Tutulemma of near equator Partial Solar Eclipse 2016

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Abstract. Tutulemma which stands for tutulma (eclipse) and analemma is a Turkish name to describe analemma which contains solar eclipse. The photographs of analemma which looks like a figure 8 pattern of the solar path in the sky throughout a year is very common. However, this observation is rarely done in low latitude countries, especially tutulemma’s plot. Related to the eclipse event on 9 March 2016, we built the first tutulemma in Indonesia which contains partial solar eclipse observed from the rooftop of LAPAN Bandung office. The purpose of this endeavor is also to understand how the sun moves in one year, particularly at low latitude region based on observation data. We took the picture of the Sun every week at the same time of the day (the time of the eclipse). In this observation, we used a tripod and DSLR camera with a variable ND filter to take the data. To obtain the pattern, the weekly data were combined by image stacking using the same foreground. Finally, we got a figure 8 shaped pattern tutulemma which a bit different from high latitude country ones.

1. Introduction

As it is described in the book Sun Heavenly Mathematics and Architecture [1], analemma is the trajectory traversed by the Sun across the sky in a certain elapsed time when the picture of the Sun is taken from the Earth surface at the same position and time along a year. The combination effect of 23.5° obliquity of Earth's axis and the elliptical orbit of the Earth causes the Sun seems to move up and down in the sky and generates two loops like figure 8. In Northern hemisphere, the highest point of apparent position of the Sun in figure 8 is generated around the Summer Solstice [2]. Then, it starts moving down the sky, generating the first loop of the figure 8 and it repeats similarly during the winter months to generate the second loop of the figure 8 curve. Other than the elliptical Earth’s orbital path, the Sun is not in the center of the Earth’s orbit. It means that there are one part of the orbital path, called Perihelion, which is closer to the Sun and the farther one, Aphelion. Consequently, the Earth seems like move faster around the Sun when it is at Perihelion in Winter Solstice than when it is at Aphelion. This has the effect of flattening out the bottom half of the curve.

The first successful single photo frame of an analemma was taken from February 27th, 1978 to February 17th the next year by Dennis di Cicco [2], an amateur astronomer from New England. The analemma's position is determined not only by the latitude at which the images are taken, but also by the time of day. The direction of the analemma also differs depending on the observer location on Earth. [2] Observers in the Northern hemisphere will obtain an analemma curve with the broader loop at the bottom and observers at the North Pole will observe only the top loop of the analemma. Meanwhile,
observers in the Southern hemisphere will see otherwise. Higher or lower latitude will give more vertical photographs of figure 8 analemma. The apparent variation position of the Sun has been intensively studied by astronomers as it is well understood and mathematically calculated [3][4]. Based on theory, the analemma at the equator should look like completely horizontal 8-shaped even though probably no one has ever made equatorial analemma’s photographs.

There are some analemma portraits, which contains the image of a solar eclipse known as Tutulemma. Tutulemma derived from the Turkish word tutulema (eclipse) and analemma which means analemma containing eclipse. The first tutulemma photograph published by Tunç Tezel from Turkey who succeed taking the pictures with the background of the sun’s path in one year and total solar eclipse occurring in March 29, 2006 using a playground as its foreground [5]. In Asia, particularly Indonesia, analemma portrait has not been quite popular or perhaps yet unpublished. Therefore, Tutulemma team consisting 7 members in LAPAN has been formed with three main aims. First, we want to make the first analemma photograph in Indonesia which contains imagery of solar eclipse 2016. As it was conducted in the office rooftop of LAPAN Bandung, the eclipse image was Partial Solar Eclipse (PSE) only. Second, we want to proof how the analema’s figure in latitude -6˚ is consistent with the theory. The trajectory traversed by the Sun in Indonesia which located near the equator would be very unique and different with those from Turkey or high latitude countries which had already made a lot of analemma photographs. Theoretically, analemma at near equator will shaped like horizontally tilting figure 8. Third, for educational purpose, such as understanding how the sun moves in one year particularly at low latitude region based on observation data, studying equation of time and coordinate system. There are some variations in the length of a solar day and the difference between solar time and mean time. The variations are encapsulated in an expression called the Equation of Time (the term ‘equation’ is used here in a historical sense, meaning a correction or adjustment) [6].

2. Data and method
Making analemma’s photograph might look simple, however, it needs consistency, patience, and teamwork of a weekly observation along a year. We were divided in two small team consisting three up to four people which responsible taking the data according to the schedule. Data were collected every Wednesday at around 07:21 LT when maximum PSE occurs in Bandung. The shooting position and instruments must be the same throughout the year of data collection. We used DSLR camera and tripod configured to be fixed for the weekly observation shown in figure1.

![Figure 1](image1.png)
**Figure 1.** Default position of the camera and tripod.

![Figure 2](image2.png)
**Figure 2.** Dot finder seen in the FOV to match the shooting positions.

Our procedures of taking analemma data that was written in the Analemma team’s rules or Standard Operating Procedure (SOP) are as follows: image acquisition was conducted every Wednesday morning at the rooftop of LAPAN Bandung office, started from March 2015 until March 2016. There are 48 observation days in one year, which is enough to construct analemma’s path. The camera used was CANON EOS 700D, with Natural Density (ND) variable filter up to ~ 400 for reducing sunlight. Filter
was set to see the homogeneous (at certain points around the word "MAX") in which also depends on the weather. The shinier day, higher number in variable filter should be set, yet in cloudy day less number was better as the clouds also performs as filter. Camera setting were 1/60s exposure time, focal ratio f/9, ISO 100, focal 18mm (maximum zoom out), while the focus setting was adjusted using the Auto Focus (AF) or manual. For the purposes of better processing, images were taken in RAW + best JPEG mode. The position of the tripod and camera were arranged so that the field of view (FOV) finder of camera may look the same for each week (figure 2). We used several objects seen from rooftop top LAPAN Bandung office to be marked in camera finder in order to make sure, if the camera was always set at the same position in every data acquisition.

The method used in final processing was the image combining and compositing. Before that, every weekly observation images were categorized as good and bad data and were processed individually. Ideally, to get a portrait which is consistent and has equal position, it requires a fixed monopod or a fixed camera attachment like the others did. As our team only used a portable tripod, weekly images sometimes were captured in different angle and size. To get the exact sun’s position in individual frame, the appearance of foreground or scenery is very important to be used as reference. Even though in some cases, the portrait of the sun with maximum ND filter will remove the entire foreground and only leave small yellow sun’s image in dark frame. Therefore, all the best weekly images were processed separately first in order to emerge both the reference foreground and the best sun’s image in the same frame. Then, to get the desired result, after a year passing at around PSE 2016, each of those processed weekly image layers were combined one by one starting from the oldest to the newest. When the foreground of every frames were stacked precisely, we finally obtained the figure like 8-shaped from one-year solar pattern.

3. Result

During a year observations, we obtained various quality of data: sometimes good in clear sky, sometimes bad due to cloudy weather and problem in instrument even the slight observer’s error. Figure 3 and figure 4 shows the example of bad data due to the weather. On February, 10th 2016 Sun’s image was taken too bright so this kind of pictures need further processed (figure 3). On February 3rd 2016, the weather was too cloudy and unfortunately, no data was obtained. (figure 4). A whole one year, there were several weeks with these kind of bad data and two weeks of no data. However weekly data mostly look like in figure 5, which were very dark with perfect small yellow sun.

Figure 3. Image of the Sun taken on February, 10th 2016 which is too bright.  
Figure 4. Image of cloudy day taken on February, 3rd 2016.  
Figure 5. Example of good data with maximum ND Filter taken on January, 13th 2016

To complete this project, time lapse of Partial Solar Eclipse which is shown in figure 6 was taken with same instrument with maximum zoom in between 06:20 LT – 08:32 LT at rooftop office of LAPAN Bandung. In this place, the Moon covered up 88% of Sun’s disk at 07:21 LT on March, 9th 2016 Combining the maximum PSE image, which is marked in circle, with images obtained during one year around before and after PSE, finally we made a figure 8-shaped pattern as it is shown in figure 7.

It can be seen in our analemma photograph, there are some blank space around February and March due to the bad weather. We can also recognize different shape of sun’s images for each week due to the different style of the observers, instrument problem and more importantly the morning local weather. For example, the dots look bigger around summer solstice than around winter solstice, due to cloudier
weather by the time images were taken. The morning weather was getting cloudier around August, so one of the sun’s image appears not in full circle shape because the sun was hiding between the gaps of clouds.

This nearly horizontal analemma describes typical sun’s path from near equator, particularly in latitude -6° South at 7:21 am. During summer solstice around June, the sun was at Aphelion that can be considered like it moves more slowly, therefore the gaps between the dots look narrower. Meanwhile, during winter solstice around December, the gaps became wider because the earth moves faster at perihelion. The 8-shaped loop is broader at the top-right in winter solstice, because we observed from southern hemisphere. Hence, as it was calculated and discussed by the old astronomers, the shape of our one year analemma observation is certainly look like the theory we mentioned above.

4. Summary and discussion
We have briefly show our result of one year analemma’s observation which is consistent with the theory and calculation precisely for low latitude region. In reality, along a year, weekly images vary widely with the technical problems (change SOP, instrument problem), observers’ error (different angle, zoom in/out), and weather (clouds, haze). Therefore, Ideal Analemma’s photography should be conducted exactly not only with the same instrument and setup, but also with the fixed tripod/monopod and with the same person if possible (max 2). Finally, Tutulemma’s PSE in Lapan can be useful as original reference for education purpose. Indonesia is situated around the equator, so this will definitely have the distinctive characteristics of its analemma shape. Understanding the analemma can be the study of the equation of time, the coordinate system of the earth and celestial and how they move, calculation time the sun rises and sets, and some other knowledges.

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