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RESEARCH PLAN

CRUISE FR ~~7/95~~ 8/95

WORLD OCEAN CIRCULATION EXPERIMENT (WOCE)

REPEAT HYDROGRAPHIC SECTIONS BETWEEN AUSTRALIA AND INDONESIA

SEASOAR SECTION NEAR JAVA

-oOo-

Sail Fremantle 0001 Wednesday 13 September 1995
Arrive Dampier 1500 Wednesday 11 October 1995

Principal Investigators

Dr George Cresswell, Dr Stuart Godfrey, Dr Gary Meyers, Dr Sue Wijffels
CSIRO Division of Oceanography, Hobart

Dr Gani Ilahude
Indonesian Institute of Sciences, Jakarta

Prof Matthias Tomczak
Flinders Institute for Atmospheric and Marine Sciences, Adelaide

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FRANKLIN

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Itinerary

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Objectives

1. To observe the seasonal variation of Indonesian throughflow and the associated changes in hydrographic structure and regional currents.

2. To assess the representativeness of the once-off, basin-wide WOCE hydrographic survey in relation to annual and inter-annual variations.

3. To assess the consistency of estimates of the volume transport of the currents and the distribution of chemical tracers using inverse methods.

4. To survey the hydrographic front near 10°S with continuous recording instruments.

Background

The western boundary of the tropical Pacific Ocean has several passages leading into the Indonesian Seas, permitting a mean current, known as the Indonesian throughflow, to carry a large volume of upper ocean water and its chemical properties into the Indian Ocean. The properties can be traced clearly across the Indian Ocean to Africa (Rochford, 1966; Fine, 1985). The volume transport was estimated to be of order 10 Sv (Sverdrups or 10^6 m^3/s) by Godfrey and Golding (1981) and subsequently many others (see Gordon, 1986 and Fieux et al., 1994 for comprehensive summaries), but the mean value is still uncertain due in part to inaccuracies in the indirect methods used and in part to real variability of throughflow, which was not well resolved in sampling.

Godfrey (1989) found that if the Indonesian throughflow is a western boundary current, in the sense that the pressure gradient driving it against friction is confined to the western side of the Indonesian channels, then the annual mean throughflow should be a simple function of Pacific wind stresses and should have a magnitude of about 16 Sv - in reasonable agreement with some observations. However, the basic assumption that the pressure gradient is much smaller along the Australasian side of the throughflow than along the Asian side remains to be tested with an adequate hydrographic data set.

The mean route of the flow above 400 m through the Indonesian seas carries water through Makassar Strait, east of Kalimantan, turning eastward along the north coast of Java and Flores Island and flowing into the Banda Sea. Southwestward currents on either side of Timor provide the final link to the Indian Ocean, although part of the throughflow exits directly from the Makassar Strait into the Indian Ocean through Lombok Strait. The throughflow feeds into the westflowing South Equatorial Current in the Indian Ocean. It is generally accepted on the basis of chemical tracers that the throughflow has its Pacific source in the Mindanao Current. Other currents in the region between Australia and Indonesia are the Leeuwin Current (LC), the eastern gyre current (EGC), a northeastward extension of the main flow of the subtropical gyre, and the South Java Current (SJC), a seasonally varying eastward flow along the south coast of Java. Variability of the currents has been observed on all time scales. The currents have a strong seasonal cycle, associated with the strong seasonal forcing by the Asian and Australasian Monsoon winds (see Cresswell et al., 1993; Meyers et al., 1994 for details). Effects of both local and remote forcing appear in the region, for example upwelling on the south coast of Java and reflection of semiannual equatorial jets with a dynamics similar to Kelvin and Rossby waves. The maximum throughflow develops in August/September, when the local winds are most favourable for flow into the Indian Ocean. Interannual variability associated with El Nino- Southern Oscillation is expected for theoretical reasons (Clark and Liu, 1993). A strong intra-seasonal signal has been observed in current meter records (Murray and Arief, 1988; Molcard et al., 1992).

Better estimates of the throughflow transport are essential for research on climate change and variation on a global scale. The heat transport of throughflow is a crucial element in the global heat balance, affecting the meridional heat flux through the Pacific and Indian Oceans (Hughes et al., 1992), and ultimately is linked to the "Great Ocean Conveyor" formed in the North Atlantic (Gordon, 1986). Much of the heat collected by the large surface area of the tropical Pacific Ocean may move poleward to heat loss regions in the South Indian Ocean as a consequence of throughflow. On inter-annual time-scales, sea surface temperature in the Indonesian region has a strong influence on the climate system (Nicholls, 1984), in particular in Australia. Horizontal and vertical advections associated with throughflow have a measurable effect on the SST variations (Qu et al., 1993). Models of global climate variation and change which are representative of conditions in Australia probably will have to take account of the heat transport by throughflow.

The fundamental dynamics of the throughflow has been recognized as a pressure gradient from the Pacific to the Indian Ocean set up by the Pacific trade winds; however, the very complex topography, strong tidal currents and intense mixing in Indonesian Seas suggest a more complex dynamics. Improved observation of throughflow and related circulations from the surface to the ocean bottom have consequently been given a high priority in the WOCE Hydrographic Program (WHP).

The region between Australia and Indonesia has a rich horizontal and vertical chemical structure permitting the effective use of chemical tracers in an assessment of throughflow. Water from the Pacific carries characteristics (tritium, freons, T/S, T/O2) into the Indonesian seas where high rainfall and runoff and strong vertical mixing (associated with tides and topography) create unique characteristics such as the low salinity Banda Sea water which can be traced as far as Africa. The throughflow enters the Indian Ocean between Australia and Indonesia and flows adjacent to other clearly marked waters flowing in the opposite direction. High salinity water from the subtropical South Indian Ocean flows northeastward off the NW shelf at depths near 250 m and high salinity water from the North Indian Ocean flows eastward off the Java shelf.near 800 m. The tracers travelling in opposite directions through a hydrographic section can be helpful in determining a reference level for geostrophic and inverse calculations. It's also worth mentioning that the region between Australia and Indonesia is the spawning ground for an important fishery--southern bluefin tuna (SBT) (Harden Jones, 1984)--and consequently will be the focus of ecological studies during the 1990's.

A hydrological front forms near 10°S between the water of the Indonesian throughflow and the subtropical Indian Central Water. This front, one of the strongest in the world ocean, contains multiple intrusions and is characterized by diapycnal mixing (Tomczak and Large, 1989). All previous studies of the front were based on widely spaced hydrocast or CTD data. A modern instrument such as Seasoar is required to resolve the intrusions. Debatably, the structure of the front could be related to SBT spawning (F R Harden-Jones, personal communication.)

This research cruise is to use *Franklin* to survey the throughflow and hydrographic structure in the region between the northwest shelf and Java (figure 1), covering the WHP lines I10/IX1/IR6 twice during 1995. The JADE line was previously covered in August 1989 and February 1993 (Fieux et al., 1993) and (I10) will be covered again in November 1995 by the WHP (Bray and Toole, personal communication). The survey of the TOGA/WOCE XBT line from Sunda Strait to Shark Bay (WOCE line IX1), will establish a reference level for dynamic calculations using XBT data, and assess the WOCE observations in relation to inter-annual variability. Broad scale aspects of the hydrographic structure throughout the region can be studied using the proposed cruise data with previous *Franklin* data in the region: FR 4/87, FR 9/87, FR 3/88 and FR 3/95.

Research Plan

Repeat Hydrographic Sections Between Australia And Indonesia

The hydrographic observations to be collected with *Franklin* on Fr 3/93 and 7/93 are CTD-O, nutrients, and ADCP. The WOCE sections IR6 and I10/IX1 will each be covered twice. The stations will be spaced nominally at 30 mile intervals. Additional stations will be added to resolve the continental slopes and where-ever depth changes by 1000 m, if closer than 30 miles.

Survey with Seasoar

A hydrological front forms near 10°S between the the waters of the Indonesian throughflow and the subtropical Indian Ocean Central Water. This front, one of the strongest in the world ocean, contains multiple intrusions and is characterised by diapycnal mixing (Tomczak and

Large, 1989). All previous studies of the front were based on widely spaced hydrocast or CTD data. On this cruise we will use Seasoar, a towed instrument that undulates through the water column at 6 knots to a depth of 400 m, to resolve the intrusions and provide data that should allow analysis of the intrusions and the dynamics involved.

In analysing the data, we propose first to calculate the geostrophic transports through the sections by standard methods, using a variety of first guesses for a reference level, including the ocean bottom and the depth of major sills in the throughflow, about 1500 m. Tracers will be used to determine the effectiveness of reference levels, making sure that the high and low salinity tongues discussed above are moving in the right direction.

We will also use inverse methods based on the assumption that net flows across the section, beneath the Indonesian sill depth of about 1500m, can only depart by moving vertically through 1500 m in the small area enclosed by the sections and the 1500m contour (Fig. 1) - at least on annual average; and any seasonal variations should be detectable by changes in isotherm depth near 1500m, on the eastern section in Fig.1. The net flux into the entire Indian Ocean below this depth is thought to be only of order 7 Sv (Toole et al. 1993), so the net mean flow into this small region is likely to be less than 1 Sv. This argument should allow us to choose a fairly well-defined reference level, and hence to estimate the absolute transport across the sections: this approach has not been tried in the past. We also hope to obtain data in the far western Pacific, from other WOCE groups: we plan to compare the mean longshore pressure gradients along the Australasian and Asian sides of the throughflow, in order to test Godfrey's (1989) theory.

An important part of the analysis will be to determine if the WOCE observations in 1995 are representative of mean conditions. The representativeness will be assessed by comparing the thermal structure to observations from the TOGA/WOCE XBT Programme, which has maintained a frequently sampled line on the Sunda Strait to Shark Bay route (IX1) since 1983. The sampling frequency has typically been 18 to 24 XBT sections annually, with 60 miles between stations. Low density sampling (12 sections per year) has also been maintained on routes from Port Hedland to Mindanao and on Jakarta to Torres Strait. The XBT data will be used to document annual and inter-annual variability, in comparison to conditions during 1995. On the other hand the WHP hydrographic data will give information on the appropriate reference level for dynamic calculations with the XBT data and information on errors in the calculations associated with the salinity structure.
The repeat cruises will be in April and September during the Monsoon transitions. IR6 was covered in February and August of previous years, at the time of peak Monsoons. The currents in this region have a strong seasonal variation which will be minimally resolved with four cruises.

Cruise Track

The cruise track covers the WOCE sections I10/IX1 (Shark Bay - Sunda Strait) and IR6 (E Java - Northwest Cape). Following WOCE standards, 125 CTD stations to the bottom are required. The cruise covers about 3600 nautical miles. See attached cruise track and station list.

After Station 46, the sampling program will be interrupted for two days to stop at Christmas Island for fuel and water. The survey with Seasoar will be carried out for three days after leaving Christmas Island, if the departure is on time, or shortened if there are delays. The CTD survey will then resume at station 47.

Time budget (WOCE section)

Total time steaming	293	hrs at 11 knots
CTD station time	265	hrs
Seasoar survey	72	hrs
Christmas Island diversion	48	hrs
Total time	**29**	**days**

SeaSoaring

Time allowed for SeaSoaring, near Christmas Island = 3 days

Refuelling stop

A refuelling stop will be necessary at Christmas Island, in view of the *Franklin's* limited endurance. Time allowed = 2 days.

Equipment required from National Facility

CTD
24 bottle rosette
ADCP
Navigation
Meteorology,
Thermosalingraph
XBT
Seasoar

Scientific and Technical Participants

G. Meyers	CSIRO	Chief scientist
Indonesian Scientist		Co-Chief Scientist
S.Wijffels	CSIRO	
Scientist	CSIRO	
Scientist or student	University	
P. Adams	CSIRO - ORV	
B. Beattie	CSIRO - ORV	
Chemist	CSIRO - ORV	
Chemist	CSIRO - ORV	
Chemist	CSIRO - ORV	
L Pender	CSIRO - ORV	
I Helmond	CSIRO - ORV	

This research plan is in accordance with the directions National Facility Steering Committee for the oceanographic research vessel *Franklin.*

A D McEwan
CSIRO Division of Oceanography

G W Paltridge
National Facility Steering Committee

December 1994

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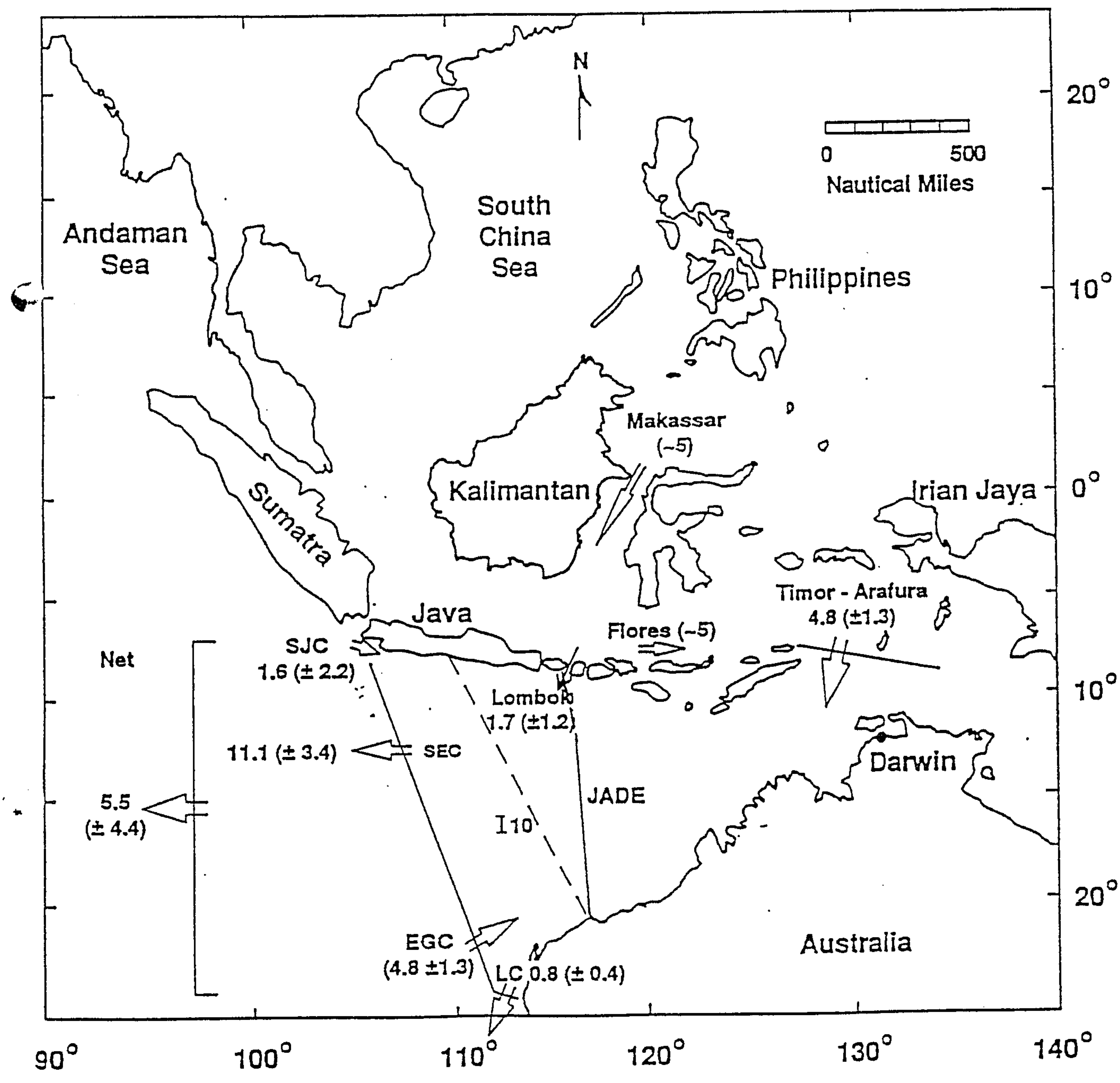
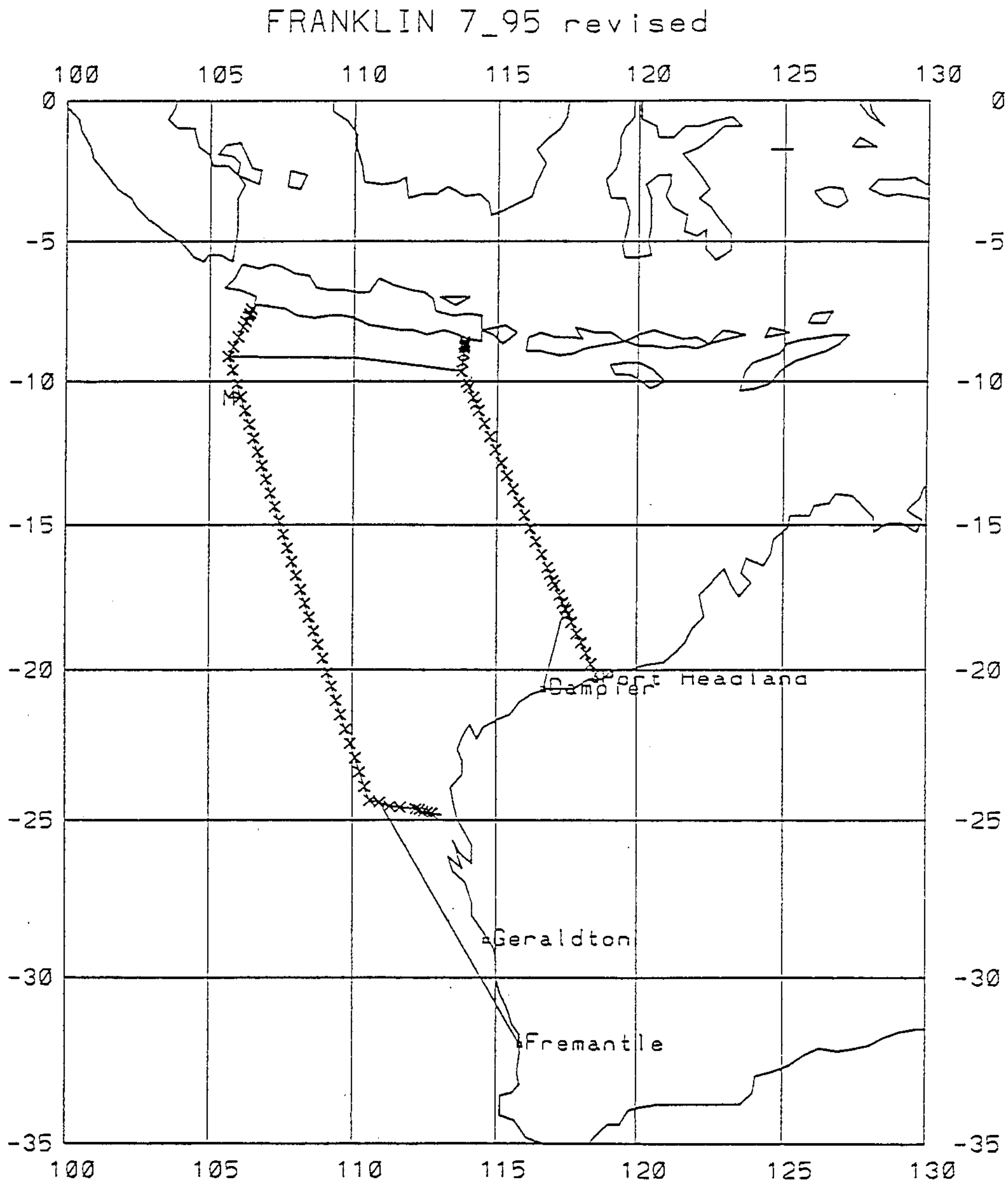


Figure 1 Main route for the throughflow down to 1000 m. Numbers near the arrows indicate estimated transports from Meyers, et al. (1993) and Murray and Arief (1988). Locations of the repeat XBT sections (Meyers, et al.), the JADE section (Fieux, et al. 1993) and the planned WOCE I-10 section are also shown. Illustration provided by N Bray.



FRANKLIN 7_95 revised
100
105
110
115
120
125
130
0
-5
-10
-15
-20
-25
-30
-35
Port Headland
Dampier
Geraldton
Fremantle

FRANKLIN ~~3~~ 7_95 SAMPLING STRATEGY:

1. Nominally 30nmi spacing. Over steep topography and at continental shelves, station spacing is decreased to reduce bottom triangle areas.

2. Carry out 2 full occupations of the shelf/slope regions to sample the boundary currents. This is aimed largely at reducing aliasing by the internal tide.

3. Angle shelf crossings to run perpendicular to the large-scale topography, so that boundary currents are oriented perpendicular to the section.

4. At each shelf crossing, cruise into the coast from the shallowest ctd station running the ADCP in bottom tracking mode.

5. Along the I10 transect, repeat the LUCIE 'Carnarvon' section where 4 previous full-depth CTD occupations exist. This section is taken out to about 110E which is roughly the boundary of the Leeuwin Current as observed in satellite images (Alan Pearce, pers. comm.).

6. If time allows, stand at a fixed isobath (500db) off Port Hedland, sampling every 3 hours for 12 hours so that we can average dynamic height at the section endpoint over a tidal cycle. At this location the baroclinic tides are known to be very large (50m isotherm displacements and 40cm/s velcities).

Station number	Position		Cast depth	Event type	Station time	Distance (delta)	
	32 03.00S	115 50.00E		way			Fremantle
1	24 25.00S	110 56.00E	2000	ctd	1:45	525.3	
2	24 33.00S	111 17.00E	1500	ctd	1:27	20.8	
3	24 35.00S	111 39.00E	1000	ctd	1:10	20.2	
4	24 38.00S	112 12.00E	500	ctd	0:50	30.2	
5	24 40.00S	112 20.00E	200	ctd	0:35	7.6	
6	24 44.00S	112 27.00E	150	ctd	0:25	7.5	
7	24 45.00S	112 37.00E	100	ctd	0:15	9.2	
8	24 47.00S	112 46.00E	83	ctd	0:15	8.4	
	24 50.00S	113 06.00E	50	way		18.4	
9	24 47.00S	112 46.00E	83	ctd	0:15	18.4	
10	24 45.00S	112 37.00E	100	ctd	0:15	8.4	
11	24 44.00S	112 27.00E	150	ctd	0:25	9.2	
12	24 40.00S	112 20.00E	200	ctd	0:35	7.5	
13	24 38.00S	112 12.00E	500	ctd	0:50	7.6	
14	24 35.00S	111 39.00E	1000	ctd	1:10	30.2	
15	24 33.00S	111 17.00E	1500	ctd	1:27	20.2	
16	24 25.00S	110 56.00E	2000	ctd	1:45	20.8	
17	24 22.20S	110 35.34E	3000	ctd	2:20	19.1	
18	23 53.76S	110 25.20E	4493	ctd	3:12	29.8	
19	23 25.32S	110 15.12E	4993	ctd	3:30	29.8	
20	22 56.82S	110 05.10E	4993	ctd	3:30	29.9	
21	22 28.32S	109 55.14E	4018	ctd	2:56	29.9	
22	21 59.88S	109 45.24E	5066	ctd	3:32	29.8	
23	21 31.38S	109 35.40E	5043	ctd	3:31	29.8	
24	21 02.82S	109 25.68E	5084	ctd	3:33	29.9	
25	20 34.32S	109 15.96E	5027	ctd	3:31	29.8	
26	20 05.76S	109 06.36E	4309	ctd	3:06	29.9	
27	19 37.26S	108 56.76E	5019	ctd	3:31	29.8	
28	19 08.70S	108 47.28E	5035	ctd	3:31	29.8	
29	18 40.14S	108 37.80E	5539	ctd	3:49	29.8	
30	18 11.52S	108 28.38E	5579	ctd	3:50	29.9	
31	17 42.96S	108 19.02E	5650	ctd	3:53	29.8	
32	17 14.34S	108 09.72E	5644	ctd	3:53	29.9	
33	16 45.78S	108 00.40E	5545	ctd	3:49	29.8	
34	16 17.16S	107 51.24E	5538	ctd	3:49	29.9	
35	15 48.54S	107 42.06E	5584	ctd	3:50	29.8	
36	15 19.92S	107 32.94E	6033	ctd	4:06	29.8	
37	14 51.30S	107 23.88E	5552	ctd	3:49	29.8	
38	14 22.62S	107 14.82E	5538	ctd	3:49	29.9	
39	13 54.00S	107 05.82E	6054	ctd	4:07	29.8	
40	13 25.32S	106 56.82E	3131	ctd	2:25	29.9	
41	12 56.70S	106 47.88E	4994	ctd	3:30	29.8	
42	12 28.02S	106 39.00E	4517	ctd	3:13	29.8	
43	11 59.34S	106 30.12E	5495	ctd	3:47	29.8	
44	11 30.66S	106 21.30E	5703	ctd	3:55	29.8	
45	11 01.98S	106 12.48E	6041	ctd	4:06	29.8	
46	10 33.30S	106 03.66E	5231	ctd	3:38	29.8	
	10 35.00S	105 40.00E		way		23.4	Christmas Isl.
	10 35.00S	105 40.00E	7200	mrg	7200:00	0.0	refuel/seasor
47	10 33.30S	106 03.66E	5231	ctd	3:38	23.4	repeat ctd
48	10 04.62S	105 54.96E	4807	ctd	3:23	29.8	
49	9 35.88S	105 46.20E	5337	ctd	3:42	29.9	
50	9 07.20S	105 37.50E	6559	ctd	4:25	29.8	
51	8 46.20S	105 47.58E	4281	ctd	3:05	23.2	
52	8 25.20S	105 57.60E	3000	ctd	2:20	23.1	
53	8 03.72S	106 07.80E	2500	ctd	2:02	23.7	
54	7 52.60S	106 13.10E	2000	ctd	1:45	12.3	
55	7 41.40S	106 18.42E	1500	ctd	1:27	12.3	
56	7 36.96S	106 20.52E	1000	ctd	1:10	4.9	
57	7 33.54S	106 22.14E	500	ctd	0:50	3.8	
58	7 27.48S	106 25.02E	252	ctd	0:38	6.7	
59	7 25.02S	106 25.02E	100	ctd	0:15	2.4	
	7 22.00S	106 26.00E		way		3.2	
60	7 25.02S	106 25.02E	100	ctd	0:15	3.2	

Station number	Position		Cast depth	Event type	Station time	Distance (delta)
61	7 27.48S	106 25.02E	252	ctd	0:38	2.4
62	7 33.54S	106 22.14E	500	ctd	0:50	6.7
63	7 36.96S	106 20.52E	1000	ctd	1:10	3.8
64	7 41.40S	106 18.42E	1500	ctd	1:27	4.9
65	7 52.60S	106 13.10E	2000	ctd	1:45	12.3
66	8 03.72S	106 07.80E	2500	ctd	2:02	12.3
67	8 25.20S	105 57.60E	3000	ctd	2:20	23.7
68	8 46.20S	105 47.58E	4281	ctd	3:05	23.1
69	9 07.20S	105 37.50E	6559	ctd	4:25	23.2
	9 10.00S	110 00.00E		way		259.7
70	9 38.94S	113 45.00E	3464	ctd	2:36	224.2
71	9 19.30S	113 46.80E	3000	ctd	2:20	19.6
72	8 59.82S	113 48.60E	2500	ctd	2:02	19.5
73	8 49.14S	113 49.62E	1500	ctd	1:27	10.7
74	8 44.10S	113 50.04E	1000	ctd	1:10	5.0
75	8 40.08S	113 50.46E	500	ctd	0:50	4.0
76	8 35.76S	113 50.82E	200	ctd	0:35	4.3
77	8 34.02S	113 51.00E	110	ctd	0:17	1.7
	8 32.00S	113 51.50E		way		2.1
78	8 34.02S	113 51.00E	110	ctd	0:17	2.1
79	8 35.76S	113 50.82E	200	ctd	0:35	1.7
80	8 40.08S	113 50.46E	500	ctd	0:50	4.3
81	8 44.10S	113 50.04E	1000	ctd	1:10	4.0
82	8 49.14S	113 49.62E	1500	ctd	1:27	5.0
83	8 59.82S	113 48.60E	2500	ctd	2:02	10.7
84	9 19.30S	113 46.80E	3000	ctd	2:20	19.5
85	9 38.88S	113 45.00E	3464	ctd	2:36	19.6
86	10 01.86S	113 54.96E	3000	ctd	2:20	24.9
87	10 13.20S	113 59.88E	2500	ctd	2:02	12.3
88	10 34.14S	114 09.00E	3000	ctd	2:20	22.7
89	10 47.79S	114 15.00E	4500	ctd	3:12	14.8
90	11 01.44S	114 21.00E	5981	ctd	4:04	14.8
91	11 28.80S	114 32.94E	3947	ctd	2:53	29.7
92	11 56.16S	114 45.00E	4998	ctd	3:30	29.7
93	12 23.46S	114 57.06E	5044	ctd	3:32	29.6
94	12 50.76S	115 09.18E	5519	ctd	3:48	29.7
95	13 18.06S	115 21.30E	5545	ctd	3:49	29.6
96	13 45.36S	115 33.54E	5597	ctd	3:51	29.7
97	14 12.66S	115 45.78E	5642	ctd	3:52	29.7
98	14 39.90S	115 58.08E	5647	ctd	3:53	29.6
99	15 07.20S	116 10.38E	5638	ctd	3:52	29.7
100	15 34.44S	116 22.80E	5621	ctd	3:52	29.7
101	16 01.62S	116 35.28E	5565	ctd	3:50	29.6
102	16 28.86S	116 47.76E	5269	ctd	3:39	29.7
103	16 42.50S	116 53.85E	4000	ctd	2:55	14.8
104	16 56.10S	117 00.36E	3000	ctd	2:20	14.9
105	17 05.04S	117 04.50E	2500	ctd	2:02	9.7
106	17 25.86S	117 14.16E	2552	ctd	2:04	22.7
107	17 40.92S	117 21.18E	2500	ctd	2:02	16.4
108	17 50.88S	117 25.86E	2000	ctd	1:45	10.9
109	17 55.80S	117 28.14E	1500	ctd	1:27	5.4
110	18 05.10S	117 32.52E	1000	ctd	1:10	10.2
111	18 22.08S	117 40.50E	500	ctd	0:50	18.5
112	18 45.36S	117 51.54E	200	ctd	0:35	25.5
113	19 04.20S	118 00.48E	100	ctd	0:15	20.6
114	19 26.16S	118 10.92E	63	ctd	0:15	24.0
115	19 48.06S	118 21.42E	35	ctd	0:15	24.0
116	20 10.02S	118 31.98E	11	ctd	0:15	24.0
117	20 10.02S	118 31.98E	11	ctd	0:15	0.0
118	19 48.06S	118 21.42E	35	ctd	0:15	24.0
119	19 26.16S	118 10.92E	63	ctd	0:15	24.0
120	19 04.20S	118 00.48E	100	ctd	0:15	24.0
121	18 45.36S	117 51.54E	200	ctd	0:35	20.6
122	18 22.08S	117 40.50E	500	ctd	0:50	25.5
123	18 05.10S	117 32.52E	1000	ctd	1:10	18.5

Station number	Position		Cast depth	Event type	Station time	Distance (delta)	
124	17 55.80S	117 28.14E	1500	ctd	1:27	10.2	
125	17 50.88S	117 25.86E	2000	ctd	1:45	5.4	
	20 40.00S	116 40.00E		way		174.0	Dampier

Data file : cr_2_rev2.dat

Total distance = 3652.0 nautical miles

Total steaming time = 365.2 hours at 10.0 knots
Total station time = 393.0 hours
======
Total time = 758.2 hours or 31.6 days
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RESEARCH SUMMARY
CRUISE FR 8/95

WORLD OCEAN CIRCULATION EXPERIMENT (WOCE)

REPEAT HYDROGRAPHIC SECTIONS BETWEEN AUSTRALIA AND INDONESIA

-oOo-

EQUATORIAL MOORING DEPLOYMENT

-oOo-

SEASOAR SECTION NEAR JAVA

Sail Fremantle 1000 Wednesday 13 September 1995
Arrive Darwin 0800 Sunday 14 October 1995

Principal Investigators

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