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Kelsey N. Scheitlin
Longwood University, scheitlinkn@longwood.edu

P. Grady Dixon
Mississippi State University

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Diurnal Temperature Range Variability due to Land Cover and Airmass Types in the Southeast

KELSEY N. SCHEITLIN

Department of Geography, The Florida State University, Tallahassee, Florida

P. GRADY DIXON

Department of Geosciences, Mississippi State University, Mississippi State, Mississippi

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ABSTRACT

This study examines the relationship between diurnal temperature range (DTR) and land use/land cover (LULC) in a portion of the Southeast. Temperature data for all synoptically weak days within a 10-yr period are gathered from the National Climatic Data Center for 144 weather stations. Each station is classified as one of the following LULC types: urban, agriculture, evergreen forest, deciduous forest, or mixed forest. A three-way analysis of variance and paired-sample *t* tests are used to test for significant DTR differences due to LULC, month, and airmass type. The LULC types display two clear groups according to their DTR, with agricultural and urban areas consistently experiencing the smallest DTRs, and the forest types experiencing greater DTRs. The dry air masses seem to enhance the DTR differences between vegetated LULC types by emphasizing the differences in evapotranspiration. Meanwhile, the high moisture content of moist air masses prohibits extensive evapotranspirational cooling in the vegetated areas. This lessens the DTR differences between vegetated LULC types, while enhancing the differences between vegetated land and urban areas. All of the LULC types exhibit an annual bimodal DTR pattern with peaks in April and October. Since both vegetated and nonvegetated areas experience the bimodal pattern, this may conflict with previous research that names seasonal changes in evapotranspiration as the most probable cause for the annual trend. These findings suggest that airmass type has a larger and more consistent influence on the DTR of an area than LULC type and therefore may play a role in causing the bimodal DTR pattern, altering DTR with the seasonal distribution of airmass occurrence.

1. Introduction

Variations in daily temperature across an area can often be ascribed to processes in surface and atmospheric interactions related to differences in land use/land cover (LULC) throughout a region. Urbanization, agriculture, and forests have all been shown to affect the temperature profile of an area, including the diurnal temperature range (DTR; Gallo 1996; Sun et al. 2006). Mearns et al. (1995) and Durre and Wallace (2001a) mention the importance of a detailed understanding of soil–vegetation–atmosphere interaction to accurately simulate seasonal DTR variations over an area.

Diurnal temperature range research involving multiple LULC types in one continuous region and time period is scarce, hindering simple comparisons between LULC types. The goal of this study is to provide more insight into the relationship between LULC and DTR by analyzing predominant LULC types (urban, agriculture, deciduous forest, evergreen forest, and mixed forest) within spatially and temporally continuous bounds. The study region is a fairly homogeneous area (with respect to climate, elevation, etc.) in the Southeast (Fig. 1). This allows for comparisons between many LULC types.

Two additional variables will be analyzed. Since air masses play such a large role in the weather over an area, their effect on DTR will be considered. Additionally, agricultural and forested areas experience seasonality in vegetation, so month of the year must be taken into account.

Prior studies note a bimodal DTR pattern in the southern United States, with two annual peaks of DTR (Leathers et al. 1998; Durre and Wallace 2001a; Sun

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Corresponding author address: Kelsey N. Scheitlin, Dept. of Geography, The Florida State University, Tallahassee, FL 32306.
E-mail: kns07g@fsu.edu

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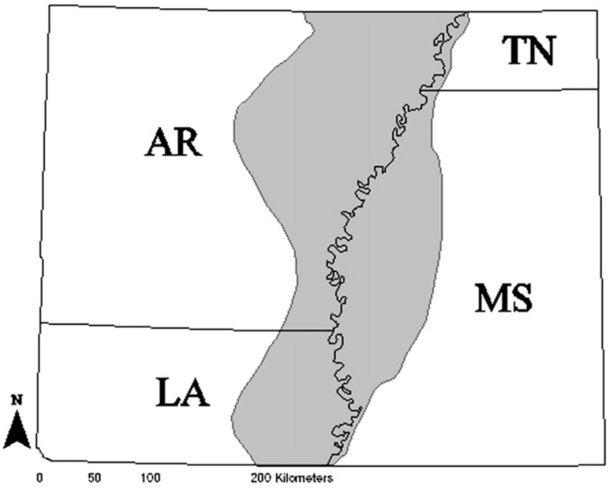

FIG. 1. Study area, with the shaded region representing ''the Delta,'' a portion of the region in the flood plain of the Mississippi River dedicated to agriculture.

et al. 2006). The pattern has been largely attributed to seasonal changes in evapotranspiration rates in the summer, and less solar radiation in the winter (Durre and Wallace 2001a). Leathers et al. (1998) introduce the idea of an additional unknown variable impacting DTR that may be unique to the southern United States that remains unspecified. Durre and Wallace (2001b) suggest the regional influx of dry continental air or trends in sunshine duration due to the Pacific decadal oscillation as possible reasoning. Separating the region into LULC types and analyzing airmass and seasonal DTR variations can provide additional insight into the causality of the bimodal pattern.

Thus, while the goal of this research is to analyze the effects of LULC on DTR, three variables (LULC, air mass, and season) are ultimately analyzed. The outcomes include the following:

- a comparison of the strength of the variables on DTR,
- information on the relationship between LULC and DTR,
- information on the relationship between air mass and DTR, largely due to the temperature and moisture content of an air mass, and
- an annual DTR pattern for the study region.

2. Background

The most commonly studied LULC and temperature phenomenon is the urban heat island, which was first researched nearly two centuries ago in London (Howard 1833). Since then, it has been shown that many aspects of urbanization can influence daily temperature, including changes in albedo (Black and Tarmy 1963) and evapotranspiration rates (Oke 1987). Grimmond and Oke (1999) found that in 10 major cities, evapotranspiration rates were well below surrounding areas. The lower evapotranspiration rate of cities is a large factor in the increased daytime high temperature (Taha 1999). The effect can be lessened with an influx of green spaces in urban areas (Dimoudi and Nikolopoulou 2003).

The urban heat island is often thought of as a daytime phenomenon, but it is even stronger at night (Oke 1987). A study in Seoul, South Korea, indicates that the average maximum urban heat island intensity occurs around 0300 LST, resulting in a smaller urban DTR (Kim and Baik 2005). According to Gallo (1996), weather stations classified as urban experience the smallest DTR of all land uses 74% of the time. Oke (1982) adds that the strength of the heat island increases in the warm season, therefore the DTR should change seasonally as well.

While less evapotranspiration in urban areas causes an increase in the daytime high temperature, increased evapotranspiration in vegetated areas causes daytime cooling during the green season. Bonan (2001) discovered that deforestation for agriculture in the Midwest, which is often accompanied by regular irrigation, acted to decrease the daily maximum temperature by approximately 1.0°C. The cooling effect is more of a factor during the day when energy is available for plants to evapotranspire, resulting in a smaller DTR, especially during the green season (Bonan 2001).

The urban and agricultural DTR examples show that albedo and evapotranspiration play a large role in the DTR. Thus, DTRs should also vary between forest types (e.g., deciduous and evergreen forests) that have differing albedo and evapotranspiration rates. Forest albedoes and evapotranspiration rates should also change seasonally, especially as deciduous forests experience leaf abscission. Based solely on evapotranspiration rates, the deciduous forests would most likely experience smaller DTRs than the evergreen forests during the green season when deciduous forests have higher evapotranspiration rates (Swift et al. 1975). Albedo should have the opposite effect, as the evergreen forests have a smaller albedo than the deciduous forests, which should allow the evergreen forest to have a smaller DTR (Stewart 1971; Oke 1987).

Although many studies associate LULC with regional temperature variability, the influence of season and air mass must not be ignored. Seasonality in vegetation (and subsequent evapotranspiration rates) and urban heat island strength provide seasonal variations in DTR. Durre and Wallace (2001a) and Sun et al. (2006) found that the southern United States experiences annual peaks of DTR in the spring and autumn, and minima in the winter and midsummer, possibly attributing this pattern

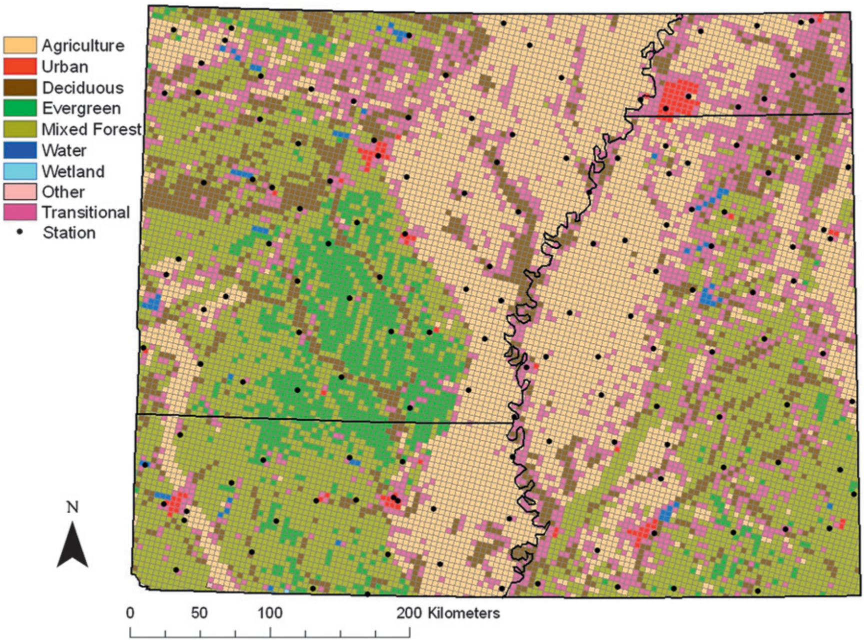

FIG. 2. Weather stations and LULC categorization after simplification scheme.

to vegetation growth and accompanying changes in evapotranspiration rates. Additionally, changes in air mass can provide daily DTR variability, as the air mass controls the temperature and amount of water vapor in an area, both of which affect surface temperature (Shukla and Mintz 1982).

This research aims to provide further understanding of the effects of urban areas, agriculture, deciduous forests, and evergreen forests on DTR in a portion of the Southeast. Several authors have noted the difficulty finding correlations between synoptic-scale patterns and surface meteorological observations, because synoptic situations are often related to a large variety of surface conditions (Kalkstein et al. 1996; Durre and Wallace 2001b). To eliminate any synoptic forcing and to isolate DTR as a variable, only synoptically weak days during the 10-yr time period (1995–2004) are used in the analysis.

3. Data: Sources, classification, and day selection

Data required for this study include LULC data, temperature data (weather station observations), and airmass data. The airmass data and weather observations are not only variables in the analysis, but are also used to classify synoptically weak days.

DTR studies use surface observations (Leathers et al. 1998; Dai et al. 1999; Bonan 2001; Durre and Wallace 2001a,b; Sun et al. 2006), satellite data (Dai et al. 1999; Sun et al. 2006), and/or modeled data (Stone and Weaver 2003; Braganza et al. 2004) for land use classification and temperature data. This study utilizes remotely sensed LULC data to classify surface weather stations by land use. Temperature data are surface observations from the weather stations.

The LULC data are obtained from the U.S. Geological Survey (USGS) National Land Cover Dataset (NLCD), based on 30-m Landsat Thematic Mapper data from the Multiresolution Land Characterization Consortium (Vogelmann et al. 1998). Since small LULC sections do not have great effects on the climate, a more simplified LULC map is made using grid cells of approximately 5 km, provided by the Hydrologic Rainfall Analysis Project (HRAP) grid from the National Weather Service (NWS). Each grid cell in the study region is classified based on its most dominant LULC, using a classification procedure similar to Scott et al. (2005). The outcome is a simplified LULC map, with each grid cell classified as urban, agriculture, water, evergreen forest, deciduous forest, mixed forest, or transitional (Fig. 2). Gallo (1996) shows that LULC effects on DTR are evident in LULC-type averages in a 10-km radius, thus the 5-km grid cells used here should well represent the DTR of the area.

The DTR data are obtained from all suitable National Weather Service cooperative stations in the study region. To be considered suitable, the stations must have daily temperature reports available at the National Climatic Data Center (NCDC) from 1995 to 2004. In the study region, 144 weather stations pass this criterion. All of the stations recorded temperatures from midnight to midnight local standard time, reporting the maximum and

TABLE 1. Number of stations S and the mean DTR (°C) for each LULC type in the study area.

LULC	S	DTR
Urban	6	12.70
Deciduous	11	13.96
Evergreen	7	13.86
Mixed forest	39	13.53
Agriculture	57	12.67
Mean	—	13.34
Total	120	—

minimum temperatures during the 24-h period. While individual stations may be missing values on particular days, they must have recorded observations for the entire study period.

Each of the suitable stations is plotted on the LULC map and classified by the LULC type of grid cell beneath it. Table 1 shows the number of stations S classified as each LULC type, except for the 24 stations classified as transitional, which will not be used in the analysis. Although stations are categorized by LULC, it is acknowledged that stations exhibit individual characteristics such as exposure, sky view, and topography. The large sample of stations and fairly homogeneous topography should ensure that LULC effects prevail in DTR analysis. Additionally, Stone and Weaver (2003) show that the effects of soil moisture and other surface parameters are at least comparable to solar effects on DTR. Thus, the LULC effects should overcome minor site dissimilarities.

Airmass data are obtained from the Spatial Synoptic Classification (SSC; available online at http://sheridan.geog.kent.edu/ssc.html). There are four SSC sites within the study area (Little Rock, Arkansas; Memphis, Tennessee; Jackson, Mississippi; and Shreveport, Louisiana). Each day the presiding air mass at each site is defined as one of the following SSCs: dry polar (DP), dry moderate (DM), dry tropical (DT), moist polar (MP), moist moderate (MM), and moist tropical (MT) (Sheridan 2002).

Since synoptic-scale forcing minimizes the influence of smaller-scale variables (such as LULC type) on temperature, only synoptically weak days will be used in the analysis. The criteria used to define synoptically weak days are similar to those used by Brown and Arnold (1998). First, the 0000 and 1200 UTC soundings from both sounding sites within the study area (Little Rock and Jackson) are gathered from NCDC for every day within the 10-yr time period. For a day to be considered synoptically weak, both soundings must indicate 850-mb winds less than 15 kt (7.7 m s^{-1}) and surface wind speeds less than 10 kt (5.1 m s^{-1}). Also, to account for any synoptic forcing in the area, all four SSC sites in the study area must indicate the same airmass type. These criteria should assure that all other meteorological variables that affect DTR are either not present or mostly constant throughout the study area. This includes, but is not limited to, cloud cover, wind speed, and precipitation. While these are all factors contributing to the DTR of an area, negating the influence of these variables allows for a thorough analysis of the effects of LULC type.

The above selection criteria result in 236 days deemed suitable for the purposes of this study, consisting of over 30 000 observations. Table 2 shows the number of monthly observations for each LULC. The winter months do not provide as large of a sample as the remainder of the year. While uneven, all of the LULC types have a large sample of at least 1300 observations.

Each observation must be associated with a DTR for its respective location. The temperature data are gathered from NCDC for the 144 classified NWS stations. DTRs for all synoptically weak days are calculated by using $T_{\max} - T_{\min}$. The resulting DTRs are used in the following section to further investigate the relationship

TABLE 2. Number of monthly observations used in this study for each LULC type, and the total for each month and LULC type.

Month	Urban	Deciduous	Evergreen	Mixed forest	Agriculture	Transitional	Total
1	16	31	19	94	151	65	376
2	45	86	54	267	418	177	1047
3	45	94	63	289	461	204	1156
4	67	125	78	400	603	253	1526
5	46	87	50	260	404	171	1018
6	179	343	203	1048	1626	708	4107
7	234	447	266	1371	2135	922	5375
8	286	565	350	1744	2680	1129	6754
9	178	347	211	1064	1679	715	4194
10	141	292	185	892	1392	584	3486
11	53	110	70	328	508	215	1284
12	10	22	13	66	103	44	258
Total	1300	2549	1562	7823	12 160	5187	30 581

TABLE 3. Results of three-way ANOVA for the DTR based on air mass, month, and LULC classifications, including mean-square error (MS), *F* value, and significance. In addition to an individual analysis of the three variables, the ANOVA tests two-way interactions between variables (·/·), and the three-way interaction (·/·/·) of all three variables. The three-way interaction is the only nonsignificant interaction.

Variable(s)	MS	*F* value	Significance
Air mass	258 970	8405.8	<0.001
Month	35 814	1162.5	<0.001
LULC	2560	83.1	<0.001
Air mass/month	1352	43.9	<0.001
Air mass/LULC	228	7.4	0.006
LULC/month	260	8.4	0.003
Air mass/month/LULC	7	0.2	0.644

TABLE 4. Mean DTR (°C) of each LULC type for every SSC, and the overall airmass mean. A boldface number indicates the LULC with the lowest DTR for each air mass.

SSC	Urban	Deciduous	Evergreen	Mixed	Agriculture	Mean
DT	16.18	17.64	17.52	17.24	**15.86**	16.89
DM	14.59	16.05	16.11	15.59	**14.46**	15.36
DP	14.34	14.82	15.94	14.69	**12.96**	14.55
MT	11.72	12.66	12.43	12.13	**11.49**	12.09
MM	**8.09**	9.64	9.37	9.64	9.42	9.23
MP	**4.79**	7.83	7.16	8.02	7.57	7.07

between LULC and DTR in the Southeast, with respect to season and air mass.

4. Analysis and results

For a simple comparison between LULC types, the overall mean DTRs are calculated for each LULC (Table 1). The smallest mean DTRs occur in agricultural areas and urban areas, while the forested areas report larger DTRs. This agrees with prior research because, as previously discussed, urban and agricultural areas have been shown to maintain relatively small DTRs. It is important to note that although urban and agricultural areas experience similar DTRs, the basis for their relatively small DTRs is different (see Bonan 2001; Oke 1982).

To test for significant differences between DTRs, a three-way analysis of variance (ANOVA) is used. A three-way ANOVA allows for an analysis of each individual variable (LULC, air mass, and month), as well as two-way interactions between two variables and a three-way interaction inclusive of all three variables. Two-way ANOVA interactions are an ideal way of testing the significance of two of the variables while controlling for the third.

The results show that there are significant differences in the means within the LULC, air mass, and month groups (Table 3). The two-way interactions between air mass and LULC, month and LULC, and air mass and month are also significant. In an ANOVA, if the interactions are significant then the most complete story is told by the interaction of the variables. Therefore, the two-way interactions between the variables are considered in the analysis. The complex three-way interaction is not significant, and is not subject to further interpretation.

While an ANOVA is helpful in determining that there is a variation in means, Tukey's post hoc test and paired sample *t* tests depict where these differences lie. Both tests reported similar results, and the results from the *t* tests are discussed in this section.

The remaining results are provided in two subsections. The first subsection addresses the interaction between LULC and air mass in influencing the DTR, and the second section addresses the annual DTR pattern, or more specifically, the influence of the interaction between LULC and month, and air mass and month. Each section provides descriptive statistics (DTR means) followed by a discussion of interesting *t*-test results.

a. LULC and air mass

The presiding air mass is a dominant factor controlling the temperature and humidity of an area. This is especially relevant to this study if evapotranspiration plays such a large role in the differences between the DTRs of different LULC types, as evapotranspiration rates are highly dependent upon available energy and moisture.

For a simple comparison between LULC and airmass types, the mean LULC DTRs are calculated for each air mass (Table 4). As shown here, the range of the DTR values is larger among the air masses for any particular LULC type than across LULC types for any particular air mass. All of the LULC types experience their DTRs in the same order relative to airmass type, with DT providing the largest DTR, followed by DM, DP, MT, MM, and MP. While the results of the ANOVA highlight the importance of the interaction between all variables, this shows that air mass likely has a more consistent influence on DTR than LULC. Supporting this idea, reading across the rows of the table clearly shows that the ranking of LULC type varies by air mass.

Also evident in Table 4, the order of the airmass DTRs shows that moisture most likely plays a larger role in DTR than temperature, since the DTRs are ranked first by moisture content, then by temperature. All of the dry air masses have larger DTRs than all of the moist air masses, and after being separated by moisture content, the warmer air masses have a larger DTR than the cooler air masses. This reinforces the suggestion of Durre and Wallace (2001b) that circulation patterns associated with small DTRs exhibit negative 1000-mb height anomalies

TABLE 5. Mean DTR difference (°C) between each LULC type for the dry air masses. A negative number indicates that the LULC type labeled in the column has a DTR less than the LULC type in the row against which it is being tested. An asterisk indicates a statistically significant difference ($\alpha = 0.05$).

Dry tropical

LULC	Urban	Deciduous	Evergreen	Mixed
Deciduous	−1.46*			
Evergreen	−1.35*	0.11		
Mixed	−1.07*	0.39	0.28	
Agriculture	0.32	1.78*	1.67*	1.39*

Dry moderate

LULC	Urban	Deciduous	Evergreen	Mixed
Deciduous	−1.46*			
Evergreen	−1.51*	−0.05		
Mixed	−1.00*	0.46*	0.51*	
Agriculture	0.13	1.59*	1.64*	1.13*

Dry polar

LULC	Urban	Deciduous	Evergreen	Mixed
Deciduous	−0.48			
Evergreen	−1.60*	−1.12*		
Mixed	−0.36	0.13	1.25	
Agriculture	1.38*	1.86*	2.98*	1.73*

TABLE 6. As in Table 5, but for moist air masses.

Moist tropical

LULC	Urban	Deciduous	Evergreen	Mixed
Deciduous	−0.93*	—	—	—
Evergreen	−0.71*	0.22*	—	—
Mixed	−0.41*	0.53*	0.30*	—
Agriculture	0.23*	1.16*	0.94*	0.64*

Moist moderate

LULC	Urban	Deciduous	Evergreen	Mixed
Deciduous	−1.55*	—	—	—
Evergreen	−1.27*	0.27	—	—
Mixed	−1.54*	0.01	−0.27	—
Agriculture	−1.31*	0.23	−0.04	0.22

Moist polar

LULC	Urban	Deciduous	Evergreen	Mixed
Deciduous	−3.04*	—	—	—
Evergreen	−2.36*	0.68	—	—
Mixed	−3.22*	−0.19	−0.87	—
Agriculture	−2.77*	0.27	−0.41*	0.45*

likely associated with moist marine air. Gough (2008) adds that moisture, especially during the warm season, limits nighttime cooling resulting in a smaller DTR.

Focusing on the dry air masses, Table 4 shows that agriculture reports the lowest DTR for all three air masses, followed by urban areas. Paired sample *t* tests show that while all other LULC differences proved to be statistically significant ($\alpha = 0.05$), agricultural and urban areas only show a statistically significant difference while under the DP air mass (Table 5).

Evapotranspiration could likely be the reason for the differences between agriculture and the other vegetated LULC types. While under the dry air masses, agricultural areas experience relatively high DTRs compared to the forests. This may result from higher evapotranspiration rates in the agricultural areas, in part due to increased moisture available from irrigation. The similarities between agriculture and urban areas are not much of a surprise because, as discussed earlier in this section, they both experience relatively smaller DTRs. There are a few possible reasons for their significant differences during the DP air mass, including the lack of energy for evapotranspiration or a seasonal aspect of the LULC types, since the DP air mass usually occurs in the cooler months.

The only notable significant difference between the forest types while under the dry air masses also occurred under the DP air mass, with deciduous having a mean DTR approximately 1.1°C less than that of the evergreen forests. These results are the opposite of what one could expect because of evapotranspiration, as deciduous forests should experience greater evapotranspirational cooling than evergreen forests. It makes sense that evapotranspiration is not the cause, since the DP air mass usually occurs when deciduous forests do not have leaves and evapotranspiration is less of a factor. One possible explanation could be that the lack of leaves in deciduous forests in the cooler months allows for more radiative cooling than in evergreen forests.

The *t* tests between LULC types for the moist air masses show urban areas having a statistically significantly smaller DTR ($\alpha = 0.05$) from all of the other LULC types, including agriculture for the MM and MP air masses (Table 6). The vegetated LULC types experienced no notable differences (although their small differences under the MT air mass are significant). The DTR differences between agriculture and urban areas must be due to moisture since they were not seen in the dry air masses. This leads the authors to believe that during the MP and MM air masses there is not enough energy available to allow evapotranspiration in the already moist environment. Thus, the vegetated areas are not undergoing as much evapotranspirational cooling and they are warming up more during the day, causing a greater DTR. This results in urban areas having significantly smaller DTRs than surrounding areas. The lack of vegetation during the months of the MP air mass, as well as the already cold air in place, also prohibits evapotranspirational cooling from occurring. During all three moist air masses the air is likely closer to being

TABLE 7. Mean DTR (°C) differences between each SSC in urban areas. A negative number indicates that the SSC labeled in the column has a DTR lower than that of the SSC in the row against which it is being tested. An asterisk indicates a statistically significant difference ($\alpha = 0.05$).

SSC	DM	DP	DT	MM	MP
DP	0.25				
DT	−1.58*	−1.84*			
MM	6.50*	6.25*	8.08*		
MP	9.79*	9.54*	11.38*	3.31*	
MT	2.86*	2.61*	4.45*	−3.64*	−6.93*

TABLE 8. The mean DTR (°C) of each LULC type for every month, and the overall monthly mean. A boldface number indicates the LULC with the lowest monthly DTR.

Month	Urban	Deciduous	Evergreen	Mixed	Agriculture	Mean
1	14.31	13.42	15.18	14.61	**12.59**	14.02
2	11.48	13.5	13.76	12.57	**11.21**	12.50
3	**11.57**	13.59	12.64	12.84	11.61	12.45
4	**14.16**	16.03	16.16	15.90	14.25	15.30
5	**13.25**	14.65	14.77	14.58	13.30	14.11
6	11.89	12.68	12.72	12.62	**11.59**	12.30
7	11.34	12.37	12.14	11.95	**11.15**	11.79
8	12.78	14.28	13.91	13.41	**12.77**	13.43
9	**13.78**	14.98	14.67	14.36	13.95	14.35
10	**14.27**	15.47	15.61	14.99	14.29	14.93
11	**12.79**	14.25	14.42	14.72	13.61	13.96
12	10.50	10.38	11.19	11.97	**9.98**	10.80

saturated. However, during an MT air mass, there is enough energy available in the atmosphere to allow the vegetation to provide some evapotranspirational cooling, decreasing the DTR of the vegetated areas and causing smaller mean differences. The MT air mass is the only air mass for which all of the *t* tests between LULC types are significantly different, and the only moist air mass where agriculture has a smaller DTR than urban areas (Table 6). Most of the mean differences between the LULC types, however, are much less for the MT air mass than for all of the other air masses.

The *t* tests were also performed between each of the air masses for all of the LULC types, for example, DT-urban versus DP-urban, etc. The mean differences of these tests, in general, proved much larger than those just between the LULC types. This shows that although differences can be seen between the LULC types while under the same air mass, air mass causes more DTR variation than LULC. Among the LULC types, urban areas experienced the most pronounced DTR differences between airmass types (Table 7), with an 11°C difference between DT and MP DTRs. Larger differences exist when comparing air masses of different moisture contents rather than different temperatures. Once again, the DTRs are separated by moisture first, then temperature.

b. *Annual DTR pattern*

To evaluate the relationship between monthly DTRs and LULC types, the monthly DTRs are calculated for each LULC type, as well as the overall mean DTR for each month (Table 8). All of the LULC types experienced their lowest monthly mean DTR in December, but vary after that. Consequently, December has the lowest monthly mean DTR, followed by July, June, February, March, August, November, January, May, September, October, and April. Both urban and agricultural areas experience the lowest DTR of all other LULC types six months of the year, agriculture having the lowest mean DTR in all of the winter (December–February) and summer (June–August) months, while urban areas have the lowest DTR in the spring (March–May) and autumn (September–November) months. These results agree with neither of the aforementioned characteristics of the two land uses—agricultural evaporation in the green season or increased summertime strength of the urban heat island. However, it must be mentioned that the dispersal of monthly observations encourages caution when interpreting the results, as December and January have only 258 and 376 data points, respectively (Table 2).

Figure 3 shows the mean DTR for each LULC by month, exhibiting a bimodal pattern for all of the LULC types. The pattern is defined by relative minimum DTRs around February and July and DTR peaks around April and October. This annual pattern of the LULC DTRs agrees with the findings of Durre and Wallace (2001a) and Sun et al. (2006), showing a summer DTR minimum, surrounded by two DTR peaks in the spring and fall. Durre and Wallace (2001a) suggest a possible cause of this summertime minimum is the increased amount of evapotranspiration in the summer, overpowering the effects of the higher sun angle and longer days, which would actually increase the DTR during the warm season. This study shows that while evapotranspiration rates alter the DTR of an area, as shown by previous studies, air mass may have a larger effect than previously believed. Although evapotranspiration does play a role in governing DTR, the differences associated with evapotranspiration are miniscule when compared to the large seasonal shifts of DTR illustrated in Fig. 3. Thus, the interaction of month and air mass is a major factor controlling the annual DTR pattern. This is reiterated by airmass frequency during particular months. During the annual DTR peak in April, the most prevalent air mass is DM, which reports the second largest DTR average. The trough in July is accompanied by a large number of MT days, and an air mass with a relatively

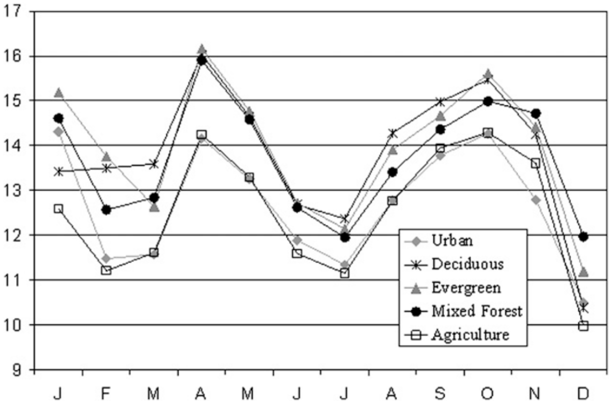

FIG. 3. Mean DTR (°C) for each LULC by month.

small DTR. Further analysis on annual airmass frequency could be beneficial for understanding the interaction between these variables.

Although all of the LULCs display a bimodal annual pattern, Fig. 3 illustrates two distinctive groups between the LULC types. Urban and agriculture have very similar monthly DTRs, lower than those of the forest types that also experience similar DTRs. The *t* tests show that urban and agricultural areas have no statistically significantly different DTRs ($\alpha = 0.05$) during the entire year, but the agricultural DTR is significantly different from the forest types for 10 of the 12 months. This defines the two monthly DTR groups, and further establishes the connection between the agricultural and urban DTRs. These results agree with the presumption that agricultural areas and urban areas would experience the lowest DTRs because of anthropogenic changes of the landscape-increased evapotranspiration over well-irrigated agricultural areas and the development of an urban heat island.

While Fig. 3 shows two clear LULC groups, the DTR variations within the groups vary throughout the year. The graph shows little disparity in within-group DTRs between March and July, and the *t* tests show no notable differences of DTRs within the groups during these months. Between August and February, when the graph shows more variability between the groups, there are some statistically significant differences between some of the forests types. The within-group disparity does not seem to correlate with the DTR peaks, troughs, or transition between the two.

It should be noted that Fig. 3 includes only synoptically weak days, and the inclusion of active weather days and associated cloud cover could alter the seasonal relationships. Sun et al. (2006) shows that winter months exhibit relatively smaller DTRs when including all sky conditions. Thus, the inclusion of active weather days should further amplify the DTR trough in the winter months, maintaining the bimodal pattern. Clouds may still play a small part in the findings even with the exclusion of days with synoptic forcing. It could be useful to analyze the relationship between cloud cover and airmass type in a synoptically weak environment. Assuming moist air masses are associated with more cloud cover than dry air masses, clouds reinforce the findings that moist air masses have smaller DTRs. If there is a strong relationship between clouds and air mass then this could potentially increase the importance of air mass on DTR.

c. *Further discussion on the role of airmass type*

Evapotranspirational cooling is cited throughout this paper as playing a part in DTR patterns. Evapotranspiration itself is a function of vegetation, moisture, and the energy to convert that moisture to water vapor (Shukla and Mintz 1982). The DTR of an area must essentially be a function of these variables as well.

Sun et al. (2006) indicate that water vapor radiative forcing (WRF) has a large effect on spatial and seasonal DTR patterns. Our study supports this idea, as the availability of moisture and energy is continually cited as the reasoning behind DTR differences. For the purposes of this study, air mass almost serves as a categorization of WRF potential, the airmass categories quantifying the amount of energy and moisture available. Additionally, air mass provides another level of understanding by including the effect of thermal differences (such as albedo) when water vapor is not playing such a large role. The results of this study indicate that moisture plays a larger role in DTR than temperature, but there is a thermal relevance of airmass categorization beyond its role in WRF. Thus, within the variables explained in this study, air mass provides the best single explanation of DTR differences. Indeed, if other variables are included, such as cloud cover or wind, WRF may be more inclusive of the overall influence of the current weather on DTR.

5. Conclusions

The main goal of this study was to assess, and add to, the known relationships between DTR and LULC type in a portion of the Southeast, where the LULC types naturally vary at uneven intervals. The relationship between LULC and DTR cannot be analyzed without consideration of air mass and season, as well as their interactions. Ultimately, this study provides a general understanding of how LULC can affect the DTR of an area, the importance of temperature and moisture content on the DTR, and the strength of the influence of LULC, air mass, and seasonality on the DTR of an area.

Agricultural and urban areas experience the lowest DTRs, although for different reasons. This is consistent with prior research that shows that urban and agricultural areas have lower DTRs than surrounding areas (Grimmond and Oke 1999; Kim and Baik 2005; Bonan 2001). More information on this similarity can be gained by looking at maximum and minimum temperatures, as agricultural and urban areas should experience large differences. The daily temperatures should also provide additional explanations for other DTR relationships discussed here.

The combined effects of air mass and LULC on the DTR of an area were also analyzed. All of the LULC types experienced their DTRs in the same order relative to air mass: DT > DM > DP > MT > MM > MP. This simple result allows for several conclusions: airmass type seemingly has a much larger and more consistent influence on the DTR of an area than the LULC type, moisture plays a larger role than temperature, and drier and warmer air masses induce larger DTRs. The resulting DTRs were dependent upon the temperature and moisture characteristics of each air mass, which, in turn, control the energy and moisture available to inhibit or enhance evapotranspiration. Within synoptically weak days, air mass controls the radiative forcing of water vapor, which has been shown to influence DTR (Sun et al. 2006).

When the monthly DTR is plotted for each LULC, it is apparent that all of the LULC types follow a similar bimodal pattern, with DTR peaks around April and October (Fig. 3). This bimodal pattern is similar to the findings of several other studies (Leathers et al. 1998; Durre and Wallace 2001a; Sun et al. 2006). While evapotranspiration rates have previously been thought of as the predominant reason for annual DTR fluctuations, it is evident that each LULC behaves similarly, regardless of vegetation. This leads to suspicion of evapotranspiration being the main cause, since urban areas should not show troughs as deep as the vegetated LULC types. It is likely that evapotranspiration and air masses both play large roles in the summertime DTR dip, which would help explain why Durre and Wallace (2001a) found a more pronounced DTR plunge in the south that comes earlier in the year and lasts longer. Since the lower latitudes experience more MT air masses and for a longer period of time, the higher relative energy allows for more evapotranspiration potential and a lessening of the DTR. Durre and Wallace (2001b) note that the winter DTR dip is due to other factors, possibly the influx of moist marine air, while the urban heat island and evapotranspiration are the least influential. Additional research should further test the roles of air mass and evapotranspiration in the annual DTR pattern. It is possible that small-scale differences, such as LULC, cause minor DTR variability within a region, but air mass controls the large-scale DTR fluctuations seen annually. Overall, although LULC type proves to have some effect on the DTR of an area, air mass seemingly prevails as having more control over the DTR. As the results of the ANOVA indicate, the entire story is not told by one of the variables, but by the interaction between them. Additional research regarding monthly airmass occurrences could help analyze the annual importance of air mass in DTR, and help further the understanding of the role of LULC in the temperature profile of an area.

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