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Heat content changes within the mixed layer of the Equatorial Pacific Ocean

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ABSTRACT

Under usual conditions, the Western Equatorial Pacific is characterized by a low heat content on the equator and a maximum one west of 170E. After the appearance of El Nino, this maximum is replaced by another one located in the Central South Pacific; this feature has been observed in 1972-73 but also in 1957-58 and 1976-77. The mechanism involves probable change of the mixed layer depth.

1. Introduction

The heat content of the ocean upper layer has received considerable attention in recent years, due to its importance in the ocean atmosphere exchanges, and mainly in tropical and equatorial areas, where high sea-surface temperatures occur. It seems also that the Pacific Ocean, due to its size (180° of longitude at the equator) is the heat tank of the planet; in the Western and Central Pacific, the sea-surface temperature is high, the upper homogeneous layer is deep and the exchanges across the sea-surface are well developed.

2. Distribution of the heat content in the Tropical South Pacific

The South Pacific Ocean is characterized by a strong variability of the hydroclimatic conditions (Donguy and Henin, 1978a). Therefore, the consideration of the mean conditions is not realistic and it is necessary to have enough data in a limited period of time for a good description of the hydroclimatic conditions.

The studied area is bounded by 150E longitude in the west, by 130W longitude in the east, by 10N in the north and by 20S in the south. The usual hydroclimatic conditions are characterized by the occurrence of the equatorial upwelling induced by an east component of the wind (trade wind) (Donguy and Henin, 1978b). Along the equator, the isotherms rise to the surface and the surface temperature is lower than on each side of the equator. Consequently, the heat content is also lower on

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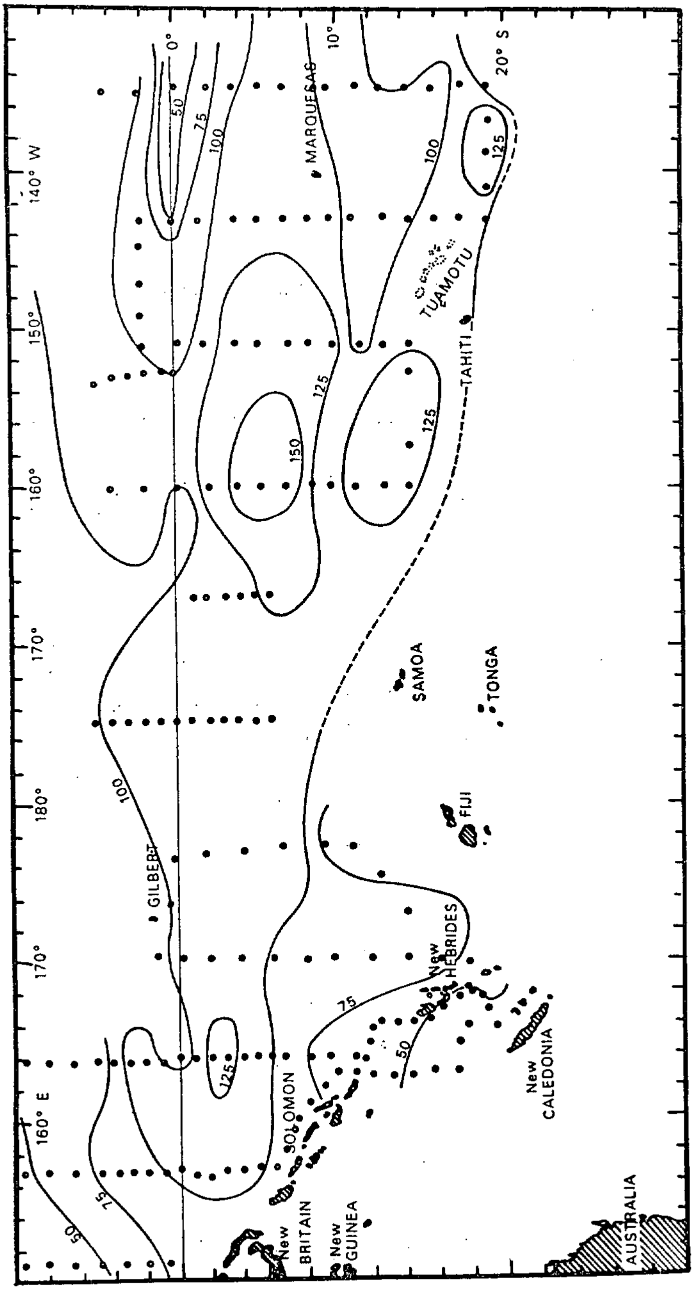

Figure 1. Depth of the mixed layer in meters, August-September 1956.

the equator than on each side. The equatorial upwelling has seasonal variations: its intensity is minimum during the north west monsoon (austral warm season, November-March) and maximum during the trade wind period (austral cold season, June-September).

Only the heat content of the shallower hundred meters is considered and the unit used is the averaged temperature from the surface to the 100 meter depth. This choice may seem questionable inside an area extending from 150E to 140W. However, from the NODC files, it is possible to describe a situation of typical austral winter (Equapac Expedition, August-September 1956) and a situation just prior to a typical austral summer (October-December 1961). Figures 1 and 2 show the depth of the mixed layers during these two periods. In the whole area from 10S to 5N this depth is mostly close to 100 meters except in a zone located in the Central Pacific where it is more than 125 meters, at 160W in 1956, at 170W in 1961.

With the Equapac Expedition data (August-September 1956) Figure 3 describes the heat distribution during a typical austral winter and shows a minimum of heat content along the equator as far westward as 170E. West of this longitude, between 6N and 12S, the heat content is over 28 units with a maximum over 29 units at 3N. The data gathered between October and December 1961 (Fig. 4) just before the austral warm season, also show an equatorial minimum of heat content; west of 177E, the heat content is over 28 units with a maximum over 29 units, wider than during the austral winter.

In usual hydroclimatic conditions, during an equatorial upwelling period, a high heat content is stored west of 180° between 5N and 15S; this heat pool is divided by the equatorial upwelling into two branches. The northern part spreads eastward transported by the North Equatorial Counter-Current and the southern part also spreads eastward transported by the South Equatorial Counter-Current.

3. Evolution of the heat content in the Western Pacific

The series of oceanographic measurements are scarce in the Pacific Ocean. However, in the westernmost part of the Pacific, data issued from monitoring carried out every year by R.V. *Ryofu Maru* along 137E north of New Guinea may be taken into consideration. According to Masuzawa and Nagasaka (1975) in this area, "the surface mixed warm water over the thermocline is as thick as 100 m or so". Consequently the heat content of the shallower hundred meters only is considered. Figure 5 shows the data as a space time diagram from 1967 to 1977. Along 137E, from the equator to 5N, the heat content from the surface to 100 meters depth is usually high, between 27 and 29 units. However, in late 1972 and early 1973, the heat content became very low, reaching less than 26 units as already pointed out by Masuzawa and Nagasaka (1975). This feature was also

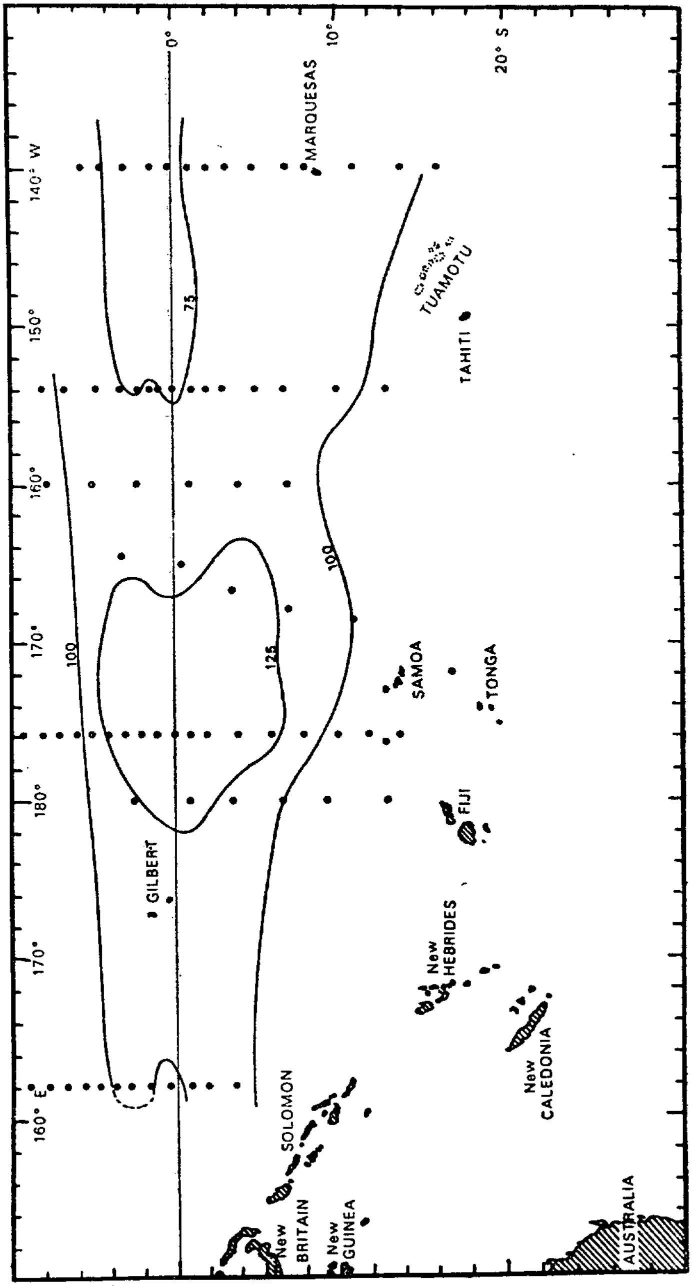

Figure 2. Depth of the mixed layer in meters, October-December 1961.

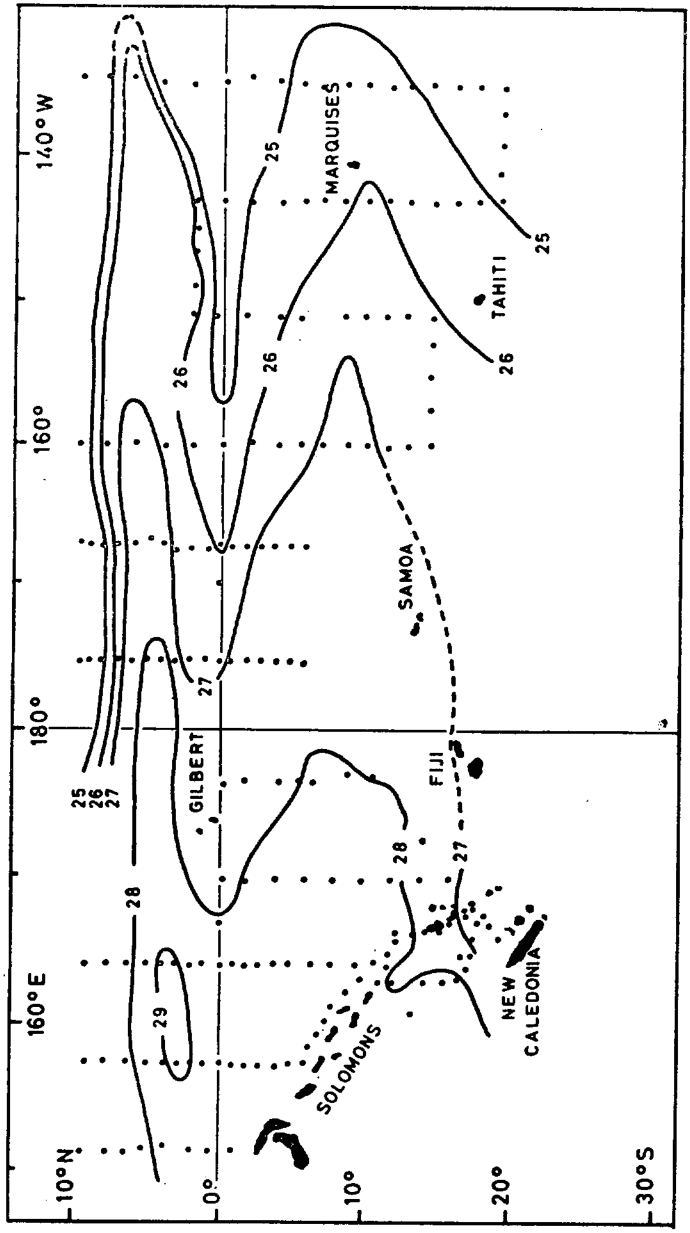

Figure 3. Heat content from the surface to 100 meters depth, August-September 1956. The unit used is the 0-100 m mean temperature.

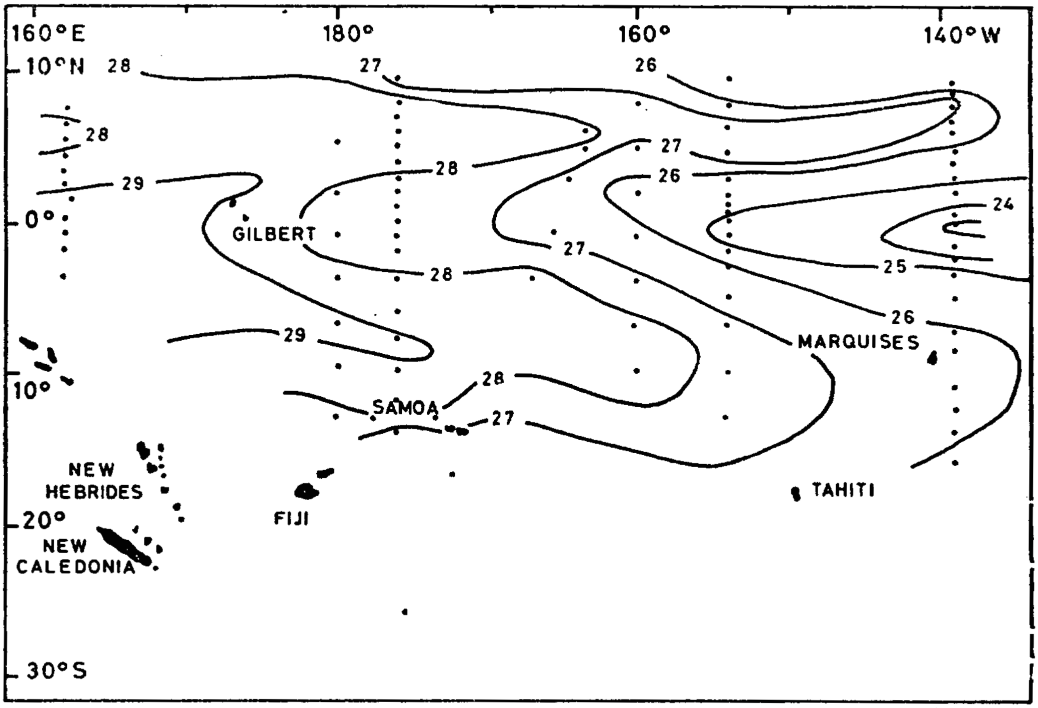

Figure 4. Heat content from the surface to 100 meters depth October-December 1961. The unit used is the 0-100 m mean temperature.

observed by White and Wylie (1977) with all the BT data covering an area extending from 130E to 180° and from the equator to 35N. During late 1972 and early 1973 at 100 meters depth, the temperature was 1°C lower than usual (Fig. 6) south of 20N with an extreme negative anomaly of 2°C in the vicinity of 10N.

This anomaly of the heat content is to be connected to the abnormal surface conditions observed in the Western Pacific in 1972-1973 (Donguy and Henin, 1976) and also to exceptional meteorological conditions. It seems that these latter had appeared after the occurrence of the 1972 El Nino event (Donguy and Henin, 1978c). The question now is to know if this heat shortage is compensated by an extra heat content located elsewhere.

4. Evolution of the heat content in the Central Pacific

All existing XBT from the NORPAX data bank have been used to establish a space time diagram approximately from Hawaii to Tahiti along a route crossing the equator in the vicinity of 155W, between 1968 and 1975 (Fig. 7). This diagram describes the heat content from the surface to the 100 meter depth. Usually, the equatorial area is characterized by a low heat content (less than 27 units) with

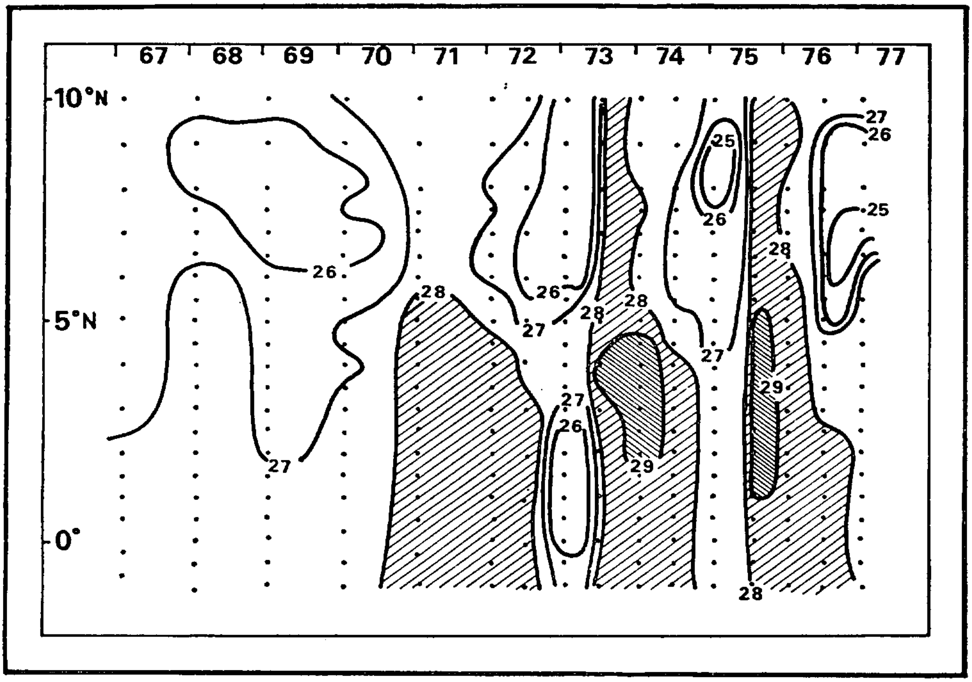

Figure 5. Heat content from the surface to 100 meters depth along the 137E meridian north of New Guinea, 1967-1977. The unit used is the 0-100 m mean temperature.

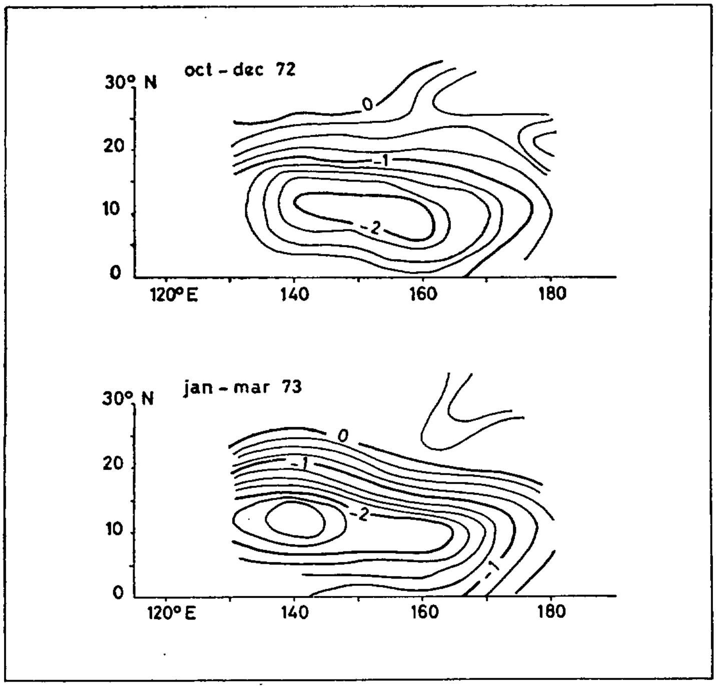

Figure 6. Temperature anomaly at 100 meters depth in degree Celsius during October-December 1972 and during January-March 1973 from White and Wylie (1977).

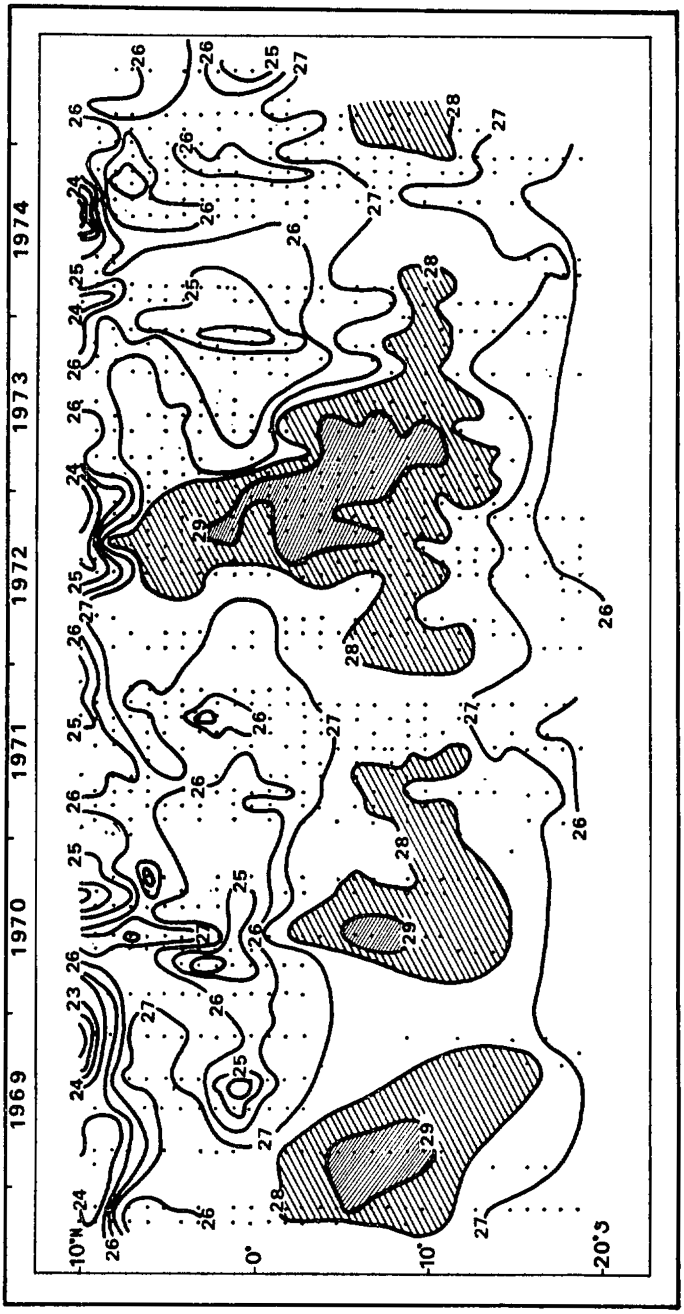

Figure 7. Heat content from the surface to 100 meters depth between Tahiti and Hawaii 1968-1975. The unit used is the 0-100 m mean temperature.

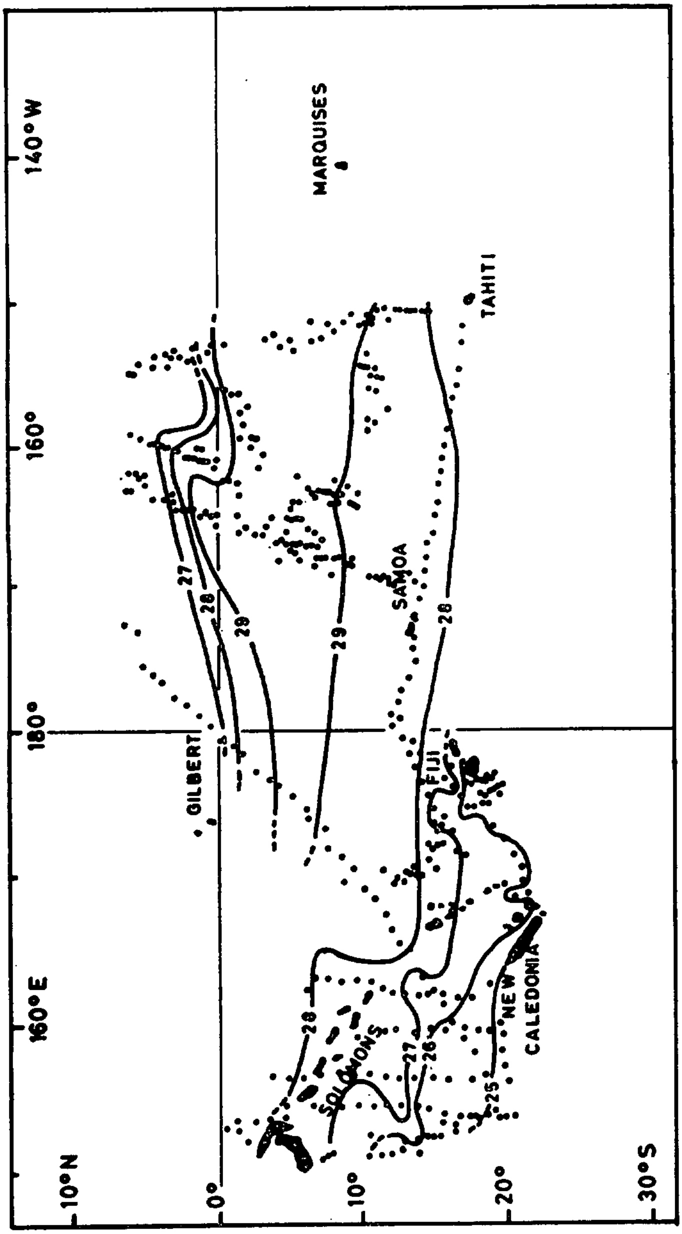

Figure 8. Heat content from the surface to 100 meters depth, October 1972-March 1973. The unit used is the 0-100 m mean temperature.

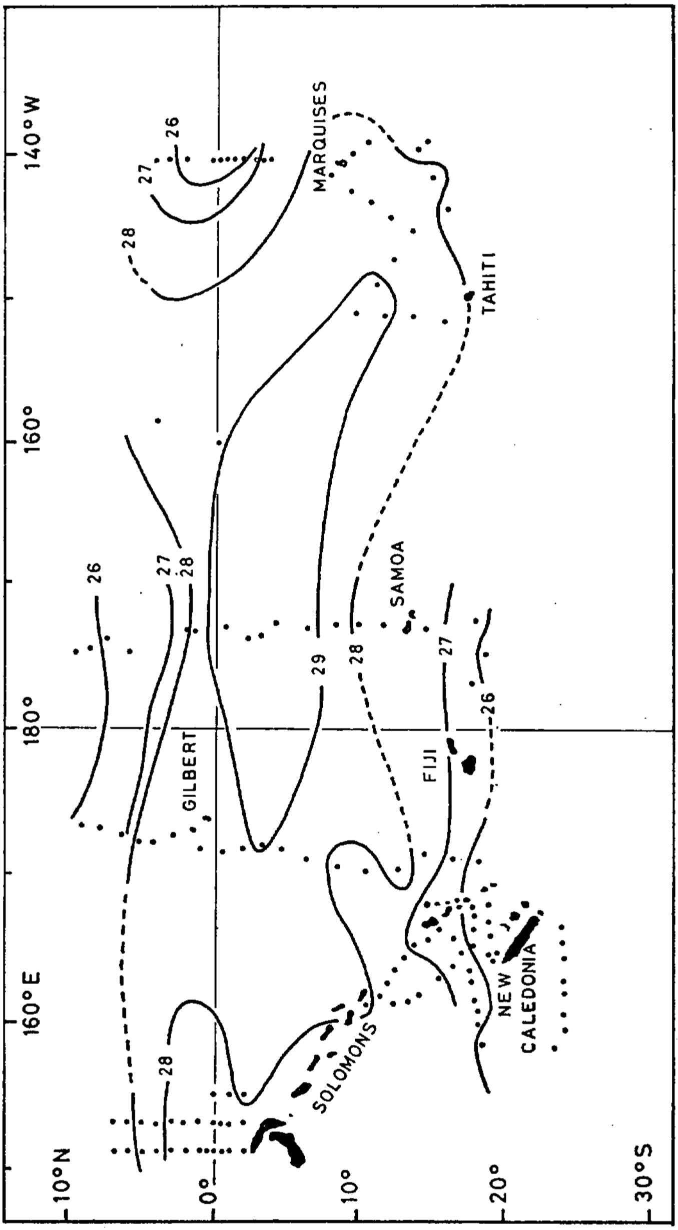

Figure 9. Heat content from the surface to 100 meters depth, November 1957-March 1958. The unit used is the 0-100 m mean temperature.

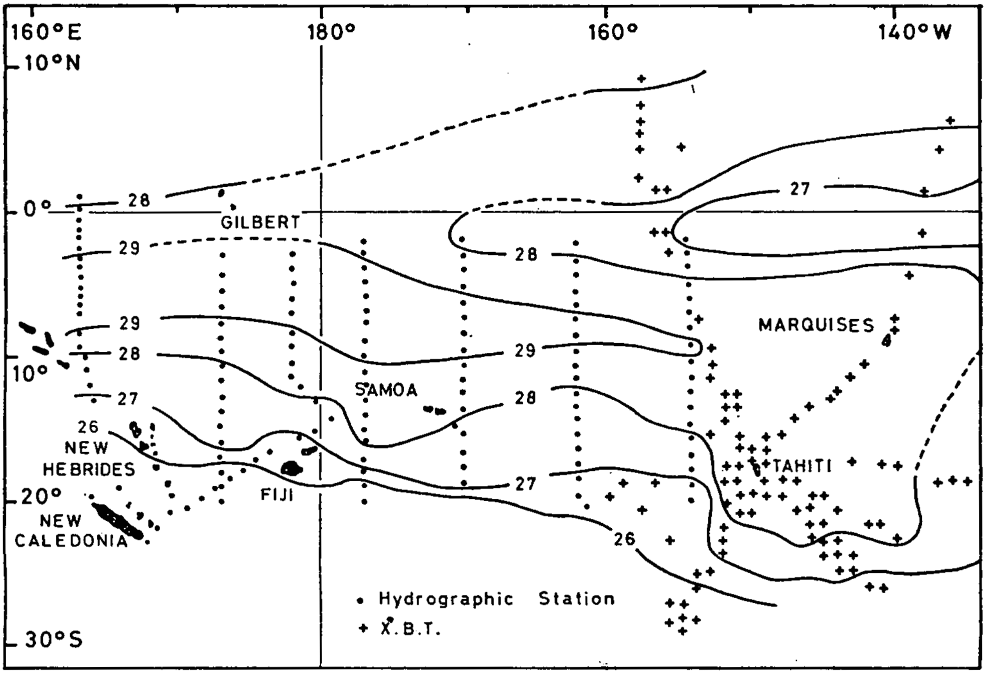

Figure 10. Heat content from the surface to 100 meters depth, November 1976-March 1977. The unit used is the 0-100 m mean temperature.

a minimum (25 units) in July-August due to the equatorial upwelling when the trade winds are the strongest. Between the equator and 10S, the heat content reaches 28 units and sometimes for a short time 29 units. However, in 1972-1973, an uncommon feature appeared: between 10N and 10S, the heat content was over 28 units with a maximum of 29 units south of the equator. This feature occurred in late 1972 and early 1973, exactly during the heat shortage observed in the Western Pacific (Fig. 5). Wyrtki *et al.* (1977) point out also a maximum of sea surface temperature along the same track in 1972-73. The following assumption may be made: during the anomalous hydroclimatic conditions occurring after El Nino, the heat pool usually located in the Western Pacific is replaced by another one located in the Central Pacific; as, during this period, the equatorial upwelling does not occur, the heat pool also spreads northward across the equator with values over 28 units.

With the help of all data available between October 1972 and March 1973 (XBT and hydrographic stations), the distribution of the heat content (Fig. 8) in the Central South Pacific shows the presence of a large maximum more than 29 units from 170E to at least 150W and from the equator to 10S. This kind of distribution, completely different from the usual one (Fig. 3 and Fig. 4) has occurred not

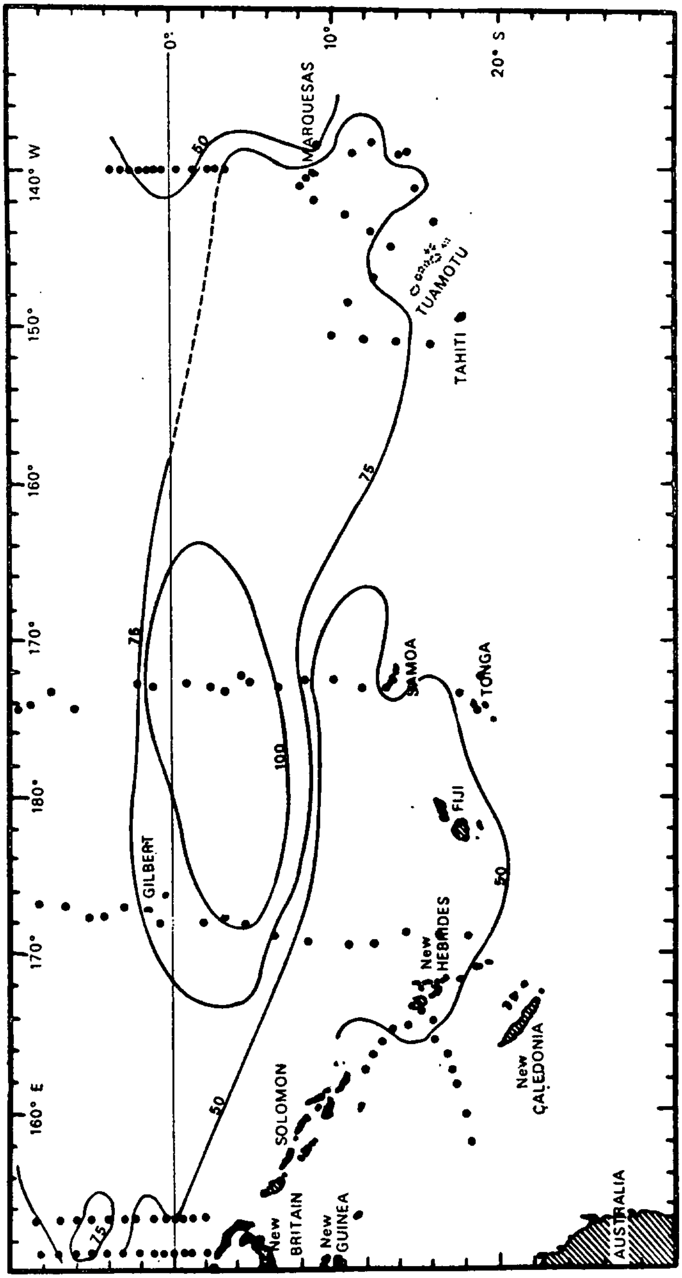

Figure 11. Depth of the mixed layer in meters, November 1957-March 1958.

only in 1972-73, but several times in the recent past and each time has been associated with El Nino events.

For example, after the strong 1957 El Nino, the heat distribution from November 1957 to March 1958, calculated from the I.G.Y. hydrographic stations (Fig. 9) shows, as in 1972-73, a maximum of more than 29 units in the Central South Pacific from 170E to 150W. After the moderate 1976 El Nino, the heat distribution from November 1976 to March 1977 (Fig. 10) also shows the same feature but not spreading as much eastward as during 1958 and 1973.

The mechanism of this heat change may be investigated. The heat content depends both on the depth and the temperature of the mixed layer. In the Equatorial Western Pacific during usual hydroclimatic conditions, this depth is close to 100 meters (Fig. 1 and Fig. 2) and the temperature between 28°C and 29°C; during anomalous hydroclimatic conditions, as in 1957-58 (Fig. 11), this depth is less than 100 meters decreasing westward, and the temperature still close to 28°C (Masuzawa and Nagasaka, 1975, Henin and Donguy, 1979). In the Equatorial Central Pacific, during usual conditions, the mixed layer depth is almost 125 meters and the temperature 28°C; during anomalous conditions, the depth is 100 meters but the temperature is higher (Wyrtki *et al.*, 1977) than during usual conditions, probably because of the absence of the equatorial upwelling. Consequently, during anomalous hydroclimatic conditions, in the Equatorial Western Pacific, the heat content is small due to the decrease of the mixed layer depth, whereas, in the Equatorial Central Pacific, the heat content is high due to the increase of the temperature. This change in the mixed layer depth has been pointed out by Wyrtki (1979) and evaluated in 1972-1973 at 50-80 meters.

5. Conclusion

Usually, in case of equatorial upwelling, west of 170E, a maximum of heat content stays in the Western Equatorial Pacific. After an El Nino event, without equatorial upwelling, this maximum is replaced by another one located in the Central South Pacific. The mechanism of this change involves a decrease of the mixed layer depth and this feature probably induces different climatic consequences which have to be studied.

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