Skyglow from the Holiday Season: Looking at Temporary Changes in Artificial Light Pollution and Night Sky Luminance

4,866 words

Abstract

This research focuses on the skyglow effected by the artificial light pollution of a rural town with a population of ~7,000 people and an elevation of 135 feet above sea level, 30 miles west of a large city in Northern California. Over the course of three months, from January to February, the luminance of the sky in this region was monitored and recorded to determine the impact of holidays as a temporary source of extra light on the overall skyglow. Lamp posts at a new construction development were illuminated on January 12th, 2020, which introduced an unexpected factor into the analysis. It was ultimately determined that sites at greater geographical distance from the population center of the town tended towards being darker as has been discovered before, and that temporary sources of excess artificial light pollution such as Christmas lights cause changes in light pollution that last for at least a month after the peak luminance has been reached.

Key words: Skyglow, Luminance, Light Pollution

Literature Review

With the increase in human population that leads to expanding urbanization, there has been a noticeable increase in the light being emanated from cities and surrounding areas (Miguel et al., 2017; International Dark Sky Association). While arguably an indicator of society's prosperity, this expansion causes artificial light pollution by producing an excess of the artificial light that emanates from places with high concentrations thereof, which returns back to Earth-bound observers as light pollution by a process called scattering (Mizon, 2012). More specifically, Rayleigh Scattering dictates that the amount of photons scattered depends on the wavelength of the photons being scattered, so shorter-wavelength photons are more likely to scatter off the atmosphere than photons with a longer wavelength. LEDs and fluorescents, which emit high amounts of blue-rich white light at wavelengths of less than 500nm, are therefore scattered more than high pressure sodium light sources, that have wavelengths of about 550 to 600 nm (International Dark-Sky Association). This process, combined with the excess of artificial light that is majority blue light causes the phenomenon of skyglow, in which the night sky appears many magnitudes brighter than it would naturally (Mizon, 2012).

The negative impacts of light pollution and skyglow are of particular interest to astronomers and biologists. For the former, skyglow impairs visibility of astronomical objects (Cinzano et al., 2001). As for the latter, biologists have noticed that not only does the skyglow affect the habits of animals like bats in their natural habitats, but certain frequencies can be harmful to human sleep cycles and therefore other aspects of human health, so having an understanding of the levels of light pollution would be arguably beneficial to the field of astronomy, and the health of the environment and humans (Boldogh, 2007). For this reason, there has been more research conducted in this area as of recent years (Hänel et al., 2018).

Since the mid-20th century, a variety of methods have been used to quantify the brightness of night skies (Hänel et al., 2018). Among the most popular research tools is the CCD camera, or charge-coupled device camera, that couples each photon that hits the silicon sensor in the camera at each point of contact with an electron, making it possible to "count" the photons and produce accurate photographs of the night sky; these are used to continuously monitor the brightness of the night sky and to measure the distribution of sky brightness (Liu et al., 2017). Others map sky brightness onto topographical maps using data from the Defense Meteorological Satellites Program (DMSP) so as to reach a more holistic understanding of light pollution, usually as a function of elevation (Cinzano et al., 2001; Hänel et al., 2018). To measure sky brightness of the past, researchers measured the degree of condensation of comets to determine how bright the comet was when it disappeared to the naked eye into the background of the night sky (Ściężor, 2013). This method was based on limiting magnitude, in which astronomers would describe the sky using the magnitude of the brightest visible star in the sky.

Class	Type of sky	Values SQM (mag/arcsec^2)	NELM (mag)
I	Excellent dark-sky site	21.7–22.0	7.6–8.0
II	Typical truly dark site	21.5–21.7	7.1–7.5
III	Rural sky	21.3–21.5	6.6–7.0
IV	Rural/suburban transition	20.4–21.3	6.1–6.5
V	Suburban sky	19.1–20.4	5.6–6.0
VI	Bright suburban sky	18.0–19.1	5.1–5.5
VII	Suburban/urban transition	18.0–19.1	4.6–5.0
VIII	City sky	18.0–19.1	4.1–4.5
IX	Inner-city sky	≤18.0	≤4.0

Figure 1

This figure shows a table of Bortle Scale Classes and their corresponding luminance values.

Note: reprinted from Impact of light pollution on the visibility of astronomical objects in medium-sized cities in Central Europe on the example of the city *of Rzeszów, Poland by Marcin Wesołowski. Retrieved from* *https://doi.org/10.1007/s12036-019-9586-1 Copyright 2019 by Indian Academy of Sciences.*

The Bortle-IX Scale, as shown in Figure 1, standardized such measurements with a classification system from Class 1, a perfect viewing site, to Class 9, an inner-city sky (Bortle; Gronkowski et al., 2017). This system is a standard for amateur astronomers, to the extent that apps like Clear Outside, designed by and for astronomers, include it in their weather forecast.

Figure 2

This figure shows a Sky Quality Meter from the company Unihedron. The scale at the bottom is a simplified diagram to contextualize the readings for the user.

As of recent years, monitoring sky brightness has become much more accessible to the general public as instruments that directly measure light, called “photometers”, have proliferated with the advent of Unihedron’s Sky Quality Meter (Figure 2), or SQM as it will be known henceforth. It is an instrument that “counts” the number of photons that hit its sensor. Originally meant as a relatively cheap method for amateur astronomers to determine the quality of their observation site, it is now widely used even by professional astronomers as a research tool for determining sky brightness (Hänel et al., 2018). For the purposes of this research, the hand-held Sky Quality Meter was used. There is an important distinction between the SQM and the SQM-L –which is the version used in this research– that must be addressed; where the SQM takes input without restriction to the field of vision, the SQM-L incorporates a built-in lens that limits the Full Width Half Maximum (FWHM) of the angular sensitivity to ~20° of sky. This means that light at half the radiance of the peak brightness comes from 20° of sky, and while light that deviates from the axis more than 10° does register, it registers less bright than actuality, allowing the researcher to specify the area of sky they are assessing. The SQM-L is more popular for this reason, as well as for its relative accessibility. The numerical data taken has been used for a variety of purposes outside of the characterization. It is important to note that the magnitude scale is logarithmic, so the darker the sky, the higher the number: a higher number means fewer photons per square arcsecond, a unit of area used for measuring the sky. Also, a difference of 1 between two readings is a difference in magnitude so a reading of 19 $mag/arcsec^2$ shows the number of photons read is 10 times the number of photons hitting the sensor as a reading of 20 $mag/arcsec^2$. Keeping this in mind, a relatively small difference in readings can mean an impactful difference in actual sky brightness.

The two papers that this research will focus on were respectively conducted in Rzeszow, Poland and in Kirksville, Missouri to describe the skyglow of each region. Researcher M. Wesołowski (2019) at the University of Rzeszow took skyglow measurements over the course of four years all over the city and in surrounding villages so as to characterize the sky brightness of the region and analyze the effectiveness of a model that was used to predict the visibility of astronomical objects in the region. In the second, student researchers Gokhale et al. (2019) at Truman State University used Sky Quality Meter (SQM-LU-Dls) to remotely monitor the light pollution on the campus. The researchers compared it to a dark site in Arizona so as to evaluate the potential harm from light pollution to the students at the school. They then used their findings to advocate for a change in light sources on campus to mitigate the issues the light sources caused.

From both of these papers comes an understanding that in order to have a more holistic understanding of skyglow, it is essential to investigate cause and distribution of the phenomenon, begging the question: what else contributes non-negligibly to artificial light pollution? As of yet, there is little to no research that investigates the relationship between the holiday season and skyglow, between society and light pollution, and none for a small, rural town in northern California. The nature of artificial light pollution and its connection to skyglow dictates that the extra lighting used during the holidays would have a measurable impact on overall skyglow of a region. Thus, the purpose of this paper is to investigate such a correlation between the effects of the more temporary change in light pollution due to the holiday season and the overall skyglow of a region. It is expected that the data will show that the effects will be small in comparison with the long-term effects found by Marcin Wesolowski (2019), and the farther away the observation site, the smaller the change in luminance.

The SQM-L is the best-suited instrument for this research given the accessibility, convenience, and accuracy as demonstrated by the extensive research done using the instrument. The data for the purposes of this research was taken at 4 separate locations, chosen to allow the most accurate characterization of the night sky above each city being investigated. The SQM-L was pointed at the zenith of each site and at an angle above the horizon in several directions; per angle per direction per site per date, there were 5 measurements done to optimize accuracy of the characterization. The analysis of this paper juxtaposes the data taken at the four sites to accomplish the dual purpose of characterizing the skyglow of a region, and demonstrating how such a beloved aspect of society as holidays could potentially be negatively affecting our environment, our health, and our access to the night sky.

Method

Data was taken following an experimental framework at several locations in a small, rural town with a population of ~7,000 people and an elevation of 135 feet above sea level, 30 miles west of a large city in Northern California. According to the app Clear Outside, it has a luminance of $20.87 mag/arcsec^2$ and it is a Class 4 sky, or a rural/urban transition sky. Class 4 is defined by Bortle as having "fairly obvious light pollution domes [apparent] over population centers… the Milky Way well above the horizon… still impressive but lacking some structure" (Bortle). This town was chosen for the convenience of access and its proximity to the relatively dark sky of the surrounding countryside, causing the data to be isolated to its localized light pollution. Similarly to the Wesołowski model research paper, data was taken at four separate locations to create a holistic picture of the sky brightness in the region of the town and its surroundings. These are known as "site A", a representative neighborhood in the town; "site B", a well-known country road just outside the town that runs to the surrounding orchards; “site C”, a site located outside the city limits; and “site D”, a crossroads where two country roads intersect each other some miles outside the town. The dates I selected to take measurements depended on the weather and the moon. Because clouds have a high albedo, or reflective capacity, they appear brighter than the surrounding night sky, and data taken on cloudy nights would be brighter than the actual luminance of the sky. Similarly, data taken when the full or half moon was in the sky would include the brightness of the moon since the moon’s brightness would introduce a value of luminance that I have deemed to be detrimental to the investigation of the skyglow around the town because my model papers also excluded the moon’s luminance from their data. So data had to be taken on clear, moonless nights.

At each of these sites, I used the SQM-L to take measurements of the skyglow of the sky region at zenith and other cardinal directions selected based on the characteristics of each site. Per direction per site per date, 5 measurements were taken, from which I took an average; my model papers suggested doing so to ensure a more accurate data point and to prevent natural variation or variation due to mechanical or operator error. For site A, I only used data at the zenith, or the point directly above the observer, due to the lamp posts obstructing the field of vision in the eastern and western directions and houses in the northern and southern directions. Also, given that this site is in the town and the intent of this research is to measure the skyglow of the sky over it, data taken at zenith would be the most representative of skyglow effected by the artificial light pollution of the town. Data taken in any other direction would be influenced by direct sources rather than the photons scattered off the atmosphere overhead. Sites B and C are both situated to the west of the town, and so in addition to zenith measurements at each, I took measurements to the east, towards the town, and to the west, towards the surrounding countryside with little to no sources of light pollution. Site D is situated to the north, so in addition to zenith measurements I took northern (away from the town) and southern (towards the town) measurements. The measurements towards the town in the cases of sites B, C and D and the zenith measurements at site A were taken to measure the skyglow of the region of sky above the town proper. The zenith measurements were taken at each site to characterize a larger area that includes the surrounding countryside, since zenith is the least affected by anthropogenic light pollution, and therefore characterizes the skyglow of the region of sky directly above the observer's location best (Birriel & Adkins, 2010). The data taken in the directions away from the town were used as "dark site" controls with which to compare the findings of the other two sets of data.

As this data was plotted as a function of time (dates), it was necessary that time was quantified in a meaningful way given the context. To do this, I found a representative average of houses that were decorated in Christmas lights in the town on dates that were within a day or two of the dates I collected luminance data. It was not always possible to take both sets of data on the same night, given scheduling conflicts. Houses with any amount of Christmas lights visible from the street were counted. I found the percent of houses decorated on each street by tallying all the houses that were decorated and dividing by the number of total houses on the street. I took the mean of all the percentages per date to find the average percentage of houses lit up in the sample of houses, which should be representative of the percentage of the town that was "lit up".

The luminance data was compared with respect to time. Data taken from the region of sky above the town accomplished the primary purpose of this research in identifying a correlational change between the increase or decrease of houses that were lit for Christmas in the town, and the luminance of the region of sky above the town and the surrounding countryside. Also, each site was compared to determine the role distance plays in the change skyglow, if any.

Data Analysis and Discussion

Measurements of the brightness of the night sky in the region of the town were taken twice in December of 2019, once the day before and once the day after Christmas, and then once a month for January and February 2020. This served to demonstrate the general trend of light pollution after Christmas day, when people begin to take down their Christmas lights. In tandem with the SQM-L measurements, I tallied the houses with Christmas lights up once a month within one to two days of taking SQM-L data and found the percent of houses with Christmas light decoration from month to month.

Data and General Conclusions

In looking at this data, on Christmas Eve there was an average of 37.51% of houses with Christmas lights up and a standard deviation of 15.74. By January, only an average of 3.05% of houses were still decorated, and by February none were illuminated with Christmas lights.

It is also important to note any external factors that could potentially influence the SQM-L measurements, which, as the research was conducted in a non-controlled environment, must be considered for an accurate analysis. There is a new housing development under construction in the town, the extremes of which reach to the country road on which site B is located. As per city officials, the lamp posts from Main Street to that country road were turned on January 12th, 2020, which falls in the middle of my data collection time frame. These lamps are LED lights, so they produce more skyglow than would other types of lights. The addition of these lights into the testing environment is highly detrimental to the integrity of the experiment, but as it was impossible to conduct it in a controlled environment, it was a risk that was accepted. Given a more forgiving time frame, I would have conducted the experiment again, with a more prescient frame of mind to obstructions.

In my data, there is an expected difference in luminance between sites, date for date. Site A, which is within the town, tends to be the brightest. Site B, just outside the town limits, tends to be the next brightest, and sites C and D, respectively 2 miles west of the town and 3 miles north of town tend to show generally the same levels of luminance. For example, where the zenith measurements at sites C and D range from ~20.4 to ~20.6 $mag/arcsec^2$, site B has a luminance range of ~20.1 $mag/arcsec^2$ to 20.35$mag/arcsec^2$ and site A does not quite reach 20 $mag/arcsec^2$ with a range of ~19.7 $mag/arcsec^2$ to ~19.9$mag/arcsec^2$. Thus, C and D tend to be darker where B is a little brighter and A is much brighter, which supports the correlation between distance from a light source to the actual brightness of the sky. That sites C and D fall generally within the same range of luminance shows that the artificial light pollution from the large city that lies to the east of site D does not have a significant impact on the sky brightness readings.

Zenith

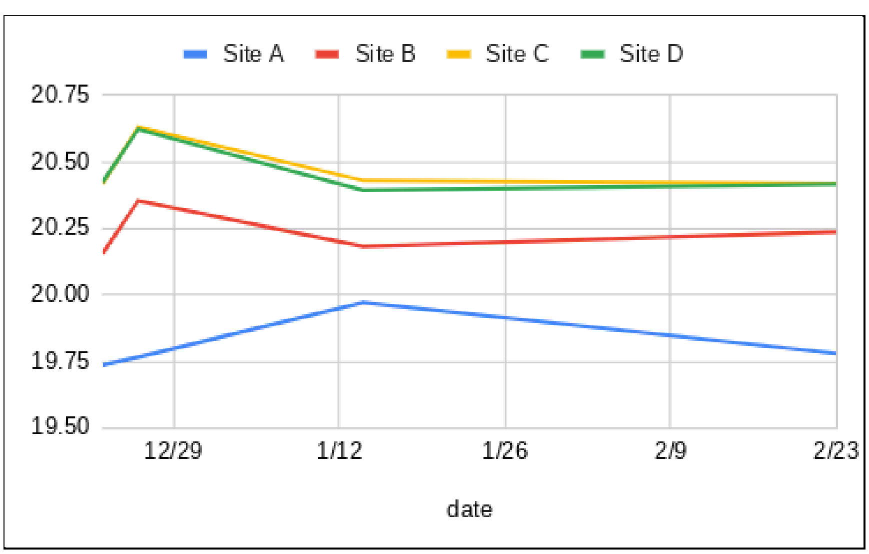

Figure 3

Comparison of zenith readings over three months between data sites A, B, C and D.

On Christmas Eve, the luminance of the sky above the town at site A had increased by 5.41% from the luminance given on Clear Outside, and 2.16% at sites C and D (First Light Optics).

According to Birriel & Adkins (2010), zenith is ideal for looking at the actual skyglow of an area as the brightness increases proportionally with the degrees away from the zenith. Figure 3 shows that the luminance of the sky decreased for all four of the sites from December 23, 2019 to December 29, 2019. Sites B, C, and D decrease more than site A, which shows that the farther from the town, the darker the sky gets, although repetition of the experiment is necessary to confirm this conclusion. Sites B, C, and D all increase in brightness in the January 14 data set while site A continues to decrease in brightness. The lights that were turned on by January 12, 2020 in the new area of construction would account for the increase in skyglow overall, where the decrease in site A may be contributed to the fact that the site was already significantly brighter than any of the other sites, or to the natural fluctuation of lights within the town. It is also worth noting that sites B, C and D increased in luminance about the same from December 29 to January 14, but that site B, which is significantly closer to the area of new construction and is generally brighter than sites C and D, saw a greater decrease in luminance from January 14 to February 23 relative to site B, though this decrease is negligibly small, so it is irrelevant to the analysis.

Looking Away From the Town

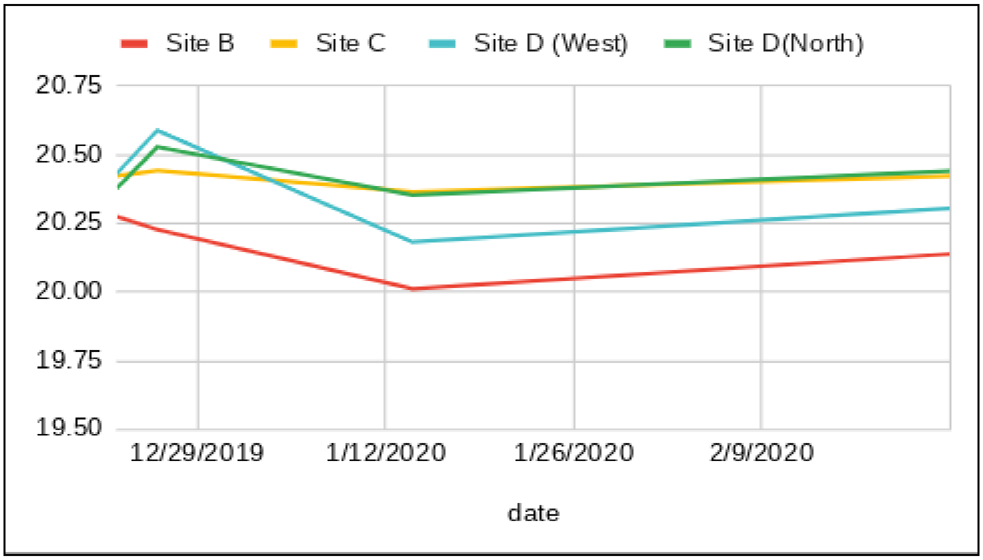

Figure 4

This graph figure shows a comparison between the measurements taken in the direction opposite the town between sites B(West), C(West) D(West) and D(North).

Each of the sites in Figure 4 follows the same general trend as the zenith readings: luminance decreases between December 23 and December 29, increases in the January 14 reading, and decreases slightly between January 14 and February 23. The only exception is site B, which gets brighter from December 23 to December 29, but as it only increased by .04 $mag/arcsec^2$ as seen in Figure 4, it is a negligible difference. Similarly, the luminance at site C on the same time interval only decreased by .02 $mag/arcsec^2$ so it can be determined that the sky opposite from the town when in the hills to the west and at the site on the outskirts of town are not noticeably affected by the decrease in light pollution from Christmas lights. However, it does support the conclusion from the previous section that the farther the site is from the town, the darker it will get in the same amount of time. In contrast, the luminance to the West and North of site D, which lies to the east of the town, decreases drastically between December 23 and December 29. While luminance increases at all sites from December 29 to January 14, it is a more noticeable change in site B, likely because site B is located right next to the new construction development. The change is greater in site D (west) also, possibly due to the high potential for airglow from the town in this reading as it lies to the northeast of the town looking east.

After January 14, all sites get darker by .1 $mag/arcsec^2$ rounding to the nearest tenths decimal point, a downwards trend that occurs in a recognizable majority of the data taken, though not by the same amount.

In this data set, measurements at site B are the brightest, falling on average in the same range, although point for point the luminance readings are lower (and thus the sky being measured is brighter). Site D varies greatly data point for data point but sites B and D have similar trend lines at ~20.50 $mag/arcsec^2$. Site C varies far less between zenith and western readings.

Looking Towards the Town

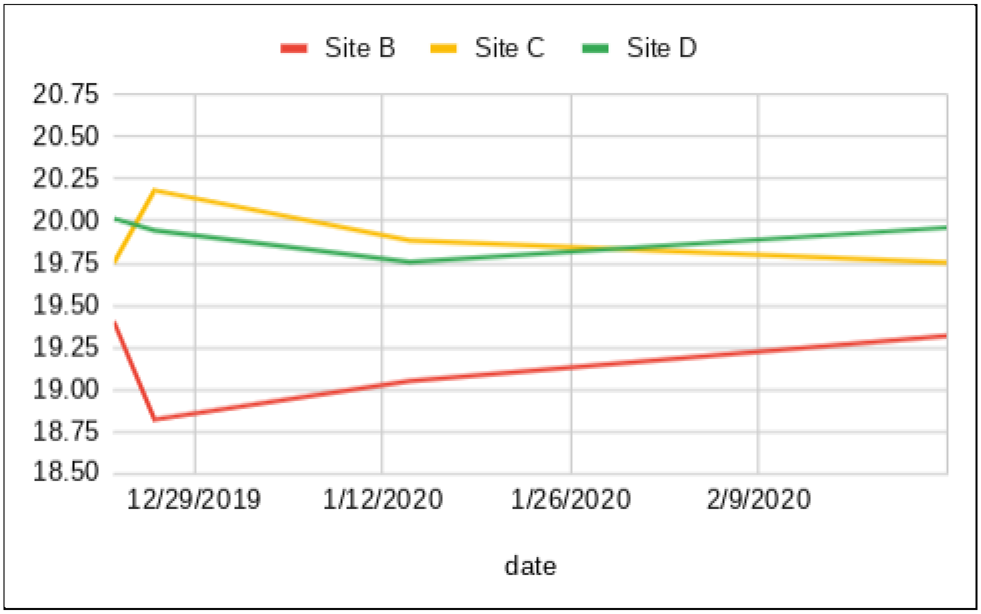

Figure 5

Comparing data taken in the direction of the town between sites B(east), C(east) and D(south).

The data taken in the direction of the town was by far the most variable in terms of the difference in luminance from point to point, variation from previous trends, variation in range of all measurements taken at a given site, variation from expectation, and standard deviation of the data points individually. That said, there are observable patterns. For example, measurements taken at site B continue to be brighter than at either site C or D, and are much brighter than measurements taken at the site at zenith or at an angle from from the zenith axis pointing in the opposite direction as the town, with a range of ~18.82 $mag/arcsec^2$ to ~19.40 $mag/arcsec^2$ where it measured ~1 $mag/arcsec^2$brighter on average at zenith. Sites C and D also exhibit the same behavior, though less drastically. For each of the five readings I took per direction per site per date, the readings taken toward the town were consistently more variable than in the other two directions; this may be due to how inherently fast paced many sources of lights in the town are: e.g. car headlights, house and business lights being turned off and on. The measurements taken at site C follow most closely my expectations for this data, and the general pattern that has been emerging: the skies get darker after Christmas day, get much brighter in the January 14 data set after the lights in the new development have been turned on but in this case it continues to brighten, although not significantly. Site D gets brighter continuously until February 23, where it begins to follow a similar trend as data sets at zenith and taken in the direction away from the town, and gets darker between January 14 and March 23.

Discussion

This research was undermined by the permanent installation of lamps in the new construction area, as after the data collection date on January 14th, it was impossible to distinguish the increase in light pollution from the new development and the decrease in light pollution that occurred when the Christmas lights were taken down. Therefore, given more time, it would be best if this experiment were repeated after the construction was completed, or in a town where no construction was taking place that would obstruct the objective of the research. However, the sudden increase in light pollution from the lamps did show the difference in how much luminance at the sites decreased and increased with corresponding changes in light pollution.

The changes being investigated are small compared to the long-term effects that Marcin Wesołowski (2019) recorded at Rzeszow, and the differences between dark site and University recorded by Gokhale et al. (2019). This is due to the relatively small change in artificial light pollution caused by Christmas lights, although the luminance of the sky has not become as dark as the Clear Outside app predicts it to be (First Light Optics). This is likely caused by the new construction's lamp posts, and although the data is trending towards being darker, to determine how long it will take for luminance to decrease to a stable point, more data must be taken. The data shows that the sky farther away from population centers tends towards being darker, and the more the skyglow will decrease after the sources of light have decreased. This did not match my hypothesis that the sites that lay further from population centers would change less than sites that were closer. However, the luminance will increase less the farther the site is from the town, which does match my hypothesis. This would suggest that the photons being emitted from the excess sources of light (the Christmas lights and the new development lamps) increased the skyglow of the overall region of sky, and when the excess sources of light were removed, there is a fixed rate at which the photons left the town-atmosphere system. This is a conclusion that has not been drawn by any paper that I have encountered, as most focus on the long-term effects of artificial light pollution.

The research that would naturally follow this would have to cover a longer span of time that included sets of data from before the holiday season and throughout the holiday season to see how long it would take for the sky brightness to return to the magnitude from before Christmas Eve, which is recognized as the time when the most decorative lights are up. Research that follows might look at the same data over the course of many years, as author Wesołowski (2019) conducted his research in Rzsezow, Poland. One might also characterize a different size of town, to determine if the magnitude of population truly made a difference to the change of luminance in and about the town.

Cities have built on and intertwined with the nature around them such that mitigating potentially harmful impacts requires a thorough investigation into the effects of a concentrated population —specifically the magnitude thereof— and the effects of their technology on nature.

The problem of artificial light pollution is not only important to astronomers, but to the animals whose habitats are being altered by the changes in night brightness and the humans whose sleep cycles are being undermined. Thus, it is just as important to look at the temporary changes in sky brightness as it is to look at the long-term impacts of growth and urbanization when investigating these impacts. The investigation this research began is vital, especially as the holiday season is celebrated recurrently and the accessibility of LEDs and other lights with high likelihood of scattering permeate the market. Malignant effects are likely to get worse over the years as these lights become more popular, and the best that can be done right now is to gather the most information possible: to learn about what causes increased and damaging levels of light pollution, and then utilize that knowledge to begin to address these effects.

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