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Sky twilight brightness at zenith expressed in magnitudes

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ABSTRACT

Most of the previously published results of the zenith sky twilight brightness, obtained by different investigators, are given in different units. These results have been converted to (mag/arcsec^2) to make a comparison between them. The variation of the colour indices (B-V) and (B-R) of the zenith sky twilight with the sun's depression will be studied. The present photometric results of the zenith sky twilight brightness expressed in mag/arcsec^2, have been obtained for the first time for blue, yellow and red colours.

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KEYWORDS
Twilight; brightness; zenith; mag/arcsec^2

1. Introduction

Twilight studies are important tools for analysing atmospheric optics and its structure. Different investigators have obtained values of the zenith sky twilight brightness in different units. Kommen et al. (1952) have measured the sky twilight brightness at Maryland for different azimuths and altitudes including zenith point. Their results have been expressed in (cd/ft^2). A programme of studying twilight brightness has been carried out in Egypt at different sites. Asaad et al. (1977a, 1977b, 1977c) measured the zenith sky twilight brightness at Helwan and Daraw by using blue and yellow wide band glass filters. Their results have been expressed in S_{10} (λ) units. Where S_{10} (λ) is the number of stars of 10th magnitudes per square degree at a certain wavelength (λ). Also, Nawar and Mikhail (1995) and Nawar (2000) have measured the zenith sky twilight brightness at Abu-Simble site using blue, yellow and red wide band glass filters. Their results also expressed in S_{10} (λ) units. Using CCD observations Patat and Ugolnikov (2006) have published values of the zenith sky twilight brightness which expressed in (mag/arcsec^2) for U B V R I colours.

In the present work, the results of the zenith sky twilight brightness obtained at different sites in Egypt will be converted from S_{10} (λ) to mag/arcsec^2. For the sake of comparison results obtained by Kommen et al. (1952) at Maryland in V band have been converted from cd/ft^2 to mag/arcsec^2. All the previous results at different sites will be compared with each other. Also, the variation of the colour index of the zenith sky twilight brightness with the sun's depression will be discussed.

2. Data and results

In the present work, we have used the published data of the zenith sky twilight brightness obtained at Daraw, Helwan and Abu-Simble. These data are expressed in S_{10} (B), S_{10} (V) and S_{10} (R) for blue (4410 A°), yellow (5500 A°) and red (7900 A°) colours respectively.

These results have been converted to mag/arcsec^2 by using the relation (1) (c.f. Nawar et al. 2007):

$$I(\lambda)\left(\text{mag/arcsec}^2\right) = -2.5 \times \log I\left(S_{10}(\lambda)\right) + 27.78 \quad (1)$$

The obtained results for Helwan and Daraw, are given in Tables 1 and 2. The results for the evening and morning twilights at Abu-Simble are tabulated in Tables 3 and 4 respectively. The Tables 1–4 give the deduced values of the zenith sky twilight brightness expressed in mag/arcsec^2 for every one degree of the sun's depression below the horizon, between 0° and 15 °, for different colours.

Kommen et al. (1952) have obtained the zenith sky twilight brightness values in V band at Maryland, near sea level. Their results were expressed in cd/ft^2. It is required now to convert these values from cd/ft^2 to mag/arcsec^2. Asaad et al. (1977c), put the following relation (2), to convert I (cd/ft^2) to I (S_{10} (λ)).

$$I\left(\text{cd/ft}^2\right) = 1.3127 \times 10^7 \times I\left(S_{10}(\lambda)\right) \quad (2)$$

By straight forward calculation from relation (1) and relation (2), we have a simple relation to convert directly from I(cd/ft^2) to I(λ) (mag/arcsec^2).

$$I\left(\lambda\right)\left(\text{mag/arcsec}^2\right) = -2.5 \times \log I\left(\text{cd/ft}^2\right) + 9.984586 \quad (3)$$

The relation (3) is used to convert Kommon's results to I(λ) (mag/arcsec^2), and tabulated in the Table 5, for the sun's depression (D°) from 0° to 15°. Figure (5) represents the results obtained after conversion.

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Table 1. Zenith sky twilight brightness with the sun's depression (D°) at Helwan for blue and yellow colours.

Helwan site				
	Blue		yellow	
D°	log I (S_{10}(B))	I (mag)	log I (S_{10}(V))	I (mag)
0	7.88	8.08	8.1	7.53
1	7.7	8.53	7.9	8.03
2	7.42	9.23	7.62	8.73
3	7.14	9.93	7.3	9.53
4	6.76	10.88	6.96	10.38
5	6.32	11.98	6.5	11.53
6	5.85	13.155	5.96	12.88
7	5.32	14.48	5.4	14.28
8	4.84	15.68	4.84	15.68
9	4.38	16.83	4.3	17.03
10	3.94	17.93	3.86	18.13
11	3.54	18.93	3.46	19.13
12	3.18	19.83	3.14	19.93
13	2.84	20.68	2.8	20.78
14	2.52	21.48	2.5	21.53
15	2.34	21.93	2.2	22.28

Table 2. Zenith sky twilight brightness with the sun's depression (D°) at Daraw for blue and yellow colours.

Daraw site				
	Blue		Yellow	
D°	log I (S_{10}(B))	I (mag)	Log I (S_{10}(V))	I (mag)
0	7.86	8.13	8.14	7.43
1	7.62	8.73	7.88	8.08
2	7.3	9.53	7.56	8.88
3	6.92	10.48	7.2	9.78
4	6.52	11.48	6.78	10.83
5	6.06	12.63	6.3	12.03
6	5.58	13.83	5.82	13.23
7	5.1	15.03	5.34	14.43
8	4.6	16.28	4.81	15.755
9	4.12	17.48	4.24	17.18
10	3.7	18.53	3.82	18.23
11	3.32	19.48	3.4	19.28
12	2.94	20.43	3.06	20.13
13	2.64	21.18	2.8	20.78
14	2.38	21.83	2.6	21.28
15	2.13	22.455	2.46	21.63

Table 3. Evening zenith sky twilight brightness with sun's depression (D°) from 1° to 16° at Abu- Simble for blue, yellow and red colours.

Evening Twilight						
Abu-Simble Average 3 days						
	Blue		Yellow		Red	
D°	logI (S_{10}(B))	I(Mag)	logI (S_{10}(V))	I(Mag)	log I (S_{10}(R))	I (Mag)
1	7.48	9.08	7.59	8.805	7.93	7.95
2	7.17	9.8	7.26	9.63	7.67	8.6
3	6.79	10.8	6.85	10.65	7.33	9.45
4	6.32	11.98	6.37	11.85	6.86	10.63
5	5.85	13.15	5.87	13.1	6.32	11.98
6	5.32	14.48	5.33	14.45	5.8	13.28
7	4.86	15.63	4.8	15.78	5.27	14.6
8	4.41	16.75	4.34	16.93	4.78	15.83
9	3.99	17.8	3.94	17.93	4.35	16.9
10	3.64	18.68	3.58	18.83	4	17.78
11	3.31	19.5	3.29	19.55	3.64	18.68
12	3.04	20.18	3.07	20.1	3.38	19.33
13	2.77	20.85	2.89	20.55	3.19	19.8
14	2.55	21.4	2.73	20.95	3.01	20.25
15	2.38	21.83	2.63	21.2	2.96	20.38
16	2.27	22.1	2.59	21.3	2.89	20.55

Table 4. Morning zenith sky twilight brightness with sun's depression (D°) from 0° to 16° at Abu-Simble for blue, yellow and red colours.

Morning Twilight						
Abu-Simble Average 3 days						
	Blue		Yellow		Red	
D°	logI (S_{10}(B))	I (Mag)	logI (S_{10}(V))	I (Mag)	logI (S_{10}(R))	I (Mag)
0	7.87	8.105	7.92	7.98	8.17	7.355
1	7.63	8.705	7.75	8.405	8	7.78
2	7.32	9.48	7.46	9.13	7.81	8.255
3	7	10.28	7.14	9.93	7.48	9.08
4	6.58	11.33	6.71	11.005	7.1	10.03
5	6.2	12.28	6.18	12.33	6.62	11.23
6	5.72	13.48	5.71	13.505	6.09	12.555
7	5.25	14.65	5.2	14.78	5.56	13.88
8	4.82	15.73	4.71	16.005	5.11	15.005
9	4.4	16.78	4.29	17.055	4.65	16.155
10	4.04	17.68	3.83	18.205	4.3	17.03
11	3.71	18.50	3.61	18.755	3.92	17.98
12	3.38	19.33	3.3	19.53	3.67	18.605
13	3.04	20.18	3.06	20.13	3.41	19.255
14	2.72	20.98	2.86	20.63	3.21	19.755
15	2.5	21.53	2.71	21.005	3.1	20.03
16	2.33	21.955	2.66	21.13	3.01	20.255

Table 5. Zenith sky twilight brightness at Maryland in V band for different sun's depression (D°).

Maryland at zenith		
D°	I (cd/ft^2)	I (mag/arcsec^2)
0	15	7.0443
3	2	9.232
6	0.06	13.039
9	0.0015	17.044
12	0.00012	19.786
15	0.00004	20.979

3. Discussion of the results

3.1. Zenith sky twilight brightness in Egypt

The observations, for evening zenith sky twilight brightness, were carried out at Helwan and Daraw. Helwan is the small town (ϕ = 29° 52` N, $\lambda$ = 31° 81` E) situated at 25 Km south of Cairo and its altitude is 115 m above sea level. While Daraw (ϕ = 24° 22` N, $\lambda$ = 32° 58` E) is the moderate village near Aswan. It is situated about 700 Km south of Cairo and its altitude is nearly 250 m above sea level. The results of Tables 1 and 2 have been drawn in Figures 1 and 2. The figures represent the variation of zenith sky twilight brightness expressed in mag/arcsec^2, for yellow and blue colours respectively, with sun's depression from 0° to 15°. It can be seen in these figures that the brightness in yellow colour is slightly higher than the blue colour by about 0.5 mag/arcsec^2. The figures also show that the curves are linear for sun's depression between 3° and 12°, indicating that the zenith sky twilight brightness change with the same rate for each one degree, during this interval. At Helwan and Daraw, it is found also, that the rates for blue colours in both of them equal to 1.15 magnitudes. In yellow colour, these rates are 1.25 for Helwan and 1.21 for Daraw.

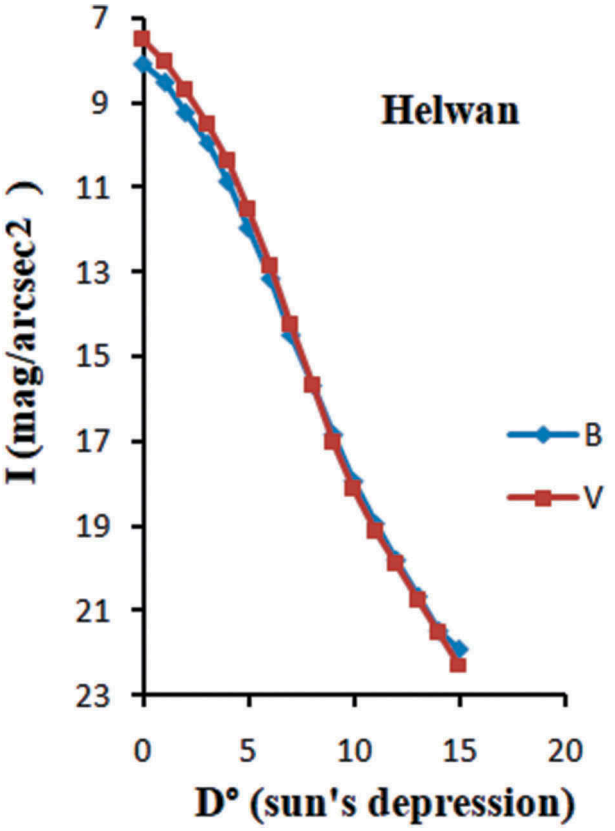

Figure 1. The relation between the zenith sky twilight brightness I (V) with sun's depression (D°) at Maryland.

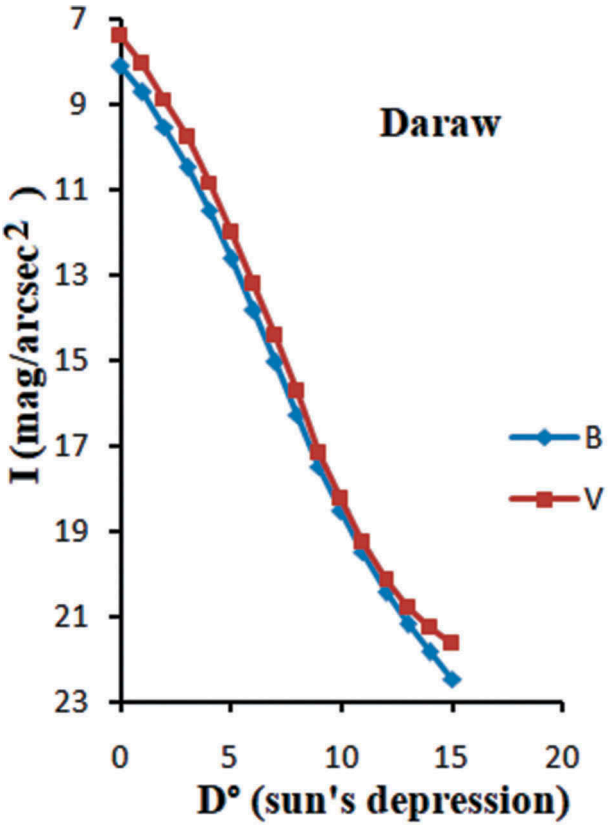

Figure 2. Variation of zenith sky twilight brightness with sun's depression (D°) at Helwan for blue and yellow colours.

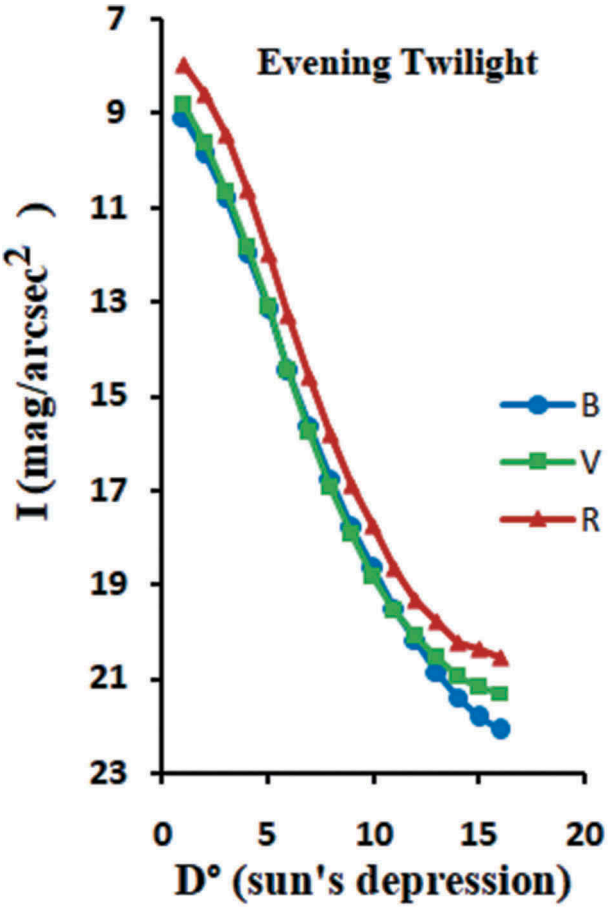

Figure 3. Variation of zenith sky twilight brightness with sun's depression (D°) at Daraw for blue and yellow colours.

Observation of the evening and the morning zenith sky twilight brightness, have been carried out at Abu-Simble site. Abu-Simble lies south of Egypt (ϕ = 22° 20` N, $\lambda$ = 30° 38` E) and its elevation is about 210 m above sea level. These results were expressed in S_{10} (B), S_{10} (V) and S_{10} (R) for blue, yellow and red colours respectively. These data have been converted into mag/arcsec^2 using the relation (1) and the results have been tabulated in Tables 3 and 4, for sun's depression between 1° and 16°, for evening twilight and from 0° to 16° for morning twilight. The results of Tables 3 and 4 have been drawn in Figures 3 and 4. In sake of comparison between the three sites mentioned before, in Egypt for evening twilight, Figures (6 and 7) are drawn, these figures clarify that there are slight differences between the evening twilight brightness in blue and yellow colours at Helwan and Daraw, but at Abu-Simble the zenith sky twilight brightness in blue is higher by maximum rating about 0.65 mag and in yellow colour by maximum rating about 1.3 mag.

3.2. Comparison between evening and morning twilight

To compare between evening and morning zenith sky twilight brightness results, which have been carried

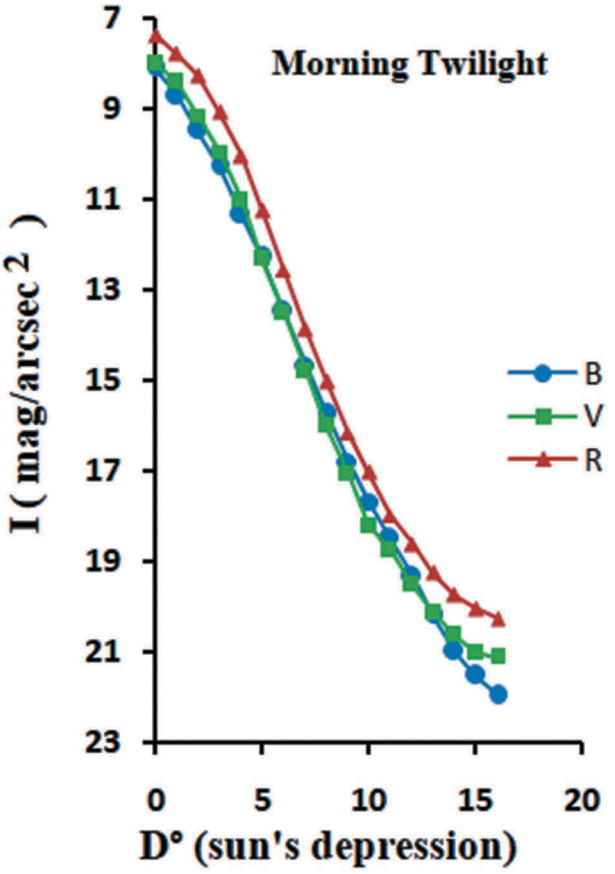

Figure 4. Variation of the evening zenith sky twilight brightness with sun's depression (D°) at Abu-Simble in blue, yellow and red colours.

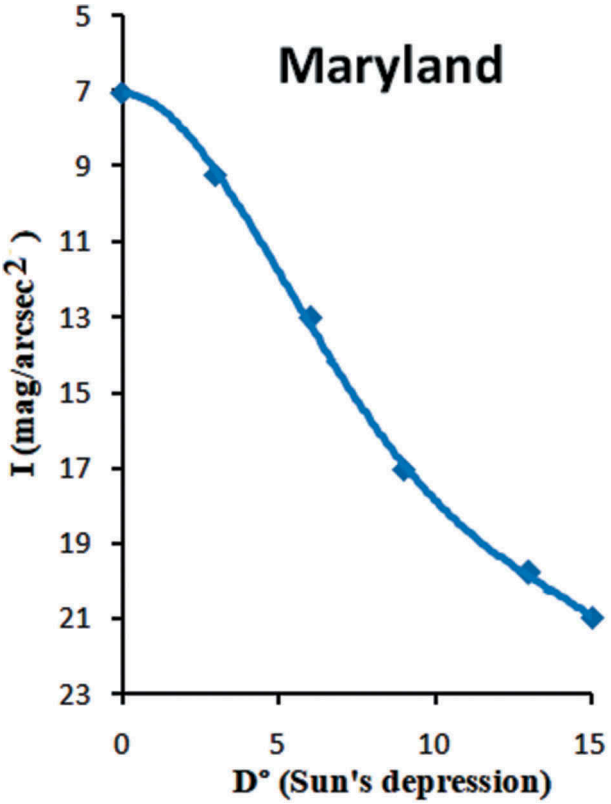

Figure 5. Variation of the morning zenith sky twilight brightness with sun's depression (D°) at Abu-Simble in blue, yellow and red colours.

out in the same night, Figures (8–10) have been illustrated from Tables 3 and 4. It can be seen from these figures that the brightness of morning zenith sky twilight brightness in the three colours is brighter than of the evening twilight results. The reason for this increase may be due to the sun's heating on the earth's atmosphere. During the daylight from sunrise to sunset, the sun heats the earth's atmosphere, making the molecular distances increase. So the scattering of sunlight in the earth's atmosphere decreases, causing a decrease in evening twilight brightness. Whenever, at night during the interval from sunset to sunrise, the temperature rapidly decreases and the molecular distances in the atmosphere decrease which increase the scattering process and increase the morning twilight brightness.

3.3. A comparison between all the previous results

The results of Tables 1–5 have been used to compare between all the previous results of zenith sky twilight brightness. Figure (11) represents that comparison, for the yellow filter. It is worth of mentioning, there is no

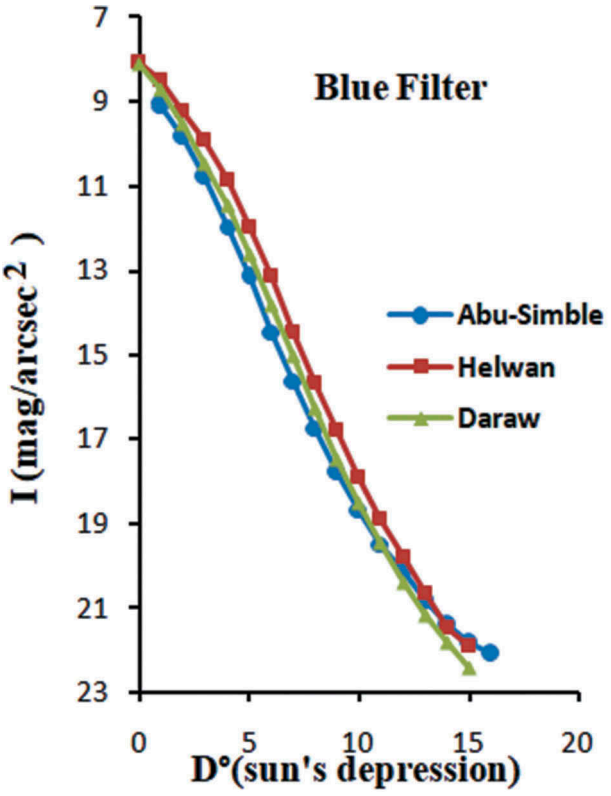

Figure 6. A comparison between the evening zenith sky twilight brightness at different sites in Egypt for blue colour.

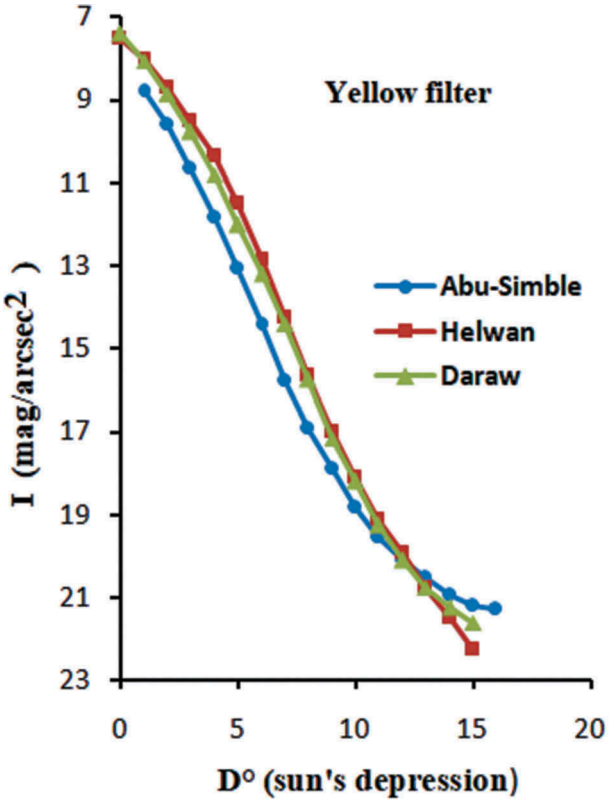

Figure 7. A comparison between the evening zenith sky twilight brightness at different sites in Egypt for yellow colour.

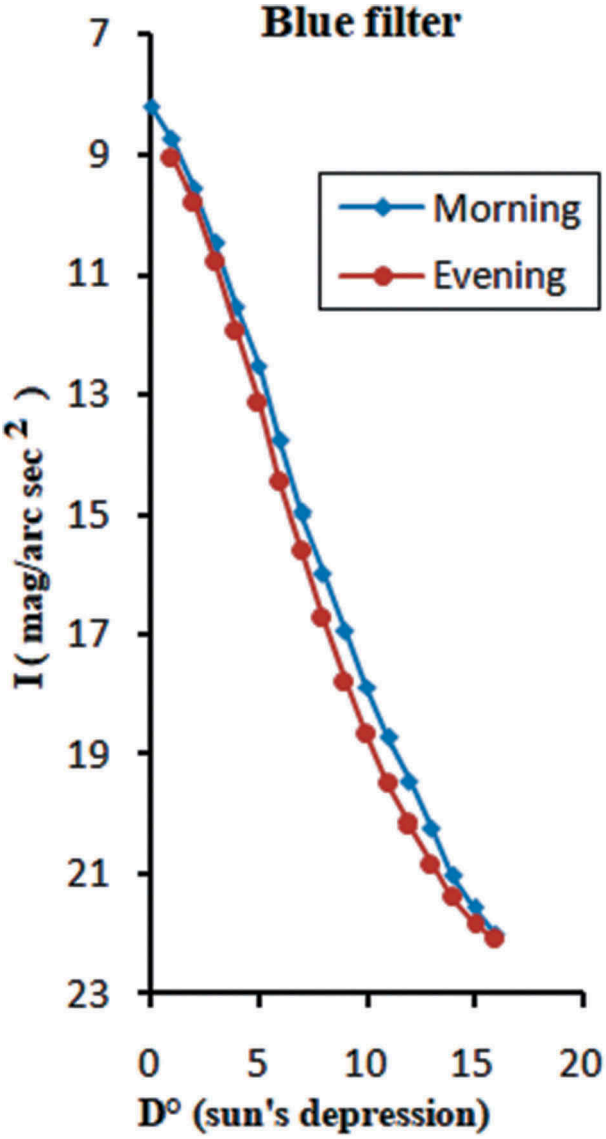

Figure 8. A comparison between morning and evening zenith sky twilight brightness at Abu-Simble for Blue filter.

comparison has been done with other filters since there is no published data at Maryland for blue and red colours. The values of zenith sky twilight brightness for sun's depression from 5° and 16°, at ESO – Paranal (Chile), using CCD camera expressed in mag/arcsec^2, published by Patat and Ugolnikov (2006). These values have been drawn also in Figure (11).

It is shown in Figure (11) that, at the beginning of the twilight; Maryland is the highest brightness, while Abu Simbel is the lowest illuminated site. The other sites (Helwan, Daraw, and Chile), seem similar in the brightness at the beginning of twilight brightness. At the end of the twilight, it is noticed that Abu-Simble, Maryland, and Chile become brighter than Helwan and Daraw. The differences in the brightness may be due to the differences in latitudes, atmospheric conditions, altitudes above sea level, seasonal variations, solar activity, and personal errors. There is no intersection at the beginning of the night, maybe due to the change in atmospheric conditions.

4. Colour index of zenith sky twilight brightness

The colour index is a physical quantity, defined as the difference between the brightness of a standard source of light at two different wavelengths. In astronomy, the colour index is used to determine the colour of the celestial object, and the colour of the star gives its temperature. To measure the colour index, it is required to find the magnitude of a star in two different wavelengths, for example in V and B, then the colour index B − V is given by the relation

$$(B - V) = m_B - m_V$$

where m_B and m_V are the blue and visible colour-magnitudes of the star. This relation can be written in terms of the intensity of the star as follows

$$(B - V) = -2.5 \times \log (I_B/I_V)$$

where I_B and I_V are the intensities of starlight in blue and visible filters.

In the study of the twilight, the colour variation is considered as one of the interesting points to study. The colour indices (B-V) and (B-R) are calculated from Tables 1–4, for each degree of sun's depression, at different sites Helwan, Daraw, and Abu-Simble. The results have been drawn in Figures 12–14. The (B-V) colour index obtained by Patat and Ugolnikov (2006), also are drawn in the same figure for comparison.

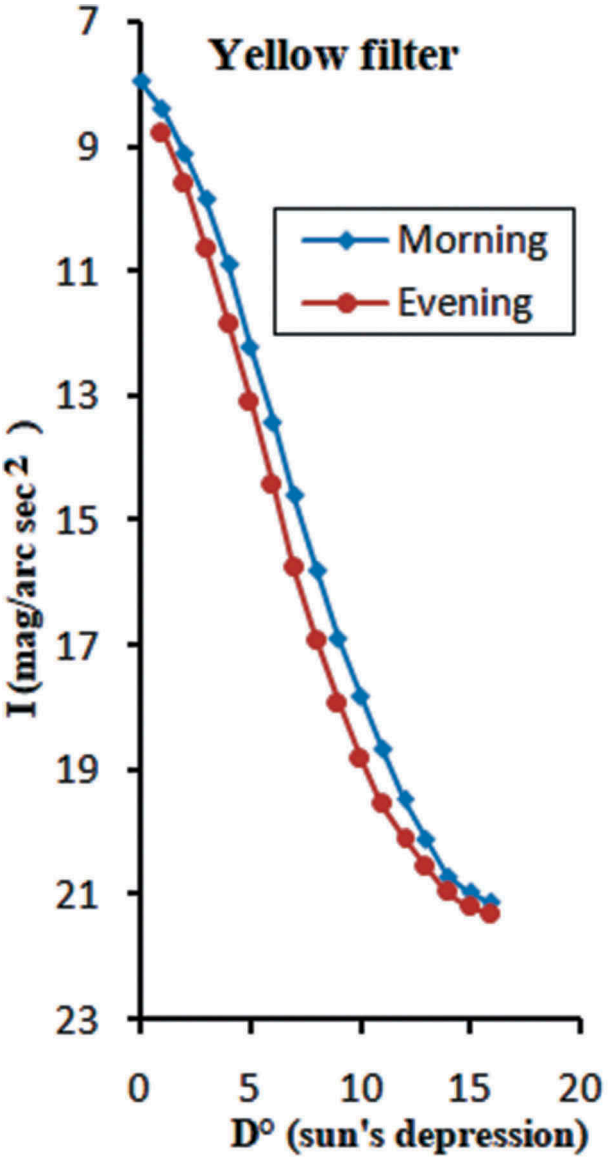

Figure 9. A comparison between morning and evening zenith sky twilight brightness at Abu-Simble for a yellow filter.

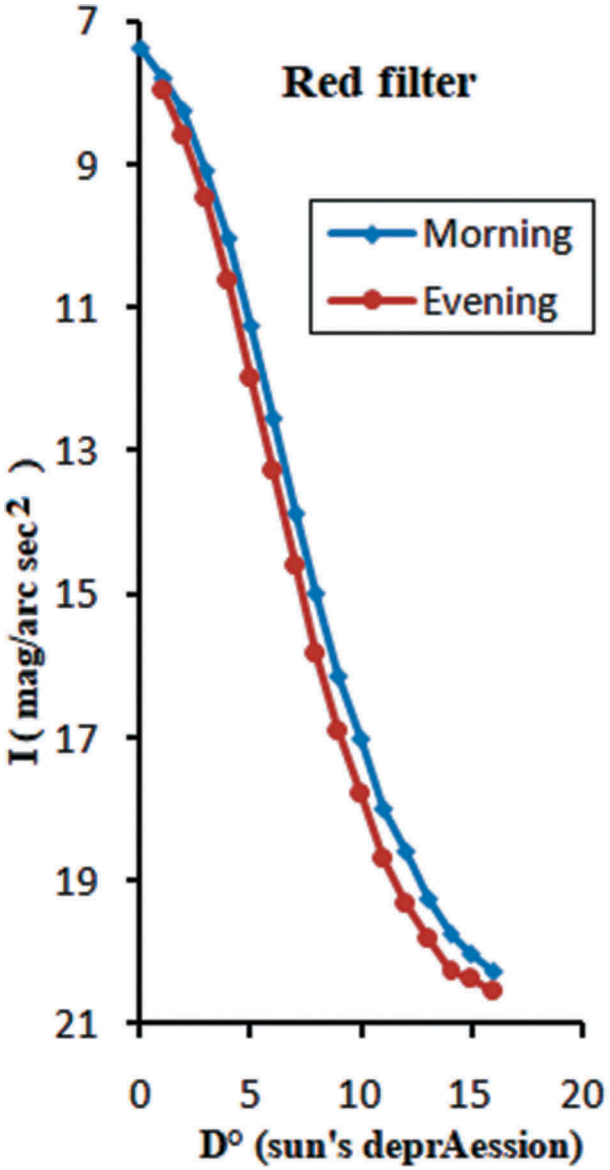

Figure 10. A comparison between morning and evening zenith sky twilight brightness at Abu-Simble for the red filter.

It can be seen from these figures that there is maximum reddening in the zenith sky twilight brightness for all sites mentioned before except Chile. The maximum reddening occupies 0.5, 2, 3 degrees at Abu-Simble, Helwan and Daraw respectively. There is no maximum reddening at Chile because there is no observation for sun's depression between 0° and 5° degree. For the sun's depression greater than 6° to 11° the sky tends to blue colouration. Again the sky twilight tends to relative red for sun's depression greater than 11°. These results show a good agreement with the results given by Rozenberg (1966).

Figure (14), represents a comparison between the colour indices (B-R) of morning and evening twilight at Abu-Simble. This figure shows that the maximum reddening appears between 2° to 4° sun's depression according to the type of the twilight (morning or evening), with a slight shift between them according to the increasing of the blue colour due to the secondly scattering in the twilight layers.

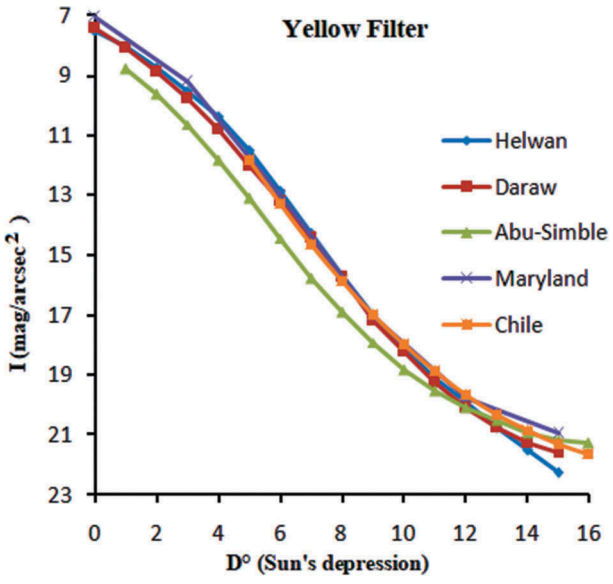

Figure 11. A comparison between, zenith sky twilight brightness with Sun's depression (D°) at different sites for a yellow filter.

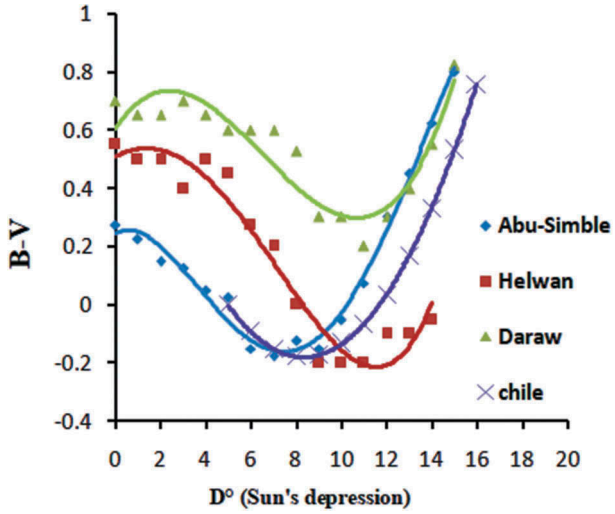

Figure 12. A comparison between (B-V) colour index of zenith sky twilight brightness with the sun's depression at different sites.

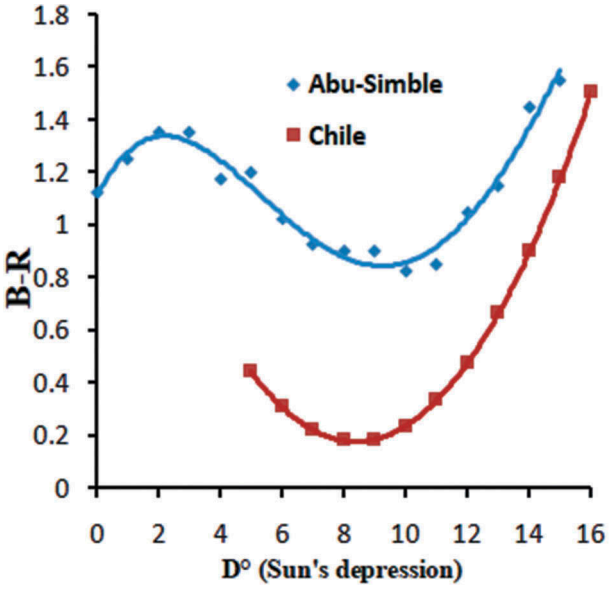

Figure 13. A comparison between (B-R) colour index of zenith sky twilight brightness with sun's depression at Abu-Simble and Chile.

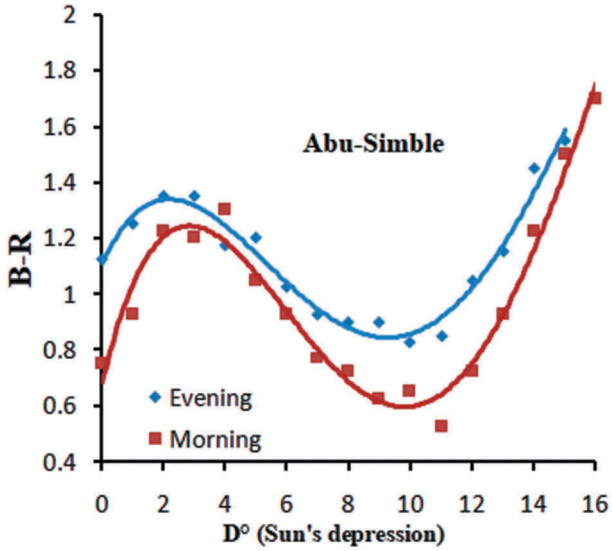

Figure 14. A comparison between (B-R) colour index of the evening and morning zenith sky twilight brightness with sun's depression at Abu-Simble.

Generally, as it is mentioned before, the differences in the zenith sky twilight brightness and colour indices are mainly due to the following factors:

(1) The variation of the geographical latitude of different sites.
(2) Solar activity effects.
(3) The change in atmospheric transparency from one site to another at observation time.
(4) Seasonal variation effect.

In the future work, the effect of different various factors mentioned before on sky twilight brightness and colour will be studied.

5. Summary and conclusion

New values of the zenith sky twilight brightness, for Daraw Helwan, Abu-Simble and Maryland expressed in mag/acrsec^2, at different wavelengths have been obtained, and represented in Figure 11. The present results have been compared with each other's, for each wavelength and with that obtained by Patat and Ugolnikov (2006), who used CCD for his observations. The (B-V) and (B-R) colour indices have been obtained, for each degree of the sun's depression for all sites mentioned before. The reasons for the differences, in colour indices for the zenith sky twilight brightness have been mentioned before.

Disclosure statement

No potential conflict of interest was reported by the authors.

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