J 4.8 MODELING THE TALLAHASSEE MINIMUM TEMPERATURE ANOMALY

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1. INTRODUCTION

Over the past fifteen years researchers have sought to understand the pattern of minimum temperatures in and around Tallahassee, Florida. During the cold season morning minimum temperatures can vary as much as 8°C between local sites. This variation creates a major concern for operational forecasters when minimum temperatures are expected to approach 0°C. The need to warn the public about damaging freezes is very important since a freeze will impact local farmers and other interests. Our research has statistically modeled the Tallahassee minimum temperature anomaly to aide in predicting freezes and generally to improve the accuracy of operational minimum temperature forecasts.

Tallahassee is located in the Big Bend region of Florida (Fig.1). The city itself has a population of approximately 150,000 people. Tallahassee is situated in Leon County with a total population near 240,000. The city is about 50 km north of the Gulf of Mexico. Uncharacteristic of many Florida cities, Tallahassee has rolling hills that affect the temperature distribution. The elevation varies from 61 m in northern Leon County to 15 m on the southern end of the county. The area contains several inland lakes and other water bodies. Additionally, as can be seen in Fig. 1, the Apalachicola National Forest is located southwest of Tallahassee. This forest surrounds the airport and consists mostly of tall pine trees.

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Official temperature readings for Tallahassee are taken in the southwestern portion of the county at the Tallahassee Regional Airport (TLH) (Fig. 2). This site has an elevation of 16.8 m and is approximately 40 km from the Gulf of Mexico. TLH is 9 km southwest of the center of downtown Tallahassee.

Previous research has shown that TLH is not representative of the minimum temperatures observed at many locations in the city. These studies have examined the available data at the regional and mesoscales. The first study, Elsner et al. (1996), compared minimum temperatures at TLH to those of other first order sites and National Weather Service (NWS) cooperative sites around the Deep South between 1965 and 1988. They found that under ideal radiational cooling conditions TLH was 2° to 6°C colder than many nearby sites under the same synoptic conditions.

Speculation about this large range of minimum temperatures has focused on elevation differences across the county. Even an article in the USA Today Weather Almanac (1994) states that:

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

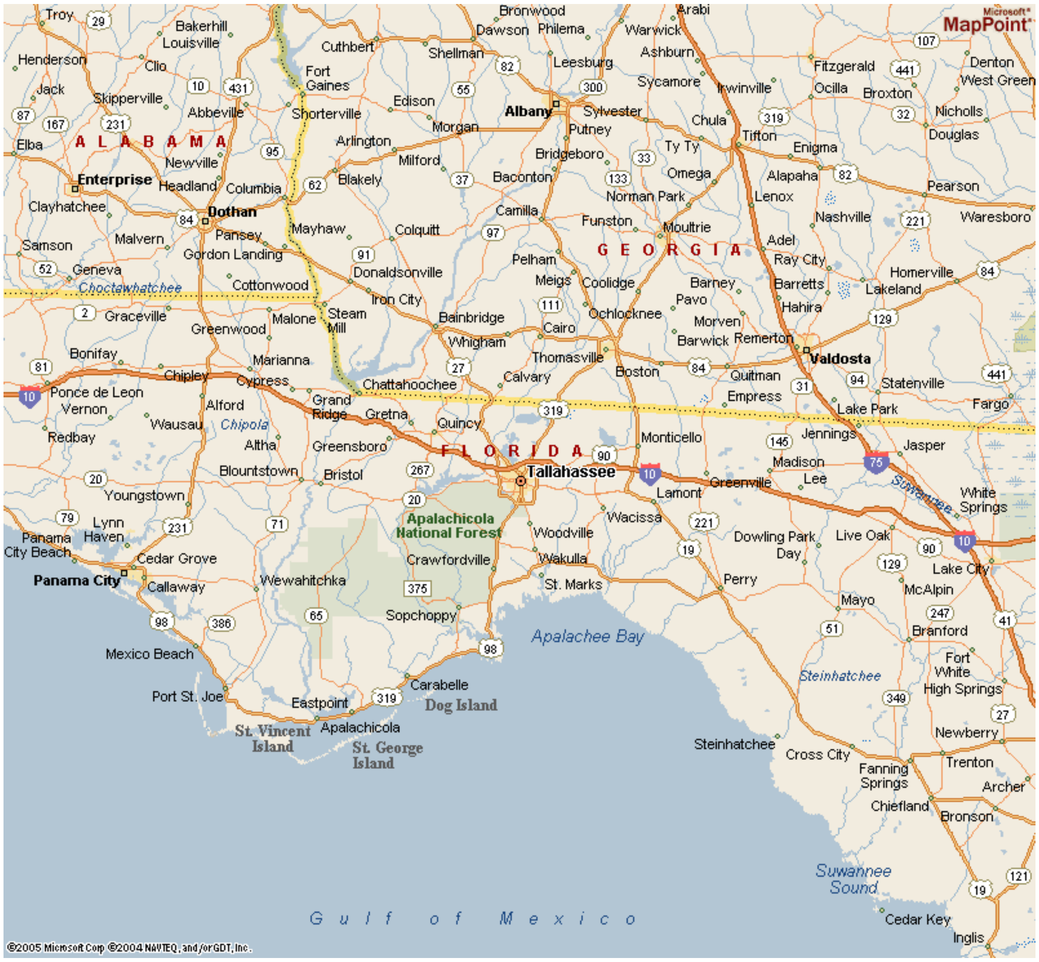

Fig. 1. Map of the Big Bend of Florida centered on Tallahassee.

Fig. 2. Map of Leon County. The star indicates the location of the official observing site at the Tallahassee Regional Airport (TLH).

Cold air drainage occurs overnight as the surface of the earth cools. As air near the surface cools, it becomes denser and tends to "slide" down hills toward areas of lower elevation. This effect is particularly pronounced in mountainous regions at night where cold air descends from the mountains into the valleys. The result is cooler valleys and warmer mountain tops on nights with strong radiational cooling. With a 50 m variation in elevation across Leon County, this hypothesis that cold air drainage is the dominant mechanism for the temperature anomaly seems plausible.

However, Elsner et al. (1996) determined that cold air drainage was not the major factor causing the anomaly. They did find that the anomaly is most pronounced during the winter season.

With the anomaly definitively identified, Elsner et al. (1996) briefly considered its behavior within the city. The home of Florida State University (FSU) meteorology professor, Henry E. Fuelberg (HEF), located 14.6 km northeast of TLH, was used to compare temperatures to those at TLH. With dense vegetation surrounding the HEF site, warmer temperatures were seen at HEF than at TLH during ideal radiational cooling events. This led the researchers to state, "This result suggests that the TLH minimum temperature anomaly might be a very local effect, at least during the cold season."

Research by Kara et al. (1997) focused on differences in soil type across Leon County as the cause of the temperature variations. Using a planetary boundary layer model to analyze the anomaly, their conclusion was similar to that of Elsner et al. (1996). The variation was believed to be a very local effect, due to variations in soil type and vegetative cover.

With the prior research suggesting that the temperature anomaly might be a very local effect, the NWS in Tallahassee and the FSU Department of Meteorology jointly began a study to examine the anomaly in more detail. This paper describes that study and its results.

2. METHODOLOGY

A network of sites (Fig. 3) was established to record daily minimum temperatures across Leon County. This network was designed to provide good spatial coverage across the county. The network utilized NWS employees, FSU professors and students, and the public to record temperature observations. The large group of observers provided sites where observations would be useful and provided outreach to the community. When a sufficient number of observers was identified, each observer's location was surveyed to determine the best spot to locate the thermometer.

Two types of thermometers were used during the study. In most cases, Taylor maximum/minimum thermometers were used (Fig. 4, left). They are U-tube mercury thermometers with metal filaments inside the bore that mark the minimum and maximum values. The data were recorded daily by the observer who then reset the filaments using an attached magnet. The thermometers were placed 1.3 to 2 m above the ground. While many sites had extensive tree canopies, we strived to place the thermometers so there was open sky above. However, this was not always possible.

To ensure that the data were taken at a similar time, morning minimum temperatures were requested. The observers recorded their minimum temperatures by 9 AM. This is particularly important during the cold season when cold fronts passing during the morning cause the 24-hour minimum to occur later in the afternoon. If it was not possible to record a minimum temperature by 9 AM, the minimum temperature and observation time were given. The morning minimum temperature observations provided continuity in the dataset throughout the study.

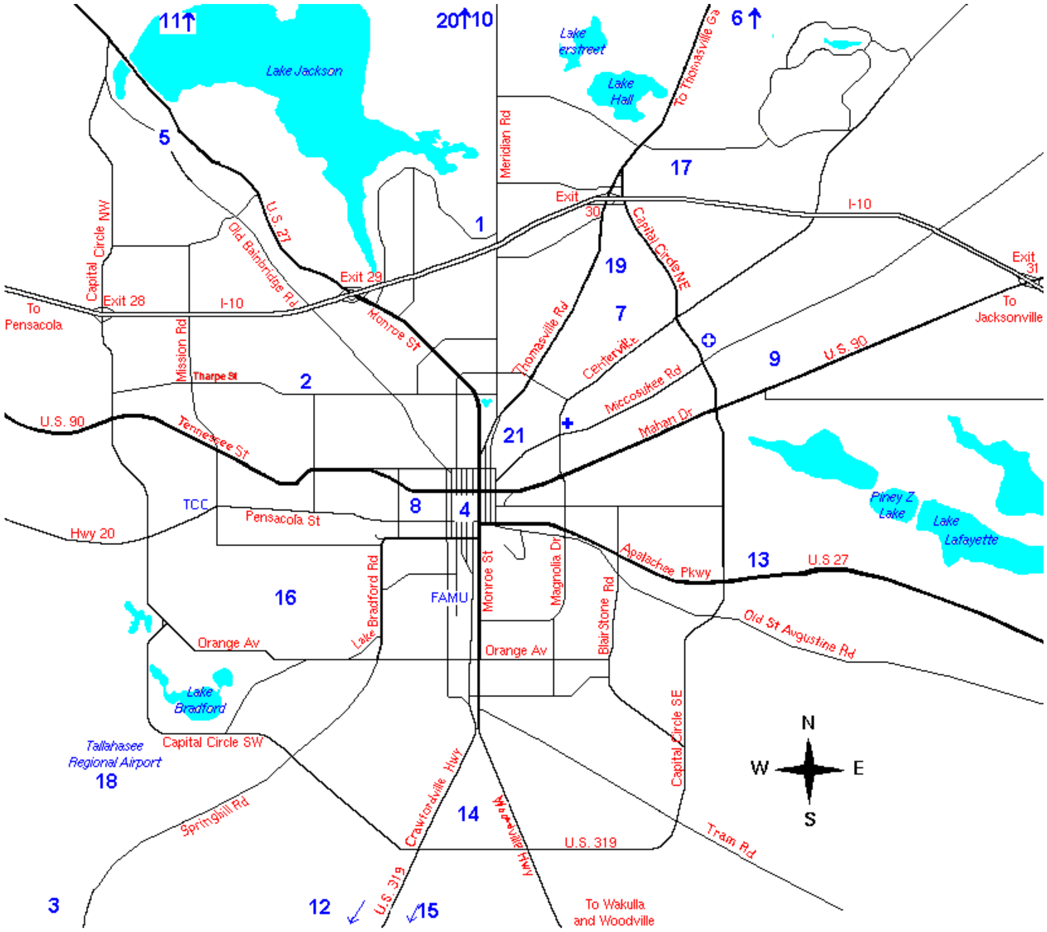

Fig. 3. Map of sites around Leon County. The numbers indicate site locations.

Fig. 4. Picture of a Taylor thermometer site (left) and an AWS Weatherbug site (right).

A network of AWS Convergence Technologies Inc. Weatherbug instruments already was in use across Leon County at the inception of our study (Fig. 4, right). These instruments were determined to be suitable for our use. However, many sites were located on the rooftops of schools or museums. Each site was examined closely to make sure that non meteorological heat sources would not adversely affect the minimum temperature readings. The data from these sites were recorded each morning at the NWS office in Tallahassee via internet.

Once all the sites were properly installed, data collection began during December 2001. The observers submitted their data to a coordinator for review and recording at the end of each month. The data were quality controlled and entered into a spreadsheet program where various statistical values were computed. The monthly data then were evaluated for statistical trends. A monthly report was generated and sent to the observers with important trends identified.

The data collection continued for three years until a sufficiently large dataset was obtained. Every site had some missing data over the three year period. When seven or fewer consecutive days were missing at a site, the missing data were subjectively estimated based on spatial patterns identified during the three years. Those recreated data then were flagged in the spreadsheet program. Approximately 2% of all data were recreated over the three year period. Although over 25 sites participated in the study at different times, stations that contained more than 10% missing data were not included for later analysis. This left 13 sites spatially distributed across Leon County that were incorporated into the statistical study.

Empirical Orthogonal Functions (EOFs) were found to produce the best results in modeling the minimum temperature anomaly. An EOF is a statistical method that determines the dominant mode or variation within a dataset (Wilks, 1995). Since most of the temperature variation in our network was believed to be due to the urban heat island and radiational cooling effects, the EOF analysis proved useful in determining the dominant pattern across the county.

In order to use the EOF analysis, a set of minimum temperature anomalies was constructed. Using the three year dataset at each site, the individual months were combined together to produce monthly averages at each site. For example, the data from all three Januarys were used to calculate a January monthly average at each location. This average then was subtracted from every daily minimum during January to produce a set of daily anomalies. The same steps were followed for the remaining 11 months. This allowed a three year time series of the anomalies to be generated during the EOF analysis.

3. RESULTS

The EOF analysis utilized 1076 days at 13 individual sites. Thirteen different modes were found in the EOF results, with the first mode accounting for 91.2% of the total variance in the network (Fig. 5), and the second mode explaining only 1.2% of the variance. With such a high percentage, this first mode was the only one used to develop the forecast model. The corresponding eigenvectors of this first mode ranged from 2.04×10^{-1} to 3.19×10^{-1}. The eigenvectors form the basis of the minimum temperature model. The time series for the first mode is displayed in Fig. 6. The higher amplitude sections of the time series correspond to the cold seasons. The rapid oscillations during the cold seasons are believed to be the passages of cold fronts through the network.

The eigenvectors of the first mode were objectively analyzed using a gradient mapping approach. This analysis (Fig. 7) is believed to represent the shape and placement of the Tallahassee heat island under idealized radiational cooling conditions.

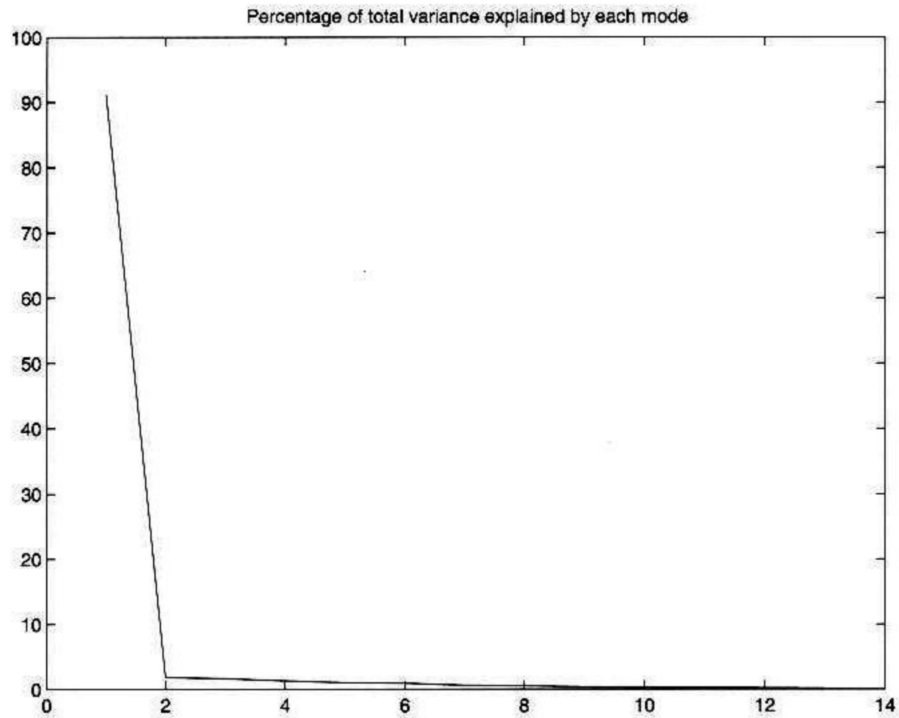

Fig. 5. Percentage of total variance explained by each mode in the EOF analysis.

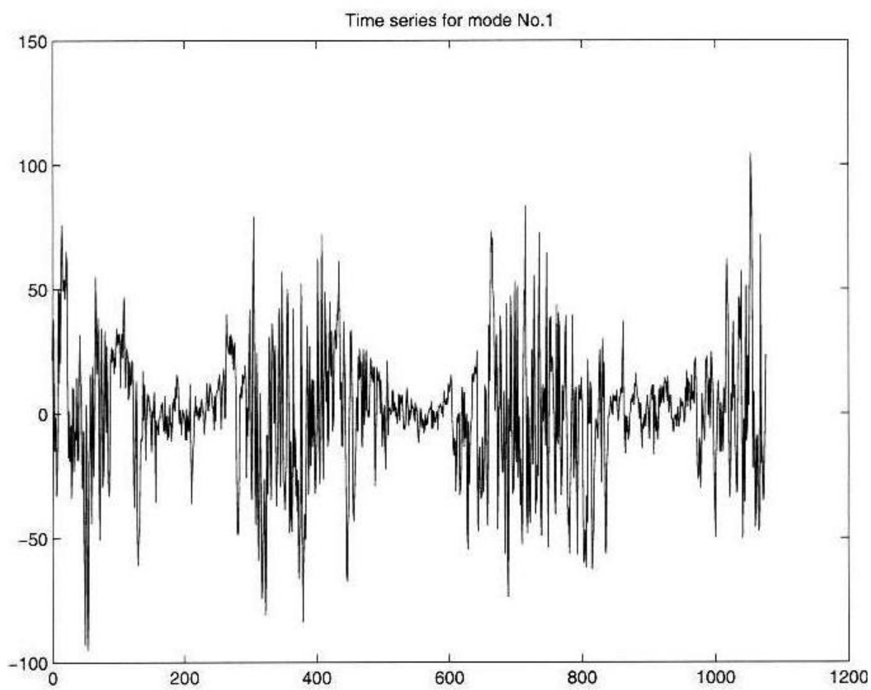

Fig. 6. Time series for the first mode of the EOF analysis. The abscissa is days in the study. The ordinate is unitless values of the EOF analysis.

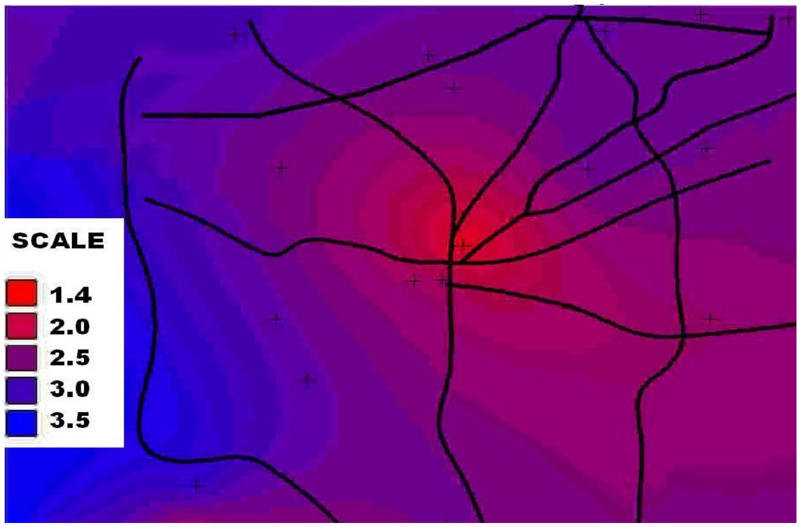

Fig. 7. Gradient map of the first mode of the EOF analysis. Red colors indicate warm regions, while blue colors indicate cooler regions. The scale on the left represents the eigenvectors multiplied by ten.

To predict minimum temperatures at each site in the network, a forecast equation was developed. The NWS in Tallahassee verifies their forecasts against data collected at the Tallahassee Regional Airport (TLH). Since temperatures for TLH are predicted each day, the model uses TLH as its initial condition. This requires that all eigenvectors be scaled to that of the airport, making TLH's eigenvector equal to 1. To allow the model to be used during each month, and not just the cold season, the monthly averages computed at each site were utilized. The forecast equation that was developed is:

$$\underset{(1)}{\text{Site Forecast}}=((\underset{(2)}{\text{TLHfcst}}-\underset{(3)}{\text{TLHavg}})*(\underset{(4)}{\text{Eigenvectorsite}}/\underset{(5)}{3.11}))+\underset{(6)}{\text{Siteavg}}$$

The six variables represent:

(1) The predicted value for a particular site in the network given the initial condition at TLH,
(2) This is the only modifiable variable, the predicted value for TLH chosen by an operational forecaster,
(3) The monthly average temperature at TLH for the particular month of interest,
(4) The eigenvector for the site being forecast,
(5) The eigenvector for TLH,
(6) The monthly average of the site being forecast.

The equation indicates that the anomaly for TLH is generated by variables 2 and 3. However, since the goal is to model the minimum temperature at each site, the respective site's monthly average is added back into the equation after the TLH anomaly is multiplied by the scaled eigenvalue for the appropriate site (variables 4, 5 and 6).

Once the forecast equation was developed, software was identified to implement it. To allow for ease of use, Microsoft Excel was chosen. The file (Fig. 8) was developed so the forecaster is only required to input his or her predicted minimum value for TLH and then press enter. Immediately after entry, predicted minima for the other 13 sites are calculated. All of the climatological and EOF data are contained within a separate background sheet. Basic statistical calculations then are performed on the model output and displayed at the bottom of the page.

The Tallahassee Minimum Temperature Model

March

TLH Forecast= 32 <-- The forecast minimum for TLH is inserted here

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Forecast Temperature Based on TLH

Site Name	February	
Bellenot	37.6	
Binkley	29.5	
Brogan	42.4	
Canopy	32.6	
Chiles	32.9	<--After the forecast minimum for TLH is entered, the
Fuelberg	36.1	forecast for each site is automatically computed and
McCool	31.5	listed in the table. For ease of use, these numbers
Nayak	33.1	are rounded to the nearest tenth degree.
Oak Ridge	30.9	
Sharp	35.6	
TLH	32.0	
Watson	34.3	
Winsberg	43.4	
Blw Frz	4	<--The number of sites forecast to be 32 F or colder.
Hard Frz	0	<--The number of sites forecast to be 25 F or colder.
Max Temp	43.4	
Min Temp	29.5	
Range	13.9	<--Various statistical values are computed here.
Average	34.8	

Fig. 8. The model interface with minima for March being computed.

Once the model was input into Excel, it was evaluated over a period of time before use by forecasters at NWS Tallahassee. Results showed that as minimum temperatures decreased below normal, their range over the network increased (Fig. 9, left). This was an expected result, confirmed by the three year dataset. Conversely, the range decreased when minimum temperatures were above normal (Fig. 9, right). However, the range of above normal minima in the network was not correctly modeled. Instead, the forecast range was not as small as actually occurs. Above normal minimum temperatures in Tallahassee usually are associated with a low cloud deck or strong winds that produce mixing. Since the first mode of the EOF only models ideal radiational cooling conditions, it does not correctly predict the minima on cloudy or windy nights. Nevertheless, it does alert the forecaster to decreasing temperature ranges. Characteristics such as this will influence whether the model is utilized by an operational forecaster on a given night.

The Tallahassee Minimum Temperature Model	
	February
TLH Forecast=	35
Forecast Temperature Based on TLH	
Site Name	February
Bellenot	38.6
Binkley	32.0
Brogan	41.8
Canopy	33.5
Chiles	34.6
Fuelberg	37.3
McCool	33.1
Nayak	34.6
Oak Ridge	32.8
Sharp	34.5
TLH	35.0
Watson	35.9
Winsberg	43.5
Blw Frz	1
Hard Frz	0
Max Temp	43.5
Min Temp	32.0
Range	11.5
Average	35.9

The Tallahassee Minimum Temperature Model	
	February
TLH Forecast=	52
Forecast Temperature Based on TLH	
Site Name	February
Bellenot	53.0
Binkley	49.4
Brogan	54.5
Canopy	49.5
Chiles	50.2
Fuelberg	52.2
McCool	47.9
Nayak	49.5
Oak Ridge	49.3
Sharp	48.7
TLH	52.0
Watson	51.5
Winsberg	54.8
Blw Frz	0
Hard Frz	0
Max Temp	54.8
Min Temp	47.9
Range	6.9
Average	51.0

Fig. 9. A below normal temperature of 35°F (left) input into February will yield a greater range than an above normal temperature of 52°F(right) input into February.

During the evaluation period, the minimum temperature model exhibited biases under certain weather conditions. When skies are clear and winds remain calm several hours before sunrise, the model has a warm bias of approximately 0.5°C at each site. When winds are greater than 2.3 m/s and/or a ceiling of clouds exists below 5000 m, the model has a cold bias, which is a function of the wind and the cloud cover. Due to these biases, the forecaster must be aware of the current synoptic situation. This model, like any other, will fail when applied to conditions for which it was not designed.

4. SUMMARY AND CONCLUSIONS

After the evaluation period, the model was used operationally by forecasters to aide in predicting freezes. Freezes in North Florida can present a dangerous threat to agriculture and other interests. Our three year dataset has shown that when TLH and surrounding rural areas reach 0°C, the urban areas of Tallahassee usually remain above 0°C. The temperature model has been very useful on these borderline nights since it shows forecasters the locations where freezing temperatures are expected. Furthermore, since many residential and commercial interests may not have insulated water pipes, hard freezes (temperatures ≤ -6°C) can be particularly dangerous. This is another example when the model has proven very useful. A final use of the temperature model has been to supply the NWS Zone Forecast Product with a more precise temperature range during non freeze situations. For example, forecasters now insert numerical ranges into the product instead of the traditional, "Lows in the lower 30s."

Based on a three month operational period at NWS-Tallahassee, the minimum temperature model has been found to perform well under ideal radiational cooling conditions. In fact, the model was one of the major sources of information that led forecasters to either issue a freeze warning or not. However, the model has had only limited success in improving minimum temperature forecasts on cloudy or windy nights. These nights are not well represented by the EOF analysis and therefore are modeled with only limited success. Despite the inaccuracies on cloudy or windy nights, the successes on radiational cooling nights have proved that the model provides important information to operational forecasters and will continue to be used to improve minimum temperature forecasts.

5. ACKNOWLEDGMENTS

Over the course of the past three years many people have provided important guidance in the development of the model. We would like to acknowledge and thank these individuals for their contributions, especially Dr. O'Brien's Ph.D. student, Peng Yu, deserves many thanks for assistance in running the Matlab program that created the EOF analysis on our dataset.

We appreciate the many temperature observers and the forecasters at NWS Tallahassee who tirelessly recorded minimum temperatures for three years. Without their efforts, this study would not have existed.

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6. REFERENCES

Elsner, J. B., H.E. Fuelberg, R. L. Deal, J.A. Orrock, G. S. Lehmiller, and P. H. Ruscher, 1996: Tallahassee, Florida, minimum temperature anomaly: Description and speculations. *Bull. Amer. Meteor. Soc.*, **77**, 721-728.

Gannet New Media, 1994: *The USA Today Weather* Almanac. Vintage Books, 316 pp.

Kara, A. B., J. B. Elsner, and P.H. Ruscher, 1997: Physical mechanism for the Tallahassee Florida minimum temperature anomaly. *J. Appl. Meteor.*, **37**, 101-113.

Wilks, D.S., 1995: *Statistical Methods in the Atmospheric Sciences*. Academic Press, San Diego. 476 pp.