THE SUMMERTIME GREAT PLAINS LOW LEVEL JET AND THE EFFECT OF ITS ORIGIN ON MOISTURE TRANSPORT

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Abstract. Radiosonde data from six stations in Kansas and Oklahoma for the period of June 16–24, 1993 indicate that a low-level jet (LLJ) occurred almost every day except on the 20th. Major characteristics of these LLJs are documented in this paper. The maximum wind speed (the jet speed) varied from 13 to 32 m s^{-1} and heights ranged from 167 to 910 m. All the jets were southerly except the one on June 19 which changed its direction dramatically from a southerly to a northerly direction in about three hours although its intensity did not change appreciably. Thermal stability of the boundary layer during these LLJ occurrences ranged from near-neutral to highly stable. All the low-level jets exhibited significant diurnal variations. Analyses show that relatively weak large-scale forcing existed for the LLJs on June 21 and June 22, while strong forcing was present on other days. Analyses also show that moisture transport by the LLJ from the Gulf of Mexico to the Great Plains depends on the location of the LLJ origin. In the two weeks of June 13–19 and 20–26, 1993, powerful storms swept through the central United States, accompanied by tornadoes, strong wind, large hail and heavy rainfall. The analyses indicate that these weather events could be a result of the interactions of the LLJs with synoptic-scale flow.

Keywords: Low level jets, Moisture transport, Nocturnal severe weather, The Great Plains

1. Introduction

During summers, the Great Plains region of the United States is characterized by frequent occurrences of nocturnal low-level jets, which are mostly from a southerly direction. Time evolution and spatial structure of the Great Plains low level jets are well documented through several field programs (Lettau and Davidson, 1957; Hoecker, 1963; Parish, et al., 1987). Climatological analysis by Bonner (1968) showed that the Great Plains LLJ is most pronounced in August and September at approximately 37° N, 98° W. A similar climatological analysis by Mitchell et al. (1995) using wind profiler observations with a higher time resolution indicates that the frequency of jets during September is almost twice than in other months. Also, weak jets are most common to the south of the area of maximum occurrence while strong jets can extend farther north and east.

It has been shown that the LLJs are often associated with nocturnal thunderstorms and severe weather events as discussed below. Pitchford and London (1962) found that a composite jet axis representing all non-frontal days during the summer

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months of 1955–1957 coincided with the line of maximum frequency of thunderstorm occurrence. They also found the occurrence of summer nocturnal thunderstorms to be closely related to regions of convergence associated with the low-level jets. Porter et al. (1955) found the low-level jets to occur frequently with squall lines. Kuettner (1959, 1971) observed that squall lines frequently form with an orientation parallel to the jet axis. Analyzing mesoscale convective complexes (MCC) over the United States during 1986 and 1987, Augustine and Howard (1991) found that, at 850 mb, warm moist air is transported by a well-defined LLJ into the MCC development region during active-MCC periods. In contrast, for the non-MCC periods, there was a reduction in the 850 mb warm advection and also a reduction in the moisture flux over the Great Plains. Several numerical simulations of the stratiform region of a midlatitude mesoscale convective system (MCS) by Chen (1986) illustrated that the LLJ is very important to sustain deep convection.

In the two weeks of June 13–19 and 20–26 of 1993, powerful storms swept through the central U.S., accompanied by tornadoes, high wind, large hail, and heavy rain. This produced severe flooding. In the first week, a cold front raced into the central region of the country. By mid-week, moist and unstable air streamed northward from the Gulf of Mexico ahead of the cold front fueling strong thunderstorms and heavy rain from the middle Missouri Valley to the upper Great Lakes. In the second week of June, a few weak fronts moved into the Great Plains region where a hot, humid, southerly flow of air was dominant at that time, generating strong to severe thunderstorms each afternoon. Various parts of the middle Missouri Valley were affected.

The fourth intensive observation period (IOP-4) of the Atmospheric Radiation Measurement (ARM) Program occurred June 15–25, 1993 and coincided with the occurrences of severe thunderstorms described above. During this period, enhanced observations were made over the southern Great Plain (SGP) region. The LLJ was well documented for eight days in this ten-day period. It appears that the LLJs might have played an important role in these weather events. The research presented here had two objectives. First, to document these LLJs with a detailed description of their structure and their characteristics; and second, to study warm moisture transport by the LLJ from the Gulf of Mexico to the Great Plains and its dependence on the LLJ origin.

2. Observation Site and Data Description

Since February 1992, a facility called the Cloud and Radiation Testbed (CART) has been developed by the Atmospheric Radiation Measurement (ARM) Program to make comprehensive observations. The CART site is located at the intersection of Kansas and Oklahoma states with an area of 350 km by 400 km (Figure 1). Ten intensive observation periods (IOPs) were conducted from 1992 to 1994. During IOP4, which occurred during 15–25 June 1993, radiosondes were launched every

3 hrs (0200, 0500, 0800, 1100, 1400, 1700, 2000, and 2300 UTC) at Kingman (KMN), Kansas, and Kingfisher (KFS), Pawhuska (PAW) and Norman (NMN), Oklahoma. Radiosondes were also launched every 6 hrs (0000, 0600, 1200 and 1800 UTC) at Dodge (DDC) and Topeka (TOP), Kansas, which are outside the CART site. Soundings included pressure, winds, temperature, and relative humidity. Soundings from the six stations indicate that the LLJ was well documented for nine days at DDC and TOP, eight days at KMN and PAW, seven days at KFS, and five days at NMN. Occurrence of these LLJs were determined following the Bonner (1968) crtiteria. As will be discussed later (Section 3), the synoptic conditions under which the LLJs occurred can be classified into two different categories. In this paper, we will focus on the characteristics of the LLJs on June 21 and June 24 which represent two typical days under the two different synoptic patterns, and compare their differences and similarities. Limitations exits in this data set. The times and the frequency of the radiosonde launches are not the same at all stations. The data at DDC, TOP, KFS and NMN were missing for several days near the surface. Fortunately, data in the region where LLJs occurred were available for several cases.

The eta step-coordinate model analyses from the National Centre for Environmental Prediction (NCEP) were obtained for the period of June 15–25, 1993. This data set contains fields of temperature, moisture, wind components, and geopotential height. It is used to provide the basic synoptic meteorological fields. The analyses are available at 0000 and 1200 UTC, and at approximately 80 km horizontal resolution. Information is available at the surface and at 50-mb intervals from 1000 mb to 100 mb. The reader is referred to Mesinger et al. (1988) for a more detailed description of the eta model.

3. Synoptic Overview

Analyses of 300 mb and 850 mb maps at 0000 (UTC) for the eight LLJs show that upper and low level synoptic circulation patterns for the LLJs on June 21 and June 22 are very different from those on the other days. The synoptic circulation patterns on June 21 and June 24 are given below.

3.1. LARGE SCALE CONDITIONS ON 21 JUNE, 1993 – TYPE A SYNOPTIC FLOW PATTERN

At 0000 UTC on 21 June the upper level (300 mb) synoptic flow pattern (Figure 2a) consisted of a strong ridge and a short wave trough located over the western and the eastern regions of the United States, respectively. At the higher altitude, the Great Plains region is downstream of the ridge and upstream of the trough. This region is therefore inactive where descending air motion generally dissipates clouds. The upper level winds were relatively weak and westerly over the Great Plains region. This pattern is very similar to the second pattern of Uccellini (1980).

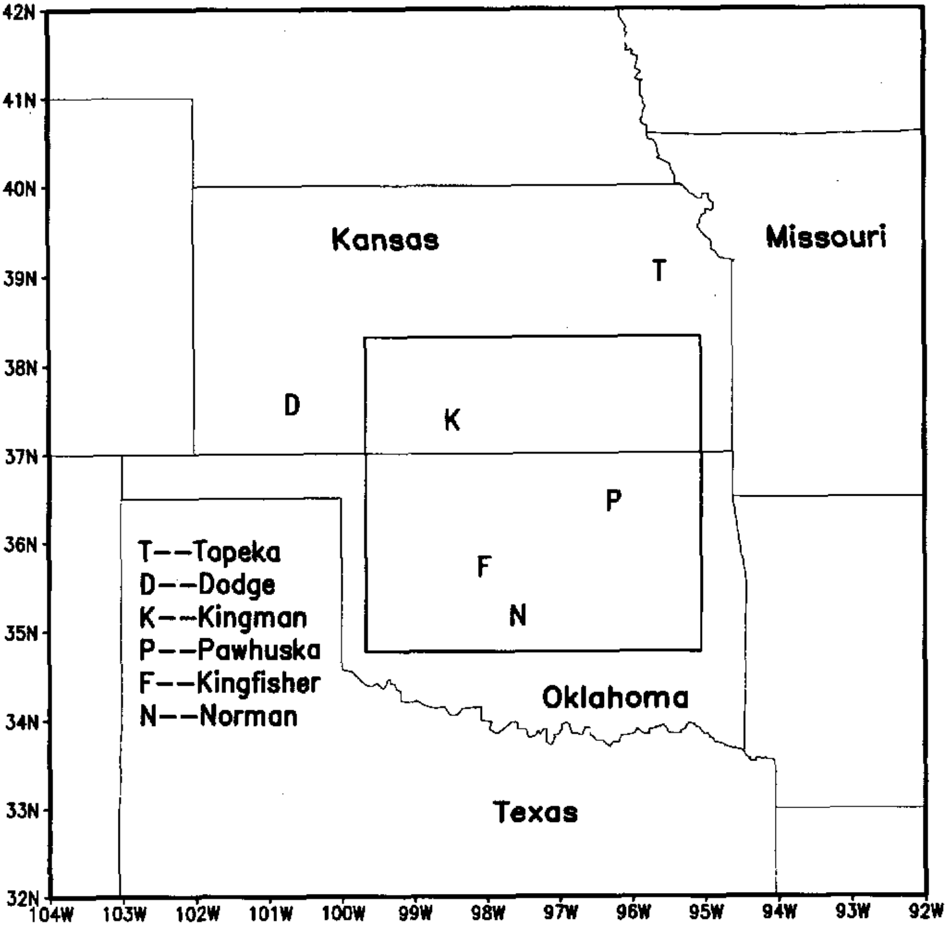

Figure 1. The sourthern Great Plains (SGP) Cloud and Radiation Testbed (CART) site and the locations of radiosonde stations.

The 850-mb weather map at 0000 UTC on 21 June 1993 (Figure 2b) shows that the central and southeast regions of the United States were controlled by the western part of a Bermuda high. A weak divergence region formed over Kansas and Oklahoma. The horizontal pressure gradient over the Great Plains was very small. Low-level winds were very weak over the Great Plains.

To show the schematic features of this type of synoptic flow pattern, the upper and low level synoptic flow charts at 0000 UTC on June 21 were combined (Figure 2c). Most of the Great Plains region weather was controlled by the Bermuda high. Under this kind of synoptic pattern, large-scale forcing is minimal for the formation and the development of the LLJ over the Great Plains. Observations show that the LLJs associated with this type of flow pattern clearly display a diurnal variation in

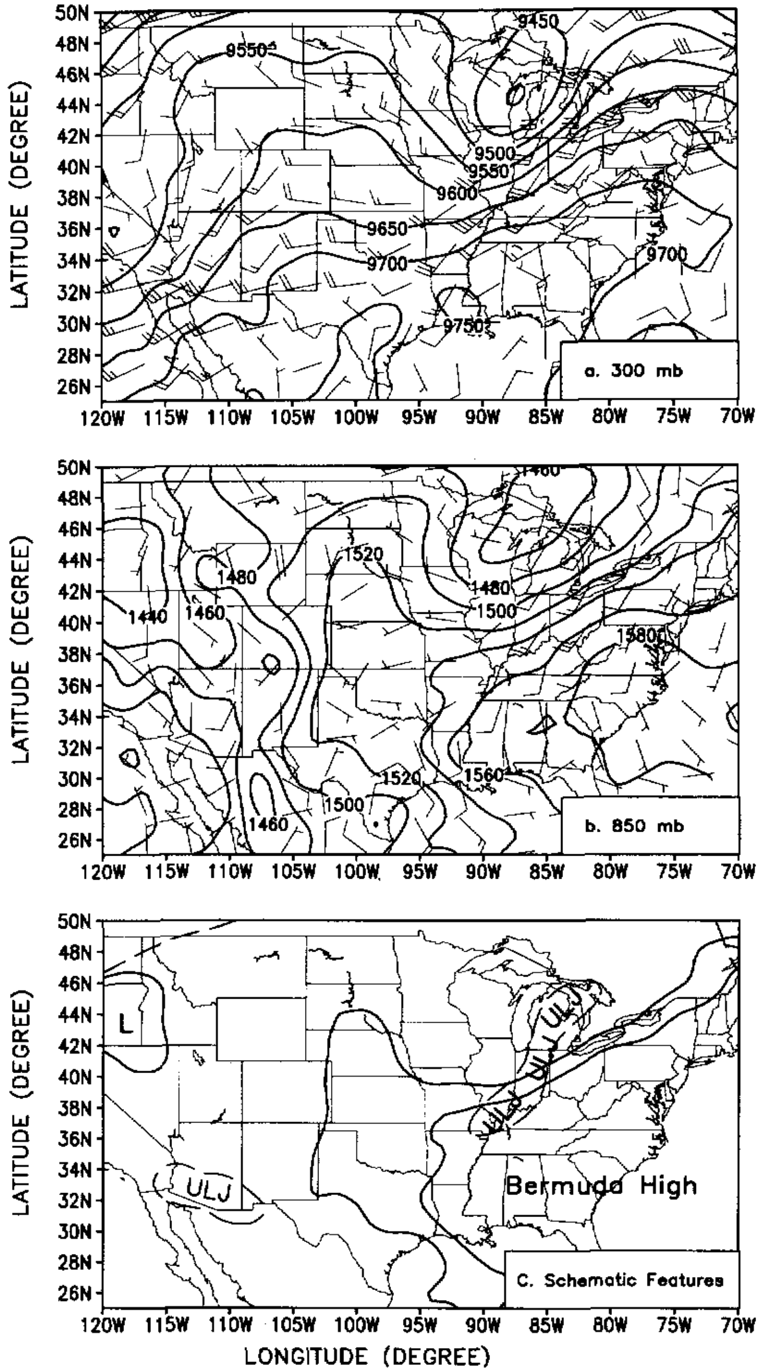

Figure 2. Synoptic weather maps at 0000 UTC on June 21, 1993. (a) 300 mb, (b) 850 mb, (c) Schematic features (ULJ – Upper level Jet, L – Low pressure system at 850 mb, H – High pressure system at 850 mb).

wind speed and reach maximum intensity in early morning. The maximum wind speeds of the LLJs normally coincide with a boundary-layer inversion.

3.2. LARGE-SCALE CONDITIONS ON 24 JUNE, 1993 – TYPE B SYNOPTIC FLOW PATTERN

The upper level synoptic flow patterns for the LLJs on other days are similar to the first type of Uccellini (1980), consisting of a strong trough over the Rockies and a ridge located over the eastern U.S. (Figure 3a). A strong upper tropospheric jet streak propagated from the northwest towards the Great Plains while the upper level winds were westerly over the Great Plains and were relatively weak. At higher altitudes, the Great Plains region is downstream from the trough and upstream of the ridge. Therefore, this region is active where ascending air motion normally occurs. This region is favorable for cyclogenesis, frontogenesis, cloud formation and precipitation, and is also conducive for the development of LLJs.

As shown in Figure 3b, at lower levels, the western and the eastern regions of the country were controlled by high pressure systems while the midwest section was controlled by a low pressure system. The low pressure system formed on the lee side of the Rocky Mountains. The Great Plains was in a transition zone with the low pressure region to the west and a high pressure region to the east. There were strong horizontal pressure gradients over the Great Plains. A strong surface cold front aligned approximately north to south moved into the Great Plains region. The LLJ was observed just ahead of the cold front.

To show the schematic features of this type of synoptic flow pattern, the upper and lower level synoptic charts at 0000 UTC of June 24th were combined (Figure 3c). This chart is very similar to Newton's (1967) chart or the chart at stage D of Djuric and Ladwig (1983). The LLJ is normally located beneath the exit region of the upper tropospheric jet streak, ahead of a strong surface cold front, and directed from the south (anticyclone) towards the north (cyclone). Under these kinds of synoptic conditions, the large-scale forcing is very strong for the formation and the strengthening of the LLJ.

4. Characteristics of the LLJ

Characteristics of the LLJs under the two different types of synoptic flow patterns discussed above have several similarities and differences. Generally speaking, all the LLJs have a height below 1000 m, a significant diurnal variation, and form in conjunction with a nocturnal inversion. However, the LLJs that form during the type A synoptic pattern have a weaker intensity, lower altitude, and stronger diurnal variation. They are also affected more by the nocturnal inversion.

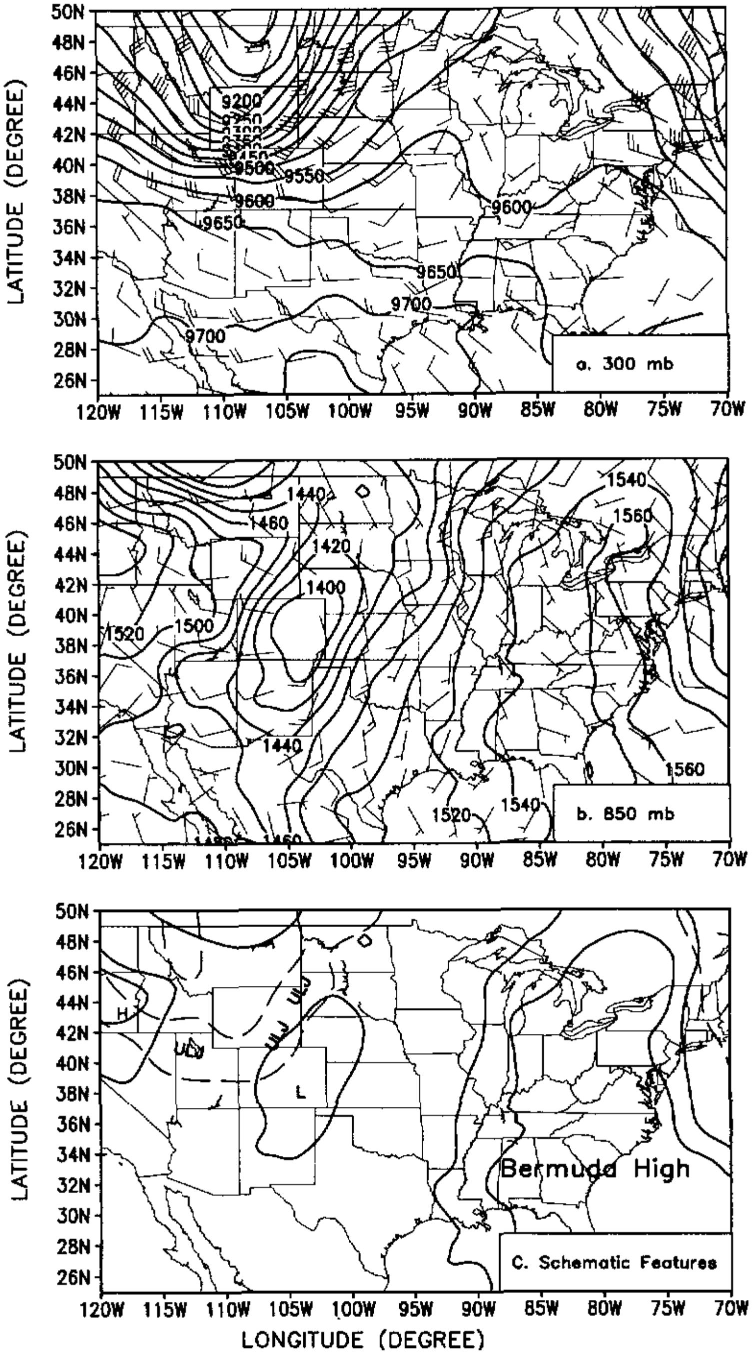

Figure 3. Synoptic weather maps at 0000 UTC on June 24, 1993. (a) 300 mb; (b) 850 mb, (c) Schematic features (ULJ – Upper level Jet, L – Low pressure system at 850 mb, H – High pressure system at 850 mb).

4.1. HEIGHTS AND STRENGTHS OF THE LLJS

On the average, heights and wind speeds of the LLJs under the type-A pattern are different from those under type-B pattern. Under the type-A pattern, LLJs have lower altitudes and weaker intensities. The heights of the LLJs on June 21 and 22, 1993 are 167 and 369 m above the ground, respectively. The average height of the LLJs is only 268 m. The maximum horizontal wind speeds for the two days are 17.9 and 15.1 m s^{-1}, respectively. The maximum average speed is 16.5 m s^{-1}. The LLJs under the type-B synoptic pattern have higher altitudes and stronger wind speeds. The heights of the six LLJs range from 384 m (June 16) to 910 m (June 24). The average height is 612.3 m. The maximum horizontal wind speeds for the LLJs under the type-B synoptic patterns vary from 18.8 m s^{-1} (June 23) to 31.5 m s^{-1} (June 24). The average is 25.0 m s^{-1}. Among the eight LLJs, six had a height lower than 500 m. These facts support the finding by Stensrud et al. (1990) that the standard operational wind profiler (404 MHz) could miss some of the LLJs that occur over the Great Plains since its data are available only at heights from 500 m above the ground. Heights and wind speeds of the LLJs under the same type of synoptic conditions also varied from station to station. Although this data set does not cover a large region for spatial analysis, observations do show that the LLJ core on these days is close to the location of the center found by Bonner (1968). The frequency of the LLJs at KMN, PAW, DDC and TOP is higher than that at KFS and NMN. This is consistent with the analysis of Bonner (1968).

4.2. NOCTURNAL INVERSIONS

The stratification in the boundary layer during the LLJ occurrences varied from weakly stable to highly stable conditions. Six out of the eight LLJs (June 16, 18, 19, 21, 22, 24) were associated with nocturnal inversions. However, the LLJs during the early hours of June 21 and 24 were associated with strong nocturnal inversions (Figure 4a and 5a). The nocturnal inversion on the night preceding June 20 started at LST 2200, and disappeared at about 0800 of next day (June 21), thus, lasting for 10 hours (Figure 4a). The top of the inversion layer was about 400 m above the ground level. The nocturnal inversion on 23 June started at LST 2300, and disappeared at about LST 0700 on 24 June, thus lasting about eight hours. The top of the inversion layer in this case was at 1300 m above the surface (Figure 5a). This figure also shows a cold front passage with the air temperature at 500 m decreasing from 23 °C at 0600 LST to 16 °C at 1200 LST.

The LLJ on June 17 is one of two formed under weakly stable conditions. The boundary-layer stratification at the early hours of June 17 was slightly stable, and neutral between 0300 LST and 0600 LST, and then became unstable (Figure 6a). The LLJ started to form around 0100 LST, reached its strongest stage around 0400 LST, and disappeared after 0700 LST (Figure 6b). The boundary-layer stratification on June 19 (Figure 7a) varied from stable condition around 0000 LST, to unstable

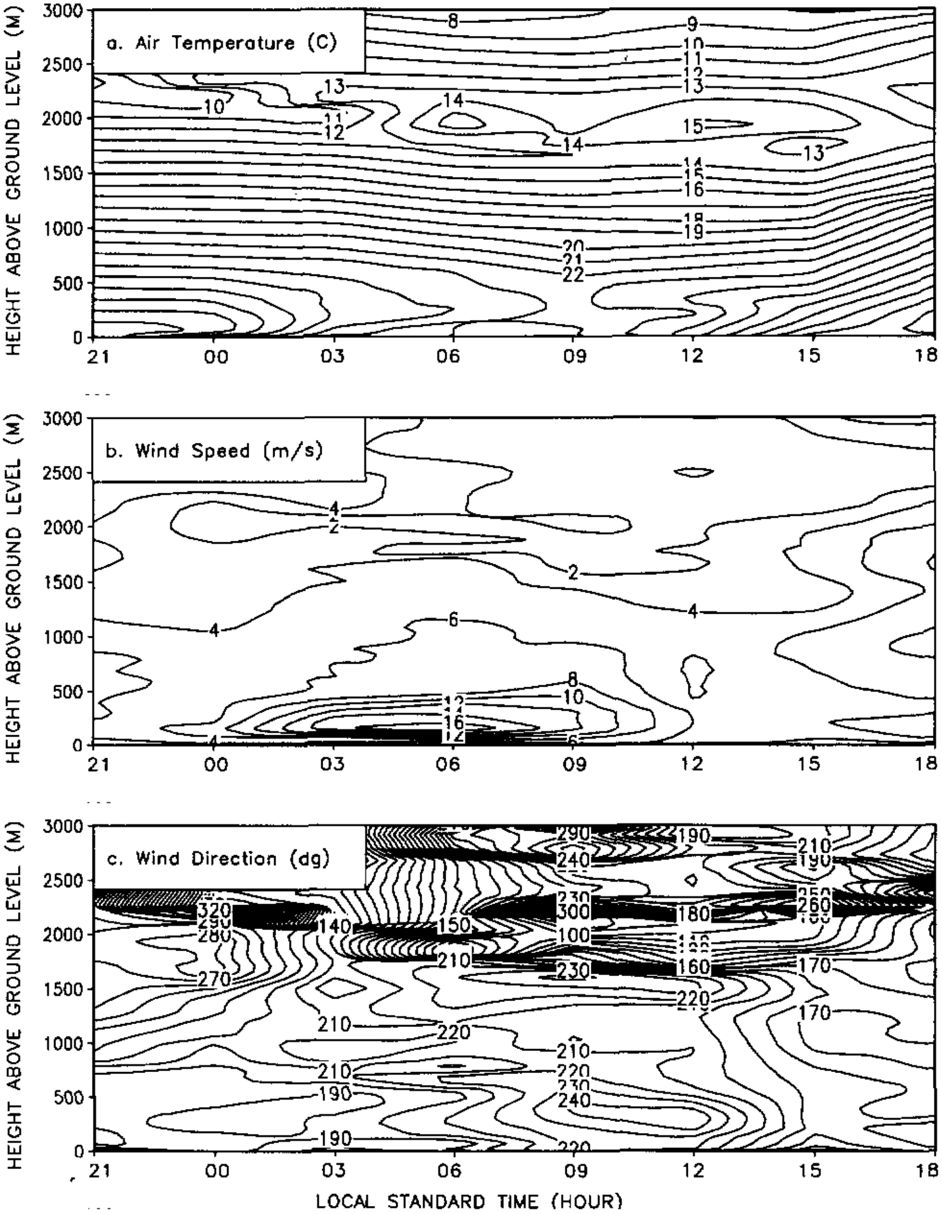

Figure 4. Height-time cross section at Kingman, Kansas (June 20–21, 1993). (a) Temperature (°C); (b) Horizontal wind speed (m s^{-1}); (c) Wind direction (degree).

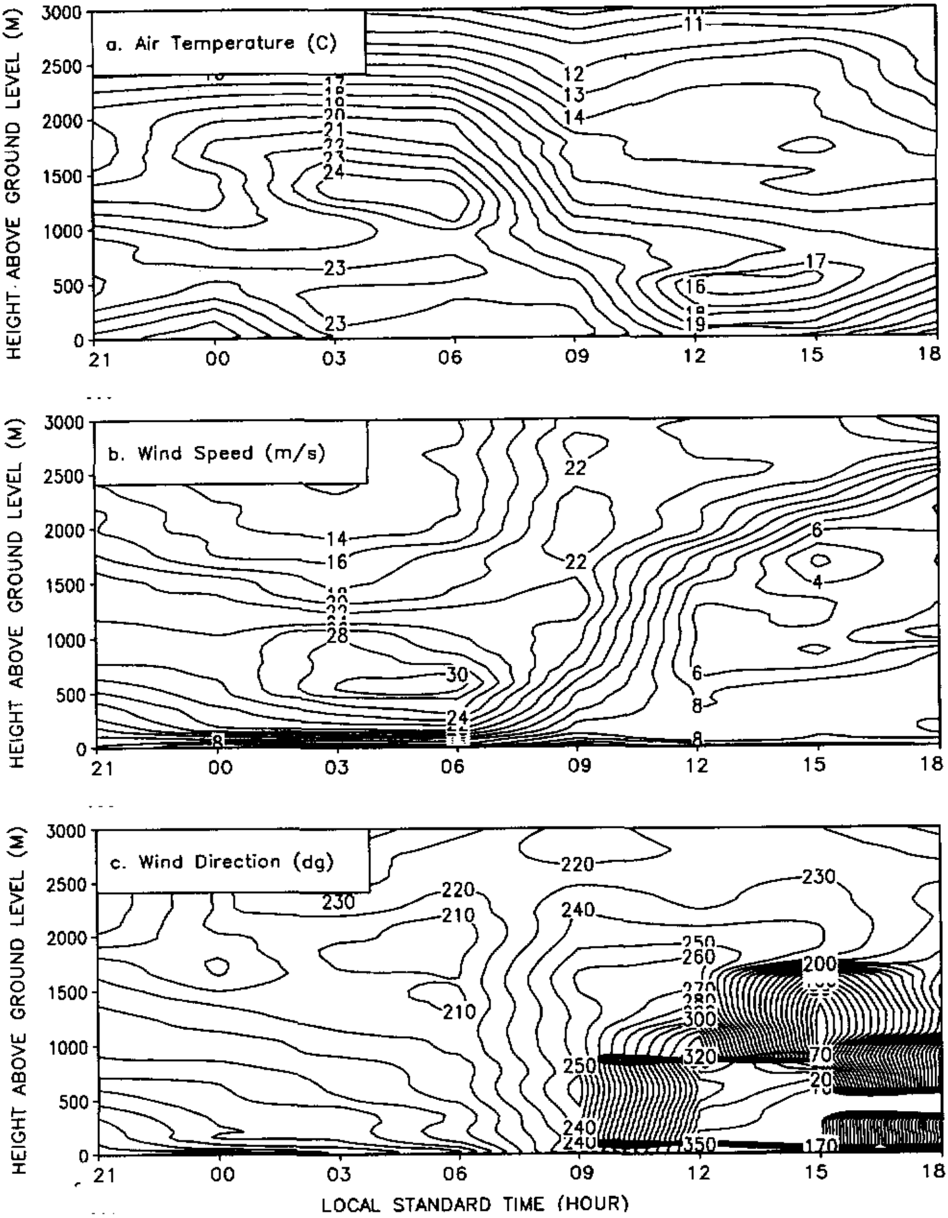

Figure 5. Height-time cross section at Kingman, Kansas (June 23-24, 1993). (a) Temperature (°C); (b) Horizontal wind speed (m s^{-1}); (c) Wind direction (degree).

around 0300 LST, then became weakly stable between 0400 and 0700 LST and changed to unstable again after 0800 LST.

4.3. DIURNAL VARIATION

All the LLJs showed significant diurnal variations. Height-time cross sections of wind speeds on June 21 and June 24 at Kingman (Figure 4b and Figure 5b) document significant diurnal variation of the LLJ between 2100 LST and 1200 LST. The LLJ (Figure 4b) began to form at 0200 LST on June 21, reached its strongest intensity (18 m s^{-1}) at 0600 LST, and disappeared after 0900 LST, thus lasting for about 7 hours. The height of the LLJ was about 200 m at Kingman. Wind speeds in the lowest 3 km layer varied between 2 and 4 m s^{-1} before 0000 and after 1000 LST. The LLJ on June 24 (Figure 5b) formed at 0100 LST, reached its strongest stage (32 m s^{-1}) at 0500 LST, and disappeared at 0700 LST. The height of the LLJ core was about 600 m at Kingman. As shown in Fig 6b, the diurnal variation of the LLJ on June 17 is apparent. The LLJ on June 19 has a shorter life cycle (Figure 7b). It began to form after 0300 LST, reached its peak (16 m s^{-1}) at 0600 LST, and disappeared around 0800 LST.

Diurnal variation of the wind direction on 21 and 24 June at Kingman was not as significant as the wind speed, although there was a change in wind direction from south to southwest (Figure 4c and 5c). On June 21 (Figure 5c), the LLJ was almost in a southerly direction (about 185°) when it began to form (0200 LST). Then its direction changed gradually to southwest (240°) at 0900 LST. Similar changes also occurred on June 24 (Figure 5c) and June 17 (6c). The direction change for the LLJ on June 19 is different from the other LLJs. As shown in Figure 7c, before 0300 LST, the wind direction was southeast (140°). Then, wind direction rapidly changed from southeast to northnorthwest and disrupted the later stage of the development of the LLJ. This change in wind direction is due to the passage of the cold front.

5. Forcing Mechanisms of the LLJ

Several forcing mechanisms have been proposed pertaining to the Great Plains LLJ: inertial oscillation, baroclinicity over sloping terrain, thermal wind over the transition zone between bare soil and vegetation region and the horizontal synoptic pressure gradient. As discussed in Section 3, two different synoptic flow patterns existed for the eight LLJs. To further demonstrate the differences in the large scale forcing under these two basic synoptic conditions, V components of the geostrophic wind (V_g) on June 21 and June 24 were calculated from horizontal pressure gradients. The differences in the V_g are apparent. At 0000 UTC of June 21, V_g was relatively small over Oklahoma and Kansas, and even negative over northern Kansas. By 1200 UTC of June 21, V_g over the region became even smaller.

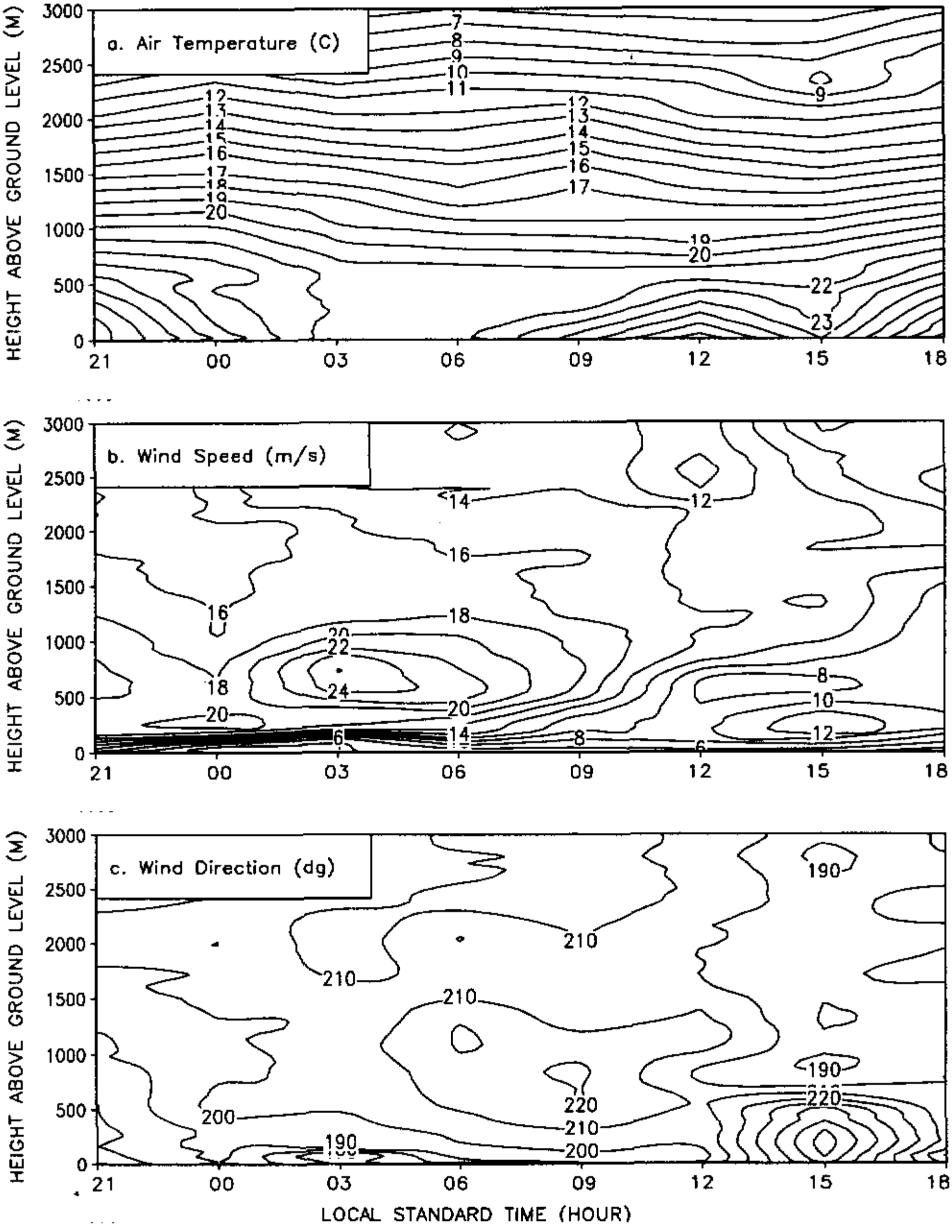

Figure 6. Height-time cross section at Kingman, Kansas (June 16–17, 1993). (a) Temperature (°C); (b) Horizontal wind speed (m s^{-1}); (c) Wind direction (degree).

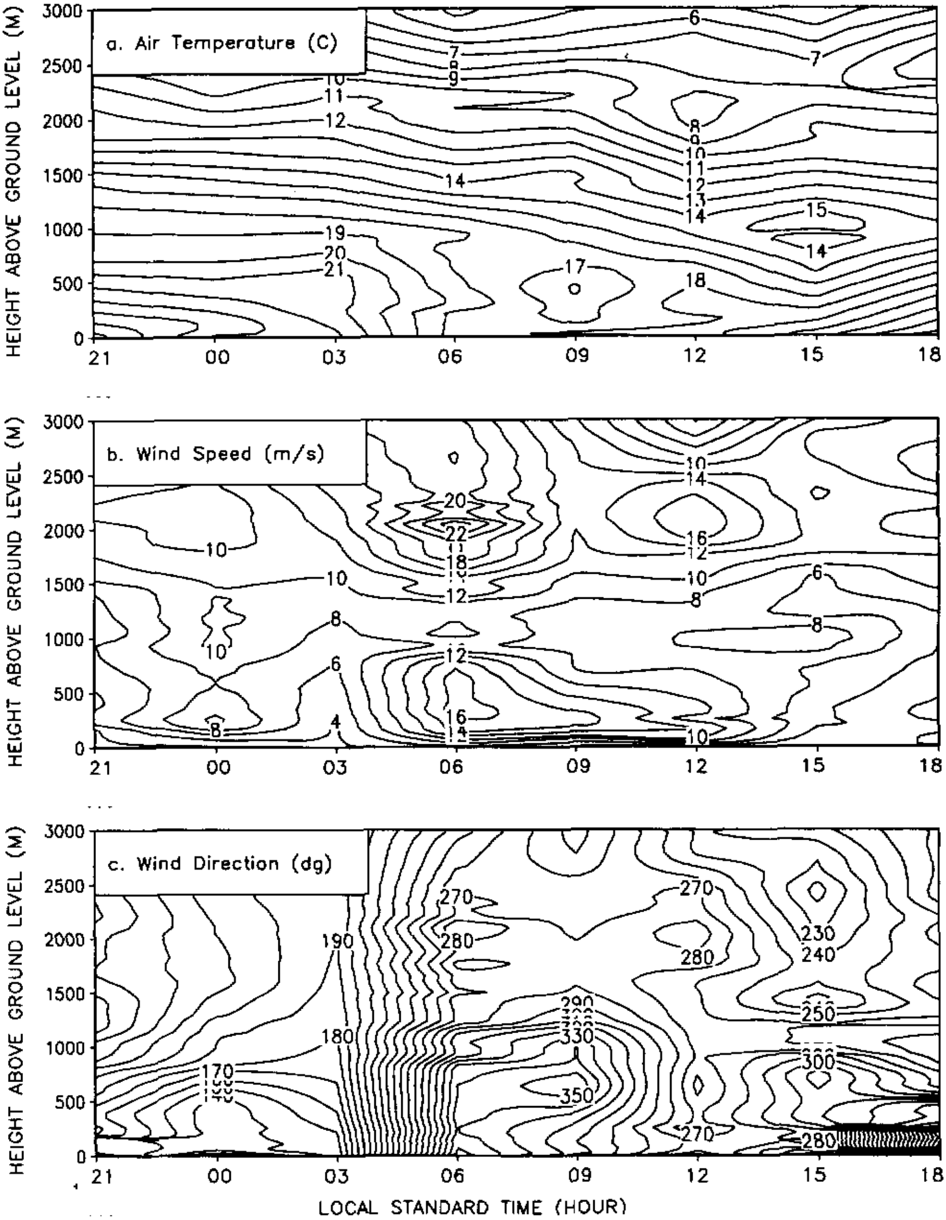

Figure 7. Height-time cross section at Kingman, Kansas (June 18–19, 1993). (a) Temperature (°C); (b) Horizontal wind speed (m s^{-1}); (c) Wind direction (degree).

However, at 0000 UTC of June 24, V_g over Oklahoma and Kansas was more than 20 m s^{-1}. However, as pointed out by Uccellini (1980), there is still a tendency for the maximum intensity to be observed in the early morning under this type of flow pattern suggesting that even with significant synoptic forcing, boundary-layer and terrain effects can still increase the magnitude of the LLJ in this region.

Hodographs at the level of maximum wind speed on June 21 at Kingman document winds at each level veering smoothly with time, and forming a closed circle (Figure 8a). The formation period of the closed circle is about 20 hours which is about one-half pendulum day. This suggests that inertial oscillation is a major mechanism for the LLJ on June 21. On June 24 at Kingman (Figure 8b), winds at the level of maximum wind speed veered with time from 2000 LST on June 23 to 0800 LST on June 24, and then remained constant. Inertial oscillation had obviously played an important role in the formation and the strengthening of the LLJ on June 24.

Comparison of windspeeds with temperatures (Figures 4, 5, 6 and 7) suggests that: (1) the LLJ core is near or below the top of the nocturnal inversion; (2) the life cycle of the LLJs and of the nocturnal inversions are almost the same, (3) the LLJs begin to form after the inversions form and (4) the LLJs disappear after the inversions weaken. It is obvious from the these results that the LLJs are significantly affected by the boundary-layer processes.

6. Moisture Transport by the LLJs to the Great Plains

The rainfall distribution pattern on June 21 is very different from that on June 24. On June 21, most of the rainfall fell over the eastern U.S., and none occurred over the Great Plains region during the last 24 hours (Figure 9a). The distribution pattern of rainfall on June 22 is very similar to the one on June 21 (not shown). However, rainfall on June 24 occurred mostly over the Great Plains (Figure 9b). The precipitation region extended from southeast to northwest and covered the entire Great Plains region. Two stations in Kansas reported 40.4 and 44.1 mm rainfall, respectively, during the 24 hours ending at 0600 LST on June 24. As discussed above, although the LLJ did occur on both 21 and 24 of June, difference in the synoptic flows on these two days may be the major cause for the difference in the precipitation distribution.

The LLJ plays an important role in severe weather events over the Great Plains in two ways. First, it generates a dynamic instability (shear instability) to enhance convection. Second, it transports warm moisture from the Gulf of Mexico to the Great Plains. Shear instability occurs always with the formation of the LLJ. However, moisture transport from the Gulf of Mexico to the Great Plains may or may not occur, depending the origin of the LLJ. The LLJ on June 21 had a lower altitude at Dodge and Kingman and a higher altitude at the other stations (Figure 10a). This suggests that the LLJ did not originate from the Gulf of Mexico, and hence could

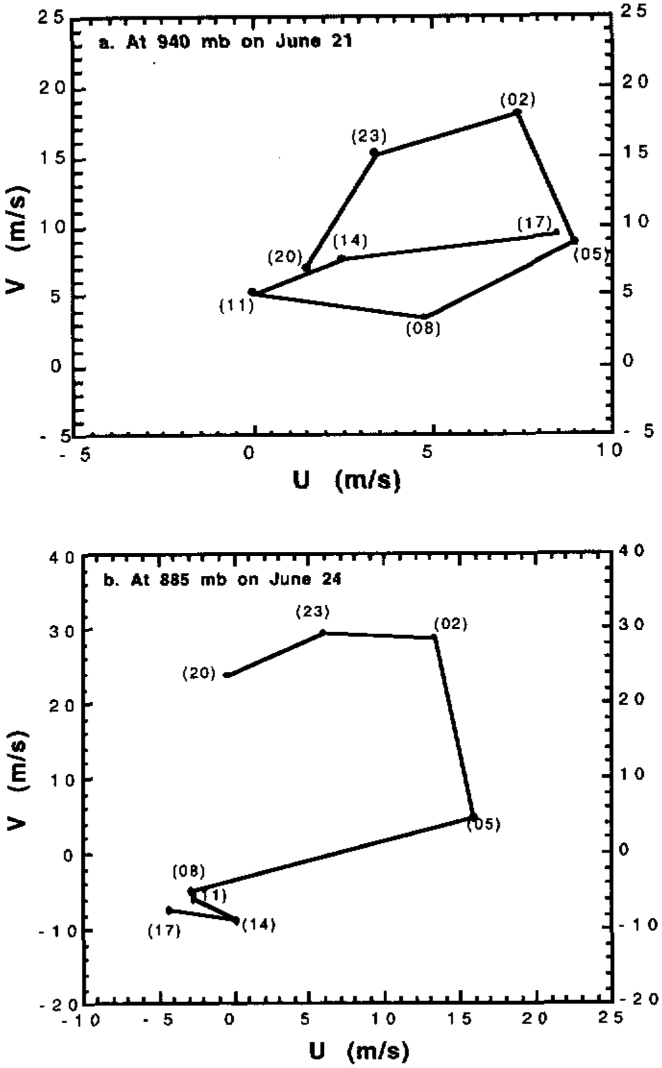

Figure 8. Hodographs of the time evolution of the LLJ on June 21 and 24, 1993. (a) At 940 mb on June 21; (b) At 885 mb on June 24.

not have transported warm moist air from the Gulf of Mexico to the Great Plains. The LLJ on June 24 had a lower altitude in the south and higher one in the north (Figure 10b), indicating that the LLJ was transporting moisture from the Gulf of Mexico to the Great Plains. The rising of the LLJ on June 24 at its northern end is due to the large scale lifting in the mid-latitude cyclone. To further demonstrate that the moisture transport by the LLJ depends on its origin, estimated temperature and moisture advections at 850 mb on June 21 and June 24 are given in Figure 11 and Figure 12, respectively. It can be seen from Figure 11 that on June 21, no horizontal

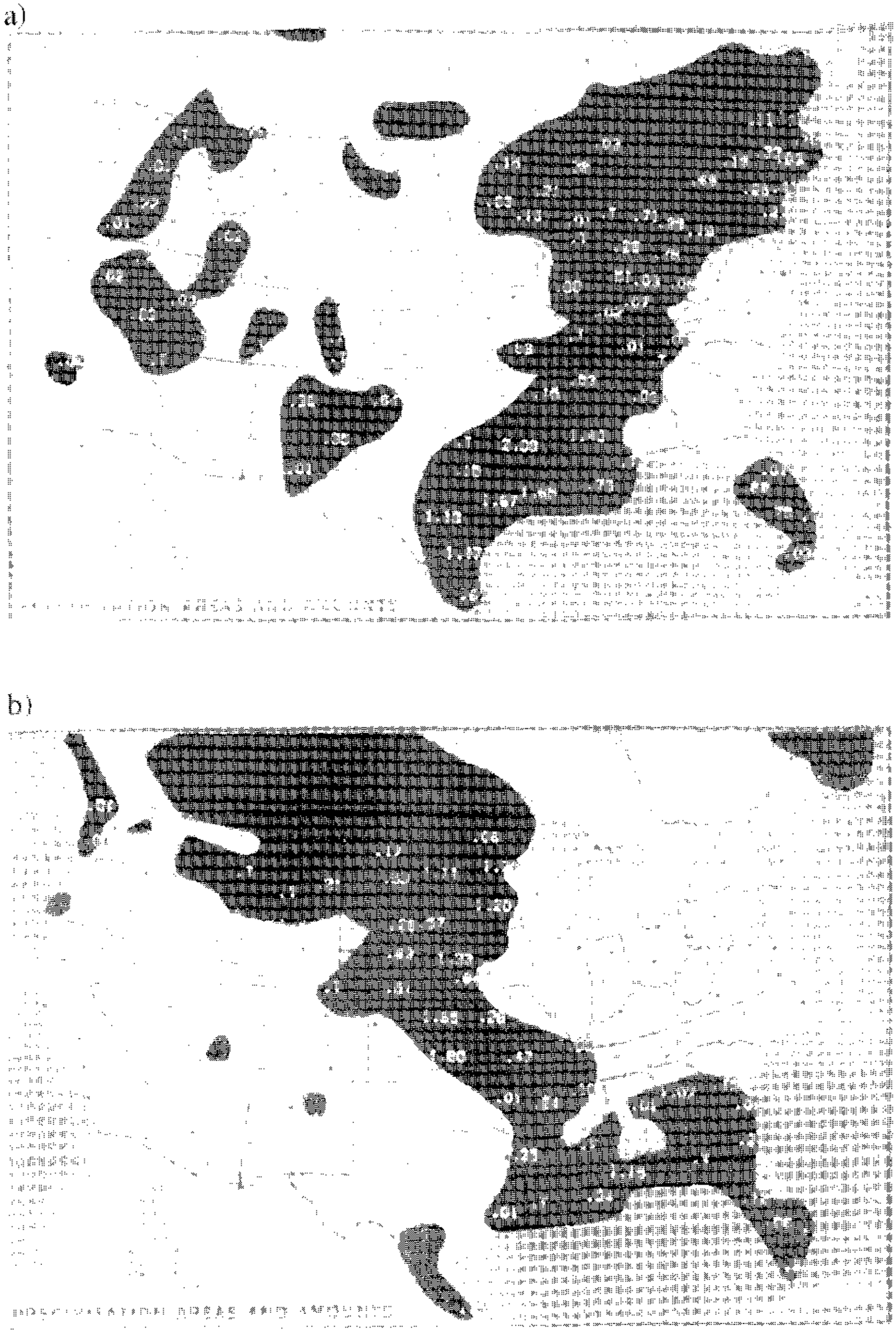

Figure 9. Spatial distribution pattern of precipitation (inch day^{-1}) ending at 1200 UTC on June 21 and 24, 1993. (a) June 21; (b) June 24.

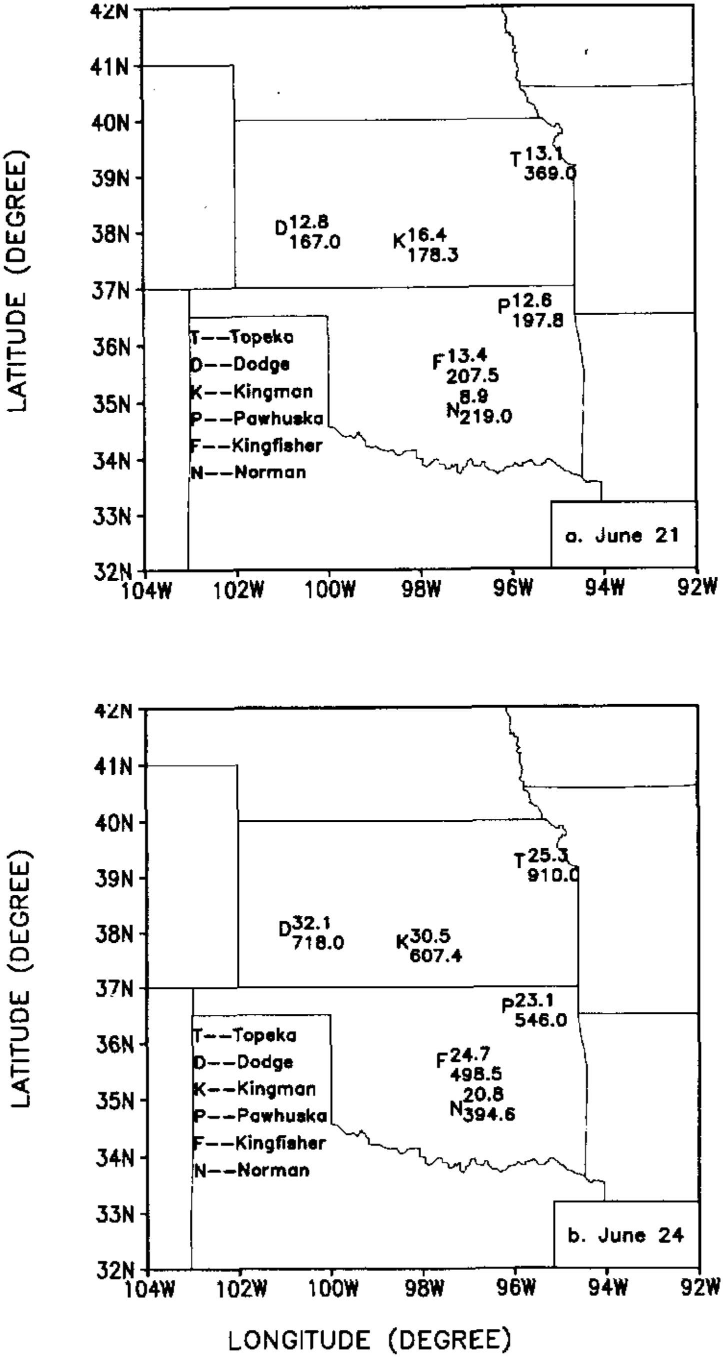

Figure 10. Maximum winds (m s^{-1}) and their height (m) at 0600 LST on June 21 and 24, 1993. (Wind speed at right-upper corner, height at right low corner).

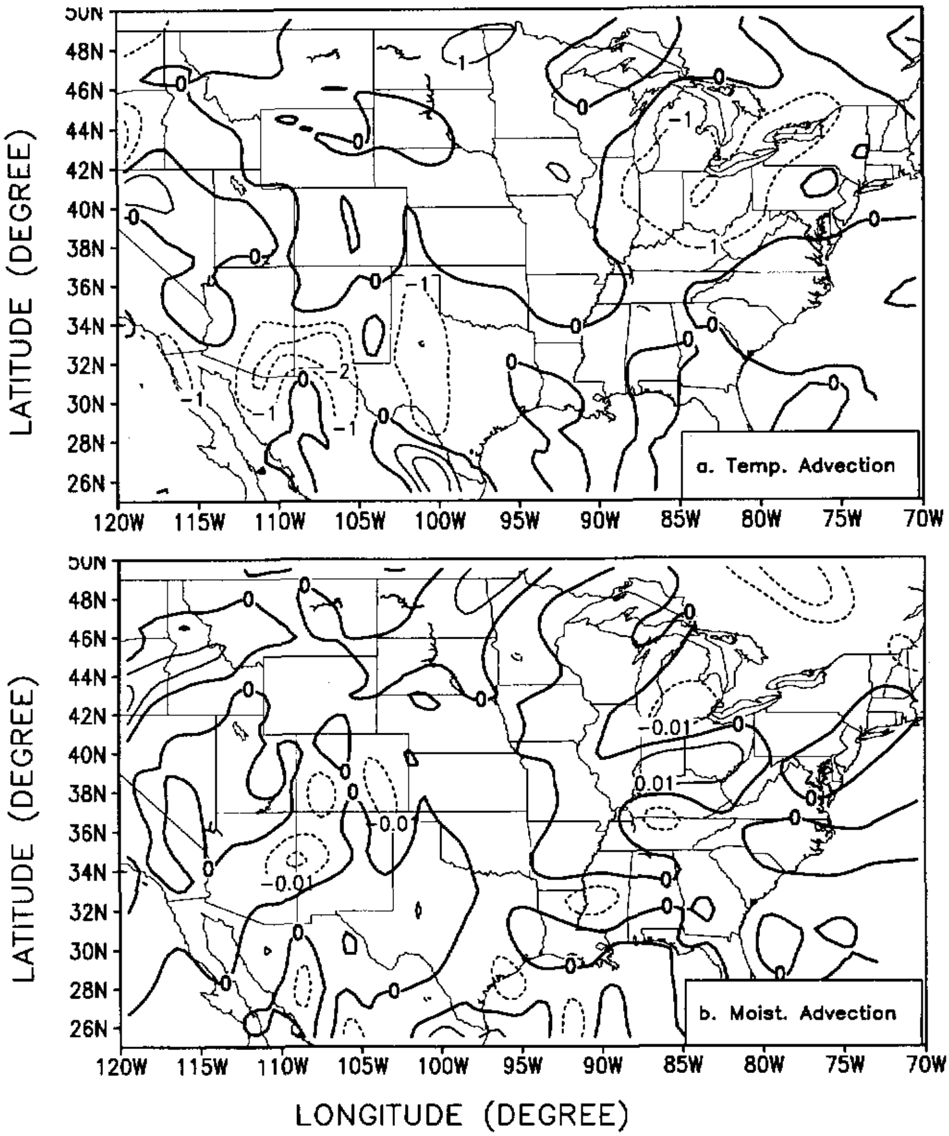

Figure 11. 850 mb advections of temperature and humidity on June 21, 1993. (a) Temperature advection; (b) Moisture advection. Contours are of 10^{-4} °C s^{-1} and 10^{-5} g kg^{-1} s^{-1} respectively.

temperature and moisture advections occurred over the most of the Great Plains, especially from the Gulf of Mexico. On June 24, in conjunction with the cold front, strong temperature and moisture advections occurred over the Great Plains (Figure 12). The temperature and moisture advections with negative values indicate that the cold frontal zone was located in the mid section of the U.S. Positive advection of both temperature and moisture occurred ahead of the cold front, indicating that

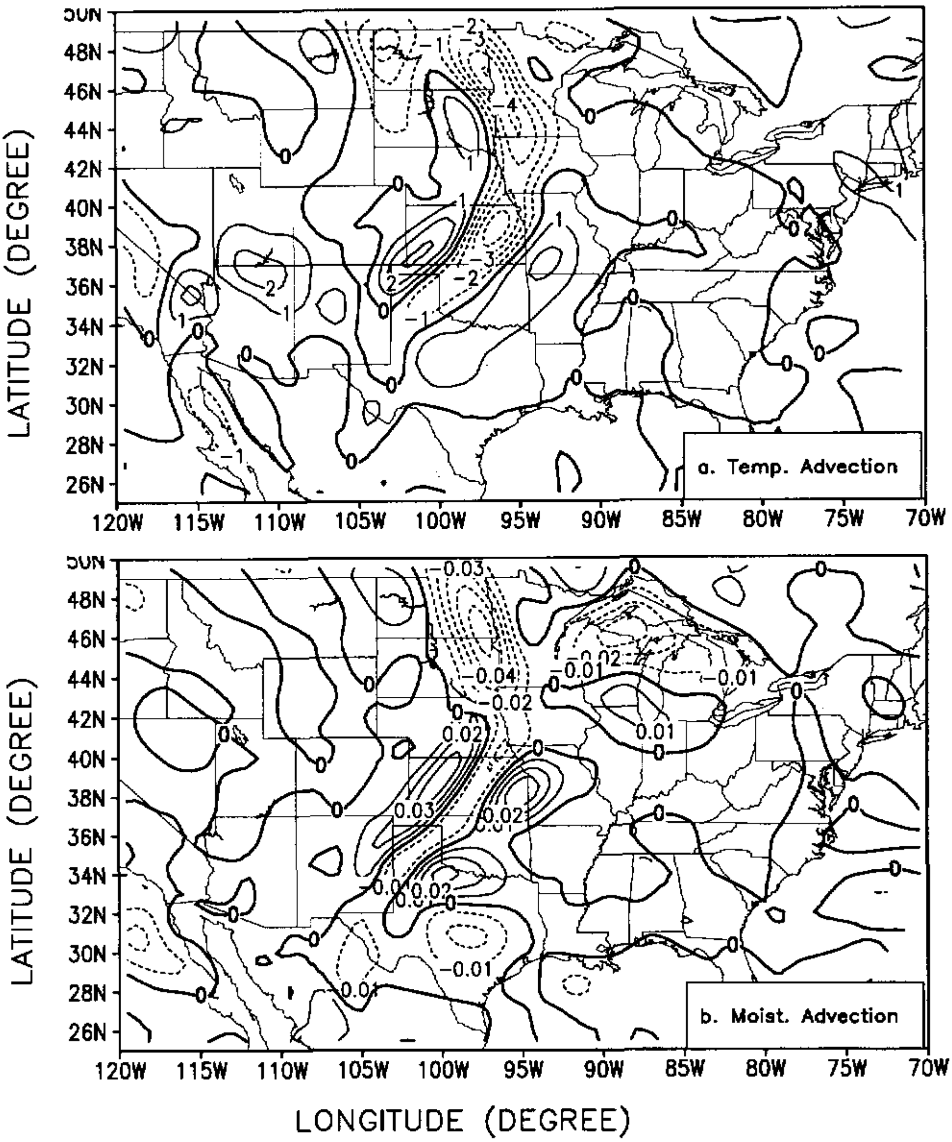

Figure 12. 850 mb advections of temperature and humidity on June 24, 1993. (a) Temperature advection; (b) Moisture advection. Contours are of 10^{-4} °C s^{-1} and 10^{-5} g kg^{-1} s^{-1} respectively.

warm and moist air was transported from the Gulf of Mexico to the Great Plains. The maximum value of temperature advection is about 2.0×10^{-4} °C s^{-1} while the maximum value of moisture advection is about 0.02×10^{-5} g kg^{-1} s^{-1}. To study the water vapour transport by the LLJ, Chen and Kpaeyeh (1993) constructed composite charts of 64 LLJ cases over the Great Plains for 11 springs (1979–89) in terms of rotational and divergent components of flows and water vapour transports.

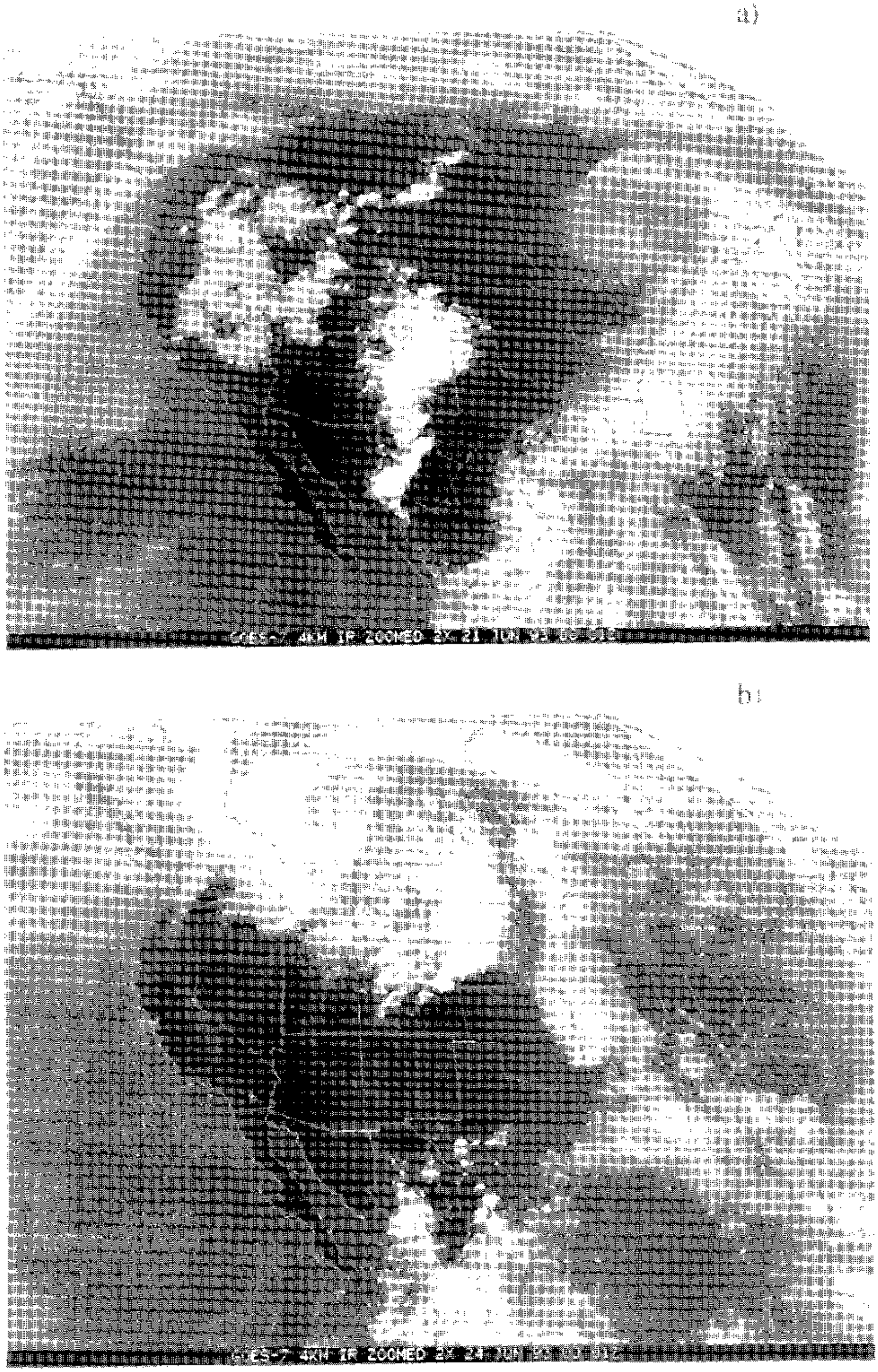

Figure 13. Infrared Satellite Imagery at 0000 UTC on June 21 and 24, 1993. (a) June 21, (b) June 24.

Their composite synoptic-scale environment of the LLJs belongs to the mature stage of the Uccellini (1980) type-1 LLJ formation which is the same as type B in this paper. Their streamfunction of water vapour transport clearly shows a moist tongue stretching along the LLJ from the Gulf of Mexico to the Great Plains. Type B synoptic flow patterns provide favourable conditions for the LLJ to transport moisture from the Gulf of Mexico to the Great Plains.

Figure 13 depicts infrared satellite imagery at 0000 UTC (1800 LST) 21 and 24 June 1993 over the North American continent. A striking feature in panel (a) of this figure for June 21 is the appearance of two major cloud systems over the eastern and western region of the USA while clear sky conditions were present over the mid section of the country. The cloud system over the eastern USA is in a comma shape with an orientation from northeast to southwest. The head of this cloud was over northeast Canada while its tail was over Louisana and southeast Texas. Moisture from the Gulf of Mexico appears to have been transported along this cloud band. The Great Plains was controlled by the dry intrusion, and no convection occurred in that region. A striking feature in panel (b) for June 24 is the appearance of two warm cloud bands over the mid section of the country while clear skies existed over the eastern and the western region of the country. The cloud bands were parallel to each other with an orientation from south to north. It can be seen that the first cloud band was connected with the cloud system over the Gulf of Mexico. The two cloud bands merged into one cloud system by 1200 UTC (not shown), and located where the first cloud was present at 0000 UTC. It is believed that the LLJ was a part of the conveyor belt of the cloud system, and thus could have played an important role in the development of the severe storm events over the Great Plains on June 24.

7. Summary

General characteristics of eight LLJs are described while two of them are documented in detail. All the jets showed significant diurnal variations. Most of the LLJs were from a southerly direction and were associated with nocturnal inversions. The LLJ cores were near or below the tops of the nocturnal inversions and the life cycle of the LLJs and that of the nocturnal inversions are almost the same. Analyses and comparisons were made of the two LLJs which occurred under two different synoptic patterns. The LLJs under the type-A pattern had lower altitudes and weaker speeds. The LLJs under the type-B synoptic pattern had higher altitudes and stronger wind speeds, and were highly interactive with synoptic flows. The results indicate that a major mechanism for the LLJ is the inertial oscillation. Synoptic forcing can enhance or suppress the development of the LLJ. Not all the LLJs examined here transported moisture from the Gulf of Mexico to the Great Plains. This is mainly because of their region of origin.

Acknowledgments

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