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ORIGINAL ARTICLE

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Evidence of long-distance transport of mountain cedar pollen into Tulsa, Oklahoma

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Abstract Previous study of Cupressaceae pollen in the Tulsa atmosphere during December and January suggested that the source of this pollen is the *Juniperus ashei* (mountain cedar) populations that occur mainly in southern Oklahoma and central Texas. The present investigation examined the evidence of long-distance transport of pollen from these populations during the 1996/1997 season at three sites in Oklahoma using Burkard traps. Two of the pollen-monitoring stations were operated in conjunction with Mesonet meteorological stations. It was found that the December and January Cupressaceae pollen occurs outside of the local season at Tulsa. Pollen concentrations are intermittent and correspond to days of peak concentrations at sites nearer the mountain cedar populations. Peak concentrations are associated with winds coming from the south over the mountain cedar areas. Diurnal rhythms show night-time peaks with a delay in timing at the northern-most site. These results are all consistent with the hypothesis that pollen is being transported over long distances from the mountain cedar populations to Tulsa, Oklahoma. These findings are important as they represent one of the few incidences of long-distance transport of pollen in significant concentrations to an area where the source vegetation is not present. Pollen-monitoring sites located in conjunction with Mesonet meteorological stations provide a unique opportunity to further examine atmospheric conditions during long-distance transport events. This will aid future studies of the spatial modeling of long-distance dispersal of pollen.

Key words Long-distance transport · Cupressaceae · *Juniperus ashei* · Mountain cedar · Pollen

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Introduction

Many studies of the dispersal distance of anemophilous pollen have focused on the deposition of pollen within relatively short distances (e.g. Raynor et al. 1970). However, there are numerous examples of pollen undoubtedly traveling long distances to arrive at a site (Ritchie and Lichti-Federovich 1963, 1967; Christie and Ritchie 1969; Hjelmroos 1991; Cambon et al. 1992). Clearly, a certain small percentage of released pollen remains airborne for a greater length of time and makes its way into a well-mixed (or turbulent) layer of the atmosphere. Faegri et al. (1989) called this the “regional component”, while Gregory (1978) described it as the “escape fraction”.

Previously Levetin and Buck (1986) discussed the distribution of the five main species of *Juniperus* in Oklahoma relative to the incidence of airborne Cupressaceae pollen at Tulsa. They proposed that the local-pollen season, during February and March, is dominated by the widespread *J. virginiana* plus other minor and ornamental species. However, Cupressaceae pollen concentrations during December and January are attributed to the long-distance transport of pollen from *J. ashei* (mountain cedar) populations in southern Oklahoma and central Texas. Since the pollen of Cupressaceae genera and species are morphologically indistinguishable from one another (Bortenschlager 1990), pollen seasons of the species are defined by observation of pollinating times in the respective populations. Levetin (1998) also showed that, over the last 16 years, the instances of long-distance transport of Cupressaceae pollen into Tulsa are neither infrequent nor inconsequential. This indicates one of the few incidences of recurrent long-distance transport events in significant concentrations to an area where the source vegetation is not present (Peeters and Zoller 1988; Frei 1997). These events are significant since mountain cedar is considered to be the most allergenic species of Cupressaceae in North America; it is the most important allergen where it grows and is equivalent to ragweed in allergenic importance (Levetin and Buck 1986).

Since mountain cedar does not grow in the Tulsa vicinity, the potential for mountain cedar to be considered as a serious allergenic threat has been under-recognized and hence allergy to it has been under-diagnosed. However, numerous anecdotal reports of allergy problems arise every December and January in Tulsa. Some allergists in the area skin test with mountain cedar extracts and find positive reactivities in some patients (Levetin and Buck 1986). The prevalence of mountain cedar allergy in the Tulsa area and the coincidence of symptoms with long-distance transport events will be the subject of future studies.

The present study examines the incidence of airborne Cupressaceae pollen at three sites in Oklahoma during the 1996/1997 season to provide more concrete evidence of the long-distance transport of mountain cedar pollen. Two of the sites are located in conjunction with Mesonet meteorological stations – a network of 114 automated monitoring stations located throughout Oklahoma which collect and archive data every 15 min. This association provides a unique opportunity to examine the atmospheric conditions present during long-distance transport events.

Materials and methods

Site description

Figure 1 illustrates the distribution of *J. ashei* according to Adams (1977). *J. ashei* has a restricted range, occurring primarily on limestone outcrops in Mexico, Texas, Oklahoma, Arkansas and southern Missouri. The largest population occurs in central Texas on the Edwards Plateau.

Three sites were chosen to study the transport of mountain cedar pollen into Tulsa, Oklahoma. Tulsa, situated in the northeast corner of Oklahoma (Fig. 1), is located at the transition between prairie and eastern deciduous forest zones. Tulsa is roughly 200 km from the nearest mountain cedar population to the south and 140 km from the Ozark population to the east. Repeated attempts to locate a population close to Tulsa reported by Hall (1952) have failed. Due to increased development over the years, it is thought that the population no longer exists (Levetin and Buck 1986). The prevailing winds at Tulsa are southerlies; therefore, the southern populations are more likely to be the source of the long-distance-transported pollen. Two other sites south of Tulsa were selected to monitor the influx of Cupressaceae pollen into Tulsa.

The Lane and Burneyville sites are situated in the post oak-blackjack oak (*Quercus stellata/Q. marilandica*) botanical zone. The Burneyville site lies between the mountain cedar population to the north, in the Arbuckle mountains, and the larger population to the south in the Edwards Plateau. Lane lies to the northeast of Burneyville, and east of the Arbuckle population (Fig. 1).

Pollen sampling

Airborne pollen was sampled with Burkard pollen and spore traps located 1.5 m above ground in association with Mesonet meteorological stations at Lane and Burneyville, Oklahoma. In addition, a Tulsa, Oklahoma trap was located 12 m above ground in an urban setting. Burkard samples were prepared in the standard way and mounted in glycerin jelly with basic fuchsin. Microscopic counts of pollen along a single longitudinal traverse were made at 400× magnification and the counts were converted to concentration as number of pollen grains/m^3 of air. On days when pollen concentrations were considerable, slides were also counted using 12 2-hrly transverse traverses.

Meteorological data

Meteorological data from the Oklahoma Mesonet sites at Lane, Burneyville and Hectorville were used for these analyses. The Me-

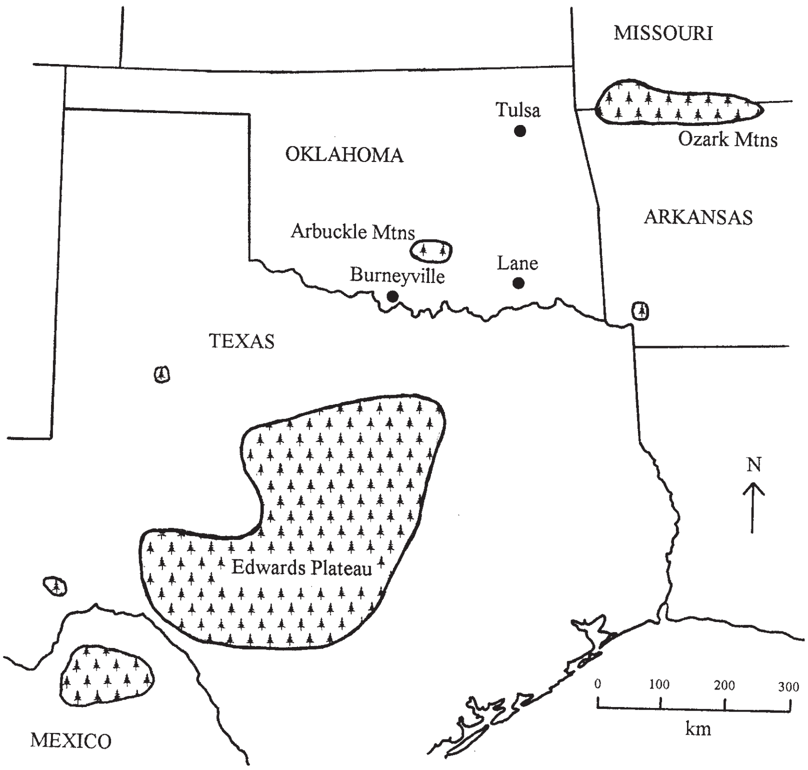

Fig. 1 Location map of Texas and Oklahoma showing the distribution of *Juniperus ashei* (*shaded areas*) and locations of pollen-sampling stations. Lane and Burneyville sites also represent the location of Mesonet meteorological stations

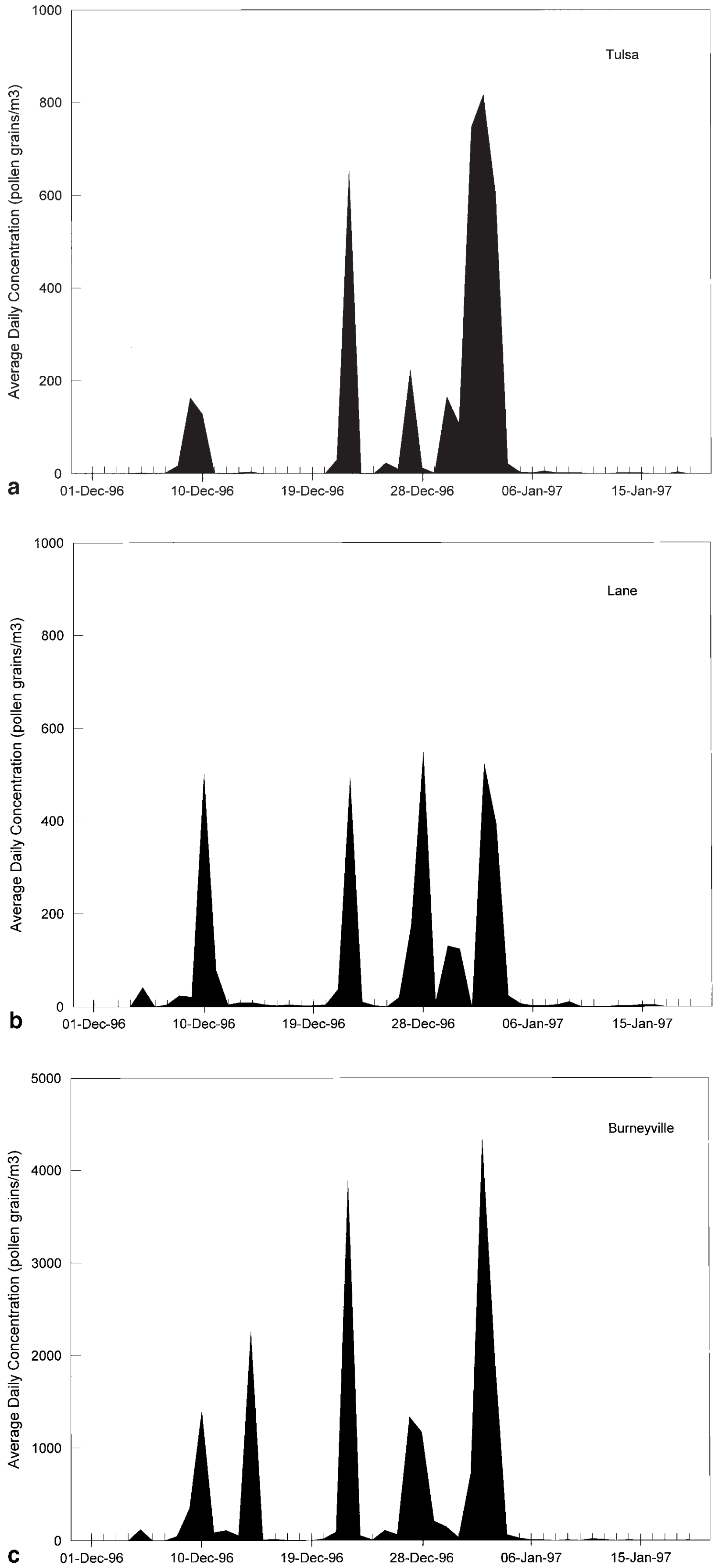

Fig. 2 Out-of-season Cupressaceae pollen concentrations during December 1996 and January 1997 at **a** Tulsa, **b** Lane, and **c** Burneyville, illustrating four to five long-distance transport events. Note the change in magnitude on the scale at **c** Burneyville

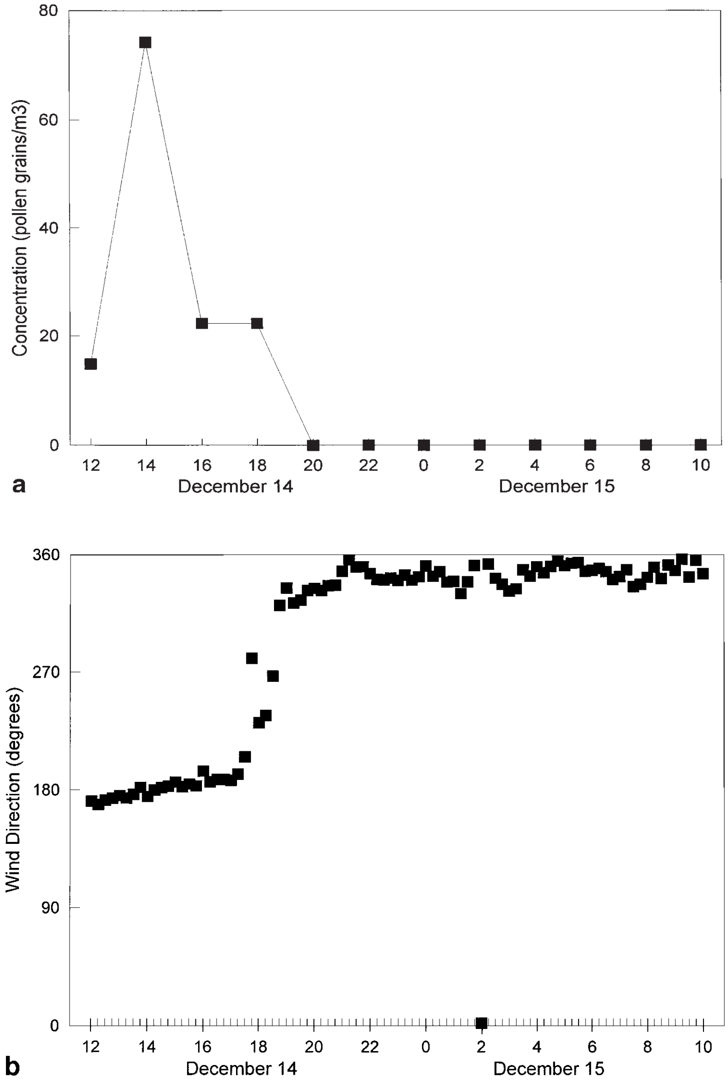

Fig. 3 **a** Concentrations of Cupressaceae pollen at 2-h intervals on the pollen-sampling day of December 14. **b** Wind direction (direction the wind is coming from) recorded during the pollen-sampling day of December 14 at the Hectorville Mesonet station (48 km from Tulsa)

sonet collects and archives data every 15 min on a suite of meteorological parameters. In order to correspond to the pollen-sampling scheme (changing of the drums at mid-day), daily meteorological datasets were constructed to match start and end times of pollen "sampling days" (mid-day to mid-day). Data values were averaged over the corresponding time of exposure in pollen traverses (daily or two hourly) with the exception of precipitation, which is reported cumulatively over the period.

Results

Although Cupressaceae pollen was present in the Tulsa atmosphere from September through to March, the main local pollen season, represented by continuous recording of pollen, occurs during February and March. In Tulsa, local season peak concentrations of *J. virginiana* pollen reached >2000 grains/m^3 whereas the similar time period at Lane and Burneyville received much greater concentrations, >7000 and >4000 grains/m^3 respectively. Pollen concentrations also reached considerable levels outside of the local season, mainly in December and January (Fig. 2a–c). Pollen concentrations were much higher at the Burneyville site, nearer the *J. ashei* population, than at either Lane or Tulsa. There were four to five major episodes of Cupressaceae pollen recorded during the December and January 1996/1997 season.

Peak days at Burneyville were reflected in considerable concentrations at Lane and Tulsa, with the exception of December 14. On December 14, concentrations >2000 grains/m^3 were recorded at Burneyville, but no significant levels were detected at Lane or Tulsa (Fig. 2a–c). Examination at 2-h intervals of the December 14 sampling day at Tulsa shows that pollen concentrations were increasing between 1200 and 1400 hours. A rapid drop in concentration occurred soon after and no pollen was recorded throughout the rest of the sampling day (Fig. 3a). Wind direction during the same period shows that winds were coming from the south until about 1800 hours when a rapid shift brought winds from the north (Fig. 3b).

Closer examination of wind direction during all sampling days shows that pollen concentrations increase when the wind blows from the south (Fig. 4a–c). This is also evident at the 2-h scale when periods of unstable wind direction or wind from directions other than south are associated with very little pollen detection (Fig. 5a,

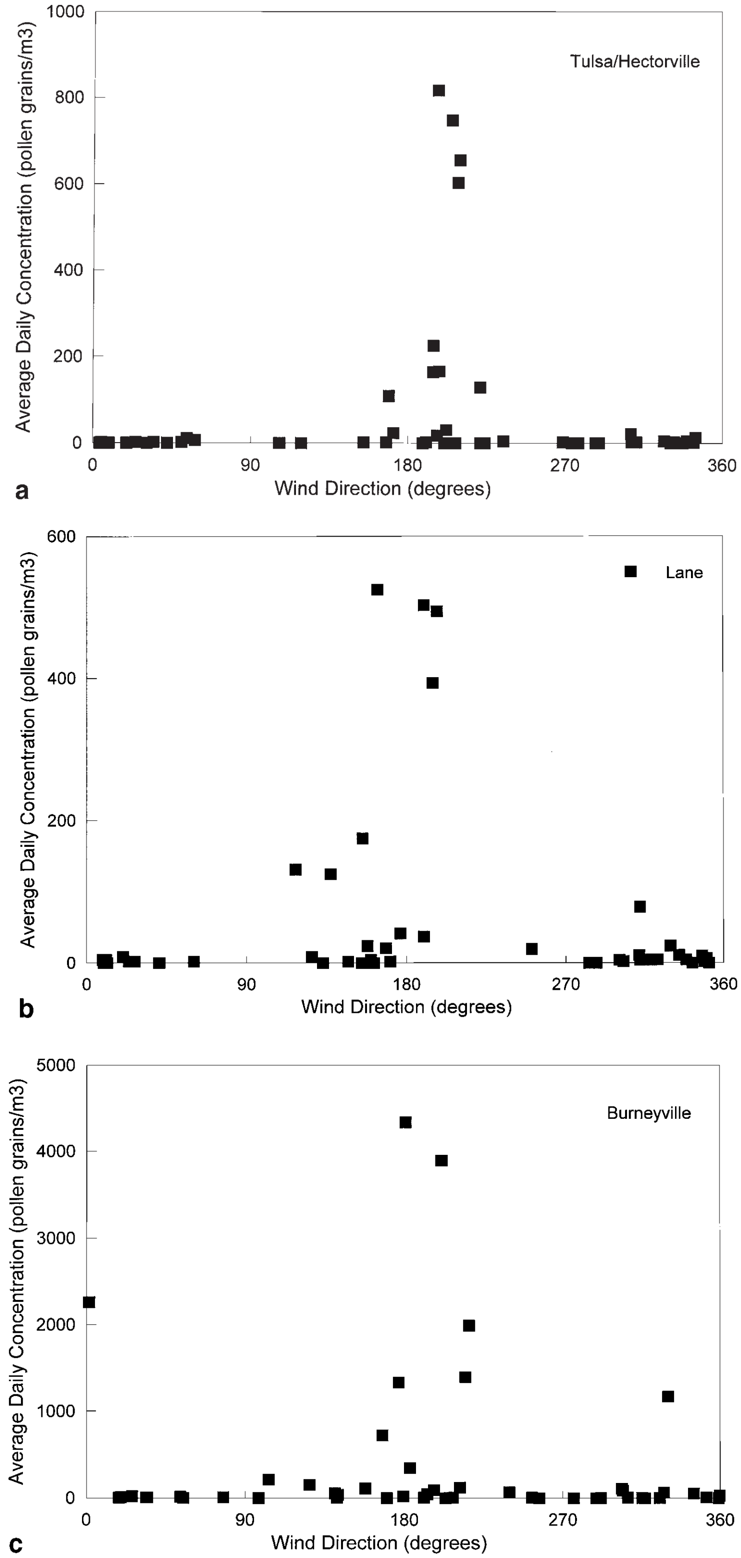

Fig. 4 Plots of pollen concentration versus wind direction at **a** Tulsa and Hectorville, **b** Lane, and **c** Burneyville. Pollen is only present in the Tulsa atmosphere when winds are coming from southerly directions

b). On December 31, the pollen concentration dropped rapidly, in association with a rapid change in wind direction.

The diurnal rhythm of pollen occurrence is elucidated by combining the two hourly counts on 14 days of significant levels of Cupressaceae pollen. At Burneyville, pollen concentrations increased in the late afternoon to a peak about midnight and then decreased again through the early morning to a minimum at 8.00 a.m. (Fig. 6a). At Tulsa, pollen concentrations did not increase until the late evening, and reached a peak at about 2.00 a.m. and then decreased throughout the rest of the morning

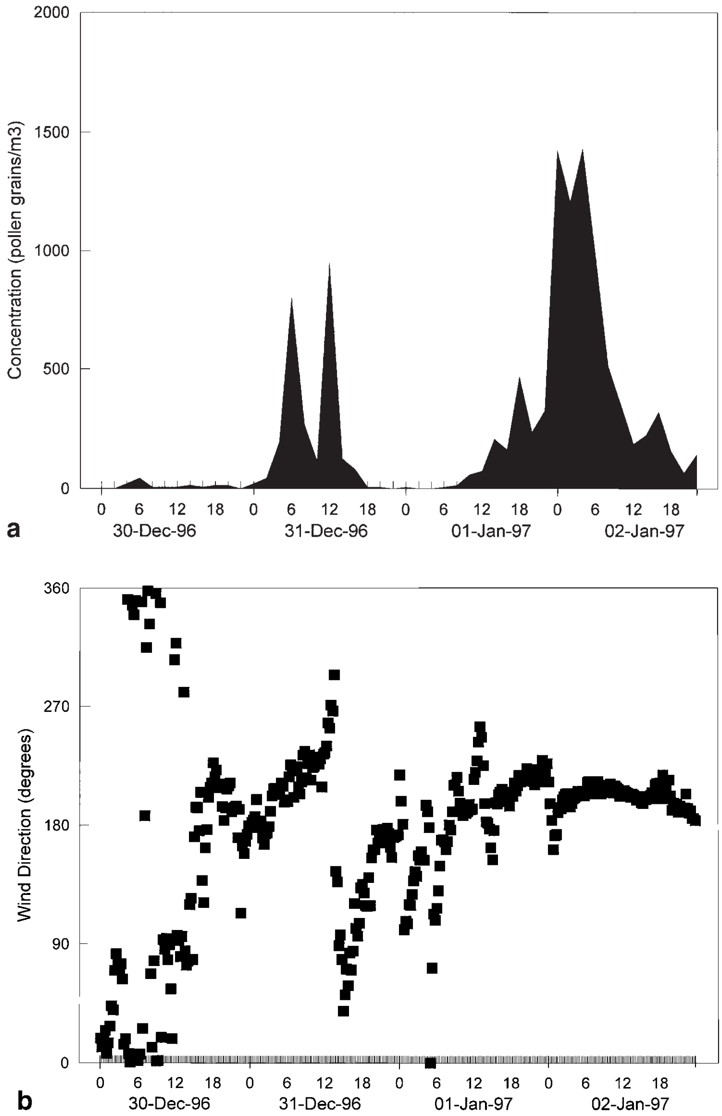

Fig. 5 **a** Concentrations of Cupressaceae pollen at Tulsa from December 30 1996 to January 2 1997. **b** Wind direction at Hectorville during the same period. Detection of pollen at Tulsa is associated with stable southerly winds

(Fig. 6b). Thus, there appears to be a lag in the daily peak pollen concentrations arriving at Tulsa.

Discussion

Several factors examined here indicate that the detection of pollen at Tulsa during December and January is due to long-distance transport events from mountain cedar populations. Firstly, Cupressaceae pollen in the Tulsa atmosphere during December and January occurs considerably outside of the local-pollen season. Eastern red cedar (*J. virginiana*), the most common taxon of the Cupressaceae in the area, does not pollinate until February and March, and there are no known local populations of mountain cedar within 140 km of Tulsa. This suggests that the Cupressaceae pollen detected at Tulsa in December and January does not come from local sources.

In addition, recordings of pollen in December and January of 1996/1997 are intermittent, with four to five major episodes often separated by several days of no pollen. Pollen of local origin is normally received continously within a reasonably well-defined pollen season. Therefore, distant sources of the Cupressaceae pollen are again indicated.

Peaks in pollen concentration at Tulsa correspond to days of peak pollen concentrations nearer the mountain cedar populations at Burneyville and Lane, although reduced in magnitude. The only exception was December 14 when very little pollen was recorded at Tulsa. During this sampling day, the winds switched direction away from the source of mountain cedar to come from northerly directions. Since the Burneyville site also has a source of mountain cedar to the north, pollen concentrations recorded at Burneyville on this day may also represent pollen orginating from the small source area to the north of this site.

Cupressaceae pollen concentrations at Tulsa and Burneyville are highest during the evening and night. The diurnal periodicity of Cupressaceae pollen at Toronto indicates a daytime peak (C.A. Rogers, unpublished data); however, this does not include mountain cedar. Al-

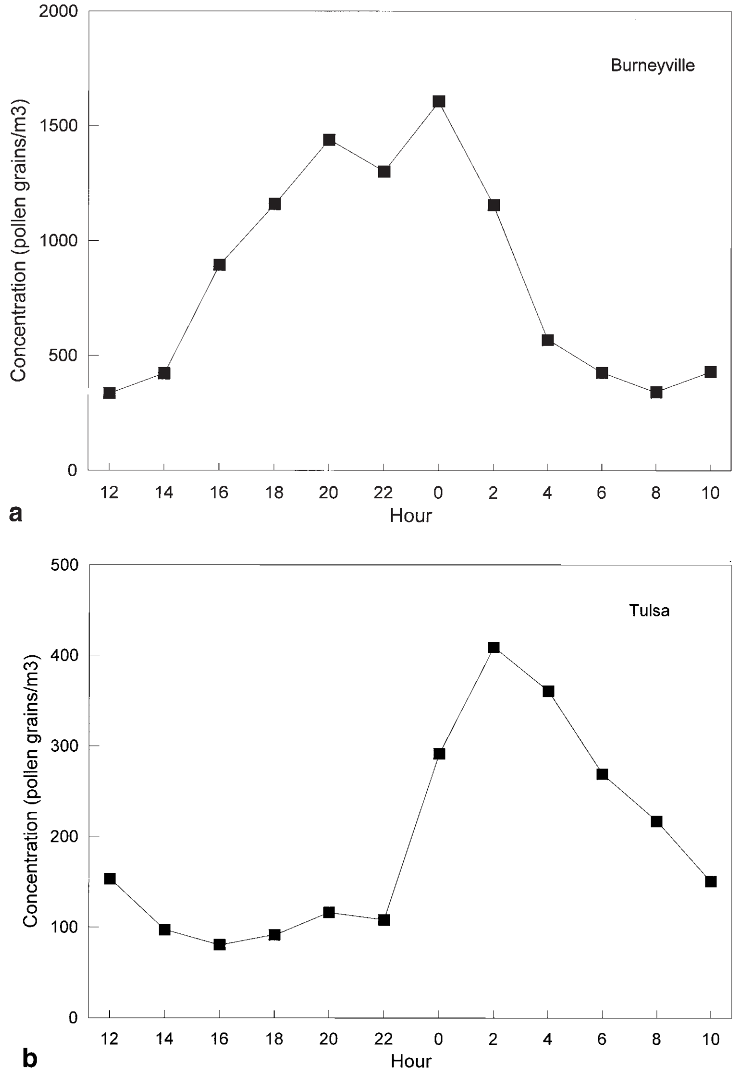

Fig. 6 Two hourly Cupressaceae pollen concentrations on 14 days in December and January averaged to show the diurnal rhythm of pollen concentration at **a** Burneyville and **b** Tulsa. The greatest concentrations occur in the evening and night with a lag in the peak at Tulsa

though we have no diurnal signature from mountain cedar, trees in general show diurnal rhythms which peak during the daylight hours (e.g. Käpylä 1984). A shift in the timing of the daily peak is consistent with other reports of pollen received from more distant sources (Norris-Hill and Emberlin 1991). In addition, there is a lag in the peak diurnal concentration arriving at Tulsa from that arriving at Burneyville. This suggests that the pollen may be moving in a cloud that is sensed as a peak at different times along the trajectory of its dispersal.

Days of peak Cupressaceae pollen concentrations correspond to southerly winds passing over the mountain cedar sources. At Tulsa, peak pollen levels are recorded only on days when the winds come from the south. There are days of southerly winds when no pollen is recorded at Tulsa, but these are likely to be days of low pollen concentration or poor dispersion from the source. No pollen is recorded at Tulsa when winds originate from any other direction.

These occurrences of long-distance transport of mountain cedar pollen are significant for many reasons. The events documented here occur over a 2-month period and last several days, whereas other studies usually record single events, which last only 4–5 days. In addition, the pollen of *J. ashei* is highly allergenic, perhaps due to very quick elution rates of proteins from the grains (Pettyjohn and Levetin 1997). The amounts of pollen that arrive with each long-distance transport event are large in comparison to most other evidence of long-distance transport (e.g. Ritchie and Lichti-Federovich 1963, 1967; Peeters and Zoller 1988; Cambon et al. 1992; c.f. Hjelmroos 1991). The atmospheric levels reached are clearly high for allergenic tree-pollen concentrations (i.e. >90 grains/m^3; Burge 1992) and could potentially pose a serious threat to sensitized individuals if the allergenicity of the grains persists. Skin test reactivity and reports of symptoms in Tulsa during the mountain cedar season suggest that at least some of the allergenicity remains intact even after long-distance transport. Thorough investigation of the medical significance of mountain cedar pollen that has been transported over long distances will be the focus of future studies.

The long-distance transport of mountain cedar from southern Oklahoma and Texas into Tulsa is an ideal system for examining further the mechanisms of long-distance transport of pollen. Mountain cedar is a highly prolific pollen producer, where significant amounts of pollen are transported and long distance events are very clear. Althoug morphologically indistinguishable from other members of Cupressaceae, mountain cedar pollen occurs with unique timing, which reduces confusion as to whether its source is local or distant. It is also important that the source of transported pollen occurs in a known and restricted range so that the source is well defined. Tulsa, well removed from the source of the vegetation, is in line with the prevailing winds and therefore regularly receives only long-distance transported pollen. This means that long-distance transport events in essence are repeated and can be analyzed statistically.

Future studies of the long-distance transport of mountain cedar will examine the quantitative reduction in concentration with distance. This and other spatial modeling work requires knowledge of the concentration at the source. We have planned to move the Lane trap down to central Texas at the edge of the mountain cedar population to obtain a better indication of the source concentrations.

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