Physical properties of southern Fiji waters

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ABSTRACT
CTD-O_2 (conductivity, temperature, depth and oxygen) data collected in the southern part of Viti Levu during the cruises (`96, `97, `98, `99 & `03) of the Japanese fisheries research vessel, Koyo-maru were analyzed to identify the isothermal layers, thermocline depths, and their annual variations. Despite the difference in years and locations during the survey, seasonal thermoclines at 50-100 m depth, permanent thermoclines at 100-600 m depth and haloclines at 250-600 m depths were found. In conjunction with the temperature, salinity and depth analysis, water mass properties were also investigated, and T-S diagrams were used to identify the water mass movement and formation. The results indicate that the water mass extending from 200-600 m originated from West South Pacific Central Water and the water mass between 600-1100 m originated from Antarctic Intermediate Water.

1 INTRODUCTION

The Japanese research vessel, Koyo-maru makes an annual voyage as part of the training of engineering and navigation student cadets. The Koyo-maru visits Southern Fiji waters in December each year to do CTD-O_2 measurements. The Koyo-maru data, in December each year from 1996 to 1999, measured at different locations of Southern Fiji waters are used to construct temperature and salinity depth profile to deduce the physical property of seawater around Fiji. The time period of these data spans El Niño, La Niña and normal seasons. December 1996 marks the onset of 97/98 El Niño, December 1997 shows the mature phase of 97/98 El Niño, December 1998 marks the La Niña and December 1999, the normal condition. Due to political situation in Fiji, there was no cruise for 3 years and the last Koyo-maru cruise took place in December 2003. The physical properties of the latest data sets were analyzed and compared with earlier data from 1996 (Ferland and Suda, 1998). This provides a good signature of seawater temperature and salinity variations in an interannual time domain.

The temperature and salinity fields also form an essential tool for identifying the *water mass* property with common formation history through T-S diagrams. Tomczak and Godfrey (1994) have shown the existence of Western South Pacific Central Water (WSPCW), Antarctic Intermediate Water (AAIW) and the Antarctic Bottom Water (AABW) in the tropical Pacific Ocean.

2 OBJECTIVES

For Pacific island countries like Fiji, the marine resources are an extremely important basis for economic development. However, there is only scant information available about the distribution of water properties within Fiji's EEZ. It is necessary to understand the nature of existing resources to develop and maintain a sustainable marine environment in the future. For example, temperature and salinity, together with pressure, are the most important physical properties affecting seawater density and control the dynamics and thermodynamic behavior of the ocean. No systematic studies of CTD-O_2 (conductivity, temperature, depth and oxygen) in the Fijian archipelago have been published previously except the reports from Ferland and Suda (1998) and Pickering and Suda (2003). Therefore, it is expected that data analyses and interpretations are important for future studies in oceanography in Fiji. In the absence of user-friendly papers on oceanographic data analysis and basic interpretation of analyzed data, for basic oceanographic research, our paper will pave a way for the beginners who need a guideline to deal with the marine data sets collected in the USP region.

3 DATA AND METHODS

In this paper we briefly looked at the CTD data collected during 1996-1999 Koyo-maru cruises and interpreted for the physical properties of Southern Fiji waters. Study areas varied every year based upon the different purposes of the cruises and the requirements of the scientists involved, however, the Koyo-maru cruises focus on the southern part of *Viti Levu* every year due to the time constraints and the insufficiently charted waters north of Fiji.

In addition to the earlier data sets, temperature and salinity depth profiles focussed on data collected during the two transects of the December 2003 cruise shown in Figure 1. Using a CTD meter provided by the National Fisheries University of Shimonoseki under its joint research programme with the University of the South Pacific the measurements were taken during the cruise of 2003. Transect 1 consisting of 6 stations is located between the 18.20º and 18.45º south latitude and along the north-south line of 178.50º longitude whereas transect 2 is located between 18.25 and 18.33º south latitude and along the north-south line of 179.31º longitude. Table 1 summarizes the location of each station for the two transects.

Furthermore, the mean temperature and salinity depth profiles for each transect were determined, together with their standard deviations, to identify their variability along the vertical stratification. The T-S relationship has been used to identify the different water mass properties and their common formation history.

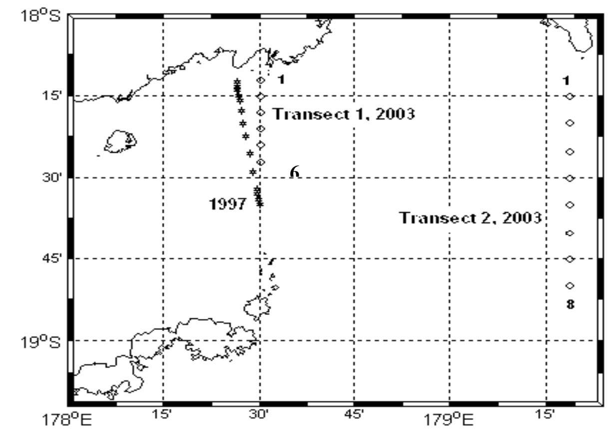

Figure 1. Location of study area and stations where measurements were taken in 1997 and 2003 (SE of Viti Levu)

Table 1. Station locations for Transect 1 and Transect 2 (December 2003)

Transect	Station	Latitude (degrees)	Longitude (degrees)
	1	-18.20	178.50
	2	-18.25	178.50
	3	-18.30	178.50
1	4	-18.35	178.50
	5	-18.40	178.50
	6	-18.45	178.50
	1	-18.25	179.31
	2	-18.33	179.31
	3	-18.42	179.31
	4	-18.50	179.31
2	5	-18.58	179.31
	6	-18.67	179.31
	7	-18.75	179.31
	8	-18.83	179.31

4 RESULTS AND DISCUSSION

4.1 ANALYSIS OF EARLIER DATA SETS

The mean vertical temperature profile (Figure 2a) during December from 1996 to 1999 indicates clear ENSO variation of SST (sea surface temperature) in the study region. The top 50 m of the water column displays lowest water temperature of 26.5°C during El Niño phase of December 1997, highest value of 28.6°C during La Niña phase of December 1998 and the average temperature of around 27°C during normal conditions. This is in agreement with Delcroix and Gouriou (2002) who showed that the SST during La Niña periods is warmer than that during El Niño period.

The seasonal thermocline, which usually develops above the permanent thermocline in summer when the SST is higher and less variable compared to winter months (Brown *et al.* 1989), is also evident around 50 m to 100 m depths. The permanent thermocline extends from 100 m to about 600 m. Below this depth, the temperature remains constant regardless of whether the condition is representative of El Niño or La Niña. Thus, the temperature up to the depth of 600 m plays the significant role in influencing density variation in the study area and therefore the surface current.

The typical mean salinity depth profile (Figure 2b) displays the surface salinity variation of 33.9 psu during non-El Niño period to about 35.3 psu during El Niño phase. Compared to the vertical dependence of temperature that exhibits a systematic maximum variability at the depth of the main thermocline, the salinity typically shows a maximum variability at the surface layers. Therefore, temperature variation is considered to be the major source of density variation as suggested by Emery and Pickard (1990). However, as with temperature, no major ENSO related salinity variation is seen in the halocline region, below the depth of 250 m, except for the 1999 period where the discrepancy could be related to the sensor drifts. Thus, the major salinity variation in the top 250 m could account for the density variation and therefore influence the surface current (Pond and Pickard, 1983). In general, large spatial variability in temperature and salinity occurs close to the surface, as expected in coastal areas.

4.2 TEMPERATURE STRUCTURE (DECEMBER 2003)

The mean vertical structure of temperature about the first standard deviation (Figure 3), shows the maximum sea surface temperature (SST) of 26.9ºC extending through the top 50 m layer for both the transects compared to the temperature of 26.5ºC in 1997 (Pickering and Suda, 2003). Below this isothermal layer lies a layer of seasonal thermocline extending to the depth of 100 m. The seasonal thermocline generally develops during the summer months when the conditions at the sea surface are less rough. This layer often forms above the permanent thermocline, a region of steep temperature gradient. For both transects, the permanent thermocline extends from 100 m to 600 m, below which no mixing occurs, therefore, the temperature change is small.

The maximum spatial (station to station) variability of temperature (≈ 1.3°C) is observed in the permanent thermocline layer. This is the region where the standard deviation about the mean is greatest, compared to that in the abyssal waters (Figure 3). This high variability is due to the different degrees of turbulent mixing during the transition of warm waters of the surface layer to the cold waters of the ocean depths in different spatial regions.

When we closely look at the temperatures of individual stations in both transects, SST at stations near the land is colder than the other stations. It is to be noted that the stations in this study are too close to each other and the effect of latitude may not be significant. Cold and less saline water running from the nearby rivers is believed to be the major cause of the cold SST in these stations near the land.

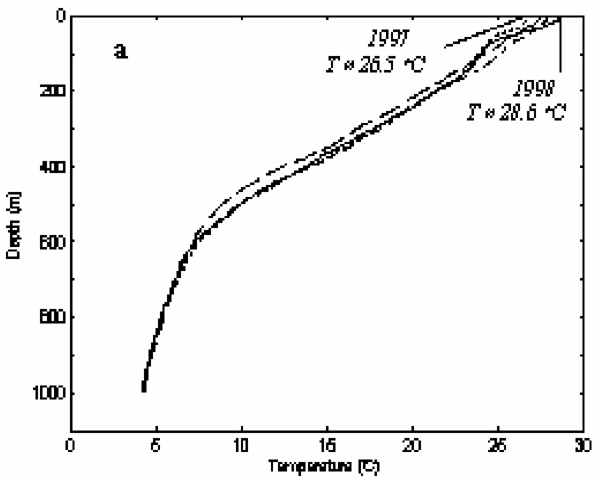

Figure 2a. A typical temperature/depth profile obtained from Koyo-maru visits (1996 - 1999)

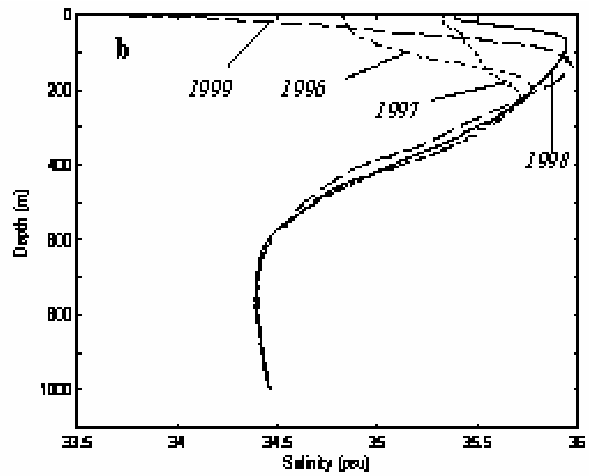

Figure 2b. A typical salinity/depth profile in the Data study region during the month of December 1996-9.

4.3 SALINITY STRUCTURE (DECEMBER 2003)

Compared to the temperature variability (≈ 0.1 psu) along the two transects, which is greatest in the main thermocline, the standard deviation of salinity shows a different vertical structure (Figure 4). The maximum variability occurs at the surface, consistent with the earlier results of Maes and Behringer (2002) for the tropical Pacific Ocean. The sharp salinity maxima of 36.6 psu is observed at the depth extending from 200 to 300 m compared to the value of 35.1 psu at the surface. The present value of sea surface salinity being slightly lower than those in 1997 (Pickering and Suda, 2003). Between 300 to 600 m layer, lies a zone of rapid salinity decrease called the halocline. A marked salinity minima of 34.4 psu is also observed from 600 to 1000 m depth. This is also the region where the salinity variability is small due to minimal influence of surface fluctuations.

Having looked at the individual stations, it was found that the surface salinity at stations near the land is less saline than other stations. It is believed to be the contributions of river run-off in the study area.

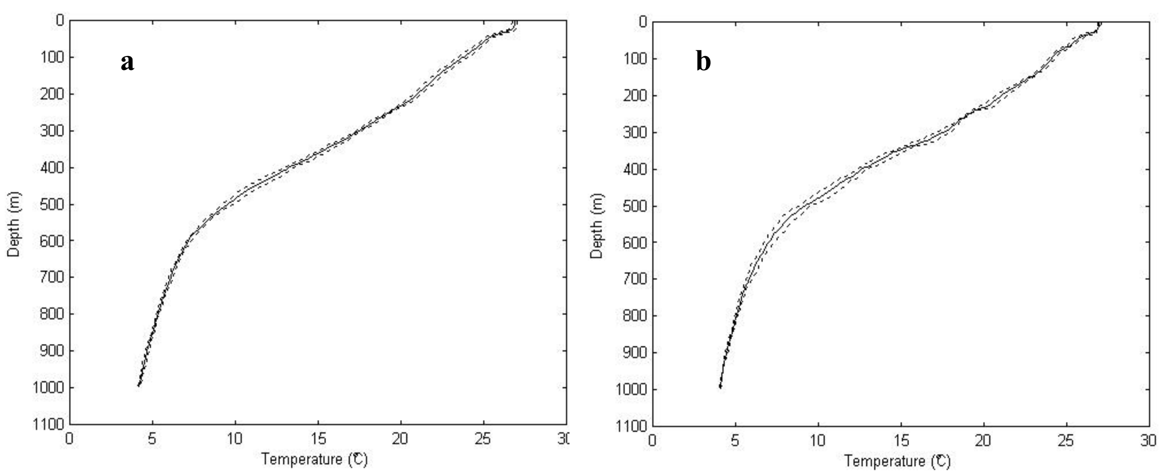

Figure 3. Mean temperature profile (solid line) with standard deviation (dashed line) for (a) Transect 1 and (b) Transect 2

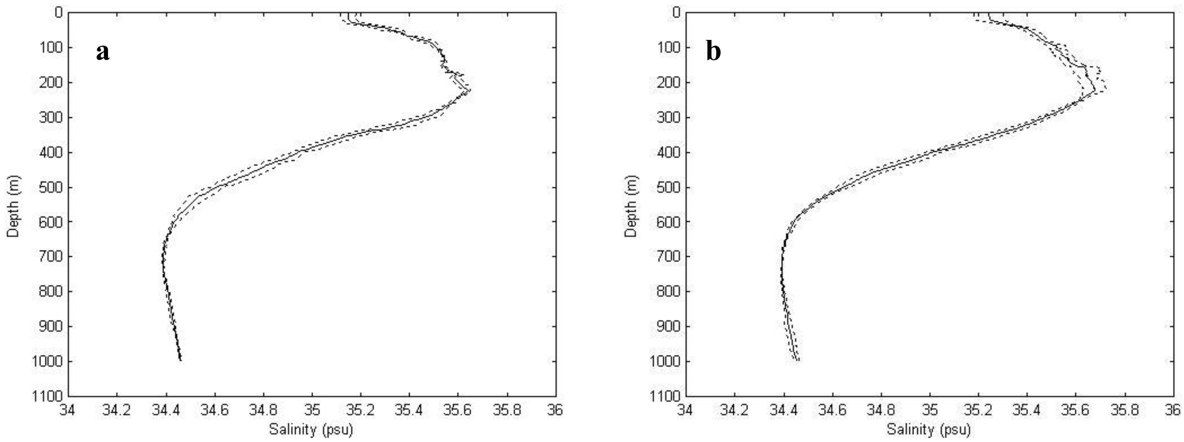

Figure 4. Means Salinity profile (solid line) with standard deviations (dashed line) for (a) Transact 1 and (b) Transact 2.

4.4 WATER MASS

Temperature and salinity form an important tool in identifying and tracing water masses in the oceans. From the T-S diagram (Figure 5), the evidence of the presence of three water masses is identified. At the surface and extending down to about 150 m, a layer of relatively fresh water (T = 26-28 ºC; S = 35.1 psu) is present. In this layer, water masses undergo property changes in response to atmospheric conditions, as indicated in the T-S diagram by the increase in standard deviation as surface is approached.

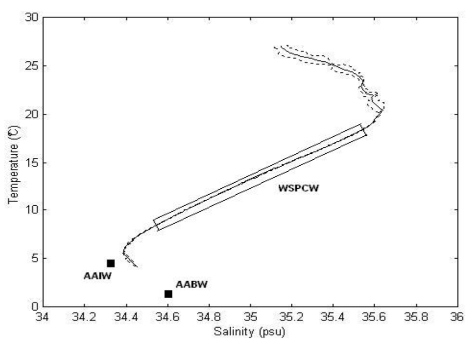

Figure 5. Mean T-S diagram and standard deviation. Data to construct this T-S diagram comes from Koyo-maru and information comes from Tomczak and Godfrey (1994) and Brown *et al*. (1989). Abbreviations are used for the West South Pacific Central Water (WSPCW), Antarctic Intermediate Water (AAIW), and Antarctic Bottom Water (AABW).

Beneath this layer, the West South Pacific Central Water [WSPCW] with T = 10-18ºC; S = 34.5 psu to 35.5 psu is found. It extends to about 600 m, encompassing the salinity maximum (S = 35.7 psu) at a depth of 200 m. Antarctic Intermediate water, AAIW (T = 5ºC, S = 34.4 psu) lies in the depth interval of 600 m to 1100 m. In the deepest layer (> 1100 m) is the Antarctic Bottom Water, AABW.

5 CONCLUSIONS

We have briefly presented a description of temperature and salinity distribution and variability along the water column in the study region. Study areas are different for every survey, however the physical properties of waters are very similar to each other (stations by stations or areas by areas).

The maximum temperature variability is observed in the permanent thermocline whereas the maximum salinity variability is observed at the surface. For all these years of survey, the permanent thermoclines are found at the depth between 100-600 m. Similarly, haloclines are found at 250-600 m depth. In conjunction with the temperature and salinity depth analysis, the T-S relationship was obtained to identify the water mass and its common formation history. The results indicated that the water mass extending from 200 – 600 m originated from WSPCW and that between 600 – 1100 m depth originated from AAIW.

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REFERENCES

1. Brown, J., Colling, A., Park, D., Phillips, J., Rothery, D. and Wright, J.1989. Seawater: Its composition, properties and behaviour, *Open University Course Team, Pergamon Press, Oxford*.
2. Delcroix, T. and Gouriou, Y .2002. Seasonal and ENSO variations of sea surface salinity and temperature in the South Pacific Convergence Zone during 1976-2000, *J Geophys. Res.,* **107 (C12)**, 8011, doi:10.1029/2001JC000 830.

3. Emery, W. J. and Pickard, G. L. 1990. Descriptive Physical Oceanography, 5th ed., *Pergamon, New York,* 320 pp.
4. Ferland, M. A. and Suda, Y. 1998. Report of the Inaugural Joint National Fisheries University-University of the South Pacific Fisheries and Oceanography Research Cruise on Board Koyo-maru, Kadavu Passage, December 1996, *Technical Report* **98(2)**, *Marine Studies Programme*, University of the South Pacific, PO Box 1168, Suva, Fiji, 66 pp.
5. Maes, C. M. and Behringer, D. 2002. Using satellite derived sea level and temperature profiles for determining the salinity variability: A new approach, *J. Geophys. Res.* **105 (C4)**, 8537-8547.
6. Pickering, T. D. and Suda, Y. 2003. Report of the 2nd Joint National Fisheries University-University of the South Pacific Fisheries and Oceanography Research Cruise on Board Koyo-maru, Kadavu Passage, December 1997, *Technical Report* **2003(2)**, *Marine Studies Programme*, University of the South Pacific, P O Box 1168, Suva, Fiji, 69 pp.
7. Pond, S. and Pickard, G. L. 1983. Introductory Dynamical Oceanography, 2nd *ed. Pergamon Press, Oxford.*
8. Tomczak, M. and Godfrey, J. S. 1994. Regional Oceanography – An Introduction, *Pergamon Press,Oxford.*