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Variations in Extratropical Cyclone Activity in Northern East Asia

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ABSTRACT

Based on an improved objective cyclone detection and tracking algorithm, decadal variations in extratropical cyclones in northern East Asia are studied by using the ECMWF 40 Year Reanalysis (ERA-40) sea-level pressure data during 1958–2001. The results reveal that extratropical cyclone activity has displayed clear seasonal, interannual, and decadal variability in northern East Asia. Spring is the season when cyclones occur most frequently. The spatial distribution of extratropical cyclones shows that cyclones occur mainly within the 40°–50°N latitudinal band in northern East Asia, and the most frequent region of occurrence is in Mongolia. Furthermore, this study also reveals the fact that the frequency of extratropical cyclones has significantly decreased in the lower latitude region of northern East Asia during 1958–2001, but decadal variability has dominated in higher latitude bands, with frequent cyclone genesis. The intensity of extratropical cyclones has decreased on an annual and seasonal basis. Variation of the annual number of cyclones in northern East Asia is associated with the mean intensity of the baroclinic frontal zone, which is influenced by climate warming in the higher latitudes. Moreover, the dipole structure of extratopical cyclone change, with increases in the north and decreases in the southern part of northern East Asia, is related to the northward movement of the baroclinic frontal zone on either side of 110°E.

Key words: ERA-40, SLP, extratropical cyclones, variability, East Asia, cyclone detection and tracking algorithms

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1. Introduction

A number of recent studies suggest that cyclone activity in both hemispheres has changed significantly over the latter half of the 20th century (IPCC, 2001; McCabe et al., 2001; Geng and Sugi, 2001; Simmonds and Keay, 2000). In the Northern Hemisphere, McCabe et al. (2001) found a significant decrease in midlatitude (30°–60°N) cyclone activity and an increase in high-latitude (60°–90°N) cyclone frequency with storm intensity increasing during 1959–1997, suggesting a poleward shift of the storm track. The western Pacific and Atlantic are characterized by an increase in cyclone intensity and deepening, although the eastern Pacific and continental North America demonstrate opposite tendencies in most cyclone characteristics (Angel and Isard, 1998; Gulev et al., 2001). Analysis also shows an increase in strong events over the North Pacific and Atlantic in winter (Lambert, 1996; Graham and Diaz, 2001). Further studies found that the changes in storm frequency correlate with changes in winter Northern Hemisphere temperature and support hypotheses that global warming may result in a northward shift of storm tracks in the Northern Hemisphere (McCabe et al., 2001), and that variations of cyclone activity over the North Atlantic are closely related to changes in the large-scale baroclinicity of the lower troposphere and the North Atlantic Oscillation (Geng and Sugi, 2001).

Eastern Asia is also a region of frequent cyclone occurrence. Cyclones occurring in East Asia are important synoptic systems that have strong impacts on the weather and climate in the region. Previous work has mostly concentrated on studying the source locations, storm tracks, and climatological features of extratropical cyclones (e.g., Zhu et al., 1981; Shou, 2002), based on very limited observed data. The techniques for identifying East Asian extratropical cyclones are

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mainly based on weather chart analysis.

Extratropical cyclones can also be deemed as extreme events, and have also experienced significant changes from long-term perspective (IPCC, 2001). However, there exists considerable uncertainty as to how extratropical cyclone activity has changed in a warmed climate, especially in the East Asia region. Recent studies suggest that in East Asia, cyclone activity is closely related to dust storm frequencies on an annual basis (Qian et al., 2001; Wang and Zhai, 2004).

Obviously, identification of extratropical cyclones based on an objective method and studying variations of cyclone activity in East Asia will further our understanding of both extratropical cyclones and climate change. This study focuses on the northern Eastern Asia region. The purpose of this study is to reveal variations of extratropical cyclone frequency and intensity with global warming, based on a newly developed objective method to identify extratropical cyclones, used with more reliable and consistent historical data. This study will further help to understand regional climate change and the causes of those variations.

2. Data and analysis technique

The European Center for Medium Range Weather Forecasts ERA-40 SLP reanalysis data covering 1958–2001 with 0000 and 1200 UTC are selected in this study. This dataset has a horizontal resolution of $2.5° \times 2.5°$. The focus region is East Asia, within 25°–60°N and 80°–140°E, except the Tibetan Plateau (Wu, 2002).

The cyclone identification and tracking algorithms used here has been reported in previous studies (Serreze et al., 1997; Geng and Sugi, 2001). It relies on the identification of low pressure centers by comparing the central grid point SLP values and the eight surrounding grid point values; a cyclone center must exist for certain consecutive observation periods (i.e., at least 12 h or 24 h) and meet a geographical tolerance limit. Intensity is based on the local Laplacian of pressure or on the pressure at each cyclone center. Mesoscale lows are unlikely to be represented due to the limited detection of synoptic-scale systems at this resolution. A cyclone tracking procedure is performed to see if a cyclone is a newly generated cyclone or just a cyclone center that existed in the previous time step.

Based on previous studies on extratropical cyclones, such as Serreze et al. (1997) and Geng and Sugi (2001), the algorithm is further improved in this study. Refering to the synoptic definition of a cyclone, the objective definition of a surface cyclone center is identified as following: (1) the SLP at a grid point is less than its eight surrounding grid point values; (2) the mean pressure difference between the central grid point and its eight surrounding grid points is larger than 2 hPa; and (3) the SLP of the central grid point is less than a newly defined tercile threshold.

The so-called tercile threshold definition is based on the following logic: Considering that an extratropical cyclone is a low pressure system in the surface pressure field in a region, the central pressure should be low over a sufficiently large region. Furthermore, as the mean SLP of a gridpoint can also change seasonally from nearly 1030 hPa in January down to 1005 hPa in July according to our climatogical statistics for East Asia (1971–2000), a fixed threshold value to define a low depression system is not appropriate. In this study, the scheme is as follows: (1) create daily tercile values based on all pressure data in the East Asia region at a specific time; (2) generate climatogical averages for the terciles during the 1971–2000 reference period for each calendar day; (3) use a 11-day filter to remove weather noise. After the above processing, the tercile thresholds for a specific time are defined. At a specific time, if the SLP is lower than the lower tercile threshold of the corresponding time, it is deemed a low depression system. The calculated tercile thresholds change seasonally, ranging from 1023.5 hPa to 1006.5 hPa in spring March–April–May (MAM), from 1003.4 hPa to 1010.8 hPa in summer June–July–August (JJA), from 1010.1 hPa to 1024.1 hPa in autumn September–October–November (SON), and from 1021.7 hPa to 1027.5 hPa in winter December–January–February (DJF).

After cyclone centers are identified, the cyclone centers are further investigated. At time step t, if there are several cyclone centers, the distances among those centers should be larger than 500 km. The weaker one will be removed if the distance between any two centers is less than or equal to 500 km. Furthermore, only the cyclone systems lasting more than 24 hours will be retained. To remove the local continental warm season thermal lows, especially in the desert and the basins in summer over northwestern and southwestern China, the cyclone speed is estimated.

A cyclone tracking procedure is performed to detect if cyclones are newly generated or just the same system that existed in the previous time step. The distances between the cyclones at time step t and the cyclones at time step $t+1$ are calculated: If (1) the cyclone center m (one of the cyclones) in time step $t+1$ is the closest one to the cyclone center n (another of the cyclones) in time step t; (2) the distance between these two centers is less than 1200 km (according to the fastest speed of cyclone propagation); and (3) the cyclone propagation direction is consistent with the steering flow, then we will say that the center m at

Table 1. The first randomly selected case of an extratropical cyclone occurred during 6–9 April 1971.

Year	Step	Time	Latitude (°N)	Longitude (°E)	central pressure (hPa)
1971	1	0000 UTC 6 April	45.0	107.5	995.7
1971	2	1200 UTC 6 April	47.5	115.0	989.8
1971	3	0000 UTC 7 April	50.0	120.0	997.3
1971	4	1200 UTC 7 April	50.0	120.0	999.1
1971	5	0000 UTC 8 April	50.0	130.0	995.8
1971	6	1200 UTC 8 April	50.0	132.5	999.4
1971	7	0000 UTC 9 April	50.0	132.5	1001.9
1971	8	1200 UTC 9 April	50.0	132.5	1007.2

Table 2. The second randomly selected case of an extratropical cyclone occurred during 10–15 May 1986.

Year	Step	Time	Latitude (°N)	Longitude (°E)	central pressure (hPa)
1986	1	0000 UTC 10 May	45.0	107.5	1004.2
1986	2	1200 UTC 10 May	45.0	105.0	994.7
1986	3	0000 UTC 11 May	47.5	102.5	997.2
1986	4	1200 UTC 11 May	45.0	107.5	990.2
1986	5	0000 UTC 12 May	45.0	112.5	991.2
1986	6	1200 UTC 12 May	45.0	117.5	990.9
1986	7	0000 UTC 13 May	45.0	122.5	991.9
1986	8	1200 UTC 13 May	45.0	125.0	997.2
1986	9	0000 UTC 14 May	40.0	130.0	993.9
1986	10	1200 UTC 14 May	40.0	130.0	994.0
1986	11	0000 UTC 15 May	40.0	137.5	996.5

time step $t+1$ comes from the center n at time step t. If one of the above (2) and (3) conditions is not satisfied, we call cyclone center m a newly generated cyclone and give it a new cyclone number.

After the cyclone detection and tracking procedures, the following information for each cyclone center is obtained: year, month, day, hour, cyclone serial number and start-end time, location, and central pressure. The above items are called the cyclone information data file.

To test the result of the newly improved algorithm, we randomly selected several cases from April 1971, May 1986, April 1987, and July 1999 to compare the calculated cyclone center positions, intensities and cyclone tracks with those from the weather charts published by the National Meteorological Center, China Meteorological Administration. Results showed that our algorithm performs sufficiently well for those cyclones. Some selected cases are given in Table 1 and Table 2, which show that the calculated center positions (latitude and longitude), intensities (central pressure), and cyclone tracks in each case agree with those in the weather charts very well (figures not shown).

3. Spatial and seasonal distribution

Figure 1 shows that the occurrence of extratropical cyclones in northern East Asia is mainly with in the

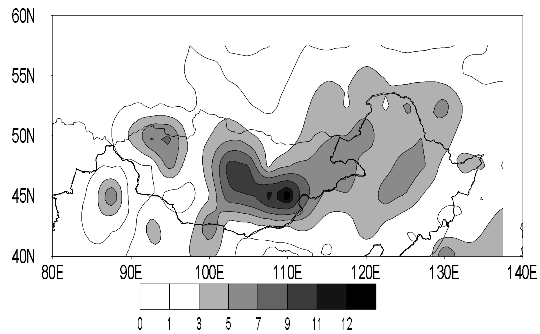

Fig. 1. Long-term mean annual counts of extratropical cyclone frequency as calculated at each grid point in northern East Asia.

40°–50°N latitudinal band. Apparently, this distributional feature is consistent with the average position of the baroclinic frontal zone. And the pressure distribution of the so-called "Mongolian cyclone" (occurs every year, and develops in central and eastern Mongolia at about 40°–50°N and 100°–115°E) and the "Northeast China low" (also called the "Northeast China cyclone", as it propagates into Northeast China, generally from Mongolia or the Yellow River Basin) are clearly displayed. The highest frequency of extratropical cyclone activity is located within 45°–50°N, 100°–120°E, in central and eastern Mongolia and the border between Mongolia and Northeast China. This result

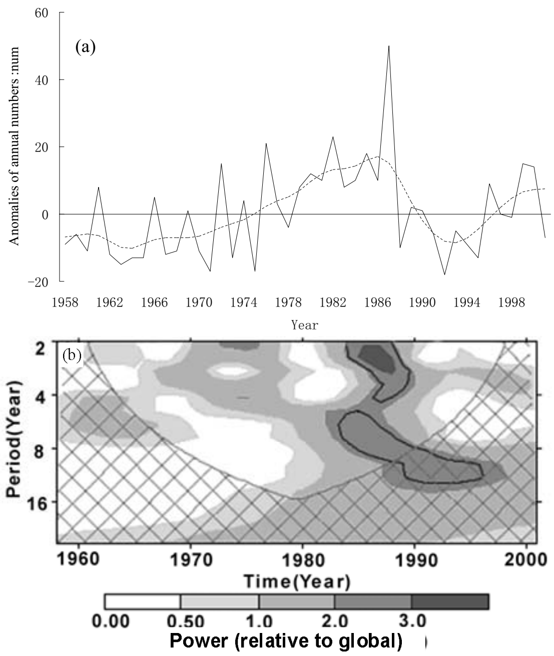

Fig. 2. (a) Anomalies of annual numbers of the extratropical cyclones in northern East Asia (40°–60°N, 80°–140°E)(smooth line is low frequency filtered). Anomalies are relative to 1958–2001 averages. (b) The wavelet power spectrum of annual numbers of the extratropical cyclones in northern East Asia (40°–60°N, 80°–140°E), using the Morlet wavelet. The x-axis is the wavelet location in time. The y-axis is the wavelet period in years. The black contours are the 10% significance regions, using a red-noise background spectrum.

is in good agreement with that from weather charts as given by Zhu et al. (1981).

Seasonal distribution of extratropical cyclones is as follows (figure not shown): in northern East Asia, monthly mean count is 9.9 and the most frequent activity is mainly observed in May, while the lowest activity is in January. There is more extratropical cyclone activity in the warm season than the cold season. The highest cyclone frequency occurs in spring (MAM), which accounts for 31.2% for the entire year, while the fewest appear in winter (DJF), which accounts for 16.3% for the entire year. And the cyclone frequency is 29.2% in summer (JJA) and 23.3% in autumn (SON).

4. Variations in frequency and intensity

4.1 *Frequency*

Figure 2a presents the variation of annual numbers of extratropical cyclones in northern East Asia. The highest activity of extropical cyclones is found in 1976, 1980, 1982, 1985, and 1987, with the highest in 1987, while the lowest activity is in 1965, 1968, 1971, 1975, 1992, and 1993. Besides this, there exists obvious decadal variability. The number of cyclones increased from the mid-1970s to the end of the 1980s. Then, the number of cyclones decreased until the early 1990s. Since the mid-1990s, cyclone frequencies have increased again.

Based on Morlet wavelet analysis (Torrence and Compo, 1998), we attempted to detect different time scale variability in frequency of the extratropical cyclones. Figure 2b reveals dominant decadal variability during the late 1980s and 1990s. Detailed analysis shows that a significant period of 8–10 years is found during the late 1980s, and another obvious oscillation occurs in the 1990s. Furthermore, there is a significant 2–4-year oscillation in the early-mid 1970s and from the late 1980s to the early 1990s.

Variations in number of seasonal (MAM,JJA,SON, and DJF) extratropical cyclones are shown in Fig. 3.

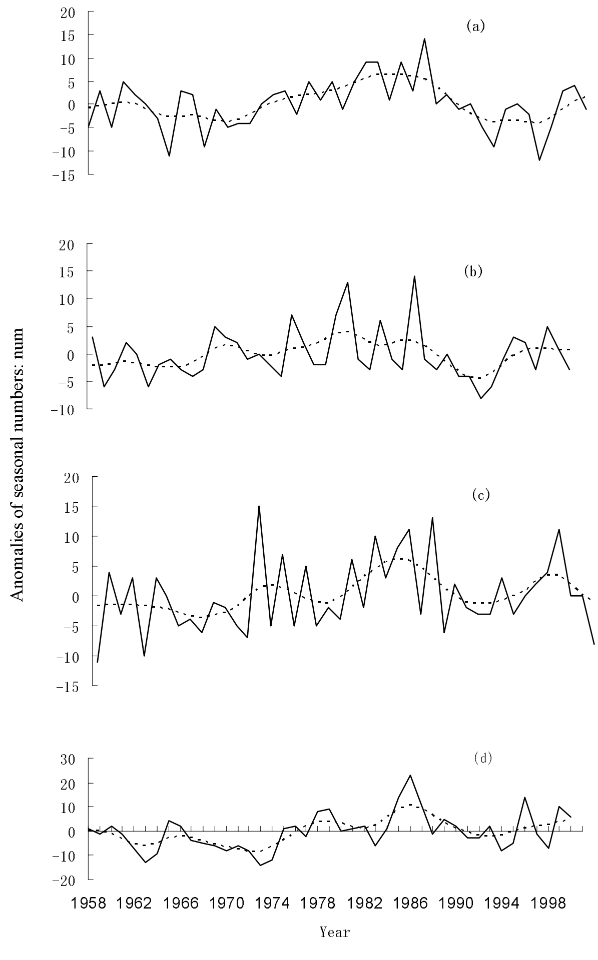

Fig. 3. Anomalies of seasonal numbers of the extratropical cyclones in northern East Asia (a: MAM; b: JJA; c: SON; d: DJF) (smooth line is low frequency filtered). Anomalies are relative to 1958–2001 averages.

Clearly, there exist large differences in annual variability. Spring cyclones were more frequent in 1987, 1985, 1982, and 1983, while they were less frequent in 1965, 1968, 1993, and 1997. Summer cyclones reached a peak in 1981 and 1987 and a lowest point in 1993. Autumn cyclones were most active in 1972 and 1987. Winter cyclones were most active in 1987 and 1997.

For decadal variability, all four seasons displayed consistent decreasing trends since the end of the 1980s. However, they all reflect increasing trends from the 1970s to the 1980s. The feature of interannual and decadal variability in the annual number of cyclones is shaped by the variation in spring cyclones.

To reveal the spatio-temporal variations of extratropical cyclone activity in northern East Asia, Fig. 4 shows that cyclone frequency has increased in the high latitudes (especially 40°–50°N) of East Asia, but decreased in the lower latitudes during the period 1958–2001. It implies that extratropical cyclone activity displays a northward shift during 1958–2001. This result seems to be consistent with the findings of McCabe et al. (2001). Nevertheless, the highest frequencies are found in the early-to-mid 1980s from 43°N to 50°N, and the second most frequent period was in the late 1990s from 45°N to 50°N. Similar results are also found in spring (figure not shown). It is not only the northward shift but also decadal variability that result in the aforementioned variations of extratropical cyclones. This suggests that decadal variability also plays an important part in the climate variability of extratropical cyclone frequencies over 1958–2001.

To further analyze the spatial pattern of cyclone frequency change in northern East Asia, differences between the earlier (1958–1979) and later (1980–2001) segments of data of extratropical cyclone frequency are calculated and plotted in Fig. 5. Interestingly, two dipole centers exist on either side of 110°E, with increased frequency of centers in the north and decreased frequency in the south. This plot indicates that extratropical cyclones in which the cyclones generate and develop in Mongolia and to the east of Baikal have increased, but extratropical cyclones in which the cyclones generate and develop in the eastern part of Xinjiang, Inner Mongolia, and over much of Northeast China have been suppressed in the latter period. This suggests a northward shift of cyclone track in East Asia.

To examine the relationship between the variations in the aforementioned dipole centers, and to check if there is any association among the four most notable centers of change in cyclone frequencies, the correlation coefficients among sub-regions A, B, C, and D (as shown in Fig. 5) are listed in Table 3. To further study these variations, and the association of extratropical

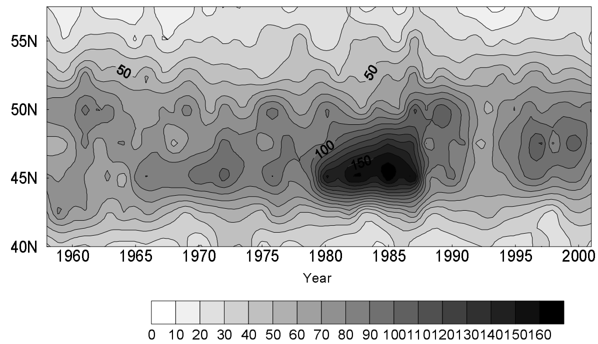

Fig. 4. Zonally averaged annual extratropical cyclone frequency in northern East Asia, units: number (40°–60°N, 80°–140°E).

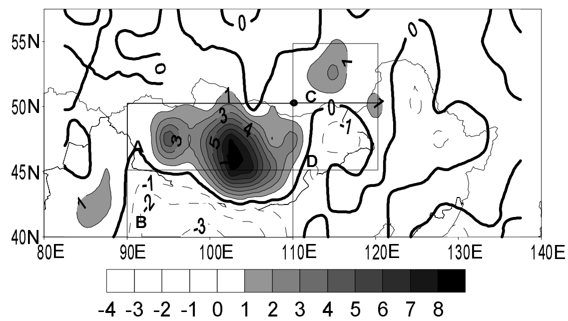

Fig. 5. Differences in annual counts of extratropical cyclones at grid points between 1980–2001 and 1958–1979 in northern East Asia (solid curves and shaded areas are for positive values, and dashed curves identify negative values).

Table 3. The correlation coefficients for extratropical cyclone frequency among four areas (Region A, B, C, D are shown in Fig. 5. The underlined coefficient is statistically significant at the 95% confidence level).

Sub-regions	A	B	C
B	$\underline{-0.30}$		
C	0.29	−0.28	
D	0.24	0.07	−0.004

cyclone activity in various subregions, Fig. 6 displays time series of extratropical cyclone frequency in these four subregions of northern East Asia. The standardized departures were computed for each latitudinal band by subtracting the respective 1958–2001 mean from each value and dividing by the respective standard deviation.

Figure 6 shows that extratropical cyclone frequencies have generally decreased in the lower latitude subregions B and D, but increased in the higher latitu-

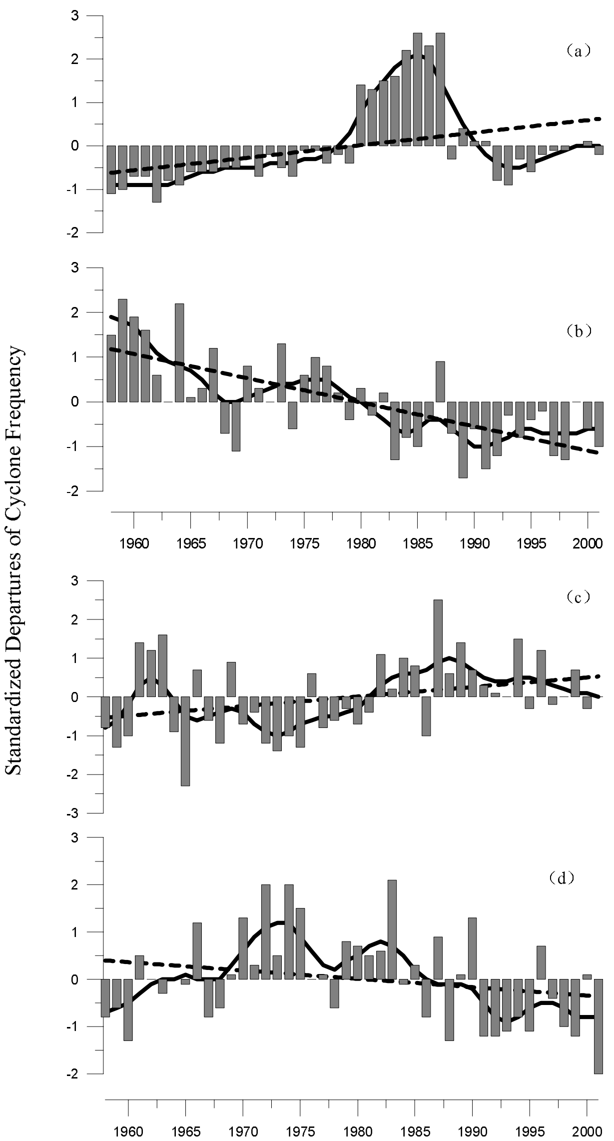

Fig. 6. Standardized departures (bars, relative to the average of 1958–2001), low frequency filtered signal (solid curves), and linear trend (dashed lines) of extratropical cyclone frequency for different regions in northern East Asia. Anomalies are calculated relative to 1958–2001 averages. Linear trends are not absolute frequency counts per decade. (a) 45°–50°N, 90°–110°E, trend: 0.29 $(10\text{yr})^{-1}$; (b) 40°–45°N, 90°–110°E, trend: −0.54 $(10\text{yr})^{-1}$; (c) 50°–55°N, 110°–120°E, trend: 0.25 $(10\text{yr})^{-1}$; (d) 45°–50°N, 110°–120°E, trend: −0.18 $(10\text{yr})^{-1}$.

de subregions A and C. However, two more features should be noted. Firstly, the changes in trends in the subregions to the east and west sides of 110°E are different. West of 110°E, extratropical cyclones have increased from 45°N northward, but to the east of 110°E, they have increased northward of 50°N. Secondly, the changes of extratropical cyclones in different sub-regions display clear decadal variability signals in addition to long-term trends. Based on wavelet analysis, it was found that in subregion A, a 15–16-years oscillation is obvious, especially in the 1980s; in subregion B, an 8-year period exists during the later 1980s until the early 1990s; in subregion C, a 7–8-year period exists in the 1960s; and in subregion D, an 8–16-year period is evident in the 1970s and a 6 year period in the 1990s. Table 3 shows there are negative correlation between A and B, and between B and C, but positive correlation between A and C. Only between the two neighboring subregions of A and B, variations of extratropical cyclones are significantly correlated. Such a result is not found to the east of 110°E. This partly displays the northward shift of cyclones.

In terms of the above analysis, though it shows that the extratropical cyclone activity has decreased in the lower latitude regions of northern East Asia during 1958–2001, decadal variability is also a dominant feature. It should be noticed that decadal variability has dominated the northern East Asian extratropical cyclone activity, especially in sub-regions A and C, where the highest frequencies are found in the early-to-mid 1980s.

4.2 *Intensity*

The intensity of a cyclone in the following study is defined by the lowest center pressure of a cyclone life period. The variation in mean intensity of northern East Asian extratropical cyclones during 1958–2001 is given in Fig. 7. It shows a deceasing trend in the mean intensity of the cyclones, with the strong end of the trend in 1968 and the weak end in 1988. Seasonally (not shown), intensities of the cyclones in all four seasons display decreasing trends, with the most obvious decease in summer, and then in autumn and relatively weak changes in spring and winter. This result is not consistent with the increasing trend in winter cyclone

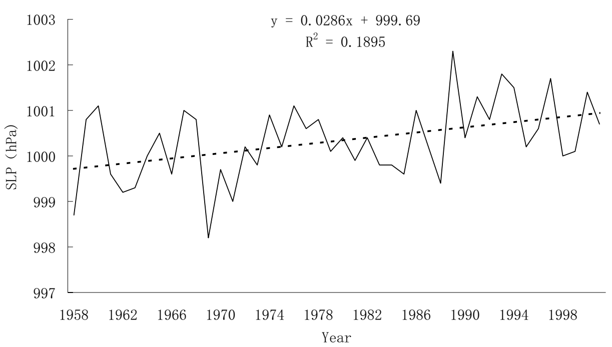

Fig. 7. Variations in intensities of northern East Asia extratropical cyclones as reflected by the averaged lowest center pressure for the entire lifetime of each cyclone.

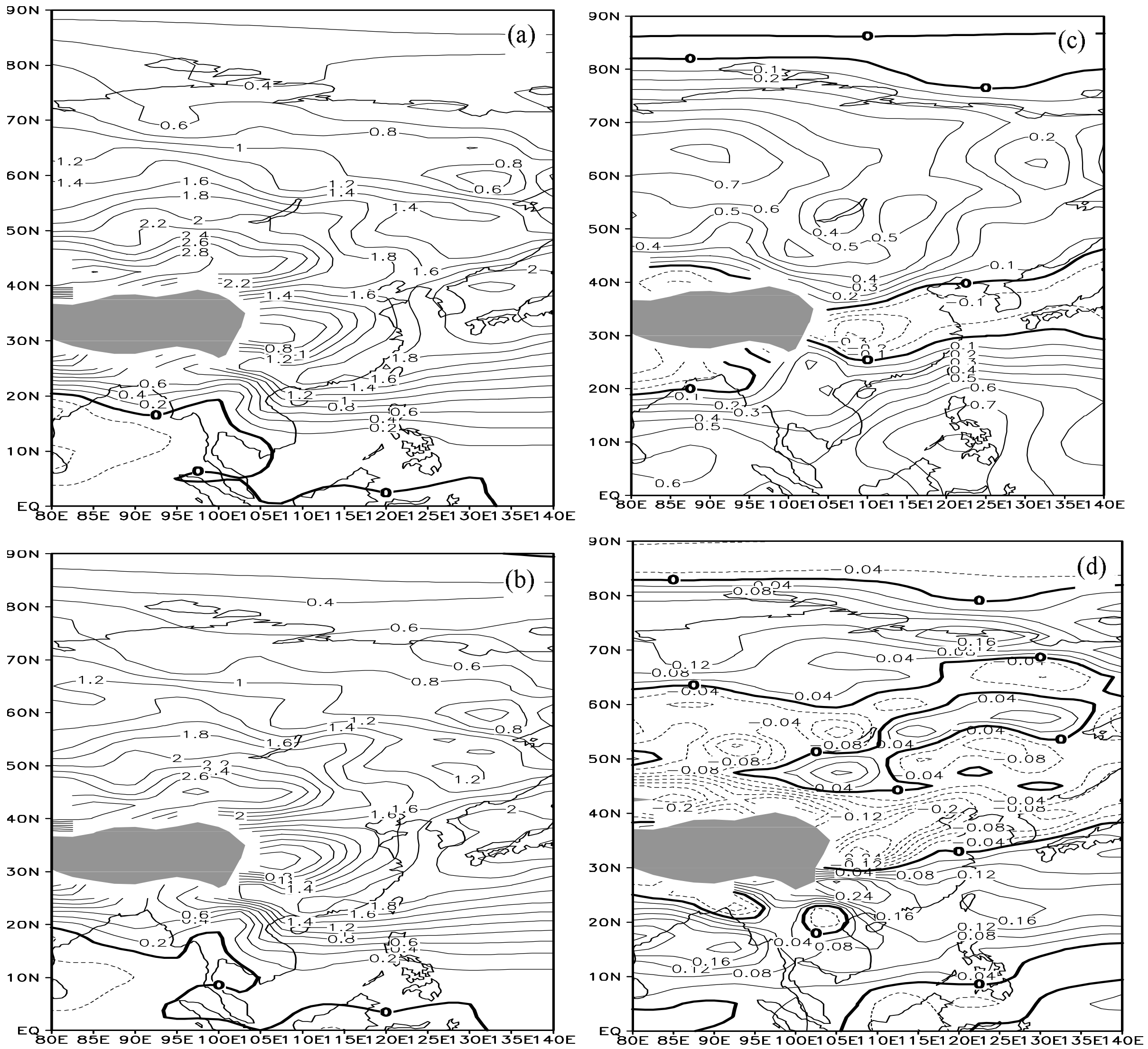

Fig. 8. (a) Meridional temperature gradients at 850 hPa between neighboring latitudes during 1958–1979; (b) Same as (a) but for 1980–2001; (c) Difference of temperature at 850 hPa between 1958–1979 and 1980–2001; (d) Difference of (a) and (b). (units: °C)

intensity for the Northern Hemisphere noted by McCabe et al. (2001). It reflects a unique regional feature of variation of Northeast Asia extratropical cyclones.

5. Causes of spatial and temporal variation

Activity of extratropcial cyclones is closely associated with the baroclinic frontal zone, which generates and develops the cyclones (Zhu et al., 1981). The regions of most frequent occurrence and of major tracks of extratropical cyclone are basically consistent with the mean location of the frontal zone. Through analyzing the variations of the meridional gradients of temperature in the lower troposphere (850 hPa), as well as the location and intensity of the baroclinic front, we attempted to study the cause of the variation in extratropical cyclones during 1958–2001.

The location and intensity of extratopical cyclones for the periods of 1958–1979 and 1980–2001 can be reflected by the meridional gradients of the temperature at 850 hPa in Fig. 8a and Fig. 8b. On average, the mean East Asia frontal zone is zonally located at about 45°–55°N. This is consistent with the region of most frequent and main tracks of northern East Asian extratropical cyclones, as reflected in Fig. 1 and Fig. 4. Figure 8c gives the variations of the temperature at 850 hPa between the period of 1980–2001 and the period of 1958–1979, which shows negative values in the latitudinal band of 20°–40°N, but positive ones in 40°–70°N in East Asia. It suggests cooling in the lower latitudes, but obvious warming in the higher latitudes. It thus has reduced the meridional gradients of lower tropospheric temperature in East Asia and further weakened the baroclinic frontal zone in the mid-latitudes. Figure 8d, which gives the difference of the meridional temperature gradients at 850 hPa between 1958–1979 and 1980–2001, reflects the northward shift of the baroclinic front zone, which is associated with the northward shift of the extratropical cyclones in East Asia as reflected in Fig. 5 and Fig. 6.

To reveal the variation in intensity of the baroclinic zone, annual mean meridional gradients of the temperature between 60°N and 40°N at 850 hPa were calculated for East Asia between 80°–140°E. The temperature gradient values between the above two latitudes reflects the intensity of the frontal zone over the study region of northern East Asia. Figures 9a and 9b show that the variation in the number of cyclones and the intensity of the frontal zone are closely related. In the years when the front zone is strong (weak), there are more (less) extratropical cyclones. When calculating the correlation for the period of 1958–2001, it is found that the annual number of cyclones and the mean intensity of the baroclinic front zone are significantly positively correlated (correlation coefficient is 0.32). This indicates that the variation in the number of extratropical cyclones is influenced by the intensity of the baroclinic front zone, which is mainly related to the temperature change in the lower troposphere at the higher latitudes in the northern East Asia region. It should be noted that the most active period of extratropical cyclones in northern East Asia is related to the largest intensity of baroclinic front zone, occurring during the early-to-mid 1980s.

The change in location of the baroclinic front was studied in Fig. 10, which was derived by finding the largest meridional temperature gradient during 1958–1979 and 1980–2001 at 850 hPa at each longitude in the northern East Asia. Clearly, a northward shift can be observed from 42°N to 47°N at about 100°E, and another more dramatic one at about 117°E between the earlier period and the later period. Such a change is associated with the two dipoles of change in extratropical cyclones revealed in section 4.1 and in Fig. 5. Obviously, the phenomena of increasing extratropical cyclones in the north and decreasing in the south and on either sides of 110°E is caused by northward movement of the baroclinic front zone related to the change of the temperature gradients at the lower latitudes.

6. Conclusions

The improved cyclone detection and tracking algorithm can objectively identify extratropical cyclone activity in East Asia.

Extratropical cyclone activity in East Asia has obvious seasonal and interannual variation. Spring is the season when extratropical cyclones are most frequently observed. The spatial distribution of extratropical cyclones shows that the most frequent activity occurs in Mongolia in northern East Asia. Extratropical cyclones occur mainly within the 40°–50°N latitudinal band in northern East Asia. This distributional feature of extratropical cyclones is consistent with the baroclinic frontal zone in the study region.

It seems that both decadal variability and long-

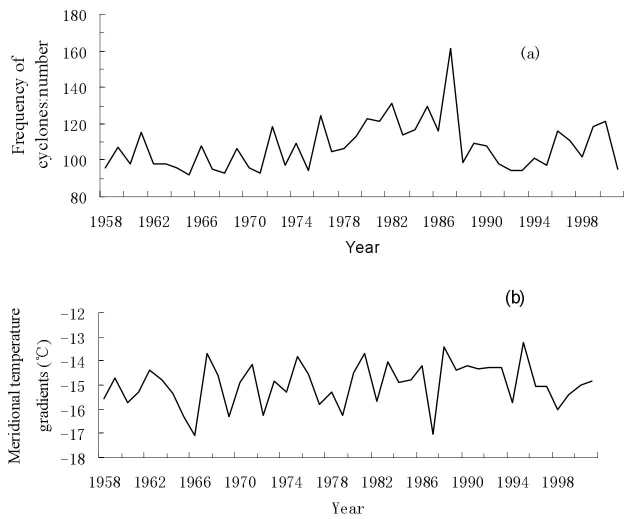

Fig. 9. (a) Variation in frequency of extratropical cyclones, averaged for the region, 40°–60°N, 80°–140°E (units: number); (b) Variation of intensity of the baroclinic zone as reflected by 850 hPa meridional temperature gradient between 40°N and 60°N, averaged for 80°–140°E. (units: °C)

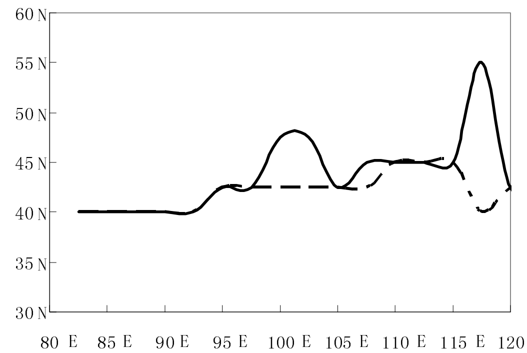

Fig. 10. Change in mean position of the front in Northeast Asia, as reflected by the largest meridional temperature gradient at 850 hPa at each longitude (solid line: mean position for 1980–2001, dashed line: for 1958–1979).

term trends are important features of climate change for extratropical cyclones in the northern East Asia region. The intensity of extratropical cyclones in northern East Asia displays deceasing trends on seasonal and annual bases. During 1958–2001, extratropical cyclone activity has decreased at lower latitudes and increased in the higher latitudes. In addition, decadal variability also has an important influence on extratropical cyclones in the northern East Asia region.

Further analysis suggests the variation in number of cyclones is closely associated with the intensity of the baroclinic frontal zone, which is mainly dominated by meridional temperature gradients between mid-latitudes and higher latitudes. Recent warming at the higher latitudes of Asia appears to contribute to the variability in extratropical cyclones in northern East Asia. The period of greatest extratropical cyclone frequency, found in the early-to-mid 1980s, can be explained by intensity variations of the baroclinic frontal zone.

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