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Woods Hole Oceanographic Institution

Hydrographic Observations from the US/PRC Cooperative Program in the Western Equatorial Pacific Ocean: Cruises 1–4

by

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January 1990

Technical Report

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Hydrographic Observations from the US/PRC Cooperative Program in the Western Equatorial Pacific Ocean: Cruises 1-4

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Approved for Distribution:

Robert C Beardsley

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Abstract

In support of the Tropical Oceans and Global Atmosphere (TOGA) program, investigators from Woods Hole Oceanographic Institution (WHOI), NOAA Pacific Marine Environmental Laboratory and the State Oceanic Administration (SOA) from both Qingdao (First Institute) and Guangzhou (South China Sea Branch) conducted hydrographic observations aboard the Chinese research vessels *Xiang Yang Hong* 5 and *Xiang Yang Hong* 14 in the western equatorial Pacific. The objective of this component of the TOGA program was to document the water mass property distributions of the western equatorial Pacific Ocean and describe the oceanic velocity field. The four cruises summarized here were conducted during the period November 1985 to June 1988 and are the first half of an eight cruise repeated survey of the region scheduled to be completed in spring 1990. Conductivity-Temperature-Depth-Oxygen (CTD/O_2) stations were collected to a minimum cast depth of 2500 m or the bottom when shallower. The cruises reoccupied the same stations to provide temporal information. Summarized listings of CTD/O_2 data together with selected physical properties of sea water for these cruises are provided here, as well as a description of the hardware used and an explanation of the data reduction techniques employed.

1. Introduction

A science and technology agreement between the governments of the United States and the People's Republic of China signed in 1983 called into existence a cooperative research program to investigate the western equatorial Pacific Ocean. The agreement in part specified a series of eight joint research cruises to the western Pacific, a program of personnel training and an exchange of scientific equipment. The National Oceanic and Atmospheric Administration (NOAA) in the U.S. and the State Oceanic Administration (SOA) in China have been charged with administering the research effort which is now considered a component of the international Tropical Ocean – Global Atmosphere (TOGA) program.

The first cruise of the cooperative study took place in late 1985/early 1986; the eighth and final cruise is scheduled for the spring of 1990. A major focus of the field program has been a repeated hydrographic sampling effort. Results from the first four cruises are summarized here. The objectives of the hydrographic program are to document the thermohaline and water mass property distributions in the western Pacific Ocean, to resolve the geostrophic transport fields of the various currents of the region, and to characterize any seasonal and interannual variations. The cruise track and nominal station positions for the cruises were chosen in an effort to resolve the major ocean currents of the western Pacific and to provide data for intercomparison with other research programs engaged in sampling the region. A 107-station sampling plan has evolved which includes coastal stations, as permission to work in territorial waters was obtained, as well as reoccupation of deep ocean sites. The reoccupation of all sites is important for studying time variability and also facilitates calibration of the sensors by exploiting the stability of the deep water properties. All four cruises were carried out aboard PRC research vessels operated by SOA. Scientific and technical personnel staffing the cruises were a combination of PRC and US scientists (Appendix 1). Cruise track charts with some station positions indicated are shown for the four cruises in Figures 1a through 1d. A station summary of the four cruises is presented in Appendix 3. A summary of the dates stations were collected on the various cruise legs is given in Table 1 below.

Table 1: Summary Station Dates by Cruise/Leg

Cruise	Leg	Dates		
1	3	January 30	–	February 18, 1986
2	1	November 18	–	December 4, 1986
2	2	December 8	–	December 16, 1986
3	1	September 22	–	October 7, 1987
3	2	October 13	–	October 22, 1987
4	1	April 23	–	May 10, 1988
4	2	May 15	–	May 23, 1988

2. Instrumentation

Two EG&G/Neil Brown Instrument Systems (NBIS) MK IIIB CTDs were used as the primary profiling instruments aboard US/PRC cruises 1 through 4. The two instruments (serial numbers 1104: CTD 11 and 1125: CTD 12) sampled temperature, conductivity, pressure and dissolved oxygen. A detailed description of this instrument can be found in Brown and Morrison (1978). A 12-position General Oceanics rosette fitted with 1.7 liter Niskin bottles was used to collect water samples for salinity and dissolved oxygen analysis aboard the vessel. Digital CTD data were acquired with a NBIS 1150 deck unit. These raw data were archived to 9-track tape via a Digi-Data model 1749 tape drive for subsequent processing on a Digital Equipment (DEC) MicroVAX II. Data were also displayed by an HP-85 computer system in real time for quality control. Figure 2 shows a schematic of the equipment employed. Salinity samples were analyzed on a Chinese salinometer similar to the Australian Autolab during cruises 1 and 4 and on a Guildline Model 8400A Autosal for cruises 2 and 3.

Water samples from the rosette sampler were also analyzed for dissolved oxygen content. Only a subset of the available samples were processed; typically alternate stations were analyzed. The titration equipment on the cruises was supplied by SOA, and all samples were processed by PRC technicians.

3. Data Collection

A series of zonal and meridional transects, with stations positioned to optimize the resolution of transport in the strong current regions near the equator and coast, were occupied during these cruises. Each cruise consists of six major sections. Zonal sections were occupied along 18°20′N, approximately 8°N and the equator. Meridional sections were occupied along 130°E, 141°30′E and 165°E (see Figure 1). During cruises 1 and 2 (Figures 1a and b) coastal stations crucial to the calculation of transports were not occupied. These stations lie in the territorial waters of the Philippines, Papua-New Guinea and the Solomon Islands. Cruises 3 and 4 (Figures 1c and d) did, however, occupy stations in coastal waters shallower than 500 m in depth of the above mentioned countries.

During cruise 1 a standard station depth of 2500 m was obtained with several stations reaching a maximum of 4500 m. Cruise 2 station depths were much the same. During cruises 3 and 4 the station depths alternated between 3500 and 4000 m or within 50–100 m of the bottom depending upon ocean depth and the strength of the current. The PRC vessels have limited ability to maneuver on the wire. Thus, strong winds or currents result in large wire angles, limiting cast depths.

4. Data Calibration and Reduction

Conductivity, temperature and pressure sensors of the CTD instruments were calibrated at EG&G/NBIS prior to and following each cruise. Instrument sensor calibrations were also completed at the calibration facility in Tianjin, China on three separate occasions. These calibrations made possible the intercomparisons of calibration standards from the two facilities. On two occasions a representative of EG&G/NBIS travelled to the Tianjin facility to evaluate the Chinese techniques. A report of this intercomparison is in draft (Millard *et al.*, 1988).

Sensor calibrations applied at sea for data workup and instrument quality control were typically the pre-cruise laboratory calibrations for conductivity, temperature and pressure. No electronic adjustments were made to the sensor interface boards during laboratory calibrations for CTDs 11 and 12. Instead, temperature, pressure, and conductivity corrections, determined by polynomial least-square fits to the laboratory calibration data, were applied to the data. Thus, the performance history of each sensor was maintained. Temperature calibrations consist of a linear or quadratic fit to seven temperature points in reference to a platinum thermometer standard. Pressure calibrations are done using a dead-weight tester at 1000 psi intervals for increasing and decreasing pressure. Temperature and pressure calibrations are used to scale the data profiles as well as the CTD component of rosette water sample data files. Conductivity calibrations are done in reference to IOS Wormley standard sea water. Additional information on CTD calibration and data processing can be found Fofonoff, Hayes and Millard (1974) and Millard (1982). Successive calibrations were compared to determine any sensor drift. Specific information on calibration techniques and the actual calibrations for each sensor for each specific cruise can be found in Appendix 2.

CTD oxygen sensor calibration coefficients were derived from comparisons to *in situ* water sample oxygen data within various station groupings (Owens and Millard, 1985). CTD conductivity sensor calibrations for each cruise were determined by considering the relationship of pre-cruise laboratory calibrations to *in situ* rosette water sample data and the very stable deep water potential temperature/salinity profiles of the western Pacific. Cruise to cruise reoccupation of station positions, and CTD instrument stability, make deep water potential temperature/salinity and potential temperature/oxygen profile intercomparison data extremely valuable in the calibration of these data sets.

5. Station Listing Description

Individual station listings have been created with the following information for all four cruises. A description of the Fortran algorithms for computing all parameters except those involving integrals and gradients are documented in UNESCO Tech. Report 44 "Algorithms for computation of fundamental properties of seawater" by N. P. Fofonoff and R. C. Millard. Starting at the left, the station variables are categorized in four groups as follows. The observed variables: temperature, salinity, and oxygen are vertically filtered values at the pressure level indicated. The standard Woods Hole Oceanographic Institution 2 dbar pressure-averaged CTD data are centered on odd pressure intervals (1,3,5,7,...) while the adopted pressure listing levels are at even pressure values with the exception of 75 and 125 dbars. The 2 dbar temperature, salinity, and oxygen data were smoothed with a binomial filter (UNESCO TR 54) and then linearly interpolated as required to the standard levels. The potential temperature, potential density anomaly, and potential density anomaly referenced to 2000 and 4000 dbars that follow in the listings were computed using the Fortran algorithms of UNESCO TR 44. The dynamic height and potential energy are integral quantities from the surface to the pressure interval indicated. These assume that the value of the specific volume anomaly of the first level of the 2 dbar

CTD data profile can be extrapolated to the sea surface. A trapezoidal integration method was employed. The next quantities: potential temperature and salinity gradients, density ratio, and Brunt-Väisälä frequency, involve the calculation of vertical gradients. Gradient quantities were estimated from a centered linear least squares fit calculated over half of the neighboring listing intervals. The calculated depth involves a dynamic height correction and a latitude dependent gravity correction.

The columns of the station listing are:

PRES DBAR: Pressure (P) level in decibars.

TEMP °C: Temperature (T) in degrees Celsius calibrated on the 1968 International Practical Temperature Scale (IPTS 1968).

SALT PSU: Salinity (S) computed from conductivity (C), temperature, and pressure according to the 1978 practical salinity scale. (UNESCO T.R. 44, pp. 6–12). C(35,15,0) = 42.914 mmho/cm.

OXYG ML/L Oxygen in units of milliliters per liter. The partial pressure of oxygen is computed from the polographic electrode measurements using an algorithm described by Owens and Millard (1985).

PTEMP °C: Potential temperature θ in degrees Celsius computed by integrating the adiabatic lapse rate after Bryden (1973) (see UNESCO T.R. 44, pp. 42–45). The reference level, Pr, for the calculation is 0.0 dbars. $\theta = \theta(S,T,P,Pr)$.

SIGTH kg/m^3 Potential Density anomaly in kilograms/m^3. Obtained by computing the density anomaly $\gamma(S,T,P)$ (density $- 1000\ kg/m^3$) at 0 pressure replacing the *in situ* temperature with potential temperature $\theta = \theta(S,T,P,0.0)$ referenced to 0 dbars. $\gamma_\theta = \gamma(S,\theta,0.0)$.

SIGM2	kg/m^3	Potential Density anomaly referenced to 2000 dbars in $kilograms/m^3$. Obtained by computing the density anomaly γ (density – 1000 kg/m^3) at 2000 dbars using potential temperature referenced to 2000 dbars $\theta = \theta$(S,T,P,2000), $\gamma_\theta = \gamma$(S,θ,2000).
SIGM4	kg/m^3	Potential Density anomaly referenced to 4000 dbars in $kilograms/m^3$. Obtained by computing the density anomaly γ (density – 1000 kg/m^3) at 4000 dbars with potential temperature referenced to 4000 dbars $\theta = \theta$(S,T,P,4000). $\gamma_\theta = \gamma$(S,θ,4000).
DYN-HT	$10\left(\frac{J}{kg}\right)$	Dynamic height in units of dynamic meters (10 Joules/kg) is the integral with pressure of specific volume anomaly (see *The Sea*, Volume I, p. 336 by Fofonoff, 1962).
POT. E	$10^{-5}\ \left(\frac{J}{m^2}\right)$	Potential energy anomaly in 10^{-5} $Joules/m^2$ is the integral with pressure of the specific volume anomaly multiplied by pressure (see *The Sea*, Volume I, p. 338 by Fofonoff, 1962).
GRD-PT	$10^3\ \left(\frac{°C}{\text{dbar}}\right)$	Potential temperature gradient in units of millidegrees Celsius per decibar. Estimated from the least squares temperature gradient over half the surrounding pressure intervals minus the center pressure adiabatic lapse rate.
GRD-S	$10^3\ \left(\frac{\text{psu}}{\text{dbar}}\right)$	Salinity gradient in psu per decibar. Estimated from the least squares salinity gradient over half the surrounding pressure intervals.
DENSITY RATIO	$\frac{\alpha}{\beta}\left[\frac{\partial T/\partial_p}{\partial S/\partial_p}\right]$	The Density ratio is the ratio of temperature stability parameter divided by the salinity stability parameter. It is the ratio of temperature and salinity gradients (calculations described previously) multiplied by the isopycnal derivative DS/DT at constant density (see UNESCO TR 40).

B-V	(1/hr)	Brunt-Väisälä frequency in cycles per hour. This is the natural frequency of oscillation of a water parcel when vertically displaced from a rest position assuming no exchanges of heat or salt with surroundings. This calculation uses the adiabatic leveling of steric anomaly (Fofonoff, 1985; Millard, Owens, and Fofonoff, 1990).
DEPTH	(m)	The depth of the pressure interval including the local gravity and dynamic height (see DYN-HT definition) corrections (see UNESCO TR 44, pp. 25–28).

The header of each station listing contains the beginning time and position for the station. Positions are determined from a transit satellite navigator or by dead reckoning from last fix. The speed of sound is an average value computed from averaged travel time of the profile. The water depth is from an echo sounder, corrected using the Carter's tables.

Acknowledgments

The officers and crew of the PRC research vessels and the US and PRC seagoing scientific staff are to be credited for their fine work. Their diligent effort in overcoming communication difficulties and cultural differences experienced during the cruises is to be commended.

The hydrographic observations on cruises 1–4 of the cooperative air-sea interaction study in the western Equatorial Pacific Ocean were conducted under the auspices of the US/PRC cooperative study in the Tropical Ocean-Global Atmosphere (TOGA) experiment. Support for WHOI involvement was provided by the National Oceanic and Atmospheric Administration through grant number NA85AA-D-AC117.

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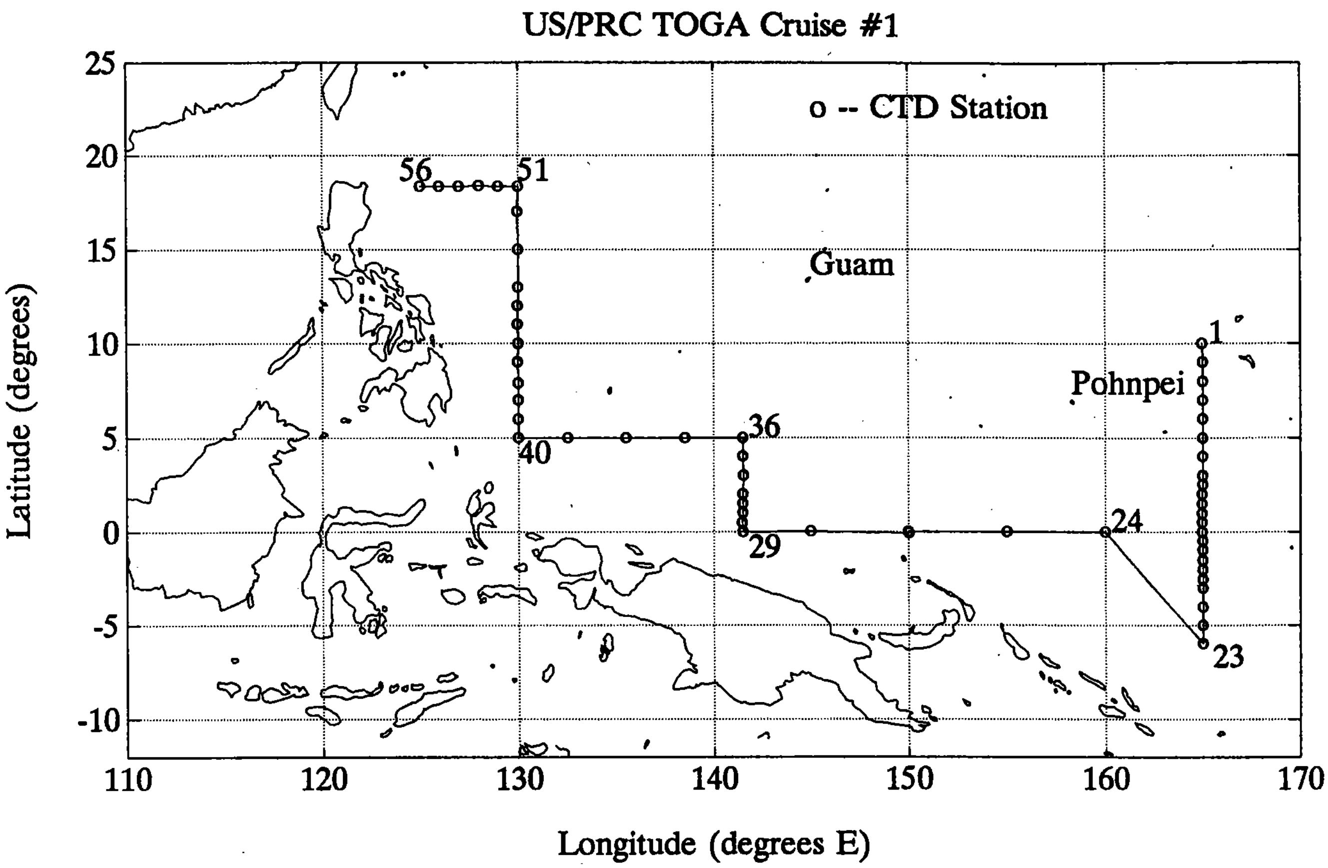
Figure Captions

Figure 1: (a–d): Ship tracks and CTD station positions with selected station numbers indicated for cruises 1 through 4.

Figure 2: Diagram of the CTD data acquisition system which utilizes an HP-85 monitoring computer and Microvax data processing computer. CTD data is logged offline on 9-track tape via the 1150 deck unit.


US/PRC TOGA Cruise #1
o -- CTD Station
Guam
Pohnpei
56
51
40
36
29
24
23
1
Latitude (degrees)
Longitude (degrees E)
25
20
15
10
5
0
-5
-10
110
120
130
140
150
160
170

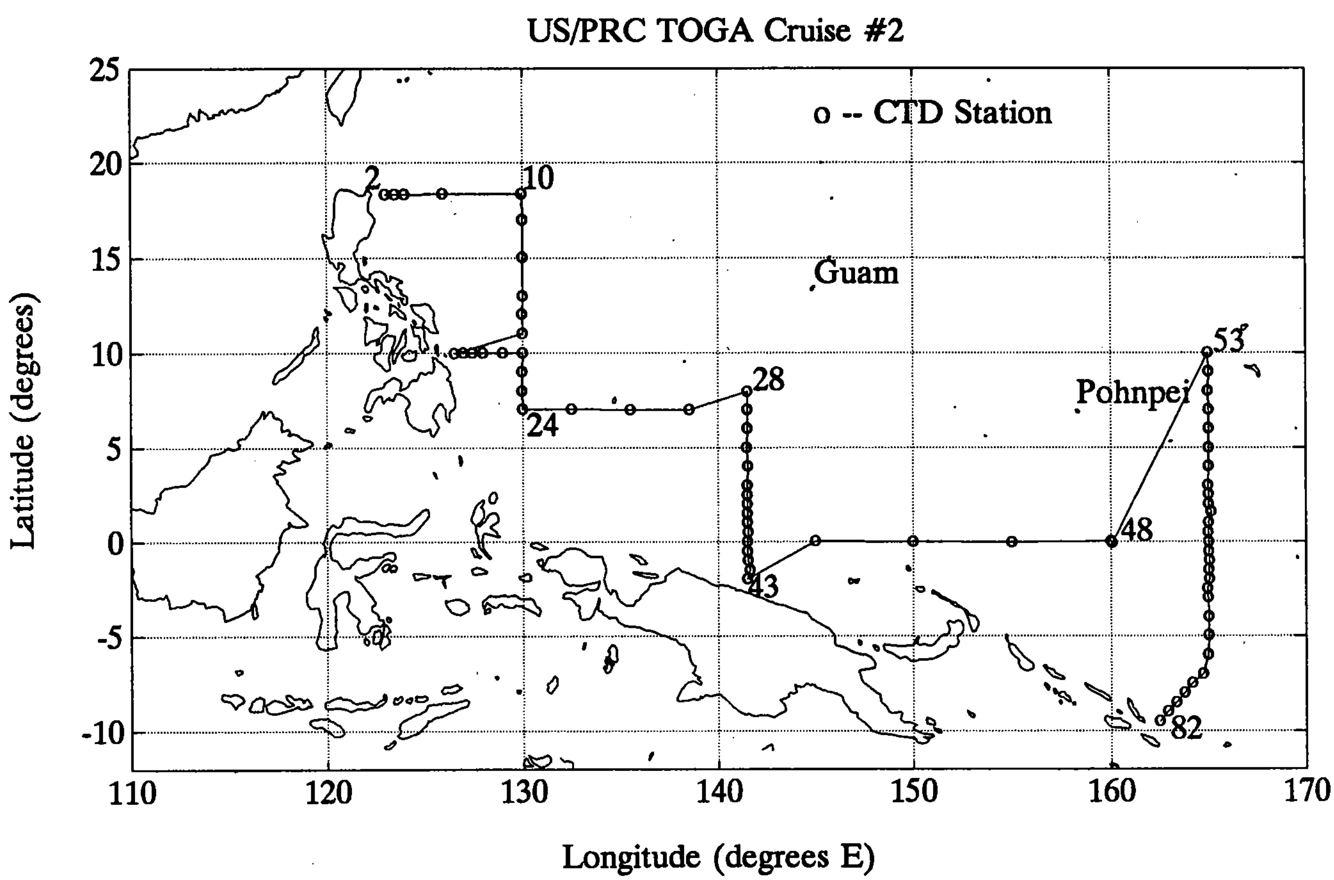
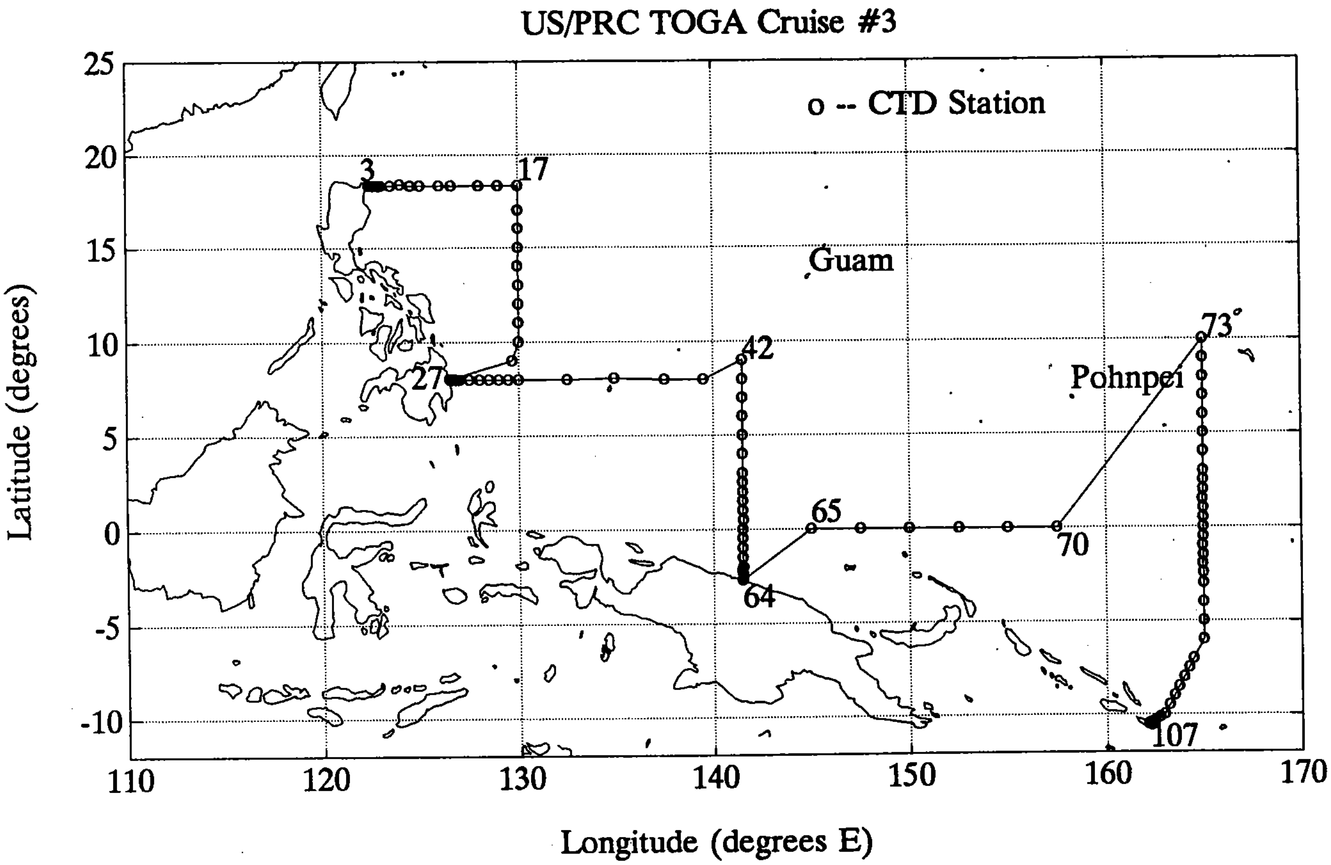
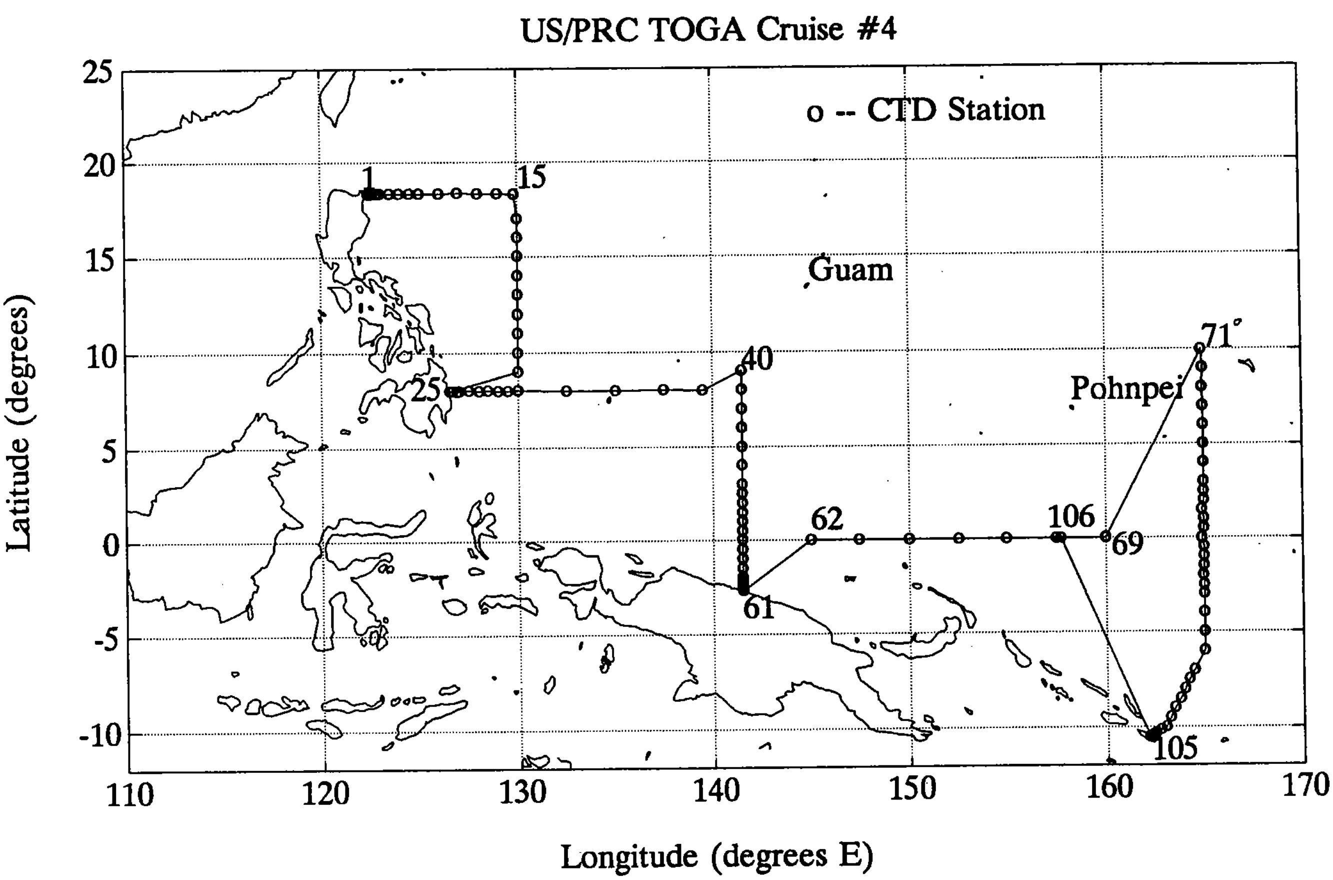

US/PRC TOGA Cruise #2
o -- CTD Station
Guam
Pohnpei
2
10
24
28
43
48
53
82
Latitude (degrees)
Longitude (degrees E)
25
20
15
10
5
0
-5
-10
110
120
130
140
150
160
170

Figure 1 (a-b)


US/PRC TOGA Cruise #3
o -- CTD Station
Guam
Pohnpei
Latitude (degrees)
Longitude (degrees E)
3
17
27
42
64
65
70
73
107


US/PRC TOGA Cruise #4
o -- CTD Station
Guam
Pohnpei
Latitude (degrees)
Longitude (degrees E)
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15
25
40
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62
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69
71
105

Figure 1 (c–d)

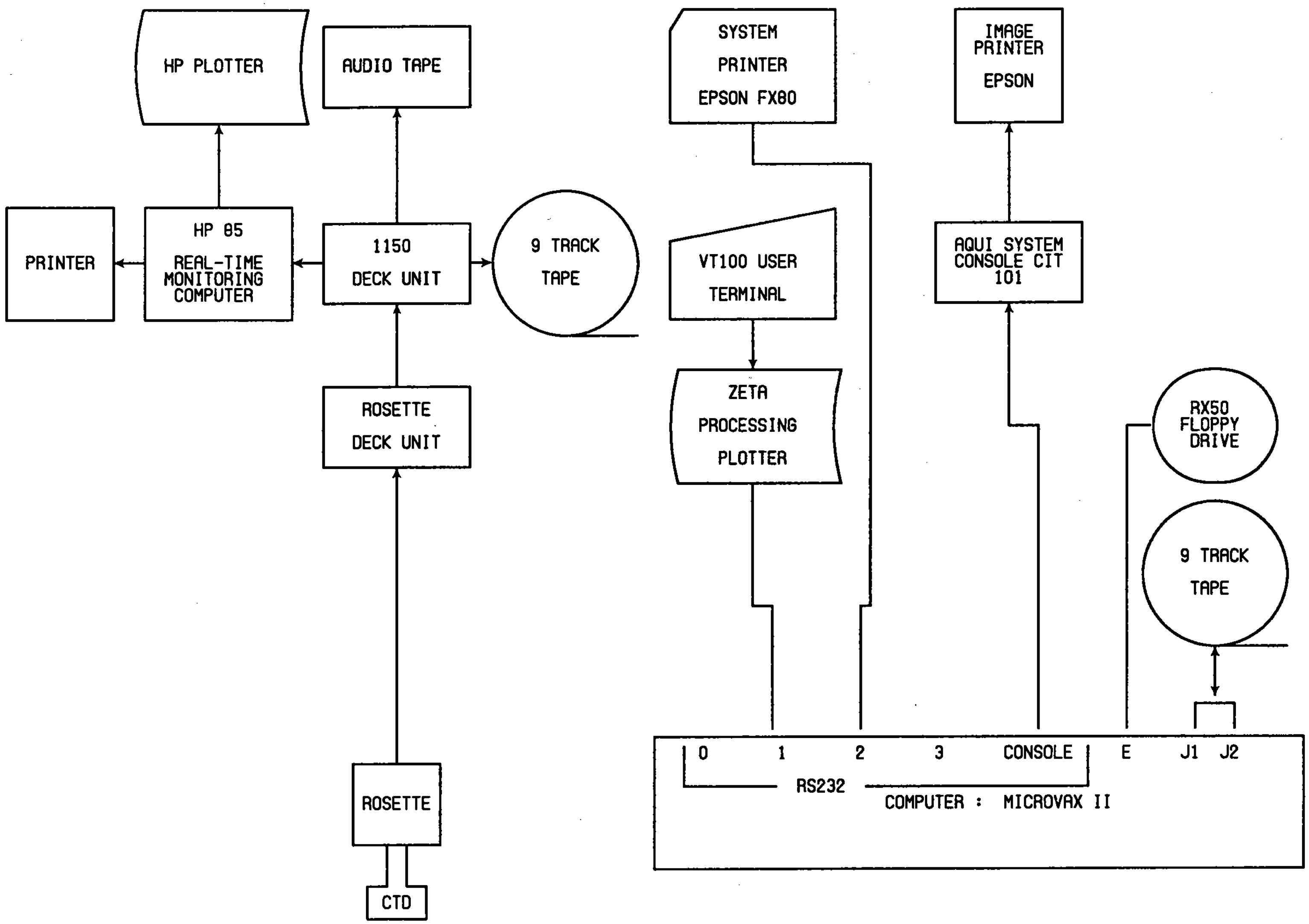
HP PLOTTER
AUDIO TAPE
SYSTEM PRINTER EPSON FX80
IMAGE PRINTER EPSON
PRINTER
HP 85 REAL-TIME MONITORING COMPUTER
1150 DECK UNIT
9 TRACK TAPE
VT100 USER TERMINAL
AQUI SYSTEM CONSOLE CIT 101
ZETA PROCESSING PLOTTER
ROSETTE DECK UNIT
RX50 FLOPPY DRIVE
9 TRACK TAPE
ROSETTE
CTD
0
1
2
3
CONSOLE
E
J1
J2
RS232
COMPUTER : MICROVAX II

Figure 2

APPENDIX 1

PRC/US Cruise 1, Leg 3 – Science Personnel

U.S.

Dick Barber	Duke University
Jane Kogelschatz	Duke University
Ken Crocker	Duke University
Bob Millard*	WHOI
Maggie Francis	WHOI
Theresa Turner	WHOI

P.R.C.

Zangshan Wang*	First Institute, SOA
Pu Shuzhen	First Institute, SOA
Li Bochen	First Institute, SOA
Liu Zanpei	First Institute, SOA
Liu Yangnian	First Institute, SOA
Jiao Yutian	First Institute, SOA
Mao Xinghua	First Institute, SOA
Wang Guiyun	First Institute, SOA
Lin Shoahua	NODC SOA Tainjin
Cui Maochang	First Institute Academia Sinica
Wang Mingwen	South China Sea Branch, SOA
Chen Dexiang	South China Sea Branch, SOA
Zhen Xianxong	South China Sea Branch, SOA
Niu Mingwen	South China Sea Branch, SOA
Huang Leshua	South China Sea Branch, SOA
Sheng Yanfeng	South China Sea Branch, SOA
Liang Zanbang	South China Sea Branch, SOA
Lai Xianwen	South China Sea Branch, SOA
Hou Jinyi	South China Sea Branch, SOA

*Chief Scientists

PRC/US Cruise 2, Leg 1 – Science Personnel

U.S.

Frank Arbusto	CTD	NOAA
Margaret Francis	CTD	WHOI
George Knapp	CTD	WHOI
Bob Millard*	CTD	WHOI
Jane Kogelschatz	Nutrients	Duke University
Guy Mathieu	CO_2	LDGO
Fernando Santiago	ACDP	University of Hawaii

P.R.C.

Wang Zangshan*		First Institute SOA
Li Bocheng	ADCP	First Institute SOA
Liu Zhanpei		First Institute SOA
Xu Bechang		First Institute SOA
Jiao Yutian		First Institute SOA
Shu Mei-xin		First Institute SOA
Zhang Haibo		First Institute SOA
Feng Yue	ADCP	First Institute SOA
Li Jingguang	Translator	IOT, SOA, Tianjin
Jigie Guo	ADCP	
Ma Yingliang		South China Sea Branch, SOA
Li Zhongzhi		South China Sea Branch, SOA
Luo Weizhong		South China Sea Branch, SOA
Zhong Anzheng		South China Sea Branch, SOA
Li Shuqing		South China Sea Branch, SOA
Guo Shixuan		South China Sea Branch, SOA
Zeng Xiangxiang		South China Sea Branch, SOA
Yu Bin		South China Sea Branch, SOA
He Zihong		South China Sea Branch, SOA
Lai Xingwei		South China Sea Branch, SOA
Tan Weihua		South China Sea Branch, SOA

Continued...

Sheng Yanfeng		South China Sea Branch, SOA
Tan Zuowei		South China Sea Branch, SOA
Zhan Junyuan		South China Sea Branch, SOA
Yang Yuchang		South China Sea Branch, SOA
Liao Kongmin	Translator	
Yang Keqi	ADCP	FIO, SOA, Qingdao

*Chief Scientists

PRC/US Cruise 2, Leg 2 – Science Personnel

U.S.

Frank Arbusto	CTD	NOAA
Linda Mangum	CTD	NOAA
Bruce Taft*		NOAA
Ellyn Montgomery	CTD	WHOI
Jane Kogelschatz	Nutrients	Duke University
Fernando Santiago	ACDP	University of Hawaii
Doug Fenton	Mooring	NOAA/PMEL
Andy Shepard	Mooring	NOAA/PMEL

P.R.C.

Wang Zangshan*		First Institute SOA
Li Bocheng	ADCP	First Institute SOA
Liu Zhanpei		First Institute SOA
Xu Bechang		First Institute SOA
Jiao Yutian		First Institute SOA
Shu Mei-xin		First Institute SOA
Zhang Haibo		First Institute SOA
Feng Yuo	ADCP	First Institute SOA
Li Jingguang	Translator	IOT, SOA, Tianjin
Jigie Guo	ADCP	
Ma Yingliang		South China Sea Branch, SOA
Li Zhongzhi		South China Sea Branch, SOA
Luo Weizhong		South China Sea Branch, SOA
Zhong Anzheng		South China Sea Branch, SOA
Li Shuqing		South China Sea Branch, SOA
Guo Shixuan		South China Sea Branch, SOA
Zeng Xiangxiang		South China Sea Branch, SOA
Yu Bin		South China Sea Branch, SOA

Continued...

He Zihong		South China Sea Branch, SOA
Lai Xingwei		South China Sea Branch, SOA
Tan Weihua		South China Sea Branch, SOA
Sheng Yanfeng		South China Sea Branch, SOA
Tan Zuowei		South China Sea Branch, SOA
Zhan Junyuan		South China Sea Branch, SOA
Yang Yuchang		South China Sea Branch, SOA
Liao Kongmin	Translator	
Yang Keqi	ADCP	FIO, SOA, Qingdao

*Chief Scientists

PRC/US Cruise 3, Leg 1 – Science Personnel

U.S.

John Albright	CTD	NOAA
Gregg LaMontagne	CTD	NOAA
Jane Kogelschatz	Biology	Duke University
Ruth Gorski	CTD	WHOI
Bob Millard*	CTD	WHOI
Laurie Raymond	CTD	WHOI
Fernando Santiago	ACDP	University of Hawaii
Jefrey Snyder	ADCP	University of Hawaii

P.R.C.

Pu Shuzhen*	CTD	First Institute SOA
Yang Keqi	CTD	First Institute SOA
Xu Hongda	ADCP	First Institute SOA
Liu Yongnian	XBT	First Institute SOA
Wan Bangjun	XBT	First Institute SOA
Feng Yue	ADCP	First Institute SOA
Liu Feng	Biology	First Institute SOA
Chen Feng	Biology	First Institute SOA
Li Bo	Biology	First Institute SOA
Wu Jianping	Meteorology	First Institute SOA
Li Ruoden	Meteorology	First Institute SOA
Wang Mingwen	CTD	South China Sea Branch, SOA
Lai Xin Wei	CTD	South China Sea Branch, SOA
Niu Zhiwang	CM	South China Sea Branch, SOA
Lin Wen Sheng	CTD	South China Sea Branch, SOA
Zhao Liu Chi	CM	South China Sea Branch, SOA
Huang Le Shua	CTD	South China Sea Branch, SOA
Huang Fang	Biology	South China Sea Branch, SOA
Tan Zhuowen	CM	South China Sea Branch, SOA
Hao Guangzhi	CTD	South China Sea Branch, SOA
Huang Huijin	CTD	South China Sea Branch, SOA
Tang Ying Hua	CTD	South China Sea Branch, SOA
Mai Hui Long	Biology	South China Sea Branch, SOA
Li Xiu Lu	Biology	South China Sea Branch, SOA
Yu Hansheng	Biology	South China Sea Branch, SOA

Continued...

Ou Qiang	Biology	South China Sea Branch, SOA
Huang Chu Guang	Biology	South China Sea Branch, SOA
Zang Yi Ling	Biology	South China Sea Branch, SOA
Qui Kesen	Meteorology	South China Sea Branch, SOA
Qui Si Ren	CTD	National Marine Meteorologic Service
Shi Guoqiang	Meteorology	Center Marine Environ. Forecasting
Ma Liming	CO_2	Center Marine Environ. Forecasting
Zheng Yu	CO_2	Center Marine Environ. Forecasting
Wang Congmin	Freon	Academia Sinica, Qingdao
Shen Zhiliang	Freon	Academia Sinica, Qingdao
Liao Kongmin	Interpreter	

*Chief Scientists