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## 1. Introduction

A number of studies have been carried out to identify the interannual variation of tropical cyclone activity in various ocean basins. Results show that over the western North Pacific, the interannual variation in tropical cyclone activity is related to the El Nino-Southern Oscillation (ENSO) phenomenon (e.g. Chan 1985; Lander 1994). The aim of this study is to investigate if and how this variability influences the number of tropical cyclones affecting Hong Kong.

## 2. Data

In this study, forty years of tropical cyclone data (1961-2000) from the Hong Kong Observatory are used. The number of tropical cyclones affecting Hong Kong is defined as the number of tropical cyclones necessitating the issuance of tropical cyclone warning signal for Hong Kong. When a tropical cyclone is within 800 km from Hong Kong (Figure 1) and may affect Hong Kong, the Hong Kong Observatory will issue a tropical cyclone warning signal to warn the local public.

Sea surface temperature and the large-scale upper air data are extracted from the re-analysis data of the United States National Center of Environmental Protection (NCEP). These re-analysis data are grid data with a horizontal resolution of 2.5° x 2.5°. A detailed description of NCEP re-analysis data can be found in Kalnay (1996).

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3. Variation of number of tropical cyclone affecting Hong Kong with Sea Surface Temperature Anomalies

As most studies suggest that sea surface temperature is closely related to tropical cyclone activity, the general pattern with which the sea surface temperature anomalies (SSTAs) over the tropical oceans is correlated to the annual number of tropical cyclone affecting Hong Kong (N) is examined. Figure 2 is a map showing the correlation between N and SSTAs in 2.5° x 2.5° grid over ocean areas. It can be seen that the strongest correlation between N and SSTAs occurs in the equatorial Central and Eastern Pacific, roughly coinciding with the four Nino regions, i.e., Nino-1+2, Nino-3, Nino-3.4 and Nino-4 (Figure 3). Table 1 shows the correlation between N and the mean annual SSTAs in each of the four Nino regions. While all of them are statistically significant at 0.05 level, the highest correlation occurs in Nino-3 and Nino-3.4. The Hong Kong Observatory has been using Nino-3.4 to classify ENSO events. The fact that the correlation of tropical cyclone number with SSTAs is highest in Nino-3.4 (as well as Nino-3) shows that this is an appropriate choice for studying the number of tropical cyclone affecting Hong Kong. In the 40-year period (1961-2000), there were occasions where SSTA in Nino-3.4 changed sign in the latter half of the year. In such cases, the SSTA in Nino-3.4 in the latter half of the year (the rainy and typhoon seasons in Hong Kong) is preferred over that of the first half of the year. Accordingly, the years 1965, 1969, 1972, 1976, 1982, 1983, 1986, 1987, 1991, 1992, 1994 and 1997 are El Nino years. The years 1964, 1970, 1971, 1973, 1974, 1975, 1988, 1989, 1995, 1998, 1999 and 2000 are La Nina years.

From the scattered diagram in Figure 4, it is seen that for warm phases of ENSO, N is relatively low while for cold phases of ENSO, N is relatively large.

The distribution of N for the 40 years (1961 - 2000) is shown in Figure 5. N ranges from 2 (in 1997, an El Nino year) to 11 (in 1974, a La Nina year), with a mean and standard deviation of 6.4 and 1.96 respectively. The Hong Kong Observatory takes N to be normal when it is within half of a standard deviation from the mean (i.e. within 6.4 ± 0.98). Taking integer values, a year is taken as having normal tropical cyclone activity when N is 6 or 7. N less than or equal to 5 will be taken as below normal, and N equal to or greater than 8 is taken as above normal. For El Nino or warm ENSO years, the average value of N is 4.8. Of the twelve El Nino years, nine have N below normal while the remaining three are normal. For La Nina or cold ENSO years, the average value of N is 7.8. Of the twelve La Nina years, six have N above normal, five are normal whereas the remaining year is below normal.

To examine how N varies with the progress of ENSO events, the values of N prior to, during and after the onset of El Nino and La Nina events are listed in Table 2. EN-1 is the year prior to El Nino onset, EN(0) is the year of onset while EN+1 is the year after onset. LN-1, LN(0), LN+1 and LN+2 are similarly defined for La Nina years.

In the nine EN-1 years, the mean value of N is 7.1. There are two years with N below normal, four years with normal N values and three years with N above normal. Of the three years with N above normal, two happen to be LN(0) or LN+1.

In the nine EN(0) years, apart from two with normal N, all other have values of N below normal.

For the three EN+1 years, one has normal N while the other two have N below normal.

In six LN-1 years, all have N less than normal. It is noted, however, that five of these six years are either EN(0) or EN+1 years.

For the six LN(0) years, one is having N less than normal, two are normal while the remaining three have N higher than normal.

For the four LN+1 years, three of them have higher than normal N while one has normal N.

For the two LN+2 years, the values of N are normal.

From the above, it can concluded that the annual number of tropical cyclones is predominantly less than normal for EN(0) years and EN+1 years. For LN(0) and LN+1 years, predominantly more tropical cyclones affect Hong Kong. No conclusion can be drawn for EN-1, LN-1 and LN+2 years.

## 4. Intermediate factors affecting tropical cyclone activity in Hong Kong

It is likely that ENSO events could affect tropical cyclone activity in Hong Kong by changing the location of tropical cyclone genesis and the steering current. These two aspects are investigated below.

Lander (1994) suggested that SSTAs are related to the longitudinal shift in the upward and downward branches of the Walker Circulation. Chen et al. (1998) further suggested a longitudinal variation of the monsoon trough in response to SSTAs. Such a shift would result in a corresponding shift of the tropical cyclone genesis locations. A plot of the mean tropical cyclone genesis locations in El Nino and La Nina years is given in Figure 6. It shows that in general the genesis positions are shifted to the east in El Nino years as compared to La Nina years. When tropical cyclones form further east, they are more likely to interact with mid-latitude systems and recurve to the north before entering the South China Sea (SCS) to affect the south China coast and Hong Kong. Vice-versa, when tropical cyclones form further to the west in La Nina conditions, chances of their entering the SCS to affect Hong Kong are relatively high.

Composite analyses are applied and composite maps of mid-tropospheric wind anomalous patterns in the fall (September to November) are constructed for years with N below and higher than normal respectively (Figure 7). An anomalous cyclonic circulation over the SCS and an anomalous anticyclonic circulation in eastern China in the case of N higher than normal are observed. This results in a strong anomalous steering current towards the coast of southern China, bringing more tropical cyclones towards Hong Kong. For the years with N below normal, the anomalous steering current over the northern part of the SCS and the western North Pacific east of Luzon is westerly. Tropical cyclones occurring over these areas are therefore less likely to affect Hong Kong.

Composite maps are also constructed to see if there are distinct differences in atmospheric steering flow pattern between El Nino and La Nina years. Figure 8 shows a marked contrast in the mid-tropospheric wind anomalous patterns near the SCS between El Nino and La Nina years. This contrast is more distinct in the fall (September to November) than in summer (June to August). In the fall, anomalous anticyclonic and cyclonic circulation patterns develop in the SCS and eastern China respectively for El Nino events. For La Nina events, anomalous cyclonic and anticyclonic circulations are observed respectively in the SCS and eastern China. These result in opposite anomalous steering flows in the areas around the Luzon Strait and the northern part of SCS for the two events. The anomalous mid-tropospheric circulation pattern for El Nino years reduces the steering of tropical cyclones towards the region near Hong Kong and thus reduces the number of tropical cyclones affecting Hong Kong. In the La Nina years, the anomalous steering flow over the Pacific east of Luzon and in the northern part of the SCS is easterly. Tropical cyclones which form over these sea areas are more likely to be steered towards Hong Kong.

## 5. Summary

Tropical cyclone activity has been found to be significantly correlated with SSTAs and ENSO events. The annual number of tropical cyclones affecting Hong Kong is well correlated with the sea surface temperature anomaly in the Nino-3.4 regions. The higher the SSTAs in the equatorial Central and Eastern Pacific, the lower the number of tropical cyclones affecting Hong Kong. This result corroborates those of the study by Liu (2000) for tropical cyclones making landfall in Guangdong. The annual number of tropical cyclones is predominantly less than normal for EN(0) years and EN+1 years. For LN(0) and LN+1 years, predominantly more tropical cyclones affect Hong Kong. No conclusion can be drawn for EN-1, LN-1 and LN+2 years.

Marked changes in the mean tropical cyclone genesis locations as well as the mid-tropospheric steering flow patterns over the northern part of the South China Sea are associated with ENSO events. Such changes are the intermediate factors affecting the tropical cyclone activity in Hong Kong.

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Table 1. Correlation coefficients between the annual number of tropical cyclones affecting Hong Kong and the averaged annual sea surface temperature anomaly in various Nino regions.

| | **Nino-1+2** | **Nino-3** | **Nino-3.4** | **Nino-4** |
|---|---|---|---|---|
| Correlation coefficient | -0.39 | -0.47 | -0.47 | -0.43 |

Table 2. Annual number of tropical cyclones affecting Hong Kong for years of (a) EN-1 (b) EN(0) (c) EN+1 (d) LN-1 (e) LN(0) (f) LN+1 and (g) LN+2.

(a) EN-1

| Mean = 7.1 SD = 1.73 | |
|---|---|
| Year | Annual no. of tropical cyclones |
| 1964 (LN(0)) | 10 |
| 1968 | 6 |
| 1971 (LN+1) | 9 |
| 1975 (LN+2) | 7 |
| 1981 | 5 |
| 1985 | 5 |
| 1990 | 6 |
| 1993 | 9 |
| 1996 | 7 |

(b) EN(0)

| Mean = 4.6 SD = 1.17 | |
|---|---|
| Year | Annual no. of tropical cyclones |
| 1965 | 6 |
| 1969 | 4 |
| 1972 | 5 |
| 1976 | 5 |
| 1982 | 5 |
| 1986 | 4 |
| 1991 | 6 |
| 1994 | 4 |
| 1997 | 2 |

(c) EN+1

| Mean = 5.7 SD = 0.94 | |
|---|---|
| Year | Annual no. of tropical cyclones |
| 1983 | 7 |
| 1987 | 5 |
| 1992 | 5 |

(d) LN-1

| Mean = 4 SD = 1 | |
|---|---|
| Year | Annual no. of tropical cyclones |
| 1963 | 4 |
| 1969 (EN(0)) | 4 |
| 1972 (EN(0)) | 5 |
| 1987 (EN+1) | 5 |
| 1994 (EN(0)) | 4 |
| 1997 (EN(0)) | 2 |

(e) LN(0)

| Mean = 7.3 SD = 1.80 | |
|---|---|
| Year | Annual no. of tropical cyclones |
| 1964 | 10 |
| 1970 | 6 |
| 1973 | 9 |
| 1988 | 6 |
| 1995 | 8 |
| 1998 | 5 |

(f) LN+1

| Mean = 8.8 SD = 1.48 | |
|---|---|
| Year | Annual no. of tropical cyclones |
| 1971 | 9 |
| 1974 | 11 |
| 1989 | 7 |
| 1999 | 8 |

(g) LN+2

| Mean = 7 SD = 0 | |
|---|---|
| Year | Annual no. of tropical cyclones |
| 1975 | 7 |
| 2000 | 7 |


Figure 1. A location map showing the area of 800 km from Hong Kong

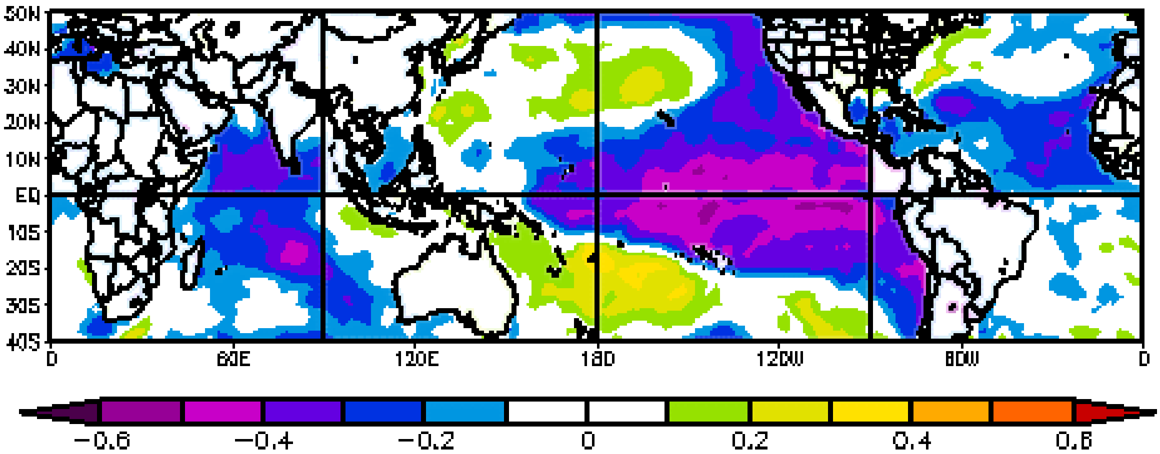



Figure 2. Correlation between the annual number of tropical cyclones affecting Hong Kong and the annual sea surface temperature anomaly in various ocean basin. (Data period: 1961-2000, the colour scale represents values of correlation coefficients. Image is provided by the NOAA-CIRES Climate Diagnostic Center, Boulder Colorado from the web site at http://www.cdc.noaa.gov/.)

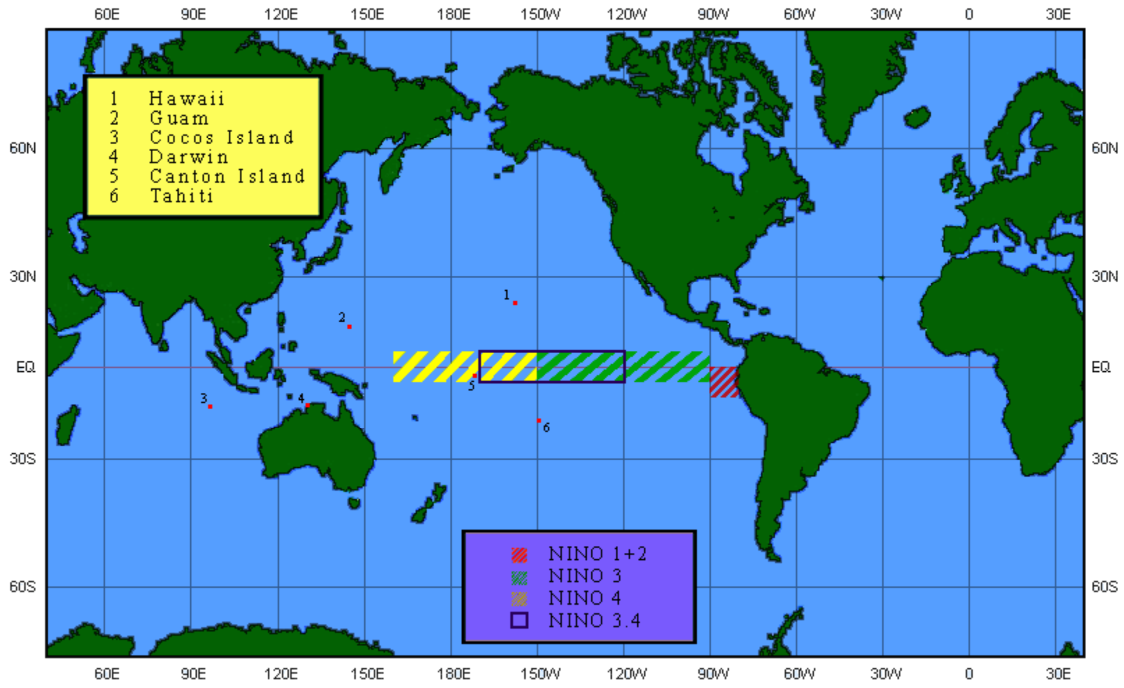



Figure 3. Location map of Nino-1+2, Nino-3, Nino-3.4 and Nino-4.

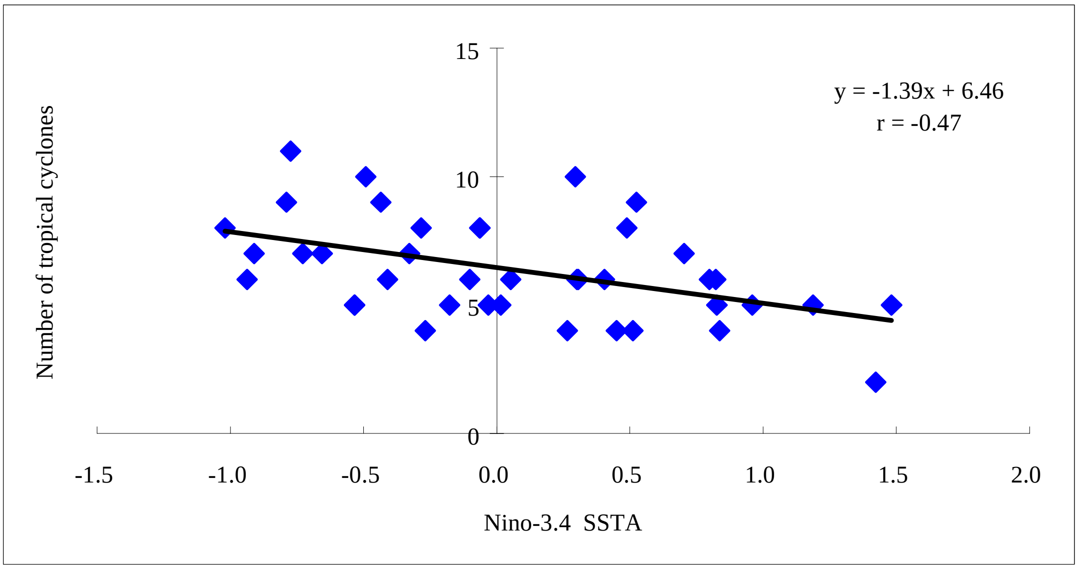



Figure 4. Scattered diagram showing the relationship between the annual number of tropical cyclones affecting Hong Kong and the sea surface temperature anomaly in region Nino-3.4.

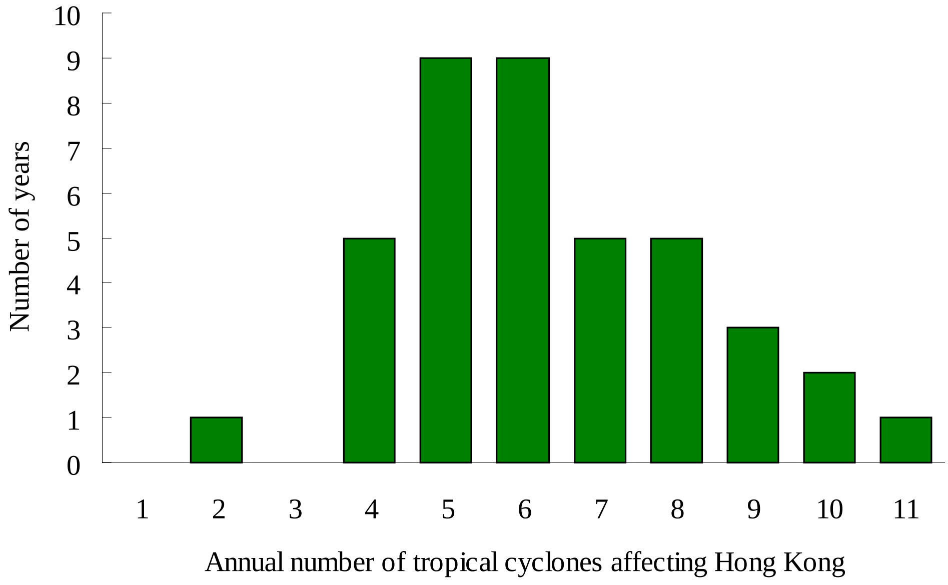



Figure 5. Frequency distribution of the annual number of tropical cyclones affecting Hong Kong

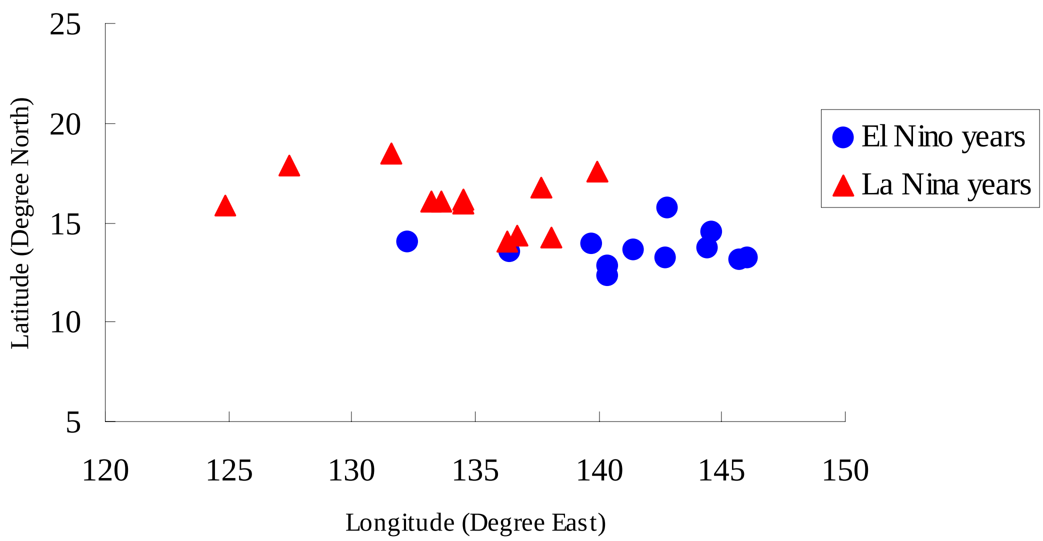
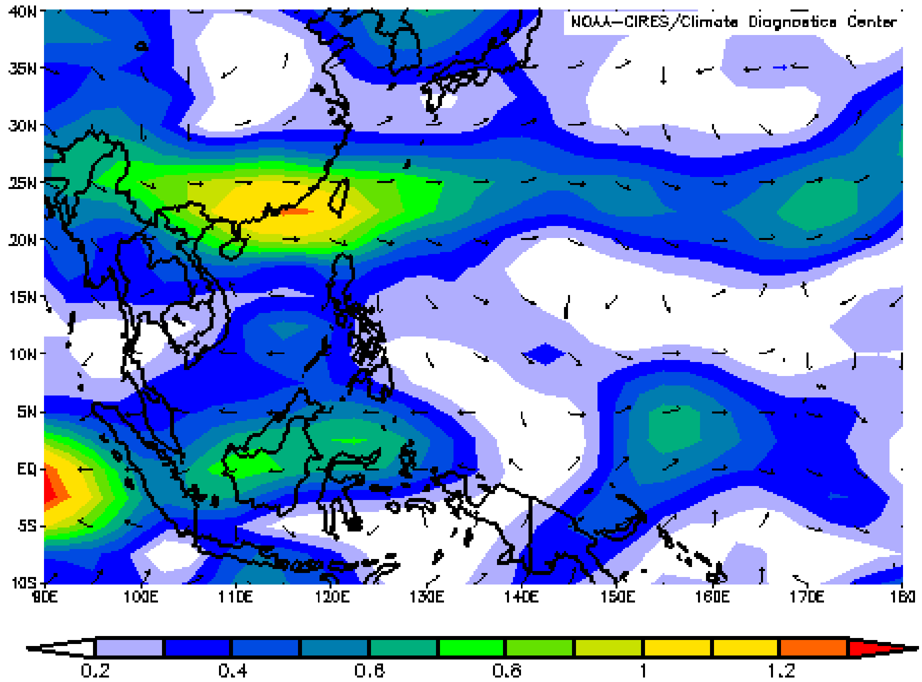



Figure 6. Mean tropical cyclone genesis location map for El Nino and La Nina years

(a) Years with N below normal (N < 6)




(b) Years with N above normal (N > 7)

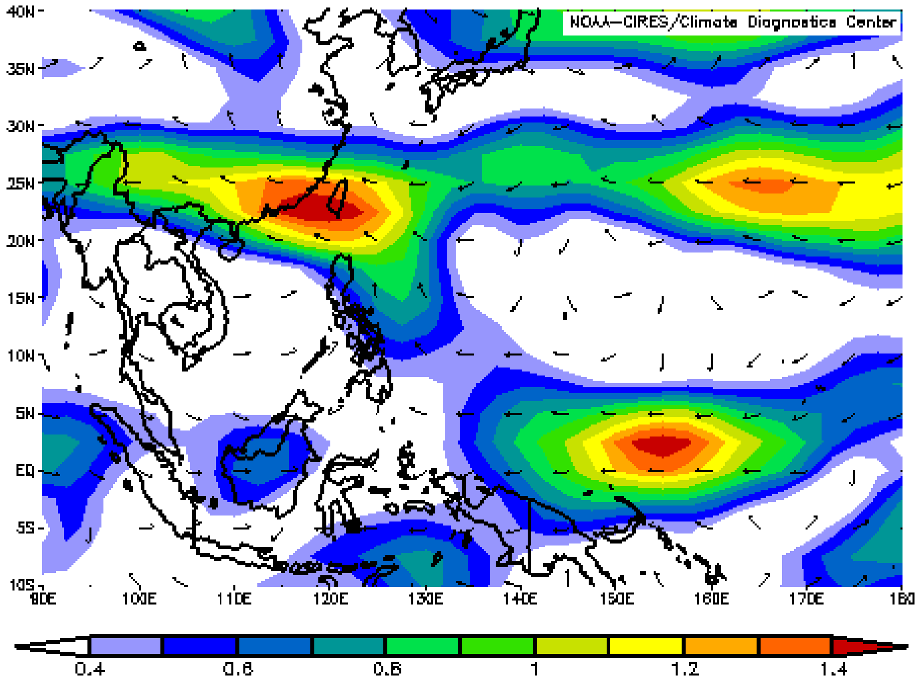
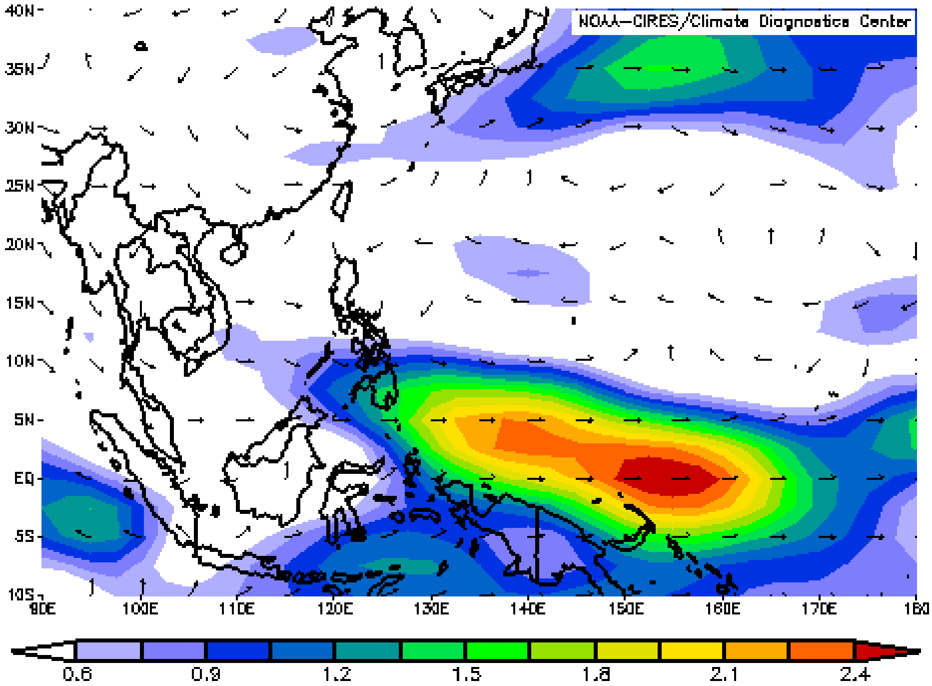



Figure 7. 500 hPa vector wind anomaly composite maps in fall for years with N (a) less than 6 (b) greater than 7. (The arrow indicates the direction of wind anomaly and the colour scale represents the magnitude of wind anomaly in m/s. Image is provided by NOAA-CIRES Climate Diagnostic Center, Boulder Colorado from the web site at http://www.cdc.noaa.gov/).

(a) El Nino summer




(b) La Nina summer

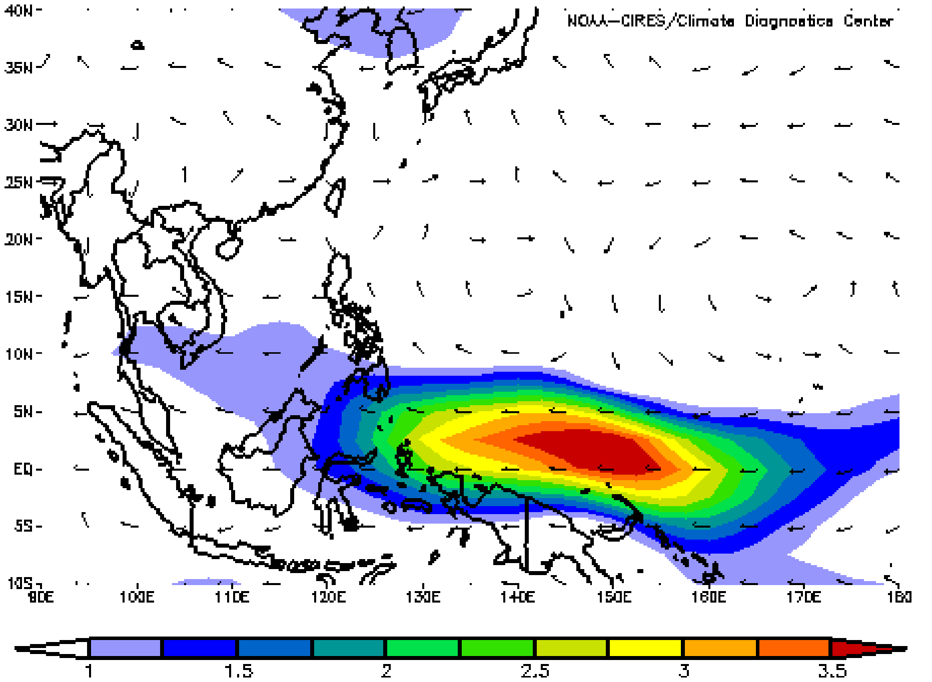
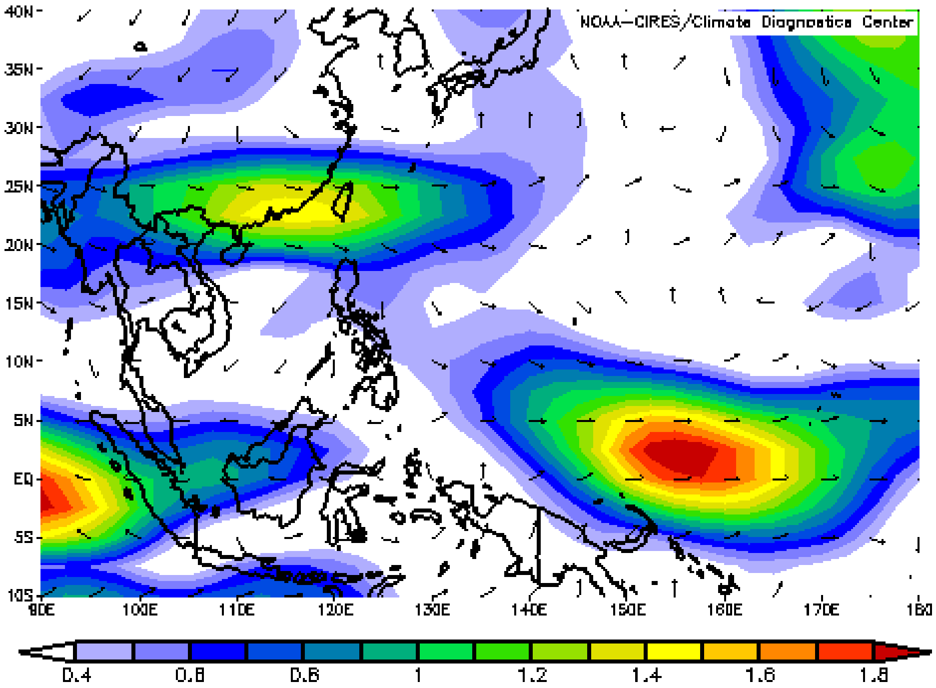



Figure 8. 500 hPa vector wind anomaly composite maps in summer for (a) El Nino years (b) La Nina years. (The arrow indicates the direction of wind anomaly and the colour scale represents the magnitude of wind anomaly in m/s. Image is provided by NOAA-CIRES Climate Diagnostic Center, Boulder Colorado from the web site at http://www.cdc.noaa.gov/).

(c) El Nino fall




(d) La Nina fall

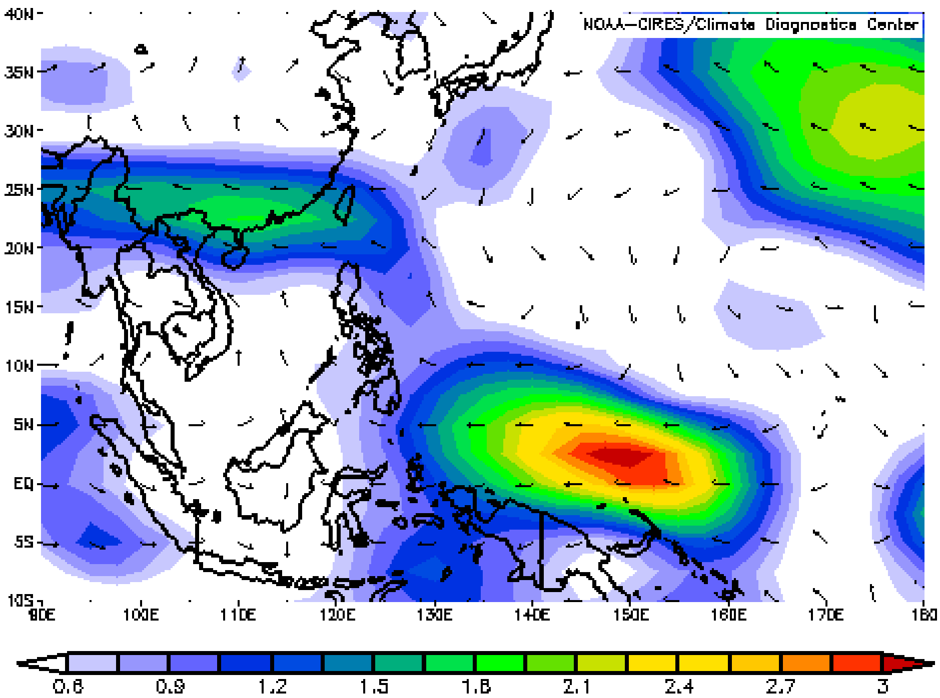



Figure 8 (cont.). 500 hPa vector wind anomaly composite maps in fall for (c) El Nino years (d) La Nina years. (The arrow indicates the direction of wind anomaly and the colour scale represents the magnitude of wind anomaly in m/s. Image is provided by NOAA-CIRES Climate Diagnostic Center, Boulder Colorado from the web site at http://www.cdc.noaa.gov/).