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Effect of ENSO on Winter Monsoon Affecting Hong Kong

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1. Introduction

One of the distinctive features in winter is the outbreak of winter monsoon surge (e.g., Lai 1989). The relationship between the interannual variability of the East Asian winter monsoon (hereafter winter monsoon for short) and ENSO had been studied by Lau and Chang (1987) and Zhang *et al.* (1997). Other studies have revealed that the winter monsoon is often weak during El Niño years and likely to be strong during La Niña years (e.g., Mu and Li 1999; Chan and Li 2004; Wu and Chan 2005).

Regarding the influence of ENSO on the interannual variation of winter monsoon surge occurrence, a higher (lower) occurrence frequency was found during El Niño (La Niña) winters (Chen *et al.* 2004). Similar result for cold surges affecting Guangzhou was reported by Ji *et al.* (2007) recently.

The present study aims at reviewing the characteristics of the winter monsoon and the associated weather conditions in Hong Kong during different ENSO conditions from 1950 to 2008. The effect of ENSO on the winter temperatures, the annual number of cold days, the duration of cold spells and the frequency of cold surge occurrence in Hong Kong will be investigated. As it has been suggested that upper air blocking events in the northern Hemisphere would be stronger during La Niña and ENSO-neutral years (Wiedenmann *et al.* 2002), an attempt has been made to see if there would exist any relationship between the weather conditions in Hong Kong and the occurrence of blocking over the Eurasian continent. The synoptic scale patterns associated with El Niño and La Niña winters will also be studied.

2. Data and Methodology

2.1 Data

The primary source of data were the hourly temperatures recorded at the Hong Kong Observatory Headquarters for the 59 winters (referring to the months of December, January and February, (DJF)) between 1950 and 2008. The annual mean and mean minimum winter temperatures in Hong Kong as well as other local parameters such as the total number of cold days (defined as daily minimum temperature ≤ 12 ^{o}C in Hong Kong) were computed.

The United States National Centers for Environment Prediction and National Center for Atmospheric Research (NCEP-NCAR) gridded reanalysis data (Kalnay *et al.* 1996) were used for the plotting of synoptic scale surface and upper-air patterns and computation of winter monsoon strength during ENSO winters.

Data for upper air blocking occurrence over the Eurasian continent between 1968 and 2008 were obtained from the archive of the University of Missouri Global Climate Change Group (available at http://solberg.snr.missouri.edu/gcc/). Details of this archive were documented by Lupo *et al*. (2008).

2.2 Definitions

2.2.1 ENSO Winters

In the present study, ENSO events of warm (El Niño) and cold (La Niña) episodes follow that defined by the Climate Prediction Center (CPC) of NOAA using 3-month running mean of sea surface temperature (SST) anomalies. This is adopted because ENSO episodes defined using 3-month periods (instead of monthly status used by other centres) would be more suitable for classification of DJF winters ENSO conditions in this study. From the list of the events on CPC's web page http://www.cpc.noaa.gov/products/analysis_monitoring/ensostuff/ensoyears.shtml, there are 17 El Niño winters (1958, 1964, 1966, 1969, 1970, 1973, 1977, 1978, 1983, 1987, 1988, 1992, 1995, 1998, 2003, 2005 and 2007), 19 La Niña winters (1950, 1951, 1955, 1956, 1957, 1965, 1968, 1971, 1972, 1974, 1975, 1976, 1985, 1989, 1996, 1999, 2000, 2001 and 2008) and 23 ENSO neutral winters (1952, 1953, 1954, 1959, 1960, 1961, 1962, 1963, 1967, 1979, 1980, 1981, 1982, 1984, 1986, 1990, 1991, 1993, 1994, 1997, 2002, 2004 and 2006) during the period from 1950 to 2008.

2.2.2 Winter Monsoon Strength

The strength of winter monsoon over southern China is defined using the Unified Monsoon Index (UMI) of Lu and Chan (1999). A winter monsoon with a standardized UMI > 0.5 (< -0.5) averaged over DJF is regarded as weak (strong) while that of $-0.5 \leq$ UMI ≤ 0.5 is categorized as neutral (Wu and Chan 2005).

2.2.3 Number of Winter Monsoon Surge Events affecting Hong Kong

The definition of winter monsoon surge or cold surge usually makes reference to the effects of the surge on the weather of a specific location (e.g., Boyle and Chen 1987). Lau and Wang (2006) pointed out that a temperature drop of several degrees within a period was adopted in various definitions of cold surge in southern China. Zhang *et al.* (1997) mentioned that an important parameter for cold surge definition was the 24 to 48-hour temperature drop. Temperature drops of 4 to 6^{o}C within 24 to 48 hours in stations over southeastern China have been used as the definition of cold surge occurrence by different authors (e.g., Chang *et al.* 1979; Lau and Lau 1984; Chen *et al.* 2004).

In Hong Kong, a 2°C drop in daily mean temperature within 48 hours has been considered to be a criterion for verifying the arrival of monsoon surge (Chu 1978; Lam 1979). On the other hand, Wu and Chan (1995) found an average of more than 4°C drop in daily mean temperature for northerly cold surges affecting Hong Kong.

In the present study, the numbers of cold surges with a drop in daily mean temperatures of at least 2, 3, 4, 5, 6 and 7°C at Hong Kong Observatory Headquarters within 2 days during different ENSO situations were examined. Thresholds beyond 7°C would result in less than one event each winter on average and thus were not considered.

2.2.4 Blocking events

Details on the definition of upper air blocking events can be found from Wiedenmann *et al.* (2002). Briefly, a blocking event is identified when the average zonal index computed as the difference in the 500-hPa height of an anticyclone poleward of 35°N with a ridge amplitude of greater than 5° latitude is negative for five or more days. For the purpose of the present study, as we wish to focus on the winter monsoon affecting Hong Kong, occurrence of blocking was considered only for blocking onset over the Eurasian continent at longitudes between 40°E and 80°E (i.e. upstream of the region of Siberia cold high[1] at low-levels).

2.3 Method

The 59 winters between 1950 and 2008 are stratified into El Niño (EN), La Niña (LN) and ENSO-neutral (NEU) categories. The ENSO influence in terms of the seasonal mean conditions was investigated by examining the possible statistical relationships between ENSO occurrence and local parameters such as the mean temperature and the frequency of occurrence of cold days. In addition, statistical analysis was carried out to see if there is any relationship between the weather conditions in Hong Kong and upper air blocking occurrence over the Eurasian continent.

Synoptic scale anomaly patterns at different levels, including surface temperature, 1000-hPa winds, 500-hPa geopotential height and 200-hPa zonal wind during EN and LN winters were constructed using NCEP-NCAR reanalysis data, with a view to studying the corresponding physical basis.

3. Results

3.1 Winter temperatures and monsoon strength

Figure 1 shows the time series of the mean winter temperature at the Hong Kong Observatory Headquarters from 1950 to 2008. Apart from the apparent interannual

[1] Ding *et al.* (1991) assigned the Siberia high at 1000 hPa to be over the region between 80-120° E and 42.5-57.5° N.

variability, a warming trend possibly related to global warming and local urbanization can be observed (Leung *et al.* 2004).

The influence of the winter monsoon on Hong Kong's mean winter temperature can be observed in Table 1a. Hong Kong is likely to have a warmer (cooler) winter against the background of the warming trend when the winter monsoon over southern China is weak (strong). This is consistent with the fact that winter temperature variations in Hong Kong can be taken as a proxy for that of southern China (Wu *et al.* 2007). As shown in Table 1b, the winter monsoon during EN (LN) conditions tends to be weaker (stronger).

Table 1a. Contingency table of the winter temperatures in Hong Kong and the strength of winter monsoon over southern China (p-value = 0.003).

Mean winter temperatures in Hong Kong	Winter Monsoon Strength (UMI)		
	Strong	Neutral	Weak
Above the trend line	3	13	12
Below the trend line	15	12	4

Table 1b. Contingency table of ENSO conditions and the strength of winter monsoon (p-value = 0.003).

ENSO	Winter Monsoon Strength (UMI)		
	Strong	Neutral	Weak
EN	2	5	10
NEU	6	13	4
LN	10	7	2

Against the background of the warming trend, the influence of ENSO on the mean temperature of Hong Kong can be seen from the contingency table (Table 2) drawn between ENSO years and daily mean temperature. Similar results are obtained for the minimum temperature (not shown). It was found that during EN (LN) winters, Hong Kong has higher (lower) mean temperatures. These are in line with a weaker (stronger) winter monsoon during EN (LN) condition as mentioned above (see Table 1).

Table 2. Contingency table of the winter temperatures in Hong Kong and the occurrence of EN and LN (p-value = 0.023). The number in the bracket indicates the number of cases of weak and strong winter monsoon respectively.

Mean winter temperatures in Hong Kong	ENSO condition	
	EN	LN
Above the trend line	11 (7,1)	5 (1,1)
Below the trend line	6 (3,1)	14 (1,9)

The above changes in mean winter temperatures are manifested in terms of the change in frequency distribution of the daily mean temperature. Figure 2a shows the frequency distribution of the daily mean temperatures in EN, LN and NEU winters while Figure 2b shows the difference in frequency distribution of the daily mean temperatures between EN (LN) and NEU winters. During EN (LN) winters, there is an increase in the occurrence frequency of higher (lower) daily mean temperatures, as compared to NEU conditions. This observation matches with the shift in mean winter temperature towards the warmer (cooler) side during EN (LN) condition. Meanwhile, it is worth noting from Figure 2b that during LN winters, there is an apparent increase in the occurrence frequency of daily mean temperatures on the cold side, say, below 12^{o}C. However, there is no observable decrease in the occurrence frequency of daily mean temperatures below 12^{o}C during EN winters.

To further examine the change in pattern of the daily temperatures during ENSO winters, the skewness (i.e. a measure of the asymmetry) of the distribution of the daily temperatures is computed. As winter is characterized by events of cold spells, distribution of daily temperature is asymmetric and skewed towards the cooler side (i.e. negative skew with the mean value being less than the mode). In fact, the skewness in the distribution of the daily temperatures for NEU winters is -0.44, as compared to a smaller negative skewness of -0.32 during EN winters and a larger negative skewness of -0.49 during LN winters.

3.2 Cold days and longest cold spell duration

In Hong Kong, cold days (CD) refer to days with a minimum temperature of 12^{o}C or below. From 1950 to 2008, the average annual number of CD is 19 days with a standard deviation of 9 days. The annual number of CD in Hong Kong decreases at a rate of 2.5 days per decade during this period, consistent with the rising trend in the mean winter temperature. Against this trend, no statistically significant relationship between the annual number of CD in Hong Kong and ENSO occurrence was found. Nevertheless, it was observed that the likelihood of having more than 30 CD (i.e. more than one standard deviation) is higher in LN winters (56 % or 5 out of 9) as compared to EN and NEU winters (22 % or 2 out of 9 for both EN and NEU winters).

Between 1950 and 2008, the average longest cold spells each winter (defined as the highest number of consecutive days with daily minimum temperature ≤ 12°C) was found to be about 7 days. While no statistically significant relationship was obtained between the duration of longest cold spell and ENSO occurrence, two discernible outliers in the longest cold spell duration can be identified, namely, 27 days in 1968 and 24 days in 2008. It is of interest to note that both 1968 and 2008 are LN years.

3.3 Frequency of cold surge occurrence

By applying a low-pass Gaussian filter (e.g., Hanna and Cappelen 2003) to remove variations with periodicities less than 10 years in the time series of the number of cold surge affecting Hong Kong, it was observed that there are more cold surges during 50-60s and fewer in the period from mid-70s to 90s (solid line in Figure 3). The results were similar for different thresholds of temperature drop used in the cold surge definition. This observation was in general consistent with that of Ji *et al.*, 2007 for Guangzhou, except that more cold surges affecting Guangzhou were observed in 90s.

Figure 4 compares the average number of cold surge events affecting Hong Kong during different ENSO conditions. It was found that EN winters are likely to have more cold surge events as compared to LN and NEU winters. This difference was found to be statistically significant at the 5% level for cold surges with a temperature drop of 4°C or more. This finding was in line with that obtained by Ji *et al.* (2007) for Guangzhou and the result of Chen *et al.* (2004) for East Asia. Li *et al.* (2001) suggested that during EN winters, the westerlies in the mid latitudes were strengthened, which would limit the development of the 500-hPa trough over East Asia. This would result in weaker cold surges but faster moving systems. Therefore, more surge events could be accommodated during EN winters.

Furthermore, it was noted from Figure 4 that the numbers of cold surges during LN and NEU winters were similar, apart from the differences for temperature thresholds less than 4°C which were not statistically significant.

In the present study, no statistical relationship could be found between the frequency of cold surge affecting Hong Kong and other local weather parameters in winter including the mean winter temperature, the number of cold days and the longest cold spell duration.

3.4 Blocking events

Figure 5 summarizes the yearly occurrence of 500 hPa blocking events between 40°E and 80°E from 1969 to 2008. Out of the 40 years, 16 years saw no blocking events in the region. It was found statistically significant at the 5% level that Hong Kong tends to be warmer in a winter with no blocking event (see Table 3). In addition, the duration of the longest cold spell tends to be shorter in winters with no blocking event.

Table 3. Comparison of the average mean temperatures, mean minimum temperatures and the longest cold spell duration in Hong Kong during different blocking conditions. All the differences were found to be statistically significant at the 5% level using the student's t-test.

Occurrence of blocking event	Meteorological parameter		
	Mean Temperature (^oC)	Mean minimum temperature (^oC)	Average longest cold spell duration (days)
Yes (24 years)	16.6	14.6	8.0
No (16 years)	17.2	15.3	4.6

From Figure 5, it can also be observed that more than half (i.e. 56% or 9 out of 16) of no blocking winters happened during EN condition. This can be demonstrated more clearly from the contingency table (Table 4) drawn between EN and non-EN conditions. However, no obvious relationship can be found for LN conditions regarding the occurrence of blocking over the Eurasian continent at longitudes between 40^{o}E and 80^{o}E.

Table 4. Contingency table of the blocking event occurrence and the occurrence of EN (p-value = 0.021)

Occurrence of blocking event	ENSO condition	
	EN	Non-EN
Yes	5	19
No	9	7

3.5 Synoptic scale features

As shown in Figure 6(a), when compared with NEU winters, the surface temperature over southern China is lower with a tight temperature gradient over southern China during LN winters. Furthermore, the 1000-hPa northerlies over southern China and the South China Sea are stronger. For EN winters, a weakening of northerlies over southern China and the South China Sea can be seen (Figure 6(b)). These synoptic observations are consistent with our previous findings of a weaker (stronger) winter monsoon over southern China during EN (LN) winters.

At the 500-hPa level, a prominent feature is the weakening of the East Asian trough in the vicinity of Japan during EN winters (Figure 7). This weakening of the East Asian trough would result in a weaker winter monsoon and a warmer winter in southern China (e.g. Sun and Sun, 1996). From Figure 7, although no significant change can be seen regarding the strength of the East Asian trough during LN winters, the large area of negative anomaly in geopotential height near Lake Baikal might suggest enhanced trough development over the region and result in stronger winter monsoon affecting southern China.

From Figure 8, an eastward (westward) shift of the East Asia Jet Stream (EAJS) at 200-hPa is observed during EN (LN) winters. This was consistent with previous findings of an eastward shift of the EAJS in EN years as studied by Rasmusson and Wallace (1983). This shift in the position of the jet stream would affect the development of a mid level trough over East Asia.

4. Conclusion

In the present study, statistical analyses were carried out to investigate the relationship between ENSO conditions and winter monsoons affecting Hong Kong. It was found that against the background of a warming trend, during EN (LN) winters, the winter monsoon over southern China tends to be weak (strong), Hong Kong tends to have higher (lower) mean winter temperatures and there is an increase in the occurrence frequency of higher (lower) daily mean temperatures. While EN winters are warmer and have weaker monsoons, there is more frequent cold surge occurrence as compared to LN and NEU winters.

Analyses showed that upper air blocking events are more common during LN and NEU winters. Winters with no blocking event are more likely to happen during EN conditions. Moreover, in winters with no blocking event, Hong Kong tends to be warmer and the duration of the longest cold spell tends to be shorter.

Synoptically, during EN winters, the 500-hPa trough over East Asia is weaker and the 200-hPa East Asia Jet Stream shows an eastward shift. This would lead to a weaker winter monsoon over southern China, resulting in weaker surface northerlies and higher temperatures. During LN winters, lower surface temperature and stronger northerlies are expected over southern China due to the stronger winter monsoon.

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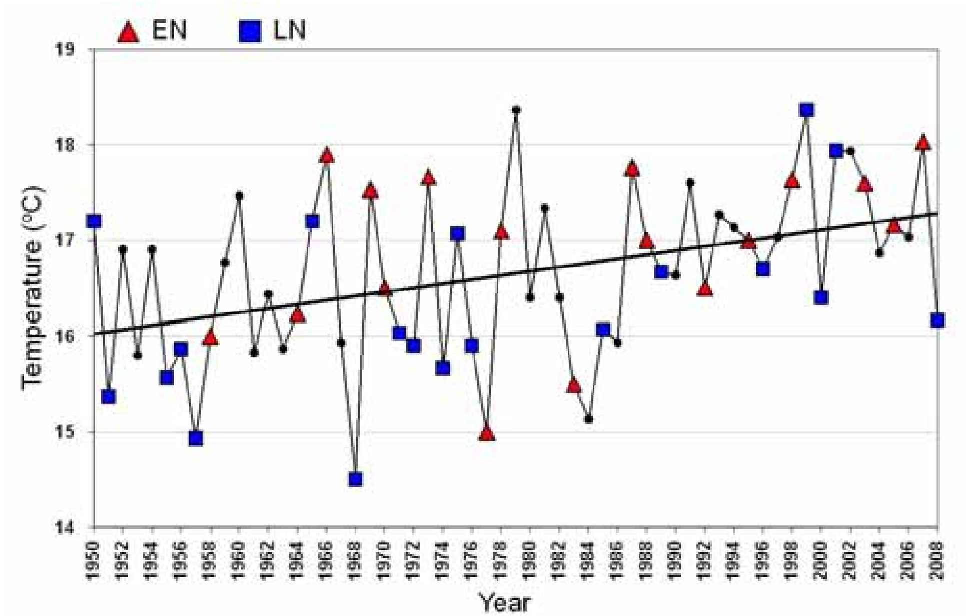

Figure 1. Time series of winter mean temperature at HKO. The dark line represents the linear rising trend which is statistically significant at the 5% level.

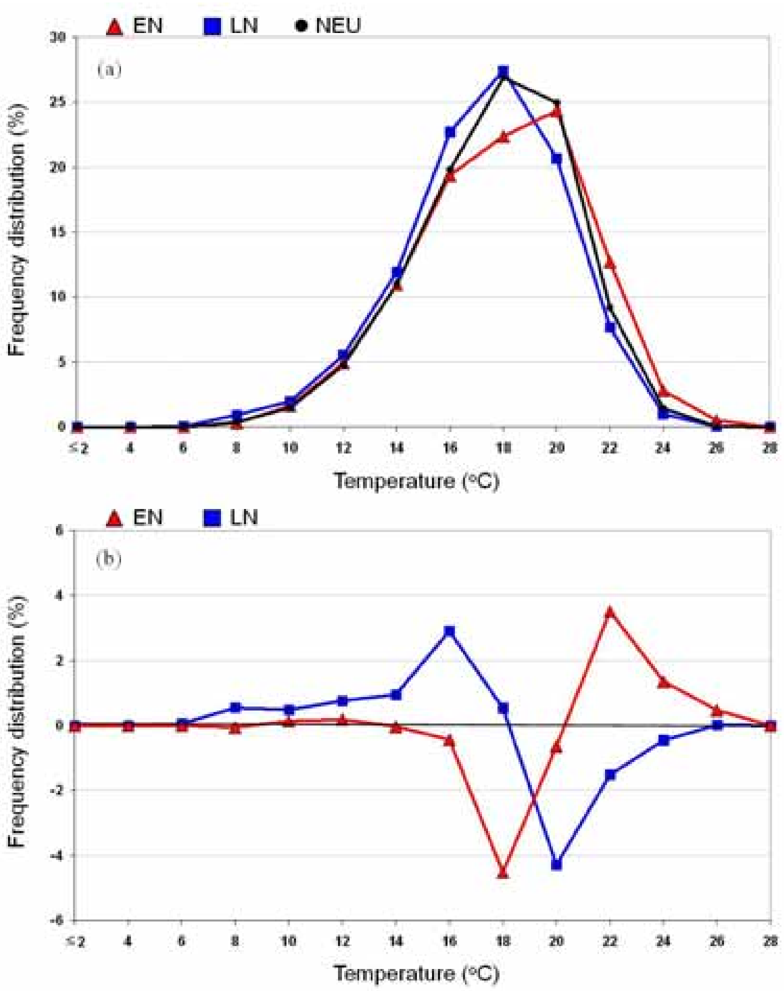

Figure 2. (a) Frequency distribution of the daily mean temperatures of EN, LN and NEU winters, (b) Difference in the frequency distribution of the daily mean temperatures between EN (LN) and NEU winters.

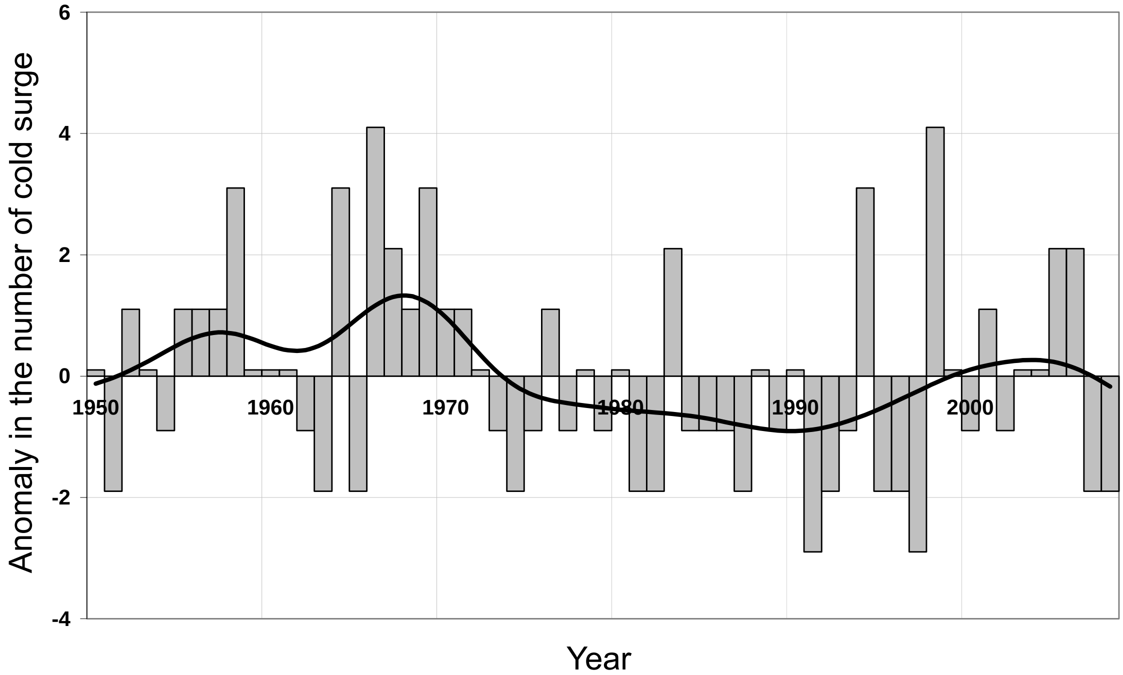

Figure 3. Anomaly in the number of cold surge affecting Hong Kong from 1950 to 2008 (using a 4°C drop in daily mean temperature in surge definition). The dark line shows the Gaussian filtered time series with periodicities less than 10 years removed.

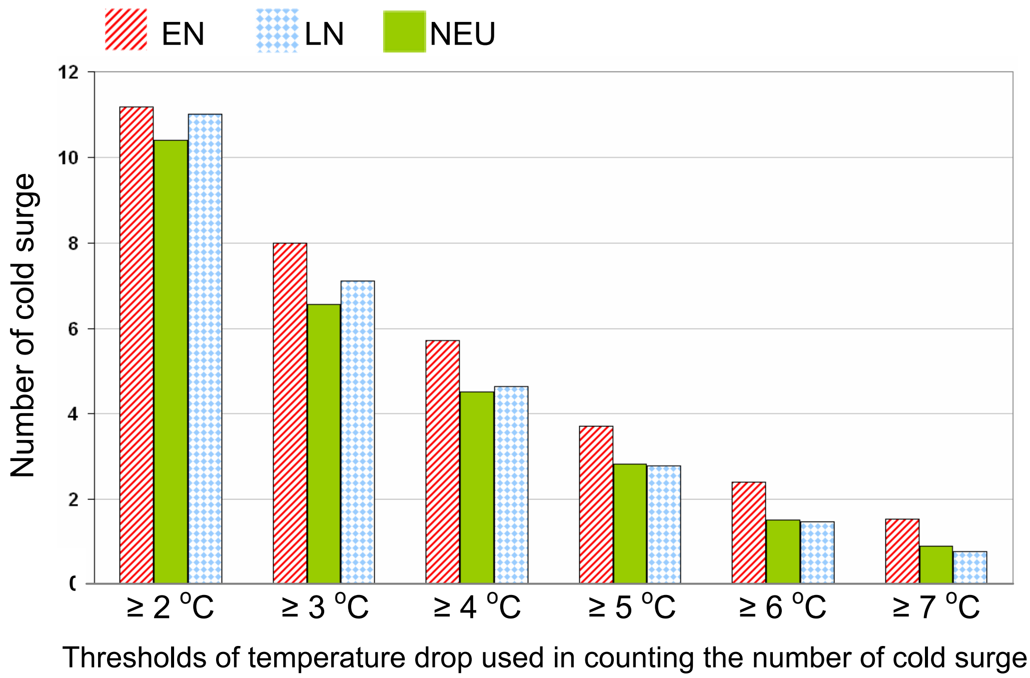

Figure 4. Average number of cold surge affecting Hong Kong during different ENSO conditions from 1950 to 2008.

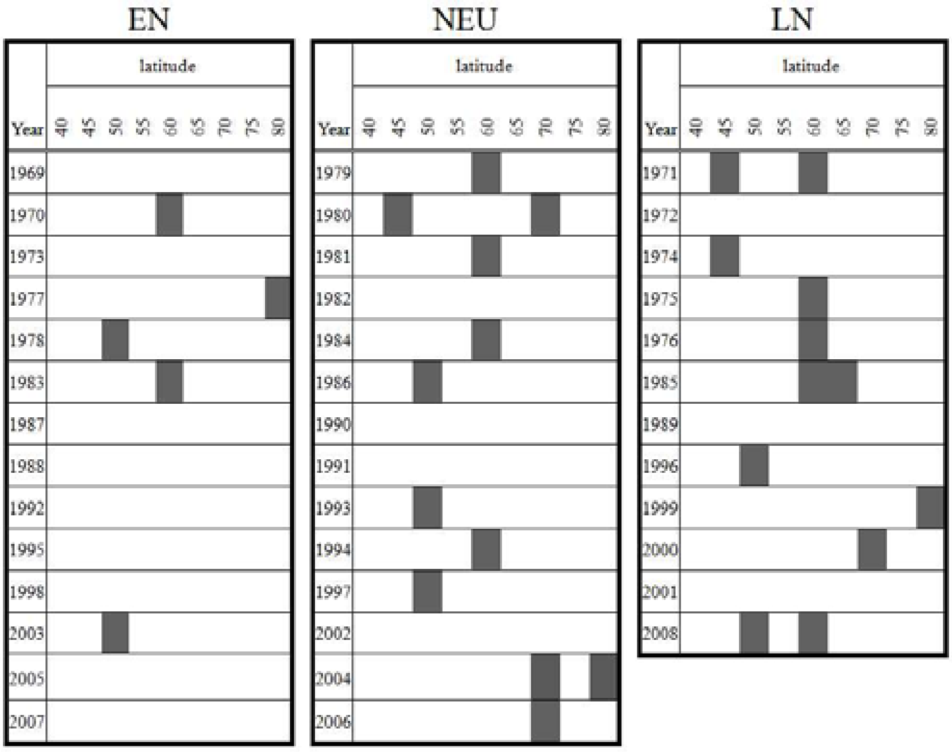

Figure 5. Occurrence of 500 hPa blocking events (shaded in light grey) over the Eurasian continent at longitudes between 40^{o}E and 80^{o}E during winters of different ENSO conditions from 1969 to 2008.

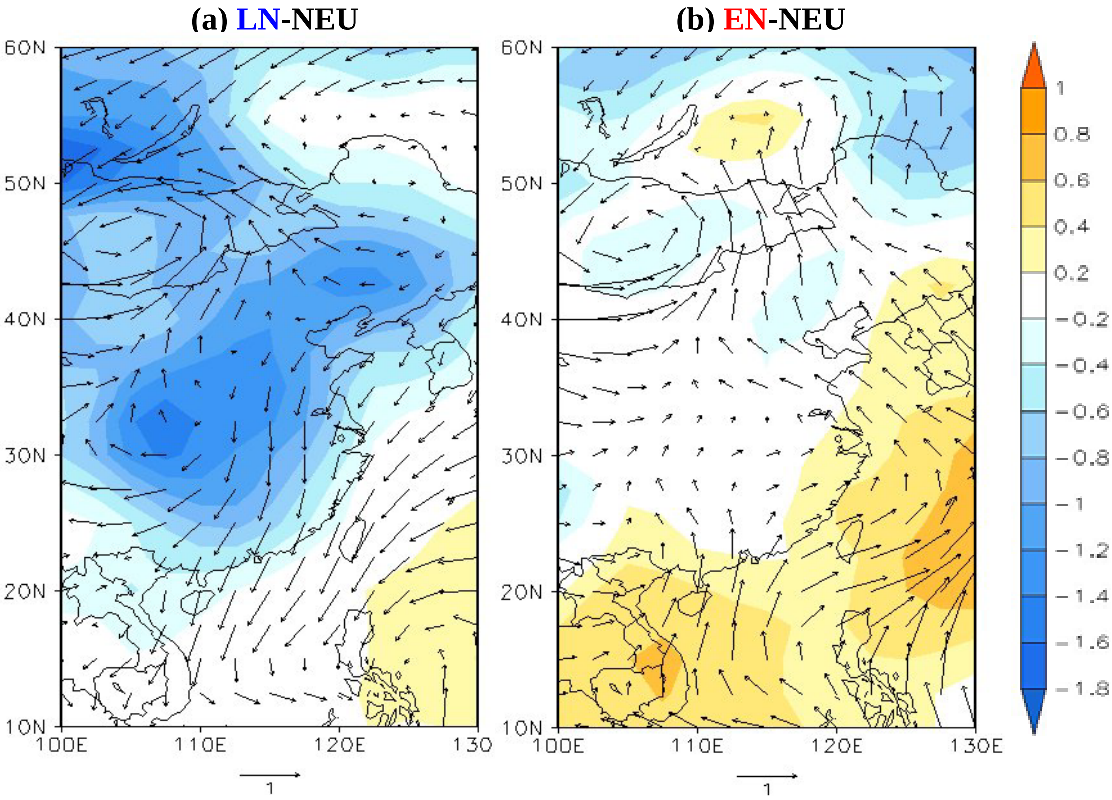

Figure 6. Anomalies in the surface temperature (^{o}C) and 1000-hPa winds (m/s) as compared to NEU condition for (a) LN and (b) EN winters.

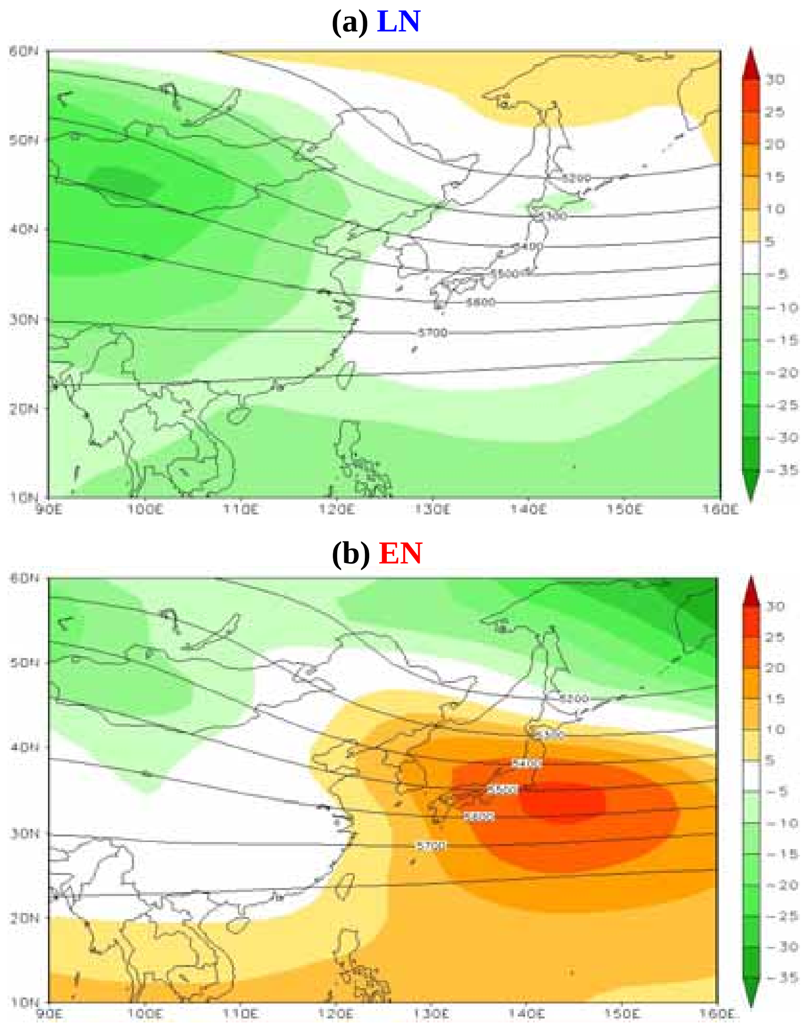

Figure 7. The dark line contours represent geopotential height at 500-hPa during NEU winters while the colour shadings denote the anomalies in 500-hPa geopotential height as compared to NEU condition for (a) LN and (b) EN winters.

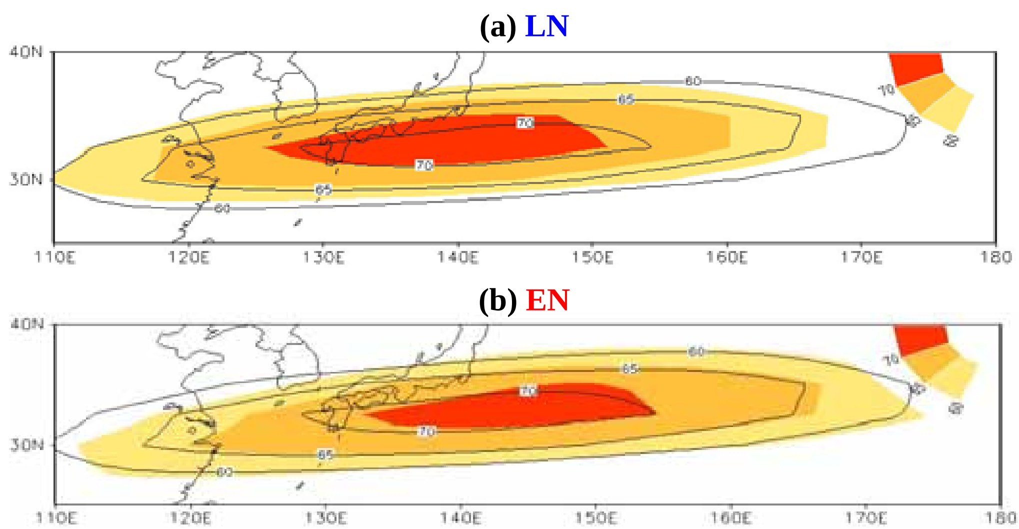

Figure 8. The dark line contours represent zonal wind speed (m/s) at 200-hPa during NEU winters while the colour shadings denote the 200-hPa zonal wind speed during (a) LN and (b) EN winters.