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Pacific Ocean
20°C depth
FSU Model
1982-1983 El Niño

Océan Pacifique
Profondeur 20°C
Modèle FSU
El Niño 1982-1983

Observed and modelled topography of the 20°C isotherm in the tropical Pacific

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ABSTRACT

Variability in depth of the 20°C isotherm observed by expendable bathythermograph during 1979 to 1983 is documented at selected locations where interannual signals are large. The observed variability is compared to the pycnocline height generated in the Florida State University tropical ocean model, forced by estimates of the observed field of trade winds. The model and observations show good agreement along the equator and in the Western Pacific. Discrepancies are found in the extra-equatorial central Pacific.

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RÉSUMÉ

Topographie de l'isotherme 20°C d'après observations et d'après modèle dans le Pacifique tropical

La variabilité en profondeur de l'isotherme 20°C observée par bathythermographe à sondes perdues de 1979 à 1983 est considérée de 20°N à 20°S et sur toute la largeur de l'Océan Pacifique. Les observations sont comparées aux profondeurs obtenues par le modèle d'océan tropical de la Florida State University (FSU), alimenté par le champ de vent réellement observé. Le modèle et les observations sont en bon accord le long de l'équateur et dans le Pacifique Ouest. Des différences apparaissent dans la partie extra-équatoriale du Pacifique central.

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INTRODUCTION

The topography of the thermocline in the tropical Pacific Ocean has a series of ridges and troughs which extend entirely across the ocean along either side of the major zonal surface currents (Wyrtki, 1974). The average topography was mapped long ago (Knauss, 1963); however, its variability has been difficult to document because the space and time scales are too large for most observational programs. Some information on variability has come from island based measurements of sea level (Wyrtki, 1979), which gives a global index of vertical displacement of the thermocline. This showed that coherent fluctuations with very large spatial scales (> 1 000 km) occur during major climate anomalies such as El Niño and Southern Oscillation (ENSO). The observed sea level fluctuations were consistent with dynamical ocean models forced by observed trade winds (Busalacchi *et al.*, 1983). Subsurface temperature measurements has to be used for further testing of the ocean models. The island observations are sparsely distributed in a vast ocean, while temperature can be measured in regions where no islands are available, in particular on transects across the major currents. In earlier studies, seasonal and interannual variability of the temperature field was first documented by compositing observations from historical data archives (Hénin, Donguy, 1980; Donguy *et al.*, 1984 *a*; Meyers, 1979 *a*; *b*). These studies showed that low-frequency signals could be observed using sparsely distributed but extensive observations, and appropriate techniques to eliminate geophysical noise due to unresolved eddy variability. The temperature signals were then related to changes in the trade winds

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during seasonal cycles and ENSO. This study presents results from a new effort to monitor subsurface temperature on an ocean wide scale.

DATA

A program of XBT observations was started in 1979 by oceanographers from France and the United States in order to obtain sequential observations of subsurface temperature, to complement the island-based sea level measurements. It is now possible to follow the evolution of thermal structure along three transequatorial shipping routes near 160°E, 160°W and 110°W, during the period 1979-1983 (Fig. 1). The western Pacific section was largely maintained by one ship plying repeatedly over the same track between New Caledonia and Japan. The Central Pacific section was maintained by four ships operating in a broad swath between the lines joining New Caledonia to Vancouver and Los Angeles to Fiji. The eastern Pacific line was maintained by four ships sailing from Panama to Tahiti and Mururoa (137°W, 22°S).

In this article, the XBT observations are used to further test the Florida State University (FSU) ocean-model (Busalacchi *et al.*, 1983), updated to cover the period of our observations and made available to us at longitudes 160°E, 180°E, 160°W, 140°W, and 110°W (Inoue, pers. comm.). The very large anomalies during the last ENSO episode are considered first. Depth of the 20°C isotherm at the equator, 7°N and 5°S on each of the three XBT tracks (Donguy *et al.*, 1984*b; c*) is compared to the same parameter from the model. In this case, latitudes 7°N and 5°S are chosen because troughs in dynamic height develop there in association with anomalous eastward currents along the equator. In the second part, the western Pacific section 20°N-20°S is compared to the model for the entire period of the study. All correlation coefficients are based on samples of size N = 70 pairs of values; it is worth noting that the intervals in longitudes are more than the decorrelation scale as defined at 7°N by White (1983).

The 20°C isotherm was selected as representative of the thermocline. In the Western and Central Pacific it is located in the middle of the thermocline. In the Eastern Pacific, this isotherm, although shallow, does not surface. The 20°C isotherm is also suitable for comparison to the pycnocline height anomaly from the model because it is near the depth of maximum density gradient and all nearly isotherms fluctuate in unison. Moreover, Rebert *et al.* (1985) have found good correlations from 15°S to 15°N between 20°C isotherm depth and both heat content and dynamic height.

RESULT

The result of the comparisons at the equator, 7°N and 5°S are summarized in the Table. A discussion is finally conducted in order to document the causes of agreements and disagreements between data and model.

Table

Correlation coefficients between the results of the model and the observed values.

Coefficients de corrélation entre les résultats du modèle et les valeurs observées.

	160°E	160°W	110°W
7°N	0.61	0.19	0.77
Equator	0.73	0.71	0.81
5°S	0.63	0.36	0.05

Equator

The dominant observed feature in 20°C isotherm depth along the equator is an eastwardly progressing deepening in this isotherm during 1982-83 (Fig. 2; Donguy *et al.*, 1984*b*). A second similar feature crossed the ocean from November 1981 to June 1982.

The FSU model reproduces these features well but their patterns are less sharp: at 110°W, 20°C isotherm reaches 140 m depth according the observations and only 100 m according the model. For the most part, isotherm depths are more shallow in the model than

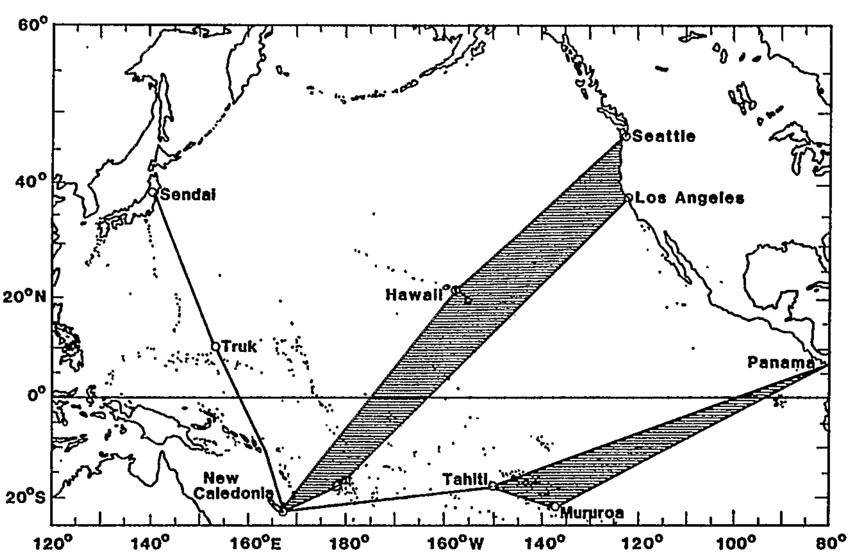

Figure 1

Tracks of the ships of opportunity and location of Truk Island.

Route des navires et position de l'île de Truck.

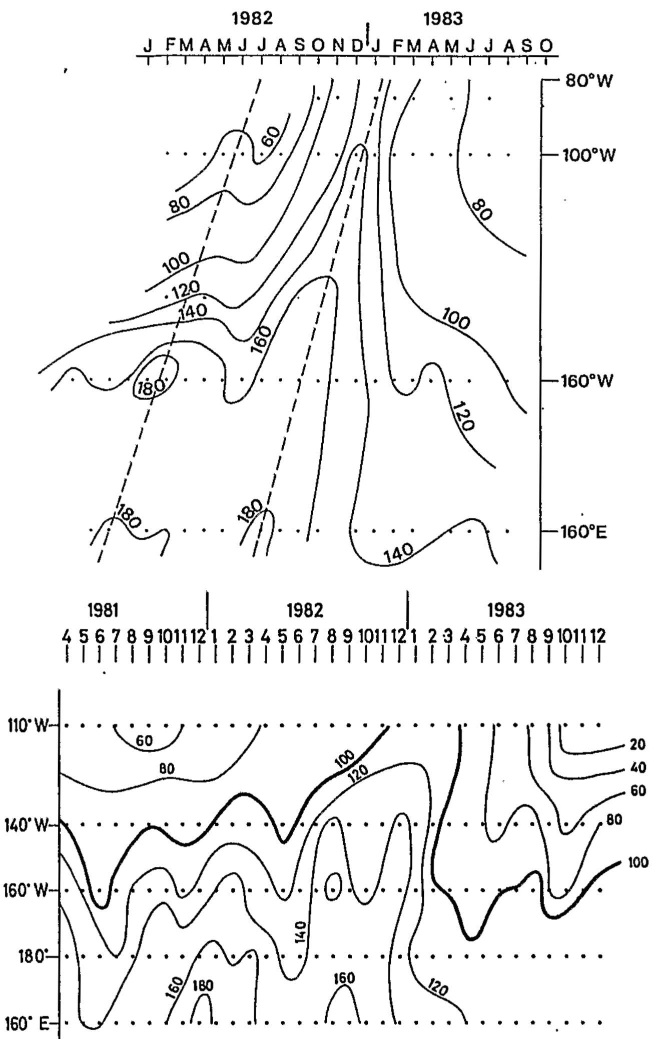

Figure 2

Depth (m) of the 20°C isotherm at the equator. Top-observed. Bottom-modelled.

Profondeur (m) de l'isotherme 20°C à l'équateur. En haut, d'après les observations. La propagation vers l'Est a été ajustée visuellement. En bas, d'après le modèle.

in the observations. By early 1983, both observed and modelled 20°C isotherm depths were essentially flat across the Pacific at a depth of 120-140 m. This disappearance of the thermocline slope has been inferred from a study of sea level by Lukas *et al.* (1984). The flat topography also appears in the model at the correct time.

The correlation between FSU model and observations is rather good. At 160°E, one obtains 0.73; at 160°W, 0.71; at 110°W, 0.81. In conclusion, along the equator, the model gives a good representation of the dominant observed features. Eastward progression of the deepening thermocline appears to be directly forced by wind anomalies (Rasmusson, 1984) which also moved eastward during the ENSO episode.

7° North

At 7°N, the dominant observed feature is a shallowing of the 20°C isotherm in the central and western Pacific after June 1982, followed by a deepening at all longitudes during the first half of 1983 (Fig. 3, top). By early 1983, the thermocline is flat, at a depth of about 80 m. In the model, the thermocline flattens out at the same time (Fig. 3, bottom) and is preceeded by shallowing in the West, then followed by deepening at all longitudes; however, although model and observations give values of the same order, the pattern is weak compared to the observations.

The return to the normal conditions after the ENSO episode is associated with the deepening of 20°C in 1983 (Fig. 3, top). A maximum depth occurs in May 1983 at 160°E, in June 1983 at 160°W and in July 1983 at 80°W, suggesting eastward progression at a speed of 2.5 m/s. This progression also appears in the model in the central and Western Pacific (Fig. 3, bottom), but does not reach 110°W. Since the model does not permit free mode moving eastward at this latitude, it seems that the return to normal is directly forced by the wind: analysis of the wind in the Western Pacific shows more drastic change than usual from easterlies in January 1983 to westerlies in June 1983. This feature has been already noticed by Busalacchi *et al.* (1983) for earlier El Niño.

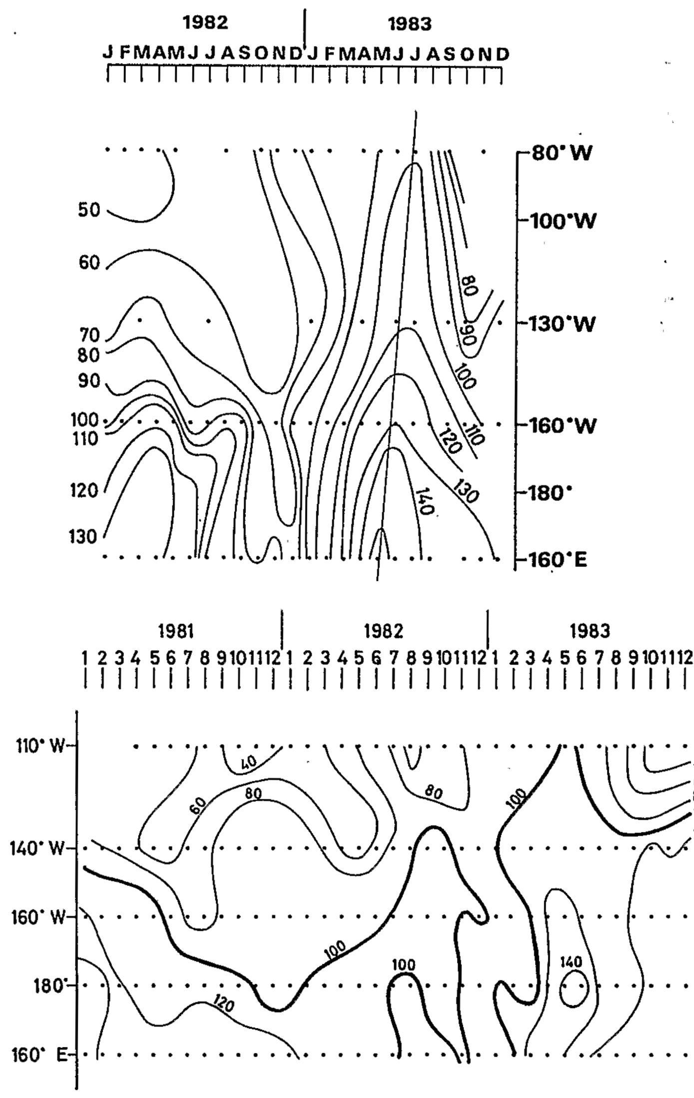

Figure 3

Same as Figure 2 for 7°N.

Idem figure 2 pour 7°N.

The correlation between model and observations is good in the Western Pacific and at the Eastern boundary but poor in the central Pacific. At 160°E, the correlation is 0.61; near 100°W, it is 0.77 (due to the track of the ship, the depth observed at 80°W is correlated with the model at 110°W); at 160°W, the correlation drops to 0.19.

5° South

At 5°S, the pattern is similar to the one at the equator (Donguy *et al.*, 1984*c*) showing a deepening of 20°C isotherm progressing from West to East from June 1982 at 160° to February 1983 at 80°W (Fig. 4, top). The same feature appears on the FSU model but reaches 110°W a few months later than in the observations (Fig. 4, bottom). Both model and observations show the flattened thermocline in the central and Western Pacific during March-April 1983. Flattening in the observations does not extend to the Eastern boundary. As on the equator, isotherm depths are more shallow in the model than in the observations. The correlation between the model and the observations is good at 160°E (0.63), poor at 160°W (0.36) and at 110°W (0.05).

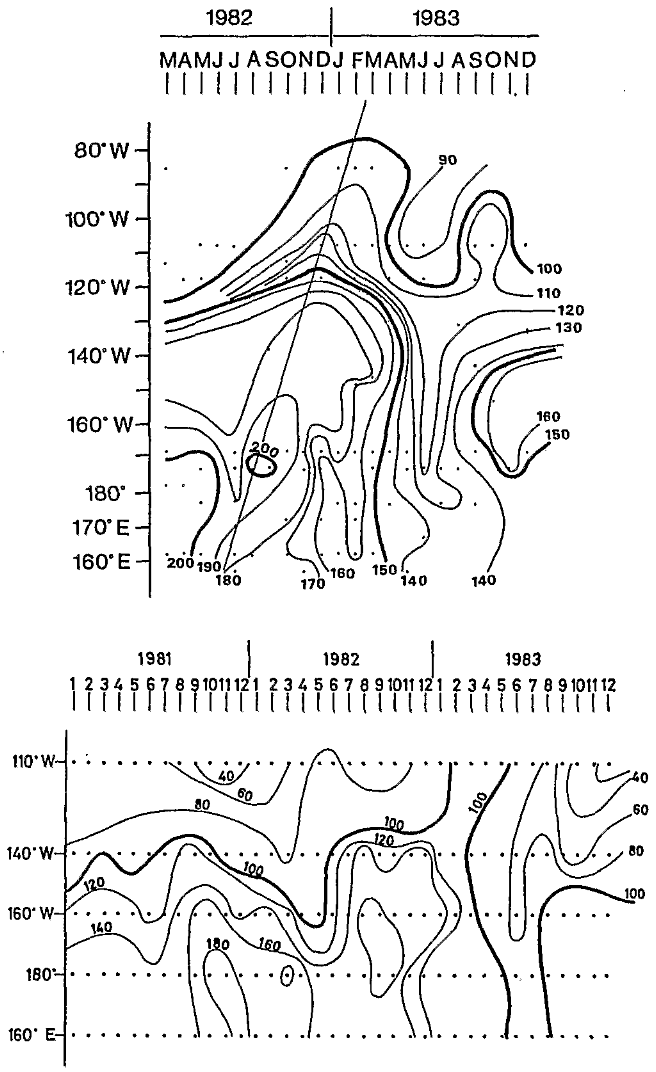

Figure 4
Same as Figure 2 for 5°S.
Idem figure 2 pour 5°S.

Western Pacific section

The comparison of depth of the 20°C isotherm and the model in Figures 2, 3 and 4 shows that the model performs well generally, along the equator and in the Western Pacific. The description of isotherm topography in the Western Pacific (Fig. 5, top) is completed by examining the nearly meridional section from 23°N to 20°S along 160°E where the model performs well. The general features were described in earlier articles (Meyers, Donguy, 1984*a; b*). Here the purpose is to compare the observed topography to the FSU model. The dominant feature is a massive shallowing that begins near the equator in mid-1982 and later in the southern hemisphere. The same features appear in the model (Fig. 5, bottom). During the years 1979 and 1980, less extensive shallowing near 7°N also appear in the model. Both the observations and the model show a maximum depth of the isotherm near 17°N and a northward displacement of the maximum during early 1981 and early 1983. In the latitude band between the equator and 10°S the model and observations do not show the same mean structure during June 1979 to June 1982. The thermocline depression to more than 200 m, usually present in the observations is missing in the model.

Sea level and thermal structure

During typical El Niño years, low sea-level is observed at Truk Island (7°21N, 151°51E; Fig. 1) starting in April (Meyers, 1982). Minimum sea-level occurs the following December and normal sea-level is recovered in April of the next year, in phase with the annual cycle. In 1982-1983, the typical change of sea level was observed at Truk Island (Fig. 6). At the same time, at 7°N, temperature data were recorded at 160°E, 160°W and 80°W. Due to baroclinic balance, a decrease of the 20°C isotherm depth, correlated with low sea-level, was observed not only at 160°E but also at 160°W, but not at 80°W.

Changes in the vertical displacement of isotherms relative to 20°C isotherm depth show a modification of vertical temperature gradient and evidence of higher vertical modes in the baroclinic response to wind forcing. The vertical structure of temperature near Truk (Fig. 7, top) shows that during the ENSO episode, all the isotherms move with nearly the same amplitude and phase. However, slight changes in the vertical temperature gradient are apparent when the same data is plotted relative to 20°C (Fig. 7, bottom). These changes in vertical density gradient in the upper 400 m suggest the existence of higer modes; but such higher modes are weak relative to the first vertical mode, which is partly why 1.5 layer models have been successful in explaining Truk sea-level (Busalacchi *et al.*, 1983).

A similar analysis of thermal structure at the equator, 160°E shows that high vertical mode activity is considerably stronger (Fig. 8). As the thermocline rises during

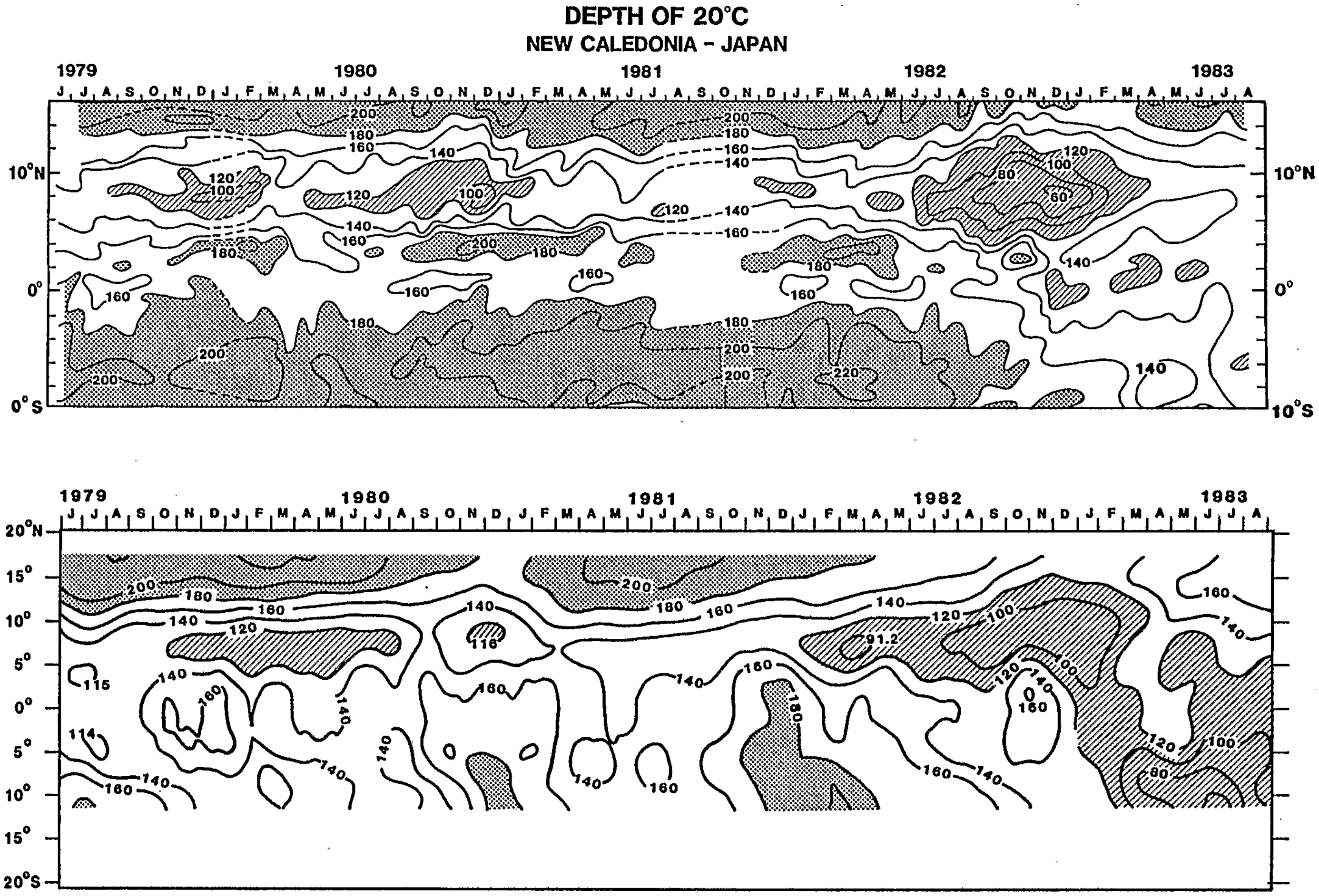

Figure 5

Same as Figure 2 for the Western Pacific 23°N *to* 20°S *near* 160°E.

Idem figure 2 pour le Pacifique Ouest de 23°N à 20°S près de 160°E.

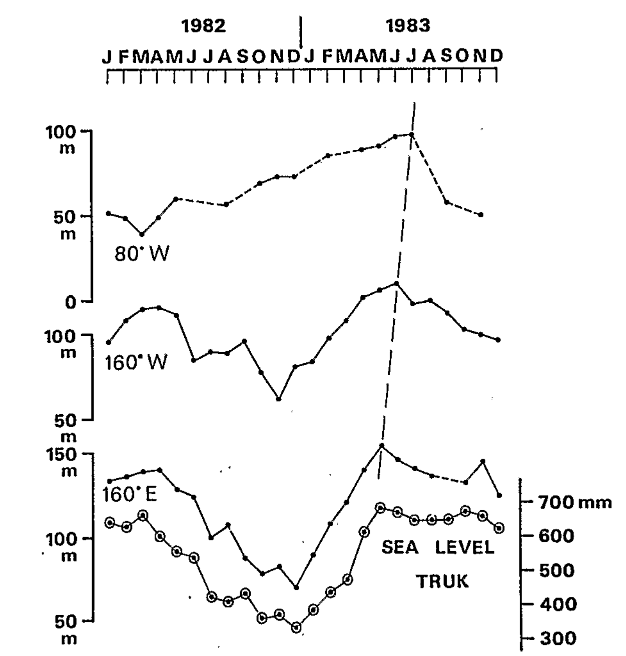

Figure 6

Depth of the 20°C *isotherm and sea level. Isotherm depths (m) near* 7°N *are plotted with depth increasing upward.*

Profondeur de l'isotherme 20°C et niveau moyen. Les profondeurs d'isotherme près de 7°N augmentent de bas en haut.

1982 and early 1983, the shallow isotherms near 25°C rise almost twice as fast as the deepest ones near 15°C, suggesting a behaviour which is not consistent with the first vertical mode. Temperature on the central and eastern tracks also show evidence of primarily first vertical mode off the equator, but higher vertical modes at the equator.

DISCUSSION

Several ocean model studies have already considered the 1982-1983 El Niño in the Pacific, as Tang and Weisberg (1984), Busalacchi and Cane (1985) and Philander and Seigel (1985). These studies, as the present one, are comparing model and observations: Tang and Weisberg (1984) considered downwelling off South America from model and from observations; Busalacchi and Cane (1985) considered sea-level in the tropical area from the model and from the measurements; Philander and Seigel (1985) compared the result of their model with the measurements made mainly in the vicinity of the equator at 159°W and 95°W. Most of these authors agree that they would get better results with more accurate wind field.

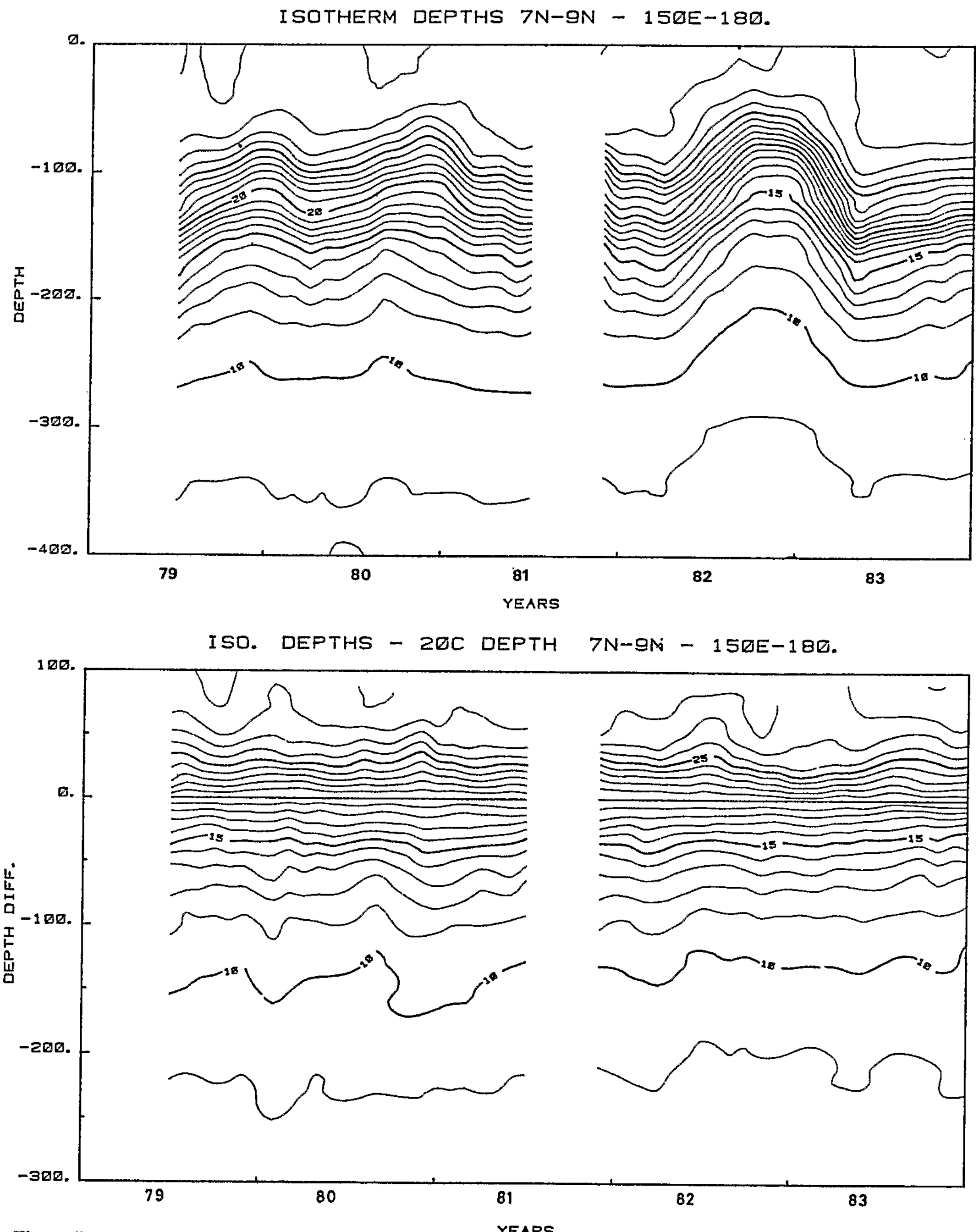

Figure 7

Isotherm depths (m) 7°-9°*N*, 150°*E*-180° *(top). Depth relative to depth of* 20°*C (bottom).*

En haut : profondeurs d'isothermes (m) 7°-9°N, 150°E-180°. En bas : profondeurs d'isothermes relatives à celle de 20°C.

In the present study, the comparison of the depth of 20°C isotherm from model to observations is encouraging because the dominant features of thermocline variability appear in a simple model which contains only the bare essentials of ocean dynamics.

The features of agreement and disagreement have to be analysed. Clearly, the discrepancies between model and data (Tab.) can result from several causes as:

1) the 1.5 layer approximation is not adequate;

2) the ocean dynamic used in the model is too coarse;

3) the wind data forcing the model is not accurate enough;

4) the 20°C isotherm is not representative of the thermocline.

The 1 1/2 *layer approximation is not adequate*

There is some evidence of a response in higher vertical modes at the equator, mainly at 160°E (Fig. 8). This feature is corroborated by a poor correlation at Kapingamarangi (1°N, 165°E) between sea level and 20°C isotherm depth (Rebert *et al.*, 1985). However, the good correlation (Tab.) between model and 20°C isotherm depth reported here is partly due to considering a short time period of one ENSO episode and partly due to the choice of the characteristic wave propagation speed in the model.

The ocean dynamic is too coarse

The rusticity of the ocean dynamic could explain the low correlation in the central Pacific, mostly at 7°N

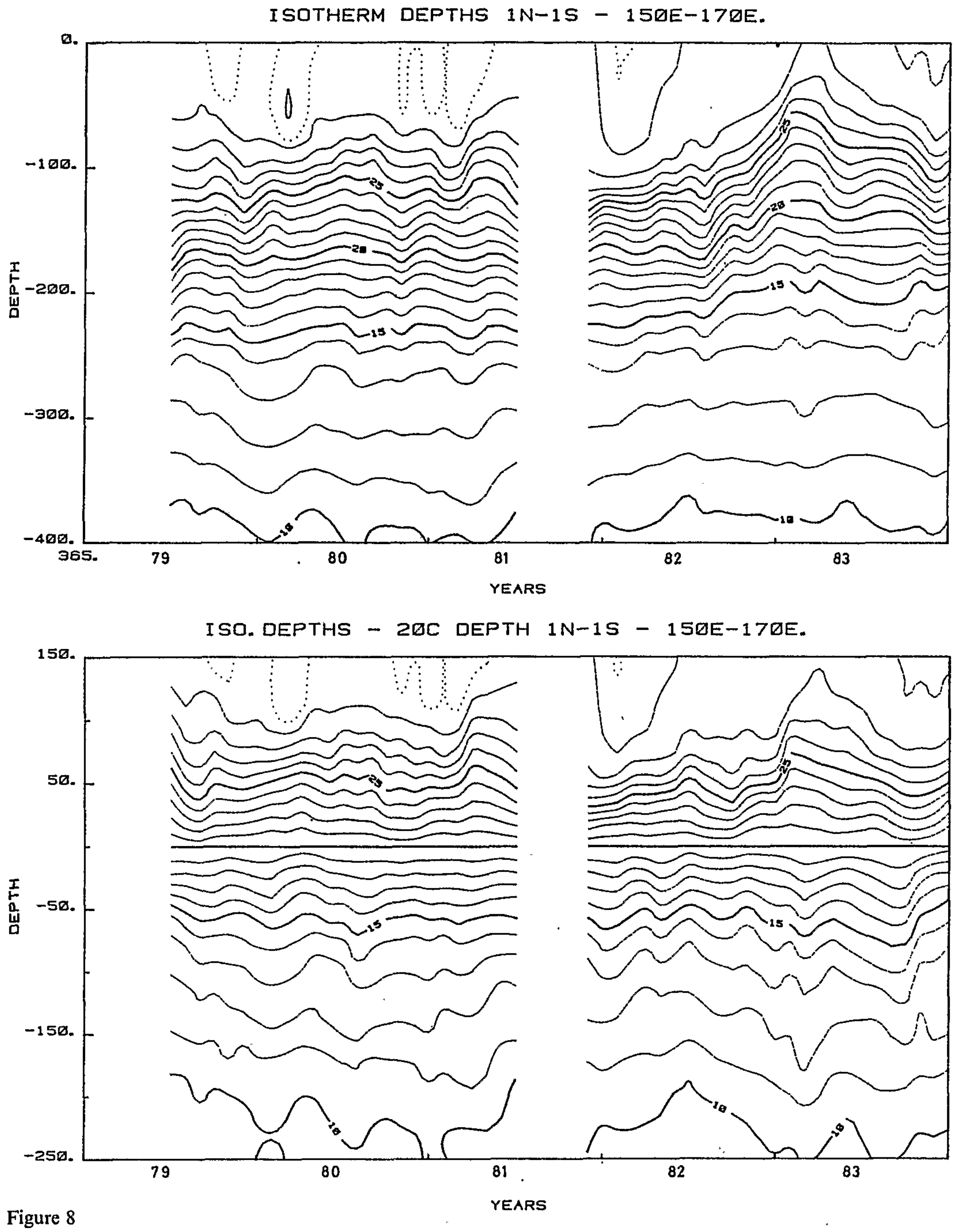

Figure 8
Same as Figure 7, for 1°*N*-1°*S*, 150°*E*-170°*E*.
Idem figure 7 pour 1°N-1°S, 150°E-170°E.

and 5°S (Tab.). Planetary waves are entering the region coming from the east side and in the real ocean they are probably associated with higher vertical modes. The 1.5 layer model has all characteristic wave speeds fixed by the choice of one parameter and thus it does not allow all equatorial and extra-equatorial waves, at first and higher vertical modes, to propagate at the correct speed. The discrepancy between observations and model is particularly great far away from the origin of the wave, *i.e.* the central Pacific. For its part, the Western Pacific is probably mainly locally forced.

The wind data forcing the model are not accurate enough

Inaccuracies of the wind fields are more important in the extra-equatorial area where the wind stress curl has a prominent influence, while in the equatorial area the dynamics are mostly affected by the integral of the wind stress (Cane, 1984). This can explain why the extra-equatorial central Pacific is not as well modelled as the equatorial Pacific (Tab.). On the other hand, the low correlation between data and model in the south-eastern Pacific could be partly explained by insufficient wind data.

The 20°C isotherm is not representative of the thermocline

In fact, it seems that the 20°C isotherm is everywhere located in the thermocline. Moreover, Rebert *et al.* (1985) have shown that the correlations between sea level and 20°C isotherm depth are good at least from

10°S to 10°N in the Western and central Pacific. The correlation is also very good at the equator in the Eastern Pacific; but unfortunately there is no direct measurement of sea level in the South-Eastern Pacific and consequently, it is difficult to analyse the cause of the very poor correlation between measurement and model (Tab.).

In conclusion, the XBT observations collected so far provide an unprecedented documentary of the tropical ocean's temperature field, which can be used to guide the development of better models.

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