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Tides and Currents in the
South of the Arabian Gulf

Internal Document No. 151

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NATURAL ENVIRONMENT RESEARCH COUNCIL

**INSTITUTE OF
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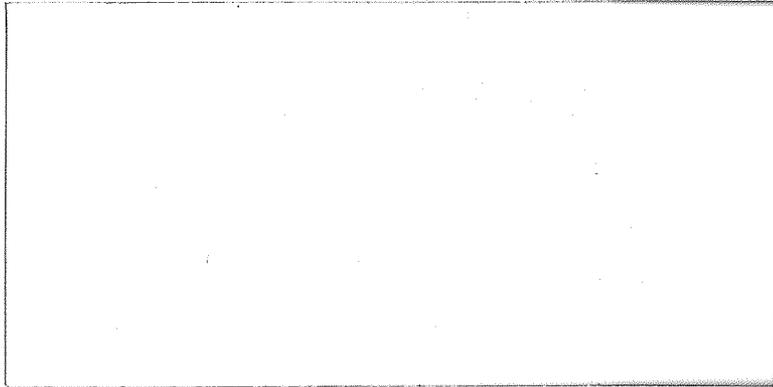Wormley, Godalming,
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## 1.1 INTRODUCTION

This report is concerned with the analysis and description of one elevation record and 10 current meter records from the Zakum Oilfield in the Arabian Gulf. A map containing the positions of the instruments is shown in Figure 1.1. Two years of sea level data were recorded near the island of Zirku and between one and three months of currents were recorded in the surrounding area on behalf of the ZADCO, ZAKUM Development Company by the SESAM company. The Institute of Oceanographic Sciences was requested to perform an analysis of the available data and to provide an interpretation of the results.

The analysis of both sea level and current meter data is done in an identical manner except that the currents are vector quantities and are resolved along North and East directions prior to analysis. The observations are decomposed into three parts which are discussed separately.

1.  The mean value plus seasonal modulations

2.  The tidal component

3.  The surge or meteorologically induced component

In dealing with the currents the data was too short to permit any estimation of seasonal modulations but in the elevations they are shown to be significantly large. At the end of the chapters on sea level and currents, estimates are given of the expected extreme conditions. Because of the limited length of the current meter records these estimates are unlikely to be exceedingly accurate but they have the advantage that the meters were deployed during a period of severe meteorological conditions.

Tidal predictions of sea level and currents have been prepared based on the various tidal analyses. For convenience these are included in a separate document.

## 2.   TIDAL ELEVATIONS

Tidal observations covering the period 4th October 1978 to 11th September 1980 and sampled at half hourly intervals were supplied on magnetic tape for the analysis and prediction of tides in the Zirku area.  The measurements were made with an Aanderaa WLR5 recorder, located at the position $24^{\circ}$ 52.5N $53^{\circ}$ 05.5E, which measured bottom pressure caused by water level and atmospheric variations.  Also available were measurements of barometric pressure and water density which were used to convert the bottom pressures into values of sea level.  IOS had access to both the pressure and elevation records but this report is primarily concerned with the analysis of the elevation data.

Previous measurements had been made at the same site from December 1977 but complications with the mooring configuration made the data unsuitable and therefore tidal analysis was confined to the data commencing October 1978 and covering a two year period.

The tide gauge was levelled to 0.735m below chart datum and was replaced at regular intervals of roughly one month duration which meant that 24 blocks of data were available for analysis.

### 2.1  DATA REDUCTION

Initially the observed data were compared for continuity with tidal predictions from an analysis supplied by Total of the 1979 data.  The results showed numerous spikes, periods of missing data which had been filled by interpolation, and sections in which complete tidal cycles were missing causing large timing errors in subsequent data.  To resolve these discrepancies the data were compared with the intervention reports which proved to be the most useful except that many of these reports were incomplete.  However, this provided 19 separate blocks of data covering the two year period in which each block was known to be self-consistent but was not consistent with adjacent blocks in respect to their timing. Harmonic analyses of the 19 blocks showed good agreement for the amplitudes of the harmonic constants from the various blocks but poor agreement for the phases suggesting, of course, that there was a timing problem.  The times derived from the constituent phases differed by 10 hours in the extreme case.

The large variation in phase made it necessary to find an alternative source of information to confirm the absolute phase of each constituent.  It was felt that the acceptable agreement in amplitude made the data recoverable if the

correct phase of one of the constituents could be identified. Ultimately we chose to identify the timing from the phase of $K_1$ taken from the most recent co-tidal chart of the Arabian Gulf. This constituent is the most spatially coherent of any in the region and this procedure led to the conclusion that most of the data blocks were time shifted by either zero hours or four hours which, of course, is the difference between local time and G.M.T. Unfortunately, there were five data blocks for which the timing could not be identified. The latter were omitted and the data, which were considered to be in local time, were time shifted to G.M.T. to agree with the remaining data. This provided approximately 406 days of valid data, the dates of which are given in Table 2.1.

### TABLE 2.1    DATA BLOCKS

| Block | | Date and Time (GMT) | | | |
|---|---|---|---|---|---|
| 1 | 0830 | 04/10/78 | – | 1600 | 02/11/78 |
| 2 | 0400 | 21/12/78 | – | 0330 | 19/01/79 |
| 3 | 0400 | 19/01/78 | – | 0330 | 17/02/79 |
| 4 | | 01/03/79 | – | | 27/03/79 |
| 5 | | 28/03/79 | – | | 16/04/79 |
| 6 | 1230 | 18/04/79 | – | 1200 | 17/05/79 |
| 7 | 1400 | 05/08/79 | – | 1330 | 03/09/79 |
| 8 | 1400 | 03/09/79 | – | 1330 | 02/10/79 |
| 9 | | 05/10/79 | – | | 02/11/79 |
| 10 | 0000 | 09/11/79 | – | 2330 | 07/12/79 |
| 11 | 0000 | 08/12/79 | – | 2330 | 05/01/80 |
| 12 | 0000 | 10/01/80 | – | 2330 | 07/02/80 |
| 13 | 0000 | 09/02/80 | – | 2330 | 08/03/80 |
| 14 | 0000 | 09/03/80 | – | 2330 | 06/04/80 |
| 15 | | 12/04/80 | – | | 06/05/80 |
| 16 | 0000 | 08/05/80 | – | 2330 | 05/06/80 |
| 17 | | 13/06/80 | – | | 08/07/80 |
| 18 | 2000 | 11/07/80 | – | 2330 | 08/08/80 |
| 19 | 0000 | 09/08/80 | – | 1930 | 06/09/80 |

Data blocks 4, 5, 9, 15 and 17 could not be timed exactly and were omitted from the harmonic analysis.

## 2.2 MEAN SEA LEVEL AND SEASONAL VARIATIONS
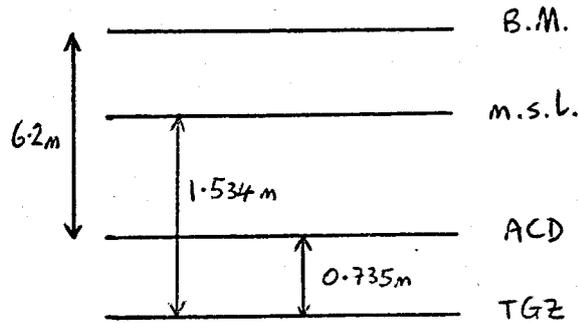


### Figure 2.1      DATUM LEVELS

msl  =  mean sea level

BM   =  Bench mark : HMS Owen plate

ACD  =  Admiralty Chart Datum

TGZ  =  Tide Gauge Zero

Figure 2.1 shows the relationship between the various levels used in this work. The analysis given in Table 2.2 is relative to the level designated TGZ. Mean Sea Level which was found to be 1.534m above TGZ, is the mean value derived from the same analysis.

Mean sea level is a constant level which can only be estimated from a suitably long series of observations. It may be subject to trends on protracted time scales but this is not a question that can be studied here. In the Arabian Gulf as elsewhere there are variations in sea level about the mean particularly on a monthly and annual basis caused by meteorological forces and by radiational inputs from the sun. Part of the annual and monthly variation is coherent with the tides and is extracted during the tidal analysis by the long period constituents Sa, Ssa, Mm, Msf and Mf. These constituents are included in our tidal predictions and further adjustment for their effect on sea level is unnecessary. Each constituent Sa and Ssa contributes 5cm to the seasonal variation.

There are some remaining seasonal modulations in sea level which are incoherent with the tides but affect sea level by up to 10cm, which is significant in relation to the tidal range. However, no regular pattern could be established for these modulations which would permit them to be used for predictions. By inference the long period tidal constituents absorb most of the predictable variations in mean sea level.

## 2.3   TIDES

Tidal analysis of the data documented in Table 2.1 gave harmonic constituents of the tide which are shown in Table 2.2. The five dominant constituents are $O_1$, $P_1$, $K_1$, $M_2$ and $S_2$, the largest of these being $K_1$.

Generally tidal regimes are classified according to the ratio $(O_1 + K_1)/(M_2 + S_2)$ which in this case has the value 2.8 making the regime dominantly diurnal. If this ratio is between 0.25 and 1.25 it is usually classified as mixed and below 0.25 is classified as semi-diurnal. The diurnal regime is caused by the effect of the semi-diurnal amphidromes to the west of Zirku Island which reduce the amplitude of $M_2$ and $S_2$. The tidal currents on the other hand are predominantly semi-diurnal thus making the elevation/current regime complex and precluding any systematic relationship between tidal streams and elevations.

There is little in the way of shallow water distortion at Zirku but there is a strong seasonal modulation not only in the mean level as already discussed but in the five dominant constituents. For example, $M_2$ is modulated annually by some 17% and on a six monthly cycle by an equal amount. These modulations are reflected in the amplitude of the constituents MA2 and MSK2 respectively in Table 2.2. $K_1$ is modulated annually by $S_1$ to the extent of 12% and similarly by $\psi_1$ and $\phi_1$. However these latter modulations may be caused by radiational tides from solar inputs and not necessarily by the same mechanism as the modulation in $M_2$. $O_1$ is modulated on a six month cycle by 13% and there may be an additional annual change which is not indicated in the table. These modulations emphasise the difficulty in deriving tides in this area from data which covers only part of a year. Presumably the current meter data suffer from equivalent variations but this is impossible to determine because of the limited duration of the records.

In spite of the problems encountered when processing the elevation data the final analysis appears to be of a reasonable quality and tidal predictions based on this analysis have been prepared including all seasonal modulations. Additionally, sea level in the Gulf is subject to meteorological surges which can affect the predicted levels. This is discussed in Section 2.4. Some non-harmonic terms have been derived from the analysis and are presented in Table 2.3. These do not have the same inference as they do for a predominantly semi-diurnal regime but they serve to give an estimate of the tidal variation in sea level.

TABLE 2.3.     NON-HARMONIC TERMS

| | |
|---|---|
| HAT | 1.51 |
| ISHW | 1.51 |
| MSL | 0.80 |
| ISLW | 0.09 |
| LAT | -0.15 |

HAT and LAT are Highest and Lowest Astronomical Tide. ISHW and ISLW
are Indian Spring High and Low Water. MSL is Mean Sea Level.
Levels are in metres relative to Admiralty Chart Datum.

A comparison has been made between the harmonic constants derived from the
analysis and the most recently published co-tidal chart for the region (Admiralty
Co-Tidal Chart No. 5081, 1976) and good agreement found between the two. The only
possible discrepancy occurs

| | $O_1$ | | $K_1$ | | $M_2$ | | $S_2$ | |
|---|---|---|---|---|---|---|---|---|
| Analysis | 0.18 | 101 | 0.34 | 156 | 0.05 | 79 | 0.13 | 25 |
| Chart 5081 | 0.19 | 115 | 0.39 | 156 | 0.05 | 90 | 0.11 | 29 |

in the phase of $O_1$ suggesting that the region of constant phase of $115^{\circ}$ south of
the Island of Zirku on the map is incorrect and should be reduced in phase. However,
since the phase of $K_1$ was used to obtain the correct timing of the elevation record,
the only conclusion that can be drawn between the chart and the analysis is that the
agreement is satisfactory.

The constituent $P_1$ is not included in the set of co-tidal charts and, since
it is almost the same magnitude as $M_2$, its omission may cause some deficiency in
tidal predictions which are based on harmonic constants extracted from the co-tidal
charts. It is advisable to include $P_1$ in such tidal predictions, probably by
relating $P_1$ to $K_1$ with a ratio similar to that given in Table 2.2. This ratio
however is very close to the assumed ratio used by the Admiralty Hydrographic
Office in their scheme for predictions.


2.4    SURGE LEVELS

Surge levels in the Gulf vary considerably with time of the year and will
obviously affect the accuracy of tidal predictions. The surges are often
meteorologically induced within the confines of the Gulf but it is believed that
occasionally external surges of a larger magnitude can enter from the Indian Ocean.
We have no way of determining the origin of the surges in the present data and so
they are treated statistically to give estimates of their magnitude and their
seasonal distribution.

The largest surges measured were 44cm positive and 30cm negative and, in general, had a period between two and four days. We have little idea how the Gulf responds as a whole to wind stress because only one elevation record was available but the evidence from the current meter records suggests that the response is widespread. Sea level over the whole Zirku/Zakum area would seem to respond simultaneously to wind fields over the Gulf.

A measure of the seasonal distribution of surge levels is shown in Figure 2.2 and Table 2.4. The figure shows the probability distribution and the statistics in the form of standard deviation, the maximum and the minimum for each data block given in Table 2.1. The statistics are arranged in a monthly pattern in Table 2.4 where the increase in surge activity during the winter season can clearly be seen.

TABLE 2.4.        SURGE STATISTICS

| DATE | STANDARD DEVIATION | MINIMUM | MAXIMUM |
|------|--------------------|---------|---------|
| Jan. 79 | 7.5 | -20.1 | 30.2 |
| Jan. 80 | 9.1 | -25.9 | 34.3 |
| Feb. 79 | 8.8 | -19.8 | 31.3 |
| Feb. 80 | 12.7 | -29.5 | 44.4 |
| Mar. 79 | 8.6 | -29.5 | 25.2 |
| Mar. 80 | 7.7 | -20.7 | 40.0 |
| Apr. 79 | 6.7 | -20.6 | 24.5 |
| Apr. 80 | 8.5 | -30.4 | 39.2 |
| May 79 | 5.3 | -22.3 | 17.7 |
| May 80 | 5.3 | -15.9 | 17.3 |
| June 80 | 4.2 | -11.8 | 13.0 |
| July 80 | 4.3 | -11.7 | 9.2 |
| Aug. 79 | 4.0 | -13.5 | 11.0 |
| Aug. 80 | 3.1 | - 8.6 | 13.6 |
| Sep. 79 | 2.9 | - 9.3 | 7.7 |
| Oct. 78 | 4.7 | -12.1 | 20.6 |
| Oct. 79 | 6.0 | -21.9 | 18.6 |
| Nov. 79 | 5.2 | -11.5 | 21.9 |
| Dec. 78 | 7.6 | -20.1 | 30.2 |
| Dec. 79 | 10.2 | -23.6 | 42.1 |

## 2.5   EXTREME LEVELS

The estimation of extreme total levels normally requires considerably more data than is available here. In order to provide some estimate of the expected extreme water level the surge level with a return period of 50 years has been derived from the surge probability distribution and has been added to the value

of Highest Astronomical Tide. The estimate is usually pessimistically high because a near extreme tide and extreme surge would rarely occur simultaneously. However, in this region this value might be considered a reasonable approximation to the 50 year total level because Indian Spring High Water and H.A.T. have the same magnitude and spring tides approaching H.A.T. occur more frequently than in a dominantly semi-diurnal regime.

Surge level (50 year return period)   =   65 cm

H.A.T. + 50 year surge                =   2.16 m (ACD)

## 3. CURRENTS

Current meters were deployed at 10 positions designated C1 through C10 in Figure 1.1 and a table giving a summary of the important parameters is given below

TABLE 3.1.   CURRENT METER DATA

|  | | | Instrument Depth(m) | Water Depth (m) | Data 1978 |
|---|---|---|---|---|---|
| $C_1$ | 25° 01.7N | 52° 59.8E | 8 | 26 | 8 March-18 April |
| $C_2$ | 25° 00.0N | 53° 01.3E | 19 | 24 | " |
| $C_3$ | 24° 53.5N | 53° 05.3E | 5 | 10 | 8 March-18 May |
| $C_4$ | 24° 49.0N | 53° 13.3E | 13 | 18 | " |
| $C_5$ | 24° 48.1N | 53° 23.3E | 14 | 19 | " |
| $C_6$ | 24° 45.4N | 53° 30.5E | 15 | 20 | 8 March-16 May |
| $C_7$ | 24° 54.0N | 53° 27.5E | 15 | 20 | 8 March- 8 May |
| $C_8$ | 24° 57.5N | 53° 43.3E | 14 | 19 | 9 March-17 April |
| $C_9$ | 24° 45.3N | 53° 45.0E | 7 | 12 | 9 March-16 May |
| $C_{10}$ | 24° 50.3N | 53° 36.3E | 9 | 14 | 17 April-16 May |

The data were recorded at 15 minute intervals on Aanderaa RCM4 current meters. Positions C1, C2 were near the loading platform, position C3 was near the Island of Zirku, positions C8 through C10 were in the Zakum Oilfield and positions C4 through C6 were placed along an isobath between Zirku Island and the oilfield.

In general the current meter observations were of a high quality and very few problems were encountered during the data processing. The tidal current regime is semi-diurnal in nature unlike the predominantly diurnal elevations.

From an operational point of view it would have been useful to relate the tidal streams to the tidal elevations at Zirku Island but this was not possible because of the different characteristics of the two tidal regimes.

The observational period was from 8th March 1978 to 18th May 1978 (71 days) but not all meters returned data for the full period. Table 3.1 gives the exact recording dates.

## 3.1   MEAN CURRENT FLOW AND LONG PERIOD VARIATIONS

The value of mean flow for each current meter position is the mean value over the period of observation once the tides are removed. Its value may not be the same as the mean annual flow but this cannot be estimated because of the limited length of data. Details of the mean flow at the 10 positions are given in

Table 3.2.

TABLE 3.2.          MEAN FLOW

| Position | Amplitude | Direction |
|----------|-----------|-----------|
| $c_1$ | 7.0 | 59 |
| $c_2$ | 6.8 | 61 |
| $c_3$ | 4.5 | -34 |
| $c_4$ | 2.7 | 66 |
| $c_5$ | 2.9 | 65 |
| $c_6$ | 2.8 | 49 |
| $c_7$ | 5.3 | 64 |
| $c_8$ | 8.5 | 66 |
| $c_9$ | 2.8 | -38 |
| $c_{10}$ | 2.7 | 33 |

Amplitudes are in cm/sec.  Direction in degrees relative to North

There is a fair degree of consistency in the above values which may not be apparent at first sight.  Generally the mean flow appears to be stronger at the meters placed in the north of the region namely positions C1, C2, C7 and C8 and diminishes in strength towards the south.  The amplitudes may be slightly exagerated because data from these positions were limited to the beginning of the recording period during which the mean flows were largest.  The residual flow is essentially in an ENE direction except at position C3, where it is strongly influenced by the island, and at positions C9 and C10 in the oilfield.

Variations in the mean flow exist on a monthly scale but nowhere do these exceed 5 cm/sec.  They are absorbed by the long period constituents Mm and M.f and are included in all tidal stream predictions.

## 3.2   TIDAL CURRENTS

Tidal currents constitute the dominant part of the observed currents. According to the classification scheme given in Section 2.3 the current regime is mixed but near to semi-diurnal.  The ratio $(O_1 + K_1) / (M_2 + S_2)$ is of the order of 0.6 for stations C4 through C7, C9 and C10.  The smallest diurnal currents were found at C3 near the Island and at C8 in the north of the oilfield where this ratio is less than 0.25.  The largest diurnal currents were measured at the loading platform giving a ratio of 1.1.

Tidal analyses were performed on the complete data sets from each position in 29 day subsets, which required a small overlap, to check the consistency of the

data. The data had previously been resolved along Easterly and Northerly directions to convert them to scaler quantities which are convenient for tidal analysis. The analysis of subsets could not be performed on the data from meters C1, C2, C8 or C10 because of the shortened recording period but gave satisfactory results for the remaining meters except for C4 and C6. There appeared to be a gradual reduction in the amplitude of the harmonic constants of about 30% through the latter records suggesting perhaps that the current meter rotors were subject to fouling. For this reason we chose to accept the analysis based on the first month of data from C4 and C6, which agreed with the regional characteristics of the currents better than the full analysis. For the other positions the analysis of the complete data was accepted.

The harmonic constants for the East and North component of current for each recording position are shown in Table 3.3. Tidal stream predictions have been prepared for two positions, C2 and C9 and are presented in a separate document.

Because of the semi-diurnal nature of the streams the dominant constituents are $M_2$ and $S_2$. The current do not vary greatly in magnitude over the area, the largest value of $M_2$ was 35 cm/sec at C3 and the lowest was 20 cm/sec at C8.

The current ellipses for $M_2$ and the other three major harmonic constituents show remarkable consistency throughout the region. They are illustrated in Figure 3.1. Generally speaking the major axes of the semi-diurnal constituent ellipses are aligned in an East - South - East (ESE) direction whereas those for the diurnal currents are normal to this direction. The eccentricity of the ellipses is small so there is no difficulty in selecting a preferred direction for the tidal flow.

Looking at the ellipses in more detail shows that $M_2$ and $S_2$ current ellipses rotate anticlockwise at C1 and C2 near the loading platform and are aligned between E and ESE. Those at C3 and C4 are almost rectilinear whereas the remainder, which are near the oilfield, rotate clockwise and have the ESE alignment. The change in sense of rotation is possibly because the currents in the deeper water near the loading platform are controlled by the amphidrome and the currents in the oilfield, where it is shallower, are governed by topographic effects. C10 appears to be slightly anomalous in comparison to the others in the oilfield but this may be attributable to the shortage of data from this position.

The smaller diurnal currents are equally well behaved except in the north-west of the region where there is a significant difference in amplitude between adjacent positions C1 and C2. Some difference was found between the semi-diurnal currents at these two positions but not to the same extent. However C2 was

situated between two banks which would account for an enhanced current at this position. Also it is not clear why the diurnal currents are small at C8 unless the meter was placed near and to the south of the chartered obstruction in this area in which case the diurnal streams would be in a shadow and the semi-diurnal streams would be largely unaffected. Alternatively the diurnal streams may diminish toward the north-east but since no other measurements were made in this area the cause is difficult to assess. The diurnal streams are also weak at C3 but this is likely to be caused by the effect of the island.

To give some idea of the magnitude of the currents at each position Table 3.4 has been prepared. In this table the direction of flow is relative to true North and has been taken from the semi-diurnal ellipses. The other notation is as follows

$$HAC = \text{Highest Astronomical Current}$$
$$MSC = \text{Mean Spring Current} = M_2 + S_2$$
$$MNC = \text{Mean Neap Current} = M_2 - S_2$$

Although these currents are assumed to flow along the directions given in the table, there will be an equal flow in the opposing direction. The Highest Astronomical Current is estimated from the sum of the semi-diurnal constituents with an adjustment for the minor axis of the diurnal currents which flow in an orthogonal direction.

TABLE 3.4.    NON HARMONIC TERMS FOR TIDAL CURRENTS

| Position | Current Direction | MNC | MSC | HAC |
|---|---|---|---|---|
| C1 | 103 | 13.8 | 29.4 | 41.6 |
| C2 | 99 | 19.7 | 38.3 | 66.4 |
| C3 | 135 | 21.5 | 49.6 | 68.5 |
| C4 | 114 | 15.2 | 36.8 | 52.9 |
| C5 | 117 | 13.9 | 34.5 | 47.1 |
| C6 | 133 | 16.6 | 34.4 | 49.1 |
| C7 | 120 | 17.0 | 33.4 | 47.6 |
| C8 | 119 | 13.0 | 28.3 | 39.7 |
| C9 | 113 | 13.0 | 28.2 | 41.9 |
| C10 | 147 | 17.0 | 33.0 | 45.5 |

The directions are in degrees relative to true North. This table is not intended to infer that tidal currents are always in the above direction but merely that the maximum tidal currents are likely to occur in this direction.

3.3   CURRENT SURGES

Current surges are in evidence on the records from all recording sites and

are remarkably coherent throughout the area. Figure 3.2 shows a sample of the first month of data from each meter in the form of a stick diagram. The data presented here is low pass filtered to remove the tidal component of current and represents the wind induced flows in the Gulf. The records displayed in this diagram are simultaneous in time except that from position C10. For clarity the compass direction on the diagrams has been rotated through 90° so that East is vertically upwards.

Particular events can be traced at almost all meters in the area although they appear to be affected to some extent by topography and/or wind direction because they are not of equal magnitude and not in exactly corresponding directions. For example, the south-easterly flow on day 75 on meter C1 is not exactly reproduced on meter C2, although the two are in close proximity.

In general the largest flows are to be found in the north of the region at positions C1, C2, C7 and C8. At C3 the flow is smaller and largely affected by the island but the similarity in structure compared to other positions can easily be seen. The flow generally appears to be in the compass quadrant between south-east and north-east with a reverse flow between south-west and north-west. Streams normal to the coastline, i.e. in a purely north or south direction, are absent. There are, of course, components of current along these directions. The forward flow is likely to be the effect of winds over the whole Gulf which consistently blow from a NW or NNW direction but the currents are rotated by the topography and ultimately exit into the Gulf of Oman. The reverse current flow when the wind decreases is marginally weaker and persists for a longer period than the forward flow. Table 3.5 contains a summary of the components of surge current along the north and east direction in terms of the standard deviation, the maximum and minimum values experienced.

The larger flows tend to be in a direction between east and north-east except for position C3 near the island where the flow is deflected towards the south-east and is very weak. The currents round the island will be extremely variable depending on position and the effect of the island may even be felt at position C4. Table 3.6 contains details of the magnitude and direction of the maximum surge currents that were experienced.

The period during which currents were measured, March to May 1978, was not covered by elevation measurements. However the measurements were made during the season when elevation surges were found to be largest in subsequent years. Consequently it might be reasonable to assume that they approximate the worst conditions.

TABLE 3.5.    STATISTICS OF CURRENT SURGES

| Position | North Component | | | East Component | | |
|---|---|---|---|---|---|---|
| | Standard Deviation | Min (cm/sec) | Max | Standard Deviation | Min (cm/sec) | Max |
| C1 | 6.2 | -10.7 | 17.2 | 6.9 | -13.2 | 17.0 |
| C2 | 5.9 | -16.2 | 19.7 | 9.5 | -17.4 | 23.5 |
| C3 | 2.7 | - 6.7 | 5.6 | 2.4 | - 5.2 | 5.7 |
| C4 | 1.9 | - 4.9 | 3.6 | 4.8 | - 7.5 | 14.3 |
| C5 | 1.6 | - 3.7 | 7.6 | 5.5 | - 9.4 | 16.8 |
| C6 | 2.8 | - 6.1 | 6.8 | 3.2 | - 5.1 | 10.1 |
| C7 | 2.5 | - 5.0 | 6.0 | 6.3 | -11.8 | 15.8 |
| C8 | 2.7 | - 4.8 | 6.1 | 6.9 | -11.0 | 16.2 |
| C9 | 3.7 | - 5.5 | 12.1 | 5.1 | - 9.5 | 15.4 |
| C10 | 1.4 | - 3.1 | 3.2 | 2.0 | - 3.8 | 4.4 |

TABLE 3.6.    MAXIMUM CURRENT SURGES

| Position | Magnitude (cm/sec) | Direction (Degree true) |
|---|---|---|
| C1 | 23.3 | 43 |
| C2 | 30.6 | 50 |
| C3 | 7.9 | 144 |
| C4 | 14.7 | 103 |
| C5 | 18.4 | 66 |
| C6 | 10.1 | 84 |
| C7 | 16.4 | 75 |
| C8 | 16.6 | 77 |
| C9 | 19.5 | 52 |
| C10 | 4.4 | 87 |

## 3.4   EXTREME TOTAL CURRENTS

The magnitude of the extreme total current is difficult to estimate because of the complex form of the current regime. The mean flows, although they are probably small enough to be neglected to a first order approximation, are in the direction ENE. The tidal currents are generally in an ESE/WNW direction for the semi-diurnal tide and SSW/NNE direction for the diurnal tide. The surge currents vary in direction but seem to produce maxima in the compass quadrant between NE

and SE. Surge currents also exist in the opposing quadrant but these appear to be marginally smaller in amplitude.

There is insufficient data to calculate the directional properties of the extreme currents and even to estimate the extreme current magnitude regardless of direction requires major assumptions. However, since the two dominant components of current are the semi-diurnal streams and the surge component, and these two are in roughly similar directions, an estimate of the extreme current has been obtained by adding the value of Highest Astronomical Current (Table 3.4) to an estimate of the current surge with a return period of 50 years. The results are shown in Table 3.7 where the magnitude of the maximum current observed during the period of deployment is shown for comparison. The 50 year surge current was estimated by assuming the surges are normally distributed and therefore that the 50 year surge can be obtained from the standard deviation, which is a robust statistic of the distribution, using a scaling factor of 3.6.

TABLE 3.7.     EXTREME CURRENTS

| Position | Maximum Observed Current | | Estimated Extreme Current |
|---|---|---|---|
| | cm/sec | $Dir^n$ | cm/sec |
| C1 | 46 | 77 | 76.6 |
| C2 | 71 | 71 | 106.7 |
| C3 | 66 | 311 | 81.5 |
| C4 | 51 | 100 | 71.5 |
| C5 | 52 | 113 | 67.7 |
| C6 | 44 | 336 | 64.4 |
| C7 | 48 | 108 | 72.0 |
| C8 | 49 | 101 | 66.4 |
| C9 | 49 | 277 | 64.6 |
| C10 | 48 | 5 | 54.3 |

The direction of the extreme current can only be estimated approximately to lie in the quadrant between NE and SE. The major disagreement with this direction occurs at positions C3, C6 and C9 where the maximum observed flow is in the opposite sense to the estimated extreme flow. However this is not unreasonable as these streams are dominated by tidal currents which have equal flows in both directions.

The magnitudes of the estimated extreme currents is obviously subject to large errors and again has not taken into account the probability of the maximum surge and maximum tidal current occurring together. However, the estimated extremes are intended to give an upper bound to the currents in the region and is all that can be achieved from data of three months duration.

4.    CONCLUSION

The data discussed in this report produces a coherent representation of
the propagation of tides and currents in the southern part of the Arabian Gulf
suggesting that the measured data is of a high quality.   Initially, there were
some problems identifying the absolute time of some of the elevation records but
these have been resolved and the results are consistent with measurements from the
surrounding area.

The current meter data provided good spacial coverage of the region and the
various components of current, mean flow, tidal current and surge current, appear
to have a consistent regional pattern.

The major limitation on the accuracy of the results is the duration of
data, particularly in the case of the currents.   Estimates have been made of
extreme conditions but these are unlikely to be highly accurate because of the
constraints associated with data length.   It is normal to use at least 20 years of
data to estimate extremes and even the elevation measurements are short in
comparison.

## TABLE 2.2    HARMONIC CONSTANTS FROM ELEVATIONS

INSTITUTE OF OCEANOGRAPHIC SCIENCES (BIDSTON OBSERVATORY)

HARMONIC TIDAL ANALYSIS.

PORT: ZIRKU ISLAND

LATITUDE: 24 52' 30" N

LONGITUDE: 53 05' 30" E

TIME ZONE: -0400

LENGTH: 405 DAYS

FROM: 4TH OCTOBER,1978          TO: 6TH SEPTEMBER,1980

UNITS: METRES          AO:   1.534

DATA SUPPLIED AS TABULATED HALF HOURLY HEIGHTS ON MAGNETIC TAPE
BY TOTAL

| | H | G | | H | G | | H | G | | H | G |
|---|---|---|---|---|---|---|---|---|---|---|---|
| SA | 0.048 | 138.83 | 2Q1 | 0.007 | 22.04 | O22 | 0.001 | 130.53 | MO3 | | |
| SSA | 0.056 | 47.78 | SIGMA1 | 0.009 | 150.57 | MNS2 | 0.003 | 53.50 | M3 | 0.005 | 237.42 |
| MM | 0.013 | 316.34 | Q1 | 0.025 | 85.55 | 2N2 | 0.003 | 285.16 | SO3 | 0.003 | 133.56 |
| MSF | 0.011 | 23.58 | RHO1 | 0.019 | 90.08 | MU2 | 0.008 | 56.50 | MK3 | 0.005 | 107.58 |
| MF | 0.019 | 32.61 | O1 | 0.182 | 101.20 | N2 | 0.022 | 5.49 | SK3 | 0.004 | 110.29 |
| | | | MP1 | 0.024 | 284.59 | NU2 | 0.009 | 5.91 | | | |
| | | | M1 | 0.011 | 114.70 | OP2 | 0.007 | 76.26 | MN4 | 0.004 | 103.89 |
| | | | CHI1 | 0.014 | 98.25 | M2 | 0.129 | 27.10 | M4 | 0.008 | 132.77 |
| | | | PI1 | 0.015 | 100.34 | MKS2 | 0.021 | 40.27 | SN4 | 0.001 | 121.66 |
| | | | P1 | 0.105 | 152.07 | LAMDA2 | 0.005 | 35.92 | MS4 | 0.004 | 190.51 |
| | | | S1 | 0.040 | 263.80 | L2 | 0.006 | 31.82 | MK4 | 0.002 | 115.63 |
| | | | K1 | 0.339 | 157.25 | T2 | 0.011 | 45.83 | S4 | 0.001 | 221.62 |
| | | | PSI1 | 0.031 | 18.51 | S2 | 0.060 | 34.71 | SK4 | 0.001 | 258.69 |
| | | | PHI1 | 0.029 | 177.74 | R2 | 0.007 | 93.12 | | | |
| | | | THETA1 | 0.009 | 184.09 | K2 | 0.028 | 75.57 | 2MN6 | 0.001 | 127.40 |
| | | | J1 | 0.015 | 145.21 | MSN2 | 0.002 | 212.40 | M6 | 0.002 | 134.11 |
| | | | SO1 | 0.012 | 62.43 | KJ2 | 0.001 | 126.85 | MSN6 | 0.001 | 157.10 |
| | | | OO1 | 0.013 | 223.11 | 2SM2 | 0.002 | 280.54 | 2MS6 | 0.002 | 210.52 |
| | | | | | | | | | 2MK6 | 0.001 | 215.79 |
| | | | | | | | | | 2SM6 | | |
| | | | | | | | | | MSK6 | 0.002 | 274.92 |

ADDITIONAL CONSTITUENTS FOR ZIRKU ISLAND
SPAN OF DATA FROM 4TH OCTOBER,1978          TO 6TH SEPTEMBER,1980

| | SIGMA | H | G |
|---|---|---|---|
| MA2 | 28.94304 | 0.023 | 43.05 |
| MA2* | 29.02517 | 0.016 | 176.48 |

## TABLE 3.3a     HARMONIC CONSTANTS FROM CURRENTS AT C1

INSTITUTE OF OCEANOGRAPHIC SCIENCES (BIDSTON OBSERVATORY)

HARMONIC TIDAL STREAM ANALYSIS.

    PORT: ZAKUM : METER C1 EAST/WEST COMPONENT

    LATITUDE: 25 01' 42" N

    LONGITUDE: 52 59' 48" E

    TIME ZONE: -0400

    LENGTH: 29 DAYS

    FROM: 9TH MARCH,1978          TO: 7TH APRIL,1978

    UNITS: CM/SEC        AO:    5.535

    DATA SUPPLIED AS TABULATED QUARTER HOURLY VALUES OF SPEED AND DIRECTION
    ON MAGNETIC TAPE BY TOTAL

|        | H     | G      |        | H     | G      |        | H      | G      |        | H     | G      |
|--------|-------|--------|--------|-------|--------|--------|--------|--------|--------|-------|--------|
| SA     |       |        | 2Q1    |       |        | OQ2    |        |        | MO3    | 1.323 | 140.97 |
| SSA    |       |        | SIGMA1 |       |        | MNS2   |        |        | M3     | 0.714 | 252.38 |
| MM     | 2.698 | 187.75 | Q1     | 0.784 | 95.85  | 2N2    | 0.589  | 141.08 | SO3    |       |        |
| MSF    | 3.136 | 189.92 | RHO1   |       |        | MU2    | 1.193  | 289.41 | MK3    | 1.050 | 203.53 |
| MF     |       |        | O1     | 3.080 | 195.72 | N2     | 4.427  | 141.08 | SK3    |       |        |
|        |       |        | MP1    |       |        | NU2    | 0.859  | 141.08 |        |       |        |
|        |       |        | M1     | 1.114 | 109.89 | OP2    |        |        | MN4    | 0.361 | 90.81  |
|        |       |        | CHI1   |       |        | M2     | 21.035 | 161.13 | M4     | 1.258 | 148.79 |
|        |       |        | PI1    | 0.114 | 241.21 | MKS2   |        |        | SN4    | 0.189 | 116.92 |
|        |       |        | P1     | 1.983 | 241.21 | LAMDA2 |        |        | MS4    | 0.554 | 132.60 |
|        |       |        | S1     |       |        | L2     | 0.883  | 227.57 | MK4    |       |        |
|        |       |        | K1     | 5.991 | 241.21 | T2     | 0.446  | 201.67 | S4     |       |        |
|        |       |        | PSI1   | 0.048 | 241.21 | S2     | 7.561  | 201.67 | SK4    |       |        |
|        |       |        | PHI1   | 0.084 | 241.21 | R2     |        |        |        |       |        |
|        |       |        | THETA1 |       |        | K2     | 2.057  | 201.67 | 2MN6   | 0.236 | 260.59 |
|        |       |        | J1     | 0.797 | 176.67 | MSN2   |        |        | M6     | 0.221 | 174.84 |
|        |       |        | SO1    |       |        | KJ2    |        |        | MSN6   | 0.256 | 306.55 |
|        |       |        | OO1    | 3.319 | 208.89 | 2SM2   | 0.462  | 88.11  | 2MS6   | 0.932 | 313.76 |
|        |       |        |        |       |        |        |        |        | 2MK6   |       |        |
|        |       |        |        |       |        |        |        |        | 2SM6   | 0.407 | 222.45 |
|        |       |        |        |       |        |        |        |        | MSK6   |       |        |

INSTITUTE OF OCEANOGRAPHIC SCIENCES (BIDSTON OBSERVATORY)

HARMONIC TIDAL STREAM ANALYSIS.

PORT: ZAKUM : METER C1 NORTH/SOUTH COMPONENT

LATITUDE: 25 01' 42" N

LONGITUDE: 52 59' 48" E

TIME ZONE: -0400

LENGTH: 29 DAYS

FROM: 9TH MARCH,1978          TO: 7TH APRIL,1978

UNITS: CM/SEC          AO:   3.252

DATA SUPPLIED AS TABULATED QUARTER HOURLY VALUES OF SPEED AND DIRECTION
ON MAGNETIC TAPE BY TOTAL

| | H | G | | H | G | | H | G | | H | G |
|---|---|---|---|---|---|---|---|---|---|---|---|
| SA | | | 2Q1 | | | OQ2 | | | MO3 | 0.130 | 350.05 |
| SSA | | | SIGMA1 | | | MNS2 | | | M3 | 0.204 | 253.23 |
| MM | 0.971 | 178.62 | Q1 | 2.191 | 117.20 | 2N2 | 0.152 | 208.09 | SO3 | | |
| MSF | 0.962 | 290.25 | RHO1 | | | MU2 | 0.243 | 26.35 | MK3 | 0.348 | 258.56 |
| MF | | | O1 | 7.359 | 162.59 | N2 | 1.140 | 208.09 | SK3 | | |
| | | | MP1 | | | NU2 | 0.221 | 208.09 | | | |
| | | | M1 | 1.205 | 63.84 | OP2 | | | MN4 | 0.538 | 275.75 |
| | | | CHI1 | | | M2 | 6.271 | 302.50 | M4 | 0.400 | 82.07 |
| | | | PI1 | 0.288 | 221.97 | MKS2 | | | SN4 | 0.316 | 57.03 |
| | | | P1 | 5.013 | 221.97 | LAMDA2 | | | MS4 | 0.939 | 7.87 |
| | | | S1 | | | L2 | 0.996 | 230.92 | MK4 | | |
| | | | K1 | 15.146 | 221.97 | T2 | 0.122 | 44.08 | S4 | | |
| | | | PSI1 | 0.121 | 221.97 | S2 | 2.070 | 44.08 | SK4 | | |
| | | | PHI1 | 0.212 | 221.97 | R2 | | | | | |
| | | | THETA1 | | | K2 | 0.563 | 44.08 | 2MN6 | 0.063 | 173.29 |
| | | | J1 | 1.793 | 0.52 | MSN2 | | | M6 | 0.342 | 5.53 |
| | | | SO1 | | | KJ2 | | | MSN6 | 0.077 | 158.30 |
| | | | OO1 | 3.693 | 117.79 | 2SM2 | 0.905 | 304.20 | 2MS6 | 0.808 | 319.48 |
| | | | | | | | | | 2MK6 | | |
| | | | | | | | | | 2SM6 | 0.488 | 55.05 |
| | | | | | | | | | MSK6 | | |

## TABLE 3.3b     HARMONIC CONSTANTS FROM CURRENTS AT C2

INSTITUTE OF OCEANOGRAPHIC SCIENCES (BIDSTON OBSERVATORY)

HARMONIC TIDAL STREAM ANALYSIS.

PORT: ZAKUM : METER C2 EAST/WEST COMPONENT

LATITUDE: 25 01' 42" N

LONGITUDE: 52 59' 48" E

TIME ZONE: -0400

LENGTH: 29 DAYS

FROM: 9TH MARCH,1978          TO: 7TH APRIL,1978

UNITS: CM/SEC          AO:   5.443

DATA SUPPLIED AS TABULATED QUARTER HOURLY VALUES OF SPEED AND DIRECTION
ON MAGNETIC TAPE BY TOTAL

| | H | G | | H | G | | H | G | | H | G |
|---|---|---|---|---|---|---|---|---|---|---|---|
| SA | | | 2Q1 | | | OQ2 | | | MO3 | 2.249 | 160.64 |
| SSA | | | SIGMA1 | | | MNS2 | | | M3 | 0.227 | 310.18 |
| MM | 3.140 | 177.73 | Q1 | 3.571 | 210.01 | 2N2 | 0.642 | 149.57 | SO3 | | |
| MSF | 6.596 | 187.43 | RHO1 | | | MU2 | 3.000 | 280.77 | MK3 | 1.162 | 179.92 |
| MF | | | O1 | 7.211 | 213.56 | N2 | 4.830 | 149.57 | SK3 | | |
| | | | MP1 | | | NU2 | 0.937 | 149.57 | | | |
| | | | M1 | 2.114 | 159.71 | OP2 | | | MN4 | 0.821 | 166.79 |
| | | | CHI1 | | | M2 | 28.827 | 162.95 | M4 | 1.816 | 96.20 |
| | | | PI1 | 0.317 | 268.43 | MKS2 | | | SN4 | 0.113 | 10.16 |
| | | | P1 | 5.515 | 268.43 | LAMDA2 | | | MS4 | 0.602 | 228.50 |
| | | | S1 | | | L2 | 1.342 | 207.19 | MK4 | | |
| | | | K1 | 16.653 | 268.43 | T2 | 0.531 | 210.62 | S4 | | |
| | | | PSI1 | 0.133 | 268.43 | S2 | 9.001 | 210.62 | SK4 | | |
| | | | PHI1 | 0.233 | 268.43 | R2 | | | | | |
| | | | THETA1 | | | K2 | 2.448 | 210.62 | 2MN6 | 0.640 | 279.91 |
| | | | J1 | 1.059 | 154.66 | MSN2 | | | M6 | 0.808 | 307.30 |
| | | | SO1 | | | KJ2 | | | MSN6 | 0.241 | 333.59 |
| | | | OO1 | 2.221 | 106.87 | 2SM2 | 0.492 | 319.60 | 2MS6 | 1.459 | 341.19 |
| | | | | | | | | | 2MK6 | | |
| | | | | | | | | | 2SM6 | 0.658 | 359.84 |
| | | | | | | | | | MSK6 | | |

INSTITUTE OF OCEANOGRAPHIC SCIENCES (BIDSTON OBSERVATORY)

HARMONIC TIDAL STREAM ANALYSIS.

PORT: ZAKUM : METER C2 NORTH/SOUTH COMPONENT

LATITUDE: 25 00' 00" N

LONGITUDE: 53 01' 18" E

TIME ZONE: -0400

LENGTH: 29 DAYS

FROM: 9TH MARCH,1978          TO: 7TH APRIL,1978

UNITS: CM/SEC          AO:    3.273


DATA SUPPLIED AS TABULATED QUARTER HOURLY VALUES OF SPEED AND DIRECTION
ON MAGNETIC TAPE BY TOTAL

| | H | G | | H | G | | H | G | | H | G |
|---|---|---|---|---|---|---|---|---|---|---|---|
| SA | | | 2Q1 | | | OQ2 | | | MO3 | 3.807 | 318.76 |
| SSA | | | SIGMA1 | | | MNS2 | | | M3 | 0.494 | 1.32 |
| MM | 2.729 | 149.91 | Q1 | 4.864 | 135.10 | 2N2 | 0.296 | 246.60 | SO3 | | |
| MSF | 1.474 | 68.27 | RHO1 | | | MU2 | 1.947 | 138.10 | MK3 | 2.427 | 5.23 |
| MF | | | O1 | 13.072 | 149.61 | N2 | 2.226 | 246.60 | SK3 | | |
| | | | MP1 | | | NU2 | 0.432 | 246.60 | | | |
| | | | M1 | 2.008 | 20.03 | OP2 | | | MN4 | 0.877 | 3.55 |
| | | | CHI1 | | | M2 | 6.651 | 295.48 | M4 | 2.120 | 29.24 |
| | | | PI1 | 0.531 | 210.51 | MKS2 | | | SN4 | 1.642 | 92.86 |
| | | | P1 | 9.252 | 210.51 | LAMDA2 | | | MS4 | 0.878 | 6.71 |
| | | | S1 | | | L2 | 0.557 | 326.85 | MK4 | | |
| | | | K1 | 27.953 | 210.51 | T2 | 0.136 | 88.05 | S4 | | |
| | | | PSI1 | 0.224 | 210.51 | S2 | 2.299 | 88.05 | SK4 | | |
| | | | PHI1 | 0.391 | 210.51 | R2 | | | | | |
| | | | THETA1 | | | K2 | 0.625 | 88.05 | 2MN6 | 0.210 | 271.26 |
| | | | J1 | 1.203 | 315.59 | MSN2 | | | M6 | 0.907 | 312.49 |
| | | | SO1 | | | KJ2 | | | MSN6 | 0.287 | 24.91 |
| | | | OO1 | 0.879 | 64.42 | 2SM2 | 0.771 | 261.59 | 2MS6 | 0.520 | 190.72 |
| | | | | | | | | | 2MK6 | | |
| | | | | | | | | | 2SM6 | 0.752 | 340.55 |
| | | | | | | | | | MSK6 | | |

## TABLE 3.3c     HARMONIC CONSTANTS FROM CURRENTS AT C3

INSTITUTE OF OCEANOGRAPHIC SCIENCES (BIDSTON OBSERVATORY)

HARMONIC TIDAL STREAM ANALYSIS.

PORT: ZAKUM : METER C3 EAST/WEST COMPONENT

LATITUDE: 25 01' 42" N

LONGITUDE: 52 59' 48" E

TIME ZONE: -0400

LENGTH: 3*29 DAYS

FROM: 9TH MARCH,1978          TO: 7TH APRIL,1978

UNITS: CM/SEC          AO:    2.554

DATA SUPPLIED AS TABULATED QUARTER HOURLY VALUES OF SPEED AND DIRECTION
ON MAGNETIC TAPE BY TOTAL

|        | H      | G      |        | H     | G      |        | H      | G      |       | H     | G      |
|--------|--------|--------|--------|-------|--------|--------|--------|--------|-------|-------|--------|
| SA     |        |        | 2Q1    |       |        | OQ2    |        |        | MO3   | 0.923 | 249.02 |
| SSA    |        |        | SIGMA1 |       |        | MNS2   |        |        | M3    | 0.487 | 14.66  |
| MM     | 1.330  | 204.48 | Q1     | 2.282 | 187.87 | 2N2    | 0.654  | 109.75 | SO3   |       |        |
| MSF    | 3.880  | 203.22 | RHO1   |       |        | MU2    | 1.962  | 262.95 | MK3   | 2.816 | 263.19 |
| MF     |        |        | O1     | 7.066 | 203.41 | N2     | 4.918  | 109.75 | SK3   |       |        |
|        |        |        | MP1    |       |        | NU2    | 0.954  | 109.75 |       |       |        |
|        |        |        | M1     | 1.430 | 131.33 | OP2    |        |        | MN4   | 0.778 | 253.96 |
|        |        |        | CHI1   |       |        | M2     | 24.710 | 140.85 | M4    | 0.803 | 242.55 |
|        |        |        | PI1    | 0.043 | 210.71 | MKS2   |        |        | SN4   | 0.392 | 333.58 |
|        |        |        | P1     | 0.744 | 210.71 | LAMDA2 |        |        | MS4   | 1.508 | 269.63 |
|        |        |        | S1     |       |        | L2     | 1.253  | 168.98 | MK4   |       |        |
|        |        |        | K1     | 2.249 | 210.71 | T2     | 0.563  | 183.07 | S4    |       |        |
|        |        |        | PSI1   | 0.018 | 210.73 | S2     | 9.542  | 183.07 | SK4   |       |        |
|        |        |        | PHI1   | 0.032 | 210.72 | R2     |        |        |       |       |        |
|        |        |        | THETA1 |       |        | K2     | 2.595  | 183.07 | 2MN6  | 0.103 | 29.22  |
|        |        |        | J1     | 0.659 | 285.70 | MSN2   |        |        | M6    | 0.175 | 313.20 |
|        |        |        | SO1    |       |        | KJ2    |        |        | MSN6  | 0.112 | 170.71 |
|        |        |        | OO1    | 2.054 | 313.53 | 2SM2   | 0.494  | 18.97  | 2MS6  | 0.386 | 299.67 |
|        |        |        |        |       |        |        |        |        | 2MK6  |       |        |
|        |        |        |        |       |        |        |        |        | 2SM6  | 0.241 | 21.28  |
|        |        |        |        |       |        |        |        |        | MSK6  |       |        |

INSTITUTE OF OCEANOGRAPHIC SCIENCES (BIDSTON OBSERVATORY)

HARMONIC TIDAL STREAM ANALYSIS.

PORT: ZAKUM : METER C3 NORTH/SOUTH COMPONENT

LATITUDE: 24 53' 30" N

LONGITUDE: 53 05' 15" E

TIME ZONE: -0400

LENGTH: 3*29 DAYS

FROM: 9TH MARCH,1978          TO: 16TH MAY,1978

UNITS: CM/SEC          AO:    3.655

DATA SUPPLIED AS TABULATED QUARTER HOURLY VALUES OF SPEED AND DIRECTION
ON MAGNETIC TAPE BY TOTAL

|        | H     | G     |         | H     | G      |        | H      | G      |       | H     | G      |
|--------|-------|-------|---------|-------|--------|--------|--------|--------|-------|-------|--------|
| SA     |       |       | 2Q1     |       |        | OQ2    |        |        | MO3   | 1.268 | 146.08 |
| SSA    |       |       | SIGMA1  |       |        | MNS2   |        |        | M3    | 0.667 | 200.22 |
| MM     | 2.475 | 30.68 | Q1      | 1.556 | 339.93 | 2N2    | 0.586  | 292.58 | SO3   |       |        |
| MSF    | 5.782 | 38.83 | RHO1    |       |        | MU2    | 1.975  | 73.69  | MK3   | 3.103 | 109.50 |
| MF     |       |       | O1      | 4.075 | 26.21  | N2     | 4.407  | 292.58 | SK3   |       |        |
|        |       |       | MP1     |       |        | NU2    | 0.855  | 292.58 |       |       |        |
|        |       |       | M1      | 1.548 | 330.81 | OP2    |        |        | MN4   | 1.198 | 42.75  |
|        |       |       | CHI1    |       |        | M2     | 23.511 | 322.00 | M4    | 1.893 | 41.64  |
|        |       |       | PI1     | 0.049 | 147.62 | MKS2   |        |        | SN4   | 0.534 | 60.47  |
|        |       |       | P1      | 0.847 | 147.62 | LAMDA2 |        |        | MS4   | 2.351 | 90.98  |
|        |       |       | S1      |       |        | L2     | 1.513  | 349.58 | MK4   |       |        |
|        |       |       | K1      | 2.558 | 147.61 | T2     | 0.593  | 12.11  | S4    |       |        |
|        |       |       | PSI1    | 0.021 | 147.67 | S2     | 10.055 | 12.12  | SK4   |       |        |
|        |       |       | PHI1    | 0.036 | 147.58 | R2     |        |        |       |       |        |
|        |       |       | THETA1  |       |        | K2     | 2.735  | 12.12  | 2MN6  | 0.176 | 288.60 |
|        |       |       | J1      | 0.679 | 114.45 | MSN2   |        |        | M6    | 0.151 | 212.78 |
|        |       |       | SO1     |       |        | KJ2    |        |        | MSN6  | 0.110 | 327.39 |
|        |       |       | OO1     | 1.133 | 147.11 | 2SM2   | 0.394  | 0.03   | 2MS6  | 0.646 | 184.23 |
|        |       |       |         |       |        |        |        |        | 2MK6  |       |        |
|        |       |       |         |       |        |        |        |        | 2SM6  | 0.351 | 206.77 |
|        |       |       |         |       |        |        |        |        | MSK6  |       |        |

## TABLE 3.3d    HARMONIC CONSTANTS FROM CURRENTS AT C4

INSTITUTE OF OCEANOGRAPHIC SCIENCES (BIDSTON OBSERVATORY)

HARMONIC TIDAL STREAM ANALYSIS.

PORT: ZAKUM : METER C4 EAST/WEST COMPONENT

LATITUDE: 24 49' 00" N

LONGITUDE: 53 13' 18" E

TIME ZONE: -0400

LENGTH: 29 DAYS

FROM: 9TH MARCH,1978          TO: 7TH APRIL,1978

UNITS: CM/SEC          AO:    3.930

DATA SUPPLIED AS TABULATED QUARTER HOURLY VALUES OF SPEED AND DIRECTION
ON MAGNETIC TAPE BY TOTAL

|        | H     | G      |        | H      | G      |        | H      | G      |       | H     | G      |
|--------|-------|--------|--------|--------|--------|--------|--------|--------|-------|-------|--------|
| SA     |       |        | 2Q1    |        |        | OQ2    |        |        | MO3   | 0.544 | 128.24 |
| SSA    |       |        | SIGMA1 |        |        | MNS2   |        |        | M3    | 0.049 | 155.91 |
| MM     | 1.656 | 164.70 | Q1     | 0.481  | 151.71 | 2N2    | 0.680  | 139.15 | SO3   |       |        |
| MSF    | 3.145 | 201.24 | RHO1   |        |        | MU2    | 0.527  | 198.42 | MK3   | 0.509 | 187.81 |
| MF     |       |        | O1     | 4.283  | 193.05 | N2     | 5.114  | 139.15 | SK3   |       |        |
|        |       |        | MP1    |        |        | NU2    | 0.992  | 139.15 |       |       |        |
|        |       |        | M1     | 0.782  | 55.19  | OP2    |        |        | MN4   | 0.168 | 281.31 |
|        |       |        | CHI1   |        |        | M2     | 24.416 | 161.55 | M4    | 0.748 | 115.42 |
|        |       |        | PI1    | 0.199  | 227.29 | MKS2   |        |        | SN4   | 0.461 | 80.75  |
|        |       |        | P1     | 3.475  | 227.29 | LAMDA2 |        |        | MS4   | 0.333 | 333.31 |
|        |       |        | S1     |        |        | L2     | 0.795  | 180.37 | MK4   |       |        |
|        |       |        | K1     | 10.498 | 227.29 | T2     | 0.551  | 201.21 | S4    |       |        |
|        |       |        | PSI1   | 0.084  | 227.29 | S2     | 9.342  | 201.21 | SK4   |       |        |
|        |       |        | PHI1   | 0.147  | 227.29 | R2     |        |        |       |       |        |
|        |       |        | THETA1 |        |        | K2     | 2.541  | 201.21 | 2MN6  | 0.232 | 266.38 |
|        |       |        | J1     | 0.986  | 268.87 | MSN2   |        |        | M6    | 0.343 | 339.83 |
|        |       |        | SO1    |        |        | KJ2    |        |        | MSN6  | 0.267 | 5.10   |
|        |       |        | OO1    | 0.748  | 288.22 | 2SM2   | 0.258  | 49.36  | 2MS6  | 0.411 | 16.81  |
|        |       |        |        |        |        |        |        |        | 2MK6  |       |        |
|        |       |        |        |        |        |        |        |        | 2SM6  | 0.310 | 95.25  |
|        |       |        |        |        |        |        |        |        | MSK6  |       |        |

INSTITUTE OF OCEANOGRAPHIC SCIENCES (BIDSTON OBSERVATORY)

HARMONIC TIDAL STREAM ANALYSIS.


PORT: ZAKUM : METER C4 NORTH/SOUTH COMPONENT

LATITUDE: 24 49' 00" N

LONGITUDE: 53 13' 18" E

TIME ZONE: -0400

LENGTH: 29 DAYS

FROM: 9TH MARCH,1978          TO: 7TH APRIL,1978

UNITS: CM/SEC          AO:   0.567


DATA SUPPLIED AS TABULATED QUARTER HOURLY VALUES OF SPEED AND DIRECTION
ON MAGNETIC TAPE BY TOTAL


|        | H      | G     |        | H      | G      |        | H      | G      |       | H     | G      |
|--------|--------|-------|--------|--------|--------|--------|--------|--------|-------|-------|--------|
| SA     |        |       | 2Q1    |        |        | OQ2    |        |        | MO3   | 0.591 | 318.27 |
| SSA    |        |       | SIGMA1 |        |        | MNS2   |        |        | M3    | 0.109 | 213.97 |
| MM     | 1.331  | 3.96  | Q1     | 1.552  | 87.24  | 2N2    | 0.244  | 295.09 | SO3   |       |        |
| MSF    | 2.782  | 27.18 | RHO1   |        |        | MU2    | 0.645  | 131.44 | MK3   | 0.759 | 73.53  |
| MF     |        |       | O1     | 5.314  | 146.23 | N2     | 1.831  | 295.09 | SK3   |       |        |
|        |        |       | MP1    |        |        | NU2    | 0.355  | 295.09 |       |       |        |
|        |        |       | M1     | 1.985  | 37.07  | OP2    |        |        | MN4   | 0.494 | 38.08  |
|        |        |       | CHI1   |        |        | M2     | 10.882 | 343.73 | M4    | 1.439 | 36.94  |
|        |        |       | PI1    | 0.282  | 201.06 | MKS2   |        |        | SN4   | 0.175 | 41.32  |
|        |        |       | P1     | 4.916  | 201.06 | LAMDA2 |        |        | MS4   | 0.874 | 92.31  |
|        |        |       | S1     |        |        | L2     | 0.625  | 314.25 | MK4   |       |        |
|        |        |       | K1     | 14.851 | 201.06 | T2     | 0.248  | 46.12  | S4    |       |        |
|        |        |       | PSI1   | 0.119  | 201.06 | S2     | 4.202  | 46.12  | SK4   |       |        |
|        |        |       | PHI1   | 0.208  | 201.06 | R2     |        |        |       |       |        |
|        |        |       | THETA1 |        |        | K2     | 1.143  | 46.12  | 2MN6  | 0.203 | 204.99 |
|        |        |       | J1     | 0.474  | 313.69 | MSN2   |        |        | M6    | 0.082 | 113.04 |
|        |        |       | SO1    |        |        | KJ2    |        |        | MSN6  | 0.121 | 231.43 |
|        |        |       | OO1    | 0.890  | 209.57 | 2SM2   | 0.651  | 238.54 | 2MS6  | 0.230 | 270.54 |
|        |        |       |        |        |        |        |        |        | 2MK6  |       |        |
|        |        |       |        |        |        |        |        |        | 2SM6  | 0.286 | 288.11 |
|        |        |       |        |        |        |        |        |        | MSK6  |       |        |

# TABLE 3.3e     HARMONIC CONSTANTS FROM CURRENTS AT C5

INSTITUTE OF OCEANOGRAPHIC SCIENCES (BIDSTON OBSERVATORY)

HARMONIC TIDAL STREAM ANALYSIS.

PORT: ZAKUM : METER C5 EAST/WEST COMPONENT

LATITUDE: 24 48' 06" N

LONGITUDE: 53 23' 18" E

TIME ZONE: -0400

LENGTH: 3*29 DAYS

FROM: 9TH MARCH,1978          TO: 16TH MAY,1978

UNITS: CM/SEC          AO:     2.538


DATA SUPPLIED AS TABULATED QUARTER HOURLY VALUES OF SPEED AND DIRECTION
ON MAGNETIC TAPE BY TOTAL

| | H | G | | H | G | | H | G | | H | G |
|---|---|---|---|---|---|---|---|---|---|---|---|
| SA | | | 2Q1 | | | OQ2 | | | MO3 | 0.452 | 182.15 |
| SSA | | | SIGMA1 | | | MNS2 | | | M3 | 0.235 | 320.51 |
| MM | 1.204 | 218.69 | Q1 | 1.025 | 192.17 | 2N2 | 0.462 | 150.05 | SO3 | | |
| MSF | 1.378 | 149.52 | RHO1 | | | MU2 | 0.726 | 320.49 | MK3 | 0.699 | 148.44 |
| MF | | | O1 | 3.191 | 204.18 | N2 | 3.472 | 150.06 | SK3 | | |
| | | | MP1 | | | NU2 | 0.674 | 150.06 | | | |
| | | | M1 | 0.551 | 224.04 | OP2 | | | MN4 | 0.303 | 25.92 |
| | | | CHI1 | | | M2 | 20.783 | 167.24 | M4 | 0.460 | 99.60 |
| | | | PI1 | 0.118 | 233.55 | MKS2 | | | SN4 | 0.142 | 55.13 |
| | | | P1 | 2.351 | 233.55 | LAMDA2 | | | MS4 | 0.259 | 143.69 |
| | | | S1 | | | L2 | 0.671 | 218.79 | MK4 | | |
| | | | K1 | 6.196 | 233.55 | T2 | 0.501 | 210.97 | S4 | | |
| | | | PSI1 | 0.050 | 233.55 | S2 | 8.489 | 210.97 | SK4 | | |
| | | | PHI1 | 0.087 | 233.52 | R2 | | | | | |
| | | | THETA1 | | | K2 | 2.309 | 210.97 | 2MN6 | 0.335 | 326.57 |
| | | | J1 | 0.404 | 108.72 | MSN2 | | | M6 | 0.427 | 316.43 |
| | | | SO1 | | | KJ2 | | | MSN6 | 0.125 | 27.72 |
| | | | OO1 | 1.410 | 206.47 | 2SM2 | 0.234 | 194.59 | 2MS6 | 0.631 | 27.77 |
| | | | | | | | | | 2MK6 | | |
| | | | | | | | | | 2SM6 | 0.454 | 117.13 |
| | | | | | | | | | MSK6 | | |

INSTITUTE OF OCEANOGRAPHIC SCIENCES (BIDSTON OBSERVATORY)

HARMONIC TIDAL STREAM ANALYSIS.

PORT: ZAKUM : METER C5 NORTH/SOUTH COMPONENT

LATITUDE: 24 48' 06" N

LONGITUDE: 53 23' 18" E

TIME ZONE: -0400

LENGTH: 3*29 DAYS

FROM: 9TH MARCH,1978          TO: 16TH MAY,1978

UNITS: CM/SEC          AO:   1.176


DATA SUPPLIED AS TABULATED QUARTER HOURLY VALUES OF SPEED AND DIRECTION
ON MAGNETIC TAPE BY TOTAL

| | H | G | | H | G | | H | G | | H | G |
|---|---|---|---|---|---|---|---|---|---|---|---|
| SA | | | 2Q1 | | | OQ2 | | | MO3 | 0.797 | 304.06 |
| SSA | | | SIGMA1 | | | MNS2 | | | M3 | 0.537 | 182.64 |
| MM | 0.451 | 300.27 | Q1 | 1.216 | 124.52 | 2N2 | 0.121 | 0.75 | SO3 | | |
| MSF | 0.511 | 34.49 | RHO1 | | | MU2 | 0.743 | 108.99 | MK3 | 0.816 | 355.29 |
| MF | | | O1 | 5.545 | 137.31 | N2 | 0.910 | 0.75 | SK3 | | |
| | | | MP1 | | | NU2 | 0.176 | 0.75 | | | |
| | | | M1 | 0.533 | 34.62 | OP2 | | | MN4 | 0.353 | 5.74 |
| | | | CHI1 | | | M2 | 10.805 | 14.41 | M4 | 1.132 | 57.32 |
| | | | PI1 | 0.193 | 208.63 | MKS2 | | | SN4 | 0.167 | 93.62 |
| | | | P1 | 3.372 | 208.63 | LAMDA2 | | | MS4 | 0.884 | 98.14 |
| | | | S1 | | | L2 | 0.165 | 118.19 | MK4 | | |
| | | | K1 | 10.187 | 208.63 | T2 | 0.307 | 67.13 | S4 | | |
| | | | PSI1 | 0.082 | 208.63 | S2 | 5.204 | 67.13 | SK4 | | |
| | | | PHI1 | 0.142 | 208.63 | R2 | | | | | |
| | | | THETA1 | | | K2 | 1.415 | 67.13 | 2MN6 | 0.191 | 251.17 |
| | | | J1 | 0.223 | 19.09 | MSN2 | | | M6 | 0.226 | 311.30 |
| | | | SO1 | | | KJ2 | | | MSN6 | 0.024 | 70.37 |
| | | | OO1 | 1.437 | 72.23 | 2SM2 | 0.219 | 46.52 | 2MS6 | 0.404 | 294.81 |
| | | | | | | | | | 2MK6 | | |
| | | | | | | | | | 2SM6 | 0.134 | 359.64 |
| | | | | | | | | | MSK6 | | |

# TABLE 3.3f    HARMONIC CONSTANTS FROM CURRENTS AT C6

INSTITUTE OF OCEANOGRAPHIC SCIENCES (BIDSTON OBSERVATORY)

HARMONIC TIDAL STREAM ANALYSIS.

PORT: ZAKUM : METER C6 EAST/WEST COMPONENT

LATITUDE: 24 45' 30" N

LONGITUDE: 53 30' 30" E

TIME ZONE: -0400

LENGTH: 29 DAYS

FROM: 9TH MARCH,1978          TO: 7TH APRIL,1978

UNITS: CM/SEC          A0:  3.554

DATA SUPPLIED AS TABULATED QUARTER HOURLY VALUES OF SPEED AND DIRECTION
ON MAGNETIC TAPE BY TOTAL

|        | H     | G      |        | H     | G      |        | H      | G      |       | H     | G      |
|--------|-------|--------|--------|-------|--------|--------|--------|--------|-------|-------|--------|
| SA     |       |        | 2Q1    |       |        | OQ2    |        |        | MO3   | 1.407 | 91.90  |
| SSA    |       |        | SIGMA1 |       |        | MNS2   |        |        | M3    | 0.667 | 152.12 |
| MM     | 1.238 | 181.44 | Q1     | 0.598 | 80.23  | 2N2    | 0.444  | 115.75 | SO3   |       |        |
| MSF    | 2.357 | 193.94 | RHO1   |       |        | MU2    | 1.845  | 298.12 | MK3   | 1.147 | 75.02  |
| MF     |       |        | O1     | 0.931 | 194.17 | N2     | 3.342  | 115.75 | SK3   |       |        |
|        |       |        | MP1    |       |        | NU2    | 0.648  | 115.75 |       |       |        |
|        |       |        | M1     | 0.759 | 123.12 | OP2    |        |        | MN4   | 0.436 | 310.68 |
|        |       |        | CHI1   |       |        | M2     | 19.494 | 145.36 | M4    | 0.564 | 53.43  |
|        |       |        | PI1    | 0.091 | 214.36 | MKS2   |        |        | SN4   | 0.749 | 57.90  |
|        |       |        | P1     | 1.584 | 214.36 | LAMDA2 |        |        | MS4   | 0.286 | 293.98 |
|        |       |        | S1     |       |        | L2     | 1.831  | 154.05 | MK4   |       |        |
|        |       |        | K1     | 4.785 | 214.36 | T2     | 0.358  | 184.03 | S4    |       |        |
|        |       |        | PSI1   | 0.038 | 214.36 | S2     | 6.068  | 184.03 | SK4   |       |        |
|        |       |        | PHI1   | 0.067 | 214.36 | R2     |        |        |       |       |        |
|        |       |        | THETA1 |       |        | K2     | 1.650  | 184.03 | 2MN6  | 0.158 | 300.17 |
|        |       |        | J1     | 0.231 | 332.16 | MSN2   |        |        | M6    | 0.941 | 293.33 |
|        |       |        | SO1    |       |        | KJ2    |        |        | MSN6  | 0.302 | 317.23 |
|        |       |        | OO1    | 1.155 | 135.98 | 2SM2   | 0.173  | 137.00 | 2MS6  | 0.720 | 315.68 |
|        |       |        |        |       |        |        |        |        | 2MK6  |       |        |
|        |       |        |        |       |        |        |        |        | 2SM6  | 0.233 | 36.76  |
|        |       |        |        |       |        |        |        |        | MSK6  |       |        |

INSTITUTE OF OCEANOGRAPHIC SCIENCES (BIDSTON OBSERVATORY)

HARMONIC TIDAL STREAM ANALYSIS.

PORT: ZAKUM : METER C6 NORTH/SOUTH COMPONENT

LATITUDE: 24 45' 30" N

LONGITUDE: 53 30' 30" E

TIME ZONE: -0400

LENGTH: 29 DAYS

FROM: 9TH MARCH,1978     TO: 7TH APRIL,1978

UNITS: CM/SEC     AO: 1.523

DATA SUPPLIED AS TABULATED QUARTER HOURLY VALUES OF SPEED AND DIRECTION
ON MAGNETIC TAPE BY TOTAL

|       | H      | G      |        | H      | G      |        | H      | G      |       | H     | G      |
|-------|--------|--------|--------|--------|--------|--------|--------|--------|-------|-------|--------|
| SA    |        |        | 2Q1    |        |        | OQ2    |        |        | MO3   | 1.946 | 322.83 |
| SSA   |        |        | SIGMA1 |        |        | MNS2   |        |        | M3    | 0.319 | 66.74  |
| MM    | 0.866  | 326.07 | Q1     | 2.376  | 85.62  | 2N2    | 0.434  | 326.32 | SO3   |       |        |
| MSF   | 2.006  | 38.96  | RHO1   |        |        | MU2    | 0.795  | 35.10  | MK3   | 1.225 | 50.60  |
| MF    |        |        | O1     | 5.451  | 143.61 | N2     | 3.265  | 326.32 | SK3   |       |        |
|       |        |        | MP1    |        |        | NU2    | 0.634  | 326.32 |       |       |        |
|       |        |        | M1     | 1.725  | 28.56  | OP2    |        |        | MN4   | 0.922 | 7.56   |
|       |        |        | CHI1   |        |        | M2     | 18.381 | 354.18 | M4    | 1.489 | 53.63  |
|       |        |        | PI1    | 0.277  | 194.56 | MKS2   |        |        | SN4   | 0.261 | 115.25 |
|       |        |        | P1     | 4.818  | 194.56 | LAMDA2 |        |        | MS4   | 1.443 | 117.05 |
|       |        |        | S1     |        |        | L2     | 1.168  | 18.21  | MK4   |       |        |
|       |        |        | K1     | 14.556 | 194.56 | T2     | 0.410  | 53.32  | S4    |       |        |
|       |        |        | PSI1   | 0.115  | 194.56 | S2     | 6.946  | 53.32  | SK4   |       |        |
|       |        |        | PHI1   | 0.204  | 194.56 | R2     |        |        |       |       |        |
|       |        |        | THETA1 |        |        | K2     | 1.889  | 53.32  | 2MN6  | 0.207 | 146.05 |
|       |        |        | J1     | 1.263  | 309.58 | MSN2   |        |        | M6    | 0.619 | 161.01 |
|       |        |        | SO1    |        |        | KJ2    |        |        | MSN6  | 0.333 | 197.28 |
|       |        |        | OO1    | 1.108  | 116.70 | 2SM2   | 0.661  | 227.53 | 2MS6  | 0.912 | 220.22 |
|       |        |        |        |        |        |        |        |        | 2MK6  |       |        |
|       |        |        |        |        |        |        |        |        | 2SM6  | 0.308 | 278.42 |
|       |        |        |        |        |        |        |        |        | MSK6  |       |        |

## TABLE 3.3g     HARMONIC CONSTANTS FROM CURRENTS AT C7

INSTITUTE OF OCEANOGRAPHIC SCIENCES (BIDSTON OBSERVATORY)

HARMONIC TIDAL STREAM ANALYSIS.

PORT: ZAKUM : METER C7 EAST/WEST COMPONENT

LATITUDE: 25 54' 00" N

LONGITUDE: 53 27' 30" E

TIME ZONE: -0400

LENGTH: 2*29 DAYS

FROM: 9TH MARCH,1978          TO: 6TH MAY,1978

UNITS: CM/SEC          AO:   4.647

DATA SUPPLIED AS TABULATED QUARTER HOURLY VALUES OF SPEED AND DIRECTION
ON MAGNETIC TAPE BY TOTAL

| | H | G | | H | G | | H | G | | H | G |
|---|---|---|---|---|---|---|---|---|---|---|---|
| SA | | | 2Q1 | | | OQ2 | | | MO3 | 1.102 | 117.36 |
| SSA | | | SIGMA1 | | | MNS2 | | | M3 | 0.151 | 299.06 |
| MM | 1.509 | 203.77 | Q1 | 0.779 | 210.28 | 2N2 | 0.437 | 146.34 | SO3 | | |
| MSF | 2.949 | 179.66 | RHO1 | | | MU2 | 1.781 | 323.24 | MK3 | 0.689 | 179.28 |
| MF | | | O1 | 1.736 | 160.05 | N2 | 3.285 | 146.34 | SK3 | | |
| | | | MP1 | | | NU2 | 0.638 | 146.34 | | | |
| | | | M1 | 0.557 | 291.92 | OP2 | | | MN4 | 0.223 | 10.01 |
| | | | CHI1 | | | M2 | 21.305 | 154.24 | M4 | 1.003 | 77.73 |
| | | | PI1 | 0.103 | 222.78 | MKS2 | | | SN4 | 0.234 | 327.58 |
| | | | P1 | 1.799 | 222.78 | LAMDA2 | | | MS4 | 0.222 | 134.63 |
| | | | S1 | | | L2 | 0.440 | 115.07 | MK4 | | |
| | | | K1 | 5.435 | 222.78 | T2 | 0.436 | 190.31 | S4 | | |
| | | | PSI1 | 0.043 | 222.81 | S2 | 7.399 | 190.31 | SK4 | | |
| | | | PHI1 | 0.076 | 222.80 | R2 | | | | | |
| | | | THETA1 | | | K2 | 2.013 | 190.31 | 2MN6 | 0.039 | 238.73 |
| | | | J1 | 0.464 | 98.17 | MSN2 | | | M6 | 0.722 | 301.56 |
| | | | SO1 | | | KJ2 | | | MSN6 | 0.158 | 347.37 |
| | | | OO1 | 2.647 | 159.48 | 2SM2 | 0.320 | 106.55 | 2MS6 | 0.594 | 342.11 |
| | | | | | | | | | 2MK6 | | |
| | | | | | | | | | 2SM6 | 0.185 | 32.73 |
| | | | | | | | | | MSK6 | | |

INSTITUTE OF OCEANOGRAPHIC SCIENCES (BIDSTON OBSERVATORY)

HARMONIC TIDAL STREAM ANALYSIS.


PORT: ZAKUM : METER C7 NORTH/SOUTH COMPONENT

LATITUDE: 25 54' 00" N

LONGITUDE: 53 27' 30" E

TIME ZONE: -0400

LENGTH: 2*29 DAYS

FROM: 9TH MARCH,1978          TO: 6TH MAY,1978

UNITS: CM/SEC          AO:   2.254


DATA SUPPLIED AS TABULATED QUARTER HOURLY VALUES OF SPEED AND DIRECTION
ON MAGNETIC TAPE BY TOTAL

| | H | G | | H | G | | H | G | | H | G |
|---|---|---|---|---|---|---|---|---|---|---|---|
| SA | | | 2Q1 | | | OQ2 | | | MO3 | 1.387 | 313.03 |
| SSA | | | SIGMA1 | | | MNS2 | | | M3 | 0.460 | 195.97 |
| MM | 1.022 | 348.62 | Q1 | 1.761 | 165.86 | 2N2 | 0.136 | 343.10 | SO3 | | |
| MSF | 0.638 | 319.88 | RHO1 | | | MU2 | 0.350 | 266.25 | MK3 | 1.000 | 58.90 |
| MF | | | O1 | 5.821 | 139.97 | N2 | 1.026 | 343.07 | SK3 | | |
| | | | MP1 | | | NU2 | 0.199 | 343.06 | | | |
| | | | M1 | 1.014 | 345.45 | OP2 | | | MN4 | 0.306 | 55.46 |
| | | | CHI1 | | | M2 | 11.379 | 0.43 | M4 | 1.250 | 49.69 |
| | | | PI1 | 0.227 | 211.70 | MKS2 | | | SN4 | 0.047 | 14.42 |
| | | | P1 | 3.955 | 211.70 | LAMDA2 | | | MS4 | 0.624 | 89.02 |
| | | | S1 | | | L2 | 0.682 | 303.22 | MK4 | | |
| | | | K1 | 11.950 | 211.70 | T2 | 0.300 | 54.18 | S4 | | |
| | | | PSI1 | 0.095 | 211.70 | S2 | 5.090 | 54.18 | SK4 | | |
| | | | PHI1 | 0.167 | 211.69 | R2 | | | | | |
| | | | THETA1 | | | K2 | 1.385 | 54.18 | 2MN6 | 0.248 | 310.94 |
| | | | J1 | 1.030 | 34.06 | MSN2 | | | M6 | 0.281 | 260.85 |
| | | | SO1 | | | KJ2 | | | MSN6 | 0.059 | 2.25 |
| | | | OO1 | 3.763 | 81.04 | 2SM2 | 0.775 | 323.52 | 2MS6 | 0.566 | 273.44 |
| | | | | | | | | | 2MK6 | | |
| | | | | | | | | | 2SM6 | 0.234 | 344.64 |
| | | | | | | | | | MSK6 | | |

# TABLE 3.3h          HARMONIC CONSTANTS FROM CURRENTS AT C8

INSTITUTE OF OCEANOGRAPHIC SCIENCES (BIDSTON OBSERVATORY)

HARMONIC TIDAL STREAM ANALYSIS.

PORT: ZAKUM : METER C8 EAST/WEST COMPONENT

LATITUDE: 24 57' 30" N

LONGITUDE: 53 43' 18" E

TIME ZONE: -0400

LENGTH: 29 DAYS

FROM: 9TH MARCH,1978          TO: 7TH APRIL,1978

UNITS: CM/SEC          AO:     7.723

DATA SUPPLIED AS TABULATED QUARTER HOURLY VALUES OF SPEED AND DIRECTION
ON MAGNETIC TAPE BY TOTAL

|       | H | G |       | H | G |       | H | G |       | H | G |
|-------|-------|-------|--------|-------|-------|--------|--------|--------|-------|-------|-------|
| SA    |       |       | 2Q1    |       |       | OQ2    |        |        | MO3   | 0.307 | 319.16 |
| SSA   |       |       | SIGMA1 |       |       | MNS2   |        |        | M3    | 0.412 | 203.62 |
| MM    | 4.614 | 191.91 | Q1    | 1.126 | 178.04 | 2N2    | 0.244  | 87.75  | SO3   |       |       |
| MSF   | 5.100 | 201.89 | RHO1  |       |       | MU2    | 0.411  | 90.72  | MK3   | 0.535 | 155.84 |
| MF    |       |       | O1     | 1.291 | 264.28 | N2     | 1.835  | 87.75  | SK3   |       |       |
|       |       |       | MP1    |       |       | NU2    | 0.356  | 87.75  |       |       |       |
|       |       |       | M1     | 0.830 | 133.32 | OP2    |        |        | MN4   | 0.349 | 349.43 |
|       |       |       | CHI1   |       |       | M2     | 17.249 | 142.16 | M4    | 1.339 | 70.01 |
|       |       |       | PI1    | 0.090 | 249.17 | MKS2   |        |        | SN4   | 0.486 | 87.79 |
|       |       |       | P1     | 1.564 | 249.17 | LAMDA2 |        |        | MS4   | 0.770 | 84.19 |
|       |       |       | S1     |       |       | L2     | 1.900  | 172.68 | MK4   |       |       |
|       |       |       | K1     | 4.726 | 249.17 | T2     | 0.365  | 182.98 | S4    |       |       |
|       |       |       | PSI1   | 0.038 | 249.17 | S2     | 6.185  | 182.98 | SK4   |       |       |
|       |       |       | PHI1   | 0.066 | 249.17 | R2     |        |        |       |       |       |
|       |       |       | THETA1 |       |       | K2     | 1.682  | 182.98 | 2MN6  | 0.065 | 165.45 |
|       |       |       | J1     | 0.193 | 74.44 | MSN2   |        |        | M6    | 0.810 | 272.02 |
|       |       |       | SO1    |       |       | KJ2    |        |        | MSN6  | 0.514 | 267.85 |
|       |       |       | OO1    | 1.314 | 209.80 | 2SM2   | 0.376  | 276.02 | 2MS6  | 1.083 | 298.21 |
|       |       |       |        |       |       |        |        |        | 2MK6  |       |       |
|       |       |       |        |       |       |        |        |        | 2SM6  | 0.510 | 346.39 |
|       |       |       |        |       |       |        |        |        | MSK6  |       |       |

INSTITUTE OF OCEANOGRAPHIC SCIENCES (BIDSTON OBSERVATORY)

HARMONIC TIDAL STREAM ANALYSIS.

PORT: ZAKUM : METER C8 NORTH/SOUTH COMPONENT

LATITUDE: 24 57' 30" N

LONGITUDE: 53 43' 18" E

TIME ZONE: -0400

LENGTH: 28 DAYS

FROM: 9TH MARCH,1978          TO: 7TH APRIL,1978

UNITS: CM/SEC          AO:   3.411

DATA SUPPLIED AS TABULATED QUARTER HOURLY VALUES OF SPEED AND DIRECTION
ON MAGNETIC TAPE BY TOTAL

| | H | G | | H | G | | H | G | | H | G |
|---|---|---|---|---|---|---|---|---|---|---|---|
| SA | | | 2Q1 | | | OQ2 | | | MO3 | 0.970 | 313.23 |
| SSA | | | SIGMA1 | | | MNS2 | | | M3 | 0.599 | 165.39 |
| MM | 0.810 | 211.63 | Q1 | 1.232 | 41.98 | 2N2 | 0.040 | 324.76 | SO3 | | |
| MSF | 1.644 | 212.12 | RHO1 | | | MU2 | 1.301 | 58.64 | MK3 | 0.337 | 61.86 |
| MF | | | O1 | 1.566 | 165.02 | N2 | 0.301 | 324.76 | SK3 | | |
| | | | MP1 | | | NU2 | 0.058 | 324.76 | | | |
| | | | M1 | 1.687 | 16.37 | OP2 | | | MN4 | 0.588 | 321.85 |
| | | | CHI1 | | | M2 | 12.095 | 339.43 | M4 | 1.162 | 28.89 |
| | | | PI1 | 0.107 | 199.85 | MKS2 | | | SN4 | 0.453 | 97.12 |
| | | | P1 | 1.868 | 199.85 | LAMDA2 | | | MS4 | 0.738 | 53.07 |
| | | | S1 | | | L2 | 1.050 | 337.46 | MK4 | | |
| | | | K1 | 5.644 | 199.85 | T2 | 0.282 | 41.51 | S4 | | |
| | | | PSI1 | 0.045 | 199.85 | S2 | 4.774 | 41.51 | SK4 | | |
| | | | PHI1 | 0.079 | 199.85 | R2 | | | | | |
| | | | THETA1 | | | K2 | 1.298 | 41.51 | 2MN6 | 0.247 | 353.38 |
| | | | J1 | 1.592 | 351.69 | MSN2 | | | M6 | 0.818 | 163.86 |
| | | | SO1 | | | KJ2 | | | MSN6 | 0.390 | 177.23 |
| | | | OO1 | 0.828 | 21.62 | 2SM2 | 0.876 | 245.51 | 2MS6 | 0.666 | 172.82 |
| | | | | | | | | | 2MK6 | | |
| | | | | | | | | | 2SM6 | 0.437 | 286.90 |
| | | | | | | | | | MSK6 | | |

## TABLE 3.3i    HARMONIC CONSTANTS FROM CURRENTS AT C9

INSTITUTE OF OCEANOGRAPHIC SCIENCES (BIDSTON OBSERVATORY)

HARMONIC TIDAL STREAM ANALYSIS.

PORT: ZAKUM : METER C9 EAST/WEST COMPONENT

LATITUDE: 24 45' 18" N

LONGITUDE: 53 45' 00" E

TIME ZONE: -0400

LENGTH: 3*29 DAYS

FROM: 9TH MARCH,1978          TO: 16TH MAY,1978

UNITS: CM/SEC          AO:   1.678

DATA SUPPLIED AS TABULATED QUARTER HOURLY VALUES OF SPEED AND DIRECTION
ON MAGNETIC TAPE BY TOTAL

|  | H | G |  | H | G |  | H | G |  | H | G |
|---|---|---|---|---|---|---|---|---|---|---|---|
| SA |  |  | 2Q1 |  |  | OQ2 |  |  | MO3 | 0.806 | 342.19 |
| SSA |  |  | SIGMA1 |  |  | MNS2 |  |  | M3 | 0.302 | 162.42 |
| MM | 0.804 | 207.60 | Q1 | 2.430 | 158.26 | 2N2 | 0.656 | 109.02 | SO3 |  |  |
| MSF | 1.256 | 222.97 | RHO1 |  |  | MU2 | 0.957 | 319.75 | MK3 | 1.293 | 53.84 |
| MF |  |  | O1 | 4.280 | 165.35 | N2 | 4.932 | 109.02 | SK3 |  |  |
|  |  |  | MP1 |  |  | NU2 | 0.957 | 109.02 |  |  |  |
|  |  |  | M1 | 1.547 | 204.69 | OP2 |  |  | MN4 | 0.286 | 328.14 |
|  |  |  | CHI1 |  |  | M2 | 18.908 | 123.72 | M4 | 0.993 | 44.66 |
|  |  |  | PI1 | 0.183 | 222.71 | MKS2 |  |  | SN4 | 0.628 | 32.71 |
|  |  |  | P1 | 3.193 | 222.71 | LAMDA2 |  |  | MS4 | 0.161 | 277.45 |
|  |  |  | S1 |  |  | L2 | 0.911 | 176.54 | MK4 |  |  |
|  |  |  | K1 | 9.647 | 222.71 | T2 | 0.428 | 160.58 | S4 |  |  |
|  |  |  | PSI1 | 0.077 | 222.72 | S2 | 7.258 | 160.58 | SK4 |  |  |
|  |  |  | PHI1 | 0.135 | 222.72 | R2 |  |  |  |  |  |
|  |  |  | THETA1 |  |  | K2 | 1.974 | 160.58 | 2MN6 | 0.037 | 204.22 |
|  |  |  | J1 | 0.954 | 135.56 | MSN2 |  |  | M6 | 0.035 | 242.49 |
|  |  |  | SO1 |  |  | KJ2 |  |  | MSN6 | 0.088 | 334.45 |
|  |  |  | OO1 | 2.101 | 170.52 | 2SM2 | 0.688 | 72.42 | 2MS6 | 0.237 | 338.96 |
|  |  |  |  |  |  |  |  |  | 2MK6 |  |  |
|  |  |  |  |  |  |  |  |  | 2SM6 | 0.117 | 243.80 |
|  |  |  |  |  |  |  |  |  | MSK6 |  |  |

INSTITUTE OF OCEANOGRAPHIC SCIENCES (BIDSTON OBSERVATORY)

HARMONIC TIDAL STREAM ANALYSIS.

PORT: ZAKUM : METER C9 NORTH/SOUTH COMPONENT

LATITUDE: 24 45' 18" N

LONGITUDE: 53 45' 00" E

TIME ZONE: -0400

LENGTH: 3*29 DAYS

FROM: 9TH MARCH,1978          TO: 16TH MAY,1978

UNITS: CM/SEC          AO:   2.260

DATA SUPPLIED AS TABULATED QUARTER HOURLY VALUES OF SPEED AND DIRECTION
ON MAGNETIC TAPE BY TOTAL

|        | H     | G      |        | H     | G      |        | H     | G      |       | H     | G      |
|--------|-------|--------|--------|-------|--------|--------|-------|--------|-------|-------|--------|
| SA     |       |        | 2Q1    |       |        | OQ2    |       |        | MO3   | 0.352 | 310.94 |
| SSA    |       |        | SIGMA1 |       |        | MNS2   |       |        | M3    | 0.878 | 186.36 |
| MM     | 0.537 | 6.76   | Q1     | 1.246 | 113.31 | 2N2    | 0.316 | 341.97 | SO3   |       |        |
| MSF    | 0.909 | 244.58 | RHO1   |       |        | MU2    | 0.713 | 36.32  | MK3   | 1.042 | 28.35  |
| MF     |       |        | O1     | 2.844 | 173.11 | N2     | 2.376 | 341.97 | SK3   |       |        |
|        |       |        | MP1    |       |        | NU2    | 0.461 | 341.97 |       |       |        |
|        |       |        | M1     | 1.203 | 133.07 | OP2    |       |        | MN4   | 0.566 | 51.97  |
|        |       |        | CHI1   |       |        | M2     | 9.577 | 348.17 | M4    | 1.230 | 50.78  |
|        |       |        | PI1    | 0.120 | 211.15 | MKS2   |       |        | SN4   | 0.195 | 90.32  |
|        |       |        | P1     | 2.086 | 211.15 | LAMDA2 |       |        | MS4   | 0.787 | 94.75  |
|        |       |        | S1     |       |        | L2     | 0.628 | 71.78  | MK4   |       |        |
|        |       |        | K1     | 6.302 | 211.15 | T2     | 0.246 | 48.56  | S4    |       |        |
|        |       |        | PSI1   | 0.050 | 211.12 | S2     | 4.156 | 48.57  | SK4   |       |        |
|        |       |        | PHI1   | 0.088 | 211.18 | R2     |       |        |       |       |        |
|        |       |        | THETA1 |       |        | K2     | 1.130 | 48.57  | 2MN6  | 0.186 | 130.10 |
|        |       |        | J1     | 0.388 | 26.53  | MSN2   |       |        | M6    | 0.019 | 20.28  |
|        |       |        | SO1    |       |        | KJ2    |       |        | MSN6  | 0.301 | 172.41 |
|        |       |        | OO1    | 1.622 | 121.63 | 2SM2   | 0.176 | 315.05 | 2MS6  | 0.437 | 183.43 |
|        |       |        |        |       |        |        |       |        | 2MK6  |       |        |
|        |       |        |        |       |        |        |       |        | 2SM6  | 0.224 | 204.00 |
|        |       |        |        |       |        |        |       |        | MSK6  |       |        |

## TABLE 3.3j    HARMONIC CONSTANTS FROM CURRENTS AT C10

INSTITUTE OF OCEANOGRAPHIC SCIENCES (BIDSTON OBSERVATORY)

HARMONIC TIDAL STREAM ANALYSIS.

PORT: ZAKUM : METER C10 EAST/WEST COMPONENT

LATITUDE: 24 50' 18" N

LONGITUDE: 53 36' 03" E

TIME ZONE: -0400

LENGTH: 28 DAYS

FROM: 18TH APRIL,1978          TO: 16TH MAY,1978

UNITS: CM/SEC          AO:    1.535

DATA SUPPLIED AS TABULATED QUARTER HOURLY VALUES OF SPEED AND DIRECTION
ON MAGNETIC TAPE BY TOTAL

| | H | G | | H | G | | H | G | | H | G |
|---|---|---|---|---|---|---|---|---|---|---|---|
| SA | | | 2Q1 | | | OQ2 | | | MO3 | 0.352 | 19.93 |
| SSA | | | SIGMA1 | | | MNS2 | | | M3 | 0.755 | 187.94 |
| MM | 0.915 | 36.99 | Q1 | 1.446 | 138.48 | 2N2 | 0.455 | 82.23 | SO3 | | |
| MSF | 1.425 | 110.45 | RHO1 | | | MU2 | 0.927 | 319.46 | MK3 | 1.225 | 63.30 |
| MF | | | O1 | 5.392 | 122.97 | N2 | 3.421 | 82.23 | SK3 | | |
| | | | MP1 | | | NU2 | 0.664 | 82.23 | | | |
| | | | M1 | 0.812 | 308.74 | OP2 | | | MN4 | 0.483 | 25.18 |
| | | | CHI1 | | | M2 | 17.614 | 123.09 | M4 | 0.975 | 60.80 |
| | | | PI1 | 0.154 | 195.44 | MKS2 | | | SN4 | 0.066 | 28.10 |
| | | | P1 | 2.683 | 195.44 | LAMDA2 | | | MS4 | 0.560 | 39.50 |
| | | | S1 | | | L2 | 0.636 | 139.91 | MK4 | | |
| | | | K1 | 8.107 | 195.44 | T2 | 0.331 | 167.03 | S4 | | |
| | | | PSI1 | 0.065 | 195.44 | S2 | 5.613 | 167.03 | SK4 | | |
| | | | PHI1 | 0.114 | 195.44 | R2 | | | | | |
| | | | THETA1 | | | K2 | 1.527 | 167.03 | 2MN6 | 0.216 | 242.23 |
| | | | J1 | 0.328 | 238.90 | MSN2 | | | M6 | 0.748 | 266.58 |
| | | | SO1 | | | KJ2 | | | MSN6 | 0.605 | 275.18 |
| | | | OO1 | 2.849 | 212.55 | 2SM2 | 1.039 | 354.09 | 2MS6 | 1.015 | 330.22 |
| | | | | | | | | | 2MK6 | | |
| | | | | | | | | | 2SM6 | 0.363 | 36.35 |
| | | | | | | | | | MSK6 | | |

INSTITUTE OF OCEANOGRAPHIC SCIENCES (BIDSTON OBSERVATORY)

HARMONIC TIDAL STREAM ANALYSIS.


PORT: ZAKUM : METER C10 NORTH/SOUTH COMPONENT

LATITUDE: 24 50' 18" N

LONGITUDE: 53 36' 03" E

TIME ZONE: -0400

LENGTH: 28 DAYS

FROM: 18TH APRIL,1978        TO: 16TH MAY,1978

UNITS: CM/SEC          AO:    2.308


DATA SUPPLIED AS TABULATED QUARTER HOURLY VALUES OF SPEED AND DIRECTION
ON MAGNETIC TAPE BY TOTAL

| | H | G | | H | G | | H | G | | H | G |
|---|---|---|---|---|---|---|---|---|---|---|---|
| SA | | | 2Q1 | | | OQ2 | | | MO3 | 1.008 | 309.61 |
| SSA | | | SIGMA1 | | | MNS2 | | | M3 | 0.687 | 179.12 |
| MM | 0.794 | 210.67 | Q1 | 1.832 | 103.24 | 2N2 | 0.574 | 321.01 | SO3 | | |
| MSF | 0.991 | 255.13 | RHO1 | | | MU2 | 0.219 | 84.08 | MK3 | 1.912 | 342.70 |
| MF | | | O1 | 7.449 | 124.57 | N2 | 4.314 | 321.01 | SK3 | | |
| | | | MP1 | | | NU2 | 0.837 | 321.01 | | | |
| | | | M1 | 0.293 | 344.94 | OP2 | | | MN4 | 0.802 | 32.10 |
| | | | CHI1 | | | M2 | 22.249 | 0.57 | M4 | 1.948 | 74.78 |
| | | | PI1 | 0.252 | 184.33 | MKS2 | | | SN4 | 0.503 | 59.47 |
| | | | P1 | 4.394 | 184.33 | LAMDA2 | | | MS4 | 1.722 | 156.45 |
| | | | S1 | | | L2 | 1.459 | 2.76 | MK4 | | |
| | | | K1 | 13.276 | 184.33 | T2 | 0.446 | 61.87 | S4 | | |
| | | | PSI1 | 0.106 | 184.33 | S2 | 7.555 | 61.87 | SK4 | | |
| | | | PHI1 | 0.186 | 184.33 | R2 | | | | | |
| | | | THETA1 | | | K2 | 2.055 | 61.87 | 2MN6 | 0.236 | 179.90 |
| | | | J1 | 0.500 | 161.85 | MSN2 | | | M6 | 0.374 | 178.03 |
| | | | SO1 | | | KJ2 | | | MSN6 | 0.344 | 172.16 |
| | | | OO1 | 2.655 | 205.02 | 2SM2 | 0.799 | 220.58 | 2MS6 | 0.902 | 213.43 |
| | | | | | | | | | 2MK6 | | |
| | | | | | | | | | 2SM6 | 0.289 | 234.80 |
| | | | | | | | | | MSK6 | | |

53° 0'E          53°30'E

+ C1

25° 0'N     + C2                       25° 0'N

+ C8

ZIRKU + C3               + C7

+ C10

+ C4

+ C5

+ C6          + C9

53° 0'E          53°30'E
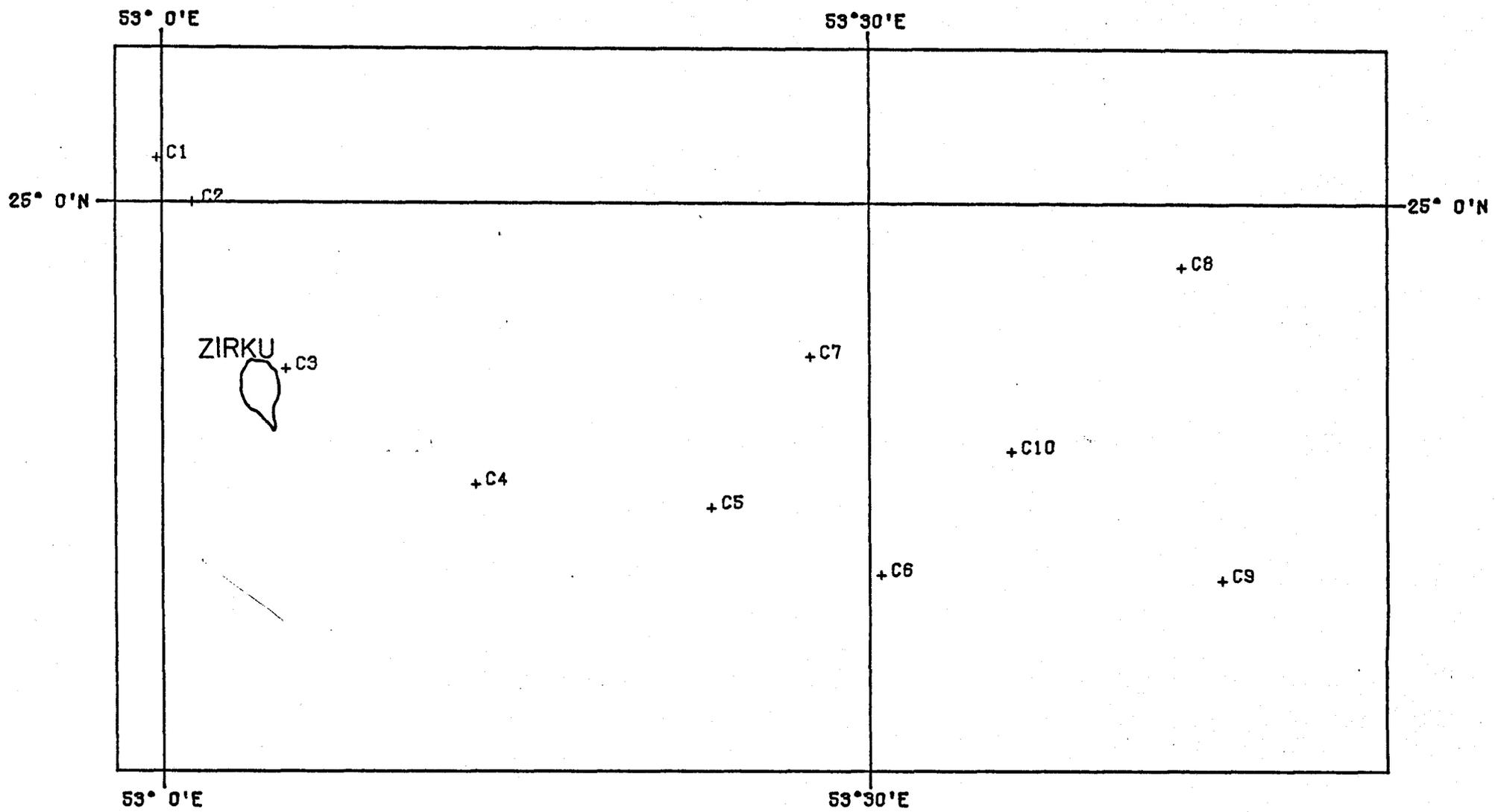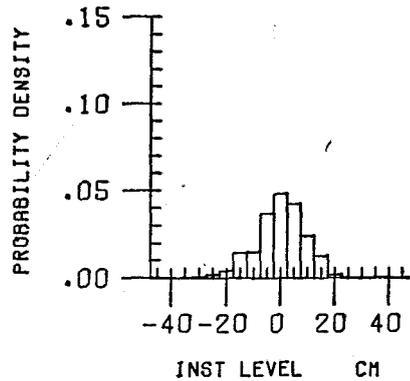
Figure I.1

BLOCK 4
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   MIN          -29.5
   MAX           25.2
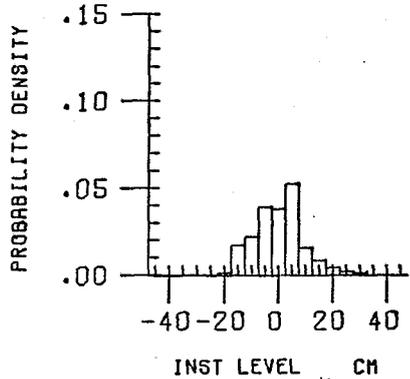
BLOCK 3
INST LEVEL       CM
   STD DEV       8.833
   MIN          -19.8
   MAX           31.3
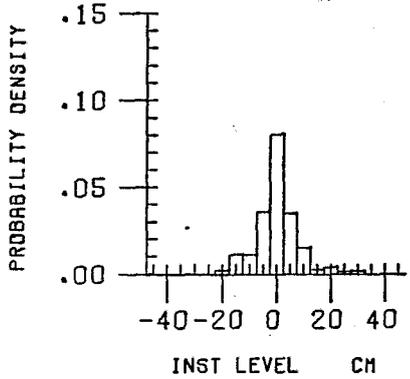
BLOCK 2
INST LEVEL       CM
   STD DEV       7.612
   MIN          -20.1
   MAX           30.2
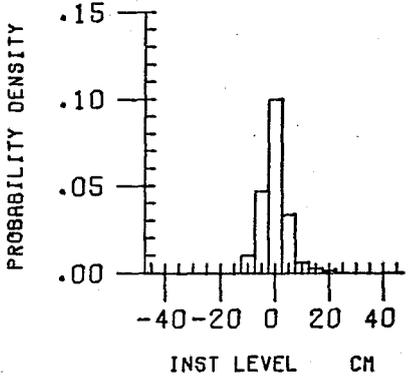
BLOCK 1
INST LEVEL       CM
   STD DEV       4.688
   MIN          -12.1
   MAX           20.6

Figure  2.2 (a)    ELEVATION  SURGE  STATISTICS
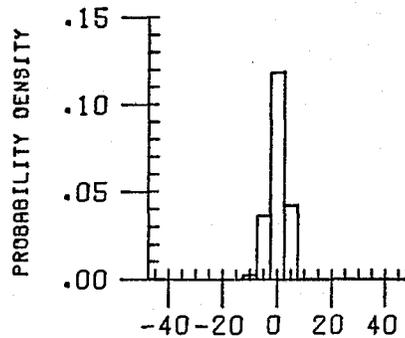
BLOCK 8
INST LEVEL       CM
  STD DEV        2.913
  MIN            -9.3
  MAX            7.7
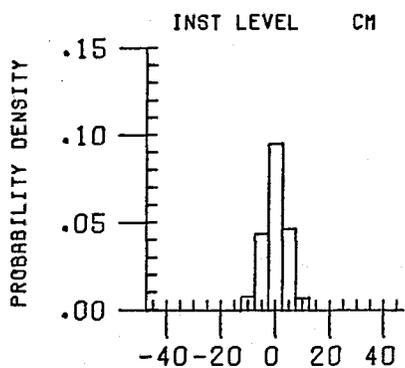
BLOCK 7
INST LEVEL       CM
  STD DEV        4.005
  MIN            -13.5
  MAX            11.0
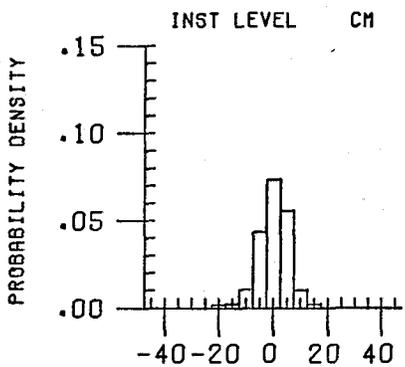
BLOCK 6
INST LEVEL       CM
  STD DEV        5.345
  MIN            -22.3
  MAX            17.7
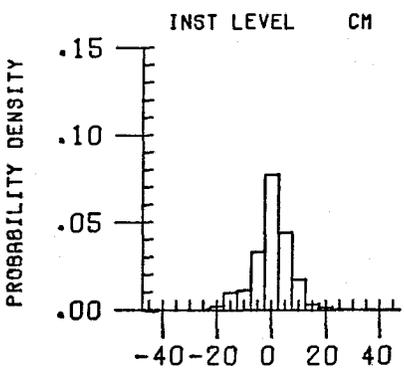
BLOCK 5
INST LEVEL       CM
  STD DEV        6.736
  MIN            -20.6
  MAX            24.5

Figure    2.2 (b)
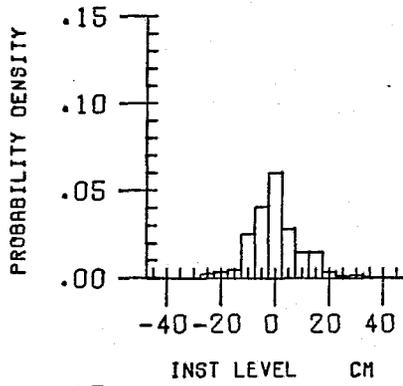
BLOCK 12
INST LEVEL    CM
  STD DEV    9.056
  MIN        -25.9
  MAX         34.3
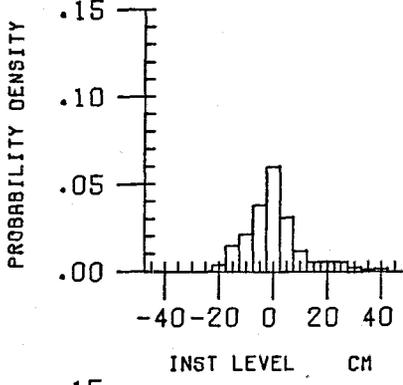
BLOCK 11
INST LEVEL    CM
  STD DEV    10.231
  MIN        -23.6
  MAX         42.1
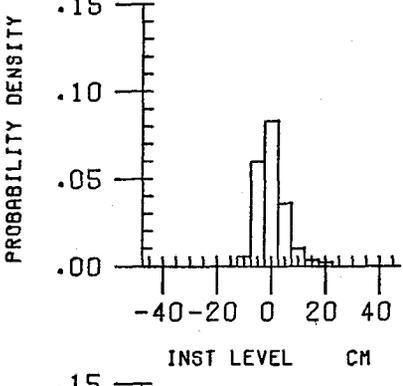
BLOCK 10
INST LEVEL    CM
  STD DEV    5.164
  MIN        -11.5
  MAX         21.9
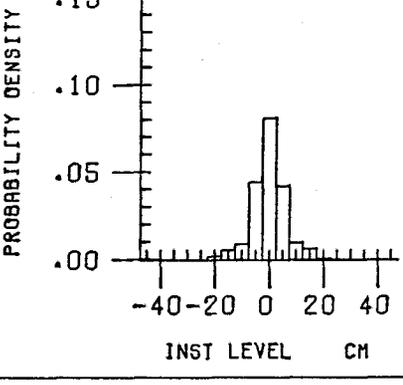
BLOCK 9
INST LEVEL    CM
  STD DEV    5.968
  MIN        -21.9
  MAX         18.6

Figure   2.2 (c)
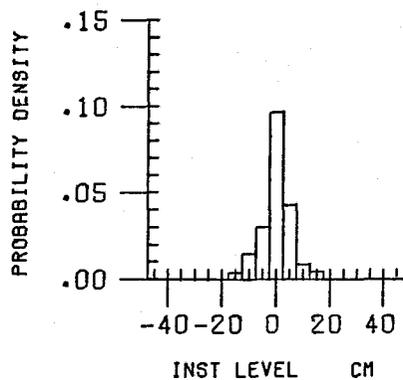
BLOCK 16
INST LEVEL     CM
  STD DEV       5.258
  MIN          -15.9
  MAX           17.3
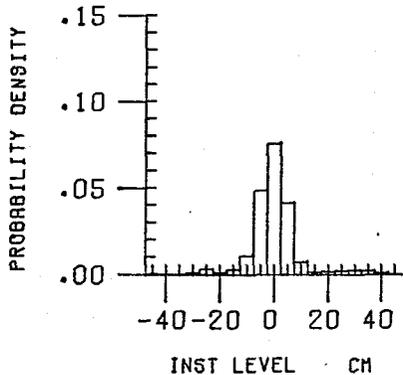
BLOCK 15
INST LEVEL     CM
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  MIN          -30.4
  MAX           39.2
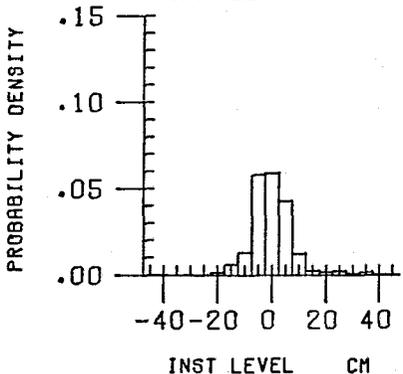
BLOCK 14
INST LEVEL     CM
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  MAX           40.0
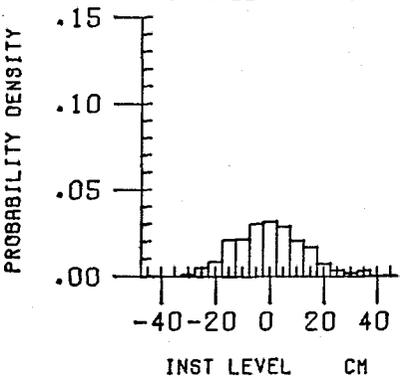
BLOCK 13
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  STD DEV      12.691
  MIN          -29.5
  MAX           44.4

Figure   2.2 ( d )
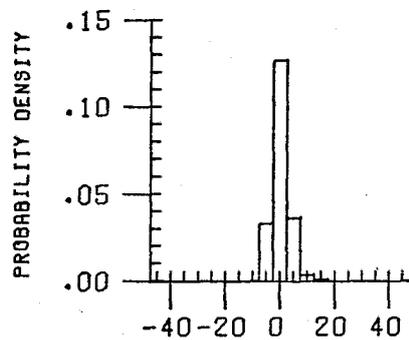
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   MIN         -8.6
   MAX          13.6
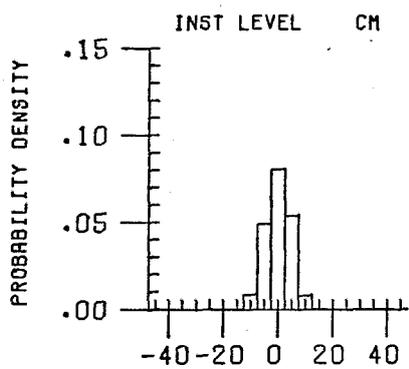
BLOCK 18
INST LEVEL      CM
   STD DEV      4.315
   MIN         -11.7
   MAX          9.2
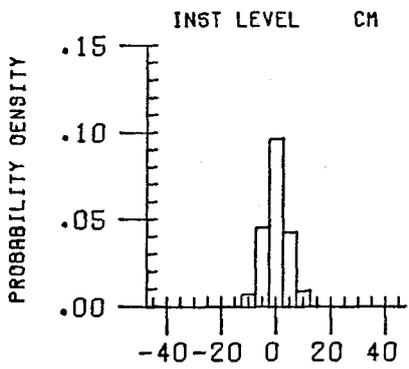
BLOCK 17
INST LEVEL      CM
   STD DEV      4.204
   MIN         -11.8
   MAX          13.0

Figure   2.2 (e)
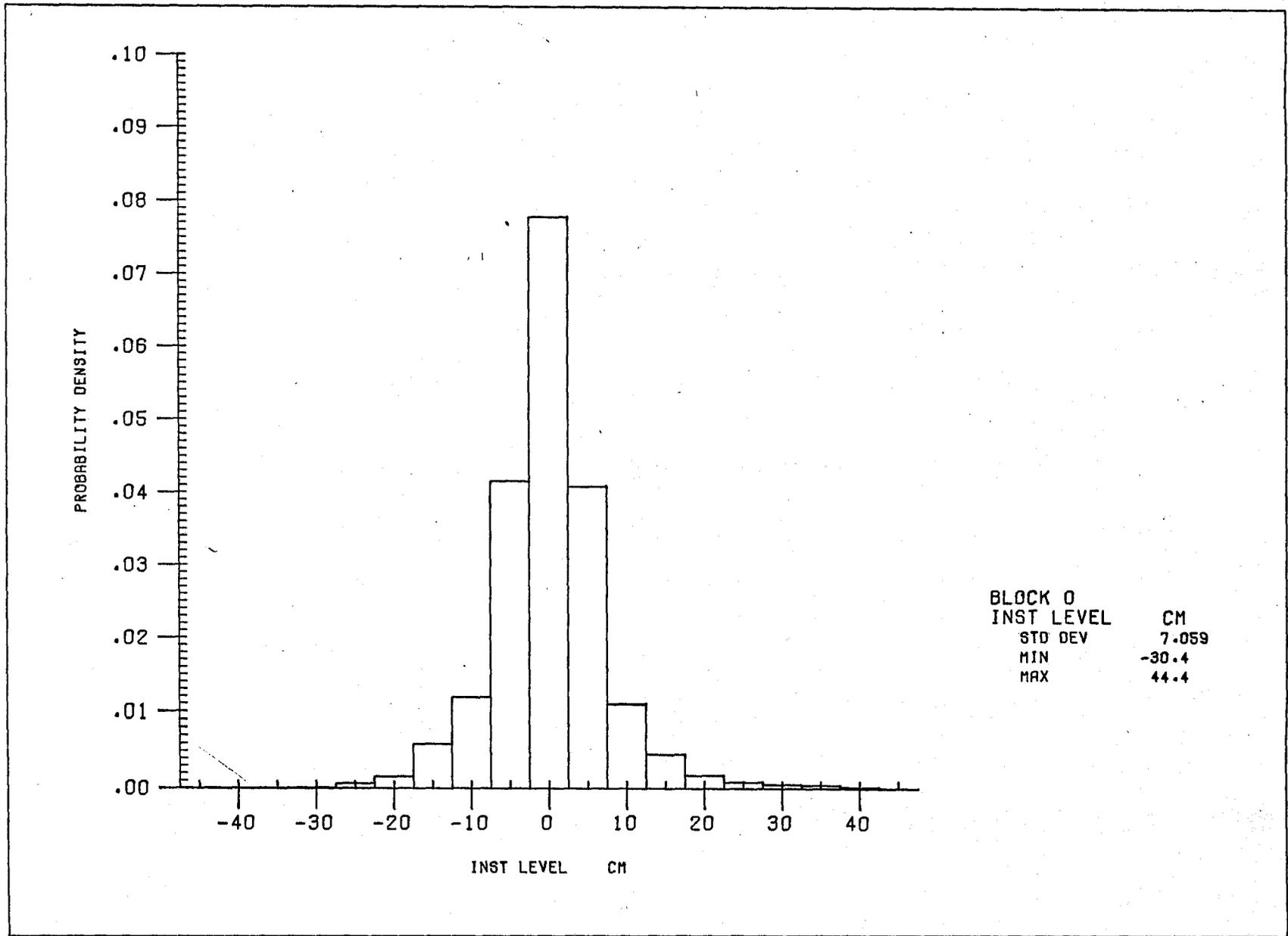
Figure 2.3    SURGE  P.D.F.  FROM  COMPLETE  DATA
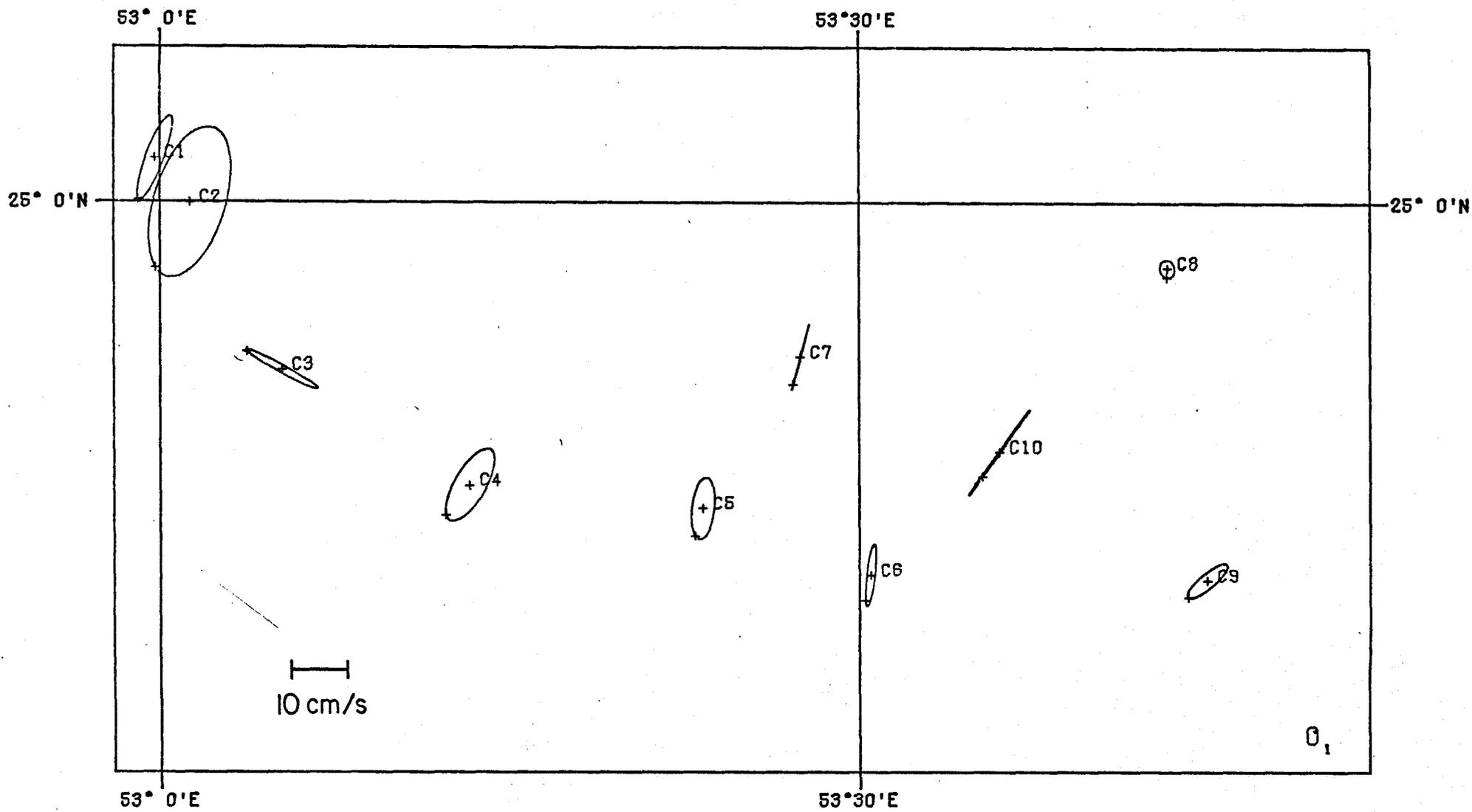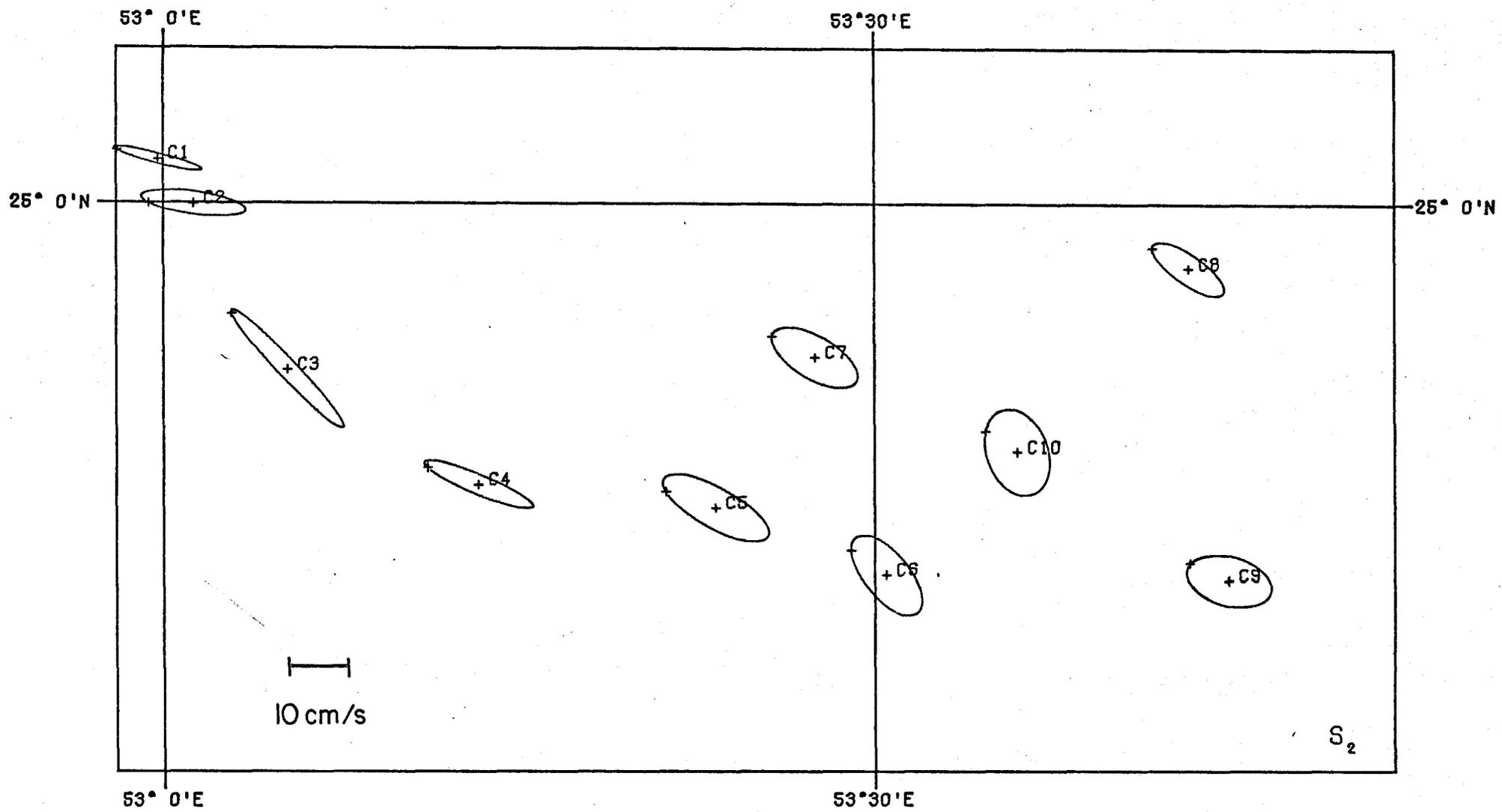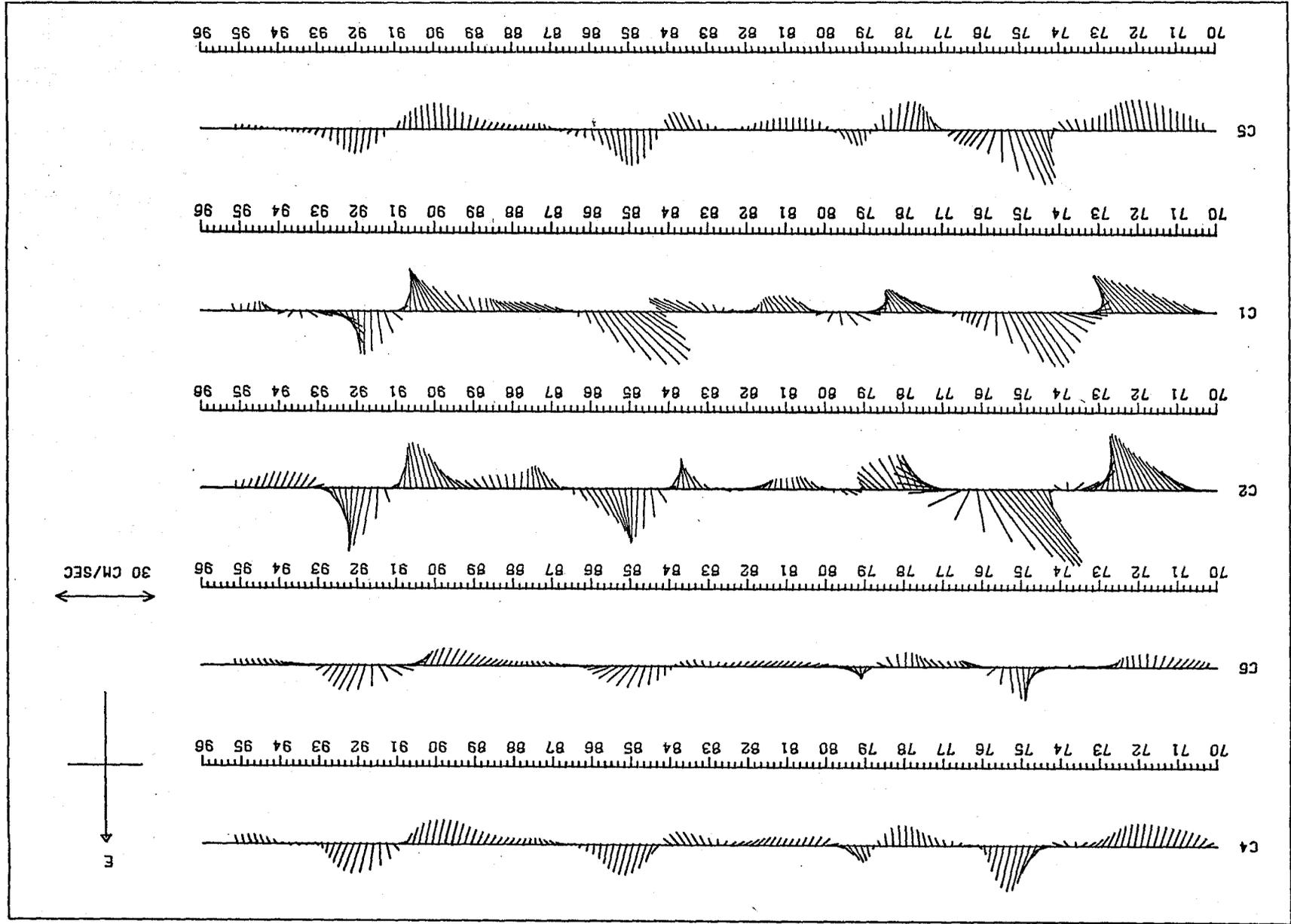
Figure 3.1(a)  CURRENT ELLIPSES
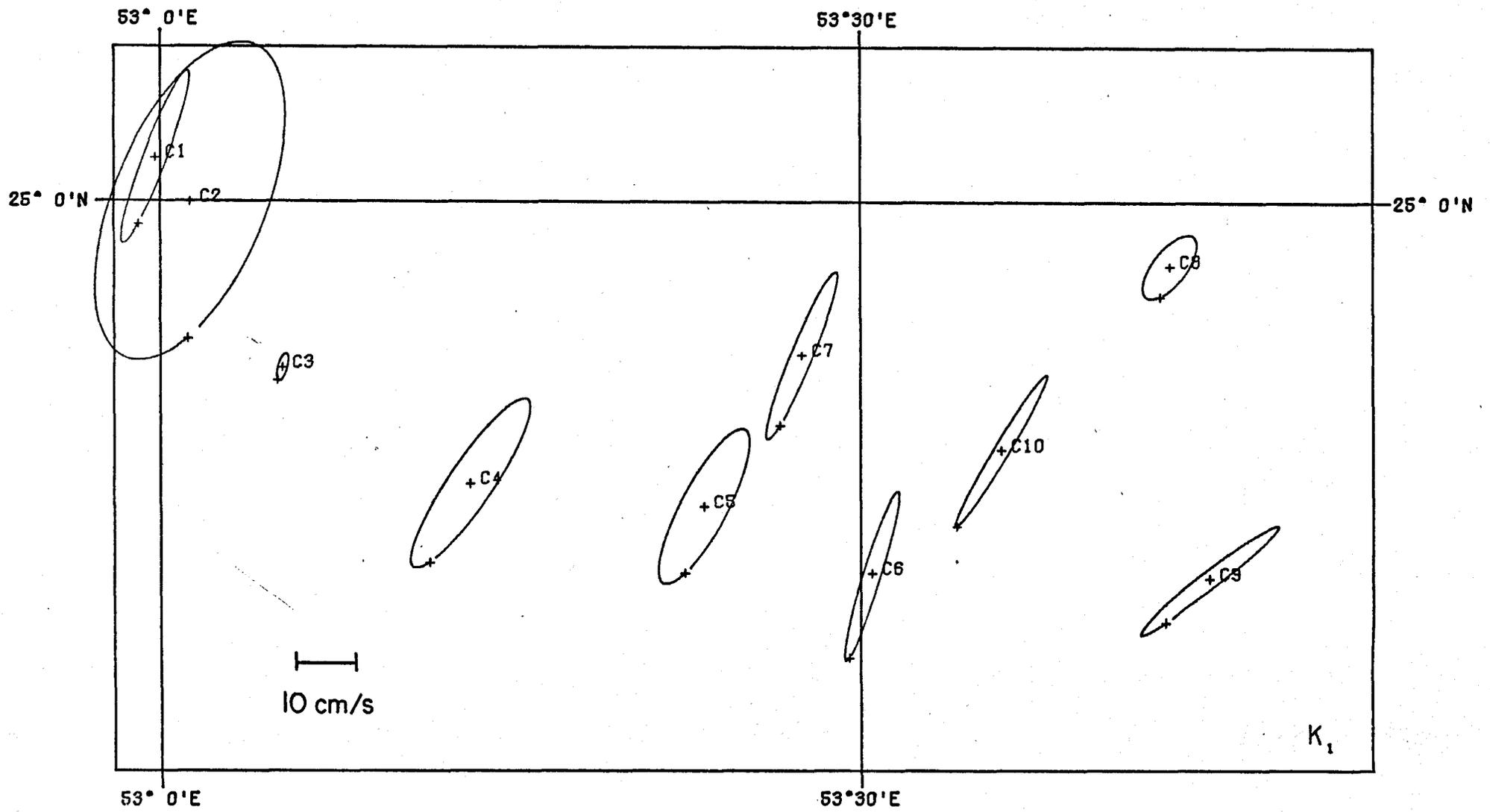
Figure 3.1(b)
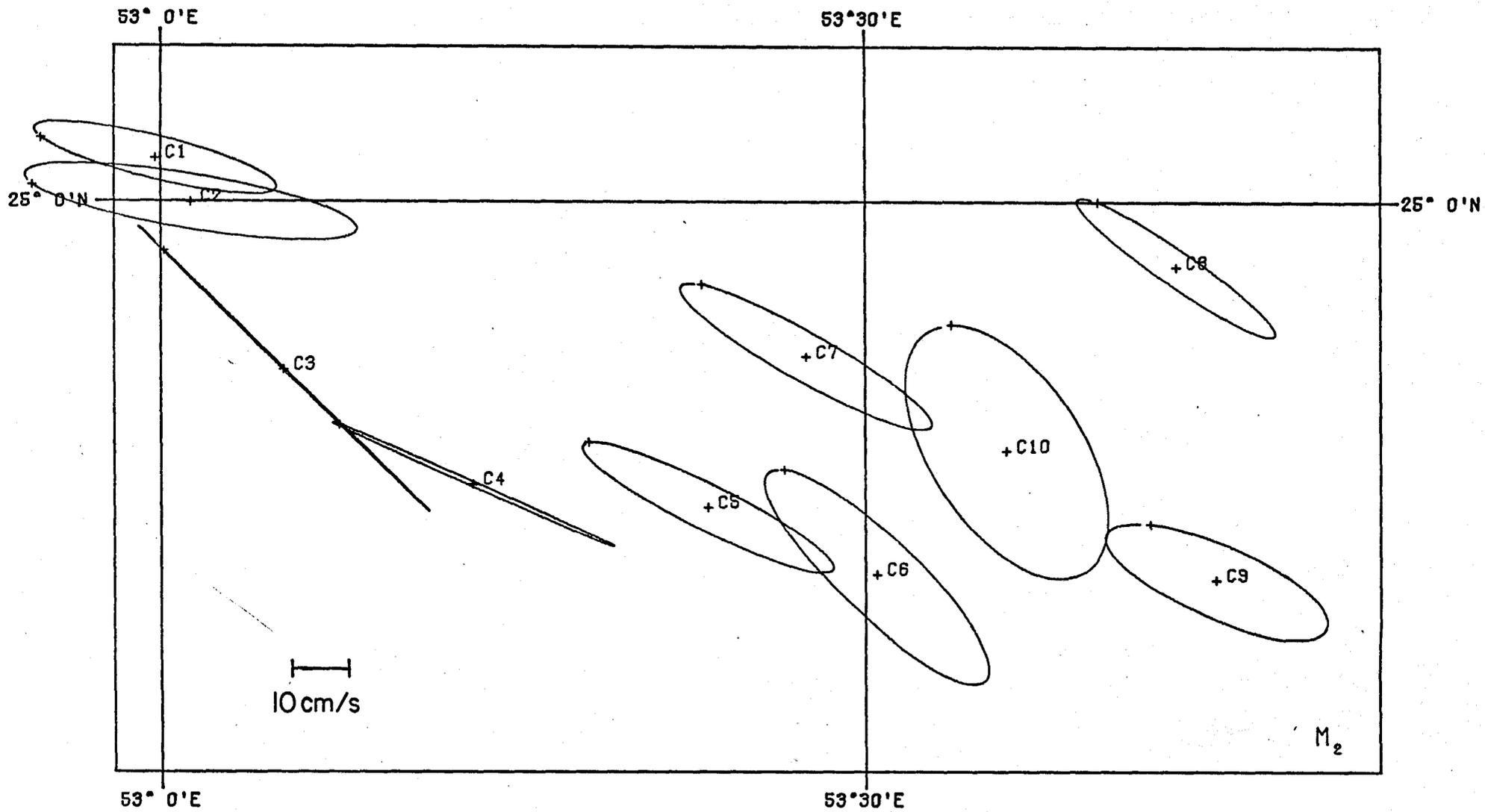
Figure 3.1(c)

Figure 3.1(d)

Figure 3.2(a)   SURGE VECTORS

Figure   3.2(b)