SYDNEY DEEPWATER OUTFALLS: EMP
A STATISTICAL SUMMARY OF CURRENT
AND TEMPERATURE DATA

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AUSTRALIAN WATER AND
COASTAL STUDIES PTY LTD

SYDNEY DEEPWATER OUTFALLS
ENVIRONMENTAL MONITORING PROGRAM
COMMISSIONING PHASE

A STATISTICAL SUMMARY OF CURRENT AND TEMPERATURE DATA FROM THE MK0 OCEAN REFERENCE STATION

INTERIM REPORT 91/01/14 MAY 1991

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Preface

This investigation was carried out by Australian Water and Coastal Studies Pty Ltd, acting on behalf of the client, the State Pollution Control Commission.

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1. Introduction

As part of the Sydney Deepwater Outfalls Environmental Monitoring Program (EMP), an Ocean Reference Station (ORS) was installed for the Water Board by Lawson & Treloar Pty Ltd under contract to AWACS. During the development of the main station, a temporary ORS (Mk 0) was deployed and was operated by Lawson and Treloar from July 1989 to April 1990.

The purpose of this report is to provide a statistical summary of current and temperature data from the Mk0 Ocean Reference Station, in order to give a preliminary understanding of the distribution of these parameters in the EMP study area. This report adds to the information available in a previous report by Griffin and Middleton (1990), included here as Appendix A, in which time series plots and a brief discussion of the main observable features in the Mk 0 Reference Station data are presented. This is an interim report, covering data from July 1989 to February 1990. Data for March and April 1990 has been omitted as it is presently unavailable in the required format, however it will be included along with Mk 1 ORS data in a report at the end of the Commissioning Phase of the EMP.

The work presented here was carried out as part of the development of SDOSIM, a Monte Carlo simulation stochastic model for the Sydney Deepwater Outfalls, described in Webb and Cox (1991).

2. Data Collection and Analysis

2.1 The Mk0 Ocean Reference Station

The Mk0 Ocean Reference Station was located approximately 3 km offshore of Clovelly in water of total depth 64 m. It was first deployed on 21 July 1989, and consisted initially of two S4 current meters at depths of 15 m and 46 m. These meters recorded instantaneous temperature and 5 min vector averages of the current at 10 min intervals. A string of eleven thermistors was added between the current meters on 19 December 1989.

A summary of the data collected by the Mk0 Reference Station during each deployment is given in Table 1 below.

Table 1: Mk0 Ocean Reference Station Data

21 July 1989 - 7 August 1989	Currents and temperatures at 46 m depth.
8 August 1989 - 21 August 1989	Currents and temperatures at 15 m and 46 m depth.
22 August 1989 - 29 August 1989	Currents and temperatures at 15 m and 46 m depth.
29 August 1989 - 18 September 1989	Currents and temperatures at 15 m depth.
19 September 1989 - 12 October 1989	Currents and temperatures at 15 m and 46 m depth.
13 October 1989 - 15 November 1989	Currents and temperatures at 15 m and 46 m depth.
19 December 1989 - 24 December 1989	Currents and temperature at 18 m and 54 m depth. Temperatures at intervals of 3.5 m between 18.7 m and 53.7 m.
25 December 1989 - 28 February 1990	Currents and temperatures at 14 m and 50 m depth. Temperatures at intervals of 3.5 m between 14.7 m and 49.7 m.
1 March 1990 - 4 April 1990	Currents and Temperatures at 14 m and 50 m depth.

2.2 Data Analysis

2.2.1 Filtering and Choice of Longshore Axis

Preliminary analysis of the data was carried out by David Griffin of the University of New South Wales Mathematics Oceanography Laboratory. As described in Griffin and Middleton (1990), Appendix A of this report, filtering of the raw data to hourly values was carried out using a low pass Fourier transform filter with cutoff frequency of 1/2 hour. The data used in this study therefore includes the effects of long period variations, such as East Australian current influences, tidal currents and large scale wind-driven currents but excludes the effects of small-scale turbulence and short period surface and internal waves.

The current meter data was provided as longshore and cross-shelf components, with the axes rotated so that the longshore direction was 13.5 degrees East of True North.

2.2.2 Statistical Analysis

Current statistics using the data from each of the two S4 current meters were calculated using all the data from July 1989 to February 1990. In doing this, the variations in depth of the current meters from one deployment to the next, after 19th November 1989, have been ignored. The results are referred to as being from either the 'top meter' (approx depth 15 m) or 'bottom meter' (approx depth 50 m).

As changes in the current meter depths would be expected to have a far greater effect on the measured temperatures, the temperature statistics were calculated using the data from 21st July 1989 to 19th November 1989 only. Data from the thermistors was not analysed as part of this study.

The statistical analysis was as follows:

1. Basic statistical parameters (mean, maximum, minimum, standard deviation, variance and skew) were calculated for current speed, longshore and cross-shelf components of current, and temperature at each of the two meters.

   The skewness describes the degree of asymmetery of the distribution about the mean. A distribution with positive skewness has an asymmetically long tail extending in the positive direction, while a distribution with negative skewness has an asymmetrically long tail in the negative direction.

2. Exceedance probability curves were calculated for current speed, longshore and cross-shelf components of current, and temperature.

3. The directional distribution of currents was obtained by dividing the data into 16 directional bins.

3. Currents

3.1 Current Speed and Direction

Basic statistics describing the hourly averaged current speed distribution are given below in Table 2. The average current speed at the top meter was 0.22 m/s, compared with only 0.13 m/s at the bottom meter. Current speeds at the top meter were also more variable, the standard deviation at the top meter being 0.15 m/s compared with 0.10 m/s at the bottom.

Table 2: Statistics of Current Speed (Units: m/s)

	N	Mean	Min	Max	SD	Var	Skew
Top current meter	4061	0.22	0.00	0.91	0.15	.021	0.86
Bottom current meter	3954	0.13	0.00	0.49	0.10	.009	1.17

Exceedance probability curves for the current speed are shown in Figure 1. The 50th percentiles (equivalent to the median value) were 0.11 and 0.20 m/s for top and bottom meters respectively.

The directional distribution of the hourly averaged current is shown below in Table 3, and also presented graphically in Figures 2 and 3. Directions shown are True and the width of each directional band is 22.5 degrees centered on the direction shown.

Table 3: Directional Distribution of Current

Direction	Top Meter		Bottom Meter	
	%	$|\bar{v}|$ (m/s)	%	$|\bar{v}|$ (m/s)
N	7.7	0.21	7.6	0.13
NNE	6.3	0.21	8.8	0.15
NE	2.1	0.09	5.8	0.13
ENE	0.8	0.07	3.3	0.09
E	0.8	0.05	2.5	0.07
ESE	0.8	0.06	2.0	0.06
SE	1.7	0.07	3.7	0.07
SSE	4.9	0.15	5.2	0.09
S	36.6	0.30	14.8	0.13
SSW	24.9	0.24	23.5	0.21
SW	4.7	0.13	7.1	0.10
WSW	2.2	0.09	4.0	0.08
W	1.8	0.08	2.4	0.08
WNW	1.1	0.07	2.5	0.07
NW	1.4	0.07	2.6	0.08
NNW	2.2	0.11	4.3	0.10

The dominance of longshore currents in the study area, due to the East Australian Current and the periodically reversing currents associated with coastal trapped waves, can be clearly seen in Figure 2. The most common current directions were to the South and SSW, (a total of 62% and 38% of the time for top and bottom meters respectively), and also to the North and NNE (a total of 14% and 16% for top and bottom meters). In Figure 3, it can also be seen that these directions also had the highest average current speeds, although this effect is more pronounced at the top meter.

It should be noted here that the data set included a long period of strong southerly currents, from September to November 1989. This was discussed in Griffin and Middleton (1990) and can be seen clearly in the time series plots in Appendix A. The persistent southerly currents were in part due to the presence of a large warm-core eddy on the shelf during November. The average current speeds in November 1989 were 0.44 m/s at the top meter, and 0.31 m/s at the bottom meter.

3.2 Longshore and Cross-Shelf Components

Separating the current into longshore and cross-shelf components gives an indication of the relative importance of the various physical forcing mechanisms in the study area.

Longshore and Cross-Shelf component statistics are given in Tables 4 and 5 below. Exceedance probability curves for the two components are shown in Figures 4 and 5.

Table 4:
Statistics of Longshore Component of Current (Units: m/s)

	N	Mean	Min	Max	SD	Var	Skew
Top current meter	4061	−0.15	−0.70	0.90	0.22	.047	0.61
Bottom current meter	3954	−0.05	−0.47	0.48	0.15	.022	−0.13

The mean longshore current was to the south for both meters. The standard deviation was greater than the magnitude of the mean current, indicating that the longshore component is directed northwards for a reasonable percentage of the time. This can be seen more clearly from the exceedance curves in Figure 4, which show that the longshore component is directed to the north about 22% of the time at the top meter, and about 37% of the time at the bottom.

Table 5:
Statistics of Cross-Shelf Component of Current (Units: m/s)

	N	Mean	Min	Max	SD	Var	Skew
Top current meter	4061	0.01	−0.24	0.20	0.06	.003	−0.19
Bottom current meter	3954	0.00	−0.24	0.25	0.06	.003	0.17

As would be expected from the results given in Section 3.1 above, the cross-shelf component was much weaker than the longshore component, with maximum current speeds of about 0.2m/s.

The average cross-shelf current was close to zero with a similar degree of variability at both meters.

3.3 Relationship Between Top and Bottom Current Directions

The results of a frequency analysis of the current directions recorded at top and bottom meters are given in Table 6. By far, the most common occurrence was for both top and bottom currents to be running between South and South-Westerly. The predominantly southerly currents at the top meter could be accompanied by currents from the whole range of possible directions at the bottom meter, whereas the converse was not generally the case.

Table 6: Relationship between Top and Bottom Current Directions

Top Direction	Bottom Direction N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
N	47	76	54	16	16	8	12	13	12	7	7	5	5	6	5	19
NNE	61	48	12	10	3	4	6	9	4	10	11	9	5	3	19	32
NE	11	5	0	1	1	0	2	2	7	3	5	6	11	8	6	11
ENE	7	2	0	0	0	0	1	1	2	3	2	1	0	4	4	4
E	4	3	1	0	1	0	3	1	3	1	3	1	3	0	0	5
ESE	3	1	0	0	0	0	1	1	4	2	2	2	1	4	3	5
SE	7	3	5	0	0	0	0	2	1	4	10	3	4	4	4	7
SSE	16	3	5	3	1	1	1	3	9	23	12	7	2	12	16	15
S	55	45	19	13	16	11	25	40	180	549	139	67	38	35	31	34
SSW	39	59	49	32	25	27	46	68	214	170	48	26	12	15	7	22
SW	9	21	23	13	11	11	18	14	12	11	10	5	4	4	4	2
WSW	4	3	13	12	5	3	9	5	12	5	6	1	0	1	0	2
W	4	6	1	10	7	1	5	4	6	6	2	1	2	2	0	1
WNW	1	5	2	9	3	2	3	4	3	2	0	2	1	1	0	0
NW	4	8	1	2	4	6	2	5	3	2	3	2	2	0	0	0
NNW	6	18	15	7	3	5	4	7	2	4	5	2	1	1	1	2

Number of data points: 3547

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4. Temperatures

As ocean temperatures are highly variable on a seasonal basis, overall statistics based on the temperatures from the Mk0 Reference Station must be interpreted carefully. This report includes temperatures measured from July to November, when ocean temperatures offshore from Sydney are generally lower than the yearly average, and stratification in the water column has not, on average, reached its maximum level.

The current meter temperature statistics are given in Table 7 below. Calculations based on the difference between the temperatures at the two metres have also been included as they provide a measure of the degree of stratification in the water column. On average, the temperature at the top meter was 1.5° greater than that at the bottom meter.

Table 7: Statistics of Current Meter Temperatures
(Units: °C)

	N	Mean	Min	Max	SD	Var	Skew
Top current meter	2356	17.7	15.6	20.4	1.1	1.2	0.11
Bottom current meter	2249	16.6	14.8	19.5	0.92	0.85	0.33
ΔT (Top - Bottom)	1841	1.5	-0.1	4.3	0.89	0.79	0.39

Exceedance probabilities of the current meter temperatures are given in Figures 6 and 7.

5. References

Griffin, D.A. and J.H. Middleton (1990), "Current, Water Temperature and Wind time-series, July 1989-April 1990. A brief report on data from the Mk0 Ocean Reference Station", *Unisearch Report prepared by Mathematics Oceanography Laboratory, UNSW*, July.

Webb A.T. and D.R. Cox (1991), "Sydney Deepwater Outfalls : Environmental Monitoring Program : Commissioning Phase : SDOSIM – A Monte Carlo Simulation Model", *AWACS Interim Report* 91/01/16 (in preparation).

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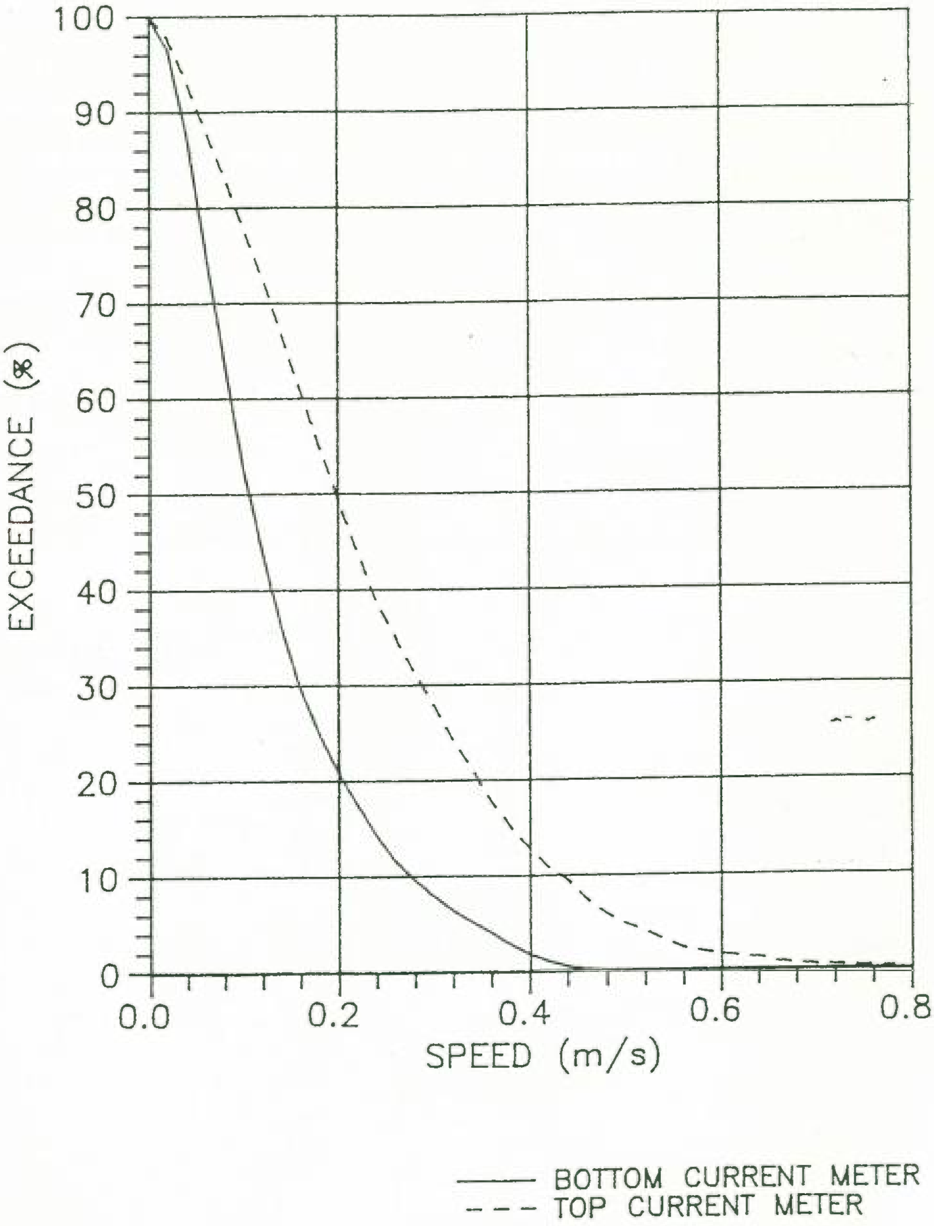

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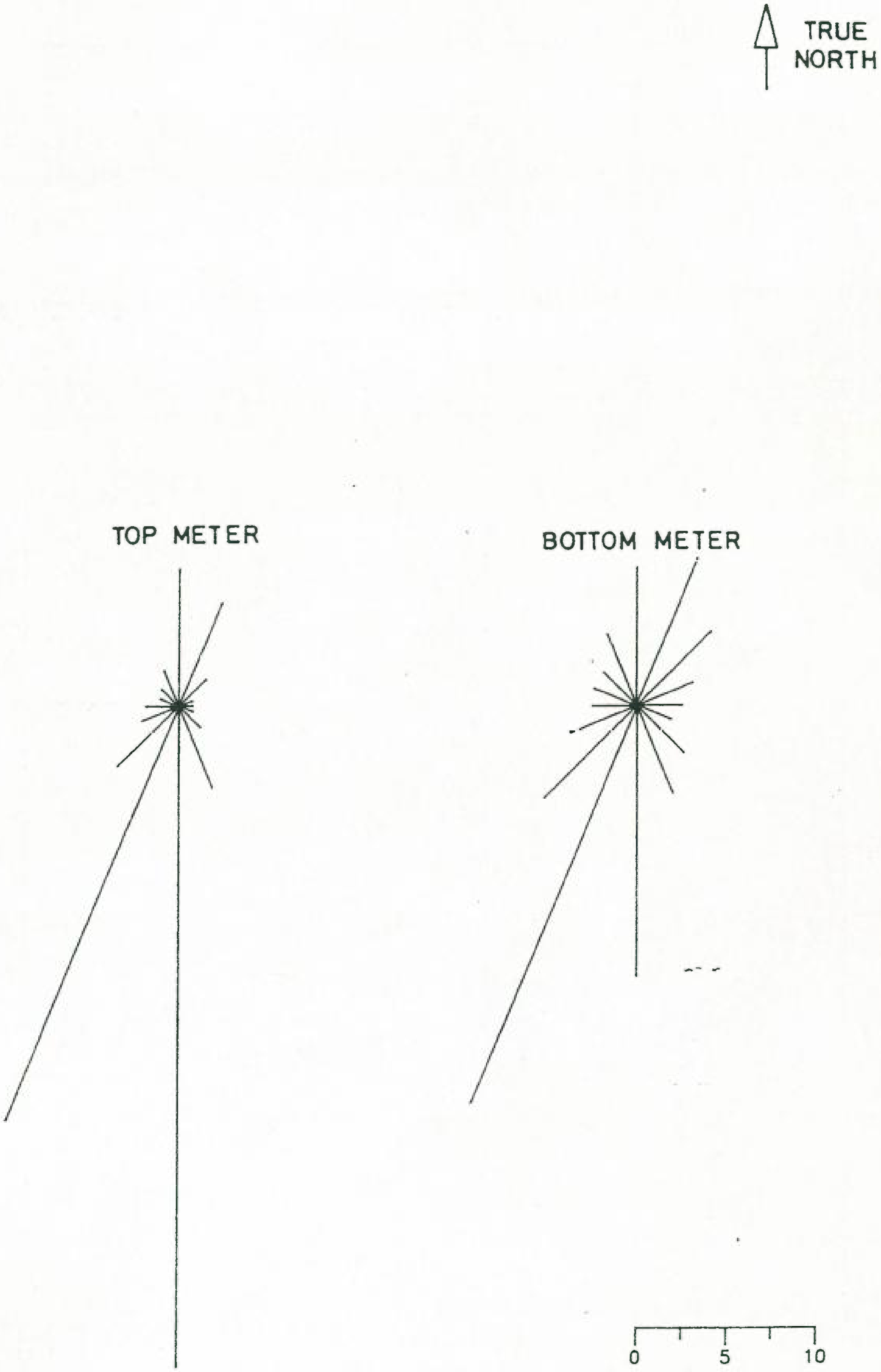
EXCEEDANCE PROBABILITY CURVES – CURRENT SPEED

FIGURE 1



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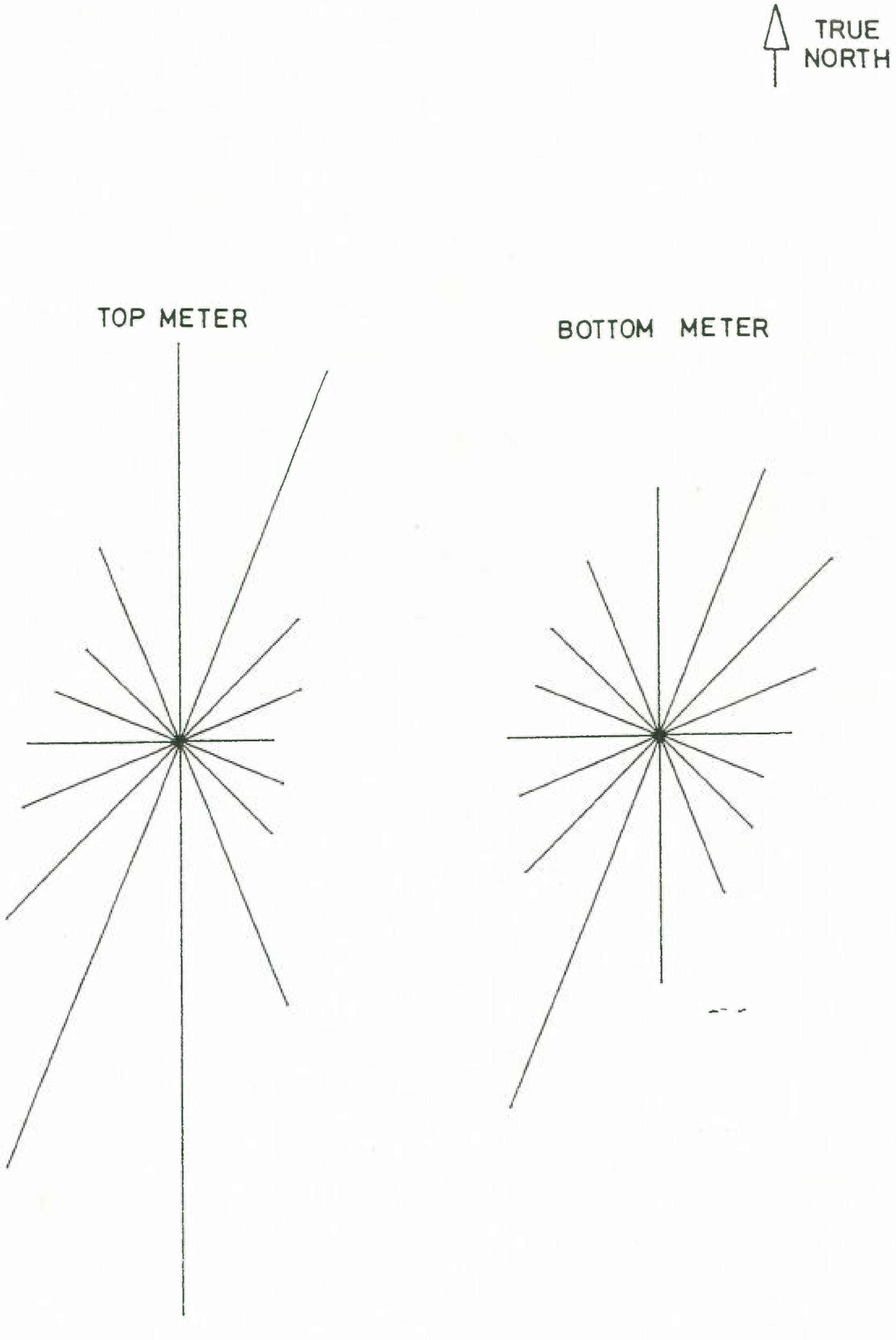
DIRECTIONAL DISTRIBUTION OF CURRENT

FIGURE 2



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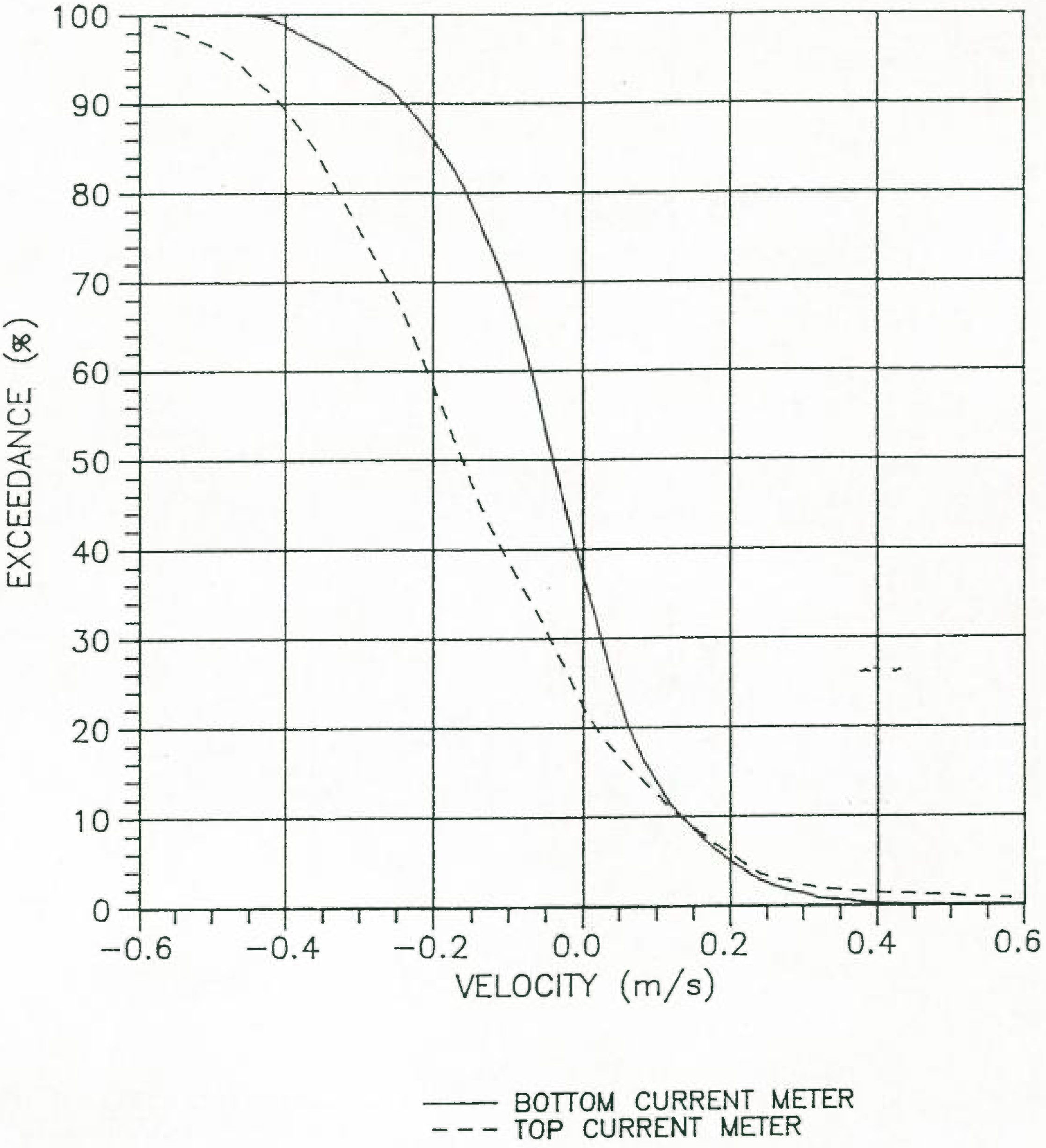
AVERAGE CURRENT SPEEDS

FIGURE 3



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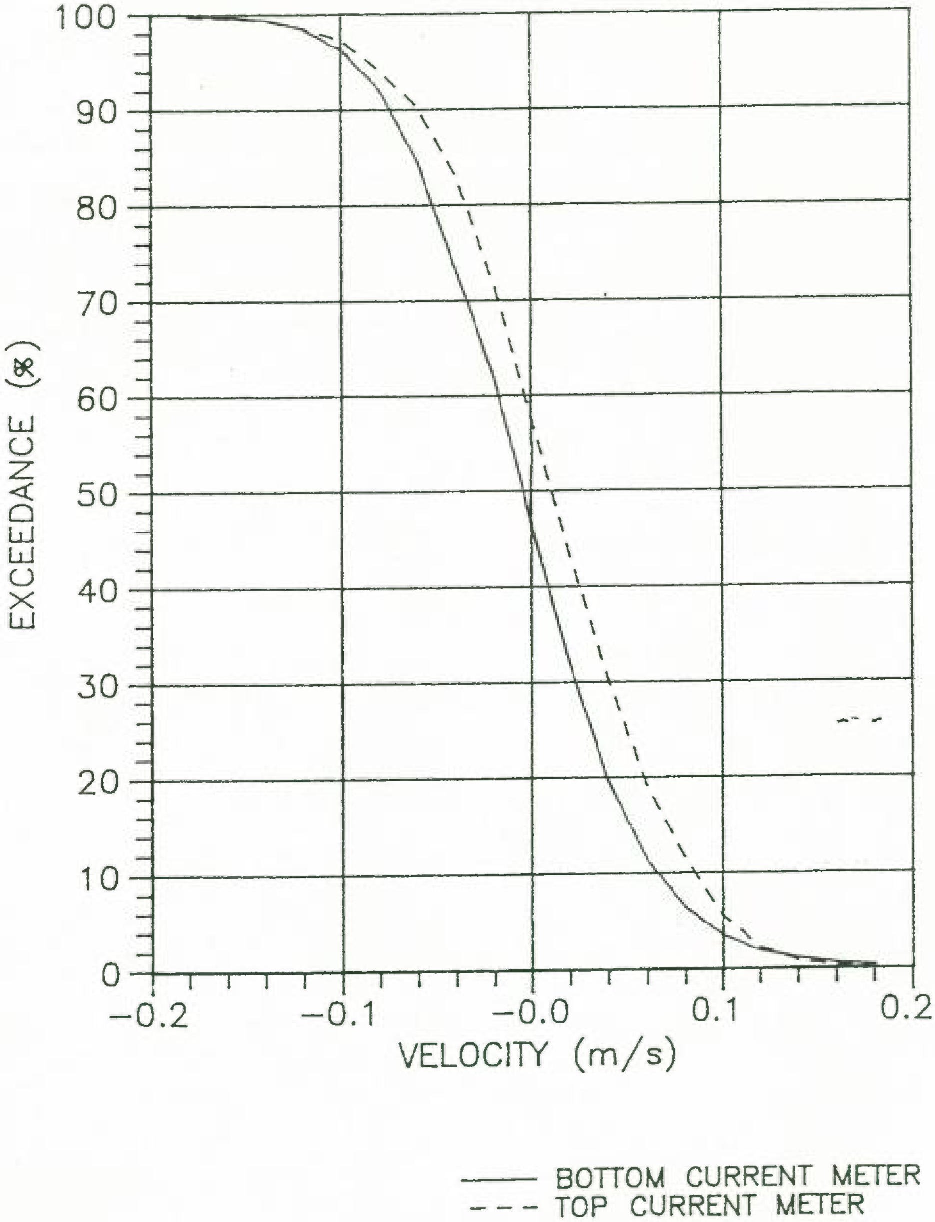
EXCEEDANCE PROBABILITY CURVES –
LONGSHORE COMPONENT OF CURRENT

FIGURE 4



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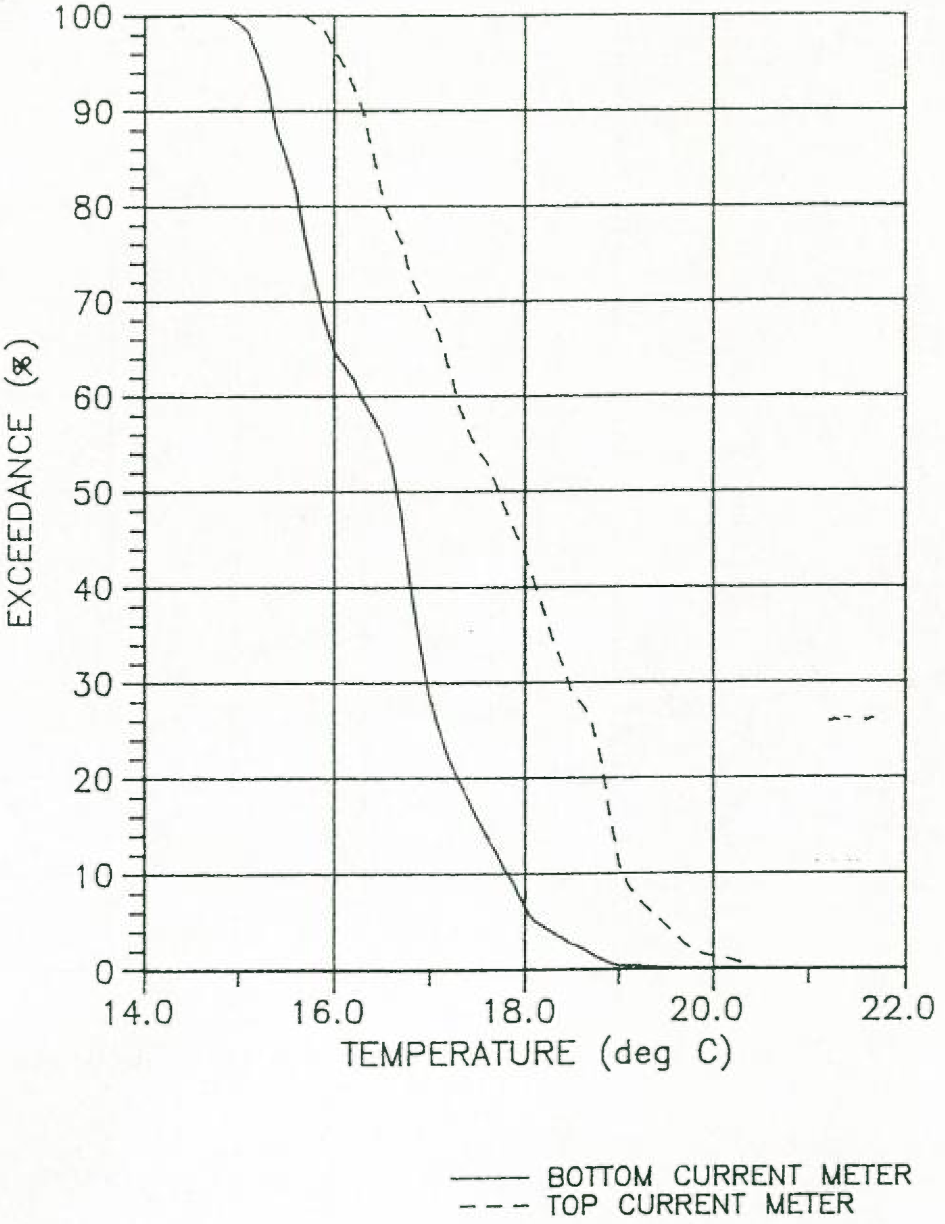
EXCEEDANCE PROBABILITY CURVES –
CROSS-SHELF COMPONENT OF CURRENT

FIGURE 5



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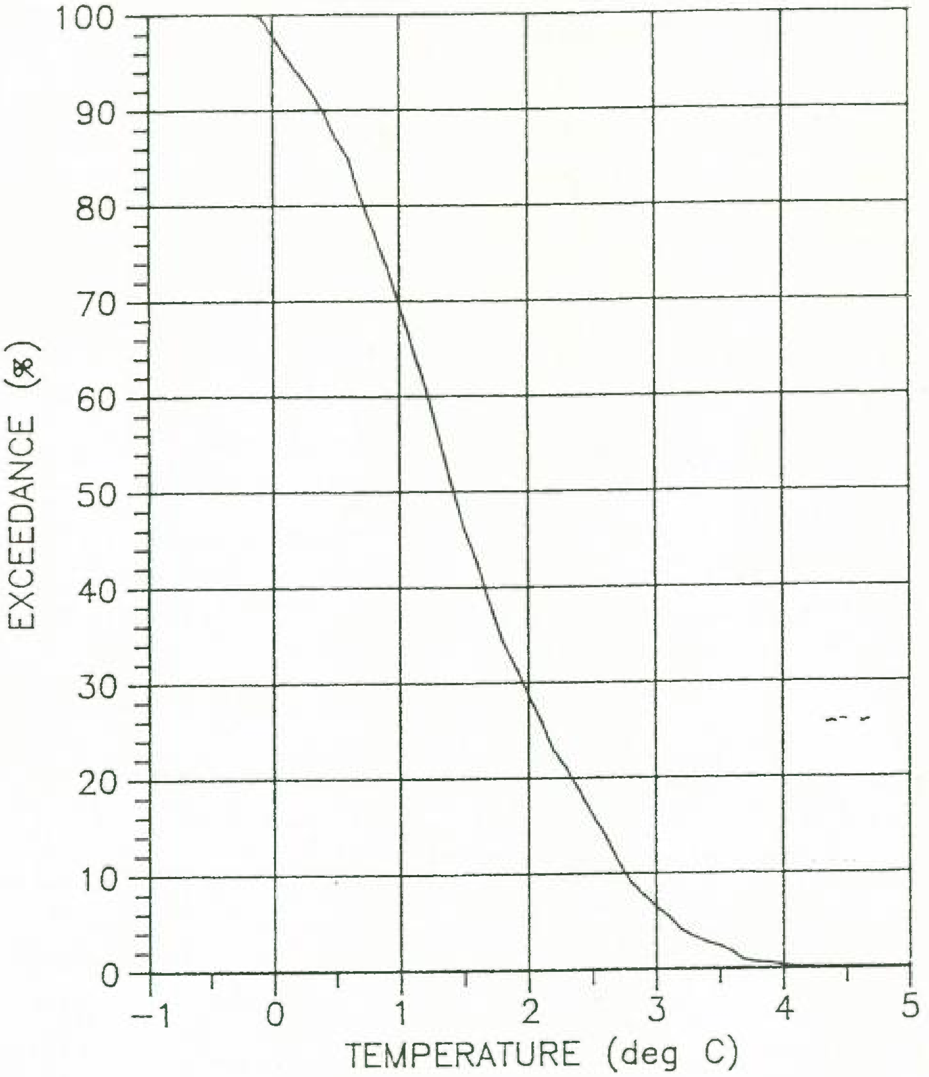
EXCEEDANCE PROBABILITY CURVES –
CURRENT METER TEMPERATURES

FIGURE 6



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EXCEEDANCE PROBABILITY CURVE –
DIFFERENCE BETWEEN TEMPERATURES
AT TOP AND BOTTOM CURRENT METERS

FIGURE 7

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APPENDIX A

CURRENT, WATER TEMPERATURE AND WIND TIME-SERIES
JULY 1989 – APRIL 1990.
A BRIEF REPORT ON DATA FROM THE MK 0 OCEAN REFERENCE STATION

by

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May 31, 1991
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Summary

Current velocity and water temperature data from the 'mk0' Ocean Reference Station located 3km off Clovelly are presented along with concurrent wind data from a high quality anemometer situated on the headland at La Perouse. The current velocity data are the first to include sufficient vertical coverage to reveal the structure of processes responsible for on-offshore transport in the Sydney nearshore region. Onshore surface flow is found to accompany offshore flow in the lower layer and an increase in the water temperature (particularly below the thermocline). A working hypothesis at this stage is that the wind-driven surface Ekman flux is reinforced by the Ekman bottom friction flux to produce the observed downwelling associated with southerly winds and/or northward currents. Conversely, upwelling is associated with northerly winds and/or southward currents. Other phenomena, including very strong southward currents due to an incursion onto the shelf of a warm-core eddy, and diurnal tidal currents are also evident in the data. Of particular note is the fact that the current at a depth of 50m in a total depth of 64m was observed to be substantially weaker than at 15m, where earlier measurement programs were concentrated. The main implication for effluent emmitted from the deepwater outfalls is that the effluent field is likely to be swept away at substantially reduced speeds (typically 0.1ms^{-1} when trapped at 50m) compared with those quoted in Water Board publicity,

Introduction

The 'mk0' Ocean Reference Station (ORS0) is a subsurface current meter mooring which was first deployed 3km east of Clovelly in 64m of water on 21 July 1989 (see Fig. 1). It is maintained by Lawson and Treloar Pty Ltd who service the meters approximately monthly. The current meters are S4 electromagnetic vector-averaging devices which store 5-minute averages of the current vector and the instantaneous temperature internally in RAM at 10-minute intervals. The S4s were at (nominal) depths of 15m and 47m prior to 19 December 1989 when the inclusion in the mooring line of a thermistor string necessitated the moving of the bottom S4 to a depth of 52m. In July/August 1990, the ORS0 is to be replaced by the ORS, a permanent surface telemetering mooring which will also feature anemometers. The highest quality wind data presently available for the Sydney coastal region is recorded at the La Perouse headland by Dr Robert Hyde of Macquarie University.

The purpose of this report is to present plots of the ORS0 and La Perouse data along with a brief discussion of the salient observable features. Other reports by UNSW Oceanography personnel prepared for the Environmental Monitoring Programme Pre-Commissioning Phase are listed in the References. In this report the discussion is divided into two sections according to the averaging interval applied to the data prior to plotting, since this determines the timescale of the processes concentrated upon. The report has the following sections:

1. **Data preparation.** Filtering, rotation to alongshore coordinates, etc.
2. **Long time scale phenomena.** The entire seven month data set is shown on one page with 12h resolution.
3. **Tidal time scale phenomena.** Hourly averaged data are plotted with one month of data per page.

1. Data preparation.

1.1 ORS0 data.

Current meter and thermistor string data were provided by Lawson and Treloar Pty Ltd following each servicing of the instruments. No editing of the data was required as no erroneous data were identified, except for two isolated temperature samples. We note, however, that the thermistor string temperatures seem to be 1°C higher than S4 temperatures, so the former are reduced here by 1° at the plotting stage.

Filtering to hourly values of the 10-minute current and temperature data was accomplished by a Fourier transform filter which sets to zero the spectral components having cyclic period less than two hours. Filtered and concatenated data files (in UNSW format) have been provided to AWACS. Current vector data are stored as eastward and northward components in ms^{-1}. Subsequent filtering to 12-hourly values is performed within the plotting program by calculating the centre-weighted running mean using a Tukey [(1+cos)/2] window with 12h half-amplitude width.

1.2 La Perouse data.

Hourly wind data were provided by Robert Hyde of Macquarie University using the meteorological convention of speed (ms^{-1}) and direction (°T) from which the wind is blowing. The data were reformatted to UNSW (oceanographic) convention (same as for current vectors). The stress (in Pascals, or N/m^2) on the sea surface was calculated following Large and Pond (1981) in the same fashion discussed by Griffin and Middleton (1990a). Wind velocity and stress data files in UNSW format have been passed on to AWACS.

1.3 Choice of alongshore axis.

It is preferable to display the data as alongshore and shore-normal components rather than as they are stored. This requires, however, that a subjective decision be made of the appropriate alongshore axis. We have chosen to use 15°T for the plots shown here, the alongshore component being labelled as V while the across-shelf (along 105°T) component is labelled U. This choice is necessarily subjective due to the complexity of the topography, an objective analysis of which would still be determined by the subjectively chosen extent of the analysis. The choice of 15° is based partly on an inspection of Fig. 1 and partly on the fact that that angle is a bisection of the principal axes of variability of the 15m and 50m current vectors. An incorrect choice of the alongshore axis results in a small amount of the real V variance appearing in U, the converse being less of a problem because V exceeds U for all motions of time scale longer than 12h. The amplitude of the erroneous U variance is given by $U'=V \tan \epsilon$ where ϵ is the error of the alongshore axis. For $\epsilon=5°$ and $V=0.4ms^{-1}$, $U'=0.035ms^{-1}$.

In the following plots, wind and current vectors are both drawn relative to the one alongshore axis. This may be mildly inappropriate due to the inevitable difference between the local topographic steering of winds and currents.

2. Long time scale phenomena.

The entire data set (filtered to 12h samples) is shown in Fig.2. Current and wind velocities are shown as vector plots oriented so that an alongshore velocity is drawn as a vector pointing up the page. The U and V components of the wind stress are plotted separately, as are the U components of the current velocity at 15m and 50m, while the V components of the current are overplotted. Temperature at 15m and 50m, recorded by the S4s, and at two intermediate depths, recorded by two of the eleven thermistors, are also overplotted. Time marker lines are drawn at times of particular interest, showing, for example, when Environmental Monitoring Programme Process Oriented Experiments (POEs) or Water Quality Cruises (WQCs) were in progress. The exact times marked and their significance are as follows:

9:00 3/8/89	Commence POE near North Head Outfall site
16:00 3/8/89	Complete POE near North Head Outfall site
12:00 24/1/90	WQC
12:00 31/1/90	WQC
8:00 15/2/90	Commence POE near Bondi Outfall site
15:00 15/2/90	Complete POE near Bondi Outfall site
12:00 23/2/90	WQC
12:00 2/3/90	WQC
12:00 6/3/90	An oil slick noted a few km offshore from Bondi
17:00 6/3/90	Oil impacts Bondi and Tamarama Beaches
12:00 11/4/90	WQC

The data are also shown in Figures 3a and 3b which include plots of the 'pseudo trajectory' taken by tracer material moving with the velocity recorded at the ORS0. As a representation of the trajectory taken by a particle originating at the ORS0 the calculation (which is simply an integration of the velocity data with respect to time) must be seen as being only a crude indicator because it assumes that the velocity field is spatially homogeneous. A more accurate interpretation of the plots is that they provide a measure of the 'length' of water to have swept past the current meter during a given time interval. The X (positive along 105°T) and Y (positive along 15°T) coordinates (km) of the particle tracked are plotted separately, shifts of the (arbitrary) origin being made by the plotting program to contain the plot within certain bounds.

Comments on individual quantities.

The La Perouse wind data clearly show the well established tendency for the strongest winds at Sydney to come from either the south or the west. August and September 1989 could be characterised by winds with a predominantly offshore component but from November 1989 through April 1990 the wind usually had an onshore component, with obvious consequences for the transport of floatables released offshore.

Thermistor data from the Ocean Reference Station vividly dispel the notion one might have that the temperature profile of waters off Sydney follows a simple annual cycle. Superimposed on the annual cycle is variability due to a host of physical processes. The data clearly show that the temperature difference between depths of 15m and 50m routinely fluctuates between zero and the annual average on time scales of a few days. Vertical motion of the thermocline position due to wave-like or horizontal advective phenomena seem to dominate vertical mixing processes because the stratification re-appears as quickly as it disappears.

The V component of the current was clearly generally southward between August and November, the 15m current being more so than the current at 50m, but 'weather band' variability on time scales of a few to perhaps ten days was equal in amplitude to the monthly means of $\approx 0.2\text{ms}^{-1}$. From December through to April, however, the monthly mean current was much reduced, being weakly southward at 15m but weakly northward at 50m. Weather band variability was high during the period, especially at 15m depth in February and March 1990 when changes of V of up to 1ms^{-1} occured over periods of a day or two. February 1990 was the wettest February on record, the greatest single downpour occuring on 3/2/90. Strong currents could well be associated with the formation of a highly mobile surface layer of comparatively fresh water, as discussed by Griffin and Middleton (1990c).

The Y coordinate of tracked particles at 15m was largely controlled by the mean southward advection from August to November 1989. Through January 1990, however, the lack of a strong mean flow resulted in particles released in early January returning to the origin in late January, having completed several 40km excursions. Advection at 50m was substantially less than at 15m, for the duration of the data set. The total southward displacement from 21 July to 30 October was only 320km and from 19 December to 4 April the net advection was only 150km, to the north, having returned to the origin briefly in early March. The intervening period in November, however, saw 300km of water sweep past the lower meter.

The U component of the current must be interpreted more carefully because of the problem with having to subjectively choose the alongshore axis. Most of that problem can be avoided, however, if we focus attention on the *difference* between the 15m U and the 50m U (provided, of course, that the compasses of the two instruments can be trusted, which we believe to be the case). Both Us are clearly much weaker than the Vs, 0.1ms^{-1} being a typical peak 12h average. An important point to note is that the 15m U tends to be directed offshore when the current is to the south, and onshore when the current is to the north, while the 50m U does the opposite. This tendency could be dismissed as compass miscalibration but the observation is in accord with other evidence as discussed below.

The quantity requiring the most careful interpretation is X, the integral of U. This is demonstrated most easily by considering the continuity equation for a two layer system in a flat bottomed ocean. Assuming that there is negligible mass flux across the interface between the layers and considering first the case for when the alongshore flow is non-divergent, or uniform in the alongshore direction, we can write $Xh = Zd$, where h is the thickness of the layer with velocity U, d is the distance to the coast and Z is the vertical isotherm displacement. Substituting $h=30$m and $d=3$km, we find that fluctuations of X having amplitudes of 3km correspond to thermocline excursions of 30m, ie complete removal of one layer from the nearshore zone. Figures 3a and 3b show that 3km fluctuations of X in one day are routine, but these are not always accompanied by massive thermocline displacements.

Weather band dynamics- U, V, T and wind correlations.

It is not the purpose of the present report to extensively analyse the data so comments here are confined to correlations which are self-evident in the time series plots. The most striking of these is the correlation of temperature with V. On almost all occasions that the alongshore flow swung to the north, the temperature (particularly at 50m) was observed to increase, while periods of intensified southward flow are clearly associated with temperature decreases. An explanation of this behaviour that is suggested by the correlation of U with V mentioned above is that northward flow is associated with downwelling of the thermocline due to onshore flow in the upper layer and offshore flow in the lower layer, while the opposite occurs during southward flow. Further evidence that this sort of circulation occurs is provided by the observed tendency of the existing cliff-face outfall plumes to remain clearer of the beaches when they head southward than when they head northward. There are two potentially contributing factors to this sort of dynamics which are closely related. One is the Ekman transport due to bottom friction which will cause the current in the bottom Ekman layer to be directed to the right with respect to the flow above. The other is the surface wind-driven Ekman transport which is to the left of the direction in which the wind is blowing. Since northward currents are usually accompanied by northward winds (Griffin and Middleton, 1990b), the upwelling or downwelling caused by the two sorts of Ekman dynamics tends to coincide and reinforce. Note, however, that the applicability of these considerations has not yet been conclusively established and should only be treated as a working hypothesis at this stage. In particular, the relative importance of the two forcing mechanisms proposed has not yet been assessed, although the general lack of strong winds at Sydney, compared to the energetic currents, is conducive to forcing by bottom friction dynamics being of greater influence.

Other processes doubtlessly also contribute to the variabilty of the thermocline position. Of the weather band phenomena which lead to thermocline displacements, Coastal Trapped Waves have recently received the greatest attention. These are waves which owe their existence to the rotation of the earth and are manifest across the entire continental shelf, the greatest thermocline excursions occuring over the continental slope. In the nearshore zone, however, their primary influence is to produce alongshore flow. The task remaining is to understand the secondary circulation that they drive in the nearshore zone.

East Australian Current influences.

Ocean temperature maps produced weekly by the Hydrographic Office of the R.A.N. provide valuable assessment of East Australian Current (EAC) behaviour off south-eastern Australia. A comparison of the the ORS0 data with the R.A.N. maps reveals a clear correspondence of EAC activity with the observed Sydney nearshore current. The most obvious correspondence between the two data sets occured when a warm-core eddy commenced to pinch off from the main flow (30/10/89 map), moved up onto the continental shelf (6/11/89 map) and remained there a while (13/11/89 map, reproduced here as Fig. 4) before rebounding back to the deep ocean (20/11/89, 27/11/89 maps). The eddy then proceeded back up onto the shelf (4/12/89 map) off Wollongong and advected southwards, appearing off Jervis Bay in the following (11/12/89) map. Unfortunately, the latter stages of the eddy's influence at Sydney were not recorded by the ORS0 due to servicing problems, but the early stages are clearly heralded by the onset of strong, steady southward flow during the first half of November, a period when 500km of water swept past the meter at a depth of 15m. The effluent field most probably could not have entered the main body of the eddy but would have been driven southward along the continental shelf until the influence of the eddy was no longer felt. It is unlikely that effluent would have maintained the velocity recorded at Sydney, and thus would not have become wrapped halfway around the eddy, or transported to Bass Strait, as Fig. 3a might suggest. It is also noteworthy that during the first half of November the greatest sustained across-shelf currents (leading to rapid changes of X) were observed, yet the temperature data show only moderate variability. The sustained offshore flow at 15m and onshore flow at 50m imply (from continuity considerations mentioned above) that the alongshore velocity V must have been divergent in the upper layer but convergent in the lower layer.

3. Tidal time scale phenomena.

The data set is replotted again in Figures 5a to 5g on an expanded time axis, at hourly resolution. Tidal currents are now apparent, being most clearly distinguishable during early August 1989. Tidal analyses have not yet been performed at UNSW on the ORS0 data but the tidal currents closely resemble those evident in the Caldwell Connell 1984-1985 data. Analyses of those data revealed that tidal currents off Sydney are not directly associated with the rise and fall of sea-level, except near enclosed waters. Instead, the (predominantly diurnal) current oscillations are due to the passage of tidal Coastal Trapped Waves (CTWs) past Sydney. These waves are short-wavelength ($\sim$270km) versions of the wind driven CTWs which are largely responsible for the weather band variability, travelling northwards at the same phase speed of about $3ms^{-1}$. Oscillations of V due to the waves have amplitudes of about $0.1ms^{-1}$during springs, but note that the spring-neap cycle is not well defined, explaining why earlier analyses of tidal currents off Sydney (using conventional narrow banded analysis procedures) failed to detect the waves. It appears, from the 1.5d to 2.5d lag of the spring-neap cycle behind that of the sea-level, that the waves have travelled perhaps 600km, putting their generation region in Bass Strait. Along the way, they become phase shifted and variably attenuated by interactions with the larger scale flow features. This hypothesis requires further testing but no other explanation is otherwise readily apparent for the irregularity of the signals. The importance of tidal variability of V to the Environmental Monitoring Program is with regard to the interpretation of fieldwork measurements designed to verify the nearfield dilution models. This is because the tidal CTWs are a potentially easily modelled major contributor to modulation of the prevailing current on time scales comparable with the duration of fieldwork.

Other dynamical processes (internal semi-diurnal tides, directly wind driven transients, turbulence generated either at the coast or by instabilities of the flow) are no doubt also important on such time scales, but present much greater challenges to the modeller.

DRAFT

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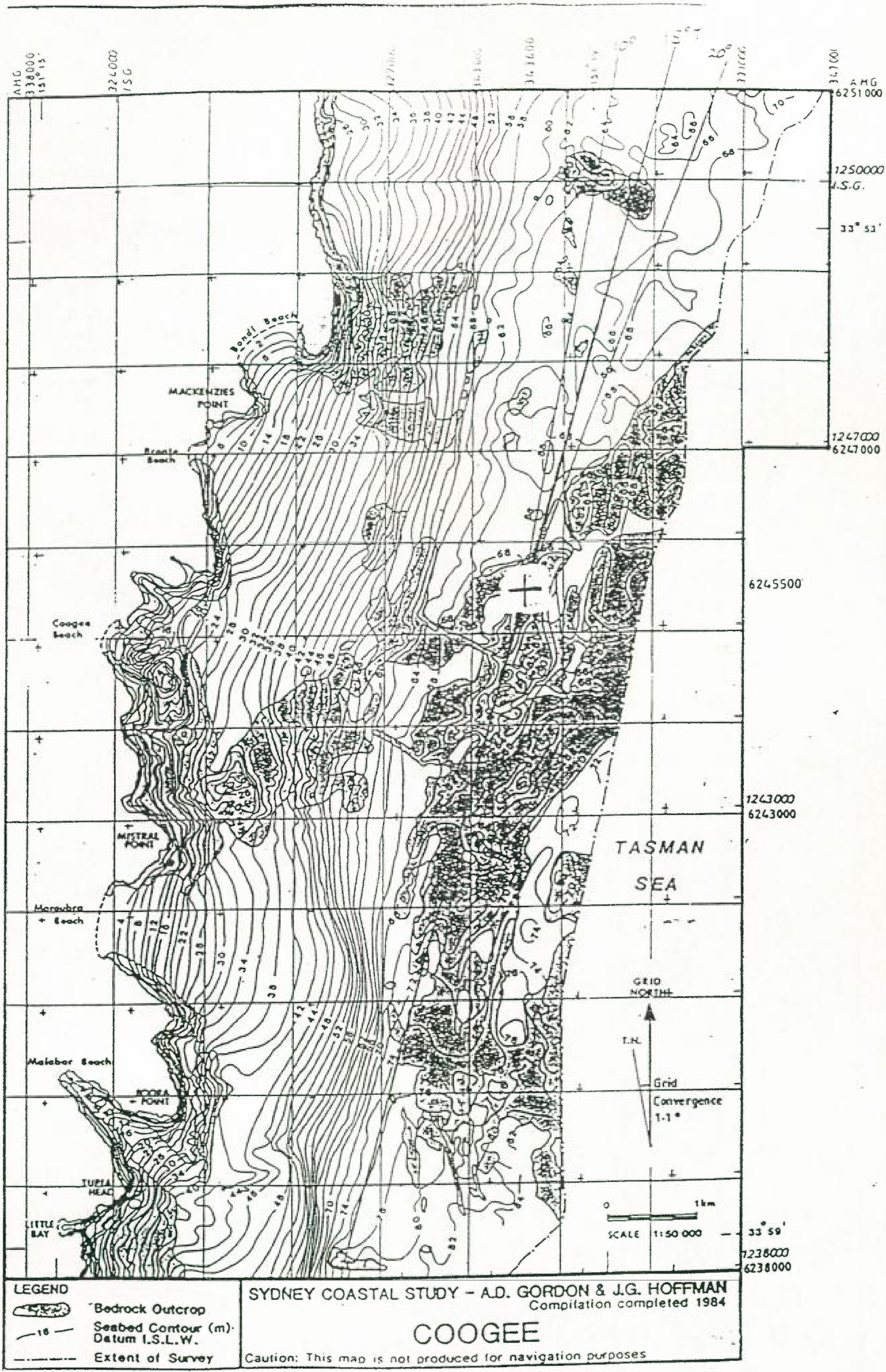

AMG 338000 151°15'
324000 ISG
AMG 6251000
1250000 I.S.G.
33° 53'
1247000 6247000
6245500
1243000 6243000
1238000 6238000
33° 59'
Bondi Beach
MACKENZIES POINT
Bronte Beach
Coogee Beach
MISTRAL POINT
Maroubra Beach
Malabar Beach
BOORA POINT
TUPIA HEAD
LITTLE BAY
TASMAN SEA
GRID NORTH
T.N.
Grid Convergence 1.1°
0
1km
SCALE 1:50 000
LEGEND
Bedrock Outcrop
Seabed Contour (m) Datum I.S.L.W.
Extent of Survey
SYDNEY COASTAL STUDY - A.D. GORDON & J.G. HOFFMAN
Compilation completed 1984
COOGEE
Caution: This map is not produced for navigation purposes

Fig. 1

Fig. 2

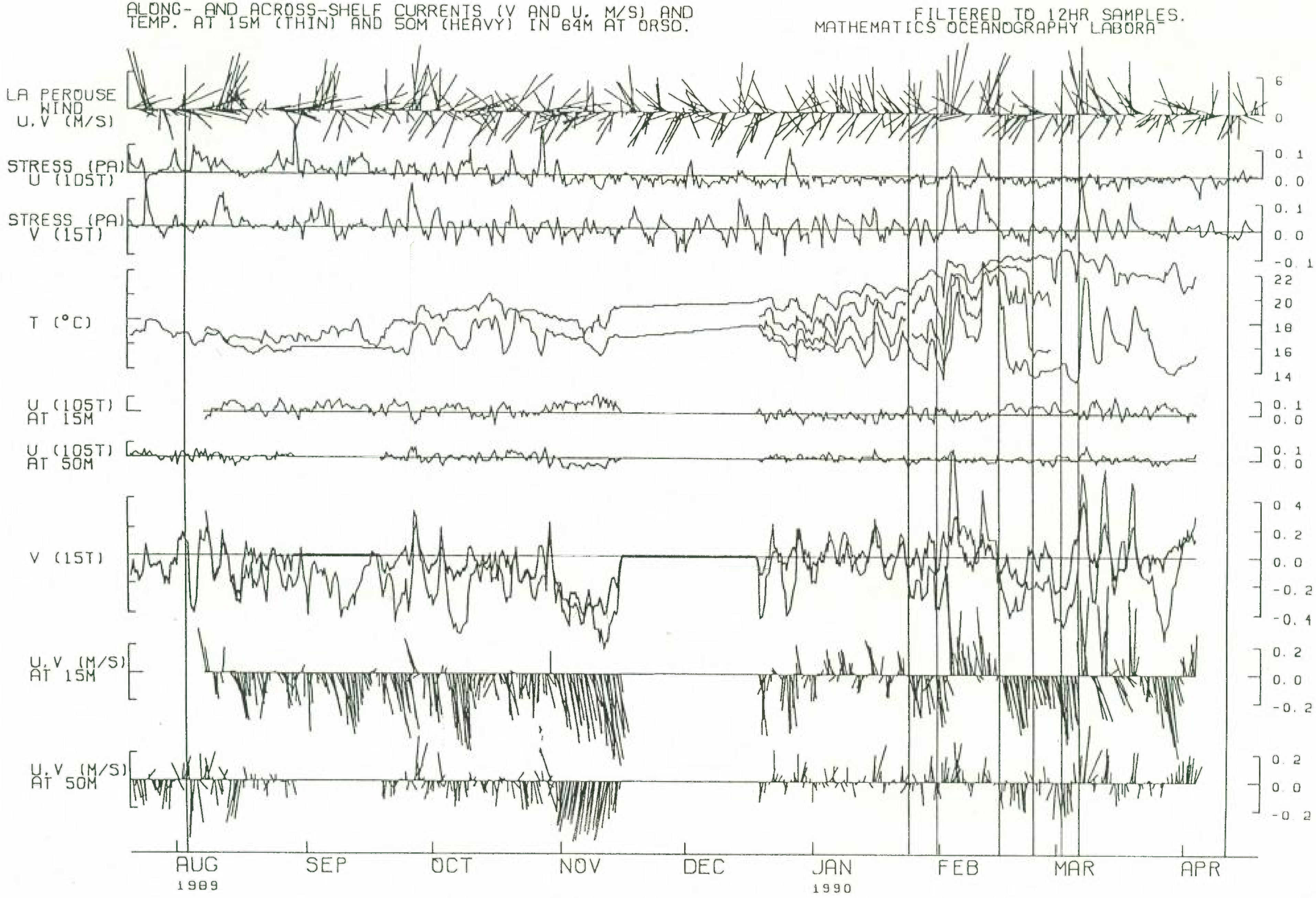

ALONG- AND ACROSS-SHELF CURRENTS (V AND U, M/S) AND
TEMP. AT 15M (THIN) AND 50M (HEAVY) IN 64M AT ORSO.
FILTERED TO 12HR SAMPLES.
MATHEMATICS OCEANOGRAPHY LABORA
LA PEROUSE WIND U,V (M/S)
6
0
STRESS (PA) U (105T)
0.1
0.0
STRESS (PA) V (15T)
0.1
0.0
-0.1
T (°C)
22
20
18
16
14
U (105T) AT 15M
0.1
0.0
U (105T) AT 50M
0.1
0.0
V (15T)
0.4
0.2
0.0
-0.2
-0.4
U,V (M/S) AT 15M
0.2
0.0
-0.2
U,V (M/S) AT 50M
0.2
0.0
-0.2
AUG
1989
SEP
OCT
NOV
DEC
JAN
1990
FEB
MAR
APR

Fig. 3a

PSEUDO TRAJECTORY (KM) OF PLUME AT 15M DEPTH.
TEMPERATURE (15 AND 50M) AND VELOCITY AT THE MKO OCEAN
REFERENCE STATION (OFF CLOVELLY, WATER DEPTH 64M).

FILTERED TO 12HR SAMPLES.
MATHEMATICS OCEANOGRAPHY LABORATORY UNSW

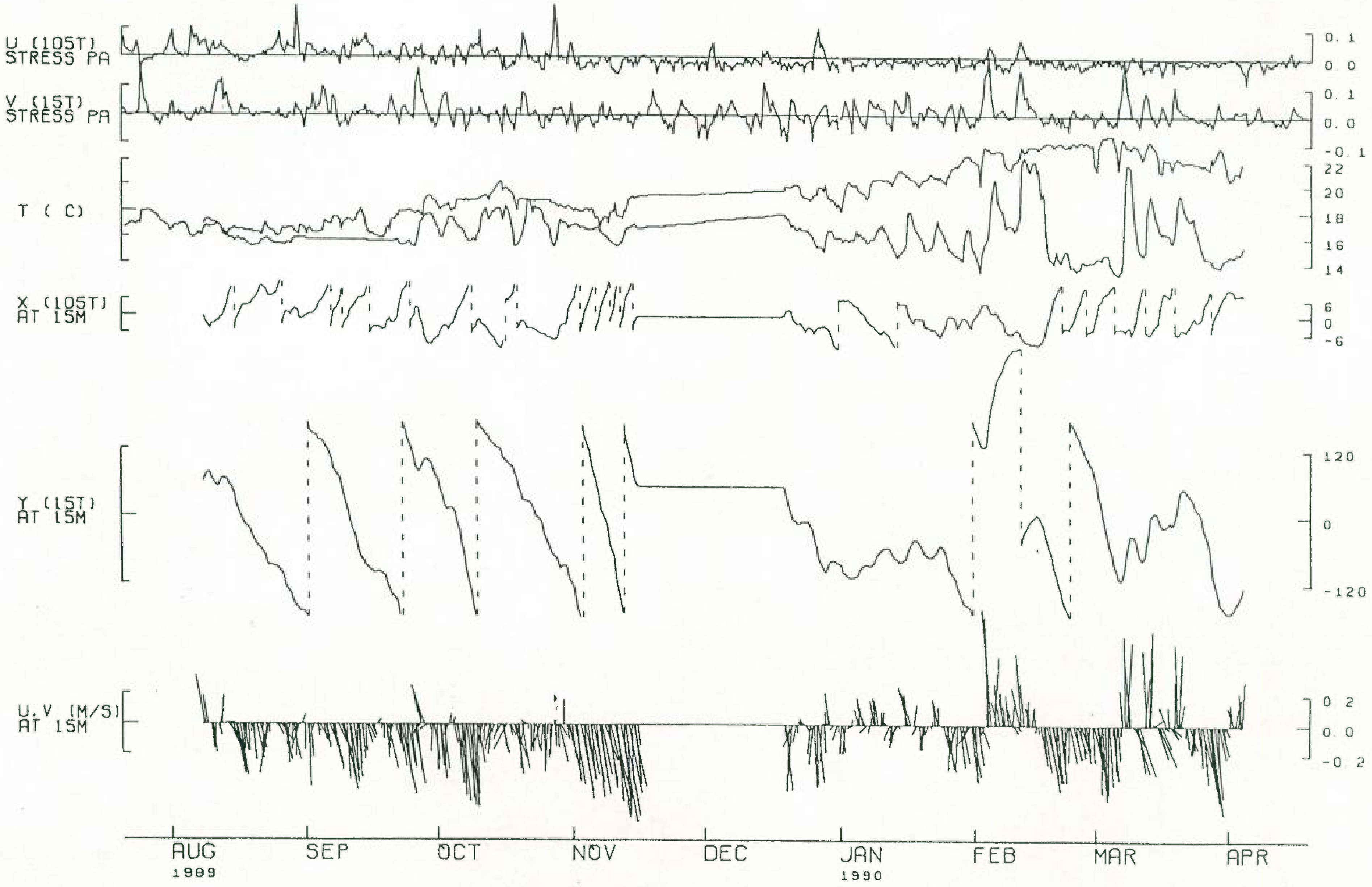
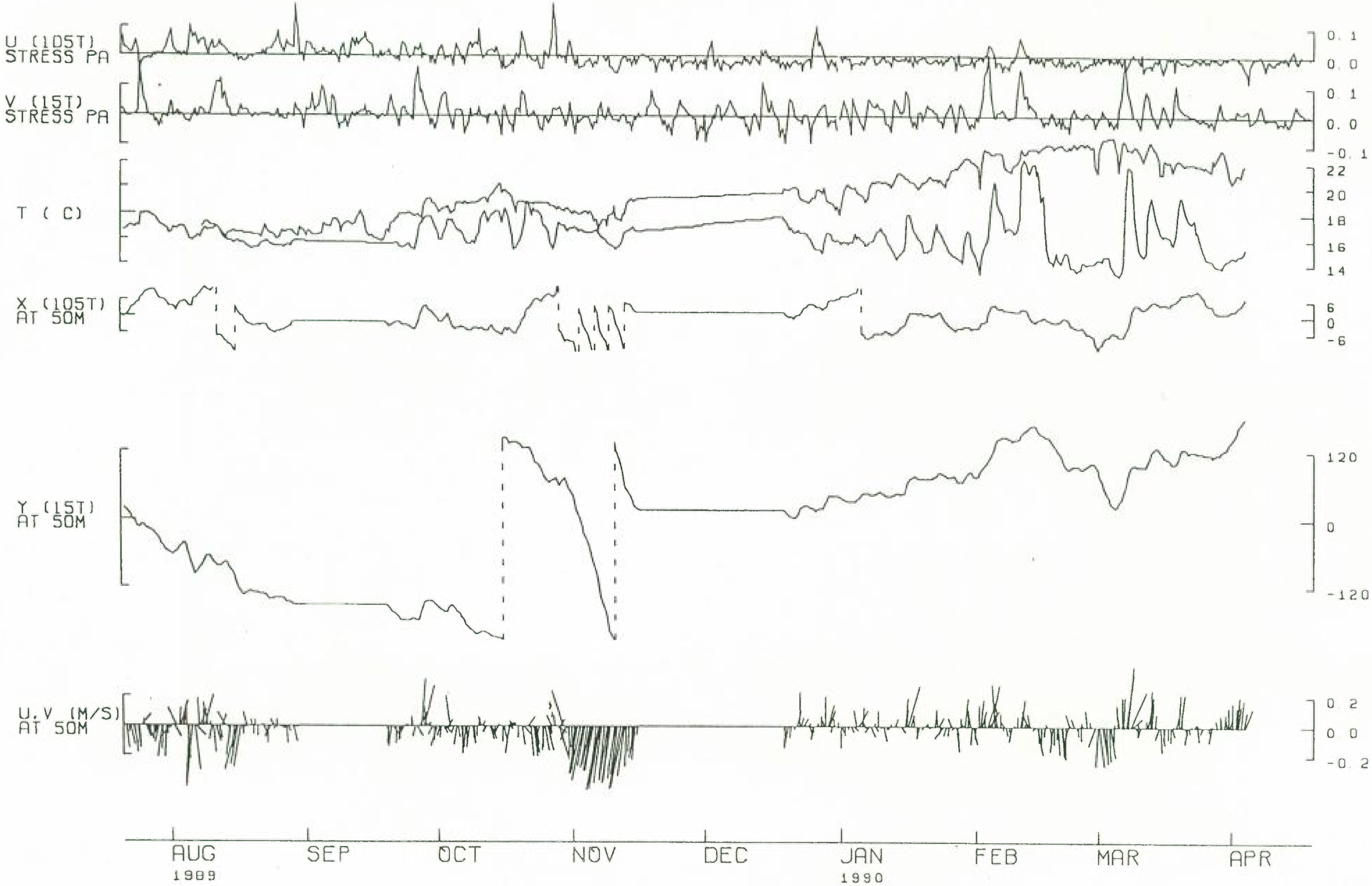


Fig. 36

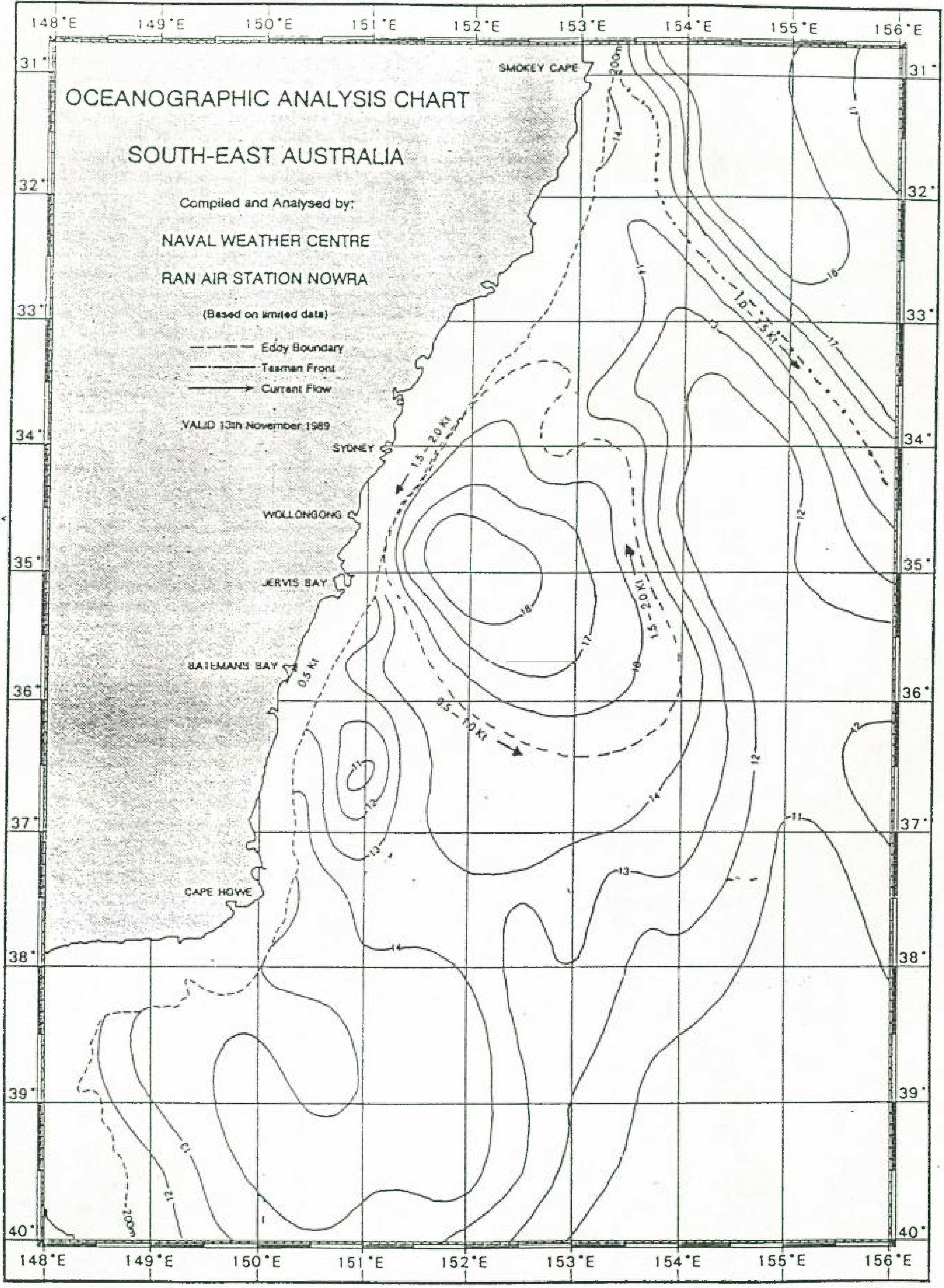
PSEUDO TRAJECTORY (KM) OF PLUME AT 50M DEPTH.
TEMPERATURE (15 AND 50M) AND VELOCITY AT THE MKO OCEAN
REFERENCE STATION (OFF CLOVELLY, WATER DEPTH 64M).

FILTERED TO 12HR SAMPLES.
MATHEMATICS OCEANOGRAPHY LABORATORY UNSW



DO 474

250m ISOTHERMS (°C)

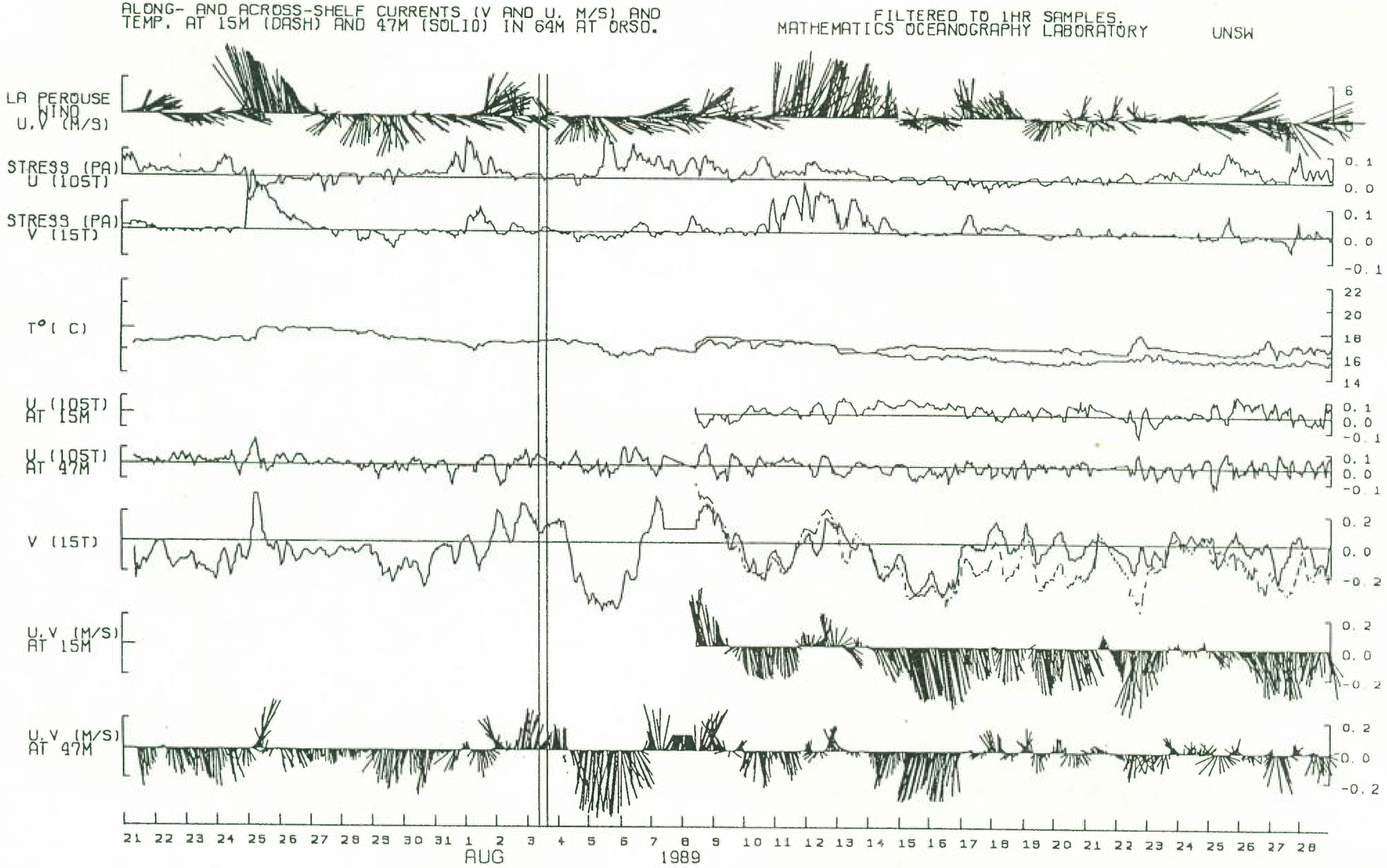


Produced by the Hydrographic Office R.A.N.

DO 474

Fig. 4

Fig. 5a


ALONG- AND ACROSS-SHELF CURRENTS (V AND U, M/S) AND
TEMP. AT 15M (DASH) AND 47M (SOLID) IN 64M AT ORSO.
FILTERED TO 1HR SAMPLES.
MATHEMATICS OCEANOGRAPHY LABORATORY
UNSW
LA PEROUSE WIND U,V (M/S)
6
0
STRESS (PA) U (105T)
0.1
0.0
STRESS (PA) V (15T)
0.1
0.0
-0.1
T° (C)
22
20
18
16
14
U (105T) AT 15M
0.1
0.0
-0.1
U (105T) AT 47M
0.1
0.0
-0.1
V (15T)
0.2
0.0
-0.2
U,V (M/S) AT 15M
0.2
0.0
-0.2
U,V (M/S) AT 47M
0.2
0.0
-0.2
21
22
23
24
25
26
27
28
29
30
31
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
AUG
1989

ALONG- AND ACROSS-SHELF CURRENTS (V AND U, M/S) AND TEMP. AT 15M (DASH) AND 47M (SOLID) IN 64M AT ORSO.

FILTERED TO 1HR SAMPLES.
MATHEMATICS OCEANOGRAPHY LABORATORY UNSW

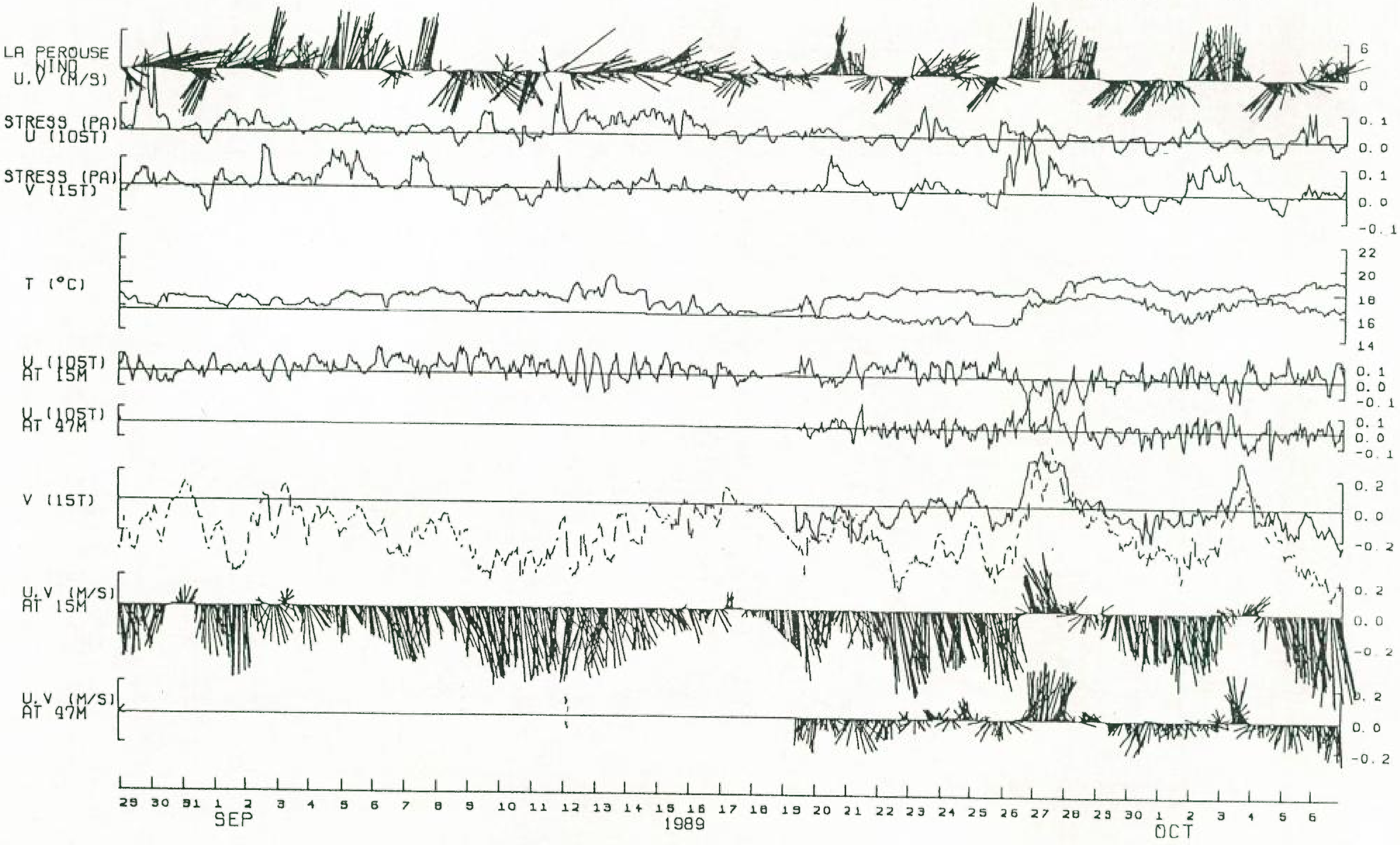
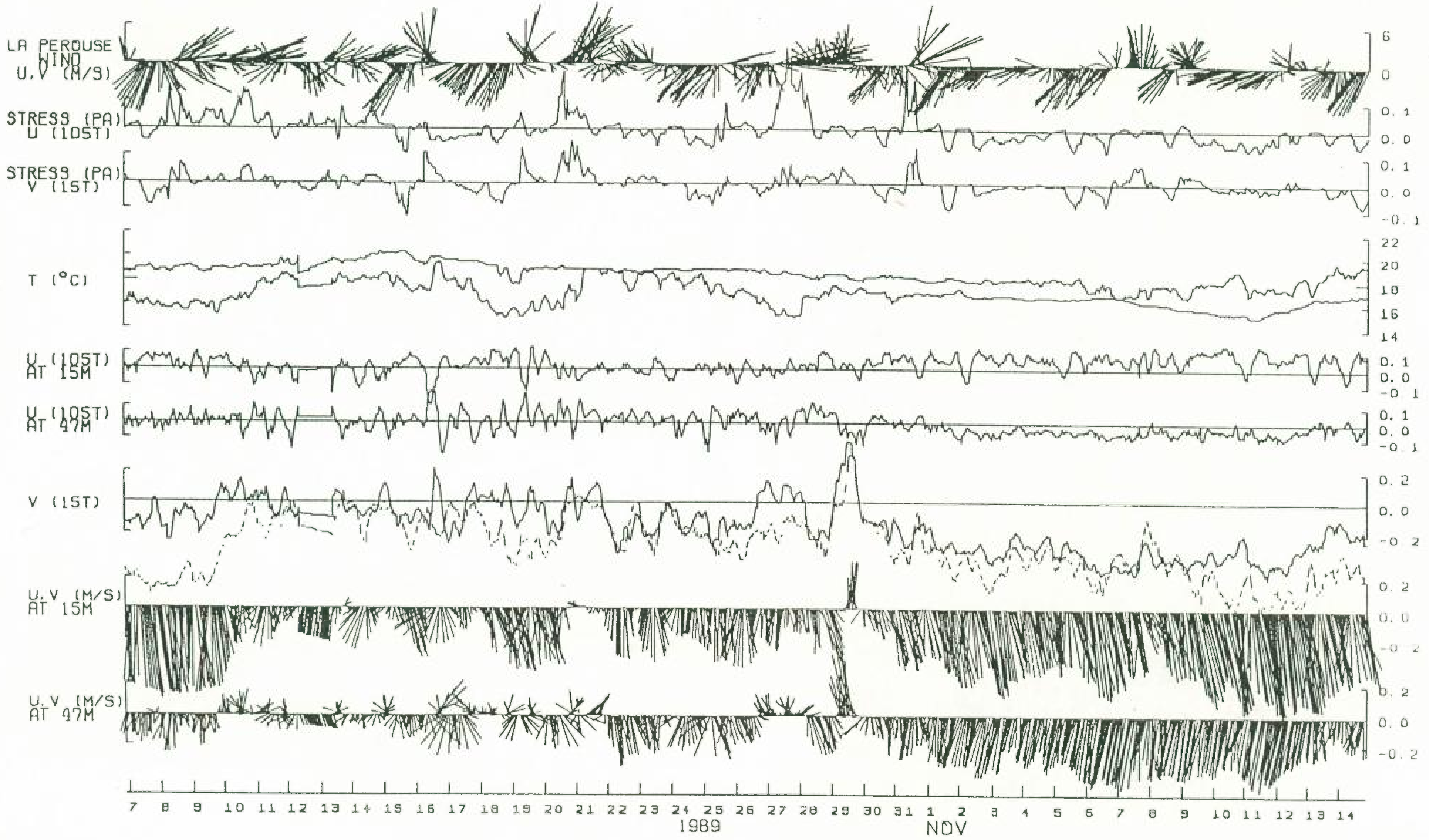


Fig. 5b

Fig. 5c

ALONG- AND ACROSS-SHELF CURRENTS (V AND U. M/S) AND
TEMP. AT 15M (DASH) AND 47M (SOLID) IN 64M AT ORSO.

FILTERED TO 1HR SAMPLES.
MATHEMATICS OCEANOGRAPHY LABORATORY UNSW



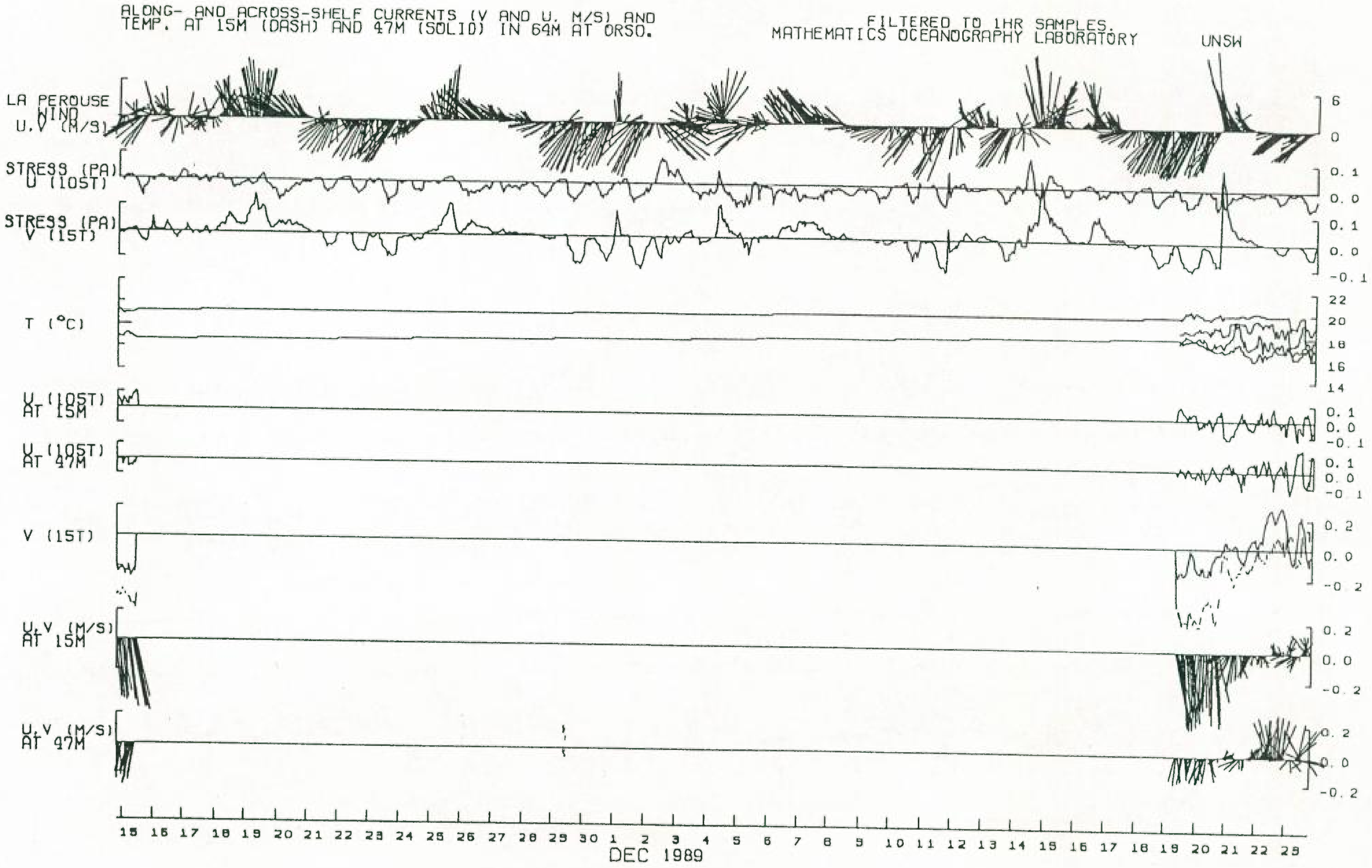
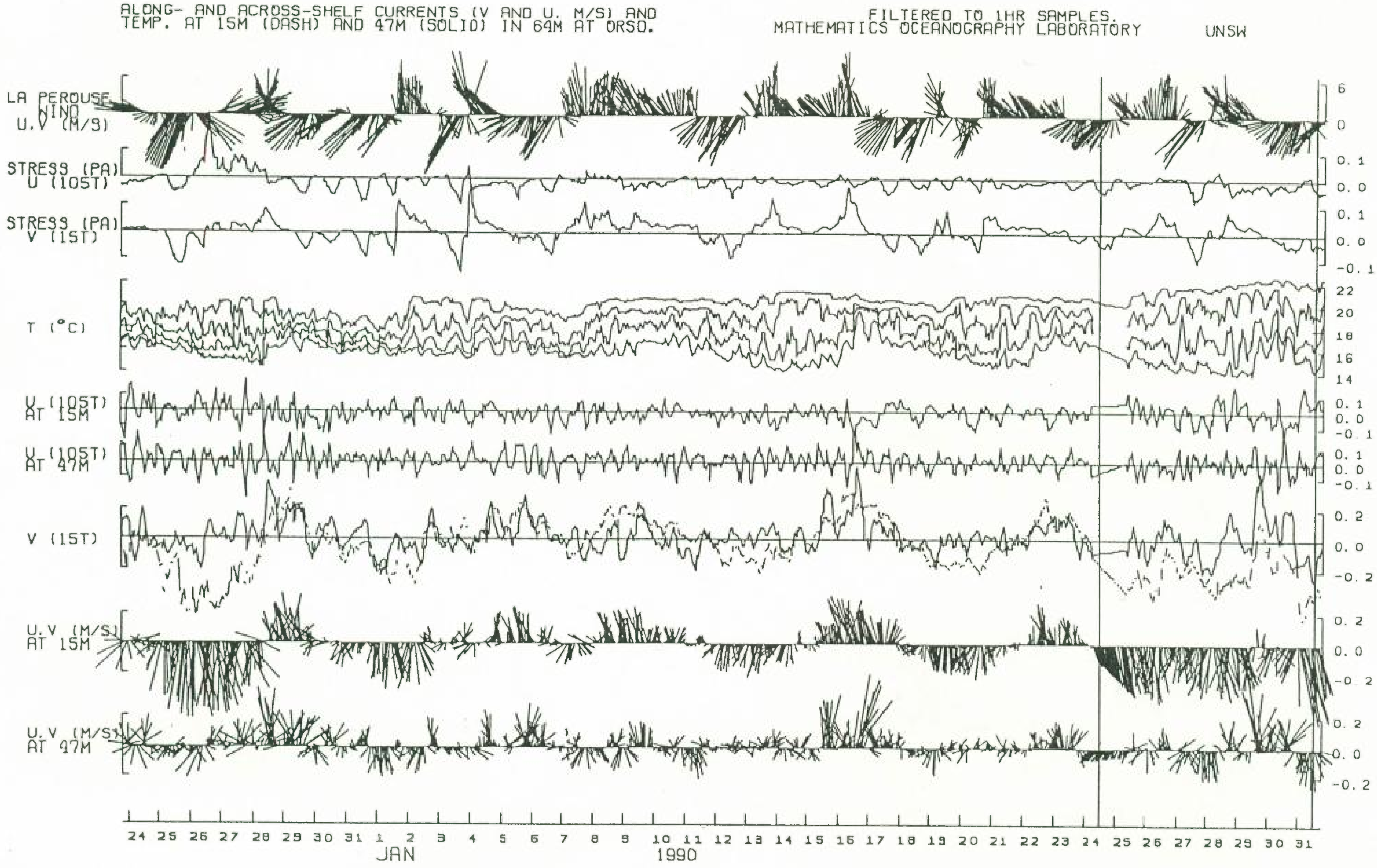

ALONG- AND ACROSS-SHELF CURRENTS (V AND U. M/S) AND
TEMP. AT 15M (DASH) AND 47M (SOLID) IN 64M AT ORSO.
FILTERED TO 1HR SAMPLES.
MATHEMATICS OCEANOGRAPHY LABORATORY
UNSW
LA PEROUSE WIND U.V (M/S)
6
0
STRESS (PA) U (105T)
0. 1
0. 0
STRESS (PA) V (15T)
0. 1
0. 0
-0. 1
T (°C)
22
20
18
16
14
U (105T) AT 15M
0. 1
0. 0
-0. 1
U (105T) AT 47M
0. 1
0. 0
-0. 1
V (15T)
0. 2
0. 0
-0. 2
U,V (M/S) AT 15M
0. 2
0. 0
-0. 2
U,V (M/S) AT 47M
0. 2
0. 0
-0. 2
15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
DEC 1989

Fig. 6d

Fig. 5e


ALONG- AND ACROSS-SHELF CURRENTS (V AND U. M/S) AND
TEMP. AT 15M (DASH) AND 47M (SOLID) IN 64M AT ORSO.
FILTERED TO 1HR SAMPLES.
MATHEMATICS OCEANOGRAPHY LABORATORY
UNSW
LA PEROUSE WIND U.V (M/S)
STRESS (PA) U (105T)
STRESS (PA) V (15T)
T (°C)
U (105T) AT 15M
U (105T) AT 47M
V (15T)
U.V (M/S) AT 15M
U.V (M/S) AT 47M
6
0
0. 1
0. 0
0. 1
0. 0
-0. 1
22
20
18
16
14
0. 1
0. 0
-0. 1
0. 1
0. 0
-0. 1
0. 2
0. 0
-0. 2
0. 2
0. 0
-0. 2
0. 2
0. 0
-0. 2
24 25 26 27 28 29 30 31 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31
JAN
1990

ALONG- AND ACROSS-SHELF CURRENTS (V AND U, M/S) AND TEMP. AT 15M (DASH) AND 47M (SOLID) IN 64M AT ORSD.

FILTERED TO 1HR SAMPLES.
MATHEMATICS OCEANOGRAPHY LABORATORY UNSW

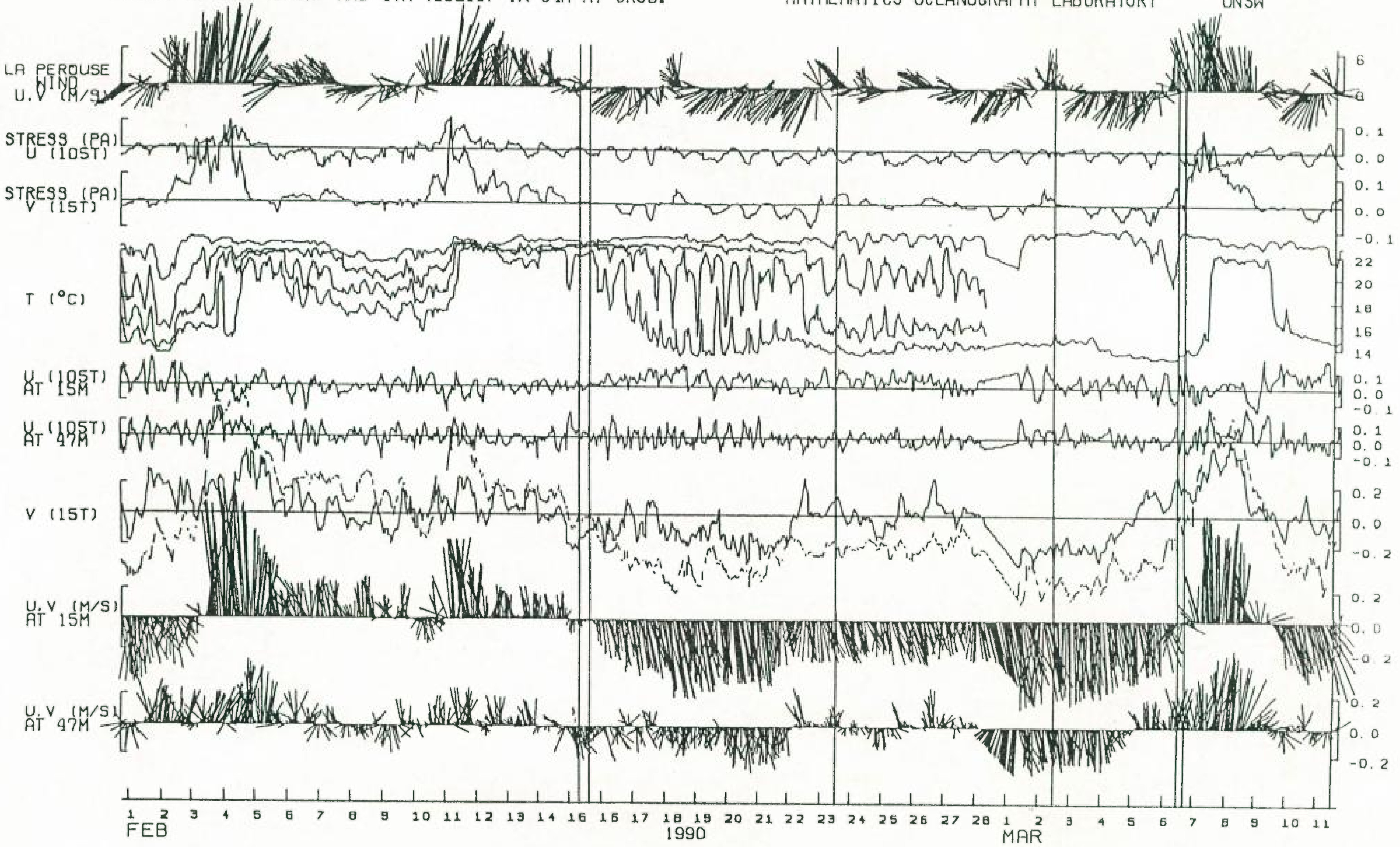


Fig. 5f

ALONG- AND ACROSS-SHELF CURRENTS (V AND U. M/S) AND
TEMP. AT 15M (DASH) AND 47M (SOLID) IN 64M AT ORSO.

FILTERED TO 1HR SAMPLES.
MATHEMATICS OCEANOGRAPHY LABORATORY UNSW

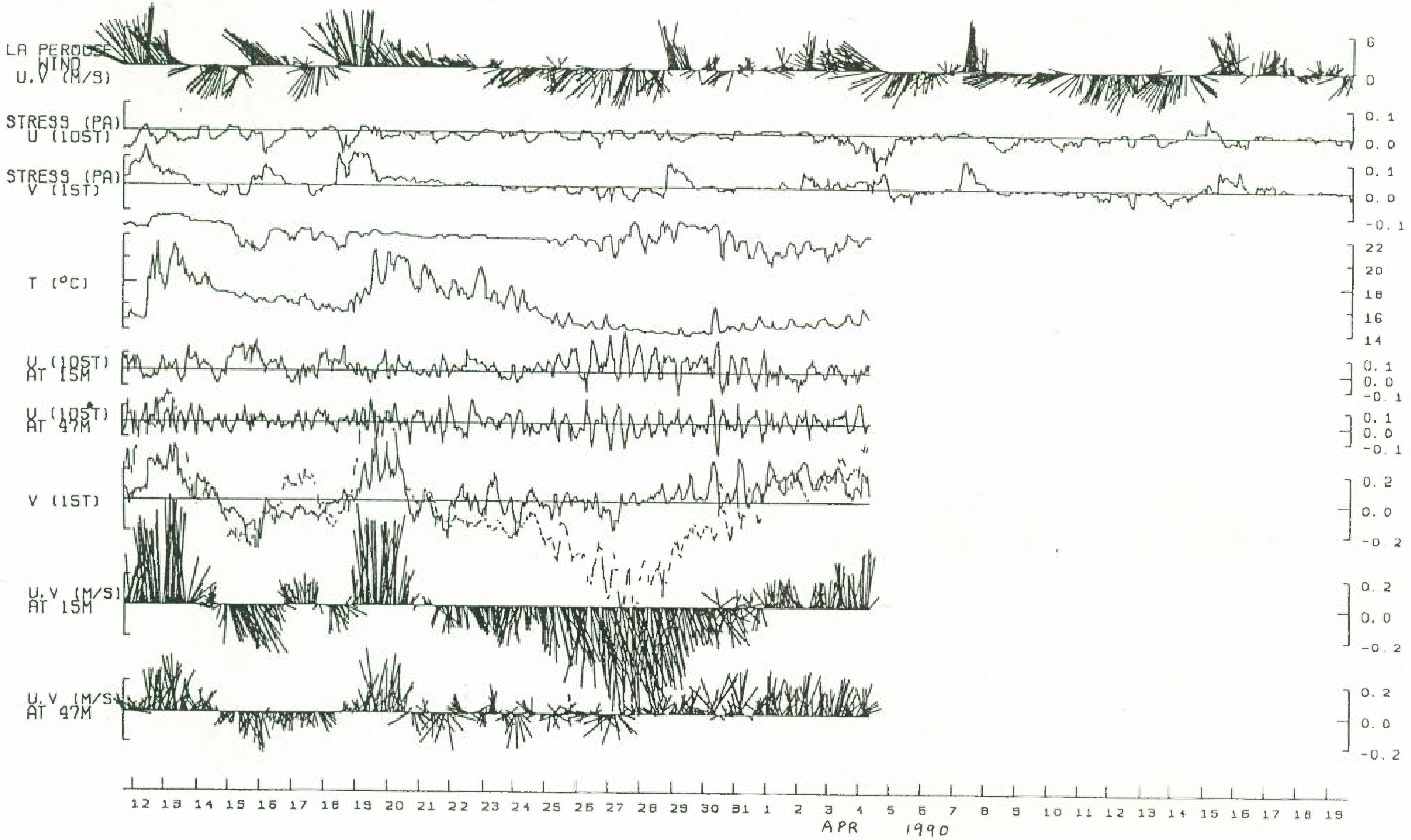


Fig. 5g

Rendell Paul

From: Rider Shirley
Sent: Monday, 18 January 1999 9:55
To: Rendell Paul
Subject: FW: SYDNEY DEEPWATER OUTFALLS

Paul, Can you help re this query?
Thanks Di

Sent: Monday, 18 January 1999 9:54
To: Pritchard Tim
Subject: SYDNEY DEEPWATER OUTFALLS

Tim,
I believe you are the person who knows about the **Environmental Monitoring Program.** We have had a request from ANSTO library for the following which we **don't** have in our collection.
1. Numerical modelling of NSW coastal circulation due to coastal trapped waves, by Macks Cahill & Middleton Post-Commisoning phase, Aug 1994
* 2. Statistical summary of current temperature data from the MkO ocean reference station by Cox Commissioning phase, May 1991
3. Linear regression analyses of alongshore currents from the ocean reference station, by Gibbs, Middleton Post-commissionsing phase, December 1993

Can you shed any light on these

Many thanks
Di Mcmillan

Di:

Pls copy + return * 2. (it is the only copy)

Nos. 1 + 3 are copies for the library.

Thanks

Randell Lee ext. 5422.