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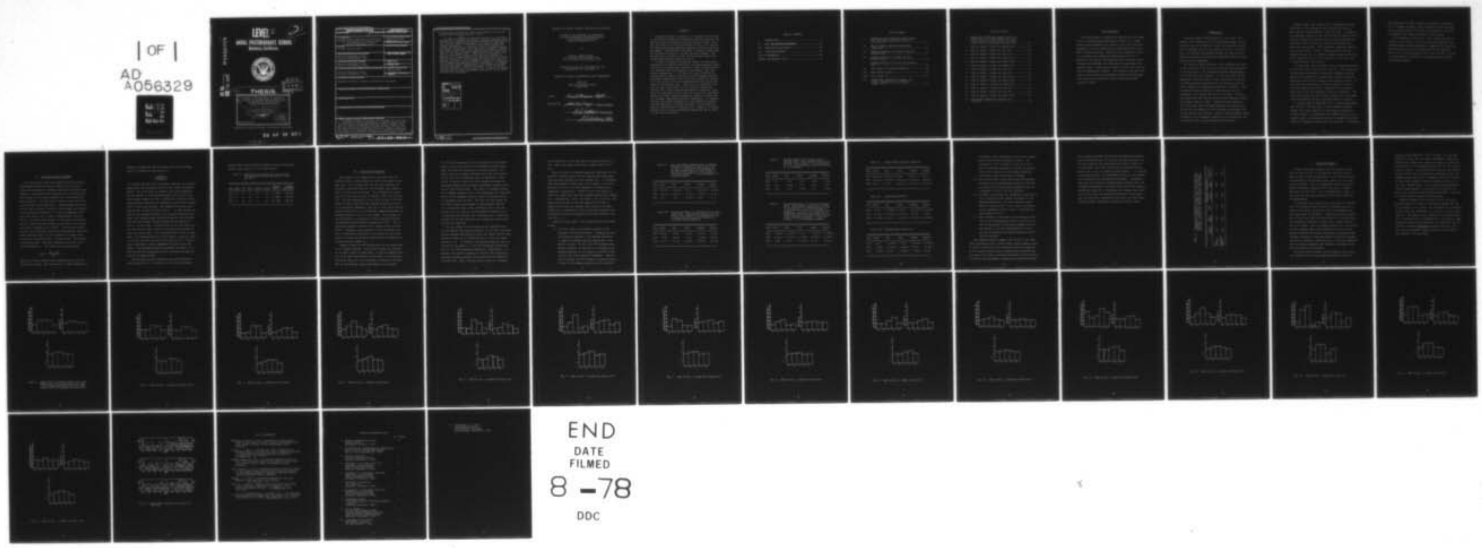

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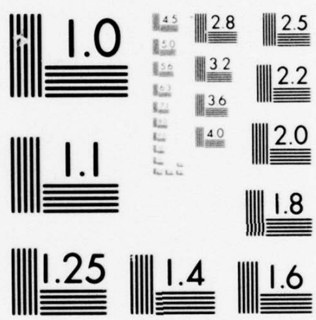

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NAVAL POSTGRADUATE SCHOOL

Monterey, California

9 Master's THESIS,

6 A STUDY OF THE VARIATION OF CONVECTIVE ACTIVITY ASSOCIATED WITH EASTERLY WAVES IN THE TROPICAL PACIFIC USING SATELLITE RADIATION DATA.

by

10 Vincent Francis Looft

11 March 1978

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Thesis Advisor: C.-P. Chang

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A composite study is carried out to deduce the structure of convective activity associated with easterly waves at five tropical Pacific radiosonde stations, Majuro, Ponape, Truk, Yap, and Koror, for the latter halves of 1974, 1975 and 1976. The data used include digitized satellite infrared radiation and albedo. The resultant structure, in general, shows maximum convective activity in or near the wave troughs. The

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered) distribution is similar to that of the humidity field composited previously by Bepristis (1977).

In order to examine the possible effects of sea-surface temperature on tropical convection, the wave-organized convection and the seasonal-mean convective fields as indicated by the satellite data are compared to the seasonal mean sea-surface temperature. It is found that west of Majuro the interannual and spatial variation of the 10-degree upstream sea-surface temperature have a much better positive correlation with those of the wave-organized convective field than those of the seasonal mean. This result is consistent with that for the latter halves of 1972 and 1973 obtained by Delaney (1977) using subjectively-digitized satellite cloud data, and Bepristis' (1977) result of a positive correlation between the waves' upper-tropospheric thermal structure and the 10-degree upstream sea-surface temperature. It suggests that the sea-surface temperature in the immediate upstream vicinity may exert a positive influence on the convective activity modulated by an easterly wave. However, no similar influence of the local sea-surface temperature can be found for the total convection.

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A Study of the Variation of Convective Activity Associated with Easterly Waves in the Tropical Pacific Using Satellite Radiation Data

by

Vincent Francis Looft
Lieutenant, United States Navy
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Submitted in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE IN METEOROLOGY AND OCEANOGRAPHY

from the

NAVAL POSTGRADUATE SCHOOL
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ABSTRACT

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I. INTRODUCTION

Previous studies (Chang and Miller, 1977; Maas, 1977; Delaney, 1977; Bepristis, 1977) have analyzed upper air and satellite data in an effort to study the interannual variation of easterly waves in the tropical Pacific. In particular, the possible relationship between the long term and spatial variations of sea-surface temperature (SST) and mean zonal wind were diagnosed.

The study by Chang and Miller (1977) analyzed the effect of the variation of the SST on the structure and properties of easterly waves. Two eight-month periods (May-December) in 1972 and 1973 were analyzed. It was found that the SST appeared to have the effect of both controlling the amount of cumulus heating associated with the waves and also possibly changing the large-scale mean wind circulation. This was deduced from the effects of both warm and cold SST anomalies in the eastern Pacific for two years. Also the wave amplitudes and vertical structure were markedly different between these two years. During the warm anomaly of 1972, the waves were equivalent barotropic in nature while during the cold anomaly of 1973 there was considerable tilt of wave axes in the vertical. Based on these findings, Chang and Miller (1977) proposed a model for the influence of SST variations on the 4-5 day easterly wave structure.

Another study, that of Maas (1977), examined the radiosonde data of five western Pacific stations for two six-month periods (June-November) in 1972 and 1973. A compositing technique, similar to that used by Reed and Recker (1971) and Reed, Norquist and Recker (1976), provided detailed information on the structure of tropical disturbances for these two time periods. This study more completely defined the easterly waves in terms of temperature and relative humidity fields, and, in general, supports Chang and Miller's (1977) finding of little or no vertical tilt for 1972 and a strong vertical tilt for 1973.

A third study, that of Delaney (1977), analyzed satellite data for the latter halves of 1972 and 1973. The subjectively-determined percentage of convective cloudiness was compared to the composites of temperature, relative humidity, meridional winds and SST, deduced from previous studies. He found that the SST appears to have an important effect on the local convective activity, organized by the tropical waves, but not on the time-mean convective cloudiness. The latter was found to be more likely influenced by the larger-scale SST gradient and the associated Walker circulation.

A fourth study, by Bepristis (1977), examined radiosonde data for 1974, 1975 and 1976, for the islands of Majuro, Ponape, Truk, Yap, Koror and in the tropical central and western Pacific. He found that the thermal structure of the easterly waves was influenced more by the immediate upstream (about 10° longitude) SST than by the local SST. In addition, there was found to exist a positive correlation coefficient of 0.71 between the phase of the vertical tilt of the waves and the vertical shear of the mean zonal wind for 1972-1976, in agreement with Chang and Miller's (1977) result.

As an extension of Bepristis' (1977) study, the main objective of this work is to use the satellite radiation data available from the NOAA satellite to composite the convective field associated with the easterly waves in the tropical Pacific of the latter halves of 1974, 1975 and 1976, in order to study possible influences on the easterly waves by SST, during these periods.

II. DATA AND ANALYSIS PROCEDURE

For this project, data were obtained from the National Environmental Satellite Service (NESS), which provided digitized information of infrared radiation, available solar radiation and absorbed solar radiation for the entire globe from January 1974 through September 1976 as measured from NOAA satellites. The data are in radiative flux form, with values in watts per square meter. Area-averaged values for day and night infrared, available solar energy, and absorbed solar energy were available on a 125x125 hemispheric grid. Each grid value is for an area of approximately 150 km x 150 km. The grid points nearest to the western and central Pacific island stations included in Bepristis' (1977) study were used to represent the stations. For stations located between two or more grid points with approximately equal distance from each point, it was necessary to average values from two or four grid points. At each station, three types of data were used. They were infrared, albedo and a combined parameter "C". The albedo was calculated using

$$\text{albedo} = \frac{E_{av} - E_{ab}}{E_{av}} ,$$

where E_{av} is the available solar energy and E_{ab} is the absorbed solar energy. The new quantity C, which combines the measure of brightness from the albedo and cloud top height from the infrared data was derived by

$$C = \frac{\text{albedo}}{(\text{infrared})^{\frac{1}{4}}} \; .$$

It is hoped that this value can better represent the relative magnitude of the convective activity than either infrared or albedo. The three types of satellite data were composited for the periods of July through December 1974 and 1975 and July through October of 1976, to obtain the convective field associated with easterly wave passages at each station during each of these three periods. The composite technique used follows that of Reed and Recker (1971). At each station the time for the maximum northerly wind, maximum southerly wind, ridge, and trough passages during each period were available from the wave passage statistics generated by Bepristis' (1977). In his study, a filtered form of the time cross section was used in order to select only waves with periods between two and ten days. The filtering caused a loss of seven days at the beginning and end of each season, leaving a total of 170 days for 1974 and 1975 and 85 days for 1976. Table I gives the number of waves composited for each station and season. The averaged period and wavelength are about 4 to 5 days and 3000 km, respectively; which are about the same for each of the three seasons.

The SST data for this study were produced from monthly charts compiled by Dr. D. McCline, of the Pacific Environmental Group, National Marine Fisheries Service which give monthly mean values at $5^{\circ} \times 5^{\circ}$ grid squares.

Table I. Numbers of waves analyzed, which passed the indicated stations during 1974, 1975, and 1976.

YEAR	KOROR	YAP	TRUK	PONAPE	MAJURO	AVERAGE PERIOD	AVERAGE WAVELENGTH
1974	39	36	41	40	40	4.4 DAYS	2930 KM
1975	40	37	39	44	38	4.4 DAYS	2930 KM
1976	17	18	19	17	22	4.4 DAYS	2930 KM

III. RESULTS AND DISCUSSION

The results of the composites of all three types of satellite data at each station and period are shown in Figures 1-15. It is evident that for all three measures the principal convective activity (low infrared, high albedo or high C) occurs near the trough. This finding is in consonance with previous findings of Delaney (1977) for 1972 and 1973. The only exceptions to this occur at Yap in 1975 and Majuro in 1976, which have the maximum convective activity in the southerly components, and Truk in 1976, which has the maximum albedo and C in the northerly component—although its minimum infrared is still in the trough. The skewness of the distribution of convective activity generally follows the moisture pattern deduced by Bepristis (1977). This is especially apparent for Yap (1975), Majuro (1976) and Truk (1976). Otherwise, there appears to be no systematic spatial or interannual variation in the pattern of the distribution of convective fields as implied by the composites of either infrared, albedo or C.

Figure 16 shows the SST distribution for all three years in the tropical Pacific. The island stations are depicted by the first letter of their name. It must be remarked that, due to the much lower density of data west of the dateline, SST values there are not as reliable as farther to the east. West of the dateline, heavy smoothings of the original

$5^{\circ} \times 5^{\circ}$ grid data were used in the analysis of the figure. Table II lists the values of the 10-degree upstream (eastward) SST from each station for the three periods. The reason that the 10-degree upstream values are used instead of the local SST is primarily based on Bepristis' (1977) study, in which he found that the 10-degree upstream SST correlates better with the upper tropospheric thermal structure of the easterly waves. The result is probably because the 10-degree upstream SST in a way represents the integrated effect of the immediate history a wave has experienced as it propagates from the east. The waves in these three periods have a typical wavelength of approximately 3000 km. It is conceivable that a wave travelling over a warm sea surface for, say, 1500 km, would undergo a different kind of influence than another wave travelling over a colder sea surface for the same distance, even though the final points may have the same SST.

For the purpose of facilitating later comparison with the interannual and spatial variations of the wave convective pattern deduced from satellite data, the highest SST for each station in Table II is indicated with a (+) and the lowest SST with a (-). In addition, the spatial variations are indicated by the arrows ($\nwarrow$), for SST increasing toward west, and ($\swarrow$) for SST decreasing toward west, respectively. In general, the spatial variation of the SST shows basically a westward increase, although local exceptions were noticed in 1975 and 1976. Also, for each station there is a decrease in SST from 1974 to 1975 and then an increase from 1975 to 1976, except for Majuro which has no change from 1975 to 1976.

Table III shows the maximum departure (amplitude) of the negative infrared values from the seasonal mean associated with each wave category for 1974 through 1976. In instances where the maximum is other than in the trough, it is so indicated by an "n" or "s" for northerly or southerly wind categories, respectively. Tables IV and V are similar to Table III, except that they show maximum departures of albedo and C, respectively. Also, for Table V, the (+) and (-) and arrows are indicated in the same manner as in Table II. Tables VI-VIII show the seasonal mean values of infrared, albedo and C, respectively, with the spatial variations and interannual variations indicated by the same notations (arrows and +, -).

Looking at these tables, the following points are worth noting:

(1) For 1974, there is a westward increase in SST throughout the station network. Accompanying this are westward increases in the maximum departures of negative infrared, positive albedo and C from Majuro to Koror. In 1975, the SST increases from Majuro to Ponape, in contrast to a decrease of the maximum departure of the convective activity indicated by the three satellite parameters. However, west of Ponape, the SST changes in a manner similar to that of the maximum departure of the satellite

Table II. Mean sea-surface temperatures 10 degrees upstream (eastward) of each station with (+) and (-) indicating the maximum and minimum respectively for each island in the three year period and the arrows indicating increases (↖) and decreases (↙) toward the west.

Year	Koror	Yap	Truk	Ponape	Majuro
1974	29.4(+)	29.4(+)	↖ 28.8	↖ 28.6(+)	↖ 28.0(+)
1975	28.7(-)	↙ 29.0(-)	↖ 27.8(-)	↙ 28.0(-)	↖ 27.8(-)
1976	29.1	29.1	↙ 29.3(+)	↖ 28.5	↖ 27.8

Table III. Maximum deviation of infrared from the seasonal mean. When maximum values occur outside of the trough it is indicated by an n or following the value for northerly or southerly wind categories.

Year	Koror	Yap	Truk	Ponape	Majuro
1974	-14.16	-12.9	-9.87	-5.43	-4.39
1975	-5.64	-11.1s	-7.8	-9.69n	-21.64
1976	-4.77	-11.45	-27.65	-13.18	-13.83s

Table IV. Maximum deviation of albedo from the seasonal mean. When maximum values occur outside of the trough it is indicated by an n or s following the value for northerly or southerly.

Year	Koror	Yap	Truk	Ponape	Majuro
1974	5.5	4.99	3.57	3.08	1.69n
1975	1.04	4.42s	1.28	2.61	4.69
1976	3.28	4.53	7.58n	3.1	3.92s

Table V. Maximum deviation of C from the seasonal mean. When maximum values occur outside of the trough it is indicated by an n or s following the value for northerly or southerly. A (+) or a (-) indicates the maximum and minimum respectively in the three year period for each island and the arrows indicate increases (↖) and decreases (↙) with westward movement.

Year	Koror	Yap	Truk	Ponape	Majuro
1974	1.61(+)	↖ 1.40(+)	↖ 1.01	↖ 0.86(+)	↖ 0.56n(-)
1975	0.30(-)	↙ 1.21(-)	↖ 0.38(-)	↙ 0.75(-)	↙ 1.48(+)
1976	0.88	↙ 1.32	↙ 2.24(+)	↖ 0.83	↙ 1.25s

Table VI. Seasonal-mean infrared radiation.

Year	Koror	Yap	Truk	Ponape	Majuro
1974	241.4(-)	235.2(-)	241.5	235.9	236.2
1975	244.6(+)	245.5(+)	246.1(+)	242.4(+)	239.8(+)
1976	241.9	235.9	236.2(-)	235.2(-)	230.7)-)

Table VII. Seasonal-mean albedo.

Year	Koror	Yap	Truk	Ponape	Majuro
1974	27.03	30.98(+)	28.91	32.28(+)	34.02(+)
1975	26.38(-)	27.08(-)	27.95(-)	32.16	33.28
1976	28.44(+)	30.39	34.63(+)	30.28(-)	32.80(-)

Table VIII. Seasonal-mean values of C.

Year	Koror	Yap	Truk	Ponape	Majuro
1974	7.05	8.20(+)	7.55	8.48(+)	9.07(+)
1975	6.90(-)	7.10(-)	7.26(-)	8.41	8.78(-)
1976	7.46(+)	8.03	9.28(+)	7.94(-)	8.84

indicators: first decreasing to Truk, then increasing to Yap and then decreasing to Koror. The situation of 1976 is similar to that of 1975 in that the westward variation of the SST is synchronous to the variation of the maximum departure quantities, except from Majuro to Ponape.

(2) On the other hand, within each period the spatial variation of the seasonal-mean convective activity as indicated by the satellite parameters does not correspond to that of the SST variation.

(3) If Majuro is excluded, the interannual variation of SST is paralleled with similar variations in the maximum departures of all three satellite parameters at each station. For C, this is indicated by the agreement of the (+) and (-) positions between Tables II and V.

(4) Also if Majuro is excluded, the interannual variation of the seasonal-mean convective activities at each station seems to correspond somewhat with the SST variation, but the correspondence is not as good as that between the maximum departure quantities and the SST.

The foregoing results suggest that the SST in the immediate upstream vicinity of each island station seems to have an effect on the part of the convective activity organized by the easterly waves, while a similar effect probably does not exist on the total convective cloudiness at each station. To confirm this hypotheses, correlation coefficients between the 10-degree upstream SST and both the maximum departures and the seasonal means of the three satellite measures, for all three periods, are calculated and listed in Table IX. In this table, the first line is for all stations and the second line is for all stations except Majuro. It is obvious that without Majuro, the easternmost station in the network, the correlations are significantly improved. Considering this case only, among the seasonal-mean variables only the infrared is marginally correlated with the SST (the negative coefficient means SST is correlated with higher cloud tops). On the other hand, the departure quantities, which represent the convection organized by the waves, all have significantly higher correlation coefficients with the SST.

Table IX. Correlation coefficients between SST and satellite variables of infrared, albedo, and C for 1974, 1975, and 1976. Values are computed for all the island stations and also for all the islands except Majuro.

	Mean Infrared	Mean Albedo	Mean C	Deviation of Infrared	Deviation of Albedo	Deviation of C
All Islands	.017	-.339	-.32	-.153	.569	.49
Excluding Majuro	-.405	.025	.079	-.428	.764	.747

IV. CONCLUDING REMARKS

The main conclusion inferred from the results of this study is that the SST in the immediate upstream vicinity seems to exert a positive influence on the convective activity modulated by the easterly waves, but not on the total convective field. This is in agreement with the 1972-1973 results obtained by Delaney (1977), who found a similar effect by the local SST. After re-examining his result, it was found that the same conclusion can be drawn using the 10°-upstream SST.

On the other hand, Delaney also found that the distribution of the seasonal-mean convective cloudiness may be related to the Walker circulation, which is correlated with the larger-scale SST gradient. Comparing the mean satellite data in this study with the cross-section of the mean zonal wind compiled by Bepristis (1977), such a simple relation can not be found. This is probably because 1972 and 1973 are the most extreme years of SST anomalies in the five year period; therefore the strong contrasting SST gradients have stronger influences in the mean Walker circulation and mean convective cloudiness, while from 1974 to 1976 the anomalies were not strong enough for any systematic influence on the mean cloudiness to be detected.

The result that at Majuro the SST seems to lack a positive influence on the wave-organized convective field is consistent with Bepristis' (1977) finding. For the same periods, he found that the upper tropospheric temperature differential between wave troughs and ridges is positively correlated with the 10-degree upstream SST for all stations except at Majuro. He postulated that waves in the eastern-central Pacific may be instigated by mechanisms other than thermal forcing and have not undergone sufficient influence of latent heat release to become thermally driven by the time they reached Majuro. As the waves continue westward, the continued exposure to increasing SST transforms the waves into convective heating dominated systems. The present result seems to support this hypothesis.

Recently, Ramage (1977) pointed out that the often-believed theory of a positive correlation between SST and local rainfall is not always true, especially in the eastern Pacific where the correlation, if it exists, is more likely negative. The present result agrees with his observation, but it indicates that, if organization is provided by large (synoptic)-scale wave disturbances, the warmer SST may contribute to enhanced <u>modulated</u> convective activity, with more rainfall probably occurring near the wave trough at the expense of the wave ridge.

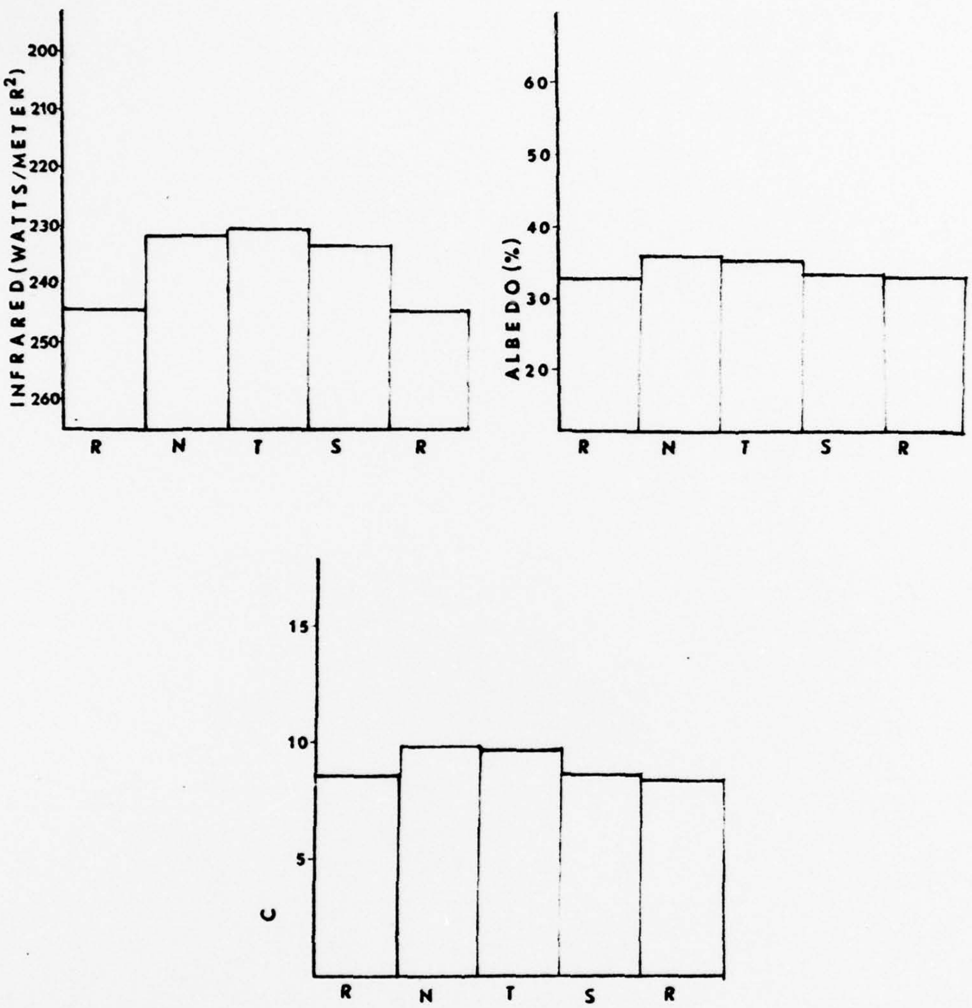

Figure 1. Composites of infrared, albedo, and C for Majuro 1974 with R indicating wave ridge, S for maximum southerly wind, T for wave trough, and N for maximum northerly wind.

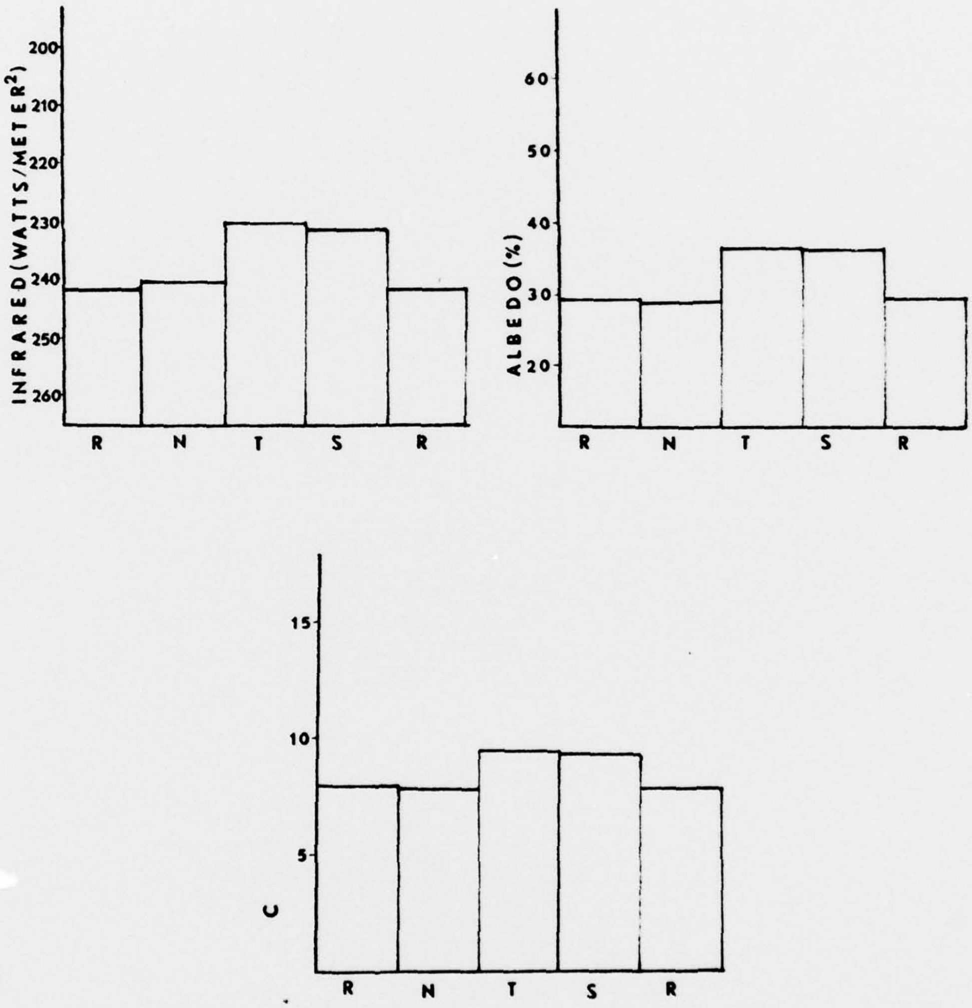

Fig. 2. Same as Fig. 1, except for Ponape 1974.

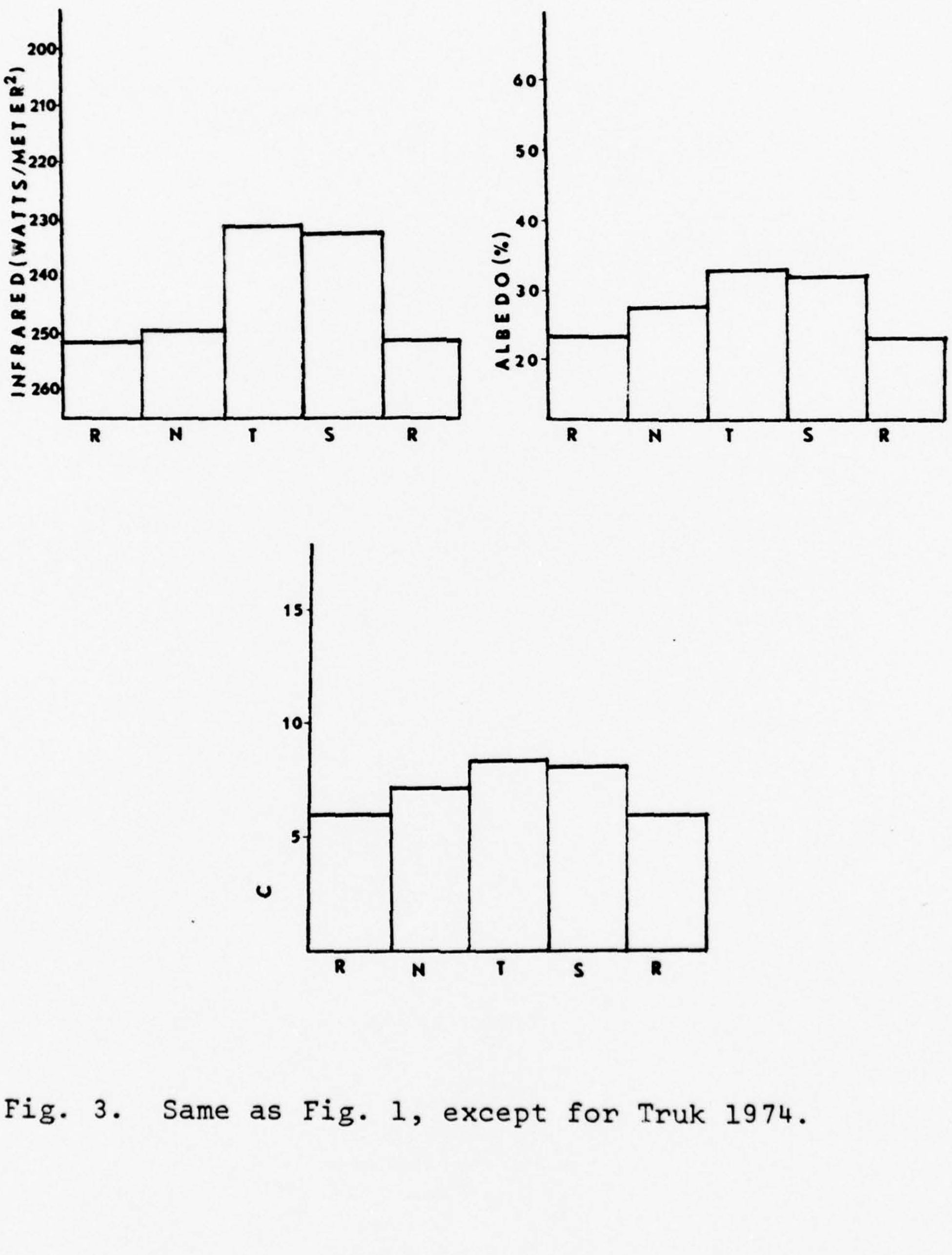

Fig. 3. Same as Fig. 1, except for Truk 1974.

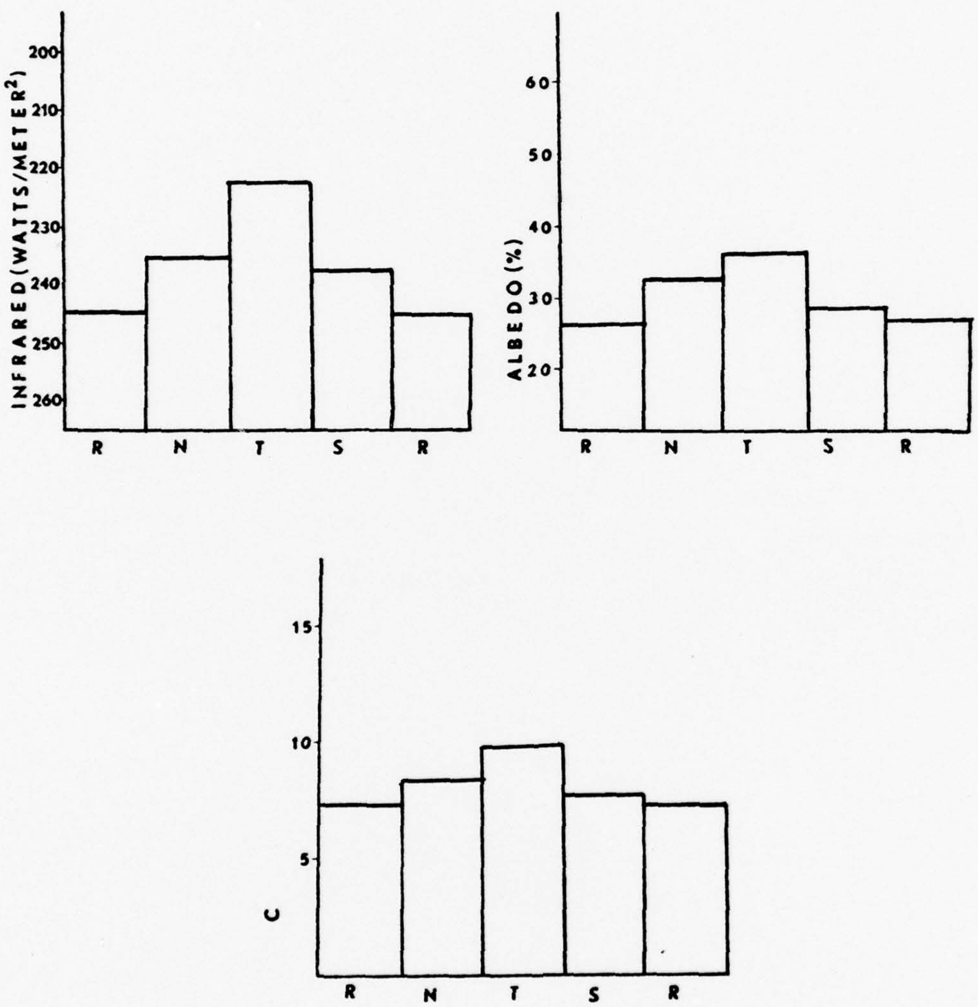

Fig. 4. Same as Fig. 1, except for Yap 1974.

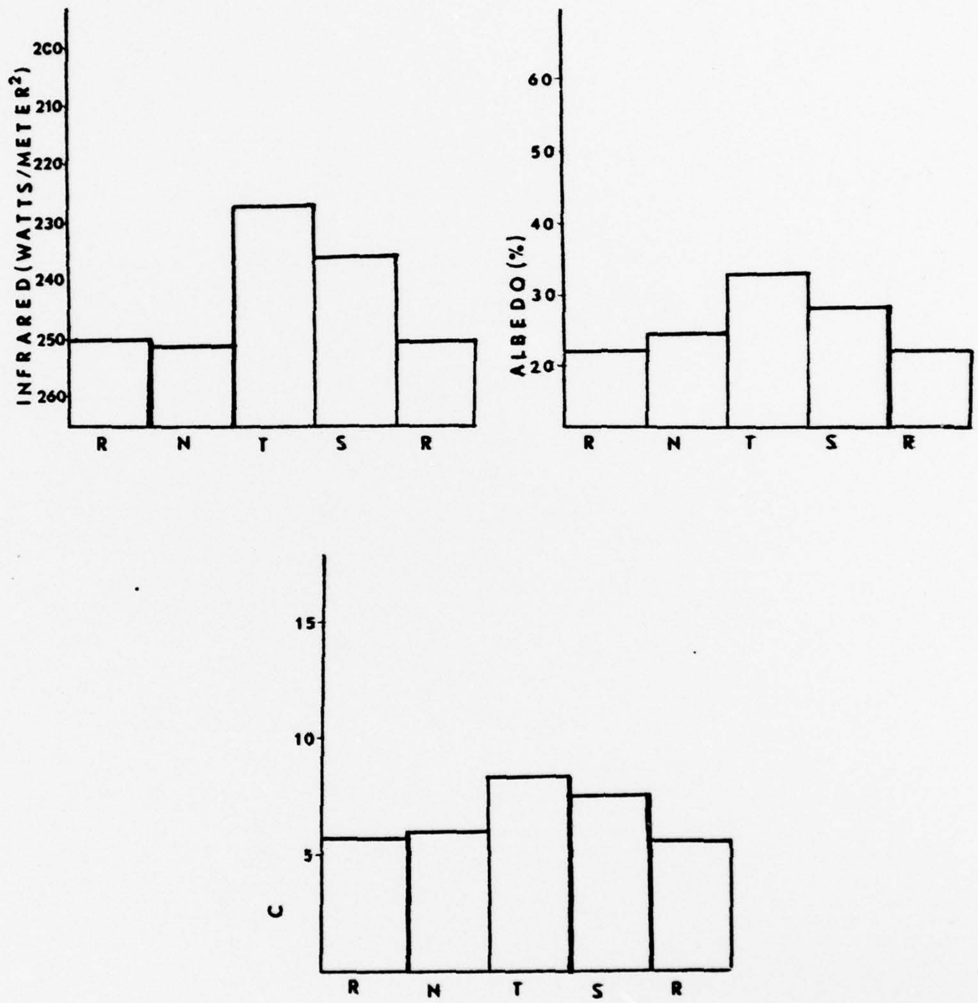

Fig. 5. Same as Fig. 1, except for Koror 1974.

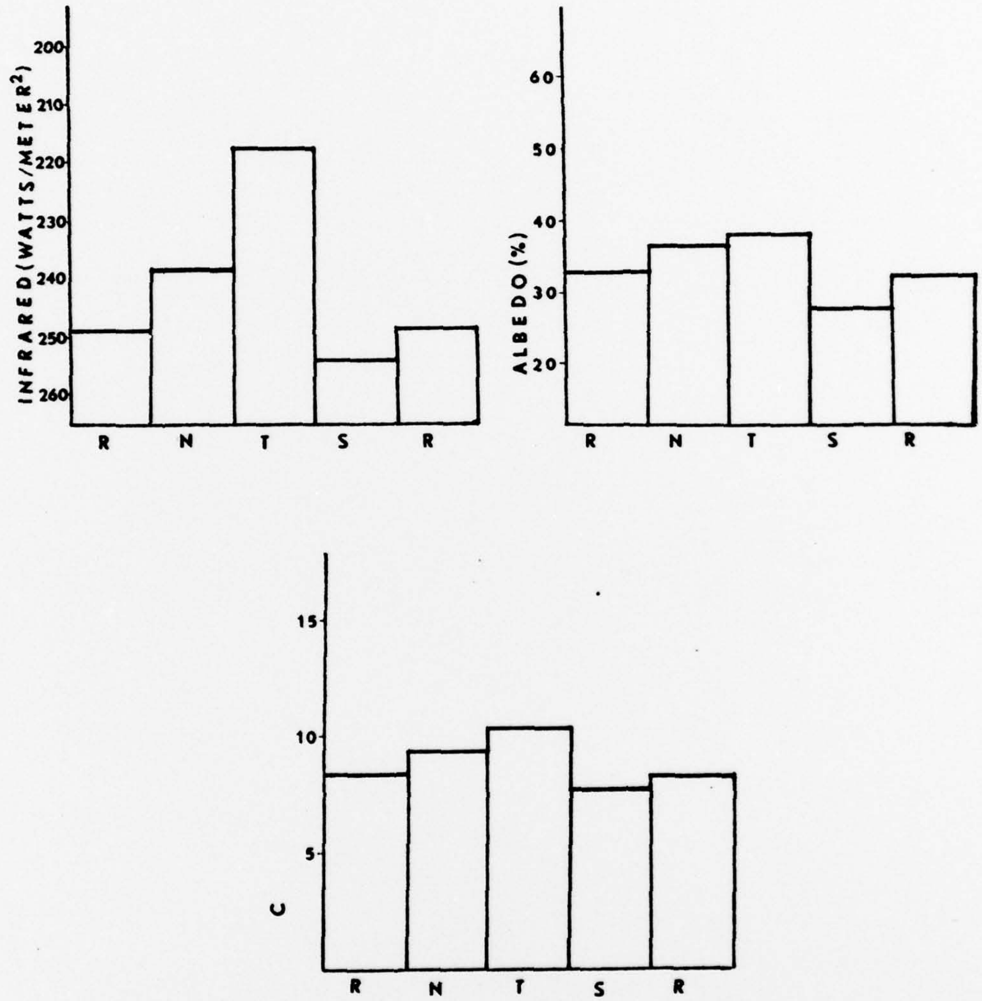

Fig. 6. Same as Fig. 1, except for Majuro 1975.

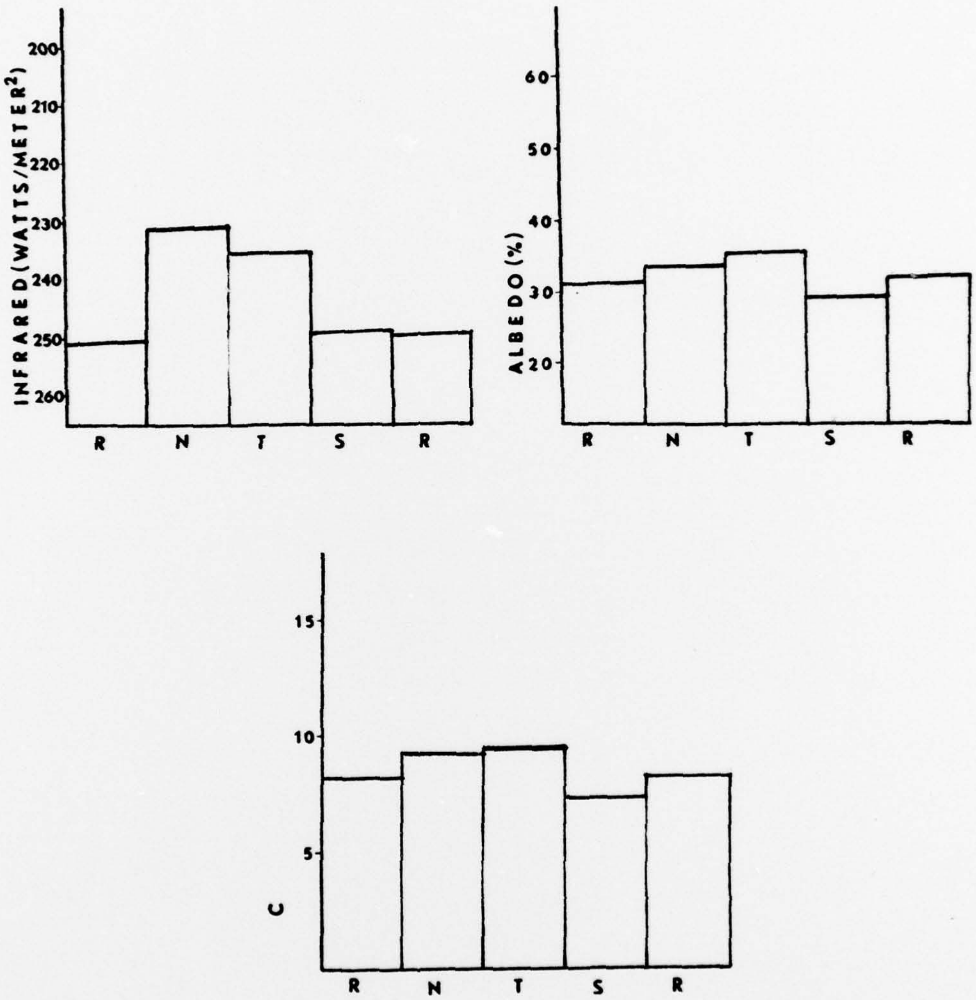

Fig. 7. Same as Fig. 1, except for Ponape 1975.

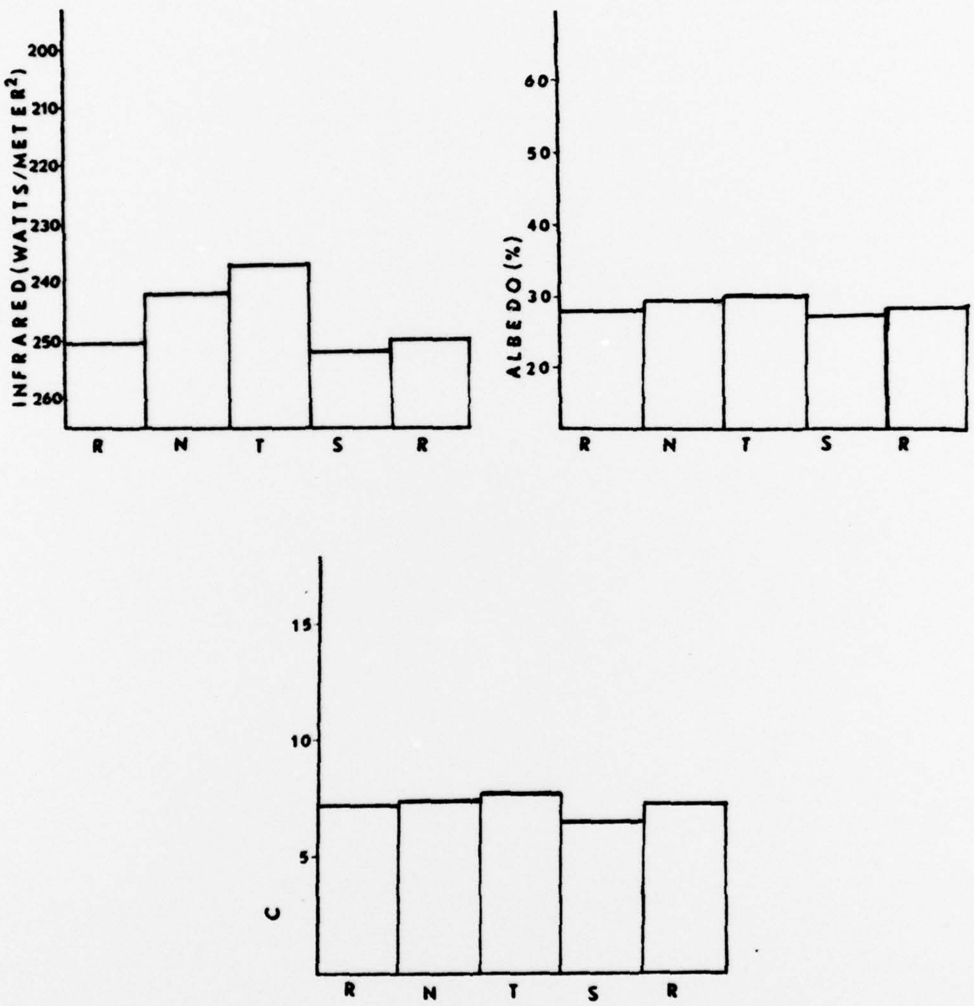

Fig. 8. Same as Fig. 1, except for Truk 1975.

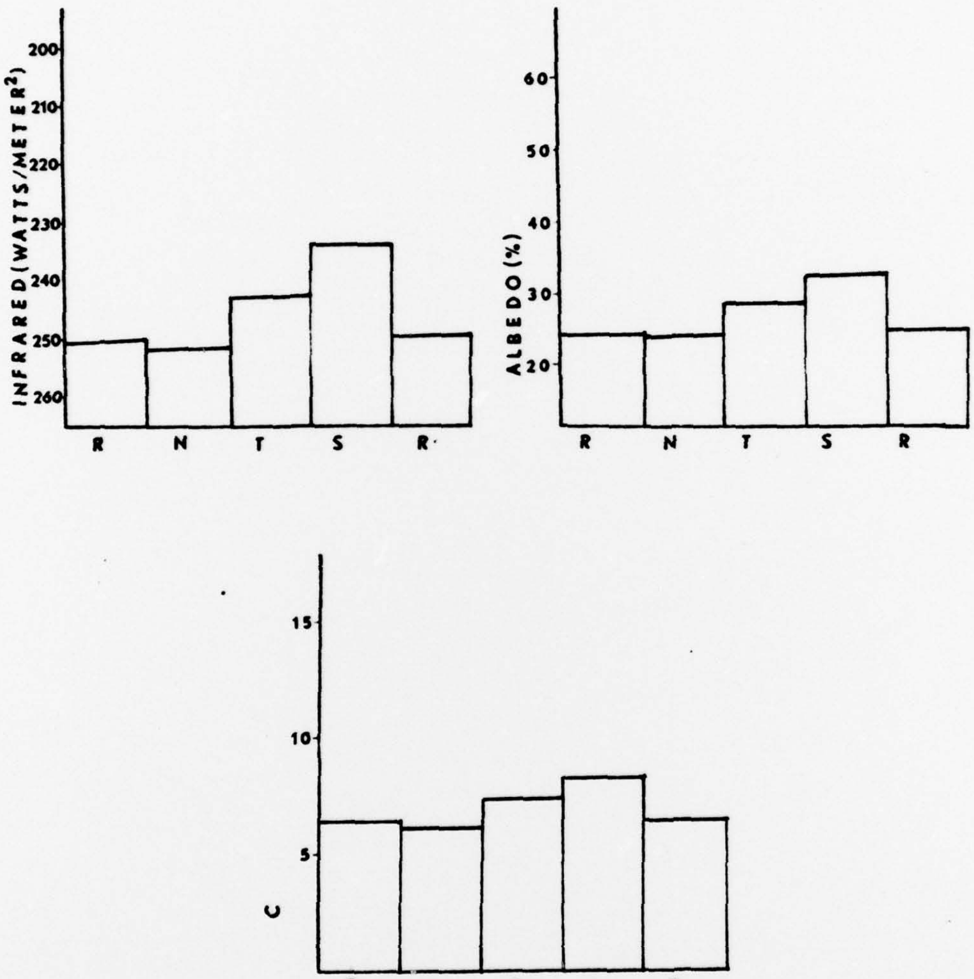

Fig. 9. Same as Fig. 1, except for Yap 1975.

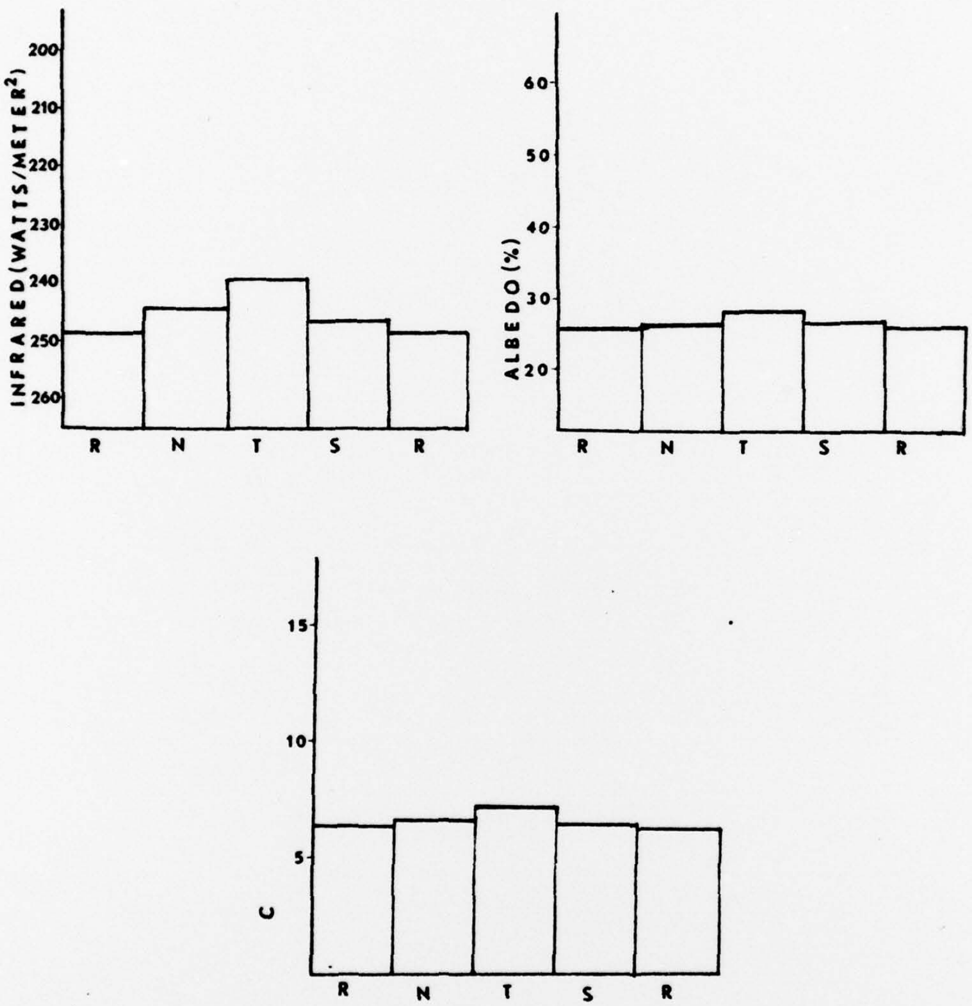

Fig. 10. Same as Fig. 1, except for Koror 1975.

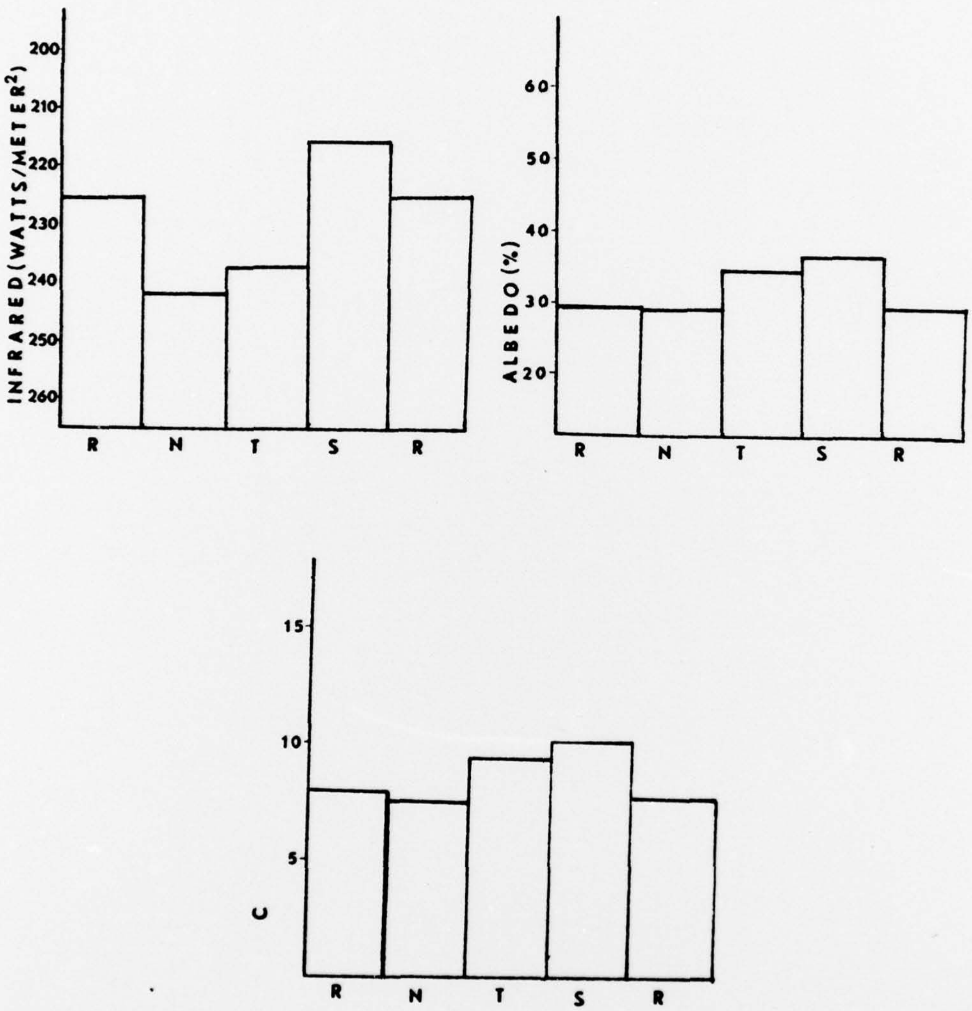

Fig. 11. Same as Fig. 1, except for Majuro 1976.

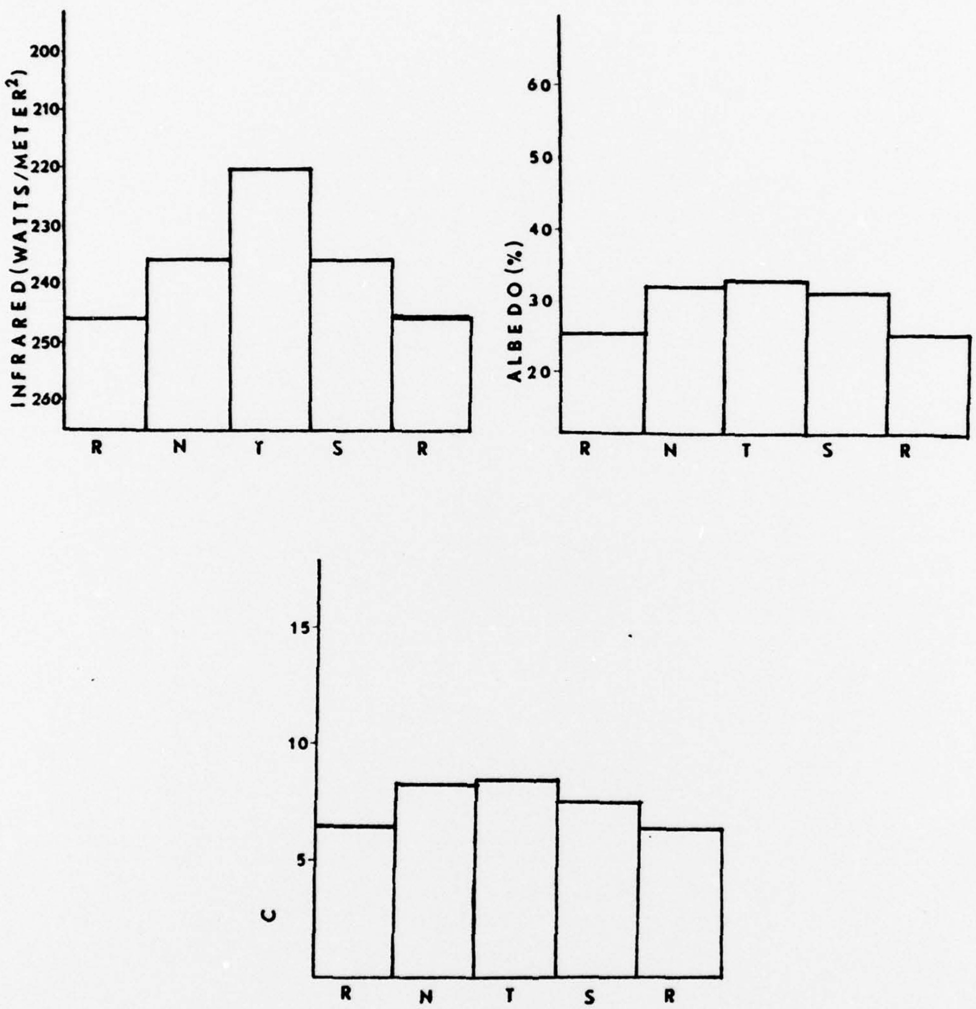

Fig. 12. Same as Fig. 1, except for Ponape 1976.

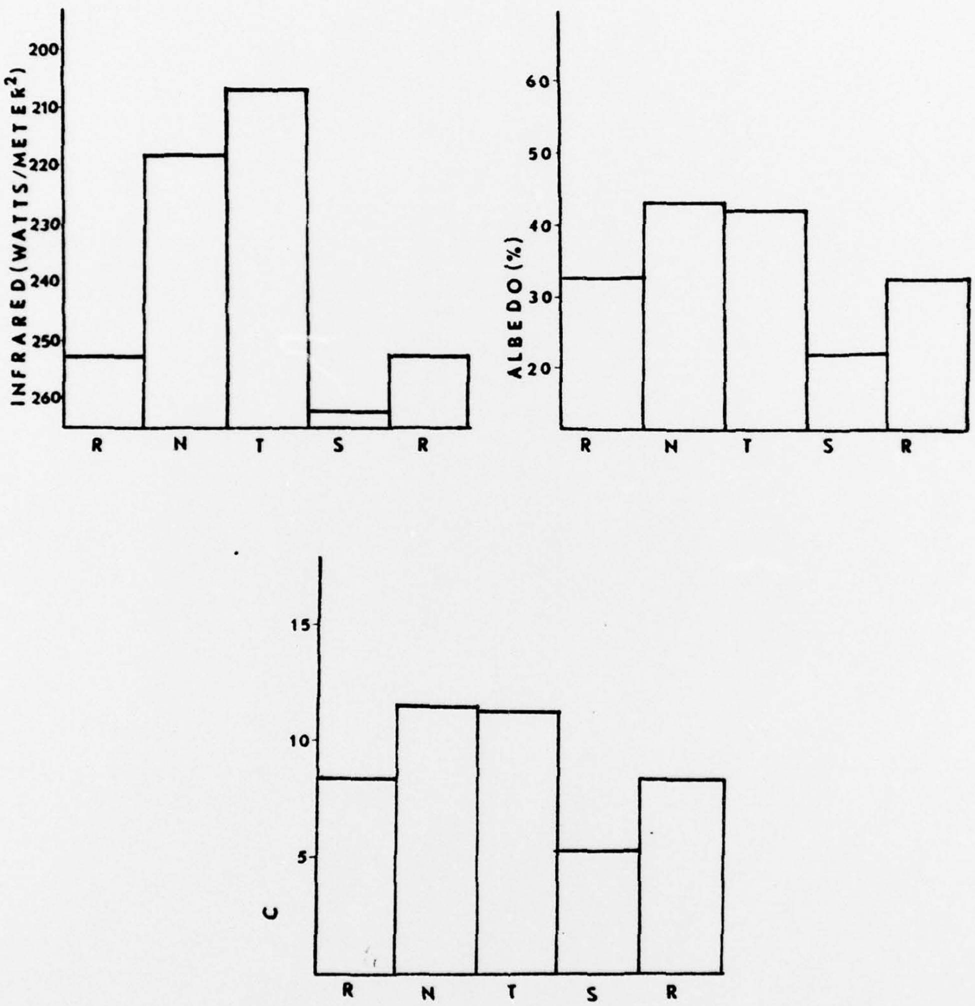

Fig. 13. Same as Fig. 1, except for Truk 1976.

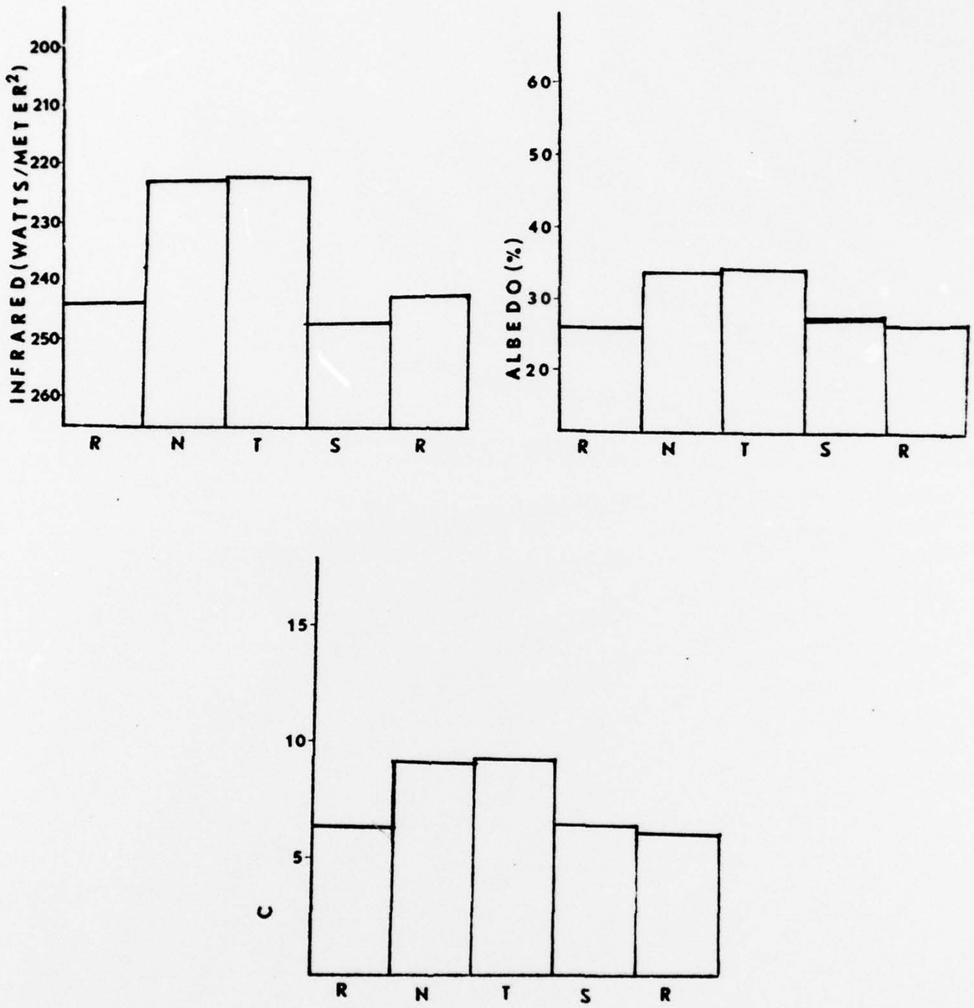

Fig. 14. Same as Fig. 1, except for Yap 1976.

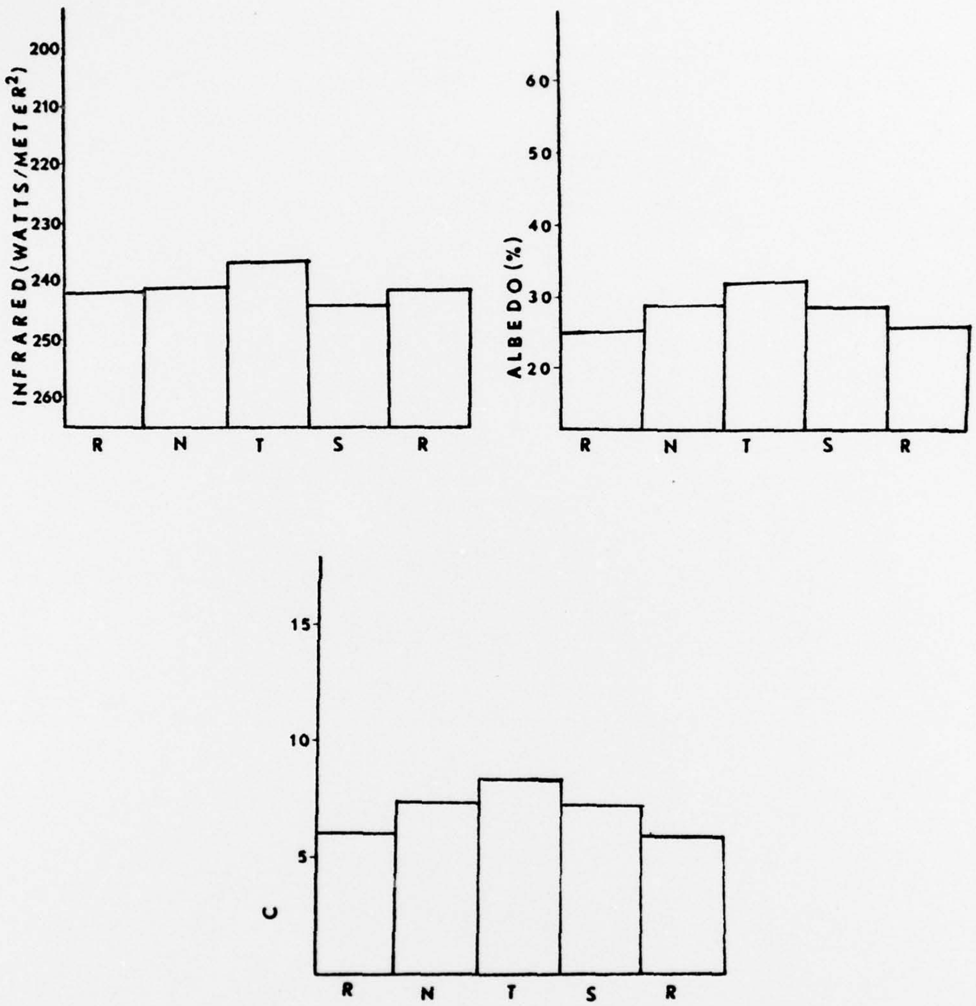

Fig. 15. Same as Fig. 1, except for Koror 1976.

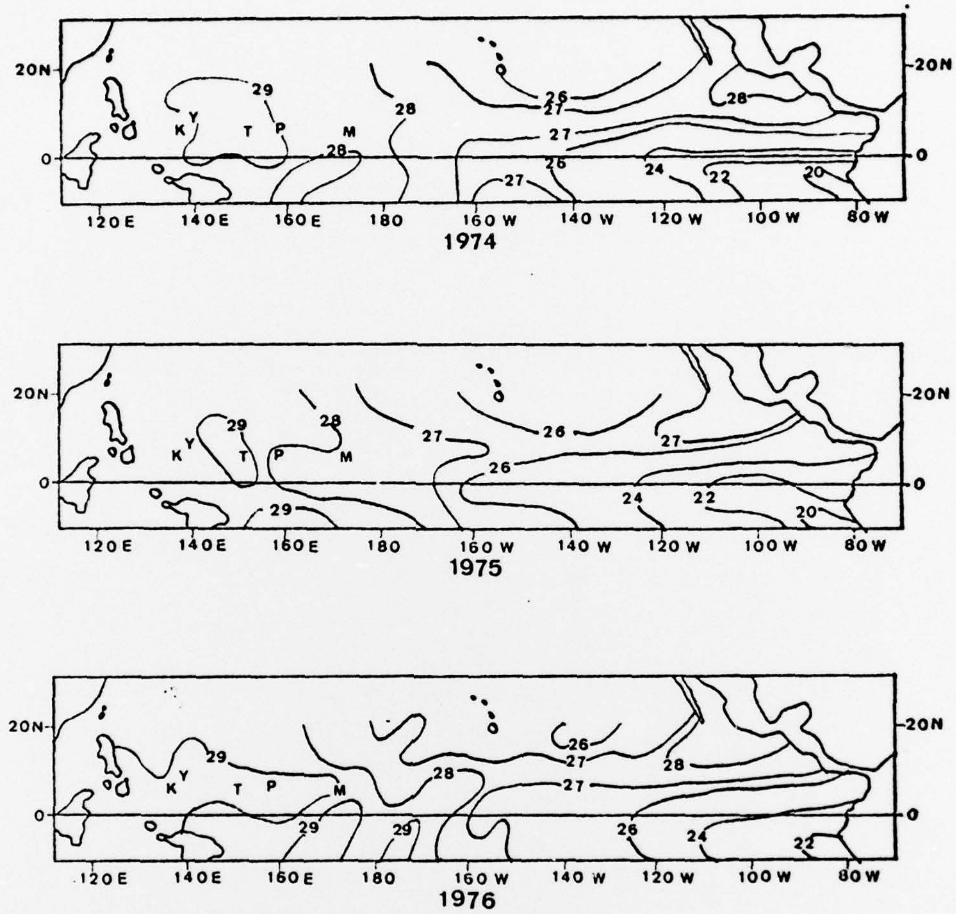

Fig. 16. Sea-surface temperature analysis for 1974-1976.

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