NOTES TECHNIQUES

SCIENCES DE LA MER

OCÉANOGRAPHIE PHYSIQUE

N° 12

1995

Traitements des données pour la validation en plein océan du niveau de la mer de TOPEX/POSEIDON dans le Pacifique équatorial ouest

Data preparation for the open-ocean validation of TOPEX/POSEIDON sea level in the western equatorial Pacific

Lionel GOURDEAU
Joel PICAUT
Marie-Jo LANGLADE
Antonio BUSALACCHI
Eric HACKERT
Michael McPHADEN
Paul FREITAG
Frank GONZALEZ
Marie EBLE
Robert WELLER

L'INSTITUT FRANÇAIS DE RECHERCHE SCIENTIFIQUE POUR LE DÉVELOPPEMENT EN COOPÉRATION

ORSTOM

CENTRE DE NOUMÉA

NOTES TECHNIQUES

SCIENCES DE LA MER

OCÉANOGRAPHIE PHYSIQUE

N° 12

1995

Traitements des données pour la validation en plein océan du niveau de la mer de TOPEX/POSEIDON dans le Pacifique équatorial ouest

Data preparation for the open-ocean validation of TOPEX/POSEIDON sea level in the western equatorial Pacific

* Lionel GOURDEAU
* Joel PICAUT
* Marie-Jo LANGLADE
** Antonio BUSALACCHI
** Eric HACKERT
*** Michael McPHADEN
*** Paul FREITAG
*** Frank GONZALEZ
*** Marie EBLE
**** Robert WELLER

* ORSTOM, Nouméa, New Caledonia
** NASA/GSFC, Greenbelt, USA
*** NOAA/PMEL, Seattle, USA
**** WHOI, Woods Hole, USA

ORSTOM

L'INSTITUT FRANÇAIS DE RECHERCHE SCIENTIFIQUE
POUR LE DÉVELOPPEMENT EN COOPÉRATION

CENTRE DE NOUMÉA

/Gourdeau L.
/Picaut, J.
/Langlade, M.J.
Busalacchi, A.
Hackert, E.
McPhaden, M.
Freitag, H.
Gonzalez, F.
Eble, M.
Weller, R.

Traitements des données pour la validation en plein océan du niveau de la mer de TOPEX/POSEIDON dans le Pacifique équatorial ouest. *Data preparation for the open-ocean validation of TOPEX/POSEIDON sea level in the western equatorial Pacific*

Nouméa : ORSTOM. Octobre 1995. 43 p.
Notes Tech. : Sci. Mer ; Océan. Phys. ; 12

Ø32MILPHY

OCEANOGRAPHIE PHYSIQUE ; APPAREIL DE MESURE ; SALINITE ;TEMPERATURE ; PRESSION ; ALTIMETRIE ; NIVEAU MARIN ; HAUTEUR DYNAMIQUE ; TOPEX/POSEIDON / PACIFIQUE

Imprimé par le Centre ORSTOM
Décembre 1995

ORSTOM Nouméa
REPROGRAPHIE

CONTENTS

RÉSUMÉ

Durant la période de vérification de la mission altimétrique franco-américaine TOPEX/POSEIDON, une expérience de validation rigoureuse des mesures altimètriques a été effectuée en plein océan dans l'ouest du Pacifique équatorial. Entre août-septembre 1992 et février-mars 1993, deux mouillages du réseau multinational TOGA-TAO situés à 2°S-156°E (profondeur 1739 m) et à 2°S-164,4°E (profondeur 4400 m) ont été equipés de capteurs supplémentaires de température, salinité et pression afin de mesurer très précisément, toutes les cinq minutes, les hauteurs dynamiques de la surface jusqu'au fond, juste sur deux points de croisement des traces au sol du satellite TOPEX/POSEIDON. Parallèlement, des écho sondeurs inversés et des capteurs de pression ont été déployés sur le fond à proximité des deux mouillages. Une étude préliminaire, confirmée par la suite, utilisant des mesures effectuées avec des sondes CTD, montre que l'ensemble des instruments le long des deux mouillages permet de mesurer les fluctuations des hauteurs dynamiques de surface avec une précision de 1 à 2 cm dyn. Cette expérience de validation a aussi bénéficié de données très complètes collectées dans cette même région durant la Période d'Observations Intensives du programme international TOGA-COARE entre novembre 1992 et février 1993.

Ce rapport technique détaille les différents instruments utilisés avec leurs calibrations et leur temps de fonctionnement. Les traitements des données du mouillage comme par exemple le bouchage des trous, les interpolations temporelle et sur la verticale, les déterminations des salinités et pressions sont décrits. A l'issue du traitement, nous disposons de series temporelles tous les cinq minutes en salinité, température et pression pour chaque capteur du mouillage. En final, des tests d'erreur sur la hauteur dynamique sont effectués. Le traitement des autres données extérieures aux mouillages comme les pressions au fond ou à la surface ainsi que celui des données altimétriques TOPEX/POSEIDON sont également expliqués.

ABSTRACT

During the verification phase of the TOPEX/POSEIDON radar altimeter mission a rigorous open-ocean validation experiment was conducted in the western equatorial Pacific ocean. From August-September, 1992 to February-March, 1993 two TOGA-TAO moorings at 2°S-156°E (1739 m depth) and 2°S-164.4°E (4400 m depth) were enhanced with additional temperature, conductivity, and pressure sensors to measure precisely the dynamic height from the surface to the bottom at 5 min intervals directly beneath two TOPEX/POSEIDON crossovers. Nearby bottom pressure gauges and inverted echo sounders were deployed as well. A pre-deployment design study using full depth CTD casts indicated this suite of instruments was capable of measuring sea surface height fluctuations to within 1-2 cm. This was confirmed by further post-deployment analyses. The validation experiment also benefitted from a comprehensive set of ocean-atmosphere measurements that were made in the region during the TOGA-COARE Intensive Observation Phase of November, 1992 - February, 1993.

This technical Report documents the instrumentation, operations at sea, and moored data processing including the techniques used to fill data gaps, interpolation in time and the vertical, and the computation of salinity and pressure. These steps have produced time series of temperature, salinity and pressure sampled at 5-minute intervals for each sensor along the mooring line. The improvement upon dynamic height estimates including a budget error is analysed. Processing of the different external data such as bottom and sea surface pressure sensors, and TOPEX/POSEIDON altimetric data are also explained.

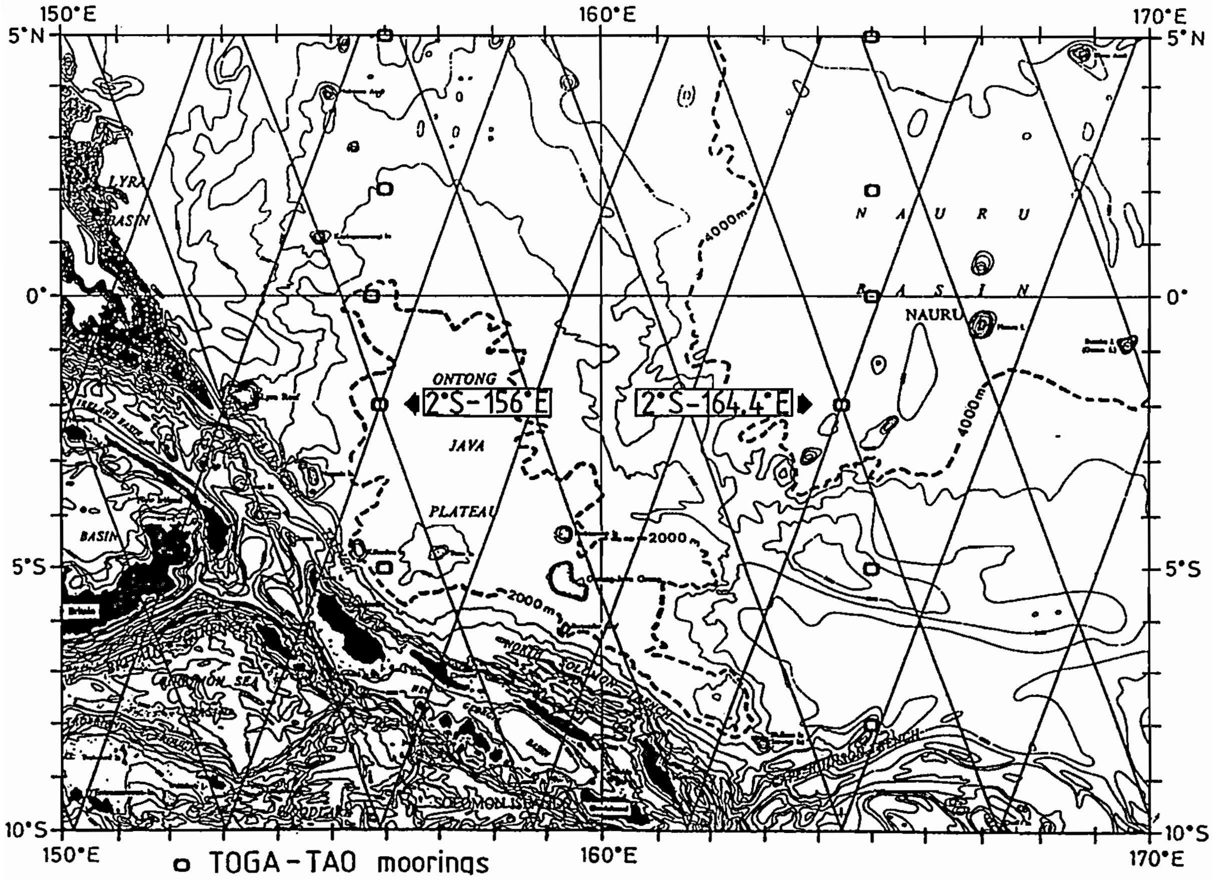


Figure 1

Location of the two TOGA-TAO validation moorings, superimposed are the TOPEX/POSEIDON tracks and the bathymetry contour. The 2000 m and 4000 m contour are accentuated, and the depths greater than 5000 m are shaded.

1. Introduction

Prior to launch, the precision of the TOPEX/POSEIDON radar altimeter instruments were projected to be of order 2.4 cm (TOPEX/POSEIDON Science Working Team, 1991). In the event this level of precision is attained in orbit, and the necessary environmental corrections are of similar order and result in an overall level of accuracy of order 4 cm. Thus, there is a clear need to rigorously validate the accuracy of TOPEX/POSEIDON sea level observations in the open ocean. Any attempt to do so is complicated by the fact that the intrinsic error of most in situ sea level estimates is of order 3 to 7 cm. Therefore, there is a fundamental difference between the anticipated TOPEX/POSEIDON accuracy and any present observational means for in situ validation.

A field experiment was carefully designed for the expressed purpose of using in situ observations to validate open-ocean TOPEX/POSEIDON altimeter retrievals in the western equatorial Pacific during the 6-month verification phase. The platforms used for this validation experiment consist of two ATLAS moorings of the TOGA-Tropical Atmosphere Ocean (TAO) Array (Hayes et al, 1991, McPhaden, 1993).

The two validation moorings used in this study were specifically situated directly beneath TOPEX/POSEIDON crossovers at 2°S-156°E and 2°S-164.4°E (Figure 1). On these two moorings, additional dedicated sensors were deployed (August-September, 1992 to February-March, 1993) based on a design study estimated to yield sea level with a 1-2 cm accuracy. Temperature and conductivity sensors were added to the mooring line, from the surface to the bottom, to estimate the steric part of changes in sea level. The shape of the mooring line was more precisely determined by additional pressure sensors. Atmospheric pressure sensors were deployed to account for the inverse barometric effect and bottom pressure sensors were deployed on nearby moorings to determine the barotropic component of pressure changes .

The two mooring sites are located in very different geographical settings. The 2°S-164.4°E mooring is anchored on an abyssal plain (4400 m) far from a coast, whereas the 2°S-156°E mooring is situated on the Ontong Java Plateau (1750 m) near the Kilinailau trench and a little more than a radius of deformation (400 km) from New Ireland and Bougainville islands.

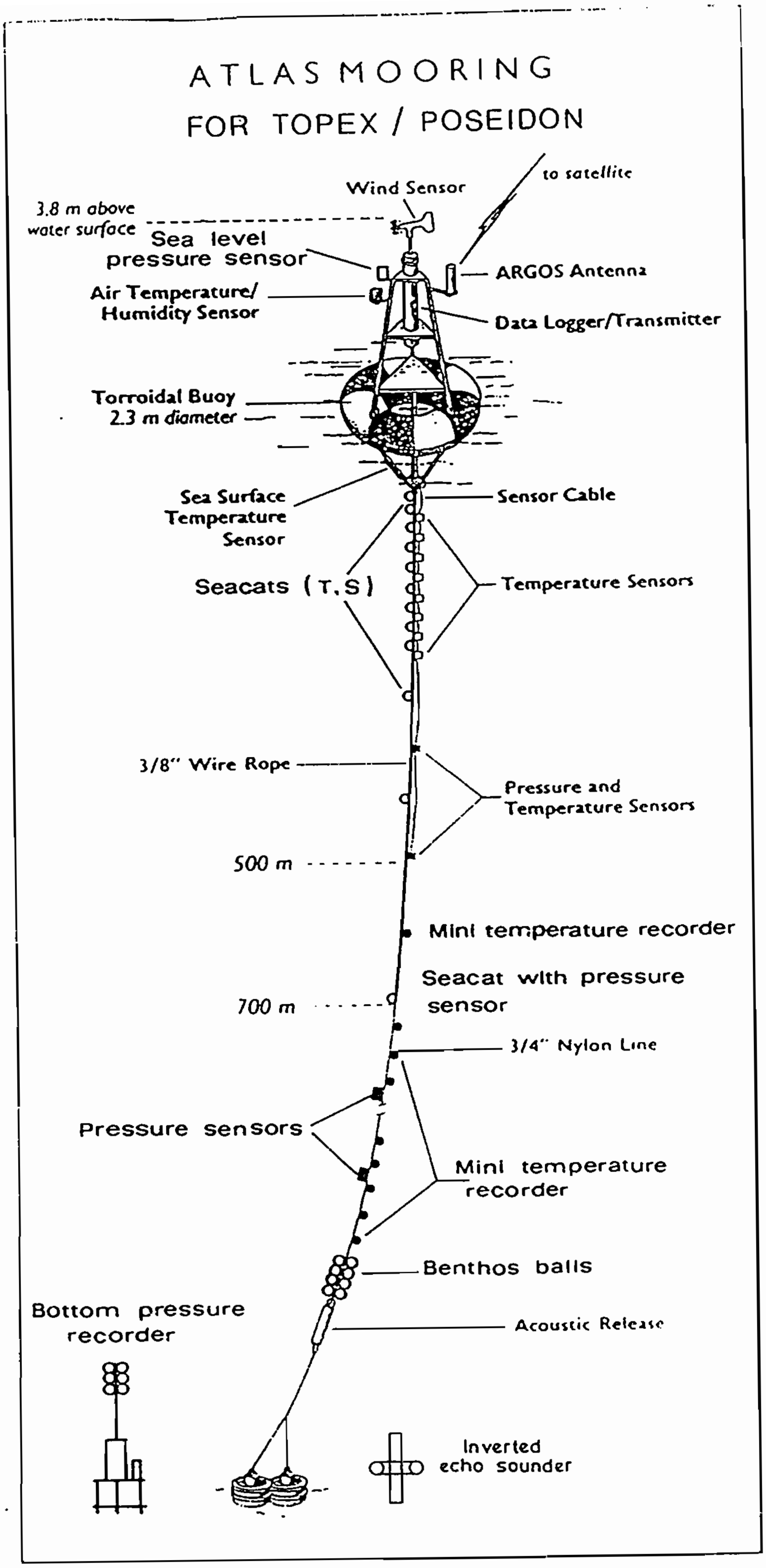


Figure 2. ATLAS mooring design with additional instrument along the line (Seacats, Mini Temperature Recorders, benthos balls), and on the bottom Inverted Echo Sounder and Bottom Pressure Recorder.

The sea level comparisons between these two sites will permit the quality of the TOPEX/POSEIDON retrievals to be interpreted with regard to the barotropic and baroclinic variability of two different depth regimes.

Section 2 described the different instrumentation and operations at sea. The processing of the mooring data (temperature, salinity and pressure) such as pre-post calibration, data gap filling, and gridding to a common 5-min sampling interval are presented in section 3. The processing of in situ data other than the TOGA-TAO moorings are presented on section 4. Section 5 focuses on TOPEX/POSEIDON data including the different corrections used and the calculation of sea level anomalies at high and low frequency.

2. Instrumentation and operations at sea

2.1. *Instrumentation* (Figure 2)

2.1.1. Standard ATLAS

The ATLAS moorings (Hayes et al., 1991) are routinely equipped with an anemometer, air temperature, relative humidity and sea surface temperature (SST) sensors at the surface. Beneath the surface a thermistor chain measured temperatures at 10 depths between 25 m and 500 m and pressure at 300 m and 500 m.

2.1.2. Enhanced subsurface measurements

The number and vertical distribution of additional temperature and conductivity sensors along the mooring lines were determined by a preliminary sampling study based on 13 (57) deep CTD casts made at (around) 2°S-164.4°E from 1984 to 1990. Surface dynamic heights relative to the bottom were calculated from a series of discontinuous T, S points taken on the CTD profiles at the proposed sensor depths and compared with their values using the complete CTD profiles. Different calculations, made with various array designs, resulted in a standard error of less than 1 dyn cm for the array eventual chosen. Because of important salinity variations in the first 500 m (Delcroix et al., 1987), thermosalinograph model SBE-16 Seacat units (manufactured by Sea-Bird Electronics, Inc., Bellevue WA) were added between the ATLAS temperature sensors. From 500 m to the bottom (1739 m at 2°S-156°E; 4400 m at 2°S-164.4°E), the salinity variations were small enough to use one Seacat at 750 m and Mini Temperature Recorders (MTRs, designed and built at NOAA/Pacific Marine Environmental Laboratory) for temperature-only measurements. Salinity at the MTR depths were determined from a mean T-S relationship.

Enhanced instrumentation on the Atlas mooring at 2°S-156°E included 16 Seacats (2 with pressure sensors), 5 MTRs, and 1 Aanderaa recorder (pressure and temperature). At 2°S-164.4°E 11 Seacats (2 with pressure sensors), 12 MTRs, and 2 Aanderaa recorders were added. The greater number of Seacats on the ATLAS at 2°S-156°E was due to the addition of 8 instruments provided by R. Lukas (University of Hawaii) as part of a separate COARE proposal to study the upper ocean thermohaline structure in the western equatorial Pacific.

Appendix 1 summarizes the different instruments on the mooring line with their depth, and their corresponding type of measurement.

2.1.3. Enhanced surface measurements

Aanderra sea surface pressure recorder were placed on the surface buoys at each site.

2.1.4. Enhanced bottom measurements

Within one mile of each ATLAS mooring, the following instruments were deployed: 1 Bottom Pressure Recorder (BPR) and 2 Inverted Echo Sounder (IES) near 2°S-156°E, 1 BPR and 1 IES near 2°S-164.4°E.

2.2. *Operations at sea, deployment and recovery*

The two ATLAS moorings at 2°S-156°E (1739 m depth, on the Ontong Java Plateau) was deployed September 11, 1992 and recovered February 22, 1993. The mooring at 2°S-164.4°E (4400 m depth, in the abyssal plain) was deployed August 26, 1992, and recovered March 22, 1993. These operations at sea were in support of the COARE-POI cruises by the R/V Le Noroit (ORSTOM- Nouméa) (Delcroix et al., 1993) and the R/V Moana Wave (University of Hawaï). The 2°S-156°E data set begin at 8h00 September 12, 1992, (UTC) and end at 18h55 February 22, 1993. At 2°S-164°E the data begin at 3h00 August 26, 1992, and end at 7h55 March 11, 1993.

3. Editing of mooring data

3.1. *Pre/post-c deployement alibrations*

Before deployment, all 27 ORSTOM and UH Seacats were pre-calibrated. After recovery, 8 (11) ORSTOM Seacats at 2°S-156°E (2°S-164.4°E) were post-calibrated at SeaBird. To continue the measurements as part of the COARE Enhanced Monitoring Phase, five University of Hawaï (UH) Seacats at 2°S-156°E were redeployed in February 1993 on the ATLAS mooring redeployed at the same site for the next year.

Post calibrations of the ORSTOM Seacats and all the MTRS were finished by August 1993. Because the five redeployed UH Seacats were not recovered until after the end of the present processing and analyses, the post calibrations of the five UH Seacats were not used for the present study. However, their post-calibration in mid-1994 indicated moderate drifts. Mean and standard deviation of the differences between pre- and post-deployment calibrations of the 18 ORSTOM Seacats, which worked well up to recovery, were -0.0013 ± 0.0016 °C for temperature and 0.0063 ± 0.0227 psu for salinity. Mean and standard deviation of the difference between pre- and post-deployment calibrations of the 15 MTRs were 0.0042 ± 0.0057 °C. Comparisons for every sensor between pre- and post calibration are presented on Appendix 2.

Theses small differences between pre- and post-calibrations were applied in the final data set through a simple linear interpolation in time.

3.2. *Data status*

On the 2°S-156°E mooring, no data were returned by one Seacat (45 m), and two Seacats (5 m and 30 m) failed to return good data after 2 months of measurements (November 22, 1992). On the 2°S-164.4°E mooring, one Seacat (137 m) failed after 2 months (December 7, 1992) and the temperature sensor of the Seacat at 400 m failed after one month (September 23, 1992). Of the 26 remaining Seacat data sets, 19 were processed at ORSTOM-Nouméa, and the other 7 were initially processed at the University of Hawaii and transferred to ORSTOM-Nouméa for further processing.

At 2°S-156°E, the 50 m ATLAS temperature sensor stopped prematurely on January 19, 1993.

At 2°S-164.4°E, the MTRs filled their internal memories and stopped 10 days prior to recovery, and no data were returned by two of the 17 MTRs. The 15 remaining MTRs were originally processed at NOAA/PMEL, and transferred to ORSTOM-Nouméa for further processing.

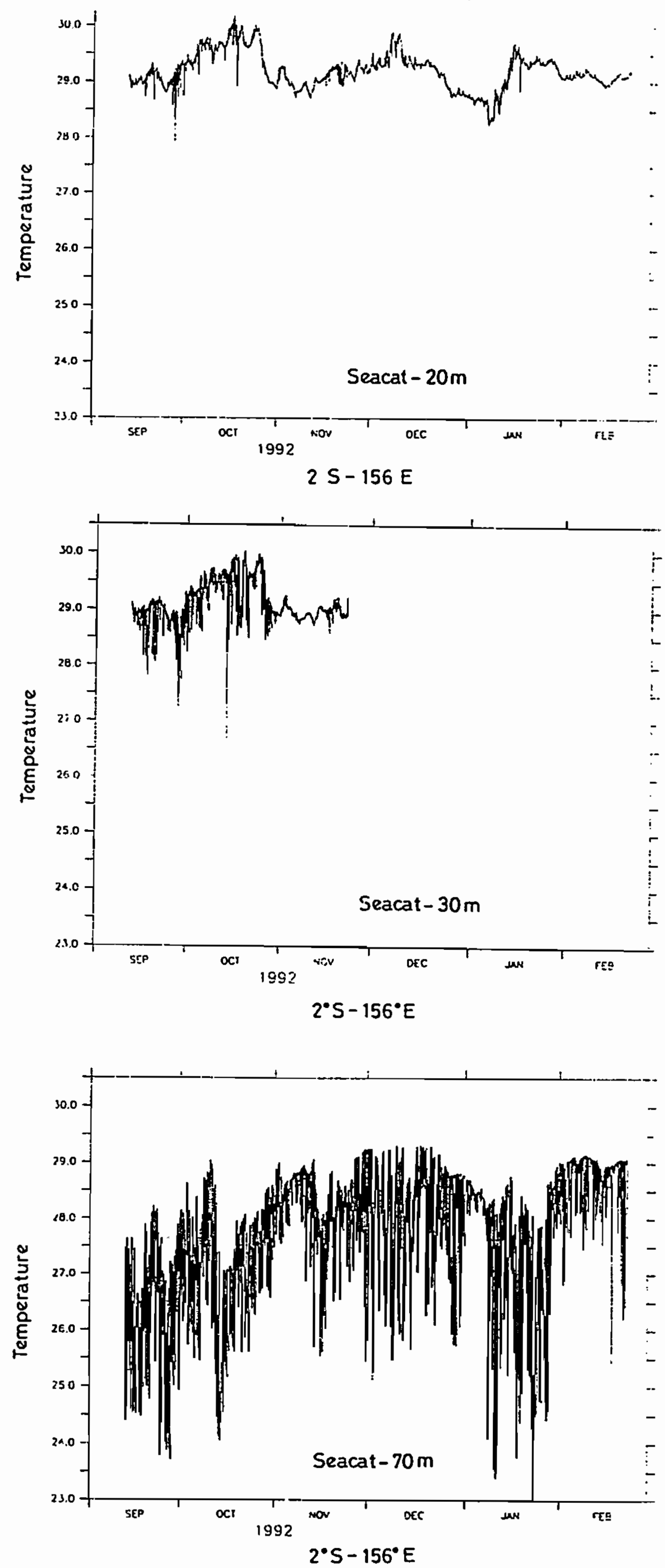


Figure 3. Example of incomplete Seacat temperature record at 30 m (2°S-156°E) (a). The time series was completed using time series of Seacat temperature at 20 m (b) and 70 m (c).

Due to an unprotected memory battery drain, all Aanderaa data were lost. Surface sea level pressure measurements were made from October 21 to March 4, 1993 at the Improved Meteorological Package (IMET) mooring located within 15 nm of the 2°S-156°E ATLAS mooring as part of a COARE proposal to study air-sea flux exchange. Continuous (7.5 min sampling) data from this mooring described in section 4.2 were made available by R. Weller (Woods Hole Oceanographic Institution).

3.3. *Time verification*

In order to be sure of their timing, each Seacat time-series were carefully cross-checked with five independent time marks: start of the instrument, instrument in the water, release of the anchor for recovery, instrument out of the water and stop of the instrument. Comparison of UTC and Seacat times at the end of the operation revealed a shift in time (over 5-6 months) generally less than a minute with a maximum of 3.6 minutes for the Seacat instrument at 750 m and 2°S-164.4°E

Post-deployment checks of MTR clocks confirmed that they were within the instruments' 5 min/year specified accuracy.

In addition, each time-series was plotted and carefully compared with the surrounding time-series on the mooring line, in order to detect a possible shift in time in the vertical structure.

3.4. *Filling gaps*

The three Seacat and the ATLAS time series which ended prematurely were extrapolated in time using the information of the previous data and the surrounding sensors (e.g. Figure 3). After removal of the mean the anomalies were first interpolated following Equation (1).

$$Xi(z) = Ca\ Xr(z\text{-}1) + Cb\ Xr(z+1) \qquad (1)$$

where z is the level with the data gap, z-1 and z+1 are the levels above and below, respectively, with complete measurements, and Xi the interpolated, and Xr the measured temperature or conductivity anomalies.

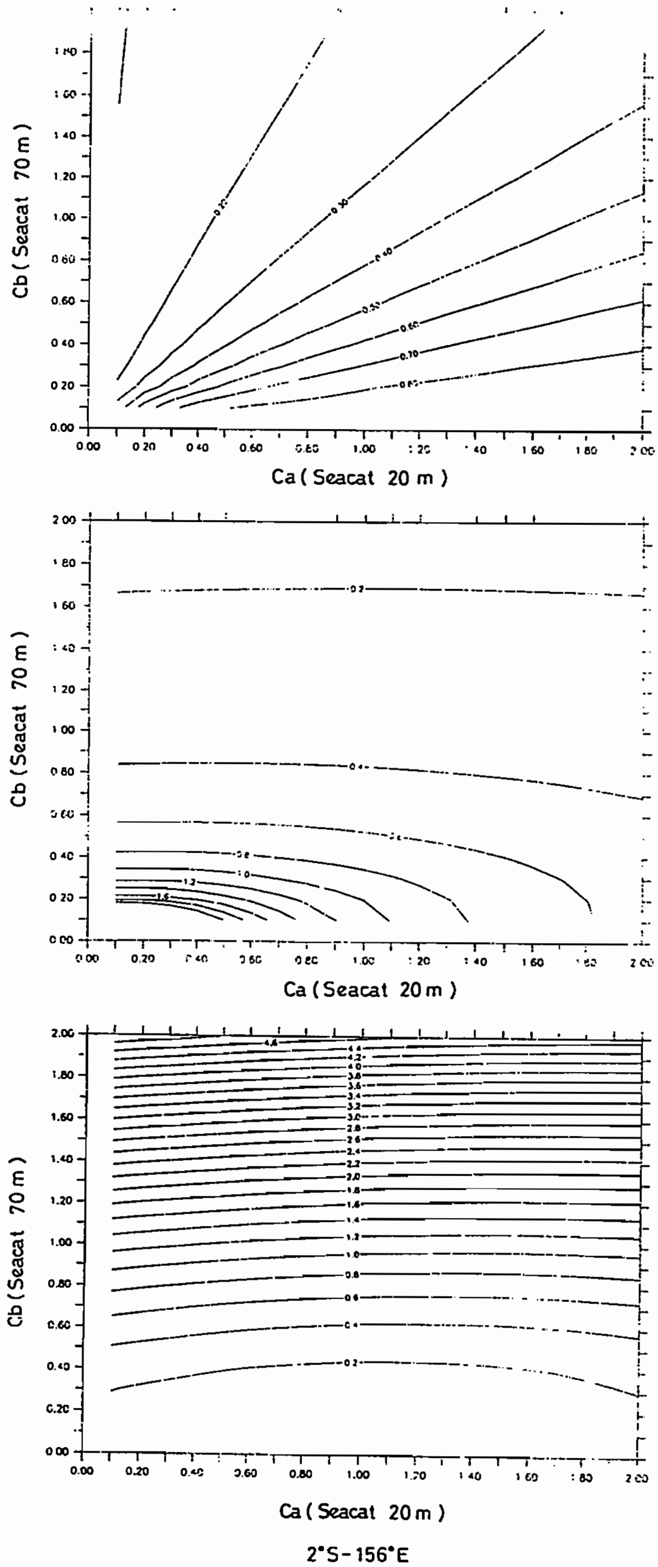


Figure 4. Determination of the Ca and Cb coefficients. For the Seacat with incomplete temperature at 30 m: (a) correlation between the measured and interpolated series (COR), (b) ratio of standard deviation of measured series versus standard deviation of the interpolated series, (c) rms difference between the measured and interpolated series.

The Ca, Cb coefficients were determined during the period T1 prior to the cessation of measurement. They were chosen such that, during this period, the interpolated series (Xi(z)) differed minimally from the measured series (Xr(z)) and additionally, the following statistical criteria must most nearly be satisfied:

- correlation between Xi(z) and Xr(z) (Cor) be close to 1
- amplitudes (rms) of Xi and Xr be similar
- rms difference between Xr(z) and Xi(z) be close to 0

This was done subjectively looking simultaneously at the three corresponding plots (e.g., Figure 4). Table 1 lists the coefficient Ca, Cb, and Table 2 the corresponding statistical parameters calculated for potential density σ_θ.

Table 1

	temperature		conductivity	
level	Ca	Cb	Cb	Cb
5 m	0.7	0.3	0.6	0.4
30 m	1.1	0.1	1.1	0.1
137 m	0.6	0.4	0.7	0.3

Table 2

level	Cor	rms ratio	rms dif.
5 m	0.99	1.00	0.01
30 m	0.74	1.14	0.14
137 m	0.72	1.01	0.26

The linear combination (Eq. 1) was then applied, during the period T2 of interrupted data, to fill the temperature and conductivity anomalies at the considered level. The mean of the series at depth z during the previous period T1 was added to these anomalies to obtain absolute "interpolated" measurements during the period T2 (Figure 5). This method could be in error if the T1 mean was not equivalent of the T1+T2 mean (i. e., if a long-term shift would have occurred during the data interruption). However, there was no way to evaluate this eventual error.

This method was validated at 30 m with independent CTD measurements taken during the COARE-POI repetitive cruise along 156°E (Delcroix et al., 1993). From December 8, 1992 to February 22, 1993, 14 CTD

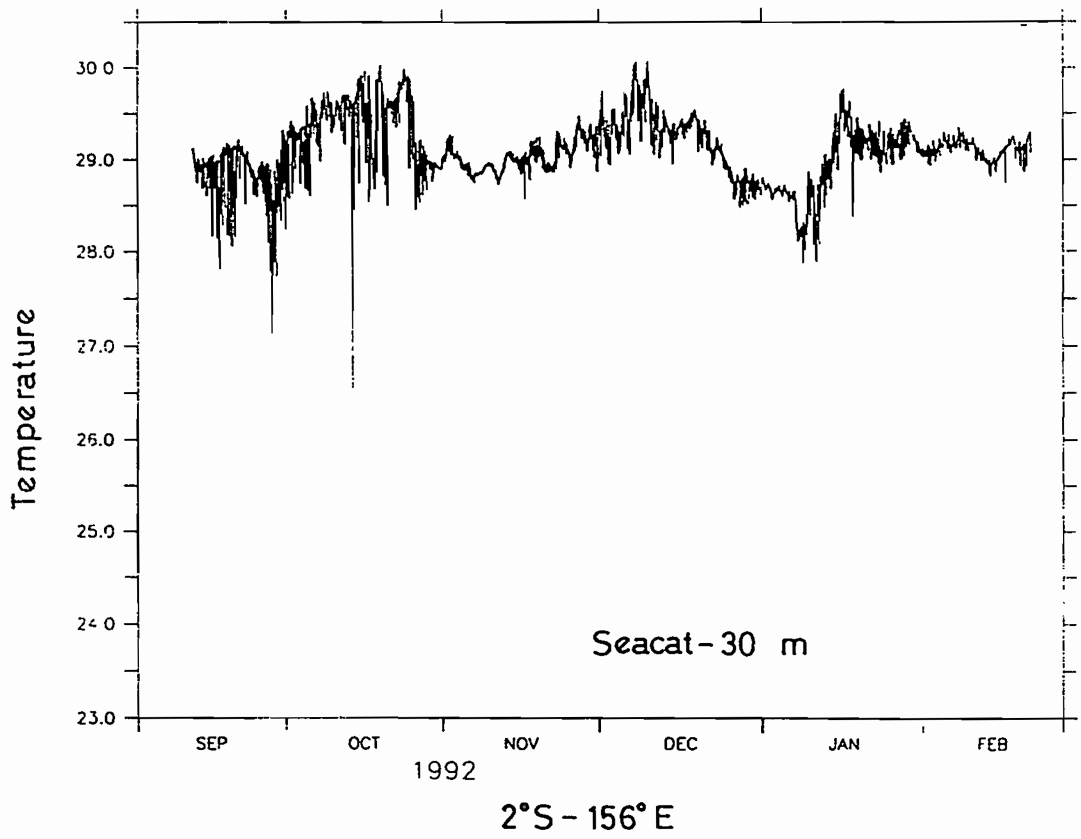


Figure 5. Final 5 min Seacat temperature series at 30 m interpolated using Ca, Cb coefficients of 1.1 and 0.1 respectively.

casts were taken at 2°S-156°E, at intervals varying from 1 to 5 days. The 14 points of σ_θ calculated from CTD measurements at 30 m were compared to the similar point in time of the "interpolated" Seacat series. Given the uncertainty in temporal synchronization between CTD and moored measurements and the fact that the CTD casts were performed within 1-2 miles of the mooring site, the agreement was very good (0.83 correlation, 0.075 rms difference, and 1.02 ratio of standard deviations) and validate the method.

At 2°S-164.4°E and 400m, the temperature sensor failed before recovery, but the conductivity sensor worked well. At the same level, conductivity and temperature were strongly correlated in time. Therefore, we chose a linear relation between temperature (Xt) and conductivity anomalies (Xc):

$$Xt = b\,Xc \qquad (2)$$

During the T1 period where temperature was available, the coefficient b was chosen such that it best satisfied the statistical criteria defined for Eq. 1. The b coefficient found was 9.9 and the different statistical parameters for temperature, salinity and σ_θ are listed on Table 3.

Table 3

	Cor	rms ratio	rms dif.
temperature	0.99	1.00	0.004
salinity	0.96	0.98	0.037
σ_θ	0.99	1.03	0.050

This relation was used to compute temperature anomalies, during the T2 period after the temperature sensor had failed. The mean over the T1 period was then added to the temperature anomalies in order to obtain absolute temperature for the T2 period.

3.5. *Interpolation of temperature and salinity every 5 min*

3.5.1. Seacat data

Most of the Seacat sensors had the same sample rate (5 min) as the MTRs. A few Seacat datasets had a sample rate of 10, 20 or 30 min (Table 4).

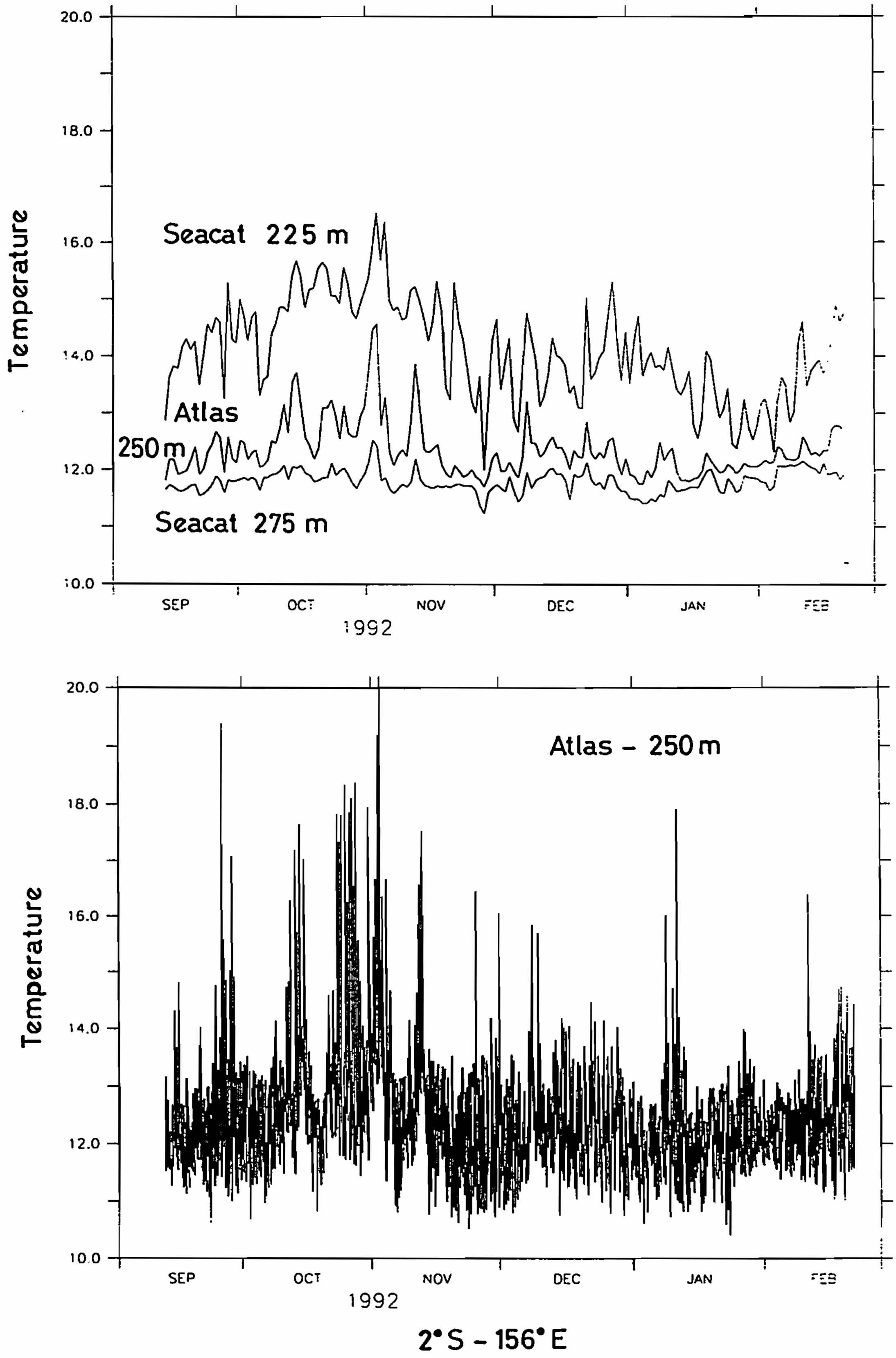


Figure 6. (a) Example of original daily ATLAS temperature at 250 m (2°S-156°E) (middle) and the adjacent daily mean Seacat temperature at 225 m (top) and 275 m (bottom). (b) Final 5-min ATLAS temperature at 250m (2°S-156°E) with respect to the original daily ATLAS temperature using Ca, Cb coefficients of 0.3 and 1.6 respectively.

Table 4

	2°S-156°E			2°S-164.4°E			
sampling (min):	30	10	10	20	20	10	10
depth (m):	1	400	750	225	275	400	750

A simple linear function in time was not used to interpolate the tome series with longer sample rates as it resulted in an unrealistic slope in the power spectrum near the Nyquist frequency. Therefore the 5 min information recorded from the nearest-in-depth Seacat (Sea5) was used to interpolate to 5 min rate the considered Seacat data. In the following, the case with 10-min sample rate is presented (Sea10).

First, Sea5 was decimated to the sampling rate of Sea10 (Sea5b). A linear regression was computed between the two Seacat data sets (Sea5b and Sea10). Second, Sea5b and Sea10 were linearly interpolated in time every 5 min (Sea5c, Sea10c). For the sensor sampling at 5 min, anomalies between the measurement (Sea5) and the linear interpolation at 5 min (Sea5c) were computed. Third, these anomalies, weighted by the regression coefficient defined above, were added to the 5 min value interpolated from the under-sampled sensor (Sea10c). This method assumed that $(5\ \text{min})^{-1}$ frequency variability and the lowest frequency variability $(10, 20\ \text{or}\ 30\ \text{min})^{-1}$ evolve in the same way at the depth of the two sensors.

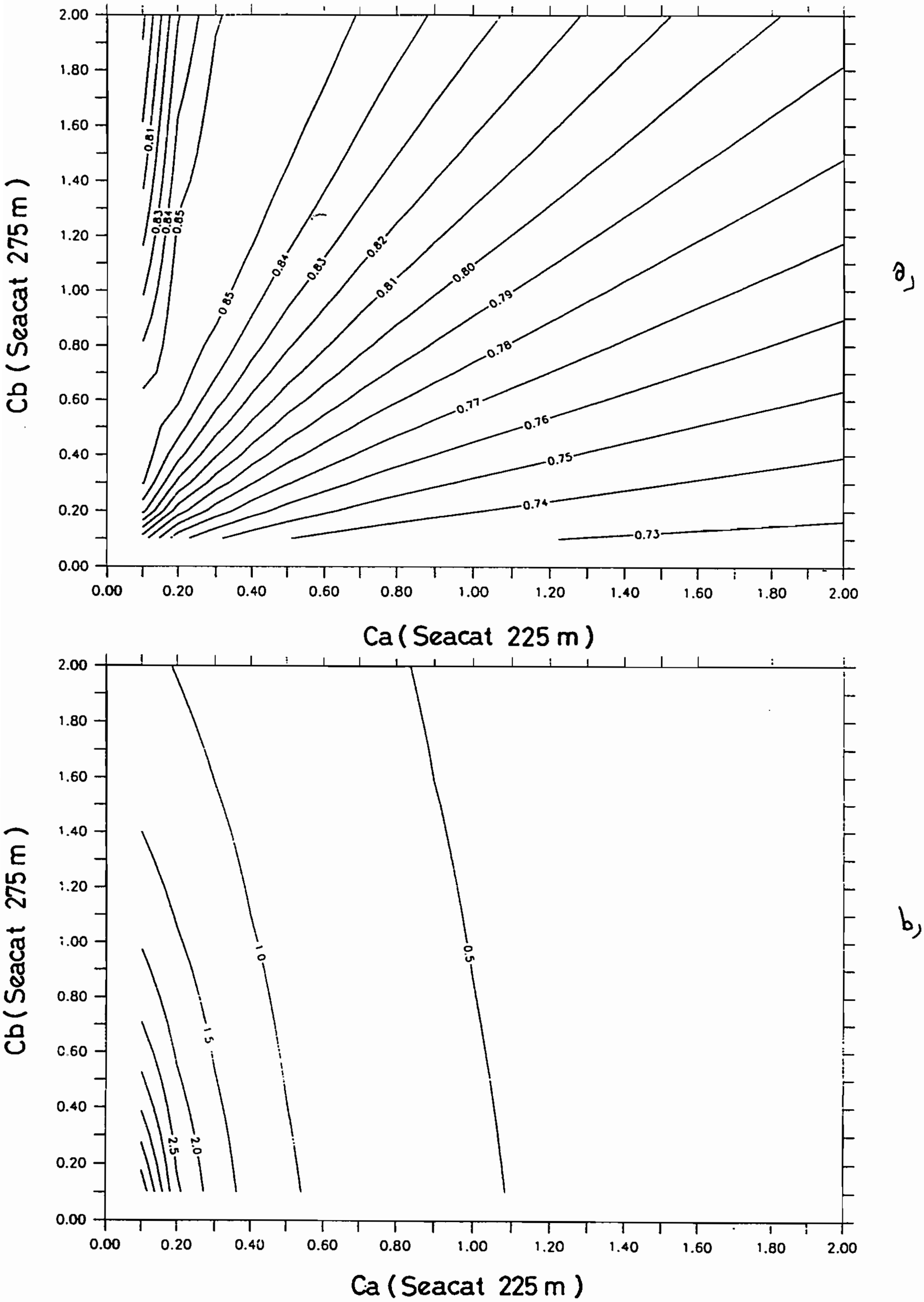
3.5.2. ATLAS data

The 10 ATLAS thermistor chain sensors provided daily mean temperature in real time. They were interpolated to the common 5 min sample rate using a similar technique which took into account the high frequency information from the two Seacat sensors surrounding each ATLAS temperature sensor. Following Eq. 1 and its statistical criteria, the ATLAS daily mean measurements were fit to an optimal combination of the daily mean Seacat series (e.g. Figure 6a) generating coefficients Ca and Cb listed in Table 5 (e.g. Figure 7).

Table 5

2°S-156°E

ATLAS depth (m):	25	50	75	100	125	150	200	250	300	500
Ca :	0.6	0.2	0.8	0.2	0.3	0.8	0.5	0.3	0.7	1.7
Cb :	0.4	0.6	0.5	1.	0.7	0.4	0.8	1.6	0.4	0.1



2°S - 156°E

Figure 7. Determination of Ca, Cb coefficients used to interpolate the daily ATLAS temperature at 250m (2°S-156°E) at a 5-min rate using the 5-min Seacat information at 225 m and 275 m adjacent to the ATLAS sensor. (a) Correlation between the measured and reconstituted ATLAS series (COR), (b) ratio of standard deviation of measured series versus standard deviation of the interpolated series for the daily ATLAS.

2°S-164.4°E

ATLAS depth (m):	25	50	75	100	125	150	200	250	300	500
Ca :	0.4	0.8	0.7	0.6	0.5	0.8	0.4	0.2	0.8	1.3
Cb :	0.6	0.2	0.5	0.8	0.5	0.4	1.	0.9	0.2	0.8

From each daily temperature series, a continuous low-frequency series sampled every 5 min was generated which preserved the ATLAS and Seacat daily mean, using a specific statistical technique (SAS/ETS, version 6). The low-frequency series was removed from the 5 min Seacat temperature to obtain 5-min temperature anomalies at the level of the two Seacats. A 5 min ATLAS anomaly was computed from these 5-min Seacat anomalies, using Eq. 1 and the previous coefficient Ca and Cb (this assumes the high-frequency and low-frequency variabilities to behave in the same way, in terms of Eq. 1). The final 5-min ATLAS temperature (e.g. Figure 6b) was obtained from the addition of this reconstructed 5-min anomaly to the low-frequency ATLAS series.

3.6. *correction of vertical displacement*

All the sensors on the mooring line were subject to vertical displacement due to horizontal movement of the buoy (e.g. barotropic tide) and/or vertical movement of the water masses (e.g. baroclinic tides). At 400 m (750 m) the vertical excursion is about 4-6 m (6-9 m). Given the vertical gradient of temperature and salinity, the variation of temperature and salinity associated with the vertical displacements at 400 m (750m) were about 7-10 (2-3) time less than the variation of temperature and salinity themselves. Despite these small ratio, the vertical displacement of the sensors in the first 750 m must be taken into account for a precise surface-to-bottom dynamic height calculation.

Due to the failure of the Aanderraa pressure sensors, our pressure tme series consisted of two ATLAS pressure series at 300 and 500 m and two Seacat pressure series at 400 and 750m. Seacat pressures were sampled every 10 min and ATLAS pressures were daily mean.

3.6.1. Removal of the drift in the ATLAS pressure

ATLAS pressure sensors were subject to significant drift. An apparent monotonically decaying drift is evident in the initial portion of the pressure

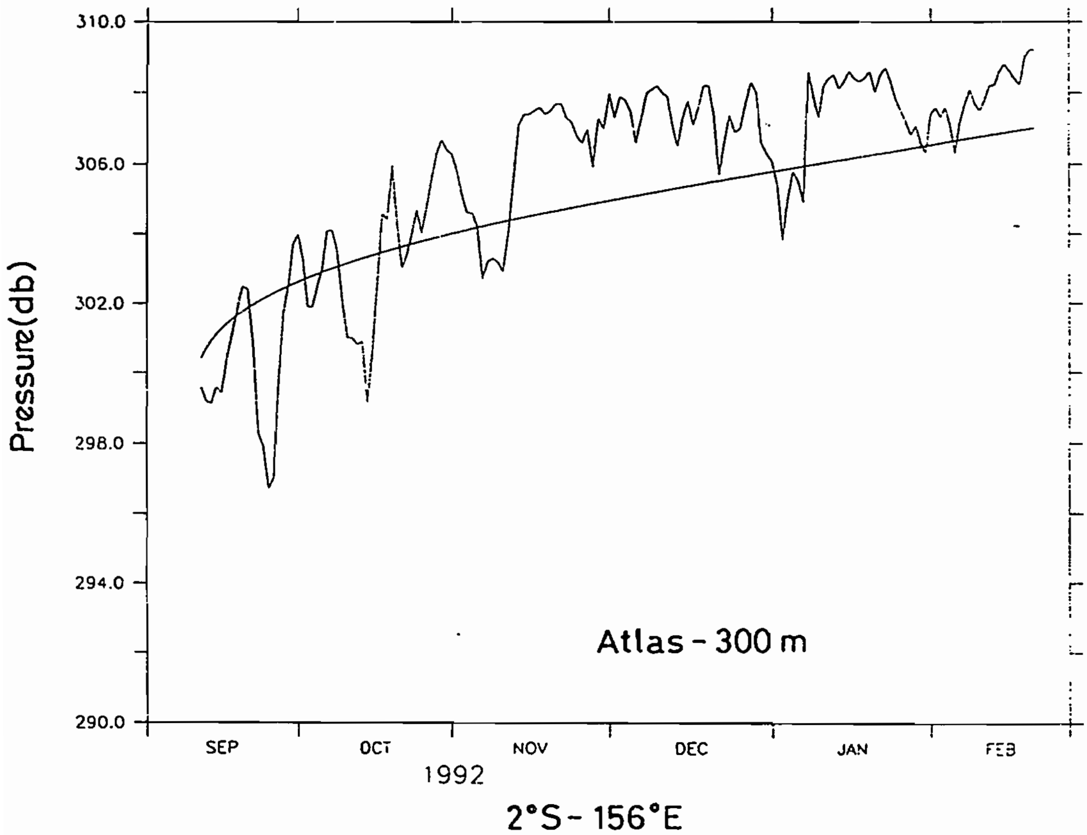


Figure 8. Evidence of the drift in the original daily ATLAS pressure (dbar) at 300 m (2°S-156°E). The drift is fitted by a function F defined in the text.

series (Figure 8). The Seacats which were equipped with higher quality pressure sensors were not subject to as great a drift. Therefore, the pressure information of the Seacats at 300 m and 750 m were used to eliminate the drifts from the ATLAS pressure measurements at 300m and 500m.

We propose a function F characteristic of the ATLAS drift in the form:

$$F(k) = Ca + \log (Cb + h(k)) + k/Cc \quad (3)$$

k is the record number

h(k) is time (in hour) corresponding to k, with h(1)=1

The coefficient Ca, Cb and Cc were chosen so that the correlation between the daily Seacat pressure and the ATLAS daily pressure minus the function F was a maximum.

The following summarizes the improvement on pressure correlation after the removal of the drift.

At 2°S-156°E:

300 m: Ca = 296 Cb = 80 Cc = 60

correlation Seacat (400 m) - ATLAS (300 m): before: 0.81 after: 0.95

500 m: Ca = 497 Cb = 50 Cc = 40

correlation Seacat (400 m) - ATLAS (500 m): before: 0.91 after: 0.96

correlation Seacat (750 m) - ATLAS (500 m): before: 0.84 after: 0.90

At 2S-164.4°E:

300 m: Ca = 296 Cb = 80 cc = 80

correlation Seacat (400 m) - ATLAS (300 m): before: 0.50 after: 0.86

500m: Ca = 494 Cb = 900 cc = 900

correlation Seacat (400 m) - ATLAS (500 m): before: 0.95 after: 0.97

correlation Seacat (750 m) - ATLAS (500 m): before: 0.92 after: 0.96

3.6.2. Interpolation of the pressure to 5 min

Seacat:

A simple linear relation was used to obtain pressure data at 5 min intervals from the 10 min Seacat pressure measurements.

ATLAS:

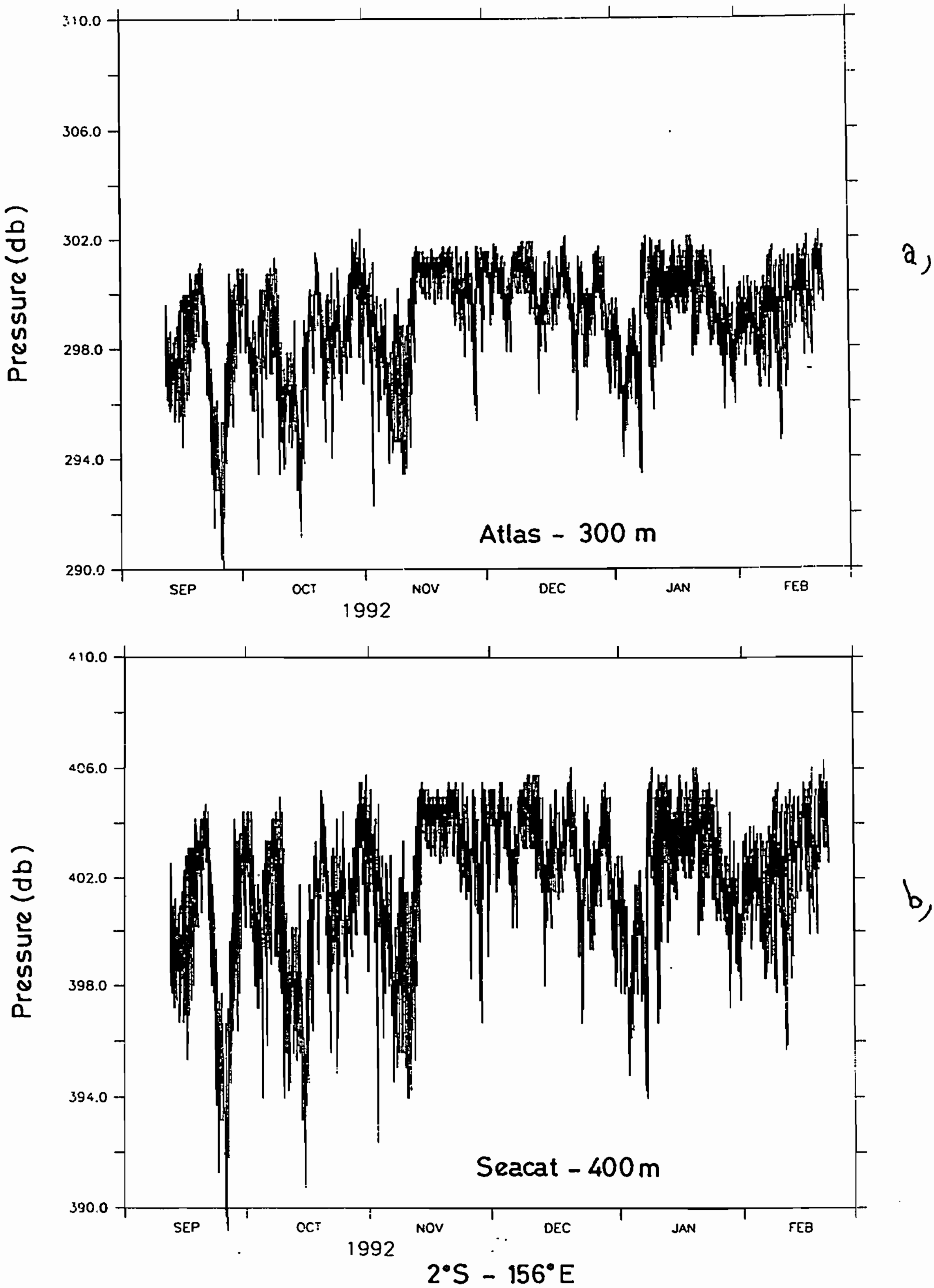


Figure 9. (a) Final 5 min ATLAS pressure at 300 m (2°S-156°E) obtained from (b) the 5 min Seacat pressure series at 400 m.

The original ATLAS daily means corrected for the drift (e.g. Figure 8) and the 5 min pressure data from the Seacat nearest to the ATLAS sensor (e.g. Figure 9b) were combined to obtain 5 min ATLAS pressures. Daily mean ATLAS and Seacat pressure anomalies (relative to their intended depths) were first computed. Second, a linear regression between ATLAS and Seacat pressure anomalies was determined. Thirdly, 5 min Seacat pressure anomalies for every daily mean were used to generate corresponding 5 min ATLAS pressure anomalies using the linear regression computed from the daily data. Fourthly, the 5-min ATLAS anomalies were applied day by day to their daily mean pressure anomalies.

At this stage, the ATLAS 5 min pressure anomalies were added to the ATLAS reference depth (expressed in dbar). The reference depth of the sensor (that is the length of the mooring line for the considered sensor) was determined at the instant when the line was vertical or nearly vertical. This was accomplished by determining the time t1 when the depth (or pressure) was maximum. The difference between this depth and the nominal (design) reference depth of the sensor was then computed. The time t1 (in hour from the beginning of the data) was found at 2°S-156°E and 2°S-164.4°E to be 2624.64 (December 13, 1992) and 2851.50 (January 9, 1993), respectively. The 5 min ATLAS pressure (p) was obtained by summing the 5-min ATLAS pressure anomalies (a) and nominal the reference depth (ref), less the pressure anomaly at the selected time t1 (e.g. Figure 9a):

$$p(t) = a(t) + ref - a(t1) \qquad (4)$$

3.6.3. Interpolation of the pressure for all sensors

The rms of pressure anomaly for the four depths (300, 400, 500 and 750 m), with pressure time series were computed and summarized in Table 6.

Table 6

	2°S-156°E	2°S-164.4°E
depth	rms (dbar)	rms (dbar)
300 m	1.83	0.89
400 m	2.58	1.37
500 m	3.64	1.87
750 m	5.08	3.94

0-300 m interpolation:

The vertical movement of the ATLAS and Seacat sensors was estimated from the 300 m pressure sensor. Using the fact that at the surface rms of pressure anomaly was null, a linear relation between depth and rms was computed. At every depth (P) between 300 m and the surface where a sensor was present, rms was calculated. We assume that at a given time the ratio of pressure anomalies between two depths was identical to the ratio of their rms. The ratio q = rms(P)/rms(300) was used to compute pressure anomalies at depth (P), a(P), from pressure anomalies at 300m, a(300).

a(P) = q*a(300)

600 m interpolation:

At 600m depth (MTR sensor), pressure anomalies were linearly interpolated from the pressure anomalies at 500 and 750 m.

Below 750 m interpolation:

The MTR were installed on nylon rope (as opposed to the Seacat and ATLAS sensors which were installed on steel wire), which can be stretched over several per cent. Due to the failure of the Aanderaa pressure sensors, at 1200 m on the 2°S-156°E mooring, and at 1300 and 1900 m on the 2°S-164.4°E mooring, it was impossible to directly correct the MTR temperatures for vertical displacement. An estimation of dynamic height error, assuming that the sensors are subject to a vertical displacement of 20 m amplitude (peak-to-through), was around 0.3 dyn cm. In any case, the dynamic height signal at depth was small enough that this type of uncertainty should not significantly alter our final surface dynamic height results (Table 7).

Table 7

Standard deviation of dynamic height calculated from the final data set (dyn cm)

	2°S-156°E	2°S-164.4°E
500 m/bottom	0.6	0.7
surface/bottom	4.1	3.4

Despite its relatively minor impact, the vertical movement of the sensors at great depth was estimated from the 750 m pressure sensor. The procedure to interpolate pressure anomalies at MTR levels was similar to that used between 300m and the surface. We used the rms of pressure anomaly at 750 m and the fact that at the bottom rms was null to compute rms at each depth between 750 m and the bottom.

The last step was to adjust pressure anomalies to their absolute value using Eq. 4.

3.7. *salinity determination*

Mean T-S relationships were constructed from the mean of 57 surface-to-bottom CTDs taken from 1984 to 1990 around 2°S-164°E, and from the mean of the 18 CTDs taken during the COARE experiment at 2°S-156°E (Figure 10).

3.7.1. ATLAS level

Four methods have been tested to determine 5-min salinity at the ATLAS depth (1 - 500 m) from the 5-min reconstructed ATLAS temperature:

- T-S relation obtained during the TOGA and COARE-POI cruises.
- Climatological Levitus T-S relation.
- interpolation of the surrounding Seacat salinities to the ATLAS sensor depth.
- interpolation of surrounding Seacat salinities to the ATLAS sensor temperature.

The last method was eliminated due to temperature inversion in the first 300 meters.

The other three methods were evaluated by comparing 0/500 dbar dynamic height computed using the COARE-POI CTD values at ATLAS sensor depths with dynamic heights computed using the different salinity estimations at the ATLAS depths.
Statistical differences between the reference dynamic height and the dynamic height computed by each method are summarized on Table 8.

Table 8

	T-S COARE-POI	T-S Levitus	interpolation
mean (dyn cm)	-0.02	5.76	0.32
rms (dyn cm)	0.67	1.00	0.62

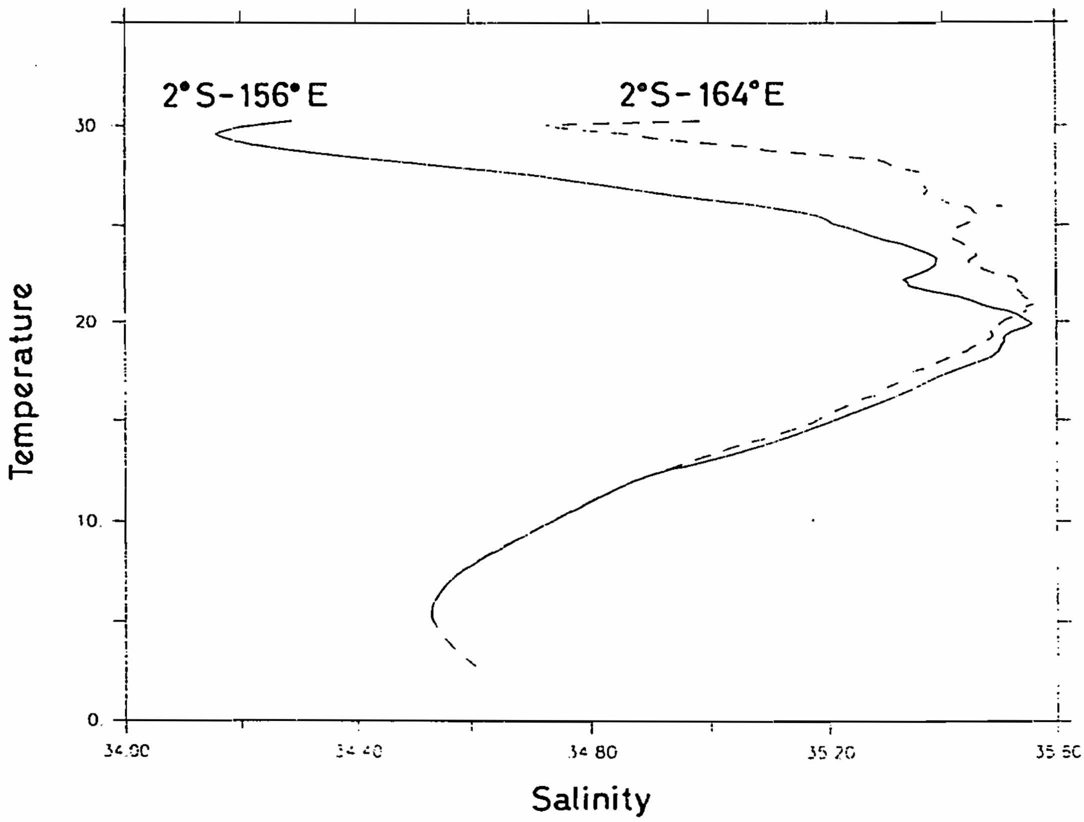


Figure 10. Mean T-S relationships at 2°S-156°E (continuous line) and at 2°S-164°E (dashed line).

"T-S Levitus" gave the worst result with a 5.76 cm mean difference. "interpolation" and "T-S COARE-POI" had similar rms differences but dissimilar mean difference. The contrast between the mean differences can be explained by salinity anomalies present during 4 CTDs at 150 m (ATLAS level) which did not extend to 132 m and 175 m (the Seacat levels). Thus, the "interpolation" method could not include this salinity information at 150 m which was present in the mean "T-S COARE-POI". Note that statistics were computed using 15 CTDs, but the "interpolation" method gave better results than "T-S COARE-POI" in 9 values out of 15 cases. Since a T-S relation relative to the period of the experiment was not available at 2°S-164°E, the interpolation method is chosen at both sites.

3.7.2. MTR levels

The majority of MTRs were beneath thes Seacats and thus no salinity data were available for interpolation. Therefore the 5-min MTR salinities were computed using the T-S relation defined during the COARE-POI cruise at 2°S-156°E and defined with all the TOGA cruises around 2°S-164.4°E.

3.8. *error budget in dynamic height*

The sum of the processing described above produced 5-min temperature, salinity and pressure time series at 28 levels from September 12, 1992 to February 22, 1993 (163 days) for the 2°S-156°E mooring (1739 m depth), and at 32 levels from August 26, 1992 to March 11, 1993 (197 days) for the 2°S-164°E mooring (4400 m depth). Surface-to-bottom dynamic height time series at 5-min interval were calculated at both locations. Sensitivity of surface dynamic height calculations to vertical sampling, salinity estimation, vertical displacement of the sensor, and inaccurate temperature were tested to give an estimate of the accuracy of the final 5-min dynamic height time series.

3.8.1. Vertical sampling

The error due to the vertical sampling on surface dynamic height was estimated from the 15 CTD casts taken at 2°S-156°E during the COARE-POI cruise. Surface dynamic heights were computed from the temperature and salinity information at the level of the ATLAS, Seacat, and MTR sensors and compared to the full 2-dbar resolution surface dynamic heights. The resultant rms difference of 0.89 dyn cm corresponds to the error due to finite number of sensors along the mooring line.

The importance of the ATLAS data was estimated by statistical differences between dynamic heights computed with all instruments (Seacat, ATLAS, MTR) and Seacat, MTR only:

	2°S-156°E	2°S-164.4°E
mean (dyn cm):	-0.73	0.82
rms (dyn cm):	0.73	1.48

3.8.2. Vertical displacement of the sensors

The influence of pressure fluctuations on surface dynamic height was estimated by comparison between dynamic heights computed when each sensor was considered at a constant depth (the reference depth) and when pressure information was used:

	2°S-156°E	2°S-164.4°E
mean (dyn cm):	-0.79	0.17
rms (dyn cm) :	0.73	1.04

3.8.3. Salinity determination

The error on surface dynamic height due to the estimation of salinity for the ATLAS and MTR sensors was calculated using the CTD measurements. Dynamic heights computed with the temperature and salinity of the CTDs at the Seacat, ATLAS and MTR levels were compared to dynamic heights computed with the same temperature and the salinity replaced in the following way: at the MTR levels the salinity was determined from the temperature and the COARE-POI T-S relation; at the ATLAS levels the salinity was determined by interpolation in depth of Seacat salinities surroundings the ATLAS. The rms difference between these two sets of dynamic heights was 0.38 dyn cm.

3.8.4. Inaccurate temperature

The effect of a temperature white noise on surface dynamic height was also estimated. For a noise characterised by a zero mean and a 0.01° standard deviation, rms difference was 0.15 dyn cm. This value doubled for a 0.02° standard deviation.

3.8.5. Summation of errors

The total error due to discrete levels, methods of estimate salinity estimation, and to inaccurate temperature was 0.98 dyn cm.

An alternate measure of the improvement gained in surface dynamic height estimated due to the processing described above was to compared the sea surface dynamic heights issued from the 15 CTDs taken during the COARE POI cruise to the 15 corresponding sea surface dynamic heights from the mooring. These dynamic heights are not strictly comparable because the CTD dynamic height was integrated over a 35 min period (the time required for a CTD cast) compared to the mooring dynamic height which was instantaneous and sampled every 5 min. Morever, the CTD measurements were made within 2-3 miles of the mooring site and in a region with significant internal waves. Therefore, out of 7 possible 5-min sea surface dynamic heights, the mooring estimate which differed least with the-CTD was chosen for comparison.

The rms difference is:

3.36 dyn cm when ATLAS are omitted

3.34 dyn cm when pressure are fixed

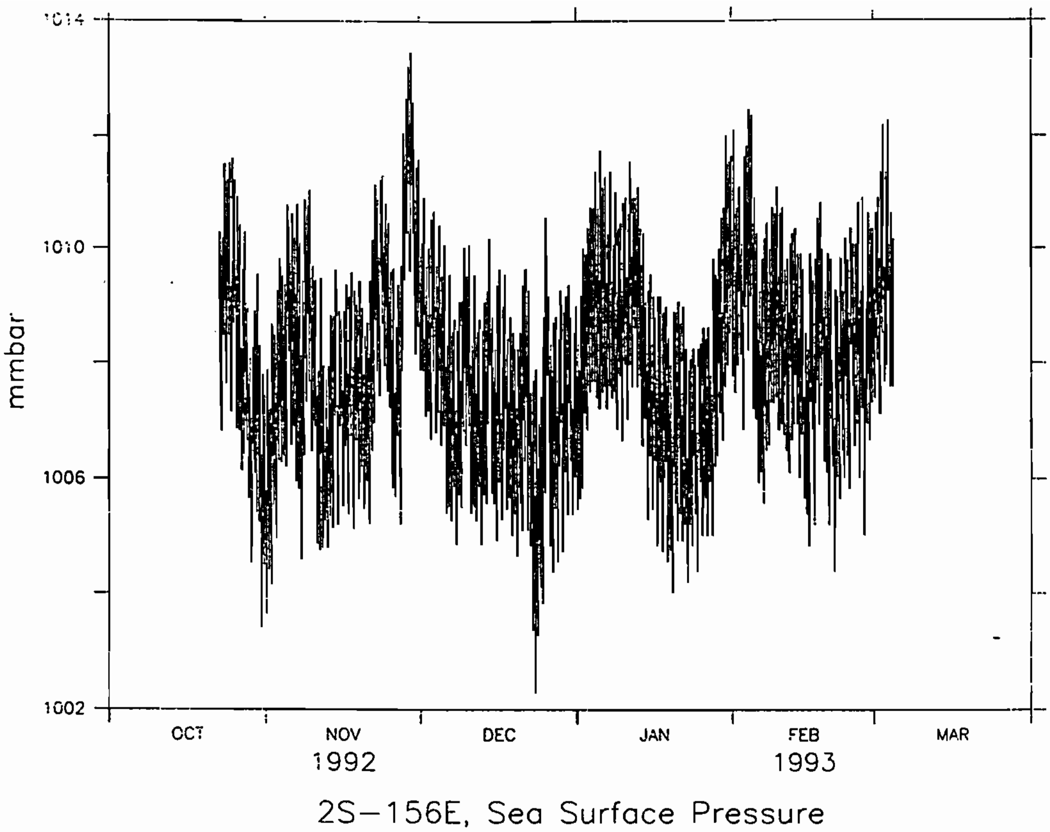
2.84 dyn cm with the complete information

4. In situ external data

4.1. *BPR data*

The two BPRs were processed at NOAA/PMEL. Data recovery was complete for the unit at 2°S-164°E (211 days) but incomplete for the unit at 2°S-156°E (21 days).

The BPR systems utilise Digiquartz pressure transducers, and record a 15 s average pressure each 15 s; this high sampling rate, coupled with 15-month deployment capabilities, provides for the measurement of oceanic processes with a wide range of time scales, including tsunamis, tides, and seasonal phenomena (Eble and Gonzalez, 1991; Mofjeld et al., 1995). Although the mean absolute pressure value can be in error by tens of centimetres, pressure changes corresponding to approximately 1 mm of standard seawater can be resolved at instrumental depths of 6000 m (Boss and Gonzalez, 1994). Crystal frequencies are converted to pressure units using the conformance equation and calibration coefficients provided by the manufacturer (Paroscientific, Inc.); this calibration is highly stable, as



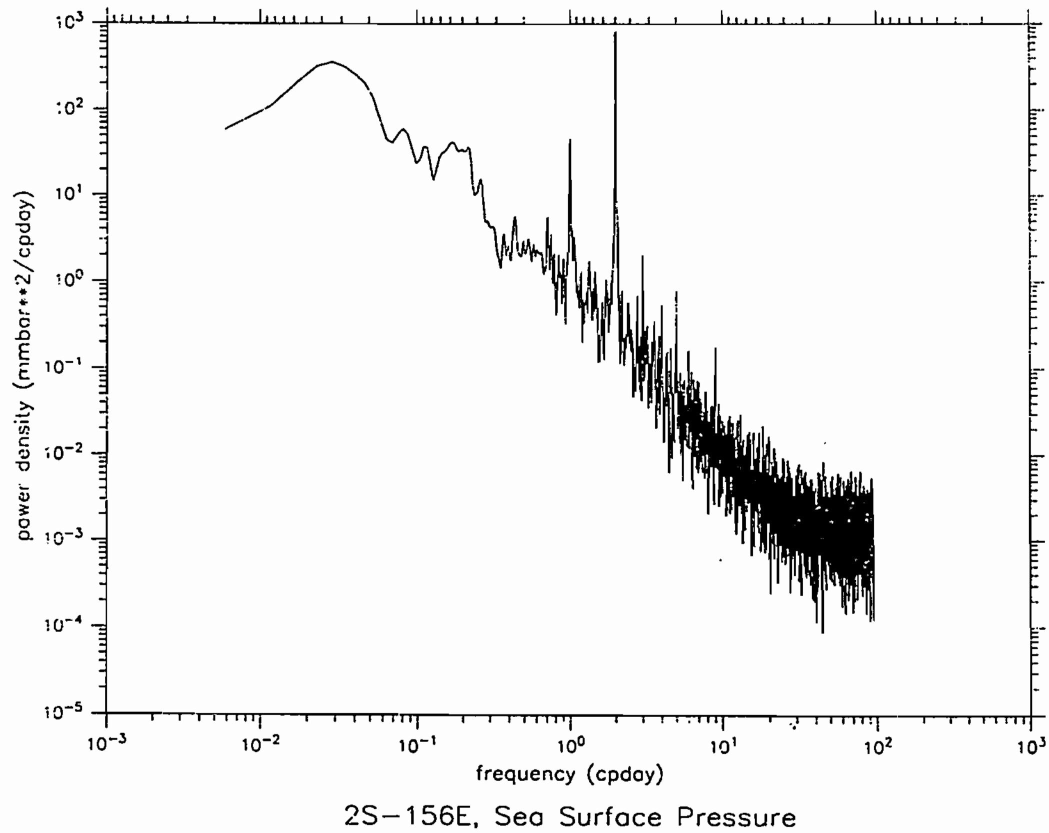


Figure 11. (a) Time series of the sea surface pressure near 2°S-156°E and (b) the corresponding spectrum.

demonstrated by the constancy of tidal constituents derived from time series acquired at the same location for as long as five years (Mofjeld et al., 1995). The data were edited to remove a small number of outliers through linear interpolation, and pressure units were then converted to equivalent water levels by using the factor 67.92 cm/psi, corresponding to a vertically averaged density value of 1.0374 gm/cm^3 and a vertically averaged value for local gravity of 978.53 cm/s^2. The 15 s data were then subjected to a 2-hour low-pass filter and sub sampled to provide an hourly time series suitable for tidal analysis. We used the harmonic analysis formulation of Foreman (1977) to estimate 62 tidal constituents.

Because accurate determination of the tides is key to this experiment, we took special care to perform direct tests for tidal constituent errors (negligible, in principle) that might be introduced by the 2-hour low pass filter, the hourly sub sampling, and the probable instrumental drift. An apparent monotonically decaying drift is evident in the initial portion of the BPR time series; a common feature of quartz crystal pressure transducers, this behavior is best modeled as an exponential function (Watts and Kontoyiannis, 1989). We therefore performed a least square fit of a constant plus exponential function, which yielded coefficient values corresponding to an initial amplitude of 13.6 cm and a decay time of 22.1 days. We subtracted this drift function from the original hourly data, performed a second tidal analysis on the resulting series, and found negligible differences between the original and new tidal constituents. Next, we noted that all constituents with periods less than 8 hours possessed amplitudes smaller than 3 mm, raising the possibility that energy in the original time series at these periods might be significantly reduced by the low-pass filtering or subsampling process. To test this possible source of error directly, we generated a test time series with unit amplitude, sample interval of 15 s, and period of 3.1 hours (corresponding to the shortest period constituent in our tidal analysis, M8). When subjected to the filter, the times series was unaffected in amplitude and phase; when this series was then subsampled at hourly intervals and a harmonic analysis was performed, an estimate of 0.88 was obtained for the amplitude. Thus, especially in light of the very small amplitudes in the shorter period bands, we conclude that errors introduced into our analysis by these processes are negligible.

4.2. *Sea Surface Pressure*

A surface mooring deployed at 156°E, 1° 45' S provided a platform for making continuous, unattended meteorological and oceanographic measurements for the duration of the COARE IOP. The mooring was deployed on October 21, 1992 from the RV Wecoma and recovered on March 04, 1993, again by RV Wecoma. The 3 m diameter surface buoy carried two redundant meteorological instruments, a Vector Averaging Wind Recorder (VAWR; Weller et al., 1990) and an Improved METeorological instrument (IMET; Hosom et al., 1995). Both instruments sampled wind velocity, relative humidity, air temperature, barometric pressure, incoming shortwave radiation, incoming longwave radiation, and sea surface temperature. IMET also recorded rain rate and supported a third set of sensors. The third set included wind velocity, aspirated air temperature, aspirated relative humidity, and rain temperature sensors.

The choice of the sensors deployed on the WHOI buoy was based on past experience with meteorological sensors on buoys and ships and on results from several years of laboratory testing (Weller et al., 1990). Barometric pressure on the VAWR was measured with a Paroscientific Digiquartz sensor fitted with a Gill parallel plate port to minimize wind-related fluctuations. The pressure was sampled for 2.6 seconds every 7.5 minutes, with the average being recorded. The sensor was 3.0 m above the sea surface. The IMET barometric pressure sensor was an AIR model AIR-DB-1A with a Gill parallel plate port, located 3.0 m above the sea surface. IMET sampled the sensor at 10 Hz and computed 1 second averages; the most recent 1 second average was recorded at the end of every minute. Studies of the long term stability and accuracy of barometric pressure sensors (Payne, 1995) show that the Paroscientifc sensors maintain an accuracy of 0.1 mb and the AIR sensors maintain an accuracy of 0.3 mb. The two barometric pressure records from the VAWR and IMET on the buoy were in good agreement, and the more accurate Paroscientific sensor time series has been used here. Pre-deployment and post-recovery calibrations in the laboratory of the Paroscientic pressure sensors showed agreement with laboratory standards to better than 0.1 mb. In the low wind speeds characteristic of COARE, the error associated with the pressure port is believed to be less than 0.1 mb. (According to Gill (1976) there is a negative bias error of approximately 0.4 mb in 20 m s^{-1} winds and 1.3 mb in 40 m s^{-1} ; COARE winds averaged 4.3 m s^{-1}). Evolution of the sea surface pressure at 2°S-156°E is plotted on Figure 11a and the spectrum reveals the importance of semi diurnal and diurnal signals (Figure 11b).

5. TOPEX/POSEIDON data

The TOPEX altimeter data to be used here are an enhanced geophysical data record (GDR) produced by the NASA Goddard Space Flight Center ocean altimetry group (courtesy of C. Koblinsky). In this data set the GDRs from the TOPEX project have been linearly interpolated every 6 km to fixed points along track and referenced to the locations of the cycle 17 ground tracks (Busalacchi et. al., 1994). The mooring locations at 2S, 156E and 2S, 164.4E fall beneath the crossovers of ascending tracks number 125 and 112 and descending tracks 43 and 30, respectively.

For the high frequency validation work all data within 0.5 degrees of the two crossover locations (2S, 156E and 2S, 164.5 E) were extracted from the data base along with all corresponding geophysical corrections. Data were excluded if the attitude exceeded 45 degrees or if any geophysical correction exceeded reasonable values (including ocean tide). Poseidon data were corrected for embias using the formula of Gaspar (Gaspar et.al, 1994) and have been merged with the TOPEX data by removing a bias which can vary from 13.5 to 21.5 cm (Vincent et al., 1994). The first 19 10-day cycles are considered here, covering the period from September 25, 1992 to March 30, 1993. 8 points total (4 along track ascending and 4 along track descending) surrounding the moorings locations were extracted for each cycles and then geophysical corrections were applied. For the purposes of evaluating the satellite versus the in situ sea level time series, the barotropic tides are removed from the altimeter data using the tidal corrections from several tide models that were at our disposal, i.e., Schwiderski (1980), Cartwright and Ray (1990), Ray et al., (1994) that included the ocean load tide. The inverse barometer effect due to atmospheric pressure loading was accounted for using the GDR correction based on the ECMWF atmospheric surface pressure analysis and on sea level pressure observed during TOGA-COARE near the 2°S-156°E mooring. The altimetric data were also corrected for dry troposphere, wet troposphere, ionosphere, and solid earth tide.

The data processing for the low frequency study differed slightly from that for the high frequency study. All TOPEX and POSEIDON data within 10 degrees longitude and 5 degrees latitude of each of the validation points (2°S-156°E; 2S-164.4E) were extracted for each of 60 cycles. Geophysical corrections were applied to the data. These included inverse barometer, dry troposphere, wet troposphere, ionosphere, and solid earth tide corrections along with corrections for the ocean tide. All these corrections were obtained from the JPL TOPEX GDR and were interpolated to 6 KM resolution along cycle 17 ground tracks. Although other tide models (Ray et. al., 1994, Cartwright and Ray, 1990) were tested, the Schwiderski tide model correction was chosen to be applied to the data because this model gives the best correlation in this area (Busalacchi et. al., 1994). Any points along track with satellite attitude greater than 45 degrees or with geophysical corrections beyond reasonable values were excluded. As with the high frequency data, the POSEIDON data was adjusted to be used with the TOPEX data by correcting for the em bias (Gaspar, 1994) and the instrument bias of 136 mm (personal communication S. Nerem). Anomalies were formed at each point along track using a 53 cycle mean. Any point which had less than 10 cycles of valid data from which to construct a mean was considered missing. Along track smoothing was completed using 400 km (72 points) as the filter length for first a median filter and then a hanning filter following previous work on Geosat data (Picaut et. al., 1990). (Note that the choice of an along track filter length did not affect correlations with TOGA data significantly). Any ascending track which terminated within the area was concatinated to the next track in order to complete the along track smoothing. A total of 34 tracks passed through one or both of the two regions.

References

Bitterman, D.S., Jr, Inverted echo sounder instrument report, Woods Hole Oceanographic Institution, *Woods Hole, Tech. Rep.*, Ref. No. 76-77, 1976.

Boss, E.F and F.I. Gonzalez, Signal Amplitude Uncertainty of a Digiquartz Pressure Transducer Due to Static Calibration Error, *J. Atmos. Oceanic Technol.*, 11, 1381-1387, 1994.

Boulanger J-Ph., and C. Menkes, Propagations and reflections of Kelvin to third Rossby waves in the Pacific Ocean as observed from TOPEX/POSEIDON and TOGA-TAO data, submitted to J. Geophys. Res., 1995.

Busalacchi, A.J., M.J., McPhaden and J. Picaut, Variability in equatorial Pacific sea surface topography during the verification phase of the TOPEX/POSEIDON mission, *J. Geophys. Res.*, Vol. 99, No. C12, 24725-24738, 1994.

Carton, J.A., E.C. Hackert, Application of multi-variate statistical objective analysis to the circulation in the tropical Atlantic ocean, *Dyn. Atmos. Oceans*, 13, 491-515, 1989.

Cartwright, D.E., and R.D. Ray, Oceanic tides from Geosat altimetry, *J. Geophys. Res.*, 95, 3069-3090, 1990.

Delcroix, T., G. Eldin, and C. Henin, Upper ocean water masses and transports in the western tropical Pacific. *J. Phys. Oceanogr.*, 17, 2248-262, 1987.

Delcroix, T., J. Picaut and G. Eldin, Equatorial Kelvin and Rossby waves evidenced in the Pacific Ocean through GEOSAT sea level and surface current anomalies, *J. Geophys. Res.*, 96, 3249-3262, 1991.

Delcroix, T., G. Eldin, C. Henin, F. Gallois, J. Grelet, M. Inall, S. Keene, M.J. Langlade, C. Menkes, F. Masia, K. Richards, Rapport de la campagne

COARE-POI à bord du N.O. Le Noroit 1 décembre 1992 - 2 mars 1993 de 5°N à 5°S le long du méridien 156°E, *Rapport de missions: Sci. mer: Oceanogr. Phys.*, 10, ORSTOM Nouméa, 338pp, 1993.

Eble, M.C. and F.I. Gonzalez, Deep-Ocean Bottom Pressure Measurements in the Northeast Pacific, *J. Atmos. Oceanic Technol.*, 8, 221-233, 1991.

Fischer, M., M. Latif, M. Flügel, and J. Zou, Assimilation of sea level data into a primitive equation model, *TOGA Notes*, 15, 1-5, 1994.

Foreman, M.G.G., Manual for tidal heights analysis and prediction. *Pacific Marine Science Report 77-10*, Institute of Ocean Sciences, Patricia Bay, Victoria, B.C., 70pp., 1977.

Gaspar, P., F. Ogor, P.-Y. Le Traon and O.Z. Zanife, Estimating the sea state bias of the TOPEX and POSEIDON altimeters from crossover differences, *J. Geophys. Res.*, Vol. 99, No. C12, 24981-24994, 1994.

Gill, G. C., Development and testing of a no-moving parts static pressure inlet port or use on ocvean buoys. *Progress Rept.*, Contract No. 01-6-038-115, NOAA Data Buoy Center, Bay St. Louis, Miss, 39529, USA, 1976.

Hayes, S. P., L. J. Mangum, J. Picaut, A. Sumi, and K. Takeuchi, TOGA-TAO: A moored array for real-time measurements in the tropical Pacific Ocean, *Bull. Am. Meteorol. Soc.*, 72, 339-347, 1991.

Hosom, D. S., R. A. Weller, R. E. Payne, and K. E. Prada, The IMET (Improved Meteorology) ship and buoy systems. *Journal of Atmospheric and Oceanic Technology*, in press, 1995.

Katz E.J., A.J. Busulacchi, M. Busnell, L; Gourdeau, M. McPhaden and J. Picaut, A comparison of Coincidental time series of the ocean surface height by satellite altimeter, mooring and inverted echo sounder, in press to *J. Geophys. Res.*, 1995.

McPhaden, M. J., A. J. Busalacchi, and J. Picaut, Observations and wind-forced model simulations of the mean seasonal cycle in tropical Pacific sea surface topography, *J. Geophys. Res.*, 93, 8131-8146, 1988.

McPhaden, M. J., TOGA-TAO and the 1991-93 El Niño-Southern Oscillation event, *Oceanography*, 6, 36-44, 1993.

Mofjeld, H.O., F.I. Gonzalez, M.C. Eble and J.C. Newman, Ocean Tides in the Continental Margin off the Pacific Northwest Shelf, *J. Geophys. Res.*, in press, 1995.

Payne, R. E., A comparison of some barometric pressure sensors. *Journal of Atmospheric and Oceanic Technology*, in press, 1995.

Picaut, J, A.J. Busalacchi, M.J. McPhaden, B. Camusat, Validation of the geostophic method for estimating zonal currents at the equator from Geosat altimetry data, *J. Geophys. Res.*, vol. 95, No. C3, 3015-3024, 1990.

Picaut, J., A.J. Busalacchi, M.J. McPhaden, L. Gourdeau, F.I. Gonzales, E.C. Hackert, Open-ocean validation of TOPEX/POSEIDON sea level in the western equatorial Pacific, in press to J. Geophys. Res., 1995.

Ray, R.D., B.V. Sanchez, and D.E. Cartwright, Some extensions to the response method of tidal analysis applied to TOPEX/POSEIDON altimetry, *Eos Trans. AGU*, 75(16), Spring Meeting Suppl., 108, 1994.

Schwiderski, E. W., On charting global ocean tides, *Rev. Geophys.*, 18, 243-268, 1980.

Watts, R.D. and H. Kontoyiannis, Deep-Ocean Bottom Pressure Measuurement: Drift Removal and Performance, *J. Atmos. Oceanic Technol.*, 7, 296-306, 1990.

Webster, P. J., and R. Lukas, TOGA-COARE: The coupled ocean-atmosphere response experiment, *Bull. Am. Meteor. Soc.*, 73, 1377-1416, 1992.

Weller, R. A., D. L, Rudnick, R. E. Payne, J. P. Dean, N. J. Pennington, and R. P. Trask, Measuring near-surface meteorology over the ocean from an array of surface moorings in the subtropical convergence zone, *Jrnl. of Atmos. Oceanic. Tech.*, 7(1), 85-103, 1990.

APPENDIX 1

Temperature (t), salinity (s) or pressure (p) measurements available for the Seacat (Sea), ATLAS (Atl), MTR or Aanderaa (Aan) instruments at the different depths

2°S-156°E

depth (m):	1	3	5	10	15	20	25	30	50	70
Instrument:	Sea	Sea	Sea	Sea	Sea	Sea	Atl	Sea	Atl	Sea
sensors:	t,s	t,s	t,s	t,s	t,s	t,s	t	t,s	t	t,s
depth (m):	75	100	112	125	132	150	175	200	225	250
Instrument:	Atl	Atl	Sea	Atl	Sea	Atl	Sea	Atl	Sea	Atl
sensors:	t	t	t,s	t	t,s	t	t,s	t	t,s	t
depth (m):	275	300	400	500	600	750	1000	1200	1500	1673
Instrument:	Sea	Atl	Sea	Atl	MTR	Sea	MTR	Aan	MTR	MTR
sensors:	t,s	t,p	t,s,p	t,p	t	t,s,p	t	t,p	t	t

2°S-164.4°E

depth (m):	10	26	37	51	62	76	87	101	112	126
Instrument:	Sea	Atl	Sea	Atl	Sea	Atl	Sea	Atl	Sea	Atl
sensors:	t,s	t	t,s	t	t,s	t	t,s	t	t,s	t
depth (m)	137	151	175	201	225	251	275	301	400	500
Instrument:	Sea	Atl	Sea	Atl	Sea	Atl	Sea	Atl	Sea	Atl
sensors:	t,s	t	t,s	t	t,s	t	t,s	t,p	t,s,p	t,p
depth (m):	600	750	1000	1200	1300	1500	1900	2000	2500	3000
Instrument:	MTR	Sea	MTR	MTR	Aan	MTR	Aan	MTR	MTR	MTR
sensors:	t	t,s,p	t	t	t,p	t	t,p	t	t	t
depth (m):	3500	3750	4000	4334						
Instrument:	MTR	MTR	MTR	MTR						
sensors:	t	t	t							

APPENDIX 2

Comparison pre-post calibration

2°S-156°E

Seacat

Temperature

Depth (m)	T pre-cal.	St. Dev.	T post-cal.	Dif. pre-post
1	29.3748	0.4577	29.3780	-0.0032
112	24.0957	1.0917	24.0957	0
132	22.8748	0.9098	22.8750	-0.0002
175	19.5113	1.3862	19.5123	-0.0010
225	14.1063	1.2909	14.1095	-0.0032
275	11.7990	0.2969	11.8003	-0.0013
400	10.1376	0.2210	10.1419	-0.0043
750	5.6958	0.2090	5.6980	-0.0022
Mean				-0.0019

Salinity

Depth (m)	S pre-cal.	St. Dev.	S post-cal	Dif. pre-post
1	34.1301	0.1341	34.1261	0.0040
112	35.1627	0.1372	35.1561	0.0066
132	35.2864	0.18217	35.2863	0.0001
175	35.3814	0.1600	35.3869	-0.0055
225	35.0672	0.1302	35.0819	-0.0147
275	34.8350	0.0279	34.8496	-0.0146
400	34.7337	0.0153	34.7399	-0.0062
750	34.5302	0.0065	34.5382	-0.0080
Mean				-0.0048

Density

Depth (m)	Sig pre-cal	St. Dev.	Sig post-cal	Dif. pre-post
1	21.3123	0.1812	21.3082	0.0041
112	23.7653	0.3619	23.7603	0.0050
132	24.2180	0.3137	24.2179	0.0001
175	25.2073	0.3836	25.2113	-0.0040
225	26.2412	0.1830	26.2519	-0.0107
275	26.5310	0.0382	26.5421	-0.0111
400	26.7537	0.0276	26.7578	-0.0041
750	27.2527	0.0227	27.2587	-0.0060
Mean				-0.0033

MTR

Depth (m)	T obs.	St. Dev.	Dif. pre-post
600	6.8362	0.2765	0.0002
1000	4.5176	0.0893	0.0025
1500	2.8897	0.0804	0.0061
1673	2.5755	0.0483	-0.0013
Mean			0.0019

2°S-164°E

Seacat

Temperature

Depth (m)	T pre-cal.	St. dev.	T post-cal.	Dif. pre-post
10	29.6134	0.5122	29.6136	-0.0002
37	29.5839	0.5327	29.5858	-0.0019
62	29.4342	0.5459	29.4348	-0.0006
87	28.0267	1.2070	28.0244	0.0023
112	25.1360	1.1883	25.1365	-0.0005
137	23.5935	0.9352	23.5958	-0.0023
175	18.9107	1.6181	18.9127	-0.0020
225	13.5200	1.0471	13.5190	0.0010
275	11.7971	0.3292	11.7981	-0.0010
750	5.7383	0.1393	5.7405	-0.0022
Mean				-0.0007

Salinity

Depth (m)	S pre-cal.	St. Dev.	S post-cal.	Dif. pre-post
10	34.4696	0.1957	34.4320	0.0376
37	34.5285	0.1763	34.4782	0.0503
62	34.6755	0.2309	34.6191	0.0564
87	34.9270	0.2396	34.8898	0.0372
112	35.1268	0.1271	35.1241	0.0027
137	35.2991	0.1521	35.2960	0.0031
175	35.4170	0.1243	35.4279	-0.0109
225	35.0094	0.1057	35.0187	-0.0093
275	34.8460	0.0260	34.8564	-0.0104
750	34.5327	0.0037	34.5382	-0.0055
Mean				0.0015

Density

Depth (m)	Sig pre-cal	St. Dev.	Sig post-cal	Dif. pre-post
10	21.4871	0.1650	21.4588	0.0283
37	21.5434	0.1563	21.5051	0.0383
62	21.7062	0.2132	21.6637	0.0425
87	22.3597	0.4954	22.3325	0.0272
112	23.4247	0.4250	23.4225	0.0022
137	24.0195	0.3521	24.0165	0.0030
175	25.3856	0.3659	25.3934	-0.0078
225	26.3213	0.1455	26.3286	-0.0073
275	26.5398	0.0437	26.5477	-0.0079
750	27.2495	0.0169	27.2535	-0.0040
Mean				0.0114

MTR

Depth (m)	T pre-cal.	St. Dev.	Dif. pre-post
600	7.0545	0.2556	0.0099
1000	4.4733	0.0916	-0.0057
1200	3.7194	0.0771	0.0073
1500	2.8787	0.0707	0.0047
2000	2.1561	0.0303	0.0146
2500	1.8144	0.0250	0.0121
3000	1.6187	0.0173	0.0018
3500	1.5084	0.0195	0.0105
3750	1.4381	0.0176	0
4000	1.3968	0.0122	0.0004
4355	1.3452	0.0109	0.0005
Mean			0.0056

Centre ORSTOM de Nouméa
B.P. A5 Nouméa Cédex Nouvelle Calédonie