The Diurnal Wind Variation in the Lowest 1500 ft in Central Oklahoma: June 1966–May 1967

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ABSTRACT

One year of wind data from a television tower in northern Oklahoma City has been analyzed on a diurnal basis. The annual mean speeds below the third level at 296 ft are lowest at night and highest during the day, and conversely the speeds up to the seventh level at 1458 ft are lowest during the day and highest at night. Generally, speed changes occur in short time periods shortly after sunrise and near sunset. Resultant wind directions veer most with height between 1700–1000 CST and least during midday. At all levels winds veer with time between 2100 and approximately 1100 CST and then back with time during the remaining hours.

1. Introduction

The NOAA National Severe Storms Laboratory (NSSL) at Norman, Okla., has collected wind and temperature data at seven levels on the 1602-ft television tower of WKY-TV in Oklahoma City since 1966 primarily to investigate mesoscale features associated with thunderstorms. The tower is located within a surface and upper air network that also is designed to gather data on thunderstorms. The NSSL and the National Weather Service Office (NWS) in Oklahoma City provide radar coverage for this area.

This paper discusses the diurnal variation of wind speed and direction at the tower. Results presented were part of a previous report (Crawford and Hudson, 1970) that examined the general properties of winds in this tower layer to provide a base for severe storm and theoretical boundary layer studies. Present study data consist of the average wind speed and direction observed during 5-min periods centered at the start of each hour during the 12 months from 1 June 1966 to 31 May 1967. Occasional equipment outages left some missing data. Missing wind directions account for 3.1% of the total possible observations (8760) at the surface level and for less than 1.5% of the observations at the other levels. Less than 0.75% of the wind speeds are missing at any level. The data were reduced from strip charts to digital form using a Benson-Lehner Oscar Model K trace reader.

2. Tower site and instrumentation²

The WKY-TV tower is about 6 n mi north of downtown Oklahoma City and about 20 n mi north of NSSL.

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This Oklahoma City area is relatively undeveloped with open fields, several small ponds, and wooded gullies on a gently rolling terrain. The tower base, at 1148 ft MSL, is in a shallow gully free of trees. It was felt that the effects of the land depression and the transmitter building 175 ft southwest of the tower would cause wind measurements near the base to be unrepresentative of ambient conditions. For this reason, the surface winds were measured on a 23-ft tower at a ground elevation 17 ft higher and 250 ft west-northwest of the base. The location is 200 ft north of the transmitter building. The wind sensor is about 10 ft higher than the building's highest section.

The television tower is of uniform triangular cross section, 10 ft on a side, from its base to 1515 ft above the ground. One side of the tower is oriented north-south, and the third leg is to the west. Bendix Friez Aerovane wind sensors with three-blade propellers and Yellow Springs linearized thermistor composite-type temperature sensors are installed at the surface level and at the following six levels above the ground: 146, 296, 581, 873.5, 1166 and 1458.5 ft.

3. Data accuracy

Wind sensors are mounted 10 ft south of the west leg. Based on wind tunnel experiments by Gill *et al.* (1966, 1967) for a model tower similar to the WKY-TV tower, wind speeds are reduced by more than 10% in the interval between 0° and 60° (12.5% of the observations were in this interval), by more than 20% in the interval 22°–38°, and by a maximum of 40% at 30°. Wind speeds are enhanced by slightly more than 10% in small

² See Carter (1970) and Sanders and Weber (1970) for further details.

FIG. 1. Diurnal variations of mean wind speeds on an annual basis. Sunrise and sunset are indicated by vertical lines.

intervals near 345° and 75° . No correction for this tower effect was applied to the data as the effect is slight for analyses of wind speed for all directions.

The reduced data contain the effects of several types of errors. These include instrument accuracy and accuracy in reading and estimating the strip charts' mean speeds and directions. Data accuracy is subjectively considered to be about ± 1 kt and $\pm 3^\circ$.

4. Diurnal wind speed variations

Dramatic changes in the atmosphere occur each day on the average as the sun rises and sets. Because diurnal variations are most prominent in the atmosphere's lower layers, changes in boundary-layer winds have been documented as well as for any other atmospheric variable (e.g., Holton, 1967; Bonner and Paegle, 1969). In their study of 11 years of summertime rawinsonde data at Fort Worth, Tex., Bonner and Paegle used data at 3-hr time intervals and 0.5-km height intervals. The current study provides additional details on the boundary-layer wind diurnal variation using a tower data-set with finer temporal (1 hr) and spatial (0.1 km) resolution.

The arithmetic mean wind speed for each hour was calculated for the entire year (Fig. 1). [The annual mean speeds (kt) in order on increasing height are: 8.1, 11.3, 13.7, 15.6, 17.2, 18.6 and 18.7.] Sunrise and sunset extremes during the year are also plotted in this figure.

Speed profiles for 0000, 0600, 1200 and 1800 (all times CST) are shown in Fig. 2.

Mean wind speeds generally increase with height and reach a maximum at level 6. An exception occurs between 1100 and 1500 when the speeds at level 2 are higher than those at level 3. No explanation is offered for this phenomenon. The inflection point magnitude is well within the mean accuracy.

Surface wind speeds, at a minimum during nighttime hours, increase from sunrise to a maximum of 10.3 kt between 1300 and 1500. The surface speed, beginning to decrease just before sunset, reaches its lowest value of the day (6.4 kt) around 2000. The mean surface speeds increase slightly after this time and remain near 7 kt until sunrise.

At upper levels, winds which are higher at night than during the day, reach a maximum of about 23 kt at levels 5 and 6 around 0000-0100 and decrease rapidly after sunrise to a minimum of 13.7 kt around 1200-1300. There is a 1-2 hr lag between the time of the upper level minimum and the surface level maximum. Usually, speed changes occur in a short time period after sunrise between 0800-1000 when the upper level winds decrease by almost 40% from nighttime maxima. Speed changes occurring around sunrise indicate profiles influenced by momentum transfer due to convective mixing during daylight hours. For instance, surface speeds begin to increase between 0500 and 0600 while upper level winds begin their marked decrease around 0700. Thus, there is a 1-2 hr lag between the time of sunrise influence on surface level and upper level winds. Levels 1 and 2 show

FIG. 2. Vertical profiles of annual arithmetic mean wind speed for 0000, 0600, 1200 and 1800 CST.

the least amount of diurnal change. Apparently these levels lie in a transition zone between the momentum transport from upper levels to the surface.

The average wind speed in the tower layer (Figs. 1 and 2)—the layer between the surface level and level 6—becomes higher at night than during the day. At midnight the average tower-layer wind speed is 16.7 kt. Twelve hours later the average wind speed in the tower layer has decreased to 12.4 kt. This change occurs because the frictional dissipation of kinetic energy is proportional to the second power of the low-level speeds (Hess, 1959). Since surface and level 1 wind speeds are highest during the day, surface friction dissipates more kinetic energy during the day than at night.

5. Diurnal resultant wind vector variations

The resultant, or vector mean, wind was calculated on an annual basis for each hour of the day. It was obtained by converting each wind observation into north-south and east-west components, summing over a given time interval, obtaining the arithmetic mean of each component, and reconverting these components into a single vector. This mean quantity must be used with care since the wind direction distribution is composed mainly of northerly and southerly winds. For example, the direction of the resultant vector at the surface level for December was 280° when 41.1% of the winds were from the southern quadrant (90° sector centered on south), 33.5% from the northern quadrant, 15.0% from the western, and 8.2% from the eastern.

The annual resultant wind vectors for the seven levels in order of increasing height are: 181° (2.6 kt), 181° (4.2 kt), 181° (5.2 kt), 181° (6.5 kt), 187° (7.6 kt), 193° (8.4 kt) and 198° (8.7 kt).

The resultant directions oscillate diurnally for the surface, and for levels 4 and 6 (Fig. 3). Of the lowest four levels, only the surface level is plotted since the four curves of the resultant direction were almost identical. This agrees with the annual resultant wind vector which has a direction of 181° at the four levels.

The wind vector, veering with elevation during the day (Fig. 3), is organized into periods of maximum and minimum changes with height. Significant veering with height in the tower layer generally occurs between 1700–1000 with the peak value of 30° occurring at 0600 (28° at 0500, 0700 and 2000). Veering with height is a minimum during the midday hours with values at 1400 within the instrument's error limits. A few hours near noon even produced backing with height below level 3 on the tower.

The maximum difference between resultant directions on the tower is 10° or less between 1100–1600. In Fig. 1 this period corresponds to the time that the tower layer was well mixed by convective motions. Essentially uniform speeds and directions during this time indicate uniform momentum in the tower layer. Since the rate of increase of convective mixing is a maximum between

FIG. 3. Diurnal variations of the resultant direction on an annual basis for the surface level, and levels 4 and 6.

0800–1000 (Fig. 1), there is a 2–3 hr lag between the time this mixing begins and the re-establishment of a balance of forces at all tower levels. Thus, while the wind vector does veer with height, veering is limited to certain periods of the day.

The diurnal oscillation of boundary-layer winds, i.e., the backing and veering of the wind vector with time during a day (well documented by Bonner and Paegle), is also apparent in the WKY data. Except for minor interruptions around sunrise, the winds at all levels veer with time between 2100 and approximately 1100. Then, wind directions back with time between approximately 1100 and 2000. At level 6 the onset of backing begins first at 0900 and thereafter works downward to the surface where backing starts at 1100. Generally, backing winds end at all levels by 2000 except at level 6. Thus, winds at each level veer approximately 14 hr a day and back 10 hr a day, with the wind vector returning to its starting point at the day's end; consequently, the average backing rate at each level was greater than the veering rate during this single year period. Backing with time is usually at a maximum between 1600 and 1800 and a minimum between 1200 and 1400. Veering with time reaches a maximum just before midnight and minimum just after sunrise. At level 6 hour-to-hour changes in the resultant direction are more uniform than those below this level. Magnitudes of the resultant direction oscillation range from 54° at the surface, to 38° at level 4, to 40° at level 6.

Deviations of the hourly resultant components from the annual resultant components (v' represents north-south components and is positive for southerly flow; u' represents east-west components and is positive for westerly flow) were computed for each hour of the 24-hr cycle (Fig. 4) to give a more detailed description of the diurnal oscillation in the boundary layer winds. This approach provided a direct comparison with the work of Bonner and Paegle. The results, which should have been the same by using either the actual or the deviation resultant vectors, are in good agreement with Bonner and Paegle's work and provide a more detailed analysis of the boundary-layer wind oscillation. The v' com-

FIG. 4. Diurnal variation of the deviations of the hourly resultant components from the annual resultant components for the 7 levels: top, v' component; bottom, u' component.

ponent shows a maximum daily variation of almost 8 kt between levels 5 and 6, and the maximum variation of the u' component, at least 6.5 kt, occurs above level 6. Southerly winds become maximum at midnight and

minimum at 1100. Westerly winds, a maximum at 0600 at level 6, gradually work downward to where westerly surface winds are a maximum at 1100. The amplitude of the u' component is greater than that of

FIG. 5. Deviation vector hodographs (see Fig. 4) for the surface level, and levels 2, 4 and 6.

the v' component below level 3. Above level 3, the reverse is true.

Hodographs of the Fig. 4 data are shown (Fig. 5) for the surface, and levels 2, 4 and 6. Except for the surface level, all hodographs show anticyclonic rotation of the deviation vector at a rate that is largest between approximately 1700–0400. This can be seen again in the diurnal oscillation of the resultant directions (Fig. 3). These hodographs, ellipsoidal in shape near the surface, become more circular at the higher tower levels. This agrees partly with Bonner and Paegle who found that their hodographs were nearly circular at elevations (above ground level) of 0.15 km (492 ft) and 0.32 km (1050 ft).

6. Summary

On an annual basis at the two lower levels, the arithmetic mean speed is lowest near midnight and highest near 1400. It reaches a maximum near midnight and a minimum during midday at levels 2 through 6. Speed changes, usually occurring in short periods just after sunrise and just before sunset, are probably associated with the onset and cessation of convective mixing.

The resultant vector veers with height during most hours of the day. Maximum veering with height is 30° at 0600 while minimum veering with height occurs during midday with backing below level 3. Winds veer with time between 2100 and 1000 and back during the remaining hours until maximum veering with time

occurs just before midnight and maximum backing between 1600 and 1800.

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