The Comparative Environment of Beijing and Topeka during the Thunderstorm Season

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ABSTRACT

Beijing, People's Republic of China, and Topeka, Kansas, United States of America, are located at approximately the same latitude and are affected by similar synoptic weather patterns. However, their thunderstorm climatology differs significantly. Rawinsonde data from the two stations are compared. It is found that the typical distribution of the oceanic subtropical high pressure areas subtly modifies the synoptic scale environment accounting for the observed differences.

1. Introduction

Beijing (Peking) is located on the North China plain at a latitude of 40°04′, and Topeka is situated in the midwestern plain of North America at a latitude of 39°04′. Because of their similar latitudes, North China and the midwestern United States are exposed to similar seasonal weather patterns. However, due to the different geographical and topographical settings, there are some significant differences in the weather experienced by these two areas.

A comparison of precipitation for the two cities shows that Topeka averages about 889 mm per year, nearly 200 mm more than Beijing. While Beijing receives more rain than Topeka during July and August, it is much drier than Topeka during the remainder of the year. Recent satellite measurements indicate that the amount of thunderstorm activity over both regions during the spring and summer is roughly equivalent (Kotaki *et al.*, 1981). Although this is contrary to classic climatologies (e.g., WMO, 1956), Watts (1969) notes that many thunderstorms over China are not reported. At Topeka, the month of May has the highest frequency of thunderstorms. In contrast, June is the month of most frequent thunder activity at Beijing. While both areas suffer damage from hail and high winds, tornadoes which occur an average of six times per year per 26 000 km^2 over northeast Kansas (Kelly *et al.*, 1978) are virtually unknown in North China.

[1] This work was accomplished during a sabbatical at NSSFC.

2. Climatic generalities

The most significant topographic difference between the two stations is their position relative to a major body of water. Beijing is within 2° of the Gulf of Bohai (Gulf of Chihli), while Topeka is about 12° away from the Gulf of Mexico. Further, the lower elevation of Beijing (32 m) as compared with Topeka (268 m) is consistent with the fact that the North China Plain is generally 200 to 300 m lower than the midwestern plain of North America. Geographically, the two stations are representative of their respective regions.

To get some quantitative information regarding atmospheric conditions at Beijing and Topeka, morning (local time) upper air soundings for the period April through July 1978 were examined. The 00 GMT sounding is taken at 0800 LST local time in Beijing, while the 12 GMT sounding corresponds to 0600 LST local time in Topeka. Although the equipment used by the two countries differ, the observing procedures and instrumental accuracy are governed by World Meteorological Organization regulations (e.g., WMO, 1968). Because of this, mean structural characteristics can be directly compared even though fine detail cannot.

TABLE 1. Monthly mean temperature, dewpoint and maximum temperature on surface (°C) at Beijing (BEI) and Topeka (TOP).

	April		May		June		July	
Year 1978	BEI	TOP	BEI	TOP	BEI	TOP	BEI	TOP
T								
Mean	13.3	13.0	18.1	17.1	24.4	23.4	25.4	25.2
Standard deviation	3.5	4.4	2.8	5.4	2.6	4.0	1.5	2.8
T_d								
Mean	−0.2	6.0	10.7	10.1	16.2	16.5	22.0	19.5
Standard deviation	6.6	4.9	5.3	5.8	3.5	4.8	1.8	2.5
T_{max}								
Mean	27.5	28.1	30.1	30.8	37.5	36.3	33.9	35.8

Surface readings from both morning and afternoon soundings were averaged to estimate mean daily temperature and dewpoint temperature values. These values should approximate the prevailing conditions at each location. A temporal averaging yielded monthly means and standard deviations (Table 1). Also, the observed daily maximum temperatures were averaged by month.

The mean surface temperatures are very similar, with Beijing being slightly warmer (1°C or less). If a standard lapse rate of 0.0065°C m^{-1} (List, 1966) is used to reduce the Topeka temperature to the Beijing elevation, the Chinese station becomes a little cooler than the North American. Even though the standard deviation in temperature for each of the four months is larger at Topeka, indicating greater day-to-day variations, the mean daily maximum temperature by month is essentially the same at the two locations.

During the spring Beijing's weather is not yet dominated by the summer monsoon circulation and associated maritime air mass. The dewpoint temperatures for April at Topeka averaged over 6°C higher than at Beijing. During May and June, both locales have similar humidities. However, by July warm, moist maritime air has spread inland onto the Chinese plain resulting in higher average humidities at Beijing than at Topeka.

During the late spring, migratory surface pressure centers and their associated frontal systems have a similar effect on both regions. During May and June, the principal cyclone tracks are located away from the areas of study. However, both Topeka and Beijing are positioned immediately to the right of secondary storm tracks (Klein, 1957). Aloft, a jet stream, with associated secondary circulations is a common phenomenon in both locales (Pogosian, 1960). Thus, "triggering" mechanisms for thunderstorms are equally prevalent.

Constant pressure surfaces are typically higher at Topeka than at Beijing (Table 2). This is related to the climatological distribution of the subtropical high pressure system, which is dictated by the geographical distribution of ocean and land. Fig. 1a shows the climatological June 700 mb height (in the unit of 10 ft—approximately 3 m) over the Northern Hemisphere. The Pacific anticyclone is enclosed within the 1040 isoheight while the Bermuda high is outlined by a 1050 contour. Note, the 1030 contour line crosses the United States (through Topeka), but does not extend into Asia.

TABLE 2. Mean height (m) of standard levels; the standard deviation is shown in parentheses for Beijing (BEI) and Topeka (TOP).

	April		May		June		July	
Year 1978	BEI	TOP	BEI	TOP	BEI	TOP	BEI	TOP
850 mb	1446	1470	1477	1478	1445	1529	1454	1533
	(36)	(63)	(23)	(43)	(37)	(37)	(26)	(16)
700 mb	3011	3040	3079	3076	3072	3163	3097	3181
	(39)	(60)	(30)	(67)	(43)	(42)	(24)	(16)
500 mb	5587	5641	5710	5718	5741	5850	5808	5894
	(83)	(96)	(59)	(96)	(66)	(66)	(34)	(23)
300 mb	9169	9269	9372	9404	9469	9591	9626	9684
	(135)	(127)	(120)	(146)	(131)	(102)	(73)	(37)

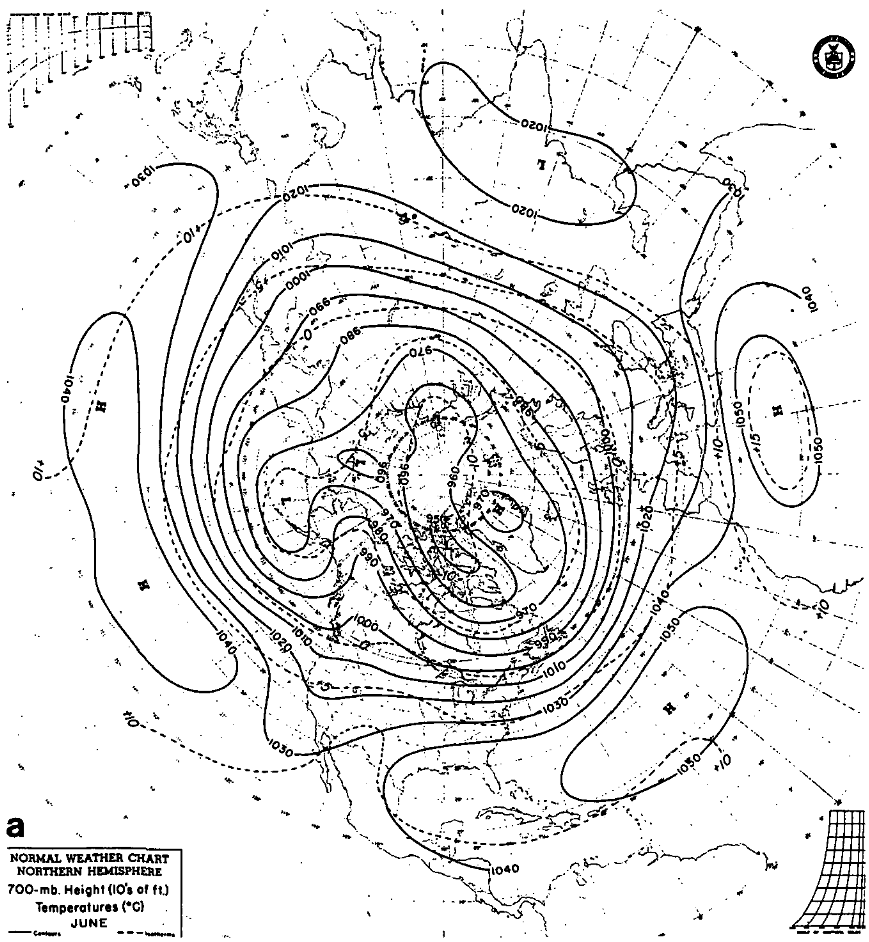

FIG. 1. Normal 700 mb chart (after Weather Bureau, 1953) for (a) June and (b) August.

Because the Bermuda high is stronger than the Pacific high, the midwestern United States is influenced by subtropical anticyclonic circulation while eastern China is not.

Climatologically, by August (Fig. 1b) the subtropical highs have strengthened by about 100 ft (approximately 30 m). The basic flow over the southern United States (30–40°N) remains from the south or southwest. However, over similar latitudes in China a significant change has occurred. The orientation of the 1020 contour is altered so that the northwest flow of June has a southerly component in August. Actual conditions during 1978 corresponded closely to the climatic normal (see Taubensee, 1978; Dickson, 1978).

The midlevel conditions are amplified at low levels. As seen in Fig. 2a, the Bermuda anticyclone has a very marked effect upon the June climate of the midwestern United States. The mean 1000 mb flow is positioned so that the Gulf of Mexico moisture is less than 10° directly upstream from Kansas. In contrast, China is unaffected by the Pacific High. The flow near Beijing has approximately a 20° land fetch. Further this flow encounters significant topographic barriers on its way from the South China Sea to the Great Plain of China.

The strengthening of the subtropical anticyclones during the spring and early summer dramatically alter the climatological 1000 mb patterns (Fig. 2b). Over Kansas a southeasterly flow is established, and the upstream distance to the Gulf of Mexico increases. A south-southeasterly flow comes into existence over North China. A direct trajectory from the Yellow and East China Seas brings low level moisture to the Great China Plain. This new flow pattern gives the surface air at Beijing more humidity than the surface air at Topeka.

The difference in the strength of the subtropical highs accounts for the different thunderstorm seasons for the two locales. In June, the extension of the subtropical high over the Gulf of Mexico induces a warm moist southerly low level flow conducive to thunderstorm activity to the midwestern plains of the United States, while a westerly or northwesterly flow prevails over

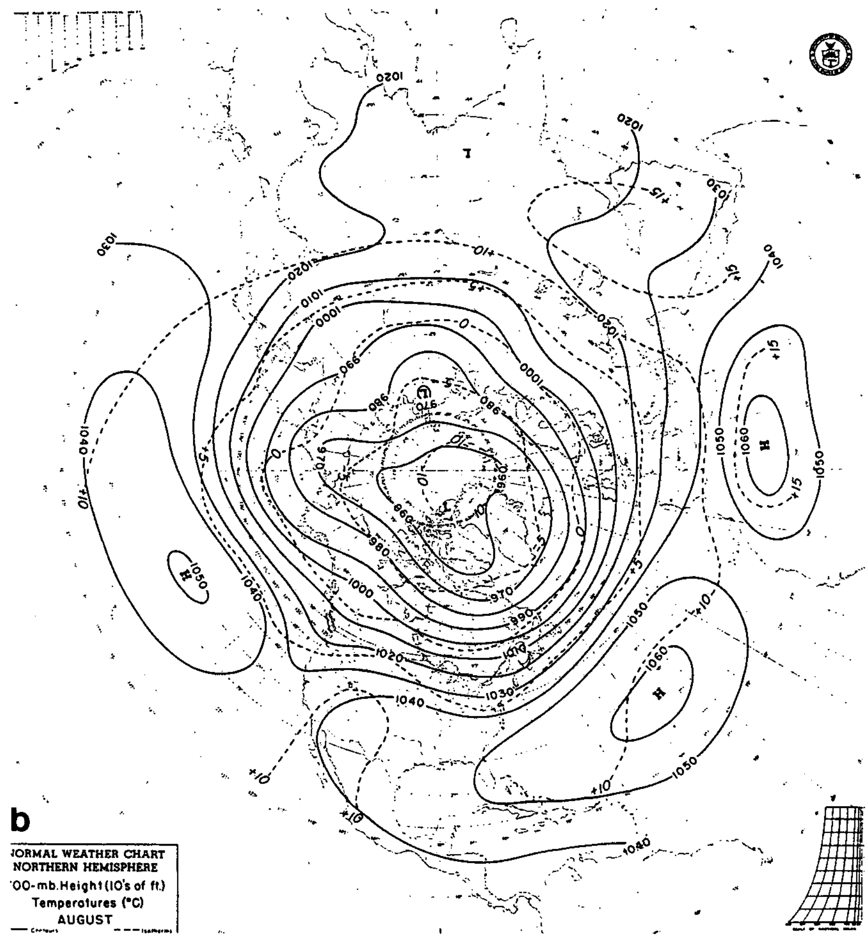

FIG. 1. (*Continued*)

China. However, by August southerly flow conducive to thunderstorms is occurring over both regions.

3. Comparative stratification

When sounding profiles for the two stations are compared, it is seen that the air column over Topeka is generally warmer than that at Beijing (Table 3). This is hydrostatically consistent with the finding of consistently higher pressure surfaces at Topeka.

From the standard deviation of mid and upper level temperatures, it can be seen that upper air systems over the North China Plain are generally stronger than those over the central United States. (Note from Table 2 that the 300 mb geopotential at Beijing also exhibited more variance than it did at Topeka.) The circulations induced by these upper systems transport moisture vertically and account for the fact that between April and June, Topeka is moister at the low levels and drier aloft than Beijing. This Topeka moisture stratification is conducive to the existence of potential instability.

Several stability indices were derived from the sounding data (Table 4). One, the K-index (George, 1960), is given by

$$K = T(850) + T_d(850) - T(500) - [T(700) - T_d(700)],$$

where T is temperature, T_d is dewpoint temperature (the pressure level is indicated in parentheses). This index is a reasonably good indicator of the atmosphere's ability to support "air mass" thunderstorms. High values require both a steep lapse rate and a deep moist layer. Values less than 20 typically indicate a lack of thunderstorm potential while values greater than 30 are indicative of a possibility of scattered thunderstorms. At Topeka, the average K index is within one standard deviation of the scattered thunderstorm criteria in all months studied. In contrast, at Beijing the April K index is well within the "no thunder" range.

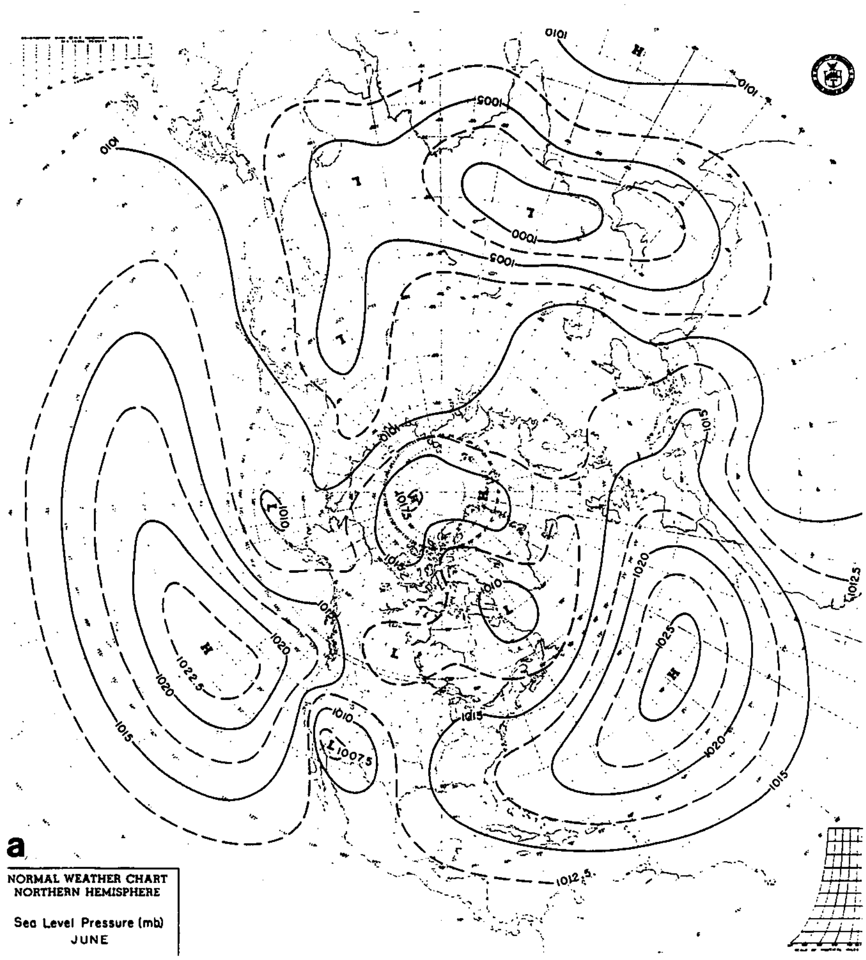

FIG. 2. Normal 1000 mb chart (after Weather Bureau, 1953) for (a) June and (b) August.

A soundings capability for supporting severe convection can also be classified by the entire totals index,

$$\text{Totals} = T(850) - T(500) + T_d(850) - T(500).$$

According to Miller (1972), totals greater than 55 indicate a strong potential for severe convection, while totals less than 50 imply a very low probability of severe thunderstorms. Surprisingly, only during April is the Beijing value markedly lower than Topeka's.

The lifted index LI discussed by Galway (1956) is also an indicator of the latent instability present in the atmosphere. It indicates the buoyancy of a lifted parcel that has the convective temperature and a moisture content corresponding to the mean low level mixing ratio. The convective temperature is defined as the temperature corresponding to the potential temperature at the top of the boundary layer warmed by 2°C and lowered adiabatically to the surface. The National Severe Storms Forecast Center rawinsonde analysis procedure (Doswell *et al.*, 1982) was used to compute the LIs and obtain mean monthly values.

As with the other indices, mean monthly values for the two stations are surprisingly similar. However, the standard deviations indicated that large fluctuations of stability occur at Topeka, while a relatively uniform instability prevailed at Beijing. This is consistent with the observation that during the summer more precipitation occurs at Beijing than at Topeka but that Topeka convection often reaches a severity level unknown in China.

For a close inspection of instability, only days with a negative LI were tabulated and averaged. In April, Topeka had seven days with a negative lifted index giving an average of −3.8. Beijing had four unstable days with an average value of −1.8. In May the monthly averages show Beijing more unstable. Topeka had 12 unstable days which averaged −4.2 while Beijing had 14 unstable days which averaged only −2.2. Similar conditions occurred in June and July. Thus, atmospheric conditions are more favorable for producing severe storms in the midwestern United States than in North China.

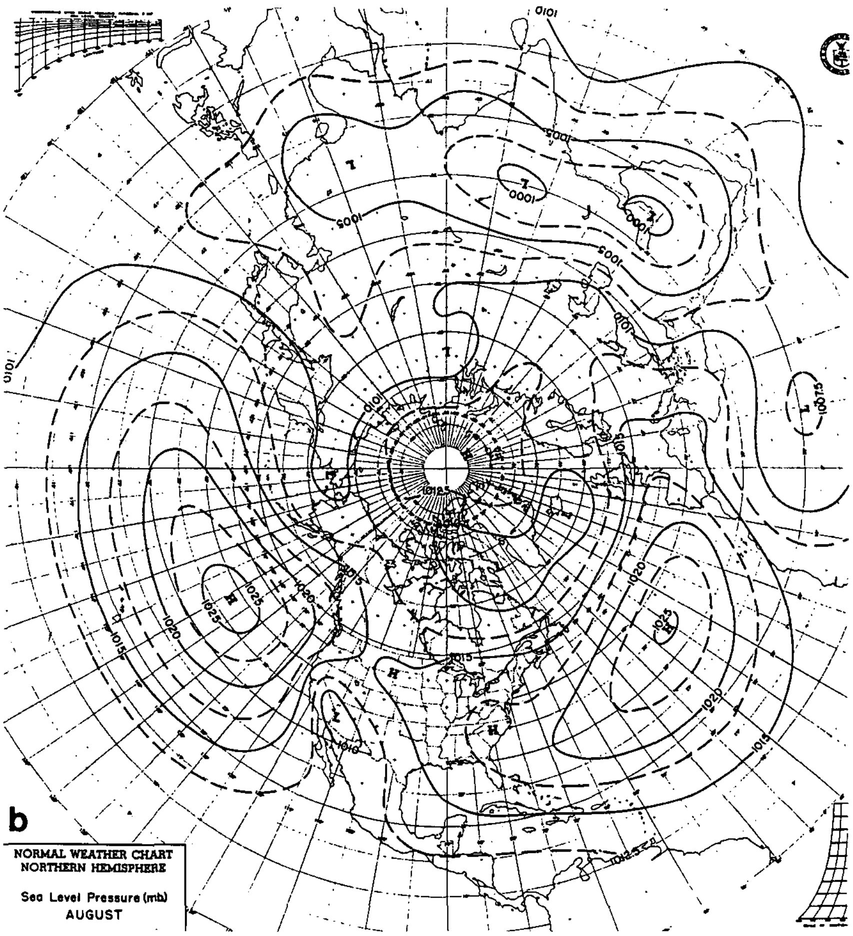

FIG. 2. (*Continued*)

The height of the wet bulb zero level (WBZH in meters), which has been correlated with severe thunderstorm occurrence, was also computed. Miller (1972) found that severe weather most often occurred when the WBZH is positioned between 2150 m and 2800 m above the surface. During May both Beijing and Topeka were within this range.

Monthly averages of precipitable water content (PWC in mm) below 400 mb indicates in April Beijing is much drier than Topeka, while in July the opposite holds. During May and June, the two stations have virtually identical water contents. While the total atmospheric water content is similar, the monthly averaged mean low level (1000 mb) mixing ratio at the two sites differ markedly. For April, May and June, the Beijing boundary layer is much drier. In July, the developing Pacific anticyclone brings enhanced low level moisture over the North China Plain.

During the spring and early summer the general characteristics of the stratification at Beijing are quite similar to those at Topeka. To find significant differences, it is necessary to look at the subtleties of the soundings. Monthly mean profiles (Fig. 3) for Beijing and Topeka illustrate the differences between the two locations.

During the spring the air column at Topeka is warmer than that at Beijing. Also during the spring, Topeka has more moisture in the lower levels and less moisture in the upper levels than Beijing. Individual profiles indicate that Topeka has distinct inversion layers above the surface through the entire thunderstorm season. (Note even the June composite for Topeka has a marked stable layer at about 850 mb above the nocturnal inversion.) Such an inversion provides a lid that retards the release of convective activity, allowing the moisture content and temperature of the boundary layer to increase without altering that of the overlying free atmosphere (Schaefer *et al.*, 1982).

4. Summary

A comparison of the atmospheric structure of Beijing and Topeka shows that the most significant difference

TABLE 3. Mean temperature and dewpoint of the standard pressure level for Beijing (BEI) and Topeka (TOP). Standard deviation shown in parentheses.

	April		May		June		July	
Year 1978	BEI	TOP	BEI	TOP	BEI	TOP	BEI	TOP
850 mb								
T	6.0	8.2	11.6	11.1	16.8	17.5	18.5	20.5
Standard deviation	(5.9)	(5.3)	(4.3)	(6.0)	(3.3)	(5.0)	(2.1)	(3.0)
T_d	−9.5	−0.7	−0.8	1.6	5.4	5.9	10.6	8.4
Standard deviation	(7.1)	(9.4)	(9.5)	(8.3)	(5.9)	(9.4)	(4.7)	(7.0)
700 mb								
T	−3.3	−0.7	2.1	2.9	6.3	7.8	9.1	10.1
Standard deviation	(5.7)	(4.6)	(4.1)	(4.0)	(3.6)	(4.5)	(1.8)	(1.6)
T_d	−20.0	−12.4	−10.0	−9.8	−6.1	−4.7	1.3	−3.5
Standard deviation	(7.4)	(10.7)	(9.6)	(10.8)	(7.4)	(10.2)	(5.4)	(10.8)
500 mb								
T	−20.8	−17.6	−15.5	−13.9	−11.5	−10.0	−6.7	−7.4
Standard deviation	(5.0)	(3.6)	(4.1)	(3.7)	(4.1)	(2.6)	(2.5)	(1.0)
T_d	−34.5	−35.5	−27.5	−30.5	−24.3	−29.5	−15.5	−28.2
Standard deviation	(7.4)	(14.2)	(8.4)	(12.4)	(6.9)	(12.7)	(8.3)	(13.6)
300 mb								
T	−47.6	−44.6	−42.1	−40.2	−36.9	−36.9	−30.9	−33.6
Standard deviation	(3.8)	(2.0)	(4.1)	(3.5)	(5.7)	(2.9)	(3.6)	(2.1)
T_d	−63.0		−48.0	−55.1	−44.9	−56.7	−39.4	−56.6
Standard deviation	(4.3)		(6.3)	(15.3)	(9.3)	(14.0)	(7.6)	(14.8)

TABLE 4. Mean parameters derived from soundings at Beijing (BEI) and Topeka (TOP). Standard deviations shown in parentheses.

	April		May		June		July	
Year 1978	BEI	TOP	BEI	TOP	BEI	TOP	BEI	TOP
K index	1 (13)	13 (17)	15 (15)	14 (18)	21 (10)	21 (16)	28 (8)	23 (16)
Totals index	38 (12)	43 (11)	42 (8)	41 (9)	45 (6)	43 (10)	42 (5)	44 (8)
WBZH (Standard deviation)	1558 (796)	1939 (866)	2567 (814)	2415 (835)	3165 (607)	3119 (643)	3914 (512)	3512 (579)
PWC (Standard deviation)	10 (4)	17 (8)	23 (10)	22 (10)	29 (10)	31 (12)	44 (12)	35 (10)
Mean low level mixing ratio (Standard deviation)	3.7 (1.6)	5.5 (2.4)	7.0 (2.7)	7.4 (3.1)	9.8 (2.8)	11.0 (3.8)	13.7 (7.1)	11.6 (1.9)
Lifted index	6.3 (5.9)	4.2 (5.8)	1.8 (4.6)	2.4 (6.4)	−2.4 (3.4)	−2.6 (5.4)	−3.3 (2.4)	−3.0 (3.6)
Mean lifted index when negative	−1.8	−3.8	−2.2	−4.2	−4.3	−5.6	−4.0	−4.3
Number of days with negative LI	4	7	14	12	19	20	27	25

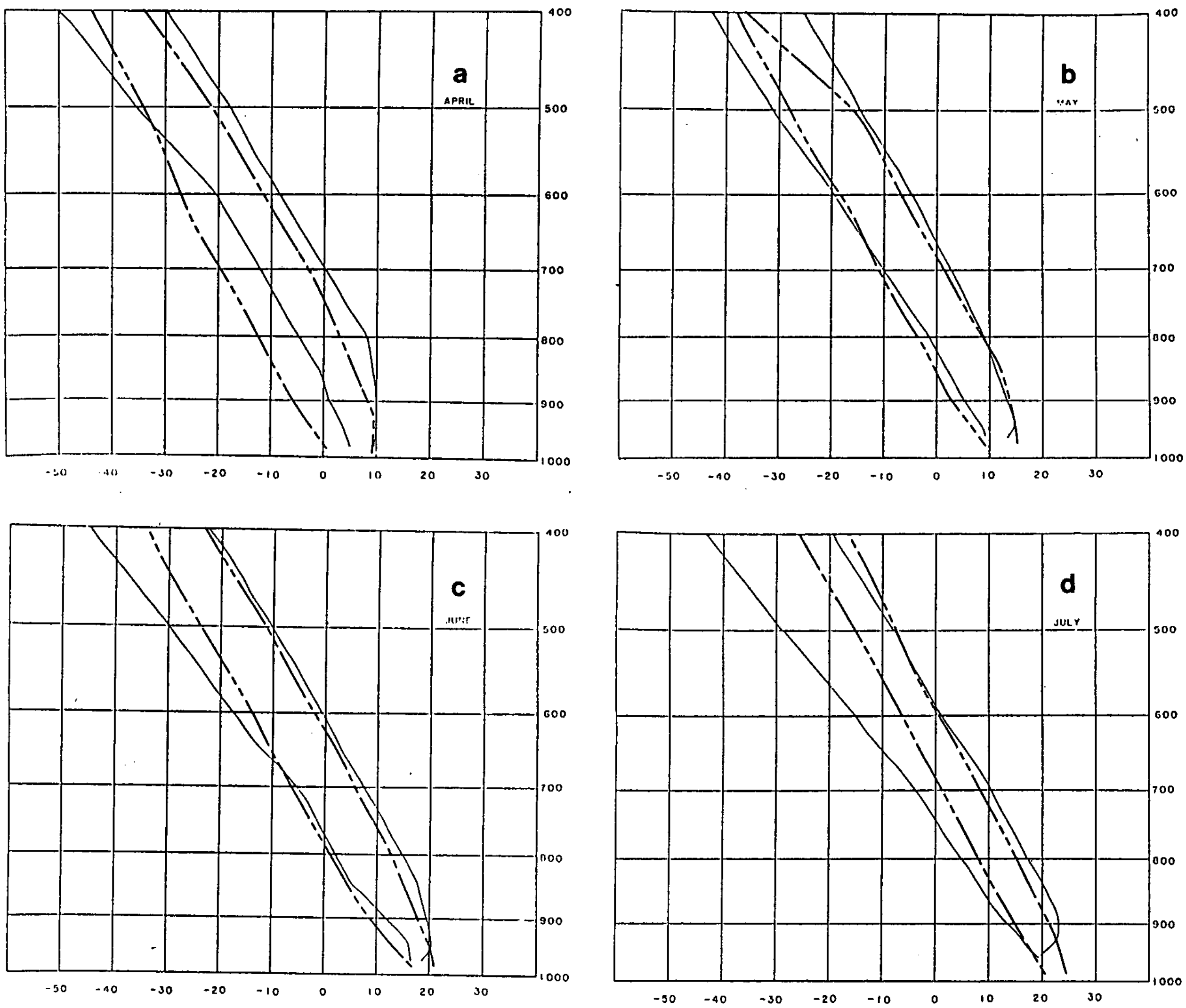

FIG. 3. Monthly mean soundings for Topeka (thin solid lines) and Beijing (thick broken lines): (a) April 1978; (b) May 1978; (c) June 1978; (d) July 1978.

is in the low level moisture content of the air columns. Because of the prevailing flow, the Gulf of Mexico provides the midwestern United States plain with an abundant supply of moisture at a time when the upper level disturbances are potent enough to support the development of strong convection. In contrast, during the entire spring when strong systems exist, the North China Plain rarely has low level moisture in amounts sufficient to support thunderstorms. This lack of moisture occurs even though the Gulf of Bohai is quite close to Beijing.

Since this paper is based on data from just one thunderstorm season, many significant features have likely not been explored. However, based upon their consistency with climatology, we believe the basic characteristics described in this paper hold for other years.

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