Record of solar activity in southeast Michigan across a one year period between 2023-2024

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Abstract. The Detroit area is situated atop a unique ecological region, with the Great Lakes holding the largest freshwater supply on Earth. Moreover, it plays a crucial role in the United States' economy. Therefore, studies focusing on the ecological status of the region are warranted. This manuscript records the visible spectra, temperature, luminous flux, and relative humidity in the Detroit area over a one-year period. The data show a relatively stable spectrum during the noon hours, as well as that the temperature appears to drop below freezing only for one month (January). The consequences of these results and their impact on the area are discussed throughout the manuscript. Moreover, the luminous flux and temperature changes observed during the April 8th 2024, eclipse are reported.

Keywords: UV-Vis spectra, Solar, Flux, Photochemistry, Photophysics, Michigan

1.1 Background

Since the dawn of agriculture humanity has been driven to find ever more efficient ways to harness the power of the sun to its needs (Sauer, 1947). Following the era of industrialization, the need to better understand solar radiation has only grown. For example, material scientists must take account of light when designing polymer coatings to ensure their durability (Andrady 2005; Jones *et al*., 2017). Similarly, engineers must take account of how the interaction of light and the exposed surface would impact the weathering of a structure (Heikkilä *et al*., 2017). Likewise, environmental scientists can use the destructive properties of light to break down unwanted chemical moieties which may contaminate the environment (Avramenko & Spiehs, 2023). Despite light being such a crucial variable across our environment the studies focused around measuring ambient lighting are relatively rare, with scientists and engineers typically relying on archival data which dates back to when modern spectrometers first became widely available nearly a century ago (Pulling 1919; Strohecker 1938).

While studies generally agree that UV radiation has increased since the start of the industrial revolution (McKenzie *et al.*, 2011; Williamson *et al* 2014), the changes along the visible spectrum are less clear. This is because exposure to higher energy UV radiation presents higher risk to public health, which naturally necessitates greater attention from the scientific community. However, irradiance along the lower energy visible spectrum from ~400 nm (3.1 eV) to ~800 nm (1.55 eV) is important for several reasons. One, photosynthesis relies on visible light in the blue (~420-470 nm) and the red (~600-700 nm) energy range (Bolton & Hall, 1991; Orona-Navar, A *et al.*, 2020). Two, there has been a movement in scientific works which has been specifically centered around developing photocatalysts which activate at visible wavelengths (Avramenko & Spiehs, 2023; Kansal *et al.*, 2014). This manuscript focuses on gathering information on the spectra as well as flux of visible light in southeast Michigan over a one-year period. Despite its relatively large industrial base as well as unique ecological position at the center of America's Great Lakes, there have been few studies aimed at measuring the solar spectra or flux in the area of Detroit, MI.

The manufacturing industry also relies on accurate data regarding the amount of solar radiation, temperature, and humidity. A multitude of American Society for Testing and Materials (ASTM) test methods have been developed to simulate the radiation expose of coatings to ensure proper performance and simulate aging, as well as ensure these methods accurately reflect the environment in which the coating is expected to serve (Mitra *et al.* 2014). This manuscript provides spectral, temperature, and humidity data which could ensure the accuracy of such methods.

1.2 Review of spectroscopy

Light's ability to excite molecules and set off a chain reaction of chemical processes across the potential energy surfaces of molecules is a property which can be harnessed, as is the case in photosynthesis, or a nuisance, as is the case in photoredox reactions in polymer coatings (Feldman 2002; Raucci *et al.*, 2020). This section of the manuscript will focus on reviewing basic spectroscopic theories on how light interacts with matter. One of the ways scientists approximate the energies of states in a molecule is through perturbation theory (Barone *et al*., 2021; Levine *et al*., 2009). The time independent Schrodinger equation provides a starting point as seen in Equation 1. The Schrodinger equation in Equation 1 is essentially a linear differential equation, in which the value of the energy and the wavefunction function is expressed as the eigenvalextent eigenvectors of the Hamiltonian *H*. Unfortunately, solving the Hamiltonian for all energy states is possible only for the simplest atoms, worse is that when light interacts with a system, it perturbs the system's energy levels, and unfortunately the exact extent of this perturbation is typically unknown (Levine *et al*., 2009). Luckily, Equation 1 can be re-written so that we can approximately solve for the Hamiltonian, as seen in Equation 2, in which the term *V* represents a small energy change in the Hamiltonian. Using Equation 2 to solve for the energy and wavefunction in Equation 1, Equations 3 and 4 are obtained. Equation 3 is the first order perturbation correction, in which a state *n* is modified with a perturbing term *V*. Applying the first order correction to estimate the wavefuntion (Psi) corresponds to Equation 4.The importance of this treatment is realizing that the perturbation allows for two orthogonal states, which would normally not interact with each other, to mix through the $\langle m|V|n\rangle$ term. Being able to connect states within a molecule that are not normally in contact with each other is one of light's unique chemical properties.

$$H|\psi_n\rangle = E_n|\psi_n\rangle \quad \text{(Equation 1)}$$

$$H = H_0 + V \quad \text{(Equation 2)}$$

$$E_n^1 = \langle n|V|n\rangle \quad \text{(Equation 3)}$$

$$|\psi_n^1\rangle = \frac{\langle m|V|n\rangle}{E_n^0 - E_m^0}|\psi_n^0\rangle \quad \text{(Equation 4)}$$

The rates at which photochemical reactions occur are governed by Fermi's golden rule, seen in Equation 5, where the transition rate (Gamma) between states *m* and *n* is dependent on the density of final states (rho), and the factor $\langle m|H|n\rangle$ is analogous to the perturbation term discussed previously (Kelly, 2022). It should be noted that Equation 5 only describes the transition rate between two states. Rury *et al*. detailed in their work that a complete photophysical picture should include the rate of molecular excitation by the light source, the non-radiative decay pathways such as inter-system crossing and internal conversion to lower lying excited or triplet states, as well as the radiative decay rate (fluorescence) (Rury & Sension, 2013). Notable in this treatment is that the rate is independent of light intensity (Klassen, 2011). Indeed, an increase in spectral irradiance will in turn increase the resulting black-body radiation of a system, not the rate at which it occurs (Varró, 2006).

$$\Gamma_{mn} = \frac{2\pi}{\hbar} |\langle m|H|n\rangle|^2 \rho_f \qquad \text{(Equation 5)}$$

2.1 Materials and Methods

The measurements were conducted at approximately 42.2 N, 83.4 W in Wayne County, Michigan approximately 20 miles northwest of downtown Detroit, MI. Figure 1 provides a map of the approximate location of the measurements. This location was chosen due to Detroit's unique ecological location in the Great Lakes region, as well as Michigan's industrial importance, putting it in a unique position in which both, environmental scientists, and manufacturers would benefit from obtaining knowledge of the spectra of light in the region. The visible spectra of sunlight approximately between 390-750 nm (3.18 eV-1.65 eV) was measured using a Goyalab GoSpectro spectrometer. The spectrometer was calibrated using the 2.84 eV, 2.54 eV, 2.27 eV, and 2.03 eV spectral lines monthly. Prior to each use the spectrometer was calibrated using the 2.03 eV spectral line. The spectrometer was placed perpendicular to the ground, pointed at the sky during the measurements. A Thorlabs 0.3 optical density filter was used to attenuate the light entering the spectrometer during data acquisition. To account for the impact of changing weather on spectral measurements observations were taken over five consecutive days, between the 19^{th} and 23^{rd} of each month, with the final monthly average reading reported. The days were selected such that the solstices are captured in the data. While sample analysis is by its nature imperfect, general guidelines, such as sampling at least 10% of a population, exist which are meant to dimmish the impact of outlying results (Montgomery, 2017) . Sampling 5 days of the month meets this basic criteria and should minimize the impact of factors such as adverse weather effects. In order to account for daylight savings time UTC time, which does not use daylight savings, was used. Measurements were taken three times daily, at UTC 12:00 which corresponds to the "morning" measurement, at UTC 16:00 which corresponds to the "afternoon" measurement, and at UTC 20:00 which corresponds to the "evening" measurement. Converted into local time the measurements correspond to 0800, 1200, and 1600 Eastern Daylight Time.

Beside the spectra, humidity and temperature readings were also taken using a ThermoPro TP50 digital hydrometer/thermometer. The procedure for these readings followed the procedure for the spectral readings in that they were taken over a five day period between the 19th and the 23rd of each month during the morning, afternoon, and evening time periods. Lastly, the illuminance (flux) of light was recorded using a Urcari digital light meter. A total eclipse of the saros series 139 occurred in the United States on April 8th 2024 (Kitchin, 2002; Kulkarni & Wolf, 2024). Due to the proximity of totality to the Detroit Metropolitan area it was possible to record the spectra, flux, as well as the temperature changes which occurred during the eclipse. The data involving the eclipse was recorded in Bowling Green, Ohio.

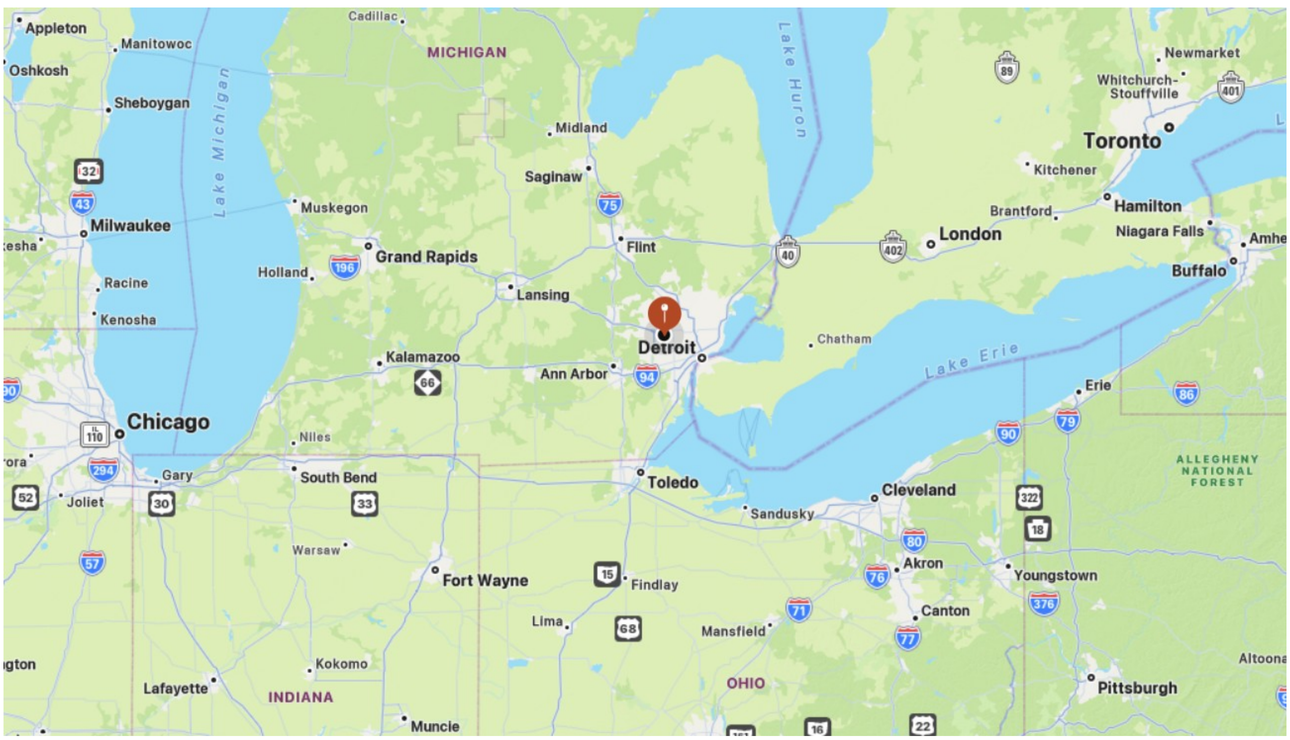

Figure 1. Approximate location within Michigan of where the solar spectra, flux, temperature, and humidity measurements were taken. Note the locations of other major North American cities such as Chicago and Toronto for additional reference.

3.1 Results

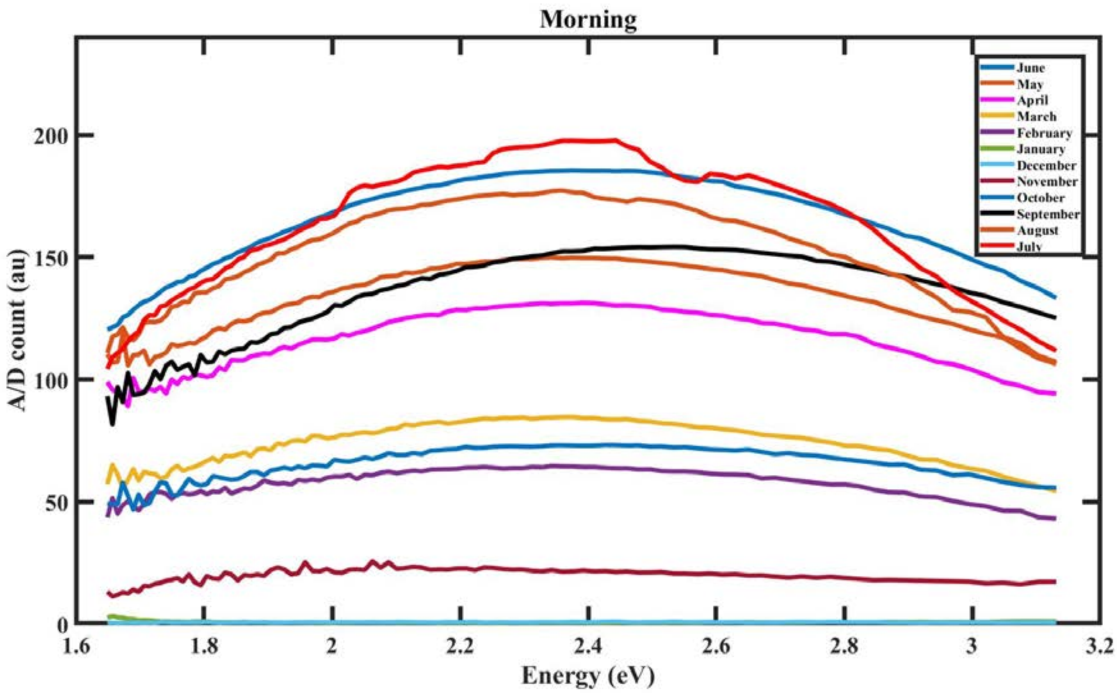

Figure 2. UV-Vis solar spectra taken at UTC 12:00 between June 2023 and July 2024 in the area of Detroit, MI, USA.

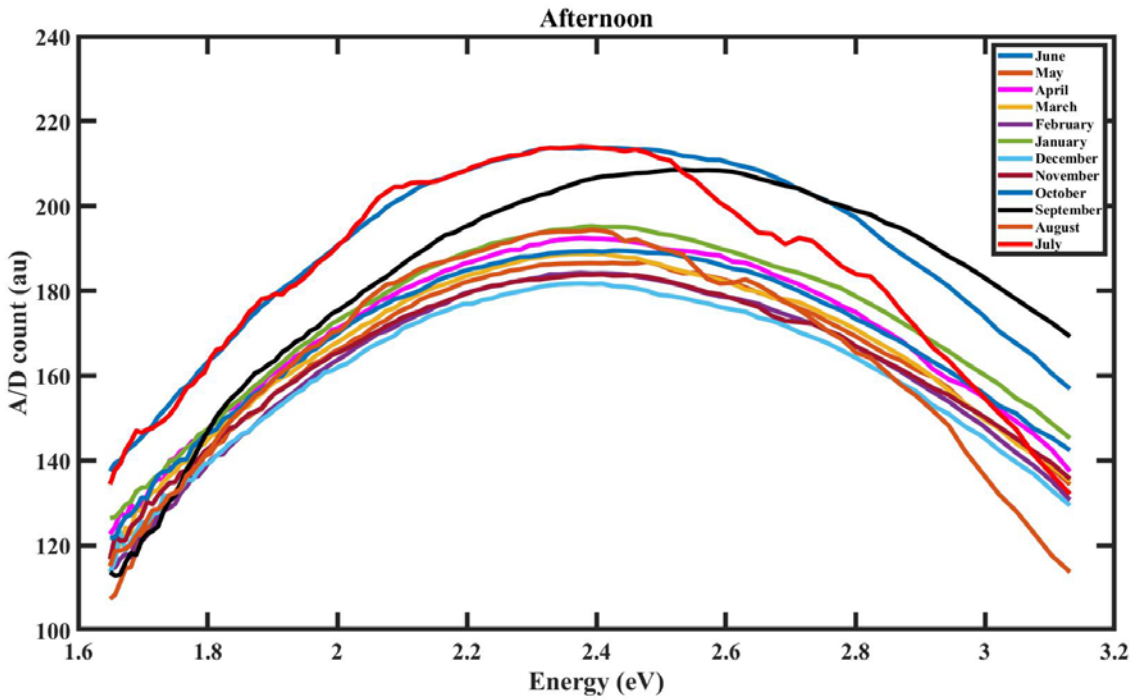

Figure 3. UV-Vis solar spectra taken at UTC 16:00 between June 2023 and July 2024, in the area of Detroit, MI, USA.

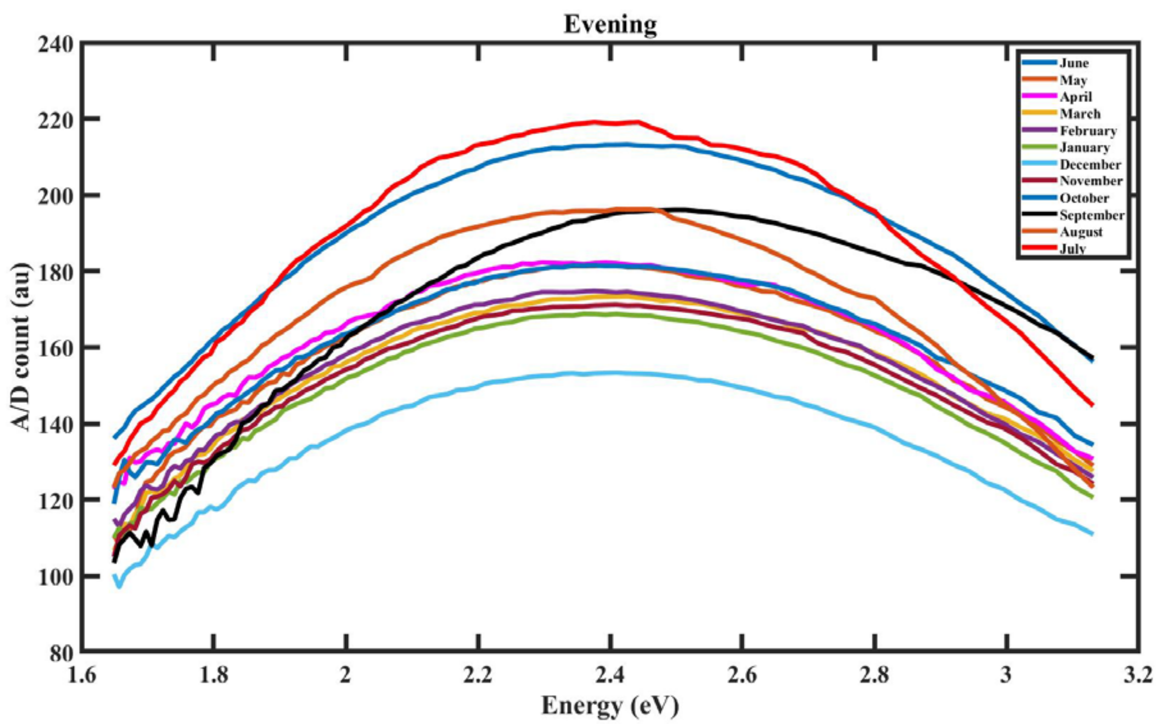

Figure 4. UV-Vis solar spectra taken at UTC 20:00 between June 2023 and July 2024, in the area of Detroit, MI, USA.

Figures 2-4 display the visible spectra collected for the morning, afternoon, and evening times over the course of one year in the Detroit area. Immediately noticeable is how the spectra collected in the mornings of December 2023 and January 2024 is effectively at the baseline of the instrument. This phenomenon is due to the fact that sunrise at the latitude in question occurs at approximately 13:00 UTC during these months, leaving little solar light that can be measured (NOAA, 2024). The afternoon data taken at 16:00 UTC seen in Figure 3 shows a largely expected data, with December being the month where the December spectra has the lowest value, while June 2023 and July 2024 have the highest values. A similar pattern is seen in figure 4 for the evening data. Another notable feature is that the spectral data rises from a value of 1.6 eV to a maximum of around 2.4 eV in all months, followed by a smooth decline in 3.16 eV. However, the July 2023 data has a notable decline in absorption near 2.6 eV, particularly notable in Figure 3. This may be due to the large wildfire phenomenon that occurred in Canada during the summer of 2023, which impacted the air quality of Michigan during this timeframe (Hu *et al.*, 2024).

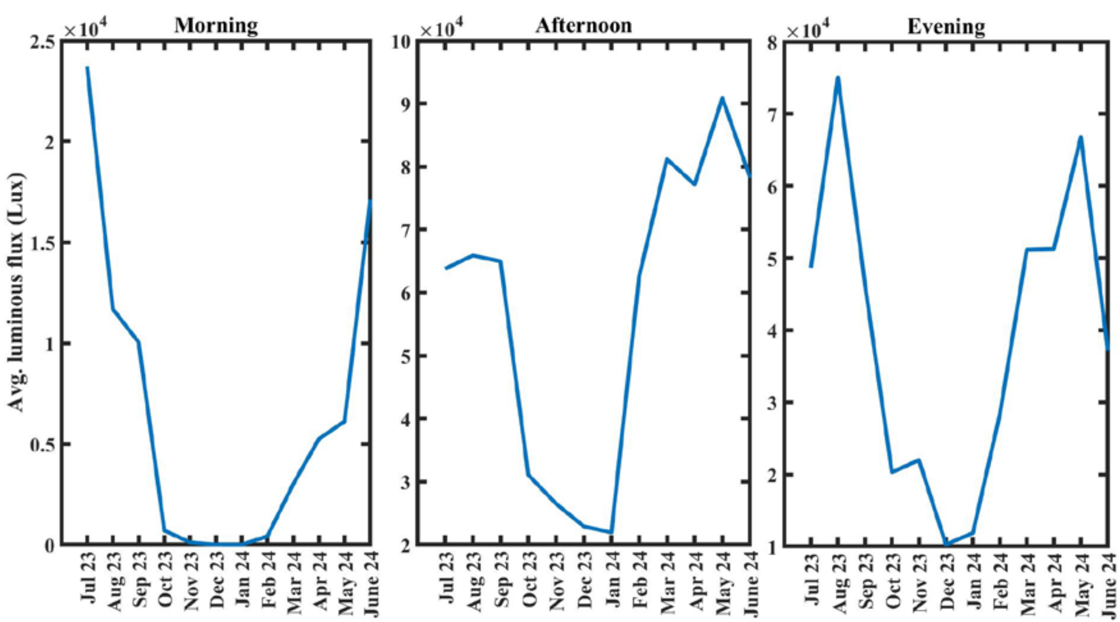

Figure 5. Average luminous flux measured in the Detroit area between June 2023 and July 2024.

Figure 5 displays the average luminous flux of solar radiation measured between July 2023 and June 2024. As expected, due to the sunrise occurring around 13:00 UTC the morning flux in December 2023 and January 2024 is near zero. The highest average morning flux was recorded in June 2023, the highest average afternoon flux was recorded in May 2024, and the highest evening flux was recorded in August 2023.

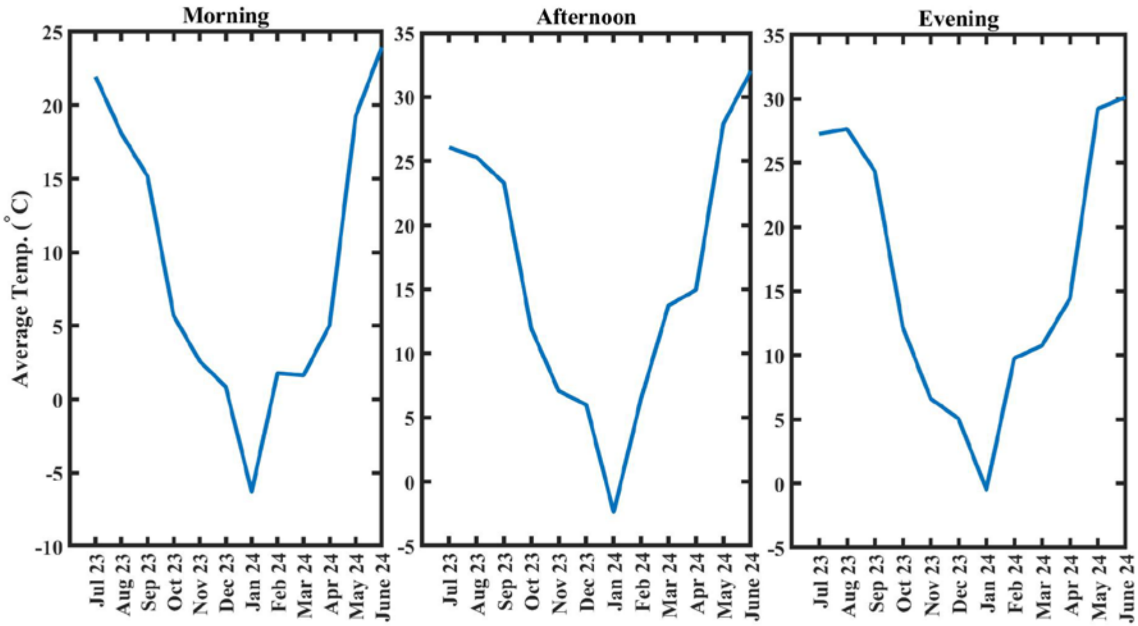

Figure 6. Average temperatures measured in the Detroit area between June 2023 and July 2024.

Average temperatures were also recorded for each month between June 2023 and July 2024, displayed in Figure 6. The temperatures follow a classic temperate climate with temperatures climbing in the summer and colling in the winter months. June 2024 was recorded as the hottest month in all time frames, morning, afternoon, and evening. January was recorded as the coldest month and the only month where the average temperatures measured below zero degrees on the Celsius scale.

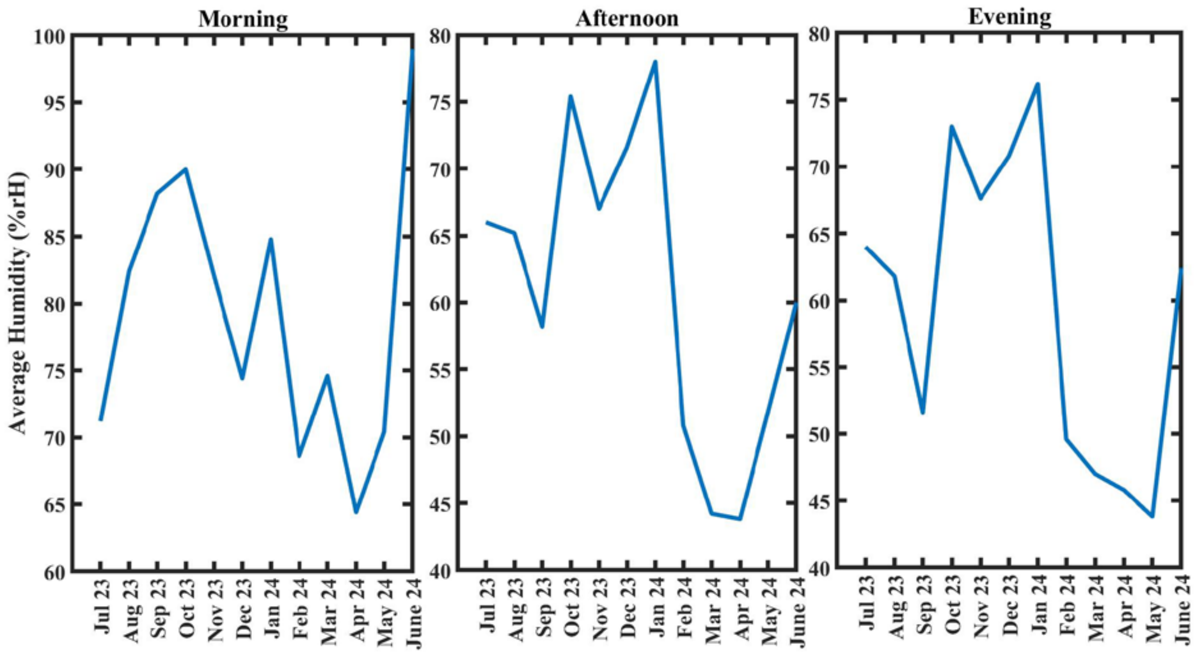

Figure 7. Average relative humidity measured in the Detroit area between June 2023 and July 2024.

Finally, the average relative humidity was recorded for each month between June 2023 and July 2024, as shown in Figure 7. The highest morning humidity was measured in July 2024, while January appears to have the highest humidity for the afternoon and evening time frames. However, note that relative humidity is a highly temperature dependent measure. Air at higher temperatures is capable of holding a larger amount of moisture per unit area, therefore, even with a lower relative humidity, the amount of moisture in the atmosphere is likely higher in the summer months (Nguyen *et al.* 2014).

3.2 Discussion

Based on the data provided in Figures 2-4 it is evident that the solar spectra peaks near 2.4 eV. Moreover, the Detroit area appears to experience a wide change in temperature, luminous flux, and humidity through the year. These large changes could have a significant impact for several industries. First, the coatings industry relies on simulated accelerated weathering tests such as natural salt spray to simulate the natural environmental effects a substrate would experience (Liu *et al*, 2023). Due to the large automotive industry presence in Michigan accurate recording of the environmental humidity, temperature, and flux data are crucial to ensure these tests accurately reflect the local environment in which the automotive parts are manufactured and stored in. Moreover, weathering of substrates is largely attributed to three factor: moisture, solar radiation, and temperature (Jones *et al*., 2017). The large changes in flux, temperature, and humidity experienced in the recorded area may allow it to become a viable outdoor exposure site to conduct weathering studies.

Environmental studies have also looked into the viability of utilizing solar radiation to destroy environmental contaminates such as antibiotics in wastewater (Avramenko & Spiehs, 2023). At first, this study suggests that the photocatalysts would be most effective in the summer months due to the larger flux of solar radiation. However, it should be noted that the large influx of solar radiation in the summer comes with the caveat of an increase in plant life which may compete to absorb the solar radiation, effectively photobleaching any photocatalyst. Therefore, the fall and spring months where the solar radiation is still present, but the local plant life has not yet had a chance to bloom may be the best time to utilize a visible light photocatalyst.

Algae blooms in Lake Erie have recently also become a concern to human health (Smith *et al.*, 2015). Caused by phosphorus runoff into the lake, the blooms would typically be suppressed due to the cold winter temperatures. However, due to the increase in temperature, as seen in Figure 6 where freezing temperatures were only experienced for one month, as well as the large solar flux which provides the photosynthetic algae with energy, the blooms have expanded. Studies using silver and titanium dioxide photocatalysts and exposed to visible light have shown promise in removing algae in a laboratory setting (Mohan *et al.*, 2022). However, these studies were conducted under laboratory conditions with constant temperature and irradiation sources. It is hopeful that knowing the approximate extent of the flux and temperature experienced in the local area could help these works take the next step of conducting *in situ* testing. It should be noted that the data gathered in the manuscript is best used for qualitative analysis as opposed to a quantitative one.

3.3 Eclipse data

A solar eclipse of saros cycle 139 occurred in the United States on April 8, 2024. The luminous flux of the solar eclipse was recorded at five time points: 30 minutes before totality, 15 minutes before totality, at totality, 15 minutes after totality, and 30 minutes after totality. The temperature was recorded at the same time increments. This data is available in Figure 8. Note that the luminous flux decreases steadily until totality, at which point it reaches zero. The luminous flux then rebounds accordingly, reaching close to its previous value 30 minutes after the eclipse. Similarly, a decrease of 4.9 degrees Celsius was recorded during the eclipse, with the temperature rebounding by 3.1 degrees Celsius 30 minutes after the eclipse. Note that the eclipse occurred at approximately 20:15 UTC. The visible spectra of the sun was also taken at five timepoints, during totality, as well as 30 and 15 minutes before and after totality, this data is presented in Figure 9. Note that despite totality occurring and the total flux dropping to 3.7 lux, a well resolved spectra was still obtained at totality. During the eclipse the spectrophotometer was not pointed 90 degrees skyward, but rather focused on the sun, which likely allowed it to capture the light of the corona, while the flux meter lacked such an optical set up.

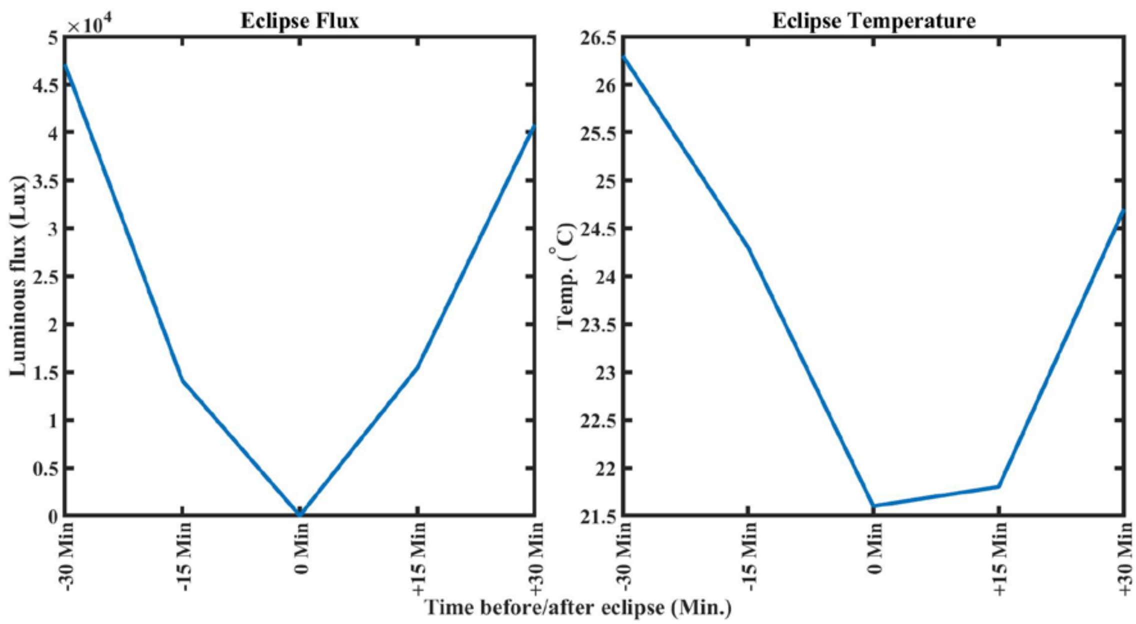

Figure 8. Left) Luminous flux during the solar eclipse. Right) Recorded temperature during the solar eclipse.

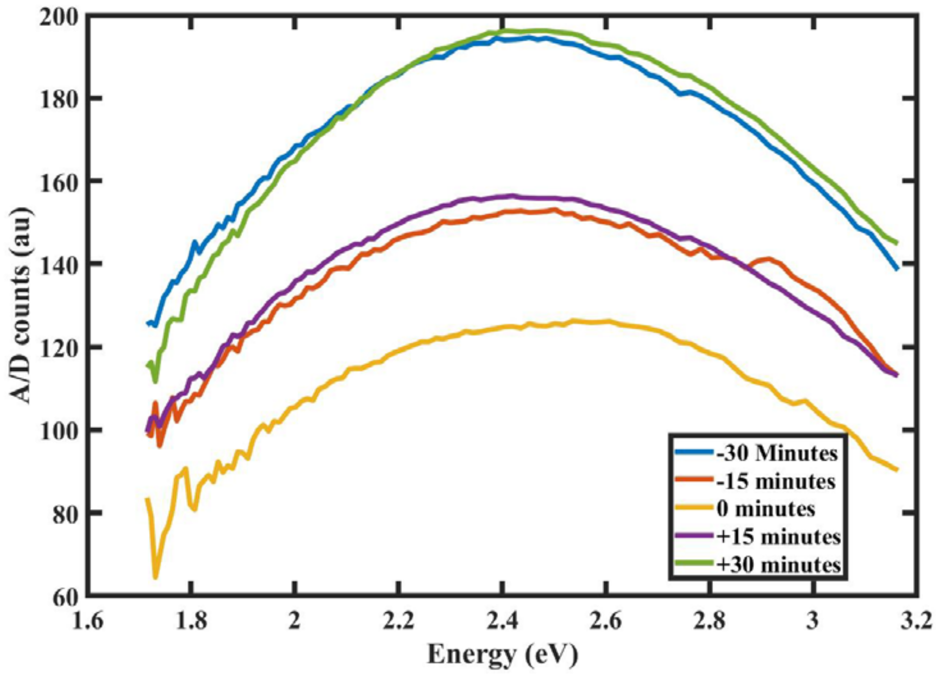

Figure 9. Visible spectra of the sun 30 minutes before (blue), 15 minutes before (red), during (yellow), 15 minutes after (purple) and 30 minutes after (green) totality.

4. Conclusion

Detroit sits atop a unique ecosystem and plays an important economic role in the United States. This study recorded the visible spectra in the area over a one-year period. It is hopeful that such data can be used by future studies to improve photocatalytic technologies which can be used to reduce algae blooms as well as other toxic pollutants in aquatic sources. Moreover, this data can be used to better engineer coatings that are tailor made to better resist temperate climates. Accurate recording of the solar spectra and flux is also necessary to address rising diseases such as skin cancer. Lastly, it is hopeful that this data can be used by future scientists to better assert the rate of change in the luminous flux, temperature, and solar spectra to better understand the impact of climate change.

Data availability

The authors have disclosed all relevant data.

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References

Andrady, A.L., 2005, Wavelength Sensitivity in Polymer Photodegradation, Polymer Analysis Polymer Physics, 47-94, https://doi.org/10.1007/3-540-61218-1_6

Avramenko, A.G., Spiehs M., 2023, Porphyrin mediated photodegradation of tylosin in aqueous media by near-UV light, Journal of Photochemistry and Photobiology A: Chemistry 441: 114698, https://doi.org/10.1016/j.jphotochem.2023.114698

Barone, V., Alessandrini, S., Biczysko, M., Cheeseman, J.R., Clary, D.C., McCoy, A.B., DiRisio, R.J., Neese, F., Melosso, M., Puzzarini, C., 2021, Computational molecular spectroscopy, Nature 1(1): 38. https://doi.org/10.1038/s43586-021-00034-1

Bolton, J.R., Hall, D.O., 1991, The maximum efficiency of photosynthesis, Photochemistry and Photobiology 4: 545-548. https://doi.org/10.1111/j.1751-1097.1991.tb03668.x

Feldman, D., 2002, Polymer weathering: photo-oxidation, Journal of Polymers and the Environment 10: 163-173. https://doi.org/10.1023/A:1021148205366

Heikkilä, A., Kazadzis, S., Meinander, O., Vaskuri, A., Kärhä, P., Mylläri, V.,; Syrjälä, S., Koskela, T., 2017, UV exposure in artificial and natural weathering: A comparative study, AIP Conference Proceedings 1810(1): 110004, https://doi.org/10.1063/1.4975566

Hu, Y., Yue X.,Tian C., 2024, Climatic drivers of the Canadian wildfire episode in 2023, Atmospheric and Oceanic Science Letters 17(4): 100483, https://doi.org/10.1016/j.aosl.2024.100483

Jones, F.N., Nichols, M.E., Pappas, S.P., 2017, Organic polymer and coatings technology, John Wiley & Sons, Hoboken, NJ.

Kansal, S.K., Kundu, P., Sood, S., Lamba, R., Umar, A., Mehta, S.K., 2014, Photocatalytic degradation of the antibiotic levofloxacin using highly crystalline TiO 2 nanoparticles, New Journal of Chemistry 38(7): 3220-3226. https://doi.org/10.1039/C3NJ01619F

Klassen, S., 2011, The photoelectric effect: Reconstructing the story for the physics classroom, Science & Education 20: 719-731. https://doi.org/10.1007/s11191-009-9214-6

Kelly, A.M., 2022, Condensed-phase molecular spectroscopy and photophysics, John Wiley & Sons, Hoboken, NJ.

Kitchin, C., 2002, Solar Observing Techniques, Springer, London.

Kulkarni, S., Wolf, L., 2024, Total solar eclipse 2024: what dazzled scientists, Nature 628(8008): 479-480. https://doi.org/10.1038/d41586-024-01054-z

Levine, I.N., Busch, D.H., Shull, H., 2009, Quantum chemistry, Pearson Prentice Hall, Upper Saddle River, NJ.

Liu, M., Peng, H., Tao, Y., Wang, J., Jie G., 2023, Comparative corrosion analysis of acrylic precoated aluminum foil under natural exposure and neutral salt-spray (NSS) testing, International Journal of Electrochemical Science 18(12): 100373. https://doi.org/10.1016/j.ijoes.2023.100373

McKenzie,R. L., Aucamp, P.J., Bais, A.F., Björn, L.O., Ilyas, M., Madronich, S., 2011, Ozone depletion and climate change: impacts on UV radiation, Photochemical & Photobiological Sciences 10(2): 182-198. https://doi.org/10.1039/C0PP90034F

Mitra, S., Ahire, A., Mallik, B.P., 2014

Mohan, H., Vadivel, S., Rajendran, S., 2022, Removal of harmful algae in natural water by semiconductor photocatalysis- A critical review, Chemosphere 302: 134827. https://doi.org/10.1016/j.chemosphere.2022.134827

Montgomery, D.C., 2017, Design and analysis of experiments, John Wiley & Sons, Hoboken, NJ.

National Oceanic and Atmospheric Administration, Sunrise/Sunset Calculator, https://gml.noaa.gov/grad/solcalc/sunrise.html

Nguyen, J.L., Schwartz, J., Dockery, D.W., 2014, The relationship between indoor and outdoor temperature, apparent temperature, relative humidity, and absolute humidity, International Journal of Indoor Environment and Health 24(1): 103-112. https://doi.org/10.1111/ina.12052

Orona-Navar, A., Aguilar-Hernández, I., López-Luke, T., Pacheco, A., Ornelas-Soto,N., 2020, Dye sensitized solar cell (DSSC) by using a natural pigment from microalgae, International Journal of Chemical Engineering and Applications 11(1): 14-17. https://doi.org/10.18178/ijcea.2020.11.1.772

Pulling, H.E., 1919, Sunlight and its measurements, The Plant World 22(7): 187-209. https://www.jstor.org/stable/43477067

Raucci, U., Savarese, M., Adamo, C., Ciofini, I., Rega, N., 2020, Modeling the Electron Transfer Chain in an Artificial Photosynthetic Machine, The Journal of Physical Chemistry Letters 11(22): 9738-9744. https://doi.org/10.1021/acs.jpclett.0c02766

Rury, A.S., Sension, R.J., 2013, Broadband ultrafast transient absorption of iron (III) tetraphenylporphyrin chloride in the condensed phase, Chemical Physics 442: 220-228. https://doi.org/10.1016/j.chemphys.2013.01.025

Sauer, C.O., 1947, Early Relations of Man to Plants, Geographical Review 37 (1): 1–25. https://doi.org/10.2307/211359

Smith, D.R., King, K.W., Williams, M.R., 2015, What is causing the harmful algal blooms in Lake Erie?, Journal of Soil and Water Conservation 70(2): 27-29. https://doi.org/10.2489/jswc.70.2.27A

Strohecker, H.F., 1938, Measurements of Solar Ultraviolet in the Chicago Area, Ecology 19(1): 57-80. https://doi.org/10.2307/1930367

Varró, S., 2006, A study on black-body radiation: Classical and binary photons, Acta Physica Hungarica Series B, Quantum Electronics 26: 365-389. https://doi.org/10.1556/APH.26.2006.3-4.18

Williamson, C.E., Zepp, R.G., Lucas, R.M., Madronich, S., Austin, A.T., Ballaré, C.L., Norval, M., Sulzberger, B., Bais, A.F., McKenzie, R.L., Robinson, S.A., Häder, D.P., Paul D.P., Bornman, J.F., 2014, Solar ultraviolet radiation in a changing climate, Nature 4(6): 434-441, https://doi.org/10.1038/nclimate2225