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The Variation Of Sun Luminance During The Year And Its Effect On The Visible Range Of The Satellite Imaging Time

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***Abstract*—**This study involves studying the difference in the sun ray luminance at satellite imaging time. Although, it is confirmed time for the same region throughout the year, changing the length of the day and the difference in the luminance of the sun throughout the year lead to different luminance of the sun falling on the earth at the time of imaging.

The remote sensors are often passive systems, i.e. record the reflected radiations and not sent them as the active systems, so, the brightness of the targets will be effected directly by the luminance of the sun's rays. Any change in the luminance will affect the brightness of the satellite imagery. This change in brightness will affect the recognition or interpretation the time change targets, also affect the visual classifiction.

The result of this research is a chart showing the sun luminance changing during the year at the satellite imaging time, and then conversing it to an empirical equation, both chart and equation can be used to get the luminance of sun light at any satellite imaging time in the study area. We also added a correcting equation to calculate the effect of day weather on luminance, because it is variable and needs to be measured by recording the weather case on the day and time of imaging.

***Key words*:** Remote sensing, luminance of the sun light, satellite imaging time.

I. INTRODUCTION

The sun is the main source of all types of electromagnetic radiation directly or indirectly. The sun's distance to the earth's surface is about 149.5 million kilometers [R.1]. The sun produces huge nuclear reactions that produce various wavelengths of electromagnetic radiation ranging from long range radios and short wavelength cosmic rays.

Electromagnetism consists of approximately 45% visible radiation and 46% thermal radiation [R.2], the spectral of solar radiation can be shown in Fig. (1).

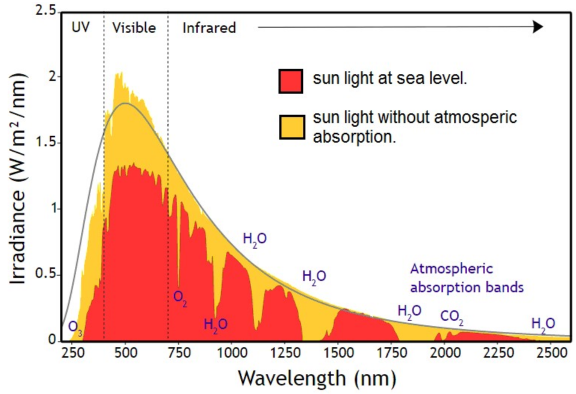


Figure (1): Spectral of Solar Radiation on Earth [R.3].

The sun luminance, radiant luminance, or radiance refers to the strength and direction of sun radiation incident on a surface. The units is W.m^{-2}. sr^{-1}, or W.m^{-2} / nm [R.4].

The sun luminance is an essential parameters in remote sensing imaging systems, although there are other factors affect the ray response of targets on the earth, like the inclination of ground, atmospheric contents or the sun position.

While M. Boulifa, et. Al., 2010, studied solar radiation evaluation by satellite images processing briefly [R.5].

A. Ibrahim, 2011, worked estimation of solar irradiance on slanted surfaces facing the south in Tanta city, Egypt [R. 6].

Bojanowsiki, 2014, quantified the solar radiation at the surface of earth with meteorological and data [R. 7].

Forsythe, John M., et al, 2015 discussed all geometric positions which affect the solar luminance and apply them to complex software [R.8].

S. Abbas Mousavi, 2017, Estimated the hourly, daily and monthly global solar radiation on inclined surfaces with re-visited models [R. 9].

Muhammad Uzair Yousuf, Mubashir Siddiqui, and **Naveed ur Rehman Naved, 2018** studied the solar energy potential estimation by measuring sun illumination hours and sky view factor on building roofs using digital images, without applying to the satellite images [R. 10].

The difference in sun luminance during the day was studied hourly by **Nasruddin, 2018** to certain areas with noting the differences of the orientation of the studying area on the earth [R. 11]. He did not apply it to the satellite image.

Parvaiz, 2018 focused on the parameters which affect the solar luminance for solar energy and electric generation [R. 12].

A. Ignatov, 2018 studied the time imaging at Equator crossing times for NOAA, ERS and EOS sun-synchronous satellites [R. 13].

II. GEOMETRY LUMINANCE OF SUN LIGHT

A. The Distance between Sun and Earth

The sun luminance is affected by many parameters depending on the distance of sun from the earth planet. The distance between Earth's surface and the sun is varied between 1.52 M km at 2 January and 1.47 M km at 22 June [R. 1]. It is clear that the luminance of sun is decreasing when sun be far because the radial energy will be distributed on wider area. Although the sun is near to earth at the winter the luminance is less due to the inclination of earth surface at the north half of the planet.

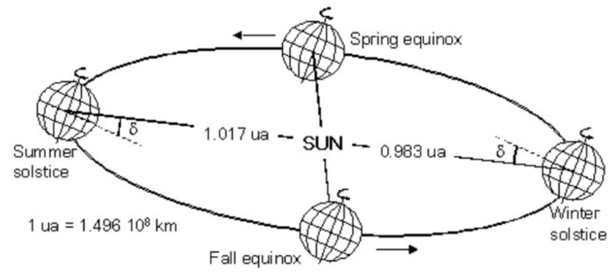


Figure (2): The varying distance between the sun and the earth [R.14].

Wald, Lucien. (2007). Solar radiation energy (fundamentals)..

B. The Inclination of Earth Rotation Axis

It is well known that the earth rotation axis is different during the year [R. 15] about 23.5º, this affect the apparent sun path.

Fig. (3) illustrates the difference in axis inclination and the difference in plane of ecliptic.

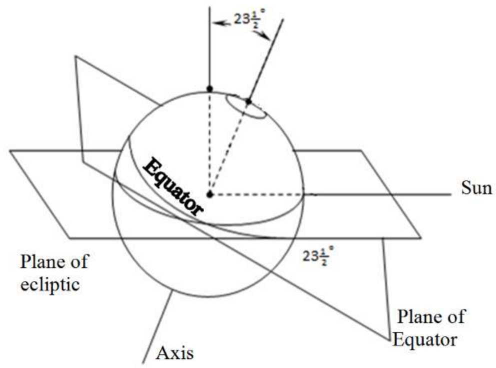


Figure (3): The 23.5º inclination of Earth's rotational axis causes the plane of the equator to cut across the plane of the ecliptic.

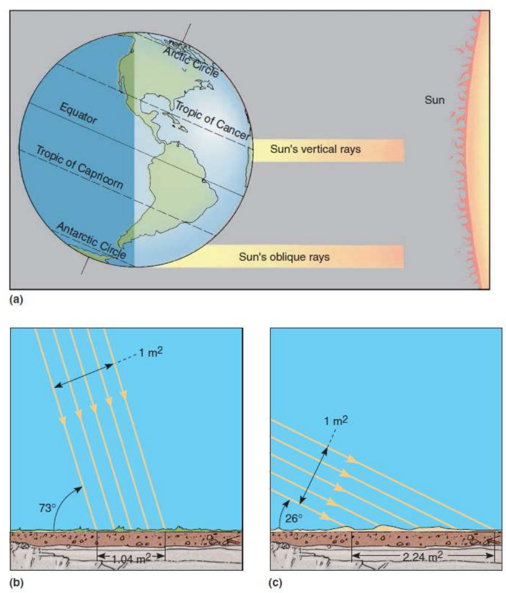


Figure (4) The effect of inclination of sun ray [R.16].

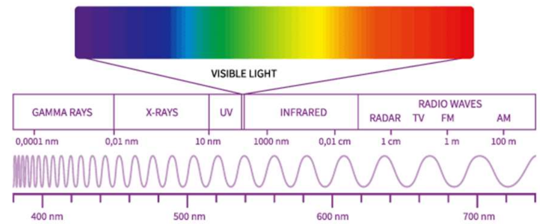
The Fig. (4, a) is the angle at which the sun's rays strike Earth's surface determines the amount of solar energy received per unit of surface area. This amount in turn affects the seasons. The diagram represents the June condition, when solar radiation strikes the surface perpendicularly on the Tropic of Cancer, creating summer conditions in the Northern Hemisphere.

In the Earth's south, the sun's rays are more slant and spread over larger areas, so it receives less energy per unit of area, making this the winter hemisphere. How would a similar figure of Earth–sun relationships in December differ. The sun's rays in summer (Fig. 4, b) and winter (c). In summer the sun appears high in the sky, and its rays hit Earth more directly, spreading out less. In winter the sun appears.

C. Weather

Weather factors affect the luminance of sunlight, but this effect can not be accurately predicted across the year but must be measured daily.

The weather condition is taken into account at the time of filming and recorded in the information attached to the satellite images [R. 17].



III. IMAGING TIME OF THE SATELLITE SENSORS

The sun gives all types of the electro-magnetic radiation which are reflected from the targets on the earth to the remote sensors. Most of orbits of the earth resources satellites are synchronization with the sun, i. e. they are imaging in the same time for all point on the earth approximately [R. 18]. This order is referred with the term Equator crossing time, which is the time when satellite pass over the Equator line on the sky, this time is according to the local time for every zone.

It is expected that the imaging time in the north half of the planet is earlier than the Equator crossing time and later in the south half. However, it does not have much impact on the purpose for which this time was chosen [R. 19].

The purposes which control the choice of imaging time are the moderate luminance and heat of the sun, and shadows at approximately 45 degrees, which can measure the height of the targets from the top view of the satellite imaging, so most the imaging satellite times is about 10:30 a. m.

IV. DIGITAL SATELLITE IMAGERY

The digital satellite imagery is a matrix of pixels captured from remote sensors mounted on the satellite and recorded on electronic media and sent to earth stations [R. 20]. Most remote sensors have passive systems that record targets by reflected sunlight or local heat. The sunlight consists of wide rage of electromagnetic rays begins from the radio waves and ends with the X and gamma rays, see Fig. (5). In remote sensing purposes only some regions of the electro-magnetic spectrum are used, these regions called bands [R. 21].

Figure (5) The electromagnetic spectrum.

The imaging is done for each band separately. The most important bands used in remote sensing are in the visible ranges, because they can by interpreted by the eye.

The brightness of the targets in the image depends on how much sun rays to be reflected from these targets [R. 22].

There are many studies on satellite images based on the comparing of two satellite images for the same area, but after several days to compare the change in water level, for example, urban expansion or other uses, and may be the time of each of the two images is different on the date or time which may include a difference in the luminance of the sun and not in the colors of the targets in the picture area, this may cause some mistakes in the interpretation or classification of the land cover features.

Therefore, measuring the luminance of the sun is necessary when comparing the two images to find a correction factor before achieving the comparison study.

V. SUN-SYNCHRONIZE ORBIT

The irradiance of sun differs along the day hour including visible or thermal rays, so the designer of satellite sensors planned to make the imaging approximately at one time during the day in every point on the earth, which is the time when the sun at an angle close to 45 degrees, and to choose this timing there are several factors: before the changes in the weather today in terms of heat, and that the shadows are very large at the beginning of the day and at the end of the photography should be in the middle of the day because the shadows will cover other features as they grow, including the use of shadow in the third dimension of the forms i.e. the height; because at the middle of day the shadow be very small in the usual [R. 23].

However, the angle of the sun is not constant at the satellite imaging time for all the days of the year, because of the difference in the angle of the radiation incident on the ground, the angle is not always 45 degrees at 10:30 a.m., and it is not easy to change the speed of the satellite in orbit to change the imaging time to take the image in the time when the sun angle is 45 degrees. What is said: that the satellite is synchronous with the sun does not mean that its orbit is related to the sun, but is meant by this approximate time when the angle of the sun is close to the year. See Fig. (6), the yellow lines is the path of satellite over the different regions in the earth. The satellite pass in the same time every day and cross the equator line in the certain time, this what is called sun-synchronized orbit of satellite [R. 24]. It is clear from Fig. (6) that the satellite pass over the north region before the equator, so we said that the imaging time not always the same.

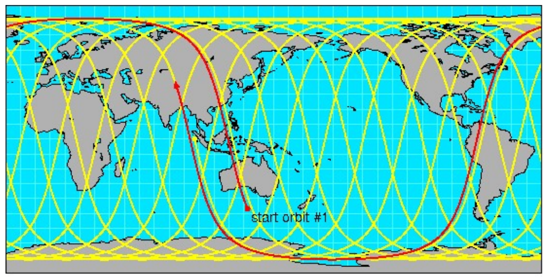


Figure (6) The slop of satellite orbits toward the west when it circulates around the Earth [R. 24].

Table (1) represents the Equator cross time for the famous satellite systems.

Table (1) The Equator Crossing Time of the Famous Satellites Systems [R. 25].

Satellite	Equator crossing time
Landsat 4, 5, 7, 8	10:00 a.m.
SPOT	10:30 a. m
QuickBird	10:30 a. m.
IKONOS	10:30 a. m.
WolrdView1, 2	11:00 a. m.

VI. CALCULATING THE SUN LUMINANCE FROM THE GEOMETRIC PARAMETERS

Basic Solar Components

- Declination Angle (δ)

Declination is the angular distance from the sun north or south to the earth's equator [R. 26].

As illustrated in figure 3, the minimum and maximum declination angle values of the earth's orbit produce seasons. Declination ranges between 23.5° north and 23.5° south. The northern hemisphere is inclined 23.5° far away from the sun some time around 21 December, which is the summer solstice for the southern hemisphere and the winter solstice for the northern hemisphere.

In the northern hemisphere and through 21 June, starting around 21 June, the southern hemisphere is positioned in a way that it is 23.5° away from the sun, meanwhile, it is winter solstice in the northern hemisphere. During the fall and spring equinoxes, which begin on 21 March and 21 September respectively, the sun passes directly over the equator [R. 27].

The declination angle (δ) can be found from Spencer's [R. 27] equation in radians.

$$\delta = (0.006918-0.399912\times \cos(\Gamma)+ 0.070257\times \sin(\Gamma)- 0.006758\times \cos(2\Gamma) +0.000907\times\sin(2\Gamma)- 0.002697\times \cos(3\Gamma)+ 0.00148\times\sin (3\Gamma) \times(180/\pi) \qquad \text{(eq. 1)}$$

$$\text{Where } \Gamma = 2\pi (d_n-1)/365 \qquad \text{(eq. 2)}$$

where n is the number of the day in the year, for example 1 January = 1, 20 February = 51, and so on.

- Hour Angle (ω)

The term (hour angle) is used for defining the rotation of the earth around its polar axis, which is equivalent to +15 per hour at the morning and -15 at the afternoon. It means the angular distance between the observer's meridian and the meridian whose plane contains the sun. The following equation can be used to calculate the hour angle in degrees. It should be noted that at noon the hour angle is zero [R. 28].

$w = 15(12 - ST)$ ……………………………… *eq.3*

where ST is the local solar time.

$ST = LT + \frac{ET}{60} + \frac{4}{60}[L_S - L_L]$ ………………… *eq. 4*

Where LT is the local standard time, Ls is the standard meridian for a local zone, LL is the longitude of the location under study in degrees and ET is the equation of time given by Tasdemiroglu [R. 29] as:

$ET = 9.87\sin 2B - 7.53\cos B - 1.5\cos B$ ……… *eq. 5*

$B = \frac{360(n-81)}{365}$ ………………………... *eq. 6*

- Effect of inclination

The inclination is the major cause in decreaing the sun luminance, all angles angles are affecting the luminance in cosine relation.

- Solar Azimuth Angle (α)

The angular displacement of the south of the beam radiation projection on the horizontal plane is named as the solar azimuth angle, see Fig. (7).

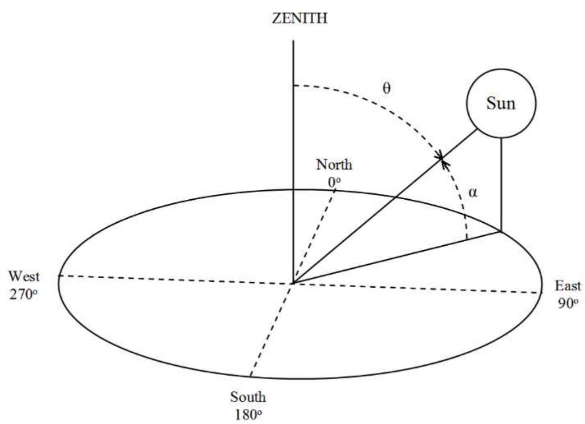


Figure (7) The sun's zenith, altitude, and azimuth angles.

The imaging time is constant for our work, so need no to calculate the difference in sun luminance for the day hours.

VII. COMPARING TWO SATELLITE IMAGES AT DIFFERENT DATES

It is noted in some researched that two satellite images are compared although they have different dates and correlate the different brightness to estimate the varying characters of the target. This is inaccurate work due two the differences in sun luminance which need to be modified.

VIII. METHODOLOGY

- *The Apparatus*

The apparatus that used in this research to record the sun luminance is the (Digital Lux meter, type LX1010B) with accuracy ranges between: 0 to 50,000 Lux, resolution 1 Lux, sampling time 0.4 second, Operating Temperature: 0° to 40°C (32° to 104°F) and Humidity: 0 to 80% RH.

. This meter is an efficient, accurate and sure way to determine luminance and light level, see Fig. (8).

Figure (8) The digital Lux meter, type LX1010B.

- *Date and study location:*

The measurements in this research where done in Najaf Governorate in Iraq, which lies (42^{o} $50^{'}$ - 45^{o} $44^{'}$) to the East of the Greenwich line, and (29^{o} $50^{'}$- 32^{o} $21^{'}$) to the north of Earth's equator [R. 30]. The apparatus were used in this research was the Digital Lux meter lx1010B, This meter is an accurate and sure-fire way to determine that the level of light meets specified criteria and obtained data will become very useful information to maintain the brightness of any environments. It records the intensity of light falling on the subject and measurements are taken from the white subject position. They measure accurately and consistently and are not affected by variances in reflectance of the subject or scene. For this reason, the meter provides accurate exposure for most situations and subjects.

Along three years we recorded the luminance of sun at the imaging time of the common satellite (Quick Bird, Landsat, SPOT, and WolrdView), Table (2) lists the luminance at 10:00 A. M. during on year every five days:

Table: 2 The annual reads of sun Luminance.

Day no.	Date	Luminance (Lux)
1	01-January	23600
5	05-January	24000
10	10-January	24300
15	15-January	24800
20	20-January	25500
25	25-January	26200
30	30-January	26900
35	04-February	27500
40	09-February	28400
45	14-February	29300
50	19-February	29700
55	24-February	30800
60	01-March	32200
65	06-March	33100
70	11-March	34000
75	16-March	34700
80	21-March	35600
85	26-March	36300

90	31-March	36900
95	05-April	37500
100	10-April	38000
105	15-April	38200
110	20-April	38700
115	25-April	39000
120	30-April	39200
125	05-May	39400
130	10-May	39500
135	15-May	39600
140	20-May	39600
145	25-May	39600
150	30-May	39600
155	04-June	39600
160	09-June	39500
165	14-June	39400
170	19-June	39400
175	24-June	39300
180	29-June	39400
185	04-July	39300
190	09-July	39100
195	14-July	39200
200	19-July	39000
205	24-July	39000
210	29-July	38900
215	03-August	38700
220	08-August	38600
225	13-August	38400
230	18-August	38200
235	23-August	37800
240	28-August	37400
245	02-September	37100
250	07-September	36400
255	12-September	36000
260	17-September	35400
265	22-September	34500
270	27-September	33800
275	02-October	32700
280	07-October	32200
285	12-October	31300
290	17-October	30300
295	22-October	29300
300	27-October	28500
305	01-November	27800
310	06-November	26500
315	11-November	26300
320	16-November	25000
325	21-November	24900
330	26-November	24300
335	01-December	23800

340	06-December	22900
345	11-December	23100
350	16-December	22400
355	21-December	22900
360	26-December	22500
365	31-December	22700

By the Curve Fitting Tool of MATLAB program (Version R2013a) the field measurements were converted to an empirical equations, see Fig. (9) represents the interface of this tool when it was applied to get a Gaussian equation.

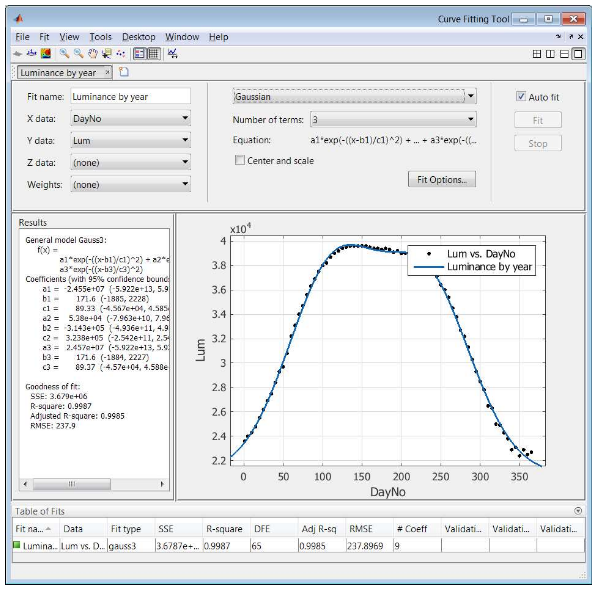


Figure (9) The interface of curve fitting tool of MATLAB 2013a, when calculation the Gaussian equation of sun luminance during a year.

Gaussian equation:

By the same tool we can get other equation to represent the variation of luminance of sun during a year. Table (3) illustrates these equations.

$$Lum_{d_n} = a_1 \times e^{-\left(\frac{d_n - b_1}{c_1}\right)^2} + a_2 \times e^{-\left(\frac{d_n - b2}{c2}\right)^2} + a_3 \times e^{-\left(\frac{d_n - b3}{c3}\right)^2} \quad \ldots \textit{ eq. 7}$$

Where:

Lum: is the luminance of sun at a certain day (d_n) by Lux unit.

$a_1, b_1, \ldots c_3$: are coefficients (with 95% confidence bounds):

a_1 = -2.455e+07 (-5.922e+13, 5.922e+13)
b_1 = 171.6 (-1885, 2228)
c_1 = 89.33 (-4.567e+04, 4.585e+04)
a_2 = 5.38e+04 (-7.963e+10, 7.963e+10)
b_2 = -3.143e+05 (-4.936e+11, 4.936e+11)
c_2 = 3.238e+05 (-2.542e+11, 2.542e+11)
a_3 = 2.457e+07 (-5.922e+13, 5.922e+13)
b_3 = 171.6 (-1884, 2227)
c_3 = 89.37 (-4.57e+04, 4.588e+04)

R-square: 0.9987
Adjusted R-square: 0.9985

RMSE: 237.9

The curve fitting tool of MATLAB can submits another equation representation for the sun luminance, fig. (10) represent it's work with Polynomial equation.

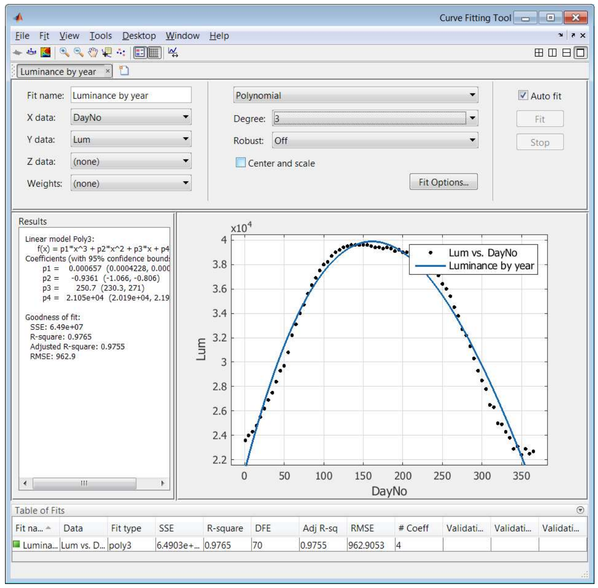


Figure (10) The interface of curve fitting tool when find the Polynomial equation of sun luminance during a year.

Linear model Poly3:

$$Lum(d_n) = p_1 \times d_n^3 + p_2 \times d_n^2 + p_3 \times d_n + p_4 \ldots \text{ eq. 8}$$

Where :

$p_1 =$ 0.000657 (0.0004228, 0.0008911)
$p_2 =$ -0.9361 (-1.066, -0.806)
$p_3 =$ 250.7 (230.3, 271)
$p_4 =$ 2.105e+04 (2.019e+04, 2.19e+04)

R-square: 0.9765
Adjusted R-square: 0.9755

A Sum of Sine Model:

$$Lum(d_n) = a_1 \times Sin(b_1 \times d_n + c_1) + a_2 \times Sin(b_2 \times d_n + c_2) + a_3 \times Sin(b_3 \times d_n + c_3) \ldots \text{ eq. 9}$$

where:

$a_1 =$ 3.9e+04 (-6.016e+07, 6.024e+07)
$b_1 =$ 0.0003474 (-1.189, 1.189)
$c_1 =$ 0.7752 (-1514, 1516)
$a_2 =$ 1.178e+04 (-3.779e+05, 4.015e+05)
$b_2 =$ 0.01202 (-0.112, 0.136)
$c_2 =$ -0.3781 (-20.17, 19.41)
$a_3 =$ 788.8 (-2003, 3581)
$b_3 =$ 0.03831 (0.008902, 0.06771)
$c_3 =$ -1.666 (-6.891, 3.559)

and

R-square: 0.9949
Adjusted R-square: 0.9943

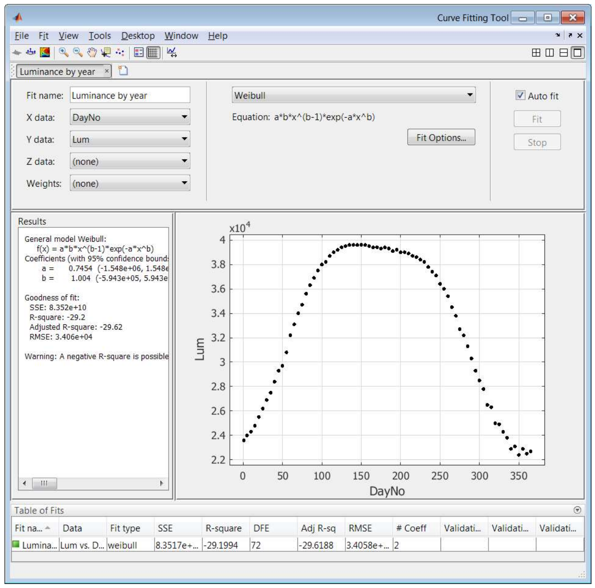


Figure (11) The interface of curve fitting when calculate the Weibull equation of sun luminance during a year.

General model Weibull:

$$Lum(d_n) = a \times d_n^{b-1} \times e^{-a \times d_n^b} \quad \ldots\ldots\ldots\ldots\ldots\ldots \; eq.10$$

Where:

$a =$ 0.7454 (-1.548e+06, 1.548e+06)
$b =$ 1.004 (-5.943e+05, 5.943e+05)

R-square: -29.2
Adjusted R-square: -29.62

IX. RESULTS AND CONCLUSIONS

From the field data and curve fitting tool, we got a set of empirical equations to calculate the luminance of sun at an date of the year, see Table (3).

Table (3): The equation set to calculation sun's luminance during a year, which calculating by the curve fitting tool.

Luminance equations (Lux)	Formula
Gaussian	$Lum_{d_n} = a_1 \times e^{-\left(\frac{d_n - b_1}{c_1}\right)^2} + a_2 \times e^{-\left(\frac{d_n - b2}{c2}\right)^2} + a_3 \times e^{-\left(\frac{d_n - b3}{c3}\right)^2}$
Polynomial	$Lum(d_n) = a_1.e^{-\left(\frac{d_n - b_1}{c_1}\right)^2} + a_2.e^{-\left(\frac{d_n - b_2}{c_2}\right)^2}$
Sum of sines	$Lum(d_n) = a_1 \times Sin(b_1 \times d_n + c_1) + a_2 \times Sin(b_2 \times d_n + c_2) + a_3 \times Sin(b_3 \times d_n + c_3)$

Weibull	$Lum(d_n) = a \times d_n^{b-1} \times e^{-a \times d_n^b}$

Now, we can compare any two or more images for the same region and any different dates of the year. It should take in consideration the different in luminance between them. The above equations are specific to Najaf Governorate with known geographical and climatic characteristics, and are specific to the imaging time of the Blackbird satellite at 10:00 A.M. But we can modify these equations to be suitable for other areas on the Earth's surface by repeating the measurements or by taking into account the percentage differences in the intensity of sunlight measured according to the angles of inclination of the Earth's surface during the year, and the difference in the intensity of the sun's rays during one day.

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