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The Accuracy of Approximate Solar Coordinates US Naval Observatory in Prayer Time Calculations

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Abstract: *This study aims to test the accuracy of Approximate Solar Coordinates (ASC) data issued by the U.S. Naval Observatory (USNO) in calculating prayer times. The method used in this research is the comparative qualitative research method. The author compares the Sun declination and equation of time data obtained from the USNO ASC algorithm with Ephemeris Hisab Rukyat data for one year. From this research, it is found that the maximum difference between the Sun declination value from the ASC USNO algorithm compared to the Hisab Rukyat ephemeris is only 15 seconds of arc. While the maximum difference in the equation of time value is only around 2 seconds. The maximum difference in the calculation of prayer time between the two is only 2 seconds. Therefore, this ASC USNO data can be used as an alternative choice in calculating prayer times. Not only because the algorithm is quite concise, but the results obtained are also accurate for prayer times.*
Keywords: *Prayer Times, Approximate Solar Coordinate, U.S. Naval Observatory.*

Abstrak: *Penelitian ini bertujuan untuk menguji keakuratan data Approximate Solar Coordinates (ASC) yang dikeluarkan oleh U.S Naval Observatory (USNO) dalam memperhitungkan waktu salat. Metode yang dipakai dalam penelitian ini adalah metode penelitian kualitatif komparatif. Penulis mengkomparasikan data deklinasi Matahari dan equation of time yang didapatkan dari hasil algoritma ASC USNO dengan data Ephemeris Hisab Rukyat selama 1 tahun. Dari penelitian ini, didapatkan hasil bahwa selisih maksimum antara nilai deklinasi Matahari hasil dari algoritma ASC USNO dibandingkan dengan ephemeris hisab rukyat hanya sebesar 15 detik busur. Sedangkan selisih maksimum nilai equation of time hanya berkisar 2 detik. Adapun selisih maksimum hasil perhitungan waktu shalat antara kedunya hanya 2 detik. Maka dari itu, data ASC USNO ini bisa dijadikan alternatif pilihan dalam perhitungan waktu shalat. Selain karena algoritmanya yang cukup ringkas, hasil yang didapatkan pun akurat untuk waktu salat.*
Kata kunci: *Waktu Salat, Approximate Solar Coordinate, U.S. Naval Observatory.*

A. Introduction

The method of hisab for the beginning of prayer time is still being studied to get the most accurate value. Sun data for this calculation is very important because prayer times depend on the position of the Sun. There are many Sun data algorithms that have been developed to determine the position of the Sun with precision. The US Naval Observatory is an institution tasked with providing highly accurate astronomical data and time information, one of which is Sun data. This algorithm is able to calculate the position of the Sun with an accuracy of about 1' arc within two centuries from the year 2000. The algorithm uses several astronomical parameters, such as the Sun's mean anomaly, the Sun's mean longitude, the Sun's geocentric apparent ecliptic longitude, recta asensio, declination, and equation of time. For navigation purposes and calculation of sunrise and sunset times, which are important components of prayer timing, the accuracy of this algorithm is sufficient. It has been used in various astronomy and navigation software, such as the Multiyear Interactive Computer Almanac (MICA), and proven capable of calculating the coordinates of the Sun, Moon, and planets with an accuracy greater than 0.1" of arc.[1]

The command to perform the prayer time based on the position of the Sun has been stated in the hadith. The position of the Sun for the Zuhr prayer begins when the Sun slips towards the west, marked by the formation of the shadow of an object on the earth towards the east. The Asr prayer begins when the length of the shadow of an object is equal to the length of the object plus the shadow of the object at Zuhr. The Maghrib prayer begins when the disk of the Sun has fully set on the western horizon, refraction by the atmosphere near the horizon causes the position of the Sun to appear higher than its actual position estimated at 34' 30" arc.[2] The Isha prayer begins when the red light disappears due to the setting of the Sun from the horizon. The red color is formed by the refractive reflection of the Sun's rays below the horizon, which are reflected to form light that is visible to the observer's eye.[3] The Fajr prayer begins with the dawn of the white lightprint that spreads across the eastern horizon. Thus, the position of the Sun must be calculated carefully and with minimal error in order to fulfill the validity of the prayer.[4]

In order to determine when it is appropriate to pray, one must make an effort based on the information found in the hadith. In this instance, the science of hisab is highly beneficial since it allows people to organize the start of prayer time without having to perform repeated, in-person observations every day. Astronomical science has advanced into the current day, where it is occasionally possible to determine the precise locations of celestial bodies, including the Sun. Astronomers and organizations have long created a variety of hisab systems, from urfi to modern hisab.

In calculating the beginning of prayer time, astronomical data such as the value of Julian's day, the declination of the sun, and the equation of time are required. The location data that are also important are the latitude and longitude coordinates of the location, altitude, and time zone. The accuracy of determining the beginning of prayer time is not only influenced by the algorithm used, but accurate data is also needed in the calculation.[5]

Pierre Bretagnon in 1982 had devised the *Variations Seculaires des Orbites Planetaries Theory* (VSOP) algorithm. The first version of VSOP was VSOP-82 which calculated only the orbital elements at any time.[6] In 1987, the algorithm was refined into the VSOP-87 version

[1]https://aa.usno.navy.mil/faq/sun_approx, diakses pada tanggal 16 Oktober 2022.

[2]Abu Yazid Raisal et al., "Simulasi Perhitungan Waktu Salat Menggunakan Spreadsheet," *Al- Marshad: Jurnal Astronomi Islam Dan Ilmu-Ilmu Berkaitan* 8, no. 1 (2022).

[3]Nur Qomariyah, "Penentuan Awal Waktu Salat (Awal Waktu Salat Asar, Magrib, Dan Isya Berdasarkan Hadis Nabi)," *AL - AFAQ : Jurnal Ilmu Falak Dan Astronomi* 2, no. 2 (January 5, 2021): 19–34, https://doi.org/10.20414/afaq.v2i2.2918.

[4]Ahmad Musonnif, *Ilmu Falak: Metode HIsab Awal Waktu Shalat, Arah Kiblat, Hisab Urfi Dan Hisab Hakiki Awal Bulan* (Yogyakarta: Teras, 2017), 62.

[5]Arief Taufikurrahman, "Simulasi Perhitungan Awal Waktu Salat Berdasarkan NOAA SOlar Calculator Menggunakan Spreadsheet," *AL - AFAQ : Jurnal Ilmu Falak Dan Astronomi* 5, no. 1 (2023).

[6]Baiq Anggi Andini, Siti Rabi'atul Adawiyah, and Arino Bemi Sado, "Implementasi Algoritma Jean Meeus Dalam Penentuan Gerhana Bulan Dan Matahari," *AL - AFAQ : Jurnal Ilmu Falak Dan Astronomi* 5, no. 1 (2023): 57–80, https://doi.org/10.20414/afaq.v5i1.7223.

conceived by Pierre Bretagnon and Gerard Francou at the Bureau des Longitudes, Paris.[7] VSOP-87 consists of 1080 periodic terms for calculating the Sun's longitude. The sophisticated algorithm developed in VSOP-87 serves as an alternative for humans to predict the positions of planets to within one ten-thousandth of a degree for thousands of years to come.[8] Then, in 1998, Jean Meeus, a Belgian meteorologist and astronomer, presented his formula, which is a condensed version of the VSOP-87 method. Jean Meeus program can produce solar data with an accuracy level of 0.01". Jean Meeus's program is capable of producing precise solar statistics through intricate computation stages.

The U.S. Naval Observatory (USNO) is one of the organizations that determines and disseminates time and astronomical data about celestial objects. USNO approximates the Sun's data using a straightforward formula. By the year 2000, the error rate is less than 1 arcminute over two centuries, even though the data acquired is an approximation of the Sun.[9] Because its calculation algorithm is comparatively simpler than others, astronomers can easily use the straightforward formula developed by USNO as a reference when determining prayer times.

The book "Planetary Programs and Tables from –4000 to +2800" has a study that examines solar data used to determine the start times of prayers, one of several earlier studies that are connected to the author's research. The purpose of this study is to compare Jean Meeus's solar data from "Planetary Programs and Tables from -4000 to +2800" with the start timings of prayers.[10] Furthermore, the study by Abu Yazid Taisal and associates used a spreadsheet that was well-known in some circles to simulate timing calculations for prayer and didn't require sophisticated programming. When compared to the Accurate Times software, the turnaround times varied from 4 seconds to 1 minute and 46 seconds.[11]

Based on the related studies that have been conducted, the study on ASC USNO in its implementation for prayer time calculations has never been done. Here, the author will attempt to conduct the study by comparing it with the Ephemeris data from the Indonesian Ministry of Religious Affairs. The purpose of this research is to analyze the accuracy level of the USNO ASC algorithm in determining prayer times, so that it can be concluded whether this algorithm is suitable for use in calculating prayer times.

B. Methods

This research uses a comparative qualitative research method to determine the effect of using the approximate solar coordinate algorithm created by the U.S. Naval Observatory on prayer times. The approach method used is comparative by comparing the Sun data with the Ephemeris algorithm of the Ministry of Religious Affairs of the Republic of Indonesia. The primary data

[7]Satria Yudhistira, "Studi Komparatif Sistem Perhitungan Gerhana Matahari Elements of Solar Eclipses Jean Meeus Dan Textbook on Spherical Astronomy W.M. Smart" (Universitas Islam Negeri Walisongo, 2019), 25.

[8]https://www.caglow.com/info/compute/vsop87, diakses pada tanggal 24 Oktober 2022.

[9]https://aa.usno.navy.mil/faq/sun_approx, diakses pada tanggal 16 Oktober 2022.

[10]Muhammad Muadz Dzulikrom, "Perhitungan Data Matahari Dalam Buku Planetary Programs and Tables From -4000 To + 2800 Untuk Pemrograman Awal Waktu Salat Menggunakan Software Microsoft Spreadsheet," *Universitas Islam Negeri Sunan Ampel*, 2022.

[11]Raisal et al., "Simulasi Perhitungan Waktu Salat Menggunakan Spreadsheet."

in this study is the USNO solar coordinate algorithm, while the secondary data source uses location coordinates and prayer times with the Ephemeris algorithm by the Ministry of Religious Affairs. The data collection technique involves calculating prayer times using USNO ASC solar data over one year in Indonesia, which is then compared with the prayer times from the Ministry of Religious Affairs for the same time and location. Data analysis is then conducted by creating graphs that display the differences in prayer times obtained using USNO ASC and the Ministry of Religious Affairs Ephemeris. The subject of the research is solar data in the form of declination values, equation of time, and the prayer times for Fajr, Dhuhr, Asr, Maghrib, Isha, thulu', and Duha within the time span of the year 2024.

C. Result and Discussion

1. Prayer Times Calculation

Three factors—solar data, criteria, and algorithms—are taken into account while determining prayer times. A variation in one of those elements may result in a different prayer pattern. The coordinates of the Sun must be determined using sun data in prayer time computations. This solar data has been freely accessible through the Republic of Indonesia's Ministry of Religious Affairs' annual ephemeris data. This study will examine and compare the outcomes of prayer times utilizing ASC USNO with the Ephemeris. The equation of time and the declination value are the solar data used to calculate prayer times. Measured along the time circle that travels through the Sun to the Sun's center point, the solar declination is the separation between the Sun and the equatorial circle The equation of time is the difference in time between the true Sun and the mean Sun.[12]

The criteria for the Sun are the position of the Sun in the celestial sphere according to the provisions established in the hadith for each prayer time. Several countries around the world set the solar altitude value for each prayer time. The solar altitude criteria used in this study follow the criteria set by the Republic of Indonesia's Ministry of Religious Affairs', which are for Maghrib prayer time -1°, Isya prayer time -18°, Subuh -20°, Thulu' -1°, and Duha 4° 30'. The Ministry of Religious Affairs also applies a 2-minute precautionary time, which is obtained from 1 minute equivalent to 27.77 km, so to cover one city area, it is estimated to be 55.54 km.[13]

The timing of sunrise, solar transit, and sunset are important events in determining the start of prayer times.[14] Careful observation is needed to determine the correct prayer times because errors in calculating the movement of the Sun can lead to incorrect prayer time schedules. For the algorithm used in prayer time calculations, there are two theories that can be

[12]Imron Hadi, "Studi Analisis Akurasi Perhitungan Awal Waktu Shalat Menggunakan Universal Astrolabe," *AL - AFAQ : Jurnal Ilmu Falak Dan Astronomi* 4, no. 1 SE-Articles (June 30, 2022): 129–56, https://doi.org/10.20414/afaq.v4i1.5154.

[13]Jayusman Jayusman, "AKURASI NILAI WAKTU IHTIYATH DALAM PERHITUNGAN AWAL WAKTU SALAT," *ASAS: Jurnal Hukum Dan Ekonomi Islam* 11, no. 1 (2019): 78–93, https://doi.org/10.24042/asas.v11i01.4644.

[14]Zainuddin, "Posisi Matahari Dalam Menentukan Waktu Shalat Menurut Dalil Syar'i," *ELFALAKY: Jurnal Ilmu Falak* 4, no. 1 (2020).

used, namely spherical triangle trigonometry and planar triangle trigonometry. Spherical triangle trigonometry discusses the angles of triangles applied to the spherical field and is related to the positions of the Earth, Moon, and Sun.[15]

2. Calculation Solar Coordinates with *Approximate Solar Coordinates* (ASC) USNO

To determine the Sun's coordinates, the U.S. Naval Observatory has created a straightforward technique. This algorithm can obtain an estimate of the Sun's coordinates with an error margin of no more than 1' arc, accurate until the year 2200. For calculations like determining the times of dawn and sunset or solar transit, this degree of precision is adequate. This algorithm offers an accuracy of roughly one nautical mile for navigational applications. The Julian day value for the day on which the solar coordinates are to be computed is necessary for this computation. Universal time is the basis for the Julian value that is employed.

The first step is to calculate the day using the Julian day formula:

a. Calculate the day:

The Julian day value is obtained using the formula:

$$\boxed{d = JD - 2451545.0}$$

$$A = INT\left(\frac{Y}{100}\right)$$

$B = 1 - A + INT\left(\frac{A}{4}\right)$, for the Julian calendar, the value of B = 0

$$JD = INT\,(365{,}25 \times (Y + 4716)) + INT\,(30{,}6001 \times (M + 1)) + D + B - 1524{,}5$$

information: Y = year
M = month
D = day

The Julian day value is subtracted from the initial time of the mentioned period, which is January 1, 2000, with a Julian day value of 2451545.0. The value of *d* is then used to calculate the mean anomaly of the Sun, the mean longitude of the Sun, and the geocentric apparent ecliptic longitude of the Sun.

b. Mean anomaly of the Sun

The mean anomaly of the Sun is a parameter of the position and time of the Sun moving in its elliptical orbit.[16] The formula to find the mean anomaly of the Sun is:

$$\boxed{g = 357.529 + 0.98560028 \times d}$$

c. Mean longitude of the Sun

$$\boxed{q = 280.459 + 0.98564736 \times d}$$

d. Geocentric apparent ecliptic longitude of the Sun (adjusted for aberration)

$$\boxed{L = q + 1.915 \times sin(g) + 0.020 \times sin\,(2 \times g)}$$

[15]Aisah Nur Eka Rahmawati, Yulianti Rusdiana, and Ilmadi, "Trigonometri Segitiga Bola Dalam Penentuan Waktu Salat," *SAINTIKA UNPAM* 4, no. 1 (2021): 90–107.

[16]Rinto Anugraha, *Mekanika Benda Langit* (Yogyakarta: Jurusan Fisika Fakultas MIPA Universitas Gadjah Mada, 2012), 74.

e. Mean obliquity of the ecliptic

$$\boxed{e = 23.439 - 0.00000036 \times d}$$

f. The Sun's right ascension

$$\boxed{\mathrm{RA} = ATAN2(\cos(e) \times \sin(L), \cos(L))/15}$$

g. Declination

$$\boxed{\mathrm{D} = ASIN\ (\sin(e) * \sin(L))}$$

h. *Equation of time*

$$\boxed{EqT = q \div 15 - RA}$$

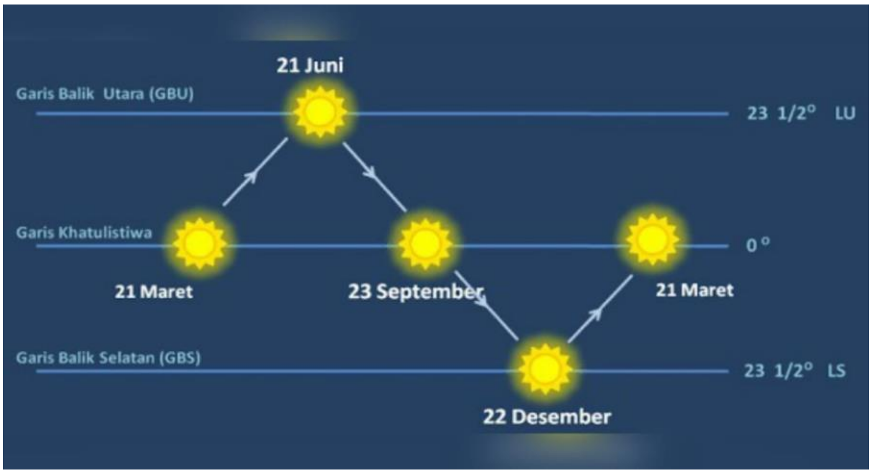
3. Comparison of ASC USNO and Ephemeris

Comparison is made between the USNO algorithm that produces solar coordinate estimates and the Ephemeris. USNO uses a brief calculation process to obtain solar coordinate estimates. It is interesting to conduct tests to determine whether the results are accurate enough to be used in calculating the start times of prayers. In calculating the start times of prayers, solar data is needed, such as the solar declination value and the equation of time. Therefore, in this study, a comparison is made between the ASC USNO algorithm and Ephemeris data to be used in finding the solar declination value, equation of time, and the prayer times of Fajr, Dhuhr, Asr, Maghrib, Isha, Thulu', and Duha.

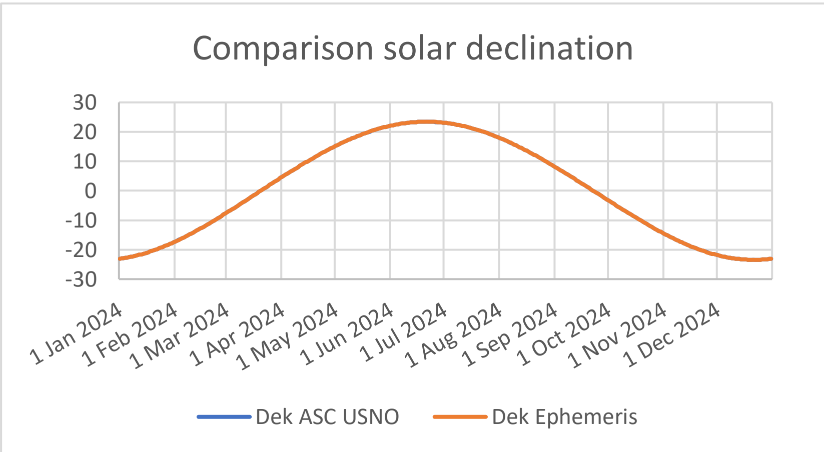
a. Comparison of solar declination ASC USNO and Ephemeris

The distance between the equator and the Sun's center point on the declination circle is known as the declination of the Sun. It is represented by δ in astronomy.[17] In this instance, the size of the shadow that sunlight casts on the surface of the Earth is determined by the declination value. The Sun's declination value is positive (+) when it is in the northern hemisphere and negative (-) when it is in the southern hemisphere. The declination value is at 0° when the Sun crosses the equator, which happens between March 21 and September 23. The Sun continues its northward journey on March 21 until it reaches the northern solstice on June 21, when the declination value reaches its maximum of +23° 27'. With a maximum negative declination value of -23° 27', the Sun then continues to journey south until it reaches the southern solstice on December 22.[18]

[17]Muhyiddin Khazin, *Ilmu Falak Dalam Teori Dan Praktik* (Yogyakarta: Buana Pustaka, 2005), 67.
[18]Slamet Hambali, *Ilmu Falak 1 Penentuan Awal Waktu Shalat & Arah Kiblat Seluruh Dunia* (Semarang: Program Pascasarjana IAIN Walisongo Semarang, 2011), 55.



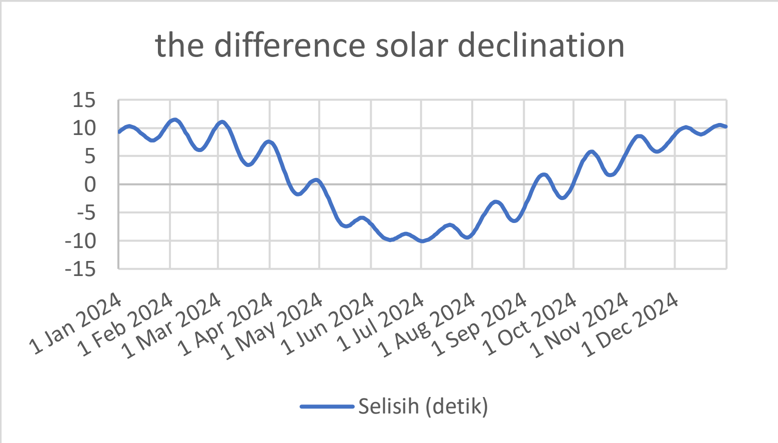
The comparison of declination values from ASC USNO and Ephemeris is shown in graph 1. To obtain these declination values, the declination values were calculated using the ASC USNO algorithm (according to the calculation sequence previously described) and the declination values with ephemeris. From the results of both algorithms, there is no noticeable difference when applied in minutes as shown in graph 1. The two curves that are formed completely overlap each other because their declination values are always the same.



Graph 1 Comparison solar declination ASC USNO and Ephemeris

b. The difference solar declination values in seconds

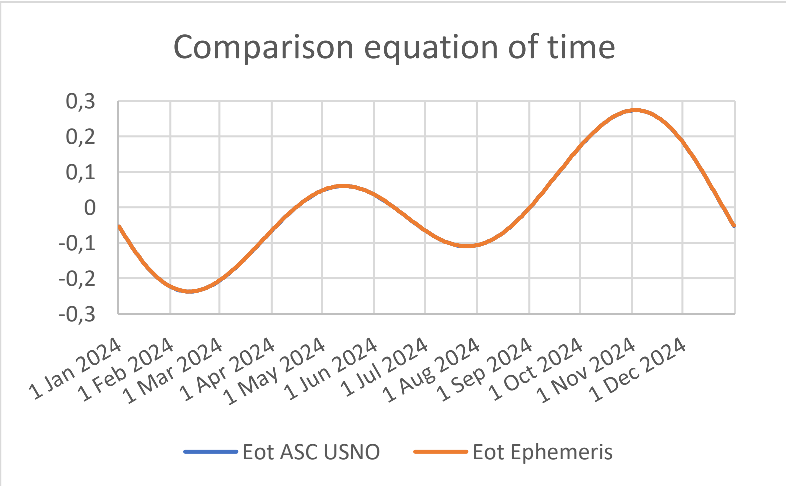
The difference in declination values between the Ephemeris and ASC USNO can be seen in more detail when displayed in seconds. In contrast to the 1-minute parameter, the declination values of ASC USNO for the year 2024 are exactly the same as the declination values of the Ephemeris. Negative results indicate that the ASC USNO algorithm is smaller compared to the Ephemeris, up to -10.09 seconds, while positive differences indicate that the Ephemeris algorithm is larger, at 11.46 seconds. From these results, it is known that the average declination difference between the two algorithms is 1.43 seconds. The declination difference between the ASC USNO and Ephemeris algorithms is illustrated in Graph 2.



Graph 2 the difference solar declination ASC USNO and Ephemeris

c. Comparison of equation of time ASC USNO and Ephemeris

The value of the equation of time is a correction to determine the mean solar time (solar mean time) from the true solar time (solar time). [19] If the true solar time occurs earlier than the mean solar time, the value of the equation of time is positive, whereas if the true solar time occurs after the mean solar time, the equation of time is negative. [20] The value of the equation of time ranges around a dozen minutes, which changes daily, but will always be the same and repeat each year. The comparison of the equation of time values between ASC USNO and the 2022 Ephemeris is displayed in the form of curves on graph 3. The results of both algorithms are always the same, as seen from the curves that overlap when parameters are used in minutes. Therefore, the ASC USNO curve is not visible at all because it is obscured by the Ephemeris curve.



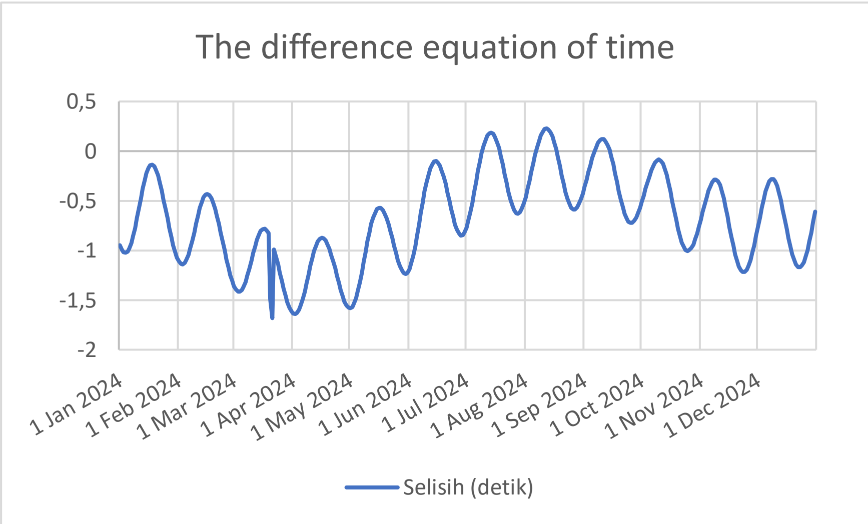
Graph 3 the comparison equation of time Ephemeris and ASC USNO

[19]Encup Supriatna, *Hisab Rukyat & Aplikasinya* (Bandung: Refika Aditama, 2007), 20.

[20]Misbah Khusurur and Jaenal Arifin, "Mengenal Equation Of Time, Mean Time, Universal Time/Greenwich Mean Time Dan Local Mean Time Untuk Kepentingan Ibadah," *Jurnal Pemikiran Hukum Dan Hukum Islam* 5, no. 1 (2014): 127.

d. The difference equation of time value in seconds

The value of the equation of time produced between the ASC USNO algorithm and the Ephemeris actually shows a difference. This difference can be seen when clarified down to the second. Presented in the graph 4 negative differences mean that the equation of time from ASC USNO is smaller than Ephemeris. The differences show that the USNO algorithm is smaller, with a maximum of 0.22 seconds, while the Ephemeris algorithm shows values larger than the USNO algorithm, up to 1.68 seconds. The average value of the difference in the equation of time between Ephemeris and the ASC USNO algorithm is -0.684 seconds.



Graph 4 the difference equation of time Ephemeris and ASC USNO

e. Comparison Zuhur prayer time

Graph 5 shows the start time of the Dhuhr prayer based on the sun's coordinates generated from the USNO ASC algorithm and Ephemeris data. The obtained solar coordinates are then used to calculate the initial prayer times using the spherical triangle theory. The results do not show any difference in the curve shapes between the two algorithms. This means that the solar coordinate values from both algorithms result in nearly the same time for the Zuhr prayer. Out of 365 samples, the difference between the ASC USNO algorithm and the Ephemeris data is no more than 2 seconds. Specifically, using the ASC USNO algorithm, the Zuhr prayer time is earlier by 0.22 seconds and later by 1.68 seconds compared to the Ephemeris data. Thus, the average value of the difference is 0.6848 seconds.

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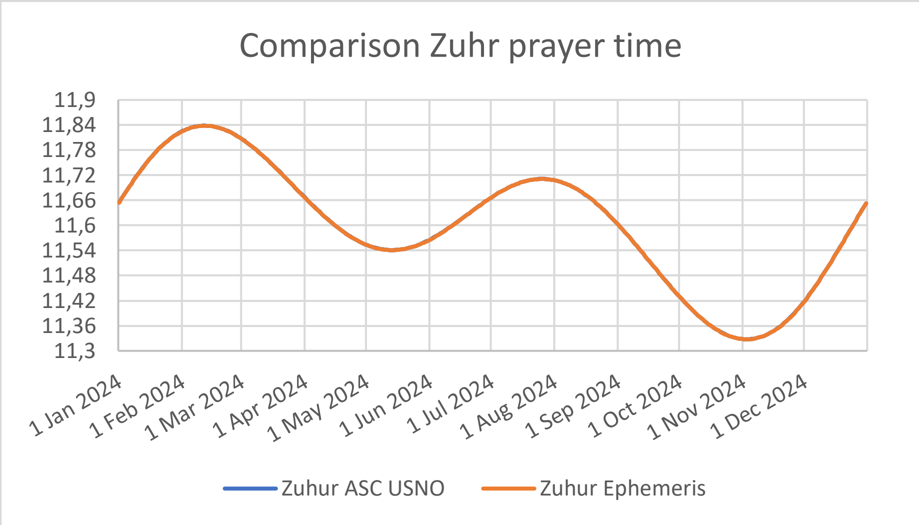
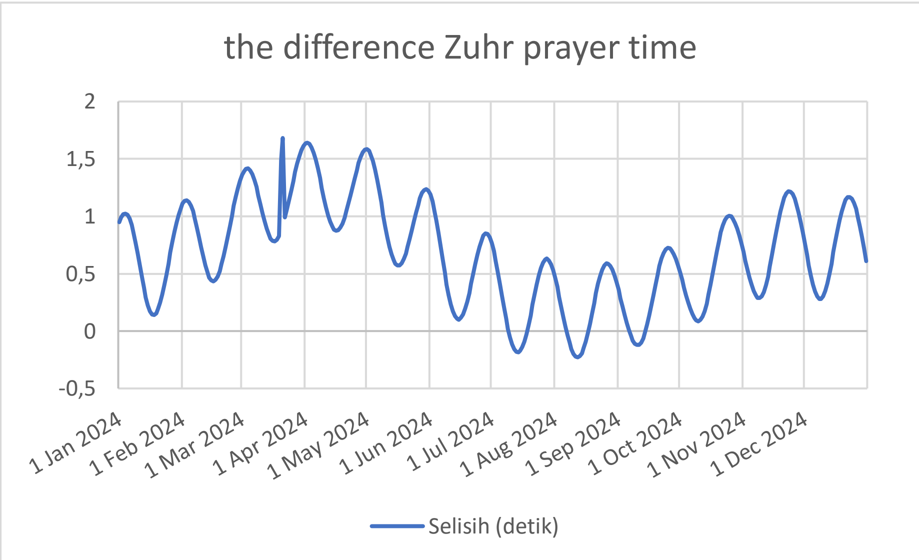


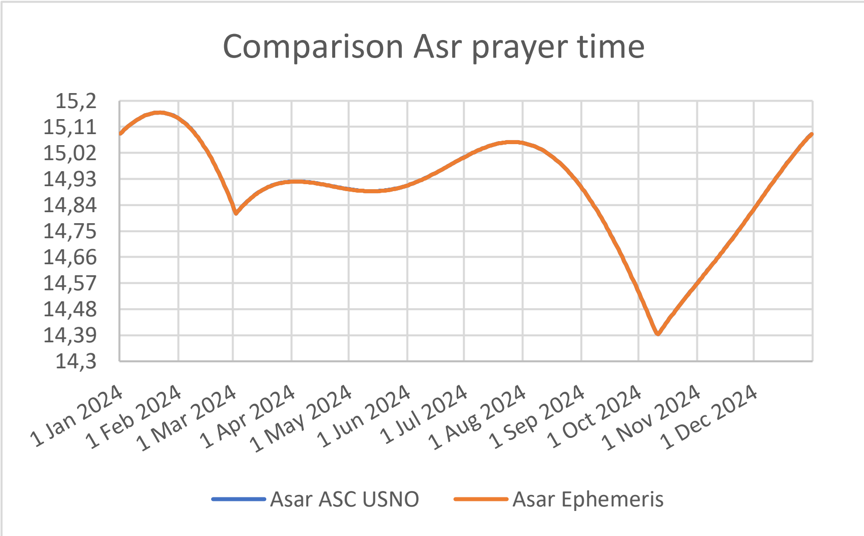
Graph 5 Comparison Zuhr prayer time ASC USNO and Ephemeris



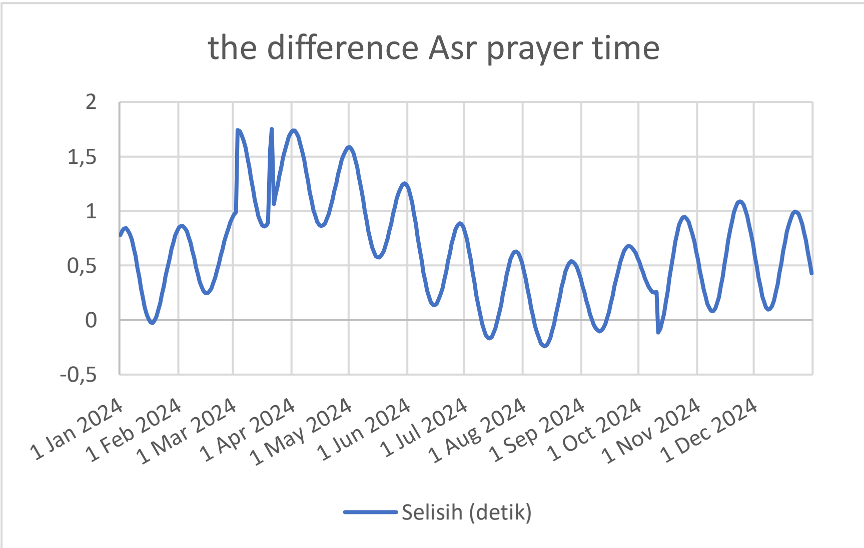
Graph 6 the difference Zuhr in seconds

f. Comparison Asr prayer time

The initial calculation results for the Asr prayer time using the sun's coordinates from the calculation process employing the ASC USNO algorithm and Ephemeris data are depicted in graph 7. The obtained sun coordinates are then used with the same algorithm to calculate the Asr prayer time. The result is that the formed curves always overlap, indicating that the times are the same and there is no difference in minute units. Both algorithms produce a difference in prayer times only in seconds, with the ASC USNO algorithm being faster by 0.24 seconds and slower by 1.75 seconds compared to the Ephemeris data. The average value of the difference is 0.629.



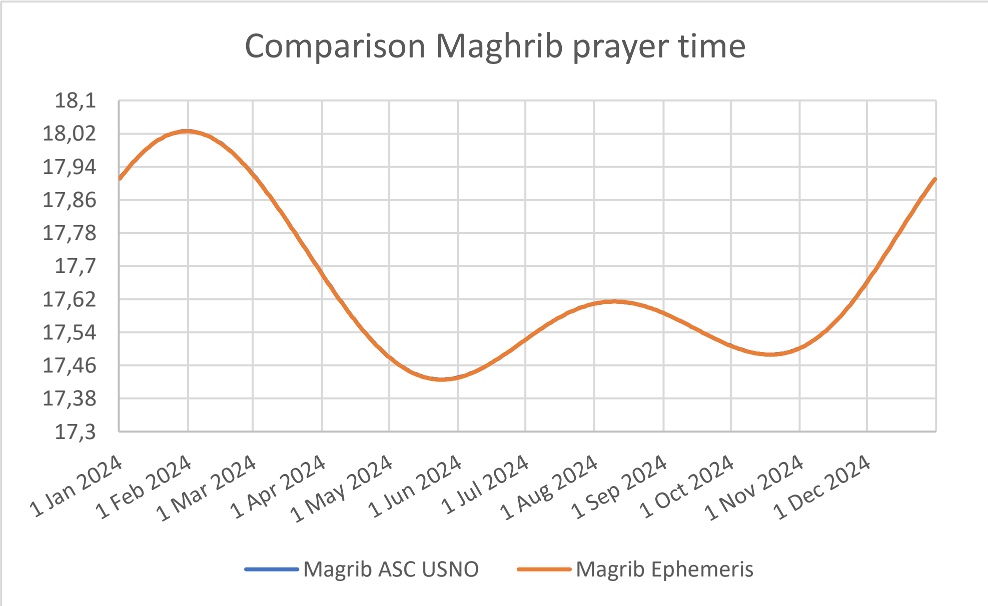
Graph 7 comparison Asr prayer time ASC USNO and Ephemeris



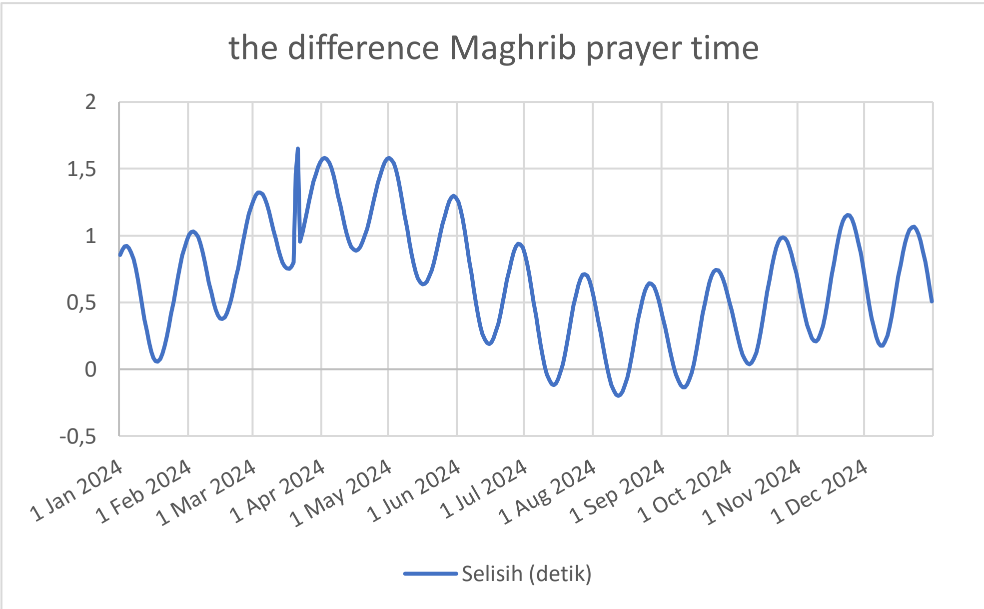
Graph 8 the difference Asr in seconds

g. Comparison Maghrib prayer time

The results of the solar coordinate calculations from the ASC USNO algorithm and Ephemeris data are implemented into the initial calculation of Maghrib prayer time. It was found that both sets of solar data produced the same Maghrib prayer time as depicted in graph 9. Both curves overlap each other so that the ASC USNO curve is always perfectly covered by the Ephemeris curve. The difference in Maghrib prayer times from the two solar coordinate algorithms is only in the seconds, specifically 0.19 seconds, which occurs because the ASC USNO algorithm is slower, and a difference of 1.65 seconds because the ASC USNO algorithm is faster than the Ephemeris data. The average of the difference values is 0.67.



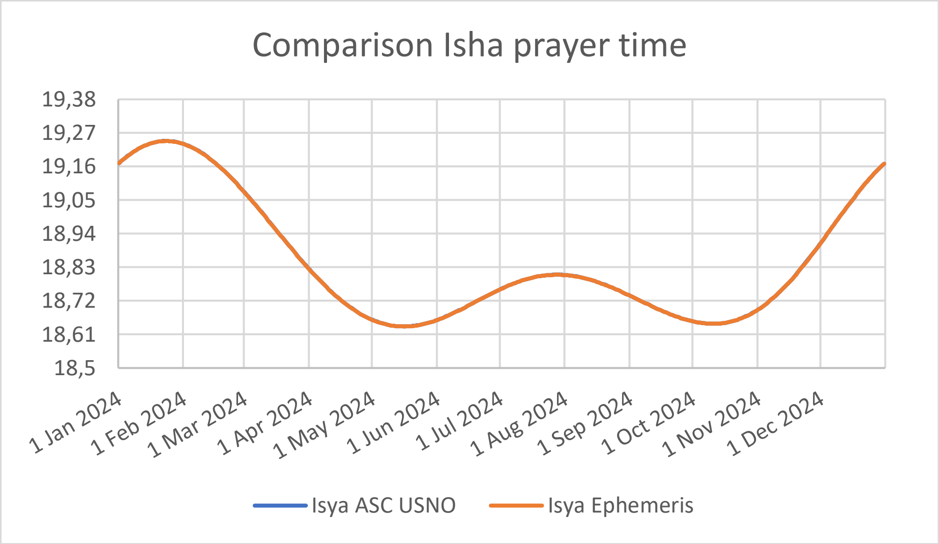
Graph 9 comparison Maghrib ASC USNO and Ephemeris



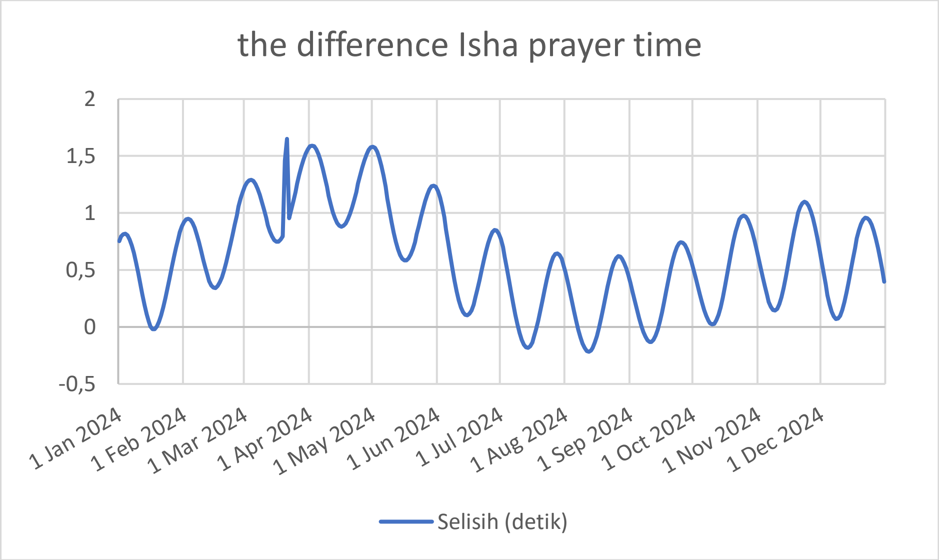
Graph 10 the difference Maghrib in seconds

h. Comparison Isha prayer time

Graph 11 depicts the initial curve of the Isha prayer time, comparing the ASC USNO algorithm and Ephemeris data as the solar coordinate data. The result shows that the two curves always move in sync because, in the graph, the orange Ephemeris curve covers the blue USNO curve. The difference that occurs is only in the seconds value, which is 0.21 seconds for the slower USNO algorithm, and 1.65 seconds for the faster ASC USNO algorithm compared to the Ephemeris data. From these difference values, the average is 0.62.



Graph 11 comparison Isha ASC USNO and Ephemeris



Graph 12 the difference Isha in seconds

i. Comparison Fajr Prayer Time

Graph 13 is the result of the initial calculation of Fajr prayer time using the sun's coordinates from the calculation process using the ASC USNO algorithm and Ephemeris data. The obtained solar coordinate values are then used in an algorithm with the spherical triangle theory tocalculate the beginning of the Fajr prayer time. The result is that the formed curves always overlap, meaning the times indicate the same time and there is no difference in minutes. Both algorithms produce a difference in Fajr prayer time only in seconds, with the ASC USNO algorithm being slower by 0.23 seconds and faster by up to 1.71 seconds compared to Fajr prayer time using Ephemeris data. The average value of the difference is 0.750.

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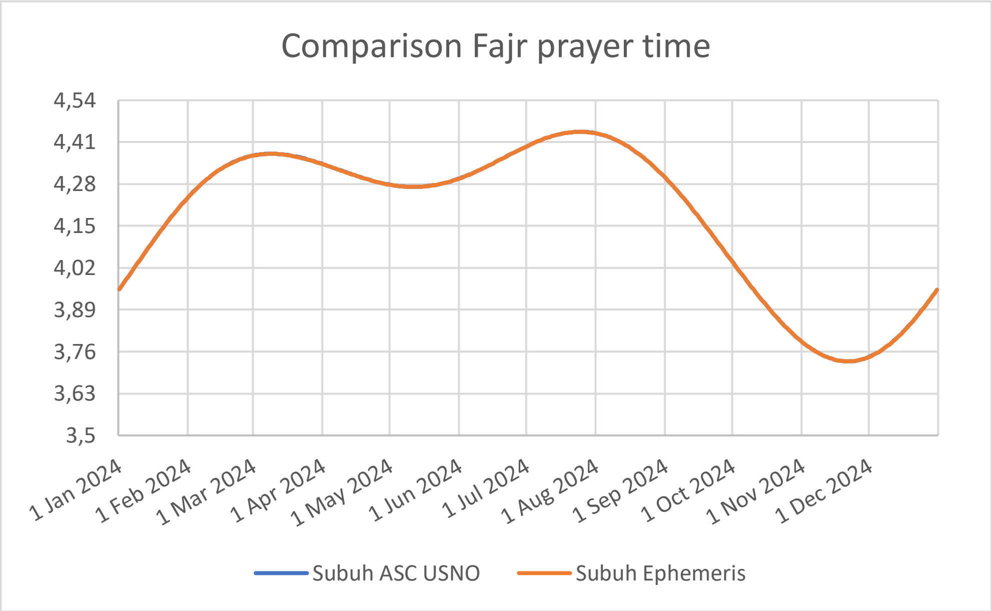
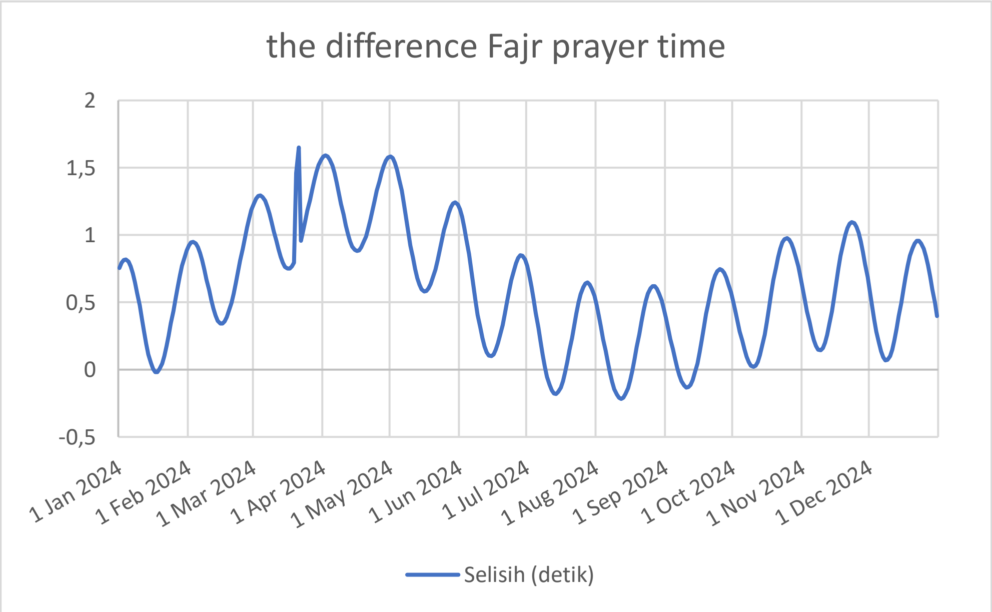


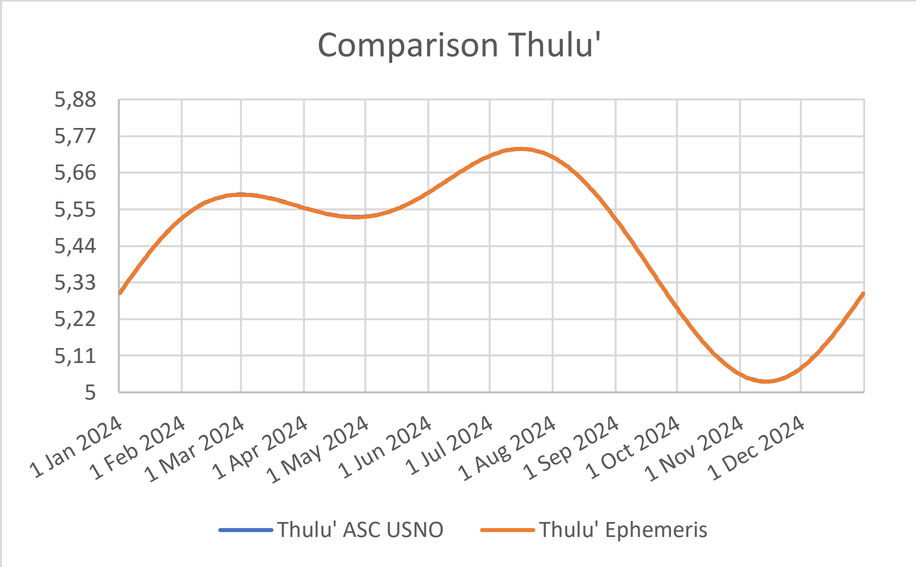
Graph 13 comparison Fajr ASC USNO and Ephemeris



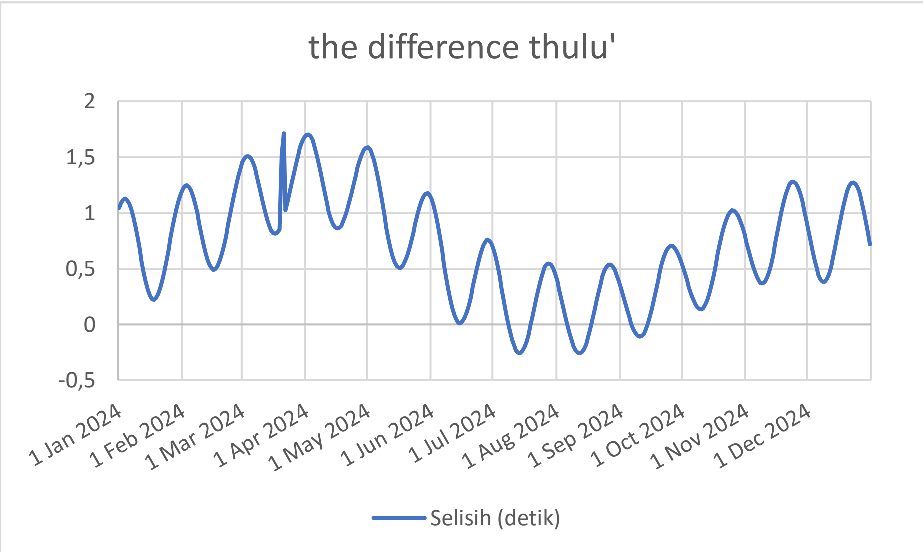
Graph 14 the difference Fajr in seconds

j. Comparison thulu'

The time of thulu' begins when the position of the sun is at -1° below the eastern horizon. In graph 15, the thulu' time is depicted by comparing the solar coordinates obtained from the ASC USNO algorithm and Ephemeris data. The result is that the ASC USNO curve and the Ephemeris curve always move at the same time in minutes. When examined in more detail using seconds, a difference is found with a value of only 0.25 seconds, where the ASC USNO algorithm is slower, and 1.71 seconds when the ASC USNO algorithm is faster than the Ephemeris data for finding the start time of thulu'.



Graph 15 comparison thulu' ASC USNO and Ephemeris



Graph 16 the difference thulu' in seconds

k. Comparison Duha

The time for Duha begins when the position of the sun is at an altitude of 3° 30'. In Graph 17, the initial comparison results of Duha time using the ASC USNO algorithm and Ephemeris data have been shown. It can be seen in the graph that there is no visible blue curve, meaning that throughout the year 2024, the Duha time from the sun's coordinates using the ASC USNO algorithm and Ephemeris data remains the same. The difference is only in the range of seconds, with the ASC USNO algorithm being 0.27 seconds slower and 1.71 seconds faster than the Ephemeris data.

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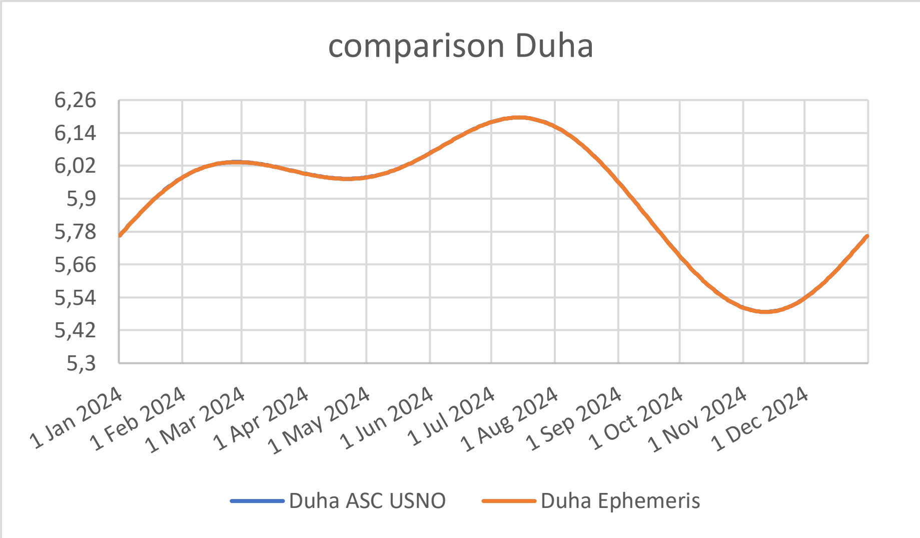
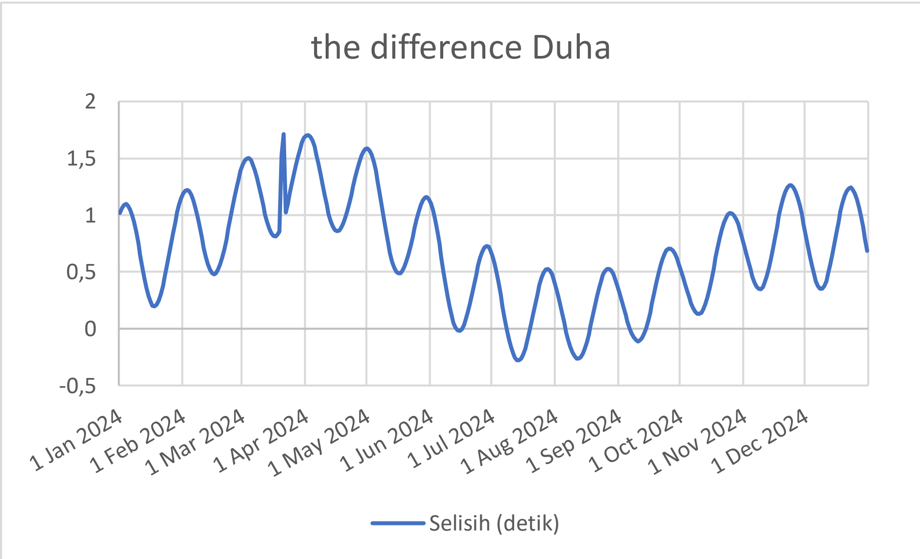


Graph 17 comparison duha ASC USNO and ephemeris



Graph 18 the difference in seconds

D. Conclusion

The U.S. Naval Observatory ASC Sun coordinate algorithm can be an alternative in calculating the beginning of prayer time. Based on tests that have been carried out by comparing the USNO ASC algorithm with the ephemeris, the results are relatively the same. From the declination value, the difference that occurs is only up to 11 seconds of arc. For the calculation of the equation of time, the comparison value is only 1 second of arc. Of the two data, the difference is no greater than 1 minute of arc. From the solar coordinate data, the prayer times of Fajr, Zuhr, Asr, Maghrib, Isha, *Thulu'*¸ and Duha are calculated using the spherical triangle theory. The difference in the results is not significant because it is only around 1 second of time. Therefore, the USNO solar coordinate algorithm is feasible to use for prayer time calculation because it is more concise while the results have no difference that will affect the beginning of prayer time.

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