Tallahassee, Florida, Minimum Temperature Anomaly: Description and Speculations

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ABSTRACT

The Tallahassee Regional Airport, on the city's southwest side, has a minimum temperature that is colder than minima of neighboring towns and other parts of Tallahassee when clear and calm conditions prevail over the area. The anomaly is described in detail with a series of comparison studies using daily minimum temperature data from nearby locations. This cold anomaly is statistically significant and is most common during the cold season. Its cause appears to be anomalous radiational cooling resulting from enhanced exposure of the ground to open sky, and local cooling rates are probably intensified by sandy soil conditions. Cold-air drainage does not appear to be an important factor.

I am the Lorax. I speak for the trees.

—Dr. Seuss

1. Introduction and motivation

Tallahassee is situated amid the rolling hills of northwest Florida near the geographic center of Leon County and has a population of approximately 134 000 residents and an area of 217 km^2 (Tallahassee–Leon County Planning Department 1995). Tallahassee's rolling landscape (the Tallahassee Hills, with elevations ranging between 15 and 75 m above sea level) is more typical of regions farther north and is unique among the major cities of Florida. The topography from the city's southside to the Gulf of Mexico (approximately 40 km to the south) is characterized by flat, sandy coastal lowlands.

Official temperature readings for Tallahassee are taken at TLH, located at the Tallahassee Regional Airport on the city's southwest side. The major question for this study is the representativeness of Tallahassee's official minimum temperatures for the region at large. For example, a forecast minimum temperature of −2°C at TLH may or may not be of concern to local growers regarding the potential of subfreezing temperatures in their specific locales. The answer is important because it is often of agricultural interest to delay harvest as long as possible before the potential for cold damage (e.g., Smith 1966).

Despite its proximity to the Gulf of Mexico and its humid subtropical climate, Tallahassee sometimes records the coldest minimum temperature of any city in a tristate area (SE Alabama, SW Georgia, and N Florida). Tallahassee's minimum temperature anomaly is most common during the cold season when subfreezing temperatures often occur. Figure 1 is the 1200 UTC minimum temperature chart for 18 March 1994, showing an example of the minimum temperature anomaly. Minima at neighboring first-order stations are 2°–6°C (4°–10°F) warmer than at TLH on this particular night when clear and calm synoptic-scale conditions prevailed over the southeast United States.

Table 1 contains elevations above sea level for TLH and the three nearest first-order reporting sites. TLH is located nearest to the Gulf Coast and is at an elevation closest to sea level. As one would expect, TLH has a warmer average nighttime minimum temperature compared with sites to the north, but on occasion TLH records the coldest minimum temperature in the

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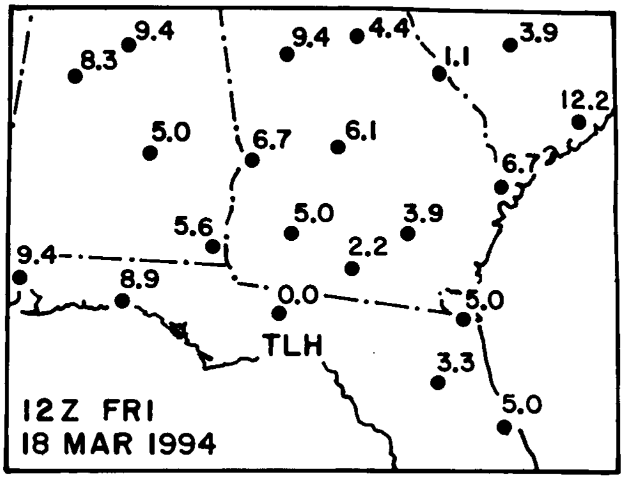

FIG. 1. National Weather Service (1200 UTC) minimum temperature chart for 1200 UTC 18 March 1994.

region. On a more local basis, there is a widespread belief that cold-air drainage is primarily responsible for the TLH minimum temperature anomaly. In fact, a quote about Tallahassee's climate from the *USA Today Weather Almanac* (Gannett New Media 1994) states,

> During the winter, cold air flowing into lower elevations [throughout Tallahassee] produces wide variations in low temperatures on clear and calm nights.

Cold-air drainage can be substantial in certain places. For example, the city of Albuquerque, New Mexico, experiences nocturnal cold-air drainage with minimum temperatures in the valleys along the city's outskirts averaging 2°–3°C (4°–5°F) lower than other city locations (Liles 1991). During exceptionally clear, calm nights, valley temperatures can be 6°C lower than at the airport site, just several kilometers away.

TABLE 1. Locations, elevations, and proximity to the Gulf of Mexico of TLH and the nearest first-order reporting sites. TLH, located at the Tallahassee Regional Airport, is closest to sea level and closest to the Gulf of Mexico.

City	Lat (°N)	Long (°W)	Elevation (m)	Distance to Gulf (km)
Dothan, AL (DHN)	31.32	85.45	122	126
Albany, GA (ABY)	31.53	84.18	59	157
Valdosta, GA (VLD)	30.78	83.28	68	106
Tallahassee, FL (TLH)	30.38	84.37	21	35

In this paper we examine the TLH minimum temperature anomaly in detail. A description of the anomaly is given in section 2. This is done using comparisons on three spatial scales: regional, local, and side by side. In section 3 we challenge the cold-air drainage hypothesis as the cause of the temperature anomaly in Tallahassee while suggesting an alternative explanation.

2. Description of the TLH minimum temperature anomaly

We first describe salient features of the TLH minimum temperature anomaly. We do this on both regional and local scales and then examine results of a side-by-side comparison between the National Weather Service's (NWS) official HO-83 temperature sensor (NWS 1982; Kessler et al. 1993) with a sheltered liquid-in-glass minimum thermometer.

a. Regional comparisons

In the first comparison we chose five NWS cooperative sites surrounding Tallahassee, located near the towns of Madison (MAD), Monticello (MON), Perry (PER), Quincy (QUI), and Wewahitchka (WEW). The sites border TLH to the east, southeast, northwest, and southwest, respectively (Fig. 2). Data were daily (24 h) minimum temperatures over a nine-year period (1984–1992). We considered only days on which all six sites recorded a minimum temperature.

The question we address is whether TLH is colder than its surrounding neighborhood under certain conditions. For a specified night, two samples are taken. Sample one is the area-averaged minimum temperature based on the five cooperative sites surrounding Tallahassee, and sample two is the minimum temperature for TLH. We test whether or not TLH's median low temperature differs significantly from the surrounding area's average median low temperature. A decision is made based on the nonparametric Wilcoxon signed rank test, which uses a ranking of the paired sample differences and requires no distributional assumptions (Daniel 1990).

We are interested in local influences that affect minimum temperatures in Tallahassee. And, since we want to compare minima for neighboring sites, it is necessary to eliminate days on which large-scale factors might have been important. For example, a cold front in the area could explain substantial regional differences in minimum temperatures unrelated to local effects. Our purpose is to compare minima when such large-scale features are not present.

Since the neighboring sites are NWS cooperative stations without complete weather observations, we devised the following criterion for determining which days to include in the sample. First, the daily minima of all sites for a given day were averaged to obtain $\langle T^{\min}\rangle$. Then, each site's minimum temperature (except for TLH) was subtracted from this regional average to obtain five differences for each day, where

$$\Delta_{\text{site}}^{\min} = T^{\min} - T_{\text{site}}^{\min}. \quad (1)$$

The average absolute difference

$$\delta = \frac{1}{5}\sum_{i=1}^{5}|\Delta_i|$$

for the five sites was 2.13°C (3.84°F) for the nine-year period. This value was chosen as a reference threshold. In order for a day to be considered in the sample of "same synoptic-scale situation," the criterion

$$-\delta \le \Delta_{\text{site}}^{\min} \le +\delta \quad (2)$$

had to be met for all five of the neighboring sites. Thus, on a given night, if all of the minima from the five sites surrounding TLH fell within plus or minus the threshold, then it was assumed that the region was under the same synoptic-scale situation.

Using this criterion for determining the same synoptic situation and requiring that data be available for all sites on that day gave a sample size of 2032 days. The reasoning behind this procedure is to isolate nights under which TLH is most likely to experience the coldest minimum temperature in the region. If under these conditions we find no significant difference between TLH and neighboring sites, it would decrease our motivation to entertain a cause.

Differences in median minimum temperatures are compared using approximate z values, Bonferonni-corrected p values, and simultaneous 95% confidence intervals shown in Table 2. Since separate statistics are computed for 5.5°C (10°F) temperature intervals of $\langle T^{\min}\rangle$ beginning with −6.7°C (20°F), the two-sided

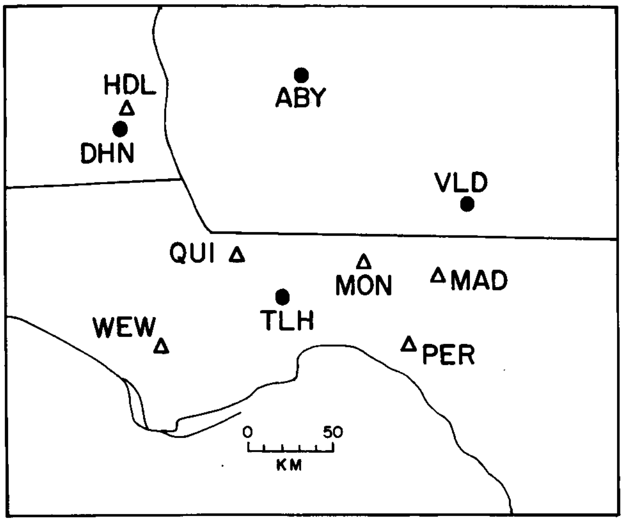

FIG. 2. Map of the tristate area showing locations of sites used in the study. Filled circles are first-order NWS sites (ABY is Albany, DHN is Dothan, VLD is Valdosta, and TLH is Tallahassee) and open triangles are cooperative sites (HDL is Headland, QUI is Quincy, WEW is Wewahitchka, MON is Monticello, MAD is Madison, and PER is Perry).

TABLE 2. Statistics for a multiple comparison between TLH minimum temperatures and average minimum temperatures for the surrounding area. Temperature ranges are in 10°F intervals and N is the number of observations, the z value is based on a normal approximation, the p value is based on the conservative Bonferonni-adjusted multiple comparison, and the 95% CI is the simultaneous confidence interval based on an individual confidence level of 99.28% with values in °C.

Temp range °C (°F)	N	z value	p value	95% CI
−6.7°– −1.7° (20°–29°)	74	−6.58	<.00001	(−2.00, −1.06)
−1.1°–3.9° (30°–39°)	170	−8.63	<.00001	(−1.89, −1.11)
4.4°–9.4° (40°–49°)	223	−9.14	<.00001	(−1.83, −1.00)
10.0°–15.0° (50°–59°)	329	−8.04	<.00001	(−1.28, −0.61)
15.6°–20.6° (60°–69°)	684	−0.60	1.00000	(−0.17, 0.11)
≥21.1° (≥70°)	548	3.61	.00214	(0.55, 0.33)
Overall	2032	−11.22	<.00001	(−0.50, −0.28)

p value for each test is multiplied by seven (the number of comparisons). This guarantees that the overall error rate for the hypothesis tests will not exceed the p value associated with the particular hypothesis test being evaluated.

The multiple comparison p values are significant in all temperature intervals below 15.6°C (60°F), with confidence intervals indicating that TLH is colder than its surrounding neighborhood. For warmer minimum temperatures, the situation is different. In the interval between 15.6° and 20.6°C (60° and 69°F), there is no difference in median minimum temperatures, and for the minimum temperatures exceeding 21.1°C (70°F), TLH is significantly warmer than its surrounding. However, TLH is significantly colder overall than its neighborhood under conditions of same synoptic-scale situation.

The above results suggest a minimum temperature anomaly for TLH, particularly during the colder months. During the warm season, large humidity gradients can exist over limited spatial scales even under the same synoptic-scale situation. For instance, an isolated heavy shower during the afternoon can result in localized low-level moisture during the following nighttime and early morning hours. In contrast, the largest moisture gradients during the colder months are associated with midlatitude frontal intrusions. These frontal days have been eliminated from the sample for failing to meet the same synoptic-scale situation criterion. The next section describes the seasonal variability of this minimum temperature anomaly.

b. Seasonal variability

To examine the seasonal variability of the anomaly, we looked at the number of TLH minimum temperature anomaly days for each month. This was done by comparing daily (24 h) minimum temperatures from TLH with those from three, more northerly stations—Headland, Alabama; Albany, Georgia; and Valdosta, Georgia. Each of these sites is located north of Tallahassee (Fig. 2). To be considered an anomaly day, the minimum temperature at TLH had to be colder than that at each of the other three sites by at least 1.7°C (3°F). Data were obtained from the Florida State Climate Center for the 24-yr period 1965–88. Months during this period for which the number of anomaly days could not be determined for each day due to missing data were excluded. The number of months ranged from a low of 21 (January and April) to a high of 24 (June, July, and August).

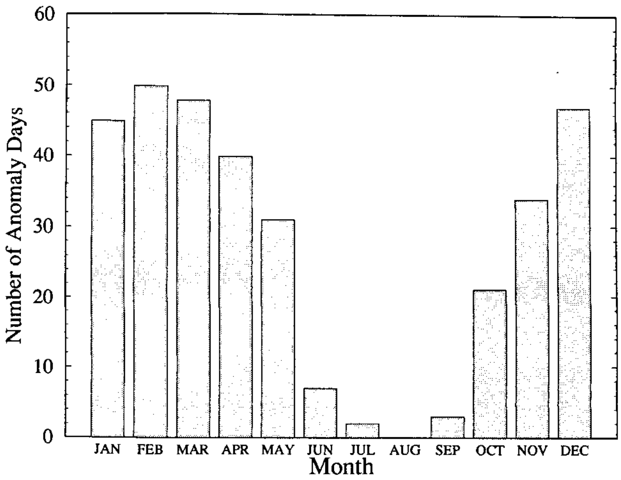

FIG. 3. Number of TLH minimum temperature anomaly days as a function of month of year for the period 1965–88. See text for methodology.

The total number of anomaly days for the 24-yr period (not weighted for missing months) is plotted for each month in Fig. 3. As anticipated, the TLH minimum temperature anomaly is most frequent during the cooler, drier months. The warm and humid months of July through September have a small number of anomaly days, with no days meeting this criteria in August. We next describe the spatial extent of this minimum temperature anomaly.

c. Local comparisons

Having confirmed the TLH minimum temperature anomaly and described its seasonal variability, we next address its representativeness on more local scales. This was done using two separate comparisons. We first compared TLH minima with those at an unofficial site located in the city of Tallahassee. The site has been maintained by one of the authors (HEF) for the past eight years. It is located approximately 16 km northeast of TLH in an urban forest at an elevation of approximately 31 m. The instrument is a liquid-in-glass minimum thermometer housed in a standard wooden shelter.

The average minimum temperature for the months of December, January, and February at the unofficial site was 44.4°F for the years 1988–92, compared with 41.7°F at TLH for the same months and period. This result suggests that the TLH minimum temperature anomaly might be a very local effect, at least during the cold season.

The second comparison involved a network of minimum thermometers near the Tallahassee Regional

Airport, all within a few hundred meters of the official TLH HO-83 temperature sensor. The local topography surrounding the airport is typical of much of Tallahassee, with rolling hills and elevations ranging from 15 to 40 m (Fig. 4). Six U-tube maximum–minimum thermometers were mounted at shelter height on 1 × 4 wooden posts. The thermometers previously had been calibrated to within 0.28°C (0.5°F) of each other using a cold-water bath. All thermometers were fully exposed and faced north. We note that sheltered temperatures might differ from unsheltered values; however, we have used all unsheltered thermometers in this local-comparison experiment, one of which was located adjacent to the official site.

Thermometer locations are shown in Fig. 4, with site descriptions given in the caption. The description "wooded" refers to widely spaced (2–3-m separation), small (<10 m) slash pine trees, and "sinkhole" refers to circular depressions of various sizes and depths caused by groundwater percolation in the underlying limestone karst of the region.

We averaged the minimum temperature readings taken from the six network locations over 30 clear, calm nights during the cold season of 1992–93. The minimum temperatures over the network are fairly uniform, with the exception of the two sinkhole sites (1 and 4) averaging 0.5°–2°C (1°–4°F) colder than the other sites. A paired t test for significance between each site's minimum temperature and site 2's minimum, where site 2 is located immediately adjacent to the HO-83 official site, is performed under the null hypothesis of no difference. Note that due to the known cool bias of unsheltered minimum temperatures, we tested only against unsheltered readings. The hypothesis of no difference in minimum temperatures is rejected at the a priori 90% confidence level only for the two sinkhole locations. Results are the same for an independent sample of the 42 clear, calm nights during the 1993–94 cold season.

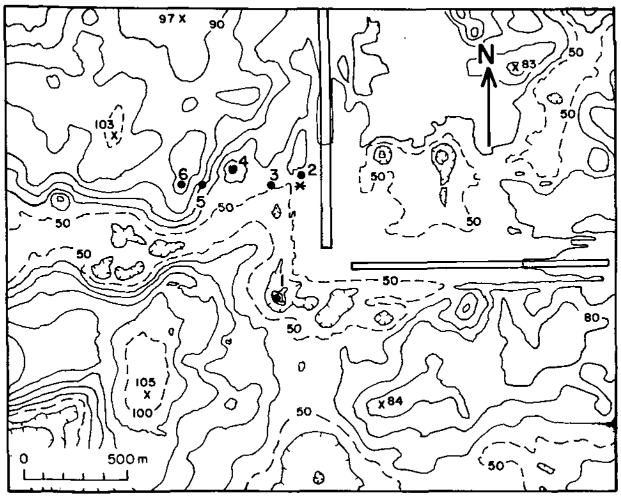

FIG. 4. Topography of the Tallahassee Regional Airport (elevation in feet) and locations of the thermometers used in the local-scale network. The asterisk is the location of the official thermometer. Runway locations are indicated by the elongated rectangles. Sites 1 and 2 are located in the open (treeless areas), and sites 3–6 are in the woods. Sites 1 and 4 are in sinkholes; 2, 3 and 6 on level ground; and 5 on sloping terrain. Elevations above sea level range from a low of 8 m for site 1 to a high of 30 m for site 6.

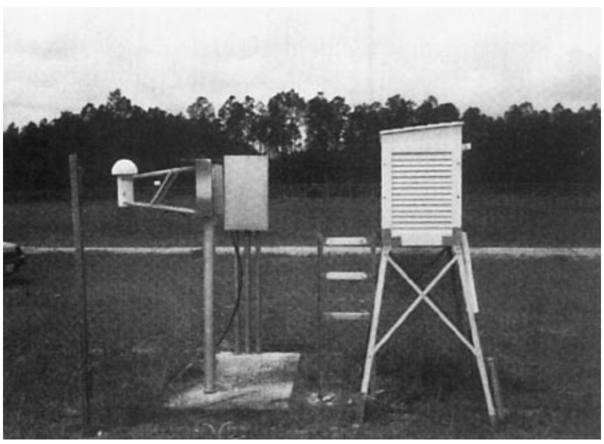

FIG. 5. Photograph of the HO-83 temperature sensor and housing (left) and nearby shelter (right) having the standard liquid-in-glass minimum thermometer. The HO-83 is the official minimum temperature sensor for TLH.

In summary, minima from the HO-83 instrument at the official site (TLH) are colder than those from the Tallahassee site located 16 km to the northeast. However, all sites in the local network are as cold, or colder (sinkholes), than the official site under clear, calm conditions. Thus, the TLH minimum temperature anomaly, although not necessarily representing the entire city of Tallahassee, does appear to represent the local region surrounding the regional airport on the city's southwest side. Very local cold anomalies are possible but appear to be limited to sinkholes.

d. Side-by-side comparisons

Another comparison involved the immediate TLH site. We call this the side-by-side comparison since we compared sheltered minimum temperatures from a standard liquid-in-glass thermometer with those from the adjacent official HO-83 sensor. Figure 5 shows the standard shelter used in this comparison and the proximity of the shelter to the HO-83. Minimum

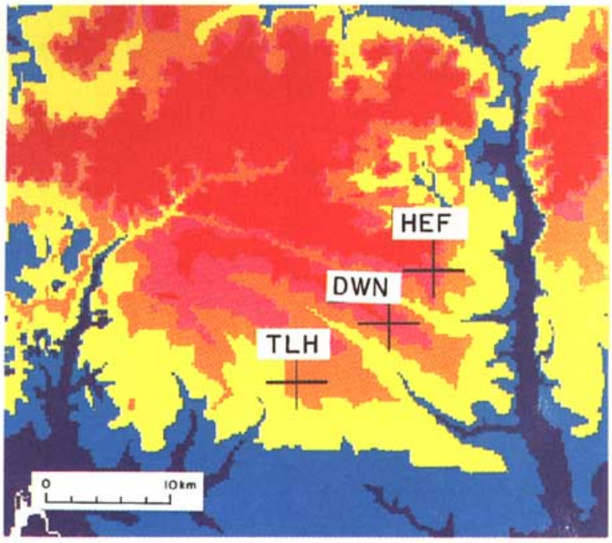

FIG. 6. Topography of the Tallahassee area, where DWN is the location of downtown, HEF is the location of the unofficial observing site used in the study. Elevations greater than 55 m are red, between 45 and 55 m are pink, between 35 and 45 m are orange, between 25 and 35 m are yellow, between 15 and 25 m are light blue, between 0 and 15 m are dark blue, and areas of missing data are denoted as white. Data are from the U.S. Geological Survey and have been smoothed for this resolution.

temperature readings were taken on the 42 clear, calm nights during the 1993–94 cold season. To our surprise, and to add a bit of irony to the study, we found that the official TLH minimum temperature averaged nearly 0.6°C *warmer* than the sheltered minimum temperature. In fact, on all 42 clear, calm nights studied the official minimum temperature reading was colder than the sheltered minimum. Thus, it is possible that the official TLH site has a minimum temperature warm bias under certain conditions. Although not completely relevant to this study, it is of interest to note that daytime warm biases with the HO-83 instrument have been reported at Tucson, Arizona (Gall et al. 1992), and at Albany, New York (Kessler et al. 1993). These biases were attributed to an inadequate aspiration rate within the HO-83 sensor housing.

3. Speculations

Having examined the TLH minimum temperature anomaly in detail, we now speculate as to its cause. As mentioned, the popular hypothesis is cold-air drainage. TLH is located at a relatively low elevation compared with the rest of Tallahassee and surrounding areas to the north. Therefore, some believe that nighttime cold air near the surface flows southward from the adjacent areas, eventually reaching TLH.

There are a few problems with this explanation. First, although the airport is at a relatively low elevation, the official site is not located in a depression where cold air can pool to the height of the temperature sensor (Fig. 4). On a larger scale, there are no highlands that completely surround the airport to trap the cold air (Fig. 6).

Another problem is identified by considering the cooling rate when skies are clear and winds are calm. As an example, Table 3 shows 1-min ASOS (Automated Surface Observing System) data on the night of 25 February 1994. The ASOS is within 100 m of the HO-83. The rapid drop in temperature under nearly calm conditions is not likely caused by advection currents. Vertical mixing is also ruled out as an explanation since the rapid cooling takes place under stable stratification (note that 0530 UTC is 0030 EST). Currently, we have not investigated this rapid cooling phenomenon in more detail.

Further evidence against the cold-air drainage explanation is provided by a recent model study (Sloan 1994). The model is a coupling of planetary boundary-layer physics (Troen and Mahrt 1986) with a two-layer soil simulation (Mahrt and Pan 1984) and a simple plant canopy specification (Pan and Mahrt 1987). The model is capable of simulating and predicting temperatures at a height of 2 m above the surface from physical processes such as cloud cover, radiation, and soil moisture. Since the model is one-dimensional, temperature changes cannot occur from horizontal advection, and there is no model topography.

Evidence against the cold-air drainage hypothesis comes from the results of Sloan (1994) showing that forecasts of Tallahassee minimum temperatures from the model for events of weak synoptic forcings were more accurate and less biased than those from the NWS Model Output Statistics (MOS). In a comparison with MOS, climatology, and persistence, the model generally gave the most accurate forecasts. These results are circumstantial since no comparisons were done to determine whether the model would produce accurate forecasts for other parts of Tallahassee.

The above problems with the cold-air drainage hypothesis beg for a more likely explanation of the TLH anomaly. The native vegetation of Tallahassee and surrounding areas of north Florida and south Georgia is a mix of trees from the southern coniferous and eastern deciduous forests including sprawling branched live oaks (*Quercus virginiana*), broad-leaved southern magnolias (*Magnolia grandiflora*), and numerous slash pines (*Pinus elliottii*). These trees can produce a dense canopy that limits the extent to which the soil is exposed to open sky. However, the area around the regional airport is a conspicuous exception to this dense canopy. The open space required for landing jet airplanes, combined with the thin canopy of the adjacent tree farms produces atypical exposure of soil to sky around the airport. Smaller clearings and/or the presence of thicker canopy limits soil exposure at the neighboring regional sites. The greater exposure of the soil to open sky at TLH permits enhanced rates of radiational cooling and heating that are uncharacteristic of the region as a whole.

TABLE 3. Tallahassee Regional Airport 1-min data for 25 February 1994. Note that a wind speed of 2 kt or less is reported as calm. Values were obtained from ASOS. Vis. is visibility, T is air temperature, TD is dewpoint temperature, W Dir. is wind direction, and W speed is wind speed.

Time (UTC)	Vis. (mi)	T °C (°F)	TD °C (°F)	W dir.	W speed (kt)
0523	10	7.2° (45°)	3.3 (38)	347	3
0524	10	7.2° (45°)	3.3 (38)	334	3
0525	10	6.1° (43°)	3.3 (38)	333	3
0526	10	6.1° (43°)	3.3 (38)	319	2
0527	10	5.6° (42°)	3.3 (38)	316	2
0528	10	5.0° (41°)	3.9 (39)	324	3
0529	10	5.0° (41°)	3.9 (39)	337	2
0530	10	5.0° (41°)	3.9 (39)	336	2
0531	10	4.4° (40°)	3.3 (38)	341	2
0532	10	4.4° (40°)	3.3 (38)	340	2

Additional evidence for the anomalous exposure hypothesis comes indirectly from the fact that the anomaly is most pronounced during the cooler months and disappears for the warmest months. During the summer, very high nighttime humidity is common over the region. Water vapor limits radiational effects but has a smaller impact on cold-air drainage.

4. Conclusions

The Tallahassee minimum temperature anomaly has been described in detail with a series of comparisons with nearby sites. Results allow for speculation as to the probable cause of the temperature anomaly.

We found that TLH, located at the Tallahassee Regional Airport on the city's southwest side, has a minimum temperature that is sometimes colder than the average minimum of neighboring towns to the north. Under the criterion of same synoptic-scale situation the cold anomaly is statistically significant when minimum temperatures for TLH are less than 16°C (60°F). Its cause appears to be anomalous radiational cooling resulting from enhanced exposure of the ground to open sky conditions. Cold-air drainage does not appear to be an important factor.

Moreover, the physiographic variability of Tallahassee might explain the very local nature of the temperature anomaly. Over much of the city the landform consists of clay and silt deposits over limestone, with surface sediments eroded and dissected by natural surface runoff that forms hills and ravines (Swanson et al. 1992). Soils are a mixture of poorly drained sand and loam, with sand confined to a very thin surface layer often removed for agricultural and homestead landscaping. In contrast, the area encompassing the airport and portions of the city's southside consists of dry hills and ridges composed of deep sands over limestone bedrock with numerous karst-formed sinkholes. Soils are highly porous with permeable sands that are excessively drained. Well-drained sand, composed largely of inorganic matter, is an effective emitter of radiation compared to a wet, loamy soil rich in organic materials. Thus, the effect of vegetation in moderating the radiative extremes is more important over the sandy soils of the airport region than in shading more loamy soils to the north.

Anomalously cold minimum temperatures resulting from enhanced sky exposure of dry soil may be significant at other locations in coastal areas. However, cities along the immediate coast would be largely unaffected by this phenomenon because of the more important influence of the nearby ocean. In this respect, Tallahassee is unique in that it lies near the coastal plain but far enough from the modifying influences of the ocean on clear, calm nights. We note that the city of Crestview in the panhandle and Cross City in the northern peninsula of Florida may also experience similar cold minimum temperature anomalies, but we have not done a systematic study.

Finally, changes in landscape such as the removal of vegetative cover may create other climatological anomalies. For instance, the ratio of sensible to latent heat flux (Bowen ratio) near the surface will increase with diminishing vegetation.

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