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Comparative Study of Observation with Theoretical Contrast using the Schaefer and Crumey Methods on the Image Result Observation Using OZT-ALTS Robotic Telescope

Robiatul Muztaba[1], Yasmin Mufidanisa[2], Muhammad Isnaenda Ikhsan[3]
[1,2,3]Institut Teknologi Sumatera
(Jl. Terusan Ryacudu, Way Huwi, Kec. Jati Agung, Kabupaten Lampung Selatan, Lampung 35365)
*Email: robiatul.muztaba@sap.itera.ac.id

Abstract

Observing the crescent moon (hilal) is crucial as it significantly impacts religious activities, particularly for the Muslim community. However, there are challenges associated with hilal observation due to its appearance as a young crescent moon, making it very small apparent size, resulting in low visibility. Additionally, hilal observations are conducted before sunset when the sky still retains brightness, causing a narrow contrast between the moon's light and the background sky. This research aims to compare the contrast values obtained from observing the hilal with the OZT-ALTS Robotic Telescope to theoretical hilal values. Two theoretical contrast methods are examined in this study. The observed contrast values show an increase over time, albeit fluctuating due to cloud interference. The Schaefer contrast also increases over time, with values similar to observed contrast. The Crumey contrast decreases approaching dusk but increases after sunset. Spearman correlation analysis is used to investigate the relationship between each contrast. Observation contrast and Schaefer show a positive Spearman correlation of 0.1413. However, the contrast between observation and Crumey shows a negative correlation of -0.0603. The correlation between Schaefer and Crumey also resulted in a negative correlation of -0.8943. Theoretical contrast in this study only shows the ideal model at the time of observation because dynamic environmental factors are difficult to model, thus the relationship between observed and theoretical contrast is weak. The theoretical contrast in this study does not can be used as a reference in hilal observation.

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A. Introduction

The use of celestial objects as signs of time has been used for centuries, one of which is the moon. Hilal or young crescent moon is one of the phases of the moon. Hilal is usually observed a few hours after conjunction and marks the turn of the month in the Hijri calendar [1, 2, 3]. Hilal observation is important because it will affect the religious activities of the

Muslim community [4]. However, there are still problems related to hilal observation, because hilal is a young crescent moon that is very small in apparent size, so its visibility is very low.

During the day, the wavelengths received by the observer range from ultraviolet to infrared, making the hilal difficult to see because the contrast difference between the background sky and the hilal is very thin. So for daytime hilal observation, an infrared filter is used to minimize the wavelength range and thus increase the contrast of hilal visibility [5]. Cloudy skies, air humidity, atmospheric thickness, and other parameters pose challenges to hilal observation. One of the problems of hilal observation isfalse-positive sighting, which occurs when the crescent moon is seen but turns out to be wrong after recalculation, either because it has extreme crescent parameters or because the moon is already below the horizon [6].

Theoretical contrast is the value of the hilal visibility contrast obtained from calculations based on the Moon-Sun angle (elongation), Moon altitude, and Sun altitude, further including atmospheric parameters such as atmospheric thickness, air pollution, light pollution, and others. The theoretical contrast is expected to describe how the contrast value of the hilal to be observed, whether it can be seen or not by the human eye in the hilal observation process.

B. Method

The data used in this study are crescent image data taken on March 22, 2023 from 12.00 WIB - 18.00 WIB (UTC+7) with a total 2,456 images [7]. This data was taken using the OZT-ALTS Robotic Telescope owned by OAIL (ITERA Lampung Astronomical Observatory) located at MKG ITERA Instrument Park, Lampung, Indonesia. The observation location is at coordinates 5°21'25.9" N, 105°18'41.7" E, and is at an altitude of 90 meters above sea level. Manta G031-B detector and Astelco NTM-500 mounting were used, and RG1000 filter(λ_{eff} = 1000nm) was used. The data obtained from this telescope instrument is in the form of an image (image) of the hilal which will then be calculated the contrast value using AstroImageJ (AIJ) software.

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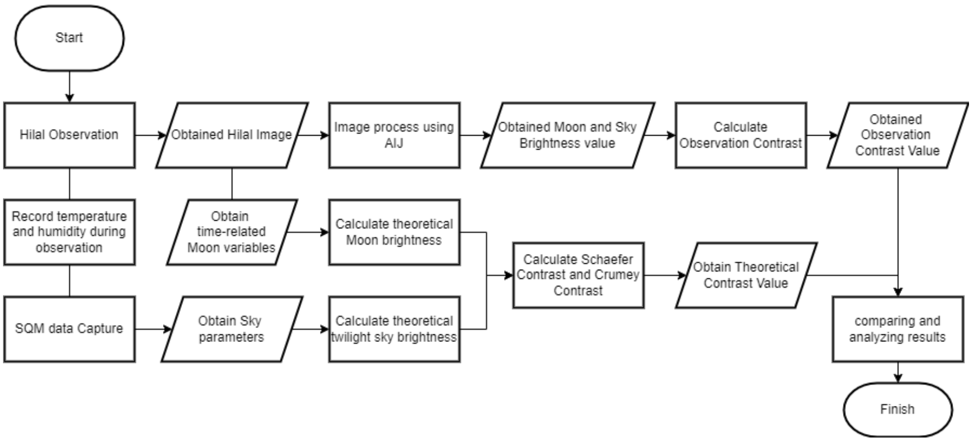

Figure 1. Research Flowchart

B.1. Twilight Sky Brightness Data

Light pollution data is also needed in the twilight sky around the research location to calculate the brightness of the sky on theoretical model. Light pollution data is obtained using Sky Quality Meter (SQM) data taken around the OZT-ALTS area to get the twilight sky brightness value.

Table 1. Twilight Sky Brightness taken from SQM

Time (UTC)	Sky Brightness (mag/arcsec^2)
10:47:07	6.64
10:47:37	6.70
10:52:37	7.23
10:57:37	7.78
11:02:37	8.60
11:07:37	9.68
11:12:37	11.02
11:17:37	12.38

B.2. Observation Contrast

To get the value of Observation Contrast, it is done by using hilal image data. From all the data obtained, images with an interval of about 15 minutes will be selected to be processed to see changes in elongation. The data will be processed using AstroImageJ (AIJ) software. AIJ is used to calculate the brightness value of an area in the image, then summing up each photon count in the pixels covered in the area [8], three points will be taken on the moon and three points on the sky at the edge of the moon to calculate the average brightness. By using this method, the value of the brightness of the hilal surface (B_{moon}) and also the brightness of the background sky (B_{sky}) in each image obtained can be taken.

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$$C_{obs} = \frac{\Delta B}{B_{sky}} = \frac{B_{moon} - B_{sky}}{B_{sky}} \tag{1}$$

Description :

C_{obs} = Observation Contrast

B_{sky} = Sky brightness

B_{moon} = Moon surface brightness

B.3. Moon Surface Brightness

The process of calculating the theoretical contrast will all use Python programming through Google Collaboratory, to find the theoretical contrast value, the position variable data (Moon elongation, Moon altitude and Sun altitude) is needed at the time of observation by adjusting the time in the image using the Skyfield library with NASA DE440 JPL ephemeris. In the theoretical model, the brightness of the light source, which is the moon, is calculated with the geometry of the angle between the Moon-Sun-Earth, the moon elongation value will be obtained [9]. If the elongation is known, the moon phase angle can also be known, and it is used to measure the area of the moon that is exposed to light when viewed from the position of the observer [10].

B.4. Atmospheric Influence

The brightness of the Moon outside the atmosphere obtained from the previous calculation will be dimmed by atmospheric influence factors. This is affected by the Moon's altitude air mass and also the extinction coefficient due to gas (Rayleigh scattering), aerosols (Mie scattering), and the ozone layer. The closer the object is to the horizon, the higher the amount of dimming due to the atmosphere, as the air mass is thicker around the horizon compared to the zenith. The Rayleigh scattering component can be calculated as a function of wavelength, height, and refractive index [10, 11]. However, the value of the Mie scattering can be influenced by the relative humidity factor, the position of the sun's right ascension (RA), and the height (elevation) of the observer [10]. The source of aerosols in the atmosphere can be many different things, which are highly variable and quite difficult to predict precisely. There are various trends that can be used to provide a fairly accurate estimate of the extinction coefficient due to aerosols. If both extinction coefficients of each component are known, the amount of dimming of the moon's brightness after passing through the atmosphere can be

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calculated. The two extinction coefficients are summed and then multiplied by the air mass of each component. Then the decrease in object brightness can be calculated with the pogson equation for magnitude [6].

B.5. Schaefer Contrast and Crumey Contrast

Once the value of the moon's brightness after passing through the atmosphere is obtained, then the brightness of the twilight sky will be calculated. The brightness of the twilight sky is influenced by the altitude of the Sun and the also the light pollution factor of the observation area. First calculate the magnitude of the twilight sky without light pollution, then calculate the brightness of the twilight sky with light pollution with data from SQM for Zenith light pollution [6]. This gives the theoretical sky magnitude value. Schaefer contrast uses the sensitivity of the human eye, so the Snellen ratio is used. A value of 20" is used in this model as a reference for normal human eyes. However, the Crumey contrast uses the equation form from the fitting model [13], using the twilight sky magnitude value converted to candela first and the crescent area converted to steradians.

C. Results and Discussion

Observation contrast is obtained from processing the observation image, one example of which is Figure 1. The hilal that appears very thin is only like a curved line, shown with a red arrow in Figure 2. It can be identified that this is hilal by looking at the data before and after which only differ by a few seconds that in the same position there is also the same thin line, and after a few minutes the line has shifted, so it is certain that the line is not a broken pixel. The part indicated by the red arrow is the region of the moon brightness and sky brightness values taken using AstroImageJ.

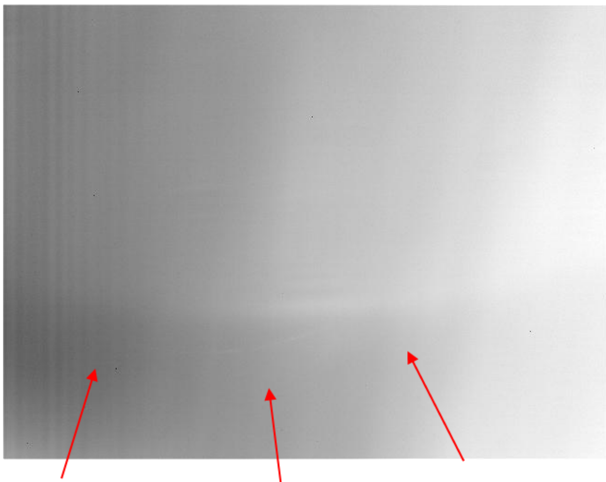

Figure 2. Hilal Image obtained from OZT-ALTS telescope

Processing of observation images produces 18 pieces of data, from which the observation image data will be taken time information when taking the image. From the time data, it can be calculated with ephemeris to get the position and geometry parameters of the moon at the time the image was taken and also fill in the empty data part in the observation contrast, so that 23 data are obtained for the theoretical contrast.

Table 2. Moon parameters obtained from ephemeris calculation

Time (UTC)	Moon Alt (°)	Moon elongation (°)	Sun-moon azimuth difference (°)	Moon Phase (%)	Moon Age (Hours)
2023-03-22 05:06:31	80.55	-3.57	48.77	0.54	8.88
2023-03-22 05:20:34	82.61	-0.44	60.02	0.55	9.12
2023-03-22 06:02:34	80.36	5.72	22.04	0.58	10.08
2023-03-22 06:17:21	77.46	6.29	14.90	0.59	10.56
2023-03-22 06:41:30	72.14	6.77	9.22	0.61	11.04
2023-03-22 07:05:19	66.61	7.04	6.62	0.63	11.76
2023-03-22 07:20:25	63.03	7.18	5.64	0.64	12
2023-03-22 07:32:28	60.16	7.27	5.07	0.65	12.48
2023-03-22 07:47:29	56.56	7.37	4.53	0.66	12.72
2023-03-22 08:02:51	52.86	7.47	4.12	0.67	13.2
2023-03-22 08:17:25	49.34	7.57	3.82	0.69	13.68

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Time (UTC)	Moon Alt (°)	Moon elongation (°)	Sun-moon azimuth difference (°)	Moon Phase (%)	Moon Age (Hours)
2023-03-22 08:32:24	45.72	7.66	3.59	0.70	14.16
2023-03-22 08:47:20	42.11	7.75	3.41	0.71	14.4
2023-03-22 09:01:52	38.59	7.84	3.28	0.72	14.88
2023-03-22 09:17:23	34.83	7.94	3.17	0.73	15.36
2023-03-22 09:30:29	31.65	8.02	3.09	0.74	15.84
2023-03-22 09:45:30	28.02	8.12	3.04	0.75	16.08
2023-03-22 10:00:30	24.39	8.22	3.00	0.76	16.56
2023-03-22 10:15:31	20.75	8.32	2.98	0.78	17.04
2023-03-22 10:30:32	17.12	8.42	2.97	0.79	17.52
2023-03-22 10:45:33	13.49	8.53	2.98	0.80	18
2023-03-22 11:02:38	9.36	8.66	3.02	0.81	18.72
2023-03-22 11:17:39	5.74	8.77	3.06	0.82	19.2

By measuring the observed contrast in the image using AIJ, and calculating the theoretical contrast in Python based on the moon parameters from the ephemeris, results were obtained. The results were obtained in the form of contrast graphs against time-varying position variables. In each plot, the Spearman rho (ρ) value and p-value are presented, and a black linear regression line is also given on each graph plot. The regression in each plot is meant to show the trend of the data, not to find the correlation value, therefore the shape of the regression sometimes does not match the Spearman correlation value.

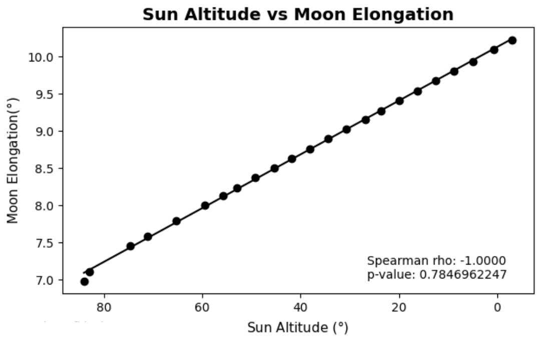

Figure 3. Correlation of the Sun's altitude with the moon's elongation

The Spearman correlation coefficient value in Figure 3 shows a value of -1, which means that the relationship is perfect but the direction is negative. The p-value is zero, which means that these two variables do have a causal relationship. These two variables are time-varying variables, the elongation of the moon will increase over time while the altitude of the Sun will decrease. The Sun altitude variable is used because it will represent the state of sky brightness, whether it is still bright or already dark (Sunset). In the graph presented, the horizontal axis has been reversed so that the value of the Sun's altitude changes with time, i.e. it continues to fall. Therefore, the resulting trend is positive even though the correlation is negative, which would apply to all plots that use the Sun's altitude on the horizontal axis.

Table 1. Comparison of the value of each contrast versus the altitude of the Sun

Sun Altitude (°)	Observation contrast	Schaefer contrast	Crumey contrast
84.12	0.01668	0.00280036	2.14212
83.05	0.0216	0.00280037	2.05273
74.64	0.03216	0.00280042	1.72156
71.18	0.03701	0.00280045	1.60047
65.38	0.0422	0.0028005	1.40241
59.57	0.04198	0.00280056	1.2075
55.86	0.03215	0.00280061	1.08435
52.89	0.04551	0.00280065	0.98647
49.18	0.05689	0.00280071	0.86526

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Sun Altitude (°)	Observation contrast	Schaefer contrast	Crumey contrast
45.38	0.04279	0.00280079	0.74262
41.78	0.04438	0.00280087	0.6284
38.06	0.04626	0.00280097	0.51401
34.36	0.03099	0.0028011	0.4046
30.75	0.02928	0.00280125	0.30436
26.89	0.03795	0.00280145	0.20688
23.63	0.03781	0.00280166	0.1352
19.9	-	0.00280197	0.07394
16.17	-	0.00280238	0.0267
12.43	-	0.00280294	0.00303
8.69	-	0.00280371	0.03306
4.96	-	0.00280482	0.11661
0.7	0.03489	0.00280674	0.29508
-3.04	0.0515	0.0028094	0.54663

The values of the change of each contrast with respect to the Sun's altitude are presented in Table 2. The highest contrast value is the Crumey contrast and the lowest is the Schaefer contrast. The observation contrast values fluctuate up and down, but still show an increase when comparing the initial and final contrast values. The blank values in the observation contrast section of Table 2 are images that were cloudy at that time, so the observation contrast could not be calculated because the moon was not in the image.

The Schaefer contrast produces a small value and the change is very small as well. Because the eye sensitivity factor and Snellen's ratio, so the small value produced can be an assumption that this is the amount of hilal contrast that can be observed with the naked eye at the time of data collection. The resulting value is very small compared to the observed contrast value obtained from the OZT-ALTS telescope, which has been designed to observe the hilal and can increase its contrast.

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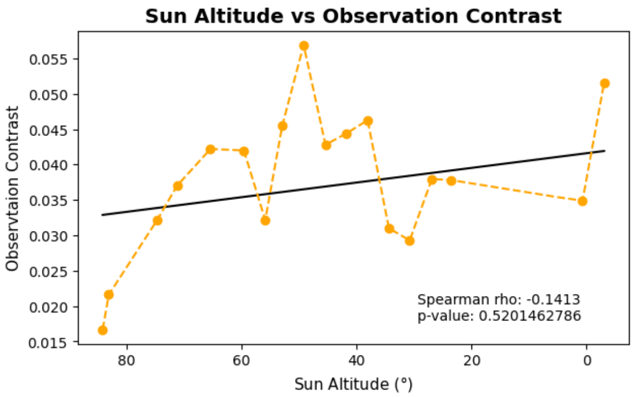

Figure 4. Fluctuation of observation contrast value

The change in the observation contrast value shown in Figure 4 shows an up and down value. Due to the condition of the image, which is mostly blocked by clouds, the contrast value can decrease if there are clouds in the image. But the shape of the plot still shows a positive trend, namely the contrast value increases over time, marked by the decreasing value of the Sun's altitude. The Spearman coefficient value is -0.1413, which means that the observed contrast and Sun altitude have a weak relationship, with a p-value of 0.5201, which means that the correlation is not significant.

The fluctuating value obtained in the observation contrast as in figure 4 is due to the condition when the image was taken very cloudy and it affects the image quality. If there are thin clouds blocking the hilal, the contrast will decrease because the difference in brightness between the hilal area and the sky becomes narrow. At some times, the cloud cover is very thick in the interval of about 1.5 hours, from the Sun's altitude of about 20° to near sunset (0°), only after the Sun sets does the hilal become visible again. This caused the hilal at that time to be unprocessable, so the data at that time was left blank.

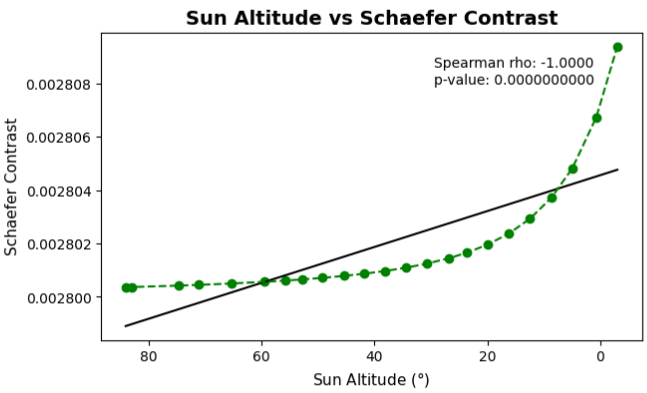

Figure 5. Increasing of Schaefer contrast to Sun altitude value

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The Schaefer contrast change graph in Figure 5 also shows an increase in value over time. The difference in the change in contrast value is not large when the Sun has not set, and then increases rapidly when the sky is dark. However, the magnitude of the change is relatively very small compared to the observed contrast. The Spearman correlation value is very good at =-1, indicating a perfect relationship of increasing Schaefer contrast as the Sun's altitude decreases. The p-value is also zero, which means that the correlation is statistically significant and the relationship is not accidental.

The Crumey contrast in Figure 6 shows the opposite trend to the other two contrasts. The other two contrasts show a negative coefficient as the contrast increases as the Sun descends, while for Crumey, the coefficient is positive which means that the contrast decreases with decreasing Sun altitude, and this relationship is statistically significant as the p-value is close to zero.

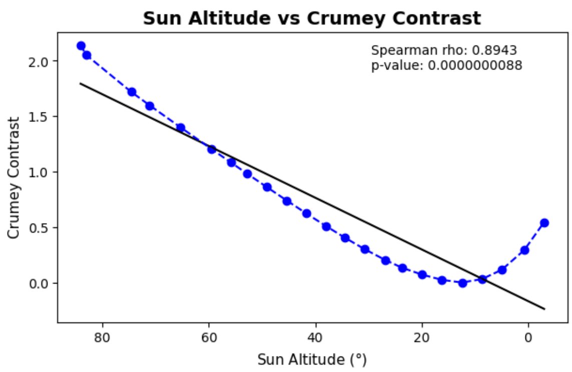

Figure 6. Decreasing of Crumey contrast to Sun altitude value

The Crumey contrast decreases towards twilight, and then increases after sunset, the turning point being at sunset. The decreasing trend in Crumey contrast but then increasing as the Sun begins to set is actually a model that matches the air mass, which is the thickening of the atmosphere in the area around the horizon [12].

A decrease in contrast value can be caused by two factors: either the brightness of the moon decreasing, or the brightness of the sky increasing [15]. The thickening of the air mass in the horizon region will make the moonlight experience a lot of extinction and decrease in brightness. At sunset, the contrast value increases again as the sky darkens. However, the Crumey equation model is the result of fitting [14] which makes the shape of the resulting curve fit the data used in the study, so it is not certain that this model is suitable and suitable if used on hilal whose parameters are extreme as in this study, namely the presence of clouds

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that are quite thick and numerous, the size of the thin hilal, and the position of the hilal which is very close to the horizon.

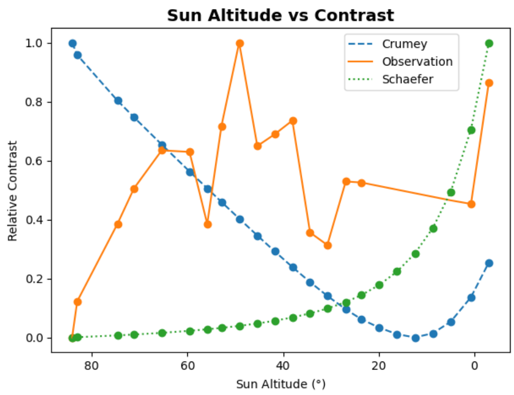

Figure 7. Comparison of contrast changes

Figure 7 is a graph of the change of the three contrasts over time, stacked into one plot, to show the shape of each. The plot does not represent the values, as the three contrasts are in different order ranges, so a vertical axis of the relative value of the contrast change is used. From the shape, each contrast has a different profile. The yellow Observation contrast fluctuates greatly, the green Schaefer contrast increases over time, and the Crumey contrast decreases until sunset and then increases. But these three contrasts still show the same thing at sunset, which is that they all increase. If it is related to the physical conditions at the time of observation, the sky had already darkened due to the setting Sun and the moon became more visible despite the large thickness of the atmosphere.

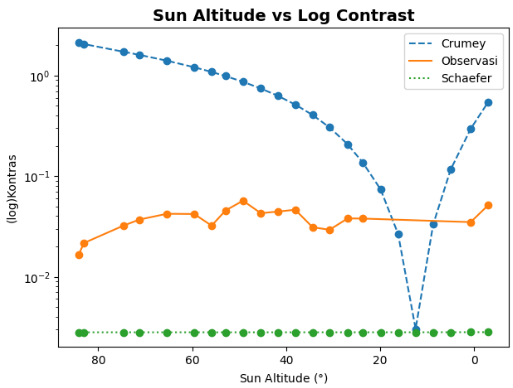

Figure 8. Comparison of contrast changes in logarithmic value

A logarithmic scale is used on the vertical axis of the graph in figure 8 to show the shape of the trends of the three contrasts in terms of their actual values, since the values of each contrast are of a different order. The Schaefer contrast tends to show no change compared to the other two contrasts because the change in value is relatively very small compared to the other two. The fluctuations of the observation contrast are still visible although they are relatively low, the increasing trend is not visible. The most noticeable graphical form of change in contrast value is the Crumey contrast where the downward trend is very clear. Shortly before sunset, the Crumey contrast value drops to equal the Schaefer contrast value.

D. Conclusion

The impact of the atmosphere around the study area will make the Schaefer contrast value very low. Whereas in the Crumey model the influence of the atmosphere will make the moon's brightness decrease as it approaches the horizon. The Schaefer contrast produces a smaller value than the observation contrast value, this shows the influence of the atmosphere on the Schaefer calculation resulting in a low contrast range. Crumey contrast shows that as the moon approaches the horizon, the contrast decreases. But at sunset the contrast shows an increase in value. The theoretical contrast in this study only shows the ideal model at the time of observation because dynamic environmental factors are difficult to model, therefore the relationship between the observed and theoretical contrast is weak. The theoretical contrast in this study cannot be used as a reference in hilal observation.

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