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Fluctuation of the South Pacific Albacore Stocks (*Thynnus alalunga*) Relative to the Sea Surface Temperature

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ABSTRACT

Both biomass and production of the south Pacific albacore stocks were estimated by the improved surplus production model. Estimations were based on the catch and effort data of the south Pacific albacore tuna longline fisheries.

Indices of the area and perimeter of the isotherms of the albacore preferred sea surface temperature and the higher sea surface temperature (over 28°C) were measured. They were then used as indices of the sea surface temperature of the south Pacific albacore tuna longline fishing grounds.

The relations between the albacore stocks and the index of the sea surface temperature were examined. The results are as follows:

(1) Fluctuations of the south Pacific albacore stocks can not be explained by the distributions of the preferred sea surface temperature alone.

(2) Fluctuations of the south Pacific albacore stocks depend mainly on the distributions of over 28°C sea surface temperature.

(3)The heavier El Niño events in 1982/83 and the particular development of the gill netters in 1989 to 1991 clearly influenced the south Pacific albacore stocks.

(4)After adjusting for the effects of the heavier El Niño events and the rapid development of the gill netters, albacore stocks show a significant correlation with the index of over 28°C sea surface temperature.

(Key words: Sea surface temperature, South Pacific albacore stocks)

1. INTRODUCTION

Following this same theory of the surplus production model, Wang (1996) suggested the IPM-method (Improved surplus Production Model) for assessing fish stocks. It was applied in assessing south Pacific albacore stocks (Wang 1997; 1999). The parameters, including annual biomass, production, and fishing mortality rate of the south Pacific albacore stocks, were estimated. The estimated maximum sustainable yield of the south Pacific albacore stocks was

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consistent with the other reports (Skillman 1975; Wetherall et al. 1979; Wetherall and Yong 1984, 1987; Wang 1988a; Yeh and Wang 1996).

Wang (1988b) tried to describe the seasonal movements of the south Pacific albacore stocks. As pointed out by Wang (1997), fluctuations of the south Pacific albacore stocks may mainly depend on the changes of the sea surface temperature. To date, no papers describing the relationships between the changes of the sea surface temperature and fluctuations of the south Pacific albacore stocks.

This paper attempts to reveal and to show the significant relationships that hold between the fluctuations of the biomass of the south Pacific albacore stocks and the changes of the sea surface temperature and to show that the indices of the sea surface temperature (over 28°C) might be a good indicator of the richness of the south Pacific alabcore stocks.

2. MATERIALS AND METHODS

Estimates of annual biomass and production of the south Pacific albacore stocks (Table 1) were adopted directly from Wang (1996; 1999). Those were calculated by the IPM-method (Improved surplus Production Model) based on the catch and effort data of the south Pacific albacore tuna longline fisheries. The fishing efforts were adjusted to the effective efforts by Honma's method (Honma 1974).

The isotherms of sea surface temperature (SST) were downloaded from the NOAA-CIRES/ Climate Diagnostics Center. Fishing grounds of tuna longline fisheries are assumed to be covered by 120E-70W and 20N-50S.

In order to get sea surface temperature indices, the areas and perimeters of the sea surface temperature will be measured along the isotherms. Both the area and perimeter of over 28°C sea surface temperatures were measured as the higher SST indices and expressed by A28C and L28C, respectively. Assuming 15-22°C as the preferred sea surface temperature of the south Pacific albacore stocks (Fishery Handbook, 1974), the preferred SST indices were measured by A15C and L15C as well.

Each index was measured at least three times. If any one of the measurements deviated by over 1%, this value was discarded and one more measurement was taken. Continuing this process until the differences among the measurements reduced to within 1%. Then, the average value was calculated and used as the SST index.

The relationships between the albacore stocks and the sea surface temperature were examined. The effects of the heavier El Niño events and the invasive gill netters were used as the adjusting factors.

Given the catch and effort data of south Pacific tuna longline fisheries, the effects of fishing efforts were estimated by both Honma's method and the generalized linear model, respectively (Yeh and Wang 1996). Assuming that all the albacore catch was exploited by tuna longline fisheries, total effective fishing effort can be raised directly by the ratio of the total catch and longline catch.

By applying the IPM-method (Improved surplus Production Model) in assessing the south Pacific albacore stocks, annual biomass, production and fishing mortality rate could be esti-

Table 1. Biomass and production (1967 - 1995).

Year	Bt unit:	ft 1000 mt
1967	102.647	63.908
1968	84.739	68.960
1969	78.291	69.103
1970	83.125	69.079
1971	56.976	63.256
1972	57.552	63.541
1973	47.134	57.282
1974	30.601	42.591
1975	32.748	44.828
1976	42.338	53.621
1977	41.605	53.019
1978	41.283	52.750
1979	32.220	44.287
1980	48.997	58.571
1981	24.769	36.016
1982	28.067	39.823
1983	32.153	44.218
1984	24.263	35.411
1985	28.845	40.688
1986	38.354	50.207
1987	30.995	43.009
1988	31.377	43.411
1989	23.224	34.152
1990	24.816	36.072
1991	26.038	37.508
1992	32.636	44.714
1993	34.924	46.995
1994	37.411	49.349
1995	35.120	47.186
mean	42.526	49.433

mated (Wang 1997; 1999).

After reviewing the distributions of the daily operating data of Taiwanese tuna longline fisheries, it is reasonable to assume that tuna longline fishing grounds may be covered in the area surrounded by 120E-70W and 20N-50S.

In order to obtain the indices of the sea surface temperature of the tuna longline fishing grounds, the distributions of the isotherms of the sea surface temperature (SST) of tuna longline fishing grounds were considered. They were downloaded directly from the image of the NOAA-CIRES/Climate Diagnostics Center.

Two kinds of the SST indices were measured from these images. One was for the higher SST area assumed to be over 28°C. The other one was for the preferred SST area, assumed to be the area surrounded by isotherms of 15°C and 22°C (Fishery Handbook, 1974). For each area, two indices, i.e., area and perimeter, were measured, respectively. They are expressed by A28C, L28C A15C and L15C, respectively. The images of the SST isotherms before 1982 are not available.

3. RESULTS

Table 1 shows the estimated annual biomass and production of south Pacific albacore stocks from 1967 to 1995. As shown in Table 1, annual biomass varied in the ranges of 23-102 thousand metric tons. The mean value has remained steady at 42,526mt. From 1981, the annual biomass was lower than the mean value. Then, it showed an increasing trend from 1989. However, relatively lower biomass appeared in 1989-1991. This period coincided with the rapid development of the gill netters in this area. Similar trends can be found in the fluctuations of annual productions (Table 1).

SST indices of the fishing grounds in 1982 to 1997 are shown in Table 2. Variations of the preferred area are comparatively more stable than in the higher SST area during the same period. A15C varied from the ranges of 24.9 to 27.8. The coefficient of variation is CV=0.030. Similarly, L15C varied from the ranges of 37.7 to 41.3. It has a lower value of CV=0.023.

In contrast, the indices of the higher SST area varied violently. A28C varied from the ranges of 25.3 to 39.4. It has a larger CV=0.120. L28C varied from the ranges of 33.4 to 49.5. It also has a larger CV=0.103. The CV values of the higher SST area are about 4 times of the preferred SST area.

The relationships between the above SST indices and annual biomass and production of the south Pacific albacore stocks are examined below.

Generally, the fluctuations of the biomass and production of the south Pacific albacore stocks are thought to depend mainly on the distributions of the preferred SST. As shown in Table 2, the variations of the indices of the preferred SST are rather stable. However, the biomass and production of the south Pacific albacore stocks fluctuated severely. Hence, no

Table 2. Index of sea surface temperature. (120E - 70W, 20N - 50S).

year	A28C	L28C	A15C	L15C
1982	36.432	45.646	26.372	40.269
1983	33.690	44.932	24.977	37.712
1984	27.394	40.558	27.059	40.677
1985	25.266	33.440	27.465	40.619
1986	30.279	39.104	27.059	40.033
1987	37.393	48.914	26.554	39.947
1988	30.336	41.049	26.799	41.296
1989	26.756	37.714	27.260	40.972
1990	32.653	46.701	27.729	40.274
1991	34.098	49.460	27.232	40.338
1992	32.618	44.788	26.122	40.342
1993	30.564	47.295	26.322	40.564
1994	33.858	49.256	26.667	40.963
1995	34.349	44.365	26.288	40.911
1996	30.679	43.217	27.075	41.066
1997	39.356	46.446	24.970	38.771
mean	32.233	43.930	26.622	40.297

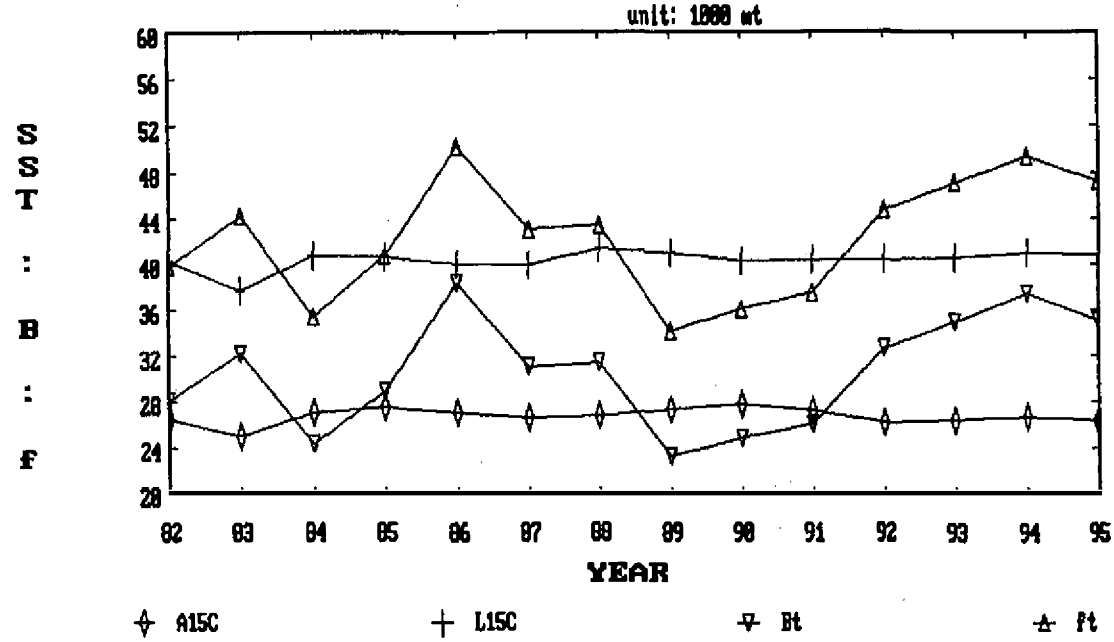

Fig. 1. Relations: A15C, L15C, Bt, ft.

significant correlation between them can be found (Figure 1).

For the higher SST area, biomass and production fluctuate roughly with SST indices (Figure 2). There seems to have been a time delay of one year. As shown in Figure 3, the fluctuations of the albacore stocks are fairly consistent with the SST indices of the following year except in 1982, 1983 and 1990, 1991, 1992.

In 1982/83, there were the heavier El Niño events. Hence, the remarkable deviations in 1982 and 1983 may be assumed to be related to the occurrence of the heavier El Nino events.

If the assumption that the heavier El Niño event takes much time to form" is accepted, it is reasonableto think that fish stocks will be affected continuously over a longer time period under a heavier El Niño event. As an indicator, albacore stocks in 1981 and 1982 should be adjusted in order to accurately reflect the relationships between the albacore stock and the SST index.

Base on the above assumptions, 1981's albacore stock might be adjusted to be the average value of 1980 and 1981, and 1982's albacore stock to be the average value of 1980, 1981 and 1982. Then, the correlation between the south Pacific albacore stocks and the A28C SST index are improved but it is yet non-significant (r=0.46355ns with df=13 as shown in Figure 4). Deviations in 1990, 1991, and 1992 are still remarkable (Figure 5).

As shown in Table 3, especially rapid developments of gill netters in 1989 to 1991 are noticeable. Percentages of the catch of gill netters in these three years are particularly high.

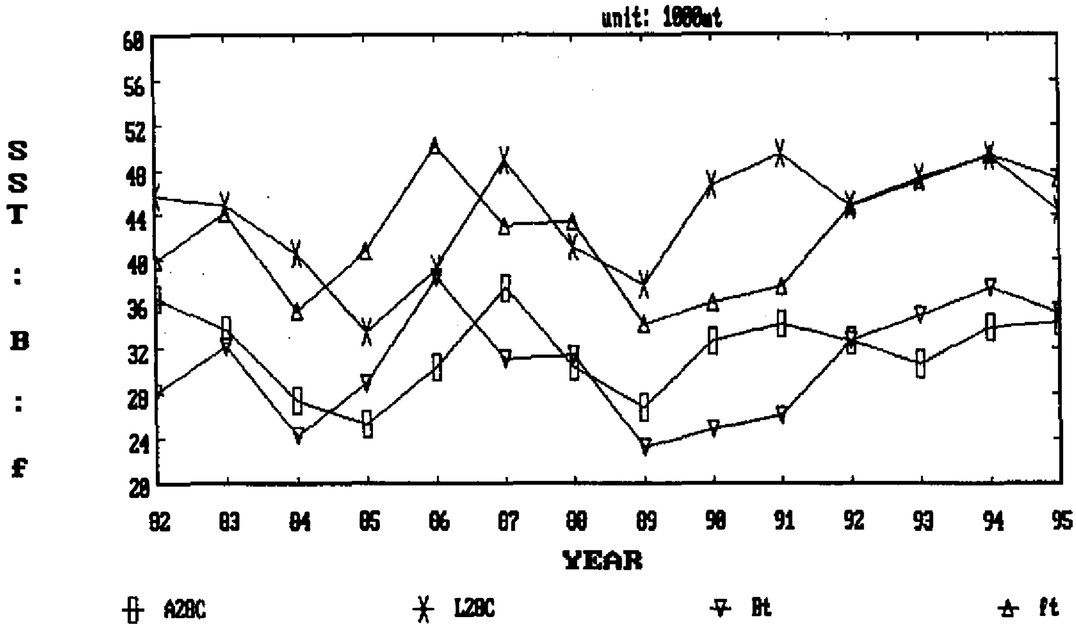

Fig. 2. Relations: A28C, L28C, Bt, ft.

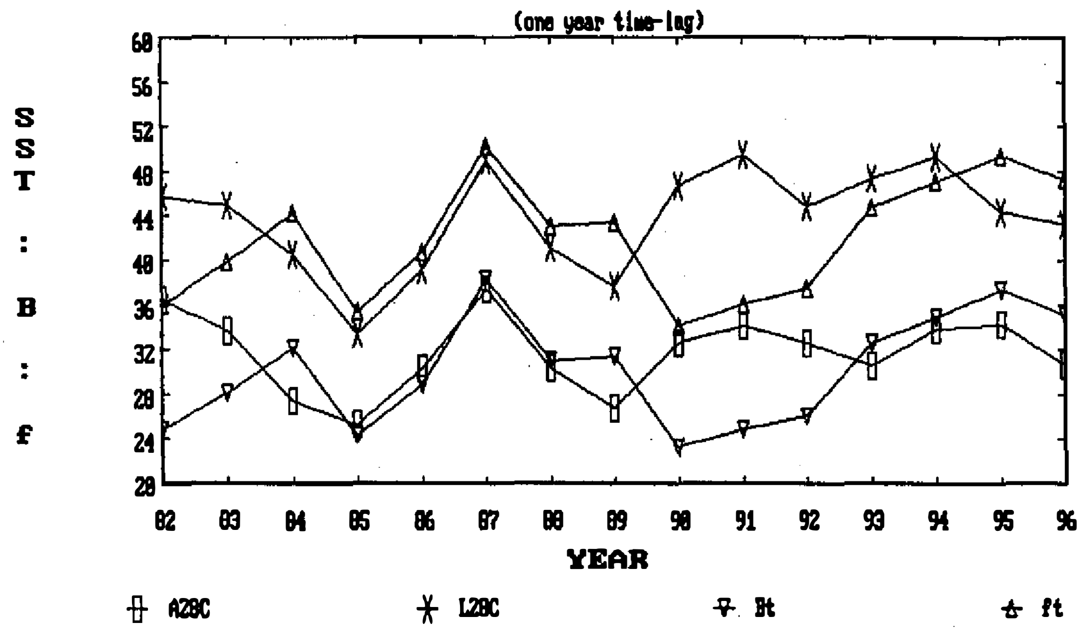

Fig. 3. Relations: A28C, L28C, Bt, ft.

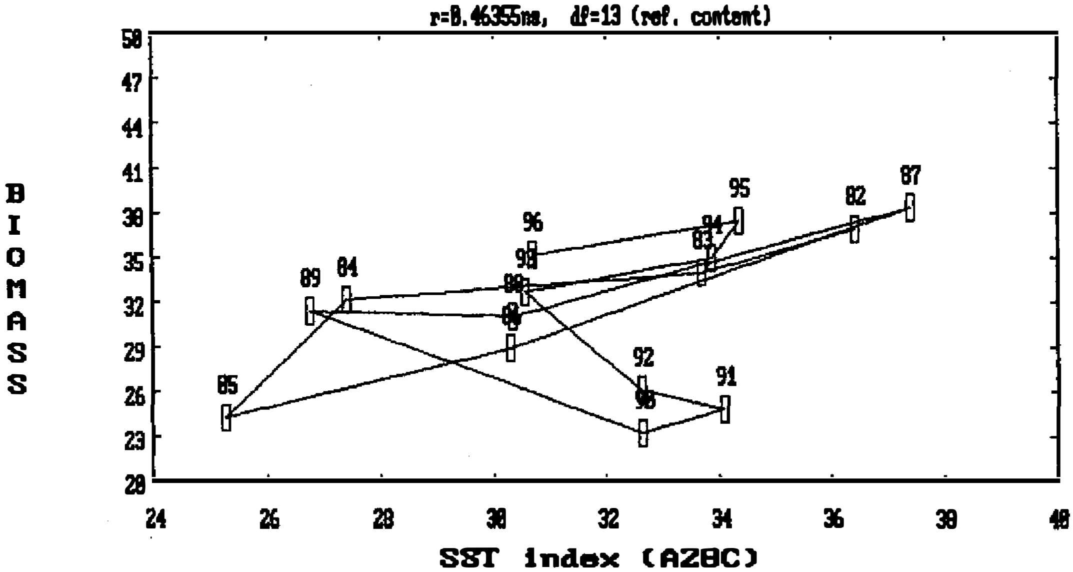

Fig. 4. Correlation: A28C and Bt.

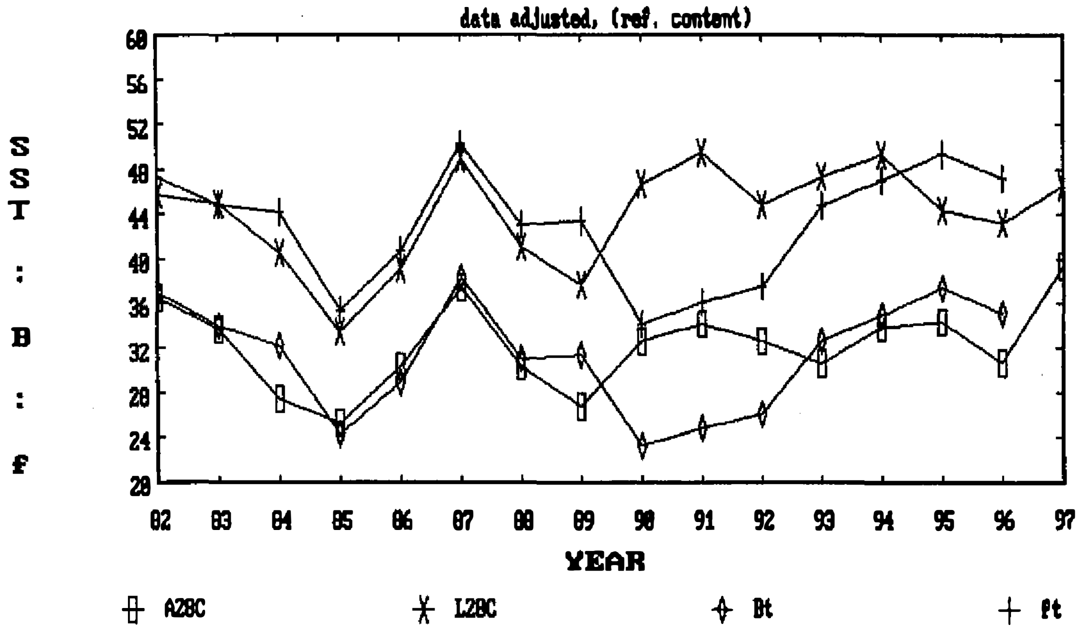

Fig. 5. SST index and Bt, ft.

Table 3. Catch composition (1982 - 1994).

year	albacore LL	catch SF	%
1982	30.235	2.441	7.470
1983	24.653	0.785	3.086
1984	20.936	4.362	17.242
1985	28.041	5.190	15.618
1986	35.523	3.857	9.794
1987	29.091	2.908	9.088
1988	31.122	9.006	22.443
1989	21.681	30.449	58.410
1990	20.847	14.291	40.671
1991	19.068	9.274	32.722
1992	26.475	7.063	21.060
1993	26.875	4.989	15.657
1994	30.105	5.073	14.421
1995	31.564	8.503	21.222

note: % by SF*100/(SF+LL)
1. 1982-94:adopted from the report of 6th SPAR meeting, Table 1 and 2.
2. 1995: adopted from "TUNA FISHERY year book 1996" of SPC, Table 59 and Table 61

Especially in 1989, it occupies over half of the total catch of the albacore stocks. In 1991, it is higher still at 32.722%.

The target species of the gill netters is the younger albacore. They are generally of pre-recruit or in recruiting to the tuna longline fisheries. Hence, the particularly high fishing pressure caused by gill netters should be considered an another important factor contributing to the fluctuation of the albacore stocks. Here, the effects of the gill netters are adjusted as follows. It can be assumed that the effects caused by gill netters revealed in the catch composition are mainly in recruits (given weight one) and pre-recruits (given weight two). Thus, the catches of the heaviest gill net fishing pressures, 1989 to 1991, should be adjusted as follows by Table 3.

$$R_t=SF_t/(SF_t+LL_t)$$

$$RA_t=(R_{t-1}+2*R_t)/3$$

$$B'_t=B_t*(1+RAt)$$

$$f'_t=f_t*(1+RAt)$$

Here:

SF=catch of surface fisheries
LL=catch of longline fisheries
R=ratio of the surface fisheries in the total catch
RA=adjusted factor used to adjust the albacore stocks
t=year, 1989-1991
B_t=biomass, estimated by the improved surplus production model
f_t=production, produced by the biomass Bt
B'_t=adjusted biomass
f'_t=adjusted production

According to the above adjustments, Figure 6 reveals that fsirly simultaneous fluctuations in the albacore stocks and the indices of the higher SST can be noted. However, even when adjusted as above, the deviations of some years are still rather larger.

Comparing the deviations (Figure 6) with the percentages of the catch of the surface fisheries (Table 3), the larger discrepancy seem to be relative to the unstable fishing pressures caused by the gill netters. As shown in Figure 6 and Table 3, the relative larger deviations in 1984, 1989, and 1993 to 1996 correspond to the larger variations of percentages in 1983, 1988, and 1992 to 1995, respectively. They also revealed time delay of one year.

If estimated sizes of the albacore stocks are adjusted as above, their correlation decrease (Figure 7). Anyway, Figure-7 also shows a simultaneous fluctuation trend except in 1989,

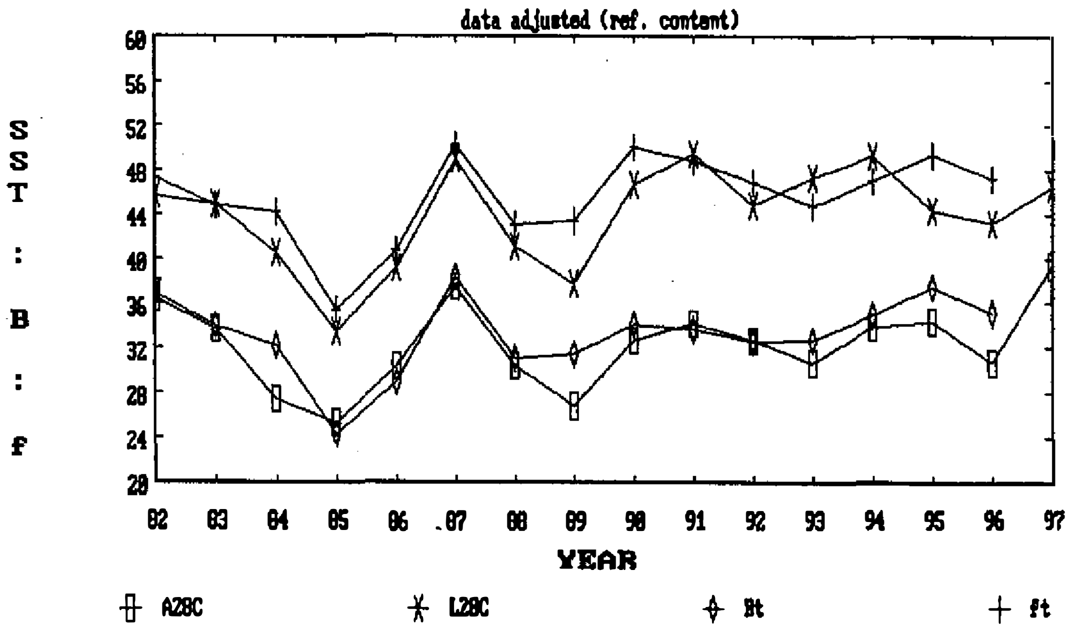

Fig. 6. SST index and Bt, ft.

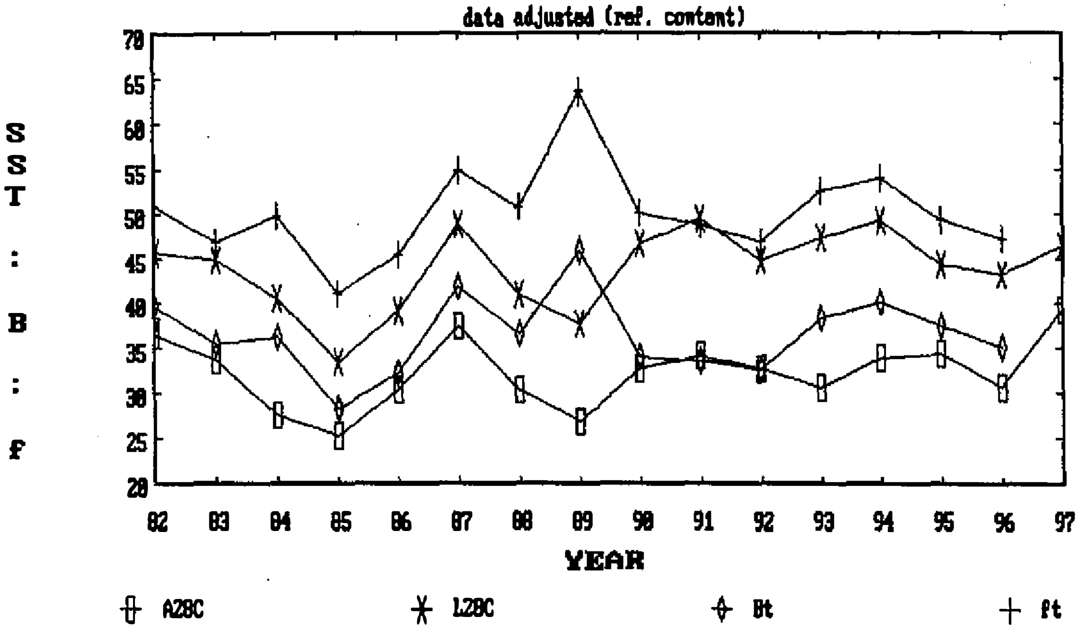

Fig. 7. SST index and Bt, ft.

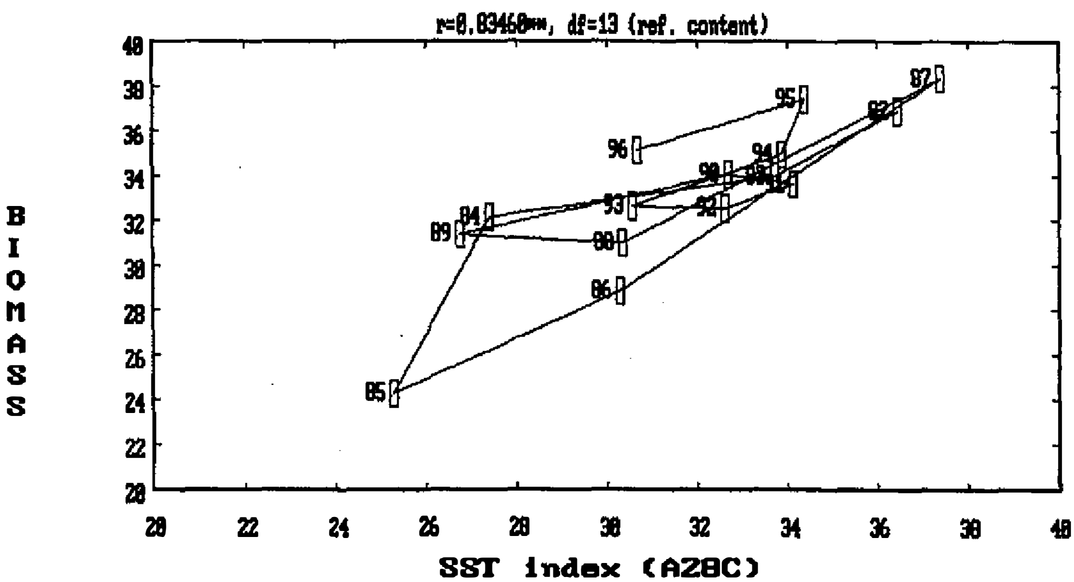

Fig. 8. Correlation: A28C and Bt.

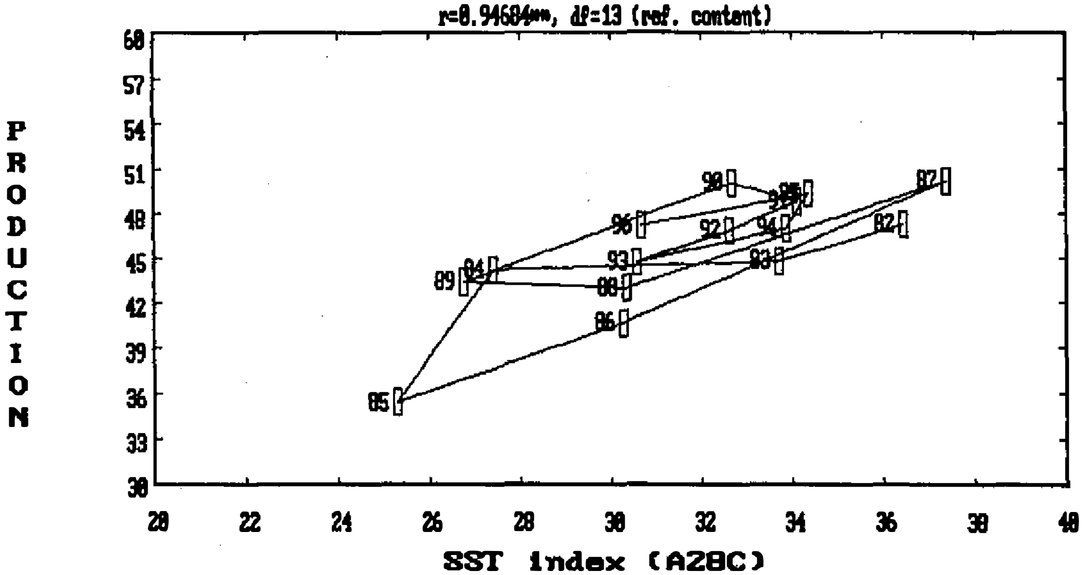

Fig. 9. Correlation: A28C and ft.

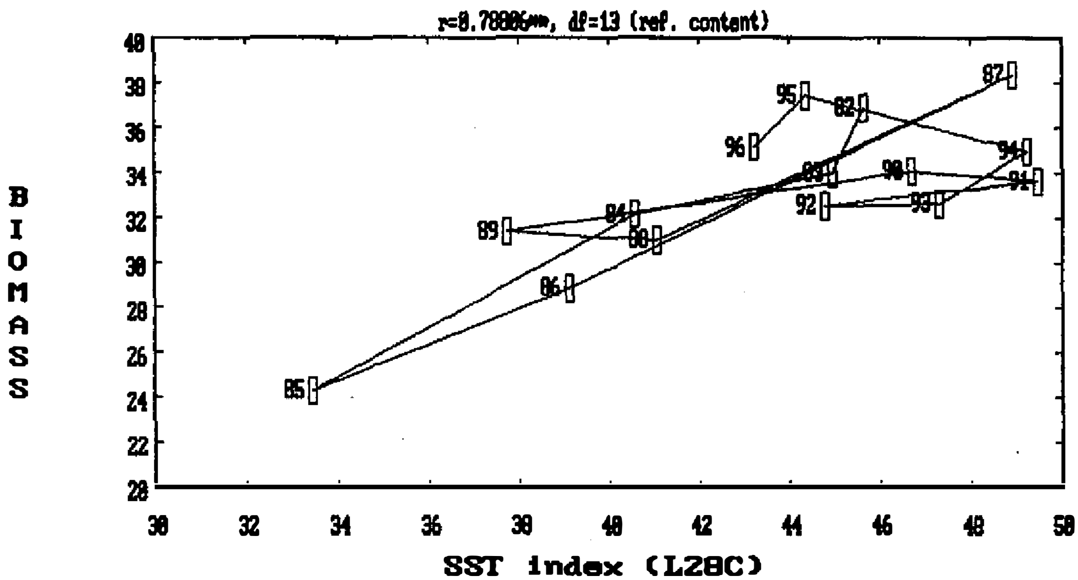

Fig. 10. Correlation: L28C and Bt.

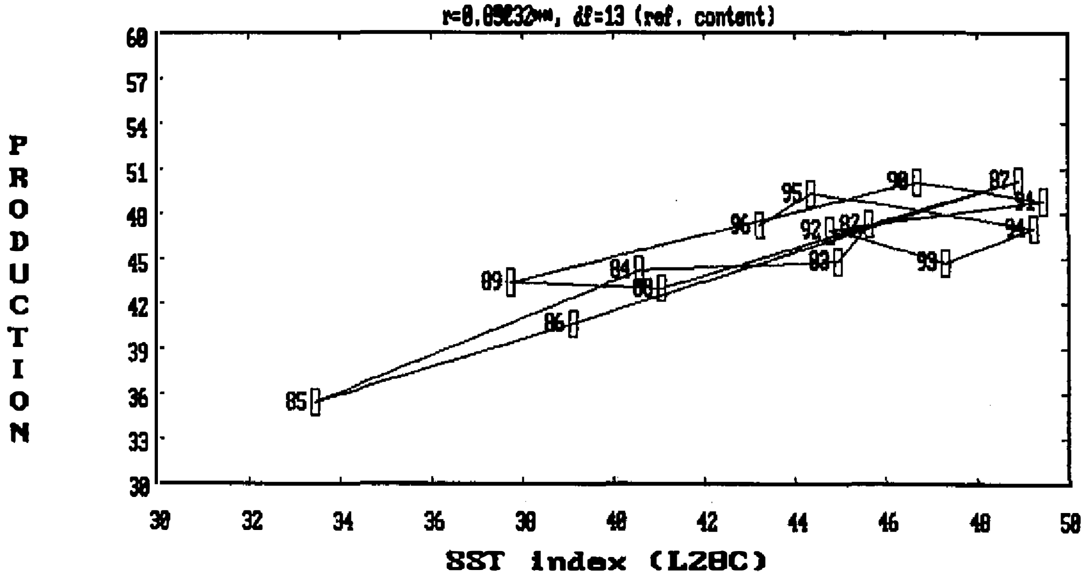

Fig. 11. Correlation: L28C and ft.

i.e., between 1988's albacore stocks and 1989's index of SST.

Fluctuations of the fish stocks are always influenced by biological factors, environmental conditions and human exploitation. In practice, it is not easy to distinguish the influential factors and/or to differentiate the relative strengths of the factors. As shown in Figure 8 to Figure 11, the very high correlation coefficients (significant over 1% level) are sufficient to explain that the fluctuations of the south Pacific albacore stocks are mainly dependent on changes in the higher sea surface temperature.

The correlation between A28C and L28C (Figure 12) and between the biomass and production (Figure 13, without adjustment) are very significant. Thus, it implied the conclusion that the fluctuations of the south Pacific albacore stocks are closely related to the distributions of the sea surface temperature over 28°C.

4. DISCUSSION

Generally, fish stocks are always affected by biological factors, environmental conditions and human exploitation.

In the south Pacific Ocean, albacore stocks are mainly exploited by tuna longline fisheries, especially by the Taiwanese tuna longline fishery. Reviewing the history of the Taiwanese tuna longline fishery in this area, no significant changes of fishing gear or fishing grounds can be detected (Wang 1988a, 1988b; Yeh and Wang 1996). However, there were two noticeable factors in this area. One was the El Nino event occurring in the eastern Pacific Ocean.

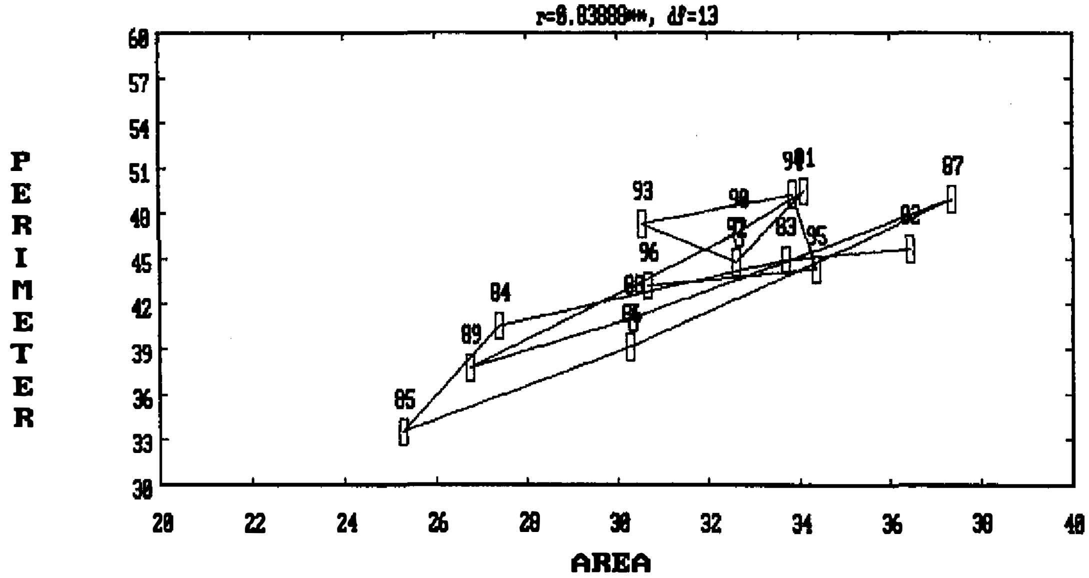

Fig. 12. Correlation: A28C and L28C.

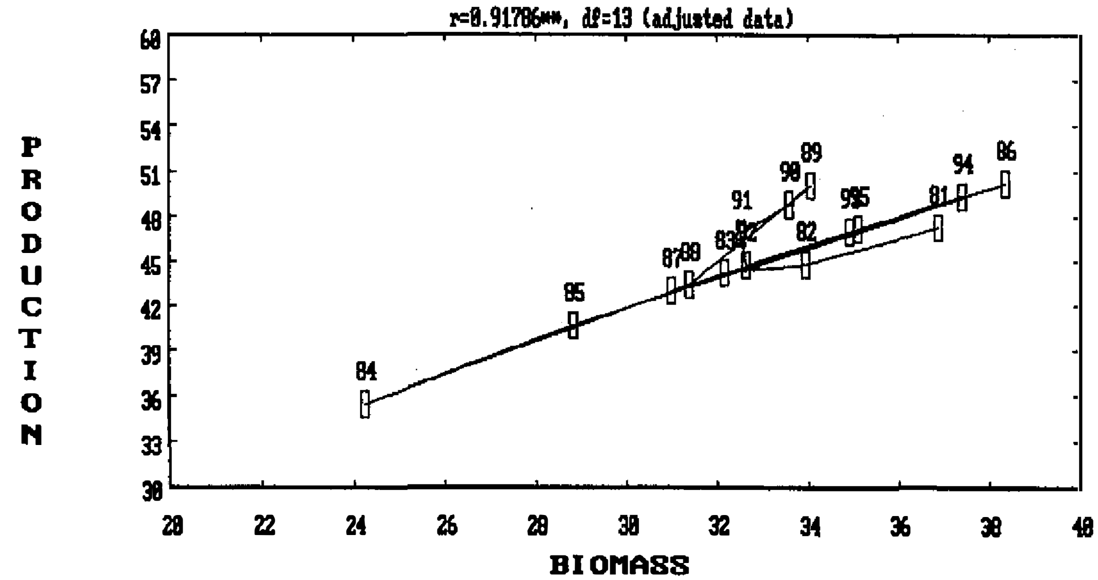

Fig. 13. Correlation: Bt and ft.

The other one was the gill netters entering the south Pacific Ocean. Excluding human exploitation, these two factors might be considered to be the two most important factors affecting the fluctuations of the south Pacific albacore stocks. An interesting topic for study would be the relationships between the albacore stocks and these two factors.

Although this paper can not point out how these two factors affect the south Pacific albacore stocks, it clearly reveals a significant correlation between the stocks and the indices of the distributions of the higher sea surface temperature after adjusting for the influences of the heavier El Nino events and the noticeable development of gill netters.

Biomass and production were directly estimated by the IPM-method without consideration of the effects of environmental conditions or gill netters. Isotherms of the sea surface temperature were directly downloaded from the NOAA-CIRES/Climate Diagnostics Center without consideration of the distributions of fishing grounds or fishing pressures of tuna longline fisheries. Hence, it is believed that their significant correlation is not simply an accidental coincidence.

Certainly, the discrepancies for some years were yet rather large (Figure 6). They may be attributed to the following factors.

(a) Different pressure of the gill netters,
(b) Different strength of the El Nino events,
(c) Different length of time delay caused by El Niño events or gill netters,
(d) How long the influences might be continuous,
(e) Erroneous information of the catch and effort data and/or the sea surface temperature data,
(f) Highest sea surface temperature it increases and the distributed area surrounding by the 28°C isotherm grows
(g) Other unidentified factors affecting the albacore stocks

Overall. (1) the assumptions of one year time-lag, (2) adjusting 1982 and 1983 albacore stocks for the heavier El Niño events, and (3) adjusting 1989, 1990, 1991 albacore stocks for the remarkable developments of the gill netters seem to be reasonable and acceptable. Hence, a very high correlation between the albacore stocks and the indices of the higher sea surface temperature is significant for explaining the fluctuation of the south Pacific albacore stocks. It is believed that the south Pacific albacore stocks are certainly influenced by the changes in the distributions of the higher sea surface temperature, especially in the area of over 28°C sea surface temperature.

5. CONCLUSIONS

In this paper, the relationships between the albacore stocks and the indices of the sea surface temperature were examined. The results of this study are as follows.

(1) The preferred sea surface temperature cannot be used as the sole indicator of the fluctua

tions of the south Pacific albacore stocks.

(2) Albacore stocks varied, with a one year time-lag, by the strength of the sea surface temperature over 28°C.

(3) Albacore stocks might be strongly influenced by particularly heavy El Niño events and particularly rapid expansion of the gill netters.

(4) The correlations between the albacore stocks and the indices of higher sea surface temperature were very high if the albacore stocks were adjusted for the influences caused by the heavier El Niño events and the rapid expansion of the gill netters.

(5) After the adjustments of the albacore stocks, the deviations of some years are still rather large. They might be due to other as yet unindetified factors.

(6) Distributions of the sea surface temperature over 28°C are sufficient for explaining the fluctuations of the south Pacific albacore stocks.

APPENDIX

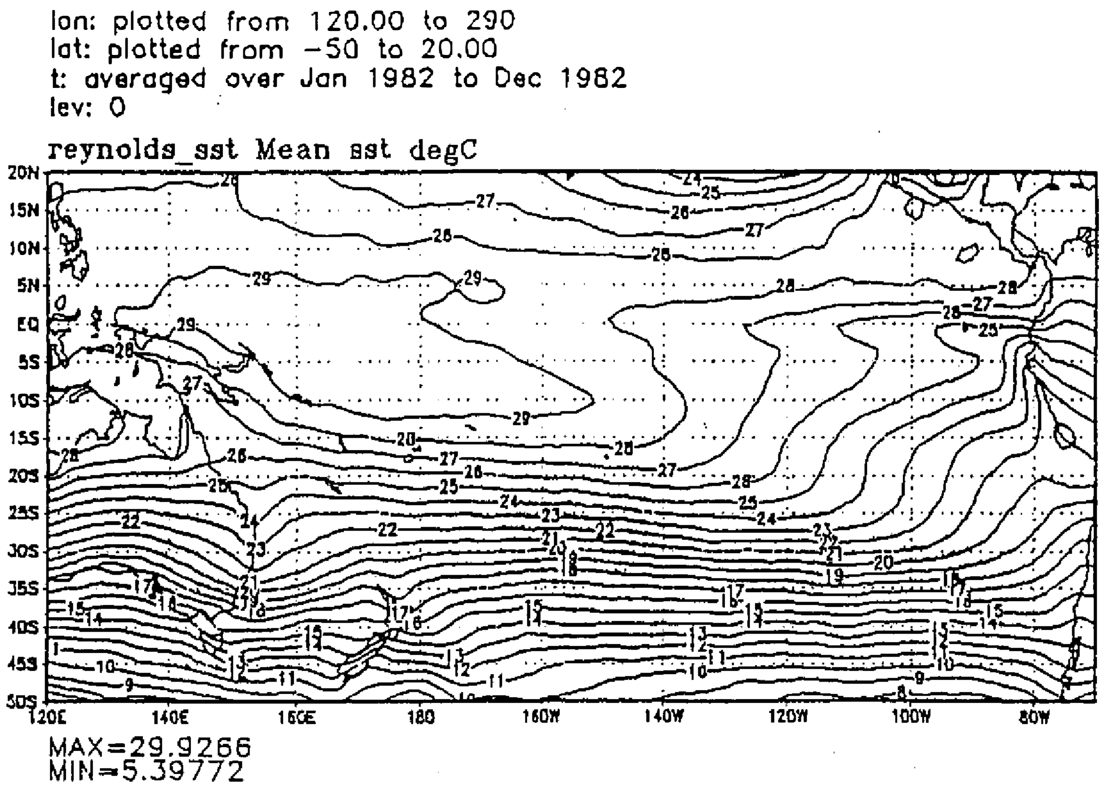

Fig-A1: Distribution of the Isotherm in 1982.

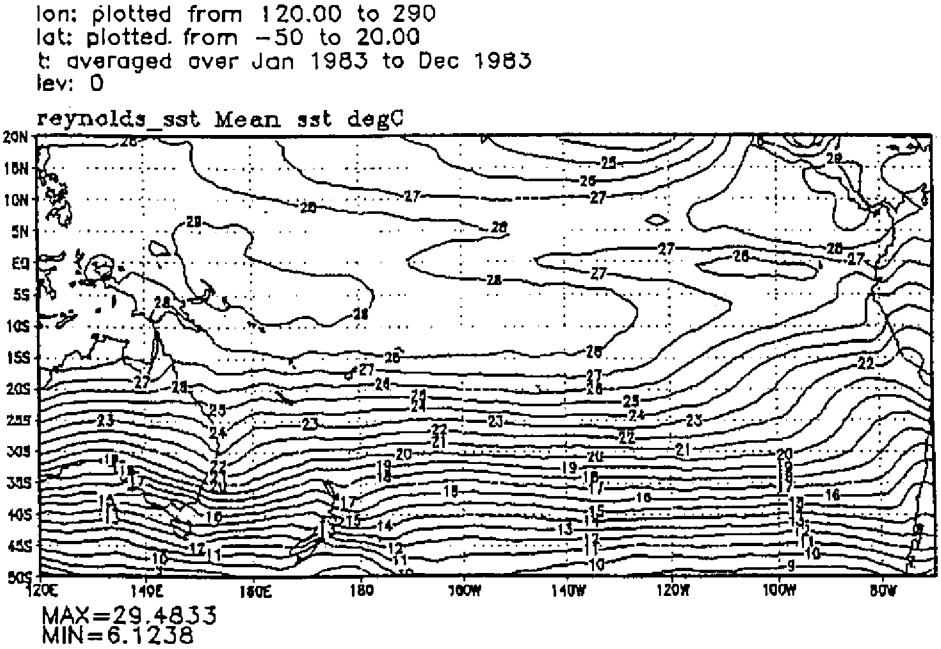

Fig-A2: Distribution of the Isotherm in 1983.

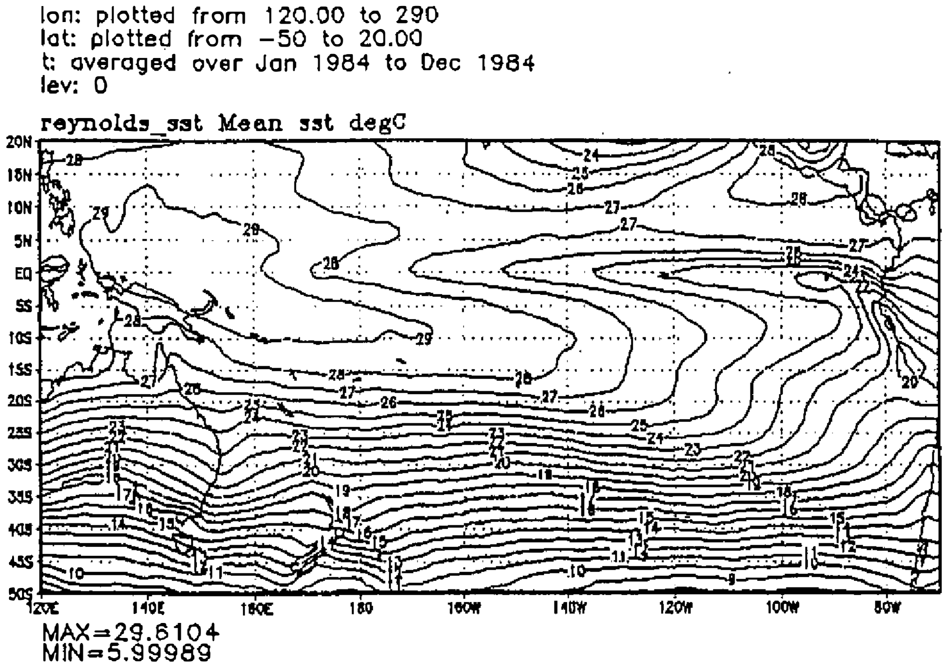

Fig-A3: Distribution of the Isotherm in 1984.

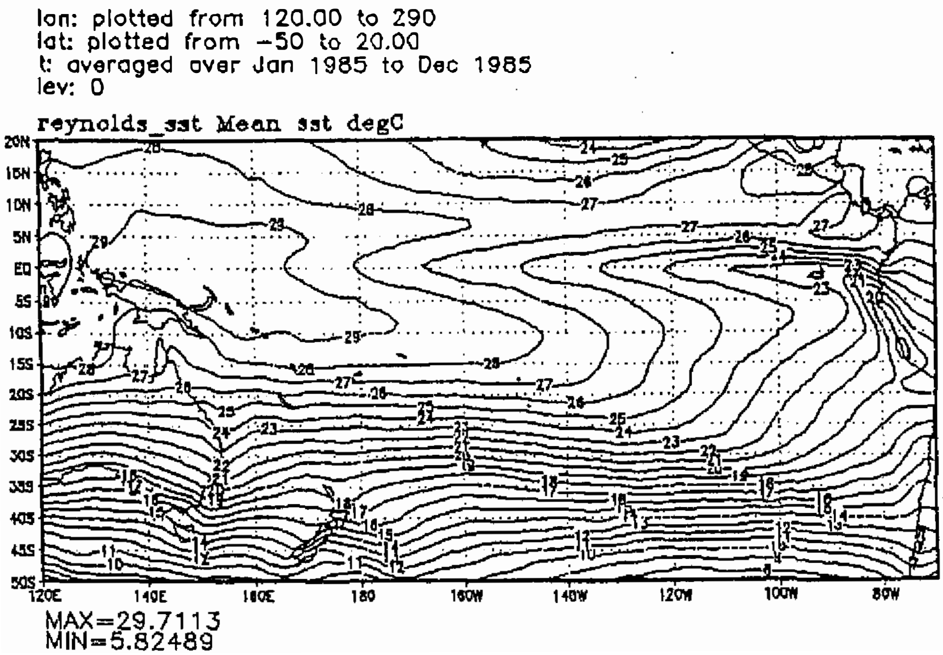

Fig-A4: Distribution of the Isotherm in 1985.

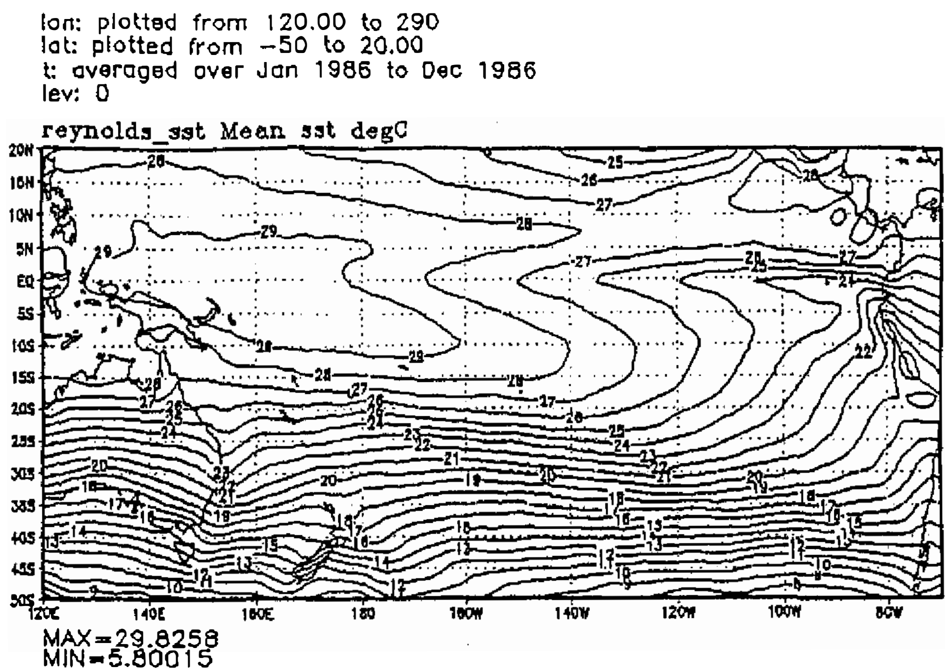

Fig-A5: Distribution of the Isotherm in 1986.

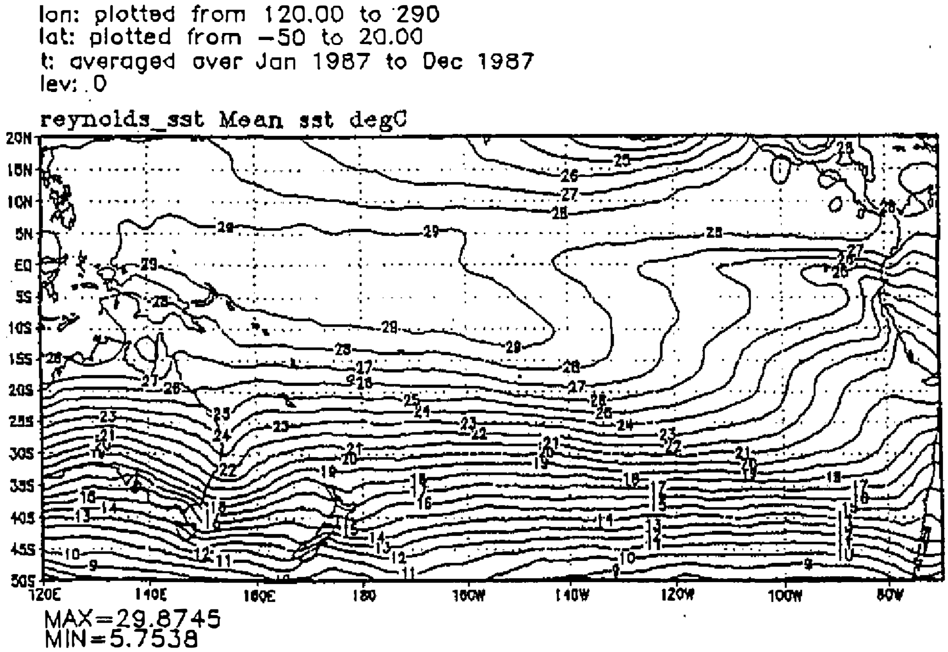

Fig-A6: Distribution of the Isotherm in 1987.

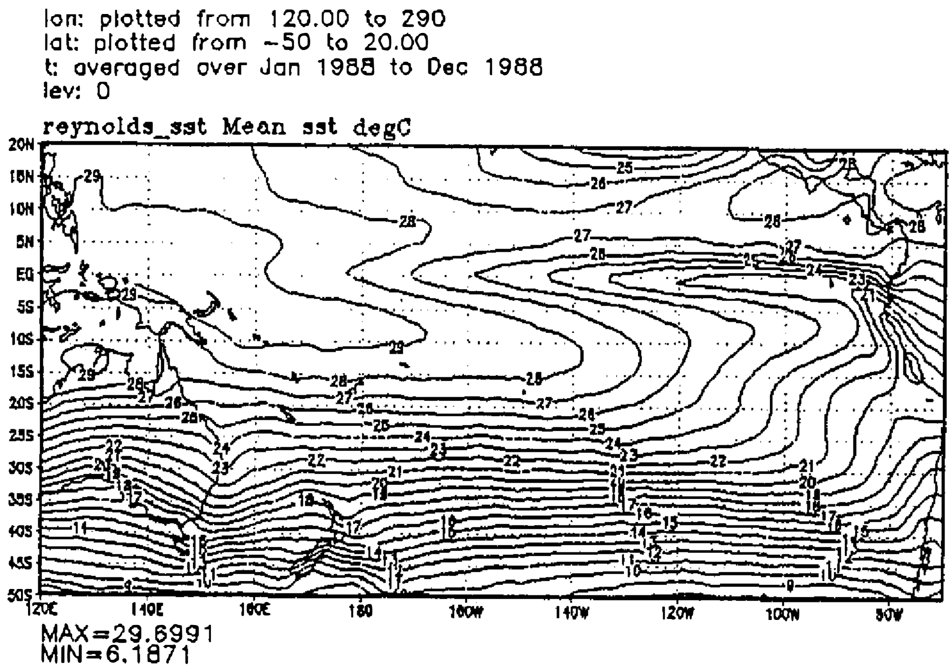

Fig-A7: Distribution of the Isotherm in 1988.

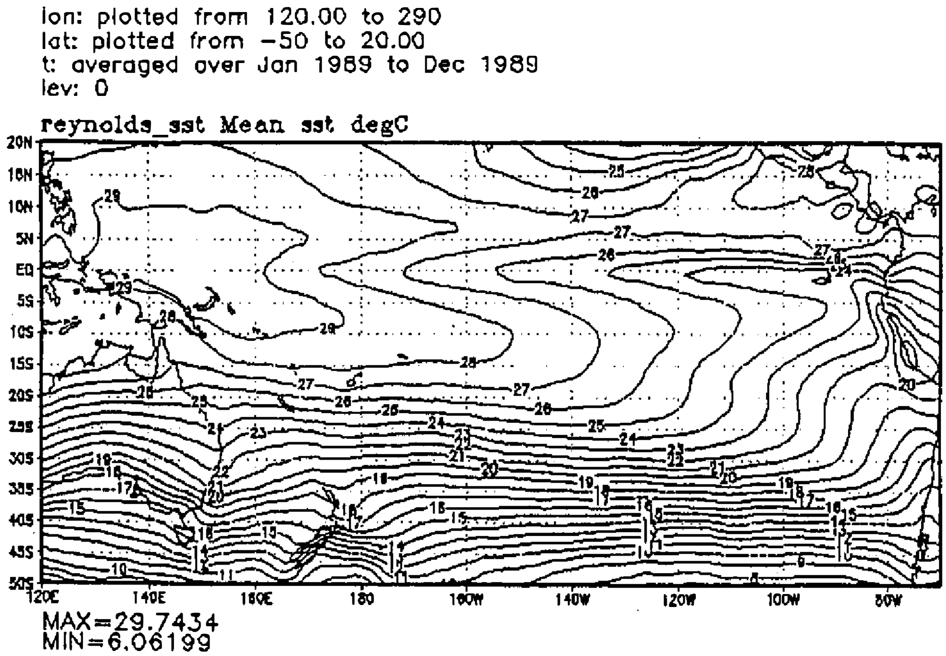

Fig-A8: Distribution of the Isotherm in 1989.

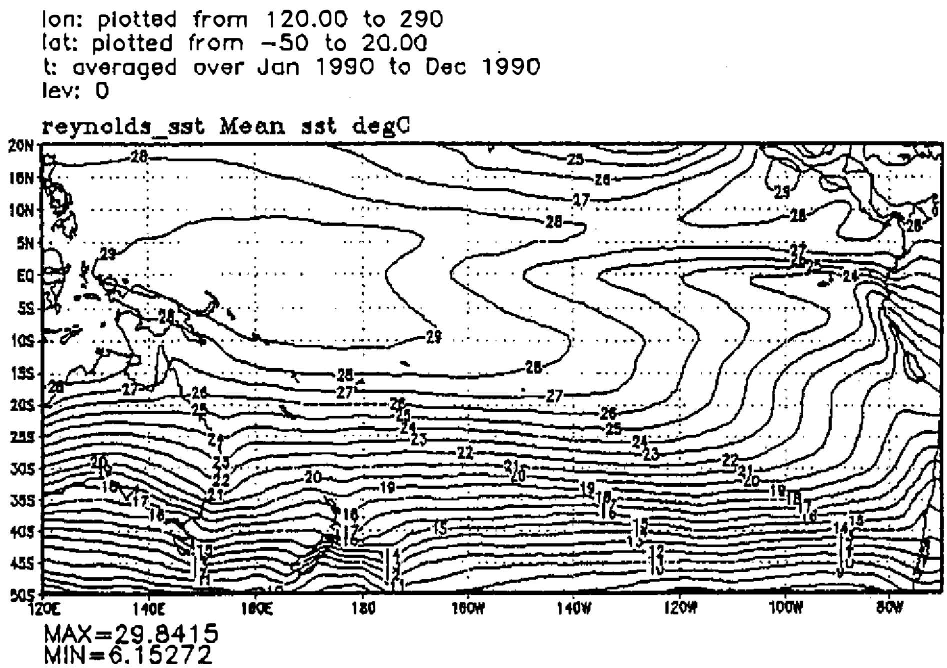

Fig-A9: Distribution of the Isotherm in 1990.

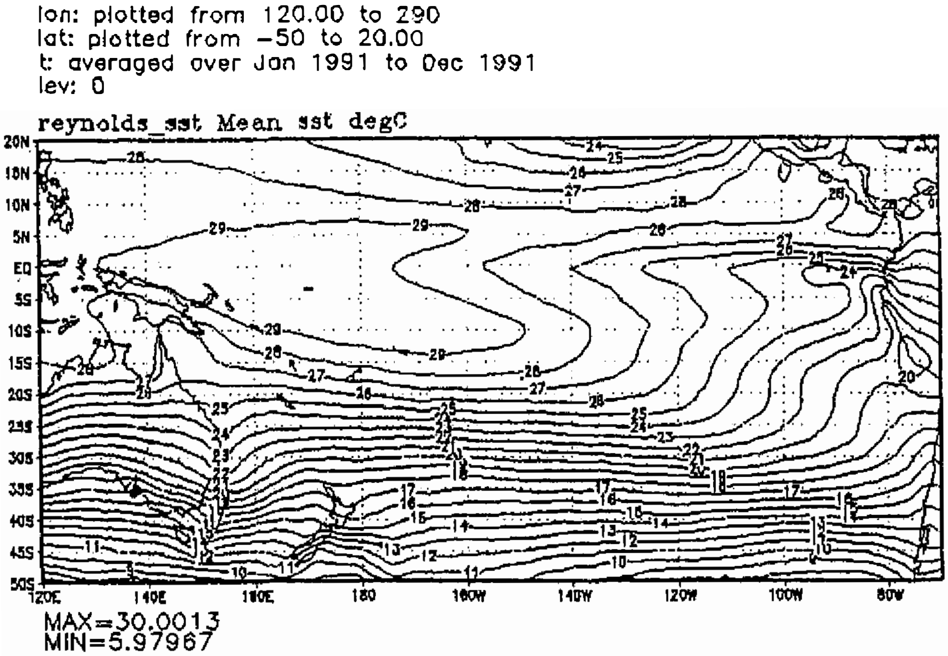

Fig-A10: Distribution of the Isotherm in 1991.

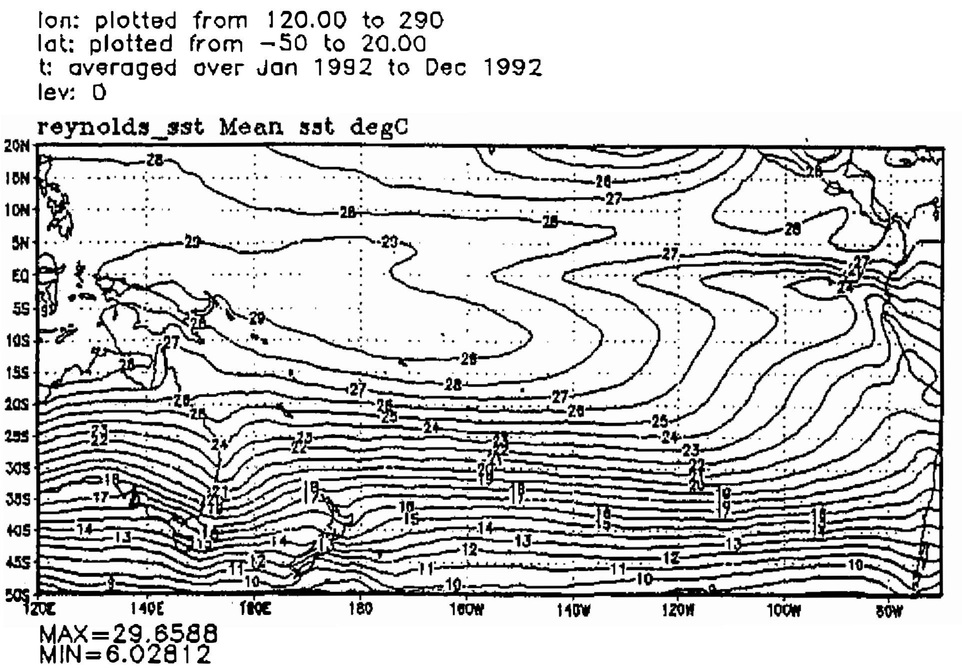

Fig-A11: Distribution of the Isotherm in 1992.

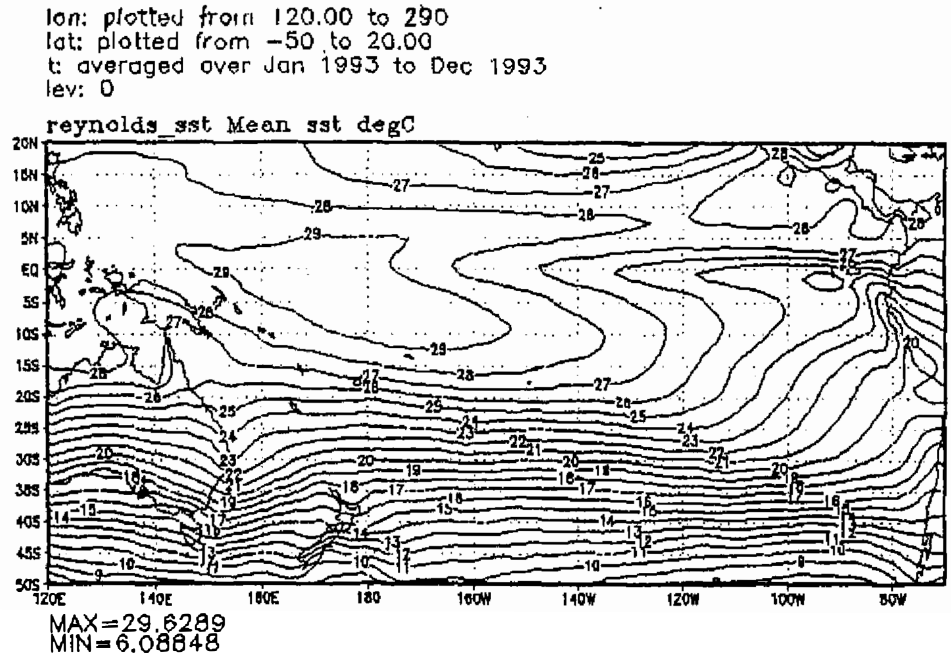

Fig-A12: Distribution of the Isotherm in 1993.

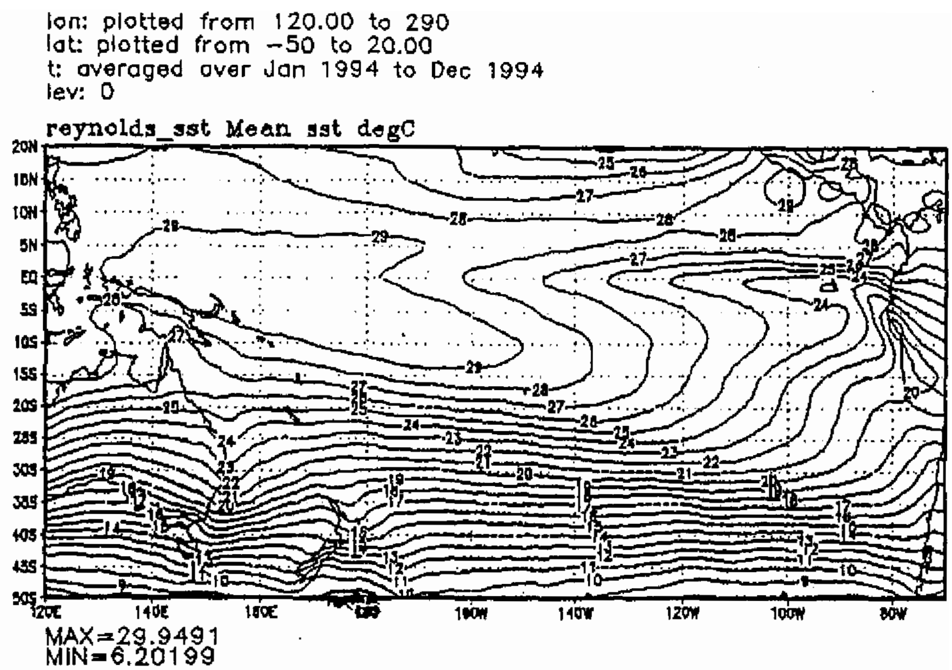

Fig-A13: Distribution of the Isotherm in 1994.

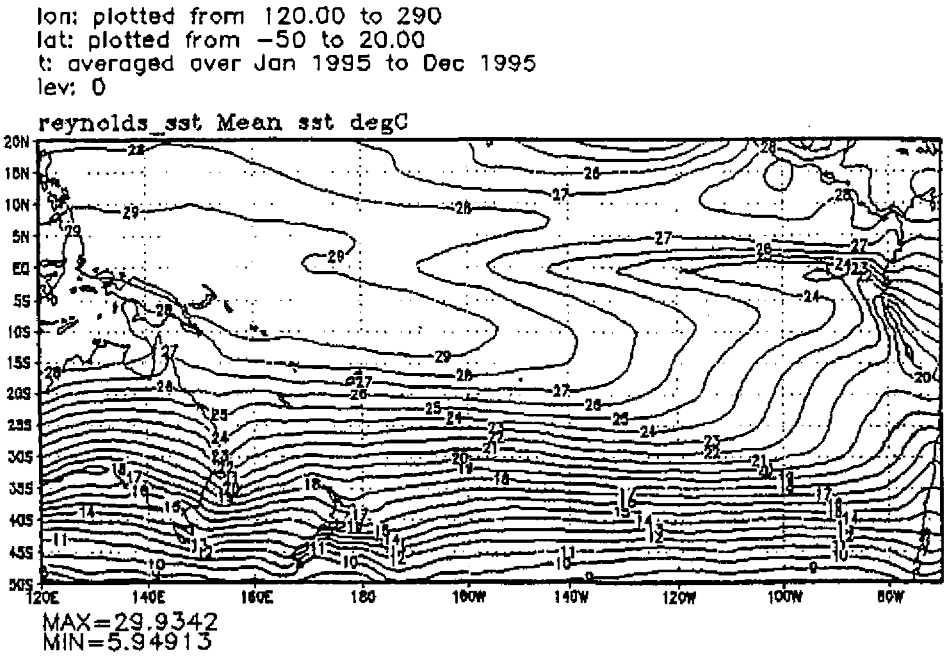

Fig-A14: Distribution of the Isotherm in 1995.

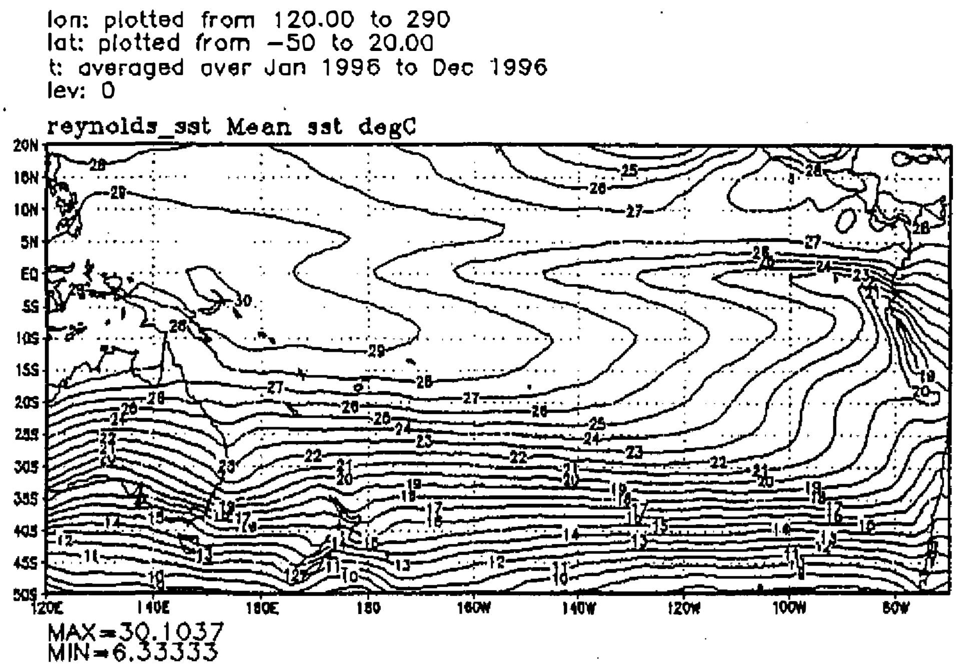

Fig-A15: Distribution of the Isotherm in 1996.

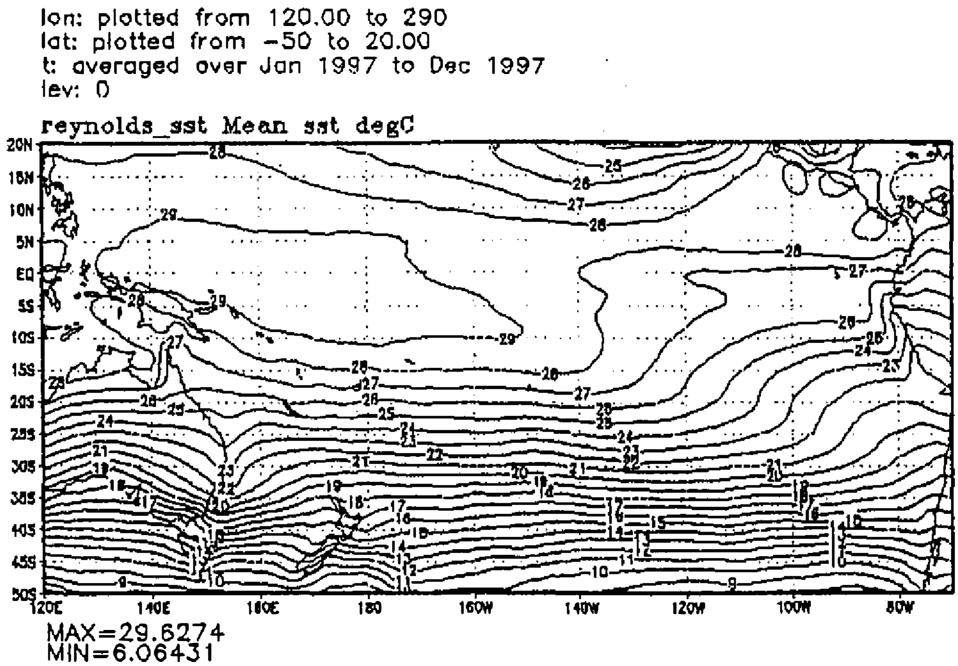

Fig-A16: Distribution of the Isotherm in 1997.

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