Solar Ultraviolet (UV) Radiation Exposure in an Eastern North Carolina Outdoor Working Environment During Cold Months

By

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Professions that are predominantly based outdoors have the risk of workers being exposed to solar ultraviolet (UV) radiation every day and during every season. Multiple studies have been conducted on outdoor workers' UV exposure during spring and summer months, but studies detailing their exposure during winter months are rare. The purpose of this study was to assess the UV exposure of groundskeepers employed at East Carolina University (ECU) during cold seasons (fall, winter, spring) compared to the summer season and to determine if UV exposure during cold seasons exceeded the Threshold Limit Values (TLVs) set by the American Conference of Governmental Industrial Hygienists (ACGIH) as occupational exposure limits. Area monitoring of UV radiation was conducted to measure the UV effective irradiance (UV_{eff}) using a weatherproof erythema UV detector and a digital data-logging radiometer. Ambient temperature was also collected using the OSHA-NIOSH Heat Safety Tool app. Data were collected for one year in order to have data for every season. Data analysis was conducted using analysis of variance (ANOVA) to compare UV_{eff} by month and season, and using Pearson correlation coefficient to analyze the strength and direction between UV_{eff} and ambient temperature. Results showed that hourly and daily UV exposures exceeded the 1-hr and 8-hr TLVs, respectively, during cold months. The hourly TLV exceedance percentages for November, December, January and February were 78.0%, 62.7%, 73.4% and 74.3%, respectively. December had the lowest hourly (0.0020 ± 0.0018 mW/cm^2) and daily ($0.0020 \pm$

0.0006 mW/cm^2) mean UV_{eff} but 62.7% and 100% of the hourly and daily data still exceeded the 1-hr and 8-hr TLVs. The seasonal average UV_{eff} for summer (0.0095 ± 0.0025 mW/cm^2) was significantly higher than winter (0.0034 ± 0.0017 mW/cm^2). The seasonal average UV_{eff} for fall (0.0044 ± 0.0017 mW/cm^2) compared to the summer is much lower and is closer to the winter average. The seasonal average UV_{eff} for spring (0.0096 ± 0.0026 mW/cm^2) compared to the summer is slightly higher and is also higher than the winter and fall averages. Overall, the UV_{eff} positively correlates with the ambient temperature, as expected. Study findings demonstrate that groundskeepers and other outdoor workers, as well as the general public, should continue to use preventive measures to reduce UV exposures during the cold months to reduce risk to UV-related adverse health effects.

Solar Ultraviolet (UV) Radiation Exposure in Outdoor Working Environment During Cold Months

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By

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When applying to East Carolina University for my undergrad, I always said I would stop and never get my master's degree. In this day and age, a master’s degree is needed and some say it is now the equivalent of the way a bachelor's degree would set you apart from the rest. Getting this degree has not been easy, but the administration I have encountered up until this point have made all the difference. First, I would like to thank my high school AP Environmental Science teacher Laurie Cone. I always cared about the environment and how us as humans impacted it, but her passion for the environment inspired me more than she knows. Second, I would like to thank William Hill. His excitement on the first day I met him when considering taking up Environmental Health gave me the excitement to commit. Not only that, but the energy he brought to class everyday made me into a morning person at times and I would not dare miss his class. His class was typically the highlight of my week. Third, I would like to thank Stephanie Richards for taking the time to talk to me about the MSEH program. She has been such a huge help making sure I had all my requirements and her Pest and Vectors class made me realize that my love for bugs never died. Thanks to her, I was also able to become a graduate assistant and that helped me tremendously. Finally, I would like to thank Jo Anne Balanay. I have had the pleasure of her being my professor as well as a mentor. She has helped me immensely with the research and writing of my thesis. Dr. Balanay, I appreciate you and I am more grateful for you than you know. Thank you all, I would not be where I am without your inspiration and encouragement.

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I. INTRODUCTION

Ultraviolet radiation (UV) is naturally and artificially occurring non-ionizing radiation emitted by the sun or sources of artificial light (CDC, 2020). Overexposure to UV radiation is known to cause skin aging, sunburn, cancer, eye damage, and disrupt the function of immune system regulation (CDC, 2020). On the other hand, minimal to moderate UV exposure benefits the body by stimulating vitamin D production in the skin (McKenzie et al., 2009). The amount of radiation that reaches Earth's surface and a person's skin is dependent on sun position, latitude in reference to the sun's position, cloud coverage, altitude, ozone, and surface reflection (WHO, 2003). Exposure levels can vary based on: UV ray type, skin covering, occupation, recreation, ozone levels, seasons and a number of environmental factors. The risk of overexposure to UV radiation is present every day and risk levels differ throughout the day, week, month, and year.

The dangers of exposure to UV have been known for generations. At first, people were advised, on any given hot day, that they should wear sunscreen or stay indoors. Then, the cosmetic market (e.g., lotion, foundation) started incorporating Sun Protection Factor (SPF) into their products (Wilson, et al., 2012). The dangers of exposure to UV in winter months were not known until approximately 1994 (Simic et al., 2008). Research done in recent years shows that UV radiation exposure limits in the winter months can be exceeded, similar to the summer months (ACGIH, 2019).

II. LITERATURE REVIEW

Ultraviolet Radiation Types

Ultraviolet radiation is electromagnetic (EM) and high energy wavelengths the size of molecules (FDA, 2020). Mckenzie, et al. (2009) published a study detailing the benefits and risks of UV exposure. They explained small quantities of UV can provide public health benefits for people, as this radiation stimulates vitamin D production. The quantity of UV exposure refers to the intensity of exposure on the UV Index scale (1-13, lowest to highest) for a given amount of time. The higher the intensity, the lower the amount of time necessary for vitamin D to be produced. For example, the study specifically shows that if the UVI is at level 1, then 20 minutes is sufficient for the body to produce vitamin D (Mckenzie, et al., 2009). However, over exposure can throw off the body's homeostasis and can cause various issues, including wrinkles, hair loss, blisters, rashes, cancer, and immune regulation disorders (Wilson et al., 2012). There are three types of UV radiation: UVA, UVB, and UVC. The UVC and some UVB forms cannot penetrate the ozone, hence, rendering some UVB and all UVA radiation as public health threats if overexposure occurs (Wilson et al., 2012). The UVA form includes the longest wavelengths (320-400 nm) and can be divided into two subgroups: UVAI (320-400 nm) or "far UVA" and UVAII (320-340 nm) or "near UVA" (Wilson et al., 2012). The wavelength range of UVB (290-320 nm) and UVC (200-290 nm) also differ (Wilson et al., 2012). The longer (i.e., higher) the wavelength, the deeper the waves can penetrate through the skin (Wilson et al., 2012). Radiation from UVA can penetrate the dermis and UVB can penetrate the epidermis (Wilson et al., 2012). Moreover, radiation from UVA is present throughout the day because it can penetrate windows and automobile glass, while UVB cannot (Wilson et al., 2012).

Sources of UV Exposure

Exposure to UV can happen naturally or artificially. Natural UV radiation comes from the sun, leading to direct and/or indirect exposure by reflecting off surfaces (e.g., water). Sources of artificial UV radiation include tanning beds, mercury vapor lighting (stadium or gym lights), some lasers, halogen, fluorescent, and incandescent lights (CDC, 2020). Workers in occupations that utilize electric welding arcs, germicidal lamps, UV curling lamps and black lights are exposed to artificial UV radiation (WHO, 2003).

UV Index

In 1994, the National Weather Service (NWS) and the US Environmental Protection Agency (EPA) adopted the UV Index as the standard to forecast the intensity of UV radiation (EPA, 2004). Fioletov et al. (2010) stated that, since the introduction of the UV Index by Canada in 1992, the Index has become a widely used parameter to characterize solar UV and help people avoid excessive levels of UV radiation. Factors affecting the UV Index include: sun elevation, total atmospheric ozone, cloud coverage, reflection from snow, and local pollution (Fioletov et al., 2010). The UV Index is also used to estimate UV exposure levels in studies investigating the impact of UV on other biological and photochemical processes, such as melanin production, cellular functions, and vitamin D production (CDC, 2020). The UV Index is ranked by color (green, yellow, orange, red, and purple) to indicate the degree of intensity in accordance with the exposure category (low, moderate, high, very high, and extreme) and number range (1-2, 3-5, 6-7, 8-10 and 11+) to give a numerical degree of intensity (EPA, 2004). The World Health Organization (WHO), World Meteorological Organization, United Nations Environment Programme, and International Commission on Non-Ionizing Radiation Protection collaborate to provide consistency worldwide when reporting UV data using the Global Solar

UV Index (EPA, 2004). The Global Solar UV Index is the updated version of the former UV Index that was used prior to May 2004. The previously used UV Index only gave exposure categories and index number: Minimal (0-2); Low (3-4); Moderate (5-6); High (7-9); and Very High (10+) (EPA, 2004). In the US and Canada, the average UV Index values during peak exposure time in the summer range from a low 1.5 in the Arctic to an extreme 11.5 over southern Texas and at high elevations can reach up to 20 in Hawaii (Fioletov et al., 2010). There are several sources that forecast UV radiation and these indices are encouraged for global use to protect health (EPA, 2004).

Ground-based spectrometer, broad-band filter radiometer and multi-filter radiometer measurements are used to determine UV Index values (Fioletov et al., 2010). Estimating UV Index values from other types of geophysical observations, primarily column ozone and cloud thickness, are done with radiative transfer models (Fioletov et al., 2010). Satellite measurements of atmospheric ozone and cloud cover can also be used for UV Index values (Fioletov et al., 2010).

Effects of UV Exposure

Radiation from UV is classified as a complete carcinogen because it is a mutagen and a non-specific damaging agent (D'Orazio et al., 2013). It is a tumor initiator and promoter, causes skin cancer, and influences skin disorders (D'Orazio et al., 2013). Radiation from UV affects the skin, which is comprised of the inner dermis and the other epidermis layers (D'Orazio et al., 2013). Melanocytes, located in the epidermis, synthesize melanin (a UV-blocking dark pigment) for keratinocytes (D'Orazio et al., 2013). Keratinocytes are found in every epidermis layer and their accumulation provides some of the natural sunscreen that protects skin by blocking penetration of UV radiation (D'Orazio et al., 2013). Brenner and Vincent (2008) explained how melanin deposits work to provide skin with natural protection against UV radiations. Eumelanin within the melanin pigment is what scatters and absorbs UV radiation (Brenner & Vincent, 2008). There is an inverse relationship between melanocytes, melanin, and melanosome deposition with UV protection, whereas an increasing deposition of melanin provides a thicker layer through which UV radiation must penetrate (Brenner & Vincent, 2008). Different races have different amounts of melanin containing eumelanin and naturally fair skinned people are at a higher risk of the adverse effects of UV exposure because they lack enough melanin containing eumelanin (D'Orazio et al., 2013).

Chronic UV exposure causes premature skin aging, decreases immune response to environmental pathogens, and increases the risk for developing malignant neoplasms (Wilson et al., 2012). Malignant transformations and immunosuppression of cells is a result of the covalent joining of pyrimidine dimers because the DNA synthesis process does not go through the typical checks/balances and misprints may go unnoticed (Wilson et al., 2012). Immunosuppression contributes to skin cancer and is the result of damaged DNA causing protective mechanisms in the skin to fail (Wilson et al., 2012).

Exposure to UV radiation is generally discussed in a negative manner; however, UV can also provide health benefits. This radiation can be used to treat vitamin D deficiency, seasonal affective disorders, psoriasis, sarcoidosis, and other cutaneous related conditions (Wilson et al., 2012). Vitamin D helps the body absorb calcium and without it, susceptible populations are at higher risk of rickets (in children), osteomalacia (in adults), osteopenia/osteoporosis, and fractures (in elderly) (Wilson et al., 2012). According to McKenzie et al. (2009), the degree of vitamin D production in the body depends on ozone, one's angle according to the closest latitude, the time of day and geographic variability of UV exposure. On a summer day (optimally at noon), vitamin D production takes effect within a minute and more vitamin D is produced as more skin is exposed to UV radiation from the sun (McKenzie et al., 2009). African Americans living in northern states suffer severe vitamin D deficiencies due to darker skin needing a greater UVR dose and is also attributed to diet (Fioletov et al., 2010). Light therapy can be used by creating bright light and dawn simulations (with artificial sources of UV) to treat seasonal affective disorders, reduce the severity of depression, and provide relief from psoriasis (McKenzie et al., 2009). Moreover, UV radiation can have antiproliferative and anti-inflammatory effects through downregulation of T-cell response to antigens (Wilson et al., 2012). However, erythemal effects, reddening and damage of the skin, can start to occur after 15 min of UV exposure; thus, it is important to observe the UV Index (natural UV) and duration of time spent directly exposed to UV radiation (McKenzie et al., 2009).

Protective Measures Against UV Radiation

It is beneficial to acclimatize skin to UV exposure, activating naturally occurring melanin in skin (Rendell et al., 2020). A moderate amount of time can be spent in the sun while wearing sunscreen with SPF. The SPF is defined as the dose of UV radiation required to produce minimal erythema dose (MED) on protected skin after the application of 2 mg/cm^2 of the product divided by the UV radiation required to produce one MED on unprotected skin (Rendell et al., 2020). The MED measures the efficacy of UVB radiation absorption (Rendell et al., 2020). An SPF of 15 means 93.3% of UVB is absorbed by the sunscreen, SPF 30 is 96.7%, SPF 45 is 97.8% and SPF 50 is 98%. Sunscreens can be either physical (i.e., reflect/scatter/absorb UV) or chemical (i.e., converts absorbed energy into a longer, lower energy wavelength) (Wilson et al., 2012). The use of sunscreen protection sometimes gives a false sense of security because the SPF is indicative of the length of protection. SPF 15 and SPF 30’s percentage of protection has a less than 4% difference, but people using the sunscreen will assume it means they get double the protection when it is a miniscule difference (Miner & News, 2012). Other methods for sun protection include wearing tightly woven or SPF-treated clothing, sunglasses with side panels and UV protection, wide-brimmed hats, limit time in the sun, and/or take breaks in shaded areas (EPA, 2014; NIOSH, 2014). The Occupational Safety and Health Administration (OSHA, 2005) recommends wearing a wide-brimmed hat instead of a baseball cap to protect the neck, ears, eyes, forehead, nose, and scalp, and wearing sunglasses that block 99-100% of UVA/B radiation. These protective measures are recommended particularly between the hours of 10 AM and 4 PM, when UV rays are the most intense (OSHA, 2005). The previously stated precautions also pertain to worker protection against solar UV exposures (OSHA, 2005; NIOSH, 2014).

Occupational Exposure to UV Radiation

Occupation plays a huge role in workers' risk due to UV exposure. A study by Boniol et al. (2015) in France assessed occupational UV exposure by estimating the median daily standard erythemal UV dose (SED). One SED is equivalent to 100 J/m^{-2} (joules per meter squared) and Joules are a unit of measurement for energy. Findings of the same study showed that the highest UV doses were observed among gardeners (1.19 SED), construction workers (0.92 SED), agricultural workers (0.95 SED), and culture/art/social science workers (0.92 SED). Culture/art/social science workers are a group of people that do not immediately come to mind when it comes to UV exposure, but they should come to mind more often because they are the ones whose profession and research involve traveling and spending time outdoors while studying and researching cultures around the world (Boniol et al., 2015).

Beck et al. (2018) conducted a study among eastern North Carolina (NC) groundskeepers to assess occupational exposure to UV radiation and heat stress. The same study found that groundskeepers' UV exposures at noon and afternoon exceeded the American Conference for Governmental Industrial Hygienists (ACGIH) Threshold Limit Values (TLVs®) in the observed 30 min, 2 h, 4 h, and 8 h periods due to the duration of time spent working outside and depending on the season. TLVs are values that give a limit for any type of exposure for a given amount of time. June had the highest TLV exceedance percentages (i.e., 90.8% corresponding with 30 min exposure and 100% corresponding with 2 h, 4 h, and 8 h exposures) (Beck et al., 2018). The high percentages are referring to the number of data points that exceed the TLV.

Another study by Dillane and Balanay (2020) was conducted in eastern NC to assess UV exposure in an agricultural setting. Findings indicate the mean UV Index differs throughout the day and was highest in the late morning to afternoon between 10 am and 4 pm and lowest in the evening (Dillane and Balanay, 2020). Between April and August, the highest TLV exceedance percentages were 99.9-100%, corresponding to hourly and daily exposure (Dillane and Balanay, 2020). The lowest exceedance was observed in the evening but was still high at 99.44%. Given the measured UV exposure, the calculated amount of time for an agricultural worker to spend outside in the sun was from 1.67 min to 1.45 h (Dillane and Balanay, 2020). Due to the highest UV Index measured during noon and afternoon, it was recommended that the amount of time spent working outside during these times should not exceed 10 min without the use of UV protection (Dillane & Balanay, 2020).

Schneider et al. (2018) conducted a study on occupational UV exposure and sun-protective behavior in German outdoor workers that included the typical workers that come to mind when referring to outdoor workers, but also included: roofers; mail carriers; firefighters; police officers; locksmiths; mechanics; sports coaches; early years and kindergarten teachers; street sweepers; and civil engineers. In the study, approximately 24 h were spent working outside in the summer in a typical week. Out of all the outdoor workers, at least one instance of sunburn was reported among 19% of them (Schneider et al., 2018), indicating UV radiation exceeded TLV limits. The remainder of the outdoor workers reported taking protective measures such as using sunscreen on their face and exposed parts of the body, wearing sunglasses, covering their head, staying in the shade, and wearing a sleeved shirt that covers their shoulders (Schneider et al., 2018).

Serrano et al. (2009) analyzed the UV exposure amongst lifeguards and gardeners in Valencia, Spain. When analyzing the SED, the study showed gardeners receiving a mean dose of 4.13 +/- 0.60 SED/day and lifeguards receiving 11.43 +/- 2.15 SED/day (Serano et al., 2009). The effective dose is defined as 1.3 SED/day, hence gardeners' and lifeguards' exposures exceeded standard limits. The lifeguards receive the highest levels of exposure between the two groups, and this is a cause for enacting necessary protective measures since lifeguards have more skin exposed during work hours (Serrano et al., 2009). It is advised that the gardeners also enact protective measures because Gimenez et al. (2015) found on average, gardeners were exposed to 4.13 +/- 0.6 SED. Gimenez et al. (2015) analyzed UV exposure in construction workers in Valencia, Spain. During the spring, the average UV exposure was observed as 18.72 SED, exceeding the limits for skin types 1 to 4. In the summer, the average UV exposure was observed as 31.2 SED, also exceeding limits for skin types 1 to 4. The skin types refer to the amount of pigment, type 1 being very fair and type 4 being very dark. The study concluded that no matter the season, exposure limits are exceeded within an hour (Gimenez et al., 2015).

Peters et al. (2019) conducted a study during the late summer/early fall of 2016 analyzing UV radiation exposure among outdoor workers in British Columbia, Ontario, and Nova Scotia in Canada. The same study showed the average UV exposure for workers in the three provinces was 6.1 SED. The highest average (7.3 SED) was measured in Ontario, and the lowest (4.5 SED) in British Columbia. Utility workers (10.4 SED) averaged a higher UV radiation dose compared to municipal workers (5.5 SED) (Peters et al., 2019). The UV exposure of outdoor construction workers in Britain was observed (measured with devices affixed to the workers' hard hats) and analyzed (Cherrie et al., 2021). The aforementioned study showed UV exposure ranged from 0 to 13.47 SED among 67 workers (mean UV exposure levels was 2 SED) (Cherrie, et al., 2021).

Modenese et al. (2018) conducted a study on outdoor workers in various countries in Europe. For construction workers in Australia there was a daily exposure of 9.9 SED, 11.9 to 28.6 SED in Switzerland, and 6.11 SED in Spain. The readings in Switzerland depend on altitude, wherein 11.9, 21.4 and 28.6 SED were measured based on plain, middle and high mountain altitude, respectively. Among farmers in New Zealand, France, Austria, and Tuscany, the average exposure was measured to be 14.5 SED in April. Lifeguards were exposed to 1.7 to 6.9 SED of UV radiation in North America (Modenese et al., 2018).

UV Exposure and Cold Temperatures

During months of extremely cold temperatures, chlorine is converted into its reactive forms that deplete and destroy the ozone layer (Manney et al., 2020). This especially occurs in the stratospheric ozone layer over the Arctic (Manney et al., 2020). Manney et al. (2020) found that the destruction of the ozone layer by the active chlorine continues through Spring, and the Arctic affected by this depletion is exposed to more UV radiation than otherwise. The same study observed that chlorine activation and ozone depletion peaked at lower altitudes in 2020 compared to 2011. Due to depletion of the ozone layer that was measured in 2020, some parts of the world experienced higher levels of UV radiation than others (Manney et al., 2020). Hunter et al. (2019) found a depleted stratospheric ozone above Australia. It is possible that similar stratospheric ozone depletion patterns could be observed in the US, given the right circumstances, especially in the northern portions of the country. The level of erythema effective UV radiant exposure (H_{er}) was measured over the course of almost 25 years from 1991 to 2015. The overall trend for H_{er} during winter months was the lowest compared to the spring, summer and fall months, but levels were variable and correspond with total ozone. There is typically more cloud coverage during the winter due to more moisture, so the low H_{er} can be attributed to clouds reflecting UV radiation, thereby preventing the radiation from reaching the Earth's surface (Hunter et al. 2019).

A study by Rendell et al. (2020) was conducted in England that compared UV exposure during hot and cold months. The study found that higher temperatures result in higher UV doses measured in test subjects but temperature was not indicative of UV risk. The discrepancy can be attributed to people's varying seasonal habits. Specifically, people spend a lot of time outdoors in the summer because the weather is nice and warm, while people are less likely to spend so much time outdoors in the winter because it is cold (Rendell et al., 2020). Moreover, people are also more likely to wear more articles of clothing that cover most of the skin's surface area during winter season. Most of the skin is covered by a jacket and pants; however, eyes, neck, face, ears, and head may still be vulnerable to UV exposure, leading to recommendations of using lotions with SPF or sunscreen on these target areas (Rendell et al., 2020).

In a study by Thieden et al. (2006), the patterns of occupational UV exposure among Danish indoor workers were compared between the warmer half (April – September) and the colder half of the year (October – March). During the winter, the ambient UV dose was 394 SED (10.5% of the annual ambient UV dose). Compared with summer, the workers had a lower percentage of ambient UV radiation (0.82% compared to 3.4 %), a lower solar UV dose, less time outdoors per day with positive dosimeter measurements, and no exposure (0 SED) per day on most monitored days (Theiden et al., 2006). The study concluded that UV exposure was low for the indoor workers, so they do not need to take extra precautions to protect themselves (Thieden et al., 2006).

On the recreational side of UV exposure, a study by Andersen et al. (2010) found that, by measuring temporal, seasonal, altitudinal, and meteorological factors, predictions can be made about the prevalence of UV radiation exposure at ski resorts in North America, along with associated sun protection behaviors. Study results showed that temperature was not a strong predictor of UV exposure; however, predictors included proximity to noon, deviation from winter solstice, and clear skies, with location having a small impact. Adults were observed taking UV precautions on days with clear skies, but on cloudy days and/or when it felt colder outside, they did not take as many UV protection precautions but instead worried about keeping warm (Andersen et al., 2010). Although clouds do give some protection against UVR, people at high altitudes especially should still apply sunscreen and cover up as much skin as they can (Andersen et al., 2010).

Different parts of the body receive different amounts of UV exposure at different times of the day. A study by Baczynska et al. (2013) was conducted during an Austrian winter to observe the effect of altitude, position of the sun, and different environmental and atmospheric conditions (e.g., temperature) on an individual when exposed to UV radiation. The measurements of UV exposure and risk were measured on surfaces with different angles and found that UV rays impact the body at near vertical angles. Study results showed that the angle of any surface in question and the altitude, position, and direction of the sun all matter when assessing UV radiation (Baczynska et al., 2013). Different parts of the body can also be affected due to localized exposure, especially if someone is working indoors (Baczynska et al., 2013). In Switzerland, Milon et al. (2006) conducted a study to show that UV exposure depends on activity as well as the environment. The variation in posture and/or the orientation of a worker accounted for 38% of variance in individual exposure (Milton et al., 2006).

III. PURPOSE AND SPECIFIC AIMS OF THE STUDY

The main purpose of this proposed research is to assess the solar ultraviolet (UV) exposure of groundskeepers employed at East Carolina University (ECU) during cold seasons. The specific aims of the study are to:

1. Assess solar UV exposure of groundskeepers during the cold seasons (fall, winter, spring) compared to the American Conference of Governmental Industrial Hygienists (ACGIH) Threshold Limit Values (TLVs)
2. Compare UV exposure between the cold seasons (fall, winter, spring) and the summer season
3. Determine the extent to which a correlation exists between UV exposure and ambient temperature/heat index during cold seasons (fall, winter, spring)

IV. HYPOTHESIS AND RESEARCH QUESTIONS

Hypothesis 1: Solar UV exposure levels during the cold seasons are significantly lower than during the summer season.

Rationale 1: Thieden et al. (2006) found that, during winter months, workers experienced 10.5% of the annual ambient UV radiation, had a lower percentage of ambient UV radiation, and a lower solar UV dose compared to summer months. The SED range in the winter was 0.2-52 compared to 69-363 in the summer. Rendell et al. (2020) showed that in the colder months (February – March), the daily UV doses were 25-50% lower than the long-term average, compared to the summer months being 40-75% higher than the long-term average.

Hypothesis 2: Solar UV exposure during the cold seasons exceeds the ACGIH Threshold Limit Values.

Rationale 2: Beck et al. (2018) wrote that the 30 min exposure exceeded ACGIH TLV for all seasons and months. This was especially evident around noon and afternoon when the exposure limits were exceeded in hot months. During cold months, UV exposure occurs primarily in the morning (Beck et al., 2018). Rendell et al. (2020) showed that, although the daily UV doses in the cold months are lower than the long-term average of 1.1 SED, that did not impact the risk of sunburn. This means that the risk was still present and the ACGIH TLV threshold limit was exceeded.

This proposed research aims to answer the following research questions:

1. Are the solar UV levels during the cold seasons low enough for people not to take precautionary measures?
2. What times of day in the winter is the risk of UV exposure the highest and lowest?
3. Is there a winter month when the risk of UV exposure is generally higher or lower?
4. Do the collected UV_{eff} levels exceed ACGIH TLVs?
5. How does UV exposure in summer differ compared to the UV exposure in winter?
6. What is the relationship between UV exposure level and ambient temperature in cold seasons (fall, winter, spring) compared to summer?

V. SIGNIFICANCE OF THE STUDY

There are a number of factors that affect exposure levels of UV radiation (e.g., UV radiation type, skin covering, occupation, recreation, ozone levels, seasons, and environmental factors). It is important for people to take the necessary precautions to reduce UV exposure and protect public health. Comparing the UV data by season will give insight on how to better advise the public and outdoor workers on how to protect themselves from overexposure to UV radiation. Most existing data about occupational UV exposure in the winter has been conducted outside of the US and mainly for indoor workers. Also, many datasets focus on recreational rather than occupational UV exposure. The collected data for this study spans over the course of a year, so there is data from the summer to compare to the cold seasons (fall, winter, spring). Preliminary analysis of data shows that, during the cold seasons, UV levels peak before or around noon, but the peaks during the hot seasons are seen around or after noon and the high levels of exposure have a wider time span of peak UV levels.

The results of this research will inform recommendations that help protect workers from UV exposure, especially during the cold seasons because the data will strictly pertain to the exposure that outdoor workers could experience and the time of exposure. The data will also aid in which precautions are recommended for outdoor workers. Something that is noticeably not considered is the lack of freedom for outdoor workers to choose when they get to take a break or where they get to work. The goal of this research would ultimately be to give practical advice on precautions for outdoor workers and their employers. This research is limited because data is being collected in Greenville, North Carolina, and there would be a greater benefit if data was collected all over the country, but for now this will give insight into what some outdoor workers experience and will still allow for others to be more aware of their exposures.

VI. METHODOLOGY

Study Site

The study site was conducted at the south side entrance of Carol Belk Building, which is located on campus of East Carolina University in Greenville, NC within Pitt County. The monitoring spots (i.e., where the UV equipment was set up) within the study site were located on the grass and mulch area to the left when facing the entrance of Belk Building. Originally during winter, the site was located on the midline of the left lawn and approximately two feet from the sidewalk. However, during spring season, the setup began interfering with the groundskeepers' activities (e.g., mowing, edging), so then it was moved to the center of the mulch to the right of the lawn, but still on the left side of the south side of the Belk Building. The area with mulch also has a number of small and medium sized shrubs. The groundskeepers did not resurface the mulch area often, so when the setup was placed there, it was undisturbed compared to when it was on the grass.

UV monitoring

UV radiation monitoring was conducted on the study site using a weatherproof erythema UV detector (PMA2102C, Solar Light Co., Inc., Glenside, PA) and a digital datalogging radiometer (PMA2100, Solar Light Co., Inc., Glenside, PA), as shown in Figure 1. The detector and radiometer were setup on the mulch in front of ECU's Belk building, with the detector mounted on a tripod 3.5 ft above the ground (Figure 2). The radiometer was factory calibrated prior to the start of data collection on October 5, 2020. Trial runs were conducted on September 23 and 28, 2020 from 8 AM to 6 PM on both days. For each monitoring day, the UV effective irradiance (UV_{eff}) (mW/cm^2) was data logged every minute from 8:00 AM–6:00 PM for 164 days within the period of October 5, 2020 to October 5, 2021, to cover all seasons in a year. The UV_{eff} is a way to measure UV exposure and can be defined as the incident power divided by the receptor surface area in watts per square meter. UV_{eff} was used because that is how the radiometer measures the levels of UV radiation. The hourly average UV_{eff} indices were calculated and compared to the ACGIH TLV for the UV radiation effectiveness irradiance (ACGIH, 2019) to determine acceptability of worker exposure to UV. The maximum exposure time, t_{max} (s), for each hourly average UV_{eff} was calculated using the following equation (ACGIH, 2019):

$$t_{max}\ [s] = 0.003\ [J/cm2]\ /\ UV_{eff}\ \ [W/cm^2] \qquad (1)$$

a

B

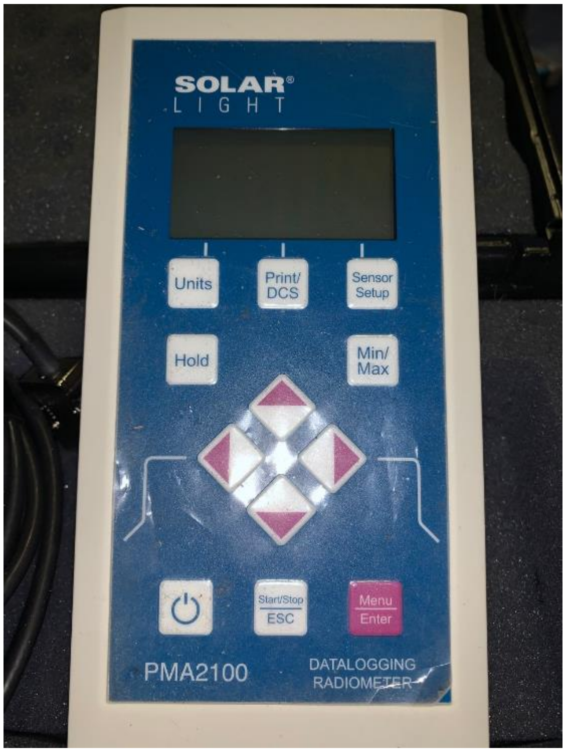


Figure 1. Equipment for UV Monitoring: a) Weatherproof erythema UV detector, b) Datalogging radiometer

Figure 2. UV Detector and radiometer set up on the mulch in front of the Belk Building

Comparison of UV_{eff} with ACGIH TLVs

The ACGIH TLVs used for comparison to UV exposures were the 1-h and 8-h exposure limits. To determine if the 1-h exposure limit was exceeded, the hourly mean UV_{eff} indices were compared to the TLV of 0.0008 mW/cm^2. To determine if the 8-h exposure limit was exceeded, the daily mean UV_{eff} indices were compared to the TLV of 0.0001 mW/cm^2 (ACGIH, 2019). The 8-hr TLV were used to assess the acceptability of the daily worker exposure because the amount of time considered to be the typical workday is 8 hours, although it may vary and exceed that time depending on the industry, such as in the collected data in this study. Thus, the daily mean and the 8-hr TLV were used as workday comparisons.

Use of Mobile App

Two mobile applications (apps) were used in the collection of weather data: 1) EPA Sunwise UV Index and 2) OSHA-NIOSH Heat Safety Tool. The EPA UV Index app (version 4.1) was used to collect data on the predicted hourly UV index rating from 9 AM to 6 PM for all data collection days. At the beginning of the monitoring day (i.e., 8 AM), the app was opened and 27858 was entered as the zip code of the study site. The hourly forecast tab was selected, and a screenshot was taken for later use. The UV risk assignment through the EPA UV Index app is categorized into five risk levels: low (0-2), moderate (3-5), high (6-7), very high (8-10), and extreme (11+).

The OSHA-NIOSH Heat Safety Tool app (version 3.1) was used to collect data on current hourly air temperature (°C), relative humidity (%), heat index (°C) and corresponding risk levels from 8 AM to 5 PM for all data collection days. Through the OSHA-NIOSH app, the risk was categorized into five levels based on the heat index: minimal, low, moderate, high, and extreme risk. App data were obtained by taking a screenshot of the OSHA-NIOSH app's heat index page at the beginning of every hour from 8 AM to 5 PM. The study site zip code (27858) was used in both apps to retrieve desired data that corresponds to the study site. At the end of every monitoring day, the data were organized into a spreadsheet.

Data Analysis

At the end of each collection day, UV data were downloaded from the radiometer using the Solar Light PMA organizer software (Glenside, PA).city and state of software developer). The data downloaded into the organizer were saved as a CSV file for compatibility with Microsoft Excel software. Once the CSV file was opened in Excel, it was then saved as an Excel workbook file in order to keep the original data intact and unedited. Since the radiometer records

UV data every minute during the collection window, the hourly average UV_{eff} was calculated by adding the values within each hour (e.g., 8:00 - 8:59 AM) and dividing the sum by 60. The hourly risk assignment, depending on the data collected from the UV radiometer, was categorized into five risk levels: low (>2), moderate (3-5), high (6-7), very high (8-10), extreme (11+) based on the EPA UV Index app. The risk was assigned based on the rounding of the UV Index calculation: (Hourly Average*10,000)/25.

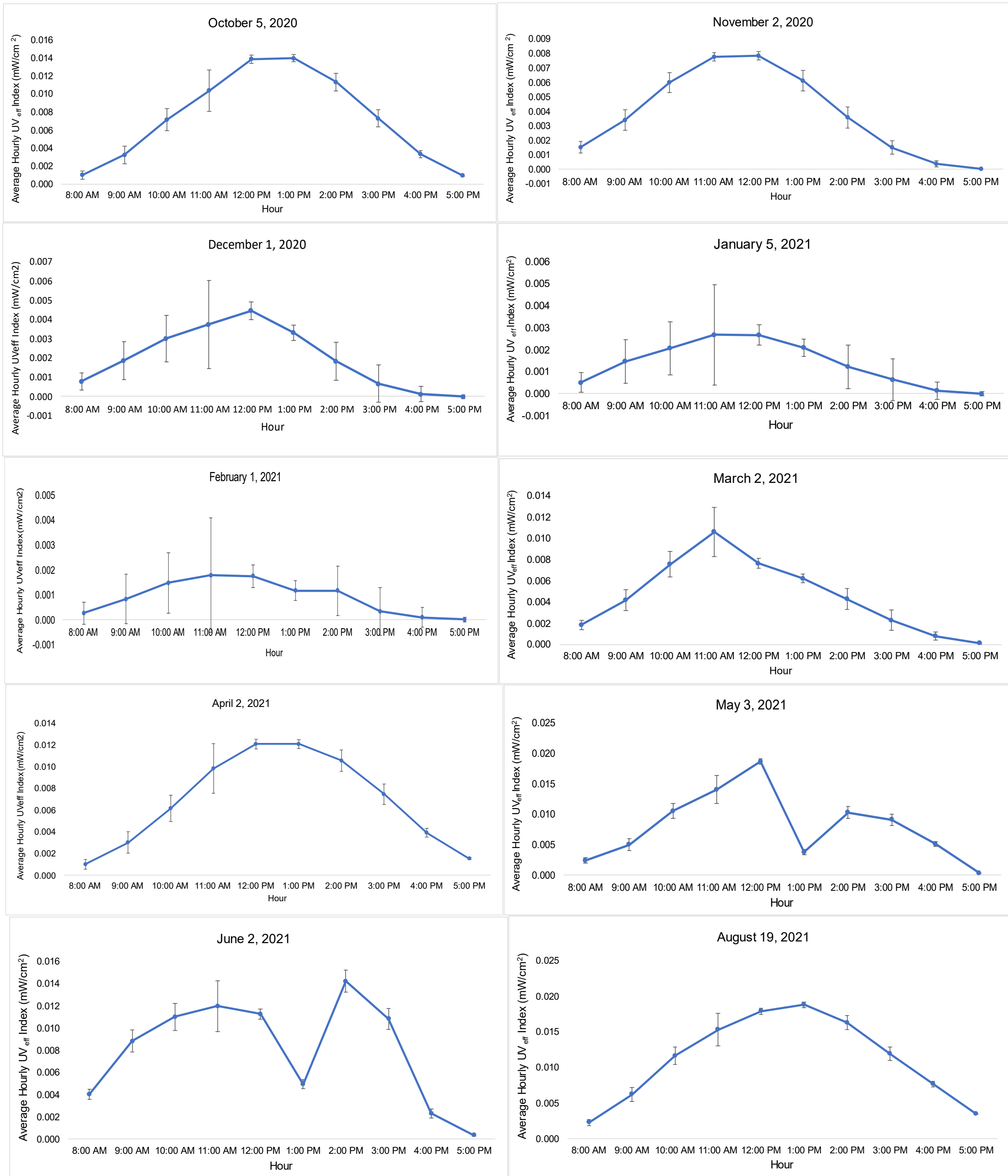
The daily, monthly, and seasonal average UV_{eff} indices were calculated from the data collected from the radiometer and UV detector. The average UV_{eff} indices were compared by day, month, and season to determine if there was a specific time when the UV_{eff} was potentially at its highest for the day, month, and/or season. The fall season was from October 5th to December 20th. The winter season was from December 21st to March 19th. The spring season was from March 20th to June 19th. The summer season was from June 20th to September 21st. The seasonal cutoffs were determined by the day of the seasonal solstice and that day marked the start of the season. Graphs were generated to analyze data trends on hourly, daily, monthly, and seasonal UV exposure.

Similar to a study by Dillane & Balanay (2021), analysis of variance (ANOVA) was conducted to compare the following indices: (1) daily mean UV_{eff} by month and season; (2) daily maximum UV_{eff} by month and season; (3) hourly mean UV_{eff} by month and season; and (4) hourly maximum exposure time (t_{max}) by month and season. Pearson correlation test was conducted to analyze the strength and direction of the correlation between UV_{eff} and ambient temperature. The Statistical Package for Social Sciences (SPSS version 25, IBM, Armonk, NY) was used to analyze the data. $P < 0.05$ was considered as statistically significant.

VII. RESULTS

Hourly Average UV_{eff} Index

Figure 3 shows the hourly average UV_{eff} index for a sample monitoring day for each monitored month (October 2020 to September 2021). The sample monitoring day for October showed a bell-shaped curve that peaked between 12 PM and 1 PM, with the lowest UV exposure risks at 8 AM and 5 PM. November showed a bell-shaped curve skewed slightly to the right with a lower peak than October around 12 PM, with the lowest UV exposure risk before 5 PM. December showed a lower (compared to November) and distinct peak at 12 PM, with the lowest UV exposure risk at 5 PM. January showed a shallower bell-shaped curve slightly skewed to the right that peaked between 11 AM and 12 PM, with the lowest UV exposure risks at 5 PM. February showed a shallower bell-shaped curve slightly skewed to the right that peaked at 11 AM, with the lowest UV exposure risk at 5 PM. March showed a higher and pointed peak at 11 AM, with the lowest UV exposure risk at 5 PM. April showed a high bell-shaped curve that peaked between 12 PM and 1 PM, with the lowest UV exposure risk at 5 PM. May showed double peaks, with the highest peak at 12 PM and the lowest UV exposure at 5 PM. June showed double peaks, with the highest peak at 2 PM and the lowest UV exposure at 5 PM. The drastic drop in UV exposure risk at 1 PM in these figures can be attributed to cloud coverage. August showed a bell-shaped curve that peaked around 1 PM, with the lowest UV exposure risk at 8 AM. September showed double peaks, with the highest peak around 1 PM and the lowest UV exposure at 8 AM. During the winter season, the UV exposure was highest between 11 AM and 12 PM, lowest at 8 AM and/or at 4 PM.



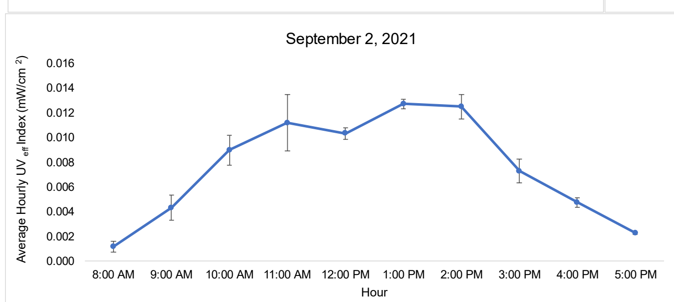


Figure 3. Hourly average UV$_{eff}$ index (mW/cm^2) on a selected monitoring day by month, Greenville, NC, October 2020 to September 2021. Error bars are included to show any uncertainty in the data. July data is missing due to equipment malfunction.

Figure 4 shows the hourly average UV_{eff} index for all monitoring days for each monitored month (October 2020 to September 2021). The entire month of monitoring in October showed a trend of decreasing peaks. Throughout the month, the highest UV exposure remained between 12 PM and 1 PM, not exceeding 0.015 mW/cm^2 and the lowest UV exposure risk was around 8 AM or between 4 PM and 5 PM. The entire monitoring month of November showed a trend of decreasing peaks. Throughout the month, the UV exposure peaks shifted to the right from 12 PM to 11 AM and the UV_{eff} never exceeded 0.009 mW/cm^2. The highest peak was above 0.008 mW/cm^2, and the lowest UV exposure was before 5 PM, which was consistent for every monitoring day. December measurements did not show a decreasing or increasing trend among the peaks, and the peaks were staggered. The highest peak was under 0.006 mW/cm^2 and the lowest peak was a under 0.002 mW/cm^2. On any given monitoring day, the UV exposure typically peaked around 12 PM. The entire monitoring month of January shows an initial increasing trend, then became staggered. Throughout the month, the highest exposure was typically around 12 PM and the highest peak was approximately 0.0055 mW/cm^2. The lowest risk of UV exposure was consistently before 5 PM. The entire monitoring month of February showed double peaks and an increasing trend, with the highest peak at 0.012 mW/cm^2 and the highest UV exposure ranging from 11 AM to 1 PM. The lowest UV exposure was before 5 PM or at 5 PM. The entire monitoring month of March showed an overall increasing trend. There was a 3-day period with significantly lower peaks, afterward the trend continued and started to decrease slightly towards the end of the month. The highest UV exposure was between 11am and 1pm and varied depending on the day, with the highest peak at approximately 0.015 mW/cm^2. The lowest UV exposure shifted from around 5 PM to around 8 AM. The entire monitoring month of April showed an increasing trend. The highest UV exposure was between 11 AM and 1

PM, depending on the day, with the highest peak at approximately 0.024 mW/cm^2. The lowest UV exposure was typically around 8 AM. The partial monitoring month of May showed a slightly decreasing trend. The highest UV exposure was either around 12, 1, or 2 PM, with more of the days having the highest UV exposure at 1 PM. The highest peak was at approximately 0.024 mW/cm^2. The lowest UV exposure alternated between 8 AM and 5 PM. The entire monitoring month of June showed a slightly increasing trend. The highest UV exposure varied between 12 PM and 1 PM, but there was a clear shift from 12 PM to 1 PM during the middle of the month. The highest peak was right above 0.025 mW/cm^2 and the lowest UV exposure alternated between ~ 8 AM and ~5 PM. The entire monitoring month of August showed a slightly increasing trend. The highest UV exposure was typically around 1 PM, with the highest peak under 0.02 mW/cm^2. The lowest UV exposure was typically around 8 AM. The entire monitoring month of September showed a decreasing trend. The highest UV exposure shifted from 1 PM to 12 PM to 11 AM, with a significant dip before the last 5 days of monitoring. The highest peak was at approximately 0.019 mW/cm^2.

Figure 5 shows the hourly average UV_{eff} index on all monitoring days for the entire study period from October 5, 2020 to September 30, 2021. From October to November of 2020, there was a downwards trend in the peaks. After November 19, 2020, the lowest hourly peaks were observed through February 3, 2021. February 4, 2021 started the upwards trend that peaked on June 21, 2021. The highest peaks occurred on June 18 and 21, 2021.

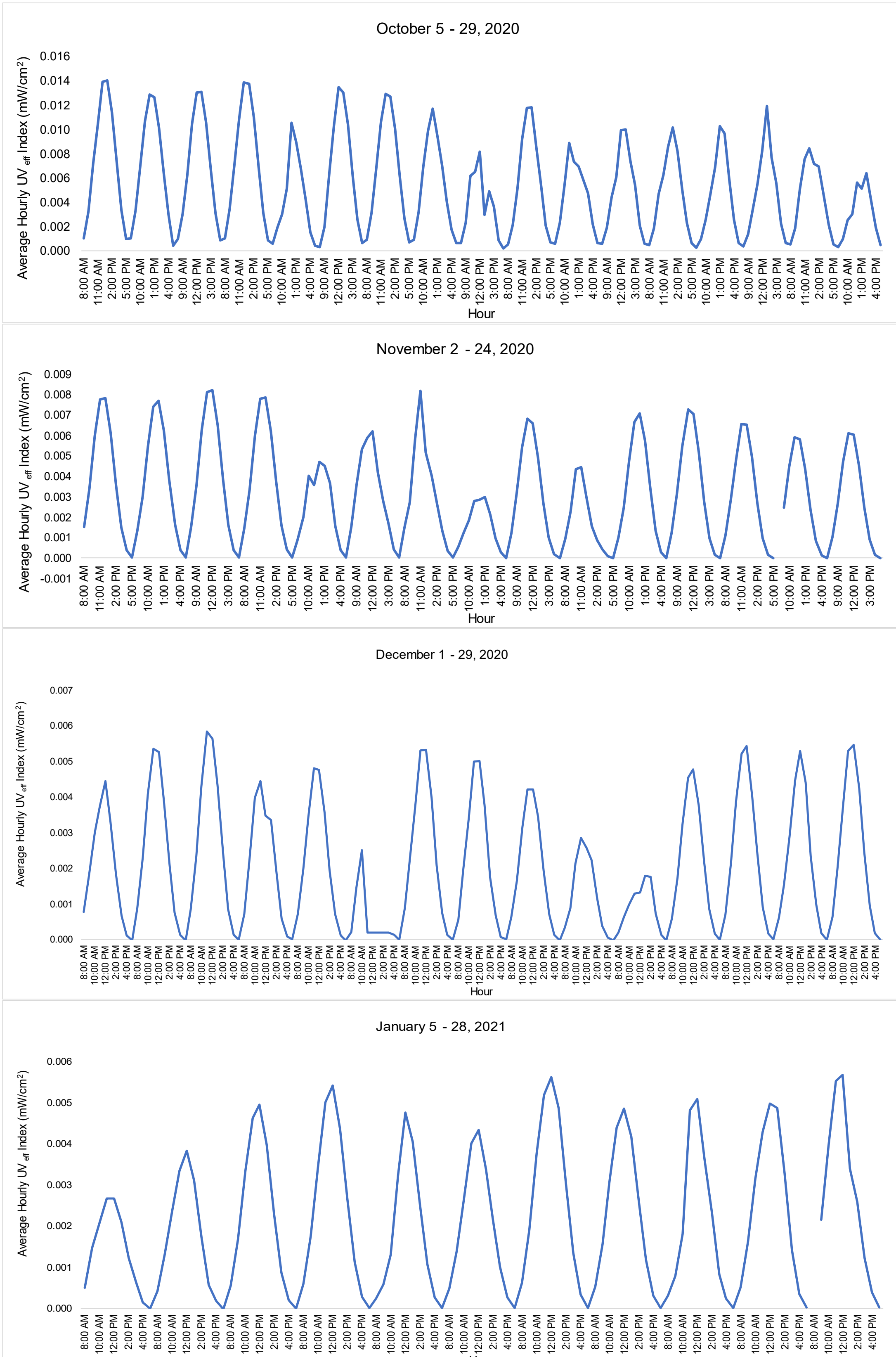


Figure 4. Hourly average UV_{eff} index (mW/cm^2) on all monitoring days by month, Greenville, NC, October 2020 to September 2021. July data is missing due to equipment malfunction.

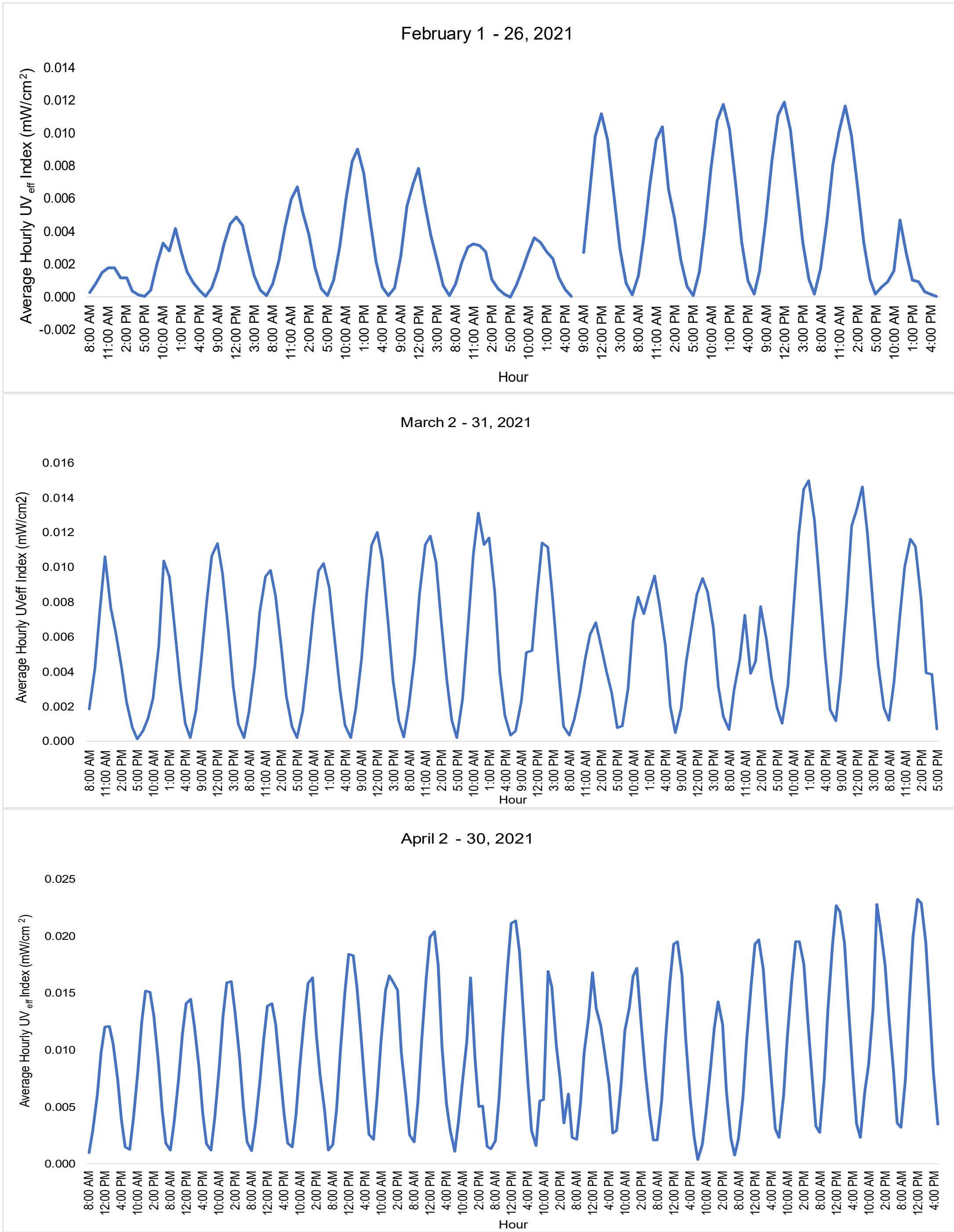


Figure 4. Hourly average UV$_{eff}$ index (mW/cm^2) on all monitoring days by month, Greenville, NC, October 2020 to September 2021. July data is missing due to equipment malfunction. (cont'd)

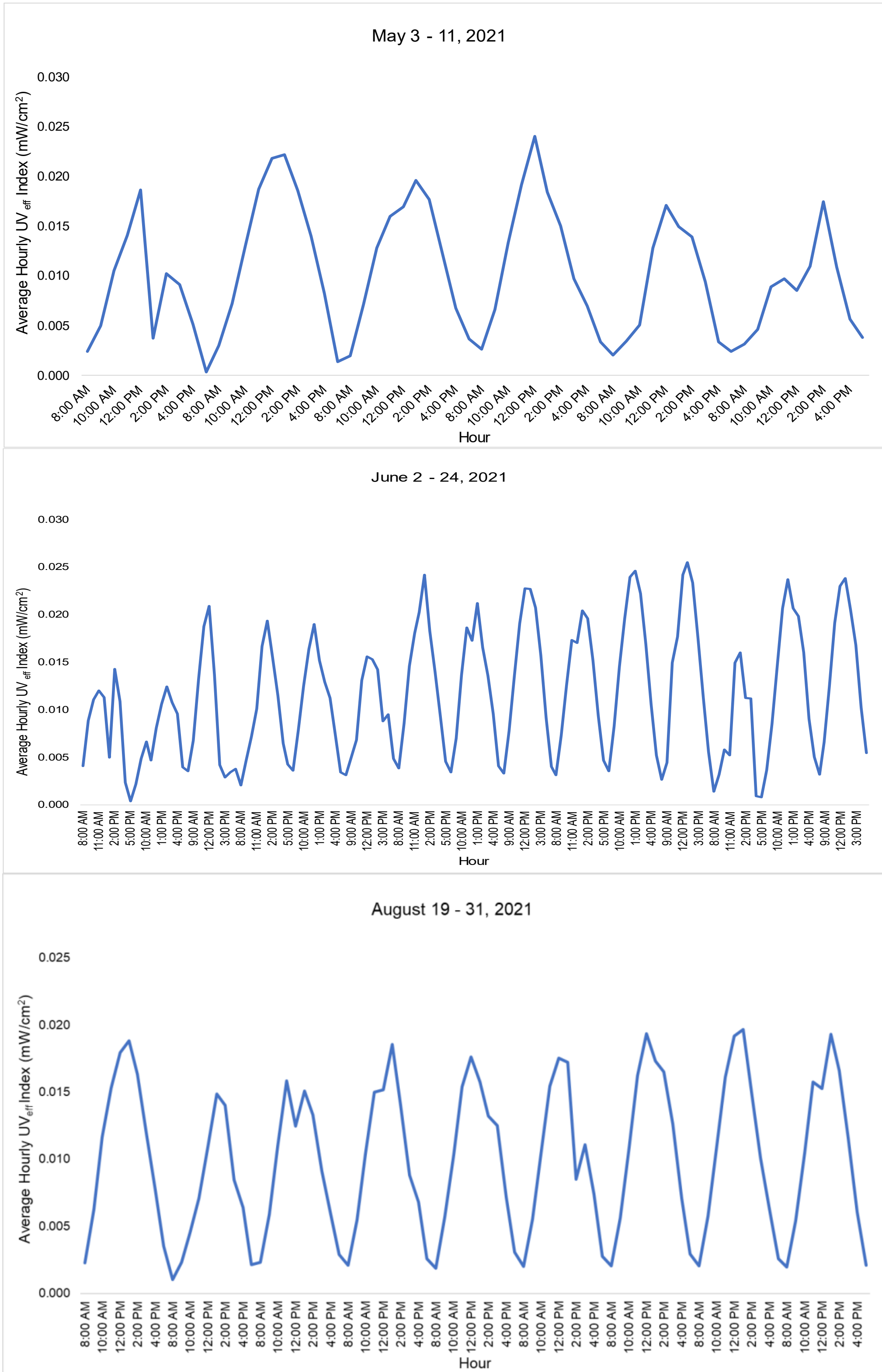


Figure 4. Hourly average UV_{eff} index (mW/cm^2) on all monitoring days by month, Greenville, NC, October 2020 to September 2021. July data is missing due to equipment malfunction. (cont'd)

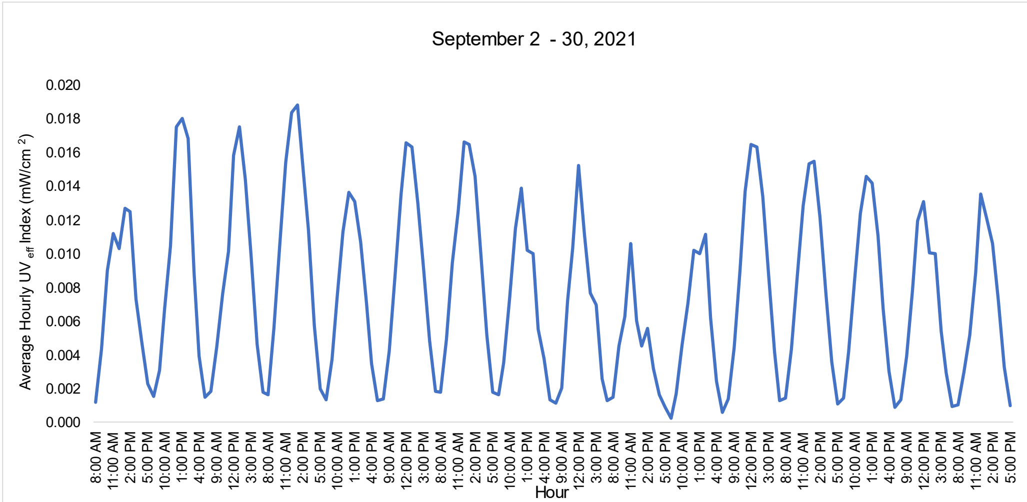


Figure 4. Hourly average UV$_{eff}$ index (mW/cm^2) on all monitoring days by month, Greenville, NC, October 2020 to September 2021. July data is missing due to equipment malfunction. (cont'd)

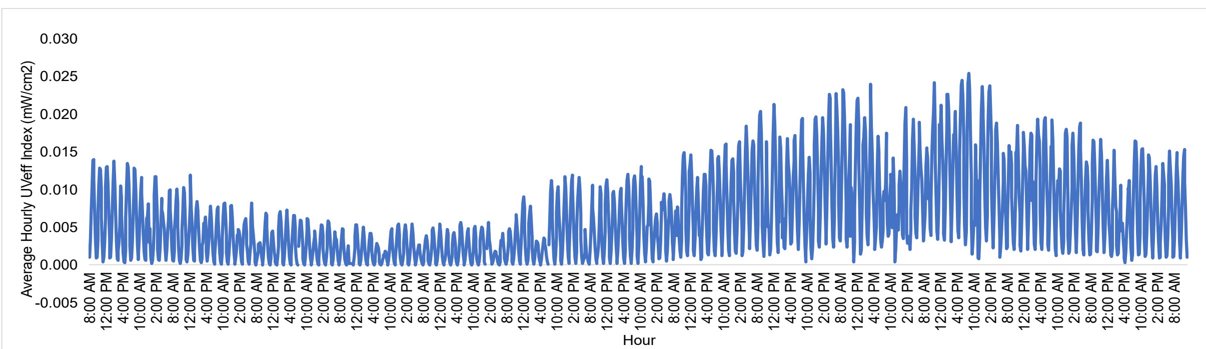


Figure 5. Hourly average UV$_{eff}$ index (mW/cm^2) on all monitoring days for the entire study period, Greenville, NC, October 5, 2020 to October 5, 2021

Daily Average and Maximum UV$_{eff}$ Index

Figure 6 shows the daily average and maximum UV$_{eff}$ index for the entire study period from October 5, 2020 to October 5, 2021. The graph shows a peak in the last monitoring week of June. From October to November of 2020, there was a downwards trend in both the daily average and maximum UV$_{eff}$ indices. After November 10, 2020, a period of low daily indices was observed through February 15, 2021. The lowest daily index was on December 19, 2020.

February 16, 2021 started the upwards trend that peaked on June 22, 2021. After the peak in the graph, there was a downward trend until the end of the monitoring period.

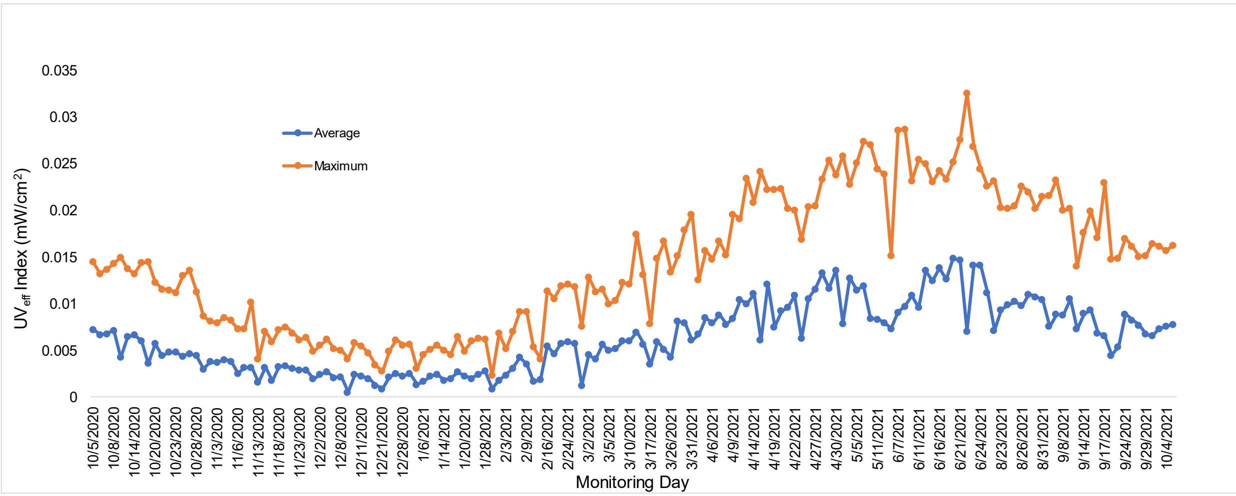


Figure 6. Daily average and maximum UV_{eff} index (mW/cm^2) for the entire study period, Greenville, NC, October 5, 2020 to October 5, 2021. July data is missing due to equipment malfunction

Figure 7 shows the daily average and maximum UV_{eff} index for all monitoring days for each monitored month (October 2020 to September 2021). October showed a downward trend for both the daily average and maximum UV_{eff}. The maximum peaked on three days (October 12, 16 and 27). Similarly, November showed a downward trend for both the daily average and maximum UV_{eff}. The two data sets parallel each other, but the averages were lower overall compared to the maximum. There was a peak right above 0.01 mW/cm^2 UV_{eff} on November 11 of the maximum daily line, but the daily average line did not have a distinguished peak. The highest average was 0.004 mW/cm^2 UV_{eff} on November 4. Compared to the October graph, November marked the beginning of the decline in UV_{eff}. December showed no trends in the daily average and maximum UV_{eff}. The two lines paralleled each other, with the daily average showing less variation in the UV_{eff} than the daily maximum. January showed an upward trend in

UV_{eff} for both the daily maximum and average values. The maximum values peaked above 0.006 mW/cm^2 UV_{eff} on January 19. The average values peaked on the same day around 0.0027 mW/cm^2 UV_{eff}. The decline in the UV_{eff} can be attributed to an increase in cloud coverage. January marked the beginning of an overall upwards trend in UV_{eff} for 2021. February showed a steep upward trend, with the data varying drastically between days. There were three points that peaked around 0.012 mW/cm^2 UV_{eff} of the maximum values on February 23 to 25. On those same days, there were three peaks around 0.004 mW/cm^2 UV_{eff} that paralleled within the average values. Any significant dips in the UV_{eff} can possibly be attributed to cloud coverage. The lowest points of the average values were closer to each other in terms of UV_{eff}. The lowest points of the maximum values were ~0.002 mW/cm^2 UV_{eff} apart from each other and resemble numbers in January. March showed an upwards trend for the maximum values peaking around 0.2 mW/cm^2 UV_{eff} on the last day of the month. The average values peaked around 0.009 mW/cm^2 UV_{eff} on March 29. Both sets of values showed a decline in UV_{eff} values on the March 17 and 26. During the winter season between December 21, 2020 and March 19, 2021, the peaks observed were frequently in the middle of the month and/or towards the end of the month. The times of day the UV_{eff} was the lowest at 8 AM and/or 5 PM, the highest was between 11 AM and 12 PM. April measurements exhibited upward trends with variabilities, especially within the maximum values. The highest point within the maximum values was 0.025 mW/cm^2 UV_{eff} on April 29. For the average, the highest point was about 0.14 mW/cm^2 UV_{eff} on April 30. The month of May was a partial monitored, but slight trends were observed within the two data sets. The maximum showed a slight upwards trend, and the average showed a slight downwards trend. The maximum values remained relatively around 0.25 mW/cm^2 UV_{eff} and around 0.01 mW/cm^2 UV_{eff} for the average values. The highest values occur on two dates: May 4 for the average values and May 6 for the maximum values. June showed an upwards trend for both the maximum and average data sets. The highest maximum peak value of 2021 was about 0.033 mW/cm^2 UV_{eff} on June 22. The average data set diverged on May 22 by having its lowest data point at about 0.007 mW/cm^2 UV_{eff}, but not the lowest of 2021. This may be attributed to outliers because of varying cloud coverage throughout the day. August showed an upwards trend for the average UV_{eff} and a downwards trend for the maximum UV_{eff}. Towards the end of the entire monitoring period, within August, the start of a downward trend was observed. There was not a lot of variability within the two data sets and the sets diverged but did not parallel. August 20 marked the maximum's highest point at about 0.024 mW/cm^2 UV_{eff} and the lowest average point of about 0.007 mW/cm^2 UV_{eff}. The lowest point within the maximum set was around 0.2 mW/cm^2 UV_{eff} on August 24 and 30, while the highest daily average was around 0.02 mW/cm^2 on August 19. September showed a downward trend with some variability within both data sets. The highest data point for the maximum was around 0.23 mW/cm^2 UV_{eff} on September 17 and was around 0.1 mW/cm^2 UV_{eff} on September 10 for the average. The lowest data point for the maximum was around 0.014 mW/cm^2 UV_{eff} on September 13 for the maximum and around 0.005 mW/cm^2 UV_{eff} on September 21 for the average. September marked the beginning of a steeper downward trend in UV_{eff} for 2021.

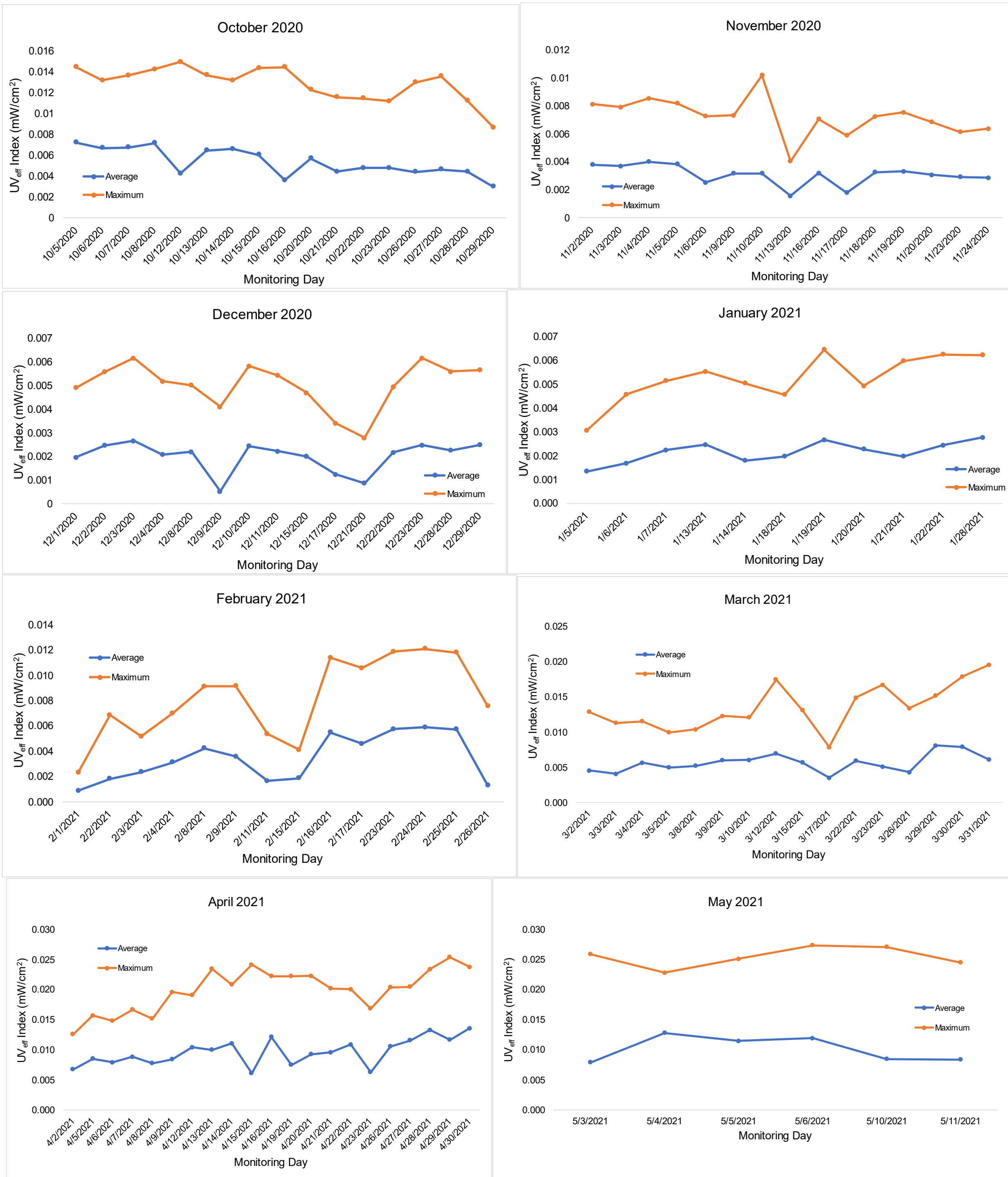


Figure 7. Daily average and maximum UV_{eff} index (mW/cm^2) on all monitoring days by month, Greenville, NC, October 2020 to September 2021. July data is missing due to equipment malfunction.

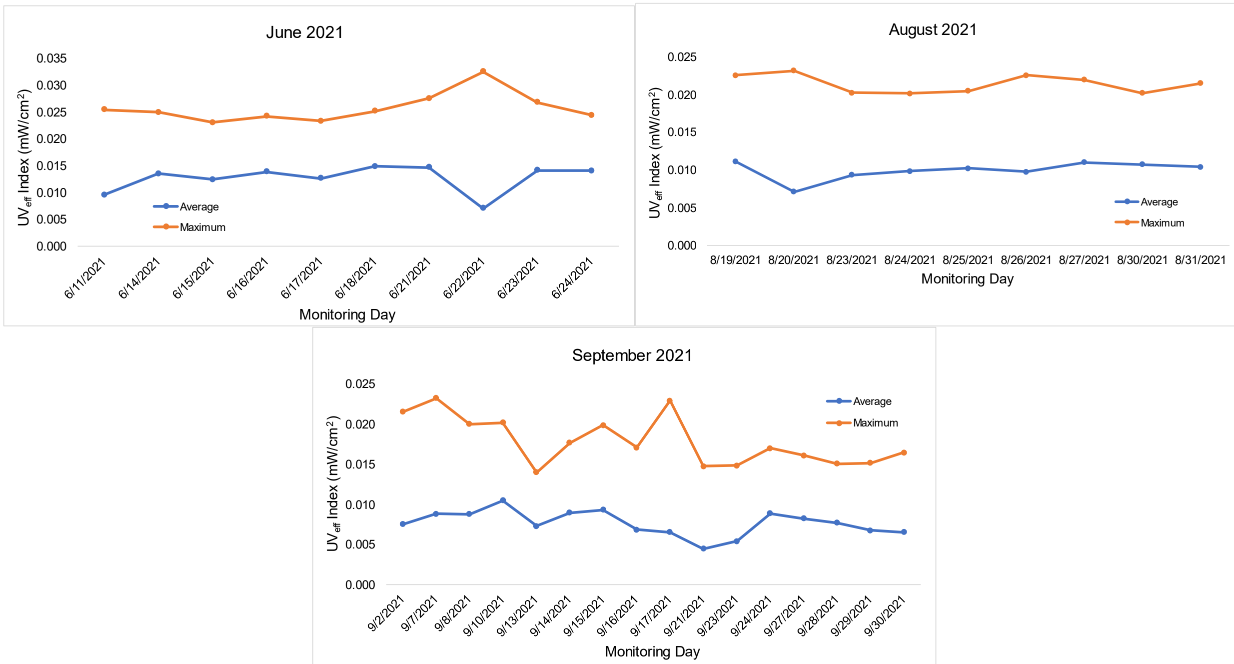


Figure 7. Daily average and maximum UV_{eff} index (mW/cm^2) on all monitoring days by month, Greenville, NC, October 2020 to September 2021. July data is missing due to equipment malfunction. (cont'd)

Monthly Average and Maximum UV_{eff} Index

Figure 8 shows the monthly average and maximum UV_{eff} index for the entire study period (October 2020 to September 2021). October to December showed a downwards trend that remained constant through January. At the beginning of the monitoring period, October had an average UV_{eff} of 0.0057 ± 0.0015 mW/cm^2 and a maximum UV_{eff} of 0.0163 mW/cm^2. December had the lowest average UV_{eff} of 0.0020 ± 0.0006 mW/cm^2 and the lowest maximum UV_{eff} of 0.0062 mW/cm^2. February to June showed an upward trend that peaked in June. June had the highest average UV_{eff} of 0.0115 ± 0.0028 mW/cm^2 and the highest maximum UV_{eff} of 0.0326 mW/cm^2. There was missing data from July due to equipment failure. Data collection continued in August to show the UV_{eff} values starting to decline. The average UV_{eff} for September was 0.0077 ± 0.0016 mW/cm^2. December had the lowest daily maximum and average UV_{eff}

compared to the other months in the winter season. This also means the risk of UV exposure would generally be lower in December. February was the month with the highest daily average and maximum UV_{eff} values. This was determined because March is partially a winter month since spring begans on March 20, 2021. If March was not a partial month, then March would be the winter month with the highest daily average and maximum UV_{eff} values.

The daily average and maximum UV_{eff} in December (0.002 ± 0.0006 mW/cm^2 and 0.0062 mW/cm^2, respectively) and January (0.0022 ± 0.0004 mW/cm^2 and 0.0065 mW/cm^2, respectively) were significantly lower than the other months. The daily average and maximum UV_{eff} in June (0.0115 ± 0.0028 mW/cm^2 and 0.0326 mW/cm^2, respectively) was significantly higher compared to the other months wihtin the monitoring period. October to January showed a downward trend in the average and maximum UV_{eff}. February to June showed an upward trend, with missing data in July due to equipment malfunction. August and September showed the maximum UV_{eff} plateauing, but a downward trend for the average UV_{eff}. The data for the monthly and average UV_{eff} follow the same patterns and trends. The overall means of the daily average UV_{eff} were statistically different ($F=59.97$, $P<0.01$) by month. Similarly, the overall means of the daily maximum UV_{eff} were statistically different ($F=106.29$, $P<0.01$) by month. This demonstrates that there are statistically significant differences in the average and maximum UV_{eff} when comparing the data between the months of the monitoring period (October 2020 to September 2021). Appendices B1 and B2 show the SPSS statistical output tables.

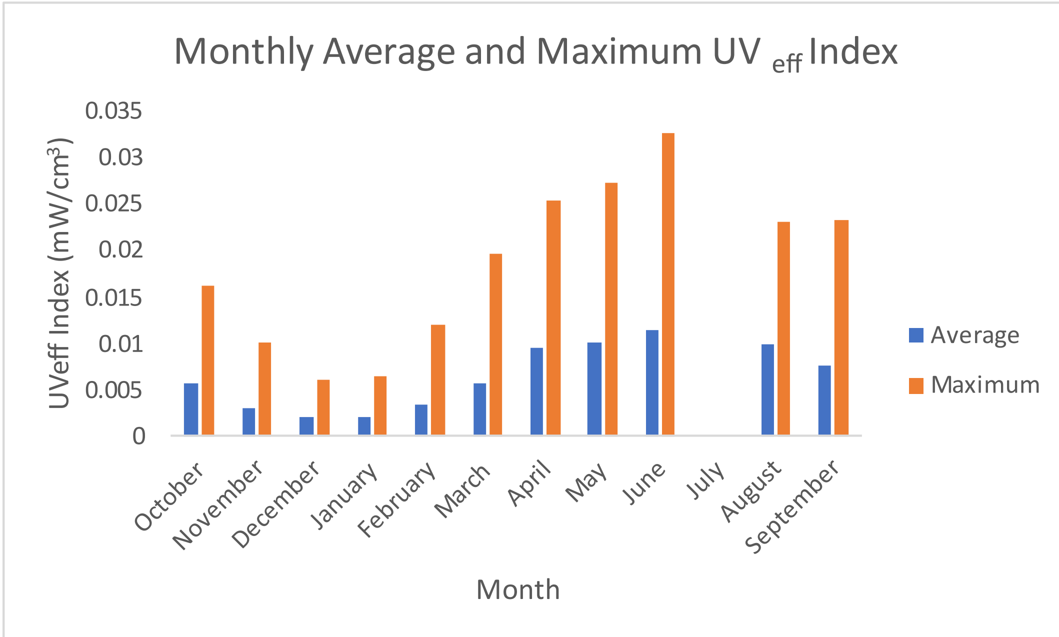


Figure 8. Monthly average and maximum UV_{eff} index (mW/cm^2) for all monitoring months, Greenville, NC, October 2020 to September 2021. July data is missing due to equipment malfunction.

Seasonal Average and Maximum UV_{eff} Index

Figure 9 shows the average and maximum UV_{eff} index by season (fall, winter, spring and summer). There was an upward trend overall in the maximum UV_{eff} for all seasons. The average UV_{eff} decreases for fall, compared to winter, then increases and levels out during the spring and summer. The average UV_{eff} in the fall is 0.0044 ± 0.0021 mW/cm^2 and the maximum is 0.0170 mW/cm^2. There is a steeper increase from the winter, from a maximum UV_{eff} of 0.0175 mW/cm^2 and an average of 0.0034 ± 0.0017 mW/cm^2, to the spring with a maximum UV_{eff} of 0.0287 mW/cm^2 and an average of 0.0095 ± 0.0025 mW/cm^2. A lower seasonal maximum and average was expected for the winter compared to the fall, but only the average reflected those expectations.

The overall means of the daily average UV_{eff} were statistically different (F=82.98 $P<0.01$) by season. Similarly, the overall means of the daily maximum UV_{eff} were statistically different (F=118.50, P<0.01) by season. The seasonal data P-values reveal a statistically significant difference in the average and maximum UV_{eff} between the seasons. Comparing winter and summer data, there was a statistically significant difference in the seasonal maximums (F=198.25, P<0.01) and averages (F=129.71, P<0.01). The highest maximum and average UV_{eff} was in the summer an the lowest was in the winter. The maximum UV_{eff} in the summer (0.0326 mW/cm^2) was about twice the value, compared to winter (0.0175 mW/cm^2). The average UV_{eff} in the summer (0.0095 ± 0.0025 mW/cm^2) was more than three times the value of winter (0.0034 ± 0.0017 mW/cm^2). The maximum UV_{eff} in the summer was significantly higher (F=117.51, P<0.01) compared to Fall, which was about twice the value (0.0170 mW/cm^2). The maximum UV exposure in the Spring (0.0287 mW/cm^2) was about twice the value of fall. The maximum UV_{eff} in spring was twice the value of winter. The UV exposures for the summer and spring were not significantly different for the average (F=0.02, P=0.90) and maximum (F=0.07, P=0.79) values. Appendices B3 and B4 show the SPSS statistical output tables.

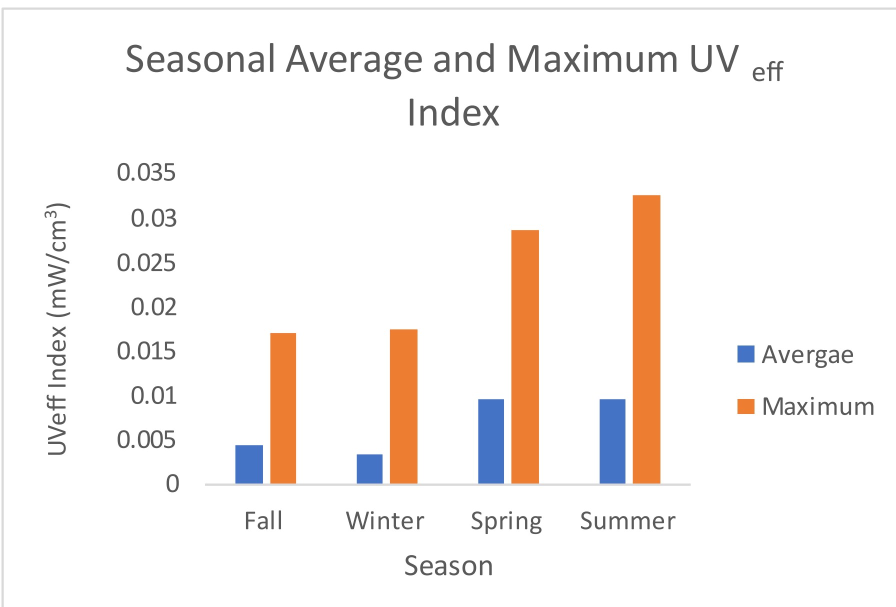


Figure 9. Average and maximum UV_{eff} index by season (Fall, Winter, Spring and Summer), Greenville, NC, October 2020 to September 2021

Maximum Exposure Time (t_{max})

Table 1 shows the mean, minimum, and maximum t_{max} values by month and season. The monthly means ranged from -569.5 ± 9510.0 min to 449.5 ± 2454.0 min. The monthly minimums ranged from -33577.7 min to 3.3 min. The monthly maximums range from 49.6 min to 59745.4 min. The seasonal means ranged from -60.1 ± 5409.0 min to 10.7 ± 15.5 min. The seasonal minimums ranged from -33577.7 min to 2.0 min. The seasonal maximums ranged from 65.4 min to 59745.4 min. The month with the lowest t_{max} was February, which means winter had the lowest t_{max}. The month with the highest t_{max} was December and the season with the highest was Fall. The average t_{max} values were not statistically different by month (F=0.68, P=0.74) and by season (F=0.05, P=0.99). Appendices B5 and B6 show the SPSS statistical output tables.

Table 1. Mean, minimum and maximum t_{max} (maximum exposure times) for hourly mean UV_{eff} by month and season. July data is missing due to equipment malfunction.

Parameter	Mean ± SD (minutes)	Minimum (minutes)	Maximum (minutes)
Month			
October	27.2 ± 40.6	3.3	290.5
November	104.7 ± 3378.8	-14196.3	29573.7
December	-569.5 ± 9510.0	-97401.1	59745.4
January	449.5 ± 2454.0	-4961.8	17315.6
February	-141.2 ± 2900.6	-33577.7	2550.4
March	30.0 ± 58.6	3.3	396.8
April	10.6 ± 13.3	2.1	125.8
May	10.5 ± 19.6	2.1	150.1
June	8.3 ± 13.5	2.0	138.2
August	8.7 ± 8.3	2.5	49.6
September	14.9 ± 21.7	2.7	219.6
Season			
Fall	-60.1 ± 5409.0	-9740.1	59745.4
Winter	4.2 ± 2347.2	-33577.7	17315.6
Spring	10.7 ± 15.5	2.0	150.1
Summer	10.5 ± 11.1	2.0	65.4

Comparison of UV_{eff} with ACGIH TLVs

Table 2 shows the percentage of the hourly and daily mean UV_{eff} index exceeding the corresponding ACGIH TLV by month and season. All the monitored months had hourly and daily mean UV_{eff} indices exceeding the 1-hr and 8-hr TLV at varying degrees. All the days in each month and each season were exceeded according to the 8-hr TLV. Based on the 1-hr TLV, August had the highest exceedance rate (100%) while December had the lowest (62.7%). Summer had the highest exceedance rate (99.8%), while fall had the lowest exceedance rate (85.3%). There was a risk of over-exposure to UV in the summer, compared to winter, but there remained a risk of over-exposure in the winter season.

Table 2. Mean Ultraviolet Effective Irradiance (UV_{eff}) Index and number and percentages of hourly and daily mean UV_{eff} Index exceeding ACGIH Threshold Limit Values (TLV) for UV radiation effectiveness Irradiance by month and season. July data is missing due to equipment malfunction.

Parameter	**Hourly Mean UV_{eff} Index (mW/cm^3)**	**Hours Monitored (N)**	**Hours Exceeding TLV[a]**		**Daily Mean UV_{eff} Index (mW/cm^3)**	**Days Monitored (N)**	**Days Exceeding TLV[b]**	
Month			n	%			n	%
October	0.0057 ± 0.0042	200	175	87.5	0.0057 ± 0.0015	20	20	100
November	0.0031 ± 0.0025	150	117	78.0	0.0031 ± 0.0007	15	15	100
December	0.0020 ± 0.0018	150	94	62.7	0.0020 ± 0.0006	15	15	100
January	0.0021 ± 0.0018	109	80	73.4	0.0022 ± 0.0004	11	11	100
February	0.0034 ± 0.0033	140	104	74.3	0.0035 ± 0.0018	14	14	100
March	0.0056 ± 0.0039	160	144	90	0.0056 ± 0.0013	16	16	100
April	0.0097 ± 0.0061	210	208	99	0.0096 ± 0.0022	21	21	100
May	0.0102 ± 0.0063	60	59	98.3	0.0102 ± 0.0021	6	6	100
June	0.0115 ± 0.0067	150	148	98.7	0.0115 ± 0.0028	15	15	100
August	0.0010 ± 0.0056	90	90	100	0.0010 ± 0.0012	9	9	100
September	0.0077 ± 0.0051	160	158	98.8	0.0077 ± 0.0016	16	16	100
Season								
Fall	0.0044 ± 0.0039	510	410	85.3	0.0044 ± 0.0021	51	51	100
Winter	0.0034± 0.0032	1061	967	91.1	0.0034 ± 0.0017	107	107	100
Spring	0.0096 ± 0.0061	440	433	98.4	0.0096 ± 0.0026	44	44	100
Summer	0.0095 ± 0.0061	230	229	99.6	0.0095 ± 0.0025	23	23	100

[a] ACGIH TLV for 1-hr exposure duration = 0.0008 mW/cm^3
[b] ACGIH TLV for 8-hr exposure duration = 0.0001 mW/cm^3

UV_{app} Index from EPA App

Figure 10 shows the hourly UV_{app} index for the entire study period (October 5, 2020 – October 5, 2021), with the values peaking in June. October 2020 to December 2020 showed a downward trend from peaking at 6 UVI to 2 UVI. December 2020 to the end of January 2021 averaged a peak of 2 UVI. During this period, 5 days exhibted peak values of 3.5 UVI. February to March 9 showed an upward trend with many variations, with the highest peaks averaging 5 UVI. There was a three-day period in the middle of March that peaked at 4, 5, and 3 UVI. After that, until the middle of April, the peaks averaged a UVI of 7, with 2 days at 6 UVI and 1 day at 5 UVI. The middle of April to late June showed a steady upwards trend to a peak of 10 UVI, with a lot of variation. August to the end of the study period shows a gradual downward trend with some variation.

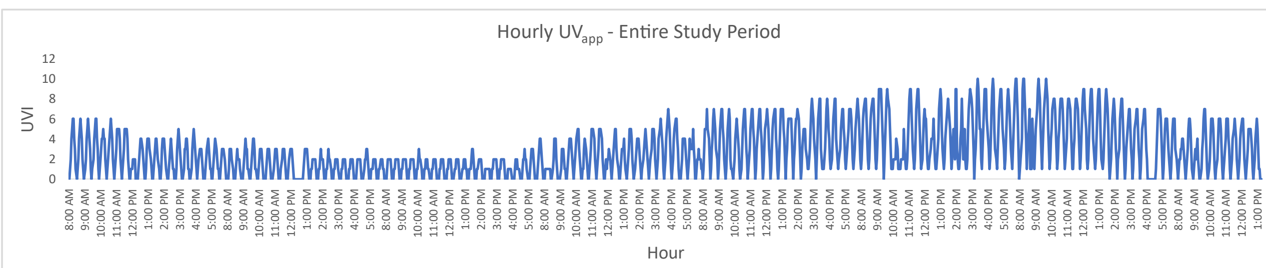


Figure 10. Hourly UV_{app} index for the entire study period, Greenville, NC, October 5, 2020 – October 5, 2021

Figure 11 shows the hourly UV_{app} index for all monitoring days for each monitored month (October 2020 to September 2021). October 2020 showed a downward trend with little variation, with the UVI remaining between 6 and 4 UVI. One day in the middle of the month had the lowest peak at 2 UVI. November did not show a trend and most of the days peaked and/or plateaued at 3 UVI. The highest peaks in the month were at 4 UVI and they were a consecutive two days on two occasions, three days apart. There was a trend of a jagged downward slope on five of the peaks, which can be attributed to a constant UVI value for more than one hour at a time. December showed little variation, with the highest four peaks at 3 UVI and the remainder at 2 UVI. All the peaks at 3 UVI plateaued for at least 3 hours. Many of the peaks also have jagged slopes. January 2021 showed little to no variation, with the highest peak at 3 UVI and the lowest peak at 1 UVI. The remainder of the peaks plateaued at 2 UVI and all but one peak had at least one jagged side. The UVI levels for January were the most constant thus far. February showed a steep upward trend with variation. The highest three peaks plateaued at 5 UVI and the lowest two peaks plateaued at 1 UVI. The end of February marked the beginning of higher peaks. March showed an upward trend with a lot of variation as well. The highest five peaks were at 6 UVI and the lowest peak was at 3 UVI. Most of the peaks did not show uniformity in the increase or decrease in UVI on any given day. April showed an upward trend with some variation. The highest peaks were at 9 UVI and the lowest peak plateaued slightly at 5 UVI. At the end of April, the app was reporting UVI data for earlier times in the day, so the base of the peaks was no longer touching the x-axis since there were more data for the entire day. The month of May showed many variations because of low monitoring days. There was an overall upward trend, with the highest peaks slightly plateaued at 9 UVI and the lowest peak was at 4 UVI. The peaks' incline becomes steeper throughout the days with a steep decline. June had an upward trend with some variation. The highest six peaks in June, the highest measured for the year, were at 10 UVI, while the lowest peaks were at 5 UVI. The lowest peaks were part of three days consisting of double peaks attributed to cloud coverage that increased in the middle of the second and third days of the double peaks. August showed a slight upward trend with little variation and more uniformity. The highest 4 peaks were at 9 UVI, with 3 of them slightly plateaued, and the remainder of the peaks were the lowest at 8 UVI. September showed a downward trend with a lot of variation. The highest peak slightly plateaued at 8 UVI and the lowest peak was a part of a double peak toward the end of the month at 3 UVI. September showed the app data was not available for the early hours and the peaks became less uniform. The few days of October do not show a trend, but there is a little variation. The highest 2 peaks were at 6 UVI, with one of them slightly plateaued, and the remaining peak was the lowest at 5 UVI.

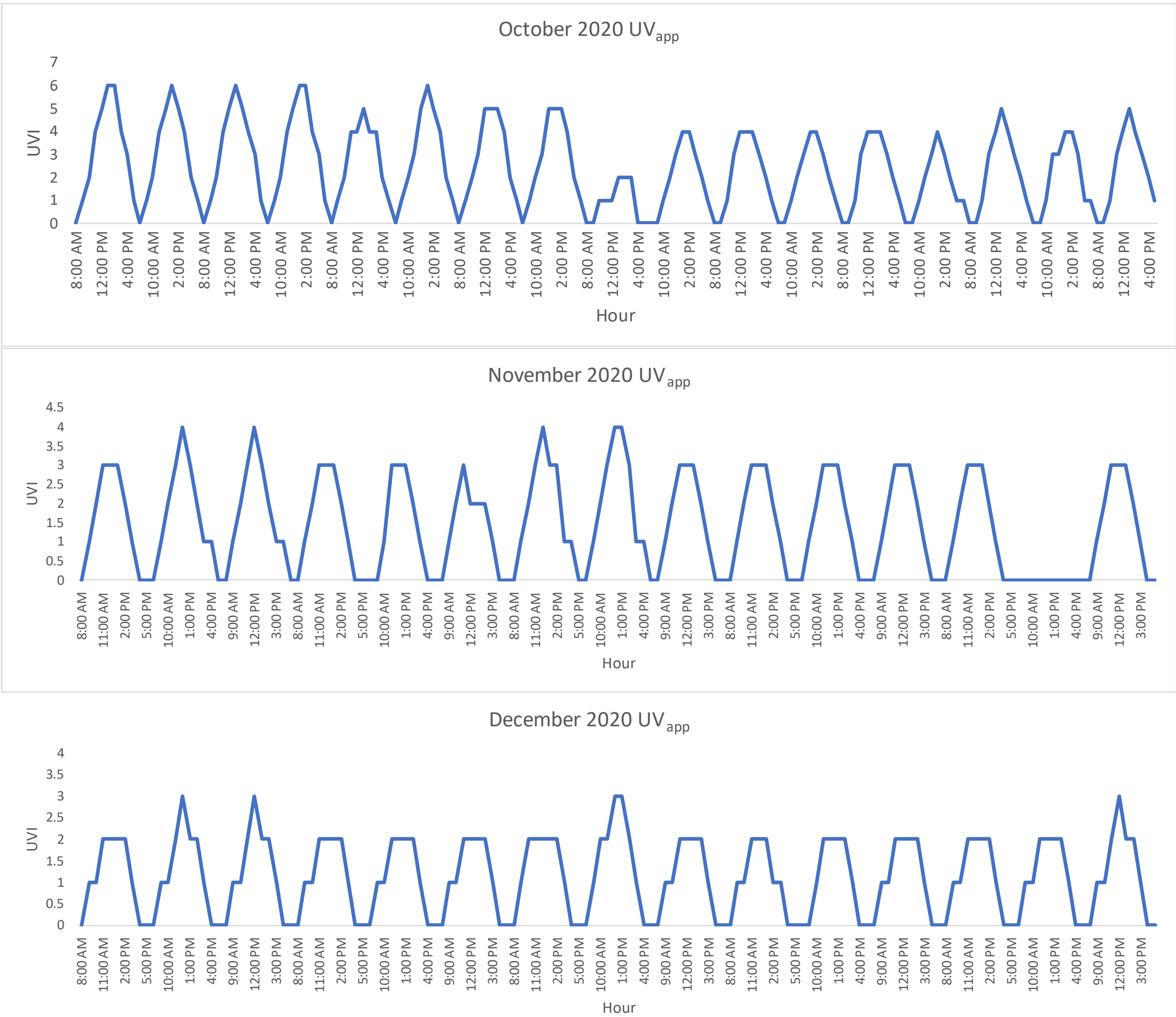


Figure 11. Hourly UV_{app} index for all monitoring days for each monitored month, Greenville, NC, October 2020 to September 2021. July data is missing due to equipment malfunction.

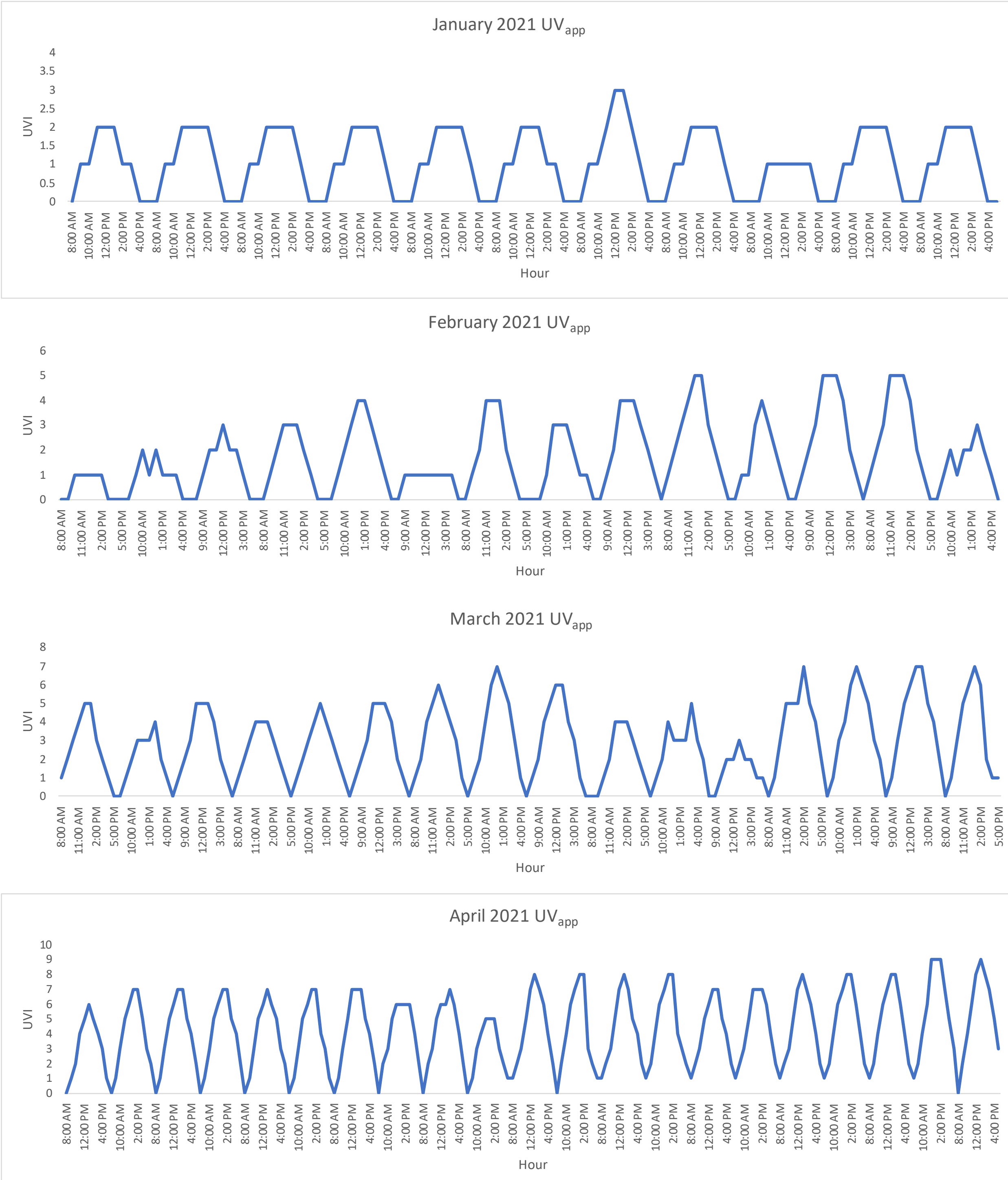


Figure 11. Hourly UV_{app} index for all monitoring days for each monitored month, Greenville, NC, October 2020 to September 2021. July data is missing due to equipment malfunction. (cont'd)

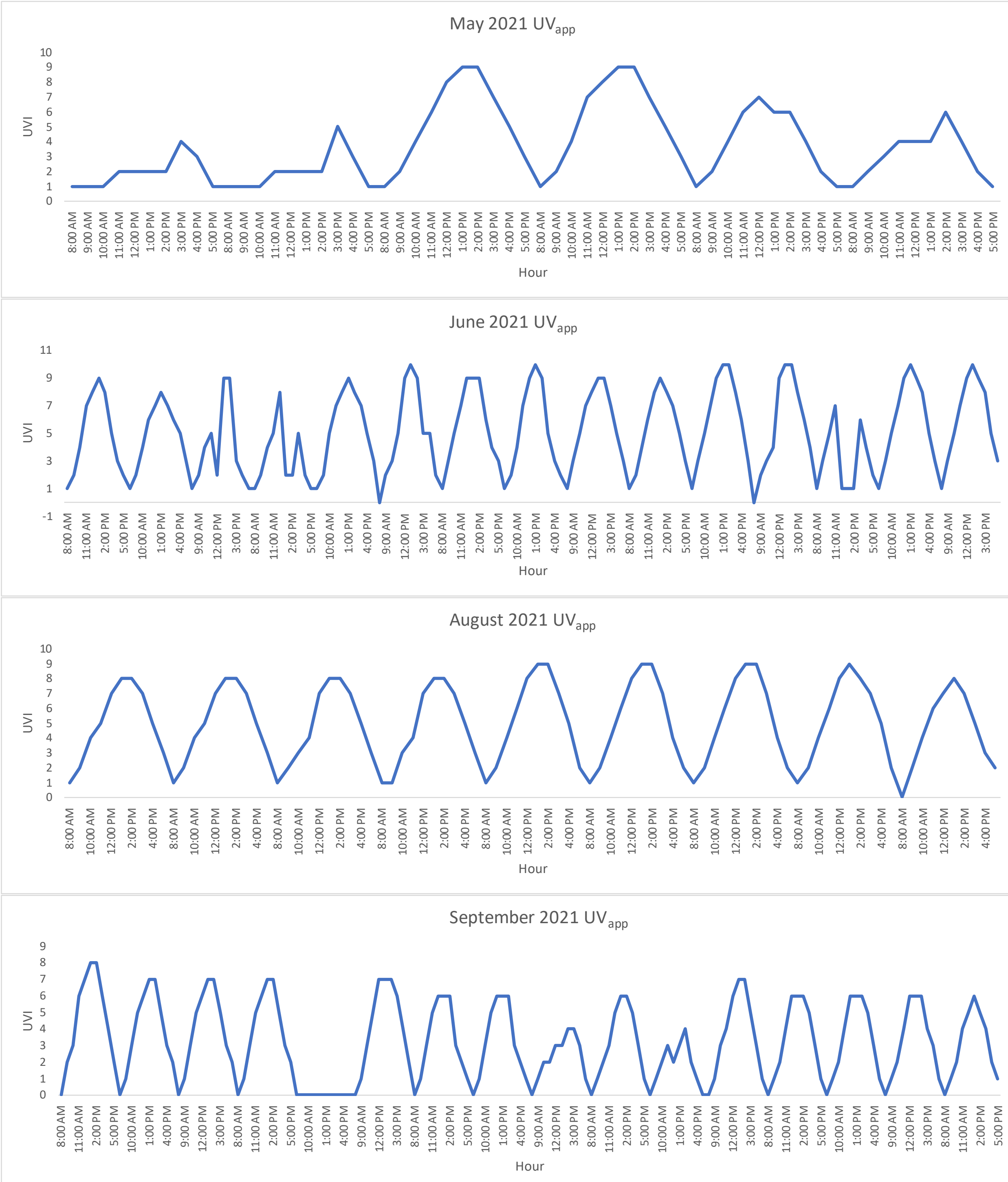


Figure 11. Hourly UV_{app} index for all monitoring days for each monitored month, Greenville, NC, October 2020 to September 2021. July data is missing due to equipment malfunction. (cont'd)

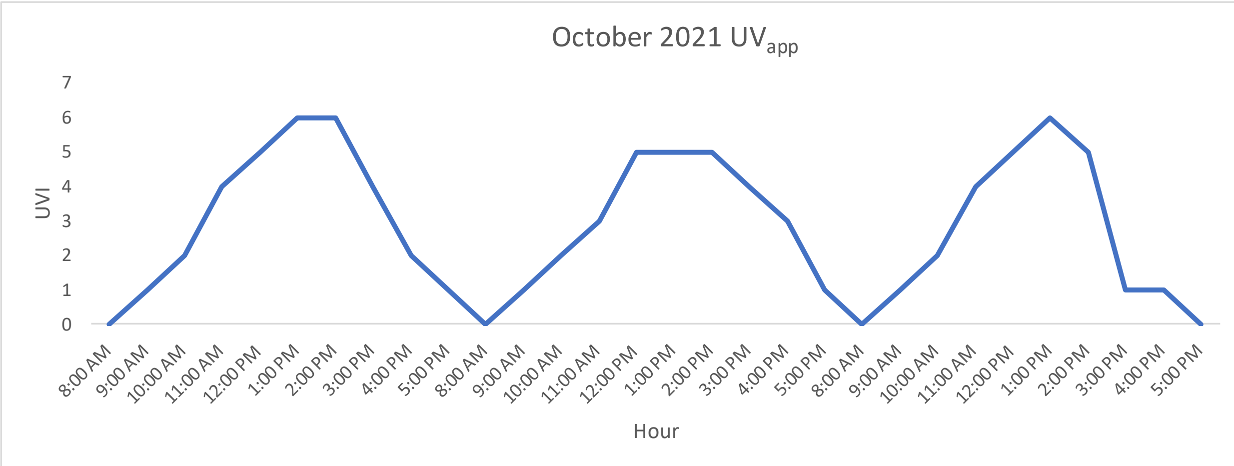


Figure 11. Hourly UV_{app} index for all monitoring days for each monitored month, Greenville, NC, October 2020 to September 2021. July data is missing due to equipment malfunction. (cont'd)

Figure 12 shows the daily average UV_{app} index for the entire study period from October 5, 2020 to October 5, 2021. The graph peaks right above 6 UVI at the end of June, with the lowest daily average of 1 UVI in February. There was variation within each month, especially within the summer months.

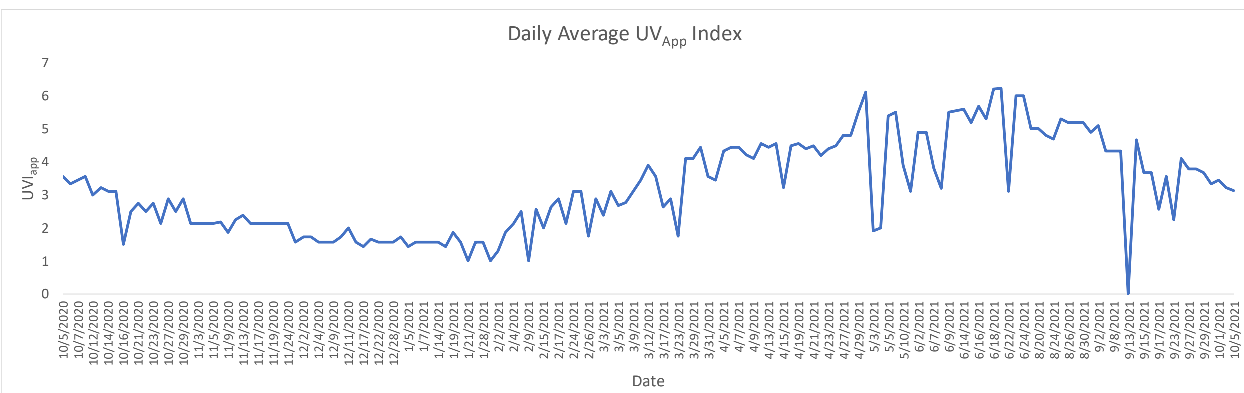


Figure 12. Daily average UV_{app} index for the entire study period, Greenville, NC, October 5, 2020 to October 5, 2021

Figure 13 shows the daily average UV_{app} index for all monitoring days for each monitored month (October 2020 to September 2021). October 2020 showed a decreasing trend and high variation. The highest point was 3.6 UVI and the lowest point was 1.5 UVI. There was a drastic decrease in UVI between October 15 and 17, then another slight decrease between October 25 and 27. November did not show a trend, but the graph did decrease then increase before continuing to be steadily above 2 UVI. The highest point was about 2.4 UVI and the lowest point was about 1.9 UVI. December showed a downward trend and some variability. The values dipped below 1.5 UVI as the lowest and highest points were the same at 2 UVI. The UVI values were overall lower than November's. January 2021 showed a slight downward trend with some variability due to the highly variable time between January 17 and 23. Most of January remained around 1.6 UVI, with the highest point above 1.8 UVI and the lowest point at 1 UVI. February showed an upward trend, with the highest point (about 3.1 UVI) at the end of the month (between February 23 and 25), and the lowest points (1 UVI) on February 1 and 9. March showed an upward trend, with the highest point (4 UVI) around March 30 and the lowest point (about 1.7 UVI) between March 22 and 24. April showed an upward trend, with the highest point (about 6.2 UVI) on April 30, and the lowest point (about 3.2 UVI) between April 14 and 16. The lowest point was a significant decrease in the average UVI, but after that the average resumed the upward trend. The month of May showed an upward trend with low variability. There was a steep increase in the average UVI from the lowest point of about 1.9 UVI on May 3 to the highest point, about 5.4 UVI. Around May 6, the average UVI began to decrease through the middle of the month. An assumption can be made that through the end of the month, the average UVI began to increase. June showed an upward trend with some variability. The lowest point was about 3.2 UVI on June 22 and the highest point was ~6.1 UVI from June 18 to 21, then again on June 23 and 24. August showed a decreasing trend, with a gradual decrease in the average UVI between August 20 and 24, then a steep increase on August 25. After leveling out at 5.2 UVI from the 26th to 30th, there was a steep decline on the 31st. September showed a decreasing trend, with the highest point (about 5.1 UVI) on September 2 and the lowest point (2.25 UVI) was on the 23rd. The 14th was the start of the high variability of September. October showed a downward trend and little to no variability, with the highest point (about 3.45 UVI) on October 1 and the lowest point (right above 3.1 UVI) on October 5.

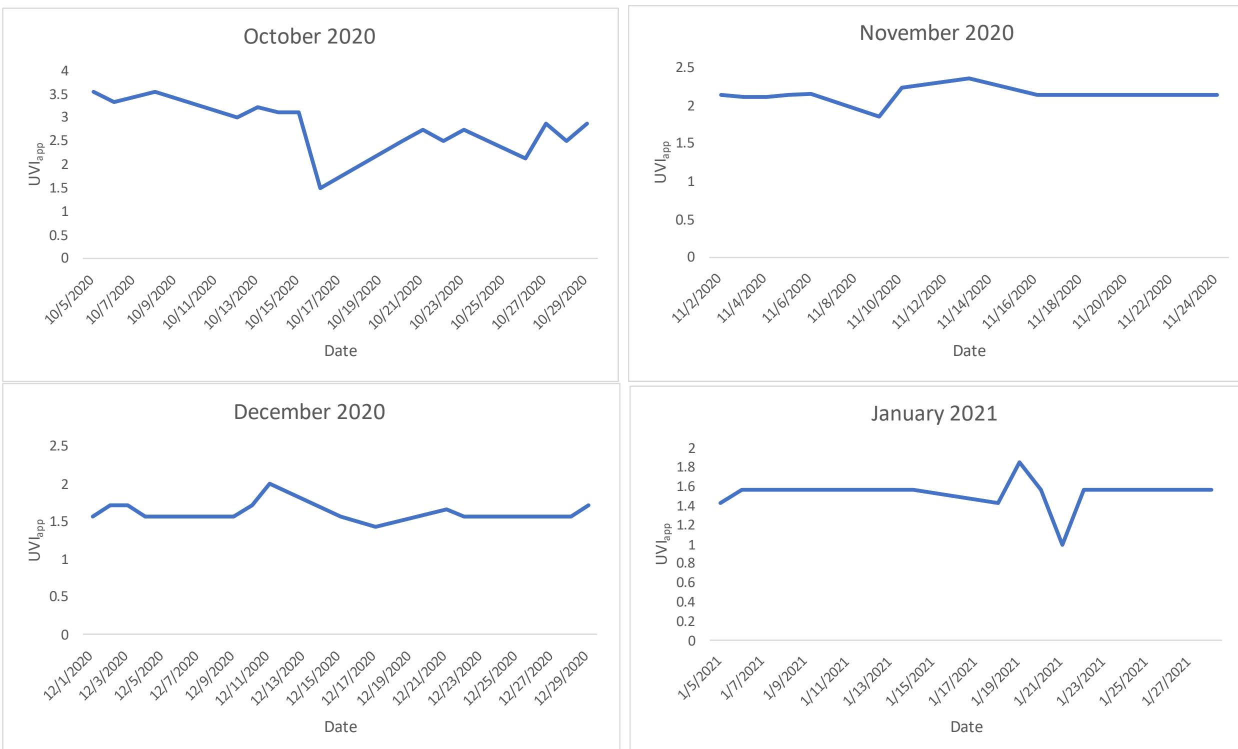
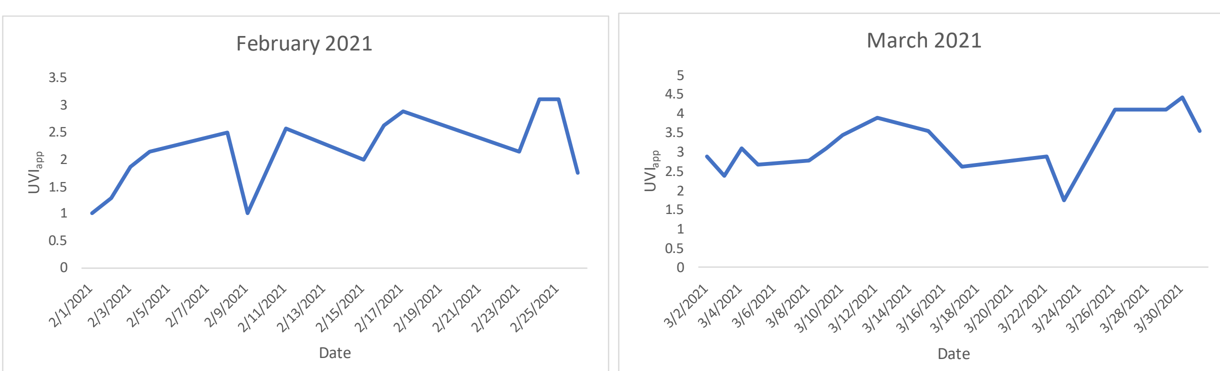


Figure 13. Daily average UV_{app} index for all monitoring days for each monitored month, Greenville, NC, October 2020 to September 2021



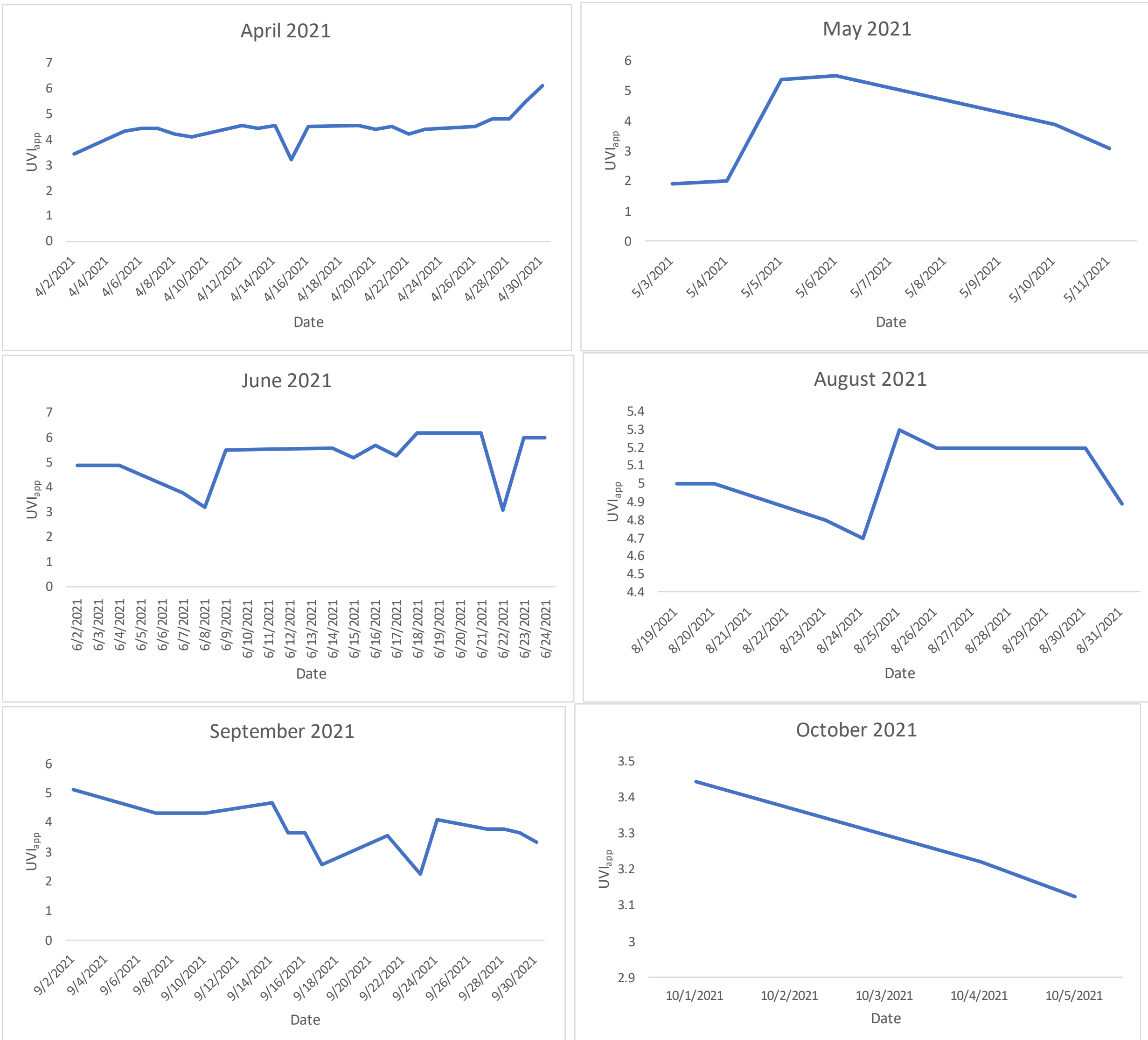


Figure 13. Daily average UV_{app} index for all monitoring days for each monitored month, Greenville, NC, October 2020 to September 2021. July data is missing due to equipment malfunction. (cont'd)

Monthly Average UV_{app} Index

Figure 14 shows the monthly average UV_{app} index for the entire study period (October 2020 to September 2021). The overall upward trend peaked in June around 5.2 UVI and the lowest in January around 1.6 UVI. October to January showed a decline in the average monthly UVI. February, with the exception of May, to June showed an increase in the average monthly

UVI. There was no data for July due to equipment failure. From August to September showed a decline in the average monthly UVI. During the winter season, from December to March, the highest UV exposure was in March and the lowest was in January.

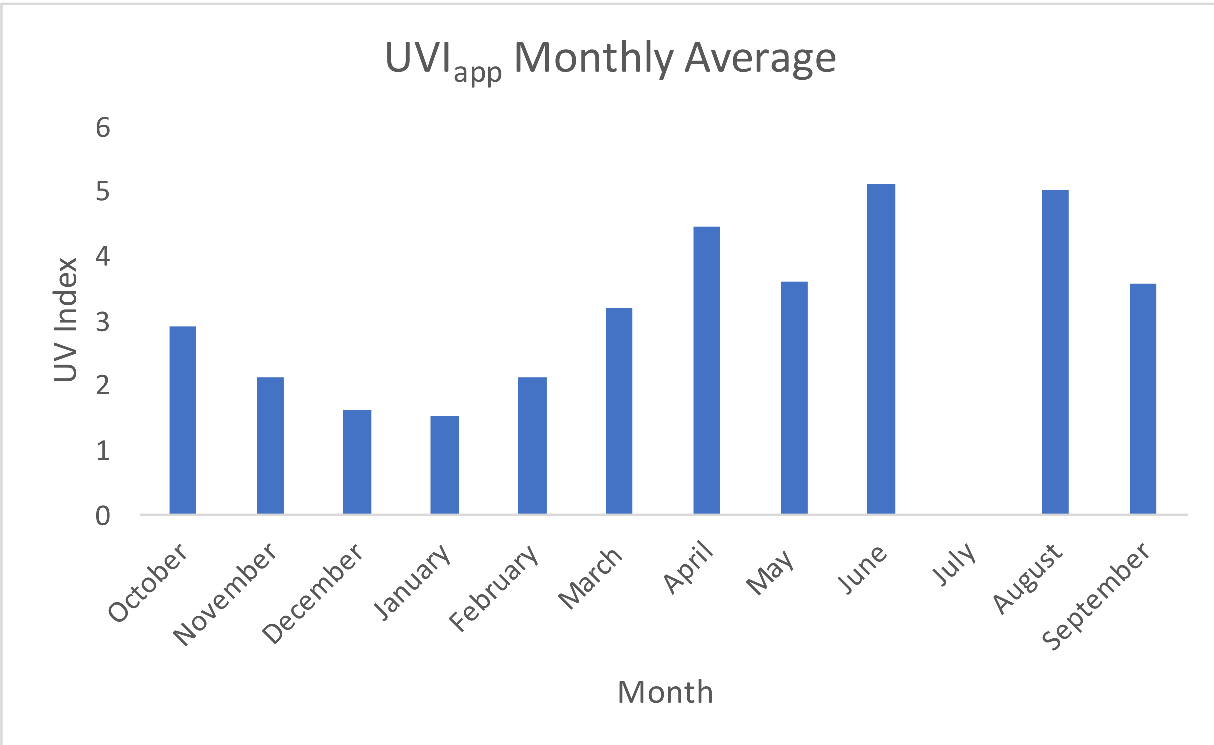


Figure 14. Monthly average UV_{app} index for the entire study period, Greenville, NC, October 2020 to September 2021. July data is missing due to equipment malfunction.

Seasonal Average UV_{app} Index

Figure 15 shows the average UV_{app} index by season (fall, winter, spring and summer). The graph shows an overall upward trend that peaks in the summer. In decreasing order, the seasonal average can be ranked as follows: summer, spring, fall, then winter. The average UVI for summer and winter were 4.5 and 2.1, respectively, with the average summer UVI being more than twice the average winter UVI. This means the exposure risk is higher in the summer and overexposure can happen faster. In the winter, the risk of overexposure still exists but may not happen as fast as the summer.

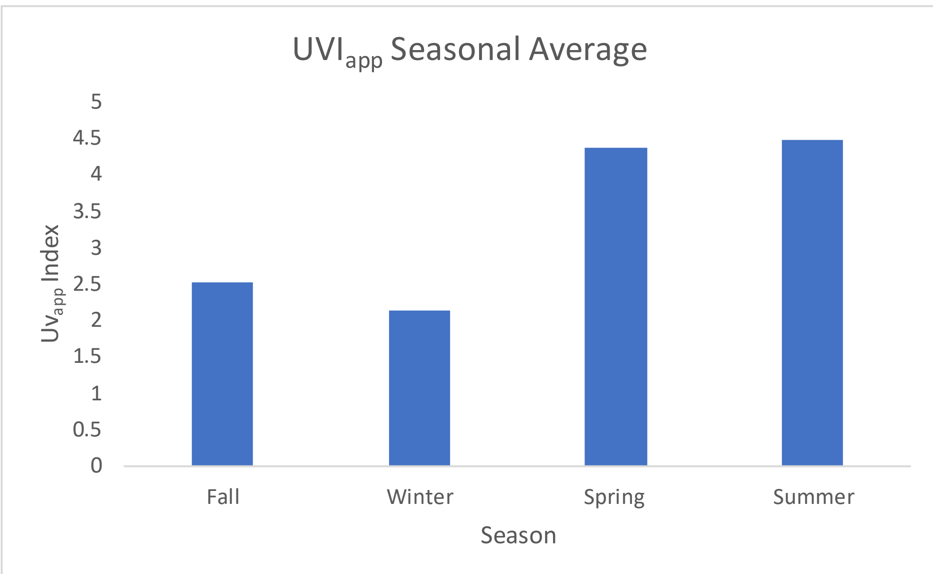


Figure 15. Average UV_{app} index by season, Greenville, NC, October 2020 to September 2021

Ambient Temperature from OSHA-NIOSH App

Figure 16 shows the hourly ambient temperature and the daily average ambient temperature for the entire study period from October 5, 2020 to October 5, 2021. The hourly graph (Figure 16A) showed a distinct peak between April 2 and April 5, 2021, likely the 3rd of April. The temperature at the peak was about 47°C. The lowest temperatures of the year were on December 3 (-1.7°C), and 8 (-1.1°C), 2020; January 28 (-0.6°C) and February 3, 2021 (-0.6°C).

The lowest temperature was -1.7°C. The graph shows high variability because every day shows different temperatures that are not often identical on consecutive days.

Figure 16B shows a distinct peak in the daily average ambient temperature around April 5, 2021 at about 43°C. The lowest point was about 2°C around February 5, 2021. There was high variability throughout the year, with twin peaks after December 5. After February 5, the average temperatures increased, then a decline occurred after September 5. The trends of these figures follow the same patterns as the previous figures that were focused on the UV_{eff} (Figure 5) and UV_{app} data (Figure 10).

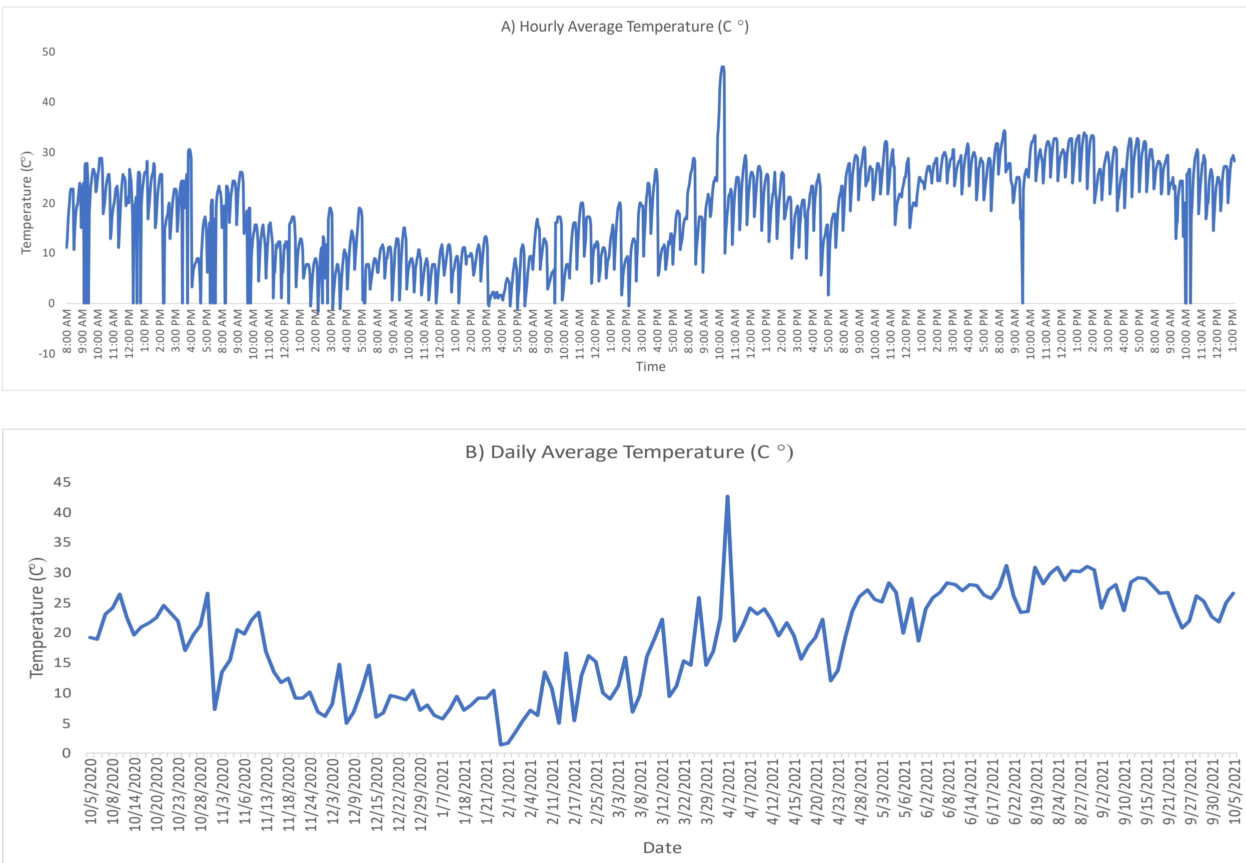


Figure 16. Hourly (A) and daily average (B) ambient temperature (°C) for the entire study period, Greenville, NC, October 5, 2020 to October 5, 2021. July data is missing due to equipment malfunction

Correlation between UVeff and Ambient Temperature

Figure 17 shows the overall correlation between the hourly average ambient temperature and the hourly average UV_{eff} for the entire study period, which was used to determine if the ambient temperature can be used as a proxy for UV_{eff} and vice versa. The graphed showed a positive but moderate correlation ($R = 0.518$; $0.3 < R < 0.5$) between temperature and UV_{eff}. There were a few outliers in the data, but they did not affect the correlation of the two variables. The positive and moderate correlation does not necessarily indicative of low temperatures meaning there is little to zero risk of UV exposure. The assumption that the temperature is not indicative of UV exposure risk because of the outliers. Finally, Figure 17 demonstrates that the risk of UV exposure was present at the lowest temperatures.

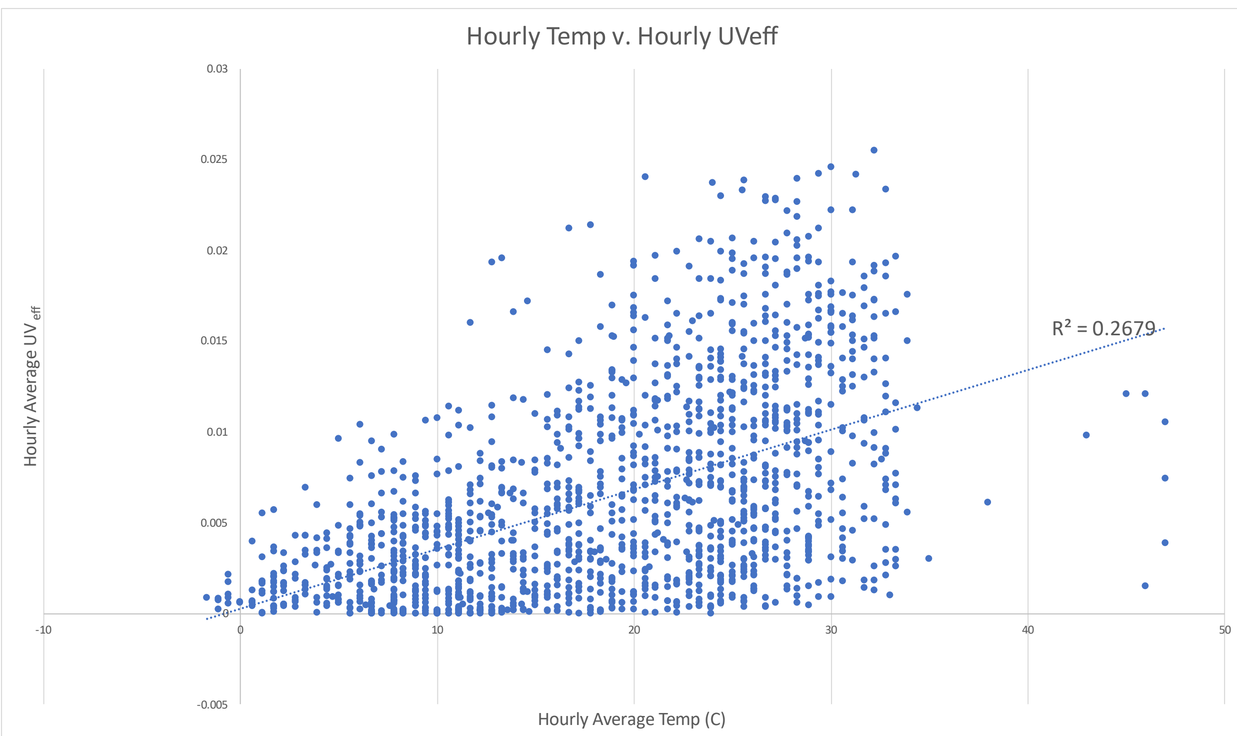


Figure 17. Overall correlation between hourly average ambient temperature (°C) and hourly average UV effective irradiance, UV_{eff} (mW/ cm^2)

VIII. DISCUSSION

This study shows that UV exposures during the winter and fall seasons were significantly lower than those during the summer. This partly supports the study's first hypothesis, which states that solar UV exposure levels during the cold seasons were significantly lower than during the summer season. Similarly, Thieden et al. (2006) found that, during the winter season, workers experienced lower amounts of radiation compared to the summer season. However, the UV exposures in the summer and spring seasons were not significantly different. This is an important finding because groundskeepers start their work at the beginning of spring season, with some even starting right before spring. This implies that UV preventive measures must be implemented starting the spring season, even if the temperature is still relatively cool. These measures included using lotions with SPF or sunscreen to target areas that are not covered by clothing (Rendell et al., 2020). Implementing such preventives measures should not be delayed until the summer season. Groundskeepers work outside, tending to the grounds in the summer. Therefore, they are exposed for longer periods. This would increase the gap of exposure discrepancy between the warm seasons (spring and summer) and the cold season (winter).

The second hypothesis of this study states that solar UV exposure during the cold seasons exceeds the ACGIH TLV, which is supported by the study results. Comparing the hourly UV_{eff} to the 1-hr TLV for the entire monitoring period showed a large percentage of exceedance monthly (from 62.7% in December 2020 to 100% in August 2021) and seasonally (from 85.3% in Fall to 99.6% in Summer), similar to the 2020 study conducted by Dillane and Balanay (2021). Comparing the daily UV_{eff} to the 8-hr TLV for the entire monitoring period showed 100% exceedance for both the monthly and seasonal averages. This data shows that outdoor workers are at risk for UV overexposure on any given day throughout the year, including the cold months. During the winter season, it is commonly assumed that the risk of UV overexposure is low. One reason for such an assumption is that it being cold outside is frequently equated to the sun not having a great effect on the amount of UV ray exposure. During the summer season, the public will generally take the necessary safety precautions to reduce their risk of UV exposure. In contrast, during the winter season, the public may be less likely to take the same precautions because of the cold ambient temperature and to them, cold equates to no or little UV exposure risk. Andersen et al. (2010) observed adults taking protective measures on cold days with clear skies in a recreational setting compared to cloudy days when the same measures should still be taken. This may lead to a false sense of security among the public, including outdoor workers. Although UV exposure was significantly lower during the winter season than the summer season, that does not necessarily mean that there is no risk of exposure that exceeds the 1-hr and/or 8-hr TLV.

The risk is present during the cold months due to peak exposure times, between 11 AM and 1 PM. Beck et al. (2018) also found that the peak UV exposure times were at noon or in the afternoon. Dillane and Balanay (2020) also found the peak exposure time was between 10 AM and 4 PM. That supports this study's claim that peak exposure time is between 11 AM and 1 PM. It is possible that as the outdoor workers are working, they get hot and shed layers which can increase the skin surface left exposed. It is recommended that outdoor workers apply sunscreen to areas that are not covered, wear sunglasses, a hat with a brim, long sleeve clothing, take their lunch break at the peak time of exposure, and if possible, do the bulk of their work before or after the peak period (EPA, 2014; NIOSH, 2014).

The winter season of 2020 – 2021 was December 21st, 2020 to March 19th, 2021. The lowest risk occurred in December and the highest risk occurred at the beginning of March. There was a positive but moderate correlation between UV_{eff} and ambient temperature, demonstrating that the temperature increased as the UV_{eff} increased. Rendell et al. (2020) also found that higher temperatures result in high UV doses, which correlates to a high UV_{eff}. Trends on daily averages of the UV_{app} index and ambient temperature for the entire monitoring period also showed similar behavior when comparing the daily UV_{eff} index over time. The fall, winter, and spring have lower UV_{eff} and ambient temperature data compared to the summer, when the data peaks and is overall higher. The average and maximum summer UV_{eff} were about twice as high as the winter average and maximum UV_{eff}. $P < 0.05$ was proof the averages were s significantly different, with summer being higher than winter. The p-value being so small typically means the null hypothesis is rejected, but in this case the null hypothesis that summer UV_{eff} is higher than winter UV_{eff}.

This study has several strengths and limitations. Data collection was consistent during the entire study period, but the data for July was missing due to corruption in the data files. Another limitation was the length of time it took for the files to be investigated and equipment maintenance. Moreover, findings from this study may be representative of some southeastern states that experience all four seasons but may not represent the states that are relatively warmer year-round with higher temperatures in the summer season like the state of California. Different parts of the U.S. and the world experience higher levels of UV radiation than others (Manny et al., 2020). On the other hand, an important strength of this study is that it is the first study, to our knowledge, that investigated the potential UV exposure risk of outdoor workers during cold seasons in the southeastern US. Workers were not assessed, but the UV_{eff} data was collected in an area workers would typically be. The data can also apply to the general public. In addition, the UV monitor set-up was undisturbed by groundskeepers, so there was no inaccurate data in terms of unexplainable dips in the data sets.

It is recommended that future studies are conducted that investigate the personal exposure of outdoor workers through personal monitoring, type of clothing the outdoor workers wear during the winter season, their work habits, schedule and specific work environment, and that assess the UV exposures of outdoor workers in hotter regions (e.g., southern states) of the US during colder months. It would also be beneficial to collect UV_{eff} data in the shade to prove a reduced risk. A multilinear correlation between UV_{eff}, temperature, and relative humidity can be conducted to see how humidity may affect UV_{eff}, if it has an affect. It would be beneficial to have outdoor workers wear personal monitors, similar to the Thieden et al. (2006) study to show the effect of posture and worker orientation (Milton et al., 2006).

IX. CONCLUSION

This study shows that the risk of overexposure to UV radiation was present during the winter season. The 1-hr TLV was exceeded for the majority of the hours during the monitoring period and the 8-hr TLV was exceeded 100% of the time on any given monitoring day. The highest UV exposure was measured during the summer, with the lowest exposure during the winter. Here, June had the highest UV exposure and December had the lowest. In accordance with common assumptions, the ambient temperature and UV exposure are positively but moderately correlated, but that does not mean that when the temperature is low, there is little to zero risk of UV exposure. Outdoor workers are most at risk for exposure because the peak time period of the highest UV_{eff} in any given season, 11am – 2pm, is most likely when they would be outside to perform work because it will also be the warmest. Outdoor workers should take precautionary measures to protect themselves during winter months, as they would during the summer months, including wearing protective clothing/accessories, sunglasses and sunscreen and taking breaks in the shade. There is not much published data, research, or literature surrounding outdoor workers regarding exposure to UV during the cold months from occupational health and safety sources. This study provides the data to show the risk of UV exposure in the winter. During the winter season, most people do not consider the possibility of UV exposure risk due to the cold ambient temperature. This would better inform workers and employers of the risks and hopefully minimize any UV exposure-related illness from the workplace.

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XI. APPENDICES

Appendix A: Sample of Collected Raw Data from October 5 – 29, 2020

Spread sheet for collected data from October 5 – 29, 2020												
Date	Hour	Average UV_{eff} (mW/cm^2)	SD UV_{eff} (mW/cm^2)	Tmax (min)	UVI - Meter	UV Risk Cat - Meter	UVI - App	UV Risk Cat - App	Temp (C)	RH (%)	HI (C)	Heat Risk Cat - App
10/5/2020	8:00 AM	0.0010	0.0004	50.1	0	Low			11.1	93	11.1	Minimal
10/5/2020	9:00 AM	0.0032	0.0010	15.4	1	Low	1	Low	12.8	86	12.8	Minimal
10/5/2020	10:00 AM	0.0072	0.0012	7.0	3	Moderate	2	Low	16.1	72	16.1	Minimal
10/5/2020	11:00 AM	0.0104	0.0023	4.8	4	Moderate	4	Moderate	18.3	65	18.3	Minimal
10/5/2020	12:00 PM	0.0139	0.0005	3.6	6	High	5	Moderate	20	59	20	Minimal
10/5/2020	1:00 PM	0.0140	0.0004	3.6	6	High	6	High	22.2	52	22.2	Minimal
10/5/2020	2:00 PM	0.0114	0.0010	4.4	5	Moderate	6	High	22.7	50	22.7	Minimal
10/5/2020	3:00 PM	0.0073	0.0010	6.8	3	Moderate	4	Moderate	22.7	47	22.7	Minimal
10/5/2020	4:00 PM	0.0033	0.0004	14.9	1	Low	3	Moderate	22.7	45	22.7	Minimal
10/5/2020	5:00 PM	0.0009	0.0001	53.7	0	Low	1	Low	22.8	49	22.8	Minimal
10/6/2020	8:00 AM	0.0010	0.0004	49.2	1	Low			10.6	96	10.6	Minimal
10/6/2020	9:00 AM	0.0033	0.0009	15.3	1	Low	1	Low	13.9	83	13.9	Minimal
10/6/2020	10:00 AM	0.0069	0.0012	7.2	3	Moderate	2	Low	16.7	74	16.7	Minimal
10/6/2020	11:00 AM	0.0106	0.0009	4.7	4	Moderate	4	Moderate	18.3	53	18.3	Minimal
10/6/2020	12:00 PM	0.0128	0.0004	3.9	5	Moderate	5	Moderate	19.4	49	19.4	Minimal
10/6/2020	1:00 PM	0.0126	0.0005	4.0	5	Moderate	6	High	19.6	47	19.6	Minimal
10/6/2020	2:00 PM	0.0101	0.0010	5.0	4	Moderate	5	Moderate	21.2	45	21	Minimal
10/6/2020	3:00 PM	0.0063	0.0011	7.9	3	Moderate	4	Moderate	22.6	43	22.6	Minimal
10/6/2020	4:00 PM	0.0030	0.0009	16.7	1	Low	2	Low	23.9	41	23.9	Minimal
10/6/2020	5:00 PM	0.0004	0.0006	112.0	0	Low	1	Low	23.3	44	23.3	Minimal
10/7/2020	8:00 AM	0.0010	0.0004	52.0	0	Low			15	96	15	Minimal
10/7/2020	9:00 AM	0.0030	0.0008	16.6	1	Low	1	Low	17.8	87	17.8	Minimal
10/7/2020	10:00 AM	0.0062	0.0011	8.1	2	Low	2	Low	20.6	81	20.6	Minimal
10/7/2020	11:00 AM	0.0104	0.0011	4.8	4	Moderate	4	Moderate	23.9	69	23.9	Minimal
10/7/2020	12:00 PM	0.0130	0.0005	3.8	5	Moderate	5	Moderate				
10/7/2020	1:00 PM	0.0131	0.0004	3.8	5	Moderate	6	High	27.2	54	26.7	Low
10/7/2020	2:00 PM	0.0105	0.0010	4.8	4	Moderate	5	Moderate	27.8	51	27.8	Low
10/7/2020	3:00 PM	0.0066	0.0012	7.5	3	Moderate	4	Moderate				
10/7/2020	4:00 PM	0.0031	0.0009	16.4	1	Low	3	Moderate	27.8	49	27.8	Low
10/7/2020	5:00 PM	0.0008	0.0004	59.1	0	Low	1	Low	25	58	25	Minimal
10/8/2020	8:00 AM	0.0010	0.0005	48.5	0	Low						
10/8/2020	9:00 AM	0.0034	0.0009	14.6	1	Low	1	Low	17.8	78	17.8	Minimal
10/8/2020	10:00 AM	0.0070	0.0011	7.1	3	Moderate	2	Low	20.6	68	20.6	Minimal
10/8/2020	11:00 AM	0.0108	0.0021	4.6	4	Moderate	4	Moderate	23.3	59	23.3	Minimal
10/8/2020	12:00 PM	0.0138	0.0004	3.6	6	High	5	Moderate	24.4	54	24.4	Minimal
10/8/2020	1:00 PM	0.0137	0.0005	3.6	5	Moderate	6	High	25.6	48	25.6	Minimal
10/8/2020	2:00 PM	0.0110	0.0011	4.6	4	Moderate	6	High	26.7	45	26.7	Low
10/8/2020	3:00 PM	0.0069	0.0012	7.2	3	Moderate	4	Moderate	26.7	44	26.7	Low
10/8/2020	4:00 PM	0.0031	0.0010	16.1	1	Low	3	Moderate	26.1	44	26.1	Minimal
10/8/2020	5:00 PM	0.0008	0.0004	59.7	0	Low	1	Low	25.6	47	25.6	Minimal
10/12/2020	8:00 AM	0.0006	0.0003	85.5	0	Low			22.2	90	21.7	Minimal
10/12/2020	9:00 AM	0.0019	0.0004	26.7	1	Low	1	Low	22.8	90	22.2	Minimal
10/12/2020	10:00 AM	0.0030	0.0006	16.7	1	Low	2	Low	24.4	87	23.9	Minimal
10/12/2020	11:00 AM	0.0051	0.0019	9.8	2	Low	4	Moderate	25.6	85	25.6	Minimal
10/12/2020	12:00 PM	0.0105	0.0019	4.8	4	Moderate	4	Moderate	26.7	82	26.1	Low
10/12/2020	1:00 PM	0.0089	0.0007	5.6	4	Moderate	5	Moderate	28.9	77	26.7	Low
10/12/2020	2:00 PM	0.0067	0.0011	7.5	3	Moderate	4	Moderate	28.9	77	26.7	Low
10/12/2020	3:00 PM	0.0042	0.0012	11.9	2	Low	4	Moderate	28.9	77	26.7	Low
10/12/2020	4:00 PM	0.0015	0.0003	33.5	1	Low	2	Low	28.9	77	26.7	Low
10/12/2020	5:00 PM	0.0004	0.0002	131.7	0	Low	1	Low	26.7	79	26.1	Low
10/13/2020	8:00 AM	0.0003	0.0004	167.2	0	Low			17.8	100	17.8	Minimal
10/13/2020	9:00 AM	0.0019	0.0006	25.7	1	Low	1	Low	18.9	90	18.9	Minimal
10/13/2020	10:00 AM	0.0062	0.0016	8.0	2	Low	2	Low	20	84	20	Minimal
10/13/2020	11:00 AM	0.0102	0.0020	4.9	4	Moderate	3	Moderate	21.7	79	21.7	Minimal
10/13/2020	12:00 PM	0.0135	0.0003	3.7	5	Moderate	5	Moderate	23.3	69	23.3	Minimal
10/13/2020	1:00 PM	0.0130	0.0006	3.8	5	Moderate	6	High	24.4	66	24.4	Minimal

Appendix A: Sample of Collected Raw Data from October 5 – 29, 2020

Spread sheet for collected data from October 5 – 29, 2020 (cont'd)												
10/13/2020	2:00 PM	0.0103	0.0010	4.8	4	Moderate	5	Moderate	25	64	25	Minimal
10/13/2020	3:00 PM	0.0062	0.0015	8.1	2	Low	4	Moderate	25.6	62	25.6	Minimal
10/13/2020	4:00 PM	0.0026	0.0010	19.5	1	Low	2	Low	25.6	64	25.6	Minimal
10/13/2020	5:00 PM	0.0006	0.0003	83.9	0	Low	1	Low	23.3	74	23.3	Minimal
10/14/2020	8:00 AM	0.0009	0.0004	56.2	0	Low			12.8	83	12.8	Minimal
10/14/2020	9:00 AM	0.0031	0.0009	16.2	1	Low	1	Low	14.4	75	14.4	Minimal
10/14/2020	10:00 AM	0.0068	0.0012	7.4	3	Moderate	2	Low	17.2	65	17.2	Minimal
10/14/2020	11:00 AM	0.0106	0.0011	4.7	4	Moderate	3	Moderate	19.4	56	19.4	Minimal
10/14/2020	12:00 PM	0.0129	0.0003	3.9	5	Moderate	5	Moderate	20	54	20	Minimal
10/14/2020	1:00 PM	0.0127	0.0005	3.9	5	Moderate	5	Moderate	21.1	46	21.1	Minimal
10/14/2020	2:00 PM	0.0100	0.0011	5.0	4	Moderate	5	Moderate	22.8	40	22.8	Minimal
10/14/2020	3:00 PM	0.0061	0.0012	8.2	2	Low	4	Moderate	23	39	23	Minimal
10/14/2020	4:00 PM	0.0026	0.0008	19.1	1	Low	2	Low	23.3	37	23.9	Minimal
10/14/2020	5:00 PM	0.0007	0.0003	74.8	0	Low	1	Low	21.7	47	21.7	Minimal
10/15/2020	8:00 AM	0.0009	0.0004	56.0	0	Low			11.1	93	11.1	Minimal
10/15/2020	9:00 AM	0.0031	0.0009	15.9	1	Low	1	Low	13.9	86	13.9	Minimal
10/15/2020	10:00 AM	0.0069	0.0012	7.2	3	Moderate	2	Low	17.2	78	17.2	Minimal
10/15/2020	11:00 AM	0.0098	0.0024	5.1	4	Moderate	3	Moderate	20.3	71	20.3	Minimal
10/15/2020	12:00 PM	0.0117	0.0021	4.3	5	Moderate	5	Moderate	22.8	64	22.8	Minimal
10/15/2020	1:00 PM	0.0094	0.0014	5.3	4	Moderate	5	Moderate	24.4	58	24.4	Minimal
10/15/2020	2:00 PM	0.0070	0.0007	7.2	3	Moderate	5	Moderate	25.6	52	25.6	Minimal
10/15/2020	3:00 PM	0.0040	0.0011	12.6	2	Low	4	Moderate	25	56	25	Minimal
10/15/2020	4:00 PM	0.0017	0.0004	28.9	1	Low	2	Low	25	56	25	Minimal
10/15/2020	5:00 PM	0.0006	0.0003	78.5	0	Low	1	Low	24.4	62	24.4	Minimal
10/16/2020	8:00 AM	0.0006	0.0002	84.0	0	Low			19.4	93	19.4	Minimal
10/16/2020	9:00 AM	0.0023	0.0008	21.8	1	Low			20	90	20	Minimal
10/16/2020	10:00 AM	0.0062	0.0016	8.1	2	Low	1	Low	20.6	90	20.6	Minimal
10/16/2020	11:00 AM	0.0065	0.0013	7.7	3	Moderate	1	Low	21.1	87	21.1	Minimal
10/16/2020	12:00 PM	0.0081	0.0031	6.1	3	Moderate	1	Low	20	90	20	Minimal
10/16/2020	1:00 PM	0.0030	0.0015	16.9	1	Low	2	Low	26.7	87	26.7	Low
10/16/2020	2:00 PM	0.0049	0.0012	10.3	2	Low	2	Low	25.3	87	25.3	Minimal
10/16/2020	3:00 PM	0.0036	0.0012	13.8	1	Low	2	Low	24.4	84	24.4	Minimal
10/16/2020	4:00 PM	0.0009	0.0004	58.8	0	Low			21.1	78	21.1	Minimal
10/16/2020	5:00 PM	0.0002	0.0001	290.5	0	Low			17.8	93	17.8	Minimal
10/20/2020	8:00 AM	0.0005	0.0003	94.0	0	Low						
10/20/2020	9:00 AM	0.0021	0.0007	23.7	1	Low			18.3	93	18.3	Minimal
10/20/2020	10:00 AM	0.0051	0.0013	9.8	2	Low	1	Low	19.4	90	19.4	Minimal
10/20/2020	11:00 AM	0.0092	0.0012	5.4	4	Moderate	2	Low	20	90	20	Minimal
10/20/2020	12:00 PM	0.0117	0.0004	4.3	5	Moderate	3	Moderate	21.2	87	21.2	Minimal
10/20/2020	1:00 PM	0.0118	0.0007	4.2	5	Moderate	4	Moderate				
10/20/2020	2:00 PM	0.0086	0.0022	5.8	3	Moderate	4	Moderate	23.3	78	23.3	Minimal
10/20/2020	3:00 PM	0.0055	0.0010	9.2	2	Low	3	Moderate	26.1	66	26.1	Minimal
10/20/2020	4:00 PM	0.0021	0.0008	24.1	1	Low	2	Low	26.1	67	26.1	Minimal
10/20/2020	5:00 PM	0.0007	0.0003	73.6	0	Low	1	Low	25.6	70	25.6	Minimal
10/21/2020	8:00 AM	0.0005	0.0002	92.8	0	Low						
10/21/2020	9:00 AM	0.0023	0.0008	22.1	1	Low			19.4	93	19.4	Minimal
10/21/2020	10:00 AM	0.0054	0.0010	9.3	2	Low	1	Low	21.7	87	21.7	Minimal
10/21/2020	11:00 AM	0.0089	0.0009	5.6	4	Moderate	3	Moderate	23.3	79	23.3	Minimal
10/21/2020	12:00 PM	0.0073	0.0017	6.9	3	Moderate	4	Moderate	24.4	74	24.4	Minimal
10/21/2020	1:00 PM	0.0069	0.0018	7.2	3	Moderate	4	Moderate	25.6	67	25.6	Minimal
10/21/2020	2:00 PM	0.0058	0.0008	8.6	2	Low	4	Moderate	26.1	64	26.1	Minimal
10/21/2020	3:00 PM	0.0047	0.0007	10.7	2	Low	3	Moderate	26.1	62	26.1	Minimal
10/21/2020	4:00 PM	0.0021	0.0006	23.3	1	Low	2	Low	26.1	62	26.1	Minimal
10/21/2020	5:00 PM	0.0006	0.0003	83.1	0	Low	1	Low	28.3	56	28.3	Low
10/22/2020	8:00 AM	0.0005	0.0002	92.6	0	Low			16.7	90	16.7	Minimal
10/22/2020	9:00 AM	0.0019	0.0006	26.5	1	Low			18.3	84	18.3	Minimal
10/22/2020	10:00 AM	0.0044	0.0007	11.4	2	Low	1	Low	20	81	20	Minimal
10/22/2020	11:00 AM	0.0061	0.0006	8.3	2	Low	2	Moderate	22.2	76	22.2	Minimal
10/22/2020	12:00 PM	0.0099	0.0012	5.0	4	Moderate	3	Moderate	23.9	69	23.9	Minimal
10/22/2020	1:00 PM	0.0100	0.0008	5.0	4	Moderate	4	Moderate	25	62	25	Minimal
10/22/2020	2:00 PM	0.0074	0.0006	6.8	3	Moderate	4	Moderate	25.6	60	25.6	Minimal

Appendix A: Sample of Collected Raw Data from October 5 – 29, 2020

Spread sheet for collected data from October 5 – 29, 2020 (cont'd)												
10/22/2020	3:00 PM	0.0054	0.0011	9.3	2	Low	3	Moderate	26.1	56	26.1	Minimal
10/22/2020	4:00 PM	0.0021	0.0006	24.0	1	Low	2	Low	27.8	53	27.8	Low
10/22/2020	5:00 PM	0.0006	0.0003	87.7	0	Low	1	Low	27.2	55	27.2	Low
10/23/2020	8:00 AM	0.0005	0.0002	107.6	0	Low			15	96	15	Minimal
10/23/2020	9:00 AM	0.0019	0.0007	26.9	1	Low			16.1	93	16.1	Minimal
10/23/2020	10:00 AM	0.0047	0.0011	10.8	2	Low	1	Low	18.3	84	18.3	Minimal
10/23/2020	11:00 AM	0.0062	0.0008	8.1	2	Low	3	Moderate	21.1	77	21.1	Minimal
10/23/2020	12:00 PM	0.0085	0.0014	5.9	3	Moderate	4	Moderate	22.8	68	22.8	Minimal
10/23/2020	1:00 PM	0.0101	0.0009	4.9	4	Moderate	4	Moderate	23.9	61	23.9	Minimal
10/23/2020	2:00 PM	0.0082	0.0009	6.1	3	Moderate	4	Moderate	25	56	25	Minimal
10/23/2020	3:00 PM	0.0050	0.0009	9.9	2	Low	3	Moderate	25.6	54	25.6	Minimal
10/23/2020	4:00 PM	0.0023	0.0007	21.9	1	Low	2	Low	25.6	53	25.6	Minimal
10/23/2020	5:00 PM	0.0006	0.0003	80.8	0	Low	1	Low	25.6	55	25.6	Minimal
10/26/2020	8:00 AM	0.0002	0.0001	241.7	1	Low			14.4	86	14.4	Minimal
10/26/2020	9:00 AM	0.0009	0.0003	54.1	0	Low						
10/26/2020	10:00 AM	0.0025	0.0007	19.7	1	Low	1	Low				
10/26/2020	11:00 AM	0.0046	0.0005	10.8	2	Low	2	Low	15	87	15	Minimal
10/26/2020	12:00 PM	0.0068	0.0007	7.3	3	Moderate	3	Moderate	15.6	84	15.6	Minimal
10/26/2020	1:00 PM	0.0103	0.0013	4.9	4	Moderate	4	Moderate	16.7	81	16.7	Minimal
10/26/2020	2:00 PM	0.0096	0.0010	5.2	4	Moderate	3	Moderate	17.2	81	17.2	Minimal
10/26/2020	3:00 PM	0.0059	0.0011	8.5	2	Low	2	Low	17.8	81	17.8	Minimal
10/26/2020	4:00 PM	0.0025	0.0008	19.6	1	Low	1	Low	19.4	75	19.4	Minimal
10/26/2020	5:00 PM	0.0006	0.0003	78.5	0	Low	1	Low	20	73	20	Minimal
10/27/2020	8:00 AM	0.0003	0.0001	148.1	0	Low			12.8	96	12.8	Minimal
10/27/2020	9:00 AM	0.0014	0.0004	37.0	1	Low			14.4	90	14.4	Minimal
10/27/2020	10:00 AM	0.0034	0.0006	14.8	1	Low	1	Low	16.7	87	16.7	Minimal
10/27/2020	11:00 AM	0.0055	0.0006	9.1	2	Low	3	Moderate	18.9	81	18.9	Minimal
10/27/2020	12:00 PM	0.0082	0.0017	6.1	3	Moderate	4	Moderate	20.6	76	20.6	Minimal
10/27/2020	1:00 PM	0.0119	0.0012	4.2	5	Moderate	5	Moderate	21.7	71	21.7	Minimal
10/27/2020	2:00 PM	0.0076	0.0013	6.5	3	Moderate	4	Moderate	22.8	66	22.8	Minimal
10/27/2020	3:00 PM	0.0055	0.0013	9.0	2	Low	3	Moderate	22.8	66	22.8	Minimal
10/27/2020	4:00 PM	0.0022	0.0006	22.6	1	Low	2	Low	22.8	68	22.8	Minimal
10/27/2020	5:00 PM	0.0006	0.0003	82.3	0	Low	1	Low	22.2	71	22.2	Minimal
10/28/2020	8:00 AM	0.0005	0.0002	102.7	0	Low			14.3	96	14.4	Minimal
10/28/2020	9:00 AM	0.0018	0.0008	27.1	1	Low			16.1	93	16.1	Minimal
10/28/2020	10:00 AM	0.0050	0.0007	9.9	2	Low	1	Low	18.9	84	18.9	Minimal
10/28/2020	11:00 AM	0.0075	0.0014	6.6	3	Moderate	3	Moderate	21.2	78	21.1	Minimal
10/28/2020	12:00 PM	0.0084	0.0013	5.9	3	Moderate	3	Moderate	22.8	73	22.8	Minimal
10/28/2020	1:00 PM	0.0072	0.0015	7.0	3	Moderate	4	Moderate	23.9	66	23.9	Minimal
10/28/2020	2:00 PM	0.0069	0.0010	7.2	3	Moderate	4	Moderate	24.4	64	24.4	Minimal
10/28/2020	3:00 PM	0.0044	0.0008	11.4	2	Low	3	Moderate				
10/28/2020	4:00 PM	0.0021	0.0005	24.0	1	Low	1	Low	24.4	62	24.4	Minimal
10/28/2020	5:00 PM	0.0005	0.0003	93.7	0	Low	1	Low	24.4	69	24.4	Minimal
10/29/2020	8:00 AM	0.0003	0.0001	189.0	0	Low			18.9	97	18.9	Minimal
10/29/2020	9:00 AM	0.0009	0.0003	53.0	0	Low			20.6	90	20.6	Minimal
10/29/2020	10:00 AM	0.0025	0.0005	20.0	1	Low	1	Low	23.9	87	23.9	Minimal
10/29/2020	11:00 AM	0.0030	0.0007	16.7	1	Low	3	Moderate	25.6	79	25.6	Minimal
10/29/2020	12:00 PM	0.0056	0.0012	9.0	2	Low	4	Moderate				
10/29/2020	1:00 PM	0.0051	0.0014	9.8	2	Low	5	Moderate	30	67	30	Low
10/29/2020	2:00 PM	0.0064	0.0014	7.8	3	Moderate	4	Moderate	30.6	65	30.6	Low
10/29/2020	3:00 PM	0.0041	0.0008	12.1	2	Low	3	Moderate	30.6	65	30.6	Low
10/29/2020	4:00 PM	0.0019	0.0004	26.7	1	Low	2	Low	30	67	30	Low
10/29/2020	5:00 PM	0.0004	0.0003	115.3	0	Low	1	Low	28.9	69	28.9	Low

Appendix B: SPSS Statistical Output

B1. ANOVA: Daily Average UV_{eff} by Month

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
October	20	0.11405	0.005702	2.11E-06
November	15	0.046256	0.003084	4.9E-07
December	15	0.030184	0.002012	3.97E-07
January	11	0.023671	0.002152	1.91E-07
February	14	0.048335	0.003453	3.37E-06
March	16	0.090322	0.005645	1.64E-06
April	21	0.202468	0.009641	4.74E-06
May	6	0.060973	0.010162	4.61E-06
June	15	0.172295	0.011486	7.86E-06
August	9	0.089916	0.009991	1.48E-06
September	16	0.12294	0.007684	2.43E-06

ANOVA

Source of Variation	*SS*	*Df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.001628	10	0.000163	59.97489	7.71E-47	1.895638
Within Groups	0.000399	147	2.71E-06			
Total	0.002027	157				

Appendix B: SPSS Statistical Output

B2. ANOVA: Daily Maximum UV_{eff} by Month

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
October	20	0.268111	0.013406	3.59E-06
November	15	0.108973	0.007265	1.92E-06
December	15	0.075634	0.005042	9.34E-07
January	11	0.057907	0.005264	9.93E-07
February	14	0.114577	0.008184	1.01E-05
March	16	0.21681	0.013551	1.03E-05
April	21	0.42013	0.020006	1.23E-05
May	6	0.1528	0.025467	2.95E-06
June	15	0.37782	0.025188	1.44E-05
August	9	0.19321	0.021468	1.41E-06
September	16	0.28663	0.017914	9.21E-06

ANOVA

Source of Variation	*SS*	*Df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.007355	10	0.000736	106.2859	4.34E-62	1.895638
Within Groups	0.001017	147	6.92E-06			
Total	0.008372	157				

Appendix B: SPSS Statistical Output

B3. ANOVA: Daily Average UV_{eff} by Season

Fall vs. Winter

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Fall	51	0.223811	0.004388451	4.53038E-06
Winter	40	0.135137	0.003378422	3.03891E-06

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	2.29E-05	1	2.28695E-05	5.899046858	0.017159831	3.948084
Within Groups	0.000345	89	3.87681E-06			
Total	0.000368	90				

Winter vs. Spring

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Winter	40	0.135137	0.003378422	3.03891E-06
Spring	44	0.423206	0.009618317	6.70078E-06

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.000816	1	0.000815808	164.505441	2.69446E-21	3.957388
Within Groups	0.000407	82	4.95916E-06			
Total	0.001222	83				

Spring vs. Summer

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Spring	44	0.423206	0.009618317	6.70078E-06
Summer	23	0.219256	0.009532858	6.43662E-06

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1.1E-07	1	1.10313E-07	0.016685377	0.897620514	3.98856
Within Groups	0.00043	65	6.61137E-06			
Total	0.00043	66				

<u>Summer vs. Fall</u>

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Summer	23	0.219256	0.009532858	6.43662E-06
Fall	51	0.223811	0.004388451	4.53038E-06

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.00042	1	0.000419505	82.049229	1.62845E-13	3.973897
Within Groups	0.000368	72	5.11284E-06			
Total	0.000788	73				

<u>Summer vs. Winter</u>

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Winter	40	0.135137	0.003378422	3.03891E-06
Summer	23	0.219256	0.009532858	6.43662E-06

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.000553	1	0.000553126	129.7104485	9.75321E-17	3.998484

Within Groups	0.00026	61	4.26431E-06
Total	0.000813	62	

All Seasons

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Fall	51	0.223811	0.004388451	4.53038E-06
Winter	40	0.135137	0.003378422	3.03891E-06
Spring	44	0.423206	0.009618317	6.70078E-06
Summer	23	0.219256	0.009532858	6.43662E-06

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.001252	3	0.000417476	82.98048898	5.3754E-32	2.663328
Within Groups	0.000775	154	5.03101E-06			
Total	0.002027	157				

Appendix B: SPSS Statistical Output

B4. ANOVA: Daily Maximum UV_{eff} by Season

Fall vs. Winter

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	51	0.522379	0.010242725	1.78947E-05
Column 2	40	0.316733	0.007918325	1.24121E-05

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.000121	1	0.000121119	7.818015484	0.006337221	3.948084
Within Groups	0.001379	89	1.54922E-05			
Total	0.0015	90				

Winter vs. Spring

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	40	0.316733	0.007918325	1.24121E-05
Column 2	44	0.93692	0.021293636	1.85116E-05

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.003748	1	0.003748359	240.1162458	4.40156E-26	3.957388
Within Groups	0.00128	82	1.56106E-05			
Total	0.005028	83				

Spring vs. Summer

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Column 1	44	0.93692	0.021293636	1.85116E-05
Column 2	23	0.49657	0.02159	1.61727E-05

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	1.33E-06	1	1.32665E-06	0.07486746	0.78524487	3.98856
Within Groups	0.001152	65	1.77199E-05			
Total	0.001153	66				

Summer vs. Fall

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Column 1	23	0.49657	0.02159	1.61727E-05
Column 2	51	0.522379	0.010242725	1.78947E-05

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.002041	1	0.00204103	117.5128996	8.72951E-17	3.973897
Within Groups	0.001251	72	1.73686E-05			
Total	0.003292	73				

Winter vs. Summer

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Winter	40	0.316733	0.007918325	1.24121E-05
Summer	23	0.49657	0.02159	1.61727E-05

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.00273	1	0.002729548	198.247404	7.90537E-21	3.998494
Within Groups	0.00084	61	1.37684E-05			

Total	0.003569	62

All Seasons

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Fall	51	0.522379	0.010242725	1.78947E-05
Winter	40	0.316733	0.007918325	1.24121E-05
Spring	44	0.93692	0.021293636	1.85116E-05
Summer	23	0.49657	0.02159	1.61727E-05

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.005842	3	0.001947286	118.5021027	8.11774E-40	2.663328
Within Groups	0.002531	154	1.64325E-05			
Total	0.008372	157				

Appendix B: SPSS Statistical Output

B5. ANOVA: Average Maximum Exposure Time (t_{max}) by Month

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
October	200	325969.7	1629.849	5934633
November	150	936073.4	6240.489	4.08E+10
December	150	-5053902	-33692.7	3.26E+11
January	110	2939503	26722.75	2.15E+10
February	140	-1177794	-8412.82	3.01E+10
March	160	287557.4	1797.234	12350981
April	210	133225.1	634.4052	634649
May	60	37816.87	630.2812	1382926
June	150	74601.29	497.3419	651305.4
August	90	46989.03	522.1003	248091.2
September	160	142659.6	891.6223	1694527

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	2.65E+11	10	2.65E+10	0.679874	0.744058	1.836723
Within Groups	6.11E+13	1569	3.9E+10			
Total	6.14E+13	1579				

Appendix B: SPSS Statistical Output

B6. ANOVA: Average Maximum Exposure Time (t_{max}) by Season

<u>Fall vs. Winter</u>

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Fall	510	-1836172	-3600.34	1.05E+11
Winter	400	101122.2	252.8055	1.97E+10

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	3.33E+09	1	3.33E+09	0.049236	0.824447	3.85172
Within Groups	6.14E+13	908	6.76E+10			
Total	6.14E+13	909				

<u>Winter vs. Spring</u>

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Winter	400	101122.2	252.8055	1.97E+10
Spring	440	283299.5	643.8625	868408.9

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	32041557	1	32041557	0.00341	0.953448	3.852579
Within Groups	7.87E+12	838	9.4E+09			
Total	7.87E+12	839				

<u>Spring vs. Summer</u>

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Spring	440	283299.5	643.8625	868408.9
Summer	230	144449	628.0391	447489.8

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	37818.85	1	37818.85	0.052228	0.819301	3.855417
Within Groups	4.84E+08	668	724111.8			
Total	4.84E+08	669				

<u>Summer vs. Fall</u>

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Summer	230	144449	628.0391	447489.8
Fall	510	-1836172	-3600.34	1.05E+11

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	2.83E+09	1	2.83E+09	0.039091	0.843323	3.85409
Within Groups	5.35E+13	738	7.25E+10			
Total	5.35E+13	739				

<u>Winter vs. Summer</u>

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Winter	400	101122.2	252.8055	1.97E+10
Summer	230	144449	628.0391	447489.8

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	20561306	1	20561306	0.00164	0.967711	3.856309

Within Groups	7.87E+12	628	1.25E+10			
Total	7.87E+12	629				

<u>All Seasons</u>

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Fall	510	- 1836172	-3600.34	1.05E+11
Winter	400	101122.2	252.8055	1.97E+10
Spring	440	283299.5	643.8625	868408.9
Summer	230	144449	628.0391	447489.8

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	5.83E+09	3	1.94E+09	0.049879	0.985272	2.610549
Within Groups	6.14E+13	1576	3.89E+10			
Total	6.14E+13	1579				