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THE IMPACT OF OKLAHOMA'S WINTER WHEAT CROP ON THE MESOSCALE ENVIRONMENT

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1. INTRODUCTION

The quantity, type, and condition of vegetation strongly influence the fluxes of energy and moisture in the atmospheric boundary layer (Taylor and Lebel 1998). Vegetation affects the surface albedo and, hence, the amount of net radiation entering the surface energy budget. The partitioning of this incoming energy into latent and sensible heat flux is determined, in part, by the amount of evapotranspiration from plants (Mahfouf et al. 1987). These fluxes, in turn, impact the temperature and moisture profiles in the lower atmosphere.

At the mesoscale, the differences in surface fluxes over vegetation and over dry, bare soil can result in differential heating which generates a sea breeze-like circulation, or a "vegetation breeze" (Segal et al. 1988; Mahfouf et al. 1987). Observations indicate that vegetation breezes and other "inland breeze" circulations can have an appreciable effect on the formation of shallow cumulus clouds (Rabin et al. 1990; Garrett 1982). Numerical simulations indicate that these circulations can provide preferred regions for focusing atmospheric instabilities and initiating convective development (Chen and Avissar 1994; Chang and Wetzel 1991; Mahfouf et al. 1987; Garrett 1982).

These studies and others highlight that mesoscale areas of vegetation can alter the convective environment on the mesoscale. However, these studies are somewhat limited in their real-world applicability. Past observational studies have focused on specific events (i.e., case studies), relatively short time periods, or small regions. Past numerical studies have modeled highly idealized simulations or have lacked an extended set of regional observations for model initialization and verification. In all cases, the authors have acknowledged these shortcomings and attribute the limitations to a lack of long-term, mesoscale observations across a large area. To fill this gap in adequate measurements, this study uses Oklahoma Mesonet surface data in its observational analyses. Future research also will employ these data in numerical simulations.

Winter wheat, which accounts for about three-fourths of U.S. wheat production, is sown in the fall and harvested in the late spring or early summer. During early spring, the mature wheat crop forms a swath about 150 km wide that extends from southwest Oklahoma into north-central Oklahoma and southern Kansas (Rabin et al. 1990). On either side of this band is sparse or dormant vegetation, especially in extreme western Oklahoma and the Panhandle. During the late spring or early summer, wheat is harvested and previously dormant grassland has grown. The result is a band of short stubble and bare soil surrounded by mature prairie grasses. Hence, Oklahoma's wheat belt affords scientists the opportunity to study a band of either abundant or sparse vegetation when compared to adjacent land. Just as important, the width of this band is consistent with the preferred scale of mesoscale vegetation breeze circulations – the local Rossby radius of deformation (Anthes 1984; Pielke et al. 1991; Chen and Avissar 1994). Oklahoma is an optimal real-world environment to examine mesoscale vegetative influences on the atmosphere.

This study examines whether monthly and daily averaged surface temperature and moisture fields are significantly affected by the evolution (e.g., during growth and within one month after harvest) of Oklahoma's winter wheat crop. Section 2 overviews the data used in this study, including Oklahoma Mesonet observations, land cover information, spectral vegetation index products, and county yields of Oklahoma wheat. Sections 3, 4, and 5 present preliminary results, acknowledgements, and cited references, respectively.

2. DATA

2.1 *Definition of Oklahoma's Wheat Belt*

For this study, the ***winter wheat belt*** is defined as the swath of land across Oklahoma and Kansas that is characterized by either winter wheat or a winter wheat/grassland mix as the foremost land use types. ***Oklahoma's wheat belt*** is defined as that subset of the winter wheat belt which is located solely within Oklahoma.

Land cover characterized as winter wheat or a mix of grassland and winter wheat was outlined and used as the definition of the border of Oklahoma's wheat belt. The land cover characterization used was the North America Land Cover Data Base from the U.S. Geological Survey (USGS). The data base was constructed from 1-km Advanced Very High-Resolution Radiometer (AVHRR) data spanning April 1992 through March 1993. It has a 1-km nominal spatial resolution and includes a Lambert Azimuthal Equal Area projection (Loveland et al. 1999).

2.2 *Observational Data*

This observational study utilizes land and atmospheric surface layer measurements from over 110 automated sites in the statewide Oklahoma Mesonet (http://www.mesonet.ou.edu; Brock et al. 1995). The Mesonet dataset extends from 1994 to the

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present and includes the following variables at every station: air temperature at 1.5 m, relative humidity at 1.5 m, wind speed and direction at 10 m, rainfall, station pressure, incoming solar radiation, soil temperature at 10 cm under both bare soil and natural sod cover. Additionally, 9-m air temperature, 2-m wind speed, 5-cm soil temperature under both bare soil and sod, and 30-cm soil temperature under sod have been measured by at least half of the Mesonet sites. All above-ground measurements are reported every five minutes; soil temperature measurements are reported every 15 minutes.

Quality control of the data is accomplished in several steps. First, laboratory personnel calibrate all Mesonet sensors prior to deployment in the field. Second, field technicians visit each site at least three times per year to clean equipment, mow vegetation, and conduct sensor intercomparisons. Third, the Mesonet central computer system operates an extensive set of automated quality assurance routines. These routines are detailed by Shafer et al. (2000) and include step, range, persistence, like-sensor, and nearest neighbor tests. Finally, a quality assurance meteorologist manually examines the data.

2.3 *Spectral Vegetation Indices*

The winter wheat crop's growth and condition was monitored through the use of a spectral vegetation index. Satellite reflectances are used to produce spectral vegetation indices, or SVIs, which describe some aspects of the vegetative state. SVIs are surrogates for the amount and condition of vegetation and for estimates of surface fluxes (Deering et al., 1992). Currently, SVIs rely on the fact that vegetation absorbs strongly in the red portion of the spectrum and scatters in the near-infrared.

In this study, products derived from the normalized difference vegetation index (NDVI), a common SVI generated from AVHRR data, are employed. NDVI is defined as follows:

$$\text{NDVI} = (\boldsymbol{NIR} - \boldsymbol{red}) / (\boldsymbol{NIR} + \boldsymbol{red}) \, ,$$

where ***NIR*** is the amount of energy measured in the near-infrared spectral band and ***red*** is the amount of energy measured in the red portion of the spectrum.

The primary NDVI-derived product used in this study is visual greenness, designated by the Forest Service Intermountain Fire Sciences Lab of the U.S. Department of Agriculture (Burgan and Hartford 1993). Visual greenness depicts the current greenness of the vegetation compared to a very green reference, such as an alfalfa field. Wet or densely vegetated areas appear green, and dry or sparsely vegetated areas appear red to tan. Values range from 0 to 100%. To generate this product, seven days of NDVI observations are composited at each pixel; the highest value of NDVI during that week is extracted into the image. The visual greenness product from the Oklahoma Fire Danger Model (Carlson and Engle 1998) is utilized in this study.

The author demonstrated a relationship between visual greenness and the health of the winter wheat crop by comparing a late April 2000 visual greenness map with the recorded status of that year's winter wheat harvest. By visual inspection, the counties occupied by the greatest percentage of dark green pixels (representing high vegetative greenness) coincided with the counties that also recorded the highest wheat production in Crop Year 2000 (Oklahoma Agricultural Statistics Service 2000). Conversely, counties which recorded relatively low wheat production in 2000 did not contain substantial acreages of winter wheat and were associated with lower visual greenness values.

3. RESULTS

Evidence that Oklahoma's winter wheat crop modifies the surface layer has been noted by scientists at the Oklahoma Climatological Survey since 1996. Manual quality assurance procedures for Oklahoma Mesonet data included the creation of monthly average maps for measured variables. Quality assurance managers noted a swath of anomalously high monthly averaged dew points across the growing wheat belt during November and April and a corresponding swath of anomalously warm monthly averaged air temperatures during July across the harvested wheat belt. Although these anomalies did not occur every year between 1996 and 2001, they illustrated the probability that Oklahoma's wheat belt modifies its mesoscale environment.

A preliminary analysis of Mesonet observations documents these previously identified anomalies. These analyses include monthly and daily anomalies.

3.1 *Overview of a Wheat Crop Year in Oklahoma*

An overview of the development of Oklahoma winter wheat will aid in the interpretation of all results. Because these results discuss Year 2000 data, the 1999-2000 winter wheat crop year is reviewed.

"Green-up" of the winter wheat fields commenced at the end of October 1999, followed by rapid crop growth during November. Crop dormancy began during December, and the crop's visual greenness slowly decreased from December 1999 through February 2000. The green-up recommenced during early March, and visual greenness values steadily increased to a peak during mid-April. By early May, other species of vegetation had started to grow across Oklahoma, masking the boundaries of the wheat belt. A minimum in visual greenness values across the wheat belt became noticeable during late May, revealing the onset of harvest of Oklahoma's winter wheat. By June, the disappearance of growing wheat was manifest by a distinct minimum in visual greenness. Except for the growth of other species near several river beds that cross the wheat belt, growing vegetation within the wheat belt remained sparse throughout the summer.

3.2 *Monthly Anomalies*

To determine whether Oklahoma's wheat belt significantly impacts the mesoscale environment, monthly averages of several variables were calculated. If the wheat belt's influence occurs rarely (e.g., on days with specific environmental conditions), then monthly averages should not show a distinct pattern of change across the wheat belt. If, however, the wheat belt frequently or continually affects its environment, then its location should be manifest in the monthly averages.

For this study, TMAX, TMIN, and TAVG are defined as the maximum, minimum, and average daily air temperatures (in deg C), respectively. In addition, DMAX is defined as the maximum daily dew point (in deg C). All derived variables are applicable at 1.5 m above ground and are calculated for midnight to midnight Central Standard Time (CST).

Figure 3.1 displays maps of TMAX averaged monthly for November 1999, April 2000, and July 2000. A distinct minimum in the values of monthly averaged TMAX is colocated with the winter wheat belt during November (Fig. 3.1a), a month previously noted to be a period of rapid wheat growth. From 1994 through 2000 (not shown), this minimum consistently appears in the monthly averaged TMAX for November. Maps of monthly averaged values of TMAX for the period of December 1999 through April 2000 (Fig. 3.1b) display a similar cool bias over the dormant or growing wheat. The most pronounced latitudinal gradient in TMAX values (about 1-1.5˚C over 80-100 km) occurs across north-central Oklahoma, including Grant, Garfield, and Alfalfa counties. These same counties produced the highest wheat yields during Crop Year 2000.

During May 2000 (not shown), the pattern in monthly averaged TMAX across Oklahoma became disorganized because wheat belt temperatures no longer exhibited a distinct cool anomaly. As noted earlier, May is identified as the month when the green-up of other vegetation species occurs statewide. By June, the month when the harvest of wheat occurs, a warm anomaly commences and remains evident in the data through July (Fig. 3.1c) and August. In fact, during 92 (out of 183) days from June and July of 1999, 2000, and 2001, there was a distinct warm anomaly in daily maximum air temperatures. Although the July warm anomaly is persistent from year to year, the TMAX pattern during August typically becomes disorganized. By August, vegetation generally dies or becomes senescent across the western half of Oklahoma. Monthly averaged values of TMAX during September and October 2000 (not shown) do not reveal any definitive anomaly across the wheat belt.

The characteristic patterns noted above in the maps of monthly averaged TMAX also are apparent in maps of monthly averaged TAVG (not shown), though the magnitude of all anomalies is reduced for the monthly averages of the latter variable. Maps of daily minimum temperature (TMIN) averaged for each month (not shown) primarily exhibit the marriage of a latitudinal temperature gradient (i.e., temperature increases as latitude decreases) and an elevation gradient (i.e., temperature increases as elevation decreases). Hence, the warmest monthly averaged values of TMIN occur in southeast Oklahoma, which corresponds to the lowest elevation and the most southern latitude in Oklahoma.

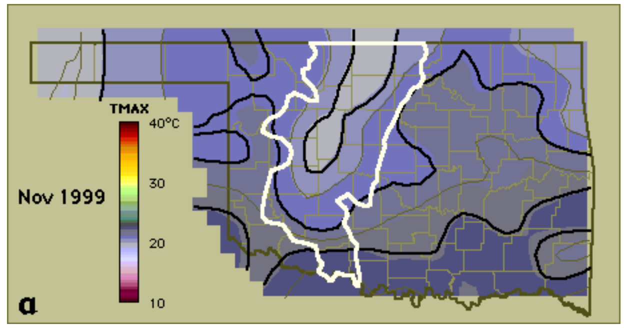

Figure 3.1a. Map of the monthly averaged values of TMAX (maximum daily air temperature) during November 1999. The white outline represents the defined boundary of Oklahoma's winter wheat belt.

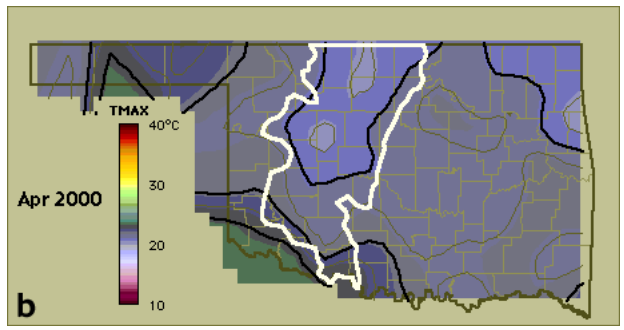

Figure 3.1b. Same as Fig. 3.1a except for April 2000.

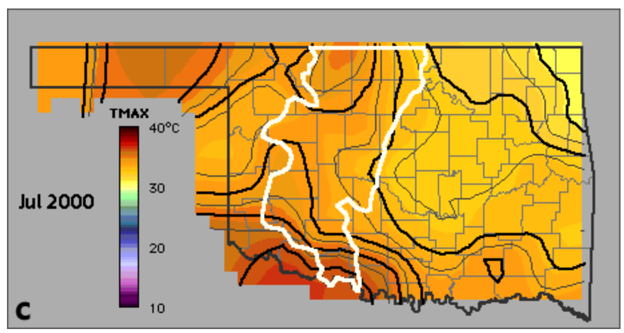

Figure 3.1c. Same as Fig. 3.1a except for July 2000.

The relationship between the surface-level moisture field and winter wheat growth also is demonstrated in maps of monthly averaged values of DMAX (maximum daily dew point). Figure 3.2 displays the monthly averaged values of DMAX during November and April 2000. A slight moist bias exists over Oklahoma's wheat belt between November and April. During May, the statewide pattern begins to shift to a predominantly east-west gradient, which is attained by July (not shown). The meridional pattern continues through September 2000.

Although its intensity varies from year to year, a moist anomaly over the wheat belt occurs during all Aprils from 1995 to 2001 (not shown), with perhaps the strongest signal evident in west-central and north-central Oklahoma. A minimum of DMAX east of the wheat belt along the Oklahoma-Kansas border enhances the appearance of the moist anomaly.

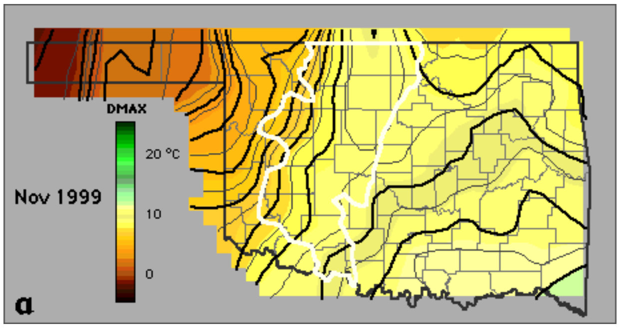

Figure 3.2a. Map of the monthly averaged values of DMAX (maximum daily dew point) during November 1999. The white outline represents the defined boundary of Oklahoma's winter wheat belt.

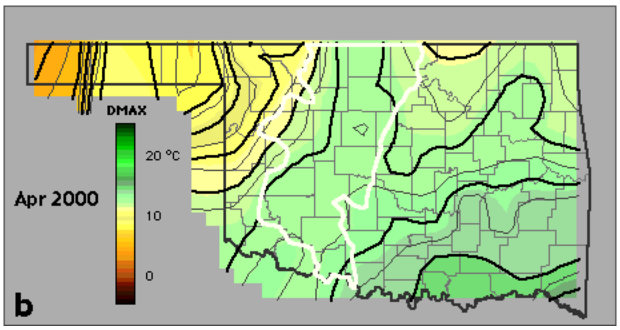

Figure 3.2b. Same as Fig. 3.2a except for April 2000.

3.3 *Daily Anomalies*

Using data from the period 1999 to 2001, the author documented about 50 days between 15 March and 1 June that reveal evidence of heightened DMAX values (daily maximum dew point) over Oklahoma's winter wheat belt compared to adjacent grassland. By two-week periods, the number of days classified as showing evidence of these heightened DMAX values is 19 days between 15 March and 31 March, 12 days between 1 April and 15 April, 12 days between 16 April and 30 April, six days between 1 May and 15 May, and two days between 16 May and 1 June. Over half of these cases reveal a DMAX enhancement only across five or six counties in north-central Oklahoma. It is probable that the advection of moisture from the Gulf of Mexico masks some DMAX signatures from the wheat fields across southern Oklahoma.

Figures 3.3 and 3.4 display DMAX for 4 April and 5 April 2000, spring days when Oklahoma's wheat crop significantly impacted its environment. The white outline represents the boundary of the wheat belt defined for this study. The associated visual greenness map is displayed in Fig. 3.5 for the week ending 6 April 2000.

3.3.1 *4 April 2000*

On 4 April 2000, winds across the main body of Oklahoma were light and southerly or southeasterly throughout the day, with wind speeds strengthening slightly during the afternoon. Winds across the Panhandle were westerly until about 1700 CDT, when they began to veer to the north. Statewide average wind speeds were 3.6 $m\ s^{-1}$. Rainfall events associated with frontal passages occurred on 28 March, 29 March, 31 March, and 1 April, with the most significant rainfall occurring in southwestern Oklahoma.

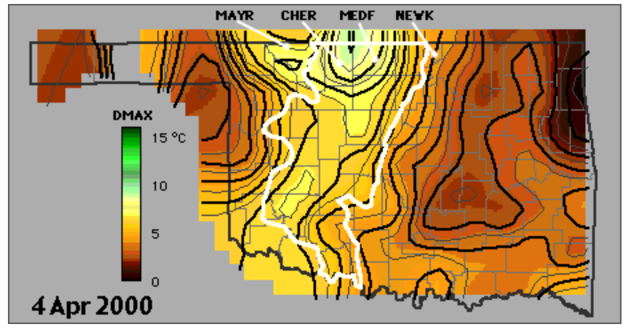

Figure 3.3. Map of the maximum dew points for 4 April 2000. The white outline represents the defined boundary of Oklahoma's winter wheat belt.

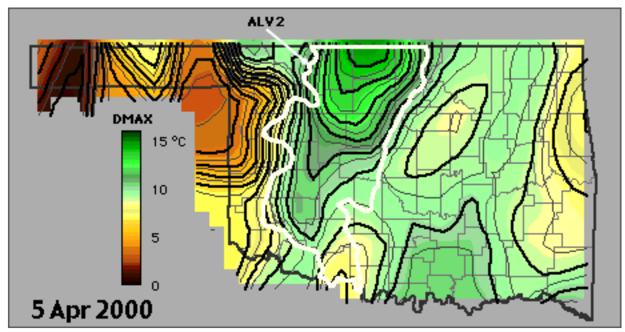

Figure 3.4. Same as Fig. 3.3 except for 5 April 2000.

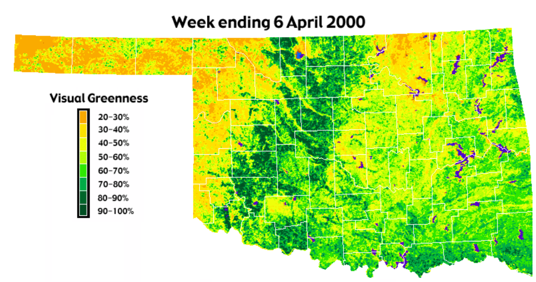

Figure 3.5. Visual greenness map from the Oklahoma Fire Danger Model for the week ending 6 April 2000. The dark band in western Oklahoma represents growing wheat.

Patterns in the DMAX field for 4 April (Fig. 3.3) mimic the pattern in the visual greenness map (Fig. 3.5) moreso than they do the rainfall pattern of the previous week. May Ranch (MAYR), which received 3.5 cm of rain from 27 March to 4 April, observed a maximum dew point of 5.5˚C on 4 April; Cherokee (CHER), which recorded 0.8 cm of rain during the same week, observed a maximum dew point of 10.7˚C on 4 April. On the eastern side of the wheat belt, Newkirk (NEWK), which received 3.1 cm of rain during the previous week, measured a maximum dew point of 5.2˚C on 4 April. On the other hand, Medford (MEDF) recorded 1.7 cm of weekly rainfall and a DMAX of 9.7˚C on 4 April. A host of other comparisons could be made to illustrate the efficiency at which growing vegetation recirculates water back to the atmosphere as compared to non-growing vegetation.

On 4 April at 1700 CDT, a 4˚C dew point difference existed between the Cherokee and Alva Mesonet sites (31 km apart), and a 9˚C difference was observed between Cherokee and May Ranch (64 km apart). About 1700 CDT, the weather radar at Vance Air Force Base (KVNX), located in north-central Oklahoma, detected several isolated convective elements within 100 km of the radar. Movement of the convection was toward the east or northeast, corresponding to the 10-m wind directions. At 1830 CDT, KVNX detected the development of a southwest-to-northeast-oriented thin line in southeast Woods County. Movement of the thin line was toward the northwest, perpendicular to that of surrounding echoes, including one echo that moved within 10 km of the thin line. By 1930 CDT, the thin line was undetectable. Between 1700 and 1830 CDT, winds at the Alva Mesonet site (ALV2) backed from 220˚ to 165˚, reflecting the passage of a surface boundary. During this 90-minute period, dew points increased by 3.3˚C at Alva. Hence, it is possible that the thin line represented the boundary of a vegetation breeze. A detailed examination of this possibility is reserved for future work.

3.3.2 *5 April 2000*

No rain fell during the clear days of 4 April and 5 April; however, wind speeds significantly increased from one day to the next in response to an approaching low pressure system. Winds were southerly or southwesterly across the state for most of the day on 5 April, with wind speeds averaging 6.4 m s^{-1} statewide and gusting to about 15 m s^{-1}. Wind speeds in western Oklahoma were slightly higher than those in the eastern half of the state. Skies on 5 April were uniformly clear statewide.

A comparison of the DMAX fields on 4 April (Fig. 3.3) with those on 5 April (Fig. 3.4) demonstrates a dramatic intensification of transpiration from the 4th to the 5th. The primary features evident in Figure 3.4 are the region of significantly elevated DMAX values over the wheat belt and the associated intensification (as compared to 4 April) of the DMAX gradient in far western Oklahoma. Daily maximum dew points within the wheat belt ranged from 11-17˚C whereas those just east of the wheat belt ranged from 9-11˚C. DMAX values just west of the wheat belt ranged from 4-10˚C, with two notable exceptions: 12.4˚C at Buffalo and 12.0˚C at Freedom. The Buffalo and Freedom Mesonet sites are located near wheat fields, although they were installed well outside of the defined wheat belt. In particular, at Freedom, wheat fields are grown in a small region just southwest of the Freedom site.

A time series of 5-minute dew point and wind direction observations from the Freedom site (Fig. 3.6) dramatically illustrates the advection of moisture from the wheat fields. When winds were from the northwest (between 270˚ and 340˚), dewpoint temperatures tended to decrease or remain steady. In contrast, winds between 230˚ and 270˚ were associated with rapid increases in dew point. The impact was most dramatic between 1300 and 1400 CDT, when the wind direction repeatedly shifted from just north of due west (>270˚) to just south of due west (<270˚). Not surprisingly, the dewpoint temperatures repeatedly decreased and increased by 2-3˚C.

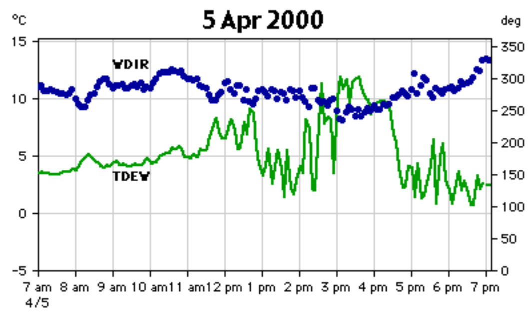

Figure 3.6. Graph of 5-minute measurements of dew point (solid line, TDEW) and wind direction (dots, WDIR) at the Freedom Mesonet site between 0700 and 1900 CDT on 5 April 2000.

As in the 4 April 2000 case, KVNX detected the development of a thin line that was oriented from the southwest to the northeast and was located in southeast Woods County. At 1630 CDT on 5 April, the thin line was evident in the radar's precipitation mode. While other nearby echoes progressed toward the east, the thin line remained quasi-stationary until 1830 CDT, when it began to move northwestward. As before, the thin line became undetectable by 1930 CDT. Winds at the Alva Mesonet site backed from 253˚ at 1620 CDT to 192˚ at 1625 CDT; a corresponding increase of 7.7˚C occurred in the dew point observations during this 5-minute period. Between 1630 and 1845 CDT, the wind directions at Alva varied between 178˚ and 288˚; between 1845 and 1930 CDT, winds remained southerly or south-southeasterly. These wind measurements appeared to coincide with the thin line's movement. The observations are consistent with documented attributes of a vegetation breeze. Further investigation is required to confirm that vegetation breezes occurred on 4 April and 5 April.

4. CONCLUSION

The results of this study demonstrate that Oklahoma's winter wheat belt has a dramatic impact on the near-surface temperature and moisture fields, both during the period when winter wheat is growing and during the two-month period after harvest. In particular, the following results are noted in this study:

1. Maps of monthly averaged values of TMAX (maximum daily air temperature) for Crop Year 2000 display a cool anomaly over the growing wheat from November 1999 through April 2000. A warm anomaly exists over Oklahoma's wheat belt during June and July 2000.
2. Maps of monthly averaged values of DMAX (maximum daily dew points) for Crop Year 2000 display a slight moist anomaly over the growing wheat from November 1999 through April 2000. The moist anomaly is evident during each April between 1995 and 2001.
3. From 1999 to 2001, the author has documented about 50 days between 15 March and 1 June that show evidence of heightened DMAX values over Oklahoma's winter wheat belt as compared to adjacent grassland. More than half of these days exhibit dewpoint enhancements — but only across five or six counties in north-central Oklahoma, where the winter wheat yields were the largest.
4. From 1999 to 2001, the author has documented about 90 days between 1 June and 31 July that show evidence of heightened TMAX values over Oklahoma's harvested wheat belt as compared to adjacent, growing grassland. These warm anomalies are most prominent across the harvested areas of north-central Oklahoma.
5. Case studies from Spring 2000 indicate that the presence of growing wheat can impact the maximum daily dew points on days with both weak and moderate winds, in both moist and dry air masses, and both early and late in the spring wheat growing season. Days with clear skies were selected to maintain uniform solar forcing across the state.
6. Examination of wind and dew point data from the Freedom Mesonet site demonstrates the impact that moisture advection from wheat fields can have on local dew point measurements.
7. On two of the case study days (4 April and 5 April), evidence of a possible vegetation breeze in Woods County has been documented.

5. ACKNOWLEDGEMENTS

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