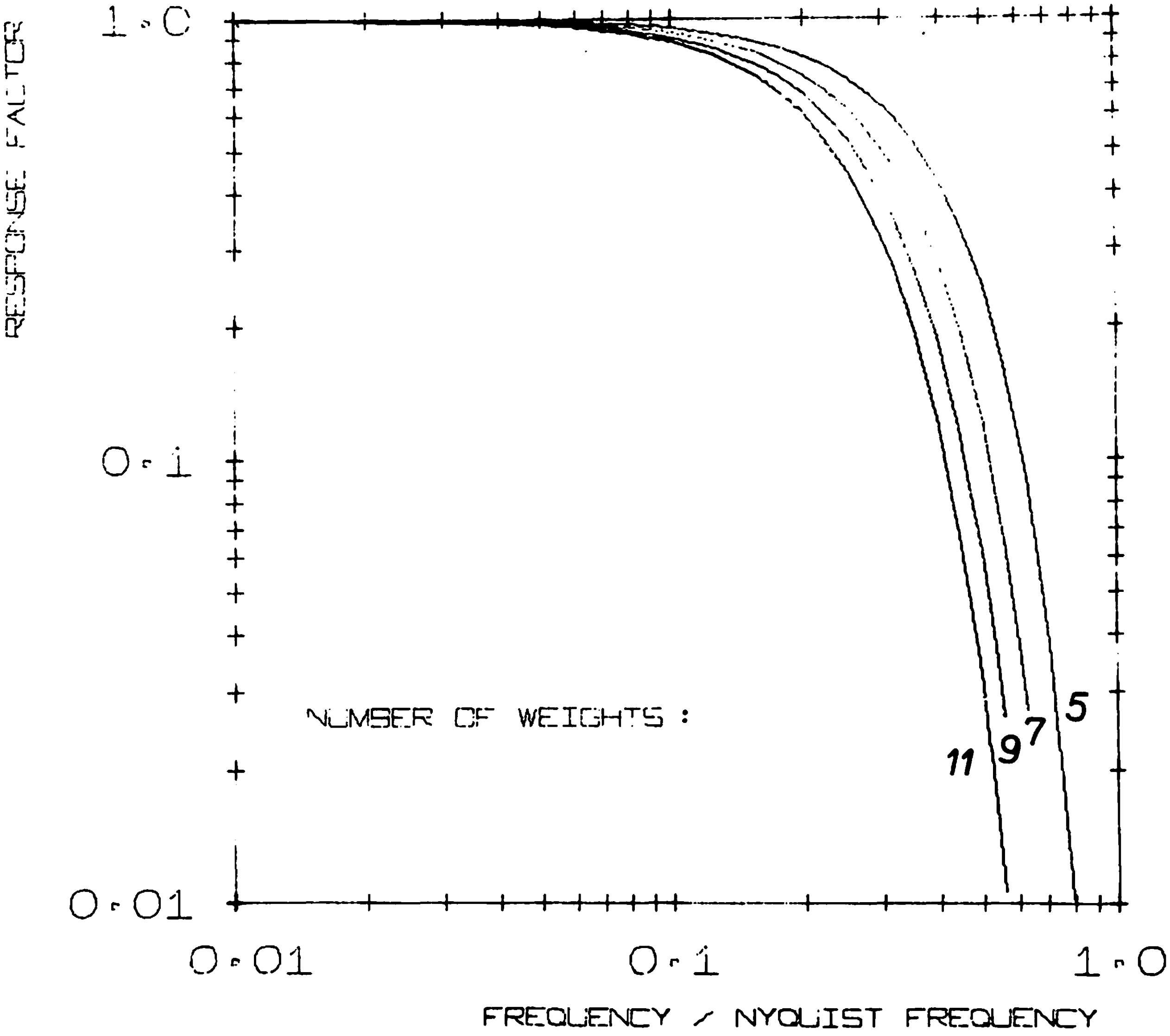

Fig. 5. Responses for various binomial filters

The smoothed series were used to construct the time-series plots shown for the various records in the appendix. Histograms taken from the original series are the only presentation of the data in polar coordinates (Appendix).

The temperature and depth records were read, and digitized on the same equipment as used for the current meters, except that the 70-mm film was magnified about seven and a half times. These records were easier to read; the temperature appears as a bar graph, and the depth as a dotted curve. The reading rate from film numbering to final edited listing (program PETE) for temperature or depth was about 1500 frames hr^{-1}. Data for each parameter were then condensed sequentially on cards and listed. Data so processed constitute the archived form and are referred to as the original series. Time plots of the original series for the various records are shown in the appendix.

Smoothed wind data plots for time periods of the major velocity records are presented in the appendix. Wind records from the Columbia River Lightship (for location see Fig. 1) were obtained from the Weather Bureau, National Oceanic and Atmospheric Agency (NOAA). The quality of these data is undoubtedly poor for several reasons. The wind velocity was sampled by different observers every six hours, an excessively long interval subject to potential aliasing. Furthermore offshore winds at the Lightship may not be representative of the coastal winds because of the local topographic features and the channelling effect of the Columbia River mouth.

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CRUISE LOG

10 July 1967 Cruise

Vessel: RV *Oceaneer*
Position: 46°24.7'N 124°29.5'W
Depth of water: 137 m
Set at: 1620 PDT, 11 July 1967

The secondary anchor was set approximately 0.5 mi south of the primary anchor.

Braincon current meter serial number 31600110 was placed 3.5 m above the bottom.

On the night of 17 July, the surface float was spotted several miles from the moorage. It was recovered; all lines had been cut or unshackled. While no direct evidence concerning the responsible party exists, circumstantial evidence indicates that probably some component of the Soviet fishing fleet, which was operating its bottom trawls in the area, inadvertently caught the installation in a trawl. The department was unable to communicate with the Soviets concerning the incident. An attempt to recover the installation is described below.

Position: 46°23.8'W 124°19.9'N
Depth of water: 80 m
Set at: 1340 PDT, 11 July 1967

The secondary anchor was set approximately 0.5 mi south of the primary anchor.

Braincon current meter serial number 31600163 was placed 3.5 m above the bottom.

All gear was recovered at 1330 PDT, 31 August 1967 by the RV *Ranos Bell*, except for the small surface marker over the submerged buoy. All current speeds were erratic or nil after 13 August, probably due to chemical fouling of the savonius rotor bearings. Data have been processed as Record A.

27 July 1967 Cruise

Vessel: RV *Oceaneer*

The cruise intentions were to attempt to recover the installation of 11 July located at the 137 m depth and to dispatch another sequence of drifters.

Nothing was recovered during the attempt. Although the dragging operation amply covered the area, the *Oceaneer's* grappling equipment was marginal to unsatisfactory.

29 August 1967 Cruise

Vessel:	RV *Ranos Bell*
Position:	46°23.4'N 124°22'W
Depth of water:	82 m
Set at:	1535 PDT, 31 August 1967

The secondary anchor was set approximately 0.5 mi south-southeast of the primary anchor.

Current meters and temperature-depth recorders were placed as follows:

Height above bottom	Histogram Current Meter Serial No.	Temperature-Depth Recorder Serial No.
2.5 m	--------	1480027
3 m	31600157	-------
15 m	31600158	-------

Only the surface float and part of the ground line were recovered. The surface float had apparently broken loose and was discovered off Vancouver Island around mid-September. When graciously returned to the University in early December by the CNAV *Laymore*, the float was little damaged except for cut bridle lines. Three attempts to retrieve the installation by grappling are described below.

In June 1968 an Astoria fisherman caught instrument 157 in his bottom trawl, and subsequently abandoned it at the Union Oil Dock in Astoria. Custody was recovered through action of the Clatsop Community College, Astoria, Oregon. Data were nearly lost again when the film was exposed during development. By comparing high-contrast positives with the negative, 90% of the data were recovered, now designated Record B.

Position:	46°23.3'N 124°32.4'W
Depth of water:	141 m
Set at:	0945 PDT, 31 August 1967

The secondary anchor was set approximately 0.5 mi southeast of the primary anchor.

Braincon current meter serial number 31600159 and a temperature-depth recorder serial number 1480026 were placed at 3 m and 2.5 m, respectively, from the bottom.

Only the surface float has been recovered. It apparently broke loose in a severe storm which immediately followed the placement and washed ashore at Gearhart, Oregon. Two attempts to retrieve the installation by grappling are described below.

3 November 1967 Cruise

Vessel:	USCGC *Magnolia* (WLB-328)

Cruise intentions were to drag at the 141-m and 82-m locations, if either recovered to replace with another installation. A third location closer inshore (at the 55-m mark) was contemplated, on the assumption that this position would be less susceptible to Soviet fishing operations.

Each position was dragged for approximately two hours with no positive results. The cruise was then discontinued for the *Magnolia* to attend a higher priority Coast Guard assignment.

20 November 1967 Cruise

Vessel:	USCGC *Magnolia* (WLB-328)
Position:	46°23'36"N 124°14'15"W
Depth of water:	48 m
Set at:	1100 PST, 21 November 1967

The secondary anchor was set approximately 0.5 mi south of the primary anchor. The surface float was a nest of three steel mine net buoys welded together and around a 15-ft length of 2-inch galvanized pipe. The pipe projected above the buoy to join with an aluminum mast holding a radar reflector and a light as on previous float (described above). The lower section extended 4 ft below the buoy and was shackled to 14 ft of 3/4-inch chain for ballast. There was no marker buoy placed above the submerged buoy.

Braincon current meter serial number 31600170 was placed 3.5 m above the bottom.

Instrument 170 turned up on a fisherman's front lawn in Grayland, Washington, in May 1968. He had picked up the submerged float and current meter off Westport after a less curious and more fearful fisherman had scooped it up in his gear and subsequently thrown it back in the sea. The data have been processed as Record C.

29 November 1967 Cruise

Vessel:	RV *Thomas G. Thompson*

Cruise intentions were to continue dragging operations for the two installations as on the 3 November cruise.

Dragging lasted for approximately 7 hrs at the 141-m installation with no positive results. After 5 hrs of dragging at the 89-m installation, the grapnel was found to have a deep 1/4-inch cut indicating that the ground line had passed over the grapnel. Failure to retain the wire was interpreted as either a break or some kind of disengagement. Barbs were welded on the grapnel in hope of catching the line on another pass. However, the operation was discontinued in submission to the ship's schedule and weather.

9 January 1968 Cruise

Vessel: RV *Ranos Bell*

Cruise intentions were to continue dragging at the 89-m installation.

The cruise was terminated prior to reaching the area. The RV *Ranos Bell* began to take on water through the caulking to such a degree that the safety of the ship and its crew would have been jeopardized if the cruise had continued or the weather worsened.

1 February 1968 Cruise

Vessel: USC&GS *Davidson*

Cruise intentions were the same as with the 9 January cruise.

Dragging commenced on 0000 5 February and continued until 0735 when the grapnel was raised. Approximately 700 ft of the ground line was brought aboard. One end was broken and the other unshackled. There is a fair possibility that this instrument string still remains. An attempt was then made to recover the 48-m installation by dragging since the surface float was absent. Dragging lasted for 3 hrs. Since the position information on this installation was considered very good, and since that very moment two fishing craft were towing a drag net over the location, it was concluded that this array had probably been caught inadvertently by American trawlers. Attempts leading to the disclosure of information concerning this installation failed.

2 April 1968 Cruise

Vessel:	USCGC *Magnolia* (WLB-328)
Position:	46°10.9'N 124°10,8'W
Depth of water:	65 m
Set at:	1230 PST, 2 April 1968

The mooring had been changed to the acoustic release design. The installation was located near the Columbia River Lightship for protection from fishing operations.

Braincon current meters serial numbers 31600169 and 31600173 were placed at 4 m and 20 m above the bottom, respectively. The ORE acoustic release serial number 210E113 was placed just above the anchor.

On 11 April the installation surfaced and was retrieved by the lightship. All the equipment except the anchor and the 1-m leader to the anchor were recovered. The release device may have triggered accidentally, although the unusual tilt on the bottom current meter suggests that the mooring was fouled. Perhaps the anchor wire fouled in such a way that it chafed against the concrete anchor. No exact evidence is available. Both meters functioned properly during the eight-day submergence, processed as Records D and E. Record D, the deeper one, will not be used because of its unusual tilt.

14 May 1968 Cruise

Vessel: USCGC *Magnolia* (WLB-328)
Position: 46°11.3'N 124°11.2'W
Depth of water: 59 m
Set at: 1024 PST, 13 May 1968

The mooring was the same as the 2 April installation.

The same instruments from the 2 April installation were used. The acoustic release was tested, checked out satisfactorily, and it was decided to try it again.

On 15 May the installation surfaced and was retrieved by the Lightship. All equipment was recovered. The release device had triggered accidentally; it was returned to the manufacturer. Both meters functioned properly for the two-day period, and their data have been processed as Records F and G.

16 July 1968 Cruise

Vessel: USCGC *Magnolia* (WLB-328)
Position: 46°11.0'N 124°11.0'W
Depth of water: 64 m
Set at: 1107 PST, 16 July 1968

The mooring was the same as the previous two installations, except that the new anchor was two railroad wheels welded together.

The same current meters were used. A new factory-tested ORE acoustic release serial number 210E120, of different frequency, was used.

On 18 July the installation surfaced and was retrieved by the *Magnolia* while operating in the area. The release had tripped accidentally and was returned to the factory. Both meters functioned properly for the two-day period, and their data have been processed as Records I and J.

6 August 1968 Cruise

Vessel: USCGC *Magnolia* (WLB-328)
Position: 46°10.9'N 124°11.1'W
Depth of water: 64 m
Set at: 1515 PST, 6 August 1968

The mooring was the same as the previous installations except that a Geodyne Corporation time release model A-8550 was used. A 110-m safety tether was attached between the anchor and the release device.

The time release was 1 m off the bottom. Braincon current meters serial numbers 31600169, 31600173 and temperature-depth recorder serial number 5310009 were placed at 3 m, 19 m, and 53 m respectively above the bottom.

The time release was set to trigger at 1100 on 17 September 1968 (the date of the scheduled U.S. Coast Guard replenishment run to the Lightship). On 17 September the weather prohibited the scheduled run. The personnel on the Lightship failed to see the instruments surface at 1100, nor subsequently, any evidence that they had surfaced. The weather at the time was poor: visibility 1-2 km, rain, wind 10 m sec^{-1} from the southwest, and a 3-m sea. The weather became worse, not subsiding for several days.

There has been no indication of the disposition of this installation. The Lightship location was abandoned after this attempt. While the Lightship offered protection from fishing operations, it jeopardized an installation by being an anchor site for ships waiting passage over the Columbia River Bar and for small vessels during foul weather.

Position:	46°24.7'N 124°20.0'W
Depth of water:	80 m
Set at:	1226 PST, 6 August 1968

At the request of the University of Washington the U. S. Coast Guard agreed to place a lighted sea buoy in 80 m of water at 46°25'N and 124°20'W. The buoy would provide protection to submerged instruments from domestic fishing and would be just inside the 12-mi limit to reduce complications with foreign fishing and shipping. The intention was to leave the buoy in this location to provide a permanent mooring site for the University's oceanographic instruments, which would be set within a 600-m range of the sea buoy.

The mooring was the same as previous installations except that an ORE acoustic release serial 210B121 was used. A 150-m long safety tether of 9/16-inch braided nylon was attached between the anchor and the release device.

The release was 1 m above the bottom. Braincon current meters 38100121, 38100122, and temperature-depth recorder 5310008 were placed at 3 m, 20 m, 71 m respectively above the bottom.

Only the temperature-depth recorder was recovered; its data have been processed as Record AB.

23 September 1968 Cruise

Vessel:	USCGC *Magnolia* (WLB-328)

The cruise intended to recover the installation at the Sea Buoy, to set another, and to investigate the Lightship installation.

At 1105 the array surfaced several seconds after the first acoustic interrogation. The safety line apparently did not pay out completely, judging bv the strain on the line. Just prior to bringing the upper current meter on board, the line caught in the hinge of the chain stopper. In this sharp crevice the line soon parted. The *Magnolia* then dragged the position with a grapnel for about two hours.

At 1500 PST 23 September another installation was set 500 m north of the Sea Buoy. The mooring was the same except that no tether was attached. Acoustic release 210B130, Braincon current meters 3160156 and 3160163, and temperature-depth recorder 5310008 were placed 2 m, 3 m, 20 m, 68 m respectively above the bottom. All of these instruments were successfully recovered and their data have been processed as Records M, N, and AC.

The *Magnolia* received orders to proceed to Coos Bay, Oregon, delaying any search for the instruments near the Lightship. She did steam over the location while returning to port to see if the installation could be located on the fathometer, with negative results.

24-26 September 1968 Cruise

Vessel:	MV *Tom & Al*

The cruise intended to search by dragging for the instruments missing at the two locations.

On 24 September just after the *Tom & Al* begam dragging near the Lightship, she hit a snag (later guessed to be the wreck of the *Mary Anne*) and lost both doors and the dan-line. Everything was retrieved by grappling except for one door. The grapnel was then set at the expected position of the instruments, 800 m of cable were let out, and a circular course was steamed. After several sweeps, the search was terminated in order to return to port to replace the door.

On the morning of 25 September, the *Tom & Al* proceeded to the Lighted Sea Buoy. Two sweeps with the dan-line and ten sweeps with a net were made on range circles and on bearing lines from the Sea Buoy. Control was inhibited by the lack of a bearing circle and a range strobe on the radar. The net hauls showed that the bottom was being scraped; however, it is difficult to assess how consistently the net remained on the bottom for turning and maneuvering the vessel caused the outside door to fly off the bottom. Ideally the sweep should have been about 45 m wide. On the way back to port several sweeps were again made at the Lightship location.

Again on 26 September the *Tom & Al* returned to the Sea Buoy. After placing a marker over datum, sweeps were made to either side and through the marker. This was done four complete times. Sweeps were also made on the range circle, on the bearing line, and even on the bearing reciprocal. Maneuvering was restricted by the Sea Buoy and the newly set instrument array.

On the afternoon of 8 October the USCGC *Ivy* (WLB-329) spent four hours dragging the Lightship location. Circular sweeps were made about a trailing grapnel.

10 December 1968 Cruise

Vessel:	USCGC *Magnolia* (WLB-328)

The cruise intended to recover the installation set at the Sea Buoy on 23 September.

All equipment was recovered and the data have been processed as Records M, N, and AC.

19 December 1968 Cruise

Vessel:	MV *Tom & Al*
Position:	360 m 197°T from the Sea Buoy
Depth of water:	80 m
Set at:	1140 PST, 19 December 1968

The mooring configuration was the same as the installation on 23 September 1968.

Acoustic release 210B130, Braincon current meters 3160157, 3160170, and temperature-depth recorder 5310066 were set at 2 m, 3 m, 20 m, and 68 m respectively above the bottom.

All equipment was recovered successfully from the USCGC *Ivy* (WLB-329) on 19 February 1969. All instruments except for current meter 170, which failed to run at all due to clock failure, operated properly and their data have been processed as Records O and AD.

9 March 1969 Cruise

Vessel:	MV *Roseann Hess*
Position:	400 m 180°T from the Sea Buoy
Depth of water:	80 m
Set at:	1245 PST, 9 March 1969

This mooring held four current meters and the lower sphere float was set 45 m above the bottom.

The instruments included the following:

Instrument	Height above bottom
acoustic release 210B130	2 m
current meter 3810054	3 m
current meter 3160170	10 m
current meter 3810057	20 m
current meter 3160156	30 m
temperature-depth recorder 5310066	73 m

All equipment was recovered successfully from the USCGC *Ivy* (WLB-329) on 5 May 1969. Meters 54 and 57, even though new-from-the-factory, kept erratic time and on each the set screw that holds the magnetic rotor follower to the gear train shaft was loose. Meter 170, which had been laboratory checked and had a new clock installed, failed to run due to a short in the film advance circuit. Meter 156 recorded only direction after the first 14 days, when the magnetic follower began to slip, failing to turn the gear train. Recorder 66 ran satisfactorily.

11 April 1969 Cruise

Vessel:	MV *Sonar Belle*

The purpose of the cruise was to search for the instruments lost off the *Magnolia* on 23 September 1968.

The *Sonar Belle* was rigged with an underwater television camera, fitted in a 4 cu-ft cage, free to swivel 360° in the horizontal and 180° in the vertical, and equipped with flood lighting. With a three-point moor the ship could accurately search an 0.5-km arc, 180-m-wide swath of the sea bottom. Monitoring and video tape facilities were on deck. The cage was equipped with a grabbing device for recovery.

The search was an immediate failure because of zero visibility. There appeared to exist a highly turbid layer from 3-4 m off the bottom. Vertical accuracy was encumbered by surface swell. No evidence of a solid bottom was detected. A 120-cm two-by-four piece of wood was lashed to the cage so as to extend it downward 50 cm, and was scaled off to provide a more quantitative viewing. The 1/2 ton cage was eased to the bottom until the tension was relieved. It was then raised from the turbid layer. The cage had apparently sunk in 4 cm and the two-by-four was undamaged and unjostled. Samples of the bottom were taken, and the video tape of the operation was kept.

25 May 1969 Cruise

Vessel:	MV *Tom & Al*
Position:	270 m 190°T from Sea Buoy
Depth of water:	80 m
Set at:	1313 PST, 25 May 1969

The mooring configuration was the same as the cruise on 9 March 1969.

The instruments included the following:

Instrument	Height above bottom
acoustic release 210B130	2 m
current meter 3810073	3 m
temperature-depth recorder 5310069	4 m
current meter 3810057	10 m
current meter 3810054	20 m
current meter 3160163	30 m
current meter 3160156	60 m
temperature-depth recorder 5310066	73 m

All equipment was recovered safely from the MV *Kathy Jo* on 16 July. Data from recorders 69 and 66 were processed satisfactorily as Records AF and AG, and the data processed from meters 73 and 163 were designated as Records S and V. The rest of the meters, 57, 54, and 156 had been administered only the routine maintenance suggested in the Braincon instruction manuals. Since their films had not been processed from the last installation, the fact that these meters were only recording direction was not realized. Directional data from these meters have been processed and designated as Records T, U, and W.

Experience from the last two installations described illustrated the unfortunate necessity of completely stripping and reassembling the meters regardless of whether they have come from the field or factory.

21 August 1969 Cruise

Vessel:	MV *New Mexico*
Position:	180 m 225°T from Sea Buoy
Depth of water:	80 m
Set at:	1402 PST, 21 August 1969

The mooring configuration was the same as the previous cruise.

The instrumentation was as follows:

Instrument	Height above bottom
acoustical release 210B130	2 m
current meter 3810073	3 m
temperature-depth recorder 5310069	4 m
current meter 3810057	20 m
current meter 3160170	30 m
current meter 3160163	60 m
temperature-depth recorder 5310066	73 m

All equipment was recovered safely from the MV *Kathy Jo* on 22 October. The Accutron programmer for meter 73, Record X, failed after one week, and that for meter 57, Record Y, failed after two weeks; speed and direction sensors failed to give an exposure for all quadrants, necessitating hand editing and interpolation for some of the data. Data quality for Record Y is poor. Data from meters 170 and 163 have been processed as Records Z and AA. Data from recorder 69, Record AH, were good; and data from recorder 66, Record AI, were good except that part of the pressure trace was off scale.

TABLE I SUMMARY OF OBSERVATIONS

RECORD	INSTRUMENT	INCLUSIVE DATES Day/Month/Year	LOCATION		WATER DEPTH	METER DEPTH	COMMENTS ON MOORING	COMMENTS ON DATA
A	316 current meter	11/7-16/8/67	46-23.8N	124-19.9W	80 m	77 m		Direction resolution poor
B	316 current meter	31/8-30/10/67	46-23.5N	124-22.0W	82 m	79 m	Mooring destroyed by fishing	Good
C	316 current meter	21/11/67-19/1/68	46-23.6N	124-14.1W	50 m	47 m	Mooring destroyed by fishing	Good
D	316 current meter	2-10/4/68	46-10.9N	124-10.8W	64 m	61 m	Pretrip on acoustic release Meter fouled	Excessive tilt data poor
E	316 current meter	2-10/4/68	46-10.9N	124-10.8W	64 m	44 m	Pretrip on acoustic release	Good
F	316 current meter	13-15/5/68	46-11.3N	124-11.2W	59 m	56 m	Pretrip on acoustic release	Good
G	316 current meter	13-15/5/68	46-11.3N	124-11.2W	59 m	39 m	Pretrip on acoustic release	Good
I	316 current meter	16-18/7/68	46-11.0N	124-11.0W	64 m	61 m	Pretrip on acoustic release	Good

TABLE I *continued*

RECORD	INSTRUMENT	INCLUSIVE DATES Day/Month/Year	LOCATION	WATER DEPTH	METER DEPTH	COMMENTS ON MOORING	COMMENTS ON DATA
J	316 current meter	16-18/7/68	46-11.0N 124-11.0W	64 m	44 m	Pretrip on acoustic release	Good
M	316 current meter	23/9-14/11/68	46-25.0N 124-20.0W	80 m	77 m		Good, except for several days' loss due to rotor fouling
N	316 current meter	23/9-20/11/68	46-25.0N 124-20.0W	80 m	60 m		Good
O	316 current meter	19/12/68-16/2/69	46-24.8N 124-20.0W	80 m	77 m		Good
P	381 current meter	9/3-4/5/69	46-24.8N 124-20.0W	80 m	77 m		Direction only instrument failure
Q	381 current meter	9/3-4/5/69	46-24.8N 124-20.0W	80 m	60 m		Direction only instrument failure
R	316 current meter	9/3-4/5/69	46-24.8N 124-20.0W	80 m	39 m		Direction only after 23/3/69
S	381 current meter	25/5-16/7/69	46-24.8N 124-20.0W	80 m	77 m		Good

TABLE I *continued*

RECORD	INSTRUMENT	INCLUSIVE DATES Day/Month/Year	LOCATION	WATER DEPTH	METER DEPTH	COMMENTS ON MOORING	COMMENTS ON DATA
T	381 current meter	25/5-16/7/69	46-24.8N 124-20.0W	80 m	70 m		Direction only instrument failure
U	381 current meter	25/5-16/7/69	46-24.8N 124-20.0W	80 m	60 m		Direction only instrument failure
V	316 current meter	25/5-16/7/69	46-24.8N 124-20.0W	80 m	49 m		Good
W	316 current meter	25/5-16/7/69	46-24.8N 124-20.0W	80 m	19 m		Direction only instrument failure
X	381 current meter	21-28/8/69	46-24.8N 124-20.0W	80 m	77 m		Instrument failed after 1 week
Y	381 current meter	21/8-15/10/69	46-24.8N 124-20.0W	80 m	60 m		Some data lost due to instrument failure
Z	316 current meter	21/8-15/10/69	46-24.8N 124-20.0W	80 m	50 m		Direction resolution poor
AA	316 current meter	21/8-16/10/69	46-24.8N 124-20.0W	80 m	19 m		Good

TABLE I *continued*

RECORD	INSTRUMENT	INCLUSIVE DATES Day/Month/Year	LOCATION	WATER DEPTH	METER DEPTH	COMMENTS ON MOORING	COMMENTS ON DATA
AB	531 press-temp	2/8-23/9/68	46-24.8N 124-20.0W	80 m	5 m		Good
AC	531 press-temp	23/9-10/12/68	46-24.8N 124-20.0W	80 m	12 m		Pressure resolution poor
AD	531 press-temp	19/12/68-16/2/69	46-24.8N 124-20.0W	80 m	6 m		Good
AE	531 press-temp	9/3-4/5/69	46-24.8N 124-20.0W	80 m	7 m		Good
AF	531 press-temp	25/5-16/7/69	46-24.8N 124-20.0W	80 m	77 m		Good
AG	531 press-temp	25/5-16/7/69	46-24.8N 124-20.0W	80 m	15 m		Good
AH	531 press-temp	21/8-22/10/69	46-24.8N 124-20.0W	80 m	77 m		Good
AI	531 press-temp	21/8-16/10/69	46-24.8N 124-20.0W	80 m	10 m		Good; pressure gauge offscale

TABLE II

STATISTICS ON RECORDS

RECORD	NUMBER OF OBSERVATIONS	VARIABLE	MEAN	MAXIMUM	MINIMUM	STANDARD DEVIATION
A	2333	U*	-1.34	18.7	-20.3	7.0
		V*	1.27	18.5	-27.9	7.6
B	4388	U	-3.77	20.9	-26.1	6.8
		V	5.83	37.8	-17.9	8.8
C	4250	U	-4.91	62.1	-61.0	15.9
		V	4.57	79.0	-50.5	25.3
E	582	U	10.81	25.7	-14.5	8.2
		V	-13.26	14.0	-25.1	7.2
F	150	U	-3.80	10.6	-23.4	8.6
		V	5.11	15.8	-6.3	5.6
G	149	U	-5.26	12.4	-26.2	11.0
		V	8.76	23.1	-6.3	7.5
I	154	U	2.56	25.4	-21.4	10.2
		V	-6.83	16.1	-31.0	10.5
J	153	U	-5.16	14.9	-33.2	11.7
		V	-11.85	21.9	-41.1	16.0
M	3737	U	-1.54	21.6	-28.8	7.7
		V	2.31	32.8	-22.0	9.3
N	4175	U	0.20	29.8	-31.2	10.9
		V	10.84	51.0	-32.4	18.6
O	4225	U	-3.37	19.6	-26.0	7.4
		V	5.23	57.1	-24.6	13.3
R	985	U	1.16	31.3	-25.4	13.1
		V	-7.09	34.2	-30.4	16.6
S	3740	U	-0.49	17.3	-17.4	6.6
		V	0.07	32.9	-25.4	9.6
V	3730	U	-0.91	22.2	-23.3	8.7
		V	-6.08	44.2	-42.2	14.4
X	498	U	-1.84	12.9	-20.0	7.9
		V	2.18	30.9	-18.3	8.9

TABLE II *continued*

RECORD	NUMBER OF OBSERVATIONS	VARIABLE	MEAN	MAXIMUM	MINIMUM	STANDARD DEVIATION
Y	951	U	2.17	16.2	-17.7	6.7
		V	1.70	39.5	-19.6	11.7
Z	3934	U	-3.76	31.8	-31.6	9.9
		V	4.83	39.1	-33.2	11.4
AA	3992	U	3.63	53.7	-35.5	14.2
		V	4.51	57.8	-48.6	19.4
AB	3350	D*	4.78	6.3	2.6	1.6
	3350	T*	14.64	17.0	10.5	1.1
AC	5656	T	11.62	15.7	8.7	0.9
AD	3745	D	5.88	8.0	3.5	0.9
	3576	T	8.07	11.1	4.8	1.1
AE	3845	D	6.76	8.6	4.5	0.7
	3845	T	9.73	11.7	8.3	0.5
AF	3734	D	76.39	78.8	73.5	0.8
	3734	T	7.85	8.4	6.5	0.3
AG	3360	D	3.88	5.6	1.8	0.8
	3360	T	15.16	16.7	12.7	0.7
AH	4341	D	77.04	78.7	75.1	0.7
	4344	T	7.36	7.9	6.7	0.2
AI	4148	D	9.94	10.3	8.4	0.5
	4148	T	12.94	15.2	8.7	1.3

*Units for the variables are as follows: U and V in cm/sec^{-1}, D in m and T in °C.

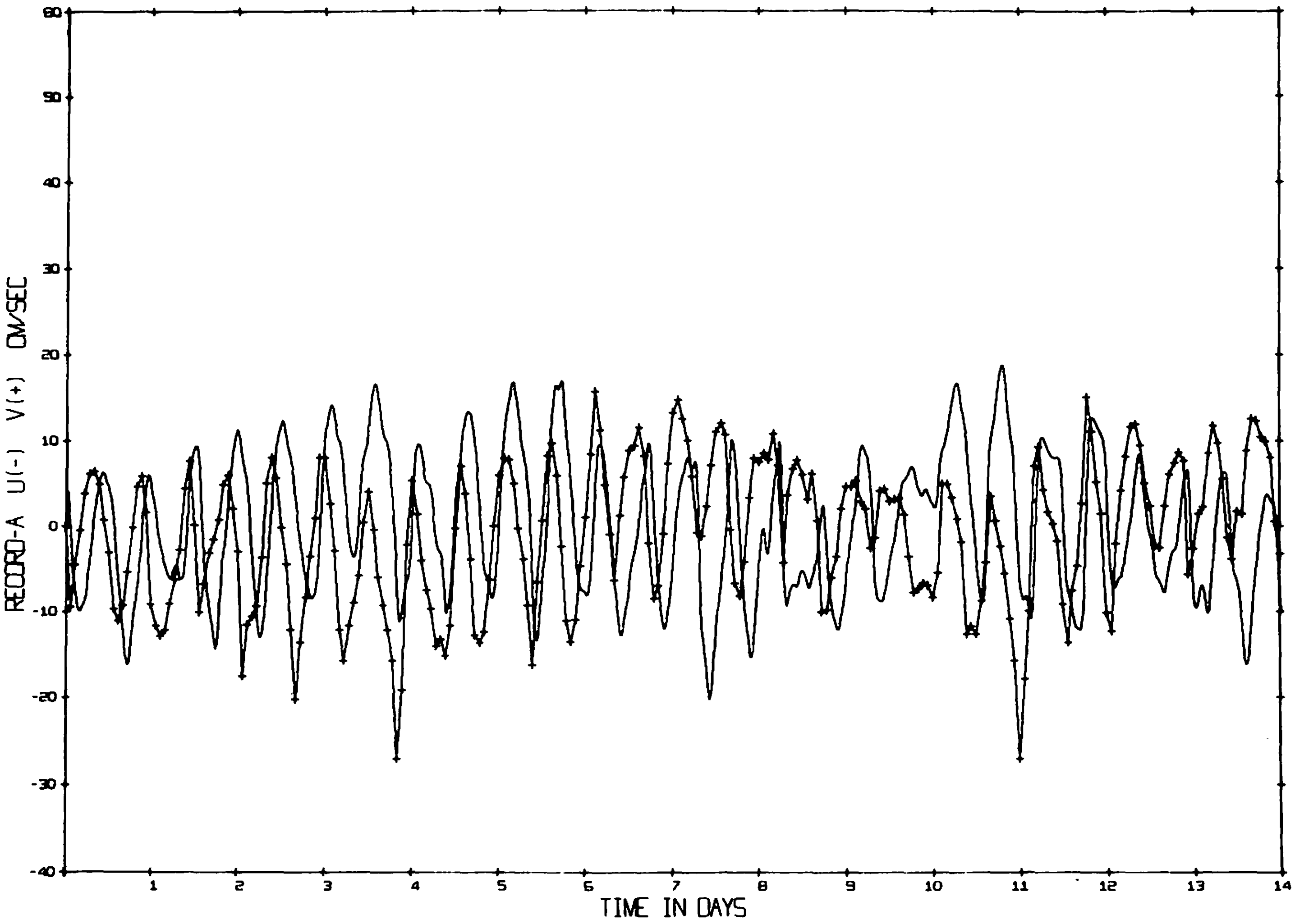


Fig. A-1. Record A time series. Start time: 1600 11 July 1967

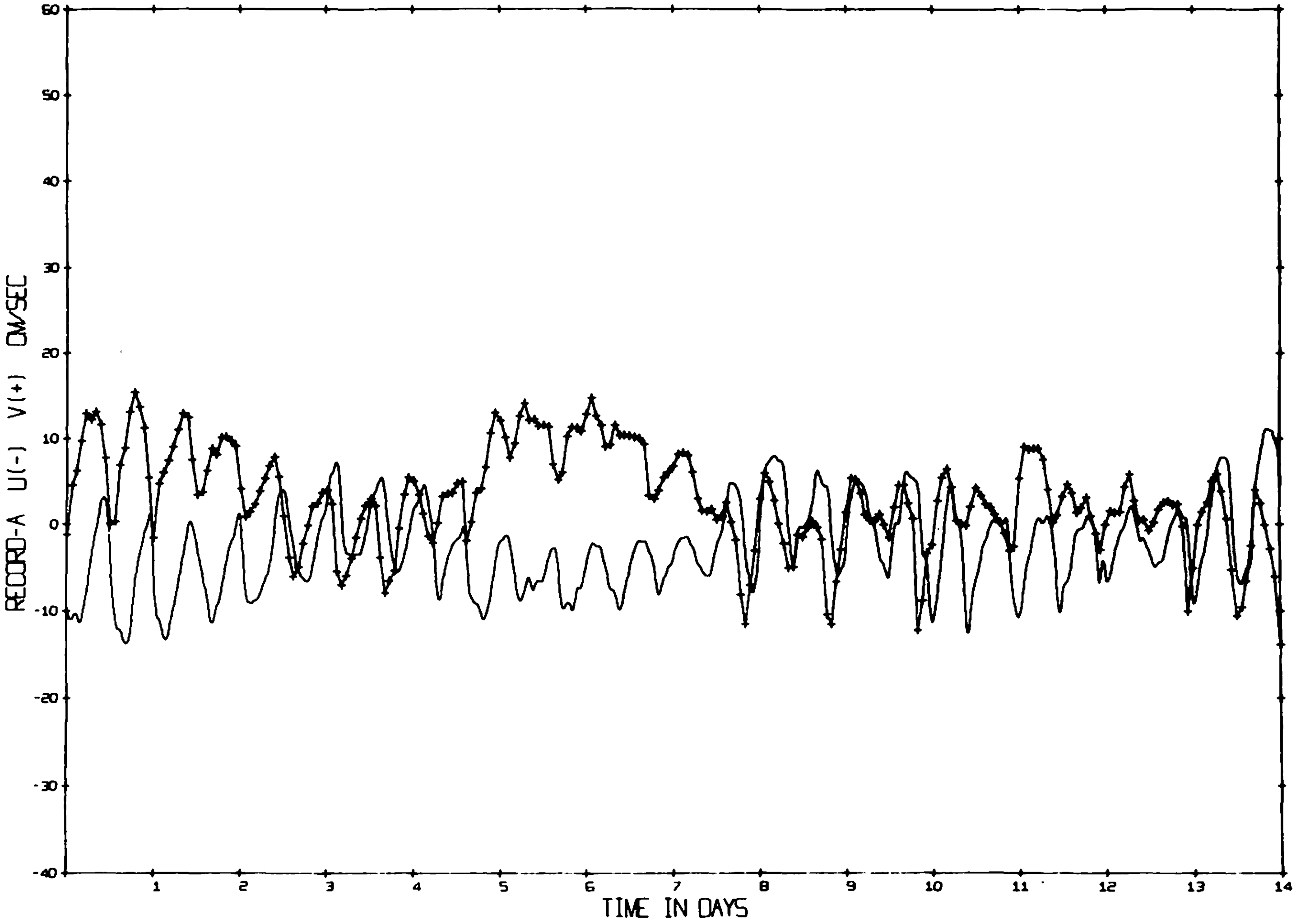


Fig. A-1 (cont.). Start time: 1600 25 July 1967

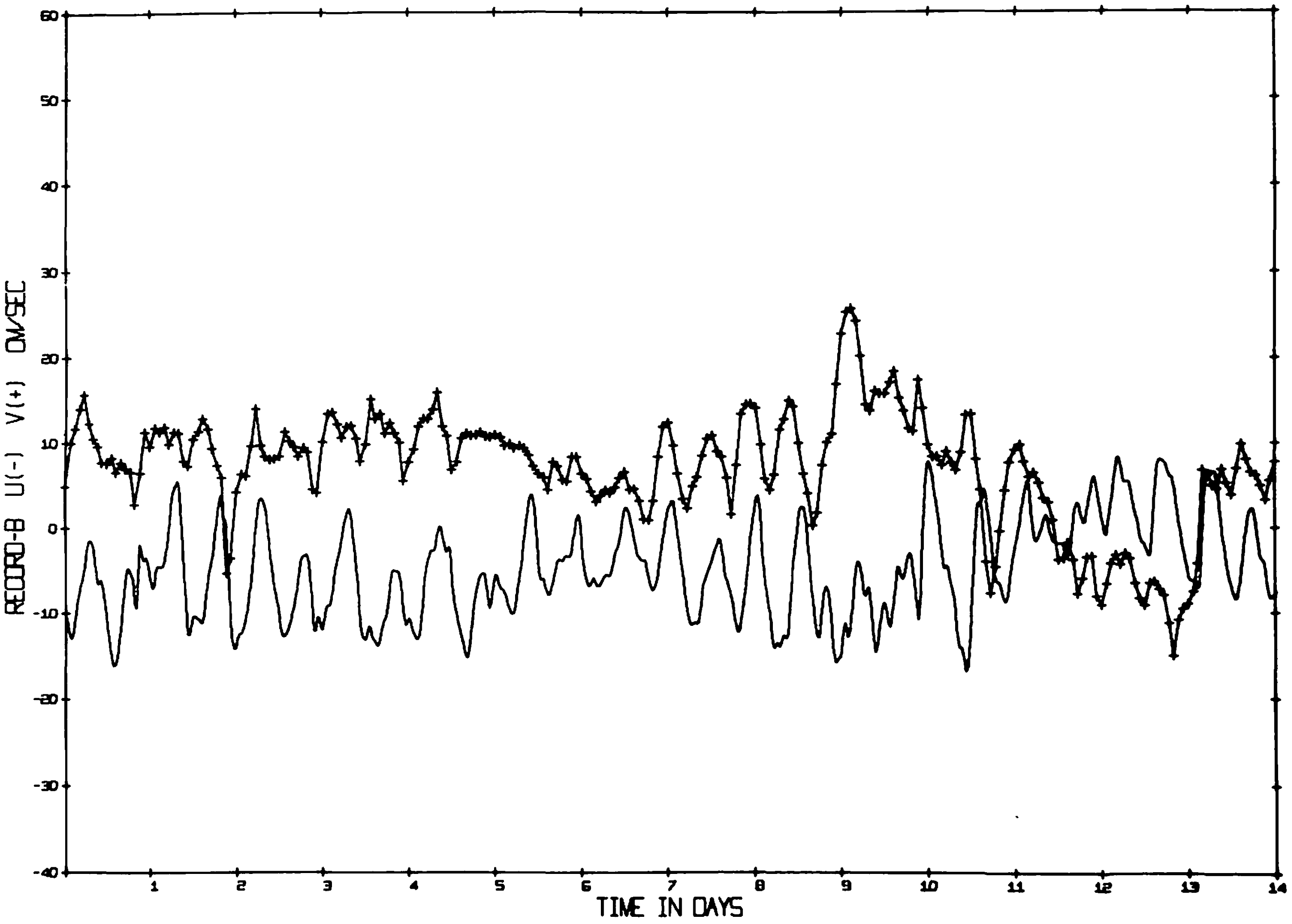


Fig. A-2. Record B time series. Start time: 1600 1 September 1967

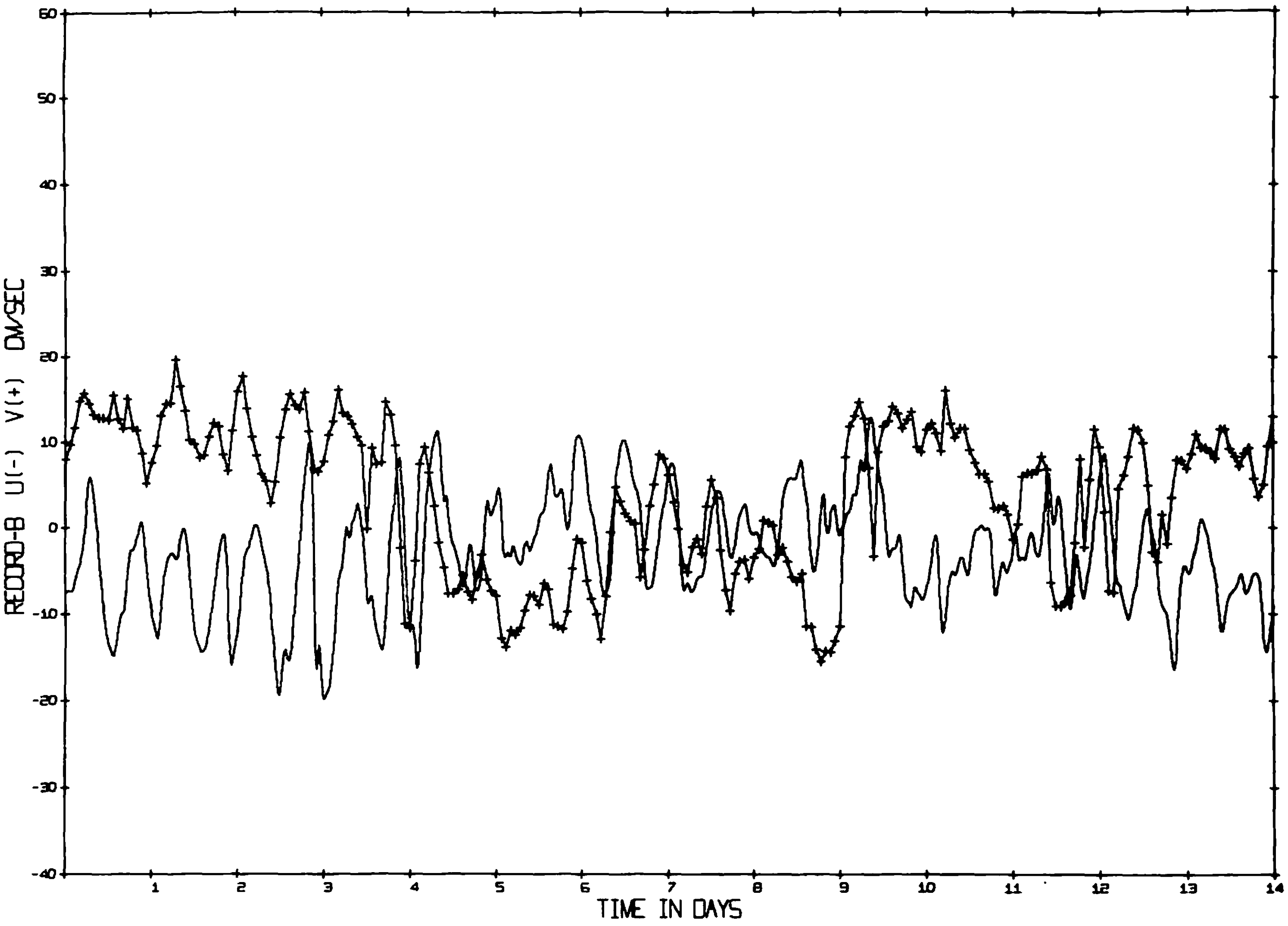


Fig. A-2 (cont.). Start time: 1600 15 September 1967

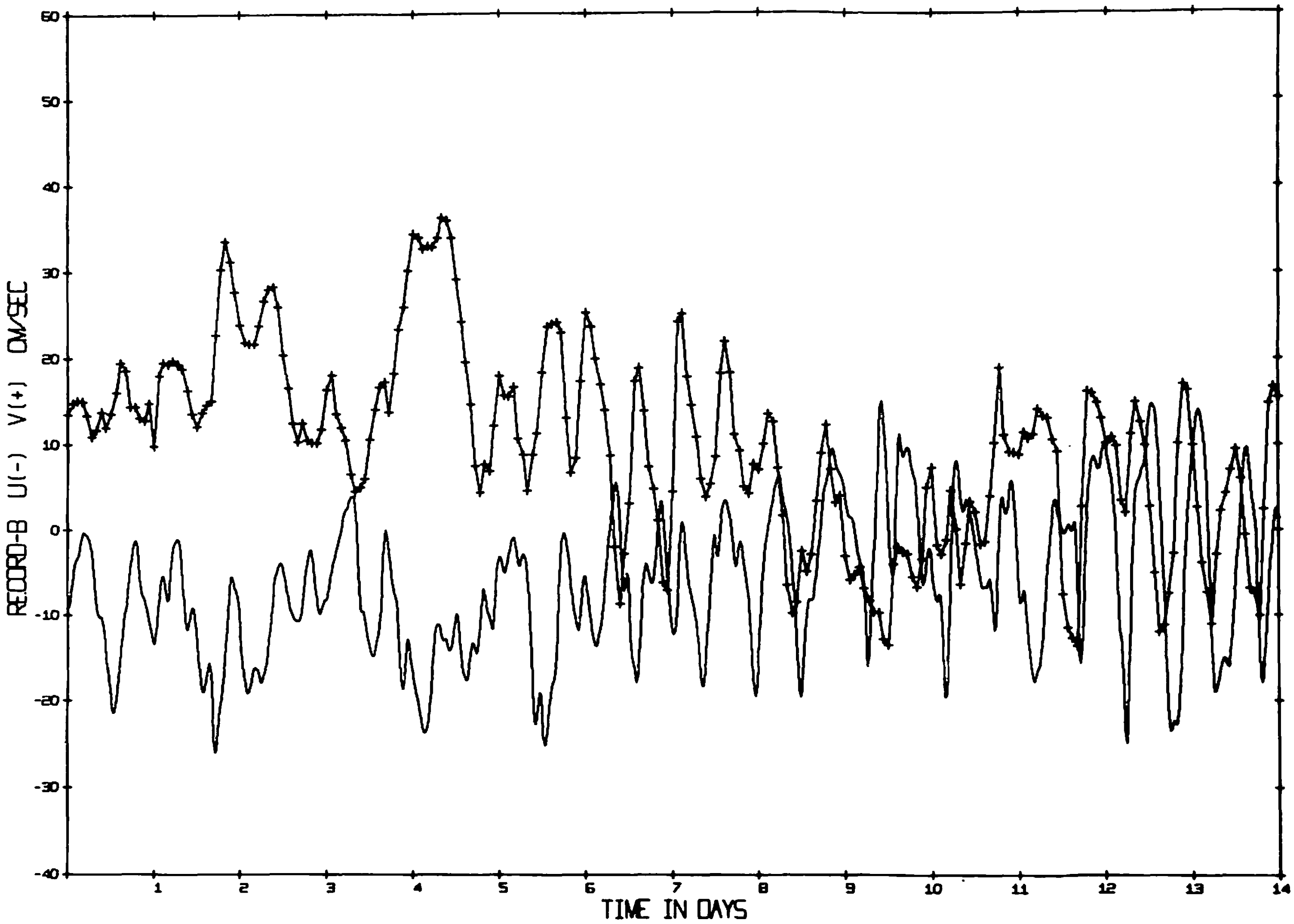


Fig. A-2 (cont.). Start time: 1600 29 September 1967

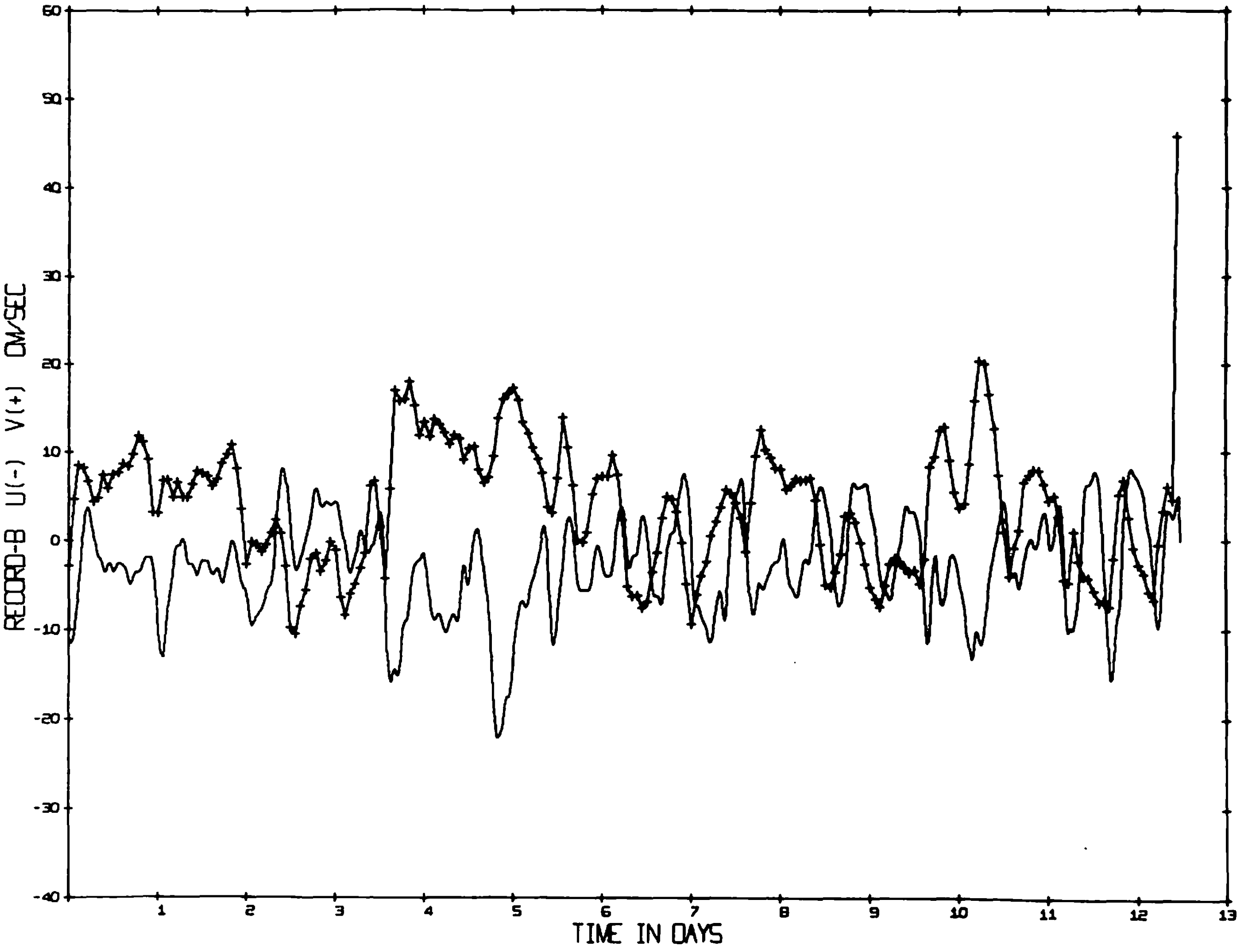


Fig. A-2 (cont.). Start time: 1600 13 October 1967

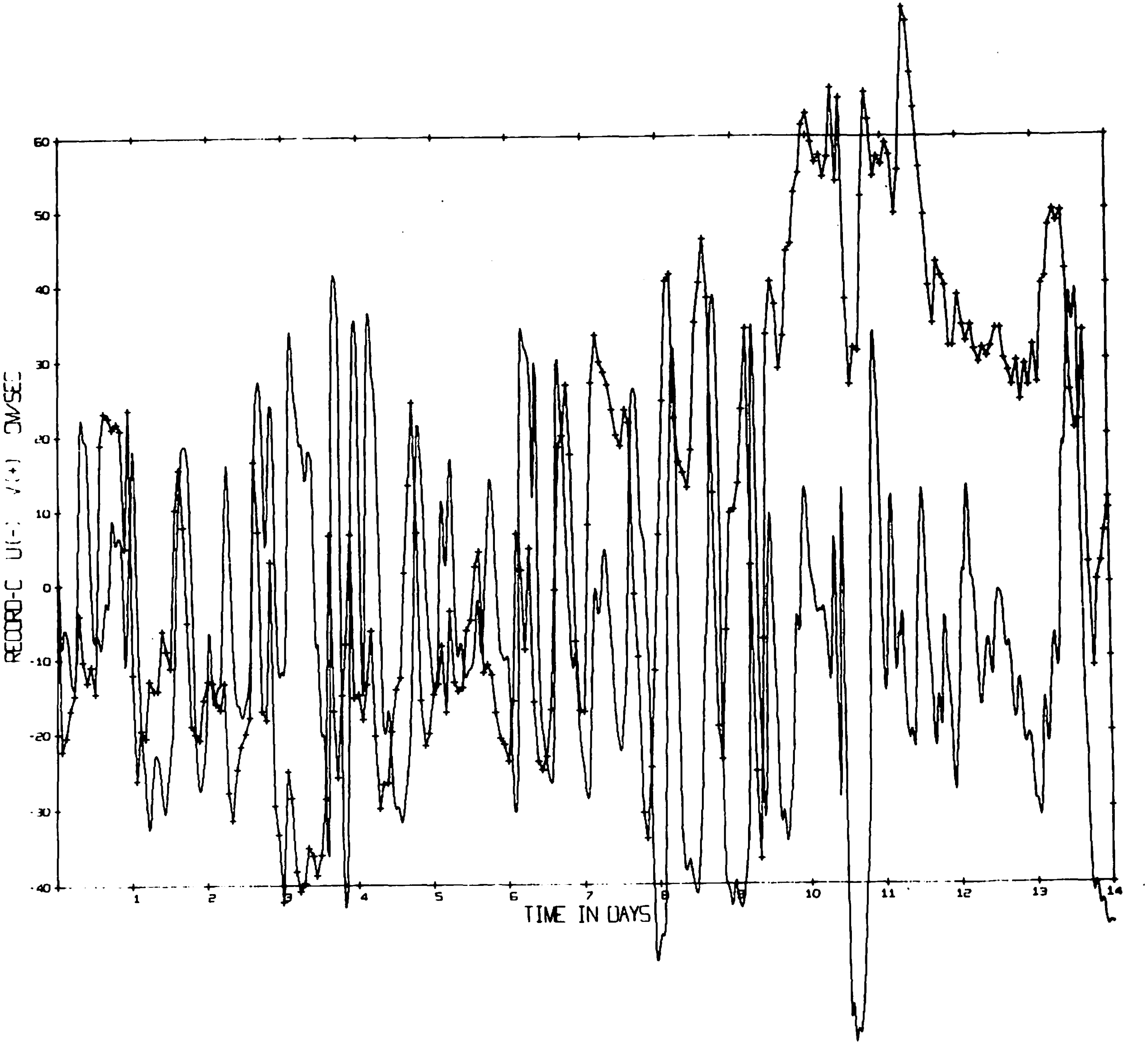


Fig. A-3. Record C time series. Start time: 2100 21 November 1967

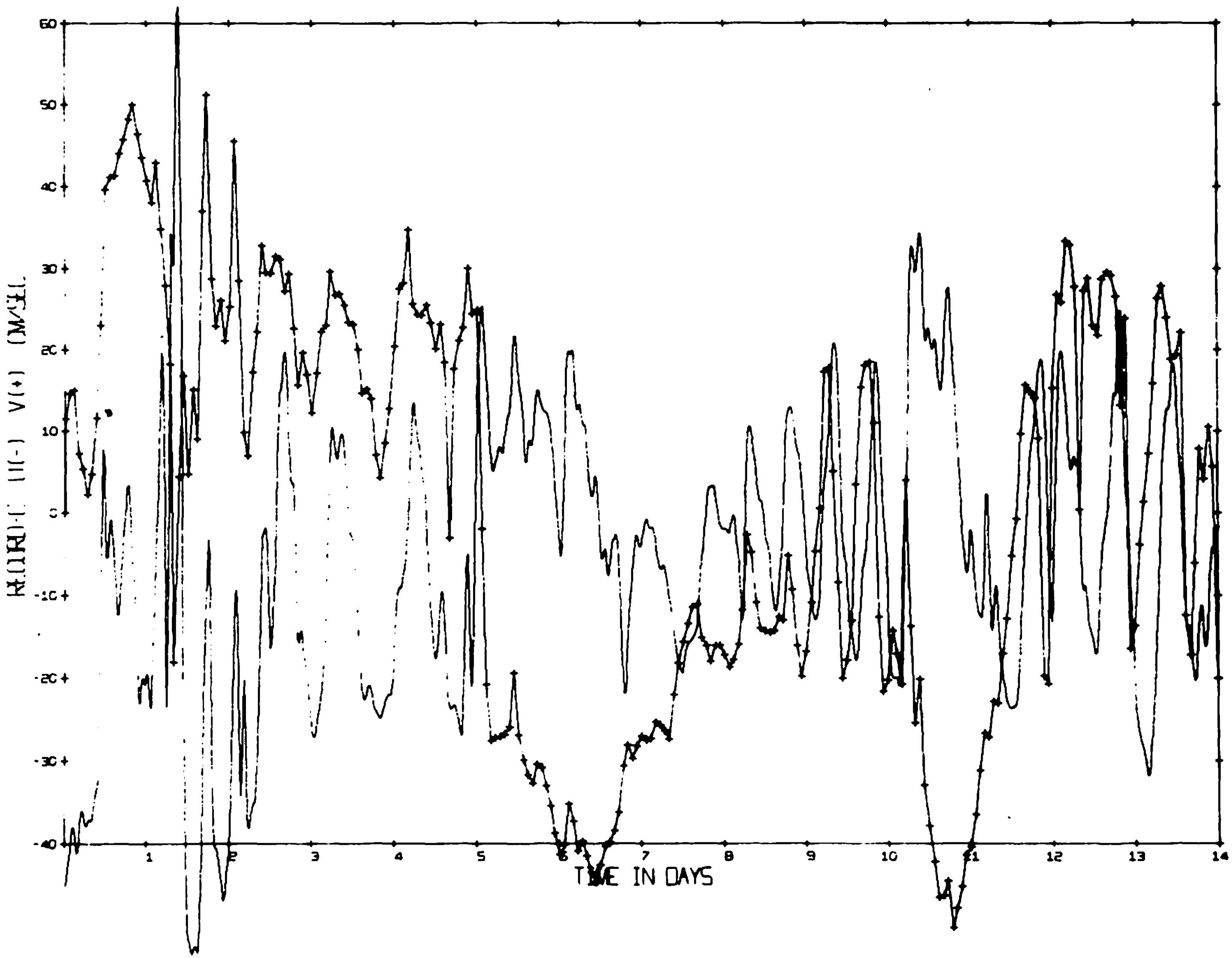


Fig. A-3(cont.). Start time: 2100 5 December 1967

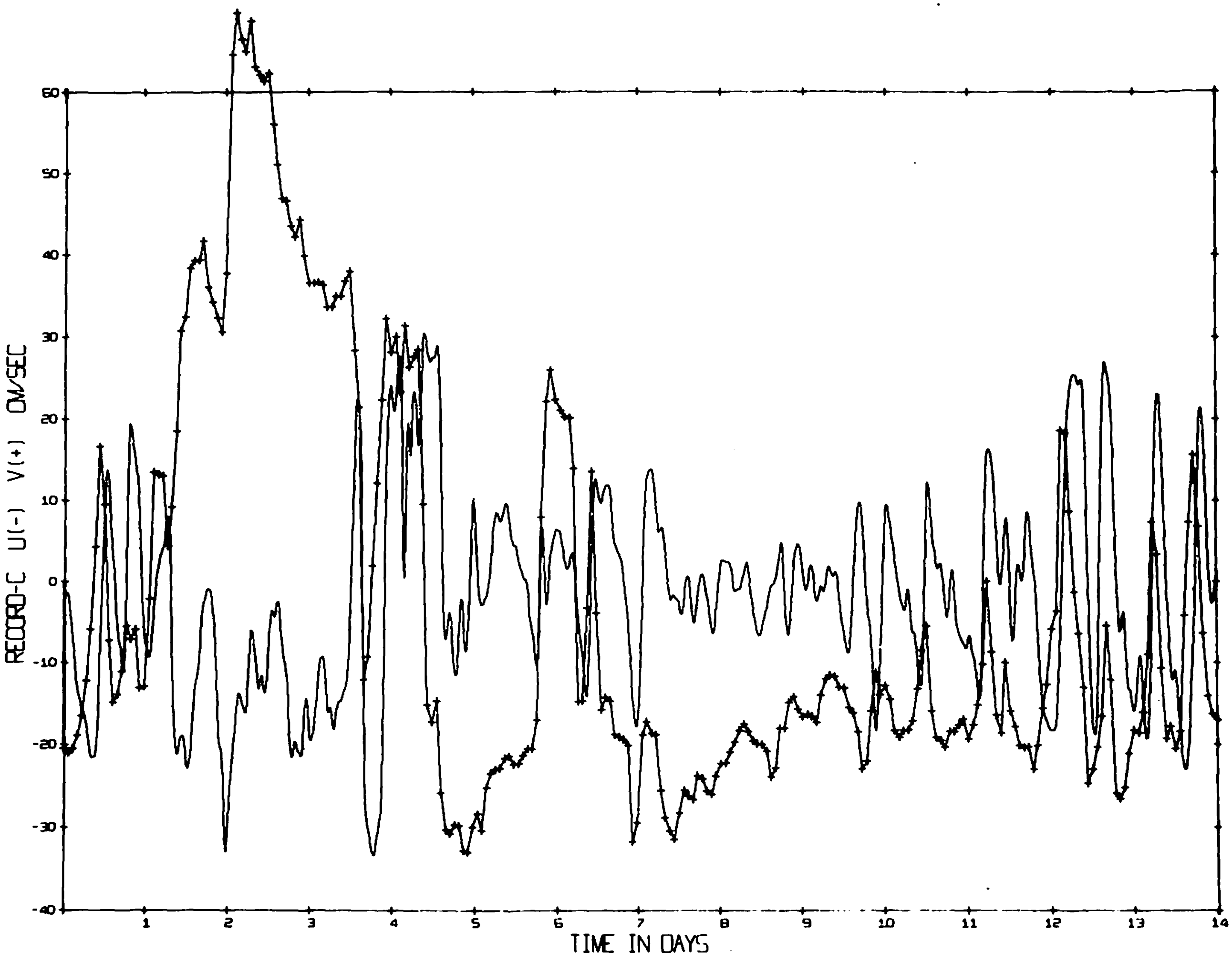


Fig. A-3 (cont.). Start time: 2100 19 December 1967

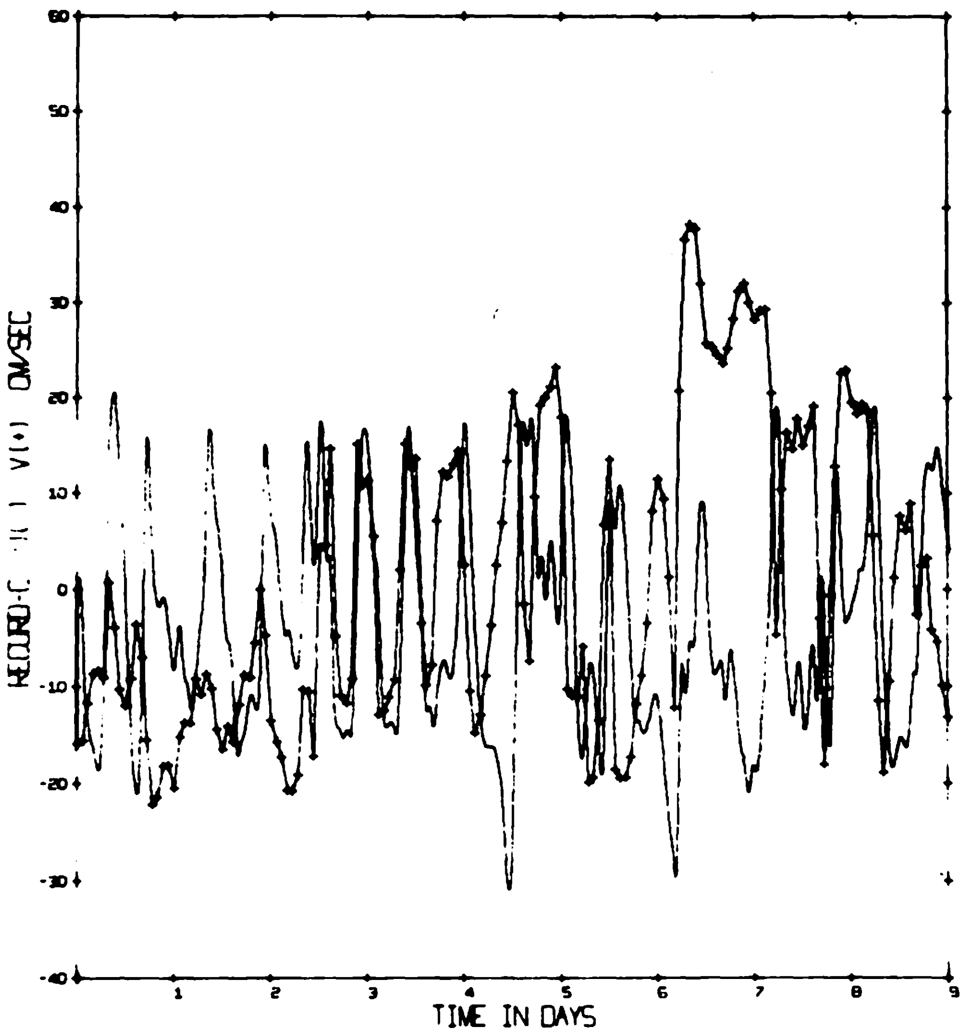


Fig. A-3 (cont.). Start time: 2100 2 January 1968

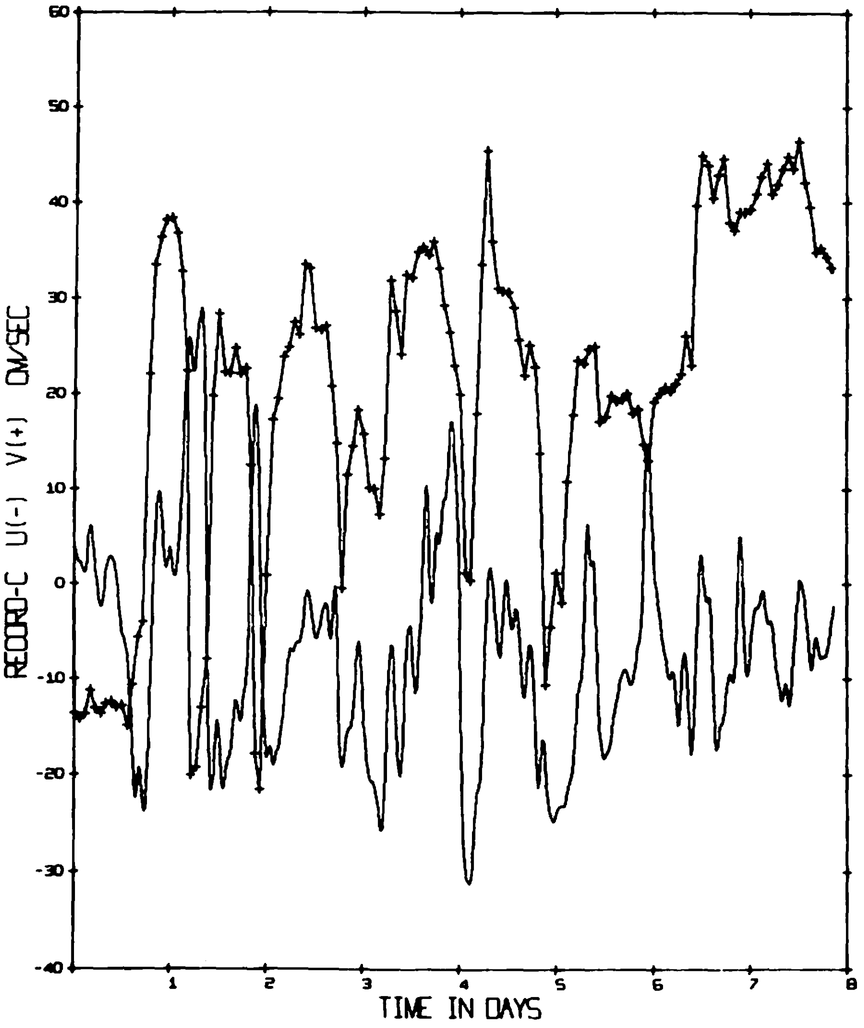


Fig. A-3 (cont.). Start time: 2100 11 January 1968

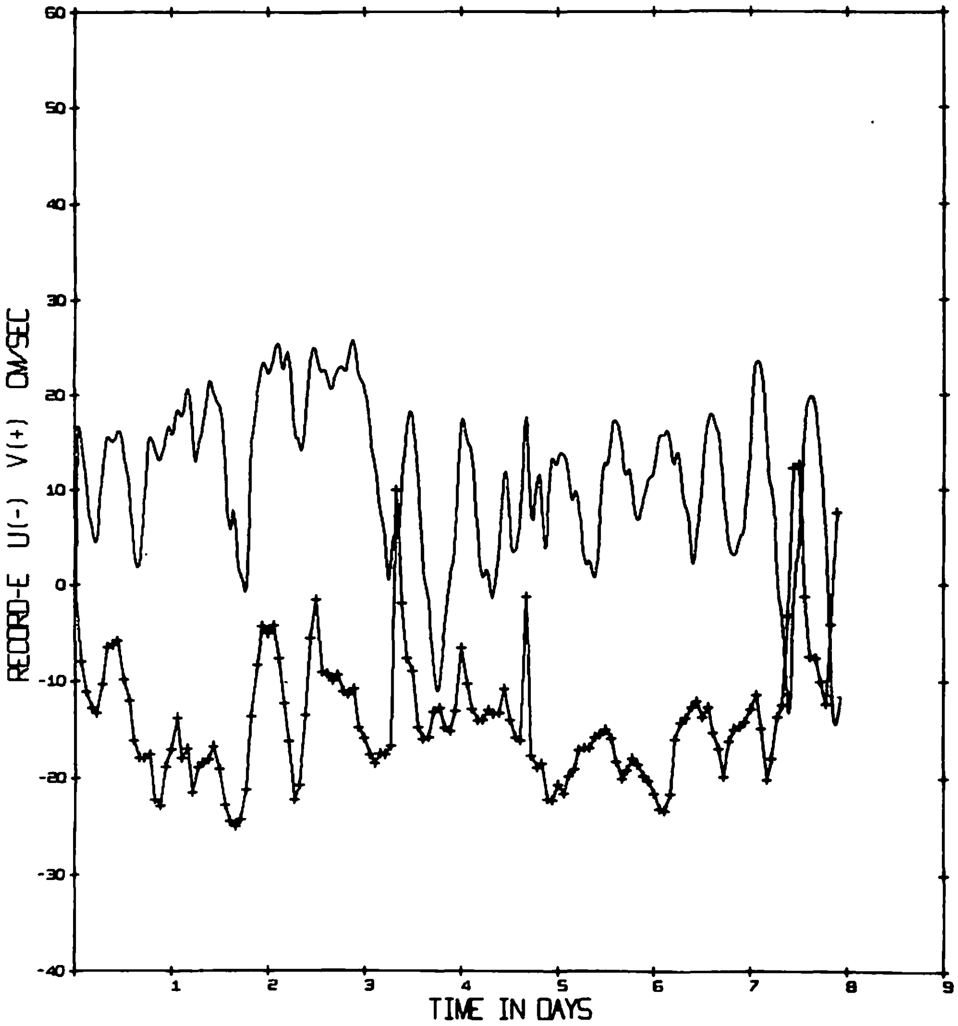


Fig. A-4. Record E time series. Start time: 1400 2 April 1968

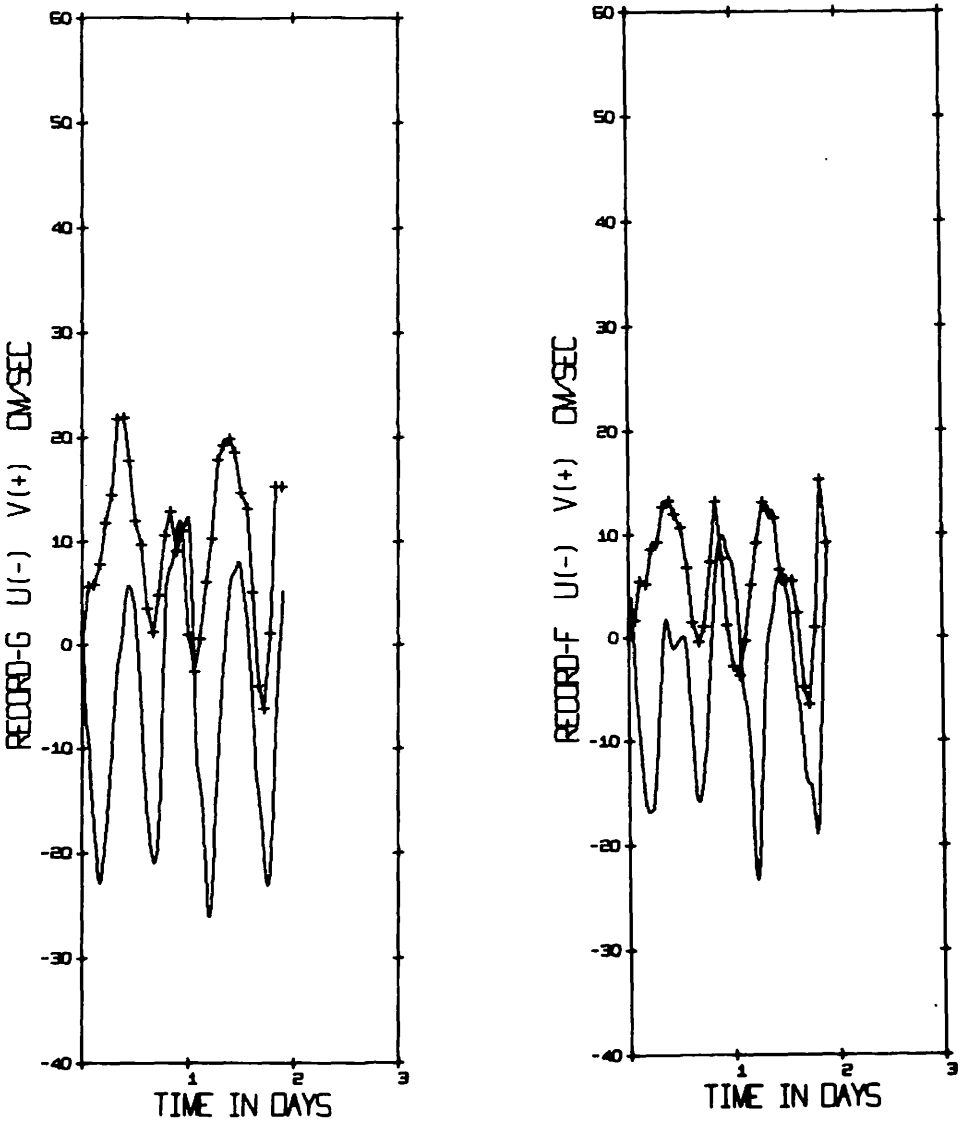


Fig. A-5. Records G (left) and F (right) time series. Start time: 1200 13 May 1968

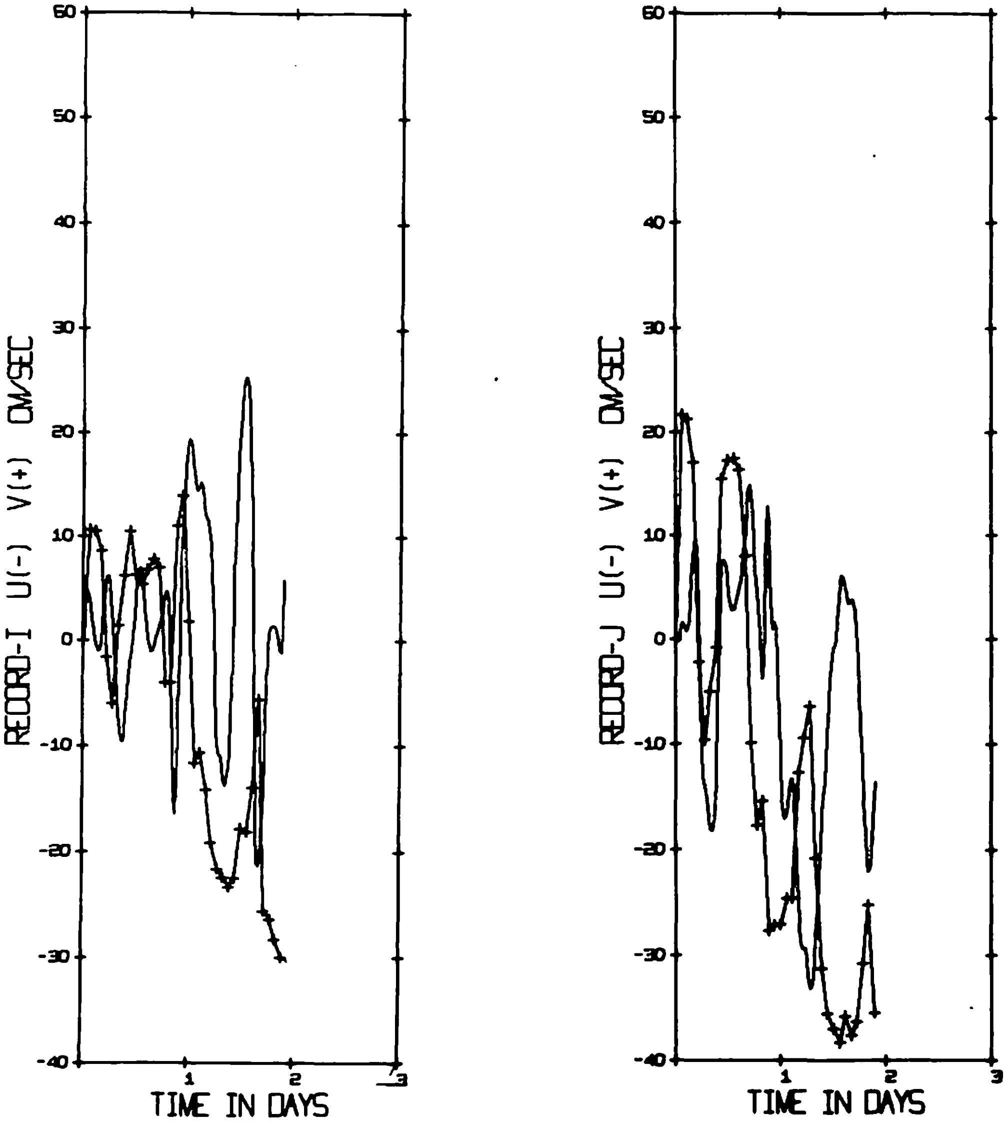


Fig. A-6. Records I (left) and J (right) time series. Start time: 1300 16 July 1968

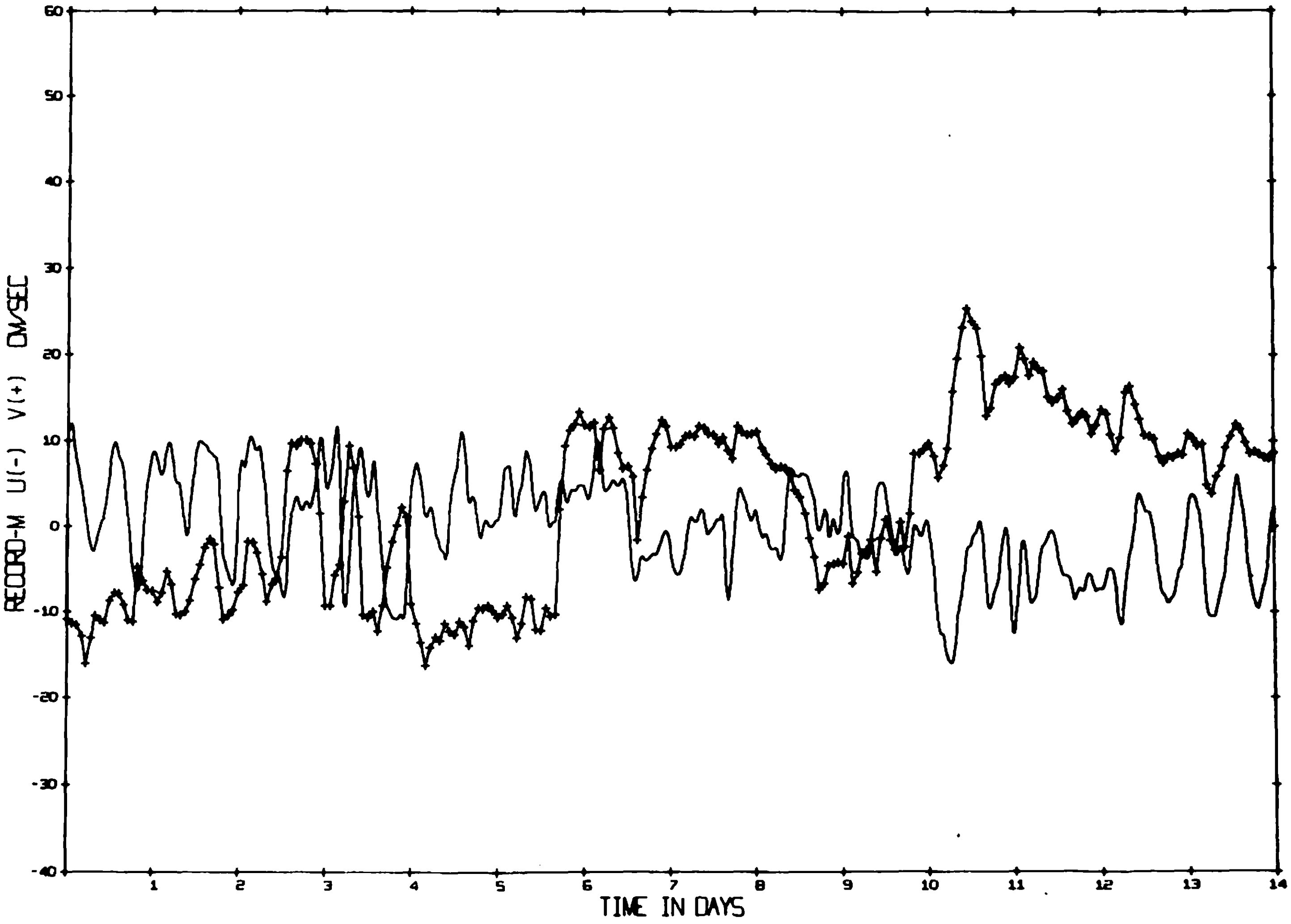


Fig. A-7. Record M time series. Start time: 2000 23 September 1968

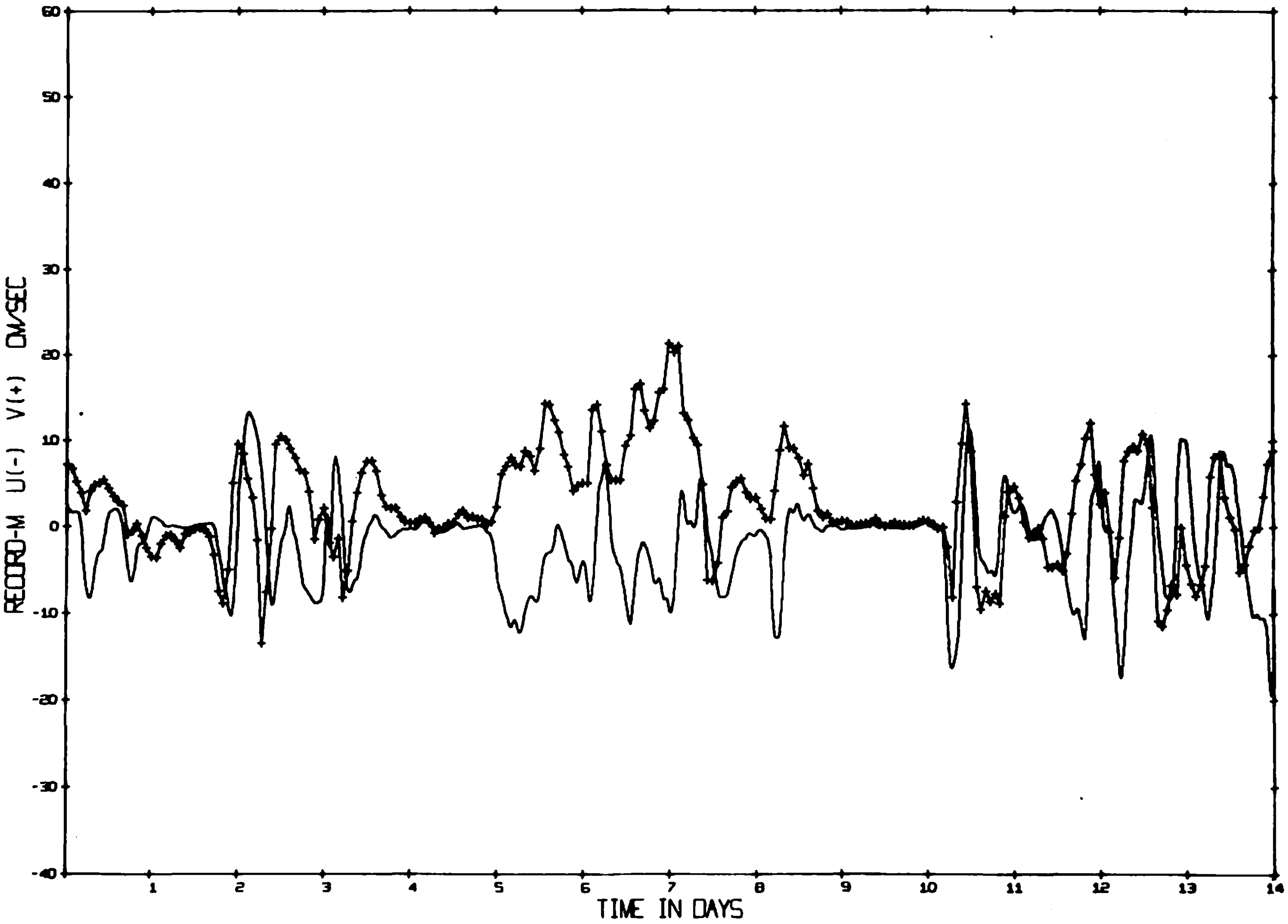


Fig. A-7 (cont.). Start time: 2000 7 October 1968

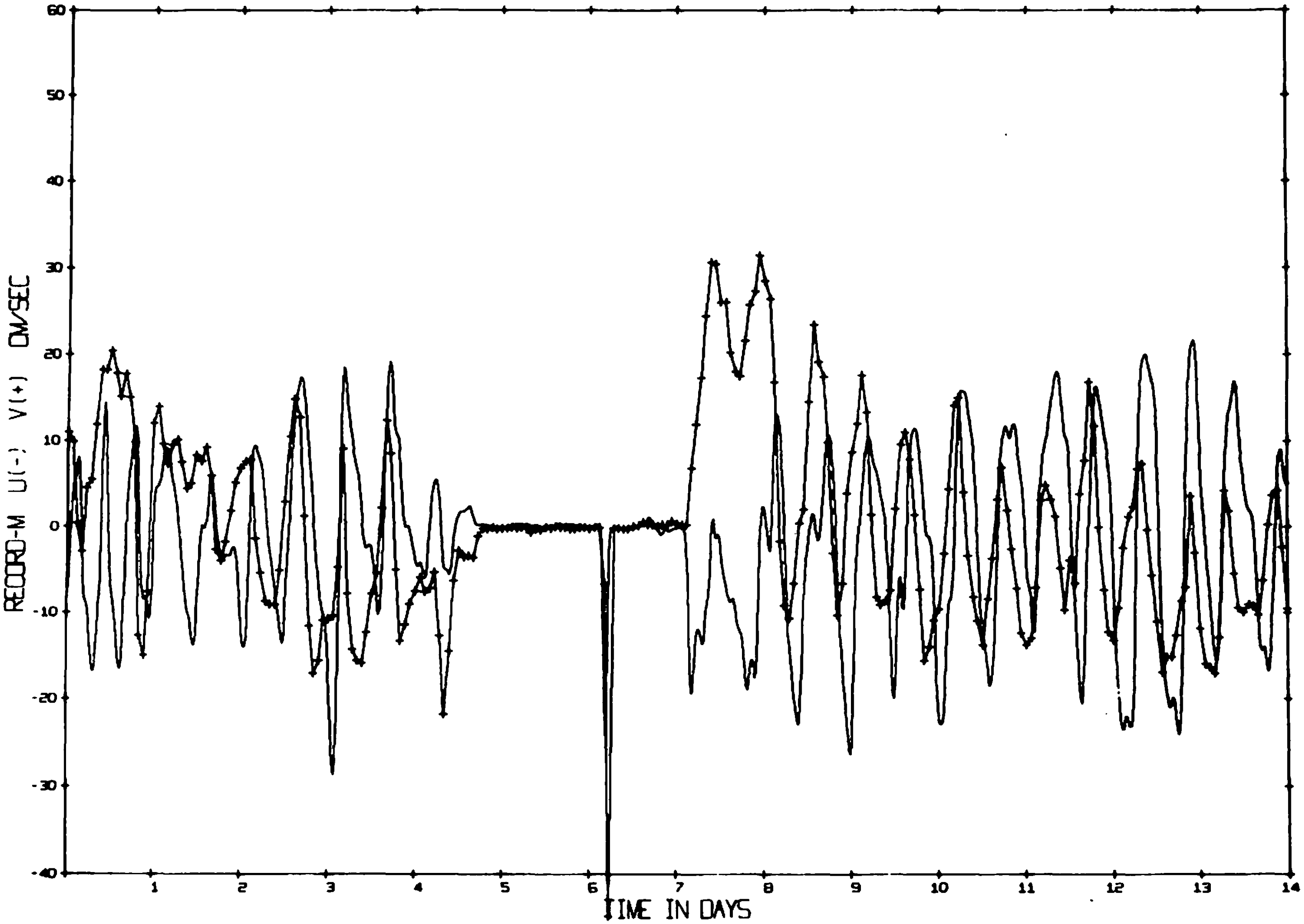


Fig. A-7 (cont.). Start time: 2000 21 October 1968

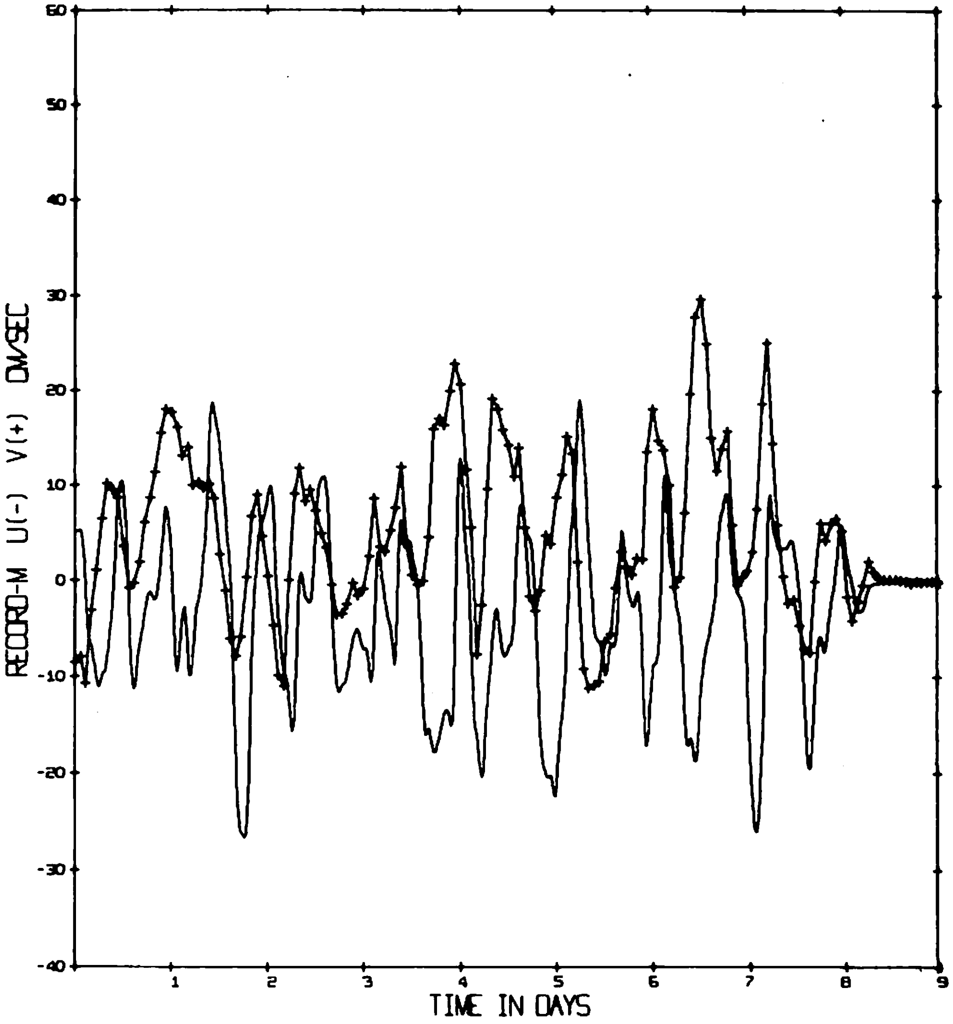


Fig. A-7 (cont.). Start time: 2000 4 November 1968

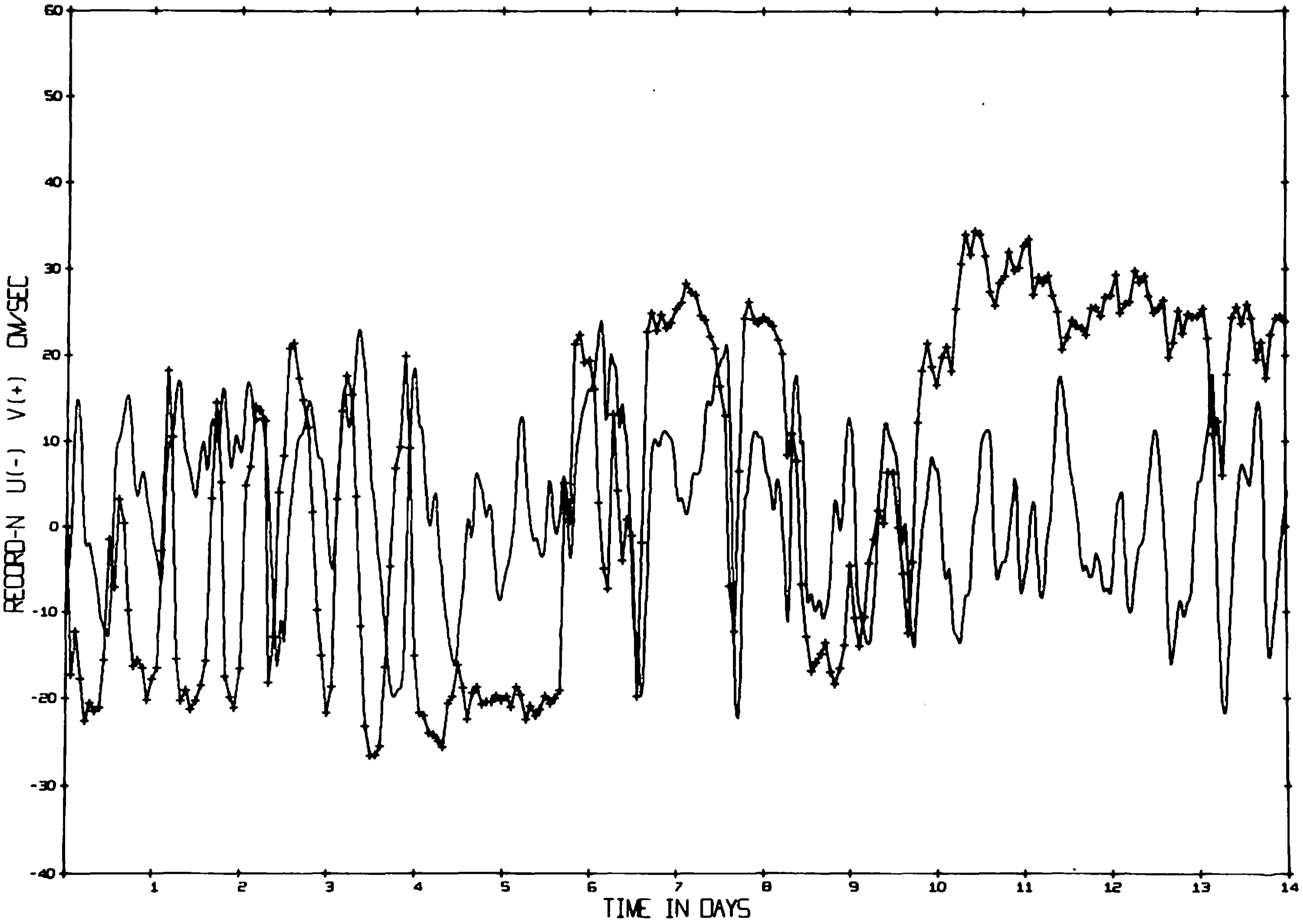


Fig. A-8. Record N time series. Start time: 1900 23 September 1968

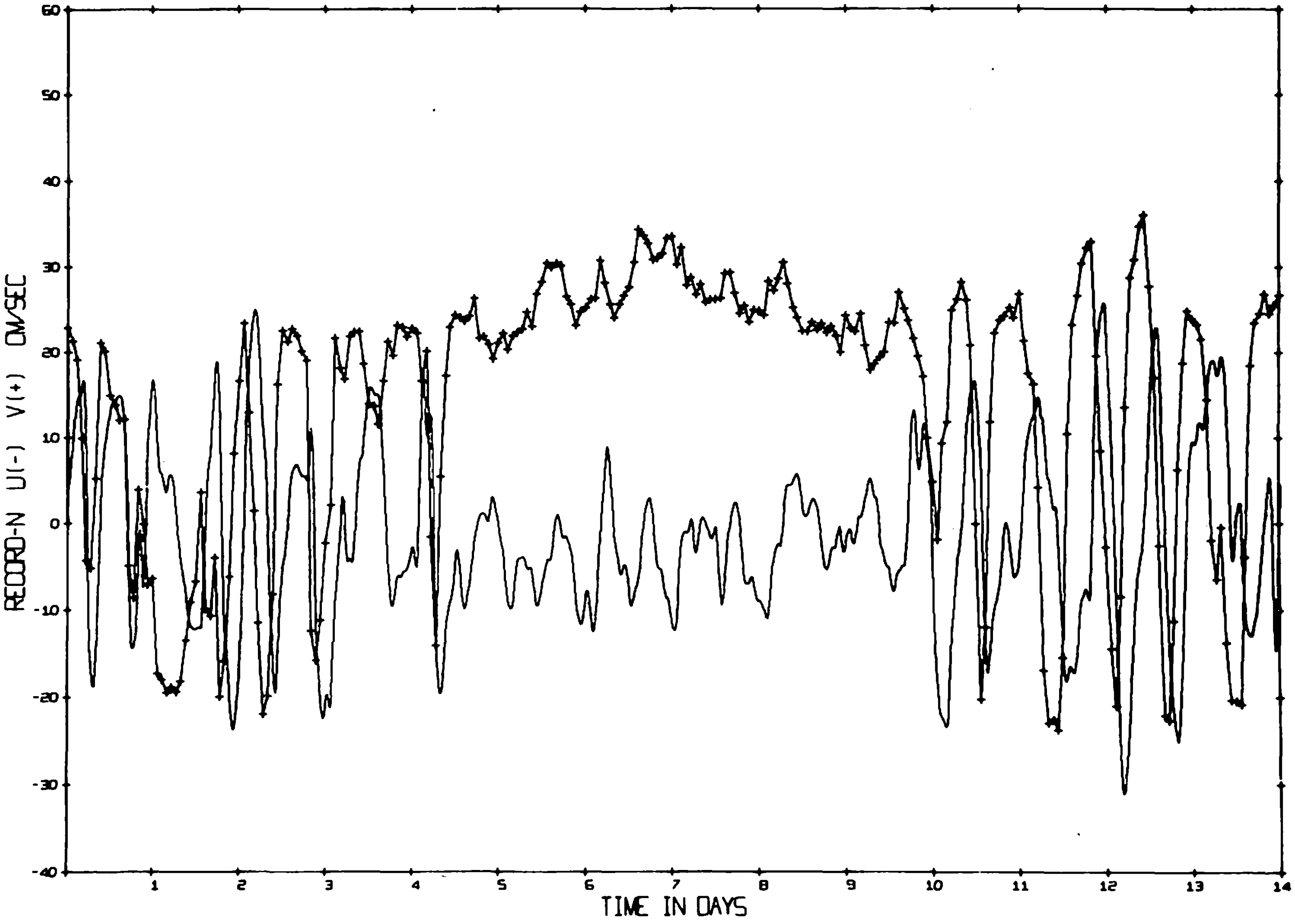


Fig. A-8 (cont.). Start time: 1900 7 October 1968

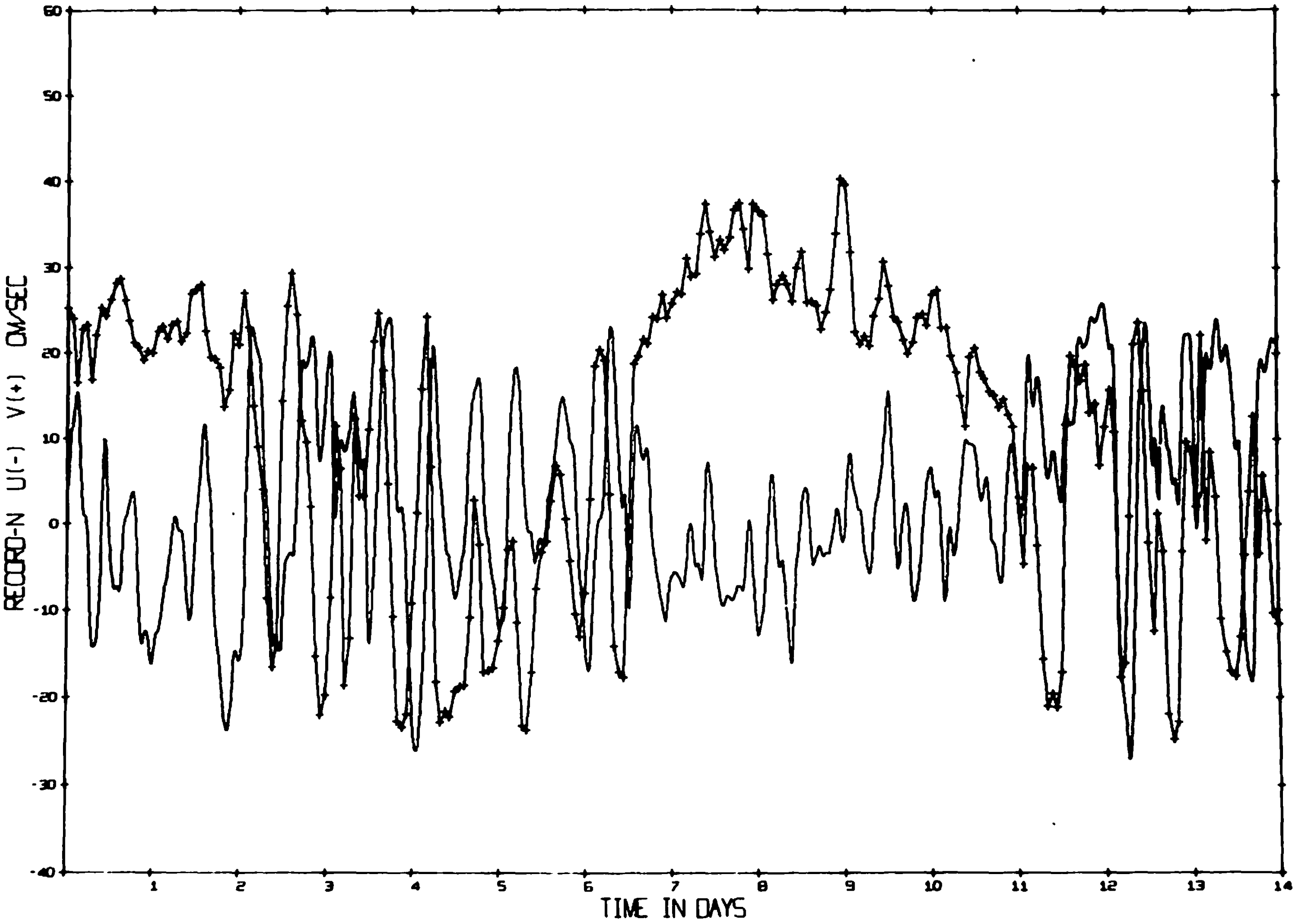


Fig. A-8 (cont.). Start time: 1900 21 October 1968

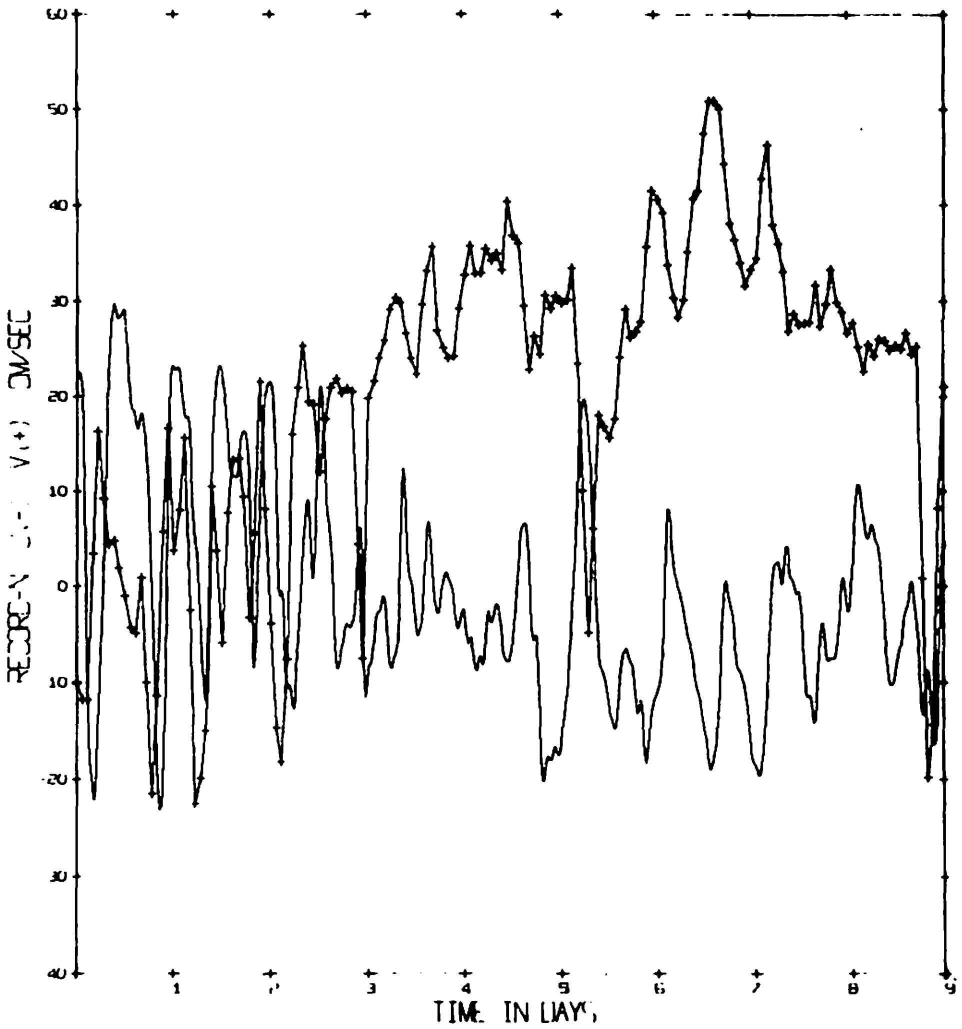


Fig. A-8 (cont.). Start time: 1900 4 November 1968

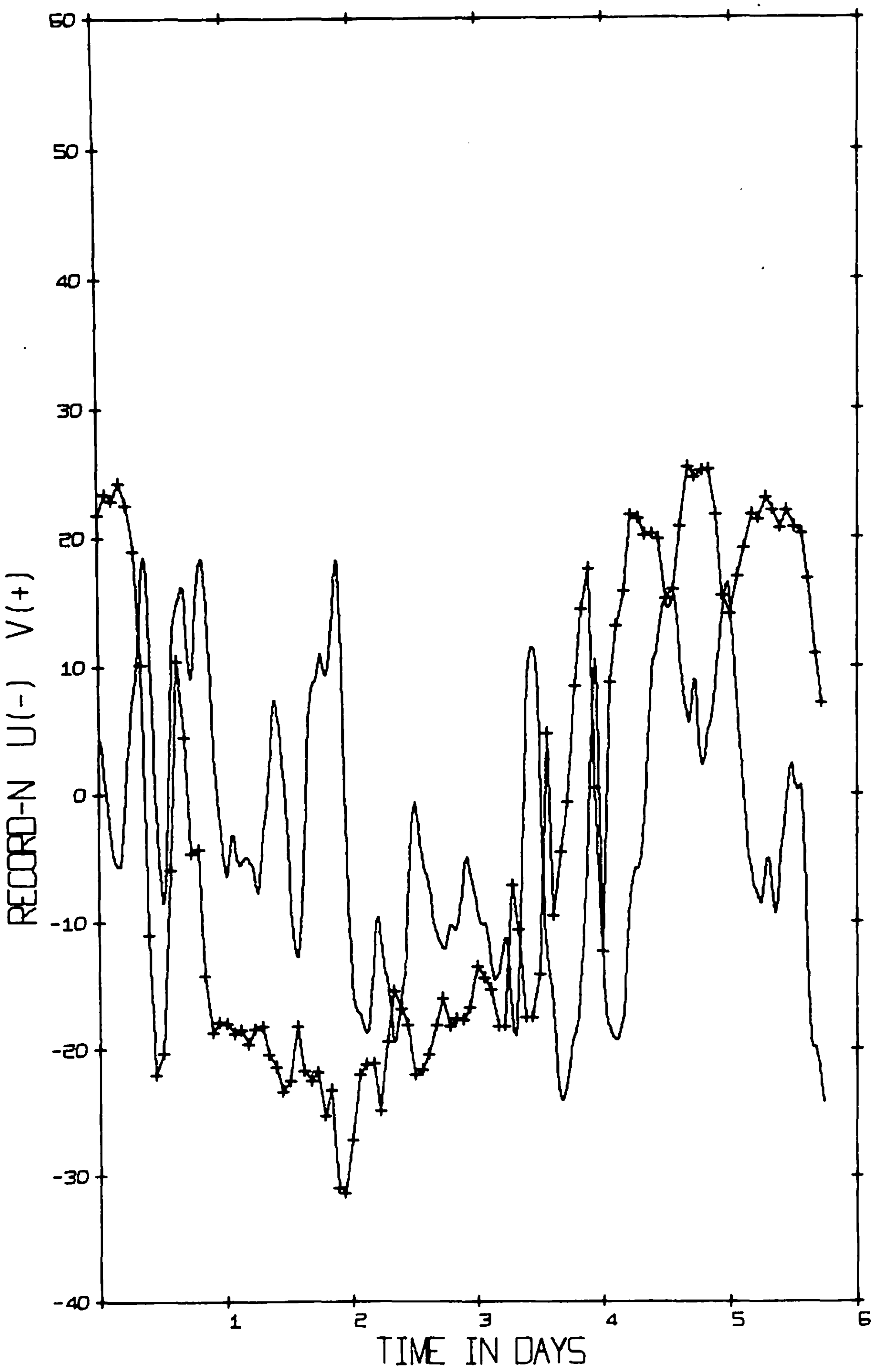


Fig. A-8 (cont.). Start time: 1900 13 November 1968

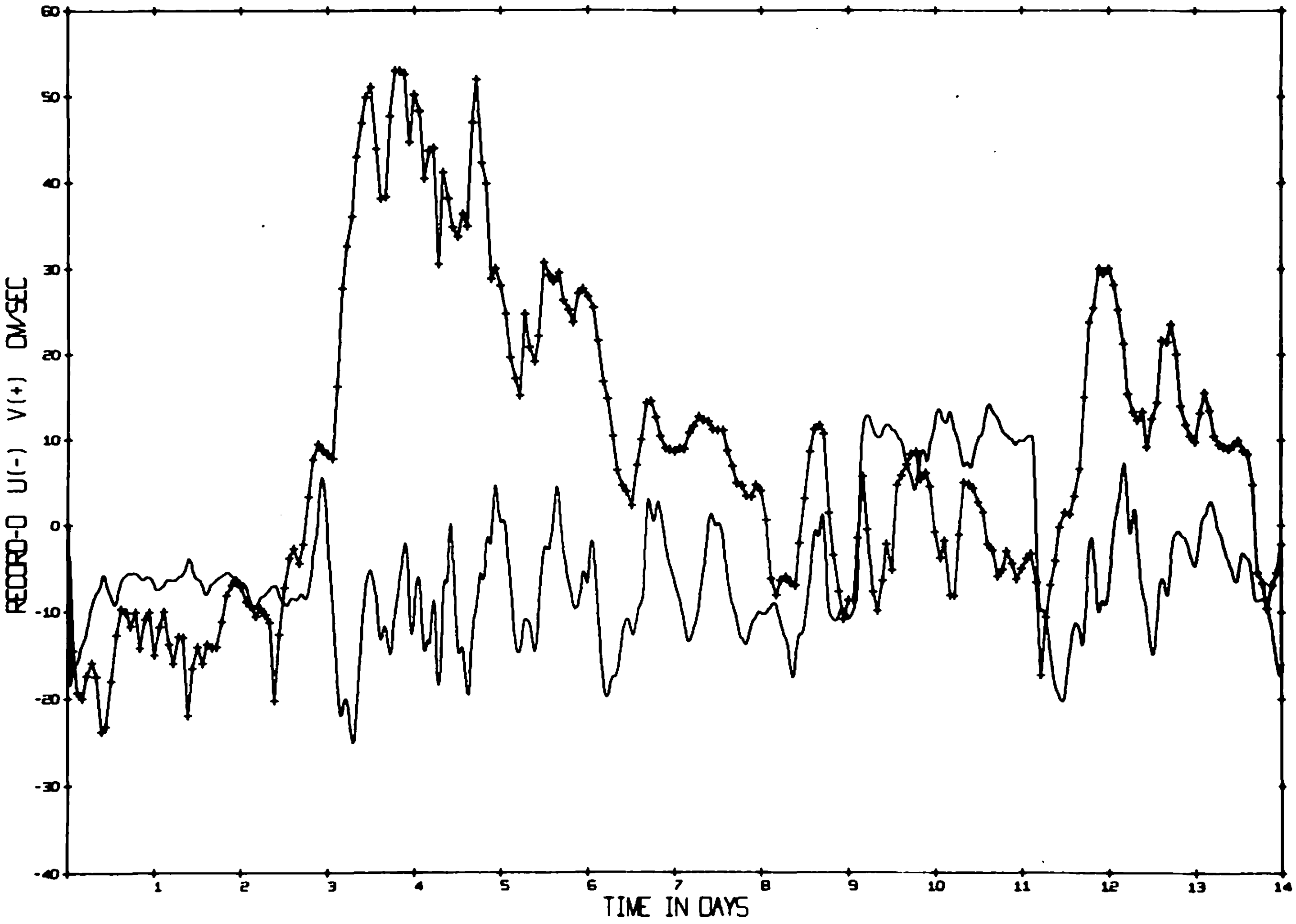


Fig. A-9. Record O time series. Start time: 1300 19 December 1968

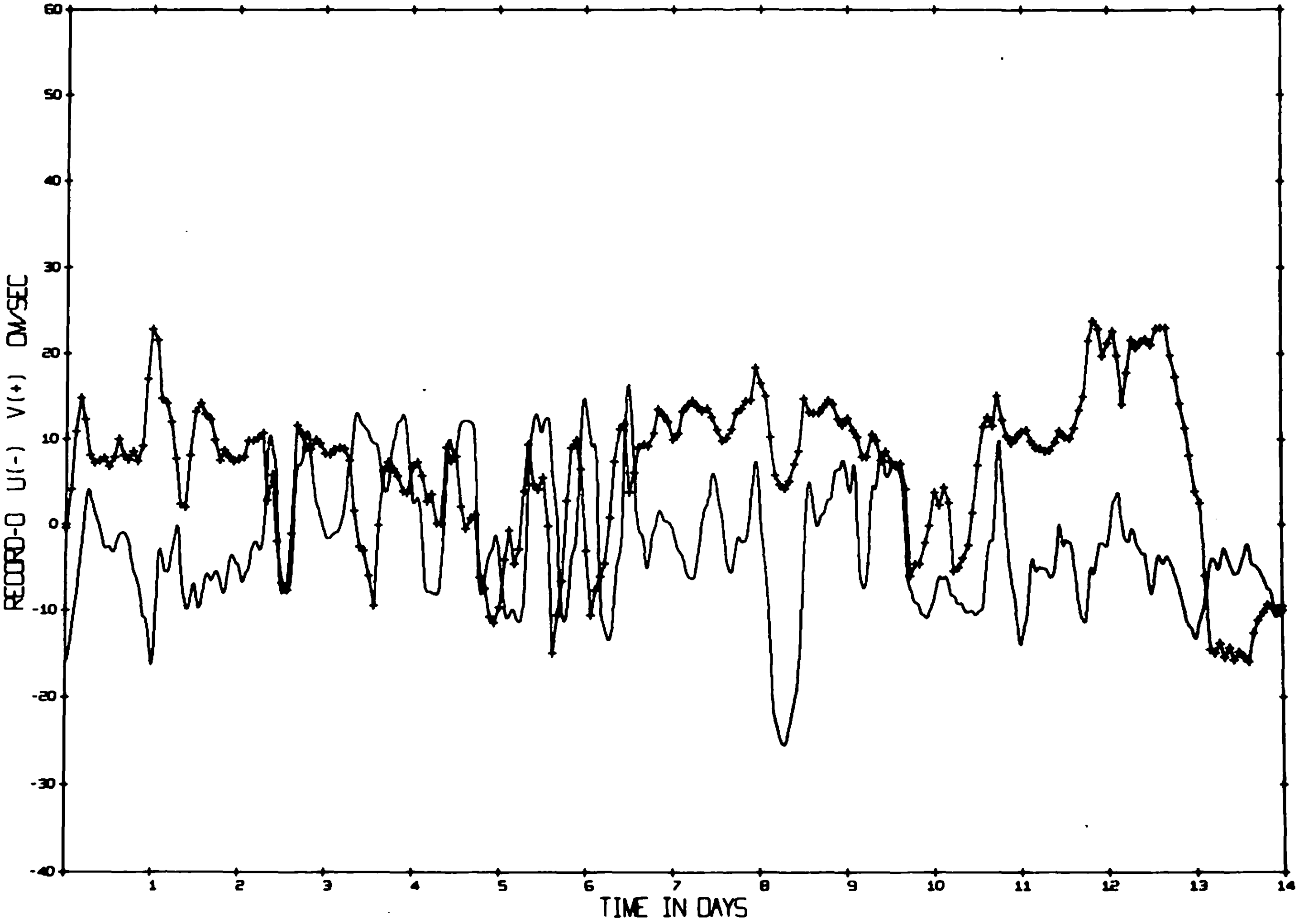


Fig. A-9 (cont.). Start time: 1300 2 January 1969

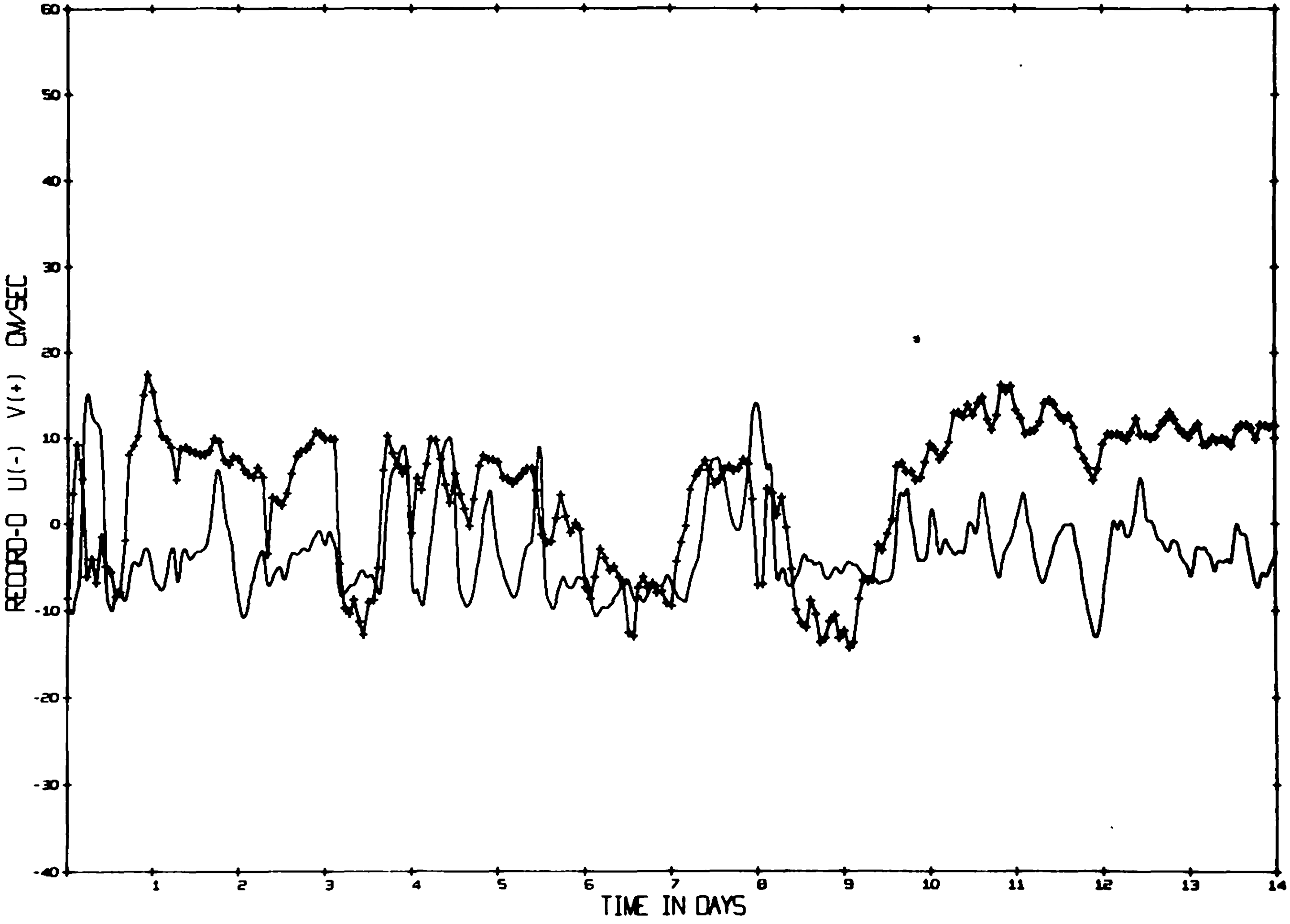


Fig. A-9 (cont.). Start time: 1300 16 January 1969

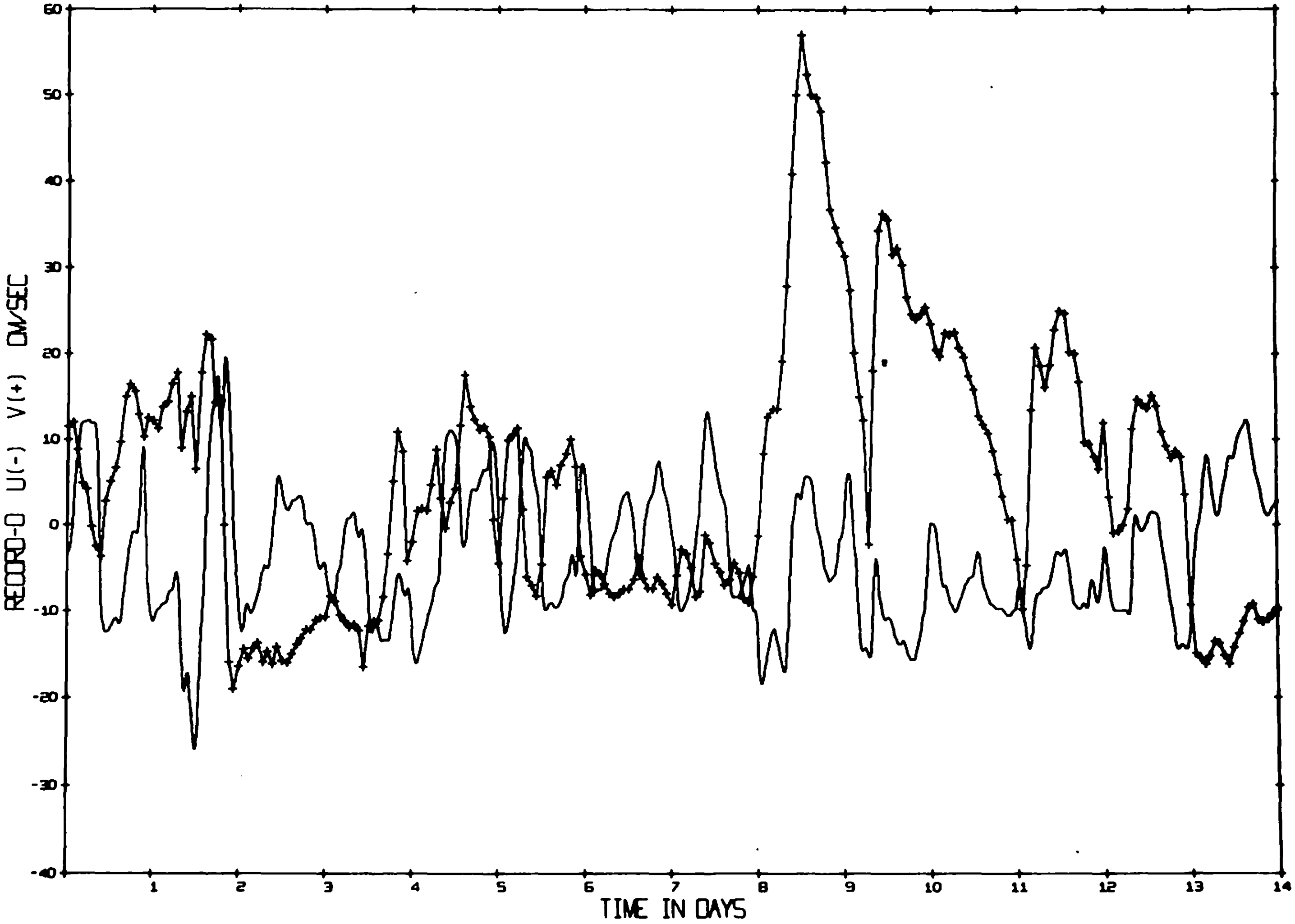


Fig. A-9 (cont.). Start time: 1300 30 January 1969

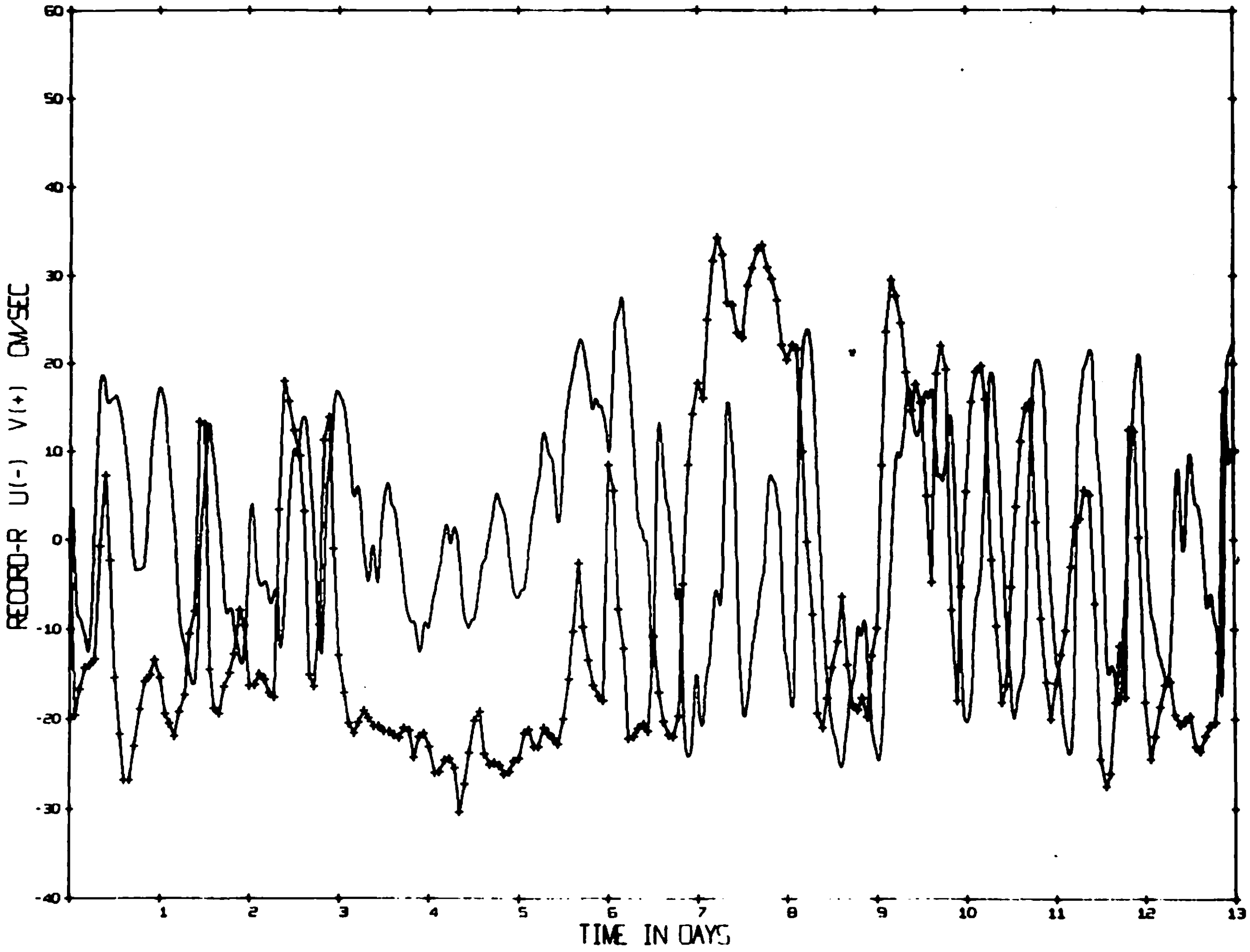


Fig. A-10. Record R time series. Start time: 1400 9 March 1969

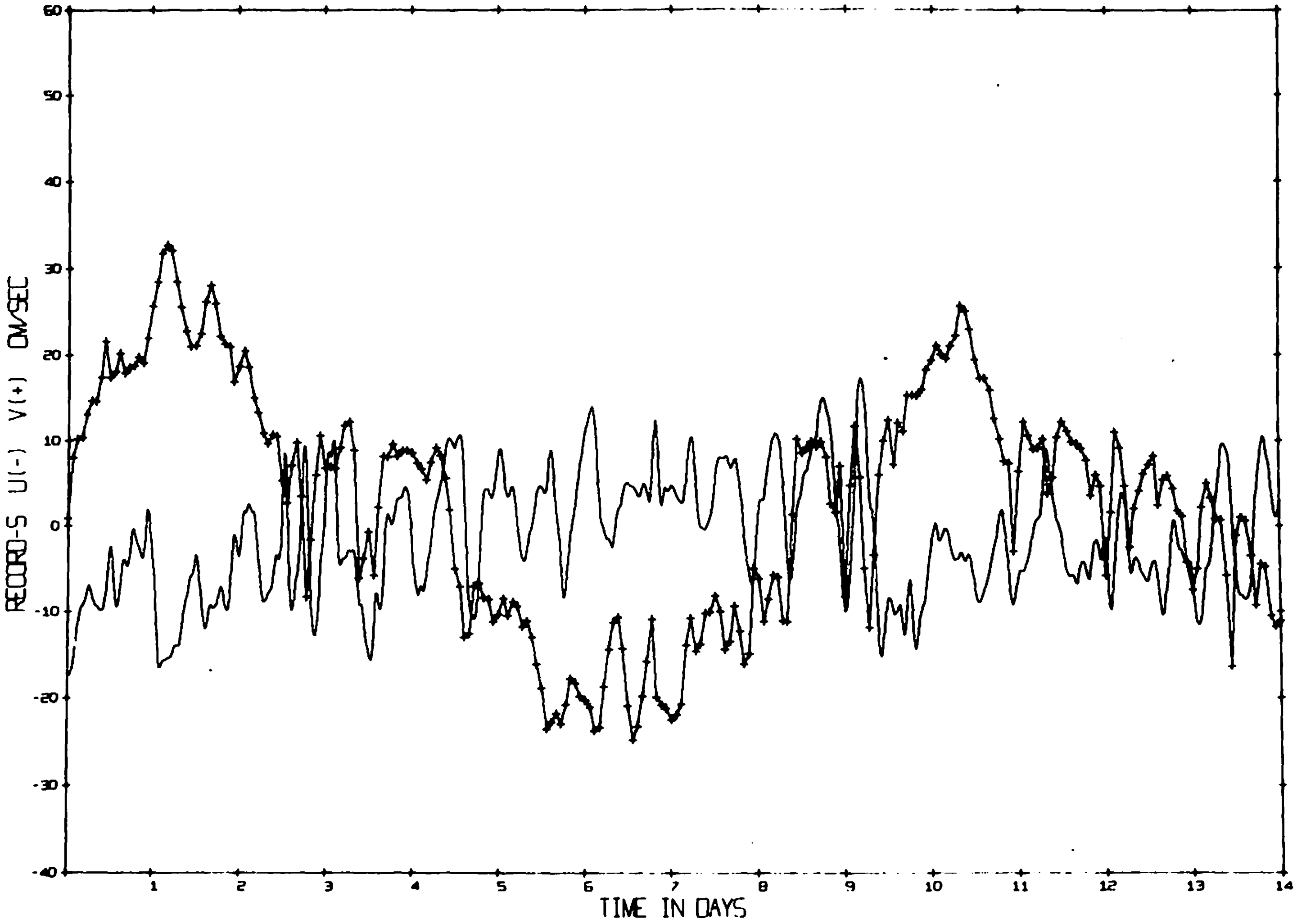


Fig. A-11. Record S time series. Start time: 1900 25 May 1969

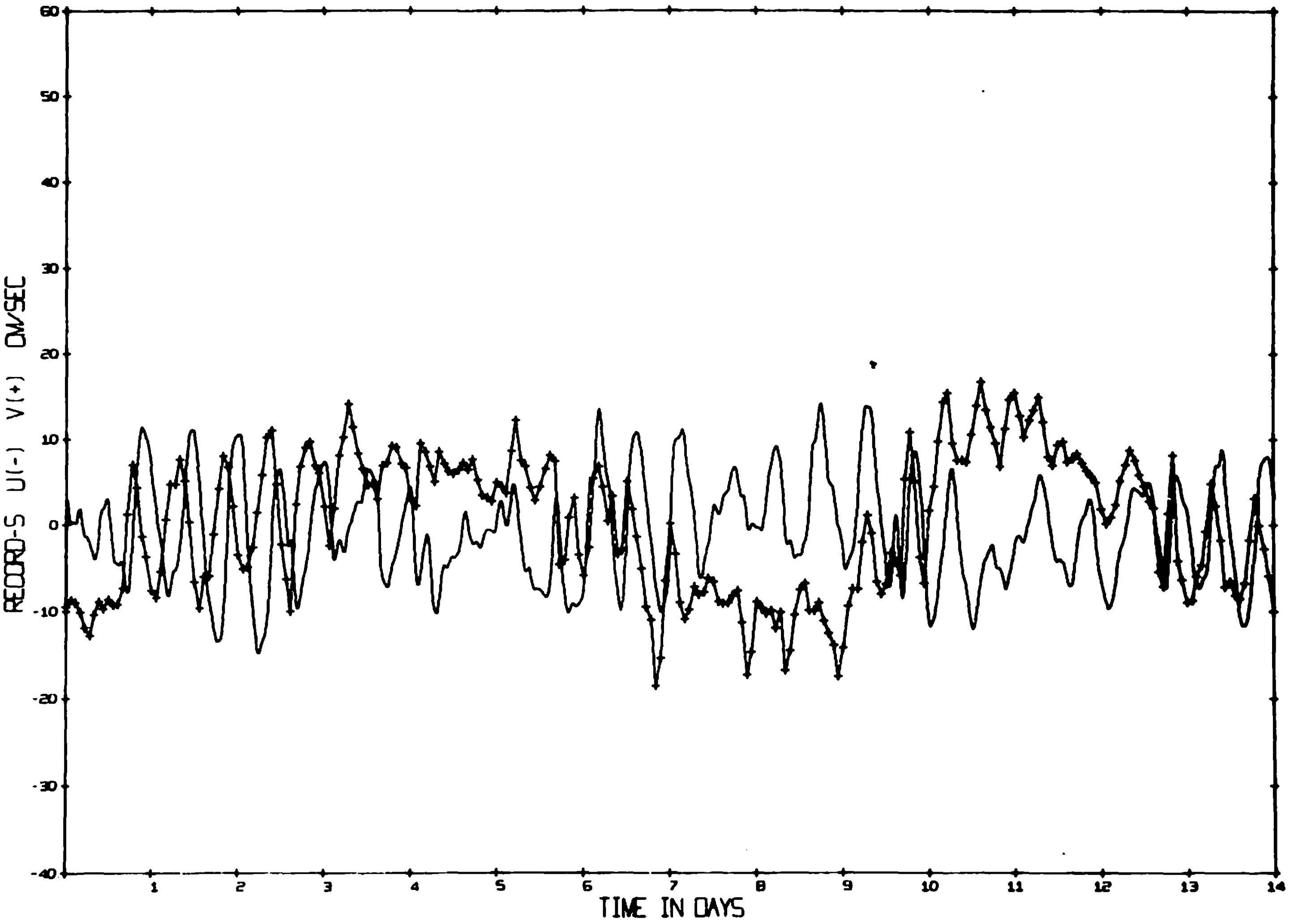


Fig. A-11 (cont.). Start time: 1900 8 June 1969

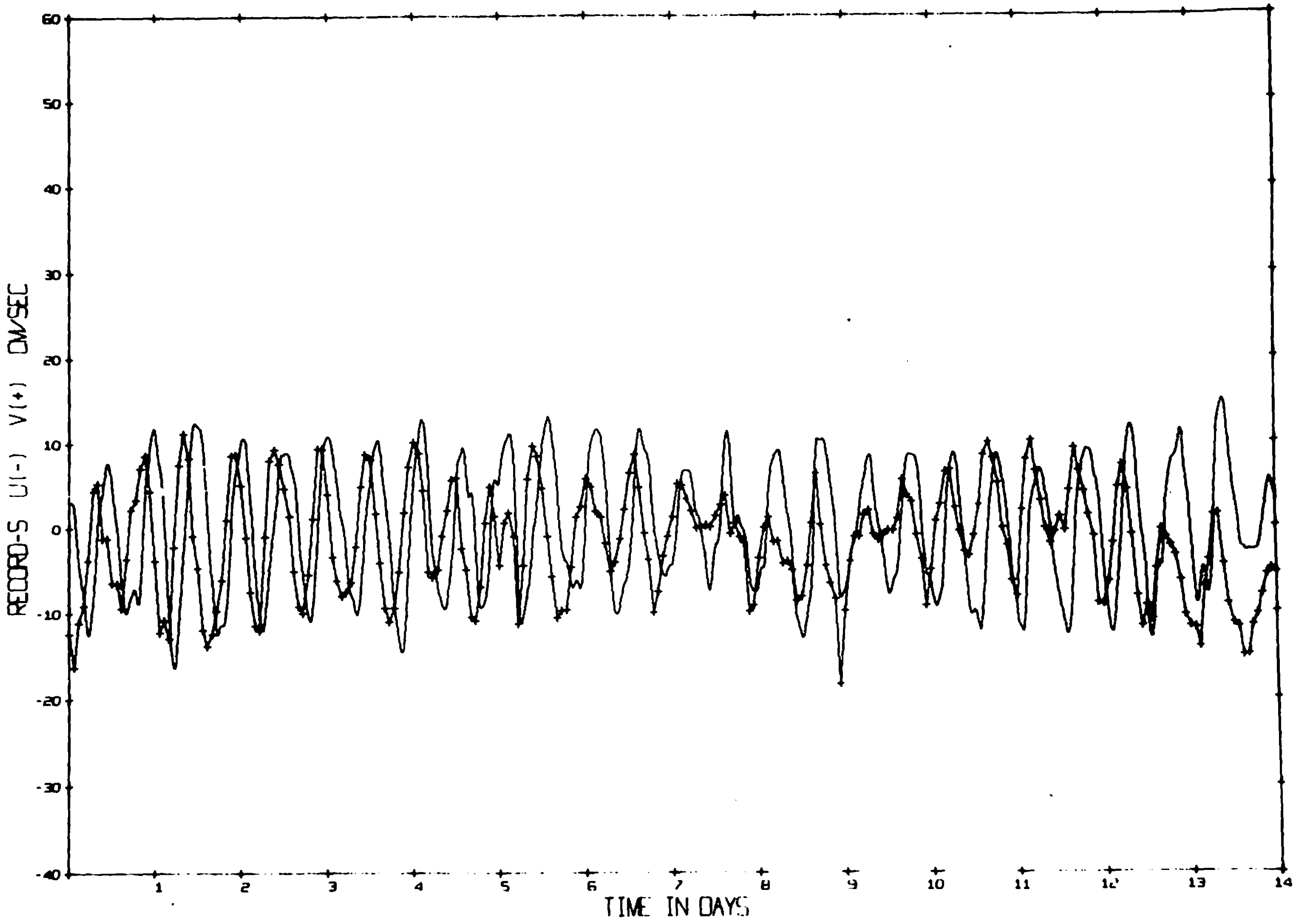


Fig. A-11 (cont.). Start time: 1900 22 June 1969

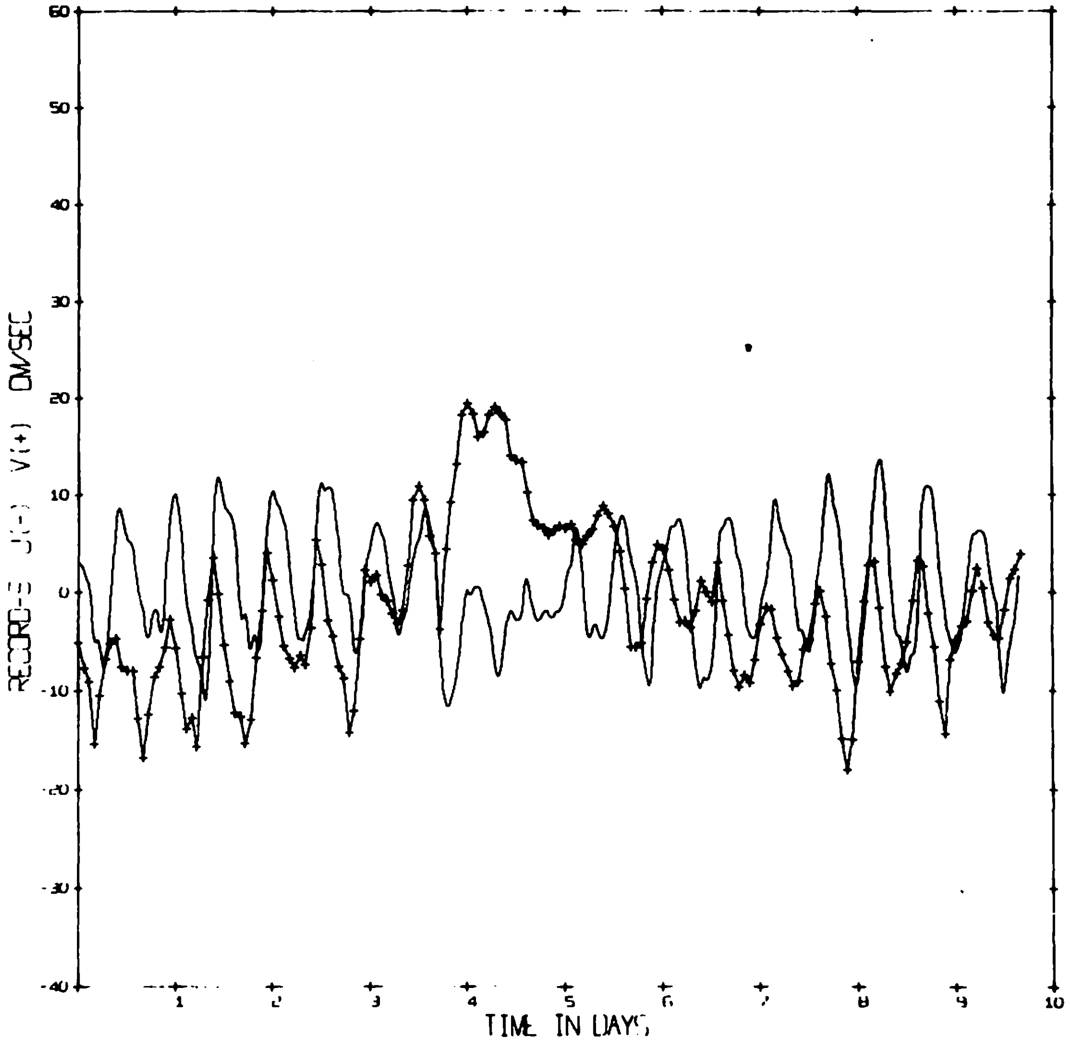


Fig. A-11 (cont.). Start time: 1900 6 July 1969

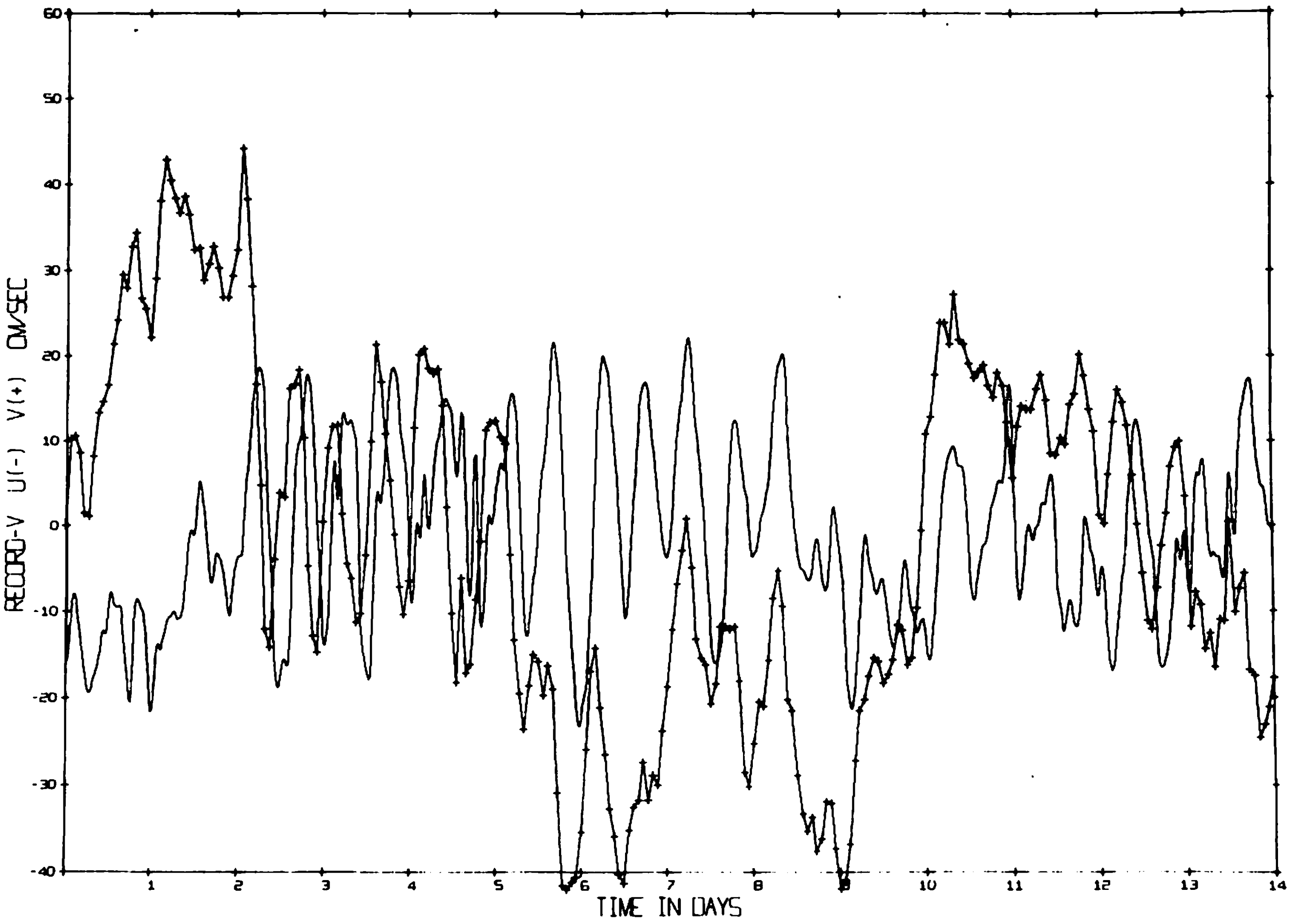


Fig. A-12. Record V time series. Start time: 2000 25 May 1969

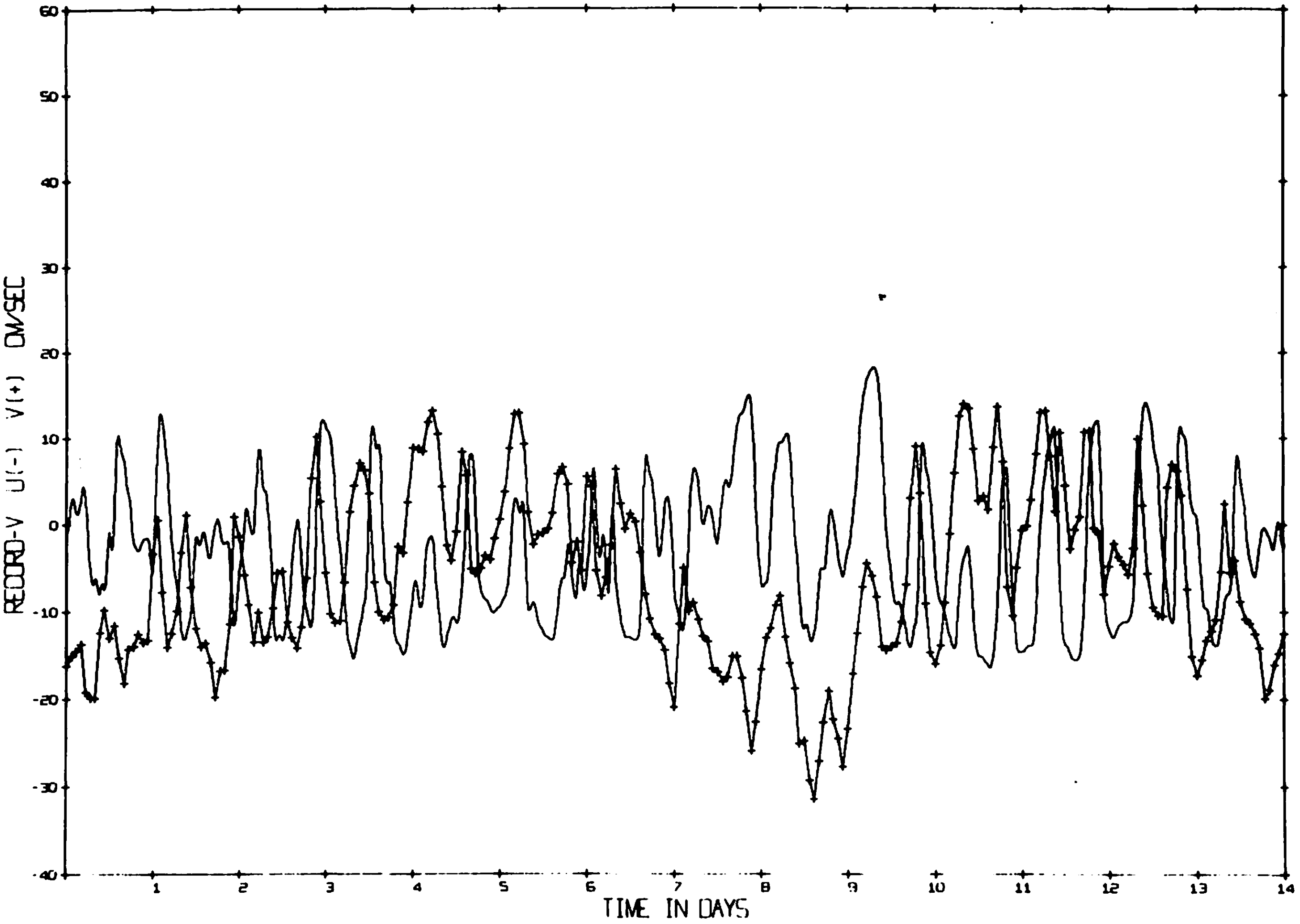


Fig. A-12 (cont.). Start time: 2000 8 June 1969

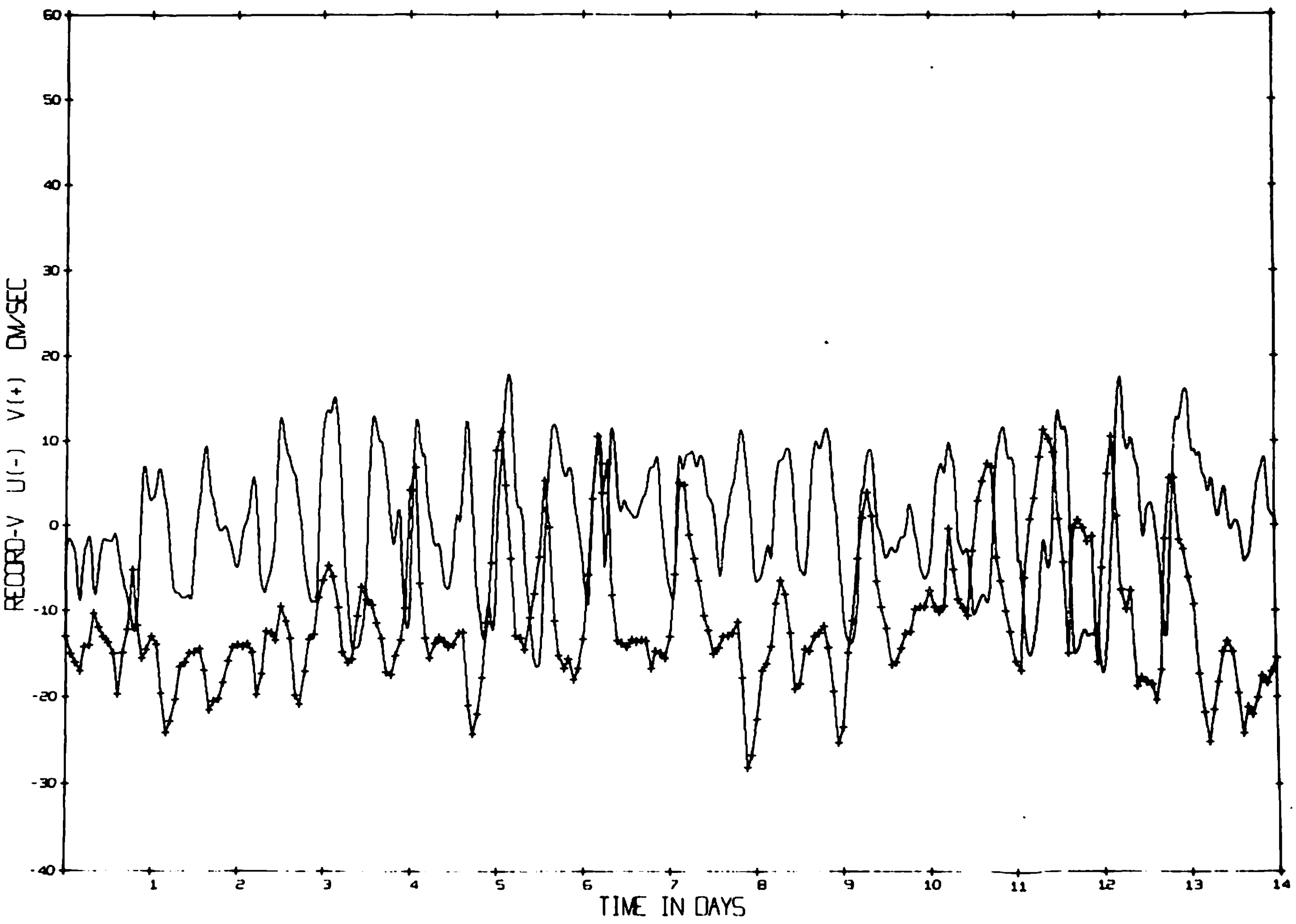


Fig. A-12 (cont.). Start time: 2000 22 June 1969

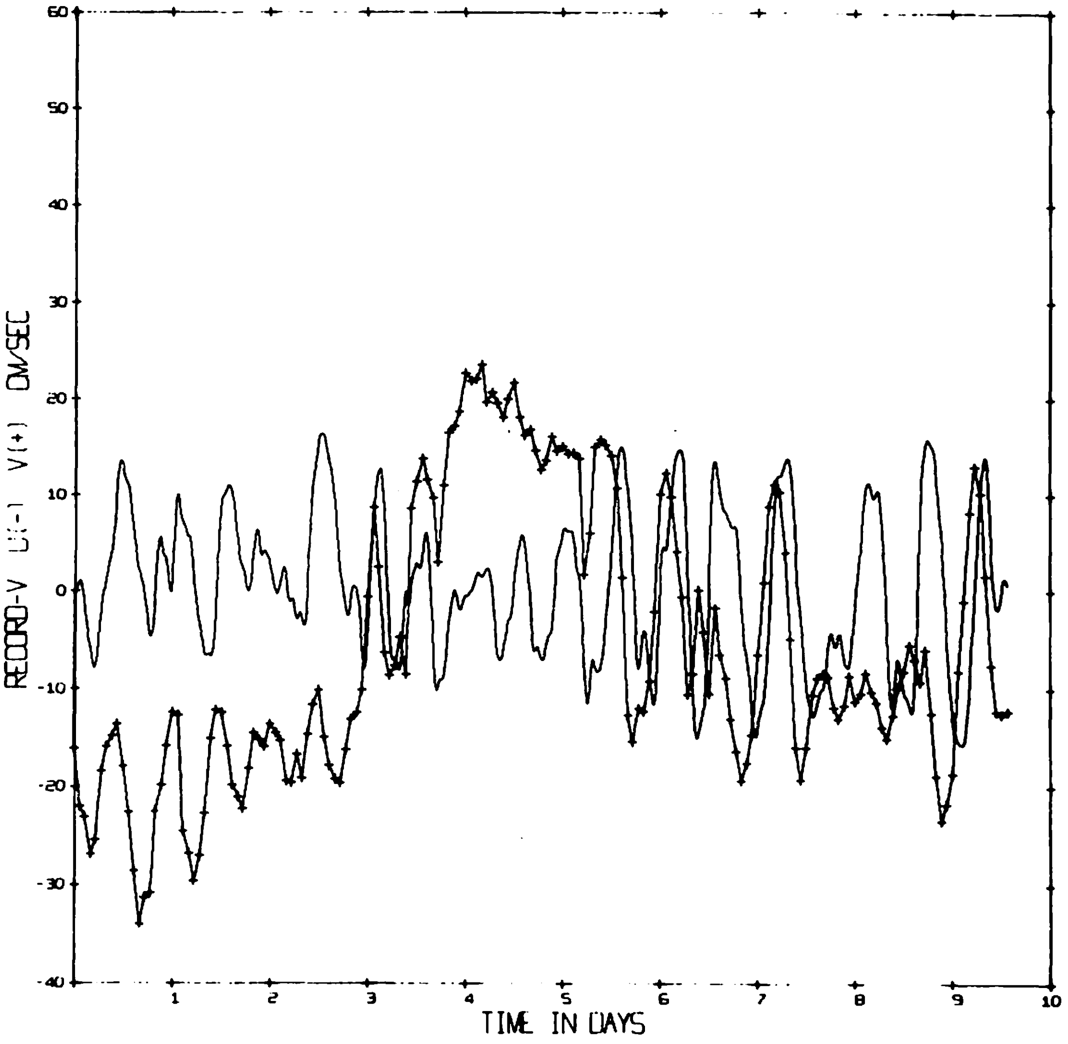


Fig. A-12 (cont.). Start time: 2000 6 July 1969

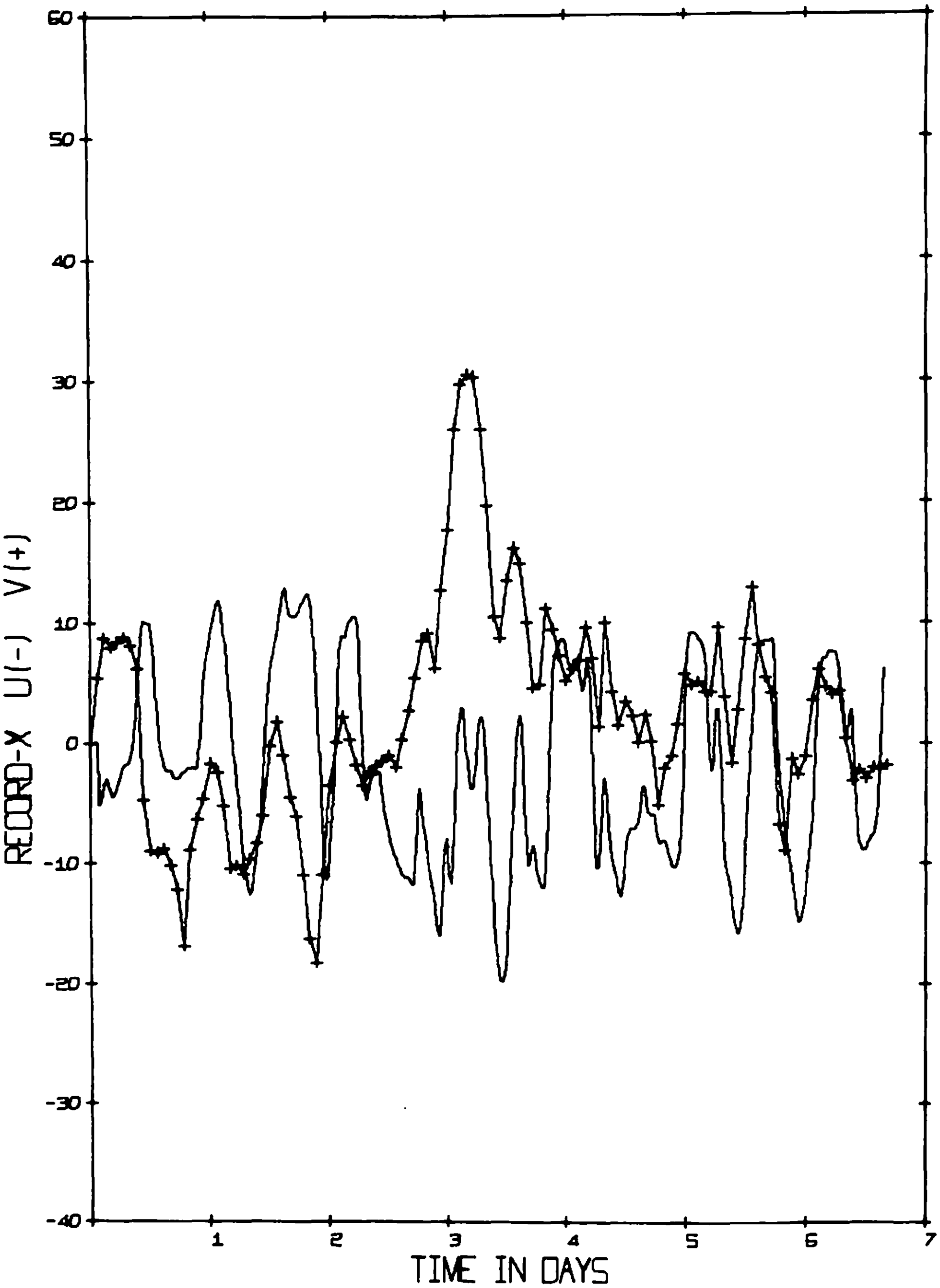


Fig. A-13. Record X time series. Start time: 1900 21 August 1969

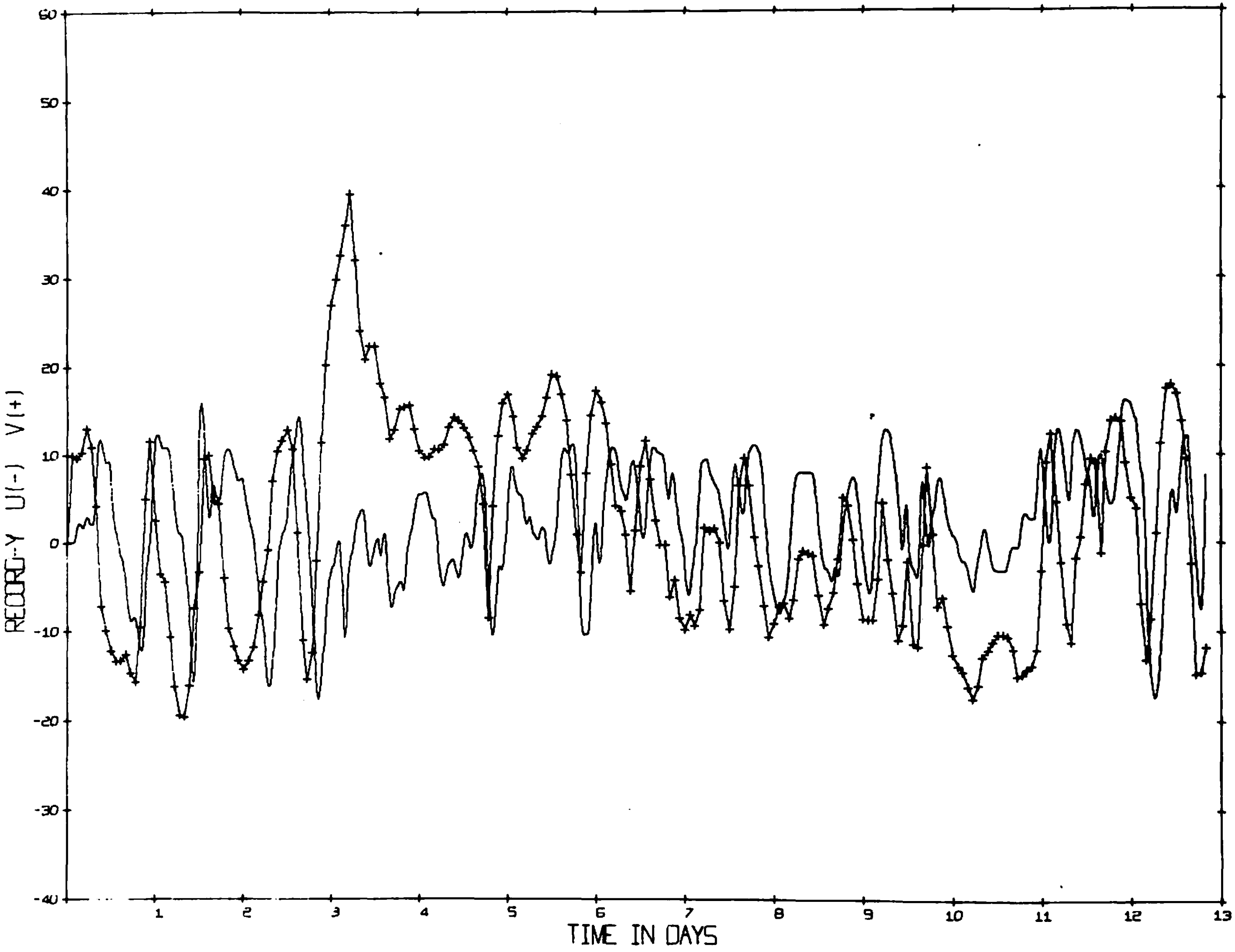


Fig. A-14. Record Y time series. Start time: 1900 21 August 1969

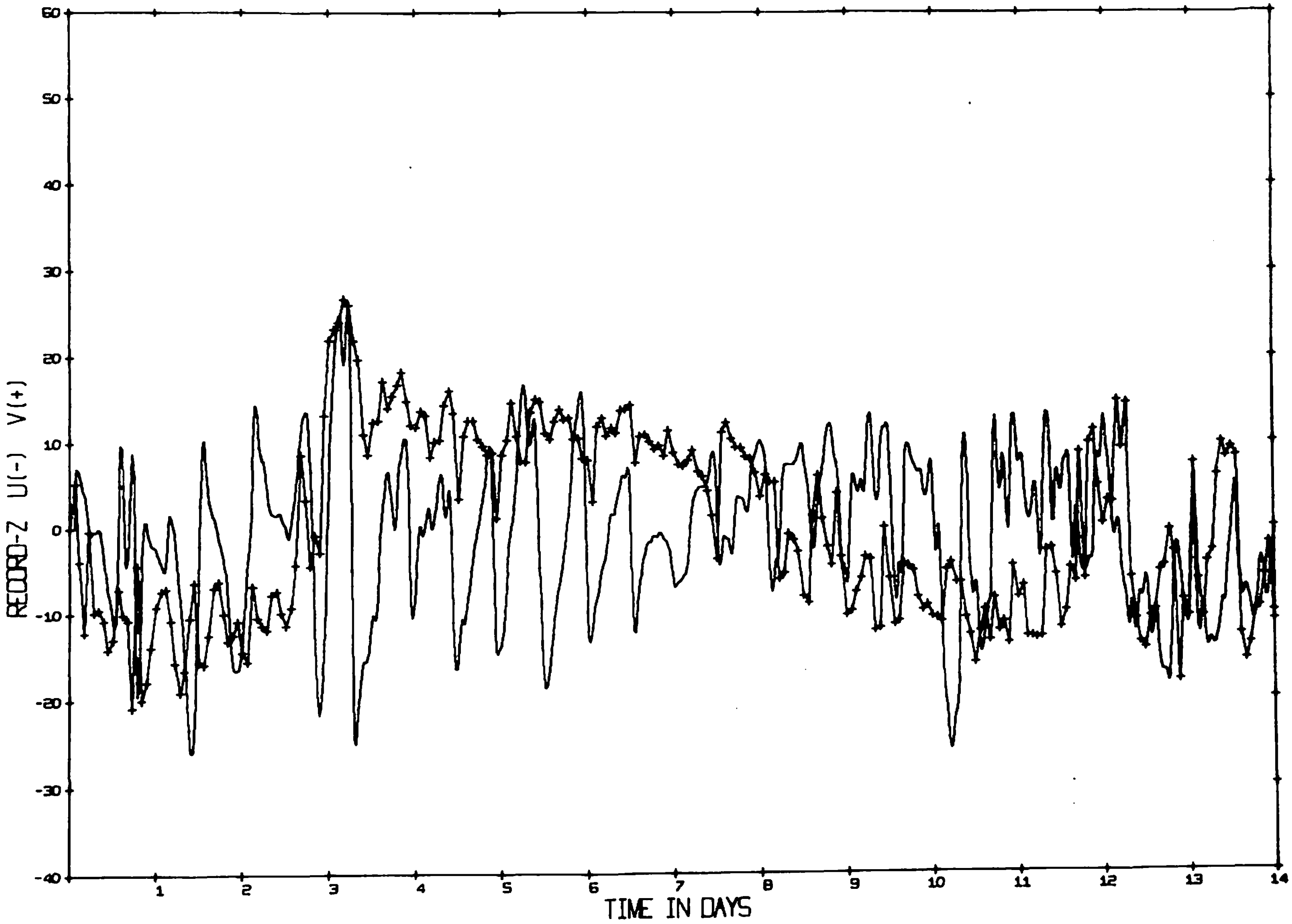


Fig. A-15. Record Z time series. Start time: 1900 21 August 1969

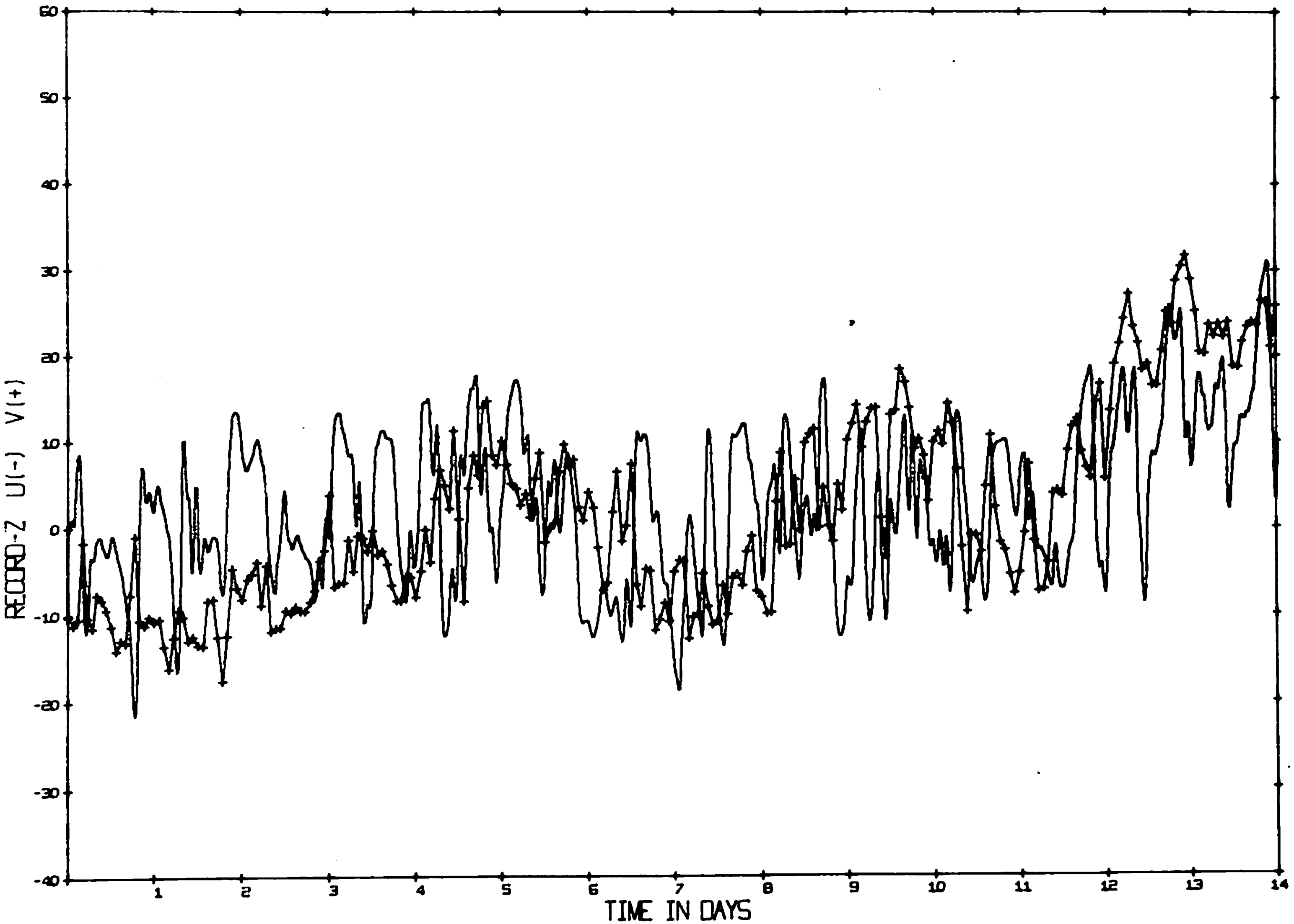


Fig. A-15 (cont.). Start time: 1900 4 September 1969

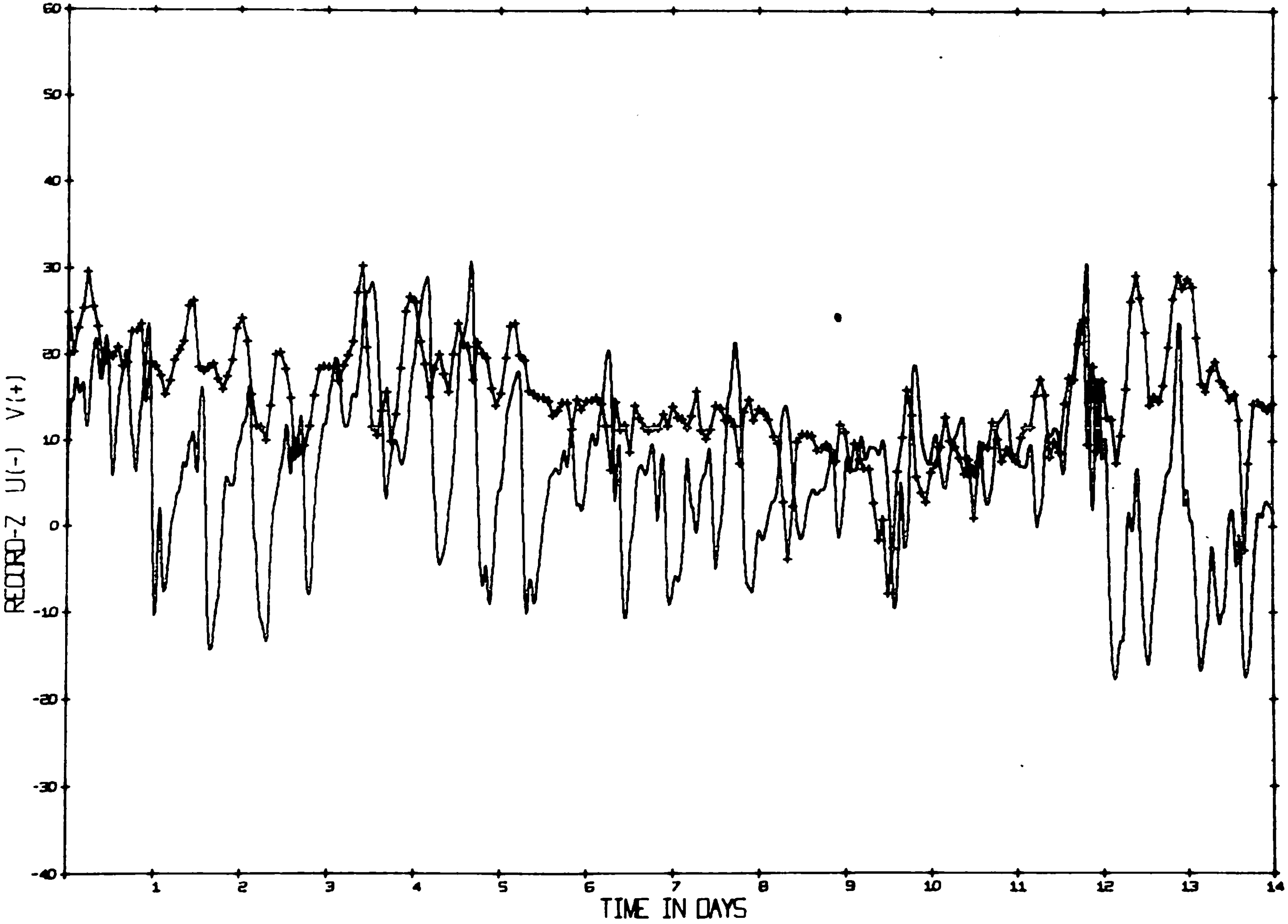


Fig. A-15 (cont.). Start time: 1900 18 September 1969

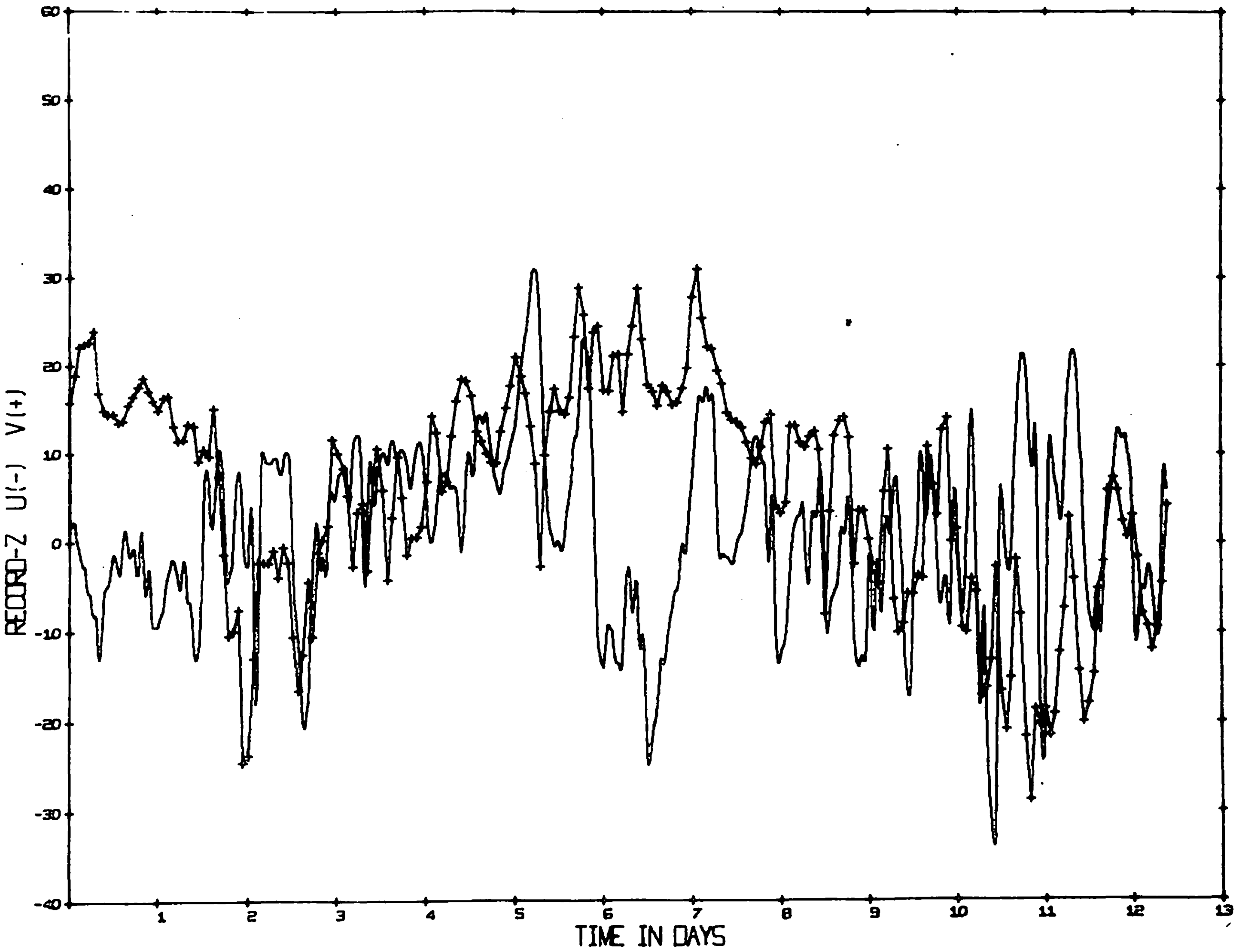


Fig. A-15 (cont.). Start time: 1900 1 October 1969

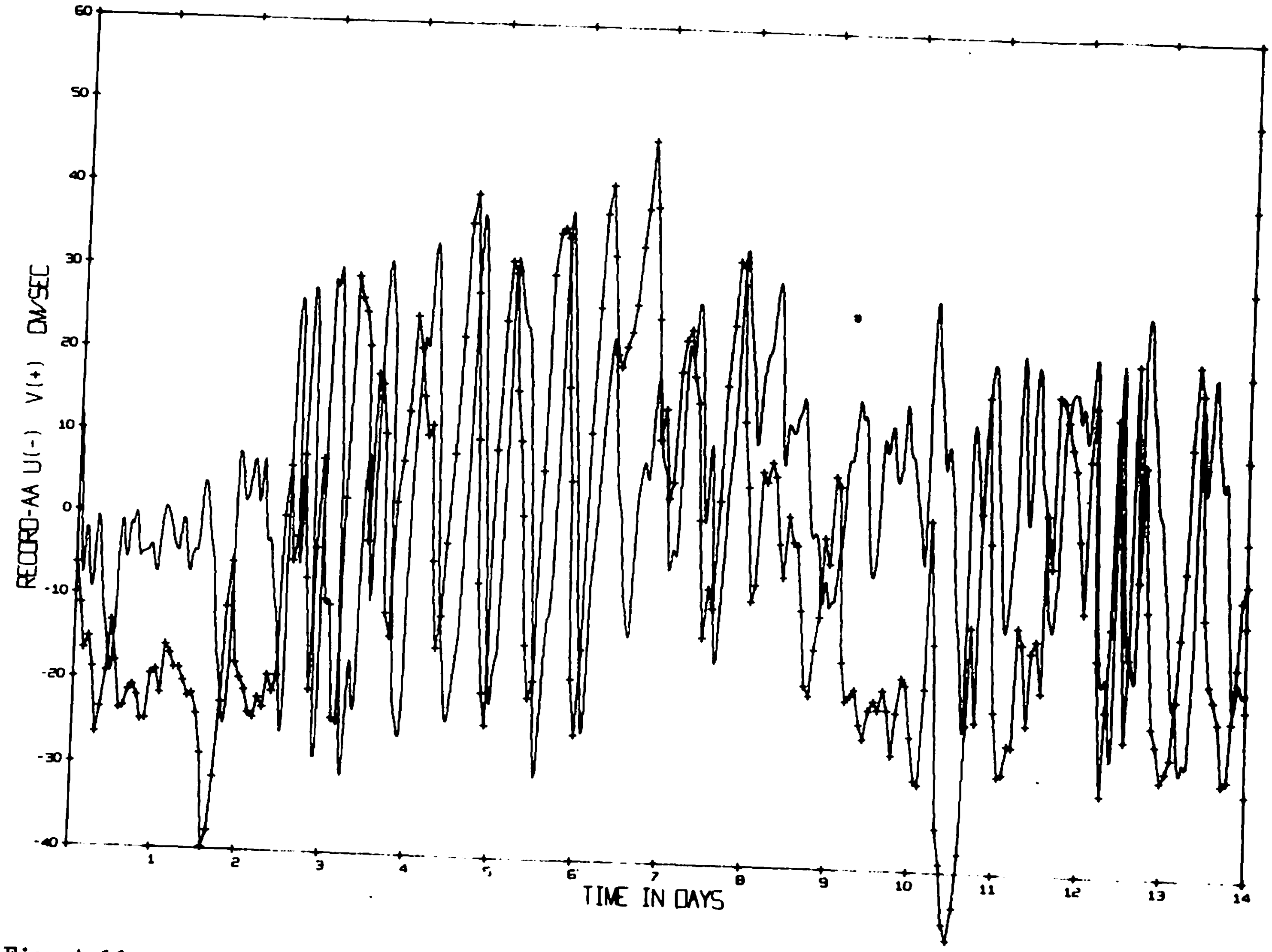


Fig. A-16. Record AA time series. Start time: 2000 21 August 1969

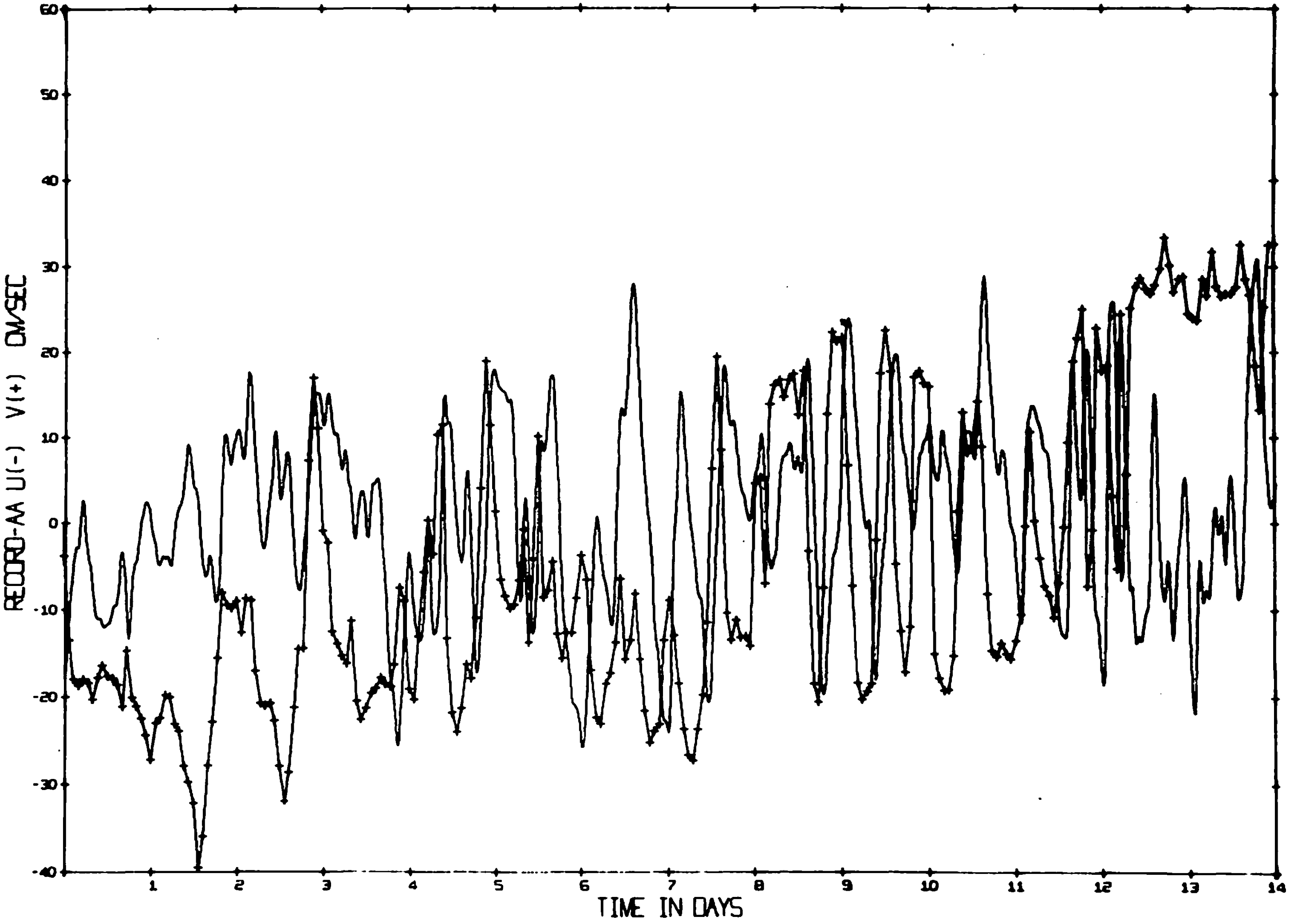


Fig. A-16 (cont.). Start time: 2000 4 September 1969

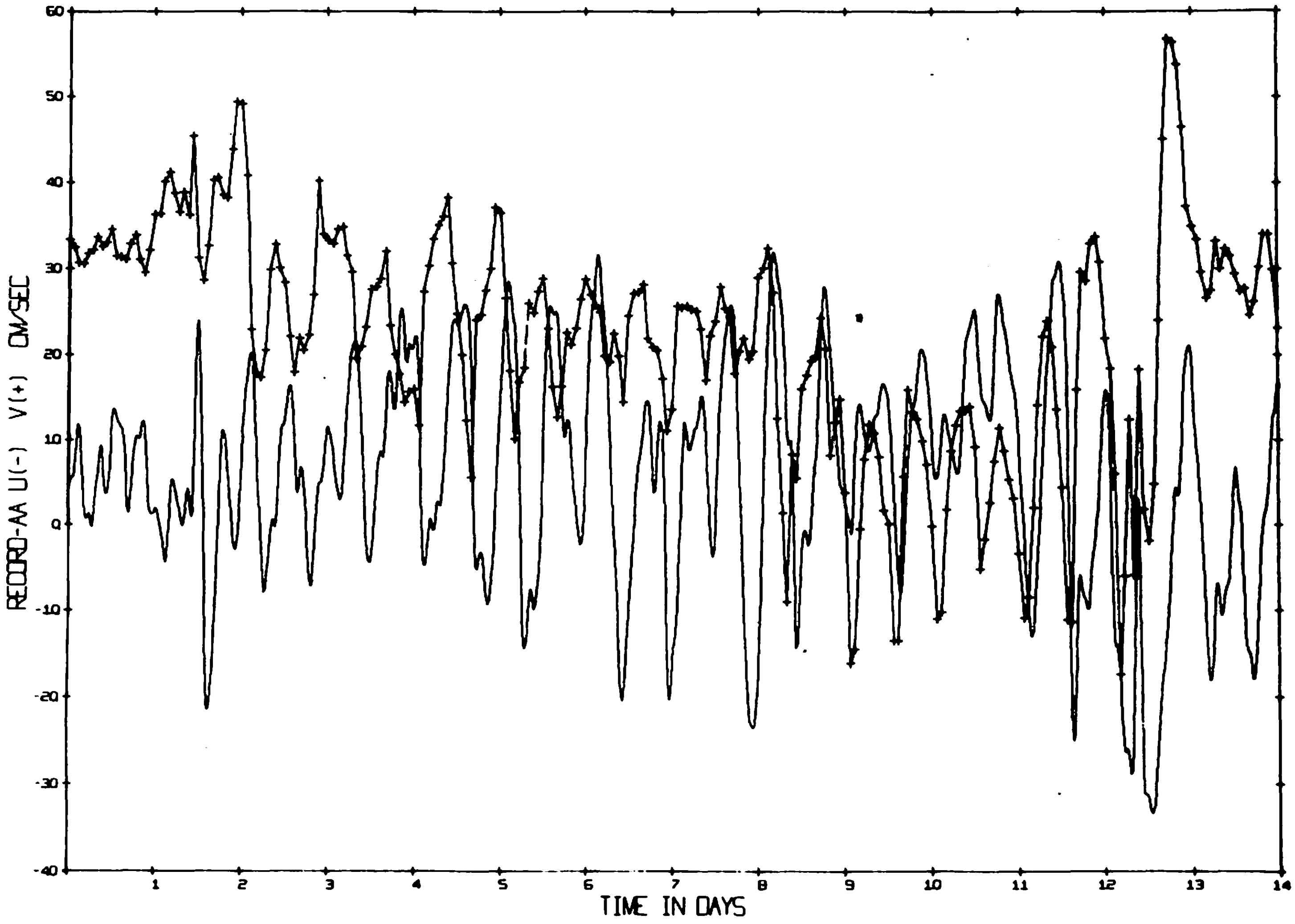


Fig. A-16 (cont.). Start time: 2000 18 September

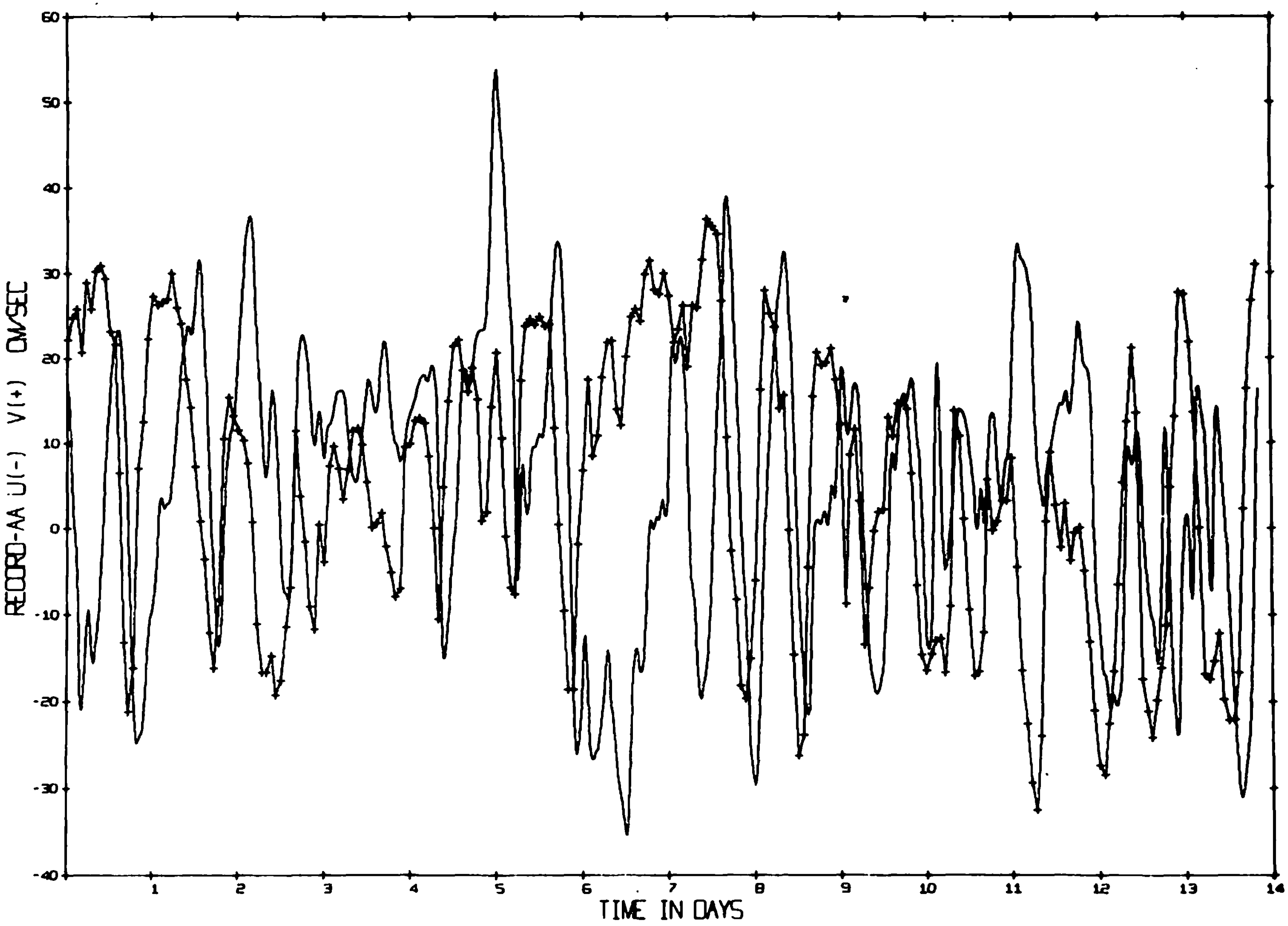


Fig. A-16 (cont.). Start time: 2000 2 October 1969

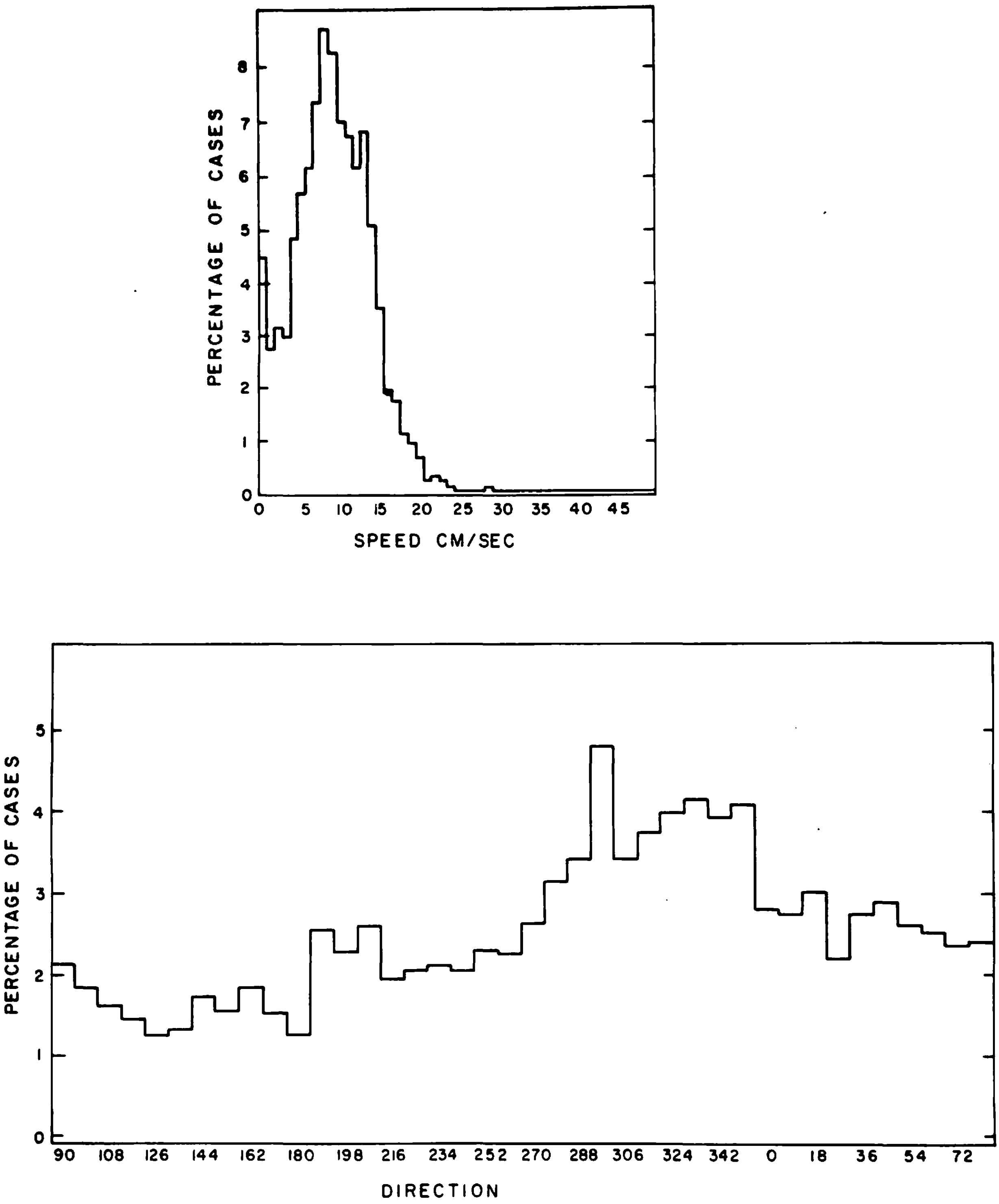


Fig. A-17. Histograms for Record A

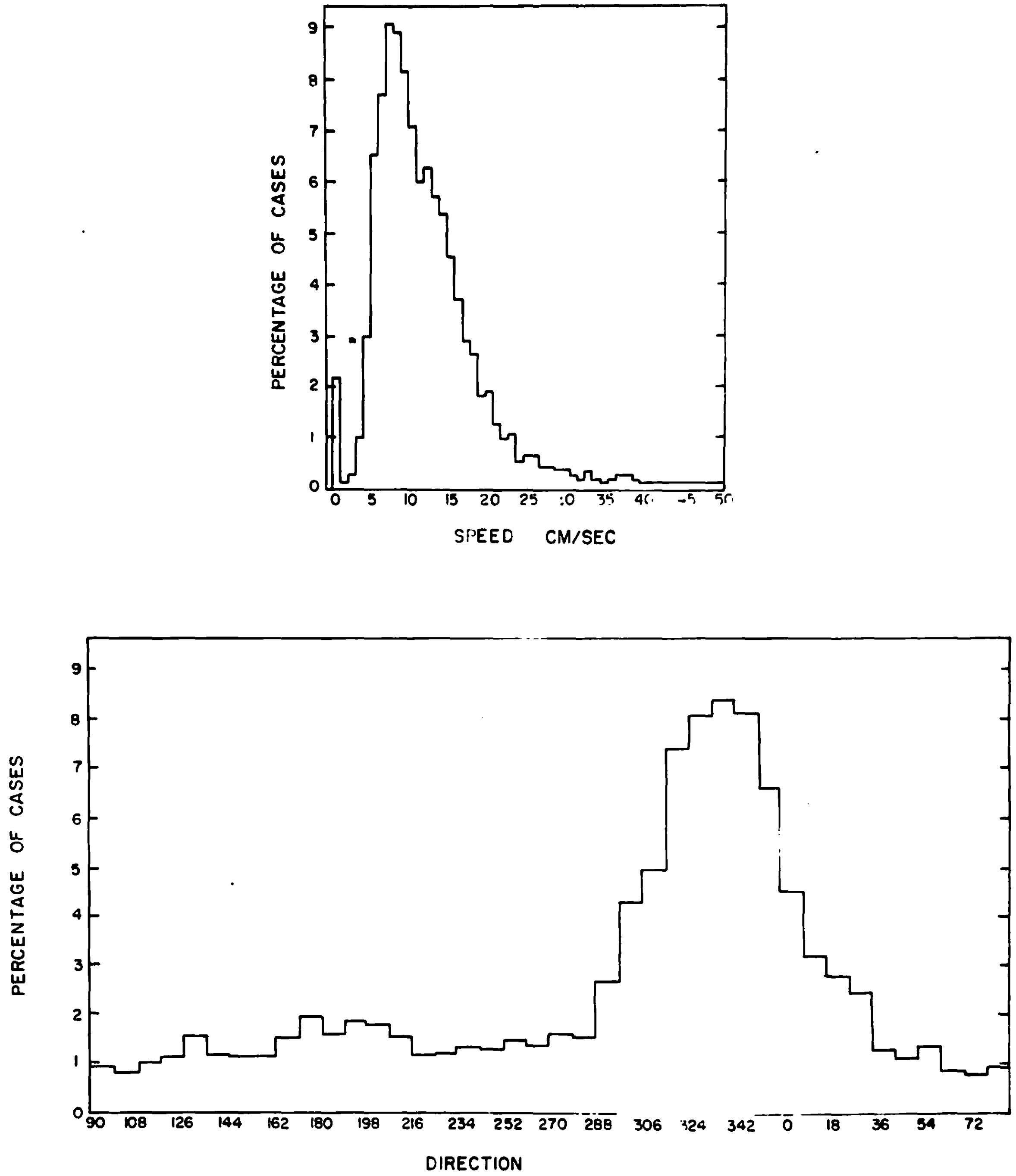
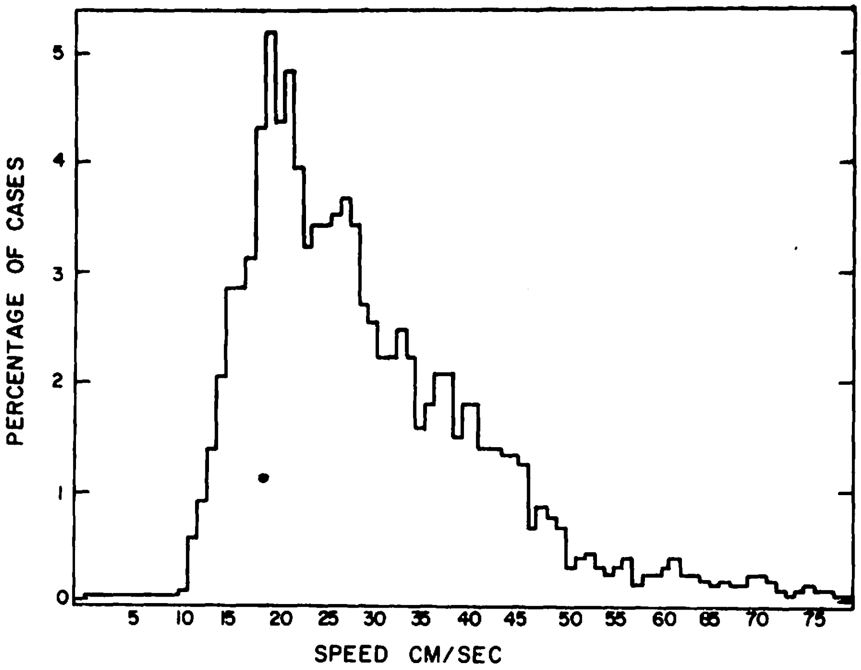


Fig. A-18. Histograms for Record B



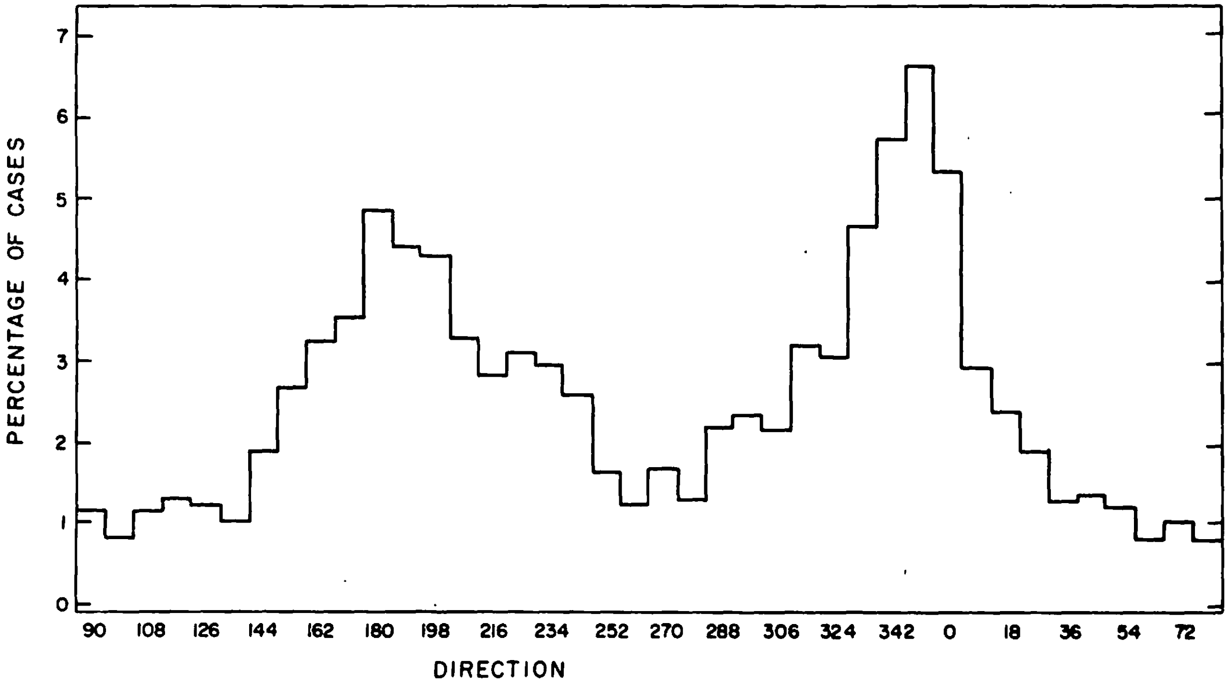
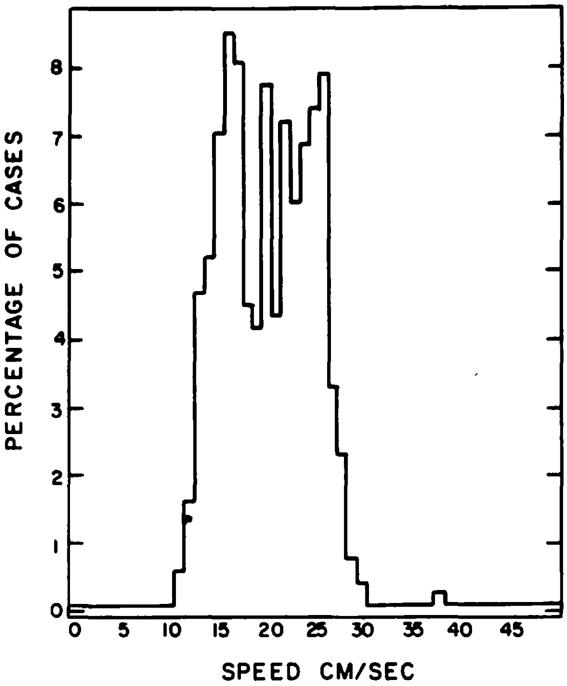


Fig. A-19. Histograms for Record C



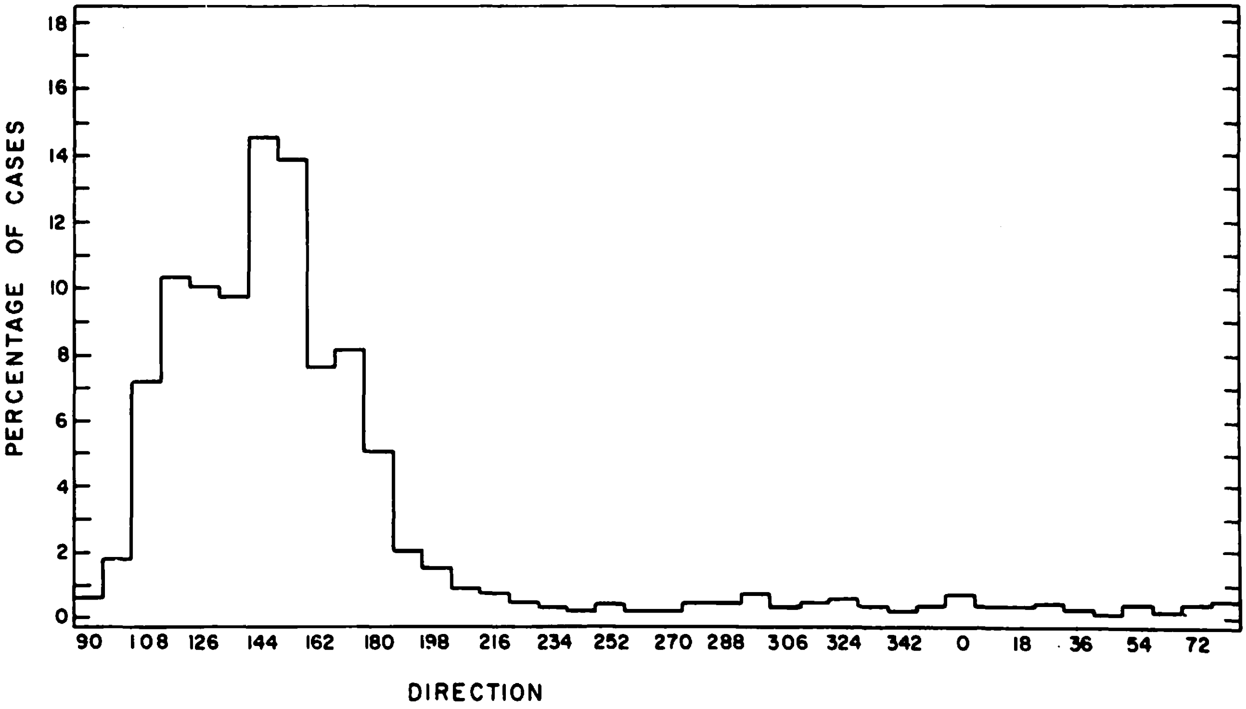
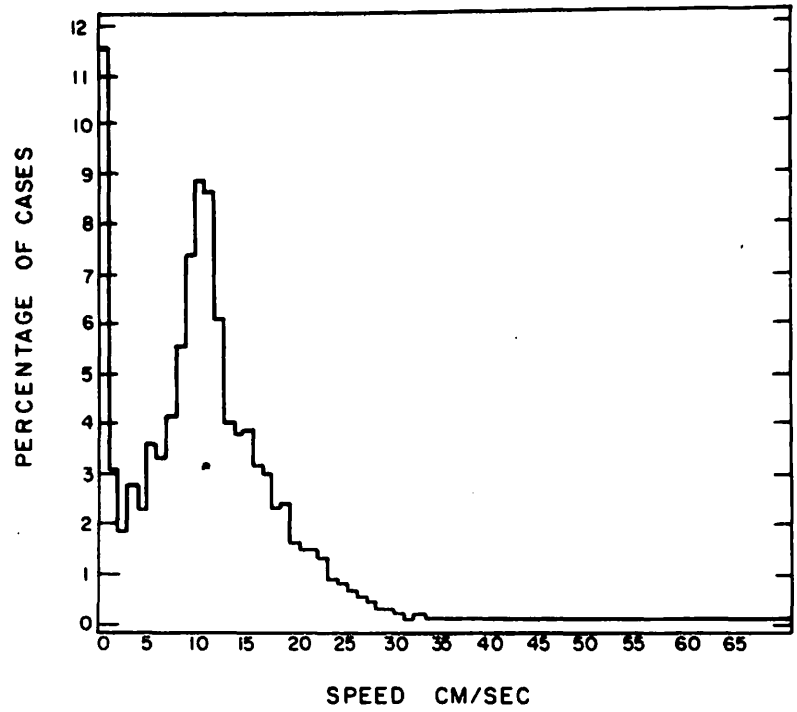


Fig. A-20. Histograms for Record E



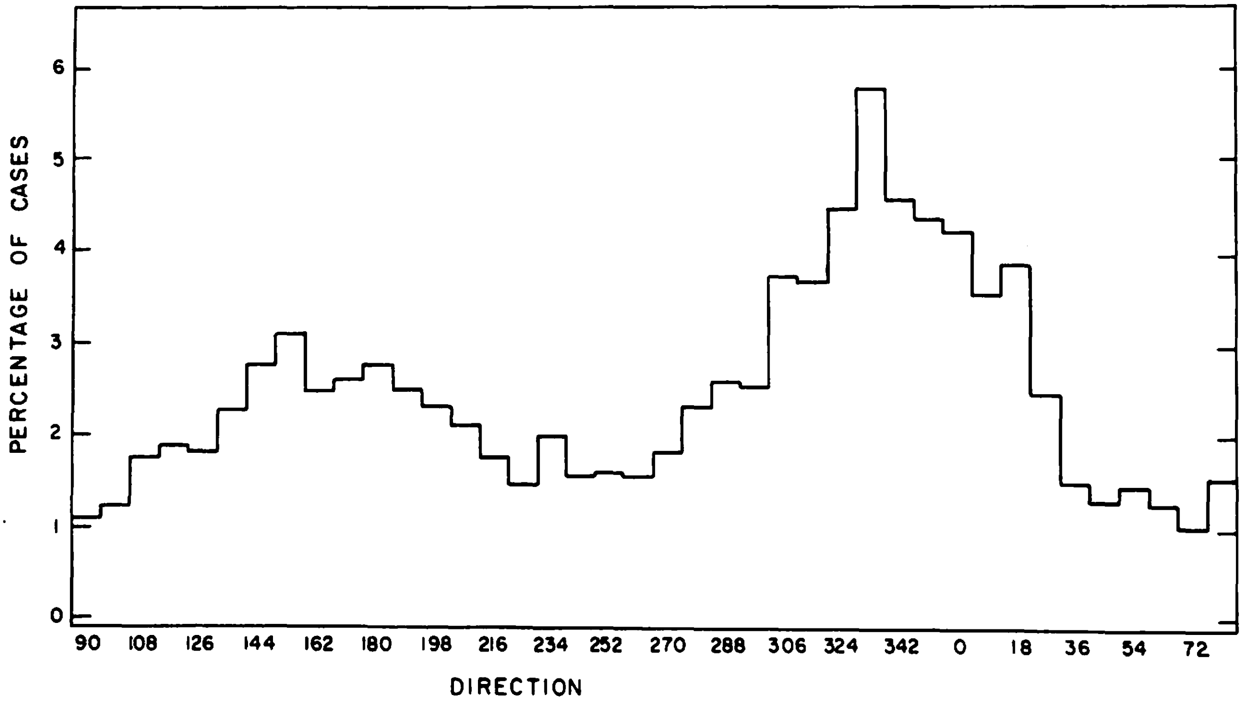


Fig. A-21. Histograms for Record M

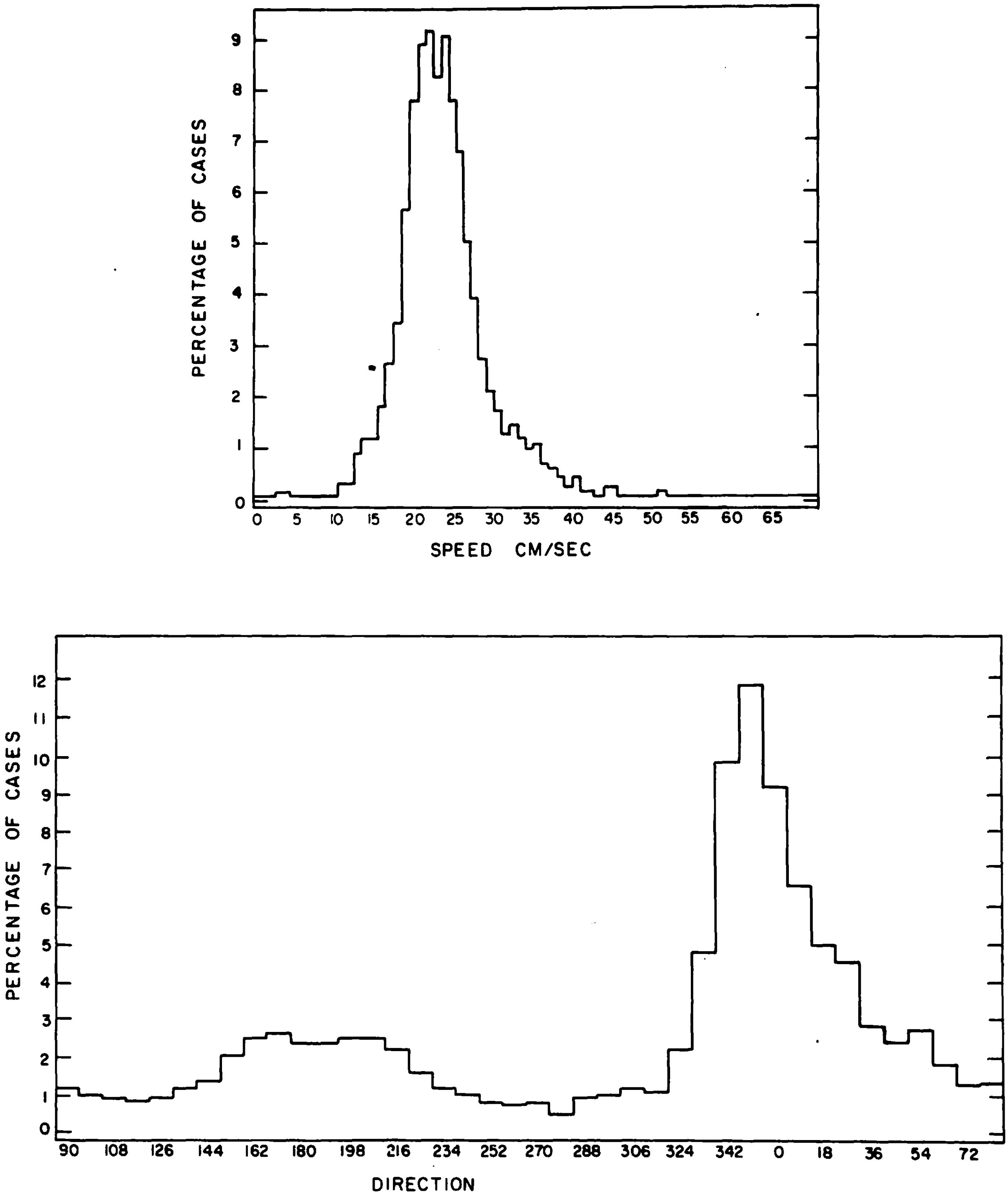
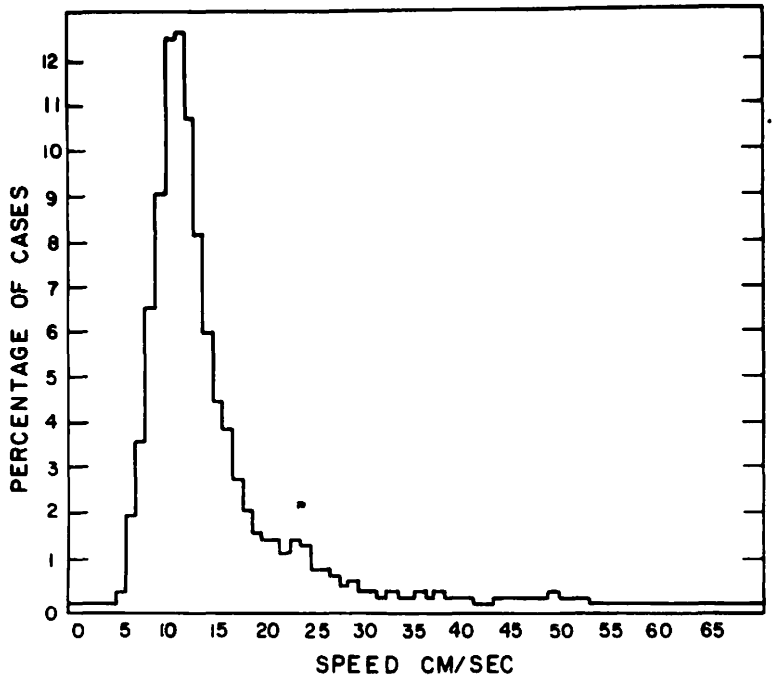


Fig. A-22. Histograms for Record N



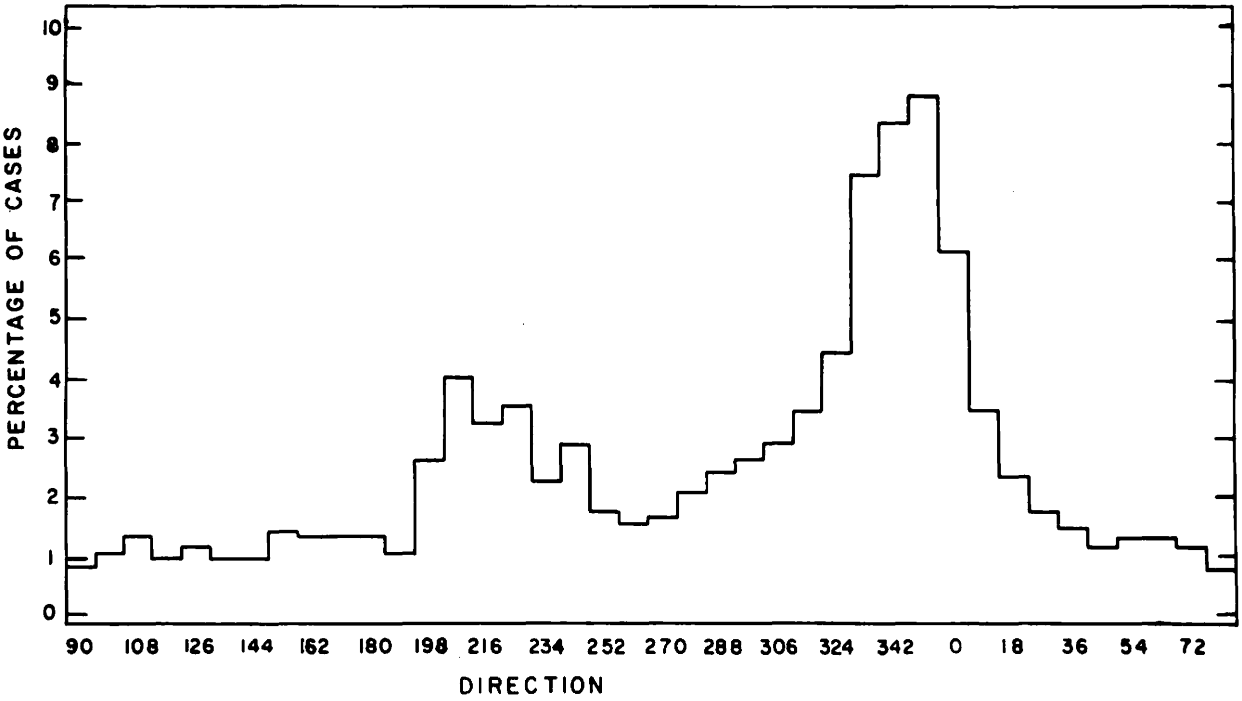
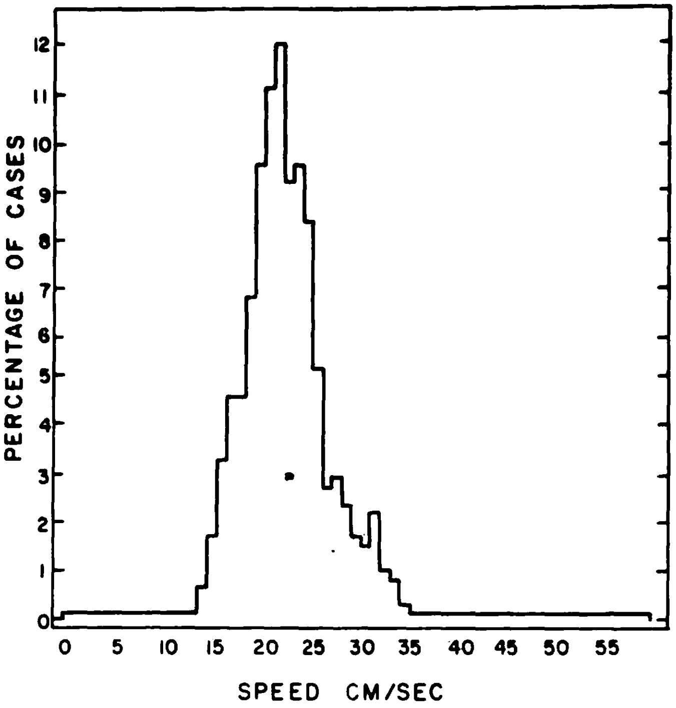


Fig. A-23. Histograms for Record 0



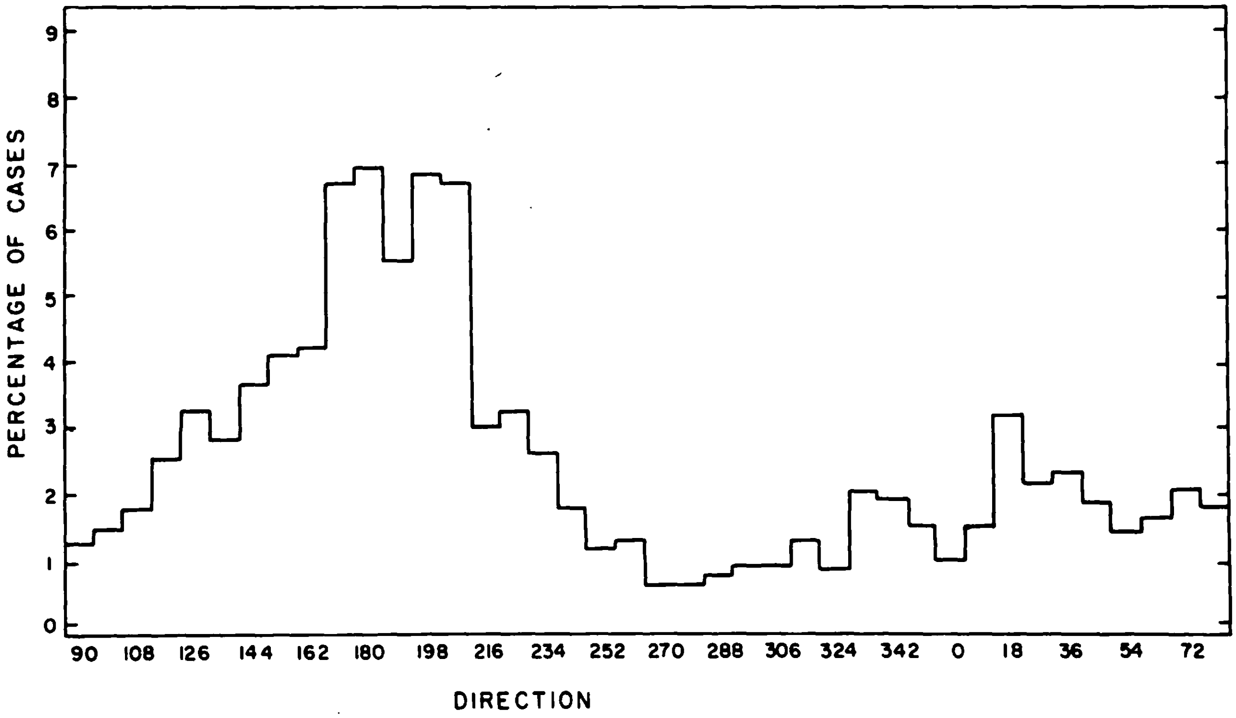
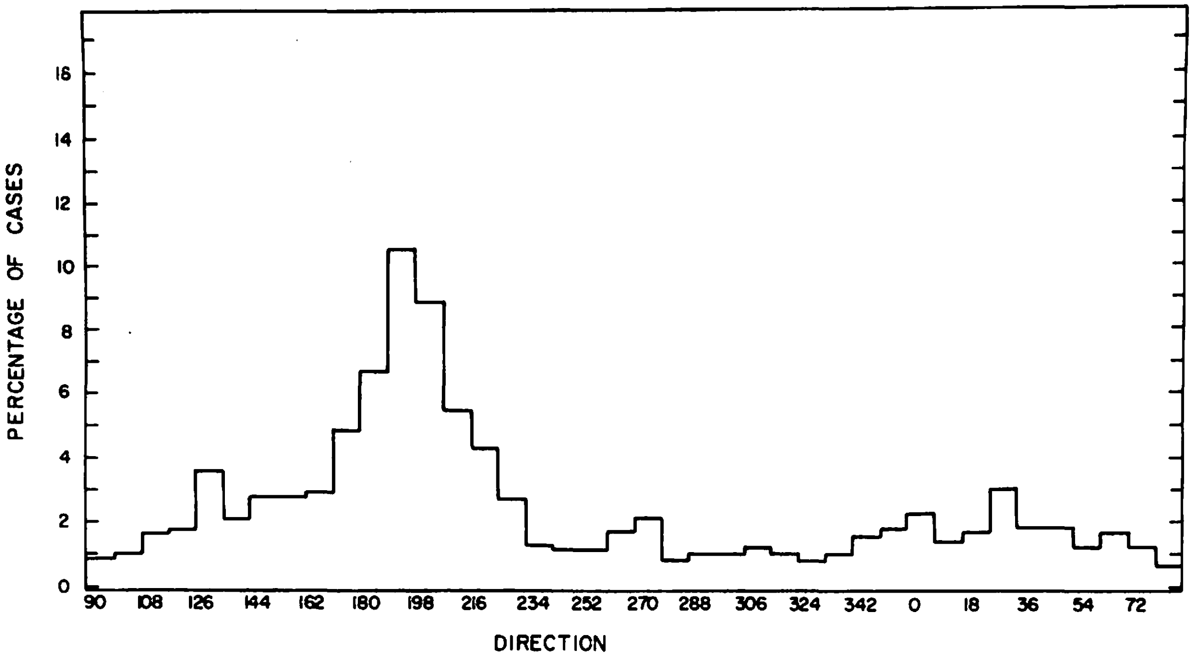


Fig. A-24. Histograms for Record R



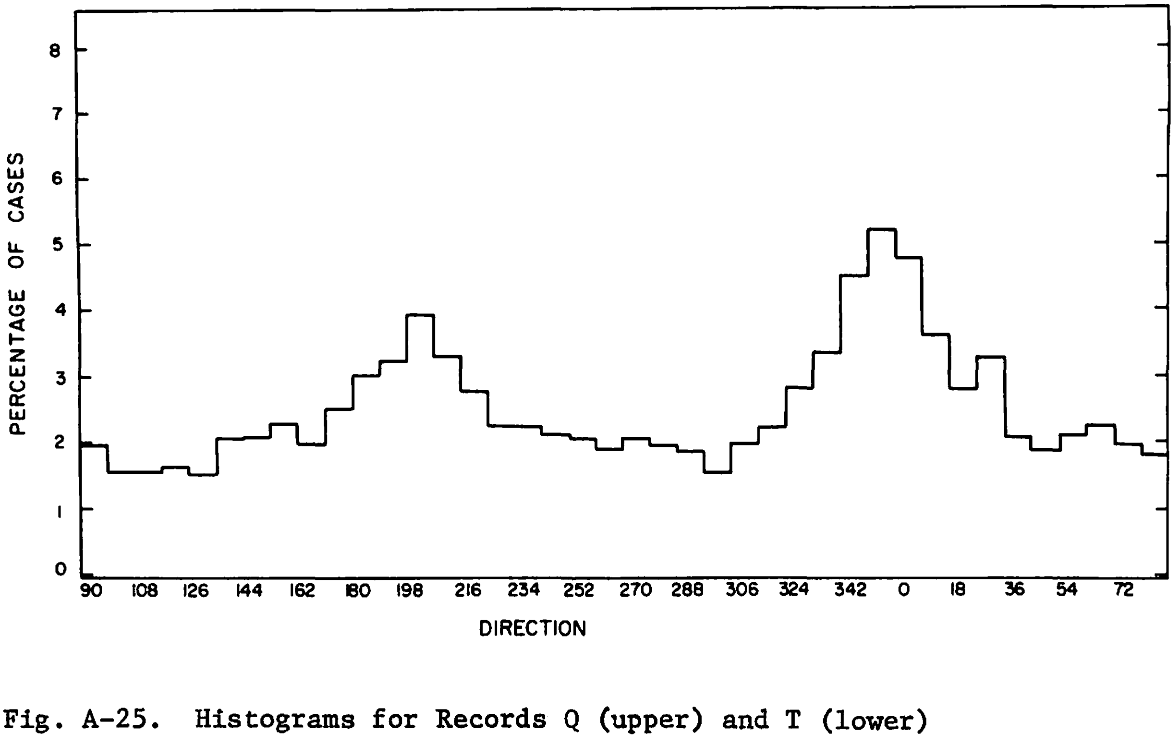
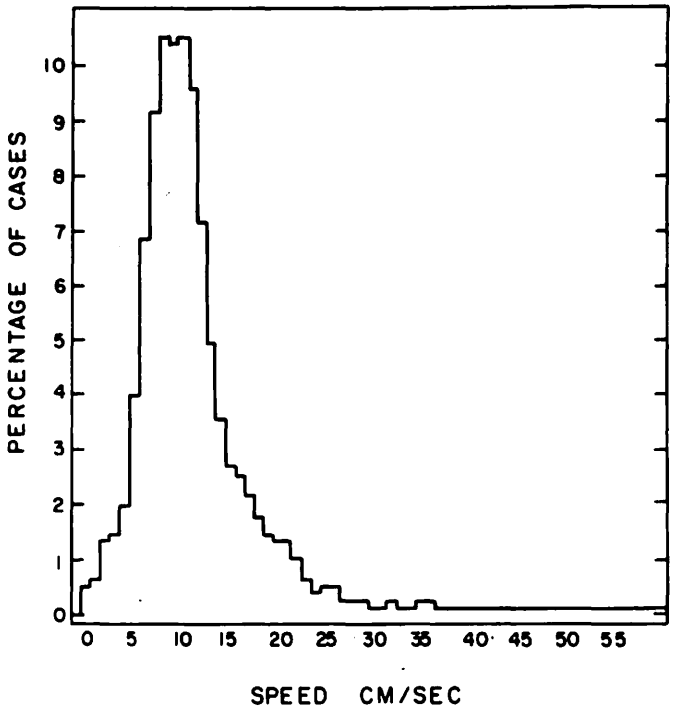


Fig. A-25. Histograms for Records Q (upper) and T (lower)



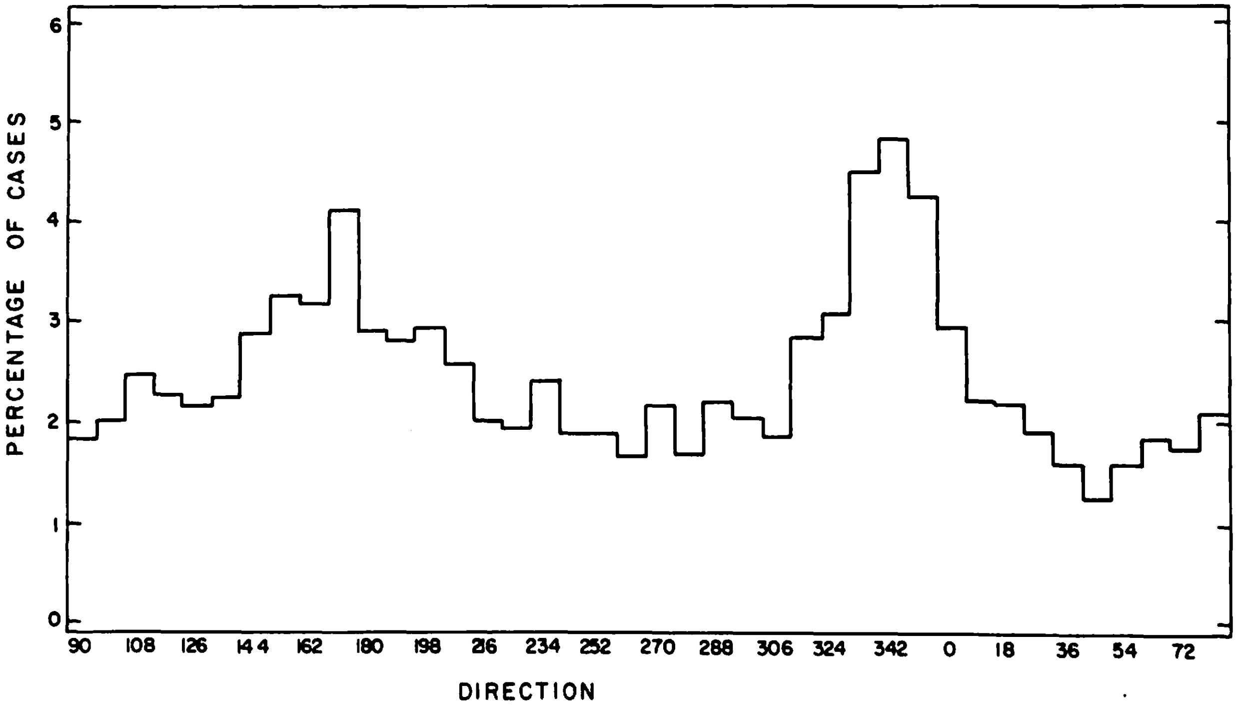
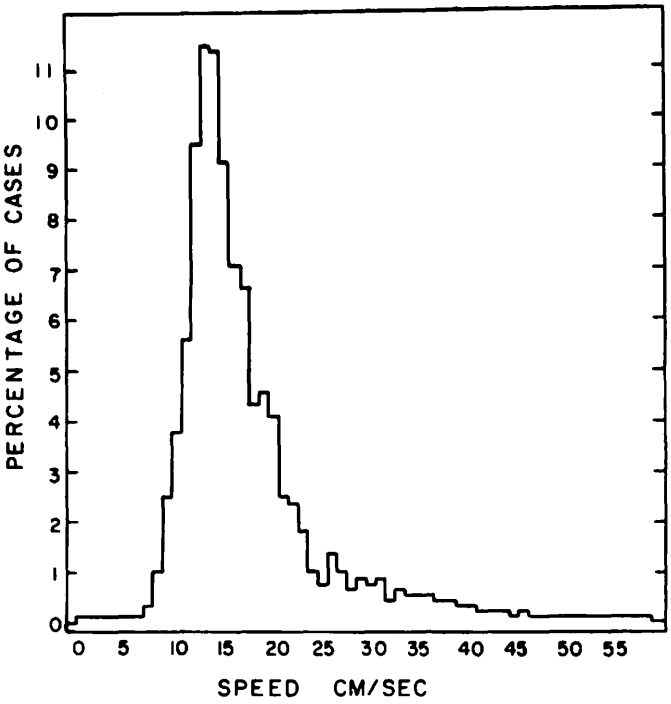


Fig. A-26. Histograms for Record S



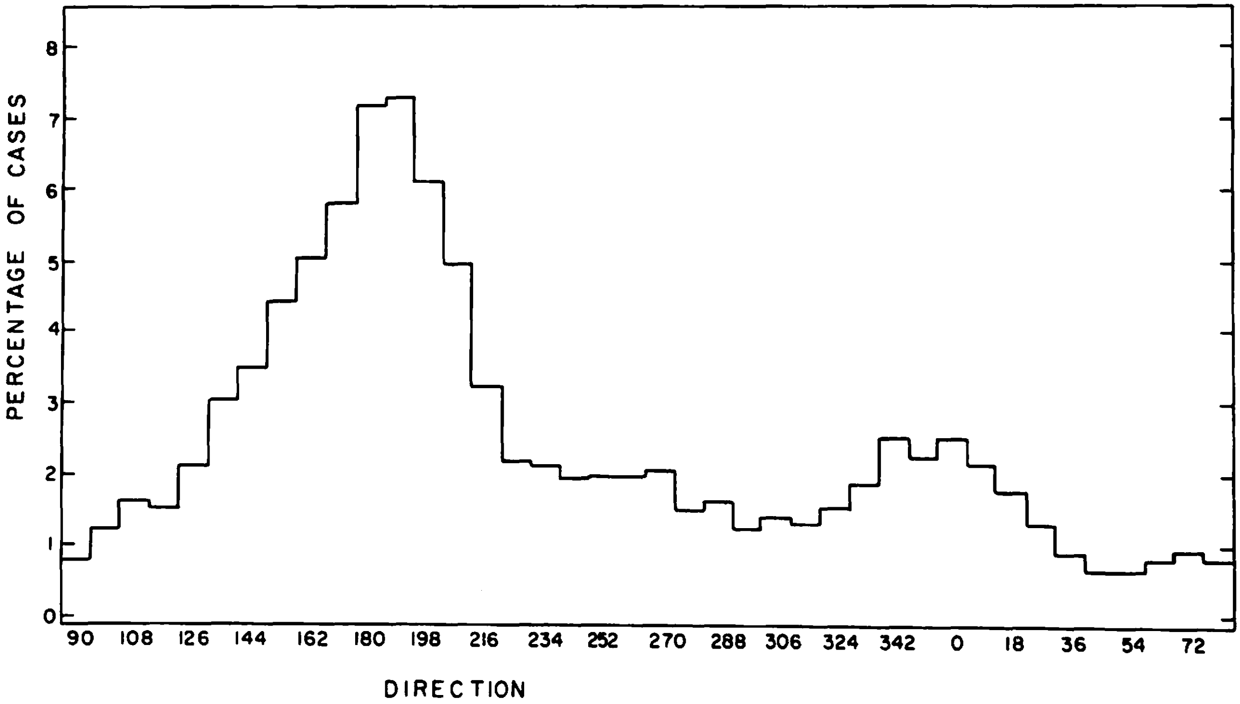


Fig. A-27. Histograms for Record V

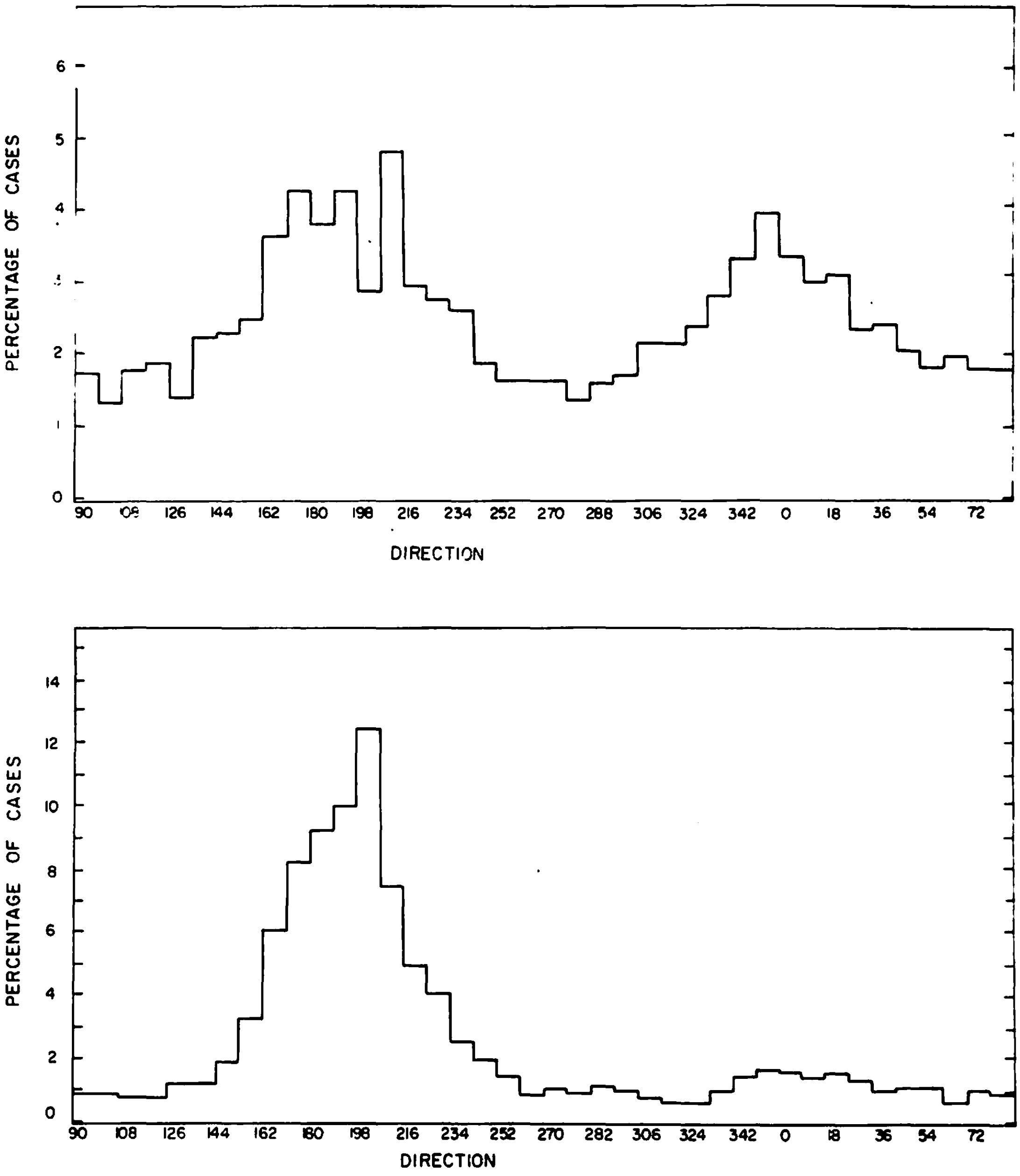


Fig. A-28. Histograms for Records U (upper) and W (lower)

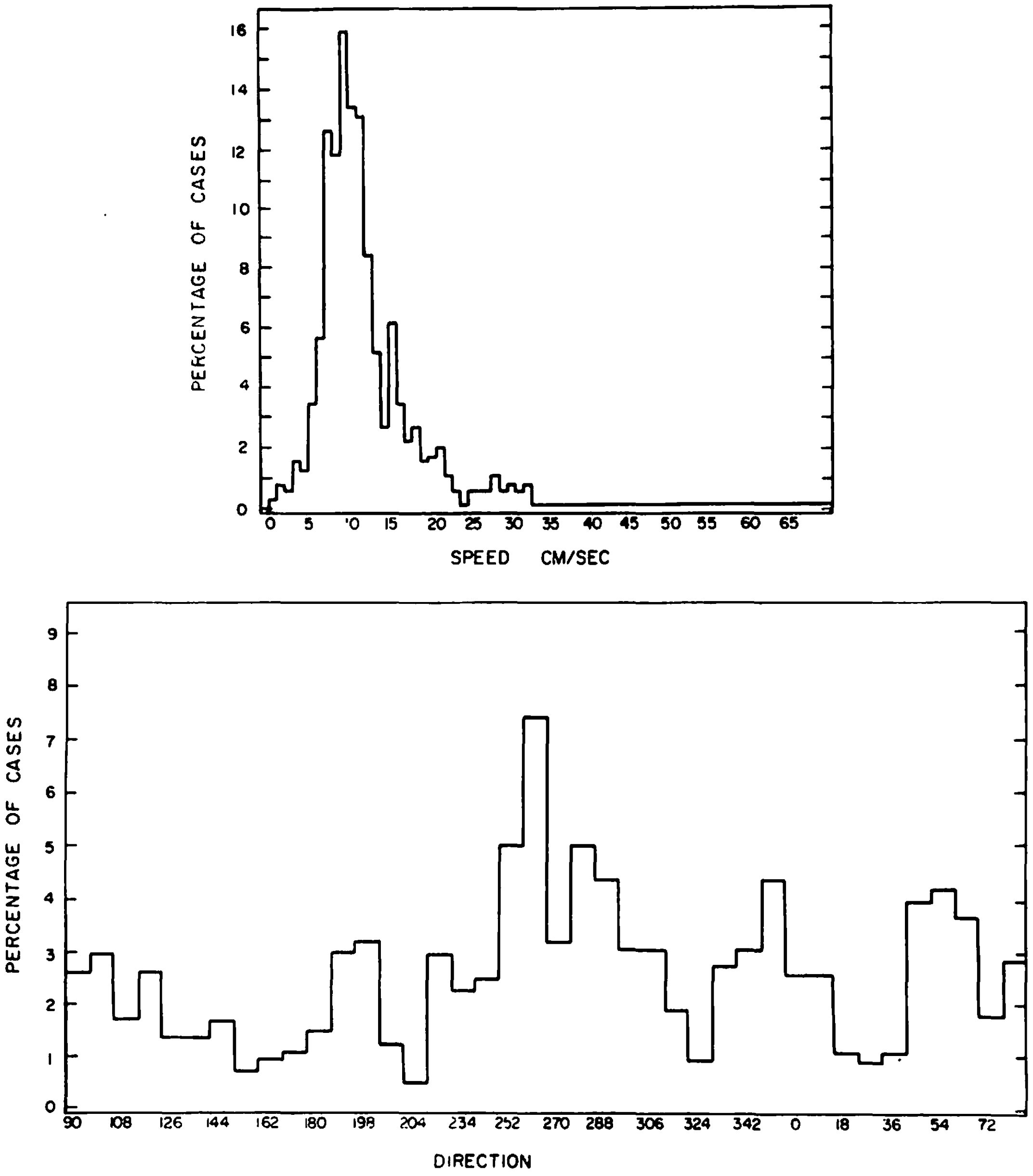
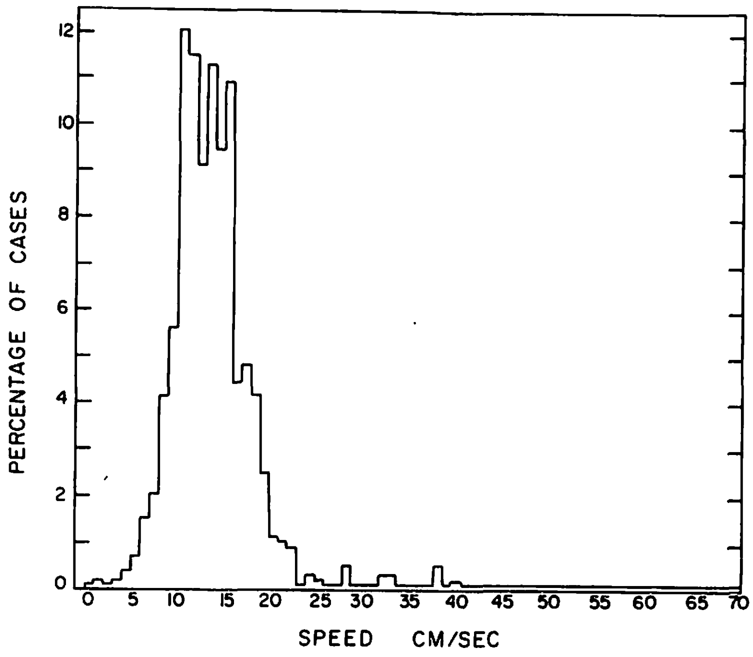


Fig. A-29. Histograms for Record X



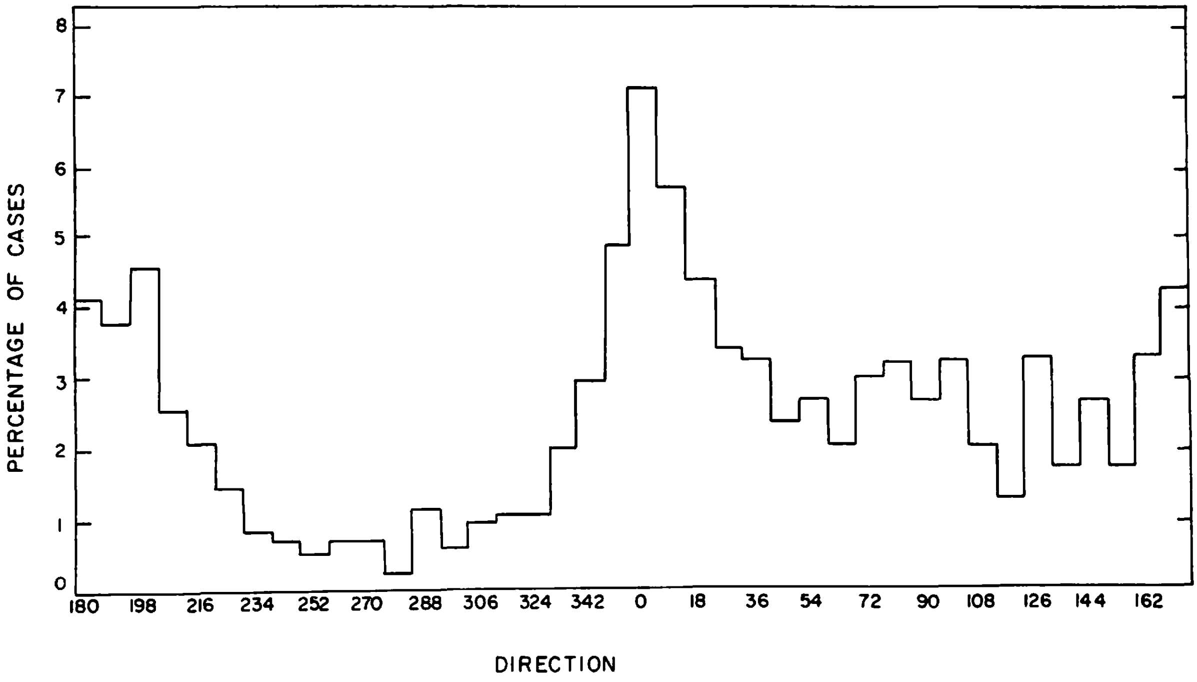
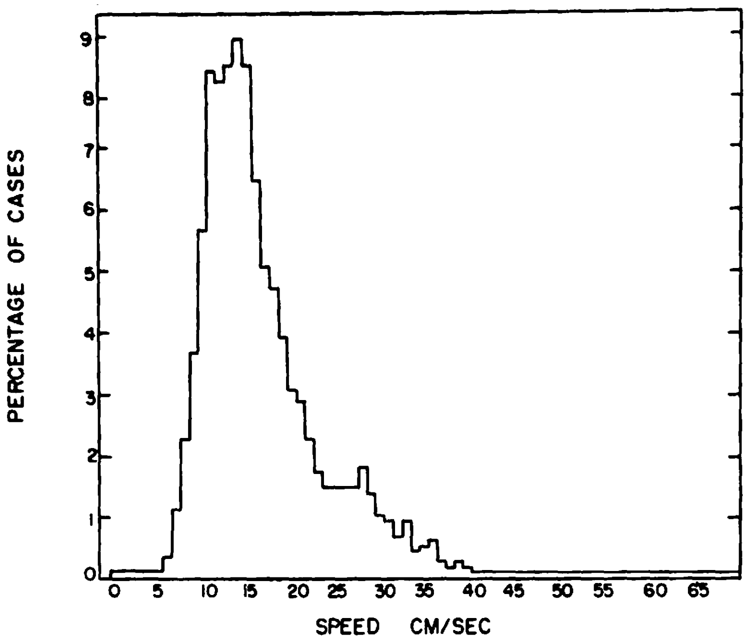


Fig. A-30. Histograms for Record Y



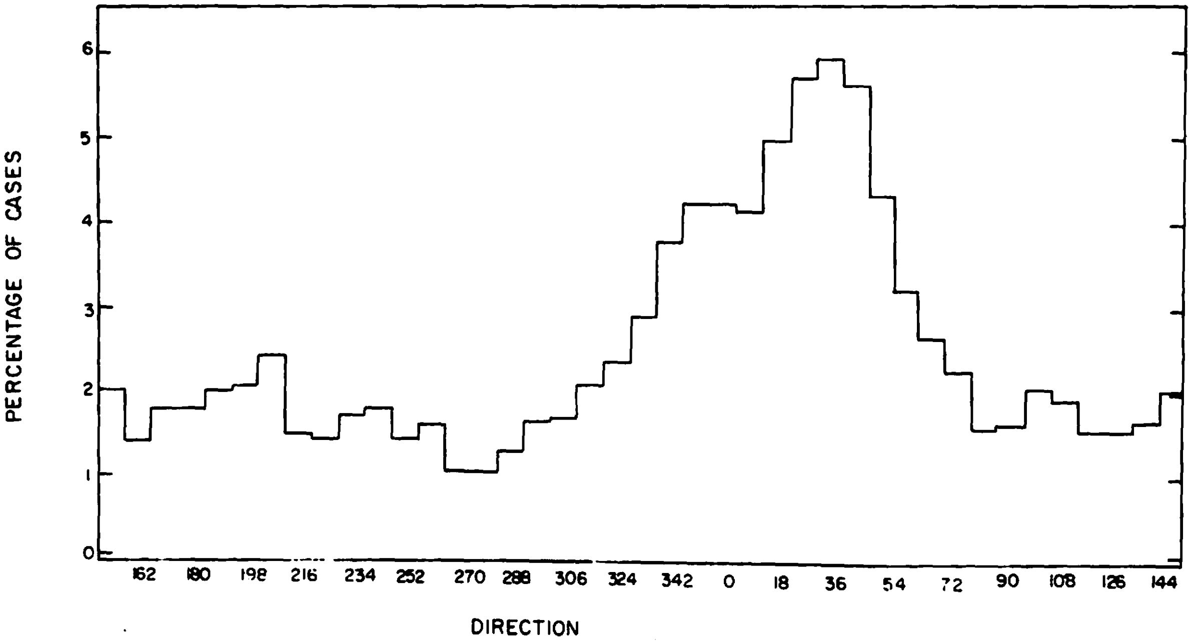
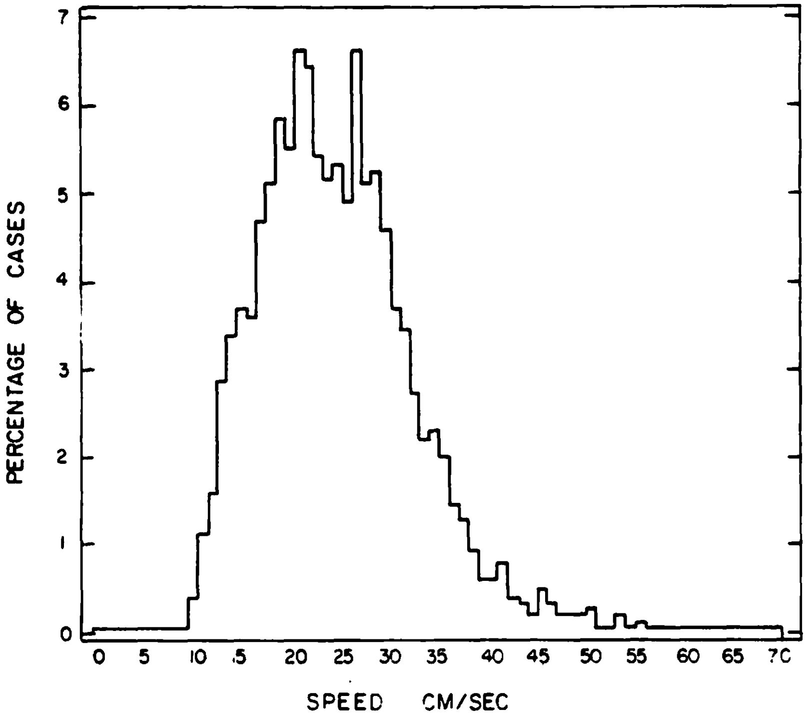


Fig. A-31. Histograms for Record Z



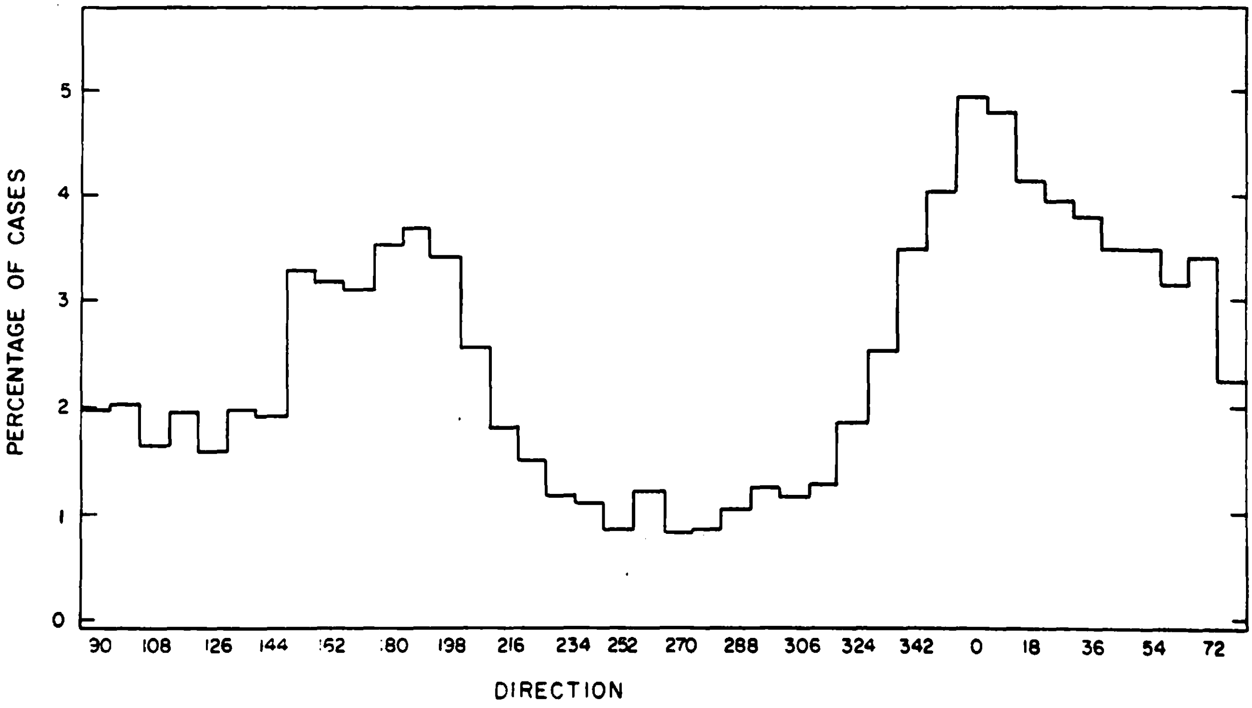


Fig. A-32. Histograms for Record AA

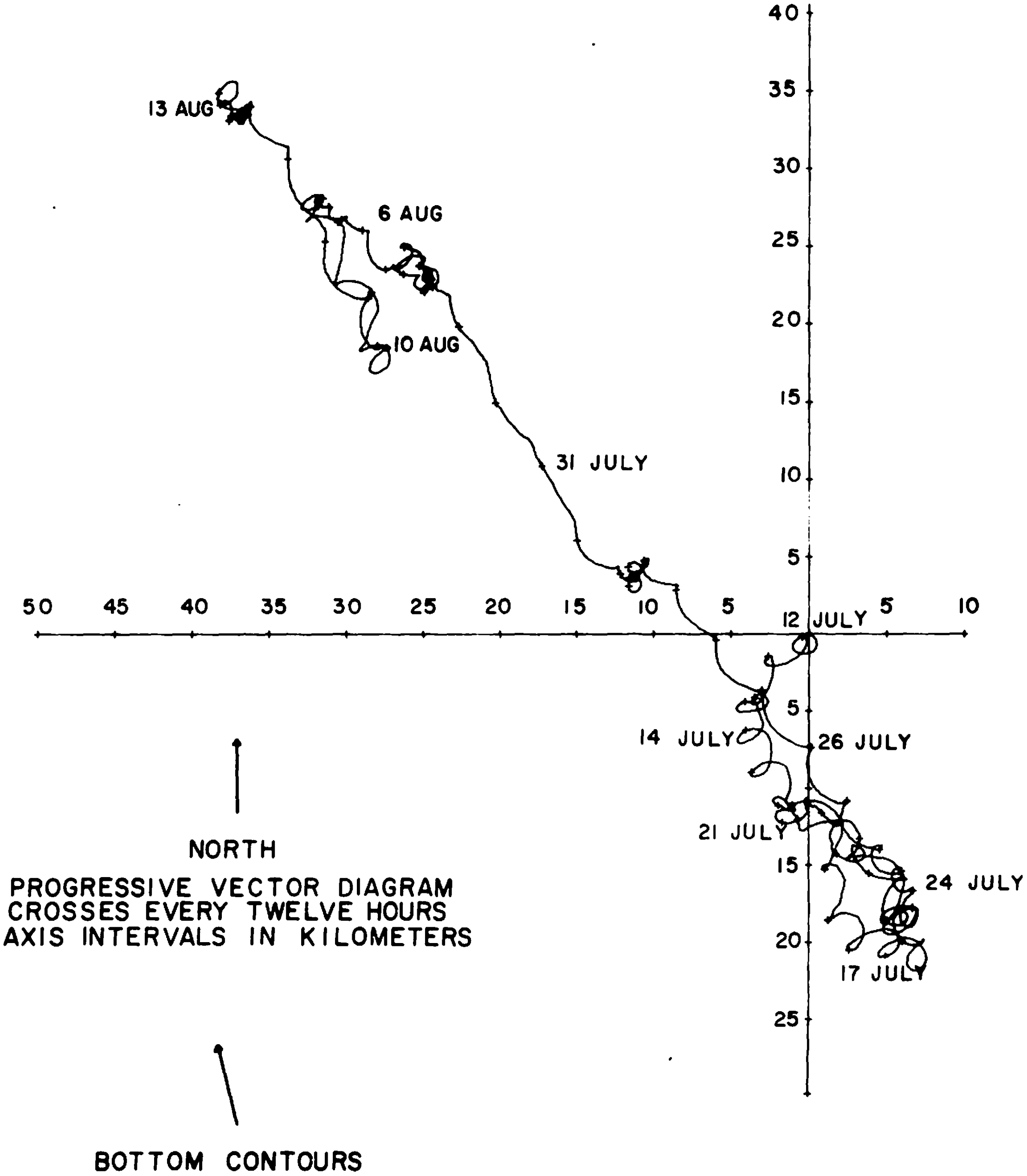


Fig. A-33. Progressive vector diagram for Record A, 12 July to 13 August 1967

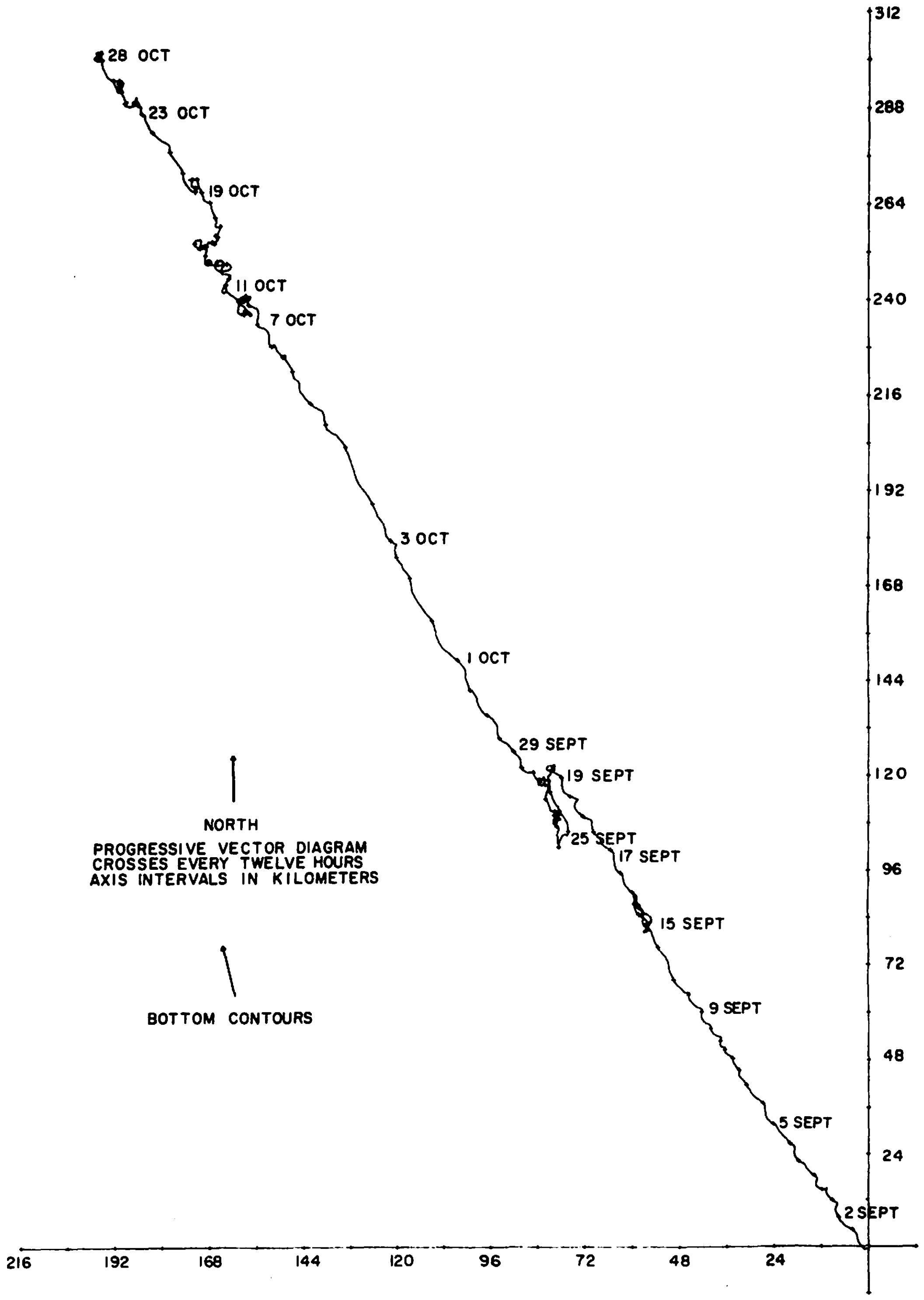


Fig. A-34. Progressive vector diagram for Record B, 1 September to 28 October 1967

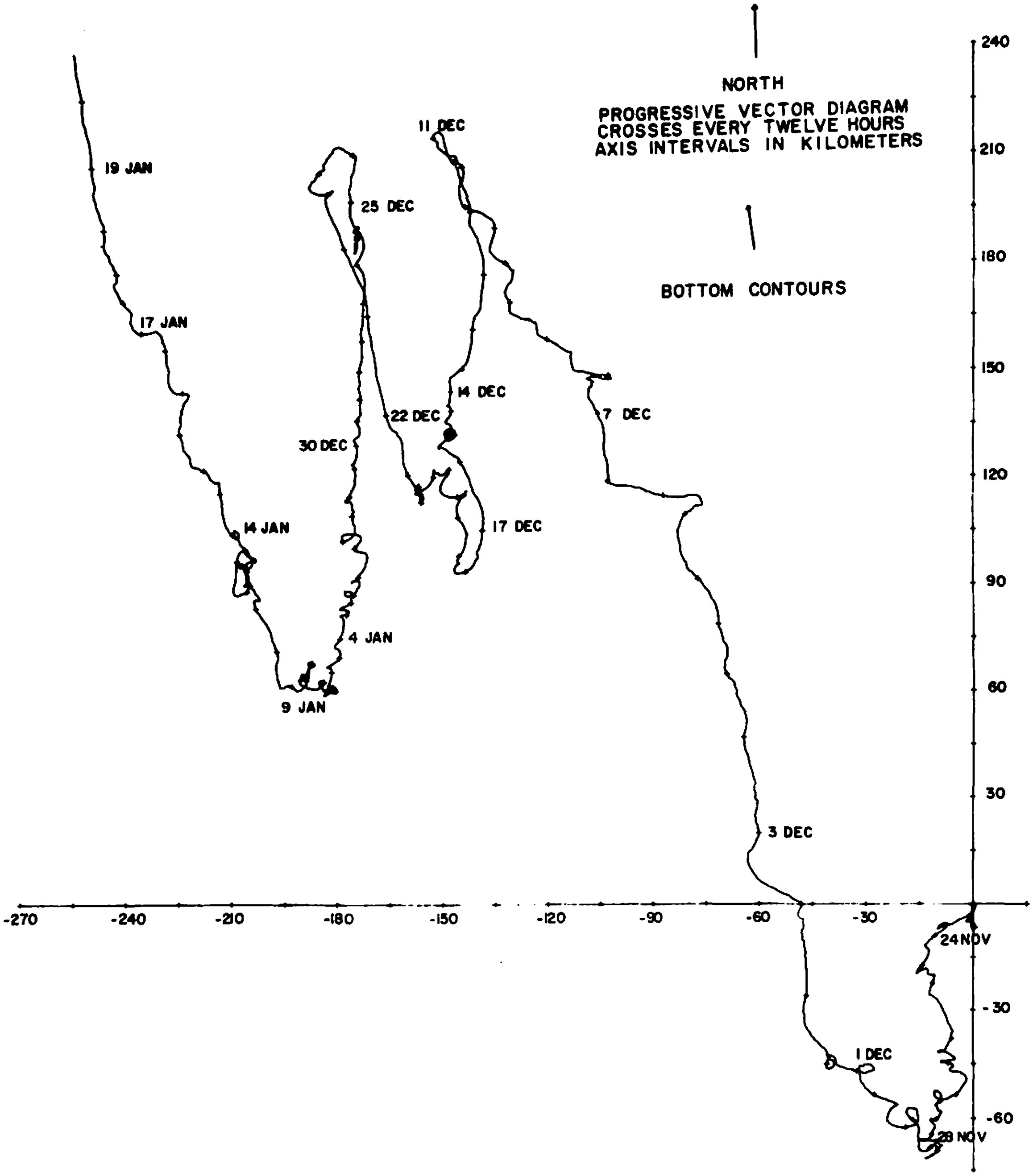


Fig. A-35. Progressive vector diagram for Record C, 23 November 1967 to 19 January 1968

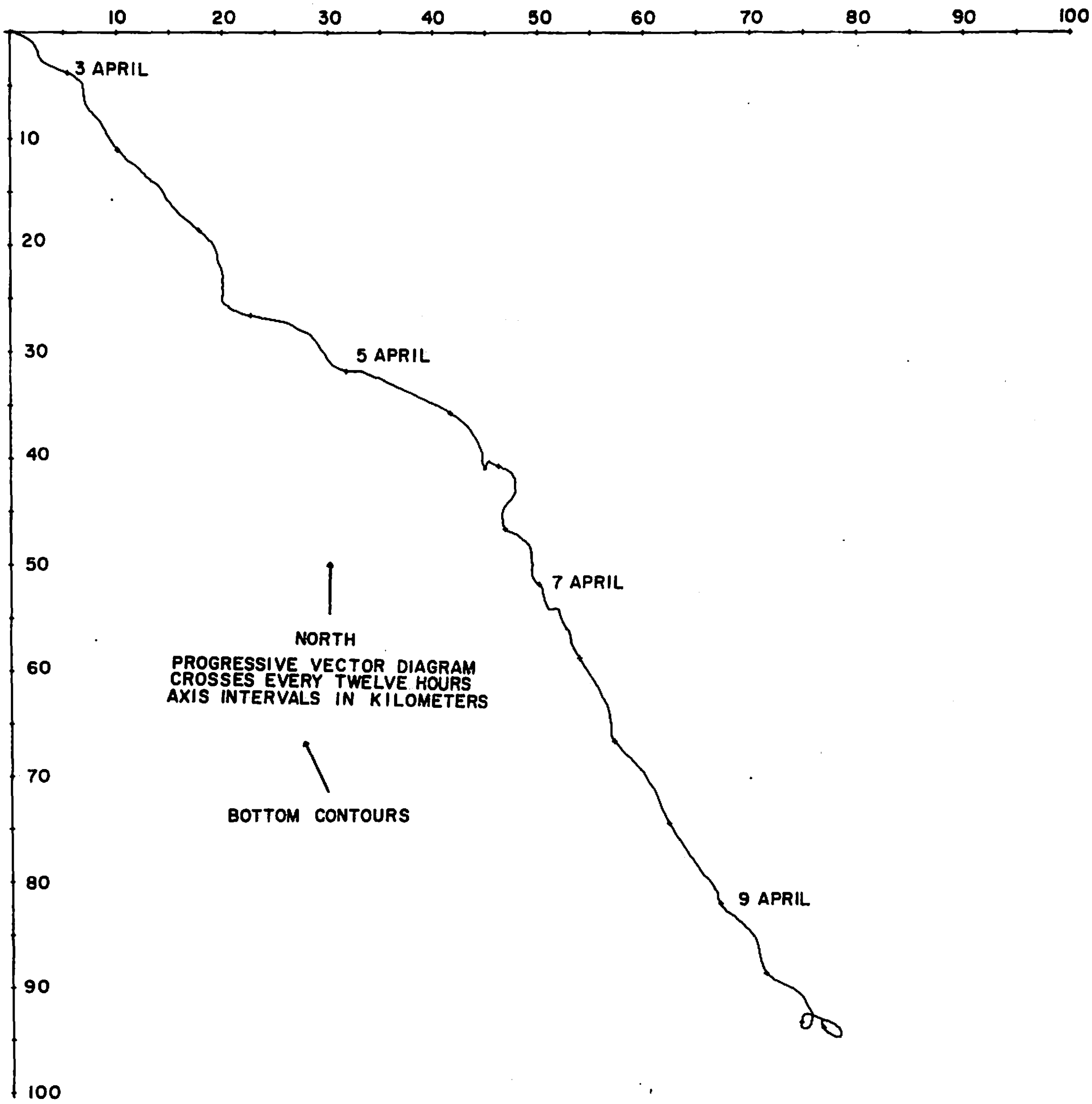


Fig. A-36. Progressive vector diagram for Record E, 2 to 9 April 1968

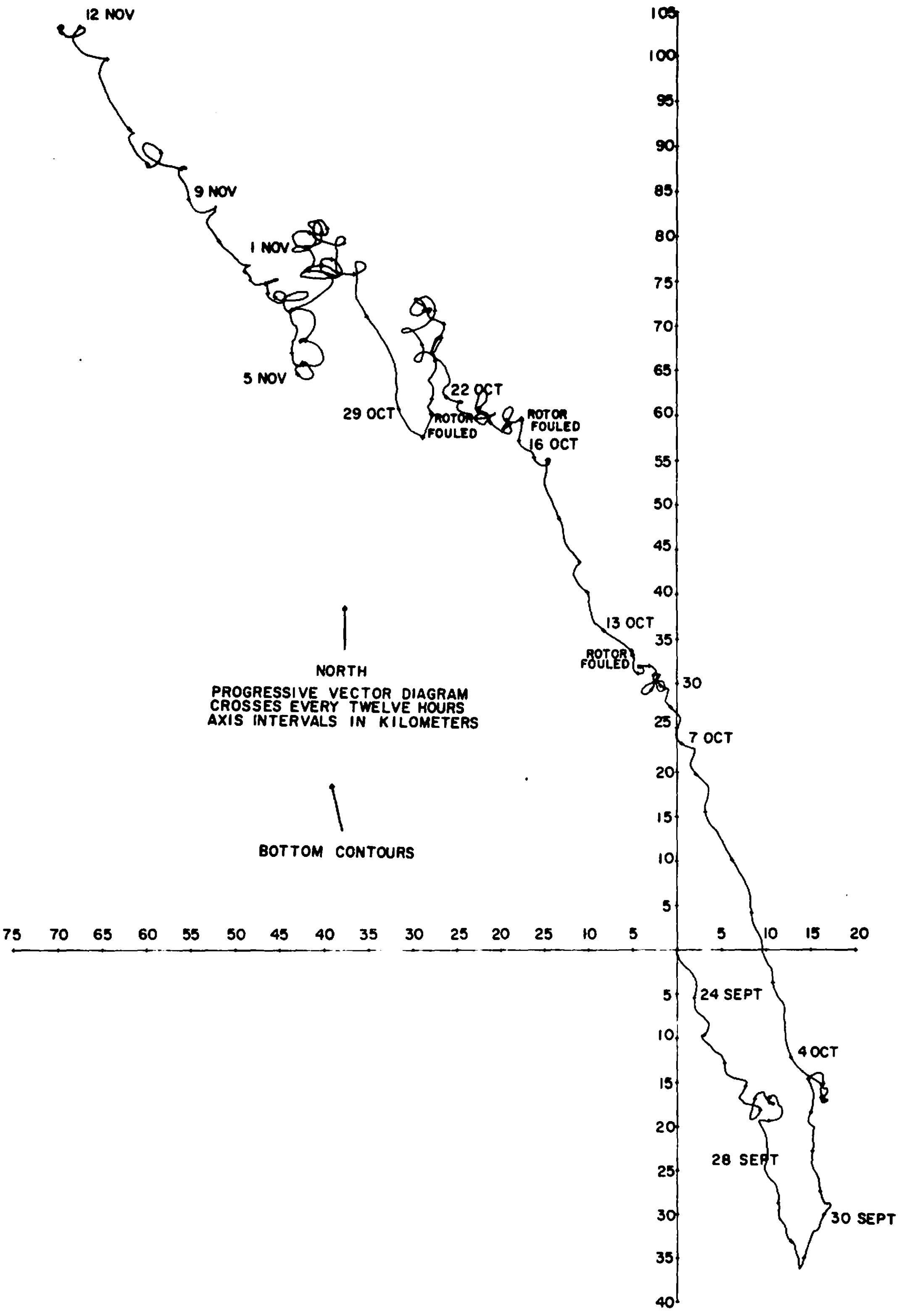


Fig. A-37. Progressive vector diagram for Record M,
23 September to 12 November 1968

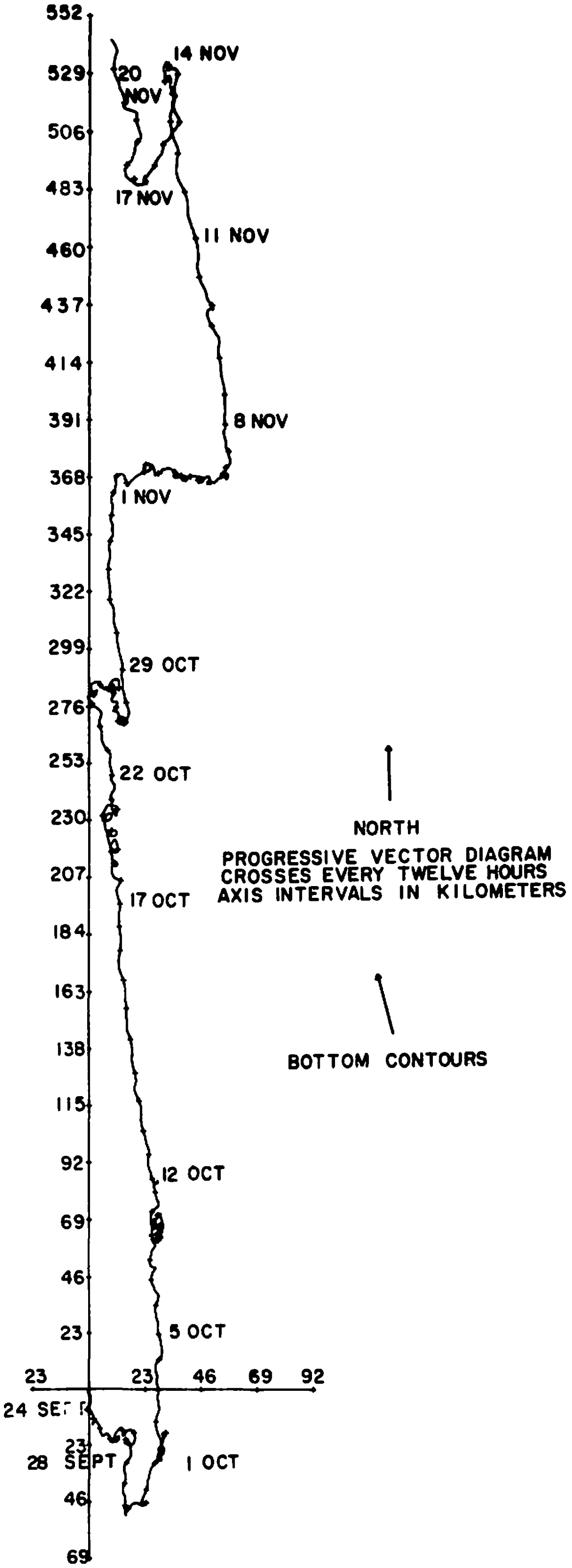


Fig. A-38. Progressive vector diagram for Record N, 23 September to 20 November 1968

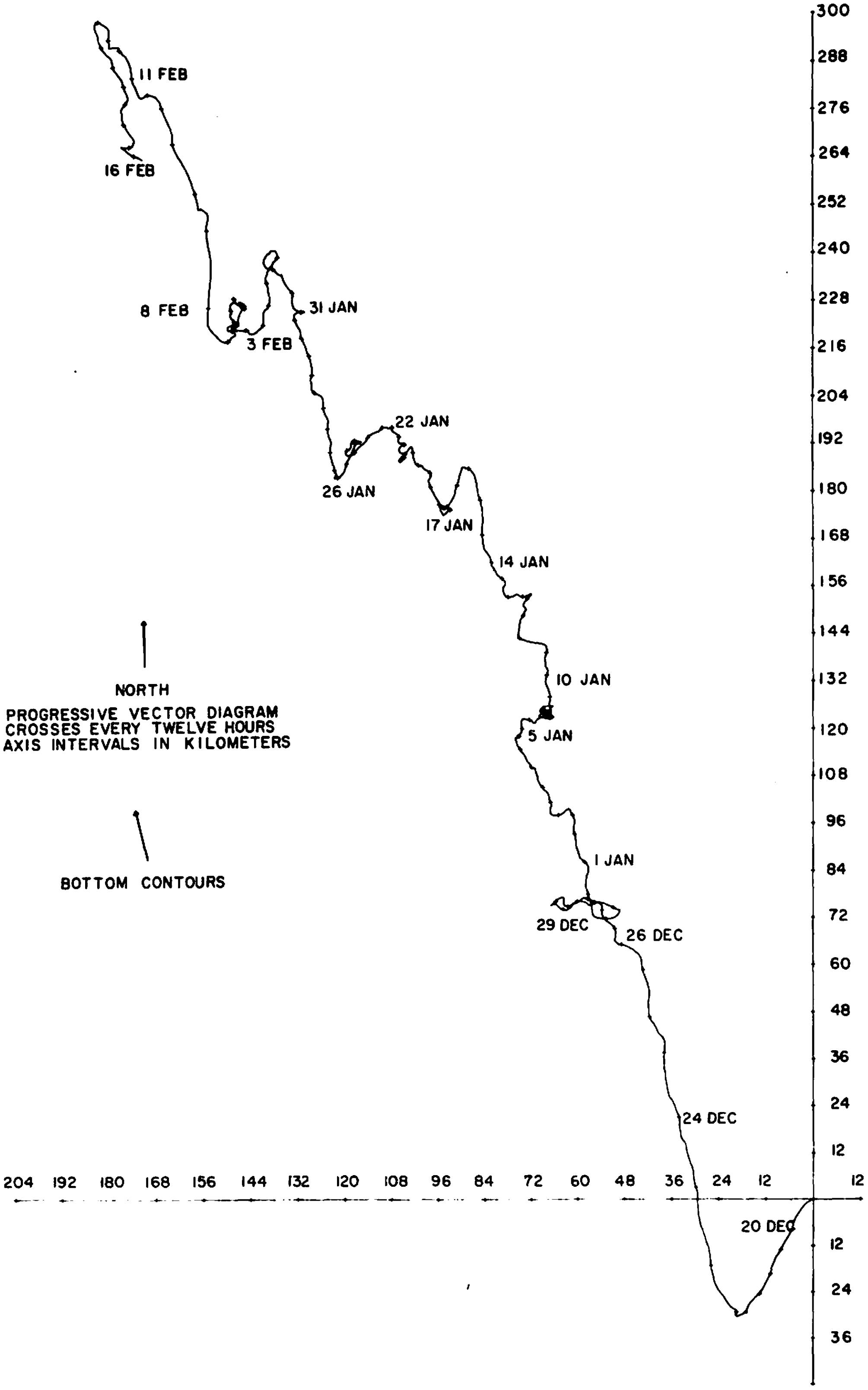


Fig. A-39. Progressive vector diagram for Record O, 19 December 1968 to 16 February 1969

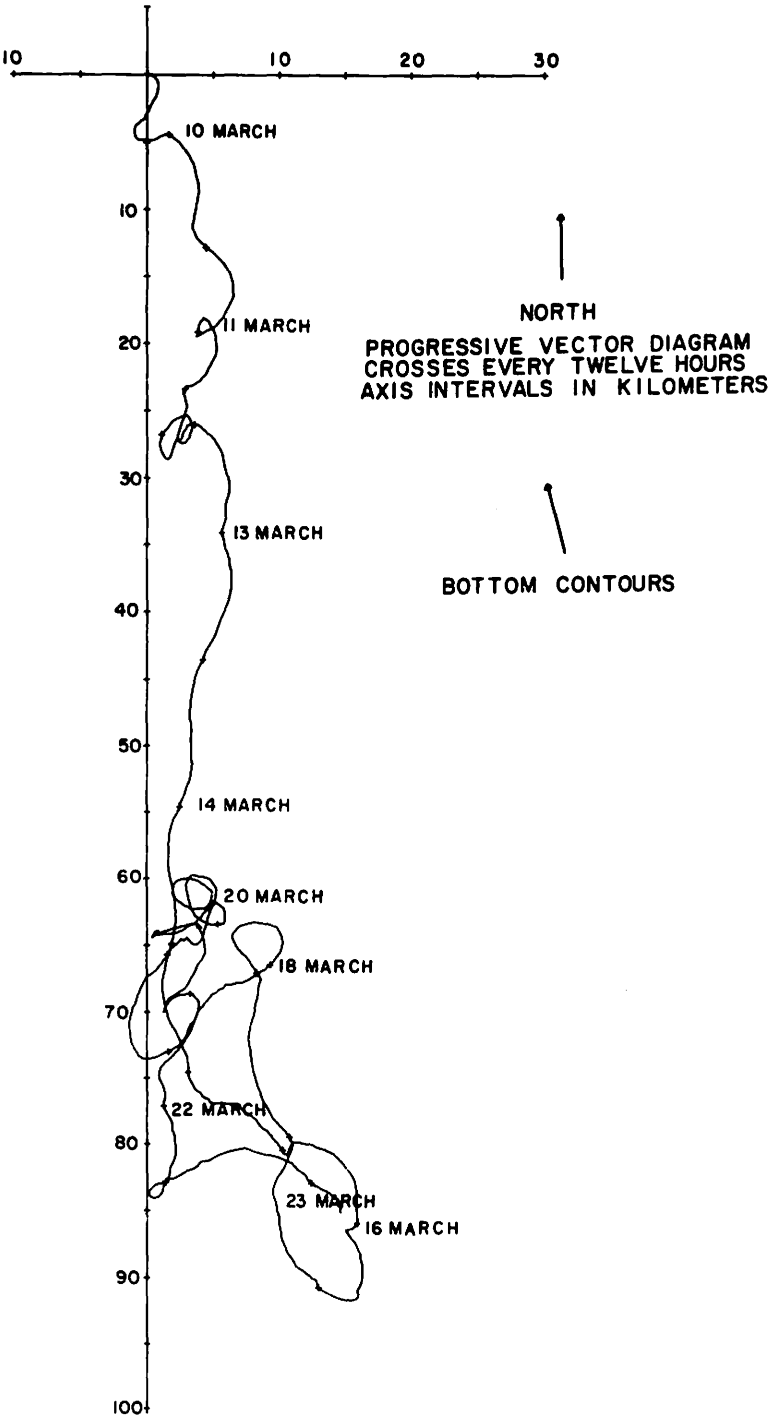


Fig. A-40. Progressive vector diagram for Record R, 9 to 23 March 1969

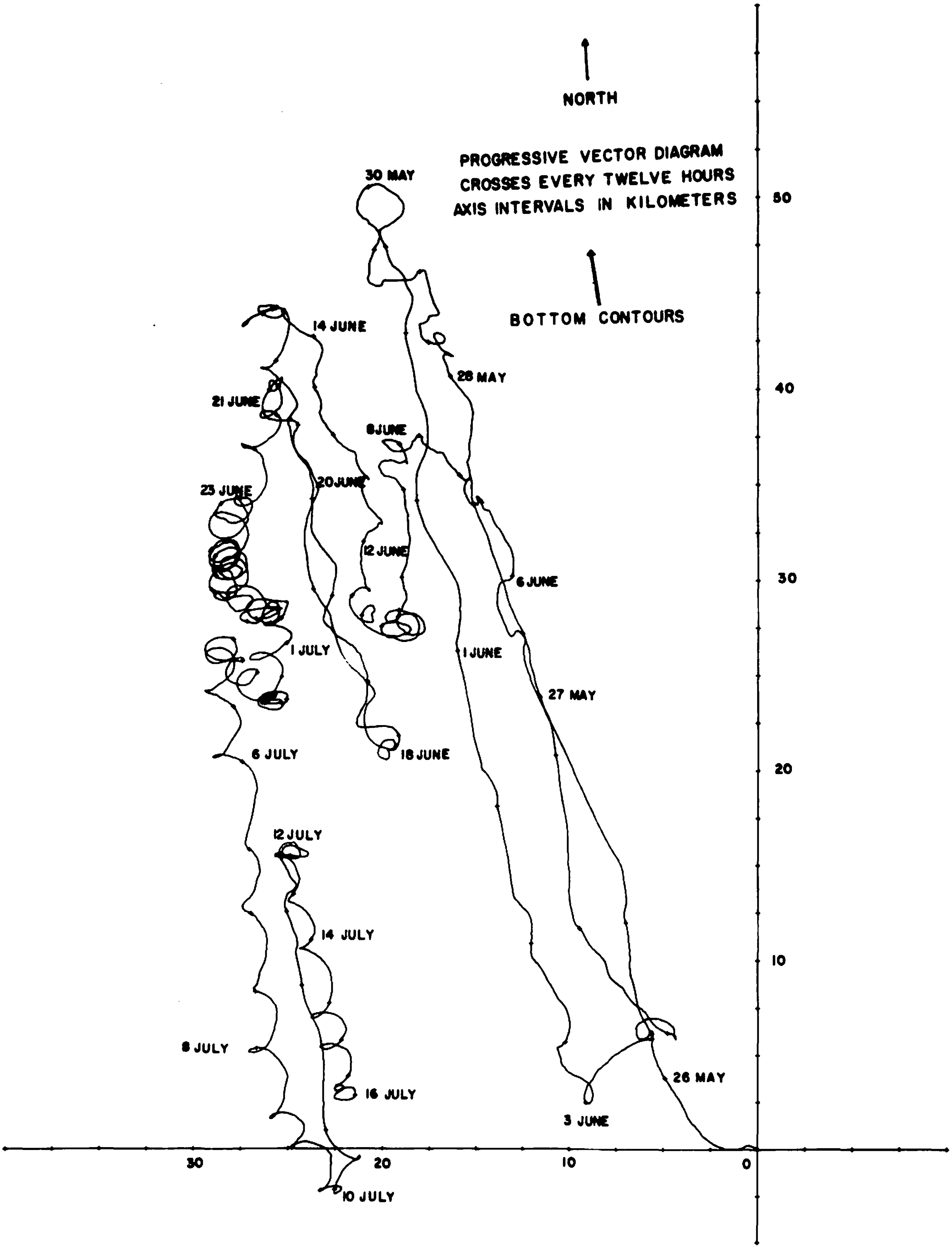


Fig. A-41. Progressive vector diagram for Record S, 25 May to 16 July 1969

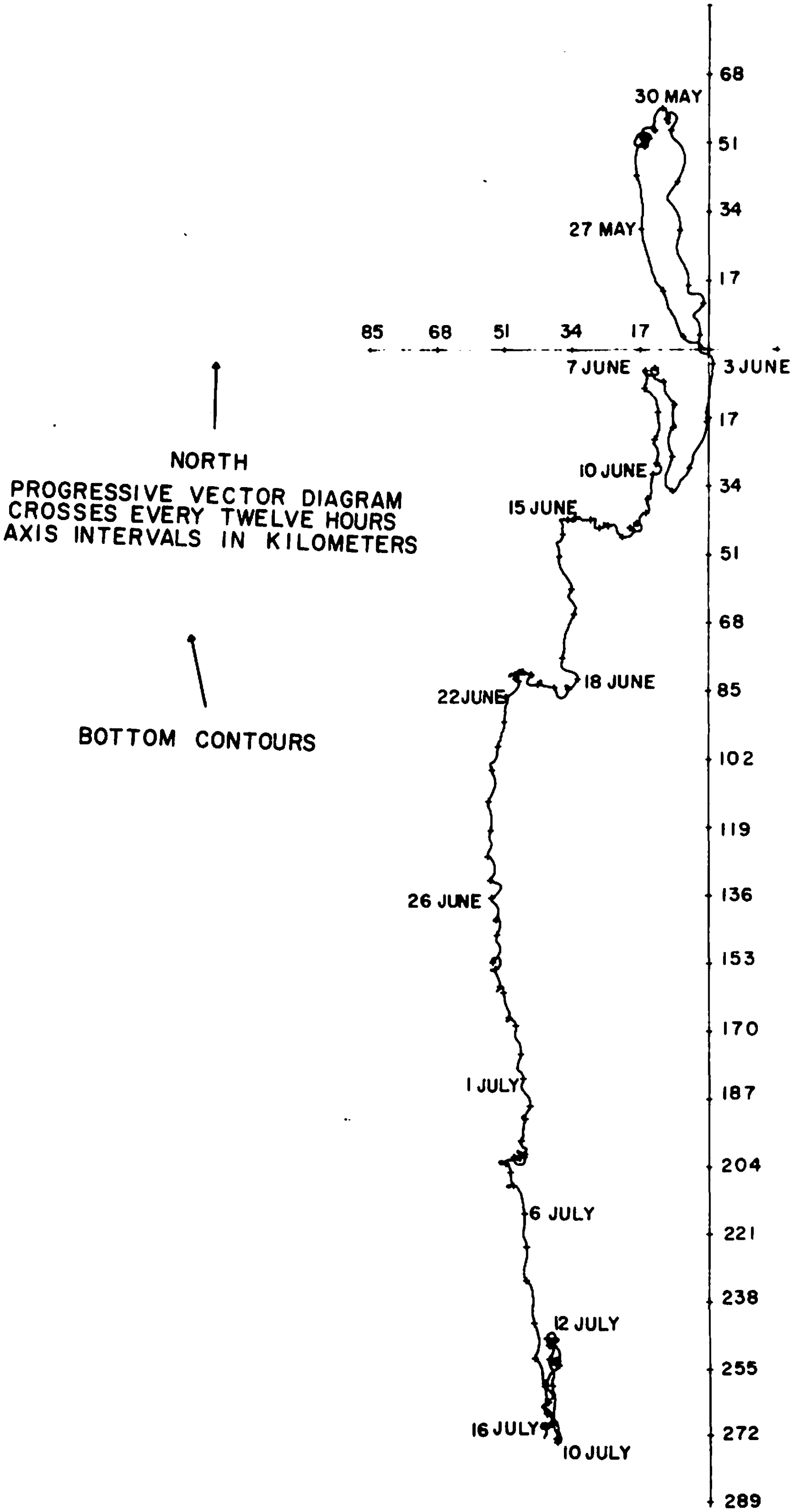


Fig. A-42. Progressive vector diagram for Record V, 25 May to 16 July 1969

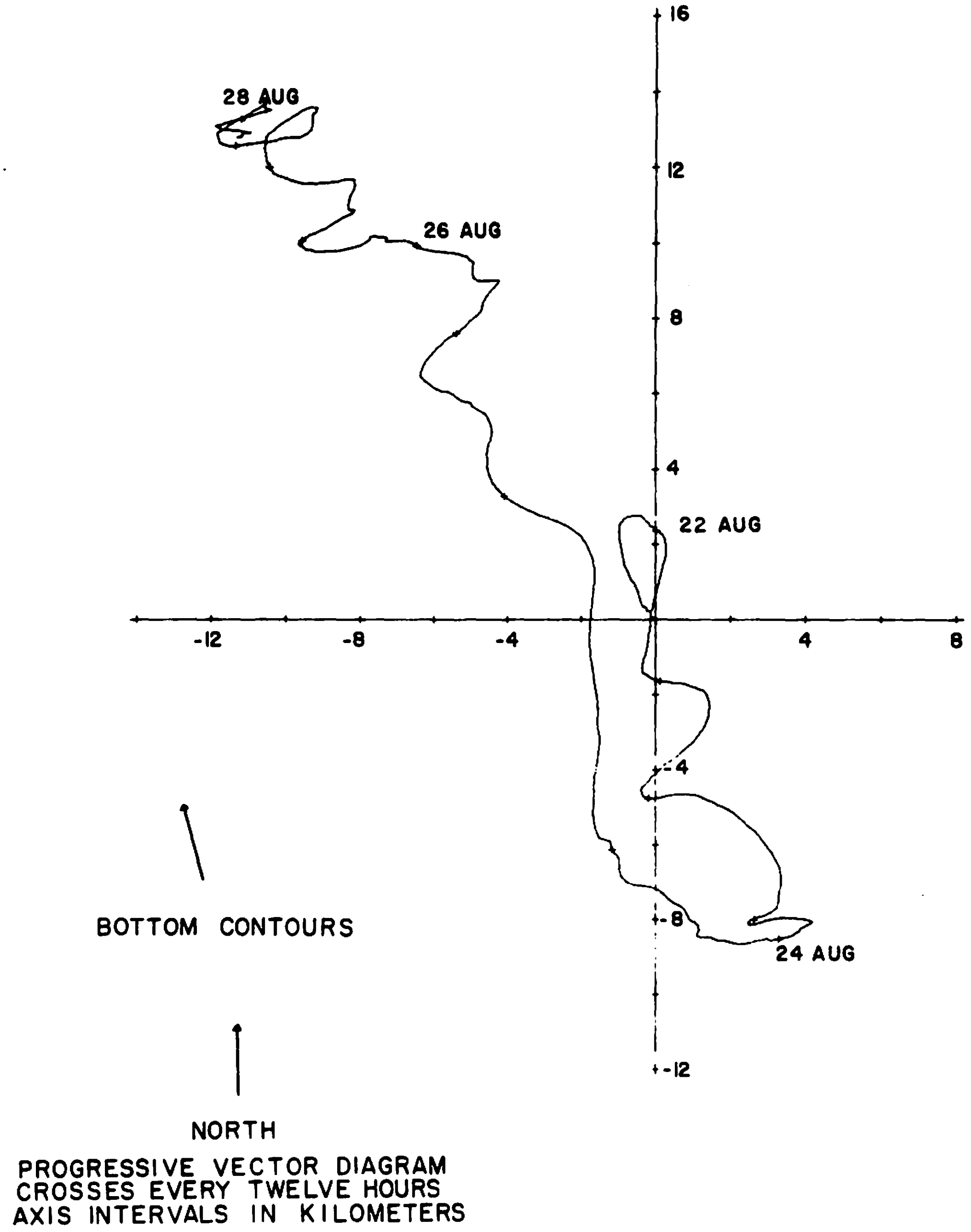


Fig. A-43. Progressive vector diagram for Record X, 21 to 28 August 1969

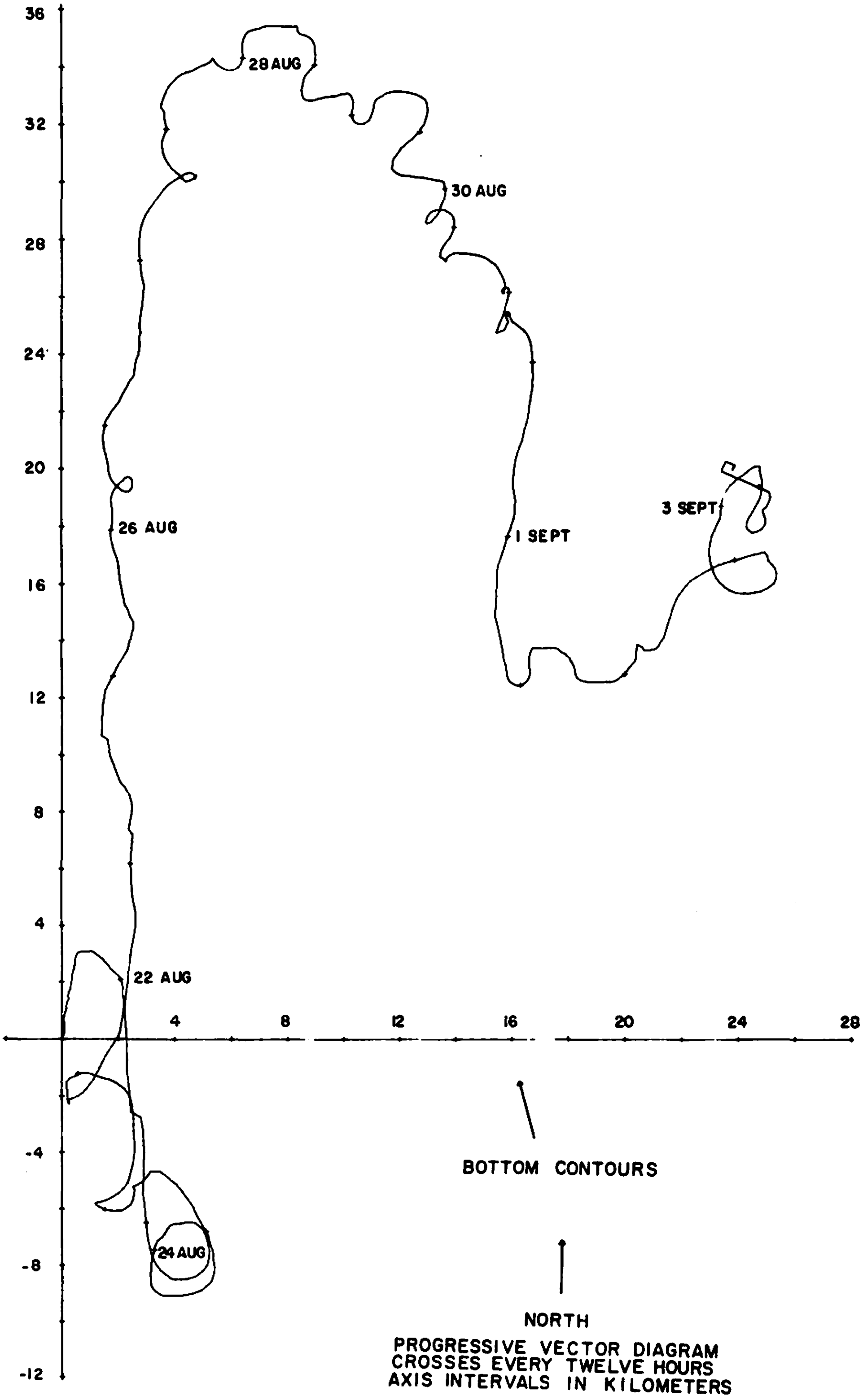


Fig. A-44. Progressive vector diagram for Record Y, 21 August to 3 September 1969

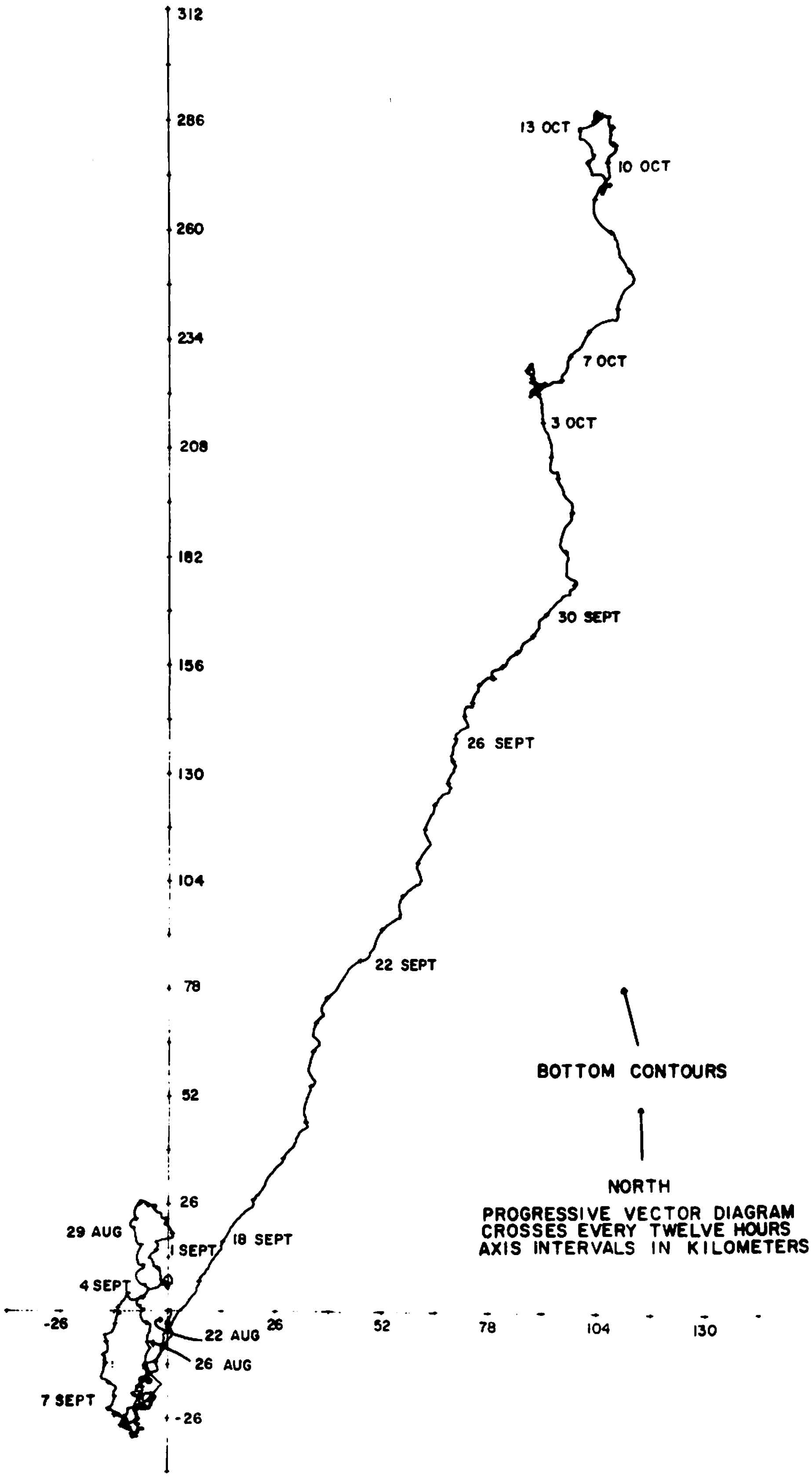


Fig. A-45. Progressive vector diagram for Record Z, 21 August to 14 October 1969

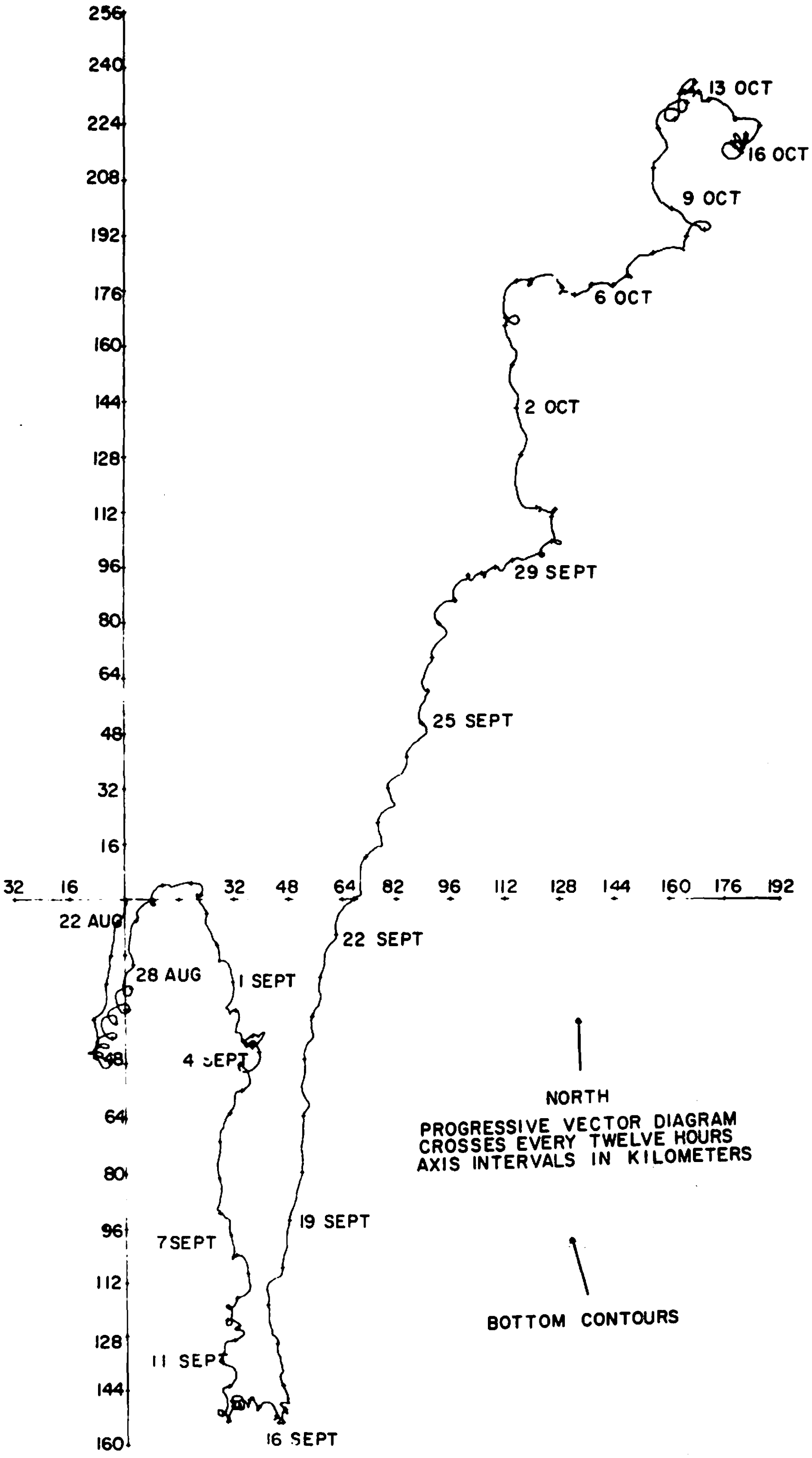


Fig. A-46. Progressive vector diagram for Record AA, 21 August to 16 October 1969

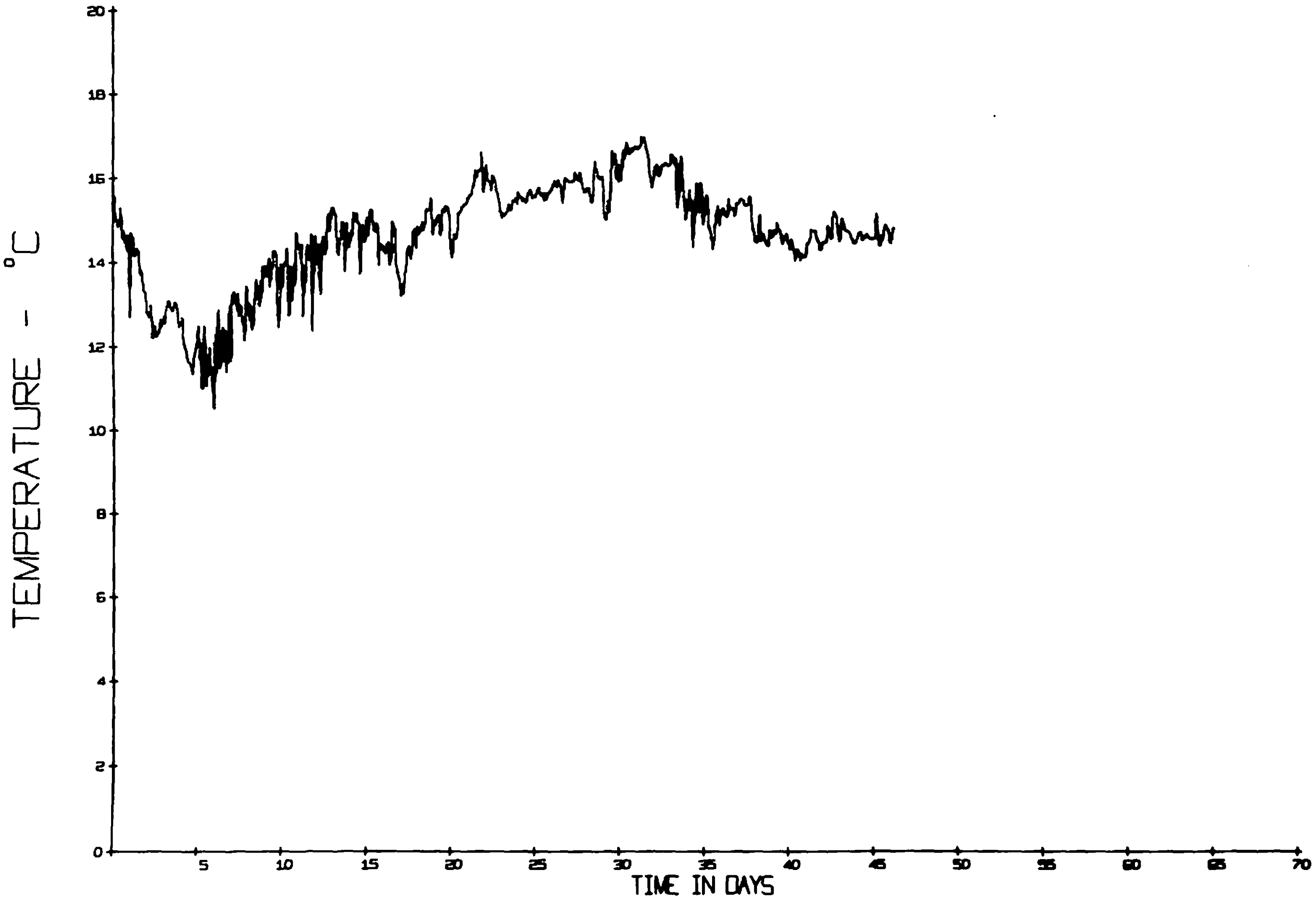


Fig. A-47. Temperature Record AB

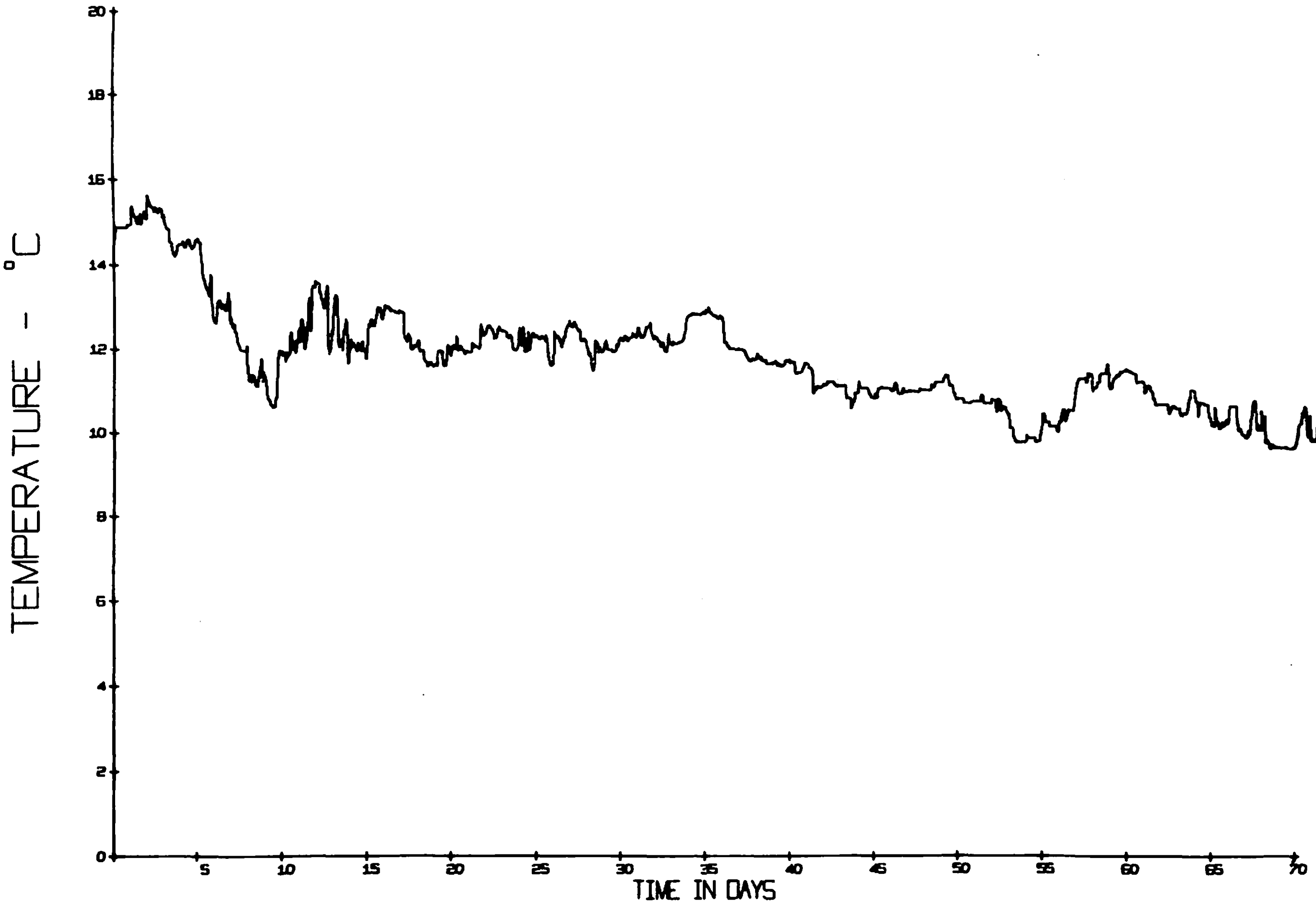


Fig. A-48. Temperature Record AC

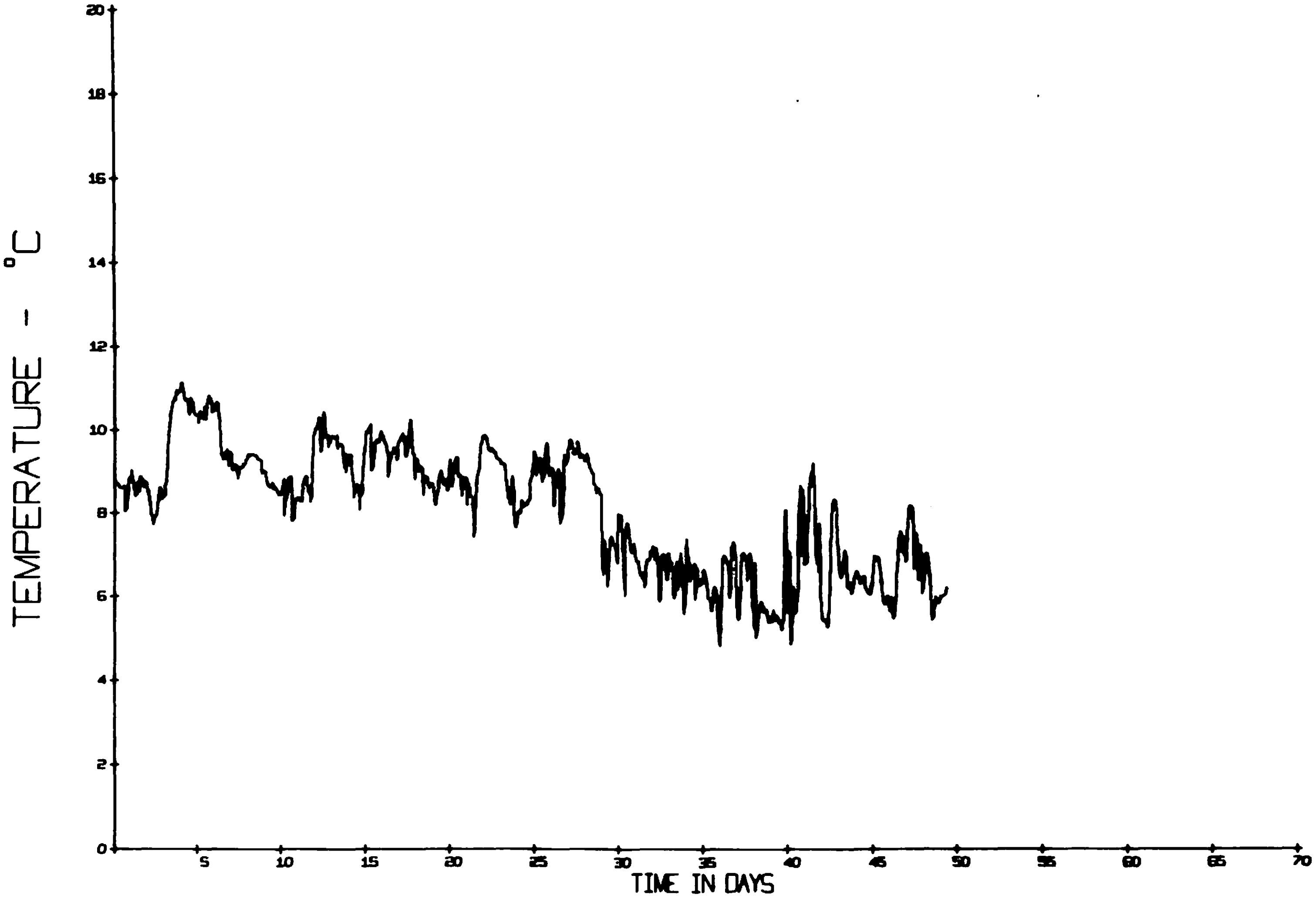


Fig. A-49. Temperature Record AD

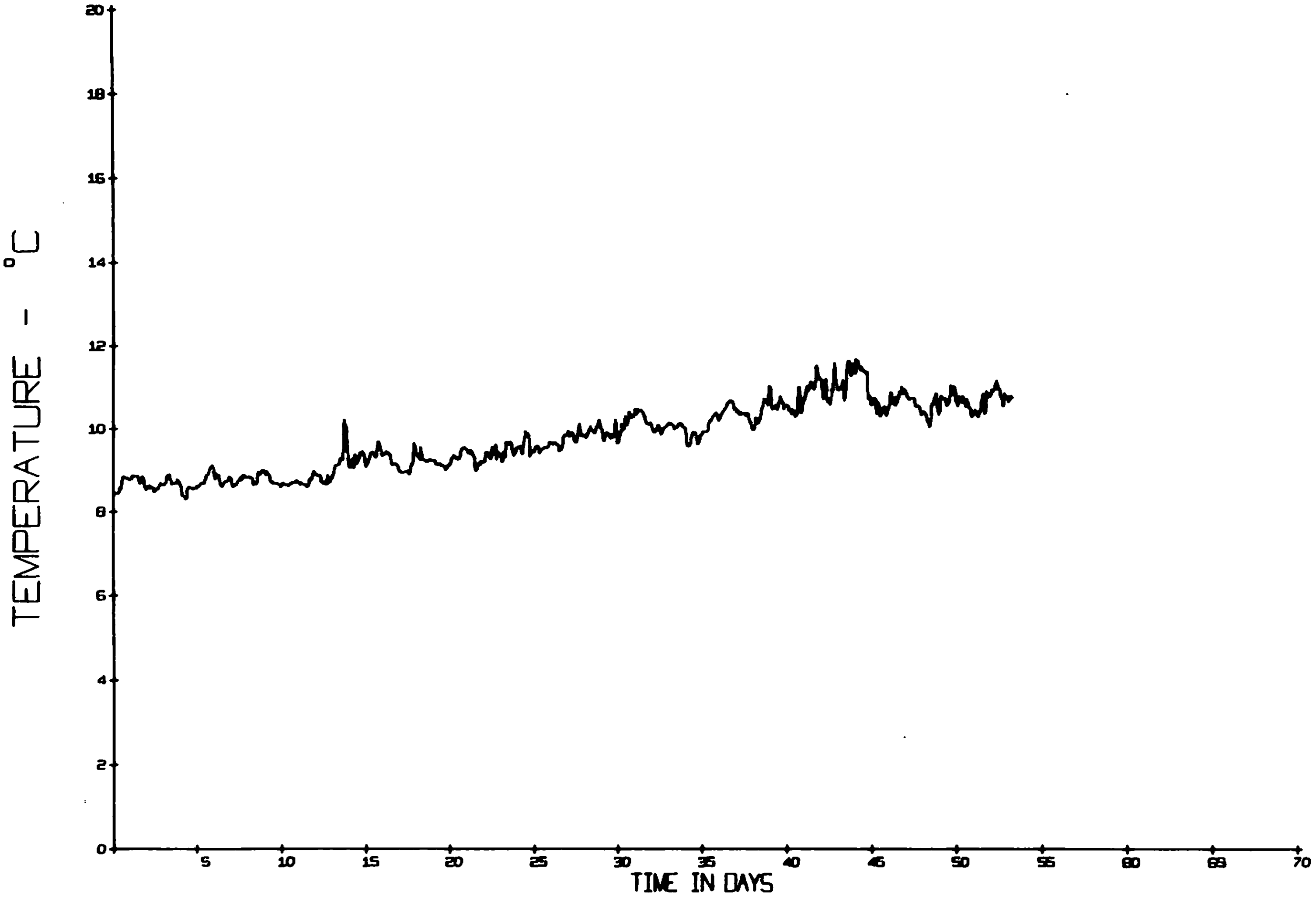


Fig. A-50. Temperature Record AE

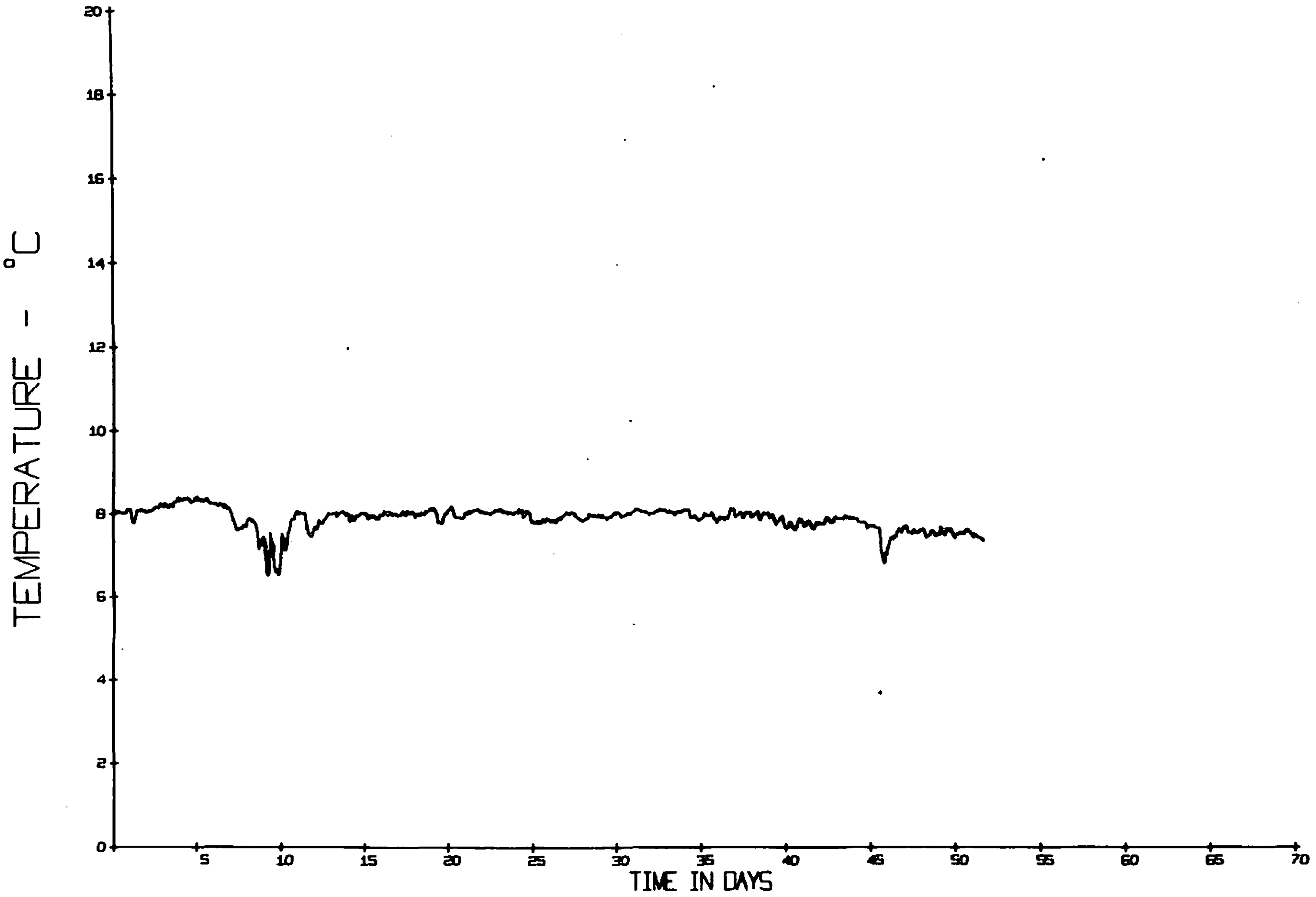


Fig. A-51. Temperature Record AF

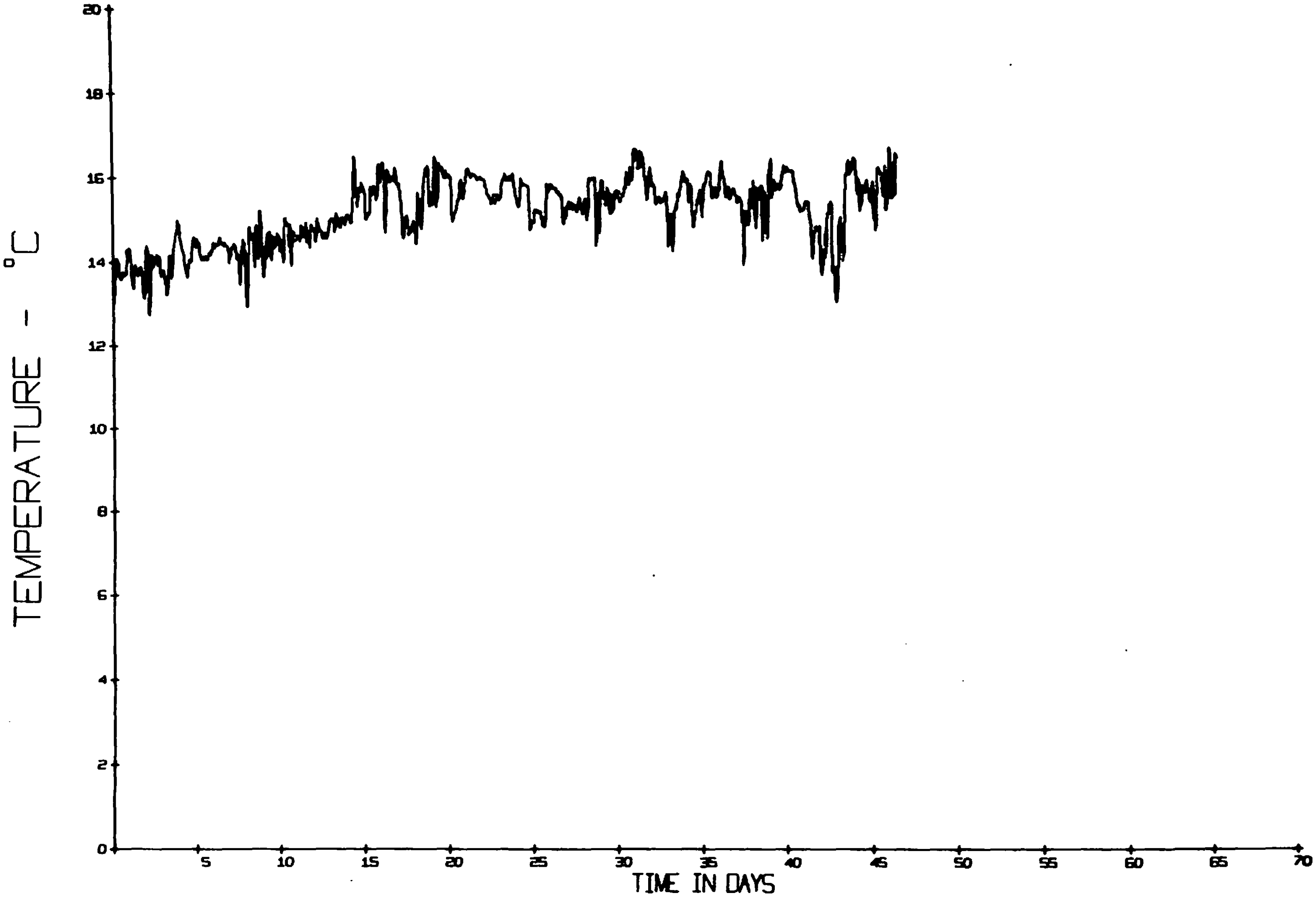


Fig. A-52. Temperature Record AG.

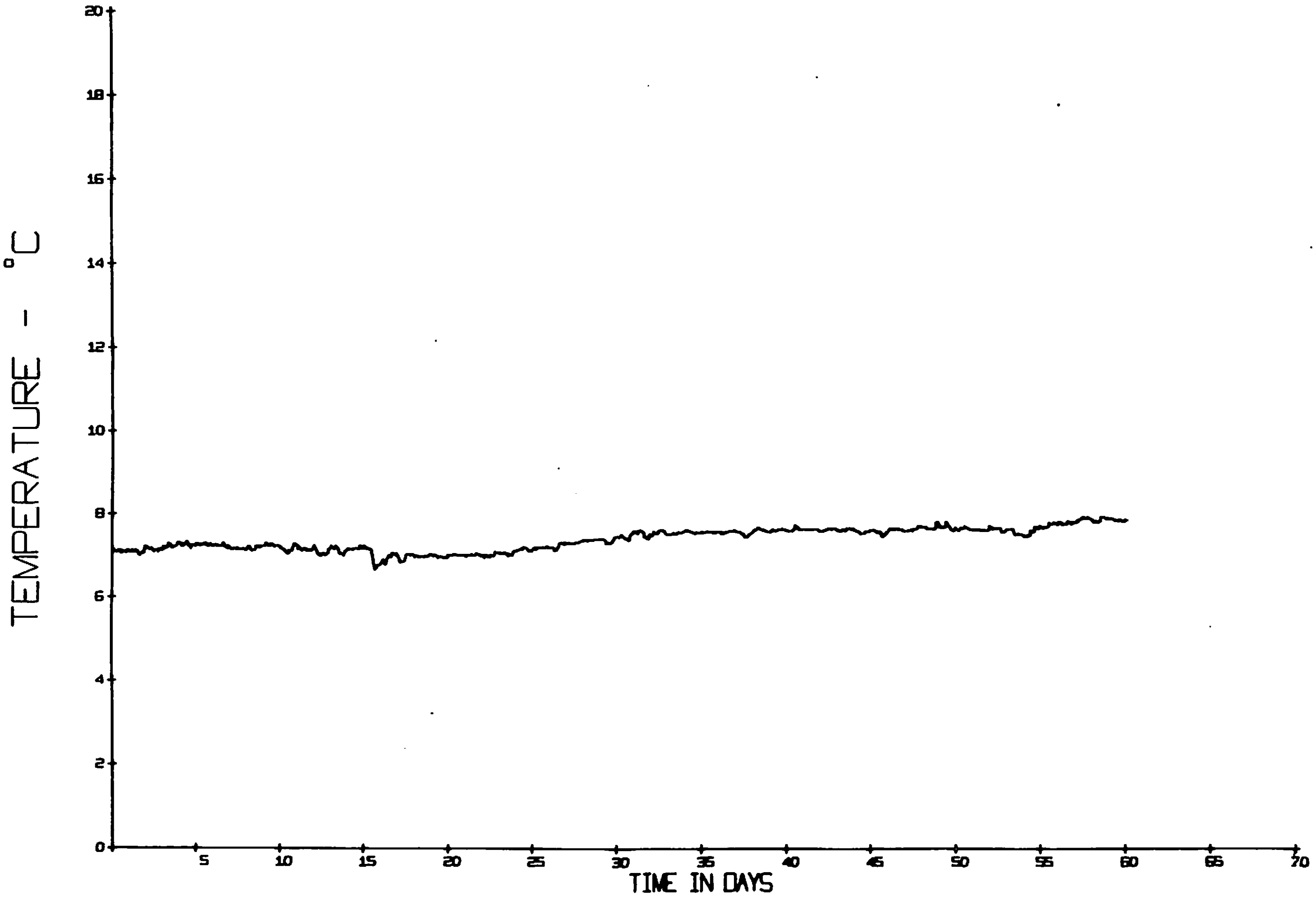


Fig. A-53. Temperature Record AH

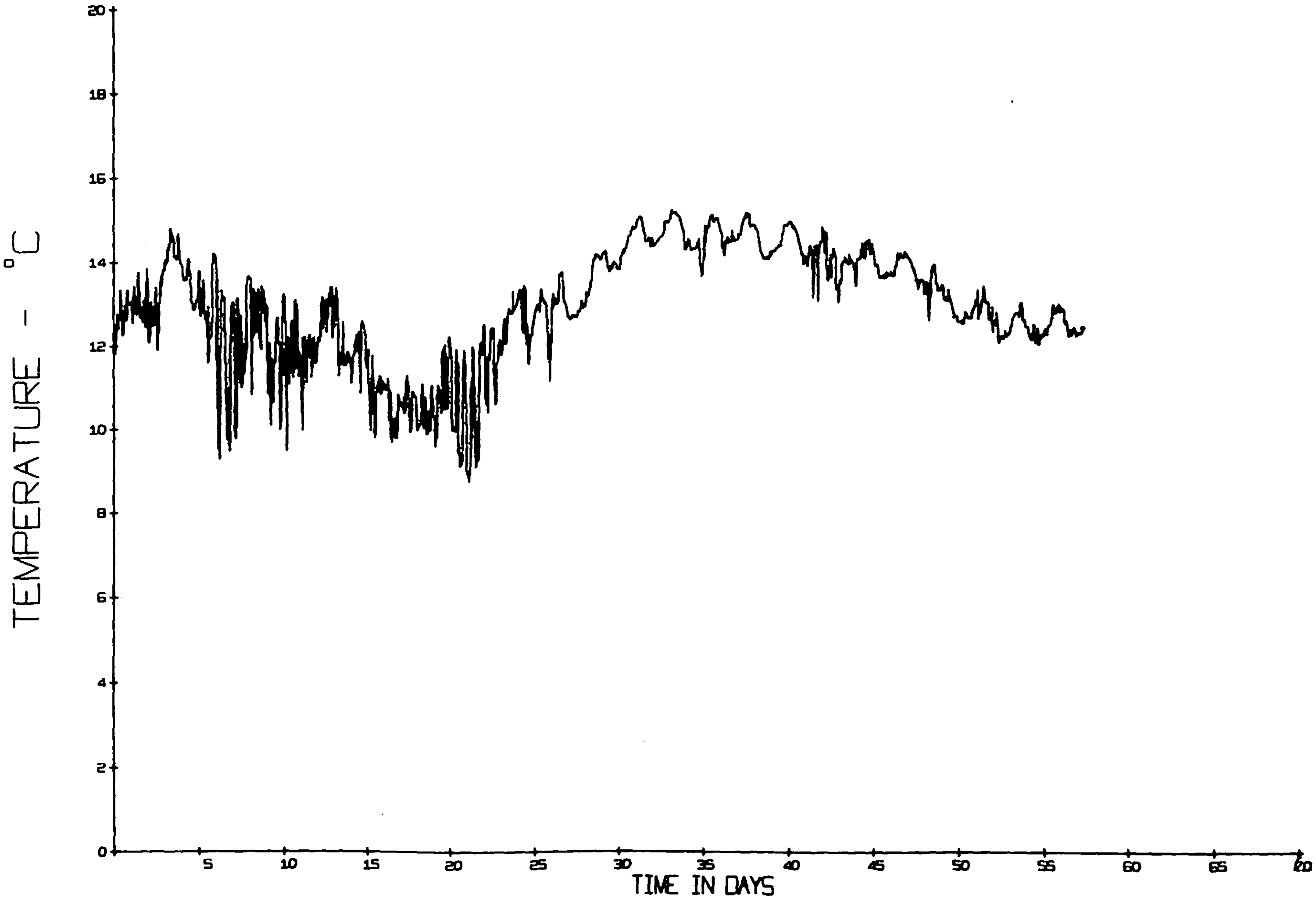


Fig. A-54. Temperature Record AI

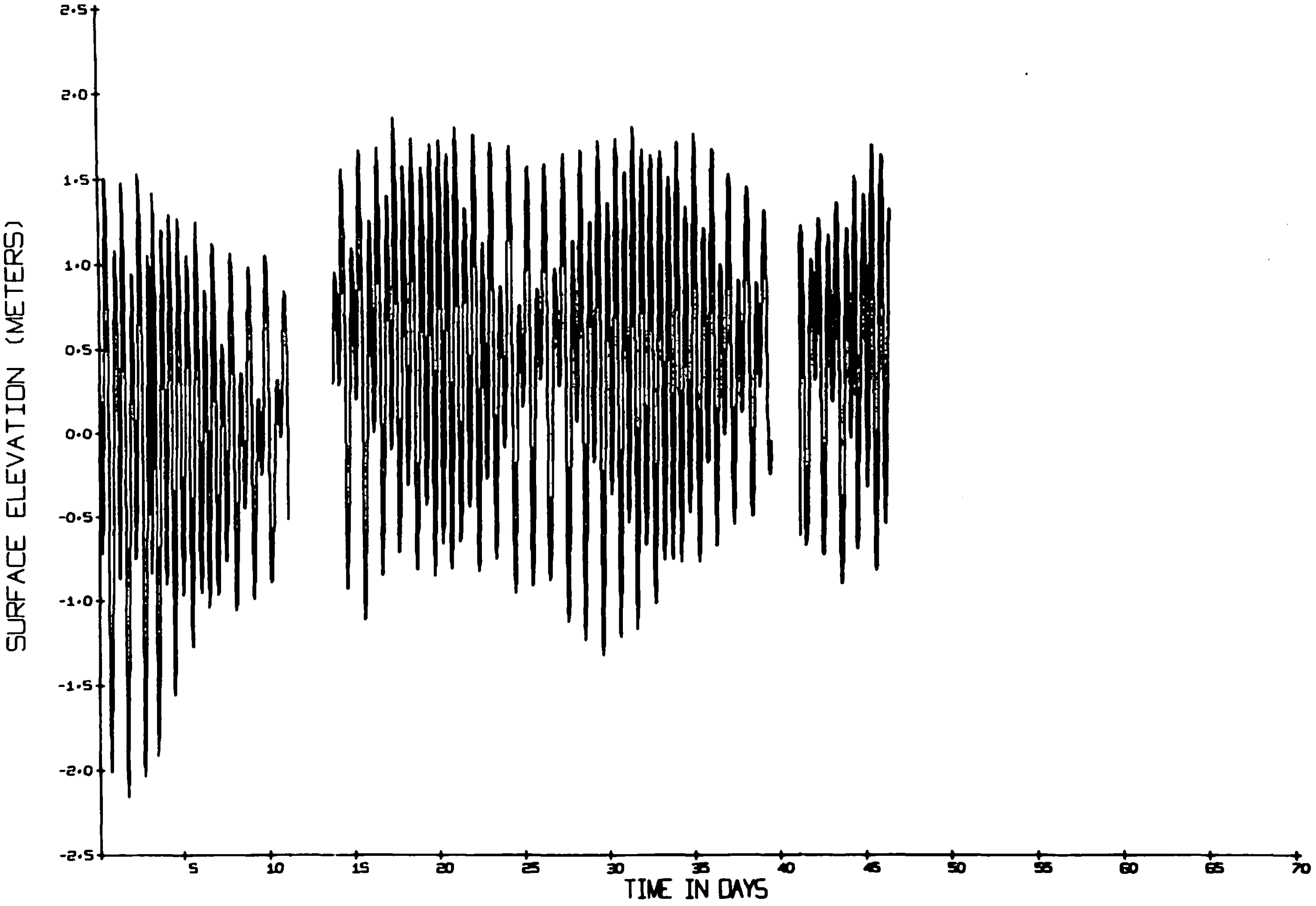


Fig. A-55. Pressure Record AB

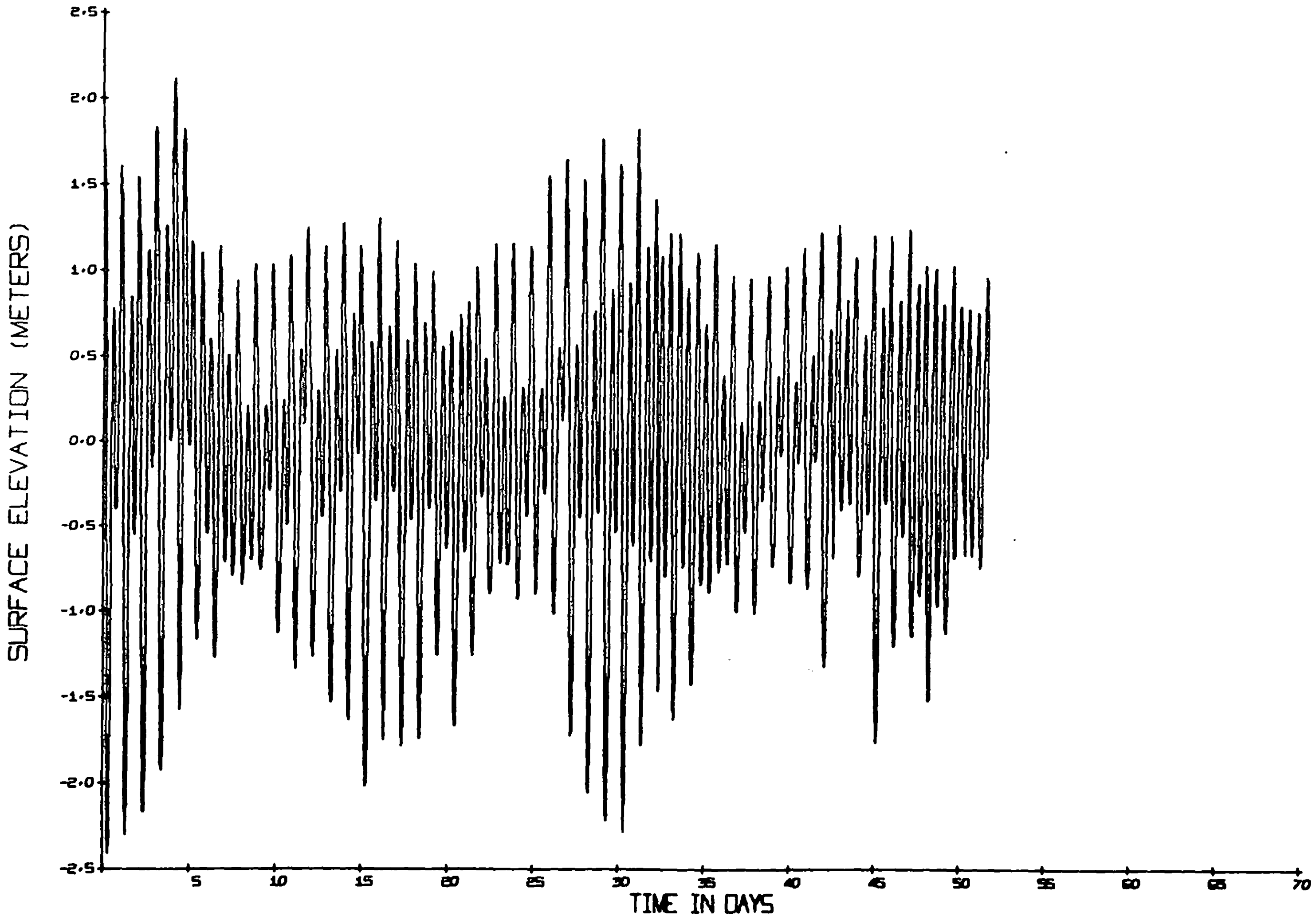


Fig. A-56. Pressure Record AD

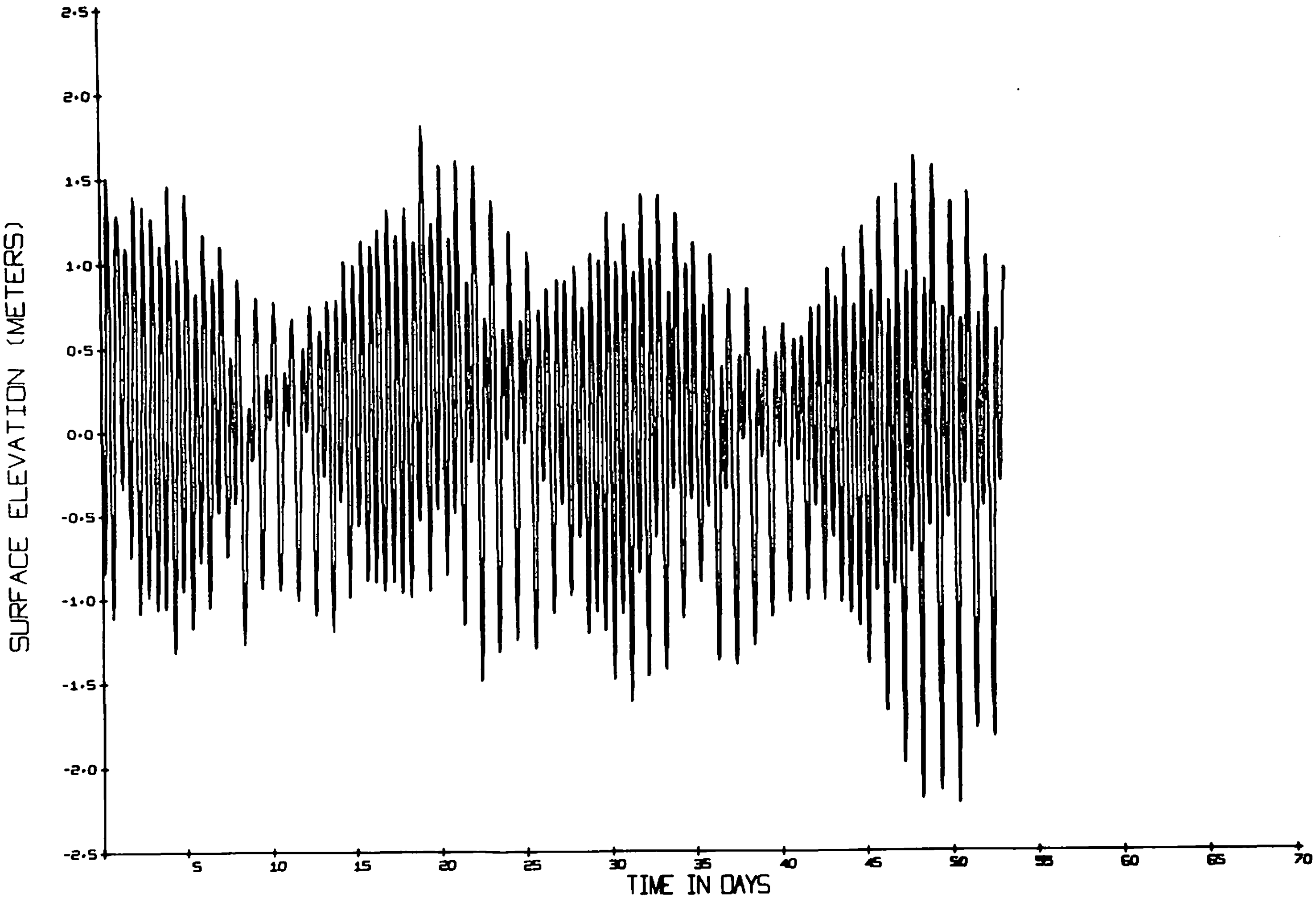


Fig. A-57. Pressure Record AE

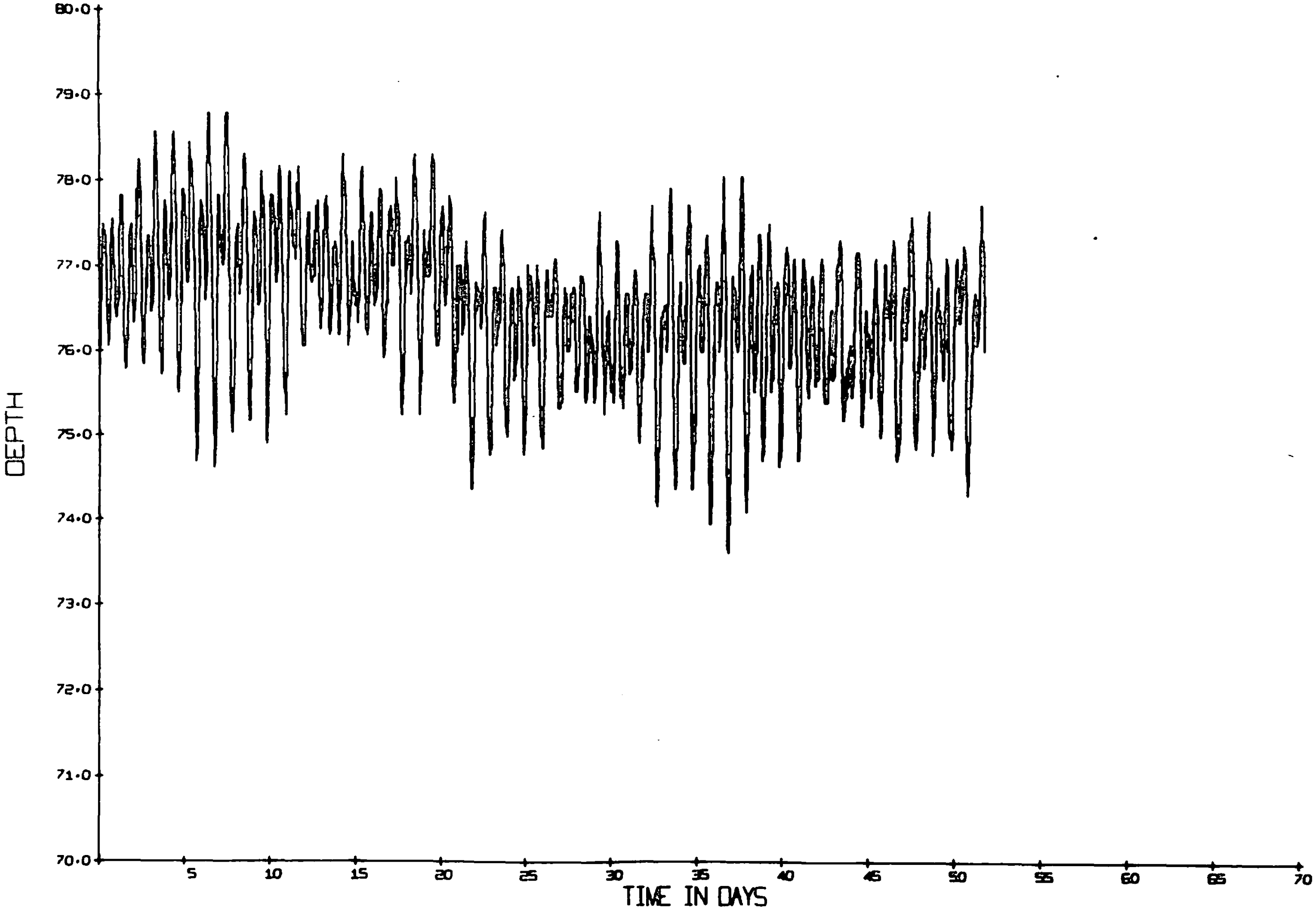


Fig. A-58. Pressure Record AF

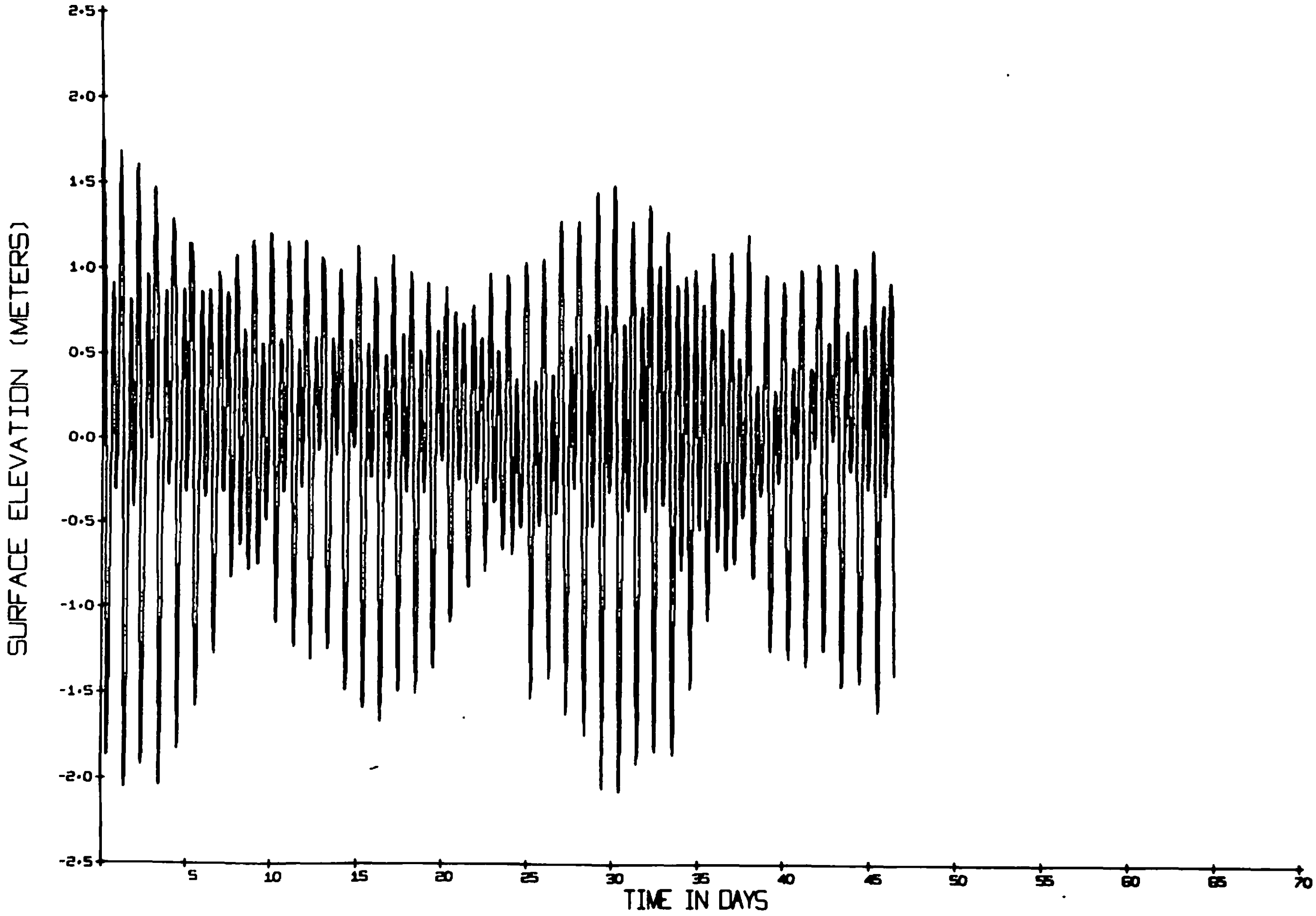


Fig. A-59. Pressure Record AG

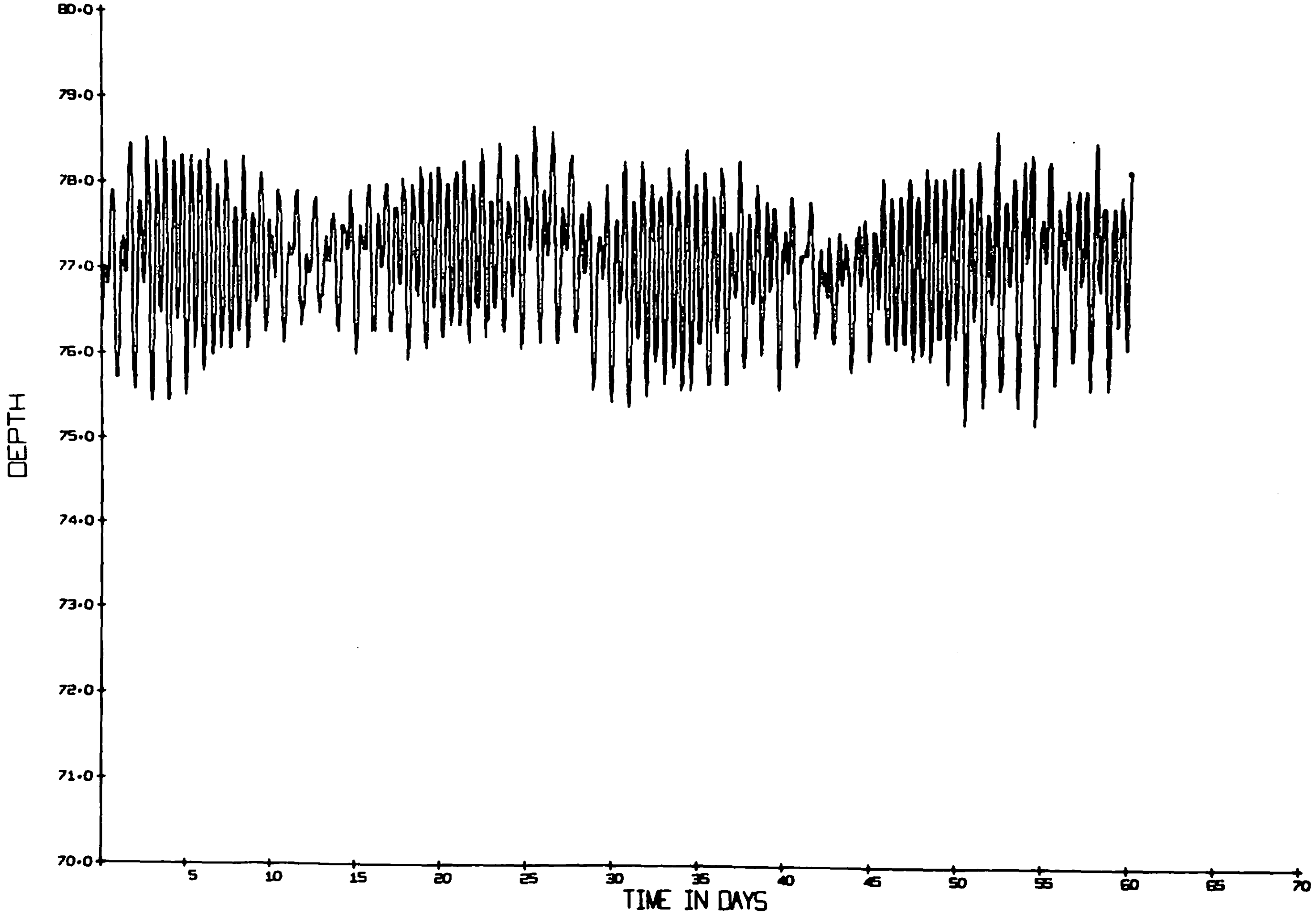


Fig. A-60. Pressure Record AH

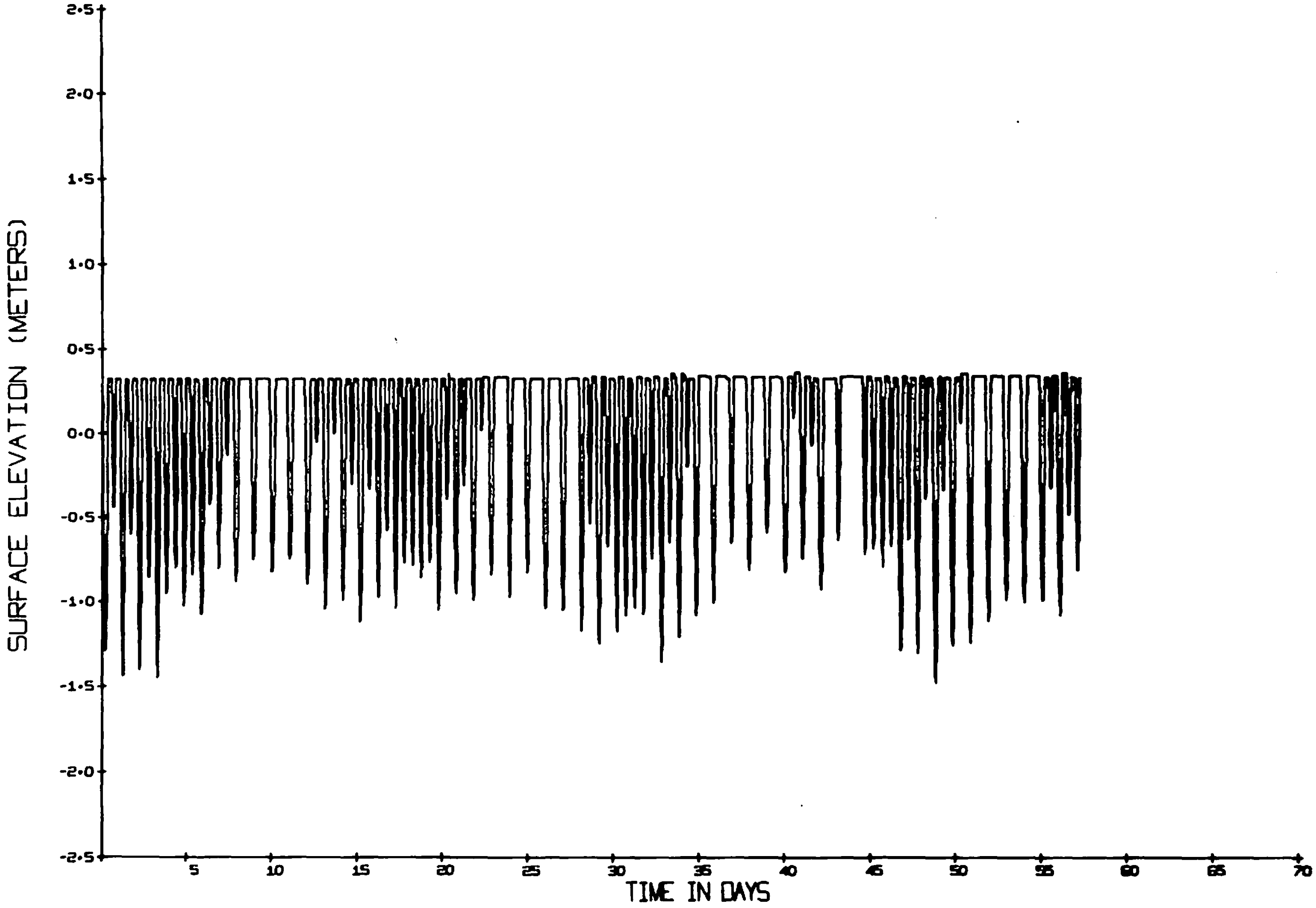


Fig. A-61. Pressure Record AI

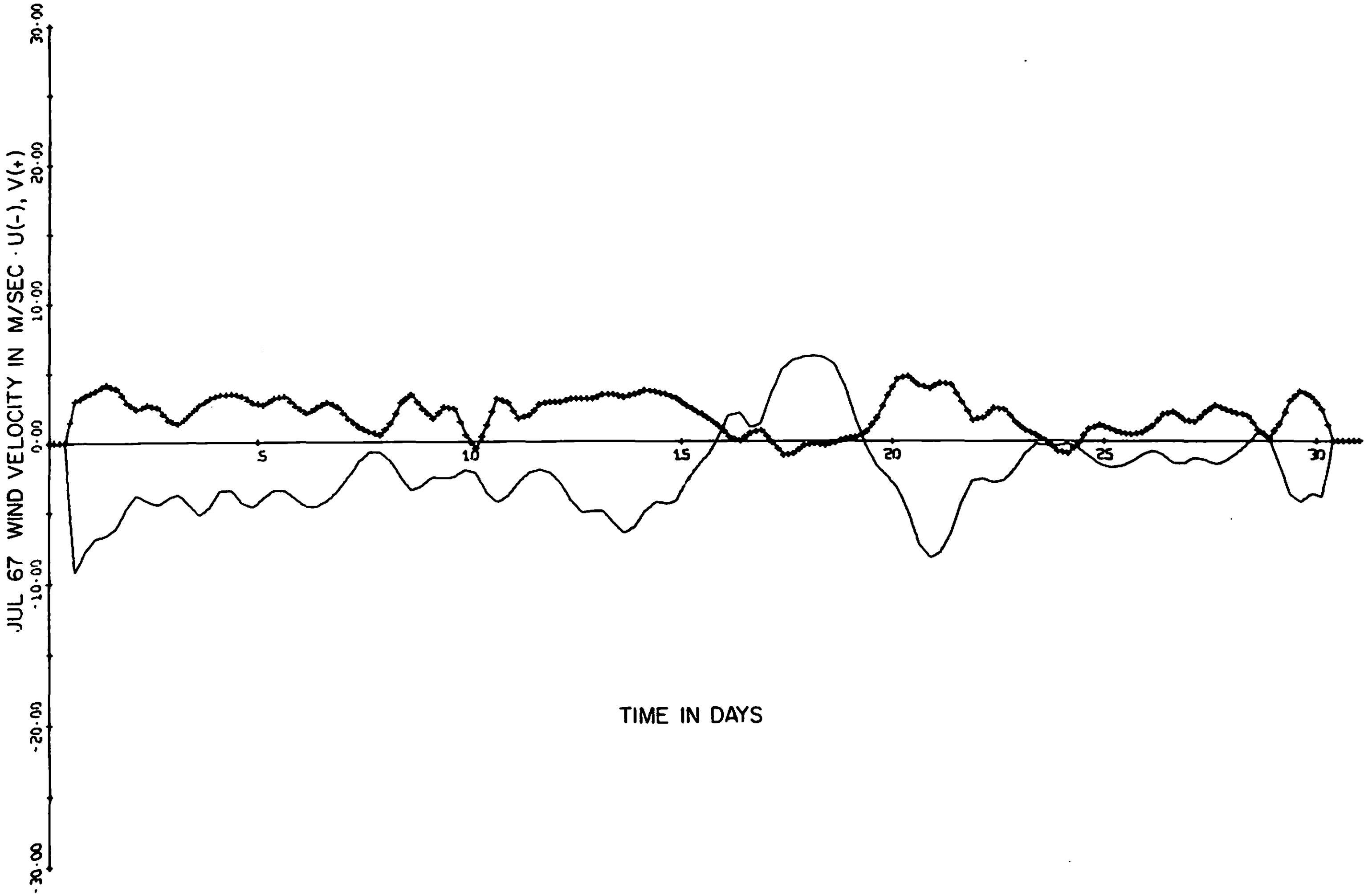


Fig. A-62. Wind at Columbia River Lightship; U(N+, S-) and V(E+, W-). July 1967

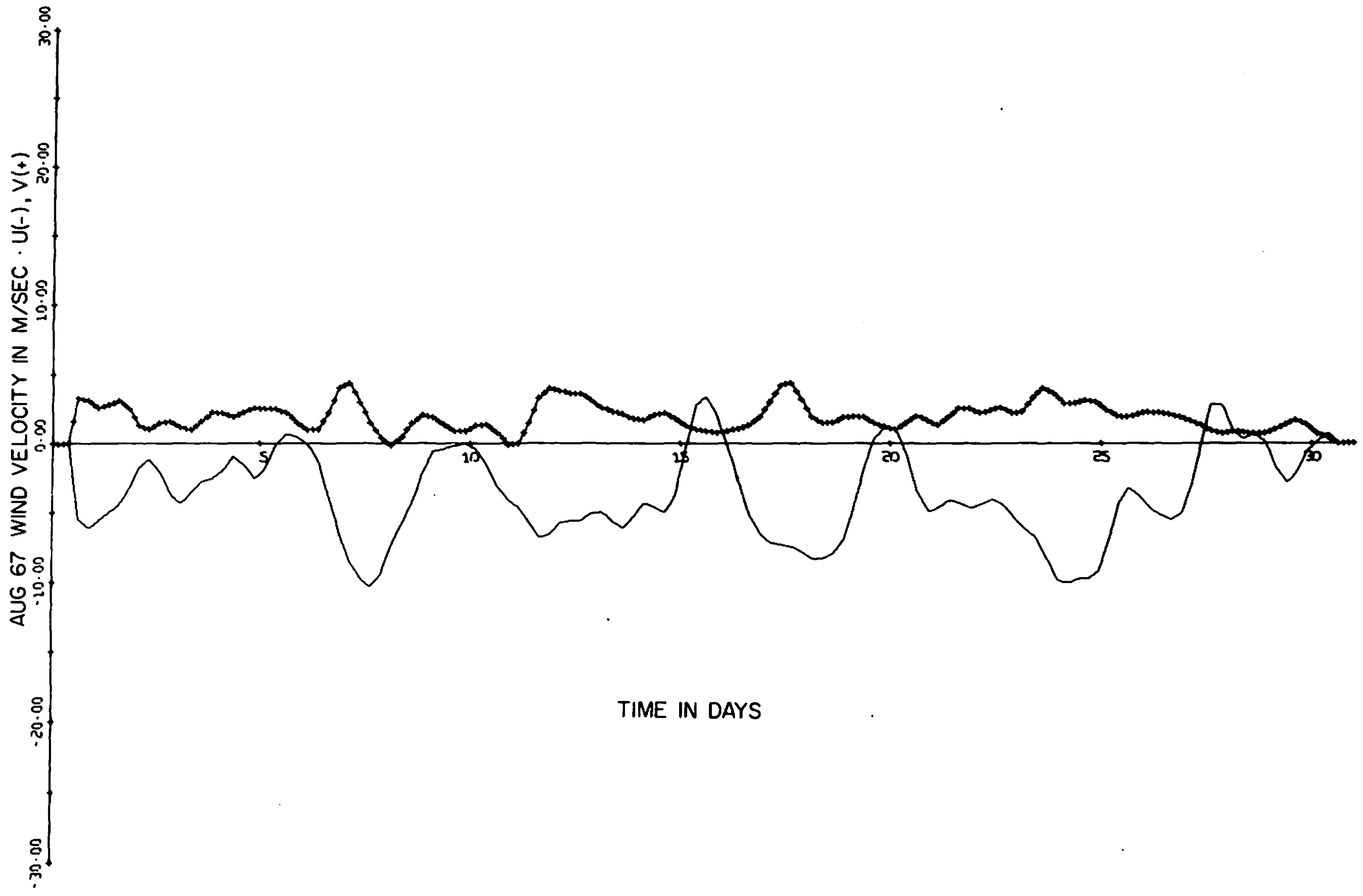


Fig. A-63. Wind at Columbia River Lightship; U(N+, S-) and V(E+, W-). August 1967

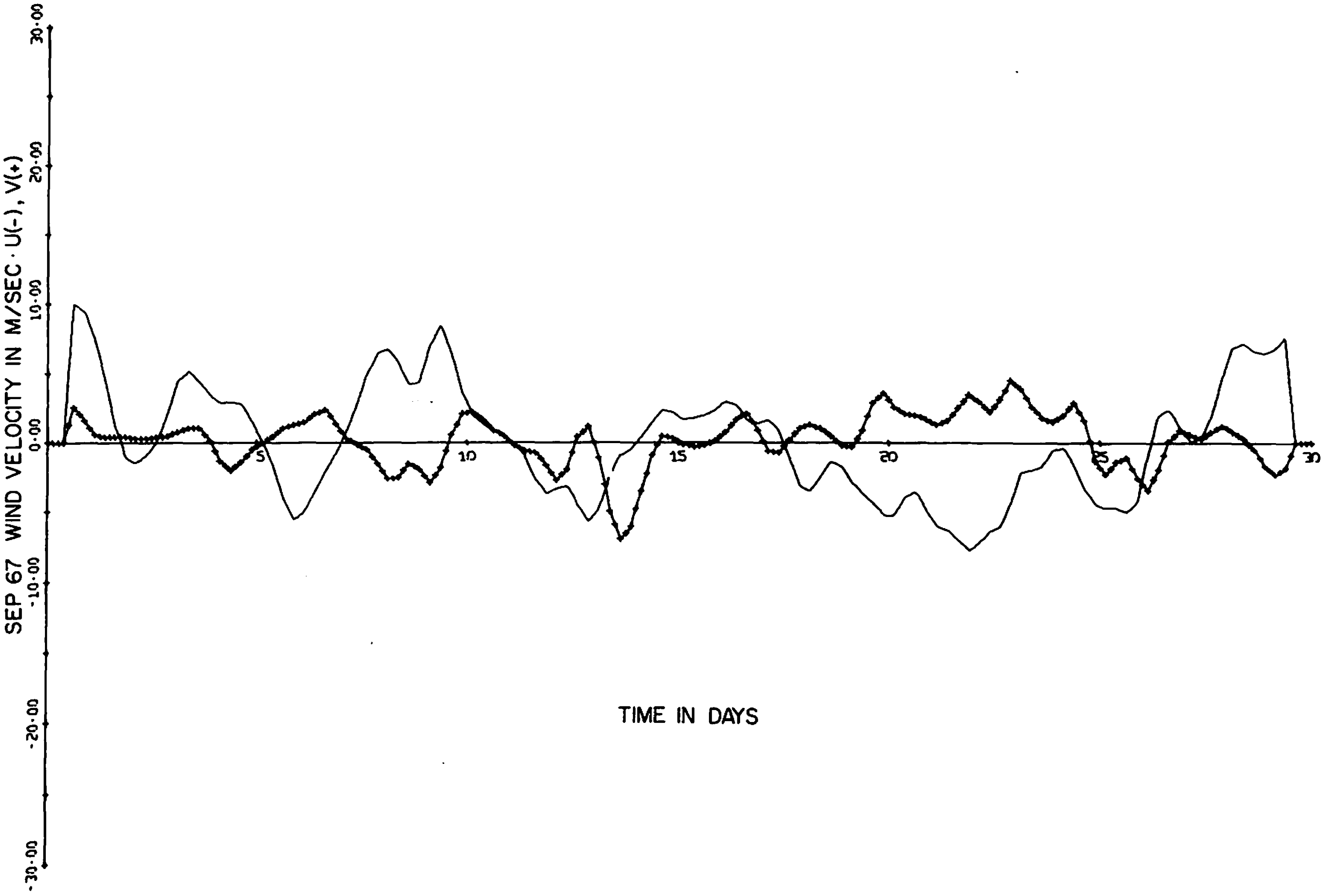


Fig. A-64. Wind at Columbia River Lightship; U(N+, S-) and V(E+, W-). September 1967

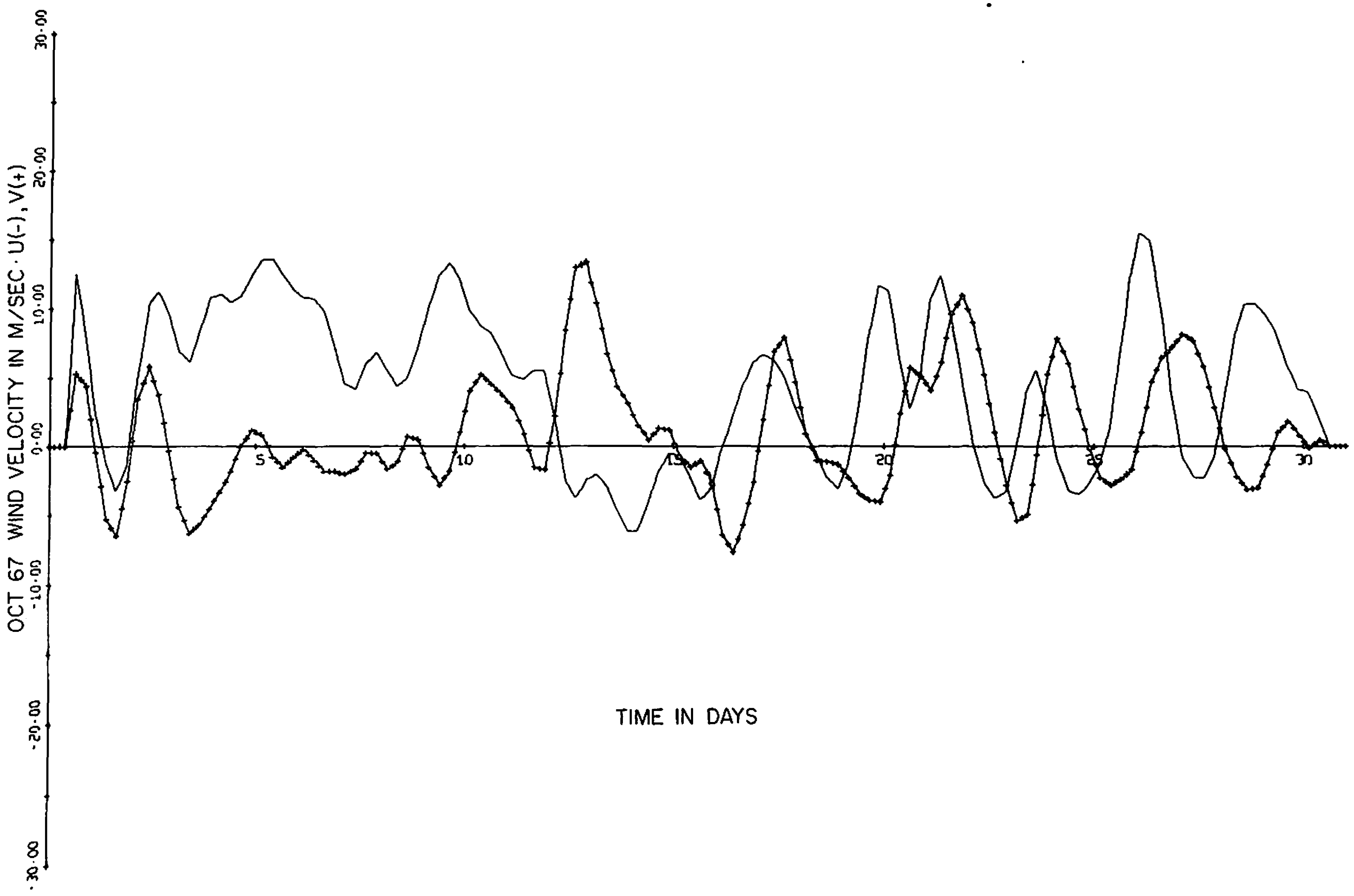


Fig. A-65. Wind at Columbia River Lightship; U(N+, S-) and V(E+, W-), October 1967

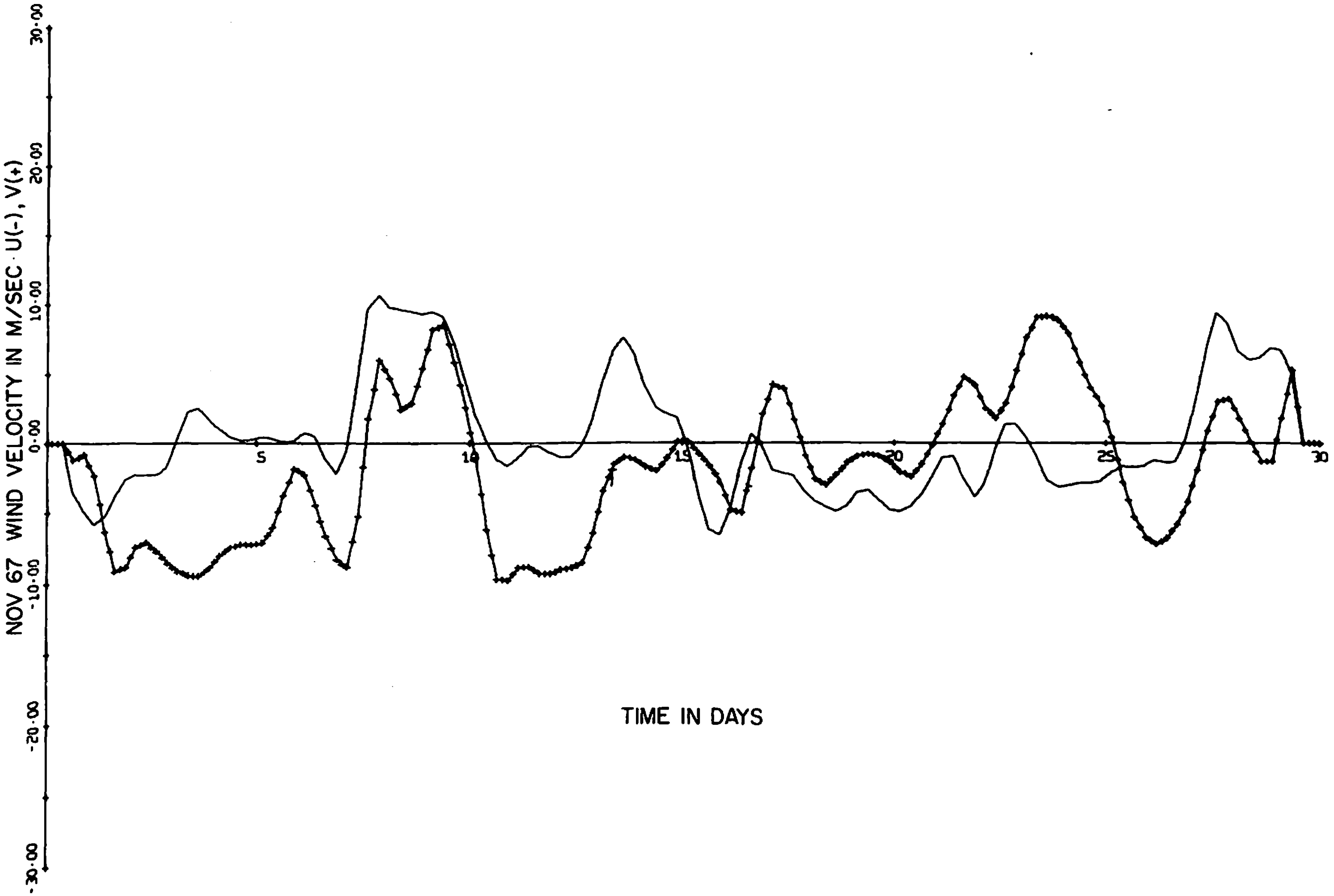


Fig. A-66. Wind at Columbia River Lightship; U(N+, S-) and V(E+, W-). November 1967

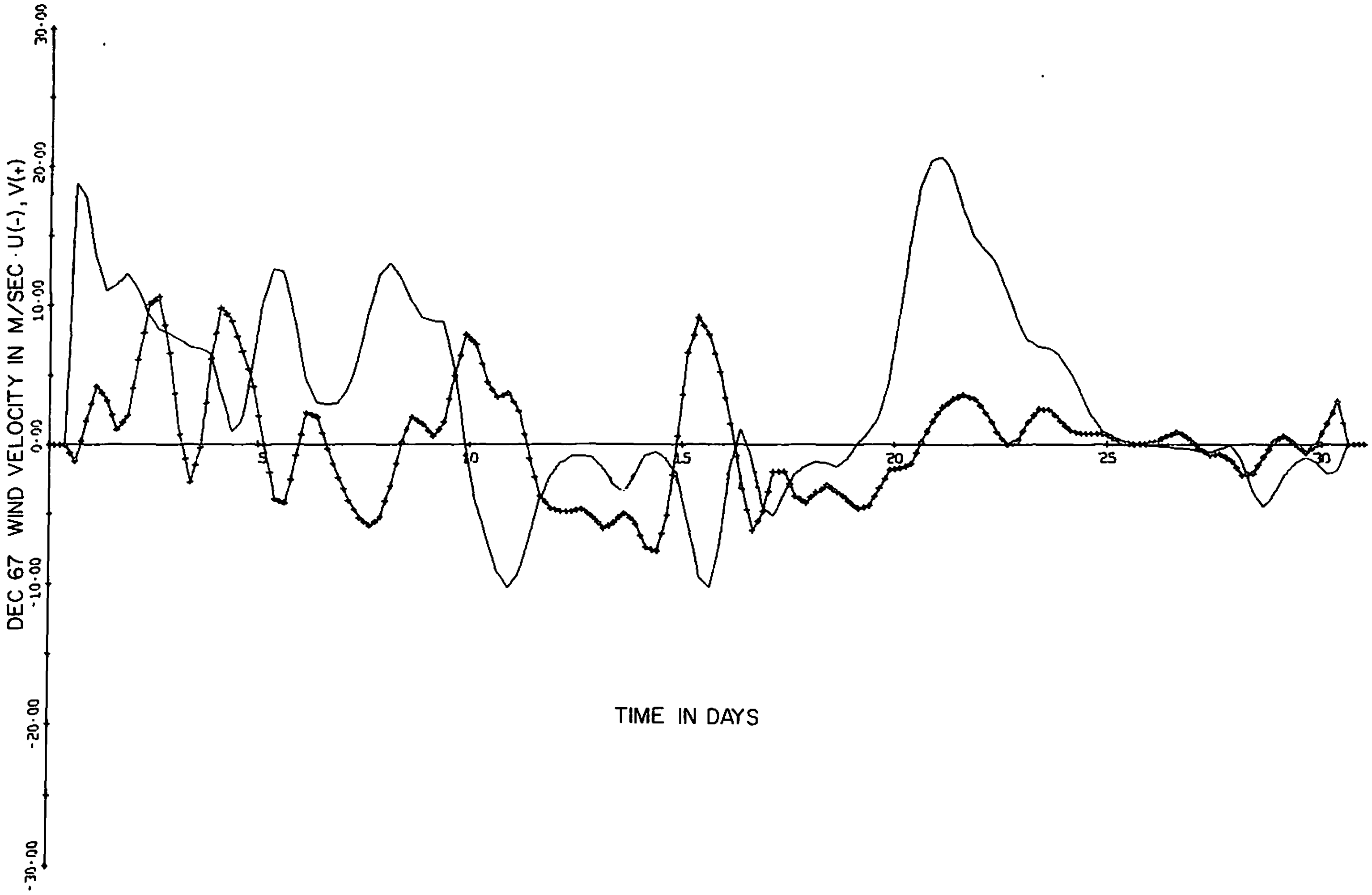


Fig. A-67. Wind at Columbia River Lightship; U(N+, W-) and V(E+, W-). December 1967

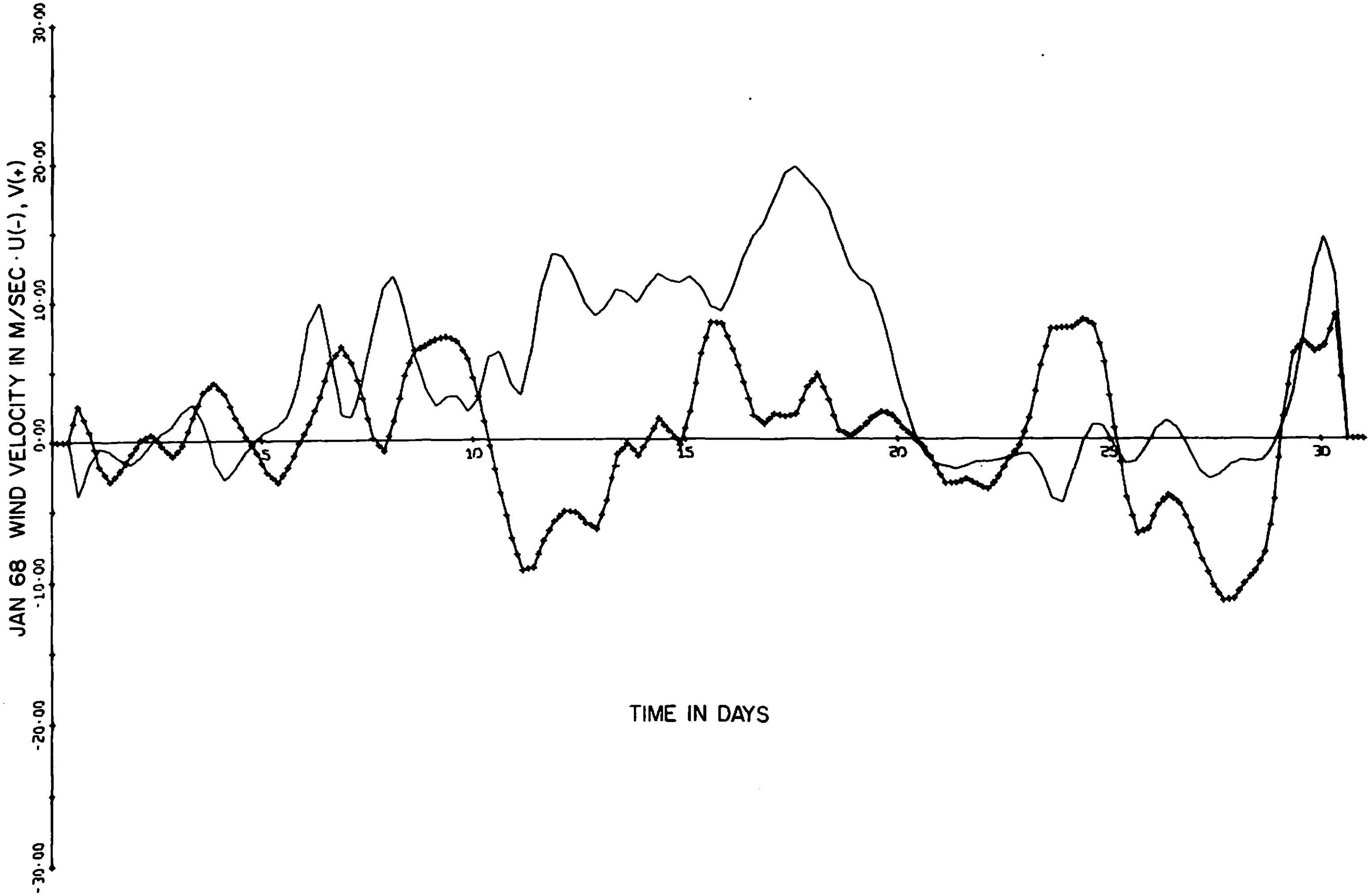


Fig. A-68. Wind at Columbia River Lightship; U(N+, S-) and V(E+, W-). January 1968

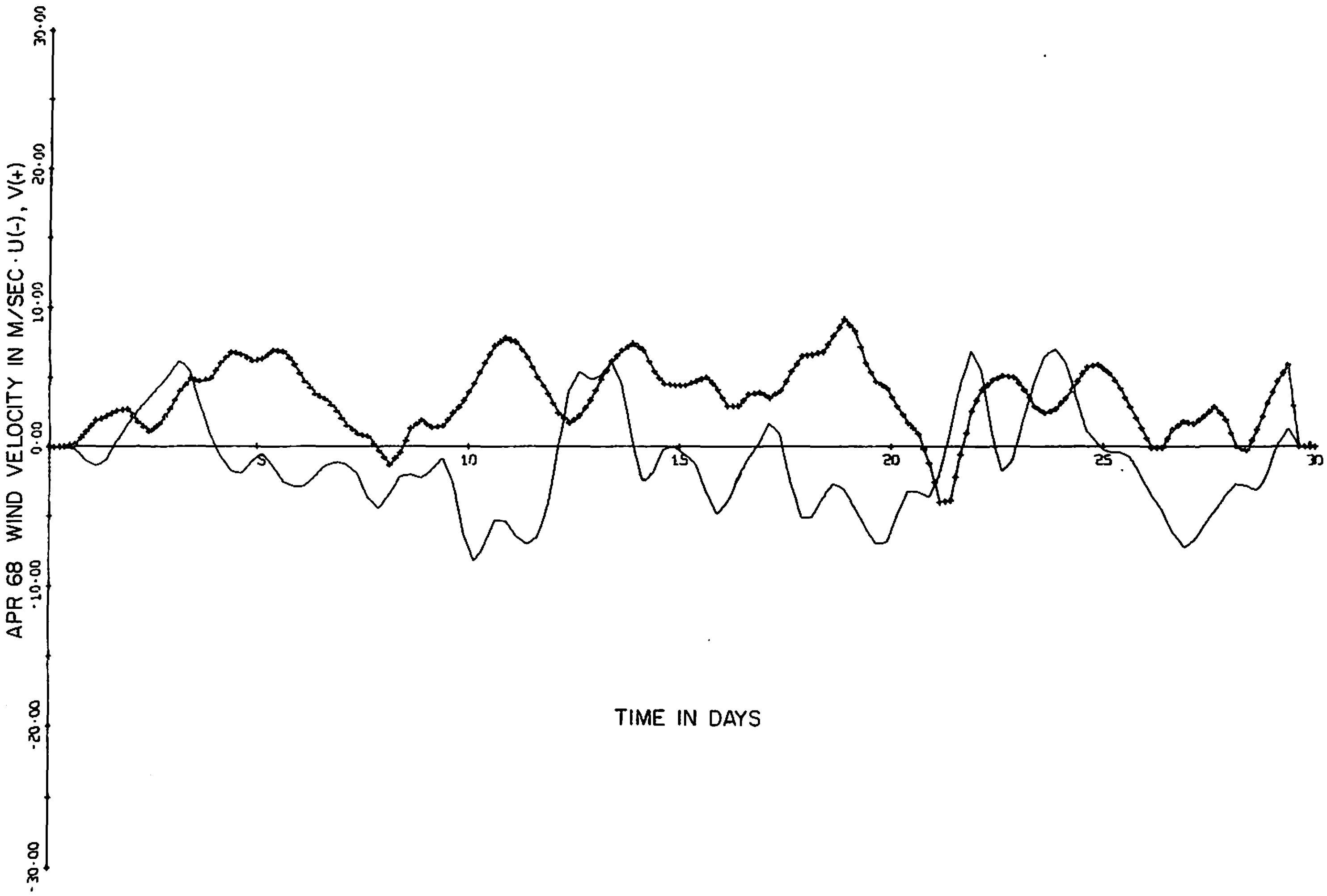


Fig. A-69. Wind at Columbia River Lightship; U(N+, S-) and V(E+, W-). April 1968

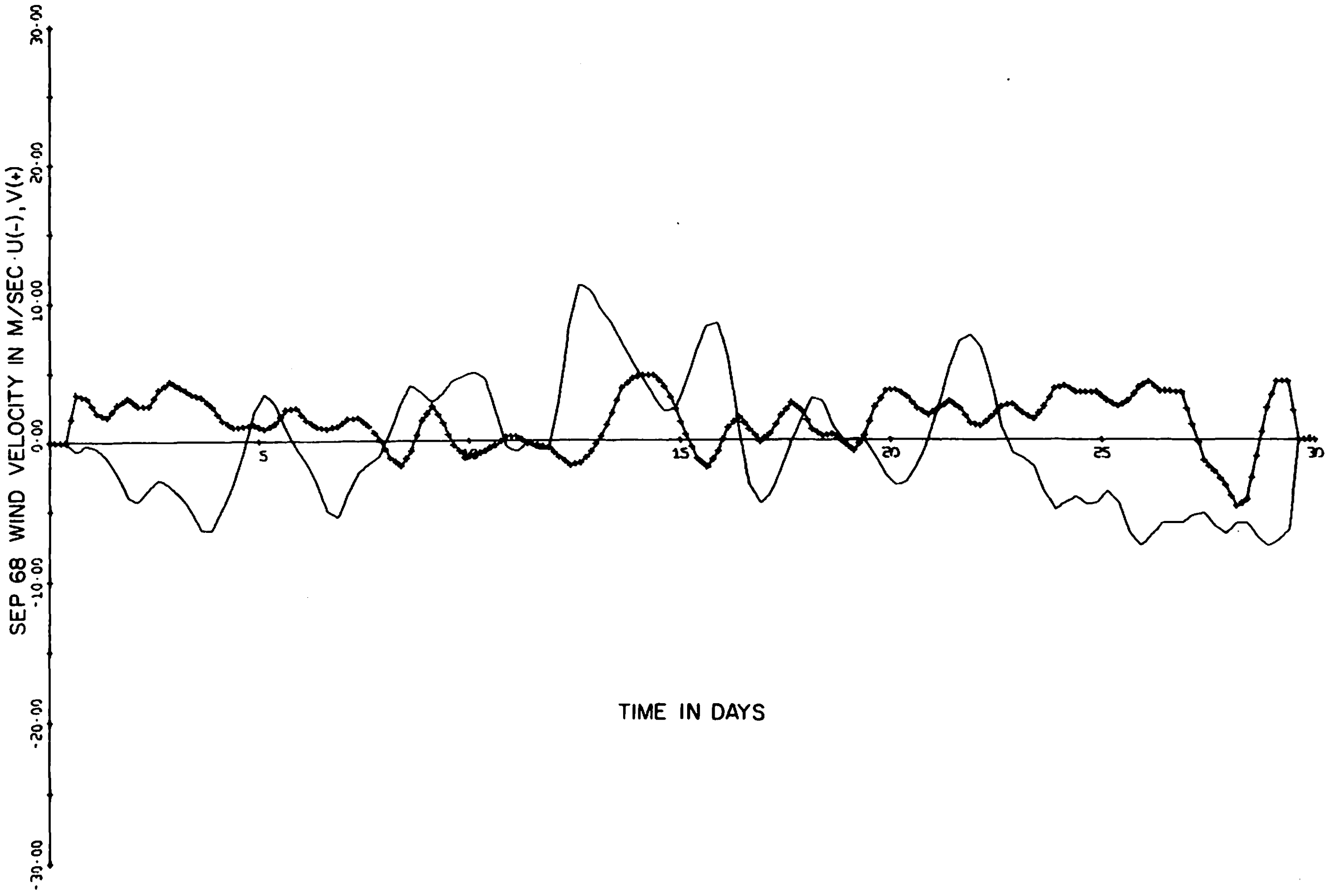


Fig. A-70. Wind at Columbia River Lightship; U(N+, S-) and V(E+, W-). September 1968

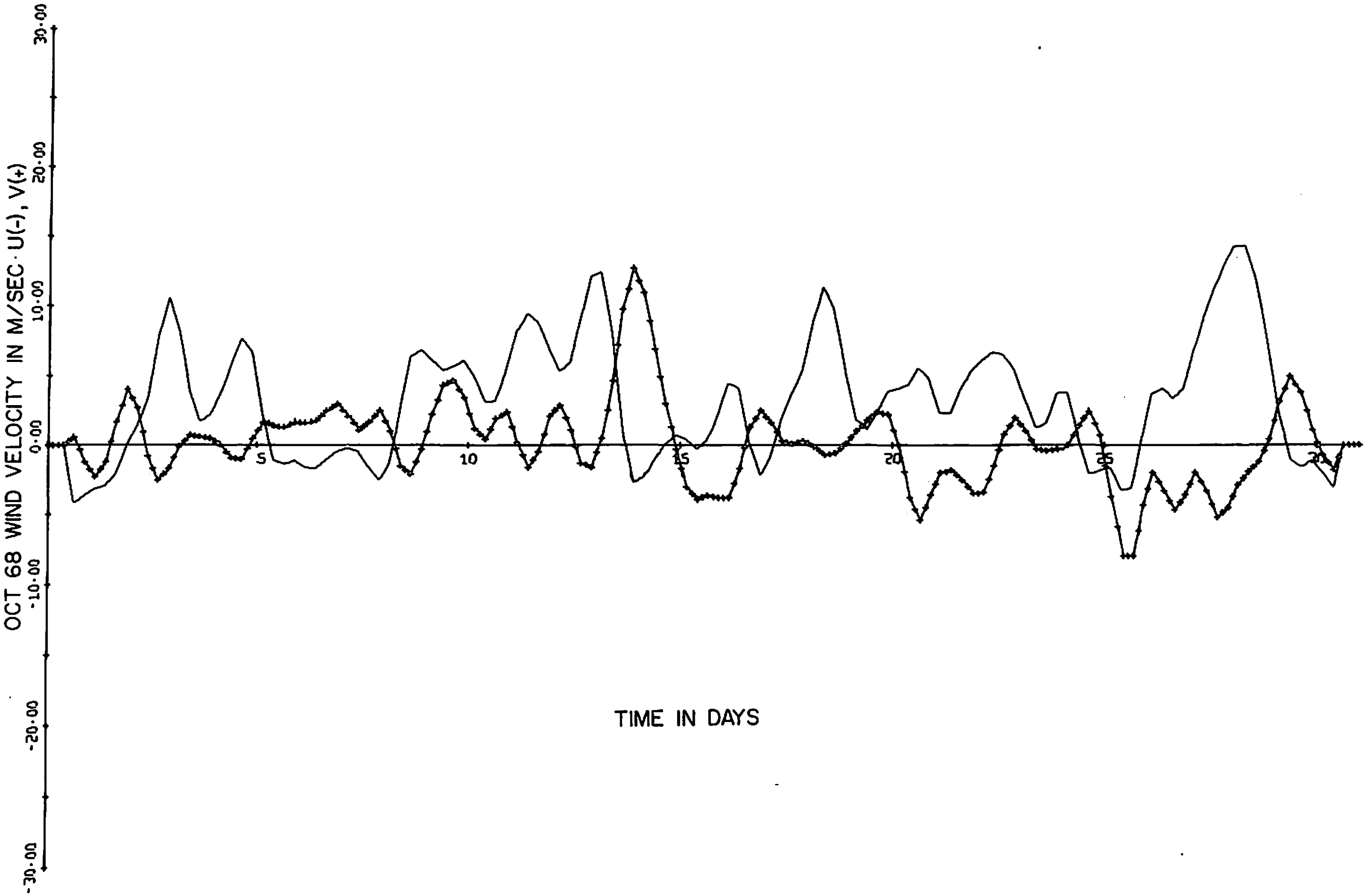


Fig. A-71. Wind at Columbia River Lightship; U(N+, S-) and V(E+, W-). October 1968

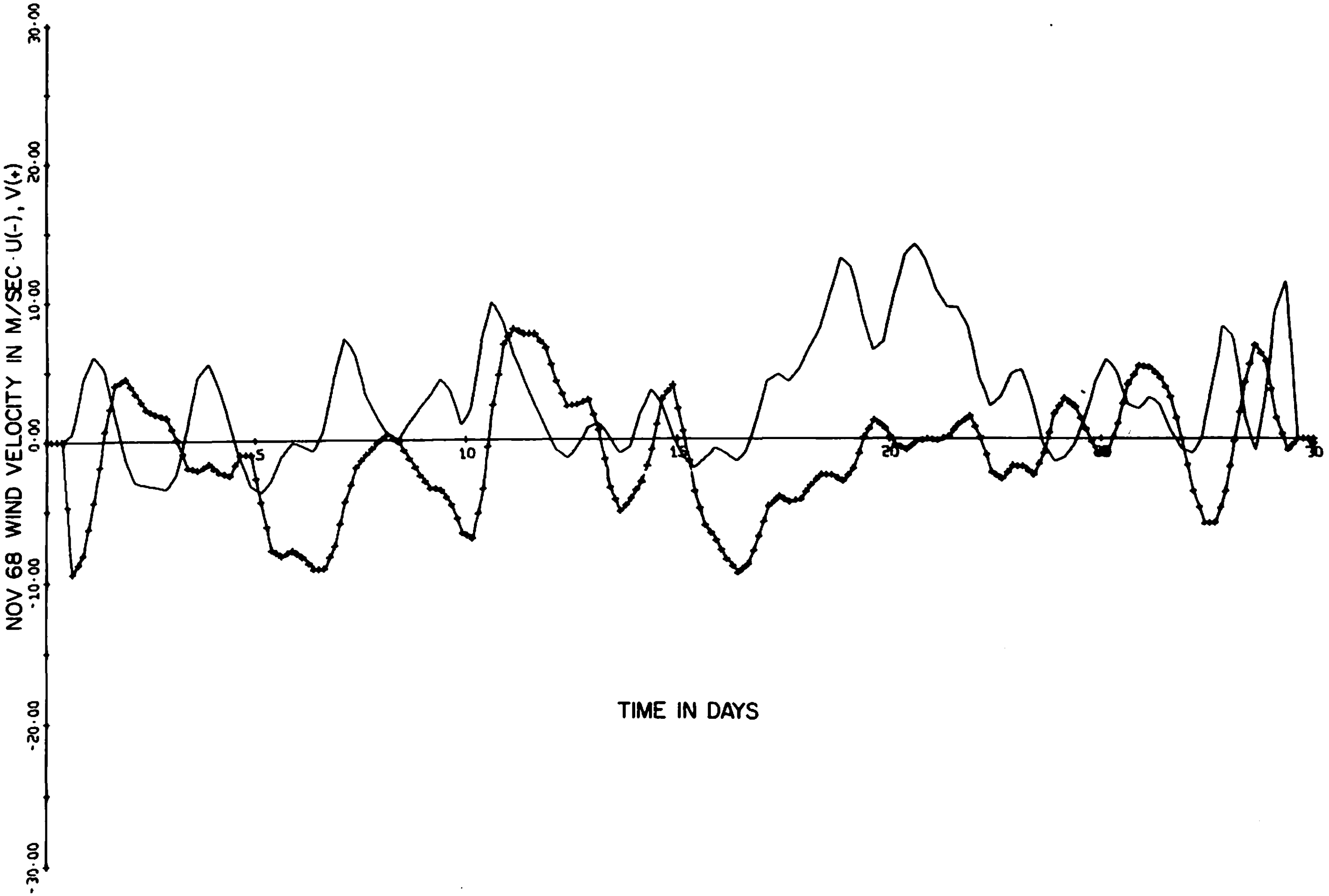


Fig. A-72. Wind at Columbia River Lightship; U(N+, S-) and V(E+, W-). November 1968

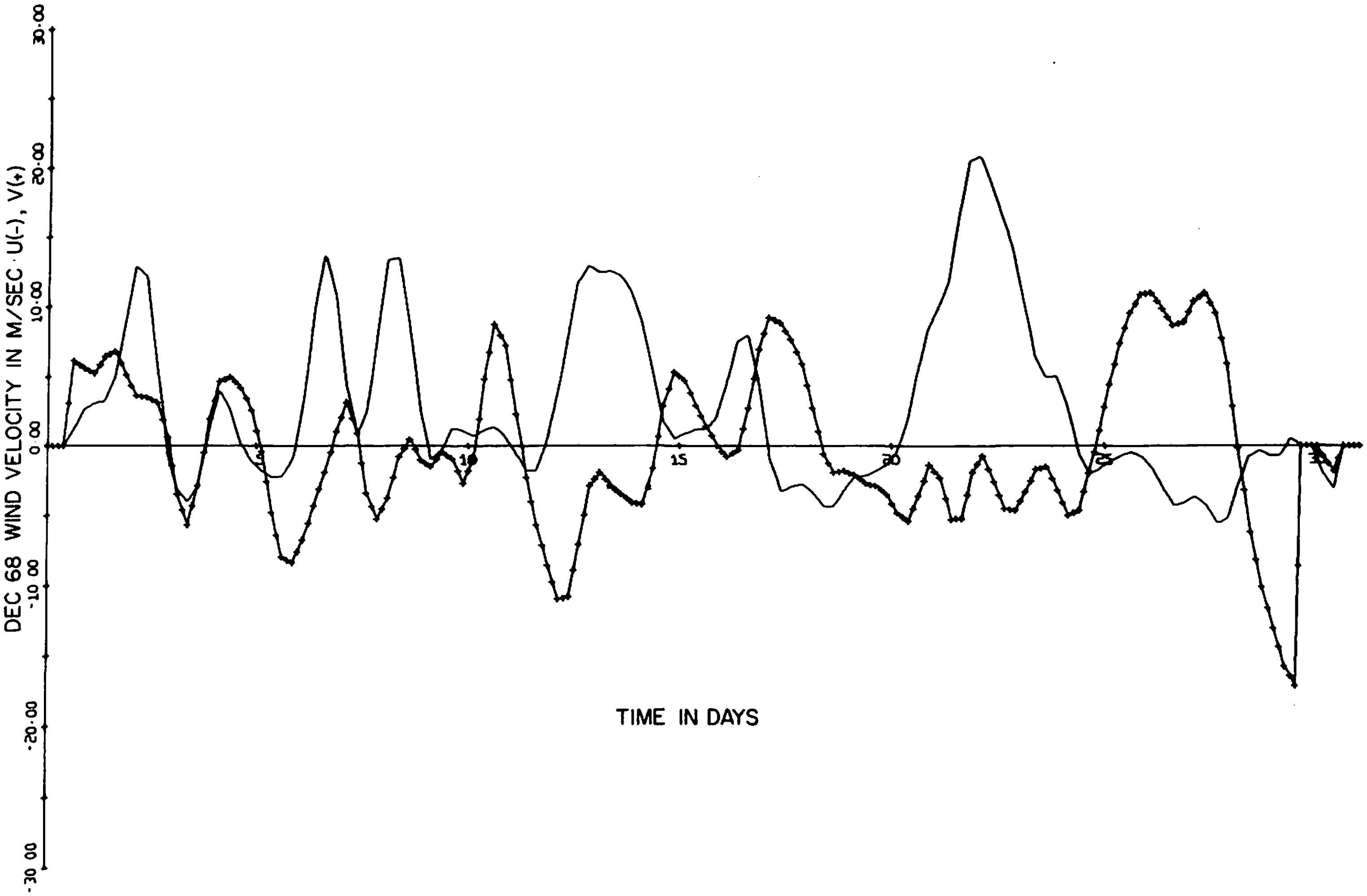


Fig. A-73. Wind at Columbia River Lightship; U(N+, S-) and V(E+, W-). December 1968

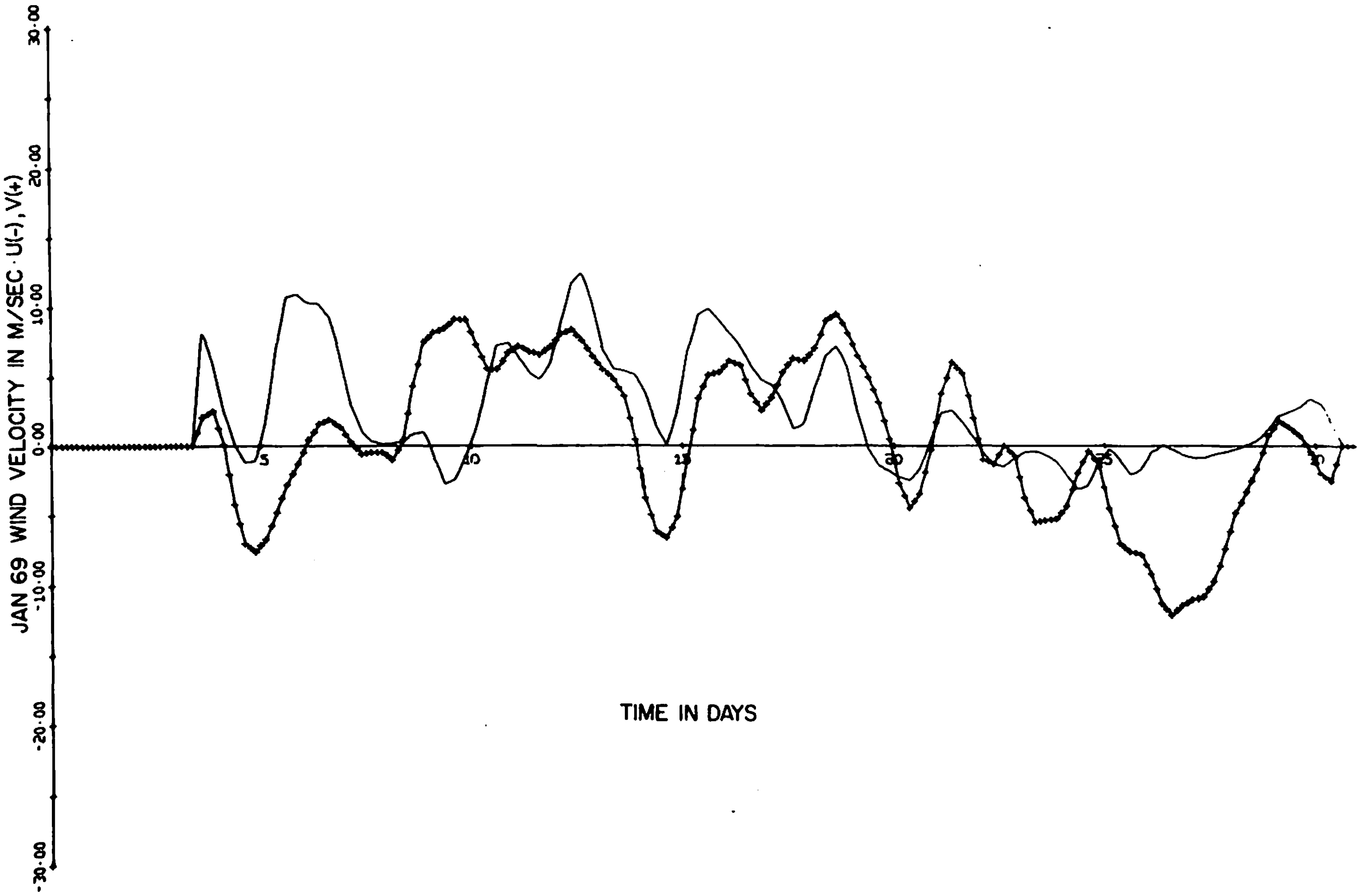


Fig. A-74. Wind at Columbia River Lightship; U(N+, S-) and V(E+, W-). January 1969

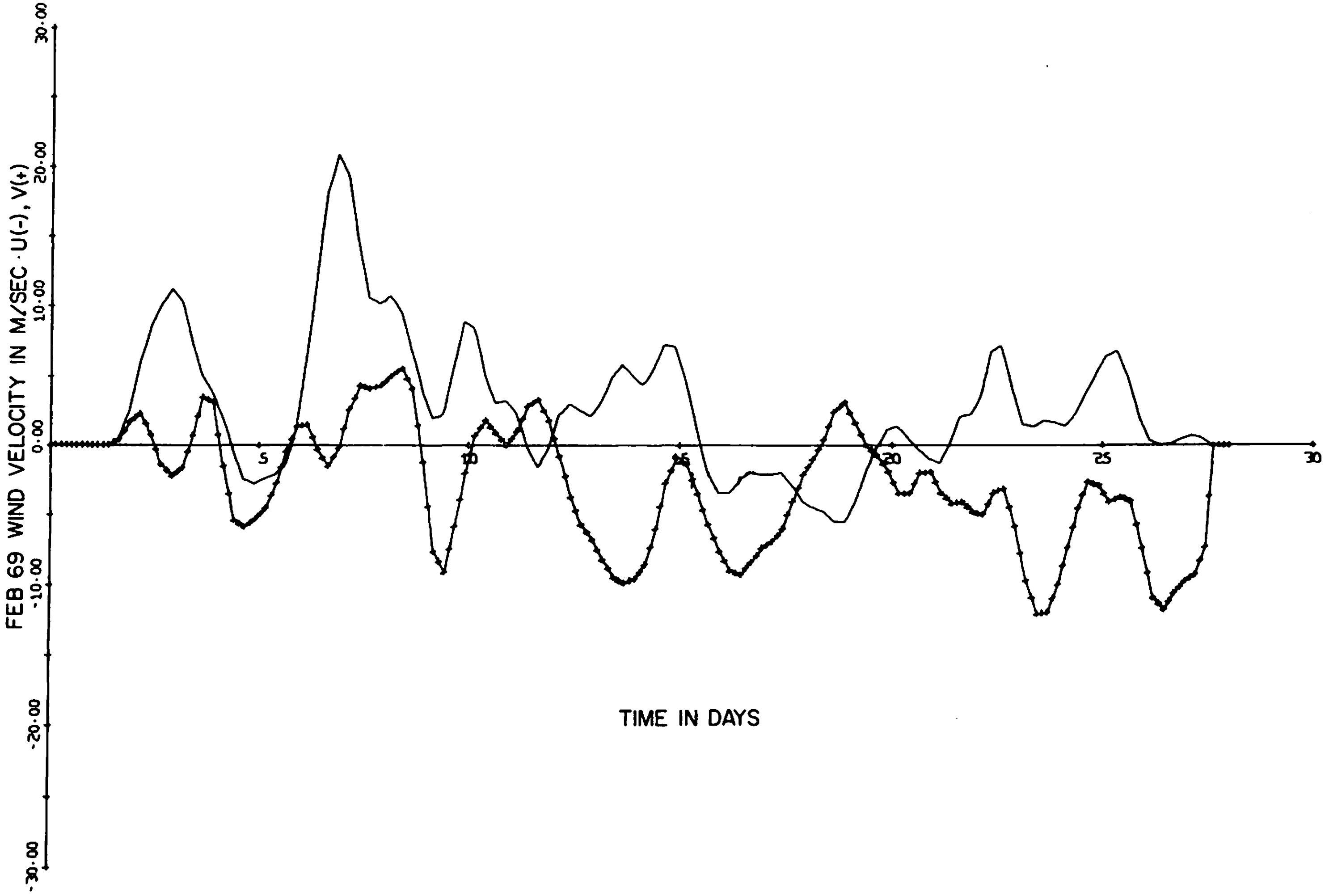


Fig. A-75. Wind at Columbia River Lightship; U(N+, S-) and V(E+, W-). February 1969

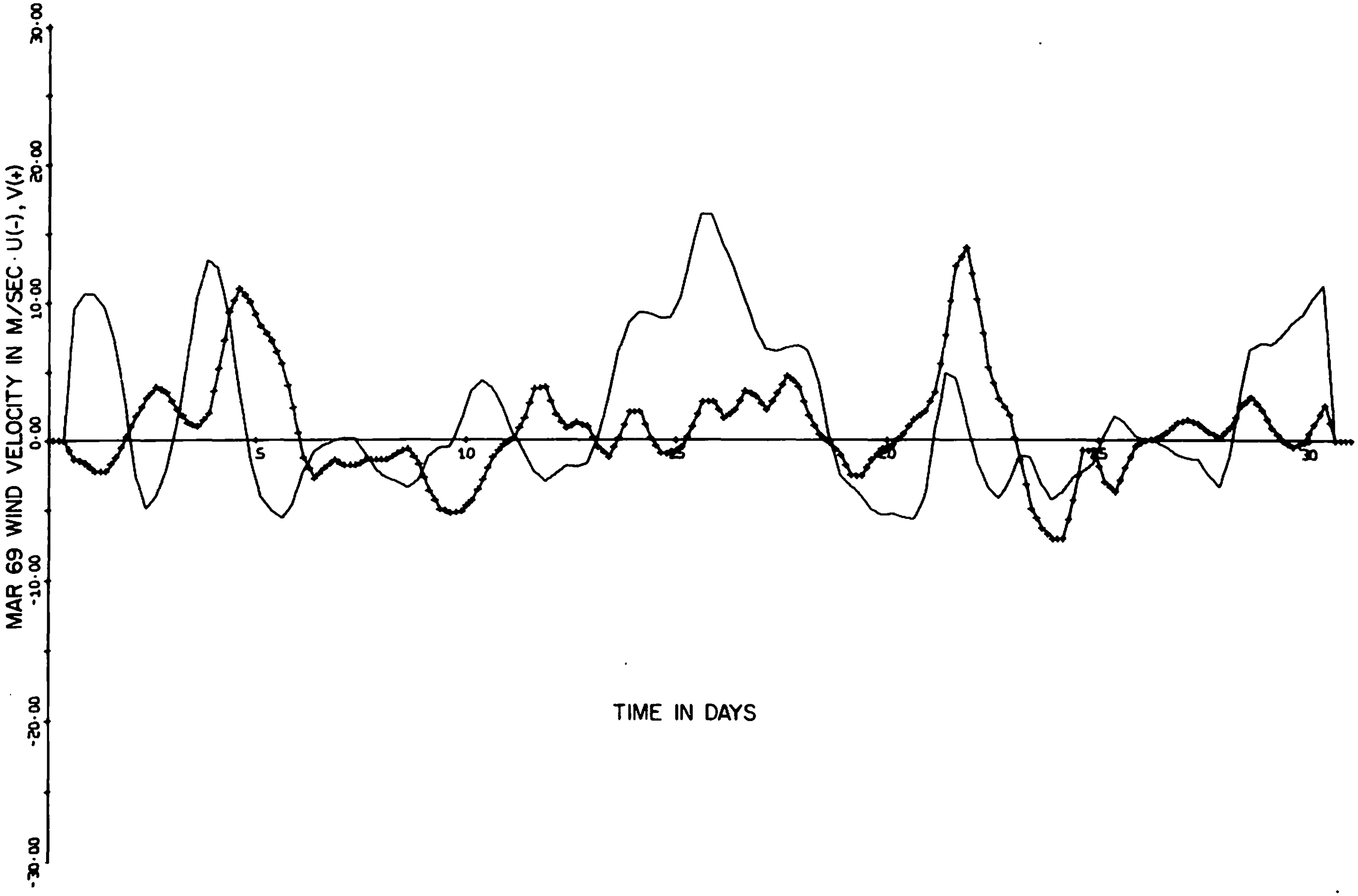


Fig. A-76. Wind at Columbia River Lightship; U(N+, S-) and V(E+, W-). March 1969

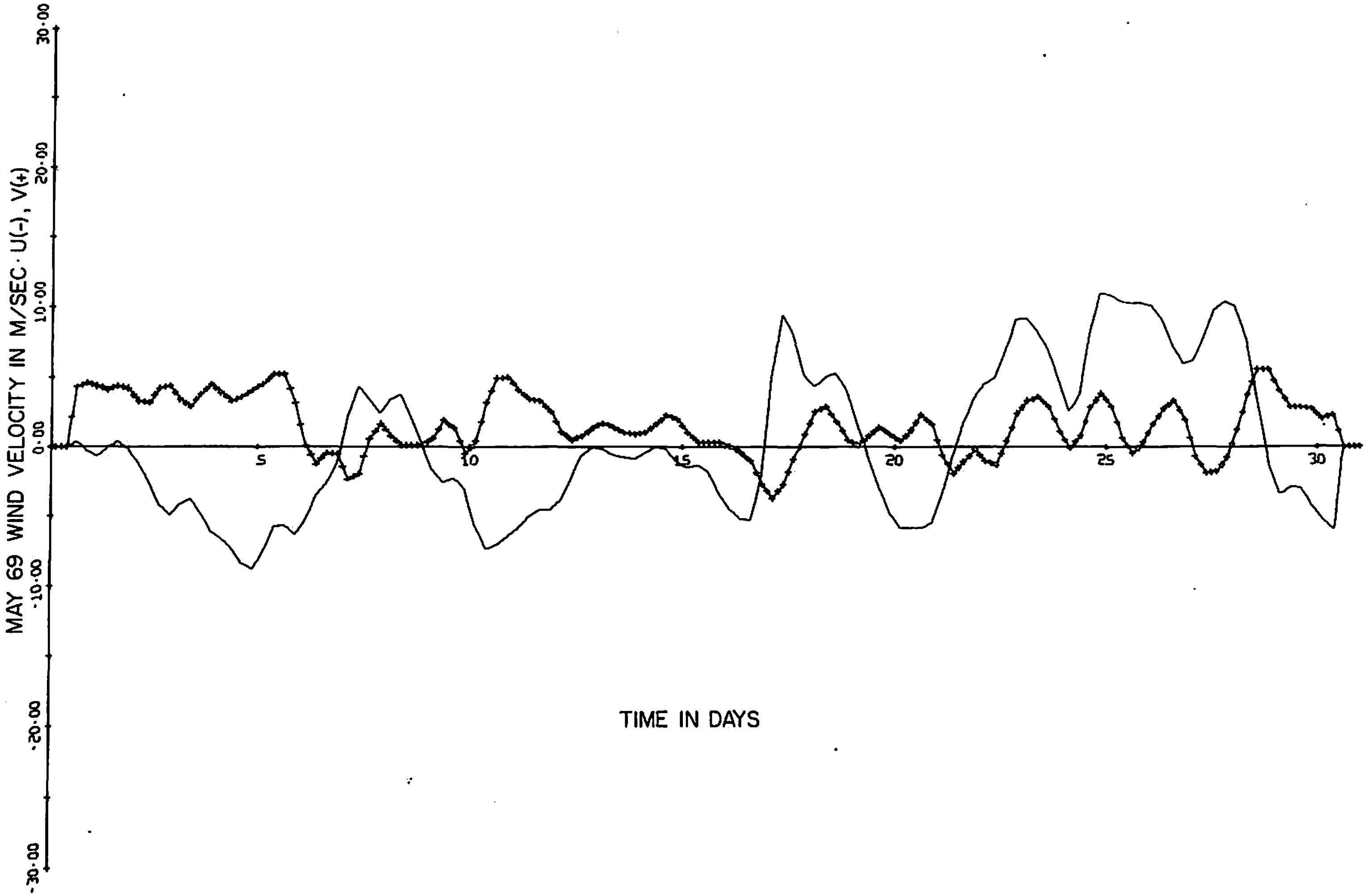


Fig. A-77. Wind at Columbia River Lightship; U(N+, S-) and V(E+, W-). May 1969

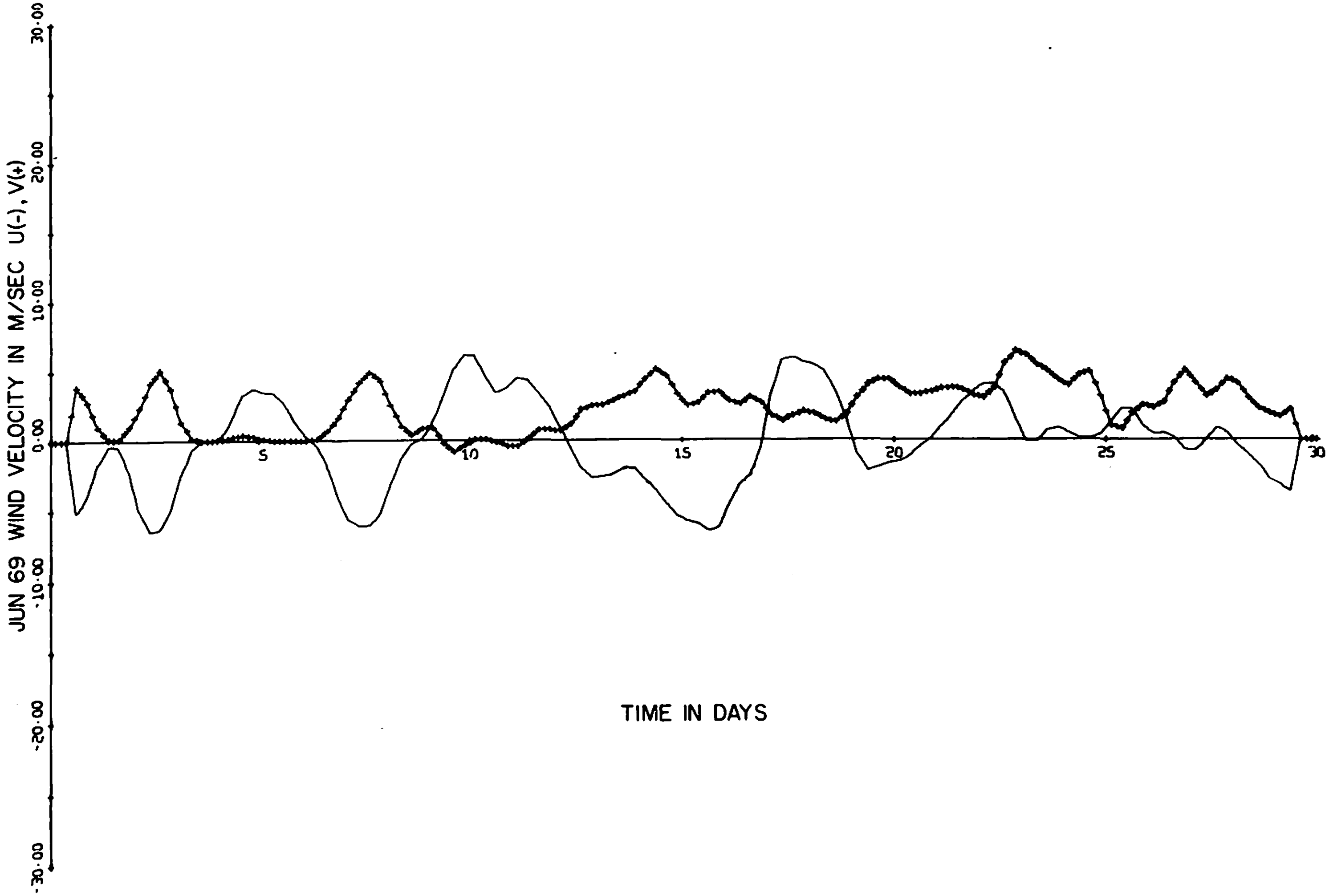


Fig. A-78. Wind at Columbia River Lightship; U(N+, S-) and V(E+, W-). June 1969

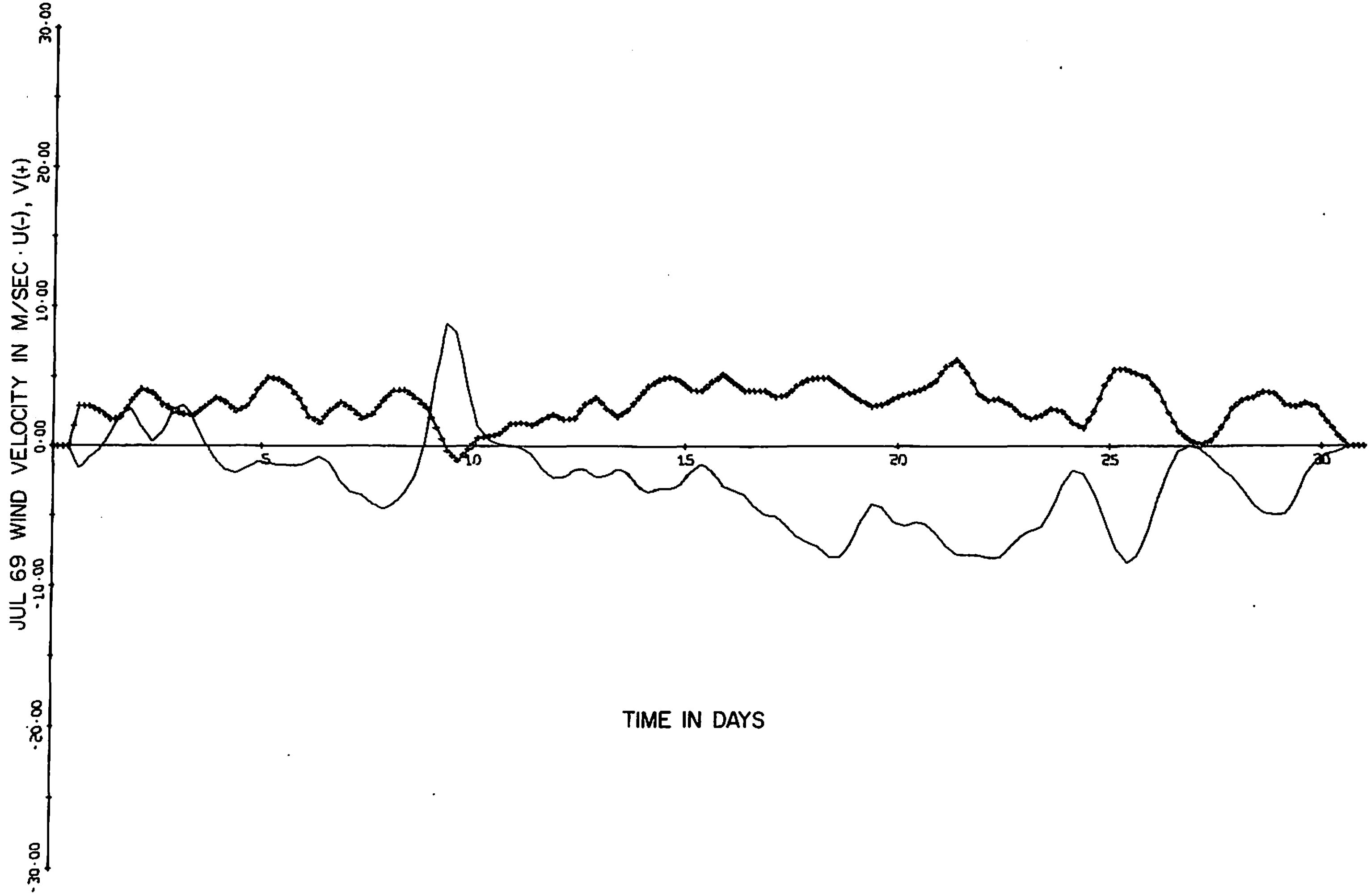


Fig. A-79. Wind at Columbia River Lightship; U(N+, S-) and V(E+, W-). July 1969

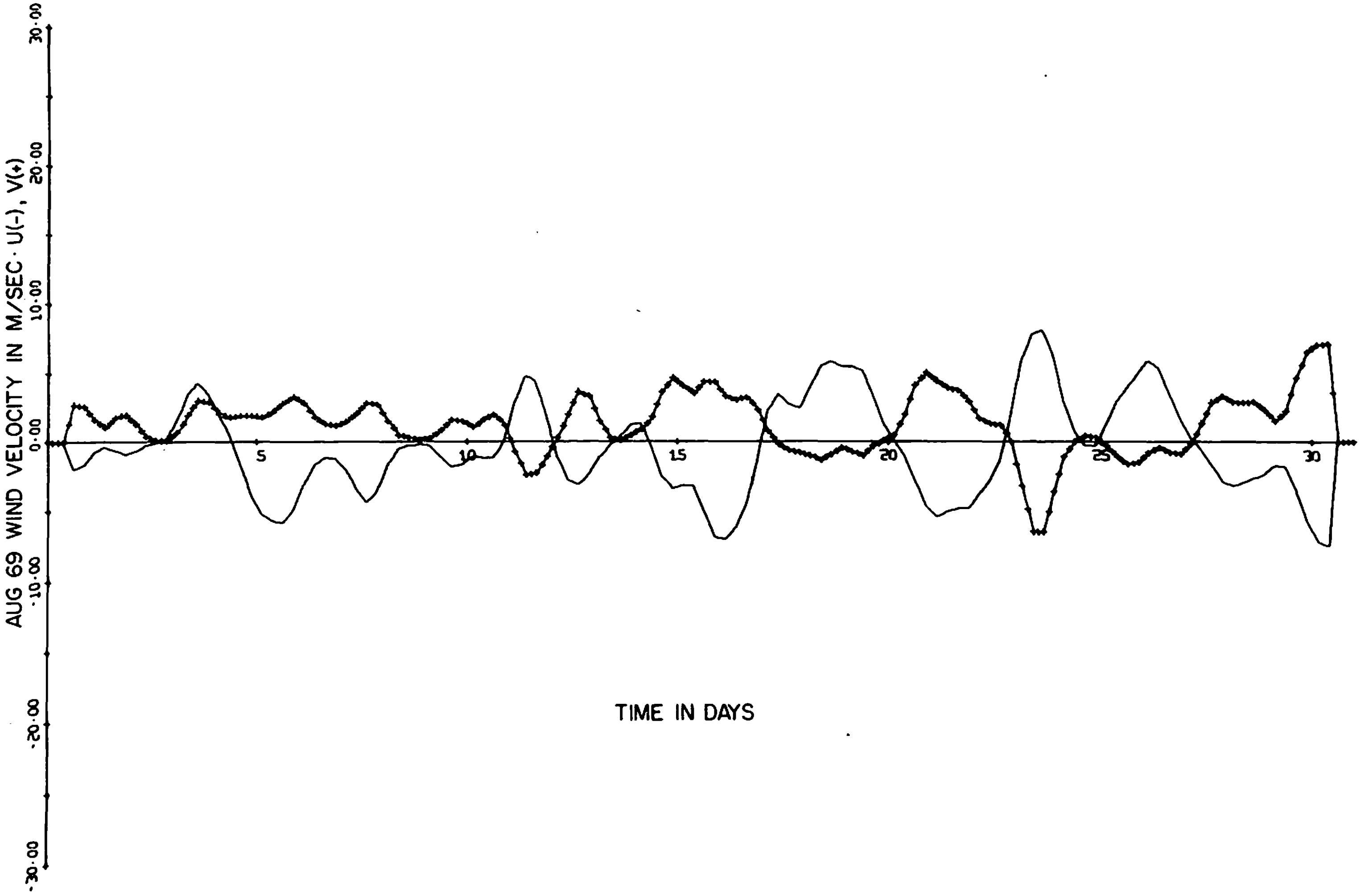


Fig. A-80. Wind at Columbia River Lightship; U(N+, S-) and V(E+, W-). August 1969

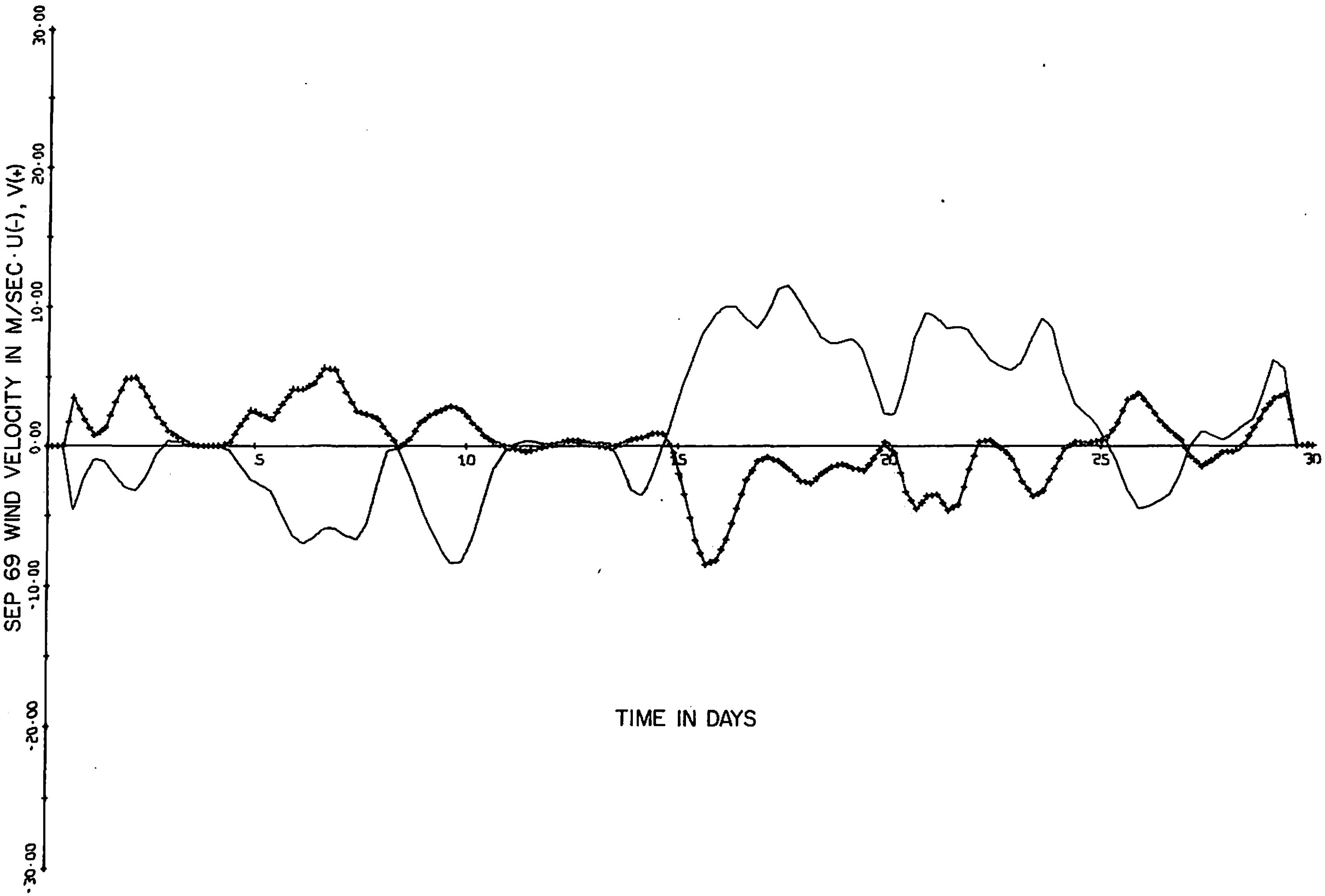


Fig. A-81. Wind at Columbia River Lightship; U(N+, S-) and V(E+, W-). September 1969

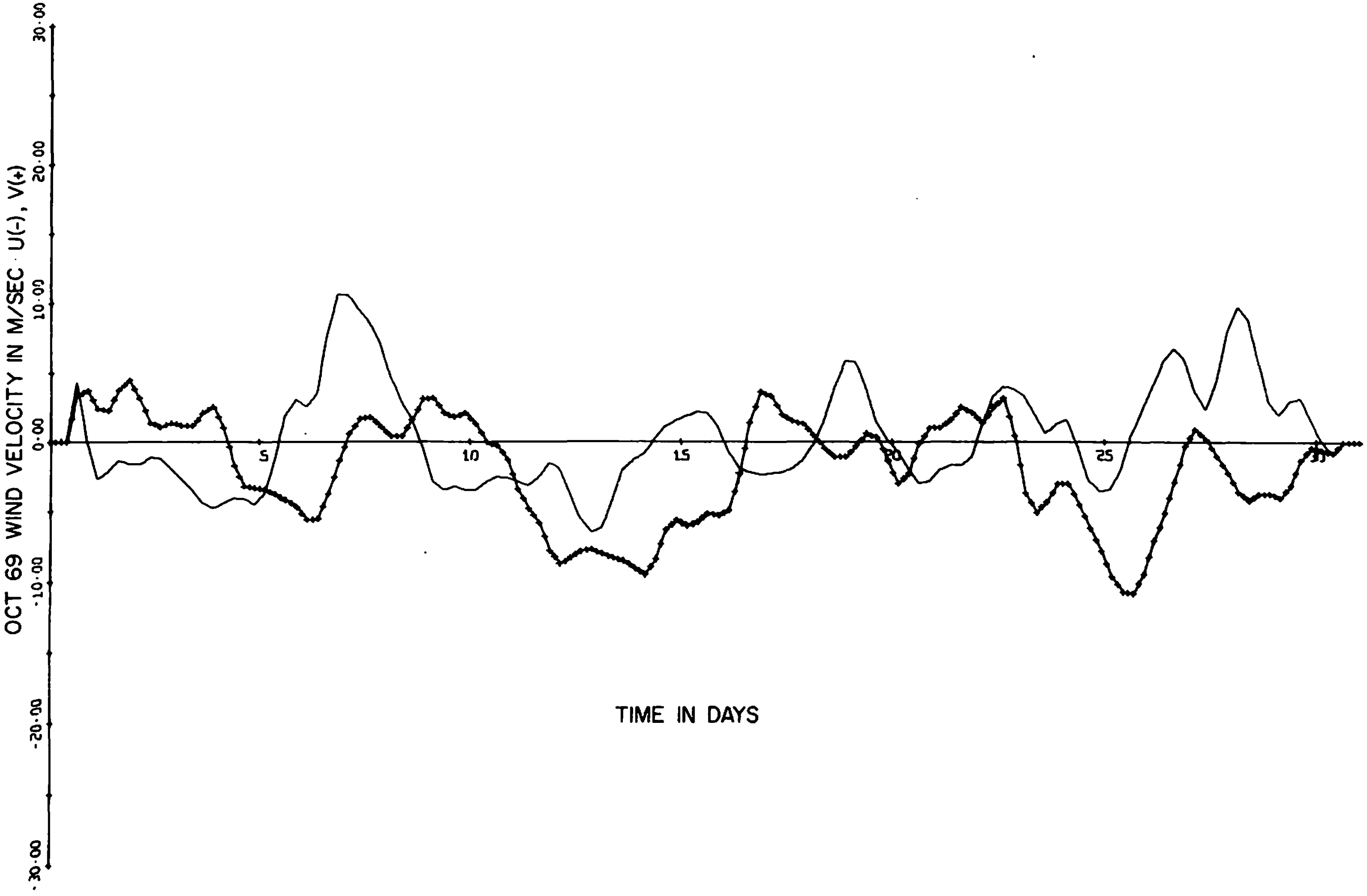


Fig. A-82. Wind at Columbia River Lightship; U(N+, S-) and V(E+, W-). October 1969