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A COMPOSITE SATELLITE STUDY OF THE 1972-73 EASTERLY WAVES IN TH--ETC(U)

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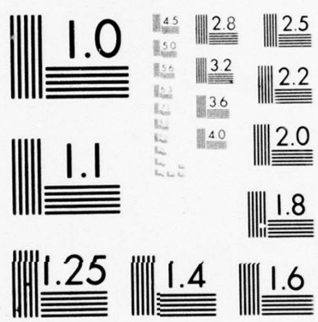

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NAVAL POSTGRADUATE SCHOOL

Monterey, California

THESIS

A COMPOSITE SATELLITE STUDY OF THE
1972-73 EASTERLY WAVES
IN THE TROPICAL WESTERN PACIFIC

by

Dennis Michael Delaney

September 1977

Thesis Advisor: C.-P. Chang

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In order to obtain further insight into the structure and properties of easterly waves in the tropical western Pacific, subjectively digitized satellite data for the latter half of the years 1972 and 1973, which possess respectively warm and cold sea-surface temperature anomalies, are analyzed using a compositing technique to obtain composites of percentage convective cloud cover during wave passage. → next page

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cont→ The composites are then compared to composites of temperature, relative humidity and meridional winds. The results, in certain ways, are in agreement with those obtained previously by spectral analysis in the proposed structural tilt of the waves. Significant new results are also obtained. The effects of the local sea-surface temperature influence are most important only for the convective activity organized by the waves. On the other hand, the time-mean cloudiness is a factor of the larger-scale sea-surface temperature gradient and the associated Walker circulation. Moreover, the vertical structure of the waves may be a function of the vertical shear, but it is unrelated to convective activity.

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A Composite Satellite Study of the 1972-73 Easterly Waves in the Tropical Western Pacific

by

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Lieutenant, United States Navy
B.E.S, The University of Texas at Austin, 1971

Submitted in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE IN METEOROLOGY AND OCEANOGRAPHY

from the

NAVAL POSTGRADUATE SCHOOL
September 1977

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ABSTRACT

In order to obtain further insight into the structure and properties of easterly waves in the tropical western Pacific, subjectively digitized satellite data for the latter half of the years 1972 and 1973, which possess respectively warm and cold sea-surface temperature anomalies, are analyzed using a compositing technique to obtain composites of percentage convective cloud cover during wave passage. The composites are then compared to composites of temperature, relative humidity and meridional winds. The results, in certain ways, are in agreement with those obtained previously by spectral analysis in the proposed structural tilt of the waves. Significant new results are also obtained. The effects of the local sea-surface temperature influence are most important only for the convective activity organized by the waves. On the other hand, the time-mean cloudiness is a factor of the larger-scale sea-surface temperature gradient and the associated Walker circulation. Moreover, the vertical structure of the waves may be a function of the vertical shear, but it is unrelated to convective activity.

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I. INTRODUCTION

Krueger and Winston (1974), in a study of planetary-scale circulation over the tropics, found that anomalous changes in the energetics of the tropics could produce subsequent anomalous circulation patterns. Using operational wind analyses prepared by the National Meteorological Center, they found, for the 1971-1972 season, that the anomalous weakening of the trade winds over most of the Pacific during the summer of 1972 was associated with a major shift in the tropical energy sources - a weakening of both atmospheric and oceanic circulations as well as a general rise in the sea-surface temperature.

In such a varying planetary mean state, one may expect changes in synoptic-scale disturbances as well. Previous studies have found considerable variations in synoptic-scale tropical disturbances such as easterly waves (Wallace, 1971). An important scientific problem is whether the interannual and spatial variation in the planetary-scale flow and the sea-surface temperature may influence the variation of the synoptic-scale disturbances.

Chang and Miller (1977), in a spectral analysis of tropical easterly waves during the second half of 1972 and 1973, found considerable variation in the structure and properties of the disturbances between the two seasons. In the tropical eastern Pacific the 1972 season was characterized by abnormally large warm sea-surface temperature anomalies, while the 1973 season showed abnormally large cold sea-surface temperature anomalies (Figs. 1a-d). The warm anomaly was 2°C above normal. The cold anomaly was considered significant not only because its magnitude was 2°C below normal, but because it also introduced quite an abrupt temperature change in a very short time span. The effect of these anomalies is shown in Figures 1 a-b. In 1972 the anomaly almost completely removed the normal zonal sea-surface temperature gradient, while the intense cold anomaly of 1973 sharpened the gradient in the central Pacific.

The periodicity of the waves in both seasons was found to be 4-5 days, in agreement with previous studies (Wallace, 1971; and others). A low-level zonal wavelength on the order of 3300 km was deduced for both periods. However, the vertical structure and amplitudes of the waves exhibited marked differences. An attempt was made to spectrally analyze the thermal and moisture structures, but the results were inconclusive due to lack of coherence between the relative humidity and v-component wind spectra, and poor coherence between the temperature and v-component wind spectra for 1973.

A later study, that of Maas (1977), using compositing techniques similar to those of Reed, Norquist, and Recker (1976) was made in an attempt to clarify and confirm the results of Chang and Miller (1977). The periodicity of the waves inferred from the compositing technique was 4-5 days, in agreement with the earlier spectral analysis, and the lower-tropospheric wavelength was found to be on the order of

3000 km. Both studies indicate a near-vertical structure for the 1972 season, while the 1973 period shows strong vertical shear and the corresponding structural tilt of the waves. Both studies attribute this to the intensity of the Walker circulation[1], brought about by the cool sea-surface temperature in the eastern Pacific during 1973.

The purpose of this study is to attempt to acquire further insight into the differences in the properties of the waves of the anomalous 1972-1973 seasons in the tropical western Pacific, using satellite data. A complete set of satellite data in the form of tropical mercator mosaics were made available by the National Environmental Satellite Service, covering the months of June through October for both years. This study uses a method suggested by Payne and McGarry (1977) to digitize the raw satellite data, and a compositing technique to obtain cloudiness distributions of the waves from the digitized data. The results are used with previous results by Chang and Miller (1977) and Maas (1977) to deduce possible causes for the interannual and spatial differences of the wave properties in the tropical western Pacific.

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[1]This is the zonal circulation induced by the east-west sea-surface temperature gradient, as defined by Bjerknes (1969).

II. DATA

Data for this study were obtained from two sources. Satellite images, visual for 1972, both visual and infrared for 1973, were obtained from the National Environmental Satellite Service for the months of June through October for each year. Radiosonde data were obtained from the five reporting stations of Majuro, Ponape, Truk, Yap and Koror (Fig. 2) for comparison with the satellite imagery.

Since digitized satellite data are not available for this time period, the data were drawn from the available imagery and subjectively reduced to provide the necessary material for this study.

The satellite images were obtained in the form of microfilmed tropical mercator projections. For ease in analysis, the western Pacific equatorial region was photo-enlarged as prints covering a day-to-day sequence from June through October for each of the three data sets. The quality of the photographs was generally good. Occasional overexposures and partial (sometimes total) areas of missing data averaged approximately 1 day in 30, or less than 4% of the data base and therefore are assumed to have minimal detrimental effects on the overall composites.

The images were further reduced to an area corresponding with that of the radiosonde reporting stations of Koror (7°N,

$134^{\circ}E$), Yap ($9^{\circ}N$, $138^{\circ}E$), Truk ($8^{\circ}N$, $152^{\circ}E$), Ponape ($6^{\circ}N$, $158^{\circ}E$), and Majuro ($7^{\circ}N$, $171^{\circ}E$). These stations provided at least once-daily radiosonde reports of wind, temperature, and relative humidity, which will be discussed later. A 15° x45° region, lying within the boundaries formed by equator to $15^{\circ}N$ and $130^{\circ}E$ to $175^{\circ}E$, encompassing the reporting stations, was chosen for analysis. The area was further divided into 1° squares by means of a grid overlay designed to fit the analysis area of each photograph. Brightness categories for the cloud coverage, chosen in a manner similar to that of Payne and McGarry (1977) were then subjectively assigned to each 1°-square within the analysis area, with the dominant category being assigned to any square having more than one category. The 1972 data were assigned categories once daily. The two data sets for 1973 were analyzed twice daily (visible data during daytime and infrared during nighttime). There were three categories chosen: areas of no clouds indicated by black or very dark grey, were given category 0; category 1 was assigned to the medium, or uniform grey areas, indicating clouds with mid-level tops; bright white, or extremely light grey areas (depending on exposure) were given category 2, indicating clouds with the highest and coldest tops. The visual data were examined closely in areas of flat whiteness for signs of cumulus towers, and the strongly convective categories were determined on that basis.

The percentage of category 2 clouds within a 5°-square centered on each of the reporting stations were then determined, in order to minimize the effects of subjectively assigning the brightness categories. The time series of the percentage convective cloud cover for each reporting station in both periods of interest are presented in Figures 3 a-e. The time-mean percentage cloud cover for each period at each reporting station are given in Table I.

The times for the various phases of the wave passage (ridge, maximum northerly wind, trough, and maximum southerly wind) at each of the five stations were determined by the time series of the lower-tropospheric vertically-averaged (1000 mb to 500 mb) meridional wind components used by Maas (1977). Data points corresponding to these times were used to obtain the percentage convective cloud cover at each station during the various stages of wave passage for each of the reporting periods.

The time cross-section was filtered to eliminate all waves outside the range of periods of interest. Thus, only those waves with periods between 2 and 10 days were considered.

Since only once-daily reports of cloud coverage were available for the 1972 season, for those reports of wave phase category falling between the daily satellite cloud reports, cloud reports occurring 12 hours before and after were averaged to provide a percentage convective activity estimate. For the 1973 season, the nighttime infrared reports were used to fill in the gaps in the visual intervals so that the number of convective cloud reports corresponded exactly to the number of wave-phase reports.

A compositing technique similar to that used by Reed, Norquist and Recker (1976) was employed to analyze convective cloud cover for both periods. These percentages were then normalized so that their mean would equal the seasonal average percentage cloud cover given in Table I. Graphs of these composites are given in Figure 4, for Koror-Yap (KY), Truk-Ponape (TP) and Majuro, respectively. Graphs of the individual stations are contained in Appendix A.

Histograms depicting the frequency of occurrence of relative maximum convective cloud cover were also prepared, using a method similar to that of Payne and McGarry (1977). Identifiable waves were divided into 8 segments, trough, ridge, maximum northerly and southerly wind components, as well as the midpoints between these phases. The records of percentage cloud cover were examined for individual waves, and the frequencies of occurrence of local maximum for each wave phase category were used to construct the histograms (Figure 5).

The radiosonde data received for the five reporting stations were also used to obtain wave composites of zonal and meridional wind components, temperature, and relative humidity for both 1972 and 1973. The temperature and relative humidity composites appear in Figures 6-8 and the records of v-component winds are shown in Figures 9-10.

The time-mean SST distribution within each period as well as the anomalies from the 1972-1976 5-season mean were based on the SST data archives of the Pacific Environmental Group, National Marine Fisheries Service.

III. RESULTS

A. WAVE STATISTICS

Table II gives the statistics of the time and zonal scales of the waves deduced from the composite analysis. For the five-month study period during the two anomalous years, for stations west of Majuro, there were slightly more waves in 1973 (35.4) than in 1972 (33.4). Majuro experienced the same number of waves in both years. The year 1973 exhibits an average periodicity of 4.3 days, with a corresponding average wavelength of 2900 km. The periodicity shown for the warm anomaly year (1972) was 4.6 days, and the average wavelength for this period was found to be 3000 km.

B. PERCENTAGE CONVECTIVE CLOUD COVER

Figure 4 shows the composited results of percentage convective cloud cover due to passage of the waves at the reporting stations. Due to their proximity, and the similarities observed in their individual distributions, Koror and Yap (KY) and Truk and Ponape (TP) have been averaged to provide a simpler basis for discussion. Individual station profiles are given in Appendix A. Note from the figures that, with the exception of Majuro 1973, all the stations show maxima in the trough region. This indicates enhancement of convective activity in the wave troughs, except at Majuro in 1973, whose curve suggests that a substantial portion of the convective cloudiness is not organized by the waves.

Mean values of cloudiness were also plotted at each station in Figure 4. These mean values exhibit a steady decrease in cloudiness westward from Majuro to Koror in 1972. The mean cloudiness for 1973 is near uniform from Majuro to Koror with very slight variations. Note that the mean cloudiness in 1973 is greater than in 1972 at KY, but at TP and Majuro the mean cloudiness of the two seasons is about the same.

The departures of cloudiness from the mean in the vicinity of the trough were noted also. For 1972 these values indicate a general increase toward the west. The values noted for 1973 show a dramatic increase from Majuro to TP, followed by a decrease from TP to KY.

The extent of the representations of wave structure by the time-series data at an individual station were evaluated by constructing composites of the spatial distribution of cloudiness during passage of the trough axes. Upon examination of the histograms (Figure 5) and the distributions of percentage cloud cover it was found that the westernmost stations Koror, Yap, Truk and Ponape, exhibited quite similar patterns in the distribution of convective activity. Only Majuro deviated from the collective pattern. Therefore, Truk and Majuro were chosen to construct the horizontal distributions of cloud cover during passage of the troughs. These distributions shown in Figure 11 are based on data from the original 1°-squares with a 5-point smoothing to make them comparable to the 5°-square data used in individual time series composites. This compositing was done for Truk for both seasons covering an area $5^{\circ} \times 30^{\circ}$, with the island in the center of the area. The spatial composite for Majuro is not as complete, covering an area 5° wide and 15° downstream from the station, but only 3° upstream. The reason for this upstream foreshortening lies in shortsightedness in extracting the raw data from the satellite imagery, but the incomplete composite distribution is sufficient for the purpose of comparison with the time-series composites. The distributions represented in these figures indicate enhancement and suppression of convective activity in patterns quite similar to those of percentage cloud cover in Figure 4, thus they indicate that the results of the individual station time series analyses indeed represent propagating spatial waves rather than just local fluctuations.

The histograms which show the percentage frequency of occurrence of local maxima in cloud cover as a function of wave phase category are shown in Figure 5 for KY, TP and Majuro. All stations with the exception of Majuro 1973 show the greatest frequency of occurrence to be in the trough region as is shown by the composites of cloudiness in Figure 4. Majuro 1973 exhibits a relatively flat, unorganized structure. The frequency of occurrence is somewhat higher for 1972 than for 1973 at all stations during the passage of the trough. This is somewhat inconsistent with the results of the percentage cloudiness composites, and it is felt that this discrepancy is probably due to the inclusion of some quite weak fluctuations in the statistical analysis.

C. TEMPERATURE

The composites of the vertical temperature structures are given in Figures 6-8 for KY, TP and Majuro. All the stations show a warm core in the middle-upper troposphere except Majuro. An upper-level cold core is usually indicated above the warm core levels. For TP 1973 this upper-level cold core is most intense and at higher levels, apparently reflecting more vertically developed convective activity in the troughs. At Majuro in 1972 the trough appears to be very slightly cold core near 300 mb where the upward motion is usually maximum. The 1973 trough at Majuro indicates a well-defined cold core. It must be noted that in the tropics errors of temperature observations are probably comparable to the actual fluctuations most of the time. Therefore, the well-defined pattern of Majuro 1973 probably indicates a stronger cold core than that of Majuro 1972.

D. RELATIVE HUMIDITY

The composites of the moisture structure are given in Figures 6-8 also. Note that with the exception of Majuro 1973, all stations in both years have large, well-defined moisture centers in the vicinity of the trough. Majuro 1973 shows no such organization, with its moist region expanding over half a wavelength ahead of the trough. A maximum was noted in the vicinity of the northerly wind component. In general, moisture maxima during 1972 were found at a higher level than in 1973. Note also that the vertical structure of the moisture fields agrees closely with the vertical tilt of the meridional wind structure of the waves found in previous studies by Chang and Miller (1977). The structure at all stations in 1972 shows very little tilt, while for 1973 the stations east of Yap indicate strong eastward tilt with height in the lower troposphere (the vertical tilt at Koror is slightly westward with height in 1973, as shown in Figure A.1).

E. MERIDIONAL VELOCITY

Graphs of the v-component winds taken from an earlier composite study (Maas, 1977) for comparison indicate greater low-level amplitude of the waves for the 1972 season (Figures 9 - 10). Note that the wave structure in the upper levels is out of phase with that in the lower levels for 1972. Very little tilt is indicated at any of the stations during this period. The 1973 data exhibits no such equivalent barotropic structure in the zonal wind field. Majuro and TP indicate general eastward tilt with height, while KY shows slight westward tilt in the lower troposphere.

IV. DISCUSSION

The cloud cover composites depicted in Figure 4 indicate that the convective cloudiness is least organized by the wave passage at Majuro, compared to the other stations to the west. This is consistent with the thermal structure in the wave troughs. For 1972 the waves at Majuro show a weak cold core, when the trough cloudiness is 6.3% above the mean. For 1973 the cold core is more definitive and the trough cloudiness is only 1.5% above the mean (Table Ib). Since these thermal structures imply a kinetic energy sink, they suggest that one or more energy sources other than latent heat release are operating near or upstream of Majuro. The difference between the cold core structures at Majuro for the two years is also consistent with the relative humidity distribution (Figure 6), namely, for 1972 the moisture field is already better organized when the waves reach Majuro, compared to 1973 when it is ill-organized until the waves pass Majuro. Examining the SST distributions in Figure 1, it appears that the difference in the cloudiness, temperature, and moisture fields between the two years may be explained by the difference in the SST's upstream of Majuro, The warmer eastern central Pacific anomalies in 1972 may favor convection thus organizing the moisture and cloudiness fields and, in turn, causing those waves reaching Majuro to have a weaker and ill-defined cold core compared to 1973.

As the waves continue propagating westward past Majuro, Table I and Figure 4 suggest that the influences of the sea-surface temperature may be relevant for explaining consistently the convective activity induced by the waves. During 1972 it can be seen from Table I that there exists a small but steady westward increase in the modulation of the convection due to the passage of the wave trough, which is continuous for at least 40° of latitude (4000 km) from Majuro to Koror. This occurs when the sea-surface temperature rises by ~0.7°C from Majuro to TP and ~0.5°C from TP to KY for 1972 (Figure 1). During the same period the time-mean percentage cloudiness actually decreases substantially from Majuro westward to Koror (Table Ia). From the mean zonal wind deduced by Chang and Miller (1977), it seems that this decrease in the mean cloud cover stems from the noted eastward migration of the upward branch of the Walker circulation, 60° from its normal position near the Philippine Islands to the vicinity of the dateline, during this period of anomalously warm SST in the eastern-central Pacific. The present results suggest that the slight westward increase in the sea-surface temperature tends to enhance the wave-organized cumulus convection, while the time-mean cloudiness appears to be controlled by the Walker circulation.

During 1973, the results shown in Table Ib indicate a dramatic increase in the modulation of convective cloudiness by the waves from Majuro to TP, coinciding with a sharp rise in the SST of ~2°C between the stations (Figure 1). As the waves propagate further westward towards KY, a reduction in the positive deviation in the troughs from the mean cloudiness can be seen, apparently responding to a reverse in the SST gradient. The magnitude of this gradient (~0.8°C) is significantly less than the upstream one, and the reduction in the trough cloudiness deviation is also much smaller (by a factor of 2) compared to the increase (by a factor of 10) from Majuro to TP. The time-mean cloudiness for the 1973 season indicates no substantial variation between the stations, again suggesting that only the convective field organized by the waves may be influenced by the local SST.

The temperature and moisture (relative humidity) composites shown in Figures 6-8 also provide support to the above interpretation of the east-west distribution of the wave-modulated convective cloudiness. As mentioned earlier, the temperature composites indicate warm core structures at all stations with the exception of Majuro. The magnitudes of these warm cores are consistent with the pattern of convective modulation indicated in Table Ib. The 1972 results indicate a slight increase in the magnitude of the warm cores with westward propagation, in agreement with the increased deviations of trough cloudiness. During 1973, the thermal structure changes from a well-defined cold core at Majuro to a well-defined warm core at TP, followed by a slight decrease in the magnitude of the warm core at KY. This is again consistent with the dramatic increase in convective modulation from Majuro to TP, followed by a decrease from TP to KY. The latent heat release by the deep convection apparently causes the thermal structure to change accordingly.

The relative humidity composites are also remarkably consistent with the results obtained for the convective cloudiness (Figure 4), adding credibility to the subjective method of analysis employed in digitizing the satellite imagery.

The vertical tilt of the waves indicated in Figures 6-8 is consistent with the results of Chang and Miller (1977), especially the lower-tropospheric structure of the relative humidity which seems to be a much better indicator of the vertical tilt of the waves than that of the temperature. For 1972 there is very little tilt in this field, while for 1973 stations to the east of Yap exhibit definite eastward tilt in the lower troposphere and Koror exhibits a slight tilt westward. These are also in agreement with the vertical structure of the meridional wind fluctuations deduced by Maas (1977) which are shown in Figures 9-10. The theory by Chang and Miller (1977) that the differences in structure stem from the seasonal variations in the vertical shear of the mean zonal wind, brought about by the influence of the large scale east-west temperature gradient on the zonal Walker circulation, seems to offer a reasonable explanation. As was shown by earlier studies (Krueger and Winston, 1974; Ramage, 1977; Chang and Miller, 1977), the magnitude of the near-equatorial zonal overturnings during the 1972 season was quite weak. On the other hand, a strong Walker cell occurred in 1973, indicating markedly greater vertical shear outside the upward branch for that year.

The composites of wave amplitude based on the meridional wind component (Maas, 1977) given in Figures 9-10 indicate that the waves are influenced by the local variations in sea-surface temperature in the thermal and convection fields only. No change in wave amplitude can be discerned in the east-west direction within each period. The 1972 amplitudes are ~3 ms^{-1} and the 1973 amplitudes are ~1.5 ms^{-1}.

The seasonal difference in the wave amplitude indicates the possibility of an upstream influence from the differing SST structures in the eastern-central Pacific. If one assumes comparable energy sources initiated in this region, then during 1973 the better-defined cold core caused by the cold sea-surface temperatures would act as a stronger kinetic energy drain, damping the amplitude of the generated waves. On the other hand, in 1972 the effect of this energy sink is lessened as the warmer sea-surface temperatures reduce the intensity of the cold core, causing the waves reaching Majuro to have larger amplitudes than 1973.

It has been noted, however, that the waves within the reporting area propagate westward with no discernible change in amplitude. It is suggested that these waves may have reached an equilibrium intensity prior to reaching Majuro, so that further increase in amplitude with the latent heating is balanced by increased cumulus damping.

This study being similar to theirs, the histogram method of analysis employed by Payne and McGarry (1977) was prepared for comparison. The general profile at each station obtained by this method (Figure 5) are consistent with that of the cloudiness, but in most cases the differences between the seasons are not sufficient to discern any systematic pattern for meaningful interpretations.

V. CONCLUSIONS

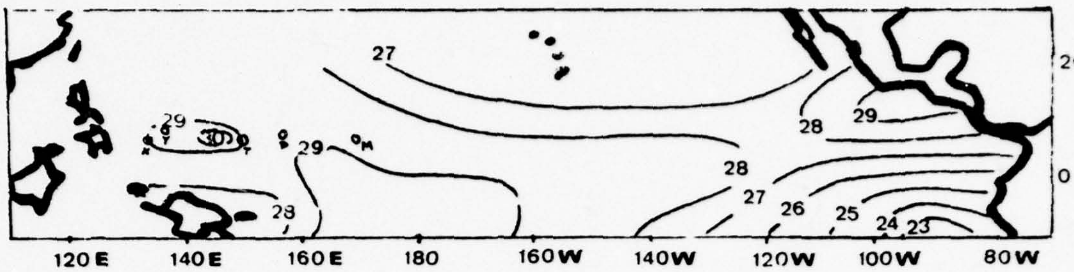
The conclusions drawn from the above analysis are as follows:

1. The vertical structure of the waves may be influenced by the vertical mean wind shear associated with the Walker circulation as suggested by Chang and Miller (1977), but it appears to be unrelated to the magnitude of the convective activity. In 1973, the maxima in both vertical tilt and wave-organized convection occur at TP.

2. The local effects on tropical easterly waves by the SST are most noticeable in the temperature, moisture and wave-induced convective fields and not in the wind fluctuations.

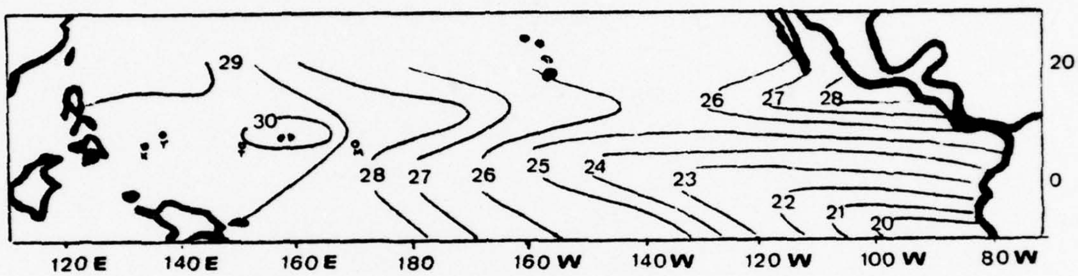
3. The time-mean cloudiness is a factor of large-scale features, being an emanation of the east-west temperature gradient and the associated Walker circulation.

4. Ramage (1977) suggested that a correlation of SST and local precipitation on a seasonal scale does not exist because, although near Canton Island a positive correlation is usually observed, in the other parts of the tropical ocean negative or low correlations frequently occur. However, the present results indicate that, while seasonal mean cloudiness associated with the large scale sea-surface temperature gradients may have different types of correlations with the sea-surface temperature anomalies, the local sea-surface temperature effect does seem to be important in the organization of deep convection by synoptic scale disturbances.



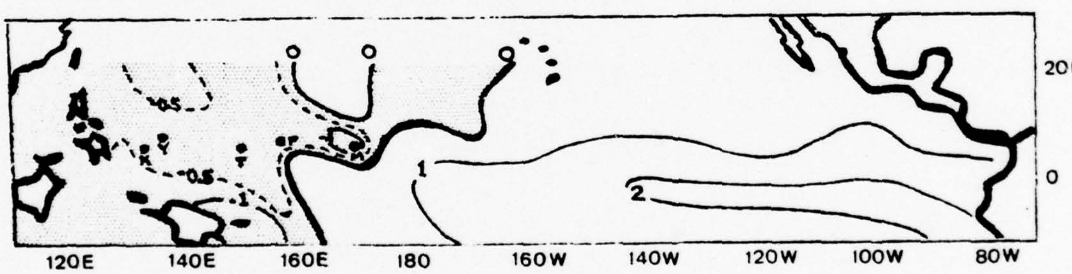
1972

(a)



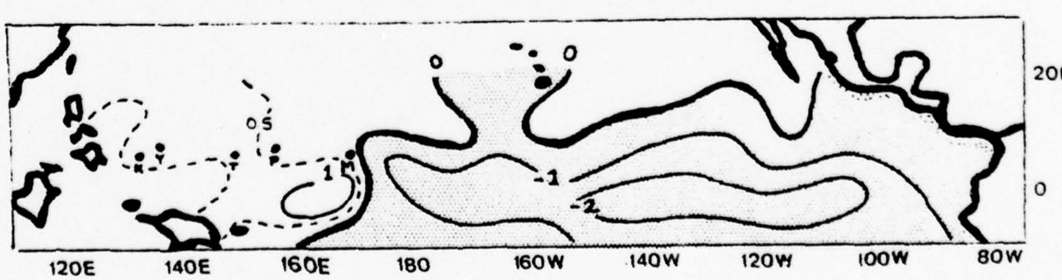
1973

(b)



1972

(c)



1973

(d)

Fig. 1. Sea-surface temperaures ($^{\circ}$C) for (a) 1972 and (b) 1973 the anomalies from the 5-year mean (c) and (d).

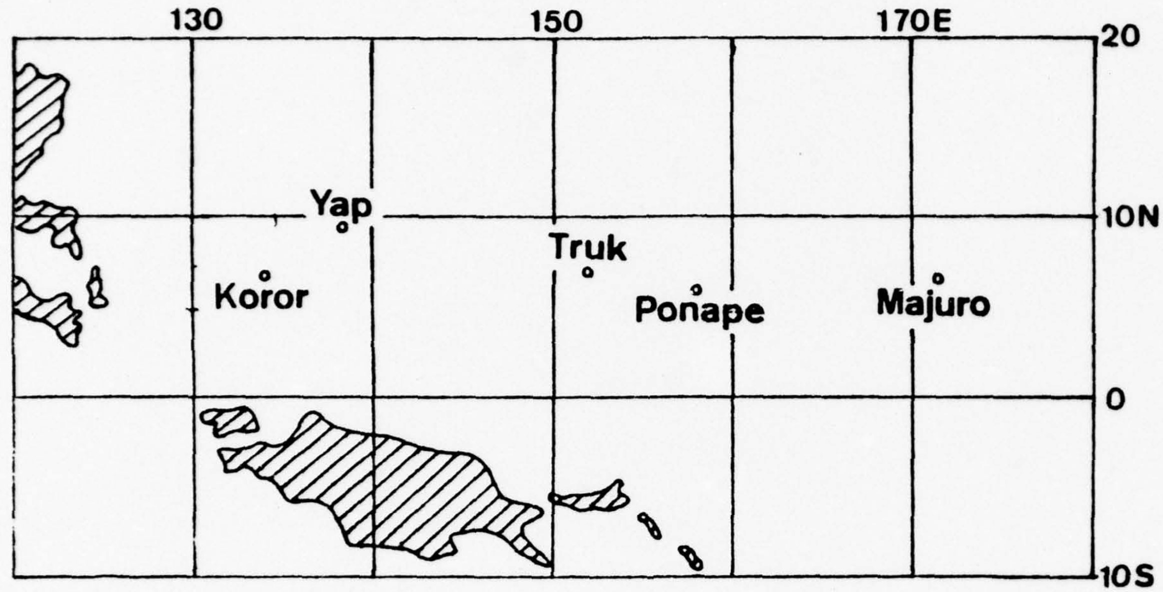


Fig. 2. Stations used in this study.

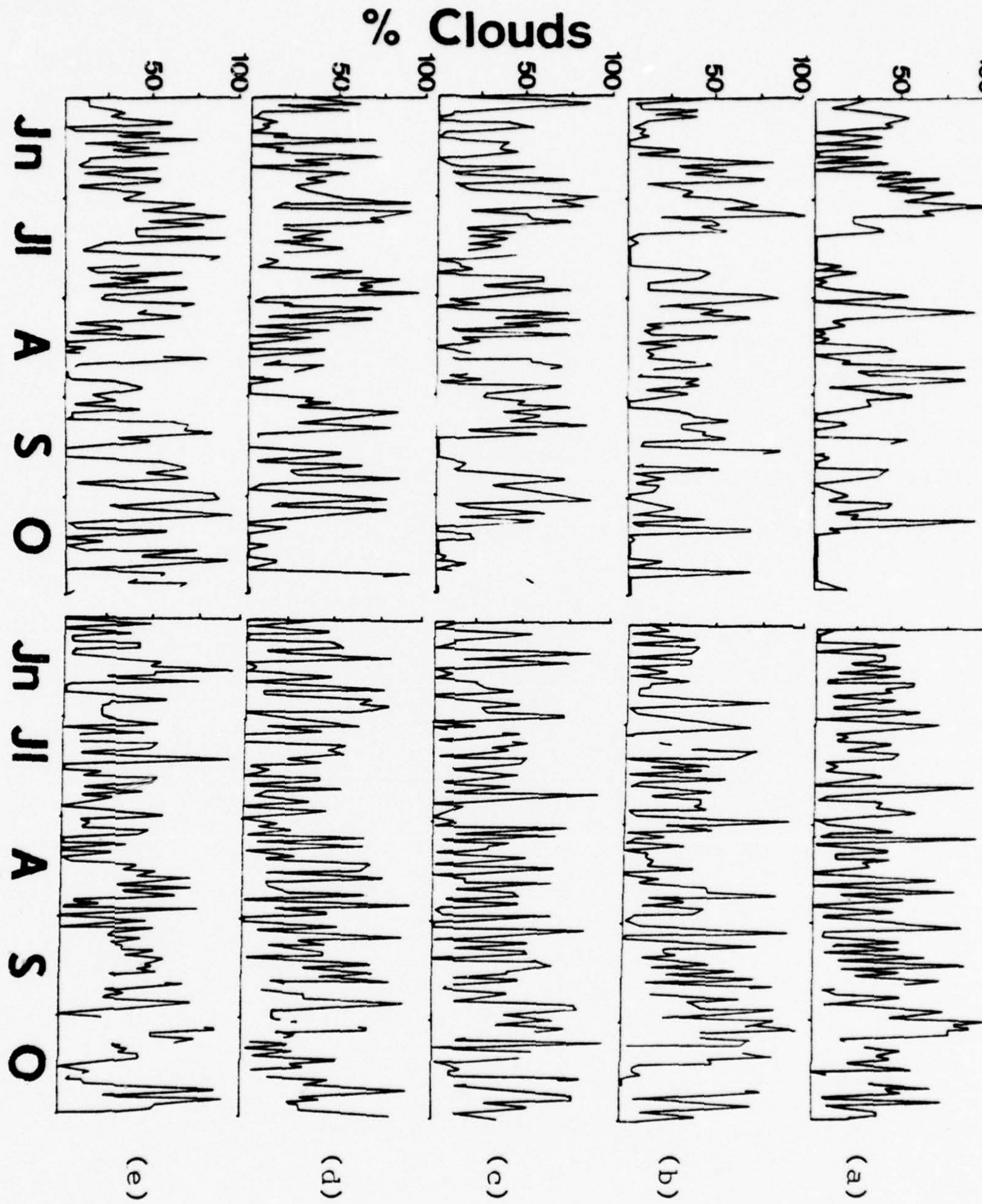


Fig. 3. Time series of percentage convective cloudiness for (a) Koror, (b) Yap, (c) Truk, (d) Ponape, (e) Majuro.

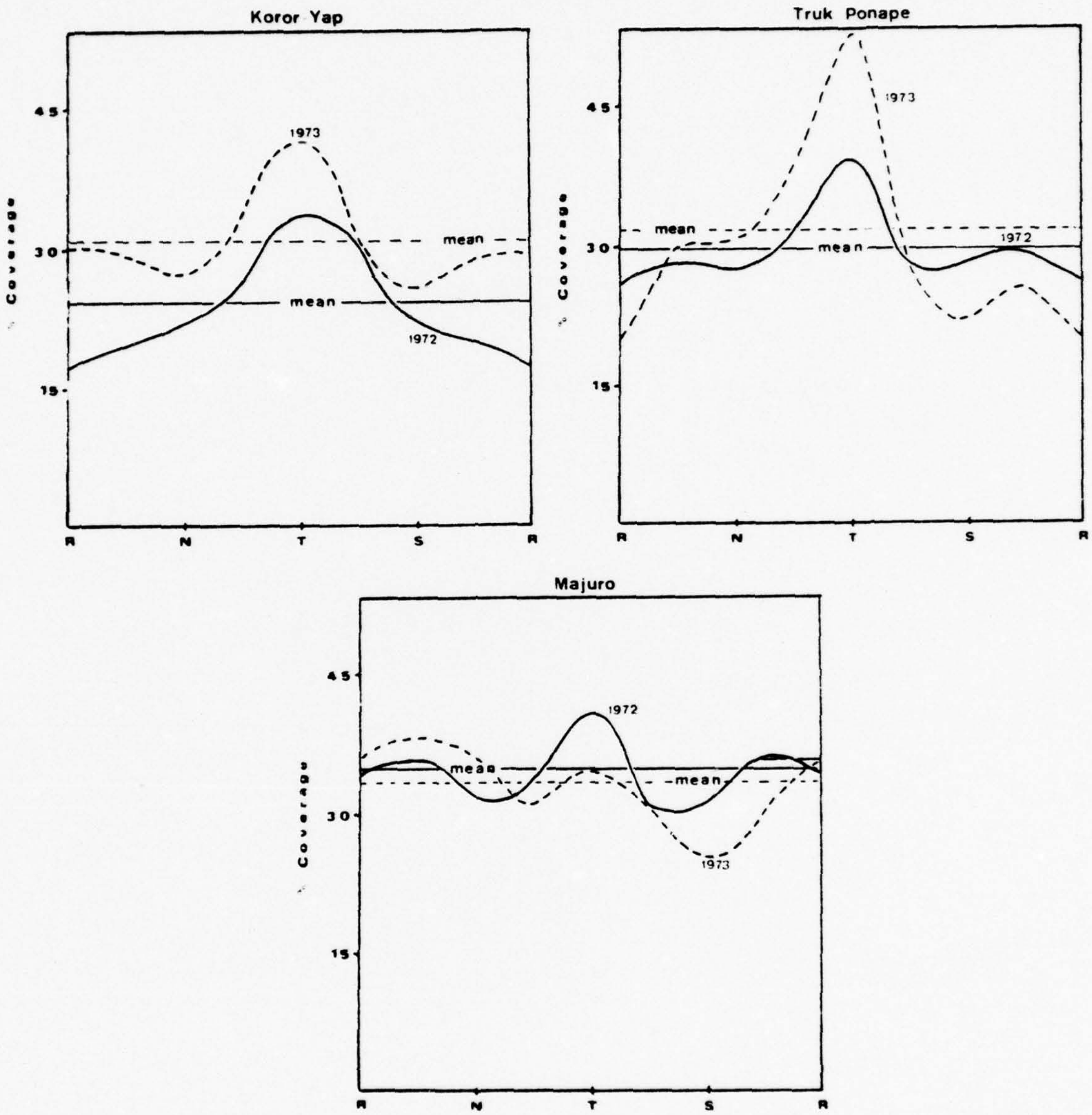


Fig. 4. Percentage convective cloud cover during wave passage for the indicated stations.

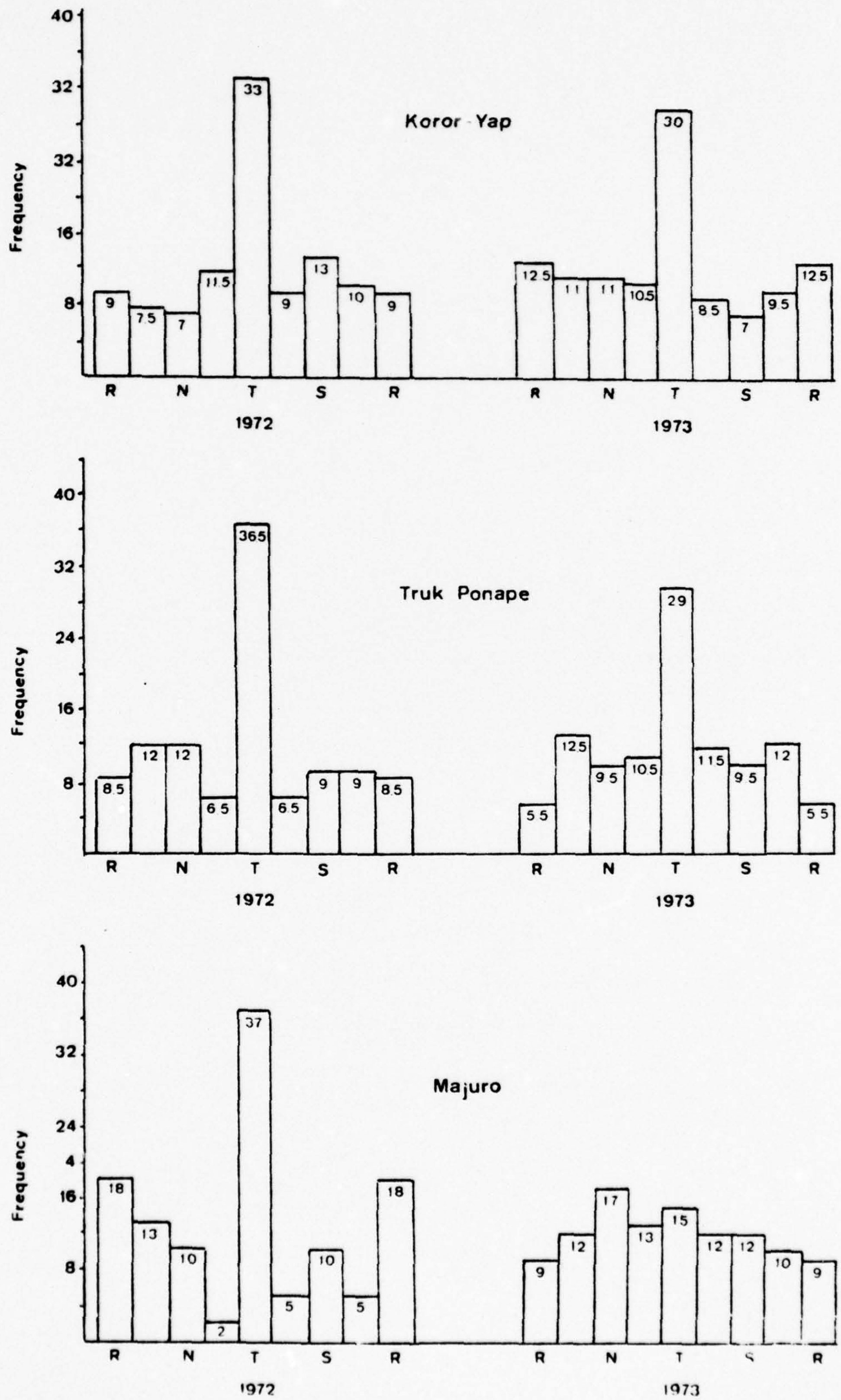


Fig. 5. Frequency of occurrence of relative maximum cloud coverage during wave passage in 1972 and 1973.

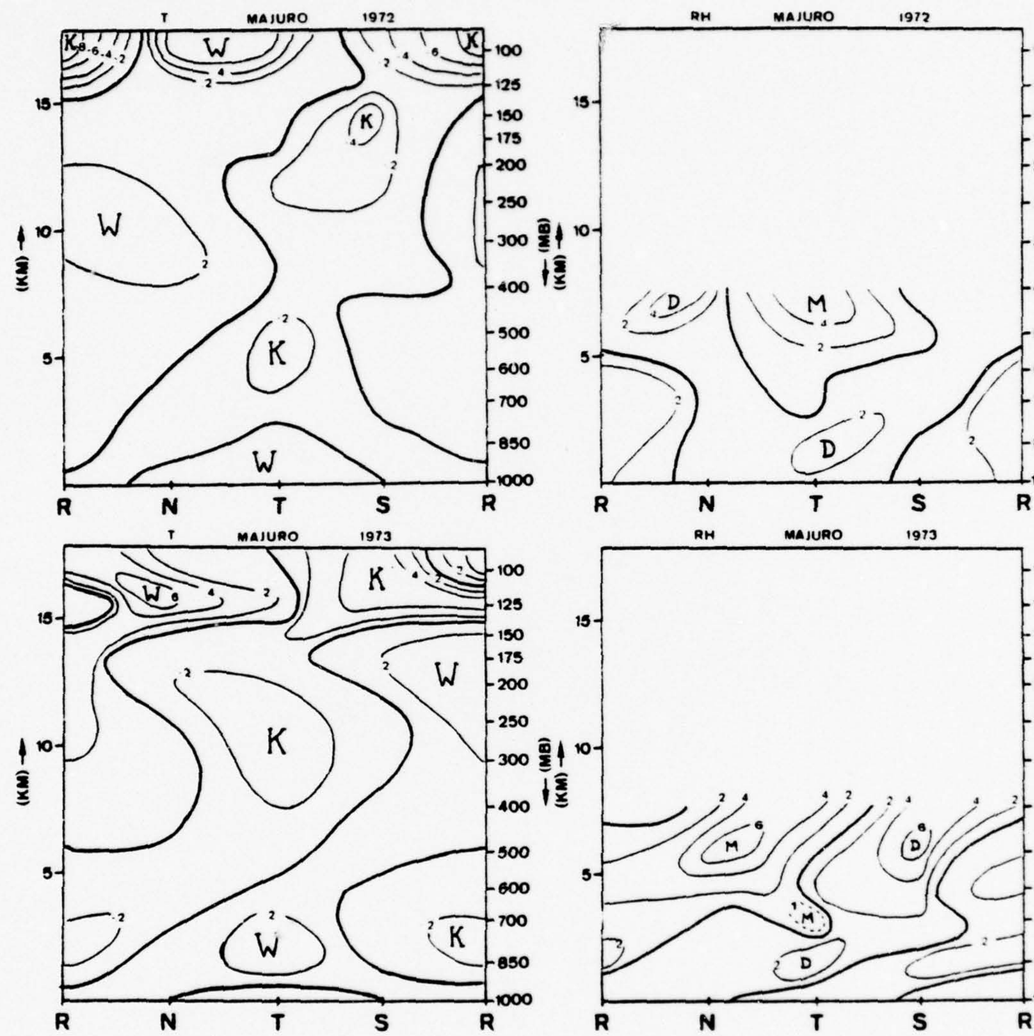


Fig. 6. Vertical composites of temperature and relative humidity for Majuro during 1972 and 1973.

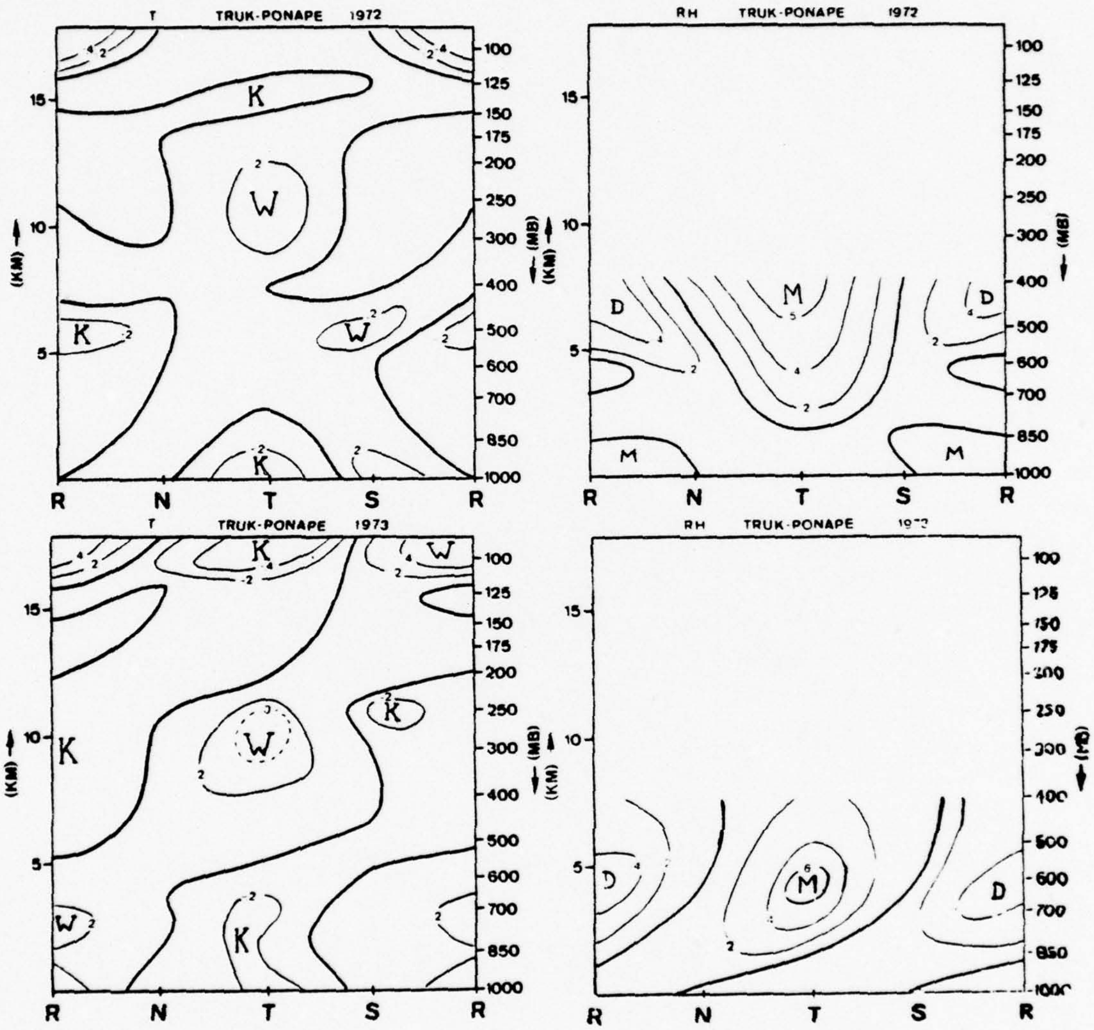


Fig. 7. Vertical composites of temperature and relative humidity for Truk-Ponape during 1972 and 1973.

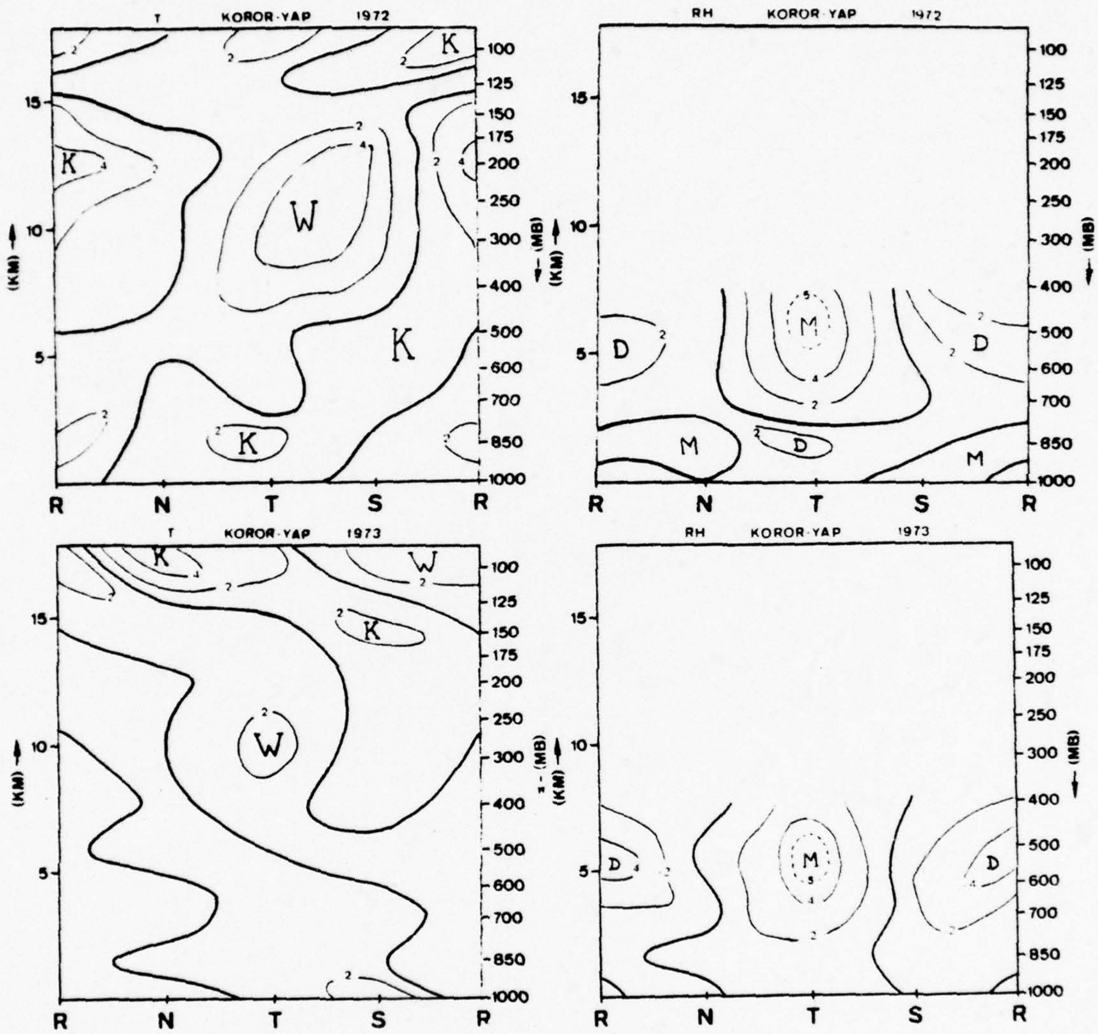


Fig. 8. Vertical composites of temperature and relative humidity for Koror-Yap during 1972 and 1973.

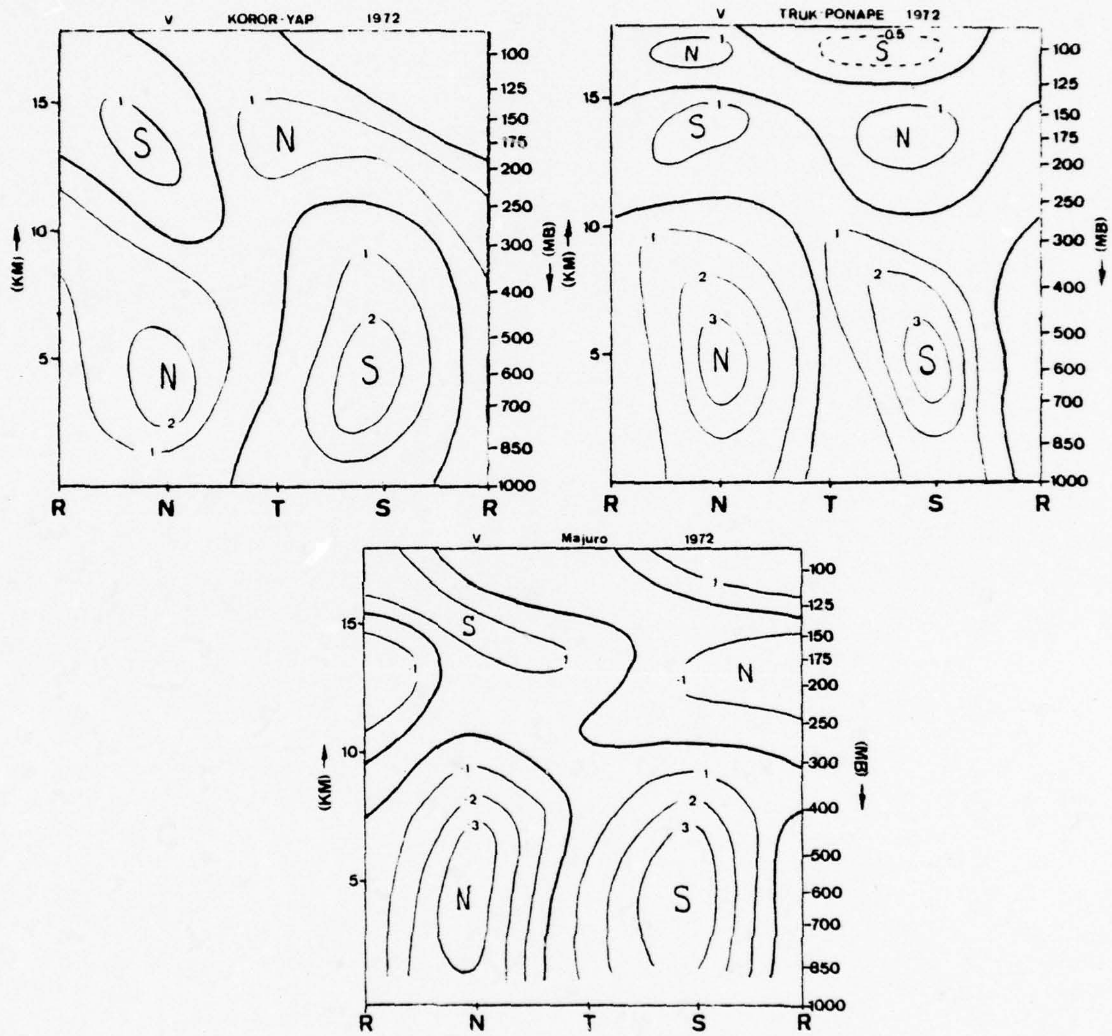


Fig. 9. Composite vertical structure of v-component winds during 1972 for the indicated stations.

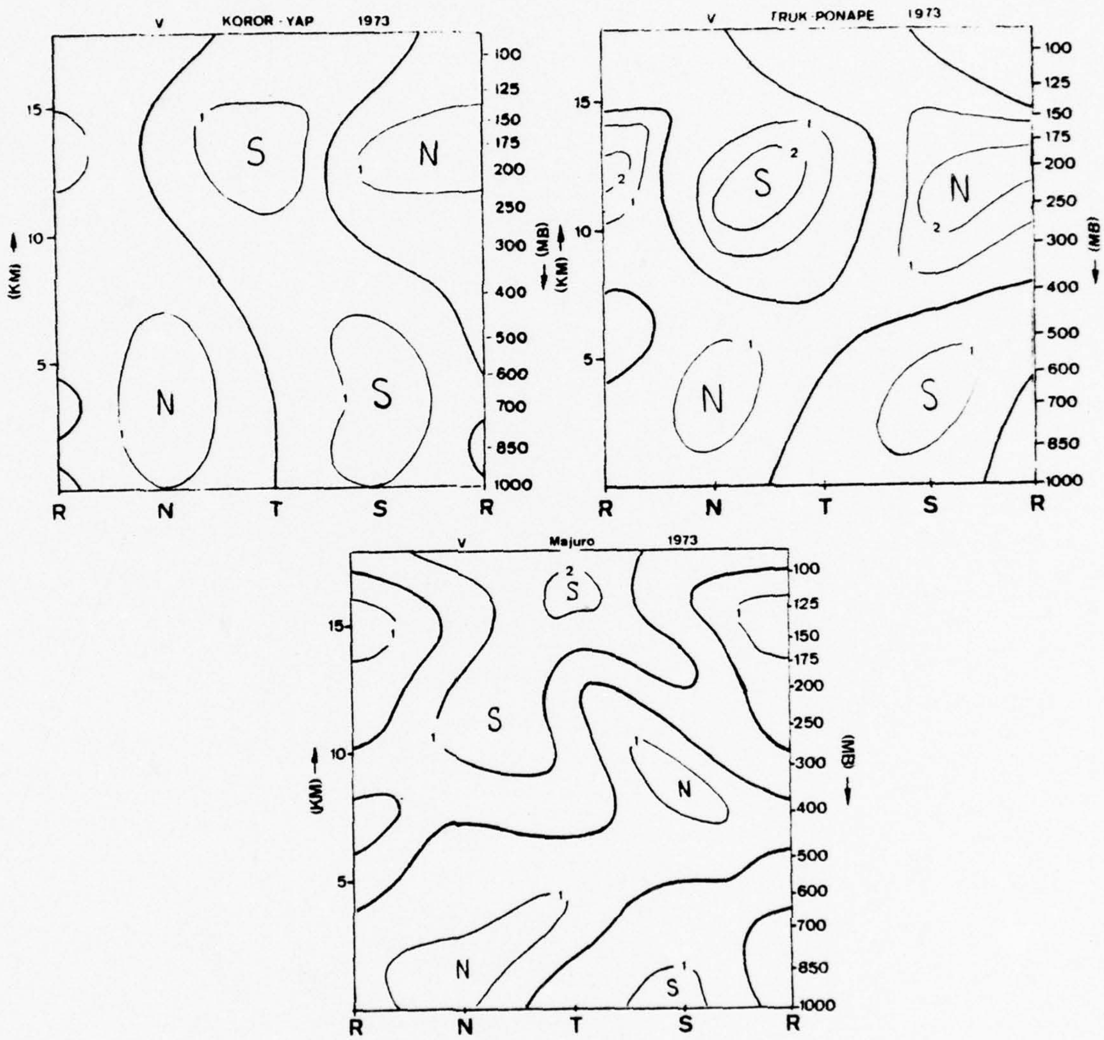


Fig. 10. Composite vertical structure of v-component winds during 1973 for the indicated stations.

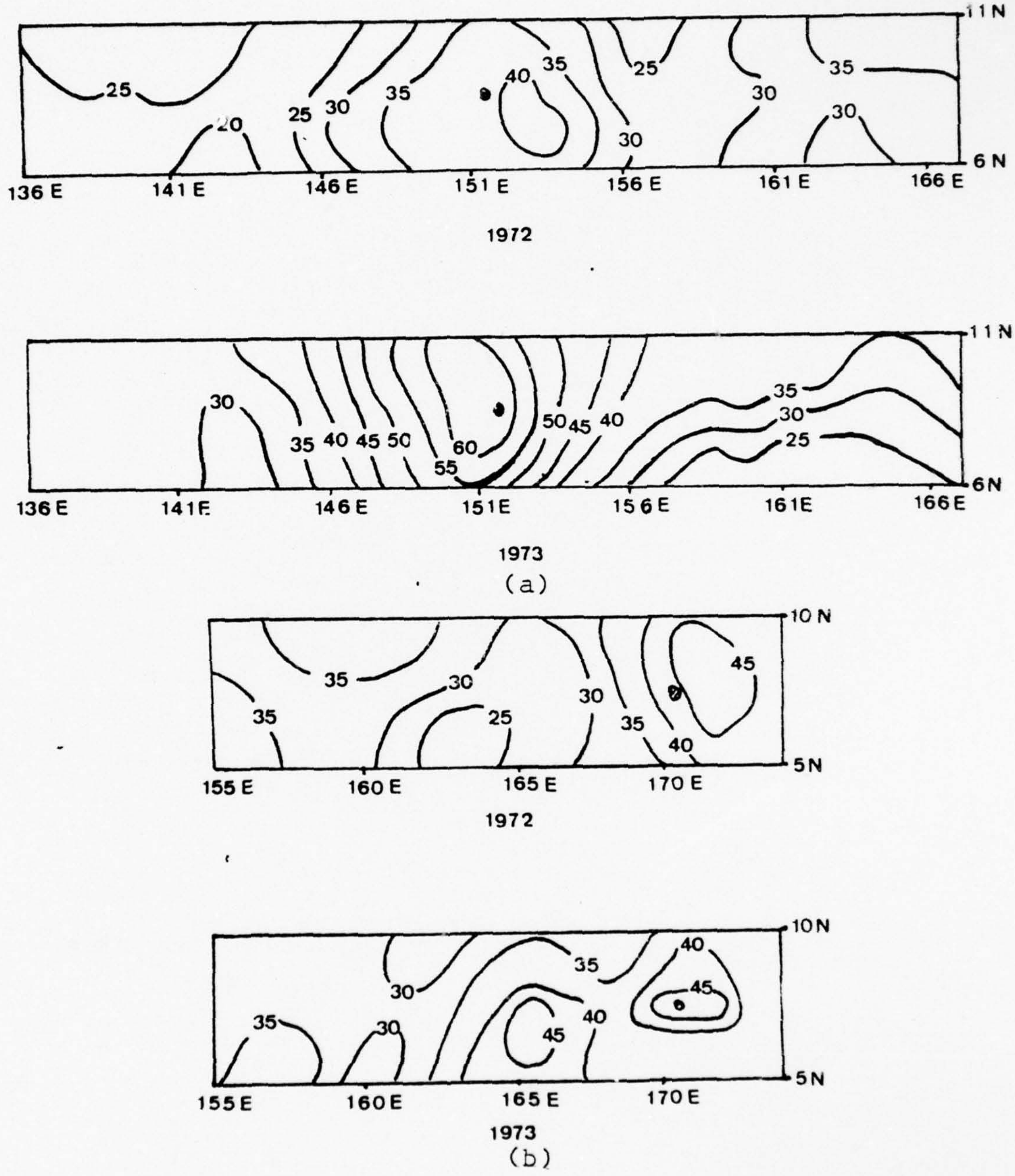


Fig. 11. Composite spatial distribution of clouds during trough passage for 1972 and 1973 for (a) Truk and (b) Majuro.

Year	Koror-Yap	Truk-Ponape	Majuro
1972	23.6	29.8	34.7
1973	30.4	31.1	32.9

(a)

Year	Koror-Yap	Truk-Ponape	Majuro
1972	10	8.9	6.3
1973	10.7	20.5	1.5

(b)

TABLE I. (a) Time-mean percentage convective cloud cover for the indicated stations during 1972 and 1973, and (b) the departures from the mean at the given stations.

Year	Koror-Yap	Truk-Ponape	Majuro	Avg.
1972	31	35.5	34	33.4
1973	34	37.5	34	35.4

(a)

STATISTICS	1972	1973
Wavelength (km)	3000	2900
Period (days)	4.6	4.3

(b)

TABLE II. Wave statistics
(a) Numbers of waves passing the indicated stations during 1972 and 1973, and the yearly average.
(b) Average horizontal wavelength and periodicity for 1972 and 1973.

Appendix A

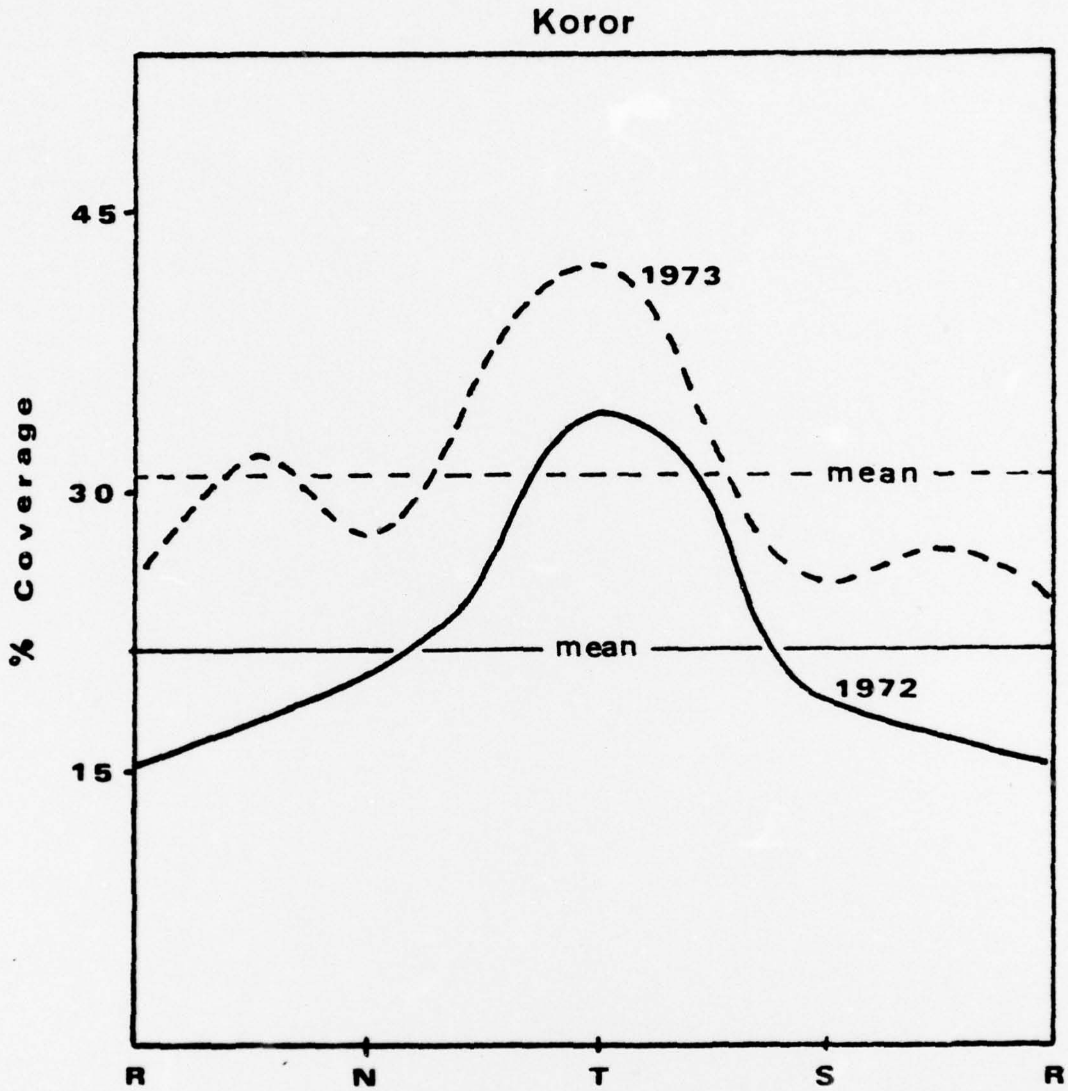


Fig. A.1. Percentage convective cloud cover during wave passage in 1972 and 1973 for Koror.

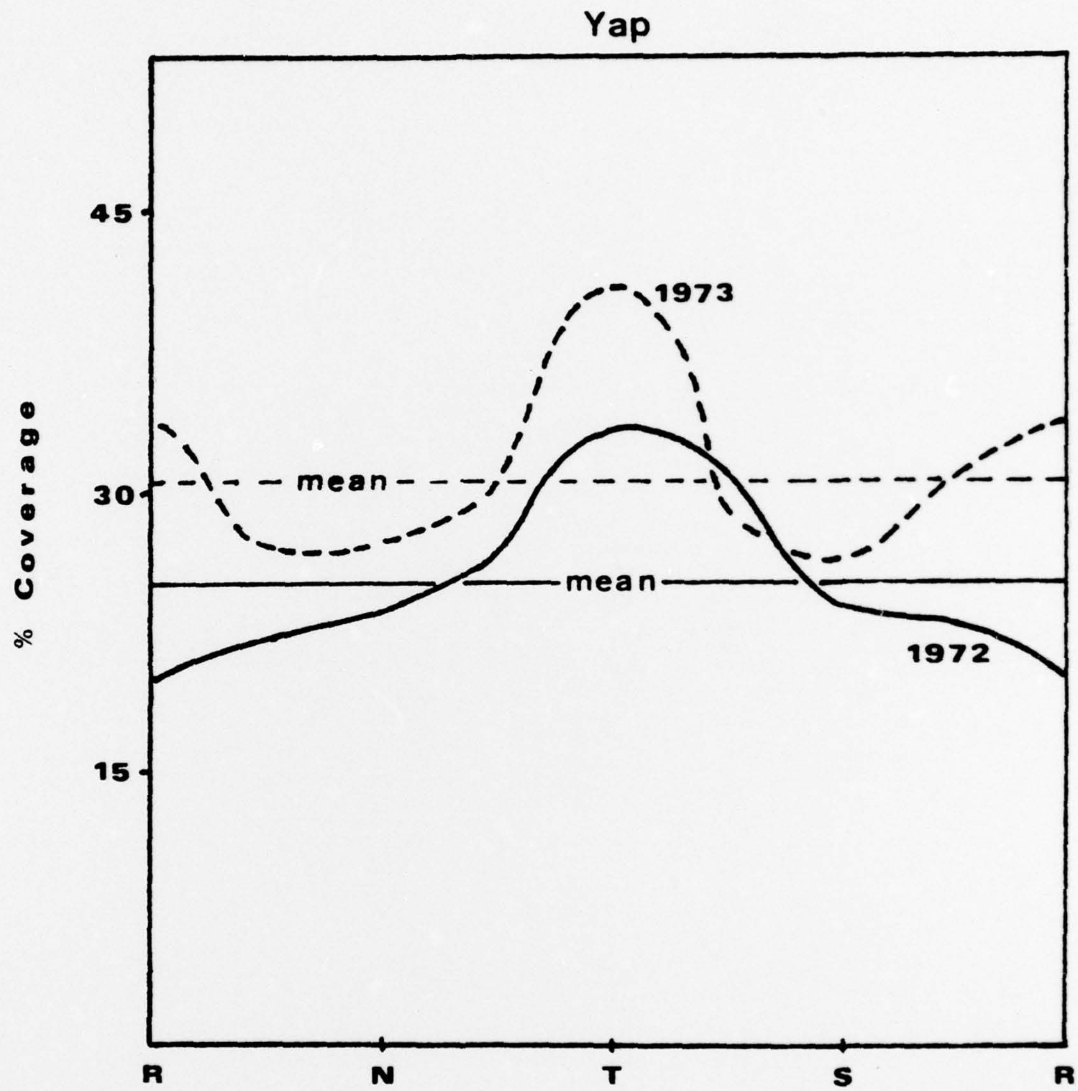


Fig. A.2. Percentage convective cloud cover during wave passage in 1972 and 1973 for Yap.

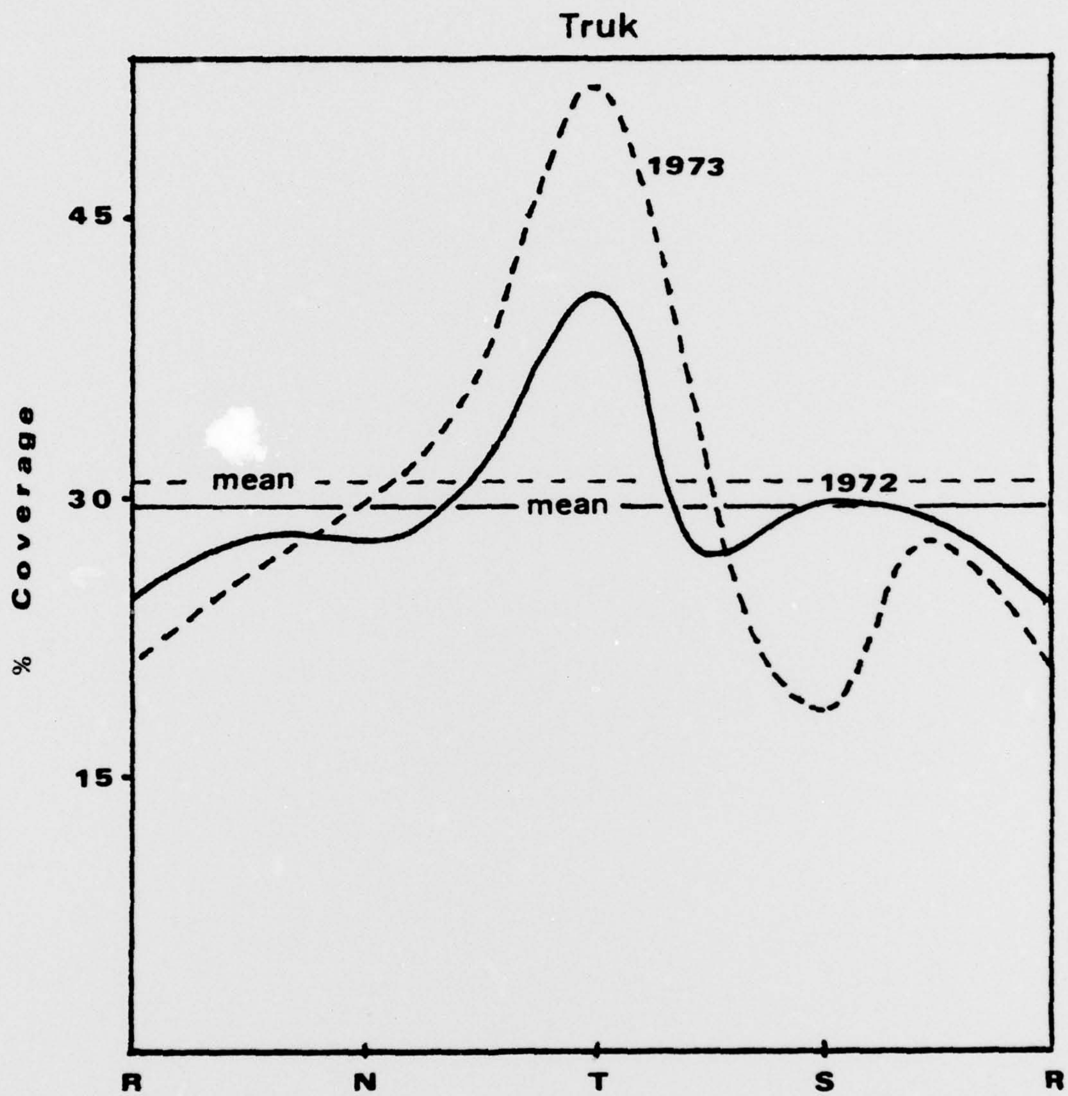


Fig. A.3. Percentage convective cloud cover during wave passage in 1972 and 1973 for Truk.

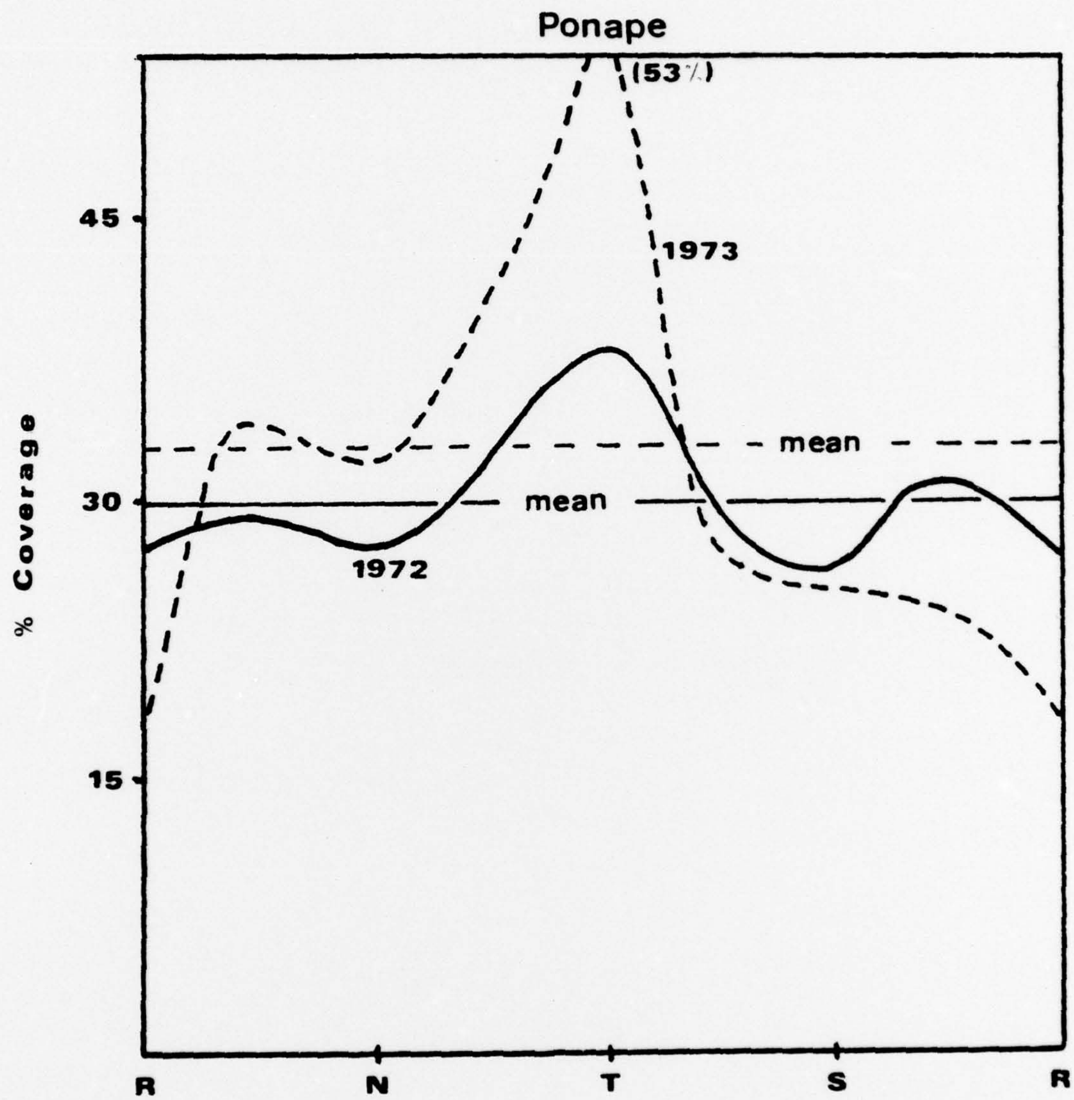


Fig. A.4. Percentage convective cloud cover during wave passage in 1972 and 1973 for Ponape.

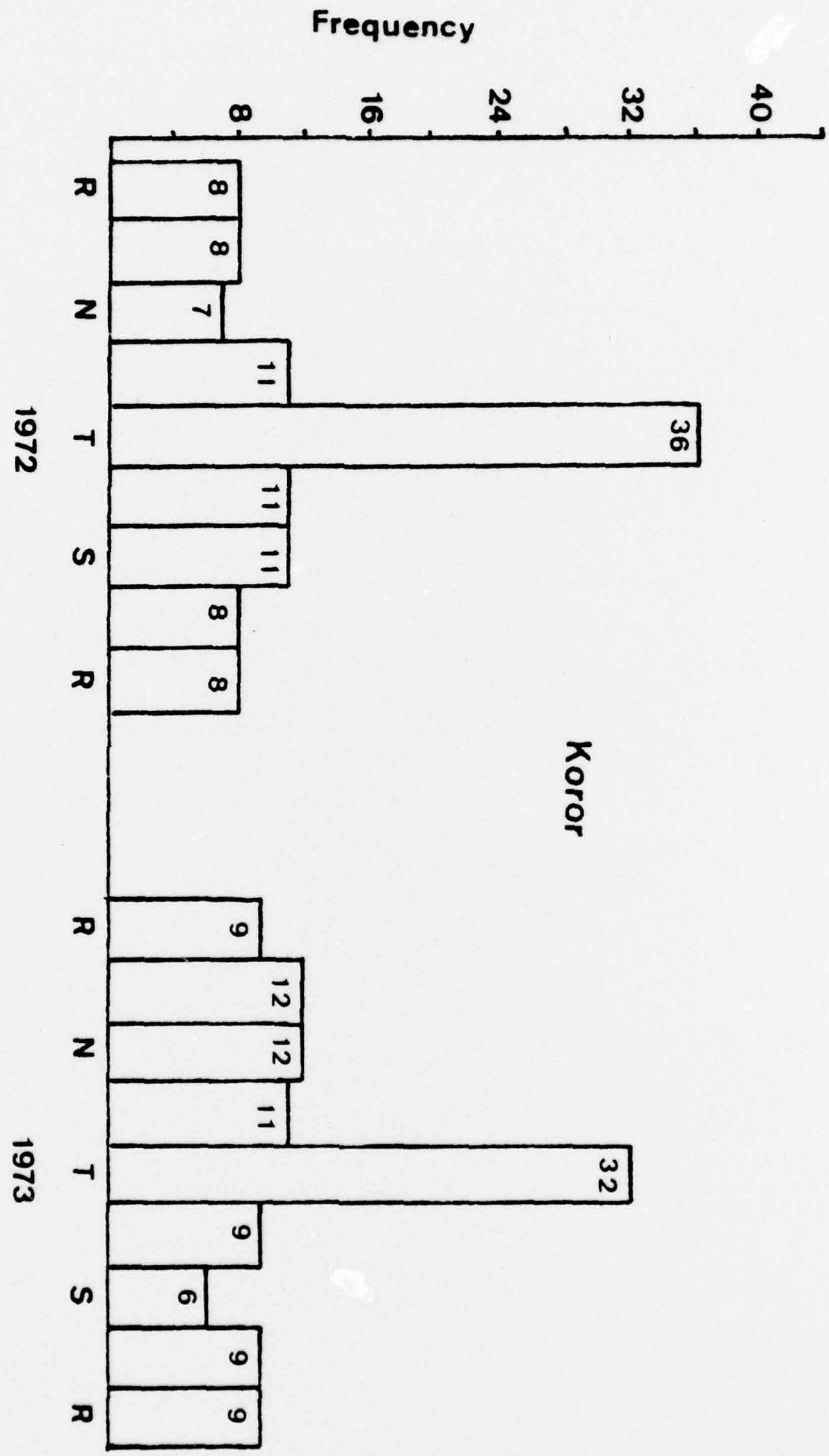


Fig. A.5. Frequency of occurrence of relative maximum convective cloud coverage during wave passage in 1972 and 1973 for Koror.

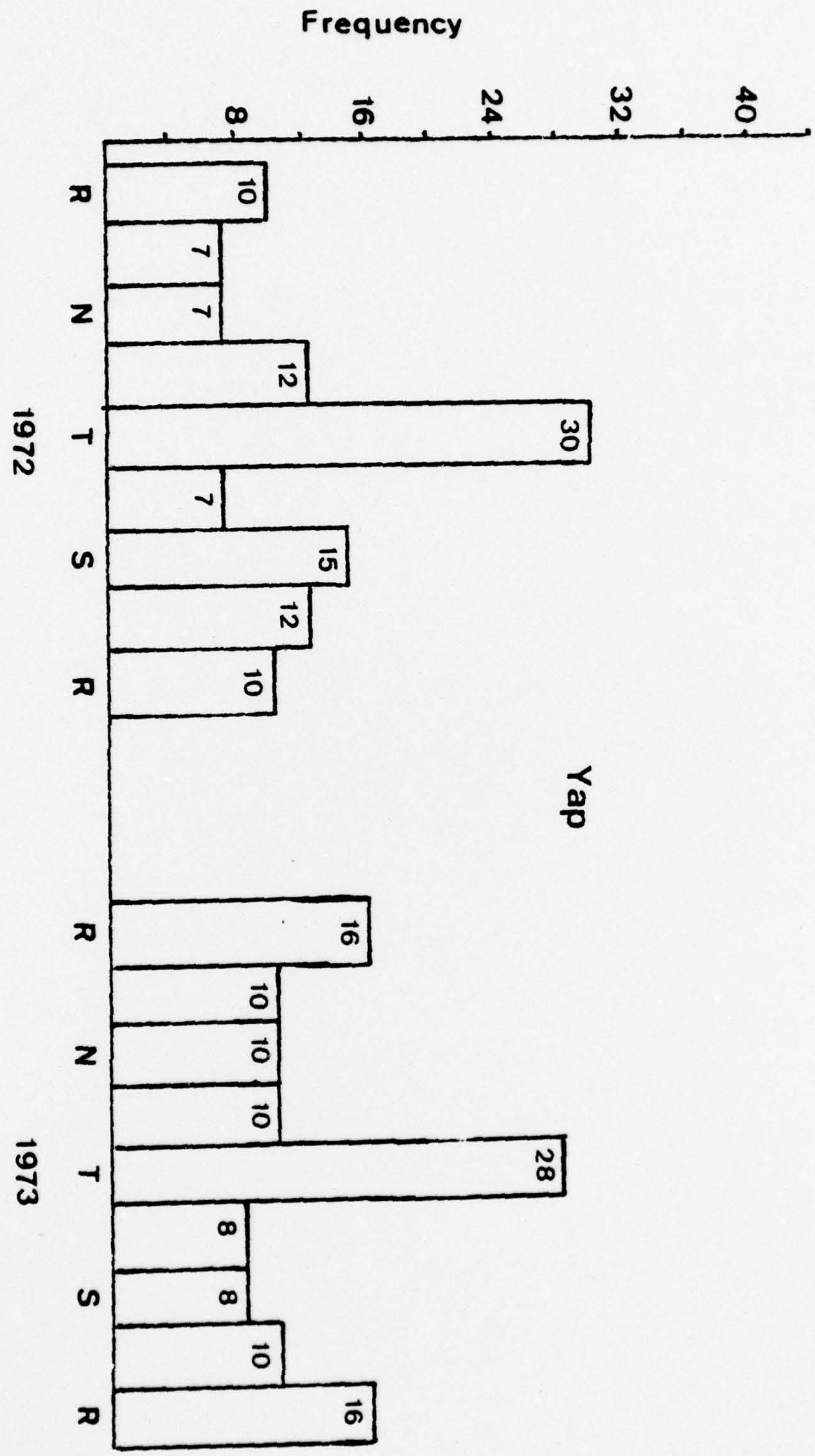


Fig. A.6. Frequency of occurrence of relative maximum convective cloud coverage during wave passage in 1972 and 1973 for Yap.

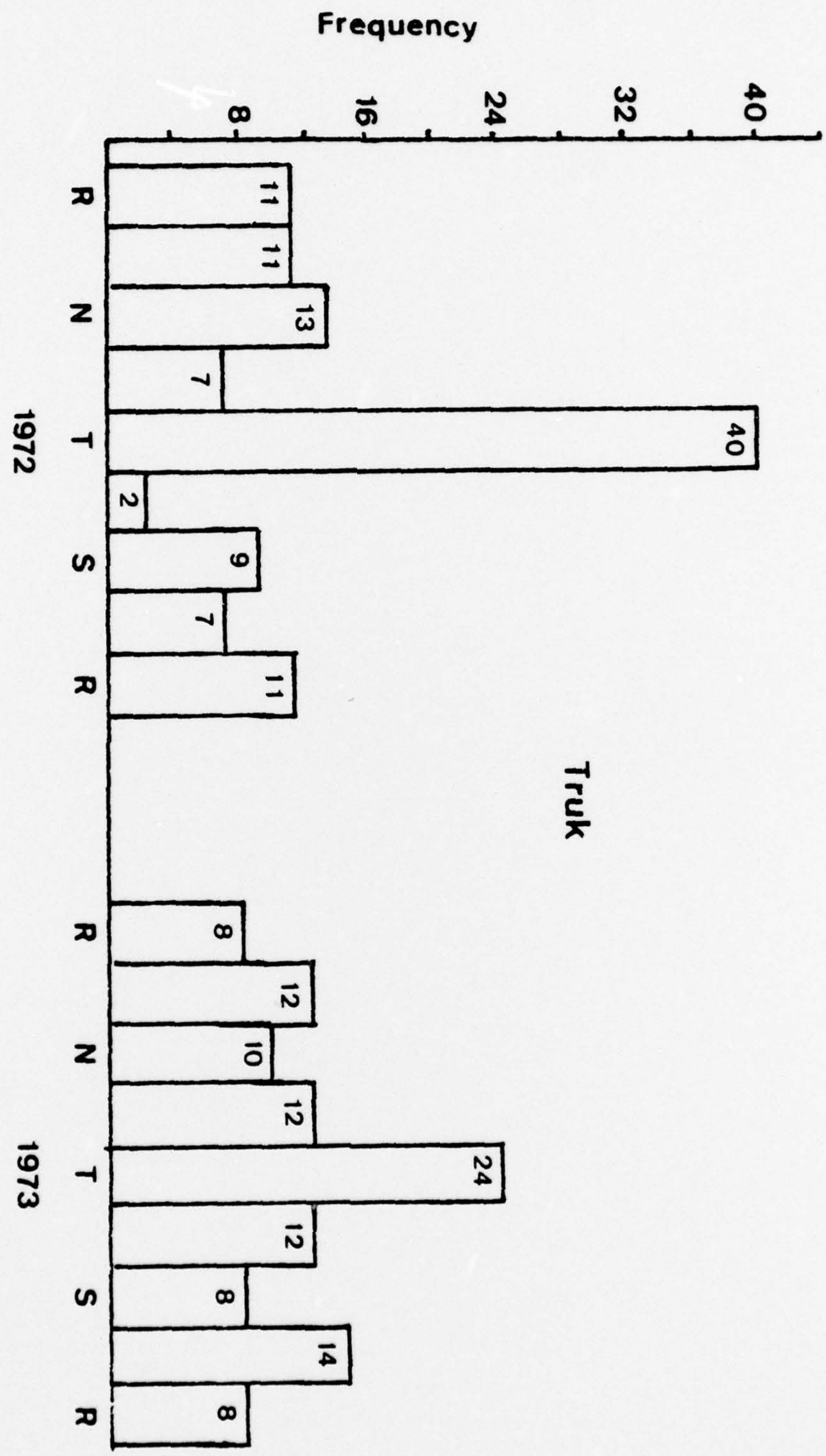


Fig. A.7. Frequency of occurrence of relative maximum convective cloud coverage during wave passage in 1972 and 1973 for Truk.

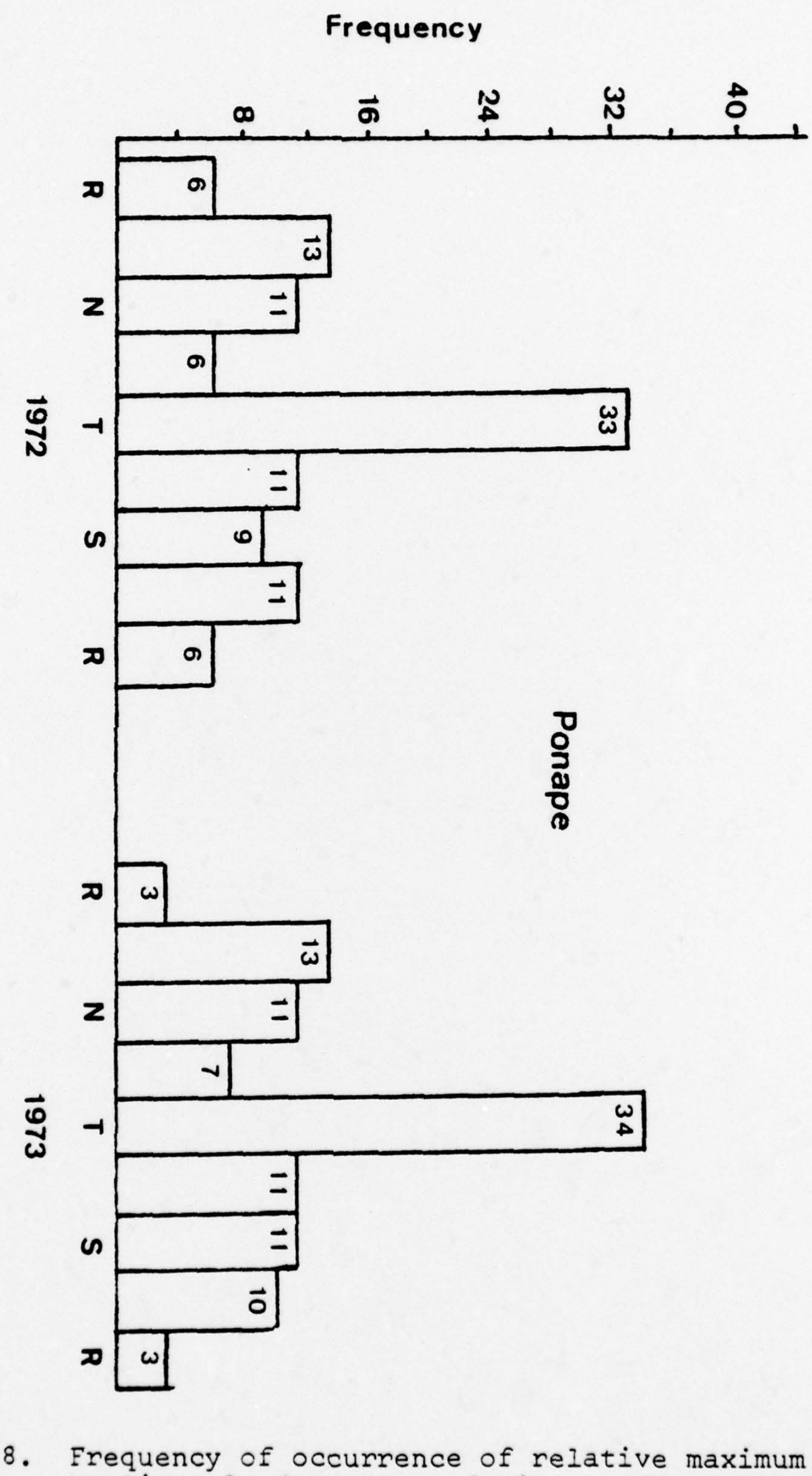


Fig. A.8. Frequency of occurrence of relative maximum convective cloud coverage during wave passage in 1972 and 1973 for Ponape.

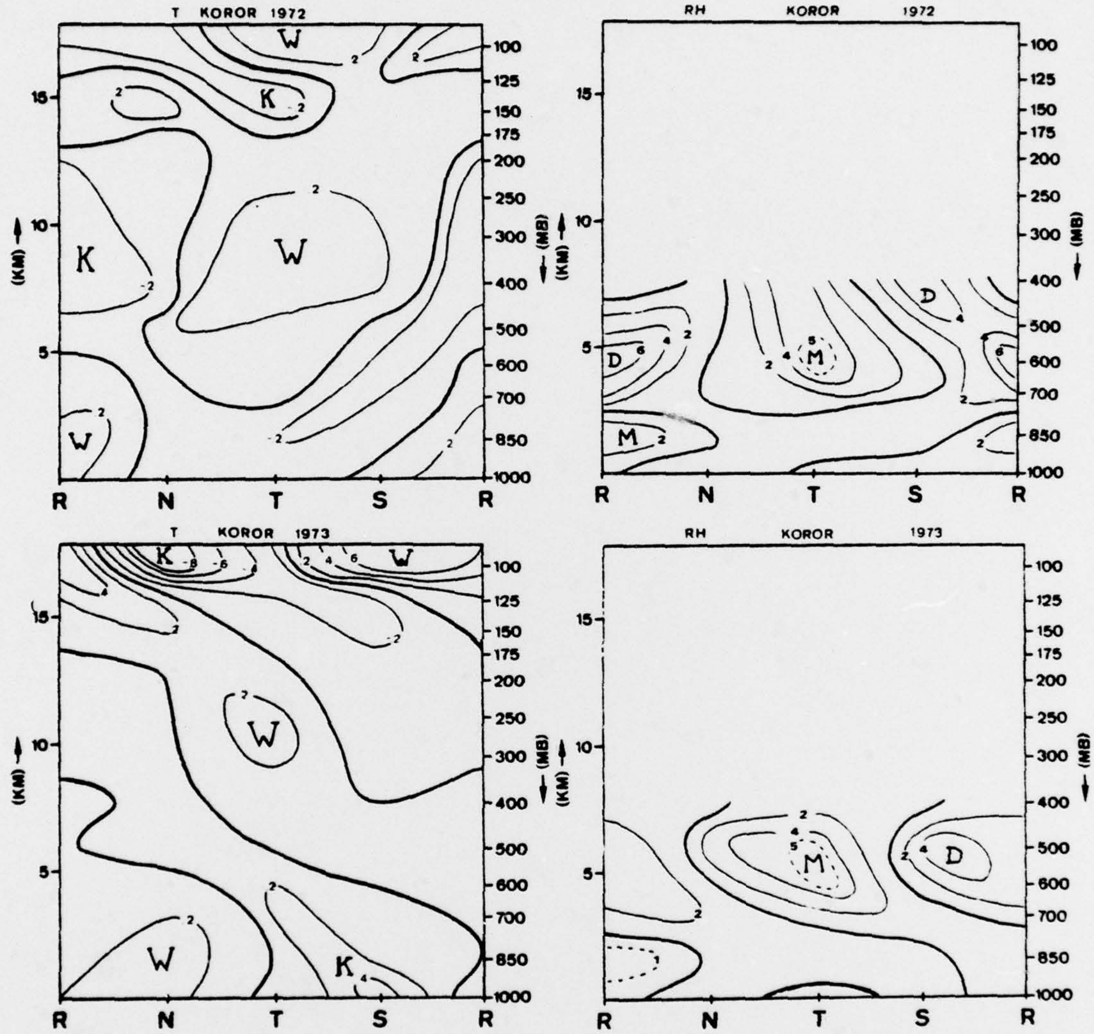


Fig. A.9. Vertical composites of temperature and relative humidity for Koror during 1972 and 1973.

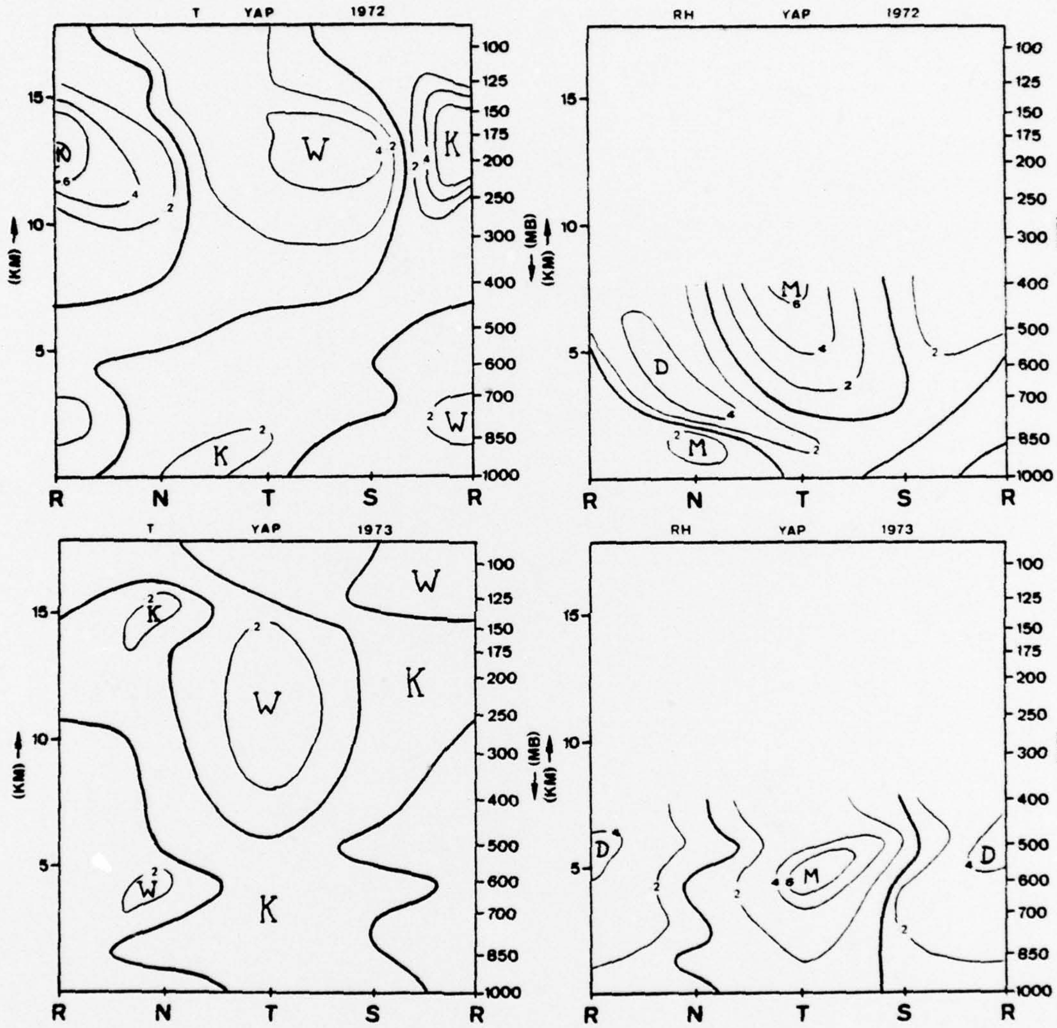


Fig. A.10. Vertical composites of temperature and relative humidity for Yap during 1972 and 1973.

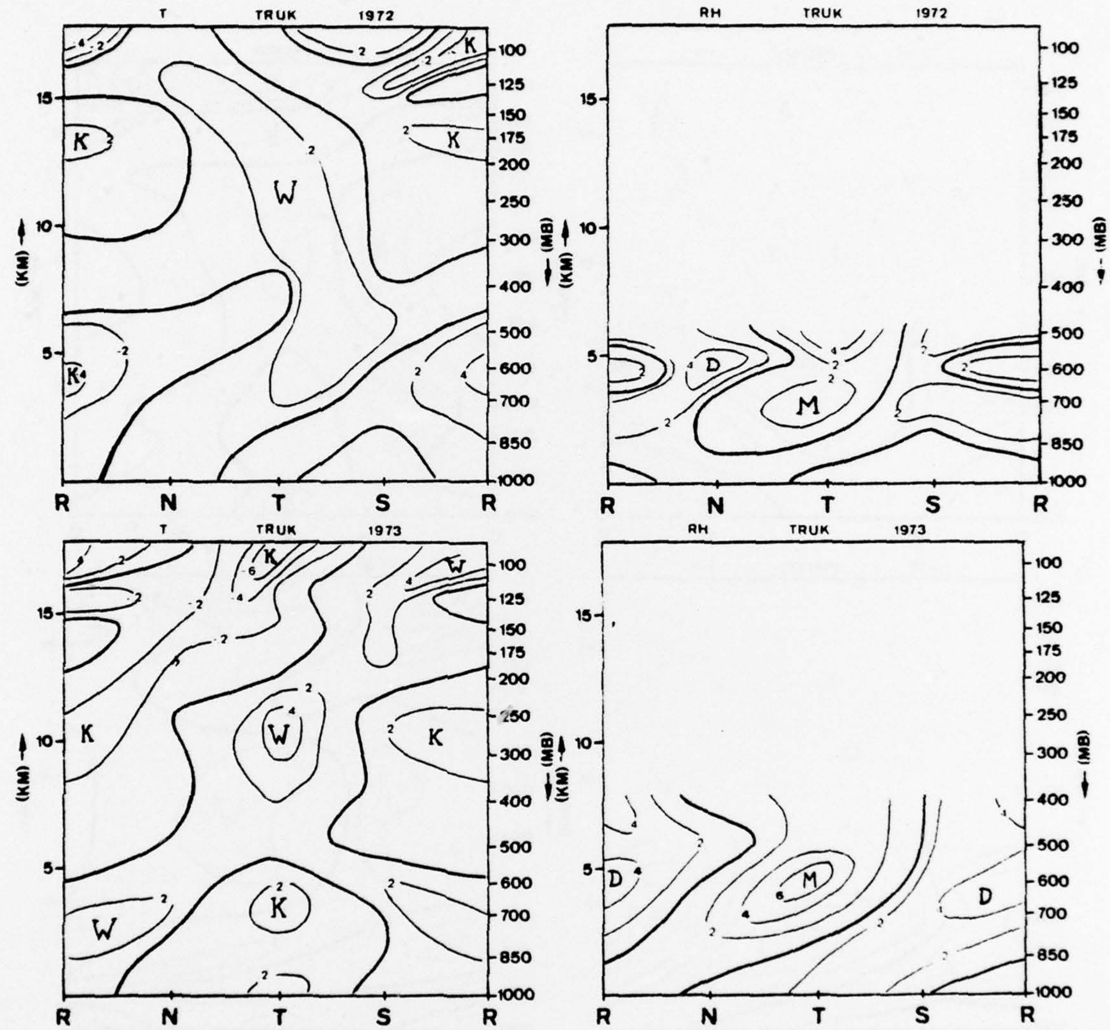


Fig. A.11. Vertical composites of temperature and relative humidity for Truk during 1972 and 1973.

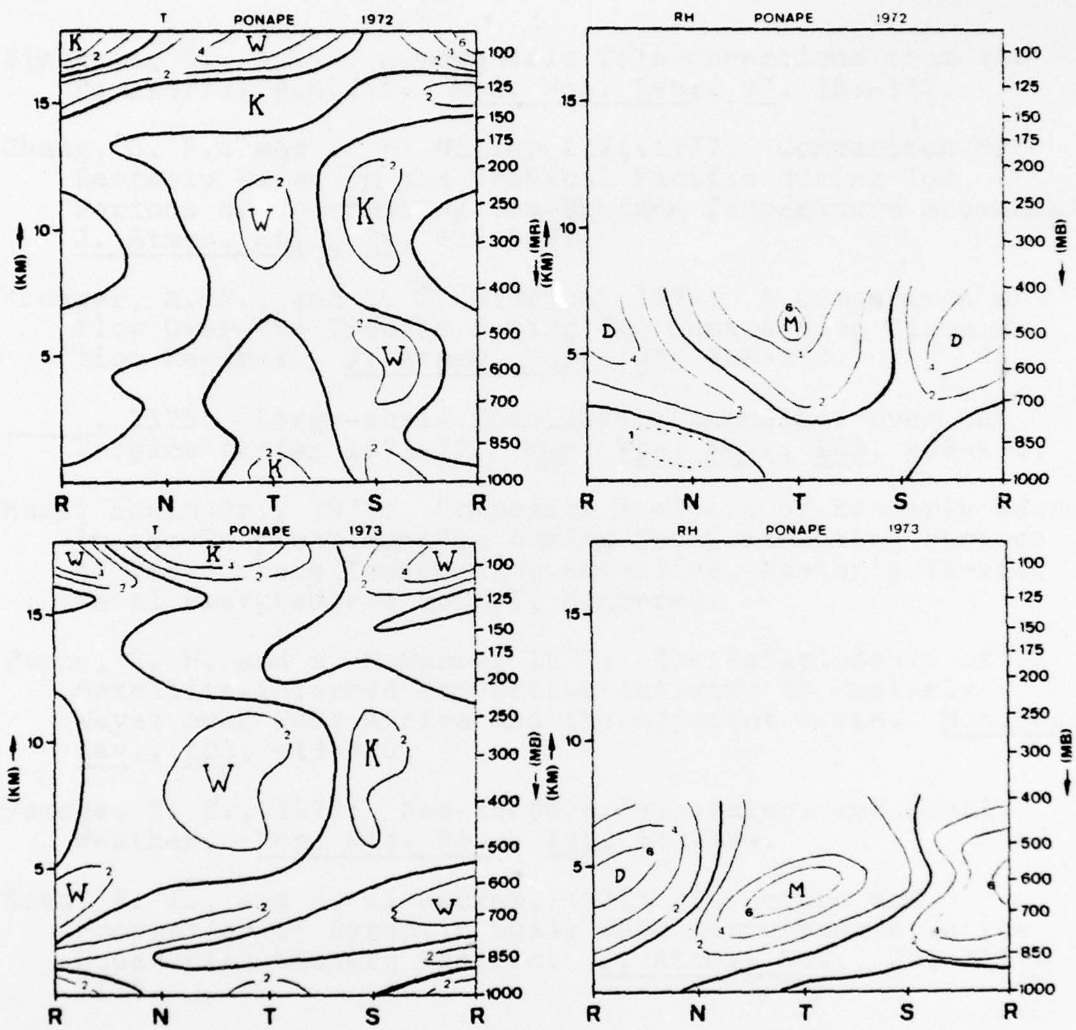


Fig. A.12. Vertical composites of temperature and relative humidity for Ponape during 1972 and 1973.

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