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Understanding the effect of revolution and rotation of the earth on prayer times using accurate times

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Abstrak

Waktu salat erat kaitannya dengan posisi Matahari terhadap Bumi. Posisi Matahari terhadap Bumi dipengaruhi oleh revolusi dan rotasi Bumi. Tiga kota dipilih untuk melihat pengaruh revolusi dan rotasi Bumi terhadap waktu salat di berbagai belahan Bumi yaitu kota Stockholm mewakili Bumi belahan utara, kota Wellington mewakili Bumi belahan selatan, dan kota Pontianak mewakili daerah khatulistiwa. Waktu salat dihitung menggunakan perangkat lunak *Accurate Times* pada saat ekuinoks, soltis musim panas, dan solstis musim dingin tahun 2020. Lokasi yang berada di lintang tinggi akan merasakan perbedaan waktu salat yang besar sepanjang tahun disebabkan adanya perbedaan panjang siang dan malam. Perangkat lunak *Accurate Times* dapat menunjukkan perbedaan waktu salat di berbagai belahan Bumi. Daerah yang terkadang mengalami siang selama 24 jam atau mengalami malam selama 24 jam sulit dalam menentukan waktu salat. Ada dua pilihan untuk mengatasi hal ini yaitu menyesuaikan dengan negeri tetangga yang malam dan siangnya dapat dibedakan atau mengikuti waktu salat di Mekah dan Madinah.

***Kata Kunci**:* waktu salat, revolusi, rotasi Accurate Times

Abstract

Prayer time is closely related to the position of the Sun toward the Earth. The position of the Sun against the Earth is affected by the revolution and rotation of the Earth. Three cities were chosen to see the effect of revolution and rotation of the Earth on prayer times in the hemisphere, namely Stockholm city representing the northern hemisphere, Wellington city representing the southern hemisphere, and Pontianak city representing the equatorial region. Prayer times are calculated using the Accurate Times software during the equinox, summer solstice, and winter solstice in 2020. Locations in high latitudes will experience large differences in prayer times throughout the year due to differences in day and night lengths. Accurate Times software can show the prayer times difference in the hemisphere. Areas that sometimes experience day for 24 hours or night for 24 hours are difficult in determining prayer times. There are two options to overcome this problem, namely adjusting to neighboring countries where night and day can be distinguished or following prayer times in Mecca and Medina.

Keywords: prayer times, revolution, rotation, Accurate Times

Introduction

Prayer is a form of worship for Muslims and is divided into two, namely obligatory prayer and circumcision prayer. The obligatory prayers consist of five, namely Fajr, Zuhur, Asar, Maghrib, and Isha. In its implementation, the prayer time has provisions, namely an initial and final limit. Zuhr time starts when the Sun slips, which is shortly after the Sun reaches its culmination point in its daily cycle until it enters the Asar time. Asar time starts when the shadow of an object is as long as the object itself is added with the shadow at its culmination until it enters Maghrib time. Maghrib time starts when the sun sets, which is when the entire disk of the sun is invisible to the observer until it enters the Isha prayer. Isha time is marked by the fading of the red light in the western part of the sky, which is a sign of the entry of the dark night. Fajr time starts from dawn Sadik until sunrise. Prayer times are closely related to the position of the Sun on Earth.

The Sun's position is influenced by the Earth's rotation. Earth's rotation is the rotation of the Earth on its axis, which ends at the north and south poles[1]. Earth takes time to rotate on its axis for 23 hours 56 minutes 5.09054 seconds, which causes day and night[2]. The Earth rotates from west to east, causing the daily pseudo motion of the Sun. The daily pseudo motion of the Sun is the movement of the Sun that appears to be moving from east to west. In addition to causing the daily pseudo motion of the Sun, the Earth's rotation also results in day and night, time differences, the shape of the Earth is fast, and there is a difference in gravity on the Earth's surface[3].

The position of the Sun also is influenced by Earth's revolution. Earth's revolution is the movement of the Earth around the Sun for 365.25 days. The distance between the Earth and the Sun will change due to an elliptical orbit When circling the Sun. When the Earth is at the closest distance to the Sun is called perihelion. When the Earth is at its farthest distance from the Sun is called aphelion. Earth will move faster when it is closer to the Sun than when it is far from the Sun.

During the Earth's revolution, the Earth's axis of rotation is not perpendicular to Earth's orbit but is tilted to form an angle of 23,5^{o}. It causes the position of the Sun as if it is moving from north to south of the equator, and vice versa. This event is called the annual apparent motion of the Sun. Changes result in changing seasons and differences in the length of day and night in different parts of the world. The farther Sun from the equator, the greater the difference in the length of day and night. It causes the daily prayer times changing throughout the year.

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[1] Arwin Juli Rakhmadi Butar-Butar, *Waktu Shalat Menurut Sejarah, Fikih, Dan Astronomi* (Malang: Madani, 2017).

[2] HL Rahmatiah, "Urgensi Pengaruh Rotasi Dan Revolusi Bumi Terhadap Waktu Shalat," *Elfalaky: Jurnal Ilmu Falak* 1, no. 1 (2017): 59–79.

[3] Abu Yazid Raisal, "Berbagai Konsep Hilal Di Indonesia," *Al-Marshad: Jurnal Astronomi Islam Dan Ilmu-Ilmu Berkaitan* 4, no. 2 (2018): 146–55, https://doi.org/10.30596/hours.v4i2.2478.

Indonesia is located on the equator, so the difference in prayer times that is influenced by Earth's rotation and revolution is not too striking. To understand the changes in prayer times throughout the year caused by Earth's rotation and revolution, we need an application that can show the prayer times throughout the year. One such application is the Accurate Times. Accurate Times can show prayer times based on the location and time you want. Apart from that, the Accurate Times can also show the beginning of the Hijri month and convert the Gregorian date to Hijri.

Earth's Revolution

Earth surrounds the Sun as the center of the solar system for 365.25 days or one Earth year. This term is known as the Earth Revolution. The plane of Earth's orbit around the Sun is called the ecliptic. Earth is evolving in a negative direction (counterclockwise), meaning that if we are in a spacecraft just above the North Pole, then we will see the Earth circling the Sun in a counterclockwise direction. Two events can prove the motion of the Earth's revolution. Kepler's first law states that the planets move in elliptical orbits with respect to the Sun that is located at one of its focal points. The deviation of an ellipse from the circle is measured using eccentricity. The eccentricity is the ratio of the distance of the two foci to the long diameter (Major diameter) of an ellipse. The eccentricity of a circle is zero, and the eccentricity of Earth's orbit is only 0.017, so it is close to a circle[4].

When the Earth revolves, the distance between Earth and the Sun will change due to an elliptical orbit. When the Earth is at the closest distance to the Sun is called perihelion. Perihelion comes from the Greek word "purl" which means near, and "helios" which means the Sun. When the Earth is at its farthest distance from the Sun is called aphelion. Aphelion comes from the Greek word "ap" which means far away. Earth is at perihelion in January and at aphelion in July, as shown in Figure 1. Earth's perihelion distance is 146.6 million km, and Earth's aphelion distance is 152.65 million km. The average distance from the Sun to Earth is 150 million km or 1 AU (astronomical unit)[5].

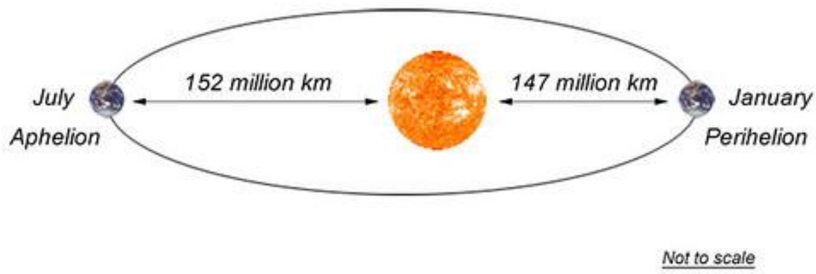


Figure 1. Earth's Closest and Farthest Distance to the Sun (https://www.infoastronomy.org)

[4] B Tjasyono, *Ilmu Kebumian Dan Antariksa* (Bandung: Remaja Rosdakarya, 2013): 4.
[5] Tjasyono: 26.

The Earth's revolution causes several events that can be felt by observers on Earth, namely the annual pseudo motion of the Sun, differences in the length of day and night, changing seasons, and different visible constellations.

1. The annual pseudo motion of the Sun

Throughout the year, the Sun is not always at the equator, sometimes in areas north of the equator and areas south of the equator. This event is known as the annual pseudo motion of the Sun. The annual pseudo motion of the Sun is limited by a latitude of 23.5^{o} N that is called the tropical Cancer and 23.5^{o} S that is called the tropical Capricorn. It is due to the effect of the tilt of the Earth's axis on the ecliptic plane of 23.5^{o}. Latitude is a line parallel to the equator.

The position of the Sun at the equator is called the equinox. The equinox occurs twice as long as the Earth goes around the Sun, namely on March 21 it is called the spring equinox, and September 23 is called the autumn equinox for the northern hemisphere. At the equinox, the length of day and night is the same 12 hours everywhere on Earth. Solar energy at the maximum equator then decreases towards the poles, and at the poles, the energy of the Sun approaches zero. The position of the Sun at 23.5^{o} N occurs on June 21, called the summer solstice and the position of the Sun at 23.5^{o} S occurs on December 22, called the winter solstice for the northern hemisphere.

The Sun will be visible at the equator on March 21 (spring equinox). Then the Sun moves northward until it reaches its maximum point on June 21 (summer solstice). The Sun moves back towards the equator until September 23 (autumn equinox). Then moves southward until it reaches its maximum on December 22 (winter solstice). Then the Sun moves northward past the equator. This back and forth motion is called the annual pseudo motion of the Sun. It is called pseudo because it is not the Sun that is moving but the Earth.

Figure 2 is an example of the annual pseudo motion of the Sun. The Sun is shot at the same location and at the same time but on a different month. From figure 2, it can be seen that the position of the Sun is different during the summer solstice, the equinox, and the winter solstice[6].

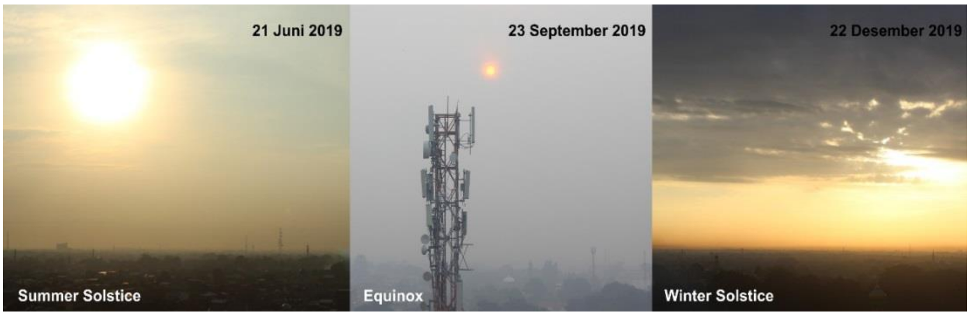


Figure 2. The Annual Pseudo Motion of the Sun

[6] Abu Yazid Raisal et al., "Posisi Matahari Pada Saat Ekuinoks , Summer Solstice , Dan Winter Solstice Di Observatorium Ilmu Falak Universitas Muhammadiyah Sumatera Utara," *Jurnal Riset Dan Kajian Pendidikan Fisika* 7, no. 1 (2020): 35–41, https://doi.org/10.12928/jrkpf.v7i1.15772.

2. The difference in the length of day and night

Daytime is calculated when the center of the Sun's disc is on the eastern horizon at sunrise to the western horizon at sunset. Figure 3 shows when the Sun rises. At the equator, the length of day and night is the same, which is 12 hours. In other latitudes, the length of day and night is not always the same. While in the polar region daytime occurs for six months and the next six months at night. The farther the place and the Sun's position are from the equator, the greater the difference in the length of day and night.

Figure 3. Sun Rise (https://www.pixabay.com)

The duration of day and night is the same in all places on Earth at 12 hours during the equinox. When the Sun moves to the north or south equator, the length of day and night will change between the northern hemisphere and the southern hemisphere. On June 21 or during the summer solstice, the Northern Hemisphere will experience daytime that is longer than the night. Even areas located above 66.5^o N to the Northpole (90^o N) will experience daytime for up to 24 hours. Meanwhile, the southern hemisphere will experience daytime that is shorter than the night. Areas located above 66.5^o S to the Southpole (90^o S) will not experience daytime for 24 hours.

On December 22, or when the winter solstice is reversed, the northern hemisphere experiences daytime that is shorter than the nights. Areas located above 66.5^o N to the Northpole (90^o N) will experience nights for 24 hours. Meanwhile, the southern hemisphere will experience daytime that is longer than the night. Areas located above 66.5^o S to the Southpole (90^o S) will not experience nighttime for 24 hours, as shown in Figure 4.

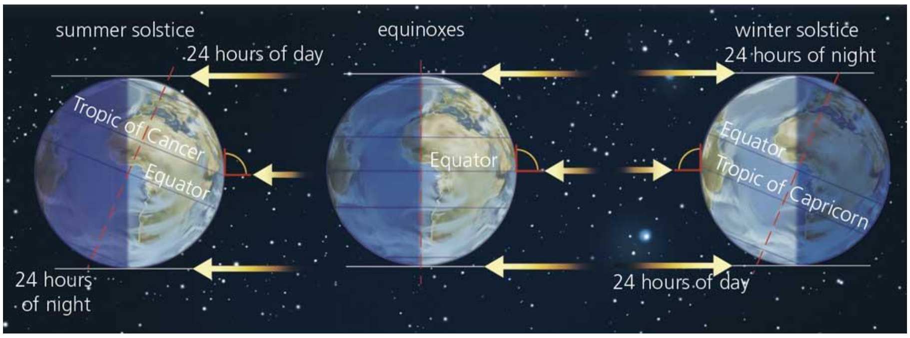


Figure 4. Length of Day and Night in the Hemisphere (https://www.blinklearning.com)

Astronomically, the duration of daylight for the equatorial region is exactly 12 hours. But it takes 3.5 minutes for the upper half of the Sun to disappear below the horizon at sunset. At sunrise, it takes 3.5 minutes before the center of the Sun's disc is on the horizon. So for areas on the equator, the length of day throughout the year is 12 hours 7 minutes[7]. Table 1 shows the duration of daytime by latitude in the northern hemisphere.

Table 1. Duration of Daytime by Latitude in the Northern Hemisphere

Latitude (degree)	Winter solstice	Equinox	Summer solstice
0	12h 0m	12h 0m	12h 0m
10	11h 25m	12h 0m	12h 38m
20	10h 48m	12h 0m	13h 12m
30	10h 4m	12h 0m	13h 56m
40	9h 8m	12h 0m	14h 52m
50	7h 42m	12h 0m	16h 18 m
60	5h 33m	12h 0m	18h 27m
70	0	12h 0m	2 months
80	0	12h 0m	4 months
90	0	12h 0m	6 months

3. Change of seasons

The difference between daytime and night duration that occurs throughout the year causes a difference in the heat received by the Earth. For areas on the equator whose daytime and night duration is relatively the same as Indonesia, there are only two seasons, namely the dry season and the rainy season. Meanwhile, areas at high latitudes have four seasons, namely spring, summer, autumn, and winter. The Earth's revolution and the tilt of the Earth's rotation axis to the ecliptic plane cause the change of seasons throughout the year, as shown in figure 5.

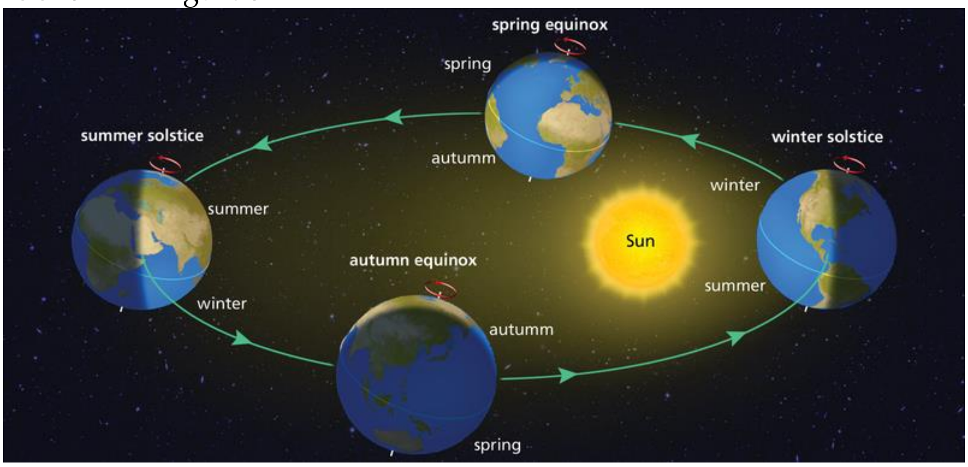


Figure 5. Change of Season Due to Earth's Revolution
(https://www.blinklearning.com)

[7] Tjasyono, *Ilmu Kebumian Dan Antariksa*: 65.

From March 21 to June 22, the north pole is increasingly leaning towards the Sun, and the south pole is further away from the Sun. It causes the northern hemisphere to experience spring and the southern hemisphere to experience autumn. On June 21, the Sun is on the solstice line, and the north pole is facing the Sun. The northern hemisphere gets more warmth than the southern hemisphere so that the northern hemisphere experiences the peak of summer and the southern hemisphere will experience winter.

Summer in the Northern Hemisphere and winter in the Southern Hemisphere last until September 23. From September 23 to December 22, the south pole begins to approach the Sun so that the northern hemisphere enters autumn and the southern hemisphere enters spring. On December 22, the south pole will be in the closest position to the Sun so that the southern hemisphere occurs in summer and the northern hemisphere occurs in winter as shown in table 2.

Table 2. Change of Seasons on Earth

Date	Northern hemisphere	Southern hemisphere
March 21– June 21	Spring	Autumn
June 21 – September 23	Summer	Winter
September 23 – December 22	Autumn	Spring
December 22 – 21 Maret	Winter	Summer

4. The constellations that look different

The stars in the sky are grouped into constellations. Each of the constellations is given a specific name according to prevailing customs. The constellations are used to make it easier to locate them on the celestial sphere. Along the ecliptic, there are 12 constellations known as the zodiac. The name of the constellation is thought to have originated from ancient Babylonia but then gradually changed due to Egyptian and Greek influences. The names of the constellations are Aries (sheep), Taurus (bull), Gemini (twins), Cancer (crab), Leo (lion), Virgo (girl), Libra (scale), Scorpio (scorpion), Sagittarius (archer), Capricorn (sea goat), Aquarius (water bearer), and Pisces (fish).

In ancient times, people divided the ecliptic into twelve parts with the same magnitude, namely 30^{o}. This division is done to make it easier to find the position of the Sun, Moon, and Planets with the stars as reference points. When the Earth circles the Sun throughout the year, the Sun appears to be in one zodiac constellation then moves to another zodiac constellation, as seen in Figure 6. Humans as observers on Earth will see different constellations because observers on Earth see from different directions.

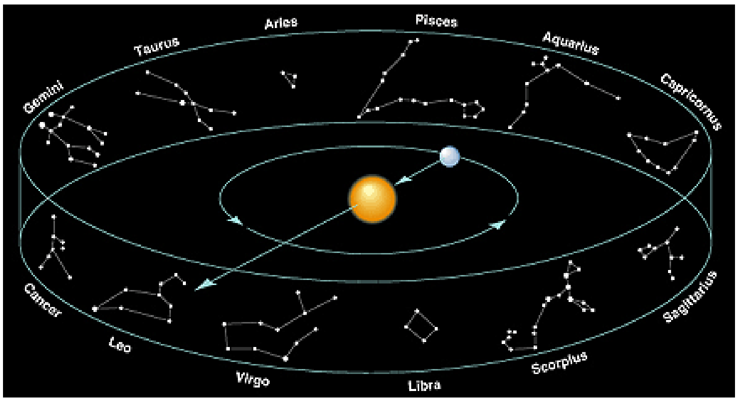


Figure 6. Effect of the Earth Revolution on the Visibility of the Constellations (https://www.quora.com)

Earth's Rotation

In addition to revolution, Earth also rotates. Rotation is the movement of the Earth on its axis, which ends at the north pole and south pole[8]. The Earth's rotation period is 23 hours 56 minutes (sidereal day) and rotates from west to east. The Earth's axis of rotation is not perpendicular to the ecliptic plane but is tilted by 23.5°. The rotation speed at the equator is about 1667 km/h. In one turn, regions that are at the equator will undergo a longer path than other areas on the Earth's surface. The distance traveled by a place will be smaller when it approaches the poles. The layers of the atmosphere closest to Earth also rotate so that observers at the equator will not feel winds at speeds of 1667 km/h. Earth's rotation results in several events such as the daily pseudo motion of celestial bodies, the occurrence of day and night, the occurrence of time differences, the shape of the Earth is fast, and the difference in Earth's gravity[9].

1. The daily pseudo motion of celestial bodies

Celestial bodies such as stars and the sun will appear to be moving up from the east then setting in the west. This event is called daily pseudo motion because it is only visible to observers on Earth. Which is moving is the Earth rotating from west to east so that the heavenly bodies appear to be appearing from east to west. The star travels its trajectory for 23 hours 56 minutes. The sun's daily pseudo motion occurs for 24 hours or one solar day. The Moon's daily pseudo motion is longer than the others namely 24 hours 50 minutes. The difference is because the position of the stars always remains in the sky. The sun has another pseudo cycle due to revolutions, while the Moon has a monthly cycle around the Earth (Moon's revolution).

[8] Mohammad Odeh, "Accurate Times," International Astronomical Center, 2019, http://www.icoproject.org/accut.html#wha.

[9] D Endang, *Kosmografi* (Yogyakarta: Ombak, 2014): 289.

2. The occurrence of day and night

The part of the Earth's surface facing and backward from the Sun will change due to the rotation of the Earth. The Earth's surface facing the Sun is daytime, and the Earth's surface facing the Sun is night. The length of day and night is not always the same on the Earth's surface. At the equator, the duration of day and night is almost the same throughout the year. While areas far from the equator, there is a difference between the length of day and night for 24 hours.

3. The occurrence of a time difference

The regular difference between day and night caused by Earth's rotation causes a difference in time on Earth. In the area that faces the sun first, the time will be faster than the area to the west. The time difference is 1 hour for every 15 degrees of longitude difference[10]. Longitude is an imaginary line connecting the north pole and the south pole. Time zones around the world are based on the 0o meridian time at Greenwich, known as Greenwich Mean Time (GMT). Indonesia that extends from 95° East Longitude to 141° East Longitude is divided into three time zones, namely Western Indonesian Time (WIB), Central Indonesian Time (WITA), and Eastern Indonesian Time (WIT), as shown in Figure 7. Standard meridian 105° East Longitude, 120° East Longitude, and 135° East Longitude, respectively, are defined as the boundaries of WIB, WITA, and WIT. WIB has a difference of +7 hours from GMT, WITA has a difference of +8 hours from GMT, and WIT has a difference of +9 hours from GMT.

Figure 7. Time Zones in Indonesia (https://www.mapsofworld.com)

4. The ellipsoid shape of the Earth

The shape of the Earth is not perfectly round but an ellipsoid like a pressed ball. It is because the Earth has rotated since the Earth was still soft. Measurements show that getting 1o near the poles is longer than at the equator.

[10] Rahmatiah, "Urgensi Pengaruh Rotasi Dan Revolusi Bumi Terhadap Waktu Shalat."

The diameter at the equator is 12.756 km longer than the diameter at the pole that is 12.714 km, as shown in Figure 8.

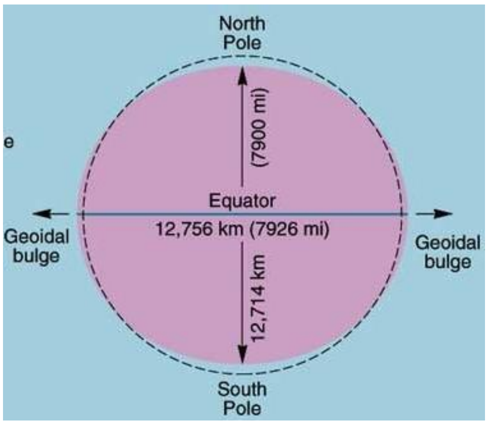


Figure 8. The Diameter of the Earth (https://www.quora.com)

5. The difference in Earth's gravity

   The magnitude of gravity is not always the same on the Earth's surface. The gravity at the poles is bigger than at the equator. It is because the poles are closer to the center of the Earth than areas on the equator. The poles do not seem to rotate with the Earth because they are right on the Earth's axis, while the places on the equator revolve around a circle the size of the Earth's circumference. This rotating force will weaken gravity.

Prayer times

Prayer is a form of worship for Muslims and is divided into two, namely obligatory prayer and circumcision prayer. The obligatory prayers consist of five, namely Fajr, Zuhr, Asar, Maghrib, and Isha. In its implementation, the time of prayer must have provisions, namely the beginning and ending limits. Prayer times are closely related to the position of the Sun on Earth[11]. The position of the Sun is a main astronomical aspect of determining prayer times because the Sun's movements change throughout the day and the year. Some of the daily data of the Sun related to determining prayer times are altitude, culmination, sunrise and sunset, refraction, low horizon, parallax, and shafaq. The altitude and culmination are related to the timing of Zuhr and Asr. Sunrise, sunset, and shafaq are related to determining Fajr, Maghrib, and Isha. Meanwhile, refraction, low horizon, and parallax are used to correct and accurate prayer times as a whole.

1. Zuhr prayer time

   The time for Zuhr prayer starts when the Sun slips, which is shortly after the Sun reaches its culmination point in its daily cycle until it enters the Asr

[11] Butar-Butar, *Waktu Shalat Menurut Sejarah, Fikih, Dan Astronomi*: 1.

prayer time. For caution and certainty when Zuhur is formulated since the entire roundabout of the Sun leaves its culmination.

2. Asr prayer times
The time of the Asr prayer begins when the shadow of an object has the same length as the object itself plus the shadow at the culmination. The Asr prayer time ends when it enters the Maghrib prayer time. In addition, some say that the Asr prayer time is halfway between the culmination and sunset.
3. Maghrib prayer time
The Maghrib prayer time starts at sunset, which is when the entire disk of the Sun is invisible to the observer until it enters the Isha prayer time. The average solar disk visible from Earth has a diameter of 32 arc minutes. In determining the time of Maghrib prayer, several corrections are needed using refraction, semidiameter, and low horizon.
4. Isha prayer time
The time of Isha prayer is marked by a fading red light on the western horizon. Astronomically, this event is known as dusk astronomical twilight, which is when the Sun's altitude is 18^{o} below the western horizon. The height of the Sun that is used as a reference for Isha prayer times is different for each Islamic organization in the world, as shown in Table 3[12].

Table 3. The Sun's Altitude for Isha Prayer Times in Several Islamic Organizations

Islamic Organizations	Sun's altitude
Western Islamic Organizations	-15 ^{o}
Muslim World League	-17 ^{o}
Egyptian General Authority of Survey	-17,5 ^{o}
‘Aisya Charity, City of Montreal Canada	-17,5 ^{o}
University of Islamic Sciences, Karachi	-18 ^{o}
JAKIM, Malaysia dan Badan Hisab dan Rukyat Dep. Agama Indonesia	-18 ^{o}
Umm Al-Qura of Saudi Arabia	-20 ^{o}

5. Fajr prayer time
The time for Fajr prayer starts from the dawn of Sadiq until the time of sunrise. Sadik dawn in astronomy is understood as the beginning of astronomical dawn. The Ministry of Religious Affairs in Indonesia sets the standard for the publication of the Sadiq dawn as the beginning of fajr prayer time when the Sun's altitude of 20^{o} below the horizon. Just like the Isha

[12] Mohammaddin et al., “Astronomical Determinations for the Beginning Prayer Time of Isha ’,” *Middle-East Journal of Scientific Research* 12, no. 1 (2012): 101–7, https://doi.org/10.5829/idosi.mejsr.2012.12.1.1673.

prayer time, there is a difference in the Sun's altitude in determining the start of Fajr time in various countries around the world, as shown in Table 4[13].

Table 4. The Sun's Altitude for Fajr in Different Countries

Convention	Sun's Altitude
Shiah Ithna Ashari (Jaafari)	-16 ^{o}
Islamic Society of North America (ISNA)	-15 ^{o}
Muslim World League (MWL)	-18 ^{o}
Umm Al-qura Makkah	-18,5 ^{o}
Egyptian General Authority of Survey	19,5 ^{o}
University of Islamic Science, Karachi	-18 ^{o}
Malaysia	-20 ^{o}

Prayer time can be determined by looking directly at the position of the Sun or seeing the shadow of an object. In addition, prayer times also can be determined by calculating. In calculating prayer times, there are two essential astronomical measures, namely the equation of time and the declination of the Sun. The equation of time is the time difference when reading a solar clock and a mechanical clock. It occurs due to the uneven movement of the Sun due to the combination of the tilt of the Earth's axis and the Earth's elliptical orbit[14]. as latitude, the longitude, meridian pass, time correction of the area, the height of the Sun, the semi-diameter of the Sun, the refraction of the Sun, the low horizon, and the height of the place[15]. In general, the data needed to calculate prayer times are as follows:

- Latitude (φ)
- Longitude (λ)
- Longitude locator (λ_d)
- Sun's Declination (δ)
- Equation of time (e)
- Meridian Pass (MP)
- Correction time area (KWD)
- The angle of time (t)
- Semi diameter of the Sun (s.d)
- Sun refraction (R')
- Low horizon (Dip)
- Sun's altitude (h)
- Height (m)

[13] Siti Asma' Mohd Nor and Mohd Zambri Zainuddin, "Sky Brightness for Determination of Fajr and Isha Prayer by Using Sky Quality Meter," *International Journal of Scientific & Engineering Research* 3, no. 8 (2012): 1–3.

[14] Nor and Zainuddin.

[15] Muhammad Hidayat, "Penyebab Perbedaan Hasil Perhitungan Jadwal Waktu Salat Di Sumatera Utara," *Al-Marshad: Jurnal Astronomi Islam Dan Ilmu-Ilmu Berkaitan* 4, no. 2 (2018): 204–18.

From the data above, in determining the time of obligatory prayer, it can be formulated as follows:

a. Zuhr prayer time = $(12-e)-\frac{(\lambda-\lambda_d)}{15}$
b. Asr prayer time = $(12-e)+\frac{t}{15}-\frac{(\lambda-\lambda_d)}{15}$
c. Maghrib prayer time = $(12-e)+\frac{t}{15}-\frac{(\lambda-\lambda_d)}{15}$
d. Isha prayer time = $(12-e)+\frac{t}{15}-\frac{(\lambda-\lambda_d)}{15}$
e. Fajr prayer time = $(12-e)+\frac{t}{15}-\frac{(\lambda-\lambda_d)}{15}$

What distinguishes between the times of Asr, Maghrib, Isha, and Fajr lies in the Sun's altitude (h). At Asr prayer time, the Sun's altitude can be calculated by the equation

$$\text{Cotan}\, h = \tan(\phi-\delta)+1$$

Meanwhile, the Sun's altitude at Maghrib is 1o below the horizon. The Sun's altitude at Isha is 18o below the horizon. The Sun's altitude at Fajr is 20o below the horizon. It depends on the policy that is believed. Calculation of prayer times can be done manually or using an application. There have been many applications that make it easier to calculate prayer times in various places, one of which is the Accurate Times.

Accurate Times

There have been many software tools that make it easy to calculate prayer times in various places, one of which is the Accurate Times. Accurate Times is the official program adopted by the Jordanian Ministry of Islamic Affairs for calculating prayer times in Jordan. This program was written by Muhammad Odeh, chairman of the Islamic Crescents' Observation Project (ICOP). This program can calculate astronomical events such as prayer time, solar time, moon time, moon phase, Qibla direction, convert the dates of the Hijri-Gregorian and vice versa, and so on. This application is used to get the most accurate results in calculating these astronomical events. When compared with astronomical almanacs, all the results obtained are the same with an accuracy of about one second, except for the Zuhr prayer time, where the maximum error is about 0.03 seconds[16].

[16] Odeh, "Accurate Times."

Method

Three cities were chosen to represent areas in the Northern Hemisphere, Southern Hemisphere, and the equator. It is done to see the effect of Earth's revolution and rotation on prayer times in the hemisphere. Stockholm city in Sweden represents the northern hemisphere with coordinates 59°19'58 "N 18°03'52" E, Wellington city in New Zealand represents the Southern Hemisphere with coordinates 41°19'00" S 174°48'00" E, and Pontianak city in Indonesia represents the equator with coordinates 0°01'12" S 109°20'24" E.

Prayer times are calculated using the Accurate Times software during the equinox, summer solstice, and winter solstice in 2020. The data required by the Accurate Times to calculate prayer times are the desired date, desired location, summertime, additional time, and altitude. The Sun is below the horizon. The Sun's altitude for the Fajr and Isha prayer times is determined to be 20° and 18° below the horizon, respectively, following the existing standards in Indonesia.

In addition to prayer time, the time when the sun rises also counted as time Sunrise is the deadline for dawn prayers. The prayer times will be compared during the spring equinox, summer solstice, autumn equinox, and winter social climate. The daytime duration of each city also is calculated using the equation.

Duration of daytime = Maghrib prayer time - sunrise time

The determination of prayer times using the Accurate Times follows the following procedures:

1. Run the Accurate Time application, and the display will appear, as shown in Figure 9.

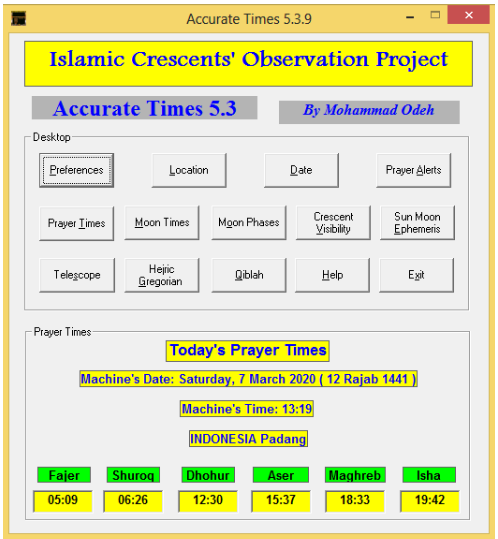
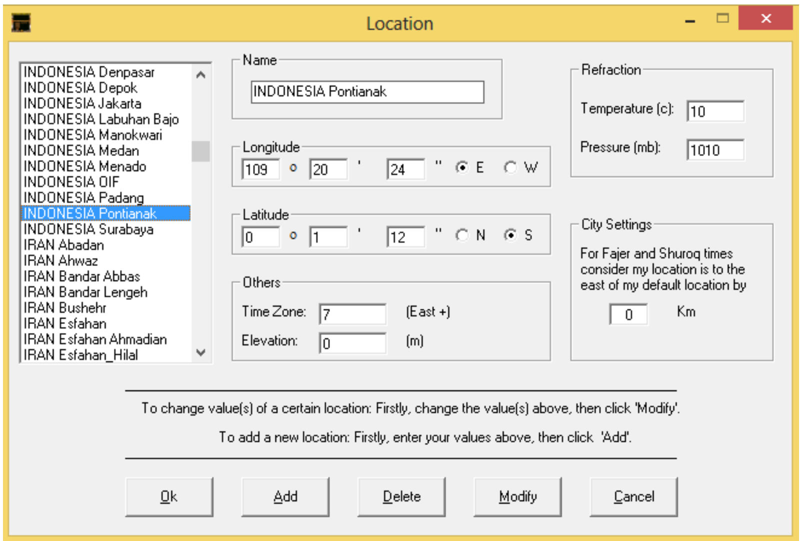


Figure 9. Accurate Times Display

2. Select the Location menu, then specify the location you want to observe, then click OK. If the location to be observed is not in the list, add a new location by

entering the coordinates of the location you want to observe, then click Add as shown in Figure 10.



Gambar 10. Location Display

3. Select the Preference menu to determine the height of the Sun. In Twilight, select Custom and fill in the Fajer angle and Isha angle with the height of the Sun below the horizon to determine the time for Fajr and Isha prayer time, as shown in Figure 11.

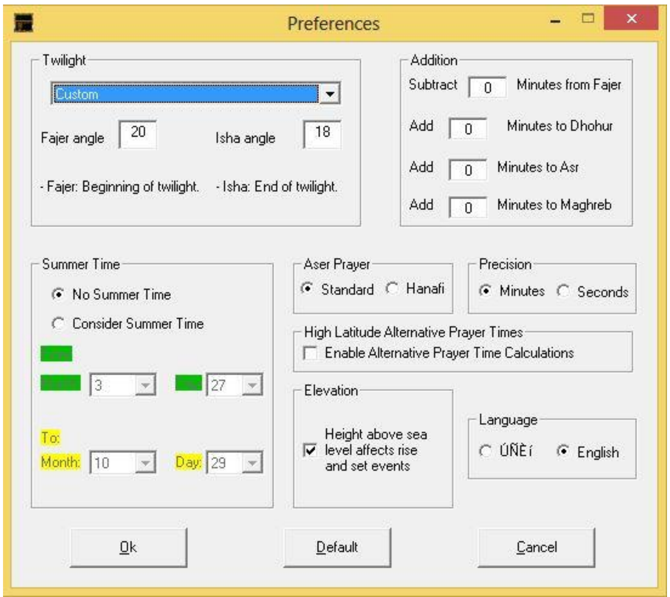


Figure 11. Preferences Display

4. Select the Date menu to determine the desired date. Select Do calculations for one day only, then fill in the date you want to find the prayer time, then click OK as shown in Figure 12.

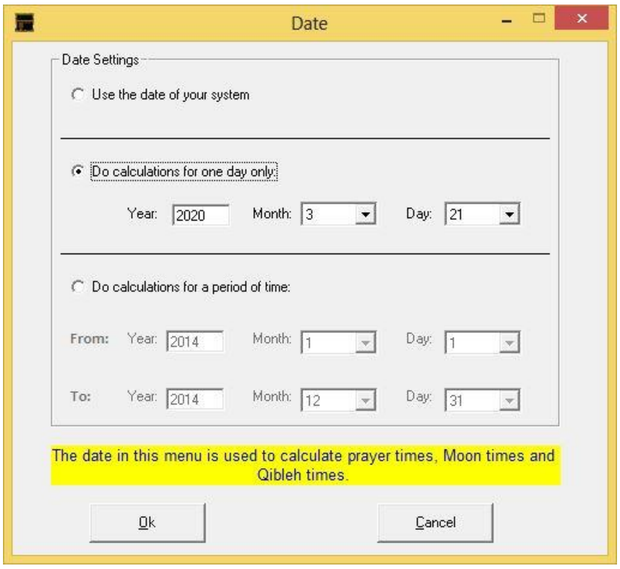


Figure 12. Date Display

5. Select the Prayer Times menu to see the prayer times on that date, as shown in Figure 13.

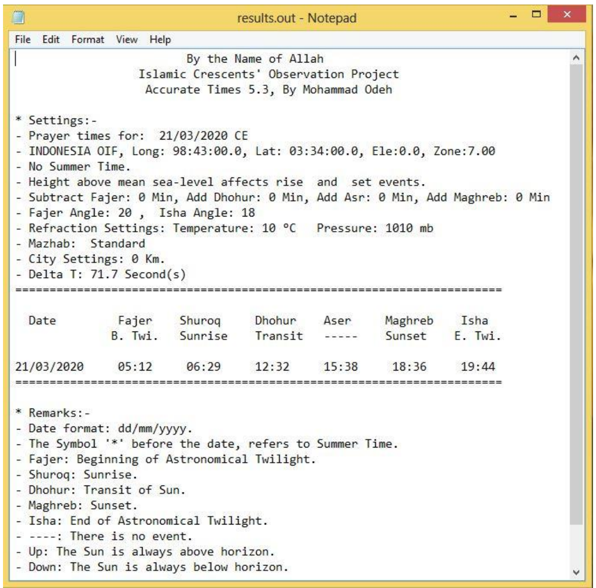


Figure 13. Display of Prayer Times from Accurate Times

Result

The locations of the cities of Stockholm, Pontianak, and Wellington on the world map are shown in Figure 14. Stockholm, Pontianak, and Wellington are shown respectively by red, yellow and green arrows. Prayer times adjust to the time zone of each city. Stockholm City has a time zone of +1 GMT, Pontianak city has a time zone of +7 GMT, and Wellington city has a time zone of +12 GMT. The three cities have a positive value (+) from GMT that indicates that they are located in the east of Greenwich city. The selection of the three cities was not based on longitude but based on latitude.

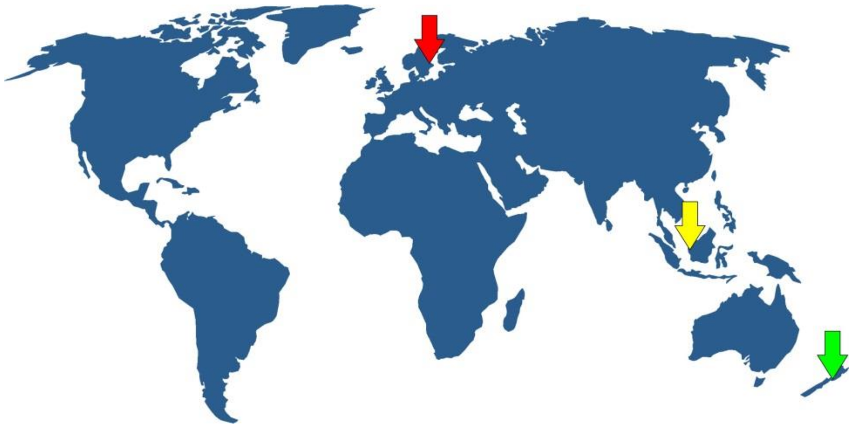
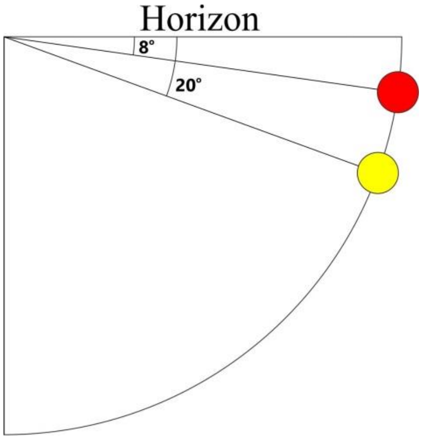


Figure 14. Location of Stockholm, Pontianak, and Wellington on the world map

Table 5. Prayer Times in Stockholm City

Prayer times	21/3/2020	21/6/2020	23/9/2020	22/12/2020
Fajr	03:03	bright	02:53	05:46
Sunrise	05:44	02:28	05:33	08:41
Zuhr	11:55	11:50	11:40	11:47
Asr	15:05	16:30	14:46	12:44
Maghrib	18:07	21:12	17:45	14:52
Isha	20:29	bright	20:05	17:30

Table 5 shows the prayer times in the city of Stockholm during the spring equinox, summer solstice, autumn equinox, and winter solstice. During the spring equinox, Fajr prayer time in the city of Stockholm is 03:03 local time. Not much different from the Fajr prayer time during the autumn equinox that occurs at 02:53 local time. There is a 10 minutes difference between the Fajr prayer times during the spring equinox and the autumn equinox. It is due to the different time averaging values on that date so that the Fajr prayer times are not the same even though the Sun is both right at the equator. During the summer solstice, the Fajr prayer time shows the word bright. It is because the city of Stockholm is at $5^{9o}19'58$ "North Latitude, so the height of the Sun at the lower peak is around 8^{o} below the horizon, while the Sun's height for the Fajr prayer time is determined to be 20^{o} below the horizon as shown in Figure 15. The red circle shows the Sun's height at the lower culmination, while the yellow circle shows the limit for the height of the Sun for Fajr prayer, which is 20^{o} below the horizon. The sky in Stockholm city will remain influenced by the Sun's light refracted by the atmosphere even though the Sun has set until the Sun rises again. The same thing happened in the evening prayer.



Gambar 15. The Sun's Altitude at the Lower Culmination during the Summer Solstice in Stockholm City

There are different views among scholars to overcome this problem. Some scholars say that the five obligatory prayer times for areas near the poles are adjusted to neighboring countries with moderate lengths of night. Meanwhile, some other scholars argue that the determination of prayer time has to be adjusted to the prayer times in Mecca and Medina[17]. With the Sun's declination value of -23.5^{o} and + 23.5^{o}, then areas that are above 66.5^{o} North Latitude and above 66.5^{o} latitude will have a time of experiencing daytime for 24 hours or vice versa at night for 24 hours. The day starts when the Sun is 0^{o} in the east, and night begins when the Sun is 0^{o} in the west. Meanwhile, in determining the Fajr and Isha prayer time, the height of the Sun is 20^{o} and 18^{o} when referring to the Ministry of Religious Affairs in Indonesia. It causes areas that are above 46.5^{o} North Latitude and 46.5^{o} South latitude at one time will be hard to determine the Fajr and Isha prayer time.

During the winter solstice, the Fajr prayer time is shown to be longer than during the equinox and summer solstices, which is 05.46 local time. It is because during the winter solstice, Stockholm city, which is in the northern hemisphere, experiences winter so that the duration of the night is longer than daytime that results in longer Fajr prayer times. Other prayer times also show a big difference between the winter and summer solstices except for Zuhr prayer times. Among other prayer times, the Zuhr prayer times are not much different on these four days, although the duration of day and night changes throughout the year.

Table 6 shows the prayer times in Pontianak city during the spring equinox, summer solstice, autumn equinox, and winter solstice. The duration of daytime and night is the same throughout the year in Pontianak city. It is because the city of Pontianak is at the equator so that the resulting prayer times are not

[17] Odeh.

much different every day. Even though the Sun is at the northernmost point or the southernmost point, it does not change the duration of daytime and night. The difference in prayer times is due to the time averaging values that change throughout the year.

Table 6. Prayer Times in Stockholm City

Prayer times	21/3/2020	21/6/2020	23/9/2020	22/12/2020
Fajr	04:30	04:17	04:15	04:14
Sunrise	05:47	05:41	05:32	05:37
Zuhr	11:50	11:44	11:35	11:41
Asr	14:51	15:10	14:35	15:07
Maghrib	17:53	17:48	17:38	17:45
Isha	19:02	19:03	18:47	19:00

Table 7 shows the prayer times in Wellington city during the spring equinox, summer solstice, autumn equinox, and winter solstice. During the spring equinox, Fajr prayer time in Wellington city is 04:41 local time. Not much different from the Fajr prayer time during the autumn equinox that occurs at 04:25 local times. There is a 16 minutes difference between the Fajr prayer times during the spring equinox and the autumn equinox. The difference is due to the different time averaging values on that date so that the Fajr prayer times are different even though the Sun is both rights at the equator. During the summer solstice, the Fajr prayer time is longer than during the equinox, which is at 05:56 local time. It is because Wellington city in the Southern Hemisphere experiences winter so that the duration of the nighttime is longer than the daytime.

During the winter solstice, the Fajr prayer time is shown earlier than the equinox and summer solstices, which is 02:14 local time. It is because Wellington city in the southern hemisphere experiences summer during the winter solstice so that the duration of the daytime is longer than the nighttime that results in earlier Fajr prayer times. Even though it is winter, Fajr prayer time in Wellington city still can be detected in contrast to the city of Stockholm that shows the word "bright" during Fajr prayer. It is because Wellington city has latitude 41^{o}19'00" S, is lower than Stockholm city of that has a latitude of 59^{o}19'58" N. So that the Fajr prayer time in Wellington city still can be detected. Other prayer times also show a big difference between the winter and summer solstices except for Zuhr prayer times. Among other prayer times, the Zuhr prayer times shown are not much different on the four days, although the duration of day and night changes throughout the year.

Table 7. Prayer Times in Wellington City

Prayer Times	21/3/2020	21/6/2020	23/9/2020	22/12/2020
Fajr	04:41	05:56	04:25	02:14
Sunrise	06:24	07:47	06:09	04:44
Zuhr	12:28	12:23	12:13	12:19
Asr	15:52	14:41	15:39	16:21

Maghrib	18:31	16:58	18:18	19:54
Isha	20:03	18:38	19:51	22:04

Table 8 shows the daytime durations for the cities of Stockholm, Pontianak, and Wellington during the spring equinox, summer solstice, autumn equinox, and winter solstice. The duration of the daytime is obtained by subtracting the Maghrib prayer time that coincides with sunset and sunrise.

Table 8. The Duration of Daytime in Stockholm, Pontianak, dan Wellington

Location	21/3/2020	21/6/2020	23/9/2020	22/12/2020
Stockholm	12h 23m	18h 43m	12h 12m	6h 10m
Pontianak	12h 6m	12h 7m	12h 6m	12h 7m
Wellington	12h 6m	9h 11m	12h 9m	15h 10m

On March 21 and September 23, 2020, or at the equinox, the duration of daytime for the three cities is not much different, which is around 12 hours. On June 21, 2020, during the summer solstice for the Northern Hemisphere, the duration of daylight for the three cities looks very different. It is because the north pole reaches its closest position to the sun so that the northern hemisphere experiences summer and the southern hemisphere experiences winter. Stockholm city in the northern hemisphere experiences summer and has the longest daytime duration of 18 hours 43 minutes. Wellington city in the southern hemisphere experiences winter and has the shortest daytime duration of 9 hours 11 minutes. Pontianak city that is at the equator experiences the duration of daytimes is around 12 hours. On December 22, 2020, during the winter solstice for the northern hemisphere, the south pole reaches its closest position to the sun so that the northern hemisphere experiences winter and the southern hemisphere experiences summer. Stockholm city in the northern hemisphere experiences winter and has the shortest daytime duration of 6 hours and 10 minutes. Wellington city in the southern hemisphere experiences summer and has the longest daytime duration of 15 hours 10 minutes. Meanwhile, the duration of daytime in Pontianak city that is at the equator is 12 hours 7 minutes.

Conclusion

Prayer times refer to the position of the Sun from before rising to after setting. Muslims in Indonesia do not feel the difference in prayer times throughout the year because they are located on the equator. Meanwhile, locations at high latitudes will experience a big difference in prayer times throughout the year due to differences in the length of day and night. Even for areas around the poles, sometimes they cannot see the Sun for 24 hours or always see the Sun for 24 hours. It is influenced by the revolution and rotation of the Earth throughout the year. Accurate Times application can show the prayer times difference in the hemisphere. With the Sun's declination value of -23.5^{o} and $+ 23.5^{o}$, then areas that are above 66.5^{o} north latitude and above 66.5^{o} south latitude will have a time of experiencing daytime for 24 hours or experiencing nighttime for 24 hours. The day starts when the Sun is 0° in the east, and night begins when the Sun is 0° in the west. When referring to the Ministry of Religious Affairs in Indonesia in determining the time of Fajr and Isha, the Sun's height is 20° and 18° below the horizon. It causes it to be hard to determine the time for Fajr prayer and the time for Isha prayer at an area that is above 46.5° north latitude and 46.5° south latitude. There are two options to overcome this problem, namely adjusting to neighboring countries where night and day can be distinguished or following prayer times in Mecca and Medina.

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