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THE IMPACT OF WIND SPEED ON NIGHTTIME MICROSCALE TEMPERATURE GRADIENTS

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1. INTRODUCTION

The nighttime air temperature near the earth's surface is difficult to predict accurately. One of the most challenging problems is the large temperature gradients that develop at small scales, particularly on clear nights. These gradients are extremely sensitive to the wind speed. In this paper, the impact of wind speed on microscale nighttime temperature gradients is analyzed. The analysis is based on three years of observations from the Oklahoma Mesonet (Brock et al. 1995) and the Crosstimber Micronet, an automated microscale surface observation network in central Oklahoma.

2. SCIENTIFIC BACKGROUND

Numerous recent studies have shown that low-lying areas experience anomalously low temperatures on clear nights with light wind. Simonsen (2001) and Fiebrich and Crawford (2001) studied observations from the ARS Micronet, a mesoscale observation network located in Oklahoma's Little Washita Watershed. The watershed is located in southwest Oklahoma, 60 km southwest of the Crosstimber Micronet. They observed horizontal temperature differences of up to 10°C across distances of less than 30 km. Studies in other areas found similar temperature gradients across mesoscale domains.

Relatively few studies have focused on microscale gradients. One such study by Clements et al. (2003) examined nighttime temperatures at Peter Sinks, Utah, an area known for anomalously cool nighttime temperatures. They found that the anomalously cool temperatures at the bottom of the sinkhole were created by a turbulence-free layer of air that developed near the ground. The lack of turbulent mixing (i.e., sensible heat flux) allowed this layer to cool more rapidly than the air above it.

They concluded that the most important factor was the sheltering of wind by the walls of the sinkhole. A similar phenomenon is known to occur in areas that are sheltered by trees (Gustavsson et al. 1998). A variety of observations (not shown) have indicated that the turbulence-free layer also develops at the Crosstimber Micronet, which is sheltered by hills and trees.

This turbulence-free layer is hereby called the Uncoupled Surface Layer (USL), because the layer is in contact with the ground surface but not coupled with the ambient stable boundary layer above it. It is further defined as a stable layer where turbulence is negligible.

At locations where the USL is present, nighttime temperatures are substantially lower than in areas where the USL is not present. When a shallow USL develops across hilly terrain, higher elevations are above the top of the USL. Thus, temperatures at higher elevations are substantially higher. But when the USL is deeper than the height of the terrain, relatively weak temperature gradients are observed.

Development of the USL requires sufficiently weak flow. Thus, its existence and depth are dependent on the mechanical forcing (i.e., wind speed) across the region and local barriers to the flow. It follows that microscale nighttime temperature gradients also are dependent on these factors. At a given location where barriers to the flow are stationary, the nighttime microscale temperature gradient is hypothesized to be closely related to the wind speed across the region.

3. METHODOLOGY

This manuscript focuses on nighttime meteorological conditions observed across a portion of central Oklahoma and across a 200 m x 100 m parcel of land known as the Crosstimber Micronet. The Micronet is situated on the southern slope of a small hill. That hill is approximately 12 m tall and 180 m from the base to the ridge. The Micronet contains several automated surface observation stations that are oriented in a line from the ridge to the base of the hill (Fig. 3.1).

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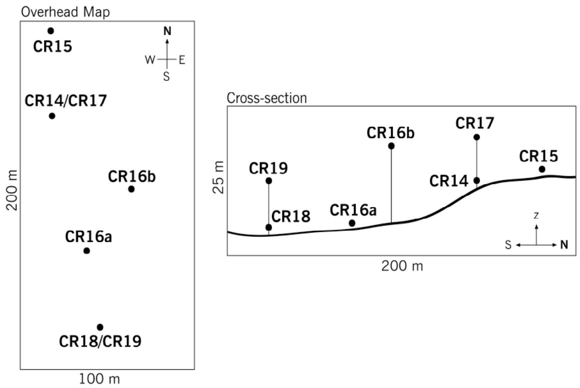

Figure 3.1. Map (overhead and cross-section) showing Crosstimber Micronet sites.

The study domain is approximately 50 km x 50 km and is centered approximately 40 km southeast of Oklahoma City (Fig. 3.2). The Crosstimber Micronet is located near the center of the domain and is surrounded by five Oklahoma Mesonet sites.

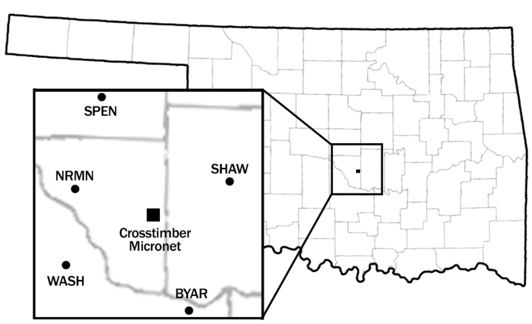

Figure 3.2. Map of Oklahoma showing the locations of the Crosstimber Micronet and surrounding Oklahoma Mesonet sites.

This study is based on approximately 3 years of observations from September 2002-June 2005 at the Crosstimber Micronet and five surrounding Oklahoma Mesonet sites. Each observation is an average of 100 samples over a period of 5 minutes.

The analysis is limited to observations during clear nights. Approximately 56% of the nights in the dataset were classified as clear. The observed net radiation at the Crosstimber Micronet was used to classify each night as "clear" or "not clear". A night was considered clear if the net radiation was less than –10 W/m^2 for at least 80% of the night. Thus, nights with short periods of cloud cover were classified as clear nights.

The mesoscale wind speed is defined as the average wind speed observed across the five Oklahoma Mesonet sites that surround the Crosstimber Micronet. Calm conditions at the Micronet are defined by an average 5-minute wind speed of less than 0.1 m/s. Under such conditions, the USL is assumed to be present. ΔT is defined as the observed temperature difference across the Micronet (i.e., temperature difference between CR18 and CR15) at 1.5 m above ground level.

4. RESULTS

Within the 5-acre Crosstimber Micronet, large temperature gradients were frequently observed. At 1.5 meters above the ground, the temperature difference observed across the Micronet (ΔT) reached as high as 11°C (Table 4.1).

Month	Average ΔT	Clear night avg. ΔT	Largest ΔT
Jan	1.5°C	2.3°C	9.6°C
Feb	1.3	2.3	9.0
Mar	1.7	2.6	9.7
Apr	1.6	2.2	10.7
May	1.4	1.8	7.5
Jun	1.2	1.6	5.0
Jul	1.5	1.7	5.4
Aug	1.4	1.6	6.2
Sep	1.8	2.1	6.0
Oct	1.7	2.1	8.0
Nov	1.5	2.9	11.3
Dec	2.3	2.8	10.4

Table 4.1. Average largest nightly temperature difference (ΔT; °C) across the Micronet and largest temperature difference observed across the Micronet.

Nights with the largest ΔT were characterized by calm conditions in the valley (CR18) and non-calm conditions at higher locations (e.g., CR15 and CR17). In other words, the USL was present at CR18 but not at the higher sites (Table 4.2).

	Mesonet		CR17		CR18	
ΔT	Wspd	% calm	Wspd	% calm	Wspd	% calm
0-1	4.41	0	1.77	13.0	0.41	43.3

1-2	2.34	0	0.35	66.9	0.02	94.5
2-3	2.24	0	0.23	73.3	0.01	98.4
3-4	2.57	0	0.37	58.4	0.01	98.1
4-5	2.85	0	0.51	43.2	0.01	98.1
5-6	3.00	0	0.63	31.8	0.01	97.9
6-7	3.20	0	0.74	24.9	0.01	95.9
7-8	3.38	0	0.99	14.7	0.01	96.7
8-9	3.41	0	1.09	11.3	0.01	97.3
9-10	3.86	0	1.12	18.6	0.01	100

Table 4.2. Average wind speeds and percentage of observations that are calm as a function of temperature difference across the Crosstimber Micronet (ΔT; °C) for all seasons during the study period.

During periods when ΔT was small (i.e., less than 1°C), the wind was usually non-calm at all locations. But when ΔT was greater than 1°C, the wind was nearly always calm at CR18. On the nights with the largest ΔT values, the USL was present (i.e., the wind speed was below 0.1 m/s) at CR18 but not at the other sites. When the USL was present across the entire Micronet, temperature differences were moderate (i.e., 1-4°C).

The presence of the USL is a function of the wind speed across the region and the degree of sheltering at the particular location (Fig. 4.1). At very sheltered locations such as CR18, the USL usually was present with mesoscale wind speeds below 4 m/s, and sometimes was present with mesoscale wind speeds as high as 7 m/s. But at less sheltered sites such as NRMN, the Mesonet site nearest the Micronet, much lower mesoscale wind speeds (i.e., < 0.5 m/s) were required for USL development at 2 m AGL. Such low wind speeds on the mesoscale are rare in central Oklahoma. Thus, the USL is rare at exposed sites such as NRMN.

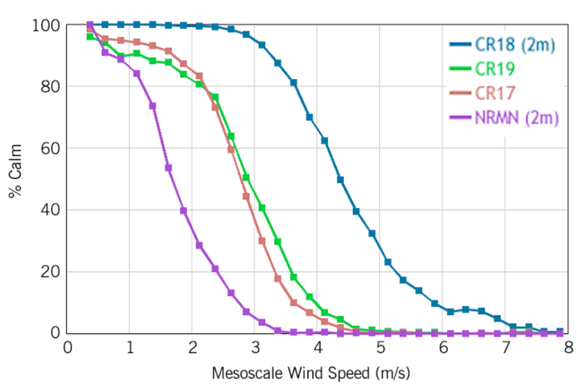

Figure 4.1. Percentage of clear-night observations when the USL was present (i.e., wind speed < 0.1 m/s) as a function of average wind speed across the five Oklahoma Mesonet sites.

When the mesoscale wind speed was 3 m/s, the percentage of observations where the USL was present at NRMN was less than 5%, but that percentage was above 90% at CR18. When the mesoscale wind speed exceeded 5-6 m/s, the USL became rare (i.e., less than 10% of observations) at CR18 and was not observed at the other Micronet or Mesonet sites.

The correspondence between USL occurrence and ΔT is striking.

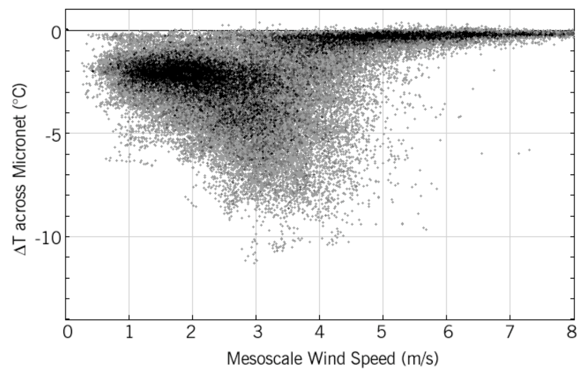

Figure 4.6. ΔT as a function of mesoscale wind speed.

With mesoscale wind speeds above 5 m/s, when the USL was not present at CR18, the temperature differences were minimal. And with mesoscale wind speeds below 2 m/s, when the USL usually was deep enough to cover the entire Micronet, ΔT was less then 3°C. But with mesoscale wind speeds of 2.5-5 m/s, the observed ΔT was significantly higher than when the mesoscale wind speed was above or below that range. The 2.5-5 m/s range corresponds extremely well with the range at which the USL is common at CR18 and relatively rare at CR17 (Fig. 4.1).

Large temperature differences across the Micronet (i.e., greater than 7°C) have not been observed with mesoscale wind speeds below 2 m/s; yet the largest temperature differences occurred when the mesoscale wind speed was near 3 m/s. Thus, a slight change in the mesoscale wind speed from 2 m/s to 3 m/s can have a strong impact on the temperature gradient across the Micronet.

5. CONCLUSIONS

The largest nighttime microscale temperature gradients do not occur on nights with the weakest wind. They occur when the ambient mesoscale wind speed is strong enough to allow mixing at higher elevations but sufficiently weak to allow a turbulence-free USL to develop across lower elevations. At the Crosstimber Micronet, this was shown to occur with mesoscale wind speeds between 2.5-5 m/s.

Large temperature gradients across the Micronet are very common because the 2.5-5 m/s range corresponds closely with the most frequent range of wind speeds observed across central Oklahoma (not shown). At other locations that are more sheltered or less sheltered than the Micronet, a different range of wind speeds is likely to create the largest microscale temperature gradients.

6. ACKNOWLEDGEMENTS

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