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Night sky brightness above Zagreb, Croatia, 2012-2017

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Abstract

Night sky brightness at the RGN site (near the centre of Zagreb, Croatia) was monitored from January 2012 to December 2017. The gathered data shows that the average night sky brightness in this period did not change significantly, apart from differences caused by yearly variations in meteorological parameters. The nightly minima, maxima and mean values of the sky brightness do change considerably due to changes in meteorological conditions, often being between 2 and 3 magnitudes. The seasonal probability curves and histograms are constructed and are used to obtain additional information on the light pollution at the RGN site. They reveal that the night sky brightness clutters around two peaks, at about 15.0 mag/arcsec^2 and at about 18.2 mag/arcsec^2. The tendency to slightly lower brightness values in spring and summer can also be seen in the data. The two peaks correspond to cloudy and clear nights respectively, the difference in brightness between them being about 3 magnitudes. A crude clear/cloudy criterion can be defined too: the minimum between two peaks is around 16.7 mag/arcsec^2. The brightness values smaller than this are attributed to clear nights and vice-versa. Comparison with Vienna and Hong-Kong indicates that the light pollution of Zagreb is a few times larger.

Keywords

Light pollution, night sky brightness, site testing, atmospheric effects, Zagreb

1. Introduction

Light pollution (LP) is most simply defined as any artificial light that spills into the environment. More elaborate definitions of various aspects of light pollution can be found in literature (see for instance **Mizon 2012**) or on the web pages devoted to light pollution, like those of the International Dark Sky Association (***IDA1, 2017***) or Wikipedia (***Wiki2, 2017***). The impact of light pollution on the environment and humans is very complex and still not well understood (see for example **Narisada, 2004**). In all studies of such an impact, the most important parameter is the amount (intensity) of the light pollution and its duration. Techniques of measuring and characterization of light pollution are still evolving and just a few instruments and procedures exist today (**Hanel, 2017**). Apart from global data on light pollution in the form of various satellite images and maps (see for instance **Falchi, 2016**), data for sites or environments are still scarce and not monitored on a regular basis. In Croatia, light pollution was, to our knowledge, mentioned for the first time in an article in a popular astronomy magazine in 1993 (**Andreić, 1993**). The first efforts to measure light pollution were taken during the 2002 Summer school of astronomy that took place in Višnjan, Istria (*ZEC, 2018*). Since, at that time, no dedicated instruments for measuring light pollution existed, an astronomical CCD camera was used in these attempts. In 2006, all-sky photography and SQM instruments were introduced and the first usable data on LP was obtained, limited to several places in the Istria peninsula. The first model of light pollution in Croatia was finished in 2007. (Andreić, 2011). The situation today is not much better. Apart from a few measurements that amateur astronomers did for their needs (***LPO1, 2018***) and a few measuring campaigns in the past (see for instance **Andreić, 2012**; **Sharma 2015**), the only systematic long-time observations of light pollution are those carried on at the RGN site (started in 2012.) and at the site of the Merenje observatory, located about 30 km NW from Zagreb (started in 2014).

2. Data acquisition and reduction

The night sky brightness was measured by an SQM-LE instrument (***Unihedron1, 2017***) permanently placed on the roof of the building (see **Figure 1**) of the Faculty of Mining, Geology and Petroleum Engineering in Zagreb (45.80701° N, 15.96398° E, approx. 150 m above sea level). The building itself is near the town centre, about 1.2 km air-line from the Zagreb main square. The instrument looks straight into the zenith. As the faculty building is among the highest in the surrounding area,

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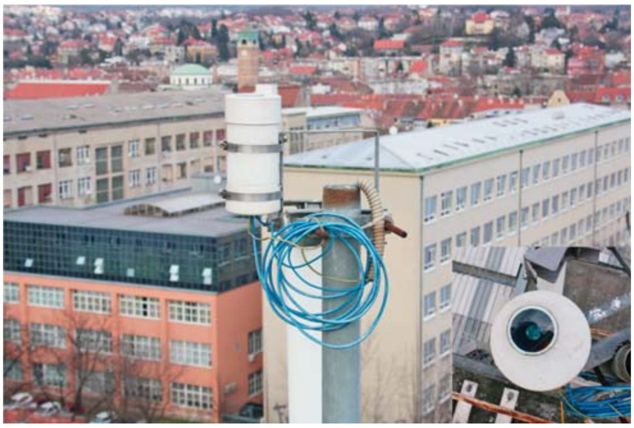

Figure 1: The SQM-LE instrument is mounted on the roof of the faculty building. The instrument itself is put inside a protective box (white) for protection from environmental impacts. The only maintenance required is periodical cleaning of the glass window on the top of the protective box. The inset at bottom-right shows top view of the enclosure, with glass window and the instrument visible inside.

there is no direct influence of lights from nearby buildings or street lighting on the measurements. The data is read by a remote PC connected to the SQM-LE by an ethernet cable. The instrument operates continuously, apart from power and hardware failures that produced several large and a lot of smaller "holes" in the data set in the abovementioned period.

The SQM measures the sky brightness in standard astronomical units of magnitudes per square arc-second. This brightness scale is used throughout this paper. This astronomical brightness scale is a reversed logarithmic scale (Wiki1 2017) meaning that larger values on the scale represent smaller brightness. The measuring unit is called "magnitude" and is equal to a brightness ratio of 2.512 (or, exactly the 5th root of 100). If conversion to linear units is needed, one can use the following **Formula 1 (**Unihedron2 2017**)**:

$$[\text{value in cd/m}^2] = 10.8\times10^4 \times 10^{(-0.4*[\text{value in mag/arcsec2}])} \quad (1)$$

The main reasons for the popularity of SQM instruments are affordability and ease of use. On the other hand, they are not built to professional standards and this should be kept in mind during the data analysis process. Both the manufacturer (***Unihedron3, 2017***) and the independent analyses of the instrument accuracy (**Cinzano, 2005**; **Schnitt, 2013**) lead to the same conclusion: the accuracy of the SQM is of the order of 10 %, a very nice achievement when we take into consideration that this accuracy is kept over a large range of brightness levels (about 10^4 on linear scale).

The measured brightness values are displayed with two decimal places of the magnitude scale, indicating

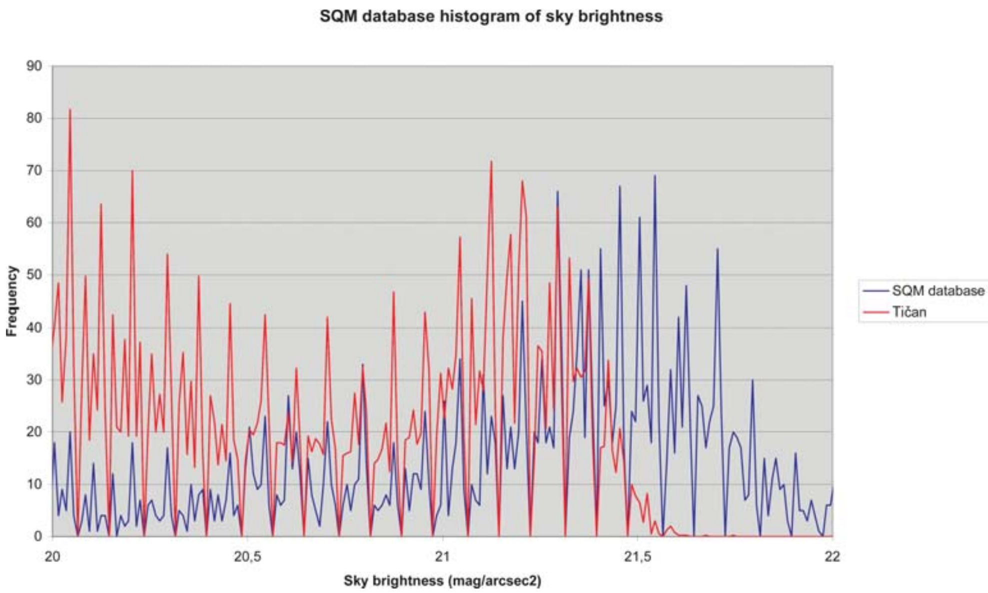

Figure 2: The detail of a histogram of measured values of the night sky brightness with a 0.01 magnitude bin width clearly shows that some brightness values never appear in the SQM measurements. At the same time, nearby values (a few hundredths of magnitude larger or smaller) are quite common, giving the histogram the appearance of a periodically oscillating curve. The red line represents a histogram created from 32000+ measurements made with an SQM-LE instrument at the astronomical observatory Tičan (Istria peninsula, near the town of Višnjan), while the blue line represents a histogram created from 4000+ measurements from the world-wide base of SQM measurements (SQM database 2017) that is created by collecting data from observers all over the world. These observers used hand-held SQM or SQM-L devices on their own, meaning that almost each measurement was made with a different device, proving that the effect is not a malfunction of a particular unit but a common characteristic of all SQM devices. To ease comparison, the Tičan curve frequencies are divided by 4.

accuracy of the order of 1 %. The second decimal place is not needed at all, as 10 % accuracy is represented by tenths of the magnitude (i.e. the first decimal place), but the instrument shows it. In detailed analysis of our data, we discovered that internal A/D conversion in the SQM cannot produce all values of brightness levels that the display can show. The reason for such behaviour is hard to detect without complete knowledge about the device construction and conversion process. This does not degrade the abovementioned 10 % accuracy but can cause problems if one tries to do analysis on finer brightness levels, as some intensity values at the 1 % level are not present at all. This is nicely illustrated in **Figure 2**.

The raw data (see **Figure 3**) were first reduced in size by rejecting measurements taken during the daytime. The SQM cannot measure large sky brightness that appears during the daytime, but is not smart enough to stop measuring during the day. Thus, about 50% of the data is meaningless values that are removed from the data set before further analysis. After that, the data is divided

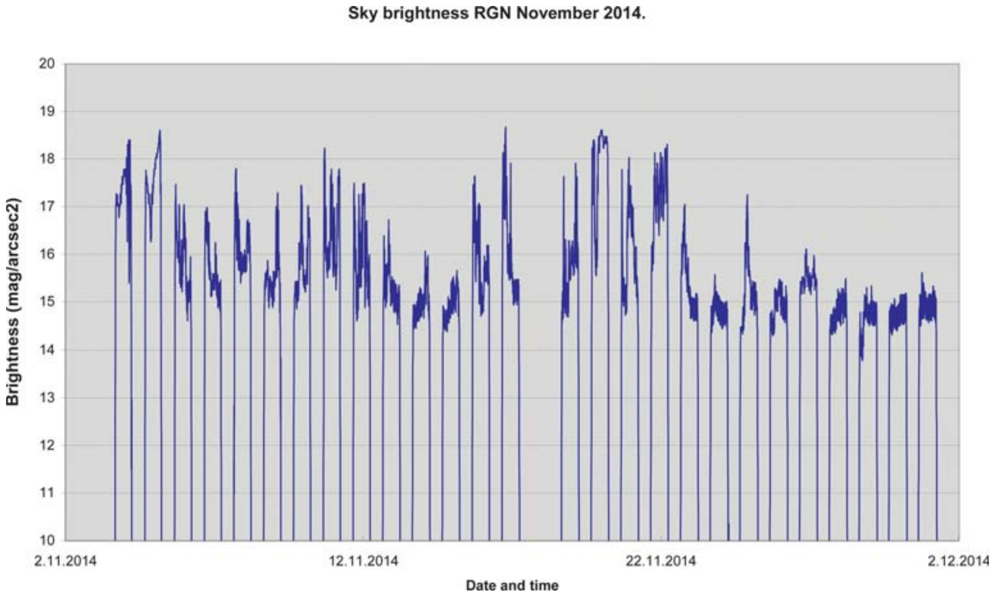

Figure 3: The raw measurements of the sky brightness, as taken by the SQM-LE instrument. Note that astronomical brightness scale is used. This is a reversed logarithmic scale (i.e. larger magnitude values represent lower brightness).

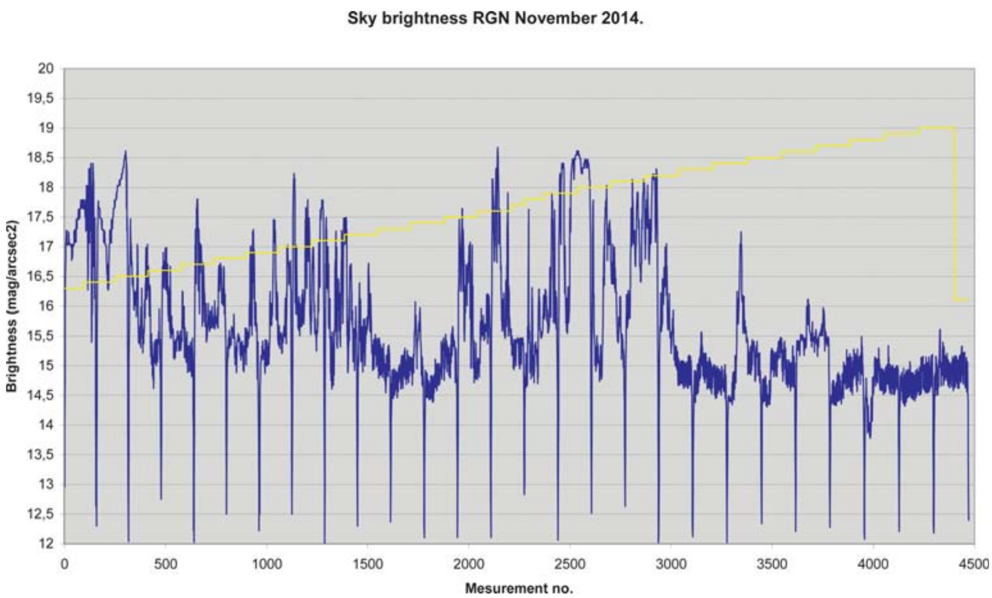

Figure 4: The sky brightness graph after removing day measurements and time stamps from the dataset. The yellow line represents days in the current month and serves to detect any "holes" (missing data) in the dataset. It is created using the formula (day number)/10+16. Note that the day number changes at midnight. The brightness peaks at the end/beginning of night are caused by twilight.

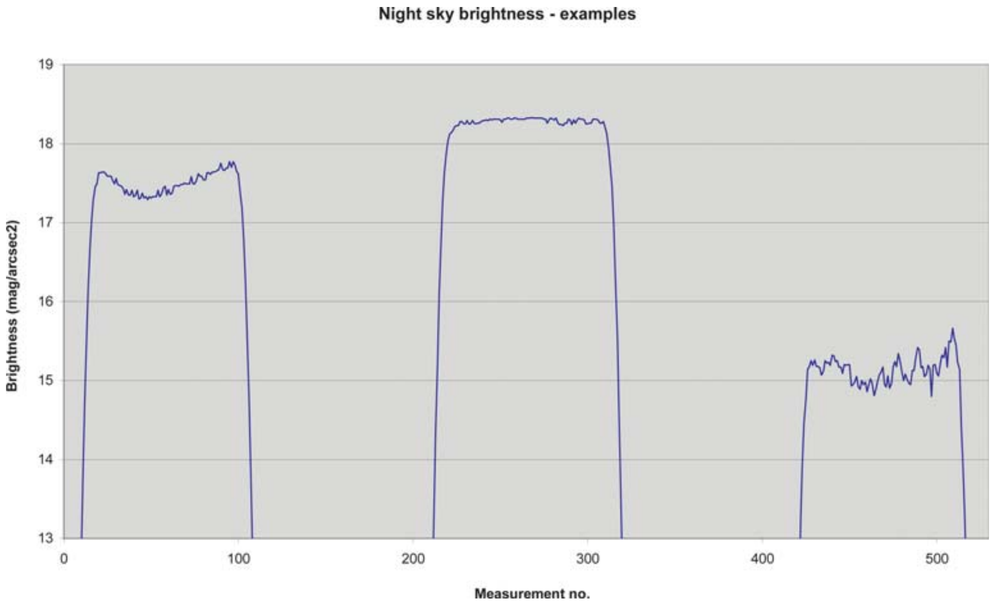

Figure 5: The examples of a clear night with a strong moonlight (left), a clear, moonless night (middle) and a cloudy night (right). All three examples are from measurements at the RGN site. The effect of moonlight is more pronounced on sites with less light pollution.

into more manageable sets covering individual months of the year in question.

Next, the time stamps of individual data points are replaced by the ordinal number in the current data set. If this is not done, the daily gaps will still be present on the graphs. The intention behind the removal of the date/time stamps is to use the graph area more efficiently. To retain basic information about the dates of the measurements in question, the day number (in the month in question) was kept in the dataset. An example plot of such a dataset is shown in **Figure 4**. Such plots were created for the whole time period from January 2012. up to December 2017. These plots are very useful in interpreting the results of the measurements. They can all be accessed on the Light Pollution Observatory site (***LPO2, 2018***).

The first question that arises when analysing such a dataset is whether the sky was clear, clouded or foggy. At least for a heavily light polluted site, as is this one, the answer can be found quite easily: the clouds scatter much more light downwards than the clear atmosphere, and consequently, the brightness of the night sky measured during cloudy nights is much larger, typically 3 or more magnitudes for this particular site. Also, the brightness oscillations are much faster and often larger than in the case of a clear night. The effect of the moonshine can be detected as a slow, and rather smooth, rise (or drop) of the sky brightness. These conditions are illustrated in **Figure 5**. If needed, the periods when the Moon is above the horizon can be easily obtained from a planetarium or ephemerids software, for instance SkyChart (***SkyChart, 2017***) or Ephem (***Ephem, 2017***), both being freeware.

The way the analysis is carried on depends on the purpose for which the results are needed. If we are looking for clear sky values, as needed by astronomers (both professional and amateur), we will search for the minimum brightness, as this determines the best observing conditions achievable at the site in question. Additionally, the frequency of occurrence of such conditions, and the duration of such periods of good sky conditions will be of interest.

On the other hand, if we are trying to assess the influence of light pollution on the biosphere, we will be more interested in the maximal sky brightness, as this is supposed to cause the most impact on the biosphere, and in the frequency of occurrence and the duration of such conditions. The mean values of sky brightness on a nightly, monthly and yearly basis could also be of importance. For such purposes, the cloudiness and presence/absence of the Moon are of secondary interest, or not relevant at all.

To cover all these requirements, it was decided to determine minima, maxima and average values of sky brightness on a nightly basis. The results of these calculations are given graphically in **Figures 6 to 8**. After that, yearly statistics are extracted from the datasets and are summarized in **Table 1**.

3. Results and discussion

In the period between January 2012 and December 2017, about 1/4 (28 %) of the data was lost for different reasons. The most problematic in this aspect are years 2015 and 2016, for which data exists only for the first half of the year. However, the remaining data is more than enough for a sound analysis, and summary statistics (see **Table 1**) do not show any significant differences from year to year that could be related to the missing data.

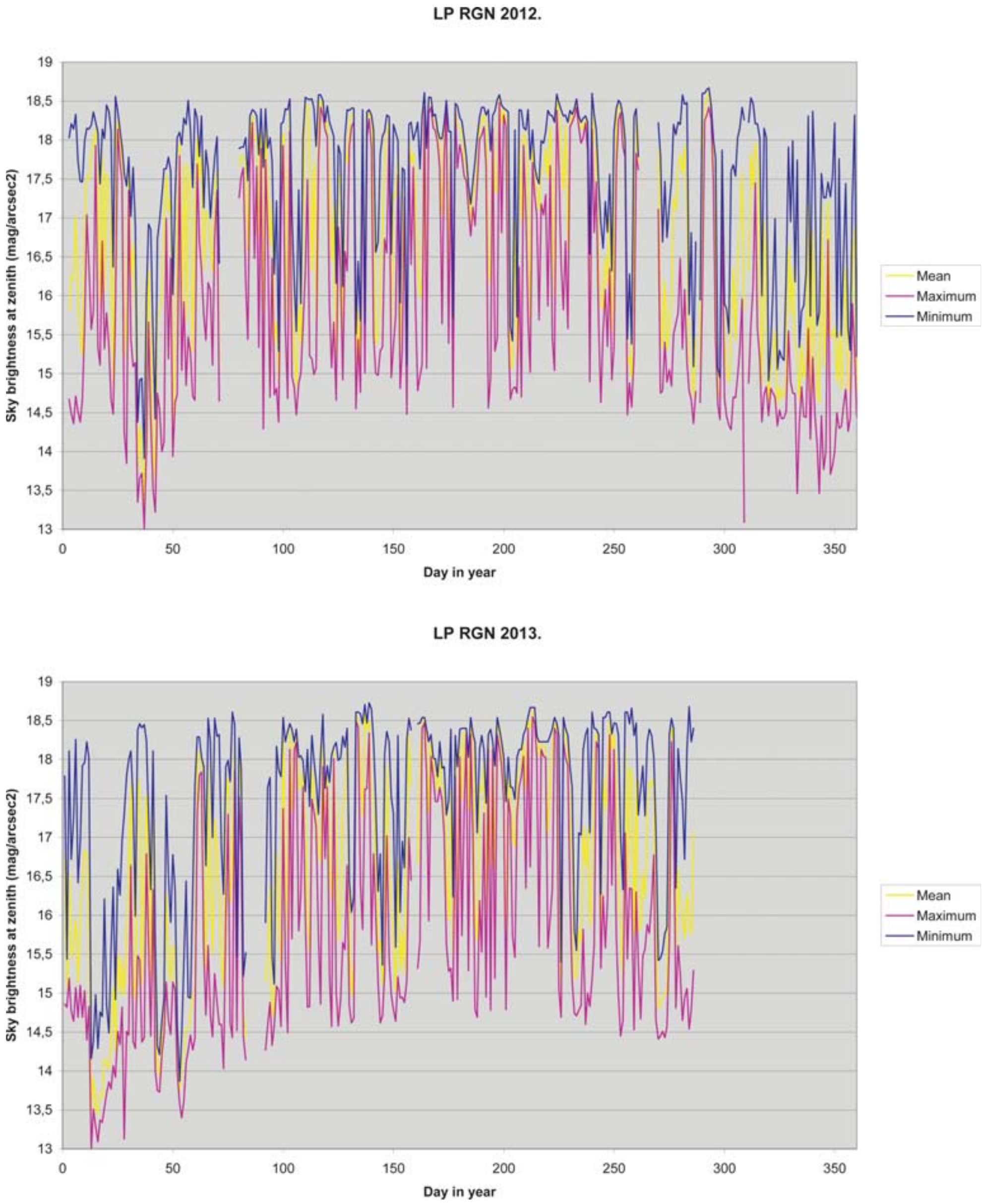

Figure 6: The nightly minima, maxima and average values of sky brightness for years 2012. and 2013.

The first fact that strikes the eye when looking at the graphs on Figs. 6 to 8 is that all the parameters (i.e. minima, maxima and mean values of the sky brightness) change considerably on a nightly basis. The main cause for these variations are changes in meteorological conditions (clouds, fog, atmospheric transparency) that reflect themselves in the amount of light pollution caused. The primary source of light pollution (artificial light) does not change so much and not so rapidly, a fact that can be confirmed by the long-term stability of average night sky brightness over the years (see **Table 1**).

Also, rapid changes that happen during one night are considerable, often being greater than 2 or even 3 magnitudes. Even the mean variations are considerable, being between 1.7 and 1.9 magnitudes from year to year (expressed as yearly averages).

Due to these rapid variations, **Figures 6 to 8** look crowded and difficult to interpret. Thus, the most important statistical data about light pollution on the RGN site are gathered in **Table 1**, and later also presented in different forms in **Figures 9** and **10**.

Table 1 summarises yearly minimums, maximums and average values of the measured sky brightness followed by the nightly variation of these values (also expressed as minimal, maximal and mean values observed over the years), together with information on the number of nights that provided the data for the statistics. The main conclusion that can be drawn from **Table 1** is that the average level of light pollution at the RGN site does not change significantly during the monitoring period (2012 to 2017). This does not mean that the light pollution produced by the town of Zagreb is also stable, it just

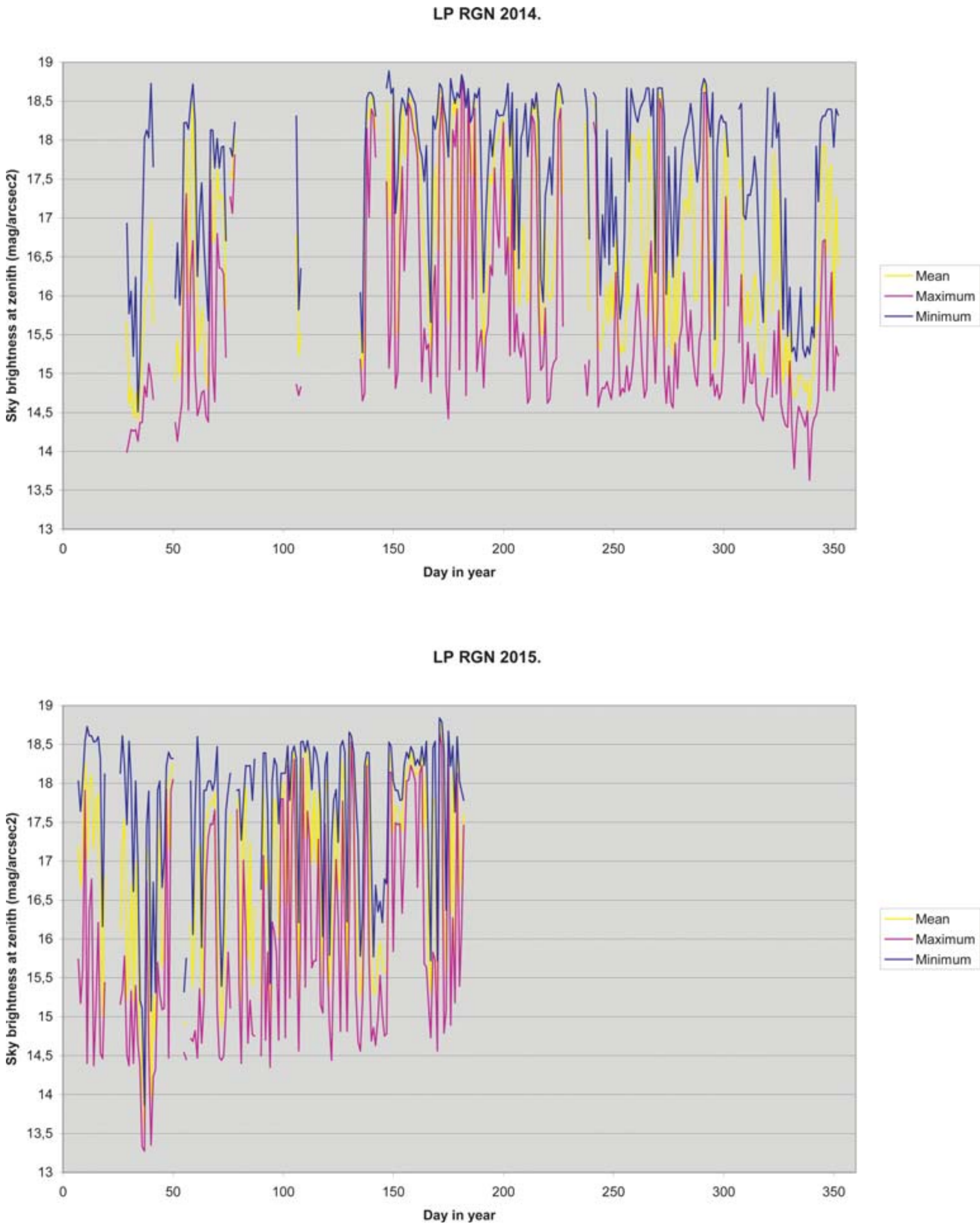

Figure 7: The nightly minima, maxima and average values of sky brightness for years 2014. and 2015.

states the fact that it is stable near the centre of the town. Considering that the centre is fully formed and illuminated a long time ago, it is reasonable to expect that no major changes in the amount of public lighting (being the main cause of light pollution in a town) occurs here. However, the situation might be quite different in suburbs that are rapidly growing, and the public lighting network expands there. What changes this growth produces cannot be concluded from measurements taken near the town centre (the RGN site) and would require additional measuring sites in suburbs that currently do not exist.

Apart from the basic information collected in **Table 1**, the probability that at any given moment (at night of course!) the sky brightness will be smaller (or greater) than a certain value can be needed. This data is given in **Figure 9** in the form of cumulative probability curves derived from the complete dataset at hand. One must keep in mind that seasonal variations are quite large from year to year, so these curves can be used as a rough guide only. Also, it should be noted here that meteorological seasons are used throughout this text.

Finally, a histogram of sky brightness is constructed from all the available data, also on a seasonal basis in Fig. 10). It gives the probability that at any given moment the sky brightness will have a certain value (or more precisely, will be in the corresponding brightness bin). The histogram bins are 0.1 mag in width, corresponding to the accuracy of the SQM device and avoiding bad data representation at finer scales, described be-

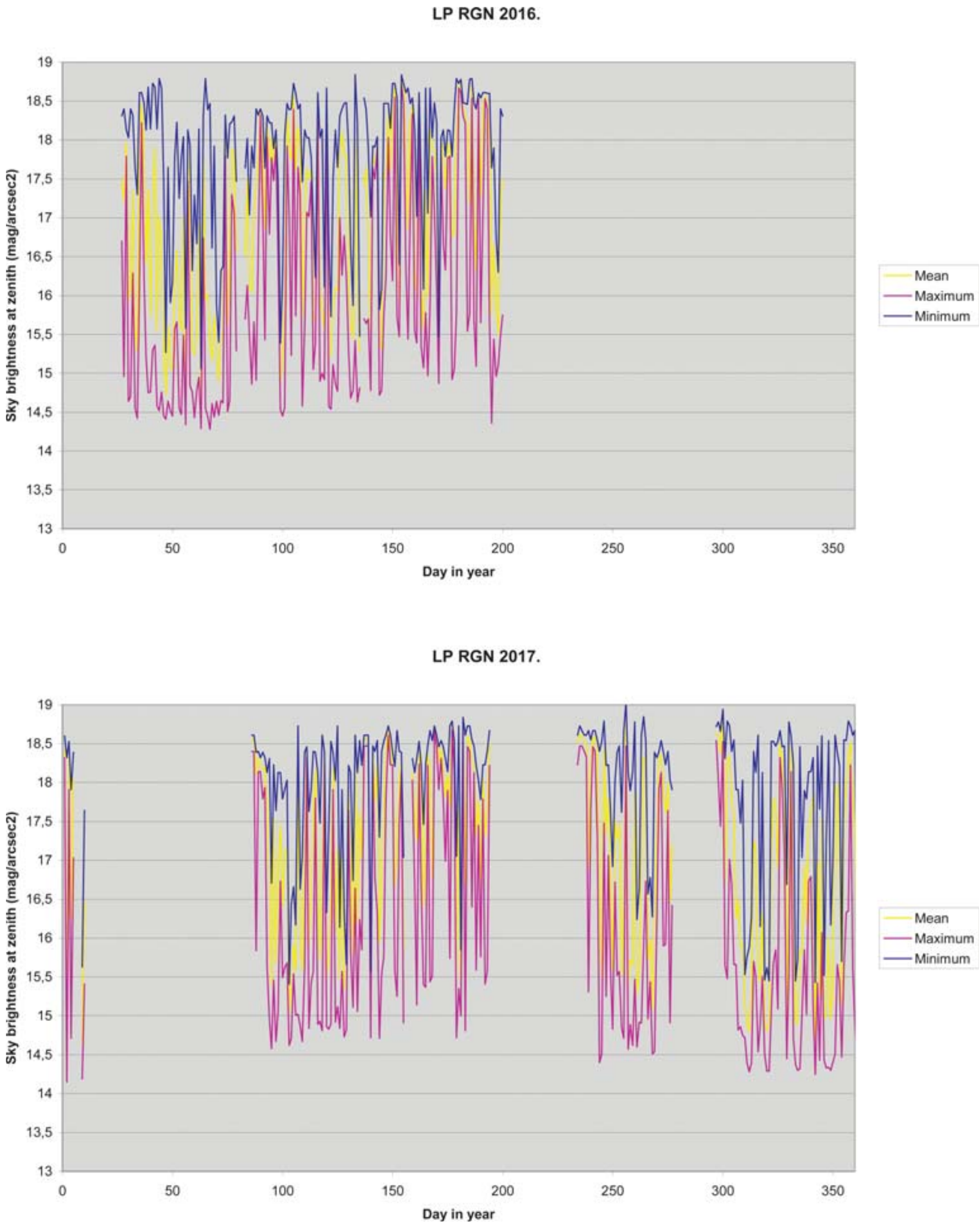

Figure 8: The nightly minima, maxima and average values of sky brightness for years 2016. and 2017.

fore. Again, the seasonal variations in data from year to year are considerable, so the histogram should be used with some caution in mind.

Both **Fig. 9** and **Fig. 10** confirm the fact that summer (and spring) provide better observing conditions (less light pollution) than autumn and winter. One should however also consider that the duration of the night changes considerably over the year, and that in winter/autumn, nights quite often start as clear and end as clouded or fogged.

The histogram in Fig. 10 reveals an interesting fact: the brightness values clutter around two peaks, one at about 15.0 mag/arcsec^2 and the other at about 18.2 mag/arcsec^2, both showing a tendency to move slightly toward lower brightness values in spring and summer. The explanation of this effect is rather straightforward: the nights are either mostly clear or mostly cloudy. Clear nights result in lower sky brightness, the values clustering around the second peak, and the cloudy nights result in much larger sky brightness that clusters around the first peak. The difference between them is about 3 magnitudes, in accordance with previous conclusions. The slight drift toward lower brightness in spring/summer is the result of the generally dryer and more transparent atmosphere in this period of the year. Note that these facts cannot be read from the statistics gathered in **Table 1**, as in doing these statistics, all values are drawn in equally regardless of the sky condition. We can derive a crude clear/cloudy criterion from the histogram: the minimum between two peaks is at around 16.7 mag/arc-

Table 1: Yearly statistics of nightly minima, maxima and average values of sky brightness and its nightly changes (variations) for years 2012. to 2017. All brightness values are expressed in magnitudes per arc-second squared. The last row gives mean values for the whole period of measurements (2012-2017).

Year	sky brightness			nightly variations			number of nights	missing nights
	max.	min.	mean	max..	min.	mean		
2012.	13.01	18.67	16.80	0.08	5.17	1.66	346	20
2013.	13.00	18.73	16.64	0.07	4.18	1.70	276	89
2014.	13.63	18.89	16.66	0.06	3.87	1.94	244	121
2015.	13.27	18.84	16.90	0.08	4.33	1.78	161	204
2016.	14.20	18.94	16.99	0.06	4.27	1.83	324	41
2017.	14.15	19.03	17.08	0.07	4.20	1.88	227	138
mean	13.54	18.85	16.85	0.07	4.34	1.80	263	102

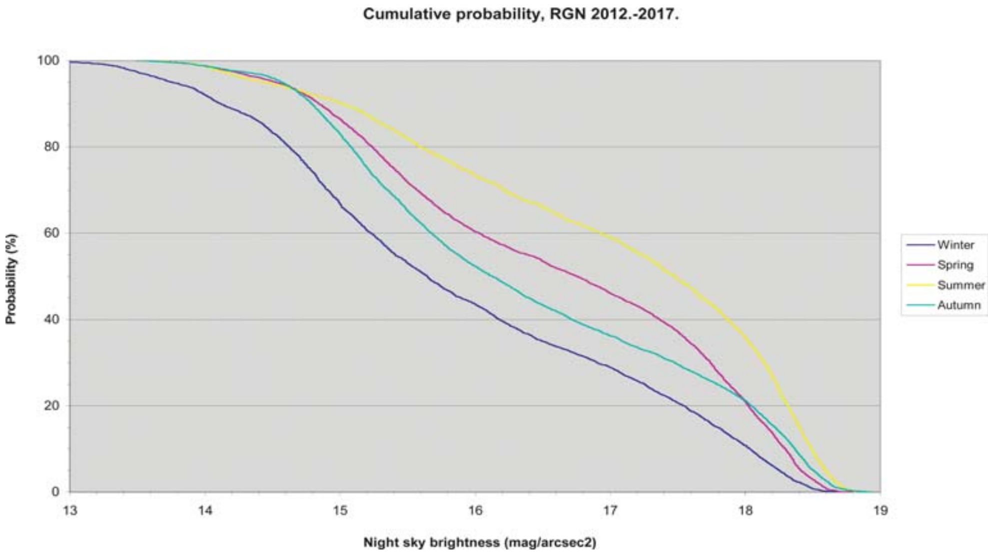

Figure 9: The average cumulative probability that the night sky brightness will be smaller than a given value, derived from all measurements available during the 2012.-2017. period

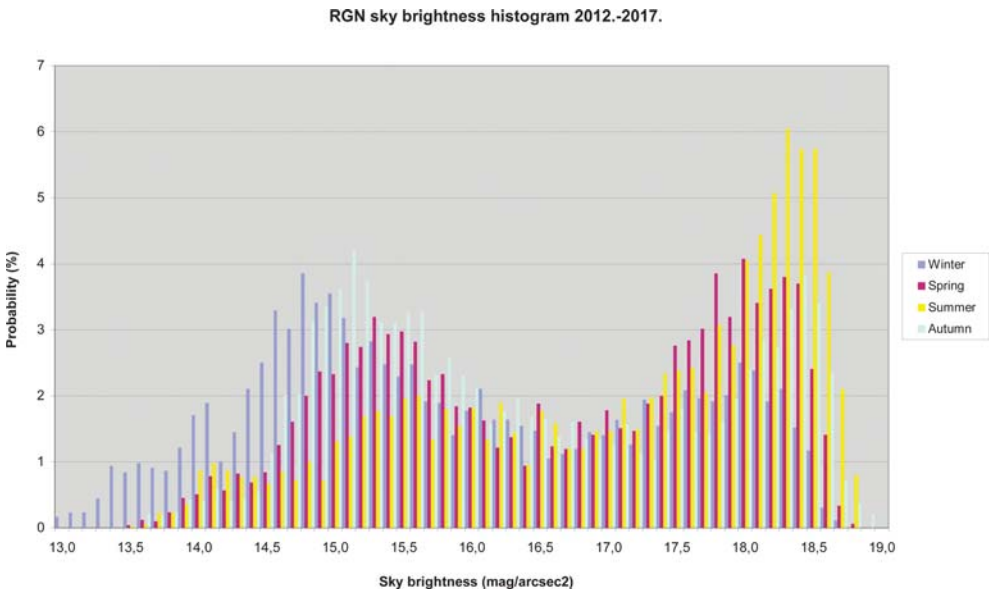

Figure 10: The histogram of the night sky brightness at RGN site derived from all measurements available during the 2012.-2017. period. Again, the histogram is created for meteorological seasons and should be taken as an average of seasonal behaviour during the period 2012.-2017. The bins in the histogram are 0.1 magnitude in width.

sec^2 so the brightness values smaller than that (larger magnitude values!) can be attributed to clear nights and vice-versa. This criterion is only approximate, but quite usable. Note also that positions of the two peaks and the minimum between them depend on the site in question, mostly on the strength of the light pollution, but also to some extent on metrological characteristics of the site in question. Keeping that in mind, this conclusion cannot be generalised without actual measurements on the site in question.

Last, but not least, the question on how this data compares with other towns arises. Similar measurements were reported for Vienna in 2014 (**Puschnig, 2014**) with a mean night sky brightness of 16.3 and 19.1 mag/arcsec^2 for cloudy/clear conditions. The population of Vienna is around 1.7 million, while that of Zagreb is about 0.8 million. Yet, the cloudy night sky in Zagreb is 1.3 mag/arcsec^2 (about 3.2 times) brighter, while the clear night sky is about 0.9 mag/arcsec^2 (about 2.3 times) brighter, both values indicating that Zagreb is a lot more light-polluted than Vienna. Furthermore, the value obtained for the mean night sky brightness in Hong-Kong, a heavily populated metropolis with a population of about 7.1 million, is 16.8 mag/arcsec^2 (**Pun, 2014**). The authors made a lot of effort to exclude the influence of moonlight on the measurements but did not try to separate clear from cloudy conditions. The corresponding value for Zagreb is 16.9 mag/arcsec^2, indicating that in this case, Zagreb is heavily over lighted too.

4. Conclusions

The measurements of the night sky brightness at the RGN site cover the period between January 2012. and December 2017. with about 1/4 (28%) of the data missing. The statistical analysis of the data (see Table 1.) does not show any significant differences from year to year, apart from differences caused by yearly differences in meteorological conditions. It was found that all parameters (i.e. minima, maxima and mean values of the sky brightness) change considerably on a nightly basis, mostly due to changes in meteorological conditions, often being larger than 2, sometimes even 3 magnitudes. The primary source of light pollution (artificial light) does not change so rapidly, as is confirmed by the long term stability of average night sky brightness over the measured period. Considering that the centre of Zagreb was fully formed a long time ago, this is expected. The situation might be quite different in suburbs that are rapidly growing but assessing the effects of this growth on light pollution would require additional measuring sites in suburbs that currently do not exist.

The seasonal probability curves and histograms provide additional information on light pollution at the RGN site. However, seasonal variations are quite large from year to year, so that information should be used with some caution in mind. The histograms reveal that the brightness values clutter around two peaks, one at about 15 mag/arcsec^2 and the other at about 18.2 mag/arcsec^2, with a tendency of slightly lower brightness values in spring and summer. The two peaks correspond to cloudy and clear nights respectively, with a difference in brightness between them of about 3 magnitudes. The slightly lower brightness values observed in spring/summer are linked to the dryer and more transparent atmosphere in this period of the year. A crude clear/cloudy criterion is derived too: the minimum between two peaks is at around 16.7 mag/arcsec^2. Brightness values smaller than that are attributed to clear nights and vice-versa. This conclusion is site dependent and cannot be generalised without measurements on other sites. Last, but not least, a comparison with similar measurements taken in Vienna and Hong-Kong indicates that Zagreb produces non-proportionally large amounts of light pollution.

5. *Acknowledgements*

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6. References

6.1. Published references

Andreić, Ž- (1993): Vratite nam noćno nebo. Čovjek i Svemir, 35, 2-3, 28-31.

Andreić, Ž., Korlević, K., Andreić, D., Bonaca, A., Korlević P. and Kramar, M. (2011): Svjetlosno onečišćenje u Republici Hrvatskoj. Građevinar, 63, 757-764. (in Croatian)

Andreić, Ž., Andreić, D. and Pavlić, K. (2012): Near infrared light pollution measurements in Croatian sites. Geofizika, 29, 143-156.

Falchi, F., Cinzano, P., Duriscoe, D., Kyba, C. C. M., Elvidge, C. D., Baugh, K., Portnob, B. A., Rybnikova, N. A. and Furgoni, R. (2016): The new world atlas of artificial night sky brightness. Science Advances, 2, 1-25, DOI: 10.1126/sciadv.1600377

Cinzano P. (2005): Night sky photometry with Sky Quality Meter. ISTIL Internal report no. 9, Thiene, URL: http://www.inquinamentoluminoso.it/download/sqmreport.pdf (accessed 17th December 2017.)

Hanel, A., Posch, T., Ribas, S. J., Aube, M., Duriscoe, D., Jechow, A., Kollath, Z., Lolkema, D. E., Moore, C., Schmidt, N., Spolestra, H., Wuchterl, G., Kyba, C. C. M. (2017): Measuring night sky brightness: methods and challenges. arXiv:1709.09558v1 [astro-ph.IM] 27 Sep 2017 (submitted to JQSRT)

Mizon, B. (2012): Light Pollution. Springerch. 2, p. 33-51

Narisada, K. and Schreuder, D. (2004): Light pollution handbook, Springer ch. 4, p. 79-114

Pun, C. S. J., So, C. W., Leung, W. Y. and Wong, C. F. (2014): Contributions of artificial lighting sources on light pollution in Hong Kong measured through a night sky brightness monitoring network. arXiv:1401.1200v1 [astro-ph. IM] 4 Jan 2014

Puschnig, J., Posch, T. and Uttenthaler, S. (2014): Night sky photometry and spectroscopy performed at the Vienna University Observatory. Journal of Quantitative Spectroscopy and Radiative Transfer, 139, 64-75. Schnitt, S., Ruhtz, T., Fischer, J., Hoelker, F., Kyba, C. C. M. (2013): Temperature Stability of the Sky Qulity Meter. Sensors, 13, 9, 12166-12174, doi: 10.3390/s130912166

Sharma, I., Mostečak, A., Andreić, Ž. (2015): Svjetlosno onečišćenje grada Zagreba u periodu prosinac 2010. - srpanj 2011. Rudarsko-geološko-naftni zbornik, 30, 1, 9-17, DOI: 10.17794/rgn.2015.1.3 (in Croatian)

6.2. Internet sources

Ephem 2017, URL: https://pypi.python.org/pypi/ephem/ (3. 12. 2017.)

IDA1 2017, URL: http://www.darksky.org/light-pollution/ (14. 12. 2017.)

LPO1 2018, URL: http://lpo.rgn.hr/measurements/sky_brightness_manual_mesurements.pdf (19. 2. 2018.)

LPO2 2018, URL: http://lpo.rgn.hr/ (19. 2. 2018.)

SkyChart 2017, URL: https://www.ap-i.net/skychart/start?id=en/start (3. 12. 2017.)

SQM database 2017, URL: http://unihedron.com/projects/darksky/database/ (3. 1. 2018.)

Unihedron1 2017, URL: http://www.unihedron.com/projects/sqm-le/ (14. 12. 2017.)

Unihedron2 2017, URL: http://www.unihedron.com/projects/darksky/magconv.php (17. 12.2017.)

Unihedron3 2017, URL: http://www.unihedron.com/projects/darksky/cd/SQM-LE/SQM-LE_Users_manual.pdf (14. 12. 2017.)

Wiki1, 2017, URL: https://en.wikipedia.org/wiki/Magnitude_(astronomy) (17. 12. 2017.)

Wiki2 2017, URL: https://en.wikipedia.org/wiki/Light_pollution (17. 12. 2017.)

ZEC 2018, URL: http://sci.hr/ (19. 1. 2018.)

SAŽETAK

Osvijetljenost noćnoga neba iznad Zagreba, Hrvatska, 2012. – 2017.

Svjetlosno onečišćenje iznad zgrade RGN fakulteta (u blizini središta Zagreba) mjereno je od siječnja 2012. do prosinca 2017. Prikupljeni podatci pokazuju kako je prosječna svjetlina noćnoga neba u tome razdoblju približno konstantna, osim godišnjih razlika prouzročenih promjenjivim meteorološkim uvjetima. Noćni minimumi, maksimumi i srednje vrijednosti svjetline neba znatno se mijenjaju zbog takvih uvjeta, često s iznosima između 2 i 3 magnitude. Sezonske krivulje kumulativne vjerojatnosti i sezonski histogrami sačinjeni na osnovi izmjerenih podataka daju dodatne informacije o svjetlosnome onečišćenju na mjestu RGN fakulteta. Oni pokazuju da se vrijednosti svjetline neba grupiraju oko dva maksimuma – oko 15,0 mag/arcsec^2 i oko 18,2 mag/arcsec^2. Obje vrijednosti pokazuju mali pomak prema nižim vrijednostima u proljeće, tj. ljeto. Ta dva maksimuma odgovaraju oblačnim i vedrim noćima, s razlikom u svjetlini od oko 3 magnitude. Također se može odrediti grubi kriterij za oblačne i vedre noći, gdje granica u svjetlini između njih odgovara minimumu histograma između tih dvaju maksimuma. Svjetline manje od oko 16,7 mag/arcsec^2 pripisuju se vedrim noćima i obratno. Usporedba s Bečom i Hong Kongom pokazuje da Zagreb proizvodi neproporcionalno veliko svjetlosno onečišćenje.

Ključne riječi:
svjetlosno onečišćenje, svjetlina noćnoga neba, testiranje lokacije, atmosferski efekti, Zagreb

Author contribution

Željko Andreić (Full Professor) made the entire researching and publishing process.