Introduction

The MoonandSun is a software for calculating position of Sun and moon in the observer’s sky. You can find rising setting and transit times for sun and moon. Tables of phases of moon during a year and lunar based Hijri months can be created.

Also, you can create Gregory, Iranian calendars of sun, moon times or Islamic prayer times.

All calculation is based on precise equations from " Astronomical Algorithms" by Jeen Meeus, NOVAS Fortran software from Naval Observatory Vector Astrometry Software and SOFA Fortran software libraries from International Astronomical Union.

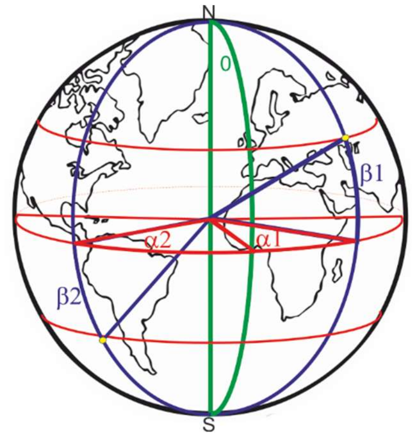
Kind of user friendly panel created with C# , so user can easily input data, modify them or change parameters.

Please send your comments to:

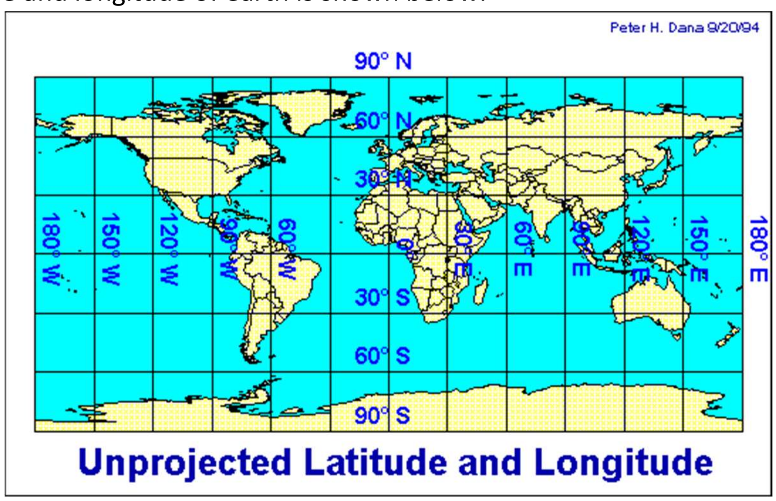
Amin Khiabaniaminkhiabani@outlook.com

Geographical Coordinates

To specify location of any point on planet earth, geographical coordinates system is used. Usually a set of three numbers represent any location.

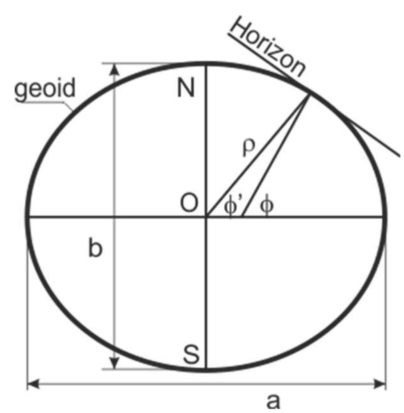


- Longitude is angle between reference or 0.0 meridian, green color in picture, and meridian passing through point. Meridian are hypothetical circles passing through north and south poles of earth. Meridian passing through Greenwich (London) is reference meridian. Longitudes of meridian east of reference meridian ($\alpha 1$) are positive numbers from 0.0 to 180.0 degrees, and the ones at west of reference meridians ($\alpha 2$) are negative numbers ranging 0.0 to -180.0 degrees.
- Latitude is angle between equator and any circle parallel to equator which passes through the point. Latitudes are positive angles from 0.0 to 90.0 degrees at North hemisphere ($\beta 1$) and negative numbers ranging 0.0 to -90.0 degrees ($\beta 2$) at south hemisphere. Un-projected latitude and longitude of earth is shown below.



- Elevation or altitude is difference of height of and point and sea level in meters.

Planet earth is not a perfect sphere one does not consider irregularities of surface, it is more ellipsoid which is called *geoid*. Any cross section of this geoid along any meridian, will show a long axis at equator, a, and short axes from north to south pole, b. Assume f is flattening of earth.



$\varphi' = geocentric\ latitude\ of\ center\ O$

From IAU 2009 System of Astronomical Constants:

$$a = 6378136.6$$

$$f = \frac{a-b}{a} = \frac{1}{298.25642}$$

$$\frac{b}{a} = 1 - f = 0.99664718$$

From Jean Meeus "Astronomical Algorithms" we have: At poles and equator $\varphi = \varphi'$. For all other latitudes: $|\varphi| < |\varphi'|$.

Assume *H* is height above sea level in meters. The following are needed for astronomical calculations.

$$\tan u = \frac{b}{a} \tan \varphi$$

$$\rho \sin \varphi' = \frac{b}{a} \sin u + \frac{H}{6378136.6} \sin \varphi$$

$$\rho \cos \varphi' = \frac{b}{a} \cos u + \frac{H}{6378136.6} \cos \varphi$$

Difference between geographical latitude and geocentric latitude reaches to its maximum at latitude 45 degrees. Which is 11' minutes and 32.73" seconds.

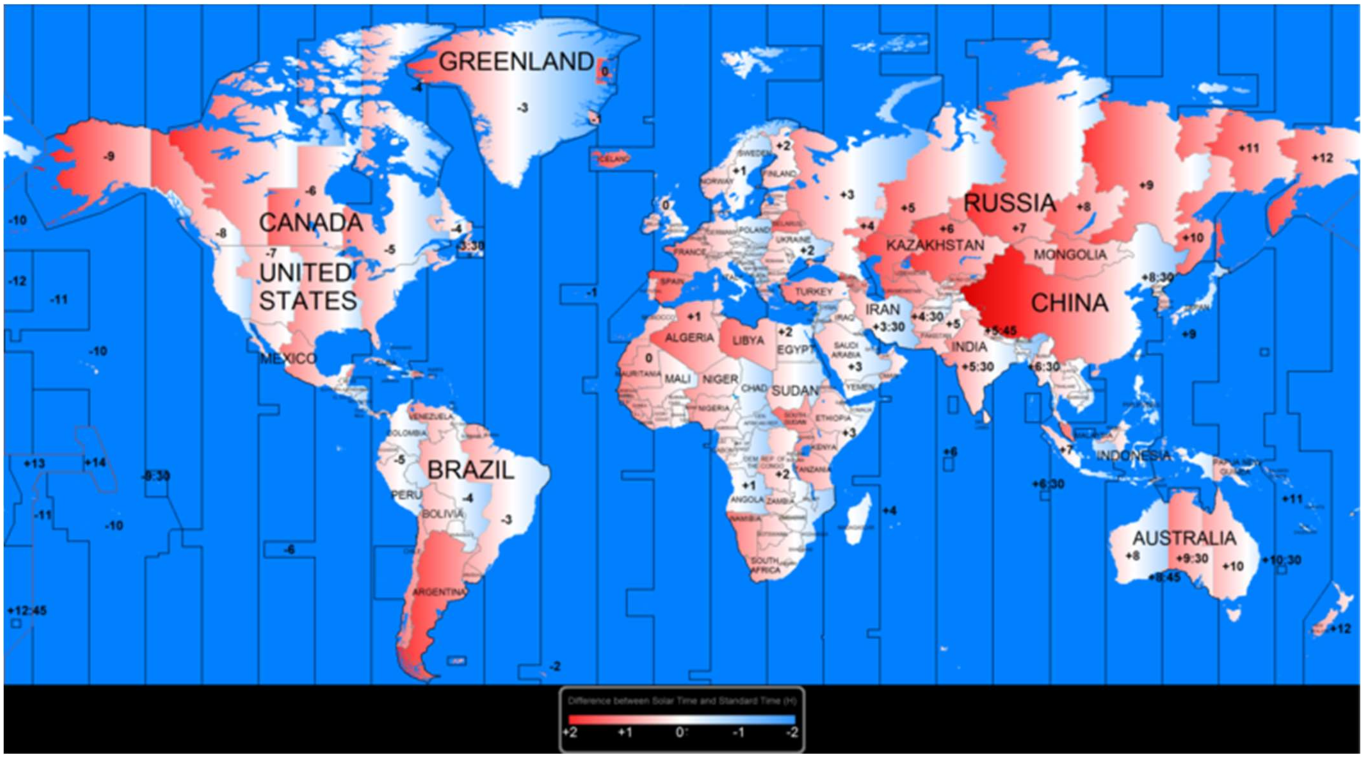
$$\varphi - \varphi' = 692.73 \sin(2\varphi) - 1.16 \sin(4\varphi)$$

References:

1- Astronomical Algorithms, Jean Meeus.
2- IAU 2016 System of Astronomical Constants
3- [Map projections overview.]()

Time Zone

A time zone is a region which has the same standard time. Earth rotates about its axes in 24 hours, therefore rotation of every 15 degrees of longitudes takes 1 hour to complete. Assume at location “A” with longitude of “a“ degrees, time zone is set in a way that transit of sun (Noon) occurs at 12.0 O’ clock. With same time zone, for location “B” with longitude of “ $a \pm 15.0$” degrees west of point “A” noon will occur at 1.0 O’clock. Human activities mostly coordinated with sun light, therefore, geographical areas within 15 degrees, usually have same, time zone. Official time zone is also time difference of reference 0.0 meridian (London, Greenwich) and any location.



Political map showing how a great part of the world has a gap between the official time and the solar. [Wikipedia]

Reference: [Wikipedia]

Solar Coordinates

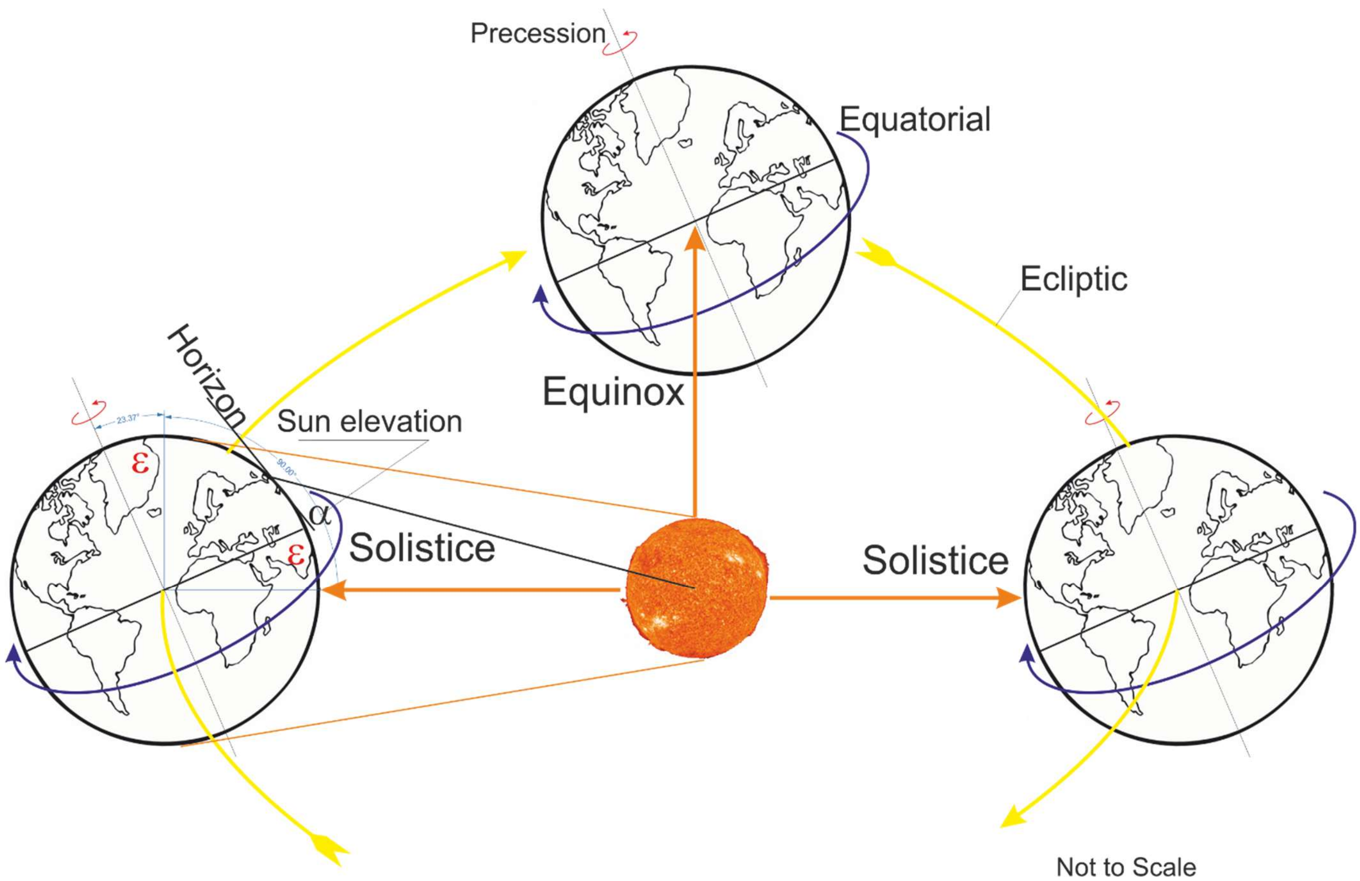
Position of sun in observer's horizon is sum of three main movement or rotation:

1- Rotation of planet earth around sun. Earth rotate around the Sun at mean distance of one Astronomical unit, which according to IAU Astronomical Constance, is: au = 149597870700 m. During one complete revolution around the Sun, which takes one year, distance varies. The plane of rotation with sun at one of the centers is called ecliptic.

2- Rotation of planet earth around its own axes, which causes, day and night. The plane of this rotation which is equator, makes an angle with plane of ecliptic. This angle is called obliquity of ecliptic, and it is:

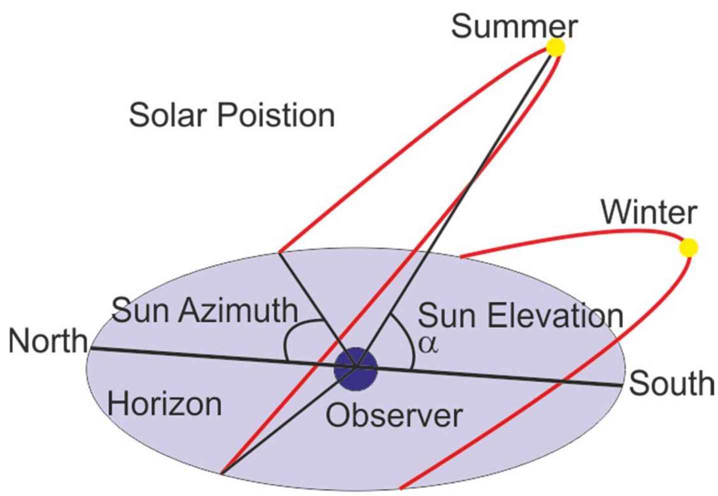
Mean obliquity of the ecliptic: $_{J2000}$ 23° 26' 21.406" = 84381.406"

3- Precession and nutation. Precession is the rotation of axes of earth rotation. It is like rotation of axes spinning top. Precession has period of 26000 years. It changes ecliptic angle.
Nutation is periodic oscillation of axes of earth rotation.



These rotations and ecliptic angle causes day and night and seasonal changes. During winter of Northern hemisphere, sun shines more direct to southern hemisphere, (left side of diagram). At Northern hemisphere sun rays are more oblique and it does reach higher latitudes. At summer of northern hemisphere, it is vice versa. Sun shines more directly at northern hemisphere and sun rays reach to all latitudes. At equinoxes (Spring and Autumn) Sun rays equally reach both hemispheres.

From observers view, sun goes to higher elevations (Angle α) at summer time than winter time, and stays longer at sky.



Based on “Astronomical Algorithms” in NREL technical report, “Solar Position Algorithm for Solar Radiation Applications” by Ibrahim Reda and Afshin Andreas, step by step describes how to find position of sun and calculate times of sunrise, sunset, and transit(Noon).

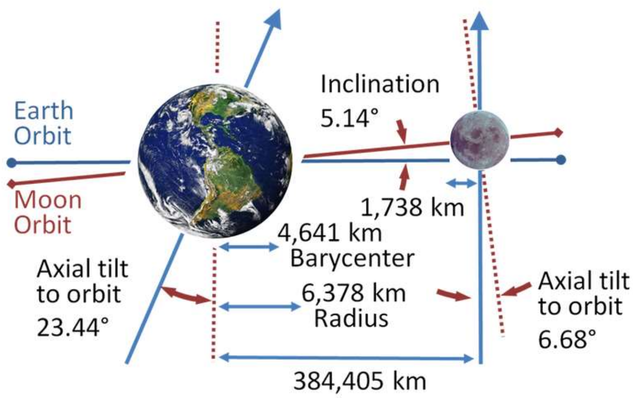
The same procedure is used for this software, with these exceptions. For obliquity of ecliptic instead of Jean Meeus data, ETILT subroutine from NOVAS package is used also, for nutation, NOD subroutine from NOVAS package is used. To find difference of UT and TT software from SOFA package is used. For effect of atmospheric refraction, Saemundsson method from university of Iceland is used. To find exact rise and set times, after interpolation as descried in “Astronomical Algorithms”, more precise location of sun calculated by iteration.

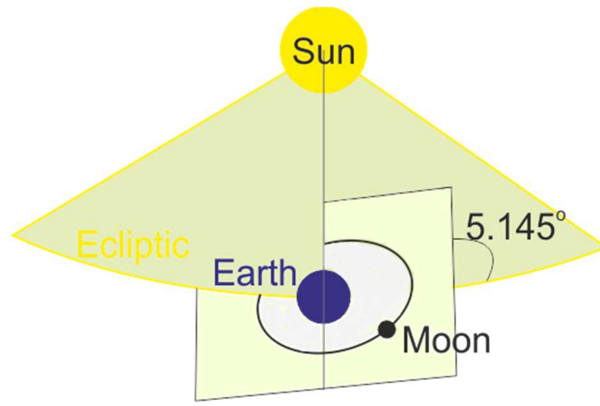
References:

1- NREL technical report, “Solar Position Algorithm for Solar Radiation Applications” by Ibrahim Reda and Afshin Andreas
2- IAU Standards of Fundamental Astronomy.
3- Naval Observatory Vector Astrometry Software (NOVAS)

The Moon

Natural satellite of plant earth, the Moon, rotate around its axes and around earth in such a synchronized way that, people on earth can see only one side the Moon. Moon orbit around earth takes 27.321661 days. Moon orbit is an eclipse with nearest distance(Perigee) of 362600 km and furthest distance of 405400 km. Moon rotation around its own axes also takes 27.31661 days, that is why we can see only one side of the Moon. Moon equatorial radius is 1738.1 km and its polar radius is 1736.0 km. Moon plane of orbit has angle of 5.145 degrees with plane of earth ecliptic. Moon axial tilt to moon plane of orbit is 1.5425 degree.





Source of picture: [Wikipedia, Moon]

Position of Moon

To find position of the Moon for observer on any location of earth, we have used algorithms from Jean Meeus book "Astronomical Algorithms". The accuracy of results is within 10 seconds of longitude of moon and 4 seconds of latitude of moon which are good for are purposes. Using these equations, we find geocentric (observer at center of earth) longitude and latitude of center of the moon, referred to mean equinox of the date. By calculating apparent sidereal time and equatorial horizontal parallax of the moon and transformation of coordinates, we find topocentric position of the Moon for any location on planet earth.

To find these first we have to find Moon's mean longitude, referred to the mean equinox of date, L', mean elongation of the Moon, D, Sun's mean anomaly M, Moon's mean anomaly, M', Moon's argument of latitude (Mean distance of the Moon from ascending node), F.

To get desired precision, effect of 120 correction term on above items considering effect of eccentricity, E, on correction terms and 3 more arguments, should be incorporated in calculations.

More precise calculations of NOVAS, VSOP87 or VSOP2013 rely on ephemerides file or data files.

Visibility of The Moon

As already mentioned rotation of the Moon around earth takes 27.321661 days, but for observer on earth, because of rotation of earth around sun, it takes 29.530587 days.

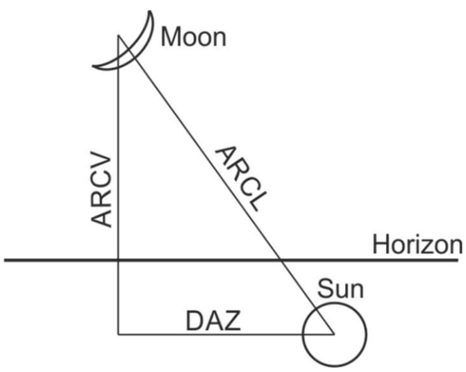
$$\frac{1}{T_{synodic}} = \frac{1}{T_{Moon}} - \frac{1}{T_{Era}}$$

$$\frac{1}{T_{synodic}} = \frac{1}{27.32166} - \frac{1}{365.256363}$$

By solving equation, $T_{synodic}$ = 29.30587 which is called lunar month. During lunar month, due to position of the Moon and Earth, part of the Moon will be illuminated by the Sun. This is called phases of the Moon. The times of new Moon, first quarter, full moon and last quarter are at which the excess of apparent geocentric longitude of the Moon over apparent geocentric of the Sun is 0, 90, 180 and 270 degrees. Instead we have use procedure from "Astronomical Algorithms" which gives times of phases of the moon with mean error of 3.72 seconds and maximum error of 17.4 seconds. Also, we have use illuminated fraction of the Moon.

Visibility of new moon is an important issue for declaring new months in lunar calendars. Important astronomical parameters which affect visibility of new lunar month are:

- **Age,** which is the time difference of time of astronomical new moon (conjunction of moon and sun) and time of first visit of new crescent. With this software, we can find time of new moon with precision of 3.7seconds to maximum error of 17.4 seconds and of time of any sunset after new moon. Minimum age of 13.5 hours for aided sighting of new crescent, and 17.0 hour for naked eye sighting of new crescent is considered.
- **Lag,** time difference of the Moon set and Sunset. Minimum lag of 21.0 minute for aided crescent sighting and 30.0 minutes for naked eye sighting is considered.
- **Elevation of crescent,** at time of sunset + 4/9 lag time, elevation of crescent is calculated.
- **Difference of azimuth angle of center the Sun and center of Moon crescent, DAZ**
- **Difference of altitude of center of sun and center of crescent, ARCV.**
- **Angular separation of Sun and Moon crescent, ARCL.**
- **Crescent width, the width of the lit area of the Moon measured along the Moon's diameter, W.**



Visibility of new moon has been investigated by many. Two recent method are to check visibility of moon crescent.

1- "A Method for Predicting the First Sighting of the New Crescent Moon", by BD Yallop. In this method quantity q calculated by: $q = (ARCV - (11{\cdot}8371 - 6{\cdot}3226\, W' + 0{\cdot}7319\, W'^{\,2} - 0{\cdot}1018\, W'^{\,3})) / 10$
where W' is topocentric width of crescent, which is calculated as: $W' = SD' (1 - \cos ARCL)$ where SD' is topocentric diameter of the Moon. New moon crescent criteria as following:

$q > +0{\cdot}216$	Easily visible (ARCL $\geq 12°$)
$+0{\cdot}216 \geq q > -0{\cdot}014$	Visible under perfect conditions
$-0{\cdot}014 \geq q > -0{\cdot}160$	May need optical aid to find crescent
$-0{\cdot}160 \geq q > -0{\cdot}232$	Will need optical aid to find crescent
$-0{\cdot}232 \geq q > -0{\cdot}293$	Not visible with a telescope ARCL $\leq 8{\cdot}5°$
$-0{\cdot}293 \geq q$	Not visible, below Danjon limit, ARCL $\leq 8°$

2- "NEW CRITERION FOR LUNAR CRESCENT VISIBILITY" by MOHAMMAD SH. ODEH. In this method quantity v calculated by: $V = ARCV-(-0.1018W3 +0.7319W2 -6.3226W +7.1651)$
Where W is topocentric width of crescent

$V \geq 5.65$ Crescent is visible by naked eyes.

$2 \leq V < 5.65$ Crescent is visible by optical aid, and it could be seen by naked eyes.

$-0.96 \leq V < 2$ Crescent is visible by optical aid only.

$V < -0.96$ Crescent is not visible even by optical aid.

References:

1- Astronomical Algorithms" by Jean Meeus

2- رویت هلال ماه – آشنایی با مقدمات نجومی استهلالی دکتر چمشید قنبری و محمد مهدی مطیعی

3- روش پیشبنیوضع رویت هلال ماه در ایران . محمد رضا صیاد

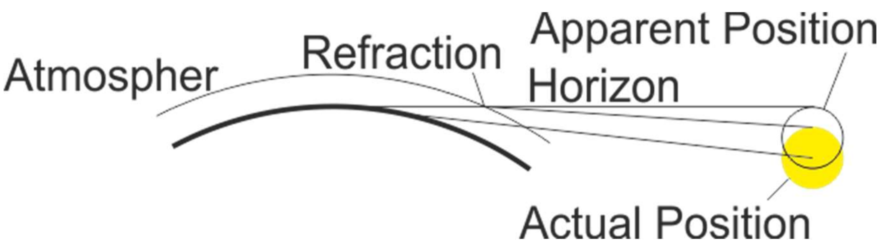
4- Wikipedia, Moon

5- A Method for Predicting the First Sighting of the New Crescent Moon", by BD Yallop

6- NEW CRITERION FOR LUNAR CRESCENT VISIBILITY by MOHAMMAD SH. ODEH

Atmospheric Refraction

When enter in its pass light rays enters different medium, because of different transmittance property of material, it refracts or bends. The same phenomena happen when light from outer space enters earth atmosphere. Refraction of light get its highest value at rise and set, because it must pass more distance in atmosphere. Refraction of light causes observers to see rise earlier than when if it there were not any atmosphere, and to see set time later than no atmosphere. It also causes flatness of sun and moon at rise and set.



Saemundsson equation is used to find apparent location of sun or moon.

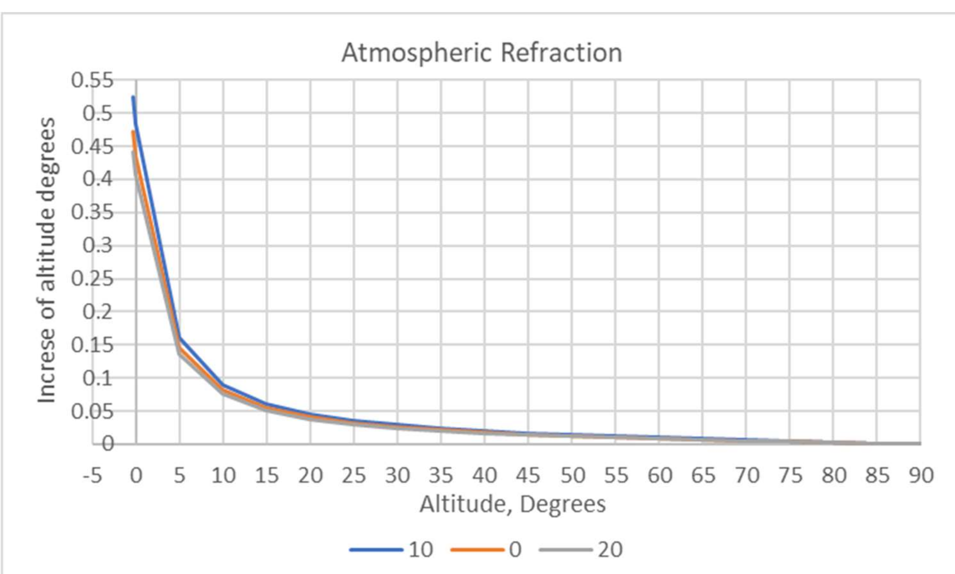
$$R = \frac{1.02}{\tan\left(h + \frac{10.3}{h + 5.11}\right)}$$

Where h is true altitude in degrees.

Atmospheric properties which affect refraction and considered in mathematical models are, temperature and pressure. Therefore

$$R \times \frac{P}{1010} \times \frac{283}{273 + T}$$

Where P is atmospheric pressure, millibar and T is temperature in centigrade. Lower the pressure like high elevations, or higher the temperature such as warm climates, less effect of refraction. Humidity also affects atmospheric effects, but it is not considered in this simplified model. Graph of atmospheric effect for pressure of 1010 millibar and temperature of 10 degree Celsius, pressure of 880 millibar and temperatures of 0 and 20 degrees Celsius, presented here.



To find atmospheric pressure and temperature, two atmospheric models are used, Standard atmospheric model, which, atmospheric temperature and pressure decreases as elevation increases. In troposphere, in every kilometer increase of elevation, temperature drops 6.5 degrees. It is independent of latitude, longitude and date.

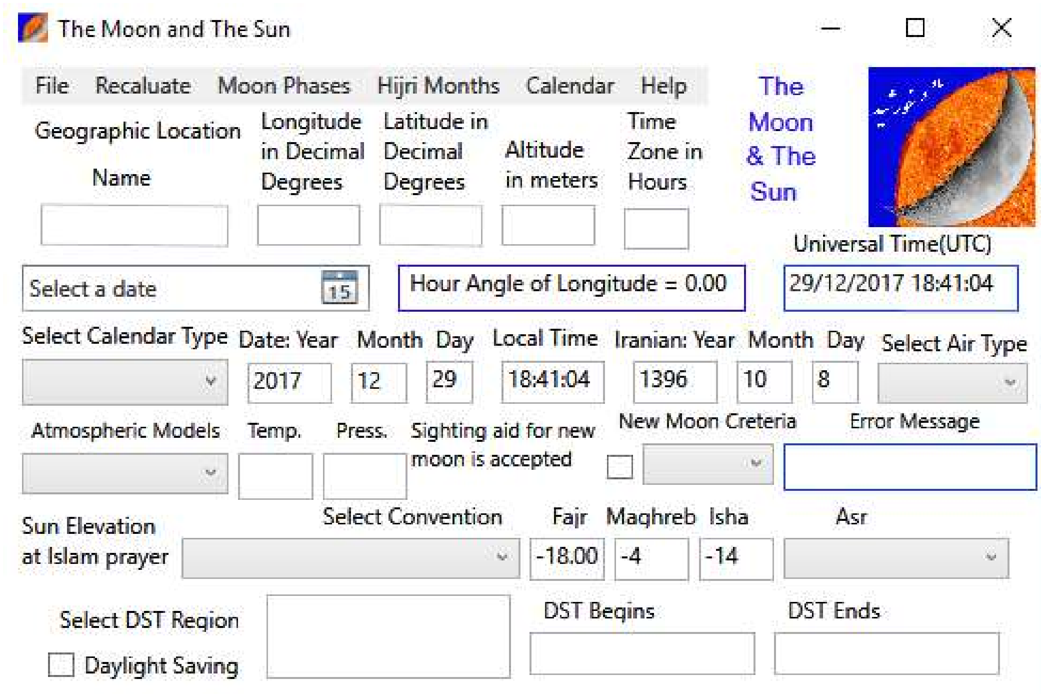
Other model is MSISE model which is empirical model based on data. Pressure and temperature depend on date, latitude, longitude and elevation.

Iranian Calendar

Iranian calendar is solar based calendar. New year time is spring equinox. For centuries astronomers and scholars , worked on tables to predict, which year is leap year. The result is an accurate calendar. However, with precise mathematical models of sun movement, predicating, equinoxes within reasonable precision is readily available. Iranian leap year rule is “leap year is the year that equinox happens before noon and next year equinox happens after noon”. Therefore, it is not difficult task to check consecutive years to see, when leap year rule happens. Iranian leap years interval is usually 4 years, but when spring equinox happen very close to noon, interval became 5 years.

Using Software

This is input panel:



Geographic Coordinate

Please enter geographical location coordinates as decimal degrees in corresponding boxes. For longitude of locations east of 0.00 or reference meridian, enter positive numbers 0.00 to 180.00, and for longitude of locations west of reference meridian enter negative decimal numbers 0.00 To -180.00 For latitude of northern hemisphere enter positive numbers from 0.00 to 90.00 degrees and, for southern hemisphere enter negative numbers 0.00 to -90.00 degrees. Elevation in meters above sea level from -29.0 to 9000.0 meters. To find geographical coordinates of any location, please check any of these websites.

www.gps-coordinates.net

http://elevationmap.net

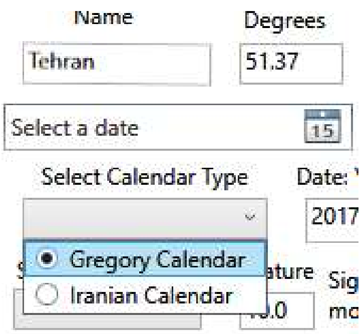
www.bahesab.ir/map/geographic

Time Zone

Rotation of planet earth takes approximately 24 hours to complete, therefore every 15 degrees of longitude take one hour. So, a location at longitude of 45.0^{o} degrees has 3 hours' time difference with reference meridian. Usually places within one-hour difference are in one-time zone, but administrative areas may have different time zone than calculated one, therefore to find time zone of any desired location please time zone map at www.timeanddate.com website.

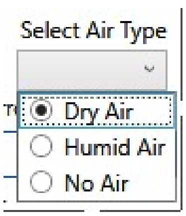
Date and Time

At startup program gets date and time of computer for its calculations. You can change date and time directly typing at date or time boxes. Two types of calendar included, Gregory Calendar and Iranian calendar. Gregory Calendar is default, but if you select any type and save location, it will be saved as default type. In case of Gregory calendar, you can change date by change calendar drop down button. After changing time or date, click Recalculate to see the results. If you have selected Gregory calendar, you an change Gregory date, and for Iranian calendar, you can change Iranian date.



Atmospheric Refraction

Atmosphere affects rise and set times of moon and sun, also visibility of new moon. Three conditions considered. Dry air for arid areas, or if sighting new moon with aid such as binocular or telescope is accepted. Wet air for humid air and naked eye sighting of new moon. No air when effect of air is not considered. Pressure and temperature of air affects atmospheric effects. To select click on "Select Air Type" bar and from drop down click on desired item, and then hit enter key.



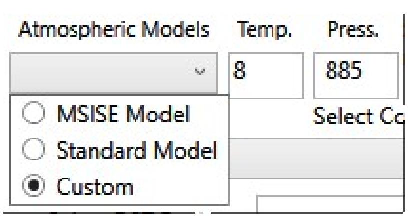
Atmospheric Models

Pressure and temperature affect atmospheric refraction. To calculated atmospheric pressure and temperature, two methods used. Standard atmospheric model, which calculates pressure and temperature, from geographical altitude. In this model pressure and temperature does not change for date and location.

Other model is MSISE model, which is an empirical model, and pressure and temperature not only depend on elevation or geographical altitude, but also location and date.

By knowing local metro logical data, user can enter pressure in millibar and temperature in Celsius, in appropriate boxes.

To select click on "Atmospheric Models" bar and from drop down click on desired item, and then hit enter key.



New Moon Criteria

Visibility of new moon crescent has been an important discussion for centuries. For sighting new moon there are criteria from centuries ago to resent years. two resent one from Yallop and Odeh used in this software.

There is an option for either one, which software checks both methods, and any one admits view of new moon, shows the results.

Islamic Prayer Times

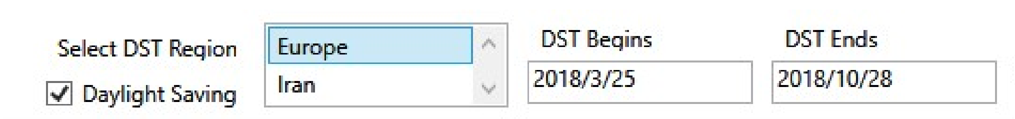
Please select conventions for elevation of the Sun at prayer times, also convention of length shadow at Asr prayer time. For more information please visit these sites.

Prayertime.org

azangoo.com

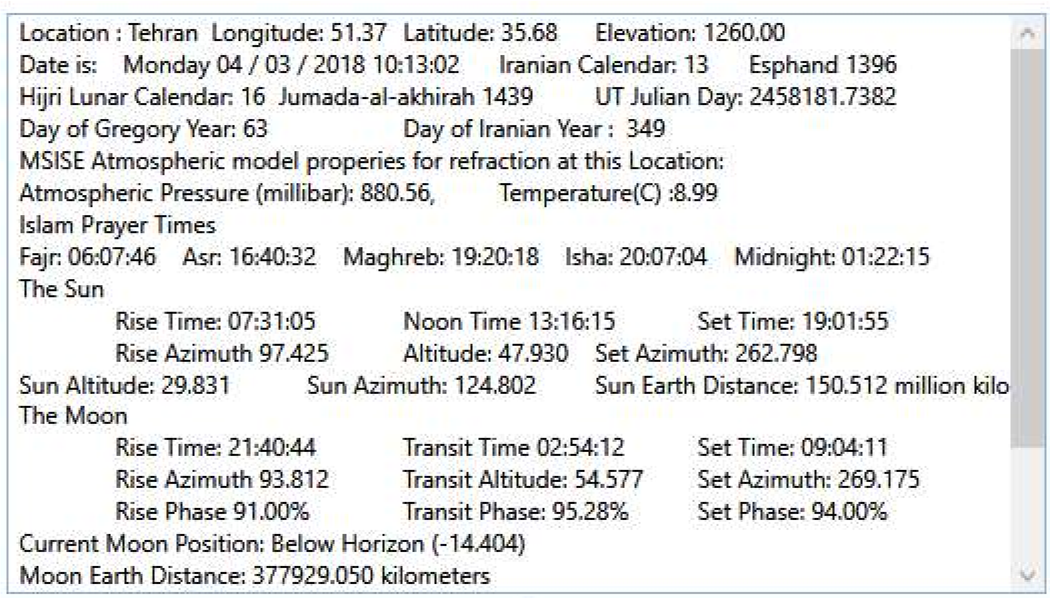
Daylight saving Time

Now most countries do not use day light saving times (DST), but in case by selecting DST, form four region user can select proper one. One region is custom. In this option user should enter starting date and ending date of DST, in proper format. After selecting region based on calendar type, starting date, and end date of daylight saving time will be showed in corresponding boxes. If you change calendar, after selecting DST , date type will not change, therefore , please deselect , DST box and start over again.

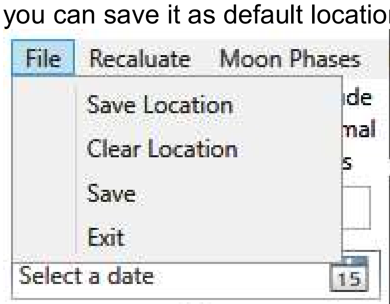


Getting Results

After starting program, panel will show output data. If you have saved geographic location and setting, calculated items will be based on them.


Location : Tehran Longitude: 51.37 Latitude: 35.68 Elevation: 1260.00
Date is: Monday 04 / 03 / 2018 10:13:02 Iranian Calendar: 13 Esphand 1396
Hijri Lunar Calendar: 16 Jumada-al-akhirah 1439 UT Julian Day: 2458181.7382
Day of Gregory Year: 63 Day of Iranian Year : 349
MSISE Atmospheric model properies for refraction at this Location:
Atmospheric Pressure (millibar): 880.56, Temperature(C) :8.99
Islam Prayer Times
Fajr: 06:07:46 Asr: 16:40:32 Maghreb: 19:20:18 Isha: 20:07:04 Midnight: 01:22:15
The Sun
Rise Time: 07:31:05 Noon Time 13:16:15 Set Time: 19:01:55
Rise Azimuth 97.425 Altitude: 47.930 Set Azimuth: 262.798
Sun Altitude: 29.831 Sun Azimuth: 124.802 Sun Earth Distance: 150.512 million kilo
The Moon
Rise Time: 21:40:44 Transit Time 02:54:12 Set Time: 09:04:11
Rise Azimuth 93.812 Transit Altitude: 54.577 Set Azimuth: 269.175
Rise Phase 91.00% Transit Phase: 95.28% Set Phase: 94.00%
Current Moon Position: Below Horizon (-14.404)
Moon Earth Distance: 377929.050 kilometers

If you wish to check frequently position of Sun, Moon for any location, type of calendar, and other selected items, you can save it as default location. When program starts, it will use these settings.



After entering data and selecting items, click on "Recalculate" at menu bar, check the results at panel. If results are correct, then click on "File" at menu bar and click on " Save Location". You can clear default location by clicking on "Clear Location"

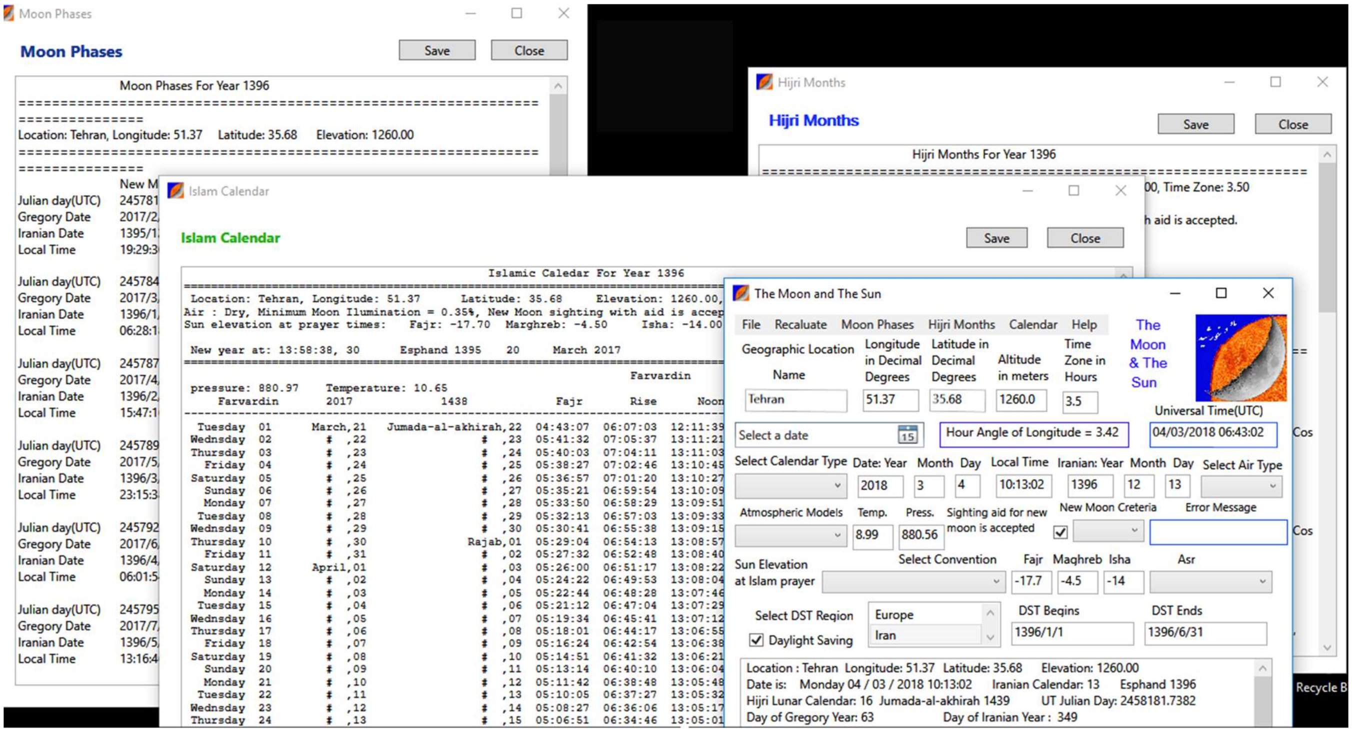
If you wish to save results, by clicking on "Save" Windows saving panel will show up and you can save it as text file.

Every time changing date, time, or any item, by clicking on "Recalculate" you will get new results.

If you click on "Moon Phases", Moon Phases for the year on panel window will show up. You save it as text file, or close the window.

By clicking on "Hijri Months", window will show up with start of new Hijri months at Gregory and Iranian calendar, with calculated criteria for year and location.

You create three type of calendar, Astronomical, with sun and moon data for any Gregory or Iranian year, Moon calendar and Islamic calendar, which shows prayer times based on selection of prayer conventions.



To download executables click hear.

https://sites.google.com/view/moon-and-sun/home

To download with source code click hear

https://github.com/AminKH/MoonSun