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ANOMALIES OF EARTH SURFACE GRAVITY FIELD (*g*) DURING TOTAL LUNAR ECLIPSE (TLE) ON JANUARY 31 AND JULY 28 2018 USING VIDEO TRACKER ANALYSIS ON PENDULUM HARMONIC MOTION

MUHAMAD GINA NUGRAHA[1,*], RADEN GIOVANNI ARIANTARA[1], ANNISA NURJANAH[1], HARBI SETYO NUGROHO[1], JUDHISTIRA ARIA UTAMA[1], DUDEN SAEPUZAMAN[1], HANA SUSANTI[1], FITRI NURUL SHOLIHAT[1], ANGGI HANIF SETYADIN[1], KARTIKA HAJAR KIRANA[2]

[1]Departemen Pendidikan Fisika FPMIPA, Universitas Pendidikan Indonesia,
Jl. Dr. Setiabudhi 229 Bandung 40154, Indonesia
[2]Departemen Geofisika FMIPA, Universitas Padjadjaran,
Jl. Raya Bandung-Sumedang Km 21, Jatinangor 45363, Indonesia
*Corresponding Author: muhamadginanugraha@upi.edu

Abstract

This study was conducted to determine the change in the earth's surface gravity field (*g*) during the total lunar eclipse (TLE). Data were collected in Bandung, Indonesia with coordinates of 6 ° 51' 48" S, 107 ° 35'40" E on January 31, 2018 with time duration from 05:36 p.m. to 10:53 p.m. local time, and on July 28, 2018 with time duration from 11:58 p.m. to 06:26 a.m. local time. The surface gravity field of the earth is determined by using a pendulum that is optimized with nylon straps to prevent the rotation of pendulum itself, the use of mirror boards to identify and eliminate pendulum conic motion, and video analysis using Tracker to determine pendulum oscillation period more precisely. The results showed a decrease in the value of the earth's surface gravity field at the peak phase of the total lunar eclipse in both eclipse phenomena, with average of $g = 9.7236366301$ m/s^2 on 31 January 2018 and $g = 9{,}7692416374$ m/s^2 on 28 July 2018. This trend of a decrease in earth's surface gravity field is consistent with one study result obtained previously on March 9, 2016 during Total Solar Eclipse (TSE) observation. Based on our results, the alignment of these three main bodies (Sun-Earth-Moon) during eclipse (both solar and lunar eclipses) may affect the measurement of Earth's surface gravity field.

Keywords: Gravity, Pendulum, Total lunar eclipse, Tracker.

1. Introduction

During the solar eclipse on June 30, 1954, Maurice Allais, a Nobel laureate in economics, reported an anomalous precession of the plane of oscillation of a Foucault pendulum. The same author reported another observation of the effect at the moment of a solar eclipse on October 2, 1959, using the paraconical pendulum he invented [1]. Since then many authors had attempted to detect any anomaly reported in Allais' work that may appear around total solar eclipses; some had succeeded and others had failed.

Saxl and Allen [2] observed such an anomaly in the period of their torsion pendulum on the solar eclipse on 7 March 1970. Their finding suggests that the greatest change of period occurs between the onset of the eclipse and its midpoint. Contrary to Saxl and Allen [2], Kuusela [3, 4] found negative results from measurements during two solar eclipses (July 22, 1990, in Finland and July 11, 1991, in Mexico) despite getting equipped with Saxl-and-Allen type torsion pendulum. Positive results with gravimeter in gravity field measurement were reported by Wang et al. [5] and Yang and Wang [6]. However, such an effort to detect the anomaly during the Solar eclipse using simple apparatus also obtained various results [7-9]. So far, the anomaly detected (if any) has only been based on the measurements during solar eclipses. There is then a question asking if the lunar eclipse can also affect the Earth's surface gravity field. To answer this question, we investigated the change in the Earth's surface gravity field during total lunar eclipses (TLE) occurred on January 31, 2018, and July 27-28, 2018, which could possibly be observed from Indonesia.

The total lunar eclipses that occurred throughout 2018, all can be observed from Indonesia region. Figures 1 and 2 show the crossing path of the Moon inside the Earth's penumbra and umbra along with the contact times between the limb of the Moon's disk and the Earth's penumbra and umbra in universal time (UT, Western Indonesia Time = UT + 7 hours). The alignment of the Sun-Earth-Moon during this phenomenon will affect the results of gravitation force onto the Earth and therefore may result in a change of the Earth's surface gravity field [10].

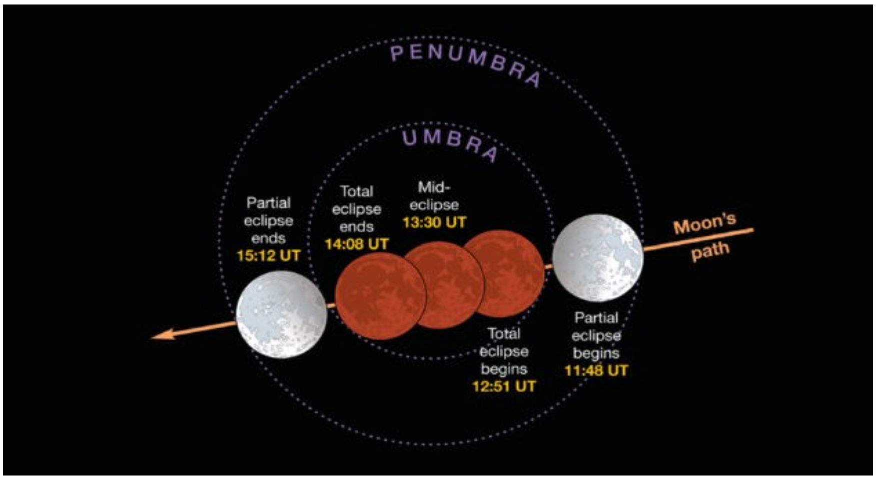

Fig. 1. Crossing path of the Moon inside the Earth's umbra and penumbra during total lunar eclipse on January 31, 2018 (Credit: Sky and telescope).

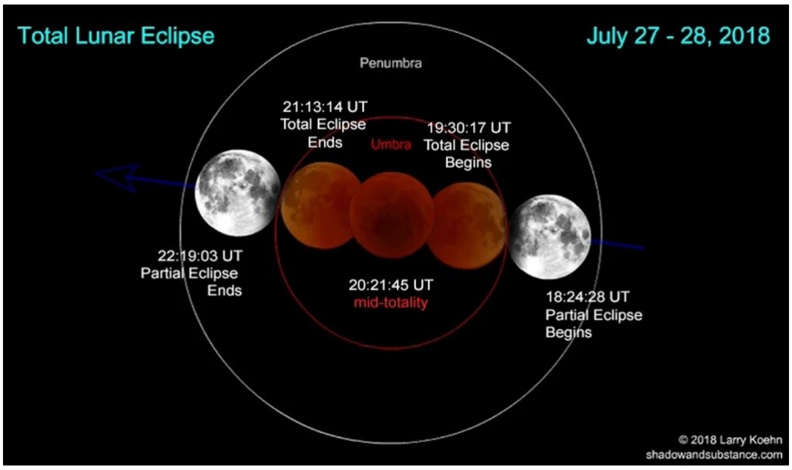

Fig. 2. Crossing path of the moon inside the earth's umbra and penumbra during total lunar eclipse on July 27-28, 2018 (Credit: Larry Koehn).

2. Method

The study was conducted at the Fundamental Physics Laboratory, Universitas Pendidikan Indonesia, Bandung with coordinates of 6° 51' 48" S, 107° 35' 40" E at the time of TLE occurred on January 31, 2018, with a duration of 05:36 p.m. to 10:53 p.m. local time, on July 28, 2018, with a duration of 11:58 p.m. until 06:26 a.m. local time. Data were collected for each phase of TLE with a duration of 10 minutes for each eclipse phase (5 minutes prior and 5 minutes after the respective phase). Details of the timing of data acquisition are shown in Tables 1 and 2.

Data acquisition was conducted by measuring the oscillation period of a spherical metal pendulum tied to a nylon rope. The ball-shaped pendulum is chosen to minimize air friction and make it easier to determine the centre of mass. Nylon rope is used because this type of rope does not have fibre like the yarn in general so that it minimizes the rotation of pendulum, besides having a light mass. During data acquisition, the conic motion is one thing that needs to be corrected for mathematical pendulum-like the one used here. Therefore, a mirror board is placed on the back of the pendulum and the camera is placed to minimize errors. Mirror boards and cameras are used to ensure that pendulum motion remains in the same plane. The setting of the apparatus can be seen in Fig. 3.

Table 1. TLE data acquisition on January 31, 2018.

Phase	Universal time	Western Indonesian time	Local time (Bandung)	Acquisition data time	
				Start	End
P1	10.51.15	17.51.15	17.41.15	17.36.15	17.46.15
U1	11.48.27	18.48.27	18.38.27	18.33.27	18.43.27
U2	12.51.47	19.51.47	19.41.47	19.36.47	19.46.47
TLE peak	13.29.49	20.29.49	20.19.49	20.14.49	20.24.49
U3	14.07.51	21.07.51	20.57.51	20.52.51	21.02.51
U4	15.11.11	22.11.11	22.01.11	21.56.11	22.06.11
P4	16.08.27	23.08.27	22.58.27	22.53.27	23.03.27

Table 2. TLE data acquisition on July 28, 2018.

Phase	Universal time	Western Indonesian time	Local time (Bandung)	Acquisition data time	
				Start	End
P1	17.13.00	00.13.00	00.03.00	23.58.00	00.08.00
U1	18.24.06	01.24.06	01.14.06	01.09.06	01.19.06
U2	19.29.54	02.29.54	02.19.54	02.14.54	02.24.54
TLE peak	20.21.42	03.21.42	03.11.42	03.06.42	03.16.42
U3	21.13.30	04.13.30	04.03.30	03.58.30	04.08.30
U4	22.19.18	05.19.18	05.09.18	05.04.18	05.14.18
P4	23.30.18	06.30.18	06.20.18	06.15.18	06.25.18

Fig. 3. Set of experiment apparatus.

The pendulum swung with an initial deviation angle of 5° for each phase of TLE to ensure the pendulum moves harmonically. The pendulum movement during oscillation was recorded using a high-resolution camera (30 frames per second (fps)) placed right in front of the pendulum.

The process of analysing pendulum motion was done by using Tracker software to obtain a period of a pendulum. Tracker software is a Java-based application for analysing and modelling videos from Open Source Physics (http://www.opensou rcephysics.org/). Period determination by using this application was considered more accurate [11]. Tracker software has been widely used to analyse the parameters of moving objects and is used to measure various parameters including gravitational acceleration in parabolic motion, object velocity, acceleration, displacement and determination of oil viscosity coefficient [12-18]. The pendulum period was then used to determine the value of the Earth's gravitational field through the equation of harmonic motion found in fundamental physics lecture:

$$g = \frac{4\pi^2 l}{T^2} \quad (1)$$

where g is the earth's surface gravity field, l is the length of the rope, and T is the period of oscillation.

The earth's gravitational field is not only influenced by mass interactions between the Earth-Moon-Sun system, but also by the configuration (the angle of elongation) and the distance between these two objects to earth [19, 20]. In this research, the distance of the Sun-Earth and Earth-Moon obtained using simulator software that is very commonly used, namely the Stellarium (https://stellarium.org/).

3. Results and Discussion

Based on data processing result using tracker software, the average period (*T*) of harmonic oscillation motion in pendulum was obtained in each total lunar eclipse phase on January 31, 2018, and July 28, 2018, as shown in Fig. 4.

The earth's gravitational field is determined by substituting the period value in Eq. (1). Tables 3 and 4 show the values of the average period of a pendulum, Earth-Moon distance, Sun-Earth distance, and the gravitational field on the Earth during the total lunar eclipse on January 31, 2018, and on July 28, 2018, for each eclipse phase.

Change in the Earth's surface gravitational during TLE on January 31, 2018, is shown in Fig. 5. Change in the earth's gravitational surface during TLE on July 28, 2018, are clearly visible in Fig. 6.

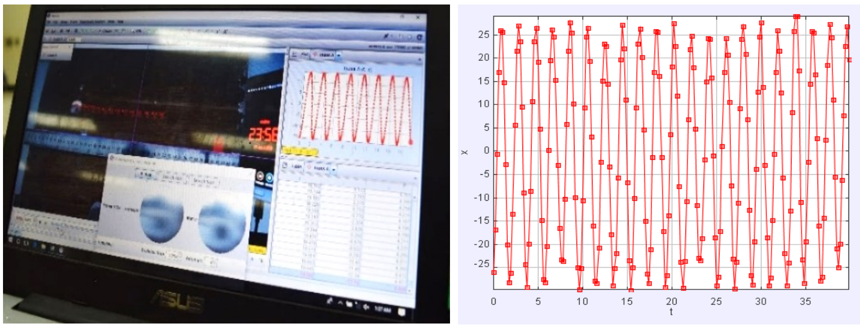

Fig. 4. Results of pendulum motion video analysis using tracker.

Table 3. Pendulum period and the gravitational field on the Earth's surface during the total lunar eclipse of January 31, 2018.

Phase	Acquisition data time		Average of pendulum period (second)	Average of Earth's surface gravitational field (m/s^2)	Average distance of Sun-Earth (km)	Average distance of Moon-Earth (km)
	Start	End				
P1	17.36.15	17.46.15	2.4981580248	9.7332996886	147383822.2136	359969.370
U1	18.33.27	18.43.27	2.4991072071	9.7258029619	147383822.2136	360045.945
U2	19.36.47	19.46.47	2.4993728396	9.7237256523	147398782.0007	360134.020
TLE peak	20.14.49	20.24.49	2.5014649569	9.7073617082	147398782.0007	360188.575
U3	20.52.51	21.02.51	2.4997128888	9.7210662752	147398782.0007	360244.365
U4	21.56.11	22.06.11	2.4992143517	9.7249629218	147398782.,0007	360340.015
P4	22.53.27	23.03.27	2.4986681157	9.7292372026	147398782.0007	360429.450

Table 4. Period and the gravitational field on the surface of the earth during the total lunar eclipse of July 28, 2018.

Phase	Acquisition data time		Average of pendulum period (second)	Average of Earth's surface gravitational field (m/s^2)	Average distance of Sun-Earth (km)	Average distance of Moon-Earth (km)
	Start	End				
P1	23.58.00	00.08.00	2.4607916658	9.7692416421	151916637.6959	399946.5
U1	01.09.06	01.19.06	2.4607916667	9.7692416355	151916637.6959	400365
U2	02.14.54	02.24.54	2.4607916669	9.7692416338	151916637.6959	401199
TLE peak	03.06.42	03.16.42	2.4607916676	9.7692416277	151916637.6959	402114.5
U3	03.58.30	04.08.30	2.4607916664	9.7692416373	151916637.6959	403208.5
U4	05.04.18	05.14.18	2.4607916662	9.7692416395	151916637.6959	404771
P4	06.15.18	06.25.18	2.4607916654	9.7692416456	151909157.8023	406541

Based on Figs. 5 and 6, there is a change in the gravitational field on the surface of the Earth, which is influenced by the total lunar eclipse with the same pattern. The gravitational field value on the Earth's surface gradually decreases at the onset of penumbral phase, umbral phase and total phase until it reaches the lowest value at the peak of TLE, g = 9.7236366301 m/s^2 on January 31, 2018, and g = 9.7692416374 m/s^2 on July 28, 2018, and then again gradually increased at the end of total phase, umbral phase and penumbral phase. These values differ by 0.98% and 0.52% from the calculated value after latitude corrected [21], respectively.

Changes in the Earth's gravitational field occurred in both TLE were strongly influenced by the position (configuration) of the Sun-Earth-Moon system. Based on Tables 3 and 4, at the peak of TLE, the Sun-Earth-Moon configuration is in a straight-line position, which is indicated by 180o elongation, so the resultant force experienced by objects on the Earth's surface will reach the lowest value due to the gravitational force of the moon and the gravitational force of the Sun is in opposite direction as shown in Fig. 7.

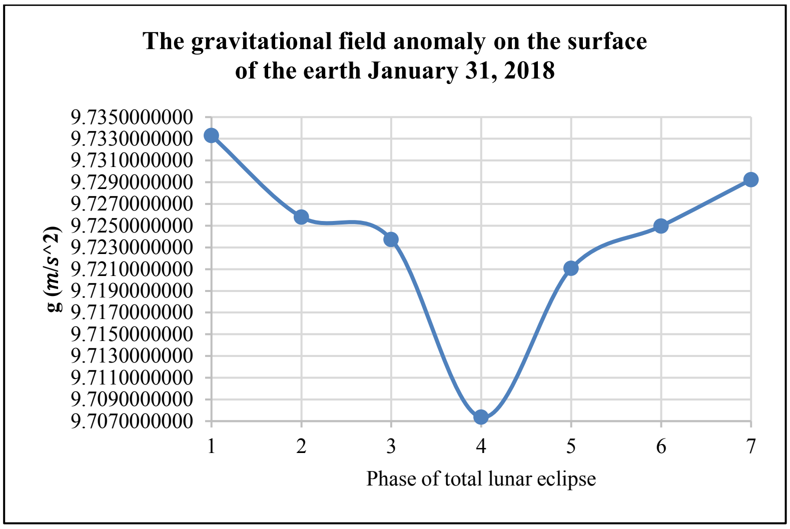

Fig. 5. The Earth's surface gravity field anomaly during TLE of January 31, 2018.

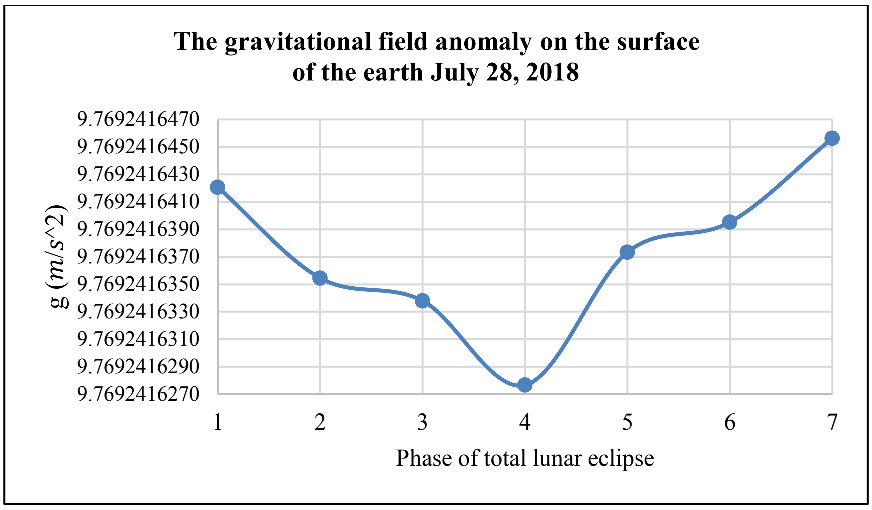

Fig. 6. The Earth's surface gravity field anomaly during TLE of July 28, 2018.

Fig. 7. Illustration of 180° elongation angle.

This also explains how the change in the earth's surface gravitational field in each phase, which has a decrement pattern reaches the peak of TLE and increases again afterwards. Monthly change in the distance of the Sun-Earth-Moon is not so significant to change the value of the earth's surface gravitational field. However, the influence of differences in the Sun-Earth-Moon distance at the moment of eclipses can be seen when comparing the value of the gravitational field in both TLE events.

Based on Tables 3 and 4, the Earth-Moon distance for TLE in January 2018 was closer than TLE in July 2018. The closer the distance gets, the greater the Moon's gravitational pull on the Earth and thus, the smaller the value of Earth's surface gravitational field. As far as we know, there is no published literature investigating the surface gravity acceleration anomaly on the Earth related to the phenomenon of a total lunar eclipse.

Interestingly, the tendency of the pattern we obtained from the two TLE corresponds to a similar pattern that we encountered during the observation of a total solar eclipse (TSE) on Terentang Beach, Bangka Island, Indonesia, on March

9, 2016 [9]. We can say that natural phenomena such as TLE and TSE can affect the measurement of the Earth's surface gravitational force. Furthermore, eclipse phenomena can also affect on organic material such as photodecomposition of organic material [22] and plants [16].

4. Conclusions

The TLE on January 31, 2018, and July 28, 2018, has been proven to affect the value of the gravitational field on the surface of the Earth. We noted that in both TLE phases there was a decrement pattern of Earth's surface gravitational field reaching the lowest value at the peak phase. The average value of g is 9.7236366301 m/s^2 for TLE on January 31, 2018, and g = 9.7692416374 m/s^2 for TLE on July 28, 2018.

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