

# FRANKLIN

National Facility  
Oceanographic Research Vessel

## RESEARCH SUMMARY

Cruise FR 6/95

### INTERNAL TIDAL EVOLUTION ON THE NORTHWEST SHELF

#### Itinerary

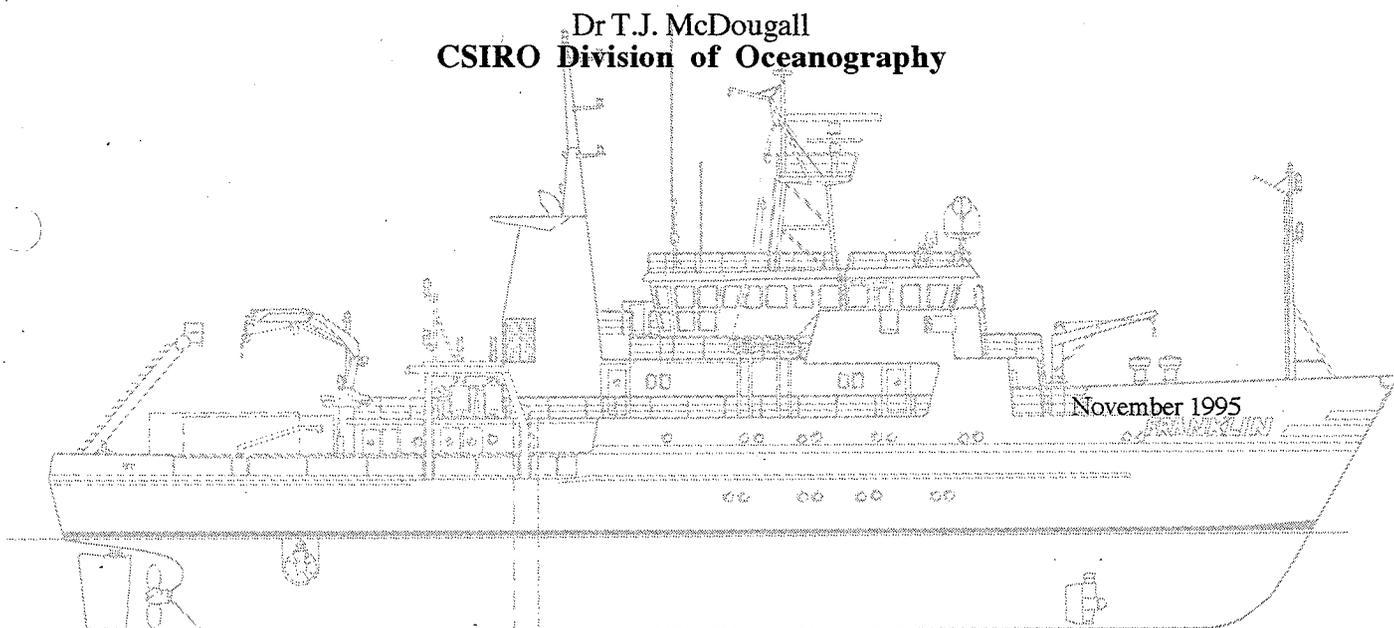
Sailed Fremantle 0800 17 June 1995

Arrived Fremantle 0800 9 July 1995

**Moored Measurements and CTD sections of the flow of Deep and Bottom Water into the Western Australian Basin of the Indian Ocean**

#### Principal Investigator

Dr T.J. McDougall  
CSIRO Division of Oceanography



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**R.V. Franklin**  
**National Facility**  
**Oceanographic Research Vessel**

**Research Summary**  
**Cruise FR06/95**

**Itinerary**

|         |           |      |     |              |
|---------|-----------|------|-----|--------------|
| Sailed  | Fremantle | 0800 | Sat | 17 June 1995 |
| Arrived | Fremantle | 1700 | Wed | 28 June 1995 |
| Sailed  | Fremantle | 2200 | Wed | 28 June 1995 |
| Arrived | Fremantle | 0840 | Sun | 9 July 1995  |

**Principal Investigator**

Dr T. J. McDougall, CSIRO Division of Oceanography

**Cruise Objectives**

(i) To deploy moored current meters in the passage between Cape Mentelle and Broken Plateau to measure the flow of Deep and Bottom water into the West Australian Basin.

(ii) To use the moored current-meter data together with several realisations of the hydrography across the section between Cape Mentelle and Broken Ridge to deduce the flow of Bottom, Deep and Intermediate Waters in this region.

(iii) To estimate the vertical diffusivity across the potential temperature surfaces less than 1.1°C in the West Australian Basin using the deduced volume flow rates of Deep and Bottom water across the section from Naturaliste Plateau to Broken ridge.

(iv) By obtaining more reliable estimates of the equatorward flux of deep and bottom water into the West Australian Basin, contribute to the estimate of the poleward heat flux borne by the Indian Ocean.

**Personnel****Ship's Crew**

|                |                  |                      |
|----------------|------------------|----------------------|
| Master         | Neil Cheshire    |                      |
| Mate           | Dick Dougal      |                      |
| 2nd Mate       | Ian Menzies      |                      |
| Chief Engineer | Terry Carruthers | (1st part of cruise) |
| 1st Engineer   | Peter Harding    | (2nd part of cruise) |
|                | Ray Elliot       |                      |
|                | Don Roberts      |                      |
| Elec. Engineer | Yannick Hansen   |                      |
| Bosun          | Bruce Mackerras  |                      |
| AB             | Rosco Bryson     |                      |
| AB             | Norm Marsh       |                      |
| AB             | Sao Wong         |                      |
| Greaser        | John Formosa     | (1st part of cruise) |
| Chief Steward  | John Tilley      | (2nd part of cruise) |
|                | Gary Hall        |                      |
| Chief Cook     | Tom Oates        |                      |
| 2nd Cook       |                  |                      |

**Scientific Party**

|                  |                                  |                      |
|------------------|----------------------------------|----------------------|
| Trevor McDougall | CSIRO Oceanography               | Chief Scientist      |
| David Jackett    | CSIRO Oceanography               |                      |
| Fred Boland      | CSIRO Oceanography               |                      |
| Danny McLaughlan | CSIRO Oceanography               |                      |
| Kevin Miller     | CSIRO Oceanography               |                      |
| Jeff Dunn        | CSIRO ORV Computing              |                      |
| Phil Adams       | CSIRO ORV Electronics            |                      |
| Mark Rayner      | CSIRO ORV Hydrology              |                      |
| David Terhell    | CSIRO ORV Hydrology              |                      |
| Karen Edwards    | Canberra Institute of Technology | (1st part of cruise) |
| Swee Hin Cheng   | Royal Malaysian Navy             |                      |

## Cruise Narrative

We departed Fremantle on time at 0800 on Saturday 17th June and headed south to begin a line of stations westward along 34° 10' S (about the latitude of Cape Mentelle). The first station was done in 165m of water at 2130hrs. After the second station (CTD cast #02) we did another one (CTD cast #03) at the same location where we fired all twelve bottles at the salinity minimum at 1000m. When CTD #04 was begun (at about 0800 on the 18th June Local Time), the bow thruster malfunctioned and the CTD was retrieved from 100m so that the engineers could work on the problem. For several days thereafter the bow thruster could only deliver 50% of its full thrust and this restricted the weather conditions in which we could work.

With short interruptions due to the weather of only a few hours, we managed to do CTD casts #05 to #12 over the course of the next few days while deploying two moorings, M10 and M9 on Wednesday 21 June.

After deploying the third mooring, M8, on the morning of Thursday 22 June the wind picked up, gusting to 35 knots and we were unable to do any work for more than 24 hours. On Friday evening we did do two more CTDs and then we deployed the fourth mooring, M7 on Saturday morning 24 June. The wind then picked up again, gusting to its usual 35 knots as another front threatened all day and eventually passed us at dinner time. We could do no work for another 24 hours, until 1030AM on Sunday 25 June when we did CTD #015. There followed two more CTDs and mooring M6 at 10:23 LT on Monday morning 26 June.

Following CTD #18 at 17:30LT on Monday 26 June we had to turn around and head for Fremantle because the first engineer had taken ill. We docked at Fremantle two days later at 1700LT Wednesday 28 June. The chief steward also saw the doctor in Fremantle and was diagnosed with a hernia and so was ordered off the ship. Fortunately, a replacement chief steward was found at short notice and our sailing was not delayed because of this. While in port we took on 60 tons of fuel, and we departed at 2200LT.

The sailing back to our working location was calm and uneventful. A fire drill was performed on Friday morning. The weather remained very favourable while we completed the remaining five mooring deployments and associated CTD casts. The CTD system gave a small problem on three successive casts. After having been in the water for four hours, it overflowed a buffer in the top few hundred metres of water, just before bringing it back on deck.

After completing 28 CTD casts on the line between Naturaliste Plateau and Broken Ridge, we steamed to the northwest in the direction of Tryal Ridge from where we began 11 CTD casts at a spacing of 12 miles in a direction towards Fremantle. The aim of these stations was to measure the slopes of density surfaces deeper than 4000 m as an indication of the amount of deep transport that goes north on the eastern side of Tryal Ridge. The density section revealed rather weak slopes of neutral surfaces.

## Summary of work completed

The primary aim of this cruise was to deploy the ten current meters and this was done successfully. Figure 1 shows the cruise track and the positions of the ten moorings, M1 - M10 (laid in the reverse order). In addition, 39 CTD casts were made, mostly in deep water. The first 28 of these were on the same line as that of a cruise of RRS *Charles Darwin* in 1987 and many of these 28 casts were designed to be at the same position as casts from that cruise. These 28 casts were basically on two straight courses, with casts #01 - #13 being at constant

latitude, and #14 - #28 towards the WNW. The long detour to Fremantle between moorings M6 and M5 is obvious on the cruise track.

The deepest part of the gap between Broken Plateau and Naturaliste Plateau lies between M1 and M10, with an average depth in this region greater than 5000 m. Figure 2(a) shows the section of neutral density in this deep gap on this cruise and this is to be contrasted with the corresponding section (Figure 2(b)) from the *Charles Darwin* section from 1987. The deep density field has evidently changed dramatically, although it is not known on what timescale these changes may occur.

Higher in the water column there has been a very distinct and statistically significant change of the water masses over the 7.5 years since the *Charles Darwin* cruise. This is illustrated in Figure 3 where the potential temperature anomaly of the Charles Darwin casts in this region are plotted against neutral density. The first step in forming this figure was to form the average potential temperature as a function of neutral density for the present cruise, labelled  $\theta(1995)$ , in Figure 3. The scatter of the individual casts of the present cruise about the mean value is no more than  $\pm 0.05^\circ\text{C}$ . By contrast, it is seen in Figure 3 that in the density range  $26.9 \text{ kg m}^{-3}$  to  $27.25 \text{ kg m}^{-3}$  the 1987 cruise data was warmer along density surfaces by about  $0.1^\circ\text{C}$ . This density range corresponds to the water between the Sub-Antarctic Mode Water and the salinity-minimum (Intermediate) Water, and covers the depth range from about 550 m to 900 m.

This cooling along density surfaces over the past 7.5 years of  $0.1^\circ\text{C}$  is consistent with the observed cooling on density surfaces in this region over longer periods (work in progress, Bindoff and McDougall). Moreover, such cooling on density surfaces is consistent with a warming (and some freshening) at the sea surface at the latitudes where these water masses are formed.

Figure 4(a) shows the  $S-\theta$  curve of all the first 28 CTD casts of this cruise. There is a significant variation of the water masses at and below the salinity minimum showing that water of this density comes from both north and south of the section. By contrast, at a potential temperature of  $2.15^\circ\text{C}$  the  $S-\theta$  curve is very tight for all these casts. In fact, the variation of salinity at constant  $\theta$  was only  $\pm 0.0017$  psu even before any post-cruise calibrations.

The  $S-\theta$  curves for the second CTD section are shown in Figure 4(b). The outlying cast #33 is very obvious, but Figure 4(c) shows that its properties lie in the envelope of the water mass variations found on the southern section. The anomalous water on cast #33 was found between 1100 m and 1600 m. This feature had no signature on the neighbouring casts and the density field indicated that it was an SCV (Submesoscale Coherent Vortex).

## **Acknowledgments**

The entire *Franklin* crew is thanked for their excellent support and cooperation throughout the cruise. I am very grateful to Dr Yvonne Bone for forgoing two days of her cruise, FR07/95, so allowing us to complete the planned work of this cruise.

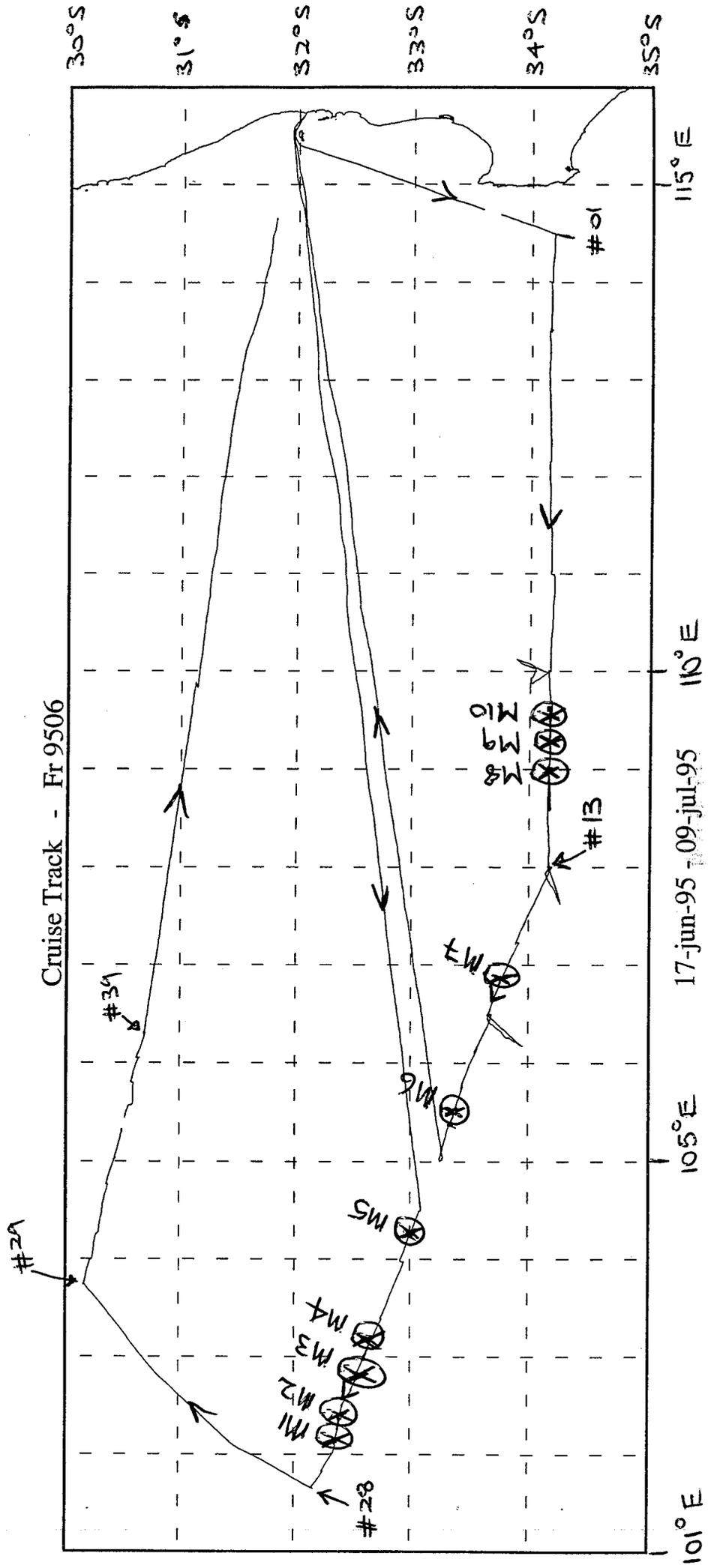


Figure 1

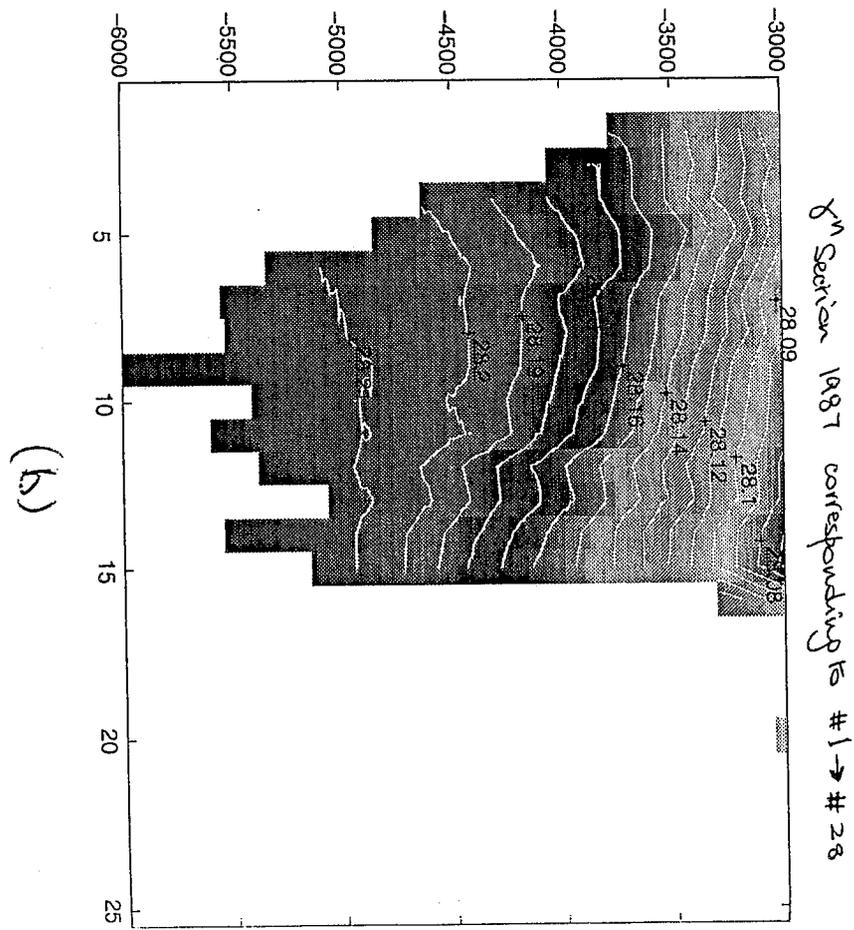
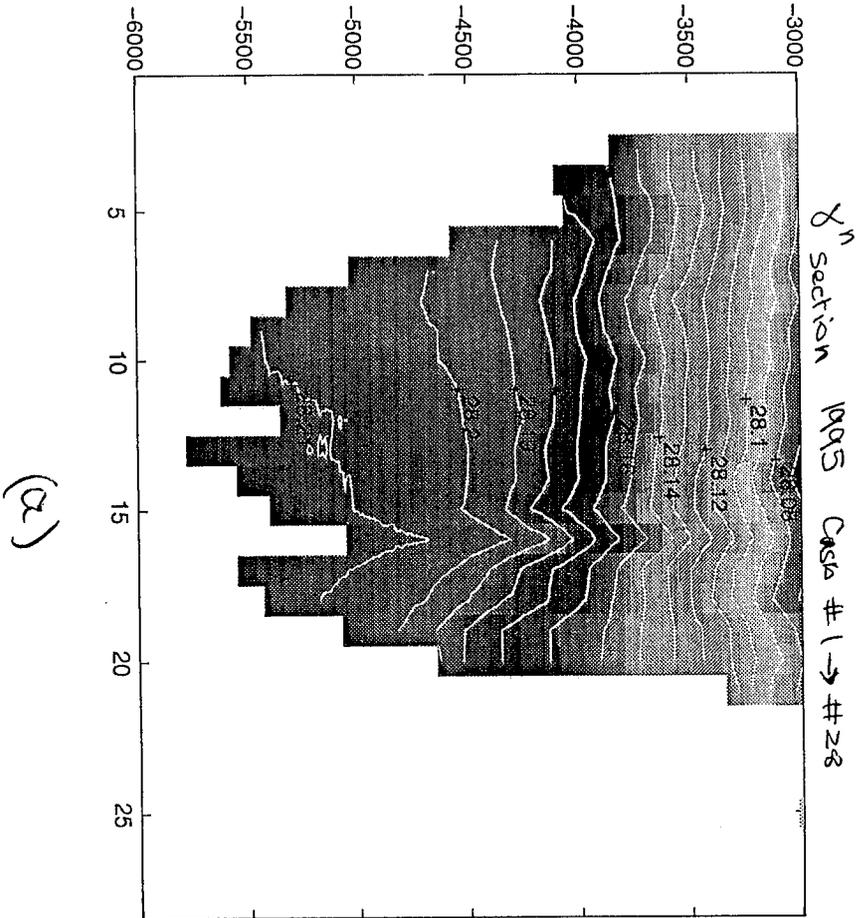


Figure 2.

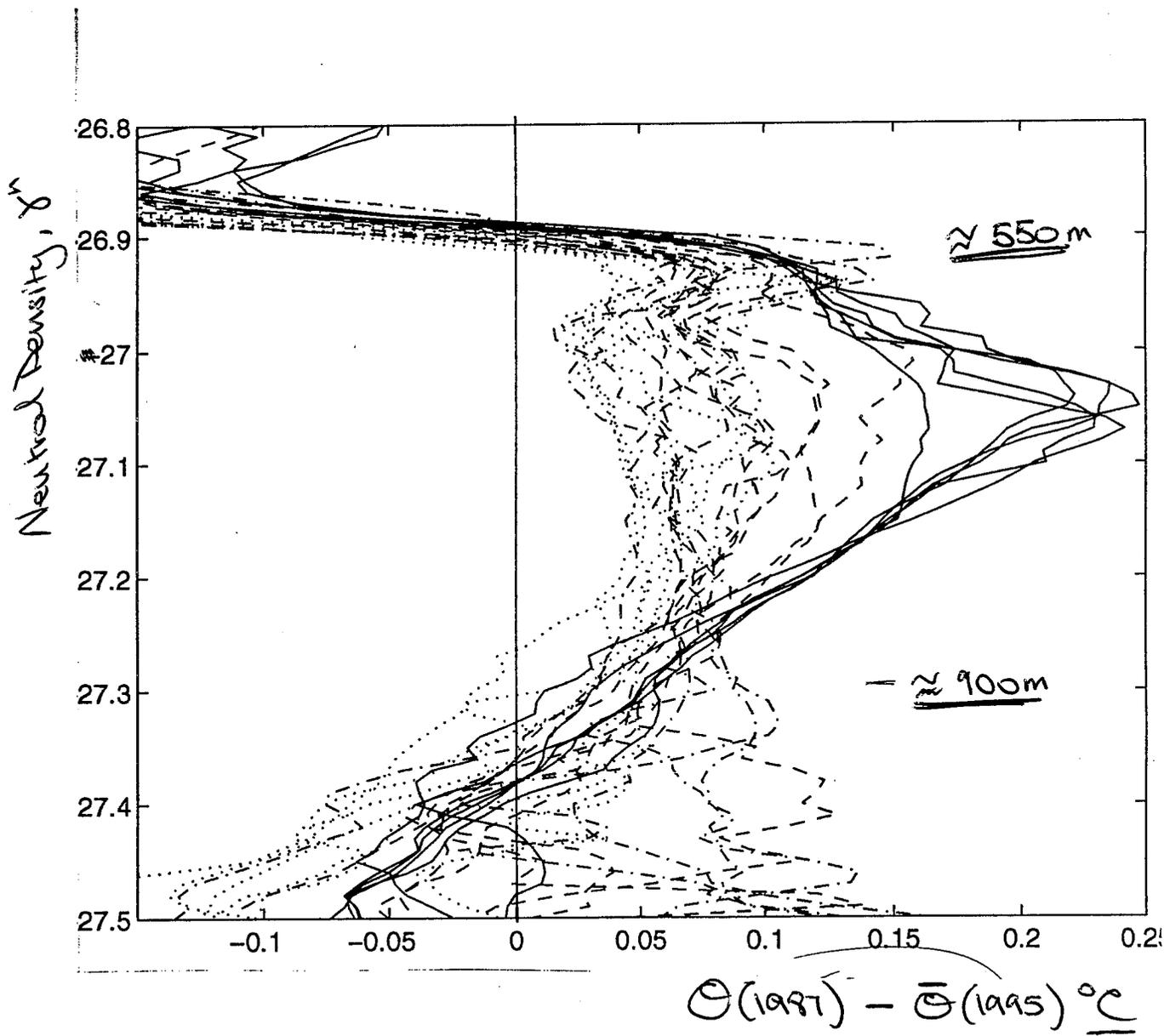
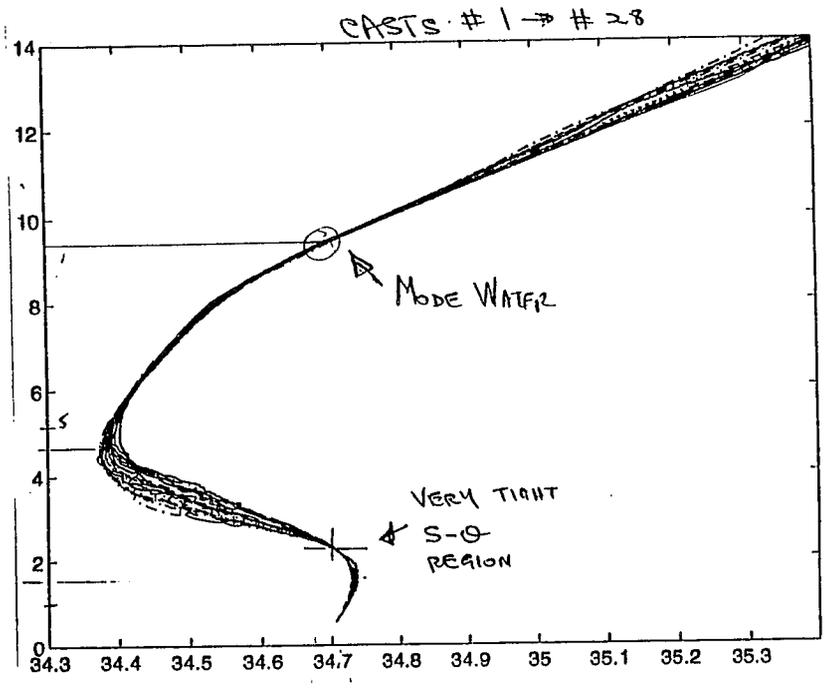
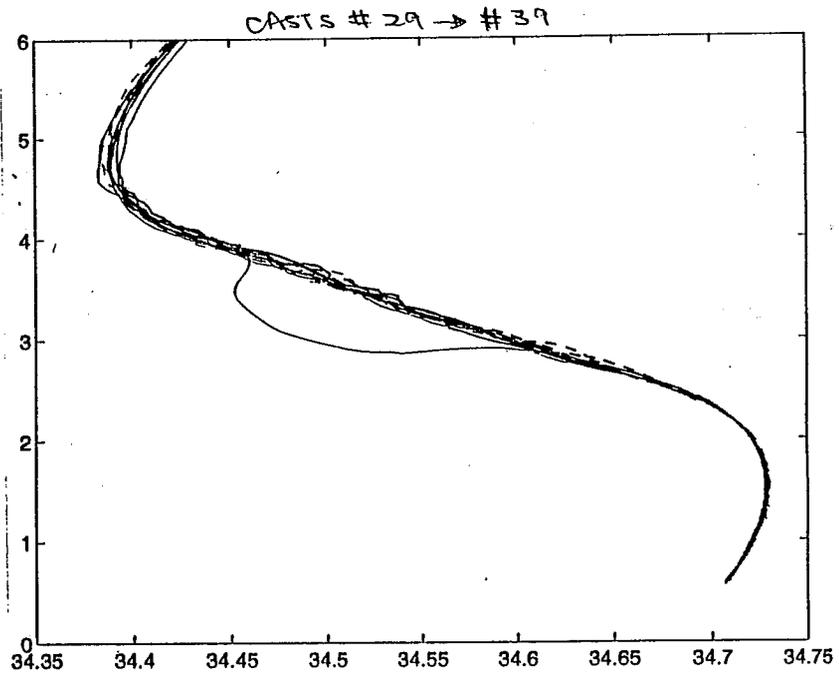


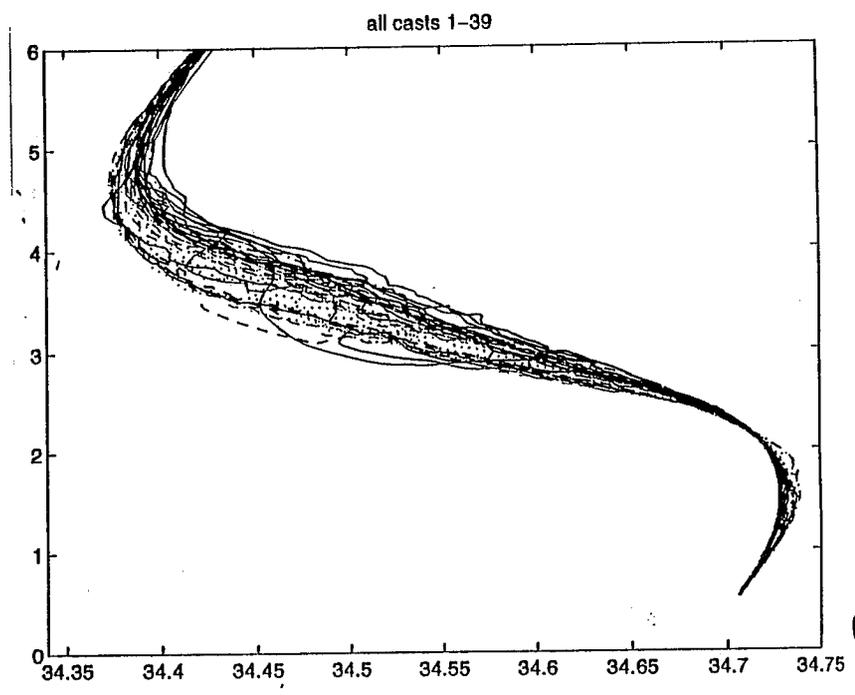
Figure 3



(a)



(b)



(c)

Figure 4

**CTD Processing Notes**  
**Fr 6/95**  
**Neil White**

This Cruise was part of a study of the flow of deep and bottom water into the West Australian Basin of the Indian Ocean.

CTD unit number 8 (an EG&G Mk IIIC unit) was used for all stations. There are 41 stations, numbered 1 - 41.

The main instrumental problem on this cruise was with the Mk IIIC digitising circuitry for the multiplexed channels - this problem has affected a number of these units in use around the World. This only affected the oxygen channels on this cruise.

The problem was fixed after this cruise.

**Pressure calibration**

Data from the stainless steel pressure transducer was used for all stations.

Constants from the last laboratory calibrations were used but a new offset term was calculated for each station from the pressure of the first 'in water' data records. These offsets had a range of 1.1 decibars.

**Temperature calibration**

Temperature calibration constants from the last laboratory calibrations were used.

**Conductivity calibration**

Calibrations were done by calculating a bias, conductivity slope and station-dependant term for groups of stations as was done by WHOL. The final grouping settled on was: stations 1-17, 18-28 and 29-41. After calibration the standard deviation of the salinity residuals for the whole cruise is .0027 psu. This is good, but is partly so because nearly all of the samples were deep. It would have been helpful to have had a few more samples shallower than 1,000m.

**Problems with oxygen data**

A problem with the digitising board for the multiplexed channels caused some jumps in the oxygen data, especially in deep water. The problem may also occur in shallower water, but may not be apparent because of the greater noisiness and rates of change of the data in shallower water. This problem has been encountered by a number of institutions using the IIIC units and a fix has been issued by GO. Examination of the raw data did not suggest an easy way of fixing the data, as it does not seem to be a simple 'sticky bit' problem.

In addition, there were a number of glitches in shallower water that were edited out. In summary, the following cuts were made to oxygen data:

| <u>Station</u> | <u>Depth Range</u> |
|----------------|--------------------|
| 8              | 1,760 - 2,320      |
| 9              | 1,680 - 2,320      |
| 10             | 1,680 - 2,160      |
| 11             | 1,800 - 2,300      |
| 12             | 1,900 - 2,500      |
| 13             | 3,260 - 3,740      |
| 14             | 2,400 - 3,360      |
| 15             | 2,420 - 3,660      |
| 16             | 2,500 - 3,600      |
| 17             | 2,000 - 3,000      |
| 18             | 2,100 - 3,000      |
| 19             | 3,600 - 4,300      |
| 20             | 3,700 - 4,400      |
| 21             | 3,600 - 4,280      |
| 22             | 3,660 - 4,160      |
| 23             | 3,060 - 4,140      |
| 24             | 3,400 - bottom     |
| 25             | 3,520 - bottom     |
| 26             | 3,520 - bottom     |
| 27             | 2,180 - 2,340      |
| 29             | 2,400 - 3,300      |
| 30             | 1,880 - 2,520      |
| 31             | 1,880 - 2,440      |
| 32             | 1,700 - 2,400      |
| 33             | 1,580 - 2,140      |
| 34             | 1,540 - 2,220      |
| 35             | 1,380 - 1,900      |
| 36             | 1,400 - 1,900      |
| 37             | 1,350 - 1,700      |
| 38             | 1,480 - 1,960      |
| 39             | 1,380 - 2,100      |
| 40             | 1,600 - 2,100      |
| 41             | 1,600 - 1,960      |

#### **Other Edits**

Some other edits were made to remove bad data due to fouling of the conductivity cell or where the filters did not handle salinity spiking well. None of these edits caused gaps in the data.

The surface salinities for stations 23 and 24 look low but this seems to be real.

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# Notes on ADCP data for Fr 6/95

## 1 Features of this voyage

GPS "SA" degradation (see section 2) was in force during this voyage, and GPS coverage was 100%.

A very small amount of on-station data was mildly corrupted in the top 50 m by one acoustic beam intersecting water dragged by the CTD wire. All but the most subtly affected bins have been removed (as there is no way of correcting for this effect).

### 1.1 Profiles integrated

**Bottom track corrected, no reference layer averaging in final integration:**

21 20 minute profiles (6% of voyage covered).

**GPS corrected**

1473 20 minute profiles (97% of voyage covered). Use with care, if at all, as SA was active.

491 60 minute profiles (97% coverage).

**Non-integrated profiles (3 minute ensembles)**

All possible ensembles with best available correction (bottom track preferred).

## 2 GPS data degraded by SA (Selective Availability)

The US Department of Defence, who operates the GPS satellites, has introduced deliberate complex errors into GPS data. It is generally considered that these errors cannot be removed without extra equipment and post processing (and even then cannot be achieved with deep ocean work.)

The characteristics of SA errors are probably changed from time to time, however they usually seem to be across quite a wide time spectrum. Of most concern for ADCP data are the errors of order 50 cm/s over 5 to 10 minute periods. There also appears to be a smaller and lower frequency component, the worst case so far observed had a residual error of 6 cm/s after averaging an hour's data.

### 2.1 The implications for ADCP data are:

- individual GPS corrected ensembles (3 minute or less) often have errors of around .5 m/s.
- The existence of such errors prohibits the use of some quality control measures, especially of course  $dv/dt$ .
- 20 minute integrated profiles will usually have little extra error, maybe 1 or 2 cm/s. However, at times low frequency components of SA may cause larger errors, up to 10 or 20 cm/s.
- 60 minute profiles will rarely have more than 1 or 2 cm/s extra error.
- Incomplete 20 minute profiles (low 'icover' percentage) are less reliable because they are probably incomplete due to a break in GPS coverage, and data adjacent gaps is usually of poorer quality. Also, the SA errors are less likely to have been removed by averaging.

- 
- Bottom track and shear data are, of course, unaffected by this. When using GPS to get ship's position, these errors are negligible (200m or 300m at most).

### 3 Calibration

ADCP water profile vectors are calibrated by being rotated through an angle  $\alpha$  and multiplied by scaling factor  $1+\beta$ . The rotational calibration primarily corrects for misalignment of the transducer with respect to the ship, of the ship with respect to the gyro compass, and the error in the gyro compass. The scaling multiplier primarily corrects biases arising from the profiler itself. Both of these calibrations make a large difference to the resultant currents, particularly because they are both applied to the usually large ship-relative currents. For example, a scaling multiplier of .01 applied when the water velocity with respect to the ship is 6 m/s alters the measured absolute currents by 6 cm/s. Calibration is particularly difficult when the coefficients change with time, as appears to be the case on this voyage.

**Results for this voyage:**

$$\alpha = 1.20 \qquad 1 + \beta = 1.011$$

### 4 Data Quality

The data provided should not be taken as absolutely true and accurate. There are many sources of error, some of which are very hard to quantify. Often the largest error is that of determining the ship's actual velocity.

#### **Accuracy of water velocity relative to the ship**

The theoretical approximate short-term velocity error for our 150 kHz ADCP is:

$$\text{sigma} = (\text{pulse length} \times \text{square root of pings per average}) - 1$$

For a 3 minute ensemble with say 170 pings, using 8m pulse, this gives a theoretical error of 1 cm/s for each value (that is, independantly for each bin).

For 20 minute profiles, with say 1150 pings averaged, the error in measuring the velocity of the water relative to the ship is probably reduced to the long term systematic bias. Of this bias, RDI says

"Bias is typically of the order of 0.5 - 1.0 cm/s. This bias depends on a variety of factors including temperature, mean current speed, signal/noise ratio, beam geometry errors, etc. It is not yet possible to measure ADCP bias and to calibrate or remove it in post-processing."

As well as that, there are the transducer alignment and gyro-compass errors, which probably have a residual effect after calibrating of roughly:

0.4 cm/s per m/s of ship speed, due to say 0.4 uncertainty and variation in alignment angle.

0.4 cm/s per m/s of ship speed, due to say 0.004 uncertainty and variation in scaling factor

This gives us say 0.6 cm/s error per m/s of ship speed, or 3.5 cm/s at 12 knots.

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Other sources of bias might be the real-time and post-processing data screening, and depth-dependant bias.

**GPS profiles**

In the presence of SA, errors are larger and even very large errors cannot be removed by  $dv/dt$  screening (because this would bias the long term average - there is reason to assume that given a long enough period the accumulated SA error is close to zero).

**Bottom track profiles**

Firstly note that errors arising from transducer alignment and gyro limitations will substantially cancel out. Normally, the accuracy of screened bottom track data appears to be of the same order of accuracy as non-SA GPS, that is, about 2 - 3 cm/s for a 20 minute profile.