An Analysis of Surface Ultraviolet Radiation Levels in Southeastern Michigan Compared with Select Atmospheric Data

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Abstract:

In this research, an **Arduino** Uno Rev3 using a SI1145 **UV** IR Visible sensor was constructed to collect **UV** index levels. A commercial grade UV detector (Sunknown) was also used to collect data to compare with the data collected using the Arduino based sensor we built and coded. Cloud data was also obtained using the **GLOBE Observer App** on our phones. We followed the clouds protocols within the Observer App and collected numerous types of data including cloud type, coverage, opacity, etc. We also measured surface temperature data using an Etekcity Lasergrip 774 infrared thermometer. All data was collected twice daily on a uniformly grassy area in front of Crestwood High School in Dearborn Heights, Michigan from August through September 2022 (a total of 41 days). This research sought to quantify possible relationships between **UV** index levels based on cloud coverage and type and other associated atmospheric parameters. We also sought to determine whether there was a correlation between **UV** index levels and ground temperature. We found clear relationships between cloud coverage and **UV** levels, cloud type and **UV** levels, cloud opacity and **UV** levels, and **UV** levels and ground temperature. Our data showed that increased cloud coverage and opacity decreased **UV** levels. Cirrus clouds were found to block the least amount of **UV** whereas stratus and cumulus blocked the most. Knowing how atmospheric data can affect **UV** index levels, may help school personnel know how best to assure that students are safely protected when engaging in outdoor activities. In the future, we would like to extend our research to see how sun angle and clouds affect **UV** levels through changing seasons at mid-latitudes.

Key Words: Arduino, GLOBE Observer App, Ultraviolet (UV)

Research Questions:

The following questions were asked in this research:

1. How does cloud coverage affect ultraviolet radiation?
2. How is ultraviolet radiation affected by different cloud types?
3. How is surface temperature affected by ultraviolet radiation?
4. What time of day are clouds more effective in blocking UV rays –Solar Noon or during the afternoon?

Null Hypotheses:

1. Cloud coverage has no correlation with ultraviolet radiation.
2. Cloud types have no effect on ultraviolet radiation.

3. No correlation exists between surface temperature and ultraviolet radiation levels.

Introduction and Review of Literature:

Ultraviolet radiation (UV) is a type of electromagnetic radiation with wavelengths shorter than those of visible light but longer than X-rays. There are three different types of ultraviolet light - UVA, UVB, and UVC. UVA's wavelengths range from 315 to 400-nm, UVB's wavelengths range from 280 to 315-nm, and UVC's wavelengths range from 200 to 280-nm. UVC doesn't reach Earth's atmosphere due to it being absorbed in Earth's stratosphere. Our instruments measured the UV index which measures UVA and UVB. UV radiation is present in sunlight. While UV radiation is necessary for vitamin D and is used in various industrial and medical applications like treating lymphoma, eczema, psoriasis, and vitiligo, "risk of skin cancer is heavily influenced by UV exposure" (D'Orazio). Prolonged exposure to UV radiation can have harmful effects on living organisms: skin damage, eye damage, and increased risk of skin cancer are all possible effects of UV radiation. Because of this, it is important to take precautions to minimize exposure of bare skin to UV radiation. Using sunscreen, hats, and wearing protective clothing are just some of the many precautions that can be taken.

To minimize the risk of damage from UV radiation, we looked at correlations between clouds and UV index measurements. Clouds have been found to block UV from reaching the ground "McKenzie et al. [1991, 1996] reported attenuation due to clouds of 25–30% in the global UV reaching the ground" (Calbó 7). Cloud coverage has also been found to have a relationship with UV index levels. "For images in which the cloud fraction is in the range 10%–20% (∼10 500 images), reduced cases occurred in 3%" (Pfister 1432). "…cloud fractions within 40%–60% (∼1400 images) caused 42% reduced" (1432). As cloud coverage increases, so does its ability to block ultraviolet light. However, as Dianne E. Godar states "UV-B changes much more dramatically than does UV-A because UV-B is readily absorbed and reflected by the clouds and atmosphere" (Godar 739). UV-B is blocked more by clouds than UV-A so our data will show more of relationship between clouds and UV-B than UV-A. The data we collect will help keep students from Crestwood High School safe by providing this data to school personnel so that after-school activities can be planned on days which are safest for students.

Research Methods:

Our team measured UV index, air temperature, humidity, dew point, barometric pressure, and wind speed using GLOBE atmospheric protocols where they exist. We determined the UV index using standard values between 0 and 11+, with levels above 11 being extremely dangerous. The UV index is used to measure the intensity of the sun, combining wavelengths of UVA (315-400-nm) and UVB (280-315-nm). We collected data using an Arduino sensor we engineered and constructed and compared it with a commercial device called a SunKnown UV Detector.

We realized early on that it would be quite expensive to purchase a research grade UV detector. Because of this, we decided to build our own using inexpensive sensors purchased online and coded it using Arduino IDE. We made modifications to some of the designs found online and synched our device using USB with our laptop to collect data.

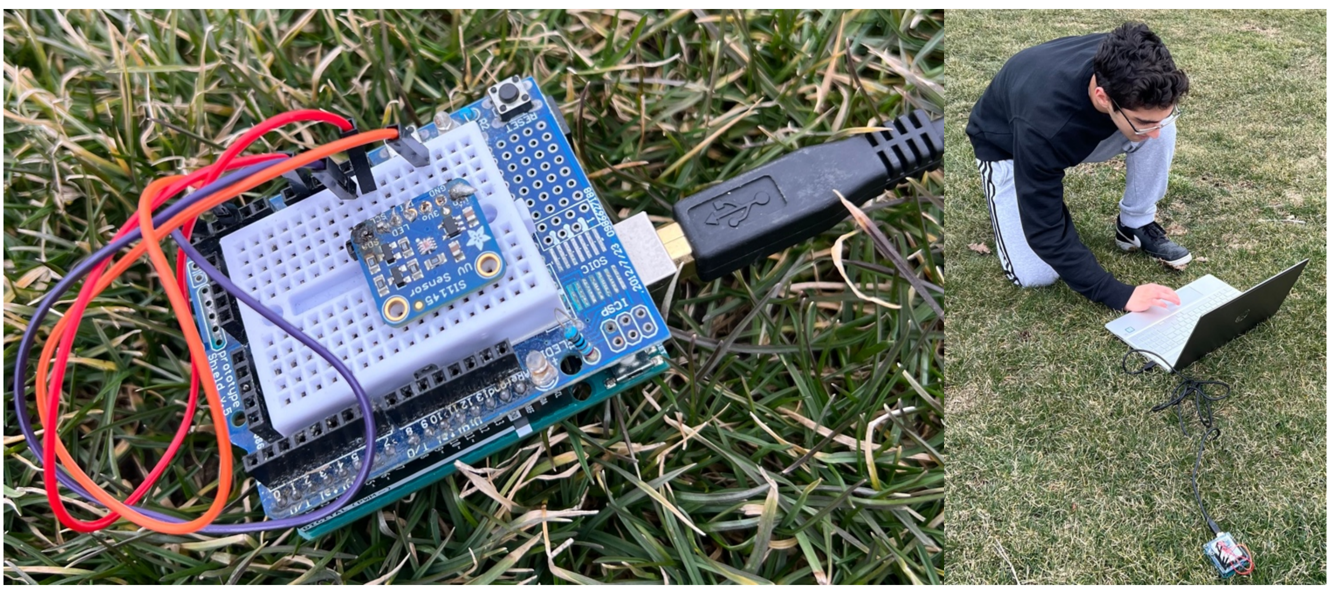
Using instructions from DroneBot Workshop we assembled an Arduino UV index sensor. We decided to use an Arduino uno rev 3 board for the base. We had two options for the UV sensor, the SI1145 and the SENS-43UV Analog sensor. We decided on the SI1145 because it is more compatible with the Arduino uno. We had to solder the pins for the ports used: VIN, GND, SCL, and SDA. Once we connected the sensor to our laptop, we were able to view the readings from the serial monitor of the Arduino IDE application.

Cloud data was collected using the GLOBE Observer app and determining cloud coverage and type. We also measured surface temperature using an Etekcity Lasergrip 774 infrared thermometer using GLOBE protocols for data collection including taking 9 measurements over a uniform defined site.

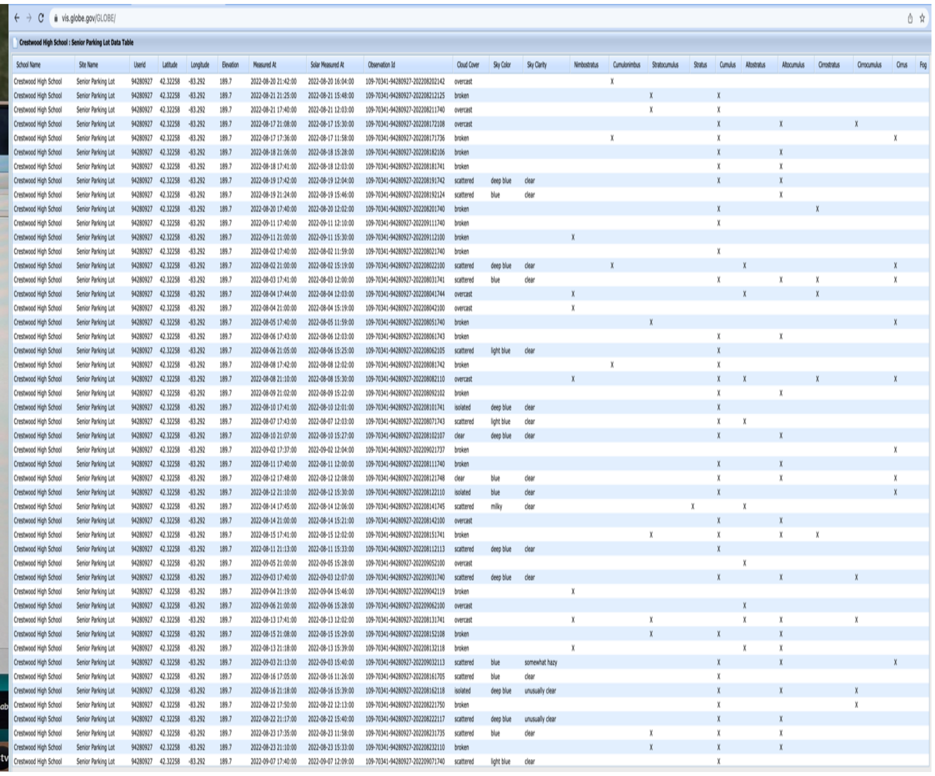
Figures 1-2. Commercial UV Index detector. Figure 1 (left) is a closeup photo of the SunKnown UV Detector. Figure 2 (right) is an image of a student researcher using the UV detector to collect UV index values.

Figures 3-4. Infrared Thermometer. Figure 3 (left) is a closeup photo of the Etekcity Lasergrip 774 infrared thermometer. Figure 4 (right) is an image of a student researcher using the infrared thermometer to collect ground temperature measurements.

Our team consisted of five (5) members who alternated days to collect data. To keep our data consistent, it was necessary to carefully construct detailed research protocols and methods. Our data collection took place from August 2, 2022 to September 11, 2022. We collected data twice a day to compare data collected at Solar Noon and in the afternoon (5 P.M. EST). For our data site, we chose a spot that had good sky visibility with no obstructions so that no matter what time of day it was the sun was easily visible.



Figures 5-6. Arduino UV Detector. Figure 5 (left) is a closeup photo of the Arduino Uno Rev 3 with an SI1145 sensor. Figure 6 (right) is an image of a student researcher using the Arduino Sensor to collect UV index values.

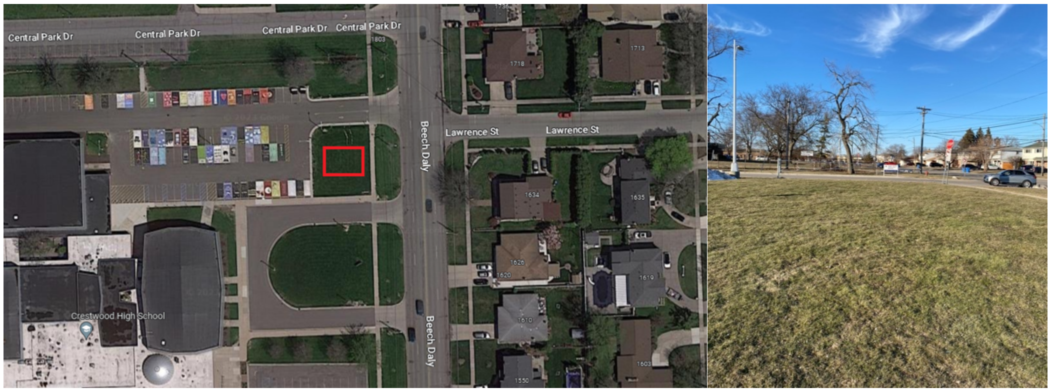


Figures 7-8. Arduino IDE data and GLOBE cloud visualization data. Figure 9 (left) shows the Arduino IDE app collecting UV index levels from our sensor. Figure 10 (right) shows a sample of the cloud data we uploaded to GLOBE.

Our Arduino sensor can collect ultraviolet, infrared, and visible light to the nearest hundredth place. For consistent data, we devised specific protocols: when collecting data, we first placed the Arduino sensor in the center of the site facing south and made sure that there were no shadows obstructing sunlight. Then we reoriented any wires that could be obstructing the sensor. We designed our program to collect 5 readings over a 10 second interval. As the Arduino collects the data, we point the SunKnown UV Detector towards the sun moving it around for 10 seconds. We moved it around for 10 seconds to make sure the value was more representative of the time period. We designed this procedure so that if a cloud temporarily blocked the sun for only a few seconds it wouldn't represent the UV index level accurately.

After collecting UV levels, we conducted cloud observations on the GLOBE app and collected surface temperature with an infrared thermometer. When collecting surface temperature levels, we made sure to face away from our shadows to keep our data accurate and consistent. After collecting our own data, we recorded UV, air temperature, humidity, dew point, barometric pressure, and wind speed using GLOBE protocols, and compared them to the data that we collected with our own sensors.

Results:



Figures 9-10. Research Site. Figure 11 (left) is an overview of the data site at Crestwood High School Dearborn Heights, Michigan, USA. Latitude 42.19, Longitude -83.17, elevation 216.3 meters. The red square shows the site where all data was collected. Figure 12 (right) is our testing site viewed from the ground. *Google Maps. (n.d.). [map of research site next to Crestwood Highschool]. Retrieved March 7, 2023, from https://maps.app.goo.gl/cPMNoqEPWE4UoYAp6?g_st=ic.*

Our measurement site is the hill in front of the senior parking lot at Crestwood Highschool. At our latitude the sun is never directly overhead, even at Solar Noon. At this time of year, the sun rises a bit north of east and sets slightly north of west. Our study site was selected because the sun was always visible (depending on the weather) from morning, Solar Noon, to later afternoon.

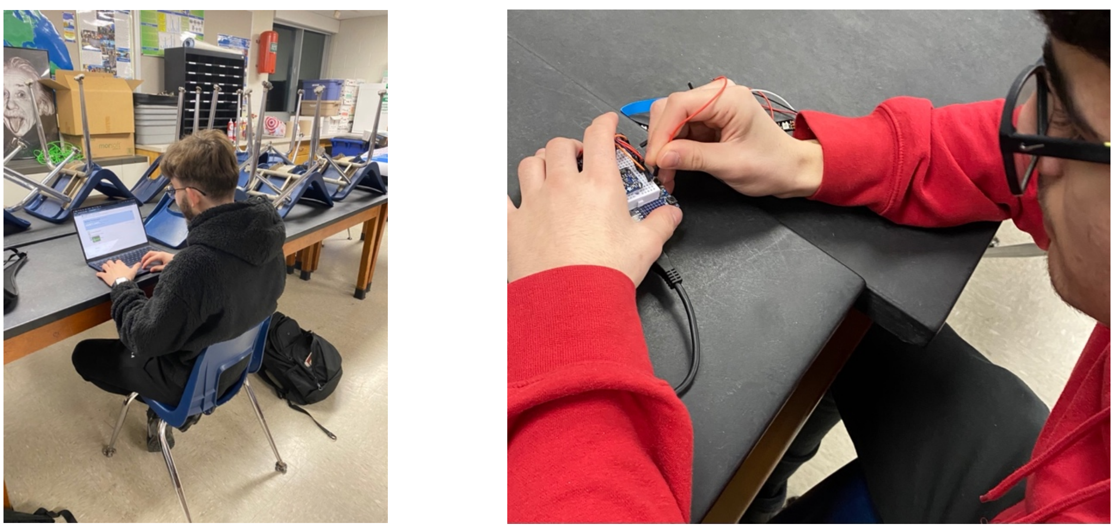


Figure 11-12. Data Entry. Figure 11 (left) shows a member of our group entering in data into the GLOBE data entry site. Figure 12 (right) shows a member of our group working on our sensor.

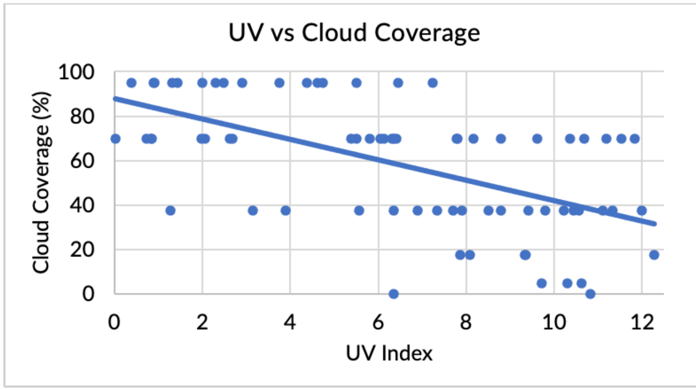


Figure 13. Cloud Coverage and UV Index. The scatterplot above compares the measured UV index value with percent cloud coverage for the 41 days data was collected. The correlation between these two variables was found to be moderate with a value of -.5331 indicating that as cloud coverage decreased, UV radiation index value increased.

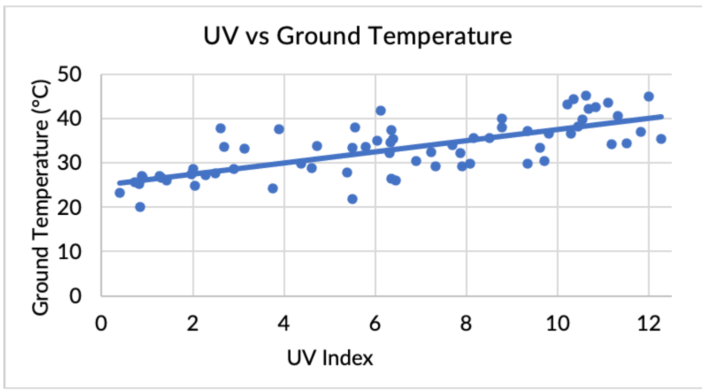


Figure 14. Ground temperature and UV Correlation. The scatterplot above shows the correlation between ground temperature and UV index value. The correlation was found to be strong with a value of .7255. This indicates that as UV index value increases so does ground surface temperature.

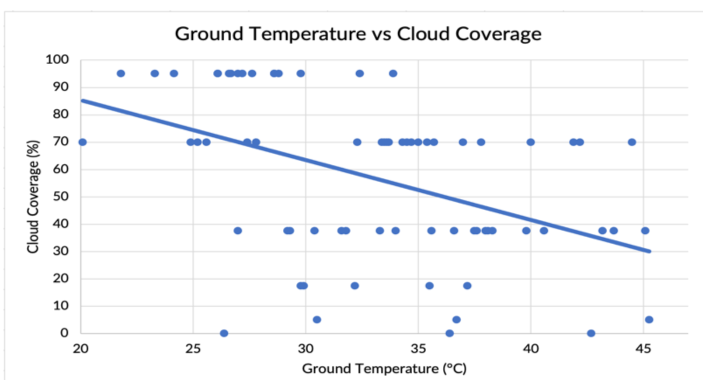


Figure 15. Ground Temperature vs Cloud Coverage. The scatterplot above shows the correlation between ground temperature (°C) and cloud coverage (%). The correlation was found to be moderate with a value of -.44637. This indicates that as cloud coverage increases ground temperature decreases.

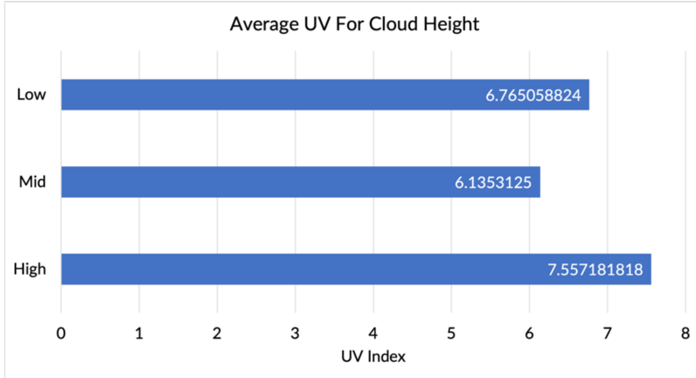


Figure 16. Average UV Index for cloud height. The bar graph above shows the average UV index value of the samples collected 2 times a day over a 41-day span. The average UV index value received at ground surface was found to be highest when high clouds were present. In this research there was not a significant difference between UV index value at low and mid-level clouds.

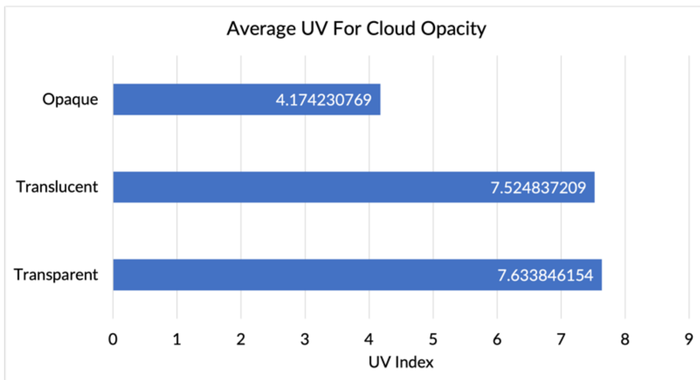


Figure 17. Average UV Index for Cloud Opacity. The bar graph above shows the average UV index value for when different cloud opacities were present. When more opaque clouds were present the UV index value dropped. Clouds which were classified as opaque significantly dropped UV levels compared to translucent and transparent clouds. When opaque clouds were present average UV was found to be 4.174 compared to average UV when translucent clouds were present which was 7.524 and 7.633 when transparent clouds were present. A significant change in average UV was not found between translucent and transparent clouds.

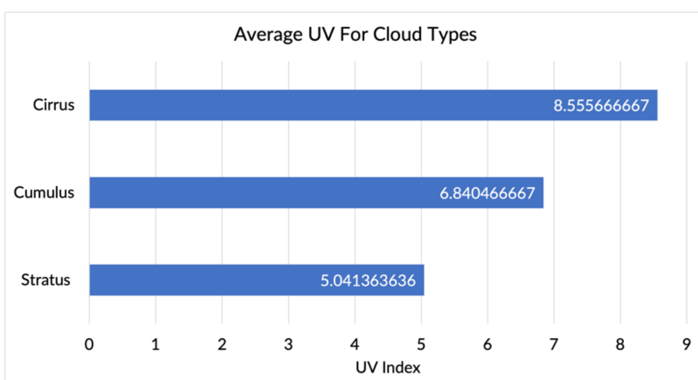


Figure 18. Average UV for Cloud Types. The bar graph above shows the average UV index value for days when different clouds types were present. Cirrus cloud types were found to block the least amount of UV with an average UV of 8.555. Cumulus cloud types had an average UV of 6.840. Stratus cloud types were found to block the most UV with an average amount of 5.041.

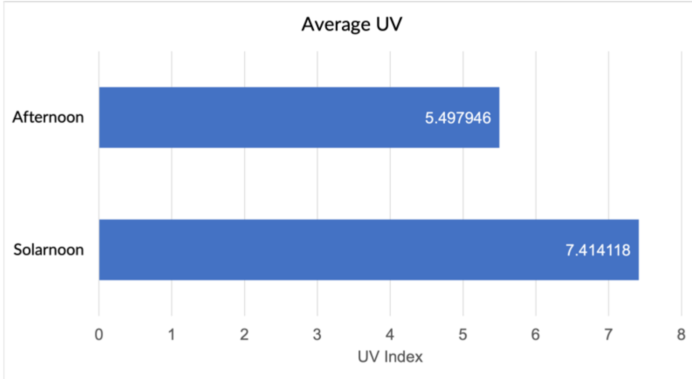


Figure 19. Average UV for Different Times of Day. The bar graph above shows the average UV index value for the afternoon which we measured at 21:00 UTC and Solar Noon which we measured when the sun was directly overhead. The average UV index value was higher for Solar Noon than the afternoon. This could be due to clouds being more efficient at blocking UV during the afternoon and the sun not being directly overhead during the afternoon.

Discussion:

Ultraviolet radiation levels were found to have relationships with cloud coverage and surface temperature. UV levels were also affected by cloud type, altitude, and opacity. We found that as cloud coverage increases, UV levels decrease. We also discovered that as UV levels increase, ground temperature levels increase. We also found that as cloud coverage increases, the surface temperature decreases. UV levels were also found to be affected by cloud types. Cirrus clouds blocked the least amount of UV, while stratus clouds were found to block the most. Cloud opacity also affected UV levels. Opaque clouds blocked the most UV, while transparent and translucent clouds blocked less. A significant difference in UV blocking power of transparent and translucent clouds was not found. Cloud altitude was also a significant factor in blocking UV. Days with high clouds were found to have the highest UV, while days with mid and low-level clouds were found to have the lowest UV. We also found that UV is lowest in the afternoon. This is due to the sun not being directly overhead such as the case with Solar Noon. Clouds could also be more efficient at blocking UV during the afternoon.

A possible source of error in our data is the fact that days with one cloud type such as cumulus could have also had other cloud types present such as cirrus. This was not considered when finding the average UV for days that had a certain type of cloud type present. This possible source of error also exists in the averages for UV of days with different cloud altitudes and cloud opacities.

A similar study conducted by Josep Calbó, David Pagès, and Josep-Abel González found similar results. The researchers found that increased cloud coverage blocked more UV radiation. They stated that “attenuation may be undetectable for very thin clouds or small cloud amount but may be as high as 99% under extremely thick clouds” (Calbó 7). This is similar to what we concluded since our data supported the claim that higher cloud coverage and opacity reduces UV index.

Through our findings we reject the null hypothesis that states cloud coverage has no correlation with ultraviolet radiation. There is clear evidence that UV levels decrease as cloud coverage increases. Due to our moderate strength correlation of -.5331. We also reject the null hypothesis that states cloud types have no effect on ultraviolet radiation. There is clear evidence that different cloud types have an effect on ultraviolet radiation levels. On days which cirrus clouds were present, the average UV level was 8.5556. On days in which cumulus clouds were present, the average UV level was 6.8404. On days in which stratus clouds were present, the average UV level was 5.0413. We also reject the null hypothesis that states there exists no correlation between surface temperature and ultraviolet radiation. There is clear evidence that as ultraviolet radiation increases so does surface temperature. There is a .7255 between surface temperature and ultraviolet radiation levels.

People can now use our UV sensor which is made with an Arduino Uno Rev 3 board combined with an SI1145 sensor. This combined with cloud data using GLOBE protocol determines if it is safe to go outside without skin protection. Various personnel such as lifeguards and coaches and everyday people could use our research methods to determine the safety of going outside without skin protection.

Conclusion:

From the data we collected, we saw several correlations between the variables. With these correlations we were able to answer our 4 research questions. We found a strong positive correlation between ground temperature and UV index. This shows that with an increase of UV rays there will most likely be an increase of ground temperature. We also found a correlation between cloud coverage and UV index. The correlation found here was a moderate negative correlation, meaning as cloud coverage increased UV radiation would decrease and vice versa. If cloud coverage is high, you would likely have a higher UV. If cloud coverage is low, you would likely have lower UV. We also found a moderate correlation between ground temperature and cloud coverage. This is also another indicator of solar intensity. We were also able to find the average UV for differing cloud types. We found that cirrus cloud types have the highest average UV index levels, cumulus clouds found an average in the middle, and stratus clouds we found lowest average of UV index levels. However, there is a limitation to this. When the averages between cloud types and UV rayswere being constructed, certain days may have multiple cloud types, but only one cloud type was considered, which can skew the calculated average.

This data can be used to help predict which days will have a higher UV and what precaution should be taken to avoid the harmful effects of prolonged exposure to UV rays. Since the correlation between UV index and ground temperature is strong, ground temperature can also be used as a determinate for how dangerous it is to go outside. This can help decide whether outdoor activities should take place and what measures should be taken to reduce the risk of damage from UV rays.

One way we can improve our research methods is to increase the length of our study and measure various times of day. We can do future protocols by taking this data in different seasons and seeing how consistent our results are and if the correlations are the same. The GLOBE Program might want to consider adding ultraviolet light as a protocol.

Citations:

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DroneBot Workshop. (2018, September 5). *Arduino UV Index Meter - Working with Ultraviolet Light* [Video]. YouTube. https://www.youtube.com/watch?v=dBljvUBZqI8

Acknowledgements:

Throughout our project we worked with our former AP Environmental Science teacher and our GLOBE/science club advisor Diana Johns. Mrs. Johns helped train us in identifying cloud types and opacity. She also advised us while we wrote our research paper. This improved the quality of our research and conclusions. We'd also like to thank the GLOBE Mission Earth staff at the University of Toledo for providing both equipment and providing other resources. The GLOBE AREN Project was also instrumental in supporting us with essential materials needed to support our research.

Badges:

I make an impact:

The researchers hope to receive the "I make an impact" badge as their research not only can be used to benefit their school and community but also schools and communities around the globe. This data can be used to determine whether sports teams and other outdoor activities should take place. This research also helps predict which days sunscreen should/needs to be worn. With an increase of cloud coverage, we found that UV decreases, so outdoor activities would be able to occur on these days with little to no protection needed. However, on days with very minimal to no cloud coverage these outdoor activities should be avoided or approached very cautiously, and the correct protection should be used like sunscreen, a hat, and sunglasses. Schools can use this correlation data to determine if sport practices should still be held by referring to the cloud coverage, and if they find it to be too low resulting in higher UV rays, practices and games can potentially be canceled to keep students safe from harmful effects from prolonged exposure to UV rays.

I am a data scientist:

The researchers hope to receive the "I am a data scientist" badge as they have collected data using their Arduino, thermometer, UV sensor, and Globe Observer app. The researchers also collected and organized data from the mobile app Weather Bug. This information was then organized onto a Google sheet by day and time. The researchers took data for 41 days and we took data twice a day, once at Solar Noon and another at 17:00 UTC. It was later made into graphs to compare the relationship between the different variables collected in this research. However, the researchers did run into some limitations with their research. One limitation in the research is that the cloud coverage was taken in ranges rather than specific percentages which lowers the accuracy of the cloud coverage correlations. Another limitation was when the averages between cloud types and UV rays were being constructed, certain days may have had multiple cloud types, but only one cloud type was considered which can skew the calculated average.

I am an engineer:

The researchers hope to earn the "I am an engineer badge". When organizing the project, the researchers wanted to have a way to measure UV with a device that they created. They decided on using an SI1145 sensor on an Arduino Uno Rev 3 to collect their UV values. The researchers were faced with multiple challenges during the process of making the sensor: not having a soldering machine and the LCD display not being compatible with the program are just a few. The researchers had to obtain a soldering machine from a community member. The researchers had to solder the pins for the ports used: VIN, GND, SCL, and SDA. The researchers decided to use a breadboard on the Arduino to be able to connect the SI1145. Rather than using an LCD, the researchers chose to have their data presented on the serial monitor of Arduino IDE and be saved directly to their laptops. This way, there is a smaller room for error; the researchers did not have to manually record the Arduino's readings.