TIDAL AND RESIDUAL CURRENTS NEAR THE CONFLUENCE OF THE SACRAMENTO AND SAN JOAQUIN RIVERS, CALIFORNIA

RESULTS OF MEASUREMENTS, 1984-85

By Jeffrey W. Gartner

U.S. Geological Survey

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GEOLOGICAL SURVEY

Dallas L. Peck, Director

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CONTENTS

ILLUSTRATIONS

TABLES

CONVERSION FACTORS

Conversion factors for terms used in this report are listed below:

Multiply	By	To obtain
centimeter (cm)	0.3937	inch (in)
centimeter per second (cm/s)	0.3937	inch per second (in/s)
kilometer (km)	0.6214	mile (mi)
meter (m)	3.281	foot (ft)
cubic meters per second (cms)	35.31	cubic feet per second (cfs)

Temperature in degrees Celsius (^{o}C) can be converted to degrees Fahrenheit (^{o}F) as follows:

$$^{o}F = 1.8 \times {}^{o}C + 32$$

TIDAL AND RESIDUAL CURRENTS NEAR THE CONFLUENCE OF THE SACRAMENTO AND SAN JOAQUIN RIVERS, CALIFORNIA

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ABSTRACT

Current-meter data collected in 1984 and 1985 at four stations in the Sacramento and San Joaquin River Delta near the confluence of the rivers are compiled in this report. Measurements include current speed and direction, and water temperature. For each of the seven deployments, data are presented in two forms: (1) results of harmonic analysis; and (2) plots of tidal current speed and direction versus time, and plots of temperature versus time. In addition, Eulerian residual currents have been compiled using vector-averaging techniques.

Results of harmonic analysis indicate that the tidal currents are generally bi-directional and the principal current direction depends on basin bathymetry. Current speed shows a spring/neap variation of about a factor of two. The tide is mixed but closer to semidiurnal than to diurnal. Differences in Eulerian residual flows during the measurement periods or between deployments in 1984 and 1985 at any station are insignificant.

INTRODUCTION

The deployment of current meters and the processing and analyses of tidal-current data are a part of an extensive interdisciplinary study undertaken by the U.S. Geological Survey to better understand the interactive physical, chemical, and biological processes that affect the San Francisco Bay estuarine system (fig. 1). As part of this study and in conjunction with an interagency[1] outflow curtailment experiment, current meters were deployed near the confluence of the Sacramento and San Joaquin Rivers. The equipment was deployed and data collected to aid in studying the effects of changes in water export (Cross-Delta Flow) on water residence time in the Sacramento and San Joaquin Delta. Current meters employed record current speed and direction, and water temperature and conductivity at 2-minute intervals for deployment periods of approximately 4 to 5 weeks.

The purpose of this report is to present current-meter data collected at the study site in 1984 and 1985 in a form useful to users. Data are shown graphically in the form of time-series plots. Speed and direction data have been harmonically analyzed to determine the amplitude and phase of the primary tidal constituents (harmonic constants). The harmonic constants are used to qualitatively define the tide and may be used for tidal predictions. Eulerian residual currents have been determined by vector averaging the time series. A brief summary of the field program

and data processing procedures is given below. More complete descriptions of equipment, and deployment, recovery, maintenance, and data processing procedures are given by Cheng and Gartner (1980, 1984).

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[1]U.S. Geological Survey, U.S. Bureau of Reclamation, U.S. Fish and Wildlife Service, California Department of Water Resources, California Department of Fish and Game, and California State Water Resources Control Board.

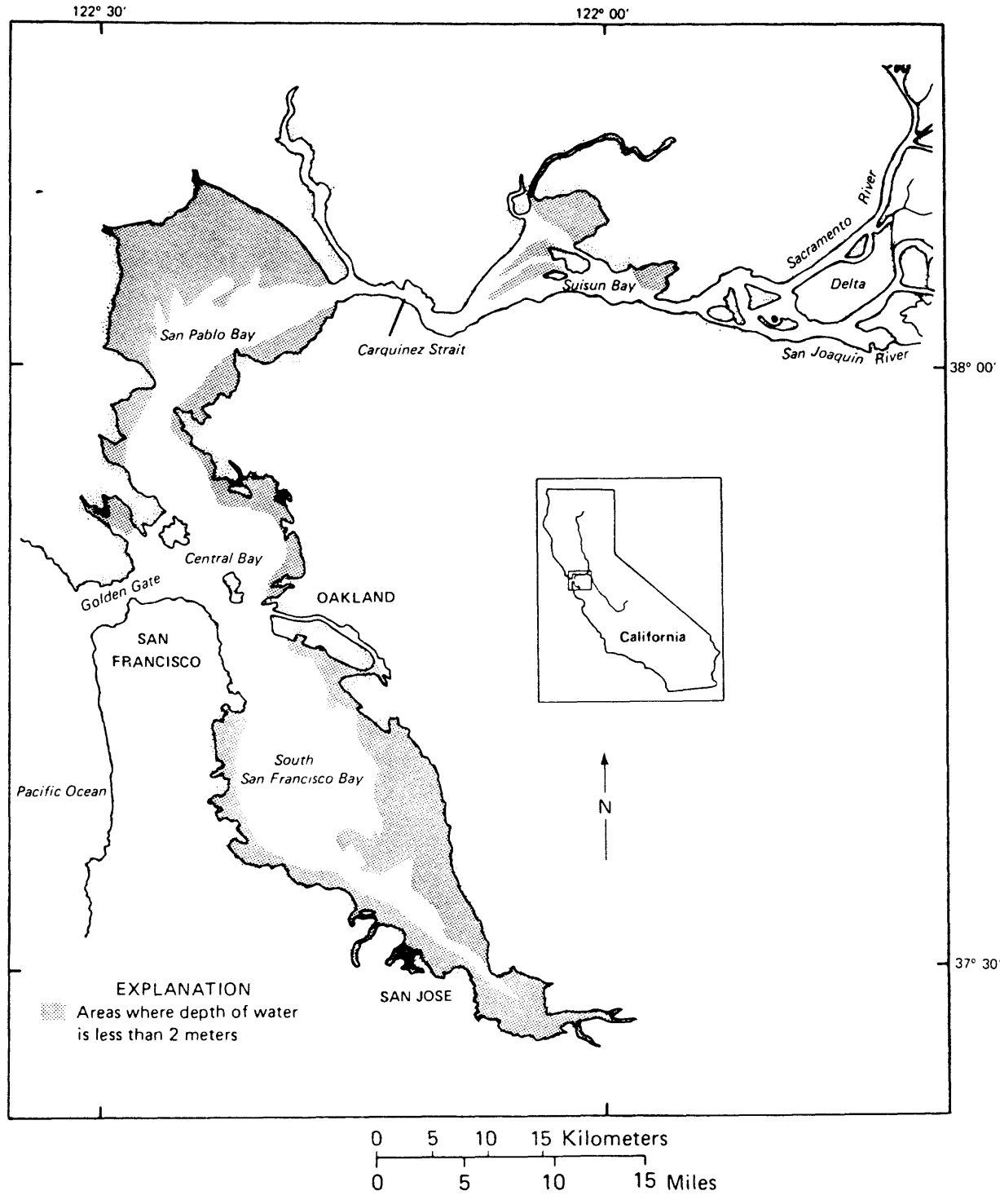

Figure 1. Map of San Francisco Bay estuarine system.

FIELD PROGRAM

Study site

The study site (fig. 2) was located near the west side of the Sacramento and San Joaquin Delta near Kimball Island and Antioch, California. Four current meters were deployed across the estuary. One array (fig. 3) was located north of the Stockton ship channel, two current meters were located midestuary just south of the ship channel, and the fourth current meter was located near the Antioch-side shoreline. Except near the shorelines and at a central shoal area, water depths in the area are generally 10 to 15 m. Prevailing winds are from the southwest in the area during March, April, and May (Conomos, 1979; Gartner and Cheng 1983). Conductivity at the site was below the threshold of the sensor on the current meters (5 mS/cm; about $3^{o}/oo$ salinity at water temperatures encountered) during the study.

Tidal currents

Tidal currents in San Francisco Bay consist of the sum of several semidiurnal and diurnal partial tidal constituents (partial tides). Because frequencies of the partial tides are different, the resulting tides in San Francisco Bay vary constantly as the partial tides move in phase (reinforcing each other) and out of phase (canceling each other) in a fortnightly cycle. The net effect of these phase differences gives rise to

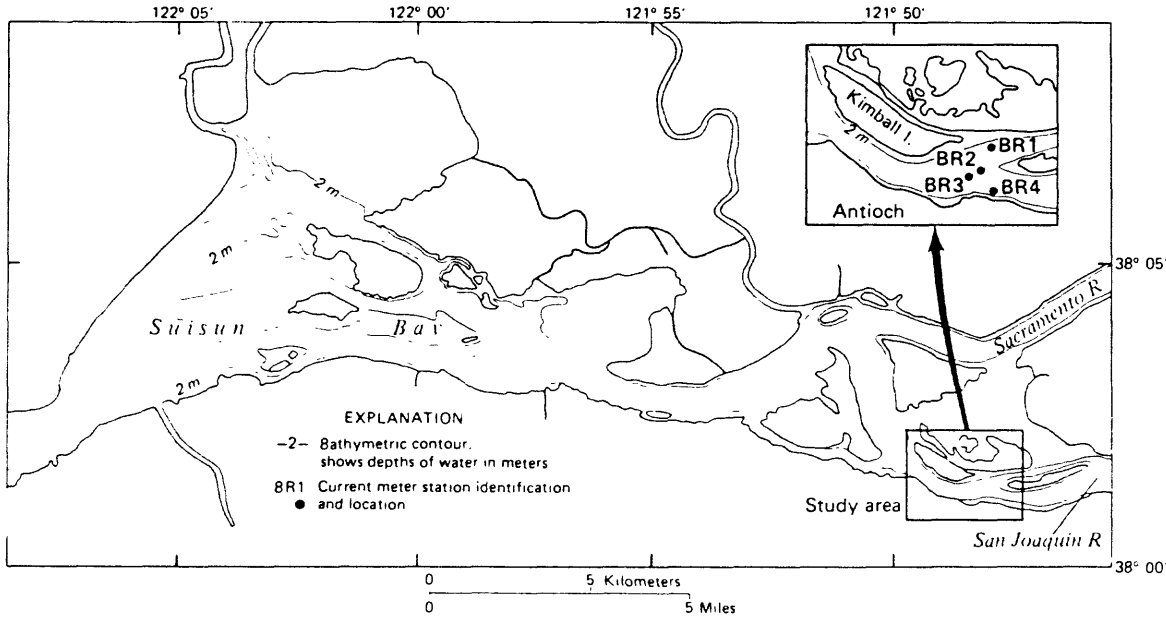

Figure 2. Map of Suisun Bay region. Inset shows locations of current-meter moorings.

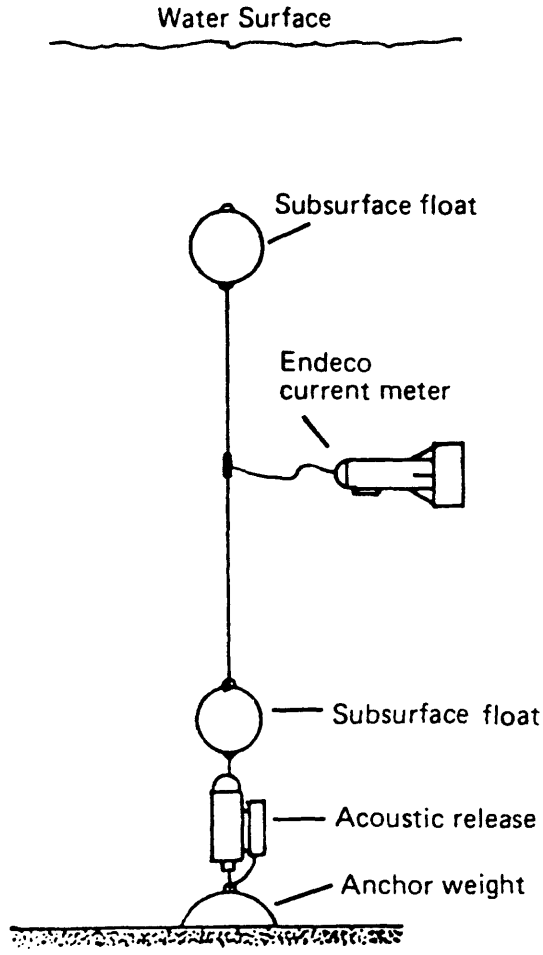

Figure 3. Current-meter mooring design used in study.

the spring and neap variations (in addition to other less pronounced cyclic variations) of tides and tidal currents. One of the objectives of the study is to measure tidal currents and define the partial tides from the data. The partial tidal constituents can be used to predict tidal currents. The accuracy of the prediction depends on how closely field conditions during the data collection period and prediction period match. Clearly, the longer the time-series of field data, the better each tidal frequency can be separated and the more accurately each partial tide can be computed. Therefore, self-recording current meters which are capable of recording tidal current speed and direction for a minimum of 15 days were used.

Equipment

Current meters used in the study are Endeco-174[2] digital-recording current meters. The Endeco-174 is an axial-flow, ducted-impeller current meter which records data on a magnetic tape cartridge. Data can be recorded for up to about 40 days when the data-recording interval is selected to be 2 minutes. Accuracy specifications for Endeco-174 current meters provided by the manufacturer (Endeco Inc., Marion, Mass.) (Endeco 1978) are as follows: speed, $\pm$3.0 percent of full scale (223 cm/s) above

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[2]Use of trade name in this report is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey.

the threshold (2.6 cm/s); direction, $\pm$7.2°; temperature, $\pm$0.2 °C; and conductivity, $\pm$0.55 mS/cm.

Current speed is determined by measuring the displacement of an encoder-disc driven by an impeller through a magnetic coupler and a 500:1 reduction gear. Current direction (current meter heading) is determined from the output of a damped magnetic compass. Temperature is determined by a thermilinear thermistor and conductivity by an induction type electrodeless-conductivity probe. Current speed is the average speed over the sampling interval (2 minutes) while current direction and water temperature and conductivity are instantaneous values at the time of sampling.

Current-meter data

Seven current-meter records were collected at the study site during 1984 and 1985. Deployment lengths were 29 and 33 days. One current meter was not recovered at the same time as the others and the record from that meter is 39-days in length). Figure 2 shows the approximate geographic location of the current meters. The precise latitude and longitude and the water depth for each current meter at mean lower low water (MLLW) are compiled in table 1. The positions of current meter were determined by horizontal sextant fixes determined to the nearest second of arc ($\pm$31 m). Additionally, the sextant readings were backed up with radar, loran C, and visual fixes. Also included in table 1 are the depths at which the current meters were deployed, and the deployment and recovery dates for all data included in this report. All

reference times have been converted to Pacific Standard Time and Julian date. Table 1 and figure 2 define the complete spatial and temporal distributions of the current-meter data.

Table 1.--Current-meter stations near the confluence of the Sacramento and San Joaquin Rivers, 1984-1985

Station number	Latitude (North)	Longitude (West)	Deployment date	Recovery date	Water depth (meters)	Meter below MLLW (meters)
BR1	38°01'24"	121 48'15"	4/23/84	5/22/84	7.0	3.9
BR1	38°01'22"	121 48'17"	3/28/85	4/30/85	8.5	5.6
BR2	38°01'14"	121 48'20"	4/23/84	5/22/84	7.9	4.5
BR2	38°01'12"	121 48'22"	3/28/85	4/30/85	12.8	9.4
BR3	38°01'10"	121 48'26"	4/23/84	5/22/84	13.7	8.2
BR4	38°01'06"	121 48'14"	4/23/84	6/1/84	10.3	6.4
BR4	38°01'06"	121 48'16"	3/28/85	4/30/85	11.9	5.9

DATA PROCESSING PROCEDURES

Data translation

Data tapes from Endeco-174 current meters were read and translated into computer readable codes utilizing a special tape reader (Cheng and Gartner, 1979). The 2-minute interval data were examined for possible record gaps, and individual sensor calibration constants were applied to convert the data to engineering units. Salinity (conductivity) was below the threshold of the conductivity sensors and these data are not shown. All computer programs used in the processing of these data are documented in Cheng and Gartner (1980).

Current speeds and directions (2-minute interval) were vector-averaged to produce a new time series of 30-minute averaged data. Similar time series of 30-minute averaged temperature data were also computed. The time-series of 30-minute average data were used as input for subsequent harmonic-analyses and time-series plots.

Time-series plot

A time-series plot of data is one of the most useful ways for displaying current-meter data in a clear and concise manner. Time-series plots of all data records are given in the Appendix. The 30-minute, vector averaged tidal-current velocities are plotted in the form of speed and direction (relative to true north)

versus time. Time-series plots are used to provide a visual display of temporal variations of tidal currents and their associated properties. A time-series plot of water temperature (30-minute averaged) versus time is also given for each data record.

Harmonic analysis

The method of harmonic analysis for tidal-current data is well documented in Schureman (1940) and Cheng and Gartner (1984). In all cases the data sets are truncated to an even number of M_2 cycles (56 cycles maximum). The M_2 cycle (12.42 hours) is used for this purpose because it is by far the most dominant tidal constituent (partial tide) in San Francisco Bay. The angular frequencies of the tidal constituents included in the analysis are given in table 2.

Six harmonic constituents (O_1, K_1, N_2, M_2, S_2, M_4) were computed for east-west and north-south tidal velocity components. Results of harmonic analysis of current-meter records collected during the study are included in the Appendix. The tidal constituents determined may be used for prediction of tidal currents at the same location (Cheng and Gartner, 1984). In addition to pertinent notes concerning the current-meter deployment and recovery and the harmonic constituents, the summary sheets shown in the Appendix include some general properties of tidal currents computed by the harmonic analysis program such as the root-mean-squared (RMS) current speed, spring and neap tidal current maxima, principal tidal current direction, tidal current form number (a measure

Table 2.--Principal astronomical partial tidal constituents

Symbol	Period (solar hours)	Angular frequency (degrees per hour)	Species
K_1	23.93	15.0411	Luni-solar diurnal
O_1	25.82	13.9430	Principal lunar diurnal
M_2	12.42	28.9841	Principal lunar semidiurnal
S_2	12.00	30.0000	Principal solar semidiurnal
N_2	12.66	28.4397	Larger lunar elliptic semidiurnal
M_4	6.21	57.9682	Lunar quarter diurnal

of the type of tide), and Eulerian residual current (time averaged velocity) (Cheng and Gartner, 1984). Depending upon the usable length of the record, the time average velocities are computed for every 12 M_2 tidal cycles, and an even number less than 12 M_2 cycles for the remaining available data in the record. The time average for the entire record length (maximum even M_2 cycles) is also given.

SUMMARY AND CONCLUSIONS

Tidal current

At all stations, the tidal currents are generally bi-directional although the records from BR2 and BR3 indicate about 190° between flood and ebb directions. The principal current direction depends strongly on the local basin bathymetry. There is a spring and neap variation of the tidal current speed up to a factor of about two. Form numbers less than 0.25 indicate a semi-diurnal tide while form numbers greater than 3.0 indicate a diurnal tide. Form numbers between 0.25 and 3.0 indicate mixed tides. As the form numbers (0.47 to 0.56) indicate, the tidal currents are mixed semidiurnal and diurnal types; however, the tidal current type is closer to semidiurnal than diurnal.

Time-series plots (1984 and 1985) for the array at station BR2 indicate some anomalies in the current direction (fig. 4). The deviations are unusually consistent, occuring only during neap tide periods and taking the form of missing current reversals. In each case it is the ebb flow which does not appear during the weaker of the daily ebb flows. This is a typical result of a situation which occurs when the internal compass in an Endeco current meter hangs up because the meter is not floating horizontally (not balanced). The fact that direction readings were often constant during these periods and the meters used for both deployments had old style compass gimbal mounts installed (which allow for less tilt before locking), indicates that the anomalies

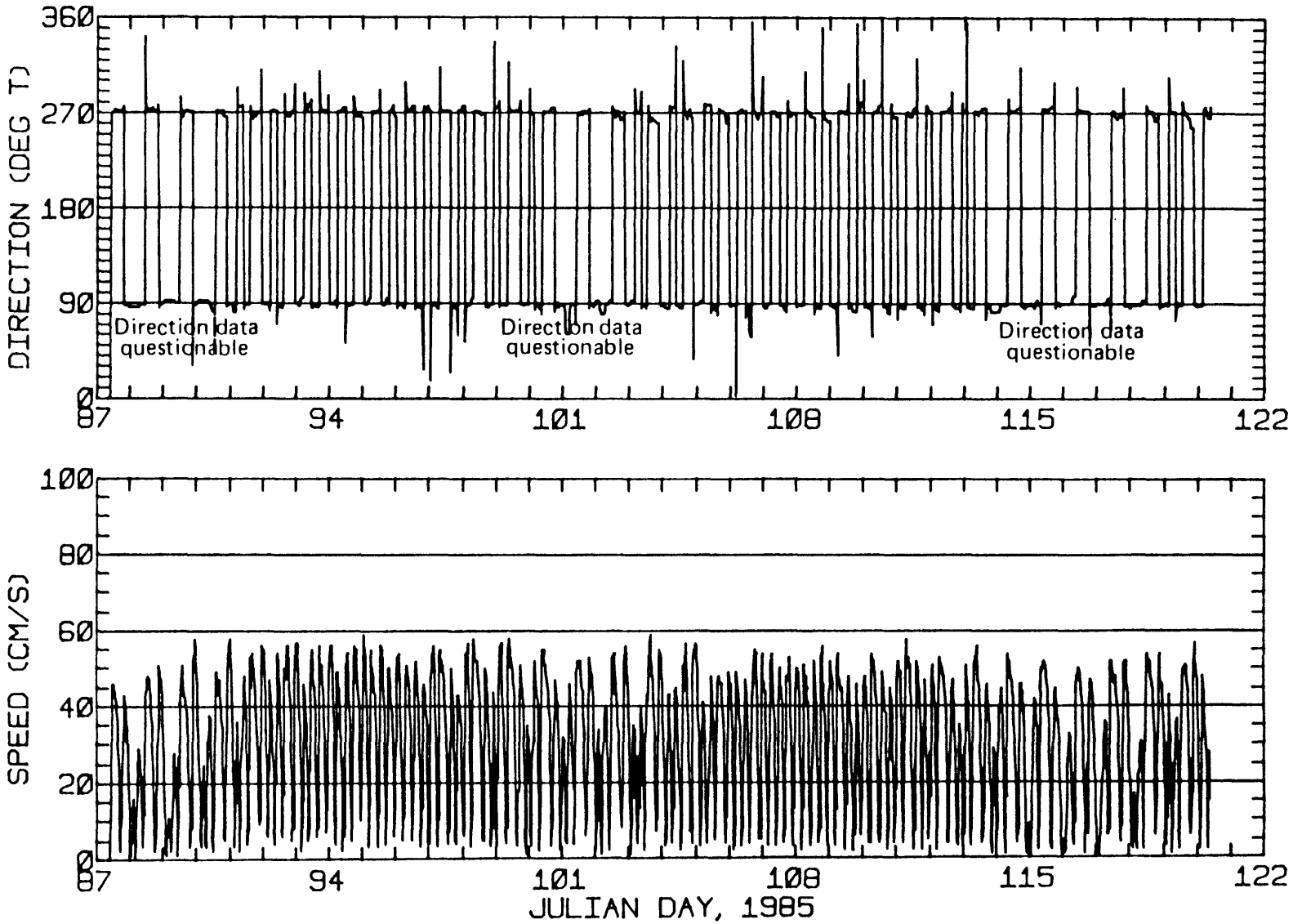

Figure 4. Time-series plot of current-meter record at station BR2. Labels indicate where direction data are questionable.

are probably caused by erroneous direction data. Nevertheless, the consistency of the anomalies during both years and the fact that they show up only at station BR2 may mean that there are other factors involved in addition to low current flows. Other factors may be the bottom topography in the area (note the shoal to the east of the current-meter position), and Cross-Delta Flows. For this reason, harmonic analyses were performed on these records without omitting the sections of questionable data. The sections of questionable direction data are noted on the time-series plots in the appendix.

Eulerian residual current

The Eulerian residual current is defined as the vectorial average of the current-meter data made over several (even number) M_2 tidal cycles. This serves to average out the tidal signal; what remains is the Eulerian residual. The Eulerian residual current is generally a factor of ten smaller than the tidal current. As the speed accuracy of the current meter is about $\pm$7 cm/s and the current meter record represents current speed only at a single point in the water column (and the water depth varies over the tidal cycle), one must be careful in drawing conclusions from differences in the Eulerian residual currents. Differences in Eulerian residuals of less than about 5 cm/s are probably insignificant. As the Eulerian residual current is computed for the same period of time as is the harmonic analysis, results at station BR2 must be evaluated cautiously. Even though the questionable direction readings cover only a small part of the entire record, if

incorrect, they will tend to cause computations of residual currents at the station to have too much of an up-estuary (+ east) component. The computed Eulerian residual currents are given in the summary for each current-meter data file in the form of north/south (north = +) and east/west (east = +) components. The factors that affect the Eulerian residual currents are rather complex. Basin bathymetry, Delta outflow, spatial distribution of tidal currents (tidal current shear), long term temporal variations of tidal currents (spring and neap variations), and wind forcing at the water surface are all important factors that may have effects on the magnitude and spatial distribution of the Eulerian residual currents (see Walters, 1982; Walters and Gartner, 1985; Cheng and Gartner, 1985). Since the Delta outflow is one of the variables that affect the Eulerian residual current, the averaged values of the Delta outflow during the study period have been computed from Dayflow summary (California Department of Water Resources, 1984) and are given in the summary sheets (1985 data are preliminary).

Examination of the Eulerian residual currents (time averaged velocity) and mean Delta outflow values listed on the harmonic analysis summary sheets show that changes in Delta outflow of several hundred cubic meters per second are not sufficient to determine significant changes in residual flows as determined by the vector averaged current meter data. Differences in Eulerian residual currents during a deployment period and between 1984 and 1985 deployments at any station are insignificant. However, there do appear to be generally consistant residual flows. Residual

flows at station BR1 are clearly down estuary (west). At stations BR2, BR3, and BR4 Eulerian residual flows are generally north (from the San Joaquin toward the Sacramento River) but may be of too low a value to be meaningful. Significant differences in Eulerian residual flows would be expected when comparing records from high Delta discharge periods to those of low Delta discharge periods.

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APPENDIX

The current-meter data are presented chronologically and station-by-station. For each file, the measured data and the results of analyses are presented in two forms: (1) results from the harmonic analyses; and (2) time series plots of tidal-current velocity (speed and direction) versus time, and temperature versus time. These results are given in the order of station numbers as listed in table 1.

The following abbreviations are used in the appendix:

MLLW Mean Lower Low Water (a tidal reference datum).

PST Pacific Standard Time.

CM/S Centimeters per second.

DEG T Degrees true (angular measurement from true north).

DEG Degrees (angular measurement).

RMS Root Mean Square.

CMS Cubic meters per second.

****
* SUMMARY OF HARMONIC ANALYSIS *
****

CURRENT METER STATION: BR184
POSITION: 38 1'24"N 121 48'15"W
METER TYPE: ENDECO
WATER DEPTH: 7.0 M (MLLW)
METER DEPTH: 3.9 M (BELOW MLLW)
START TIME OF SERIES: 4/23/84 1234 PST JULIAN DAY=114
APPROXIMATE RECORD LENGTH IS 56 M2-CYCLES

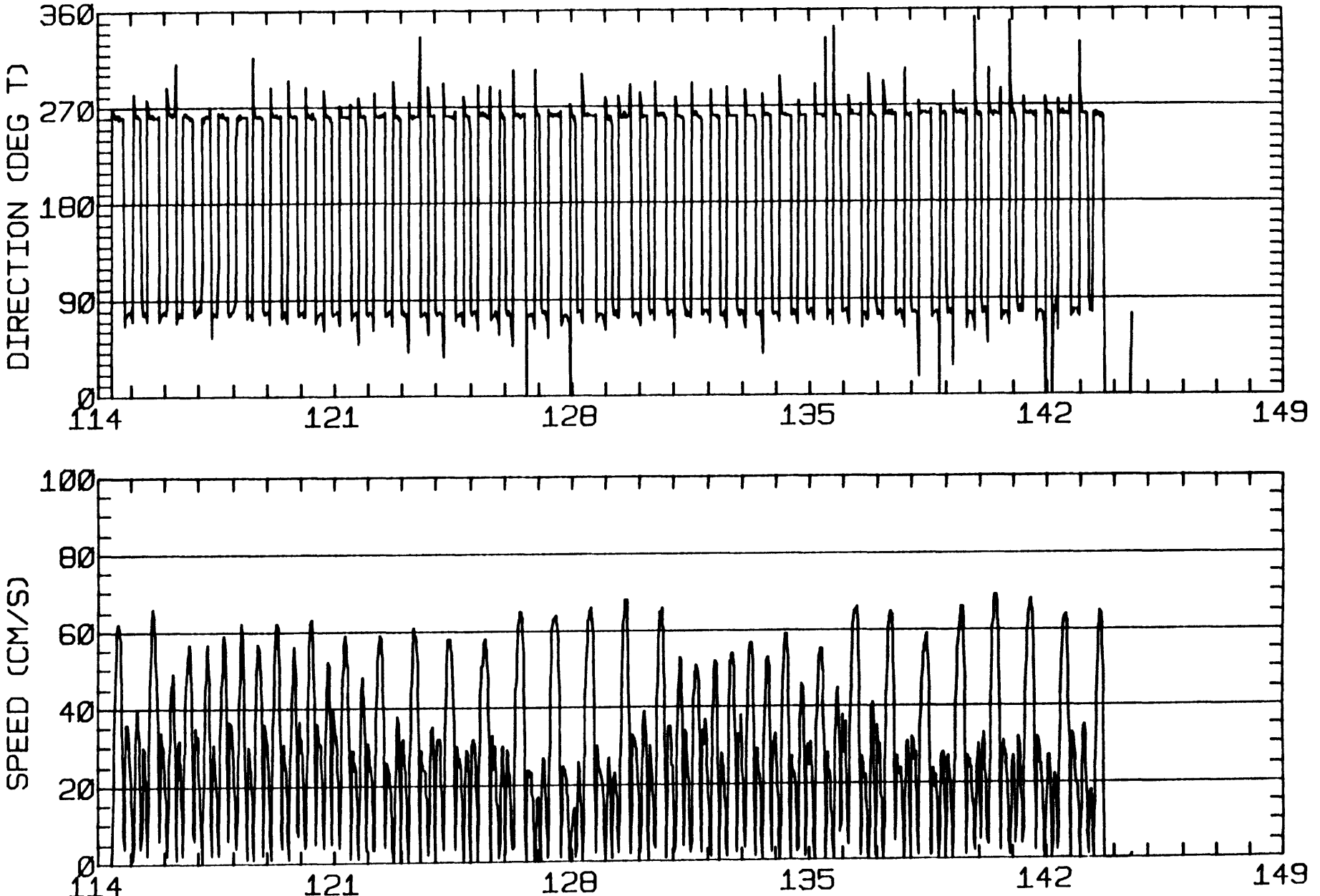
TIDAL ELLIPSES OF SIX MAJOR CONSTITUENTS:

CONSTITUENT	MAJOR (CM/SEC)	MINOR (CM/SEC)	DIR (DEG T)	PHASE (DEG)	ROTATION
O1	9.88	0.06	81.9	113.2	CLOCKWISE
K1	16.05	0.15	81.5	109.5	CLOCKWISE
N2	5.05	0.29	80.7	16.4	ANTI-CLOCKWISE
M2	38.91	0.27	80.4	59.4	ANTI-CLOCKWISE
S2	7.08	0.03	80.8	32.5	CLOCKWISE
M4	4.30	0.26	77.4	28.4	ANTI-CLOCKWISE

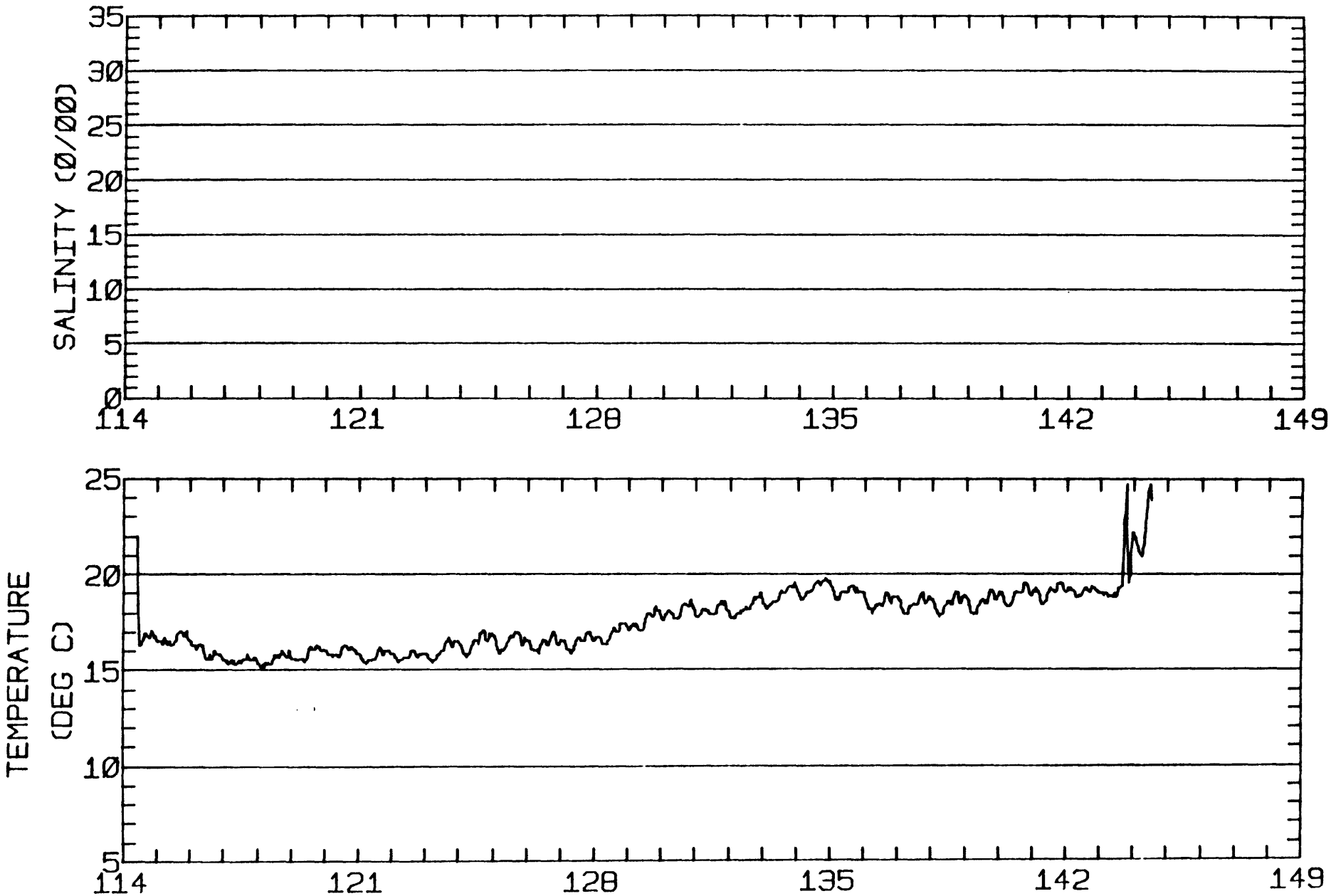
RMS SPEED:	34.4 CM/SEC
SPRING TIDAL CURRENT MAXIMUM:	71.9 CM/SEC
NEAP TIDAL CURRENT MAXIMUM:	25.7 CM/SEC
PRINCIPAL CURRENT DIRECTION:	80.9 DEGREES TRUE
TIDAL FORM NUMBER:	0.56
STANDARD DEVIATION U-SERIES:	7.93 CM/SEC
STANDARD DEVIATION V SERIES:	1.78 CM/SEC

TIME AVERAGED VELOCITY AND MEAN DELTA OUTFLOW:

INTERVAL	NO OF M2 CYCLES	EAST-WEST (CM/SEC)	NORTH-SOUTH (CM/SEC)	OUTFLOW CHIPPS IS. (CMS)
1	12	-12.5	-0.7	208.
2	12	-10.2	-0.3	153.
3	12	-10.4	-0.5	349.
4	12	-11.4	-0.6	367.
5	8	-12.8	-0.7	420.
ALL	56	-11.4	-0.6	



CURRENT METER OBSERVATIONS (30 MINUTE AVERAGES)
USGS STATION BR184 38- 1-24N 121-48-15W
METER 003.1 METERS ABOVE BED. WATER DEPTH 007.0 METERS.



CURRENT METER OBSERVATIONS (30 MINUTE AVERAGES)
USGS STATION BR184 38- 1-24N 121-48-15W
METER 003.1 METERS ABOVE BED. WATER DEPTH 007.0 METERS.

****
* SUMMARY OF HARMONIC ANALYSIS *
****

CURRENT METER STATION: BR185
POSITION: 38 1'22"N 121 48'17"W
METER TYPE: ENDECO
WATER DEPTH: 9.4 M (MLLW)
METER DEPTH: 6.4 M (BELOW MLLW)
START TIME OF SERIES: 3/28/85 1236 PST JULIAN DAY= 87
APPROXIMATE RECORD LENGTH IS 56 M2-CYCLES

TIDAL ELLIPSES OF SIX MAJOR CONSTITUENTS:

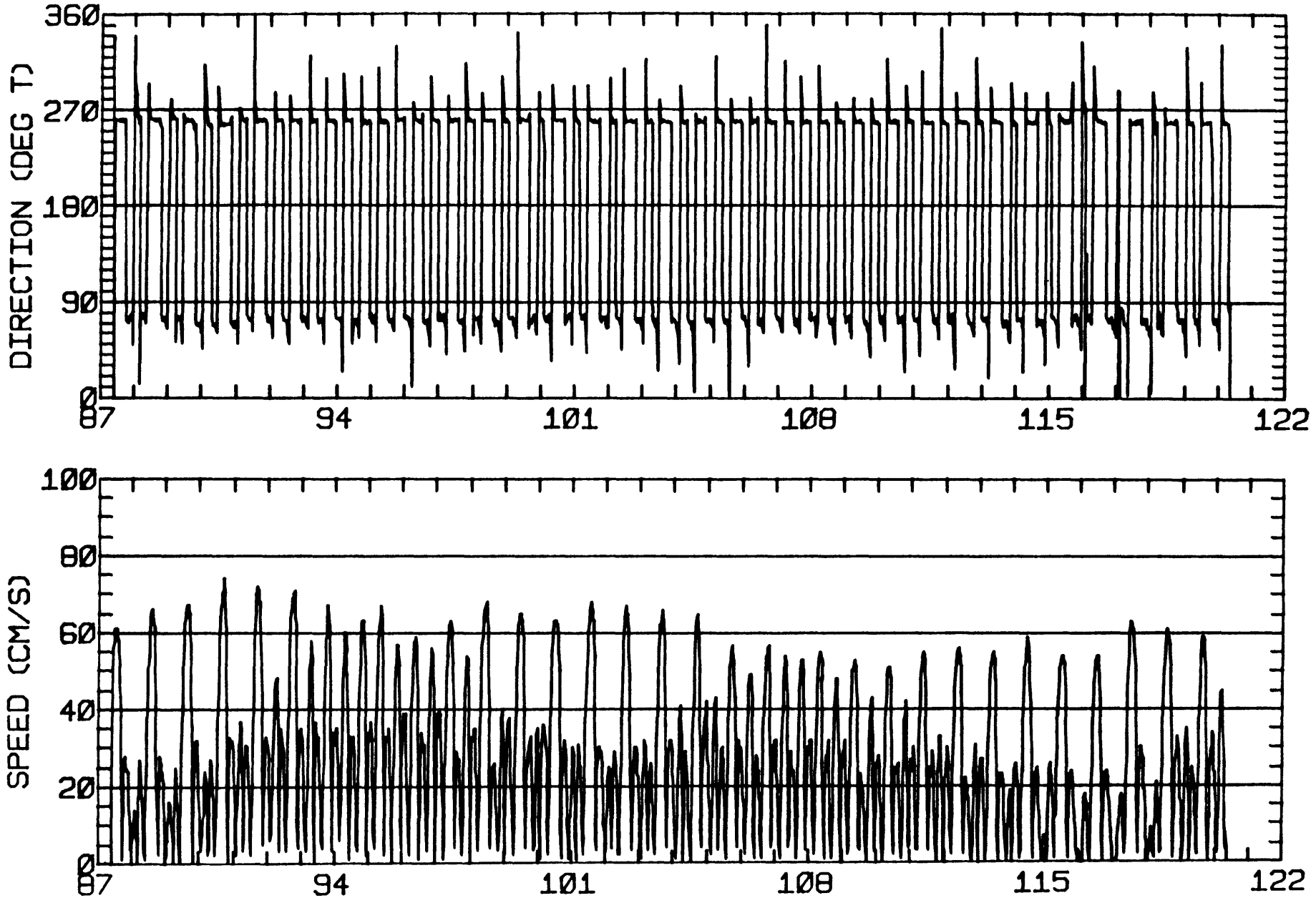
CONSTITUENT	MAJOR (CM/SEC)	MINOR (CM/SEC)	DIR (DEG T)	PHASE (DEG)	ROTATION
O1	10.99	0.15	78.1	112.2	CLOCKWISE
K1	14.23	0.01	78.4	116.5	CLOCKWISE
N2	9.83	0.14	78.1	39.5	ANTI-CLOCKWISE
M2	39.01	0.64	77.3	62.4	ANTI-CLOCKWISE
S2	8.83	0.06	76.5	46.0	ANTI-CLOCKWISE
M4	3.78	0.30	80.1	32.4	ANTI-CLOCKWISE

RMS SPEED:	34.3 CM/SEC
SPRING TIDAL CURRENT MAXIMUM:	73.1 CM/SEC
NEAP TIDAL CURRENT MAXIMUM:	26.9 CM/SEC
PRINCIPAL CURRENT DIRECTION:	77.5 DEGREES TRUE
TIDAL FORM NUMBER:	0.53
STANDARD DEVIATION U-SERIES:	6.24 CM/SEC
STANDARD DEVIATION V SERIES:	1.78 CM/SEC

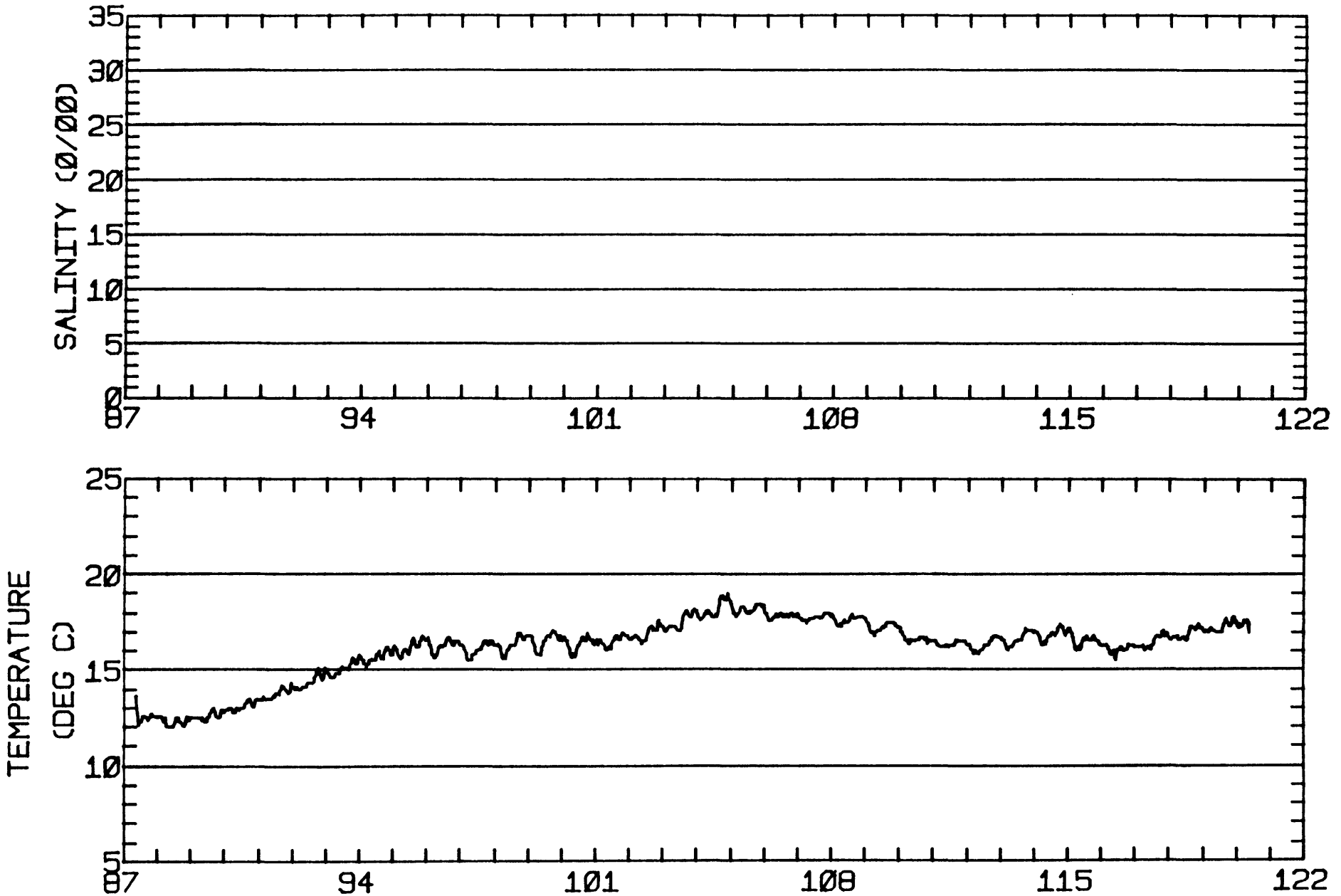
TIME AVERAGED VELOCITY AND MEAN DELTA OUTFLOW:

INTERVAL	NO OF M2 CYCLES	EAST-WEST (CM/SEC)	NORTH-SOUTH (CM/SEC)	OUTFLOW CHIPPS IS. (CMS)*
1	12	-12.5	-0.9	323.
2	12	-12.2	-0.5	257.
3	12	-9.8	-0.5	165.
4	12	-9.7	-0.7	164.
5	8	-8.6	-0.6	185.
ALL	56	-10.7	-0.7	

* Source: Preliminary daily records (Delta outflow index with bypass)



CURRENT METER OBSERVATIONS (30 MINUTE AVERAGES)
USGS STATION BR185 38- 1-22N 121-48-17W
METER 002.9 METERS ABOVE BED. WATER DEPTH 009.4 METERS.



CURRENT METER OBSERVATIONS (30 MINUTE AVERAGES)
USGS STATION BR185 38- 1-22N 121-48-17W
METER 002.9 METERS ABOVE BED. WATER DEPTH 009.4 METERS.

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* SUMMARY OF HARMONIC ANALYSIS *
****

CURRENT METER STATION: BR284
POSITION: 38 1'14"N 121 48'20"W
METER TYPE: ENDECO
WATER DEPTH: 7.9 M (MLLW)
METER DEPTH: 4.5 M (BELOW MLLW)
START TIME OF SERIES: 4/23/84 1234 PST JULIAN DAY=114
APPROXIMATE RECORD LENGTH IS 56 M2-CYCLES

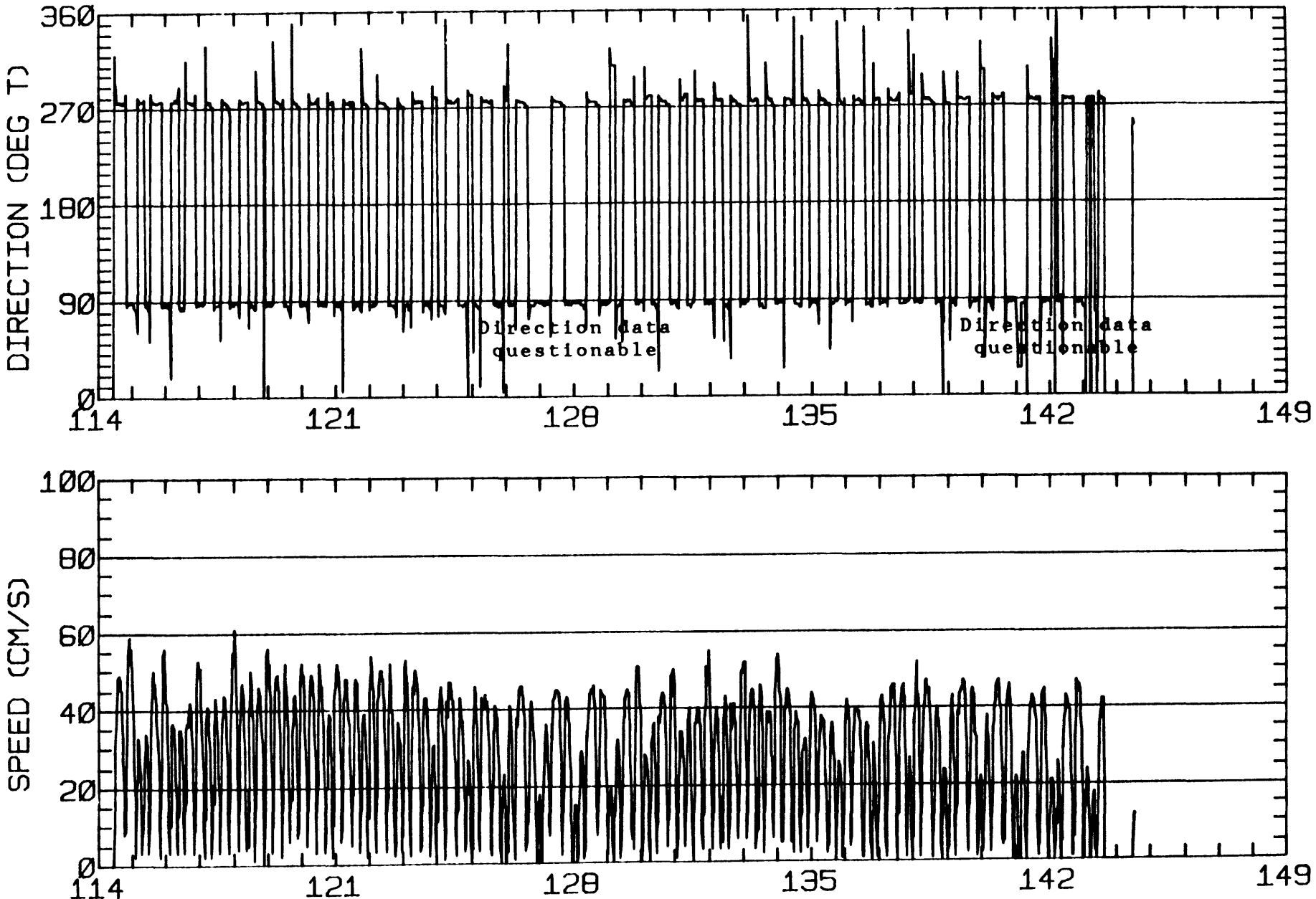
TIDAL ELLIPSES OF SIX MAJOR CONSTITUENTS:

CONSTITUENT	MAJOR (CM/SEC)	MINOR (CM/SEC)	DIR (DEG T)	PHASE (DEG)	ROTATION
O1	8.84	0.20	91.2	101.1	ANTI-CLOCKWISE
K1	16.62	0.26	91.4	111.5	ANTI-CLOCKWISE
N2	4.86	0.18	93.3	36.3	ANTI-CLOCKWISE
M2	35.31	0.69	91.6	73.8	ANTI-CLOCKWISE
S2	10.00	0.23	90.2	41.8	ANTI-CLOCKWISE
M4	2.84	0.44	76.3	145.0	CLOCKWISE

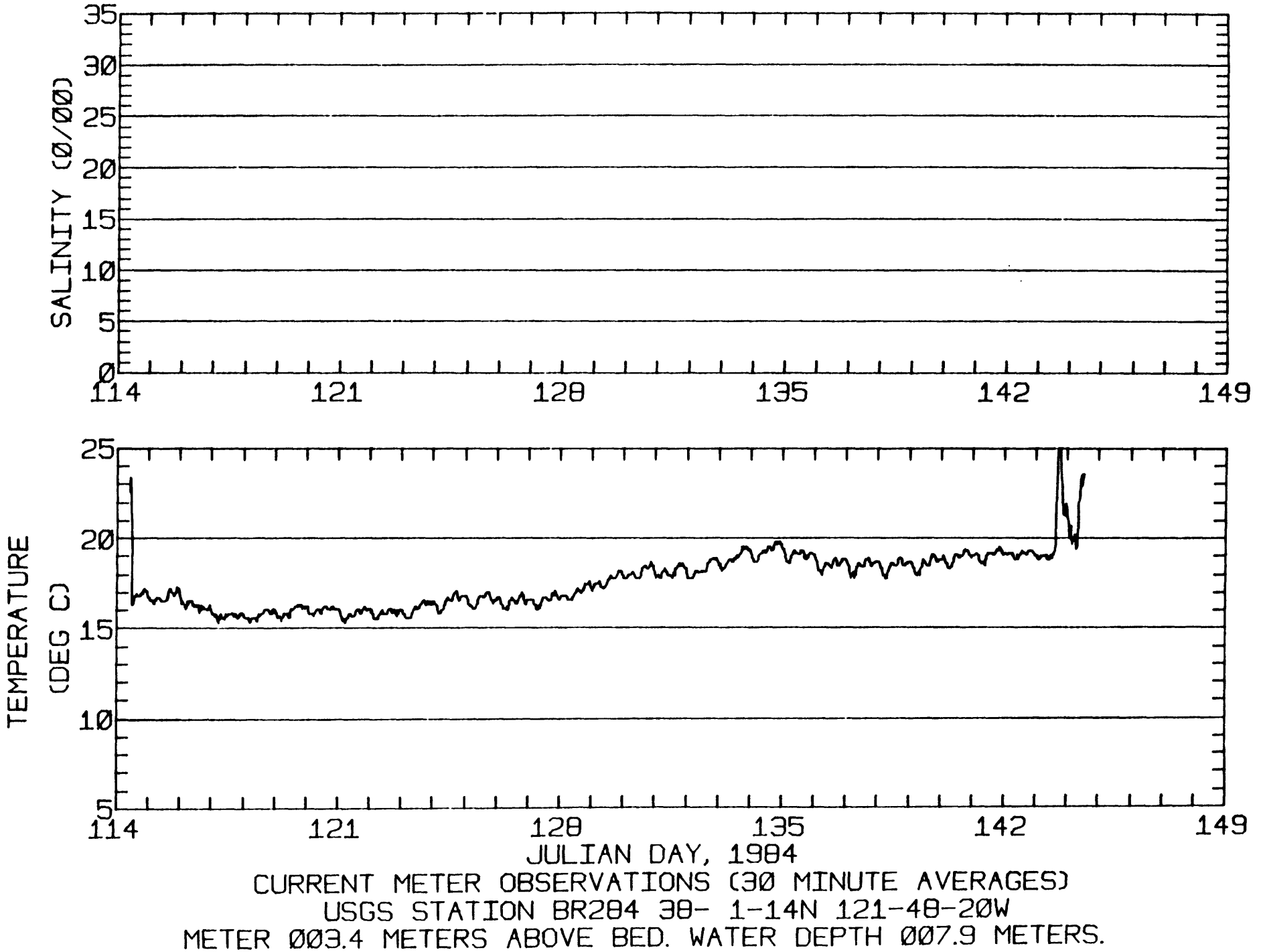
RMS SPEED:	32.1 CM/SEC
SPRING TIDAL CURRENT MAXIMUM:	70.8 CM/SEC
NEAP TIDAL CURRENT MAXIMUM:	17.5 CM/SEC
PRINCIPAL CURRENT DIRECTION:	91.3 DEGREES TRUE
TIDAL FORM NUMBER:	0.56
STANDARD DEVIATION U-SERIES:	11.60 CM/SEC
STANDARD DEVIATION V SERIES:	2.32 CM/SEC

TIME AVERAGED VELOCITY AND MEAN DELTA OUTFLOW:

INTERVAL	NO OF M2 CYCLES	EAST-WEST (CM/SEC)	NORTH-SOUTH (CM/SEC)	OUTFLOW CHIPPS IS. (CMS)
1	12	0.1	3.0	208.
2	12	-0.2	3.1	153.
3	12	1.0	2.7	349.
4	12	-0.1	2.7	367.
5	8	-1.0	3.0	420.
ALL	56	0.0	2.9	



CURRENT METER OBSERVATIONS (30 MINUTE AVERAGES)
USGS STATION BR284 38- 1-14N 121-48-20W
METER 003.4 METERS ABOVE BED. WATER DEPTH 007.9 METERS.



CURRENT METER OBSERVATIONS (30 MINUTE AVERAGES)
USGS STATION BR284 38- 1-14N 121-48-20W
METER ØØ3.4 METERS ABOVE BED. WATER DEPTH ØØ7.9 METERS.

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* SUMMARY OF HARMONIC ANALYSIS *
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CURRENT METER STATION: BR285
POSITION: 38 1'12"N 121 48'22"W
METER TYPE: ENDECO
WATER DEPTH: 12.8 M (MLLW)
METER DEPTH: 9.4 M (BELOW MLLW)
START TIME OF SERIES: 3/28/85 1236 PST JULIAN DAY= 87
APPROXIMATE RECORD LENGTH IS 56 M2-CYCLES

TIDAL ELLIPSES OF SIX MAJOR CONSTITUENTS:

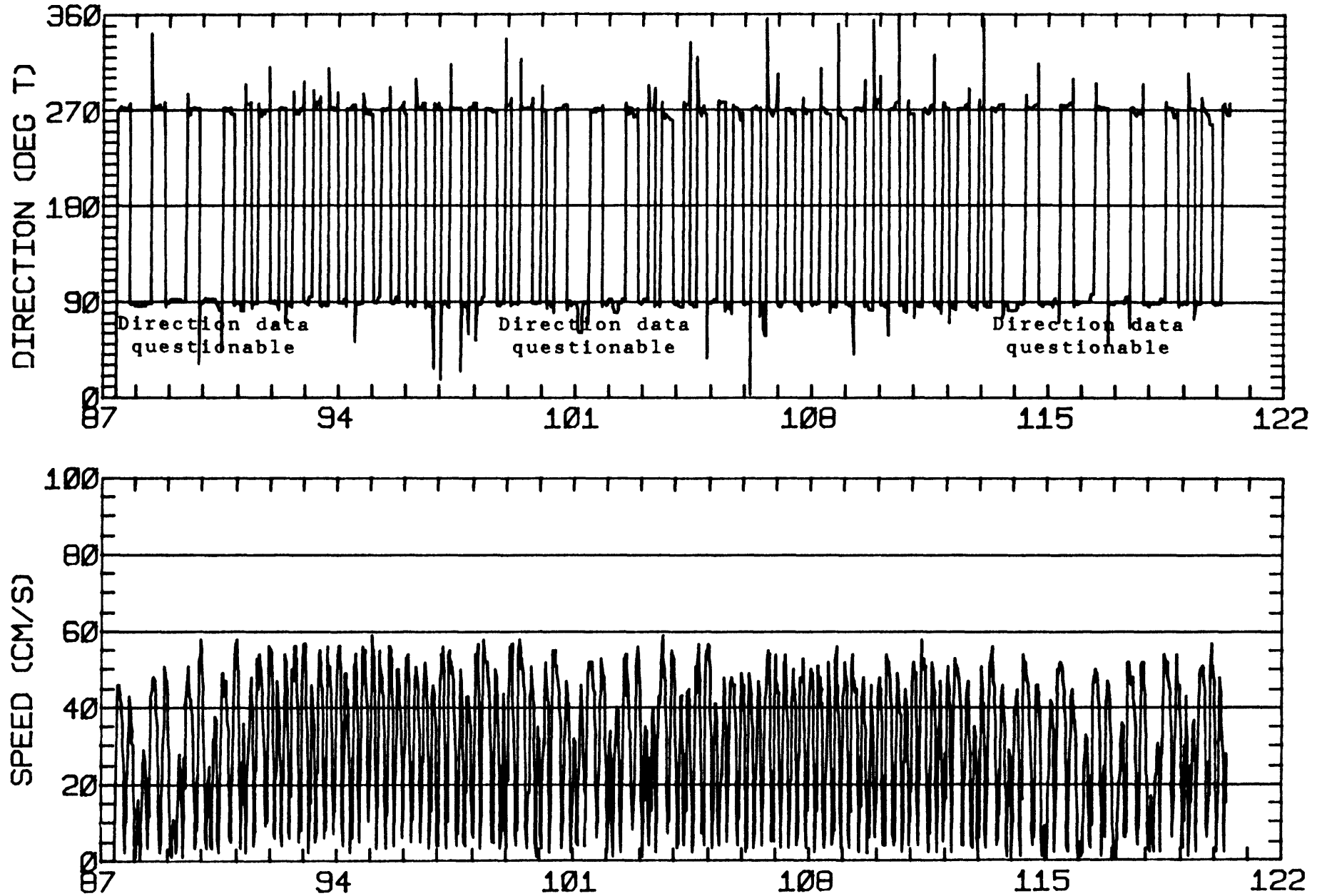
CONSTITUENT	MAJOR (CM/SEC)	MINOR (CM/SEC)	DIR (DEG T)	PHASE (DEG)	ROTATION
O1	11.93	0.19	88.3	115.5	ANTI-CLOCKWISE
K1	15.77	0.19	91.2	120.0	ANTI-CLOCKWISE
N2	8.29	0.18	90.0	51.7	CLOCKWISE
M2	36.87	0.23	89.9	80.6	ANTI-CLOCKWISE
S2	12.74	0.05	89.3	70.5	CLOCKWISE
M4	4.57	0.15	92.2	192.5	CLOCKWISE

RMS SPEED: 35.5 CM/SEC
SPRING TIDAL CURRENT MAXIMUM: 77.3 CM/SEC
NEAP TIDAL CURRENT MAXIMUM: 20.3 CM/SEC
PRINCIPAL CURRENT DIRECTION: 89.8 DEGREES TRUE
TIDAL FORM NUMBER: 0.56
STANDARD DEVIATION U-SERIES: 15.29 CM/SEC
STANDARD DEVIATION V SERIES: 2.12 CM/SEC

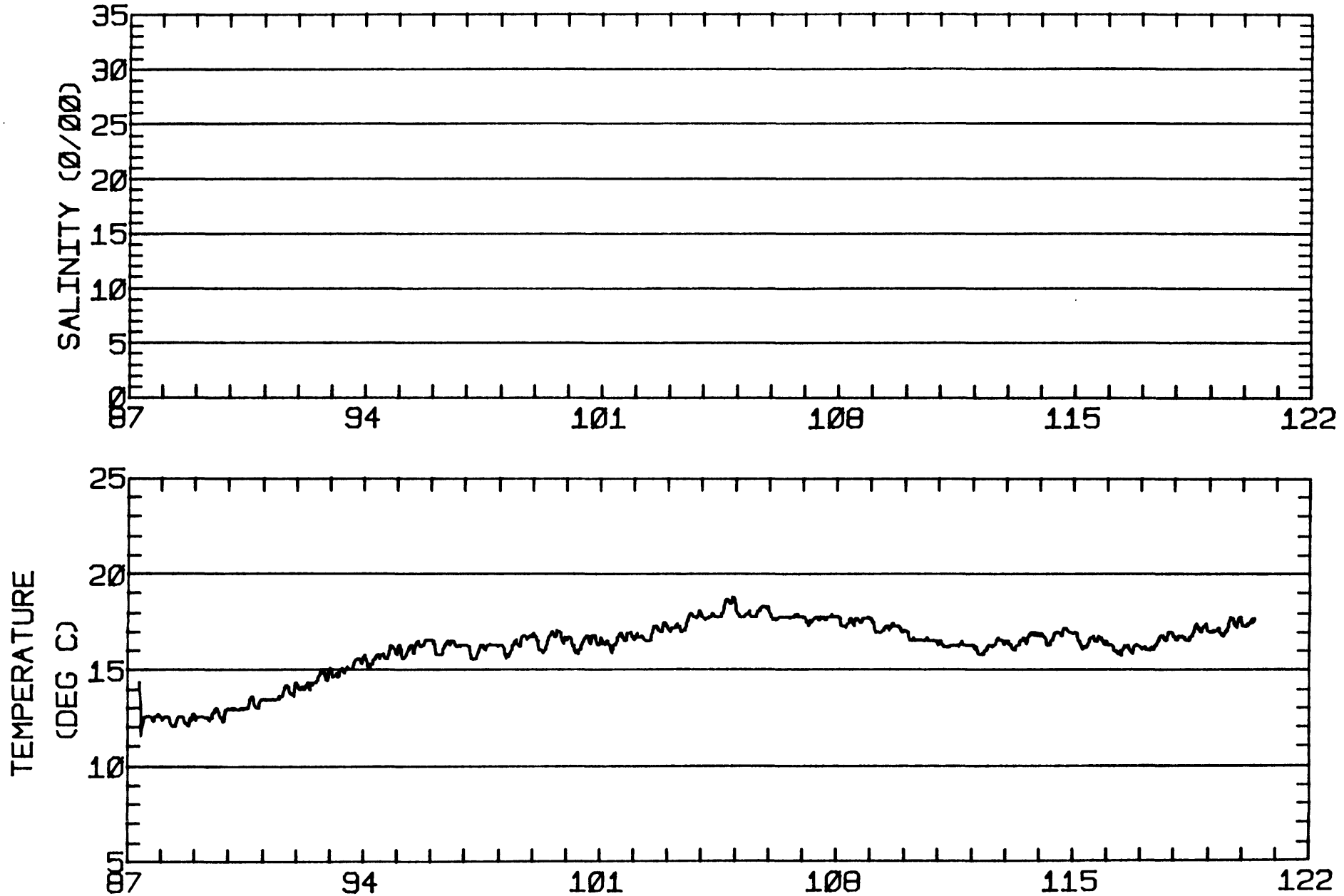
TIME AVERAGED VELOCITY AND MEAN DELTA OUTFLOW:

INTERVAL	NO OF M2 CYCLES	EAST-WEST (CM/SEC)	NORTH-SOUTH (CM/SEC)	OUTFLOW CHIPPS IS. (CMS) *
1	12	1.7	0.9	323.
2	12	-1.2	1.3	257.
3	12	1.6	0.8	165.
4	12	-2.5	1.4	164.
5	8	0.1	1.5	185.
ALL	56	-0.1	1.2	

*
Source: Preliminary daily records (Delta outflow index with bypass)



CURRENT METER OBSERVATIONS (30 MINUTE AVERAGES)
USGS STATION BR285 38- 1-12N 121-48-22W
METER 003.4 METERS ABOVE BED. WATER DEPTH 012.8 METERS.



CURRENT METER OBSERVATIONS (30 MINUTE AVERAGES)
USGS STATION BR285 38- 1-12N 121-48-22W
METER ØØ3.4 METERS ABOVE BED. WATER DEPTH Ø12.8 METERS.

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* SUMMARY OF HARMONIC ANALYSIS *
****

CURRENT METER STATION: BR384
POSITION: 38 1'10"N 121 48'26"W
METER TYPE: ENDECO
WATER DEPTH: 13.7 M (MLLW)
METER DEPTH: 8.2 M (BELOW MLLW)
START TIME OF SERIES: 4/23/84 1234 PST JULIAN DAY=114
APPROXIMATE RECORD LENGTH IS 56 M2-CYCLES

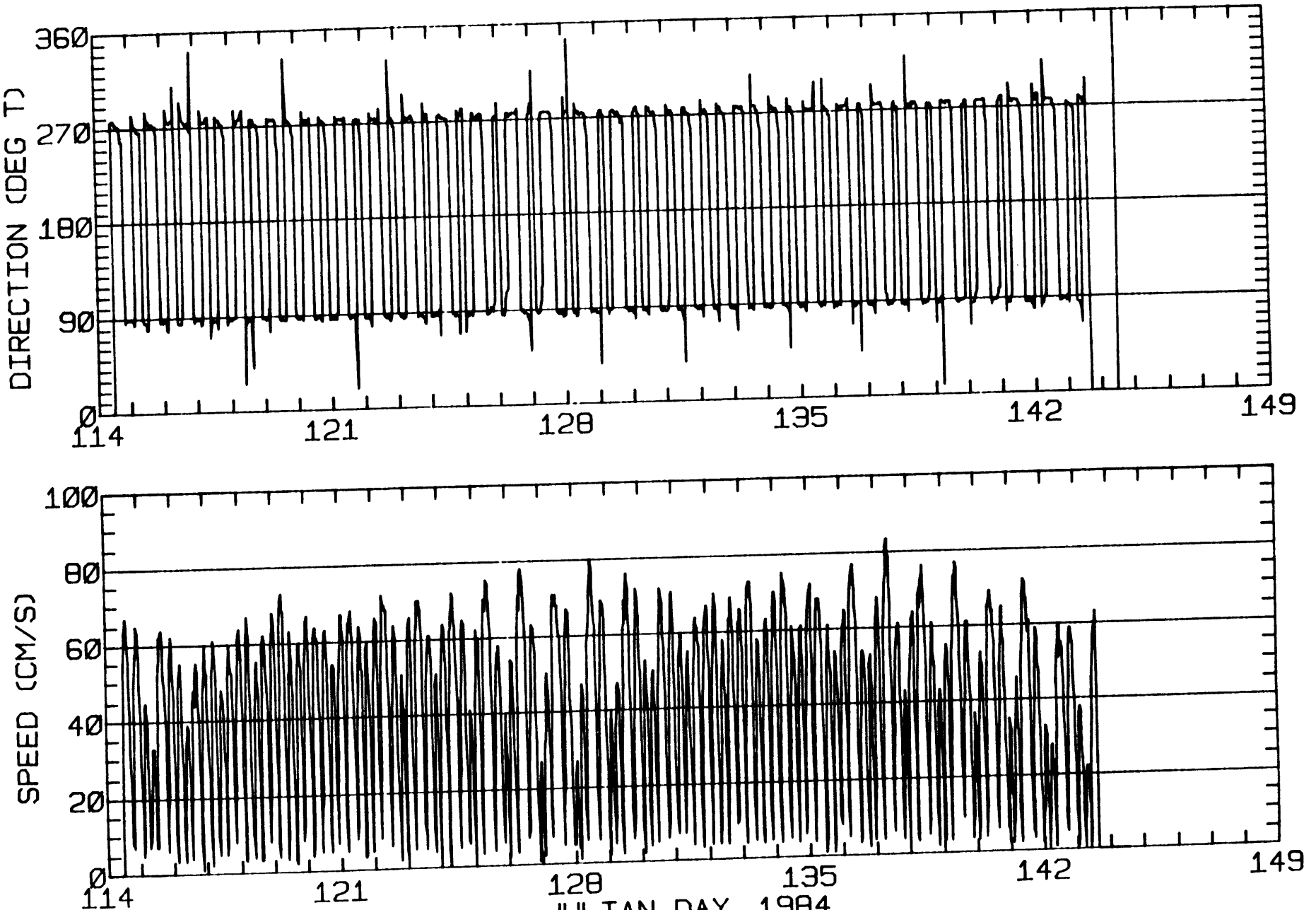
TIDAL ELLIPSES OF SIX MAJOR CONSTITUENTS:

CONSTITUENT	MAJOR (CM/SEC)	MINOR (CM/SEC)	DIR (DEG T)	PHASE (DEG)	ROTATION
O1	11.86	0.12	93.0	104.6	CLOCKWISE
K1	22.69	0.10	93.0	106.2	ANTI-CLOCKWISE
N2	9.06	0.26	92.4	39.4	ANTI-CLOCKWISE
M2	55.43	1.02	91.5	69.0	ANTI-CLOCKWISE
S2	12.61	0.18	88.8	47.8	CLOCKWISE
M4	1.87	0.47	58.0	116.2	ANTI-CLOCKWISE

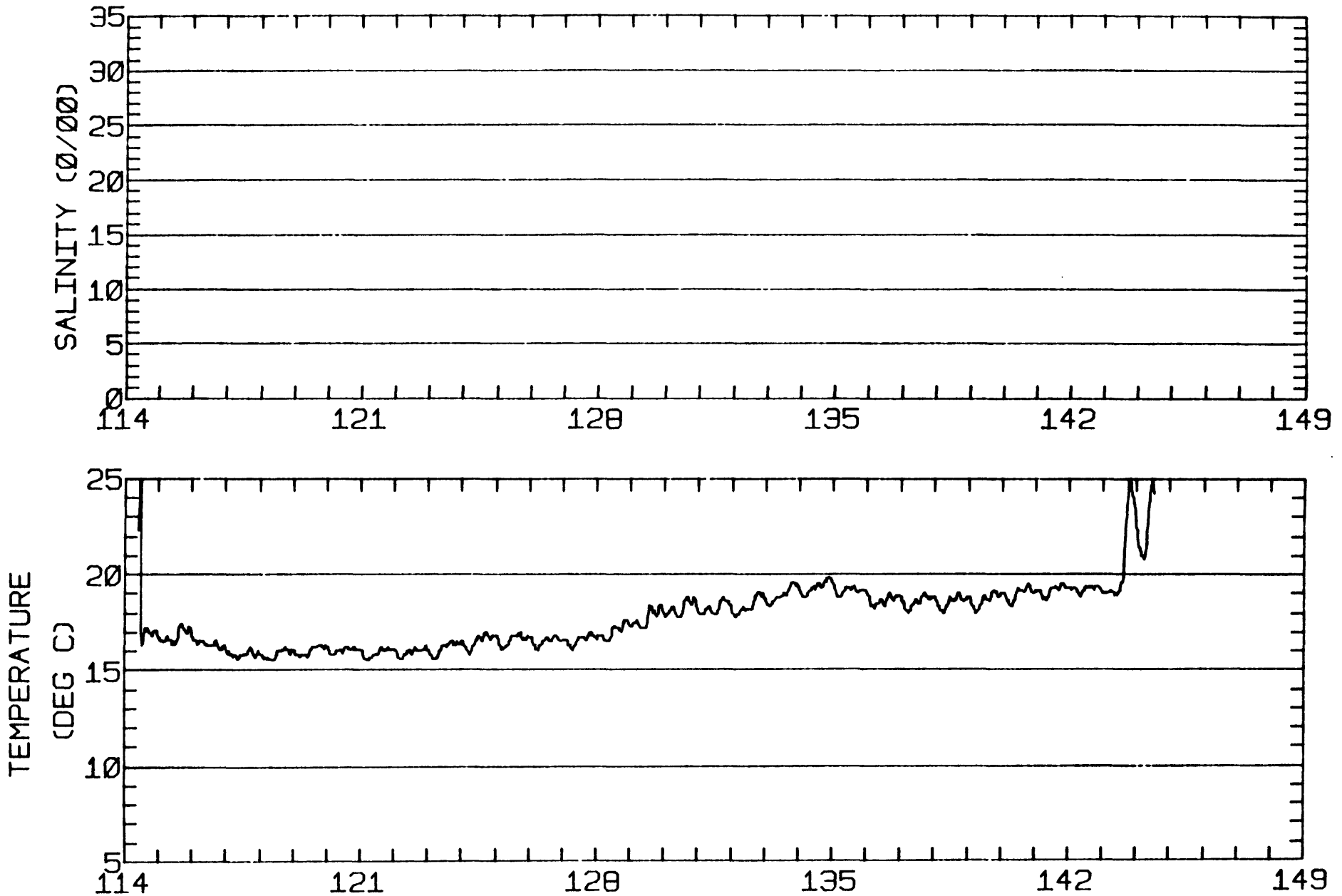
RMS SPEED: 46.3 CM/SEC
SPRING TIDAL CURRENT MAXIMUM: 102.6 CM/SEC
NEAP TIDAL CURRENT MAXIMUM: 32.0 CM/SEC
PRINCIPAL CURRENT DIRECTION: 91.7 DEGREES TRUE
TIDAL FORM NUMBER: 0.51
STANDARD DEVIATION U-SERIES: 11.33 CM/SEC
STANDARD DEVIATION V SERIES: 2.09 CM/SEC

TIME AVERAGED VELOCITY AND MEAN DELTA OUTFLOW:

INTERVAL	NO OF M2 CYCLES	EAST-WEST (CM/SEC)	NORTH-SOUTH (CM/SEC)	OUTFLOW CHIPPS IS. (CMS)
1	12	-3.0	2.5	208.
2	12	-1.5	2.6	153.
3	12	-2.2	2.6	349.
4	12	-3.2	2.8	367.
5	8	-4.7	2.6	420.
ALL	56	-2.8	2.6	



CURRENT METER OBSERVATIONS (30 MINUTE AVERAGES)
USGS STATION BR304 38- 1-10N 121-48-26W
METER 005.5 METERS ABOVE BED. WATER DEPTH 013.7 METERS.



CURRENT METER OBSERVATIONS (30 MINUTE AVERAGES)
USGS STATION BR304 38- 1-10N 121-48-26W
METER 005.5 METERS ABOVE BED. WATER DEPTH 013.7 METERS.

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* SUMMARY OF HARMONIC ANALYSIS *
****

CURRENT METER STATION: BR484
POSITION: 38 1' 6"N 121 48'14"W
METER TYPE: ENDECO
WATER DEPTH: 10.3 M (MLLW)
METER DEPTH: 6.4 M (BELOW MLLW)
START TIME OF SERIES: 4/23/84 1234 PST JULIAN DAY=114
APPROXIMATE RECORD LENGTH IS 56 M2-CYCLES

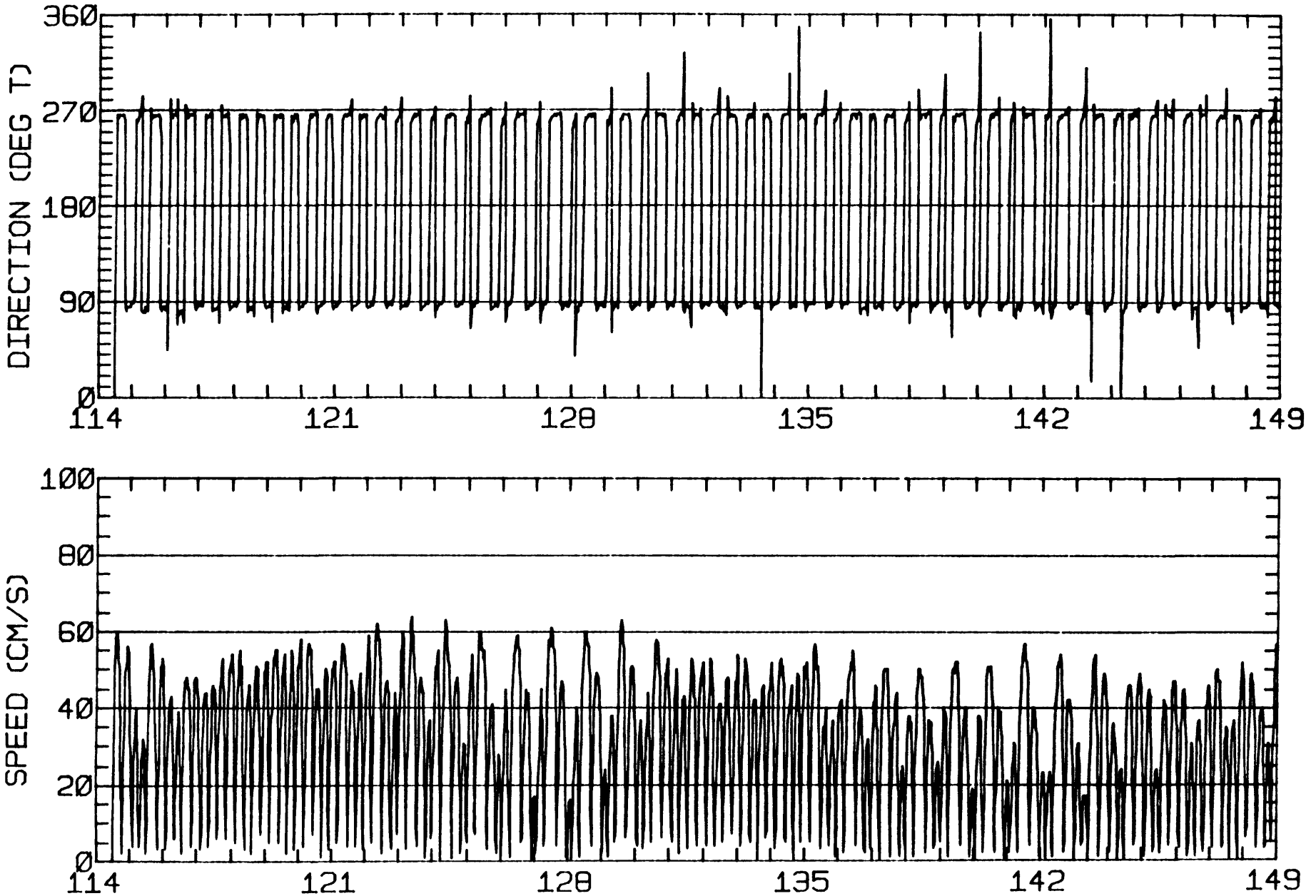
TIDAL ELLIPSES OF SIX MAJOR CONSTITUENTS:

CONSTITUENT	MAJOR (CM/SEC)	MINOR (CM/SEC)	DIR (DEG T)	PHASE (DEG)	ROTATION
O1	9.22	0.03	84.2	106.5	ANTI-CLOCKWISE
K1	17.66	0.16	87.1	106.7	CLOCKWISE
N2	5.37	0.23	86.5	35.3	CLOCKWISE
M2	44.05	0.74	85.8	61.8	CLOCKWISE
S2	9.37	0.14	84.2	35.9	CLOCKWISE
M4	1.30	0.07	88.2	60.3	CLOCKWISE

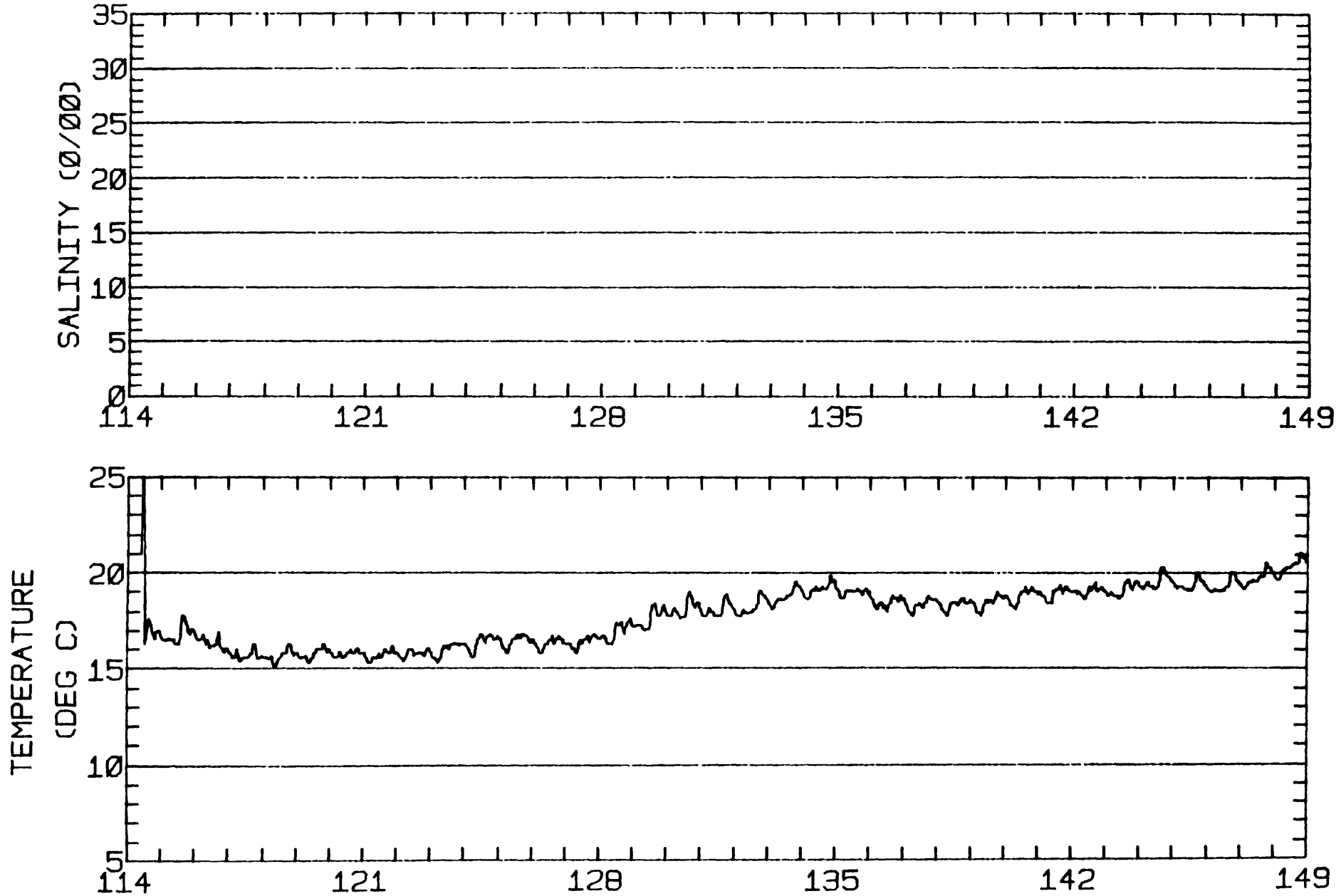
RMS SPEED:	36.4 CM/SEC
SPRING TIDAL CURRENT MAXIMUM:	80.3 CM/SEC
NEAP TIDAL CURRENT MAXIMUM:	26.2 CM/SEC
PRINCIPAL CURRENT DIRECTION:	85.7 DEGREES TRUE
TIDAL FORM NUMBER:	0.50
STANDARD DEVIATION U-SERIES:	9.13 CM/SEC
STANDARD DEVIATION V SERIES:	1.52 CM/SEC

TIME AVERAGED VELOCITY AND MEAN DELTA OUTFLOW:

INTERVAL	NO OF M2 CYCLES	EAST-WEST (CM/SEC)	NORTH-SOUTH (CM/SEC)	OUTFLOW CHIPPS IS. (CMS)
1	12	-2.4	-0.1	208.
2	12	-1.5	-0.6	153.
3	12	-1.1	-0.4	349.
4	12	-2.5	-0.4	367.
5	8	-4.4	-0.4	420.
ALL	56	-2.2	-0.4	



CURRENT METER OBSERVATIONS (30 MINUTE AVERAGES)
USGS STATION BR484 38- 1- 6N 121-48-14W
METER 003.9 METERS ABOVE BED. WATER DEPTH 010.3 METERS.



CURRENT METER OBSERVATIONS (30 MINUTE AVERAGES)
USGS STATION BR484 38- 1- 6N 121-48-14W
METER Ø03.9 METERS ABOVE BED. WATER DEPTH Ø10.3 METERS.

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* SUMMARY OF HARMONIC ANALYSIS *
****

CURRENT METER STATION: BR485
POSITION: 38 1' 6"N 121 48'16"W
METER TYPE: ENDECO
WATER DEPTH: 11.8 M (MLLW)
METER DEPTH: 7.9 M (BELOW MLLW)
START TIME OF SERIES: 3/28/85 1236 PST JULIAN DAY= 87
APPROXIMATE RECORD LENGTH IS 56 M2-CYCLES

TIDAL ELLIPSES OF SIX MAJOR CONSTITUENTS:

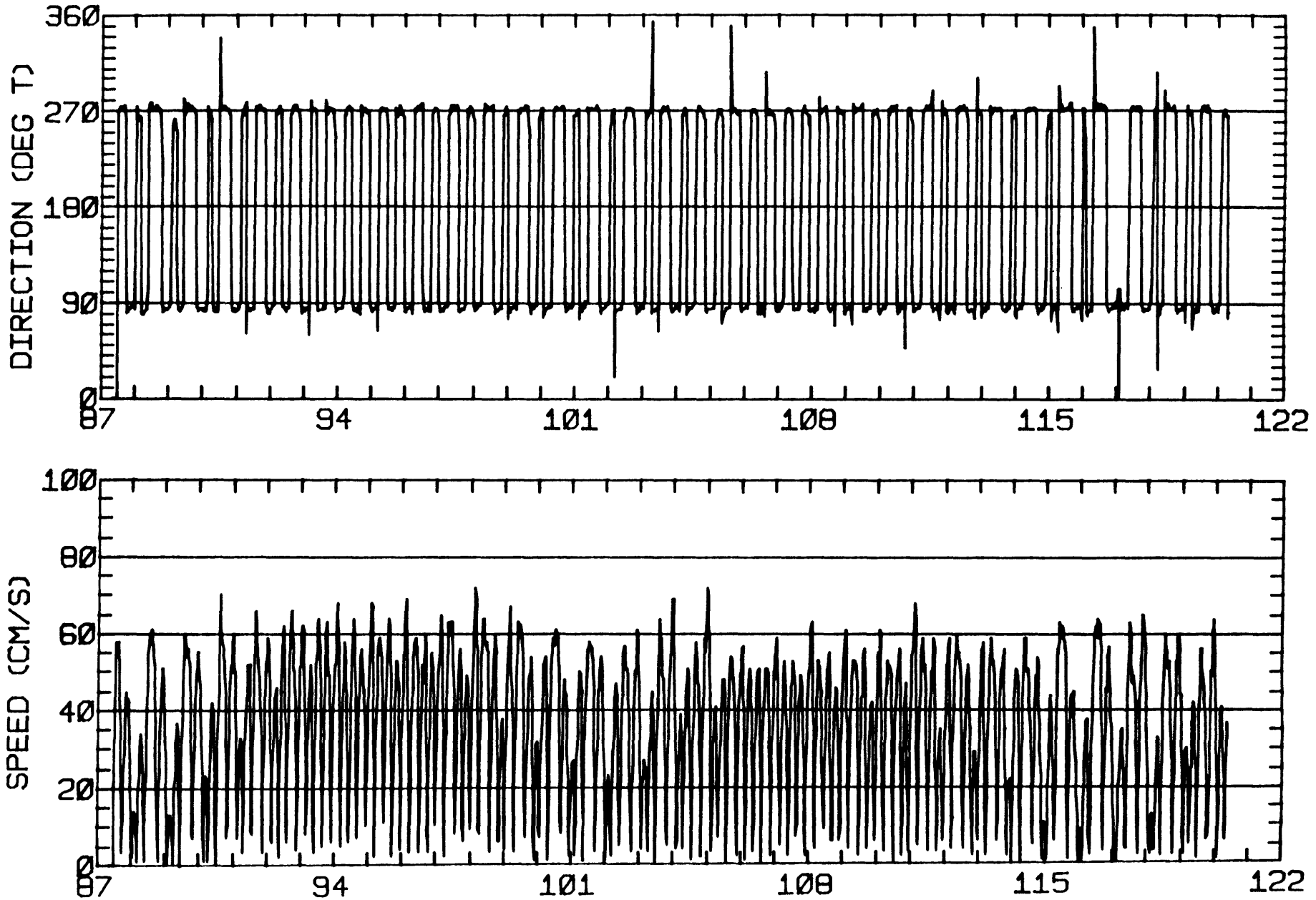
CONSTITUENT	MAJOR (CM/SEC)	MINOR (CM/SEC)	DIR (DEG T)	PHASE (DEG)	ROTATION
O1	11.65	0.27	90.5	108.7	CLOCKWISE
K1	17.41	0.04	90.8	111.0	ANTI-CLOCKWISE
N2	10.36	0.08	89.4	42.1	CLOCKWISE
M2	48.84	0.09	88.1	66.0	CLOCKWISE
S2	12.96	0.35	86.4	56.4	CLOCKWISE
M4	1.98	0.21	58.4	117.4	ANTI-CLOCKWISE

RMS SPEED:	40.5 CM/SEC
SPRING TIDAL CURRENT MAXIMUM:	90.9 CM/SEC
NEAP TIDAL CURRENT MAXIMUM:	30.1 CM/SEC
PRINCIPAL CURRENT DIRECTION:	88.7 DEGREES TRUE
TIDAL FORM NUMBER:	0.47
STANDARD DEVIATION U-SERIES:	9.29 CM/SEC
STANDARD DEVIATION V SERIES:	2.03 CM/SEC

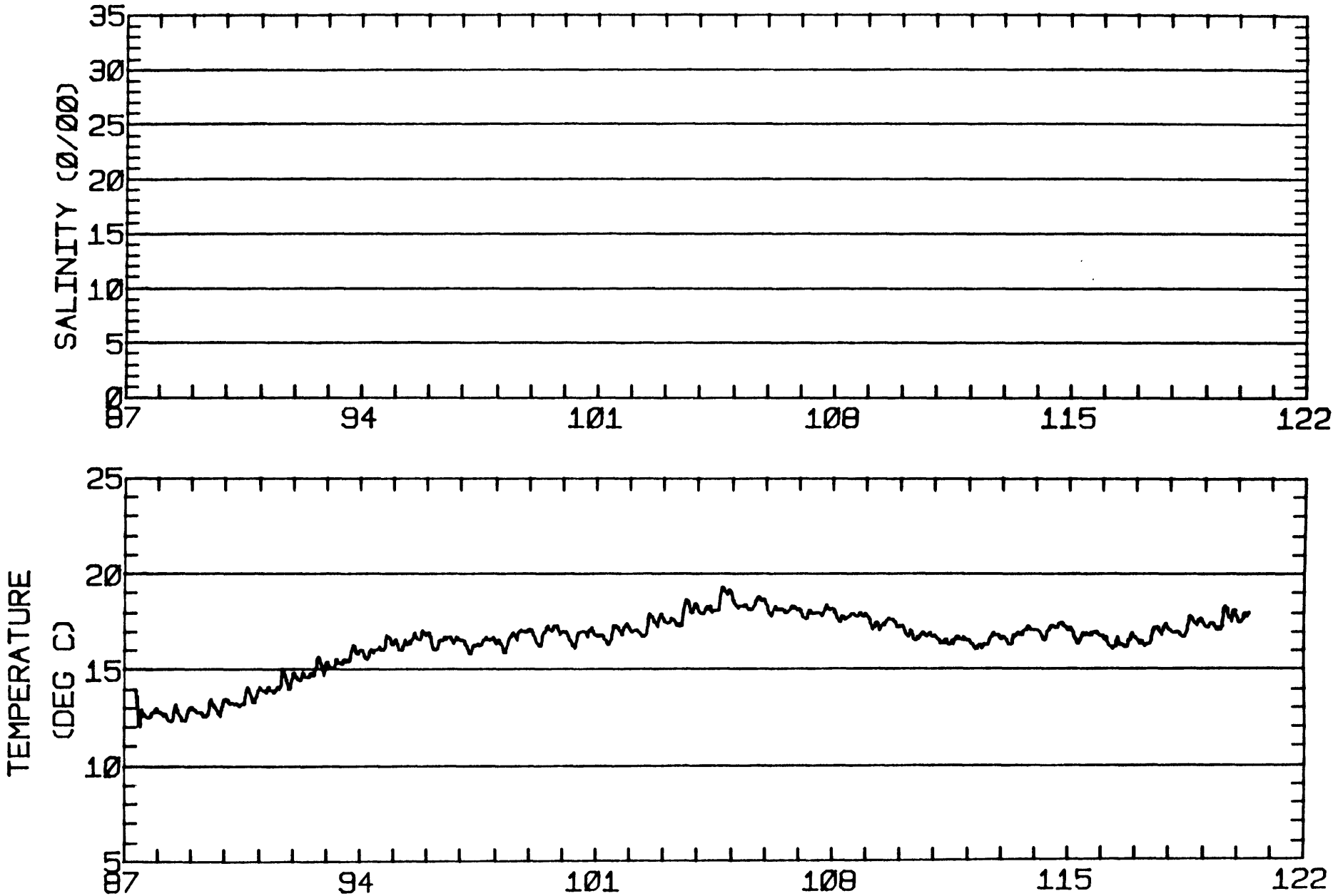
TIME AVERAGED VELOCITY AND MEAN DELTA OUTFLOW:

INTERVAL	NO OF M2 CYCLES	EAST-WEST (CM/SEC)	NORTH-SOUTH (CM/SEC)	OUTFLOW CHIPPS IS. (CMS)*
1	12	0.0	2.3	323.
2	12	0.3	2.3	257.
3	12	1.6	1.7	165.
4	12	1.5	1.9	164.
5	8	-1.1	1.9	185.
ALL	56	0.6	2.0	

*Source: Preliminary daily records (Delta outflow index with bypass)



CURRENT METER OBSERVATIONS (30 MINUTE AVERAGES)
USGS STATION BR485 38- 1- 6N 121-48-16W
METER 003.9 METERS ABOVE BED. WATER DEPTH 011.8 METERS.



CURRENT METER OBSERVATIONS (30 MINUTE AVERAGES)
USGS STATION BR485 38- 1- 6N 121-48-16W
METER 003.9 METERS ABOVE BED. WATER DEPTH 011.8 METERS.