Summertime Low-Level Jets Over the Great Plains

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Introduction

The sky over the southern Great Plains Cloud and Atmospheric Radiation Testbed (CART) site of the Atmospheric Radiation Measurement (ARM) Program during the predawn and early morning hours often is partially obstructed by stratocumulus, stratus fractus, or cumulus fractus that are moving rapidly to the north, even though the surface winds are weak. This cloud movement is evidence of the low-level jet (LLJ), a wind speed maximum that occurs in the lowest few kilometers of the atmosphere. Owing to the wide spacing between upper-air sounding sites and the relatively infrequent sounding launches, LLJ evolution has been difficult to observe adequately, even though the effects of LLJs on moisture flux into North America are large (Rasmussen 1967).

Beginning in the spring of 1994, a 915-MHZ radar wind profiler became operational at the ARM CART site near Lamont, Oklahoma (Stokes and Schwartz 1994). The hourly profiler data from this site show that the LLJ is a common feature of the nighttime environment over the southern Great Plains during the summer. A total of 56 LLJs are indicated in the available data between 1 June and 2 October 1994. Even though the level of maximum wind speed within the LLJ occurs throughout a large range of heights (Figure 1), the level of maximum wind speed is below 500-m AGL for 46% of the observed LLJs. This indicates that summertime LLJs frequently develop very close to the ground surface and therefore are impossible to observe accurately with the National Oceanic and Atmospheric Administration (NOAA) 404-MHZ radar wind profilers as presently configured with the lowest data level at 500 m above ground level (AGL).

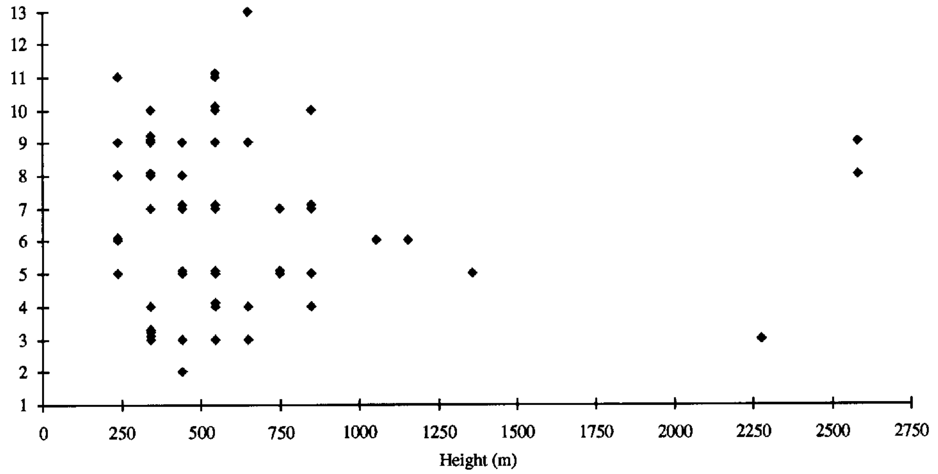

Figure 1. Plot of the time of maximum wind speed (UTC) from the low-level jets observed using the ARM program 915-MHZ radar wind profiler vs. the height of this maximum wind speed (m).

This lack of routine wind observations within the lowest 500 m AGL presents a significant challenge to the accurate observation of the LLJ. Fortunately, a number of WSR-88Ds[(a)] are operational across the Great Plains (Figure 2). Radial velocity data from these radars are used routinely to calculate the horizontal wind components from the Velocity-Azimuth Display (VAD) technique (Browning and Wexler 1968) every 304-m mean sea level (MSL) in the vertical and at 30-min time intervals. Therefore, radar coded messages (RCMs), which contain the VAD wind information, are examined in order to better assess the diurnal and horizontal structure of the LLJ over the southern Great Plains.

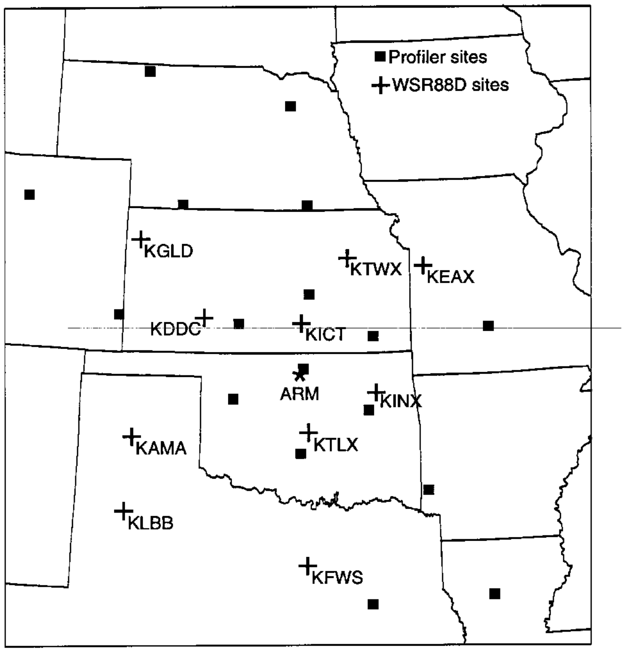

Figure 2. Locations of the WSR-88D radar sites, the ARM 915-MHZ radar wind profiler, and the NOAA 404-MHZ wind profilers.

Observations

During June 1994, the ARM profiler data documented the presence of 28 LLJs out of 29 days with data. Similar numbers of LLJ cases are found in an examination of the VAD winds from the WSR-88Ds, with similar structures in the LLJ observed by the ARM profiler and the nearest several WSR-88Ds. In general, these data suggest that the LLJ forms earlier in the western plains than in the eastern plains, although this is not true for every case. As an example, data from 4-5 June show a LLJ stretching from Texas to Kansas with the strongest wind speeds located in western Kansas (Figure 3). While the LLJ is well-developed by 0600 UTC, it does not reach maximum amplitude across much of the plains until 0900 UTC. The time of the wind speed maximum within the LLJ increases from 0900 UTC at Dodge City, Kansas, to near 1200 UTC at Twin Lakes, Oklahoma, as winds veer throughout the night.

Model Simulation

The development and evolution of these summertime LLJs potentially are a challenge to numerical weather prediction models, owing to the finite number of vertical model levels, difficulties in parameterizing the nocturnal planetary boundary layer, and the lack of data with sufficient horizontal and vertical resolution to create a realistic model initial condition. To assess the ability of present numerical weather prediction models to simulate the complex structure of the LLJ in the Great Plains region, the 4-5 June event is simulated using the Penn State - National Center for Atmospheric Research (NCAR) mesoscale model. This model includes the

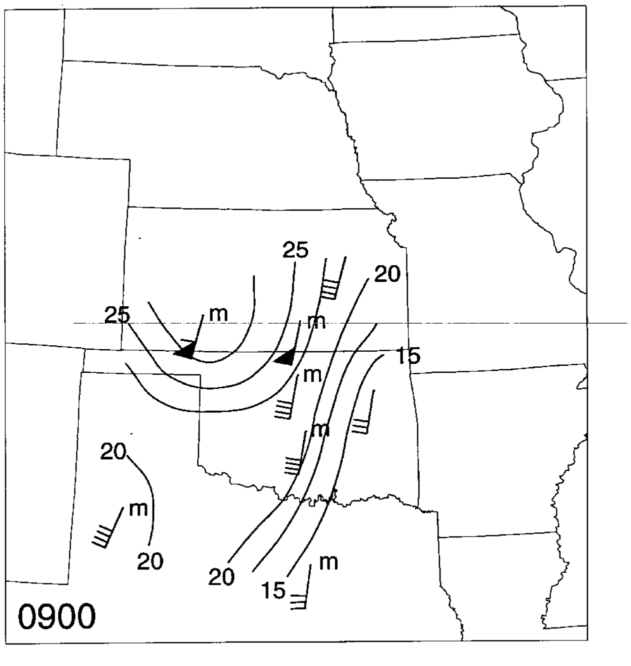

Figure 3. Plot of maximum wind speeds within the lowest 1.5 km of the atmosphere at 0900 UTC 5 June 1994. Each barb represents 5 m/s. Letter m indicates that the wind speed at this time was the maximum observed for this event.

(a) Weather Surveillance Radar - 1988 Doppler

Kain-Fritsch convective parameterization scheme, a Gayno-Seaman 1.5 order turbulence closure scheme for the planetary boundary layer, a surface energy budget that includes the effects of clouds, and explicit microphysics (see Stensrud and Fritsch 1994 for details). The model simulation from 4-5 June reproduces many of the structures deduced from the remotely-sensed wind observations (Figure 4). The model places the maximum wind speeds within the LLJ near DDC as observed, has the correct orientation of the shear zone, has the time of maximum LLJ wind speed earlier to the west than to the east, and has the level of maximum wind speed higher in Kansas than in either Oklahoma or Texas. However, the model winds are everywhere slightly less than observed and the model fails to reproduce the strong low-level winds at Lubbock, Texas. Thus, while the model captures much of the general LLJ structure, it misses several details.

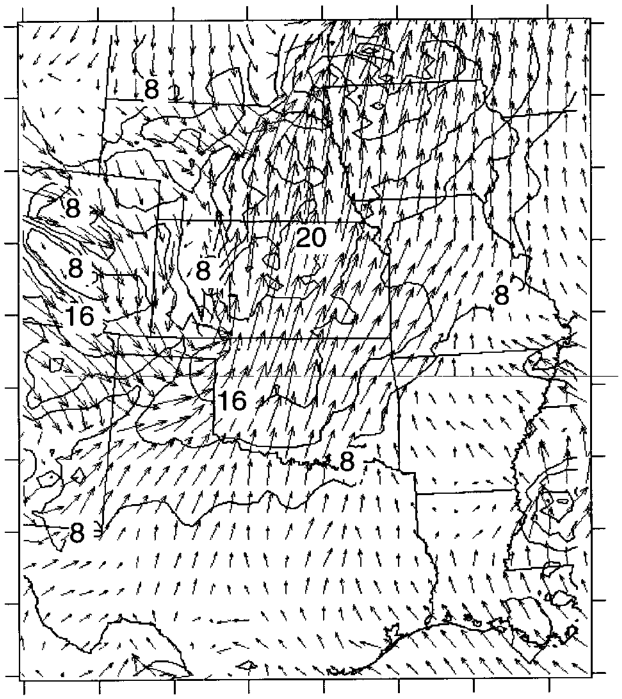

Figure 4. Model wind vectors with wind speed contoured every 4 m/s at 0900 UTC 5 June 1994. Model sigma level of 0.95.

In addition to examining the ability of the model to simulate the LLJ, the model also is used to identify the physical mechanisms of LLJ development and evolution. Low-level jets over the Great Plains have been hypothesized to be produced by inertial oscillations (Blackadar 1957), baroclinicity over sloping terrain (Holton 1967), boundary currents (Wexler 1961), and isallobaric forcing (Uccellini 1980). Often none of these mechanisms alone can explain the observations. However, during the summertime, when the influences of large-scale systems are reduced, it may be that the important mechanisms for LLJ development can be identified. In addition, it is possible that these mechanisms will be different in different regions of the Great Plains, depending upon the underlying terrain slope and typical boundary layer structures.

To investigate the importance of the various mechanisms of LLJ development, all of the tendency terms from the model momentum equations are saved every 1.5 min for selected grid points (Figure 5). The v-component tendencies calculated from grid points near DDC indicate that the pressure-gradient force is the most important mechanism for LLJ development on this day, with both horizontal and vertical advective components acting to offset one another after the simulation has been going for 12 hours. In contrast, the v-component tendencies at TWX, located farther to the east, indicate that the Coriolis and pressure-gradient forces drive the acceleration of the wind (not shown). This result, while preliminary, does lend some credence to the idea that the mechanisms of LLJ development can be ordered according to importance based upon where the jet develops during the summertime.

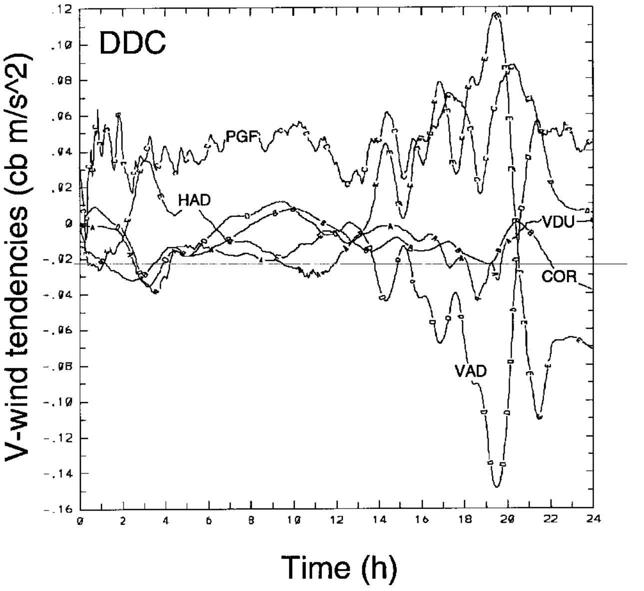

Figure 5. Average model grid point tendencies at sigma 0.95 near DDC from the pressure gradient force (PGF), horizontal advection (HAD), vertical advection (VAD), vertical diffusion (VDU), and Coriolis (COR). Units in cb m s^{-2}.

Discussion

The simulation of one LLJ case during June 1994 has been examined and shown to reproduce many of the observed features documented using the remotely sensed winds from the ARM 915-MHZ wind profiler and the WSR-88Ds. In order to better understand LLJ development and the ability of present numerical weather prediction models to simulate the LLJ, the entire month of June 1994 will be simulated and the model results compared with observations. This study will present the most detailed look to date at summertime LLJ structures over the southern Great Plains that are so important to the water vapor flux into and within North America. The identification of the most important mechanisms for LLJ development and evolution should lead to improved representations of LLJs in global circulation models, since the important physical processes necessary for jet development during the summertime can then be incorporated into the general circulation models.

Acknowledgments

The authors wish to thank Mr. Daniel Mitchell for converting all the RCM data into a usable format and for assisting in display of the model data. Code for the Penn State - NCAR mesoscale model was provided by Penn State, and scientists at both Penn State and NCAR are thanked for their dedication to building such an easy-to-use modeling system. The preparation of this preprint was supported in part by the ARM Program of the U.S. Department of Energy, through Pacific Northwest National Laboratory Contract 144880-A-Q1 to the Cooperative Institute for Mesoscale Meteorological Studies.

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