

## Is there a weekend effect in diurnal temperature range at Pascagoula and Agricola, MS?

<sup>1</sup>Madhuri S. Mulekar, <sup>2</sup>Sytske Kimball, and <sup>1</sup>Jeffery M. Boone

<sup>1</sup>Department of Mathematics & Statistics, University of South Alabama, Mobile, AL 36688-0002, USA

<sup>2</sup>Department of Earth Sciences, University of South Alabama, Mobile, AL 36688-0002, USA

### Abstract

Human activities have been linked to the changes in the earth's climate. Studies indicate increase in the global mean air temperature during the industrial growth period. Since human activities tend to follow weekly cycles, the existence of a weekend effect on low-level air temperatures is suspected. Temperature data from two different stations is used to determine the existence of a weekend effect in the diurnal temperature range and to estimate the size of the effect. The sites are located in coastal areas of Mississippi, one in Pascagoula and one in Agricola. Temperature (and other data) was collected for every minute but was averaged to appropriate time intervals. A significant weekend effect was observed at both sites.

### 1. Introduction

Eilperin (2005) reported that Goddard Institute of Space Studies calculated 2005 to be the hottest year on record, surpassing 1998's record. Climatologists used readings from 7,200 international weather stations in their calculations. While global temperatures are on the rise, different trends might be seen at individual sites. Studies show that some localized temperatures are increasing, while others are declining (Franklin & Mulekar, 2006; Gray, 2003; Kark and Annexe, 1998). For decades, questions that scientists have been pursuing are: Are human activities associated with such changes in temperatures? If yes, which human activities have a greater influence? What kind of effects do human activities have on temperatures? How can we reduce the effects of such activities? Etc.

There are many different indicators of climate change and one of them is the average diurnal temperature range (DTR). The DTR is used commonly as an index of climate change and variability. DTR is defined as the difference between the daily maximum temperature and daily minimum temperature. According to Foster and Solomon (2003), the global temperature has risen by approximately  $0.6 \pm 0.2$  K in the industrial era and to some extent, human activities might have played a significant role in this change in the Earth's climate. Although not spatially uniform, many areas have seen a decrease in DTR over land (Easterling, et al. 1997). In fact, Dai, et al. (2001) and Stone and Weaver (2002,

2003) showed the global DTR decreased by about  $0.2^{\circ}$  C over the last century due to greenhouse effect. Some scientists suspect that natural variability alone is not responsible for this decrease and human activities may have aided it considerably.

Braganza, Karoly, and Arblaster (2004) suggest that such trends in the temperatures can be due to changes in either the maximum or minimum temperatures. The global warming trend might be due to a higher increase in daily minimum temperatures than the increase in the daily maximum temperatures (Karl, et al, 1993, Stone and Weaver, 2003, Jin and Dickinson, 2002, and New, et al. 2000) leading to a lower daily DTR. This trend is stronger closer to the Polar regions. In other words, it is the nighttime temperatures that are affecting the changing climate.

Karl, et al. (1984) studied temperatures recorded by a network of 130 stations across the United States and Canada. They reported significant decreasing trends in the monthly DTR between 1941 and 1980. However the physical mechanism responsible for this decreasing trend in DTR was not known. They also showed that the trends in the max and min temperatures differ considerably from trends in mean temperatures. The DTR reported in many regions is subject to a pronounced weekly cycle associated with weekend, thus a weekend effect.

Kan et al (2007) reported a strong association between DTR and daily mortality in Shanghai, China. They hypothesized that large DTR values might lead to environmental stress and thereby become a risk factor for death. They observed a significant effect of DTR on cardiovascular mortality during both cold and warm days, but on respiratory mortality only on cold days.

Studies have shown that the changes in DTR are strongly correlated with cloud cover and soil moisture (Stone and Weaver, 2003, and Makowski, et al. 2007), while being fairly insensitive to changes in mean temperatures or scattering of sunlight by surface aerosols (Stone and Weaver, 2003). The effects of vehicular traffic in urban areas on the pollution, atmospheric chemistry, and DTR are well-documented (Forster and Solomon, 2003; Beale, 2003). Travis, et al (2004) studied the role of jet aircraft contrails in climate during the grounding of all commercial aircraft after the 9/11 tragedy. They reported

an increase in the DTR which was in line with an increase reported during the prior grounding incident.

Forster and Soloman (2003) examined over 40 years of temperatures from about 10,000 stations worldwide reported to the Global Daily Climatological Network. They found significant weakly cycles in DTR in many regions. Although opposite cycles of ozone were also observed, they didn't think the ozone level was a likely cause of the DTR cycles. They suspected one of the reasons for the varying patterns in the weekend effect could be due to downwind transport of pollutants.

Short-period relative measures of temperatures changes such as DTR are in general insensitive to such issues as changes in instrument placement or slow changes in the environment such as urbanization or land use. And therefore, they are more effective in detecting changes in climate over time and useful for spatial comparisons.

## 2. Data Collection

Using measurements at 2 and 10 m above the ground of daily temperatures, we are interested in determining if there is any evidence of a weekly cycle in diurnal temperatures in the rural Mississippi Gulf coast region where human and industrial activity is limited.



Figure 1: A map showing locations of Pascagoula and Agricola, Mississippi

A pilot study (Mulekar and Boone, 2007) was conducted to investigate differences in DTR trends in rural and urban areas of the Gulf coast region and to determine a need for a large scale investigation of diurnal temperatures in this area. Data collected by two rural locations of the University of South Alabama Mesonet, Bay Minette, AL and Mt. Vernon, AL and one urban location of the Louisiana State University Agricultural Center, Baton Rouge, LA over a 3-month period was

used. The population of Baton Rouge has increased considerably in the post-Katrina period due to migration from disaster-struck New Orleans since late 2005. This sudden influx of population left the city of Baton Rouge with a shortage of facilities, which led to significantly increased human activity and traffic congestions. Results of this study indicated existence of a significant weekend effect in the diurnal temperatures at Baton Rouge (p-value = 0.0416). However, no significant evidence of the weekend effect was observed at the two rural areas (Bay Minette: p-value = 0.1908 and Mt. Vernon: p-value = 0.1002).



Figure 2: Agricola, MS Mesonet station

For the current study, data was collected at Agricola, MS (July 3, 2006 - June 11, 2007) and Pascagoula, MS (July 18, 2006 - June 11, 2007). See

Figure 1 for the geographical locations of Pascagoula and Agricola. The University of South Alabama Mesonet installed weather stations at these two locations in 2005 and they started archiving data in 2006. Pascagoula is a small coastal town of population about 25,000. The main industry/business in this town is shipbuilding. However, the majority of employees do not live in Pascagoula and prefer to commute every day from Mobile, Alabama, or Gulfport, Mississippi. Most of Pascagoula south of Highway 90 was destroyed by hurricane Katrina in 2005. Agricola is a small community, 40 miles directly north of Pascagoula with no major employers. Commuting or traffic jams are not the problems experienced by Agricola.

The weather stations that collected the data are Mesonet stations owned by the University of South Alabama Mesonet. Figure 2 shows a picture of the Mesonet station at Agricola, MS that was used to collect data. The station at Pascagoula, MS is similar to the one at Agricola, MS.

These stations measure data for several different weather variables including temperature, relative humidity, precipitation, 2- and 10-meter wind speed, and wind direction. The Mesonet station tower is approximately 10 m (30 ft) high with the temperature probe and anemometers located at 2- and 10-meter heights above the ground.

Table 1: Data collection period

Location	Period	Days used	Complete weeks used
Agricola	July 3, 2006 – June 11, 2007	329	49
Pascagoula	July 18, 2006 – June 11, 2007	344	46

These stations recorded temperatures at 2 meters above ground on the Celsius scale once every minute. Data collected by the two stations for a fairly comparable time period was used in the analysis. The data was missing for a couple days from Agricola. Changes in temperatures recorded at 10 meters from ground were not analyzed due to some incorrectly recorded data.

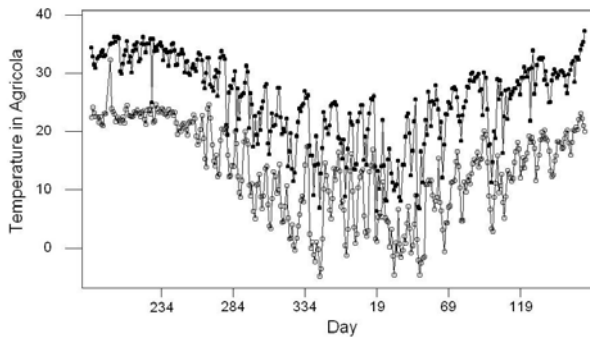


Figure 3: Maximum and Minimum temperatures in Agricola

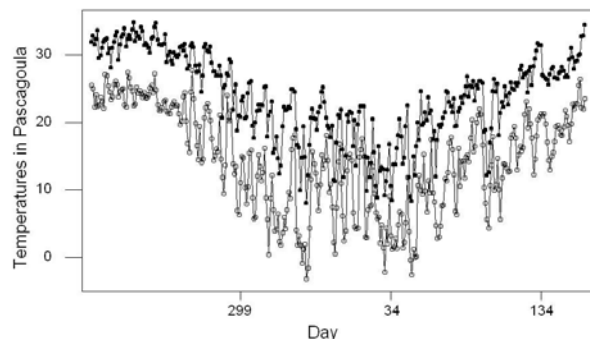


Figure 4: Maximum and Minimum temperatures in Pascagoula

All the analysis was conducted using statistical software JMP®, a product of SAS, Inc and Minitab®. The significance of the results was established using 5% level of significance. Correlations were studied using Pearson's correlation coefficient. The means of two groups were compared using t-tests and those of more than two groups were compared using F-test. The Shapiro-Wilk test was used to determine normality of underlying distributions. Since sample sizes were fairly large, techniques with large-sample approximations were used.

### 3. Diurnal temperatures and weekend effect

From Agricola and Pascagoula respectively, data for 51 and 48 weeks was available including partial weeks on both ends. As a result, data from 49 and 46 complete weeks was used for some of the analysis. Monday was designated as the beginning of the week. The daily minimum and maximum temperatures were calculated for each day from the temperatures recorded every minute.

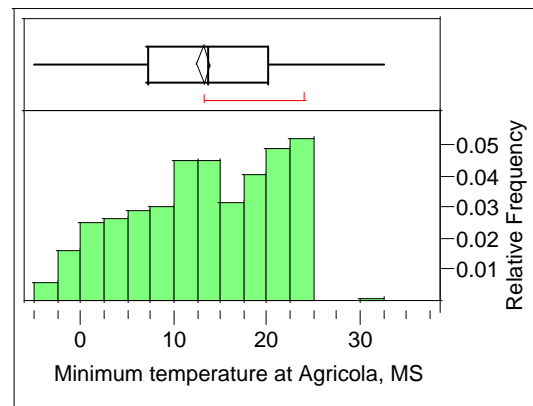


Figure 5: Distribution of daily minimum temperature at Agricola, MS

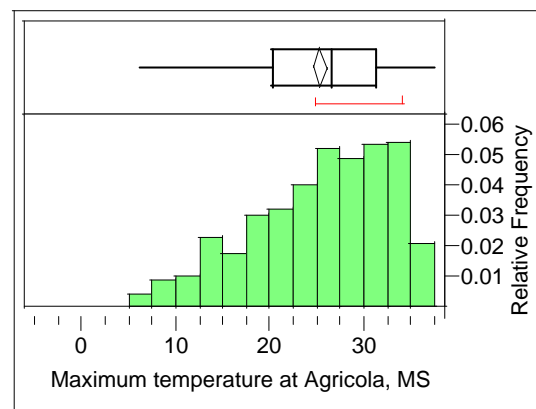


Figure 6: Distribution of daily maximum temperature at Agricola, MS

Table 2: Daily minimum and maximum temperatures (in degree Celsius)

	Daily Min	Daily Max	p
Agricola	13.17 ± 7.77	25.33 ± 7.30	< 0.0001
Pascagoula	14.36 ± 7.64	23.90 ± 6.42	< 0.0001

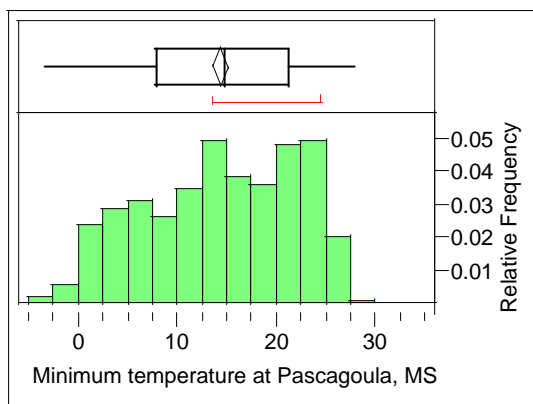


Figure 7: Distribution of daily minimum temperature at Pascagoula, MS

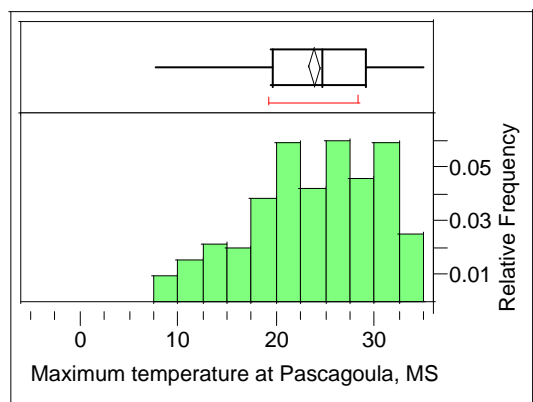


Figure 8: Distribution of daily maximum temperature at Pascagoula, MS

The daily minimum and maximum temperatures show a yearly cycle at both locations (see Figure 3 and Figure 4). The distributions of minimum (see Figure 5 and Figure 7) and maximum temperatures (see Figure 6 and Figure 8) are considerably left-skewed indicating higher temperatures on most days at both locations, which agrees with their warmer climates. At Agricola, the minimum temperatures were in the range (-4.83, 32.33) with a median of 13.68 degrees Celsius, whereas at Pascagoula they were in the range (-3.21, 27.75) with a median of 14.88 degrees Celsius. At Agricola the maximum temperatures were in the range (6.375, 37.26) with a median of 26.60, whereas at Pascagoula they were in the

range (8.20, 34.81) with a median of 24.60°C. Agricola had a larger range of minimum and maximum temperatures. It also had a lower median minimum and a higher median maximum than Pascagoula, indicating a higher DTR. As seen from the statistic in Table 2, the daily maximum was observed to be significantly higher than the daily minimum at both locations. The difference in temperatures may be due to the difference in proximity to the Gulf of Mexico. To what can the difference in DTR be attributed?

Table 3: Summary statistics of DTR

DTR	Agricola	Pascagoula	Difference
Mean	12.16	9.54	2.71
Std Dev	3.53	3.14	2.46
Median	11.97	9.38	2.83
IQR	5.21	4.59	2.98
Range	(0.32, 19.90)	(2.58, 20.58)	(-10.64, 8.18)
N	343	330	330

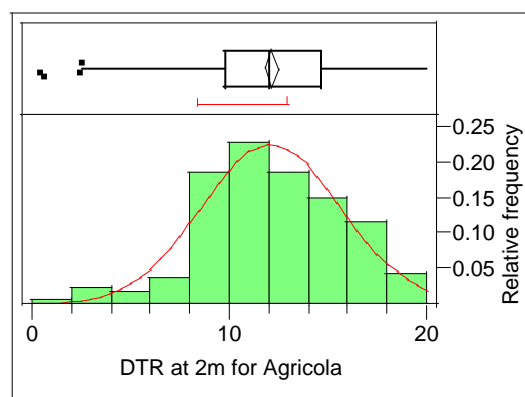


Figure 9: Distribution of DTR at 2 m for Agricola

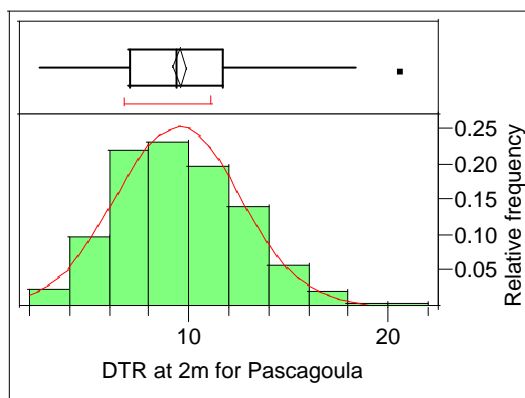


Figure 10: Distribution of DTR at 2 m for Pascagoula

In Agricola, on 90% of days, the recorded daily DTR was at most 17.13°C whereas in Pascagoula it was 13.52°C.

Agricola also showed a higher inter-quartile range indicating more variation in DTR values.

The distributions of DTR are mound-shaped and look comparatively more symmetric than the distributions of minimum and maximum temperatures. However, they are not normal (Agricola:  $p = 0.0005$  and Pascagoula:  $p = 0.0386$ ). In fact the distribution is left-skewed for Agricola (see Figure 9) with a few outliers on the lower end indicating days with unusually low DTR, i.e. days on which the temperature did not vary very much. On the other hand, the distribution of DTR at Pascagoula (see Figure 10) is right-skewed with an outlier on the higher end indicating a day with an exceptionally high DTR, i.e. a day on which the temperatures dropped (or increased) by an unusual amount. It shows that Pascagoula had more days with less variation in day-time and night-time temperature, whereas Agricola had more days with larger variation in day-time and night-time temperatures. This difference is likely due to the difference in location (Coastal versus inland). There is a strong positive correlation between the DTR observed at the two locations ( $r = 0.76$ ) though the average DTR at Agricola is significantly higher than that at Pascagoula ( $p < 0.0001$ ).

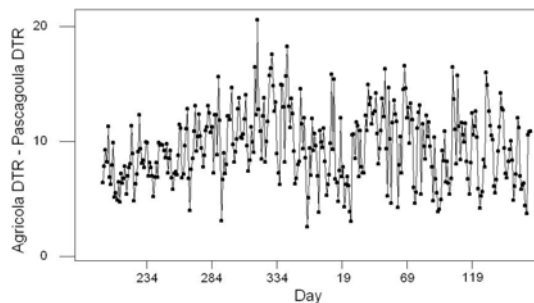


Figure 11: Difference in DTR at Agricola and Pascagoula

The difference in DTR at Agricola and Pascagoula varied considerably. They ranged from  $-10.64^{\circ}\text{C}$  to  $8.18^{\circ}\text{C}$ . On 90% of the days, the difference in DTR was  $0.13^{\circ}\text{C}$  or higher. In fact, on about 8% of the days Agricola had a higher DTR than Pascagoula. The difference in DTR values (see Figure 11) also shows seasonal variation over the year with differences highest during the Fall season (4<sup>th</sup> quarter of year) and lowest during the Winter (1<sup>st</sup> quarter of year). As seen in Figure 12, the distribution of the differences in DTR shows that there were five different days on which the difference was extremely low. All of those days were just before the beginning of the Fall season or after the end of Fall. After ignoring these outliers, the distribution for the differences looks fairly symmetric and normal-like.

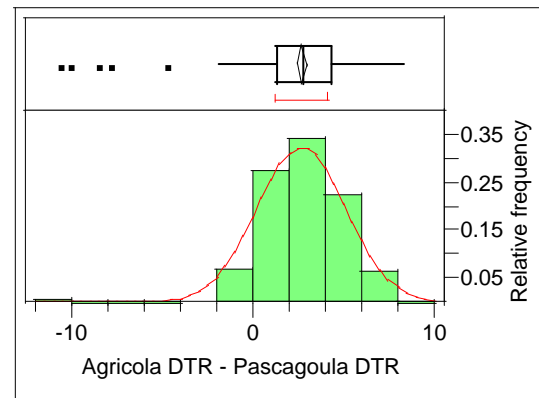


Figure 12: Difference in DTR at Agricola and Pascagoula

At both locations, significant differences were observed in variances of DTRs from week to week using Levene's test (Agricola:  $p = 0.0002$ , and Pascagoula:  $p = 0.0021$ ). After these differences in variances were taken into account, the mean DTRs too differed significantly from week to week ( $p < 0.0001$  for both Agricola and Pascagoula).

Comparison of DTR by the day of the week using time series plots showed prominent weekly cycles. Even when averaged over all weeks, the mean DTR showed a dip in the middle of the week at both locations (see Table 4). For each day of the week, the paired t-test showed the mean DTR of Agricola to be significantly higher than the mean DTR of Pascagoula ( $p < 0.0001$  for each day). When the mean DTR was compared by the day of week no significant differences were observed for either Agricola ( $p = 0.5195$ ) or Pascagoula ( $p = 0.8046$ ). The mean differences were not significant by day of the week ( $p = 0.8616$ ). There was significantly high positive correlation between the DTR at Agricola and Pascagoula. This correlation was highest on Friday ( $r = 0.82$ ) and Saturday ( $r = 0.82$ ) and lowest on Wednesday ( $r = 0.55$ ) followed by Thursday ( $r = 0.66$ ). There is no significant difference among DTR correlations on Friday through Tuesday which ranged from  $r = 0.78$  to  $r = 0.82$ .

The pattern of DTRs observed at these two stations is opposite to what Forster and Solomon (2003) observed in many Midwest stations. They observed maximum DTRs at Midwest stations on Tuesdays or Wednesdays, which they suspected was due to 1-2 days delay from West Coast, a part of shifting pattern due to traveling pollutants downwind. At Agricola and Pascagoula (see Table 4), however, the average DTR was observed to be among the lowest on Wednesday and Thursday and the highest on Saturdays.

Table 4: Mean DTR by the day of week

Day of Week	Agricola			Pascagoula			Corr Coeff
	n	Mean	SD	n	Mean	SD	
Mon	50	12.45	3.24	48	9.83	3.41	0.78
Tue	49	12.37	3.44	47	9.63	3.26	0.80
Wed	49	11.31	4.01	47	9.10	3.12	0.55
Thu	48	11.75	3.54	47	9.17	3.20	0.66
Fri	48	12.14	3.43	47	9.34	3.19	0.82
Sat	49	12.68	3.59	47	9.89	3.29	0.82
Sun	50	12.38	3.47	47	9.78	2.54	0.78

Considering Saturday, Sunday, and Monday as weekend and Wednesday, Thursday, Friday as a weekday, then the week-end-effect is defined as the difference between the mean DTR for Sat-Mon and the mean DTR for Wed-Fri (Forster and Solomon, 2003). A significant weekend effect was observed at both stations (see Table 5). The mean DTR was significantly higher on weekends than weekdays (Agricola:  $p = 0.031$  and Pascagoula:  $p = 0.046$ ). At this point there are no guesses about the causes for this pronounced weekend effect, however it is not likely to be due to traffic patterns as the weekend effect is more significant at a very rural location without traffic congestions. However, both stations are located at schools and both may, therefore, experience more traffic activity during weekdays than on weekends. One way to determine if this is a factor, is to include holidays and school breaks in the weekend category and to exclude Mondays from the weekend category, while adding Mondays and Tuesdays to the weekday category.

Table 5: Mean DTR for weekday and weekend

Location	Weekday	Weekend	p
Agricola (145)	11.73 ± 3.66	12.50 ± 3.66	0.031
Pascagoula (141)	9.20 ± 3.15	9.83 ± 3.09	0.046
p	< 0.0001	< 0.0001	

As seen from Table 5, on weekdays as well as on weekends the mean DTR was significantly higher at Agricola compared to Pascagoula ( $p < 0.0001$  for both weekdays and weekends).

#### 4. Conclusions

- Within a given week, no significant difference was observed in DTR from day to day.
- The mean DTR differed significantly from week to week.
- The mean DTR was highest on Saturday and lowest on Wednesday in both the locations.
- There is significant positive correlation between the DTR at the two locations.
- Both locations showed a significant weekend effect.

- Agricola had significantly higher mean DTR than Pascagoula when matched by the day.
- The weekend effect is not likely a result of changing traffic patterns at these locations, unless local school traffic has an impact.

The University of South Alabama Center for Hurricane Intensity and Landfall Investigation (CHILI) is in the process of installing additional weather stations across the Gulf Coast area. These stations are expected to be fully functional by late 2007. We plan to revisit this problem with more spatial data over a longer period than was used here.

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