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Micro-gravity measurements during the total solar eclipse of 9 March 2016 in Indonesia

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Abstract. Since 1950s, several authors have reported the so-called anomalous gravity during the total solar eclipses through various experiments. To address this issue, in the moment of the total solar eclipse of 9 March 2016 passing most regions in Indonesia, we undertook microgravity measurements using two precise gravimeters. The measurements were made at two locations: (1) Poso (central Sulawesi), a location close to the centre passage of the total eclipse and (2) Lembang (West Java), the site of Bosscha Observatory, where the partial solar eclipse occurred. The two sites are selected to measure the possible different influence of the eclipse on aligning the three objects. The measurements were recorded three days before and one day after the eclipse at various intervals from 30 seconds to a short time at 5 seconds. The finer recording was performed several hours before and after the total eclipse. This measurement allowed detailed analysis, not only in time but also in frequency range. A detailed analysis is presented in this paper. We consider all possible geophysical as well as atmospheric effects. The residual data show that the shielding effect, usually thought as responsible factor on anomalous gravity, is not significant.

1. Introduction

The anomalous gravity associated with the total solar eclipse (TSE) was reported by several authors (see [1], [2] and references therein) and certainly needs to be confirmed by various measurement. One of the possible explanations is the hypothesis of gravitational shielding [3] occurred during the TSE. This phenomenon may result when there exists an alignment of three massive objects, the Sun, the Moon, and the Earth, particularly during the total solar eclipse [1], [2]. Since the first serendipitous measurement made using the paraconical pendulum–a modification of Foucault pendulum–the so-called Allais effect [4], various methods of gravity measurements have been proposed and performed [1] during the TSE. In fact, variation effects on gravity related to the TSE are subject to many things, besides the solid planetary body. One may also consider the possibility of ocean loading or the phenomena related to atmospheric effects. In general, two methods to observe these effects utilize a kind of Foucault pendulum and gravimeter.

An interesting result of gravitational acceleration measurement using a very precise D-type gravimeter was reported from the 1997 total solar eclipse in Moho (China) [5]. The residual gravity shows a significant change that the authors identified to correspond to the totality of the eclipse, in particular to the first and fourth contacts of the eclipse [5]. However, similar measurement made during

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other solar eclipses show no evidence of gravity variation, such as in Finland [6]. Meanwhile, the measurement using a sort of Foucault pendulum seems to show another variation [5] of gravity.

In this paper, we report our measurement of vertical gravity to test the possible gravitational shielding effect on the ground during the recent total solar eclipse of 9 March 2016 passing most regions in Indonesia. Two micro-gravimeters were used. One instrument was put in Kalora Village (Poso, Central Sulawesi, at coordinate S 1° 22.862' E 120° 45.221'), that is, a location close to the centre passage of the total eclipse, and the other instrument was put at Lembang, the site of Bosscha Observatory (at coordinate S 6° 49.478' E 107° 36.986'), where the partial solar eclipse can be observed. If the variation of gravity occurs, we expect that the rate could be different at both sites.

2. Observations

We used the CG-5 LaCoste-Romberg micro gravimeter to measure the vertical gravity expressed in µgal. This gravimeter is more sophisticated than D-type gravimeter used in the 1997 observations [5], although both instruments could measure at similar accuracy in µgal.

During the measurement conducted at Kalora (Poso area), the instrument was installed inside a farming house about 300 m away from the main road. The gravimeter was put on a concrete base specially made for this observation, while at Lembang area, the instrument was put inside an isolated room at Bosscha Observatory. During the four days measurement, the temperature variation in the instrument is about 1.02° C, and the ambient room temperature was 29° C and 23° C in Kalora (Poso) and Lembang, respectively. Hence, according to the calibration standard, the effect of temperature variation was negligible during both measurements. Meanwhile, position tilting of the instrument was always remotely monitored and an average tilt of less than 7 arcsec was found. Therefore, the gravimeter worked in stable condition during the whole measurements.

Since Poso is located very close to the passage of the total eclipse, and in fact it is very close to the equator, the data recording in Kalora (Poso) was changed regularly and was made more frequently close to the totality of the eclipse. The CG-5 gravimeter recorded data in flash memory from 2-minute to 5-second intervals during four consecutive days of measurement. When the eclipse was close to the totality at the duration of two hours, the vertical gravity was recorded at 5 second interval each. After the totality on 9 March 2016 at 11:46 am until 10 March 2016, the gravimeter recorded at one minute interval. Subsequently, the measured data were downloaded into a computer for further processing. The data reduction takes into account the effects of tide [8], instrumental drift, data smoothing during the totality of the eclipse, and frequency analysis.

3. Result of observations

The vertical gravity observations during the TSE were performed in two locations, at Kalora (Poso, Central Sulawesi) which is very close to the shore (about 300 m), and at Lembang (West Java) which is in a mountain site at an altitude of about 1300 m. Table 1 shows different local time of the eclipse. During the eclipse, the elevation of the Sun was about 21°.

Table 1. Eclipse of 9 March 2016 in two locations in Indonesia at local time

City	Start time	Start Tot eclipse	Max. eclipse	End tot eclipse	End time	Remark
Kalora/Poso	7:28:10	8:38:21	8:39:41	8:41:01	10:02:00	Total eclipse, near shore
Lembang	6:19	~7:15	~8:59	10:38	11:34	Partial eclipse, in mountain

Figure 1 shows the raw data for the four days of measurement and the tidal effect is clearly seen. Modelling of this effect using a formalism from [6] allows to remove this effect from the data. The box in figure 1 shows the time of the TSE. Comparison of the timing between the eclipse and the tide shows that the tide gave its influence at some later time after the eclipse. So, it needs some time to get a maximum tide, and the influence of the vertical gravity due to the eclipse is therefore low enough.

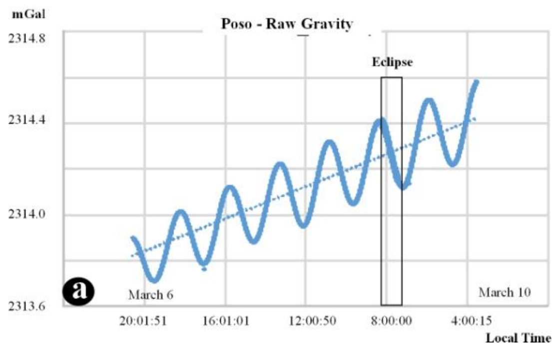

Figure 1. The raw gravity data, at Poso, during four days measurement

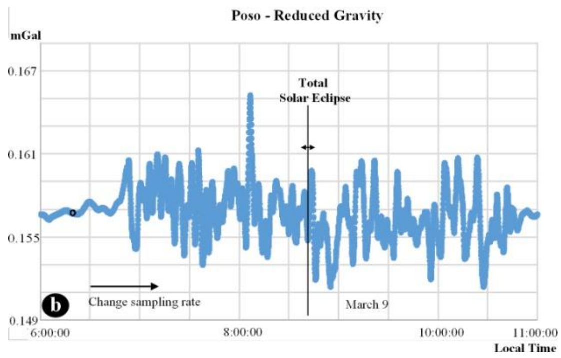

Figure 2. The reduced gravity data, at Poso. The gravity data reduced from tide and drift for five hours.

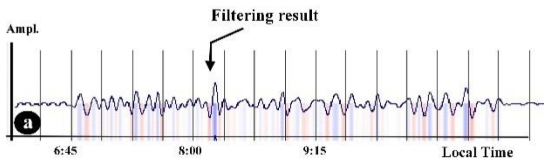

Figure 3. The reduced gravity data during eclipse and frequency respond (2-4 mHz) at Poso

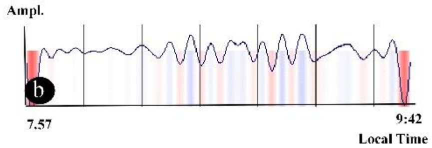

Figure 4. The reduced gravity data during eclipse and frequency respond at Bandung

Subsequently, the remaining question to ask: Is there any microgravity variation observed during the short duration of the eclipse?

As mentioned earlier, anomalous gravity was reported during the total solar eclipse [1], [2]. A precise vertical gravitation measurement during the TSE in Moho region in 1997 was conducted [5], and it is suggested that the shielding effect could probably occur during the TSE to explain the variation of vertical gravity during the totality of the eclipse. However, our measurement, shown in figure 2, does not provide similar results to [5]. The features of gravity signal observed in [5] are rather similar to Mexican hat in the digital signal model. The signals detected in [5] show a significant peak-valley variation of gravity curve near the first and the fourth contact of the eclipse. Our data, shown in figure 2, do not detect this feature.

In our case, the remaining signal appears to be similar to "tremor" in seismology. Alternatively, the signal is similar to accelerograph in seismology for recording micro earthquake, where the unit is in m/s^2 (See the CG-5 Manual or the IDA project using gravimeter, for seismology observation [9]).

Moreover, we can generate the spectrum of our data as displayed in figure 3. The spectrum shows several peaks at certain frequencies obtained during the eclipse. After applying bandpass filtering at (1, 2, 7, 10 mHz), we can get a slightly strong feature for 2-4 mHz, as shown in figure 3. This low frequency signal may correspond to long period seismogram, similar to free oscilation of the Earth (in S or T mode) [10][11]. We infer that it is similar to microtremor for period of 6-7 minute. On the other hand, for data from Lembang observations (in mountain site), the sampling rate taken was at 30 second interval, as shown in figure 4. We can see that the feature is not strong compared to data from Poso measurement. If it is not due to the shielding effect from the eclipse, in the following we propose the possible source of this feature.

4. Discussion

The vertical variation of gravity during the total solar eclipse is important to observe using the very precise gravimeter to investigate the possible existence of gravitational shielding effect [2], [3]. Our measurements suggest that the small variation of vertical gravity is not merely due to the TSE, but we should also take into account the huge ocean movement, very close to measurement site in Poso. In fact, the ocean mass was attracted to move toward the center of the alignment during the eclipse. The emergence of unique anomalous gravity with the shape of *Mexican hat* during the Moho 1997 eclipse and reach 5 μgal of variation certainly raised an important issue. Some authors propose that it could be due to atmospheric effects [1]. However, similar measurement conducted during the TSE in Finland [6] do not detect the same phenomena. Their results are rather similar to our ambient signal detected in our measurement, as shown in figure 1.

We propose that during total solar eclipse, not only the gravity between the three major bodies that can yield the gravity variation, but also wind and ocean that may contribute to the tidal effect. The tide itself will reach a certain gravity value after the eclipse is over. While reaching the peak of the tide, we suppose that the ocean movement hits the surface slowly as “hum” or “little tsunamy”. We note that the hum or tsunamy effect on ocean can be detected by seismometer as high as 4-10 mHz [12]. Therefore, we propose that small gravity variation detected in figure 3 is the results of the effect of hum or little Tsunami, instead of due to gravitational shielding.

5. Conclusion

The measurement of vertical gravity during the total solar eclipse in Poso does not support the shielding effect. Instead, a signal of 2-4 mHz detected from our measurement is a result of the ocean movement (hum or little Tsunami) hitting the seashore during tide following the eclipse.

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