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TEMPERATURE ERRORS IN TAO DATA INDUCED BY MOORING MOTION

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Marguerite E. McCarty, Linda J. Mangum, and Michael J. McPhaden

ABSTRACT. Moored subsurface temperature measurements from the Tropical Atmosphere Ocean (TAO) Array are subject to errors resulting from vertical motion of the instrumented mooring line. The magnitude of the errors depends on both environmental conditions and mooring design. This report describes a method for estimating these errors using subsurface pressure data to determine vertical excursions of the mooring line. For taut-line moorings examined, typical mooring motion-induced temperature errors are largest in the upper thermocline, with root mean square (RMS) errors of 0.15°–0.45°C. Slack-line moorings typically have larger RMS errors (0.3°–1.1°C), in some cases with maxima at the lowest instrumented depth. These errors are correctable using processing procedures developed in this report.

1. INTRODUCTION

The Tropical Atmosphere Ocean (TAO) Array comprises about 70 moored buoys which measure meteorological and oceanographic variables in the Equatorial Pacific. The moorings extend from 137°E to 95°W, roughly between 8°N and 8°S. The TAO Array was established by the Tropical Ocean Global Atmosphere (TOGA) Program as part of a 10-year (1985–1994) effort to study climate variability on seasonal to interannual time scales, with the particular aim of increasing understanding of the El Niño-Southern Oscillation phenomenon (McPhaden, 1993, 1995). Development of the buoys and the array began under the Equatorial Pacific Ocean Climate Studies (EPOCS) program and other predecessors of TOGA. The maintenance of the array since 1994 has been assumed by the Global Ocean-Atmosphere-Land System (GOALS) component of the Climate Variability and Prediction (CLIVAR) program; TAO is also viewed as a contribution to the Global Climate Observing System (GCOS) and the Global Ocean Observing System (GOOS).

Most of the moorings in the TAO array are Autonomous Temperature Line Acquisition System (ATLAS) moorings which measure winds, air temperature, relative humidity, sea-surface temperature, subsurface temperature at 10 depths down to 500 m, and subsurface pressure at two depths. These moorings have been deployed primarily in a taut-line configuration. However, at two sites slack-line moorings have been maintained, one in relatively shallow water (5°S, 156°E) and one in the strong and highly sheared Equatorial Undercurrent (0°, 125°W).

Mooring line motion causes vertical displacement of the temperature sensors and introduces error into temperature records assumed to be from fixed depths. Although most of the moorings are taut-line moorings designed to minimize vertical excursions, the mooring will respond to surface wind forcing and changes in the surface and subsurface currents. Typical watch circles for the surface toroid on taut-line moorings are 2–4 km in waters near 4000 m deep. Further details on mooring dynamics and design can be found in Berteaux (1976).

Presented in this report is a procedure for using pressure records to estimate the error induced in the temperature records by depth excursions of the mooring line. The method was applied to data from seven taut-line ATLAS moorings and two slack-line moorings. The results are described and discussed below.

2. INSTRUMENTATION AND DATA PROCESSING

The upper part of an ATLAS mooring consists of a toroidal float on which is mounted an instrumentation tower. Seven hundred meters of wire rope connect to a bridle bolted to the underside of the float. On a taut-line mooring, ¾" nylon line makes up the majority of the remaining length to the anchor. The length of the nylon line, which stretches under tension, is adjusted to yield a scope for the entire mooring of about 0.985. Slack-line moorings are similar, but contain a section of floatable polyolifin line just above the anchor and have a scope of around 1.35.

Temperature and pressure sensors are enclosed in pods incorporated into the temperature cable, a polyurethane-jacketed, double-armored, three-conductor cable (Hayes *et al.*, 1991). The temperature cable runs parallel to the wire rope and is clamped to it; they move in tandem. ATLAS temperature sensors are Yellow Springs Instrument Co., Inc. (YSI) model 46006 thermistors. The temperature I/O boards convert thermistor resistence to voltage, voltage to frequency, and frequency to counts, and output the counts. The combined instrumental error for SST measurements is 0.030°C. The combined instrumental error for subsurface temperature measurements is about 0.1°C (Freitag *et al.*, 1994). SST sensors are fixed on the mooring bridle at 1 m depth. Nominal depths for subsurface temperature sensors on eastern Pacific (95°–140°W) buoys are 20, 40, 60, 80, 100, 120, 140, 180, 300, and 500 m. For western and central Pacific (137°E–155°W) moorings the nominal temperature sensor depths are 25, 50, 75, 100, 125, 150, 200, 250, 300, and 500 m.

Pressure measurements are made by Senso-Metrics ported semiconductor strain gauge pressure transducers (model SP91CFD). The sensor range is 0 to 1000 psi (0 to 689 db; 1 psi equals 0.6895 db); no manufacturer's specifications are available for long term stability estimates. Thermal sensitivity for these sensors is approximately 0.02% of full scale per 1° Fahrenheit (or 0.25 db per °C). To minimize thermal sensitivity during calibrations, all 500-m (300-m) pressure modules are calibrated at 8°C (11°C).

Pressure calibrations were performed at PMEL using a Ruska dead-weight tester and a Calumet Industries Environator van. Sensors were placed in the environmental chamber and allowed to equilibrate at the calibration temperature. Pressures were applied by adding plates to the dead-weight tester for different pressures levels for first increasing pressure and then decreasing pressure at five levels from 138 to 586 db. At least 4 samples were recorded and averaged at each pressure level. A simple linear fit was then used to compute the regression coefficients for each sensor. Sensors with maximum residuals for the linear fit less than 0.2 db were deployed in the field. After recovery of the mooring, the pressure sensors were recalibrated using the above procedure. Comparisons of pre- and post-deployment calibrations for individual sensors showed relatively large differences, typically averaging 2 to 4 db for a 1-year deployment. In some cases, changes up to 15 db were observed.

The ATLAS data logger/transmitter in the buoy instrumentation tower averages temperature and pressure values over 24 hours and telemeters them to shore via the Argos system (Hayes *et al.*, 1991). In most of the deployments selected for analysis in this report, pre-deployment calibration values have been applied to the data. However, in two cases, the pressure records were recalculated using the post-deployment calibrations. These will be noted below.

3. DEPLOYMENT SELECTION

The deployments were selected to cover a variety of geographic positions, oceanographic conditions, water depths, and mooring scopes. These included moorings on and off the equator from the eastern, western, and central Pacific; deployments from El Niño and non-El Niño periods; relatively shallow and deep-water moorings; and taut-line and slack-line moorings. A single mooring deployed in the central equatorial Indian Ocean in 1993 is also included in this report.

Deployments were selected for inclusion in this analysis only if they had complete or near-complete data records for a minimum of 6 months. The deployments necessarily had complete pressure records for the time period. All selected moorings had complete subsurface temperature records. The SST records, which are not affected by vertical excursions of the mooring line, were incomplete in two cases; ET342 (0°, 156°E) had 6 days of missing values scattered through the first half of the record and ET177 (8°N, 110°W) had a 3-month gap. A complete wind record for the time period was considered desirable, but not necessary.

In addition, an attempt was made to choose only deployments for which the pressure sensors displayed little or no drift and for which the buoy itself didn't move during the deployment period. It was possible to meet these two criteria in all but one case. One mooring, ET214, violated both criteria, but it was used anyway because it was the only mooring in the Indian Ocean. ET214 showed an obvious drift in the 300-m pressure record (Fig. 1). The drift was corrected by a method described below. Also, from late July 1993 to early January 1994 ET214 moved from its initial position at 0.103°N, 80.54°E to 0.076°S, 81.142°E. Most of the movement occurred in one stage in early November 1993 during a period of strong westerly winds (Fig. 1). The move in November appeared to have ended in water shallower than the initial deployment depth. Afterwards, the pressure records showed shallower values, which is consistent with a slacker line (Fig. 1).

Table 1 lists the 9 moorings selected, along with their positions, the beginning and ending dates for the portion of the records used in this analysis, the scopes, and the water depths.

4. TEMPERATURE REMAPPING

4.1 General method of remapping

The first step in remapping the temperature data was to estimate a depth for each daily value from each sensor. The top of the temperature cable was assumed to be at 1 m depth (actual depth

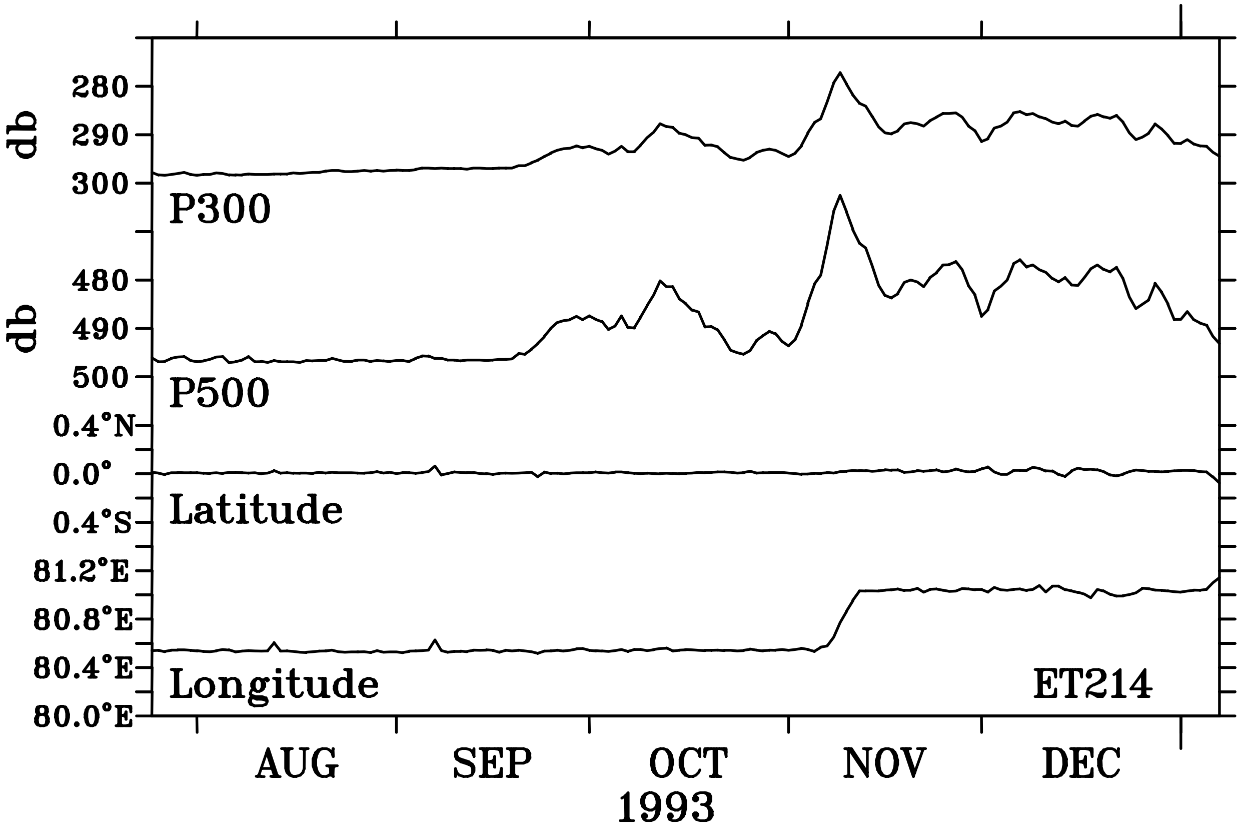

Fig. 1. Time series plots of 300-m pressures, 500-m pressures, latitude, and longitude from the Indian Ocean mooring, ET214, nominally located at 0°, 80.5°E.

Table 1. Position, mooring designator, beginning and end dates of data used, mooring scope, and water depth for each mooring selected for this analysis.

Position (lat, long)	Mooring designator	Begin	End	Scope	Depth (m)
0°, 80.5°E	ET214	25 Jul 93	07 Jan 94	0.986*	4662*
5°N, 156°E	ET344	22 Jul 95	23 Apr 96	0.985	3607
0°, 156°E	ET342	20 Jul 95	23 Apr 96	0.984	1973
5°S, 156°E	ET310	28 Dec 94	24 Apr 96	1.349	1500
5°N, 155°W	ET297	24 Oct 94	28 Dec 95	0.985	4600
0°, 155°W	ET296	22 Oct 94	26 Dec 95	0.986	4676
0°, 125°W	ET288	09 Sep 94	30 May 95	1.357	4651
8°N, 110°W	ET177	20 Oct 92	11 Sep 93	0.988	4250
2°N, 110°W	ET178	05 Nov 92	08 Jul 93	0.985	3819

* Mooring moved. Scope and depth listed are the values at the deployment site. Final scope and depth are unknown.

is 1.2 m); the cable was assumed to form a straight line 299 m long between the 1-m fixed point and the depth indicated by the 300-m pressure sensor, and a straight line 200 m long between the 300-m and 500-m pressure sensor depth values. The pressure data were converted to depths using the method of Saunders and Fofonoff (1976). The temperature sensor depths were estimated by linear interpolation between the 1-m and the two subsurface pressure sensors. In some cases, before being used in the temperature remapping scheme, the pressure records were subjected to adjustments described below in sections 4.2 and 4.3.

After estimating a set of sensor depths for a single day, the temperature values for that day were remapped by linear interpolation to the standard ATLAS depths for that mooring. Instead of extrapolating adjusted sensor depths to 500 m, a 450-m value was chosen as the deepest standard level in the remapped data. An uncorrected 450-m temperature record was also calculated by linear interpolation between uncorrected records at the nominal depths of 300 and 500 m.

4.2 Adjusting pressure records for depth offsets

The maximum possible depth of an instrument is determined by the length of the mooring line between the instrument and the point where the line is fixed to the bottom of the bridle, plus the distance from the bottom of the bridal to the surface. When the moorings are deployed the instruments are attached to the wire rope at or near marked, premeasured points. If the instrument is placed exactly at the premeasured point and there was no error in measuring and marking the line, the set of maximum possible depths for a mooring will be identical to the nominal depths as listed in section 2. The wire rope was measured by a Reelomatic mechanical counter manufactured by Olympic Instruments (Vashon Island, Washington). The in-house estimate of the error for this measurement is ±1% of the sensor depth (Hugh Milburn, personal communication). In addition, when the instruments are deployed, it can be difficult to mount them exactly at the marked points, introducing additional error, though typically less than ±1 m.

For the purposes of this analysis, the possible errors in measurement and instrument placement were ignored because of concerns about the potential for even larger pressure sensor errors. It was assumed that the maximum depth that an instrument could possibly reach was equal to the nominal depth of the instrument. Thus, in the interpolation scheme described above, the line lengths used are determined by the nominal depths of the sensors. The alternative approach of assuming that the pressure records were correct, but the line measurement was in error, is discussed below in section 5.5.

When depth values were calculated from the pressure sensor readings, some deployments had depth values deeper than the nominal depths of the sensors. For these deployments, the calculated depth record was examined and the deepest value was noted. This value is called the maximum measured depth for the sensor. The expected effect of remapping temperature records is that the remapped temperatures will be colder than the unremapped temperatures, due to the instruments being displaced upward by line motion into warmer water. In cases where the maximum measured depth indicated by a pressure sensor was deeper than the nominal depth, the remapped temperatures could be warmer than the original temperatures for much of the water column, masking the effect of the upward excursions.

In order to see the effects of the upward displacements for those moorings where the maximum measured depth was deeper than the nominal depth, pressure records were adjusted by adding a constant offset that yielded a corrected maximum measured depth equal to the nominal depth. Five of the chosen deployments required correction of either the 300-m pressure record or both the 300- and 500-m pressure records. Corrections ranged from –0.21 to –9.21 db (Table 2).

The fact that pressure records are obviously offset downward for some deployments implies that for other deployments the pressure records may be offset upward by similar amounts. There is no way to distinguish between a record that is offset upward and a record from an instrument that never reached its maximum possible depth because it was continually displaced upward by stresses on the mooring line.

4.3 Other pressure corrections

The 300-m pressure record from the Indian Ocean mooring, ET214, showed an obvious drift (Fig. 1). An attempt was made to correct the record for the apparent change in sensor calibration. An estimate of the trend was made for the first 58 days of the record, where the pressure record was a fairly straight line. The trend was estimated by linear least squares regression. That trend was then removed from the entire record length, and the mean of the record was adjusted so that the mean of the first week of corrected data equaled the mean of the first week of uncorrected data. The size of the correction varies from negligible in July 1993 to about 5 db (deeper) in January 1994 (Fig. 2).

Table 2. Sites that required pressure records to be adjusted and the adjustment required for each record. Pressure records were adjusted such that when depths were calculated from the pressure values, the maximum depth was equal to the nominal depth of the sensor. Adjustments needed are shown in db for the 300-m pressure record (p300) and the 500-m pressure record (p500).

Position (lat, long)	Mooring designator	p300 adjustment (db)	p500 adjustment (db)
5°N, 156°E	ET344	–3.61	N/A
5°S, 156°E	ET310	–0.21	–3.21
5°N, 155°W	ET297	–3.21	–9.21
0°, 155°W	ET296	–0.32	–0.83
0°, 125°W	ET288	–2.72	N/A
Mean		–2.01	–4.42
Std. Dev.		1.63	4.32

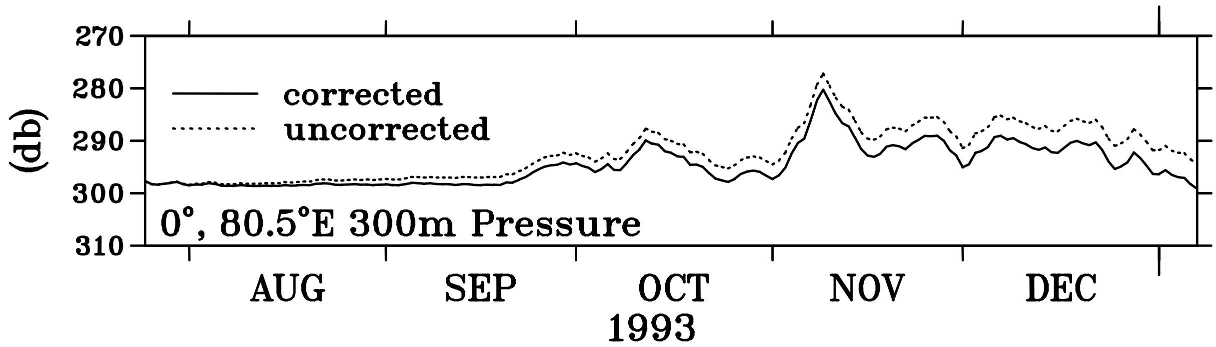

Fig. 2. Time series plot of the 300-m pressure records from 0°, 80.5°E. Dotted line is the original pressure record. Solid line is the pressure record after correcting for the estimated drift of the pressure sensor.

For the deployments at 0°, 125°W (ET288) and at 0°, 155°W (ET296), the post-deployment calibrations of the pressure sensors were judged to be of higher quality than the pre-deployment calibrations. The pressure records were recalculated using the post-deployment calibration coefficients.

4.4 Pressure record variability

After adjustment, the 300-m pressure records for the chosen deployments typically exhibit standard deviations of about 1–3 db (Table 3). The standard deviations of the adjusted 500-m pressure records are about twice that. The deployment at 8°N, 110°W (ET177) shows the smallest variability in the pressure records. The standard deviation of the ET177 300-m pressure record is 0.8 db; for the 500-m record it is 1.5 db. At 0°, 125°W (ET288) the combination of a slack-line mooring and a fast, highly-sheared current regime led to large excursions of the 300-m and 500-m sensors. The standard deviation for the 0°, 125°W 300-m pressure record is 8.1 db; for the 500-m record it is 20.0 db.

Statistics for the 0°, 80.5°E pressure records were calculated in two parts: 25 July 1993 to 7 November 1993 (before the buoy moved) and 12 November 1993 to 7 January 1994 (after it moved).

Prior to the move, the 300-m pressure sensor data have a mean of 297 db; the mean after the move is shallower, 292 db. Similarly, before the move, the 500-m pressure sensor data have a mean value of 493 db; the mean for the data after the move is 481 db.

The remapped temperature, adjusted pressure, and wind data for each deployment are presented in the appendices.

5. RESULTS

5.1 Temperature differences

In order to examine the effect of remapping the temperature records, a temperature difference field was calculated for each deployment by subtracting the remapped temperature records from the

Table 3. 300-m pressure mean and standard deviation; 500-m pressure mean and standard deviation. Pressure records were subjected to adjustments described in the text. Statistics for the mooring at 0°, 80.5°E are divided into two parts: (a) before the move into shallower water, 25 July 1993 to 7 November 1993; (b) after the move, 12 November 1993 to 7 January 1994.

Position (lat, long)		300-m pressure Mean (db)	300-m pressure Std. dev. (db)	500-m pressure Mean (db)	500-m pressure Std. dev. (db)
0°,	80.5°E (a)	297	2.5	493	5.1
0°,	80.5°E (b)	292	2.7	481	4.5
5°N,	156°E	300	1.3	499	2.7
0°,	156°E	298	2.0	497	3.6
5°S,	156°E	299	3.6	489	11.2
5°N,	155°W	300	1.3	500	2.7
0°,	155°W	300	1.1	499	2.8
0°,	125°W	289	8.1	467	20.0
8°N,	110°W	300	0.8	498	1.5
2°N,	110°W	298	2.7	494	5.6

original records. Contour plots of the temperature difference fields, profiles of the mean and standard deviations of the difference records, and profiles of the mean and standard deviations of the vertical displacements are presented in the appendices. The plots show that for all the moorings except the one at 0°, 125°W, the maximum temperature difference occurs in the upper thermocline. A typical RMS value for the temperature differences from the record showing the maximum effect of remapping is in the 0.15°–0.3°C range; typical mean and standard deviation values for the same record are in the 0.1°–0.25°C range (Table 4). For points above and below the thermocline the temperature difference records generally have RMS differences of around 0.1°C or less, though a few show secondary maxima of around 0.2°C at the interpolated 450-m depth, where the line experiences a greater range of motion.

Two notable outliers are the slack-line mooring at 0°, 125°W and the Indian Ocean mooring at 0°, 80.5°E, which apparently converted itself to a slack-line mooring by moving to shallower water. The Indian Ocean mooring has the record with maximum temperature differences in the thermocline, but with an RMS value of 0.45°C prior to the move and 1.1°C after the move. The mooring at 0°, 125°W showed the maximum temperature difference at the (interpolated) depth of 450 m. At this site the 500-m sensors experienced vertical displacements with a mean of about 35 m. The large vertical displacement through a gentle temperature gradient yielded greater temperature differences for the interpolated 450-m record than the smaller displacements through the thermocline. The RMS temperature difference at 450 m was 0.66°C; a secondary maximum of 0.51°C occurred in the thermocline at 120 m. It is interesting to note that the other slack-line

Table 4. For each mooring, the nominal depth at which mean ΔT (original temperature minus remapped temperature) is greatest, and the mean, standard deviation, and RMS ΔT for that depth. Statistics for the 0°, 80.5°E mooring are divided into 2 parts: (a) before the move into shallower water, 25 July 1993 to 7 November 1993, and (b) after the move, 12 November 1993 to 7 January 1994.

Position (lat, long)		Depth of max Mean ΔT (m)	Max mean ΔT (°C)	Std. dev. ΔT(°C)	RMS ΔT(°C)
0°,	80.5°E(a)	100	0.353	0.284	0.453
0°,	80.5°E(b)	120	0.946	0.552	1.110
5°N,	156°E	125	0.119	0.096	0.153
0°,	156°E	125	0.219	0.167	0.275
5°S,	156°E	200	0.247	0.241	0.345
5°N,	155°W	120	0.206	0.214	0.297
0°,	155°W	120	0.144	0.093	0.172
0°,	125°W	450	0.571	0.321	0.655
8°N,	110°W	60	0.141	0.072	0.158
2°N,	110°W	60	0.168	0.186	0.250

mooring, ET310, at 5°S, 156°E, sited in a less energetic current regime than the 0°, 125°W mooring, had a maximum RMS temperature difference of 0.34°C in the thermocline and displayed a secondary maximum of 0.27°C at 450 m.

5.2 Depth-averaged temperatures

Depth averages of both the original and remapped temperature records were calculated between 0 and 450 m to assess the effect of remapping over the whole of the instrumented depth. The depth averages for each mooring are presented in the appendices as overplotted time series and as scatter plots. For the taut-line moorings, typical RMS differences between depth averages from remapped and unremapped data are 0.05 to 0.1°C. The slack-line moorings, including that at 0°, 80.5°E after the move, show larger RMS differences, with the one at 0°, 125°W showing an RMS difference of 0.31°C. (Table 5).

5.3 Displacement of 20°C isotherm

The effect of remapping the temperature records can also be examined in terms of isotherm displacement. For each mooring, daily values for the depth of the 20°C isotherm were calculated by linear interpolation from both the unremapped data and the remapped data. The RMS displacements for taut-line moorings range from 0.4 to 2.0 m. All but one of the taut-line moorings have RMS displacements of 1.0 m or less. The RMS displacements for the slack-line moorings range from 2.9 to 3.8 m (Table 6). Time series plots and scatter plots of the isotherm depths can be found in the appendices.

Table 5. **ΔT** mean, standard deviation and RMS where **ΔT** represents the depth-averaged original temperatures minus the depth-averaged remapped temperatures. Depth averages were calculated between 0 and 450 m. Statistics for the 0°, 80.5°E mooring are divided into 2 parts: (a) before the move into shallower water, 25 July 1993 to 7 November 1993, and (b) after the move, 12 November 1993 to 7 January 1994.

Position (lat, long)		**ΔT** Mean (°C)	**ΔT** Std. dev. (°C)	**ΔT** RMS (°C)
0°,	80.5°E(a)	0.10	0.05	0.11
0°,	80.5°E(b)	0.18	0.05	0.18
5°N,	156°E	0.04	0.03	0.05
0°,	156°E	0.10	0.06	0.12
5°S,	156°E	0.12	0.12	0.17
5°N,	155°W	0.03	0.02	0.04
0°,	155°W	0.04	0.02	0.05
0°,	125°W	0.27	0.15	0.31
8°N,	110°W	0.04	0.01	0.04
2°N,	110°W	0.08	0.06	0.09

Table 6. Mean remapped 20°C isotherm depth and the mean, standard deviation, and RMS displacement (Δz) of the 20°C isotherm depth. Δz is defined as the difference between the original minus remapped 20°C isotherm depths. Statistics for the 0°, 80.5°E mooring are divided into two parts: (a) before the move into shallower water, 25 July 1993 to 7 November 1993, and (b) after the move, 12 November 1993 to 7 January 1994.

Position (lat, long)		z(20.0°) Mean (m)	Δz(20°C) Mean (m)	Δz(20°C) Std. dev.(m)	Δz(20°C) RMS (m)
0°,	80.5°E(a)	110.3	1.5	1.0	1.8
0°,	80.5°E(b)	121.5	2.7	1.0	2.9
5°N,	156°E	153.6	0.7	0.6	0.9
0°,	156°E	173.4	1.7	1.1	2.0
5°S,	156°E	198.1	2.0	2.1	2.9
5°N,	155°W	111.2	0.6	0.5	0.7
0°,	155°W	103.8	0.6	0.5	0.8
0°,	125°W	85.1	3.1	2.2	3.8
8°N,	110°W	66.9	0.4	0.2	0.4
2°N,	110°W	68.5	0.7	0.6	1.0

Table 7. ΔDH mean, standard deviation and RMS, where ΔDH represents the dynamic height from the original temperatures minus the dynamic height from the remapped temperatures. Dynamic heights were calculated between 0 and 450 m. Statistics for the 0°, 80.5°E mooring are divided into two parts: (a) before the move into shallower water, 25 July 1993 to 7 November 1993, and (b) after the move, 12 November 1993 to 7 January 1994.

Position (lat, long)	ΔDH Mean (dyn. m)	ΔDH Std. dev. (dyn. m)	ΔDH RMS (dyn. m)
0°, 80.5°E(a)	0.014	0.008	0.016
0°, 80.5°E(b)	0.014	0.008	0.016
5°N, 156°E	0.005	0.004	0.006
0°, 156°E	0.010	0.006	0.012
5°S, 156°E	0.010	0.010	0.015
5°N, 155°W	0.003	0.002	0.004
0°, 155°W	0.003	0.002	0.004
0°, 125°W	0.021	0.012	0.024
8°N, 110°W	0.003	0.001	0.004
2°N, 110°W	0.006	0.005	0.008

5.4 Dynamic heights

Dynamic heights between 0 and 450 db were calculated for each deployment from both the original temperatures and the remapped temperatures. Salinities for the dynamic height calculation were interpolated from a set of T-S values constructed for each site from the World Ocean Atlas annual temperature and salinity climatologies (Levitus *et al.*, 1994; Levitus and Boyer, 1994). Time series plots and scatter plots of both sets of dynamic heights are shown for each deployment in the appendices. Except for the slack-line moorings, the RMS differences between the two sets of dynamic heights for each site range from 0.003 to 0.012 dyn m. The RMS differences for the slack-line moorings are greater. The largest RMS difference, 0.024 dyn m, is from the 0°, 125°W site (Table 7).

5.5 Changing the assumption about pressure sensor errors

To examine the significance of adjusting the pressure records rather than adjusting the length of the line in the temperature remapping procedure, two of the five moorings that required pressure adjustments were remapped a second time using the assumption that the pressure sensors were more accurate than the line measurement. In these two cases, the unadjusted pressure records were used in the remapping procedure, and the maximum measured depths were used to determine line lengths. The cases that were remapped a second time are the 0°, 125°W mooring, which in the first remapping showed the greatest error due to line motion, and the 5°N, 155°W mooring, which required the largest adjustment to the pressure records for the first remapping. For the second remapping of the 5°N, 155°W data, the line lengths were set to yield a maximum possible depth for the 300-m sensors of 303.2 m and a maximum possible depth for the 500-m sensors of 509.1 m. For 0°, 125°W, line lengths were set so that the maximum possible depth of the 300-m sensors was 302.7 m. The maximum measured depth from the 0°, 125°W 500-m pressure sensor was shallower than 500 m, so the maximum possible depth of the 500-m sensors was set to the nominal depth.

The errors calculated assuming that the deepest measured depth indicates the position of the sensor on the mooring line are, for all variables (temperatures from specific depths, depth averaged temperatures, 20°C isotherm depth, and dynamic heights), virtually indistinguishable from those calculated by the previous method (Table 8).

Table 8. Mean, standard deviation and RMS of ΔT(120 m), ΔT(450 m), **ΔT**, Δ*z*(20°C), and ΔDH for time series based on temperatures remapped by two different methods. ΔT(120 m) represents the original 120-m temperature minus the remapped 120-m temperature. ΔT(450 m) represents the original 450-m temperature minus the remapped 450-m temperature. **ΔT** represents the depth averaged original temperatures minus the depth averaged remapped temperatures. Δ*z*(20°C) represents the depth of the 20°C isotherm calculated from the original temperatures minus the depth of the 20°C isotherm calculated from the remapped temperatures. ΔDH represents the dynamic height from the original temperatures minus the dynamic height from the remapped temperatures. Temperature remapping done by Method 1 was based on pressure records that had been adjusted so the maximum measured depth equaled the nominal depth. Temperature remapping done by Method 2 was based on the assumption that actual pressure sensor depth equaled the maximum measured depth.

(a) 5°N, 155°W

		Method 1			Method 2		
Variable	Units	Mean	Std. dev.	RMS	Mean	Std. dev.	RMS
ΔT(120m)	°C	0.21	0.21	0.30	0.21	0.21	0.29
ΔT(450 m)	°C	0.03	0.02	0.03	0.02	0.02	0.03
ΔT	°C	0.03	0.02	0.04	0.01	0.02	0.03
Δz(20°C)	m	0.6	0.5	0.7	0.6	0.5	0.7
ΔDH	Dynamic m	0.003	0.002	0.004	0.002	0.002	0.003

(b) 0°, 125°W

		Method 1			Method 2		
Variable	Units	Mean	Std. dev.	RMS	Mean	Std dev.	RMS
ΔT(120 m)	°C	0.41	0.30	0.51	0.41	0.30	0.51
ΔT(450 m)	°C	0.57	0.32	0.66	0.58	0.32	0.66
ΔT	°C	0.27	0.15	0.31	0.27	0.15	0.31
Δz(20°C)	m	3.1	2.2	3.8	3.1	2.2	3.8
ΔDH	Dynamic m	0.021	0.012	0.024	0.021	0.012	0.024

6. CONCLUSION

Remapping temperature records by the above method indicates that the effect of depth excursions is typically 1½ to 2½ times greater than instrumental temperature error for taut-line moorings. The effect on slack-line moorings is greater. The size of these corrections underscores the need for accurate and reliable pressure sensors on the ATLAS moorings so that corrections can be made in both real-time and post-deployment processing. This analysis also underscores the need for more accurate line measurement to remove ambiguities about how corrections are applied. To address this need, a new line measuring system with linear drive belts (model MVP FC-25) manufactured by P.T.T. Inc. (Hayward, California), with a manufacturer's stated accuracy of 0.07%, has recently been acquired.

A move has begun to replace the present style of ATLAS mooring with a reengineered next-generation ATLAS system. The reengineered ATLAS system will be deployed in either taut-line or slack-line configurations, but with the temperature cable replaced by inductively coupled sensors mounted on the wire rope. The new design allows pressure sensors at three depths rather than two. The sensor of choice at present is the Paine model 2111-30-660-02 strain-gauge-type pressure sensor with a nominal accuracy of ±2 db (Milburn *et al.*, 1996).

It is anticipated that eventually most, if not all, of the TAO array will be instrumented with next generation ATLAS moorings of the slack-line variety. Hence, temperature remapping for depth excursions will become a mandatory part of data processing to correct for mooring motion-induced temperature errors. Ongoing efforts at PMEL are directed at refining and further testing of error estimation algorithms discussed in this report. We are also developing procedures whereby necessary temperature corrections can be applied on a routine basis to real-time and delayed-mode ATLAS mooring data streams.

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APPENDICES

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