# 9 TIME

## 9.1 The Solar System

The solar system consists of the Sun and nine major planets of which the Earth is one. In addition to these planets, there also exists a considerable number of planetary moons (each locked into an orbit around a parent planet) and huge number of asteroids. All the planets (and their associated moons) plus all the asteroids orbit the Sun, which may, for the purposes of this manual, be considered as the stationary centre round which all the planets revolve. The Sun is self-luminous, whilst the planets reveal their presence by reflecting the Sun's light. Distances in the universe are given in light-years, which tells us how far light travels in one year at almost 300 000 km a second. Sunlight, for instance, takes a full 8 minutes to cross the 150 million km to the Earth.

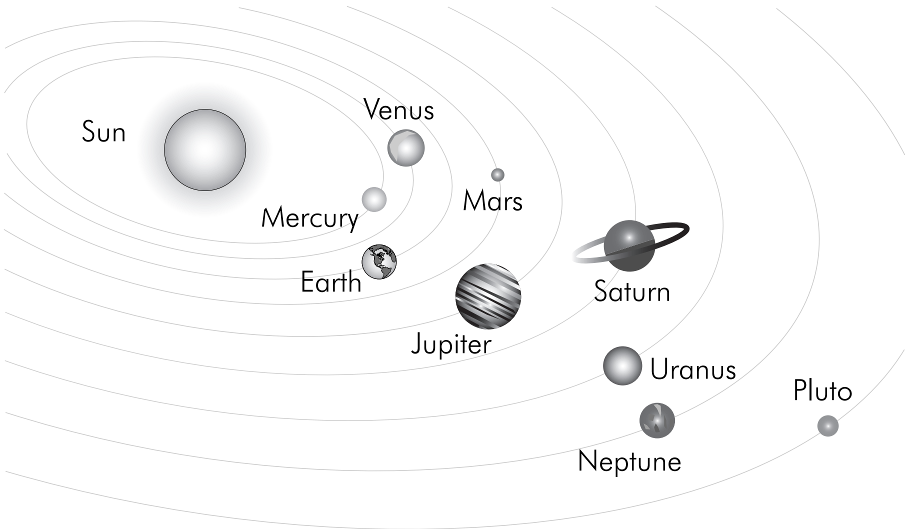



*Figure: NV 9.1*

The paths of the planets are elliptical, and they are almost in the same plane. Some of the planets themselves have captive bodies revolving around them called satellites. The Moon is the only natural satellite of the Earth.

> The Solar system consists of the Sun, the Earth and its Moon and the Planets and their moons.
>
> Today, only the Sun, The Earth and the Moon are of interest to aeronautical navigation.

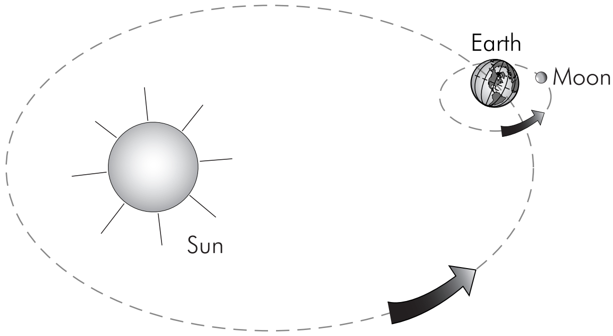



*Figure: NV 9.2*

An astronomer named Kepler evolved certain laws relating to the motion of planets in their orbits. These laws state that:

- The straight line connecting the Sun and a planet (Radius vector) sweeps out equal areas in equal intervals of time.
- Each planet moves in an ellipse, with the Sun at one end of its foci;
- The square of the sidereal (annual) period of a planet is proportional to the cube of its mean distance from the sun.

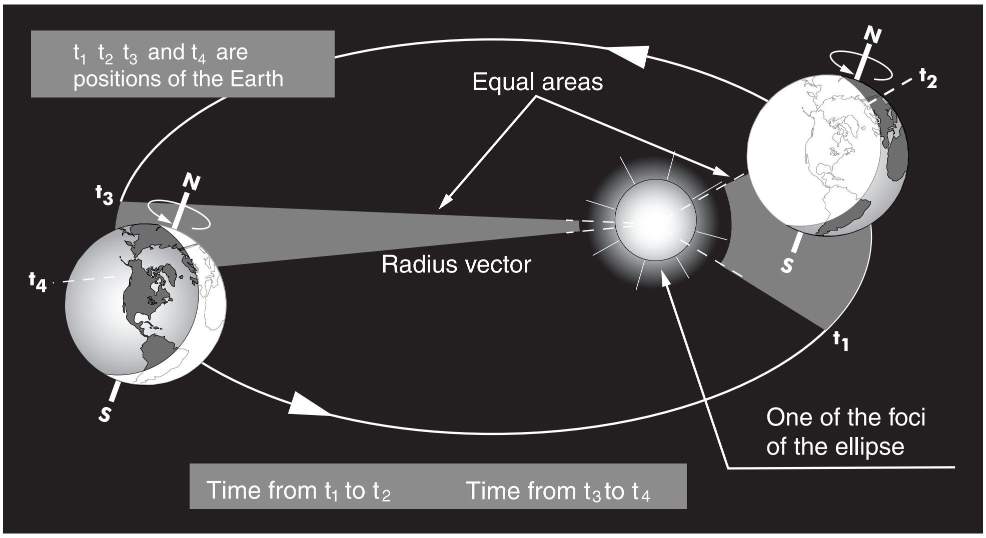



*Figure: NV 9.3*

Since the path of the Earth around the Sun is not a circular one, the distance between the Sun and the Earth will vary throughout the year. About January 2 the Earth is at a point of the orbit called perihelion, which is closest to the Sun. Six months later at about July 2, the Earth is farthest away from the Sun, at a point called aphelion.

According to Kepler's law the radius vector is supposed to sweep out equal areas in equal intervals of time. For this to happen, the speed of the Earth at perihelion will have to be faster along its orbit than at aphelion, so actually, the Earth moves with a varying speed in its orbit around the Sun.

It takes the Earth about 365 and ¼ days to complete one orbit of the Sun. The Civil Year or Calendar Year is defined as exactly 365 days. At the end of each 4 years, when the extra ¼ day adds up to one whole day, there is obviously a need to get rid of the extra day by giving ourselves a Leap Year of 366 days.

The movement of the planet Earth is twofold: The Earth rotates on its own axis in a West to East direction, resulting in the diurnal changes (the shifting between day and night) in a 24 hour period. One day is therefore the approximate timespan of one revolution of the Earth about its own axis. One particular meridian is used as reference for this measurement of time, and the instant at which the Sun is directly over this meridian is called a "transit". This happens at the time of day when the Sun is at the highest with reference to the horizon.

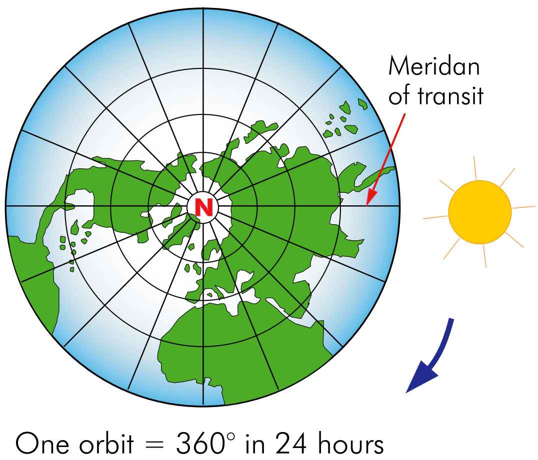



*Figure: NV 9.4*

The second one is the annual movement, which causes the seasonal changes. One year is the approximate time span of one complete orbit of the Earth about the Sun. This annual movement is the reason for the seasonal changes, because the axis of the Earth varies its position with respect to the Sun as it moves around in its orbit. When the northern part of the Earth axis is inclined towards the Sun, we experience summer in the Northern Hemisphere, and winter in the Southern Hemisphere. During northern winter the situation is just opposite, the northern part of the earth axis tilts away from the Sun.

> The Earth is moving around the Sun in a yearly, elliptic orbit. This orbit follows laws evolved by Kepler, and it follows that the distance between the Sun and the Earth and the Earth's speed in orbit vary slightly during a year.

> The Earth rotates on its axis once in a 24 hour period. The Sun will consequently be observed to transit any meridian at 24 hours intervals. This movement causes different light conditions during the day (24 hour period).

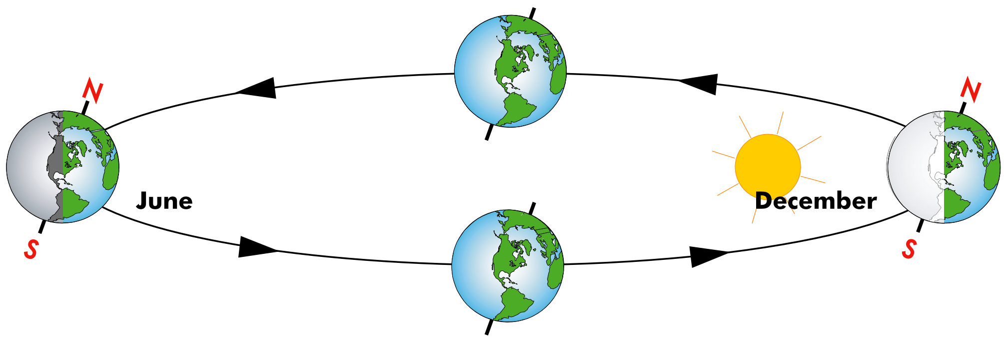



*Figure: NV 9.5*

More precisely, the varying position of the Earth axis with respect to the Sun is caused by the plane of the Earth's Equator being inclined at an angle of about 23°27' to the plane of its orbit round the Sun. Since the Earth follows an elliptic path, the Earth axis will change its position with respect to the Sun during the year, as illustrated in figure NV 9.5.

When the Earth has maximum inclination towards the Sun, it is summer solstice and the date is approx. June 21. Half a year later, on approx. December 22 we get winter solstice and the angle of inclination is maximum in the opposite direction. The solstices are illustrated in figure NV 9.6.

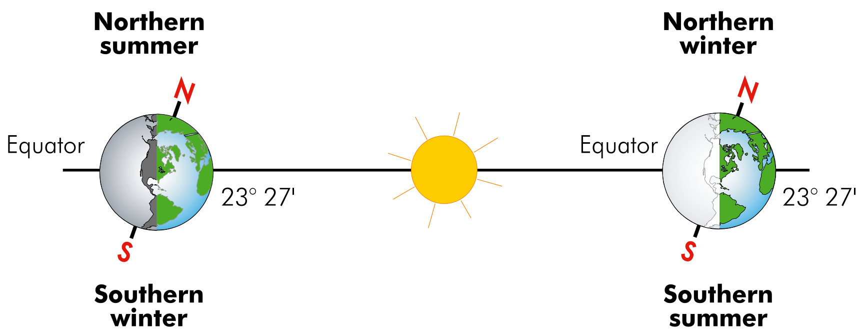



*Figure: NV 9.6*

When the axis of the Earth is at right angles to the Sun, days and nights are of same length everywhere on the Earth's surface. This happens twice a year, about March 21 and September 23, and are called the Vernal (spring) Equinox and Autumnal Equinox respectively.

> The Earths orbit around the Sun takes one year, and this movement causes the seasonal changes on the Earth (Spring, summer, autumn and winter). The seasonal changes are due to the angle of 23°27' between the axis of the Earth and the plane of the orbit.

So far we have looked at the Earth and the Sun from a point in space. But since we are actually observers on the Earth, it seems to be somewhat different. The sun as seen in the sky is called the true Sun or apparent Sun, and it appears to pass the

Earth from East to West once every day. But it is, in fact, the rotation of the Earth on its own axis that causes this apparent motion of the Sun travelling across our skies, hence the term "apparent" passage of the Sun.

The term "apparent solar time" is used to describe time based upon the Sun as it appears in the sky, and the term "apparent solar day" therefore is the time interval between two successive transits of the real Sun at the same meridian. The apparent solar day, as illustrated in figure NV 9.7, commences when the Sun crosses an observer's anti meridian.

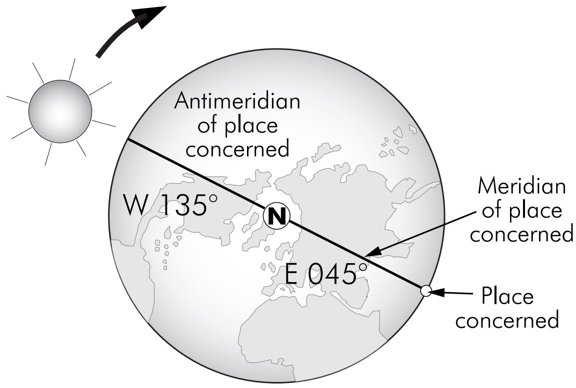



*Figure: NV 9.7*

> It has been chosen to use the Sun as reference for a global time system, and it was first decided that mid-day (noon) should be when the sunlight was strongest. This occurs when the Sun transits a meridian. It was also chosen to specify every day by a date, the change of date taking place at the time of least activity. In earlier times this was when it was darkest, at midnight, or when the Sun transits the anti-meridian.

Since the speed of the Earth in its elliptical path varies throughout the year, this phenomenon will influence the Sun, as it appears to revolve around the Earth. As a result, the apparent length of the day varies throughout the year, making it difficult to establish a system of telling time based on the apparent Sun. If the length of the day varies, the subdivisions of the day, - hours, minutes and seconds would also vary throughout the year. In addition, since the Earth rotates on its axis in an anticlockwise direction, and also revolves round the Sun in an anticlockwise direction; the Sun will appear to have moved in space and the Earth will have to rotate through more than 360° to produce two successive transits. (Figure NV 9.8). These difficulties led to the concept of "mean time".

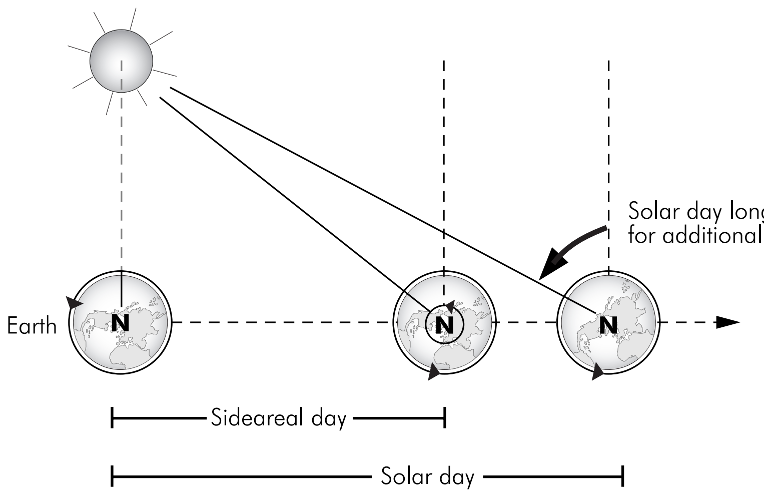



*Figure: NV 9.8*

The difficulties could have been resolved by using a datum located at an infinite distance away in space. If such a datum had been used there would have been no relative motion between the Earth and that datum and the rotation of the Earth would have been noted to be almost constant.

Successive transits of the datum are separated by a time interval of approximately 23 hours 56.3 minutes. This is called a "sidereal day" and is also illustrated at figure NV 9.8.

A mean day is an artificial unit of constant length, based on the average of all apparent solar days over a period of years. A mean Sun is imagined to travel round a circular path in the same plane as the Equator and at a constant speed; thus the Mean Sun will leave a meridian and return to it exactly 24 hours later of mean time. Because the length of the day is 24 hours, and that the sun seems to complete one circuit around the Earth in this time, the sun will travel 15 degrees per hour, or 1 degree per 4 minutes.

Time reckoned using the mean Sun is called "mean solar time" and is nearly equal to the average apparent solar time. The difference in length between the apparent day (based upon the "true" Sun) and the mean day (based upon the fictitious "Mean" Sun) is never as much as a minute. The differences are cumulative, however, with the result that the imaginary mean Sun is considered to precede or follow the apparent Sun by approximately a quarter of an hour at certain times during the year.

As the Earths speed in orbit around the Sun is not constant, the length of one day and the next will vary when the time system is based on the Sun as we observe it from the Earth, the Apparent Sun. To make all days throughout the year equally long, an artificial sun, called the Mean Sun, was introduced. To an observer on the Earth, the artificial Mean Sun seems to move along the Equator at constant speed, making the duration of days, the hours, minutes and seconds constant throughout the year. The only drawback of the Mean Sun is that we cannot see it!

The relationship in time between the Apparent Sun and the Mean Sun is described by **"The Equation of Time":**

Equation of time = Apparent time – Mean time

The Equation of Time is most frequently established at noon. At noon
LMT is 1200, and the apparent noon is half way between sunrise and sunset, which may be found from the Air Almanac tables for that day.

Example: What is the Equation of time on 11 Jan?

| | | |
|---|---|---|
| From the Air Almanac: | Sunrise: | 0605 LMT |
| | Sunset: | 1811 LMT |

Noon Apparent time = (0605 + 1811) : 2 = 1208 LMT

Equation of time = Apparent time – Mean time
Equation of time = 1200 – 1208 = -8 minutes

This means that the Mean Sun on this day is 8 minutes ahead of the Apparent Sun, which we observe in the sky.

> The difference between the Apparent Time and the Mean Time is given by the term "Equation of Time":
>
> Equation of Time = Apparent Time – Mean Time

To get an overview of how the Sun changes its declination during the course of a year, it is useful to look at how the Sun's apparent orbit on the celestial sphere is projected on to the surface of the Earth. This apparent path is called the "Ecliptic".

The summer season in the Northern Hemisphere (and the winter season in the Southern Hemisphere) starts when the Sun is directly overhead the equator at noon on the day of the Vernal Equinox, March 21. Thereafter the Sun is constantly increasing its declination until approx. June 21, the Summer Solstice, when it reaches the northernmost point of its path. At this date the Sun is directly overhead, (in zenith) at latitude 23°27' North. The Sun now starts its travel towards the Equator, which it reaches on approx. September 23, when the summer season in the Southern Hemisphere sets in. On December 22 the Sun has come to the lowest point of its path, and an observer at 23°27' South will see the Sun directly overhead at local Noon. After this date it begins to move north again to complete the cycle, being 3 months later back overhead the Equator at the Vernal Equinox.

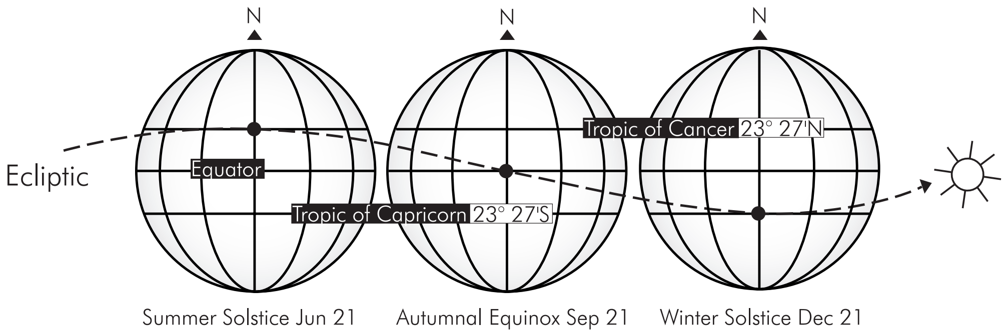



*Figure: NV 9.9*

It is of interest to note that the position of the Sun, and indeed all other bodies in space, may be given in coordinates that can be related to the Earth coordinate system.

The equivalent of latitude is called "Declination" and is measured in degrees North or South of the Celestial Equator (which is parallel to the Earth's Equator).

The equivalent of longitude is called "Greenwich Hour Angle (GHA)". This is measured westwards from Greenwich through 360°.

Using these coordinates, it is possible to establish a position on the Earth directly below the body in space.

As we observe a star or the Sun, it appears to rise in the sky to a maximum then descend towards the West until it sinks below the horizon. The vertical angle of the body (measured from the horizon) will initially increase then, at transit, will start to decrease. This vertical angle is of interest to navigators and others who study the positions of heavenly bodies (and I do mean the ones in space).

> When the Sun's declination is 1230N, its position is 12,5° North of the celestial equator

## 9.2 The Arctic and Antarctic Circles

The parallels of latitude 66°33' North and South are known as the Arctic and Antarctic Circles, respectively. There is a correlation between the latitudes 23°27' North and South and these circles, because the difference between 90° and 66°33' is exactly 23°27'. When the Sun has reached up to 23°27' North at Summer Solstice, the sunrays will pass over the pole, and because of the rotation of the Earth, the Sun will stay above the horizon 24 hours a day in all places north of the arctic circle at that date.  This phenomenon is called midnight sun.

From the time of Summer Solstice, the midnight sun area decreases starting from the arctic circle and up towards the pole, where the sun sets once for all that year at about September 21. The area of darkness all day now gradually increases from the pole as the Earth axis moves away from the Sun. Because the sunrays

don't reach further north, at Winter Solstice the Sun will stay below the horizon all day in all places north of the Arctic Circle.
The same situation of darkness and continuous daylight occurs south of the Antarctic Circle, but at opposite time periods to those in the Northern Hemisphere.

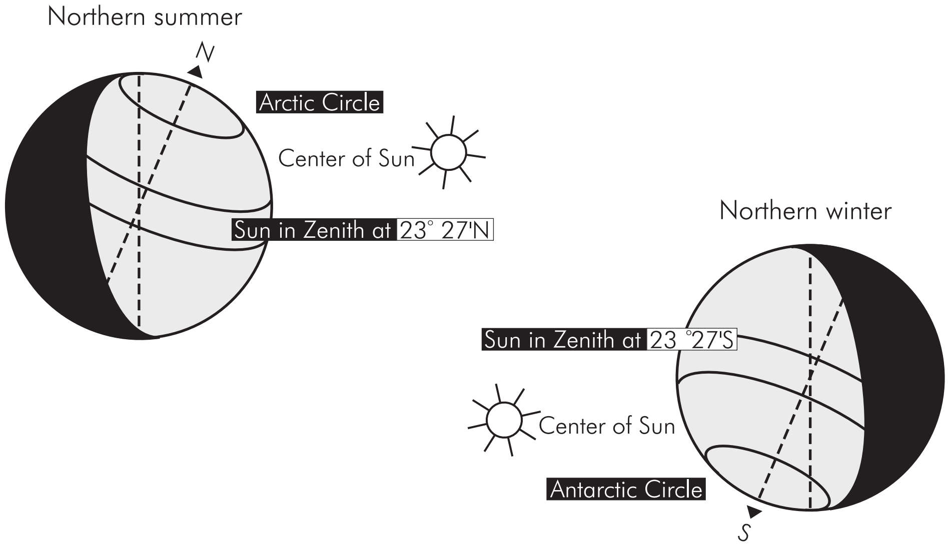



*Figure: NV 9.10*

> At the North Pole the Sun will be above the horizon from Vernal Equinox until Autumnal Equinox; from Mar 21 to Sep 21.

> The Arctic Circle at 6633N and the Antarctic Circle at 6633S are the lowest latitudes where Midnight Sun and Polar Nights may be observed.

## 9.3 Relationship between longitude and time

Time is a measure of the rotation of the Earth, and any given time interval can be represented by a corresponding angle through which the Earth turns. So when we say that the time is 2 a.m.; it is a way of expressing that the Sun has moved through an angle of 2 x 15° = 30° since the time it passed the meridian which is used as point of reference.

It has been established that the mean Sun travels at a constant rate, and that the Earth makes one complete rotation of 360° with respect to the mean Sun in 24 hours. The Equator can therefore be divided into 24 hours, as well as into 360°.

This establishes the following relationship between arc and time:

| ARC | TIME |
|---|---|
| 360 degrees | 24 hours |
| 15 degrees | 1 hour |
| 1 degree | 4 minutes |
| 15 minutes of arc | 1 minute |
| 1 minute of arc | 4 seconds |

Although “arc to time” - tables are found in the Air Almanac and in Route Manuals, the arc to time relationship above should be recalled by memory!
Some examples:

Convert 12 hr 04 min to arc units.
- 12 hr x 15° = 180° (since 1 hr = 15°)
- 04 min = 1°; (since 4 min = 1°)

Adding these we get 181°

Convert 4 hr 23 min to arc units.

- 4 hr x 15 = 60° (since 1 hr = 15°)
- 23 min divided by 4 = 5° + remaining 3 min; (since 4mins =1°)
- Remaining 3 min of time x 15 = 45' of arc; (since 1min. = 15’ arc)

Adding these we get 065° 45'

Convert 345° 30' of arc of longitude to time units.

- 345° divided by 15 = 23 hr ;
- 30' divided by 15 = 2 min of time ;

Adding these, we get 23 hr 02 min

Convert 155° 49' of arc of longitude to time units.

- 155° divided by 15 = 10 hr + remaining 5°
- Remaining 5° x 4 = 20 min of time
- 49' divided by 15 = 3 min of time + remaining 4'
- Remaining 4' x 4 = 16 sec of time;

Adding these, we get 10 hr 23 min 16 sec

When converting a change in longitude to a difference in time, we assume that the Sun is moving westwards across the meridians at a rate of 15 degrees pr hour.

## 9.4 Local Time

Local Apparent Time is the time at one particular meridian, measured by reference to the apparent Sun. For every place on the Earth, the sun will rise in the East and set in the West. Noon at a particular meridian is when the Sun is directly overhead that meridian. Since the sun will be passing the meridian of the place at 1200 noon, it will be in the south (for an observer whose latitude is North of the Sun's declination) at that place at that time.(Figure NV 9.11). So if we know the direction of South (180 degrees), and we are able to see the sun, we will also be able to determine an approximate time of day. This was the principle used in early days when sundials were used to measure time of day.

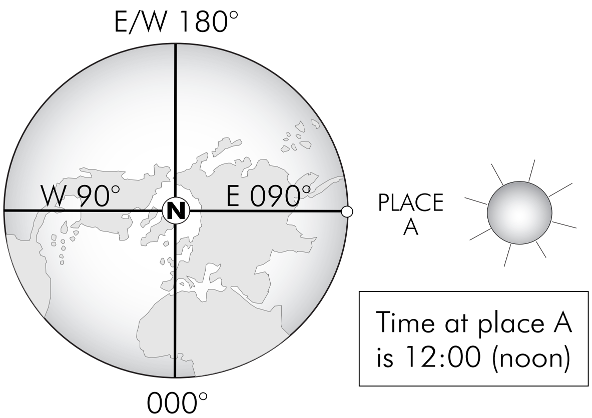



*Figure: NV 9.11*

Since the Sun cannot transit two meridians at the same time, no two meridians have exactly the same local time. The difference in time between two meridians is the time of the Sun's passage from one meridian to the other. If two meridians are 30° apart, their time differs by two hours. The local time will be later at the easternmost of the two, as can be seen in the figure NV 9.12.

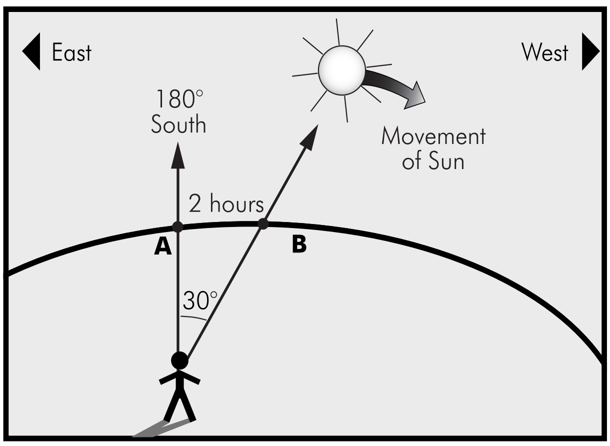



*Figure: NV 9.12*

> Local time may be established for any particular meridian. All positions on this meridian will have the same local time. It is 1200 local time when the Sun is passing the meridian in question.

When the Sun is overhead the meridian at A, at 1200 local time, there will be another two hours before the Sun is overhead point B.
When the Sun is overhead point A, the time of point B is 1000 local time, and an observer at point B will have to wait another 2 hours for the Sun to come overhead his position at noon.

Meridians of longitude further East are Ahead in Local Time
Meridians of longitude further West are Behind in Local Time

> As the Sun's movement as seen from the Earth is westerly, places to an observers East are ahead (fast) in local time, and places to the West are behind (slow) in local time. (The terms in brackets are used in the Air Almanac)

## 9.5 Local Mean Time (LMT)

Local Mean Time at the observer's meridian is measured by reference to the mean Sun. The time of day in LMT is measured as the angle, converted to time, from the observer's anti-meridian westward to the mean Sun.(Figure NV 9.13)

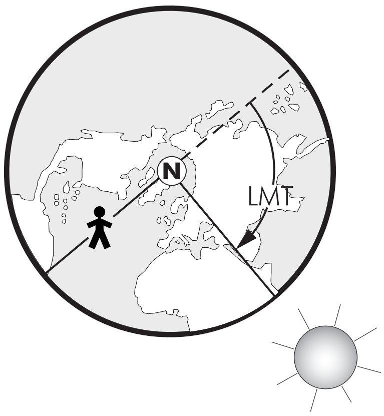



*Figure: NV 9.13*

The mean Sun transits the observers anti-meridian at LMT 0000 (2400), after which a new day commences at the observers meridian (Figure NV 9.14). The beginning of the day at any place is always midnight (LMT 0000). As an example, midnight at a place on longitude 40° E will be when the mean sun transits the anti-meridian of 40°E, i.e. 140°W.

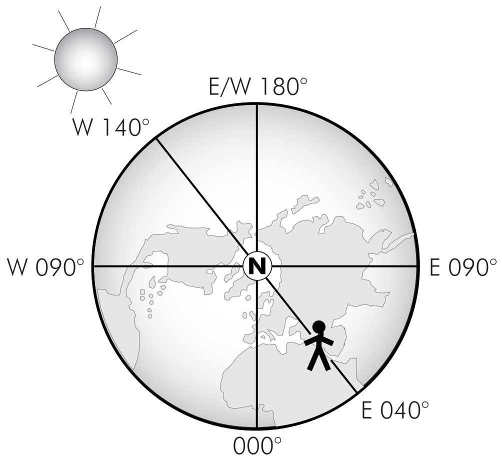



*Figure: NV 9.14*

The Local Mean Time is always later at the easternmost of two positions, since the Sun has crossed the easternmost position first, and the day is older there. The city of Kiev in Russia is at longitude 030° E. At sunrise in Kiev, it is still dark in London which is at longitude 0. Sunrise in London will not occur until 2 hours later.

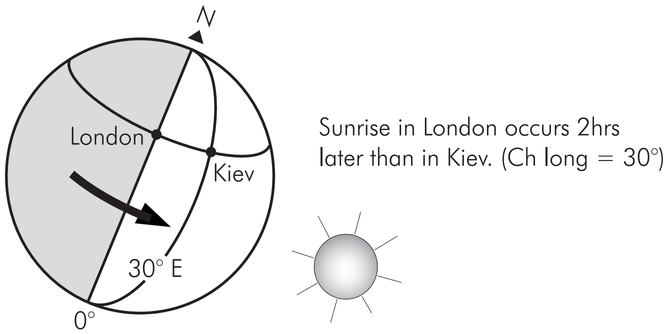



*Figure: NV 9.15*

It would be awkward to use the local mean time as a universal system of telling time, since the LMT is always referred to the meridian of a specific location. Every place would have its own time, to the great confusion of travellers. In aviation, the main use of LMT is for computations of such phenomena as sunrise, sunset and twilight.

To avoid confusion about time in general, it has been decided that the 000° E/W meridian is the standard meridian to which all LMT's should be referred. LMT on the 000° E/W meridian, also known as the Prime Meridian, is called Coordinated Universal Time.

> Local Mean Time is based on the Mean Sun, travelling across the meridians at constant speed 15° pr hour.
> Only positions located at the same meridian will have the same LMT

Since an unlimited number of different LMTs exists, Universal Time Coordinated (UTC) has been established as a world wide common reference for time.

For navigation purposes, UTC equals LMT for the Greenwich meridian.

## 9.6 Coordinated Universal Time (UTC)

UTC is the Local Mean Time at the meridian of longitude that runs through the observatory at Greenwich, near London. UTC is a new term for the well known Greenwich Mean Time (GMT), and has been established as the international standard time for navigational and weather reporting purposes, as well as for all aeronautical communications around the world.

The Greenwich meridian, at longitude 0 (000° E/W), is also known as the Prime Meridian. A day, with reference to UTC, commences when the mean Sun is in transit with the anti-meridian of 000° E/W, namely the 180° E/W meridian. Time of day in UTC is therefore the angle at the pole, converted to time, from the 180° E/W meridian westward to the mean Sun.

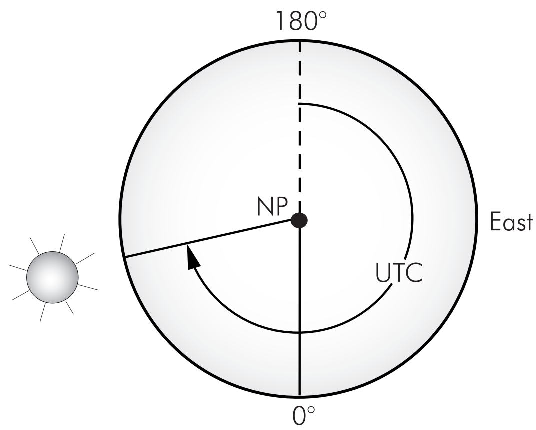



*Figure: NV 9.16*

Because the Sun appears to travel from East to West, it will cross easterly meridians before it is in transit with the 000° E/W meridian. Thus, LMT of places East of the 000° E/W meridian will be ahead of UTC, and places West of the 000° E/W meridian will be behind UTC.

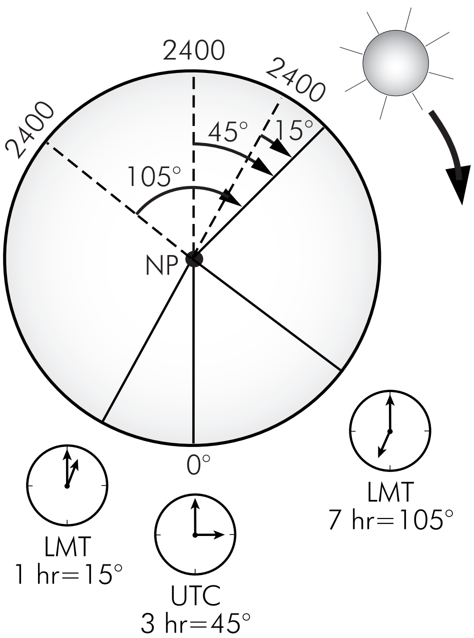



*Figure: NV 9.17*

To convert the LMT into UTC and vice-versa, the rule is:

Longitude West, UTC best
Longitude East, UTC least.

("Best" and "least" means that a time in the morning, let's say 1000, is "least" compared to 1600 in the afternoon.)

An example:
If LMT is 2100 on the 150° E meridian of longitude, what is the time in UTC? Remember that as 15° of arc = 1 hour, then 150° = 10 hours, and that "Longitude East, UTC least".

| | |
|---|---|
| 21:00 LMT | at 150° E |
| - 10 hours | arc to time |
| = 11:00 UTC | |

If any doubt arises whether to subtract or add the "arc to time", you are recommended to make a sketch of the situation as seen from a point above the North Pole.

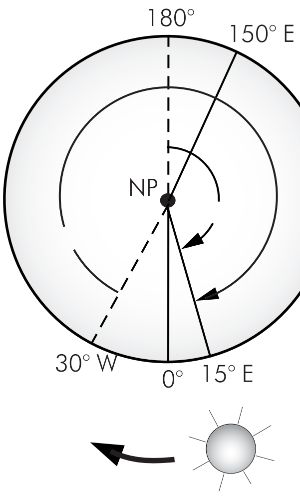



*Figure: NV 9.18*

Figure NV 9.18 illustrates this type of sketch constructed as follows.
Start by placing the Sun in a position 21 hours of sun travel from the anti-meridian of 150° E (15°x 21 = 315°). It can immediately be seen that the angle from the 180° meridian to the mean Sun representing UTC is a smaller angle, thus the "arc to time" will have to be subtracted from the LMT to get UTC.

Another example:
If the time in UTC is 1330, what is LMT at the 105°00' W meridian?
Remember that "Longitude West, UTC best", and that an arc of 105° corresponds to 7 hours of Sun travel.

| | |
|---|---|
| 13:30 UTC | |
| - 7 hours | arc to time |
| = 06:30 LMT | at 105° 00"W |

Then make a sketch to confirm the answer.

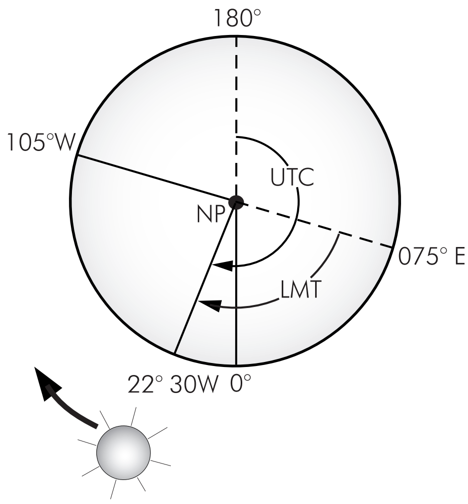



*Figure: NV 9.19*

Yet another example:
If the time in UTC is 0900, what is LMT at the 037° 45' W meridian?

| | |
|---|---|
| 09:00 UTC | |
| - 2:31 | arc to time |
| = 06:29 LMT | at 037° 45' W |

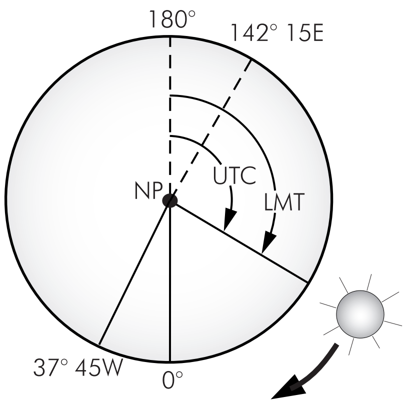



*Figure: NV 9.20*

One standard time, such as UTC, could have been used all over the world to regulate man's activities, but then in most longitudes the time would not have its usual relation to the Sun's position in the sky. A compromise between the use of one standard time and the use of local time at each meridian has been worked out in the system of standard time zones.

1. UTC = LMT - Long E (at 15° pr hour)
2. UTC = LMT + Long W (at 15° pr hour)
3. LMT = UTC + Long E (at 15° pr hour)
4. LMT = UTC - Long W (at 15° pr hour)

## 9.7 Zone time

The Earth is divided into 24 time zones, each of them 15° of longitude in width. This relationship gives a difference of exactly 1 hour between the time zones. Each zone uses LMT of its central meridian as time reference, and the zone goes 7.5° either side of that meridian.

The Prime Meridian is the central meridian of the first of the time zones, and is designated by the number 0. The other zones are designated by numbers up to +12 and -12, each indicating the number of hours which must be added, - or subtracted from the various zone times to obtain UTC.

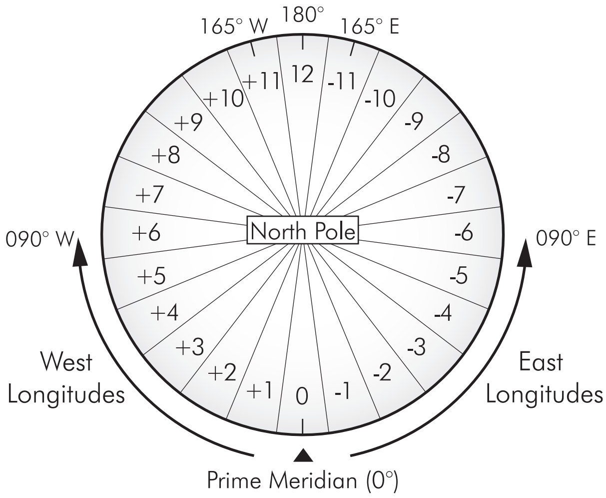



*Figure: NV 9.21*

Sometimes the zones are designated by letters of the alphabet for additional reference (zone 0 = Z, zone -1 = A).

An example:
The local zone time at 150° E in zone -10 (K) is 2200. What is the time in UTC? Since the zone is -10, 10 hours must be subtracted from the zone time to obtain UTC, thus the time is 1200 UTC. (Remembering also that East longitudes are ahead in time).

The zone time system does not worry about state borders, a fact that makes it rather unfit for use as a time system to regulate peoples activities.

> Zone Time equal the LMT for the centre meridian in 1 of 24 zones. Each zone is 15° long wide, and the centre meridian in Zone 0 is the Greenwich meridian. Eastern longitudes are numbered with negative zone numbers, western longitudes with positive.

## 9.8 Standard Time

In some countries, especially those with a large east-west extent which overlap more than one time zone, there is obviously a need for a common standardised time that can be used throughout.

The borders of the time zones are determined by meridians, while the borders of the Standard Time-belts are determined by the frontiers of states or natural geographical borders. Thus, a particular meridian is selected as a standard meridian by the governments of the states concerned and this meridian is taken as the reference for the Standard Time (ST) within that state. Standard Time is the official time used in a country or state. It is often listed as “Local Time” in timetables and newspapers, but keep in mind that this is actually the Standard Time and should not be confused with local mean time.

The difference in time between the UTC and the Standard Time for each state is listed in the Air Almanac and in some of the "Route Manuals".

Standard Time

-Add to UTC to give Standard Time
-Subtract from Standard Time to give UTC

| | |
|---|---|
| Afghanistan | 04 hr 30 min. |
| Albania (*) | 01 hr |
| Austria | 01 hr |

(*) Summer time may be kept in these countries.

Countries like the USA, Canada and Australia have such a large east-west extent, that one common standard time is inconvenient. Thus, multiple time belts are in use, each of them having their own Standard Time.

An example that involves both UTC, LMT, ZT and ST:

Time is 0800 UTC. What is the LMT, Zone Time (ZT) and Standard Time (ST) at Stavanger Airport in Norway, geographical position 58°52' N 005°38' E?

| | |
|---|---|
| 000° E/W | 0800 UTC |
| Arc to time | 22 minutes |
| Stavanger | 0822 LMT |

| | |
|---|---|
| 000° E/W | 0800 UTC |
| Zone time diff. | 0000 |
| Stavanger | 0800 Zone Time |

The "zone time difference" is found by determining the closest meridian that can be divided by 15. This meridian is the reference for the actual time zone, in this case the 000° E/W meridian, and time zone 0.

| | |
|---|---|
| 000° E/W | 0800 UTC |
| Standard time diff. | + 1 hour |
| Stavanger | 0900 Standard Time |

The time difference between UTC and ST is found in the Air Almanac or in Route Manuals. Norway is 1 hour fast on UTC, so simply add an hour.

There is one golden rule when dealing with most of the time problems - always work through UTC!

> Standard Time (ST) has been politically established for counties or parts of a country. ST is the legal time used by the citizens of that area or country.
> Standard times are published in the Air Almanac and other publications. Standard time is in the Air Almanac stated as a period of time, and as being fast or slow on UTC.

## 9.9 Daylight saving time

Most communities (but not all) further adjust their local time according to the season of the year. When this is done, the local time is advanced 1 hour in the spring, and the daylight saving time (summer time) is in effect. In the autumn the clocks are set back to Standard Time again.

## 9.10 Date line

If an observer were to travel westward from the Prime meridian, the clock has to be set back 1 hour for each 15° of longitude to keep track on LMT. The observer would eventually arrive at longitude 179° 59' W, where the LMT becomes 12 hours less than UTC.

Imagine another observer at the same time travelling eastward from the Prime meridian. The clock has to be advanced 1 hour for each 15° of longitude to keep track on LMT, so that when arriving at longitude 179° 59' E, the LMT becomes 12 hours more than UTC. Thus there is a full day of 24 hours difference between the two travellers, although they cross the same meridian.

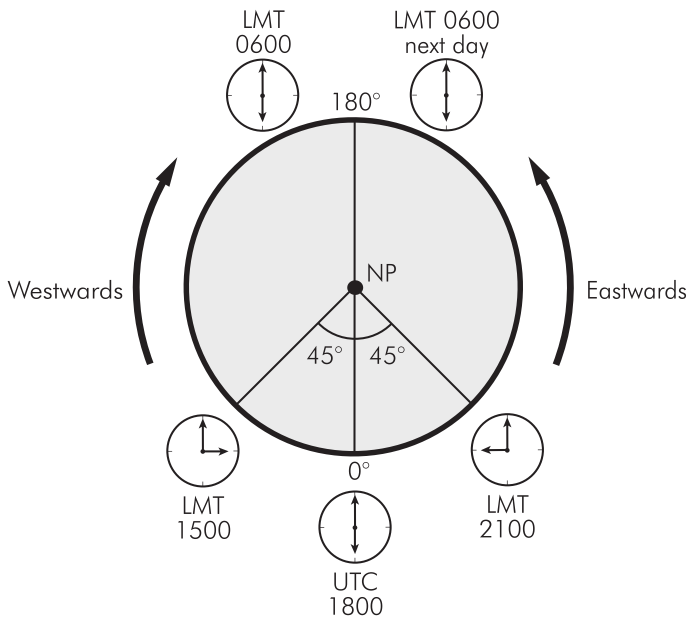



*Figure: NV 9.22*

To avoid this inconvenience, the 180° meridian is chosen as the International Date Line, where a corrective action is taken. The date line follows the meridian, except from minor divergences to keep groups of islands together on the same day. Crossing the date line, one day is gained or lost, depending on the direction of travel. Making a complete trip around the world, you would therefore lose a day travelling westwards, and gain a day travelling eastwards.

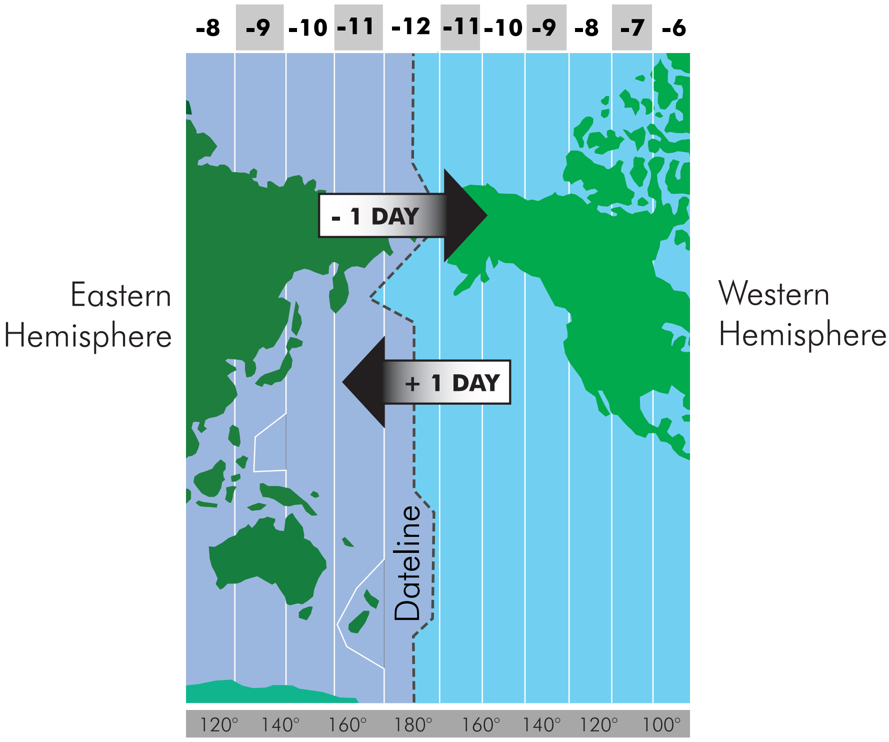



*Figure: NV 9.23*

Crossing the date line from the eastern hemisphere to the western hemisphere (on easterly heading), the clock must be set back 24 hours, while crossing from the western hemisphere to the eastern hemisphere (on westerly heading), the clock must be advanced 24 hours. As an example, when it is Monday on the eastern side of the date line, it is Sunday on the western side.

> Passing the date line on an easterly track: Subtract 1 date
> Passing the date line on a westerly track: Add 1 date

## 9.11 The change of date

To an observer the local civil date changes at 2400 (0000). Thus the date changes as the mean Sun transits the observer's anti-meridian.

It is always midnight somewhere in the World. At any instant the meridian at which the sun is in transit is the anti-meridian of a location where the LMT is 2400/0000. At the same instant of course, it is 1200 LMT for an observer at the Sun's meridian. When the anti-meridian is at longitude180° E/W, the whole world momentarily shares the same date.
This situation is illustrated in figureNV 9.24.

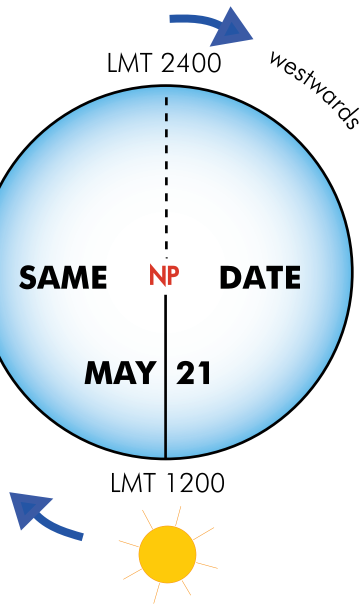



*Figure: NV 9.24.*

From that moment on, a new date begins in East longitudes. As the anti-meridian moves westward, it kind of pushes the old date before it and drags the new date after it.

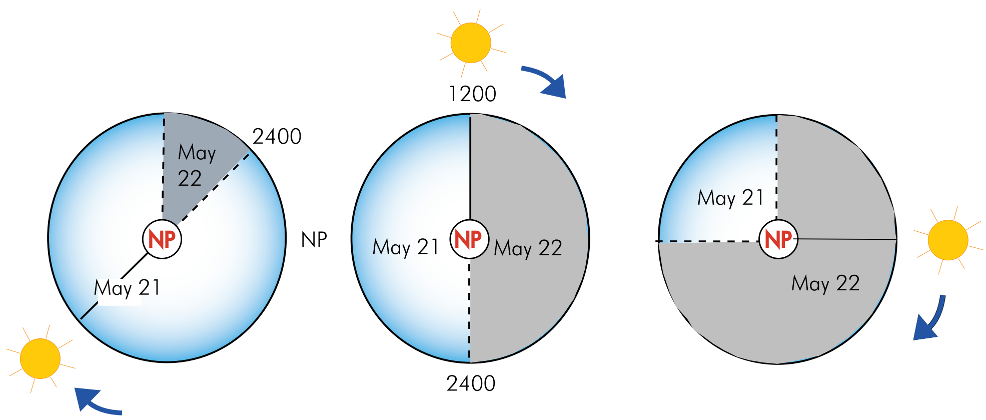



*Figure: NV 9.25*

The area of the old date decreases and the area of the new date increases as the anti-meridian (of the meridian where the Sun is in transit) moves westward. When the mean Sun passes the Prime meridian, the old date is crowded out, and a newer date begins east of the 180° meridian. Then the process starts all over again.

> At exactly 1200 UTC, the whole world will have the same date.
> At all other times, the world will have two different dates: The Old Date or the New Date.
> The area having the New Date will extend westwards from the 180°E/W meridian.

An example:
A flight on a westerly track crossed the date line (from the western hemisphere to the eastern hemisphere) at 1135 UTC March 3. Point of departure was Pitlekaj in Siberia (67°00' N 173°20' W).

What is the date and crossing time in LMT, ST and ZT for Pitlekaj? Remember that UTC = LMT at the Prime meridian (000° E/W).

| | | |
|---|---|---|
| 000° E/W | March 3 | 1135 UTC |
| arc 173° 20' to time | | - 11hr 33min |
| Pitlekaj | March 3 | 0002 LMT |
| | | |
| 000° E/W | March 3 | 1135 UTC |
| Standard time diff. | | + 13 hours |
| Pitlekaj | March 4 | 0035 ST |
| | | |
| 000° E/W | March 3 | 1135 UTC |
| Zone time diff. | | - 12 hours |
| Pitlekaj | March 2 | 2335 ZT |

Note that close to the date line, a place can have three different dates at the same time.

> When converting between UTC, LMT, ZT and ST, a change of date will be required if you end up with a time higher than 2400 or with a negative time. You should then substitute 24 hrs with 1 date.
>
> 2606 UTC Oct 5 = 2606 – 2400 UTC Oct 5 + 1 = 0206 Oct 6
>
> -0517 LMT Nov22 = -0517 + 2400 LMT Nov 22 – 1 =
> 1843 LMT 21 Nov

## 9.12 Sunrise and sunset

The time of sunrise and sunset is when the upper limb of the sun is coincident with the observer's visible horizon. At the moment of this vision, the centre of the sun is actually 0.8 degrees (50 ' of arc) below the horizon, but due to refraction we see it as higher than it really is.

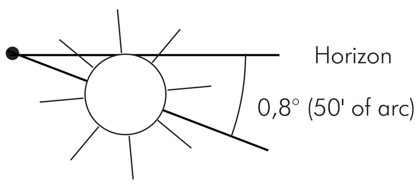



*Figure: NV 9.26*

Sunrise and sunset tables have been worked out, based on given dates and the actual latitude of the observer. No wonder then that the times at which sunrise and sunset occur depend upon two things: the date and the latitude of the observer. In summer sunrise (SR) is earlier and sunset (SS) is later. In winter the reverse occurs, resulting in daylight hours being shorter than in summer. By studying the extract from a SR table below, it can be seen that the time of SR changes by several minutes in a 3-day period, and that the change is more pronounced the higher the latitude. In extreme high latitudes the time of sunrise and sunset differ by around 40 minutes from one day to another at certain times of the year, while at low latitudes the times of SR / SS change by only a minute or two each day.

> Sunrise or Sunset occurs when the centre of the Sun is 0,8° below the horizon. At this time the upper limb of the Sun touches the horizon.

The time of sunrise and sunset for any one date varies slightly from year to year. The variation is negligible in the mid-latitudes, while in the very high latitudes (above 65° latitude), the difference is in excess of two minutes in some seasons. Nevertheless, some of the unofficial almanacs have chosen to present one fixed, permanent table representing an average of several years.

**SUNRISE TABLE**
February

| Latitude | Feb 1 | Feb 4 | Feb 7 |
|---|---|---|---|
| **N72°** | 1031 | 1007 | 0946 |
| **N70°** | 0948 | 0932 | 0916 |
| **N68°** | 0919 | 0907 | 0854 |
| — | | | |
| **N52°** | 0742 | 0736 | 0730 |
| **N50°** | 0734 | 0730 | 0724 |

As the table indicates, the times of SR and SS also depend upon the latitude of the observer, as shown in figure NV 9.27.

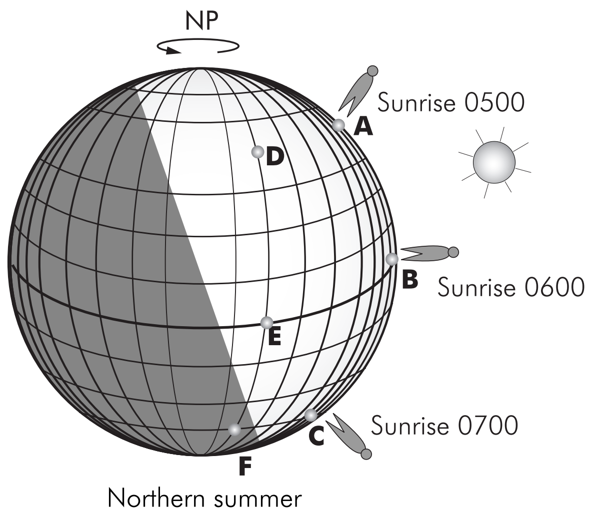



*Figure: NV 9.27*

Although all three observers are on the same meridian, they will experience different sunrise and sunset times due to being on different latitudes. Each of the observers will pass from the dark to the lit area at different LMT's.

If instead the observers are staying on one particular latitude, all places regardless of longitude, will experience sunrise and sunset at the same Local Mean Time. Thus, the time of the occurrences at specified Latitudes on the Prime Meridian may be taken as the same for all longitudes. This in fact makes it a whole lot easier, since the tables of sunrise and sunset can be made with reference to only one meridian.

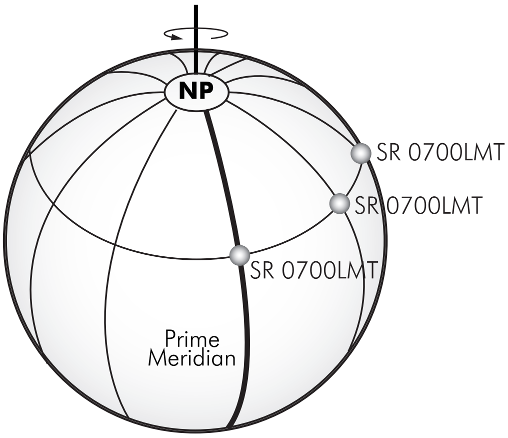



*Figure: NV 9.28*

The rising and setting tables tell the time in UTC of the phenomenon at suitable intervals of latitude for the Prime Meridian. Since UTC = LMT at the Prime Meridian, the corresponding phenomenon will occur at approximately the same Local Mean Time on any other longitude provided the latitude is the same. To obtain the UTC of SR / SS at a particular place other than on the Prime meridian, the longitude must be converted to time. Keep in mind that:

Longitude West, UTC best
Longitude East, UTC least

The tabulation in the tables covers every band of latitude for dates that may vary from three to nine days apart. The bands of latitude are sometimes 2° apart, sometimes 5° apart and sometimes 10° apart. To find the times of SR and SS on a particular date on the observer's latitude, it might be necessary to interpolate. It will usually be sufficiently accurate to use the times given for the nearest tabular date; however for the purpose of solving examination questions, interpolation is required.

An example:
What is the time in UTC for sunrise in position 51°12' N 045°22"W on February 5?

| **Latitude** | **Feb 1** | **Feb 4** | **Feb 7** |
|---|---|---|---|
| **N72°** | 1031 | 1007 | 0946 |
| **N70°** | 0948 | 0932 | 0916 |
| **N68°** | 0919 | 0907 | 0854 |
| — | | | |
| **N52°** | 0742 | 0736 | 0730 |
| **N50°** | 0734 | 0730 | 0724 |

First of all start to interpolate between the dates Feb 4th and and Feb 7th for both latitudes N52° and N50°. At both latitudes there is a 6 minute difference in time between SR at those dates, so by dividing 6 minutes by the number of days, the change per day turns out to be 2 minutes.
The times of sunrise on Feb 5th:

**N52°** 0734 (Feb 4th 0736 minus 2 minutes)
**N50°** 0728 (Feb 4th 0730 minus 2 minutes)

The difference in time of SR between N52° and N50° is 6 minutes, and more interpolation is required. The two degrees of latitude equals 120' (2°dlat = 2x60'). The time difference between the two latitudes is 6 minutes, so 6 divided by 120 = 0.05, which is the change per 1 minute of latitude.

Latitude 51°12' N is 72' further up from 50°N (60'+12'), so the difference in time can be found as 72 x 0.05 = 3.6. Rounded up this means that 4 minutes must be added to the time of sunrise at 50°N:

The time of sunrise on Feb 5th at 50°12' N is 0728 + 4 min = 0732 LMT

To obtain UTC of sunrise at 50°12"N 045°22"W, the longitude must be converted to time applying the usual rule:

| | | |
|---|---|---|
| sunrise | : | 07 32 LMT |
| arc to time | : | + 03hr 01min |
| sunrise | : | 10 33 UTC |

The time of sunrise on Feb 5th at 50°12' N 045°22"W is 1033 UTC

In high latitudes the sun may be above or below the horizon 24 hours a day. This phenomenon is called midnight sun and continuous Northern or Southern night respectively. In the SR / SS-tables the following symbols indicate the occurrence of these conditions:

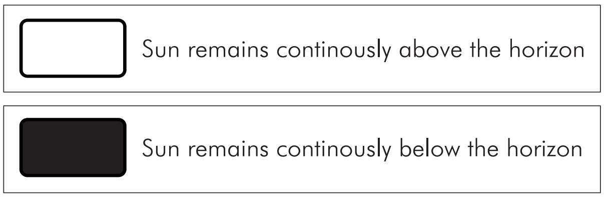



*Figure: NV 9.29*

## 9.13 Twilight

The period of incomplete light when the sun is not too far below the horizon is called twilight. It is considered to commence in the morning, or end in the evening, when the sun's centre is 18° below the horizon. Twilight is divided into three stages: The period between sunrise or sunset and the sun's centre being 6° below the horizon on its way up or down is called Civil Twilight. In this period everyday tasks are just possible without artificial light, and only the brightest planets will be seen.

The next stage of Twilight is called Nautical Twilight. That's when the sun's centre is between 6°and 12° below the horizon, and the degree of illumination when the sun is 12° below the horizon is such that general outlines of ground objects are just visible and the bright stars are visible.

Finally, when the sun's centre is between 12° and 18° below the horizon Astronomical Twilight is said to occur. When the sun's centre is 18° below the horizon, it is completely dark.

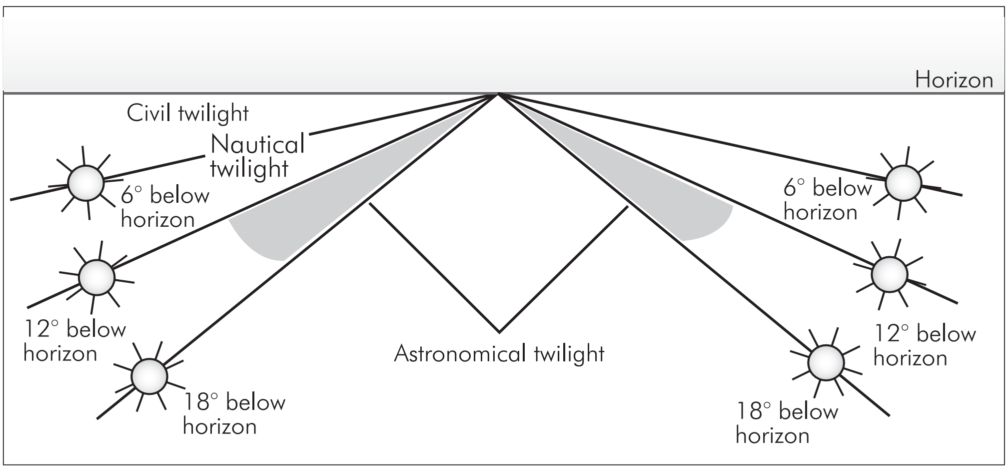



*Figure: NV 9.30*

The first of these stages; the Civil Twilight, is the one we're concerned with. A table in exactly the same form as the sunrise and sunset table has been worked out, so that the LMT of end of evening civil twilight (EECT) and beginning of morning civil twilight (BMCT) can be obtained in the same way as the SR and SS.

> Of the 3 degrees of twilight, the Civil twilight is of concern to air navigation, because it sets the limits for day-flying.

Morning Civil Twilight

| Lat ° | April 2 | 5 | 8 |
|---|---|---|---|
| N10 | 0536 | 0534 | 053 |
| 0 | 0540 | 0539 | |
| S10 | 0543 | | |

Evening Civil Twilight

| Lat ° | November 19 | 22 | 25 |
|---|---|---|---|
| N10 | 2022 | 2028 | 203 |
| 0 | 2035 | 2042 | |
| S10 | 2050 | | |

*Figure: NV 9.31*

The tabulated time of end of evening civil twilight and beginning of morning civil twilight is LMT at the Prime Meridian. The difference in longitude must be converted to time and added to the tabulated time when longitude is Westerly, and subtracted from the tabulated time when longitude is Easterly.

Just as in high latitudes when there are occasions of 24 hours daylight or darkness, there are occasions where twilight lasts all day or night. The following symbol indicates the occurrence of this condition:

//////

**Variation of Twilight with Latitude**

In the Tropics the sun rises and sets at almost 90 degrees to the horizon. This is shown in figure NV 9.32. The period of twilight is quite short because the sun is travelling the shortest way through the twilight zone, making the onset of daylight or night quite rapid.

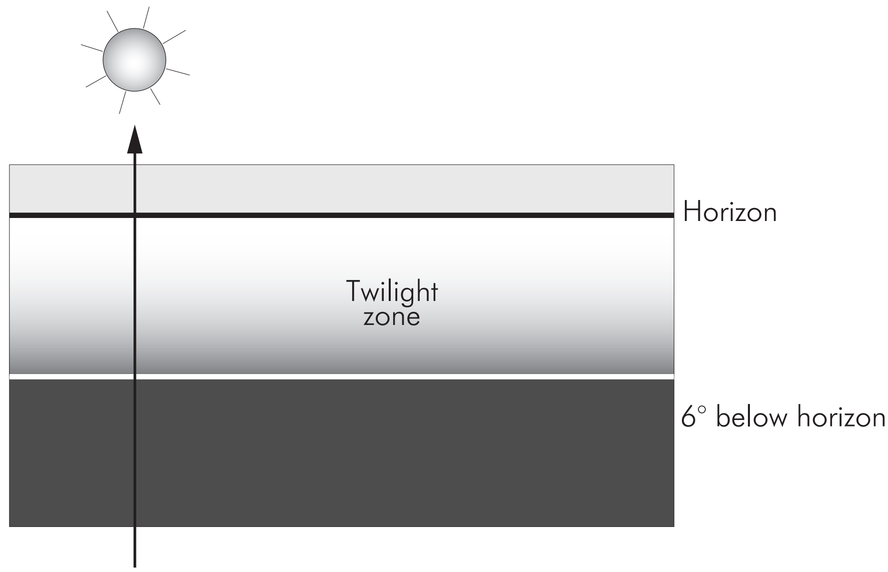



*Figure: NV 9.32*

In the higher latitudes towards the North and South poles the Sun does not travel the shortest way through the zone and the period of twilight is much longer, so that the onset of daylight or darkness is far more gradual than in the tropics, as shown in figure NV 9.33.

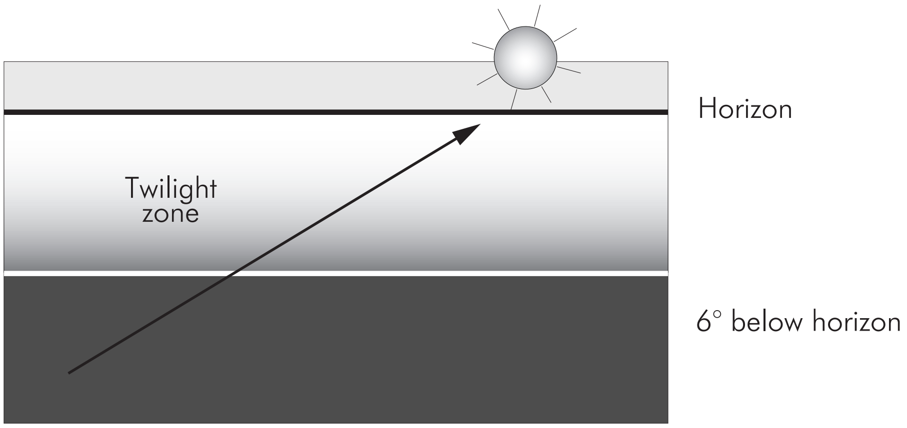


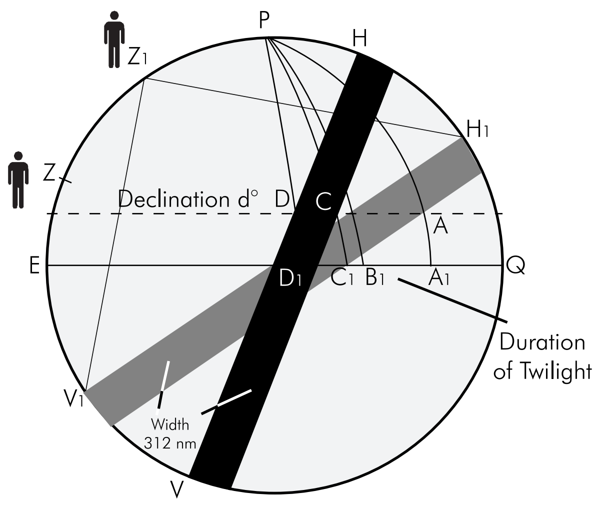

*Figure: NV 9.33*

> The Twilight zone is commonly described as the zone from the Horizon to 6° below the horizon.

> The twilight periods will generally last longer at higher latitudes than at Equator, where they are generally shortest.

The diagram below shows two observers, Z and Z1, their respective horizons, VH and V1H1, and associated twilight belts. The Sun, declination d° crosses observers Z1's twilight zone from A to B, the duration of twilight being A1B1. For observer Z, the sun crosses from C to D giving duration C1D1.

As can be seen on the diagram, the duration A1B1 is greater than C1D1, and therefore the duration of twilight increases with increased latitude.




Variation of Twilight with Latitude

*Figure: NV 9.33a*

**Variation of Twilight with Declination**
The duration of twilight also varies with the season of the year due to the Earth's varying inclination towards the Sun. In figure 9.34 the Earth is drawn with its axis oriented to the plane of the Ecliptic for Summer solstice Spring/Autumn equinox: and Winter solstice. The 6° twilight zone is shown and it becomes immediately apparent that, as Latitude increases the duration of twilight increases and vice versa.

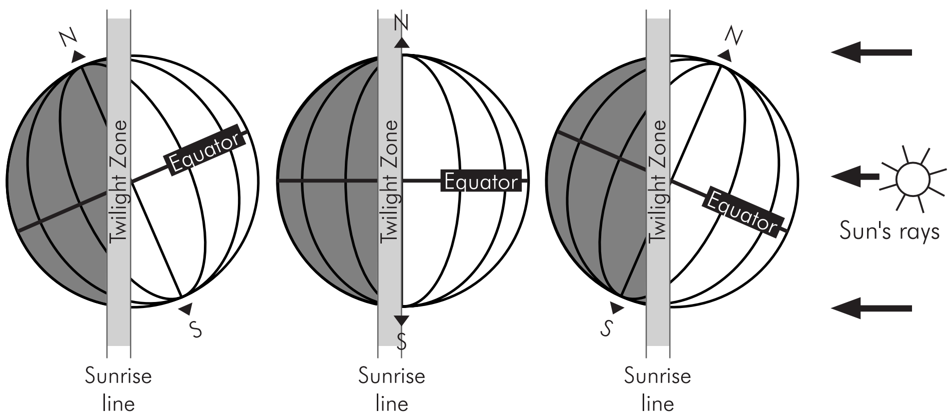
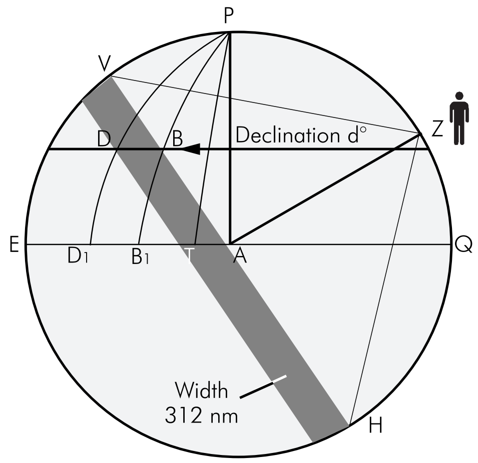



*Figure: NV 9.34*

The diagram below shows an observer Z and his visible horizon VH with its associated twilight belt. The sun is shown with declination 0° and d°. When declination is 0°, the duration of twilight is AT and for declination d° the duration is B1D1. B1D1 is greater than AT, therefore the duration of twilight increases as declination increases.




Variation of Twilight with Declination

*Figure: NV 9.34a*

The twilight period has a particular significance that is well worth a thought. It is around twilight that the ionosphere starts to move with consequences for the use of radio navigation aids and high frequency radio transmissions. The effective range of MF radio aids is reduced, the ADF signals might become more unreliable and the HF voice transmissions suffer from increased noise.

Sunrise, sunset and twilight tables are found in official publications like the Air Almanac, in several unofficial almanacs like Route Manuals, Flight Guides and in some newspapers. Tables are also normally available from Air Traffic Service units and Met offices.

> Beginning of Morning Civil Twilight (BMCT) is when the Suns centre is 6° below the horizon, and MCT ends at Sunrise when the Suns upper limb is first visible at the horizon.

> End of Evening Civil Twilight (EECT) is when the Suns centre is 6° below the horizon, and ECT starts at Sunset when the Suns upper limb is last visible at the horizon.

> The twilight periods generally become longer when the Suns declination is high.