NEAR SURFACE METEOROLOGICAL IMPACTS: RESULTING FROM A TOTAL SOLAR ECLIPSE

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ABSTRACT

Conducted research on America's 21 August 2017 total solar eclipse revealed impacts on near surface meteorological variables, such as, solar radiation and temperature. The main goal is to quantify the reduction of solar radiation, the strength of temperature inversion, and locate when the maximum inversion transpires, during eclipse events. Considering temperature inversions have the tendency to increase pollution density, it is a call for health safety concerns. The Oklahoma Mesonet provided the observation data of two Oklahoma sites, Miami located at the North-East corner of Oklahoma, which was the most relatively close site to the 100% totality path and Hollis located at the South-West corner of Oklahoma with greater distance away from its relative 100% totality. Solar radiation, temperatures at 9-meters and 1.5- meters, UTC time, and dates ranging from 10 August 2017 to 31 August 2017, were stripped to administrate the research. The average of ten days before and after the 21 August 2017, rendered the theoretical values of what the typical 21 August 2017 would have been without the eclipse taking place. The theoretical values and observed data inserted into the percent error formula quantified the reduction of solar radiation and change of air temperatures at the eclipse maximum, where the eclipse is at its highest point in the sky. The difference between temperatures at 9-meters and 1.5-meters, are proportional to atmospheric lapse rates and temperature inversions. Another goal within this research, appraised five-minute versus one-minute data resolutions for the Miami station; with the objective: to find which temporal resolution is more efficient for future research in solar radiation and temperature variables. Numerical values were compared at the eclipse maximum to evaluate the efficiencies. The main research concluded, when decreasing the distance to 100% totality, there is an increase of: solar radiation percent error, total eclipse duration time and temperature inversion feedback. Furthermore, inversion maximum starts five-minutes before the solar eclipse maximum and ends five-minutes after. Where heavy pollution exists and individuals with elevated health risks are the spectators at the prime of an eclipse, the awareness may be crucial. The resolution results show minimal difference amongst five-minute and one-minute datasets, which means five-minute data resolutions are adequate for this type of analyses.

1. INTRODUCTION

A solar eclipse (Fig. 1) occurs when the moon blocks the Sun's direct path to Earth. The latitude and longitude of a specific point on Earth paired with where the solar eclipse takes place in space, varies the reduction of solar radiation that would have been fed to Earth. In the northern hemisphere, solar radiation averages are greater during the summer season, between June to September. Daily solar radiation is greatest at solar noon, where the sun is at its highest overhead. The significance of solar radiation is that it increases air temperatures during the day, where you can expect temperatures in the lower troposphere to be greater at the surface and decrease with height, termed lapse rate.

Figure 1. *2017 solar eclipse in Mannford, Oklahoma taken by Todd Crane.*

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During a diurnal day, after the solar noon, solar radiation and atmospheric temperatures begin to decline. The Earth is always giving off (blackbody) energy, even during the day. However, the incoming radiation from the sun is larger during the daytime, thus it is a net gain and a loss during the nighttime. The atmosphere’s relatively higher heat capacity property absorbs the Earth’s blackbody energy and warms air temperatures. At nightfall, due to the Earth’s lower heat capacity and the shortage of incoming solar radiation, the Earth’s surface cools to the point that its temperature is lower than air temperatures above. Leading to the reversal of lapse rate, now called temperature inversion. To clarify, temperature inversion is when air temperatures increase with height, which then establishes a layer of warmer air atop cooler air; acting as a top barrier, minimizing air circulation, and intensifying air pollution densities.

The reduction of solar radiation caused by solar eclipse events, induces early temperature inversions. This study on solar eclipse provides knowledge of the impacts within the atmosphere, specifically in this case, low level atmospheric temperature inversions and solar radiation. The conducted research probed the 21 August 2017 solar eclipse, which crossed the United States. The Oklahoma Mesonet observed data was utilized from two positions in the state of Oklahoma, one closest to totality (MIAM) and the other furthest (HOLL). Air temperature measurements at 1.5-meters and 9-meters above the ground provided temperature inversion extensivity and duration time. Solar radiation and temperature difference averages were calculated for ten days before and after 21 August 2017 to provide the typical diurnal theoretical values to quantify impact strengths. One -minute data and five-minute data were analyzed individually for the Miami Station to determine the most effective temporal resolution for an analysis of eclipse events in the future.

2. LITERATURE REVIEW

Recent study of the 21 August 2017 solar eclipse under 100% totalities path located in the state of Kentucky, gathered a collection of observation data from the Kentucky Mesonet and took similar data sets like that of the Oklahoma Mesonet and found that solar radiation at the surface decreased from >800 to 0 W m^{-2} and the air temperature decreased by about 4.5°C. (Mahmood et al. 2020) Another 2017 eclipse study (Turner et al. 2018) took three Oklahoma Mesonet sites located in north-central Oklahoma and underwent “about 89% blockage”, also resulted in solar radiation reductions and temperature reductions at all three sites. These two analyses of the 2017 eclipse utilized solar radiation and temperature changes but lacked temperature inversions numerical results.

Past research on temperature inversions state, the decrease of temperature with height is known as the lapse rate. (Stull. 1999) These decreases produce negative values. When you have the temperature increase with height this is called temperature inversion, producing positive values. Temperature inversions usually occur at night fall everywhere, however there are conditions that promote inversions to occur more frequently and with higher results. Specific regions on earth are classified as anticyclone and cyclone. The anticyclonic class is associated with the maximum activity, and the cyclonic class with the minimum activity. (Milionis and Davies, 2008) This means locations where anticyclone weather phenomena occur have the highest frequency and strength results of temperature inversions. The Central region of North America, where the state of Oklahoma is located, is an anticyclone region. Other temperature inversion enhancers are related to certain weather conditions. “Clear skies and calm winds, which favour the formation of surface (base-height on the ground) nocturnal radiation inversions, are typical for anticyclonic weather, while strong winds, cloudiness and rain, which inhibit the formation of such inversions, are typical for meteorological depressions.” (Milionis and Davies, 2008) The 21st of August analyzed in Oklahoma, had clear cloudless and windless weather condition that increased inversion effects. These effects are important to understand because, the atmosphere is in stable equilibrium inside the inversion layer and therefore it does not favor vertical movements of air. The temperature inversion may result in increased concentration of air pollutants at the lower layers of the atmosphere. (Lazaridis. 2011) In another study, they also found that “at the local scale, the thermal inversion layer forms near the surface and plays a central role in controlling the surface radiative cooling and air pollution dispersion.” (Fochesatto. 2015) These three studies analyze when inversions are likely to increase via regions, weather conditions, time of day (ex. At night fall) but fail to study, solar eclipse event which skew night fall to occur in the middle of the day.

3. DATA SOURCE

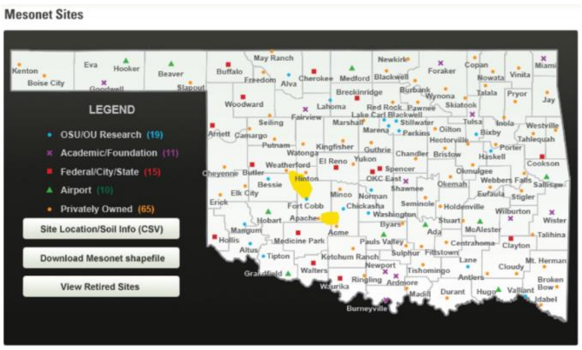

Figure 2. Oklahoma Mesonet Station Name Map, taken from http://mesonet.org

The Oklahoma Mesonet (Fig. 2) is a collection of 120 weather stations located throughout the state of Oklahoma. Each station measures meteorological observations every three seconds to get five-minute average data sets. Additionally, during the total solar eclipse event, they collected one-minute data sets. Each site has their own calibrations and are stationed on flat land areas that are isolated from societal influences, irrigated areas, lakes, forests, and low covered vegetations. Solar radiation is measured in Watts per square meter with Li-Cor Pyranometer sensors. The placement of the sensor is facing upwards to reject other sources of radiation not coming from the sun. The accuracy is ±0.5%. Air temperature at 1.5-meters and 9-meters above the ground are collected with RM Young 41342 Platinum RTD Probe sensors with an accuracy of ±0.5°C. Variations in wind speeds influence the accuracy with 9-meter collections, the lower the speeds the more accurate the readings. For the solar eclipse event, wind speeds were low.

4. METHODOLOGY

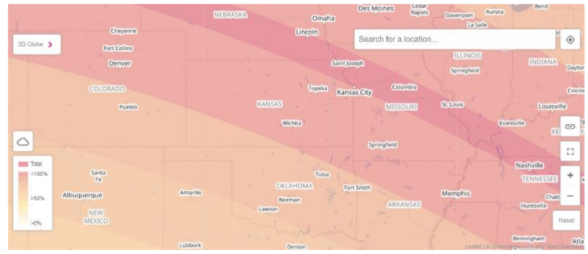

Figure 3. Map of Total Solar Eclipse path on 21 August 2017 taken from Timeanddate.com

Oklahoma was not situated under the path of 100% totality during the 21 August 2017 solar eclipse (Fig 3.). Given the Oklahoma Mesonet data, picking the two sites to analyze were determined by distance away from totality. The closest Oklahoma Mesonet station Miami, located ~295 km away at the northeast corner and the furthest site Hollis, located at the southwest corner of Oklahoma, ~691 km away, were picked. This is to find whether there are variabilities within the duration of the eclipse and inversion episodes at different distances.

Solar radiation observation data at each site were then individually plotted on graphs to show the solar trends of the day influenced by the eclipse. Each site being at difference locations, had their own unique eclipse notable UTC times, developed with the trends on the solar radiation graphs. The start time of the eclipse was established right before the first major solar radiation drop, visually, the first peak. Also associated with the solar radiation first maximum value. The eclipse maximum is located at the lowest point within the two peaks and where solar radiation is reduced to its lowest, then when the solar radiation increases to the next highest peak through time, this is considered the end of the solar eclipse and where solar radiation follows the typical diurnal cycle. At each site, these specific times and numerical values are recorded and utilized for later analyses.

9-meter and 1.5-meter temperatures were subtracted to resemble temperature over height atmospheric trends. The resulting differences were then plotted to devise a time frame of when lapse rates or temperature inversions took place. The key to this analysis is to note the UTC times where there are shifts between the positive and negative values. Degree values being negative are known to be typical lapse rates, values equating to 0 °C are known as a temperature equilibrium amongst the two heights, and lastly, values that are positive are known as temperature inversions. The time range from the first 0 °C to the last, creates the temperature inversion time duration.

To evaluate the impacts on solar radiation and temperatures, the averages of 10 days before and after the 21 August 2017 were calculated at each site. These values now considered the theoretical values of the 21 August 2017 without the eclipse, are then compared graphically to the observed data. Furthermore, the notable eclipse maximum and temperature difference maximum UTC times previously recorded, help with the retrieval of the numerical solar radiation and temperature difference data for the theoretical. To quantify solar radiation and temperature difference manipulation done by the eclipse, both these sets of data were inserted into the percent error formula. Below is the percent error formula.

$$\%\ Error = \frac{|Theoretical - Observed|}{|Theoretical|} * 100$$

The Miami and Hollis observation data were then plotted and analyzed to see whether distance away from totality influence, eclipse duration, temperature inversion duration, and impacts. The comparisons of the notable times established by solar radiation and temperature difference graphs at each station and the impact values at those specific times were broken down and interpreted.

The two-resolution data were plotted to see any major differences, then the specific eclipse maximum and temperature difference maximum times were compared between the solar radiation data and temperature difference data.

5. *RESULTS*

5.1 *MIAMI STATION*

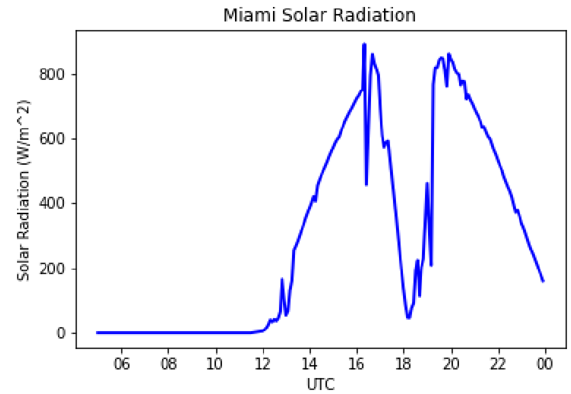

Figure 4. Miami solar radiation over UTC.

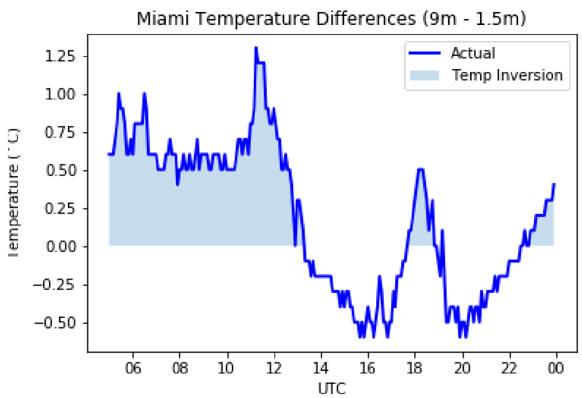

Figure 5. Miami temperature difference over UTC.

MIAMI Event Observation Overview

Analyses of the solar radiation and temperature difference data observed.

Figure 4 visually shows that at 1620 UTC the eclipse began and where solar radiation maxed at 892 W m^{-2}. The eclipse reached its full potential at 1815 UTC and declined solar radiation to 47 W m^{-2}. The eclipse then ended at 1955 UTC allowing the solar radiation to arrive at its second max of 614 W m^{-2}. The eclipse duration at Miami from peak to peak summed to, 3 hours and 35 minutes.

Atmospheric temperature differences (Fig 5.) equated to 0 °C during the eclipse at 1740 UTC. Then continued to increase in temperature till 1810 UTC, where the temperature difference maxed at a positive 0.50°C. Here it maintained its max value for ten minutes. The next 0°C, was met at 1850 UTC and lasted till 1855 UTC, which is a five-minute temperature equilibrium between 9-meters and 1.5-meters. The temperature inversion duration of time from zero to zero, summed to 1 hour and 15 minutes.

Solar Radiation comparison between Observed vs Theoretical

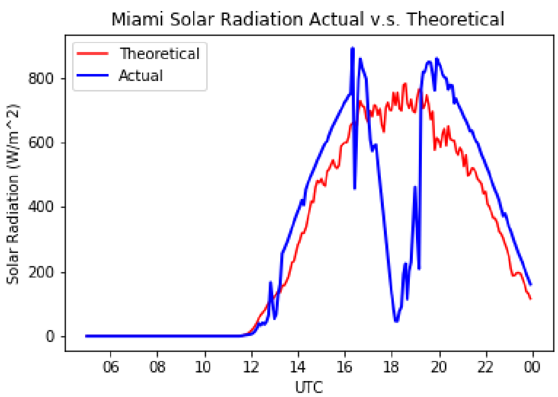

Figure 6. Comparison of the Miami solar radiation of 21 August 2020 observed, and the theoretical value calculated.

At 1815 UTC the eclipse maximum caused the solar radiation to dip down to 47 W m^{-2}, whereas within the theoretical data, this value was calculated at 755 W m^{-2}. The theoretical and observed solar radiation at the eclipse max differed by 708 W m^{-2}. The percent error measured ~94% decrease from the theoretical. Meaning, there was a 94% solar radiation manipulation done by the eclipse at the Miami site. (Fig 6.)

Temperature Differences between Observed vs. Theoretical

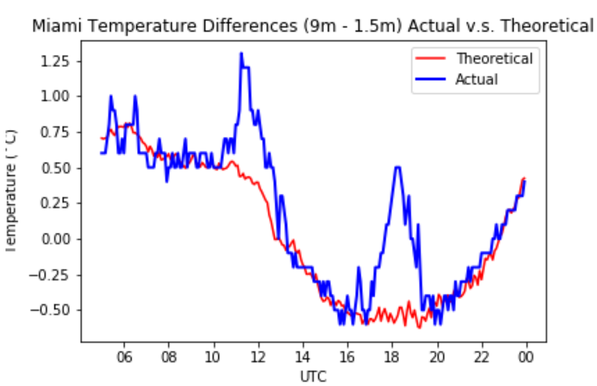

Figure 7. Temperature difference of 21 August 2017 that was observed and theoretical values calculated.

A 0.50°C temperature difference within the observed eclipse data (Fig 7.) was seen at 1810 UTC. At this temperature difference, temperature inversion was at its max strength and lasted for 10 minutes, till 1820 UTC. The theoretical provided two values during this length of time, the average of those two, calculated a lapse rate of -0.53°C. The observed and theoretical differed by 1.03°C and the percent error at this specific time equated to a whopping 195% from the theoretical.

5.2 *HOLLIS STATION*

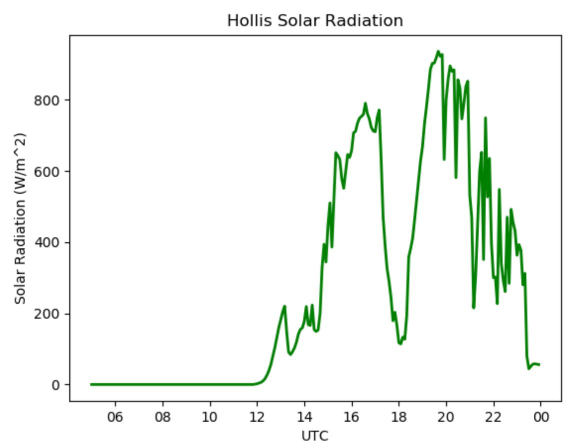

Figure 8. Hollis solar radiation over UTC.

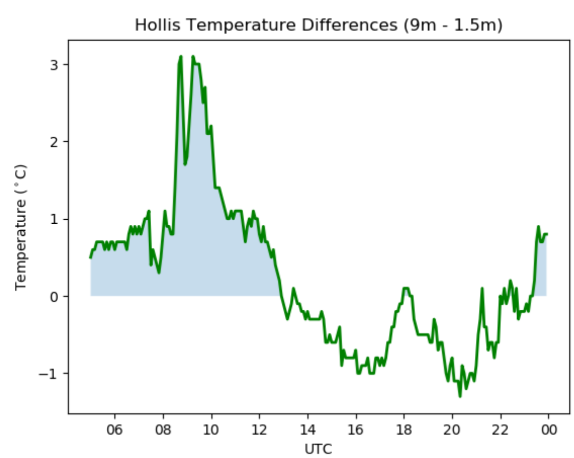

Figure 9. Hollis temperature difference over UTC.

HOLLIS Event Observation Overview

Analyses of the solar radiation and temperature difference data observed.

Hollis's eclipse initiated at 1710 UTC, where the solar radiation maxed at 771 W m^{-2} and was about to fall. (Fig 8.) At 1805 UTC the eclipse maximum hit and the solar radiation dropped to 114 W m^{-2}. After the eclipse maximum, the solar radiation started to increase again till 1940 UTC; ending the increase at 936 W m^{-2} and eclipse duration. The eclipse duration at Hollis totaled 2 hours and 30 minutes.

As for temperature difference (Fig 9.), the negative temperature differences raised to 0°C at 1755 UTC, which held for five minutes. Then at 1800 UTC the temperature difference reached a max positive 0.10°C for ten minutes. After those ten minutes, the temperature difference positive values start heading back down to 0°C. At 1815 UTC, the atmosphere between the two heights were at a temperature equilibrium and maintained the equilibrium for five minutes until it eventually switched to lapse rate trends. The total duration of temperature inversion totaled 20 minutes.

Solar Radiation comparison between Observed vs Theoretical

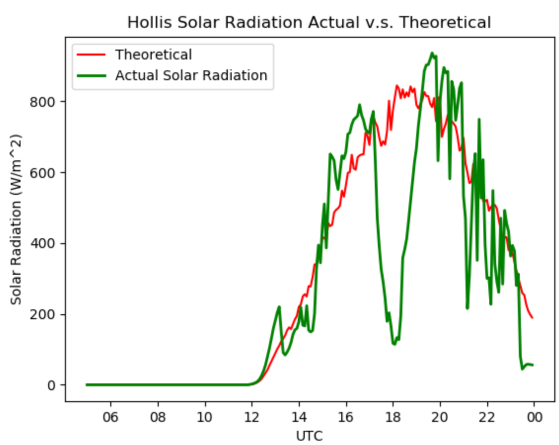

Figure 10. Hollis solar radiation observed versus theoretical calculated.

At the eclipse maximum time, the observed solar radiation was 114 W m^{-2} and the theoretical was 811 W m^{-2}. Numerically this is a 697 W m^{-2} difference from the theoretical. An 86% decrease from the theoretical solar radiation calculated with the percent error formula. (Fig 10.)

Temperature Differences between Observed vs. Theoretical

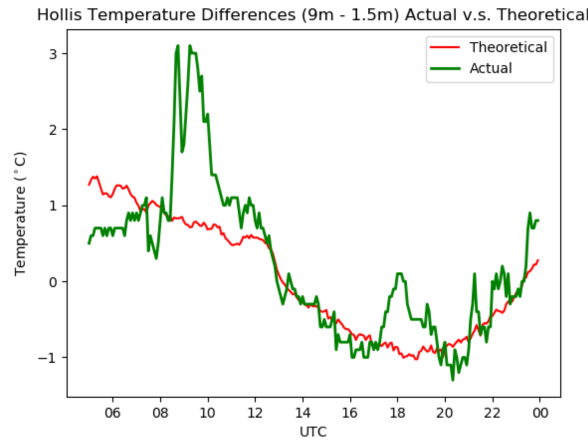

Figure 11. Hollis temperature differences observed versus theoretical calculated.

The observed temperature difference max was met at 1800 UTC; maintaining a 0.10°C temperature difference till 1810 UTC. The theoretical average value for this time range, calculated an average -0.90°C. Thus, there was a 1.0 °C temperature difference gain at this point of time caused by the eclipse. The percent error amongst the temperature difference calculated to roughly 111%. (Fig 11.)

5.3 *TIME DURATION AND IMPACT COMPARISON OF MIAMI AND HOLLIS*

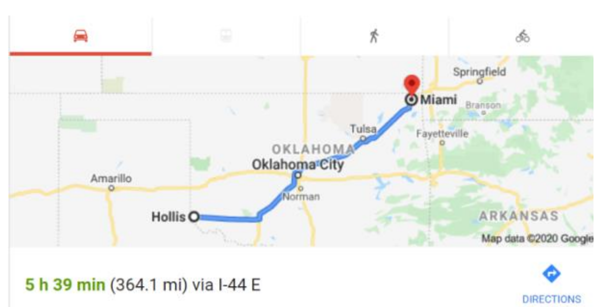

Figure 12. A visual taken off Google Maps, that shows the distance between stations.

Solar Radiation Analysis

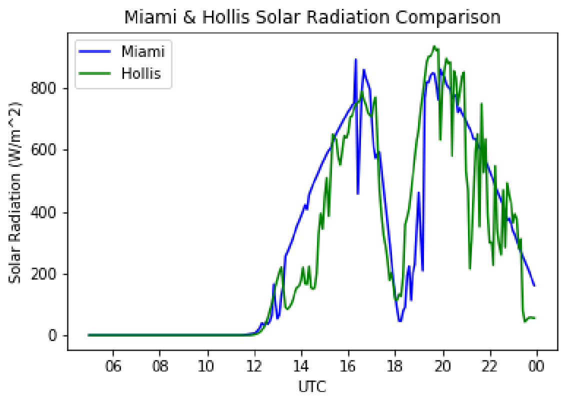

Figure 13. Solar radiation comparison of Miami and Hollis.

The Miami solar eclipse started at 1620 UTC, where its solar radiation at this time recorded at 892 W m^{-2}. Hollis solar eclipse started at 1710 UTC, and its solar radiation was 771 W m^{-2}. (Fig 13.) The Miami eclipse started 50 minutes before Hollis's, its solar radiation was initially higher than Hollis's and differed by 121 W m^{-2}. At 1815 UTC, the Miami solar radiation had declined to its lowest of 47 W m^{-2}. Hollis's, solar radiation low dropped to 114 W m^{-2} at 1805 UTC. The Miami eclipse maximum occurred ten minutes after Hollis's eclipse maximum and solar radiation differed by 67 W m^{-2}, where Miami's solar radiation was impacted more than Hollis's. Miami's eclipse ended at 1955 UTC, where the second peak of solar radiation ended back up to 614 W m^{-2}. Hollis's eclipse ended at 1940 UTC and its solar radiation increased to 936 W m^{-2}. The Miami eclipsed ended 15 minutes after Hollis and the radiation values differed by 322 W m^{-2}, where Hollis's second solar radiation max exceeded Miami's. Overall, Miami's eclipse duration was 1 hour and 5 minutes longer than Hollis's and the reduction of solar radiation was much greater than Hollis's.

Temperature Differences Analysis

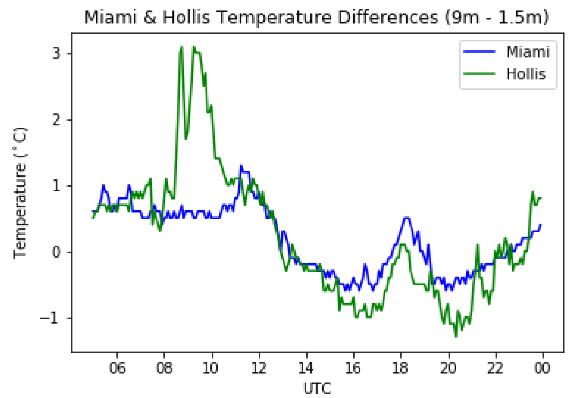

Figure 14. Miami and Hollis temperature difference analysis.

Temperature difference reached a 0°C equilibrium at 1740 UTC in Miami, but in Hollis, the 0°C equilibrium was reached at 1755 UTC and lasted for five minutes. It took 1 hour and 20 minutes from the start of its solar eclipse to reverse lapse rate at Miami and only 45 minutes of time had passed in Hollis for its lapse rate to reverse. Temperature difference maximum at Miami was stronger than Hollis's by 0.40°C and occurred at 1810 UTC, which then continued for ten minutes. Hollis's maximum temperature difference started at 1800 UTC with a value of 0.10°C and kept it for ten minutes as well. From the start of the eclipse times, it took Miami 1 hour and 50 minutes for the highest temperature inversion to be reached and took Hollis 50 minutes for it to reach its highest temperature inversion strength. The next 0°C to reverse the temperature inversion in Miami was met at 1850 UTC and kept an atmospheric temperature equilibrium till 1855 UTC. At Hollis, 0°C hit again at 1815 UTC till 1820 UTC, another five minutes of temperature equilibrium. The overall temperature inversion duration at Miami lasted longer than Hollis by 55 minutes and the temperature inversion maximum at Miami was stronger than Hollis's max.

5.4 RESOLUTION DATA COMPARISON

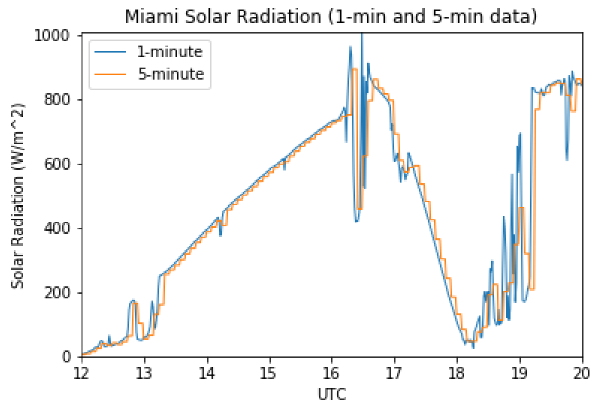

Figure 15. Miami solar radiation: one-minute and five-minute resolution comparison.

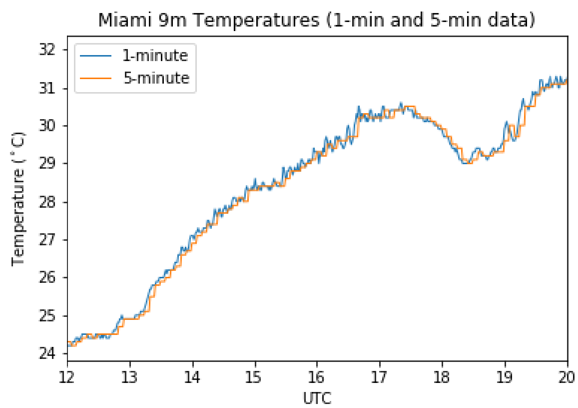

Figure 16. Miami 9-meter air temperatures: one-minute and five-minute resolution comparison.

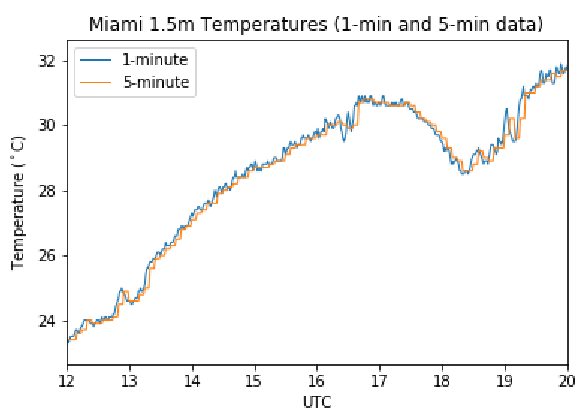

Figure 17. Miami 1.5-meter air temperatures: one-minute and five-minute resolution comparison.

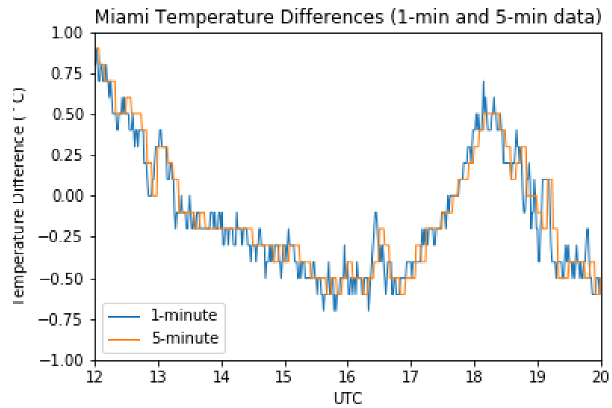

Figure 18. Miami temperature difference between 9-meters and 1.5-meters: one-minute and five-minute resolution comparison.

Figures 15-18 all show the graphical comparisons of one-minute and five-minute resolutions of various atmospheric attributes. Within each graph, the two data resolutions follow the same trends, tracing over each other. Based off the previous Miami specific time analysis, where the eclipse max time is at 1815 UTC and temperature inversion max time is 1810 UTC, a numerical comparison of solar radiation and temperature differences at these times had minimal differences. The one-minute data revealed solar radiation at this time to be 46.0 W m^{-2} and a temperature difference of 0.40°C, whereas five-minute data of solar radiation showed 47.0 W m^{-2} and a temperature difference of 0.50°C.

6. CONCLUSION

This study of the 21 August 2020 solar eclipse revealed that a solar eclipse does in fact impact meteorological near surface solar radiation and air temperature observations. It induced an early nightfall, forcing solar radiation reductions, the reversal of atmospheric lapse rates at two Oklahoma Mesonet stations.

Roughly 295 km away from totality, the Oklahoma Miami station solar radiation reduced as much as 94% at the prime of the eclipse. It also experiences a temperature over height reversal, where instead of temperatures decreasing with height near the surface, they increased with height causing temperature inversions and a 195% error from the norm. The duration of the eclipse extended for 3 hours and 35 minutes, whereas the duration of the temperature inversions totaled 1 hour and 15 minutes. Within the temperature inversion duration, the temperature difference max was reached ten minutes before the prime eclipse max time and overlapped it another ten minutes after.

Further away by ~691 km, Hollis solar radiation during the prime of the eclipse declined 86% from its theoretical norm and temperature inversions occurs with a 111% error. The whole eclipse took 2 hours and 30 minutes and temperature inversions lasted 20 minutes. The max temperature difference at Hollis, like Miami, overlapped the prime eclipse max by ten minutes before and after.

The utilization of five-minute solar radiation and temperature data against one-minute data resulted in the same outcome. This leads to the conclusion that five-minute data sets of this kind, are efficient. Other atmospheric variable may need to use one-minute data resolutions, but for this case of solar radiation and temperature, five-minute was adequate.

When the distance away from totality grows, the duration of the eclipse and temperature inversion episodes become smaller. The strength of eclipse impacts on solar radiation and temperature differences also become smaller with distance. But, at the two distances, during the prime viewing time of the eclipse, both sites experienced the same duration of temperature max overlapping for ten minutes. This information may be crucial to know if spectators of a solar eclipse event are immersed in heavily polluted areas, that may have a greater potential of increasing pollution densities.

Acknowledging these variations creates an identity for each place experiencing a total solar eclipse. To understand our atmospheric changes due to a solar eclipse, we need to expand information at every location to better map effects on the atmospheric properties, specifically temperature inversions. Quantifying temperature inversion feedback strengths and durations help in preparation of land use planning, for example, if an eclipse goes over land that ejects dangerous particulate matter, it is important to know when all temperature inversions take place because temperature inversions are correlated to stagnate dense pollution. Collecting individual weather station data, analyzing the data further to see the range of temperature inversion, enhance our preparation for future solar eclipse events.

To further this type of research, the study of highly air polluted regions and how much temperature inversions quantifiably change pollution densities, and how long an individual could resist harmful pollution of many difference kinds, may be of interest.

7. ACKNOWLEDGEMENTS

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