TerraRover 2 Engineered to Detect and Record Potential Atmospheric Implications of the 2024 Solar Eclipse

Student Researchers:
Hadi Boussi, Maher Harp, and Hala Komaiha

School:
Crestwood High School
Dearborn Heights, MI 48127

Science Teacher:
Mrs. Diana R. Johns

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Abstract:

In this research, student researchers engineered a suite of microsensors designed to detect and record atmospheric parameters potentially useful for sensing weather variations during the upcoming 2024 Solar Eclipse taking place on April 8th, 2024. These sensors were attached to a NASA TerraRover 2 originally designed to take surface temperature measurements. The researchers specifically utilized a TerraRover 2 to ensure a consistent measurement of data and ensure that potential human error was not a limitation. The parameters sensed by the TerraRover 2 include air pressure, air temperature, humidity, light intensity, sound, and a proximity sensor. To detect wind, the researchers used an Arduino proximity sensor connected to a handheld pinwheel. This allowed the researchers to calculate wind speed based on the number of spins counted while testing. Each sensor was independently programmed using the Arduino programming language and wired onto Arduino Uno Boards. The researchers' goal for this research was to develop protocols that will ultimately be utilized in comparing data the week before, during, and the week after the April 8th Total Solar Eclipse. Understanding the variations between each testing period would allow the researchers to make conclusions about the microclimate effects of a solar eclipse. In the future, the suite of sensors on the TerraRover 2 can be expanded to measure different protocols. The microsensors on the TerraRover 2 can be a significant and novel way to monitor changes during a solar eclipse wirelessly.

Key Words: Arduino, Total Solar Eclipse, TerraRover 2, Microsensors, Engineering

Research Questions

The following research questions guided our research on the modification of a TerraRover 2 for detecting possible atmospheric changes during the 2024 Total Solar Eclipse on April 8th, 2024.

1. Can a TerraRover 2 be modified to monitor air pressure, air temperature, humidity, light intensity, sound, and wind speed?

2. Can we engineer a cost-effective solution to monitoring wind speed compared to the use of an expensive anemometer?

3. Are there differences in air pressure, air temperature, humidity, light intensity, sound, and wind speed before, during, and after a total solar eclipse.

Null Hypotheses:

1. A TerraRover 2 cannot be modified to monitor air pressure, air temperature, humidity, light intensity, sound, and wind speed.

2. The researchers cannot engineer a cost-effective solution to monitoring wind speed compared to the use of an expensive anemometer.

3. There are no differences in air pressure, air temperature, humidity, light intensity, sound, and wind speed before, during, and after a total solar eclipse.

Introduction and Review of Literature:

A total solar eclipse occurs when the moon passes between the Earth and the Sun, completely blocking out the Sun's light. This coverage results in potential atmospheric changes on Earth compared to before and after the eclipse. Before the eclipse, as the moon begins to travel in front of the sun, the wind on Earth may exhibit minimal fluctuations (Eugster, 2017). During the eclipse, the wind patterns may experience further alterations as the moon progressively covers more and more of the solar disk, impacting local temperature gradients and atmospheric pressures. As the sun becomes completely covered by the moon during totality, there could be a sudden drop in temperature, which can influence local wind currents (Eugster, 2017). Additionally, the reduction in sunlight intensity can lead to a temporary decrease in atmospheric turbulence, potentially affecting wind behavior. Changes in wind patterns can influence weather systems, potentially leading to localized weather disturbances. After the eclipse, as the moon uncovers the sun, wind patterns may gradually return to their pre-eclipse state.

As the moon slowly covers the sun, light intensity gradually diminishes, leading to a subtle decrease in solar radiation. During the solar eclipse, light intensity reaches its absolute lowest point, casting a shine over the surroundings (Stewart, 1940). Light intensity slowly increases as the moon's shadow recedes from the Earth, thus leading to the return of daylight.
Despite this dimming, the sound levels in the environment may remain relatively constant, with typical background noises prevailing (Buckley, 2018). Meanwhile, the sudden darkness during totality might result in a noticeable decrease in ambient noise, as diurnal animals quiet down in response to the perceived nighttime. As sunlight returns, ambient noise levels may rise again as diurnal animals resume their activities, filling the air with their calls and chatter (Hartstone-Rose, 2020). Variations in light intensity can profoundly affect ecosystems as well as plant photosynthesis rates and animal behavior (Wimalasekera, 2019). The fluctuations in ambient noise levels may impact wildlife, particularly species sensitive to auditory cues for communication and navigation.

Recognizing the impact of a total solar eclipse on specific atmospheric parameters can be imperative in understanding how celestial events influence Earth’s atmosphere and ecosystems. This can allow us to anticipate potential disruptions in weather patterns and wildlife behavior caused by solar eclipse events. As such, we are using a mobile TerraRover 2 to sense various atmospheric parameters mentioned above to determine the true variation of certain variables due to the eclipse. It was advantageous to use the TerraRover 2 as it reduces the potential for human error with measurement variables staying constant such as height. Additionally, hand-held devices require at least one researcher per device and parameters associated with that device. In comparison, the TerraRover 2 would only require one to two researchers per testing location. Overall, the utilization of a TerraRover 2 in the collection of these atmospheric parameters is the most effective and accurate solution.

Research Methods:

The TerraRover 2 was previously outfitted with only a surface temperature and relative humidity sensor. To expand the suite of air quality sensors on the TerraRover 2, the researchers added a carbon monoxide, carbon dioxide, ultraviolet light, particulate matter and sound sensor in 2023 to remotely monitor air quality events. The researchers took a completely new approach in 2024, repurposing the TerraRover 2 to detect atmospheric parameters that may be influenced by the total solar eclipse.

The researchers began by programming each of their 4 sensors (a BME280, LM393, VCNL4010, and a CZN-15E) using the Arduino programming language and Arduino IDE. Furthermore, they wired each sensor onto a designated breadboard and Arduino Uno board. The sensors were attached onto a platform 0.2 meters above the ground. However, since there wasn't an affordable way to sense wind speed directly from a microsensor, the researchers had to engineer a new, cost-effective solution. They utilized a proximity sensor and pinwheel to calculate the number of times that the pinwheel completed a full rotation within a specific time period.

In this research, trial data was taken to assure proper calibration for the TerraRover's use during the upcoming 2024 North American Total Solar Eclipse. Using GLOBE atmospheric protocols, atmospheric data was obtained and later inputted into the GLOBE database. They transferred this data to a Microsoft Excel and each sensor output was visualized. As the April 8th Solar Eclipse approaches, the researchers plan to start phase two of their project: recording and interpreting atmospheric parameters possibly affected by the eclipse. These parameters will be interpreted and visualized in the same way that the tentative data was.

Results:

The high school where this research was conducted lies within a heavily populated suburban neighborhood and is bounded by a road to the east with fairly heavy traffic throughout the day.

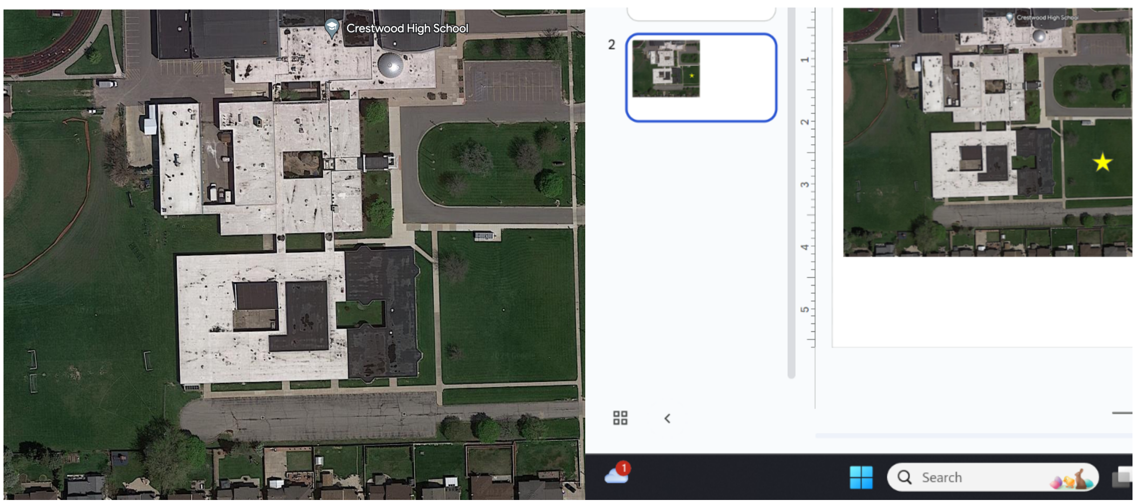

Figure 1 and Figure 2. Research Site. Image on the left is an overview of Crestwood High School's location within Dearborn Heights, Michigan, USA. Latitude 42.19, Longitude -83.17, elevation 216.3 meters. Image on the right shows the research site where light intensity, sound, proximity, temperature, humidity, and pressure data were collected.

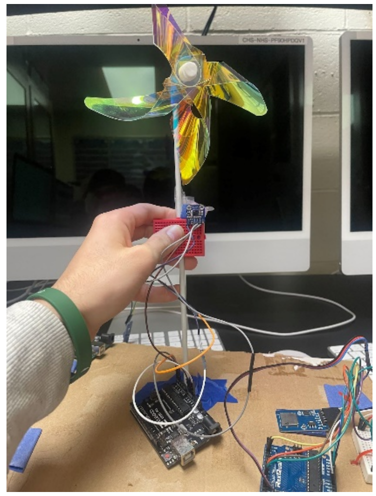

Figure 3. VCNL4010 Proximity/Light sensor. Image above displays the Proximity Sensor the researchers used to collect wind speed data. The sensor was placed on the top of the TerraRover 2, secured on an elevated platform. The VCNL4010 Proximity/Light sensor was programmed by the researchers using the Arduino IDE and Arduino programming language.

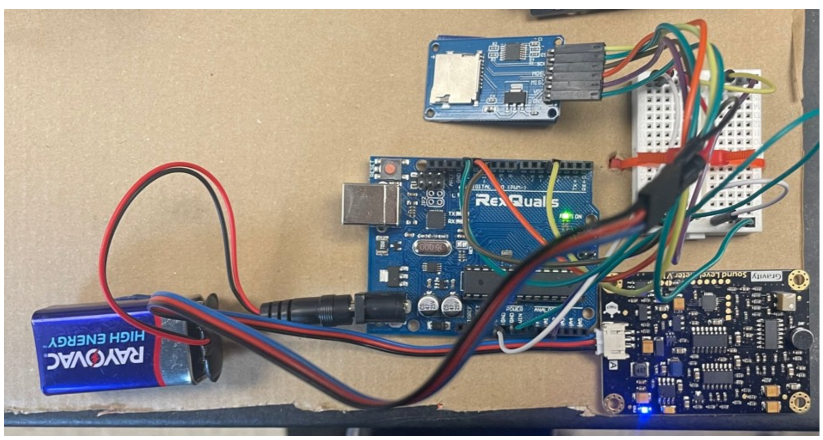

Figure 4. Sound Sensor. Image above displays the Sound Sensor the researchers used to collect sound (dBA) data. The sensor was placed on a platform connected onto the TerraRover 2. The sound sensor was programmed by the researchers using the Arduino IDE and Arduino programming language.

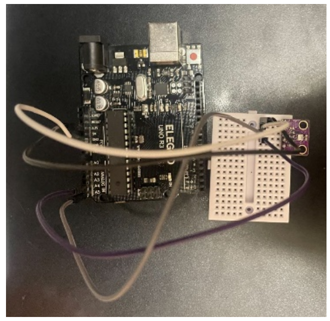

Figure 5. BME280 Temperature, Humidity, and Barometer Sensor. Image above displays the BME280 Temperature, Humidity, and Barometer Sensor the researchers used to collect temperature and humidity data. The sensor was placed on a platform connected onto the TerraRover 2, secured by industrial zip-ties. The BME280 Temperature, Humidity, and Barometer Sensor was programmed by the researchers using the Arduino IDE and Arduino programming language.

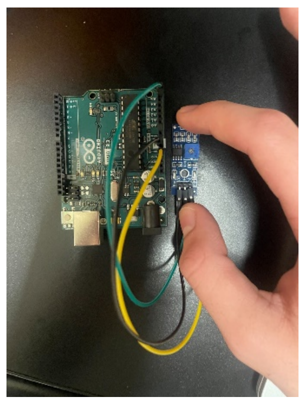

Figure 6. Photo Resistor Sensor. Image above displays the Photo Resistor Sensor the researchers used to collect light intensity data. The sensor was placed on a platform connected onto the TerraRover 2, secured by industrial zip-ties. The Photo Resistor Sensor was programmed by researchers using the Arduino IDE and Arduino programming language.

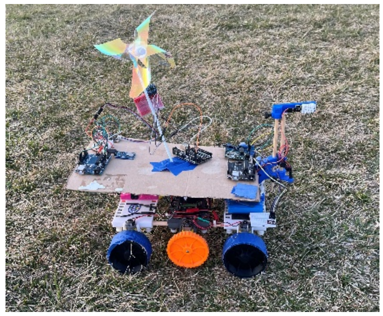

Figure 7. TerraRover 2. Image above includes the mobilization aspect of the research, the TerraRover 2. The TerraRover 2 was provided by NASA GLOBE AREN Project from Mr. David Bydlowski and Mr. Andy Henry. The TerraRover 2 gave insight to the researchers about how much mobilization is important in terms of light intensity, sound, proximity, temperature, humidity, and pressure. The TerraRover 2's use can be extended to collecting data and information on the effects of a solar eclipse, a natural phenomenon. The TerraRover 2's data collection is precise and the TerraRover 2 does not feel the effects of the solar eclipse, such as irritation from looking at the phenomenon.

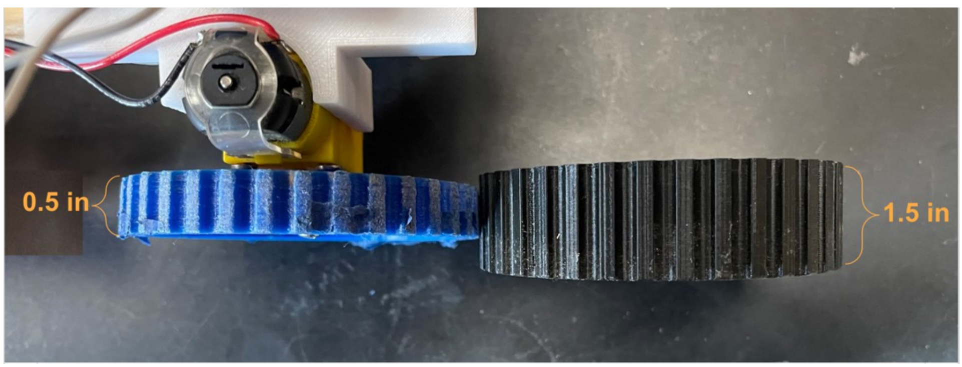

Figure 8. 3D-printed TerraRover 2 Wheels. Image above includes the different dimensions of the wheels used during data collection. The researchers independently used computer-aided design (CAD) to model new wheels for the TerraRover 2 with an increase to 1.5 inches. The researchers were aided by Mr. Andy Henry during the modeling process and 3D-print the design at Wayne RESA.

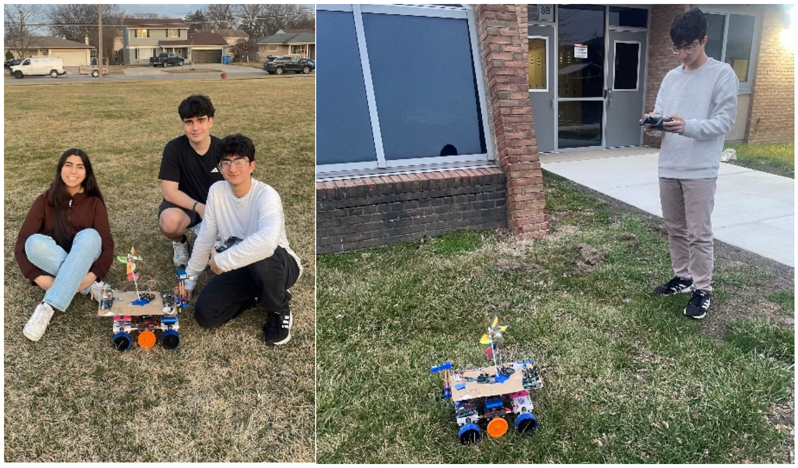

Figure 9 and Figure 10. TerraRover 2's Use at Crestwood High School. Images above greatly shows TerraRover 2 at Crestwood. Throughout the research, the TerraRover 2 was being driven to efficiently collect data for light intensity, sound, proximity, temperature, humidity, and pressure.

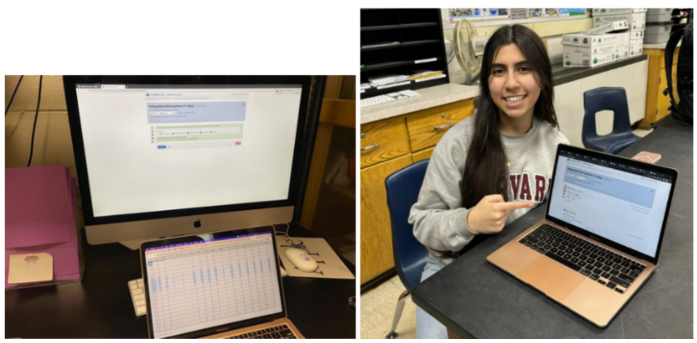

Figure 11 and Figure 12. Data Entry. To impute their data, the researchers used the GLOBE website's "SCIENCE Data Entry" area. The researchers logged the light intensity, sound, proximity, temperature, humidity, and pressure of the day they collected data. The researchers plan on using this data to later monitor the correlation of weather changes with all atmospheric concentrations sensed. Figure (right) shows the researcher, Hala Komaiha, inputting the collected data into the GLOBE Website.

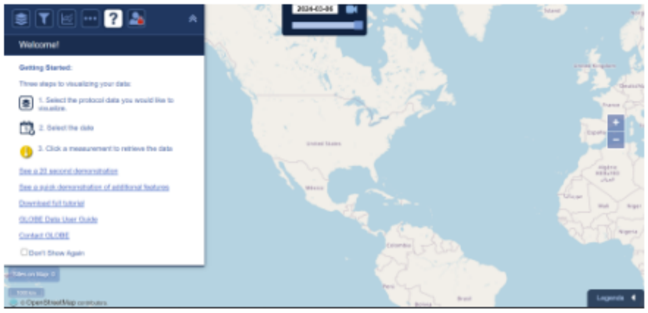

Figure 13 and Figure 14. GLOBE Visualization Page. The image above shows the researchers' data points using the GLOBE Visualization Page.

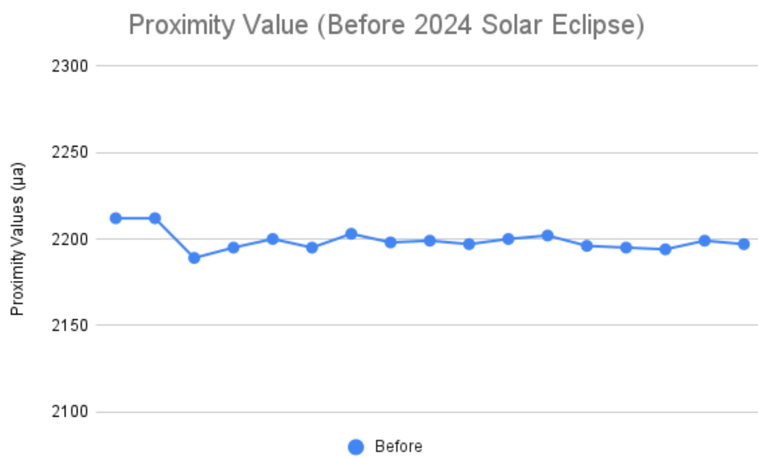

Figure 15. Comparison of Proximity Values on Research Site. The line graph above shows the different proximity values as a pinwheel blocks the proximity sensor on the research site. As you can see, the proximity counts varied around 2200 counts. During testing, wind was present; however, the wind was quick, shortening the pinwheels movement.

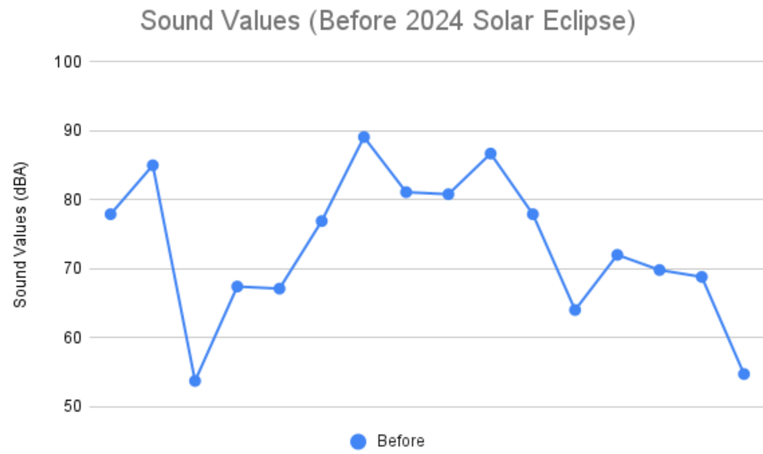

Figure 16. Comparison of Sound Values on Research Site. The line graph above shows the different sound values on the research site. As you can see, the sound values showed great variation. The research site is an open field close to a frequent road. This explains the large variation as cars would frequently drive by, making different corresponding noises.

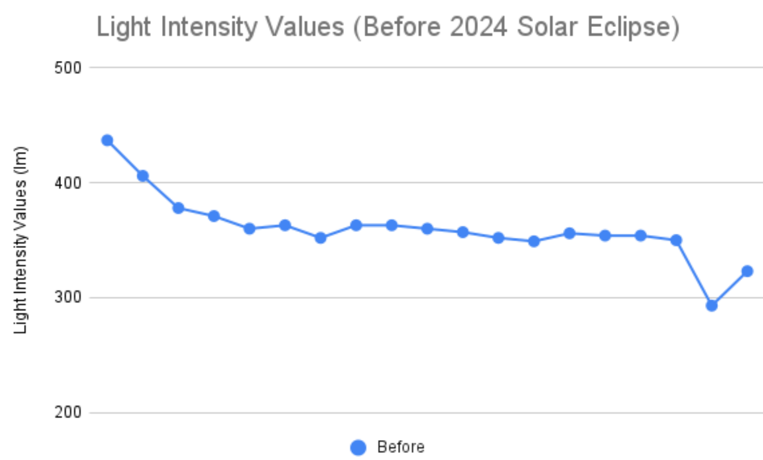

Figure 17. Comparison of Light Intensity Values on Research Site. The line graph above shows the different light intensity values on the research site. As you can see, the light intensity values decreased and plateaued. The research site was on an open field with little to no vegetation to block the light intensity sensor. This explains the large values.

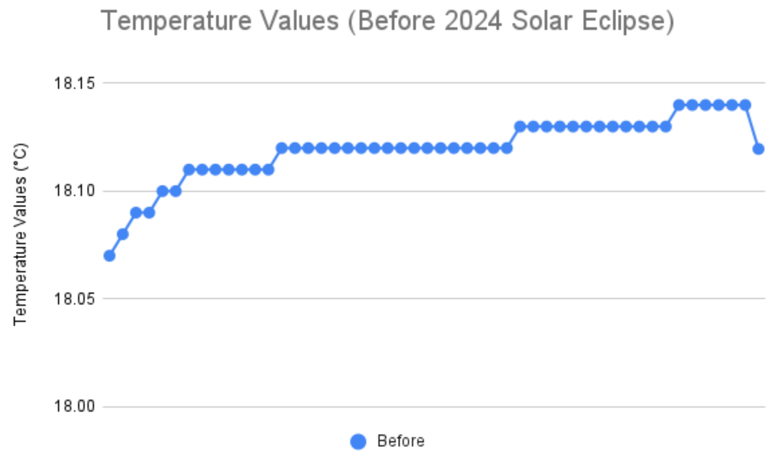

Figure 18. Comparison of Temperature Values on Research Site. The line graph above shows the different temperature values on the research site. As you can see, the temperature values increased throughout testing. This staggered increase could be accounted for by the presence of sunlight onto the grassy field, the elevation of the sensor, and the presence of wind.

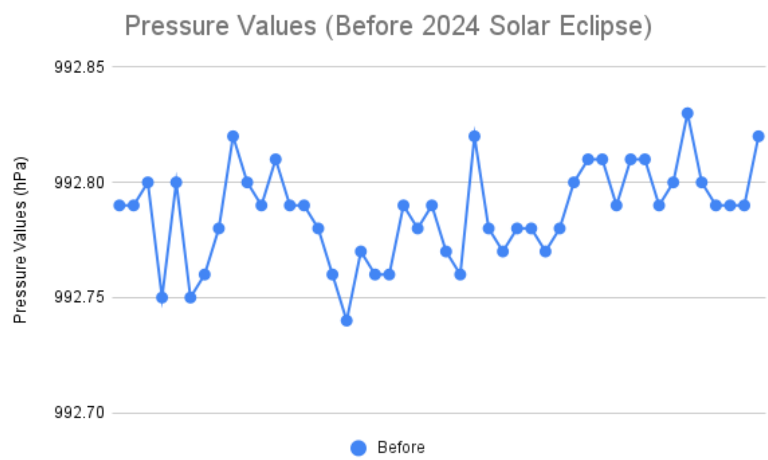

Figure 19. Comparison of Pressure Values on Research Site. The line graph above shows the different pressure values on the research site. As you can see, the pressure values showed great variation. This variation could be accounted for by the fluctuations of the temperature and humidity, which is seen in Figures 19 and 21.

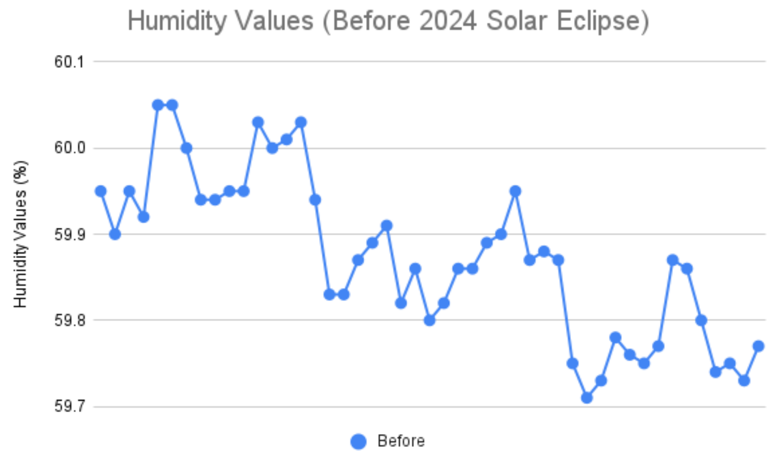

Figure 20. Comparison of Humidity Values on Research Site. The line graph above shows the different humidity values on the research site. As you can see, the humidity values decreased with great variation throughout testing. This decrease could be accounted for by the difference in temperature and wind as particulates in the air could carry away moisture.

All of the programmed sensors worked well when collecting data remotely with the TerraRover 2. The results show different levels of each parameter found at the open field research site.

Discussion:

Air pressure, air temperature, humidity, light intensity, sound, and wind speed (based on outputs of a proximity sensor) measurements were taken on March 4th. This data was taken to represent the data we will be collecting the week before, during, and the week after the April 8th Solar Eclipse. The location where data was measured was our Band Practice Field, an open, grassy, field directly in front of Crestwood High School. This location is near a busy road, Beech Daly, where passing cars and pedestrians walking by can impact sound levels. On March 4th, light intensity values varied from about 290 lm to about 440 lm; proximity values varied from 2190 µa to 2220 µa; sound values varied from 50 dBA to 90 dBA, air temperature values varied from 18.07°C to 18.14°C; air pressure values varied from 992.74 hPa to 992.83; and humidity values varied from 59.7% to 60.05%.

Along with comparing atmospheric parameters before, during, and after the total solar eclipse, the researchers want to compare variables like air temperature and light intensity to their measured amounts during the 2017 Solar Eclipse. GLOBE research previously written by Maysam Aidibi, Leanne Alawieh, Ali Eter, Sara Komaiha, and Hana Salami at Crestwood High School measured air temperature and light intensity during the 2017 Total Solar Eclipse at only 80% totality. In comparison, the 2024 Total Solar Eclipse will be at 98.8% totality at Crestwood High School. With this, it will be interesting to compare these variables to explain the potential impact totality has on atmospheric parameters.

A possible source of error in our research is the accuracy of the microsensors. To verify the sensors' results and data collection, the researchers could compare their data with professional grade sensors; however, these professional grade sensors are often outside of the researchers' budget range.

The researchers were able to reject their first null hypothesis. The TerraRover 2 was modified to record air pressure, air temperature, humidity, light intensity, sound, and wind speed measurements. The researchers also rejected their second null hypothesis since they were able to find sensors that captured the data they wanted while simultaneously being cost effective. The researchers are unable to reject or fail to reject their third null hypothesis due to insufficient evidence. The researchers will be able to conclude this decision by April 15th, 2024 once all data is collected.

Conclusion:

The most recent solar eclipse visible in North America occurred on August 21, 2017, captivating millions with its rare and awe-inspiring display. This event marked the first total solar eclipse visible from coast to coast in the United States in nearly a century. As such, experiencing the effects of a solar eclipse is a rare opportunity for most. Given this rarity, scientists seize the chance to study the various effects they produce. The researchers employed a wide array of Arduino sensors to capture data to compare atmospheric parameters before, during, and after the upcoming solar eclipse on April 8th, 2024. The parameters measured include air pressure, air temperature, humidity, light intensity, sound, and wind speed.

The April 8th, 2024, solar eclipse can affect human lifestyle. This collection of wind speed data through the proximity sensor before the solar eclipse can help scientists further understand Atmospheric Boundary Layer Behavior and Local Wind Patterns. Atmospheric Boundary Layer Behavior is changes in the lower atmosphere's temperature distribution due to the decrease in solar radiation, and studying wind systems can help the researchers understand how the Atmospheric Boundary Layer responds to sudden changes in solar heating. The researchers' collection of sound data during the solar eclipse can help them understand the possible change in animal behavior and mating patterns as some of these animals are dependent on certain sound patterns. Collection of light intensity data can help the researchers understand how solar radiation is affected during the solar eclipse. The researchers' data collection of humidity levels can help them understand the change in humidity, aiding a better understanding of possible cloud formation. The solar eclipse can also allow the researchers to understand dynamics of atmospheric temperature dynamics. Changes in solar radiation levels can create temperature variations in the atmosphere. The change in solar radiation causes a temporary cooling effect, decreasing the temperature. Monitoring the temperature of the Earth before, during, and after the eclipse can allow us to understand the effect of a solar eclipse on the Earth's surface temperature. Finally, pressure data collection can allow the researchers to understand short term weather data and patterns as well as climate studies. The change in solar radiation can also allow the researchers to understand its effects on the climate by analyzing pressure variations.

Understanding the importance of measuring each of these parameters, the researchers worked to find cost-effective sensors for each. This was to ensure the project was accessible all across the world to measure data before, during, and after the eclipse in a similar manner. This was the main mission of the project as influenced by ideas given by Marilé Colón Robles. Working with our project mentor and former AP Environmental Science teacher, Mrs. Diana Johns, she provided us with the knowledge of the TerraRover 2 and its wide scope of abilities. Mrs. Johns introduced both researchers to the different effects that may be affected from a solar eclipse. Most importantly, Mrs. Johns introduced both researchers to the GLOBE program in early 2021.

Limitations:

While the researchers are prepared for the April 8th Total Solar Eclipse, there are still some limitations to the research which they hope to mitigate before the data collection dates. One of these limitations is the creation of a wireless data logging and collecting system. Currently, each sensor is required to be connected to a laptop that constantly saves data locally. However, the researchers already have a plan to code and connect a corresponding SD data logging module to each of the sensors, ensuring a consistent and wireless saving of measurements. Other aspects of the project took up more time which is what restricted the researchers from adding this data logging module earlier. One other, more time-consuming, aspect includes finding microsensors that were specifically compatible with the specific Arduino Uno model to memory storage constraints with other models.

A second limitation of this study is the accuracy of each of the microsensors. The goal of this project was finding and utilizing cost-effective sensors; however, this comes with the risk of inaccurate sensors. With the use of more professional sensors, the collected data would be more precise than the current sensors attached to the TerraRover 2. The researchers plan to validate their data through comparison with professional-grade sensors at local labs.

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Acknowledgements:

Working with Mr. David Bydlowski of the NASA AREN program was very educational and inspiring for the researchers. He allowed the researchers to use the TerraRover 2 for their research. Additionally, speaking with Marilé Colón Robles of NASA Langley enabled the researchers to understand a greater depth about the variations that may be seen during a solar eclipse. The researchers also worked with their former AP Environmental Science teacher, GLOBE Advisor, and Science Club Advisor – Mrs. Diana Johns. Inside and outside the classroom, Mrs. Johns has informed both researchers about the solar eclipse. Through working with all their mentors, the researchers were able to truly understand the long-term importance and potential implications of their research.

I Make an Impact:

The researchers hope to receive the "I Make an Impact" badge as the implementation of this research can make both a local and global difference. TerraRover 2s outfitted with numerous types of air quality sensors can be used around the Detroit metropolitan area. This will allow us to map our region's air quality results. Locally, these results could be used to notify building personnel if air quality results are outside of the range that is safe for humans. The use of TerraRover 2s will also allow us to gather air quality data in places otherwise not viable for humans. On a smaller scale, firefighters could use a TerraRover 2 to gather carbon monoxide/dioxide data to get an idea of what is going on inside a burning building. On a larger scale, we could use the TerraRover 2 to gather air quality data of numerous locations in our solar system like Mars. This would allow us to compare air quality on Earth, an overpopulated planet, to air quality with somewhere that has never been inhabited, to our current knowledge.

I Am A STEM Professional:

The researchers hope to receive the "I Am A Stem Professional" badge for their collaboration with Mr. David Bydlowski of the NASA AREN program. He was there to guide students on any arising issues of the connection between the Arduinos and sensors. This also includes attempting to get the sensors to save data wirelessly which will ultimately be solved through the use of an SD card. Mr. David Bydlowski also provided the technology needed for the TerraRover 2's main functions. He also was able to collaborate with Marilé Colón Robles of NASA Langley who provided strong insight on the research, offering various ideas the researchers ended up utilizing.

I Am a Data Scientist:

The researchers hope to receive the "I Am A Data Scientist" badge for their collection, interpretation, and organization of data. The researchers coded and wired the TerraRover 2 to continuously save data as they drove the TerraRover 2 around. From there, the researchers created multiple bar graphs of the three trials of every location that data was collected at. The data collected shows the volume of impact towards the research of particulate matter as the data connects to real-life public areas (Crestwood High School) and the particulate matter, carbon monoxide, carbon dioxide, ultraviolet light, and sound levels found in that area. Due to global quarantine, air pollution rates had dramatically decreased during the COVID-19 pandemic. Ultrafine particle concentrations are said to have dropped as much as 50%! As the world continues to fully open back up, vehicle and industrial air pollution emissions are unfortunately increasing rapidly once again. Our limitations were time constraints and validity of all sensors.

I Am an Engineer:

The researchers hope to receive the "I Am an Engineer" badge because in the beginning of the research, the researchers approached the problem of limited space on the TerraRover 2 for the anticipated four new sensors. This problem led the researchers to brainstorm and produce prototypes of different additions to increase capacity. During the brainstorm, a possible design was to expand the TerraRover 2 on the sides. This would be achieved as the researchers would attach the platform to the base of the TerraRover 2 with diagonal skewers. The prototype was made with a 15-in. x 11-in. sturdy cardboard platform; to eliminate the movement of the Arduino sensors. Although, the researchers realized this method may not work because the platform would be covering the main power source and the radio signal with the controller. Also, the height of the Arduino sensors would be too short to log and collect accurate data points. The next prototype consisted of a similar model that is already being in use for the particulate matter sensor with a fitted 3D-printed design and skewers to create a tower-like structure. Although, this concept was not tried because with the contrasting size of each Arduino sensor and the balance of each Arduino sensor, inaccurate results may be present. The final prototype that the researchers ended up using was an elevated platform being supported with a vertical structure onto the middle of the base of the TerraRover 2, away from the radio signal and main power source. This design also solved the problem with the elevation of each sensor as each sensor is at a height sufficient for accurate outputs. This design also solved the problem with the imbalance of each sensor as each sensor was securely attached onto the flat platform with industrial adhesive. During the process of independently programming with the Arduino IDE and Arduino programming language and wiring each sensor onto its corresponding Arduino, the researchers had an issue with the Arduino library of the carbon monoxide sensor. This library consisted with all of the programming that the carbon monoxide should "already" know, which would make the process of programming the carbon monoxide smoothly. But the library primarily being in use with similar projects was terminated because of the newer versions of the Arduino Unos. The researchers tackled this problem by modifying and creating a new and updated open-source library for all carbon monoxide sensors. This library did not only help the programming issue for the researchers, but also future Arduino project with the carbon monoxide for anybody with internet access. Expanding from the researchers' prior research with the TerraRover 2, the researchers wanted to make the process of data collecting and logging through a wireless system. While speaking to Mr. David Bydlowski and Mr. Andy Henry, the researchers resulted with the attachment of SD cards onto each Arduino Uno and ultimately each Arduino sensor. This efficiently increased the experience of data collecting for the researchers. During the wiring process of the different Arduino sensors, the researchers found out that the SD card data logging and collecting module and the particulate matter both needed 5V power from the Arduino Uno. The researchers solved this minor issue with attaching a 9V battery through the SCP port attached onto the Arduino Uno. With the experience of the TerraRover 2 that the researchers hold, the researchers wanted to change the thickness of the TerraRover 2 wheels because of the different terrains the TerraRover 2 would be going through to collect data. The new wheels would potentially give the TerraRover 2 a smoother ride, giving more accurate results of each sensor. The researchers independently learned and used CAD modeling software to model a fitted TerraRover 2 wheel with a 1-inch increase. This would result with a 0.5-in to a 1.5-in. Mr. Andy Henry at Wayne RESA helped the researchers with the ability of using Wayne RESA’s 3D-printers to print 4 new 1.5-in wheels.