Measurement of atmospheric refraction near the horizon at Teluk Kemang

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ABSTRACT Astronomical observations near the horizon have historically been measured for naval navigation and for determining the time of sunset. We had measured the variation of astronomical refraction near the horizon based on sun motion with an instrument called theodolite. We have collected several measurements of refraction from Telok Kemang, one of 26 sites for sighting young crescent in determining the month of Ramadhan, Syawal and Zulhijjah in Malaysia. Our measured values for refraction near the horizon is 35 arcminutes as compared to the standard value adopted 34 arcminutes.

ABSTRAK Pencerapan astronomi berhampiran ufuk telah dilaksanakan sejak dahulu kala untuk tujuan pelayaran dan menentukan waktu terbenam matahari. Kami telah mengukur perubahan pembiasan astronomi berhampiran ufuk berdasarkan pergerakan matahari dengan menggunakan peralatan yang dinamakan Theodolit. Kami telah mengumpul beberapa pengukuran pembiasan dari Telok Kemang, salah satu dari 26 tempat yang telah diwartakan untuk cerapan hilal untuk menentukan bulan Ramadhan, Syawal dan Zulhijjah di Malaysia. Nilai ukuran kami untuk pembiasan berhampiran ufuk ialah 35 arka minit berbanding nilai piawai yang diterima pakai iaitu 34.5 arka minit.

(refraction, aerosol, refreclive index, scattering)

INTRODUCTION

Over 90% of the atmosphere is located within the first 20km from the surface; the highest clouds cirrus occurs about 10km above the surface. The thickness of the atmosphere varies with latitude, maximum at the equator and considerably thinner at the poles. The effects of the atmosphere upon the appearance of an object lying outside it are direct functions of the length of the light path through it from the object to the observer. The length of the light path through the atmosphere is considerably greater if an object is observed at the horizon as compared to the zenith. The atmosphere interferes with the light from stars in a number of ways including absorption, scattering, reflection and refraction. The effect of scattering and refraction is also seen in the colour of objects near the horizon. The atmosphere is composed of gases and various types of particulate matter. As we have noticed that light of shorter wavelength, blue is more likely to strike a molecule of gas or particulate matter than a longer wavelength red, thus blue light is scattered while red light passes through. This effect is much more pronounced if light has to pass through more atmospheres, hence the rising and setting sun appears red/orange while the sky filled with scattered light appears blue.

Ground-based astronomical observations at visible wavelengths are affected by refraction. A light ray coming from a celestial body is slightly deflected toward the earth when passing obliquely through the atmosphere. This phenomenon is called refraction effects exist because of tropospheric variations in density and water vapour partial pressure as a function of position. Astronomical refraction addresses ray-bending effects for objects outside the Earth's atmosphere relative to an observer within the atmosphere. When a celestial object is observed through the Earth's atmosphere, its light is bent by refraction thus; the azimuth-to-declination calculation must include a correction for refraction. Astronomical refraction has long been studied, with significant contributions from the early times of Ptolemy, Kepler, Newton and many others (1). Astronomers all over the world have engaged extensively in analysing refraction because of its importance for the discipline of astrometry. However, astrometry is always been conducted for stars well at least 30^0 above the horizon. According to Smart (2), the solutions to the refraction integral all diverge as the horizon is approached. Furthermore, near the horizon the refraction can be determined from observations such as simple models given by Bruin (3), or complicated models suggested by Garfinkel (4). In modern times, Garfinkel program has been accepted as a standard that is used in most situations where accuracy is required.

However, Garfinkel program is entirely based on the U.S. Standard Atmosphere, an assumption that is valid as an average. In the real atmosphere we are certain is never an exact match to this ideal, deviations from the ideal atmospheres are common in real life and will lead to the value of observed refraction that is appreciably different from the calculations of Garfinkel.

RAY PATH MODEL

The index of refraction always depends on density, and the density of the atmosphere strongly depends on altitude, therefore light propagating in the atmosphere is bent typically toward regions of higher density or lower altitudes. Figure 1 illustrates simple refraction geometry for the angle of deviation for viewing an astronomical object by an observer at altitude z_0 and inclination angle α within a spherically stratified atmosphere surrounding the earth.

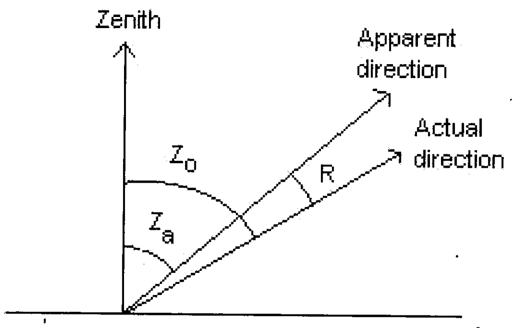

Figure 1. Astronomical refraction

When a celestial object is observed through the Earth's atmosphere, its apparent zenith distance z_a will be less than its true (topocentric) zenith distance z_0 by amount R called 'atmospheric refraction'. The general expression for atmospheric refraction is

$$R = z_0 - z_a \text{ or rearrange as}$$
$$z_0 = R + z_a$$

According to Minnaert (5), that a series of accurate sunset timings could be used as a measure of refraction and its daily variation. However, we have made several measurements of altitudes of the sun during sunset over an ocean horizon. All measurements were made with the whole solar disk visible without being hidden by cloud from altitude approximately 16^0 until the horizon with theodolite.

OBSERVATIONAL TECHNIQUE AND DATA

A theodolite is basically a telescopic sight, which can be rotated about a vertical and a horizontal axis. The angle of elevation is read from the vertical circle, the horizontal direction from the horizontal circle. Theodolites are primarily used for surveying, but they are excellent navigation instruments as well. Traditionally, theodolites measure zenith distances but now modern models are available for altitude measurement.

The equipment used was a Topcon GTS-700 Digital Theodolite with a reported accuracy of 1". The solar observational procedure followed the guidelines as outlined in the Survey Regulations 1976 Appendix V. Each observation of 1-minute apart consisted of four pointing to the sun on two circles, as shown in figure 2. On circle left, the left edge of the sun disc was placed tangentially to the vertical cross hair with the horizontal cross hair bisecting it and both the horizontal and vertical readings were taken. Using the slow motion screws, the cross hairs were carefully brought to right edge of the sun and the readings were again recorded. The procedure was repeated on circle right.

The means of the horizontal and vertical angles gave the position of the centre of the sun. Table 1 gives the values of atmospheric refraction correction angle, R at corresponding altitudes times and dates of observations.

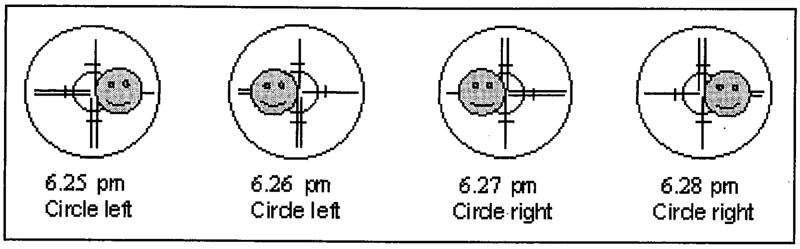

Figure 2. – Measurement techniques

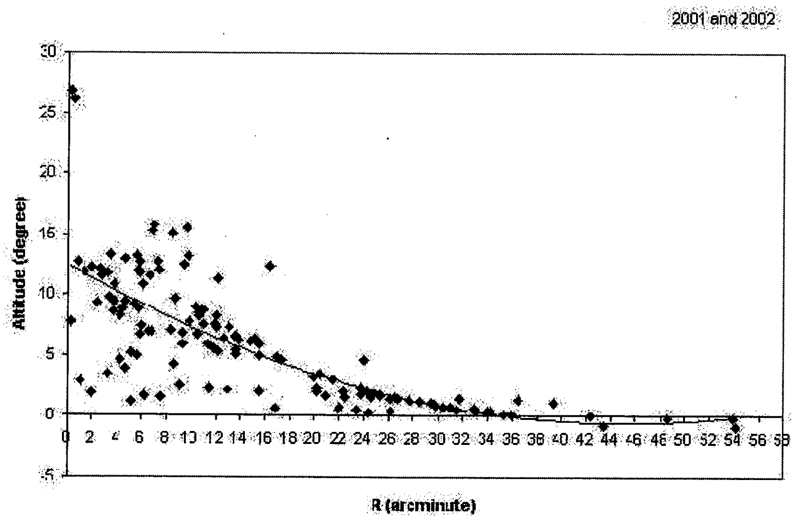

Figure 3. Altitude against refraction correction angle

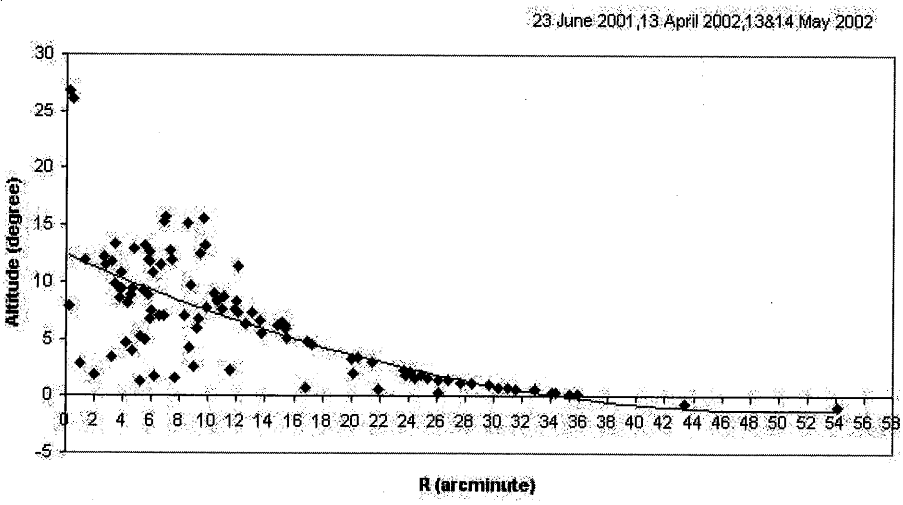

Figure 4. Altitude against refraction correction angle for cloudless day

Table 1. Shows the atmospheric refraction correction angle, R with corresponding altitudes, times and dates of observations.

Date	Time ±1s	Altitude (degree) ±0.003	R (arcminute) ±0.25
23 May 2001 (29 Safar 1422)	18 49	5.87	11.33
	18 40	5.57	11.83
	18 51	5.34	12.18
	18 52	5.13	13.67
	18 55	4.6	24.00
	19 16	-0.002	42.25
	19 17	-0.13	48.57
24 May 2001 (1Rabiulawal 1422)	18 45	6.74	10.6
	18 46	6.56	13.65
	18 47	6.33	13.92
	19 05	2.23	20.23
	19 06	2.03	22.30
	19 07	1.85	25.28
	19 08	1.63	26.53
	19 09	1.49	31.80
	19 10	1.33	36.50
	19 11	1.15	39.30
23 June 2001 (1Rabiulakhir 1422)	18 27	11.95	1.33
	18 28	11.75	3.23
	18 29	11.51	2.73
	18 32	10.84	3.83
	18 38	9.48	4.67
	18 39	9.27	5.42
	18 41	8.81	5.78
	18 49	7.00	6.82
	18 50	6.75	5.90
	18 51	6.54	7.03
	19 00	4.51	8.85
	19 01	4.27	8.22
	19 03	3.83	9.48
	19 04	3.60	9.53
	19 05	3.38	9.80
	19 19	0.44	26.08
	19 20	0.22	26.82
22 July 2001 (1 Jamadilawal 1422)	19 21	0.75	21.98
	19 22	0.54	23.33
	19 23	0.32	24.3
	19 27	-0.13	53.87
18 Sept 2001 (30 Jamadilakhir 1422)	18 15	13.23	24.4
	18 16	12.75	1.30
	18 17	12.49	0.40
	18 18	12.27	3.40
	18 30	9.28	4.10
	18 31	9.01	2.50
	18 32	8.78	3.90
	18 33	8.51	2.10
	18 59	2.21	21.50
	19 00	2.003	25.80
13 April 2002 (30 Muharam 1423)	18 06	15.789	7.02
	18 07	15.595	9.60
	18 08	15.312	6.84
	18 09	15.104	8.52
	18 17	13.23	9.72
	18 40	8.62	3.72
	18 43	7.82	0.18
	18 44	7.47	5.94
	18 53	5.26	5.16

Date	Time ±1s	Altitude (degree) ±0.003	R (arcminute) ±0.25
	18 55	4.95	5.58
	18 56	4.68	4.20
	18 58	4.26	8.58
	18 59	3.95	4.68
	19 01	3.43	3.18
	19 03	2.87	1.02
	19 05	2.54	9.00
	19 06	2.33	11.46
	19 07	1.93	1.98
	19 08	1.75	6.18
	19 09	1.53	7.62
	19 10	1.24	5.16
	19 13	0.69	16.80
	19 14	0.53	21.90
	19 15	0.36	26.16
	18 40	8.62	3.72
	18 43	7.82	0.18
	18 44	7.47	5.94
	18 53	5.26	5.16
	18 55	4.95	5.58
	18 56	4.68	4.20
	18 58	4.26	8.58
	18 59	3.95	4.68
	19 01	3.43	3.18
	19 03	2.87	1.02
	19 05	2.54	9.00
	19 06	2.33	11.46
	19 07	1.93	1.98
	19 08	1.75	6.18
	19 09	1.53	7.62
	19 10	1.24	5.16
	19 13	0.69	16.80
	19 14	0.53	21.90
	19 15	0.36	26.16
13 May 2002 (30 Safar 1423)	18 16	13.37	3.42
	18 17	13.17	5.58
	18 18	12.92	4.74
	18 19	12.72	7.32
	18 22	11.99	5.76
	18 32	9.66	8.76
	18 35	8.98	10.38
	18 36	8.75	11.04
	18 37	8.51	10.68
	18 38	8.27	10.68
	18 41	7.57	10.98
	18 42	7.35	12.06
	18 46	6.45	15.12
	18 47	6.22	15.36
	18 48	5.98	15.42
	18 52	5.03	15.48
	18 53	4.82	16.92
	18 54	4.59	17.28
	19 05	2.09	24.18
	19 06	1.85	23.76
	19 07	1.63	24.48
	19 08	1.43	26.76
	19 09	1.21	27.72
	19 11	0.78	30.36
	19 12	0.56	31.50
	19 13	0.36	34.08
	19 14	0.16	35.88

Table 1. (Continued)

Date	Time ±1s	Altitude (degree) ±0.003	R (arcminute) ±0.25
14 May 2002 (1 Rabiulawal 1423)	18 06	15.789	7.02
	18 07	15.595	9.60
	18 08	15.312	6.84
	18 09	15.104	8.52
	18 17	13.23	9.72
	18 19	12.70	5.82
	18 20	12.51	9.36
	18 21	12.16	2.64
	18 22	12.01	7.44
	18 23	11.74	5.82
	18 24	11.52	6.60
	18 25	11.38	12.12
	18 27	10.80	6.12
	18 38	8.29	12.00
	18 40	7.78	9.84
	18 41	7.58	11.88
	18 42	7.36	13.02
	18 43	7.05	8.34
	18 44	6.83	9.30

Date	Time ±1s	Altitude (degree) ±0.003	R (arcminute) ±0.25
	18 45	6.66	13.62
	18 46	6.41	12.66
	18 47	6.21	14.82
	18 48	5.88	9.24
	18 50	5.48	13.68
	18 59	3.46	20.46
	19 00	3.22	19.98
	19 01	3.00	21.48
	19 04	2.33	23.70
	19 05	2.04	20.16
	19 06	1.88	24.90
	19 07	1.65	25.32
	19 08	1.424	26.10
	19 09	1.23	28.50
	19 10	1.01	29.70
	19 11	0.80	31.02
	19 12	0.59	32.88
	19 13	0.38	34.26
	19 14	0.16	35.34

RESULTS AND CONCLUSION

For our measurements we used two programmes which calculate the true position of moon and sun. These programmes are Moon52 (based on British Almanac) and Rukyah93 (based on Japanese Ephemeris) for the angular deviation of an astronomical object observed through a standard atmosphere as a function of elevation angle. The atmospheric refraction index, R is obtained by subtraction of the observed data by the theoretical data taken from the programmes. The values from each position were than plotted with altitudes as shown in figure 3. Six days out of the 10 days of measurement of the sun position we are not able to observe the sun disc disappeared below the horizon. From the graph, the value of refraction at the horizon is determined as 36.5 arcminutes. However, four days out of the 10 days of measurement of the sun position we are able to observe clearly the sun disc disappeared below the horizon. Figure 4 shows a plot of atmospheric refraction, R with altitudes for a very cloudless day. The large scatter seen at R values < 20 arcminutes is due to the aerosol content in the atmosphere during measurement. The measured value of refraction at the horizon is determined as 35 arcminutes. This measured value is closed to the refraction correction angle for a standard atmosphere that is 34.5 arcminutes. The deviation of the measured values from the standard is due to typical variations in the atmospheric index of refraction. As we already know, dispersion of refractive index causes the refraction correction angle to vary slightly for different wavelengths (colors).

Acknowledgement The author will like to thank you the staff from the Geodesy Department, Land Survey and Mapping Malaysia for their helpful and guidance in taking the measurements. I would like to extend my appreciation to Ministry of Science, Technology and Environment (MOSTE) and Islamic Centre Malaysia (JAKIM) for the financial support to carry out this project.

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