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Night sky brightness monitoring network in Wuxi, China

Hengtao Cui a,*, Junru Shen a, Yuxuan Huang a, Xinrong Shen a, Chu Wing So b, Chun Shing Jason Pun b

a Jiangsu Tianyi High School, Wuxi 214101, Jiangsu, China
b Department of Physics, The University of Hong Kong, Pokfulam, Hong Kong

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A B S T R A C T

The rapid development of cities has brought tremendous pressure to astronomical observation, energy security, and the ecosystem. Automatic monitoring of night sky brightness (NSB) can help us to understand its regional differences and time variations of NSB effectively and to investigate the human and natural factors which lead to these changes. In this paper, the construction of Wuxi City night sky brightness monitoring network (WBMN) in China is presented. In addition to introducing the equipment and the installation of the network, a brief analysis of the data obtained from the stations will also be presented. The impact of human activities on the NSB is illustrated through its changes during the Spring Festival (lunar new year) and non-festival nights, and through a comparison study between NSB data taken from locations of different land uses. It is concluded that, while the reduction in human activities after non-festival midnights or the reduction in moon illumination near the new moon epoch led to darker night skies, brightening of the night skies may be attributed to fireworks displays during the nights of Spring Festival in 2019. On the other hand, the absence of fireworks during the Spring Festival in 2020 may explain the darker night skies. Finally, there is an evidence that the urban developments in Wuxi are degrading night sky quality.

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1. Background and previous research

1.1. Area of interest

Tianyi Astronomy Society of the Jiangsu Tianyi High School, Wuxi, China was officially established in April 2008. Stargazing, as the most important activity of the Society, has become more difficult in recent years. The main reason is that light pollution in the city is becoming more serious. Fig. 1 is a nighttime remote sensing image of Wuxi area detected by the Luogia-01 satellite developed by the Wuhan University, China. According to Bortle Scale [1], sky brightness has nine levels. Level 1 is the best-conditioned “completely dark sky” and Level 9 was the worst “downtown sky”. Except for the dark area of Taihu Lake in the middle and Xiyang Mountain in the west, it is hard to find the Level 5 sky or below in Wuxi. In Jiangsu Tianyi High School, which is 6.2 km away from the city center, the sky is colorful, such as white, gray and orange. Megrez in the Great Dipper is unobservable. In the Taihu Eighteen Bay area, which is 10 km away from the city, the Milky Way near the zenith is unobservable throughout the night but galaxy M33 can be observed through binoculars [2].

1.2. Previous research

The Society has started the project “light pollution study group” since 2011. The Society organizes students to observe the changes of NSB within one night from the city center to urban area, then to suburbs, outer suburbs and the countryside to improve their understanding on light pollution. The Society purchased nine Sky Quality Meter (SQM) units from Canada in 2012. After more than two years of data collection and analysis, the Society published essays which fully analyzed the difference of NSB of regions with different land uses in Wuxi, the variations of NSB with the distance from the city center, the variations of NSB in different directions, altitudes, and the time periods and the possible reasons behind them [2,3]. In 2016, the Society modeled and analyzed the shape, distribution and operation of campus streetlamps based on investigation and experiment [4,5]. It is concluded that there is a positive correlation between NSB and artificial light source in Wuxi City urban area and the dissipation of artificial light source at a lower height has a more significant effect on the NSB.
1.3. Wuxi night sky brightness monitoring network (WBMN)

Ground-based measurements of NSB by SQM are very common worldwide. Researchers built monitoring networks to assess the extents of light pollution within their areas of interest, mainly restricted in Europe [6–8]. With the exception of a city-wide NSB study in Hong Kong [9], there are currently no ground-based systematic measurements of NSB in China.

To fill the gap, the construction of the Wuxi Night Sky Brightness Monitoring Network (WBMN) was started in 2018. WBMN was organized by the Tianyi Astronomy Society, with the help of the Astronomy Union of Wuxi Schools (AUWS) with Nanjing High School, Qingyang High School, Shanming High School, Wangzhuang Experimental Primary School and other units. WBMN is also a part of the Globe at Night – Sky Brightness Monitoring Network (GaMN).1

The research goals of WBMN mainly include: study the short-term influence of artificial light on the night sky, focusing on the changes of NSB between evening and morning twilights; study the long-term influence of artificial light source on the night sky, focusing on the changes in the NSB as the economy develops, population grows and industrial upgrades; study the influence of natural factors on NSB, focusing on the impacts of moon phase changes, cloudiness, and air quality on night light brightness; study the variations of NSB in different areas, including the difference in nighttime brightness between cities at different levels of development, between different industry types in new rural areas and old rural areas, and between urban and rural areas.

2. Instrumentation and installation

2.1. Instrumentation

The equipment used by the research group is the Sky Quality Meter - Lens Ethernet (SQM-LE), an automatic photometer produced by Unihedron in Canada. The SQM-LE is an international mainstream automatic photometer which can continuously monitor the brightness of the night sky and transmit real-time data through internet. The size of SQM-LE is only 3.6 × 2.6 × 1.1 inches.

1 Project website: http://globeatnight-network.org/.

It is powered by a 5–6 V DC. The maximum sampling time is 80 s and the minimum sampling time is one second. The optical sensor of SQM-LE is TAOS TSL237 high sensitivity optical frequency converter with Hoya CM-500 near-infrared blocking filter. The sensitivity at 19° from the axis of the SQM-LE photoreceptor is 10 times lower than that at the central axis, and the brightness at 20° and 40° from the central axis is 3 to 5 magnitudes lower than that at the central axis. The unit of measurement is magnitude per square arcsecond (mag/arcsec² in short).

2.2. Monitoring stations

It’s required to ensure that SQM-LE can accurately monitor the NSB in the area where the site is located, not only avoiding the direct influence of surrounding artificial light and ground shadows, but also avoiding the interference of light near the horizon. Therefore, the monitoring stations of WBMN are all located in outdoor open spaces with a wide view, such as the roof terrace of buildings (Fig. 2).

In order to meet the demands of future research, we visited five districts (Liangxi District, Binhu District, Xinwu District, Xishan District, Huishan District) in Wuxi city and two other cities (Jiangyin, Yixing) to identify possible locations for WBMN. After contacting potential collaborators, two urbanized areas (Dongting in Xishan District, Wangzhuang in Xinwu District), three suburban areas (Binhu District Science and Education Pioneer Park, Jiangyin Economic Development Zone, Yicheng in Yixing City), and one rural area (Qingyang in Jiangyin City) were identified (Fig. 1).

After over half a year of planning and over half a year of construction, Yixing No. 1 Station and Binhu No. 2 Station have been successfully installed in February and June 2019 respectively (Fig. 3).

Yixing No. 1 Station (the SQM-LE with the serial number 3143, also coded as “Wux” under GaN-MN) is located at Kunming Technology Co., Ltd., Kunming 128 Innovation Industrial Park, Yixing Economic Development Zone, with a latitude and longitude of 31.407 N °, 119.808E°. The station is located in the suburb of Yixing City between Ge Lake and Huangui Lake, with a reputation as the back garden of Yangtze river delta. Although the site is surrounded by farmland, its east and south sides are adjacent to the Yixing Economic Development Zone. With the construction of the Yixing Economic Development Zone, future site area will inevitably be highly urbanized.

Binhu No. 2 Station (the SQM-LE with the serial number 3139, also coded as “BhD” under GaN-MN) is located at Jiangsu Zheqin
Binhu No. 2 Station is the second monitoring station of WBMN, which was officially completed on June 8, 2019 and began to work.

The monitoring data of WBMN stations are refreshed every half minute. Up to December 2019, more than 700,000 data have been transmitted and stored in the GaN-MN’s database through internet. Data information includes data creation time, data received time (both in UTC and local time, UTC+08:00), SQM-LE serial number and sky brightness reading. After logging in to the GaN-MN’s database, we can download data for research.

3. Data collection and analysis

3.1. Data collection

Yixing No. 1 station is the first monitoring station of WBMN. Since the successful construction of the site on February 1, 2019, SQM-LE has been working steadily for more than eight months.

3.2. NSB at Yixing No. 1 Station

Taking the night of March 7–8 (new moon night) in 2019 as an example, the NSB data from 30 min after the end of astronomical twilight (19:01, local time hereafter) to 30 min before the start of astronomical twilight (5:09) are analyzed (Fig. 4). According to the data of cloud cover from 00:00 to 23:00 on March 7–8 (local time, hereafter) from Wuxi Meteorological Bureau, it was partly cloudy (75% sky was covered by cloud on average). It is found that the sky was darker after midnight than those before midnight, and the darkest period appeared before the morning civil twilight. This situation reflects that the light produced by human activities have huge effects on the local NSB. When the time moved to 21:00 and 22:00, all major kinds of commercial activities and entertainment ends, one after another. As a result, the decrease of artificial light usage significantly reduced the local light pollution.

Previous researches studied the relationships between electricity usage behaviors and western cultural events like Christmas and Ramadan with Suomi-NPP satellite data [10]. We want to analyze the Spring Festival, a major eastern event, as a socio-cultural factor in the brightness of the local night sky. The Festival (also known as the Lunar New Year) is arguably the most famous traditional festival on the Chinese calendar, with new year celebrations peaking near midnight of the Festival. The Spring Festival usually falls on the day of the second new moon after the winter solstice because the Chinese calendar was set based on the lunar cycle.

Taking the night of February 7–8 (Spring Festival night, near new moon), March 7–8 (new moon night) and March 21–22 (full moon night) in 2019 as examples, the NSB data from 19:00 to 5:00 are analyzed (Fig. 5). Besides partly cloudy on March 7–8, according to the data of cloud cover from 00:00 to 23:00 on February 7–8 and March 21–22 from Wuxi Meteorological Bureau, there were overcast (100% sky was covered by cloud on average).
We found that, first, being different from that in normal “new moon night” and “full moon night,” the sky was slightly brighter between 20:00 to 22:00 during the Spring Festival nights. This may be closely related to the Chinese custom of setting off fireworks to celebrate the Spring Festival. Second, the sky during Spring Festival nights brightened again around 3:00 to 4:00. This may be closely related to the tradition of setting off fireworks to welcome the Chinese god of prosperity. Third, the average NSB in the Spring Festival night was 16.8 mag/arcsec², but the average NSB in the new moon night was 18.6 mag/arcsec². This could be probably due to the fireworks during the Spring Festival that created direct light and indirect light scattered from explosive dusts. But the relationship between firework dusts and light pollution could not be concluded in this stage. Fourth, the average brightness of full moon night was 16.4 mag/arcsec², slightly brighter than that of Spring Festival night and far brighter than that of new moon night. This shows that the full moon with an apparent magnitude of −13 has a great effect on the NSB. This observation agrees with the circalunar impact on NSB examined in [7]. Fifth, the data in new moon night had a change ranging about 2 mag/arcsec². This change was more significant between 21:00 and 22:00, which indicated the time interval when commercial, entertainment, and landscape lightings of half urbanized areas are all turned off.

We compared the NSB data of two nights: Spring Festival of 2019 (February 7–8) and 2020 (January 27–28) (Fig. 6). According to Chinese traditional lunar calendar, the two nights we compared are 3rd-4th of the first month of new year. The Moon was at waxing crescent phase and moon age was 3−4 days. According to Wuxi Meteorological Bureau, the data of cloud cover from 00:00 to 23:00 on January 27–28 indicated an overcast state. The East and South of Yixing No. 1 Station was Yixing Economic Development Zone. In the past year, industrial site and residential site were increasing significantly and the scale of human activity was expanding. Thus, the lighting of roads and buildings in surrounding areas has been changed. According to Yixing Government’s online official accounts “Civilized Yixing”, in 2019, Yixing furthered its renovation of old buildings and neighborhood during which engineers upgraded the lighting system, garden lights, and night lights in many communities. For example, last year, the city initiated the Fanli Bridge lighting project, which used 500 sets of railing lights and 5800 m of washing-wall lights to outline the beauty of the bridge.

It can be seen from the figure that: first, in both 2019 and 2020, the sky was darker after 21:00−22:00, which reflects the effects of successive shutdowns of local commercials, entertainment, landscape and other lighting facilities around the similar time. Second,
in both 2019 and 2020, the sky was brighter between 3:00 and 4:00, which reflects the influence of the local custom of setting off fireworks to welcome the god of prosperity and other gods on the brightness of night sky. Third, compared with that of 2019, the midnight during the Spring Festival in 2020 was brighter, which was caused by the local economic and industrial development, increase in city scale and lighting degree improvement. Fourth, compared with that of 2019, the sky after midnight of 2020 Spring Festival was darker. This is due to local government's latest ordinance to ban fireworks in 2020. The banning was related to the break-out of novel coronavirus COVID-19 during which local government called on people to go out less to increase social distance.

3.3. NSB among WBMN stations

We took the NSB data of Xing No. 1 station and Binhu No. 2 station in the early hours of June 11 (clear night) and June 12 (cloudy night) in 2019 as examples to analyze the impact of cloud on NSB and the light pollution conditions among stations. We picked the NSB readings from 1:30, 2:30 and 3:30 at both nights at both locations to represent the hourly NSB changes then drew Fig. 7. These timings were picked to avoid moonlight (moon set at around 00:55 and 01:30 on June 11 and 12 respectively) and sunlight (astronomical twilight started at around 03:30 on both dates).

As seen from Fig. 7, the clear night sky was about 0.5 to 1.2 mag/arcsec² darker than cloudy night sky. This is because the artificial light on the ground will directly or through reflection shine on the clouds, and the clouds will scatter these lights backwards, thereby amplifying the impact of artificial light on the ground, resulting in a brighter sky.

To measure how cloud coverage affects sky brightness in an urban environment, the authors in [11] employed the same device, SQM-LE, as we did. Compared with their site selections classified as urban, suburban, and rural, our present stations in Xing and Binhu are suburban areas that share only a slight difference. Regarding the timing, we eliminated the influence of moonlight in cloud analysis by choosing the time after moon set and by choosing moonless nights. Different from our cloud classification as clear and cloudy, they divided cloud conditions into three types—clear, partly cloudy, and overcast. Their results indicated that cloud coverage has a strong amplification effect on light pollution, and sky brightness increase as cloud coverage increases. The cloud amplification made the luminance of night sky in urban Berlin 10.1 times (or roughly 2.5 mag/arcsec²) brighter on overcast nights than on clear moonless nights, which, compared with our 0.5 to 1.2 mag/arcsec² difference in brightness, is much stronger contrast.

NSB data obtained from the Catalan Light Pollution Network (XCLCat) has been analyzed in [12] to evaluate the impact of clouds or fog on the night sky. They installed SQMs at the places with ceilometers for assessing the interaction of clouds and NSB. Thanks to the ceilometer presence, they added available cloud information to NSB to do a combined study. They found NSB to be more stable in the absence of clouds compared to the presence of clouds. In particular, our works were different from their works as they lumped the effect of clouds and fog together without explicitly dividing the two matters while we didn’t consider the effect of fog in detection. According to their results, NSB could be six times brighter (more than 2 mag/arcsec²) with clouds compared to a clear night in Barcelona. Again, this amount of amplification was larger than our case. On the other hand, clouds did not amplify the effect of light in natural protected areas in the Montsec mountain range, but the effect was in the opposite direction. Because clouds can block natural sources, NSB can thus be reduced. It could be concluded that clouds coverage could either be brightening or darkening the sky, depending on the level of light pollution in specific areas. Further studies are requested to confirm this property in China if NSB was observed in a darker area.

Comparing the clear sky data at 01:30, the night sky in Xing was 0.3 mag/arcsec² brighter than that in Binhu because Xing No. 1 station located in a commercial and industrial area, while Binhu No. 2 station located near a tourism area. This means that the development of industry and commerce has a much greater impact on the night sky brightness than natural factors.

4. Recommendation

Throughout the construction of WBMN, we have learned the methods of the construction and the operation of the NSB monitoring network, which provided useful experience for the future expansion of WBMN in WuXi or other cities. By analyzing the NSB data collected from two stations, we found the main factors influencing the night sky data include natural factors such as the moon phase and weather, artificial factors such as the degree of economic development and human activities during important events and festivals. Our research provides an important reference for the future site selection. If the research aims to study the impact of urbanization in mainland China, the site should be located in the rural or semi urban areas.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

CRediT authorship contribution statement

Hengtao Cui: Investigation, Writing - original draft. Junru Shen: Data curation, Writing - original draft. Yuxuan Huang: Investigation, Formal analysis. Xinrong Shen: Methodology, Writ-
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