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# Long-term Change in Tropical Cyclone Activity in the Western North Pacific

K.H. Yeung, M.C. Wu, W.L. Chang & Y.K. Leung

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**Tropical Cyclone Activity in the Western North Pacific**

K. H. Yeung, M. C. Wu, W. L. Chang and Y. K. Leung
Hong Kong Observatory

## Abstract

The Hong Kong Observatory's best track data shows that in 7 of the recent 10 years between 1995 and 2004, the annual number of tropical cyclones in the western North Pacific was below the 1961-1990 normal of 31. This represented a reversal of the upward trend in the two decades before 1995 which was preceded by a downward trend between 1961 and the mid-1970s. The overall pattern suggested the existence of a long-term trend in tropical cyclone activity in the western North Pacific modulated by interannual and interdecadal variability, and merits investigation against the background of global warming and rising sea surface temperatures.

Results of linear regression analysis applied to the Observatory's best track data suggests that between 1961 and 2004, the annual number of tropical cyclones occurring in the western North Pacific have been decreasing at a rate of about 1.6 per decade. This decline in tropical cyclone activity might possibly be due in part to a seeming decrease in convection over the western North Pacific during the same period. For typhoon activity, no statistically significant trend has been identified suggesting that there was no increase in tropical cyclone intensity in the western North Pacific between 1961 and 2004.

Spectral analysis of the tropical cyclone time series yielded spectral peaks at 2.4, 3.4, and 18 years. The 3.4-year spectral peak, whose periodicity coincides with that of the El Niño-Southern Oscillation, is statistically significant at the 5% level when tested against the red noise spectrum. Singular Spectrum Analysis shows that interdecadal variations and long-term trends explain only about 26% of the variance, with interannual oscillations accounting for the remaining 74%.

Broadly similar results have been found for tropical cyclones in the South China Sea.

## 1. Introduction

Some 30 tropical cyclones form in the western North Pacific every year, the most prolific of all the ocean basins (Chen and Ding 1979). Chan and Shi (1996) noted that in the western North Pacific, the total annual number of tropical storms and typhoons as well as the annual number of typhoons have been decreasing between the early 1960s and the mid-1970s, and increasing between the mid-1970s and the mid-1990s.

The Hong Kong Observatory’s best track data shows that in 7 out of the 10 years between 1995 and 2004, the annual number of tropical cyclones in the western North Pacific was fewer than the 1961-1990 average of 31. This possibly is a sign that in recent years, tropical cyclone activity in that basin might again be reverting to a less active phase.

Besides Chan and Shi (1996), Chan and Liu (2004) described recent tropical cyclone activity in their study of tropical cyclone activity and sea surface temperature anomalies (SSTs) in the western North Pacific. Overall, the long-term trend in tropical cyclone activity in the western North Pacific is a topic not much studied.

Using the Hong Kong Observatory’s best track data between 1961 and 2004, this paper examines the long-term trends as well as interannual and interdecadal variations in tropical cyclone activity in the western North Pacific. Furthermore, as tropical cyclones in the area (10-25$^{o}$N, 105-120$^{o}$E) of South China Sea can affect the South China coast and Hong Kong, a similar analysis has been carried out to understand its long-term trend and periodicities for tropical cyclones in that basin.

## 2. Data and Methodology

### 2.1 Data

In this study, tropical cyclone activity in the western North Pacific and the South China Sea between 1961 and 2004 is represented by the annual number of tropical cyclones and typhoons in these two basins. The source is the Hong Kong Observatory's best track data. Outgoing Longwave Radiation (OLR) data are extracted from the webpage of NOAA’s Climate Diagnostic Centre http://www.cdc.noaa.

## 2.2 Methodology

Following the practice of Wigley and Raper (1990) in their study of the natural variability of climate systems, oscillations with periodicities of 10 years and longer are defined as low-frequency or long-term variations, and oscillations with periodicities shorter than 10 years are defined as high frequency or short term variations. In the context of this paper, the former will be referred to as interdecadal variations and the latter interannual variations.

The time series of tropical cyclone and typhoon activities are firstly low-pass filtered with a Gaussian filter (see for example, Hanna and Cappelen 2003) and the results are plotted to aid visual inspection and preliminary analysis.

Trends and their statistical significance are assessed using linear regression analysis and the t-test (see Easterling *et al.* 1997, IPCC 2001). Statistical significance is then verified by the non-parametric Mann-Kendall test. This test has the advantages of not being predicated upon the normal distribution and is insensitive to outliers (Sneyers 1990, Fu and Wang 1992). Since the Mann-Kendall test gives only the significance and the direction of the trend but not the trend itself, the non-parametric Sen's slope estimator (Sen 1968) is employed to corroborate the trend obtained by linear regression. Like the Mann-Kendall test, Sen's slope estimator can be applied to data that do not come from a normal distribution, and is not affected by outliers.

Interannual and interdecadal variations are identified by spectral analysis using the Multitaper Method (MTM). Compared with Fourier and other traditional methods of spectral analysis, the spectral estimates given by MTM have lower variance and higher resolution (see for example, Ghil *et al.* 2002). Furthermore, as the lag-1 autocorrelations of all the time series under study are greater than zero, the statistical significance of the spectral peaks obtained by MTM are tested against the red-noise spectrum (Wilks 1995).

Singular Spectrum Analysis (SSA) is used to elicit the amount of variance separately explained by interannual and interdecadal variations including trends. Details of the SSA technique can be found in Jiang and Ding (1998), Golyandina *et al.* (2001) as well as others.

## 3. Tropical Cyclone and Typhoon Activity in the Western North Pacific

### 3.1 Preliminary analysis

Figure 1 shows the time series of the annual number of tropical cyclones and typhoons in the western North Pacific. A downward trend can be seen in the Gaussian filtered series of the annual number of tropical cyclones. This trend is not as evident in the case of typhoons.

The correlation between the Gaussian filtered, i.e., interdecadal tropical cyclone and typhoon time series is 0.81, statistically significant at the 5% level. This indicates that the interdecadal behaviour of these two series is similar. Both tropical cyclones and typhoons have higher activity in the early 1960s, and the late 1980s and early 1990s. The mid-1970s, the late 1990s and early 2000 are periods of low activity. The amplitudes of these interdecadal variations appear to be small.

For interannual variations, the correlation of the two residual series (the time series resulting from the difference between the original and the filtered series for tropical cyclones, and that resulting from the difference between the original and the filtered series for typhoons) is 0.56. This figure is lower than the correlation for interdecadal activity albeit it is still statistically significant at the 5% level.

Trends, interannual and interdecadal variations are now examined using the methodologies described in Section 2.

### 3.2 Trends

Linear regression shows that between 1961 and 2004, the annual number of tropical cyclones in the western North Pacific declined at 1.6 per decade. This trend is significant at the 5% level (t-test). Similarly, the Mann-Kendall test indicates the presence of a statistically significant (5% level) downward trend. Sen's (1968) method gives a decreasing trend of 1.3 per decade, slightly fewer than the 1.6 obtained from linear regression.

Linear regression also shows that between 1961 and 2004, there was no statistically significant trend in typhoon activity in the western North Pacific. The Mann-Kendall test gives a similar result. An absence of trend suggests that although SSTs in the western North Pacific appears to be rising (Chan and Liu 2004), the intensity of tropical cyclones apparently has not increased in the past 40 years.

3.3 Interannual and interdeacadal variations

Figure 2 shows the MTM spectral estimates for annual tropical cyclone and typhoon activity in the western North Pacific. For tropical cyclones, one sees that the spectral peaks are found at approximately 2.4, 3.4 and 18 years, with only the 3.4-year spectral peak reaching or exceeding the 95% confidence limit of the red noise spectrum. The 18-year spectral peak indicates modulation by interdecadal influences. That this spectral peak does not exceed the 95% confidence limit is probably because of interdecadal variations being smaller than interannual variations.

For typhoons, the largest peaks are located at 2.4, 3.4, 3.9 and 17 years. Of these, the 3.4 and 3.9-year spectral peaks exceed the 95% confidence limit. As in the case of tropical cyclones, interdecadal influence is implied by the presence of the 17-year spectral peak although this peak does not reach the 95% confidence limit. In comparison, Chan and Shi (1996) have found using variance analysis spectral peaks at 2, 5 and 7 years for typhoon activity in the western North Pacific.

The 2.4-year spectral peak is very close to the periodicity of the Quasi-Biennial Oscillation (QBO), while those of the 3.4- and 3.9-year peaks are close to that of the El Niño-Southern Oscillation (ENSO). The 17 and 18-year spectral peaks may be possibly associated with the 15 to 25-year periodicity of the Pacific Decadal Oscillation (PDO) although this remains to be confirmed.

3.4 Variance explained

SSA shows that for both the tropical cyclone and typhoon annual series, interdecadal variation including the trend explains respectively 26% and 18% of the total variance. In other words, most of the variations in tropical cyclone and typhoon activity in the western North Pacific are of an interannual nature.

## 4. Tropical Cyclone and Typhoon Activity in the South China Sea

4.1 Preliminary analysis

Figure 3 shows the annual number of tropical cyclones and typhoons in the South China Sea between 1991 and 2004, as well as the Gaussian filtered, that is, the interdecadal series. The correlation between the two filtered series is 0.38, statistically significant at the 5% level. The correlation between the residual series, that is, interannual series, is 0.49, also statistically significant at the 5% level.

The filtered series of tropical cyclone activity seems to show a long-term trend. The annual number of tropical cyclones in 2002, 2003 and 2004 are all a third fewer than the 1961-1990 long-term average of 12.4. Periodicities is harder to identify visually. For typhoons, there appear to be no apparent long-term trend, but small amplitude variations of about 10 years in period seem to be present.

### 4.2 Trends

Linear regression shows that the annual number of tropical cyclones in the South China Sea decreased at a rate of 0.8 per decade between 1961 and 2004. This trend is statistically significant at the 5% level. The Mann-Kendall test and Sen's technique yield similar results. For typhoons, no statistically significant trend was revealed by both the t-test and the Mann-Kendall test. This signifies no increase in the intensity of tropical cyclones in the South China Sea.

### 4.3 Interannual and interdecadal variations

Figure 4 shows the MTM spectral estimates for tropical cyclones and typhoon activity in the South China Sea between 1961 and 2004 as well as the corresponding red-noise spectra. One can see that as in the case of tropical cyclones in the western North Pacific, the largest spectral peak has a periodicity of 3.6 years and it exceeds the 95% confidence limit. Spectral peaks are also found at 3.2, 6 and 8 years although none of them reaches the 95% confidence limit. There is no spectral peak for periods of 10 years or more implying an absence of interdecadal modulation. These findings are broadly consistent with the 3 and 8-year periodicities found by Liu (2000) for tropical cyclones making landfall over Guangdong, and by Xie and Ji (2000) for tropical cyclones affecting Guangdong.

For typhoon activity in the South China Sea, spectral peaks are found at 2.9 and 3.2 years, both peaks exceeding the 95% confidence limit. MTM reveals the existence of a 12-year interdecadal variation confirming the observation in the preliminary analysis. As in the case of the western North Pacific, this spectral peak does not reach the 95% confidence limit as did its interannual counterparts but indicates that interdecadal modulation is likely present in typhoon activity in the South China Sea.

4.4. Variance explained

SSA shows that for tropical cyclones in the South China Sea, about 18% of the variance are explained by interdecadal variations and trend with the remainder explained by interannual variations. In the case of typhoons in the South China Sea, SSA was not able to extract the proportions of variance attributable to the long and short term variations. That this might sometimes occur with the SSA technique has been noted by Golyandina *et al.* (2001). The length of the time series under study, and its particular structure are some of the factors determining whether individual variances can be so identified.

## 5. Discussion

That annual tropical cyclone activity over the western North Pacific seems to have decreased significantly is inconsistent with sea surface temperature rise and the findings of some models that such activity should increase with an increase in sea surface temperature (Chan and Liu 2004).

On the other hand, between 1961 and 2004 the annual average Outgoing Longwave Radiation (OLR) over the western North Pacific between 5-25$^{o}$N,130-180$^{o}$E where most of the tropical cyclones form appears to be increasing (trend significant at the 5% level). This increase in OLR indicates that convection in that region of the western North pacific has been decreasing.

The correlation between OLR and the annual number of tropical cyclones in the western North Pacific is -0.52, statistically significant at the 5% level. This signifies that the decrease in tropical cyclone activity in the western North Pacific may possibly be explained in part by the apparent reduction in convection over that ocean basin. In the equatorial western North Pacific (5$^{o}$S-5$^{o}$N,130-180$^{o}$E) where few tropical cyclones form, OLR also exhibits a statistically significant (at the 5% level) upward trend between 1961 and 2004. The large scale OLR trend found here is therefore likely to be of a different nature than the tropical cyclone-OLR feedback mechanism discussed by Sobel and Camargo (2004).

## 6. Conclusions

Analysis of Hong Kong Observatory's best track data suggests that between 1961 and 2004, the annual number of tropical cyclones occurring in the western North Pacific has decreased at a rate of about 1.6 per decade. This trend is statistically significant. One possible reason for this downward trend is the seeming decrease in convection over the western North Pacific during the same period. On the other hand, no statistically significant trend was found for the annual number of typhoon occurring in the western North Pacific between 1961 and 2004, suggesting that intensity of the tropical cyclones has not increased.

Results for the South China Sea are largely similar. The annual number of tropical cyclones in that basin was found to be decreasing at 0.8 per decade. Again, no statistically significant trend was found for typhoons.

Interdecadal variations (including trend) in tropical cyclone activity in the western North Pacific, as well as that in the South China Sea seem to be not as significant as interannual variations, the fractions of variance explained being 26% and 18% respectively. Interannual variations with a period around 3.5 years, coinciding with that of El-Niño-Southern Oscillation, seems to be the most prominent in tropical cyclone activity in both the western North Pacific and the South China Sea.

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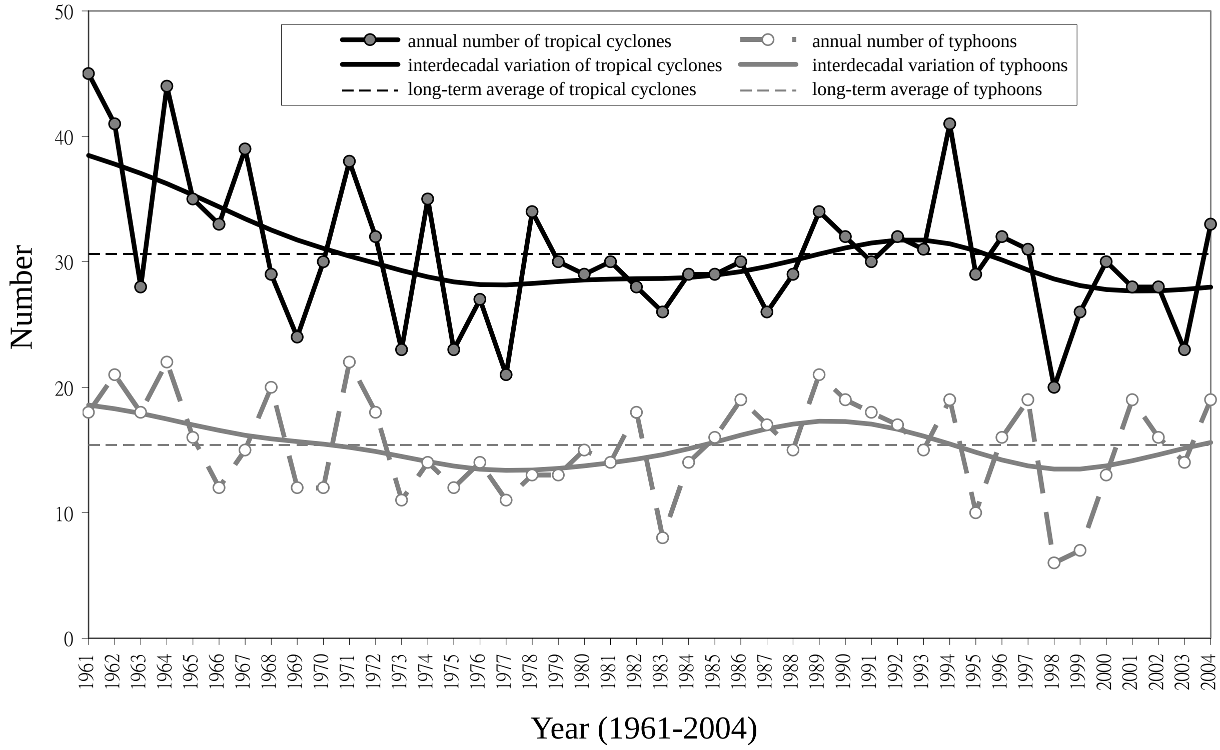



Figure 1. Time series of tropical cyclones and typhoons in the western North Pacific. Interdecadal variations (continuous lines) are obtained by applying a Gaussian filter to remove variations with periodicities that are less than 10 years.

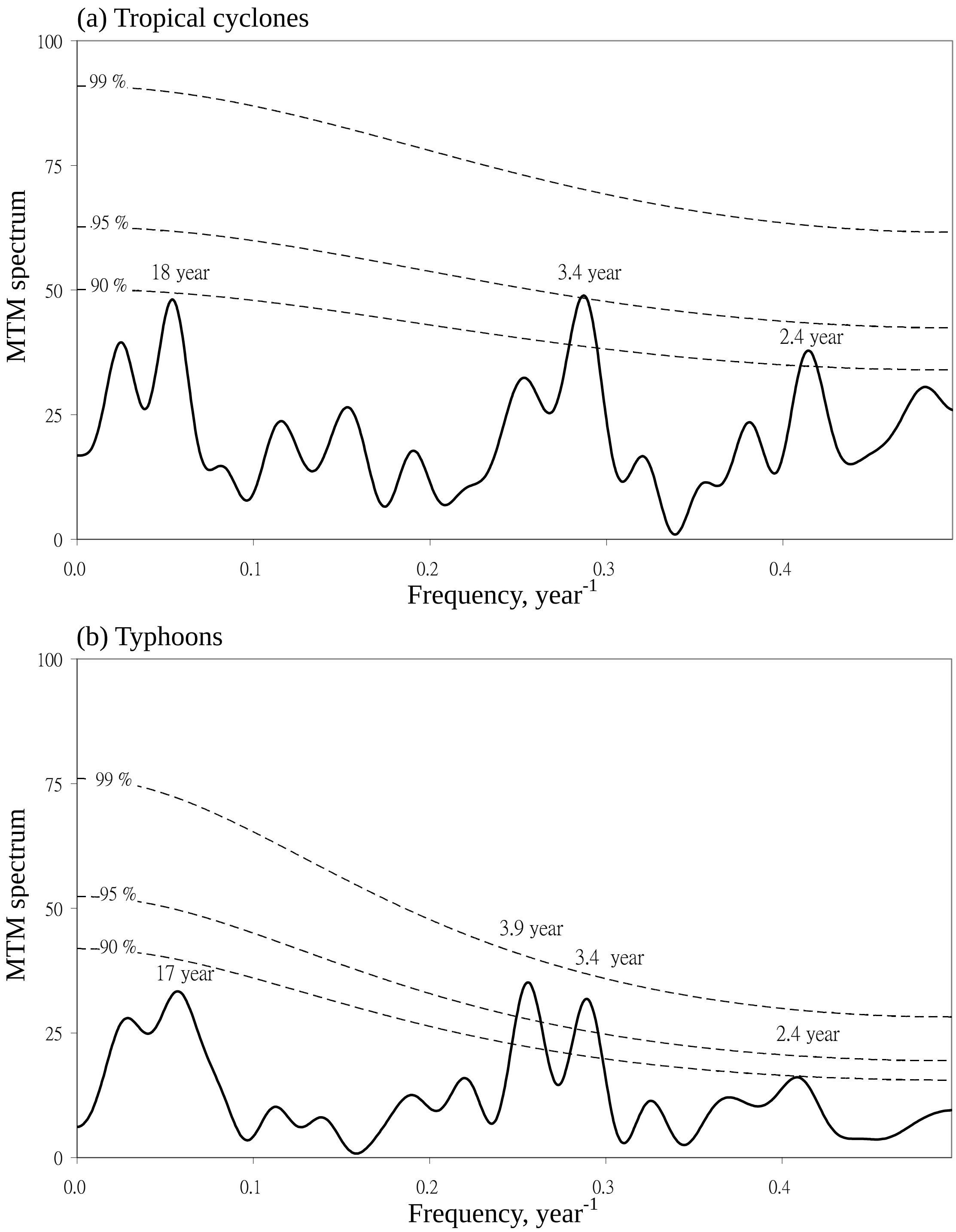



Figure 2. MTM spectrum of the annual number of (a) tropical cyclones and (b) typhoons in the western North Pacific. The 90%, 95% and 99% confidence levels with respect to the red noise spectrum are shown by the dashed lines.

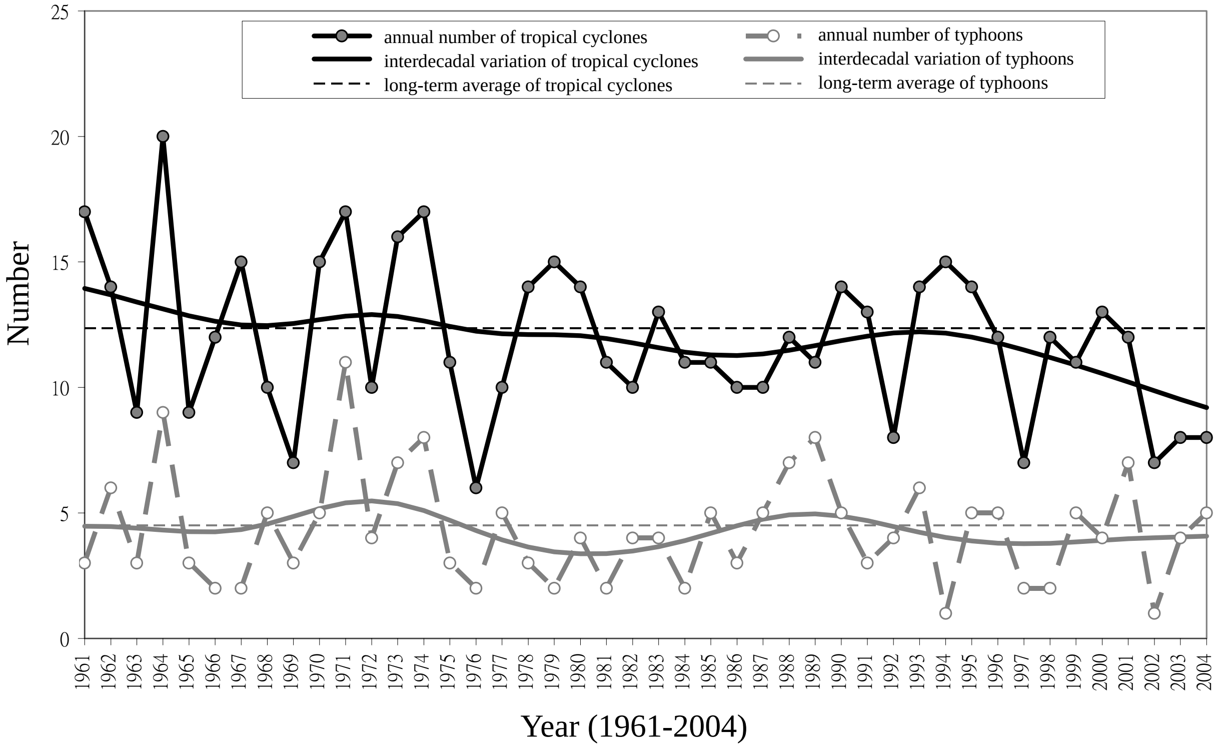
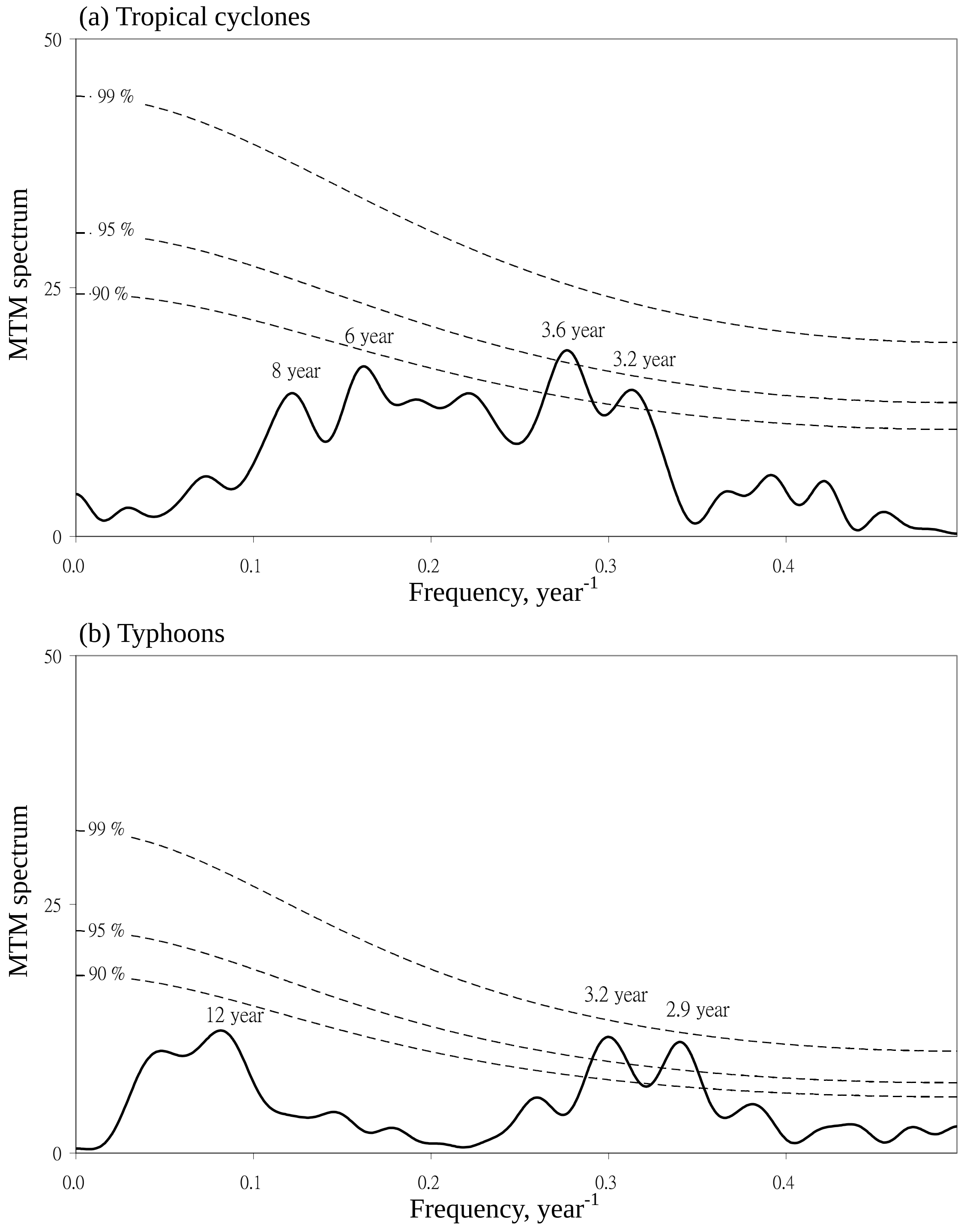



Figure 3. Time series of tropical cyclones and typhoons in the South China Sea. Interdecadal variations (continuous lines) are obtained by applying a Gaussian filter to remove variations with periodicities that are less than 10 years.

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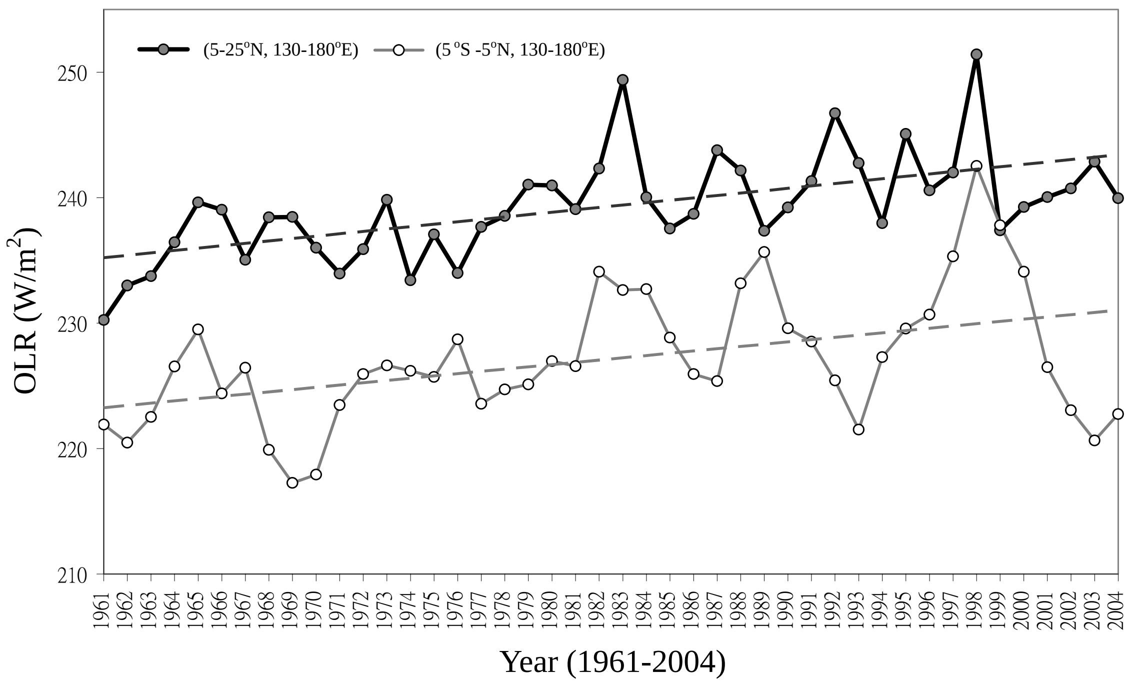


Figure 5. Annual mean Outgoing Longwave Radiation (OLR) in the regions 5-25°N, 130-180°E (upper graph) and 5°S-5°N, 130-180°E (lower graph) in the western North Pacific. Dashed lines indicate the respective long-term OLR trends in these two regions.