

# Comparison of Soil Temperatures at Pascagoula and Agricola, MS

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## Abstract

Environmental scientists use soil temperatures in various applications, including input to global circulation models and to verify and groundtruth satellite observations. Agricultural scientists use them to predict changes in crop and woodland productivity. Soil temperatures fluctuate annually and daily and are affected mainly by variations in air temperature and solar radiation. Data collected by University of South Alabama Mesonet stations located in rural Mississippi over a period of about 600 days was analyzed. These stations recorded soil temperatures at the ground surface and below ground at 5, 10, 20, 50, and 100 cm on the Celsius scale once every minute. Significant seasonal and yearly cycles were observed in soil temperatures. The diurnal temperature ranges showed significant variation by season and location, coastal versus inland; with higher consistency deeper into the soil.

**Key Words:** Soil temperatures, air temperatures, diurnal temperature range, DTR

## 1. Introduction

One of the indicators of climate change and variability is the average diurnal temperature range (DTR). DTR is defined as the difference between the daily maximum temperature and daily minimum temperature. A pilot study conducted by Mulekar and Boone (2007) to investigate differences in DTR trends in rural and urban areas of the Gulf coast region indicated the existence of a significant weekend effect in the diurnal temperatures at the urban area of Baton Rouge during the aftermath of hurricane Katrina. However, no significant evidence of the weekend effect was observed at the two rural areas of Bay Minette and Mt. Vernon during the same time period.

Mulekar, et al. (2007) conducted a follow-up study of daily temperature measurements at 2 and 10 m above the ground in the rural Mississippi Gulf coast region. Data was collected at Agricola, MS (July 3, 2006 - June 11, 2007) and Pascagoula, MS (July 18, 2006 – June 11, 2007). This study indicated no significant difference in mean DTR from day to day within a given week, but significant difference from week to week. Both locations showed a significant weekend effect. Agricola showed significantly higher mean DTR than Pascagoula when matched by the day. Given the locations and demographic as well as activity characteristics of these towns, the authors concluded that the weekend effect is not likely to be a result of changing traffic patterns at these locations, unless local school traffic has an impact.

The current study extends the previous work on air temperatures to soil temperatures at Agricola and Pascagoula, MS.

## 2. Data Collection

For the current study, data was collected at Agricola, MS (July 3, 2006 - February 1, 2008) and Pascagoula, MS (July 18, 2006 – February 1, 2008). Some data was unusable because of malfunctioning probes and was omitted from further analyses. The geographical locations of Pascagoula and Agricola are shown in Figure 1. Pascagoula is a small coastal town with a population of about 25,000. Agricola is a small rural community, 40 miles directly north of Pascagoula. The University of South Alabama Mesonet installed weather stations at Agricola and Pascagoula, Mississippi in 2005. These stations started archiving data in 2006.

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 meteorological

variables. These stations recorded temperatures 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 soil temperatures were recorded at the ground surface and below ground at 5, 10, 20, 50, and 100 cm depths. The air temperatures were recorded at the surface and above ground at 150, 200, 950, and 1000 cm heights.



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



Figure 2: Agricola, MS Mesonet station

All the analysis was conducted using statistical software JMP<sup>®</sup>, a product of SAS, Inc and Minitab<sup>®</sup>. The significance of the results was established using 5% level of significance. Correlations between numerical variables 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. Since sample sizes were fairly large, techniques with large-sample approximations were used.

For the analysis purpose, seasons were defined using months as follows:

- Fall: September, October, November
- Winter: December, January, February
- Spring: March, April, May
- Summer: June, July, August

### 3. Analysis and results

In this study, the following questions are addressed:

- How do diurnal and annual soil temperature cycles vary with depth?
- To what degree do atmospheric temperature variations force soil temperature variations?

The daily minimum and maximum soil temperatures at different depths at two different locations over the study time-period are plotted in Figure 3. Both locations indicate a seasonal cycle in soil temperatures at all depths. These plots show that the mean daily maximum temperatures are significantly higher at Pascagoula than Agricola ( $p < 0.0001$ ) at all depths. Also, larger mean differences between daily maximum and minimum temperatures are observed at Pascagoula than at Agricola ( $p < 0.0001$ ). It was also observed that the mean difference in daily maximum and minimum temperatures decreased deeper into the soil (see Table 1).

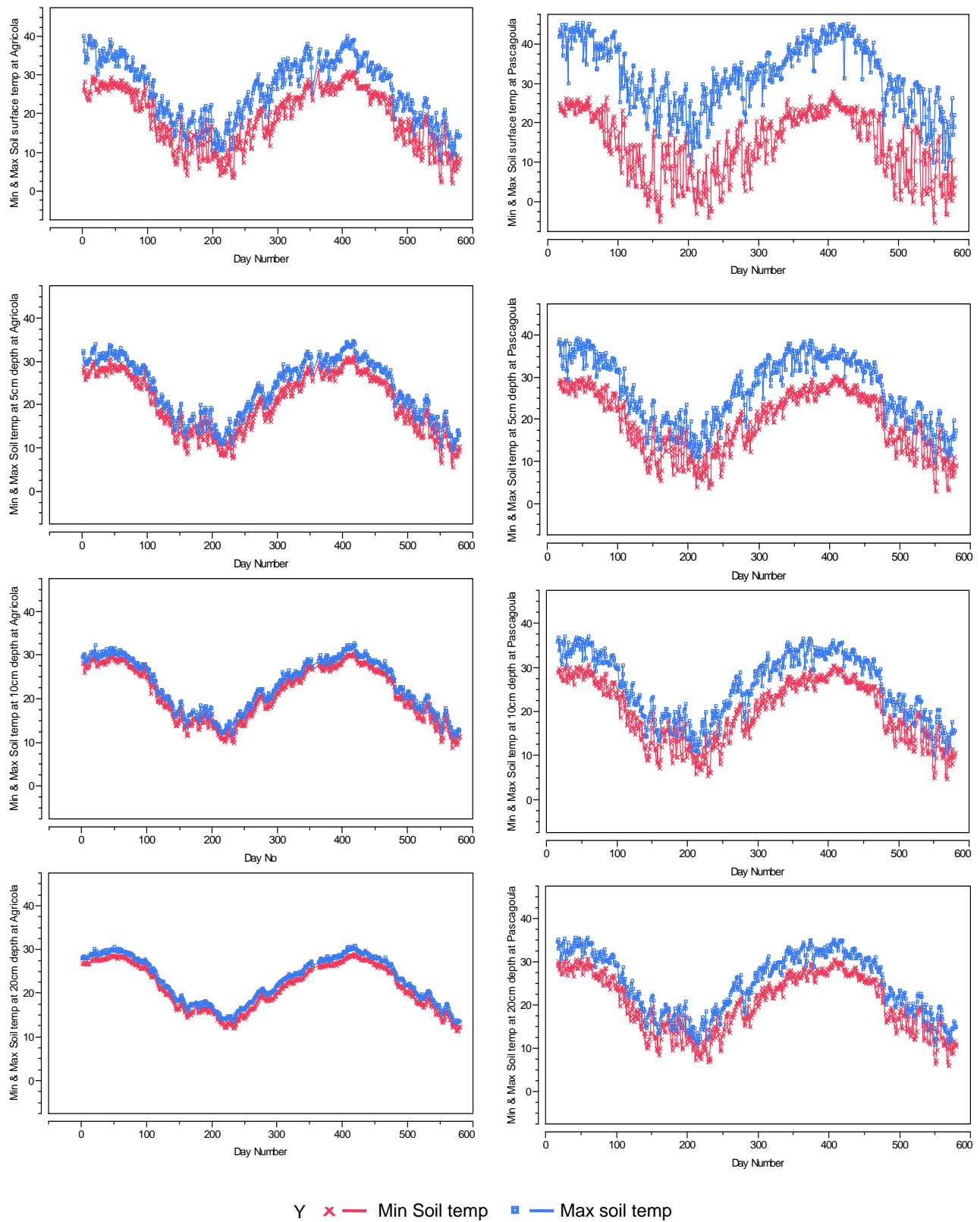


Figure 3: Minimum (red) and maximum (blue) soil temperatures at different depths at Agricola (left) and Pascagoula (right).

Table 1: Summary statistics for soil temperatures at Pascagoula, MS

| Depth        | Agricola (n = 565) |                  |       | Pascagoula (n = 564) |                  |       |
|--------------|--------------------|------------------|-------|----------------------|------------------|-------|
|              | Mean $\pm$ Std Dev |                  | r     | Mean $\pm$ Std Dev   |                  | r     |
|              | Max                | Min              |       | Max                  | Min              |       |
| Soil Surface | 25.89 $\pm$ 8.14   | 18.64 $\pm$ 7.49 | 0.958 | 31.81 $\pm$ 8.48     | 13.87 $\pm$ 8.32 | 0.854 |
| 5 cm         | 23.50 $\pm$ 6.82   | 20.25 $\pm$ 6.73 | 0.993 | 26.71 $\pm$ 7.89     | 18.89 $\pm$ 7.30 | 0.955 |
| 10 cm        | 22.89 $\pm$ 6.09   | 21.04 $\pm$ 6.12 | 0.997 | 25.52 $\pm$ 7.36     | 19.72 $\pm$ 6.98 | 0.972 |
| 20 cm        | 22.90 $\pm$ 5.25   | 21.29 $\pm$ 5.25 | 0.997 | 24.79 $\pm$ 6.96     | 20.17 $\pm$ 6.73 | 0.981 |
| 100 cm       | 31.05 $\pm$ 8.48   | 13.13 $\pm$ 8.28 | 0.849 | 23.15 $\pm$ 4.78     | 21.69 $\pm$ 4.82 | 0.995 |

The association between soil surface temperature and soil temperatures at different depths was investigated at both locations. Figure 4 and Figure 5 display scatterplots of daily mean soil temperatures at 5 cm and 100 cm depths respectively against the mean soil surface temperatures. Both sites display a strong correlation between soil surface and soil 5 cm temperature and the slopes of the regression lines are similar. In both cases, the 5 cm soil temperature is usually slightly warmer than the soil surface temperature. The correlation between the temperature at 100 cm depth and soil surface temperature is lower than at 5 cm depth, at both locations. The 100 cm soil temperatures showed less variation for a range of soil surface temperatures at Pascagoula, indicating lesser effect of surface temperature on deeper soil temperatures on Gulf Coast than inland. The slope of the regression line is steeper at Agricola (220) than Pascagoula. At Pascagoula the 100 cm temperature is mostly warmer than the soil surface temperature for surface temperature below about 20°C and colder for surface temperatures above about 20°C.

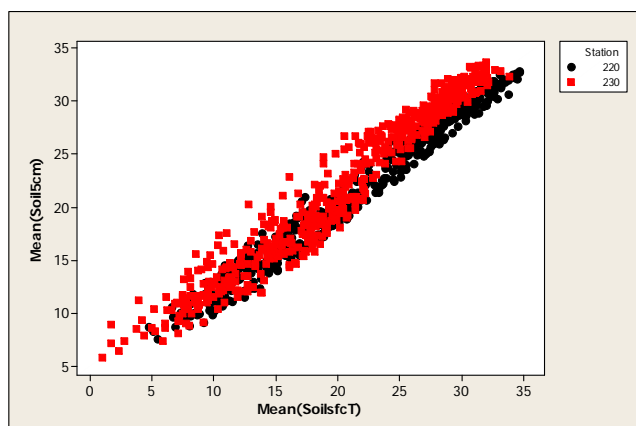


Figure 4: Correlation between mean soil surface temperature and mean soil temperature at 5 cm depth at Agricola (black dots) and Pascagoula (red squares).

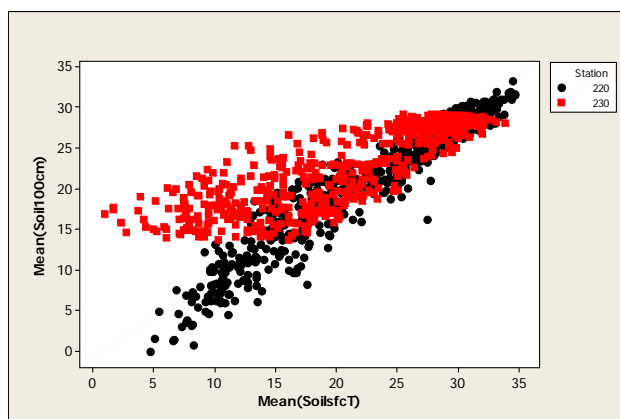


Figure 5: Correlation between mean soil surface temperature and mean soil temperature at 1 m depth (right) at Agricola (black dots) and Pascagoula (red squares)

The boxplots of daily minimum and maximum soil temperatures at different depths for two locations (see Figure 6 and Figure 7) show that the minimum soil temperature tends to increase with depth at both locations. The minimum soil surface temperature at Pascagoula tends to be lower than that at Agricola and also displays more variability. The maximum soil surface temperature tends to decrease with depth at both locations. The maximum soil surface temperature at Pascagoula tends to be higher than that at Agricola. In other words, very cold/warm temperatures at the surface do not penetrate all the way down into the soil.

The boxplots of daily minimum and maximum air temperatures at different heights for two locations (see Figure 8 and Figure 9) show that the minimum air temperature tends to increase with elevation at both locations. At Agricola the minimum soil surface temperature is higher than the minimum air temperature, whereas at Pascagoula it is lower. The minimum 1.5m air temperature at Pascagoula has a slightly larger median than at Agricola, yet the median of the minimum soil surface temperature is lower. This indicates that the soil type at Agricola probably differs from that at Pascagoula. Similarly, the maximum 1.5m air temperature at Pascagoula has a slightly lower median than at Agricola, yet the median of the maximum soil surface temperature is higher. In other words, the soil surface temperature at Pascagoula responds differently to the low level air temperature than that at Agricola. This indicates that the soil types

at both locations are different. This can be confirmed by 1) identifying the soil types and 2) comparing solar radiation input at both sites.

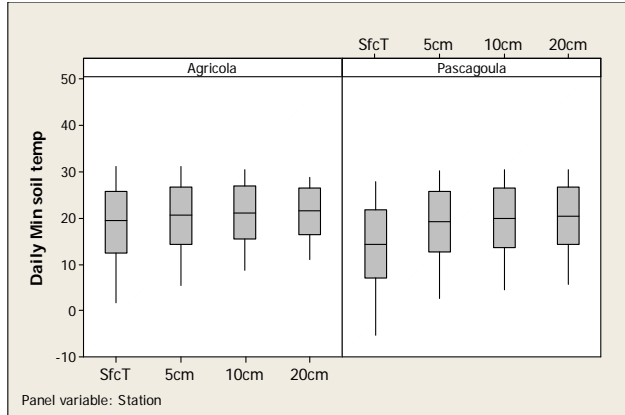


Figure 6: Comparison of distributions of daily minimum soil temperatures at different depths at Agricola and Pascagoula

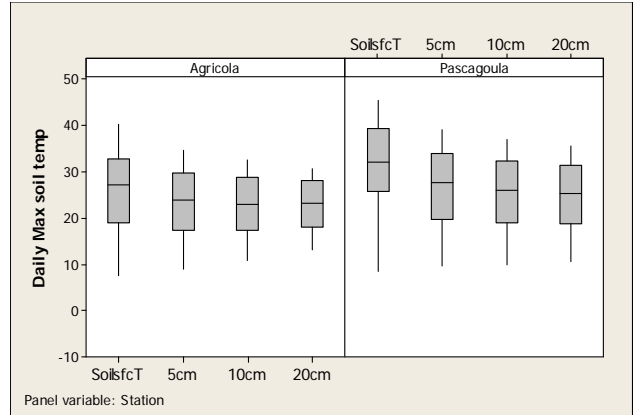


Figure 7: Comparison of distributions of daily maximum soil temperatures at different depths at Agricola and Pascagoula

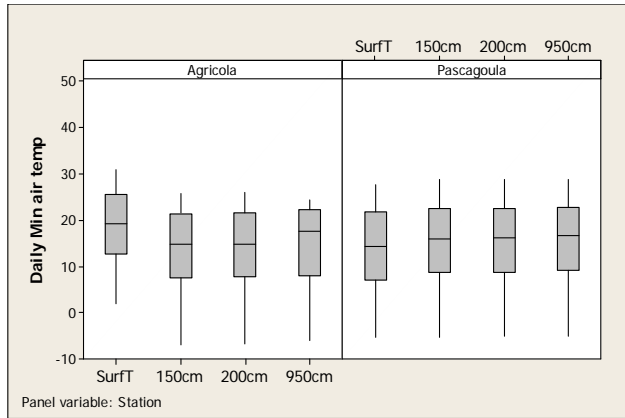


Figure 8: Comparison of distributions of daily minimum air temperatures at different levels at Agricola and Pascagoula

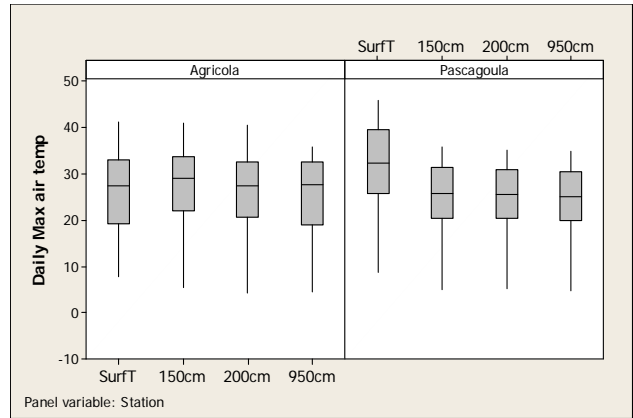


Figure 9: Comparison of distributions of daily maximum air temperatures at different levels at Agricola and Pascagoula

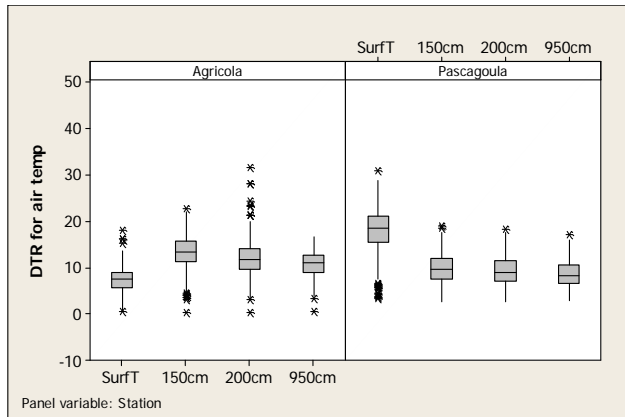


Figure 10: Comparison of distributions of DTR of air temperatures at Agricola and Pascagoula

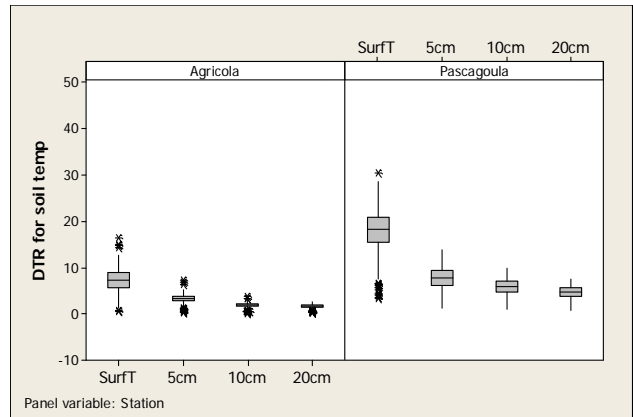


Figure 11: Comparison of distributions of DTR of soil temperatures at Agricola and Pascagoula

The distributions of DTR for air and soil temperatures at the two locations are displayed in Figure 10 and Figure 11. Pascagoula displays significantly higher soil DTR than Agricola at all depths ( $p < 0.0001$ ). At both locations, soil DTR decreased with depth. Similarly, at both locations, air DTR (at 150 cm and above) decreased with altitude. Daily minimum soil temperatures increased and maximum soil temperatures decreased with depth, resulting in a lower soil DTR with depth. The soil DTR showed higher day-to-day variation at surface and became more consistent with depth.

As seen from Figure 12, at Pascagoula, the mean soil surface temperature is significantly higher than at Agricola for all 4 seasons. This is reflected in somewhat higher soil temperatures in Pascagoula as well. Soil temperatures drop off with depth in both locations for all seasons. At Agricola and Pascagoula the largest soil surface temperatures occur in the spring. An exception is the soil surface temperature at Pascagoula which displays a maximum in the fall. The minimum mean soil temperatures occur in the winter at all depths and at both locations.

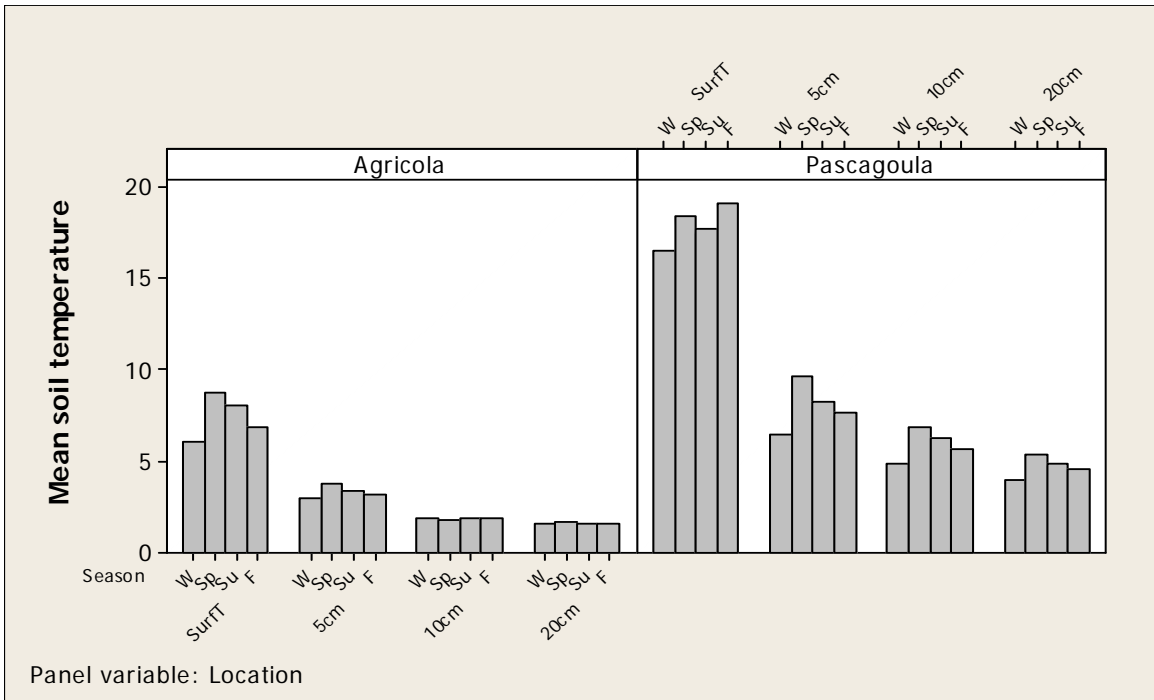


Figure 12: Mean soil temperatures at Agricola and Pascagoula by season

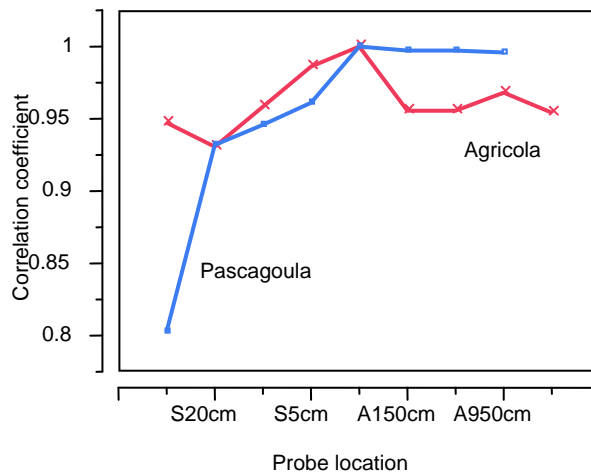


Figure 13: Correlation between surface and soil (S) /air (A) temperatures.

The trend in correlation between surface temperatures and soil/air temperatures by depth/altitude is shown in Figure 13. At Agricola, the correlation between surface and soil/air temperature decreases slightly with depth/height. At Pascagoula, the correlations remain fairly similar for air at all heights, but drops considerably for soil with depth.

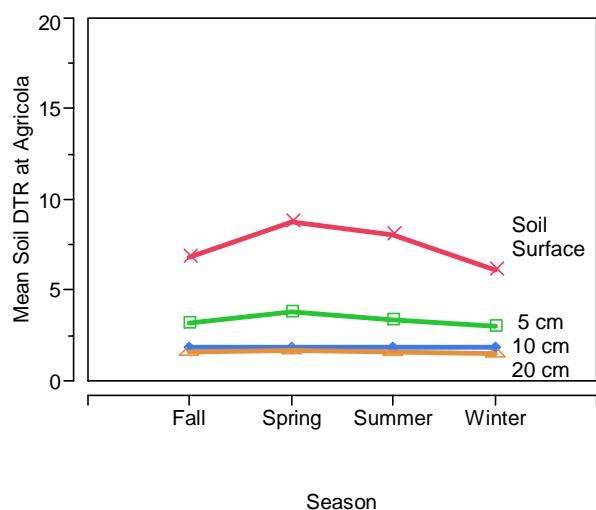


Figure 14: Mean soil DTR at Agricola by season

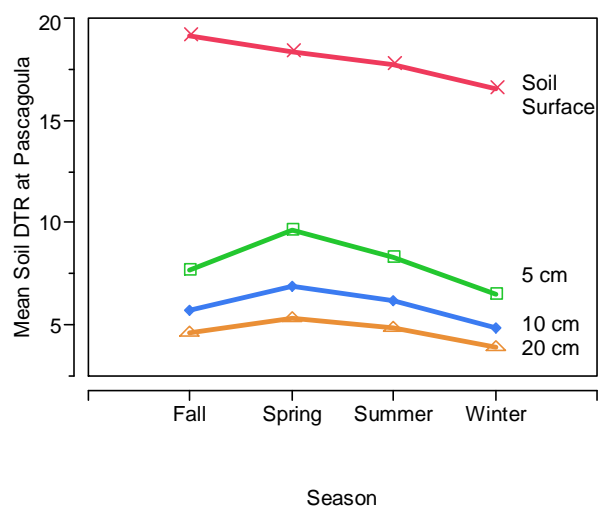


Figure 15: Mean soil DTR at Pascagoula by season

The mean soil DTR by season at Agricola and Pascagoula respectively are shown in Figure 14 and Figure 15. At all depths diurnal soil temperature ranges are larger at Pascagoula than at Agricola. At both locations, the amplitude of the diurnal cycles (i.e. the diurnal temperature range) decreases with depth. Both sites display changes in the diurnal range with season, except for Agricola at the 20 and 100 cm depths. At the soil surface Pascagoula's largest diurnal range occurs in the fall, while Agricola's occurs in spring. Deeper down, the maximum diurnal range occurs in spring at both sites. The smallest diurnal range occurs in winter at both sites and all depths.

#### 4. Conclusions

According to studies Karl, et al. (1993), Stone and Weaver (2003), Jin and Dickinson (2002), and New, et al. (2000) the global warming trend might be due to a higher increase in daily minimum air temperatures than the increase in the daily maximum air temperatures leading to a lower daily air DTR. This trend is stronger closer to the Polar regions. In other words, it is the night-time air temperatures that are affecting the changing climate. Similar results were observed in soil temperatures. Pascagoula, which is on the Gulf of Mexico showed significantly higher DTR than Agricola, which is about 40 miles north inland.

Farmers and applicators monitor the soil temperature of fields before application of fertilizer. Unfortunately, it is not the air temperature, but the soil temperature that controls seed germination. Hillel (1982), Marshall and Holmes (1988), and Wu and Nofziger (1999) showed that the annual variation of daily average soil temperature at different depths can be estimated using a sinusoidal function. The similar pattern is observed, both at Agricola and Pascagoula.

At deeper level, soil temperature changed at different rates with respect to surface temperature at two locations. This may be as a result of difference in distance from Gulf and soil type.

#### Acknowledgements

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