Sky brightness and twilight measurements at Jogyakarta city, Indonesia

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Abstract. The sky brightness measurements were performed using a portable photometer. A pocket-sized and low-cost photometer has 20 degree area measurement, and spectral ranges between 320-720 nm with output directly in magnitudes per arc second square (mass) unit. The sky brightness with 3 seconds temporal resolutions was recorded at Jogyakarta city (110^0 25' E; 70^0 52' S; elevation 100 m) within 136 days in years from 2014 to 2016. The darkest night could reach 22.61 mpass only in several seconds, with mean value 18.8±0.7 mpass and temperature variation 23.1±1.2 C. The difference of mean sky brightness between before and after midnight was about -0.76 mpass or 2.0 times brighter. Moreover, the sky brightness and temperature fluctuations were more stable in after midnight than in before midnight. It is suggested that city light pollution affects those variations, and subsequently duration of twilight. By comparing twilight brightness for several places, we also suggest a 17^0 solar dip or about 66 minutes before sunrise for new time of Fajr prayer.

1. Introduction

Observing the starry sky on a clear, moonless night, from a location well away from population centers, can be unsettling moment. The enormous dome of the heavens may engender feelings of borderless and remoteness, and the ceiling of thousands of stars are visible to the unaided eye [1]. Moreover, the daily alternation between day and night, vice-versa is one process of nature whose regular repetition exerts a striking impact on the structure of organisms and the way of life of every inhabitant of our planet. The change does not occur instantaneously but over the rather protracted period known as twilight. Transportation, religious worship, the schedule of work in the fields, artificial lighting, in fact the whole routine of daily life must often be adapted to the varying illumination of twilight. The starry night and twilight belong to the few primeval natural phenomena that should be protected by all people, in about the same way as phenomena like nature, sunset or the beach. One should think that both directly affect our living conditions on so great a scale that science would long since have reached some depth of understanding as to the nature and behavior processes [2]. Night sky brightness means a cultural heritage. It refers to the condition in the night sky with moonless light. In the visible light regime, the sky brightness is affected by natural airglow, direct or scattered light, zodiacal light, and light pollution from man-made artificial light. Moreover, the city light pollution can extend many kilometers beyond the boundaries of the city. There are a number of different brightness units in use in the different fields of night sky brightness with their individual traditions and advantages. However, those have a conversion formula or tables [3], [4]. In this case, sky brightness was expressed in magnitude per arcsec square (mpass) unit [4].

Twilight is a neglected natural phenomenon with gradual and elusive sky brightening or darkening compare with more distinct light transition of sunrise and sunset. Twilight sky brightness is classified into three distinct phases according to solar elevation and the prevailing visibility conditions due to the illumination level: a) civil twilight ($-6^0 < \text{solar dip} < 0^0$), when terrestrial objects can still be distinguished by human observers, b) nautical twilight ($-12^0 < \text{solar dip} < -6^0$), when only object outlines are visible, and c) astronomical twilight ($-18^0 < \text{solar dip} < -12^0$), when the illumination level is low enough such that stars and other astronomical objects are available for observation [5]. In Islamic country, morning and evening twilights are related to obligatory prayers of Fajr (dawn) and Isya (night) prayer, respectively. Unfortunately, there is no world consensus for solar dip in both prayer times. Islamic countries use solar dip within interval 15 to 20 degrees. In Indonesia, the largest solar dip of 20 degree has been long accepted for starting Fajr prayer, without supporting some quantitative observational results.

All human outdoor lighting is functional for being the enhancement of the visibility and/or of the aesthetics (decorative lighting). Excessive outdoor lighting causes light pollution, which represents a loss as regards electric energy. Good lighting design ensures that the light comes where it is needed, and does not fall elsewhere. It may cause considerable economic and environmental losses [6]. Light pollution depends on two factors: light emission and scattering particle abundance. The latter is variable over the world. It depends of course on population density but even more so on affluence. Most countries do not have yet a legislature, which would permit the imposition of pollution control. Aerosols, particles floating in the atmosphere, can have many different sources. The most common are, apart from water droplets in haze and clouds, dust particles from industry, agriculture and deserts, salt crystals from the sea, soot from diesel engines, ash from volcanoes and forest fires [1]. The close relationship between light pollution and air pollution is then pointed out by [7] [8] [9]. Long term sky brightness monitoring has been done before, which was correlated with solar activity [10].

This paper will report single point measurement of sky brightness and twilight using simple, palm-size, and USB connected photometer. Unihedron Sky Quality Meter (thereafter SQM) was quantified the quality of the night sky with three seconds time resolution at Jogyakarta city, one of the famous cultural heritage cities in Indonesia, for 136 days on year 2014 to 2016. The effect of city light pollution and based on solar dip twilight were also described by comparing to other places with application to beginning of Fajr prayer which is important for Islamic community.

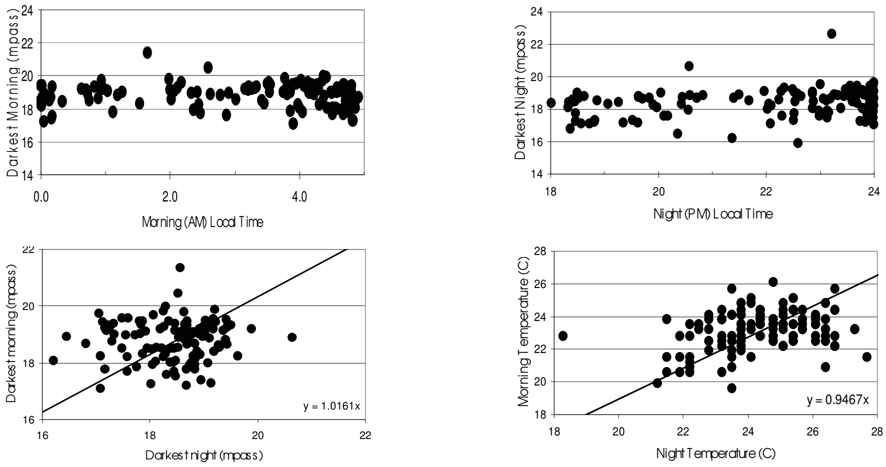

Figure 1. (from left to right) Distribution of the darkest sky brightness before sunrise, (a) and after sunset, (b). The relation between the darkest night and morning, (c) and their temperatures, (d).

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2. Distribution of sky brightness and temperature

The darkest morning sky brightness (after midnight) could reach 21.34 mpass, with mean value of 18.81±0.70 mpass (see Figure 1.a). It is noted that the fluctuations can be obtained by calculating standard deviation of data. On the other hand, the mean value of night sky brightness (before midnight) gave 18.44±0.85 mpass with the darkest night reached 22.61 mpass (see Figure 1.b). It is seen that the darkest brightness at night and morning was directed toward midnight and before twilight in the morning, respectively. We also noted that sky brightness fluctuations in the morning were more stable (see Figure 1.c) and temperatures were cooler (23.25±1.15^{0}C) than before midnight (24.72±1.22^{0}C), as shown in Figure 1.d.

3. Twilight

The patterns of morning and evening twilight at Jogyakarta showed no significantly difference of about 4%, due to light pollution, as given in Figure 2.a. and 2.b. It means that the atmospheric layers are relatively the same structures in the east and west directions, respectively. Later, we selected only morning twilight. The sky brightness of evening twilight was shifted to the left at about 50 minutes after sunset, and showed darker sky brightness than morning twilight brightness, as seen in Figure 2.a.

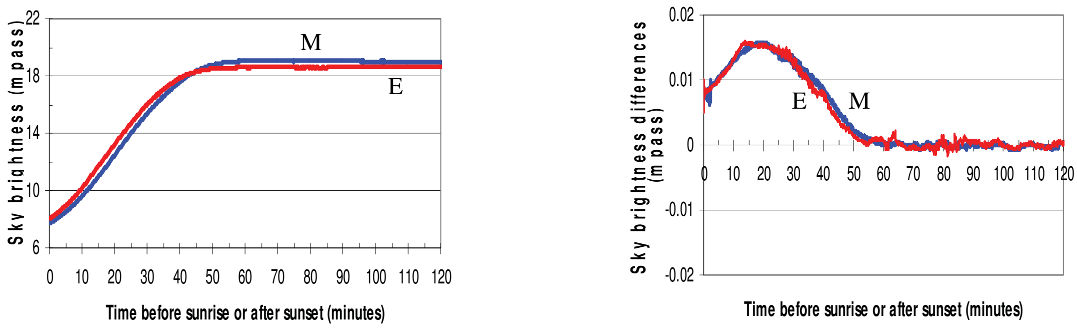

Figure 2. The morning with blue lines - M (a), and evening with red lines - E twilights (b)

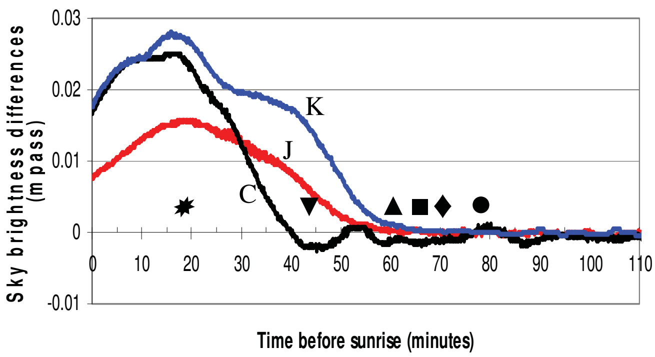

Figure 3. Morning twilight at Kupang (K), Jogyakarta (J), and Cimahi (C) cities with average solar dip 20^0 (circle), 18^0 (diamond), 17^0 (square), 16^0 (triangle), 12^0 (reverse triangle), and 6^0 (star)

Both light pollution and air pollution contribute to the sky brightness at Jogyakarta city, especially between 15 to 50 minutes after sunset or before sunrise. Aerosol particles in lower atmosphere will

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absorb the sunlight, so that they make darker sky. Then, they will scatter the city light, causing brighter sky for 50 minutes after sunset. The shifted sky brightness at evening twilight becomes one indicator for light pollution.

Figure 3 shows sky brightness differences of morning twilight with moving average curves for several cities, Cimahi (107^0 32'E; 6^0 53' S; elevation 700 m; Dec. 18, 2013), Kupang (124^0 0'E; 9^0 40' S; elevation 1300 m; May 10, 2013), and Jogyakarta (110^0 25'E; 7^0 52' S; elevation 100 m; May 18, 2015). It is clear that morning twilight at Cimahi had strongly affected by light pollution due to shifted curve, relative to intermediate level at Jogyakarta, and the darkest one at Kupang. Those cities have no any regulation about outdoor lighting. The brightening sky toward time of sunrise is clearly not linear, as showed in Figures 2 and 3. The different scale heights of atmospheric components allow each to be observed for different periods of interaction in twilight. However, smaller than 6^0 solar dip or civil twilight (about 19 minutes before sunrise), sky brightness differences gave the same pattern which implies the same lowest atmospheric height. The nautical twilight (12^0 solar dip and about 44 minutes before sunrise) was indicated by a hump at Kupang. The astronomical twilight was given by no sky brightness differences (about 70 minutes before sunrise). Figure 3 shows that sky brightness starts to increase at about 16^0 solar dip or about 62 minutes before sunrise. By using the above observational results, we argue that assuming 20^0 (about 79 minutes before sunrise) or larger solar dip for Fajr prayer needs a revision. We propose a 17^0 solar dip (about 66 minutes before sunrise), as a new reference angle for Fajr prayer.

4. Conclusions

We have used 136 days with high temporal resolution of sky brightness measurements at Jogyakarta city within year 2014 to 2016. We summarized as follow (1) the darkest of sky brightness fluctuations in the morning (after midnight) were more stable (18.81±0.70 mpass) and temperatures were cooler (23.25±1.15^{0}C) than before midnight 18.44±0.85 mpass and 24.72±1.22^{0}C, respectively, (2) light pollution contributed about 4% in the evening twilight at Jogyakarta, (3) twilight sky brightness is not a linear brightening, (4) we propose a 17^0 solar dip (about 66 minutes before sunrise), as a new reference angle for Fajr prayer.

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