I.O.S.

MOORED CURRENT METER DATA FROM THE MADEIRA ABYSSAL PLAIN (GME) 1ST DEPLOYMENT (1984)

BY

P.M. SAUNDERS

REPORT NO. 221
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OCEAN DISPOSAL OF HIGH LEVEL RADIOACTIVE WASTE
A RESEARCH REPORT PREPARED FOR THE DEPARTMENT OF THE ENVIRONMENT

NATURAL ENVIRONMENT RESEARCH COUNCIL
INSTITUTE OF OCEANOGRAPHIC SCIENCES

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WORMLEY

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RADIOACTIVE WASTE MANAGEMENT

Research Programme 1985/86

DoE Report No. DoE/RW/86.010

Contract Title: Studies of large and local scale advection and dispersion relevant to the Great Meteor East location.

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Report Title: Moored Current Meter Data From the Madeira Abyssal Plain (GME), 1st Deployment (1984).

Author: P.M. SAUNDERS

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Abstract (100-200 words as desired)

Near bottom currents have been measured at three closely spaced sites in the N.E. Atlantic for 13 months. Locations were selected in the Great Meteor East study site area, near 31°30'N 25°W, one on the abyssal plain, one on top of a small abyssal hill about 400 m high and one on its flank just above the plain. Current meters were moored 10, 100, and 1000 m above the local bottom (5438 m, 5398 m and 4999 m) in January 1984 and recovered in February 1985.

This report displays the characteristics of the currents in numerous tables and figures. In the mean they are found to be very weak and though adjacent moorings are separated by only 12 km and 27 km the year-long current directions differ radically. Current variations are principally due to semi-diurnal tides, inertial oscillations and eddies the latter of which migrate over the moorings. The tidal energy meets expectations as does the eddy energy with magnitude 2-3 cm^2s^{-2}. Horizontal (isopycnal) diffusivity is estimated as about $2x10^2$ m^2s^{-1}.

Currents 10 m above the bottom exceed 10 cm/s least frequently on the plain and most frequently at the hill-foot. The influence of the hill is surprisingly large. At all three sites the strongest currents are found near the sea bed. Speeds also show a Weibull distribution and rough 50 year return currents are inferred.

Keywords: 126,299 - Ocean circulation/dispersal, DoE sponsored research

This work has been commissioned by the Department of the Environment as part of its radioactive waste management research programme. The results will be used in the formulation of Government policy, but at this stage they do not necessarily represent Government policy.

CONTENTS

PREFACE

The research described in this report is concerned with the scientific assessment of the feasibility of the disposal of heat generating radioactive waste (HGW) into the deep sea environment. It deals with the deep ocean water column and is aimed at understanding both the mechanism of and the rate of dispersion of a trace substance released from the sea bed. Interest is focussed on a fixed site [Great Meteor East - GME] near 31°30'N and 25°W where the tracer is imagined released but the dispersion of the tracer by currents requires investigation around the site too.

The Natural Environment Research Council, through the Institute of Oceanographic Sciences, has a contract with the Department of the Environment (DoE PECD 7/9/216-42/84) to complete 2 years of detailed water movements near the sea bed at the GME study site and to report on the oceanography of the area together with estimates of dispersion rates and the occurrence of strong currents.

This report summarises the results of the first year's current measurements at GME: it will be followed by a second report analysing the second deployment of instruments which have just been recovered (December 1985).

INTRODUCTION

Measurements of currents near the sea-bed in the very deep parts of N.E. Atlantic Ocean have been carried out in the past 5 years at IOS. Both moored current meters and drifting neutrally buoyant floats have been employed and the results have been reported in the literature[1]. Financial support for this work was provided by the Department of the Environment.

A new programme of measurements in the water column was started in 1984. These include observations of currents at a specific site (GME) employing moored current meters and measurements of dispersion using a group of neutrally buoyant floats drifting freely at a depth of 3000 m and tracked from acoustic listening stations. Both measurement programmes are to last at least 2 years.

After one year had elapsed (February 1985) the moorings at GME were recovered and a second deployment made. These have also been recovered (December 1985) and a third deployment made. It is planned to recover this instrumentation in August 1986 yielding a continuous record of 2.5 years length. This report describes the moored current meter data for the first year. A companion report describing profiles of the density field derived from instrumentation lowered from a ship has also been produced[2].

MOORING DESCRIPTION

Three moorings were deployed in early February 1984 from RRS Discovery on cruise 144 and were recovered on RRS Charles Darwin on cruise 1/85 in late February 1985. The moorings were approximately 1000 m high and each supported 3 Aanderaa RCM5 current meters: the mooring locations, instrument and water depths are shown in table 1 and a sketch of their disposition shown in figures 1 and 2. Each mooring had current meters nominally 10,100 and 1000 m above the bottom and was of 10 mm and 12 mm braided polyethylene construction. Each had a 300 kg chain anchor and, for buoyancy, six 17" diameter glass spheres mounted in pairs on bars. The acoustic releases, immediately above the anchor, were of IOS series '200' design. IOS mooring numbers were assigned as follows:-

365 on the PLAIN, 366 at the HILL-FOOT and 367 on the HILL-TOP. Instruments on each mooring are numbered from the top down, viz 36501 is 1000 m above bottom and 36503 just 10 m above bottom, both on mooring 365.

TABLE 1 Mooring Information

Identification	Latitude,°N	Longitude,°W	Water depth, m*	Instrument depths,m*+
365 PLAIN	31 31.3	24 45.4	5438	4343,5334,5428
366 HILL-FOOT	31 31.1	25 01.1	5398	4307,5295,5388
367 HILL-TOP	31 29.7	25 09.6	4999	3907,4906,4989

* Corrected according to Carter's tables

\+ All instruments Aanderaa RCM5

INSTRUMENTATION AND DATA QUALITY

The data were gathered with Aanderaa RCM5 current meters. The instrument casings were uncoated but painted and their end caps were manufactured to IOS specifications. Each instrument was individually calibrated for rotor speed, compass direction and temperature. The rotor stall speed is close to 1.5 cm/s (for new rotors and new bearings). The calibration data of rotor speed versus current for the nine instruments could not be distinguished and the following relation was used for all:-

$$s = 46.8\ \Omega + 1.5$$

where Ω is the number of revolutions/second and s is the current in cm/s. Each instrument had individual direction calibrations, with the pre-deployment and post-recovery calibrations agreeing within ±3°. The temperature bridge circuit was modified[11] to give a sensitivity (and accuracy) of about 2.5 mdeg C. The RCM5 data acquisition is controlled by a clock with an accuracy of ±1 second per day: given the duration of this experiment the data sample interval was selected as 1 hour.

The data recovery was generally good, 8 of the instruments furnishing year-long records of currents: the exception was 36601 (see table 2). However useful temperatures were measured on only 5 of the 9 instruments (see table 2).

TABLE 2 Duration and Quality of Records

Ident.	Depth, m	Start	End	Duration days	Comments
PLAIN					
36501	4343	30 Jan '84	23 Feb '85	390	
02	5334	"	"	"	
03	5428	"	"	"	
HILL-FOOT					
36601	4307	5 Feb '84	23 Feb '85	384	No directns, no temps
02	5295	"	"	"	Temps unreliable
03	5388	"	"	"	Speeds end 11 Jan '85
HILL-TOP					
36701	3907	6 Feb '84	5 Dec '85	303	Short
02	4906	"	23 Feb '85	384	No temps
03	4989	"	"	384	

DATA PROCESSING

Data were translated from 1/4" field tape to 1/2" computer compatible magnetic tape using a reader of IOS construction and a HP2100 computer. Subsequently processing and archiving of data was carried out on the NERC Honeywell 66/DPS 300 at Bidston.

Data were first checked for time-base errors; reconciliation was always possible after partial or repeated data cycles were recognised. Calibration data were applied for speed (see the section on Instrumentation), temperature and direction. The latter variable was converted from one of its 1024 possible values by means of a look-up table determined from approximately 20 calibration values. The correction for magnetic deviation at the field site was also made (13°W).

Temperature and direction measurements are made on the hour, and speed is the average for the hour preceding. To take account of these differences, pairs of direction and temperature values are averaged and associated with the intervening speed and all assigned a mid-hour time. Deployment and recovery transients are removed at the beginning and end of the series and outliers (bad data) replaced by absent data values. Providing data gaps are of short duration missing values can subsequently be interpolated.

Because of the very weak currents encountered at abyssal depths the rotor is commonly stalled (10-40 per cent of the time). It is IOS practice to set the current speed equal to the stall value at this time (1.5cm/s): experience shows that the difference resulting from this practice and setting the value equal to zero is very small. Most important conclusions result from the energetic events (strong currents) for which the very weak current treatment is irrelevant.

SUMMARY OF RESULTS

The mean values for the (approximately) year-long records are presented in table 3 for each of the eight (working) instruments. The currents are very weak as found in records on the abyssal plain in the N.E. Atlantic[3]. In the lowest 100 m they have quite different directions at the three sites, viz: - PLAIN - west, HILL FOOT - south and HILL TOP - east. At a height 1000 m above the bottom there is more similarity between the two records and the currents are perceptibly weker than the near-bottom measurements.

A history of the currents at the three sites is shown in figures 3 and 4. The variations in the flow are interpreted[1] as resulting from the passage of eddies which are the oceanic counterpart of atmospheric cyclones and anticyclones. Like the latter they intensify, migrate and decay. In figure 3 arrows depicting the currents with tidal components removed are shown as a time-series. The similarity between the currents at the three levels is apparent, especially on the plain (365). There are also plots of the speed (magnitude of the current) and of the temperature. The former plot highlights strong-current events and the latter reveals the very small changes found in the lowest 100 m above bottom which often have a front-like structure[4]. In figure 4 the virtual displacement of water (integration of currents) is shown for the three sites. This again reveals the similarity of the currents particularly on the plain and the differences found above the hill-top. Only at the hill foot is the current steady in direction: the direction is approximately parallel to the height contours on the flank of the hill just west of the mooring site.

TABLE 3 Record means of speed direction and temperature

Ident.	Nom. ht above bottom, m	Speed cm/s	Direction °T	Temp. °C	Duration days
PLAIN					
36501	1000	0.67	269	2.444	390
02	100	0.87	274	2.482	390
03	10	0.88	288	2.492	390
HILL-FOOT					
36601	1000	-	-	-	-
02	100	2.10	199	-	384
03	10	2.10	192	2.494	342
HILL-TOP					
36701	1000	0.30	220	2.482	303
02	100	1.30	067	-	384
03	10	1.54	085	2.439	384

STATISTICAL CHARACTERISTICS OF THE CURRENTS

Eighteen pages of the report are given up to a statistical analysis of the variability of the measurements; these are found in table 5 at the end of this volume.

Part 1 is a statistical analysis of the circa 9000 1 hourly values of the currents and temperatures. For the variables east, north, speed and temperature the mean, std. deviation, skewness, kurtosis and extremes are listed. (A Gaussian random variable has a kurtosis of 3 and a skewness of 0.) The 'uncertainty' of the mean is an estimate of the approximation of the record mean to the climatological value. If σ^2 is the variance about the mean, the uncertainty of the mean ε is calculated from the approximate expression $\varepsilon^2 = \frac{2\sigma^2 I}{T}$ where T is the record duration and I the integral time scale[5]. (I = 7 days was assumed). The covariance and correlation coefficients amongst the variables are also calculated.

Under the heading direction and variability, the principal axes of variability are prescribed. In general a plot of the current variability about the mean covers an elliptical area and the direction of maximum variance and its value are determined from expressions found in the literature[6].

TABLE 4 Prediction of semi-diurnal tidal currents from Schwiderski[7]

UNITS	cm/s	cm/s	cm/s
Component	M_2	S_2	N_2
Major axis	3.5	1.2	0.9
minor axis	1.0	0.25	0.3
ellipticity	-0.3	-0.2	-0.3
directn. N from E	050	050	045
phase, deg.	-3	19	-25

The lower section of part 1 presents the results of a tidal analysis and contains estimates of the semi-diurnal components M_2 (principal lunar), S_2 (principal solar) and N_2 (larger lunar elliptic) tides. The 'direction' is the direction of the maximum tidal current and the 'phase' is the phase of that maximum in the NE quadrant with respect to the maximum equilibrium tide at Greenwich. The data may be compared with the predictions of Schwiderski (see table 4) employing a dynamical ocean model and tide height data from island and coastal sites. The agreement is quite satisfactory. The percentage of the rotor for which the rotor is stalled is found at the bottom of Table 5 part I. The figure is generally smaller 10-100 m above the sea-bed than 1000 m above it.

Table 5 part II describes similar statistics derived from a low-pass and sub-sampled version of the data. Inertial, tidal and higher frequency internal waves are removed from the data employing a tapered cosine filter: with it the variance at 24 hrs period is reduced by only a factor of 4 but at semi-diurnal period is reduced by a factor of 10^5. The statistics of table 5 part II describe the low-frequency or eddying motions uninfluenced by tidal and inertial processes: variances and covariances are less than for the unfiltered records. The mean potential temperature (the temperature which the ocean would have if brought adiabatically to the surface pressure) is derived with the aid of CTD lowerings made on each site. Potential temperature is approximately conserved above the benthic boundarylayer.

ROTARY SPECTRA

The frequency content of the currents is revealed by spectral analysis. Since current is a vector two independent components can be prescribed. The rotary spectrum which resolves the current into clockwise and anticlockwise is a natural co-ordinate system revealng the influence of the earth's rotation. Figure 5 shows these rotary components for the unfiltered and deepest current meter record at each site. The sharp peak of the semi-diurnal tide is apparent with the broader (clockwise) inertial oscillation on its left. Throughout the internal wave band $\log_{10}(\text{freq}) > 0$ the clockwise component exceeds the anticlockwise but at lower frequencies the components have equal energy. The energy rise up to the lowest frequency indicates that the dominant eddy period exceeds 50 days.

HORIZONTAL DIFFUSION BY EDDIES

The rate of mixing of a tracer along density surfaces (approximately horizontal) is a function of scale. Diffusion at scales larger than the eddy size is determined by the energy of the flow and the integral time scale[8]. This latter quantity is estimated from the lagged correlation coefficients by a procedure described elsewhere[9]: values are reported in Table 6. The variance of the eddy currents is found in table 5 II and combined with the integral time scales to give eddy diffusivity values which range from $(0.6\text{–}3.4)\times10^2\ m^2s^{-1}$ with an overall mean of $1.8\times10^2\ m^2s^{-1}$. The values are quite similar to others reported for the abyssal NE Atlantic[1].

TABLE 6 Horizontal (isopycnal) diffusion by eddies

	Eulerian Integral time scale, days		Specific K.E. $cm^2\ s^{-2}$	Diffusivity $10^2\ m^2\ s^{-1}$
365			(2.38	0.8
PLAIN	E-4.2	N- 3.3	(4.28	1.4
			(4.51	1.5
366			(-	-
HILL-FOOT	E-4.7	N- 4.9	(3.88	1.6
			(3.97	1.6
367			(2.06	1.8
HILL-TOP	E-8.3	N-14.3	(2.33	2.0
			(3.09	2.5

EXTREME CURRENTS

Strong currents near the bottom can scour the sea-bed, putting sediment into suspension and carrying it considerable distances before redeposition. In the context of radio-active waste disposal research such a process is important because of the rapidity and quantity of tracer that might be moved.

The frequency with which near bottom currents exceed speeds between 10 and 15 cm/s has been estimated from the measurements made at each of the three sites: see table 7. Examining the frequency with which speeds exceed 10 cm/s, for which there are sufficient data to yield statistically reliable results, it is seen that;-

(a) the frequency of 'strong' currents is a maximum 10 m above the bottom at each of the sites

(b) on the plain the frequency of 'strong' currents is a minimum:

at the hill-foot it is a maximum, and on the hill-top intermediate. The ratio is 1:4:3, a surprisingly high amplification induced by the presence of the hill.

Such differences if maintained for geologically long periods might result in substantially smaller sedimentary thicknesses on hills than on the plains surrounding them.

The probability of an observation period having a speed less than a certain value has been plotted against speed according to Weibull, Fisher-Tippett I and Lognormal distributions[10]. The plot using a Weibull distribution yields an approximately linear relationship for the three sites, see figure 6, allowing extrapolations to be made. The right hand margin of figure 6 with $1-P = 2x10^{-6}$ represents one observing hour in $5x10^{5}$ hours or approximately 50 years. The adventurous might extrapolate the distributions to give a 50 year return at the PLAIN of about 13 cm/s, and 20 cm/s on both HILL-FLANK and HILL-TOP.

TABLE 7 Hours per year for which hourly mean speed is exceeded

Speed (exceeded) in cm/s	Ht. above PLAIN in m			Ht. above HILL-FOOT in m			Ht. above HILL-TOP in m		
	10	100	1000	10	100	1000	10	100	1000
15				2		1	3		
14				6	5	3	12	3	
13			3	14	12	7	31	12	
12	1	1	5	27	23	14	48	26	1
11	9	10	17	67	56	25	87	45	11
10	41	36	32	162	126	59	126	88	27
Mooring No.		365			366			367	
Instrument No.	03	02	01	03	02	01	03	02	01

ACKNOWLEDGEMENTS

The author wishes to express his gratitude to Dr. W.J. Gould for his supervision of the design, deployment and recovery of the moorings. He also wishes to thank Messrs. J.W. Cherriman, I. Waddington for the preparation of the mooring components and of the Aanderaa current meters; also to them and the officers and crew of both RRS Discovery and RRS Charles Darwin for their wholehearted assistance in the work at sea. The assistance of Mr. Peter Challenor with the statistical analysis is also acknowledged.

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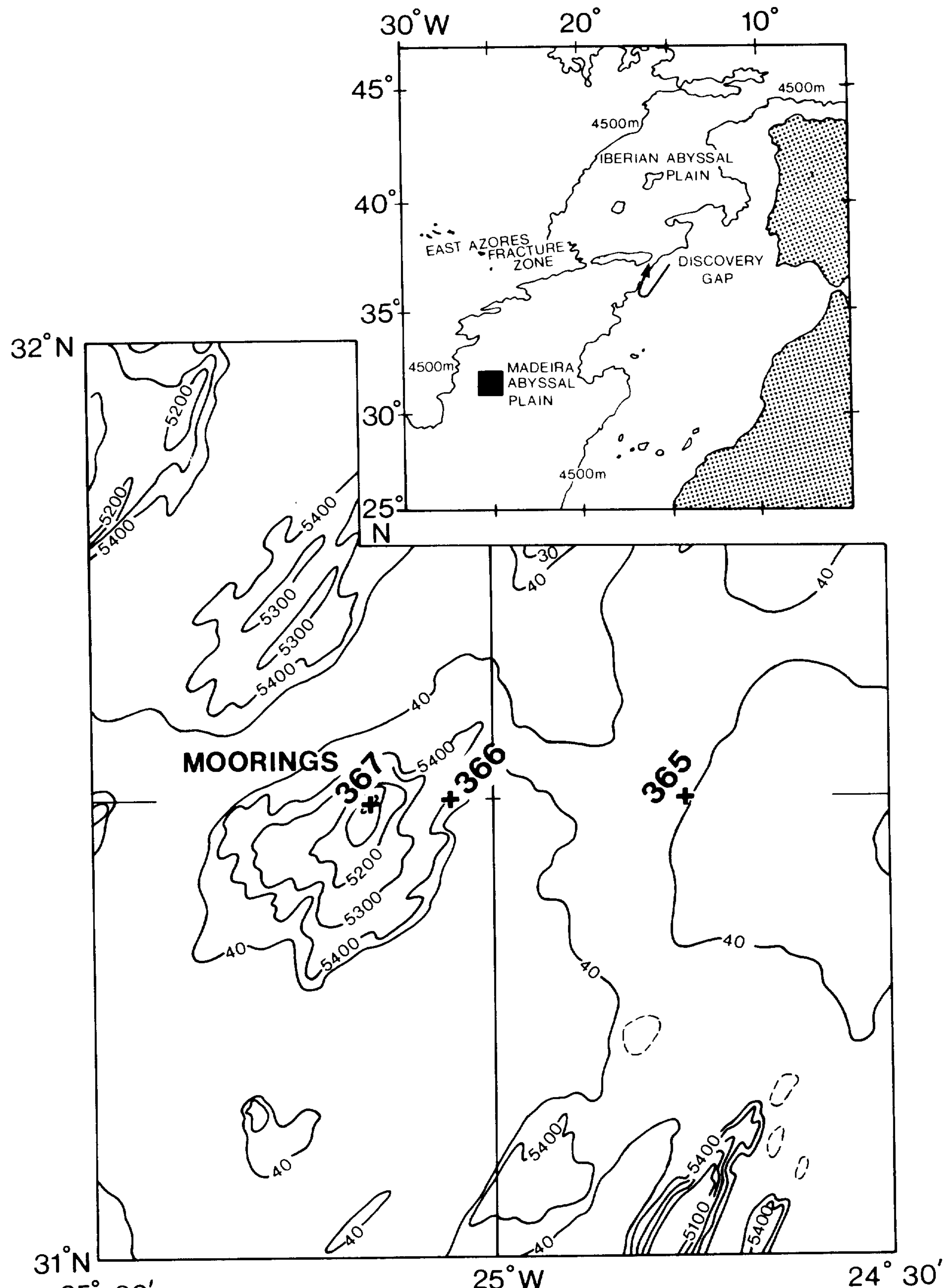
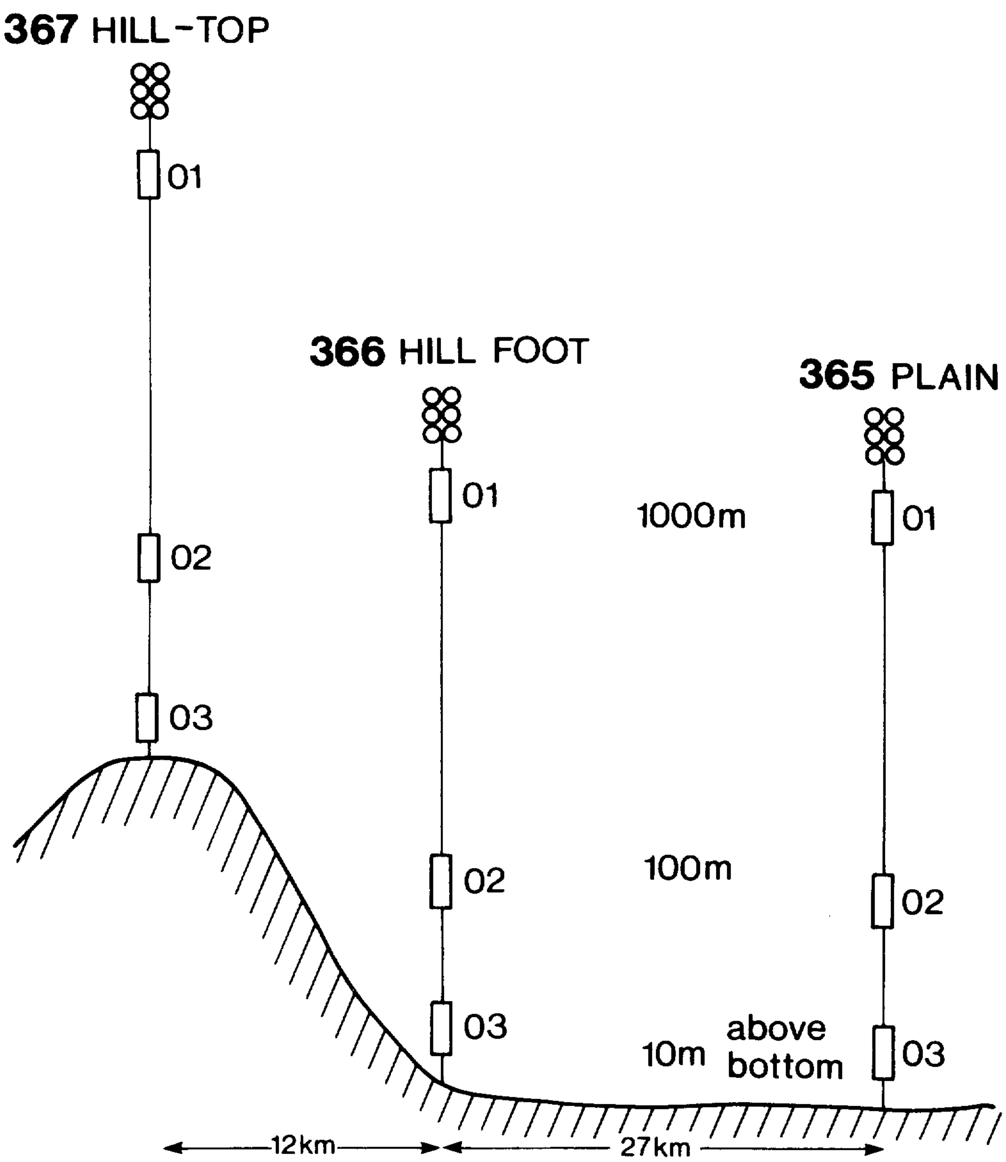
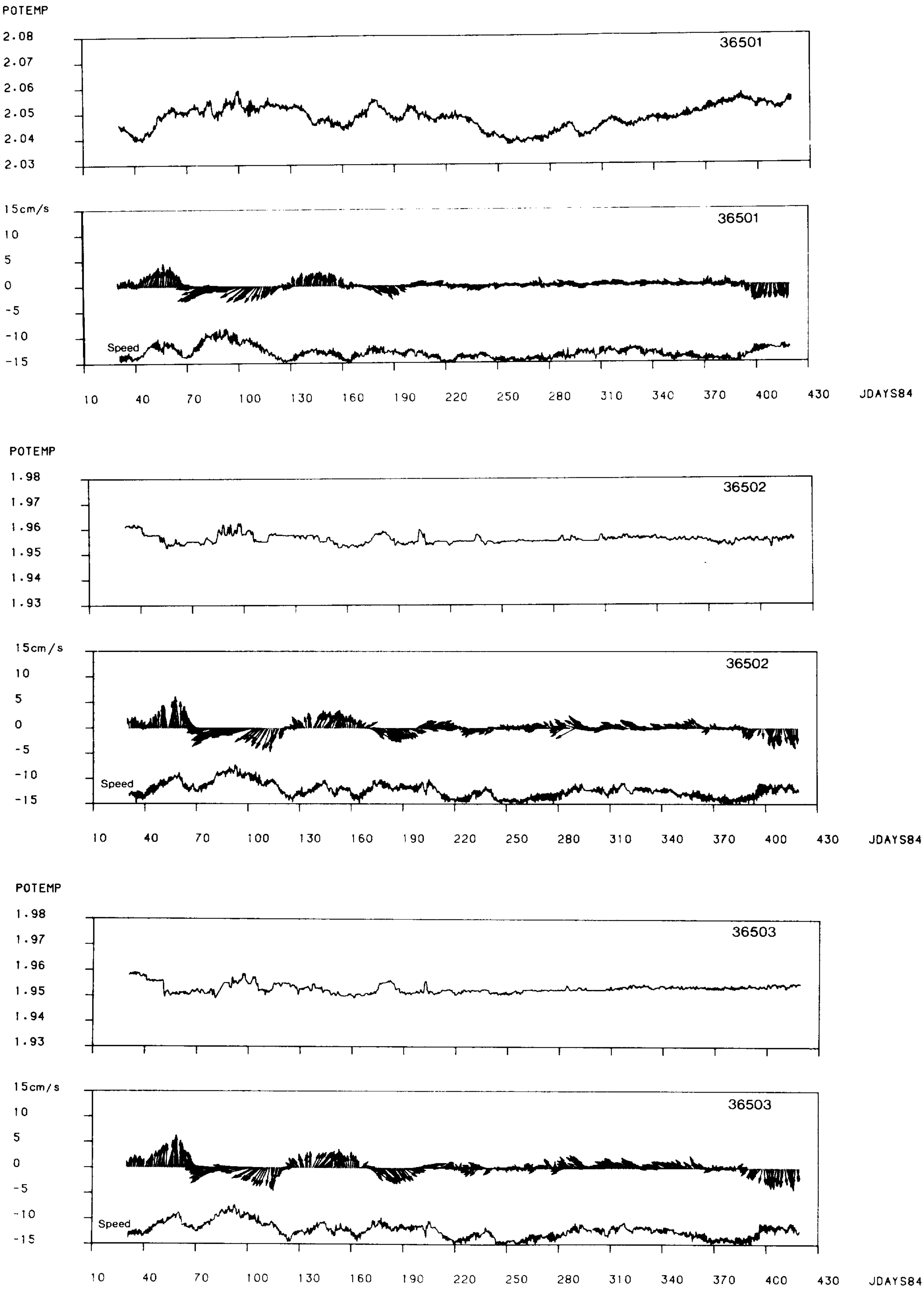


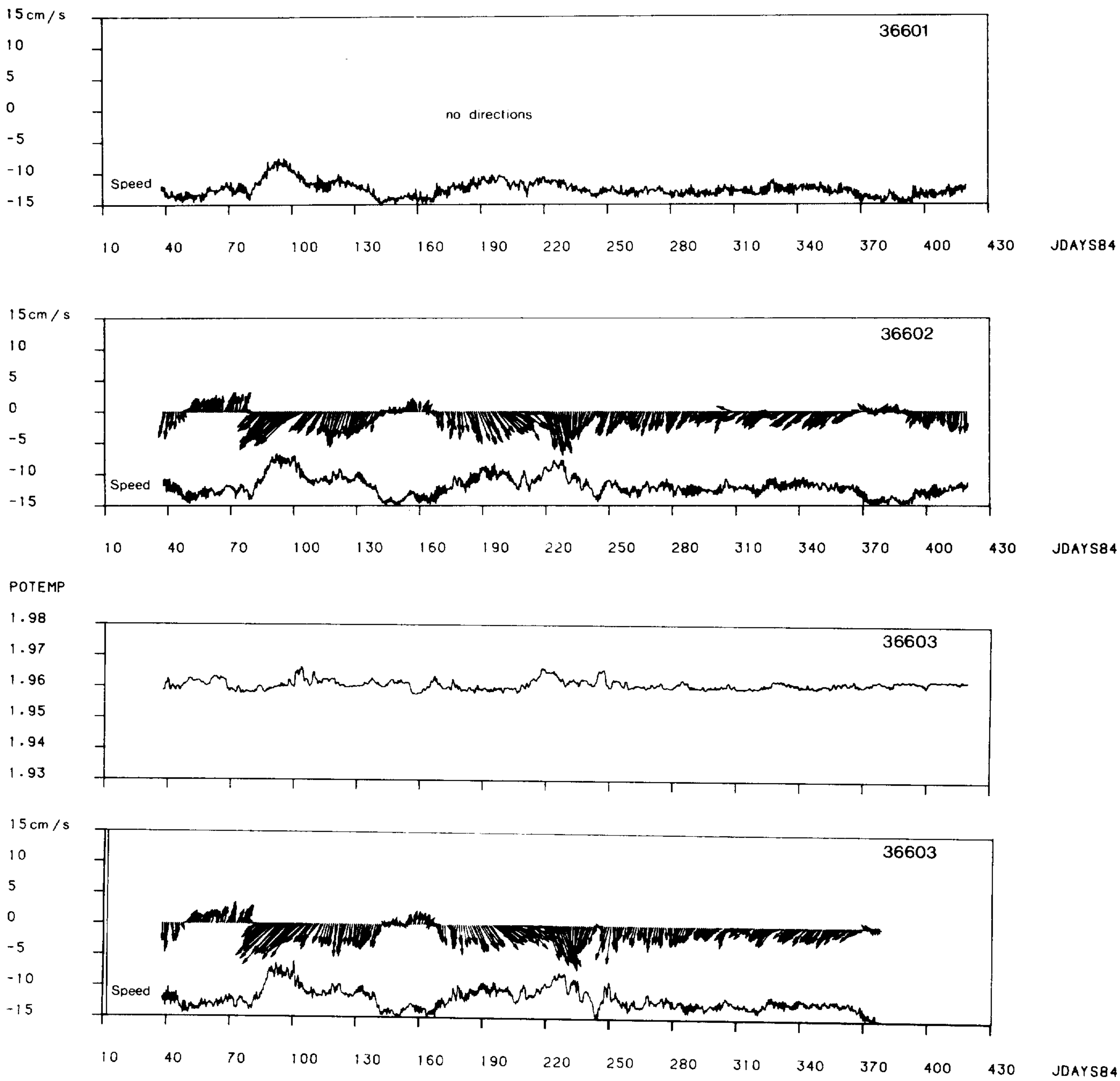
1. Map of GME study site showing moorings locations.



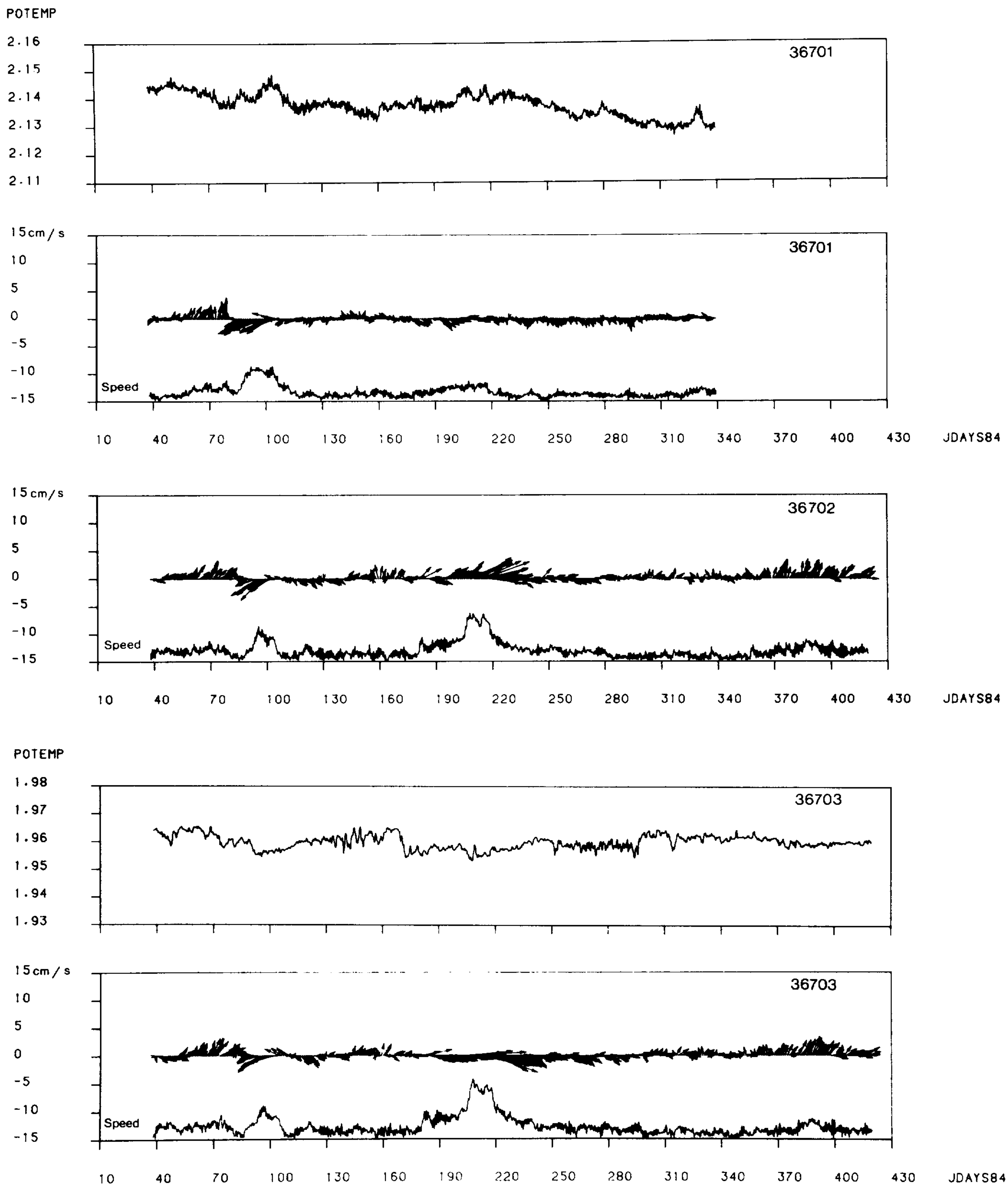
2. Schematic cross-section of the 3 moorings and 9 current meters described in this report



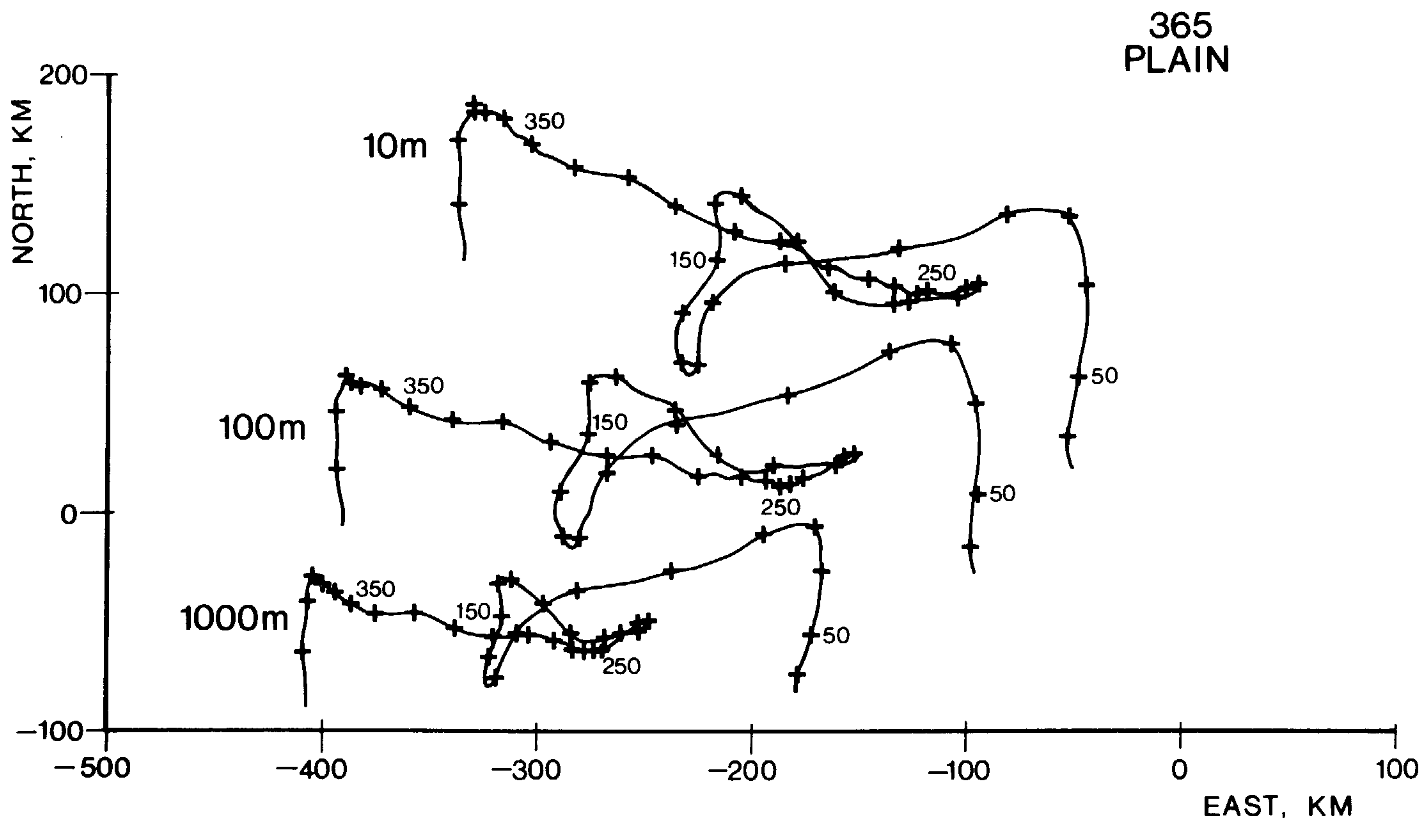
3. Time series of (potential) temperature, current and speed for mooring 365 PLAIN



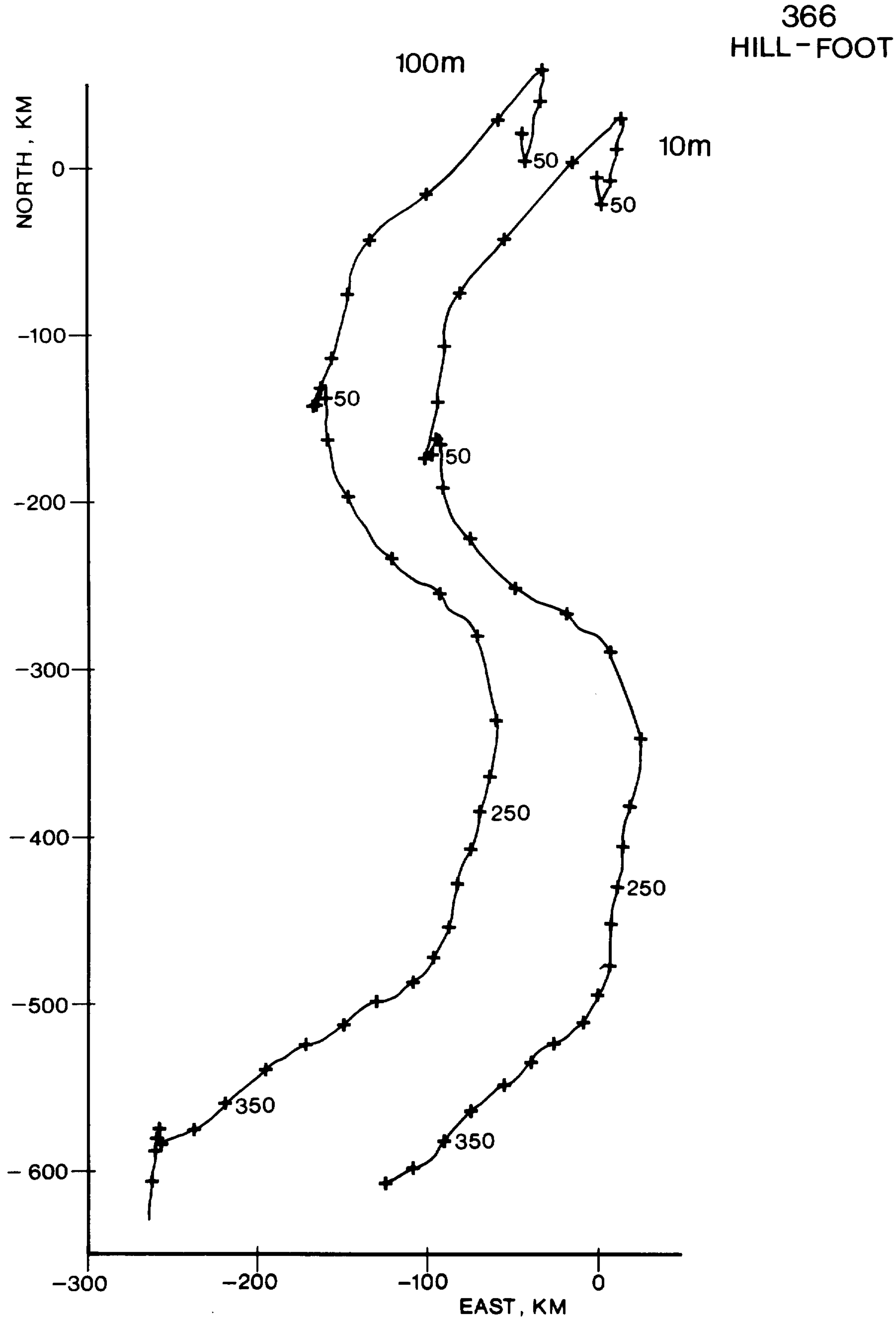
3. Time series of (potential) temperature, current and speed for mooring 366 HILL-FOOT



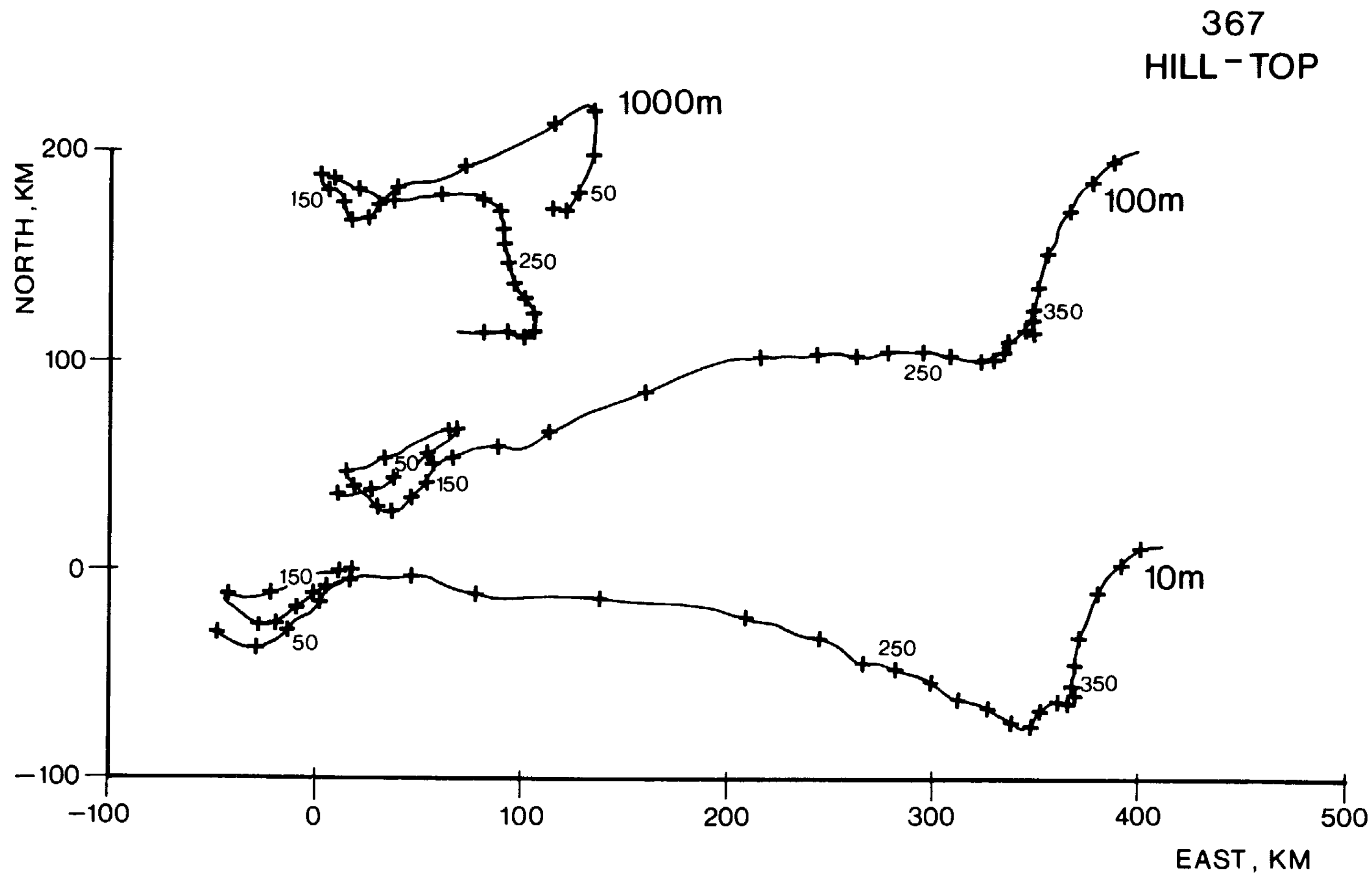
3. Time series of (potential) temperature, current and speed for mooring 367 HILL-TOP



4. Virtual displacement of water: 10 days intervals are indicated as +



4. Virtual displacement of water: 10 days intervals are indicated as +



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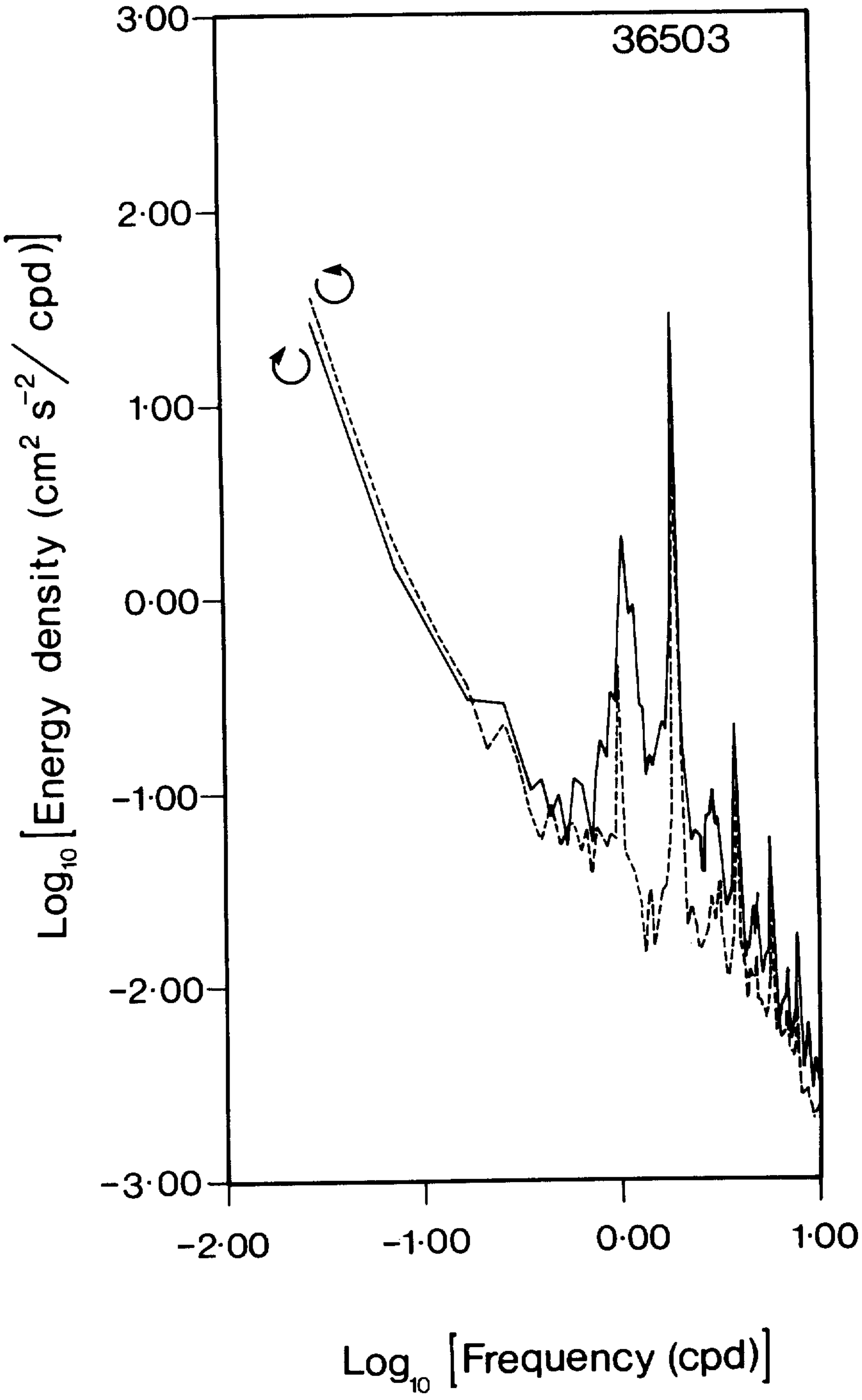
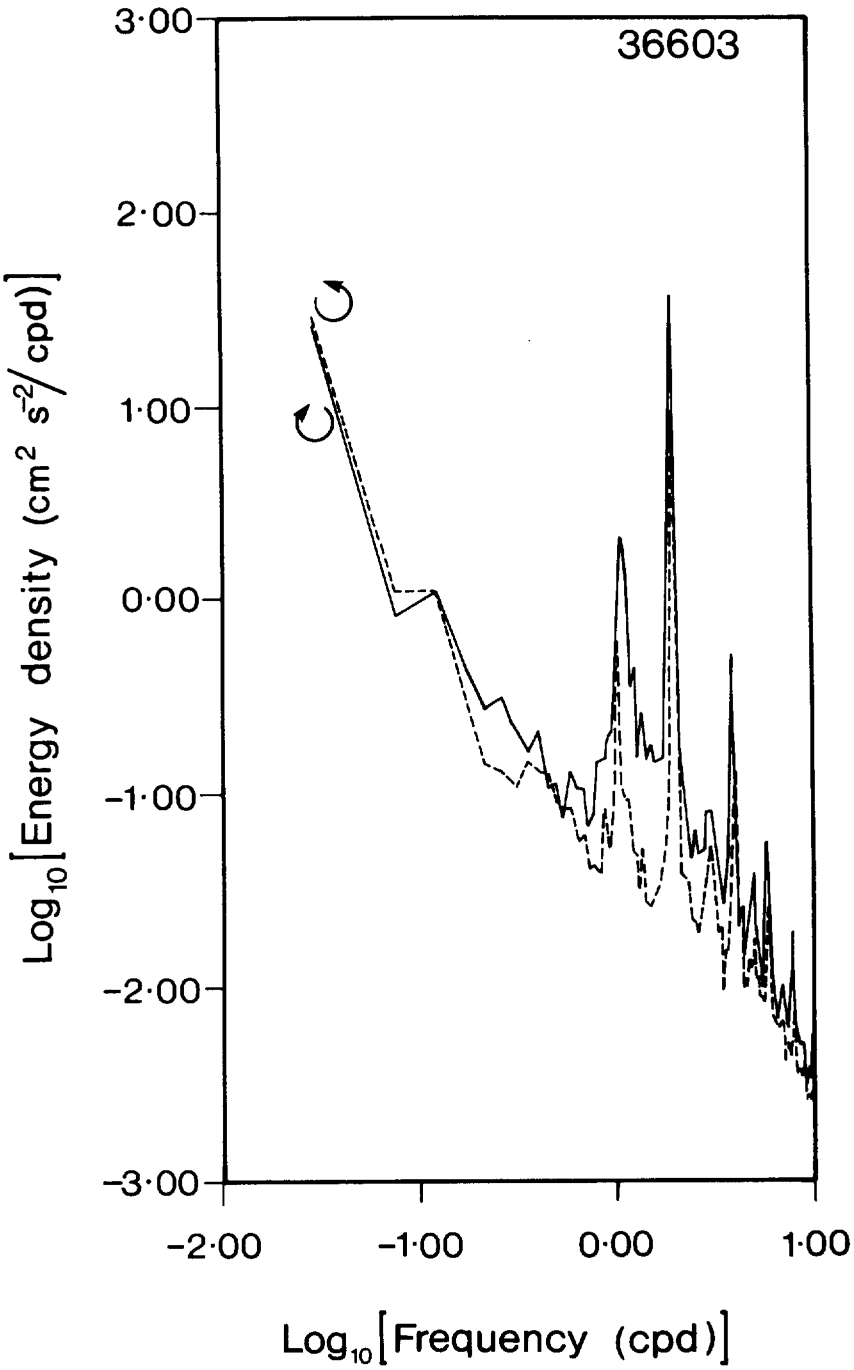
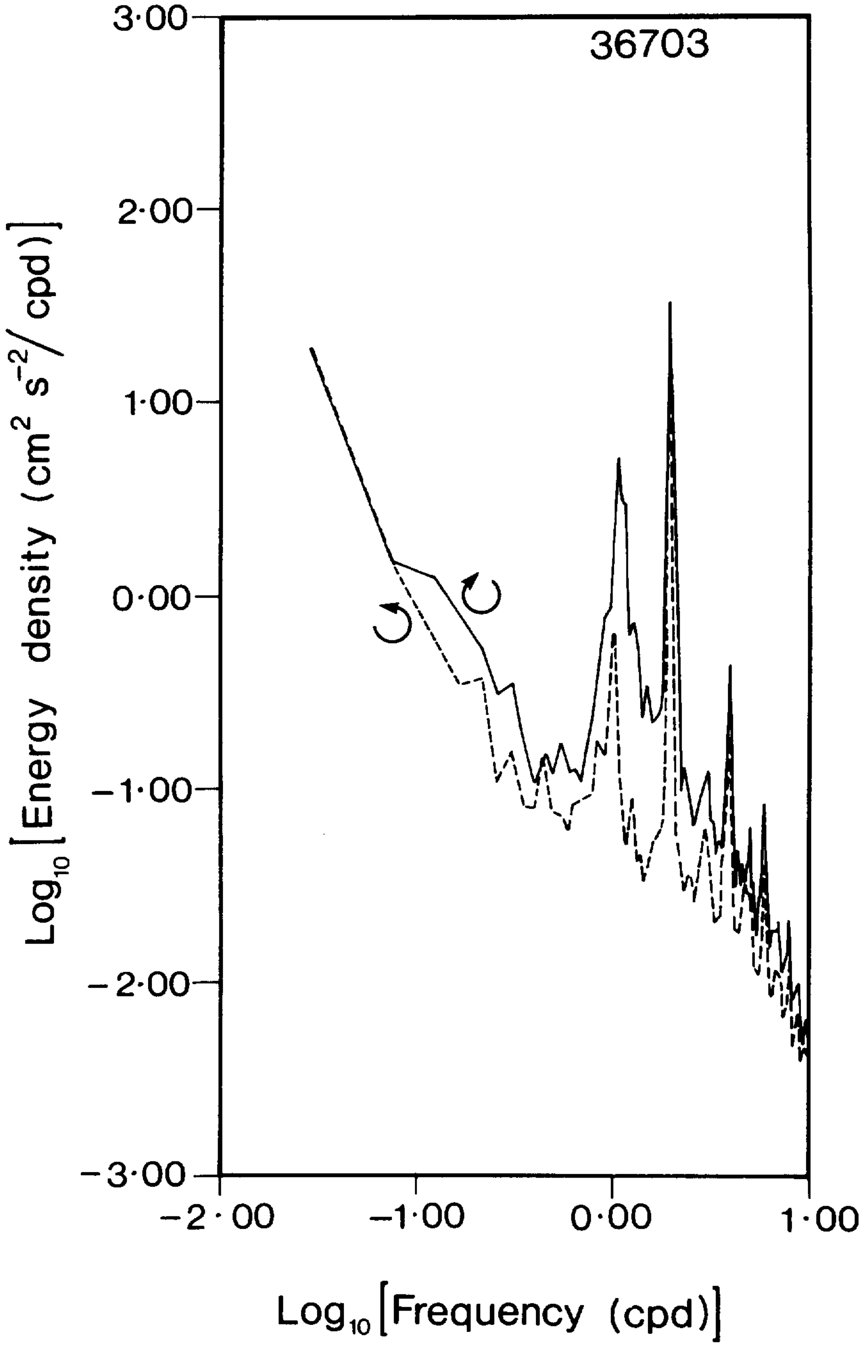


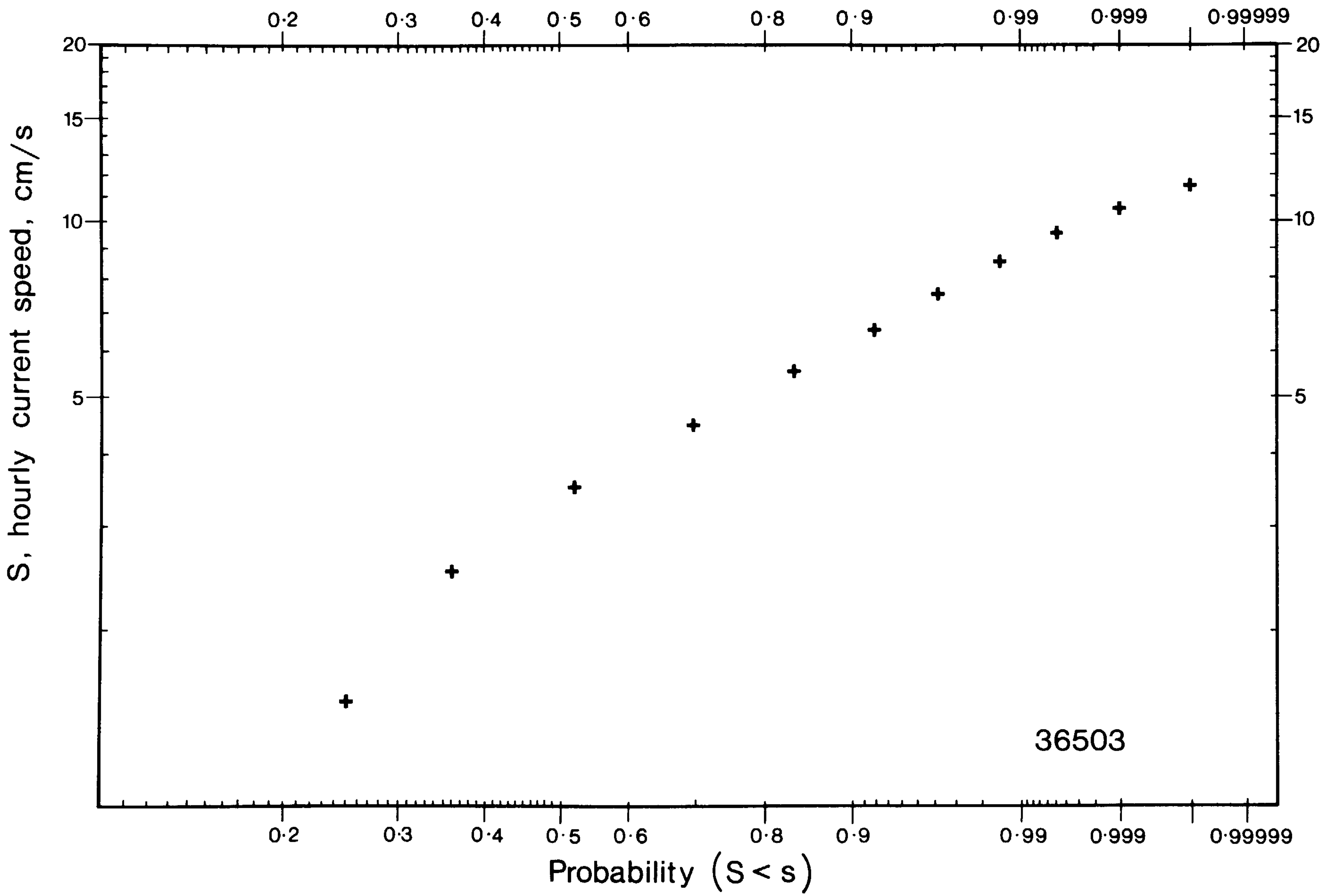
5. Rotary spectrum of 1 hour currents 10 m above sea-bed 365 PLAIN



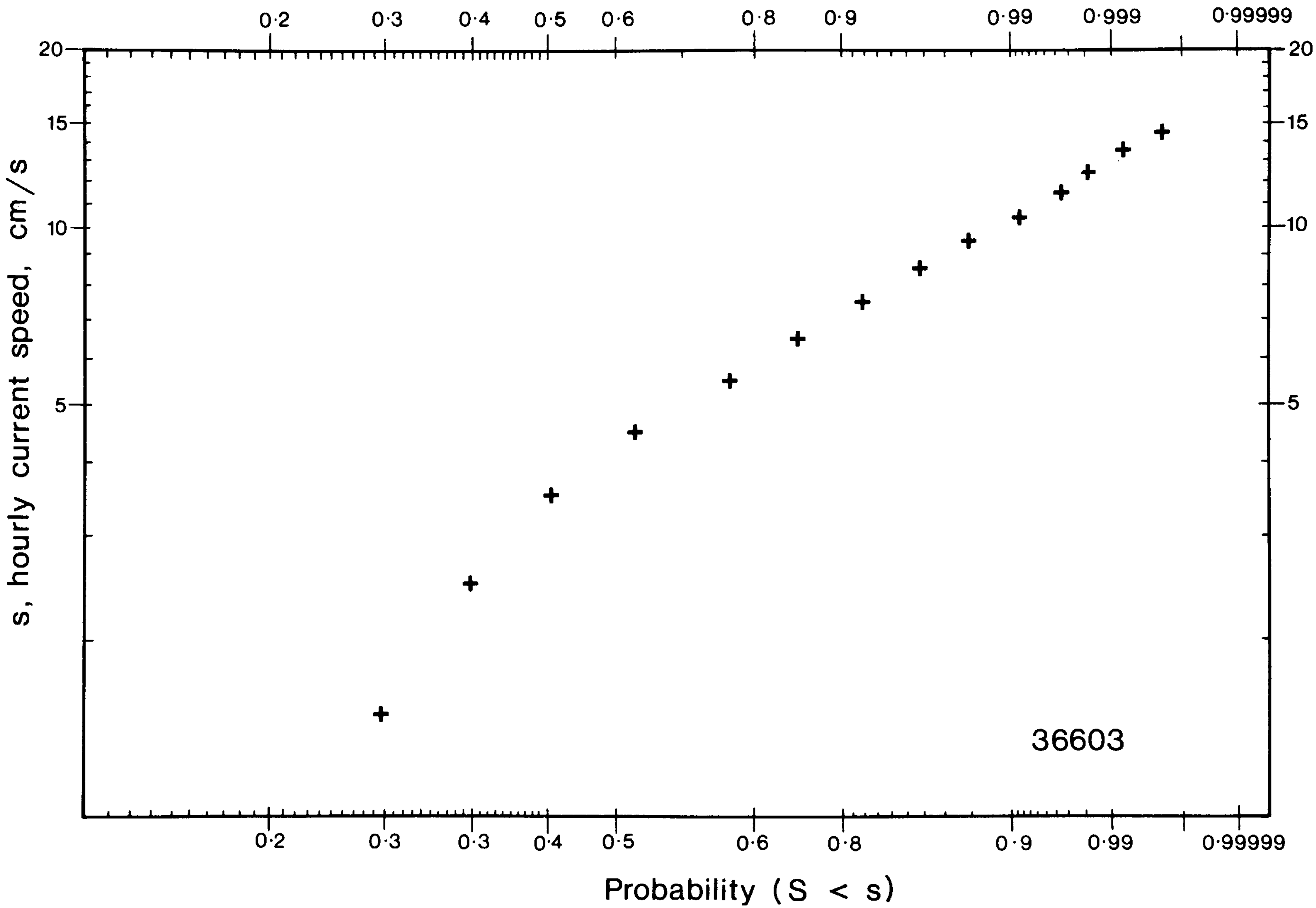
5. Rotary spectrum of 1 hour currents 10 m above sea-bed 366 HILL-FOOT



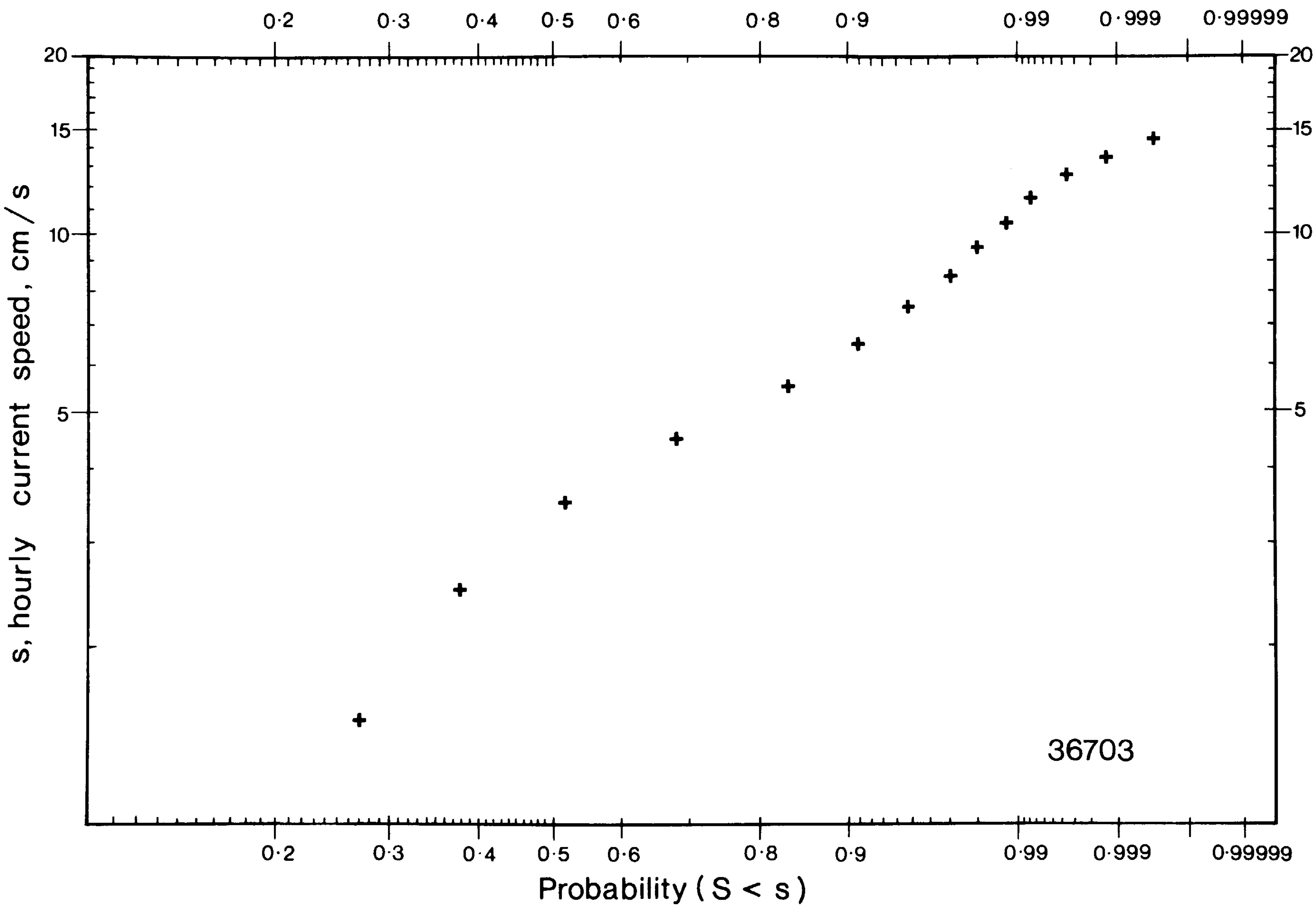
5. Rotary spectrum of 1 hours currents 10 m above sea-bed 367 HILL-TOP



6. Probability of current speed 10 m above sea-bed less than a specified value. The plot linearises a Weibull distribution. 365 PLAIN



6. Probability of current speed 10 m above sea-bed less than a specified value. The plot linearises a Weibull distribution. 366 HILL-FOOT



6. Probability of current speed 10 m above sea-bed less than a specified vlaue. The plot linearises a Weibull distribution. 367 HILL-TOP

TABLE 5(I)

RECORD-LONG STATISTICS

IDENTIFICATION 36501			NUMBER OF DATA CYCLES 9372	
INTERVAL 1 HR(S)	FROM 30-I-84		TO 23-II-85	
INSTRUMENT RCM5 6225	DEPTH 4343 m		DEPTH OF WATER 5438 m	

UNITS	cm/s	cm/s	cm/s	deg C
VARIABLE	EAST	NORTH	SPEED	TEMPERATURE
MEAN	-0.67	-0.02	2.90	2.444
UNCERTAINTY	0.45	0.5	0.4	.001
STD. DEVIATION	2.32	2.56	1.99	.0056
SKEWNESS	-0.73	-0.10	1.39	-
KURTOSIS	1.58	0.83	1.34	-
MINIMUM	-11.98	-9.30	1.5	2.425
MAXIMUM	6.29	9.72	13.20	2.463

UNITS	cm^2/s^2	m°C cm/s	m°C cm/s	m°C cm/s
VARIABLES	EAST-NORTH	EAST-TEMP	NORTH-TEMP	SPEED-TEMP
COVARIANCE	2.55	0.14	-1.49	1.32
CORREL. COEFF.	0.43	0.01	-0.10	0.12

DIRECTION and VARIABILITY

DIRECTION OF	(MEAN	269 °T	AND ITS MAGNITUDE 0.67 cm/s
	(MAX. VARIABILITY	038	AND STD. DEVIATION 2.93
	(MIN. VARIABILITY	128	AND STD. DEVIATION 1.83

TIDES (SEMI-DIURNAL)

UNITS	cm/s M_2	cm/s S_2	cm/s N_2
MAJOR AXIS	2.75	1.00	0.61
MINOR AXIS	1.04	0.27	0.21
ELLIPTICITY	-0.38	-0.27	-0.34
DIRECTION, N FROM E	059	053	046
PHASE, DEG	-8	29	-35

COMMENTS 52 PER CENT ROTOR STALL

TABLE 5(II)

RECORD LONG STATISTICS

FOR LOW PASS VERSION OF DATA

IDENTIFICATION 36501 NUMBER OF DATA CYCLES 1556

INTERVAL 6 HR(S) FROM 30-I-84 TO 22-II-85

SEE COMPANION SHEET FOR FURTHER DETAILS

DIRECTION AND VARIABILITY

DIRECTION OF	(MEAN	269 °T	AND ITS MAGNITUDE 0.67 cm/s
	(MAX. VARIABILITY	055	AND STD. DEVIATION 1.75
	(MIN. VARIABILITY	145	AND STD. DEVIATION 1.30

VARIANCE

UNITS	cm^2/s^2	cm^2/s^2	cm^2/s^2	$(m°C)^2$
VARIABLES	EAST	NORTH	K.E.	TEMPERATURE
VARIANCE	2.61	2.14	2.38	21.0

COVARIANCE

UNITS	cm^2/s^2	m°C cm/s	m°C cm/s	m°C cm/s
VARIABLES	EAST-NORTH	EAST-TEMP	NORTH-TEMP	SPEED-TEMP
COVARIANCE	0.63	-0.49	-2.32	2.10
CORREL. COEFF.	0.27	-0.07	-0.35	0.36

MEAN POTENTIAL TEMPERATURE OF RECORD 2.048°C

TABLE 5(I)

RECORD-LONG STATISTICS

IDENTIFICATION 36502		NUMBER OF DATA CYCLES 9372
INTERVAL 1 HR(S)	FROM 30-I-84	TO 23-II-85
INSTRUMENT RCM5 5204	DEPTH 5334 m	DEPTH OF WATER 5438 m

UNITS	cm/s	cm/s	cm/s	deg C
VARIABLE	EAST	NORTH	SPEED	TEMPERATURE
MEAN	-0.87	-0.06	4.03	2.482
UNCERTAINTY	0.6	0.65	0.4	.0004
STD. DEVIATION	2.94	3.26	1.94	.0020
SKEWNESS	-0.03	-0.02	0.53	-
KURTOSIS	-0.32	-0.40	-0.10	-
MINIMUM	-10.11	-10.24	1.50	2.477
MAXIMUM	7.77	10.65	12.39	2.490

UNITS	cm^2/s^2	m°C cm/s	m°C cm/s	m°C cm/s
VARIABLES	EAST-NORTH	EAST-TEMP	NORTH-TEMP	SPEED-TEMP
COVARIANCE	3.17	-0.98	-0.21	0.56
CORREL. COEFF.	0.33	-0.17	-0.03	0.15

DIRECTION and VARIABILITY

DIRECTION OF	(MEAN	274 °T	AND ITS MAGNITUDE 0.87 cm/s
	(MAX. VARIABILITY	036	AND STD. DEVIATION 3.60
	(MIN. VARIABILITY	126	AND STD. DEVIATION 2.51

TIDES (SEMI-DIURNAL)

UNITS	cm/s	cm/s	cm/s
	M_2	S_2	N_2
MAJOR AXIS	3.44	1.19	0.78
MINOR AXIS	1.23	0.28	0.25
ELLIPTICITY	-0.36	-0.24	-0.32
DIRECTION, N FROM E	061	057	040
PHASE, DEG	-14	24	-34

COMMENTS 14 PER CENT ROTOR STALL

TABLE 5(II)

RECORD LONG STATISTICS

FOR LOW PASS VERSION OF DATA

IDENTIFICATION 36502 NUMBER OF DATA CYCLES 1555

INTERVAL 6 HR(S) FROM 30-I-84 TO 22-II-85

SEE COMPANION SHEET FOR FURTHER DETAILS

DIRECTION AND VARIABILITY

DIRECTION OF	(MEAN	274 °T	AND ITS MAGNITUDE 0.87 cm/s
	(MAX. VARIABILITY	065	AND STD. DEVIATION 2.23
	(MIN. VARIABILITY	155	AND STD. DEVIATION 1.89

VARIANCE

UNITS	cm^2/s^2	cm^2/s^2	cm^2/s^2	$(m°C)^2$
VARIABLES	EAST	NORTH	K.E.	TEMPERATURE
VARIANCE	4.72	3.84	4.28	3.1

COVARIANCE

UNITS	cm^2/s^2	m°C cm/s	m°C cm/s	m°C cm/s
VARIABLES	EAST-NORTH	EAST-TEMP	NORTH-TEMP	SPEED-TEMP
COVARIANCE	0.53	-0.99	-0.28	0.73
CORREL. COEFF.	0.12	-0.26	-0.08	0.29

MEAN POTENTIAL TEMPERATURE OF RECORD 1.956°C

TABLE 5(I)

RECORD-LONG STATISTICS

IDENTIFICATION 36503		NUMBER OF DATA CYCLES 9372	
INTERVAL 1 HR(S)	FROM 30-I-84	TO 23-II-85	
INSTRUMENT RCM5 5201	DEPTH 5428 m	DEPTH OF WATER 5438 m	

UNITS	cm/s	cm/s	cm/s	deg C
VARIABLE	EAST	NORTH	SPEED	TEMPERATURE
MEAN	-0.84	0.28	3.97	2.492
UNCERTAINTY	0.6	0.6	0.4	.0004
STD. DEVIATION	3.08	3.11	2.03	.0020
SKEWNESS	-0.16	-0.15	0.59	-
KURTOSIS	-0.23	-0.19	-0.17	-
MINIMUM	-10.28	-9.65	1.5	2.486
MAXIMUM	8.58	10.08	12.21	2.500

UNITS	cm^2/s^2	m°C cm/s	m°C cm/s	m°C cm/s
VARIABLES	EAST-NORTH	EAST-TEMP	NORTH-TEMP	SPEED-TEMP
COVARIANCE	3.27	-0.82	-0.52	0.46
CORREL. COEFF.	0.34	-0.14	-0.09	0.12

DIRECTION and VARIABILITY

DIRECTION OF	MEAN	288 °T	AND ITS MAGNITUDE 0.88 cm/s
	MAX. VARIABILITY	044	AND STD. DEVIATION 3.58
	MIN. VARIABILITY	134	AND STD. DEVIATION 2.51

TIDES (SEMI-DIURNAL)

UNITS	cm/s M_2	cm/s S_2	cm/s N_2
MAJOR AXIS	3.44	1.17	0.78
MINOR AXIS	1.16	0.27	0.32
ELLIPTICITY	-0.34	-0.23	-0.41
DIRECTION, N FROM E	051	048	034
PHASE, DEG	-12	24	-34

COMMENTS 16 PER CENT ROTOR STALL

TABLE 5(II)

RECORD LONG STATISTICS

FOR LOW PASS VERSION OF DATA

IDENTIFICATION 36503 NUMBER OF DATA CYCLES 1555

INTERVAL 6 HR(S) FROM 30-I-84 TO 22-II-85

SEE COMPANION SHEET FOR FURTHER DETAILS

DIRECTION AND VARIABILITY

DIRECTION OF	(MEAN	288 °T	AND ITS MAGNITUDE 0.88 cm/s
	(MAX. VARIABILITY	077	AND STD. DEVIATION 2.23
	(MIN. VARIABILITY	167	AND STD. DEVIATION 2.01

VARIANCE

UNITS	cm^2/s^2	cm^2/s^2	cm^2/s^2	$(m°C)^2$
VARIABLES	EAST	NORTH	K.E.	TEMPERATURE
VARIANCE	4.94	4.08	4.51	3.2

COVARIANCE

UNITS	cm^2/s^2	m°C cm/s	m°C cm/s	m°C cm/s
VARIABLES	EAST-NORTH	EAST-TEMP	NORTH-TEMP	SPEED-TEMP
COVARIANCE	0.21	-0.88	-0.57	0.32
CORREL. COEFF.	0.05	-0.22	-0.16	0.12

MEAN POTENTIAL TEMPERATURE OF RECORD 1.953°C

TABLE 5(I)

RECORD-LONG STATISTICS

IDENTIFICATION 36601		NUMBER OF DATA CYCLES 9207	
INTERVAL 1 HR(S)	FROM 5-II-84	TO 23-II-85	
INSTRUMENT RCM5 4738	DEPTH 4307 m	DEPTH OF WATER 5398 m	

UNITS	cm/s	cm/s	cm/s	deg C
VARIABLE	EAST	NORTH	SPEED	TEMPERATURE
MEAN			3.87	
UNCERTAINTY			0.4	
STD. DEVIATION	none	none	2.07	none
SKEWNESS			0.63	
KURTOSIS			0.07	
MINIMUM			1.50	
MAXIMUM			15.51	

UNITS	cm^2/s^2	m°C cm/s	m°C cm/s	m°C cm/s
VARIABLES	EAST-NORTH	EAST-TEMP	NORTH-TEMP	SPEED-TEMP
COVARIANCE				
CORREL. COEFF.				

DIRECTION and VARIABILITY

DIRECTION OF	MEAN	269 °T	AND ITS MAGNITUDE 0.67 cm/s
	MAX. VARIABILITY	038	AND STD. DEVIATION 2.93
	MIN. VARIABILITY	128	AND STD. DEVIATION 1.83

TIDES (SEMI-DIURNAL)

UNITS	cm/s	cm/s	cm/s
	M_2	S_2	N_2
MAJOR AXIS			
MINOR AXIS			
ELLIPTICITY			
DIRECTION, N FROM E			
PHASE, DEG			

COMMENTS 22 PER CENT ROTOR STALL
NO TEMPERATURE OR DIRECTION DATA

TABLE 5(I)

RECORD-LONG STATISTICS

IDENTIFICATION 36602 NUMBER OF DATA CYCLES 9207
INTERVAL 1 HR(S) FROM 5-II-84 TO 23-II-85
INSTRUMENT RCM5 5205 DEPTH 5295 m DEPTH OF WATER 5398 m

UNITS	cm/s	cm/s	cm/s	deg C
VARIABLE	EAST	NORTH	SPEED	TEMPERATURE
MEAN	-0.68	-1.99	4.56	
UNCERTAINTY	0.65	0.65	0.45	
STD. DEVIATION	3.31	3.27	2.30	none
SKEWNESS	-0.04	0.14	0.52	
KURTOSIS	-0.56	-0.40	-0.11	
MINIMUM	-10.76	-11.75	1.5	
MAXIMUM	9.43	8.15	14.73	

UNITS	cm^2/s^2	m°C cm/s	m°C cm/s	m°C cm/s
VARIABLES	EAST-NORTH	EAST-TEMP	NORTH-TEMP	SPEED-TEMP
COVARIANCE	4.59	-	-	-
CORREL. COEFF.	0.42	-	-	-

DIRECTION and VARIABILITY

DIRECTION OF (MEAN	199 °T	AND ITS MAGNITUDE	2.10 cm/s
DIRECTION OF (MAX. VARIABILITY	046	AND STD. DEVIATION	3.92
DIRECTION OF (MIN. VARIABILITY	136	AND STD. DEVIATION	2.50

TIDES (SEMI-DIURNAL)

UNITS	cm/s M_2	cm/s S_2	cm/s N_2
MAJOR AXIS	4.12	1.30	0.70
MINOR AXIS	1.41	0.40	0.14
ELLIPTICITY	-.34	-.31	-.20
DIRECTION, N FROM E	039	056	028
PHASE, DEG	-22	20	-57

COMMENTS 12 PER CENT ROTOR STALL
TEMPERATURE DATA DISCARDED

TABLE 5(II)

RECORD LONG STATISTICS

FOR LOW PASS VERSION OF DATA

IDENTIFICATION 36602 NUMBER OF DATA CYCLES 1527

INTERVAL 6 HR(S) FROM 6-II-84 TO 22-II-85

SEE COMPANION SHEET FOR FURTHER DETAILS

DIRECTION AND VARIABILITY

DIRECTION OF	(MEAN	199 °T	AND ITS MAGNITUDE 2.10 cm/s
	(MAX. VARIABILITY	024	AND STD. DEVIATION 2.13
	(MIN. VARIABILITY	114	AND STD. DEVIATION 1.79

VARIANCE

UNITS	cm^2/s^2	cm^2/s^2	cm^2/s^2	$(m°C)^2$
VARIABLES	EAST	NORTH	K.E.	TEMPERATURE
VARIANCE	3.44	4.31	3.88	-

COVARIANCE

UNITS	cm^2/s^2	m°C cm/s	m°C cm/s	m°C cm/s
VARIABLES	EAST-NORTH	EAST-TEMP	NORTH-TEMP	SPEED-TEMP
COVARIANCE	0.50	-	-	-
CORREL. COEFF.	0.13	-	-	-

MEAN POTENTIAL TEMPERATURE OF RECORD -°C

TABLE 5(I)

RECORD-LONG STATISTICS

IDENTIFICATION 36603			NUMBER OF DATA CYCLES 9207	
INTERVAL 1 HR(S)		FROM 5-II-84	TO 23-II-85	
INSTRUMENT RCM5 5202		DEPTH 5388 m	DEPTH OF WATER 5398 m	

UNITS	cm/s	cm/s	cm/s	deg C
VARIABLE	EAST	NORTH	SPEED	TEMPERATURE
MEAN	-0.43	-2.06	4.22	2.494
UNCERTAINTY	0.6	0.6	0.5	0.0003
STD. DEVIATION	3.16	3.10	2.49	0.0017
SKEWNESS	-0.04	-0.10	0.72	-
KURTOSIS	-0.10	-0.09	-0.06	-
MINIMUM	-10.41	-12.86	1.50	2.489
MAXIMUM	10.46	7.48	15.28	2.500

UNITS	cm^2/s^2	m°C cm/s	m°C cm/s	m°C cm/s
VARIABLES	EAST-NORTH	EAST-TEMP	NORTH-TEMP	SPEED-TEMP
COVARIANCE	4.23	-0.18	-0.75	0.48
CORREL. COEFF.	0.43	-0.03	-0.14	0.11

DIRECTION and VARIABILITY

DIRECTION OF	(MEAN	192 °T	AND ITS MAGNITUDE 2.10 cm/s
	(MAX. VARIABILITY	046	AND STD. DEVIATION 3.74
	(MIN. VARIABILITY	136	AND STD. DEVIATION 2.36

TIDES (SEMI-DIURNAL)

UNITS	cm/s M_2	cm/s S_2	cm/s N_2
MAJOR AXIS	3.81	1.26	0.65
MINOR AXIS	1.20	0.40	0.09
ELLIPTICITY	-0.31	-0.32	-0.14
DIRECTION, N FROM E	038	055	028
PHASE, DEG	-27	15	-59

COMMENTS 19 PER CENT ROTOR STALL
SPEED, EAST, NORTH END AFTER 8197 CYCS, i.e. on 11-I-85

TABLE 5(II)

RECORD LONG STATISTICS

FOR LOW PASS VERSION OF DATA

IDENTIFICATION 36603 NUMBER OF DATA CYCLES 1527

INTERVAL 6 HR(S) FROM 6-II-84 TO 22-II-85

SEE COMPANION SHEET FOR FURTHER DETAILS

DIRECTION AND VARIABILITY

DIRECTION OF	(MEAN	192 °T	AND ITS MAGNITUDE 2.10 cm/s
	(MAX. VARIABILITY	025	AND STD. DEVIATION 2.16
	(MIN. VARIABILITY	115	AND STD. DEVIATION 1.80

VARIANCE

UNITS	cm^2/s^2	cm^2/s^2	cm^2/s^2	$(m°C)^2$
VARIABLES	EAST	NORTH	K.E.	TEMPERATURE
VARIANCE	3.50	4.43	3.97	2.2

COVARIANCE

UNITS	cm^2/s^2	m°C cm/s	m°C cm/s	m°C cm/s
VARIABLES	EAST-NORTH	EAST-TEMP	NORTH-TEMP	SPEED-TEMP
COVARIANCE	0.55	-0.07	-0.56	0.30
CORREL. COEFF.	0.14	-0.03	-0.18	0.12

MEAN POTENTIAL TEMPERATURE OF RECORD 1.961°C

TABLE 5(I)

RECORD-LONG STATISTICS

IDENTIFICATION 36701 — NUMBER OF DATA CYCLES 7274

INTERVAL 1 HR(S) — FROM 6-II-84 — TO 5-XII-84

INSTRUMENT RCM5 6707 — DEPTH 3907 m — DEPTH OF WATER 4999 m

UNITS	cm/s	cm/s	cm/s	deg C
VARIABLE	EAST	NORTH	SPEED	TEMPERATURE
MEAN	-0.19	-0.23	3.16	2.482
UNCERTAINTY	0.6	0.45	0.35	.0015
STD. DEVIATION	2.83	2.30	1.84	.0076
SKEWNESS	-0.31	-0.01	1.03	-
KURTOSIS	0.33	-0.14	0.69	-
MINIMUM	-11.64	-7.02	1.50	2.458
MAXIMUM	7.82	7.21	12.21	2.516

UNITS	cm^2/s^2	m°C cm/s	m°C cm/s	m°C cm/s
VARIABLES	EAST-NORTH	EAST-TEMP	NORTH-TEMP	SPEED-TEMP
COVARIANCE	3.29	-4.02	-3.16	3.09
CORREL. COEFF.	0.51	-0.19	-0.18	0.22

DIRECTION and VARIABILITY

DIRECTION OF	MEAN	220 °T	AND ITS MAGNITUDE 0.30 cm/s
	MAX. VARIABILITY	056	AND STD. DEVIATION 3.19
	MIN. VARIABILITY	146	AND STD. DEVIATION 1.75

TIDES (SEMI-DIURNAL)

UNITS	cm/s M_2	cm/s S_2	cm/s N_2
MAJOR AXIS	2.93	1.29	0.47
MINOR AXIS	0.49	0.41	0.03
ELLIPTICITY	-0.17	-0.31	-0.07
DIRECTION, N FROM E	039	051	035
PHASE, DEG	-30	10	-58

COMMENTS 35 PER CENT ROTOR STALL
SHORT RECORD

TABLE 5(II)

RECORD LONG STATISTICS

FOR LOW PASS VERSION OF DATA

IDENTIFICATION 36701 NUMBER OF DATA CYCLES 1205

INTERVAL 6 HR(S) FROM 7-II-84 TO 4-XII-84

SEE COMPANION SHEET FOR FURTHER DETAILS

DIRECTION AND VARIABILITY

DIRECTION OF (MEAN	220 °T	AND ITS MAGNITUDE	0.30 cm/s
DIRECTION OF (MAX. VARIABILITY	080	AND STD. DEVIATION	1.72
DIRECTION OF (MIN. VARIABILITY	170	AND STD. DEVIATION	1.07

VARIANCE

UNITS	cm^2/s^2	cm^2/s^2	cm^2/s^2	$(m°C)^2$
VARIABLES	EAST	NORTH	K.E.	TEMPERATURE
VARIANCE	2.82	1.29	2.06	20.2

COVARIANCE

UNITS	cm^2/s^2	m°C cm/s	m°C cm/s	m°C cm/s
VARIABLES	EAST-NORTH	EAST-TEMP	NORTH-TEMP	SPEED-TEMP
COVARIANCE	0.57	0.33	0.16	1.93
CORREL. COEFF.	0.30	0.04	0.03	0.37

MEAN POTENTIAL TEMPERATURE OF RECORD 2.138°C

TABLE 5(I)

RECORD-LONG STATISTICS

IDENTIFICATION 36702		NUMBER OF DATA CYCLES 9206	
INTERVAL 1 HR(S)	FROM 6-II-84	TO 23-II-85	
INSTRUMENT RCM5 5206	DEPTH 4906 m	DEPTH OF WATER 4999 m	

UNITS	cm/s	cm/s	cm/s	deg C
VARIABLE	EAST	NORTH	SPEED	TEMPERATURE
MEAN	1.19	0.51	3.75	
UNCERTAINTY	0.6	0.55	0.4	
STD. DEVIATION	3.00	2.83	2.15	none
SKEWNESS	0.01	0.14	0.91	
KURTOSIS	0.50	-0.07	0.69	
MINIMUM	-10.91	-7.94	1.5	
MAXIMUM	14.04	12.19	13.03	

UNITS	cm^2/s^2	m°C cm/s	m°C cm/s	m°C cm/s
VARIABLES	EAST-NORTH	EAST-TEMP	NORTH-TEMP	SPEED-TEMP
COVARIANCE	3.69			
CORREL. COEFF.	0.43			

DIRECTION and VARIABILITY

DIRECTION OF	(MEAN	067 °T	AND ITS MAGNITUDE 1.30 cm/s
	(MAX. VARIABILITY	049	AND STD. DEVIATION 3.50
	(MIN. VARIABILITY	139	AND STD. DEVIATION 2.19

TIDES (SEMI-DIURNAL)

UNITS	cm/s M_2	cm/s S_2	cm/s N_2
MAJOR AXIS	3.45	1.30	0.68
MINOR AXIS	0.90	0.45	0.15
ELLIPTICITY	-0.26	-0.35	-0.22
DIRECTION, N FROM E	048	064	037
PHASE, DEG	-21	22	-58

COMMENTS 24 PER CENT ROTOR STALL
NO TEMPERATURE DATA

TABLE 5(II)

RECORD LONG STATISTICS

FOR LOW PASS VERSION OF DATA

IDENTIFICATION 36702 NUMBER OF DATA CYCLES 1527

INTERVAL 6 HR(S) FROM 7-II-84 TO 22-II-85

SEE COMPANION SHEET FOR FURTHER DETAILS

DIRECTION AND VARIABILITY

DIRECTION OF	(MEAN	067 °T	AND ITS MAGNITUDE 1.30 cm/s
	(MAX. VARIABILITY	079	AND STD. DEVIATION 1.88
	(MIN. VARIABILITY	169	AND STD. DEVIATION 1.06

VARIANCE

UNITS	cm^2/s^2	cm^2/s^2	cm^2/s^2	$(m°C)^2$
VARIABLES	EAST	NORTH	K.E.	TEMPERATURE
VARIANCE	3.31	1.35	2.33	

COVARIANCE

UNITS	cm^2/s^2	m°C cm/s	m°C cm/s	m°C cm/s
VARIABLES	EAST-NORTH	EAST-TEMP	NORTH-TEMP	SPEED-TEMP
COVARIANCE	0.80	-	-	-
CORREL. COEFF.	0.38	-	-	-

MEAN POTENTIAL TEMPERATURE OF RECORD - °C

TABLE 5(I)

RECORD-LONG STATISTICS

IDENTIFICATION 36703 NUMBER OF DATA CYCLES 9206
INTERVAL 1 HR(S) FROM 6-II-84 TO 23-II-85
INSTRUMENT RCM5 5203 DEPTH 4989 m DEPTH OF WATER 4999 m

UNITS	cm/s	cm/s	cm/s	deg C
VARIABLE	EAST	NORTH	SPEED	TEMPERATURE
MEAN	1.41	0.13	4.04	2.439
UNCERTAINTY	0.7	0.5	0.45	.0006
STD. DEVIATION	3.59	2.57	2.27	.0028
SKEWNESS	0.29	0.10	1.00	-
KURTOSIS	0.20	-0.37	1.46	-
MINIMUM	-10.66	-8.04	1.50	2.432
MAXIMUM	15.18	8.62	15.23	2.447

UNITS	cm^2/s^2	m°C cm/s	m°C cm/s	m°C cm/s
VARIABLES	EAST-NORTH	EAST-TEMP	NORTH-TEMP	SPEED-TEMP
COVARIANCE	2.98	-0.95	0.98	-1.18
CORREL. COEFF.	0.32	-0.09	0.13	-0.19

DIRECTION and VARIABILITY

DIRECTION OF (MEAN	085 °T	AND ITS MAGNITUDE	1.54 cm/s
(MAX. VARIABILITY	068	AND STD. DEVIATION	3.75
(MIN. VARIABILITY	158	AND STD. DEVIATION	2.33

TIDES (SEMI-DIURNAL)

UNITS	cm/s M_2	cm/s S_2	cm/s N_2
MAJOR AXIS	3.80	1.29	0.76
MINOR AXIS	0.90	0.43	0.06
ELLIPTICITY	-0.24	-0.34	-0.09
DIRECTION, N FROM E	034	051	025
PHASE, DEG	-19	24	-57

COMMENTS 19 PER CENT ROTOR STALL
TEMPERATURE DATA OF LOW QUALITY

TABLE 5(II)

RECORD LONG STATISTICS

FOR LOW PASS VERSION OF DATA

IDENTIFICATION 36703 NUMBER OF DATA CYCLES 1527

INTERVAL 6 HR(S) FROM 7-II-84 TO 22-II-85

SEE COMPANION SHEET FOR FURTHER DETAILS

DIRECTION AND VARIABILITY

DIRECTION OF	MEAN	085 °T	AND ITS MAGNITUDE 1.54 cm/s
	MAX. VARIABILITY	096	AND STD. DEVIATION 2.20
	MIN. VARIABILITY	006	AND STD. DEVIATION 1.36

VARIANCE

UNITS	cm^2/s^2	cm^2/s^2	cm^2/s^2	$(m°C)^2$
VARIABLES	EAST	NORTH	K.E.	TEMPERATURE
VARIANCE	4.78	1.40	3.09	6.0*

COVARIANCE

UNITS	cm^2/s^2	m°C cm/s	m°C cm/s	m°C cm/s
VARIABLES	EAST-NORTH	EAST-TEMP	NORTH-TEMP	SPEED-TEMP
COVARIANCE	-0.37	-1.28	0.87	-2.14
CORREL. COEFF.	-0.14	-0.24	0.30	-0.51

MEAN POTENTIAL TEMPERATURE OF RECORD 1.960°C

*DOUBTFUL