KOKO HEAD, OAHU, SEA-SURFACE TEMPERATURES AND SALINITIES, 1956–73, AND CHRISTMAS ISLAND SEA-SURFACE TEMPERATURES, 1954–73

GUNTER R. SECKEL[1] AND MARIAN Y. Y. YONG[2]

ABSTRACT

Sea-surface temperatures and salinities have been collected twice weekly at Koko Head, Oahu, Hawaii, since 1956; and at Christmas Island in the central equatorial Pacific, sea-surface temperatures have been collected daily since 1954. In 1971, Seckel and Yong used harmonic analysis as a curve-fitting method to bring these observations, 1 yr at a time, through 1969, into a form useful for descriptive and numerical applications. In this paper the analyses are updated through 1973 and the method is used to describe the entire data series.

The data series have been separated into several scales of variability: long-term variability (periodicities larger than 1 yr), short-term variability (12-mo and shorter periodicities), average annual cycle (the 12-, 6-, 4-, and 3-mo periods), and the residual variability that characterizes individual years (the short-term variability with the annual cycle removed). In contrast to the Koko Head temperature where the annual cycle predominates, the interannual variability predominates, at times obscuring the annual cycle, in the Koko Head salinity and Christmas Island temperature. The interannual change of the Koko Head salinity can be about three times, and that of the Christmas Island temperature can be about four times the average annual variability. In the average annual temperature and salinity cycles at Koko Head the amplitudes of the 6-, 4-, and 3-mo periods are small in relation to the 12-mo period. In the average annual temperature cycle at Christmas Island, however, the amplitude of the 6-mo period is almost one-half that of the 12-mo period. The residual variations exhibit changing amplitudes and periodicities at intervals of more than 1 yr that resemble amplitude and frequency modulations.

Speculations are made about processes that contribute to the temperature and salinity variations. It appears that in addition to the heat exchange across the sea surface, advection contributes materially to the observed changes at Koko Head and Christmas Island.

Harmonic coefficients resulting from the analyses are listed in the appendices to facilitate reproduction of the data presented.

In an earlier paper, Seckel and Yong (1971) used harmonic analysis as a curve-fitting method, bringing rapidly into usable form regularly sampled sea-surface temperatures and salinities. Analyses were made of sea-surface temperature and salinity obtained once or twice weekly from 1956 to 1969 at Koko Head, Oahu (lat. 21°16′N, long. 157°41′W,), and of sea-surface temperature obtained daily from 1954 to 1969 at Christmas Island (lat. 1°51′N, long. 157°23′W). The temperature and salinity variations for each year were then specified by sets of harmonic coefficients and phase angles. Values calculated at 15-day intervals from the resulting annual functions were used in long-term analyses of the entire data records. These analyses showed that interyear differences in the Koko Head salinity and Christmas Island temperature were larger than seasonal changes.

The long-term changes in surface properties reflect climatic scale ocean-atmosphere processes and, in turn, affect these processes. The changes in properties and processes affect life in the sea. For example, the Koko Head salinity changes indicate primarily changes in the advection produced by variations in ocean circulation (Seckel 1962). It was postulated that changes in circulation also affect the concentration and, therefore, the availability of skipjack tuna caught in Hawaii (Seckel 1972).

The long-term changes in the Christmas Island temperatures are linked with large-scale (at least ocean-wide) ocean-atmosphere processes. Bjerknes (1969) related anomalously high tem-

[1]Southwest Fisheries Center Pacific Environmental Group, National Marine Fisheries Service, NOAA, c/o Fleet Numerical Weather Central, Monterey, CA 93940.

[2]Southwest Fisheries Center Honolulu Laboratory, National Marine Fisheries Service, NOAA, P.O. Box 3830, Honolulu, HI 96812.

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peratures and high precipitation at Canton Island in the central equatorial Pacific with intensification of the Hadley circulation and changes in the "southern oscillation." Quinn (1974) related an index of the southern oscillation (the difference of atmospheric pressure between Easter Island and Darwin, Australia) with El Niño phenomena and abnormally high rainfall in the equatorial Pacific. One of the latter is the failure of the Peruvian anchovy fishery. The large interyear differences of equatorial sea-surface temperatures undoubtedly affect the biota in as yet undescribed ways.

It is of value, therefore, to bring the results of monitoring into a form that is useful for fishery applications. Toward this objective we have 1) updated our previous Koko Head and Christmas Island analyses through 1973; 2) analyzed the long series (18 yr for Koko Head, 20 yr for Christmas Island) and separated changes into long-term variability, the annual cycle, and the short-term variability that characterizes individual years; and 3) speculated about the processes that affect the changes evident in the data records.

THE 1970-73 UPDATE

Sampling and Processing

Koko Head, where bucket samples for temperature and salinity determinations were taken twice weekly, is located at the exposed, eastern shore of Oahu. At this location, cliffs extend into the water, and temperature and salinity samples have been found to be representative of offshore conditions. At Christmas Island, bucket temperatures were obtained daily near the plantation village on the ocean side of the lagoon entrance. Measurements were made during the morning at each location.

The procedures used to derive the harmonic coefficients for the 1970-73 observations were the same as those described by Seckel and Yong (1971). Fourier analysis was performed on the residuals from a linear fit so that the temperatures and salinities are expressed as a function of time, t, by

$$S = K + bt + \sum_{n=1}^{k} C_n \cos \omega (nt - \alpha_n) \ldots \qquad (1)$$

where $K = F(t_0) + \frac{A_0}{2}$, $\omega = \frac{2\pi}{T}$, and k is the highest harmonic in the series. $F(t_0)$ is the first observed value, A_0 is the Fourier coefficient for $n = 0$, C_n are the coefficients for $n \neq 0$, and α_n are the phase angles. b is the slope of the straight line joining the first and last observations of the fundamental period, T.

The fundamental period for the Koko Head analyses was 365 days. For the Christmas Island analyses the fundamental periods were 120 which for a full year followed in sequence with a 30-day overlap from Julian day 1 to 20, 91 to 210, 181 to 300, and 271 to 390 extending 25 days into the following year.

Results

Results of the analyses for the update years are presented in the appendices. Coefficients and phase angles for the Koko Head temperatures and salinities are found in Appendix A, Tables 1 and 2. Figures of the expected values computed from the harmonic functions together with the observed values for the Koko Head temperatures and salinities are found in Appendix B, Figures 1 and 2. The coefficients and phase angles for the Christmas Island temperatures are found in Appendix C, and the plotted functions together with the observed values are found in Appendix D.

Standard errors of estimate for the fitted Koko Head temperatures and salinities and Christmas Island temperatures are listed in Appendix E, Tables 1, 2, and 3, respectively.

Christmas Island Data Problems

Observer problems at Christmas Island caused the sea temperature sampling to be interrupted from May 1972 to April 1973. The data gap was reduced by Hawaii Institute of Geophysics (HIG) bucket temperatures obtained daily since November 1972 near the airport on the northeast shore of the island. Although NMFS (National Marine Fisheries Service) sampling resumed in April 1973, HIG data were used in our analysis for the entire year. In our long-term analysis the remaining data gap between May and November 1972 was closed by linear interpolation. Mean monthly temperatures obtained from the two sampling sites indicate that NMFS temperatures are on average about 0.5°C lower than the HIG values (Table 1). The HIG data have not been adjusted to reflect this temperature difference.

The large scatter of data at Christmas Island

TABLE 1.—Mean monthly sea-surface temperature (°C), Christmas Island: National Marine Fisheries Service station (NMFS) and Hawaii Institute of Geophysics station (HIG).

Date		NMFS	HIG
1973	May	26.6	26.2
	June	24.7	25.6
	July	23.6	25.2
	August	23.9	24.5
	September	23.8	24.1
	October	23.4	23.8
	November	23.0	23.3
	December	23.4	23.5
1974	January	23.9	24.0
	February	24.1	24.3
	March	24.6	24.7
	April	24.7	25.2
	May	23.9	24.9
	June	23.6	25.0
	Average	24.1	24.6

in comparison with that at Koko Head indicates another data problem. The scatter probably is caused by sampling of water in the shallow beach area that is more sensitive to changes in the local heating-cooling processes than the deep water of an offshore site.

Finally, there are no systematically observed sea-surface temperatures near Christmas Island against which the shore measurements can be calibrated. However, the monthly pamphlet *Fishing Information*[3] contains a temperature chart for the equatorial Pacific. Contours near Christmas Island are based on insufficient observations to reproduce the temperature distribution reliably. Therefore, the values from these charts, plotted on the annual graphs of Appendix D, show large variations in the difference between the *Fishing Information* temperatures and Christmas Island observations. On average the *Fishing Information* values are 1.3°C higher than the midmonth expected values with differences ranging from −1.2° to 4.1°C.

The discrepancy between the temperature sets, in part, may be due to a tendency toward a warm bias of merchant vessel temperature reports. More probable, however, Christmas Island temperatures, being measured in the morning, reflect the effect of night cooling in shallow water that would be in excess of the temperature decline taking place in deeper, offshore water.

Despite the apparent discrepancies between the beach and offshore temperatures, the data from the shore sampling sites reflect climatic scale anomalies. For example, both the Christmas Island record (Seckel and Yong 1971) and the Canton Island record (Bjerknes 1969) show the equatorial cold anomaly of 1955-56, the warm anomaly of 1957-58, and the anomalous biannual temperature variations of 1963-67.

ANALYSES OF LONG-TERM DATA RECORDS

In this section we present harmonic analysis results of the entire data series and separately display the long-term variability, the short-term variability, the average annual cycle, and the variability that characterizes individual years.

The entire data series is expressed by the function

$$S_L = A + \sum_{n=1}^{k} C_n \cos \omega (nt - \alpha_n) \ldots \qquad (2)$$

where A gives the average value of the series, k is the highest harmonic of the analysis, and other symbols have the same meaning as given for Equation (1).

Input values for these analyses were calculated at 15-day intervals from the annual analyses presented in this and our previous paper (Seckel and Yong 1971). Analysis of the 1956-73 Koko Head data was carried to the 72d harmonic and of the 1954-73 Christmas Island data to the 80th harmonic so that the shortest period resolved in each series is 3 mo. Analyses were carried out on the residuals from a linear fit as in the analyses of the annual data sets. The harmonic and linear coefficients for the long-term series are listed in Tables 1, 2, and 3 of Appendix F.

The fitted curves resulting from these analyses together with the input values are shown in panels A of Figures 1, 2, and 3. Dominant in the Koko Head temperature is the annual variation without pronounced longer term trends other than the rise of maximum and minimum temperatures from 1966 to 1968. In contrast to the Koko Head temperature curve, the salinity curve shows longer term variations that are larger than the seasonal variations. Also, during some years such as in 1957, annual variation is not apparent. The Christmas Island temperatures convey a similar picture; interannual changes are larger than the annual changes. Again, the latter may be obscured or absent as during the years 1963-66 and in 1973 when biannual changes dominated.

[3]*Fishing Information*. March 1970 through December 1973. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Southwest Fish. Cent., La Jolla, Calif.

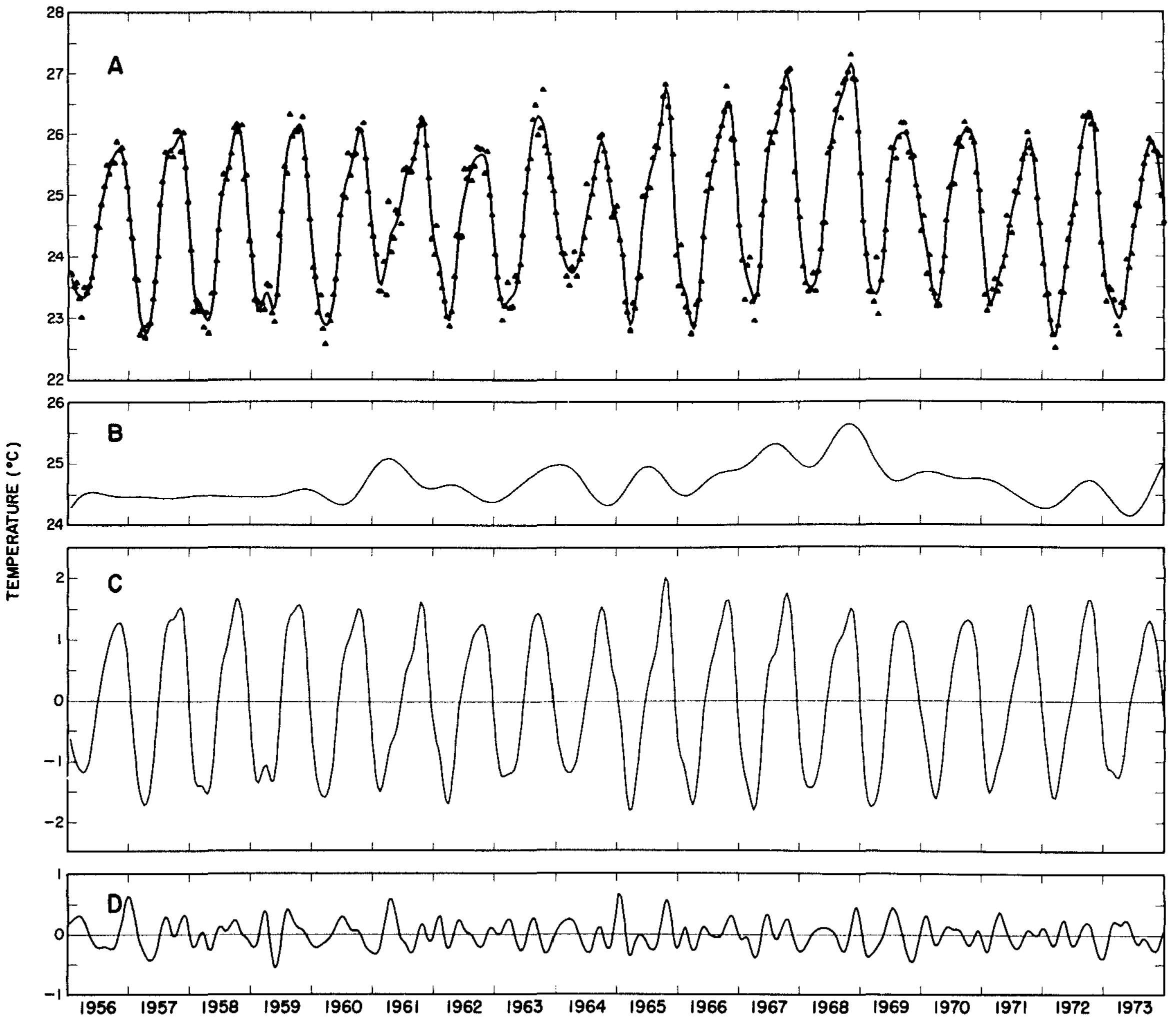

FIGURE 1.—Koko Head temperature, 1956-73: A. Fitted curve with a 3-mo resolution (n = 1-72). B. Long-term variation (n = 1-17). C. Short-term variation (n = 18-72). D. Residual variation (n = 19-35, 37-53, 55-71).

The amplitudes (C_n) of the long-term analyses (Figure 4) confirm these qualitative impressions. In the Koko Head temperature, the amplitude of the annual sinusoid (18th harmonic) is dominant and almost six times as large as the largest amplitude of the long periods. In the Koko Head salinity and Christmas Island temperature, on the other hand, long periods have the largest amplitudes. For the Koko Head salinity the amplitude of the fourth harmonic is larger than that of the annual sinusoid and for the Christmas Island temperature the amplitude of the first harmonic is almost twice that of the annual sinusoid.

Long-Term Changes

When long-term changes are of interest, the annual and shorter term variability can be filtered by a variety of methods including the commonly used 12-mo moving average method. After harmonic analysis has been used as a curve-fitting technique, however, it is simple to evaluate only the terms in the harmonic function up to but not including the annual sinusoid in order to display long-term changes. Thus, in Equation (2), the Koko Head temperatures and salinities were evaluated for n = 1 to 17 and the Christmas Island temperatures for n = 1 to 19. The resulting

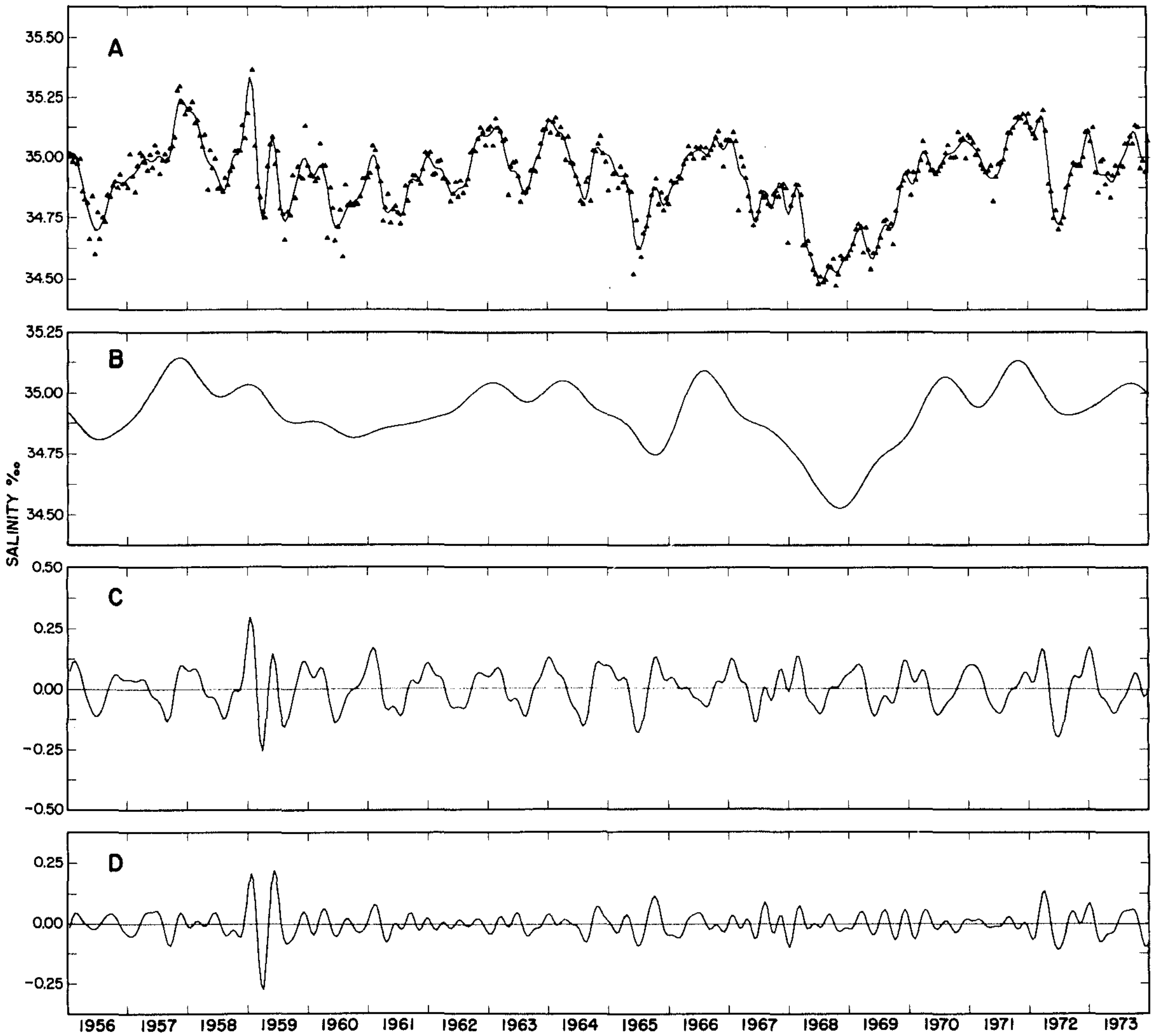

FIGURE 2.—Koko Head salinity, 1956-73: A. Fitted curve with a 3-mo resolution (n = 1-72). B. Long-term variation (n = 1-17). C. Short-term variation (n = 18-72). D. Residual variation (n = 19-35, 37-53, 55-71).

curves are shown in panels B of Figures 1, 2, and 3.

In the Koko Head temperature little variation due to the longer period harmonics is apparent until 1960 when perturbations of 0.5° to 1°C began. A rising temperature trend between 1966 and 1968 was followed by a decline to a pre-1960 temperature level. Both the Koko Head salinity and Christmas Island temperatures show the large perturbations previously noted. At Koko Head a pronounced salinity decline began in 1966, reaching almost 34.5‰ in 1968 before rising again to a range near 35‰. Times of high Christmas Island temperatures stand out. A prominent feature is the pronounced temperature decline during 1973 from one of the highest values to the coldest temperatures observed during the 20 yr of our record.

Short-Term Changes

The short-term changes relative to the long-term trends are another scale of interest that can be obtained by subtracting the moving average or the long-term values of the previous section from the monthly observations. In our case, and

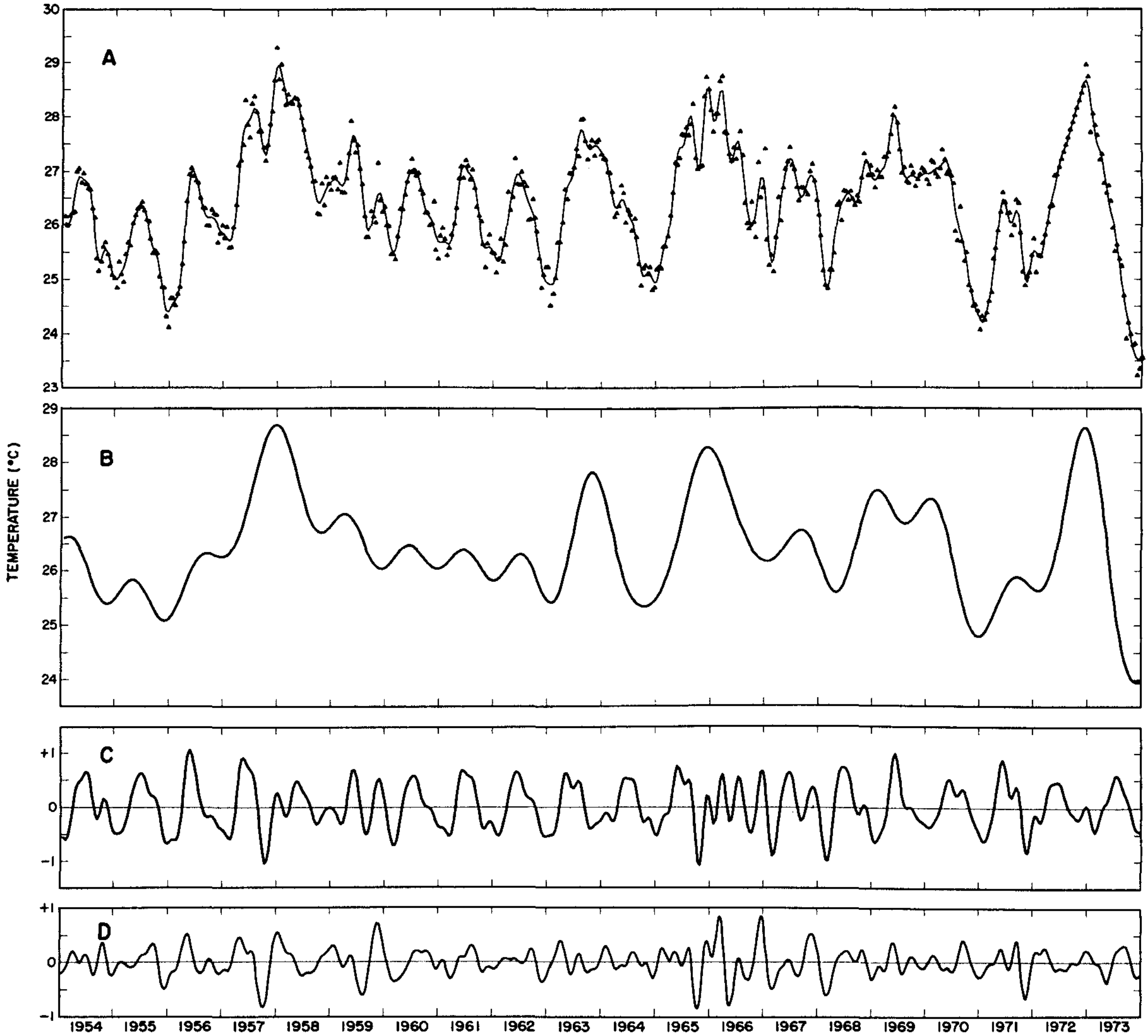

FIGURE 3.—Christmas Island temperature, 1954-73: A. Fitted curve with a 3-mo resolution (n = 1-80). B. Long-term variation (n = 1-19). C. Short-term variation (n = 20-80). D. Residual variation (n = 21-39, 41-59, 61-79).

when variations of <3 mo need not be resolved, it is simple to display short-term changes by evaluating the higher harmonics in Equation (2) beginning with the annual sinusoid (n = 18-72 for Koko Head, n = 20-80 for Christmas Island). The resulting curves are shown in panels C of Figures 1, 2, and 3.

The Koko Head temperature curve looks similar to the initial harmonic fit (Figure 1A) because the long-term changes are small in comparison to the annual variations. In the case of the Koko Head salinity and the Christmas Island temperature, the annual variations that during some years were obscured by the long-term trends are clearly apparent. At Koko Head low salinities occur during spring and summer and high salinities during fall and winter. At Christmas Island high temperatures occur in late spring and low temperatures in fall or winter.

Annual Sinusoid and Its Harmonics

Evaluation of the annual sinusoid and its harmonics yields the mean annual variation. For annual analyses the harmonics n = 1, 2, 3, and 4 have periods of 12, 6, 4, and 3 mo. For the 18-yr

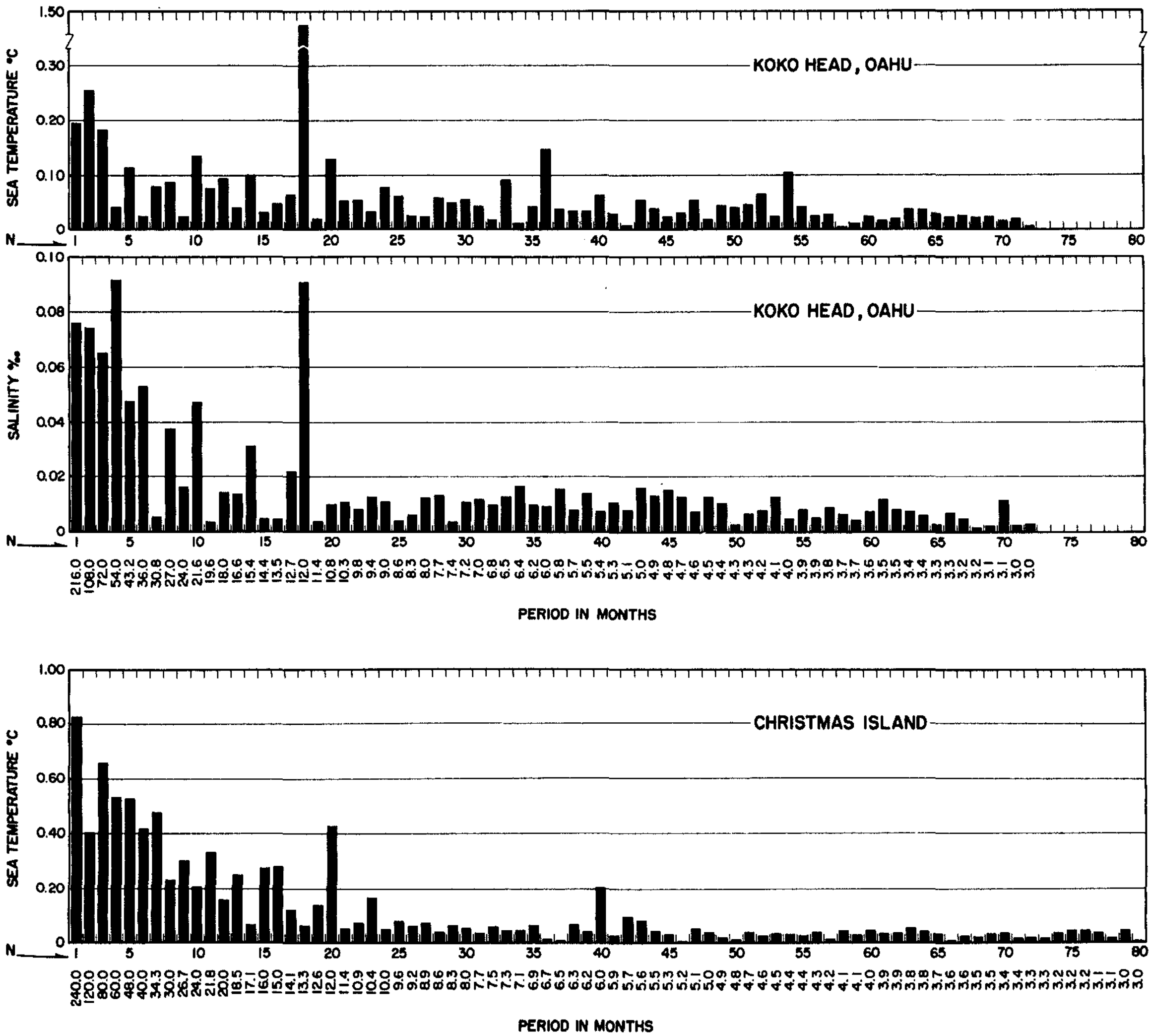

FIGURE 4.—Absolute magnitude of amplitudes of the long-term harmonic functions for Koko Head temperatures, 1956-73; Koko Head salinities, 1956-73; and Christmas Island temperatures, 1954-73.

Koko Head series, these periods are given by $n = 18, 36, 54,$ and 72; and for the 20-yr Christmas Island series, they are given by $n = 20, 40, 60,$ and 80. The mean annual variations evaluated from Equation (2) are shown in Figure 5 panels A, B, and C.

The mean annual temperature range of 3°C at Koko Head is about twice the long-term range. In contrast, the mean annual salinity range is 0.2‰ and only about 30% of the long-term range. At Christmas Island the mean annual temperature range is 1°C and only one-quarter of the long-term range.

At Koko Head the annual sinusoid, although visibly modified, dominates the mean annual changes. In both the temperature and the salinity, the amplitude of the annual sinusoid is an order of magnitude larger than that of the 6-, 4-, and 3-mo sinusoids (Figure 4). In the case of the temperature, the interference pattern of the 6- and 4-mo sinusoids is such that during the first half of the year the annual sinusoid is not visibly affected. Constructive interference by these sinusoids depresses the annual sinusoid by about 0.2°C in August, which causes first an increase by that amount in October and then a decrease by the end

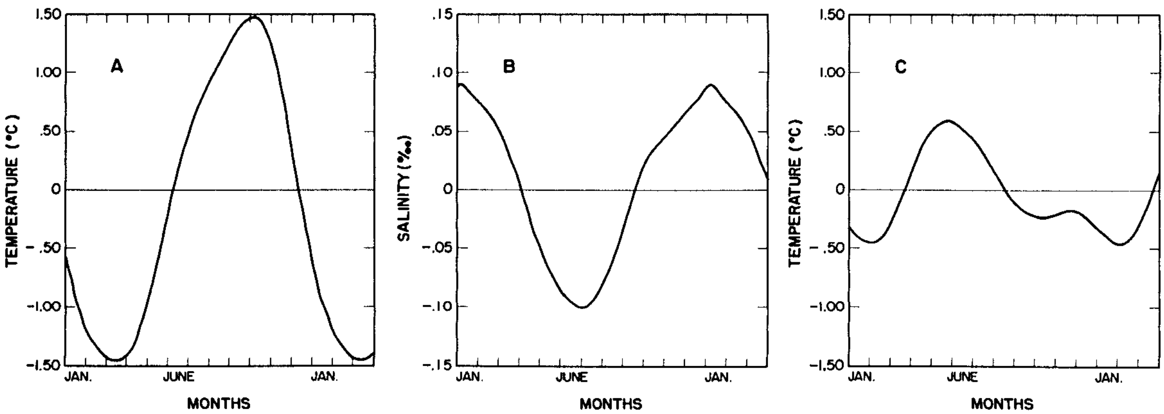

FIGURE 5.—Mean annual variations: A. Koko Head temperatures (n = 18, 36, 54, 72). B. Koko Head salinities (n = 18, 36, 54, 72). C. Christmas Island temperatures (n = 20, 40, 60, 80).

of the year. Consequently, the mean annual curve reflects the temperature trends evident in individual years in that warming lasts between 1 and 2 mo longer than cooling and the cooling rate is higher than the warming rate.

Departures of the mean annual salinity variation from the annual sinusoid, evident in Figure 5B, are not significant.

In contrast to the Koko Head spectra, the amplitude of the 6-mo sinusoid at Christmas Island is large enough to produce a significant modification of the annual sinusoid (Figure 5C). The absolute amplitudes of the 12-, 6-, 4-, and 3-mo sinusoids are 0.43°, 0.21°, 0.04°, and 0.003°C, respectively. Thus, the mean annual temperature variation at Christmas Island has the typical interference pattern produced by a 12- and a 6-mo sinusoid as illustrated in Figure 6. The residual curve, namely the difference between the mean annual curve and the annual sinusoid, is approximately the 6-mo sinusoid.

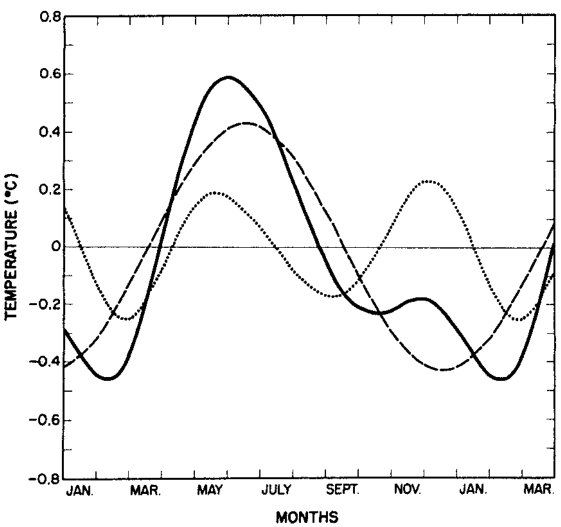

FIGURE 6.—Interference patterns of sinusoids for mean annual variation at Christmas Island. Solid line – n = 20, 40, 60, 80; dashed line – annual sinusoid (n = 20); dotted line – remaining variation (n = 40, 60, 80).

Residual Variations

The dominant feature in the short-term curves (panel C of Figures 1, 2, 3) is the annual variation superimposed upon which is the variability that characterizes each year. This "residual" variability is obtained by evaluating in Equation (2) the short-term variability without the annual sinusoid and its harmonics (n = 19-35, 37-53, and 55-71 for Koko Head, and n = 21-39, 41-59, and 61-79 for Christmas Island). Residual variability is shown in panel D of Figures 1, 2, and 3.

The residual curves are the interference pattern produced by all the sinusoids used in the evaluation. The irregular amplitudes and periodicities occurring at intervals of more than 1 yr give an impression of amplitude and frequency modulations. For example, in the Koko Head salinity curve, relatively large perturbations occur in groups during 1959, 1964-65, 1967-68, 1969-70, and 1972-73. In the Christmas Island residual temperature curve, relatively large perturbations during 1955-60 are followed by smaller perturbations during 1960-65 and by larger perturbations again during 1965-68. These modulations are of a long-term nature but do not appear to be related with the variations shown in panel B of Figures 1, 2, and 3.

On the Separation of Variability Into Various Time Scales

Although there are a number of curve-fitting procedures such as were reviewed by Holloway (1958), we have found Fourier analysis to be a convenient method for the Koko Head and Christmas Island time series. The filtering described above is a byproduct of this method and serves interpretive and descriptive purposes.

Although the moving average method is not recommended for climatological time series,[4] it is commonly used. For this reason, curves obtained by the moving average and the harmonic analysis methods are compared in Figures 7 and 8. The long-term as well as the residual curves of the two procedures are similar though not identical. The amplitudes of the long-term variations are larger in the curves derived by harmonic analysis than in those derived by the moving average method. This difference is to be expected because, in contrast to the harmonic method, input values in the moving average method are weighted equally.

The examples in Figures 7 and 8 were chosen because they illustrate limitations, in terms of physical interpretations, of the filtering techniques. A time series of the sea-surface temperature (salinity) is the signature of processes that govern the observed changes. What information about the governing processes, then, can be inferred from the time series? For example, is the observed change of temperature the result of an anomaly in the local heat exchange across the sea surface and advection produced by the local wind driven current, or is this temperature change a part of a larger scale change with the local processes remaining normal? The examples in panel B of Figures 7 and 8 exhibit variations with an annual periodicity during 1957 in the Koko Head salinity and during 1963, 1964, and 1965 in the Christmas Island temperature although this periodicity is not apparent in panel A of Figures 2 and 3. In these cases were annual variations, such as produced by annually varying processes, present or were they absent?

In the case of the moving average method, 2 yr of data are required to provide the smoothed curve for a single year. At Koko Head the normal midyear declines in salinity occurred during 1956 and 1958, affecting the shape of the smoothed 1957 curve. Consequently the residual curve showed an annual variation during 1957 (Figure 7B). At Christmas Island (Figure 8B), the residual temperature curve during 1964 also exhibits an annual variation, a maximum in spring and a minimum in fall, although no seasonal trends were indicated during the adjacent years (Figure 3A). In this case, was the normal annual variation in temperature present but obscured by the long-term trend?

In the harmonic analysis procedure the dominant signal in the annual variation is produced by the annual sinusoid. The amplitude of this period is determined by all the data in the series and contributes the same amount to the short-term variations of every year shown in panel C of Figures 1, 2, and 3. For example, a time series could be synthesized by combining a long-term variation with one that has an annual periodicity

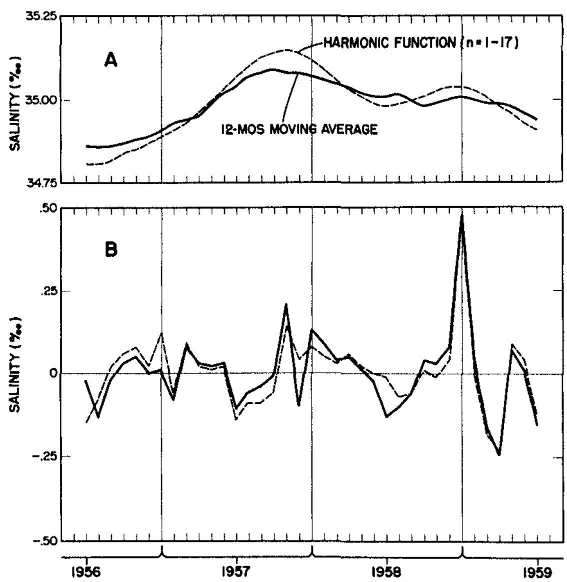

FIGURE 7.—Koko Head salinity, 1956-59: A. Long-term variation produced by 12-mo moving average and by harmonic function (n = 1-17). B. Short-term variation (monthly input values minus long-term values). Solid line — 12-mo moving average; dashed line — harmonic function (n = 1-17).

[4]Climate change. Tech. Note 79, WMO-No. 195, Tp. 100. Secr. World Meteorol. Organ., Geneva, Switz., 1966, 79 p.

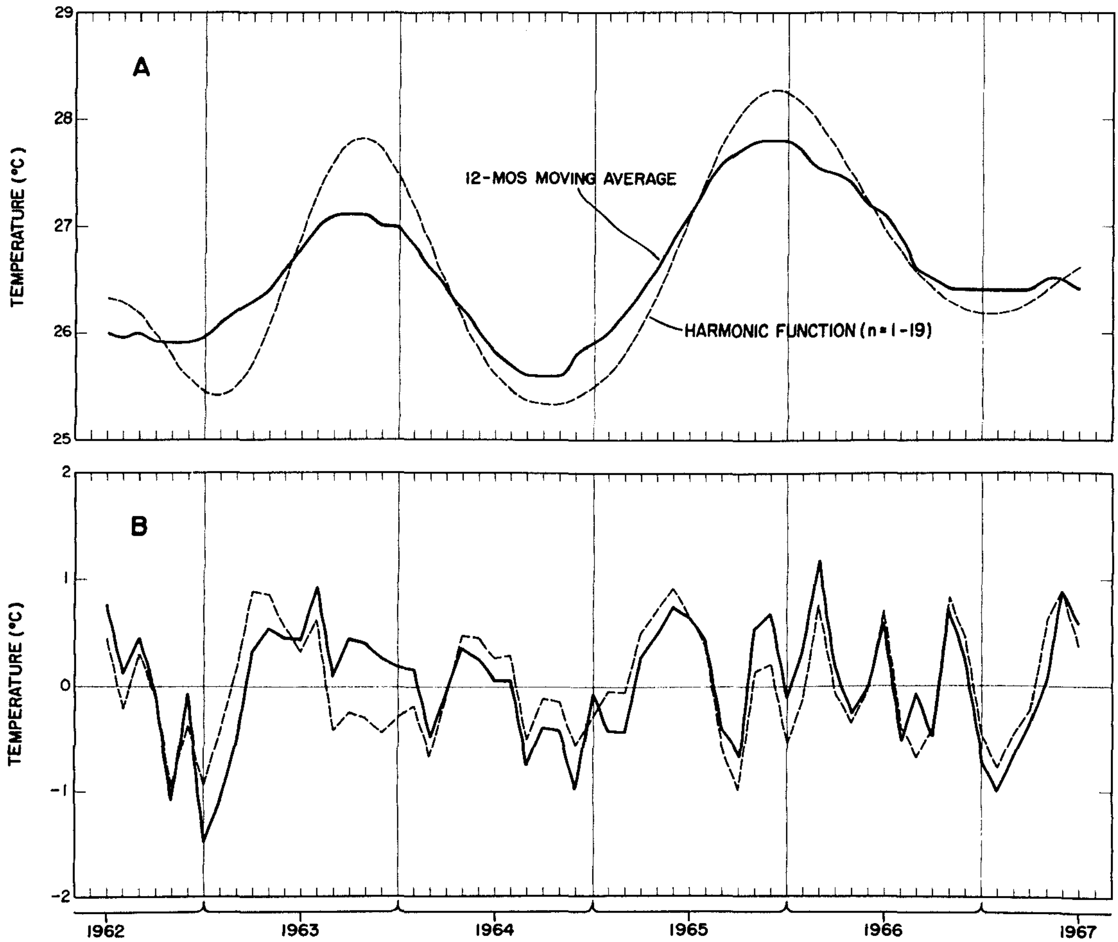

FIGURE 8.—Christmas Island temperature, 1962-67: A. Long-term variation produced by 12-mo moving average and by harmonic function (n = 1-19). B. Short-term variation (monthly input values minus long-term values). Solid line — 12-mo moving average; dashed line — harmonic function (n = 1-19).

every second year. After harmonic analysis and separating the hypothetical curve into a long-term and a short-term variation, the latter would exhibit an annual periodicity during every year.

Thus, the mathematical procedure cannot answer the questions posed above. The procedures illustrated in Figures 7 and 8 as well as other procedures, separate the scales of variability but there is no basis for inferring that the long-term changes are related with, possibly, ocean-wide processes and short-term changes with local processes. Only if the local processes are measured is there a physical basis for the separation into different scales of change.

Speculations About Temperature and Salinity Variations

It is not the purpose of this paper, and the information is not available, to investigate the causes for the temperature and salinity variations that have been described. Nevertheless, such an investigation would further an understanding of the fishery environment as well as the ocean-atmosphere linkages. It is useful, therefore, to speculate about the processes affecting changes in surface properties.

In Hawaiian waters air-sea interaction processes and advection appear to dominate the local change of temperature and salinity (Murphy et al. 1960; Seckel 1960, 1962). Advection is the product of the surface temperature (salinity) gradient and the component of the current normal to the isotherm or salinity isopleth. Generally near Hawaii the temperature increases and the salinity decreases equatorward. Consequently, with a northward component of flow, advection would increase the temperature and decrease the salinity at Koko Head.

The usual spring salinity decline at Koko Head is best explained by advection. It is estimated that at the latitude of Hawaii there is an excess of evaporation over precipitation with the highest excess occurring during spring and summer (Seckel 1962). Thus, since the salinity is increasing with depth, the only source of lower salinity water lies south of the islands.

On average the orientation of isotherms is northwest-southeast and that of salinity isopleth is zonal. In this case only the meridional component of flow causes salt advection, but both meridional and zonal components of flow cause heat advection. Consequently, meridional components of flow causing salinity variations do not necessarily produce temperature variations. Coincident changes of salinity and temperature that appear to be advection related, tend to occur during late winter and early spring when the North Equatorial Current is weak. For example, between days 60 and 110 of 1973 (Appendix B), decreasing and increasing temperatures corresponded with increasing and decreasing salinities. Pronounced coincident temperature and salinity variations occurred during the first half of 1959 and are most evident in the residual curves, panel D of Figures 1 and 2.

Coincident changes in temperature and salinity during specific seasons are not necessarily associated in the longer term. From 1956 through 1959 when the long-term salinity variations were pronounced, there was no long-term temperature change (panel B of Figures 1, 2). Later, a strong salinity decline lasting from 1966 to 1968 corresponded with a temperature increase. Then, as the salinity returned toward 35‰, the temperature also returned to the pre-1965 values. The first situation may mean that there were climatic shifts in the general northwest-southeast direction, parallel to the isotherms, thus causing a long-term change in the salinity but not in the temperature. In the second situation the climatic shift was first northward and then southward, affecting both temperature and salinity.

White (1975) described secular changes in baroclinic transport and morphology of the North Pacific subtropical gyre and indicated that during the years of low maximum transport the southwest portion of the gyre extended farther south than during the years of large transport. Similarly, it is possible that higher baroclinic flow and tightening of the gyre near Hawaii will result in lower salinity and a relaxation of flow will result in higher salinity. The long-term changes in the Koko Head salinity do not correspond with the changes described by White and are only in partial agreement with the supposition when tested against Wyrtki's (1974) North Equatorial Current index. The supposition, therefore, is in error or, the local wind induced surface flow, superimposed on the baroclinic flow, plays an important part in the long-term salinity changes.

At Christmas Island, in addition to the heat exchange and advection, the effect of wind-induced equatorial divergence is a process affecting the sea-surface temperature. Unfortunately, meteorological observations suitable for the calculation of heat exchange across the sea surface were not made on the island. Estimates made by Wyrtki (1966) and Seckel (1970) indicate the net heat exchange across the sea surface near Christmas Island to lie in the range of about 100 to 300 cal cm^{-2} day^{-1}. Assuming that the heat is distributed through a column of water 50 m deep, this process can produce temperature changes from about 0.6° to 1.8°C/mo. Temperature increases within this range are observed (Figure 3A).

An important term in the net heat exchange is the radiation from sun and sky that is affected in the equatorial region of the central Pacific by large variations in cloudiness (Bjerknes et al. 1969). The effect of such variability is most pronounced in late fall and early winter (Seckel 1970, figure 6). For example, the average net heat exchange near Christmas Island for November 1963 to January 1964 was calculated to be 177 cal cm^{-2} day^{-1}, and for the same months 1 yr later, 274 cal cm^{-2} day^{-1}. The average calculated radiation from sun and sky during the same periods was 372 cal cm^{-2} day^{-1} and 440 cal cm^{-2} day^{-1}, respectively, and accounted for 70% of the interyear difference in the net heat exchange. The Christmas Island water temperature declined in the first and rose in the second of these years (Figure 3A).

Heat gain across the sea surface cannot produce a temperature decline and, therefore, other processes must affect the temperature. One of these processes is heat advection that, at the Equator, is the product of the zonal current and the zonal temperature gradient. A raft designed for underwater biological observations was set out in February 1964 near the Equator at about long. 150°W and drifted westward 1,084 km (585 n.mi.) in 194 h (Gooding and Magnuson 1967) giving an average speed of 155 cm s^{-1}. A current with the speed of the raft, given a zonal temperature gradient of 0.5°C/10° of longitude, would produce a temperature change of more than 1.8°C/mo. A slower surface current, 30 cm s^{-1}, was observed on the Equator at long. 140°W during April 1958 (Knauss 1960). This current with the same zonal temperature gradient as before would produce a temperature decline of about 0.4°C/mo.

The South Equatorial Current indices presented by Wyrtki (1974) reflect large variability in the zonal current such as cited above. Additionally, monthly charts of sea-surface temperature (Eber et al. 1968) show the zonal gradient at the Equator to range from zero to >1°C/10° of longitude. Advection, therefore, is expected to play a large role in the temperature variations observed at Christmas Island.

Near the Equator the wind field is a key element in the evaporative heat loss, the cloudiness (affecting the radiation flux across the sea surface), upwelling, and in driving the equatorial currents. Quinn's (1974) southern oscillation (SO) index is related to the central South Pacific trade winds. It is not surprising, therefore, to find coherence in the changes of the SO index, Wyrtki's current index, and the Christmas Island temperature. Selecting the pronounced features of Figure 3B, declining SO index values during 1956, 1963, 1965, 1968, and 1971-72 correspond with rising temperatures. Increasing index values during 1964, 1966, and 1970 correspond with declining temperatures. During the first series of years South Equatorial Current speeds are declining and during the second series they are increasing.

SUMMARY

In this paper we have used harmonic analysis to make Koko Head temperature and salinity time series and Christmas Island temperature time series available for descriptive as well as numerical applications.

Time series data can be treated by a number of mathematical procedures in order to elicit important information. Initially, however, the presentation of the data in graphical form is most useful. The graphs in the appendices indicate the nature of the annual variations, and Figures 1, 2, and 3 indicate the nature of the long-term variations.

Although spectral analysis is not the objective of our work, the curve-fitting procedure further serves the descriptive purposes in that it permits separation of the time series into different scales of variability (panels B, C, D of Figures 1, 2, 3). For example, at Christmas Island the interannual temperature variation is as much as four times the average annual variation (Figures 3B, 5C). Equivalent figures of Koko Head salinity show that the interannual change can be about three times as large as the average annual variation.

Results of our analyses are also useful in numerical applications. Coefficients and phase angles (Appendices A, C, F) rather than observed values can be used for further calculations. In this manner the sampling variability apparent in the graphs of Appendices B and D is filtered out and variations of undesired duration can be omitted.

The separation of the time series into different scales of variability is a mathematical procedure and physical inferences must be made with caution. For example, Figures 2C and 3C show an annual cycle during every year although no annual cycle was apparent during 1957 in Figure 2A or during 1963, 1964, and 1965 in Figure 3A. The procedure does not indicate whether during these years the processes producing the annual cycle were absent or whether they were present but obscured by other processes. In another example, a 12-mo and a 6-mo sinusoid combine to reproduce the mean annual temperature cycle at Christmas Island. Again, the procedure does not indicate whether there exists a process affecting the temperature with a 6-mo periodicity.

Available information indicates that advection is an important process affecting the observed temperature and salinity variations. At Christmas Island large changes in the zonal component of the South Equatorial Current appear to cause large variations in advection. At Koko Head changes in the North Equatorial Current (Wyrtki

1974) do not correlate with the salinity changes, and variations in the meridional component of flow appear to cause the seasonal and long-term salinity changes.

On the basis of the long-term temperature curve at Koko Head (Figure 1B) one might conclude that interannual changes in environmental processes are unimportant. The Koko Head salinity curve (Figure 2B) shows such an inference to be incorrect and illustrates the value of monitoring more than one property at a location.

An understanding of the processes governing the temperature and salinity changes is pertinent to fishery management problems. Our speculations about these processes illustrate that good correlations between environmental properties and biological concentrations do not necessarily imply causal relationships. An example is the good correlation between skipjack tuna captures in the eastern Pacific yellowfin tuna regulatory area and central equatorial Pacific temperatures or the southern oscillation index, the skipjack tuna catches lagging about 18 mo.[5] Do these correlations mean that temperatures in the central equatorial Pacific determine larval survival and year-class strength or do they mean that the currents affect the concentration and distribution of skipjack tuna in the eastern Pacific with the temperature variations being ancillary? These questions are important if environmental factors are to be included in fishery population models.

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[5]Bi-monthly report, November-December 1974. Inter-Am. Trop. Tuna Comm., La Jolla, Calif.

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APPENDIX A

Sea-surface temperatures and salinities, Koko Head, Oahu, 1970-73: Phase angles and coefficients for harmonic functions.

$$S = K + bt + \sum_{n=1}^{k} C_n \cos \omega(nt - \alpha_n),$$

$$\omega = \frac{2\pi}{365} \text{ days}^{-1},$$

t is the time in days beginning with the first day in each year.

APPENDIX A TABLE 1.—Phase angles and coefficients for sea-surface temperatures, Koko Head, 1970-73.

PHASE ANGLES IN DAYS

	N-VALUES												
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13
1970	72.20	-80.01	52.33	38.44	81.41	50.88	-77.02	18.41	-89.79	85.22	-52.91	74.02	-84.68
1971	62.89	31.68	3.24	22.53	71.72	32.74	66.98	3.50	-10.93	-7.10	87.40	-80.98	-74.60
1972	62.93	21.24	68.54	-63.91	64.06	-70.46	83.06	-57.87	-48.34	-43.74	-8.51	76.71	24.69
1973	72.41	-4.17	-88.28	-59.54	-32.96	-89.25	-83.30	-50.69	57.26	-41.10	-19.01	-74.37	80.19

AMPLITUDES

	N-VALUES														
YEAR	K	B	1	2	3	4	5	6	7	8	9	10	11	12	13
1970	25.5140	-0.0039	-1.8222	0.3590	-0.0552	-0.1421	-0.1264	-0.0868	0.1389	-0.1037	0.0876	-0.0646	0.0463	0.0780	0.0461
1971	24.7393	-0.0014	-1.3848	-0.3917	-0.1076	-0.1512	-0.1155	0.0318	-0.0722	0.0299	-0.1358	0.0295	0.0181	-0.0085	-0.0198
1972	24.4534	0.0003	-1.7160	-0.2903	0.0787	-0.1542	0.1731	-0.0360	-0.0577	0.0270	-0.0318	-0.0655	-0.0336	-0.0226	0.0417
1973	23.7849	0.0036	-1.0235	-0.0600	-0.1372	-0.1433	-0.1347	-0.0319	-0.0484	0.0860	0.0569	-0.0463	-0.0632	0.0468	0.0724

APPENDIX A TABLE 2.—Phase angles and coefficients for sea-surface salinities, Koko Head, 1970-73.

PHASE ANGLES IN DAYS

	N-VALUES												
YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13
1970	75.16	-60.43	16.34	70.03	35.34	30.83	-37.70	-38.82	-26.93	-46.86	-77.26	21.73	-2.76
1971	-51.94	-80.21	-63.27	24.14	-45.10	-73.97	60.91	76.63	-34.16	-67.62	-14.74	36.53	-53.75
1972	9.27	-51.54	-89.46	-72.61	-11.74	-20.48	61.79	78.55	59.38	84.94	10.15	24.89	-24.50
1973	-82.26	88.25	23.40	-17.29	1.01	-27.39	-65.68	-60.90	37.04	90.17	-3.22	-50.96	2.98

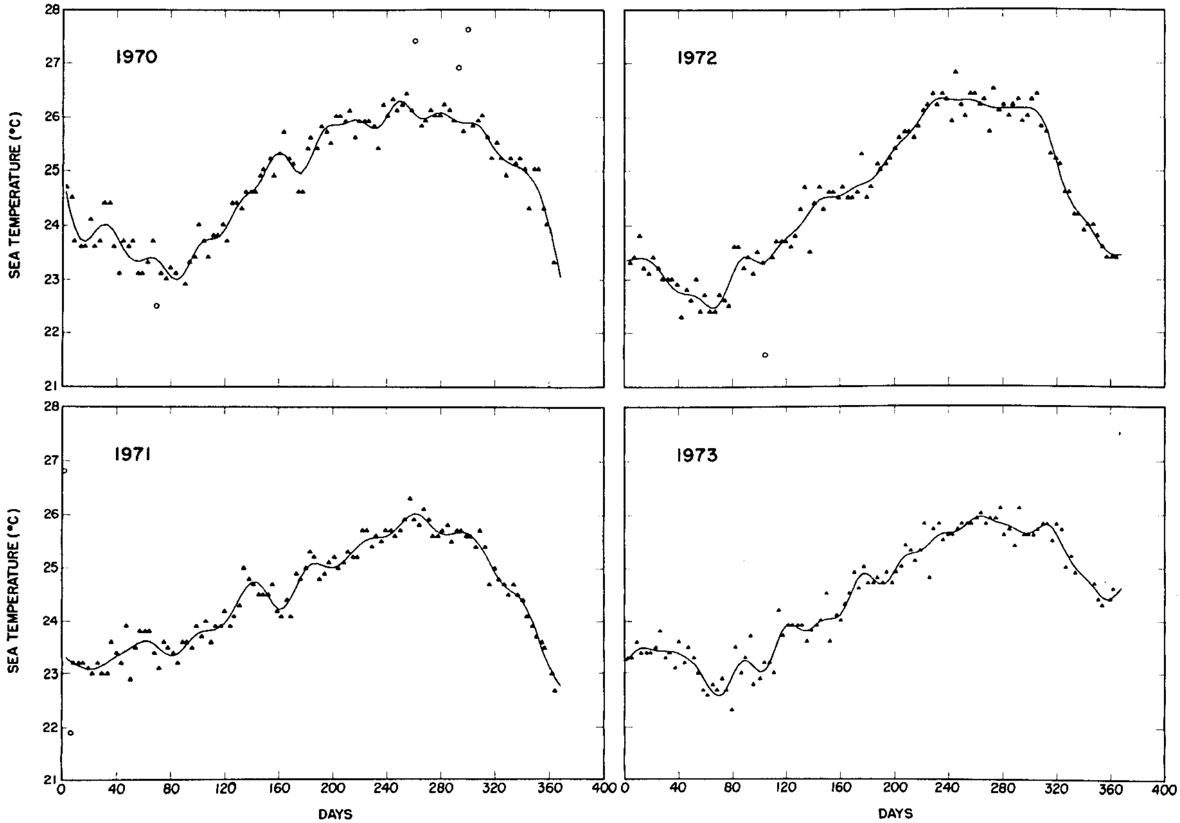
AMPLITUDES

	N-VALUES														
YEAR	K	B	1	2	3	4	5	6	7	8	9	10	11	12	13
1970	34.8321	0.0009	0.0691	-0.0482	-0.0141	0.0196	0.0353	0.0107	-0.0073	0.0024	0.0002	0.0033	0.0059	-0.0115	-0.0105
1971	35.0025	0.0002	0.1115	-0.0132	0.0050	0.0111	-0.0078	0.0208	0.0160	-0.0036	0.0126	-0.0134	-0.0084	-0.0027	-0.0096
1972	34.9629	0.0	0.1838	-0.0807	0.0324	0.0365	0.0209	-0.0133	-0.0010	-0.0046	0.0127	0.0157	-0.0052	0.0089	-0.0085
1973	35.0231	-0.0002	0.0960	0.0213	0.0250	0.0341	0.0401	-0.0057	-0.0190	-0.0220	-0.0207	-0.0270	-0.0018	-0.0116	-0.0175

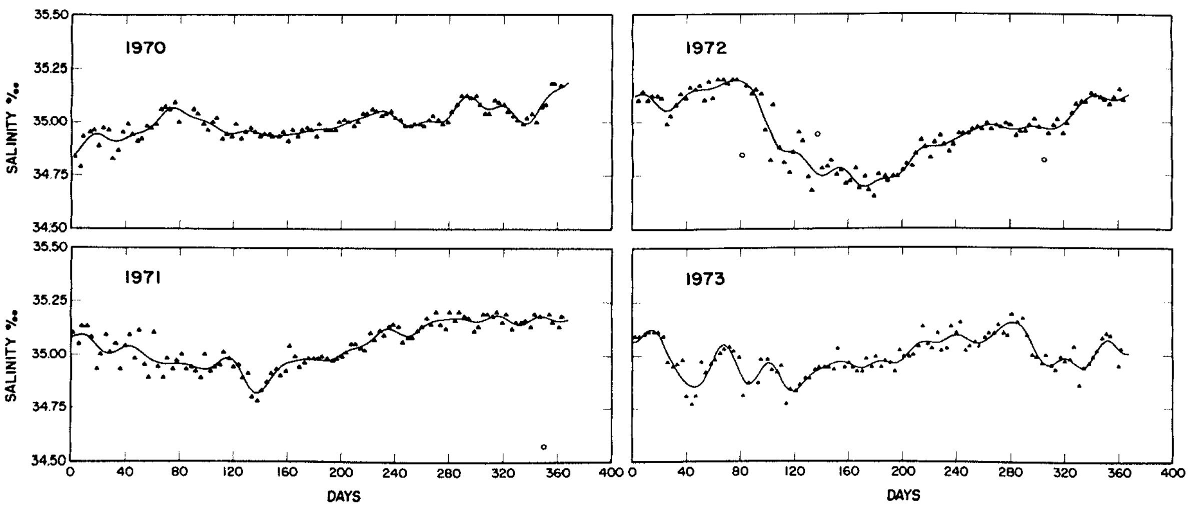
APPENDIX B

Sea-surface temperatures and salinities, Koko Head, Oahu, 1970-73: Fitted curves with observed values for each year.

Note: Circled observations have not been used in the harmonic analysis.



APPENDIX B FIGURE 1.—Sea-surface temperatures, Koko Head, 1970-73.



APPENDIX B FIGURE 2.—Sea-surface salinities, Koko Head, 1970-73.

APPENDIX C

Sea-surface temperatures, Christmas Island, 1970-73: Phase angles and coefficients for harmonic functions for each quarter of the year.

Days 1 to 120 = First quarter,
91 to 210 = Second quarter,
181 to 300 = Third quarter,
271 to 390 = Fourth quarter, extending 25 days into new year,

$$S = K + bt + \sum_{n=1}^{k} C_n \cos \omega (nt - \alpha_n),$$

$$\omega = \frac{2\pi}{120} \text{ days}^{-1},$$

t is the time in days beginning with the first day of each quarter.

PHASE ANGLES IN DAYS

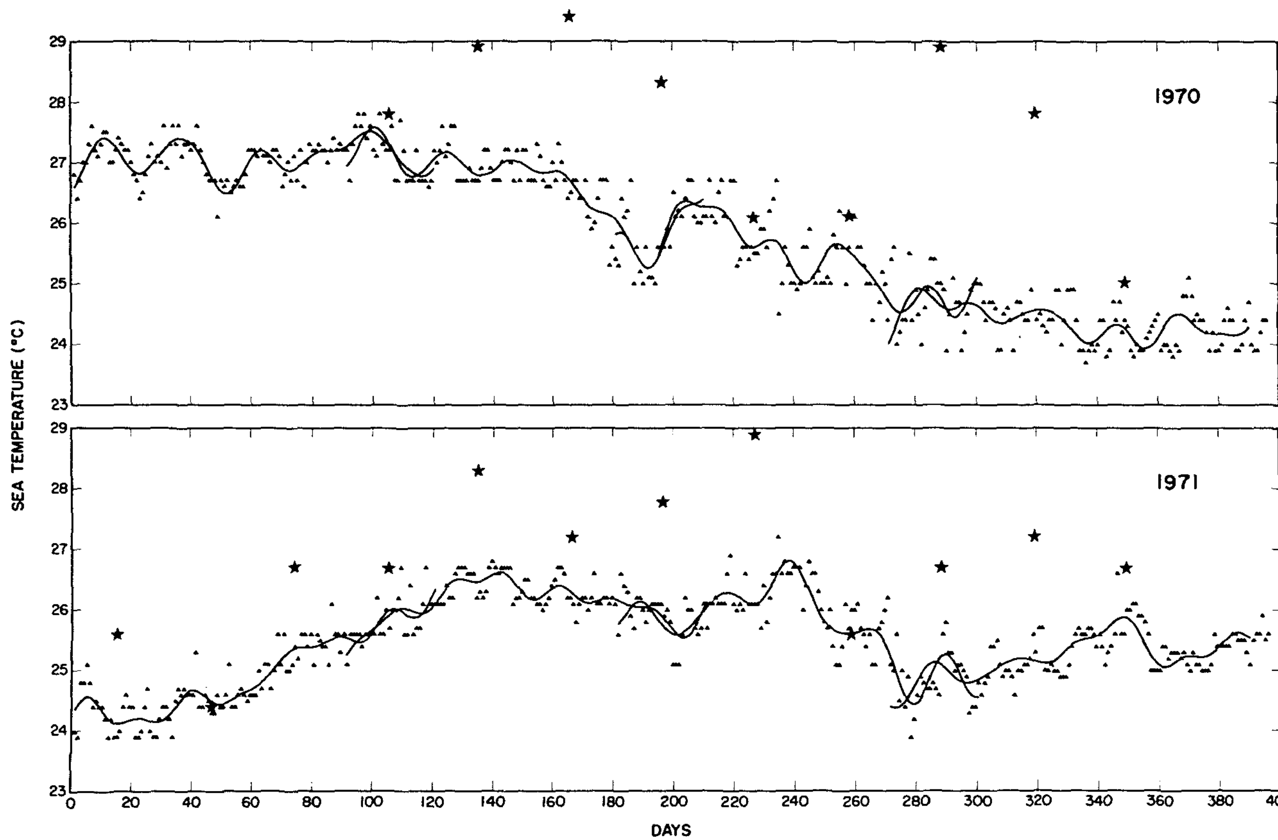
		N-VALUES						
YEAR	QU.	1	2	3	4	5	6	7
1970	1	12.44	-6.13	-16.78	-28.73	-2.08	6.81	16.58
	2	-22.81	17.61	7.60	14.33	0.98	13.95	-6.74
	3	-22.04	-10.25	-16.75	28.25	20.57	9.51	18.38
	4	26.63	-22.46	-18.15	-13.17	25.90	16.12	3.83
1971	1	-9.01	18.72	0.88	-23.22	-19.97	23.78	26.91
	2	-14.62	-11.07	-29.19	-19.30	18.78	-28.03	12.39
	3	-3.95	-4.74	8.40	-13.89	-2.60	-6.05	-20.05
	4	-7.34	24.95	-13.18	3.21	11.76	-16.66	25.18
1972	1	7.89	-27.53	-29.51	-14.94	-26.14	12.85	-22.64
	2	-7.77	-27.22	20.06	4.35	-1.33	21.18	19.69
	3	-6.13	-10.93	-15.60	29.25	28.39	21.23	18.53
	4	1.16	21.36	11.98	1.52	24.55	0.57	-19.27
1973	1	28.56	26.13	9.53	-4.76	-15.17	26.74	24.63
	2	28.96	21.19	12.08	25.17	-8.93	-29.78	-13.43
	3	23.99	-18.26	7.15	-11.40	-20.11	-13.68	16.48
	4	17.68	26.83	-28.88	27.12	-18.74	-21.21	18.01

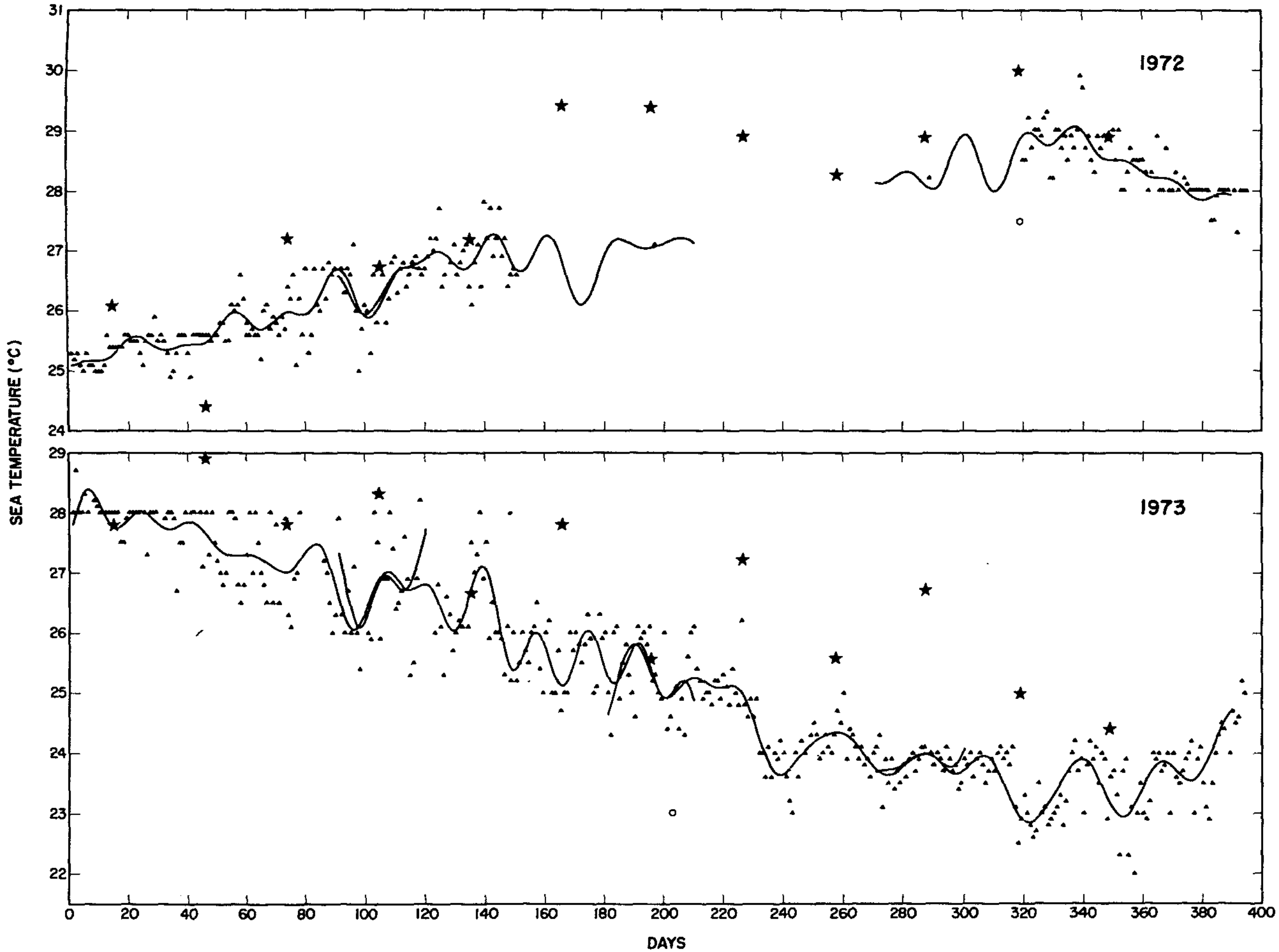
AMPLITUDES

				N-VALUES						
YEAR	QU.	K	B	1	2	3	4	5	6	7
1970	1	26.8641	0.0034	0.0851	-0.1983	-0.0753	-0.2552	-0.1641	0.0452	-0.0599
	2	26.8841	-0.0041	-0.4763	0.3681	0.1609	0.0824	-0.0936	-0.1511	-0.0466
	3	25.7091	-0.0049	-0.4564	-0.2126	0.1819	-0.0754	0.1993	0.0843	0.1664
	4	24.1813	0.0033	0.3638	-0.1038	-0.1890	-0.0981	0.1259	-0.0722	-0.0883
1971	1	23.9165	0.0176	0.1871	0.0905	0.1309	-0.1024	-0.0435	0.0735	0.1056
	2	25.6009	0.0083	-0.5389	-0.1219	-0.1488	-0.1029	0.0518	0.0146	0.0975
	3	26.3106	-0.0098	-0.5171	0.2021	0.0472	0.1281	-0.2729	-0.0850	-0.0912
	4	24.6692	0.0091	-0.2184	0.2117	0.0760	-0.1346	-0.0573	0.0830	-0.0717
1972	1	25.0308	0.0133	0.0496	-0.0682	-0.0819	0.1725	0.0891	-0.0918	-0.1120
	2	26.5641	0.0038	-0.1173	0.2415	-0.1913	0.0576	0.2075	-0.1676	0.1233
	3	27.3256	0.0120	-0.2914	-0.5543	0.5778	-0.2506	0.7280	-0.1929	-0.6557
	4	28.5013	-0.0019	-0.3996	0.1060	-0.0935	0.1104	0.1171	-0.1484	0.1384
1973	1	27.2621	0.0017	0.6704	0.3264	0.2433	0.0114	-0.1570	0.2590	0.0926
	2	27.3407	-0.0223	-0.1509	-0.3212	-0.0538	-0.2381	0.1734	-0.0976	0.3913
	3	24.6561	-0.0033	0.6202	-0.2669	0.2438	-0.2662	-0.1172	-0.1539	-0.0632
	4	23.0800	0.0092	0.5485	0.2358	0.1139	0.2970	0.1569	0.1038	0.0243

APPENDIX D

Sea-surface temperatures, Christmas Island, 1970-73: Fitted curves with observed values for each year. Circled observations have not been used in the harmonic analysis. Stars indicate values taken from *Fishing Information*.





APPENDIX D FIGURE 1.— Sea-surface temperatures, Christmas Island, 1970-73: Fitted curve with observed values for each year. Circled observations have not been used in the harmonic analysis. Stars indicate values taken from *Fishing Information* (see text footnote 3).

APPENDIX E

APPENDIX E TABLE 1.—Standard error of estimate (°C) for each annual temperature function at Koko Head, 1970-73, with harmonic analysis carried out in sequence to $n = 1, 2, 3, \ldots$ and 13.

	n-values												
Year	1	2	3	4	5	6	7	8	9	10	11	12	13
1970	0.41	0.32	0.32	0.30	0.29	0.28	0.26	0.25	0.24	0.24	0.23	0.22	0.22
1971	0.37	0.26	0.25	0.23	0.22	0.22	0.21	0.21	0.18	0.18	0.18	0.18	0.18
1972	0.35	0.29	0.28	0.26	0.23	0.23	0.22	0.22	0.22	0.22	0.21	0.21	0.21
1973	0.29	0.29	0.28	0.26	0.24	0.24	0.23	0.23	0.22	0.22	0.22	0.21	0.21

APPENDIX E TABLE 2.—Standard error of estimate (‰) for each annual salinity function at Koko Head, 1970-73, with harmonic analysis carried out in sequence to $n = 1, 2, 3, \ldots$ and 13.

	n-values												
Year	1	2	3	4	5	6	7	8	9	10	11	12	13
1970	0.055	0.043	0.042	0.040	0.031	0.030	0.029	0.029	0.029	0.029	0.029	0.027	0.026
1971	0.047	0.046	0.046	0.045	0.044	0.042	0.040	0.040	0.039	0.038	0.037	0.037	0.036
1972	0.080	0.058	0.054	0.047	0.044	0.043	0.043	0.043	0.042	0.041	0.040	0.040	0.040
1973	0.068	0.066	0.064	0.059	0.052	0.051	0.050	0.047	0.045	0.040	0.040	0.039	0.037

APPENDIX E TABLE 3.—Standard error of estimate (°C) for each quarterly temperature function at Christmas Island, 1970-73, with harmonic analysis carried out in sequence to $n = 1, 2, 3, \ldots$ and 7.

		n-values									*n*-values						
Year	Quarter	1	2	3	4	5	6	7	Year	Quarter	1	2	3	4	5	6	7
1970	1	0.35	0.32	0.31	0.25	0.23	0.22	0.22	1972	1	0.36	0.35	0.35	0.33	0.32	0.32	0.31
	2	0.46	0.37	0.35	0.35	0.34	0.32	0.32		2	Data sets incomplete or missing						
	3	0.50	0.47	0.46	0.45	0.43	0.43	0.42		3							
	4	0.39	0.38	0.36	0.35	0.34	0.33	0.33		4							
1971	1	0.30	0.30	0.28	0.27	0.27	0.27	0.26	1973	1	0.64	0.60	0.59	0.59	0.58	0.55	0.55
	2	0.30	0.29	0.27	0.26	0.25	0.25	0.24		2	0.71	0.68	0.69	0.66	0.65	0.64	0.58
	3	0.42	0.39	0.38	0.37	0.33	0.32	0.32		3	0.53	0.49	0.46	0.42	0.41	0.40	0.39
	4	0.34	0.31	0.30	0.29	0.28	0.28	0.27		4	0.46	0.43	0.43	0.37	0.35	0.34	0.34

APPENDIX F

Harmonic coefficients for the long-term series. Coefficients for each harmonic term in the series

$$S = a + bt + A_0 + \sum_n (A_n \cos n\omega t + B_n \sin n\omega t)$$

are given in the tables below. Harmonic analysis was performed on the residuals from a linear fit. If t is in months, for the Koko Head series, $\omega = \frac{2\pi}{216}$, and the first month in January 1956; for the Christmas Island series, $\omega = \frac{2\pi}{240}$, and the first month is January 1954.

APPENDIX F TABLE 1.—Coefficients for Koko Head temperature. $a = 23.7009$, $b = 0.0020$.

	0	1	2	3	4	5	6	7	8	9
					A_n					
0	0.5478	−0.1755	−0.1397	0.1131	0.0279	−0.0538	0.0263	0.0583	−0.0782	−0.0245
10	0.0174	0.0760	−0.0642	0.0401	0.0905	0.0168	−0.0439	0.0641	−0.2483	−0.0055
20	0.1262	−0.0126	−0.0035	−0.0263	0.0408	−0.0211	−0.0253	−0.0235	0.0576	−0.0279
30	−0.0428	0.0019	−0.0060	0.0497	−0.0114	0.0191	−0.0134	−0.0348	−0.0041	−0.0258
40	0.0332	0.0042	−0.0024	−0.0502	0.0274	0.0056	0.0239	−0.0040	−0.0171	−0.0274
50	0.0377	−0.0436	0.0015	−0.0116	−0.1030	0.0298	0.0257	0.0154	−0.0007	0.0068
60	0.0162	−0.0113	−0.0050	−0.0267	0.0202	0.0202	0.0231	−0.0107	0.0145	−0.0234
70	−0.0174	0.0117	−0.0067							
					B_n					
0	—	0.0887	0.2135	0.1425	0.0305	0.0989	0.0023	0.0552	0.0418	0.0052
10	0.1329	0.0093	0.0696	0.0044	0.0437	−0.0274	0.0195	−0.0056	−1.4540	0.0197
20	0.0262	0.0509	0.0531	0.0198	0.0676	0.0572	−0.0049	0.0035	0.0105	−0.0409
30	−0.0313	0.0422	−0.0177	−0.0767	−0.0058	0.0373	−0.1468	−0.0175	0.0347	0.0226
40	0.0519	0.0306	0.0078	−0.0188	−0.0288	0.0258	0.0207	−0.0533	0.0105	−0.0327
50	0.0151	−0.0145	0.0652	−0.0230	−0.0113	−0.0283	−0.0074	0.0238	0.0050	0.0090
60	0.0188	−0.0138	0.0200	0.0272	−0.0316	−0.0222	0.0053	−0.0254	0.0177	−0.0083
70	0.0011	−0.0167	−0.0020							

APPENDIX F TABLE 2.—Coefficients for Koko Head salinity. $a = 35.0141$, $b = 0.0001$.

	0	1	2	3	4	5	6	7	8	9
					A_n					
0	−0.1228	0.0366	0.0685	−0.0653	−0.0894	0.0441	−0.0034	−0.0048	0.0165	0.0163
10	0.0286	−0.0017	0.0109	−0.0128	−0.0156	0.0024	0.0043	0.0093	0.0903	−0.0020
20	−0.0004	−0.0095	0.0032	−0.0127	0.0017	−0.0035	0.0020	−0.0101	−0.0034	0.0028
30	0.0020	0.0117	−0.0043	−0.0097	−0.0132	−0.0023	−0.0091	0.0094	−0.0067	−0.0039
40	−0.0057	0.0085	0.0070	0.0040	−0.0136	−0.0098	−0.0035	0.0041	0.0030	−0.0053
50	−0.0031	−0.0062	0.0070	0.0130	−0.0002	−0.0092	−0.0053	−0.0002	0.0064	0.0046
60	−0.0006	−0.0048	−0.0039	−0.0021	0.0013	−0.0008	−0.0063	0.0002	0.0014	−0.0022
70	0.0089	−0.0016	0.0028							
					B_n					
0	—	0.0663	−0.0287	−0.0063	0.0206	0.0174	−0.0532	0.0026	−0.0221	0.0006
10	−0.0372	−0.0034	−0.0095	−0.0047	0.0268	−0.0041	0.0007	−0.0199	0.0085	0.0034
20	−0.0099	−0.0050	−0.0075	−0.0012	−0.0108	0.0020	0.0058	0.0075	0.0131	0.0026
30	0.0109	0.0028	0.0088	0.0086	−0.0105	−0.0095	0.0021	0.0126	0.0043	0.0138
40	−0.0050	−0.0067	−0.0039	0.0158	−0.0005	−0.0121	−0.0124	0.0064	0.0125	0.0092
50	−0.0002	0.0028	0.0037	0.0001	0.0050	0.0003	0.0001	−0.0089	−0.0003	−0.0000
60	0.0074	0.0108	−0.0071	−0.0070	0.0059	−0.0028	0.0028	0.0049	−0.0011	0.0007
70	0.0072	−0.0021	0.0015							

APPENDIX F TABLE 3.—Coefficients for Christmas Island temperature. $a = 26.1443$, $b = -0.0054$.

	0	1	2	3	4	5	6	7	8	9
					A_n					
0	1.5694	−0.2024	−0.3409	−0.1310	0.1924	0.3505	−0.1455	−0.4605	−0.1400	−0.2839
10	0.1658	−0.3162	0.0228	−0.2507	−0.0381	0.1309	0.2614	0.0088	−0.0257	0.0569
20	−0.4204	−0.0517	−0.0635	0.0676	0.0431	0.0179	0.0014	−0.0727	−0.0298	−0.0637
30	0.0295	−0.0316	−0.0583	−0.0133	0.0264	0.0040	0.0073	−0.0021	−0.0587	−0.0397
40	0.1025	−0.0243	−0.0049	0.0496	−0.0108	0.0176	0.0054	−0.0458	0.0351	−0.0144
50	0.0100	0.0321	0.0211	−0.0272	0.0145	−0.0076	0.0085	0.0031	−0.0410	0.0141
60	0.0369	−0.0001	0.0292	−0.0495	−0.0385	−0.0080	−0.0065	0.0232	−0.0204	0.0170
70	0.0134	0.0126	−0.0021	−0.0141	0.0203	−0.0178	−0.0085	0.0325	0.0144	0.0445
80	0.0022									
					B_n					
0	—	−0.8028	−0.2146	−0.6457	−0.4963	−0.3942	−0.3880	0.1339	−0.1839	0.0969
10	−0.1253	0.1038	0.1556	−0.0039	0.0555	0.2400	0.1030	0.1198	−0.0589	0.1246
20	0.0883	0.0041	0.0403	−0.1501	−0.0233	0.0791	−0.0622	−0.0063	0.0252	0.0138
30	0.0456	0.0172	0.0133	−0.0420	−0.0357	0.0625	0.0097	0.0054	0.0347	−0.0026
40	−0.1791	−0.0090	0.0979	−0.0668	−0.0407	0.0247	0.0003	−0.0241	0.0154	−0.0151
50	0.0073	0.0230	0.0144	0.0196	−0.0277	−0.0250	0.0374	−0.0110	0.0054	0.0258
60	−0.0250	0.0336	−0.0219	−0.0223	−0.0124	−0.0314	0.0035	−0.0044	0.0041	0.0267
70	−0.0323	0.0071	−0.0183	−0.0084	0.0289	−0.0417	0.0431	−0.0055	0.0038	0.0022
80	0.0022									