An Analysis of Particulate Matter Data Collected by Monitoring at Various Altitudes Using Aeropod Technology

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Abstract:

During the 2020-2021 school year, a group of researchers from Crestwood High School in Dearborn Heights, Michigan, collected data on **particulate matter** (PM) concentrations as measured at two different **altitudes** using a consumer grade **PocketLab Air** device. Various surface weather parameters and PM counts were taken on the school's soccer field. An "Into the Wind" 7 ft Levitation Delta Kite (outfitted with a **PocketLab Air** device attached to a Globe-certified custom, 3D printed Aeropod) was flown at 122 meters high to collect the same atmospheric parameters as those measured at the surface. PM data collected was compared with a permanently mounted **PurpleAir** device located in a school courtyard to validate the reliability of the **PocketLab Air**. The goal of this research was to see what differences might exist between ground and high altitude PM. PM levels were measured at a higher altitude to determine if particulates produced from local factories and landing aircraft at a nearby regional airport might be detectable. Ground level PM concentrations are important because of the health risks of inhaling ultrafine particles over long periods of time. Knowing what atmospheric conditions exacerbate $PM_{2.5}$ and PM_{10} levels could possibly be utilized by high school sports teams to modify their activities during episodes of poor air quality. An analysis of the data showed little variation between PM levels on the ground and at higher altitudes. However, **PocketLab Air** PM concentrations are somewhat positively correlated with relative **humidity** and directly correlated with **wind speed**. Moving forward, more research on PM should be conducted where sports and other physical exertion take place because this increases the inhalation of fine PM, which other research has found to be involved in potentially negative health outcomes.

Key words: Particulate Matter, PocketLab Air, PurpleAir, Aeropod, Humidity, Wind Speed

Research Questions:

The following research questions are relevant not only to our local area, but to the global community as well. Through these questions, researchers were able to investigate $PM_{2.5}$ and PM_{10} trends as compared with select weather parameters and then apply the results to the real world. Determining particulate matter levels in local areas is essential in order to advise individuals when they should consider modifying their outdoor activities.

1. How does $PM_{2.5}$ and PM_{10} measured at ground level (1.2 meters from the ground surface) vary from $PM_{2.5}$ and PM_{10} measured at an altitude of approximately 122 meters or 400 feet above the surface?
2. How does PM data derived from the PocketLab compare with PM data reported from a PurpleAir device?
3. How does PM data compare with select atmospheric data such as humidity and wind speed?
4. Can $PM_{2.5}$ and PM_{10} measurements be utilized effectively by high school sports teams to modify their activities during episodes of poor air quality (high particulate matter counts).

Null Hypotheses:

1. There is no difference in $PM_{2.5}$ and PM_{10} values at the ground surface as compared with $PM_{2.5}$ and PM_{10} data collected at a height of 122 meters.

2. There is no difference in Particulate Matter (PM) data collected by either the PocketLab or PurpleAir device.

3. There is no relationship between PM data with humidity and wind speed.

4. $PM_{2.5}$ and PM_{10} measurements cannot be utilized effectively by high school sports teams to modify their activities during episodes of poor air quality (high particulate matter counts).

Why this research is important:

The site by which the research was conducted is relatively close to the original factory complex of the Ford Motor Company (Dearborn, MI) and on a major flight pathway of the Detroit Metropolitan Airport located (Wayne, MI). Both these factors combined make Dearborn a heavily industrialized city. Of the six (6) criteria air pollutants regulated by the U.S. Environmental Protection Agency, levels of particulate matter often exceed safe levels at our school, as shown by the researchers' PurpleAir sensor. High concentrations of particulate matter in the atmosphere are linked to numerous health issues in humans including asthma, bronchitis, and cardiovascular problems (Morishita 2014). According to the American Lung Association, preadolescent children, the elderly, and those with pre-existing cardiopulmonary health conditions, being the most vulnerable populations, remain the most susceptible to these health issues. Measuring particulate matter levels at our school allows us to assess the air quality specific to the microclimate of our study site and allows us to make safety recommendations to our school's outdoor sport teams regarding safe exercise and physical exertion. Numerous other outdoor activities take place on the Crestwood High School campus throughout the school year. As a result, the trends we discovered in $PM_{2.5}$ and PM_{10} may play an important predictive role in determining the types of atmospheric conditions that could potentially be hazardous for rigorous outdoor exercise. Crestwood High School is a very sports-oriented school, so this research may help to provide information to assist coaches at our school to make informed decisions regarding whether or not to allow strenuous activity on days with high PM levels. Drones may seem like an attractive way to collect data, however, this leads to more expenses and maintenance can be costly. While inexpensive drones are a possible option, they cannot carry the weight of heavy weather sensors. Another limitation regarding the use of drones includes strict FAA and licensing restrictions; it simply isn't a viable option for many schools in Michigan. The AREN Project, in contrast to drones, is able to use NASA based Aeropod technology to carry heavier devices that can be used to measure particulate matter and other weather parameters relatively inexpensively. This research validates the premise that Aeropod technology can be deployed globally to retrieve accurate and relatively inexpensive data as long as wind is present. Large-scale weather conditions can be investigated remotely through the use of satellites. However, microclimates and their associated weather conditions are not as well understood because weather satellites currently do not have the ability to collect precise data (higher resolution) in small areas like our high school campus. The Crestwood High School campus has its own unique microclimate created by a host of environmental factors including surface types with different albedos, variable tree density, open areas, and neighborhoods located nearby with residential homes and businesses. Studying the effects of our microclimate within the larger community of Dearborn Heights can help to begin to scratch the surface on creating a possible database of how larger weather patterns affect us and our community.

Figure 1-2: Initial Test Flights. The researchers used the summer months of 2020 to learn how to fly the PocketLab Air onto the kite. Due to the fact that the PocketLab Air is heavier in weight than the instruments the researchers used in the past, the researchers had to better master the technique of kite flying. To add, due to the weight of the PocketLab, windier days were required in order to get it up in the air. Figure 1 (left) shows the initial test flight of the PocketLab Air attached to the kite at 122 meters. Figure 2 (right) shows the PocketLab Air on the Aeropod at an altitude of 122 meters.

Figure 3-4: Site of Data Collection. The data that the researchers collected was recorded at Crestwood High School's Practice Soccer/Football field. This site consists of short grass in an urban setting, and the climate of this site is cold and temperate, with a considerable amount of precipitation. The site is typically very muddy due to the large amounts of snow that have melted over the course of the months the researchers took data. It also has many areas of standing water, ice, and snow all on the same field due to differing areas of the field having differing surface temperatures. Figure 3 (left) is a map of Crestwood High School, and the site the researchers recorded data. Figure 4 (right) is 304.8 meters high, and it shows the site where data was collected (in the top right), the football field, etc. This photo was caught by a Monocam Aeropod that the researchers flew.

Investigation Plan:

An Aeropod equipped kite was flown throughout the summer 2020 in order to find the safest way to collect data on particulate matter at higher altitudes. The PocketLab Air is a heavier device than other instruments that had been flown previously and adjustments had to be made regarding optimal launch and landing procedures. Flights took place from September 2020 through January 2021 whenever the weather was suitable for the launch of equipment. A 7-ft Levitation Delta Kite outfitted with NASA/AREN Aeropod technology was used to fly the PocketLab Air to collect data on $PM_{2.5}$. After mastering kite flying and developing the data collection protocol, a series of 21 flights and their data were collected. Mr. David Bydlowski of the NASA/AREN Program assisted the researchers by guiding them on proper equipment maintenance and answering any questions that arose. Mr. Andy Henry also helped with the 3-D printing of a device to secure the PocketLab sensor. Appropriate weather conditions, such as adequate wind speeds, were necessary in order to ensure safe flying. Weather parameters, such as temperature, dew point, relative humidity, barometric pressure, and $PM_{2.5}$ were measured at ground level, and then compared with measurements at an altitude of 122 meters. The site used for this investigation was the Crestwood High School soccer/football practice field lot - exact location of latitude 42º32’10.60” N and longitude - 83º29’45.25” W.

Introduction and Review of the Literature:

Particulate matter refers to the complex combination of tiny, lightweight solid and liquid droplets that can be suspended in air for extended periods of time. The two main types analyzed in most research include PM_{10} (fine particles with diameters less than 10 micrometers) and $PM_{2.5}$ (ultrafine particles with diameters less than 2.5 micrometers). Much of inhaled PM_{10} can be filtered out by our body's nose and upper respiratory passageways. However, $PM_{2.5}$ is more dangerous than PM_{10} because it can infiltrate into the deeper part of the lungs. $PM_{2.5}$ that reaches the alveoli can permanently damage gas exchange. Examples of PM_{10} include dust, smoke, soot, and ash, which can be seen by the naked eye. Contrastingly, $PM_{2.5}$ can only be seen under a special type of microscope. Examples of $PM_{2.5}$ include ultrafine particles such as those derived from tobacco smoke, ash, smoke from cooking, particulates exhibited from factories and power plants, suspended tiny droplets, and chemicals in the air. Numerous health studies have found a clear correlation between "epidemiological and experimental findings" that clearly indicate the role of particulate matter in the development and progression of respiratory diseases (Schwarze 2006). There has also been a significant association between particulate matter concentration and mortality stemming from cardiovascular disease as well (Panyacosit 2000). The weather in Dearborn Heights is affected primarily by the highly variable prevailing southwesterlies. It is important to note that local wind speeds and wind directions in Dearborn Heights, MI are also a function of weather fronts and their associated high and low air pressure which are known to affect particulate matter concentrations. As of right now, to obtain accurate particulate matter measurements, very expensive, research grade equipment is necessary. Universities, state, and federal agencies are currently some of the only agencies that can afford research grade particulate matter sensors. However, if K-12 schools could obtain near research grade level sensors, such as the PurpleAir, the amount of particulate matter data across several different locations would increase which in turn would allow communities to make the best decisions for the people that belong to them. Crestwood High School is a very sports-oriented school, so this research could assist athletic directors at our school in making decisions that prioritize the safety and health of those involved in such activities based on PM readings. Crestwood High School is also located right under one of the main flight paths that pass through the Metro Detroit area. Being under one of the main flight paths poses a significant problem, as ultrafine particulate matter emitted by aircrafts spread far beyond airports, and greatly affect particulate matter levels in surrounding urban areas potentially miles away from the origin point (Parker 2015).

Research Methods and Materials ***(Including GLOBE Data!)*****:** Multiple weather parameters, including air temperature, relative humidity, dew point, and barometric pressure, were recorded using data from the PocketLab Air, then compared to Crestwood High School's WeatherBug weather station for validity. The WeatherBug weather station is a near research-grade instrument directly reports its measurements to the GLOBE database. $PM_{2.5}$ was collected at ground level using a Pocketlab Air attached to a 1.2 meter high tripod. Before the PocketLab was attached, the researchers left the Pocketlab out to acclimate to outside conditions to ensure accurate results. The Pocketlab continuously collected data every 10-15 seconds for about 5 minutes. The researchers recorded a total of 21 days of data. After the data was recorded on the PocketLab Air, it was then transmitted to a laptop via Bluetooth. Subsequently, the data was arranged and averaged in Microsoft Excel. Before the researchers could fly, the researchers had to make a decision as to whether conditions were suitable to fly or not. If wind speeds were below 9 miles per hour, or over 20 miles per hour, conditions were deemed unsuitable. Additionally, the researchers could not fly if there was precipitation, too much haze, etc. If and when the conditions were deemed suitable, the researchers flew an "Into the Wind" 7-foot Levitation Delta Kite at an altitude of 152 meters, with the PocketLab attached to a Globe-certified custom, 3D printed PocketLab Aeropod. The PocketLab continuously took data at an altitude of about 152 meters every 15 seconds. During these 15 seconds, the PocketLab would collect data on various weather parameters such as air temperature, dew point, relative humidity, barometric pressure, $PM_{2.5}$ and PM_{10} over the course of 10 minutes.

Figure 5-6: Weather instrumentation. The data was recorded on a PocketLab Air (left) attached to a 1.2 meter high tripod (right). Figure 6 (right) shows the PocketLab Air 1.2 meters high collecting surface ground weather and particulate matter data continuously every 15 seconds. Researchers were careful to level the instrument to be certain that wind speed and direction were accurately recorded. Weather data was not collected directly at the surface to avoid wind turbulence which could have affected the results.

Figure 7-9: Kite Data Collection. After the PocketLab Air was finished collecting ground data, the researchers sent the PocketLab up 122 meters into the air to take data once more. Figure 7 (left) shows the researchers checking weather conditions to deem if flying is suitable. Once a decision is reached, the researchers flew the kite (middle) with the PocketLab attached. When the PocketLab Air is finished collecting data, the researchers take down the kite (right) and transfer all the data into Microsoft Excel.

When the 10 minutes were over, the kite was brought down, and the data collected was transported to a laptop via Bluetooth. The data was then all averaged out in Excel. All flights were logged onto the ArcGis website, a GIS mapping software, along with making a spreadsheet. The data was then analyzed to see how PM on the surface compared to in the air could affect nearby areas. During mid-November, the researchers were able to acquire a PurpleAir sensor, which was used to collect data to compare with the PocketLab Air for the remaining flights. Particulate matter in the air can travel to other nearby areas and can be quite detrimental to the air quality. By measuring particulate matter in the air, we can see what type of particulate matter is abundant that travels to other areas, such as ultrafine particles such as those found in $PM_{2.5}$, or more coarse particles such as those found in PM_{10}.

Figure 10-11: Aeropod Technology Used. The PocketLab Air was attached to a custom, 3-D printed Aeropod to collect PM and weather data 122 meters in the air (left). The Monocam was attached to the Monocam Aeropod and sent 305 meters in the air to capture an image of the field used for data collection (right).

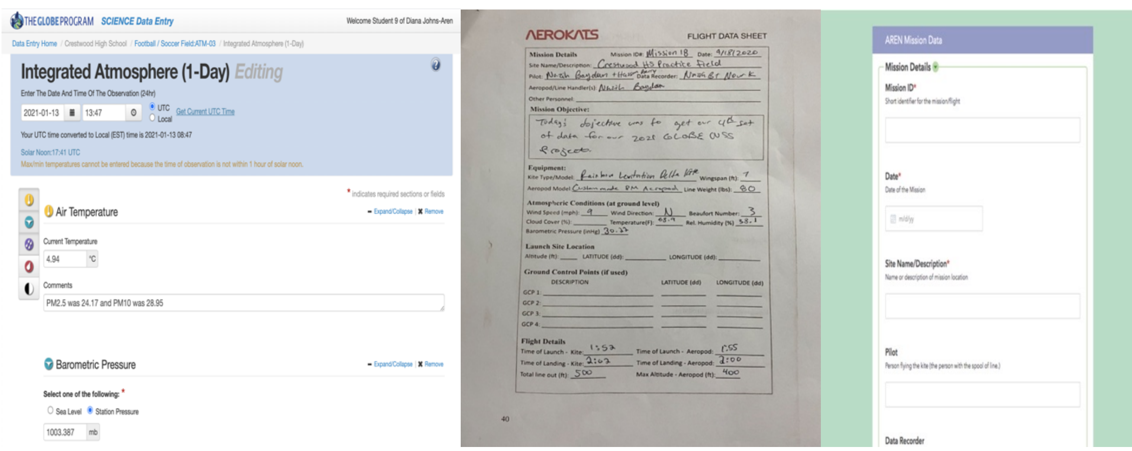

Figure 12-14: Data Entry. The researchers used the "SCIENCE Data Entry" section of the GLOBE website to impute their data. The researchers logged a total of 21 flights, with $PM_{2.5}$ and PM_{10} values added into the comments. Figure (left) shows the researchers imputing the air temperature, relative humidity, barometric pressure, and $PM_{2.5}$ and PM_{10} values of their January 13th flight, or Flight #21. The researchers also logged all of their data in their AREN booklet (middle). Finally, the researchers imputed all of their data into the ArcGis website (right).

Figure 15-16: Princess Chulabhorn in Nakhon Si Thammarat, Thailand. Figure 15 (left) shows the researchers last year at Thailand initially flying the kite that the researchers at Crestwood sent them. As they mastered the technique of flying, they gradually increased altitude at which they flew (right). The researchers hoped to pursue a joint project with the researchers in Thailand, however, the COVID-19 pandemic hindered their ability to communicate and work together.

Results:

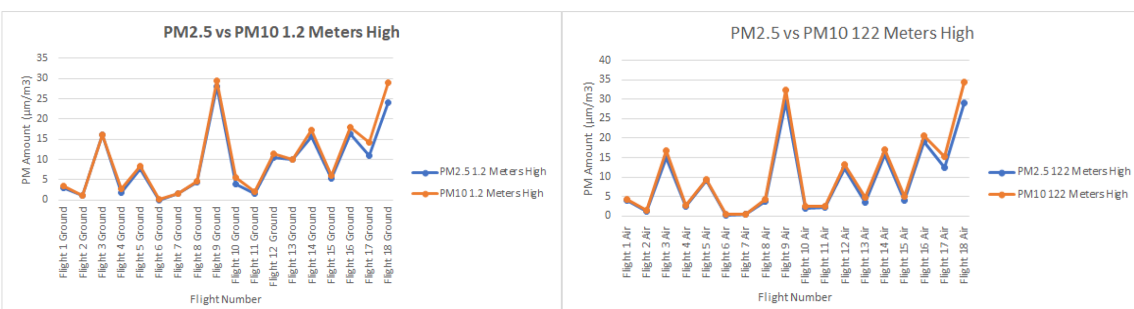

Figure 17-18: PocketLab Air $PM_{2.5}$ and PM_{10} on ground level (left) as compared to higher altitude (right). Data obtained from the PocketLab Air for both size PM shows little variation for different altitudes. The close relationship that $PM_{2.5}$ and PM_{10} amounts have on both graphs was noticed. Either the air column does not have perceptible differences in the size of PM present from the ground upwards or the device is unable to sufficiently resolve size differences in a measurable way.

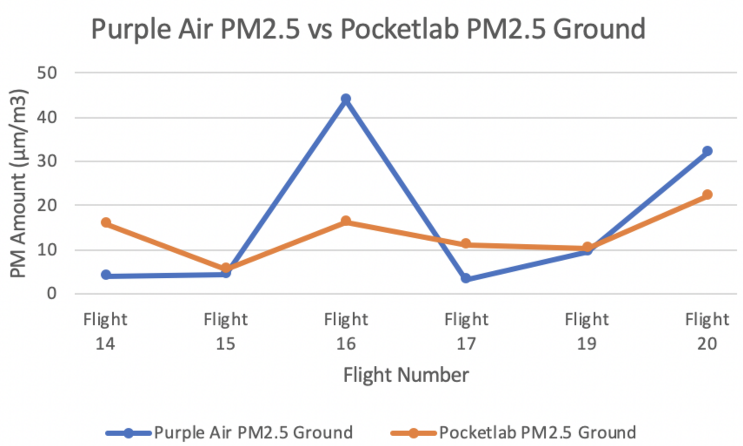

Figure 19: Comparison of PurpleAir $PM_{2.5}$ and PocketLab $PM_{2.5}$ two meters above the surface. While there are differences in the values derived from the Purple Air and PocketLab, the general trends of each of the devices are relatively similar. Because the Purple Air is a near research grade level device, it happens to be much more sensitive to particulate matter and measures the concentrations present with greater accuracy.

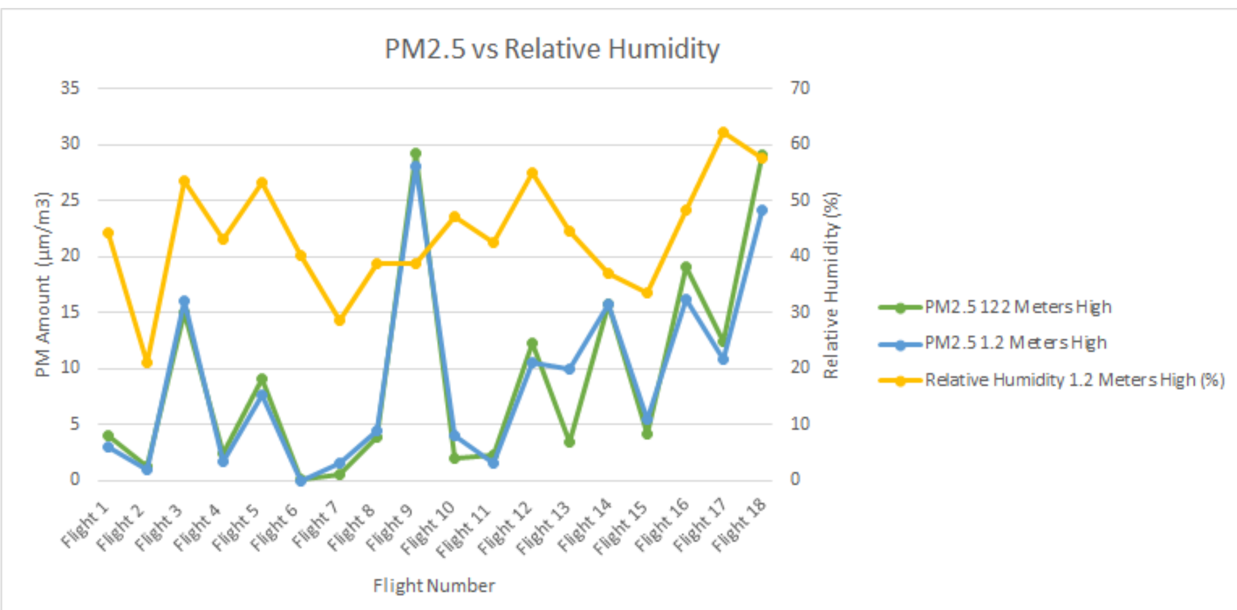

Figure 20: Comparison of PocketLab Air $PM_{2.5}$ and surface relative humidity. $PM_{2.5}$ from the PocketLab Air and relative humidity appear to be somewhat correlated with each other throughout the study period. As relative humidity increases, levels of surface and upper level particulate matter increase as well. A possible explanation for this positive correlation is suspended chemicals and ultrafine particulates might adsorb to water droplets in the air, thus causing higher $PM_{2.5}$ levels on days with higher relative humidity.

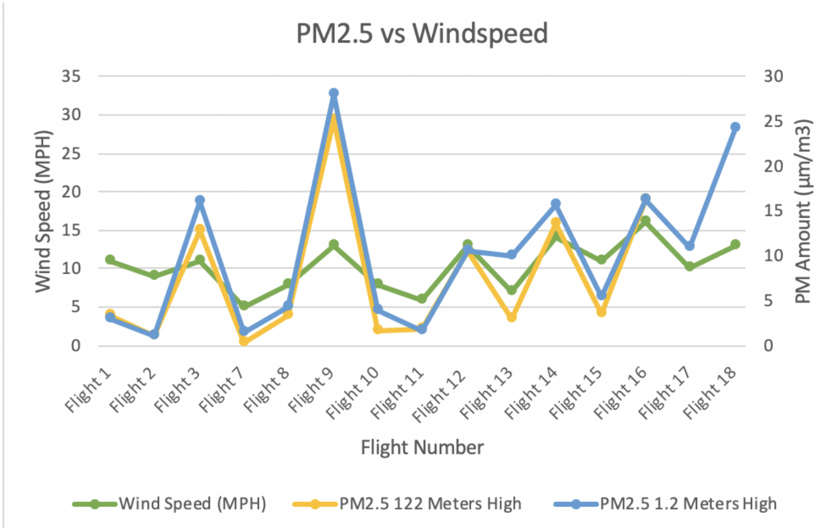

Figure 21: Comparison of PocketLab Air $PM_{2.5}$ and wind speed. PocketLab Air $PM_{2.5}$ and wind speed seem to have a positive correlation with one another. Higher wind speeds appear to relate fairly closely to higher $PM_{2.5}$ amounts. A possible explanation for this might be that higher wind speeds cause friction at the Earth's surface allowing loose fine-grained particles to be picked up and become airborne.

Discussion:

$PM_{2.5}$ and PM_{10} collected from the PocketLab Air both do not vary significantly from ground levels as compared with similar data obtained with the kite at higher altitudes. The amounts of $PM_{2.5}$ and PM_{10} recorded by the PocketLab Air were relatively the same each time values were collected, with PM_{10} being just a bit higher at both altitudes. $PM_{2.5}$ obtained by the PocketLab Air compared with itself and PM_{10} obtained by the PocketLab Air compared with itself when investigated at 1.2 meters vs 122 meters, yielded similar values as there was little variation in the concentrations at ground level as opposed to high altitudes. The Purple Air is a higher quality, more research-grade device as compared with the PocketLab Air. This may help to explain variations in values when data collected from both devices are compared. $PM_{2.5}$ and PM_{10} from the PocketLab Air compared with relative humidity did show positive correlation. As relative humidity increased, levels of $PM_{2.5}$ and PM_{10} also increased. Our data suggests that wind speed appears to show a positive correlation with higher PM counts. A possible explanation for this might be that higher wind speeds cause friction at the Earth's surface allowing loose fine-grained particles to be picked up and become airborne.

Possible sources of error in this investigation may include not letting the PocketLab Air acclimate long enough to outside weather conditions, not allowing the PocketLab to remain in the air long enough to collect sufficient data, and not keeping the kite completely vertical, which would alter the altitude consistency at which the researchers flew. Another possible source of error is the inaccuracy of the PocketLab device itself. However, despite these possible limitations, the PocketLab maintained consistency in its readings. In comparison with a study conducted in Pakistan on particulate matter concentrations in relation to altitudes and weather parameters, there was a direct correlation between increasing relative humidity and increasing particulate matter concentrations. Similarly, as winds and wind speeds increased, particulate matter concentrations also increased (Zona 2015). This same occurrence was also experienced by the Crestwood researchers and is demonstrated by the graphs shown above. As wind speed and relative humidity increased, $PM_{2.5}$ and PM_{10} concentrations also increased, showing a direct correlation. The researchers had to accept their first null hypothesis, as there was not a significant difference in $PM_{2.5}$ and PM_{10} values at the ground surface as compared with $PM_{2.5}$ and PM_{10} data collected at a height of 122 meters. PM_{10} was only found to be slightly higher at the ground and at a higher altitude. The researchers rejected their second null hypothesis, as there was variation in the $PM_{2.5}$ and PM_{10} data collected by both devices. However, the data yielded showed that the trends were very similar in both devices. The researchers rejected their third null hypothesis, as they found positive correlation between PocketLab Air PM data with humidity and wind speed. The researchers rejected their fourth null hypothesis as well, as they were able to talk with Crestwood's administration and are making a plan for the future to regulate high school athletics while taking into account particulate matter levels to ensure athletics are safe to hold.

Conclusion:

2020, although a tough year for most of us, marked the 50th anniversary of the Clean Air Act. In the years that followed the enactment of this far-reaching legislation, it has become even more important to study the composition and concentrations of atmospheric pollutants and to investigate the possible roles they play in negative health outcomes. After analyzing the data collected during this research, it was evident that $PM_{2.5}$ and PM_{10} values were consistently similar no matter what vertical height they were measured at. This may be due to how the PocketLab Air measures these two different sized particles rather than to any real differences in amounts present. On the other hand, it is possible that we didn't fly the PocketLab high enough to measure more detectable differences. Because of Crestwood's close proximity to the airport, the researchers are not permitted to fly any objects at higher altitudes. The results of this investigation point to relative humidity and wind speed as being possible factors in determining high or low levels of particulate matter. The data from the PocketLab was different than data obtained with the PurpleAir. Although different, the PM trends were similar. The researchers concluded that the PocketLab Air device is still good for noting trends in particulate matter although we believe that PM counts taken by the PurpleAir are both more accurate and precise.

Due to the global pandemic affecting nations worldwide, studying $PM_{2.5}$ and PM_{10} is now more important than ever. Because of COVID-19's effects on the upper respiratory system, ultrafine or fine particles such as $PM_{2.5}$ and PM_{10} will be even more detrimental to human health, possibly increasing mortality due to their numerous negative health effects on the human heart and lungs. By measuring local $PM_{2.5}$ and PM_{10}, students involved in school athletic activities can be warned on days that they might be exposed to high levels of particulates within the air. Teaching staff and coaches can make informed decisions about whether or not to allow outdoor play. Lungs damaged by inhaling fine particulate matter can lead to increased pulmonary and heart issues if COVID is contracted. In the future, the researchers could improve their methods by flying the kite at a more vertical angle, allowing the PocketLab to acclimate to outside conditions, and using another instrument to collect data that could give more accurate numbers than the PocketLab. The researchers are also planning to implement a system within Crestwood High School that allows school administrators to determine if $PM_{2.5}$ and PM_{10} levels are too high for outside sporting events to be held on certain days. Working with Mr. David Bydlowski of the NASA AREN program was very educational and inspiring for the researchers. He worked with and advised them on how to improve their research methods, and provided instruments even amidst the restrictions put in place by the COVID-19 pandemic. In working with him, the researchers truly understood the importance of their research, as studying air quality and particulate matter is as significant as it has ever been due to the COVID-19 pandemic.

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Acknowledgements: A special thank you to Mr. David Bydlowski and Mr. Andy Henry of the NASA GLOBE AREN Project for their technical support and their tremendous patience. Without their mentoring, our project would have never gotten off the ground. Also, a special thank you to Mr. Thapanawat Chooklin of Princess Chulabhorn in Thailand, and all their hard work and involvement with our project. Although the COVID-19 pandemic took away the chance for the researchers at Crestwood and the researchers at Princess Chulabhorn in Nakhon Si Thammarat, Thailand to work together. Despite this, they still built an amazing connection with them and felt really inspired to be in contact with students from a completely different continent. This amazing experience was able to occur thanks to the GLOBE Program. To add, the researchers want to thank Mrs. Marile Colon Robles a project scientist for NASA GLOBE Clouds at NASA Langley Research Center in Virginia for being a main contributor in inspiring and guiding the researchers to study and take data on air quality, and highlighting the importance particulate matter plays in our world. Thank you for speaking with our Advanced Placement class during the first part of the pandemic almost a year ago.

Badges:

***I Make An Impact*:** The researchers hope to earn the "I Make An Impact" badge as making an impact was the main objective behind their research. By analyzing the data they collected and using it to draw conclusions on particulate matter, the researchers were able to target under which weather conditions health hazards may arise within their schools and surrounding area's microclimate. Crestwood High School is a strong athletics-based school, and the researchers' study on PM could potentially help coaches and administration determine whether athletics are safe to hold by taking into account particulate matter levels. PM readings should be measured where physical activity takes place due to the strenuous breathing associated with it which results in increased inhalation of the air and its contents, such as particulate matter.

***I Am A Data Scientist*:** The researchers hope to earn the "I Am A Data Scientist" badge due to their organization and analysis of the data they collected, the relationship of the researcher's own complex data to other scientific studies, and inferences they hope to make using their data. The researchers had to collect, organize, average, and analyze over Microsoft Excel sheets that had thousands of data points. The researchers had to categorize the many parameters on many days from two different devices. A significant amount of the results the researchers found agreed with other scientific studies, as shown in a study the researchers cited that recorded PM level changes at different altitudes. Both studies indeed found a positive correlation between relative humidity and particulate matter levels in many of their conductions. The researchers hope to use their findings to make inferences in the future regarding particulate matter. During the COVID-19 pandemic, worldwide levels of particulate matter decreased due to global quarantine, and less pollution from automobiles, aviation, etc. Unfortunately, the researchers infer that particulate matter levels within the next year are going to increase as the world opens back up. Some limitations of the data the researchers collected include not letting the kite reach a completely vertical angle, making the altitude not exact when the kite was flying, and not letting the PocketLab Air acclimate to outside weather conditions for long enough.

***I Am A Stem Professional*:** The researchers hope to earn the "I Am A Stem Professional" badge upon their collaboration with Mr. David Bydlowski of the NASA AREN program. Mr. David Bydlowski was there to guide the researchers in everything they needed, and was there to direct the researchers to places where they could find answers. Working with Mr. David Bydlowski was very educational and inspiring for the researchers. He worked with and advised them on how to improve their research methods, and provided instruments even amidst the restrictions put in place by the COVID-19 pandemic. In working with him, the researchers truly understood the importance of their research, as studying air quality and particulate matter is as significant as it has ever been due to the COVID-19 pandemic.