Analytical Study of the Effects of the Low-Level Jet on Moisture Convergence and Vertical Motion Fields at the Southern Great Plains Cloud and Radiation Testbed Site

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Introduction

The Atmospheric Radiation Measurement (ARM) Southern Great Plains (SGP) Cloud and Radiation Testbed (CART) is located in a region that is strongly affected by a prominent meteorological phenomenon--the Great Plains Low-Level Jet (LLJ). Observations (Means 1952; Pitchford and London 1962; Parish et al. 1988; Frisch et al. 1992) have shown that the LLJ plays a vital role in spring and summertime cloud formation and precipitation over the Great Plains. An improved understanding of the LLJ characteristics and its impact on the environment is necessary for addressing the fundamental issue of development and testing of radiational transfer and cloud parameterization schemes for the general circulation models (GCMs) using data from the SGP CART site.

A climatological analysis of the summertime LLJ over the SGP has been carried out using hourly observations from the National Oceanic and Atmospheric Administration (NOAA) Wind Profiler Demonstration Network and from the ARM June 1993 Intensive Observation Period (IOP). The hourly data provide an enhanced temporal and spatial resolution relative to earlier studies which used 6- and 12-hourly rawinsonde observations at fewer stations.

Data Description

The wind profiler network consists of 31 stations scattered mostly across the Great Plains. The densest part of the network is in Oklahoma and Kansas (Figure 1). This station distribution is nearly ideal for LLJ observations, as the maximum frequency and development of the LLJ occur here (Bonner 1968). In this study, hourly averaged wind profiles were used to provide data to maximum heights of 19 km, with vertical resolution of 250 m. Analyses were performed using a mean climatological day that was constructed from

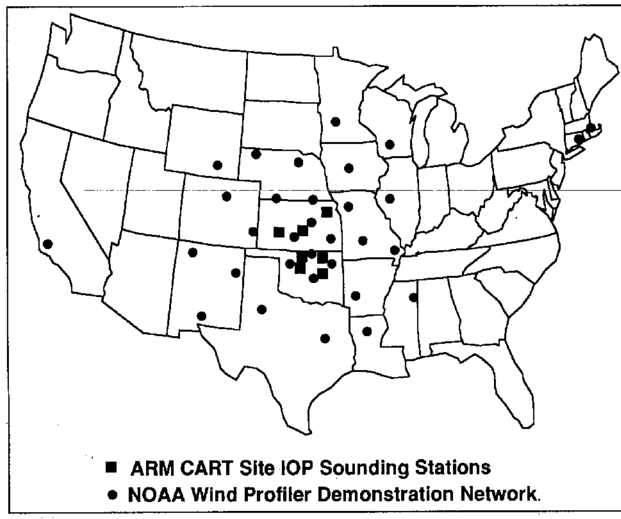

Figure 1. The NOAA wind profiler demonstration network and the sounding sites during the ARM June 1993 IOP.

hourly wind data obtained over the 62-day period-of-record from June 15 to July 15, 1991, and from June 15 to July 15, 1992.

LLJ Wind Characteristics

The longitudinal variation of mean winds is shown in Figure 2, which presents the 62-day-average vertical wind profiles for 1400 CST and 0200 CST at stations aligned W-E near the latitude of the Oklahoma-Kansas border. The mean wind is from the south and southwest in the lower atmosphere and veers gradually with height to blow from the west and southwest. The strongest winds are found between 95 to 98°Wlongitude. Winds in the daytime are relatively uniform with height due to strong vertical turbulent mixing, but at night between 95 to 98°W, a wind maximum appears

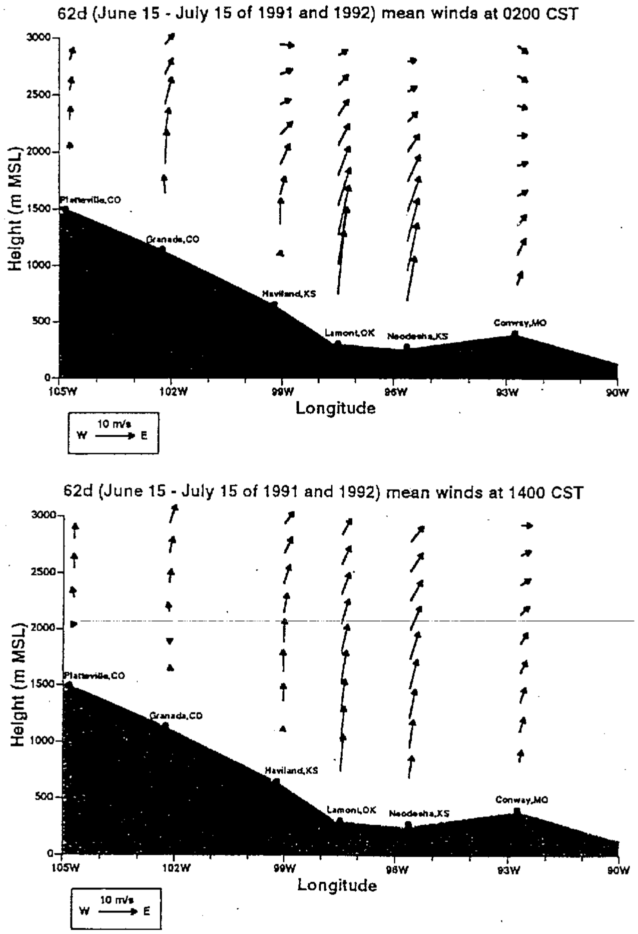

Figure 2. Vertical wind profiles at 1400 and 0200 CST averaged over the 62-day period from 15 June to 15 July in 1991 and 1992 at wind profiler stations aligned W-E near the latitude of the Oklahoma-Kansas border.

below 1000 m and the wind speed decreases rapidly with height, forming the LLJ. As the LLJ strengthens, its direction remains nearly constant.

The diurnal changes in wind speed and the latitudinal variation of the boundary-layer winds are documented in Figure 3, which shows the southerly wind component for a climatological mean day at Lamont, Oklahoma, and Palestine, Texas. Boundary-layer winds undergo a diurnal oscillation at both sites, with a nighttime maximum occurring around midnight and a daytime minimum occurring in the afternoon. However, the oscillation at Lamont leads that at Palestine by about 2 hours, suggesting that the timing of the LLJ has a latitudinal dependence. This earlier phasing at the higher latitudes is a feature of

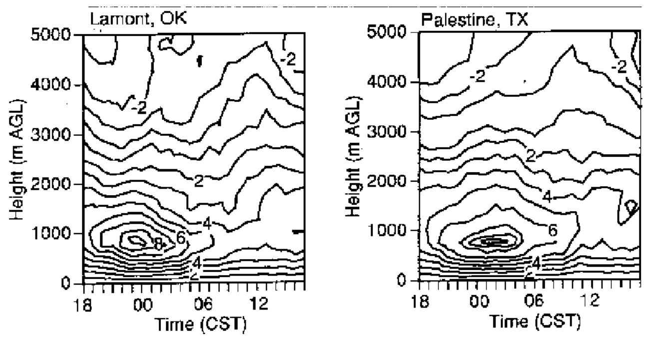

Figure 3. Time-height cross section of the south-north component of mean wind speed at Lamont, Oklahoma and Palestine, Texas.

observations at other sites (not shown), and is consistent with Blackadar's (1957) inertial oscillation theory.

The conclusion that the inertial oscillation seems to play an important role in the evolution of the LLJ is also suggested by the hodographs in Figure 4, which show a smooth clockwise turning of mean wind with time at all stations, consistent with predictions of the inertial oscillation theory.

Vertical Motion and Moisture Convergence

LLJ-induced mean vertical motion and moisture convergence are estimated for the ARM SGP CART site using data from soundings released at the CART site during the two-week ARM IOP in June 1993. Figure 5 shows the two-week-average vertical motions and the time rate of change of the mixing ratio for all hours of the day. The low-level moisture increased rapidly after sunset as the jet intensified, advecting moist air from the Gulf of Mexico into the south central Great Plains. Meanwhile, strong rising motions developed at night due to the low-level convergence caused by the LLJ. This rapid rise of warm, moist air acts as a triggering mechanism for the development of convective clouds and thunderstorms frequently observed in this region.

Frequency of the LLJ

The diurnal variation of LLJ frequency is shown in Figure 6 for stations around the CART site. At all stations, the LLJ frequency exhibits a strong diurnal oscillation. Although the frequencies at each hour differ a little from one station to another, the frequency distributions are nearly the same at all stations. The frequency increases

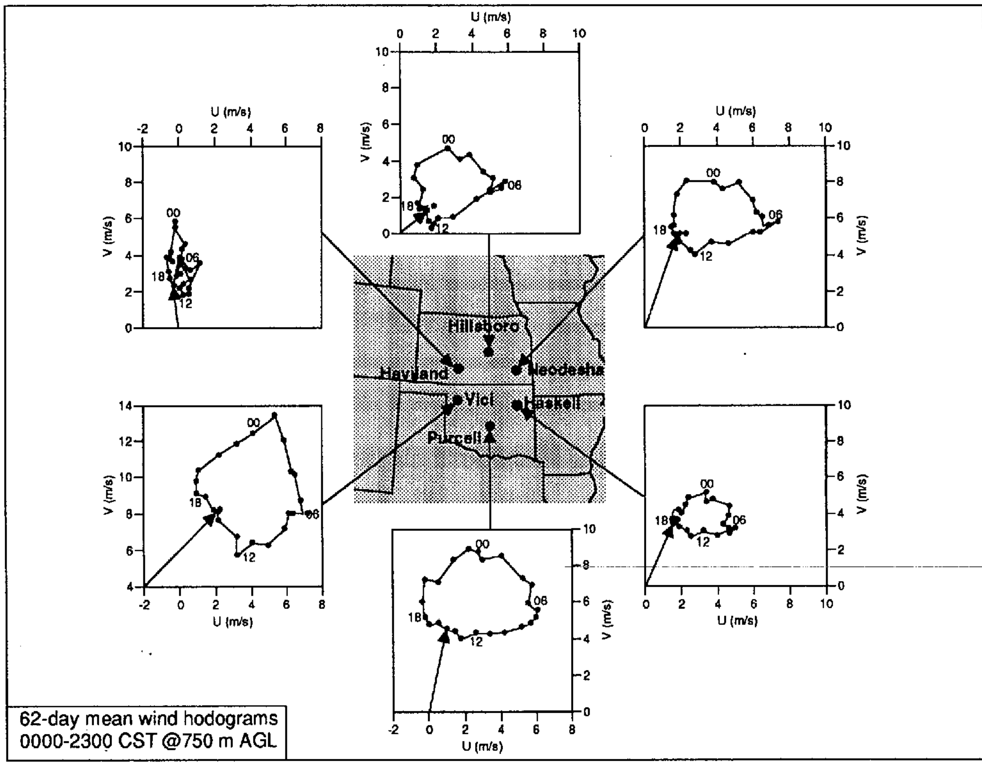

Figure 4. Hodographs of mean wind at six stations in Oklahoma and Kansas.

dramatically from a few percent at 18 CST to 40-60% by midnight. The LLJ frequency, then, decreases rapidly from 06 CST to noon and remains low throughout the afternoon. Notice that the daytime frequency is small but not zero. The daytime LLJ appears to be associated with passages of fronts or squall lines and is not resolved by large-scale models.

Conclusion

The climatological analyses show the ARM SGP CART site is frequently under the influence of the Great Plains LLJ in the summer season. The mean wind direction of the LLJ is from the south-southwest and the mean wind speed is between 10 to 15 m/s. The LLJ frequency exhibits a strong diurnal oscillation, with large values during nighttime and small values during daytime. This strong southerly jet produces low-level moisture convergence and rising motions at the top of the boundary layer and helps to trigger the nocturnal development of convective clouds and precipitation in this region. The earlier phasing of the LLJ oscillation at the higher latitudes and the smooth clockwise turning of the mean wind with time at each station suggest that the inertial oscillation plays an important role in the evolution of the LLJ.

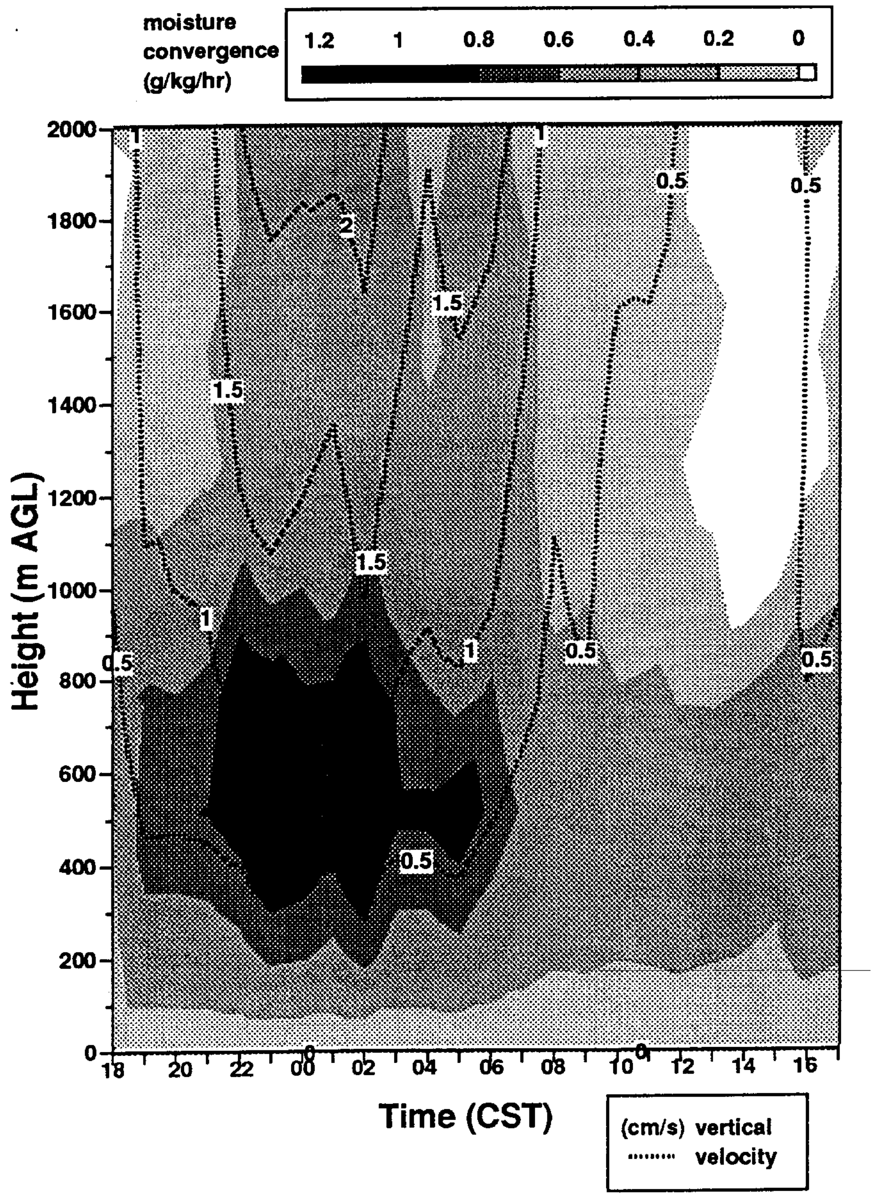

Figure 5. Two-week averaged vertical velocity and the time rate of change of the mixing ratio for all hours of the day at the CART site.

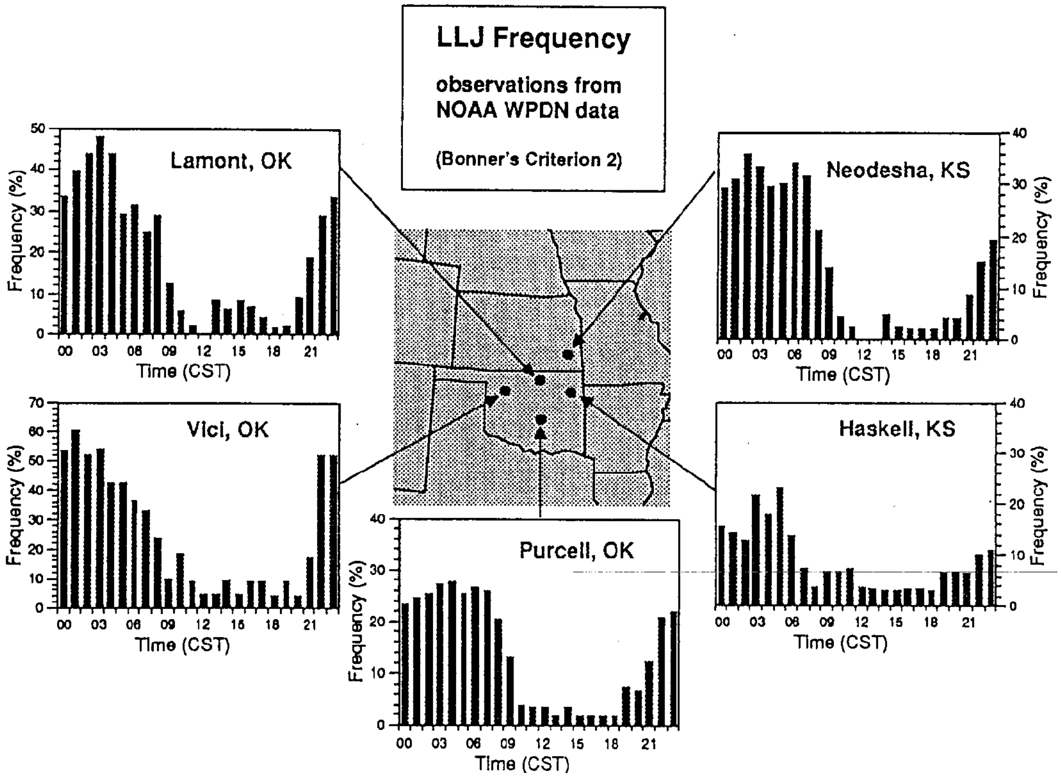

Figure 6. Diurnal variation of the LLJ frequency at selected stations.

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