An analysis of SQM Data for the Kishwauketoe Nature Conservancy

Simon D. Mork[1]

[1] University of Chicago, 1009 E 57th St, Chicago, IL 60637

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Abstract:

We present a schema for routinely and accurately measuring the quality of the night sky given a one-dimensional stream of SQM readings stretching back many months (or years) at five-minute intervals. Data was analyzed with Python[1][2] and included splicing and cleaning the data to account for daylight hours, cloudiness, and ambient moon brightness. We find that the Kishwauketoe Nature Conservancy can be described as having an intrinsic sky-brightness of 20.36±0.02 mag/arcsec^2.

Introduction:

The Kishwauketoe Nature Conservancy (KNC), located in Williams Bay, Wisconsin, is, at the time of writing, in the process of drafting an application to the International Dark Skies Association for an Urban Night-Sky Place designation. As such, it was required that accurate measurements of the quality of the sky at KNC needed to be taken to supplement the application. To facilitate this, a single Unihedron SQM-LU-DL sky quality meter[3] was deployed in the heart of KNC on 2/26/2021 and remains mounted to a permanent fixture. It records the sky-brightness in mag/arcsec^2 every 5 minutes and stores the data locally. Data was retrieved on a roughly bi-monthly basis and combined into one master data file. We report an analysis of the data recorded from 2/26/2021 to the most recent retrieval date of 6/29/2021.

Methodology:

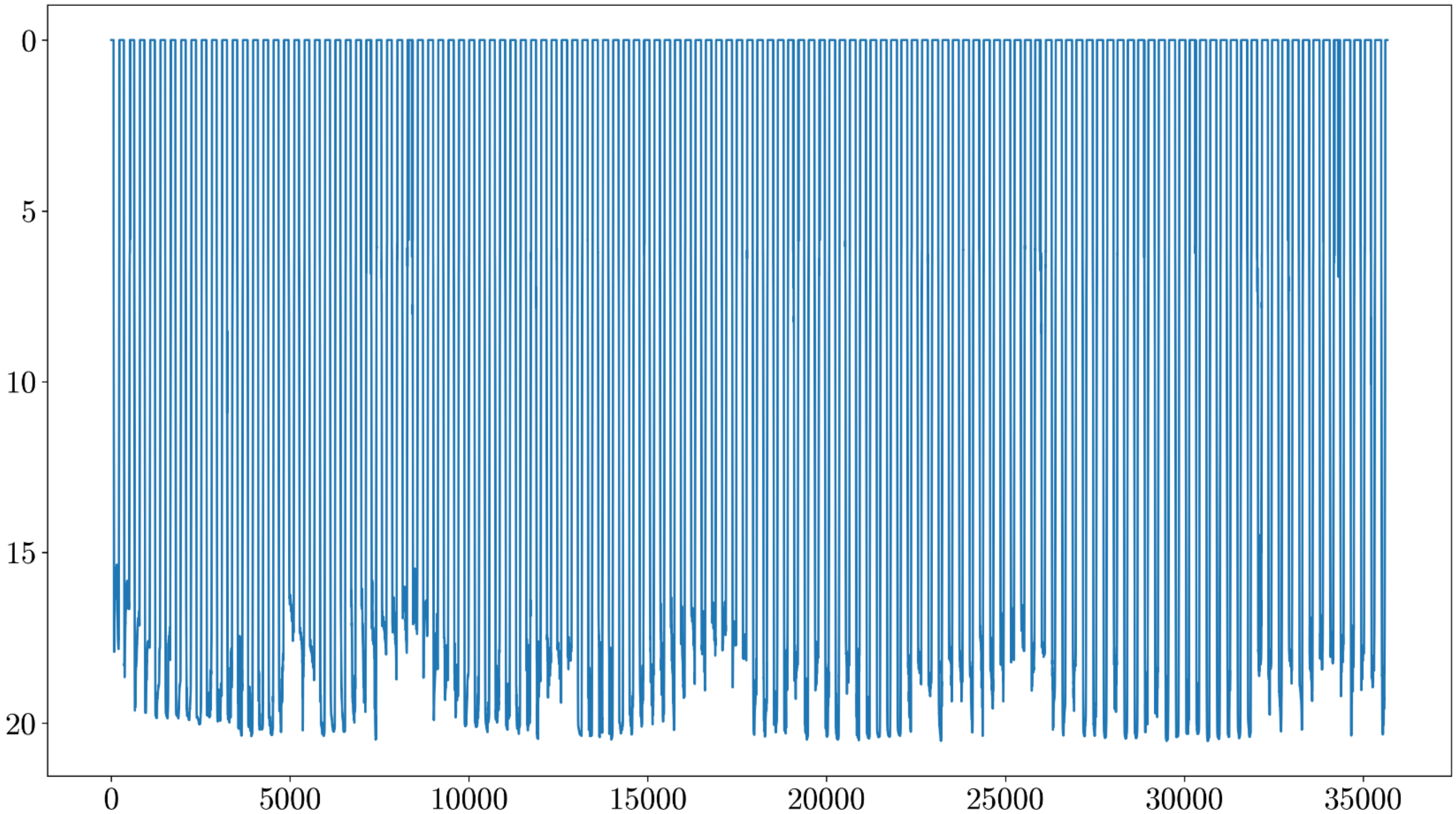

Figure 1: A continuous line plot of brightness (mag/arcsec^2) vs time (number of 5-minute intervals since 2/26/2021). The y-axis inverted for intuitiveness: a lower point represents a darker sky.

Simply plotting the one-dimensional data raw in Figure 1, we can see how there is a nice cyclic behavior between times when the sensor reads 0 (daylight hours) and then spikes (nighttime hours). Each "peak" in the graph is one day in real-time. However, this visualization lacks clarity and readability. To resolve these issues, each day of data was plotted over the last to give a better representation of trends in sky-brightness over time. This was achieved by splicing the data into chunks by day where each "day" period is defined as 288 five-minute intervals starting at noon. Once this was completed, each day's worth of data was graphed as a separate line in Figure 2.

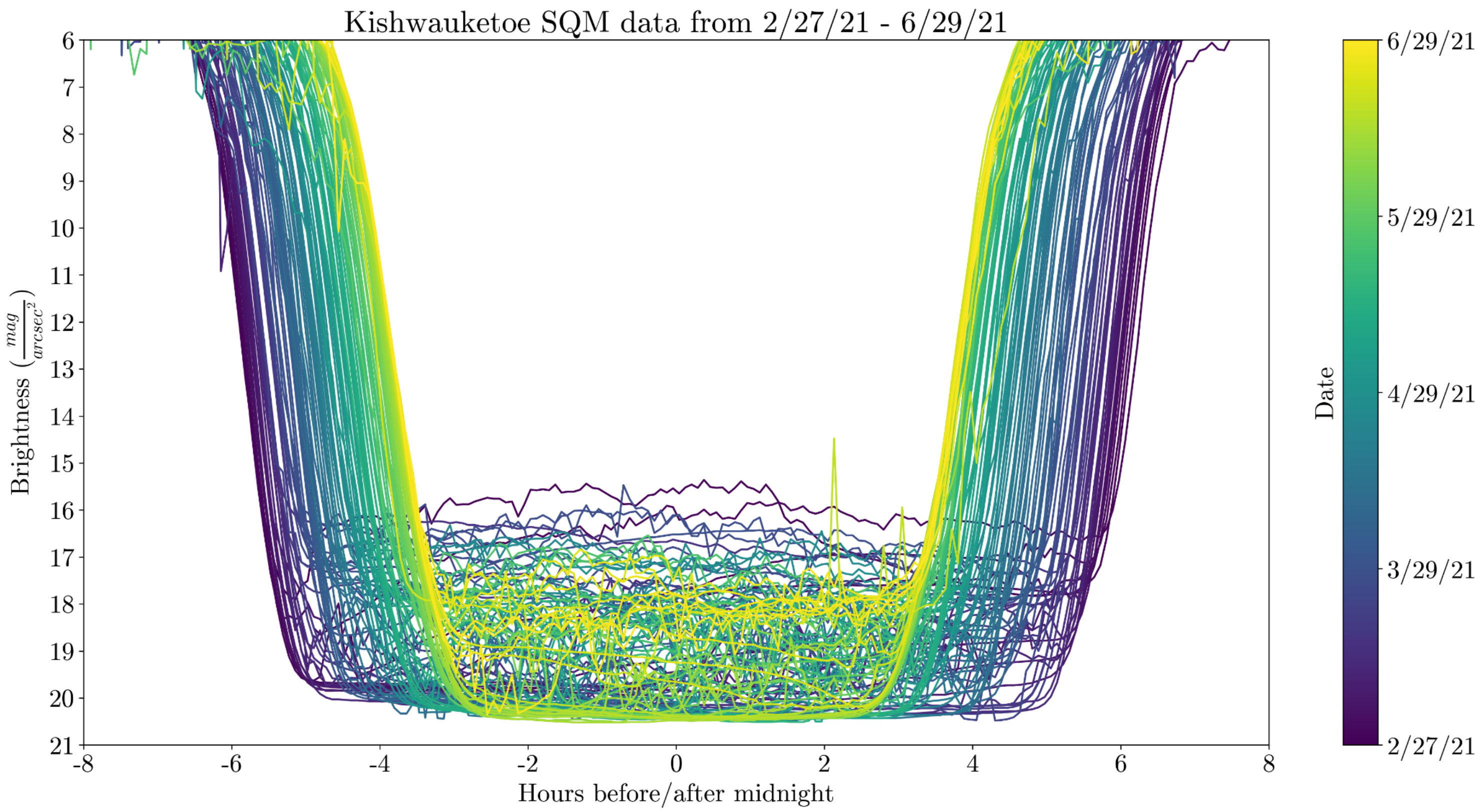

Figure 2: A continuous line plot of brightness (mag/arcsec^2) vs time (hours before/after midnight). Data is overplotted sequentially by day with color representative of date (see colorbar).

As can be seen in Figure 2, the data consistently becomes “narrower” as the days proceed from February to June. This is consistent with what is expected for nighttime hours as the months progress in Wisconsin: nights are longer in the winter (February) and shorter in the summer (June). However, not all nights have perfectly smooth lightcurves, potentially due to cloud coverage and/or light from the moon. Rather, a significant number of nights have lightcurves that are jagged or diverge from the otherwise inverted bell shape that would ideally appear from a clear, moonless night.

Moon Effect:

On moonlit nights, or any night in which the moon is partially lit and above the horizon, the light from the moon will cause the sky to be noticeably brighter than when it is not visible. The intensity of this effect varies with the phase of the moon. On a clear night with a full moon out, the sky can only get as dark as 18 mag/arcsec^2 [4]. However, on nights where the moon is up and in a waning/waxing crescent phase, the skyglow from the moon is negligible in all but the darkest sites.

Cloud Effect:

Since clouds scatter the light from ground-based sources, this causes the graphs to appear more jagged than the smooth ones created from clear nights. Since KNC is not in a completely rural area, light from the surrounding community and the greater Geneva Lake area reflects off clouds to brighten the overall sky. Since the sky will brighten more on cloudy nights in light-polluted areas compared to completely dark areas, cloud brightness can indicate how light-polluted an area is. The opposite effect occurs in darker areas since the clouds principally block the starlight instead of reflecting city-light as they do in more populated areas[5].

In order to get a rudimentary idea of how our brightness measurements trend over time for KNC, a box plot for each night of data was calculated and then plotted sequentially. Since astronomical twilight (when the sky is considered “dark” enough for astronomical observations) varies on a nightly and seasonal basis, only data within the timespan of 04:00 to 08:00 UTC for each night was considered when creating the boxplots. This was done for simplicity’s sake, since, as can be observed from Figure 2, this timespan is dark regardless of the season at KNC. A least-squares-regression (LSQR) line was then created based on each night’s median value (means were too inaccurate due to dataset skewing and outliers) and then plotted. The combined plots are shown in Figure 3

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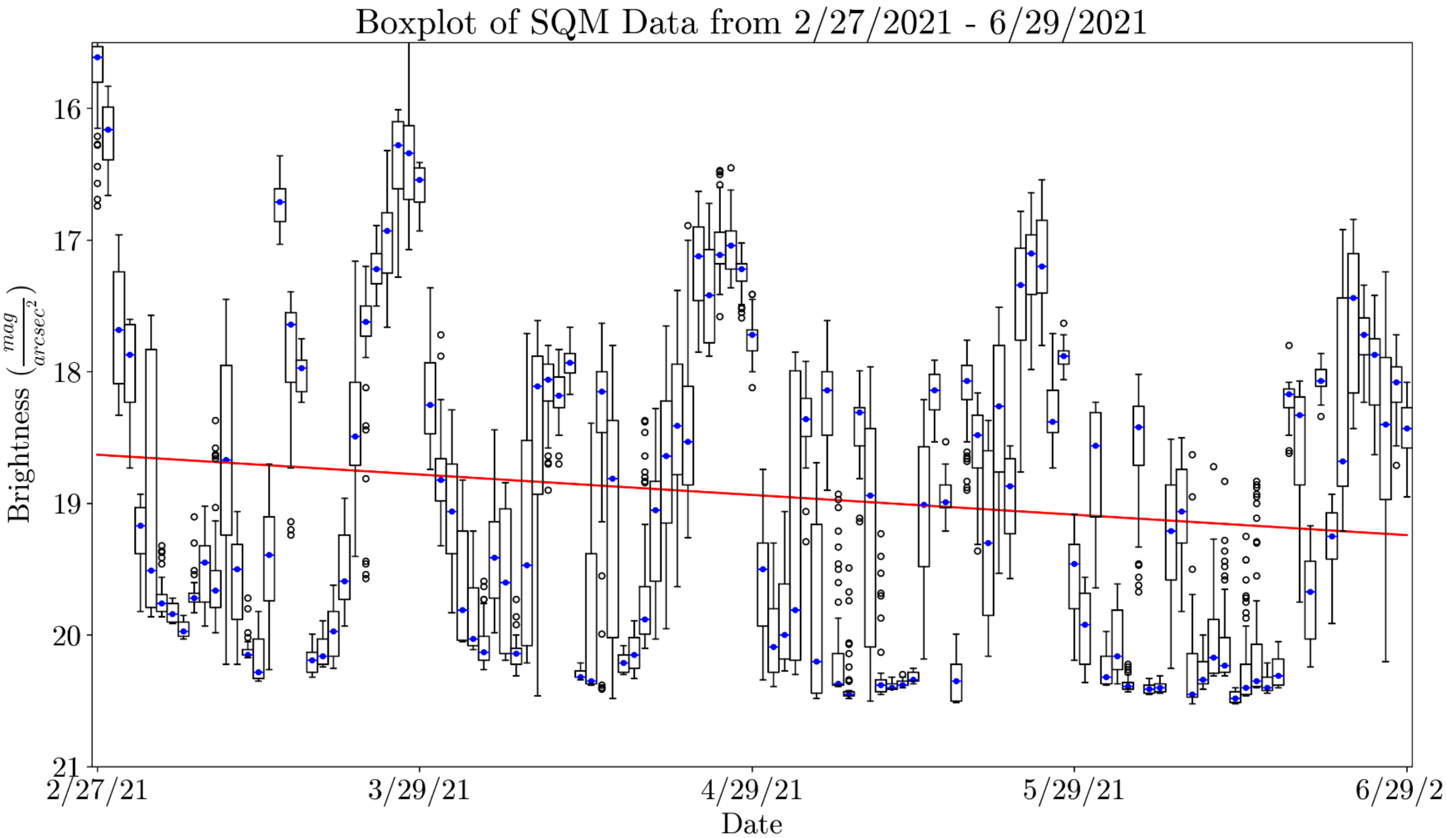

Figure 3: Box plots of brightness (mag/arcsec^2) for each day of spliced (04:00 - 08:00 UTC) data. Median values for each day are plotted as blue dots with their LSQR line plotted in red.

Analysis:

As can be seen from Figure 3, the LSQR line has a slightly positive slope of 0.005 (appearing negative due to the inverted y-axis). However, this slight increase over time may be caused primarily by the sensor itself reading slightly lower in the winter and higher in the summer rather than any human intervention[5].The Midwest is generally cloudier in winter as opposed to summer[6], and snow, like clouds, can also reflect city lights into the sky[5]. To account for the two biggest factors influencing sky-brightness—cloud coverage and moon brightness—the KNC data was cross-referenced with historical weather data as reported by VisualCrossing for the Williams Bay ZIP code (53191)[7]. A new dataset was created excluding any day that did not have perfectly clear cloud coverage for the timespan of 04:00 to 08:00 UTC. Histograms for both datasets were then created in Figures 4 and 5.

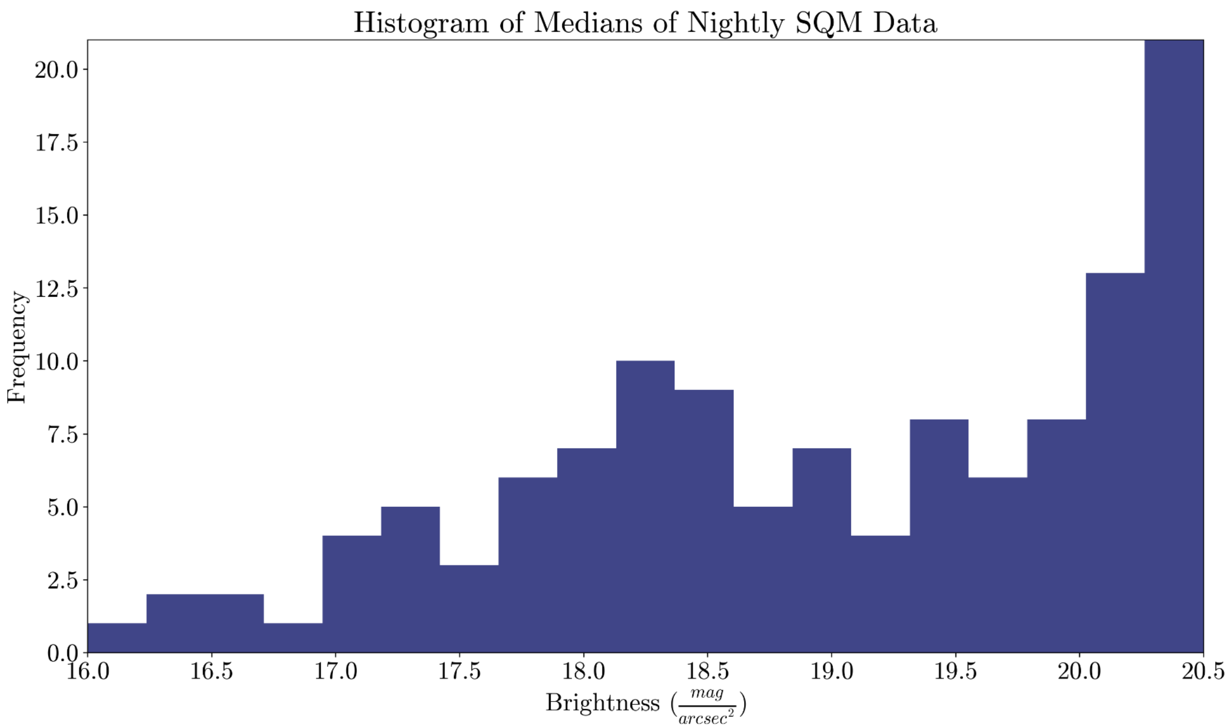

Figure 4: Histogram of median brightnesses (mag/arcsec^2) for each day (no filtering).

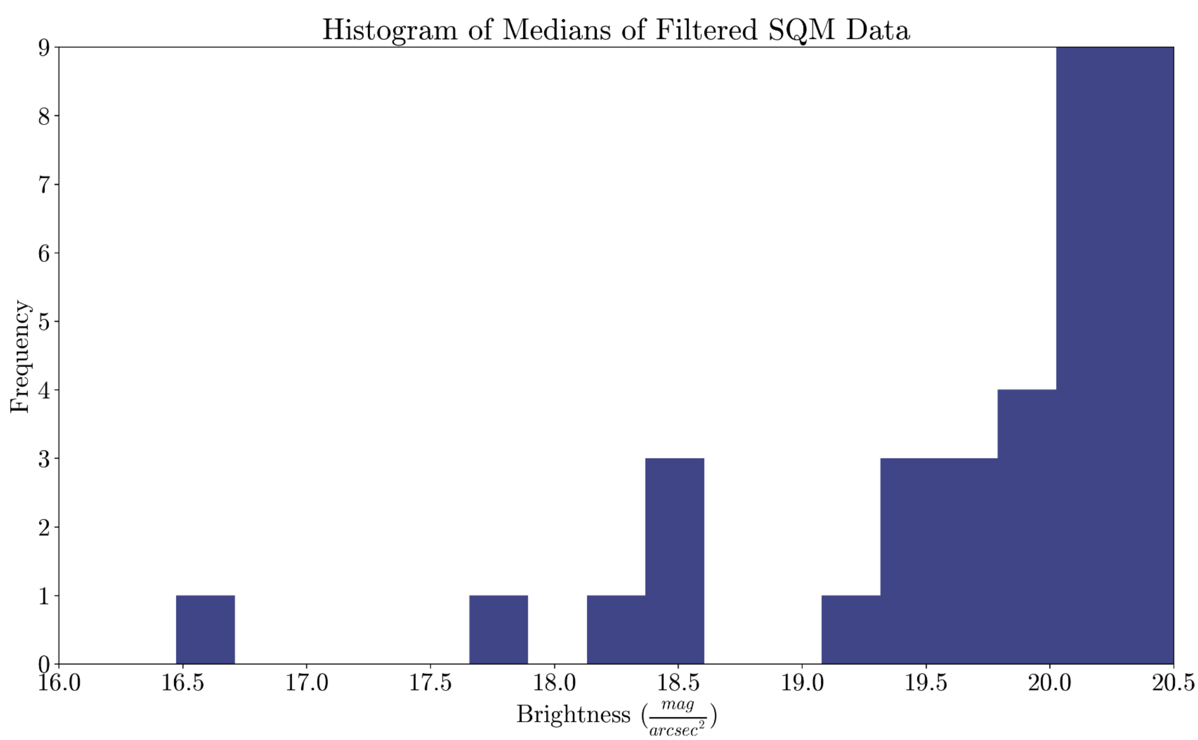

Figure 5: Histogram of median brightnesses (mag/arcsec^2) for each day (no cloudy days).

Comparing Figure 4 and Figure 5, a significant proportion of days that had a median brightness below 19 mag/arcsec^2 were excluded after weather filtering was conducted. However, there were still days that were not filtered out which had a median brightness that was less than ideal. One cause that was immediately identified was that moonlit days were not yet excluded from calculations. To verify this, and also to check that filtering had truly removed days with clouds, Figure 2 was recreated with the weather-filtered dataset and is shown in Figure 6.

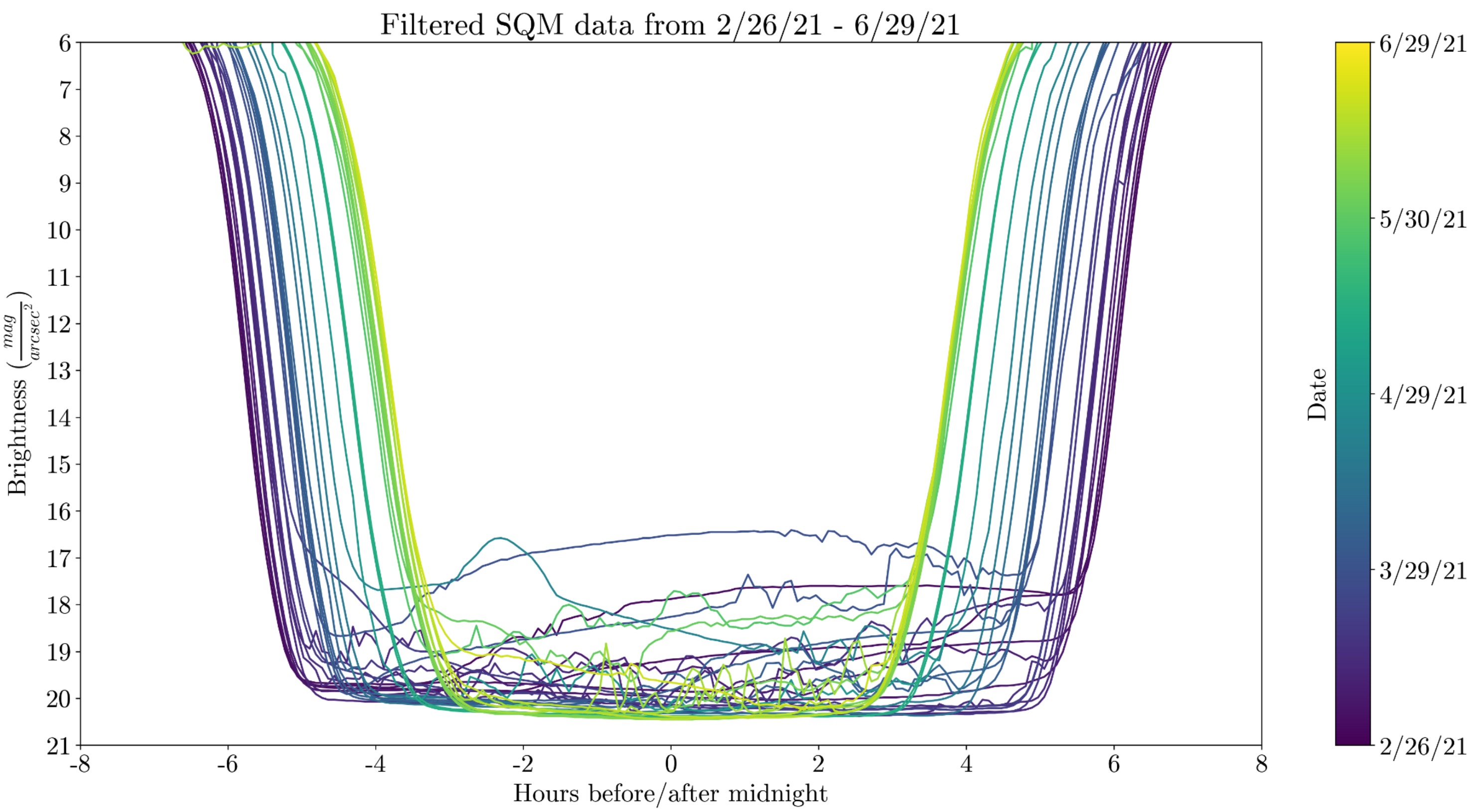

Figure 6: A continuous line plot of brightness (mag/arcsec^2) vs time (hours before/after midnight) for days reported as having clear weather around midnight by VisualCrossing.

As Figure 6 shows, our weather data succeeded in filtering out the majority of the noise that was otherwise present in data shown in Figure 2. However, a number of days still have jagged lightcurves at some points along the graph. This is representative of some cloud coverage that evidently slipped through the cracks. Since we are unsure of the exact methodology VisualCrossing uses to determine cloud coverage for a given ZIP code, it is possible that the cloud coverage data they report is representative of larger trends in the southeast Wisconsin area, and not a specific measurement for Williams Bay itself. The data was filtered a second time by manually plotting each day of data reported by VisualCrossing as having clear skies for a visual inspection of whether it was truly clear based on the smoothness of its respective lightcurve. As such, only lines without any jaggedness around midnight were accepted as clearIn addition, since days that were brightened by a full moon had not yet been filtered out of the dataset, only days where the moon was below the horizon from 04:00 - 08:00 UTC were accepted. Of the 35 days identified by the weather data as being "clear", only 10 were truly clear with no moon present. A final histogram for these 10 days was then created.

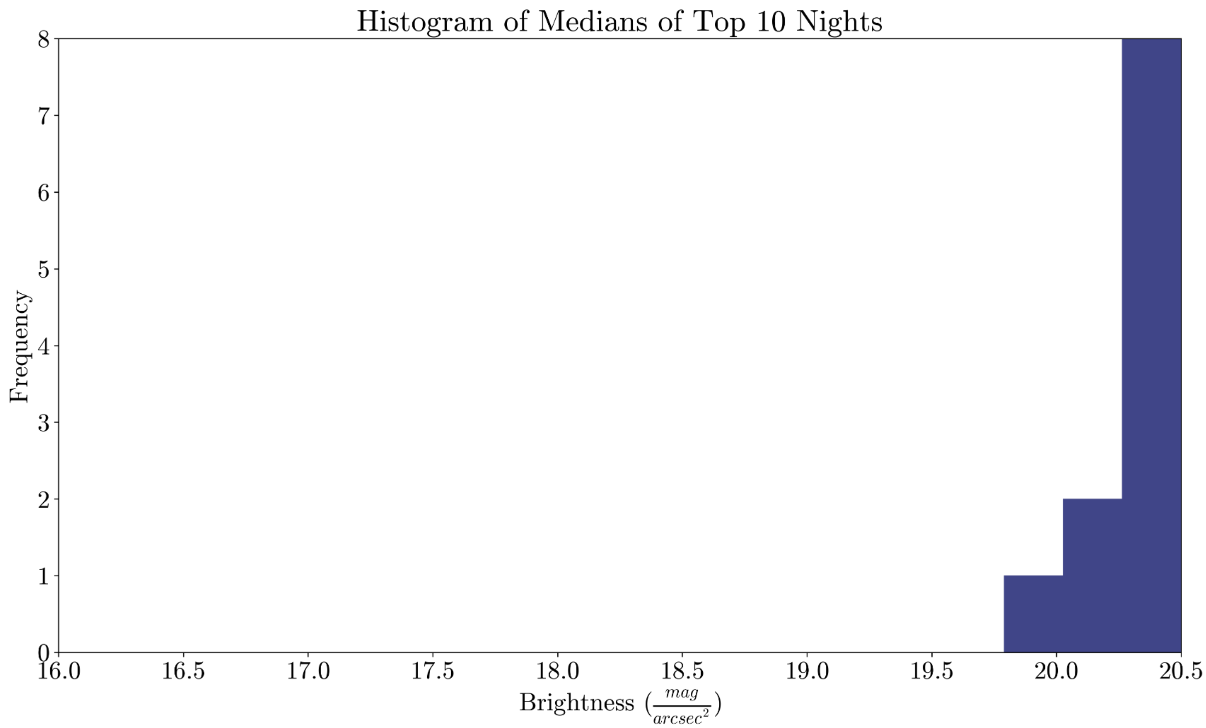

Figure 7: Histogram of median brightnesses (mag/arcsec^2) for the ten clear nights.

A median of the final dataset that generated the histogram shown in Figure 7 was then calculated to be 20.34 mag/arcsec^2. Within the final dataset, a span of three perfectly clear nights during a new moon was identified. Taking the median brightness of these three days and then the median of these three medians produces a sky-brightness measurement of 20.38 mag/arcsec^2 in a best-case scenario for KNC. Combining these two boundaries identified in a typical and best-case scenario gives us a value of 20.36±0.02 mag/arcsec^2.

Verification:

In order to verify that the value of 20.36±0.02 mag/arcsec^2 is an accurate measurement for the quality of the night-sky at KNC, a density plot was also created for the unfiltered SQM data in order to get a more intuitive sense of the long-term trends of the sky-brightness at KNC and is shown in Figure 8.

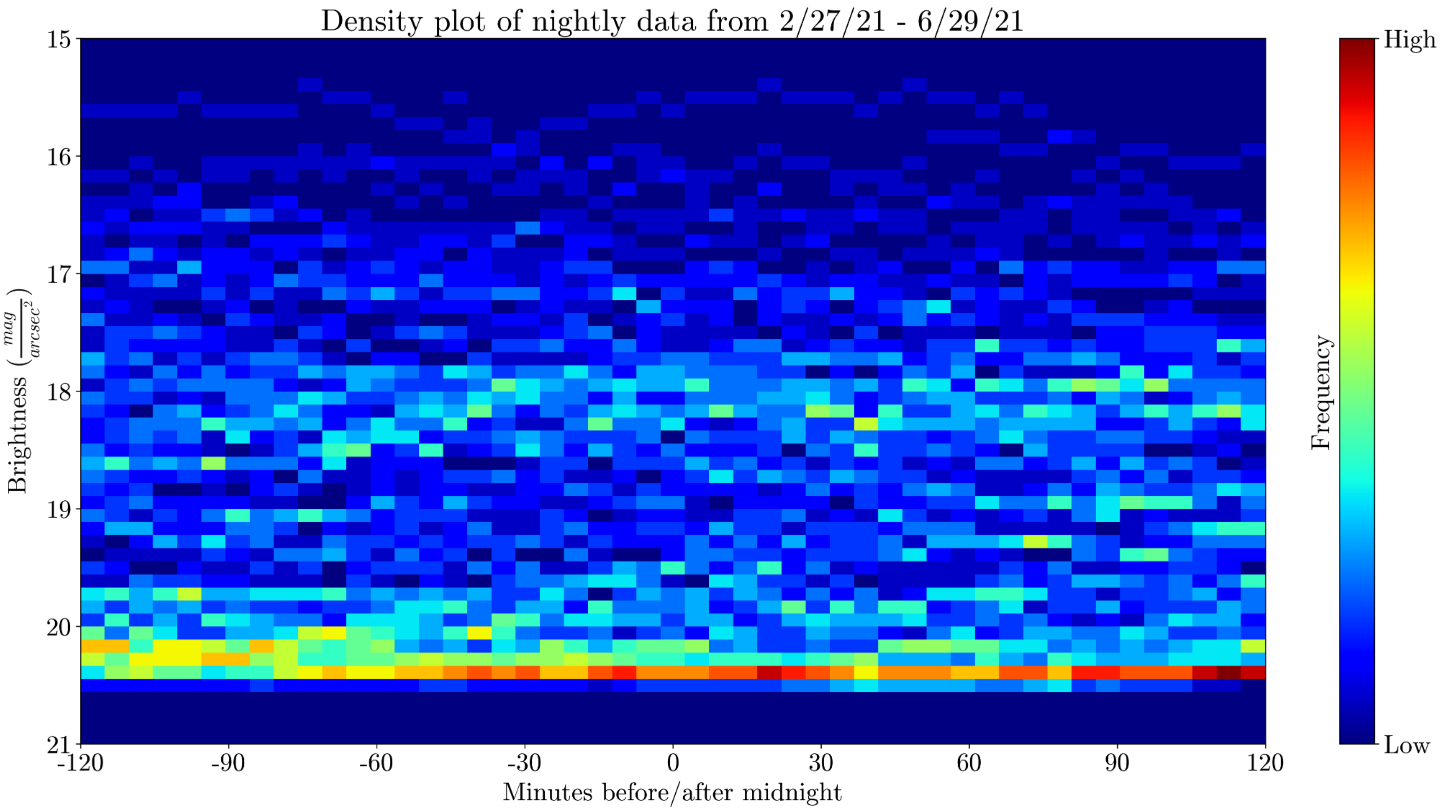

Figure 8: Density plot of brightness (mag/arcsec^2) near midnight.

The reddest region appears right at the bin corresponding with 20.36 mag/arcsec^2. This fits perfectly between our two measurements of both the median of the medians for the ten clear days and three perfect days mentioned at the end of the analysis section. This is a strong indicator that our measurement of 20.36±0.02 mag/arcsec^2 for the long-term sky-brightness at KNC is accurate.

A number of other observations can be made from Figure 8. One being that, based on based on the moon effect and cloud effect discussed in the methodology section, we can see the significant amount of noise present above the orange-red line generated from clear and dark conditions in Figure 8. In particular, there is a second, duller ridge present in Figure 8 at roughly 18 mag/arcsec^2 that is likely caused by brightness of the moon since the sky-brightness during a full moon is roughly 18 mag/arcsec^2 [4]. Since the ridge at 18 mag/arcsec^2 very likely originates from the full moon, the majority of the other noise present in the data is likely caused primarily from cloud coverage (and perhaps a small amount from snow reflection). We can verify both of these claims by creating a second density plot using only the ten clear-sky moonless days identified by both weather data and a visual inspection.

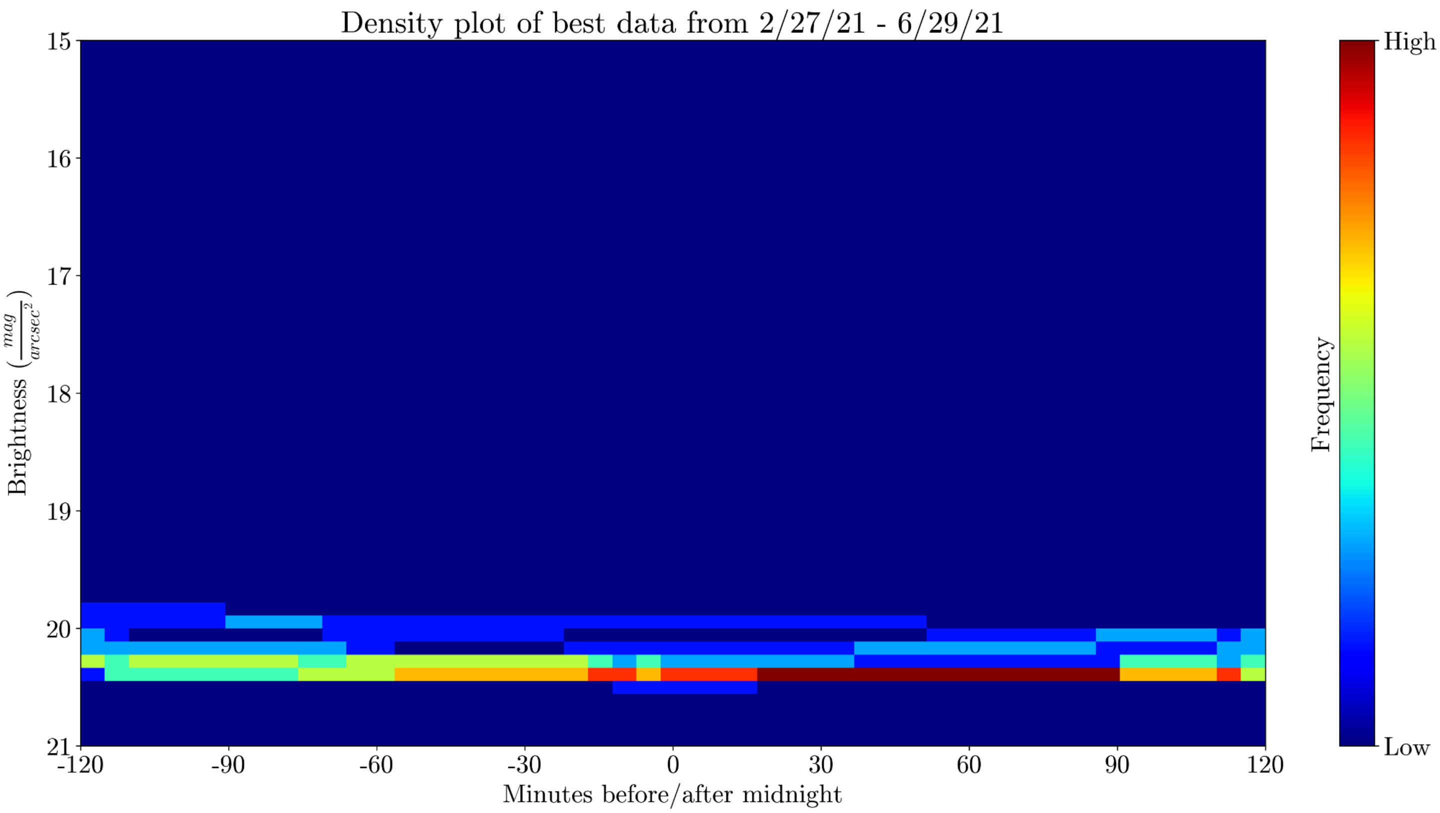

Figure 9: Density plot of brightness (mag/arcsec^2) near midnight for the ten best days identified.

Comparing both Figure 8 and Figure 9, we can see how by removing both moonlit nights and cloudy nights from our dataset, virtually no noise makes it through into the final dataset. Both of these plots support our assessment that the quality of the night sky at KNC, as a single measurement, is 20.36 ± 0.02 mag/arcsec^2.

Dataset	Median of daily medians (mag/arcsec^2)
Raw Data	19.06
VisualCrossing Filtered	20.03
Manually Filtered	20.34
Best Case Scenario	20.38

Table 1: Summary of filtering operations done to determine the quality of the night-sky at KNC. Raw data indicates no filtering, VisualCrossing filtered indicates initial weather filtering. Manually filtered indicates by-hand weather filtering and moon filtering. Best case indicates perfect conditions (no clouds/new moon).

Future Studies:

Other analyses have posited that the effect of light reflecting off snow-covered surfaces might produce a measurable change in the overall brightness of the sky[5]. This was not considered in this analysis, partly because snow had only accumulated in Williams Bay for 10 days out of the 123 considered in this study, and also because such analyses of SQM data found that snow had minimal effect in changing the overall trends of sky-brightness data[5]. In addition, other studies found that the sensor reported higher values of mag/arcsec^2 for lower temperatures and lower values of mag/arcsec^2 for higher temperatures[5]. We believe this is what causes the positive slope for the LSQR line in Figure 3, but more study is recommended to quantify just how significant the influence is. In general, this study has also uncovered the beneficial aspects of operating a weather sensor alongside the location at which any SQM sensor is deployed. Not only would the weather measurements be more accurate, but it would provide a second dataset from which to make adjustments based on.

Conclusion:

We have outlined a step-by-step and repeatable way of reducing SQM data down to a single value representative of the condition of the night sky for a clear, moonless night at any given site. This aids in quantifying how bright an area is so that simple measurements can be compared to one another in a way that is easy for anyone to understand and may help ease the process of disseminating information during public outreach. Graphs presented within may also aid in the communication of our results.

Acknowledgements:

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